Relaying Communications Channels

Application Guide

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TABLE OF CONTENTS

3. On-Off Single Function Keyed Carrier

4. PLC FSK Carrier

5. SSB Power Line Carrier

6. Audio Teleprotection Channels

7. Multi-Function Audio Teleprotection

8. Fiber Optics

Page

9. Pre- Emphasis Transmit Combiner

10. Simplified Modal Analysis

11. FREQPLN: A Computer Program for Frequency Planning

12. Auxiliary Coupling Devices

13. Bandpass Line Tuners

14. Bypass Circuits

15. Resonant and Wideband Bandpass Line Tuners

16. Two-Frequency Line Tuner Bandwidths

17. Highpass Line Tuners

18. Appendix

LIST OF FIGURES

Page

LIST OF TABLES

SECTION 1

INTRODUCTION

PURPOSE

This Application Guide contains recommendations for using Relaying Communications channels, also called teleprotection channels, for protecting High Voltage Transmission lines. It discusses relaying applications of Power Line Carrier(PLC) channel equipment to power lines and voice-grade channels (telephone, microwave, fiber optic, or SSB PLC channels). The guide reviews utility communication system requirements, presents channel recommendations for protective relaying, and outlines factors to consider when applying specific teleprotection channel equipment. Also included is a discussion of the line equipment required with dedicated teleprotection PLC, which includes coupling capacitors and line traps.

In addition, this guide is supplemented by including the design methods required to select Line Tuners, auxiliary coupling devices, and considerations for tuning these devices for optimum coupling to the power line. Also see reference [22] which it replaces.

This guide supplements other General Electric publications on protective relaying. For detailed product information, refer to the GE Protection and Control Products Catalog (GEZ7723). A glossary of commonly used teleprotection terms is provided in the Appendix. Reference [1 and 35] provide additional information on the application of Power Line Carrier.

UTILITY COMMUNICATION SYSTEMS

Several types of communication systems are available to the power system user - including Microwave, Private and Leased Telephone circuits, Power Line Carrier, and fiber optics. Each system satisfies a particular need or application.

Company-owned communication systems generally include power line carrier facilities, since high-voltage transmission lines provide a very reliable medium for communication. Therefore, PLC is normally used for the most important services, such as protective relaying. Where the communication medium employs voice-grade channels - whether microwave, telephone or single-sideband Power Line Carrier - audio tone teleprotection channels may be applied, and in some cases these channels serve as redundant paths in parallel with PLC channels. Audio tone channels are also applicable for use with fiber optic systems.

SERVICE REQUIREMENTS

Although this Guide is primarily concerned with the application of channel equipment for protective relaying, it is well to first understand the basic utility service requirements involving channels. These requirements or functions can be categorized as follows:

A. Protective relaying (teleprotection)
   1. Line protection
   2. Equipment protection
B. Telemetering and Telecontrol
   1. Analog telemetering
   2. Supervisory control and data acquisition (SCADA)
   3. Remote alarm systems
   4. Automatic generation control (AGC)

5. System security
C. Telephony (voice communication)
1. Simplex
2. Full duplex
3. Speech-plus tone service
4. Signalling
D. Bulk data transmission

Requirements for services other than protective relaying between two points in a power system may influence the choice of channel equipment for protective relaying, as well as communication medium. It is appropriate, therefore, to briefly define the other functions provided by power system communications.

Analog telemetering permits remote measurement of current, voltage, real and reactive power, pressure, position, flow and many other electric and non-electric data. It is the complete process of sensing, transmitting, and utilizing data for recording and control, from one point to another. It is both a measuring device and an essential input element in remote control equipment. Generally, variable frequency ranges (5-15 Hz, 10-30 Hz, or 6-27 Hz) have been used that can operate over any intermediate channels. A separate analog telemeter system is applied for each quantity to be measured. In some cases, a protective relay channel has been used on a "shared" basis to send telemetering signals when the relay function is at rest. Because of the emergence of SCADA systems, analog telemetering is giving way to digital telemetering, which utilizes multiplexing techniques for telemetering several quantities over a common system.

SCADA systems of today are designed to provide the basic supervisory control functions, plus multi-mode data acquisition. SCADA systems are generally scanning-type systems offering multi-mode-station operation, continuous checking of communications and remote equipment, high speed status change reporting and high speed data collection. The master and remote stations communicate with each other by a series of digital messages consisting of words employing high security digital coding. The basic supervisory functions of control, indication, and setpoint control are provided, including multi-mode data acquisition. Channel speeds ranging from 120 to 9600 bits per second are feasible.

In certain critical areas, alarm reporting is basic to detecting and locating failures at remote stations. As many as 3200 alarm inputs can be monitored over a single tone channel. Scanning speeds up to 2400 bps are feasible employing digital encoding systems.

Automatic generation control (AGC) provides the functions of tie-line and load-frequency control. To a large extent, direct digital control (DDC) systems have replaced analog control systems. DDC systems scan the unit generation and tie flows and generate raise/lower pulses to be sent to the individual units under control. These functions have been incorporated into today's SCADA systems.

System security involves the application of real-time computers to improve the reliability of system operation. Overall operation for reliability means keeping the power system in a normal state: i. e., all customer and interconnection demands are met, no apparatus or lines are overloaded and the consequences of an unexpected contingency are minimal. If the system departs from this state for any reason, the objective is to restore it to the normal state in the minimum time. The digital computer and SCADA systems offer the opportunity to improve the security of the power system.

Telephony (voice communication) is available in several forms. Simplex voice communication involves the use of one single carrier frequency. Only one terminal transmits at a time. Coordinated transfer during conversation is accomplished manually on a "push to talk" basis or automatically by means of voice-operated relays. Simplex telephony offers the advantages of party-line conversations and frequency conservation.

Duplex voice communication provides simultaneous transmission from each terminal. Separate frequencies are used for the two directions. It offers the advantages of easier normal conversation, routing through manual or automatic exchanges, and speech-plus tone operation. Where party-line operation is required, the circuits must be cascaded and more frequencies are required.

Speech-plus operation provides telemetering and control via audio tones above the voice frequencies. Speech intelligibility is feasible over a bandwidth of 300 Hz to 2000 Hz, and the remainder of the channel is used for continuous tones. The voice and tone frequencies are separated by filters. Voice communication signalling is accomplished by loud speaker calling, ringdown signalling, dial pulses, or on-hook/off-hook status of the telephone set.

Bulk data transmission is used for such items as billing, maintenance and unit scheduling information, models, system status, load forecasting, etc.

All of the above services, in addition to protective relaying, represent the basic communication requirements of a utility. It is important that the <u>total</u> system communication needs be evaluated in any given application. This is necessary to arrive at the most efficient use of the available spectrum and the best balance between technical and economic requirements for a given application. Communication systems are available that will give priority to the relaying function, whenever a multi-function system is used.

RELAYING CHANNEL REQUIREMENTS

Protective relaying is unique in that the channel is faced with very stringent - and seemingly contradictory - security and dependability requirements [2, 3, 4, 5, 34]. Security requires that the channel <u>never</u> give a false trip output. Dependability requires that the channel <u>always</u> gives a trip output when a trip input is received. In addition, the channel is required to provide an operation time of generally not over 15 milliseconds, back-to-back, which includes the transmitter time (after being keyed), the receiver response time, and the operating time of the output device. It does not include channel propagation time, which is primarily a function of the communication channel bandwidth and the intervening communication system medium.

Security and dependability considerations for the channel equipment include the following:

A. Security
   1. Noise
   2. Alien signals
   3. Frequency translation
B. Dependability
   1. Surge-withstand capability (SWC)
   2. Noise (impulse and random)
   3. Alien signals

References [4] and [5] discuss several system protection requirements. Among the system protection factors to consider related to protective relaying channels, are:

1. Importance of the bulk power transmission system

2. Availability of other communication facilities if one system is out of service

3. Requirements for signalling under worse-case conditions

4. Economics of the relaying channel system

Fault-clearing time may be critical to the bulk power system. For example, will power system instability result if high-speed pilot tripping is not achieved at both ends of a transmission line? Or, what are the consequences of a false trip or failure to trip?

Occasionally, some applications allow the use of alternate communication facilities, if one system is out of service. That is, to what extent can one system be compromised because another communication system exists?

If signalling is required under worse-case conditions, such as arcing disconnects, fault conditions, bad weather or unusually high noise from series capacitor gaps, these factors must also be evaluated in the application of protective relaying channels.

A relaying channel may be designed and planned based on a minimum system (lowest cost) or a maximum performance system using the latest state-of-the-art techniques. These trade-offs must be evaluated for each application.

TYPES OF TELEPROTECTION CHANNELS

There are two basic types of signals used for teleprotection channels:

1. Keyed carrier (AM or ON-OFF carrier)

2. Frequency-shift-keyed (FSK) carrier

The various types of General Electric teleprotection channel equipment are classified in Table 1-1. These channels are referred to as Single function channels as opposed to SSB power line carrier, which is a multi-function channel.

Keyed Carrier (AM or ON-OFF Carrier)

Keyed carrier is normally OFF, and intelligence is transmitted by turning the carrier ON and OFF. This type of signal, illustrated in Figure 1-1, is normally used in blocking-type relaying systems. This type of equipment produces an RF keyed-carrier signal which can be coupled to a power line for transmission (dedicated power line carrier). The frequency of a baseband-type keyed carrier equipment might be in the frequency range from 29-31 kHz, and this signal could be applied to a SSB power line carrier channel with a baseband in this frequency range for transmission on a multi-function SSB carrier channel.

Keyed carrier is sometimes referred to as AM (amplitude modulation), because the equipment is usually designed to also provide an auxiliary voice function employing amplitude modulation.

Frequency Shift-Keyed (FSK) Carrier

An FSK signal is always ON, which provides a means of continuously monitoring the channel to be sure that it is operable. FSK channels are also less susceptible to noise and generally have a greater operating range than AM keyed-carrier channels.

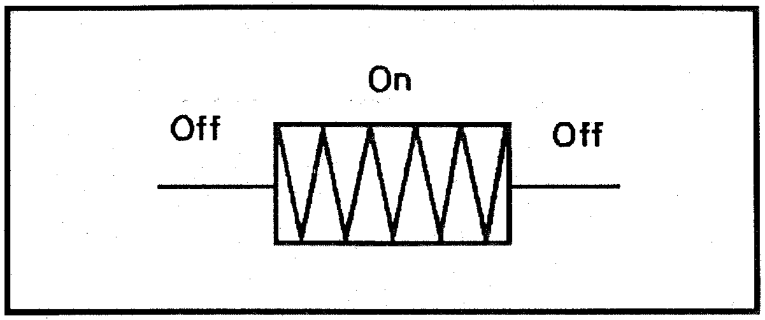


Figure 1-1 Keyed Carrier

Table 1-1
Types of Teleprotection Channel Equipment

Type of Signal	Equipment Type	Frequency of Signal	Method of Transmission
Keyed Carrier (AM or ON_OFF PLC direct or baseband)	WB and NB Blocking type Carrier Dedicated PLC	30 kHz to 511 kHz	Coupled to transmission line (PLC)
	WB and NB Blocking type Carrier Baseband PLC	29-31 kHz (PLC baseband frequency)	Applied at baseband level to SSB PLC channel for transmission over power line
FSK (PLC, Tone, or Fiber Optic)	NB, MB, and WB FSK Dedicated PLC	30 kHz to 500 kHz	Coupled to transmission line (PLC)
	MB and WB FSK Baseband PLC	29-31 kHz (PLC baseband frequency)	Applied at baseband level to SSB PLC channel for trans-mission over power line
	AUDIO TONE Audio Telepro-tection Channel Equipment	Audio frequency tones 1190 to 3315 Hz	Voice-grade channel: o private telephone line o leased telephone line o microwave channel o PLC channel Fiber optic link
	MULTI FUNCT TONE Audio Teleprotection Channel Equipment	Audio frequency tones 540 to 3060 Hz	Voice-grade channel: o private telephone line o leased telephone line o microwave channel o PLC channel Fiber optic link

FSK channels have been available with two-frequency operation, as illustrated in Figure 1-2. Two-frequency operation is used in transfer-trip applications for line or equipment protection. It is also used for unblocking line relaying.

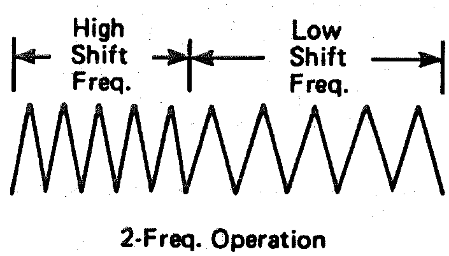


Figure 1-2. Frequency-Shift-Keyed Carrier

FSK equipment is generally available for teleprotection channels (Table 1-1). This equipment provides an RF signal which can be coupled to a power line for transmission (dedicated PLC). Versions of this equipment are also available for application to the baseband of PLC SSB channels and to the analog microwave baseband. Audio tone equipment using the same FSK technique is also available for transmission over voice-grade channels (telephone lines, voice multiplex channels for transmission over microwave channels and PLC SSB channels) and various fiber optic links.

Fiber Optics

Optical fibers and other components are being extensively developed for telecommunications and teleprotection applications [6]. The utility industry is interested in fiber optics for several basic reasons:

1. Immunity to EMI and ground potential rise;

2. Small size/weight cables (potentially low cost);

3. Relatively low-loss transmission;

4. Wide bandwidth capability.

Optical fibers are packaged with protective sheathing and strength members to form cables equivalent to conventional wire cables in their ability to withstand environmental effects and stresses during installation. Because of the enormous bandwidth and signal-handling capabilities of optical fibers, one fiber will do the job of many conventional twisted wire pairs, so that the size and weight of trunk lines can be reduced significantly. The tremendous bandwidths available in fiber optic system may be used for T1 type channel transmission, or the optical fiber equivalent called SONNET, and high speed data and video channel communications. Equipment is available to transmit teleprotection signals over multiplex digital channels or to use dedicated fibers for this purpose. As the equipment use becomes more widespread, the sharing of channels with other functions should become common for optical fiber systems.

Electrically, the fiber optic material is a dielectric. It is excellent for transmitting communications or teleprotection signals in applications which are subject to differences in potential (GPR). It is also immune to radio frequency interference (RFI) and electromagnetic radiation.

SECTION 2

CHANNEL APPLICATION

Contents of Section 2

TELEPROTECTION CHANNEL EQUIPMENT

AVAILABLE CHANNELS

Manufacturers of PLC channel equipment offer several types of teleprotection channel equipment. Some manufacturers offer more variety in channel selection. Each of the channel types is designed to satisfy requirements for a particular relaying scheme by the user:

1. Dedicated PLC blocking-type channels
2. Baseband PLC blocking-type channels
3. Dedicated PLC tripping-type channels
4. Baseband PLC tripping-type channels
5. Audio teleprotection channels
6. Multi-function audio teleprotection channels

This section of the Application Guide will review the basic types of pilot relaying, the channel application factors, outline the selection of teleprotection channel equipment, and discuss the basic design of power line carrier, audio tone, and fiber optic teleprotection channels.

CHARACTERISTICS

Complete descriptions of relaying channels are provided by the manufacturer in product brochures. The equipment may also be described in manufacturer's catalogs. Table 2-1 provides a comparison of the key characteristics of some of the different types of channels available for protective relaying.

TYPES OF PILOT RELAYING

Pilot channels for teleprotection have been in use for a number of years. A communication channel is required when protective relay responses must be compared between two or more terminals to determine the fault location. High voltage transmission line protection is the most common type of application. Another frequent application is where the fault detecting relay is remote from the circuit breaker that isolates the fault. The latter application is known as direct transfer tripping.

The following discussion provides a brief review of the basic types of pilot relaying and outlines the advantages and disadvantages of the different types of teleprotection schemes. Several references discuss the various factors to consider in the application of pilot relaying [4,5,7]. A pilot relaying scheme is classified by the type of relaying channel used and the fault detection principle applied. For any given relaying scheme, the overall relaying time depends on the channel response time and the operating time of the fault detecting relays. Three basic relaying schemes are briefly discussed - blocking, tripping, and ac pilot wire relaying.

BLOCKING SCHEMES

Transmission line faults are detected in high speed using either phase comparison relaying or directional comparison relaying. In both cases, the channel is operated in a trip permission mode and is used to block tripping of the protected line for external faults.

The phase comparison scheme shown in Figure 2-1 is a more generally applicable type of current differential line protection. A mixing network is used to derive a single-phase signal at power system frequency which is proportional to the line currents at each terminal. This ac signal is used to modulate a communication channel to accomplish the phase angle comparison of the currents entering and leaving the zone. The internal fault shown in Figure 2-1 produces in-phase network and receiver signals resulting in trip outputs at both ends of the line. If the fault had been external to terminal A, the current direction at A would be reversed, causing the receiver signal at A and the network signal at B to be reversed. This would prevent tripping at both A and B for the external fault.

It should be noted that a phase comparison blocking scheme has the channel in trip permission condition in standby, and keys the channel to the non-trip (block) condition every half cycle when the fault detectors are operated. The blocking scheme is biased toward dependability, since channel or remote relay failure would result in local relay tripping for internal and external faults. An ON-OFF channel is commonly used in a blocking scheme, with OFF being the trip permission condition. This provides added dependability in the presence of internal fault attenuation when a power line carrier channel is used.

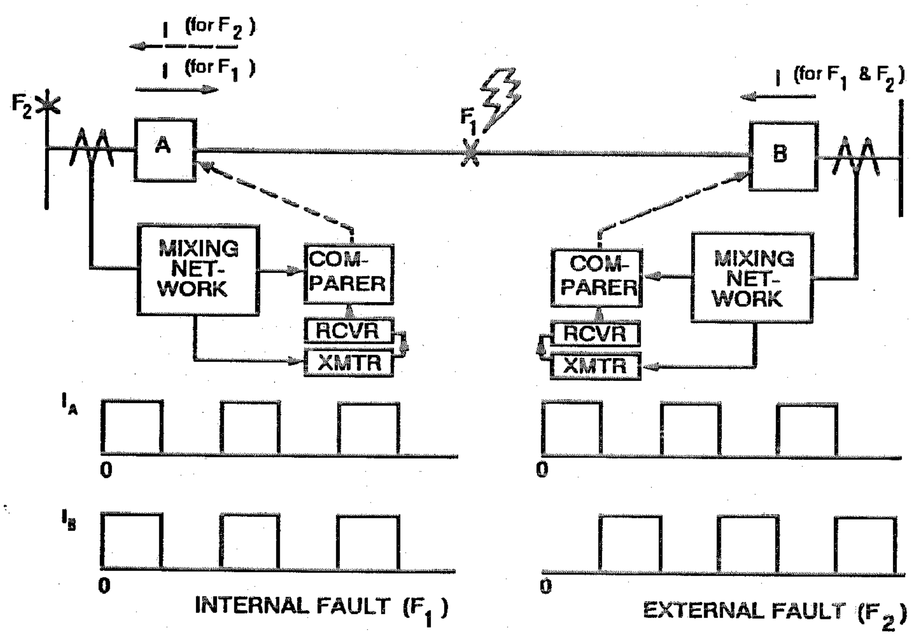


Figure 2-1 Phase Comparison Blocking

Table 2-1A
Teleprotection Channel Guide

	Dedicated PLC Equipment			
Characteristic	On-Off	NB FSK	MED. BW FSK	WIDE BW FSK
Function (2)	Blocking-type Line Relaying	Tripping-type Equipment and Line Relaying		
Advantages and Limitations	Voice Available. High Speed Limited Operating Range	Channel Monitor, High Operating Range Normally No Voice		
Modulation	ON-OFF	FSK	FSK	FSK
Channel Time (1)	WB 1.5/2 ms; NB 3/5 ms	29 ms	10-14 ms	4-9 ms
Power Output	10 watts 100 watts	1-Watt guard, 1-Watt trip; 10-W guard, 10-W trip 1-W guard, 10-W trip; 10-W guard, 100-W trip(exalt 100-watt guard, 100-watt trip		
Operating Range (dB)	40 (for 10 watts) 50 (for 100 watts)	63 (1 watt) 73 (10 watts) 83 (100 watts)	53 (for 1 watt) 63 (for 10 watts) 73 (for 100 watts)	
Frequency Range (kHz)	30 - 511	← 30-500 →		
Power Supply	← 48, 125 or 250 Vdc →			
Voice Available?	Yes	No	No	No

Notes: (1) Channel times are for back-to-back condition. Where two times are given, first figure is operate time and second figure is reset time.

Table 2-1B
Teleprotection Channel Guide (Continued)

	Audio Tone Equipment		PLC Baseband Equipment			
Characteristics	SINGLE FUNCTION CHANNELS	MULTI FUNCTION CHANNELS	ON-OFF	ON-OFF	MED. BW FSK	WIDE BW FSK
Function(2)	TT and Line Relaying	TT and Line Relaying	Phase Comparison	Directional Comparison	TT, Directional Comparison	TT, Phase Comparison or Directional Comp.
Advantages and Limitations	Requires Voice-Grade Channel	Performs 3 TT Uses one voice Channel (w/wo Voice)	← Used with GE SSB-PLC for Multi-Function Operation →			
Modulation	FSK	FSK	ON-OFF	ON-OFF	FSK	FSK
Channel Time (1)	4-21 ms	10-21 ms	2/3 ms	3/5 ms	7 ms with SS Relay, 11 ms with EM Relay	4 ms
Power Output	To 0 dBm with +15 dBm Option	-45 to +8 dBm with 10dB Exalt	← Depends on SSB-PLC Selection and Application →			
Operating Range (dB)	-40 dBm Rx Sensitivity	-30 dBm Rx Sensitivity	← Depends on SSB-PLC Selection and Application →			
Frequency Range (kHz)	Specify Audio Frequency (Hz)	Specify Audio Frequency (Hz)	30	30.75	29 or 31	31
Power Supply	← 48, 125 or 250 Vdc →					
Voice Available	NO	NO	← Yes, Using Associated SSB-PLC →			

Notes: (1) Channel times are for back-to-back conditions. Where two times are given, first figure is operate time and second figure is reset time.
(2) TT = Transfer Trip

TRIPPING SCHEMES

A phase comparison tripping scheme is shown in Figure 2-2, where the channel is keyed to the trip permission condition every half cycle during the fault. The tripping scheme is biased toward security, since failure of the channel or relays would result in non-operation of the local relay for external and internal faults. A frequency-shift keyed channel is normally used in a tripping scheme, and the non-trip (block or guard) frequency is monitored continuously.

A blocking directional comparison scheme requires blocking directional relays at each terminal, connected to detect faults away from the protected line. The channel is operated with the trip permission condition in standby and is only used to block the remote overreaching directional relay for external faults, as shown in Figure 2-3. The blocking

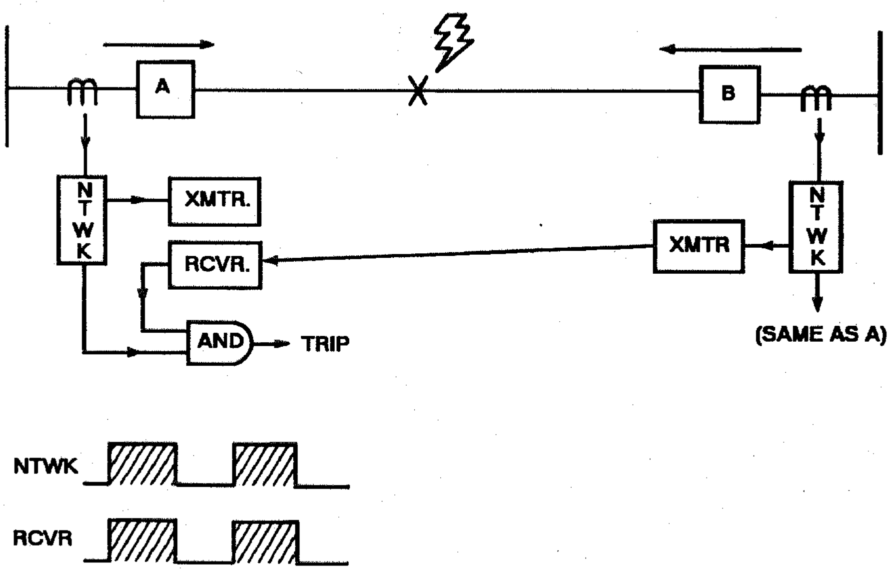


Figure 2-2. Phase Comparison Tripping

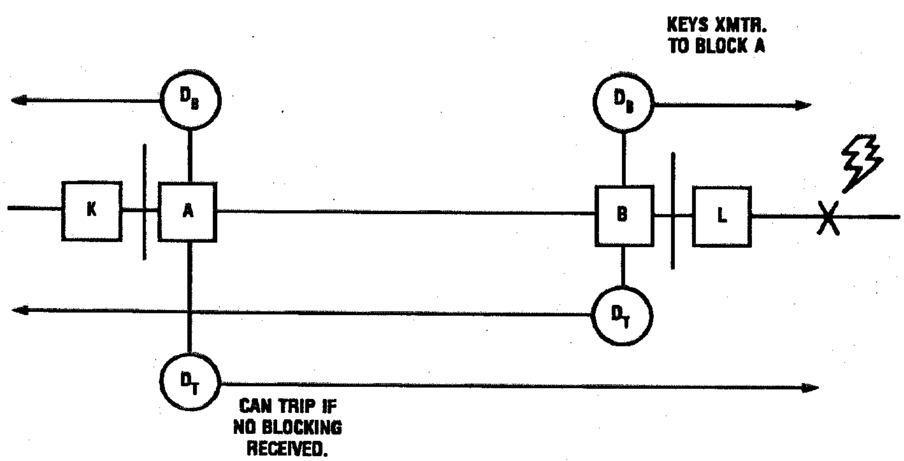


Figure 2-3. Directional Comparison Blocking

scheme is biased towards dependability since local tripping is unaffected by channel failure, weak fault current infeed at the remote terminal, or operation failure of the remote relays. However, loss of the channel can cause false tripping for an external fault, and therefore, is less secure. An ON-OFF power line carrier channel is most frequently used for a blocking scheme, with the channel OFF condition providing trip permission.

Directional distance relays can be used with a channel in a directional comparison tripping scheme, as shown in Figure 2-4, to provide high-speed clearing of faults. A directional (67) relay compares the direction of current with a polarizing voltage, and has almost unlimited sensitivity to faults in the forward direction. Adding overcurrent (50) supervision restricts the directional unit operation to faults in the protected line's vicinity. A directional distance (21) relay set to overreach the protected line with a limited margin gives the least exposure to external faults, and therefore, the greatest security.

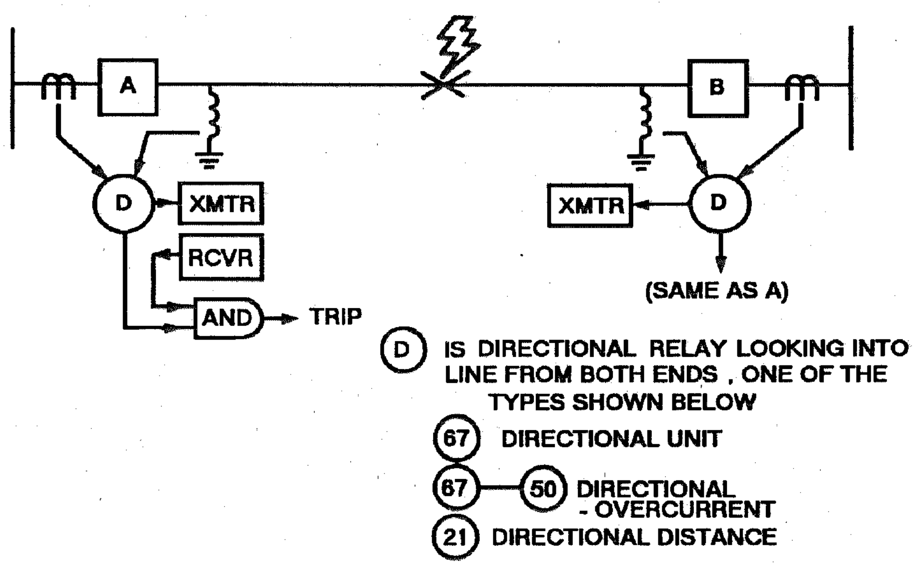


Figure 2-4. Directional Comparison Tripping

The tripping directional comparison scheme, shown in Figure 2-4, is biased toward security. When the directional relays looking into the line detect a fault, they key the local transmitter continuously to the trip permission condition, and attempt a receiver supervised trip. Failure of the channel or remote relays will result in failure to trip for external or internal faults. A frequency-shift scheme is usually used, with GUARD frequency monitoring for added dependability. The phase comparison channel requirements for speed, symmetry, and low distortion do not apply to directional comparison, since the channel is simply switched from non-trip to trip permission condition for the duration of the fault. Directional comparison is more frequently applied than phase comparison because it is reasonably independent of channel characteristics and the effects of load and fault current. Directional comparison is used with all types of channels, and can be applied in shared channel arrangements with direct transfer tripping over the same path.

Direct transfer tripping is applied for tapped lines, for transformer equipment failures, and breaker failures. A frequency-shift channel is normally used for direct transfer-tripping, permitting continuous monitoring for added dependability. In many applications, two channels are used with the receiver outputs connected in series to provide security against false tripping due to operational or test errors or alien signals. This additional security consideration exists because the trip is accomplished at the receiving end without supervision by a local fault detecting relay.

AC PILOT WIRE RELAYING

Present day ac pilot wire relays of domestic manufacture [8] convert the three-phase line currents into a single-phase quantity of sequence components, as shown in Figure 2-5. These single-phase quantities at each terminal of the line are compared via a metallic pilot wire to determine if the protected line is internally faulted. This system is a form of current differential relaying.

AC pilot wire relaying generally has good dependability in operation, provided it is properly applied, and the wire pilot has the required characteristics. Adequate wire channels for use with ac pilot wire relays are now becoming quite difficult to obtain by leasing. The problems are a low enough loop resistance and circuit capacitance and getting a hard-wire pilot. A more serious limitation to wire and cable applications is the effect of induced voltages during primary power system faults. Privately owned and installed pilot wires are being used by some utilities and in large industrial locations. In either case, pilot wire relaying is generally limited to the protection of short two-terminal lines and less critical lines, provided the wire pilot limitations can be met. When applied to three-terminal lines, the pilot wire must be a three-legged T connection with the loop resistance of all three legs limited in magnitude and balanced very closely.

DC pilot wire monitoring relays are frequently applied with an ac pilot wire relaying scheme to continuously monitor the pilot. This monitoring will detect open, shorted, grounded or reversed polarity pilot wires.

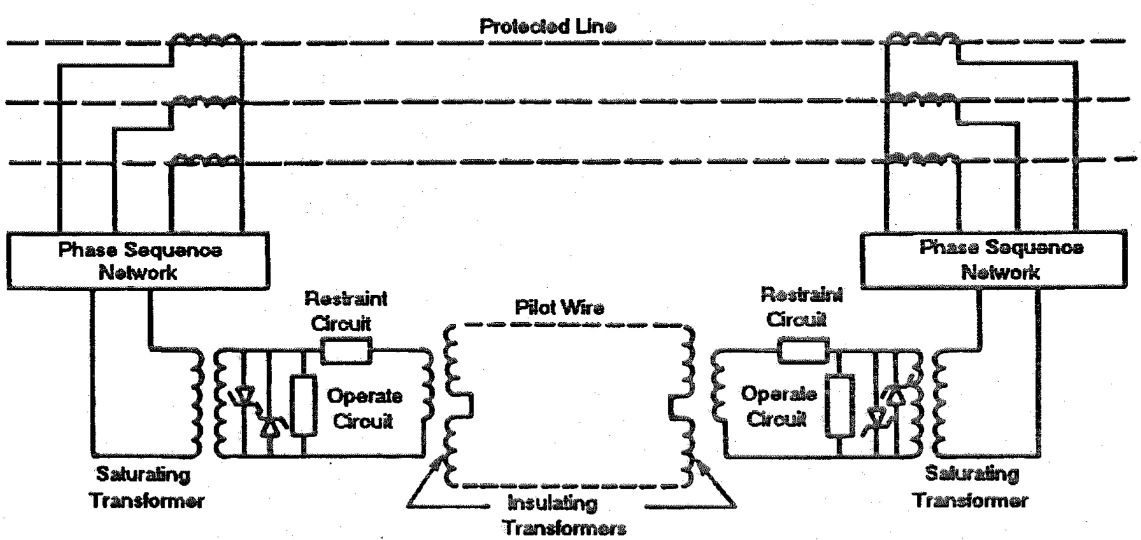


Figure 2-5 Simplified Diagram AC Pilot Wire Relaying

CHANNEL APPLICATION FACTORS

Several factors must be evaluated when selecting channel equipment for relaying applications. Some of these factors are based on the relaying system requirements and others are influenced by the use of particular channel equipment or the communication medium on which the channel is applied. The major factors which influence the choice of channel equipment are:

1. Communication medium
2. Channel time

3. Dependability versus security
4. Channel requirements -Single versus multi-channel
5. Protection: Equipment versus line relaying protection
6. Line length (equipment operating range)
7. Frequency range
8. Channel spacing
9. Noise level: line, equipment and faults
10. Minimum SNR
11. Redundancy requirements
12. Blocking versus tripping-type channel
13. Fault trip-through capability
14. Voice communication requirements
15. Noise detection and suppression
16. Power output: normal and exalt
17. Power supply
18. Protection against surges
19. Protection against frequency translation

A brief discussion of each of these factors follows:

Communication Medium: The transmission path for dedicated PLC relaying may include overhead line, pipe-type cable or a combination of overhead line and cable. Audio teleprotection channels may operate over voice-grade SSB carrier, microwave, leased telephone fiber optic or multiplex channels, private wire circuits (direct or carrier), or a fiber optic link. Baseband teleprotection uses the intermediate frequency (baseband) of SSB power line carrier or the baseband of an analog microwave system. Channel equipment must be applied within the limits of the communication medium selected.

Channel Time: A particular relaying scheme is designed to operate within a specified time. One of the main objectives of protective relaying is to provide simultaneous high-speed tripping at all terminals for equipment and line faults. Channel speed is made as fast as possible, consistent with a well-designed channel. Relay system time consists of two parts: channel time and protective relaying operating time. Channel time is subject to many variables and includes the interval between transmitter keying by the protective relays and receiver output. The physical length of the path to be traversed and the medium through which the signals are to be propagated affect the total channel time. Therefore, channel time, in the context of channel equipment design, refers to the back-to-back times of the transmitter and receiver only, since the communication medium and path is not under the control of the designer. The concept of high speed, or minimum channel time will usually refer to a wideband channel. The comparison is relative, with the narrower bandwidth channel of a certain type having the longest channel time (slowest speed) and the wider bandwidth channel having the shortest channel time (highest speed). When comparing audio channels or power line carrier channels, the narrow band channels will be slowest, and as bandwidth increases, so does the channel speed, and inversely, the channel time.

Dependability Versus Security: Dependability and security considerations recognize the very desirable properties of always giving a trip output when required and never giving a false trip. The channel design takes into account protection against noise, transients, alien or interfering signals, frequency translation (if applicable), and disturbances on the communication medium or in the channel equipment. Reference [5] addresses several considerations of speed, dependability, and security in pilot relaying schemes.

Channel Requirements: Channel requirements over a given line section will determine whether multi-function SSB carrier or single-function (dedicated) carrier should be used for protective relaying. When three or more functions are required over a given line section, SSB carrier generally proves more economical than single-function carrier. In either case, channel equipment is available that provides the speed, dependability and security requirements of protective relaying.

Protection: Depending on the application, specific types of channel equipment are applied for equipment and line protective relaying. Equipment protection can generally tolerate slower channel speed, in the order of 25 to 90 ms, whereas with line relaying, channel speeds as low as 3 ms are often desirable.

Line Length: Line length is of importance because of the path attenuation imposed on the channel equipment and its effect on the equipment operating range. All channels are applied with an operating margin in both receiver sensitivity and signal-to-noise ratio to allow for possible changes in attenuation and noise level. Generally, tripping-type carrier channels have an operating range that is greater than blocking-type channels. For the same SNR conditions, an FSK channel is approximately 7 dB better than a keyed carrier channel.

Frequency Range: Frequencies in the range of 30-500 kHz have been employed for carrier relaying, as this frequency range is high enough to be isolated from the 60 Hz power frequency and from the noise it creates, yet not so high as to encounter excessive attenuation. Audio teleprotection equipment operates on specific frequencies within the range of 1190 to 3315 Hz. Choice of operating frequencies is a function of speed requirements and of total frequency planning.

Channel Spacing: Channel spacing is a function of the bandwidth and isolation requirements for each of the available relaying channels. In the case of audio teleprotection channels, the available frequencies are pre-determined for a fixed spacing of 170, 240, 340, or 1000Hz, with the widest spacing providing the fastest channel time.

Noise Level: The noise level on a high voltage transmission line depends on the voltage of the line which may contribute to corona noise effects. The presence of switching transients and voltage surges may also depend on the geographic location of the line. Icing conditions may contribute to the noise, as well as to the line losses at power line carrier frequencies. The types and frequency of faults may also be related to the line location and the relative occurrence of lightning storms, wind storms, and other weather related phenomena.

Minimum SNR: Since the quality and performance of a relaying channel depends essentially on the signal-to-noise ratio (SNR) at the receiving end, the level of noise at the receiver is important. Each of the PLC and audio teleprotection channels is designed to operate within a specified minimum SNR. The performance of the relaying channel can be predicted by the SNR at the receiving end of the channel. It is important to adhere to the minimum SNR specified for a given channel.

Redundancy Requirements: Redundancy is generally considered in multi-function SSB carrier equipment. Some SSB carrier equipment may use redundancy to improve channel dependability by using dual RF power amplifiers which automatically sectionalize upon component failure and continues to operate at a reduced power level. In addition, redundant "Hot standby" using two sets of common equipment may be applied. Both sets of common equipment operate continuously and are driven from a single set of voice channel equipment operating through a common baseband repeater. If one set of common equipment should fail, the faulty common equipment is automatically disabled and the "hot standby" is switched over.

Redundancy may also be enhanced by providing two separate communications paths for the protection signals to traverse. These two paths may include audio tone channels over leased telephone line or microwave as one path with power line carrier furnishing the second path. Either path may be chosen as the primary communications link, depending on the history of channel dependability and reliability, or the two channels may equally share the responsibility for protecting the lines or equipment. Availability of fiber optic channels or privately-owned communications mediums will certainly effect the planning for dual channels over different mediums. Some utilities use primary and secondary protection schemes over the same medium, where there is essentially two separate systems for redundancy in case either fails.

Blocking versus Tripping Channel: The choice of blocking- or tripping-type channels is determined by the particular relaying scheme being applied. Both audio and PLC channels are available from suppliers for several relaying schemes. References [4] and [5] review the choices of relaying schemes and communication channels.

Fault Trip-through Capability: Fault trip-through capability is of no concern with blocking-type channels, since signalling is not required for internal faults. On the other hand, tripping-type channels via PLC for line relaying must be able to operate correctly upon loss of the channel signal. For this reason, logic circuits are generally used to provide proper operation upon loss of signal. Audio teleprotection via microwave is not faced with the problem of sending a tripping signal through power line faults. When using wire lines, ground potential rise may cause troublesome noise during fault conditions.

Voice Communication Requirements: Generally, some means of voice communication for maintenance purposes is required. Some blocking-type carrier channels provide this option during idle channel time. SSB channels inherently provide the possibility for voice communication.

Noise Detection and Suppression: Noise detection and suppression is included in most channel equipment to sort the incoming signals and yield the desired output. This provides protection against false operation from spurious noise or frequencies.

Power Output, Normal and Exalt: Power output characteristics of both carrier and audio tone relaying channels should be chosen to provide dependable signals. High continuous or exalt power may be supplied. The exalt option is preferred, since high continuous power is more likely to cause interference problems. Normal block-type carrier channels operate at a 10-watt or 100-watt output. Tripping-type carrier may operate at 1-watt GUARD/10 watt TRIP or 10-watt GUARD/100-watt TRIP. An exalt option is also available with audio tones.

Power Supply: Channels for protective relaying are designed for battery operation to provide reliable relaying. The dc battery supply can be either the user's station battery source or a separate station battery used for communications at a different voltage.

Protection Against Surges: All teleprotection channel equipment should be constructed so that it will not be damaged nor an erroneous output given when subjected to the surge withstand capability (SWC) test defined in ANSI Standard [2] C37.90.10-1989, as follows:

"The SWC test wave is an oscillatory wave, frequency range of 1.0 MHz to 1.5 MHz, voltage range of 2.5 kV to 3.0 kV crest value of the first half cycle peak, envelope decaying to 50% of the crest value of the first peak in not less than 6 μs from the start of the wave. The source impedance of the surge generator used to produce the test wave shall be from 150 ohms to 200 ohms. The test wave to be applied to a test specimen at a repetitive rate of not less than 50 tests per second for a period of not less than 2.0 seconds."

Protection Against Frequency Translation: Frequency translation is a change in frequency produced by the communication media. Such changes can make TRIP frequencies out of GUARD frequencies. Some audio equipment is designed to prevent false tripping by the use of an optional pilot tone transmitter and pilot tone receiver. The pilot receiver might consist of a bandpass filter in series with a narrow band band-reject filter, both centered on the pilot frequency. Either the loss of pilot or pilot translation squelches the receiver to prevent false operation.

Applications utilizing dual channels provide an up-shift, down-shift option which also provides a certain degree of frequency translation protection. Where dual channels are applied to switch to single channel operation, a pilot tone transmitter and receiver are essential.

CHANNEL SELECTION GUIDE

APPLICATION REQUIREMENTS

Selection of relaying channel equipment is dependent on several application requirements. Among the more common considerations are the following:

1. Channel medium
   a. Power line carrier
   b. Telephone or microwave voice-grade channel
   c. Fiber optic cable
2. Blocking - versus tripping-type relaying
3. Equipment versus line protection
4. Single- versus multi-function requirements
5. Combined equipment protection and line protection
6. Channel monitoring requirements
7. In-service testing
   a. Dual channel
   b. Checkback
   c. Local loop
8. Available spectrum and frequency spacing
9. Line noise and channel attenuation
10. Ground potential rise on wire line facilities serving electric power stations
11. Line configuration

SELECTION PROCESS

The logic for selecting relay channel equipment is presented in Figures 2-6A-C, based on the factors listed above. As indicated in the figures, the selection begins with the choice between power line carrier, microwave, telephone or fiber optics. Factors concerning economics, channel density, the need for voice communications, available spectrum, and susceptibility to interference will also dictate the selection of the channel type.

As shown in Figure 2-6B, if microwave is used, either FSK audio tone in single or dual channel configuration may be applied. Multi-function audio tone with three independent functions over a single equipment may also be applied. A baseband FSK channel, similar to the PLC FSK channels at line frequency, may also be applied.

As shown in Figure 2-6C, if leased or private wire telephone is used and ground potential rise (GPR) problems are not a factor, audio tone equipment may be used in blocking or tripping-type relay schemes. If GPR is a problem, a fiber optic entrance link should be considered [6].

If a fiber optic link is available, either single or multi-function audio tone may be used, depending on the channel time requirements. In either case, the audio tone is interfaced to an optical transmitter and receiver for dedicated signal transmission via the fiber optic link. Multiplexed protection channels of either digital (T1 or Sonnet) or analog AM may be transmitted over optical fiber.

If power line carrier is used (Figure 2-6A), the number of functions (relaying plus others) will determine the use of either single-function dedicated carrier or single-sideband, multi-function carrier. Generally, when three or more functions are involved, channel economics and better utilization of the carrier spectrum will favor the use of single-sideband, multi-function carrier.

Continuing through the logic of Figure 2-6A, assuming a single-function carrier is applicable, the desire for continuous channel monitoring is considered next. Channel monitoring is provided with tripping-type or frequency-shift (FSK) carrier. If equipment protection is desired, such as transformer protection, then narrow band FSK carrier is used. If in-service testing is required, dual channel narrow band FSK carrier equipment should be used.

If line protection with FSK carrier is required, either medium bandwidth FSK or wide bandwidth FSK carrier would be used, depending on the time requirements and available carrier spectrum. The medium bandwidth FSK carrier allows closer frequency spacing than the wide bandwidth FSK carrier where spectrum conservation is more important than time. The wideband FSK carrier channel would be used where high speed is the most important consideration. Similarly, if in-service testing is required, dual channels would be applied.

As shown further in Figure 2-6A, when continuous PLC channel monitoring is not required and single-function carrier is satisfactory, then a blocking type relay channel would be applied. The ON-OFF blocking equipment would be used, and if in-service testing is required, then checkback equipment would be added.

If instead, as shown in Figure 2-6A, multi-function carrier is better suited to the application requirements (three or more functions), single-sideband (SSB) would be applied. With SSB carrier, a choice must be made between baseband or voice channel for the relay channels. Baseband relaying offers faster channel times, reliability is not affected by the loss of a voice channel, and this channel does not require voice channel equipment.

Figure 2-6A shows a variety of baseband relaying channels for both equipment protection and line protection. If, instead of baseband, a voice channel is more suitable, then audio tone of either the single-function or multi-function type can be applied for equipment protection or line protection utilizing directional or phase comparison relaying.

Figures 2-6A-C illustrated a wide variety of relaying channels and a number of ways to fulfill the protective relaying requirements. Not described in the figure are the factors of line noise, channel attenuation and line configuration. As in all channel applications, a minimum signal-to-noise ratio (SNR) must be provided for acceptable performance. The following section defines the minimum tolerable SNR values. In general, a frequency-shift channel can operate through a wider range of attenuations, offers opportunity for lower power transmitter equipment, and can tolerate lower SNR's than ON-OFF channel equipment.

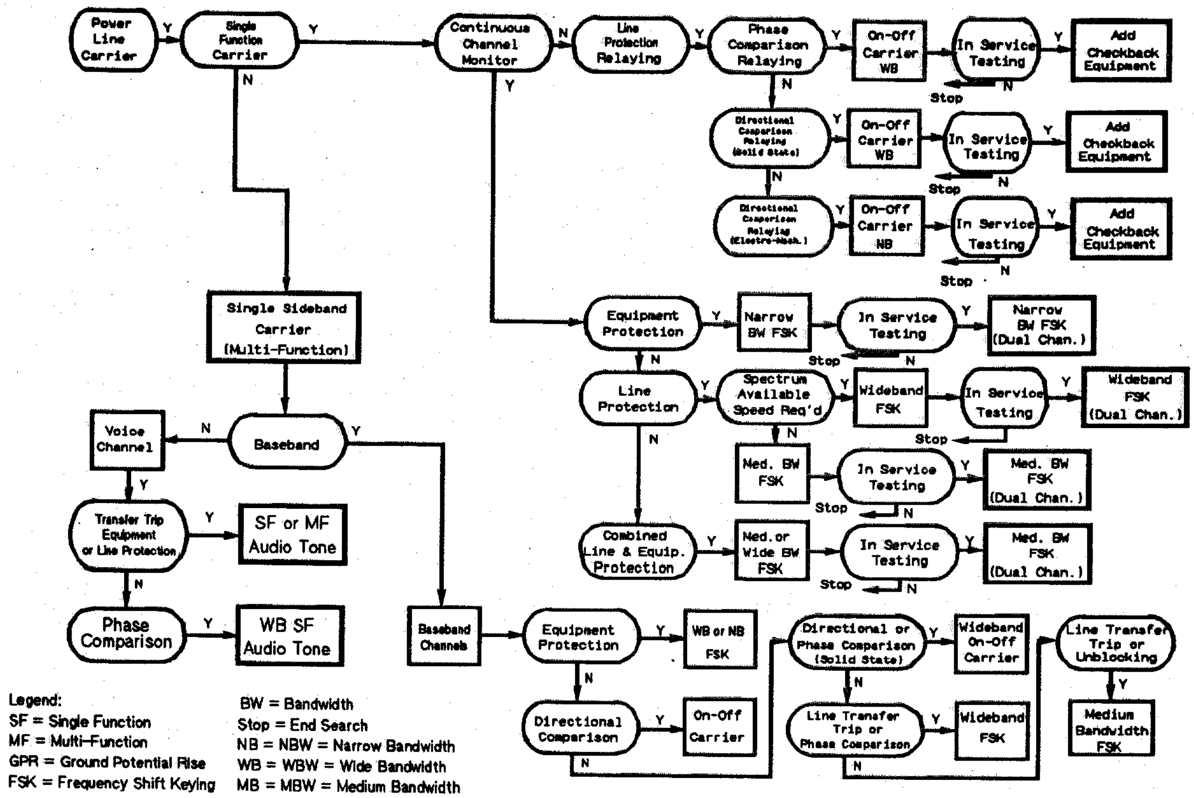


Figure 2-6A. Logic of Selecting PLC Relay Channels

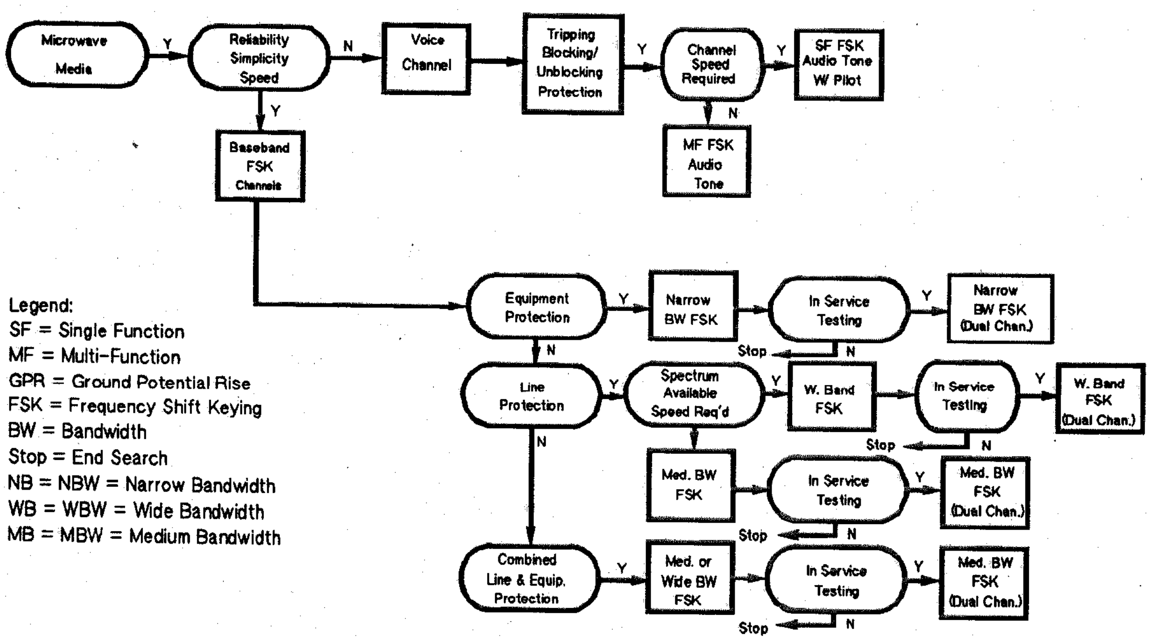


Figure 2-6B. Logic of Selecting Microwave Relay Channels

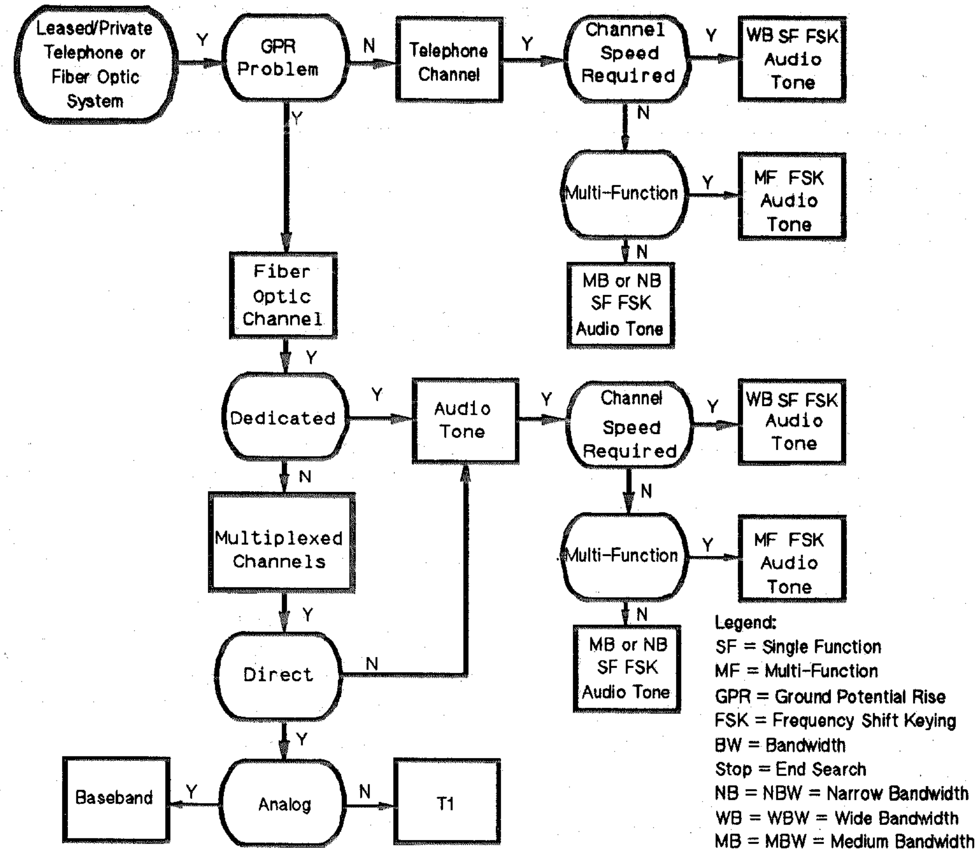


Figure 2-6C. Logic of Selecting Telephone and Fiber Optic Relay Channels

When leased or private wire telecommunication facilities enter an electric power station, they may be subject to ground potential rise (GPR), longitudinal induction, lightning, switching surges, and contact with power lines. These problems have jeopardized the communications integrity in some applications. To overcome these problems and preserve the telecommunication system dependability and security, fiber optic cables are being applied as an entrance link to the power station [6].

Another consideration concerns line configurations. In some cases, a terminal may have weak infeed on internal faults, which requires an FSK tripping-type channel to achieve simultaneous high-speed tripping at all terminals. However, it should be kept in mind that it is not always possible to ensure that tripping-type channels via power line carrier will get a trip signal through on a faulted line. To improve the trip-through capability, multi-phase coupling should be considered.

Table 2-2

Minimum Tolerable SNR Values for Relaying Channels

Function	Equipment	SNR (dB)
Single-Function Carrier		
⊖ Phase Comparison	WB ON-OFF	20
⊖ Directional Comparison	NB ON-OFF	15
⊖ Transfer-Trip		
25-100 ms	NB PLC FSK**	-5*
10 ms	MED. BW PLC FSK**	0*
5 ms	WIDE BW PLC FSK**	2*
Multi-Function Carrier	PLC SSB	
⊖ Baseband		
Phase Comparison	BASEBAND PLC FSK	20
Directional Comparison	BB ON-OFF CARRIER	15
Transfer Trip		
10 ms	MED. BW BB FSK	5
5 ms	WIDE BW BB FSK	7
⊖ Audio Tone (Transfer-Trip)		
4 ms*, 1000-Hz Spacing	HIGH SPEED FSK	+5
7 ms, 340-Hz Spacing	MED.SPEED FSK	0
10 ms, 240-Hz Spacing	MED./LOW SPEED FSK	-1
14 ms, 170-Hz Spacing	LOW SPEED FSK	-3
10 ms, 340-Hz Spacing	MULTI-FUNCT FSK	0
Voice-Grade Lines		
⊖ Audio Tone (Transfer-Trip)		
4 ms, 1000-Hz Spacing	HIGH SPEED FSK	+5
7 ms, 340-Hz Spacing	MED. SPEED FSK	0
10 ms, 240-Hz Spacing	MED./LOW SPEED FSK	-1
14 ms, 170-Hz Spacing	LOW SPEED FSK	-3
Microwave Baseband FSK		
25-100 ms	NARROW BW FSK	+5
10 ms	MED. BW FSK	+10
5 ms	WIDE BW FSK	+12

NOTES: ALL Channel times are for a noise-free channel. *Assumes 10 dB exalt on trip.

SIGNAL-TO-NOISE RATIO

Of primary importance in the application of channel equipment is adherence to the specified minimum signal-to-noise ratio (SNR). The performance of a channel can be predicted by the SNR at the receiving end of the channel. Table 2-2 gives the recommended minimum values. SNR is determined by taking the received signal level (in dBm) and subtracting from it the prevailing noise level (in dBm) for a 3 kHz bandwidth at the receiver terminal. This results in a value of SNR expressed in dB. To provide a usable signal for a given channel, the received signal must not be less than that which satisfies the specified minimum tolerable SNR.

OPERATING RANGE AND MARGIN

Each channel has a specified maximum operating range. This is determined by the transmitter power output (dBm) and the respective maximum receiver sensitivity (dBm). In general, the channel equipment is never set to its maximum receiver sensitivity, since this makes the receiver more susceptible to noise. Similar to SNR, each channel is applied to satisfy the recommended operating margin.

Figure 2-7 illustrates several important concepts in the application of channel equipment. For purposes of this illustration, a blocking ON-OFF carrier set has been chosen. Figure 2-7 shows a plot of signal level in dBm versus distance in miles for the assumed transmission line. For this case, a coupling loss of 5 dB is assumed at the transmitting and receiving ends. Based on the assumed 115 kV, 40 mile long transmission line, and the operating frequency of 200 kHz, the path loss is 15 dB. The resulting signal level at the receiver is +15 dBm.

Note the operating range of the channel. For the case illustrated, this is simply:

```
Transmitter output ..................+40 dBm @ 10 W level
Recommended receiver sensitivity ....-0 dBm
                                     ----
Operating range                       40 dB
```

Next, note the SNR for the received signal level for this assumed operating condition. For the transmitter output (+40 dBm) and the assumed path attenuation (15 dB), the received signal level (+20 dBm) on the line is determined. The signal level on the line is used because both the signal and noise are attenuated by the receiver coupling loss, and the SNR is unchanged. In this case the typical maximum noise level on the line is assumed to be -10 dBm. Therefore, the SNR is:

```
Received signal level (on line) ............+20  dBm
Line noise level .........................-(-10) dBm
                                          --------
SNR .......................................30 dB
```

In Figure 2-7, the recommended receiver sensitivity is set well above the line noise level. Therefore, in this case, channel performance is affected by the operating range, because the channel is limited by path attenuation rather than by noise. The SNR of 30 dB is well above the minimum of 15 dB considered adequate for directional comparison blocking carrier. If required, a 10 dB advantage in operating range and SNR can be obtained by using a 100 watt transmitter. Generally, 10 watts has been found to be adequate for all except unusual applications.

Note also in Figure 2-7 that an operating margin of 15 dB is provided. This is the difference between the received signal level and the channel receiver sensitivity setting which, in this case, is set equal to the recommended receiver sensitivity. Operating margin serves as a reserve upon which to draw during periods of increasing attenuation. This is where the term "reserve signal" is derived.

Table 2-3 lists the operating ranges and recommended operating margins for typical protective relaying channel equipment.

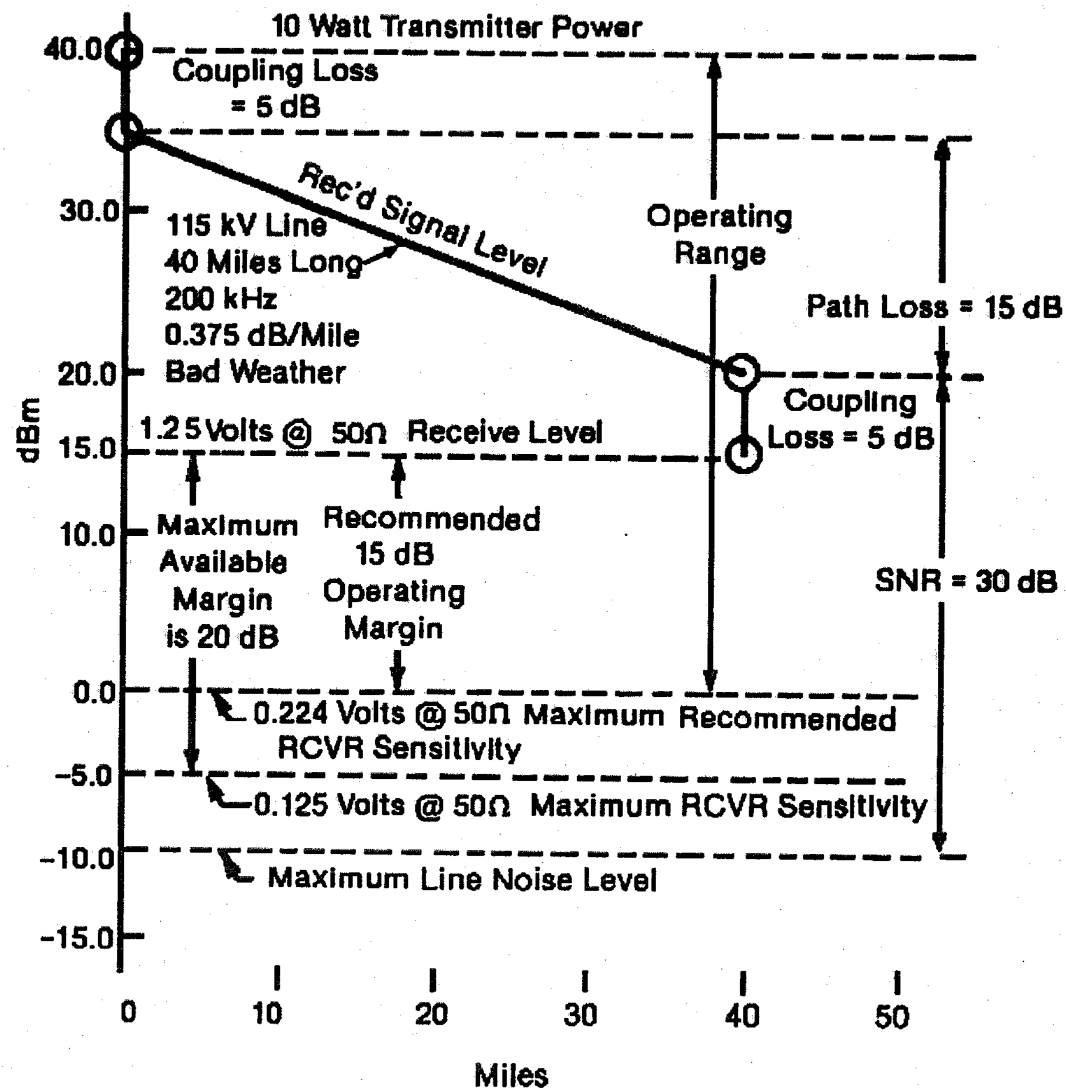


Figure 2-7 Operating Range and SNR for Directional Comparison Blocking Carrier Channel

Table 2-3
Recommended Operating Margins

PLC Equipment Type	Operating Range (dB)	Operating Margin (dB)
WB ON-OFF NB ON-OFF	45 for 10 watt 45 for 10 watt	15 15
 NB FSK MED.BW FSK WIDE BW FSK	1 W 10 W 100 W 63 73 83 53 63 73 53 63 73	 10-25* 10-25* 10-25*
SSB-PLC, BASEBAND ON-OFF CARRIER MED. BW FSK WIDE BW FSK AUDIO TONE MULTI-FUNCT.AUDIO TONE	 Depends on system config. Depends on system config. Depends on system config. Depends on system config. Depends on system config.	 15 10-25* 10-25* 10 10
MICROWAVE BASEBAND (ALL BANDWIDTHS)	Depends on microwave system configuration	10
AUDIO TONE	Greater than 40	10
MULTI-FUNCT. AUDIO TONE	Greater than 40	10

*For unblocking applications (U logic), the minimum values shown for margin are recommended to assure a channel permissive output (for conditions involving signal attenuation resulting from faults internal to the protected line section). For applications requiring direct trip through line-fault attenuation, the higher values shown for margin are recommended to enhance channel performance for this specific system requirement.

SELECTION TABLES

Table 2-4 lists the preferred carrier channels for various relaying applications. The table lists the type of relaying functions, the corresponding channels that would be applied based on the relaying system to be used, the channel time in milliseconds, the channel output module, and pertinent remarks concerning the channel.

Table 2-5 lists the single-function relaying channel characteristics for carrier and audio tone applications. The following information is provided:

1. Channel frequency range in kHz
2. Nominal spacing between like equipment in Hertz
3. Nominal bandwidth of the channel in Hertz
4. The type of modulation used: frequency-shift (FSK) or ON-OFF
5. Nominal channel time (back-to-back) in milliseconds
6. Type of transmitter keying available
7. Types of available receiver output modules
8. Applicable relaying functions
9. Remarks pertinent to the channel

Table 2-4
PLC Equipment Application Preferences[5]

Function	Equipment Type: ON-OFF	Equipment Type: FSK with Logic (1)	Equipment Type: FSK w/o Logic	Channel Time in ms(2)	Type of Output (4)	Remarks
BLOCKING	(WB) (NB) BASEBAND BASEBAND			1.5/2.0 3/5 3/5 (6) 3/5 (6)	T R T R	 SSB only SSB only
UNBLOCKING		(WB)U (MB)U	(WB) (MB)	5 10 (3)	S, T R, T	
PERMISSIVE UNDERREACHING OR OVERREACHING TRANSFER TRIP (single channel)		(WB)P (MB)P (NB)P	(WB) (MB) (NB)	5 10 (3) 25-100	S, T R, T R	Used for freq. conservation
PERMISSIVE UNDERREACHING OR OVERREACHING TRANSFER TRIP (dual channel)						Not recommended unless test functions or customer preference demands
DIRECT UNDERREACHING TRANSFER TRIP (dual channel)		 (WB)P 	(MB) (NB)	10 (3) 5 25-100(3)	R, S, T S, T R	Preference based on conservation of freq. spectrum Used for freq. conservation
DIRECT TRANSFER TRIP (dual channel)		(NB)D,P (MB)D,P (WB)D,P	(NB) (MB) (WB)	25-100 10 (3) 5	R R, S, T) S, T)	Preference based on conservation of freq. spectrum.
PHASE COMPARISON ⊖Single mixed ⊖Single mixed	 (WB) (NB)			 1.5/2.0 3.0/3.0	 T T	 Single freq. applications SSB only
COMBINED LINE RELAY AND DIRECT TRANSFER TRIP		(WB)T (MB)T		6/2 9/3 (3)	R, S, T) R, S, T)	Use MB FSK where relay time permits spectrum conservation

NOTES:
(1) (WB)U indicates "U" logic, (WB)P indicates "P" logic, etc.
(2) Where two times are given, first figure is operate time and second figure is reset time.
(3) Add 4 ms for relay output.
(4) R = relay output, S = SCR output, T = 5-volt output.
(5) Since this table covers only power line carrier channels, Audio tone equipment is not included.
(6) If faster channel time is desirable, wideband versions of ON-OFF baseband channels are available. Wideband channel time is 2/3 ms.

Table 2-5
Teleprotection Channel Frequency Spacing and Interface Guide

Equipment Type	Frequency in kHz	Nominal Spacing in Hz	Nominal BW in Hz	Nominal Channel Time in ms*	Keying (See Legend)	Receiver Output (See Legend)	Function	Remarks
				WITHOUT VOICE				
Audio Tone	1.445-	170	85	17**	7	3	TT, PTT	Increase channel time by
	3.315			14**	2	2	TT, PTT	4 ms with trans. filter
				14**	7	4	TT, DTT	
Audio Tone	1.200-	240	120	13**	7	3	TT, PTT	Increase channel time by
	3.120			10**	2	2	TT, PTT	3 ms with trans. filter
				10**	7	4	TT, DTT	
Audio Tone	1.190-	340	170	10**	7	3	TT, PTT	Increase channel time by
	3.23-			7**	2	2	TT, PTT, Unblk.	2 ms with trans. filter
				7**	7	4	TT, DTT	
Audio Tone	1.53-	1000	480	7**	7	3	TT, PTT	Increase channel time by
	2.55			4**	2	2	TT, PTT	1 ms with trans. filter
				4**	7	4	DTT	
Audio Tone	1.53-	1000	480	4**	2	2	ϕ Comp.	Increase channel time by
	2.55							1 ms with trans. filter
Multi-funct.	0.54-	200	960	10	1	1	TT, PTT	Increase channel time
(NB) tone	3.06							4 ms for heavy duty
								relay output
Multi-funct.	1.1-	500	1920	15	1	1	TT, PTT	Increase channel time
(WB) tone	2.61							4 ms for heavy duty
								relay output
NB FSK PLC	30-500	500	200	32	1	3	TT, PTT	
				20	2	2	PTT	(See Legend)
MBW FSK PLC	30-500	1500	500	14	1	3	See Table 2-4	6
				9	2	2	See Table 2-4	6
				9	1	4	See Table 2-4	6
				11	1	5	E/M Unblocking	
WBW FSK PLC	30-500	3000	1000	6	2	2	Unblocking with	
							DTC Logic.	
							See Table 2-4	
ON-OF CXR w/	30-511	2000	1300	3/5	8	SCA 9	E/M Unblocking	
Unblock. Aux								
ON-OFF CXR(NB)	30-511	2000	1300	3/5	8	SCA 9	Dir. Comp.	
ON-OFF CXR(WB)	30-511	4000	3300	1.5/2	2	2	Dir. Comp. &	
				WITH VOICE				
ON-OFF CXR(NB)	30-511	2000	1300	3/5	8	SCA 9	Dir. Comp.(E/M)	
ON-OFF CXR(NB)	30-511	2000	1300	3/5	2	2	Dir. Comp.(SS)	
ON-OFF CXR(WB)	30-511	4000	3300	1.5/2	2	2	Dir. Comp. &	
							ϕ Comp. (SS)	

LEGEND: 1 = Dry contact (no external voltage)
2 = 5 volts, 20 mA
3 = Multiple contact relay on G&T - (relatively slow speed)
4 = SCR (30 A for 10 ms, 10 A for 1 sec.) requires external reset contact
5 = Nominal single contact - time 3 ms
6 = Add 4 ms to channel time when logic panel is not used
7 = Voltage keying recommended from external source because of isolated (DC-DC converter) power supply. Switched battery voltage available for wetting the user's dry contacts when required.
8 = Station Battery
9 = Formerly BCA relay.

* Channel times are for back-to-back condition. Where two times are given, first figure is operate time and second figure is reset time.

** Without transmit filters.

In addition to single-function carrier, multi-function single-sideband (SSB) is also available for protective relaying. Table 2-6 describes the characteristics of available SSB relay channels. Similar information is provided as given in Table 2-5. Based on the foregoing, a wide variety of relaying channels are available to the user to meet particular application needs. Together with the generalized flow charts in Figures 2-6A-C, Tables 2-5 and 2-6 provide a guide to assist the user in selecting the relaying channel best suited to a given application.

Table 2-6
SSB Relay Channel Characteristics

Equipment Type	SSB Line Freq. in kHz	Nominal Spacing in Hz	Nominal Bandwidth in Hz	Mod.	Nominal Channel Time in ms*	Keying (See Legend)	Receiver Output (See Legend)	Function/Remarks
(BASEBAND)								
ON-OFF	40-500	+	700	AM	3/3	1	1 or SCA	Dir. Comp.
ON-OFF	40-500	+	700	AM	3/3	1 or 2	1 or 2	ϕ or Dir. Comp. (SS)
MBW FSK	40-500	++	500	FSK	7,11 or 14	1 or 2	2, 3 or 4	TT, Unblocking
WBW FSK	40-500	++	1000	FSK	4	1 or 2	2 or 4	TT, Unblocking ϕ Comp.
(AUDIO)								
TONE(SF)	40-500	170	85	FSK	19 16 16	5 2 5	3 2 4	TT, PTT TT, PTT TT, DTT Increase channel time by 4 ms with Tx output filter
TONE(SF)	40-500	240	120	FSK	15 12 12	5 2 5	3 2 4	TT, PTT TT, PTT TT, DTT Increase channel time by 3 ms with Tx output filter
TONE(SF)	40-500	340	170	FSK	12 9 9	5 2 5	3 2 4	TT, PTT TT, PTT TT, DTT Increase channel time by 2 ms with Tx output filter
TONE(SF)	40-500	1000	480	FSK	6	2	2	ϕ Comp: Increase channel time by 1 ms with Tx output filter
TONE(SF)	40-500	1000	480	FSK	6	1	SCA	Dir. Comp.
TONE(MULTI) (NB)	40-500	200	960	FSK	10	1	1	TT, PTT Increase channel time 4 ms for heavy duty relay output
TONE(MULTI) (WB)	40-500	500	1920	FSK	15	1	1	TT, PTT Increase channel time 4 ms for heavy duty relay output

LEGEND:
1 = Dry contact (no ext. voltage)
2 = 5 volts, 20 mA
3 = Multiple contact relay on G & T (relatively low speed)
4 = SCR (30 A for 10 ms, 10 A for 1 sec), requires external reset contact
5 = Voltage keying recommended from external source because of isolated (DC-DC converter) power supply.
Switched output available on request, for battery supply to user's dry contacts when required.

* Channel times are for back-to-back condition without transmit output filter. Where two times are given, first figure is operate time and second figure is reset time.
\+ Normally inserted at 30.75 kHz in baseband; 30.0 kHz for ON-OFF phase comparison.
++ Med. BW FSK normally inserted at 29.0 kHz and 31.0 kHz in baseband; WB FSK normally inserted at 31.0 kHz in baseband

PLC TELEPROTECTION CHANNELS

FREQUENCY SPACING

The spacing between operating frequencies of PLC equipment is of major importance in planning PLC systems to make maximum use of the frequency spectrum and to prevent interference.

Frequently, two or more units of equipment must be coupled to the power transmission line through a common line tuner and coupling capacitor. In other applications, two or more units may be at the same station but are coupled to opposite ends of the station power bus. Many other equipment arrangements are encountered in practice, and different degrees of isolation between equipments must be provided by proper choice of frequency spacing.

The spacing used is a function of equipment combinations as well as equipment characteristics, such as receiver selectivity. The isolation can be obtained with a variety of auxiliary coupling devices, such as balanced and skewed hybrids, series L/C units, bandpass filters, branching Lowpass/Highpass filters, and by using two-frequency line tuners. Tables 2-7A through 2-7F which follow give frequency spacing for many types of General Electric Power Line Carrier equipments assuming either 15 dB or 30 dB of isolation. **The system planner should be cautioned that 30 dB of isolation is difficult to achieve using RF hybrids which depend on the return loss of a line tuner for the major portion of this isolation.** Filters provide a more dependable degree of isolation, but the spacing required to provide this isolation is usually greater than the minimum spacing of the equipment determined by receiver selectivity.

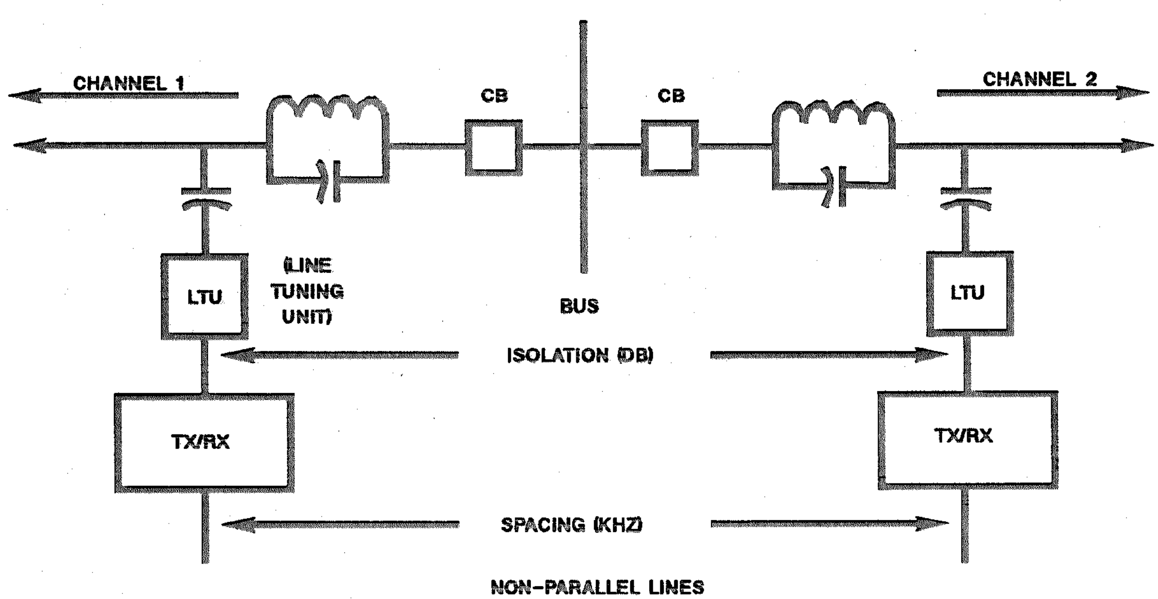


Figure 2-8. Bus Isolation for Non-Parallel Lines

The 15 dB isolation is more appropriate for most applications. When combining transmitters, a minimum of 15 dB isolation must be provided between the transmitters to prevent intermodulation distortion. Figures 2-8 and 2-9 show some types of PLC applications and the points where frequency spacing and isolation are required. When making system measurements, it is important to make measurements across resistive loads since the inputs of line tuners and the outputs of frequency selective filters are not constant impedances with frequency. Level measurements and isolation measurements can only be made when the impedance is known. (See a discussion of system measurements on page 2-49).

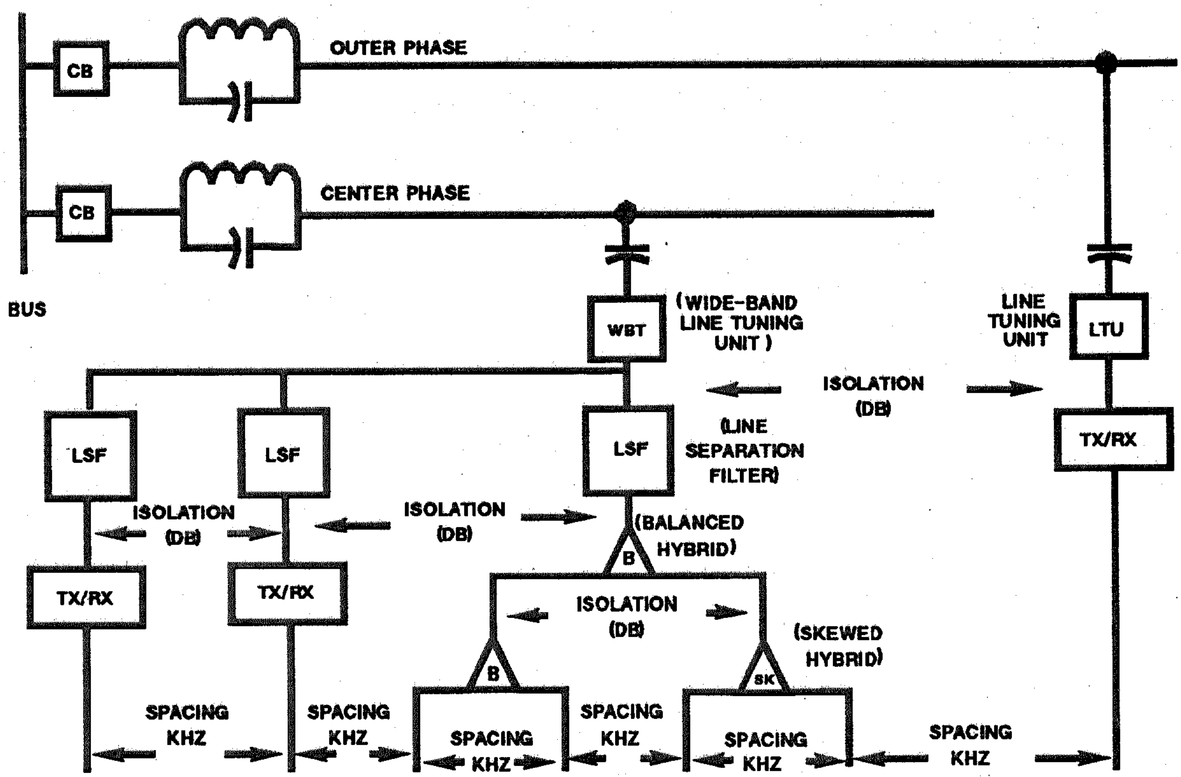


Figure 2-9. Spacing for Single Line, One or More Phases

Table 2-7A

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	CAO (CART) 1,2, & 4	CS-6 Without Voice	CS-7 Without Voice	CS-12 Without Voice	CS-16		CS-17	
							With Voice	Without Voice	With Voice	Without Voice
CAO(CART) 1,2 & 4 Note 1, 2 & 5		15.0 30.0	Notes 1 & 2	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	4 kHz 3 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	4 kHz 4 kHz
CS-6 (Note 5) Without Voice		15.0 30.0	9 kHz 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz
CS-7 (Note 5) Without Voice		15.0 30.0	6 kHz 5 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	5% or 6 kHz 4% or 5 kHz	5% or 8 kHz 4% or 6 kHz	5% or 6 kHz 4% or 5 kHz	5% or 8 kHz 4% or 5 kHz	5% or 6 kHz 4% or 5 kHz
CS-12 Without Voice		15.0 30.0	4 kHz 3 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	3 kHz 2 kHz
CS-16	With Voice	15.0 30.0	8 kHz 6 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	6 kHz 5 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz
CS-17 (Note 4)	With Voice	15.0 30.0	8 kHz 4 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	4 kHz 4 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2 kHz 2 kHz
CS-26 B Phase Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 6 kHz	9 kHz 8 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	5 kHz 4 kHz	9% or 9 kHz 8% or 8 kHz	5% or 5 kHz 4% or 5 kHz	5 kHz 4 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz
CS 26 & 27 Directional Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	4 kHz 4 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	5 kHz 4 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	5 kHz 4 kHz

Table 2-7B

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	CS-26B Phase Comp. Wide Filter		CS-26 & 27(A&B) Directional Comp. Wide Filter		CS26 & 27(A&B) Directional Comp. Narrow Filter		CA-30, 31 & 33	CA-40, 41 & 42
			With Voice	Without Voice	With Voice	Without Voice	With Voice	Without Voice		
CAO(CART)1, 2 & 4		15.0 30.0	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	4 kHz 4 kHz	8 kHz 6 kHz	4 kHz 3 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS-6 (Note 5) Without Voice		15.0 30.0	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 9 kHz 8% or 8 kHz	9% or 12 kHz 8% or 9 kHz	9% or 12 kHz 8% or 9 kHz
CS-7 (Note 5) Without Voice		15.0 30.0	5% or 8 kHz 4% or 6 kHz	5% or 6 kHz 4% or 5 kHz	5% or 8 kHz 4% or 6 kHz	5% or 6 kHz 4% or 5 kHz	5% or 8 kHz 4% or 6 kHz	5% or 6 kHz 4% or 5 kHz	5% or 12 kHz 4% or 9 kHz	5% or 12 kHz 4% or 9 kHz
CS-12 Without Voice		15.0 30.0	9 kHz 8 kHz	5 kHz 4 kHz	9 kHz 8 kHz	5 kHz 4 kHz	8 kHz 6 kHz	3 kHz 2 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS-16	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	12 kHz 9 kHz	12 kHz 9 kHz
	No Voice	15.0 30.0	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS-17 (Note 4)	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	12 kHz 9 kHz	12 kHz 9 kHz
	No Voice	15.0 30.0	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	2 kHz 2 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS-26A&B Phase Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	12 kHz 9 kHz	12 kHz 9 kHz
	No Voice	15.0 30.0	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	6 kHz 5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS26/27A&B Directional Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	12 kHz 9 kHz	12 kHz 9 kHz
	No Voice	15.0 30.0	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	5 kHz 4 kHz	12 kHz 9 kHz	12 kHz 9 kHz

Table 2-7C

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	Type 50 51A&B & 52A	Type 61A	Type 71A	Type 51C	Type 61C	Type 71C	CS-27C/28A Narrow Filter	CS-26C/28A Wide Filter
CAO(CART) 1,2 & 4		15.0 30.0	4 kHz 3 kHz	4 kHz 3 kHz	4.5 kHz 3.0 kHz	4 kHz 3 kHz	4 kHz 3 kHz	4.5 kHz 3.0 kHz	1.5 kHz 1.5 kHz	3.0 kHz 3.0 kHz
CS-6 (Note 5) Without Voice		15.0 30.0	9% or 9 kHz 8% or 8 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	1.5 kHz 1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	4.0 kHz 4.0 kHz
CS-7 (Note 5) Without Voice		15.0 30.0	5% or 6 kHz 4% or 5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	1.5 kHz 1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	4.0 kHz 4.0 kHz
CS-12 Without Voice		15.0 30.0	3 kHz 2 kHz	3 kHz 2 kHz	4.5 kHz 3.0 kHz	3 kHz 2 kHz	3 kHz 2 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	4.0 kHz 4.0 kHz
CS-16	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz	6 kHz 5 kHz
CS-17 (Note 4)	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	2 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2 kHz 2 kHz	4 kHz 4 kHz
CS-26A&B Phase Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz
CS26/27A&B Directional Comp. Wide Filter	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz	7 kHz 6 kHz

Table 2-7D

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	CAO (CART) 1,2, & 4	CS-6 Without Voice	CS-7 Without Voice	CS-12 Without Voice	CS-16		CS-17	
							With Voice	Without Voice	With Voice	Without Voice
CS26/27A&B Directional Comp. Narrow Filter	With Voice	15.0 30.0	8 kHz 6 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	4 kHz 3 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2 kHz 2 kHz
CA-30, 31, & 33		15.0 30.0	12 kHz 9 kHz	9% or 12 kHz 8% or 9 kHz	5% or 12 kHz 4% or 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CA-40, 41, & 42		15.0 30.0	12 kHz 9 kHz	9% or 12 kHz 8% or 9 kHz	5% or 12 kHz 4% or 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 50, 51 & 52 (A & B)		15.0 30.0	4 kHz 3 kHz	9% or 9 kHz 8% or 8 kHz	5% or 6 kHz 4% or 5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2 kHz 1.5 kHz
Type 61A		15.0 30.0	4 kHz 3 kHz	2.5 kHz 1.5 kHz	2.5 kHz 1.5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2.5 kHz 1.5 kHz
Type 71A		15.0 30.0	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	4.5 kHz 3.0 kHz
Type 51C		15.0 30.0	4 kHz 3 kHz	2.0 kHz 1.5 kHz	2.0 kHz 1.5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2.0 kHz 1.5 kHz
Type 61C		15.0 30.0	4 kHz 3 kHz	2.5 kHz 1.5 kHz	2.5 kHz 1.5 kHz	3 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2.5 kHz 1.5 kHz
Type 71C		15.0 30.0	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	4.5 kHz 3.0 kHz
CS-27C/28A Narrow Band		15.0 30.0	1.5 kHz 1.5 kHz	2 kHz 2 kHz	2 kHz 2 kHz	2 kHz 2 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	2 kHz 2 kHz
CS-26C/28A Wide Band		15.0 30.0	3.0 kHz 3.0 kHz	4 kHz 4 kHz	4 kHz 4 kHz	4 kHz 4 kHz	8 kHz 6 kHz	6 kHz 5 kHz	8 kHz 6 kHz	4 kHz 4 kHz

Table 2-7E

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	CS-26B Phase Comp. Wide Filter		CS-26 & 27 A&B Directional Comp. Wide Filter		CS26 & 27 A&B Directional Comp. Narrow Filter		CA-30, 31 & 33	CA-40, 41 & 42
			With Voice	Without Voice	With Voice	Without Voice	With Voice	Without Voice		
CS26/27A&B Dir. Comp. Narrow Filter (Note 4)	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	12 kHz 9 kHz	12 kHz 9 kHz
	No Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	2 kHz 2 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CA-30, 31, & 33		15.0 30.0	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CA-40, 41, & 42		15.0 30.0	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 50, 51 & 52 (A,B)		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	2 kHz 1.5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 61A (Note 3)		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	2.5 kHz 1.5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 71A (Note 3)		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	4.5 kHz 3.0 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 51C		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	2.0 kHz 1.5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 61C		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	2.5 kHz 1.5 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 71C		15.0 30.0	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	4.5 kHz 3.0 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS27C/28A Narrow Band		15.0 30.0	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	2.0 kHz 2.0 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CS26C/28A Wide Band		15.0 30.0	8 kHz 6 kHz	5 kHz 4 kHz	8 kHz 6 kHz	7 kHz 6 kHz	8 kHz 6 kHz	4.0 kHz 4.0 kHz	12 kHz 9 kHz	12 kHz 9 kHz

Table 2-7F

Minimum Frequency Spacing as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type		Isolation in dB	Type 50 51 & 52	Type 61A	Type 71A	Type 51C	Type 61C	Type 71C	CS-27C/28A Narrow Filter	CS-26C/28A Wide Filter
CS26/27A&B Dir. Comp. Narrow Filter (Note 4)	With Voice	15.0 30.0	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz	8 kHz 6 kHz
	No Voice	15.0 30.0	2 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	4.0 kHz 4.0 kHz
CA-30, 31, & 33		15.0 30.0	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
CA-40, 41, & 42		15.0 30.0	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz	12 kHz 9 kHz
Type 50, 51 & 52 (A,B)		15.0 30.0	0.5/1.5 kHz 0.5/1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	1.5 kHz 1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	3.0 kHz 3.0 kHz
Type 61A (Note 3)		15.0 30.0	2.5 kHz 1.5 kHz	1.5/2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.5 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz
Type 71A (Note 3)		15.0 30.0	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	3/4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.0 kHz 4.0 kHz	5.0 kHz 5.0 kHz
Type 51C		15.0 30.0	1.5 kHz 1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	1.5 kHz 1.0 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.0 kHz 2.0 kHz	3.0 kHz 3.0 kHz
Type 61C		15.0 30.0	2.5 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	2.5 kHz 1.5 kHz	2.5 kHz 1.5 kHz	4.5 kHz 3.0 kHz	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz
Type 71C		15.0 30.0	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.5 kHz 3.0 kHz	4.0 kHz 4.0 kHz	5.0 kHz 5.0 kHz
CS27C/28A Narrow Band		15.0 30.0	2.0 kHz 2.0 kHz	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz	2.0 kHz 2.0 kHz	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz	2.0 kHz 2.0 kHz	4.0 kHz 4.0 kHz
CS26C/28A Wide Band		15.0 30.0	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz	5.0 kHz 5.0 kHz	3.0 kHz 3.0 kHz	4.0 kHz 4.0 kHz	5.0 kHz 5.0 kHz	4.0 kHz 4.0 kHz	4.0 kHz 4.0 kHz

BASIC PLC SYSTEM

As shown in Figure 2-10, a basic power line carrier system consists of three distinct parts: the terminal assemblies consisting of transmitters, receivers and protective relays; the coupling and tuning equipment, which provides a means of connecting the terminals to selected points on the power transmission line; and the transmission line itself, which provides a suitable path for the transmission of carrier energy in the PLC band of

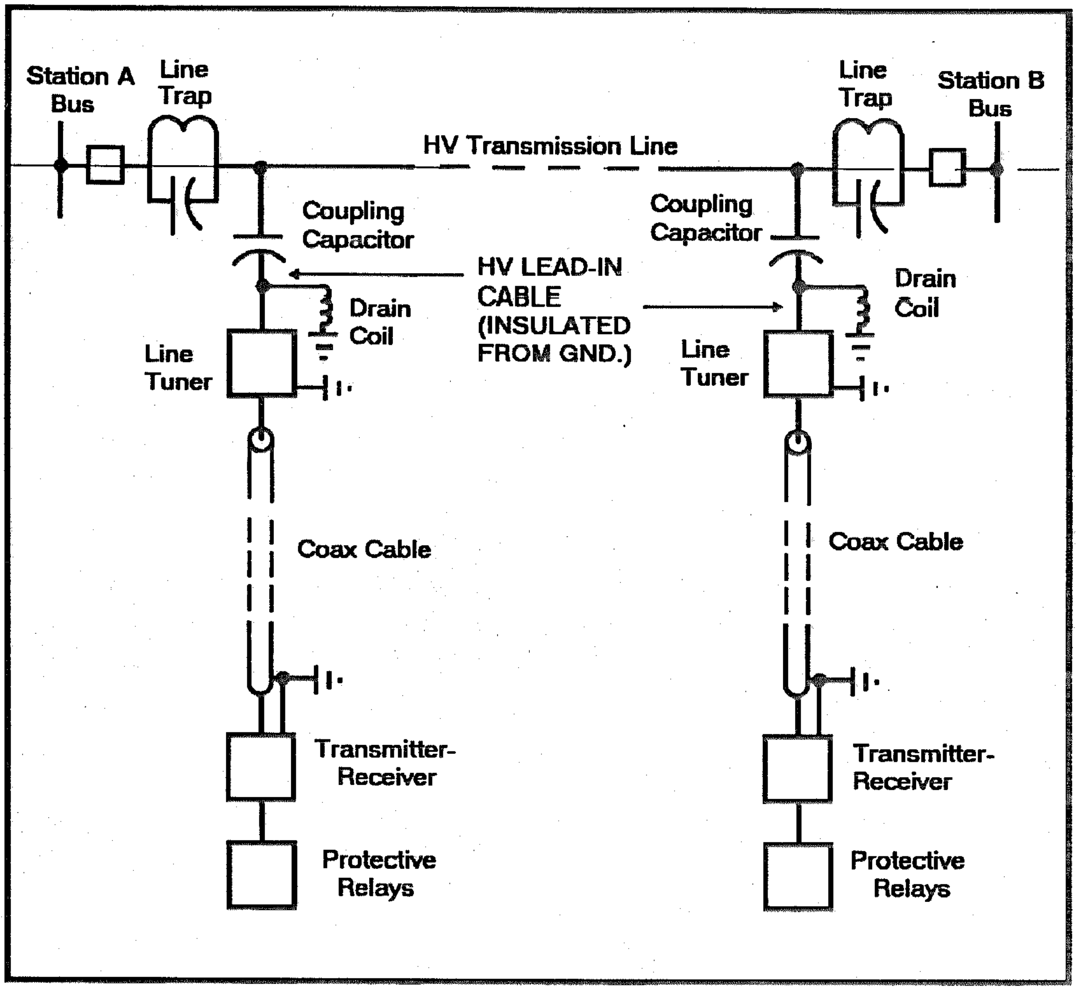


Figure 2-10. Basic PLC System for Protective Relaying

frequencies between terminals. At the terminals, one or more transmitters and/or receivers may be required, depending on the number of functions to be performed.

Coupling to power transmission lines is accomplished by means of high-voltage coupling capacitors which provide a low-loss path to the carrier signals, while at the same time blocking 50/60 Hz power frequency energy from the carrier equipment.

Line traps are inserted in power lines to minimize the loss of carrier power into adjacent lines and to prevent external ground faults from short circuiting the carrier signal of the unfaulted line. By proper choice of carrier frequencies, several functions can operate over the same power line without interference. Frequently, some of the carrier equipment can be used in common by two or more services, thus minimizing the investment.

The high voltage transmission line is used extensively for power line carrier relaying. It is capable of providing the simultaneous functions of communication and electric energy transmission. Power line carrier is used for pilot relaying and other company-owned communications. This is accomplished by coupling different types of PLC channels to the transmission line.

PLC is a technique by which low radio-frequency currents are propagated over metallic conductors. For carrier relaying, this may be an ac or dc transmission line or pipe-type power cable. The primary difference between HV power transmission and PLC transmission is the frequency of operation. Although the fundamental principles of both are the same, many factors of primary importance at carrier frequencies are negligible at power frequencies.

Frequencies in the range of 30-500 kHz have been employed for PLC relaying and other communication purposes, as this frequency range is high enough to be isolated from the transmission line and the noise it creates, yet not so high as to encounter excessive attenuation. Although frequencies somewhat lower than 30 kHz can be used, it is rather difficult to efficiently couple these frequencies to the transmission line by using coupling capacitors.

In power line carrier transmission, very low efficiency (in the order of 1%) is quite common. Losses in any transmission circuit are made up of resistance and leakage losses or, as they are commonly defined, series and shunt losses, respectively. The energy losses of carrier transmission do not involve large amounts of power and, therefore, do not represent an appreciable economic loss.

Transmission line facilities must be suitable for PLC. Under the user's prerogative are the relaying functions to be applied and the coordination of these functions into an existing system. Generally, relaying is a point-to-point system, using separate electronic equipment, but it may be incorporated into a multi-function SSB system. The signalling method depends on the channel used for the particular relaying system. If other services are required, in addition to protective relaying, then the best technical and economical method of combining the services via PLC must be evaluated. In addition, effective use must be made of the available carrier spectrum.

Application of a PLC system for pilot relaying considers the types of relaying channels available, the transmitter-receiver equipment characteristics, and the reliability and quality of performance required. An adequate transmission path must be furnished by the user under both switching and adverse weather conditions. Preliminary application studies of a PLC system will evaluate the trapping and coupling requirements, the carrier channel loss, the noise level at the receiver location, the effect of weather on losses and noise, the calculation of signal-to-noise ratio (SNR), and frequency separation requirements.

TRANSMISSION LINE CHARACTERISTICS

Three characteristics of power lines must be considered for the proper application of power line carrier. These are: (1) the expected line attenuation, (2) the surge or characteristic impedance of the transmission line involved, and (3) the expected line noise under both fair and adverse weather conditions.

Line Attenuation

Line attenuation is affected by the method of coupling, with phase-to-ground coupling being used most commonly. Attenuation in overhead transmission lines may be determined by performing the operations indicated in Figure 2-11 and by using the additional data in

Tables 2-8 through 2-10. Figure 2-11 and Tables 2-8 through 2-10 have been extracted from reference [1]. Additional factors concerning channel losses are discussed in Reference [1]. This graphical method is easy to apply. The results are usually very conservative. For more accurate results, the method described in Section 10 of this guide gives results closer to actual values. For very accurate characterization of EHV lines, a full blown physical Modal analysis is generally used. When phase-to-phase coupling is used, there is a definite return path over another phase wire and the line losses are usually lower than for phase-to-ground coupling. Modal analysis demonstrates that when all three phases of the transmission line are used to couple the PLC signal, this method (Mode 1) of coupling results in the lowest

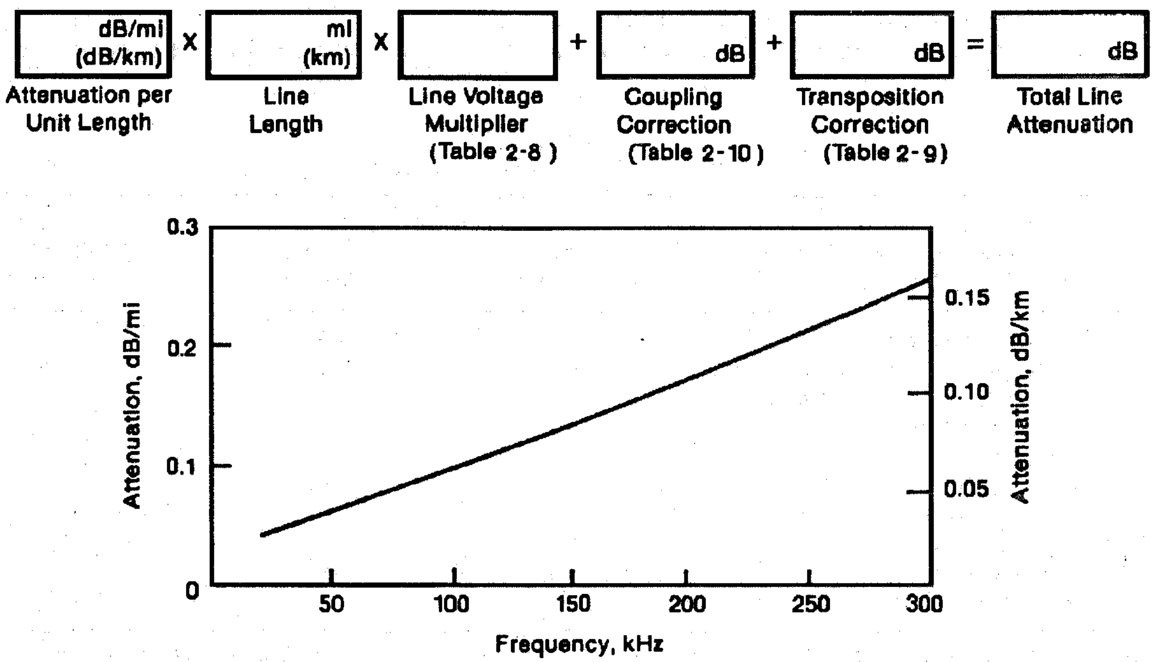


Figure 2-11. Method of Determining Attenuation for an Overhead Transmission Line

Table 2-8

Line-Voltage Multipliers

Line Voltage (kV)	Fair Weather	Adverse Weather*
34.5	1.46	2.19
69	1.20	1.80
115	1.11	1.66
138	1.00	1.50
230	0.78	0.98
345	0.72	0.90
500	0.54	0.68
765	0.50	0.63

*Under certain severe frost conditions, extreme losses can occur.

Table 2-9
Transposition Corrections*

Number of Transpositions	<10 mi (16 km)#	Correction (dB) >100 mi (160 km)#
1	0	6
2-4	0	8
5 or more	0	10

* Apply for 345 kV and higher.
# Linear interpolation should be used to determine loss between limits of line length.

Table 2-10
Coupling Correction Factors

Type of Coupling/ Shield Wires	Correction (dB) <5 mi (8 km)*	>50 mi (80 km)*	>150 mi (240 km)*
Mode 1 coupling	0	-2	-
Center phase to outer phase	0	0	-
Center phase to ground:			
Al or Cu wire	0	1	-
Steel wire	1	4	-
No shield wire**	8	8	-
Outer phase to ground:			
Al or Cu wire	0	-	13
Steel wire	1	-	15
No shield wire**	19	-	19

*Linear interpolation should be used to determine loss between limits of line length.
**Subject to wide variations.

propagation losses. However, Mode 1 coupling is more expensive than phase-to-ground or phase-to-phase coupling. Mode 1 coupling is generally used in applications which are extremely critical and require the highest degree of reliability and performance.

Characteristic Impedance

The characteristic impedance of a transmission line is important since it affects the coupling capacitor coupling efficiency and the bandwidth of line tuning equipment. The lower the characteristic impedance, the higher the coupling capacitor size required to minimize coupling losses. In addition, the characteristic impedance of a transmission line is important to the consideration of system losses such as shunt losses that may occur from adjacent lines and other loads. Typical surge or characteristic impedances for overhead lines and pipe-type power cables are given in Table 2-11.

Table 2-11
Typical Surge Impedance of Overhead and Pipe-Type Cable

Type of Conductors	Phase-to-Phase Coupling	Phase-to-Ground Coupling
Overhead Line		
Single conductor	650-800 ohms	350-500 ohms
Bundled conductor (2-wire)	500-600 ohms	250-400 ohms
Bundled conductor (4-wire)	420-500 ohms	200-350 ohms
Pipe Type Cable	40-100 ohms	20-50 ohms

Fault Attenuation

In many cases, PLC provides the only communication link with certain stations in a power system. This link may be utilized for voice communication, telemetering, supervisory control and protective relaying. Therefore, the utmost reliability is required in such a PLC system. In particular, the communication system may need to maintain communications during sustained faults or during the application of temporary linemen's grounds to the power line to which the PLC signals are coupled.

PLC relaying systems must operate satisfactorily during transient-arcing faults and must withstand high noise. Supervisory control systems on the other hand, should remain in operation during all forms of sustained fault, but may perhaps be permitted to be interrupted momentarily from the noise of a fault arc.

Table 2-12 is based upon measurements made on a 230 kV line, and PLC attenuation was measured with phase-to-phase and phase-to-ground coupling for various types of faults. This table is a summary of the maximum average additional attenuation for faults at various locations along the line for each type of coupling. To obtain the total attenuation during a fault, these values must be added to the normal line attenuation.

Table 2-12. Additional Attenuation Due to Faults

Type of Fault	Connection	Additional Attenuation in dB with Fault at			
		0 Miles	0.5 Mile	2.0 Miles	50 Miles
One Phase Grounded	ϕ to ϕ	11	11	11	11
	ϕ to Gnd.	38	20	17	11
Three Phases Grounded	ϕ to ϕ	50	40	37	37
	ϕ to Gnd.	58	48	39	37
One Phase Open	ϕ to ϕ	---	11-14	---	11
	ϕ to Gnd.	---	30-36	---	13-15
Three Phases Open	ϕ to ϕ	---	-----	----	46-76
	ϕ to Gnd.	---	-----	----	46-76

Line noise levels may be less than shown in these graphs. It is estimated that the values given are not exceeded more than 1% of the time for adverse weather or 25% of the time for fair weather.

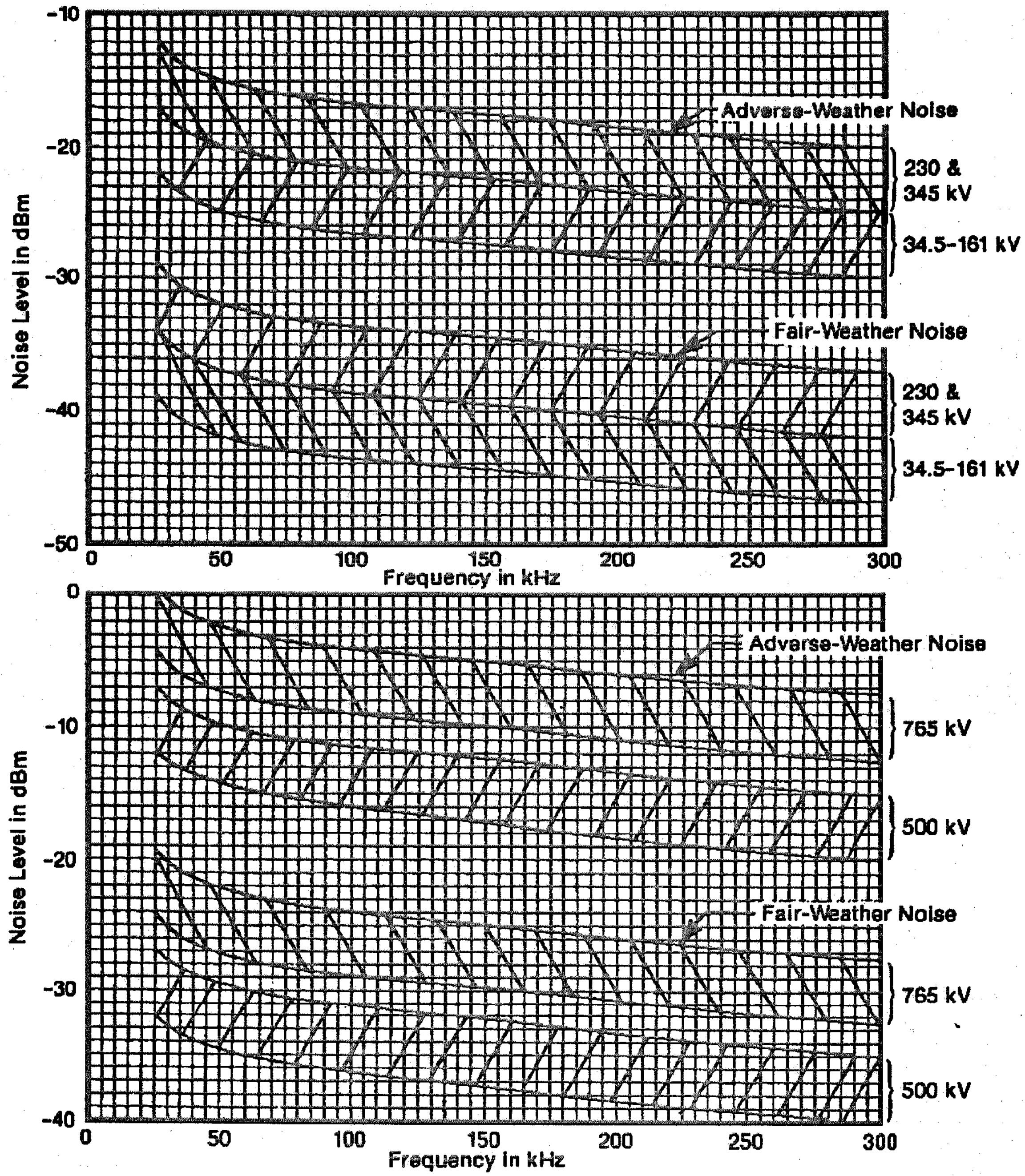


Figure 2-12. Range of Transmission Line Noise Levels (3 kHz Bandwidth)

Line and Fault Noise

The performance of a relaying channel, as noted earlier, depends essentially on the signal-to-noise ratio at the receiving end. The noise on the power line limits the amount of attenuation that a PLC channel can tolerate. Figures 2-12 and 2-13 give typical values of average (random) and impulse noise on power lines respectively. The noise levels in Figure 2-12 are typical average noise levels in a 3 kHz bandwidth at a 50 ohm impedance level. Figure 2-13, on the other hand, shows impulse noise levels over the nominal carrier frequency band.

Channel Performance Analysis

Figure 2-14 illustrates an example transfer trip line protection application. Figure 2-14 will be used to evaluate the PLC channel performance including channel loss, system loss, and signal-to-noise ratio (SNR).

A 100 mile, 345 kV line is assumed with one transposition at the center of the line. The shield wire is steel reinforced aluminum conductor (ACSR) cable.

Permissive underreaching transfer-trip (PUTT) line fault protection is the function to be provided. A bi-directional, single-function, 1-watt GUARD, 10 watt TRIP (EXALT) FSK channel is assumed with 3 kHz spacing between the transmitter and receiver. Medium bandwidth FSK gives a continuous channel monitor by transmission of the GUARD frequency. This bandwidth channel conserves the PLC spectrum, compared to wide bandwidth FSK, but this channel is slightly slower than the wider bandwidth channel. P logic is chosen for PUTT.

The carrier frequencies are assumed to be grouped near 100 kHz and RF hybrids are used for isolation between the transmitter and receiver. Coupling to the transmission line is center phase-to-ground. Single frequency line tuning and line traps are used, tuned at 100 kHz. Figure 2-15 illustrates the various system losses to be considered when evaluating the channel performance. Table 2-13 summarizes the typical losses to be expected for the application assumed in Figure 2-14. Therefore, based on Figure 2-14 and Table 2-13, the system loss from station A to Point B1 in Figure 2-14 is:

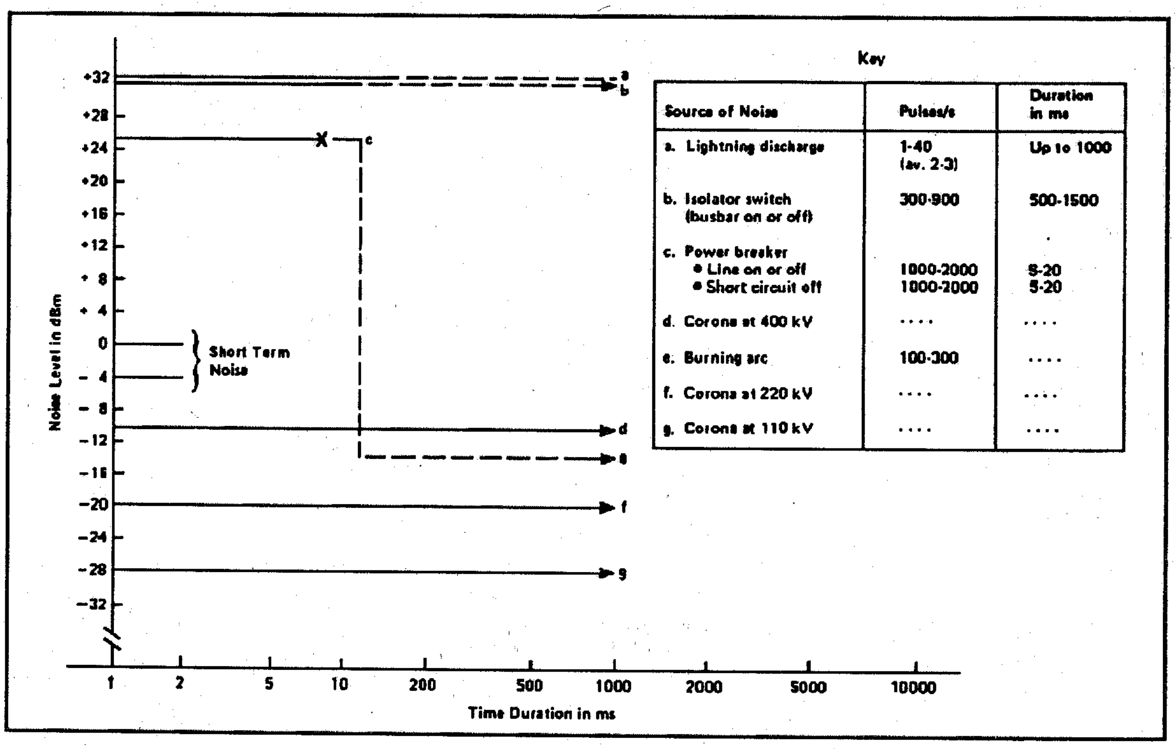
Hybrid	3.5 dB
Coupling	1.0 dB
Coupling mode correction	1.0 dB
Shunt	1.0 dB
Line	9.0 dB
Transposition	6.0 db
System Loss @ B1 =	21.5 dB

The foul weather noise for a typical 345 kV line at 100 kHz is -19 dBm. Since the coupling equipment at station B will attenuate both the signal and noise by the same amount, the SNR is determined at point B1. Hence:

Transmitter signal (1 W)	+30.0 dBm
System Loss at point B1	21.5 dB
Received signal level at B1	8.5 dBm
Line noise	-19.0 dBm
SNR = 8.5 - (-19)	27.5 dB (foul weather)

Table 2-13
System Losses

Loss Item	Loss Value (dB)
Line Trap Shunt Loss	1.0
Coupling Mode Correction	1.0
Coupling Loss (Tuner and Coax)	Allow 1.0
Line Attenuation	7.0
Foul Weather Attenuation (add 25% correction factor)	8.75 (round off to 9.0)
Transposition Loss	6.0
Hybrid	3.5



Key

Source of Noise	Pulses/s	Duration in ms
a. Lightning discharge	1-40 (av. 2-3)	Up to 1000
b. Isolator switch (busbar on or off)	300-900	500-1500
c. Power breaker		
• Line on or off	1000-2000	5-20
• Short circuit off	1000-2000	5-20
d. Corona at 400 kV	....	....
e. Burning arc	100-300	....
f. Corona at 220 kV	....	....
g. Corona at 110 kV	....	....

Figure 2-13. Typical Impulse Noise Levels on Power Lines (4 kHz Bandwidth)

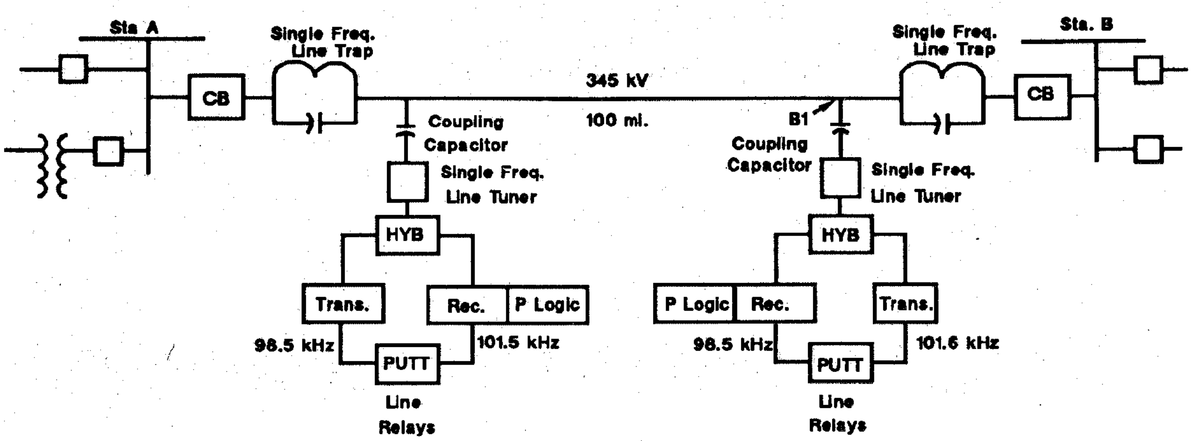


Figure 2-14. Transfer Trip Line Protection

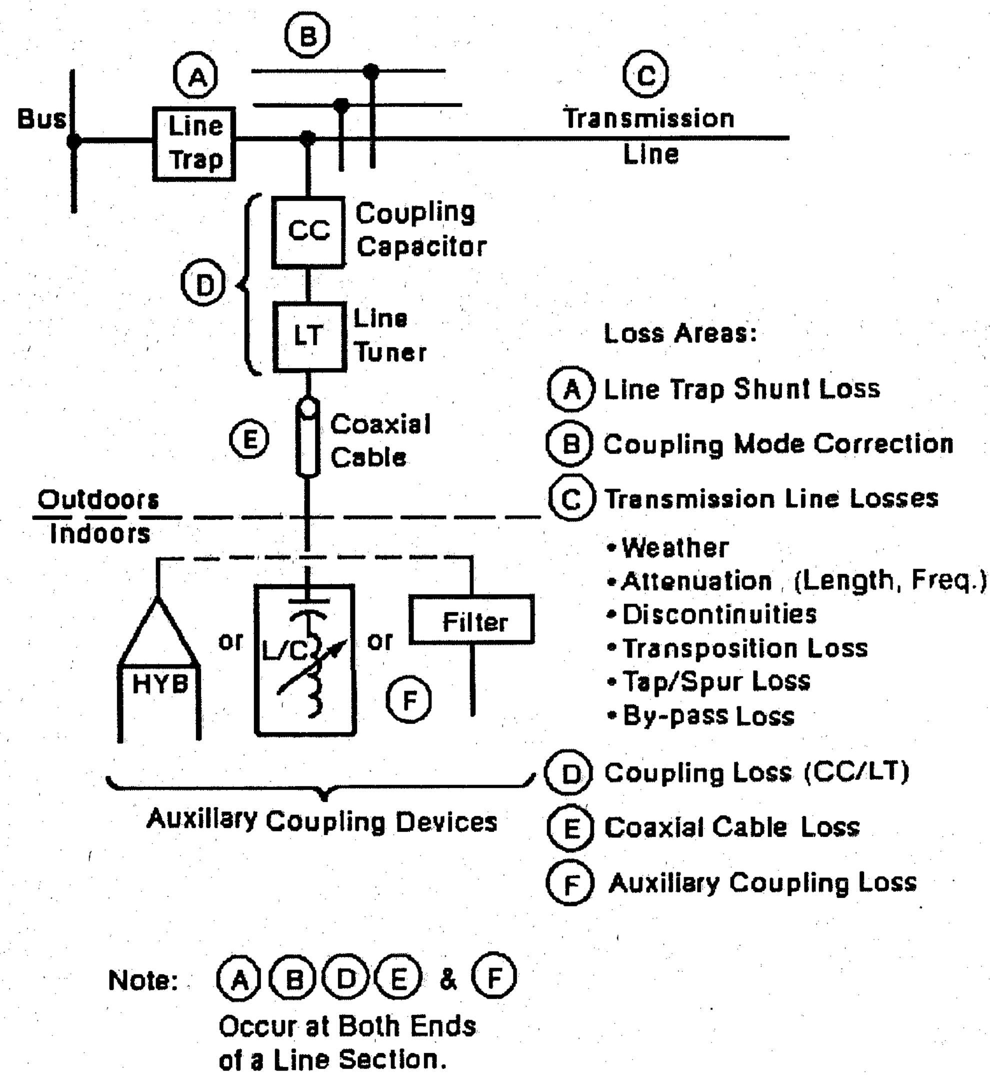


Figure 2-15. System Losses

The 1 watt level is used for SNR calculations since the system must operate at the guard level in foul weather. The 10 dB exalt will increase the ability of the channel to signal through a fault. The calculated SNR is well above the 0 dB minimum required for the medium bandwidth FSK channel. The total channel loss is based on fair weather analysis, namely:

Attenuation to B1	19.5 dB (fair weather)
Coupling loss (Station B)	1.0
Shunt loss (Station B)	1.0
Hybrid loss (Station B)	3.5
Total	25.0 dB (fair weather)

This calculation is made to be sure that the carrier receiver has adequate sensitivity for the given application. For this purpose, the fair weather loss figure (for the transmission line) is used.

The typical receiver sensitivity for the medium bandwidth FSK channel is normally adjusted so that the alarm relay operates for 10 dB increase in channel loss beyond the fair weather loss. A margin for reliability is added to give a total operating margin of 15 dB. For the medium band FSK channel, a 1 watt transmitter has an operating range of 53 dB. The receiver operating range must be adequate to include:

Total Attenuation	25 dB
Margin	15 dB
Total	40 dB (versus 53 dB available)

Hence, for this example, the following is adequate for the medium bandwidth FSK channel:

Transmitter Power	1 watt (+30 dBm)
Coupling	Center phase-to-ground
Frequency	Grouped near 100 kHz
SNR	27.5 dB (0 dB minimum required)
Operating Margin	15 dB (up to 28 dB available in this example)

This example has illustrated the method of evaluating the channel performance for a single-function power line carrier system.

COUPLING CONFIGURATIONS

The objective of the coupling equipment is to transfer through this circuit the greatest amount of the power provided by the transmitters at the sending end station, and to provide the lowest loss path at the receive end of the circuit to complete the circuit in any situation which may develop. This includes fair weather, inclement weather, ice conditions, and in fault conditions and during any switching. The amount of equipment required to provide this function will depend on the number of functions coupled, the importance of always getting a signal from one end of the line to the other, and the frequency selection. The complexity of the coupling circuit relates to its redundancy, and in most situations to the receive levels required. The cost of the coupling circuitry also depends on the complexity, or number of phases coupled. In some situations the CCVT's are part of the station equipment, but line traps must be added to all coupled phases, and at taps to prevent these circuit ends from reducing the receive levels to unacceptable values.

In order to maximize the coupled energy to the line, the selection of line traps, coupling capacitors or CCVT's, line tuners, and auxiliary coupling should be made with coupling efficiency in mind. An important consideration is to use compatible line tuners and line traps. Therefore, single frequency traps and single frequency line tuners should be used together and at all ends (including taps) if this is all that is required. However, if the application calls for wide band tuners and traps, then these two components should match at all terminals on the line. This means that two-frequency tuners are not used with wideband traps, and conversely. The tuners and traps provide the bandwidth limiting characteristics of the coupling circuit, and these also determine the degree of match for transmitters and receivers, as well as hybrids. Reflections will result when any circuit end is not terminated in the passband of the system. This includes the entire band of frequencies transmitted from any station.

Instrumentation is available to measure the reflected power at all line ends and to optimize the tuning and coupling to the lines. Wideband tuners are available to cover the bandwidth of most coupling requirements. Subsequent sections of this guide detail the techniques which have proven to be successful in optimizing the tuning of line tuners.

The most common and simplest mode of coupling carrier to a power line is phase-to-ground coupling, shown in Figure 2-16. The transmitter-receiver is coupled through a line tuning unit and coupling capacitor between one phase and ground. A line trap is also used in the coupled phase. For the lowest attenuation of the PLC signal, the center phase is used. Actually, as the signal propagates down the line, it converts into its natural mode of propagation and the return path is over the two outside phase wires. This method of coupling is generally used on short to medium length lines. Presence of a ground wire does improve the propagation of the PLC signal. If the outer phase wire is used for coupling or if the ground wire is steel or not used, the PLC transmission efficiency suffers. Also, with this method of coupling, there is no redundancy for single contingency short or open circuits. In addition, depending on the location and type of fault on the transmission line, the additional attenuation due to faults may vary from 11 to 76 dB [9].

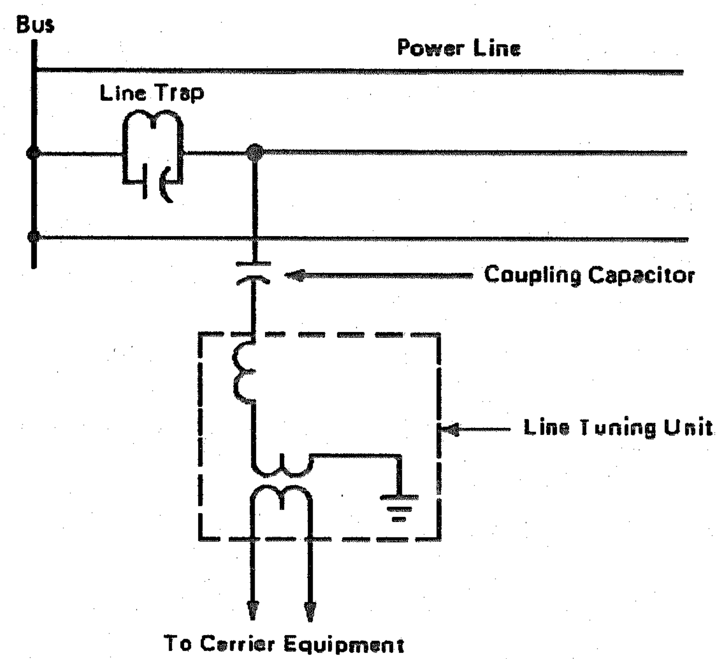


Figure 2-16 Phase-to-Ground Coupling

Interphase coupling, Figure 2-17, consists of coupling the transmitter-receiver between two phase wires. It operates balanced to ground and automatically converts to phase-to-ground coupling, with about 3 dB additional loss, if a short or ground occurs on one of the coupled phases. This prevents complete loss of the PLC signal. Lowest attenuation is provided when the carrier is coupled to adjacent phase wires.

As shown in Figure 2-17, two line traps, two coupling capacitors and two line tuners are used. This method of coupling provides about 3 dB improvement in coupling efficiency compared to phase-to-ground coupling when the coupled phase is the center phase. Since it does operate balanced to ground, with the signal going down one of the coupled phases and returning on the other coupled phase, the presence of the ground wire is less critical. Phase-to-phase coupling is recommended for use on long transmission lines and for relay applications using primary and secondary carrier coupling.

For close-in faults on a power line using interphase coupling, the additional attenuation due to the fault is about two-thirds to one-fifth less than with phase-to-ground coupling, depending on the type of fault [9]. For faults further out on the line, the additional attenuation is about the same as with phase-to-ground coupling.

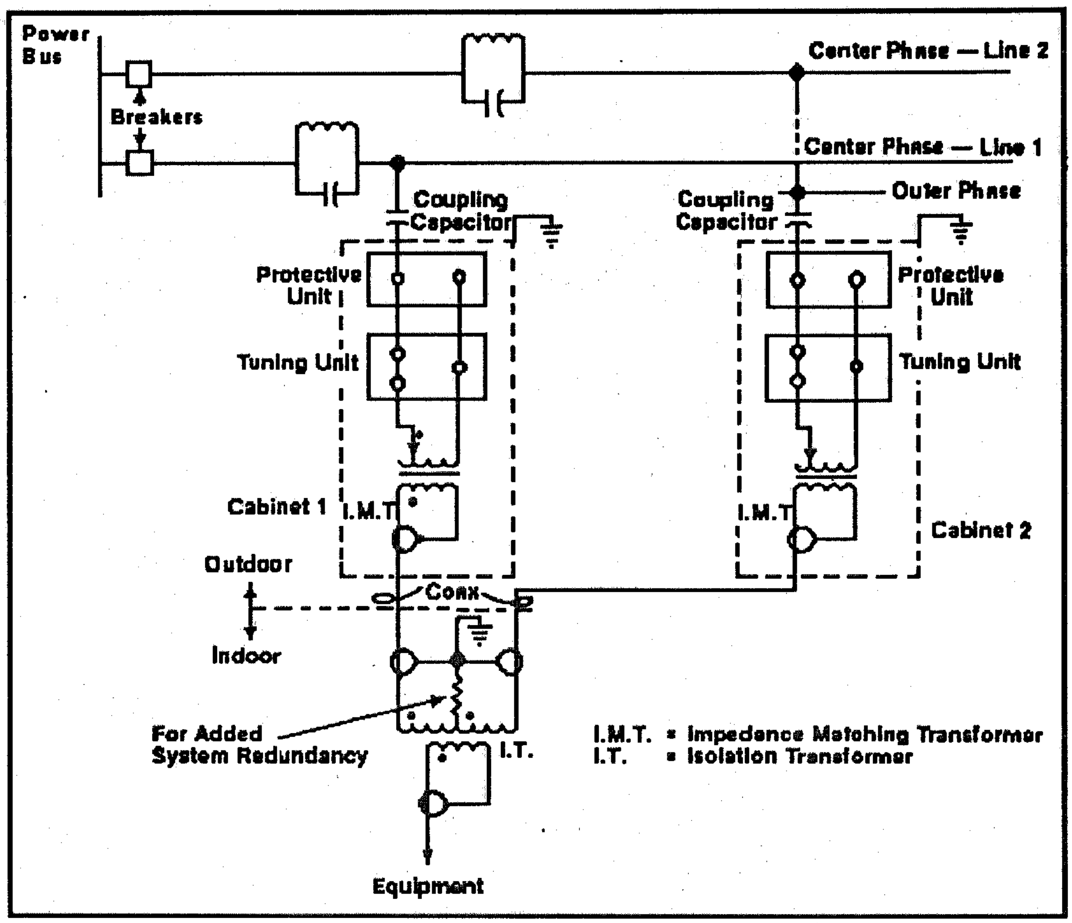


Figure 2-17. Two-Cabinet Interphase or Intercircuit Coupling

Mode 1 coupling, Figure 2-18, consists of coupling the transmitter-receiver equipment to all three phases. A 3 dB improvement in coupling efficiency is obtained over phase-to-phase coupling. Generally, Mode 1 coupling is applied on critical service, long EHV lines or series-compensated lines. With this method, the signal is transmitted down the center phase and returns on the two outer phases.

In Figure 2-18, the line equipment consists of three line traps and coupling capacitors per terminal. Also, three outdoor line tuning units and impedance matching transformers are used, including indoor low impedance (50 ohm) isolation/balance transformers and standard coax cables. This system automatically reverts to phase-to-ground or phase-to-phase coupling for opens or shorts on the coupled phases, thus providing a highly dependable and redundant system. The additional coupling loss under this condition of operation is 3 dB when the system reverts to phase-to-phase coupling and 5 dB for phase-to-ground.

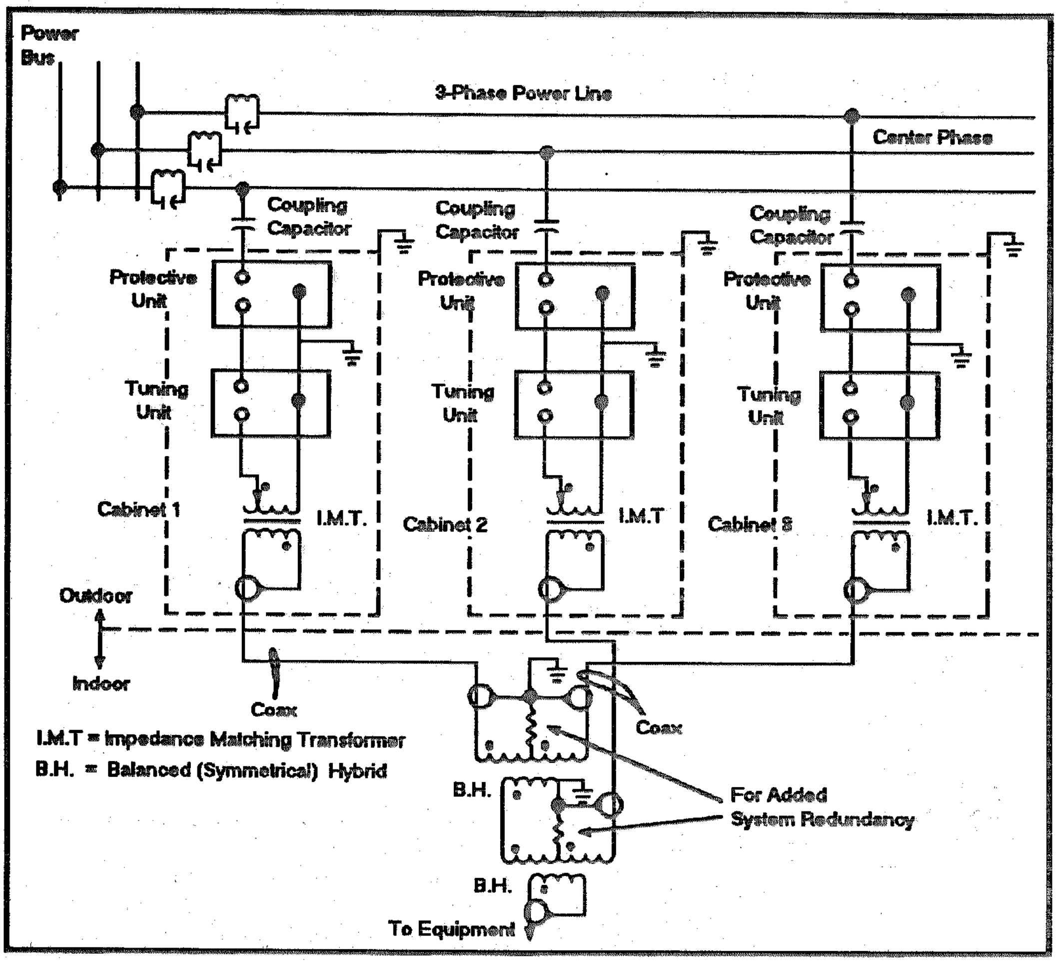


Figure 2-18. Mode 1 Coupling

Primary and Secondary Carrier Coupling

Often, the relaying on a particular line is so important that carrier is used for primary communication and another medium, such as microwave or audio tones over wire lines, is used as the second communication medium. In the event of failure in one system, the second system performs the required function.

Some power line carrier systems have been designed to provide primary and secondary communication. However, most of these systems have been combined and interconnected into a common coupling network and a failure within the coupling network may result in failure of both systems or reduced coupling efficiency.

A coupling network (patented by General Electric) allows power line carrier to be used for <u>both</u> primary and secondary communication equipments, thus eliminating the expense of a second communication medium.

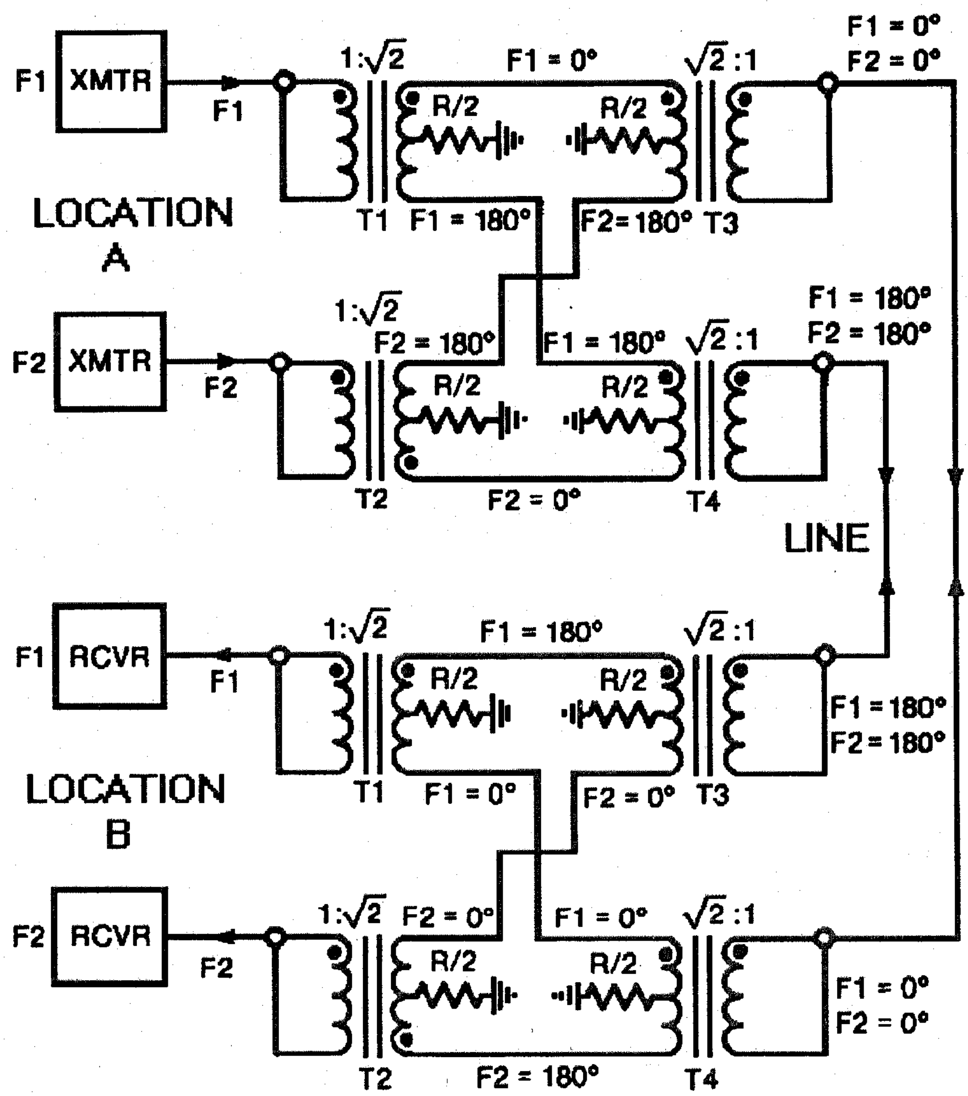


Figure 2-19. Balanced Combiner

The method uses a balanced combiner coupling network which is designed to offset the disadvantages of a "common coupling network." The modes of propagation are generated for the primary and secondary circuits separately and then combined. Proper phase and magnitude of voltages associated with each function are maintained in an independent manner.

The balanced combiner, as illustrated in Figure 2-19, accepts two different transmit signals (one signal into each of the two input ports), divides each input signal for transmission over two different wires, and establishes the proper phase shifts in each signal such that the signal on one conductor wire is 180 degrees out of phase with the same signal on the second conductor wire.

With balanced loads and the phasing shown, no current will flow in resistors R/2 of transformers T1 and T2. The transmit signal power coupling into the inputs of transformers T1 and T2 is divided and connected to the appropriate inputs (to achieve proper phasing) of transformers T3 and T4. On a conductor-to-conductor basis, the signal loss associated with transformers T1 and T2 consists of the transformer insertion loss only which is typically 0.1 dB or less. For example, the transmit signal F1 coupled into the input port of transformer T1 is divided, with half of the signal power appearing at each of the output ports of transformer T1. The two output ports of transformer T1 are connected to the appropriate input ports of transformers T3 and T4. Therefore, on a conductor-to-conductor basis, half of the transmit signal F1 is connected to transformer T3 for transmission over one phase wire, and the other half of the F1 signal is connected to transformer T4 for transmission over the second phase wire.

Since two different transmit signals (F1 and F2) are coupled into the two input ports of transformers T3 and T4, current does flow through resistors R/2 of transformers T3 and T4 resulting in a 3.0 dB signal loss through each transformer. Therefore, on a conductor-to-conductor basis, the total net transmit signal loss through the balanced combiner is typically 3.2 dB.

At the receive end, both signals (F1 and F2) are received on each conductor wire (180 degrees out of phase). The balanced combiner shifts the signals received on one of the phase wires 180 degrees and combines them (in phase) with the signals received on the second conductor wire.

Both types of coupling devices, the balanced transformer and the balanced combiner, are physically mounted within their respective cabinets and connections to the line tuners are made by two separate coaxial cable runs. This method of mounting and the use of the two runs of coaxial cable provides increased system dependability in that should one coaxial be damaged or taken out of service, the communication system will remain in service with a 6.0 dB reduction in signal level.

A balanced combiner designed for Mode 1 coupling is also available. Essentially, the combiner functions as described for the interphase scheme but provides proper signal distribution with correct phase relationships on each phase conductor. Alternately, high-pass and low-pass filters can be used to replace hybrid transformers T3 and T4 in Figure 2-19. This arrangement features lower loss than the hybrid transformer approach. Insertion loss is typically less than 0.5 dB, giving a total loss of less than 1.0 dB for the network. Minimum practical spacing between the high-pass and low-pass frequency bands is approximately 10 % of the geometric mean frequency involved. (See Section 12, Appendix C for a detailed description of low-pass /high-pass applications.)

Line Equipment

The application of line equipment in a basic power line carrier system includes trapping, coupling, tuning equipment and line-separation equipment, in addition to the channel transmitter and receiver equipment. Several typical arrangements are illustrated in Figures 2-20 through 2-23. Characteristics of each arrangement are also noted, along with pertinent application information. Resonant and wide-band tuning and trapping for different channel applications are illustrated.

Line traps are available in a number of continuous current ranges and inductance ratings. They are designed for resonant-tuned single and two-frequency trapping, fixed wide-band and adjustable wide-band trapping, and untuned operation. Table 2-14 summarizes the ratings of the various types of line traps. (See reference [32]).

Table 2-14

Line Trap Ratings

Current Ratings		Inductance						
		0.265 mH			0.53 mH	1.06 mH		1.59 mH
$I_{Cont.}$ (Amps)	I_{2-Sec} (KA)	Reso-nant	Fixed WB	Adjust able WB	Factory-Adjusted WB	Factory-Adjusted WB	Untuned	Untuned
400	15	X	X	X	X	X	X	X
800	20	X	X	X	X	X	X	X
1200	36	X	X	X	X	X	X	X
1600	44	X	X	X	X	X	X	X
2000	63	X	X	X	X	X	X	-
3000	63	X	X	X	X	X	X	-
4000	80	X	X	X	X	-		-

The 0.265 mH traps are available in a number of frequency ranges and are provided with either resonant, fixed wide-band or adjustable wide-band tuning packs which can be readily converted from one type of tuning to another. The higher inductance models are available with factory-adjusted wide-band tuning packs. High inductance models offer improved bandwidth characteristics for use in single-sideband and other wide-band applications.

Coupling capacitors are grouped according to the relative capacitance of the capacitor. The Extra-High-C capacitors provide capacitances about three times larger than the High-C capacitors. Table 2-15 lists typical available coupling capacitors and coupling capacitor voltage transformers (CCVT's). (See reference [31]).

Coupling capacitors consist of one or more porcelain-clad, oil-filled capacitor modules bolted to the top of a suitable base housing. The base contains various carrier accessories for carrier coupling and, where applicable, a coupling capacitor voltage transformer (CCVT). As shown in Figures 2-20 through 2-23, the capacitor is operated with a line tuner to provide efficient transfer of carrier energy between the transmitter or receiver and the high voltage line. Normally, the coupling capacitors provide phase-to-ground coupling, but where the application requires it, the signal is fed to more than one phase by the use of additional coupling capacitors.

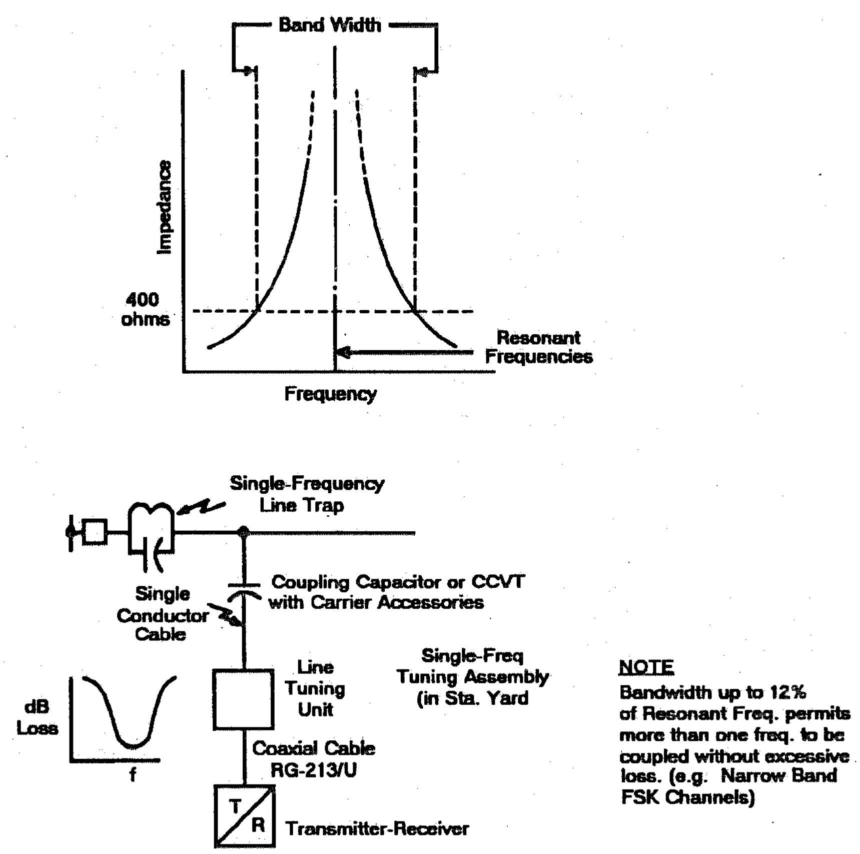
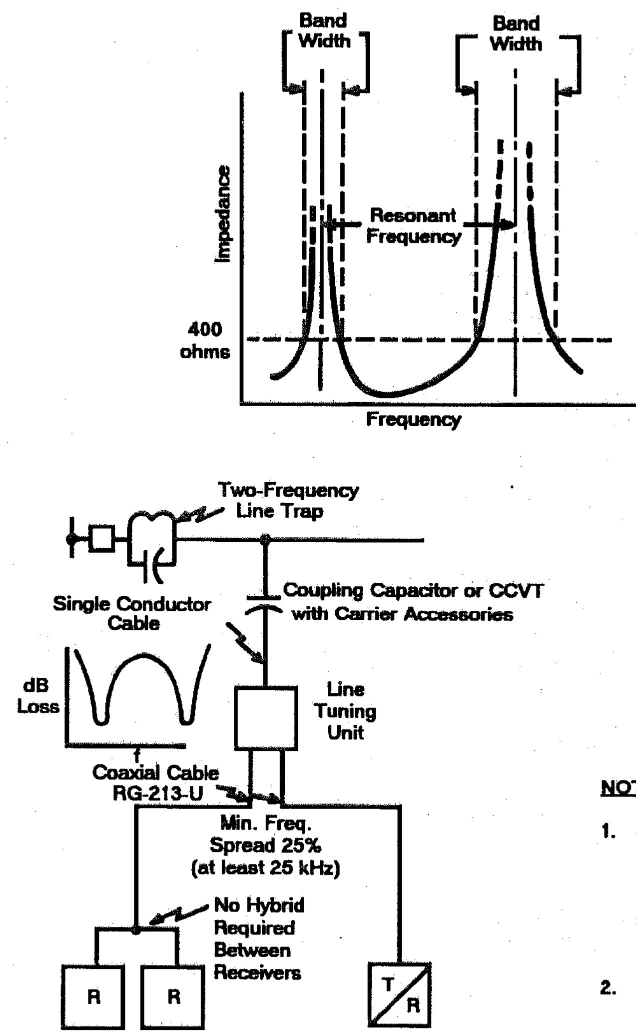


Figure 2-20
Single-Frequency Resonant Tuning and Trapping for Blocking Carrier Application

Table 2-15
Coupling Capacitor and CCVT Ratings

Rated System Voltage in kV	Capacitance in Microfarads	
	High-C	Extra-High-C
66/69	0.010	-
115	0.006	0.02
138	0.005	0.0165
161	0.0043	0.015
230	0.003	0.010
345	0.00215	0.0075
500	0.0015	0.005



NOTES

1. Losses of line tuning assemblies and wideband filters decrease as C. C. or CCVT capacitance, line impedance or frequency increases.

2. Passband of line tuning assemblies widens as C. C. or CCVT capacitance , line impedance or frequency increases.

Figure 2-21. Two-Frequency Resonant Tuning and Trapping with ON-OFF Carrier and FSK Receivers

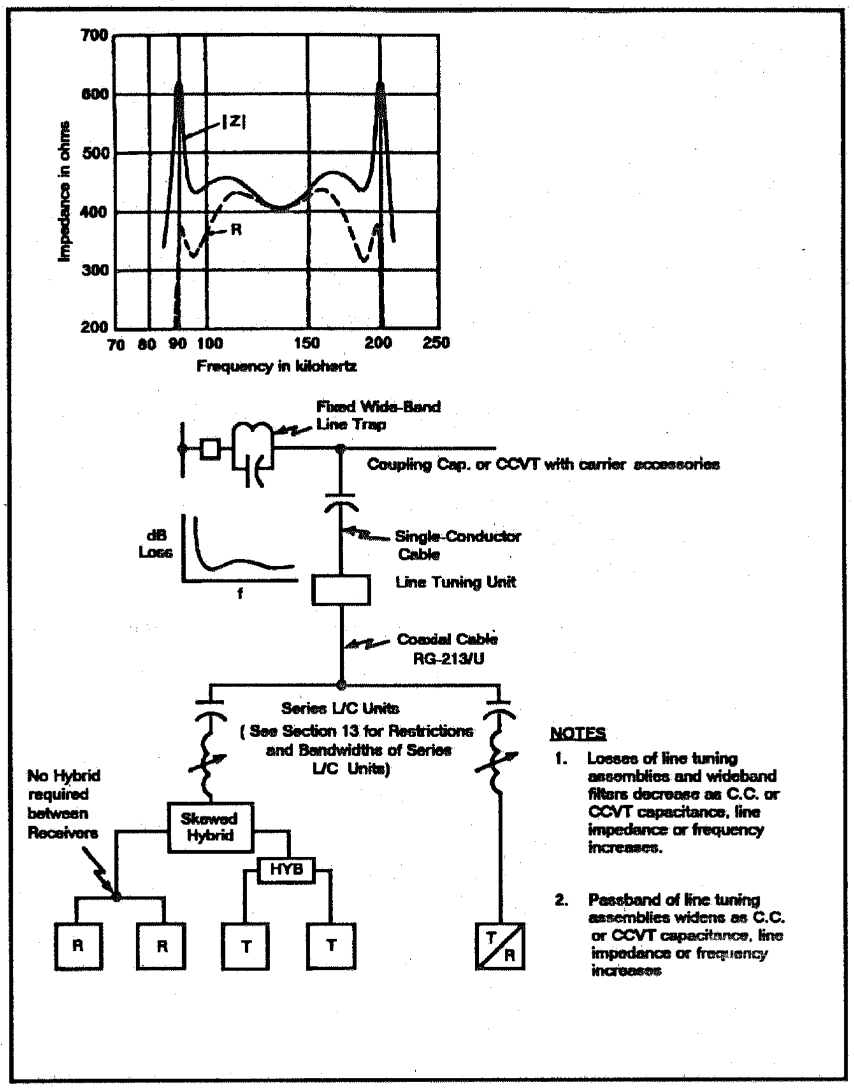


Figure 2-22. Wide-band Tuning and Trapping with L/C Units and Hybrids

The CCVT is a power frequency voltage divider, with a tap brought out of the bottom capacitor unit to provide inputs for protective relays and/or metering equipment. CCVT's are normally used on all three phases. To insure freedom from ferroresonance, suppression filter networks are used to dampen subharmonic oscillations. The filter also improves the voltage transformer transient response without imposing much load on the CCVT to obtain the transient-response improvement.

For various tuner/coupling capacitor combinations, the bandwidth available for bandpass applications is proportional to the value of the capacitance for a specified geometric mean frequency (GMF). Thus, wide-band applications require large values of capacitance. Higher order line tuners can provide wider bandwidths using the same capacitor value. (See section on bandpass line tuners.) Also see reference [33].

In pipe-type cable applications, the low impedance of the cable can cause the coupling loss to be significant. The coupling bandwidth is also reduced by about ten-to-one compared with overhead line applications. To overcome this problem. Extra-High-C capacitors are generally applied. Line tuning equipment is connected in series with the high voltage coupling capacitor to provide:

1. Efficient carrier coupling to the power line or cable
2. Carrier bypasses around discontinuities
3. Attenuation of undesired signals
4. Impedance matching of the carrier equipment to the power line or cable
5. Protection of personnel and electronic equipment from the high voltage of the power line

As illustrated in Figures 2-20 through 2-23, several types of tuners are available including:

1. Resonant: single or two-frequency
2. Wide-band: high-pass or band-pass

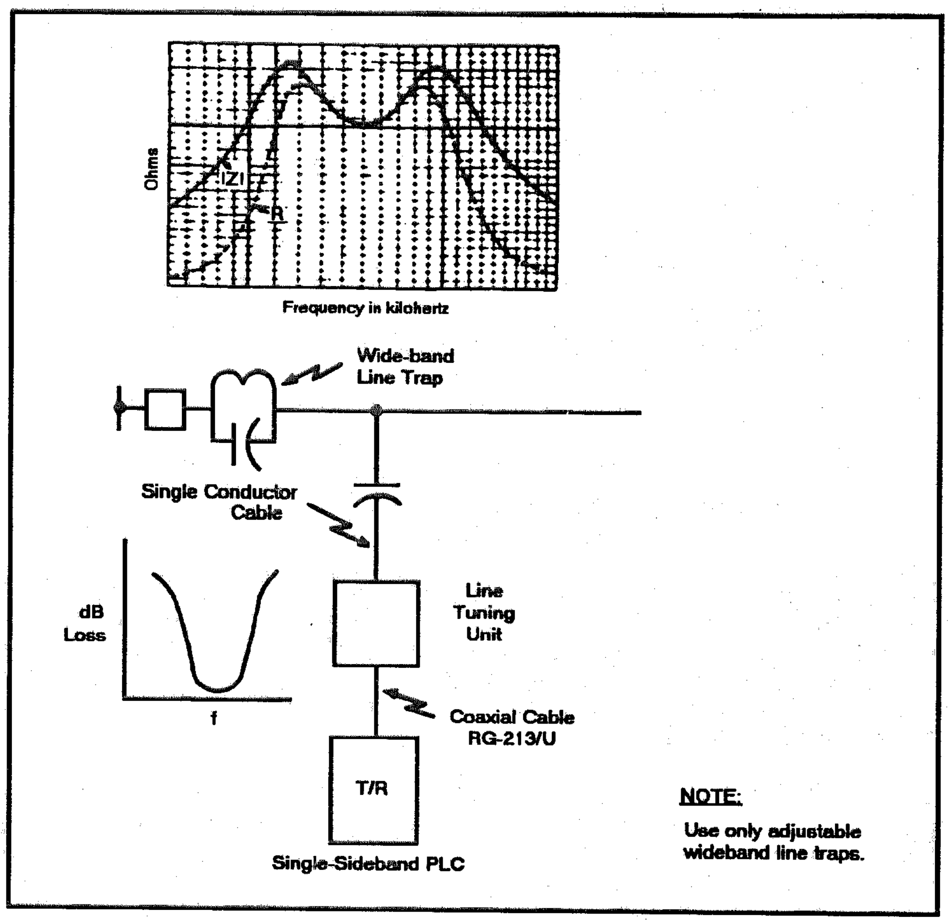


Figure 2-23. Adjustable Wide-band Tuning with SSB Carrier

Single-frequency tuners provide the simplest application of resonant tuning. The losses caused by the line tuner/coupling capacitor combination vary with frequency, capacitance of the coupling capacitor, line tuner characteristics and apparent impedance of the power circuit. When more than one frequency must be coupled to the line, the tuner can be operated off resonance or a broadband tuner may be required. It is common practice to operate a number of narrow-band, frequency-shift channel equipments through a single-frequency tuner. The passband of a single frequency tuner is a function of the coupling capacitance, the line impedance, and the resonant frequency.

Two-frequency resonant tuners (Figure 2-21) are used when two signals are to be coupled to the line and the impedance mismatch of a single-frequency tuner off resonance cannot be tolerated. In general, the coupling loss of a two-frequency tuner is twice that of a single frequency tuner and the bandwidth is much smaller than a single-frequency tuner. (Refer to Section 16 of this guide for more detailed information on bandwidth comparison of resonant line tuners.)

Wide band tuners (Figure 2-22 and 2-23) provide a broadband approach to coupling, such as the application of single-sideband equipment shown in Figure 2-23. They are available in band-pass and high-pass tuners. The bandpass tuner is designed to pass a maximum band of frequencies on both sides of a geometric mean frequency (GMF), which is defined as the square root of the product of the band-limit frequencies. The high-pass tuner (Figure 2-22) is an adjustable wide-band tuner, designed to pass a maximum band of frequencies whose low frequency "cutoff" is determined by the value of the coupling capacitor and the line impedance. High-pass tuners find limited application in PLC circuits because of their limited use at low PLC frequencies.

SYSTEM MEASUREMENTS

It is common practice to make measurements between components of a PLC transmitter/receiver scheme, at a station where the individual components may consist of transmitters, receivers, series L/C units, balanced or skewed hybrids, balanced combiners, filters, and different types of line tuners. As a general statement, these measurements are almost always incorrect, if a voltage reading (or level) is taken and translated into a power reading. In the case of receivers, the measurements may give incorrect information. Another general statement relating to level measurements (even with a high impedance selective voltmeter) says that only those readings taken across a resistive load, where this load is the only termination, are correct. All of the components of a PLC system possess a finite return loss, which means that these devices are not perfect transducers. (All input power is not transmitted through the device.)

From the explanation of return loss, reflected power, standing wave ratio, etc. given in the following paragraphs, each of these devices has an impedance which changes with frequency, and the actual impedance may be different from the stated impedance by the allowance made with the return loss specification. The specification for line tuners and transmitters requires a return loss of at least 12 dB. The line tuner impedance at the 50 ohm input may vary from 30 ohms to 83 ohms (resistive) or by similar values in an actual system where the impedances are complex - a combination of real and imaginary values. If the system return loss is 30 dB, there may be a 6% variation in the impedance, which relates directly to the voltage which a meter would read when placed across the input or output of any device in the system. Most PLC systems have a return loss in the range from 10 dB to 20 dB, which changes with frequency.

When tuning is required in a PLC system, whether related to L/C units or line tuners, it is best to use a device which measures reflected power, and to tune for minimum reflected power in the frequency range of the equipment connected to the series L/C unit or to the line tuner. Best results can be achieved when using a power source which can be tuned across the entire range of frequencies at the station rather than to use only the transmitters as signal sources.

As an example of the typical system measurement, take the case of a system with one transmitter, one receiver, and a single frequency line tuner using a skewed hybrid for isolation. A measurement at the line side of the skewed hybrid looking into the coaxial cable with a selective, high impedance voltmeter may seem correct. The transmitter is a 50 ohm device and the line tuner and skewed hybrid are also 50 ohm devices. What is wrong with this measurement?

The transmitter output is almost always a bandpass filter with a finite return loss which varies with frequency. The transmitter itself usually has a return loss of 12-15 dB when compared to 50 ohms. The line tuner has a return loss of 12 dB minimum. With all of these devices interacting at this point, the impedance at the input to the coaxial cable may be anywhere in the 30 to 85 ohm range, or the range may even be wider for a lower return loss. Since the voltage measured at this point will follow the impedance, the reading at the coax is meaningless. The source impedance (output impedance of the transmitter filter) is unknown and the load impedance (input impedance of the line tuner) is also unknown.

The loss through the skewed hybrid in the receive path does not always measure 12-13 dB because of the actual impedance of the coaxial cable interface between the transmitter and the line tuner. If the impedance is high at this point and at this frequency, the loss will appear higher than 12 dB. If the impedance is lower than 50 ohms, the converse will be true. The level at a receive frequency may increase at the coax input as a result of tuning while the actual receive output may go down. The best compromise will be realized with the highest return loss or with minimum reflected power in the frequency range of the devices at the station. The input level to the receiver can only be measured accurately across a resistive load, or at a location where the impedance is constant with frequency. Generally speaking, the input of a passive filter will usually give incorrect readings of received input level. The output of the receive filter is the preferred location (At the receiver input) to measure input level.

Four-Terminal Parameter Relationships

These parameters are all related to a constant called the reflection coefficient (or reflection factor) which is defined as:

$$\rho = \frac{R - Z}{R + Z} \qquad (1)$$

where R is the terminating impedance of the network, and Z is the impedance looking into the network. "Z" does not have to be a pure resistance, and the behavior of ρ for different values of Z is shown in Appendix B of Section 13 of this Guide.

Other parameters used to describe a reactive network are:

1. Standing wave ratio (S)
2. Amplitude response, or ripple (A_{db})
3. Reflected power (P_r)
4. Return loss (R.L.)
5. Impedance (real) variation (R_{min} and R_{max})

The relationships between these parameters as they relate to the reflection coefficient, ρ, are shown below:

$$\rho = \frac{S - 1}{S + 1} \qquad (2)$$

$$S = \frac{\rho + 1}{\rho - 1} \qquad (3)$$

$$A_{db} = -10 \log_{10}(1 - \rho^2) \qquad (4)$$

$$P_r(\%) = 100 * \rho^2 \qquad (5)$$

$$R_{min} = \frac{(1 - \rho)R_o}{1 + \rho} \qquad (6)$$

$$R_{max} = \frac{(1 + \rho)R_o}{1 - \rho} \qquad (7)$$

$$R.L. = 20 \log_{10}(1.0/\rho) \qquad (8)$$

$$R.L. = 10 \log_{10}(1.0/\rho^2) \qquad (9)$$

$$= 10 \log_{10}(100/P_r)$$

$$= 10 \log_{10}(100) - 10 \log_{10}(P_r)$$

$$= 20 - 10 \log_{10}(P_r) \qquad (9a)$$

Since ρ can be a complex quantity, the formulas above are given for the values of ρ that are real only, and they result in non-complex values. A table of the values of S, A_{db}, P_r, R.L., R_{min}, and R_{max} is given for reference. Notice that for ρ =0.2 (20%), S = 1.5; A_{db} = 0.1773 dB; P_r = 4.0 %; and R.L. = 14.0 dB. Also, the reflected power for R.L. = 10 dB is 10%, with a ripple (or rolloff) of 0.457 dB. Understand that these are all theoretical values which do not include the losses in the reactive elements. The values of R_{min} and R_{max} assume a terminating impedance of 50 ohms. Formula (9a) gives a direct relationship between return loss and reflected power.

Table 2-16
4-Terminal Device Relationships

ρ (%)	S	A_{db}	P_r (%)	R.L. (dB)	R_{min} (ohms)	R_{max} (ohms)
1.0	1.02	0.00043	0.01	40.0	49.0	51.0
2.0	1.04	0.00174	0.04	33.98	48.0	52.0
3.0	1.06	0.00391	0.09	30.45	47.1	53.1
4.0	1.08	0.00695	0.16	27.96	46.1	54.2
5.0	1.10	0.01087	0.25	26.02	45.2	55.3
8.0	1.17	0.02788	0.64	21.94	42.6	58.7
10.0	1.22	0.04368	1.00	20.00	40.9	61.1
15.0	1.35	0.09883	2.25	16.47	36.9	67.6
20.0	1.50	0.17730	4.00	13.97	33.3	75.0
25.0	1.67	0.28030	6.25	12.04	30.0	83.3
31.6	1.92	0.4568	9.98	10.00	26.0	96.2
50.0	3.00	1.249	25.00	6.02	16.6	150.0
70.7	5.85	3.0	50.12	3.00	8.5	292.0

SYSTEM LOSSES

Other losses not related to coupling the signals to the transmission lines will be discussed under the various system losses.

SHUNT LOSSES

Shunt losses may be defined as losses contributed by any and all leakage paths to ground, which attenuate the PLC energy. The shunt loss of a station bus and other transmission lines is illustrated in Figure 2-24.

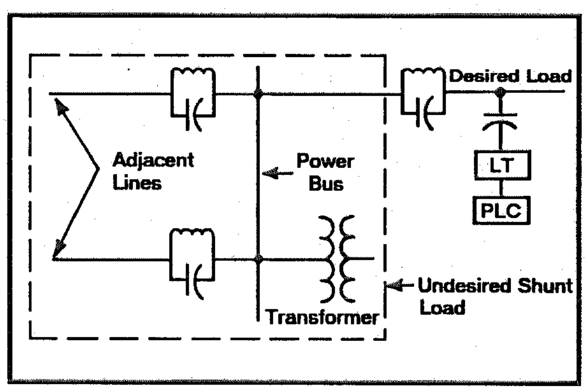


Figure 2-24. Carrier Shunt Losses

The path for shunt losses is easier to visualize from the equivalent circuit of Figure 2-25.

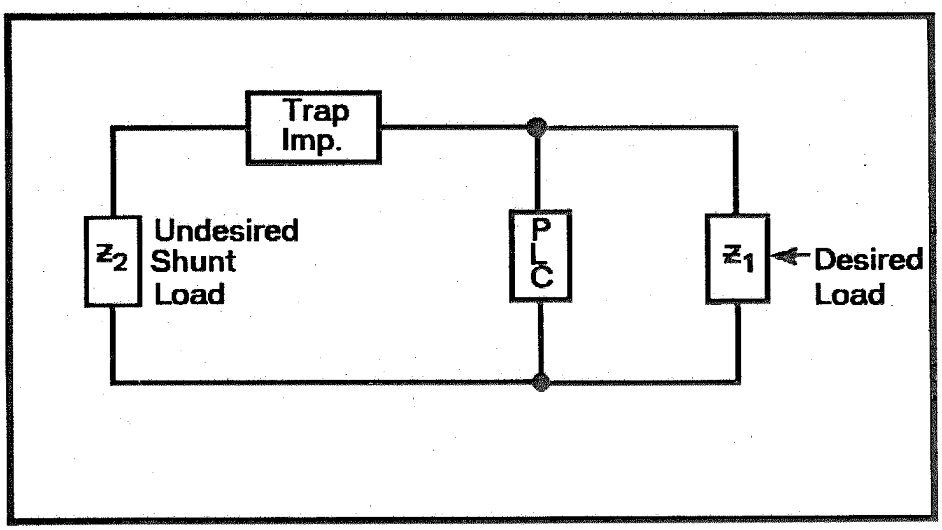


Figure 2-25. Equivalent Circuit of Shunt Losses in Figure 2-24.

The shunt loss of a station bus in primarily due to the capacitance of the breaker and transformer bushings, and the capacitance of bus insulators. The capacitance to ground of a bushing is approximately 200 pF, and about 50 pF for a bus insulator. These values are a function of line voltage. A station bus having six bushings and 20 bus insulators per phase would have a capacitive shunt impedance of approximately 2.5 kilohms at 30 kHz, 750 ohms at 100 kHz, and 400 ohms at 200 kHz. In cases where the bus impedance is unknown, it is suggested that an impedance of 800 ohms be used below 100 kHz, and 400-500 ohms above 100 kHz. The shunt loss of a bus (with line traps) may be calculated from the equivalent circuit of Figure 2-25 with the equation:

$$\text{dB of Loss} = 10 \log \frac{Z1 + Z2 + \text{Trap Imp.}}{Z2 + \text{Trap Imp.}}$$

Referring to Figure 2-24 and assuming an impedance of 400 ohms for each adjacent line, 1000 ohms for the transformer, and 400 ohms for the bus, the shunt load would be:

$$Z2 = \frac{1}{\frac{1}{400} + \frac{1}{400} + \frac{1}{1000} + \frac{1}{400}} = 118 \text{ ohms.}$$

Therefore, with a line trap of 400 ohms, the equivalent load becomes as shown in Figure 2-26.

The equivalent load impedance then is found by:

$$R_L = \frac{(118 + 400) \quad (400)}{(118 + 400) + 400} = 226 \text{ ohms.}$$

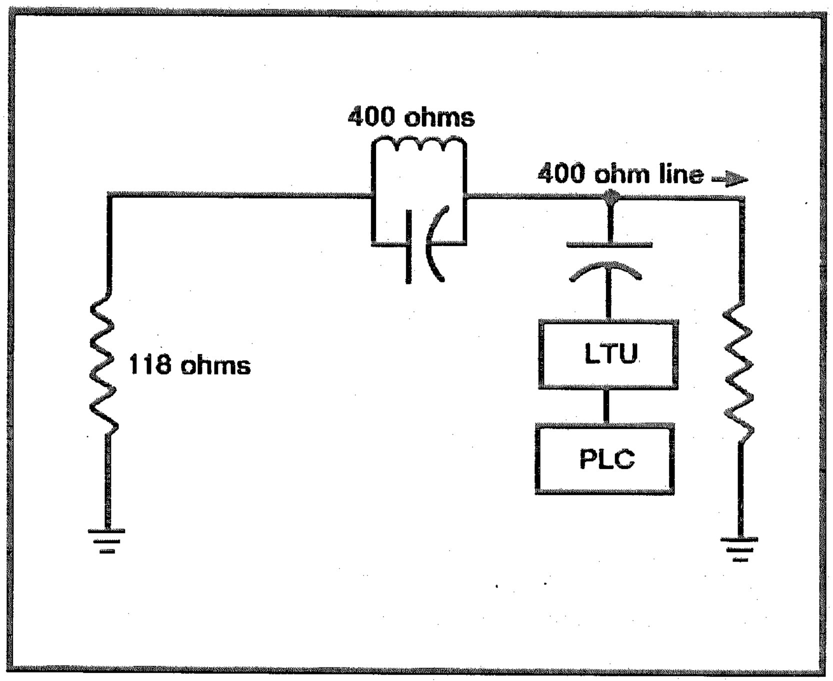


Figure 2-26. Equivalent Load for Carrier Terminal

Although the preceding calculations were made on a real impedance basis, the actual bus shunt loading is capacitive, and the impedance will change with any change in load or electrical configuration of the bus.

One function of the line trap is to reduce the losses due to undesired signal paths. As an example of the effectiveness of the line trap in this function, refer to Figure 2-26. If the line trap were omitted in this application, the shunt loss would be

$$10 \log (Z1 + Z2)/Z2 = 6.5 \text{ dB}.$$

With a line trap of 400 ohms impedance, the loss is 2.5 dB, and with 1500 ohms impedance, it is only

$$10 \log (Z1 + Z2 + \text{Trap Imp.})/(Z2 + \text{Trap Imp.}) = 1.0 \text{ dB}$$

Illustrated in Figure 2-30 is the variation of shunt loss as a function of line trap impedance and number of external lines, with a 400 ohm transmission line impedance.

By-Pass Losses

Shunt losses at a by-pass differ from those at a transmitting or receiving location due to the double effect of the shunt impedance, as illustrated in Figure 2-27. With the exception of one less external line, the shunt impedance of the bus is the same as the one shown in Figure 2-26. The by-pass has two shunt paths, one on either side of the bus (shunt paths No. 1 and No. 2 in Figure 2-27.). Therefore, a by-pass has double shunt loading and, assuming zero impedance of the by-pass, the equivalent circuit is as shown in Figure 2-28. Combining the two effective shunt loads gives the equivalent circuit of Figure 2-29 from which calculations can be made.

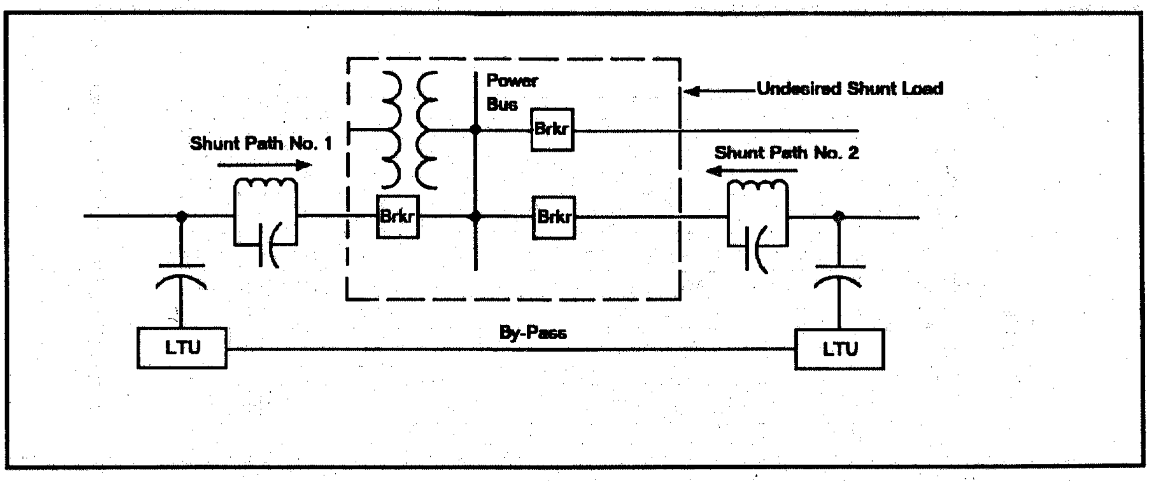


Figure 2-27. By-Pass with Shunt Losses

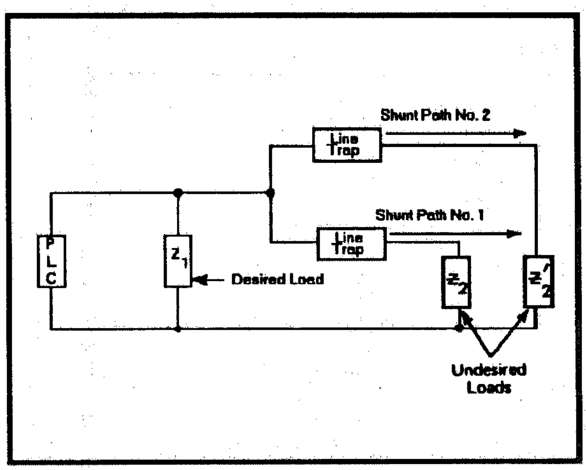


Figure 2-28. Equivalent Circuit of By-Pass Shunt Loss

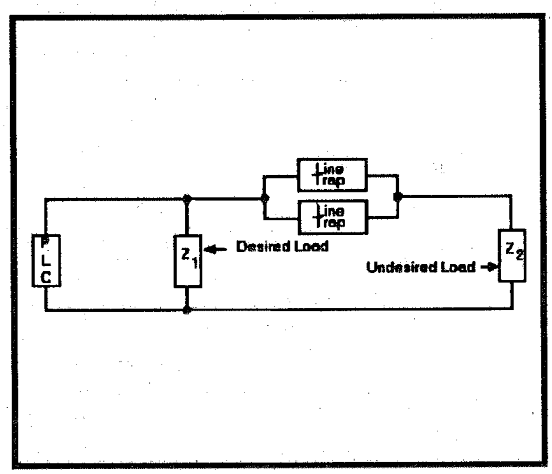


Figure 2-29. Revised Equivalent Circuit of By-Pass Shunt Loss

Two possible situations (with and without line traps) might exist at the by-pass. Therefore, both situations will be shown.

Trapped By-Pass

With line traps, the equivalent circuit is as shown in Figure 2-28. The undesired load consists of one external line (assumed to be 400 ohms), one transformer (assumed to be 1000 ohms), and the station bus (assumed to be 400 ohms).

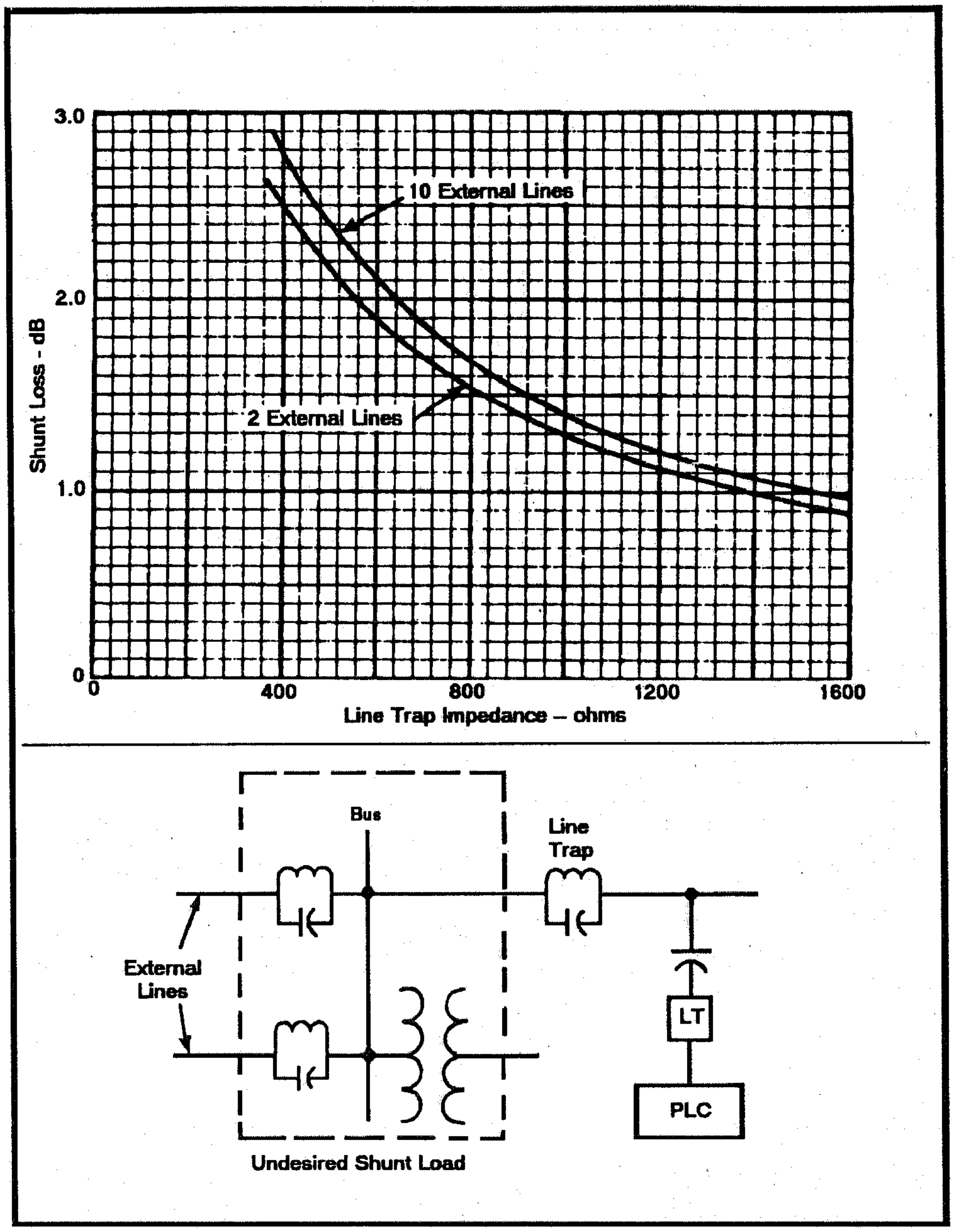


Figure 2-30. Shunt Loss as a Function of Line Trap Impedance and Number of External Lines

This would give a total shunt impedance of 167 ohms.

$$\frac{1}{\frac{1}{400} \quad \frac{1}{1000} \quad \frac{1}{400}} = 167$$

With line traps of 400 ohms each and the desired load of 400 ohms, the shunt loss would be 3.2 dB as calculated below:

$$10 \log \frac{Z1 + Z2 + \frac{\text{Trap Imp.}}{2}}{Z2 + \frac{\text{Trap Imp.}}{2}} = \frac{400 + 167 + 400/2}{167 + 400/2} = 3.2 \text{ dB}$$

With line traps of 1500 ohms, and the same desired load impedance, the shunt loss would be:

$$10 \log \frac{400 + 167 + 1500/2}{167 + 1500/2} = 1.6 \text{ dB}$$

In applications where the by-pass is three-way (by-pass from one line to two others), the three line traps must be considered in parallel when calculating shunt losses.

Illustrated in Figure 2-31 is the variation in by-pass shunt loss as a function of line trap impedance and number of external lines, with a 400 ohm transmission line impedance.

Untrapped By-Pass

In applications where line traps are not used, shunt losses increase by almost 2 to 1, as shown in the calculation below:

$$\text{dB loss} = 10 \log \frac{Z1 + Z2}{Z2}$$

$$= 10 \log \frac{400 + 167}{167} = 5.3 \text{ dB}$$

The increase in loss without using traps having an impedance of 400 ohms amounts to 2.1 dB. The increase over the loss using 1500 ohm traps is 3.7 dB.

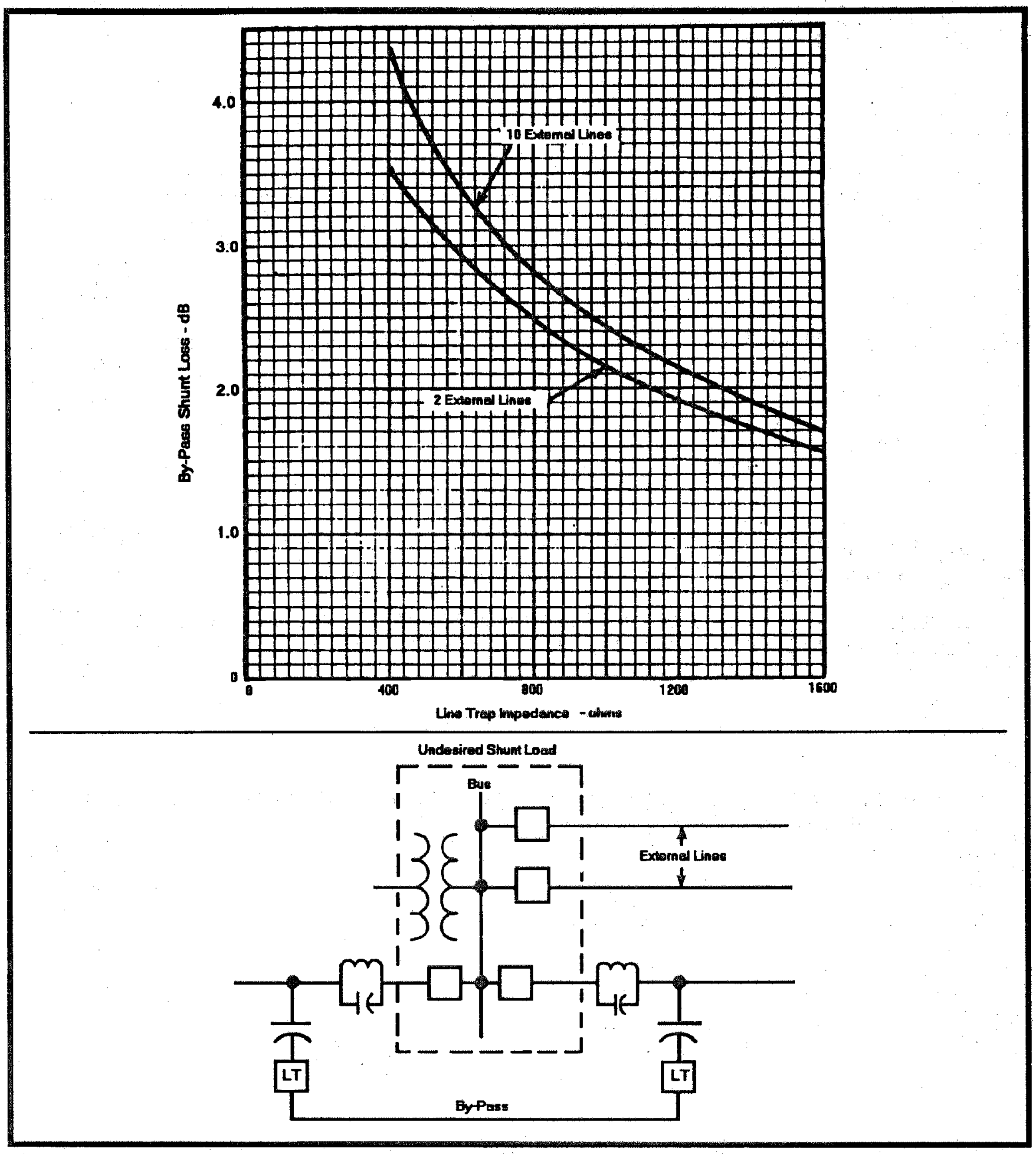


Figure 2-31. By-Pass Shunt Loss as a Function of Line Trap Impedance and Number of External Lines

Coaxial Cable

Coaxial cable is used in PLC applications as a low impedance interconnection between the carrier terminal equipment and the transmission line, as illustrated in Figure 2-32. RG-8/U coaxial cable has a nominal impedance of 52 ohms, and a capacitance of 29.5 pF per foot. Typical characteristics are listed in Table 2-17.

Table 2-17. Typical Attenuation Characteristics of RG-8/U

Frequency of Operation	Loss per 1000 Feet
30 kHz	0.38 dB
50 kHz	0.44 dB
100 kHz	0.55 dB
150 kHz	0.66 dB
200 kHz	0.77 dB
300 kHz	0.90 dB

The normally accepted use of coaxial cable is the interconnection between the carrier terminal equipment and the line tuner. Also, it is used between two line tuners for a by-pass connection and for interconnections between tuners for multi-phase coupling installations.

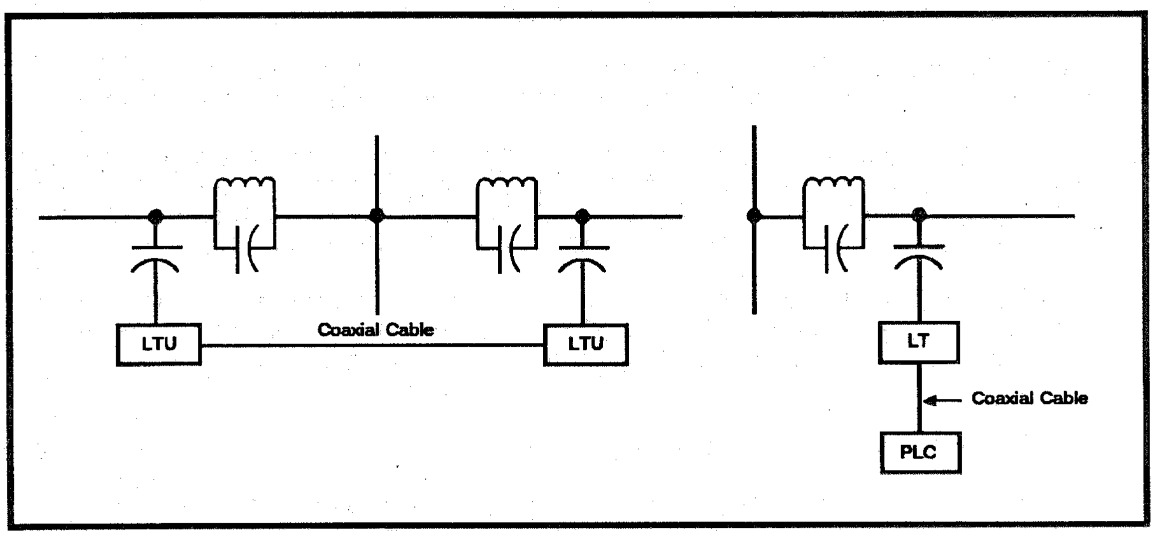


Figure 2-32. Portions of Carrier Path Using Coaxial Cable

Overhead Lines

Mismatch losses on a transmission line are quite often pronounced and troublesome. These losses can be classified into three types: shunt, series, and multipath.

Shunt losses: Since shunt losses caused by the undesired load of a station bus, as illustrated at Stations "A" and "B" of Figure 2-33 have been previously discussed, this section will deal with losses of tapped lines. In Figure 2-33, two line taps are shown. One is the line tap between Stations "B" and "C", and the other Station "C" itself. Determination of the shunt loss contributed by these taps is quite simple, provided the length of the line is not such as to produce reflections.

Effect of Impedance Mismatch: The shunt loss contributed by the impedance mismatch of the tap is simply:

$$\text{Loss in dB} = 10 \log \ (Z1 + Z2)/Z2$$

Where: Z1 = Line Toward Receiver
Z2 = Impedance of Tap Line

As an example, Figure 2-33 shows two taps, one with an impedance of 400 ohms, and one with 1000 ohms. First, consider the 400 ohm tap between stations "B" and "C". The shunt loss at this point is 3.0 dB as calculated below:

$$\text{Loss} = 10 \log (400 + 400)/400 = 10 \log 2 = 3.0 \text{ dB}.$$

The shunt loss at Station "C" is, using the same equation, 1.46 dB:

$$\text{Loss} = 10 \log (400 + 1000)/1000 = 10 \log 1.4 = 1.46 \text{ dB}.$$

Each shunt loss along a line can thus be calculated, and the total must be included in the over-all line attenuation for the affected line section.

Effect of Reflections: For a tapped line such as the line shown in Figure 2-33 with a tap between Stations "A" and "C", the following characteristics are appropriate:

Unterminated Lines: For unterminated lines (not terminated with carrier equipment operating on frequencies under consideration, or a line terminating into a power transformer) the maximum out-of-phase reflected signal occurs when the line length is electrically equal to one quarter wavelength, or odd multiples thereof.

Shorted Lines: For shorted lines (where power line connects to an underground cable of low impedance), the maximum out-of-phase reflected signal occurs when the line is electrically equal to one-half wave-length, or multiples thereof.

$$\text{Full Wavelength in Feet} = 984/\ (F \text{ in MHz})$$

With an untrapped line falling into either category listed above, the reflected energy will be out of phase with the transmitted signal, and can cause attenuation, or even complete cancellation of the through signal. To minimize this cancellation effect, line traps are placed in the tapped line in close proximity to the main line, as illustrated in Figure 2-33.

The signal traveling out on the tapped line will be attenuated 10 to 15 dB by the line trap. The amount of attenuation is dependent upon the trap impedance with respect to that of the main line. The higher the trap impedance, the greater the attenuation will be.

The reflected signal will undergo a similar attenuation while passing through the trap on its return to the main line. Therefore, the reflected signal will be attenuated by an amount equal to twice the attenuation of the trap, thereby minimizing its effect on the through signal. When trapping a tapped line, the trap impedance should be as high as possible; therefore no attenuation curves for traps as a function of impedance are provided here.

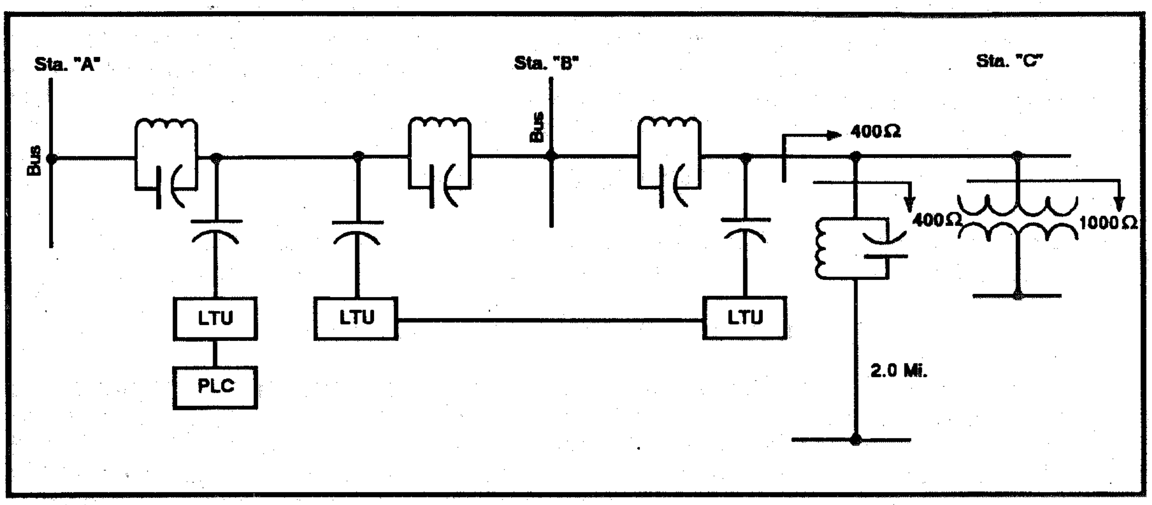


Figure 2-33. Overhead Line Shunt Loss

Series: Losses due to a series mismatch occur when an overhead line is connected to a power cable, as illustrated in Figure 2-34.

In such applications, the loss at each junction may be calculated by the equation:

$$\text{dB loss} = 20 \log\{(Z1 + Z2)/[2(Z1*Z2)^{1/2}\}$$

Where : Z1 = impedance of overhead line
Z2 = impedance of power cable.

For the case shown in Figure 2-34, the mismatch loss is 7.4 dB.

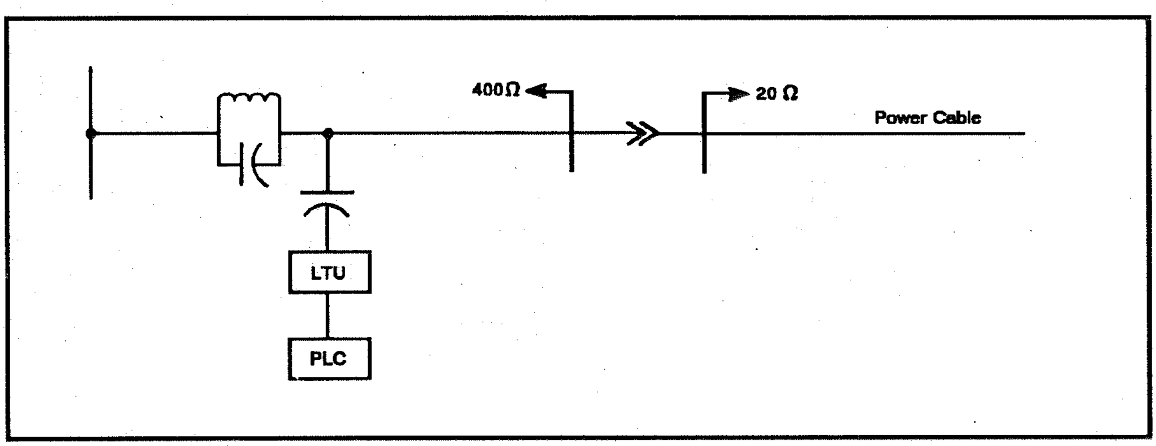


Figure 2-34. Junction of Overhead Line with Power Cable

Power Devices: In some applications of PLC, power may be transmitted through a tapped line without the addition of line traps for isolation. This case is demonstrated in Figure 2-35. In a situation such as this, the transformer at the tap could very well have an impedance high enough to prevent excessive carrier losses.

Line traps are used to provide isolation of a transmission line from circuit breakers, transformers, and similar equipment located in generating stations, or substations, and other transmission lines which are connected to the line section. Thus, if a fault occurs in any of the power equipment or on another line, the carrier signal is not dissipated in the fault. Traps are mandatory for a protective relaying system utilizing a carrier signal for the transmission of intelligence between the two terminals. If the transmission line is not thus isolated, the protective relays may trip the wrong circuit breakers.

STANDING WAVES

Standing waves are a phenomenon that exist, and are detrimental to transmission on all transmission lines that are not terminated in their characteristic impedance.

Effect of Improper Termination

A line not properly terminated carries two signals: the transmitted signal and the reflected signal. At certain points along the line these signals are in phase and add, while at other points they are out of phase and subtract, as is illustrated in Figure 2-36. These curves are for a line with zero attenuation, and a load impedance different than the characteristic impedance of the line. With such a mismatch in load impedance, the phase relation of the reflected wave to the incident wave is not always 90 degrees as is shown in Figure 2-36, but is constantly changing with frequency and as the load impedance changes with respect to the characteristic impedance. Therefore, the resultant wave is one which constantly changes in amplitude, frequency and distortion content, which can cause more distortion in the receiving equipment. This distortion can cause intermodulation products to create trip signals for guard signals, and other undesirable transmission characteristics. A phase relationship of 90 degrees was chosen in Figure 2-36 for simplicity.

Effect of an Open Line

A transmission line which is one-quarter wavelength (or odd multiples thereof) long and open on one end reflects the voltage wave back towards the source unchanged in magnitude and polarity, as is illustrated in Figure 2-37.

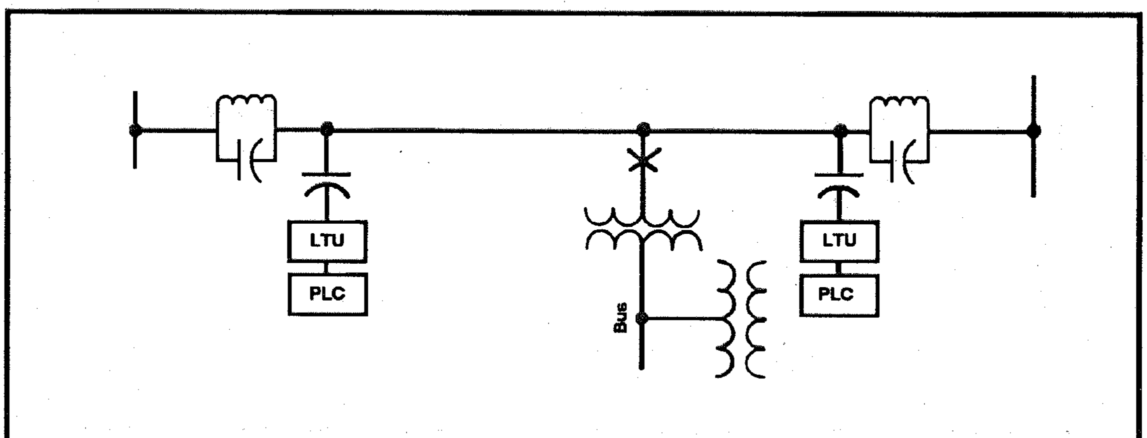


Figure 2-35. Transmission Past a Power Bus

By the time the wave returns to its source, it travels an effective distance of one half wavelength, and is 180 degrees out of phase with the incident wave. Thus, complete cancellation of the signal occurs.

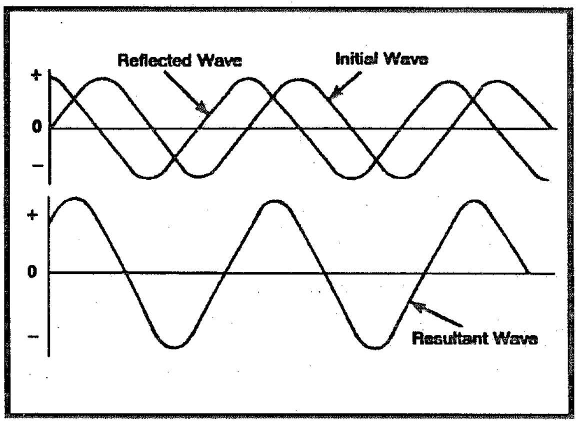


Figure 2-36. Resultant Wave with Reflected Wave 90 Out of Phase with Initial Wave. Load Impedance Different from Line Impedance

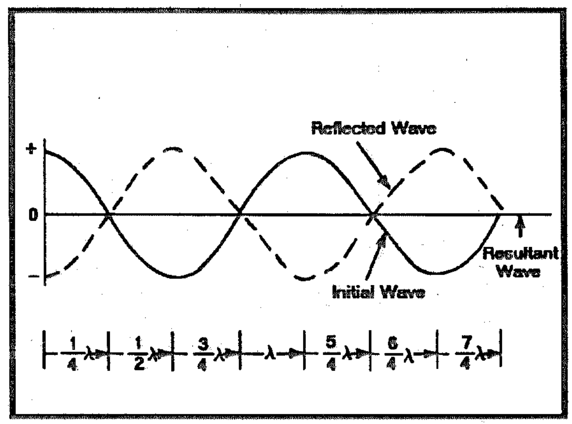


Figure 2-37 Reflection of Open Line

Effect of a Shorted Line

A transmission line which is shorted at one end will suppress the voltage wave completely, but the current wave will be at a maximum. The current wave is reflected back to the source end of the line with the same polarity and magnitude. The current wave reflection is then the same as the voltage wave reflection of Figure 2-37.

A line which is one-half wavelength (or multiples thereof) long will have current reflections which will completely cancel the incident wave. The signal effectively travels one full wavelength in travelling out one-half wavelength and back the same length. The reflected wave is 180 degrees out of phase with the incident wave at the source.

When the line is not terminated in its characteristic impedance, the plot of instantaneous voltage and current appears as waves, and are called standing waves. These waves, as shown in Figure 2-38, are motionless and are not true waves in the same sense as the initial and reflected waves.

Effect of Standing Waves on PLC Application

Standing waves have a greater effect on PLC applications when a tap line is connected to the main line (Figure 2-39). As discussed previously, an open-ended line of one-quarter wavelength, or a shorted line of one-half wavelength, has reflections 180 degrees out of phase with the incident wave, resulting in complete signal cancellation. Therefore, a tapped line meeting either of these two conditions effectively shorts out the signal on the main line. This shorting occurs at frequencies for which the tap line length satisfies the wavelength equation.

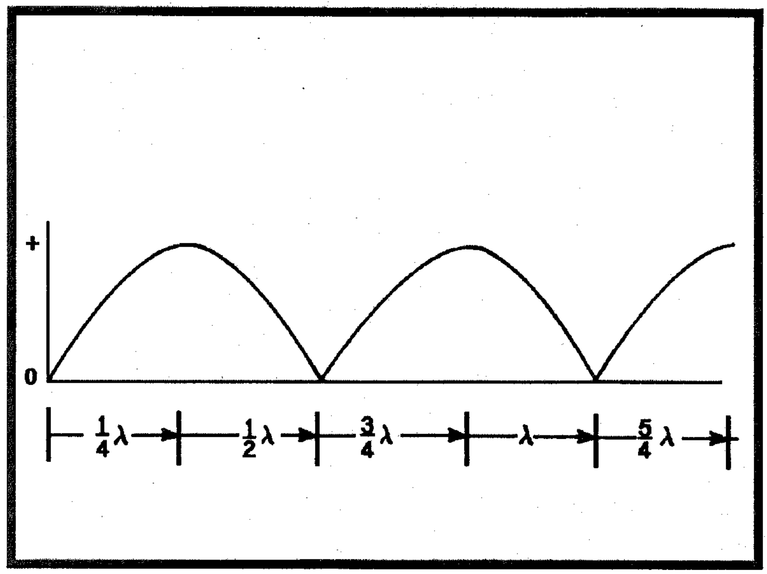


Figure 2-38. Standing Waves on a Line

For a tapped line whose length is different from one-quarter or one-half wavelength, complete cancellation will not occur, since the incident and reflected waves are not 180 degrees out of phase. This reflected wave does cause a varying gain or loss of the main line signal, and can also produce delay distortion. This distortion is caused by the adding or subtracting process of the incident and reflected waves which is delayed by the time required for the wave to complete the trip to the end of the tap, and to return to the main line.

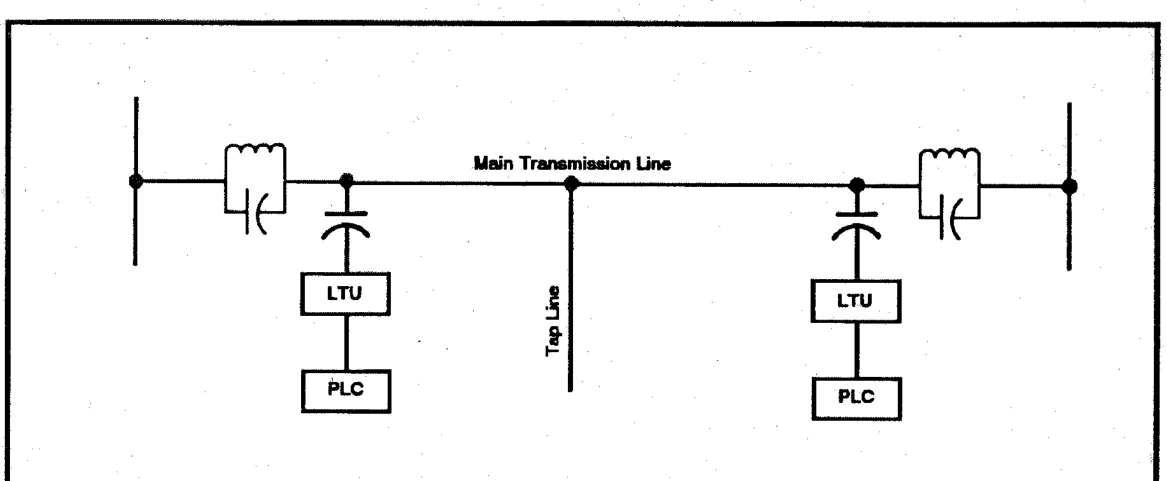


Figure 2-39. Typical Tapped Line Configuration

Tapped lines having a length which causes signal cancellation only do so for a relatively narrow band of frequencies. The tapped line will act as a narrow-band slot filter, with the filter being effective at the frequencies for which the line acts as a short circuit to the main line signal.

For an open-ended line of any length, the curves in Figure 2-40 may be used to determine the frequencies at which the line will act as a short. To use these curves, locate the stub line length on the lower scale. The intersection of each line with the vertical length lines gives the frequency at which the tapped line will short the signal on the main line. Cancellation occurs at every odd quarter wavelength. For example, a tapped line two miles long would present a signal short at frequencies of 23.5 kHz, 71.0 kHz, 117.0 kHz, etc. Shorted stub lines of one-half wavelength would result in a similar set of curves. No data is available to show the bandwidth over which the signal cancellation occurs. Maximum attenuation occurs for the two-mile stub at 23.5 kHz.

Minimizing Tapped Line Effects

The first requirement to determine the resonant frequency of a tapped line is to know the length. The length determines the resonant frequencies at which problems may occur on the main line signal.

An obvious solution to a resonant line problem is to change the frequency to one which does not resonate with the line in question. The question of how much change in the frequency is adequate to eliminate the resonant line problem requires an answer. Although no data is available to indicate the range of frequencies over which the line will resonate, experience indicates that an effective length change of plus or minus one-half mile will take the line out of resonance to the point that the attenuation effect can be ignored. Since the line length cannot be changed, the curves of Figure 2-40 indicate the amount of frequency change necessary. For example, assume that the desired operating frequency range is 24 kHz to 40 kHz, with a tapped line two miles long. Since Figure 2-40 indicates that the tapped line is resonant at 23.5 kHz, the lower frequencies will not pass the tapped line. To determine the lowest frequency limit of frequencies which will pass the tap, enter the chart at 1.5 miles and move to the intersection of the first quarter wavelength curve. This gives a frequency of 31 kHz, which is the lowest acceptable frequency for this application.

Therefore, a frequency range of 32 to 48 kHz is acceptable. This gives a 16 kHz band, and the upper frequency is safe since the next odd quarter wavelength frequency does not occur until 70 kHz.

A wider bandwidth requirement would require the installation of a line trap on the stub which blocks the same band of frequencies as line traps at the substations on the main line.

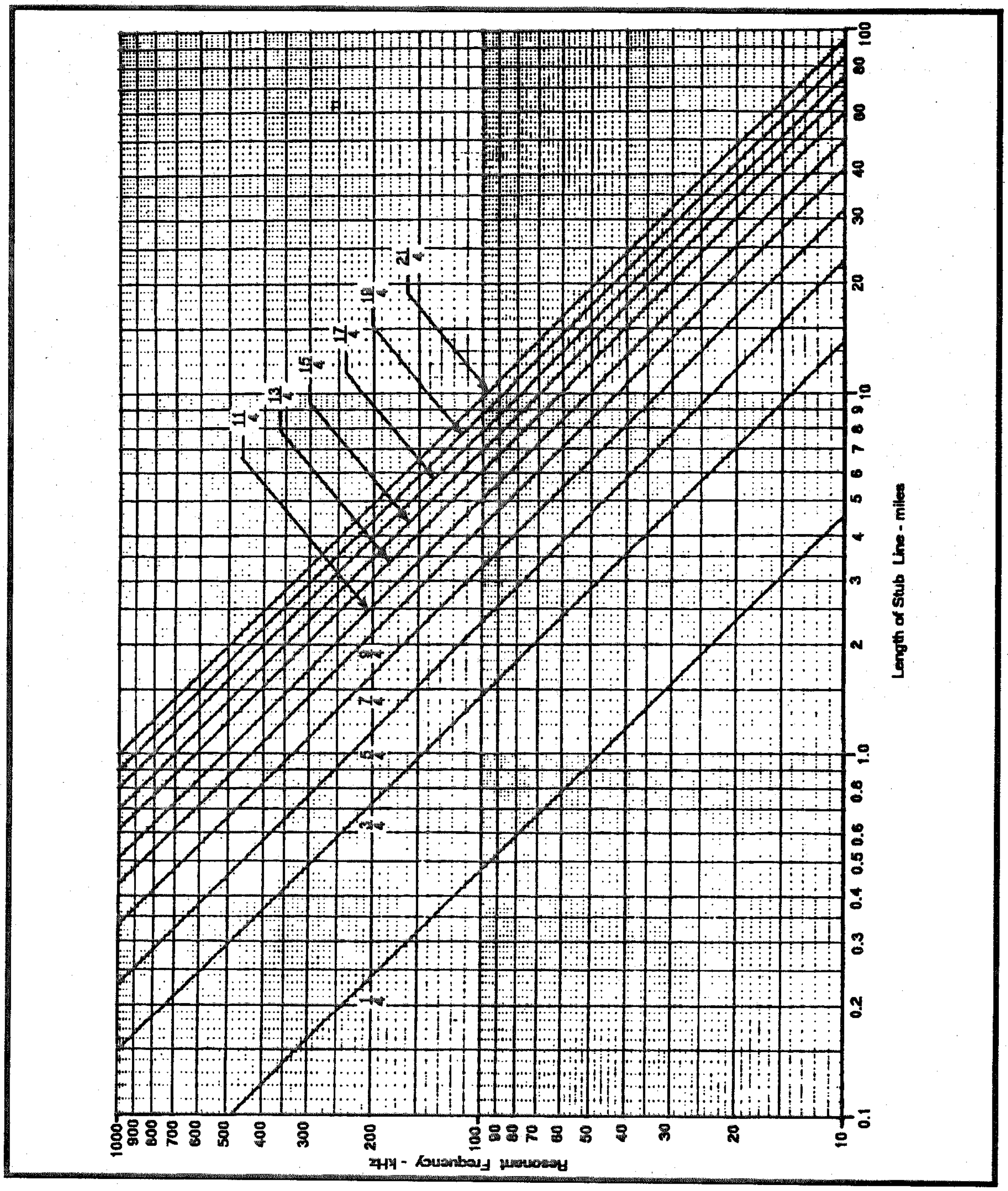


Figure 2-40. Resonant Frequencies of Open-Ended Tapped Lines

POWER CABLES COMBINED WITH OVERHEAD LINES

2

GENERAL CONSIDERATIONS

The limitations in applying Power Line Carrier to circuits involving a combination of overhead line and power cable are due to three principal factors: (1) the relatively high attenuation of the cable portion, (2) a series impedance mismatch at the junction due to the impedance difference between the characteristic impedances of the line and the cable, and (3) the added losses due to standing wave reflections from the junction point, together with wide difference in mode of propagation between the line and the cable. This section discusses each possible problem area separately in detail. (See reference [37]).

Power cables offer a very reliable communications medium because of their rugged, high voltage construction. Applications of discreet carrier frequencies on shorter circuits of mixed facilities are usually practical because the losses encountered can be absorbed in the electronic equipment operating range. This includes the use of 100 watt power amplifiers to overcome coupling losses and losses caused by the mixed facility junction(s). Wide band applications of Power Line Carrier on mixed facilities are generally not practical because of the variations of characteristics with frequency. However, single-channel SSB applications are often feasible. In cases where the power cable portion has excessive attenuation, as in cables with cross-bonded sheaths, a communication cable bypass of the power cable may be required. Bypassing either the overhead line or the cable portion eliminates the problems associated with the junction point, but care must be exercised that the communications cable is not damaged due to induced voltage or difference in ground potential during system faults. Magnetic shielding of the communications cable bypass is advisable if the location is in the flux field of a high current power circuit. Treatment of communications cable to handle protective relaying communications is discussed later in this section.

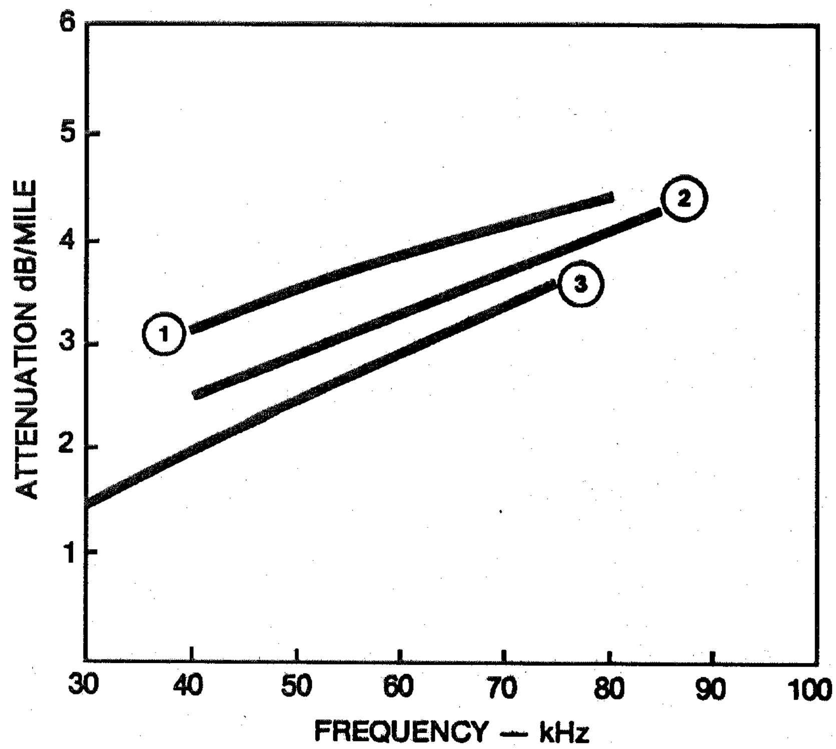
The ideal approach to a mixed facility is to make frequency vs. attenuation measurements in each direction before selecting frequencies. If the practical approach of testing is not possible, calculations will provide a reliable indication of performance as outlined in the material which follows when the characteristics and lengths of the circuit are accurately known. The calculations provide a means to avoid possible troublesome frequencies, which is the best approach to deal with reflections.

POWER CABLES

Power Line Carrier transmission losses in power cables vary greatly, depending upon the construction of the cable.

Single-Conductor Types - Single-conductor power cables with solidly grounded sheaths exhibit reasonably low transmission losses, and usually are satisfactory for PLC applications. For estimating purposes, the RF attenuation values of RG-8U coaxial cable may be used to determine the losses for single-conductor power cable with solidly grounded sheaths.

Single-Conductor Types with Cross-Bonded Sheaths- Single-conductor cables with cross-bonded sheaths or transformer-bonded sheaths are <u>not suitable for PLC circuits</u>. If a PLC signal is coupled to a single conductor cable with cross-bonded sheaths, a sheath is introduced at each sheath junction, which produces a high loss from the multiple paths introduced. If sheath-bonding transformers are used, the inductance of the sheath-bonding transformer causes high loss in the PLC frequency band. By-passing of these transformers has been tried without success.



① 138 kV. 1250 MCM, 1 COPPER SKID WIRE, PUB. SER. ELEC. AND GAS N.J. TEST ON 10.9 MI.

② 138 kV. 1250 MCM, 2 COPPER SKID WIRE, PUB. SER. ELEC. AND GAS N.J. TEST ON 10.9 MI.

③ 345 kV. 2000 MCM, CONSOLIDATED EDISON CO. TEST ON 15 MI AND 18.3 MI.

Figure 2-41 . Pipe-Type Cable Attenuation Curves

Pipe-Type Cable - With this type of cable, the loss at PLC frequencies varies with the type of construction of the shielding tapes used on each individual conductor. In order to reduce 60 Hz losses, these tapes are very thin (5 mils) and are spirally wound around the cable insulation along with a paper tape which insulates the turns of the shield tape. In order to protect the cable as it is pulled into the pipe, two or three skid wires are wound in a long pitch spiral around each cable on top of the shielding tape, and these skid wires provide the return path for PLC signals.

Figure 2-41 illustrates how the attenuation varies on different cables with different construction. Curves 1 and 2 are typical of present type construction and show that high-conductivity skid wires are an advantage. Most cable manufacturers can supply information on the loss in the PLC frequency band, surge impedance, and velocity of propagation (V.P.) of their cables.

The surge impedance of the cable is a function of the conductor size and the insulation thickness.

SERIES MISMATCH LOSS

Losses due to series mismatch are the result of a connection of an overhead line to a power cable, as illustrated in Figure 2-42. In such applications, the loss at each such junction may be calculated by the equation:

$$\text{dB Loss} = 20\ \text{Log}[\{ Z1 + Z2\}/\{2\sqrt{Z1 * Z2}\}]$$

Where: Z1 = impedance of overhead line
Z2 = impedance of power cable

Therefore, in the example of Figure 2-42, the loss would be 7.4 dB, as calculated below:

$$\text{Loss} = 20\ \text{Log}[\{ 400 + 20\}/\{2\sqrt{(400)}\ (20)\}] = 7.4\ \text{dB}.$$

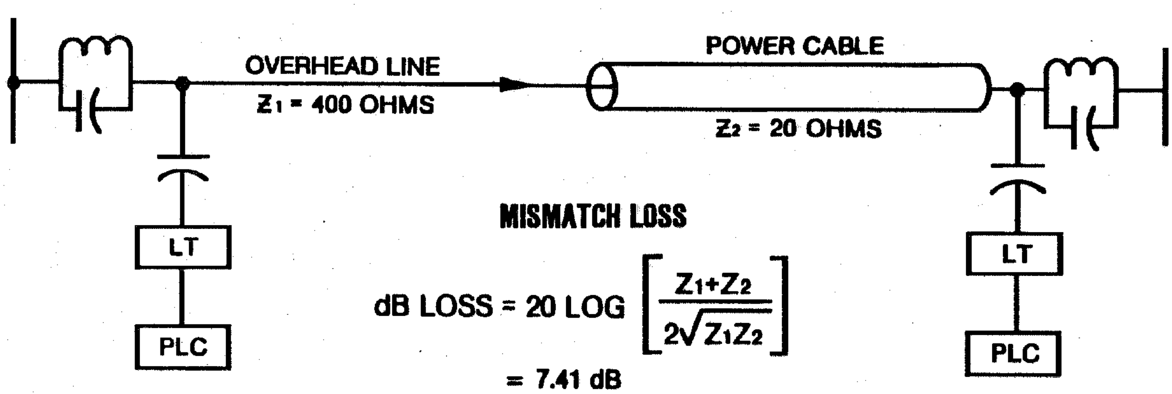


Figure 2-42. Junction of Overhead Line with Power Cable

This loss calculation presupposes the long line theory which means there is an attenuation of 15 to 20 dB in each part of the circuit (cable and line). Another criteria is that each part be long enough so that the input impedance of each section varies very little from its characteristic impedance. This situation very seldom occurs in practical installations.

FACTORS AFFECTING SIGNALS TRANSMITTED INTO OVERHEAD LINE END

Signals transmitted into the overhead line towards the cable portion are subject to cancellation and reinforcement from standing wave reflections from the junction point to the coupling point. Frequencies to avoid can be determined from the familiar frequency vs. wavelength formula used for antenna calculations. From the overhead line end, when the line portion is short, the input impedance varies widely with frequency. From the case in Figure 2-42, if the cable portion has 10 dB or more attenuation, then the propagation characteristics of the overhead lines can be analyzed as equivalent to terminating the overhead line at the junction point with 20 ohms. Then, assuming an idealized (zero loss) overhead line, the input impedance would vary from 20 ohms to 8000 ohms from zero to a length corresponding to $\lambda/4$. From a length corresponding to $\lambda/4$ to $\lambda/2$, the impedance varies from 8000 ohms back to 20 ohms. When attenuation is considered, the impedance swing may not be quite as wide between $\lambda/4$ and $\lambda/2$. In between these points ($\lambda/8$, $3\lambda/8$, etc.) the impedance is close to 400 ohms (resistive) with a reactive component.

Since the overhead line involves several multiples of $\lambda/4$ or $\lambda/2$, the input impedance does not swing between quite as wide limits because of attenuation of the reflected wave. When the overhead line attenuation is 3-5 dB or more, the reflected wave has little effect on the input impedance to the line and this impedance only varies slightly around the normal characteristic impedance of the overhead line. In this situation, there is no need to avoid certain frequencies as outlined above. Before any generalizations are made, the line attenuation described here is the loss of the line itself - not that attenuation caused by shunt losses, coupling losses, tap-lines, or external factors.

The full wavelength for the frequency under consideration may be calculated from the following formula:

$$\lambda = [(186.3)(V.P.)]/f$$

Where; λ = Wavelength in Miles
f = Frequency in kHz
186.3 = a Constant
V.P = Correction factor if propagation is less than the speed of light (in per unit)

For overhead lines, a V.P. factor of 0.98 per unit may be used in calculations. For example, the $\lambda/4$ and $\lambda/2$ distances based on this formula are:

f (kHz)	$\lambda/4$ Distance	$\lambda/2$ Distance
25	1.828 mi.	3.656 mi.
50	0.914 mi.	1.828 mi.
100	0.457 mi.	0.914 mi.

The best practice at this time is to avoid frequencies corresponding to $\lambda/4$ and $\lambda/2$ because of the wide departure of the input impedance from the normal characteristic of the overhead line. For instance, at $\lambda/2$, tuning and matching would be the same as at the far end of the power cable; that is, matching into 20 ohms for the case in Figure 2-42. At $\lambda/4$ it is almost impossible to practically match the high impedance (8000 ohms) with existing matching components.

Frequencies should be chosen that are in between these two points and multiples thereof. Special coupling arrangements will help to solve the $\lambda/4$ and $\lambda/2$ cases on a single-frequency basis. The majority of applications involve at least two frequencies: one frequency for line protection and a second frequency for transfer trip, or equipment protection. The practice of using primary and backup line protection with dual channel transfer trip has eliminated the two-frequency line tuner from consideration in mixed facility applications since the bandwidths required for multi-channel PLC equipment are not possible with two-frequency tuners. Two-frequency line tuners for cable circuits have limited bandwidth. (See the section on Two-frequency line tuner bandwidths.)

Coupling to different phase wires for different frequency bands and functions for cables and for mixed facility circuits has been tried with success. The line tuners at the cable terminal and at the overhead terminal should cover the same bandwidth. This may dictate using extra-hi-C coupling capacitors at the cable end along with higher order line tuners (3rd or 4th order) to obtain adequate bandwidth.

FACTORS AFFECTING SIGNALS TRANSMITTED INTO CABLE END

Signals transmitted into the cable portion are less subject to reflection problems, since the rather high cable loss will attenuate reflected signals. Referring to Figure 2-42, the input impedance at the coupling point to the cable at the right end of the figure in an idealized case (no cable attenuation and an infinitely long overhead line beyond the junction point) would be 1 ohm at $\lambda/4$ and odd multiples thereof. At $\lambda/2$ and even multiples thereof, the impedance would be 400 ohms.

Obviously it would be impossible to couple through a coupling capacitor and deliver much energy to 1 ohm. When attenuation is taken into account, the reflected wave is reduced and the actual impedance is never as low as 1 ohm. However, the input impedance can be much lower than 20 ohms and would severely aggravate the coupling loss.

Calculations for wavelength in the cable should be based on the actual velocity-of-propagation factor for the cable involved. If the data is not available, a range of 0.40 to 0.55 can be assumed for the V.P. factor (in per unit). Based on a V.P. = 0.40, the following cable lengths yield $\lambda/4$ and $\lambda/2$ distances of:

f(kHz)		λ/4 Distance	λ/2 Distance
25	0.744 mi.	1.488 mi.	
50	0.372 mi.	0.744 mi.	
100	0.186 mi.	0.372 mi.	

Therefore, the band of frequencies close to $\lambda/4$ should be avoided and those frequencies around $\lambda/2$ are the most desirable. Probably at $3\lambda/4$, and certainly at $5\lambda/4$ and beyond, the cable attenuation on the reflected signal is great enough that this effect can be ignored.

COUPLING CAPACITOR LOSSES FOR LOW IMPEDANCE APPLICATIONS

The PLC signal loss in coupling capacitors for overhead line applications is generally very small and can be neglected. For low impedance cable circuits the loss in the coupling capacitor can become very significant since the coupling capacitor resistive component at PLC frequencies is comparable in magnitude to the cable impedance. Some of the new film type capacitors have a much lower resistive component than earlier dielectrics, but even these losses can be comparable to shunt losses for overhead line installations.

This loss can be calculated using the voltage divider principle in order to take this factor into account for each application.

Figure 2-43 provides a convenient method for estimating coupling capacitor loss penalties for low impedance cable applications. For cases where cable and coupling capacitor impedances are equal, note that a 6.0 dB loss penalty will occur in each coupling capacitor since only one half of the transmitter voltage is applied to the cable impedance. To keep the coupling loss relatively low, "extra-high-C" capacitors are usually required for the higher voltage power cable PLC applications.

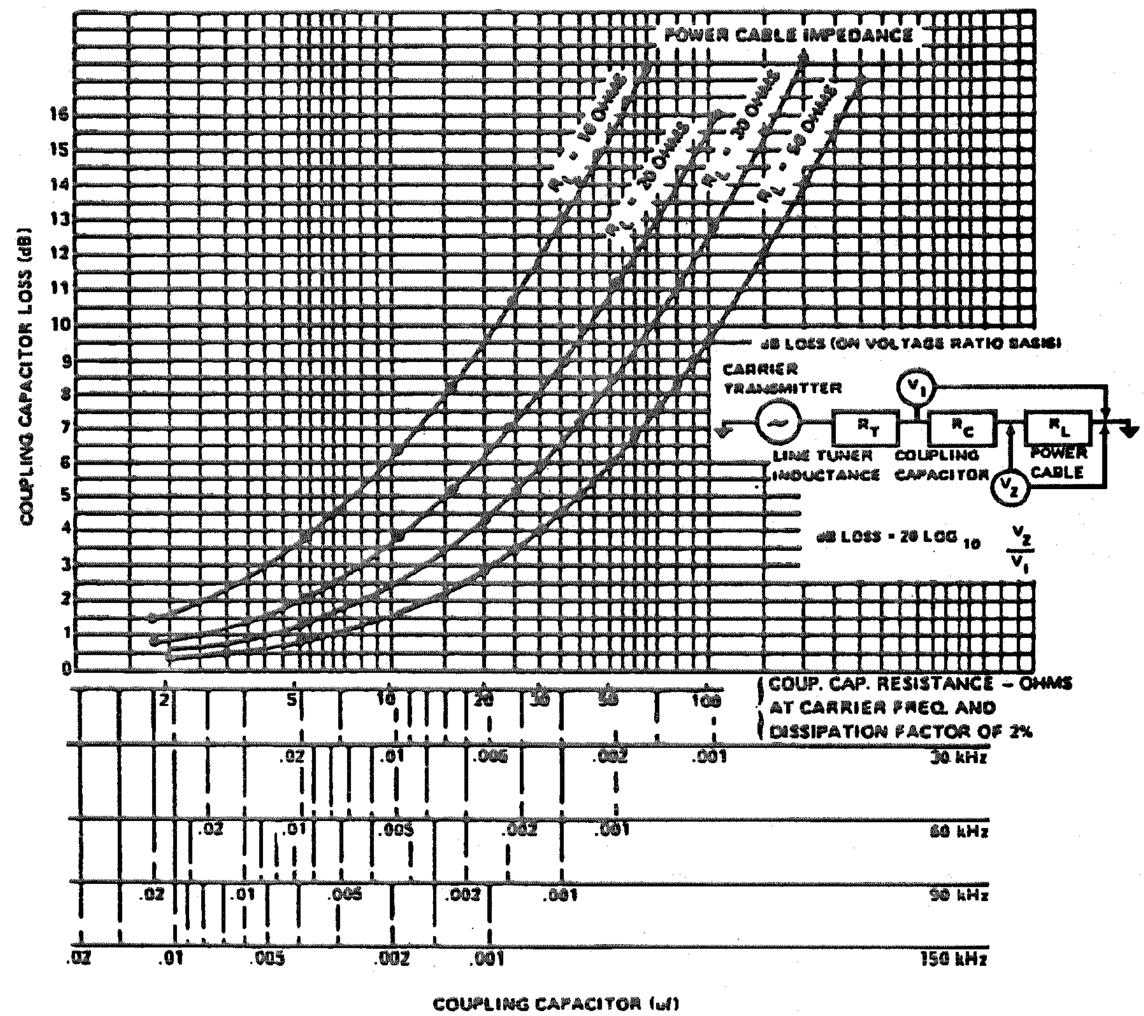


Figure 2-43. Coupling Loss Penalty Due to Coupling Capacitor Resistive Component for Power Cable (Lower Impedance) PLC Applications

BYPASSING THE CABLE-OVERHEAD LINE JUNCTION TO ELIMINATE REFLECTIONS AND MISMATCH LOSSES

One method that eliminates the effect of the overhead line/power cable impedance mismatch at PLC frequencies is to provide a bypass of the junction using line tuning equipment, line traps, and coupling capacitors. This circuit is shown in Figure 2-44. The transmission line is now capable of wideband transmission with the bandwidth limitation primarily caused by the size of the coupling capacitors. The line tuners on the overhead line section may be of a less complexity than the cable tuners on the cable section. The coaxial cable connecting the two line tuners is at 50 ohms. Each section can be tuned individually and connected together to bypass the junction.

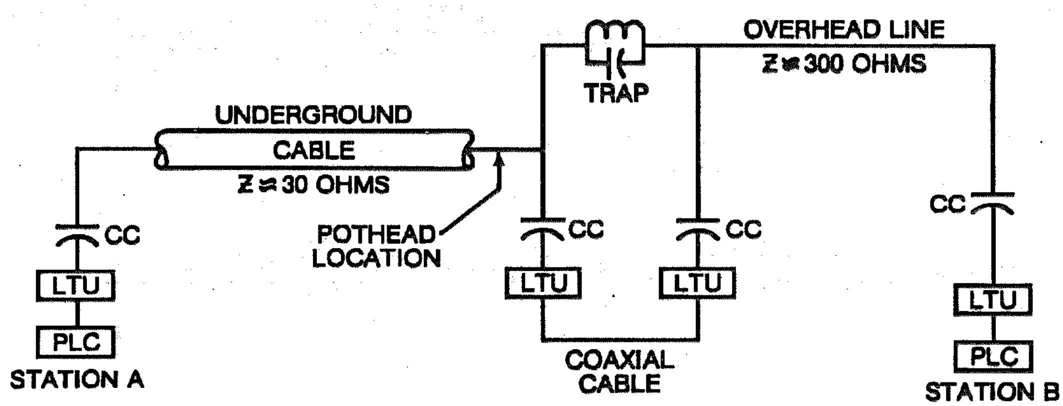


Figure 2-44. Bypass of Power Cable/Overhead Line Junction

This method requires additional expenditure, but allows for future expansion without the problem of determining the frequencies by calculation or pre-measurement. The shunt loss at the junction may be up to 6 dB, depending on the trap impedance in the frequency band. The capacitor loss is usually a significant part of this on the cable side.

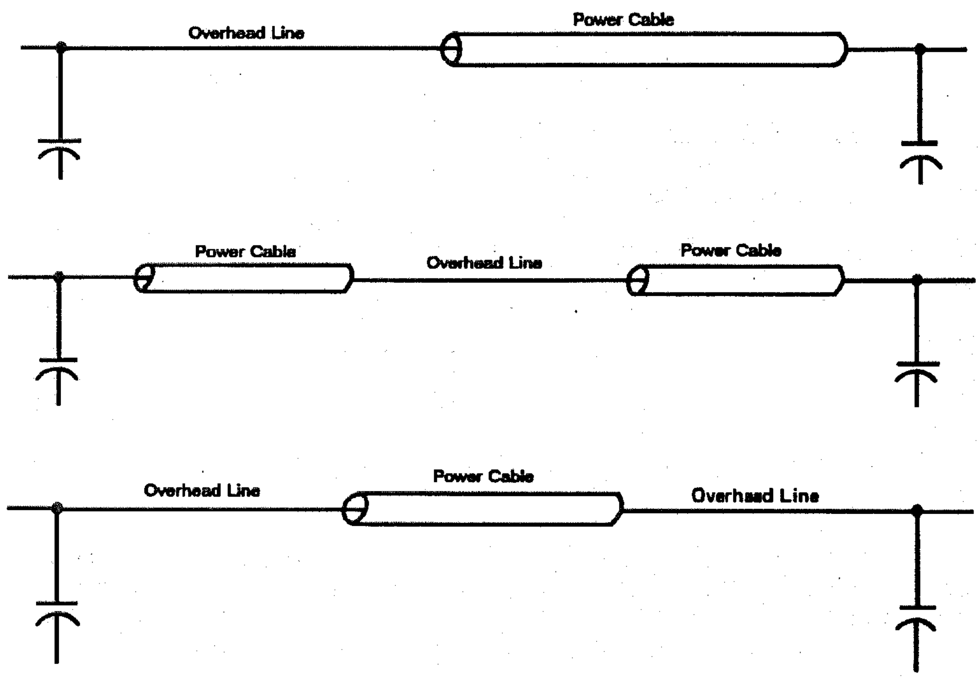
SUMMARY

Each portion of the combination facility should be analyzed to determine possible problem areas. Once feasible frequencies are determined, the attenuation for each portion can be calculated and summed to get total loss. Since there are so many possible combinations of overhead line and cable circuits, it is impossible to outline a generalized solution. Some typical diagrams of combination circuits are shown in Figure 2-45, with notes to help avoid troublesome frequencies.

Odd multiples of $\lambda/4$ are likely to be the most troublesome in either the power cable or overhead line, but only for the first $\lambda/4$ in the cable- compared to perhaps fifteen $\lambda/4$ lengths in the overhead line. Better carrier PLC transmission should result from choosing frequencies for $\lambda/2$ lengths in the cable, but this approach on the short overhead lines would require proper selection of coupling components.

On longer overhead lines feeding into power cables, consideration should be given to phase-to-phase coupling rather than line-to-ground. PLC energy coupled to other phases in the overhead line will be lost for line-to-ground cable transmission, except on the coupled phase. Phase-to-phase coupling is more efficient than ground-return coupling because phase-to-phase coupling does not require retrieval of PLC energy that strays to other phases. Because of the high cost of coupling on higher voltage cable circuits, the phase-to-phase coupling approach probably could not be justified except on longer haul circuits where signals would be marginal without the more efficient type of coupling.

The bandwidth required to transmit multi-channel signals on a power cable or a combination facility may dictate the use of separate coupling circuits for each function. All three cables of a three-phase line may be coupled in a phase-to-ground mode to transmit through the facility. A study of the line tuner bandwidths for wideband tuners may dictate that wider bandwidths are required. Since tuner bandwidths vary directly with line impedance, cable tuners may have from 1/10 to 1/15th the bandwidth of overhead line tuners. Two-frequency line tuners should never be used on cables or combination circuits.



RULES FOR FREQUENCY SELECTION VS. WAVELENGTH

POWER CABLE

1. Avoid $\lambda/4$ length for first wavelength. Beyond that, reflected waves should not interfere unless cable has unusually low attenuation.
2. Select frequencies for $\lambda/2$ to get reinforcement advantage if possible.
3. Frequency selection is not critical if cable carrier transmission loss per section exceeds 3 dB (usually about 1 mile.)

OVERHEAD LINES

1. Avoid $\lambda/4$ lengths plus odd multiples of $\lambda/4$ to about $15\lambda/4$ lengths.
2. Avoid $\lambda/2$ lengths on very short overhead lines, unless plans are made for possible low impedance matching for this particular frequency.
3. Frequency selection is not critical if overhead line carrier attenuation per section exceeds 3 dB (usually 10 to 50 miles, depending on line voltage and frequency).

Figure 2-45. Typical Combination Circuits

In applications requiring transmission of PLC signals through a power system fault, interphase coupling on a balanced line basis offers more capability for signalling during a disturbance. This higher impedance results in more efficient coupling from reduced losses in the coupling circuit. Data on transmission losses on combined facilities is very limited. A comparison of the losses should be made before resorting to the higher investment of a phase-to-phase connection. Phase-to-phase coupling on a pure cable circuit shows no improvement over phase-to-ground coupling.

AUDIO TELEPROTECTION CHANNELS

GENERAL

Equipment to meet the relaying requirements using audio tones via voice channels is a function of the communication medium. Voice channels are available over SSB power line carrier, wire line, leased telephone, fiber optic links and cables, fiber optic multiplex systems and microwave. Among the factors to consider in applying audio tones are the following:

1. Transmission characteristics
2. Signal and channel arrangements
3. Signal transmission
4. Noise
5. Frequency translation
6. Alien tones
7. Transients
8. In-service testing

VOICE CHANNELS

SSB Power Line Carrier

The channel characteristics of a typical SSB power line carrier transmitter/receiver equipment are given in Table 2-18.

The attenuation characteristics in SSB carrier are a function of the power line and the carrier frequency chosen. This is a separate consideration in evaluating carrier performance. Similarly, noise characteristics on the power line are considered when determining the signal-to-noise (SNR) ratio for the application (Table 2-2).

Leased Telephone

The availability of leased telephone channels varies from country to country and from telephone company to telephone company. In the United States, several standard offerings are available (Table 2-19). For many audio-tone relaying systems, one or more of these offerings will meet the channel requirements.

Reference [3] (see Appendix) provides an excellent treatise on arrangement of leased channels to improve reliability by increasing the dependability or security of the relaying function. Telephone channels can be arranged as follows:

1. Single audio-tone signal (one GUARD and one TRIP) over a single telephone channel
2. Two audio-tone signals (two GUARDS and two TRIPS) over a single telephone channel
3. Two audio-tone signals (two GUARDS and two TRIPS) over separate telephone channels

With leased telephone channels, the mode of operation may be half- or full-duplex. If it is half-duplex, the transmit and receive relay functions share the same two-wire circuit, and it is necessary to directly combine tone transmitter and receiver units. Hence, tone frequencies cannot be duplicated and would be spaced according to the available frequencies. If, however, the leased voice channel is full-duplex, the four-wire circuit allows the tone frequencies to be duplicated on each two-wire circuit.

Table 2-18
Channel Characteristics of a Typical PLC SSB Set

Channels..................	Single, dual or four-channel	
Type of service...........	Two-point or multi-point	
Mode of operation.........	Full duplex	
Termination...............	Four wire (adaptors provide other terminations)	
Bandwidth	Standard Channel	Wideband Channel
Nominal..................	300 to 3400 Hz	300 to 3700 Hz
Speech plus (voice)......	300 to 2000/2200 Hz	300 to 2400 Hz
Tones above voice........	2250/2500 to 3400 Hz	2670 to 3700 Hz
Tone levels		
Input range............	-20 to +10 dBm	
Output range		
Full audio..........	+10 to -10 dBm	
Speech-plus.........	+10 to 15 dBm	
Envelope delay............	Unequalized data channel meets C2 conditioning requirements. Equalized data channel exceeds C4 conditioning. See Table 2-19 for definition of C2 and C4.	
Input/Output Impedance.....	600 ohms (balanced to ground)	

Microwave

Microwave is best suited for systems requiring a substantial number of voice channels in an overall application. Since microwave normally handles voice communications, dispatching, VHF radio, supervisory control and data collection, these facilities are normally centrally located at a main dispatch center and do not necessarily require microwave terminals at all substations. Thus, special facilities may be required to interconnect substations with a utility's microwave system. Nevertheless, microwave system protection has been applied to two types of pilot relaying protection: transformer and circuit breaker failure protection, and transmission line protection.

Figure 2-46 is a very simplified block diagram showing the utilization of audio tones in the voice channels of a single-hop microwave system. Here, audio tones in the range of 400 to 3000 Hz are applied to the voice channel. Alternatively, the sub-carrier (baseband) can be used directly for pilot relaying.

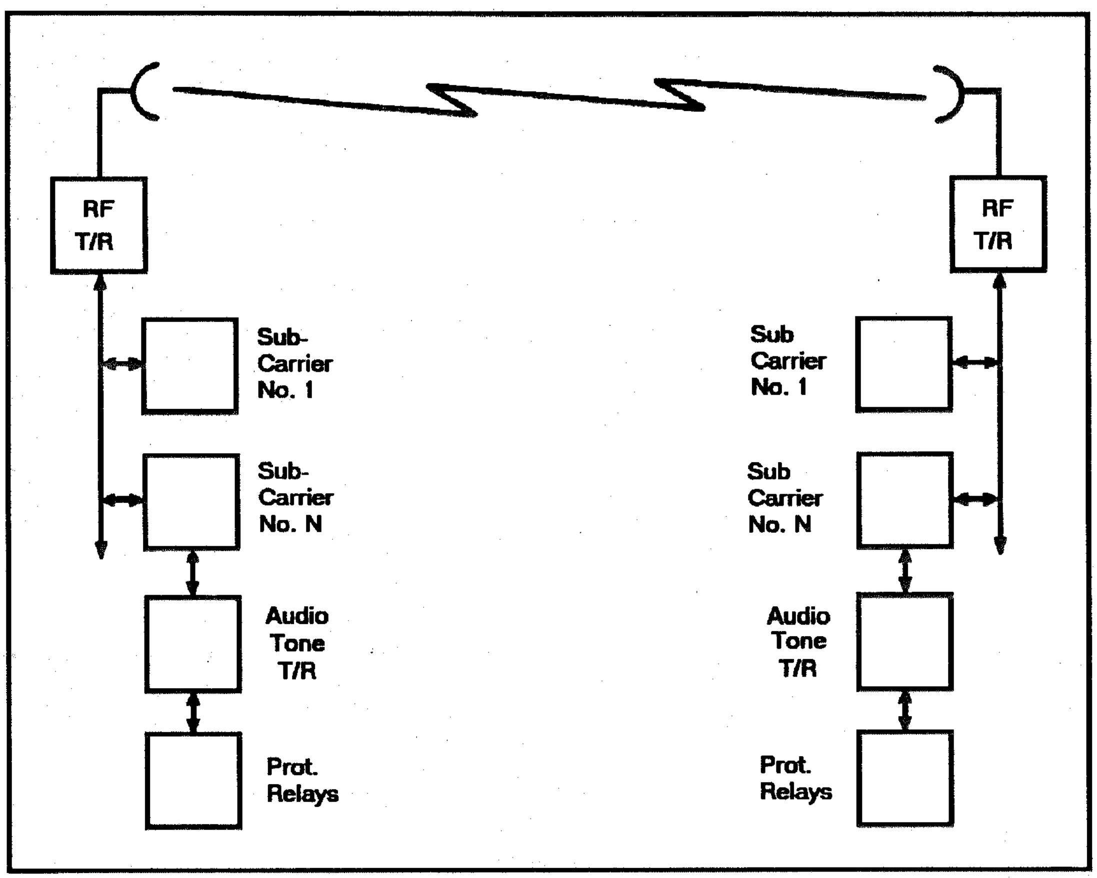


Figure 2-46. Microwave Relaying

Table 2-19

Representative Specifications for Voice-Bandwidth Protective Relaying Channel and Alternate Voice-Data Channel

	Protective Relay Channel		3002 Channel		C_1 Conditioning		C_2 Conditioning		C_4 Conditioning	
Circuit desig. use	Protect. Relay. Only		Alternate Voice Data or Data Only							
General char. Type of service			two point or multipoint						two point or multipoint maximum or four points	
Mode of operat.	1-way - 2-wire		One way, two way simultaneous, two way nonsimultaneous							
Method of term.	2-way - 4-wire		Two wire or four wire							
Recom. imped. of term. equip.	600Ω 10% resistive over the voice band and balanced									
Max. sig. pwr	0 dBm 3 second avg.;+16 dBm rms (Note 1)		0 dBm 3 s average +13 dBm instantaneous							
Atten. char. Initial ckt loss	16 ± 1 dB at 1004 Hz									
Expected variation	short-term ± 3 dB long-term ± 4 dB									
Frequency response (Ref. 1004 Hz) (Note 2)	Freq. Range (kHz)	Var. (dB)	Freq. Range (kHz)	Var. (dB)	Freq. Range (kHz)	Var. (dB)	Freq. Range (kHz)	Var. (dB)	Freq. Range (kHz)	Var. (dB)
	.3-3.0	-2 - +6	.3-3.0	-3 - +12	.3-2.7	-2 - +6	.3-3.0	-2 - +6	.3-3.2	-2 - +6
	.5-2.8	-1 - +3	.5-2.5	-2 - +8	1.0-2.4	-1 - +3	.5-2.8	-1 - +3	.5-3.0	-2 - +3
					.3-3.0	-3 - +12				
Frequency error	no more than ± 5 Hz									
Delay Char. Absolute delay	not specified									
Envelope Delay	Freq. Range (kHz)	Dist'n (µS)	Freq. Range (kHz)	Dist'n (µS)	Freq. Range (kHz)	Dist'n (µS)	Freq. Range (kHz)	Dist'n (µS)	Freq. Range (kHz)	Dist'n (µS)
	.8-2.6	< 2000	.8-2.6	< 1750	1.0-2.4	< 1000	1.0-2.6	< 500	1.0-2.6	< 300
					.8-2.6	< 1750	.6-2.6	< 1500	.8-2.8	< 500
							.5-2.8	< 3000	.6-3.0	< 1500
									.5-3.0	< 3000
Noise Char. Message Ckt. noise	see Note 3									
Impulse noise	not specified		see Note 4							
Other Char. Local Chan. Bal.	less than 1%		not specified							

Notes:

1. +16 dBm signal is classified as an enhanced signal
2. Direct current continuity (metallic circuits) is not provided on any of these offerings.
3. Facility Length

Facility Length (Mi)	Noise at receiver not to exceed
0-50	28 dBrnc
51-100	31 dBrnc
101-400	34 dBrnc
401-1000	38 dBrnc

4. Impulse noise:

Threshold with Respect to Received 1004 Hz Test-Tone Power	Maximum Counts above Threshold Allowed in 15 min
-6 dB	15
-2 dB	9
+2 dB	

NOISE

Careful application of voice channel equipment is required if false tripping due to noise is to be prevented, or if tripping in the presence of noise is required. On a microwave radio multiplex or SSB carrier audio channel, the noise energy is equally distributed over the audio range. On leased physical telephone channels, there is more energy at the lower audio frequencies, particularly that noise produced by arcing carbon block gaps.

Some audio tone equipment uses both inband and wide-band noise protection and sensing. Wide-band protection aids security against high energy impulse noise, allows fast detection and delays receiver response to a false trip signal by switching a fixed amount of delay into the receiver. Wide-band detection retains optimum speed and dependability of the receiver. Wide-band noise protection is usually capable of being strapped out if desired. In general, on leased channels, use of carbon blocks is not recommended because of the high noise which these devices may generate. If safety requirements dictate that protection gaps be used, then audio channel frequencies above 2000 Hz should be used.

Multi-function audio teleprotection tone equipment differs from the usual FSK audio tone equipment in that, although it uses the same FSK transmitter approach, the system has four separate AM receivers which provide two output functions from a single terminal [11]. Four-frequency operation (GUARD plus three TRIP frequencies) allows the two outputs to function independently of each other as well as simultaneously with each other. The advantage of this technique is that it allows the relaying function to command all of the power allotted to this channel. This system can realize a SNR advantage of 6 dB without lessening its performance compared to a dual FSK signal system.

Noise on a SSB voice channel is not a significant problem, provided the system application is designed to give the requisite minimum SNR for the system involved.

FREQUENCY TRANSLATION

Frequency translation is a change in frequency caused by communication media that can transform a GUARD signal frequency into a TRIP frequency. This change in frequency can be produced by microwave multiplex channels and leased telephone voice channels.

If frequency translation is likely to occur, a pilot tone should be used with the audio tone equipment. In general, the pilot frequency should be above 2000 Hz, except for systems which require two independent tone systems on a common channel. For this application, if frequency translation is possible, dual pilots should be used. These pilot frequencies are typically at frequencies of 595 Hz and 2465 Hz. In dual channel systems, an up-shift, down-shift combination can be used to provide partial protection against frequency translation.

Frequency translation in multi-function audio tone equipment will cause the receivers to squelch since the narrow receiver bandwidths will not respond to a guard signal with a frequency shift great enough to be detected as a trip signal. The receiver frequency drift from guard to trip would result in a loss of signal alarm.

If the protective relaying audio tones utilize a permissive relaying scheme, protection against frequency translation can be omitted.

ALIEN TONES

Unwanted tone signals may appear on a leased telephone voice channel. This may be the 1000 Hz test tone for channel equipment. Some tests use a sweep-signal generator with frequency ranges from 20 Hz to 3000 Hz. Good practice requires that telephone channel testing be carefully coordinated to prevent false operation of protective relaying equipment.

Some FSK audio tone equipment may have the ability to detect GUARD and TRIP signals simultaneously. This two-signal receiving capability permits alien trip tone detection. If both signals are present simultaneously (indicating that one of the signals is an alien tone) for more than a timed period, say 50 ms, the alien tone detection circuit squelches the receiver. After an alien tone squelch, the system requires a GUARD signal (without TRIP) for a given time period before unsquelching the receiver.

Multi-function audio tone equipment generally requires the loss of GUARD and the presence of only one of three possible TRIP commands before a TRIP output is permitted. This feature aids security against false operation in the presence of an alien tone.

TRANSIENTS

Teleprotection channel equipment should be designed and constructed so that it will not be damaged nor give an erroneous output when subjected to the surge withstand capability (SWC) test defined in ANSI Standard C37.9-1989. Most all teleprotection channel equipment for PLC application will meet this criterion.

LINE TERMINATION EQUIPMENT

Line termination equipment for audio tone channels for use with microwave and SSB carrier applications is very simple. It consists of a line-termination module connected between the unbalanced output of the tone transmitter or unbalanced input of the tone receiver and the balanced voice channel line.

On the other hand, audio tone relaying via telephone lines requires careful application. The service is critical and must function during faults. Protective devices which are "noise producers" should be avoided where possible, since audio tone relaying is noise sensitive. The basic objective in protecting telephone lines serving utility substations are (1) to protect personnel, terminal equipment and cable facilities, and (2) to provide communications integrity and service reliability.

A recommended protection system for a teleprotection channel on a leased telephone circuit is shown in Figure 2-47. The isolation transformer is a one-to-one transformer used to protect the tone circuits. It is usually rated 20 kV from primary to secondary and 20 kV from both windings to ground. The transformer has low insertion loss (less than 1-2 dB) in the audio frequency range. The substation and wire communication facilities are isolated between the primary and secondary of the transformers.

The gas tube in Figure 2-47 is a three-element tube with a 150-300 volt dc striking voltage. It is located on the substation side of the isolation transformer to provide protection for personnel and equipment in the event of a breakdown of the isolation transformer. Under fault conditions, the gas tubes should not normally fire, thus avoiding noise problems.

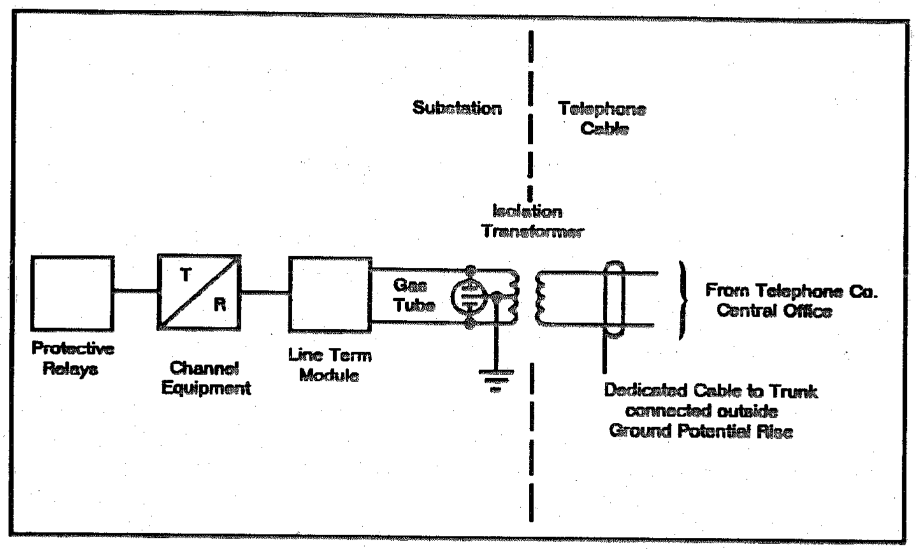


Figure 2-47. Telephone Line Protection Circuit

In general, neutralizing transformers on telephone circuits should not be used with audio teleprotection channels, since they can saturate during high current fault conditions and cause high noise levels. Similarly, carbon blocks produce noise on the circuit when a power system fault causes them to flash and are often noisy thereafter. Thus, where possible, carbon blocks should be avoided.

OPTICAL ENTRANCE

Increased fault current capability of transmission lines has led to substantial ground potential rise problems at substations. Fiber optic cables provide an alternate to the use of isolation transformers. This special interface permits maximum attention to personnel safety, while minimizing protector noise and induced voltages.

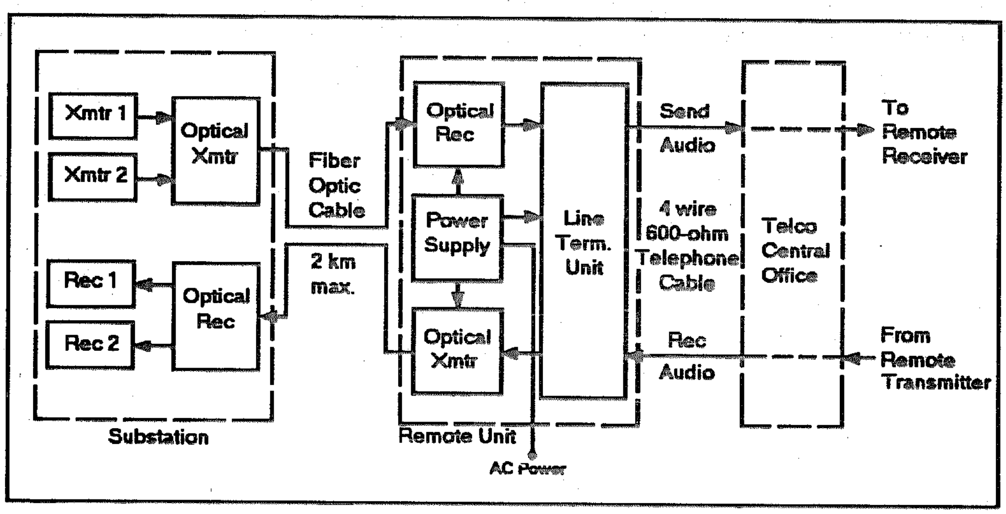


Figure 2-48. Optical Interface Link

An optical interface unit is available for use with both FSK single-function tone and multi-function tone equipment. This unit is remote from the area of the influence of ground potential rise. The remote unit is a pole-mount device requiring an external power source. A typical system configuration is shown in Figure 2-48.

IN-SERVICE TESTING

Audio tone teleprotection channels are continuously monitored by a GUARD tone. This equipment may also be equipped with a signal-loss detector and a loss of signal alarm. Loss of signal and squelch input are used to disable trip output for instances of communication channel malfunction. Other monitored functions can be sent to an optional relay alarm unit for remote alarms.

In two-channel (tones) direct transfer-trip equipment installations, the switching should be arranged to prevent tripping while testing. Where only one tone channel is used, the protection with direct transfer-tripping schemes must be removed for in-service testing. However, permissive relaying schemes using one tone channel can be checked while in service. Auxiliary panels are available for audio tone systems to provide manual test, semi-automatic test, target (channel trip), reclosure blocking and initiate, breaker failure initiate and breaker tripping, automatic throwover and SCR test.

The multi-function audio tone equipment status is both monitored and reported. Visual indiction is shown by an LED, with remote indication via a normally energized relay such that malfunction or removal of any module, including the power supply, is reported.
A local loop test (automatic) function is available in a bi-directional system to check all active circuits with the exception of the trip relays. The test circuit consists of a clock circuit, a sequencer, a logic and evaluation circuit, and a relay to alarm an unsuccessful test sequence

An automatic check-back test function is available for bi-directional systems which not only checks all local circuits but the remote circuits and channel medium as well.

A manual remote loop-back test sequence can also be performed on the Multi-function audio tone equipment with the aid of test switches located on the front of the transmitter module. These switch closings cause the various trip frequencies to be sent to the remote end. The remote receiver, responding to the trip signal from the master end, keys its own transmitter and provides loopback to the master station.

SECTION 3

ON-OFF SINGLE FUNCTION KEYED CARRIER

Contents of Section 3

SOLID STATE KEYED CARRIER CHANNELS HISTORY

Keyed carrier channels have been through several modifications and refinements since being designed as solid state- or transistorized- channels in the early 1960's. This equipment has been called "AM", "Blocking Carrier", "On-Off Carrier", "Radio", as well as combinations of these names. The name that ANSI uses is Single Function ON-OFF equipment. The equipment has been used for line protection with either a wideband channel for either phase comparison relaying or directional comparison, or with a narrow band channel for directional comparison line protection.

Other functions have been incorporated into these channels which operate on a shared basis since the channel is usually in a quiescent state when not transmitting a protection signal. In a blocking mode, the protection signal is only required for protecting the line by blocking tripping of breakers for faults on external line sections. These channels have been equipped with optional functions such as: a maintenance voice channel; supervisory control transmitting up to 35 pulses/sec; or for telemetering.

Early versions of ON-OFF or Keyed Carrier channels required a fairly wide channel with spacings from 2 kHz to 8 kHz, depending on the bandwidth of the receiver filter and the presence of a voice modulator. (See spacing tables in section 2; pages 2-23 through 2-28 of this guide.)

The construction of this equipment has followed the general evolution of communication equipment from a flat panel type unit, which required a large area of rack space with components in a vertical arrangement (shallow depth), to the present construction which uses a horizontal module type shelf approach with a greater depth and density. The evolution through solid state components -transistors, integrated circuits, digital IC's, and single to multilayer printed circuit boards - has been used to make the packaging compact and allow for additions of options using digital technology.

The frequency range of the first solid state units produced in the early 1960's covered the 30 kHz to 200 kHz range and was called CS26A/27A by GE. This range was extended to 300 kHz with later modifications of this equipment in the 1970's and was called CS26/27B. Later, and present day versions of this equipment in a modular construction moved the range to cover the entire Power Line Carrier frequency band of 30 to 500 kHz. This equipment was the CS26/27C series (and CS28).

Compared to Power Line Carrier FSK (Frequency Shift Carrier) equipment, the operating range of ON-OFF equipment is much smaller. Even with a 100 watt power amplifier the range is usually 50 dB. The usual power output of ON-OFF equipment is 10 watts, which gives an operating range of 35-40 dB. Considering the operation of the usual ON-OFF channel, this range is adequate for transmission on an un-faulted line. FSK channels are usually required to transmit and receive signals on faulted lines.

An ON-OFF channel operating on either a two-terminal, or on a multi-terminal line will have all transmitters and receivers essentially tuned to the same frequency. On lines with more than two transmitters (terminals), the transmitter frequencies are off-set from the channel center frequency, and from each other, by at least 100 Hz to prevent signal cancellation or a slow beating of the signals at the receivers which could simultaneously receive signals from more than two transmitters coming from the other terminals.

The first generation solid state ON-OFF PLC equipment (GE CS26/27A) used crystal controlled oscillators and mixers to generate the channel frequency. This mixed frequency at the transmitter was further amplified and possibly switched or modulated for the various optional functions. A special oscillator, using quartz crystals, and filters were required for each frequency. The possible channels were usually spaced at 0.5 kHz intervals in the available frequency range. This requirement meant that each set was ordered for a specific operating frequency and new crystals and filters had to be secured to change frequencies. A typical system block diagram of the first generation solid state ON-OFF carrier set is shown in Figure 3-1. This diagram shows the voice option of the channel with a separate filter and voice modulator which used AM modulation and required a fairly wide spectrum compared to modern SSB modulators. Each function had its own filter specially suited for the frequency assigned. The crystal oscillator operated at the line frequency of the channel. The blocking function would override the voice function if the channel were required to transmit a blocking signal. There was no skewed hybrid in the set to direct the flow of signals to the line and to the receiver. The entire system, with the voice option and a meter/analyzer unit, required 15 rack units of space, or 26.25 inches of standard 19 inch rack area. The Transmitter/Receiver unit required 17.50 inches of mounting space. The active devices of that day were Germanium transistors.

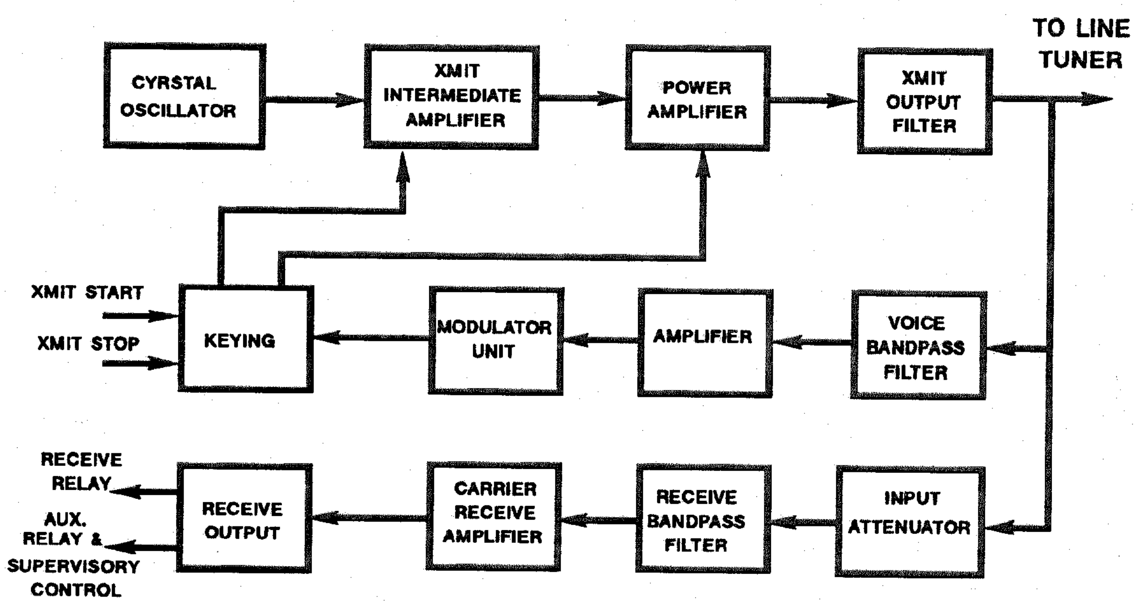


Figure 3-1. First Generation ON-OFF Blocking Carrier Set

The next version of this type of ON-OFF channel (GE CS26/27B), shown in block diagram form in Figure 3-2, was introduced in the 1970's. The equipment was essentially the same system design with the notable exception of the addition of a skewed hybrid, which provided a low loss path for the transmitted signal and isolation between the local transmitter and receiver. The active devices were converted to silicon, and the channel frequency was derived from the mixing of a 2 MHz crystal with a crystal displaced from 2 MHz by the channel frequency. This gave a more stable and exact channel frequency. The crystals were matched across the temperature range to minimize the change of frequency difference with temperature. A more selective receiver allowed closer spacing for directional comparison channels. Individual crystals and filters were required at each different channel frequency. The frequency limit was 300 kHz. The concept of Reduced Power for tests was introduced. The space requirements were reduced to 12.25 inches in a standard 19 inch rack for the Transmitter/Receiver. A 100 watt power capability was also available. This channel could also provide a voice capability, although that option is not shown in Figure 3-2.

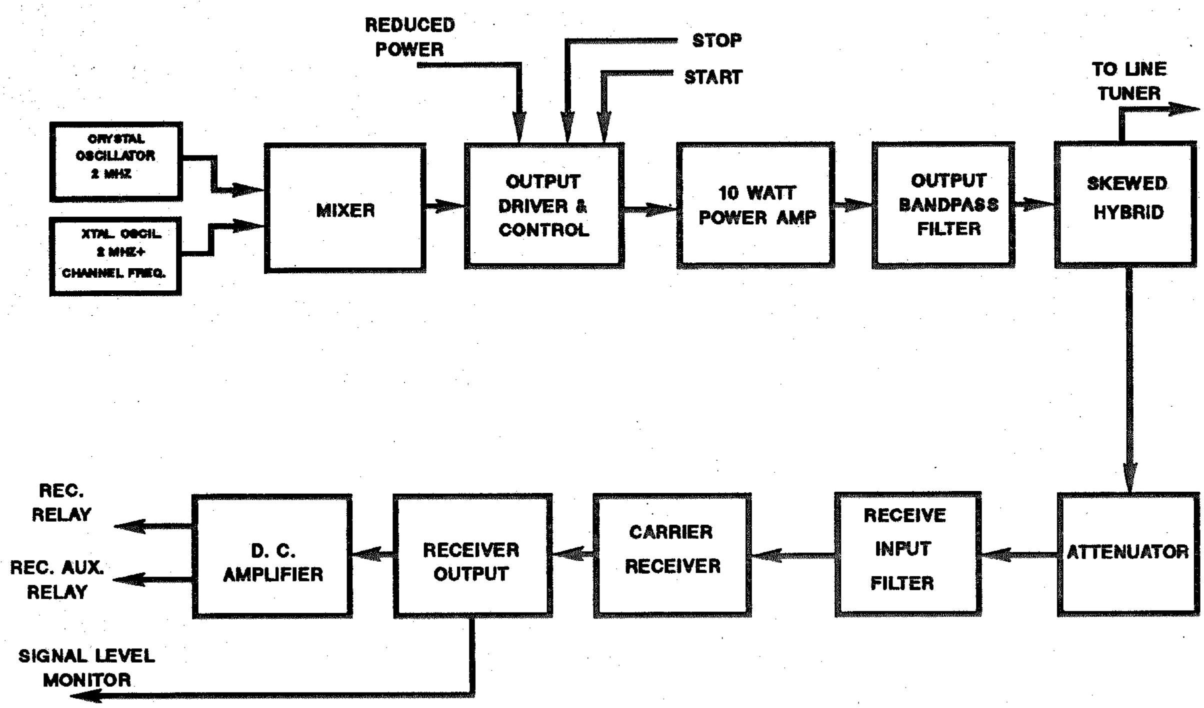


Figure 3-2. Modified First Generation ON-OFF Blocking Carrier Set

The second generation ON-OFF equipment (GE CS26/27C) uses a programmable synthesizer to set the frequency of the transmitter and receiver. The fact that the transmitter and receiver both operate on the same frequency allows the filtering to be done in the same filter. No special filters are required for the voice option, which was implemented on a separate module. Filters in this equipment that do the final selectivity have generally been of the a linear phase type for best response to ON-OFF modulation (or switching) of the carrier to minimize ringing.

The first generation solid state ON-OFF equipment used a meter as the diagnostic means for level alignment and margin setting. The advent of the digital microprocessor has spurred the development of complex check-back, loop test, and other diagnostic functions in second generation ON-OFF equipment. Frequency programmability has been the single most important advance to simplify the application of this equipment. Further use of microprocessors to generate digital data streams for use by substation host computers will allow greater use of remote monitoring of channel functions. This advance is seen as the step to third generation solid state ON-OFF equipment.

SYSTEM APPLICATIONS

ON-OFF single function keyed carrier channels are solid-state power line carrier transmitter-receiver equipment designed for line protection. On a "shared" basis, when the channel equipment is not being used for protective relaying, it can also be used for low-speed (wide-band - 120 baud, and narrowband - 60 baud) supervisory control and/or telemetering and maintenance voice. Table 3-1 summarizes the system applications of this equipment.

Wideband ON-OFF carrier solid-state channel equipment operates in conjunction with solid-state relay equipment or modular relays [21] that utilize channel control logic compatible with the priorities of the wideband ON-OFF carrier set input controls. Narrowband ON-OFF keyed carrier solid-state channel equipment operates in conjunction with solid-state modular relays (SLS) [20] or electromechanical relay schemes (incorporating an SCA carrier auxiliary relay) that utilize channel control logic compatible with the priorities of the narrowband ON-OFF keyed carrier input controls.

Keying input controls are START, STOP, SUPERVISORY and REDUCED POWER. Each control can be programmed for keying voltage and polarity. START can be programmed for "Apply voltage to start" or "Remove voltage to start". START and STOP are both programmable for priority.

Priorities for START PRIORITY are:

1. START ON switches the transmitter to full power.
2. STOP ON inhibits all inputs except START.
3. SUPERVISORY ON switches the transmitter to full power unless STOP is ON.
4. REDUCED POWER ON switches the transmitter to reduced power if STOP is not ON. If START or SUPERVISORY switches are ON, the transmitter will be switched to full power.

Priorities for STOP PRIORITY are:

1. STOP ON inhibits all inputs.
2. START ON switches the transmitter to full power unless STOP is ON.
3. SUPERVISORY ON switches the transmitter to full power, unless STOP is ON.
4. REDUCED POWER ON switches the transmitter on to reduced power unless STOP is ON. If START or SUPERVISORY switches are ON, the transmitter will be switched to full power.

START, SUPERVISORY or STOP keying disable the Voice, Checkback and Loop Test functions. Keying can be by using the station battery or a 5 volt, 20 ma input.

The ON-OFF keyed carrier is keyed ON and OFF by signals from associated relay equipments. The keying action causes the transmitter output to follow these signals. These keyed RF signals are received, attenuated, filtered, amplified and detected. The rectified signals are supplied to the associated external solid-state equipment. The output also actuates the signal alarm relay; this may be either continuous or a 60 Hz square wave.

Table 3-1

ON-OFF Keyed Carrier Application

Chan. Equip. Type	Application		Freq. Range (kHz)	BW (Hz)	Channel Speed (ms)	Pwr. Output (watts)	Oper. Range (dB)	Battery Volts
	Line Relaying	Other						
Wide-band ON-OFF keyed carrier	Phase comparison Directional comparison	Maintenance voice Supervisory control, 120 baud Keyed CXR telemet'rng	31-535	3300 nom.	Pick up 1.5 Drop out 2.0	10 100	40 50	48 125 250
Narrow-band ON-OFF keyed carrier	Directional comparison	Maintenance voice Supervisory control, 60 baud Keyed CXR telemet'rng	31-535	1300 nom.	Pick up 3.0 Drop out 5.0	10 100	40 50	48 125 250

The ON-OFF keyed carrier uses battery voltage to key SUPERVISORY ON and REDUCED POWER ON. A 5 volt at 20 milliampere signal or battery voltage may be used to key START and STOP. Either bandwidth ON-OFF keyed carrier requires a dry contact closure to key START, STOP, SUPERVISORY ON, and REDUCED POWER ON.

The standard output for the receiver is two form "C" contacts rated at 100 Va. A 5 volt at 20 milliampere output signal is optionally available. A transistor switch connected in series with battery voltage and a receiver auxiliary relay R coil is also available. The necessary resistors are added to this circuit to limit the current to a nominal 30 milliamperes or 200 milliamperes, depending upon the requirements of the receiver auxiliary relay (e.g., SCA) R coil.

Since phase comparison relaying keys the channel ON/OFF on a half-cycle time basis, a contact or relay interface is generally not recommended due to concern for an adequate life of the device. Therefore, a wideband ON-OFF keyed carrier is invariably used for phase comparison with SLD relays utilizing the 5 volt at 20 milliampere interface signal. Any bandwidth ON-OFF keyed carrier option can be used for directional comparison relaying.

Each of the relays can differentiate between faults which are external or internal to the protected line section. If a fault occurs outside the protected line section, the associated directional relays and fault detectors cause the transmitter to send a carrier blocking signal which prevents the circuit breakers from tripping. However, if the fault occurs inside the protected section, the relays and fault detectors cut off the transmitter so that the blocking signal is not sent, and the breakers trip. Failure of the carrier system does not prevent tripping of the breaker during an internal fault. However, loss of the channel can cause false tripping for an external fault, and therefore, is less secure.

Pilot relaying is characterized by an intercommunication system between two or more terminals of a transmission line, over which information is transferred from terminal to terminal. It is necessary for the relays at the terminals of a protected line to compare, via the carrier channel, what each terminal of the relay "sees" under fault conditions.

A blocking scheme uses both tripping and blocking relays at all terminals of a transmission line. Tripping relays are set to detect all faults anywhere on the protected line. Blocking relays are set to detect external faults.

Directional relays at each terminal determine whether the fault is internal or external to the protected line section. Internal faults cause the directional relays at both terminals to operate and external faults operate the directional relays at only one terminal. It is the function of the carrier channel to indicate instantaneously to both terminals of the protected line whether or not the directional relays at both terminals have operated.

Briefly, in the directional comparison blocking scheme, if the fault is external, carrier is transmitted for the duration of the fault from one terminal to block tripping at the other terminal. If the fault is internal, carrier transmission is stopped instantaneously at both terminals and both breakers are tripped. Also, if there is no fault, carrier is not transmitted from either terminal. The channel is called on to operate only during external faults that are within reach of the blocking functions.

Directional tripping relays operate to stop carrier transmission and fault detecting relays are used to start carrier transmission. It is vital to start carrier and block tripping for every external fault. Therefore, the CARRIER START fault detectors must operate faster and be more sensitive than the directional units. Summarized below are the basic characteristics of a directional comparison scheme and its associated carrier equipment:

1. The transmission of carrier from any terminal prevents tripping of the opposite terminal of the protected line section.

2. For external faults, the operation of a blocking relay initiates a signal to block tripping at the remote terminal of the protected line.

3. Carrier transmission is stopped at each terminal for internal faults by the operation of the directional relays at each terminal, thereby allowing tripping at each terminal. The tripping relays have preference over the blocking relays in the control of the local transmitter.

4. Carrier transmission is off under normal, unfaulted conditions.

Reference [4] describes the directional comparison relaying scheme in more detail. It also lists the following advantages and limitations of the directional comparison blocking scheme.

Advantages:

1. Highly dependable.

2. Does not require operation of the communication channel to trip.

3.Applicable on all types of line configurations, even on lines with weak infeed terminals.

Limitations:

1. Loss of communication channel can cause overtripping.

2. Less secure.

The basic principles of phase comparison relaying are also described in Reference [4]. Briefly, the role of wideband blocking-type ON-OFF keyed carrier channel equipment is to permit comparison of the phase angle of the current leaving the remote terminal with that of the local terminal. If these two currents are essentially in phase, there can be no fault in the protected line section. If these two currents are essentially 180ø out of phase, there is a fault on the line. When a fault occurs that produces sufficient current to operate the level detector, the mixing network in the phase comparison relaying scheme provides two outputs. These two outputs are 60 Hz square waves, one of which keys the wideband ON-OFF channel transmitter. The wideband ON-OFF channel is used as a blocking pilot so that receipt of a carrier signal blocks tripping. The second output of the mixing network is fed to a comparer. Carrier start is arranged in such a way that the transmitter is keyed only on positive half-cycles. The comparer operates to trip the associated circuit breaker only on negative half-cycles if no receiver carrier signal is present. Summarized below are the basic characteristics of a phase comparison scheme and its associated carrier equipment:

1. For external faults, the single-phase current outputs from the mixing networks at the two ends of the line are 180ø out of phase with each other. This results in keying the transmitters at both terminals on alternate half-cycles. This causes the receivers at both terminals to receive a continuous carrier signal which blocks the comparers from tripping either breaker.

2. For internal faults, the currents flowing into both terminals are in phase, causing the mixing network outputs to be in phase. For this condition, the transmitters at both terminals are keyed simultaneously every other half cycle. Absence of a received carrier signal plus a negative half-cycle signal from the mixing network produces a trip output from the associated comparer. Thus, the breakers at both terminals are tripped during this half cycle.

3. Carrier transmission is off under normal, unfaulted conditions.

Reference [4] summarizes the advantages and limitations of the SLD phase comparison blocking relay scheme as follows:

Advantages:

1. Simple - One relay provides protection for all faults.

2. Does not require an ac potential supply.

3. Not affected by system swings.

4. Not affected by zero sequence mutual effects.

5. Dependable - does not require channel operations for internal faults.

Limitations:

1. Relatively insensitive.

2. Relatively slow since tripping is permitted only on alternate half cycles. The operating time can be decreased by using dual phase comparison which would permit tripping every half cycle.

3. Phase comparison relaying requires a high-speed wide-band channel.

4. Less secure - loss of channel can cause overtripping.

5. Single pole tripping and reclosure require additional devices for phase selection.

AUXILIARY FUNCTIONS

In addition to the pilot relaying function, some auxiliary functions available with the ON-OFF keyed carrier or ON-OFF keyed carrier include:

1. Supervisory control and keyed-carrier telemetering
2. Telephone
3. Alarm and indication (reserve signal)
4. Automatic checkback
5. Unblocking
6. Loop test

Supervisory control and keyed-carrier telemetering using coded-pulse signaling, is applicable when the channel is not in use for the relay function. Speeds up to 60 baud or 120 baud are feasible, depending on the bandwidth of the receiver bandpass filter as shown in Table 3-1. However, when the relaying function is required, it takes priority over the supervisory control and keyed-carrier telemetering functions. Separate equipment is required for the supervisory control and telemetering functions.

In addition to protective relaying, a telephone voice modulator option provides a convenient service channel for maintenance or emergency use. As with supervisory control and telemetering, the protective relays take priority over voice modulation for the brief duration of the fault.

For voice operation, the voice module is used to provide the audio interface between the telephone handset and the basic relaying channel. The system uses single-sideband (SSB) modulation and provides a simplex maintenance channel of order wire quality (300-1600 Hz bandwidth). When the telephone handset is plugged into the telephone jack, or the extension telephone is lifted off the hook, the alarm circuit is opened, thus preventing the local alarm from ringing. Pressing the push-to-talk button on the handset turns on the transmitter at reduced power and connects the microphone to the modulator input. The varying microphone output modulates the transmitter output. When the transmitter signal is received at the remote station, the alarm relay is energized to operate the alarm bell. This occurs once each time the push-to-talk bottom is pressed. As soon as the remote operator plugs in his telephone, this interrupts the bell circuit and conversation can begin. Only one person can speak at a time. The ON-OFF keyed carrier voice option is not compatible with older equipment, because the new voice option uses single-sideband (SSB) modulation, which permits closer channel spacing.

A reserve-signal check function is also available. When the reserve-signal send test switch is operated, the transmitter sends carrier at reduced power, resulting in reduced signal level at the remote terminal. Reserve signal can be monitored by keying the remote transmitter's send and reduced-power switches. The receiver LED's can provide an indication of full received power versus reduced power, which is basically the receiver margin setting. There is a built-in meter which provides a direct reading of the reserve signal level. This meter also serves to monitor the transmitter RF power output level. Alarms are also available to monitor loss of power and RF output.

An automatic checkback feature is available with the ON-OFF keyed carrier [10]. The checkback feature periodically checks the condition of each transmitter, receiver and transmission channel at intervals programmable between 1 and 255 hours. Operation is automatic and is checked both at full power and at reduced power. The checkback procedure can also be initiated manually from either the master unit or a remote unit.

The checkback system includes one master checkback module and remote modules. The checkback procedure is automatically initiated by the master unit, which sends a coded signal to each remote unit to initiate a timed response. The master unit interrogates each remote at full power and then repeats the process at reduced power. If a valid return signal is received, the channel status is satisfactory. If no response is received, an alarm is initiated. The system will send the signal three times before initiating the alarm. The master checkback module is available with a counter which can be strap ped to record either the number of successful or unsuccessful interrogations.

An unblocking scheme is optionally available with the ON-OFF keyed carrier. It provides continuous carrier during normal line conditions. Thus, continuous monitoring and alarming of the local transmitter/receiver and remote receiver are provided. If a fault occurs external to the protected line section, the blocking signal continues to be transmitted, preventing the unfaulted line section from tripping out. If an internal fault occurs, the blocking signal is removed (unblocked), allowing the line section to trip out. Since the unblocking requires continuous transmission during normal line conditions, voice operation, loop test and checkback cannot be used.

A loop test feature allows the testing of the channel at the local station and adjustment of the receive level from remote transmitters which also possess this feature. The local station can remotely key the transmitters at the other stations to allow an operator to set the local receive margin and level.

FREQUENCY CONSIDERATIONS

The ON-OFF keyed carrier covers a frequency range from 31 kHz to 535 kHz as shown in Figure 3-3. Each channel can be centered at 500 Hz intervals. The channels are available in 10 frequency bands. Normally, only one channel is used in any one of the 10 bands. The relaying function preempts the voice function or auxiliaries.

If both the transmitter and receiver are on the same channel center frequency, a demodulated "zero output" signal will result. Therefore, the receiver is always set at the channel center frequency and the transmitter is programmed (offset) for only one of the following: -125 Hz, +125 Hz, -250 Hz, +250 Hz, -375 Hz, +375 Hz, -500 Hz or +500 Hz from channel center frequency.

All of the ON-OFF keyed carrier equipment in a given line section operates on the same channel frequency. Because attenuation increases with increased frequency, the lower frequencies are generally used on long lines and the higher frequencies on short lines.

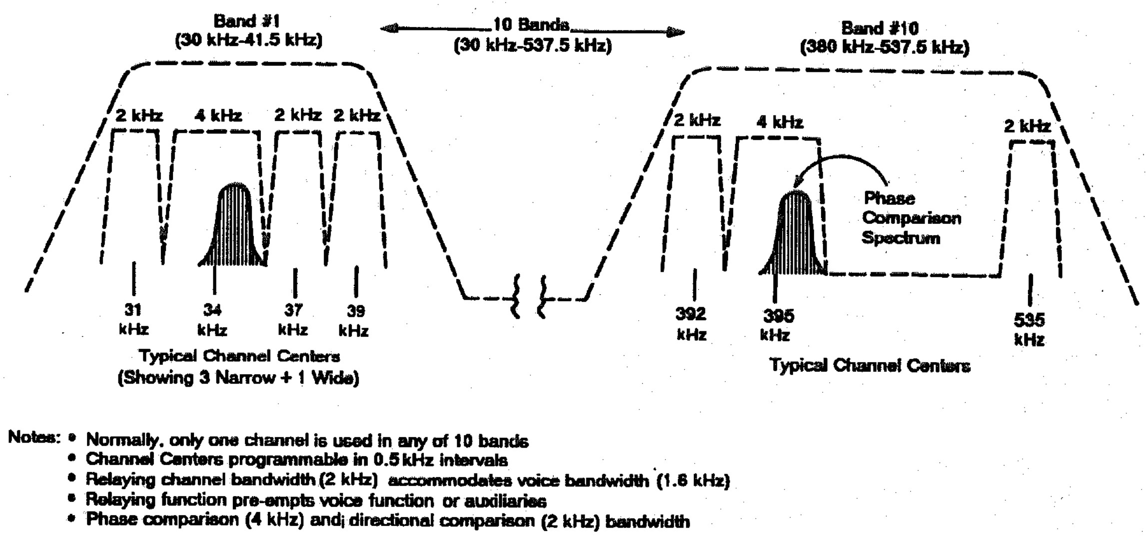


Figure 3-3. ON-OFF Keyed Carrier Channel Spacing "Examples"

Recommended minimum frequency spacing is a function of the isolation between the transmitter and receiver equipment applied on each line section; namely, non-parallel (adjacent) lines or parallel lines. Table 3-2 gives the recommended minimum frequency spacing between the ON-OFF keyed carrier transmitter-receiver equipment as a function of this isolation. Table 3-2 also shows spacing requirements between the ON-OFF keyed carrier and other General Electric channel equipment.

TYPICAL CONFIGURATIONS AND EQUIPMENT

A typical two-terminal carrier pilot relaying system using the ON-OFF keyed carrier is shown in Figure 3-4. Depending upon the type of relaying applied, the narrowband or wideband ON-OFF keyed carrier would be used. The equipment per terminal would consist of the following:

1. Solid-state transmitter-receiver assembly, wideband ON-OFF keyed carrier (or narrowband ON-OFF keyed carrier).
2. Built-in optional equipment (must be specified):
3. External optional equipment (must be specified):
4. Line equipment, including:
   - Coupling capacitor voltage transformer.
   - Single-frequency resonant line trap.
   - Single-frequency line tuner, for phase-to-ground coupling, single coax type

Table 3-2

Typical Minimum Frequency Spacing in kHz as a Function of dB Isolation Between Transmitter and Receiver

Equipment Type	Required Degree of Isolation (dB)	SSB 1,2 and 4 Channel	ON-OFF KEYED CARRIER		FSK Unidirectional			FSK Bi-Directional		
			WB Filter	NB Filter	Nbw FSK	MBW FSK	WBW FSK	NBW FSK	MBW FSK	WB FSK
SSB 1,2 and 4 Channel	5	0/4**	3***	1.5***	4	4	6.0			
	15		3	1.5	4	4	4.5			
	30		3	1.5	3	3	3.0			
ON-OFF keyed * Carrier Wide-Band	5		4	4	3	4	5			
	15		4	4	3	4	5			
	30		4	4	3	4	5			
ON-OFF keyed * Carrier Narrow Band	5			2	2	3	4			
	15			2	2	3	4			
	30			2	2	3	4			
Narrow BW FSK	5				0.5	1.5	3.0	1.5	3.0	6.0
	15				0.5	1.5	2.5	1.5	2.5	4.5
	30				0.5	1.5	2.0	1.0	1.5	3.0
Medium BW FSK Medium Speed	5					1.5	3.0		3.0	6.0
	15					1.5	2.5		2.5	4.5
	30					1.0	2.0		1.5	3.0
Wide BW FSK High Speed	5						3.0			6.0
	15						3.0			4.5
	30						3.0			3.0

*With or without voice.
**Contiguous spacing (0) is permitted if baseband repeating is not used and total attenuation between transmitter and receiver is ≥43 dB.
***Bandedge of SSB to center frequency of ON-OFF keyed carrier.

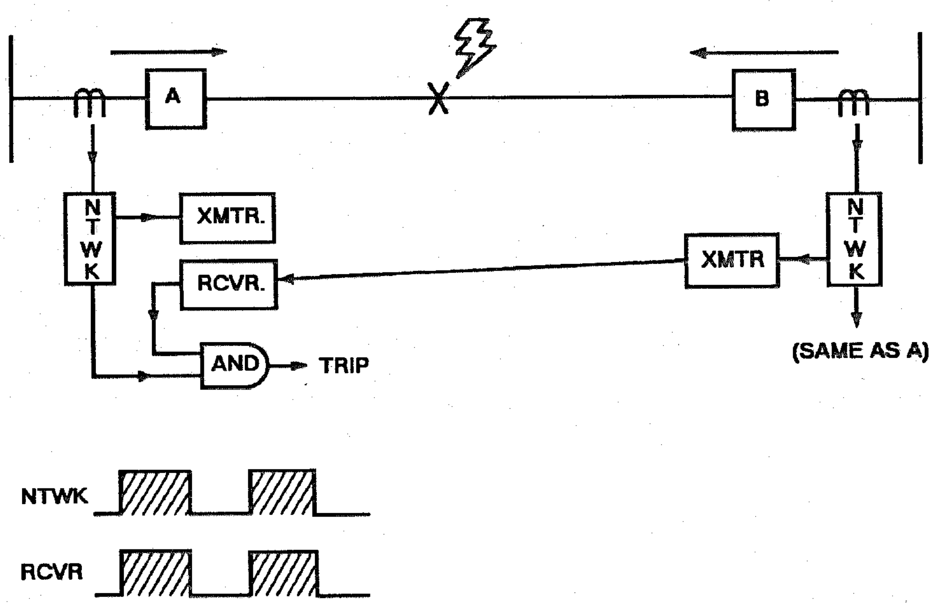


Figure 3-4. Two-Terminal Carrier-Pilot Relaying

Of course, the equipment listed above would change if additional carrier functions (other channels) were a part of the application. For example, additional channel equipment may require two-frequency or wide-band tuning and trapping. Each application would be treated according to the requirements.

OPTIONS AND ACCESSORIES

Optional equipment available with the ON-OFF keyed carrier channel equipment includes:

1. Voice modulator, when voice for maintenance is required
2. Operation from 250 Vdc battery
3. 100 watt amplifier for high attenuation applications
4. Reserve signal-level and RF output indication
5. Checkback and loop test equipment for in-service testing
6. Meter-analyzer for measuring the performance of carrier-current equipment
7. Cabinets and racks for standard 19-inch panels, complete with interconnecting harness and plugs
8. Relay interface module ON-OFF keyed carrier

Battery clamp and isolation interfaces are applied in relay channel applications to protect the channel equipment against current and voltage surges. ANSI C37.90-1978 defines the SWC requirements. All General Electric channel equipment meets these requirements.

A battery clamp is not required on the ON-OFF keyed carrier power supply inputs. If transients exceed 2.5 kV and are below 5 kV, a battery clamp should be considered. If transients exceed 5 kV, steps must be taken by the user to eliminate them.

With ON-OFF keyed carrier channel equipment, battery clamps are applied as follows:

1. Relay systems using non-isolated power supplies:
   a. One clamp in a common cabinet for relay and channel equipment
   b. For channel equipment remote from the relays, provide one clamp with the relays and separate clamp for the channel equipment
2. Modular design, isolated power supplies:
   a. One clamp per battery or
   b. One clamp per physical location

For 5 volt interfaces (i.e., ON-OFF keyed carrier and static relays) with separate cabinets for the channel equipment and static relays, or systems having more than 10 feet of separation, provide isolators at the relay end and channel end of the interface.

PRINCIPLES OF OPERATION

With the exception of bandwidth, and the protective relay scheme for which the equipment is used, the block diagrams of the wideband and narrowband ON-OFF keyed carrier are identical. A simplified block diagram including voice and checkback options is shown in Figure 3-5. As shown, the transmitter-receiver unit is used for the transmission and reception of carrier high speed signals over high voltage power lines for directional comparison or phase comparison relaying and supervisory control.

The transmitter-receiver shelf includes a power supply module, a transmitter module, a power amplifier module (unless the 100 watt amplifier is used), a receiver module and an RF interface module. The voice module and checkback module are optional. The 100 watt RF amplifier, 250 volt dc keying regulator and the unblocking panel are also optional and mounted separately in the mounting rack.

The power supply is a dc-to-dc converter which operates from unregulated 48, 125 or 250 volt dc station battery and provides regulated ±12 volts dc to power all modules in the shelf.

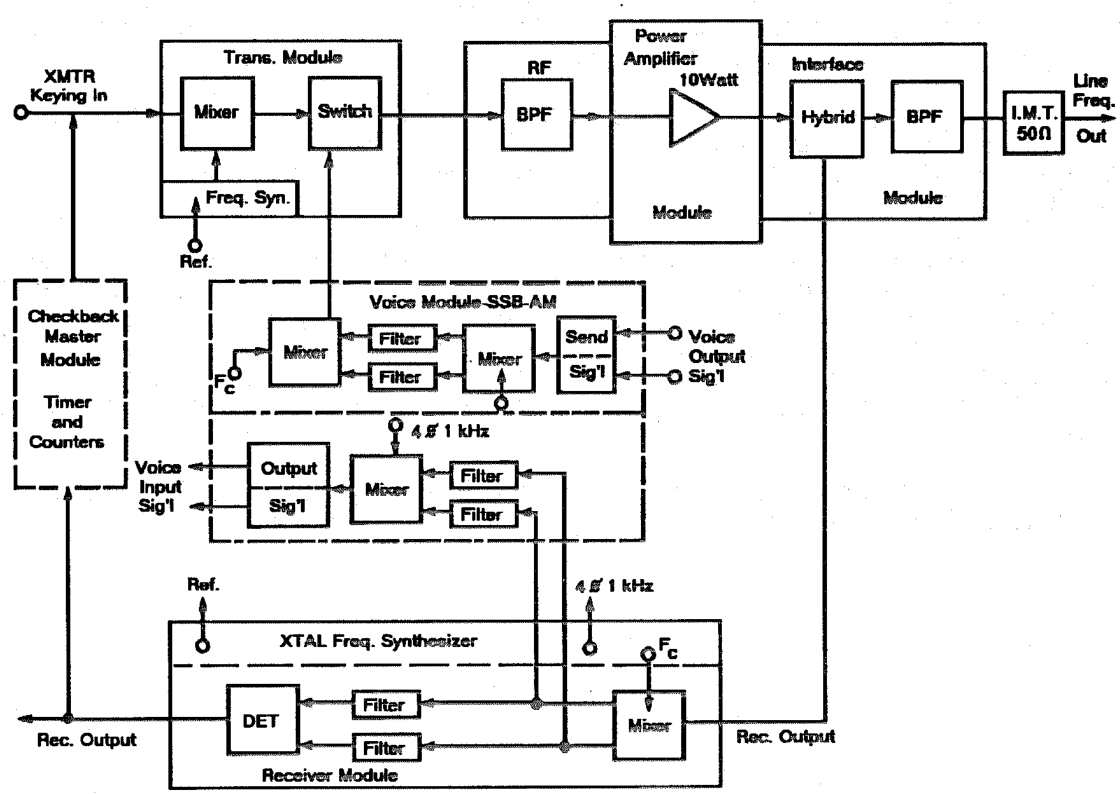


Figure 3-5. ON-OFF Keyed Carrier Simplified Block Diagram Including Voice and Checkback Options

The transmitter module contains a frequency synthesizer which is field programmable from 30 to 535 kHz in steps of 125 Hz. The narrowband transmitter uses 2 kHz channel spacing and the wide-band model uses 4 kHz spacing.

The power amplifier module amplifies the output of the transmitter module to provide 10 watts of RF power. (If the separate 100 watt amplifier is used, the PA module is not used.)

The receiver module also contains a frequency synthesizer which is field programmable from 30-535 kHz in steps of 250 Hz. The receiver's output circuits interface directly with solid-state relays in wideband ON-OFF keyed carrier systems or electromechanical relays in narrowband ON-OFF keyed carrier systems. A separate auxiliary relay output is available for monitoring or supervisory control purposes.

The RF interface module contains a skewed hybrid for proper impedance matching and isolation. Also, this module contains bandpass filters which provide harmonic reduction and line transient protection.

The voice module is used to provide an audio interface between the telephone handset and the basic relaying channel. The system uses single-sideband (SSB) modulation and provides a simplex maintenance channel of order wire quality (300-1600 Hz bandwidth). Signaling is accomplished by transmitting a 200 Hz tone when the push-to-talk button is depressed on the handset. The receiver is activated as in normal relaying operation, and the output through external relays can operate an alarm. Plugging the handset into the phone jack interrupts the alarm circuit locally.

The transmitter-receiver unit is a shelf-type chassis, for mounting on 19-inch wide racks and consists of a series of interconnected units and subassemblies. Optional equipment is also available. (Consult the latest brochures describing the current equipment for options and features available.)

For reliable operation, a 15 dB operating margin is generally recommended for directional comparison relaying and a 20 dB margin for phase comparison relaying. With the receiver set at its design sensitivity, the receiver input attenuator is adjusted until the receiver output current (or voltage) is at the knee of its operating curve. This establishes the operating margin, which means the RF signal input may decrease 15 dB for directional comparison relaying or 20 dB for phase comparison before the relay output starts to decrease.

A portion of the received signal is rectified and tapped off for an external microammeter to read the relative level of the signal being received.

SECTION 4

PLC FSK CARRIER

Contents of Section 4

4 ▶

HISTORY OF SOLID STATE PLC FSK CHANNELS

Like the blocking carrier, or ON-OFF channels, the PLC FSK channels have been through several modifications and refinements since the introduction of solid state devices. This equipment was first used for equipment protection using either permissive or direct transfer trip relaying schemes. The first solid state FSK channels were built on flat panels which consisted of component modules using wire-wrap circuit boards and solid state active circuits. This equipment was referred to as the "A" version FSK channels.

TYPE "A" FSK EQUIPMENT

The frequency range was limited to the frequencies from 30 kHz to 250 kHz. Station battery voltages of 48VDC, 125VDC, and 250 VDC were accommodated. Individual modules could be tested and replaced or repaired. Test points and jacks were provided for test and alignment.

The rack space required for the transmitter depended on the station battery voltage. The 48VDC and 125Vdc 10 watt unit used 10 rack units of shelf space. The 250VDC, 10 watt transmitter used 12 rack units *(RU) of shelf, or cabinet space. A meter unit used an additional 3RU of space. (* 1 RU = 1.75 inches)

The transmitter could deliver 10 watts up to 200 kHz. This output power dropped off to 6 watts at 250 kHz. Dual crystal oscillators operated at 2 MHz and at 2 MHz plus the guard frequency. The second oscillator was shifted downward by 200 Hz when the transmitter was shifted to trip.

The first generation PLC FSK equipment had only the capability of the narrowband channel. This was the 200 Hz shift. A block diagram of the GE CT51A transmitter is shown in Figure 4-1. The output filter was used for a band of frequencies, and there were 19 groups of filters to cover the 30 kHz to 250 kHz frequency range. A 1-watt version of the transmitter used the same output filter and used 7RU of shelf. The 10 watt transmitter was driven by the 1 watt circuit.

The concept of exalting the power output of the transmitter is used in this equipment. Germanium transistors and silicon diodes were the active devices.

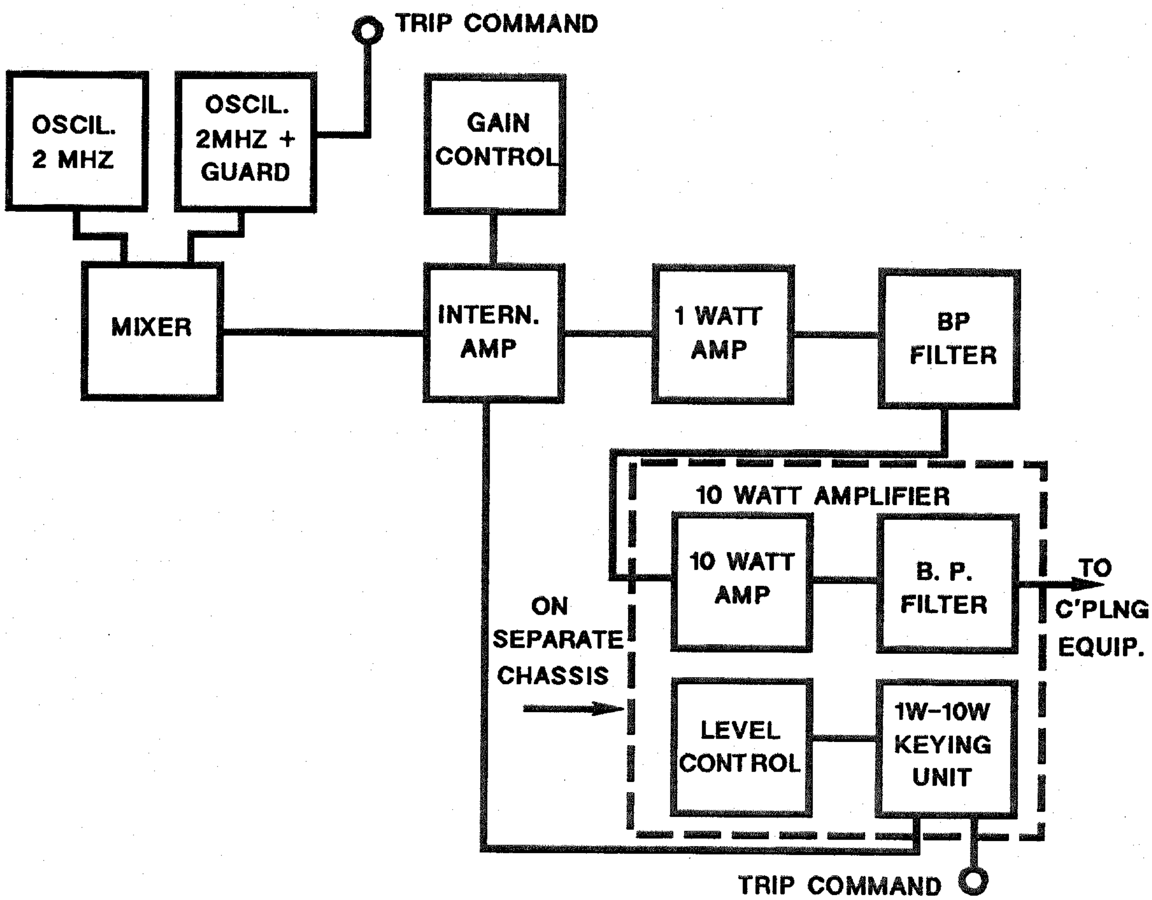


Figure 4-1. Version "A" FSK Transmitter Block Diagram

The companion receiver also was constructed on a flat plate chassis. The input filter of the receiver was a quartz crystal circuit which was selected for each receiver frequency. The block diagram of the GE CR51A receiver is shown in Figure 4-2. The mixer used a single crystal at the channel frequency plus the 10 kHz IF frequency. A discriminator was used in concert with the IF filter at 10 kHz to emphasize the guard frequency signal to keep noise from causing the channel to false trip. A carrier alarm was used to indicate changes of greater than -10 dB in the level of the guard signal. A signal level indicator, in the form of an optional meter panel, required a 3 RU space in addition to the 6RU required by the receiver.

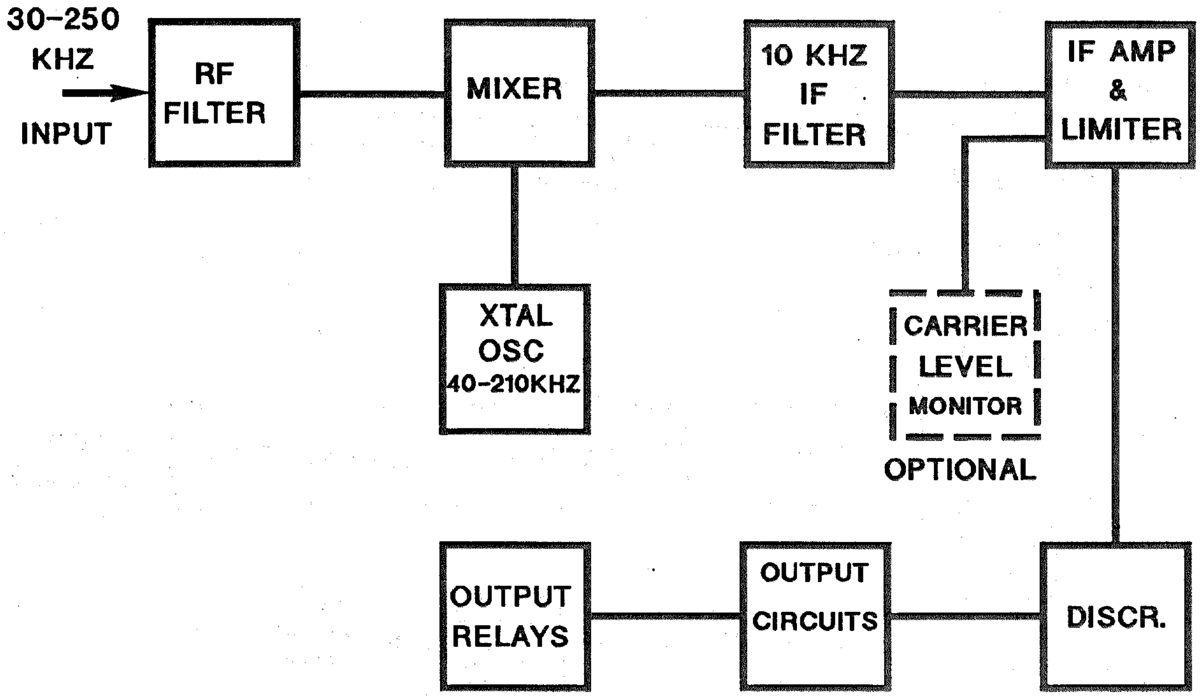


Figure 4-2. Version "A" FSK Receiver Block Diagram

TYPE "B" FSK EQUIPMENT

The next version of PLC FSK channels was called the "B" version for the narrow band channel (CT/CR51B), the medium bandwidth (CT/CR61A) and the wide bandwidth (CT/CR71A) channels were introduced using the same construction and system concept. The individual components of the "A" version were packaged in slide-in modules to reduce the space for a transmitter or a receiver to 4RU. If a 250 volt battery was used, a regulator was required which used 2RU of shelf space. A block diagram of the transmitter is shown in Figure 4-3, and the receiver block diagram is shown in Figure 4-4.

The transmitter consisted of five modules in a shelf, with one blank slot. The receiver contained up to seven modules including the logic circuits used in the CR61/71A receiver. A panel meter mounted on a panel at the top of the shelf indicated the receive level for monitoring and margin setting. The CR51 receiver contained no logic.

The frequency generation in the CT51 was a pair of 2MHz crystal oscillators; the CT61/71 used two 6MHz crystal oscillators, offset by the channel frequency (plus the shift) of the channel. The generation and frequency shift was all done in the Oscillator/Driver module of the system. A 3-frequency version of the channel was available for the CT/CR71A. The transmitter used a standard 10-watt Power Amplifier and a frequency dependent output filter.

The basic equipment did not have a 100-watt capability, but an external 100 watt PA could be included to boost the output for long lines (high loss) circuits, and for power cable applications.

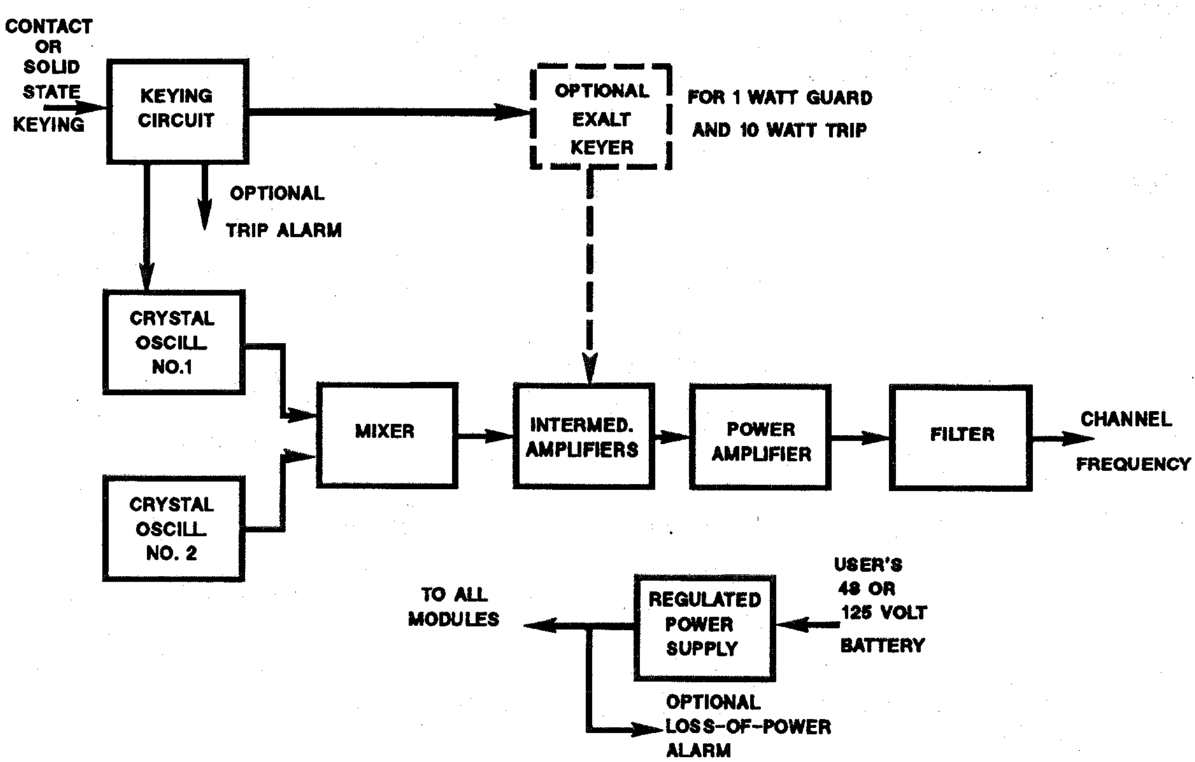


Figure 4-3. Version "B" FSK Transmitter Block Diagram

The receivers were essentially the same as the "A" version units. The CR61A/71A versions, however, used 29 kHz as the IF.

Various versions of the discriminator were available to offset the guard and trip signals. A balanced discriminator with no offset was also available. The limitation on the receiver continued to be the use of specific crystals in the oscillators for each channel frequency, and a specially made crystal filter for each channel. The frequency range of the standard channel was up to 300 kHz, but special channels were available up to 500 kHz with a small sacrifice in power output. The transmitter output filter was also special for each frequency. The normal channel availability was every 0.5 kHz in the PLC frequency range, although some channels were built off the 0.5 kHz spacing to eliminate intermodulation problems.

The introduction of logic in controlling output circuits that communicated with the Guard and Trip relays was made in the CR61/71A equipment. Different types of logic were available for use with various protective relaying schemes. Alarms were included in the Transmit and Receive circuits. A loss of power alarm, carrier level alarm, and channel status alarm were available. The logic types used with this equipment are also used in present modern equipment designs and are described later in this section.

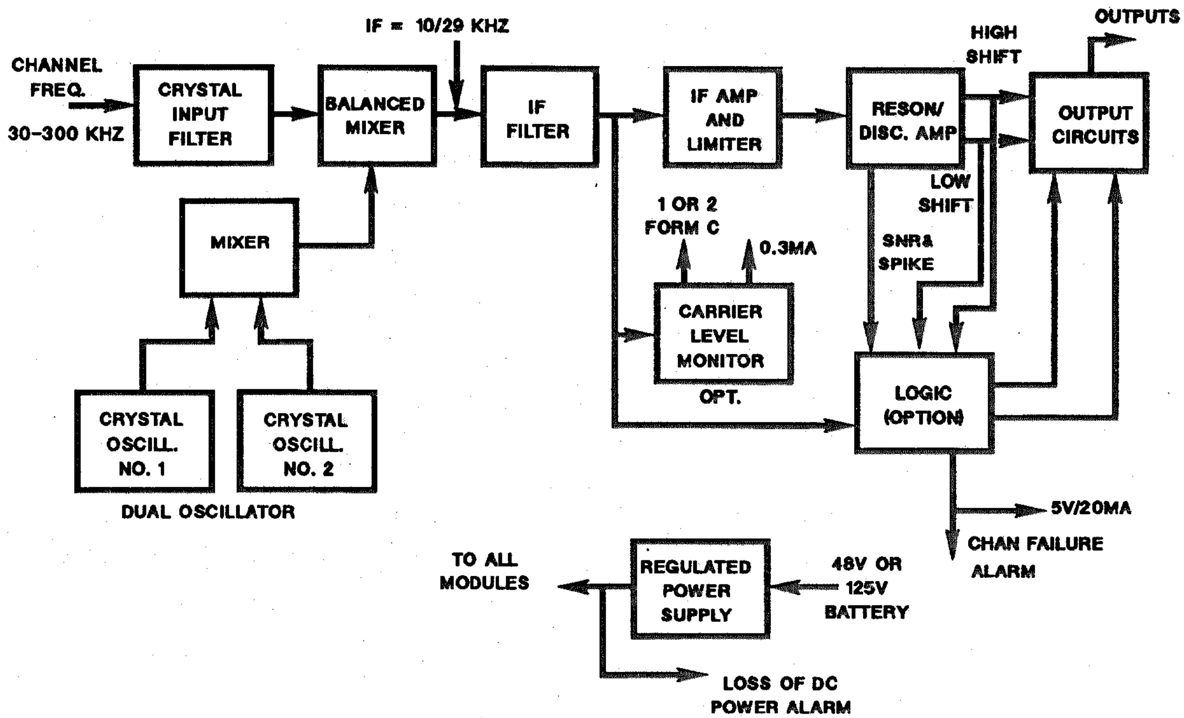


Figure 4-4. Version "B" FSK Receiver Block Diagram

All of this equipment was built on printed circuit boards, but the backplane wiring of the shelves continued to be point-to-point hard wiring. The receiver sensitivity for the CR61/71A was 15 mV. The CR51B had a sensitivity of 5 mV or 15 mV.

MODERN FSK EQUIPMENT

Modern PLC FSK channels are built using solid state devices such as large scale integrated circuits, operational amplifiers, digital logic, and programmable frequency synthesizers and filters. The trend to miniaturization of all the equipment makes possible a transmitter and receiver shelf using only 4RU of space for bi-directional channels including an optional skewed hybrid. The circuits for narrowband, medium bandwidth, and wide bandwidth FSK channels are the same. The channel frequency can be set to any frequency from 30 kHz to 500 kHz and can be easily changed in the field. A block diagram is shown in figure 4-5.

MECHANICAL DESCRIPTION

Modern FSK equipment designs typically consists of a shelf assembly and plug-in modules (or cards). The shelf has a height of 4 RU (1RU = 1.75 inch) and is designed for mounting in a standard 19" rack.

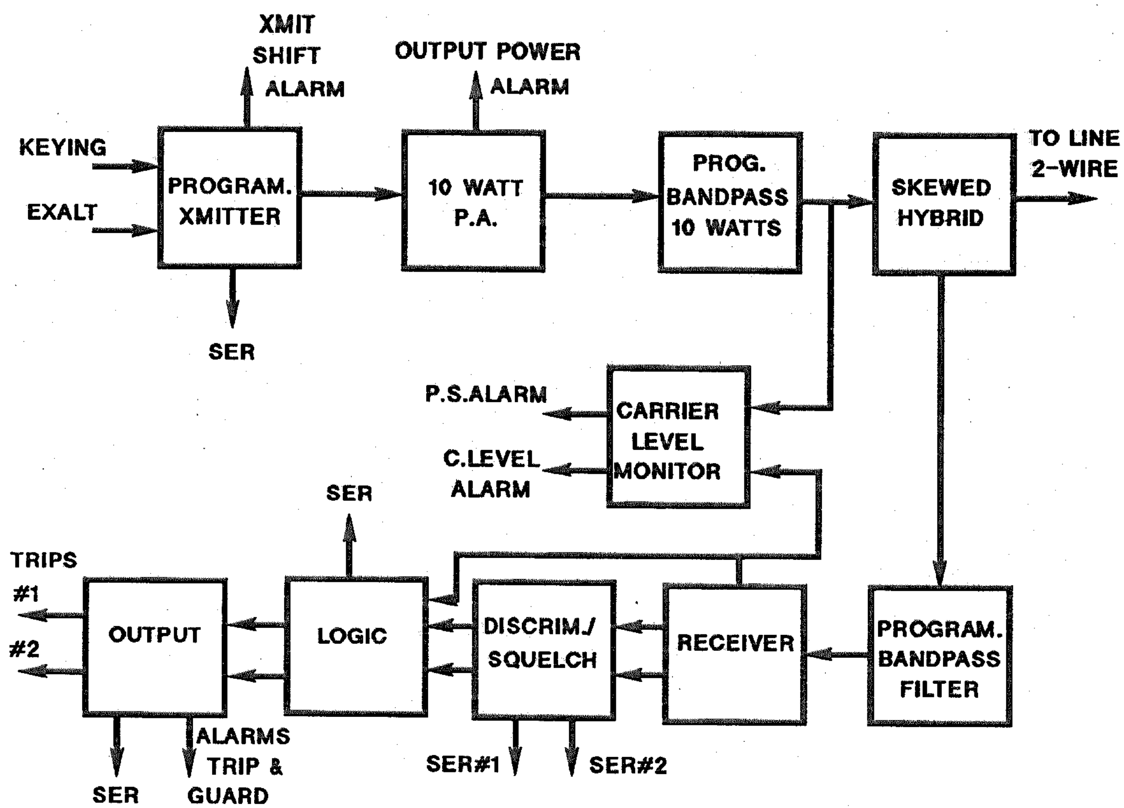


Figure 4-5. Modern Solid State FSK System Block Diagram

The modules are plug-in type and have extractors in the upper front part of the card to facilitate extraction. The gold plated fingers in the back of the card mate with a card edge connector mounted on the backplane of the shelf. For each pin position there is actually a pair of electrically connected fingers -one on the component and one on the solder side of the board. Each card has a keying slot which mates with a key in the card edge connector to prevent insertion into the wrong shelf slot.

The shelf consists of a case, see-through glass door, card guides and backplane. The backplane is a printed circuit board with card edge connectors and surge capacitors on the inside of the case and terminal blocks and RF connectors on the outside. There are two RF connectors: a UHF connector associated with the transmitter or the hybrid output, and a BNC connector associated with the receiver input (4-wire application). An impedance matching transformer with a 50Ω and 75Ω tap is also provided.

A number of optional harnesses are available with two types of terminal boards - EB-25 and sliding link - and four different lengths. The equipment is available as transmitter only, receiver only and transmitter/receiver.

The 100W amplifier is a separate unit.

ELECTRICAL DESCRIPTION

The signals are commonly referred to as guard and trip signals or frequencies. The guard and trip frequencies are shifted +100Hz and -100Hz for narrow band equipment; +250Hz and -250Hz for medium bandwidth ; and +500Hz and -500Hz for wide bandwidth equipment, respectively, from the channel frequency. The channel frequencies are available from 30 to 500kHz in .5kHz steps.

The glass front door allows the user to view the LEDs and (optional) Channel Level Monitor (CLM) meter without opening the door. The LED colors and their location have been arranged to aid the user to determine the status of the equipment. The top row uses green LEDs and indicates either a guard or " normal" condition. The second row uses red LEDs, indicating a trip condition. The third and fourth row use green or red LEDs to show other conditions. Sequence of events recording (SER) plug-ins are used at various locations to monitor system parameters.

Common Equipment. Two modules which serve either, or both, transmitter or receiver systems are the Power Supply and the RF Interface modules. The Power Supply is an isolated DC to DC converter. This unit converts the battery voltage to an internal supply voltage of ±12VDC. The RF Interface module contains the transmitter and receiver filters and an optional skewed hybrid. The module may contain one or both filters depending on the system needs.

Transmitter. Two basic transmitter systems are available: the standard system with output power of 10W; and, an optional system with an external power amplifier to provide 100W. In addition to the modules described previously under Common Equipment, a transmitter card and a 10W amplifier module are required. The 100W system requires an external 100W amplifier in place of the 10W amplifier.

The **Transmitter** card generates the guard and trip frequencies. A numerically controlled modulated oscillator which controls the channel frequency is programmed with a 10 position DIP switch. The guard and trip signal levels can be individually adjusted with potentiometers. The adjustment range allows the system to be set up for either 1W/10W, or 10W/10W output power (multiply by 10 when 100W amplifier is used). The guard and trip frequencies are controlled by the keying input, which can be strapped for any of the battery voltages. For operation from 220/250V batteries a voltage dropping resistor has been installed on the backplane. With an input voltage applied, the signal shifts to trip and the level changes depending on the potentiometer setting. The status of guard or trip is indicated with a green and red LED, respectively. An optional second input is the external exalt input. With an input applied (same parameters as keying input) the guard signal can be exalted (increased) to trip level without changing to trip frequency. A green LED indicates that this input has been activated. The shift-to-trip alarm (STA) is activated anytime the keying input is active. SER monitoring is provided.

The **Power Amplifier** module amplifies the signal from the transmitter to a level of 10W (into a nominal load impedance of 50Ω). A green LED indicates that the amplifier is generating at least 50% of power (with respect to guard power). Along with that LED an alarm relay is also provided. A red LED indicates an amplifier overload condition due to over-current or over-voltage present in the output stages.

The external **100W Amplifier** performs the same function and provides the same alarms as the 10W card except that the output power is 100W. The output filter in the power amplifier is a band-pass type to attenuate harmonics of the transmitted frequency.

Receiver. The receiver consists of three modules: A receiver module, discriminator/squelch module and an output module. A logic module is optional. Additionally, the power supply card and the RF interface card discussed previously under Common Equipment are also required.

The receive signal passes through the RF Interface card to the Receiver card. The channel frequency is selected on this module. A frequency synthesizer consisting of a crystal controlled oscillator, a phase-lock loop and a programmable divide-by-N counter generates the channel frequency. The programming is done by a 10 position switch and a jumper. The frequency is programmed the same as the channel frequency. The receiver is a Zero-IF receiver. An input signal with a frequency exactly the same as the channel frequency would produce an IF frequency of 0Hz. Since the guard and trip frequencies are always shifted plus or minus 100Hz, 250Hz, or 500Hz from the channel frequency, the IF frequency thus becomes either 100Hz, 250Hz or 500Hz. This receiver also contains the mixer. The local carrier is mixed with the incoming signal in the mixer to produce an IF signal. Actually, two IF signals, phase shifted by 90ø, are generated. The phase shift is either +90ø or -90ø which depends on the incoming signal frequency being shifted either high or low. Each of the IF signals is then processed through a active low-pass filter. This low-pass filter determines the receiver selectivity. The two IF signals are full wave rectified and summed for the purpose of signal level metering. Within the mixer the two phase-shifted signals IFA and IFB are also fed to a limiter circuit where two limited IF signals LIFA and LIFB are produced. The receiver is normally operated at a certain signal level (margin) above its sensitivity. A step attenuator (6dB steps) and a vernier are provided to adjust the incoming signal level.

The **Discriminator/Squelch** module performs two functions. First, the discriminator function determines if the incoming signal is on the guard or the trip frequency and converts the information into distinct guard and trip "logic" outputs. Second, the squelch function monitors the channel level and signal-to-noise ratio and blocks the trip output during an abnormal channel condition. The two signals, LIFA and LIFB, from the receiver are fed to the solid-state discriminator The output of the discriminator is a DC voltage, one polarity for guard and opposite polarity for trip. As these voltages exceed a certain threshold the output stages are activated. The guard stage has a fast pick-up and slow drop-out response; the trip stage just the opposite. These time delays reduce the probability of unwanted trip outputs. To further improve the dependability and security performance of the receiver a squelch is provided. LEDs indicate signal presence and circuit conditions. The LIFA signal is used to determine a noisy channel condition and to indicate squelching action. SER plug-in positions are provide for monitoring the receiver functions.

Several **Output** modules are available. All Output modules provide one form C contact for guard alarm and one form C contact for trip alarm. Outputs are DC isolated from the receiver. Each module also provides a pair of connectors to accept a SER board. The **Relay HD** output provides relays with tripping duty (heavy duty) contacts. Three variations of contacts are available: Guard and trip interconnected (logic AND function); guard and trip not interconnected (intended for external interconnection); and trip only. The **SCR** output module provides two SCRs, rated for tripping duty and DC isolated from each other. The **TSTR** output module provides two transistors, rated for tripping duty and DC isolated from each other. The **Relay HS** output provides two high-speed, low duty relays intended for interfacing with Transmission Line Protection Relays. (e.g. GE MOD-10) The **5V/20mA** output provides an electronic output intended for interfacing with GE MOD-III Static Relays.

Tables 4-1 and 4-2 show a listing of the keying inputs and the receive output characteristics for this equipment.

Receiver Logic Options. Available logic features include D, P, U and T logic. The **Logic** D/P module can be strapped for either D or P logic. The **Logic U/T** module can be used in either mode by using one or both logic outputs. A brief description of the logic features follows:

D logic requires guard reset before trip
P logic requires signal reset before trip
U logic provides trip for loss of signal (otherwise same as P logic)

T logic provides two outputs, one performing the same as P logic, the other one performing the same as U logic

Diagnostics. The CLM module provides at least a power supply alarm (PSA). In a transmitter system it may (optionally) also include a meter to measure the transmit output level (TXM). In a receiver system it will always provide the PSA and carrier level monitoring (CLM) with (optional) meter. The circuitry is always there to drive an external meter (0-3mA), although no meter may be present on the card. The sequence of events recording (SER) option is available for the transmitter, the receiver, or both. The SER option consists of a small plug-in board using a fast reed relay with one form A dry-contact. This output is intended for interfacing with a sequence of event recorder.

Table 4-1

PLC FSK Keying Inputs

Option	Description	Comments
A	1)Keying, DC isolated	Keying voltage can be 5, 48, 125 or 250 volts DC (Jumper selectable)
B	1) Keying, DC isolated 2) External Exalt, DC Isolated	Same as Above Same as Above

Table 4-2

PLC FSK Receive Outputs

Option	Type	Comments
R,A,B	Relay	30A for 200 ms at 15-second intervals 280 VDC max. voltage.
C, D	SCR or Transistor	Same as Above, DC Isolated
T	Relay, High speed	280 VDC max, 15 mA, max.
E	Solid-state	5 volt dc at 20 mA

SECURITY AND DEPENDABILITY

Two very important characteristics of a Power Line Carrier(PLC) channel used for protective relaying are the Security and Dependability of the channel.

Security is that facet of reliability which relates to the certainty that a relaying channel will not operate incorrectly under noisy conditions, or the ability of the channel to prevent noise from generating a change of state in the receiver when no change command was transmitted.

Bursts of noise are applied to the transmission path at different signal-to-noise ratios (SNR). P_{uc}, which is the probability of an unwanted command (false trip), is the ratio of unwanted commands to the number of noise bursts. Typical curves (Figure 4-6) show P_{uc} versus S/N for the FSK receivers - FSK-NBW, FSK-MBW, and FSK-WBW. A second scale expresses the security in terms of number of false outputs per 1000 noise bursts (T/NB). The false trips were counted only if the duration was at least 0.3ms.

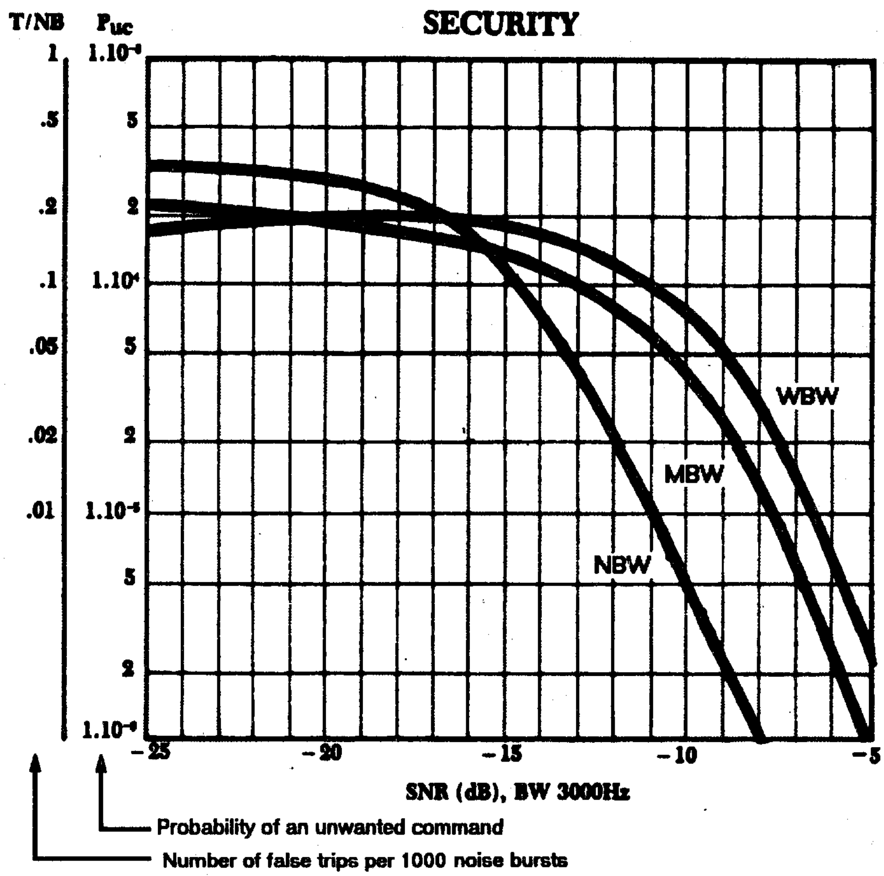


Figure 4-6. Typical Security Curves for FSK Channels

Dependability is that facet of reliability which relates to the degree of certainty that a relaying channel will operate correctly under noisy conditions, or the ability of the receiver to produce an output when a change of command has been issued at the transmitter.

Bursts of noise are applied to the transmission path at different SNRs. Simultaneously, the transmitter is being keyed to trip (change of command). P_{mc}, which is the probability of a missed command, is calculated as one minus the ratio of received commands to the number of transmitted commands (and noise bursts). Typical curves (Figure 4-7) show the P_{mc} versus SNR for the different bandwidth FSK receivers. A second scale expresses dependability in terms of the number of missed trips per 100 commands (and noise bursts) applied ($MT/10^2$). The curves are based on a trip window equal to 1.5 times the noise free channel time and are counted only if the false trip lasted at least 0.3ms.

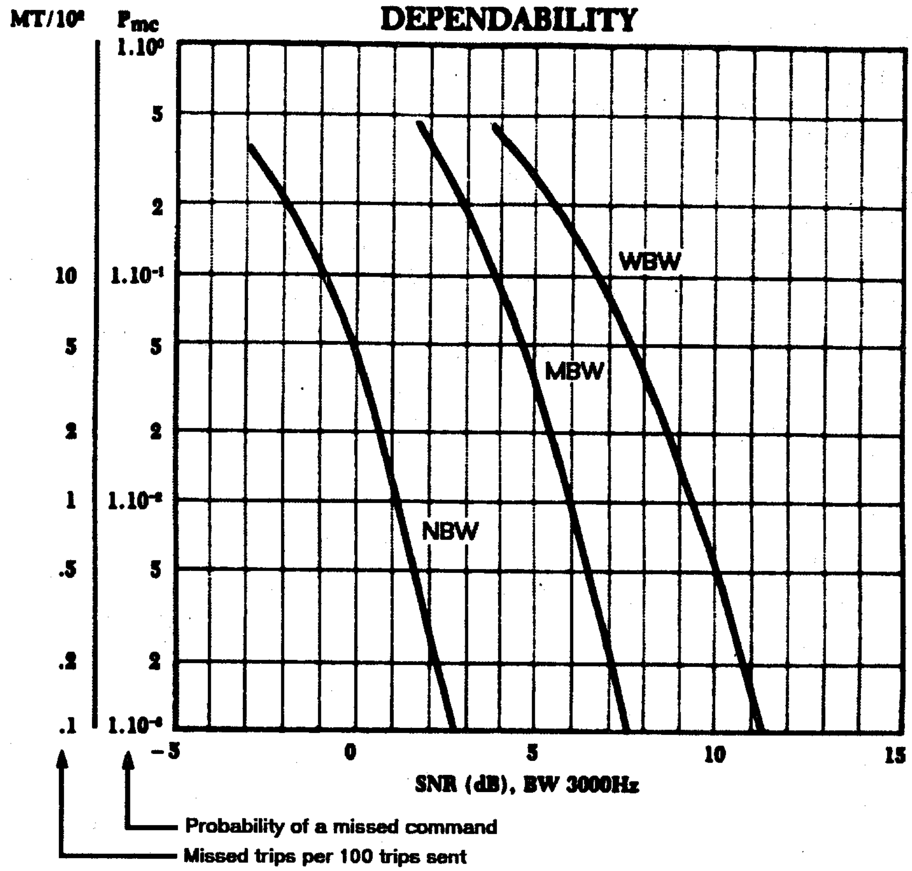


Figure 4-7. Typical Dependability Curves for FSK Channels

SYSTEM APPLICATIONS

General Electric literature describing transferred-trip applications is extensive. (See Reference [4]) FSK power line carrier channel equipments are designed for both equipment protection and line protection. The equipment can be either one-way for transferred-trip applications, such as transformer protection, or two-way where line protection or breaker failure protection is required. In addition to transformer protection, shunt reactors can similarly be protected by differential relays and one-way carrier transmission.

Generally, the applications of the PLC FSK equipment can be classified as follows:

Narrowband PLC FSK Applications:

- Power transformer equipment protection
- Shunt reactor equipment protection

Medium BW and Wide BW PLC FSK Applications:

- Line protection
    - Direct-underreaching transfer trip
    - Permissive underreaching transfer trip
    - Permissive overreaching transfer trip
    - Unblocking relaying
    - Combined unblocking and direct transfer trip
    - Phase-comparison relaying
- Circuit-breaker failure protection

In normal operation, a GUARD signal is continuously transmitted. At the receiver, the reception of the GUARD frequency acts to produce blocking of the breaker trip circuit. At the same time, the GUARD signal provides continuous monitoring of the carrier system. When a fault does occur, the fault-sensing device causes the transmitter to shift operation and send a TRIP frequency. Reception of the TRIP frequency by the receiver acts to release the GUARD output and operate the TRIP output in the receiver. The GUARD and TRIP outputs are connected in series with each other and with the breaker trip coil. Thus, the GUARD output must drop out and the TRIP output pick up before operating current can be supplied to the breaker trip coil.

In the case of equipment protection, differential relays are used at the transformer or shunt reactor to shift the frequency of the carrier transmitter to directly trip the remote breaker, while simultaneously tripping the local low-side breaker. In the case of line protection, the relay system is classified as either direct or permissive, depending on whether the receive terminal trips the breaker directly or if the local fault-detecting relays must also operate before tripping can occur. Line protection may incur tripping through a fault and requires special receiver logic in the event of loss of signal, as discussed later.

Application of the channel equipment may be either single- or dual-channel operation. In dual-channel operation, two transmitters are used at each transmitting terminal and two receivers at the receiving terminal. The dual-channel system is highly desirable in that both channels must operate before tripping can occur, thus increasing channel security. Furthermore, the dual system also permits testing of each channel separately without the receive terminal trips the breaker directly or if the local fault-detecting relays must also danger of accidentally tripping the associated breaker. Some users apply the receiver outputs in parallel to increase dependability. Figure 4-8 illustrates the channel transmitter and receiver requirements for several single- and dual-terminal applications. "T" and "R" represent the frequency-shift transmitter and receiver, respectively. The subscripted "f" represents the nominal center frequency for each of the channels. With FSK operation, two-way channels require a separate operating frequency in each direction.

Table 4-3 provides a comparison of the salient features of the channel equipment. A wide bandwidth FSK channel offers the highest channel speed (5 ms) and is recommended primarily for high-speed solid-state relaying line protection. The minimum channel speed for Medium BW FSK channels is 10 ms, but its bandwidth is only half that of the wide bandwidth FSK. Therefore, where frequency conservation is important, Medium BW FSK is used whenever the 10 ms channel speed is acceptable. Narrow bandwidth FSK channels, with a minimum channel speed of 25 ms, are fast enough for most transformer-protection systems. FSK equipments are available with various types of logic modules, namely:

1. Type D (GUARD RESET before TRIP), for use in direct trip and direct underreaching relaying schemes. This logic increases security against false trips at the expense of dependability to trip.

2. Type P (SIGNAL RESET before TRIP), for use in permissive underreaching and overreaching line relaying. This logic increases the dependability of the trip signal. P logic is used in many direct trip applications (e.g., breaker protection) where it is

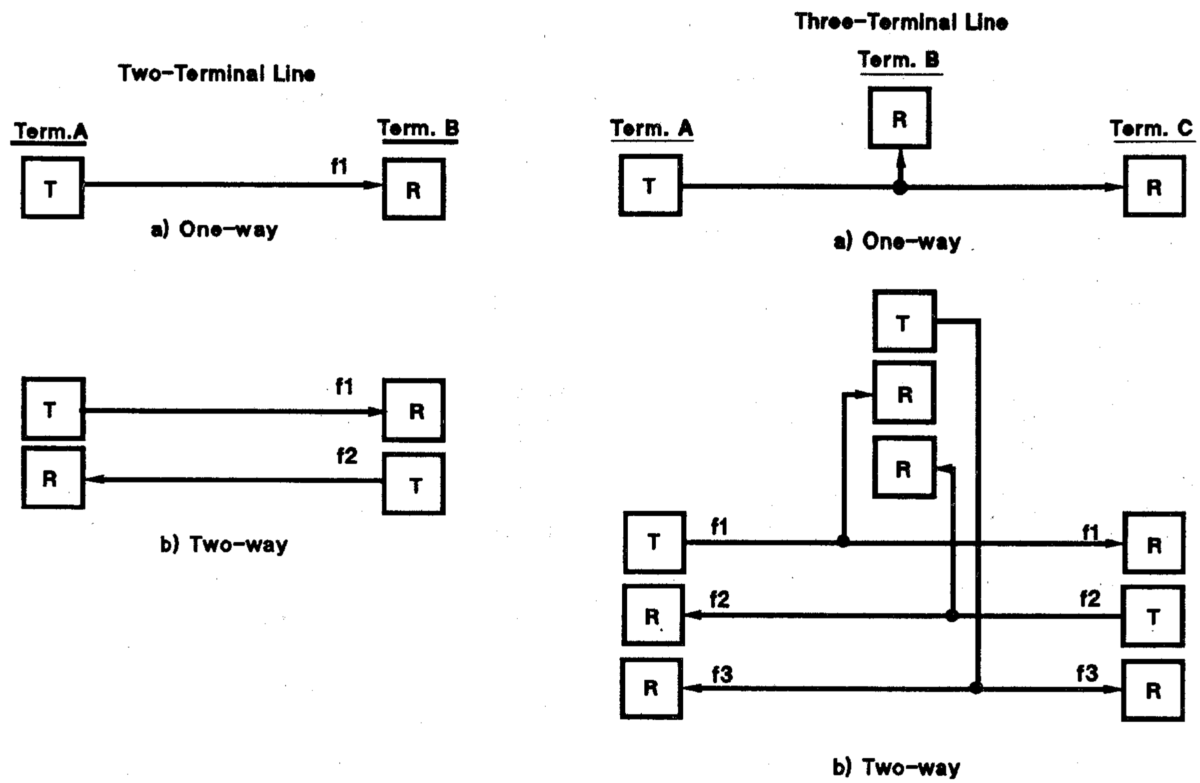


Figure 4-8. Frequency-Shift Transmitter-Receiver Arrangements for One- and Two-Way Applications

desired not to receive the GUARD signal before producing a trip output.

3. Type U (loss of signal allows trip), for use in unblocking relay schemes. This logic produces a momentary trip output upon loss of signal (reduced signal level).

4. Type T (U and P combined), for use with single-channel, two-function applications; provides two logic outputs, a type P output and an type U output.

The logic modules are discussed more fully in the section which follows.

Frequency-shift carrier equipment requires only a narrow band of frequencies. This allows "single frequency" line tuning and traps in the line coupling circuit, even when two-way dual channels are used. However, RF hybrid units are required to separate the closely spaced transmit and receive frequencies. These RF hybrids, usually a skewed hybrid, can be within the transmitter/receiver equipment or furnished as external units.

The maximum operating range is a function of the transmitter output and the corresponding receiver sensitivity as listed in Table 4-3. Of course, operating margin and application conditions would normally prohibit the use of the maximum receiver sensitivity setting.

RECEIVER LOGIC

An optional Receiver Logic module can be supplied as an integral part of the receiver.

Table 4-3

Characteristics of Present PLC FSK Teleprotection Channel Equipment

Feature	NBW FSK	MED. BW FSK	WIDE BW FSK
Frequency Shift...........			
Guard...................	+100 Hz	+250 Hz	+500 Hz
Trip....................	-100 Hz	-250 Hz	-500 Hz
Frequency Range...........	30-500 kHz	30-500 kHz	30-500 kHz
Power Output (1)			
Guard....	1 or 10 watts	1 or 10 watts	1 or 10 watts
Trip....................	10 watts	10 watts	10 watts
Operating Range (maximum)			
1-Watt Output...........	63 dB	53 dB	53 dB
10-Watt Output..........	73 dB	63 dB	63 dB
100-Watt Output...	83 dB	73 dB	73 dB
Receiver Bandwidth			
At 2-dB Points.........	200 Hz	500 Hz	1000 Hz
At 60-dB Point	1000 Hz	3000 Hz	6000 Hz
Max Rcvr Sensitivity......	5 mV (-33 dBm)	15 mV (-23 dBm)	15 mV (-23 dBm)
Receiver Logic............	See Table 4-4	See Table 4-4	See Table 4-4
Minimum SNR			
(Guard level) (2)	-5 dB	0 dB	+2 dB
Channel Speed			
Solid-State Output	25 ms(3)	10 ms	5 ms
Relay Output			
Heavy Duty..............	29 ms(3)	14 ms	9 ms
High Speed	25 ms(3)	5 ms	5 ms
Power Supply....	48, 125 or 250 Vdc	48, 125 or 250 Vdc	48, 125 or 250 Vdc

NOTES:

(1) 100 watt optional (with separate RF amplifier)

(2) Assumes 10 dB exalt at Trip Frequency

(3) Adjustable up to 100 ms (in three steps)

This logic system allows the optimum balance between security and dependability that is required for any application. The recommended guidelines for the use of the logic are shown in Table 4-4 after the discussion of the different logic functions.

The logic module receives several inputs and determines whether or not to initiate an alarm output. The inputs which supply the logic module with the necessary information are:

- GUARD signal, from the discriminator/squelch module
- TRIP signal, from the discriminator/squelch module
- Squelch (SNR and loss of signal) from the discriminator/squelch module
- Receiver level from the receiver module

The first three inputs are used in all logic modules. Any abnormal condition would block the logic TRIP output and activate an alarm relay (called channel status alarm or CSA). The same input is activated for either a questionable Signal-to-Noise Ratio or a loss of signal. The fourth input is used only with the **U** and **T logic**. This signal is used by the logic to produce a time limited "Unblocking" (Tripping) output when the receive level drops below a preset amount from the normally received level (either 10, 5, or 0 dB above the receive sensitivity).

Figure 4-9 and 4-10 show block diagrams for the D/P logic and the U/T logic circuits, respectively. A more detailed description of each logic follows. It should be noted that there can not be a TRIP input when the SQUELCH input is low because of circuitry on the discriminator/squelch module from where these signals are taken.

The logic available with the FSK receivers is based on the following considerations:

- Security against false trips
- Trip dependability under adverse conditions
- Tripping through a fault - loss of signal

Table 4-5 defines the basic functions for each type of logic.

TYPE D LOGIC

Type D receiver logic is defined as GUARD RESET BEFORE TRIP. This logic requires that, after the channel has failed, a GUARD signal must be received before the logic can be reset to provide a TRIP output in response to a TRIP signal. This type of logic is almost always used with direct transferred trip schemes for equipment protection and in direct underreaching transferred trip (DUTT) schemes for transmission line protection where ultimate security is required. If the keying impressed upon the transmitter by the relay equipment requires holding a TRIP output for a long period of time, this logic prevents return to GUARD signal if noise interrupts the signal for 300 ms or longer. For that reason a flasher is used in the transmitter which alternates the frequency between TRIP and GUARD and therefore would reset D-logic.

The various inputs and outputs of Figure 4-9 will be characterized for possible conditions. The Supervision block controls the input to the 50/300 ms timer.

Supervision:
*High for TRIP or GUARD signals <u>and</u> SQUELCH is HIGH.

**This switch is closed for D-logic (GUARD reset before TRIP); and opened for P-Logic (GUARD or TRIP reset before TRIP). Inputs are as follows:

Inputs:

GUARD: High for TRIP (Not GUARD); Low for GUARD.

TRIP: High for TRIP; Low for GUARD (Not TRIP).

SQUELCH: High for good channel; low for noisy channel or loss of signal

Outputs:

CSA (Channel Status Alarm): High for good channel; low for bad channel. (Note: the alarm relay is not shown.)

Logic Trip: Follows the TRIP Input unless CSA is low.

Referring to Figure 4-9, the operation of the Type D logic is as follows. When the GUARD signal is present and the SQUELCH input is high, no ALARM is initiated, the Channel Status Alarm (CSA) remains high, and no TRIP output is provided. Similarly, when the TRIP signal is present and the SQUELCH is high, no ALARM is initiated, CSA remains high, but now a TRIP output is provided.

When the conditions controlling the SQUELCH input are not healthy and the GUARD signal is present, two conditions can occur. If the abnormality of the SQUELCH input is less than 300 ms, there is no ALARM, CSA remains normal, and no TRIP output is provided. However, if the abnormality is longer than 300 ms, the 50/300 TIMER times out, an ALARM is initiated, but no TRIP output is provided.

When a TRIP signal is present and then the SQUELCH input goes low, two conditions can occur. If the abnormality is less than 300 ms, there is no ALARM, CSA is normal, and the TRIP Output is allowed as soon as the abnormality returns to the healthy state. However, if the abnormality is longer than 300 ms, the 50/300 TIMER times out, an ALARM is initiated, and the TRIP input is prevented from appearing at the LOGIC TRIP output. For tripping to occur, the GUARD must reset for 50 ms minimum and the channel must shift again to the TRIP signal to allow TRIP; the ALARM is turned off and CSA returns to normal.

It will be noted that the Type D logic provides enhanced security against false trip after a channel failure.

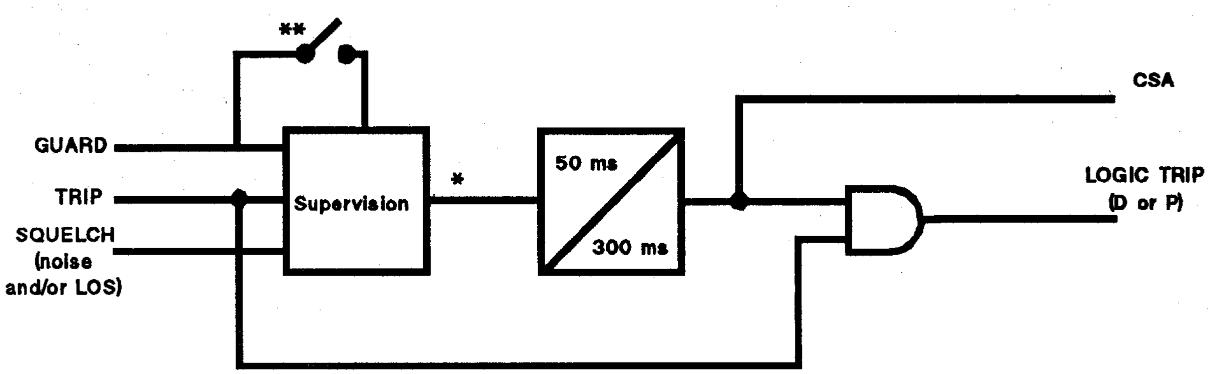


Figure 4-9. Type D and P Logic

TYPE P LOGIC

The Type P logic is defined as SIGNAL RESET BEFORE TRIP. After the channel has failed, this logic can be reset to normal by receipt of either a GUARD or a TRIP signal. This type of logic is often used with permissive overreaching and permissive underreaching transferred trip schemes (POTT and PUTT). By user preference, P logic is typically used, instead of D logic, with the direct transferred trip and direct underreaching transfer trip schemes. P logic increases the dependability of the TRIP signal. P logic is the same as Type D, except that GUARD reset is not required to TRIP after an abnormality of the SQUELCH input that exceeds 300 ms. (Note: The switch "**" is open for this logic.)

When a TRIP signal is present (Figure 4-9) and then the squelch input goes ow, two conditions can occur. If the abnormality is less than 300 ms, there is no ALARM, CSA remains normal, and TRIP is allowed as soon as the abnormality returns to the healthy state. If the abnormality is longer than 300 ms, the 50/300 TIMER times out, an ALARM is initiated, but TRIP is not allowed until 50 ms after the SQUELCH input returns to normal.

The Type P logic increases dependability, compared to D-Logic, of the TRIP signal after a channel failure.

TYPE U LOGIC

The Type U logic is described as LOSS OF SIGNAL LEVEL ALLOWS TRIP, it is not necessary with this logic to receive a signal in order to allow tripping. This type of logic is always used with unblocking relay schemes. After the channel has failed, the logic can be reset to normal by receipt of either a GUARD (Block) or TRIP (Unblock) signal. U logic is arranged to allow the desired TRIP (Unblock) output when the SQUELCH input is normal, while the signal level is below a pre-set threshold setting. Line relaying internal fault characteristics exhibit low line noise (until the breaker opening begins) and high attenuation. The U logic functions the same as P logic ,with the additional condition that a TRIP signal is also produced for 300 ms when the loss of signal level occurs.

The various inputs and outputs of Figure 4-10 will be characterized for possible conditions. The supervision block controls the 50/300 ms timer.

Supervision:
*High for TRIP or GUARD signal, and SQUELCH and LOL high

Inputs:
GUARD: High for TRIP (Not GUARD); Low for GUARD

TRIP: High for TRIP; Low for GUARD (Not TRIP)

SQUELCH: High for no noise, and good signal; Low for noisy channel and/or loss of signal

IFL: Receive IF level(analog) a DC Voltage proportional to incoming receive signal level

LOL: High for signal level above threshold; low for signal below threshold

Outputs:

CSA: (Channel Status Alarm) High for good channel; low for bad channel (Note: The alarm relay is not shown.)

Logic Trip(P): Follows TRIP input unless CSA is low (Bad Channel)

Logic Trip(U): Follows TRIP input

Referring to Figure 4-10, the operation of U logic is as follows. When the GUARD (Block) signal is present and the SQUELCH input is normal, no ALARM is initiated, CSA is normal and TRIP is not allowed. If the TRIP (Unblock) signal is present and the SQUELCH input is normal, there is no ALARM, CSA is normal, and TRIP (Unblock) is allowed.

When the SQUELCH and GUARD are high, but the receiver GUARD signal falls below the threshold, then the LOL goes low and produces a LOGIC TRIP(U). The LOL also starts the 300ms timer through the supervision circuit. The U output is therefore limited to 300 ms.

When the SQUELCH input is low and the GUARD (Block) signal is present, two conditions can occur. If the abnormality is less than 300 ms, there is no ALARM, CSA is normal, and TRIP (Unblock) is not allowed when the abnormality returns to normal. If the abnormality is longer than 300 ms, the 50/300 TIMER times out, an ALARM is initiated and CSA goes low, but TRIP (Unblock) is not allowed.

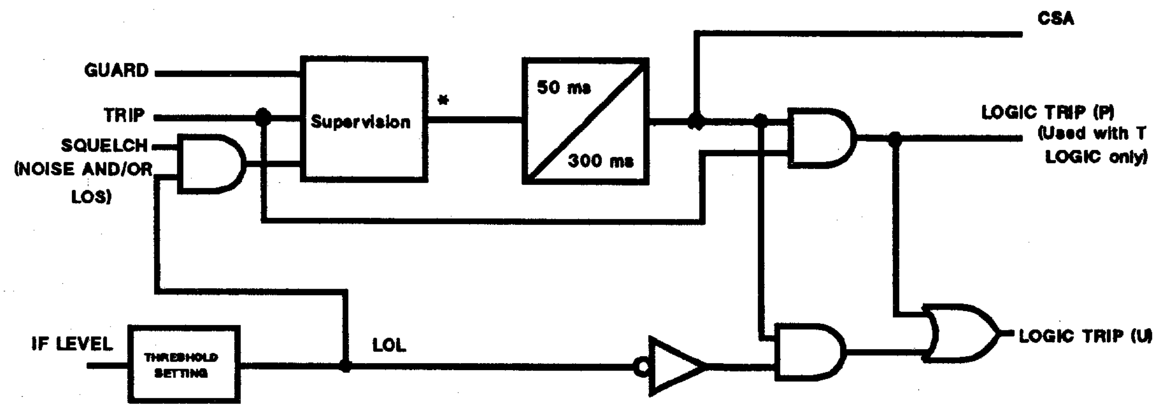


Figure 4-10. Type U Logic (Loss of Signal Allows Trip)

When a TRIP (Unblock) signal is present and the SQUELCH input then goes low, two conditions can occur. If the abnormality is less than 300 ms, there is no ALARM, CSA is normal, and TRIP (Unblock) is allowed for 300 ms if the SQUELCH is normal and the LOL is low. If the abnormality is longer than 300 ms, the 50/300 TIMER times out, an ALARM is initiated and CSA goes low but TRIP (Unblock) is no longer allowed. After 300 ms, the abnormal condition must be restored to normal for 50 ms before the logic output can go to Unblock. The Type U logic increases the TRIP dependability during conditions of low signal level.

TYPE T LOGIC

Next, consider Type T logic, which Combines Type U and Type P logic on one module. As can be seen from Figure 4-10, this logic has two outputs, a U and a P output. This means that the U output performs like the U logic and the P output performs like the P logic. A functional description was given previously.

The primary application for this logic is shown in Figure 4-13. Note that the P outputs are AND-gated for the DTT application and will thus increase the security and allow for easy channel testing as well.

Table 4-4

Channel and Logic Selection Guidelines for PLC FSK Channels

CHANNEL				Line Fault Protection	Equipment Protection	Combined Line & Equip.
Type	Band-Width (Hz)	Channel Speed	Logic Options Available	POTT, PUTT, DUTT & unblocking schemes (phase comparison with WB FSK only).	Transformer or reactor diff. protection, combined with other DTT functions.	Unblocking line fault protection, combined with other DTT functions.
NB	200	29-100 ms relay output	D,P, (U or T)	Channel speed (29 ms) is usually considered rather slow for line fault clearing.	Recommended for applications where 29 ms time is adequate, to conserve carrier spectrum. D & P logic.	Channel speed (29 ms) is usually considered rather slow for line fault clearing.
MB	500	10 ms electronic output 14 ms relay output	P,D,U or T	Type P Logic is recommended for all POTT,PUTT,DUTT schemes Type U Logic is required for unblocking Type D Logic offers more security with somewhat less dependability (Note 1).	Med BW FSK is usually not recommended for equipment protection, unless 25 ms time of NB FSK is too slow. Type P Logic is recommended for all med. BW FSK direct trip schemes (Note 1).	Type T Logic provides two outputs(U & P). Spectrum savings is 33% compared to dedicated channel approach. A dual channel scheme does the work of three channels.
	1000	5 ms electronic output	P,D,U or T	Type P Logic is recommended for all POTT, PUTT, & DUTT schemes. Type U Logic is required for unblocking. use med. BW FSK if channel time is adequate	WB FSK is usually not recommended for equipment protection, unless fastest possible channel is required.	Type T Logic provides two outputs.(U & P). Spectrum saving is 33% compared to dedicated channel approach. MBW FSK is recommended to

LEGEND: POTT - Permissive Overreach Transfer Trip
PUTT - Permissive Underreach Transfer Trip
DUTT - Direct Underreaching Transfer Trip
DTT - Direct Transfer Trip

NOTES

1. Type P Logic with automatic reset with good channel status is recommended in preference to Type D Logic. Type D Logic "guard-before-trip" security feature could result in a failure to trip after 300 ms loss-of-channel unless guard is reset prior to trip keying.

Table 4-5
Logic Features

Logic Type	Relay Scheme	Logic Operation	Functional Objective
D	DUTT	GUARD reset before TRIP	Security against false trip after channel failure
P	PUTT POTT	Signal reset before TRIP	Increase dependability of TRIP signal after channel failure
U	Unblocking	Loss of signal allows TRIP	Momentary (300 ms) TRIP output after channel failure
T	Combined unblocking and Direct TT	U&P combined	Single channel two-function application

TYPICAL CONFIGURATIONS AND EQUIPMENT

A typical two-terminal line ending in a transformer with no high side breaker is shown in Figure 4-11. This illustrates the use of a blocking type channel for line protection and a narrow bandwidth FSK channel for transformer protection. Two-frequency line traps and line tuning are shown.

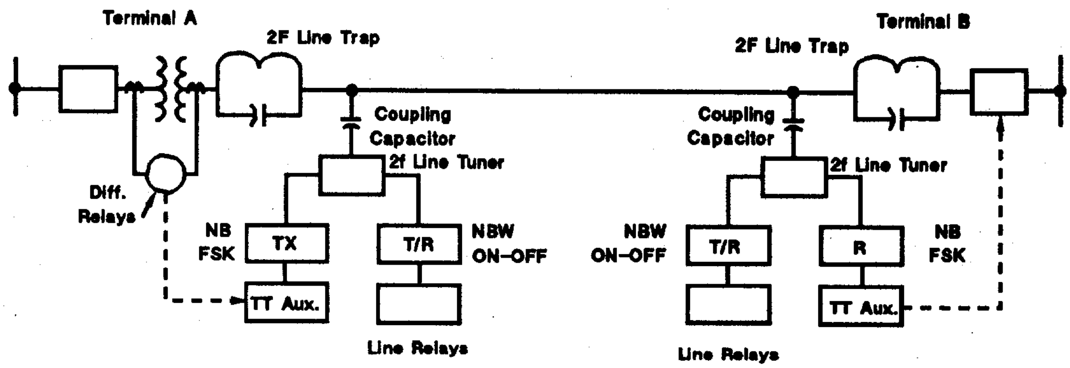


Figure 4-11. Line and Transformer Protection

The equipment would consist of the following:

Terminal A

1. Blocking carrier transmitter-receiver for use with GE line relays, including:
   - Standard keying and receiver outputs
   - Wiring harness (specify type of cabinet, open rack or existing rack)
   - Operation from 48, 125, or 25 Vdc
   - RF output power: specify 10 watts or 100 watts
   - Receiver input bandpass: specify 2000 or 4000 Hz
   - With/without voice modulator
   - Alarm and indication package
   - Optional equipment
     - Cabinet or rack
     - Telephone handset with cord and plug
     - Reserve signal indication
     - Checkback
     - Test extender

2. Narrow bandwidth PLC FSK transmitter for transformer protection
   - Wiring harness (specify type of cabinet, open rack or existing rack)
   - Operation from 48, 125 or 250 Vdc
   - RF output power: 10 watts or 100 watts
   - Transmitter keying: contact, photo coupler or solid-state
   - Operating frequency____ kHz
   - Note: for dual-channel operation, select two transformers and appropriate hybrids

- Transfer-trip test auxiliaries Optional equipment (transmit end)
  - Trip and loss of power alarm relay
  - Test extender

3. Line equipment, including:

- Two-frequency line trap
- Coupling capacitor voltage transformer
- Two-frequency line tuner, phase-to-ground coupling two coax cable type

Terminal B

1. Blocking carrier transmitter-receiver for use with GE line relays, including:

- Standard keying and receiver outputs
- Wiring harness (specify type of cabinet, open rack or existing rack)
- Operation from 48, 125, or 25 Vdc
- RF output power: specify 10 watts or 100 watts
- Receiver input bandpass: specify 2000 or 4000 Hz
- With/without voice modulator
- Optional equipment
  - Cabinet or rack
  - Telephone handset with cord and plug
  - Reserve signal indication
  - Checkback
  - Test extender

2. Narrow bandwidth PLC FSK receiver for transformer protection

- Wiring harness (specify type of cabinet, open rack or existing rack)
- Operation from 48, 125 or 250 Vdc
- Receiver output (GUARD and TRIP) relays
- Receiver output accessories
- Operating frequency___ kHz
  Note: for dual channel operation, select two receivers
- Transfer Trip Test Auxiliaries(Receive end)
  - Trip and loss of power alarm relay
  - Test extender

3. Line equipment, including:

- Two-frequency line trap
- Coupling capacitor voltage transformer
- Two-frequency line tuner, phase-to-ground coupling two coax cable type

For a two-terminal line employing a medium BW and wide BW FSK tripping-type channel for line protection, the application is similar to Figure 4-12.

In certain relay channel applications, it is desirable to accomplish two functions simultaneously over single-frequency shift channel equipment. This dual use of the channel can be accomplished using the proper combinations of medium or wide bandwidth FSK channels and logic modules. The functional application is illustrated in Figure 4-13 and a more detailed configuration is shown in Figure 4-14. Figure 4-14 shows a carrier relaying system that provides directional comparison unblocking plus a direct trip channel, the latter being used for breaker failure protection. The carrier relaying system uses duplex channels.

Through the use of shared channel equipment and appropriate logic, considerable savings are achieved in the cost of channel equipment and channel spectrum. As shown in Figure 4-14, the bi-directional channels No. 2 and No. 4 use P logic and the bi-directional channels No. 1 and No. 3 use T logic (combines both P and U logic functions). To enhance security of the direct trip function, this is accomplished by a single-channel bi-directional

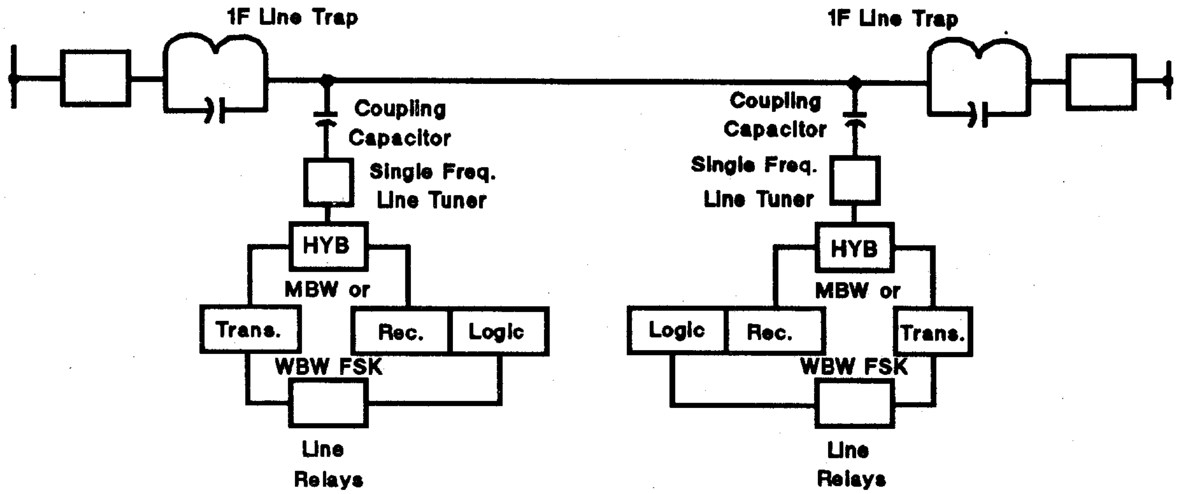


Figure 4-12. Transfer-Trip Line Protection

two-frequency medium or wide bandwidth FSK channels using U logic output. Thus, through the combined use of a two-frequency medium or wide bandwidth FSK channel transmitter and T logic, two keying functions are clearly identified.

Two-way operation of FSK channels on a three or more terminal line requires one transmitter plus one receiver for each remote terminal transmitter at each terminal. The frequencies of all transmitters are all different with enough spread between them to prevent interaction between transmitters and receivers of different frequencies. Since there is no interaction between channels, each transmitter operates only in conjunction with its associated remote receivers.

TEST AUXILIARIES

Transfer-trip auxiliaries (or test panels) are available for equipment and line protection applications of PLC FSK channel equipment. The transfer-trip auxiliaries are available for the following channel configurations:

1. Single transmitter and single receiver
2. Dual transmitter and dual receiver
3. Single bi-direction channel
4. Dual bi-directional channel

The auxiliaries are available in the following combinations:

1. Trip bus voltage, 48 Vdc, 125 Vdc or 250 Vdc
2. Supply voltage: 48 Vdc with or without loss of power alarm; 125 Vdc with or without loss of power alarm

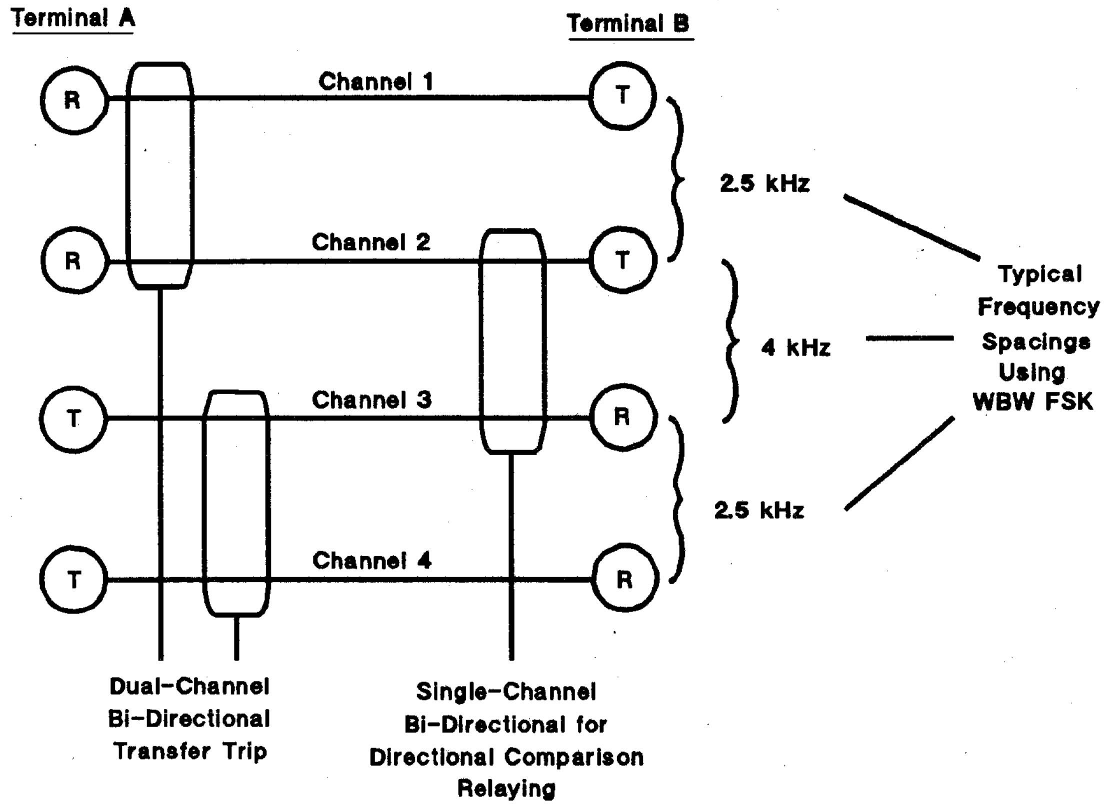


Figure 4-13. Channel Diagram of Combined Function

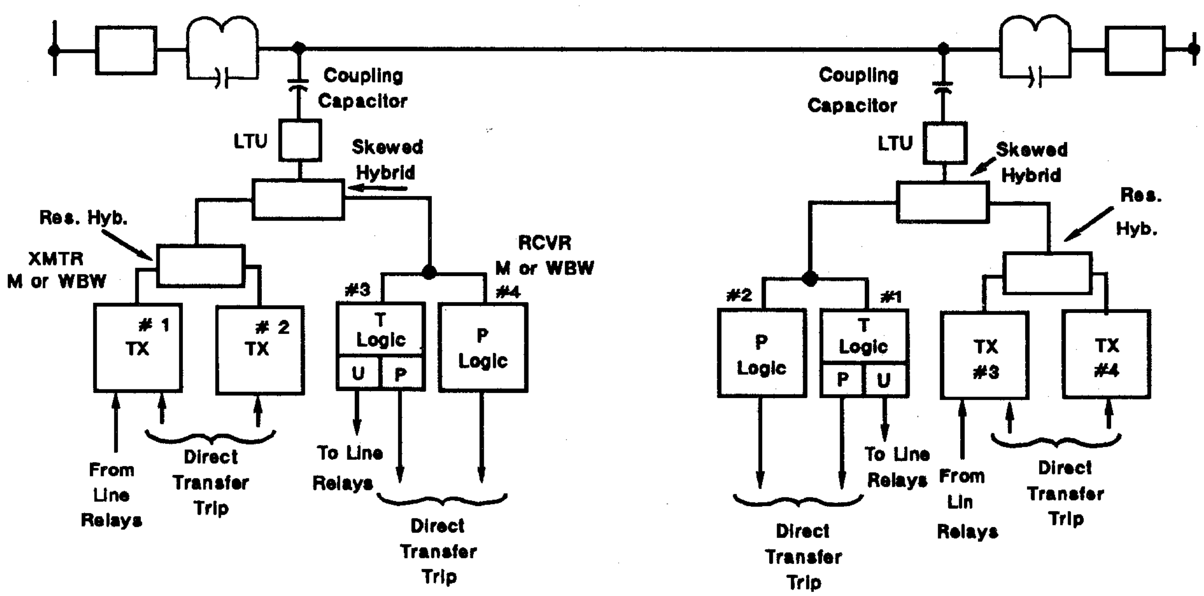


Figure 4-14. Combined Line and Equipment Protection

3. Trip test, target, seal-in, counter
   a. None
   b. Test and target
   c. Test, target and counter
   d. Test, target and seal-in
   e. Test, target, counter and seal-in

4. Channel Conversion/Checkback

   a. None
   b. Conversion (to single channel) - automatic or manual
   c. Checkback - automatic or manual initiated
   d. Checkback turn-around
   e. Conversion and checkback

5. Receiver Trip/Auxiliary Interface

   a. None or contact
   b. 5V common or 5V isolated

USE OF RF HYBRIDS

Carrier-frequency hybrids are used to connect two or more closely spaced transmitter or transmitter-receiver combinations to a common coupling circuit. Hybrids serve to increase the overall operating range and permit closer frequency spacings than would otherwise be possible. This is possible because hybrids:

1. Reduce the signal each transmitter imposes on associated receivers, thereby permitting increased receiver sensitivity

2. Reduce intermodulation products capable of causing interference in receivers, further increasing usable receiver sensitivity.

FREQUENCY CONSIDERATIONS

Recommended frequency spacing for PLC FSK channel equipment is a function of the dB isolation between transmitter and receiver equipment and between transmitters. This depends on whether a uni-directional channel or bi-directional channel is being applied. Table 4-6 describes the frequency spacing requirements.

For uni-directional applications of medium BW and wide BW FSK equipment, the minimum spacing is allowed if the received signals are within 20 dB and the applied operating margin is not more than 20 dB. In the case of bi-directional medium BW and wide BW FSK equipment, the minimum spacing is allowed if the local- and remote-transmitted signals are within 30 dB (measured at the receiver input) and the applied operating margin is not more than 20 dB.

Section 3, Table 3-2, gives the recommended minimum spacing for PLC FSK channels in applications involving other channel equipment combinations and characteristics.

Table 4-6. Frequency Spacing for Modern FSK Channels

<table>
<tr><td colspan="8">SAME STATION FREQUENCY SPACING (UNIDIRECTIONAL TX-TX)</td></tr>
<tr><td colspan="2">Uni-Directional Spacing
(Based on Receivers Selectivity)
Isolation (dB)
(for Intermodulation protection)
(10 watt or 100 watt)</td><td colspan="2">0.5 kHz
15 dB min</td><td colspan="2">1.5 kHz
15 dB min</td><td colspan="2">2.5 kHz
15 dB min</td></tr>
<tr><td colspan="8">SAME STATION FREQUENCY SPACING (BI-DIRECTIONAL TX-RX) 10 WATT TX</td></tr>
<tr><td colspan="2">ISOLATION (DB)</td><td>≥15 dB</td><td>≥30 dB</td><td>≥15 dB</td><td>≥30 dB</td><td>≥15 dB</td><td>≥30 dB</td></tr>
<tr><td rowspan="2">(Tx to any RX not on TX Freq.)</td><td>SENSITIVITY</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15 mv
5 mv</td><td>1.0kHz
1.5kHz</td><td>1.0kHz
1.0kHz</td><td>2.5kHz
------</td><td>2.0kHz
-----</td><td>4.0kHz
-----</td><td>3.5kHz
------</td></tr>
<tr><td colspan="8">SAME STATION FREQUENCY SPACING (BI-DIRECTIONAL TX-RX) 100 WATT TX</td></tr>
<tr><td colspan="2">ISOLATION (DB)</td><td>*≥15dB</td><td>≥30 dB</td><td>*≥15dB</td><td>≥30 dB</td><td>*≥15dB</td><td>≥30 dB</td></tr>
<tr><td rowspan="2">(TX to any RX not on TX Freq.)</td><td>SENSITIVITY</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>15 mv
5 mv</td><td>1.5kHz
2.0kHz</td><td>1.0kHz
1.5kHz</td><td>2.5kHz
------</td><td>2.5kHz
------</td><td>4.5kHz
------</td><td>4.0kHz
------</td></tr>
</table>

* Continuous operation at 15 dB isolation will exceed maximum input power rating of receive circuit. 20 dB isolation required for continuous operation.

OPTIONS AND ACCESSORIES

In addition to the transfer-trip auxiliaries, the following options are generally available with the PLC FSK equipment:

1. Power output: 1, 10 or 100 watts (with separate amplifier)
2. Transmitter alarm relay for:
   a. Loss of dc power (LPA) alarm
   b. Shift-to-TRIP alarm(STA)

3. Receiver alarm relay for:

   a. Loss of DC power (LPA) alarm
   b. Guard and TRIP alarm with all output options (GA & TA)
   c. Channel-failure alarm in logic module(CSA)
   d. Low-signal-level alarm in CLM output(CSA)
   e. Carrier-level monitor (CLM)

4. Sequence of events recorder (SER) outputs

Transmitter:
Shift to trip

Receiver:
Guard or Squelch
Loss of Signal or Noise Squelch
Trip Output

Logic:
Channel Status
Combined Trip, Loss of Level or "U" Logic Trip

A GE meter-analyzer unit is also available as optional equipment for measuring the performance of teleprotection channel equipment. The unit contains two 4-1/2-inch rectangular panel-type meters, one to measure RF milliamperes and the other to measure volts, ohms, milliamperes and decibels.

Battery clamp and isolation interfaces are applied in relay channel applications to protect the channel equipment against current and voltage surges. ANSI C37.90-1978 defines the SWC requirements. All General Electric channel equipment meets these requirements. 5 volt interfaces should be treated the same as blocking carrier interfaces as described in Section 3.(Page 3-12)

A battery clamp is not normally required on the PLC FSK channel power supply inputs. If transients exceed 2.5 kV and are below 5 kV, a battery clamp should be considered. If transients exceed 5 kV, steps must be taken to eliminate them.

FSK CARRIER FOR ANALOG MICROWAVE BASEBAND

A version of the modern RF FSK channels is available for connection to the baseband of existing analog frequency division (FDM) microwave systems. The FSK channel is fully frequency programmable from 40 kHz to 300 kHz in 500 Hz steps without changing any components in the system. This is a modern version of the MC22 channel equipment, which it replaces.

The interface at the transmitter output bridges directly onto the microwave baseband. Typical protective relaying schemes usually used with microwave can be realized with this equipment.

The three bandwidths usually associated with RF FSK for PLC are available. These correspond to the narrow bandwidth (BW) (± 100 Hz), medium BW (±250 Hz) and wide BW (±500 Hz) FSK channels.

Refer to Table 4-7 for the features of the various bandwidths channels. The 3 ms channel is used with a phase comparison protective relaying scheme. Since there is no hybrid in the system, spacing for uni-directional and bi-directional channels is the same. The transmitter delivers 12 mv into a 37.5 ohm load with a 10 kΩ source impedance. There is no power amplifier or output filter in the system since low level signals are required to interface with the microwave baseband. The equipment can be configured as a transmitter or as a receiver, or with both functions in the same four rack unit shelf. This equipment is an extension of the latest version FSK equipment and shares the same logic, alarms, and other features of this equipment. The receiver sensitivity is 1 mv.

Table 4-7.
Microwave Baseband FSK Characteristics

FEATURE	NBW FSK	MBW FSB	WBW FSK	WBW FSK
Frequency Shift	200 Hz	500 Hz	1000 Hz	1000 Hz
Receiver Bandwidth				
At 2 dB Points	200 Hz	500 Hz	1000 Hz	1000 Hz
At 60 dB Points	1000 Hz	2500 Hz	5000 Hz	5000 Hz
Channel Time				
Solid State Output	25ms*	10ms	5ms	3ms
Relay Output				
High Speed	25ms*	10ms	5ms	N/A
Heavy Duty	29ms*	14ms	9ms	N/A
Minimum SNR**	+5 dB	+10 dB	+12 dB	+12 dB
Channel Spacing*** (Uni-directional or Bi-directional)	0.5 kHz	1.5 kHz	2.5 kHz	2.5 kHz

*Adjustable to 100 ms (in 3 steps)
**To meet dependability
***Minimum Spacing shown

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SECTION 5

SSB POWER LINE CARRIER

Contents of Section 5

SYSTEM APPLICATIONS

Single-sideband power line carrier equipment is characterized by its multi-function capability; that is, its ability to provide several functions through a set of common electronic equipment [12]. Pilot relaying can be applied through the use of voice channel or baseband equipment associated with the SSB common equipment. Other telecommunication functions such as voice communication, telemetering, data acquisition, supervisory control, automatic generation control, and system security can also be applied over the SSB system.

SSB-PLC offers several other benefits, including: (1) equivalent speed and performance to that of single-function carrier equipment, (2) carrier spectrum conservation and economic incentives when approximately three or more functions are applied and (3) baseband relaying for improved performance and reliability.

Table 5-1 provides a comparison of the net output power available for various configurations using single-sideband and single-function channels. It will be noted that SSB, in terms of effective power at the input to the line tuning unit, is competitive with single-function channels for SSB applications using amplifiers related 200 watts and higher.

A single-sideband system may use keyed carrier blocking and frequency-shift transfer-trip channels for line and equipment protection. Although functionally the same as for any single-function application, single-sideband equipment does require different application practices. For example, SSB allows the choice of either the baseband or an audio channel to accomplish the relaying function. A SSB relaying channel shares the power output capability of the amplifier with other functions. Because the power amplifier is shared, the power available per channel is inversely proportional to the square of the number of channels applied on a given SSB system. Also, effective transmitter power levels must be calculated for the channel loadings to determine the proper application. In addition, decisions must be made as to which 4 kHz channel can be exalted during relay operations, if it is desired to boost the power output of the relay channel at the time a fault occurs. Aside from these application differences, single-sideband PLC offers the same characteristics as single-function equipment. However, it should be noted that baseband relaying can provide as much, or more, power in the relay signal as that available with single-function sets.

AUXILIARY FUNCTIONS

SSB carrier equipment is designed with the objective of meeting the needs and requirements of electric utility communication systems. With up to four voice channels on a set of common equipment, SSB carrier is well-suited for protective relaying, analog telemetering, supervisory control and data acquisition (SCADA), remote alarm systems, automatic generation control (AGC), system security, telephony, and data transmission. In

Table 5-1

Comparison of Net Power Output

SSB Relaying Capability				Equivalent Single-Function Relaying	
	Net Power Output (watts)			Net Power Output (watts) with 10-Watt Amplifier	
Configuration	5-W PA	20-W PA	100-W PA	Blocking	Transfer-Trip
1 Chan SSB with 1 Blocking Function	3.63	14.5	72.5	10	-
1 Chan SSB with 1 Transfer-Trip	1.95	7.77	38.9		7.93
1 Chan SSB with 1 Blocking and 2 TT	0.45	1.78	8.72	3.56	1.55
2 Chan SSB with 1 Blocking and 2 TT	0.49	1.95	9.8	3.56	1.55

effect, it fulfills the communication needs of operating a power system, and it does so with improved carrier frequency spectrum conservation. In addition, redundant equipment can be applied to provide reliability equivalent to single-function channel equipment. Some typical system applications will be examined.

TYPICAL CONFIGURATIONS AND EQUIPMENT

General Electric SSB equipment can provide protective relaying using baseband carrier (normally inserted at 30.75 kHz), or audio tones inserted into any full audio or speech-plus channel, with channel selection dependent upon the quantity of tones, the tone frequency and the speed required. Table 5-2 indicates the types of equipment and relaying functions available. Table 2-6 previously described the characteristics of the SSB relay channels. It also provided a guide to the types of relaying functions to be provided, expected channel speeds, and types of modulation employed for each of the relay channels using SSB carrier.

A typical application of multi-function SSB equipment for a two-terminal system is illustrated in Figure 5-1. Each terminal consists of a wideband line trap, a coupling capacitor, wideband tuning equipment, and SSB Common Equipment and Channel Equipment. A blocking baseband ON-OFF carrier set is applied in the baseband of the SSB two-channel Common Equipment. Two speech-plus channels are applied in this particular illustration. The voice portion of Channel No. 1 is used for audio FSK tones for transfer-trip purposes. Voice channel No. 2 is a speech-plus channel using audio tones on a bi-directional basis for telemetering. The functions are arbitrarily numbered f1 through f13 for identification purposes. Figure 5-1 illustrates the wide degree of flexibility available with SSB equipment.

Table 4-7.
Microwave Baseband FSK Characteristics

FEATURE	NBW FSK	MBW FSB	WBW FSK	WBW FSK
Frequency Shift	200 Hz	500 Hz	1000 Hz	1000 Hz
Receiver Bandwidth				
At 2 dB Points	200 Hz	500 Hz	1000 Hz	1000 Hz
At 60 dB Points	1000 Hz	2500 Hz	5000 Hz	5000 Hz
Channel Time				
Solid State Output	25ms*	10ms	5ms	3ms
Relay Output				
High Speed	25ms*	10ms	5ms	N/A
Heavy Duty	29ms*	14ms	9ms	N/A
Minimum SNR**	+5 dB	+10 dB	+12 dB	+12 dB
Channel Spacing*** (Uni-directional or Bi-directional)	0.5 kHz	1.5 kHz	2.5 kHz	2.5 kHz

*Adjustable to 100 ms (in 3 steps)
**To meet dependability
***Minimum Spacing shown

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Table 5-2

Available SSB Teleprotection Channel Equipment

Equipment Type	Relaying Function
Baseband:	
⊖ ON-OFF CXR	Solid-state directional or phase comparison
⊖ ON-OFF CXR	Electro-mechanical directional comparison
⊖ MBW FSK	Transfer-trip and unblocking
⊖ WBW FSK	Transfer-trip, unblocking and phase comparison
Audio:	
⊖ SF TONE	All of the above
⊖ MULTI-FUNCTION	Direct transfer-trip and permissive transfer-trip

Since a SSB system offers one to four channels, it is appropriate to consider how each of these channels can be used in a sub-multiplexing mode. Figure 5-2 shows several different applications of SSB channels. Figures 5-2A through 5-2E are standard SSB channels (300-3400 Hz bandwidth) and Figures 5-2F and 5-2G are wideband channels (300-3700 Hz bandwidth). Figures 5-2B, C, D, F and G illustrate speech-plus operation, in which teleprotection, telecontrol, telemetering and data channels are applied above the voice or within the voice band in the case of Figure 5-2G.

Each channel of a SSB system consists of a 4 kHz audio band. In Figure 5-2A, the voice channel covers a frequency range of 300 Hz to 3400 Hz, providing a wideband, high quality voice channel. A 3600 Hz AM tone is used for telephone signaling. The 4 kHz channel can be used for one voice channel, one teleprotection channel, or one data channel capable of operating from 300 to 2400 bits/sec.

In Figure 5-2B, the 4 kHz audio band is used for voice communication with six telemetering or teleprotection tones sub-multiplexed above the voice. A seventh tone is used for signaling and is standard in all voice channels. In this case, the voice is cut off at 2200 Hz to allow frequency space for the audio tones.

In Figure 5-2C, the voice function is cut off at 2000 Hz to provide a wider speech-plus band for telemetering and teleprotection. This is the arrangement that would be used for a blocking type (keyed carrier) relay system utilizing baseband blocking type relay channels. Figure 5-2D is similar to Figure 5-2C, except that the speech-plus area is utilized for two transfer-trip functions. Both 5-2C and 5-2D illustrate the use of baseband relaying.

Figure 5-2E shows a different arrangement for combinations of baseband relaying involving both frequency-shift and keyed carrier signals. In this application, the 4 kHz channel is used totally for relay functions and does not include the voice function. When this

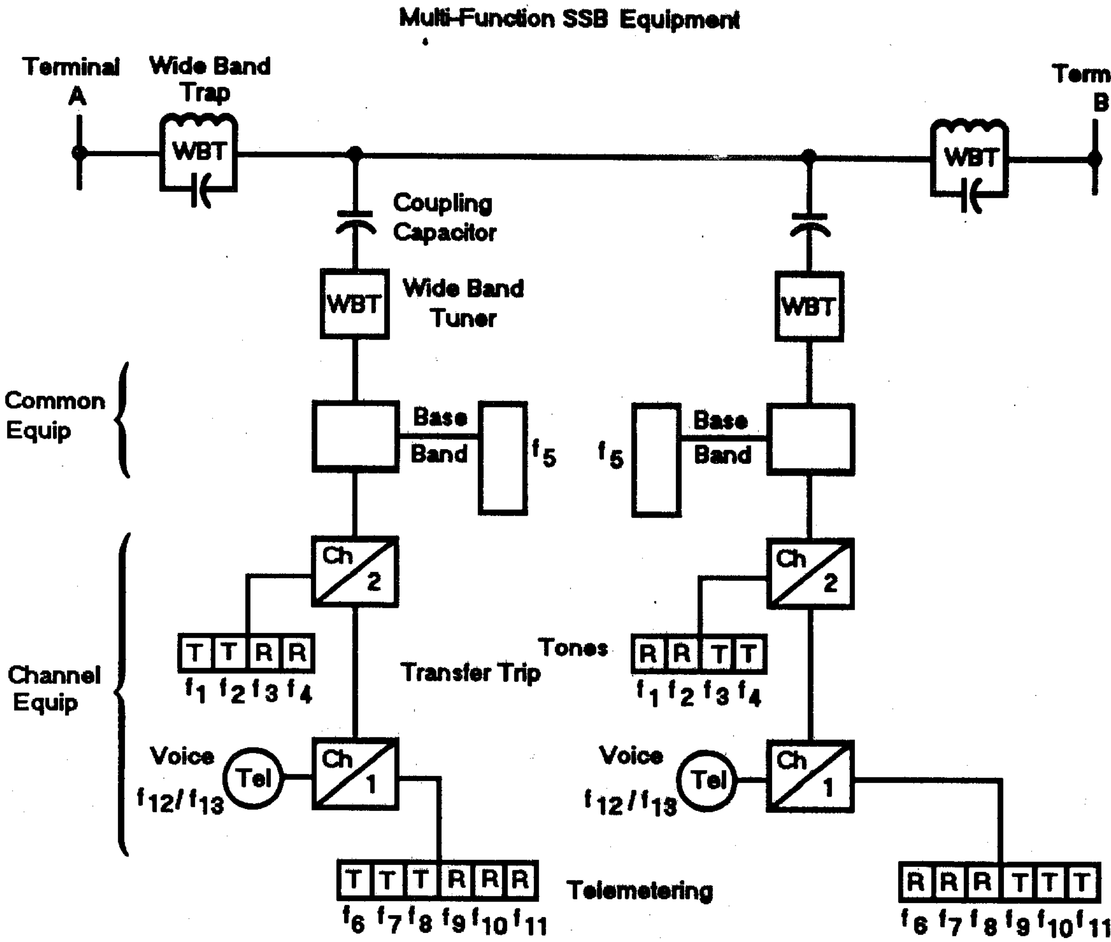


Figure 5-1. Baseband and Audio Tone Relaying via SSB Carrier

option is considered, voice is usually supplied on one of the other SSB channels.

The optional wideband channel shown in Figure 5-2F provides a 300 to 2400 Hz voice band, a signaling tone at 2580 Hz and space from 2670 to 3700 Hz for teleprotection or telemetering tones.

An alternate purpose application is illustrated in Figure 5-2G. Both voice and telecontrol signals share this channel, which is representative of the General Electric multi function audio tone teleprotection equipment. However, the voice and telecontrol signals are blocked during transmission of any trip signal.

Figure 5-3 illustrates the application of baseband ON-OFF carrier directional comparison relaying. ON-OFF baseband carrier equipment is applied here for two line sections and each operates on the same frequency, f1. At terminal B a baseband blocking filter is used to isolate each of the ON-OFF baseband carrier signals on the opposite side of a bus during a relaying function. Normally, the system operates in a multifunction communication mode.

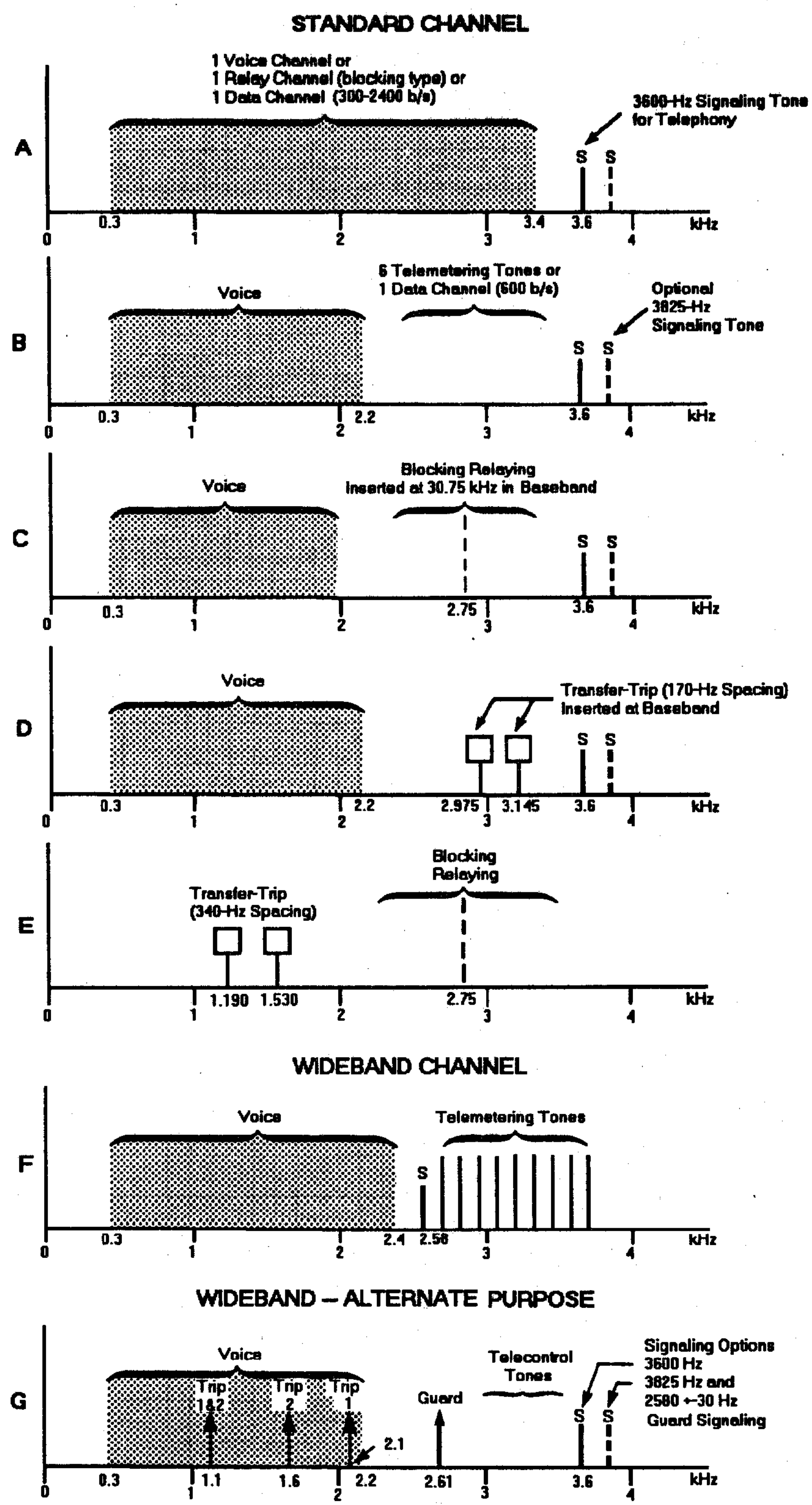


Figure 5-2. Typical SSB Channel-Utilization Diagram

In Figure 5-3, it will be noted that the baseband ON-OFF carrier is applied in the baseband for directional comparison relaying. The baseband ON-OFF carrier is applied for Line 1 and Line 2. Each baseband ON-OFF carrier operates on the same frequency, f1. At terminal B, baseband channel 1 blocking filter isolates signals during the relay function. The system normally operates in a multi-function mode.

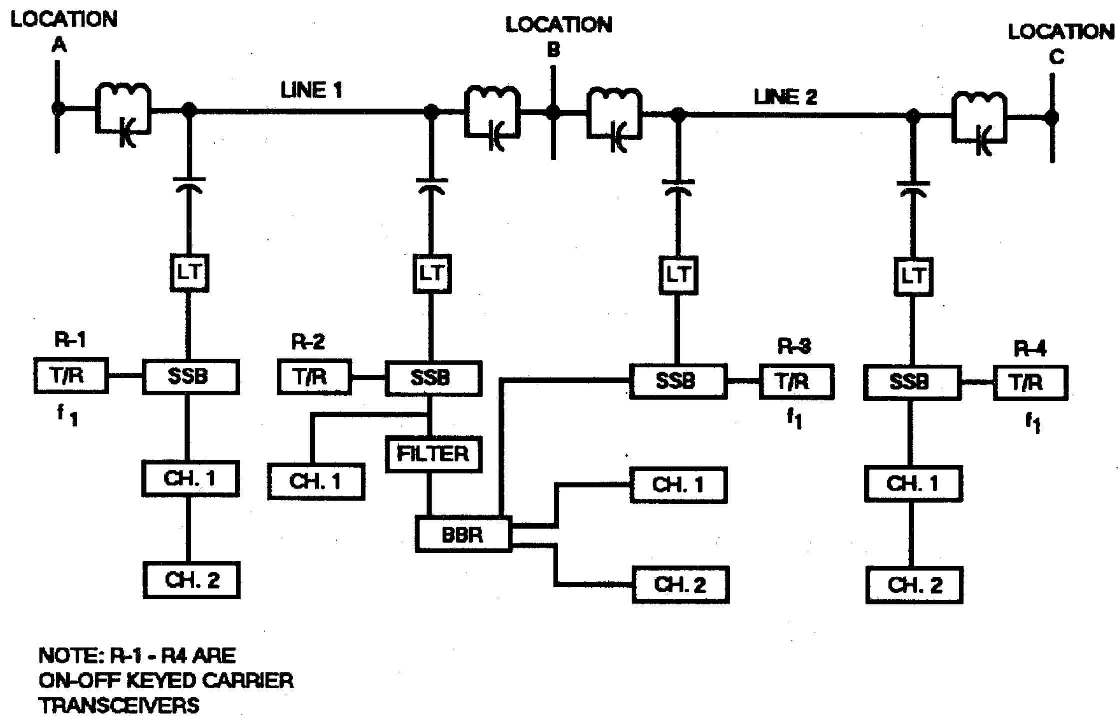


Figure 5-3. Single Sideband Baseband Relaying

Assume a fault in line section 1 (Figure 5-3). The relays at terminal B key the baseband carrier set R3 to send a blocking signal to R4 to block tripping of line section 2. This allows total power to be applied to SSB relay set R3. After the relaying function is completed, the SSB system for line 2 returns to the multi-function mode.

Figure 5-4 illustrates the use of blocking filters to permit the transmission of audio teleprotection tones on a point-to-point basis. Since this feature blocks the entire 4.0 kHz channel, the audio tones can be assigned the entire 300-3400 Hz channel frequency band, or they can utilize only the 2000-3400 Hz tones above voice frequencies. As shown, tones to the left of Station A cannot pass through the baseband repeater at this location, since they are blocked by the Channel 1 blocking filter. Audio tones utilizing the same frequencies can be assigned to the line section to the right of Station A and, therefore, do not interfere with tones for the line section to the left of Station A. Thus, Channel 1 serves as a dedicated point-to-point relay channel, while Channel 2 is baseband repeated to provide a high quality data channel.

Where a teleprotection application requires a high degree of reliability, "hot standby" operation (using two sets of common equipment) can be applied. Both set of common equipment operate continuously and are driven from a single set of voice channel equipment operating through a common baseband repeater.

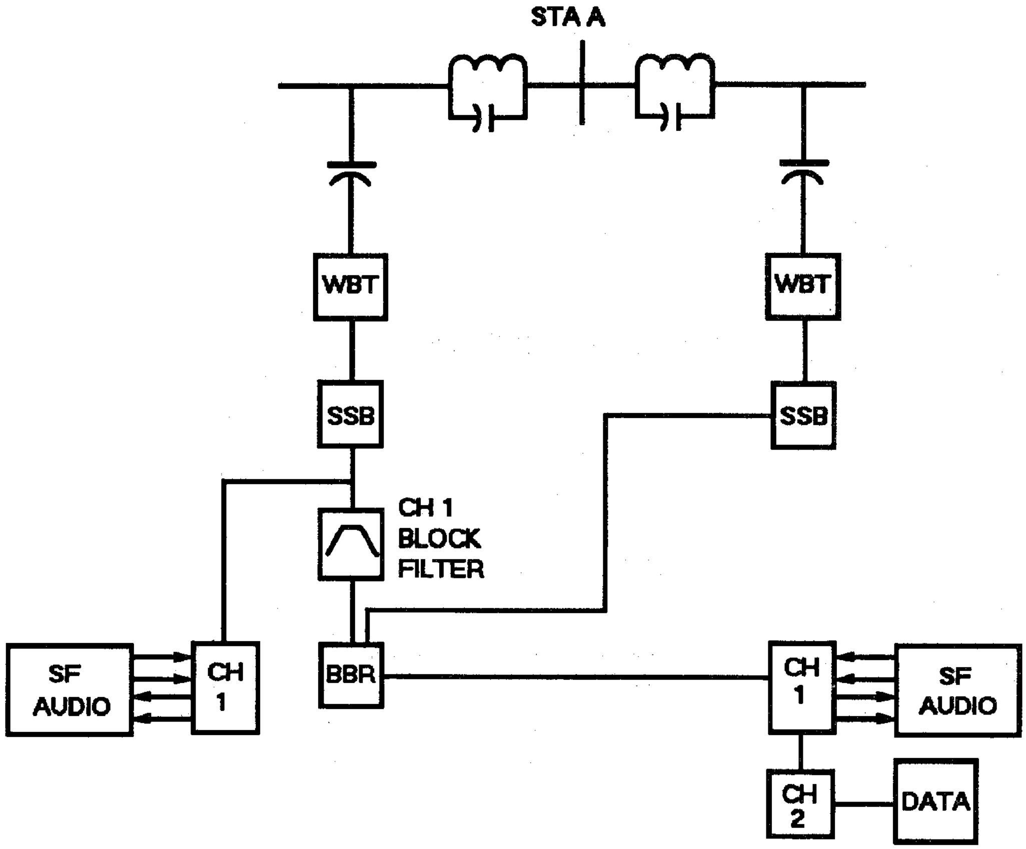


Figure 5-4. Block and Insert

Only one set of common equipment is actively connected to the transmission line. If it should fail, an electronic baseband squelch control circuit automatically disables the faulty common equipment and switches in the "hot standby" common equipment. Hence, continuity of communication is maintained for protective relaying.

Figure 5-5 shows another single-sideband configuration employing a blocking-type channel (MBW or WBW ON-OFF carrier sets) in the baseband for static relay line protection and either (not both) transfer-trip equipment in the baseband or audio single or multi-function tone.

Figure 5-5 illustrates the wide variety of SSB relaying channels available. In the baseband, both blocking and tripping type channels can be used. The characteristics of the baseband ON-OFF carrier sets are comparable to the channel characteristics of the regular MBW or WBW ON-OFF sets, respectively. The baseband transfer trip channels include the medium bandwidth and wide bandwidth FSK sets. Figure 5-5 also shows the frequencies which may be used in the baseband for the medium and wide bandwidth ON-OFF carrier sets, the medium BW and wide bandwidth FSK sets.

A system of logic is also supplied as an integral part of the baseband FSK sets receivers. The logic system allows the optimum balance between security and dependability that is required in line relaying applications and is fully described in Section 4. A comparison of the salient features of the baseband medium and wide bandwidth FSK sets is shown in Table 5-3.

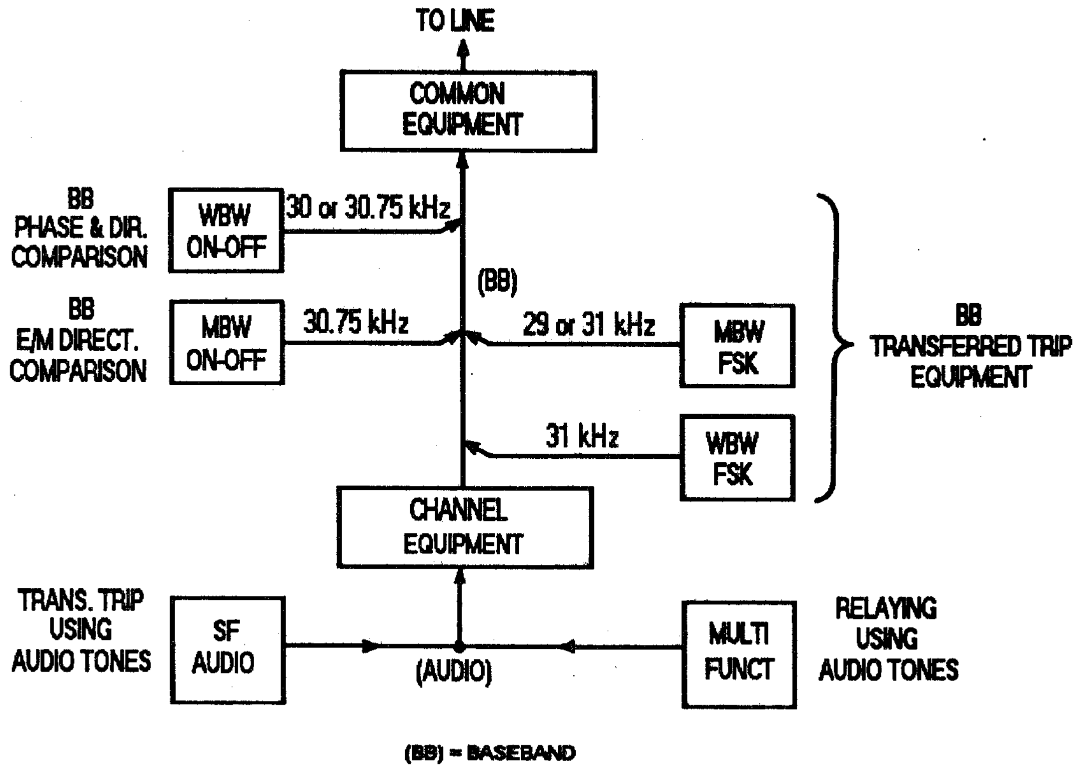


Figure 5-5. Audio and Baseband Relaying Diagram

The unblocking scheme utilizes the wide bandwidth baseband frequency-shift, which combines several features. It includes the features of a blocking scheme with those of the unblocking scheme, including true noise detection for faithful signal-to-noise determination over a wide dynamic range. It also includes high speed noise reset and blocking for the ultimate in dependability, and a logic circuit to monitor the channel status.

A shared-function direct transfer trip and directional comparison scheme using the wide bandwidth baseband FSK is also available. Both channels of a dual channel wide bandwidth baseband are equipped with T logic: U output for directional comparison and P output for direct trip. Both channels are keyed for direct trip; one channel only is keyed for directional comparison relaying.

When single function and multi-function audio teleprotection tones are applied in the voice channel, a number of features are available to improve security and dependability. This includes absolute GUARD protection, alien tone protection, protective delay to increase security against high energy noise impulses, multimode squelch protection, and multi-response receiver automatic gain control. Optionally, a pilot tone for frequency-translation protection is also available with the single function audio tones.

The choice of baseband versus audio teleprotection channels depends on the following considerations, summarized in Table 5-4:

1. Channel speed
2. System reliability

Table 5-3

Characteristics of Medium and Wide Bandwidth Baseband Teleprotection Channels

Characteristics	Transmitter-Receiver	
	Med. BW FSK	Wide BW FSK
Frequency Shift.............	500 Hz	1000 Hz
Frequency (normally).	29 or 31 kHz	31 kHz
Receiver Bandwidth		
At 6-dB points............	500 Hz	1000 Hz
At 55-dB points...........	3000 Hz	6000 Hz
Max. Receiver Sensitivity....	15 mV	15 mV
Receiver Logic......	U: Loss of signal allows trip P: Signal reset before trip D: Guard reset before trip T: U&P combined	U: Loss of signal allows trip P: Signal reset before trip D: Guard reset before trip T: U&P combined C: Center frequency, no discriminator output. Loss of signal allows trip
Channel Speed		
Solid-state or SCR output		
With logic..............	7 ms*	4 ms
Without logic...........	12 ms	10 ms
Relay output		
With logic..............	12 ms*	----
Without logic...........	17 ms	----

*Add 2 ms for P, U & T logic

3. Economics
4. Repeater requirements for adjacent line sections, e.g., data and voice
5. Isolation requirements between the two sides of the repeater
6. Need for repeating from SSB to microwave or other types of carrier equipment

In single-sideband systems, the calculation of SNR is different from that of single-function carrier systems because the maximum available transmitter output must be divided among various functions. Table 5-5 gives the minimum values of acceptable SNR for voice, baseband, and tone channels operating over SSB equipment. The SNR listed for tones depends on the receiver bandwidth characteristics.

Figure 5-6 illustrates a three-terminal application of the blocking carrier set applied in the baseband for directional comparison relaying. Two sets of SSB carrier frequencies (F1/F2 and F3/F4) are used and the third terminal uses two sets of common equipment with high-pass and low-pass filters, as shown.

Table 5-4
Comparison of Baseband versus Audio Tone Teleprotection Channels

Factors	Baseband Relaying**	Audio Tone Relaying
Channel Speed*	3 to 14 ms	4 to 19 ms
Reliability: Loss of voice channel affects relaying?	No	Yes
Economics (SSB equip.)		
Common Equip. Req'd?	Yes	Yes
Channel Equip. Req'd?	No	Yes

*Depends on type of relaying and channel
**Also available with channel-blocking filters

Table 5-5
Minimum Acceptable SNR for Various SSB Functions

Function	Equipment	SNR (dB)
Voice/Multi-Function		
Tone for Data, Relaying, Supv., etc.	SSB-PLC	15
Voice w/o Compandor	SSB-PLC	30
Voice with Compandor	SSB-PLC	15
Pilot or Signaling Tone	SSB-PLC	5
Phase Comparison Relaying	WB BASEBAND SSB	20
Directional Comparison Relaying	NB-BASEBAND SSB	15
Transfer Trip (single channel)		
7 ms channel	Med. BW BB FSK	5
4 ms channel	Wide BW BB FSK	7
4 ms, 1000-Hz spacing	SF Audio Tone	+5
7 ms, 340-Hz spacing	SF Audio Tone	0
10 ms, 240-Hz spacing	SF Audio Tone	-1
14 ms, 170-Hz spacing	SF Audio Tone	-3
10 ms, 340-Hz spacing	Multi fn. Tone	0
Unblocking Relaying	WB BB FSK	15

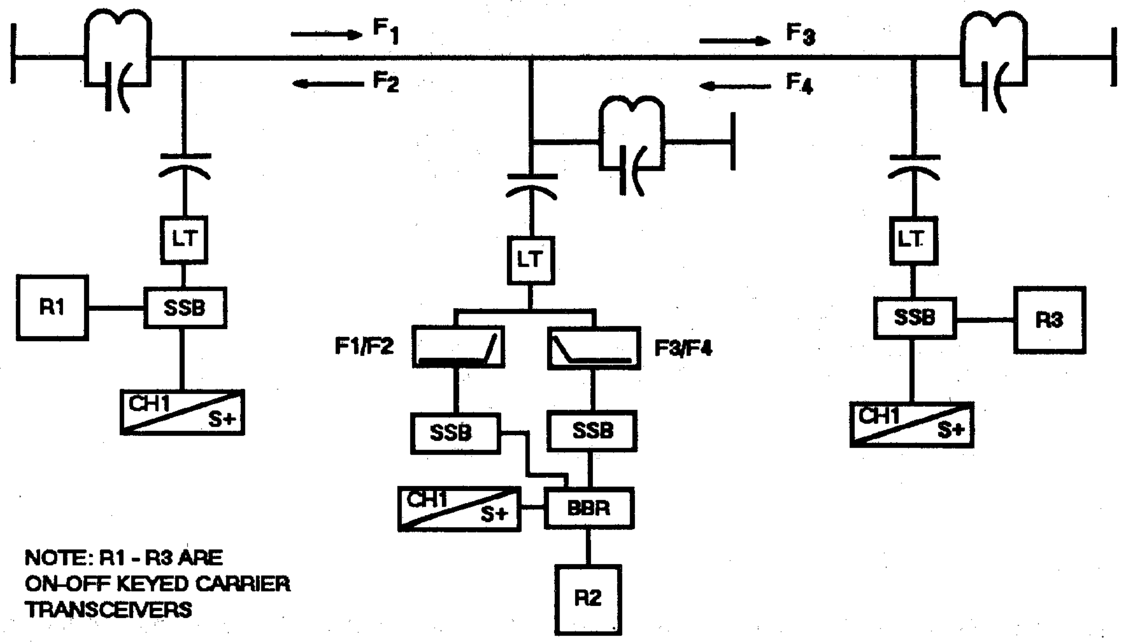


Figure 5-6. SSB System on Three-Terminal Line

FREQUENCY CONSIDERATIONS

Frequency allocation and planning for SSB systems require the following considerations, if it is to be applied into an existing carrier spectrum. The first step is to apply new frequencies only on the basis of a given allocation plan. The plan should have the basic characteristics of being established in 4 kHz slots throughout the carrier spectrum expected to be used. Table 3-2, Section 3 defines the frequency spacing requirements between SSB and other General Electric single-function carrier equipment.

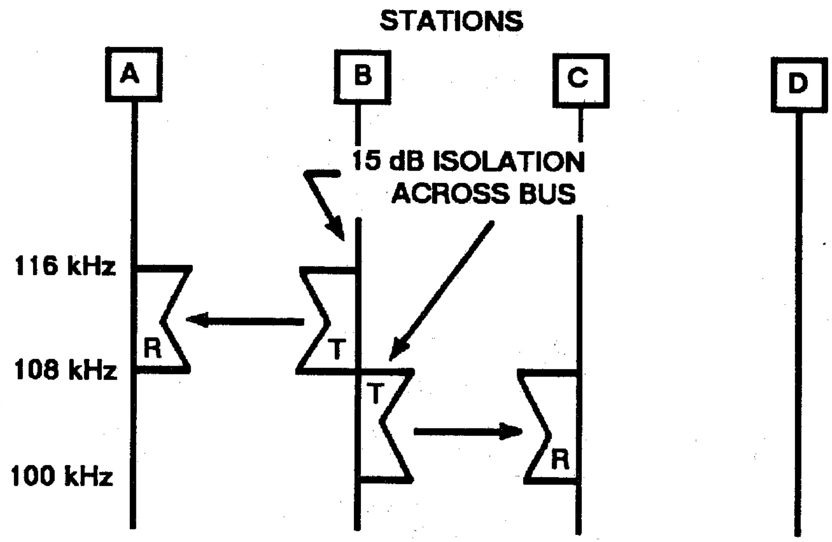
In order to obtain maximum utilization of the available spectrum and to provide a good interference-free carrier system, it is important to apply frequencies with knowledge of the power transmission system and carrier equipment involved. The following guidelines, together with the user's knowledge concerning isolation across a bus, provide information for efficient spectrum utilization.

Case 1

Signal Relationship: For transmitters of equal output connected to different lines at the same bus, and adjacent in frequency, the signal present at the output of either transmitter must have 15 dB isolation to prevent intermodulation products.

Typical Situation: For transmitters of different outputs, the dB difference in power must be added to the 15 dB isolation required.

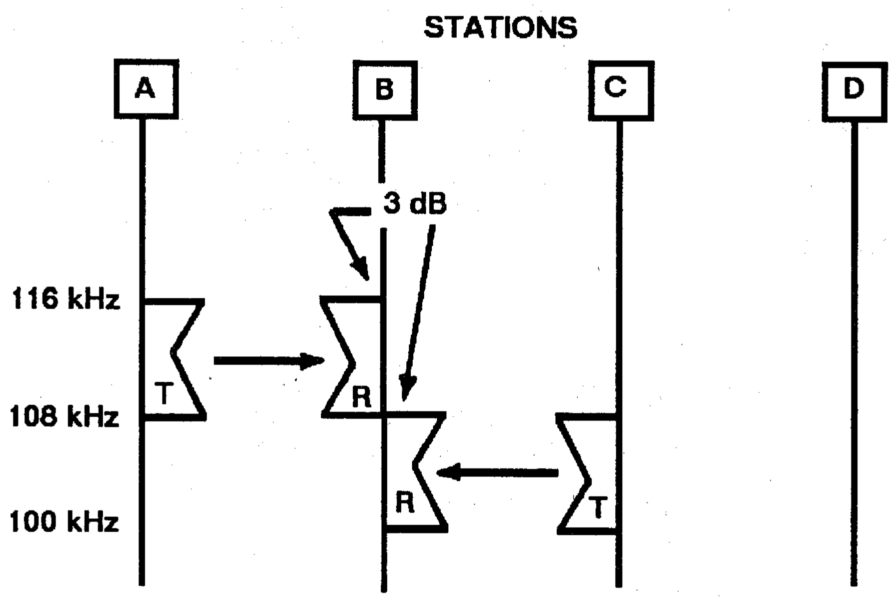
See diagram of Case 1 on next page.



Case 2

Signal Relationship: For receivers connected to different lines at the same bus and adjacent in frequency, the desired signal at each receiver should be 3 dB higher than the undesired signal from the adjacent channel. This signal level coordination is required to allow for channel receiver filter characteristics near the edge of the passband.

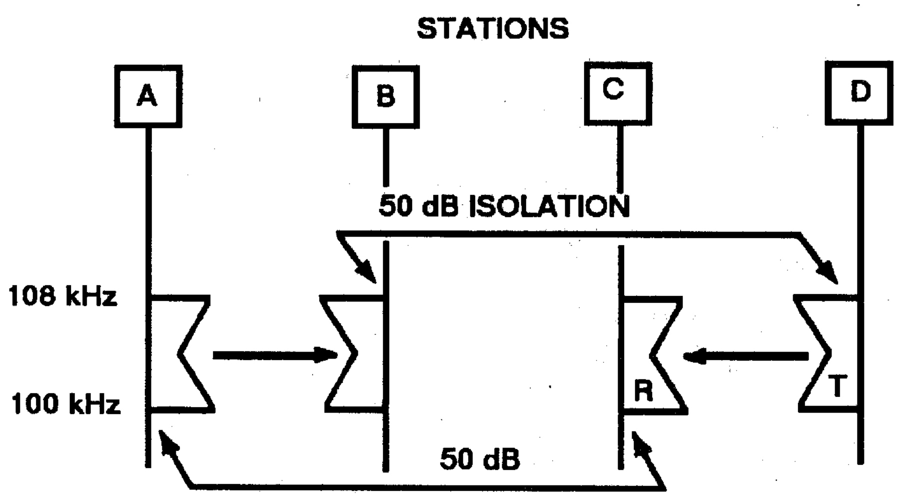
Typical Situation: Any difference in transmitter power plus the difference in attenuation must be added to the basic 3 dB requirement. In most cases, the inherent loss across the station bus is sufficient.



Case 3

Signal Relationship: If frequencies are to be repeated after two line sections and three buses with transmitters facing each other, the undesired signal at either receiver must be low enough in level to achieve the desired permissible level of crosstalk.

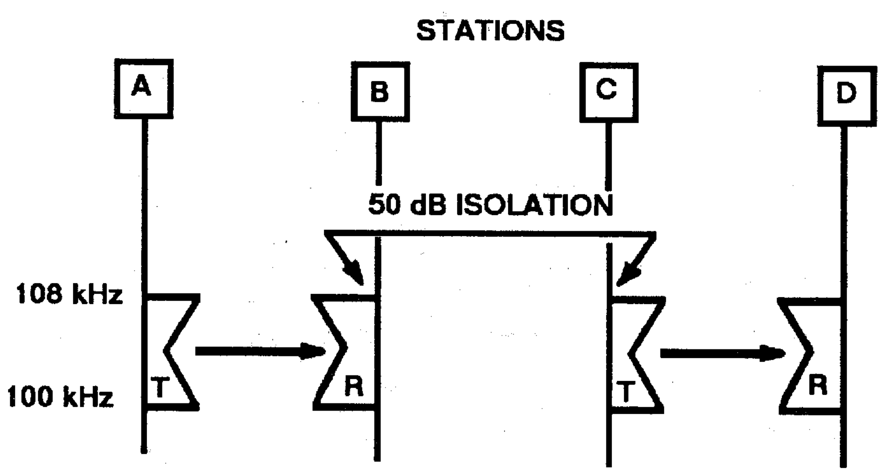
Typical Situation: For voice applications, 50 dB of isolation is usually adequate to prevent bothersome crosstalk. For some types of control signals, 30 or 40 dB isolation may suffice. More than 50 dB may be required if the end section (Line C-D) has attenuation in excess of 30 dB.



Case 4

Signal Relationship: If frequencies are repeated after one line section and two buses with transmitters facing in the same direction, the undesired signal at either receiver must be low enough in level to achieve the desired permissible level of crosstalk.

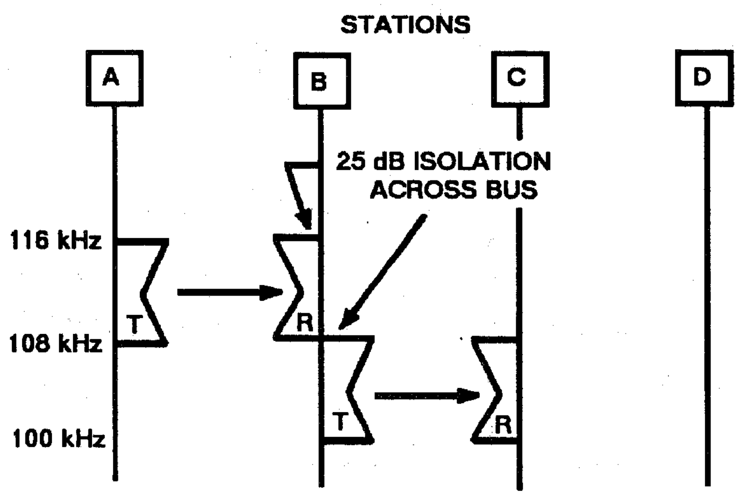
Typical Situation: 50 dB of isolation is usually required (same as Case 3). More than 50 dB may be required if the end section (line C-D) has attenuation in excess of 30 dB.



Case 5

Signal Relationship: When a transmitter and receiver are coupled to different lines at the same bus and adjacent in frequency, the undesired signal from the local transmitter at the input to the local receiver should be 3 dB below the desired signal.

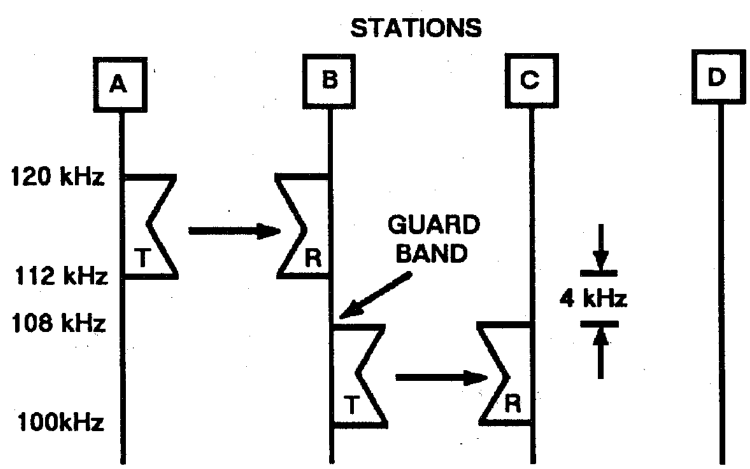
Typical Situation: Due to the close proximity of the transmitter to the receiver, usually 25 dB of isolation across the bus is desired to prevent interference or possible swamping of the receiver. More than 25 dB may be required if the attenuation of the end section (line A-B) exceeds 20 dB.



Case 6

Signal Relationship: When a transmitter and receiver are coupled to different lines at the same bus, and separated by a guard band (4.0 kHz for line attenuation over 30 dB or using baseband repeating), 15 dB or more of isolation is desired to prevent swamping of the receiver.

Typical Situation: In all cases except for a very long line between A and B (line attenuation greater than 50 dB), 15 dB of isolation is adequate.



OPTIONS AND ACCESSORIES

The essential equipment for a single-sideband PLC system includes common equipment and channel equipment. Basic equipment such as 48 volt battery and chargers, telephone instruments, telephone-switching equipment and test panels are also required. Other equipment and accessories which are necessary for teleprotection, telemetering and voice communication may include the following:

1. Baseband Teleprotection Channels
   - Wide band blocking carrier for use with static relays (MOD III or TLS) [21] for protective relaying
   - Narrow band blocking carrier for use with electromechanical or modular static (SLS) [20] relays for protective relaying
   - Medium BW and wide BW FSK PLC channels for transfer-trip protective relaying systems, including:
     - Direct underreaching transfer-trip for line protection
     - Permissive-underreaching and over-reaching for line protection
     - Unblocking relaying
     - Combined unblocking and direct transfer-trip
     - Phase-comparison
2. Audio Tone Teleprotection Channel
   - Single function tone channels for directional comparison, phase comparison and transfer-trip protective relaying systems
   - Multi function tone channels for direct trip and permissive trip protective relaying
3. Telemetering
   - 120 Hz and 170 Hz audio tone equipment
4. Repeating
   - Audio bridge for audio repeater
   - Baseband repeater
5. Optional Equipment
   - RF power amplifier (5, 20 or 100 watts)
   - 120 VAC, 50/60 Hz input in lieu of 48 Vdc
   - 125 VDC ungrounded or positive-grounded input
   - Service telephone
   - Party line selector
   - Specialized Test panel

A battery clamp is not required on the SSB power supply inputs. If transients exceed 2.5 kV and are below 5 kV, a battery clamp should be considered. If transients exceed 5 kV, steps must be taken to eliminate them.

PRINCIPLES of OPERATION

Single-sideband PLC provides transmitting and receiving channels using frequency division multiplex. Voice and tone frequencies are translated and transmitted in the range of 40 to 500 kHz. Provisions are made for use of one, two or four 4 kHz channels with one set of common equipment. Each voice channel provides a 300-3400 Hz channel (300-3700 Hz for wideband channels).

A basic single-sideband terminal consists of a power supply unit, a power amplifier unit, common equipment and channel equipment. Both common equipment and channel equipment are available and have been designed with maximum flexibility in mind, utilizing only the modules and units necessary for a particular application.

General Electric D-version SSB equipment uses modular construction to provide flexibility of application and easy field changes. Each channel unit is a module unto itself, as is the common equipment shelf, the power supply and the amplifier. The amplifier is the same size for the 5, 20 and 100 watt amplifiers. All-solid-state dc-to-dc converters are contained within the power supply module with the exception of the converter required for the 100 watt amplifier, which is housed in a separate unit.

All modules are completely enclosed, both front and back, and are arranged for front access for test and maintenance. The shelves can be pulled out for circuit maintenance and separate circuit boards are used for each part of the circuit, offering increased flexibility for options and maintenance. A test telephone and an optional test panel are available for maintenance purposes. The test panel includes a meter for measuring received tone level and an internal tone generator for insertion of test tones.

Other factors include:

- Continuously spaced channels for frequency conservation
- Capability for data transmission with specifications exceeding C4 conditioned lines
- Speech-plus tone with three ports: "through", "block" and "exalt" (1 to 20 dB for all tones)

A bridging-type power amplifier is also used for a full 5, 20 and 100 watt output. This amplifier is essentially two amplifiers in parallel, one of which could remain in service should the parallel amplifier fail.

Single-sideband is a form of amplitude modulation (AM) in that the modulated wave varies in direct relation to the amplitude of the modulating signal. However, the resultant modulated wave contains only one set of sidebands either an upper set or a lower set. In addition, most of the carrier frequency signal is suppressed. Each AM sideband contains the same intelligence. Therefore, it is possible to communicate with one sideband suppressed, since the carrier and remaining sideband can be detected by a conventional AM receiver. The primary advantage of SSB is that it requires one-half the bandwidth required for AM transmission. Also, on an equal power transmitted basis, the SSB system provides a 3 to 1 improvement in the signal-to-noise ratio over a conventional DSB AM system. Thus, a single-sideband suppressed carrier system takes advantage of both improved spectrum utilization and improved signal-to-noise ratio.

A simplified block diagram of the typical SSB terminal is shown in Figure 5-7. It consists of Common Equipment and Channel Equipment. The Common Equipment includes the carrier generation system, power supply, power amplifier and all other equipment common to all channels, including the baseband repeater where required. The Group-Send circuit converts the baseband frequencies to line frequencies, reinserts the pilot carrier frequency, and filters the output for 1, 2, or 4 voice channels, depending upon the equipment applied. The power amplifier amplifies the output of the Group-Send module to 5, 20 or 100 watts in accordance with the specified output level. Efficient separation is provided with the skewed hybrid by separating the send and receive frequencies. Use of a skewed hybrid keeps the loss in the send direction at a very low value (0.5 to 1 dB). The Group-Receiver module includes the demodulation step and operates the same as the Group-Send module, except in an opposite manner. Compensation for variation in signal level caused by line attenuation changes is provided by the AGC (Automatic Gain Control) module. Gain control is accomplished by passing both the pilot and the normal signals through the AGC circuit.

In addition to the 3600 Hz signaling tone, a 3826 Hz signaling is required for microwave compatibility.

Where a baseband repeater is applied, it offers a distinct economic advantage over audio repeaters because a baseband repeater (BBR) requires no more than one channel equipment at each location. The channel equipment is not involved in repeating thru-traffic from other locations as will be noted in Figure 5-7. The baseband repeater interfaces the common equipment at a terminal.

As shown in Figure 5-7, the Channel Equipment provides the basic modulation and demodulation step in the SSB system. It provides the necessary termination for interfacing the SSB equipment with the associated telephone, tone equipment or other devices. A channel modem provides the modulation and demodulation step which converts the audio frequency to baseband frequencies and then to line frequencies, and vice versa. Each audio channel can be occupied by voice, by voice with tones above the voice (speech-plus), or by tones alone.

5

The Speech-Plus/Voice Limiter circuit provides the means by which telemetry tones are inserted above the voice frequency band. The Limiter portion limits the voice peaks to prevent over-modulation. A transistor switch (voice block) in the voice send path permits turn-off of voice signals to allow full channel capability for tones only.

Where required, a compandor is used to improve the signal-to-noise ratio. Termination and Signaling modules in the Channel Equipment provide various terminations. In a four wire E&M termination, four wires are used to carry voice (audio) signals and two additional wires (E&M) are used for signaling IN and OUT. By means of plug-in modules, the termination unit is utilized to provide two-wire ringdown terminations. The signaling receiver responds to the incoming 3600 kHz signaling tone to produce the pulsed information as keyed or dialed at the remote end.

Figure 5-7 shows the use of an audio bridge, which is used for efficient repeating of voice, tone and signaling function on carrier or microwave channels when a local drop of the repeated intelligence is desired. Otherwise, direct four-wire E&M repeating is used. With an audio bridge, its tone repeater allows tones to be transmitted from the local drop in one direction only, as desired. The audio bridge also allows the voice portion of different numbered channels (CH-1, CH-2, etc.) to be tied together on a party line basis by providing telephone drops at the repeater station to allow talking simultaneously to two or three other remote stations.

SSB equipment operates in a two-frequency, full duplex mode. Figures 5-8 and 5-9 show the basic modulation and de-modulation scheme with the SSB equipment. There are three basic levels of frequencies:

- Audio: 300-3400 Hz
- Baseband: 16-32 kHz
- Line: 48-535 kHz

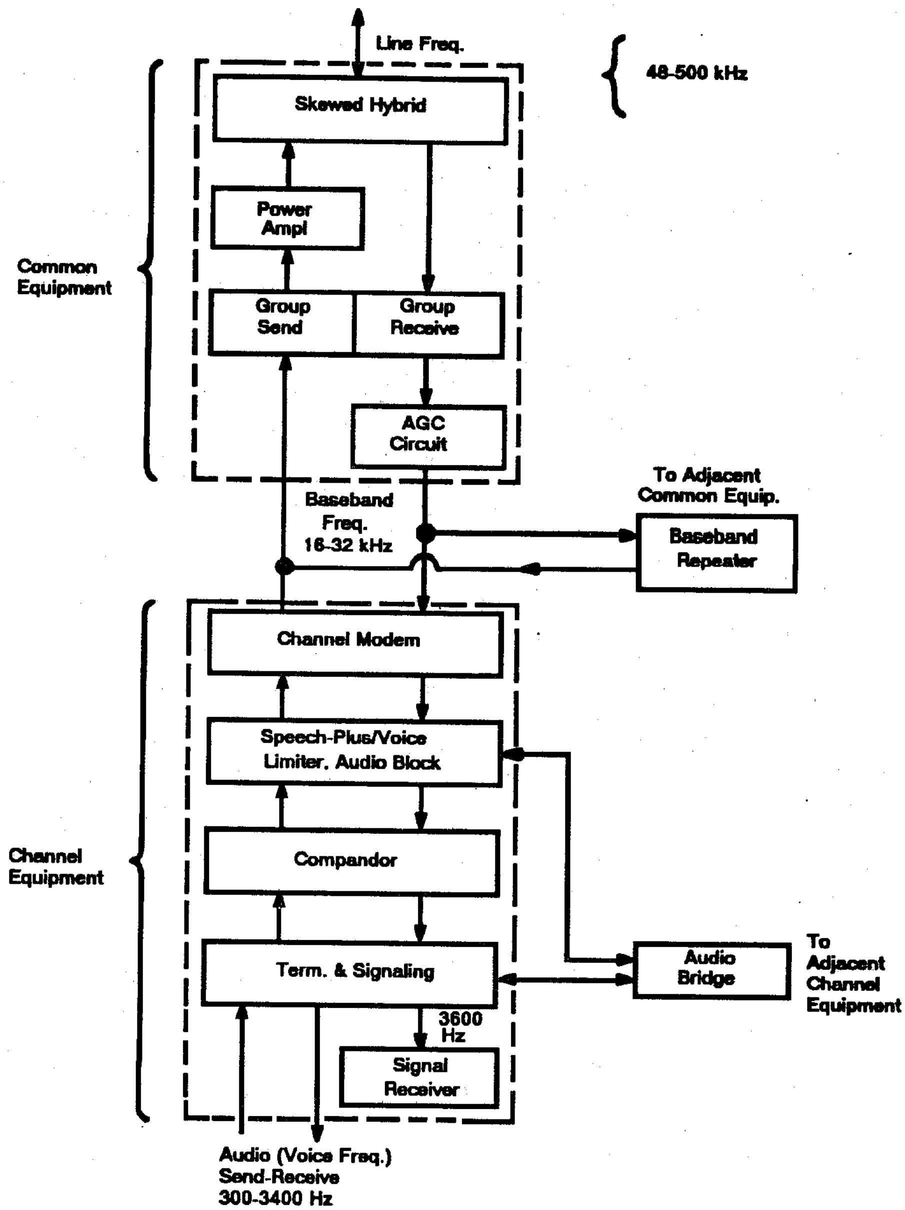


Figure 5-7. Block Diagram of Typical SSB Terminal

Four channels are illustrated.

The modulation process in Figure 5-8 is as follows. Channel 1 is mixed with the channel carrier frequency to produce two sideband frequencies: 28 kHz±4 kHz or 28-32 kHz (upper sideband) and 24-28 kHz (lower sideband). The lower sideband frequencies are not used, and channel 1 is represented in the baseband by the upper sideband frequencies, 28-32 kHz.

A similar modulation process is used for channels 2, 3 and 4. Lower and upper sideband frequencies are used as shown for these respective channels.

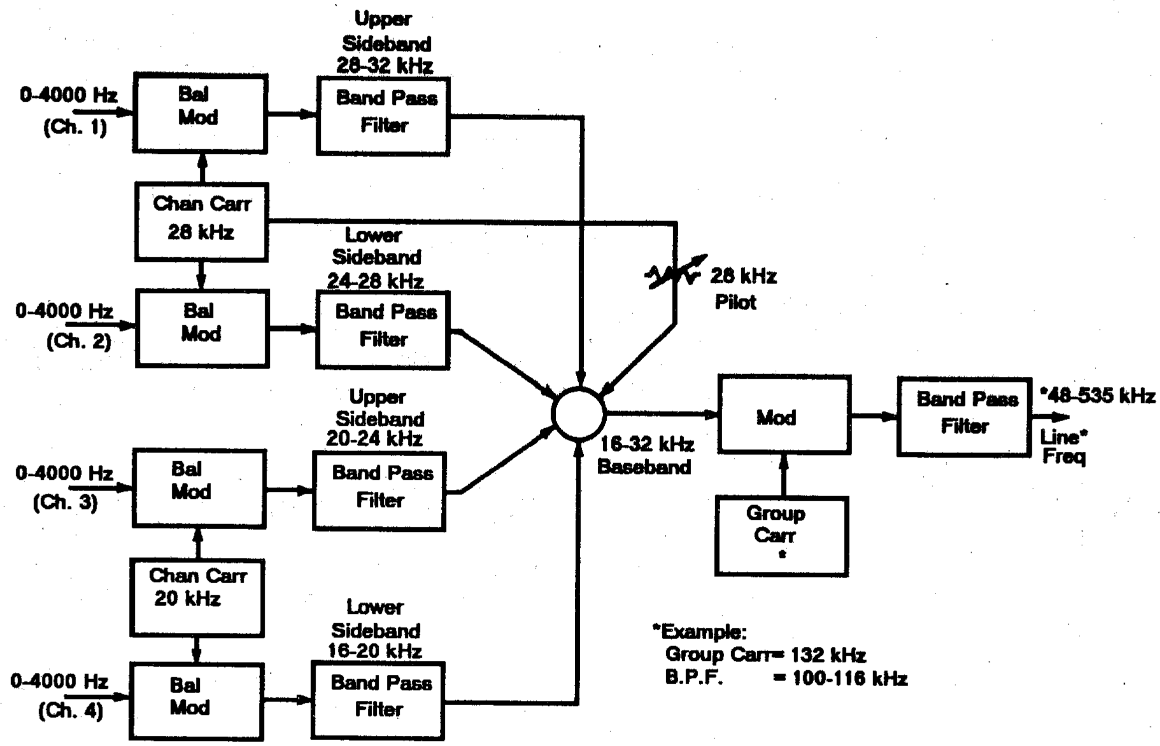


Figure 5-8. Basic Modulation Scheme - (SSB - SC - AM)

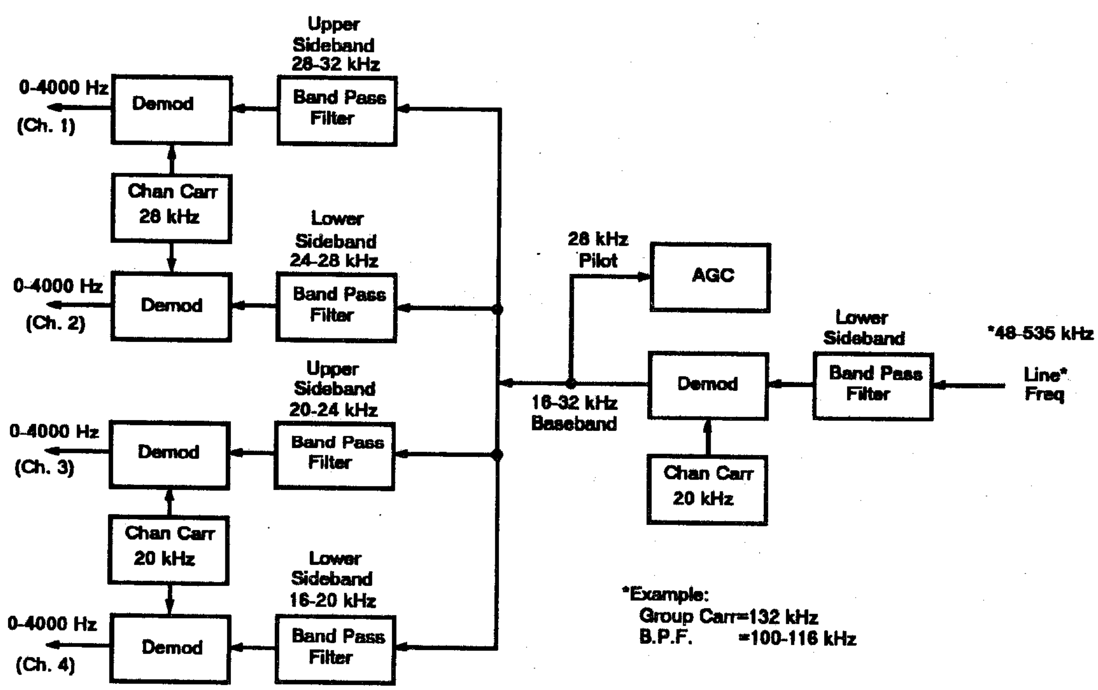


Figure 5-9. Basic Demodulation Scheme - (SSB - SC - AM)

Channels 1 through 4 use the baseband frequency range of 16-32 kHz. To convert the baseband frequencies to the power line carrier frequencies desired, a group carrier frequency is selected. For example in Figure 5-8, if the desired line frequencies are 100-116 kHz, the group carrier frequency would be 132 kHz, or 132 - (16 to 32) = 100 to 116 kHz.

A reverse procedure takes place for the de-modulation process shown in Figure 5-9.

A 28 kHz pilot is used for channel synchronization and automatic gain control.

SINGLE CHANNEL SSB EQUIPMENT

The availability of monolithic and polylithic crystal channel filters in the 5 MHz to 10 MHz frequency range for low density and high density analog multiplex systems has also made these devices available for PLC SSB use. Several SSB terminals are available which use a double conversion process to allow the major filtering to be done in the MHz region.

The first modulation step translates the usual 300-3400 Hz audio frequency band to a frequency of 5+ MHz. The second modulation step translates the single channel to the desired frequency range in the PLC band. PLC SSB requires additional amplification of the signals before transmitting this spectrum through the line tuner. A number of channels may be combined before the level of the group of channels is amplified in a power amplifier. This system also allows the individual channels to be amplified before combining the total group using bandpass filters at the line frequencies.

The carrier frequencies for the individual channels are selected by programming a synthesizer to a specific frequency which will translate channels to the PLC frequency range. The first translation carrier is a fixed frequency.

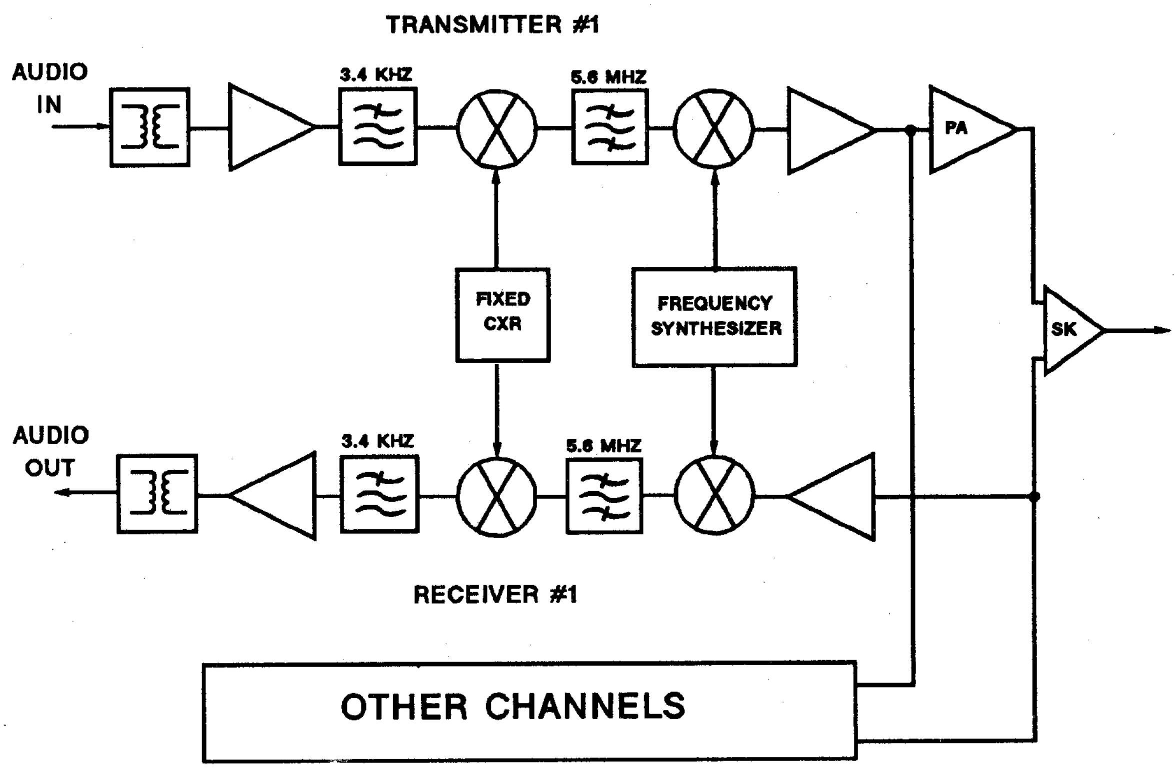


Figure 5-10. Single Channel SSB System With High Frequency Filtering

In the receiver, the process is reversed and the first translation uses a variable frequency provided by a programmable synthesizer. The translation to audio is accomplished with a fixed frequency carrier, which is the same frequency as the first translation carrier for the transmitter.

The fixed frequency carrier can be used for any number of channels at a terminal, since all of the filtering is done in the same frequency range.

Figure 5-10 shows a typical simplified diagram of a single channel SSB terminal with high frequency filtering. The usual combination of tones, voice, data, and pilot tone can be loaded into the individual channels. This equipment can be used with PLC or on private communication links, such as microwave.

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SECTION 6

AUDIO TELEPROTECTION CHANNELS

Contents of Section 6

HISTORY OF AUDIO TELEPROTECTION TONE

Audio teleprotection tone equipment has gone through a series of changes from its early designs. Power utilities use audio tone equipment for other communications applications such as low and high speed data transmission, telemetering, telegraph, dispatching, remote control, and supervisory functions. The many control and monitoring functions have been lumped together as Supervisory Control and Data Acquisition (SCADA). The audio tone used for SCADA and for various other data transmission tasks is a different system from that required for protection of power systems and power system components.

The audio tone systems, usually referred to simply as "tone", are generally of two types. Frequency shift (FS) systems have the widest application and are characterized by a constant amplitude tone which is shifted between two or more frequencies. The frequency multiplexing is done by the ability of the receivers to discriminate between signals at assigned channel frequencies. In teleprotection tone systems, the Guard is transmitted at one frequency and the trip is transmitted at another frequency.

The other type of tone system uses an AM modulation technique which switches one or more constant frequency tones between zero and full amplitude. The presence of a tone at a particular frequency denotes a particular condition.

Another version of the AM tone might be a system which transmits the same frequency for both guard and trip, but the phase of the signal is changed to denote a change in the transmitted command.

Another possible system, which is the tone equivalent of a blocking carrier set, was an audio tone system which transmitted a tone only to prevent tripping on a "healthy" line. GE Type 19 Tone was this type of tone channel equipment.

GE Type 10, Type 20, and Type 30 Tone was a version of a teleprotection tone system in the early years of solid state communications equipment. The equipment could be configured as a Transceiver with both Transmitter and Receiver capability; or a single or dual channel Transmitter or Receiver.

The filtering was done by special L/C filters designed for the channel and shift frequencies or bandwidth of the channel. An optional bandpass filter was available in the transmitter to reduce harmonic distortion. The receiver used a very selective bandpass input filter and a discriminator and lowpass filter especially designed for the channel frequency and bandwidth to select and detect a change in frequency. A squelch filter module consisted of a wideband and narrowband noise path determined by filters. A slot filter was available in one of the noise paths to detect frequency translation.

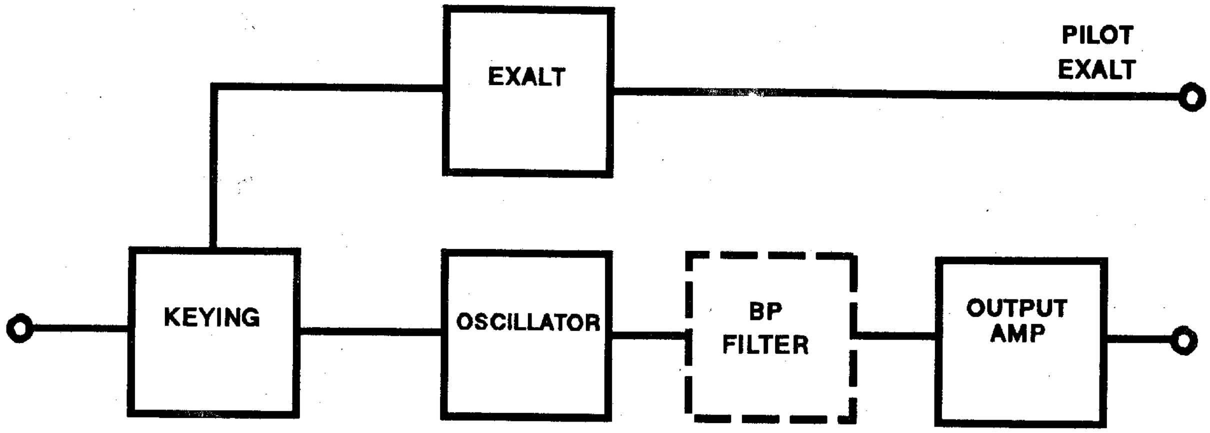


Figure 6-1. Type 30 Tone Transmitter

A simplified diagram of the transmitter is shown in Figure 6-1. The Receiver block diagram is shown in Figure 6-2. The Logic used in the system is similar to that used in modern tone equipment and the inputs to the Logic circuit of Figure 6-3 come from the Receiver and the Squelch Receiver modules.

The Type 30 tone equipment was packaged in a 19 inch shelf which was three rack units in height. The transmit frequencies were determined by resistor and capacitor values in a Wein-bridge oscillator. The frequencies and the shift were selected for the individual channel and shift required. Channel spacing of 170 Hz, 240 Hz, 340 Hz, and 1000 Hz were available. Two pilot frequencies of 595 Hz and 2465 Hz were also available.

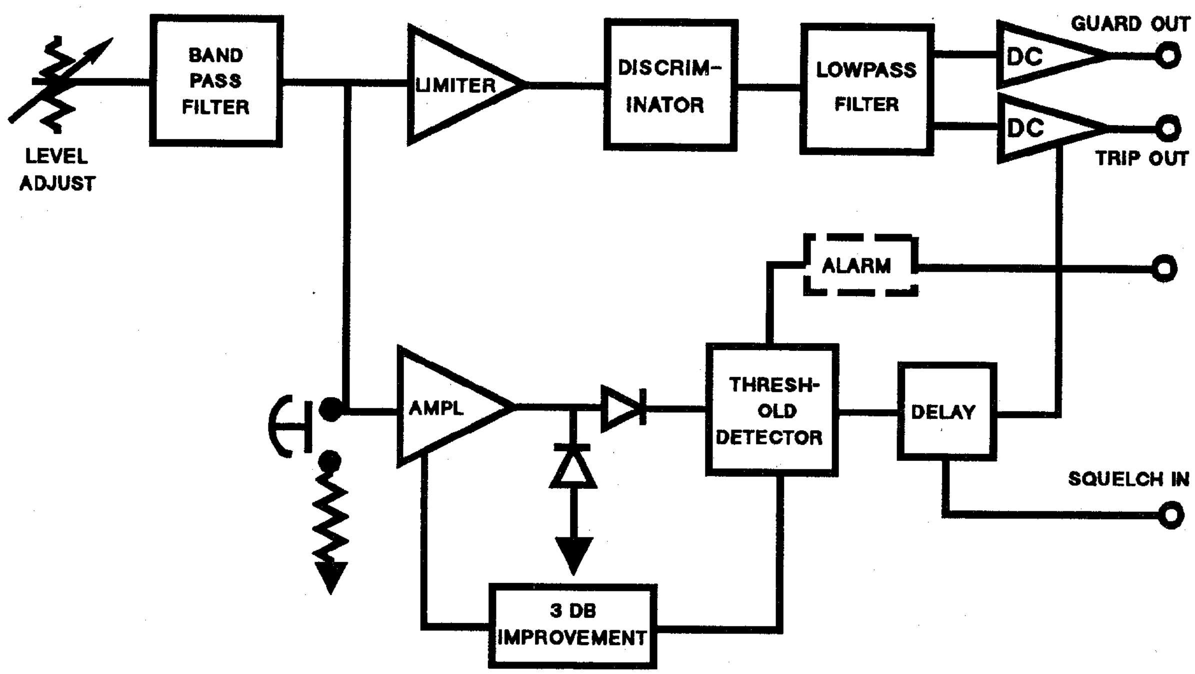


Figure 6-2. Type 30 Tone Receiver

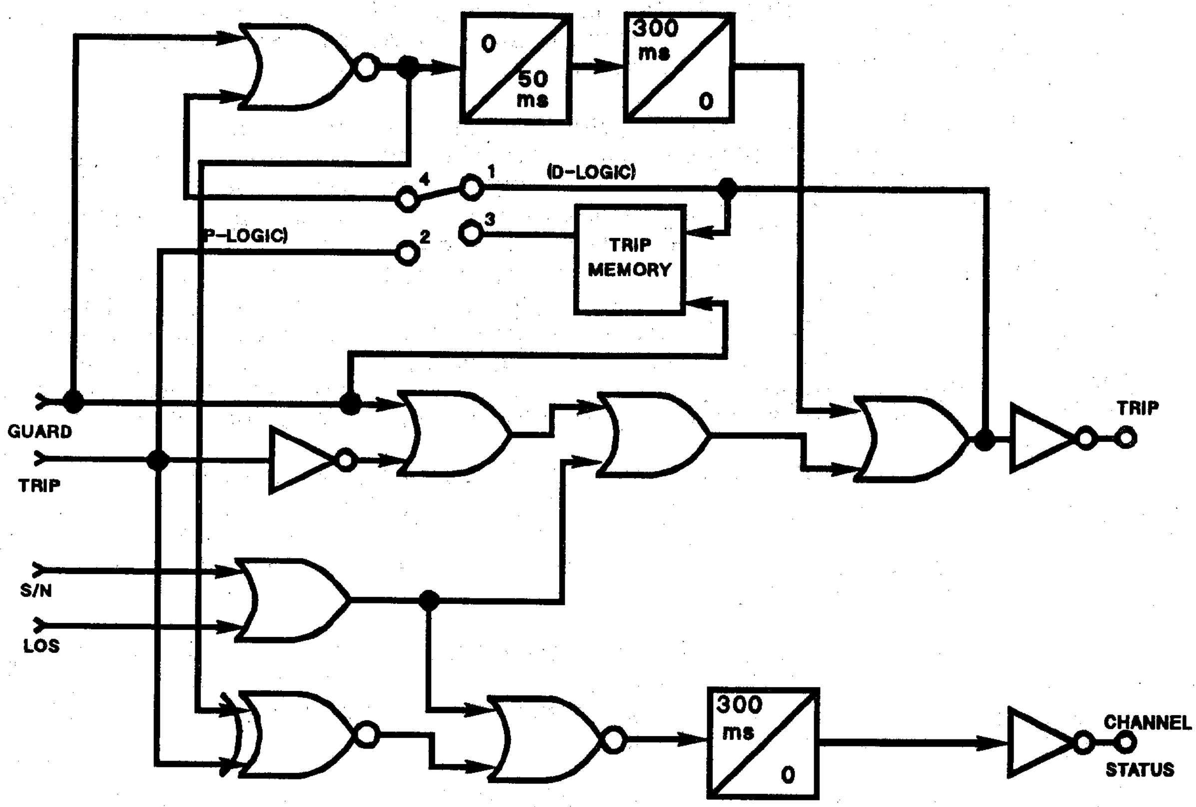


Figure 6-3. Type 30 Tone Logic Circuit

Modern Audio Tone equipment performs the same functions as the earlier versions. GE Audio Tone equipment uses a programmable frequency synthesizer to obtain the GUARD and TRIP frequencies for the various bandwidth channels. The transceiver cabinet occupies 3 Rack Units of shelf space (1 Rack Unit(RU) = 1.75 inches.) in a 19 inch EIA rack. The special receiver and transmitter filters which were specific to a particular frequency/bandwidth assignment were eliminated. The system uses active lowpass filtering. The receiver selectivity is keyed to the frequency spacing of the channel. The receiver can be programmed to any channel frequency in the frequency spacing family. The spacings are 170 Hz, 240 Hz, 340 Hz, and 1000 Hz.

Dual transmitters and receivers and a pilot channel can be housed in one shelf. This greatly simplifies the configurations for dual channel, bi-directional systems. The equipment provides the usual logic capabilities common for FSK protective relaying channels. Back plane wiring is eliminated by using a printed-wire back plane. Fiber optic channel terminations are also available. This equipment is continuously being revised to offer diagnostic options to simplify its application.

The details of the applications and some of the features of modern Audio Tone channels are given in the following paragraphs.

SYSTEM APPLICATIONS

Audio Teleprotection Channel equipment is designed to protect the transmission line and its associated transformers and reactors from damage caused by short circuits. Literature is available that describes the use of audio tones for transferred trip applications [13, 14, 15]. The equipment can be either one-way for transfer trip applications, such as transformer protection, or two-way where line protection or breaker failure protection is required. In addition to transformer protection, shunt reactors can similarly be protected by differential relays and one-way tone transmission.

Audio tone equipment provides teleprotection channels over leased or private wire lines, fiber optic cables and multiplex systems, single-sideband power line carrier systems, or microwave radio. Each media has a different set of operating requirements. Use of leased or private wire lines requires proper coordination of ground potential rise problems and the associated spark gap noise produced by power system faults and switching operations. Substantial added delay must be factored into the overall audio tone channel for certain leased circuits. Microwave circuits introduce frequency translation and intermittent fade problems in addition to protective gap noise in locations where the multiplex is remote from the radio. Power line carrier channels are exposed to high noise and system attenuation changes during the fault disturbance. Frequency translation may also be a problem unless the PLC equipment has proper temperature stability and loss of synchronization detection.

The noise spectrum characteristics encountered in audio tone applications vary between the leased circuit, microwave radio or carrier systems. Noise produced by the power frequency current to earth through gas tubes or carbon blocks in leased circuit applications has a 1/f power distribution. Noise produced in the radio or PLC circuit appears as a flat or white noise distribution at audio frequencies.

Trends in modern transmission line protection show a need for channel times ranging from 4 ms to 10 ms for line protection and 10 to 30 ms for equipment protection. This requirement for faster times also requires wideband audio tone channels which tend to have less security when exposed to high noise levels.

Audio tone channels utilizing out-of-band noise detection and AM blocking (or noise blocking) systems encounter additional loss of dependability due to the fact that the channel may be blocked by noise frequencies which may not harm the tripping channel. These include such things as interfering tones used for channel testing, cross-talk from parallel circuits, power frequency harmonics, etc.

The narrowband FSK tone system, equipped with suitable in-band noise detection and protective logic provides the most flexible building block to accommodate the requirements of the types of communication media. Channel speeds of 4 milliseconds are easily realizable for line protection functions. Additional narrowband pilot channels can be added to provide microwave frequency translation protection. Multifunctional capability can be provided by use of combined schemes in which each single channel can be used for a separate line protection function, and the dual combination can be used for equipment protection. Such a dual channel combination also provides redundancy against false operation of the direct trip function due to a single circuit or component failure. Channel testing is accomplished by operation of one channel at a time, with either the system relays or the second channel serving as a supervisory element to insure no false operation during the test routine.

Reference [15] describes the technical characteristics of a new audio tone narrowband FSK tone system equipped with absolute GUARD protection. Such a system provides an inherent blocking feature as long as the GUARD signal is present. High amplitude noise impulses, which may produce a false trip, also produce a GUARD output, thereby protecting against false trips. This receiver also utilizes a switched delay concept to further optimize dependability without sacrificing system security. Dependability may be enhanced for PLC or wire line circuits where the signal may be greatly attenuated by use of an unblocking type of receiver logic. This option provides a momentary permissive trip output upon receiving a loss of receive signal level from the level detector. Additional security for the audio tone receiver system is provided by a squelch which blocks the receiver output for high-level noise impulses. Asymmetrical AGC attack and release times also provide an optimum balance between reliability and security on PLC circuits.

Teleprotection applications of audio tone equipment include the following:

1. Direct transfer trip for equipment protection
   - Transformer and shunt reactor differential protection
   - Breaker failure protection
2. Line protection
   - Direct underreach
   - Permissive underreach
   - Permissive overreach
   - Unblocking
   - Combined unblocking and direct transfer trip
   - Phase comparison relaying
   - Directional comparison blocking

Comments pertaining to these teleprotection applications were covered in Section 4 for PLC FSK channels. The tone channels can be arranged for either single or dual-channel operation, similar to the arrangements described for PLC FSK channels. In dual-channel operation, both receivers must receive the proper signals before tripping can occur; therefore, channel security is increased. The outputs can be paralleled if redundancy is desired.

The basic security of the FSK tone receiver is derived from the received GUARD signal. The receiver output circuits are arranged so that only the combined action of a dropped-out GUARD output and a picked-up TRIP output constitutes reception of a valid transfer trip signal to trip the connected breaker. Receiver output modules are available with either SCR, transistor, relay or voltage output to meet specific application requirements.

The design of the audio tone receiver for teleprotection is unique in that the trade-offs have been balanced between security and dependability. Two basic protection systems are used: one system delays the receiver trip output when adverse line conditions exist, the second system squelches the receiver if loss of signal or an alien trip tone occurs. Extreme noise interference will also squelch the receiver.

In order to retain speed and security, switched delay protection is used. Wideband noise detection circuits protect against high energy impulse noise by delaying the receiver's response to a trip signal. This is accomplished by switched delay protection circuits and is particularly useful with high speed SCR and transistor trip output circuits.

Squelch protection is activated by several conditions: high interference, loss of signal, frequency translation of a pilot or an alien trip tone in the channel. Alien tone protection is provided by a circuit which can detect the simultaneous presence of both TRIP and GUARD signals. This status is recognized as abnormal and squelches the receiver.

When the optional logic circuit is provided, additional security features are provided such as: a requirement for guard before trip, trip window and automatic throwover to single-channel operation for use in dual-channel applications.

Figure 6-4 is a block diagram of the basic audio tone receiver. Frequency- translation protection is available as an option to protect the relaying system from false trips caused by frequency shift or shift in the associated carrier or microwave channel equipment.

It is accomplished in audio tone systems by the use of a pilot tone channel. The pilot tone transmitter is a plug-in option available at 595 or 2465 Hz. The pilot tone is transmitted continuously and is used in the remote squelch receiver to detect frequency shifts originating in the communication path. Should the pilot channel frequency be translated either up or down, a squelch action takes place.

Additional protection against frequency translation is provided in a dual-channel system by arranging one channel to trip on high-shift and the other to trip on low-shift. This feature is also helpful in protecting against alien tones introduced into the signal path. Dual-channel operation also permits testing of each tone channel while in service, without the danger of accidentally tripping the associated breakers. Single function audio tone transmitters and receivers are both programmable. The transmitter is programmable for all 30 channels, while the receiver is programmable for any channel within its frequency spacing.

Table 6-1 shows the performance characteristics of audio tone channels. The SNR data shown is for 340 Hz spacing.

RECEIVER LOGIC

Audio tone equipment has several types of receiver logic available:

D: Guard reset before trip output
P: Signal reset before trip output
U: Loss of signal allows trip output
T: Combination of U and P logic
C: For phase-comparison applications when applied to SSB-PLC systems

U and T logic are normally used on SSB channels only for line relaying applications. D and P logic are used on all types of communication channels. The function and operation of the logic modules are the same as described for medium and wide bandwidth PLC FSK channels, except that the audio tone logic does not have a "spike input" and the "LOS input" is similar to the "minimum level" input (see Section 4). D logic should only be used for direct trip schemes which require the ultimate in security. When this option is used, the remote transmitter should be equipped with the TRIP-GUARD flasher strapping feature for improved dependability. By selecting the trip-guard flasher with D logic, the transmitter output is alternately switched between trip and guard at a 50 ms rate. The D logic requires that the input return to guard for a minimum of 50 ms after a loss of trip before the logic output can go to trip. To prevent the associated GUARD and TRIP relays from following the "flash" rate, TRIP HOLD strapping should be employed. The TRIP HOLD timer "holds" the TRIP relay in the energized position during the flash rate. When the TRIP keying is returned to the GUARD state, the TRIP HOLD circuit is released within 80 ms of the last TRIP initiation. The trip-guard flasher option provides improved dependability with the D logic. A trip window option is available for added security. Guidelines for use of the logic are provided in Table 6-2.

TYPICAL CONFIGURATIONS AND EQUIPMENT

Transfer tripping is the sending of a tripping signal to a remote location over a teleprotection channel such as provided by the audio tone equipment. The tone equipment serves to transmit the information from one point to another in response to the command of a separate, fault-detecting device. In the absence of fault conditions, the GUARD tone is transmitted continuously. At the receiver, reception of the GUARD tone produces blocking of the breaker trip circuit. At the same time, the GUARD signal also provides continuous monitoring of the tone channel. When a fault occurs, the GUARD tone is removed and the TRIP tone is received, causing the GUARD output to drop out and the TRIP output to operate. In electromechanical schemes, a normally-closed GUARD output is connected in series with a normally-open TRIP output to provide a highly secure trip circuit.

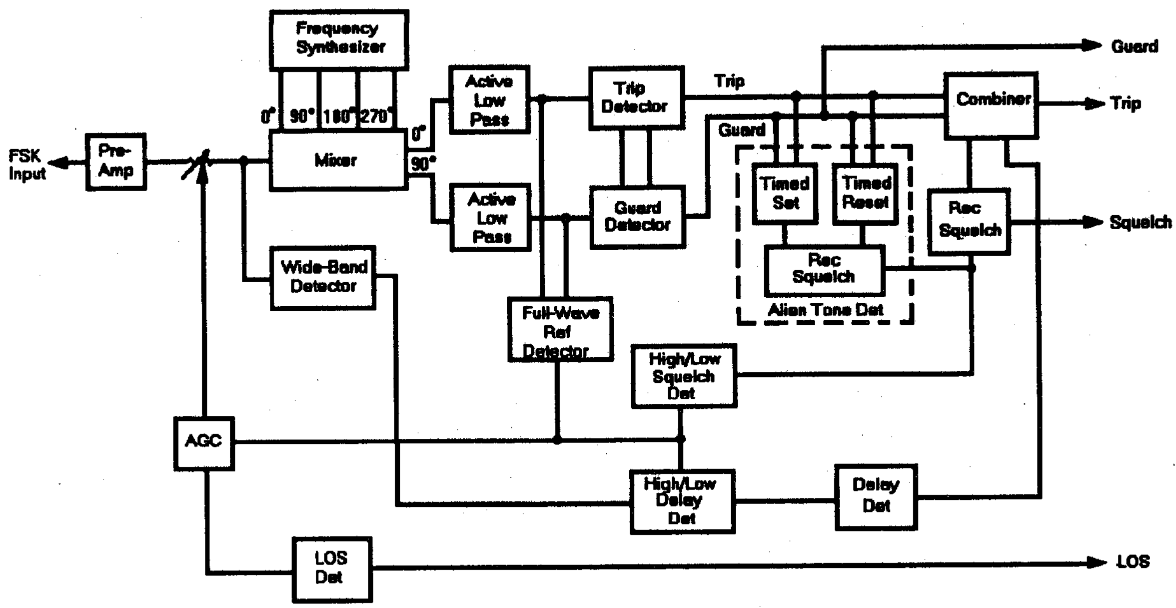


Figure 6-4. Audio Tone Receiver Functional Block Diagram

6

Table 6-1

Performance Characteristics of Single Function Audio Channels

Characteristics	Configuration		
	Single Channel	Dual Channel	Dual Channel With Pilot Protection
Trip-Thru Noise Typical SNR (Note 1)	0 dB	0 dB	+2 dB
Protected from Noise?	Yes	Yes	Yes
Protected from Frequency Translation?	No, unless pilot is used	Yes (Note 3)	Yes
Protected from Alien tones?	Yes	Yes	Yes
Capable of Secure In-Service Testing? (Note 2)	No	Yes	Yes

NOTES: 1. SNR data shown is for 340-Hz spacing, with pulsed noise impressed prior to trip.
2. With TRIP circuits of one channel in service.
3. With TRIP and GUARD inverted for each channel.

Table 6-2

Channel-Selection Guidelines for Audio Tone Teleprotection Channels

AVAILABLE audio tone CHANNELS			LINE FAULT PROTECTION	EQUIPMENT PROTECTION	COMBINED LINE & EQUIP. PROTECTION
Freq. Spacing Hz	Channel Speed	Freq. Shift Hz	POTT,PUTT,DUTT, Blocking & Unblocking Schemes, Phase Comparison with High-Speed (1000-Hz) CH only	Direct Transfer Trip (DTT) for Transformer. Reactor or other Direct Trip Functions	Unblocking Line Fault Protection. Combined with other DTT Functions
170	17 ms (Relay Output) 14 ms (Electronic Output)	±42.5	Dual Channel Recommended for Direct Trip Schemes single channel for permissive schemes. Opt. Aux. Logic Type (See Note 1). Type P Logic - Recommended for all POTT, PUTT & BUTT schemes. Type U Logic - Required for unblocking. Transistor Output avail. (for blocking schemes). Channel time (14-21 ms) usually considered rather slow for line protection. Exalt Function is available (See Note 2).	Dual Channel recommended for Direct Trip Schemes Type P Logic is recommended for all DDT schemes. Type D Logic available (See Note 3). SCR or Transistor outputs available. 170 Hz spacing recommended for all DTT Applications when 14-21 millisecond ch. time is adequate. Exalt Function is available (See Note 2).	Dual Channel Configuration is required with Type T Logic for all combined schemes. This logic provides two outputs (U & P). Bandwidth savings is 33% compared to dedicated channel approach. (A dual ch. scheme does the work of three channels). Exalt Function is available (See Note 2).
240	13 ms (Relay Output) 10 ms (Electronic Output)	±60	Basic Recommendations same as for 170-Hz Spacing. (Channel Choice depends on speed req'd vs Bandwidth available.) Channel Time 10-16 ms is usually considered adequate for most electro-mech. schemes.	Basic Recommendations same as for 170-Hz Spacing. (Ch. choice depends on speed required vs bandwidth available). Channel Time (10-16 ms) is usually considered adequate for most electro-mech. schemes.	Basic Recommendations same as for 170-Hz Spacing. (Ch. choice depends on speed required vs bandwidth available). Channel Time (10-16 ms) is usually considered adequate for most electro-mech. schemes.
340	10 ms (Relay Output) 7 ms (Electronic Output)	±85	Basic Recommendations same as for 170-Hz Spacing. This channel time (7-12 ms) is usually considered adequate for most Line Fault Protection schemes, including electronic relaying.	Basic Recommendations same as for 170-Hz Spacing. Recommended when high speed (7-12 ms) Direct Trip Function is required.	Basic Recommendations same as for 170-Hz Spacing. Recommended when high speed (7-12 ms) DTT is required (combined with electronic unblocking line protection).
1000	7 ms (Relay Output)	±240	Basic Recommendations same as for 170-Hz Spacing. To conserve bandwidth, highest speed channel is not recommended unless fastest possible speed is required.	Basic Recommendations same as for 170-Hz Spacing. To conserve bandwidth, highest speed channel is not recommended unless fastest possible direct trip is required.	Basic Recommendations same as for 170-Hz Spacing. To conserve bandwidth, highest speed channel is not recommended unless fastest possible channel speed is required.
	4 ms (Electronic Output)		Phase Comparison requires Hi-speed Tone Channel for each phase comparing function. Dual phase comparison (both 1/2 cycles 60 ms) requires two tone channels (See Note 4). Type C Logic is req'd for Power Line Carrier SSB Systems. No-logic option is satisfactory for microwave & wire-line systems. Transmitter exalt function is not recommended for Phase Comparison.	Phase comparison does not apply to equip. protection.	A separate high speed tone channel is recommended for phase comparison.

NOTES: (Continuation of Table 6-2)

1. Optional Auxiliary Logic provides alarm combining plus added security after 300 milliseconds of bad channel status.
   Basic Channel Security Logic is always included as a standard part of the single function receiver module.
2. Transmitter keying option boosts transmitter output (by jumper selection). External exalt control is also available for exalt by external dry contacts.
3. When Type D Logic option is utilized, automatic alternate TRIP-GUARD transmitter keying (flasher ckt.) is available by jumper selection.
4. Phase Comparison requires a special type receiver.

LEGEND

POTT - Permissive Overreach transfer trip
PUTT - Permissive underreach transfer trip
DUTT - Direct underreach transfer trip
DTT - Direct transfer trip

Typical applications for transformer protection and line relaying are shown in the block diagrams of Figure 6-5, 6-6 and 6-7. As previously noted in Table 6-1, several security measures are available to protect against noise, transients, alien tones and frequency translation.

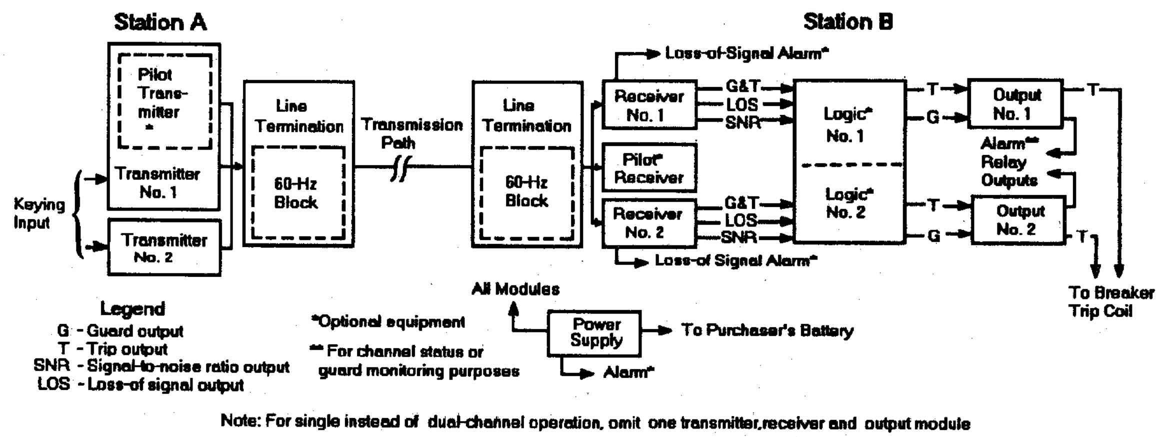


Figure 6-5. Typical Dual One-Way Terminals for Transformer Protection

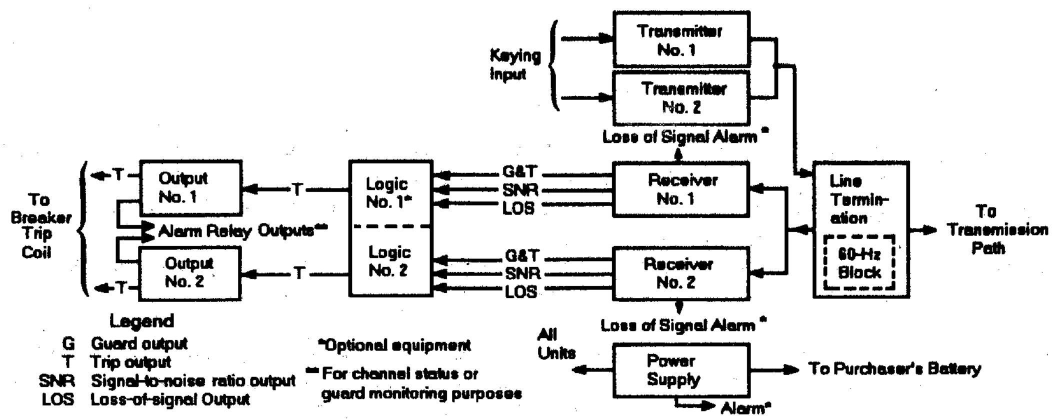


Figure 6-6. Typical Dual Bi-Directional Terminal for Line Relaying

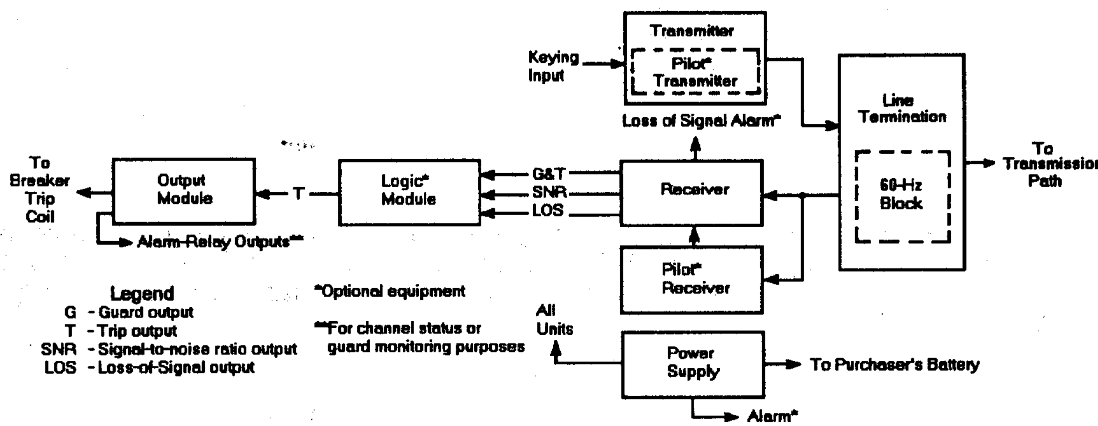


Figure 6-7. Typical Single-Channel Two-Way Terminal for Line Relaying

Table 6-3

Available Audio Tone Channel Frequencies
(other frequencies from 1200-3485 Hz available as specials)

170-Hz Spacing		240-Hz Spacing		340-Hz Spacing		1000-Hz Spacing
1445 Hz*	2465 Hz#	1200 Hz*	2400 Hz#	1190 Hz*	2550 Hz#	1530 Hz*
1615 Hz*	2635 Hz#	1440 Hz*	2640 Hz#	1530 Hz*	2890 Hz	2550 Hz*
#1785Hz*	2805 Hz	1680 Hz*	2880 Hz	1870 Hz*	3230 Hz	
1955 Hz*	2975 Hz	1920 Hz*	3120 Hz	2210 Hz*#		
2125 Hz*	3145 Hz	2160 Hz*#				
2295 Hz*#	3315 Hz					

* Not usable above voice with 2000-Hz speech-plus operation.
\# Not usable with 2465-Hz pilot. 595-Hz pilot available.

FREQUENCY CONSIDERATIONS AND CHANNEL SPEED

The available audio tone channel frequencies are listed in Table 6-3. For frequency-translation protection, a 595 Hz or 2465 Hz pilot option is available. The channel speeds indicated in Tables 2-5 and 2-6 (Section 2) are the times from closure of the transmitter keying-relay to closure of the receiver output trip contacts or firing of the receiver output SCR trip circuit in a noise-free environment. Two milliseconds should be added if the tone is to be used over SSB, microwave circuits or leased circuits using carrier channels.

OPTIONS AND ACCESSORIES

The following options and accessories are available for audio tone systems:

1. Opposite-shift frequencies on dual channels (field strappable)
2. Frequency-translation protection (pilot transmitter)
3. Logic
4. Line terminations (including fiber optic terminations)
5. Trip exalt
6. Voice-block
7. Transmitter output filter
8. Auxiliary relays and test panels
9. Cabinets and racks

For dual channels, one channel is normally supplied with "high-shift guard" and the other with "low-shift guard" to give added protection against interference caused by a sweeping signal. An added pilot tone for frequency-translation protection is available for single-channel applications where there is a possibility of a frequency shift or drift in associated multiplex equipment. The added pilot tone is also available in dual channel applications where automatic throw-over to single-channel operation is employed. It should be noted that leased telephone lines and microwave are of the derived type and include multiplexing equipment. The 2465 Hz pilot must be used on a speech-plus channel, where the voice operates in the 300-2000 Hz band.

Use of the logic module is a function of the type of relaying scheme being applied, as discussed earlier.

Line termination units are available for two-wire and four-wire applications. Four-wire terminations are essential if SSB, microwave or derived telephone circuits are used. Whenever frequency-translation protection is used, a four-wire circuit and line termination unit are required. For uni-directional applications which may be converted to bi-directional use in the future, a bi-directional line termination should be used. The two-wire line termination modules are field-convertible to the four-wire mode; conversely, the four-wire version is field-convertible to the two-wire mode. If the tone system is to be applied over fiber optic cables, the termination module is omitted and a fiber optic cable modem is located in the termination's location.

The trip exalt option boosts the trip signal level (strappable +6 or +10 dB). When applying the trip exalt feature over GE SSB channels, the voice-block option should be specified. This option for the audio tone shelf is used in conjunction with the exalt jumper strapping on the individual transmitter modules.

The isolated voice-block option is selected if the tone system is to be applied over GE SSB power line carrier and the trip exalt is desired. When the tone transmitter is keyed to trip, a voltage output blocks selected voice channels so that more power is allocated to the trip signal (exalt). The voice-block option is applied in conjunction with the tone transmitter trip signal feature.

Auxiliary relay modules provide four mercury-wetted relays with separate inputs and outputs. Their inputs will accept either + or logic (strappable) and their output contacts can be strapped either form A or form B. If desired, two relays can be dedicated to the receiver squelch alarm function.

For in-service testing, manual test modules or external panels are available for single, dual, uni and bi-directional tone systems. The external panels also can be equipped with auxiliary relays and counters as dictated by the application.

Cabinets and racks are also available to house the AUDIO TONE shelves.

PRINCIPLES OF OPERATION

Each audio tone terminal is assembled in a welded steel shelf which occupies three rack units (5.2 inches or 132 mm) in a standard EIA 19-inch cabinet or rack. The selection and number of modules used in a particular terminal depends on the application and unction of that terminal. A basic terminal consists of a power supply, transmitter, line termination module, receiver and output module.

Optionally, the following may be required:

1. Logic module
2. Pilot transmitter subassembly
3. Pilot receiver module
4. Auxiliary relay module Squelch Alarm)
5. Meter module
6. Loop test module
7. Fiber optic cable modem (in place of line termination)

This equipment operates in the audio frequency range from 595 to 3315 Hz. Channel spacings of 170, 240, 340 and 1000 Hz are available with a total of 30 channel possibilities. Each channel is frequency modulated to produce a trip or guard in the receiver. The frequency shift is 85, 120, 170 or 480 Hz. The equipment is designed for a two-wire or four-wire interface with SSB-PLC, leased lines, wire lines, microwave, or fiber optic cables.

A Brief description of the various modules follow.

POWER SUPPLY

The power supply operates from station battery (24, 48, 125, or 250 volt) and converts this to a regulated ±12 Vdc to power the entire tone shelf. An isolated dc chopper type supply, the output is rectified and filtered to provide ±12 Vdc at 400 mA. Battery surge, transient and overload protection are provided by three protective-feedback circuits. An optional low-voltage alarm relay is available which indicates reduced output voltage or loss of voltage.

TRANSMITTER

Using a dual programmable frequency synthesizer with associated output circuits, the transmitter contains optional keying, filtering and pilot circuits. The synthesizer is programmable for four shift frequencies (±42.5, 60. 85 and 240 Hz) and any of the 30 channels by means of jumper plugs on the transmitter board. Crystal stability is derived from a 3.579 MHz crystal-oscillator source.

1. Exalt: boosts the transmitter output to 0, +6 or +10 dB as it is keyed from GUARD to trip
2. GUARD exalt
3. External timed exalt
4. Voice blocking
5. Modulation reversal
6. Modulation flasher (alternate between trip and guard)
7. Trip hold

6

Battery voltage keying of the transmitter is achieved by a light beam which provides complete dc isolation between the keying source (station battery) and the transmitter. This is accomplished by using a light emitting diode, operating in the infrared region, as a light source and a photo-transistor as the detector. This highly secure keying prevents false keying due to surges or transients which may be present on the keying leads. Keying inputs are available as shown in Table 6-4. The transmitter may or may not have an exalt function. The exalt option provides a trip exalt of 0, 6 and 10 dB (strappable).

Two plug-in options are available with the main transmitter board: a 595 Hz or 2465 Hz pilot oscillator and a filter for modulation sideband suppression. This filter is seldom required and should be specified only if distortion of less than 1% is required.

PILOT

A pilot tone is used for frequency-translation protection. Using the normal tone transmitter frequency synthesizer, a 595 Hz or 2465 Hz pilot is developed, with 2465 Hz pilot is developed, with 2465 Hz being the normal application. The pilot tone detects frequency shifts originating in the communication path. The pilot receiver consists of a bandpass filter centered about the pilot frequency with a narrowband reject filter centered on the pilot. If translation occurs or if the pilot is lost, the receiver is squelched.

Table 6-4

Audio Tone Keying Options

Type	Comments
Isolated keying from station battery	10 ma at 48, 110, 125, 220 VDC
Keying from associated Electronic Relays (MOD-III)	20 mA at 5 VDC
Exalt Keying	0 dB, +6 dB and 10 dB (Strappable)

LINE TERMINATION

The line-termination module provides an isolated interface between the unbalanced output of the transmitter(s) or unbalanced input of the receiver(s) and the balanced transmission path. The composite transmit level is adjusted by a multi-turn, front-mounted, variable resistor. Transmitter output level of up to +8 dBm is available at the line termination transmit output. The receive circuits of the line termination include a lowpass filter that has a narrowband or wideband option to eliminate frequencies above the tone channels. Two-wire or four-wire operation of the line termination is plug-selectable.

RECEIVER

The tone receiver module (Figure 6-4) contains a heterodyne receiver, a phase detection circuit and precision rectifier circuits. No limiters or discriminators are used. The maximum receiver sensitivity is -40 dBm. A crystal controlled, programmable frequency synthesizer is used to provide the injection signal for a zero-IF mixer. Four synthesizer outputs are combined into two signals whose primary frequency is that of the shift frequency and whose phase difference is 90 degrees. By using phase shifters and combining circuits, this phase change is recognized as a GUARD or TRIP signal. As a result, both GUARD and TRIP signals can be received at the same time, permitting the detection of alien tones.

Two types of inband protection circuits are used in the receiver: one introduces delay to the channel and the other squelches the receiver. On channels that are not noisy, the channel speed is as published (Table 6-2), but as noise increases to where a false trip is possible, the channel is delayed to twice channel speed making a longer trip necessary. Finally, in very high noise, the receiver is turned off (squelched). A loss of signal alarm relay is included.

In addition to inband protection, a wideband (1000 to 3400 Hz) detector is used. This detector recognizes short, high-energy impulses on the transmission path and delays the receiver response.

Receiver options include:

1. Alien tone detection*
2. Fixed delay*
3. Wideband noise detection*

4. LOS squelch*

* Field strappable.

For phase comparison relaying applications using the 1000 Hz channel, the delay and alien tone protection are omitted, as simultaneous detection of guard and trip is not required for this application.

OUTPUT MODULES

Receiver output modules for four basic types are available: relay, SCR, transistor and 5 V at 20 mA for static relays. Their characteristics are described in Table 6-5.

LOGIC

Logic modules are available with the receiver for increased security and dependability. Two modules are available: D/P logic and U/T/C logic; each module has dual channel logic. The D/P logic contains:

1. D logic (for direct trip)
2. P logic (for permissive trip)
3. Coordination timer
4. Trip-hold timer
5. Trip window
6. Dual-to single-channel throwover

Using four receiver outputs LOS, squelch, guard and trip the logic module either allows or inhibits TRIP output.

Two options are subassemblies on the D/P logic module: automatic throw-over and trip-window. The throw-over option monitors the status of a two-channel application and provides single-channel operation in the event one channel goes bad. At the same time it delays the good channel by 10 ms. The trip-window option monitors the trip outputs of a dual-channel application and blocks both trip outputs if the trip inputs are not received within 25 ms of each other.

The U/T/C logic module is a permissive, dual-channel logic system which provides:

1. U logic (permissive, loss of signal allows trip)
2. T logic (combination of P and U logic)
3. C logic (for phase comparison)
4. Coordination timer
5. Trip-hold timer

The logic module monitors the same four receiver outputs as the D/P logic. With either the D/P or U/T/C logic module, trip output is allowed only when the input data indicates that the channel is capable of making the correct decision.

Table 6-5

Available Audio Tone Outputs

Type	Output Rating	Relay Contacts
Relay (Heavy Duty)	30 A for 100 ms at 10-second intervals. Max voltage 300 volts dc.	Guard: 1 form B & 1 form C Trip: 1 form A & 1 form C (All Contacts heavy duty)
Relay (High Speed)	10VA Max voltage 350 VDC second intervals. Max voltage 280 volts dc.	Guard & status: 1 form B & 1 form C. Trip 1 form C
SCR	30 A for 100 ms at 10-second intervals. Max voltage 300 volts dc.	Guard or channel status alarm: 1 form C, 100VA Trip alarm: 1 form A or B, 100VA
Transistor	30 A for 100 ms at 10-second intervals. Max voltage 300 volts dc.	Guard alarm: 1 form C (100 VA) Trip alarm : 1 form A or B (100 VA)
Electronic (5 volt)	5 volts dc at 20 mA. (non-isolated)	Trip Alarm, 1 form A or B, 100VA Chan status alarm, 1 form C,100VA (standard, but only in systems with logic)

SECTION 7
MULTI-FUNCTION AUDIO TELEPROTECTION CHANNELS

Contents of Section 7

SYSTEM APPLICATION

The multi-function (multiple command) teleprotection system provides a highly reliable, versatile and dependable communication terminal for the transmission of line or equipment protection control signals [11, 16]. Both permissive trip and direct trip relay channel functions can be provided in dedicated or shared channel applications.

7

The multi-function audio tone offers a cost-effective alternative to the single function audio teleprotection channel, particularly in power line carrier applications employing single-sideband carrier channels. The multi-function audio tone will operate over any four-wire circuit. It provides a secure, dependable, high-speed channel with the ability to operate in a high noise environment. It is suitable for operation over many transmission mediums, including single-sideband PLC,voice grade circuits, fiber optic cables, and microwave.

Two independent relay functions can be performed over a single terminal by utilizing four tones. These functions are completely independent and only one of the four possible tones (Guard, Trip 1, Trip 2, or Trip 1 and 2) is used at any one time. This permits utilizing the full power of the transmission medium, thus improving the signal-to-noise ratio.

Application features of the multi-function audio tone include the following:

- Multiple operating modes
- High security against noise
- Good dependability in the presence of noise
- Medium channel speed
- Continuous testing of modules and total system checkback
- Ease of installation and maintenance
- Sending and receiving trip counters

Several operating modes are available with the multi-function audio tone. The multi-function audio tone teleprotection equipment utilizes the basic frequency-shift (FSK) transmitter but has four separate AM receivers which provide two output functions from a single terminal. Four frequency operation (guard plus three trip frequencies) enables two output functions independent of each other, as well as simultaneously with each other.

The multi-function audio tone is designed to fit within the spectrum of a 2.5 or 4 kHz voice channel, with several operating modes as shown in Table 7-1.

Table 7-1

Multi-function Audio Tone Operating Modes

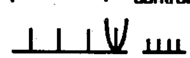
Channel Mode of Operation	Audio Channel Spectrum	Functions and Features
Wideband "Single Purpose" Dedicated channel application of teleprotection equipment to a selected channel on a single sideband PLC system. Multi-channel terminals could of course, have other independent functions (such as voice) on other channels of the same system.	Teleprotection  T1/T2 T2 T1 G	• Permissive or direct trip • Operate time "18 ms back-to-back 12 ms with PLC channel • No voice or telecontrol capability • Optional exalt (tone boost) • 4 kHz or 2.5 kHz bandwidth
Wideband "Multi-Purpose" Here the channel is used for the simultaneous transmission of telecontrol signals in channel space above the teleprotection frequencies.	Teleprotection  Tele-control	• Permissive or direct trip • Operate time "18 ms back-to-back 12 ms with PLC channel • No interruption of telecontrol or other channels of multi-channel terminal during multi-funtion tone operation. • No optional exalt • 4 kHz bandwidth
Wideband "Alternate Purpose" Both voice and telecontrol signals share this channel with the teleprotection equipment. However, the voice and telecontrol signals are blocked during transmission of any trip signal.	Teleprotection  ← Voice → Tele-control	• Permissive • Operate time "15 ms back-to-back 17 ms with PLC channel • Voice and telecontrol may be interrupted (blocked) during multi-function tone operation. No interruption of other channels on multi-channel terminal. • Optional exalt (tone boost) • Guard can serve as telecontrol signal • 4 kHz bandwidth
Narrowband "Single Purpose" The channel is used for three independent narrowband multifunction systems. No voice or telecontrol is applicable to this channel.	Teleprotection 	• Permissive or direct trip • Operate time "15 ms back-to-back 17 ms with PLC channel • No voice or telecontrol capability • Optional exalt (tone boost) • 4 kHz bandwidth

Figure 7-1 shows the basic multi-function audio tone applications, namely:

- Single purpose
- Multi-purpose
- Alternate purpose

In the wideband "single purpose" system, the voice channel is dedicated to the application of the multi-function audio tone teleprotection equipment. Multi-channel terminals could have other independent functions (such as voice) on other channels of the same system. This may be used for direct trip or permissive line protection. On a back-to-back basis, the operating time of the wideband "single purpose" multi-function audio tone is 10 ms. On a PLC channel, the operating time is 12 ms. No voice or telecontrol capability is provided. The multi-function audio tone may be provided with an optional exalt (tone boost). A 4 kHz or 2.5 kHz bandwidth may be used.

In the wideband "multi-purpose" audio tone application (Figure 7-1), the channel is used for the simultaneous transmission of the telecontrol signals in the channel space above the teleprotection frequencies. A 4 kHz bandwidth is required. Direct trip or permissive teleprotection may be applied. Optional exalt of the multi-function audio tone is not applied. The operate time is 10 ms back-to-back and 12 ms with a PLC channel. There is no interruption of the telecontrol during the multi-function audio tone operation.

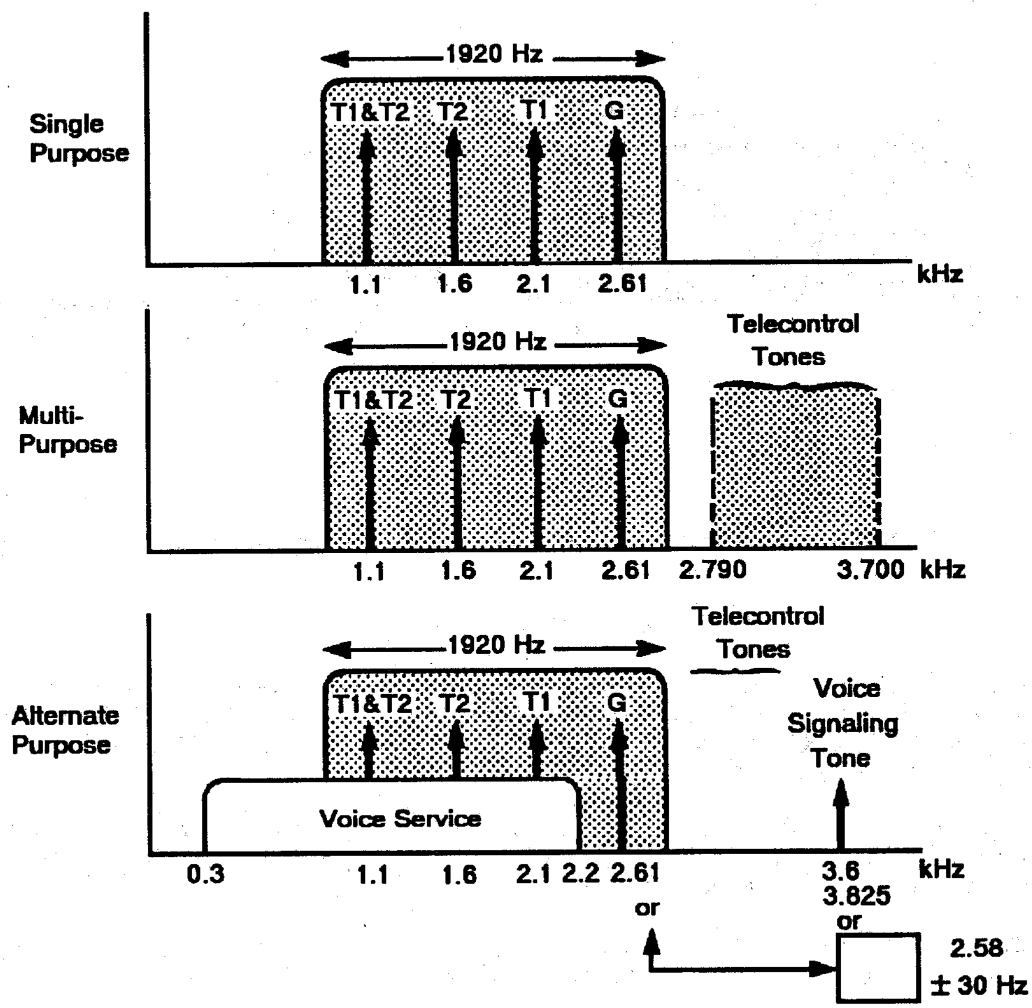


Figure 7-1. Multi-function Audio Tone Applications Wideband (1920 Hz) Models

In the wideband "alternate purpose" multi-function audio tone application (Figure 7-1), both voice and telecontrol signals share the channel with the teleprotection equipment. The voice and telecontrol signals are blocked during transmission of any trip signal. Blocking telecontrol signals requires the SSB "Tone Bus Option". This system is used for permissive teleprotection applications; the operate time is 15 ms back-to-back or 17 ms on a PLC SSB channel. The guard signal may be used for signaling purposes.

In the narrowband "single purpose" multi-function audio tone application (Figure 7-2), the channel is used for up to three independent narrowband multi-function audio tone systems. No voice or telecontrol is applicable to this channel. Each independent teleprotection system may be used for direct trip or permissive trip applications. The operating times are 15 ms back-to-back or 17 ms with a PLC SSB channel. A 4 kHz bandwidth is required.

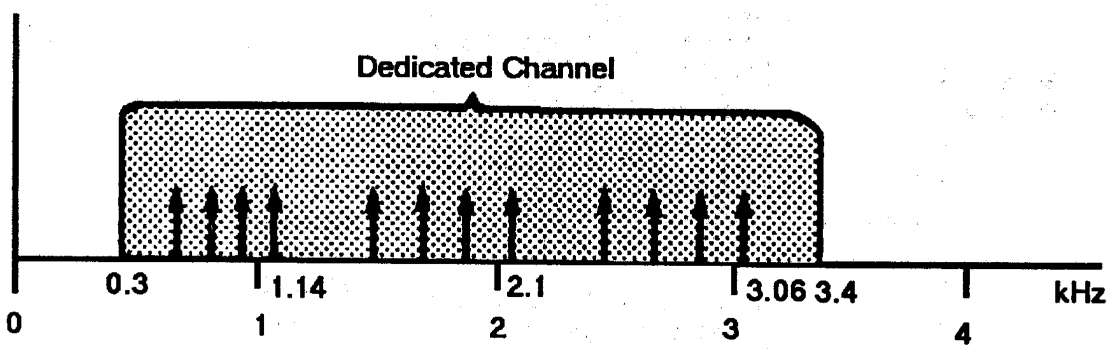


Figure 7-2. Narrowband - Single Purpose - (Three Systems)

RECEIVER LOGIC

The multi-function audio tone receiver may be strapped so that GUARD has to be present just prior to reception of the TRIP command. A TRIP window of 20 milliseconds activated on loss of GUARD will block any TRIP attempt not received within this time. This provides high security operation.

The multi-function audio tone receiver may also be strapped so that GUARD is not required just prior to a valid TRIP command, for example, after noise squelch or loss of signal. For this alternate, the system provides high dependability.

In some applications, an unblocking type output may be required upon loss of signal. An additional logic module will be provided on trip with the multi-function audio tone for this output.

Table 7-2

Multi-function Audio Tone Summary of Applications

	Purpose			
	Wideband			Narrowband
Feature	Single	Multi-	Alternate	Single
Permissive Trip	X	X	X	X
Direct Trip	X	X		X
Voice (interruptible)			X	
No Voice	X	X		X
Tones (interruptible)			X	
No Tones*	X			X
10 ms Channel	X	X		
15 ms Channel			X	X

*No telecontrol tones above multi-function audio tone tones.

In any application of the multi-function audio tone, the presence of more than one tone causes the logic to block TRIP output.

An additional measure of security with the multi-function audio tone is provided by the TRIP output relay driver design. Two transistors have to be turned on simultaneously to energize the relay. Loss-of-GUARD turns on one transistor and receipt-of-TRIP turns on the second transistor. If only one transistor is turned on, no current can flow through the relay coil. If one transistor fails, the system is automatically alarmed via the automatic test function. If this condition occurs, the automatic test sequencing is aborted.

TYPICAL CONFIGURATIONS AND EQUIPMENT

Figures 7-3 and 7-4 illustrate a typical one-way and two-way teleprotection system, respectively. The multi-function audio tone equipment transmits the information from one location to another in response to the keying inputs TRIP 1, TRIP 2 or TRIP 1 and 2 from separate fault detecting relays. In the absence of fault or tripping conditions, the GUARD tone is transmitted continuously. At the receiver, the reception of GUARD blocks tripping. The GUARD signal also provides continuous monitoring of the tone system. When tripping is required, the GUARD tone is removed and depending on whether TRIP 1, TRIP 2, or TRIP 1 and 2 are keyed, TRIP 1, TRIP 2, or TRIP 1 and 2 are produced by the receiver output to provide three independent output functions. A trip output requires the loss of GUARD and the presence of only one of the three possible TRIP commands, namely, TRIP 1, TRIP 2 or TRIP 1 and 2.

FREQUENCY CONSIDERATIONS AND CHANNEL SPEED

Table 7-3 shows the standard tone frequencies available for the various operating modes of the multi-function audio tone equipment. The multi-function audio tone is also available for direct-to-line frequencies. Here the frequencies are programmed to be contained entirely within a 2.5 kHz bandwidth. The multi-function audio tone outputs are then passed through a high-frequency adaptor which in turn, applies the relay signals to the power line. In this application, the adaptor power output is provided with the normal option of power output offered in other General Electric relay channels.

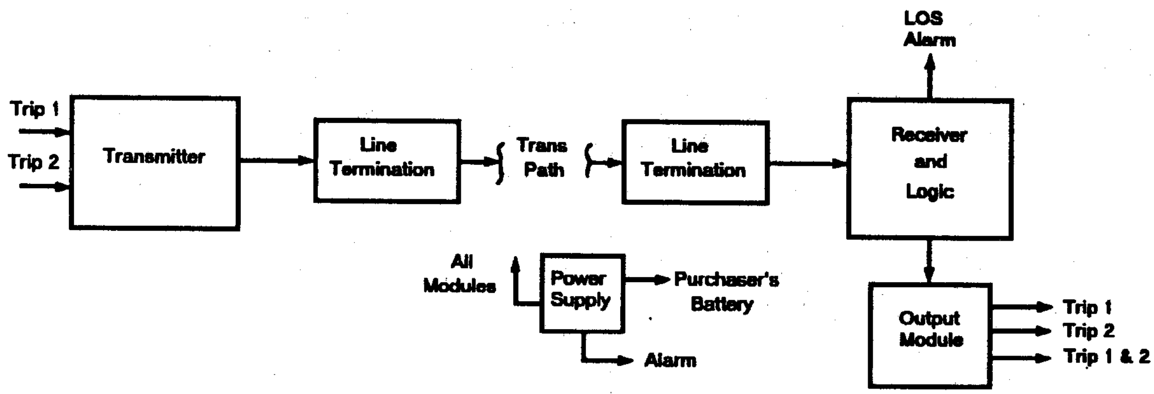


Figure 7-3. Typical One-Way Teleprotection System

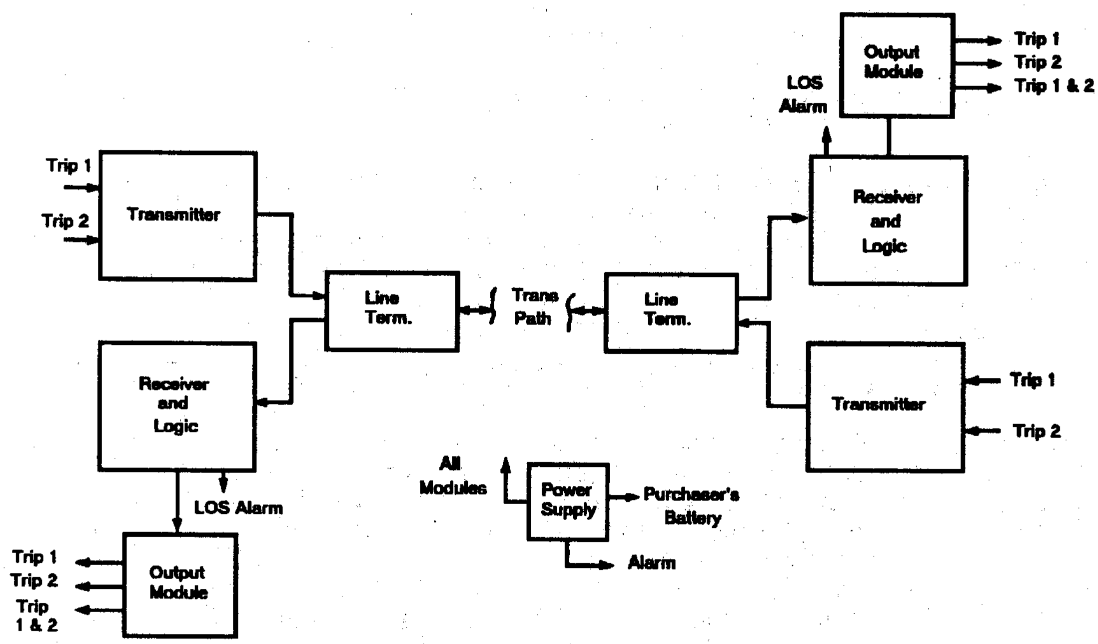


Figure 7-4. Typical Two-Way Teleprotection System

Table 7-3

Multi-function Audio Tone Standard Frequencies

Output	Wideband	Narrowband Ch. 1	Narrowband Ch. 2	Narrowband Ch. 3	Direct to Line
Guard	2610 Hz	1140 Hz	2100 Hz	3060 Hz	2100 Hz
Trip 1	2100 Hz	940 Hz	1900 Hz	2860 Hz	1600 Hz
Trip 2	1600 Hz	740 Hz	1700 Hz	2660 Hz	1100 Hz
Trip 1 and 2	1100 Hz	540 Hz	1500 Hz	2460 Hz	600 Hz

The channel speeds for the multi-function audio tone are shown in Table 7-4.

Table 7-4

Multi-function Audio Tone Channel Speeds (milliseconds)*

	Wideband			Narrowband
	Single Purpose	Multi-Purpose	Alternate Purpose	Single Purpose
Back-to-back	10	10	10	15
With PLC Channel	12	12	17	17

*Add 4 ms if 30 A relay contacts are used.

OPTIONS AND ACCESSORIES

The multi-function audio tone is available with the following options:

- Trip Counters and Testing Circuits
- Heavy Duty Trip Relays (30A)

The multi-function audio tone system status is monitored and visually reported. Provision is included for:

- Local Loop Test (automatic)
- Remote Loop-Back Test (automatic or manual)
- Alarms

Malfunction or removal of any module in the system, including the power supply, is reported by an alarm relay.

In a bi-directional system (both transmitter and receiver in the same shelf and of the same frequency), a test can be performed to check all active circuits with the exception of the trip output relays. The test module consists of a clock circuit, a sequencer, a logic and evaluation circuit, and a relay to alarm an unsuccessful test sequence. The interval between automatic tests is selectable in steps from three to 24 hours. The transmitter is keyed to produce all trip frequencies sequentially. Should the test not be completed properly, the alarm module is activated to report the problem.

Automatic testing is interrupted for a desired trip function.

A remote loop-back test can be performed by test switches on the transmitter module or automatically by selecting the automatic test module option for checkback. When provided with the trip counter option, the manual test procedure is protected by a key lock that prevents testing by unauthorized personnel. The remote receiver, responding to the trip signal from the master end, keys its own transmitter and provides a loop-back to the master end. Since the remote and master terminals both receive valid trip signals, the trip output relays will operate. If the automatic checkback option is selected, the microprocessors disable the trip circuits while the test is in process.

Visual indication of normal operation is shown on the front of the shelf. Five alarm functions are provided:

- Loss of power
- Transmitter alarm
- Receiver alarm
- General Alarm
- Test alarm (if used)

Loss-of-power activates all alarms. Loss-of-signal in the receiver activates the general alarm and the receiver alarm. Removal of any module causes an alarm to indicate the system integrity has been violated.

For heavy duty requirements, the following optional outputs are available with a subsequent increase in channel time of 4 ms:

Trip 1 Output 2 form A (normally open)

Trip 2 Output 2 form A (normally open)

Contract Rating 30 A for 100 ms at 10 second intervals. Maximum voltage 280 Vdc.

PRINCIPLES OF OPERATION

The multi-function audio tone terminal block diagram is shown in Figure 7-5. The multi-function audio tone transmitter uses a crystal-controlled master oscillator of high stability for the derivation of the four discrete audio tone frequencies generated by the programmable synthesizer. Without any keying inputs, the GUARD signal is transmitted. Upon receiving a TRIP command, the GUARD frequency is switched off and the desired

TRIP signal is sent, provided the enable (start) is activated by an external contact of the relay system (or optionally strapped closed internally). A received TRIP output requires both the loss of GUARD and the presence of only one of the three possible TRIP commands: TRIP 1, TRIP 2, or TRIP 1 and 2.

Signals received from the remote terminal are separated by filters and passed through level detectors into logic circuits for the determination of a valid trip command. The logic circuit, in addition to signal evaluation, also contains timing circuits for TRIP DELAYS (for improved security) and TRIP HOLD timing (for improved dependability).

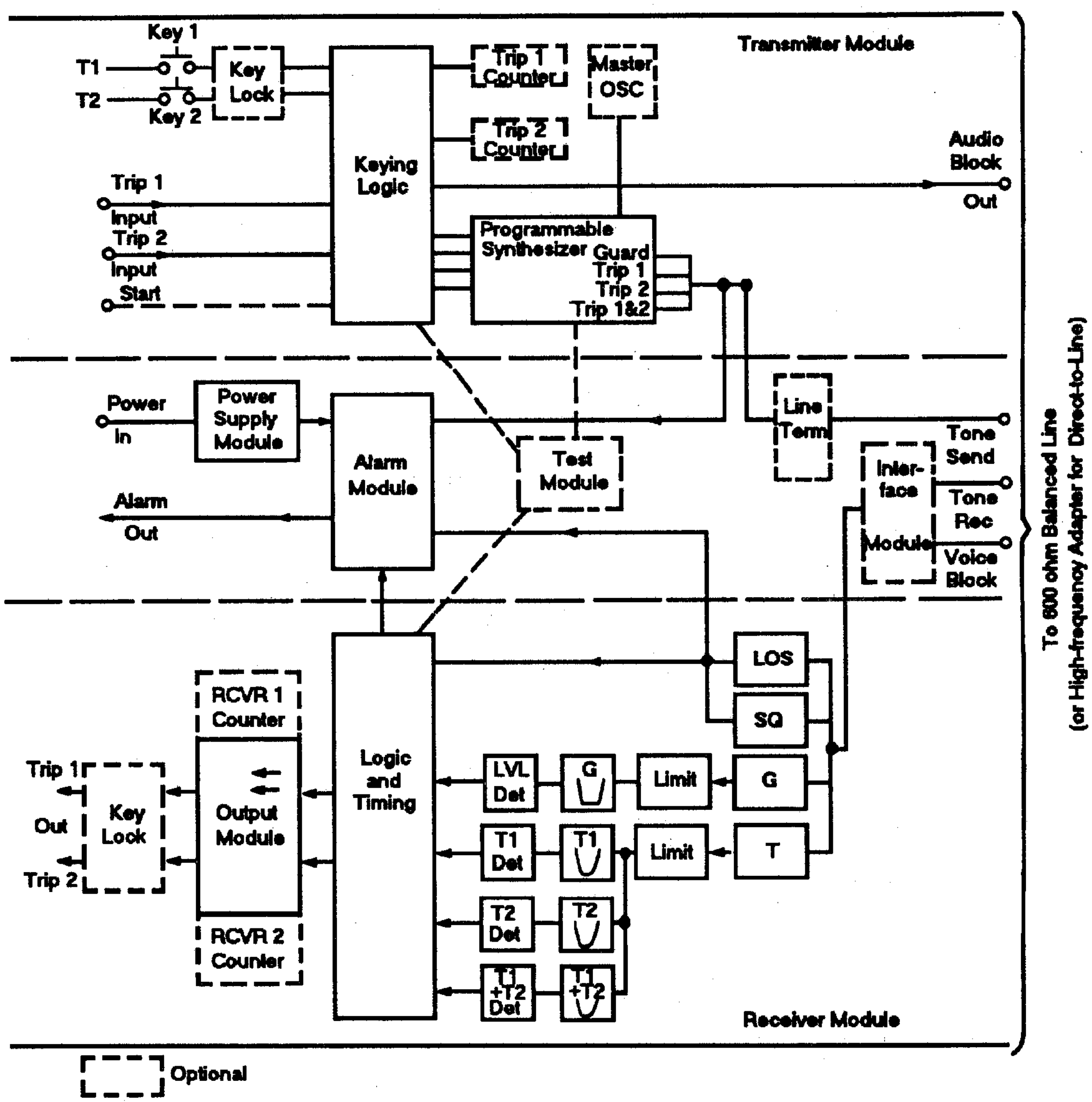


Figure 7-5. Multi-function Audio Tone Terminal - Block Diagram

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SECTION 8
FIBER OPTICS

Contents of Section 8

PILOT RELAYING CHANNELS

Pilot channels for protective relaying are commonly used for high voltage transmission line protection and for equipment direct transfer trip applications. A pilot relaying scheme is classified by the type of relaying channel used and the fault detection principle applied.

Up until recently, there were three basic types of pilot channels available, namely, wire lines and cables (leased or private), power line carrier, and microwave. Now the teleprotection services for an electric utility may also be provided with fiber optics [6, 17].

PLC is usually the most reliable type of channel, since the primary conductor signal path provides essentially 100% availability. Since it uses a pre-existing path not requiring signal repeaters, it is also the most economical type of channel for providing a small number of signals over a long distance. PLC has the disadvantages of a limited frequency spectrum and susceptibility to line noise and fault attenuation. However, its dependability and economic advantages make it the most widely used type of channel for protective relaying.

Microwave channels utilize high-frequency line-of-sight radio beams between remote stations. Microwave has the advantage of providing an independent path not affected by fault attenuation, and it will accommodate a large number of signals. Interim repeater sites are required where long distances or irregular terrain are involved. Although microwave signals can be subjected to occasional fade or frequency translation, they have adequate dependability and security for protective relaying.

Antenna towers and other expensive terminal equipment make high density microwave prohibitively expensive for system protection alone. Microwave is used when high channel density is required over the path because of voice circuit and other data requirements.

Wire line and cable have the obvious advantage of simplicity, since a direct metallic connection does not require complex high frequency coupling or terminal equipment. Hence, it is usually the most economical choice for short distances. Cables have the disadvantage, however, of being susceptible to hazards such as sleet, wind, and vandalism when routed overhead, and interference by ditching, construction, and underground flooding. A more serious limitation to wire and cable application is the effect of induced voltages during primary power system faults. As a result, wire line and cable use is usually limited to short distances and less critical applications. Another limitation is that leased circuits are becoming difficult to obtain for pilot relaying.

Since the advent of fiber optic technology, the utility industry has been interested in fiber optics for several reasons:

1. Immunity to EMI and ground potential rise;

2. Small size/weight cable (potentially low cost);
3. Relatively low-loss transmission;
4. Wide bandwidth capability.

Optical fibers are packaged with protective sheathing and strength members to form cables equivalent to conventional wire cables in their ability to withstand environmental effects and stresses during installation. Because of the enormous bandwidth and signal-handling capabilities of optical fibers, one fiber will do the job of many conventional wire twisted pairs, so that the size and weight of trunk lines can be reduced significantly.

Electrically, the fiber optic material is a dielectric. It is excellent for transmitting communications or teleprotection signals in applications which are subject to differences in potential (GPR). It is also immune to radio frequency interference (RFI) and electromagnetic radiation.

ELECTRIC POWER STATION ENVIRONMENT

Several factors must be considered when applying telecommunication facilities that enter an electric power station. Included are ground potential rise (GPR), longitudinal induction, lightning, switching surges, and contact with power lines. Control and protective relaying must perform correctly and dependably during power system faults; this represents the most stringent requirement in the design of a communication system.

The basic considerations associated with protective relaying communication services are:

1. Protection of personnel and minimizing electrical hazards;
2. Protection of terminal communication equipment and cable facilities against electric damage;
3. Protection of the communications integrity, i.e., provide the defined service reliably and correctly without false operations.

Ground potential rise (GPR) is the phenomenon that takes place when a fault-to-ground occurs on a transmission line terminated in a grounded neutral transformer bank at a power station or substation. It is the product of the power station ground grid impedance and that portion of the fault current that flows through it. The GPR zone defines the area surrounding the power station where the voltage changes from remote ground to substation ground mat voltage.

Induction from adjacent power circuits to the communication circuit is of concern with fundamental frequency power system currents and voltages. Longitudinal (magnetic) and electrostatic induction are of concern. Under balanced three-phase conditions, the fundamental frequency power currents in each of the three-phase conductors are balanced and there is no induced flow of power current in the ground or the other phases. However, in a paralleling wire-line communication circuit, the magnetic field from the current in the power conductors will induce a longitudinal voltage in the communication conductors proportional to the exposure. Under fault conditions, the induced voltage can be severe.

Lightning discharges between the cloud and earth are of primary concern in communication applications. This may cause a momentary high ground potential rise due to lightning, which may affect the communication circuit. Proper shielding of the power station will disperse the stroke current to the large area of the ground mat and tower system.

However, failure of the shielding system can produce currents in the order of 2,000 to 20,000 amperes.

Switching surges can produce voltage transients which can induce longitudinal voltage in the communication pairs up to 10 kV and cause communication interference or breakdown, unless the communication cable is shielded and paralleled with one or two bare copper wires.

If communication conductors are exposed to direct contact with power circuits, the communication circuit protector gaps will break down and disrupt the circuit or cause excessive noise. If the communication circuit is enclosed in a metal sheath, breakdown from sheath to communication conductors may occur and form a path to ground in parallel with that of the sheath.

FIBER OPTICS TECHNOLOGY

Use of fiber optics technology for teleprotection is expanding because it often provides capabilities and characteristics not available in other communication technologies.

Transmission of information is accomplished by intensity modulation of light sources, e.g., solid state lasers or LED's. Modulated light transmission is accomplished by optical waveguides. A fiber optic "waveguide" consists of a fine glass or plastic thread generally containing two elements, as shown in Figure 8-1. The central "core" region provides a path for light to travel. An outer "cladding" region provides both mechanical core protection and a low refractive index region to contain the transmitted light rays. Light rays launched into the core region are literally trapped in the optical waveguide and are transmitted in a nearly loss-less propagation. At the receiver, photons are converted to electrons and are amplified or processed electronically.

8

Basically, there are two categories of a fiber optic link: graded index and stepped index (single mode or multi-mode step-index). Figure 8-2, taken from Reference [18], shows the various types of fibers, a simplified illustration of the core and cladding, and the modes of propagation. An analog or digital input, conditioned by a transmitter, drives either an LED or semiconductor laser diode and transmits modulated light into the fiber optic cable. At the receiving end, the incident light is processed to provide a useful analog or digital output. Full-duplex operation requires two fibers. Optical wave-length multiplexing may be used in the future to obtain signal separation.

The modes or waveforms of the optical signals propagate in a manner similar to signal propagation in microwave wave guides. Multi-mode fibers have either a step-index or a graded-index characteristic (Figure 8-2). These fibers allow propagation in many modes and are defined by their refractive index. A step-index fiber refers to the abrupt change in the index or refraction between the core and the cladding. All transmission of light occurs within the core. A graded-index fiber has a refractive index which gradually decreases from the core to cladding.

The modes in a step-index fiber propagate along a zig-zag path (Figure 8-1), some reaching the end of a fiber by longer or shorter routes. Graded-index fibers have larger bandwidth and the mode propagation is periodic (Figure 8-2). Given a core index of refraction n_1, and a cladding index of n_2, there will be a critical angle such that any light entering the core at less than that critical angle will be totally reflected. This will allow the light to be propagated down the length of the fiber as shown in Figure 8-3a. This gives rise to the term numerical aperture, which is defined as the Sine of the critical angle shown in Figure 8-3b. The numerical aperture defines the cone in which incident light may be fed into the cable, and in which light will emerge from the cable. The smaller the numerical aperture, the more difficult it is to launch light into the fiber.

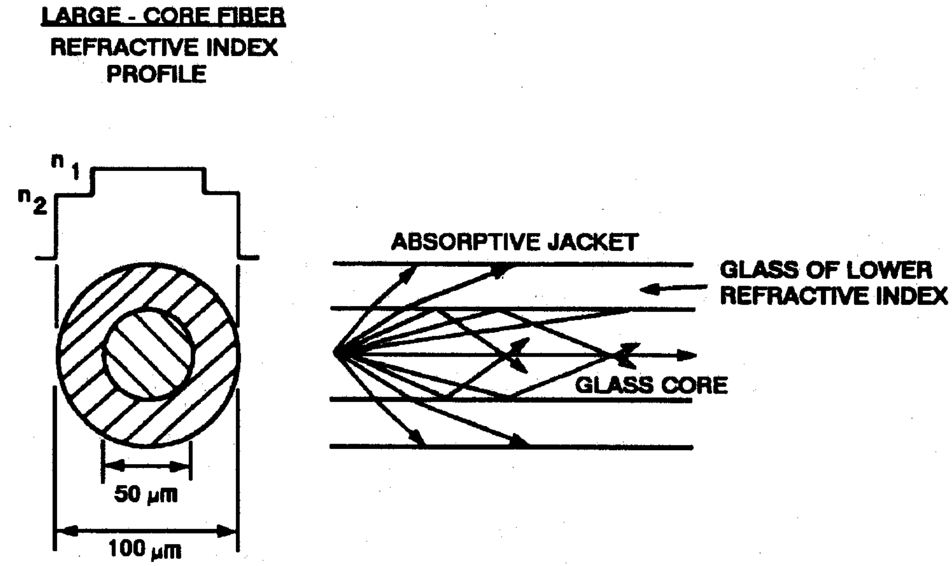

Figure 8-1. Fiber Optic Wave Guide

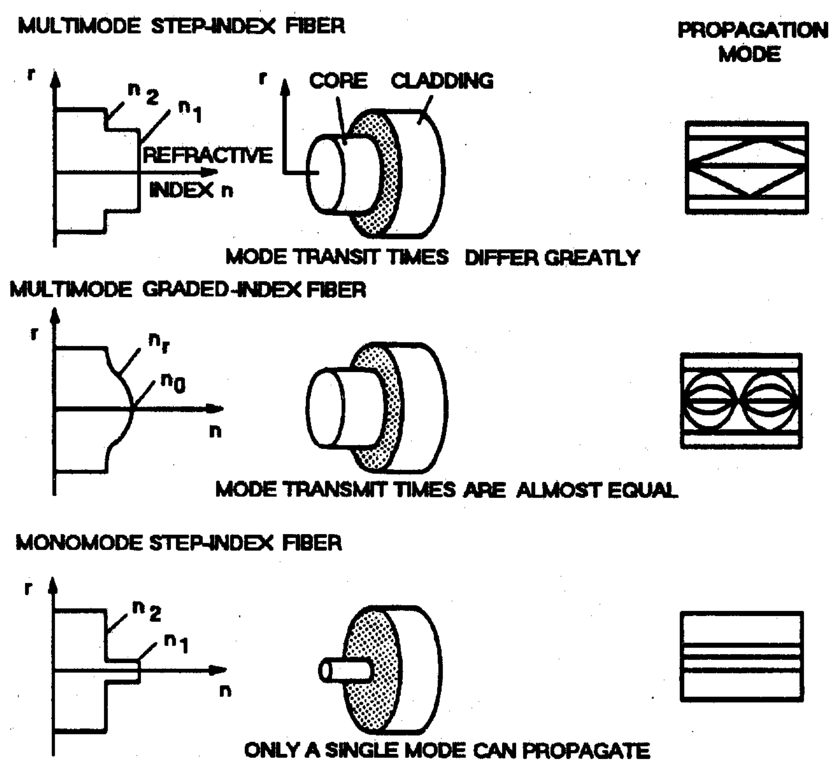

Figure 8-2. Categories of Fiber Optics

Optical fibers are packaged with protective sheathing and strength members to form cables equivalent to conventional wire cables in their ability to withstand environmental effects and stresses during installation. Because of the enormous bandwidth and signal-handling capabilities of optical fibers, one fiber will do the job of many conventional wire twisted pairs.

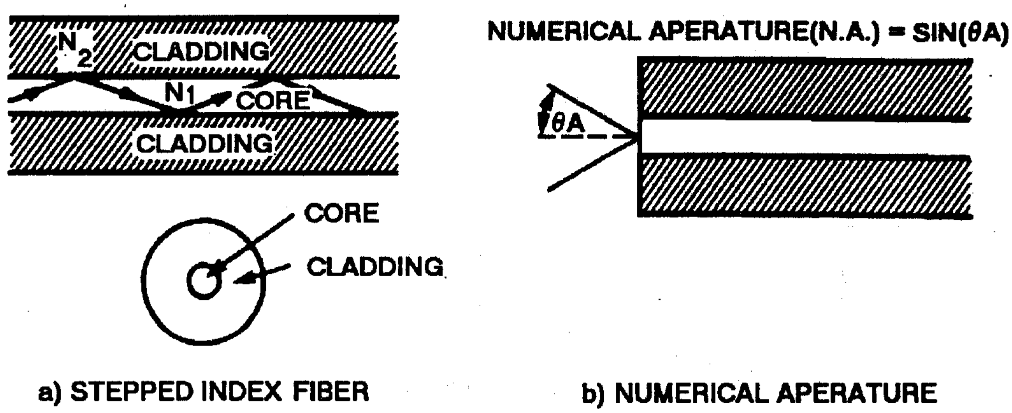

Figure 8-3. Refraction and Aperture

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Attenuation does not increase with frequency in optical waveguides if dispersion is not significant. Dispersion occurs when individual light rays traveling down an optical waveguide become "out-of-step" with one another or are no longer in phase. A properly designed system, however, will have minimum dispersion by the choice of its light source and the type and quality of its optical waveguide.

There are no severe long-term affects with glass fibers properly applied and utilized. The failure mechanism of the glass is stress corrosion. However, well designed cables will always have strength members to which connectors are attached which keep stresses on the fibers to a minimum. Temperature effects in optical cables are generally non-existent over a wide range.

An important trend in the utilization of fiber optics is progress in the reduction of transmission losses, as shown in Figure 8-4. Up to the present, most fiber optic systems have operated in the visible and near infrared region of 800 to 900 nm wavelengths. Transmission losses have been steadily reduced over the past 10 years through improved optical material purity and product techniques. The state-of-the-art for these fibers is about 1 dB/km, very close to theoretical limits, and down to attenuation numbers that are already very attractive for long distance applications. Further significant improvements at 800 nm are not likely. At 1100 to 1600 nm wavelengths, however, further reduction is possible, as shown in Figure 8-4. A transmitting system that operates between 1100 and 1300 nm has 10 times more data capacity than systems operating in the 860 nm region.

Losses for fiber optics and connectors must also be considered. These losses are as follows:

	Losses (dB)	
	Splices	**Connectors**
Present State-of-the Art	0.2-0.5	0.5-2.0
Attainable	0.05-0.1	0.2-0.5

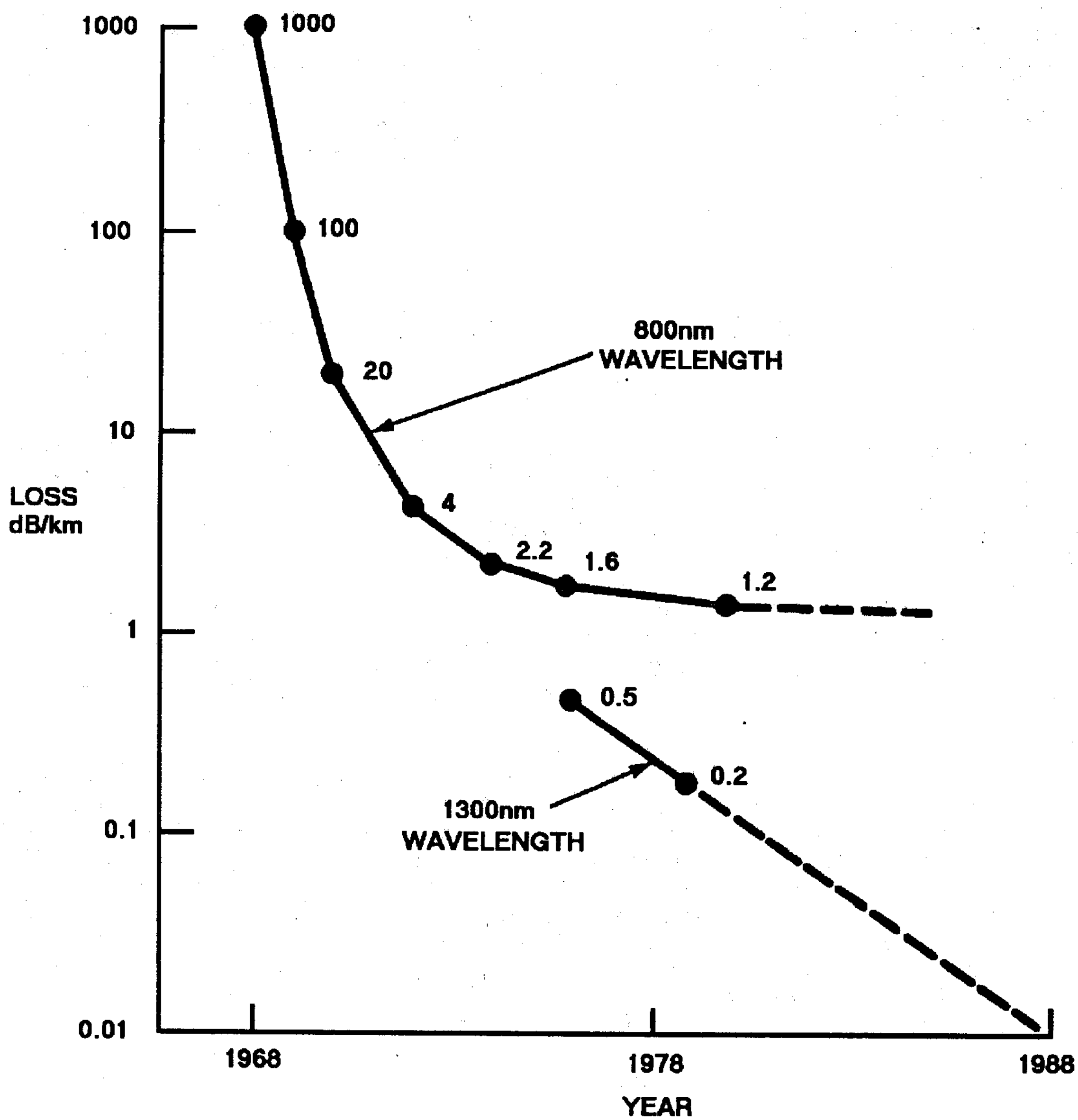

Figure 8-4. Trends in Optical Fiber Losses

Light sources and detectors have also advanced along with fiber optics. Light sources are generally of the light-emitting diode (LED) type or the injection laser diode. LED's are lower cost, more readily available, and generally have longer life (10^6 hour compared with 10^4 hours for lasers). Lasers are capable of much higher peak pulse power output than LED's.

In general, there are two types of detectors: the Planar diffused PIN (Positive Intrinsic Negative) photo-diode and the avalanche photo-diode (PAD). Avalanche photo-diodes provide high gain and improved signal-to-noise ratio, particularly at high frequency. PIN diodes are lower cost and more readily available.

Careful attention must be given to matching the source emitter and the fiber to couple maximum radiation into the fiber. Packaged assemblies have been developed where a short length of optical fiber (pigtail) is pre-assembled with one end in alignment with the source emitter or detector.

SYSTEM APPLICATIONS

Generating stations and switchyards are frequently located close together (less than 5 km). Figure 8-5 illustrates the application of a fiber-optic cable which runs uninterrupted from the power plant to the switchyard. An audio tone frequency-shift channel, coupled to an optical interface, provides reliable protective relaying between these two locations. The optical interface, or the fiber-optic modem, replaces the line termination module in an audio tone shelf.

The same principle can be applied to line protection schemes for lines with lengths of several tens of miles. Such distances will likely have to be covered with single-mode fiber. Fiber-optic modems are presently available for multi-mode and for single-mode fiber.

8

A simplified version of a typical communication circuits serving two power stations is shown in Figure 8-6. A high dielectric cable containing dedicated pairs serving the power station runs from the power station to the Central Office and extends to a point where the GPR profile has decreased to a value that is not dangerous.

Communication between the Central Offices is consistent with the reliability requirements of the dedicated cable between each power station and Central Office; general-use cable or communication facilities are used.

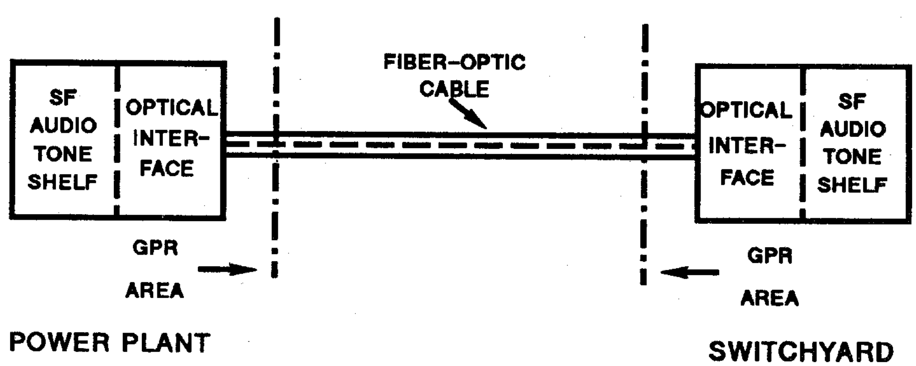

Figure 8-5. Fiber Optic Point-to-Point System

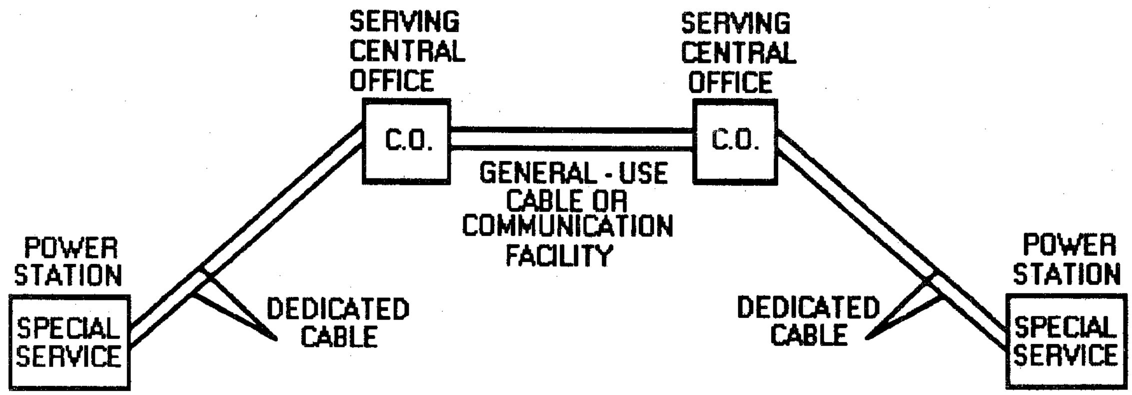

Figure 8-6. Power Utility Communication Circuit

Typically, an audio-tone frequency-shift protective relaying system is applied to the communication circuit shown in Figure 8-6. High speed, dependable operation, and high security are required for conditions such as low SNR, intermittent failure of the communication circuit, power system disturbances, frequency translation, and adverse operation of the tone equipment. Under high noise conditions, squelch or noise blocking schemes are available to make the system secure against false tripping. However, this may affect the system's ability to trip (dependability).

Figure 8-7 describes a fiber optic entrance link that interfaces with the terminal equipment in the power station on one end and the telephone wires of a Central Office on the other end [19]. The transmission media between the two ends is a fiber optic cable. It provides an improved communication channel over the use of a dedicated wire cable leading into the power station. Because of its non-metallic nature, a fiber optic cable can be used to avoid some or all of the problems associated with wire line communication facilities.

Near the substation, Figure 8-7, an audio tone four-wire line termination adaptor is provided to interface with the optical transmitter and receiver equipment. As illustrated, at the substation, the two audio transmitters modulate the LED whose light output is focused into an optical fiber. At the receive end, in the fiber-optic entrance link equipment, the optical receiver demodulates the light signal and reproduces the two audio signals. These signals are then transmitted over the send wire to the remote central office.

The same process, but in reverse order, occurs when tones are transmitted from the remote substation via the central office to the local substation. The received audio at the fiber-optic (F-O) entrance link modulates the LED (optical transmitter) whose light is coupled into a fiber going to the substation. There, the light is demodulated and the audio signals are detected in the tone receiver. The receiver produces the usual GUARD and TRIP output functions.

This system is based on wire lines and fiber-optic cables which are dedicated to the protective relaying communications. This system improves the reliability over a system without the F-O entrance link, but introduces the disadvantages of going through central offices.

Another application of fiber optics for teleprotection is the system shown in Figure 8-8. The system takes advantage of the wide bandwidth capabilities of optical fibers by multiplexing numerous functions over one fiber cable. The protection (audio) tones are multiplexed like any voice-grade channel.

The system (Figure 8-8) consists of a pulse code modulation (PCM) channel bank, a digital multiplexer, an automatic protection switch (APS), and a fiber optic transmission system (FTS). The following provides a brief description of each block.

Each voice input to the channel bank is digitized, time multiplexed with the other inputs and combined into a T-1 bit stream of 1.544Mb/s. This bit stream can either be injected into the APS and FTS or used as an input to a higher order multiplexer (MUX) which accepts several of these bit streams. The output of the higher order MUX is obviously a higher frequency bit stream than the input. For a M12 multiplexer with four T1 inputs, the data rate of the output is 6.312Mb/s. (A T1 channel bank can accommodate 24 voice channels.) At the receive end, the reverse process takes place, where the demultiplexer in the channel bank reproduces the tone signals by extracting the 8-bits representing one channel from the assigned time slot and a subsequent digital-to-analog conversion.

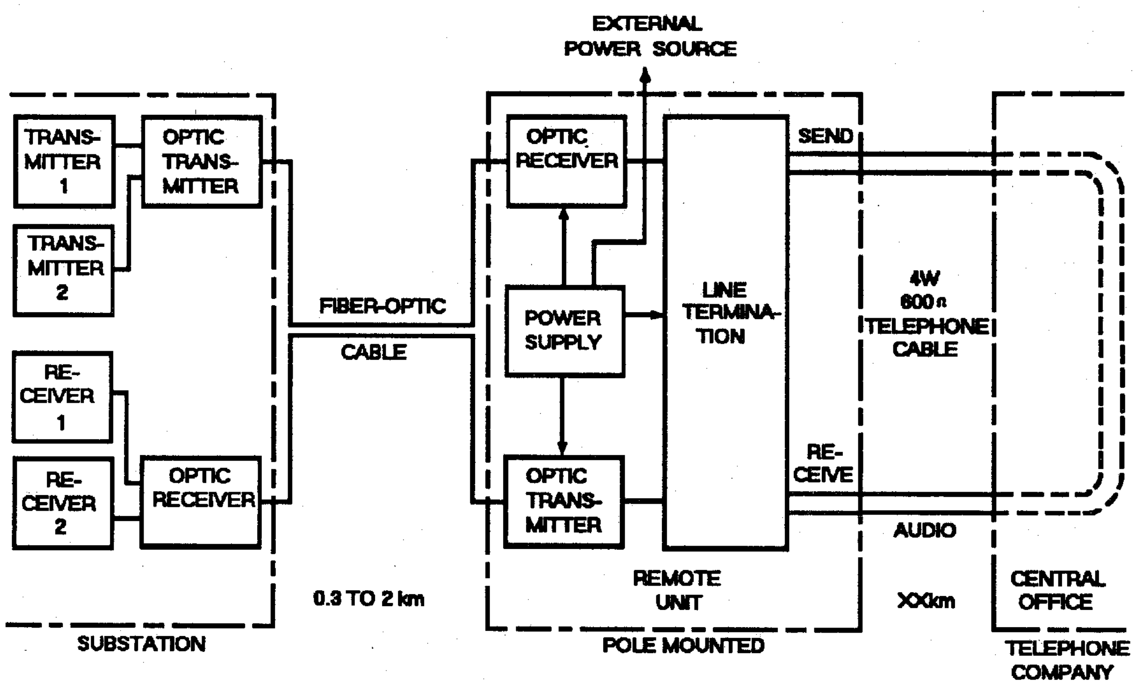

Figure 8-7. Fiber Optic Entrance Link

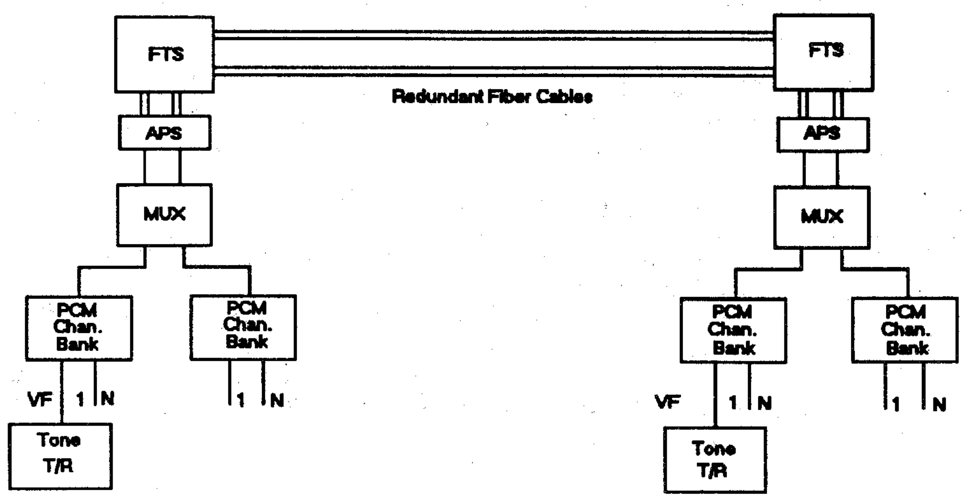

Figure 8-8. Fiber Optic Transmission System

The APS provides protection to the FTS span line; it transfers the PCM, or MUX data stream from the failed service fiber optic line to an operational redundant line. Redundant, reliable service is provided, as long as the data streams remain in synchronization.

Audio tones, such as the single function or multi function audio tones, may be applied to any one of the voice channels on the PCM channel bank for teleprotection purposes.

The previously described system using fiber optics is derived from the widely used T-Carrier system, which used coaxial cable or microwave as the medium. A relatively new multiplexing system which is designed to take advantage of the very wide bandwidths of single mode optical fibers is called SONET (Synchronous Optical Network). Figure 8-8 could depict a SONET system as well.

PRINCIPLES OF OPERATION

The General Electric fiber optic entrance link is an amplitude-modulated infrared carrier system which provides duplex operation over two optical fibers. Each fiber will accommodate one voice channel (550-3200 Hz) over a distance which is dependent on the attenuation characteristics of the optical fiber.

The optical interface unit consists of a transmit circuit and a receiver circuit. In the transmit circuit, the incoming audio signal is amplified to drive a light emitting diode (LED), which produces an infrared light output proportional to the audio signal. Temperature and distortion compensation are provided to cancel the distortion produced by the output LED. The optical signal is guided by the optical fiber for transmission to a remote terminal.

In the receive circuit, the AM optical signal from the optical fiber is guided to a positive-intrinsic-negative (PIN) diode, which detects the signal. The signal is amplified and temperature compensated. Provision is included for adjustment of the gain factor. The receiver gain control is used to set the output level.

The optical interface unit can be connected directly to single function audio tone teleprotection channels or multi function audio tone teleprotection channels as shown in Figures 8-5 to 8-7. To connect the unit to a telephone line at the remote location (Figure 8-7) requires the use of a line-termination unit for impedance matching and surge protection.

Specifications for the fiber optic audio link are described in Table 8-1.

OPTICAL POWER BUDGETING

Maximum and minimum optical transmitter output power, and maximum and minimum optical receiver sensitivity, are the fixed limits within which an optical fiber link must operate. Subtracting the receiver sensitivity from the transmitter power (Table 8-1) gives:

3 dBu -(-40 dBu) = 43 dB,

which is the allowable optical path loss (in dB).

The system losses which must be considered include the following:

⊖ Connector losses each at optical transmitter and receiver.	0.2 to 2 dB depending on connector used
⊖ Splices loss	0.05 to 0.5 dB per splice
⊖ Fiber attenuation	1.0 to 6 dB/km @ 820 nm depending on fiber used

There are losses associated with the use of different diameters of the individual fiber optic cable strands when making connections from one cable to another. These losses are usually controlled by the connector/adapter used in the application and the expected losses are furnished by the connector supplier. These losses are termed aperature losses, detector losses, and diameter losses. Splices losses, as mentioned below, are a type of connection loss.

To the system losses, a system operating margin of about 6 dB for temperature and aging should be added. For best utilization of the fiber, the wavelength of its optical transmitter LED emitter should be matched to the optical fiber wavelength. LED wavelengths range from 0.5 to 0.9 microns. If optical fibers are spliced, it is important that the diameter and numerical aperture of each fiber be the same. Otherwise, NA mismatch and diameter mismatch losses must also be added to the total system losses.

Table 8-1

Fiber Optic Entrance Link Specifications

⊖ Frequency Response: 550 to 3200 Hz ⊖ Level Stability: ±1.5 dB ⊖ Distortion: 1% maximum Signal/Noise Ratio: Function of fiber attenuation Audio Tone Interface ⊖ Optical transmitter - Input level - 0 to -10 dBm - LED output level into 60 micrometer core fiber - 2 microwatts or 3 dBu ⊖ Optical receiver - Receiver sensitivity - -40 dBu to -70 dBu - Output level - -20 dBm (adjustable in steps according to distance) - Output impedance - less than 5000 ohms ⊖ Supply voltage - ±12 vdc ⊖ Current drain - 60 mA	⊖ Remote Unit (Pole Mounted) ⊖ Optical transmitter - Input level - -14 dBm - LED output level into 60 micrometer core fiber - 2 microwatts - Input impedance - 100,000 ohms ⊖ Optical receiver - Output level - +10 to -10 dBm (adjustable in steps according to distance) - Output impedance - 10,000 ohms ⊖ Line termination unit ⊖ Send Source impedance - 10,000 ohms Output impedance - 600 ohms Output level - 0 dBM ⊖ Receive Input impedance - 600 ohms Output impedance - 600 ohms ⊖ Input level - -16 dBm ⊖ Output level - 0 to -20 dBm ⊖ Supply voltage - ±10.8 vdc ⊖ Current drain - 60 mA ⊖ Environmental ⊖ Ambient temperature -40°C to 60°C ⊖ Relative humidity 95% ⊖ Altitude up to 5000 feet

The curves of Figure 8-9 and 8-10 show typical performance of one or more audio tone signals, coupled over single mode or multi-mode fiber cable with the attenuation characteristics as noted. The minimum levels noted are the audio tone receiver's performance at a 20dB SNR. These curves are typical for single function and multi-function audio tone systems uses with the 820 or 1300 nm optic modem. The curves also provide the attenuation characteristics for a system control application.

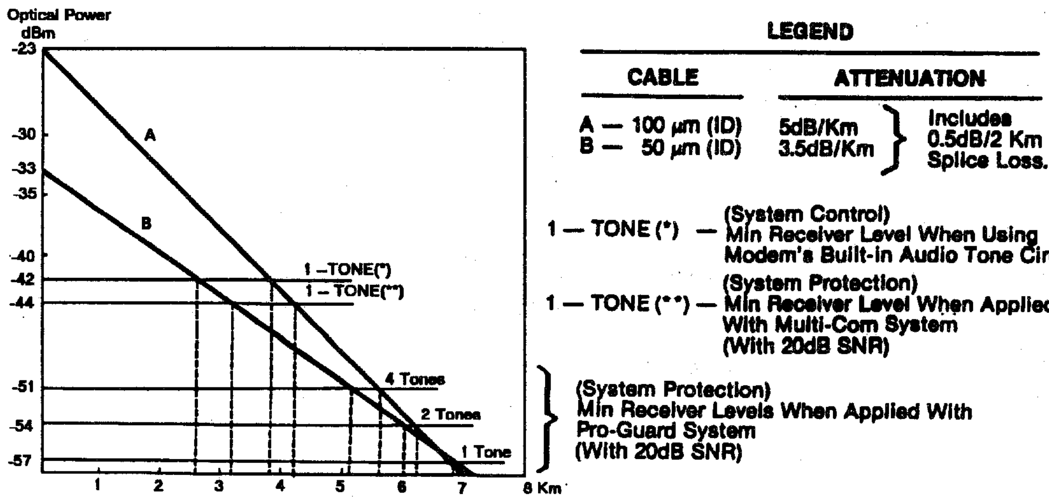

Figure 8-9. Typical Performance Curve for 820nm Fiber Optic Modem

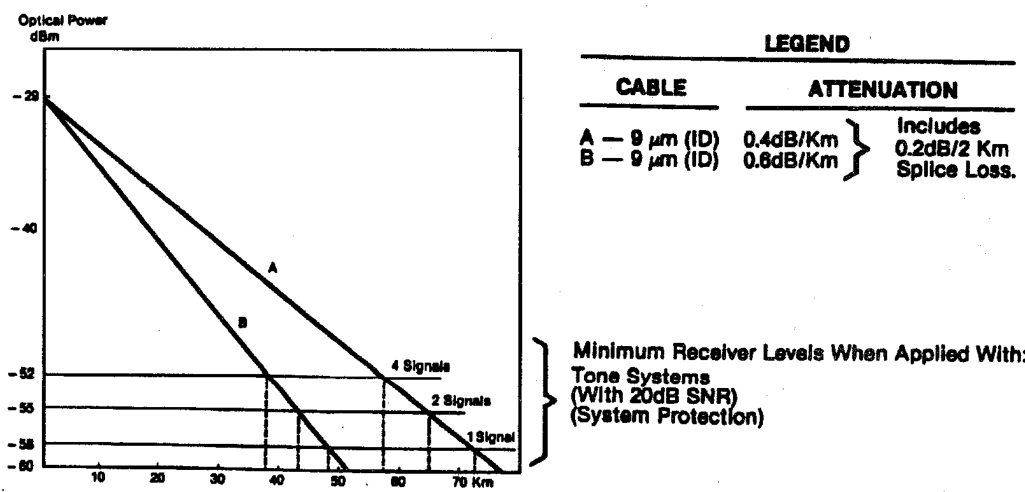

Figure 8-10. Typical Performance Curve for 1300nm Fiber Optic Modem

Fiber Link Applications

A fiber optic link is immune to all of the influences which can adversely affect the performance of telecommunications and teleprotection channels. Unlike metallic conductors, optical conductors (optical glass conductors) are immune to electromagnetic or electrostatic fields and the effects of corrosion. Because of their excellent electrical insulating characteristics, use of fiber-optic conductors greatly improves safety conditions for maintenance personnel and helps to protect the associated electronic equipment. Field tests have proven that induced noise and crosstalk, which adversely affect telecommunications channels, are negligible. Lower noise levels mean greater dependability and security on teleprotection channels when it is most needed -- during fault conditions.

System Protection

System protection with audio FSK tone channels using transfer trip and line relaying applications can interface with a fiber optic channel. These audio tone channels may be either the single function audio tone discussed in section 6 of this guide, or multi-function audio tone channels which are discussed in section 7. Either 820nm multi-mode or 1300nm single mode fiber may be used for the system protection application. The operating characteristics of typical audio channels for system protection are shown for both types of cables in Table 8-2.

Table 8-2

SYSTEM PROTECTION APPLICATION

WAVELENGTH	820 NM	1300 NM
OPTICAL		
Output level -TX	≥33dBm, 50/125μm Cable ≥23dBm, 100/125μm Cable	≥20dBm, 9/125 μm Cable
Input Level -RX	-57 to -23dBm	-58 to -30dBm
Connector Type	Series 905/906	Biconin(WECO 1016)
Mode	Multi	Single
Loss Budget	See Figure 8-9	See Figue 8-10
AUDIO		
Input Level-TX	-10dBm	-10dBm
Output Level-RX	-30 to -10dBm	-30 to -10dBm
Frequency Response	100-3600Hz(3dB)	600-3000Hz(1dB)
Distortion and Intermod	3%	3%
Level Stability	±1.0dB	±1.0dB
Input Impedance-TX	10KΩ/600 ohms	10KΩ/600 ohms
Output Impedance-RX	600/<100 ohms	600 ohms
DC POWER		
Voltage	±12Vdc	±12Vdc
Current	TX-25mA;RX-18mA	TX/RX -V,130mA;+V,20mA

System Control

System control functions can be provided in a shelf for up to ten independent control functions. Each function requires a dedicated 820nm multi-mode fiber. The functions can be either bidirectional or unidirectional. The shelf can contain either one or two power supplies. The extra power supply is available for added redundancy. This type of audio tone channel can be used for high speed control commands. This control circuit can be applied where various types of alarms or control signals need to be transmitted from one location to another with a degree of reliability and noise immunity which can only be achieved with fiber optic channels.

This channel can be applied in a "permissive" system protection applications where the inherent high security of an FSK audio tone channel using single function or multi-function tone is not required. Typical channel characteristics are shown in Table 8-3 for a 820nm multi-mode fiber.

Table 8-3

SYSTEM CONTROL APPLICATION

WAVELENGTH	820 NM
OPTICAL	Refer to System Protection
AUDIO	
Keying(isolated)	48 or 125Vdc @ 16 mA
Oscillator Frequency	
Status	170 Hz
Trip(Alarm)	2580 Hz
Trip (Alarm) Time	2 or 8 ms(Strappable)
Outputs	
Status	1 - Form A/B Contact, Rated 100VA
Trip (Alarm)	1 - Form A/B Contact, Rated 100VA
DC Power	
Voltage	±12Vdc
Current	TX 25 mA, RX - Status 18 mA, rip (Alarm) 34 mA

8

Optical Fiber Recommendations

To assist the user in pilot relaying applications, the following fiber optic cable specifications are generally recommended (Table 8-4).

Table 8-4

⊖	Number of fibers	-	Minimum of two
⊖	Fiber core diameter	-	50 microns
⊖	Fiber cladding diameter	-	125 microns
⊖	Index	-	Multi-mode, graded index
⊖	Attenuation	-	3 dB/km at 850 nm wavelength
⊖	Numerical aperture	-	Typically 0.2
⊖	Bandwidth	-	Minimum of 200 MHz
⊖	Operating temperature	-	-20°C to +45°C
⊖	Bending radius	-	20 cm or less
⊖	Connectors/splicing	-	Amphenol Series 906 connector and inline splicing, fusion type
		-	Splice loss less than 0.3 dB for fusion splicing
⊖	Cable construction	-	Suitable for direct burial, installation in buried duct, or aerial installation (application dependent)
		-	Void filled cable for aerial or direct burial cable. If in duct, void filled not required
⊖	Installation tensile strength	-	Cable of minimum pulling installation force of 90 lbs.

SECTION 9

PRE-EMPHASIS TRANSMIT COMBINER NETWORK

Contents of Section 9

(Note: Adapted from reference [27])

SYSTEM APPLICATION CONSIDERATIONS

The pre-emphasis transmit combiner is a combination of active and passive components designed to fulfill the following requirements for PLC coupling circuits:

1. Increase the availability and reliability of the coupled functions by combining all of the functions at a low level.

2. Adjust the levels of the signals at the power amplifier inputs to compensate for variations in the line loss over the coupled frequency range. When single function and SSB channels are combined, the levels can be adjusted to allow for signal-to-noise requirements of the SSB functions and for the margin requirements of the single function channels. This could result in more power being allocated for the single function protection channels versus the SSB channels. The levels can also be adjusted for the exalt function in any of the channels.

3. Provide isolation for all inputs to the combiner and outputs to the power amplifiers so that redundant paths are maintained and each input and output is separated from all others.

4. Reduce the cost of combining as compared to using high power bandpass filters or branching filters which do not have redundancy. Spacing requirements are determined by receiver selectivity. Transmitters can be spaced as if hybrids were the isolating device. The "twice bandwidth" spacing requirement for bandpass filters and the 10% spacing for branching filters is not required, resulting in frequency spectrum savings.

5. Reduce the power loss encountered when hybrids are used as combining components.

6. Reduce the cost by using fewer power amplifiers than for all other combining methods with five or more inputs.

7. Allows for future expansion of the system up to eight transmitters without adding more coupling equipment. (Individual signal levels may need to be adjusted, however.)

CIRCUIT DESCRIPTION

Figure 9-1 shows a circuit diagram of the low level transmit combiner with associated power amplifiers and combining hybrids. Up to eight inputs can be combined. For fewer than three inputs, other combining schemes may need to be considered for economy reasons.

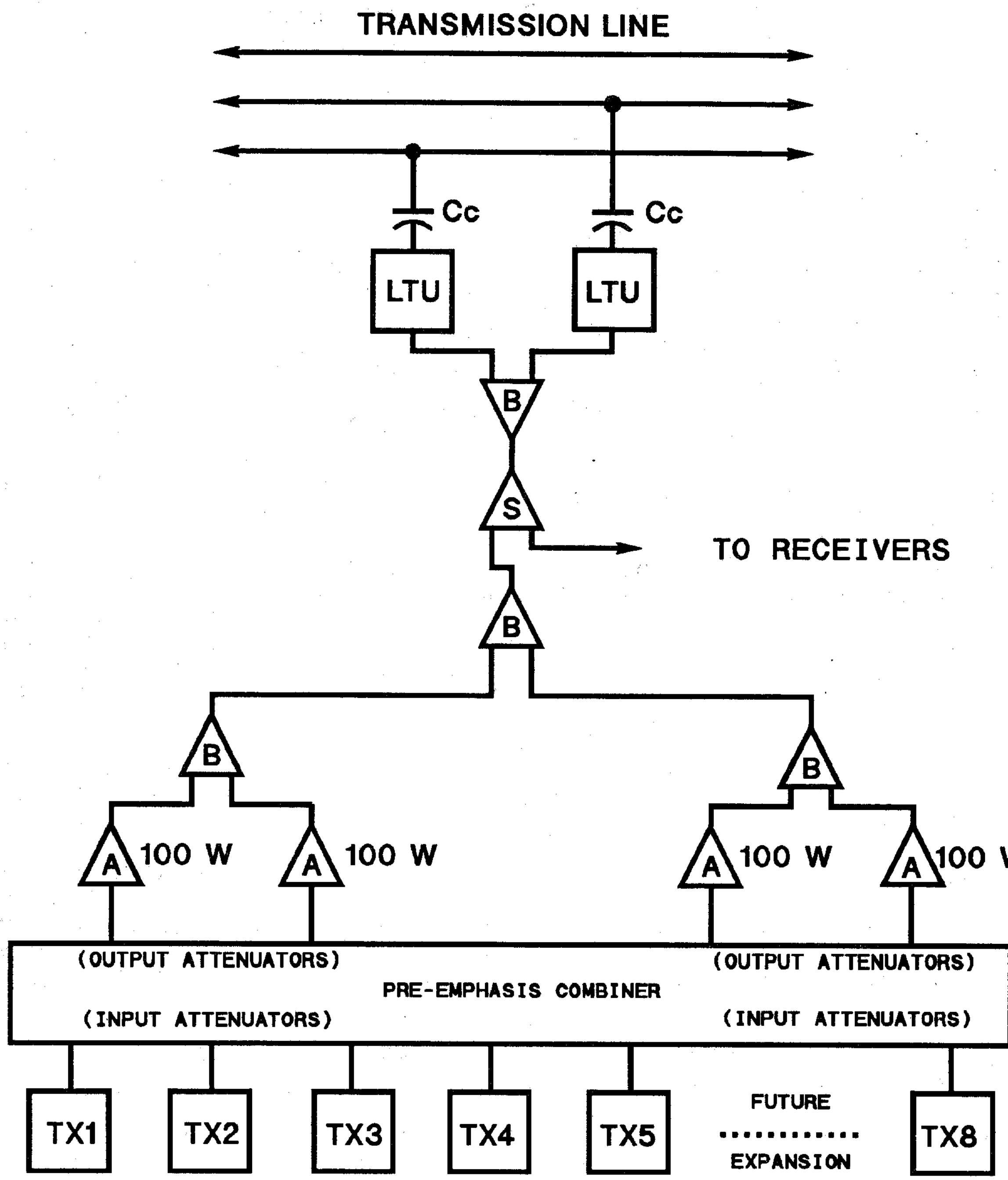

Figure 9-1. Low Level Transmitter Combiner Typical System

When compared to a system using filters as combining devices, the trade-offs are redundancy and reliability versus increased power level at higher cost. Figure 9-1 shows a system with five inputs and four outputs with 100 watt power amplifiers. The input levels are adjusted by strappable resistive attenuators to compensate for variations in line loss. The inputs are isolated from each other and unused inputs are terminated. There is sufficient gain in the circuit to compensate for the low level combining losses which makes the pre-emphasis combiner a zero loss device.

There are also resistive attenuators at all outputs for fine level adjustment. The outputs are routed to four identical power amplifiers. The power amplifier outputs are combined in three balanced hybrids with the proper phase relation such that no power is lost, except for the winding loss of the hybrid transformers. A skewed hybrid is used at the tuner interface to provide a connection for the receivers associated with the transmitters at the other end of the line section. For phase-to-phase coupling, another balanced hybrid is required to split the signals for the dual coaxial cables going to the line tuners.

In cases which involve channels which are closely spaced in the frequency spectrum, it may not be necessary to adjust the individual input levels. In this case, the combiner can be used without level correction on the input. Fine tuning of output levels may still be required to compensate for differences in amplifier gains.

LEVEL CALCULATIONS

For a power amplifier with multiple input signals, each input contributes to the output voltage in a linear fashion. The output voltage can be represented by the geometric mean of the power output and the load resistance. Thus:

$$V_o = [P_o * R]^{1/2} \qquad (1)$$

where: V_o = the output voltage across the load resistance, R.
and P_o = the power amplifier rating in watts.
(Note: The "(1/2)" exponent denotes the square root.)

The sum of the individual output voltages of the various input signals will not be equal to the output voltage with the correct relative levels. A means must be developed to determine the individual voltages with the correct relative levels. Equation (2) states the problem with the uncertain relation between the total output voltage, V_o, and the individual signal voltages, V_{o1}, V_{o2}, V_{o3}, etc.

$$V_o \overset{?}{=} V_{o1} + V_{o2} + V_{o3} + V_{o4} + \cdots V_{oN} \qquad (2)$$

The individual voltages values will be related by their relative levels. The sum of the individual values of the right side of Equation (2) must be made equal to the left-hand side so that the power amplifier is properly loaded. Equation (2) can be rewritten in the form of Equation (3) to solve this problem.

$$V_o = V_r\left(\frac{V_1}{V_r} + \frac{V_2}{V_r} + \frac{V_3}{V_r} + \cdots + \frac{V_n}{V_r}\right) \qquad (3)$$

In Equation (3), the V(o)n notation of Equation (2) is dropped for simplicity and the following changes are introduced:

> V_1/V_r; V_2/V_r; V_3/V_r; ... V_n/V_r are ratios of the individual signal voltages with a reference voltage, defined as V_r.

Equation (3) can be written in simpler form as:

$$V_o = V_r\{\ SIVR\ \}, \qquad (3.a)$$

> where {SIVR} stands for the "Sum of the Individual Voltage Ratios",

and, since Equation (1) also defines V_o, another form of Equation (3.a) can be written as:

$$V_o = [P_o \times R]^{1/2} = V_r\{\ SIVR\ \} \qquad (3.b)$$

Equation (3.b) can be solved for V_r and is shown below:

$$V_r = \frac{[P_o \times R]^{1/2}}{\{\ SIVR\ \}} \qquad (3.c)$$

At this point it should be pointed out that the reference voltage is a derived quantity which sets the levels of all of the individual signals. The voltage ratios can be calculated from the relative levels of the various outputs, and the absolute level of each of the outputs can be calculated after the summation of the individual voltage ratios determines the reference voltage, V_r. Equation (4.b), which is derived from equation (4.a), the familiar formula for calculating relative voltage levels, can be used to calculate the individual voltage ratios.

$$DB = 20\ \text{Log}\ (V_n/V_r) \qquad (4.a)$$

Therefore,

$$(V_n/V_r) = 10^{(DB/20)} \qquad (4.b)$$

To allow for the application of multiple tones, or signals, the constant, Kn, will be introduced, which represents the number of multiple signals per function, and can be any positive integer value. Equation (3) can then be rewritten to accommodate this constant.

$$V_o = V_r\{K_1\frac{V_1}{V_r} + K_2\frac{V_2}{V_r} + K_3\frac{V_3}{V_r} + \text{- - -}\ K_n\frac{V_n}{V_r}\} \qquad (5)$$

Two examples are included to demonstrate the use of the foregoing relations using five (5) channels. This includes two SSB channels with pilot, tones, and voice, and three single function channels - 2 FSK channels for equipment protection and a wideband

ON-OFF channel without the voice option. These channels, or transmitters, are arranged in the manner of Figure 9-1 with the transmitters and functions represented as in Tables 9-1A through Table 9-8A. The levels of each of the functions will be adjusted to give a relative output, (RO), from the power amplifiers. The relative outputs for the various functions are given in Table 9-2A. The Pre-emphasis combiner settings are shown in Table 9-1A. The line loss for the channels is for fair weather conditions. The high noise levels are for a 500 kv line section. A multiplier of 1.25 is used to convert these line losses to adverse conditions. The signal-to-noise ratio (SNR) calculations use the adverse weather condition losses and are shown in Table 9-8A. The combiner settings are rounded to the nearest dB.

The first example will use the full five channels with the checkback option in the ON-OFF channel. Since the checkback function is tested at full power and at reduced power, the calculation will be made at the full power level. The FSK transmitters are in the Trip (exalt) state, with full power output.

Example No. 2 will assume that the ON-OFF signal is at full power, but does not have checkback and that the FSK channels are in the exalted state (a trip signal is being sent). And, for comparison, the FSK channels will be in the non-exalted state (guard signal being sent 10 dB below the exalted level) with the ON-OFF channel sending a blocking signal at full power. The two SSB channels are considered fully operational as far as the amplifier is concerned for all cases.

EXAMPLES

EXAMPLE 1: ON-OFF CHANNEL WITH CHECKBACK

Table 9-1A

PRE-EMPHASIS SETTINGS FOR EXAMPLES					
	LINE LOSS (DB)				
TX. NO.	TX1	TX2	TX3	TX4	TX5
TX TYPE FREQ. (KHZ)					
SSB 60-64	10.8	----	----	----	----
SSB 68-72	----	11.8	----	----	----
MBW FSK 110	----	----	17.5	----	----
MBW FSK 118	----	----	----	18.5	----
WBW ON-OFF 126	----	----	----	----	19.5
ATTEN. DIFF	8.70	7.70	2.00	1.00	0.00
PRE. EMPH. INPUT ATTEN. SETTINGS	9.00	8.00	2.00	1.00	0.00

The voltage ratios of Equation (4.b) can be calculated and placed in another table. There are nine ratios in Table 9-3A corresponding to the nine levels of Table 9-2A. The ratios for SSB1 are calculated below using the relative output levels of Table 9-2A and Equation (4.c), a modified form of Equation (4.b). The remainder are filled in.

Table 9-2A

RELATIVE OUTPUT (RO) VOLTAGE LEVELS IN DB FOR TRANSMIT COMBINER EXAMPLE (WITH CHECKBACK)					
TX. NO.	TX1	TX2	TX3	TX4	TX5
Kn Function	SSB1	SSB2	MBW FSK	MBW FSK	ON-OFF
1 pilot	-9.0	-8.0	----	----	----
3 tones	-3.0	-2.0	----	----	----
1 voice	3.5	4.5	----	----	----
1 MBW FSK (exalted)	----	----	10.5	11.5	----
1 WBW ON-OFF (chk.back)	----	----	----	----	12.5

$$(V_n/V_r) = 10^{RO/20} \qquad (4.c)$$

$(V_1/V_r) = 10^{(-9/20)} = 0.3548$ (K1 = 1)
(The pilot voltage ratio)

$(V_2/V_r) = 10^{(-3/20)} = 0.7079$ (K2 = 3)
(The tone voltage ratio.)

$(V_3/V_r) = 10^{(3.5/20)} = 1.4960$ (K3 = 1)
(The voice voltage ratio.)

(K_n is the number in column 1 in Table 9-2A and the number in parentheses beside the function in Tables 9-2A through Table 9-4A.)

Adding the totals of each column in Table 9-3A, and then tallying the columns gives a grand total of 19.7586 for the sum of the voltage ratios {SIVR}. A 100 watt power amplifier with an output impedance of 50 ohms is used in these examples. Putting this into Equation (5) after calculating V_o using Equation (1) gives:

$$V_o = [P_o \times R]^{1/2} = [100 \times 50]^{1/2} = 70.71 \text{ Volts}$$

$$V_o = V_r\{SIVR\} = V_r\{19.7856\} = 70.71 \text{ Volts.}$$

or $V_r = 70.71/19.7856 = 3.5738$ Volts.

The power in each function, P_{Fn}, can be calculated using Equation (6).

$$P_{(Fn)} = \frac{[(V_n/V_r) \times V_r]^2}{R} \qquad (6)$$

The voltage ratios for each of the nine functions, from Table 9-3A, and the reference voltage is used along with the impedance (50 ohms) to find the power in each function, per amplifier which is tabulated in Table 9-4A. For SSB1, this calculation gives the power in the pilot as:

$$P_{F1} = \frac{(0.3548 \times 3.5738)^2}{50} = 0.03216 \text{ watts}$$

Table 9-3A

VOLTAGE RATIOS (V_n/V_r) FOR 5-CHANNEL TRANSMIT COMBINER EXAMPLE WITH CHECKBACK IN ON-OFF CHANNEL					
TX. NO.	TX1	TX2	TX3	TX4	TX5
Function	SSB1	SSB2	MBW FSK	MBW FSK	WBW ON-OFF
pilot(1)	.3548	.3981	----	----	----
tones(3)	.7079	.7943	----	----	----
voice(1)	1.4960	1.6788	----	----	----
FSK(1) (exalted)	----	----	3.3496	3.7583	----
ON-OFF(1) (chec.bk.)	----	----	----	----	4.2169
Total	3.9740	4.4598	3.3496	3.7583	4.2169

For the power in each of the three tones:

$$P_{F2} = \frac{(0.7079 \times 3.5738)^2}{50} = 0.1280 \text{ watts}$$

For the power in the voice signal:

$$P_{F3} = \frac{(1.496 \times 3.5738)^2}{50} = 0.5717 \text{ watts}$$

etc.

The level of the function, in volts, is simply the product of the voltage ratio for that function and the reference voltage. Thus, the pilot voltage is:

$$V_{pilot} = 0.3548 \times 3.5738 = 1.268 \text{ Volts}$$

The sum of all of the voltages of the individual functions using Equation (5) will be 70.71 volts, which represents an output power of 100 watts per amplifier. The total on-line power per function is calculated using Equation (6) and applying it to all of the functions. Table 9-4A lists the power in each function for one amplifier. (S.F. stands for single function channels -FSK and ON-OFF.)Table 9-5A lists the power for the four amplifiers.

Table 9-6A gives the voltage levels in DBM for each of the functions with four 100 watt amplifiers. These levels in DBM are calculated using Equation (7).

$$\text{Voltage level}_{DBM} = 10 \times \log (1000 \times P_{Fn}) \qquad (7)$$

Table 9-4A

POWER PER FUNCTION FOR 5-CHANNEL EXAMPLE FOR ONE AMPLIFIER (WATTS) (WITH CHECKBACK)					
TX. NO.	TX1	TX2	TX3	TX4	TX5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WBW ON-OFF
pilot(1)	.03216	.04048	----	----	----
tones(3)	.12800	.16120	----	----	----
voice(1)	.57170	.71990	----	----	----
S.F.	----	----	2.8660	3.6081	4.5423

The power sum of the individual functions is 13.248 watts for a single amplifier.

Table 9-5A

OUTPUT POWER PER FUNCTION (WATTS, FOUR AMPLIFIERS) FOR EXAMPLE WITH CHECKBACK (FOUR TIMES TABLE 9-4A)					
TX. NO.	TX1	TX2	TX3	TX4	TX5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WBW ON-OFF
pilot(1)	0.1286	0.1619	----	----	----
tones(3)	0.5120	0.6446	----	----	----
voice(1)	2.2868	2.8796	----	----	----
S.F.(1)	----	----	11.464	14.432	18.169

The value of P_{Fn} is taken from Table 9-5A for the four-amplifier power level.

Table 9-6A

VOLTAGE LEVELS(DBM) FOR EACH FUNCTION FOR EXAMPLE WITH CHECKBACK					
TX. NO.	TX1	TX2	TX3	TX4	TX5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot(1)	+21.10	+22.10	----	----	----
tones(3)	+27.10	+28.10	----	----	----
voice(1)	+33.60	+34.60	----	----	----
S.F.(1)	----	----	+40.60	+41.60	+42.60

Using these levels, the coupling losses, the line attenuation, and the line noise, the signal-to-noise ratios for the various functions can be calculated. The receive levels and the equipment margin can also be calculated. The values are collected in Table 9-7A to compute the signal-to-noise ratios. The resulting SNR values are as tabulated in Table 9-8A.

9

Table 9-7A

SUMMARY OF 5-CHANNEL PRE-EMPHASIS PARAMETERS FOR EXAMPLE WITH CHECKBACK					
Channel No. Function	1 SSB1	2 SSB2	3 MBW FSK	4 MBW FSK	5 WB ON-OFF
PWR into coax(dBm)	21.1	22.1	40.6	41.6	42.6
Coupling & Shunt loss (dB)	3.1	3.1	3.1	3.1	3.1
On-line pwr.(dBm)	18.0	19.0	27.5	38.5	39.5
Line loss Adverse (dB)	13.5	14.8	21.9	23.1	24.4
Rec. level(dBm)	4.5	4.2	15.6	15.4	15.1
Line noise(dBm)	-11.0	-11.0	-12.0	-12.0	-12.0

Table 9-8A

SIGNAL-TO NOISE RATIOS (DB) FOR EXAMPLE WITH CHECKBACK					
CHANNEL NO.	1	2	3	4	5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot	15.5	15.2	----	----	----
tel.tone	21.5	21.2	----	----	----
voice	28.0	27.7	----	----	----
Sing. funct.	----	----	27.6	27.4	27.1

EXAMPLE 2. BLOCKING ON-OFF CHANNEL WITHOUT CHECKBACK

For this example, the SSB channels will be identical to the case of Example 1. That is, all functions in the SSB channel will be fully operational at all times, since the communications and relaying functions are usually separated in location as well as in responsibility. It is usually impossible to have the communications switched off to allow all the power of the amplifiers to be used in the relaying function, although the communications channels may be rendered useless during the periods of time that faults and fault clearing are taking place.

Table 9-1A will not be repeated, since there are no changes for this example. The table numbering will remain functionally the same for this example for comparison purposes. Table 9-2B is the same as Table 9-2A except that the conditions of exalted FSK channels with the blocking channel turned off are compared to the case of non-exalted FSK channels and the ON-OFF blocking channel on at full power. The exalt level is assumed to be 10 dB above the non-exalted level.

Table 9-2B

RELATIVE OUTPUT (RO) VOLTAGE LEVELS IN DB FOR TRANSMIT COMBINER EXAMPLE (NO CHECKBACK IN ON-OFF)						
TX. NO.		TX1	TX2	TX3	TX4	TX5
Kn	Function	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
1	pilot	-9.0	-8.0	----	----	----
3	tones(tel)	-3.0	-2.0	----	----	----
1	voice	3.5	4.5	----	----	----
1	S.F.(exalt)	----	----	10.5	11.5	----
1	S.F.(non-ex)	----	----	0.5	1.5	----
1	S.F.(block)	----	----	----	----	12.5

The power in each function is calculated as in Example 1 and is collected in Table 9-4B. Table 9-5B shows the power input to the coaxial cable resulting from combining four amplifiers. Losses in the hybrids are not considered.

This example shows the result of removing a high level signal, the blocking channel at full power used for testing the channel with checkback, and using only the FSK channels alone at full power, or using the FSK channels at reduced power(guard) with the blocking ON-OFF channel at full power. In an actual system, a consideration must be made concerning the relative importance of output levels versus the advantages of the checkback feature.

The voltage ratios are calculated as in Example 1 except the non-exalted voltage ratios are added in Table 9-3B. These are identical to those of Table 9-3A except for the additions.

For the case in which the FSK channels are exalted, corresponding to the line of sums under Total(exalt), the grand total is 15.5417. The grand total for the line of sums of Total (non-exalt) is 14.8984. Using the output voltage of 70.71 volts for 100 watts RMS output power, the reference voltages for the voltage ratio sums are:

$V_{r(exalt)}$ = 70.71/15.5417 = 4.5497 Volts

and $V_{r(non\text{-}exalt)}$ = 70.71/14.8984 = 4.7461 Volts.

Table 9-3B

VOLTAGE RATIOS (V_n/V_r) FOR 5-CHANNEL TRANSMIT COMBINER EXAMPLE WITH NO CHECKBACK IN ON-OFF					
TX. NO.	TX1	TX2	TX3	TX4	TX5
Function	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot(1)	.3548	.3981	----	----	----
tel.tones(3)	.7079	.7943	----	----	----
voice(1)	1.4960	1.6788	----	----	----
S.F. exalt(1)	----	----	3.3496	3.7583	----
S.F. non-ex(1)	----	----	1.0592	1.1885	----
S.F. block(1)	----	----	----	----	4.2169
Total(exalt)	3.9740	4.4598	3.3496	3.7583	----
Total (non-exalt)	3.9740	4.4598	1.0592	1.1885	4.2169

The higher voltage ratio sum must be used to calculate the amplifier loading to prevent the power amplifier from being over-driven. The value of V_r = 4.5497 will be used in Equation (6) to find the power in each function for the non-checkback case and to compute the values in Tables 9-4B- 9-8B.

The power in the functions of SSB1 are calculated as in Example 1 in the exercise below:

The power in the pilot:

$$P_{F1} = \frac{(0.3548 \times 4.5497)^2}{50} = 0.05211 \text{ Watts}$$

The power in each of the telemetering tones:

$$P_{F2} = \frac{(0.7079 \times 4.5497)^2}{50} = 0.20746 \text{ Watts}$$

The power in the voice signal:

$$P_{F3} = \frac{(1.496 \times 4.5497)^2}{50} = 0.92650 \text{ Watts}$$

etc.
The remaining values are calculated in a similar manner and filled into Table 9-4B.

Table 9-4B

POWER PER FUNCTION FOR 5-CHANNEL EXAMPLE FOR ONE AMPLIFIER (WATTS) (NO CHECKBACK)					
TX. NO.	TX1	TX2	TX3	TX4	TX5
Function	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot(1)	.05211	.06561	----	----	----
T.tones(3)	.20746	.26120	----	----	----
voice(1)	.92650	1.1668	----	----	----
S.F. exalt(1)	----	----	4.6450	5.8476	----
S.F. non-ex(1)	----	----	0.4645	0.5876	----
S.F. block(1)	----	----	----	----	7.3618

The power sum of the individual functions is 14.11 watts with the FSK channels exalted and the ON-OFF channel turned off. This is reduced to 12.03 watts for the case with the FSK channels in normal guard state and the ON-OFF channel on at full power.

Table 9-5B

OUTPUT POWER PER FUNCTION (WATTS, FOUR AMPLIFIERS) FOR EXAMPLE WITH NO CHECKBACK (FOUR TIMES TABLE 9-4B)					
TX. NO.	TX1	TX2	TX3	TX4	TX5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot(1)	.2084	.2624	----	----	----
T.tones(3)	.8298	1.0448	----	----	----
voice (1)	3.7061	4.6672	----	----	----
S.F. exalt(1)	----	----	18.58	23.390	----
S.F. non-ex(1)	----	----	1.858	2.339	----
S.F. block(1)	----	----	----	----	29.447

Table 9-6B

VOLTAGE LEVELS (DBM) FOR EACH FUNCTION FOR EXAMPLE WITH NO CHECKBACK					
TX. NO.	TX1	TX2	TX3	TX4	TX5
Function	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot(1)	+23.20	+24.20	----	----	----
T.tones(3)	+29.20	+30.20	----	----	----
voice(1)	+35.70	+36.7	----	----	----
S.F. exalted(1)	----	----	+42.7	+43.7	----
S.F. non-exalt(1	----	----	+32.7	+33.7	----
S.F. blocking(1)	----	----	----	----	+44.7

9

Table 9-6B gives the voltage levels for the various functions in dBm which are calculated in the same manner as in Example 1. These levels are entered into Table 9-7B as in Example 1 to calculate the signal-to-noise ratio for this system configuration.

Table 9-7B

SUMMARY OF 5-CHANNEL PRE-EMPHASIS PARAMETERS WITHOUT CHECKBACK OPTION					
Channel No. Function	1 SSB1	2 SSB2	3 MBW FSK	4 MBW FSK	5 WB ON-OFF
Pwr into coax(dBm)	+23.2	+24.2	+42.7	+43.7	+44.7
Coupling and Shunt loss (dB)	3.1	3.1	3.1	3.1	3.1
On-line pwr.(dBm)	20.1	21.1	39.6	40.6	41.6
Line loss Adverse (dB)	13.5	14.8	21.9	23.1	24.4
Rec.level(dBm)	6.6	6.3	17.7	17.5	17.2
Line noise(dBm)	-11.0	-11.0	-12.0	-12.0	-12.0

The signal-to-noise ratios for each function can now be calculated, including the non-exalted single function SNR for the FSK equipment. This is summarized in Table 9-8B.

Table 9-8B

SIGNAL-TO-NOISE RATIOS (DB) (NO CHECKBACK IN ON-OFF)					
CHANNEL NO.	1	2	3	4	5
FUNCTION	SSB1	SSB2	MBW FSK	MBW FSK	WB ON-OFF
pilot	17.6	17.3	----	----	----
Tel. tones	23.6	23.3	----	----	----
Voice	30.1	29.8	----	----	----
S.F. exalted	----	----	29.7	29.5	----
S.F. non-exalt.	----	----	19.7	19.5	----
S.F. blocking	----	----	----	----	29.2

A comparison of Tables 9-8A and 9-8B shows that the levels in the system without the checkback option in the ON-OFF channel can be raised by 2.1 dB above the level calculated for the system with the checkback option. Although the checkback signal is not on all of the time, allowance must be made for the addition of this voltage to the output voltage of the amplifier. This signal must be set at its maximum level when the FSK channels are in their exalt condition (sending a trip signal) since the checkback feature is an automatic test. Without the checkback option, the normal operation calls for the FSK channels to be in the low output (guard) state and for the ON-OFF channel to be either on at full power, or to be turned off. The other condition is for the FSK channels to be sending a trip signal at full power and for the ON-OFF channel to be off. The 2.1 dB improvement in signal-to-noise, or in operating margin, is an across the board improvement (for all functions). The checkback would only be testing the low level part of the ON-OFF channel, since the power amplifiers are being used by the other channels as well, and it is doubtful if the test could detect one failure in the four power amplifiers.

The maximum power of the amplifiers will be used for very short time intervals, except for sustained faults. For Example 1, this time period would be when a trip signal is being sent and the ON-OFF channel is sending a high-level checkback signal. For Example 2, this time period also occurs when the FSK channels are sending a trip signal, but the ON-OFF channel is off. The condition of the FSK channels on guard and the blocking signal on at full power is less than the full power rating since the loading was calculated for the lower reference voltage case. Since the condition of the blocking channel operating while the FSK channels are sending a trip signal is very remote, the assumption is made that this condition will not occur.

CONCLUSIONS

The low level pre-emphasis transmit combiner is one option to consider instead of the conventional hybrid combining circuit or high power filters to provide isolation for three or more inputs. The pre-emphasis combiner is an active device which has zero loss and can combine up to eight inputs. These inputs are combined and split into four independent outputs. These outputs provide a redundancy which is not available with filter or hybrid combining. Since all signals are present at all amplifier outputs, the loss of one path (or one amplifier) will only reduce the signal level. All functions will continue to be active. The reliability is increased at the expense of a reduction in the individual power levels of each signal compared to combining transmitters with filters. Spacing between transmitters can be treated as if the isolation device is a hybrid. This allows closer spacing than with filters.

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SECTION 10
SIMPLIFIED MODAL ANALYSIS

Contents of Section 10

(Note: Adapted from reference [23].)

INTRODUCTION

Modal analysis is an analytical procedure involving matrices which utilizes combinations of basic modes to represent actual carrier currents on the line. The use of these modes to represent the RF currents is similar to the use of positive, negative, and zero sequence terms to represent the 60 Hz status on a transmission line.

Many papers on modal analysis, as applied to power line carrier transmissions, have appeared in the transactions of the Power Engineering Society, or have been presented as conference papers at its meetings. Frequently, these papers have presented highly analytical material. Usually, the calculations have been made with a computer, so that it has been difficult to obtain a simplified physical picture of how the modes operate.

In application work for Power Line Carrier, the modal theory in simplified form has proved to be useful in providing practical guidance without recourse to complex calculations. Such a simplified analysis does not replace computer calculations in all cases, but a simplified procedure can provide answers to some problems without requiring a large computer.

The calculations required to do Simplified Modal Analysis can easily be done with a personal computer or a programmable calculator if the user has a recurring need for modal analysis. The portability of calculators makes a Simplified Modal Analysis program available for a wide range of applications. Some versions of the procedure have included the ability to calculate losses on transposed lines. The formulas given in the appendix will allow the programmer to write a fairly simple program for the calculation of attenuation comparing various coupling schemes on a particular line.

Figure 10-1 represents a high voltage transmission line on which carrier signals can propagate. The carrier currents are fed to one or more phases of a high voltage transmission line through appropriate coupling components. The transmission line is a complex distributed electrical circuit in which capacitive and inductive coupling occurs between all three phases, as well as between each phase and ground (also between the phase wires and any overhead ground wires which are present). In Figure 10-1, a signal has been introduced to the center phase of the transmission line. The coupling between phases causes this center phase current to induce currents in the outer phases of the transmission line. These induced currents in the outer phases increase in magnitude relative to the magnitude of the center phase current as this combination of currents propagate down the line until a constant relative distribution is reached. The ultimate distribution of the currents is the low loss carrier mode (Mode 1). In the figure, the vectors at the end represent the low loss mode.

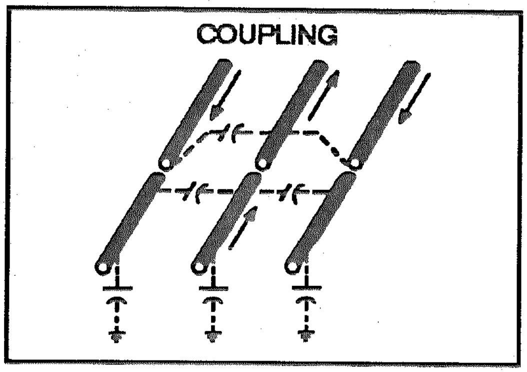


Figure 10-1

KEY ASSUMPTIONS

1. ONLY ONE THREE PHASE LINE IN A HORIZONTAL PLANE IS CONSIDERED.
2. SURGE IMPEDANCES FOR ALL PHASES AND MODES ARE THE SAME.
3. THE FORMS OF THE BASIC CURRENT MODES ARE INDEPENDENT OF FREQUENCY
4. INSTANTANEOUS CURRENTS FLOWING IN THE THREE PHASES ARE EITHER IN PHASE OR 180 DEGREES OUT OF PHASE.

Figure 10-2

The assumptions listed in Figure 10-2 are made in the following discussion:

BASIC MODES

In Figure 10-3, the three basic modes are shown as vectors. The arrows indicate instantaneous carrier current flow, and arrows pointing in opposite directions are 180 degrees out of phase.

The form designated Mode 3 is a high loss mode of propagation in which currents are simultaneously flowing in the same direction with equal magnitudes in all three phase wires. The return path is through the ground, and since the ground return path is lossy, this mode has high attenuation.

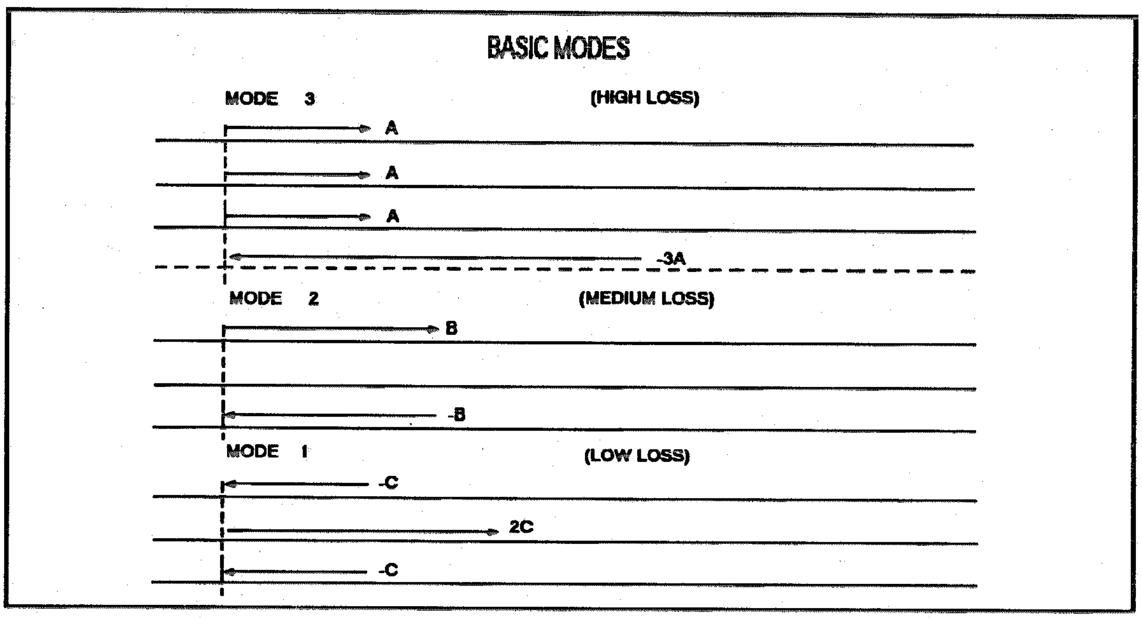


Figure 10-3

The next form, designated Mode 2, is a medium loss mode of propagation in which equal and opposite currents flow in the outside phase wires. Since there are no ground currents in Mode 2, this mode has less loss than Mode 3 with the current flow being entirely in the phase conductors.

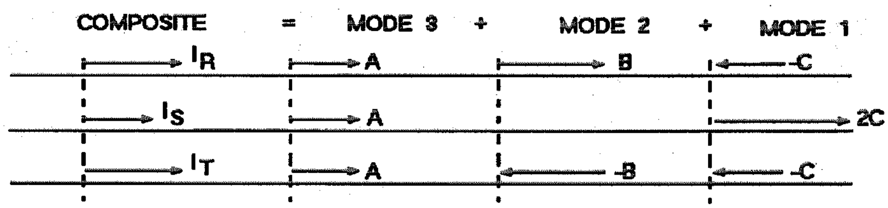
The last form, designated Mode 1, is a low loss mode of propagation in which a current flows in one direction in the center phase wire while currents of one-half this magnitude flow in the opposite direction in the outside phase wires.

An essential proposition of this modal method is that an actual carrier current distribution present on the three phases of a power line can be represented by some combination of these three basic modes. This requirement is not counter to the more complex theories of modal analysis which assume that the number of modes present in a system is equal to the number of variables present.

MODAL CONTENT

In Figure 10-4, the method for determining the modal content of a specific current distribution on the line is considered. An equation in statement form and four sets of current vectors appear at the top. The equation states that the composite (actual) current in the three phase wires, designated as I(R), I(S), and I(T), are equal phase by phase to the sum of the Mode 3, Mode 2, and Mode 1 currents. The equality statements, by phase, are shown below the vectors in equations (1), (2), and (3). These are simply three equations with three unknowns, which can be solved in a straightforward manner. Equations (4), (5), and (6) show one approach to solve for the values of A, B, and C. The results are at the bottom of the figure and show the following:

MODAL CONTENT



$I_R = A + B - C$ (1)

$I_S = A + 2C$ (2)

$I_T = A - B - C$ (3)

(1) + (2) + (3) $I_R + I_S + I_T = 3A$, $A = 1/3(I_R + I_S + I_T)$ (4)

(4) + (2) $I_S = 1/3(I_R + I_S + I_T) + 2C$, $C = 1/6(2I_S - I_R - I_T)$ (5)

(4) . (5) IN (1) $I_R = 1/3(I_R + I_S + I_T) + B - 1/6(2I_S - I_R - I_T)$

$B = 1/2(I_R - I_T)$ (6)

RESULTS:

$A = 1/3(I_R + I_S + I_T)$ $B = 1/2(I_R - I_T)$ $C = 1/6(2I_S - I_R - I_T)$

Figure 10-4

1. The value of A, the magnitude of the phase current in each of the three phase wires for the high loss mode, is one-third of the algebraic sum of the actual (or composite) currents flowing in the phases. For example, if the algebraic sum of the three currents is zero, there is no high loss mode present.

2. The value of B, the magnitude of the two currents flowing in the outside phase wires for the medium loss mode, is one-half the algebraic difference of the actual currents flowing in the outer phase wires. A value for B is obtained only if the currents are not symmetrical with respect to the center phase.

3. The value of C for the low loss mode is a little more complex. The magnitude of C is one-sixth of twice the actual current in the center phase, minus (algebraically) the actual currents in the other phases. Practically, the modal content can be determined by inspection.

In Figure 10-5, several examples of the modal content of carrier currents coupled to a three-phase line are considered. Again, the composite, Mode 3, Mode 2, and Mode 1 current vectors are shown.

In the top example, a center phase-to-ground coupling configuration is considered with a current "I" flowing in the center phase wire. The current "I" can be represented by Mode 3 and Mode 1 current vectors. The Mode 3 and Mode 1 currents can be seen, by inspection, to cancel each other on the outer phase wires giving zero current flow, and to add on the center phase wire to provide a current "I". There are no Mode 2 currents since I(R) and I(T) in the equation for "B" at the bottom of Figure 10-5 are zero.

The middle example is for a center-phase-to-outer-phase coupled case. In this situation, only Modes 2 and 1 are present, since the algebraic sum of the input currents is zero, and "A" in the equation at the bottom is zero. Again, by inspection, the Mode 2 and Mode 1 currents in each phase wire will add algebraically to give the input current for the coupled phases.

The bottom example shows an outer-phase-to-ground coupling which requires the presence of all three modes. Again, the modal currents add algebraically to equal the input currents for each of the three phases individually.

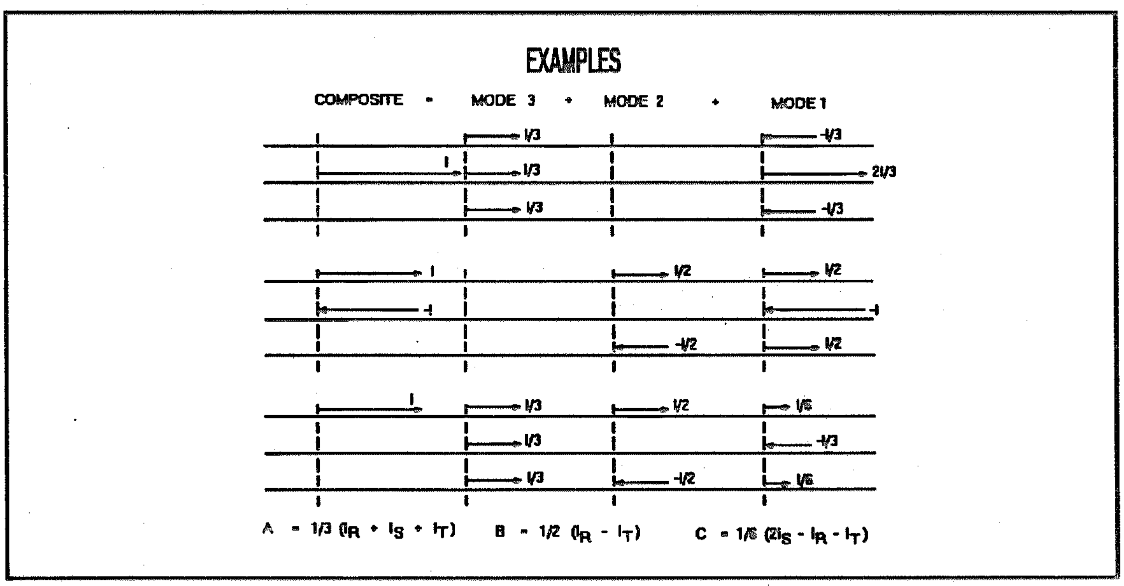


Figure 10-5

POWER IN MODES

In Figure 10-6, the distribution of the power in the modes is shown. The surge impedance was assumed to be the same for all phases and all modes. Hence, power can be stated as the sum of the squares of the various currents times the surge impedance, R. The power in the actual (composite) current, or currents, must equal the sum of the powers of modes representing the composite currents.

For example, at the top of the figure, the center-phase-to-ground would have a power equal to I^2R. This must equal the sum of the powers in the Mode 3 and Mode 1 currents, which must be equal to the input power. Therefore, stating this requirement in the following equations:

$$\text{INPUT POWER} = I^2R = \text{MODE 3 POWER} + \text{MODE 1 POWER}$$

$$\text{MODE 3 POWER} = 3R(I/3)^2 = I^2R/3$$

$$\text{MODE 1 POWER} = 2R(I/3)^2 + R(2I/3)^2 = R[\ 2I^2 + 4I^2\ ]/9$$

$$= R[\ 6I^2\ ]/9 = 2I^2R/3$$

$$\text{MODE 3 + MODE 1 POWER} = I^2R/3 + 2I^2R/3 = I^2R$$

Similarly, in the lower example, the power in the composite currents can be shown to be equal to the power in the Mode 2 and Mode 1 currents.

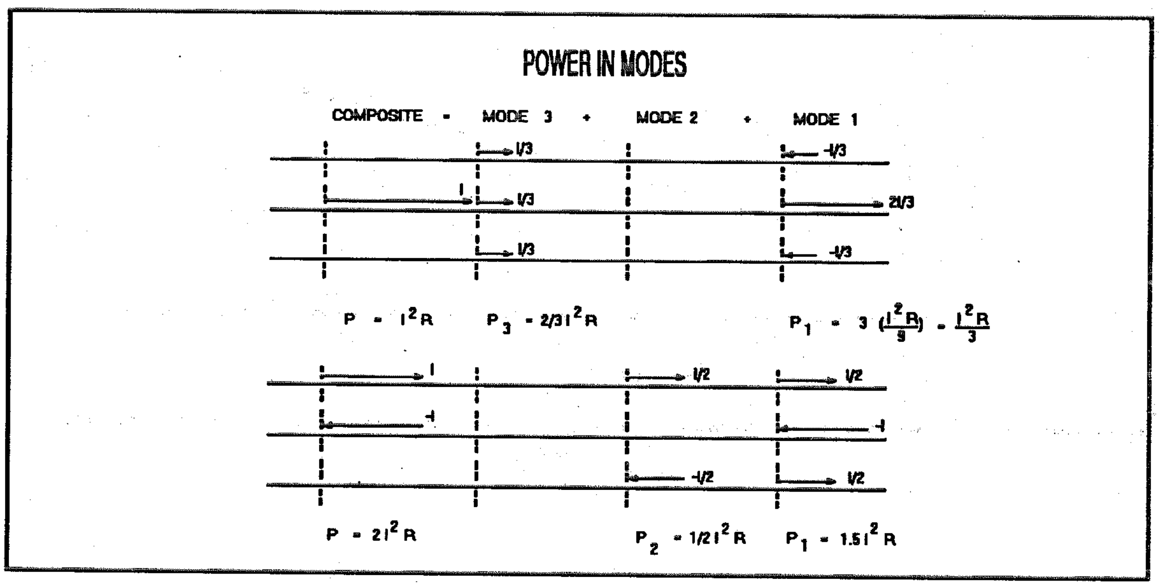


Figure 10-6

MODAL ATTENUATION

Figure 10-7 shows the approximate attenuation of the three modes as a function of frequency for a typical 345 kV line. For example, at 200 kHz the attenuation for Modes 1, 2, and 3, are 0.035, 0.1, and 1.0 dB/mile, respectively. Figure 10-8 gives line voltage conversion factors by which attenuation values for a 345 kV line can be multiplied to convert the attenuation values to a different line voltage. Thus, to convert the modal attenuation from 345 kV to 230 kV, first calculate the modal attenuations for 345 kV and multiply the results by 1.09 for mode 1; by 1.2 for Mode 2; and by 1.2 for Mode 3.

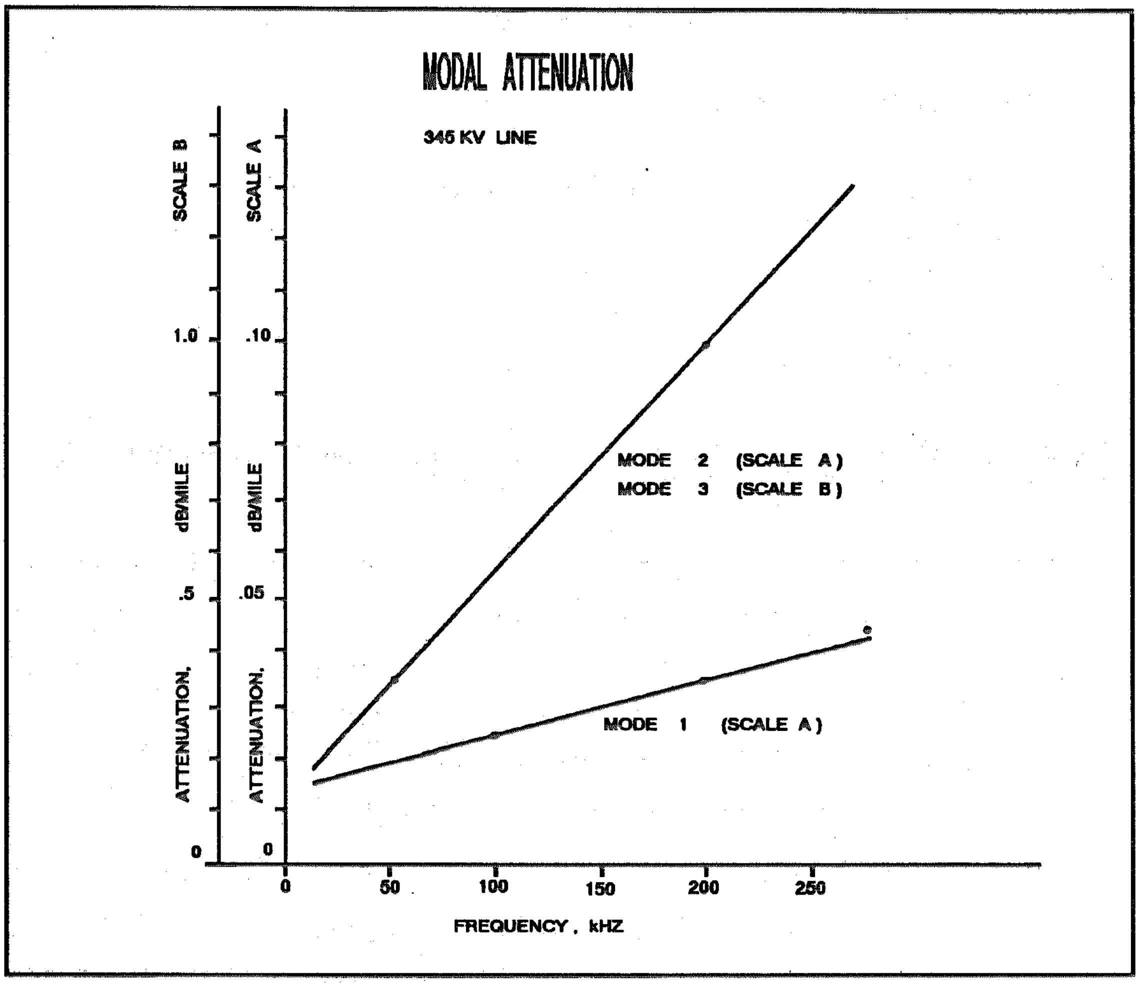


Figure 10-7

LINE VOLTAGE	MULTIPLIERS ON 345 KV VALUES		
(KV)	MODE 1	MODE 2	MODE 3
34.5	2.04	1.90	1.90
69.0	1.65	1.70	1.70
115.0	1.54	1.50	1.50
138.0	1.39	1.40	1.40
161.0	1.32	1.35	1.35
230.0	1.09	1.20	1.20
345.0	1.00	1.00	1.00
400.0	0.90	1.10	1.10
500.0	0.75	1.30	1.30
765.0	0.67	1.30	1.30

Figure 10-8 Line Voltage Conversion Factors for Modal Attenuation

MODAL PROPAGATION

In Figure 10-9, a calculation using a modal approach is made. At the upper left, the center-phase-to-ground current is shown. Below it, its equivalent in terms of the Mode 3 and Mode 1 currents is shown. Assuming a 200 mile line and a carrier frequency of 200 kHz, the Mode 3 and Mode 1 line losses can be determined using the modal attenuation per mile from Figure 10-7. The Mode 1 loss at 200 kHz would be 200 times 0.035 dB/mile, or 7 dB. The Mode 3 loss at 200 kHz would be 200 times 1.0 dB/mile, or 200 dB. The Mode 3 signal has been completely absorbed by the line. The signal at the receive end of the line is the sum of the Mode 1 and Mode 3 signals. Since no Mode 3 signal remains, the received signal is composed of the Mode 1 signal alone.

As center-phase-to-ground coupling was used, and only the signal on the center phase is coupled off the center phase conductor at the receiving end, the output current will be $0.298xI$. The total loss for the line is I^2 divided by $(0.298I)^2$, or 10.52 dB.

The tabulation at the bottom of Figure 10-9 is a convenient means of identifying the sources of loss in the line. The first conversion loss of 1.76 dB accounts for the power loss sustained in converting from a center-phase coupling to a Mode 1 set of currents at the send end of the line. This assumption that all Mode 3 power is dissipated on the line is valid for this example. The Mode 1 loss is calculated in the example to be 7 dB. The last conversion loss of 1.76 dB is the power lost in converting back to a center phase coupling scheme from a Mode 1 distribution. The power in the outside two phase wires is not useful in this coupling scheme and is a measure of the coupling efficiency of the center phase coupling compared to Mode 1 coupling.

In calculating the loss in a 345 kV line of another length, it would only be necessary to calculate the Mode 1 loss for the frequency and the line length and to add the 3.52 dB for conversion loss. This assumes that the line is sufficiently long to attenuate the Mode 3 currents at the frequency being coupled. For short lines, and for lines at low frequencies with other coupling schemes, these assumptions are not always valid.

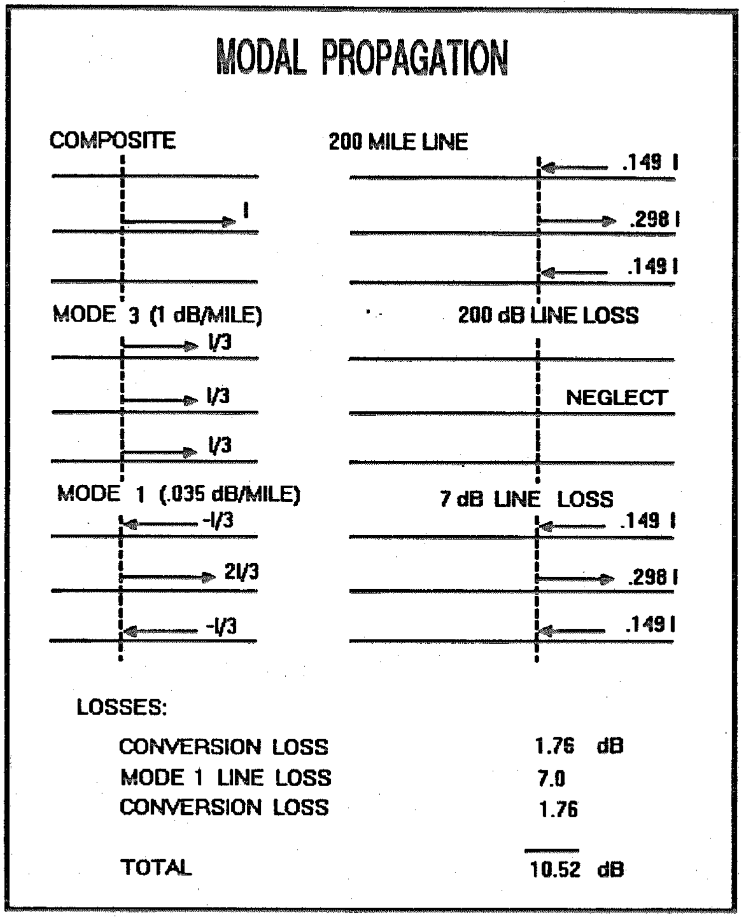


Figure 10-9

CONVERSION LOSSES

In Figure 10-10, the conversion losses are shown for several coupling schemes. The arrows on the left indicate the input current distribution to the line, and the arrows on the right indicate the Mode 1 current distribution for the inputs on the left. The Mode 2 currents have been neglected since it is assumed that there will be negligible contribution from these currents at the output of the line. Center-phase-to-ground coupling is shown again with 1.76 dB per end for a total of 3.52 dB of conversion loss. The calculation of conversion loss for center-phase-to-ground coupling is shown below.

$$\text{Con. Loss} = 20 \times \log (\text{PWR. IN})/(\text{PWR. OUT})$$

$$= 20 \times \log (I)/(2I/3)$$

$$= 20 \times \log 1.5 = 1.76 \text{ dB}$$

Center-phase-to-outer-phase coupling is shown next with 1.25 dB per circuit end for a total of 2.50 dB of conversion loss. An outer-phase-to-ground coupling is shown last. This scheme gives a very high conversion loss of 7.8 dB per end, and a total of 15.6 db for the conversion loss. The total conversion loss for these three schemes plus that for Mode 1 coupling are shown at the bottom of Figure 10-10.

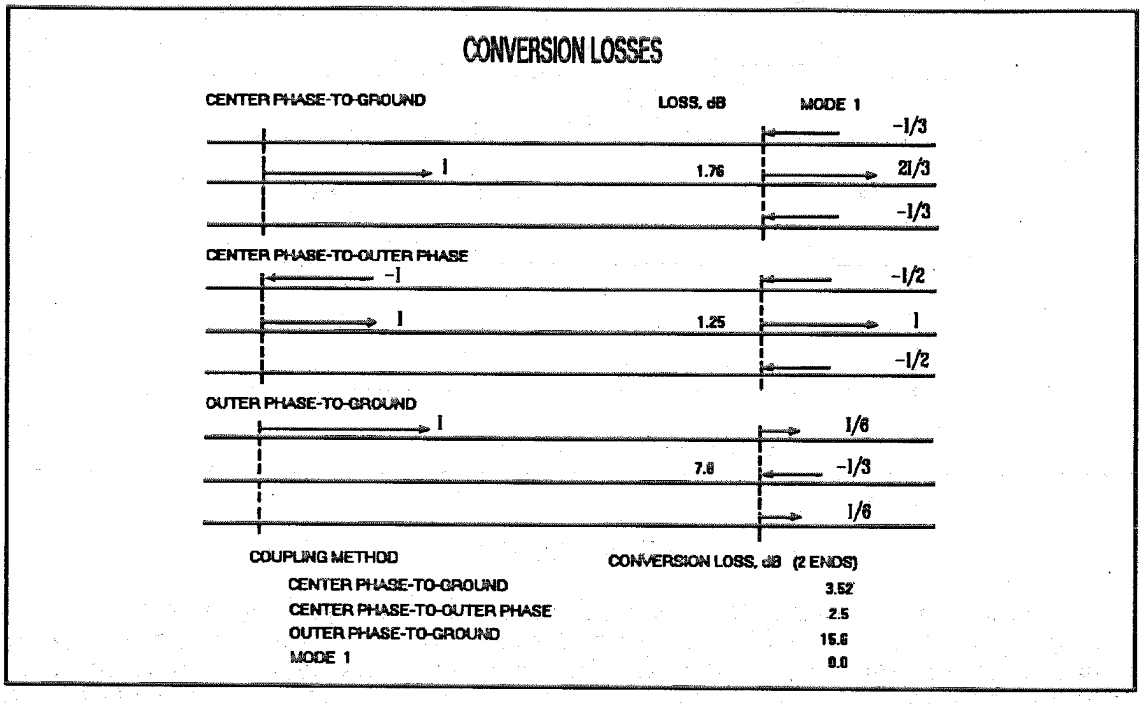


Figure 10-10

Some care must be exercised when Mode 2 components are present, since these components attenuate much more slowly than Mode 3 and can be neglected only on long lines. Where there are transpositions on long lines, the more rigorous approach using the equations in the Appendix may be used to calculate the line losses with more confidence.

The conversion losses are independent of frequency and line voltage, to a very good approximation, and can be used to compare the efficiency of various coupling schemes applied to long lines.

In Figure 10-11, the effect of a line transposition is illustrated. In the upper part of the figure, a Mode 1 current enters a transposition from the left and emerges on the right with a changed current distribution. In the lower part of the figure, the current distribution out of the transposition is converted to Mode 1 and Mode 2 current distributions. The transposition loss is calculated on the assumption that the Mode 2 power reaching the end of the line can be neglected. The loss attributed to the transposition would be 6 dB under that assumption.

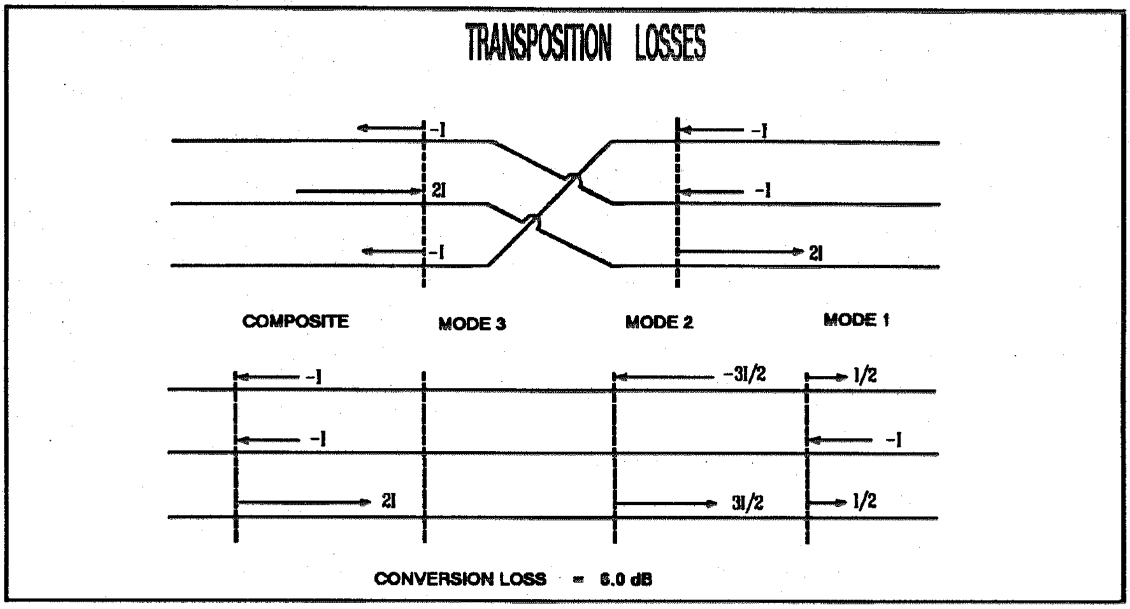


Figure 10-11

This method of calculating the losses of a line using the simplified approach to modal analysis can give useful results for many applications. The losses inherent in the coupling circuits are not included in the line loss calculations and must be added to the modal attenuation to find the total loss from sending end to receiving end of a line section. These losses include the shunt losses of the line traps, and losses in the coupling capacitors, line tuners, coaxial cables, and any filters, hybrids, or other isolating and combining components used between the transmitter(s) and receiver(s).

APPENDIX A

SIMPLIFIED MODAL ANALYSIS VARIABLES AND RELATIONSHIPS

The variables used to calculate the eventual attenuation of a high voltage power transmission line for any type of input and output coupling are described below. These variables are the phase currents into the line section; the phase currents out of the line section; the modal currents into the line section; and the modal currents out of the line section. A line section is defined here as a section of high voltage line without a transposition. The phase currents and the related modal currents will be redistributed at each transposition. For transposed lines, the output phase currents of a preceding line section become the input phase currents of the next line section.

Using this procedure does not require the addition of conversion losses, since these losses are automatically accounted for in the calculations of the currents in the individual phase wires and the assumed current injection and coupling for the coupling scheme selected. When there are transpositions, care must be exercised to keep track of the currents in all phase wires, although only one phase may be eventually coupled at the receive end of the line.

1. INPUT PHASE CURRENTS:

PI(1); PI(2); and PI(3),

where PI(1) is the input phase current to phase 1,
PI(2) is the input phase current to phase 2,
and PI(3) is the input phase current to phase 3.

Also, by definition,

$$PI(0)^2 = PI(1)^2 + PI(2)^2 + PI(3)^2$$

which will be used to calculate the attenuation at the output. A current not present is given a zero value. The relative magnitudes and algebraic signs must be retained.

2. MODAL CURRENTS INTO THE SECTION:

$$MI(1) = [2PI(2) - PI(1) - PI(3)]/6;$$

$$MI(2) = [PI(1) - PI(3)]/2;$$

$$MI(3) = [PI(1) + PI(2) + PI(3)]/3$$

where MI(1) is the Mode 1 current into the line section; MI(2) is the Mode 2 current into the line section; and MI(3) is the Mode 3 line current into the line section.

3. MODAL CURRENTS ON OUTPUT OF LINE SECTION:

$$MO(1) = MI(1)/[\ 10^{[K1 \times L(0.0001F + 0.015)]/20}]$$

$$MO(2) = MI(2)/[10^{[K2 \times L(0.00043F + 0.013)]/20}]$$

$$MO(3) = MI(3)/[10^{[K3 \times L(0.0043F + 0.13)]/20}]$$

Here, MO(1) is the Mode 1 current out of the line section, MO(2) is the Mode 2 current out of the line section, and MO(3) is the Mode 3 current out of the line section. Notice that the Mode 3 current is attenuated very rapidly on long lines at high frequency. K1, K2, and K3 are the factors listed in Figure 10-8 of the text for converting the curves of Figure 10-7 to voltages other than 345 kV for Modes 1 through 3, respectively. L is the section length in miles, and F is the frequency in kHz.

4. PHASE CURRENTS OUT OF THE LINE SECTION

$$PO(1) = MO(3) + MO(2) - MO(1)$$

$$PO(2) = MO(3) + 2MO(1)$$

$$PO(3) = MO(3) - MO(2) - MO(1)$$

where PO(1), PO(2), and PO(3) are the phase currents of phase 1, phase 2, and phase 3 out of the line section. These expressions are very similar to those expressing the composite currents R, S and T in the text with respect to the modal currents, A, B, and C.

5. ATTENUATION FOR DIFFERENT COUPLING CONFIGURATIONS

A. PHASE 1 TO GROUND.

$$ATTN(1) = -10 \log [\ PO(1)/\ PI(0)]^2$$

B. PHASE 2 TO GROUND.

$$ATTN(2) = -10 \log [\ PO(2)/\ PI(0)]^2$$

C. PHASE 3 TO GROUND.

$$ATTN(3) = -10 \log [PO(3)/ PI(0)]^2$$

D. PHASE 1 TO PHASE 2.

$$ATTN(4) = -10 \log [PO(1)^2 + PO(2)^2]/ PO(0)^2$$

E. PHASE 2 TO PHASE 3.

$$ATTN(5) = -10 \log [PO(2)^2 + PO(3)^2]/ PO(0)^2$$

F. PHASE 1 TO PHASE 3.

$$ATTN(6) = -10 \log [PO(1)^2 + PO(3)^2]/ PO(0)^2$$

G. PHASE 1 TO PHASE 2 TO PHASE 3 (MODE 1).

$$ATTN(7) = -10 \log [PO(1)^2 + PO(2)^2 +PO(3)^2]/ PO(0)^2$$

These formulas allow the computations of modal attenuations for any three-phase circuit based on a 345 kV prototype. The conversion factors listed in the table of Figure 10-8 are the result of many calculations on lines of different lengths, with or without transpositions, compared to actual measured losses. Since the attenuation is referenced to the input current(s), the magnitudes are not critical, and the final phase currents are used to calculate the attenuation based on the coupling configuration assumed.

There are instances, especially when coupling to outside phase wires on horizontally constructed lines, where a physical analysis will give the only correct estimate of the actual line losses across a band of frequencies. The results for most simplified analysis calculations are conservative.

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SECTION 11
FREQPLN
A COMPUTER PROGRAM FOR FREQUENCY PLANNING

Contents of Section 11

(Note: Adapted from reference [28]).

INTRODUCTION

The efficient use of the frequency spectrum for PLC applications requires a knowledge of the existing frequencies applied to the transmission lines and future frequency allocations of potential PLC applications on each line section. In many instances this information is available only for center frequencies of FSK and ON-OFF carrier channels. The bandwidths and required spacing of the individual transmitter-receiver pairs are not recorded. Equipment which has been in service for many years can have large bandwidth requirements compared to newer equipment. The application of voice for maintenance on blocking carrier channels may require a significant bandwidth increase over a channel without voice. SSB voice over newer blocking carrier channels may decrease bandwidth requirements by a ratio of four to one.

Frequency spacing requirements between transmitters and receivers of different types of protection equipment must be part of any frequency planning methodology. The isolation across stations, transformers, and the line loss must be considered in the selection of frequencies. The standard for repeating frequencies accepted by most PLC users is two line sections and three buses. Other considerations for repeating frequencies are contained in publication ECC-348, "Guide For Power Line Carrier Frequency Planning"[36]. A study of ECC-348 is recommended as a refresher in the concepts used in frequency planning.

A utility interested in maximum utilization of the available spectrum must not only keep a record of frequency bands in use for each line section owned by this utility, but frequency bands on interconnections with other utilities must also be considered for at least two line sections into these neighboring lines. This must be considered for any possible switching conditions.

A large system using over twenty-five line sections and many PLC transmitters will require a considerable amount of coordination to maintain an efficient frequency plan. The creation of a data base will already have been done in part for the NERC program for the PLC and Licensed Users data bases. Many utilities have their own data bases for the management of frequencies. Recently, the FCC has recognized the utilities' PLC frequencies and through the UTC have provided a means to identify each PLC frequency, bandwidth, and location. Therefore, most utilities already have access to an existing data bank of PLC frequencies.

The majority of problems with existing PLC frequency utilization lies in the methods by which the present protection has evolved. As systems have become more complex, the need for protection has increased to include more line sections and more secure and dependable techniques requiring additional channels on existing protected lines. Voltages have been increased to accommodate ever-increasing loads. Restrictions on overhead construction have increased the number of cable/overhead line circuits. The result has been a patchwork of frequency assignments and haphazard use of the available frequency band.

Instead of trying to find unused frequency bands in the bandwidth of existing line tuning equipment on their lines, some utilities have abandoned PLC and have resorted to leased lines or microwave radio channels.

To search the presently applied bands for available slots can be a formidable task when attempted by hand. A digital computer with adequate memory to accommodate the data base required to do the comparing , checking, assigning, and storing of all this information in file form for printout, or for further editing, is the obvious solution.

A new system which is not encumbered by a history of patchwork planning is a simple task for a frequency planning/assignment strategy. The computer program, FREQPLN, was developed to allow the system planner to quickly and accurately try different plans based on, but not limited to: (1) equipment already in service; (2) retiring old excessive-bandwidth equipment; (3) frequency changes; (4) existing tuner and line traps bandwidths; and (5) new construction.

The present system can be checked for interference by having the program check the existing transmitters and receivers for direct interference, or for bandwidth overlap. This interference will be determined considering system voltage changes, line section separation, parallel lines, tapped lines, and insulated shield wires.

ADVANTAGES OF COMPUTER PLANNING

Although the computer program, FREQPLN, can be instructed to perform many tasks in connection with frequency planning, the reasons for developing such a program become obvious when faced with a large system and the need to make changes or additions. A minor addition to a hand maintained frequency plan can result in many hours of work. The advantage of a computer approach to frequency planning include the following:

1. Although developing the data base to represent the entire system of a utility is a formidable task, once the data is established, changes can be made readily, validity checks can be made by isolating parts of the data, copies can be made readily, and comparisons made with dated copies. No drafting or secretarial work is necessary.

2. The program can be run repeatedly with changes made only to files before actual system changes are made to check for interference with existing frequencies.

3. Change out and replacement of obsolete and frequency inefficient equipment with newer designs may show advantages of moving equipment to alternate locations in the system to better utilize the frequencies available.

4. New construction frequency planning can make use of "frequency keys" for combinations of protection equipment. The idea of a "frequency key" is explained in ECC-348 which describes the concepts of frequency planning. The "frequency key", in short, is a concept for repeating a block of frequencies on PLC circuits based on the equipment spacing bandwidths used. For a repetitive key, frequency blocks can be repeated after three blocks.

5. As those experienced in doing frequency planning by hand know, the amount of time required to try an iteration manually is sometimes prohibitive. The question of whether there is interference with or from existing equipment can only be answered after careful analysis and checking. Many times the information is not available to make a conclusive decision. The paper work required on a small system can be very time consuming. The computer can compare line length, line voltage, frequency assignment range, bandwidth, spacing requirements for adjacent channels, isolation across busses, parallel lines, etc. The program will not assign a channel to a slot that interferes with any other channel.

6. The plotting of the frequency plan by hand is slow and tedious. The computer can make changes after checking all of the rules and plot the channels. An updated file of all of the changes can be stored for future use. When assigning transmitters and receivers to the same bus, the frequency plot is the easiest tool to use to check spacing requirements between transmitters and receivers, interference between adjacent channels, guard bands, and isolation requirements across a bus at the same station. It is much easier to see the inter-relation of bandwidths with a chart of the entire frequency plan than to imagine how the various parts interact.

EXAMPLE 1. DEFINING BLOCKS OF FREQUENCIES USING FREQUENCY KEY

To demonstrate some of the techniques used to plan frequencies for a small system, a system similar to that used in ECC-348, "GUIDE TO POWER LINE CARRIER FREQUENCY PLANNING", will be used. The number of stations has been reduced to ten (10) for simplicity in plotting the frequency plan. The approach in this problem is divided into two parts. The first part involves planning the frequency assignments based on a "frequency key". For this key, the assumption is made that the entire system will use narrow band FSK channels in a dual channel configuration and a wideband blocking carrier channel. The frequency key is shown in Figure 11-1. As far as the first part of the procedure is concerned, the five channels in the block are treated as a single entity. The second part of the procedure involves expanding this block into its parts. This involves determining the bandwidths of the individual channels for the five functions in the block. This is done as Example 2. The bandwidths are defined by a low frequency, "FLO", and a high frequency, called "FHIGH" by the program.

The system diagram of Figure 11-2 shows the ten stations. The stations are given node numbers and line designations. All lines are assumed to be 500 kv, and the line designation reflects this. (All line designations begin with "50NN" for the line voltage.) The minimum frequency for the first FSK channel is 100 kHz, and the spacing between PLC FSK channels is assumed to be as shown in Figure 11-1 - or 500 Hz. The spacing between narrowband FSK channels and the wideband blocking carrier channel is 2.0 kHz.

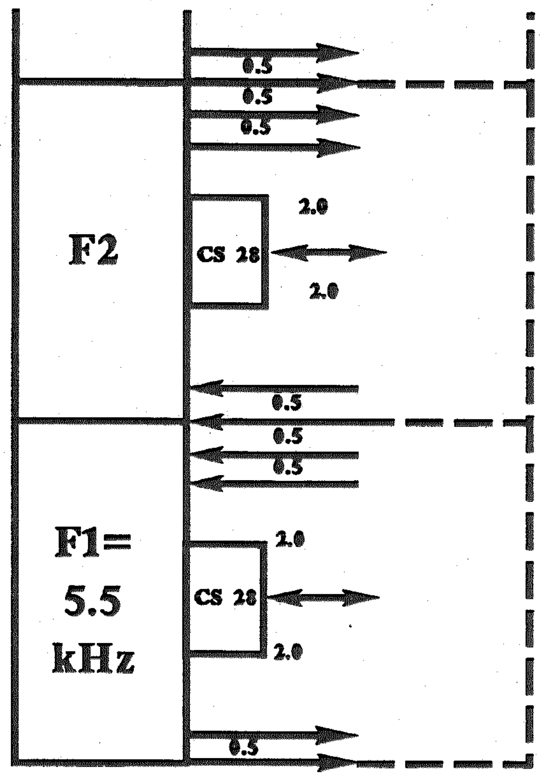

Figure 11-1. Frequency Key for Example

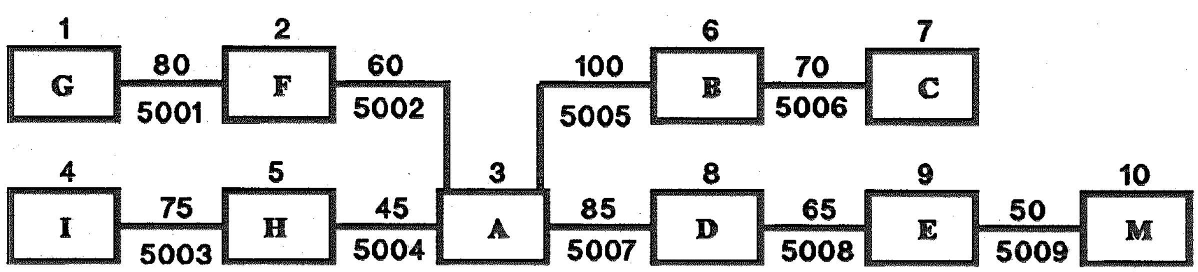

Figure 11-2. System Diagram for Frequency Planning Examples

The line lengths are assumed to be as shown in the computer program output of Figure 11-3. The characteristics of the system are all shown in Figure 11-3. For example: line 5001 is 80 miles long; its minimum frequency assignment is 99.75 kHz(this is the center frequency minus one-half the spacing to the next channel); the program is to assign one 5.500 kHz bandwidth channel to this line section; and the line section is between Stations G and F (nodes 1 and 2). The spacing bandwidth is used when there is more than one channel to be assigned to a particular line section. Since there is only one band of frequencies to be assigned in this example, this data is not used by the program, and any value may be inserted. Zeros are inserted in this case.

Refer to Figure 11-4 for the channel assignments made by **FREQPLN**. The program makes its assignments of channels based on the longest line first. Therefore, line 5005 is assigned the lowest frequency since it is the longest line. Four line sections are assigned the range from 110.750 to 116.250 kHz. The shortest line, line section 5004,is assigned the highest band of frequencies - 121.75 to 127.25 kHz.

Figure 11-5 shows a list of all of the channels in terms of their bandwidths for each station. Station A, which is node 3, has four line section terminations, and thus must have four assigned bands of frequencies. The end stations - Stations G, I, C, and M - have only one band of frequencies assigned. All others, since they are between two other stations, have two bands of frequencies assigned.

```
FREQUENCY PLANNING PROGRAM, FREQPLN, RUN (DATE)  04/23/1991  TIME  08:28:06:66

 NODE VERSUS STATION LIST
  NODE 1    STATION G 500 KV
  NODE 2    STATION F 500 KV
  NODE 3    STATION A 500 KV
  NODE 4    STATION I 500 KV
  NODE 5    STATION H 500 KV
  NODE 6    STATION B 500 KV
  NODE 7    STATION C 500 KV
  NODE 8    STATION D 500 KV
  NODE 9    STATION E 500 KV
  NODE 10   STATION M 500 KV
```

LINE DESIGNATION	LINE LENGTH	MINIMUM FREQUENCY	REQUIRED CHANNELS	ASSIGNED BANDWIDTH	STATION NODE-ONE	STATION NODE-TWO	SPACING BANDWIDTH
5001	80.00	99.75	1	5.50	1	2	.00
5002	60.00	99.75	1	5.50	2	3	.00
5004	45.00	99.75	1	5.50	3	5	.00
5005	100.00	99.75	1	5.50	3	6	.00
5007	85.00	99.75	1	5.50	3	8	.00
5003	75.00	99.75	1	5.50	4	5	.00
5006	70.00	99.75	1	5.50	6	7	.00
5008	65.00	99.75	1	5.50	8	9	.00
5009	50.00	99.75	1	5.50	9	10	.00

Figure 11-3.

LINE SECTION	BANDWIDTH OF ASSIGNED FREQUENCY (KHZ)	CHANNEL NUMBER
ASSIGNED CHANNELS STATION A 500 KV TO STATION B 500 KV 5005	99.75- 105.25	1
ASSIGNED CHANNELS STATION A 500 KV TO STATION D 500 KV 5007	105.25- 110.75	1
ASSIGNED CHANNELS STATION G 500 KV TO STATION F 500 KV 5001	110.75- 116.25	1
ASSIGNED CHANNELS STATION I 500 KV TO STATION H 500 KV 5003	110.75- 116.25	1
ASSIGNED CHANNELS STATION B 500 KV TO STATION C 500 KV 5006	110.75- 116.25	1
ASSIGNED CHANNELS STATION D 500 KV TO STATION E 500 KV 5008	110.75- 116.25	1
ASSIGNED CHANNELS STATION F 500 KV TO STATION A 500 KV 5002	116.25- 121.75	1
ASSIGNED CHANNELS STATION E 500 KV TO STATION M 500 KV 5009	99.75- 105.25	1
ASSIGNED CHANNELS STATION A 500 KV TO STATION H 500 KV 5004	121.75- 127.25	1

Figure 11-4.

NODE	LINE(I)	FLO	FHIGH	STATION NAME
1	5001	110.75-	116.25	STATION G 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
2	5001	110.75-	116.25	STATION F 500 KV
2	5002	116.25-	121.75	STATION F 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
3	5002	116.25-	121.75	STATION A 500 KV
3	5004	121.75-	127.25	STATION A 500 KV
3	5005	99.75-	105.25	STATION A 500 KV
3	5007	105.25-	110.75	STATION A 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
4	5003	110.75-	116.25	STATION.I 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
5	5004	121.75-	127.25	STATION H 500 KV
5	5003	110.75-	116.25	STATION H 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
6	5005	99.75-	105.25	STATION B 500 KV
6	5006	110.75-	116.25	STATION B 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
7	5006	110.75-	116.25	STATION C 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
8	5007	105.25-	110.75	STATION D 500 KV
8	5008	110.75-	116.25	STATION D 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
9	5008	110.75-	116.25	STATION E 500 KV
9	5009	99.75-	105.25	STATION E 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
10	5009	99.75-	105.25	STATION M 500 KV

Figure 11-5.

Figure 11-6 is a computer plot of the frequency plan. The number in the "*'s" is the station node destination for that band of frequencies. From the plot can be noted that Station A has all of the bands of frequencies except the repeated band from 110.76-116.25 kHz. There are five bands assigned, which is four less than the maximum if each line section were assigned a different band. The repeating of frequencies following the "two line sections and three buses" criterion has saved 22 kHz of bandwidth for the system.

```
       STATION G STATION F STATION A STATION I STATION H STATION B STATION C STATION D STATION E STATION M
       500 KV    500 KV    500 KV    500 KV    500 KV    500 KV    500 KV    500 KV    500 KV    500 KV
          *01*      *02*      *03*      *04*      *05*      *06*      *07*      *08*      *09*      *10*
FREQ
127.25                          /--\            /--\
126.75                          *05*            *03*
126.25                          *05*            *03*
125.75                          *05*            *03*
125.25                          *05*            *03*
124.75                          *05*            *03*
124.25                          *05*            *03*
123.75                          *05*            *03*
123.25                          *05*            *03*
122.75                          *05*            *03*
122.25                          *05*            *03*
121.75                /--\  /--\\--/            \--/
121.25                *03*  *02*
120.75                *03*  *02*
120.25                *03*  *02*
119.75                *03*  *02*
119.25                *03*  *02*
118.75                *03*  *02*
118.25                *03*  *02*
117.75                *03*  *02*
117.25                *03*  *02*
116.75                *03*  *02*
116.25      /--\  /--\\--/  \--/          /--\  /--\          /--\  /--\          /--\  /--\
115.75      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
115.25      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
114.75      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
114.25      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
113.75      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
113.25      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
112.75      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
112.25      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
111.75      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
111.25      *02*  *01*                    *05*  *04*          *07*  *06*          *09*  *08*
110.75      \--/  \--/          /--\      \--/  \--/          \--/  \--/      /--\\--/  \--/
110.25                          *08*                                          *03*
109.75                          *08*                                          *03*
109.25                          *08*                                          *03*
108.75                          *08*                                          *03*
108.25                          *08*                                          *03*
107.75                          *08*                                          *03*
107.25                          *08*                                          *03*
106.75                          *08*                                          *03*
106.25                          *08*                                          *03*
105.75                          *08*                                          *03*
105.25                          ====                      /--\                \--/          /--\  /--\
104.75                          *06*                      *03*                              *10*  *09*
104.25                          *06*                      *03*                              *10*  *09*
103.75                          *06*                      *03*                              *10*  *09*
103.25                          *06*                      *03*                              *10*  *09*
102.75                          *06*                      *03*                              *10*  *09*
102.25                          *06*                      *03*                              *10*  *09*
101.75                          *06*                      *03*                              *10*  *09*
101.25                          *06*                      *03*                              *10*  *09*
100.75                          *06*                      *03*                              *10*  *09*
100.25                          *06*                      *03*                              *10*  *09*
 99.75                          \--/                      \--/                              \--/  \--/
```

Figure 11-6. Plot of Frequency Plan Using Key of Figure 1

EXAMPLE 2. ASSIGNING SPECIFIC CHANNEL FREQUENCIES

Now that the basic plan has been developed, the problem is reduced to defining the various functional bandwidths within these bands for the frequency key of Figure 11-1. The key shows two FSK transmitters separated by 0.5 kHz. The next carrier for the blocking carrier channel is 2.0 kHz higher than the second FSK center frequency. The first narrowband FSK channel is placed at the lower end of the frequency block at 100.00 kHz. The bandwidth of the second narrowband FSK channel will be from 100.25 kHz to 100.75 kHz, for a total bandwidth of 0.500 kHz, but offset by 250 Hz from the center, or carrier, frequency. Assuming the same type of symmetry for the other functions gives the results listed in Table 11-1 for the lowest 5.5 kHz band of frequencies.

TABLE 11-1

ASSIGNED FREQUENCIES FOR FIRST 5.5 KHZ BAND FOR SECOND STEP OF FREQUENCY PLAN				
FUNCTION	CHANNEL NO.	FLO (KHZ)	FHIGH (KHZ)	CARRIER (KHZ)
NB FSK	1	99.75	100.25	100.00
NB FSK	2	100.25	100.75	100.50
WB BL. CXR	3	100.75	104.25	102.50
NB FSK	4	104.25	104.75	104.50
NB FSK	5	104.75	105.25	105.00

The values for the other four ranges can be calculated in a similar manner. These bandwidths must be specified by the user of the program and entered as a data file for "pre-assigned" frequency bands.

A second run through the program results in the listing of bandwidths and channel numbers for each line section as shown in Figure 11-7A and Figure 11-7B. The list of stations shown in Figure 11-3 for the first part of the problem is not repeated. The only change is that the "REQUIRED CHANNELS" is set to zero for all line sections since the channel frequencies have been determined and are part of the input data as "pre-assigned frequencies".

LINE SECTION	BANDWIDTH OF ASSIGNED FREQUENCY (KHZ)	CHANNEL NUMBER
PREASSIGNED OR EXCLUDED CHANNELS STATION A 500 KV TO STATION B 500 KV		
5005	99.75- 100.25	1
5005	100.25- 100.75	2
5005	100.75- 104.25	3
5005	104.25- 104.75	4
5005	104.75- 105.25	5
PREASSIGNED OR EXCLUDED CHANNELS STATION A 500 KV TO STATION D 500 KV		
5007	105.25- 105.75	1
5007	105.75- 106.25	2
5007	106.25- 109.75	3
5007	109.75- 110.25	4
5007	110.25- 110.75	5
PREASSIGNED OR EXCLUDED CHANNELS STATION G 500 KV TO STATION F 500 KV		
5001	110.75- 111.25	1
5001	111.25- 111.75	2
5001	111.75- 115.25	3
5001	115.25- 115.75	4
5001	115.75- 116.25	5
PREASSIGNED OR EXCLUDED CHANNELS STATION I 500 KV TO STATION H 500 KV		
5003	110.75- 111.25	1
5003	111.25- 111.75	2
5003	111.75- 115.25	3
5003	115.25- 115.75	4
5003	115.75- 116.25	5

Figure 11-7A.

PREASSIGNED OR EXCLUDED CHANNELS
STATION B 500 KV
TO STATION C 500 KV

5006	110.75- 111.25	1
5006	111.25- 111.75	2
5006	111.75- 115.25	3
5006	115.25- 115.75	4
5006	115.75- 116.25	5

PREASSIGNED OR EXCLUDED CHANNELS
STATION D 500 KV
TO STATION E 500 KV

5008	110.75- 111.25	1
5008	111.25- 111.75	2
5008	111.75- 115.25	3
5008	115.25- 115.75	4
5008	115.75- 116.25	5

PREASSIGNED OR EXCLUDED CHANNELS
STATION F 500 KV
TO STATION A 500 KV

5002	116.25- 116.75	1
5002	116.75- 117.25	2
5002	117.25- 120.75	3
5002	120.75- 121.25	4
5002	121.25- 121.75	5

PREASSIGNED OR EXCLUDED CHANNELS
STATION E 500 KV
TO STATION M 500 KV

5009	99.75- 100.25	1
5009	100.25- 100.75	2
5009	100.75- 104.25	3
5009	104.25- 104.75	4
5009	104.75- 105.25	5

PREASSIGNED OR EXCLUDED CHANNELS
STATION A 500 KV
TO STATION H 500 KV

5004	121.75- 122.25	1
5004	122.25- 122.75	2
5004	122.75- 126.25	3
5004	126.25- 126.75	4
5004	126.75- 127.25	5

Figure 11-7B

Figures 11-8A and 11-8B show a listing of the transmitters and receivers for each line section showing where the transmitters and receivers are located, the frequency band, the model numbers of the equipment, and are listed in pairs. This information is part of a second data file used to create the plot of the frequency plan.

TX/RX PAIRS	TRANSMITTERS BANDWIDTH	MODEL NO.	RECEIVERS BANDWIDTH	MODEL NO.	LINE NO.	STATION NAME
1	110.75-111.25	CT51-A	115.25-115.75	CR51-A	5001	STATION G 500 KV
1	115.25-115.75	CT51-A	110.75-111.25	CR51-A	5001	STATION F 500 KV
2	111.25-111.75	CT51-A	115.75-116.25	CR51-A	5001	STATION G 500 KV
2	115.75-116.25	CT51-A	111.25-111.75	CR51-A	5001	STATION F 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5001	STATION G 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5001	STATION F 500 KV
1	116.25-116.75	CT51-A	120.75-121.25	CR51-A	5002	STATION F 500 KV
1	120.75-121.25	CT51-A	116.25-116.75	CR51-A	5002	STATION A 500 KV
2	116.75-117.25	CT51-A	121.25-121.75	CR51-A	5002	STATION F 500 KV
2	121.25-121.75	CT51-A	116.75-117.25	CR51-A	5002	STATION A 500 KV
3	117.25-120.75	CS26-C	117.25-120.75	CS26-C	5002	STATION F 500 KV
3	117.25-120.75	CS26-C	117.25-120.75	CS26-C	5002	STATION A 500 KV
1	121.75-122.25	CT51-A	126.25-126.75	CR51-A	5004	STATION A 500 KV
1	126.25-126.75	CR51-A	121.75-122.25	CR51-A	5004	STATION H 500 KV
2	122.25-122.75	CT51-A	126.75-127.25	CR51-A	5004	STATION A 500 KV
2	126.75-127.25	CT51-A	122.25-122.75	CR51-A	5004	STATION H 500 KV
3	122.75-126.25	CS26-C	122.75-126.25	CS26-C	5004	STATION A 500 KV
3	122.75-126.25	CS26-C	122.75-126.25	CS26-C	5004	STATION H 500 KV
1	99.75-100.25	CT51-A	104.25-104.75	CR51-A	5005	STATION A 500 KV
1	104.25-104.75	CT51-A	99.75-100.25	CR51-A	5005	STATION B 500 KV
2	100.25-100.75	CT51-A	104.75-105.25	CR51-A	5005	STATION A 500 KV
2	104.75-105.25	CT51-A	100.25-100.75	CR51-A	5005	STATION B 500 KV
3	100.75-104.25	CS26-C	100.75-104.25	CS26-C	5005	STATION A 500 KV
3	100.75-104.25	CS26-C	100.75-104.25	CS26-C	5005	STATION B 500 KV
1	109.75-110.25	CT51-A	105.25-105.75	CR51-A	5007	STATION A 500 KV
1	105.25-105.75	CT51-A	109.75-110.25	CR51-A	5007	STATION D 500 KV
2	110.25-110.75	CT51-A	105.75-106.25	CR51-A	5007	STATION A 500 KV
2	105.75-106.25	CT51-A	110.25-110.75	CR51-A	5007	STATION D 500 KV
3	106.25-109.75	CS26-C	106.25-109.75	CS26-C	5007	STATION A 500 KV
3	106.25-109.75	CS26-C	106.25-109.75	CS26-C	5007	STATION D 500 KV
1	110.75-111.25	CT51-A	115.25-115.75	CR51-A	5003	STATION I 500 KV
1	115.25-115.75	CT51-A	110.75-111.25	CR51-A	5003	STATION H 500 KV
2	111.25-111.75	CT51-A	115.75-116.25	CR51-A	5003	STATION I 500 KV
2	115.75-116.25	CT51-A	111.25-111.75	CR51-A	5003	STATION H 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5003	STATION I 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5003	STATION H 500 KV

Figure 11-8A

1	110.75-111.25	CT51-A	115.25-115.75	CR51-A	5006	STATION B 500 KV
1	115.25-115.75	CT51-A	110.75-111.25	CR51-A	5006	STATION C 500 KV
2	111.25-111.75	CT51-A	115.75-116.25	CR51-A	5006	STATION B 500 KV
2	115.75-116.25	CT51-A	111.25-111.75	CR51-A	5006	STATION C 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5006	STATION B 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5006	STATION C 500 KV
1	115.25-115.75	CT51-A	110.75-111.25	CR51-A	5008	STATION D 500 KV
1	110.75-111.25	CT51-A	115.25-115.75	CR51-A	5008	STATION E 500 KV
2	115.75-116.25	CT51-A	111.25-111.75	CR51-A	5008	STATION D 500 KV
2	111.25-111.75	CT51-A	115.75-116.25	CR51-A	5008	STATION E 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5008	STATION D 500 KV
3	111.75-115.25	CS26-C	111.75-115.25	CS26-C	5008	STATION E 500 KV
1	99.75-100.25	CT51-A	104.25-104.75	CR51-A	5009	STATION E 500 KV
1	104.25-104.75	CT51-A	99.75-100.25	CR51-A	5009	STATION M 500 KV
2	100.25-100.75	CT51-A	104.75-105.25	CR51-A	5009	STATION E 500 KV
2	104.75-105.25	CT51-A	100.25-100.75	CR51-A	5009	STATION M 500 KV
3	100.75-104.25	CS26-C	100.75-104.25	CS26-C	5009	STATION E 500 KV
3	100.75-104.25	CS26-C	100.75-104.25	CS26-C	5009	STATION M 500 KV

Figure 11-8B

Figure 11-9 is a partial listing of the bands of frequencies at each station for all of the lines terminating at that station. This listing shows a breakdown of the twenty channels terminating on the four lines at Station A. A listing similar to this would be useful if a piece of equipment failed and a spare or replacement were available from another station. Fewer spares which were frequency sensitive would be needed if there were repeated frequencies on the system. A piece of equipment from a less critical line section could be used as a temporary spare if the frequencies matched.

The plot of the frequency plan for this example with five channels at each station on each line section is shown in Figures 11-10A and 11-10B. The "T" and "R" designations signify a transmitter or a receiver in the frequency band shown at a particular station. The node (or station) numbers are between the letters. The station name and node number is across the top of the page. The plan is continued on a second sheet (Figure 11-10B. Each page of printout will accommodate up to ten (10) stations. The present program, running on a IBM compatible 386 personal computer with a math co-processor and 2 megabytes of memory using FORTRAN 77 language, will analyze up to one hundred (100) stations and one hundred and 30 (130) line sections. The number of pages in the printout of the frequency plan is determined by the resolution desired in the printout of the frequency bands. The resolution must be at least twice the minimum frequency bandwidth. For a 500 Hz minimum bandwidth, as in the example, a 250 Hz increment is required to print all the information for a legible plot.

NODE	LINE(I)	FLO	FHIGH	STATION NAME
1	5001	110.75-	111.25	STATION G 500 KV
1	5001	111.25-	111.75	STATION G 500 KV
1	5001	111.75-	115.25	STATION G 500 KV
1	5001	115.25-	115.75	STATION G 500 KV
1	5001	115.75-	116.25	STATION G 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
2	5001	110.75-	111.25	STATION F 500 KV
2	5001	111.25-	111.75	STATION F 500 KV
2	5001	111.75-	115.25	STATION F 500 KV
2	5001	115.25-	115.75	STATION F 500 KV
2	5001	115.75-	116.25	STATION F 500 KV
2	5002	116.25-	116.75	STATION F 500 KV
2	5002	116.75-	117.25	STATION F 500 KV
2	5002	117.25-	120.75	STATION F 500 KV
2	5002	120.75-	121.25	STATION F 500 KV
2	5002	121.25-	121.75	STATION F 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
3	5002	116.25-	116.75	STATION A 500 KV
3	5002	116.75-	117.25	STATION A 500 KV
3	5002	117.25-	120.75	STATION A 500 KV
3	5002	120.75-	121.25	STATION A 500 KV
3	5002	121.25-	121.75	STATION A 500 KV
3	5004	121.75-	122.25	STATION A 500 KV
3	5004	122.25-	122.75	STATION A 500 KV
3	5004	122.75-	126.25	STATION A 500 KV
3	5004	126.25-	126.75	STATION A 500 KV
3	5004	126.75-	127.25	STATION A 500 KV
3	5005	99.75-	100.25	STATION A 500 KV
3	5005	100.25-	100.75	STATION A 500 KV
3	5005	100.75-	104.25	STATION A 500 KV
3	5005	104.25-	104.75	STATION A 500 KV
3	5005	104.75-	105.25	STATION A 500 KV
3	5007	105.25-	105.75	STATION A 500 KV
3	5007	105.75-	106.25	STATION A 500 KV
3	5007	106.25-	109.75	STATION A 500 KV
3	5007	109.75-	110.25	STATION A 500 KV
3	5007	110.25-	110.75	STATION A 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
4	5003	110.75-	111.25	STATION I 500 KV
4	5003	111.25-	111.75	STATION I 500 KV
4	5003	111.75-	115.25	STATION I 500 KV
4	5003	115.25-	115.75	STATION I 500 KV
4	5003	115.75-	116.25	STATION I 500 KV

NODE	LINE(I)	FLO	FHIGH	STATION NAME
5	5004	121.75-	122.25	STATION H 500 KV
5	5004	122.25-	122.75	STATION H 500 KV
5	5004	122.75-	126.25	STATION H 500 KV
5	5004	126.25-	126.75	STATION H 500 KV
5	5004	126.75-	127.25	STATION H 500 KV
5	5003	110.75-	111.25	STATION H 500 KV
5	5003	111.25-	111.75	STATION H 500 KV
5	5003	111.75-	115.25	STATION H 500 KV
5	5003	115.25-	115.75	STATION H 500 KV
5	5003	115.75-	116.25	STATION H 500 KV

Figure 11-9.

FREQ	STATION G 500 KV *01*	STATION F 500 KV *02*	STATION A 500 KV *03*	STATION I 500 KV *04*	STATION H 500 KV *05*	STATION B 500 KV *06*	STATION C 500 KV *07*	STATION D 500 KV *08*	STATION E 500 KV *09*	STATION M 500 KV *10*
127.25			/--\		/--\					
127.00			R05R		T03T					
126.75			====		====					
126.50			R05R		T03T					
126.25			====		====					
126.00			T05T		T03T					
125.75			T05T		T03T					
125.50			T05T		T03T					
125.25			T05T		T03T					
125.00			T05T		T03T					
124.75			T05T		T03T					
124.50			T05T		T03T					
124.25			T05T		T03T					
124.00			T05T		T03T					
123.75			T05T		T03T					
123.50			T05T		T03T					
123.25			T05T		T03T					
123.00			T05T		T03T					
122.75			====		====					
122.50			T05T		R03R					
122.25			====		====					
122.00			T05T		R03R					
121.75		/--\	/--\\--/		\--/					
121.50		R03R	T02T							
121.25		====	====							
121.00		R03R	T02T							
120.75		====	====							
120.50		T03T	T02T							
120.25		T03T	T02T							
120.00		T03T	T02T							
119.75		T03T	T02T							
119.50		T03T	T02T							
119.25		T03T	T02T							
119.00		T03T	T02T							
118.75		T03T	T02T							
118.50		T03T	T02T							
118.25		T03T	T02T							
118.00		T03T	T02T							
117.75		T03T	T02T							
117.50		T03T	T02T							
117.25		====	====							
117.00		T03T	R02R							
116.75		====	====							
116.50		T03T	R02R							
116.25	/--\	/--\\--/	\--/	/--\	/--\	/--\	/--\	/--\	/--\	
116.00	R02R	T01T		R05R	T04T	R07R	T06T	T09T	R08R	
115.75	====	====		====	====	====	====	====	====	
115.50	R02R	T01T		R05R	T04T	R07R	T06T	T09T	R08R	
115.25	====	====		====	====	====	====	====	====	

Figure 11-10A. Plot of Frequency Plan (Page 1)

115.00	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
114.75	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
114.50	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
114.25	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
114.00	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
113.75	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
113.50	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
113.25	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
113.00	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
112.75	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
112.50	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
112.25	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
112.00	T02T	T01T		T05T	T04T		T07T	T06T		T09T	T08T		
111.75	====	====		====	====		====	====		====	====		
111.50	T02T	R01R		T05T	R04R		T07T	R06R		R09R	T08T		
111.25	====	====		====	====		====	====		====	====		
111.00	T02T	R01R		T05T	R04R		T07T	R06R		R09R	T08T		
110.75	\--/	\--/	/--\	\--/	\--/		\--/	\--/	/--\	\--/	\--/		
110.50			T08T						R03R				
110.25			====						====				
110.00			T08T						R03R				
109.75			====						====				
109.50			T08T						T03T				
109.25			T08T						T03T				
109.00			T08T						T03T				
108.75			T08T						T03T				
108.50			T08T						T03T				
108.25			T08T						T03T				
108.00			T08T						T03T				
107.75			T08T						T03T				
107.50			T08T						T03T				
107.25			T08T						T03T				
107.00			T08T						T03T				
106.75			T08T						T03T				
106.50			T08T						T03T				
106.25			====						====				
106.00			R08R						T03T				
105.75			====						====				
105.50			R08R						T03T				
105.25			====			/--\			\--/			/--\	/--\
105.00			R06R			T03T						R10R	T09T
104.75			====			====						====	====
104.50			R06R			T03T						R10R	T09T
104.25			====			====						====	====
104.00			T06T			T03T						T10T	T09T
103.75			T06T			T03T						T10T	T09T
103.50			T06T			T03T						T10T	T09T
103.25			T06T			T03T						T10T	T09T
103.00			T06T			T03T						T10T	T09T
102.75			T06T			T03T						T10T	T09T
102.50			T06T			T03T						T10T	T09T
102.25			T06T			T03T						T10T	T09T
102.00			T06T			T03T						T10T	T09T
101.75			T06T			T03T						T10T	T09T
101.50			T06T			T03T						T10T	T09T
101.25			T06T			T03T						T10T	T09T
101.00			T06T			T03T						T10T	T09T
100.75			====			====						====	====
100.50			T06T			R03R						T10T	R09R
100.25			====			====						====	====
100.00			T06T			R03R						T10T	R09R
99.75			\--/			\--/						\--/	\--/

Figure 11-10B. Plot of Frequency Plan (Page 2)

CONCLUSIONS:

These examples have shown very simple applications of the frequency planning program, FREQPLN. There are techniques to use to control assignments for two-frequency tuners and traps, for multi-bandwidth channels, for tapped lines, for voltage changes, and for combination insulated shield wire (ISW) and normal phase wire power line carrier.

Fast, accurate iterations can be made without the concern of these changes interfering with present frequencies. The time to do manual frequency planning and to try different equipment combinations is usually prohibitive. The speed of the computer approach makes trial modifications possible. Different system configurations can be tried such as moving equipment, changing frequencies of existing equipment, or retiring old equipment. Updates can be made to system records in a central location and dated copies kept for reference. The records are kept in the form of computer files and paper copies an be generated easily. The flexibility of the computer approach is only limited by the imagination of the user of the program. All of the trials and changes are checked by the rules and interfering frequencies are listed. A graphical representation, or plot of the trial plan in readily available without any drafting or changing by the planner. The entire process can be done in minutes instead of requiring hours or days once the data files have been established. A computer program that is not capable of being changed is one that is not used. As more experience is gained with the program, ad-additional features, modifications, and enhancements will be added. The flexibility of the program, FREQPLN, is considered adequate for most applications. FREQPLN has been used on very large systems of more then 100 stations, as well as on small systems. A version of the program suitable for use on a personal computer is contemplated.

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SECTION 12
AUXILIARY COUPLING DEVICES

Contents of Section 12

(Note: Adapted from reference [25]).

INTRODUCTION

Auxiliary coupling devices can be defined as any component of a PLC coupling scheme used to separate or to isolate functions on the equipment side of the coaxial cable. Therefore, these devices are usually mounted inside a building with the other terminal equipment. The equipment included in passive auxiliary coupling devices includes hybrids and filters. These are bilateral devices as opposed to active combining of PLC functions using uni-directional amplifiers. These coupling devices must also combine functions at the coaxial entrance to the cable going to, or coming from, the tuner. This implies a common port, or ports, flanking, or a cascade connection.

Various combinations of hybrid and filters may be used to combine and isolate transmitters and receivers to minimize the potential for creating intermodulation distortion in PLC terminal equipment.

HYBRIDS

A PLC RF hybrid is a passive, bilateral, lossy device derived from the Wheatstone Bridge circuit which is used to isolate PLC equipment to minimize intermodulation distortion when the equipment is coupled to the same terminal or line. This implies single phase or multiphase coupling. Hybrids can also be used as auxiliary coupling devices to couple PLC signals to different lines at the same station, as in line-to-line coupling schemes. The hybrids used in PLC applications are three port devices, as opposed to multi-port hybrids which may be applied in other communication circuits. The port connected to the line tuner coaxial interface should have a minimum return loss of 10 dB for all frequencies in use at the terminal. This minimum return loss will guarantee an isolation of 16 dB minimum between equipment connected to the inputs of the hybrid for balanced hybrids, and 23 dB for the usual skewed hybrid.

12 ▶

BALANCED OR SYMMETRICAL HYBRID

The symmetrical hybrid, or balanced transformer, as it has been referred to in PLC literature, is a wideband, center-tapped transformer with a non-inductive resistor of one-half the value of the terminating impedances of the two isolated ports connected between the center tap and ground. The device is usually referred to as having two input ports or source ports and one output port (or sink port). Since the device will function as a combiner, with loss, or a splitter, without loss, the notation of the inputs and outputs is arbitrary. Figure 12-1 shows the circuit of the symmetrical hybrid , which will be referred to also as a balanced hybrid. Also shown in Figure 12-1.A is a further simplified form of the balanced hybrid circuit. Since this device is bilateral (it works in both directions), the input can be made an output, as shown in Figure 12-2, and Figure 12-2.A, and the outputs can function as inputs. In the circuit of Figure 12-1 (12-1.A), a signal is split into two signals of equal amplitude and opposite phase (0 and 180 degrees). There is no loss in the hybrid for this mode of operation. Two possibilities of interest exist for the circuit of Figure 12-2 and 12-2.A.

Case 1. A signal at input 1 at one frequency, F1, and another at input 2 at a different frequency, F2, will result in a current in the resistor $R_0/2$, and result in a three dB loss of power. (Note that no current will flow in $R_0/2$ of Figure 12-1, hence no power is dissipated.)

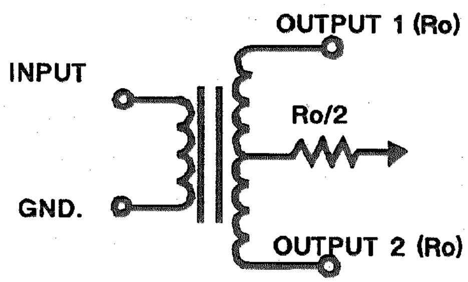


Figure 12-1

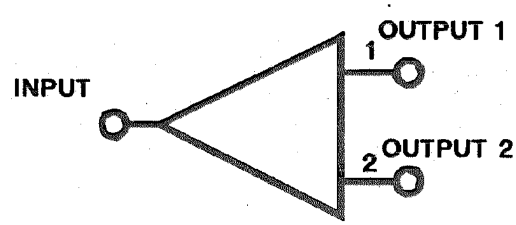


Figure 12-1A

Case 2. The second possibility of interest for the circuit of Figure 12-2 occurs when the signals at input 1 and at input 2 are of equal magnitude and frequency content, but are opposite in phase. This case is similar to the case of Figure 12-1, except the direction of signal flow is reversed. For this case, as in Figure 12-1(1.A), no current flows in $R_0/2$, hence no power is dissipated and the power is combined and delivered to the output of the transformer.

The balanced hybrid also will isolate the outputs of Figure 12-1(the inputs of Figure 12-2) from each other. The isolation between input ports is 6 dB plus the return loss at the output, or sink. Depending on the turns ratio, and the value of $R_0/2$, various impedances can be accommodated at the inputs and outputs of the hybrids. Standard values of R_0 may include 50, 75, 100, 125, or 150 ohms with strappable values of $R_0/2$ and various turns ratios to allow different values of input and output impedance to be used with the same device, as in the GE CL14BL4 balanced hybrid.

Because of its very wideband characteristics, the symmetrical hybrid can have a high power rating even for a fairly small device. The power rating of the $R_0/2$ resistor is usually the limiting component in this hybrid. Two transmitters, which are closely spaced in the frequency spectrum, can be safely combined with about 3 dB of loss using the symmetrical, or balanced hybrid. The isolation is the result of the balance of the hybrid when properly terminated at the output port. The isolation does not depend on the frequency of the devices at the inputs.

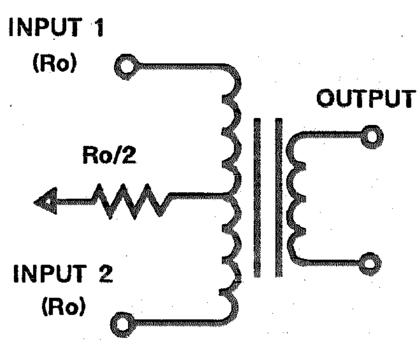


Figure 12-2

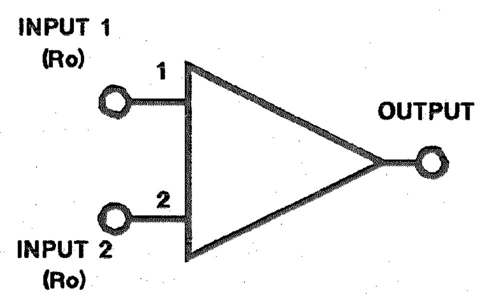


Figure 12-2A

MULTIPLE HYBRID CIRCUITS

A single balanced hybrid, such as is shown in Figure 12-1, can be used for phase-to-phase coupling. A two-hybrid connection can be used by cascading two Figure 12-1 circuits to form a Mode I coupling arrangement. Since there is a common path in both of these circuits, a failure in this path will cause the entire system to fail. Redundant connections of balanced hybrids are used to provide multiple paths for coupling to critical circuits. These redundant multiple hybrid circuits are called "Balanced Combiners", since they combine signals in a balanced manner for coupling to phase wires.

These isolated, dual, multiple phase coupling networks using symmetrical, or balanced, hybrids are interconnected to overcome this common connection disadvantage. The modes of propagation are generated separately for the primary and secondary circuits and then combined. Proper phase and magnitudes of voltages associated with each function are maintained in an independent manner. This is accomplished using a cross-coupled symmetrical hybrid approach as shown in Figure 12-3.

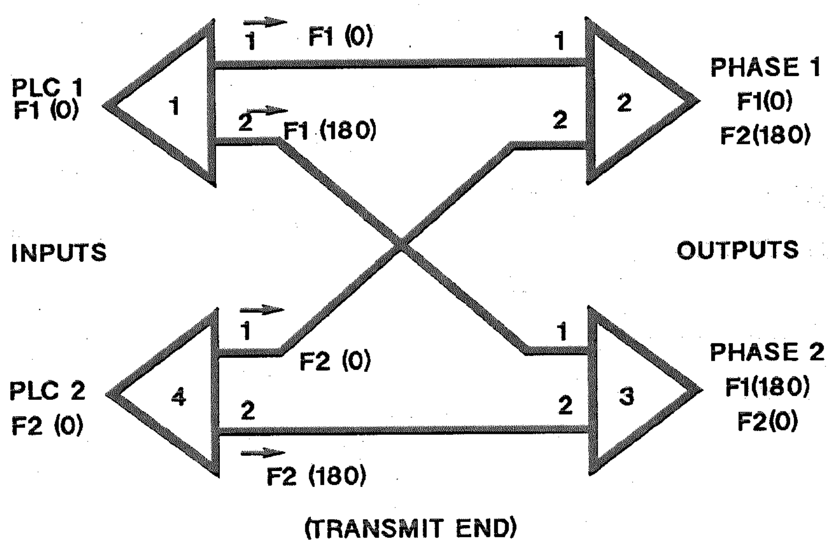


Figure 12-3

Using the simplified circuits developed in Figures 12-1 and 12-2, the circuit of Figure 12-3 is a phase-to-phase balanced combiner. Using the notation of Figure 12-1.A and Figure 12-2.A, we add numbers to the hybrids of Figure 12-3 and the following conventions: a signal at any terminal labeled "1" undergoes no phase shift going from left to right; a signal at any terminal labeled "2" undergoes a 180 degree phase shift going from left to right. The relative phases shown in Figure 12-3 will exist using these conventions. Using Case 1 for hybrids 2 and 3 of Figure 12-3, there will be 3 dB power loss in the resistors of these hybrids. The remaining power injected for the two frequencies of F1 and F2 is available at the phase 1 and phase 2 outputs. The levels of the individual signals at the phase 1 and phase 2 outputs are 6 dB below the levels at PLC1 and PLC2 because of the power splitting in hybrids 1 and 4. In Figure 12-4, we will take the magnitude of the signals at phase 1 and phase 2 as "1.0", as shown in the parentheses before the frequency and its phase. Tracing each signal, with its phase, through the combiner shows that the magnitude of the signals at the outputs is the same as at the inputs. This indicates that the outputs of the individual frequency components at PLC1 and PLC2 of Figure 12-4 are 6 dB below the inputs at PLC1 and PLC2 of Figure 12-3.

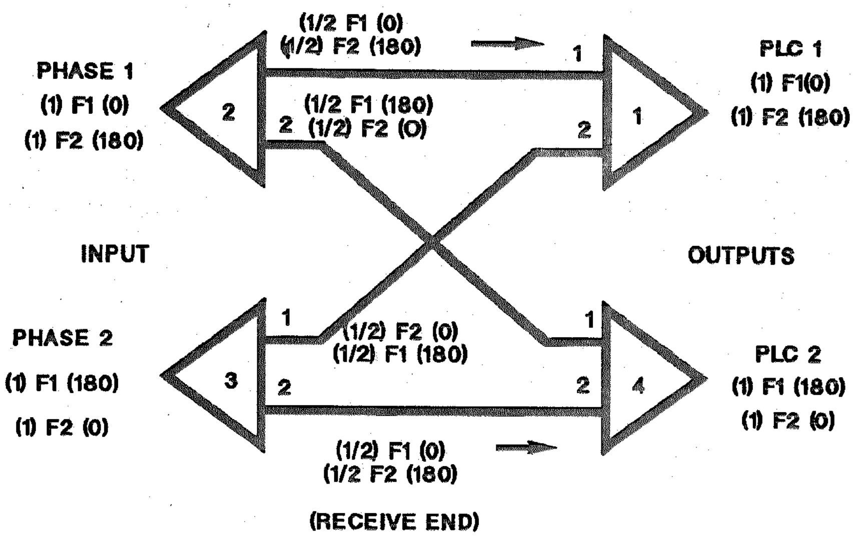


Figure 12-4

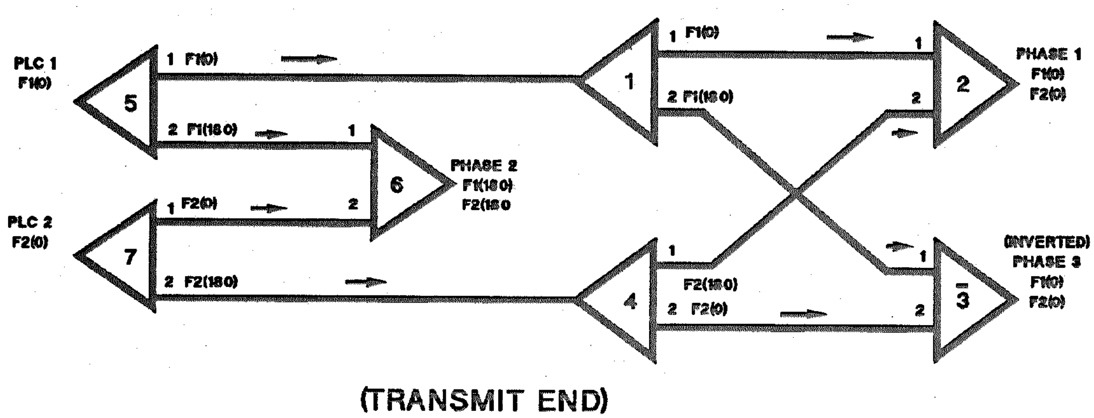


Figure 12-5

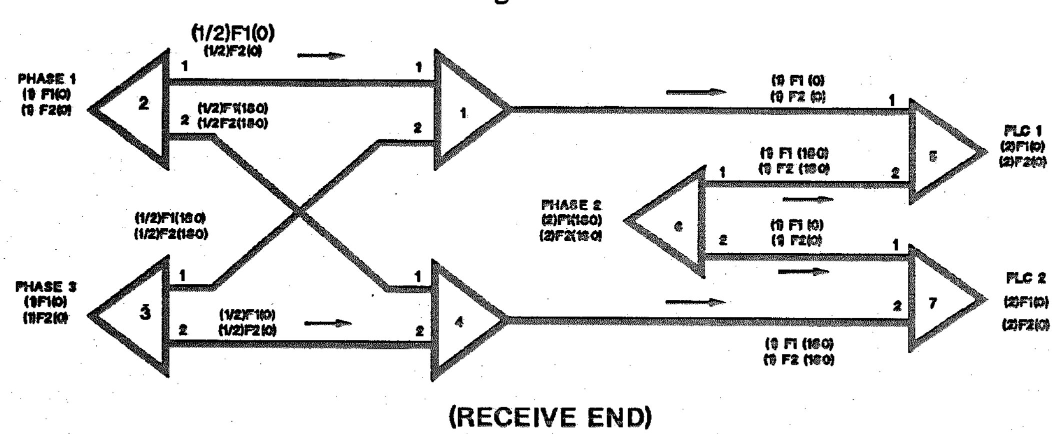


Figure 12-6

It should be remembered that the combiner is bilateral and the "outputs" of Figure 12-4 can also function as transmitter inputs. The four parallel paths in the combiners of Figure 12-3 and Figure 12-4 assure that no single contingency failure or fault will interrupt communications between stations.

The Mode I balanced combiner is more complex than the phase-to-phase combiner. This configuration is shown in Figures 12-5 and 12-6. The Mode I combiner uses seven balanced hybrids. Comparing the circuit of Figure 12-5 with that of Figure 12-3 shows that hybrids 1 through 4 of the two circuits are identical, except for the bar over hybrid number 3, indicating that all phases are inverted again from left to right. The center phase output is provided by adding hybrids 5, 6, and 7.

The magnitude of the voltages at phase 1 and phase 3 are 9 dB below the PLC1 and PLC2 inputs, and are of the same phase. The additional apparent 3 dB loss comes from the splitting of power in hybrids 5 and 7. The level at phase 2 output is 6 dB below the PLC1 and PLC2 levels by the power splitting of hybrids 5 and 7 and the 3 dB power combining loss of hybrid 6. Thus, the relative magnitudes of the three phases are 0.5, -1.0, and 0.5, which are the proper relative amplitudes and phases for Mode I coupling. The circuit of Figure 12-6 shows the receiving end version of Figure 12-5 for the Mode I balanced combiner.

The actual power loss takes place in hybrids 2, 3, and 6 of Figure 12-5 for the Mode I combiner. By following the splitting and combining actions of the various hybrids in Figure 12-6, we note that the levels at PLC1 and PLC2 are doubled. Since the output levels on phase 2 and Phase 3 are down 9 dB from the transmitted levels in Figure 12-5, the levels at PLC1 and PLC2 of Figure 12-6 are 6 dB down from the transmitted signal levels. The remaining 3 dB of power shows up at the other PLC port where it may not be utilized. The redundancy of the Mode I balanced combiner is also apparent from the many parallel paths for signal flow.

An alternate arrangement for the balanced combiner eliminates the loss in hybrids 2 and 3 of Figure 12-3 by replacing these hybrids with lowpass/highpass branching filters. This circuit also discriminates between low and high frequency channels and identical signals do not appear at both receiver inputs as in the combiners of Figures 12-4 and 12-6. The addition of another balanced hybrid will transform that into a Mode I coupling circuit. There must be at least a 10 per cent separation between the lowpass and highpass filter cutoff frequencies. The only power loss in this circuit is that of the transformer windings and the branching filters. The loss is usually less than 0.5 dB for the entire circuit.

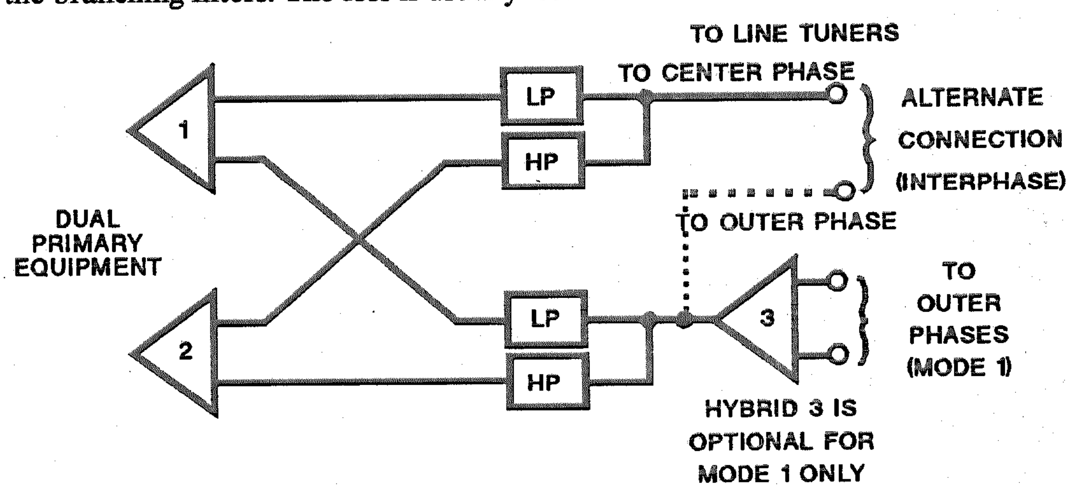


Figure 12-7

SKEWED HYBRID

The skewed hybrid is a modification of the Wheatstone Bridge circuit where unequal amounts of power are divided between a source and a sink. The circuit requires two transformers with different windings to accomplish this unequal split. Various circuits are possible, but the skewed hybrid used for PLC applications usually has less than 0.5 dB loss in one direction and greater than 12 dB loss in the other direction. The transmitter is connected to the low loss port, and the receiver is connected to the high loss port. Figure 12-8 shows the usual skewed hybrid connections. In this connection, the circuit has one source, the transmitter, and one sink, the receiver. The isolation between the transmit and receive ports depends directly on the return loss at the output port. The higher loss between the line and receive ports does not degrade the signal-to-noise ratio at the receiver, since both signal and noise levels are reduced by equal amounts.

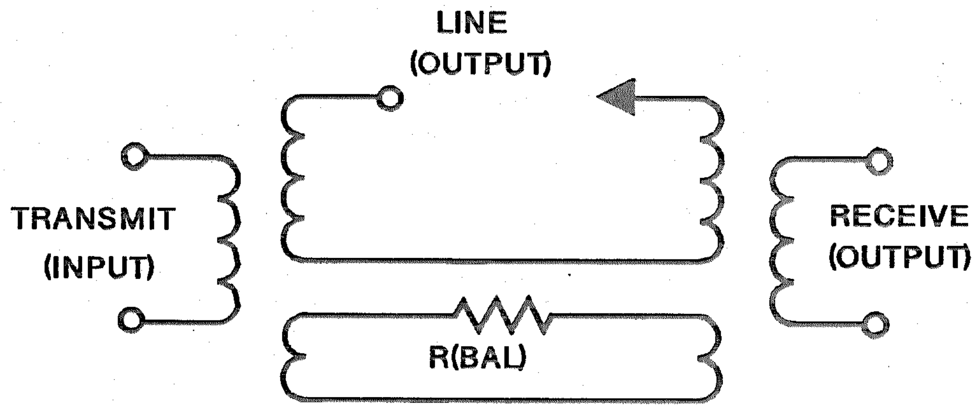


Figure 12-8. Skewed Hybrid

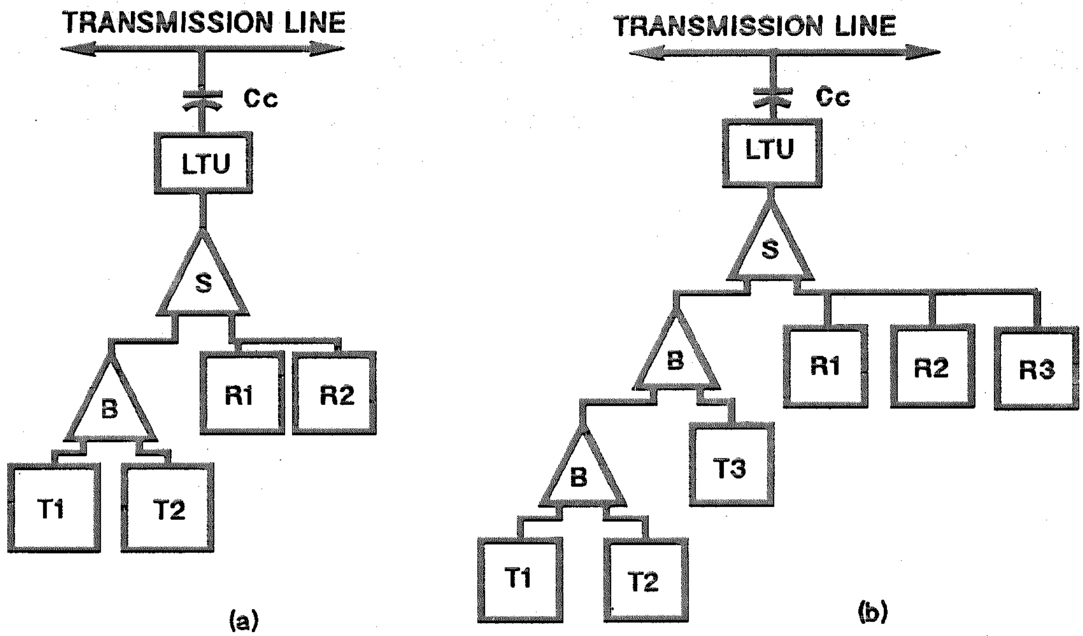
HYBRID COMBINATION CIRCUITS

Various combinations of skewed and balanced hybrids can be used as auxiliary coupling components. Two of these circuits are shown in Figure 12-9. The loss in Figure 12-9(a) attributed to the hybrids for transmitters T1 and T2 is approximately 3.5 dB. In Figure 12-9(b) the loss for transmitters T1 and T2 is about 6.5 dB, and the loss for transmitter T3 is approximately 3.5 dB.

REACTANCE OR "X" HYBRIDS

The reactance hybrid, or "X" hybrid, was used in past years to improve the "match" in coupling circuits where the coupling capacitance value was small, and the resulting bandwidth at low PLC frequencies was narrow for resonant line tuners. The reactive impedance connected to the line side of the "X" hybrid was used to match the reactive impedance looking into the coaxial cable going to the line tuner. This "match" improvement did not increase the line tuner bandwidth. Actually, the result was probably a reduction in bandwidth. A better reactive impedance match to the transmitter was the result when the reactive components were properly selected.

With the increase in the coupling capacitor values in recent years and the use of wideband tuners, the usefulness of the reactance hybrid is questionable. Only where signals are being coupled on the slopes of tuners - at 3 dB down - can the "X" hybrid improve the match of impedances, and possibly the isolation between the two input ports on the equipment side of the circuit. In this rather rare case, the coupling efficiency is poor and changing to a higher order tuner or a frequency change would be preferable, and probably less costly than a reactance hybrid.



HYBRIDS USED AS ISOLATING DEVICES TO SEPARATE TRANSMITTERS AND RECEIVERS

Figure 12-9

Thus, the "X" hybrid has been superseded by the availability of wideband tuners for increasing the coupling bandwidth and improving the return loss for coupling circuits. The wideband balanced, or symmetrical, hybrid is now used in place of the narrow band reactance hybrid to provide isolation between transmitters and to build hybrid strings.

FILTERS AS AUXILIARY COUPLING DEVICES

When the frequencies of transmitters are spaced far enough apart, the loss of combining and isolating functions may be reduced by using filters in place of balanced hybrids in auxiliary coupling circuits. The bandpass filter is usually the choice for separating transmitters. The type of bandpass filter depends on the frequency spacing of the transmitters and the required power level. The series L/C bandpass filter can be used as the most simple filter device to combine transmitters. The application of series L/C units requires a knowledge of the current limits for capacitors and inductors in the L/C unit. An extensive treatment of the approach for selecting and designing these filters is included in Appendix A.

For the separation of SSB transmitters, the bandpass filters with 4 kHz, 5 kHz, 8 kHz, and 16 kHz bandwidths are commonly used in PLC applications. As shown in Appendix B under fixed bandwidth bandpass filters, FSK transmitters and other line and equipment protection equipment can be isolated using these filters. The separation between transmitters is two bandwidths from bandedge to bandedge. The power rating of these filters is 100 watts peak effective power (PEP). Application information is given under fixed bandwidth filters.

The third type of filter used in auxiliary coupling circuits to separate bands of frequencies is the lowpass/highpass branching filter. These filters are band-splitting filters which may be used alone, or in combination with other coupling devices, to isolate and separate PLC equipment. The branching filters are designed around the 4 kHz spacing of SSB channels, but these filters can be used in any PLC application where a split of high and low frequency bands is desired. The power rating of these branching filters is 100 watts RMS. Spacing is 10% between highpass and lowpass closest frequencies. Several applications of lowpass/highpass branching filters are shown in Appendix C.

APPENDIX A.

SERIES L/C FILTERS

INTRODUCTION

There are many instances when it is possible to reduce the coupling losses usually encountered with hybrid combining by using L/C series bandpass units. Since there are definite limits restricting the use of series L/C units based on the current capacities of the components in these units, a strict adherence to application guidelines is required. For obtaining a minimum isolation of 15 dB between transmitters, the minimum spacing guidelines are required. The bandwidth of the circuit determines the insertion loss of the filter, since the "Q" is a limiting quantity. Adherence to the information contained in the graphs of this appendix will limit the loss of combining using series L/C units to less than 2 dB.

GENERAL

The coupling efficiency of L/C units is usually higher than hybrid circuits. However, higher than recommended L/C ratios can increase the insertion loss to values that are higher than for hybrid circuits.

L/C series filters give better isolation under varying load conditions than do hybrids. A load variation of 3 to 1 will change the isolation of a hybrid from 35-40 dB to 12 dB. This same variation may change the selectivity of a series L/C circuit by 3.5 to 5 dB at the 15 dB attenuation points.

The L/C series bandpass unit will not pass power with the isolation which can be achieved with hybrids. The different values of capacitance in the various L/C units have different current ratings with frequency. The inductors are also limited in the amount of RF current because of losses. Strict adherence to the maximum power ratings is necessary for each device as stated on the charts of this appendix. Exceeding the range of acceptable current limits can cause the failure of the capacitors or inductors in the series L/C units. The allowable RF current in silvered mica capacitors increases with increasing frequency and capacitor size.

DESIGN CRITERIA

The flanking of series L/C bandpass filters implies that the outputs of two or more L/C bandpass filter units will be connected to a common point. The frequency spacing, or separation, of the individual L/C units will be sufficient to allow for a minimum of 15 dB of isolation between adjacent filters. Also, each L/C unit must have a power rating equal to or greater than the power output of the PLC equipment which will be connected to its input.

The power rating for each L/C series unit is given along with the frequency range in which that device will transfer that rated power. Power levels of up to 10 watts, 20 watts, and 100 watts were selected to correspond to levels generally encountered with PLC equipment. **THESE POWER LEVELS MUST NOT BE EXCEEDED.**

Each L/C unit with its capacitor and tuning inductor has been selected to flank with another L/C unit using the same capacitor at the lower 10 dB point of the reference L/C unit. The reference L/C unit is defined as the highest frequency L/C unit. Typical curves of the attenuation characteristics of a 100 watt, CL13SM unit using a capacitor C4 are shown in Figure 12-A.1. Figure 12-A.1 shows the reference frequency to be a GMF, $F_{01}=110$

kHz. This curve shows the lower 10 dB point for the F_{o1} filter to be at 85 kHz, shown as point A on Figure 12-A.1. A second CL13SM, using the same C4 capacitor, is resonated at 85 kHz. Note that the point B on the curve of this L/C filter shows 12 dB of attenuation at 110 kHz. These curves are the individual curves of these L/C units unflanked.

When the two L/C units are flanked by connecting their outputs together, the resulting attenuation curves are as shown in Figure 12-A.2. Notice that the attenuation at point A has changed from 10 dB to 16 dB, for an increase of 6 dB. A similar change has taken place with the lower frequency, or F_{o2}, filter but on the upper side at point B. Here the attenuation has also changed by 6 dB, or from 12 dB to 18 dB. This is a sharp point in the curve caused by the double termination effect of the driving source impedance of the flanked unit on the other series circuit. The impedance of all L/C resonant circuits is assumed to be 50 ohms. This impedance sets the bandwidth of the filters. The extra 6 dB is a bonus allowing the isolation requirement of 15 dB minimum to be met while designing around the 10 dB bandwidth. Point A defines the minimum isolation as 15 dB and the minimum separation as 29 per cent.

There will be instances when the capacitor values of the flanked L/C units will not be the same, especially when more than two units are required to be flanked. The L/C unit having the widest 10 dB bandwidth will control the separation of the other L/C units.

In the curves of this appendix, each L/C unit is described by its power rating, minimum per cent spacing with other L/C units, and the 3 dB bandwidths. The bandwidths versus the GMFs have been selected to control the insertion loss to a value less than 2 dB. The insertion losses are listed on the graphs along with curves of the 3 dB bandwidths.

Examples showing the correct application of the curves are shown along with charts for strapping the capacitor and inductor values.

Since it would require an infinite number of curves in order to select the flanking L/C unit at the 10 dB point of the reference L/C, the per cent separation curves were developed. To use these curves, the highest frequency L/C unit must be selected as the reference. All of the other L/C units depend on this selection. The next lower L/C unit frequency can then be calculated using the reference L/C unit frequency and by applying formula (1). This relation is:

$$\frac{\text{Per cent Separation}}{100} = \frac{F_o(\text{high})}{F_o(\text{low})} - 1, \qquad (1)$$

where: Per cent Separation (% Sep) is read from the curves at the GMF and for the capacitor value chosen;
F_o(high) = Higher L/C GMF(kHz);
and F_o(low) = Lower L/C GMF(kHz).

The lower L/C GMF can be found for a given value of per cent separation (% Sep) by solving the above equation for F_o(low). This is equation (2).

$$F_o(\text{low}) = \frac{F_o(\text{high})}{1 + (\%\ \text{Sep})\text{x}100} \qquad (2)$$

Equation (2) can be used to determine the frequency of the next lower L/C flanking unit with either the same capacitor value or for a different capacitor value as long as the highest value of per cent separation is used. The examples show the proper application of the formula. Use Table 1 to find the model number or drawing number, capacitor stack value, inductance designation, and figure numbers that describe the L/C series unit for each power level. Use only the units whose maximum power rating matches your input power levels.

The criteria for selecting one L/C model over another for a particular application are based on the following considerations:

1) The insertion loss of the L/C Unit for the capacitance value selected: The unit with the lowest insertion loss would be preferred over a unit with higher loss.

2) The per cent spacing should be a minimum value for the application: This will result in the most efficient use of the frequency spectrum and the minimum bandwidth for line tuners and traps.

After selecting a capacitor value from the curves for a particular L/C series unit, it remains to calculate the value of inductance required to resonate with the capacitance. Formula (3) shows the universal resonance formula solved for the inductance, L.

$$L = 1/[(2\pi F_0)^2 x C] \qquad (3)$$

This relation can be used with the inductance strapping charts at the end of this appendix to determine the choice of strapping inductance range for each selected capacitor and frequency.

APPLICATION EXAMPLES

Example 1: Two 10 watt L/C units are to be used to separate one transmitter at 150 kHz and another 10 watt transmitter at a frequency to be determined. The lower frequency unit must be above 130 kHz.

Solution: Select the L/C unit. Based on the criteria given above, and examination of the choices for 10 watt transmitters, using Table 1, the two series L/C units to be compared are the CL13SE L/C unit and the 19A132137G2 L/C unit.

12

1. For L/C unit CL13SE:
   a. Per cent separation at 150 kHz is 27% for C1 from Figure 12-A.3.
   b. Insertion loss for C1 is 1.6 dB from the table on Figure 12-A.4.

2. For L/C unit 19A132137G2:
   a. Per cent separation at 150 kHz for C20 is 10% from Figure 12-A.5. Use the curve for C20 since the curve for C11 is not defined below 200 kHz and the curve for C37 requires a greater per cent separation at 150 kHz.
   b. The insertion loss for C20 is between 1.0 dB and 1.2 dB, as shown in the table of Figure 12-A.6.

The criteria given above for selecting L/C units makes the 19A132137G2 unit the best choice for this application. The CL13SE is useful for frequencies below 80 kHz, as can be determined by a comparison of the per cent separation curves below 100 kHz.

The capacitors in the 19A132137G2 L/C unit are 0.001 μF. The values given in the capacitor connection charts are for 0.01μF capacitors. To determine the inductance necessary to resonate with the C20 value in the 137G2 L/C unit, first determine that the value of C20 is 667 pF(one-tenth of the C20 value shown on the capacitor connection diagrams of page 12-35). The coil in the 137G2 unit is the LM coil. With a capacitance value of 667 pF at 150 kHz, the inductance value required for series resonance, using Equation (3), is 1.687 mH, which lies in the range of "L7" of the coil connection charts of page 12-34. Both coil and capacitor can now be strapped for the 150 kHz circuit.

3. The 10 watt, 19A132137G2 per cent separation curves would allow another L/C unit to be flanked, using capacitor C20, with a 10% separation below the 150 kHz unit.

   a. Solving equation (2) gives:

      $F_0(\text{low}) = 150/1.1 = 136.2$ kHz.

   b. Use $F_0(\text{low}) = 136$ kHz (or a lower frequency.)

Note that the per cent separation for C20 at 136 kHz is 9 per cent. This would allow another L/C unit to be flanked at 124.7 kHz with the other two units. The inductance, using equation (3), to resonate with C20, which is 667 pF, at 136 kHz is 2.05 mH. This value of inductance also lies in the range of "L7" of the coil connection charts of page 12-34. The series L/C for 136 kHz can be strapped and resonated at 136 kHz.

Example 2: A customer proposition drawing shows a blocking carrier set at a GMF of 150 kHz, a medium BW FSK set at a GMF of 112 kHz, and a medium BW FSK set at a GMF of 91 kHz. Each are 100 watt sets and are coupled through series L/C units. Can this application be approved?

Solution:

The two L/C units to be compared for this application are the CL13SM L/C unit and the 19A132137G1 L/C unit. Table 1 of this appendix gives the figure numbers of the appropriate graphs for these units. These two units are the only choices for 100 watt L/C units.

1. For the CL13SM L/C unit:

   a. At 150 kHz, the per cent separation is 33.5% using capacitor C2 from Figure 12-A.14.
   b. The insertion loss in the table of Figure 12-A.15 is 0.5 dB for C2.

2. For the 19A132137G1 L/C unit:

   a. At 150 kHz, the per cent separation, from Figure 12-A.16, is 93% using capacitor C59. This unit uses 0.001μF capacitors in the 6-capacitor stack, and the current rating requires that several capacitors be connected in parallel so as not to exceed the current limits for the individual capacitors.

The obvious choice for this application is the CL13SM L/C unit. The frequencies of the sets will be checked using equation (2).

3. The 100 watt, CL13SM per cent separation curves of Figure 12-A.14 show capacitor C2 would allow the next lower L/C unit to be placed with a separation of 33.5 per cent.
   a. Solving equation (2) for F_0(low) gives:

      F_{02}(low) = 150/1.335 = 112.3 kHz.

      The 112 kHz for the second L/C unit frequency is correct.

   b. At 112 kHz, the per cent separation curves for C2 show a value of 23 per cent. Using equation (2), the value of F_{03} can be found:

      F_{03}(low) = 112/1.23 = 91 kHz.

The curve for C2 does not extend below 110 kHz. **Therefore, C2 cannot be used below 110 kHz without exceeding the current restriction on the capacitors. The separation using capacitor C4 must be used.**

Capacitor C4 at 112 kHz requires a 29.5 per cent separation. Calculate F_{03}(low) using this value:

F_{03}(low) = 112/1.295 = 86.5 kHz.

The 3 dB bandwidth of the CL13SM series L/C unit at 86.5 kHz is approximately 12 kHz, which is much wider than the medium BW FSK set requires. Therefore, tune the third series L/C bandpass filter to 86.5 kHz and this unit will pass 87 kHz.

The customer proposition drawing will have to be changed as regards the lowest frequency at 91 kHz. This frequency will need to be changed to 87 kHz to comply with the application guidelines.

To determine the strapping of the coils for these three L/C units, first determine that the value of C2 is 2000 pF (0.002μF) from the capacitor connection charts of page 12-35. Calculate the value of inductance for 150 kHz and 112 kHz using 2000 pF. C4 is 2500 pF, or 0.0025 μF from the capacitor connection charts. Calculate the inductance required to resonate this capacitance at 86.5 kHz, using equation (3). The values are:

150 kHz:	2000pF;	562 μH.
112 kHz:	2000pF;	1.01 mH.
86.5 kHz:	2500pF;	1.35 mH.

The strapping for the 150 kHz and the 112 kHz units from the inductance strapping chart on page 12-34, and from Figure 12-A.15, shows that "L8" will tune to these values. For the 86.5 kHz unit, the inductance is in the range of "L9".

Example 3: Require four (4) 10 watt PLC sets with minimum spacing to be combined with L/C series bandpass filters. The maximum frequency is 250 kHz. Assume 0.5 kHz as the frequency increment. What are the frequencies of the sets?

Solution: Use 10 watt, 19A132137G2 L/C units. The CL13SE unit cannot be used above 150 kHz.

a. F_{01} = 250 kHz.

   The minimum spacing for capacitor C11 at 250 kHz is 9.8 per cent from Figure 12-A.5. Therefore:

F_{o2} = 250/1.098 = 227.68 kHz. (Assume 227.5 kHz).

b. F_{o2} = 227.5 kHz.

The minimum spacing for capacitor C11 at 227.5 kHz is 9 per cent from Figure 12-A.5. Therefore:

F_{o3} = 227.5/1.09 = 208.72 kHz. (Assume 208.5 kHz).

c. F_{o3} = 208.5 kHz.

The minimum spacing for C11 at 208.5 kHz is 8.2 per cent. Determine the value of F_{o4} and check that the range of frequencies still applies to C11. Therefore:

F_{o4} = 208.5./1.082 = 193.056 kHz. **This is outside the C11 range!**

Use capacitor C20 for F_{o4}. The per cent separation for C20 at 208.5 kHz is 14.3. Therefore:

F_{o4} = 208.5/1.143 = 182.415 kHz. (Assume 182.5 kHz).

Final solution: Frequencies of the four 10 watt sets are at the GMF's of 250.0, 227.5, 208.5, and 182.5 kHz. This is the closest spacing using series L/C filters as the isolating device with 10 watt transmitters.

If a closer spacing is required, hybrids or fixed bandwidth bandpass filters must be used for isolating the equipment.

SUMMARY

The graphs of this appendix show the capability of available L/C series circuits to combine PLC functions. The variables are: (1) power rating or power handling capacity; (2) minimum frequency separation; (3) 3 dB bandwidth; and (4) insertion loss when an isolation of 15 dB is maintained. Units should not be applied at a closer frequency spacing, or at a greater power rating than that shown on the graphs. Using a greater separation than that shown on the graphs will result in more than 15 dB isolation between adjacent transmitters. Applying the units at a closer spacing than that shown for a specific capacitor value may significantly increase the insertion loss of the entire system while providing less than adequate protection from intermodulation distortion.

Refer to Table 1 for the model number or drawing numbers of the series L/C units and their power ratings. The capacitors in the L/C units determine the power ratings of the units. This current rating is a function of the capacitor value and the frequency. Check the inductance strapping by calculating the value of inductance required, using equation (3), to resonate with the capacitor selected. The capacitor values can be determined from the capacitor connection charts in this appendix. The inductor strapping shown on the left-hand side of the bandwidth graphs should be used only as a guide.

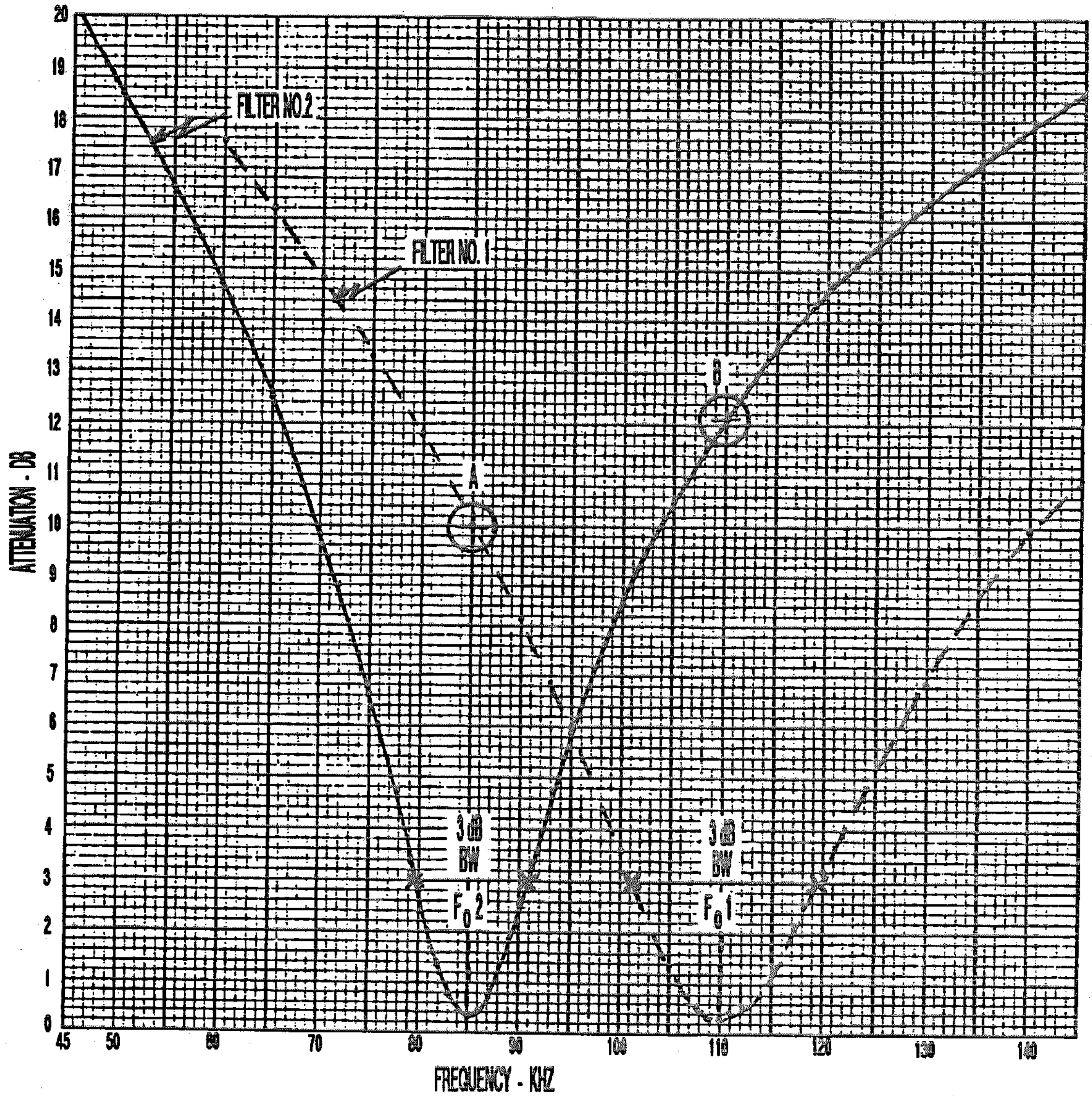


Figure 12-A.1. Typical Passband Characteristics of 100W., CL13SM Series L/C

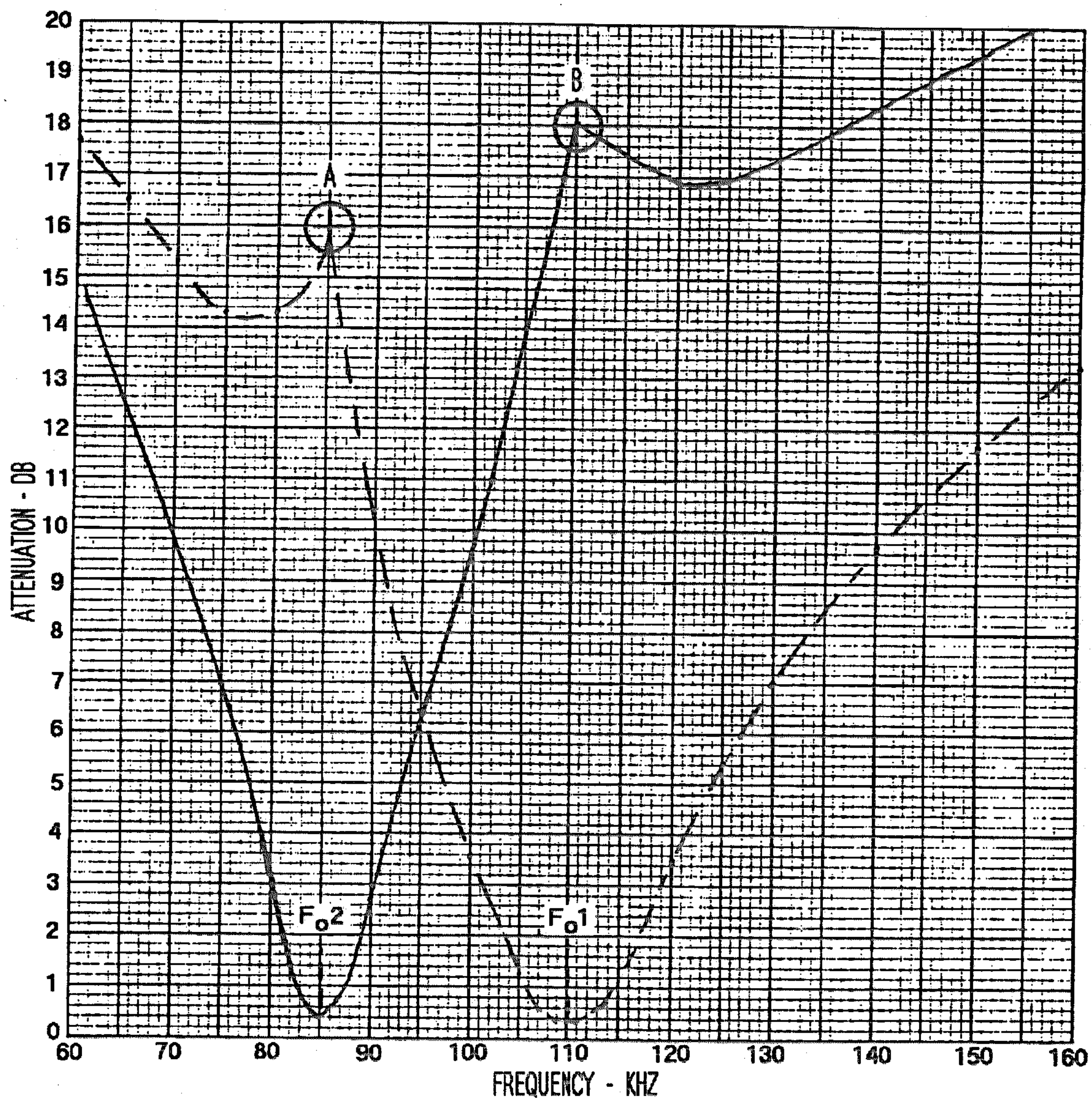


Figure 12-A.2. Isolation and Passband Characteristics
of Two Flanking 100W., CL13SM Series L/C Units at Minimum Spacing

TABLE 12-A.1

L/C REFERENCE TABLE

POWER RATING (WATTS)	L/C MODEL NUMBER OR DRAWING NUMBER	DEVICE DEFINED BY GRAPHS LABELED:
10	CL13SE (C = 0.01 μF)	% SEP. : FIG. 12-A.3 3 dB BW : FIG. 12-A.4
	19A132137G2 (C = 0.001 μF) (L = "LM")	% SEP. : FIG. 12-A.5 3 dB BW : FIG. 12-A.6
10/20	CL13SM (C = 0.01 μF)	% SEP. : FIG. 12-A.7,8 3 dB BW : FIG. 12-A.9
20	CL13SE (C = 0.01 μF)	% SEP. : FIG. 12-A.10 3 dB BW : FIG. 12-A.11
	19A132137G1 (C = 0.001 μF) (L = "LL")	% SEP. : FIG. 12-A.12 3 dB BW : FIG. 12-A.13
100	CL13SM (C = 0.01 μF)	% SEP. : FIG. 12-A.14 3 dB BW : FIG. 12-A.15
	19A132137G1 (C = 0.001 μF) (L = "LL")	% SEP. : FIG. 12-A.16 3 dB BW : FIG. 12-A.17

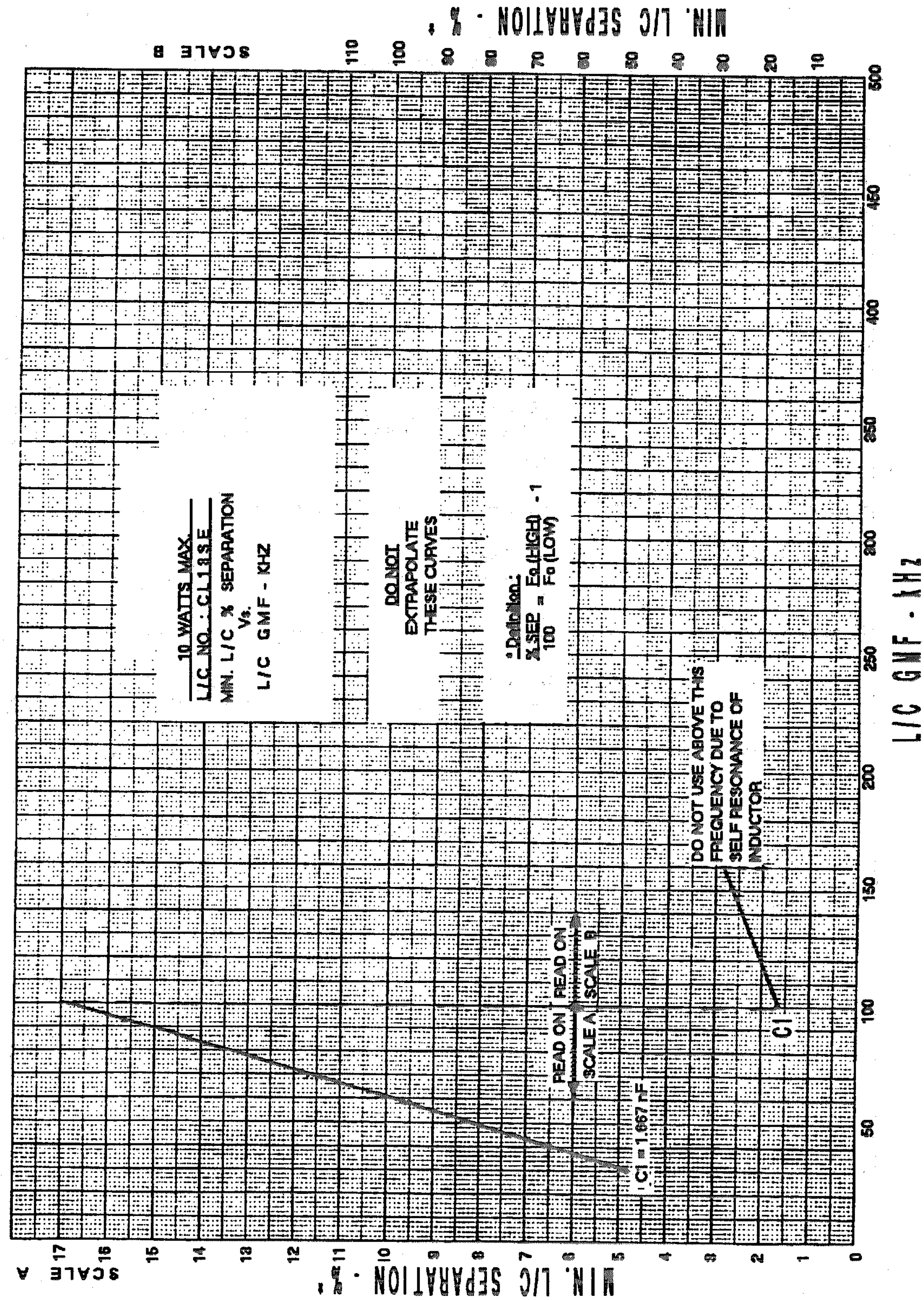
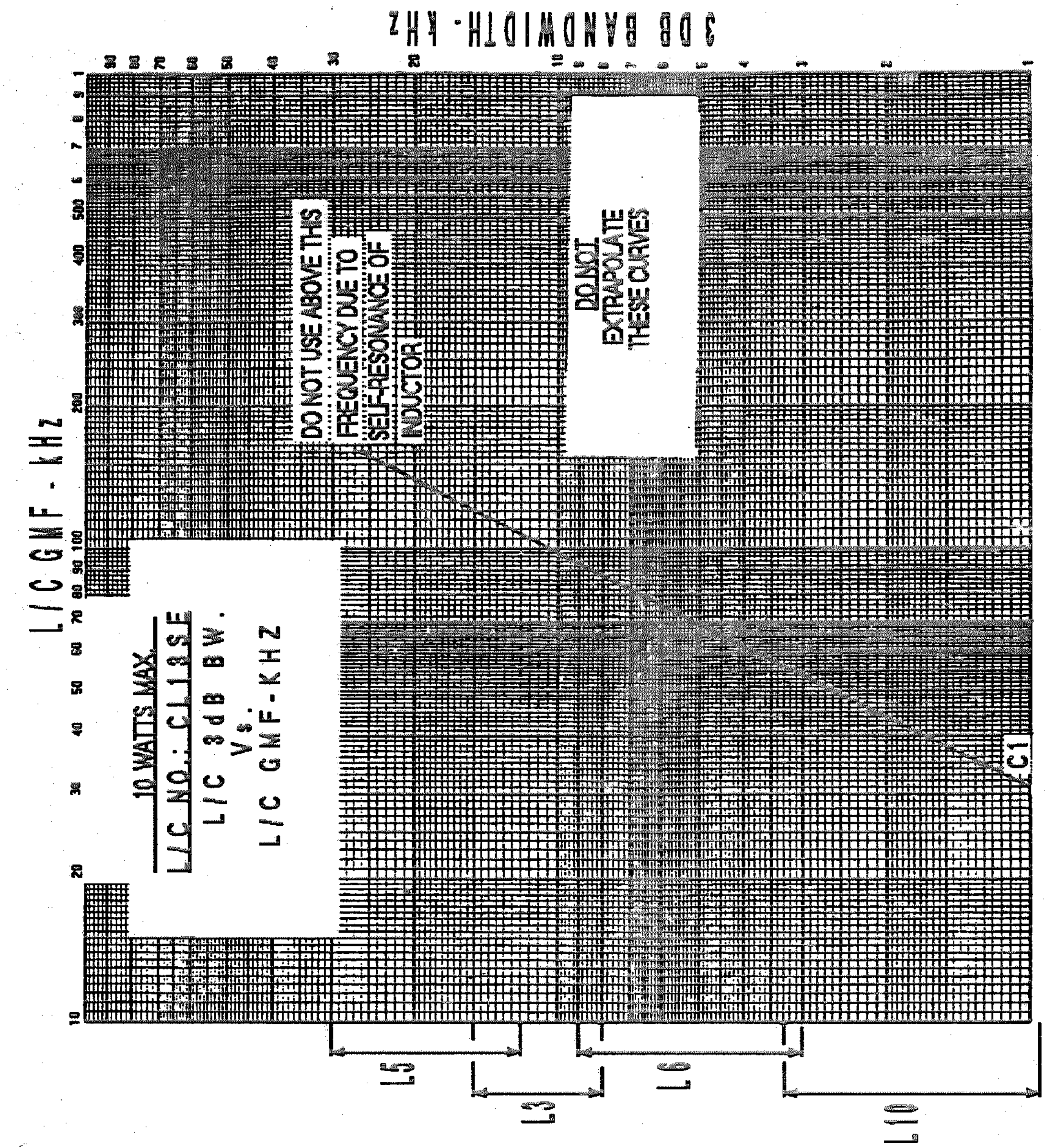

SCALE B
MIN. L/C SEPARATION - % *
10 WATTS MAX.
L/C NO. : C.L.1.8.S.E.
MIN. L/C % SEPARATION
Vs.
L/C GMF - KHZ
DO NOT
EXTRAPOLATE
THESE CURVES
* Definition :
% SEP / 100 = Fo (HIGH) / Fo (LOW) - 1
DO NOT USE ABOVE THIS
FREQUENCY DUE TO
SELF RESONANCE OF
INDUCTOR
READ ON
SCALE A
READ ON
SCALE B
C1 = 1.667 nF
C1
L/C GMF - KHz
SCALE A
MIN. L/C SEPARATION - % *

Figure 12-A.3.



FREQ. (KHZ)	INSERTION LOSS - DB
30 - 35	2.2
40 - 45	1.6
50 - 55	1.4
60 - 65	1.2
70 -	1.2
100 - 160	1.6

Figure 12-A.4.

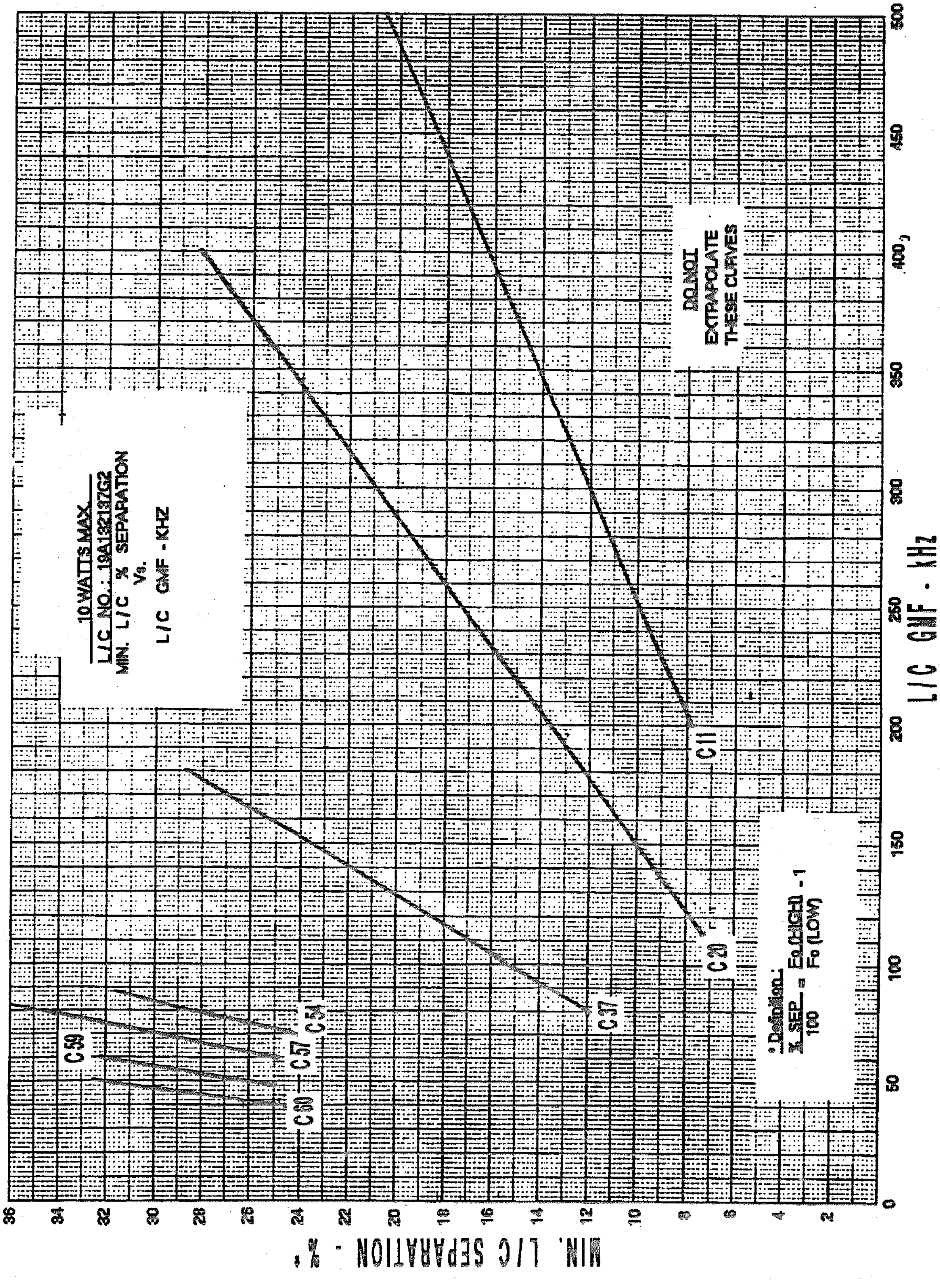
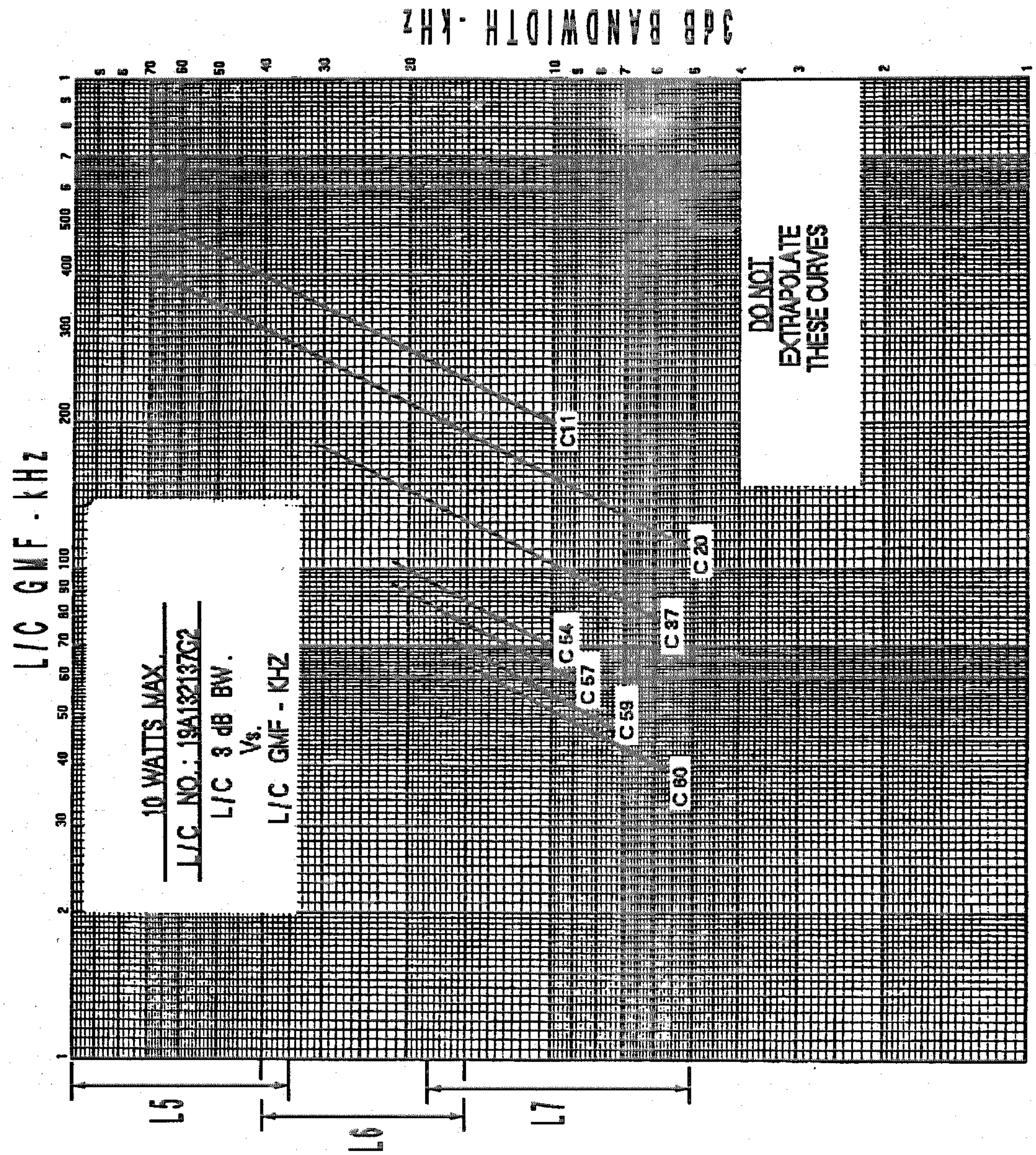

10 WATTS MAX.
L/C NO.: 19A132137G2
MIN. L/C % SEPARATION
Vs.
L/C GMF - KHZ
DO NOT
EXTRAPOLATE
THESE CURVES
C11
C20
C37
C54
C57
C59
C60
* Definition:
% SEP / 100 = Fo (HIGH) / Fo (LOW) - 1
0
50
100
150
200
250
300
350
400
450
500
L/C GMF - kHz
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
MIN. L/C SEPARATION - %*

Figure 12-A.5.



CAPACITOR NO. (nF)	INSERTION LOSS - dB
C60 - 6.0	0.3
C59 - 5.0	0.3
C57 - 4.0	0.3
C54 - 3.33	0.4
C37 - 1.50	0.7 - 0.5
C20 - .667	1.2 - 1.0
C11 - .400	1.6

Figure 12-A.6.

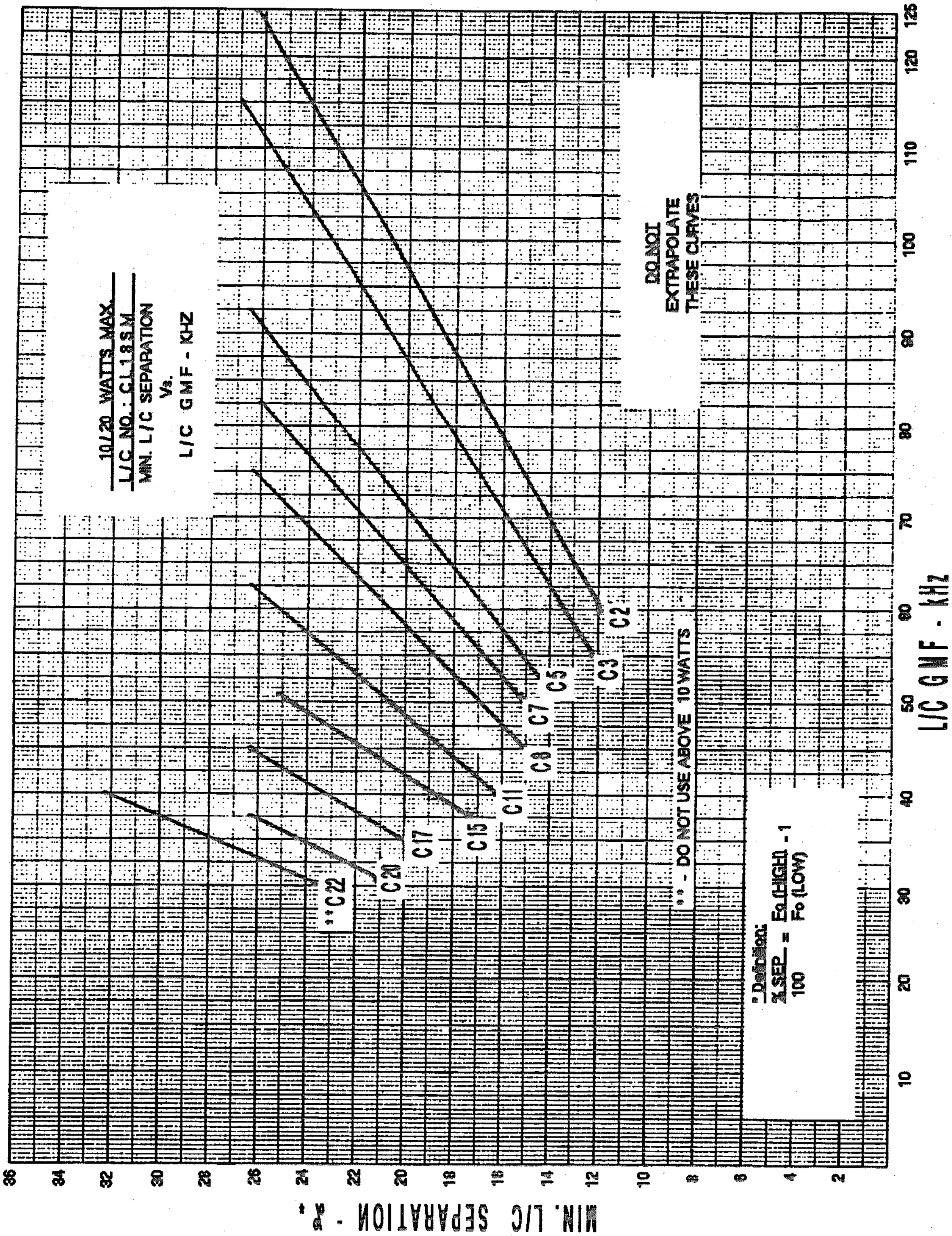

10/20 WATTS MAX.
L/C NO.: C.L.1.8.S.M
MIN. L/C SEPARATION
Vs.
L/C GMF - KHZ
DO NOT
EXTRAPOLATE
THESE CURVES
** - DO NOT USE ABOVE 10 WATTS
* Definition:
%SEP / 100 = Fo (HIGH) / Fo (LOW) - 1
C2
C3
C5
C7
C8
C11
C15
C17
C20
**C22
L/C GMF - kHz
MIN. L/C SEPARATION - %*
10
20
30
40
50
60
70
80
90
100
110
120
125
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

Figure 12-A.7.

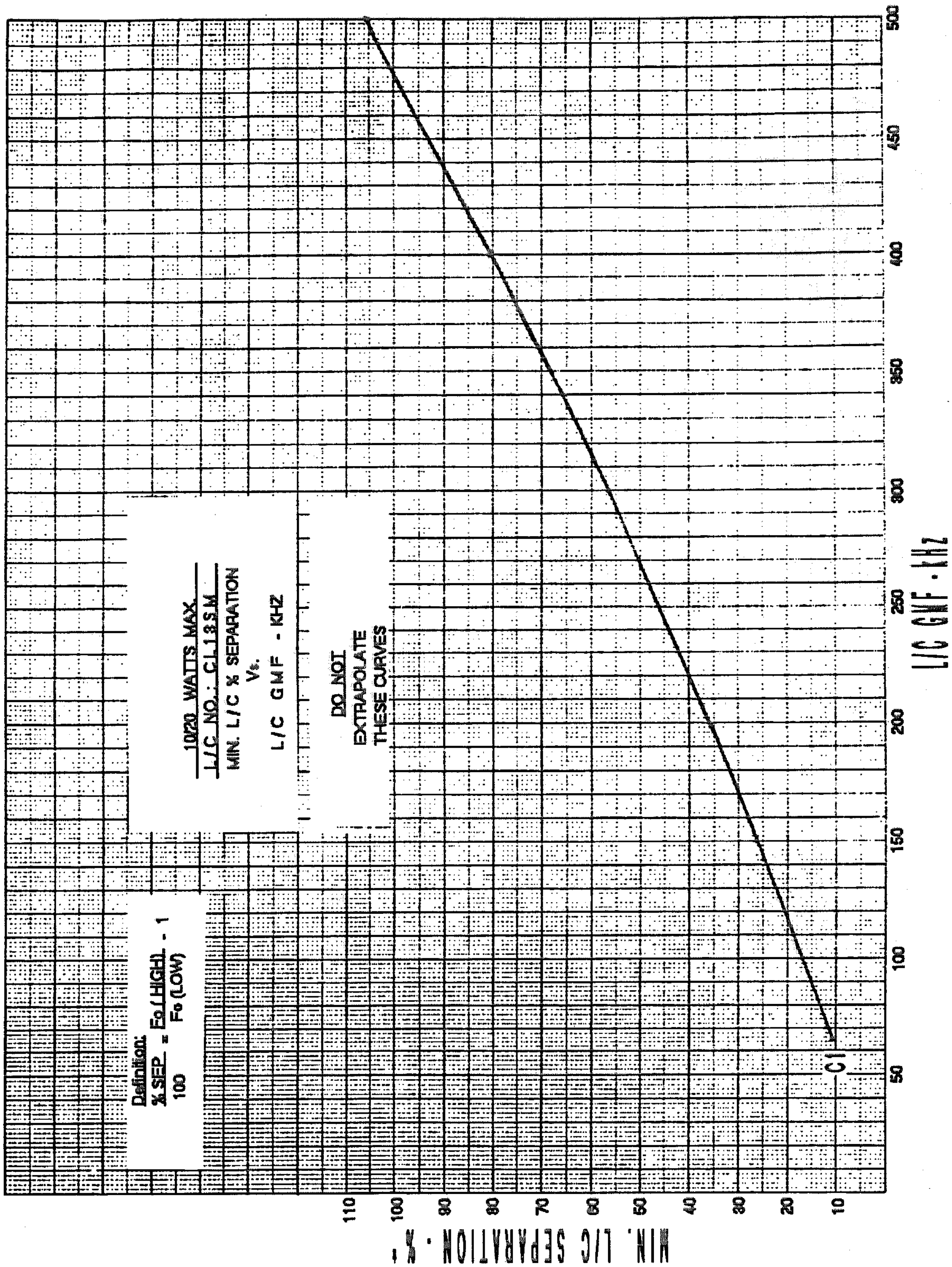
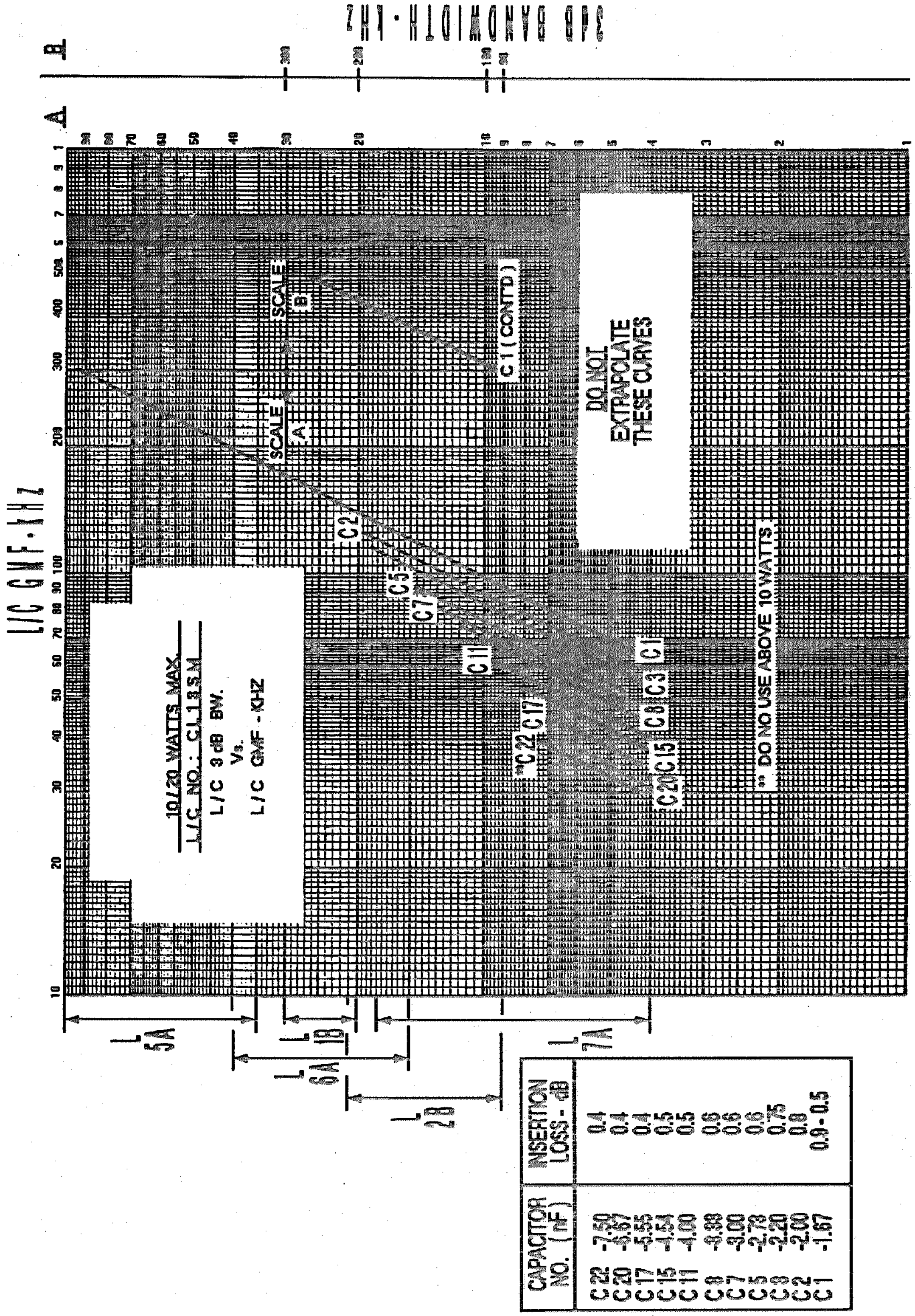

10/20 WATTS MAX.
L/C NO.: CL18SM
MIN. L/C % SEPARATION
Vs.
L/C GMF - KHZ
DO NOT
EXTRAPOLATE
THESE CURVES
Definition:
% SEP / 100 = Fo (HIGH) / Fo (LOW) - 1
C1
50
100
150
200
250
300
350
400
450
500
L/C GMF - KHz
10
20
30
40
50
60
70
80
90
100
110
MIN. L/C SEPARATION - %

Figure 12-A.8.



CAPACITOR NO. (nF)		INSERTION LOSS - dB
C22	-7.50	0.4
C20	-6.67	0.4
C17	-5.55	0.4
C15	-4.54	0.5
C11	-4.00	0.5
C8	-3.33	0.6
C7	-3.00	0.6
C5	-2.73	0.6
C3	-2.20	0.75
C2	-2.00	0.8
C1	-1.67	0.9 - 0.5

Figure 12-A.9.

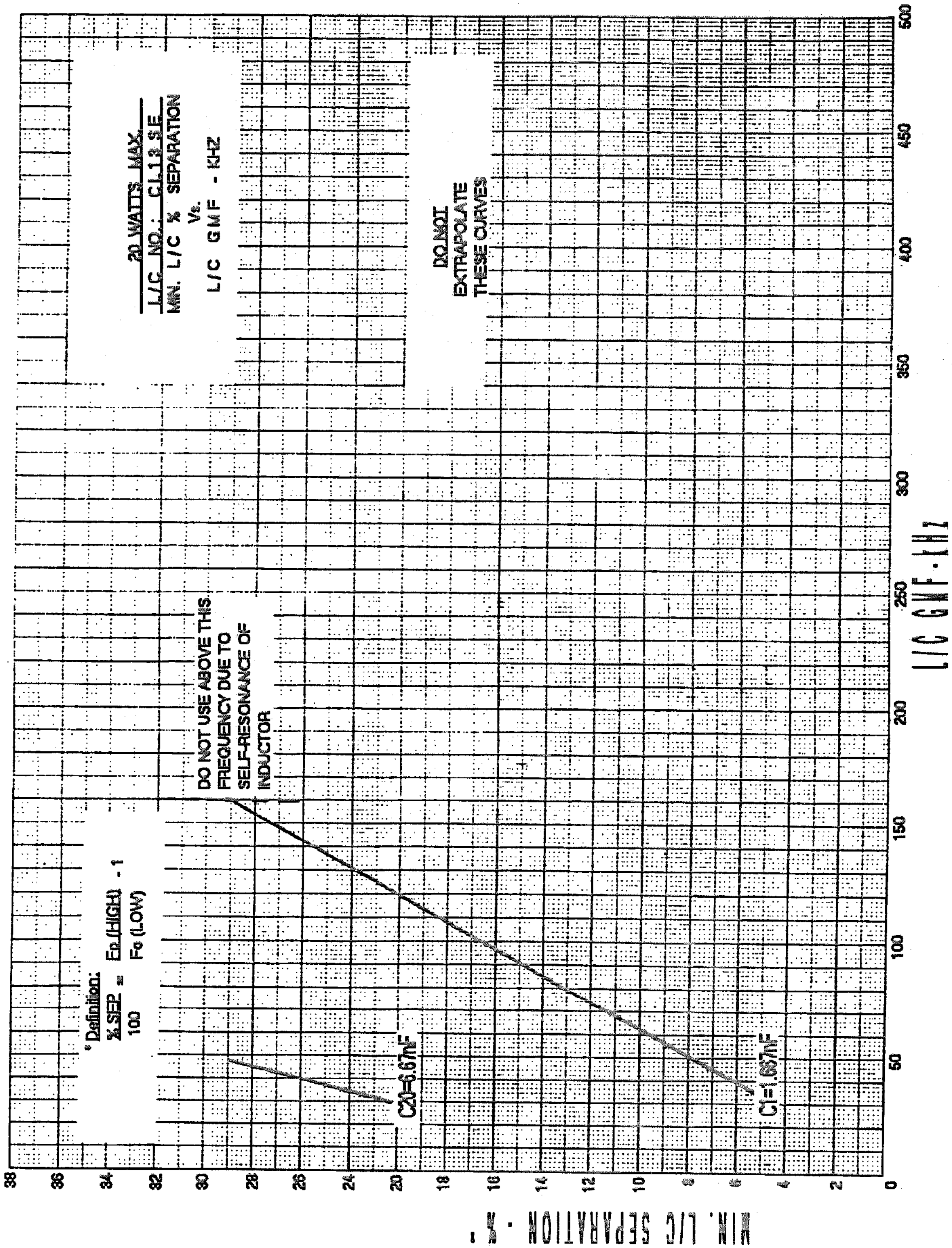
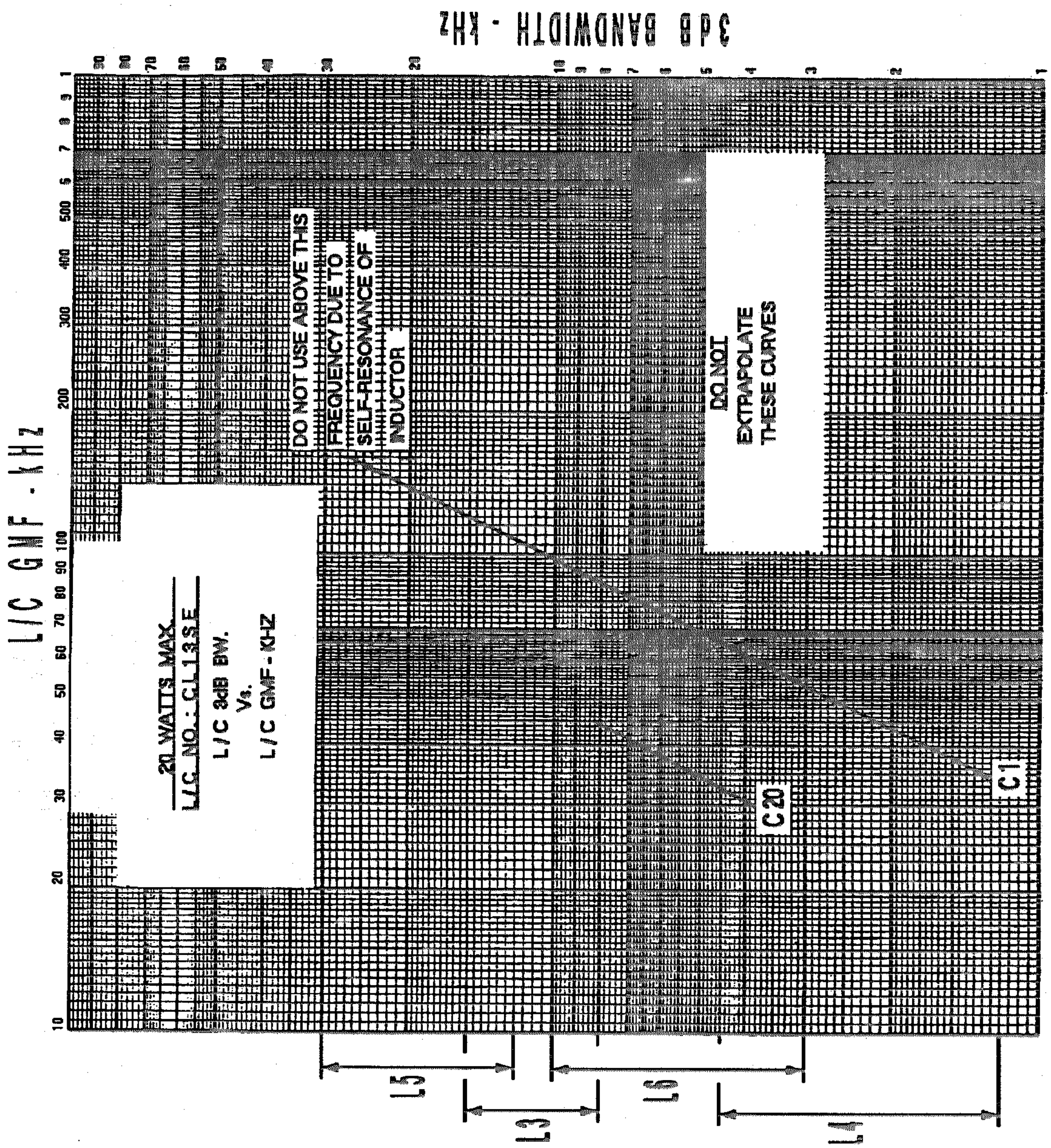


Figure 12-A.10.



FREQ- kHz	INSERTION LOSS- dB
30 - 35	0.5
35 - 40	1.6
45 - 50	1.4
55 - 60	1.2
60 - 100	1.2
140 - 160	1.6

Figure 12-A.11.

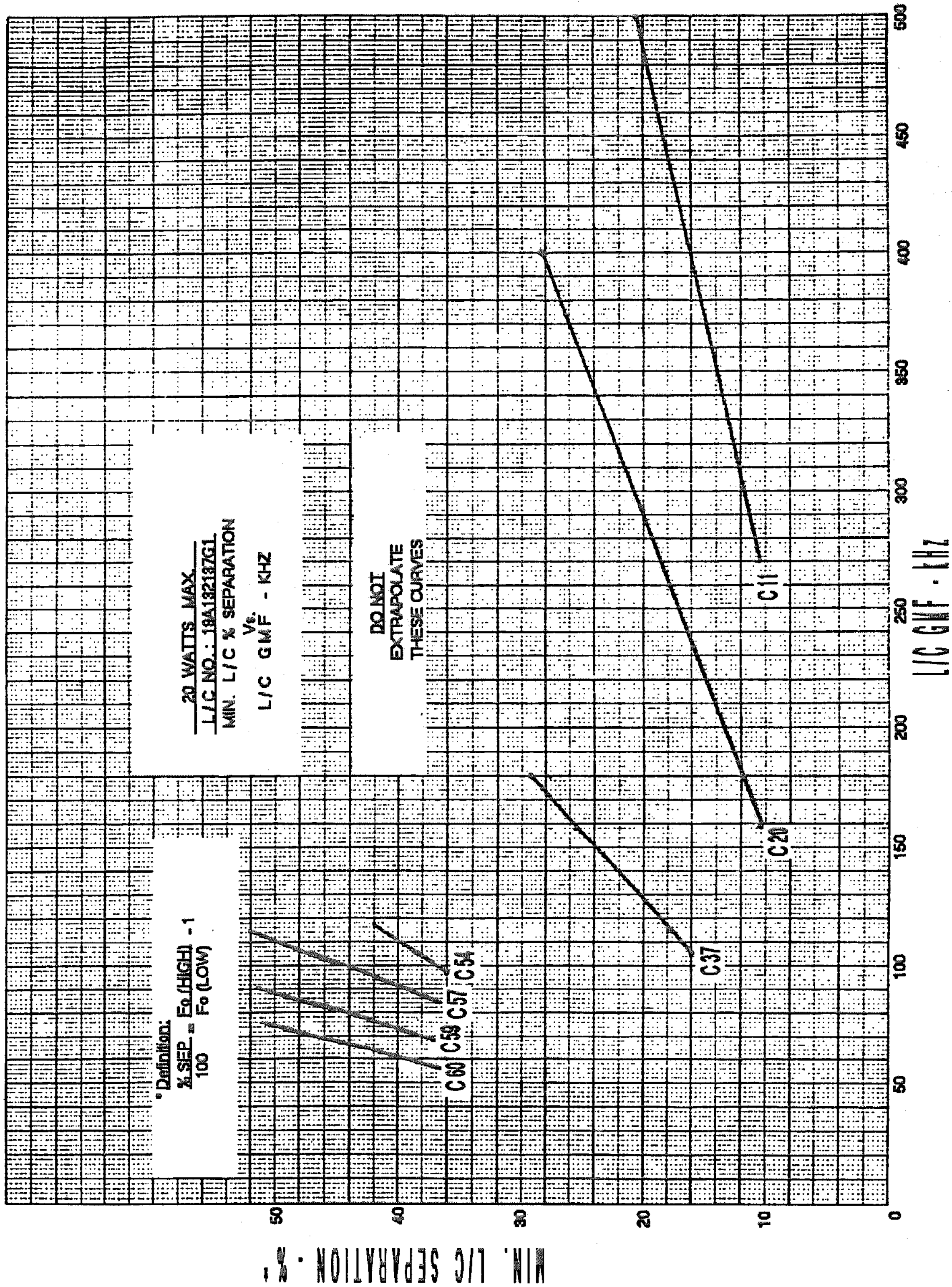
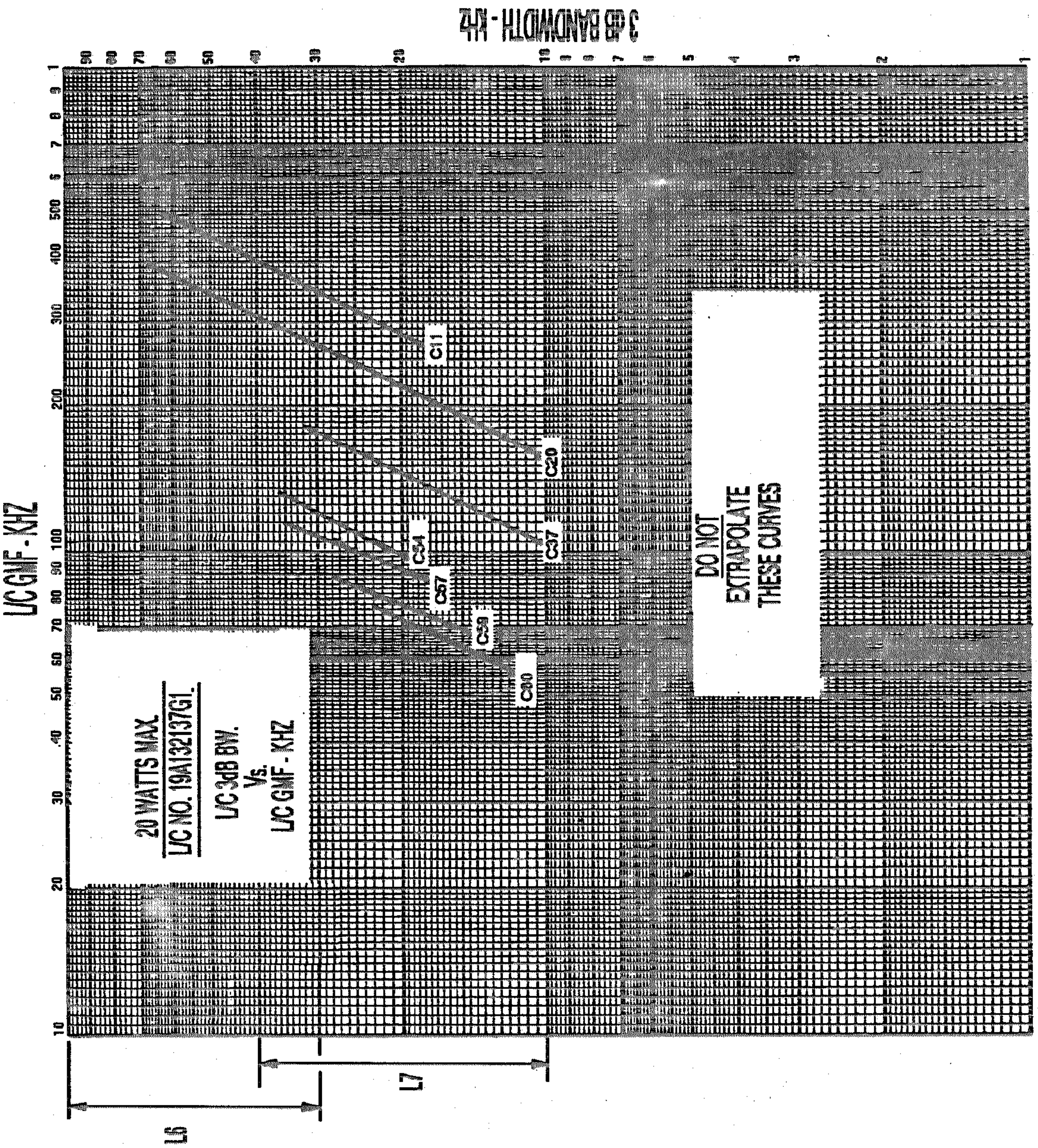


Figure 12-A.12.



CAPACITOR NO. (NI)	INSERTION LOSS -DB
C60 -6.00	0.2
C59 -5.00	0.2
C57 -4.00	0.3
C54 -3.33	0.3
C37 -1.50	0.4-0.6
C20 -0.667	1.0
C11 -0.400	1.5-1.6

Figure 12-A.13.

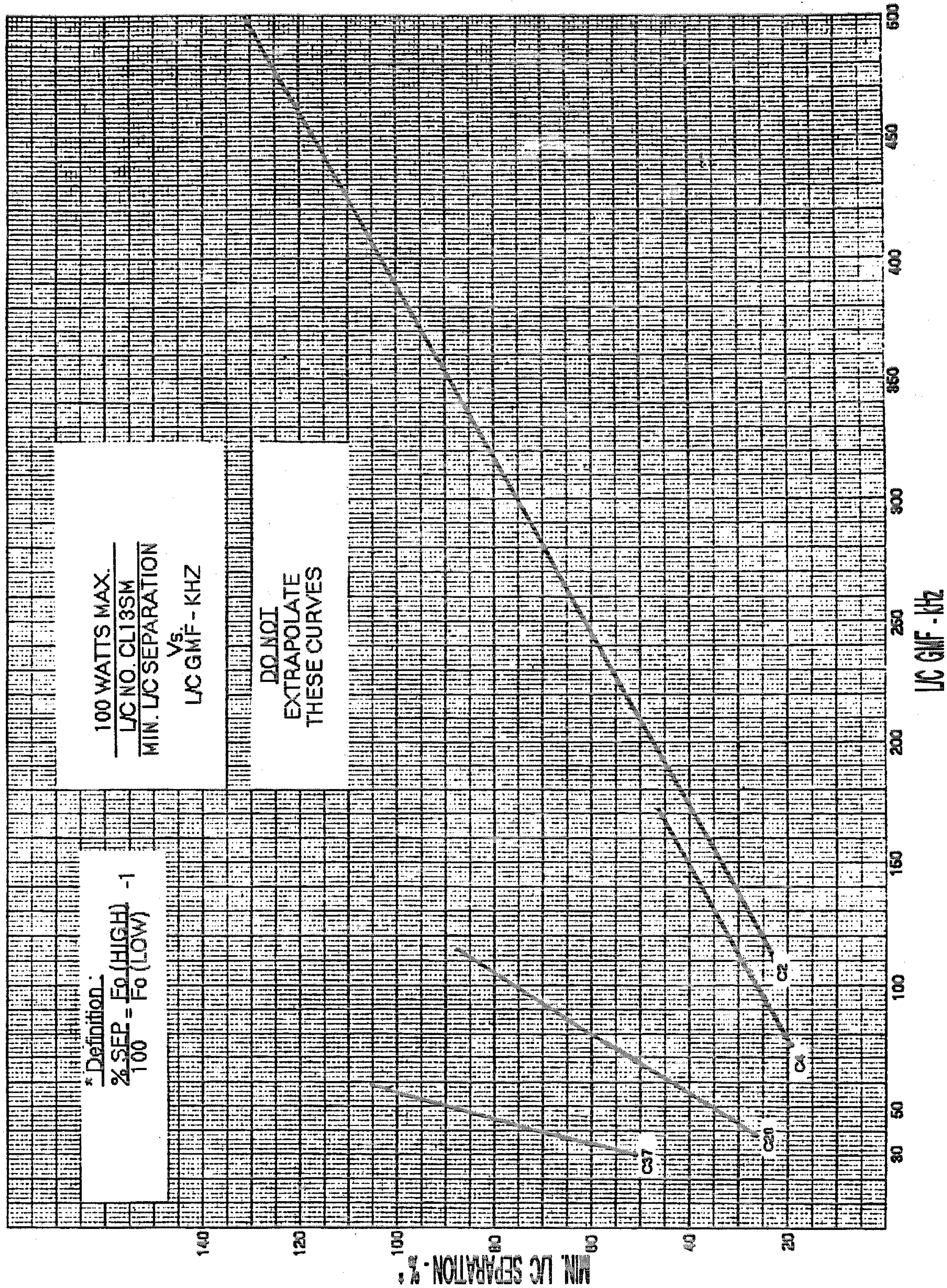
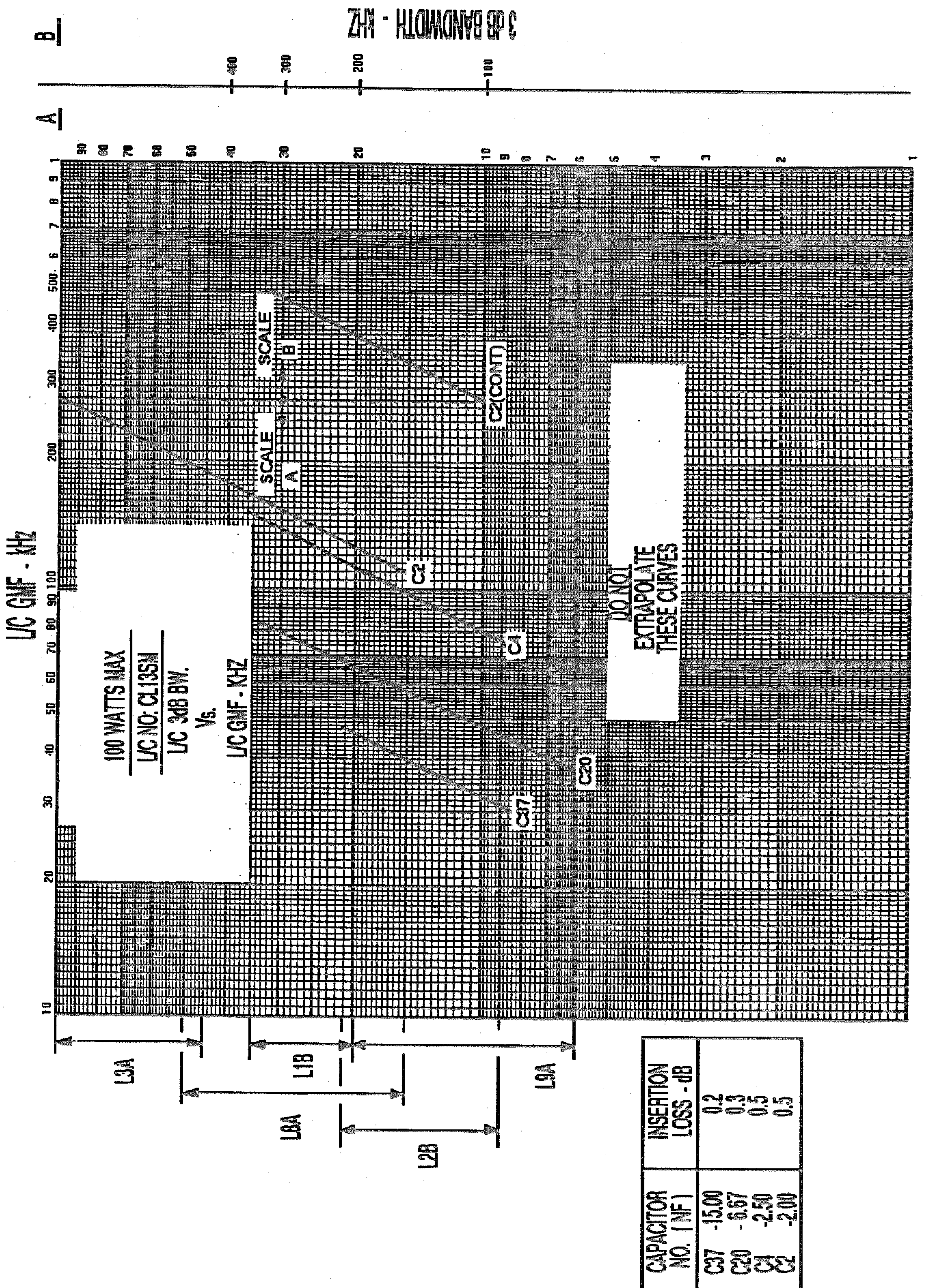


Figure 12-A.14.



CAPACITOR NO. (NF)		INSERTION LOSS - dB
C37	-15.00	0.2
C20	- 6.67	0.3
C1	-2.50	0.5
C2	-2.00	0.5

Figure 12-A.15.

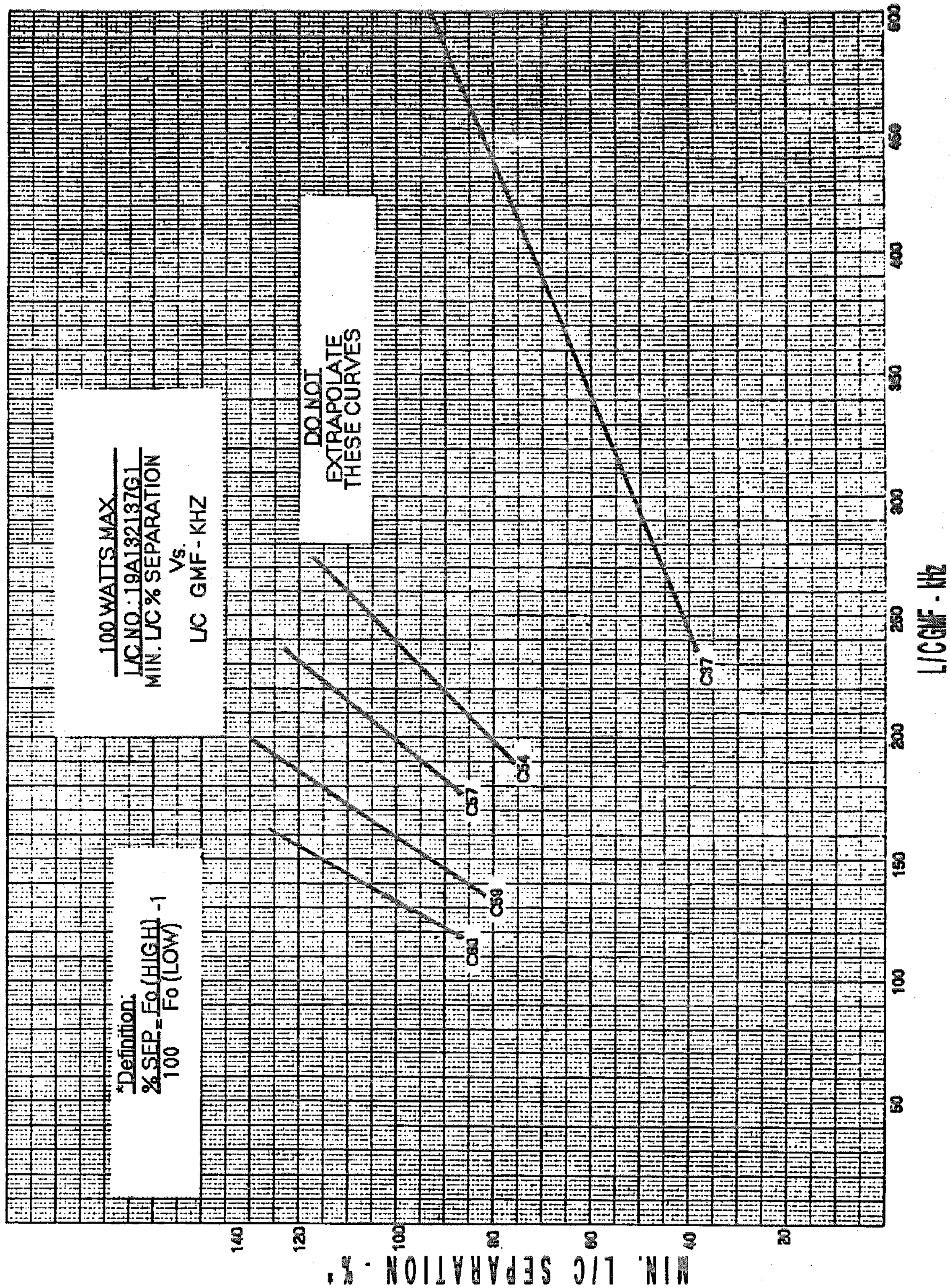
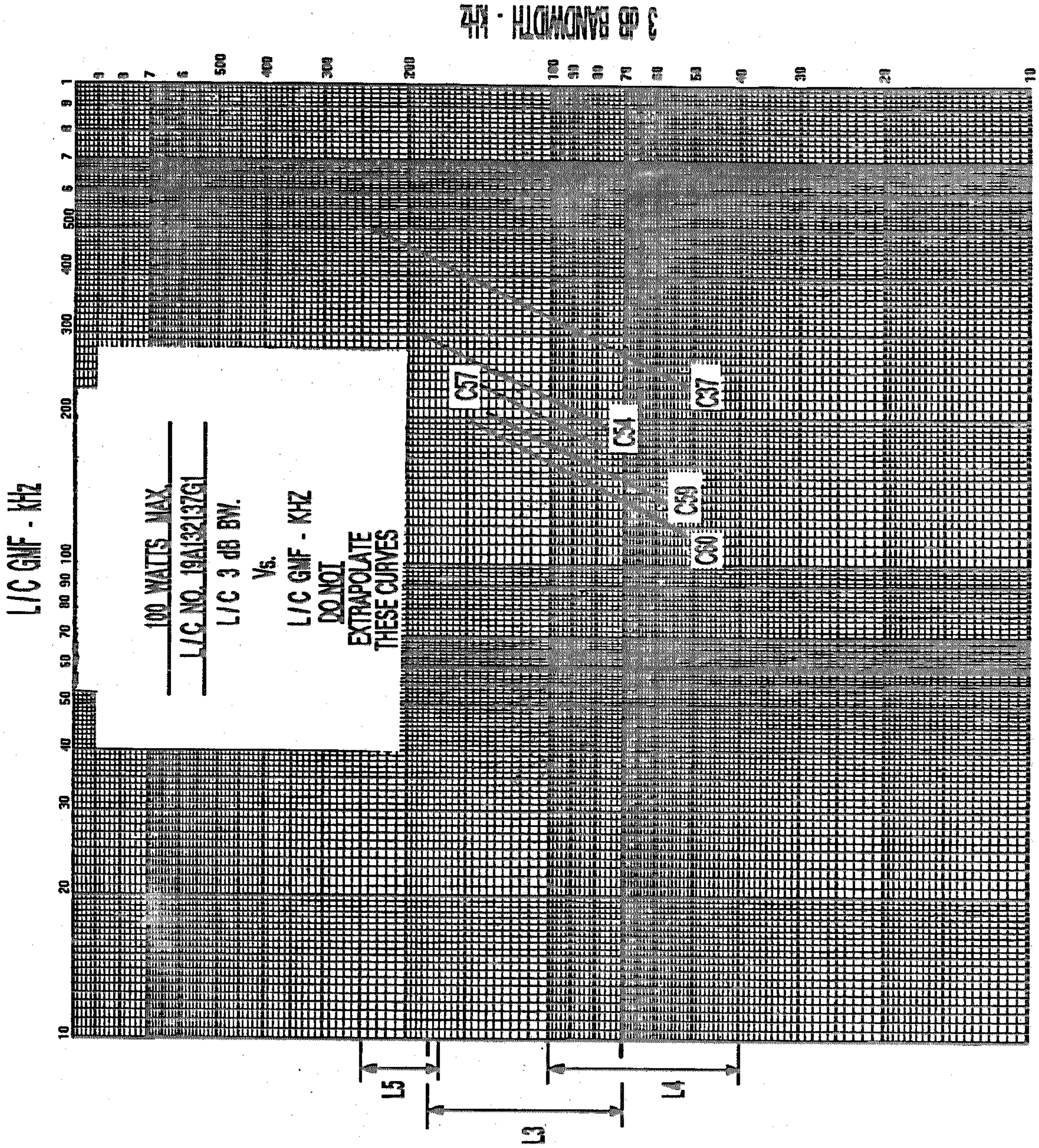


Figure 12-A.16.



CAPACITOR NO. (NF)		INSERTION LOSS - dB
C60	-6.00	0.2
C59	-5.00	0.2
C57	-4.00	0.2
C54	-3.33	0.2
C37	-1.50	0.5

Figure 12-A.17.

DESCRIPTION
SERIES L/C UNIT
MODEL 4CL13SL1, MODEL 4CL13SM1
MODEL 4CL13SE1

These Series L/C Units contain a series L/C circuit in which both L and C may be varied. They can be resonated at frequencies ranging from 1.5 mHz to 4 kHz, depending on the model, but commonly used in the 30 kHz to 400 kHz range. They can withstand power levels of up to 100-Watts.

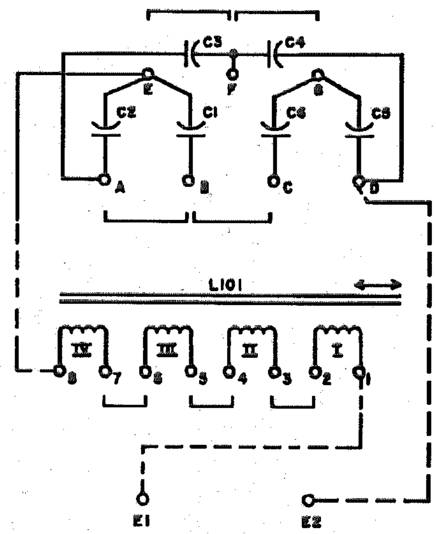
The Series L/C Units consist of an inductor and a capacitor stack. The inductor is a coil of four independent sections which can be connected by means of three self-storing metal straps. The capacitor stack consists of six 0.01 µF capacitors which can be externally connected to cover a range from 0.00167 µF to 0.06 µF in thirty-one steps by use of five self-storing metal straps.

The inductance range of Model 4CL13SL1 is between 7 µH and 1.7 mH; for Model 4CL13SM1, between 40 µH and 4mH; for Model 4CL13SE, between 35 µH and 30mH.

The Elementary Diagram is shown in Figure 1. The connection Diagram, shown in Figure 2, is used to determine the proper connections for each model when used with a particular capacitor value.

The power or current capability of the inductor is governed by frequency and inductance; that is, the higher the inductance and frequency, the lower is the current capability.

The nominal operating characteristics are shown in Table 1.



NOTE: ALL CAPACITORS .01UF IN 4CL13SE1, SH1, SL1, SM1 UNITS

Figure 1
Elementary Diagram - Series L/C Unit,
Models 4CL13SL1, 4CL13SM1, and 4CL13SE1

Characteristic	Model 4CL13SL1	Model 4CL13SM1	Model 4CL13SE1
Inductance (In 9 ranges)	7 µH - 1.7 mH	40 µH - 4 mH	35 µH - 30 mH
Capacitance (In 31 steps)	0.00167 µF to 0.06 µF	0.00167 µF to 0.06 µF	0.00167 µF to 0.06 µF
Tuning Range	1.5 MHz - 20 kHz	600 kHz - 10 kHz	150 kHz - 4 kHz
Tolerance (Of Coil)	±5%	±5%	±5%
Tolerance (Of Capacitor)	±10%	±10%	±10%
Current Rating (Of Coil)	1.7 mH: 1A at 100 kHz 7 µH: 12A at 100 kHz	4 mH: 0.8A at 100 kHz 40 µH: 6A at 100 kHz	30 mH: 0.65A at 30 kHz 35 µH: 5A at 100 kHz
Current Rating (Of Capacitor)	2A at 100 kHz	2A at 100 kHz	2A at 100 kHz
Working Voltage VDC	1200	1300	1300

Table 1

Figure 12-A.18.

12

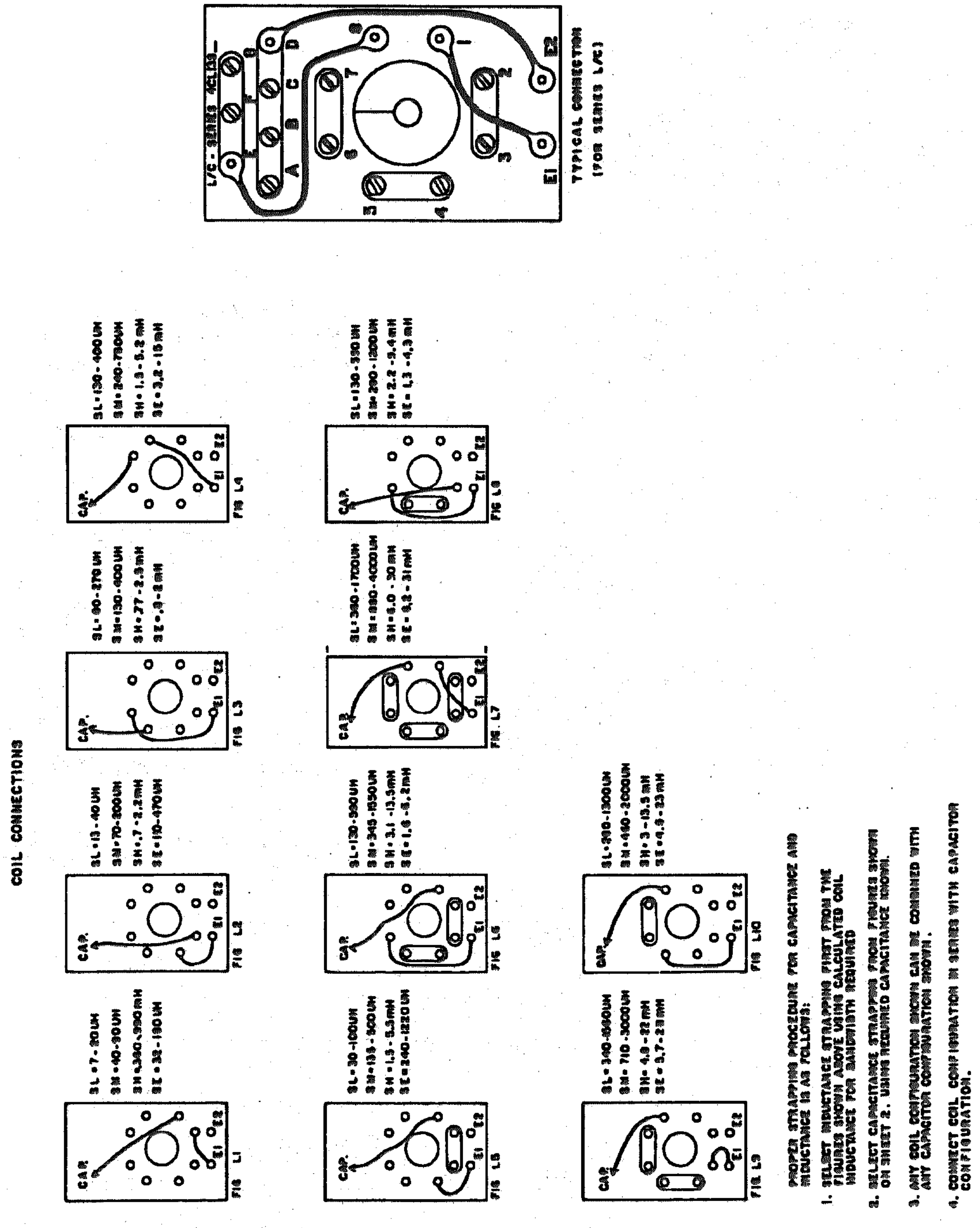
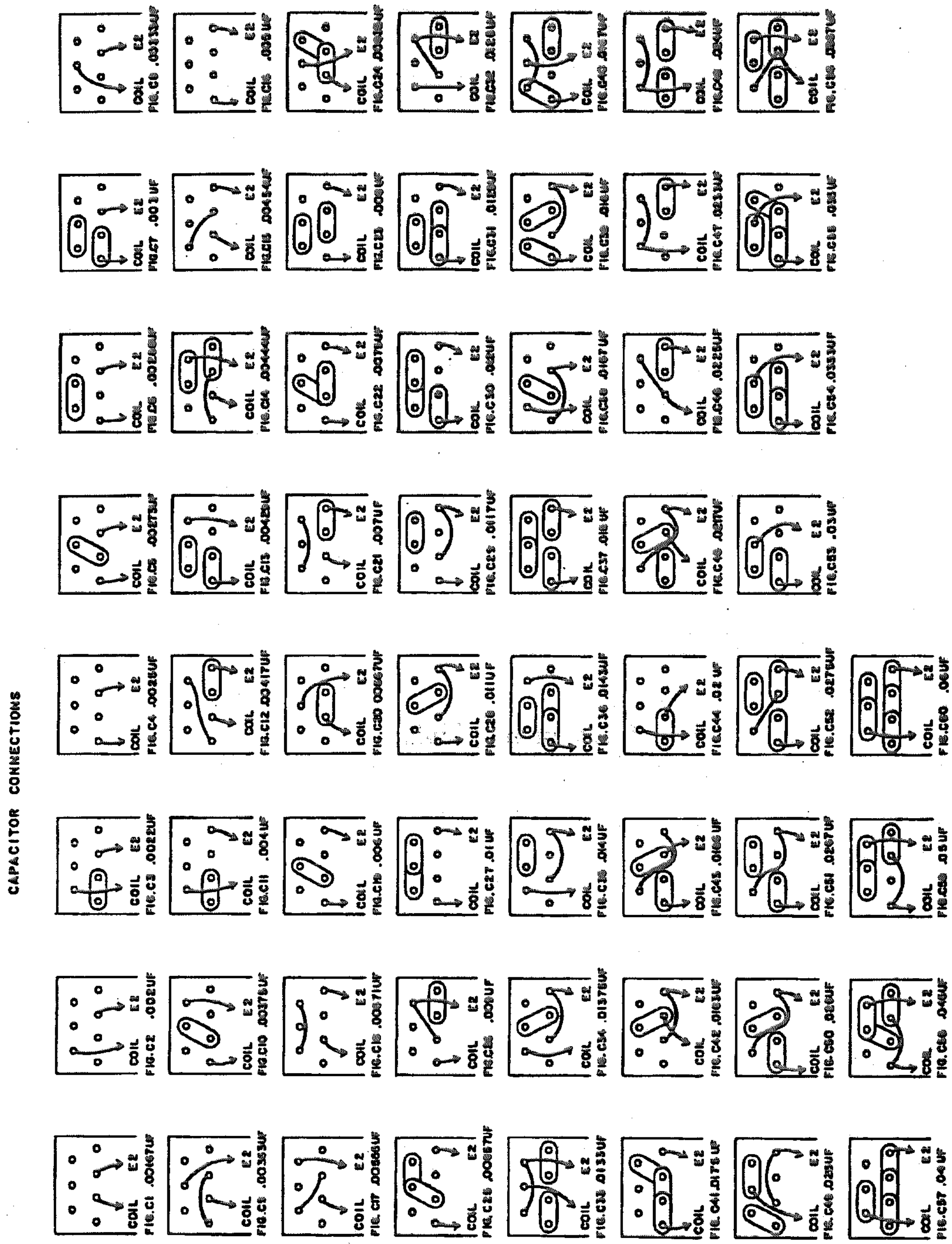


Figure 2 - Elementary Diagram

CONNECTION DIAGRAM FOR SERIES L/C UNITS

Figure 12-A.19.



Elementary Diagram

CONNECTION DIAGRAM FOR
SERIES L/C UNITS

Figure 12-A.20.

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APPENDIX B.

FIXED BANDWIDTH BANDPASS FILTERS

The frequency separation required for the higher power levels for series L/C bandpass filters may use large amounts of bandwidth, or spectrum, and this excessive bandwidth requirement for multiple PLC carrier sets may require a different combining device. If hybrids contribute unacceptable loss, and series L/C bandpass units require too much spectrum, the fixed bandwidth bandpass filter may be one solution for combining PLC carrier sets.

These filters are based on the bandwidths of 4 kHz, 5 kHz, 8 kHz, and 16 kHz. The fixed bandwidth bandpass filters are rated 100 watts PEP (peak effective power), and can be flanked at a separation, from upper bandedge to lower bandedge of the next channel, of twice the filter bandwidth. The frequency range is from 30 kHz to 500 kHz, and the insertion loss and spacing are given in Table 12-B.1. For simplicity, we will refer to these filters as "bandpass filters", as opposed to the "series L/C bandpass filters" in Appendix A.

TABLE 12-B.1.

BANDPASS FILTER CHARACTERISTICS			
BANDWIDTH (B) (kHz)	INSERTION LOSS @ 100 kHz	INSERTION LOSS @ 500 kHz	SPACING Fo1 - Fo2 (khz)
4	0.75	2.75	10
5	0.65	2.50	10
8	0.40	1.50	24
16	0.20	1.0	48

The insertion loss varies depending on the bandwidth of the filters. The spacing is center frequency to center frequency. The input and output impedances can be strapped for either 50 ohms or 75 ohms. The spacing does not change as the frequency is increased. Insertion loss values are maximum values under full power. The attenuation at the passband edge of the next flanked channel, which would be at the spacing minus the bandwidth, is a minimum of 15 dB. Figure 12-B.1 shows a representation of two bandpass filters with the standard spacing. These filters will have about 20 dB return loss in the passband in the unflanked condition.

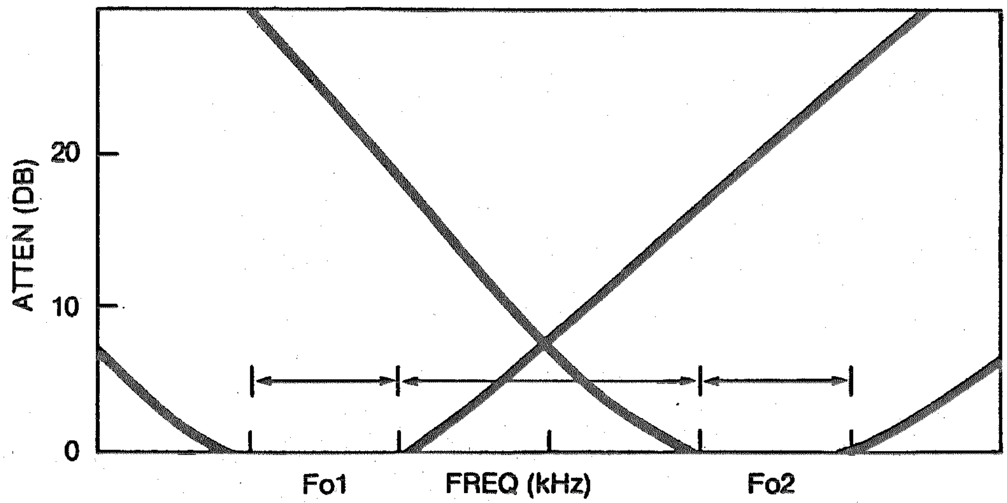


Figure 12-B.1. Typical Curves of Flanked Bandpass Filters

Figure 12-B.2 shows a PLC system with bandpass filters separating four transmitters and four receivers.

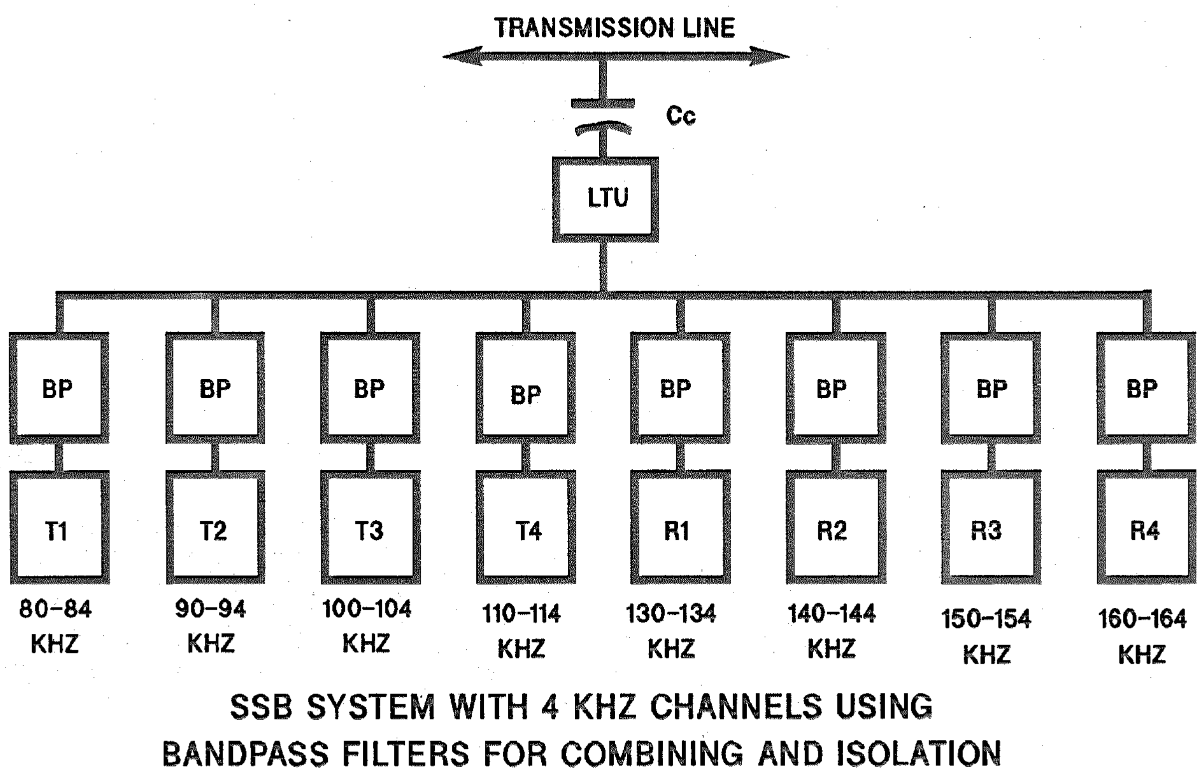
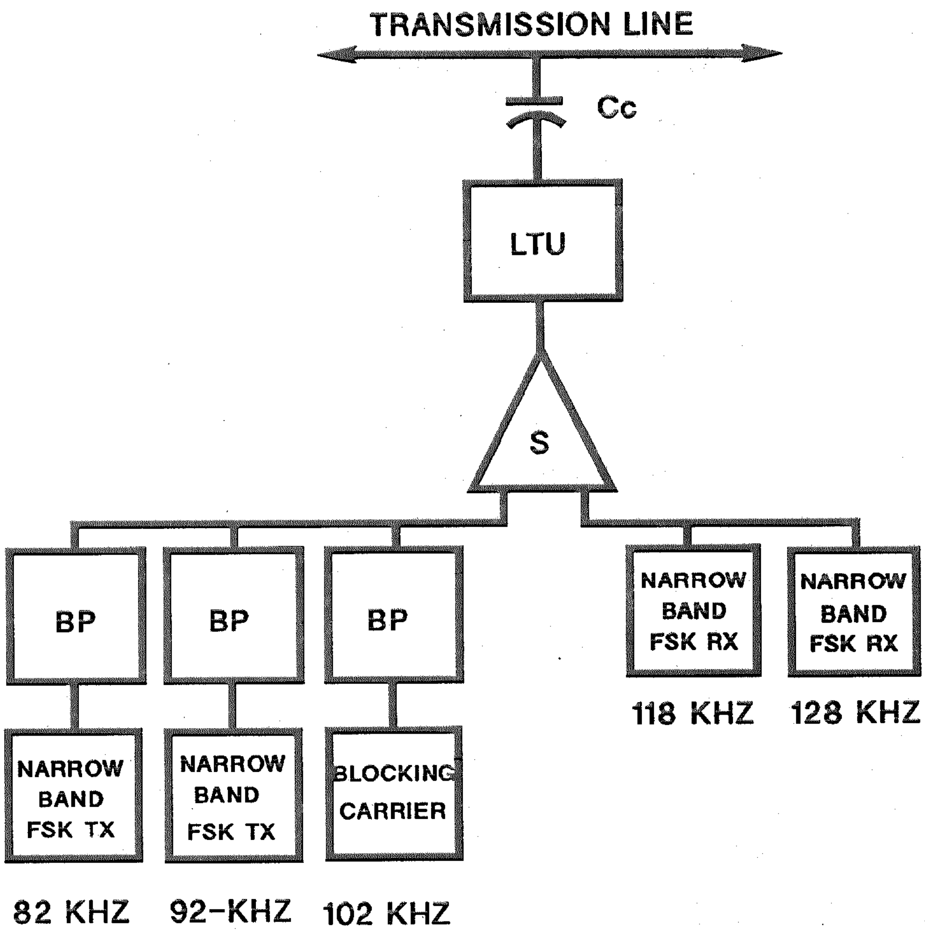


Figure 12-B.2.

Other systems may use combinations of bandpass filters and hybrids to combine transmitters and receivers. Figure 12-B.3 shows one possible connection.

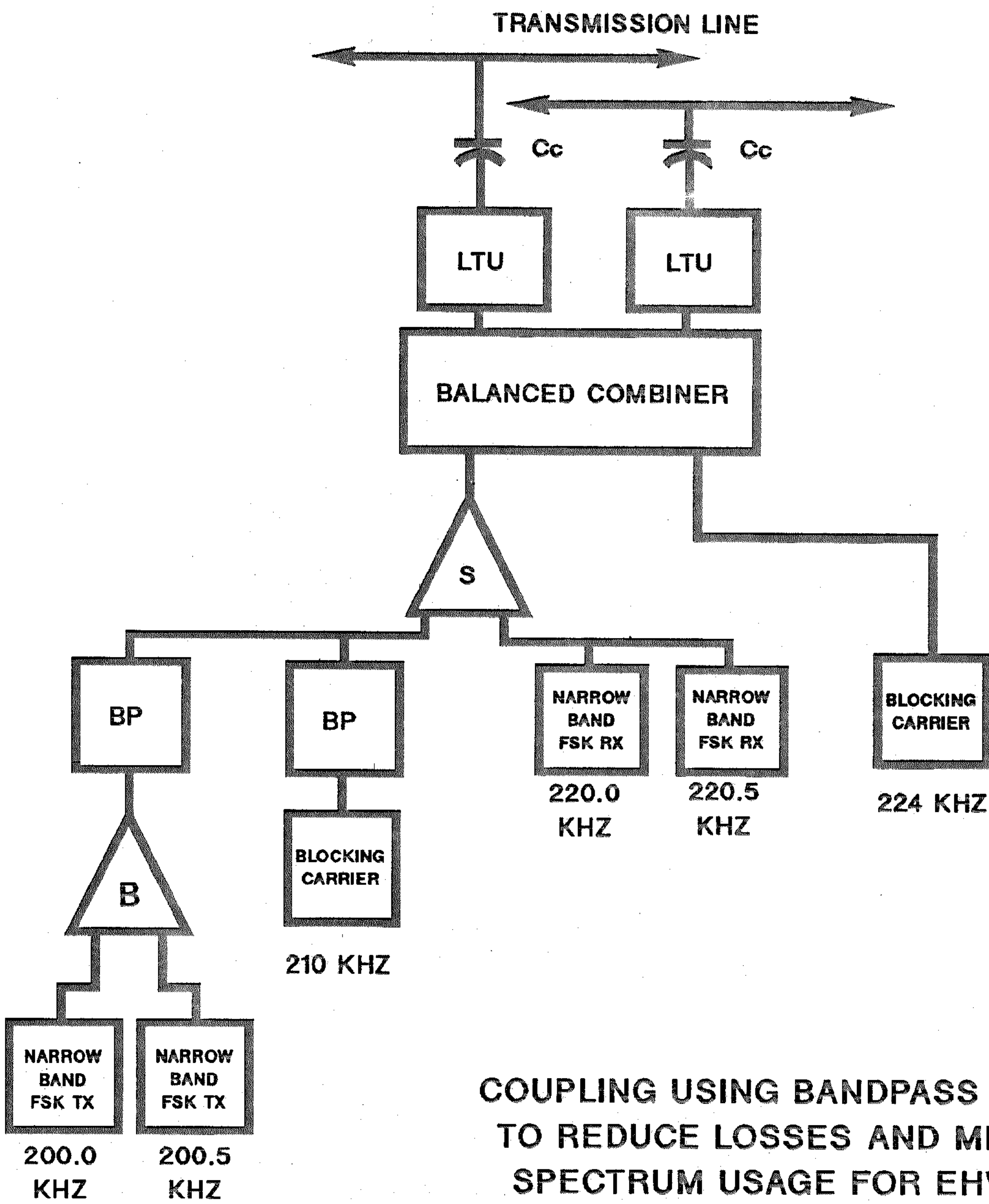


PLC SYSTEM USING BANDPASS FILTERS AND A SKEWED HYBRID TO REDUCE COUPLING LOSSES

Figure 12-B.3.

In Figure 12-B.3, the transmitters are flanked using bandpass filters and are combined into the low loss port of the skewed hybrid. The spacing is the same as the "2B" spacing in Figure 12-B.2. This connection allows the maximum amount of transmitter power to be coupled to the line while giving adequate separation of the carrier sets to prevent intermodulation distortion. The receivers are flanked directly at the high loss port of the skewed hybrid since the selectivity of the receivers is adequate to reject any adjacent channel signals.

A typical combination of PLC equipment for line and equipment protection on extra high voltage lines includes dual FSK channels for equipment protection and primary and secondary on/off blocking carrier sets for line protection. Where a minimum coupling loss and a minimum spectrum are joint requirements, the circuit of Figure 12-B.4 can be used. This circuit shows two FSK sets combined through a balanced hybrid and separated from a secondary blocking carrier set with bandpass filters. The primary blocking carrier set utilizes the other port of the balanced combiner for phase-to-phase coupling to the transmission line. The bandpass filters replaces the balanced hybrid which would be required to combine the carrier sets, thus reducing the coupling loss by about 2 dB.



COUPLING USING BANDPASS FILTERS TO REDUCE LOSSES AND MINIMIZE SPECTRUM USAGE FOR EHV LINE

Figure 12-B.4.

The bandpass filter is one option available to reduce spectrum requirements of high power L/C coupling circuits and to reduce the power loss when hybrids are the only available auxiliary coupling device.

A frequency programmable version of this filter is available which can be tuned in the field to either a 30-300 kHz range or 300-500 kHz range. This filter has a 5 kHz bandwidth and can be flanked center frequency to center frequency at 10 kHz. This can be used for single function or dual 2.5 kHz SSB channels. The filter can also be used with 4 kHz SSB channels at the same spacing as shown in Table 12-B.1. The 8 kHz and 16 kHz filters require the standard spacing. Spacing to the closest receiver should be 15 kHz for isolation.

APPENDIX C

LOWPASS/HIGHPASS BRANCHING FILTERS

The least lossy method of combining transmitters with the required isolation in PLC systems is by using a lowpass/highpass filter commonly called a "branching filter". The name is derived from the fact that the signals at the input (or output) are diverted to two paths depending on their frequencies. The low frequencies are sent through the lowpass filter branch and the high frequencies are sent through the highpass filter branch. The filters are complementary units which are designed to be flanked at their outputs. Only in the flanked condition will the correct characteristics of attenuation and ripple or return loss be demonstrated by both of the filters.

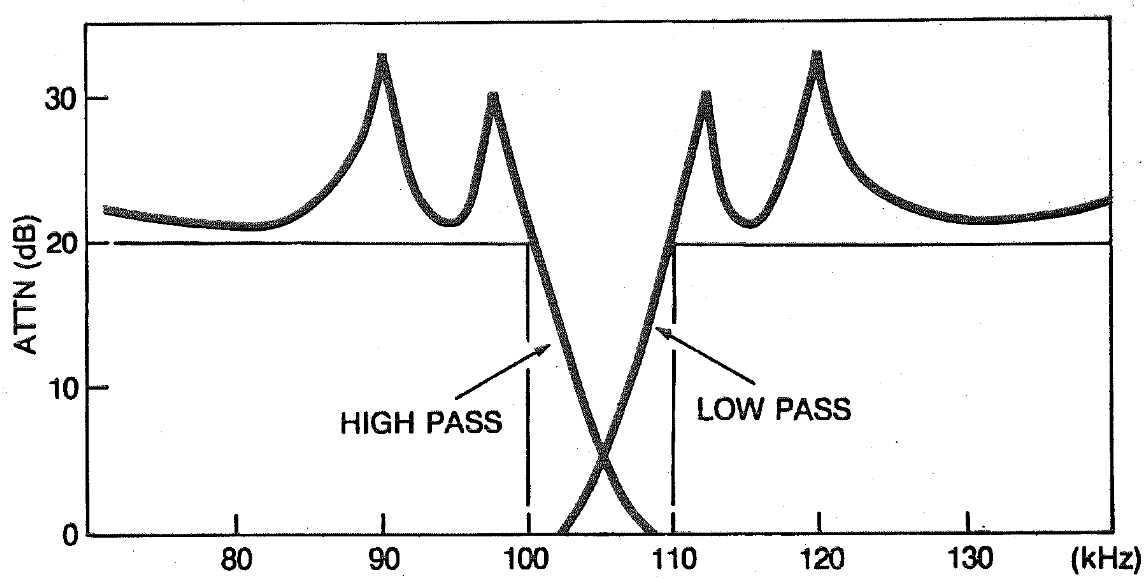


Figure 12-C.1. Attenuation Characteristic of 10 Per Cent Branching Filters

The filters are 50 ohms units. When flanked and terminated properly at all ports, there is a 10 per cent separation between the cutoff frequency of the lowpass filter and the cutoff frequency of the highpass filter. The cutoff frequency is the frequency at which the passband has not greater than 1.0 dB of rolloff. Stopband attenuation of the lowpass at the cutoff frequency of the highpass, and up to 500 kHz, is greater than 20 dB. The highpass has a complementary characteristic to the lowpass.

These filters have less than 0.5 dB insertion loss in the passband - typically less than 0.25 dB - and will pass 100 watts of RF power. The return loss is typically greater than 20 dB in the passband at any port with all other ports terminated in 50 ohms.

In addition to the use as a component in wideband bypass circuits with local drops, the branching filter can be used in band splitting and also in cascade connections, much like a bandpass filter, to isolate transmitters with at least ten per cent frequency separation. Figure 12-C.2 shows a coupling circuit using branching filters and hybrids to combine the functions of SSB and single function PLC equipment. Figure 12-C.3 shows the circuit at the other end of the line which will isolate the functions at that station. The low frequency branching filter is moved to the line side of the tuner and the SSB transmitters are separated by a 152/168 kHz branching filter.

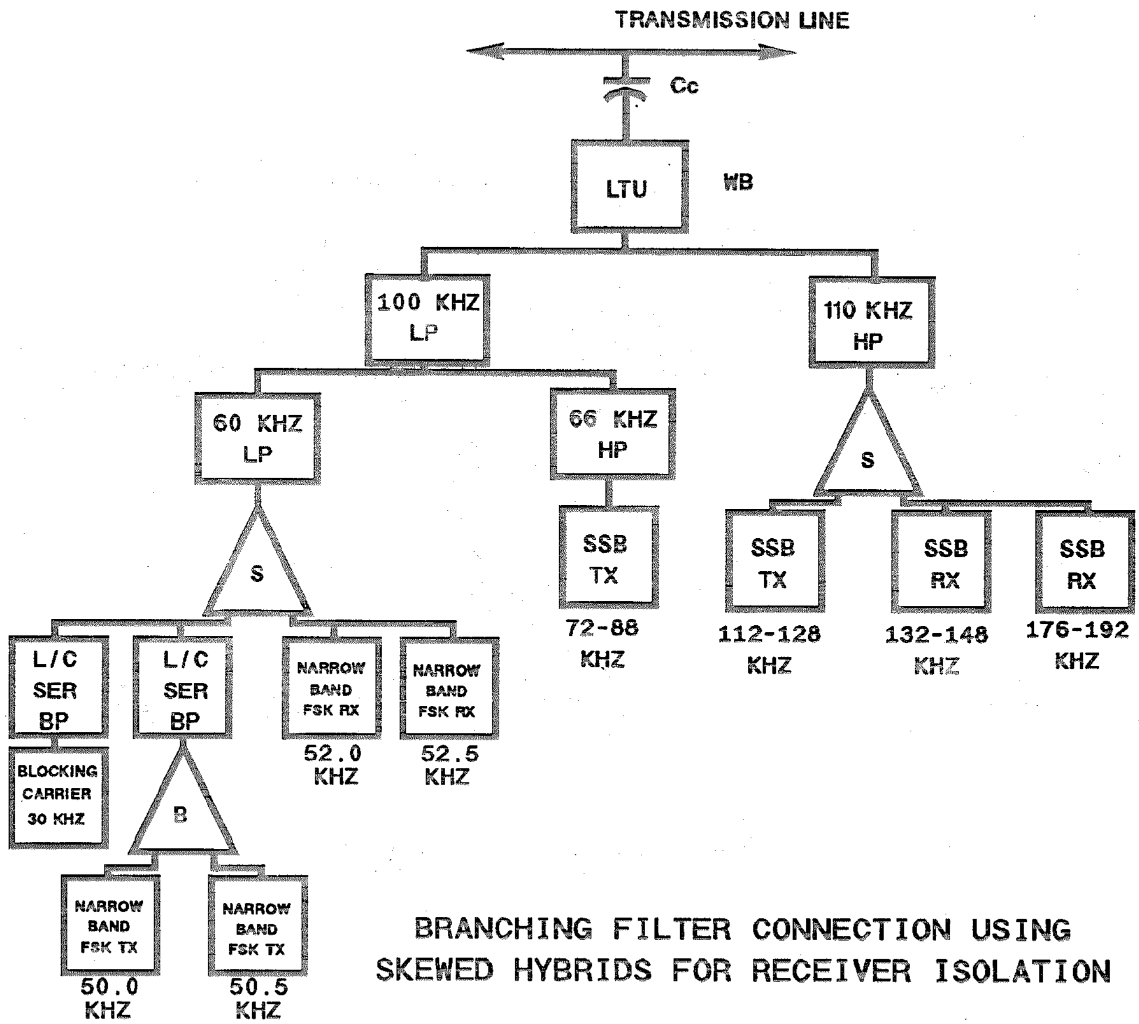


Figure 12-C.2.

The branching filter can pass a wide band of frequencies with a minimum of loss. The line tuners used with the branching filters must be wide band units and be tuned for maximum return loss across their passband, especially if hybrids are used in the auxiliary coupling circuit. No more than two branching filters should be connected in cascade when hybrids are used to as isolation devices to preserve the return loss at the hybrid output.

Figure 12-C.2 shows the combination of hybrids, L/C series bandpass filters, and branching filters used to couple five transmitters and five receivers to a wideband line tuner. The coupling loss for all transmitters, except for the FSK sets, is less than 1.0 dB. The loss for the two FSK sets is of the order of 4.0 dB. The same is true for the loss at the other station shown in Figure 12-C.3.

The wideband nature of the branching filter can be utilized in various types of coupling circuits to minimize the coupling loss. The branching filter is available with lowpass cutoff frequencies from 36 kHz to 100 kHz in 1 kHz increments. The filters from 100 kHz to 300 kHz can be tuned to almost any increment. The two units require 10.5 inches of mounting space for each filter.

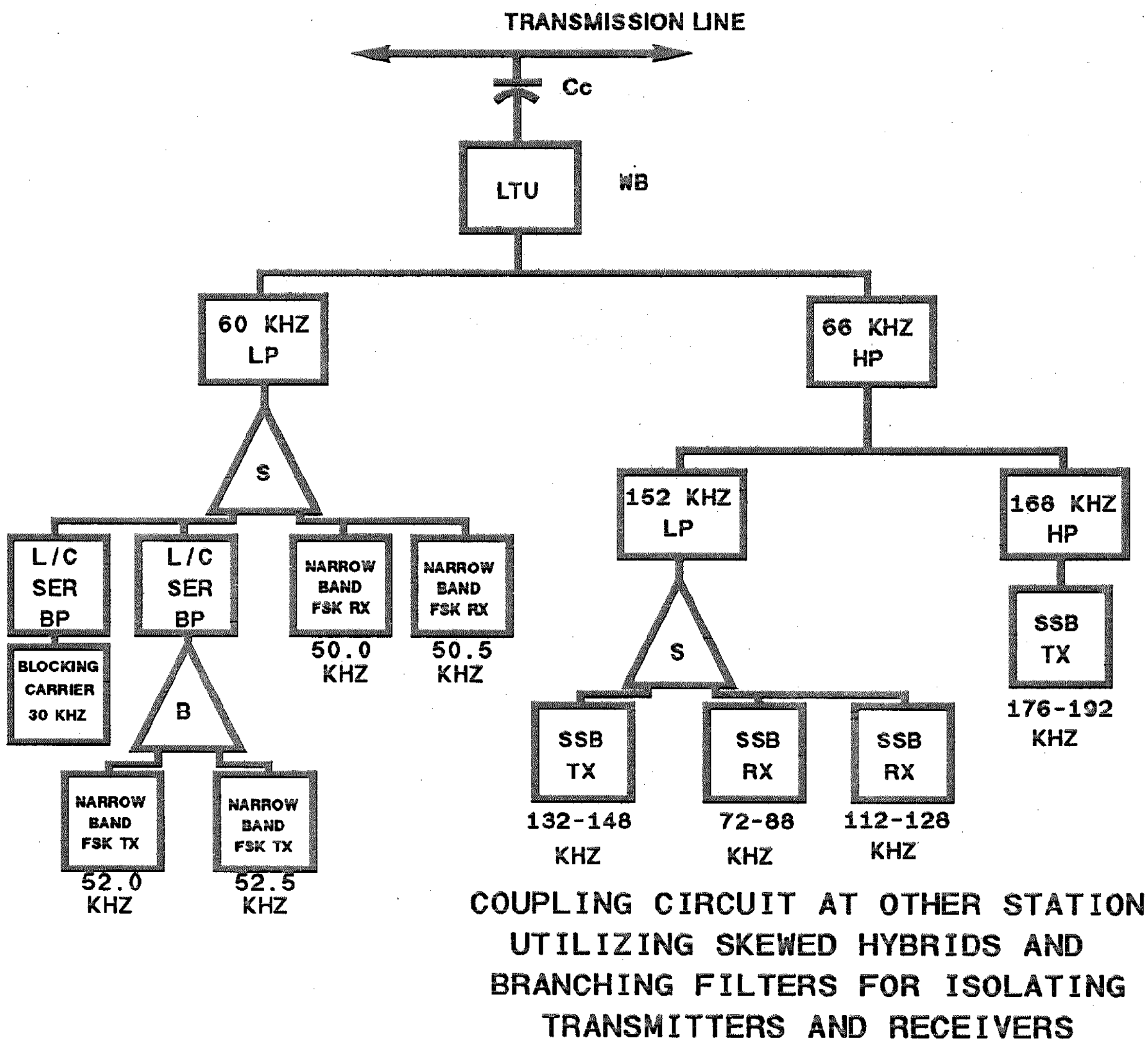


Figure 12-C.3.

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SECTION 13
BANDPASS LINE TUNERS

Contents of Section 13

APPENDICES

(Note: Adapted from reference [24]).

INTRODUCTION TO BANDPASS LINE TUNERS

The efficient transfer of PLC signals to and from high voltage transmission lines requires a network of components called a line tuner. The components of the tuner will almost always consist of: an impedance matching transformer, or IMT; an inductance to resonate with the high voltage coupling capacitor or CCVT; and a protective device which usually contains a protective gap, a power frequency blocking capacitor, a grounding switch, and possibly a drain coil. The drain coil can also be placed in the coupling capacitor, or CCVT, base to provide a low impedance path for power frequency current. An additional drain coil in the line tuner could then be detrimental to the functioning of the circuit. The second drain coil may reduce the PLC power to the transmission line since this element is a shunt inductance between the coupling capacitor and its tuning inductor, and two drain coils would effectively double the loss when only one drain coil is used. The bandpass line tuner will be defined, for the purpose of this discussion, as " a circuit of inductor and capacitor elements which are resonated to a single frequency, called the GMF or geometric mean frequency." This definition eliminates highpass tuners and two-frequency tuners.

PURPOSE

The purpose of the line tuner as a component in the coupling scheme and the role of each of the individual circuit components will be examined. The function of the line tuner is to accomplish the following:

1. Provide a means of coupling a band of frequencies, in the tuner passband, at an adequate power level to a phase wire - or wires - of an open wire, high voltage line, with a minimum loss in power.

2. Match the impedance of the line to the PLC equipment impedance (transmitters and receivers) for efficient transfer of RF power in the passband of the line tuner.

3. Provide a practical, reasonable return loss in the tuner passband to assure the isolation operation of hybrids and filters to reduce the possibility of intermodulation distortion. (The amount of isolation obtained by using hybrids is a direct function of the return loss at the coaxial cable connection to the line tuner.)

4. Provide surge and high-pot protection, and ground isolation as necessary.

5. Block the power frequency energy from entering the terminal equipment.

Only items 1. and 3. contain any requirements which may change with bandwidth. Item 2. is accomplished by the IMT. The IMT and the power frequency blocking capacitor provide the functions of items 4. and 5. A drain coil should be used in the CCVT, or coupling capacitor, or in the protection device which is part of the tuner to provide a low impedance path for the 60 Hz current.

LEAD - IN CABLE

Another very important component of the line tuner, although it is not part of the components in the outdoor cabinet, is the lead-in used to connect the coupling capacitor, or CCVT, to the line terminal of the line tuner. The type and manner of making this connection is as important as any component of the coupling system. A single conductor, Vulkene insulated, seven stranded, No. 8 AWG lead-in is used to connect the line terminal of the tuner to the coupling capacitor. Overhead, open construction must be used with this type of lead-in. Since the conductor is at the high impedance point of the series resonant circuit formed by the tuning inductor and the coupling capacitor, the leakage path(s) to ground must be carefully controlled. Failure to install and maintain the conductor properly will result in a loss of RF power from leakage resistance and a reduction in bandwidth caused by the shunt capacitance. The insulation of the lead-in must be kept dry and intact to reduce leakage across insulators. The run should be as short as practical with as few insulators as necessary. Clamping of the insulation should not violate the integrity of the insulation. The insulated, single conductor, lead-in should be carried directly through the bushing of the line tuner and connected to the line terminal. Connections at the ends of the lead-in at tuner and capacitor should be made as carefully as possible to make a clean, dry, low loss junction.

BANDWIDTH OF BANDPASS LINE TUNERS

The bandwidth of a bandpass line tuner is determined by the following variables (not considering leakage components which should be negligible in a properly installed unit):

A. The GMF (Geometric Mean Frequency), which is the frequency to which the circuits in the tuner are resonated. The GMF is defined as the square root of the product of the lower and upper passband frequencies which the tuner is required to pass. Therefore,

$$GMF = (F_{low} \times F_{high})^{1/2} \qquad (1)$$

In some cases, the bandwidth of the tuner may be much wider than that required to pass the desired band of frequencies. An adjusted value of GMF may be appropriate for this situation. (More about this later.)

B. The coupling capacitor value, C_c, (or CCVT value). C_c may be reduced by the value of the power frequency blocking capacitor, C_b. The effective value of the coupling capacitor, which will be labeled C_c', can be calculated using equation (2).

$$C_c' = (C_c \times C_b)/(C_c + C_b) \qquad (2)$$

C. The line impedance, or surge impedance value, R_L. This value varies with the line voltage, line construction, and coupling mode. The value of R_L can be determined from modal analysis of the power line. For lines of the same voltage and construction, the values are comparable. Tapped lines, short lines, and overhead line/cable circuits are exceptions to this general statement.

D. A constant, K,(*), which depends on the order of the bandpass tuner and the minimum return loss. These values are given in Table 13-1 for resonant tuners (N=1), and for wideband tuners (N =2, 3, and 4. THE ORDER OF THE TUNER, N, IS EQUAL TO THE NUMBER OF RESONANT CIRCUITS IN THE TUNER, INCLUDING THE COUPLING CAPACITOR. (* See Appendix A for source and significance of the constant, "K").

TABLE 13-1

			VALUES OF THE CONSTANT 'K'			
RETURN LOSS (DB)	REFLECTION COEFFICIENT (%)	RIPPLE (LOSS) (DB)	RESONANT	WIDEBAND		
			N = 1	N = 2	N = 3	N = 4
14.0	20.0	.177	.4070	.6983	1.1890	1.5450
12.0	25.0	.300	.5348	.8175	1.2250	1.5865
9.6	33.0	.500	.6984	.9625	1.2645	1.6364
3.0	70.7	3.000	2.0000	1.7920	1.5449	1.8702

Putting all of the parameters described above into the following equation, the bandwidths of various tuners can be calculated to determine the order of tuner required to meet almost any application requirement. Equation (3) gives the bandwidth of bandpass tuners for N= 1-4.

$$BW = 2\pi(GMF)^2 * R_L * C_c' * K \qquad (3)$$

Also,

$$BW = F_{high} - F_{low} \qquad (4)$$

and

$$(GMF)^2 = F_{high} * F_{low}, \qquad (1.a)$$

from equation (1).

Combining equations (1.a) and (4) gives

$$BW = F_{high} - (GMF)^2 / (F_{high}). \qquad (5)$$

13

And, putting this in quadratic form gives

$$F_{high}^2 - F_{high}*BW - (GMF)^2 = 0. \quad (6)$$

Using the quadratic formula, the solution for F_{high} is

$$F_{high} = BW/2 + [(GMF)^2 + (BW/2)^2]^{1/2} \quad (7)$$

and the lower passband frequency, F_{low}, is

$$F_{low} = F_{high} - BW. \quad (4.a)$$

The tables in Appendix C, which follow this explanation, make use of equations (3), (7), and (4.a) to calculate the bandedge frequencies for bandpass line tuners of order N=1-4, where the order of the tuner, again, is simply the number of resonant L/C circuits in the tuner, including the coupling capacitor. The tables use a return loss of 14 dB, a line impedance of 300 ohms, and a power frequency blocking capacitance of 0.1 microfarads.

RELATION BETWEEN LOSS, RETURN LOSS, AND REFLECTION COEFFICIENT

The bandwidth of the tuner determines the impedance looking into the coaxial cable from the terminal equipment. This impedance can be expressed as a minimum return loss in the tuner passband. Return loss, as a function of impedance, is given by the relation

$$\text{Return Loss} = 20 \log \frac{R_o + Z_{in}}{R_o - Z_{in}}, \quad (8)$$

where R_o is the equipment impedance which would give maximum return loss (usually 50 ohms or 75 ohms), and Z_{in} is the impedance looking into the coaxial cable with the tuner connected to the high voltage line.

It should also be pointed out that the individual values of the capacitors and inductors in the wideband tuners depend on the value of line impedance. If the line impedance value assumed is not correct, the values of capacitance and inductance calculated for bandpass filters of order N=2-4 result in a lower return loss than stated for a calculated bandwidth. The inductance of the resonant tuner is determined solely by the GMF and the coupling capacitance value. The only degree of freedom remaining for the resonant tuner is the setting of the transformer tap.

Rewriting equation (8), after dividing through by R_o and removing the logarithm gives

$$10^{(\text{Return Loss}/20)} = \frac{1 + Z_{in}/R_o}{1 - Z_{in}/R_o}. \quad (8.a)$$

Normalizing equation (8.a) by letting $R_o = 1$, and taking the reciprocal of the expression gives another relation which introduces another factor encountered in circuit theory called the " reflection coefficient", which was introduced without explanation in Table 13-1, and is usually denoted by the Greek letter, ρ (rho). Thus:

$$\rho = 10^{-(\text{Return Loss}/20)} = \frac{1 - Z_{in}}{1 + Z_{in}}. \quad (8.b)$$

Also, equation (8) can be rewritten as

$$\text{Return Loss} = 20 \log 1/\rho. \qquad (8.c)$$

Equation (8.b) can be expressed in a tabular form by solving for various values of the reflection coefficient, ρ , with the return loss given. The amount of loss, or ripple in the tuner passband, is also related to the reflection coefficient by equation (9). Thus:

$$\text{LOSS(DB)} = -10 \log (1 - |\rho|^2), \qquad (9)$$

and the values derived from equations (8.b), (8.c), and (9) comprise the first three columns of Table 13-1. Table 13-1 can be expanded by adding other values to the return loss column, and also by adding the values of variation of the real impedance which are necessary to give this value of return loss. This is Table 13-2, with a listing of selected values of return loss and values of Z_{in}(resistive) along with reflection coefficient and loss or ripple. The values of Z_{in} can be found by using equations (10.a) and (10.b) shown below.

$$Z_{in(low)} = (1 - \rho)/(1 + \rho) \qquad (10.a)$$

$$Z_{in(high)} = (1 + \rho)/(1 - \rho) \qquad (10.b)$$

The value of ρ in these equations is a real number.

TABLE 13-2

SELECTED VALUES OF RETURN LOSS AND CORRESPONDING VALUES OF REFLECTION COEFFICIENT, LOSS, AND REAL IMPEDANCE.

RETURN LOSS (DB)	REFLECTION COEFFICIENT (%)	LOSS (DB)	Z(low) (OHMS)	Z(high) (OHMS)
30	3.162	.00435	.9387	1.0653
28	3.981	.00687	.9234	1.0829
26	5.012	.01092	.9046	1.1055
24	6.310	.01732	.8812	1.1347
22	7.943	.02749	.8528	1.1726
20	10.000	.04365	.8182	1.2222
18	12.589	.06933	.7764	1.2880
16	15.849	.11048	.7264	1.3767
14	19.953	.17643	.6673	1.4985
12	25.119	.28305	.5985	1.6709
10	31.623	.45757	.5195	1.9249
8	39.811	.74940	.4305	2.3728
6	50.119	1.25630	.3323	3.0095
3	70.795	3.02060	.1710	5.8480

13

Looking at the values for 14 dB return loss in Table 13-2, the resistive values of the impedance can vary from about 33 ohms to 75 ohms for an equipment impedance of 50 ohms. This is a considerable variation in the resistive impedance. Other values of resistance can be calculated for other return loss values. After developing the real impedances which will give a certain value of return loss, the question of complex impedance and how it affects return loss should be answered. The influence of complex impedance on return loss based on reflection coefficient is explored in Appendix B. An important question that should be addressed is " why is return loss important in the first place?". Consider the diagram of Figure 13-1.

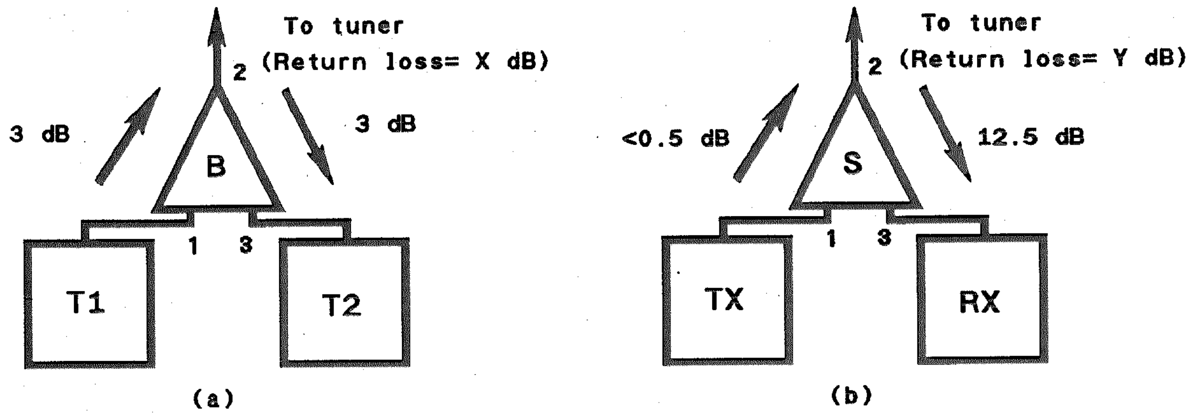

Figure 13-1

In Figure 13-1(a), the balanced hybrid is denoted by the "B" in the triangle, while the "S" in Figure 13-1(b) denotes a skewed hybrid. The isolation between the two transmitters with the balanced, or symmetrical hybrid shown in Figure 13-1(a) is the sum of the loss from port 1 to port 2, plus the loss from port 2 to port 3, plus the return loss at port 2 of X dB. Thus the isolation is 6 dB plus the return loss at the coaxial cable going to the tuner. For a skewed hybrid, the isolation is about 13 dB plus the return loss at the line side port of the hybrid. Therefore, to achieve an isolation of 20 dB for a balanced hybrid, the minimum return loss at the frequencies of the two transmitters must be 14 dB. To achieve a 25dB isolation between the transmitter and receiver of Figure 13-1(b), a return loss of at least 12 dB must be maintained at the line side of the skewed hybrid. The tuner specifications for 12 dB and 14 dB return loss are thus related to the isolation requirements for systems using hybrids as isolation devices. Using bandpass filters to achieve isolation between various transmitters and receivers is also dependent on a reasonable return loss, but this dependence is not as direct as the hybrid dependence.

COMPARISON OF TUNER BANDWIDTHS

Since the need to control the return loss has been established, the significance of the various orders of bandpass line tuners will be discussed. First, consider the curves of Figure 13-2. This graph shows the bandedge frequencies for N=1-4 bandpass line tuners using a line impedance of 300 ohms, a return loss of 14 dB, and a coupling capacitance value of 5000 pF. This chart is a plot of the data given on pages 13-28 and 13-29 of Appendix C. These curves show several characteristics of bandpass line tuners. Since the curves represent tuners with the same values of line impedance, return loss, and coupling capacitance value, the only variables are the GMF and the order of the bandpass tuner, which is controlled by the constant, K. A study of the curves reveals the following:

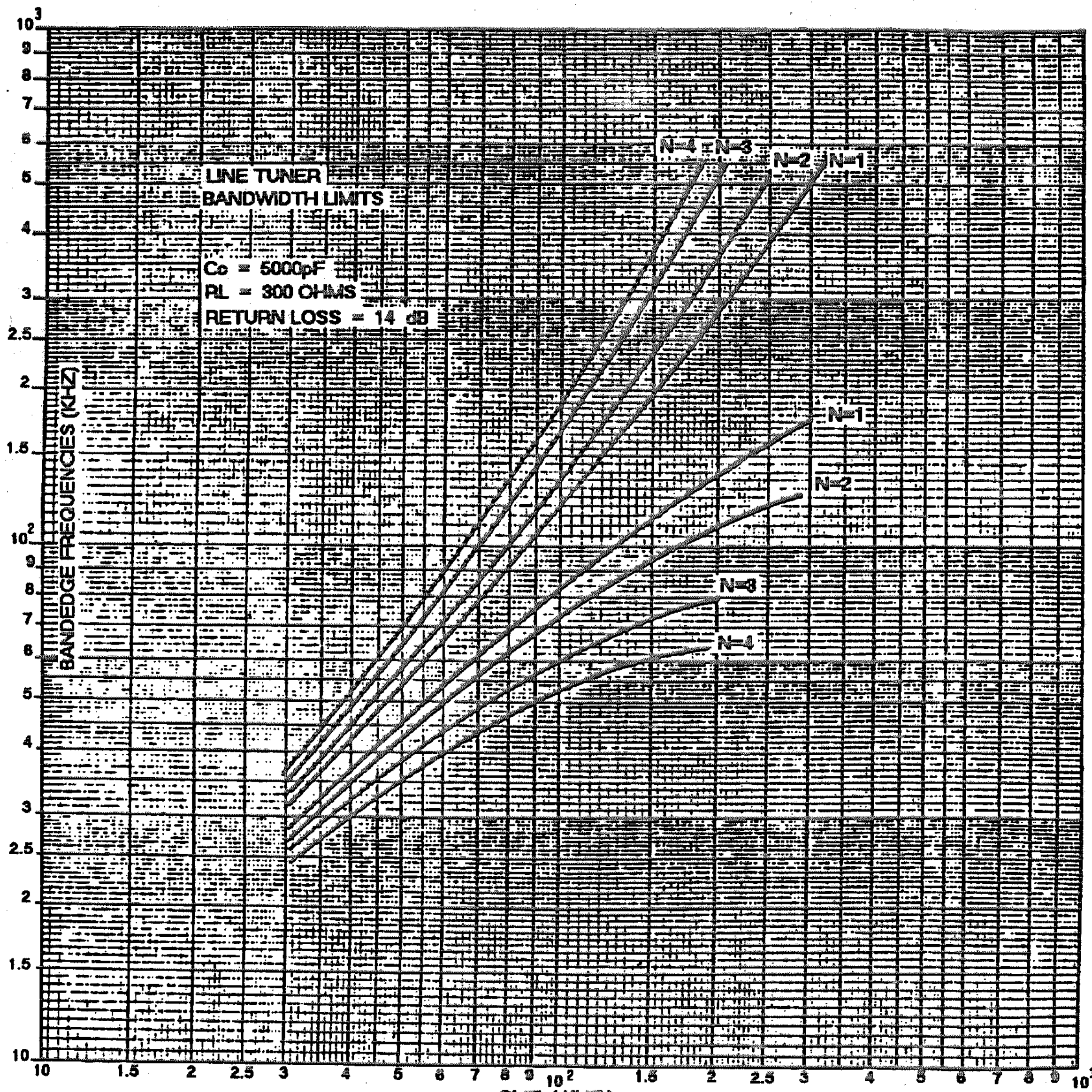

Figure 13-2

A .The resonant tuner (N=1) at a GMF of 80 kHz has a 14 dB return loss bandwidth of 23.5 kHz (69 to 92.5 kHz). This bandwidth increases to about 145 kHz (140 to 285 kHz) at a GMF of 200 kHz. Therefore, we can conclude that with a coupling capacitor size of 5000 pF, the bandwidth is sufficient for most PLC applications for a GMF of 80 kHz to 200 kHz. For a GMF above 200 kHz, the higher bandedge may have to be examined to control the noise bandwidth. The wider the noise bandwidth, the more impulse noise will affect the PLC transmitters and receivers connected to the coaxial cable from the line tuner under adverse weather conditions. The upper bandedge should be sufficient to pass the highest frequency installed on the line section with a consideration given to possible expansion. (See examples.)

13

B. As mentioned in A., the higher GMF's may give excessive bandwidth. Consider an application with carrier sets at 230 kHz and at 270 kHz. The resulting GMF is approximately 250 kHz. The resonant tuner (N-1) will give bandedge frequencies of about 160 kHz and 390 kHz for the given set of variables. This GMF will give much more bandwidth above 270 kHz than necessary even for a resonant (N=1) tuner. A GMF of 200 kHz will give bandedge frequencies of about 140 kHz and 285 kHz. The selection of GMF should consider the frequencies to be passed by the tuner, and this should be adjusted, if necessary, to limit the high frequency bandedge to a reasonable value. The reduced bandwidth will reduce the noise bandwidth of the system and improve the adverse weather condition performance.

C. For low frequency applications - below 60 kHz - the resonant tuner may be adequate for a single carrier set. But, for multiple sets - even narrowband sets - , where a bandwidth of 10 kHz or more is required, there are other options available to increase the bandwidth. The wideband (N=2) tuner will give 10 kHz bandwidth at a GMF of 40 kHz (35.3 to 45.3 kHz). For special applications, for widely spaced carrier sets, or for SSB applications, higher order tuners will increase the low frequency bandwidths. The wideband (N=4) tuner will pass the band of frequencies from 30 to 50 kHz at a GMF of 40 kHz. Smaller values of coupling capacitors and lower line impedances will reduce the bandwidth of all of these tuners. The bandwidths vary directly with these parameters. The examples shown later will show the effect of capacitor size on bandwidth.

To compare the bandwidths of the various tuners at any GMF, ratios of the constant, K, for 14 dB return loss are listed in Table 13-3.

TABLE 13-3

BANDWIDTH COMPARISON RATIOS MATRIX FOR 14 DB RETURN LOSS.				
N = 1	N = 2	N = 3	N = 4	
1.0000	1.7157	2.9214	3.7961	K(N)/K(1)
.5828	1.0000	1.7027	2.2125	K(N)/K(2)
.3423	.5873	1.0000	1.2994	K(N)/K(3)
.2634	.4520	.7696	1.0000	K(N)/K(4)

To use Table 13-3 to see the effect on the bandwidth of using a second order tuner instead of a first order tuner at a GMF of 80 kHz, enter the table on the first row. This row compares the constant "K" for the second, third, and fourth order tuners to the value of "K" for a resonant tuner. The second order tuner bandwidth is 1.7157 times that of the resonant (N=1) tuner. The bandwidth of the second order tuner is calculated using the previous resonant(N=1) bandwidth at a GMF of 80 kHz in item (A) on page 13-7. Thus,

BW(N=2) = 23.5 kHz x 1.7157 = 40.32 kHz

The actual bandedge frequencies for the second order tuner from the tabular listing on page 13-28 of Appendix C are 62.419 kHz and 102.533 kHz for a bandwidth of 40.11 kHz.

(Note: The calculations are only accurate to four digits since the values of "K" are only correct to four places.)

From Table 13-3, the benefit of using a higher order tuner to increase bandwidth is evident. A second order tuner is 71% wider than a resonant tuner at 14 dB return loss. A third order tuner is 292% wider than the resonant tuner, while the fourth order tuner is almost 380% wider than the resonant tuner. Similar comparisons can be made between the second order tuner (N=2) and the resonant tuner and N=3 or N=4 tuners.

SELECTING TUNERS FOR SPECIFIC APPLICATIONS

The tables of bandedge frequencies in Appendix C include capacitance values from 20,000 pF to 1500 pF, which covers the range of values presently available from suppliers. Equations (3), (4), and (7) may be used to compute other values of bandedge frequencies for other values of the variables in equation (3). Values of the constant, K, corresponding to other return loss values as shown in Table 13-1, can be used to compute other return loss bandwidths.

The effect of tuning, tolerance, and impedance matching must also be considered when selecting a minimum return loss bandwidth. All of these factors can only result in reducing the return loss at the tuner/equipment interface. The tabulations of bandedge frequencies, as presented on pages 13-17 through 13-53 of Appendix C for 14 dB return loss assume that hybrids are the primary isolation device, and a minimum of 10 dB return loss is required. The value of return loss is constantly changing in the tuner bandwidth so that an observation or measurement made at one or two frequencies is not necessarily the minimum value for the entire tuner bandwidth.

As shown by the bandedge listings of page 13-17 for a capacitance of 20,000 pF(0.02uF), the bandwidth for the N=4 tuner is excessive. Actually, the third order tuner (N=3) will pass the entire PLC spectrum of 30 kHz to 500 kHz with a GMF of 115 kHz. For the bandedge range from 30 kHz to 300 kHz, the range of the GMF for the second order tuner is from 50 kHz to 110 kHz for this capacitance. Notice that the resonant tuner (N=1) will give a bandwidth of 20 kHz at a GMF of 40 kHz, and a bandwidth of 232 kHz at a GMF of 135 kHz. The availability of higher order tuners to increase the coupled bandwidth should be tempered with the realization that these wider bandwidths open up the PLC equipment to high impulse noise.

The tabular listings end at the highest GMF required to pass the highest PLC frequency currently used. Using a higher GMF for the values of capacitance shown will result in excessive bandwidth and will increase the noise bandwidth of the system.

13

EXAMPLES:

Some examples to demonstrate the use of the bandedge listings are given.

EXAMPLE 1. Cc=4800 pF; RL=300 ohms; Cb=0.1 uF; Return Loss = 14 dB; required to pass frequencies from 180 kHz to 280 kHz.

SOLUTION: GMF = $(180 \times 280)^{1/2}$ = 224.5 kHz.

Refer to page 13-30 of the bandedge tables. For N=1, the bandedge frequencies for a GMF of 225 kHz are 152.999 kHz and 330.884 kHz. For N=2, these frequencies are 119.267 kHz and 434.469 kHz. The bandwidth of the resonant tuner is adequate to pass the frequency range of this application with plenty of margin. The higher order tuners (N=2, etc.) are too wide and are not appropriate for this application.

EXAMPLE 2. Cc=2400 pF; RL=300 ohms; Cb=0.1 uF; Return Loss=14 dB; required to pass frequencies from 180 kHz to 280 kHz. (Same as example 1)

SOLUTION: GMF = 224.5 kHz (From example 1)

Refer to page 13-44 of the bandedge tables. For N=1, the bandedge frequencies are 184.044 kHz and 275.071 kHz. For N=2, the bandedge frequencies are 160.077 kHz and 316.255 kHz. The resonant tuner (N=1) is too narrow since the coupling capacitor value is now only one-half of the Example 1 value. The second order tuner has adequate bandwidth and will pass the upper and lower frequencies with plenty of margin.

EXAMPLE 3. Cc=5500 pF; RL=300 ohms; Cb=0.1 uF; Return Loss = 14 dB; Required: to pass frequencies from 60 kHz to 480 kHz.

SOLUTION: GMF = $(60 \times 480)^{1/2}$ = 169.71 kHz.

Refer to page 13-26 of the bandedge tables. Only the bandedge tables for N=4 will give adequate bandwidth to pass 60 kHz to 480 kHz. The fourth order tuner is the proper choice (and the only choice.)

EXAMPLE 4: Cc=4800 pF; RL=300 ohms; Cb=0.1uF; Return Loss=14 dB; required to pass 300 kHz to 450 kHz. The customer has specified a wideband second order tuner (N=2).

SOLUTION: GMF = $(300 \times 450)^{1/2}$ = 367.42 kHz.

Refer to page 13-30 of the bandedge tables. For N=2, the highest GMF to pass the highest PLC frequency of 500 kHZ is a GMF of 250 kHz. The low bandedge frequency for this GMF is 124.642 kHz. This tuner will give a 50 kHZ margin on the high frequency side of the tuner and over 150 kHZ on the lower passband edge. Therefore, a GMF of 250 kHz is certainly high enough without exposing the PLC equipment to a wider bandwidth of noise than necessary.

(Note: If the customer had ordered a resonant tuner, the tuner could have been tuned to 300 kHz and the bandedge frequencies would have been 181 kHz and 497.24 kHz which would have been adequate for this application.)

In cases where the calculated GMF is higher than that listed for a particular capacitance, the GMF should be reduced to the GMF which will pass the highest PLC frequency in use, or some selected upper frequency to limit the bandwidth. The GMF can be adjusted to give adequate margin on both low and high bandedges without opening up the noise bandwidth unnecessarily. There is no application where the GMF should be chosen above the last set of bandedge frequencies for a particular order of tuner or circuit parameters as shown in the bandedge tables.

EXAMPLE 5: Cc=3300 pF; RL=300 ohms; Cb=0.1 uF; Return Loss =14 dB; Customer has ordered wideband second order tuner (N=2). Desired frequencies are 220 to 280 kHz.

SOLUTION: GMF = $(220 \times 280)^{1/2}$ = 248.19 kHz.

The bandedge frequencies given on page 13-36 of the tables for N=2 for a GMF of 250 kHz are 151.027 kHz and 413.834 kHz. This is a bandwidth of 262 kHz. Since the customer may never use frequencies greater than 300 kHz, 100+ kHz of that bandwidth is not needed. A change in GMF to 205 kHz will reduce the bandwidth to 176 kHz with bandedge frequencies of 134.875 and 311.586 kHz. For this application, a resonant tuner, using a GMF of 235 kHz, would have been adequate. The bandedge frequencies for the resonant (N=1) tuner are 176.877 kHz and 312.223 kHz.

EXAMPLE 6: Cc=2600 pF; RL=300 ohms; Cb=0.1uF; return loss = 14dB; Required to pass the frequencies from 75 khz to 120 kHz. Determine tuner order.

SOLUTION: GMF = $(75 \times 120)^{1/2}$ = 94.868 kHz

Refer to page 13-38 of the bandedge tables. For N=1, the bandedge frequencies are 86.631 kHz and 104.177 kHz for a GMF of 95 kHz. This is much too narrow. Find the lower bandedge frequency less than 75 kHz in the listings for a GMF of 95 kHz. The lower bandedge for an N=3 bandpass tuner is 72.768 kHz. The upper bandedge frequency is 124.025 kHz. The fourth order tuner will also be adequate, but is not necessary since the third order (N=3) has enough margin. The tuner selected is a third order wideband tuner with a GMF of 95 kHz.

CONCLUSIONS

These examples have shown some of the rules to use for bandpass line tuner design. In many instances the resonant tuner will solve the tuner application problem when the capacitance of the coupling capacitor or CCVT is large enough to satisfy the bandwidth requirements. For some low frequency applications, the wideband tuners with two or more resonant circuits must be used. Values of coupling capacitors have increased in the past few years to help to solve the bandwidth problem for low frequency line tuners. For systems where eight or more functions are coupled to the power line, the wideband tuner may be the only answer since the bandwidth of these tuners offers potential for increasing the tuner bandwidth by simply increasing the number of tuned circuits in the tuner cabinet. The increased bandwidth may also give better return loss for operation of the PLC equipment to improve isolation when using hybrids for isolating PLC functions.

The tolerance and discrete values of the capacitors in the L/C units used in the tuners must be considered in determining the bandwidth margin to allow in selecting the order of bandpass line tuner. The tolerance on the capacitors is usually 10 %. The increment in capacitor values in the strapping charts shows increments as large as 10 per cent. This will generally mean an approximate 5 per cent effect on the return loss bandwidth. The other degree of uncertainty which must also be considered is the line impedance and the ability of the IMT to match various impedances. The IMT will usually have the capability of taps at about 5% intervals from 150 ohms to 500 ohms. This range is usually sufficient to match most high voltage line impedances. As mentioned previously, the components of wideband tuners (N=2-4) depend on the value of line impedance specified. If the actual line impedance is different from the value used to determine these component values, then the return loss and bandwidth will be modified by the ratio of the actual impedance to the design impedance. The IMT setting will determine the match between the line and the equipment. Thus, for wide band tuners, the line impedance specification or selected value is not trivial. Short lines, tapped lines, and lines with cable/overhead line interfaces are special cases which must be addressed on an individual basis.

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APPENDIX A

SOURCE OF THE CONSTANT "K" AND DERIVATION OF THE BANDWIDTH FORMULA

The constant, K, is the value of the normalized lowpass inductance used to determine the bandpass inductance and the bandwidth of the line tuner. The relations used to eventually determine the parameters of equation (3) of the text are derived from equations (A.1) through (A.4). Refer to Figure 13-A.1.

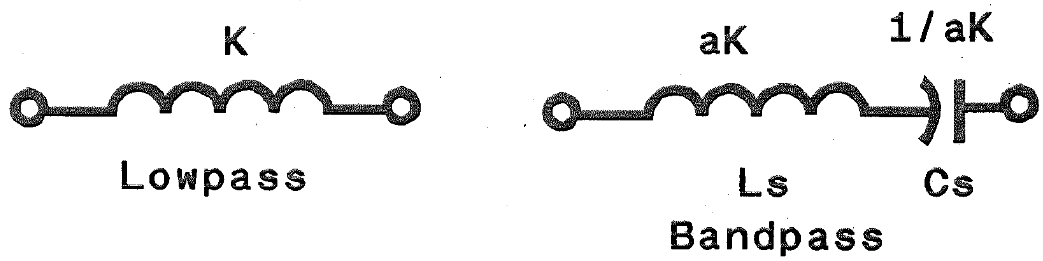

Figure 13-A.1

In Figure 13-A.1.,

$$a = Fo/BW \qquad (A.1)$$

and

$$Cs = 1/aK = Fo/(K \times BW) \ . \qquad (A.2)$$

Here, Fo is the resonant frequency of the series bandpass circuit. The actual capacitor value is obtained by denormalizing by a reference capacitance, which is related to the terminating impedance and resonant frequency by relation (A.3). Thus:

$$Co = 1/(2\pi Fo \times RL) \qquad (A.3)$$

Then Cc = Cs x Co, and combining (A.2) and (A.3), gives

$$Cc = BW/(Fo\ K\ (2\pi Fo)RL) \qquad (A.4)$$

Solving for the bandwidth, BW, gives

$$BW = 2\pi (Fo)^2\ K\ Cc\ RL, \qquad (A.5)$$

which is identical to equation (3) of the text if the GMF is substituted for the resonant frequency, Fo, and Cc' is used instead of Cc.

Since GMF, K, Cc, and RL are known quantities, the bandwidth can be calculated. The value of K is proportional to the bandwidth at a particular return loss. This is the reason why a discussion of bandwidth, without defining the return loss, loss, or reflection coefficient has no meaning.

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APPENDIX B

COMPLEX IMPEDANCE AND REFLECTION COEFFICIENT

To determine the input impedance deviation in the complex plane required to meet a specified reflection coefficient, the expression for reflection coefficient in equation (8.b) of the text will be used. This expression will be expanded in the complex r+jx plane using the following steps:

$$\rho = \frac{1 - Z_{in}}{1 + Z_{in}} = \frac{1 - r - jx}{1 + r + jx} = \frac{\{(1 - r)^2 + x^2\}^{1/2}}{\{(1 + r)^2 + x^2\}^{1/2}} \qquad \text{(B.1)}$$

Square both sides, and expand:

$$\rho^2[(1 + r)^2 + x^2] = (1 - r)^2 + x^2$$

$$\rho^2 + \rho^2 r^2 + 2r\rho^2 + \rho^2 x^2 = 1 - 2r + r^2 + x^2$$

Rearrange:

$$r^2 - \rho^2 r^2 - 2r - 2r\rho^2 + x^2 - \rho^2 x^2 + 1 - \rho^2 = 0$$

$$r^2(1 - \rho^2) - 2r(1 + \rho^2) + x^2(1 - \rho^2) + (1 - \rho^2) = 0$$

Divide through by $(1 - \rho^2)$:

$$r^2 - 2r\frac{(1 + \rho^2)}{(1 - \rho^2)} + x^2 + 1 = 0$$

Complete the square:

$$r^2 - 2r\frac{(1 + \rho^2)}{(1 - \rho^2)} + x^2 + \frac{(1 + \rho^2)^2}{(1 - \rho^2)^2} = \frac{(1 + \rho^2)^2}{(1 - \rho^2)^2} - 1$$

13

Simplify:

$$r^2 - 2r\frac{(1+\rho^2)}{(1-\rho^2)} + \frac{(1+\rho^2)^2}{(1-\rho^2)^2} + x^2 = \frac{(2\rho)^2}{(1-\rho^2)^2}$$

$$[\, r - (1+\rho^2)/(1-\rho^2)\,]^2 + x^2 = (2\rho)^2/(1-\rho^2)^2 \qquad \text{(B.2)}$$

Equation (B.2) represents a set of circles in the complex r+jx plane with the following parameters:

$$\text{Radius} = 2\rho/(1-\rho^2) \qquad \text{(B.3)}$$

$$\text{Centers at } r = (1+\rho^2)/(1-\rho^2) \qquad \text{(B.4)}$$

Figure 13-B.1 shows a family of these circles in the complex impedance plane for ρ = 5%, 10%, 20%, 30%, 40%, and 50%. A value of Zin terminating anywhere on the circumference of the circles, with its beginning a the origin, will result in a reflection coefficient which is a constant for that circle. A return loss of 14 dB would require that the impedance variation remain inside the reflection coefficient circle for 20%. The impedance looking into the coaxial cable going to the line tuner is actually a complex impedance composed of the IMT, line tuner, line trap, and the line impedance. This complex impedance is constantly changing with frequency. Faults on the line which cause any component impedance to change will also cause this return loss, or reflection coefficient, to change.

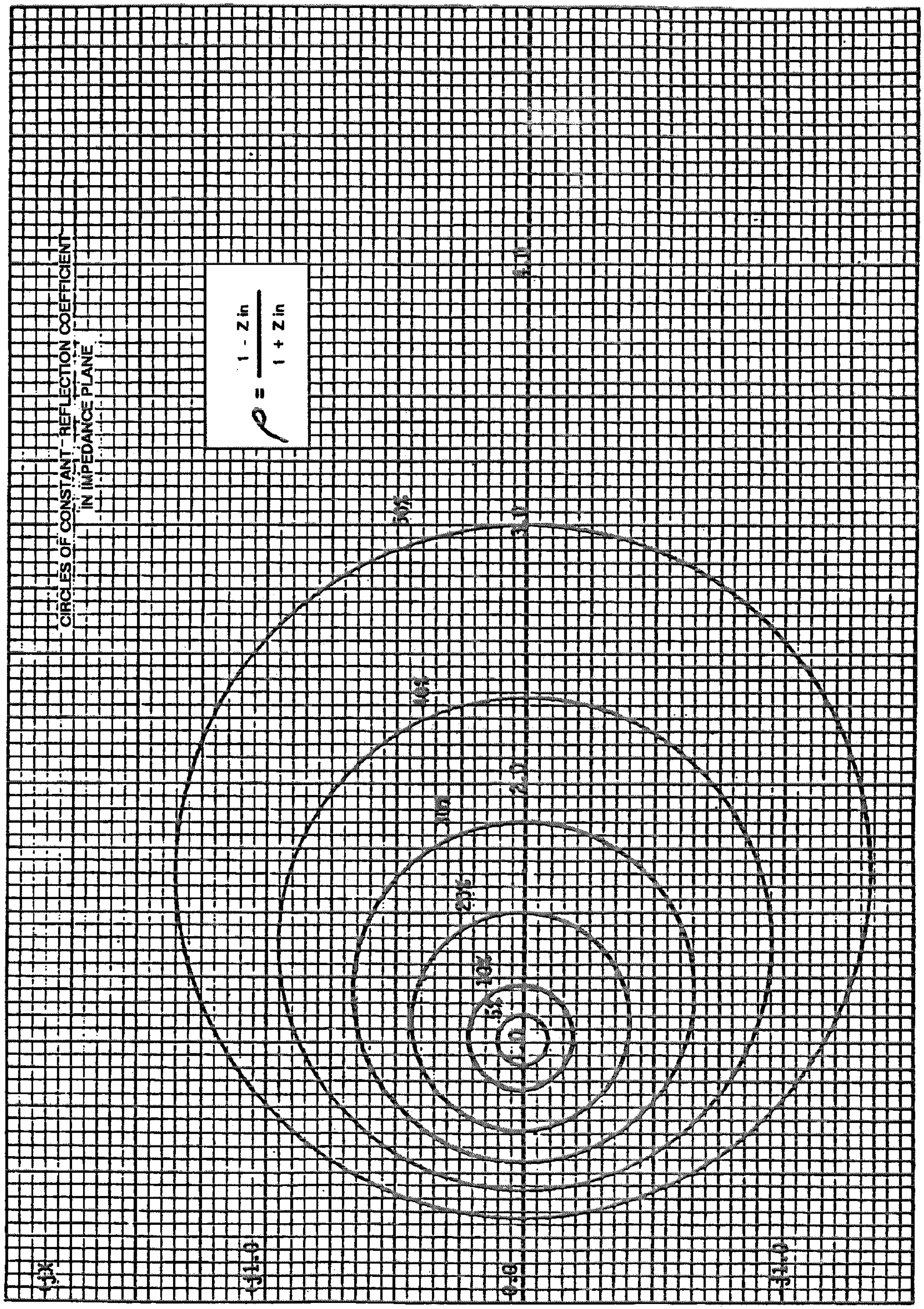
CIRCLES OF CONSTANT REFLECTION COEFFICIENT
IN IMPEDANCE PLANE
ρ = (1 - Z in)/(1 + Z in)
50%
40%
30%
20%
10%
5%
1.0
2.0
3.0
4.0
0.0

Figure 13-B.1

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APPENDIX C.

BANDEDGE FREQUENCIES FOR BANDPASS LINE TUNERS OF ORDER N = 1-4

Table 13-C.1

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 20000.00 PF(.02000 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	24.793	36.301	21.711	41.455	17.579	51.197	15.267	58.951
35.000	28.034	43.697	24.054	50.928	18.935	64.694	16.193	75.651
40.000	31.058	51.516	26.131	61.231	20.047	79.813	16.917	94.578
45.000	33.879	59.771	27.971	72.395	20.962	96.603	17.490	115.779
50.000	36.510	68.475	29.604	84.448	21.720	115.103	17.948	139.292
55.000	38.962	77.640	31.053	97.415	22.350	135.345	18.317	165.144
60.000	41.247	87.278	32.340	111.316	22.879	157.351	18.619	193.354
65.000	43.378	97.400	33.486	126.173	23.324	181.143	18.867	223.938
70.000	45.364	108.016	34.507	142.002	23.702	206.734	19.073	256.907
75.000	47.214	119.137	35.418	158.818	24.024	234.138	19.246	292.270
80.000	48.940	130.772	36.233	176.635	24.301	263.364	19.392	330.033
85.000	50.549	142.930	36.963	195.464	24.540	294.419	19.516	370.201
90.000	52.050	155.619	37.619	215.315	24.747	327.311	19.623	412.778
95.000	53.451	168.847	38.210	236.198	24.928	362.044	19.715	457.767
100.000	54.758	182.621	38.742	258.119	25.086	398.622	19.795	505.171
105.000	55.979	196.948	39.223	281.086	25.226	437.049	19.865	554.992
110.000	57.120	211.834	39.658	305.105	25.349	477.327		
115.000	58.187	227.285	40.054	330.180	25.459	519.460		
120.000	59.184	243.307	40.413	356.317	25.557	563.448		
125.000	60.118	259.904	40.741	383.518				
130.000	60.993	277.081	41.041	411.788				
135.000	61.813	294.843	41.314	441.130				
140.000	62.581	313.192	41.565	471.545				
145.000	63.303	332.134	41.796	503.037				
150.000	63.980	351.672	42.008	535.608				
155.000	64.617	371.807	42.204	569.258				
160.000	65.216	392.544						
165.000	65.779	413.886						
170.000	66.310	435.833						
175.000	66.810	458.390						
180.000	67.282	481.557						
185.000	67.727	505.337						
190.000	68.148	529.732						
195.000	68.545	554.744						

Table 13-C.2

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 16500.00 PF(.01650 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	25.506	35.285	22.762	39.540	18.943	47.511	16.717	53.839
35.000	28.972	42.282	25.397	48.234	20.595	59.480	17.902	68.429
40.000	32.241	49.626	27.776	57.604	21.986	72.774	18.857	84.851
45.000	35.324	57.327	29.923	67.674	23.159	87.438	19.631	103.155
50.000	38.230	65.394	31.861	78.467	24.153	103.509	20.263	123.379
55.000	40.969	73.837	33.610	90.003	24.996	121.017	20.783	145.554
60.000	43.549	82.665	35.190	102.302	25.716	139.989	21.214	169.701
65.000	45.980	91.887	36.618	115.382	26.333	160.445	21.574	195.840
70.000	48.270	101.512	37.909	129.257	26.864	182.402	21.877	223.985
75.000	50.427	111.546	39.078	143.942	27.323	205.874	22.133	254.145
80.000	52.459	121.999	40.138	159.449	27.721	230.873	22.352	286.330
85.000	54.373	132.877	41.100	175.791	28.068	257.408	22.540	320.546
90.000	56.177	144.188	41.974	192.977	28.373	285.487	22.702	356.799
95.000	57.876	155.938	42.769	211.017	28.640	315.116	22.843	395.093
100.000	59.477	168.133	43.494	229.918	28.877	346.301	22.966	435.431
105.000	60.986	180.779	44.155	249.687	29.086	379.047	23.074	477.817
110.000	62.409	193.883	44.760	270.332	29.273	413.357	23.169	522.252
115.000	63.751	207.448	45.313	291.858	29.439	449.233	23.253	568.739
120.000	65.017	221.481	45.820	314.271	29.588	486.680		
125.000	66.211	235.986	46.286	337.573	29.722	525.699		
130.000	67.339	250.968	46.715	361.771	29.843	566.291		
135.000	68.404	266.430	47.109	386.867				
140.000	69.411	282.377	47.473	412.864				
145.000	70.362	298.811	47.810	439.765				
150.000	71.262	315.738	48.121	467.574				
155.000	72.113	333.159	48.409	496.292				
160.000	72.918	351.078	48.676	525.921				
165.000	73.681	369.497	48.925	556.464				
170.000	74.404	388.420						
175.000	75.089	407.848						
180.000	75.739	427.784						
185.000	76.356	448.231						
190.000	76.941	469.189						
195.000	77.497	490.662						
200.000	78.026	512.650						
205.000	78.529	535.155						
210.000	79.007	558.180						

Table 13-C.3

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 15000.00 PF(.01500 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	25.833	34.839	23.253	38.705	19.603	45.912	17.434	51.622
35.000	29.404	41.662	26.030	47.061	21.409	57.219	18.761	65.294
40.000	32.788	48.799	28.557	56.027	22.948	69.722	19.845	80.623
45.000	35.995	56.258	30.858	65.624	24.263	83.460	20.736	97.657
50.000	39.033	64.049	32.950	75.872	25.388	98.471	21.471	116.436
55.000	41.909	72.180	34.854	86.790	26.354	114.784	22.082	136.989
60.000	44.633	80.657	36.587	98.395	27.185	132.425	22.593	159.342
65.000	47.212	89.490	38.165	110.703	27.904	151.414	23.023	183.513
70.000	49.653	98.685	39.603	123.729	28.527	171.769	23.387	209.518
75.000	51.963	108.250	40.913	137.487	29.069	193.506	23.697	237.368
80.000	54.149	118.192	42.109	151.988	29.543	216.635	23.963	267.074
85.000	56.218	128.517	43.200	167.244	29.958	241.168	24.193	298.641
90.000	58.177	139.231	44.198	183.265	30.324	267.113	24.392	332.078
95.000	60.030	150.340	45.112	200.059	30.648	294.477	24.565	367.389
100.000	61.785	161.852	45.948	217.635	30.934	323.266	24.717	404.577
105.000	63.446	173.770	46.716	236.001	31.189	353.485	24.851	443.646
110.000	65.019	186.100	47.421	255.162	31.417	385.139	24.969	484.599
115.000	66.509	198.847	48.069	275.125	31.621	418.230	25.074	527.438
120.000	67.920	212.015	48.666	295.895	31.805	452.763	25.168	572.165
125.000	69.257	225.611	49.216	317.477	31.970	488.739		
130.000	70.524	239.636	49.724	339.875	32.119	526.161		
135.000	71.725	254.096	50.194	363.093	32.255	565.030		
140.000	72.864	268.994	50.628	387.134				
145.000	73.945	284.335	51.031	412.002				
150.000	74.970	300.120	51.405	437.700				
155.000	75.944	316.353	51.752	464.230				
160.000	76.868	333.038	52.076	491.593				
165.000	77.746	350.177	52.377	519.794				
170.000	78.581	367.773	52.657	548.832				
175.000	79.375	385.828						
180.000	80.130	404.345						
185.000	80.848	423.326						
190.000	81.532	442.772						
195.000	82.183	462.686						
200.000	82.804	483.070						
205.000	83.395	503.925						
210.000	83.960	525.253						
215.000	84.498	547.055						
220.000	85.012	569.334						

Table 13-C.4

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 11000.00 PF(.01100 UF)   LINE IMPED.= 300.0 OHMS   CB= .100 UF

RETURN LOSS= 14.000 DB   AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	26.773	33.616	24.699	36.439	21.626	41.616	19.703	45.678
35.000	30.652	39.965	27.911	43.890	23.947	51.155	21.534	56.887
40.000	34.378	46.542	30.904	51.774	26.001	61.537	23.097	69.273
45.000	37.956	53.351	33.691	60.105	27.818	72.794	24.434	82.876
50.000	41.392	60.398	36.286	68.896	29.428	84.953	25.580	97.731
55.000	44.690	67.688	38.702	78.161	30.855	98.040	26.566	113.868
60.000	47.856	75.226	40.951	87.910	32.121	112.077	27.416	131.312
65.000	50.894	83.015	43.044	98.155	33.246	127.084	28.151	150.085
70.000	53.809	91.062	44.992	108.908	34.247	143.077	28.789	170.204
75.000	56.606	99.371	46.805	120.178	35.140	160.073	29.345	191.684
80.000	59.289	107.946	48.494	131.976	35.938	178.084	29.832	214.537
85.000	61.862	116.792	50.066	144.309	36.653	197.121	30.259	238.774
90.000	64.331	125.912	51.531	157.188	37.293	217.196	30.635	264.403
95.000	66.698	135.312	52.896	170.618	37.870	238.317	30.968	291.431
100.000	68.968	144.995	54.168	184.609	38.389	260.491	31.263	319.865
105.000	71.145	154.965	55.356	199.167	38.858	283.726	31.526	349.710
110.000	73.233	165.225	56.464	214.297	39.282	308.026	31.761	380.969
115.000	75.236	175.781	57.498	230.006	39.667	333.397	31.972	413.648
120.000	77.156	186.634	58.465	246.300	40.017	359.844	32.161	447.748
125.000	78.998	197.790	59.369	263.183	40.336	387.371	32.332	483.272
130.000	80.765	209.250	60.215	280.660	40.627	415.980	32.486	520.223
135.000	82.459	221.018	61.007	298.735	40.893	445.674	32.626	558.603
140.000	84.085	233.097	61.749	317.413	41.137	476.457		
145.000	85.645	245.491	62.445	336.696	41.361	508.331		
150.000	87.141	258.201	63.098	356.589	41.567	541.297		
155.000	88.578	271.231	63.711	377.094				
160.000	89.956	284.584	64.287	398.215				
165.000	91.279	298.261	64.829	419.953				
170.000	92.549	312.266	65.339	442.312				
175.000	93.769	326.600	65.819	465.293				
180.000	94.940	341.266	66.271	488.899				
185.000	96.066	356.267	66.698	513.131				
190.000	97.147	371.603	67.101	537.992				
195.000	98.186	387.277	67.482	563.483				
200.000	99.184	403.290						
205.000	100.144	419.646						
210.000	101.067	436.344						
215.000	101.955	453.387						
220.000	102.809	470.777						
225.000	103.630	488.515						
230.000	104.421	506.602						
235.000	105.183	525.039						
240.000	105.916	543.829						
245.000	106.622	562.971						

Table 13-C.5

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 10000.00 PF(.01000 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	27.025	33.302	25.095	35.864	22.201	40.538	20.365	44.193
35.000	30.988	39.532	28.430	43.088	24.679	49.638	22.358	54.790
40.000	34.808	45.967	31.557	50.702	26.894	59.493	24.081	66.441
45.000	38.489	52.612	34.487	58.718	28.874	70.133	25.573	79.185
50.000	42.036	59.472	37.232	67.147	30.644	81.581	26.866	93.054
55.000	45.454	66.551	39.803	76.000	32.228	93.862	27.989	108.076
60.000	48.745	73.853	42.210	85.288	33.646	106.995	28.967	124.278
65.000	51.916	81.382	44.464	95.021	34.917	121.000	29.821	141.678
70.000	54.968	89.142	46.574	105.208	36.058	135.893	30.568	160.296
75.000	57.907	97.138	48.550	115.859	37.082	151.690	31.225	180.147
80.000	60.737	105.373	50.400	126.983	38.004	168.402	31.802	201.243
85.000	63.461	113.850	52.133	138.588	38.835	186.042	32.313	223.595
90.000	66.082	122.574	53.756	150.681	39.586	204.620	32.765	247.213
95.000	68.606	131.549	55.277	163.270	40.264	224.145	33.167	272.105
100.000	71.034	140.777	56.702	176.362	40.879	244.625	33.526	298.277
105.000	73.371	150.263	58.038	189.963	41.437	266.067	33.847	325.734
110.000	75.620	160.010	59.291	204.080	41.944	288.478	34.134	354.482
115.000	77.785	170.020	60.466	218.717	42.407	311.862	34.393	384.526
120.000	79.868	180.298	61.570	233.881	42.829	336.224	34.626	415.867
125.000	81.872	190.846	62.606	249.576	43.214	361.569	34.838	448.510
130.000	83.801	201.668	63.580	265.806	43.568	387.900	35.029	482.457
135.000	85.658	212.765	64.496	282.577	43.892	415.220	35.203	517.711
140.000	87.445	224.142	65.357	299.891	44.191	443.534	35.362	554.273
145.000	89.165	235.800	66.168	317.754	44.465	472.842		
150.000	90.820	247.743	66.931	336.167	44.718	503.148		
155.000	92.414	259.972	67.650	355.135	44.952	534.454		
160.000	93.948	272.491	68.329	374.659	45.169	566.760		
165.000	95.425	285.302	68.969	394.744				
170.000	96.848	298.406	69.573	415.392				
175.000	98.218	311.807	70.144	436.604				
180.000	99.537	325.506	70.683	458.383				
185.000	100.808	339.505	71.194	480.731				
190.000	102.033	353.807	71.677	503.651				
195.000	103.213	368.412	72.134	527.143				
200.000	104.350	383.324	72.568	551.209				
205.000	105.447	398.543						
210.000	106.503	414.072						
215.000	107.522	429.911						
220.000	108.505	446.063						
225.000	109.453	462.528						
230.000	110.367	479.309						
235.000	111.249	496.407						
240.000	112.101	513.823						
245.000	112.923	531.557						
250.000	113.716	549.612						
255.000	114.483	567.989						

Table 13-C.6

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 7500.00 PF(.00750 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	27.688	32.505	26.151	34.416	23.778	37.850	22.219	40.505
35.000	31.875	38.432	29.824	41.074	26.709	45.864	24.702	49.591
40.000	35.947	44.510	33.322	48.016	29.401	54.419	26.922	59.431
45.000	39.906	50.744	36.653	55.249	31.872	63.536	28.907	70.051
50.000	43.755	57.136	39.822	62.780	34.139	73.230	30.683	81.478
55.000	47.497	63.688	42.837	70.616	36.219	83.519	32.272	93.734
60.000	51.134	70.403	45.705	78.765	38.128	94.419	33.695	106.840
65.000	54.669	77.283	48.434	87.233	39.880	105.943	34.971	120.815
70.000	58.104	84.331	51.028	96.026	41.488	118.106	36.116	135.674
75.000	61.442	91.549	53.495	105.150	42.965	130.920	37.145	151.434
80.000	64.685	98.941	55.840	114.613	44.323	144.395	38.071	168.107
85.000	67.836	106.507	58.070	124.419	45.571	158.544	38.906	185.704
90.000	70.897	114.251	60.190	134.574	46.720	173.374	39.660	204.236
95.000	73.870	122.175	62.205	145.084	47.778	188.896	40.342	223.713
100.000	76.757	130.281	64.122	155.954	48.753	205.116	40.960	244.141
105.000	79.562	138.572	65.943	167.189	49.652	222.043	41.521	265.528
110.000	82.285	147.049	67.676	178.793	50.483	239.683	42.031	287.880
115.000	84.930	155.716	69.324	190.772	51.251	258.042	42.496	311.203
120.000	87.499	164.573	70.891	203.129	51.962	277.126	42.921	335.501
125.000	89.993	173.624	72.382	215.870	52.620	296.939	43.309	360.779
130.000	92.415	182.871	73.800	228.997	53.231	317.485	43.665	387.040
135.000	94.767	192.314	75.150	242.515	53.798	338.770	43.991	414.288
140.000	97.050	201.957	76.435	256.427	54.324	360.797	44.291	442.525
145.000	99.267	211.802	77.659	270.736	54.814	383.569	44.568	471.755
150.000	101.420	221.849	78.824	285.447	55.271	407.089	44.823	501.979
155.000	103.511	232.102	79.934	300.561	55.696	431.360	45.058	533.200
160.000	105.540	242.562	80.992	316.082	56.093	456.384	45.276	565.419
165.000	107.511	253.230	82.000	332.013	56.464	482.164		
170.000	109.425	264.109	82.961	348.357	56.811	508.702		
175.000	111.283	275.200	83.878	365.115	57.136	536.000		
180.000	113.087	286.505	84.753	382.290	57.441	564.059		
185.000	114.839	298.025	85.587	399.884				
190.000	116.541	309.762	86.384	417.899				
195.000	118.193	321.718	87.146	436.338				
200.000	119.798	333.894	87.873	455.203				
205.000	121.357	346.292	88.568	474.494				
210.000	122.871	358.912	89.233	494.214				
215.000	124.342	371.757	89.868	514.364				
220.000	125.771	384.827	90.477	534.945				
225.000	127.159	398.124	91.059	555.960				
230.000	128.507	411.649						
235.000	129.818	425.404						
240.000	131.091	439.389						
245.000	132.328	453.606						
250.000	133.531	468.056						
255.000	134.700	482.740						
260.000	135.836	497.658						
265.000	136.941	512.813						
270.000	138.015	528.205						
275.000	139.059	543.834						
280.000	140.074	559.702						

Table 13-C.7

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 6700.00 PF(.00670 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	27.910	32.246	26.510	33.949	24.328	36.994	22.879	39.337
35.000	32.174	38.075	30.302	40.427	27.426	44.666	25.548	47.949
40.000	36.331	44.039	33.931	47.155	30.296	52.813	27.962	57.221
45.000	40.386	50.141	37.403	54.140	32.953	61.451	30.145	67.176
50.000	44.340	56.383	40.725	61.388	35.413	70.596	32.119	77.836
55.000	48.194	62.767	43.902	68.904	37.690	80.261	33.904	89.222
60.000	51.952	69.295	46.940	76.694	39.797	90.460	35.520	101.352
65.000	55.615	75.968	49.844	84.764	41.747	101.206	36.982	114.244
70.000	59.186	82.790	52.620	93.120	43.552	112.510	38.307	127.913
75.000	62.665	89.763	55.274	101.766	45.223	124.385	39.509	142.373
80.000	66.056	96.887	57.810	110.707	46.770	136.839	40.600	157.636
85.000	69.361	104.166	60.234	119.950	48.204	149.883	41.591	173.714
90.000	72.580	111.601	62.549	129.498	49.533	163.526	42.494	190.617
95.000	75.717	119.194	64.762	139.356	50.766	177.777	43.316	208.355
100.000	78.773	126.947	66.877	149.529	51.910	192.642	44.066	226.935
105.000	81.751	134.862	68.897	160.021	52.972	208.129	44.751	246.364
110.000	84.651	142.940	70.828	170.837	53.959	224.245	45.378	266.649
115.000	87.476	151.185	72.673	181.980	54.877	240.995	45.953	287.797
120.000	90.227	159.597	74.436	193.455	55.731	258.385	46.480	309.811
125.000	92.907	168.178	76.121	205.265	56.526	276.420	46.965	332.697
130.000	95.518	176.931	77.732	217.414	57.268	295.105	47.411	356.459
135.000	98.060	185.856	79.272	229.905	57.959	314.444	47.822	381.101
140.000	100.536	194.955	80.744	242.742	58.605	334.440	48.202	406.625
145.000	102.947	204.231	82.152	255.928	59.209	355.098	48.553	433.035
150.000	105.295	213.685	83.499	269.466	59.774	376.421	48.878	460.333
155.000	107.582	223.318	84.787	283.358	60.302	398.411	49.179	488.522
160.000	109.809	233.132	86.019	297.608	60.797	421.072	49.459	517.603
165.000	111.978	243.129	87.199	312.219	61.262	444.405	49.719	547.580
170.000	114.089	253.310	88.327	327.192	61.698	468.414		
175.000	116.146	263.677	89.408	342.530	62.107	493.099		
180.000	118.149	274.230	90.443	358.236	62.492	518.464		
185.000	120.099	284.972	91.435	374.311	62.855	544.510		
190.000	121.999	295.904	92.384	390.758	63.196	571.239		
195.000	123.849	307.028	93.295	407.579				
200.000	125.650	318.343	94.167	424.776				
205.000	127.405	329.853	95.004	442.349				
210.000	129.114	341.558	95.807	460.302				
215.000	130.779	353.460	96.577	478.636				
220.000	132.400	365.559	97.315	497.351				
225.000	133.979	377.857	98.025	516.451				
230.000	135.518	390.354	98.706	535.935				
235.000	137.017	403.053	99.360	555.806				
240.000	138.477	415.955						
245.000	139.899	429.059						
250.000	141.285	442.368						
255.000	142.636	455.882						
260.000	143.951	469.603						
265.000	145.234	483.530						
270.000	146.484	497.667						
275.000	147.702	512.012						
280.000	148.889	526.567						
285.000	150.046	541.333						
290.000	151.174	556.311						
295.000	152.274	571.502						

Table 13-C.8

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 6000.00 PF(.00600 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.109	32.018	26.834	33.540	24.830	36.247	23.485	38.322
35.000	32.441	37.761	30.733	39.860	28.082	43.622	26.331	46.524
40.000	36.677	43.625	34.481	46.402	31.119	51.416	28.930	55.305
45.000	40.817	49.611	38.084	53.172	33.953	59.642	31.305	64.686
50.000	44.866	55.722	41.547	60.173	36.597	68.312	33.474	74.685
55.000	48.823	61.959	44.874	67.412	39.063	77.439	35.455	85.320
60.000	52.690	68.324	48.070	74.892	41.363	87.033	37.264	96.608
65.000	56.471	74.818	51.139	82.618	43.509	97.107	38.917	108.564
70.000	60.165	81.443	54.087	90.595	45.509	107.671	40.428	121.202
75.000	63.775	88.201	56.918	98.827	47.375	118.734	41.810	134.536
80.000	67.302	95.094	59.635	107.319	49.115	130.306	43.076	148.576
85.000	70.748	102.123	62.244	116.075	50.739	142.396	44.234	163.335
90.000	74.115	109.289	64.749	125.098	52.254	155.012	45.297	178.821
95.000	77.404	116.596	67.153	134.394	53.669	168.161	46.272	195.044
100.000	80.617	124.043	69.461	143.966	54.990	181.851	47.167	212.012
105.000	83.756	131.632	71.676	153.818	56.225	196.089	47.991	229.732
110.000	86.822	139.366	73.802	163.953	57.378	210.880	48.749	248.211
115.000	89.816	147.246	75.842	174.376	58.458	226.232	49.448	267.455
120.000	92.740	155.272	77.801	185.089	59.468	242.148	50.092	287.469
125.000	95.596	163.448	79.681	196.095	60.414	258.634	50.688	308.258
130.000	98.385	171.774	81.485	207.400	61.300	275.695	51.239	329.827
135.000	101.109	180.251	83.218	219.004	62.130	293.335	51.749	352.179
140.000	103.769	188.882	84.881	230.912	62.910	311.557	52.222	375.318
145.000	106.366	197.667	86.478	243.126	63.641	330.367	52.662	399.248
150.000	108.902	206.608	88.011	255.649	64.329	349.766	53.070	423.970
155.000	111.378	215.707	89.484	268.484	64.975	369.759	53.450	449.489
160.000	113.796	224.964	90.899	281.633	65.583	390.347	53.803	475.806
165.000	116.157	234.382	92.257	295.099	66.155	411.534	54.134	502.923
170.000	118.462	243.960	93.563	308.884	66.694	433.322	54.442	530.843
175.000	120.713	253.702	94.817	322.990	67.202	455.714	54.730	559.567
180.000	122.910	263.607	96.023	337.421	67.682	478.712		
185.000	125.056	273.678	97.181	352.177	68.134	502.316		
190.000	127.151	283.915	98.295	367.260	68.562	526.531		
195.000	129.196	294.320	99.367	382.674	68.966	551.356		
200.000	131.193	304.894	100.397	398.419				
205.000	133.143	315.637	101.388	414.497				
210.000	135.047	326.552	102.341	430.911				
215.000	136.907	337.639	103.259	447.661				
220.000	138.722	348.899	104.142	464.749				
225.000	140.495	360.334	104.993	482.177				
230.000	142.226	371.944	105.811	499.946				
235.000	143.916	383.731	106.600	518.057				
240.000	145.567	395.695	107.360	536.512				
245.000	147.179	407.838	108.092	555.312				
250.000	148.753	420.160	108.798	574.458				
255.000	150.290	432.662						
260.000	151.792	445.346						
265.000	153.259	458.212						
270.000	154.691	471.261						
275.000	156.091	484.493						
280.000	157.458	497.911						
285.000	158.793	511.514						
290.000	160.098	525.303						
295.000	161.373	539.280						

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 6000.00 PF(.00600 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	162.618	553.444						
305.000	163.835	567.797						

Table 13-C.9

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 5500.00 PF(.00550 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.254	31.854	27.071	33.246	25.199	35.715	23.936	37.600
35.000	32.636	37.535	31.048	39.454	28.568	42.881	26.915	45.514
40.000	36.928	43.327	34.885	45.865	31.730	50.425	29.657	53.949
45.000	41.132	49.231	38.585	52.481	34.699	58.359	32.181	62.925
50.000	45.250	55.249	42.153	59.308	37.484	66.694	34.503	72.458
55.000	49.282	61.381	45.592	66.350	40.097	75.442	36.638	82.565
60.000	53.231	67.629	48.906	73.610	42.548	84.610	38.602	93.259
65.000	57.098	73.996	52.101	81.093	44.846	94.211	40.409	104.555
70.000	60.884	80.481	55.179	88.803	47.001	104.253	42.072	116.466
75.000	64.590	87.087	58.144	96.743	49.022	114.745	43.603	129.004
80.000	68.219	93.816	61.000	104.917	50.917	125.695	45.013	142.180
85.000	71.771	100.667	63.752	113.330	52.694	137.112	46.313	156.005
90.000	75.248	107.644	66.402	121.984	54.362	149.002	47.511	170.488
95.000	78.651	114.747	68.954	130.884	55.926	161.374	48.616	185.637
100.000	81.982	121.977	71.412	140.032	57.394	174.234	49.637	201.461
105.000	85.242	129.337	73.779	149.433	58.772	187.589	50.581	217.967
110.000	88.433	136.827	76.058	159.089	60.066	201.443	51.454	235.161
115.000	91.555	144.449	78.253	169.003	61.282	215.804	52.263	253.049
120.000	94.610	152.203	80.366	179.180	62.425	230.676	53.012	271.638
125.000	97.600	160.092	82.401	189.621	63.500	246.063	53.707	290.931
130.000	100.525	168.117	84.361	200.330	64.511	261.971	54.352	310.935
135.000	103.388	176.278	86.248	211.309	65.462	278.404	54.952	331.651
140.000	106.188	184.578	88.066	222.562	66.358	295.366	55.511	353.085
145.000	108.928	193.017	89.816	234.090	67.203	312.860	56.031	375.240
150.000	111.609	201.597	91.502	245.898	67.999	330.890	56.516	398.119
155.000	114.231	210.319	93.125	257.986	68.749	349.458	56.968	421.725
160.000	116.797	219.184	94.689	270.358	69.458	368.569	57.391	446.060
165.000	119.307	228.193	96.196	283.015	70.127	388.225	57.787	471.127
170.000	121.762	237.348	97.648	295.961	70.759	408.428	58.157	496.928
175.000	124.164	246.649	99.047	309.197	71.357	429.181	58.504	523.465
180.000	126.514	256.098	100.395	322.725	71.922	450.485	58.830	550.739
185.000	128.813	265.696	101.694	336.548	72.458	472.344		
190.000	131.061	275.443	102.947	350.667	72.965	494.759		
195.000	133.261	285.342	104.154	365.083	73.445	517.731		
200.000	135.413	295.393	105.319	379.800	73.901	541.263		
205.000	137.518	305.597	106.441	394.819	74.334	565.356		
210.000	139.577	315.955	107.524	410.140				
215.000	141.591	326.468	108.569	425.767				
220.000	143.562	337.137	109.577	441.700				
225.000	145.489	347.964	110.549	457.940				
230.000	147.375	358.948	111.488	474.490				
235.000	149.220	370.092	112.394	491.351				
240.000	151.024	381.396	113.269	508.523				
245.000	152.790	392.860	114.114	526.008				
250.000	154.517	404.486	114.930	543.808				
255.000	156.207	416.275	115.719	561.923				
260.000	157.860	428.227						
265.000	159.478	440.343						
270.000	161.061	452.624						
275.000	162.609	465.072						
280.000	164.125	477.686						
285.000	165.607	490.467						
290.000	167.058	503.417						
295.000	168.478	516.535						

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 5500.00 PF(.00550 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	169.868	529.823						
305.000	171.228	543.282						
310.000	172.559	556.911						
315.000	173.862	570.712						

Table 13-C.10

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 5000.00 PF(.00500 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.401	31.689	27.312	32.953	25.579	35.185	24.402	36.883
35.000	32.834	37.309	31.371	39.049	29.068	42.142	27.522	44.510
40.000	37.184	43.029	35.299	45.327	32.363	49.439	30.416	52.604
45.000	41.453	48.851	39.099	51.792	35.473	57.085	33.099	61.181
50.000	45.642	54.775	42.775	58.445	38.409	65.090	35.585	70.255
55.000	49.751	60.802	46.331	65.291	41.178	73.462	37.889	79.839
60.000	53.783	66.935	49.769	72.334	43.790	82.211	40.023	89.948
65.000	57.739	73.174	53.094	79.576	46.253	91.345	42.001	100.593
70.000	61.619	79.520	56.308	87.021	48.577	100.872	43.834	111.786
75.000	65.426	85.975	59.415	94.672	50.767	110.800	45.532	123.539
80.000	69.159	92.540	62.419	102.533	52.833	121.137	47.107	135.861
85.000	72.821	99.216	65.321	110.607	54.781	131.889	48.567	148.763
90.000	76.412	106.004	68.126	118.897	56.618	143.065	49.922	162.252
95.000	79.935	112.905	70.837	127.405	58.350	154.669	51.180	176.338
100.000	83.388	119.921	73.456	136.135	59.985	166.709	52.349	191.027
105.000	86.775	127.052	75.987	145.091	61.527	179.190	53.434	206.328
110.000	90.096	134.300	78.432	154.274	62.982	192.118	54.444	222.246
115.000	93.353	141.667	80.794	163.688	64.356	205.499	55.384	238.787
120.000	96.546	149.152	83.076	173.335	65.653	219.336	56.259	255.957
125.000	99.676	156.758	85.281	183.217	66.878	233.635	57.075	273.761
130.000	102.745	164.485	87.411	193.339	68.035	248.400	57.836	292.204
135.000	105.754	172.334	89.469	203.702	69.130	263.635	58.547	311.289
140.000	108.704	180.307	91.457	214.308	70.164	279.344	59.211	331.021
145.000	111.595	188.404	93.378	225.161	71.143	295.531	59.831	351.404
150.000	114.430	196.627	95.233	236.262	72.069	312.199	60.412	372.440
155.000	117.208	204.977	97.026	247.613	72.946	329.352	60.957	394.133
160.000	119.932	213.454	98.759	259.218	73.777	346.991	61.467	416.485
165.000	122.602	222.061	100.433	271.077	74.564	365.121	61.946	439.499
170.000	125.218	230.797	102.050	283.193	75.311	383.744	62.395	463.177
175.000	127.783	239.663	103.614	295.569	76.019	402.862	62.818	487.522
180.000	130.297	248.662	105.125	308.205	76.690	422.478	63.215	512.535
185.000	132.762	257.793	106.585	321.105	77.328	442.593	63.589	538.218
190.000	135.177	267.058	107.997	334.269	77.934	463.210	63.942	564.573
195.000	137.544	276.458	109.362	347.700	78.511	484.330		
200.000	139.864	285.993	110.681	361.398	79.058	505.956		
205.000	142.138	295.664	111.957	375.367	79.579	528.089		
210.000	144.366	305.473	113.191	389.607	80.076	550.730		
215.000	146.550	315.421	114.385	404.119	80.548	573.881		
220.000	148.691	325.507	115.539	418.907				
225.000	150.789	335.734	116.656	433.969				
230.000	152.846	346.101	117.736	449.310				
235.000	154.861	356.610	118.782	464.928				
240.000	156.836	367.262	119.794	480.826				
245.000	158.772	378.057	120.773	497.006				
250.000	160.670	388.996	121.722	513.467				
255.000	162.530	400.081	122.640	530.212				
260.000	164.353	411.311	123.529	547.241				
265.000	166.139	422.687	124.390	564.555				
270.000	167.891	434.211						
275.000	169.607	445.883						
280.000	171.290	457.703						
285.000	172.940	469.673						
290.000	174.556	481.793						
295.000	176.141	494.063						

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 5000.00 PF(.00500 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	177.695	506.485						
305.000	179.218	519.060						
310.000	180.712	531.786						
315.000	182.176	544.667						
320.000	183.611	557.701						
325.000	185.018	570.890						

Table 13-C.11

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4800.00 PF(.00480 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.460	31.623	27.410	32.835	25.734	34.973	24.592	36.597
35.000	32.914	37.218	31.502	38.887	29.273	41.848	27.771	44.111
40.000	37.288	42.910	35.467	45.113	32.622	49.046	30.728	52.070
45.000	41.583	48.698	39.308	51.516	35.791	56.578	33.478	60.488
50.000	45.800	54.585	43.029	58.101	38.789	64.452	36.033	69.380
55.000	49.942	60.571	46.632	64.869	41.623	72.675	38.409	78.758
60.000	54.008	66.657	50.122	71.825	44.303	81.258	40.616	88.635
65.000	58.000	72.845	53.500	78.972	46.837	90.207	42.667	99.023
70.000	61.919	79.136	56.771	86.312	49.231	99.530	44.573	109.932
75.000	65.766	85.531	59.937	93.848	51.494	109.235	46.344	121.374
80.000	69.542	92.030	63.001	101.585	53.633	119.330	47.991	133.358
85.000	73.249	98.636	65.967	109.524	55.654	129.820	49.522	145.894
90.000	76.887	105.349	68.837	117.669	57.564	140.712	50.947	158.989
95.000	80.458	112.170	71.614	126.023	59.370	152.013	52.272	172.653
100.000	83.963	119.101	74.301	134.588	61.077	163.728	53.507	186.892
105.000	87.402	126.141	76.901	143.367	62.691	175.863	54.657	201.714
110.000	90.777	133.294	79.416	152.363	64.217	188.424	55.728	217.125
115.000	94.089	140.559	81.849	161.578	65.660	201.416	56.728	233.131
120.000	97.339	147.937	84.203	171.016	67.026	214.843	57.661	249.736
125.000	100.527	155.430	86.480	180.678	68.318	228.710	58.532	266.947
130.000	103.656	163.039	88.683	190.567	69.541	243.021	59.346	284.768
135.000	106.726	170.765	90.813	200.686	70.700	257.781	60.108	303.204
140.000	109.738	178.608	92.875	211.037	71.797	272.993	60.821	322.257
145.000	112.692	186.570	94.869	221.622	72.837	288.660	61.489	341.932
150.000	115.591	194.651	96.798	232.443	73.822	304.787	62.115	362.233
155.000	118.435	202.854	98.664	243.503	74.757	321.376	62.702	383.161
160.000	121.225	211.178	100.469	254.804	75.643	338.430	63.253	404.721
165.000	123.962	219.624	102.216	266.347	76.485	355.952	63.772	426.914
170.000	126.646	228.195	103.906	278.135	77.284	373.945	64.259	449.744
175.000	129.280	236.889	105.541	290.170	78.043	392.412	64.717	473.211
180.000	131.863	245.710	107.124	302.454	78.764	411.353	65.149	497.319
185.000	134.397	254.656	108.655	314.987	79.450	430.773	65.556	522.069
190.000	136.882	263.730	110.137	327.773	80.103	450.672	65.941	547.463
195.000	139.320	272.932	111.572	340.813	80.723	471.054	66.303	573.503
200.000	141.712	282.263	112.960	354.108	81.314	491.918		
205.000	144.057	291.724	114.304	367.660	81.877	513.268		
210.000	146.358	301.316	115.605	381.471	82.414	535.104		
215.000	148.615	311.039	116.865	395.541	82.925	557.429		
220.000	150.828	320.895	118.085	409.874				
225.000	152.999	330.884	119.267	424.469				
230.000	155.128	341.008	120.411	439.329				
235.000	157.217	351.266	121.519	454.454				
240.000	159.266	361.660	122.593	469.846				
245.000	161.275	372.190	123.634	485.506				
250.000	163.246	382.858	124.642	501.435				
255.000	165.179	393.663	125.619	517.635				
260.000	167.075	404.608	126.567	534.106				
265.000	168.936	415.691	127.485	550.850				
270.000	170.760	426.915	128.375	567.867				
275.000	172.550	438.280						
280.000	174.305	449.786						
285.000	176.027	461.435						
290.000	177.716	473.226						
295.000	179.374	485.161						

13

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4800.00 PF(.00480 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	180.999	497.240						
305.000	182.594	509.464						
310.000	184.158	521.833						
315.000	185.693	534.349						
320.000	187.199	547.011						
325.000	188.677	559.820						
330.000	190.126	572.778						

Table 13-C.12

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4300.00 PF(.00430 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.610	31.457	27.657	32.541	26.129	34.445	25.080	35.886
35.000	33.116	36.991	31.834	38.481	29.795	41.114	28.410	43.118
40.000	37.550	42.610	35.894	44.576	33.285	48.069	31.532	50.742
45.000	41.911	48.316	39.840	50.829	36.607	55.318	34.457	58.770
50.000	46.202	54.110	43.675	57.241	39.767	62.867	37.196	67.212
55.000	50.424	59.991	47.401	63.817	42.772	70.723	39.761	76.080
60.000	54.576	65.963	51.022	70.558	45.631	78.894	42.162	85.385
65.000	58.661	72.024	54.539	77.467	48.348	87.387	44.410	95.137
70.000	62.679	78.177	57.956	84.547	50.932	96.207	46.514	105.345
75.000	66.630	84.421	61.275	91.799	53.387	105.362	48.483	116.019
80.000	70.517	90.759	64.498	99.228	55.722	114.857	50.327	127.168
85.000	74.339	97.190	67.628	106.835	57.940	124.698	52.053	138.800
90.000	78.097	103.717	70.667	114.622	60.048	134.891	53.670	150.922
95.000	81.794	110.339	73.618	122.593	62.052	145.442	55.184	163.542
100.000	85.428	117.057	76.483	130.749	63.957	156.356	56.603	176.668
105.000	89.002	123.873	79.264	139.092	65.767	167.637	57.934	190.304
110.000	92.517	130.787	81.964	147.626	67.488	179.291	59.181	204.458
115.000	95.972	137.801	84.585	156.352	69.124	191.322	60.351	219.136
120.000	99.369	144.914	87.129	165.272	70.680	203.735	61.449	234.341
125.000	102.709	152.129	89.599	174.389	72.160	216.533	62.480	250.080
130.000	105.993	159.445	91.995	183.705	73.567	229.722	63.449	266.357
135.000	109.221	166.864	94.322	193.221	74.906	243.304	64.359	283.176
140.000	112.394	174.386	96.580	202.941	76.181	257.283	65.216	300.542
145.000	115.514	182.013	98.771	212.865	77.394	271.663	66.022	318.457
150.000	118.580	189.745	100.898	222.997	78.549	286.446	66.780	336.925
155.000	121.595	197.582	102.963	233.337	79.649	301.637	67.495	355.950
160.000	124.558	205.527	104.967	243.887	80.697	317.238	68.170	375.534
165.000	127.470	213.579	106.911	254.650	81.695	333.251	68.806	395.680
170.000	130.333	221.740	108.799	265.628	82.647	349.680	69.406	416.392
175.000	133.147	230.009	110.631	276.821	83.555	366.526	69.973	437.670
180.000	135.912	238.389	112.410	288.231	84.420	383.793	70.509	459.517
185.000	138.630	246.879	114.136	299.861	85.247	401.482	71.016	481.936
190.000	141.302	255.481	115.812	311.712	86.035	419.596	71.495	504.927
195.000	143.928	264.195	117.439	323.785	86.788	438.135	71.950	528.494
200.000	146.508	273.022	119.018	336.082	87.508	457.103	72.380	552.637
205.000	149.044	281.963	120.552	348.605	88.195	476.502		
210.000	151.537	291.019	122.041	361.354	88.852	496.331		
215.000	153.986	300.189	123.487	374.331	89.480	516.594		
220.000	156.393	309.476	124.891	387.538	90.081	537.292		
225.000	158.759	318.879	126.255	400.976	90.657	558.426		
230.000	161.084	328.399	127.579	414.646				
235.000	163.369	338.038	128.865	428.549				
240.000	165.615	347.795	130.115	442.686				
245.000	167.821	357.672	131.329	457.060				
250.000	169.990	367.669	132.508	471.670				
255.000	172.121	377.786	133.654	486.518				
260.000	174.216	388.025	134.767	501.605				
265.000	176.274	398.386	135.850	516.932				
270.000	178.297	408.869	136.901	532.500				
275.000	180.285	419.476	137.924	548.310				
280.000	182.238	430.206	138.918	564.363				
285.000	184.158	441.061						
290.000	186.045	452.041						
295.000	187.899	463.147						

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4300.00 PF(.00430 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	189.722	474.379						
305.000	191.513	485.738						
310.000	193.273	497.224						
315.000	195.003	508.838						
320.000	196.704	520.580						
325.000	198.375	532.452						
330.000	200.017	544.453						
335.000	201.632	556.584						
340.000	203.219	568.845						

Table 13-C.13

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4000.00 PF(.00400 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.702	31.357	27.808	32.365	26.371	34.129	25.380	35.461
35.000	33.239	36.854	32.036	38.238	30.116	40.676	28.805	42.527
40.000	37.709	42.430	36.154	44.255	33.694	47.486	32.031	49.952
45.000	42.111	48.087	40.165	50.417	37.111	54.566	35.066	57.748
50.000	46.448	53.824	44.071	56.727	40.373	61.923	37.922	65.925
55.000	50.718	59.644	47.873	63.188	43.486	69.562	40.609	74.492
60.000	54.923	65.546	51.575	69.801	46.458	77.490	43.135	83.459
65.000	59.065	71.532	55.179	76.569	49.293	85.712	45.511	92.835
70.000	63.143	77.601	58.687	83.494	51.997	94.236	47.745	102.629
75.000	67.159	83.757	62.101	90.578	54.577	103.065	49.845	112.850
80.000	71.113	89.997	65.424	97.824	57.038	112.206	51.819	123.506
85.000	75.006	96.325	68.657	105.234	59.385	121.664	53.676	134.603
90.000	78.840	102.740	71.803	112.809	61.623	131.445	55.422	146.150
95.000	82.614	109.243	74.863	120.553	63.757	141.553	57.065	158.154
100.000	86.329	115.836	77.841	128.467	65.793	151.993	58.610	170.620
105.000	89.987	122.518	80.738	136.553	67.734	162.770	60.064	183.555
110.000	93.588	129.291	83.556	144.813	69.585	173.888	61.432	196.964
115.000	97.132	136.155	86.297	153.249	71.351	185.351	62.721	210.854
120.000	100.621	143.111	88.963	161.864	73.036	197.164	63.935	225.229
125.000	104.056	150.160	91.557	170.659	74.643	209.331	65.079	240.094
130.000	107.436	157.303	94.079	179.636	76.176	221.855	66.157	255.454
135.000	110.764	164.540	96.532	188.797	77.639	234.740	67.174	271.312
140.000	114.038	171.872	98.918	198.144	79.036	247.989	68.133	287.672
145.000	117.262	179.300	101.238	207.678	80.369	261.606	69.039	304.539
150.000	120.434	186.824	103.495	217.402	81.642	275.593	69.894	321.916
155.000	123.556	194.446	105.689	227.317	82.858	289.954	70.702	339.806
160.000	126.629	202.166	107.824	237.425	84.019	304.692	71.466	358.211
165.000	129.652	209.985	109.899	247.727	85.129	319.810	72.189	377.136
170.000	132.628	217.903	111.918	258.226	86.189	335.309	72.873	396.581
175.000	135.556	225.921	113.881	268.922	87.203	351.192	73.520	416.551
180.000	138.438	234.040	115.790	279.817	88.172	367.462	74.134	437.046
185.000	141.274	242.261	117.647	290.913	89.100	384.121	74.716	458.069
190.000	144.064	250.583	119.453	302.211	89.987	401.170	75.267	479.623
195.000	146.809	259.009	121.209	313.713	90.836	418.613	75.791	501.708
200.000	149.511	267.538	122.918	325.420	91.648	436.450	76.288	524.328
205.000	152.170	276.172	124.580	337.334	92.427	454.684	76.761	547.482
210.000	154.785	284.910	126.196	349.455	93.172	473.316	77.210	571.173
215.000	157.359	293.754	127.769	361.786	93.887	492.348		
220.000	159.892	302.705	129.299	374.327	94.572	511.782		
225.000	162.384	311.762	130.787	387.079	95.228	531.618		
230.000	164.835	320.926	132.235	400.044	95.858	551.858		
235.000	167.248	330.199	133.644	413.224	96.462	572.504		
240.000	169.621	339.580	135.015	426.618				
245.000	171.956	349.071	136.349	440.229				
250.000	174.254	358.672	137.648	454.057				
255.000	176.515	368.383	138.911	468.104				
260.000	178.739	378.205	140.141	482.370				
265.000	180.927	388.139	141.339	496.857				
270.000	183.081	398.185	142.504	511.564				
275.000	185.199	408.344	143.639	526.495				
280.000	187.283	418.617	144.743	541.648				
285.000	189.334	429.003	145.819	557.025				
290.000	191.352	439.504	146.867	572.628				
295.000	193.337	450.120						

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 4000.00 PF(.00400 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	195.291	460.852						
305.000	197.212	471.699						
310.000	199.103	482.664						
315.000	200.964	493.745						
320.000	202.795	504.944						
325.000	204.596	516.262						
330.000	206.368	527.697						
335.000	208.112	539.252						
340.000	209.828	550.927						
345.000	211.517	562.721						
350.000	213.178	574.637						

Table 13-C.14

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 3300.00 PF(.00330 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	28.917	31.123	28.167	31.952	26.951	33.394	26.104	34.477
35.000	33.531	36.533	32.519	37.670	30.888	39.659	29.762	41.159
40.000	38.087	42.009	36.777	43.505	34.680	46.136	33.244	48.129
45.000	42.587	47.550	40.943	49.458	38.331	52.829	36.556	55.395
50.000	47.030	53.157	45.019	55.532	41.845	59.744	39.705	62.964
55.000	51.418	58.832	49.007	61.726	45.227	66.885	42.700	70.843
60.000	55.751	64.573	52.907	68.044	48.481	74.256	45.547	79.039
65.000	60.029	70.383	56.721	74.487	51.612	81.861	48.253	87.560
70.000	64.253	76.262	60.452	81.056	54.623	89.706	50.824	96.411
75.000	68.423	82.209	64.100	87.753	57.519	97.793	53.267	105.599
80.000	72.541	88.226	67.668	94.579	60.305	106.127	55.589	115.131
85.000	76.606	94.313	71.156	101.537	62.984	114.713	57.795	125.012
90.000	80.620	100.471	74.567	108.627	65.559	123.553	59.890	135.248
95.000	84.582	106.701	77.902	115.851	68.035	132.652	61.881	145.844
100.000	88.494	113.002	81.162	123.211	70.416	142.013	63.773	156.807
105.000	92.356	119.376	84.349	130.708	72.705	151.641	65.570	168.141
110.000	96.167	125.822	87.464	138.343	74.905	161.538	67.278	179.850
115.000	99.930	132.342	90.509	146.119	77.020	171.708	68.902	191.940
120.000	103.645	138.936	93.485	154.036	79.054	182.154	70.445	204.415
125.000	107.311	145.605	96.394	162.096	81.009	192.880	71.912	217.278
130.000	110.930	152.349	99.237	170.300	82.889	203.888	73.308	230.536
135.000	114.502	159.168	102.015	178.650	84.696	215.182	74.635	244.190
140.000	118.027	166.063	104.731	187.147	86.433	226.764	75.897	258.244
145.000	121.507	173.035	107.384	195.792	88.104	238.638	77.098	272.703
150.000	124.941	180.085	109.977	204.588	89.711	250.805	78.242	287.569
155.000	128.331	187.211	112.511	213.534	91.256	263.269	79.331	302.846
160.000	131.676	194.417	114.987	222.633	92.743	276.032	80.368	318.536
165.000	134.977	201.701	117.407	231.886	94.173	289.096	81.356	334.642
170.000	138.235	209.064	119.771	241.293	95.548	302.465	82.297	351.166
175.000	141.451	216.507	122.082	250.857	96.872	316.139	83.195	368.112
180.000	144.624	224.030	124.339	260.578	98.146	330.121	84.051	385.482
185.000	147.755	231.634	126.545	270.458	99.372	344.414	84.867	403.277
190.000	150.845	239.319	128.700	280.497	100.552	359.018	85.646	421.500
195.000	153.894	247.086	130.806	290.698	101.688	373.937	86.390	440.153
200.000	156.903	254.935	132.864	301.060	102.782	389.172	87.101	459.238
205.000	159.872	262.867	134.875	311.586	103.836	404.724	87.780	478.756
210.000	162.801	270.882	136.839	322.276	104.851	420.595	88.428	498.710
215.000	165.692	278.981	138.759	333.131	105.829	436.788	89.048	519.100
220.000	168.545	287.164	140.635	344.153	106.772	453.303	89.642	539.928
225.000	171.359	295.432	142.468	355.342	107.680	470.142	90.209	561.195
230.000	174.137	303.784	144.260	366.700	108.556	487.306		
235.000	176.877	312.223	146.010	378.227	109.401	504.797		
240.000	179.581	320.747	147.721	389.924	110.215	522.615		
245.000	182.248	329.358	149.393	401.793	111.001	540.763		
250.000	184.881	338.056	151.027	413.834	111.758	559.242		
255.000	187.478	346.841	152.624	426.048				
260.000	190.040	355.715	154.184	438.436				
265.000	192.568	364.676	155.710	451.000				
270.000	195.063	373.726	157.201	463.739				
275.000	197.523	382.866	158.658	476.654				
280.000	199.952	392.095	160.082	489.747				
285.000	202.347	401.414	161.475	503.019				
290.000	204.711	410.824	162.836	516.469				
295.000	207.043	420.324	164.167	530.100				

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 3300.00 PF(.00330 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	209.343	429.916	165.468	543.910				
305.000	211.613	439.599	166.741	557.902				
310.000	213.853	449.375	167.985	572.076				
315.000	216.062	459.243						
320.000	218.242	469.204						
325.000	220.392	479.259						
330.000	222.514	489.407						
335.000	224.607	499.649						
340.000	226.673	509.986						
345.000	228.710	520.418						
350.000	230.721	530.945						
355.000	232.704	541.567						
360.000	234.661	552.286						
365.000	236.592	563.101						
370.000	238.497	574.012						

Table 13-C.15

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 3000.00 PF(.00300 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.011	31.022	28.324	31.775	27.206	33.081	26.425	34.059
35.000	33.658	36.395	32.730	37.427	31.229	39.226	30.188	40.579
40.000	38.252	41.828	37.050	43.184	35.117	45.562	33.786	47.357
45.000	42.794	47.319	41.285	49.049	38.873	52.092	37.224	54.401
50.000	47.285	52.871	45.437	55.021	42.502	58.821	40.509	61.715
55.000	51.724	58.483	49.506	61.103	46.006	65.752	43.647	69.306
60.000	56.113	64.157	53.495	67.296	49.390	72.890	46.644	77.180
65.000	60.451	69.892	57.404	73.601	52.657	80.237	49.506	85.344
70.000	64.739	75.688	61.235	80.020	55.811	87.797	52.238	93.801
75.000	68.978	81.547	64.989	86.554	58.855	95.574	54.846	102.559
80.000	73.169	87.469	68.667	93.203	61.793	103.571	57.336	111.623
85.000	77.310	93.455	72.271	99.970	64.629	111.792	59.712	120.997
90.000	81.404	99.504	75.803	106.856	67.365	120.240	61.980	130.687
95.000	85.450	105.617	79.262	113.862	70.005	128.919	64.145	140.697
100.000	89.450	111.795	82.652	120.990	72.553	137.831	66.210	151.033
105.000	93.402	118.038	85.972	128.239	75.010	146.980	68.182	161.699
110.000	97.309	124.346	89.224	135.613	77.382	156.368	70.064	172.700
115.000	101.170	130.721	92.410	143.112	79.669	165.999	71.860	184.038
120.000	104.985	137.162	95.531	150.737	81.876	175.876	73.575	195.720
125.000	108.756	143.670	98.587	158.490	84.005	186.002	75.212	207.747
130.000	112.483	150.246	101.580	166.371	86.058	196.378	76.774	220.125
135.000	116.165	156.889	104.512	174.382	88.040	207.009	78.267	232.857
140.000	119.804	163.600	107.383	182.525	89.951	217.896	79.692	245.946
145.000	123.400	170.381	110.194	190.799	91.795	229.042	81.054	259.395
150.000	126.954	177.230	112.948	199.208	93.575	240.450	82.355	273.207
155.000	130.465	184.149	115.644	207.750	95.291	252.122	83.598	287.386
160.000	133.935	191.138	118.284	216.429	96.948	264.060	84.787	301.934
165.000	137.363	198.197	120.869	225.244	98.546	276.266	85.923	316.854
170.000	140.751	205.328	123.401	234.197	100.089	288.743	87.009	332.148
175.000	144.098	212.529	125.879	243.289	101.578	301.492	88.049	347.819
180.000	147.405	219.803	128.306	252.521	103.015	314.516	89.043	363.869
185.000	150.673	227.148	130.683	261.894	104.403	327.817	89.994	380.301
190.000	153.901	234.566	133.010	271.409	105.742	341.396	90.905	397.116
195.000	157.091	242.057	135.288	281.067	107.036	355.255	91.778	414.317
200.000	160.242	249.622	137.519	290.870	108.285	369.397	92.613	431.905
205.000	163.356	257.260	139.703	300.817	109.491	383.822	93.413	449.882
210.000	166.432	264.973	141.841	310.911	110.656	398.532	94.180	468.250
215.000	169.471	272.761	143.935	321.152	111.782	413.529	94.916	487.010
220.000	172.473	280.623	145.985	331.540	112.869	428.815	95.621	506.164
225.000	175.440	288.561	147.993	342.078	113.920	444.390	96.298	525.714
230.000	178.370	296.575	149.958	352.765	114.936	460.257	96.947	545.660
235.000	181.265	304.665	151.883	363.603	115.918	476.416	97.570	566.005
240.000	184.125	312.832	153.767	374.593	116.867	492.868		
245.000	186.950	321.075	155.612	385.735	117.785	509.616		
250.000	189.741	329.397	157.419	397.030	118.672	526.660		
255.000	192.498	337.796	159.188	408.479	119.531	544.001		
260.000	195.221	346.273	160.920	420.084	120.362	561.641		
265.000	197.912	354.829	162.617	431.844				
270.000	200.570	363.465	164.278	443.760				
275.000	203.195	372.179	165.905	455.834				
280.000	205.789	380.973	167.498	468.066				
285.000	208.351	389.848	169.058	480.457				
290.000	210.881	398.802	170.586	493.007				
295.000	213.381	407.838	172.082	505.717				

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 3000.00 PF(.00300 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	215.851	416.955	173.548	518.588				
305.000	218.290	426.154	174.984	531.621				
310.000	220.699	435.434	176.390	544.816				
315.000	223.079	444.797	177.767	558.174				
320.000	225.430	454.243	179.116	571.695				
325.000	227.752	463.771						
330.000	230.046	473.383						
335.000	232.312	483.078						
340.000	234.550	492.858						
345.000	236.761	502.722						
350.000	238.945	512.671						
355.000	241.102	522.704						
360.000	243.233	532.823						
365.000	245.337	543.028						
370.000	247.416	553.319						
375.000	249.470	563.696						
380.000	251.498	574.159						

Table 13-C.16

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2600.00 PF(.00260 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.138	30.888	28.537	31.539	27.553	32.664	26.862	33.504
35.000	33.829	36.211	33.017	37.103	31.694	38.651	30.770	39.811
40.000	38.475	41.586	37.420	42.757	35.714	44.801	34.529	46.337
45.000	43.075	47.011	41.749	48.504	39.615	51.116	38.144	53.088
50.000	47.629	52.489	46.004	54.343	43.402	57.601	41.619	60.069
55.000	52.138	58.019	50.186	60.276	47.077	64.257	44.959	67.283
60.000	56.603	63.601	54.296	66.304	50.642	71.088	48.169	74.737
65.000	61.023	69.237	58.334	72.427	54.100	78.096	51.253	82.434
70.000	65.399	74.925	62.303	78.648	57.455	85.284	54.216	90.378
75.000	69.731	80.667	66.203	84.966	60.709	92.656	57.063	98.575
80.000	74.020	86.463	70.035	91.383	63.864	100.213	59.797	107.029
85.000	78.267	92.313	73.800	97.900	66.924	107.958	62.423	115.743
90.000	82.470	98.217	77.499	104.517	69.891	115.895	64.944	124.722
95.000	86.631	104.177	81.133	111.237	72.768	124.025	67.366	133.970
100.000	90.751	110.192	84.703	118.059	75.556	132.351	69.691	143.491
105.000	94.829	116.262	88.211	124.985	78.260	140.876	71.924	153.288
110.000	98.865	122.389	91.656	132.016	80.881	149.603	74.067	163.365
115.000	102.861	128.572	95.040	139.152	83.421	158.533	76.126	173.726
120.000	106.816	134.811	98.364	146.396	85.884	167.668	78.102	184.374
125.000	110.731	141.108	101.628	153.747	88.271	177.013	80.000	195.312
130.000	114.606	147.462	104.835	161.206	90.584	186.567	81.823	206.544
135.000	118.442	153.873	107.984	168.775	92.826	196.335	83.573	218.073
140.000	122.238	160.343	111.077	176.454	94.999	206.317	85.254	229.902
145.000	125.996	166.871	114.115	184.245	97.106	216.517	86.868	242.033
150.000	129.715	173.457	117.097	192.148	99.147	226.936	88.419	254.469
155.000	133.396	180.103	120.027	200.164	101.126	237.575	89.909	267.214
160.000	137.039	186.808	122.903	208.294	103.044	248.438	91.341	280.269
165.000	140.645	193.573	125.728	216.539	104.903	259.527	92.717	293.637
170.000	144.213	200.398	128.502	224.900	106.704	270.842	94.039	307.320
175.000	147.745	207.283	131.225	233.377	108.451	282.385	95.310	321.322
180.000	151.240	214.229	133.900	241.972	110.144	294.160	96.531	335.643
185.000	154.699	221.236	136.526	250.685	111.786	306.166	97.706	350.286
190.000	158.122	228.305	139.104	259.518	113.377	318.406	98.836	365.253
195.000	161.510	235.435	141.636	268.470	114.920	330.882	99.922	380.546
200.000	164.862	242.627	144.121	277.544	116.416	343.595	100.968	396.167
205.000	168.180	249.881	146.562	286.739	117.867	356.547	101.973	412.117
210.000	171.463	257.198	148.958	296.056	119.273	369.739	102.941	428.399
215.000	174.712	264.578	151.311	305.497	120.638	383.172	103.873	445.013
220.000	177.927	272.022	153.621	315.062	121.961	396.848	104.771	461.962
225.000	181.108	279.529	155.888	324.751	123.245	410.769	105.635	479.246
230.000	184.256	287.100	158.115	334.566	124.490	424.935	106.467	496.868
235.000	187.372	294.735	160.301	344.508	125.698	439.347	107.269	514.828
240.000	190.454	302.435	162.448	354.576	126.870	454.008	108.041	533.129
245.000	193.504	310.200	164.555	364.772	128.007	468.918	108.786	551.770
250.000	196.523	318.030	166.624	375.096	129.111	484.079	109.504	570.754
255.000	199.509	325.925	168.655	385.550	130.183	499.491		
260.000	202.464	333.886	170.650	396.134	131.222	515.156		
265.000	205.388	341.914	172.608	406.848	132.232	531.074		
270.000	208.281	350.007	174.530	417.693	133.212	547.247		
275.000	211.144	358.168	176.418	428.670	134.164	563.675		
280.000	213.977	366.395	178.271	439.779				
285.000	216.779	374.690	180.091	451.022				
290.000	219.552	383.052	181.878	462.399				
295.000	222.296	391.482	183.632	473.909				

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2600.00 PF(.00260 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

GMF (KHZ)	N=1 F(LOW) (KHZ)	N=1 F(HIGH) (KHZ)	N=2 F(LOW) (KHZ)	N=2 F(HIGH) (KHZ)	N=3 F(LOW) (KHZ)	N=3 F(HIGH) (KHZ)	N=4 F(LOW) (KHZ)	N=4 F(HIGH) (KHZ)
300.000	225.011	399.981	185.355	485.555				
305.000	227.697	408.548	187.046	497.337				
310.000	230.354	417.184	188.707	509.255				
315.000	232.984	425.888	190.338	521.309				
320.000	235.585	434.662	191.940	533.501				
325.000	238.159	443.506	193.512	545.831				
330.000	240.706	452.420	195.057	558.299				
335.000	243.225	461.403	196.573	570.907				
340.000	245.718	470.458						
345.000	248.185	479.583						
350.000	250.625	488.779						
355.000	253.039	498.046						
360.000	255.428	507.385						
365.000	257.791	516.795						
370.000	260.129	526.278						
375.000	262.442	535.833						
380.000	264.730	545.460						
385.000	266.995	555.161						
390.000	269.235	564.934						
395.000	271.451	574.781						

Table 13-C.17

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2500.00 PF(.00250 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.170	30.854	28.590	31.479	27.641	32.561	26.973	33.366
35.000	33.873	36.165	33.089	37.022	31.812	38.508	30.919	39.620
40.000	38.531	41.525	37.514	42.651	35.865	44.611	34.719	46.084
45.000	43.145	46.934	41.867	48.368	39.804	50.874	38.379	52.763
50.000	47.716	52.394	46.148	54.174	43.632	57.298	41.903	59.661
55.000	52.243	57.903	50.358	60.070	47.350	63.886	45.296	66.783
60.000	56.726	63.463	54.499	66.056	50.962	70.641	48.562	74.133
65.000	61.167	69.073	58.571	72.135	54.470	77.566	51.704	81.715
70.000	65.566	74.734	62.575	78.306	57.877	84.662	54.728	89.533
75.000	69.922	80.447	66.512	84.571	61.185	91.934	57.638	97.592
80.000	74.236	86.211	70.384	90.930	64.398	99.382	60.437	105.896
85.000	78.509	92.028	74.190	97.385	67.516	107.011	63.129	114.448
90.000	82.740	97.897	77.932	103.936	70.544	114.822	65.718	123.253
95.000	86.931	103.818	81.611	110.585	73.483	122.817	68.209	132.314
100.000	91.081	109.793	85.228	117.332	76.336	131.000	70.604	141.635
105.000	95.191	115.820	88.784	124.178	79.105	139.372	72.908	151.219
110.000	99.260	121.902	92.279	131.125	81.792	147.936	75.123	161.070
115.000	103.291	128.037	95.714	138.172	84.401	156.693	77.253	171.191
120.000	107.282	134.226	99.091	145.321	86.932	165.647	79.301	181.586
125.000	111.233	140.470	102.410	152.573	89.388	174.800	81.271	192.257
130.000	115.147	146.769	105.672	159.928	91.771	184.153	83.166	203.208
135.000	119.022	153.124	108.879	167.388	94.084	193.709	84.988	214.442
140.000	122.858	159.533	112.030	174.954	96.329	203.470	86.741	225.961
145.000	126.658	165.999	115.127	182.625	98.507	213.437	88.426	237.768
150.000	130.419	172.520	118.170	190.404	100.620	223.613	90.048	249.867
155.000	134.144	179.099	121.161	198.290	102.671	234.000	91.608	262.259
160.000	137.832	185.734	124.100	206.286	104.661	244.600	93.109	274.947
165.000	141.483	192.426	126.988	214.391	106.592	255.414	94.553	287.934
170.000	145.098	199.175	129.826	222.606	108.466	266.444	95.943	301.221
175.000	148.678	205.982	132.614	230.933	110.284	277.692	97.280	314.812
180.000	152.222	212.847	135.354	239.371	112.049	289.159	98.568	328.707
185.000	155.730	219.771	138.047	247.923	113.762	300.848	99.808	342.910
190.000	159.204	226.753	140.692	256.588	115.424	312.760	101.001	357.422
195.000	162.643	233.794	143.292	265.367	117.037	324.896	102.151	372.245
200.000	166.048	240.894	145.846	274.262	118.603	337.258	103.258	387.380
205.000	169.419	248.054	148.355	283.272	120.124	349.848	104.324	402.831
210.000	172.756	255.274	150.821	292.400	121.599	362.666	105.352	418.597
215.000	176.059	262.554	153.243	301.644	123.032	375.715	106.342	434.681
220.000	179.330	269.894	155.624	311.007	124.423	388.995	107.297	451.085
225.000	182.567	277.295	157.962	320.489	125.774	402.509	108.217	467.810
230.000	185.772	284.757	160.259	330.090	127.085	416.256	109.104	484.857
235.000	188.945	292.280	162.517	339.811	128.359	430.239	109.960	502.227
240.000	192.086	299.865	164.734	349.654	129.596	444.459	110.786	519.922
245.000	195.196	307.512	166.913	359.618	130.797	458.916	111.582	537.944
250.000	198.273	315.221	169.054	369.704	131.964	473.613	112.351	556.292
255.000	201.320	322.993	171.157	379.914	133.098	488.549	113.093	574.970
260.000	204.336	330.827	173.224	390.247	134.200	503.727		
265.000	207.322	338.724	175.254	400.704	135.270	519.146		
270.000	210.277	346.685	177.249	411.287	136.310	534.809		
275.000	213.203	354.709	179.208	421.995	137.321	550.716		
280.000	216.098	362.798	181.134	432.829	138.304	566.867		
285.000	218.965	370.950	183.026	443.790				
290.000	221.802	379.167	184.884	454.879				
295.000	224.611	387.448	186.711	466.096				

13

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2500.00 PF(.00250 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	227.390	395.795	188.505	477.441				
305.000	230.142	404.207	190.268	488.916				
310.000	232.866	412.684	192.000	500.520				
315.000	235.561	421.228	193.703	512.255				
320.000	238.230	429.837	195.375	524.120				
325.000	240.871	438.513	197.019	536.117				
330.000	243.485	447.255	198.633	548.246				
335.000	246.073	456.064	200.220	560.508				
340.000	248.634	464.940	201.780	572.902				
345.000	251.169	473.884						
350.000	253.678	482.896						
355.000	256.161	491.975						
360.000	258.620	501.122						
365.000	261.052	510.338						
370.000	263.460	519.623						
375.000	265.844	528.976						
380.000	268.203	538.399						
385.000	270.538	547.891						
390.000	272.848	557.452						
395.000	275.136	567.084						

Table 13-C.18

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2400.00 PF(.00240 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.202	30.820	28.644	31.420	27.729	32.457	27.085	33.228
35.000	33.916	36.119	33.161	36.941	31.930	38.365	31.068	39.429
40.000	38.587	41.464	37.608	42.544	36.018	44.422	34.911	45.831
45.000	43.216	46.857	41.985	48.232	39.995	50.632	38.617	52.439
50.000	47.803	52.298	46.292	54.005	43.863	56.995	42.191	59.255
55.000	52.348	57.787	50.532	59.864	47.626	63.516	45.637	66.284
60.000	56.851	63.324	54.703	65.809	51.285	70.196	48.959	73.531
65.000	61.312	68.909	58.809	71.843	54.844	77.037	52.161	80.999
70.000	65.733	74.544	62.849	77.965	58.304	84.043	55.247	88.692
75.000	70.113	80.227	66.824	84.177	61.668	91.215	58.221	96.615
80.000	74.453	85.960	70.735	90.479	64.938	98.556	61.086	104.770
85.000	78.752	91.743	74.583	96.872	68.117	106.068	63.847	113.162
90.000	83.012	97.576	78.369	103.357	71.206	113.754	66.506	121.793
95.000	87.232	103.460	82.094	109.936	74.209	121.616	69.068	130.669
100.000	91.413	109.394	85.758	116.608	77.127	129.656	71.535	139.791
105.000	95.555	115.379	89.362	123.374	79.963	137.876	73.912	149.164
110.000	99.658	121.415	92.908	130.236	82.719	146.278	76.201	158.791
115.000	103.723	127.503	96.396	137.195	85.397	154.865	78.406	168.674
120.000	107.750	133.642	99.826	144.250	87.998	163.639	80.529	178.818
125.000	111.739	139.834	103.201	151.404	90.526	172.602	82.574	189.224
130.000	115.691	146.079	106.520	158.656	92.982	181.755	84.544	199.896
135.000	119.606	152.376	109.784	166.008	95.368	191.101	86.441	210.838
140.000	123.483	158.726	112.994	173.460	97.686	200.642	88.268	222.050
145.000	127.325	165.129	116.152	181.014	99.938	210.379	90.029	233.537
150.000	131.130	171.586	119.257	188.669	102.126	220.315	91.724	245.300
155.000	134.898	178.097	122.310	196.427	104.252	230.451	93.358	257.343
160.000	138.632	184.662	125.313	204.289	106.317	240.790	94.932	269.667
165.000	142.329	191.282	128.266	212.255	108.323	251.332	96.448	282.275
170.000	145.992	197.956	131.169	220.326	110.272	262.079	97.910	295.170
175.000	149.620	204.686	134.025	228.503	112.166	273.034	99.318	308.352
180.000	153.213	211.470	136.832	236.786	114.005	284.197	100.676	321.825
185.000	156.772	218.311	139.593	245.177	115.793	295.571	101.984	335.591
190.000	160.297	225.207	142.308	253.676	117.529	307.157	103.246	349.650
195.000	163.788	232.160	144.977	262.284	119.217	318.956	104.463	364.006
200.000	167.246	239.169	147.601	271.001	120.857	330.970	105.636	378.660
205.000	170.671	246.235	150.181	279.828	122.450	343.201	106.767	393.613
210.000	174.062	253.357	152.718	288.767	123.999	355.649	107.859	408.868
215.000	177.422	260.538	155.213	297.817	125.504	368.316	108.912	424.425
220.000	180.749	267.775	157.665	306.979	126.966	381.204	109.928	440.287
225.000	184.044	275.071	160.077	316.255	128.388	394.313	110.909	456.455
230.000	187.307	282.425	162.447	325.644	129.770	407.645	111.856	472.930
235.000	190.538	289.837	164.778	335.147	131.113	421.201	112.770	489.714
240.000	193.739	297.308	167.070	344.766	132.419	434.983	113.653	506.807
245.000	196.908	304.837	169.323	354.500	133.689	448.991	114.505	524.212
250.000	200.047	312.427	171.538	364.350	134.923	463.226	115.329	541.929
255.000	203.155	320.075	173.716	374.318	136.124	477.690	116.125	559.959
260.000	206.234	327.783	175.857	384.403	137.291	492.383		
265.000	209.282	335.552	177.962	394.606	138.427	507.308		
270.000	212.301	343.380	180.032	404.928	139.531	522.463		
275.000	215.290	351.270	182.067	415.370	140.606	537.852		
280.000	218.251	359.220	184.067	425.931	141.651	553.474		
285.000	221.182	367.231	186.034	436.613	142.668	569.330		
290.000	224.085	375.303	187.968	447.416				
295.000	226.960	383.437	189.869	458.341				

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2400.00 PF(.00240 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	229.807	391.633	191.739	469.388				
305.000	232.626	399.891	193.577	480.559				
310.000	235.417	408.212	195.384	491.852				
315.000	238.181	416.595	197.161	503.269				
320.000	240.918	425.041	198.908	514.811				
325.000	243.628	433.550	200.626	526.478				
330.000	246.312	442.122	202.315	538.271				
335.000	248.969	450.758	203.975	550.189				
340.000	251.601	459.458	205.608	562.234				
345.000	254.206	468.222	207.214	574.406				
350.000	256.786	477.050						
355.000	259.341	485.943						
360.000	261.871	494.901						
365.000	264.375	503.923						
370.000	266.856	513.012						
375.000	269.311	522.165						
380.000	271.743	531.384						
385.000	274.151	540.670						
390.000	276.535	550.021						
395.000	278.895	559.439						
400.000	281.233	568.924						

Table 13-C.19

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2150.00 PF(.00215 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.282	30.735	28.779	31.273	27.952	32.198	27.368	32.885
35.000	34.025	36.003	33.344	36.738	32.230	38.008	31.446	38.955
40.000	38.729	41.313	37.845	42.278	36.404	43.951	35.396	45.203
45.000	43.395	46.665	42.282	47.892	40.477	50.029	39.220	51.632
50.000	48.022	52.059	46.657	53.583	44.450	56.243	42.922	58.246
55.000	52.612	57.496	50.969	59.350	48.326	62.596	46.505	65.047
60.000	57.164	62.977	55.220	65.194	52.107	69.089	49.973	72.039
65.000	61.678	68.501	59.410	71.115	55.794	75.724	53.329	79.226
70.000	66.156	74.068	63.541	77.116	59.391	82.505	56.575	86.610
75.000	70.596	79.679	67.612	83.195	62.897	89.431	59.716	94.195
80.000	75.000	85.334	71.624	89.355	66.317	96.507	62.755	101.984
85.000	79.367	91.033	75.579	95.595	69.651	103.732	65.694	109.980
90.000	83.698	96.777	79.477	101.917	72.901	111.110	68.536	118.186
95.000	87.993	102.565	83.318	108.320	76.069	118.642	71.285	126.604
100.000	92.252	108.399	87.103	114.807	79.158	126.330	73.943	135.239
105.000	96.476	114.278	90.833	121.377	82.169	134.176	76.514	144.092
110.000	100.664	120.202	94.509	128.031	85.103	142.181	78.999	153.167
115.000	104.817	126.172	98.131	134.769	87.963	150.348	81.402	162.465
120.000	108.936	132.188	101.700	141.593	90.750	158.678	83.725	171.991
125.000	113.020	138.250	105.216	148.504	93.466	167.172	85.972	181.746
130.000	117.070	144.358	108.681	155.501	96.113	175.834	88.143	191.733
135.000	121.085	150.514	112.095	162.585	98.693	184.664	90.243	201.954
140.000	125.067	156.716	115.458	169.758	101.207	193.663	92.273	212.413
145.000	129.016	162.965	118.772	177.020	103.656	202.835	94.236	223.110
150.000	132.930	169.261	122.037	184.371	106.042	212.179	96.134	234.049
155.000	136.812	175.606	125.253	191.812	108.368	221.698	97.969	245.231
160.000	140.661	181.998	128.421	199.344	110.634	231.394	99.743	256.660
165.000	144.477	188.438	131.543	206.967	112.842	241.267	101.459	268.336
170.000	148.261	194.926	134.618	214.682	114.993	251.320	103.118	280.262
175.000	152.013	201.463	137.647	222.490	117.089	261.553	104.722	292.440
180.000	155.732	208.049	140.630	230.391	119.132	271.968	106.274	304.872
185.000	159.420	214.684	143.569	238.386	121.122	282.567	107.775	317.559
190.000	163.077	221.368	146.464	246.476	123.061	293.351	109.227	330.504
195.000	166.702	228.102	149.316	254.661	124.950	304.321	110.632	343.708
200.000	170.296	234.885	152.125	262.941	126.791	315.479	111.991	357.173
205.000	173.860	241.718	154.892	271.318	128.586	326.825	113.305	370.900
210.000	177.392	248.601	157.617	279.792	130.334	338.362	114.578	384.892
215.000	180.895	255.535	160.301	288.363	132.038	350.090	115.809	399.148
220.000	184.367	262.519	162.945	297.033	133.698	362.010	117.001	413.672
225.000	187.810	269.555	165.549	305.801	135.316	374.124	118.155	428.464
230.000	191.223	276.641	168.114	314.668	136.893	386.432	119.272	443.526
235.000	194.606	283.779	170.640	323.635	138.430	398.937	120.353	458.858
240.000	197.960	290.968	173.127	332.703	139.929	411.639	121.400	474.463
245.000	201.285	298.209	175.578	341.871	141.389	424.538	122.415	490.342
250.000	204.582	305.501	177.991	351.141	142.813	437.637	123.397	506.495
255.000	207.850	312.846	180.368	360.513	144.200	450.935	124.349	522.924
260.000	211.089	320.244	182.709	369.988	145.553	464.435	125.271	539.630
265.000	214.301	327.694	185.014	379.566	146.872	478.137	126.165	556.614
270.000	217.484	335.197	187.285	389.247	148.158	492.041	127.031	573.876
275.000	220.640	342.753	189.521	399.033	149.412	506.150		
280.000	223.768	350.362	191.723	408.923	150.635	520.463		
285.000	226.870	358.025	193.892	418.918	151.828	534.981		
290.000	229.944	365.741	196.028	429.019	152.991	549.706		
295.000	232.991	373.512	198.132	439.227	154.125	564.638		

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 2150.00 PF(.00215 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	236.012	381.336	200.204	449.541				
305.000	239.007	389.215	202.245	459.962				
310.000	241.975	397.149	204.255	470.491				
315.000	244.917	405.137	206.234	481.128				
320.000	247.834	413.180	208.184	491.873				
325.000	250.725	421.279	210.104	502.728				
330.000	253.590	429.433	211.995	513.692				
335.000	256.431	437.642	213.857	524.766				
340.000	259.247	445.908	215.692	535.950				
345.000	262.038	454.229	217.498	547.246				
350.000	264.804	462.606	219.278	558.652				
355.000	267.546	471.040	221.030	570.171				
360.000	270.264	479.531						
365.000	272.958	488.078						
370.000	275.629	496.683						
375.000	278.275	505.345						
380.000	280.899	514.064						
385.000	283.499	522.840						
390.000	286.077	531.675						
395.000	288.632	540.568						
400.000	291.164	549.518						
405.000	293.674	558.528						
410.000	296.162	567.595						

Table 13-C.20

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1800.00 PF(.00180 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.396	30.617	28.971	31.066	28.270	31.836	27.772	32.407
35.000	34.179	35.841	33.603	36.455	32.657	37.511	31.988	38.296
40.000	38.930	41.100	38.181	41.905	36.955	43.296	36.092	44.331
45.000	43.647	46.394	42.705	47.418	41.166	49.191	40.087	50.515
50.000	48.333	51.724	47.175	52.994	45.291	55.198	43.976	56.849
55.000	52.987	57.090	51.592	58.633	49.332	61.319	47.760	63.337
60.000	57.608	62.491	55.957	64.335	53.289	67.556	51.443	69.981
65.000	62.198	67.929	60.269	70.102	57.165	73.908	55.026	76.782
70.000	66.755	73.402	64.530	75.934	60.961	80.379	58.512	83.744
75.000	71.282	78.912	68.739	81.831	64.678	86.969	61.903	90.868
80.000	75.777	84.458	72.898	87.794	68.318	93.680	65.201	98.157
85.000	80.241	90.041	77.007	93.822	71.881	100.513	68.410	105.614
90.000	84.674	95.661	81.066	99.918	75.370	107.469	71.530	113.240
95.000	89.076	101.318	85.076	106.081	78.786	114.551	74.564	121.037
100.000	93.447	107.012	89.038	112.312	82.130	121.758	77.514	129.008
105.000	97.788	112.744	92.951	118.611	85.403	129.094	80.383	137.155
110.000	102.099	118.513	96.817	124.978	88.607	136.558	83.173	145.480
115.000	106.379	124.319	100.635	131.415	91.743	144.152	85.885	153.985
120.000	110.630	130.164	104.407	137.922	94.813	151.878	88.521	162.672
125.000	114.851	136.046	108.133	144.498	97.817	159.737	91.085	171.544
130.000	119.042	141.967	111.813	151.146	100.757	167.730	93.576	180.601
135.000	123.204	147.926	115.447	157.864	103.635	175.858	95.999	189.846
140.000	127.336	153.923	119.037	164.654	106.451	184.123	98.353	199.281
145.000	131.439	159.960	122.583	171.516	109.206	192.525	100.642	208.908
150.000	135.514	166.035	126.085	178.451	111.903	201.067	102.867	218.728
155.000	139.559	172.149	129.544	185.459	114.542	209.749	105.030	228.744
160.000	143.576	178.303	132.959	192.540	117.124	218.573	107.132	238.956
165.000	147.565	184.495	136.333	199.696	119.650	227.539	109.176	249.368
170.000	151.525	190.728	139.664	206.925	122.122	236.648	111.163	259.979
175.000	155.457	197.000	142.954	214.230	124.541	245.903	113.094	270.793
180.000	159.361	203.312	146.203	221.610	126.908	255.304	114.971	281.811
185.000	163.238	209.664	149.411	229.066	129.223	264.852	116.796	293.033
190.000	167.086	216.056	152.579	236.598	131.489	274.548	118.570	304.462
195.000	170.908	222.489	155.708	244.207	133.706	284.393	120.294	316.099
200.000	174.702	228.962	158.798	251.893	135.875	294.389	121.971	327.946
205.000	178.469	235.476	161.848	259.657	137.997	304.536	123.602	340.004
210.000	182.209	242.030	164.861	267.498	140.073	314.835	125.187	352.274
215.000	185.922	248.626	167.835	275.419	142.105	325.288	126.728	364.758
220.000	189.608	255.263	170.773	283.418	144.093	335.895	128.227	377.456
225.000	193.268	261.941	173.673	291.497	146.038	346.657	129.684	390.371
230.000	196.902	268.661	176.536	299.655	147.941	357.576	131.102	403.504
235.000	200.510	275.423	179.364	307.894	149.803	368.651	132.480	416.854
240.000	204.092	282.226	182.156	316.213	151.625	379.885	133.821	430.425
245.000	207.648	289.072	184.912	324.613	153.408	391.278	135.126	444.217
250.000	211.178	295.959	187.634	333.095	155.152	402.830	136.394	458.230
255.000	214.683	302.889	190.321	341.659	156.859	414.544	137.629	472.467
260.000	218.162	309.862	192.974	350.306	158.530	426.418	138.830	486.927
265.000	221.616	316.877	195.594	359.034	160.164	438.456	139.998	501.613
270.000	225.046	323.934	198.180	367.847	161.764	450.656	141.136	516.525
275.000	228.450	331.035	200.734	376.742	163.330	463.020	142.242	531.664
280.000	231.830	338.179	203.255	385.722	164.862	475.549	143.319	547.030
285.000	235.185	345.367	205.744	394.786	166.361	488.244	144.368	562.626
290.000	238.516	352.597	208.202	403.935	167.829	501.105		
295.000	241.822	359.872	210.628	413.169	169.266	514.133		

13

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1800.00 PF(.00180 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	245.105	367.190	213.024	422.488	170.672	527.328		
305.000	248.363	374.552	215.389	431.894	172.048	540.692		
310.000	251.598	381.958	217.724	441.385	173.395	554.225		
315.000	254.810	389.408	220.029	450.964	174.714	567.928		
320.000	257.997	396.903	222.305	460.629				
325.000	261.162	404.442	224.552	470.382				
330.000	264.303	412.026	226.770	480.222				
335.000	267.422	419.655	228.960	490.151				
340.000	270.517	427.329	231.122	500.168				
345.000	273.590	435.048	233.257	510.274				
350.000	276.641	442.812	235.365	520.469				
355.000	279.669	450.622	237.445	530.754				
360.000	282.675	458.477	239.500	541.128				
365.000	285.659	466.378	241.528	551.593				
370.000	288.620	474.325	243.530	562.149				
375.000	291.560	482.319	245.507	572.795				
380.000	294.479	490.358						
385.000	297.376	498.443						
390.000	300.251	506.575						
395.000	303.106	514.754						
400.000	305.939	522.980						
405.000	308.752	531.252						
410.000	311.544	539.571						
415.000	314.315	547.938						
420.000	317.065	556.352						
425.000	319.796	564.814						
430.000	322.506	573.323						

Table 13-C.21

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1650.00 PF(.00165 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.445	30.566	29.054	30.977	28.408	31.682	27.948	32.203
35.000	34.246	35.771	33.716	36.333	32.843	37.299	32.224	38.015
40.000	39.016	41.009	38.327	41.746	37.195	43.016	36.397	43.960
45.000	43.757	46.279	42.889	47.215	41.467	48.834	40.468	50.040
50.000	48.468	51.581	47.401	52.742	45.659	54.754	44.439	56.257
55.000	53.149	56.916	51.863	58.326	49.772	60.777	48.313	62.613
60.000	57.800	62.283	56.277	63.969	53.808	66.905	52.091	69.109
65.000	62.423	67.684	60.643	69.670	57.768	73.138	55.776	75.749
70.000	67.015	73.117	64.961	75.430	61.652	79.478	59.370	82.533
75.000	71.579	78.584	69.231	81.249	65.463	85.927	62.874	89.465
80.000	76.114	84.084	73.455	87.129	69.201	92.484	66.291	96.545
85.000	80.620	89.618	77.631	93.068	72.868	99.152	69.621	103.776
90.000	85.098	95.185	81.762	99.068	76.464	105.932	72.869	111.159
95.000	89.547	100.785	85.847	105.129	79.992	112.824	76.034	118.697
100.000	93.967	106.420	89.886	111.252	83.451	119.831	79.119	126.391
105.000	98.359	112.089	93.881	117.436	86.844	126.952	82.126	134.244
110.000	102.724	117.792	97.831	123.683	90.171	134.190	85.057	142.257
115.000	107.060	123.529	101.736	129.993	93.433	141.545	87.914	150.431
120.000	111.368	129.301	105.599	136.365	96.632	149.019	90.698	158.770
125.000	115.649	135.107	109.418	142.802	99.769	156.612	93.410	167.273
130.000	119.902	140.948	113.194	149.302	102.844	164.326	96.054	175.944
135.000	124.128	146.824	116.927	155.866	105.860	172.162	98.629	184.783
140.000	128.327	152.735	120.619	162.496	108.816	180.120	101.139	193.793
145.000	132.499	158.681	124.268	169.190	111.715	188.203	103.585	202.974
150.000	136.643	164.662	127.877	175.950	114.556	196.410	105.967	212.330
155.000	140.761	170.679	131.445	182.776	117.342	204.744	108.289	221.860
160.000	144.852	176.732	134.972	189.669	120.072	213.205	110.551	231.568
165.000	148.917	182.820	138.459	196.628	122.749	221.793	112.755	241.453
170.000	152.955	188.944	141.907	203.654	125.374	230.511	114.902	251.519
175.000	156.967	195.104	145.316	210.748	127.946	239.359	116.994	261.765
180.000	160.953	201.301	148.685	217.910	130.467	248.338	119.033	272.195
185.000	164.913	207.533	152.016	225.141	132.939	257.449	121.019	282.808
190.000	168.847	213.803	155.309	232.440	135.362	266.693	122.954	293.606
195.000	172.756	220.108	158.564	239.808	137.737	276.070	124.839	304.592
200.000	176.639	226.451	161.782	247.246	140.064	285.583	126.676	315.765
205.000	180.497	232.830	164.963	254.753	142.346	295.232	128.467	327.128
210.000	184.329	239.246	168.108	262.331	144.582	305.017	130.211	338.681
215.000	188.136	245.700	171.216	269.980	146.774	314.940	131.911	350.427
220.000	191.918	252.191	174.289	277.700	148.923	325.001	133.567	362.365
225.000	195.676	258.719	177.326	285.491	151.029	335.201	135.181	374.497
230.000	199.408	265.285	180.328	293.354	153.093	345.542	136.754	386.825
235.000	203.117	271.888	183.296	301.289	155.116	356.023	138.288	399.349
240.000	206.800	278.529	186.229	309.296	157.099	366.647	139.782	412.070
245.000	210.460	285.209	189.128	317.377	159.043	377.413	141.239	424.990
250.000	214.095	291.926	191.994	325.531	160.949	388.322	142.658	438.110
255.000	217.707	298.682	194.827	333.758	162.817	399.376	144.042	451.430
260.000	221.294	305.476	197.626	342.059	164.647	410.574	145.391	464.952
265.000	224.858	312.309	200.394	350.435	166.442	421.919	146.707	478.676
270.000	228.398	319.180	203.129	358.886	168.201	433.409	147.989	492.604
275.000	231.915	326.090	205.832	367.411	169.926	445.047	149.240	506.736
280.000	235.408	333.039	208.504	376.012	171.616	456.833	150.459	521.073
285.000	238.878	340.027	211.145	384.689	173.273	468.768	151.648	535.616
290.000	242.325	347.054	213.755	393.441	174.898	480.852	152.807	550.367
295.000	245.749	354.121	216.334	402.271	176.491	493.085	153.938	565.325

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1650.00 PF(.00165 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	249.151	361.227	218.884	411.177	178.052	505.470		
305.000	252.529	368.373	221.404	420.160	179.583	518.006		
310.000	255.886	375.558	223.894	429.220	181.084	530.693		
315.000	259.219	382.784	226.356	438.358	182.555	543.533		
320.000	262.531	390.049	228.789	447.575	183.998	556.527		
325.000	265.820	397.355	231.193	456.870	185.413	569.674		
330.000	269.088	404.700	233.569	466.243				
335.000	272.333	412.087	235.918	475.696				
340.000	275.557	419.513	238.239	485.228				
345.000	278.760	426.981	240.533	494.839				
350.000	281.940	434.489	242.800	504.531				
355.000	285.100	442.038	245.040	514.303				
360.000	288.238	449.628	247.255	524.156				
365.000	291.355	457.260	249.443	534.089				
370.000	294.451	464.932	251.606	544.104				
375.000	297.527	472.646	253.744	554.201				
380.000	300.582	480.402	255.856	564.379				
385.000	303.616	488.199	257.944	574.639				
390.000	306.629	496.039						
395.000	309.623	503.920						
400.000	312.596	511.843						
405.000	315.549	519.808						
410.000	318.482	527.816						
415.000	321.395	535.866						
420.000	324.289	543.959						
425.000	327.163	552.094						
430.000	330.018	560.273						
435.000	332.853	568.494						

Table 13-C.22

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1500.00 PF(.00150 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
30.000	29.494	30.515	29.137	30.888	28.547	31.527	28.126	31.999
35.000	34.312	35.701	33.829	36.212	33.030	37.087	32.463	37.735
40.000	39.103	40.917	38.474	41.586	37.438	42.737	36.705	43.591
45.000	43.867	46.163	43.074	47.013	41.771	48.478	40.853	49.568
50.000	48.603	51.437	47.628	52.491	46.031	54.311	44.909	55.668
55.000	53.312	56.742	52.136	58.021	50.218	60.237	48.874	61.893
60.000	57.994	62.075	56.601	63.603	54.334	66.257	52.751	68.245
65.000	62.649	67.439	61.020	69.239	58.379	72.372	56.541	74.725
70.000	67.277	72.833	65.396	74.928	62.354	78.584	60.245	81.334
75.000	71.879	78.256	69.728	80.670	66.261	84.892	63.866	88.075
80.000	76.454	83.710	74.017	86.466	70.100	91.298	67.405	94.949
85.000	81.003	89.194	78.263	92.317	73.873	97.803	70.863	101.958
90.000	85.525	94.709	82.466	98.222	77.580	104.408	74.242	109.103
95.000	90.022	100.254	86.627	104.182	81.223	111.115	77.544	116.386
100.000	94.492	105.829	90.746	110.198	84.801	117.923	80.770	123.808
105.000	98.936	111.436	94.823	116.269	88.317	124.834	83.922	131.372
110.000	103.354	117.073	98.859	122.396	91.772	131.849	87.002	139.078
115.000	107.747	122.741	102.854	128.580	95.165	138.968	90.010	146.928
120.000	112.114	128.440	106.809	134.820	98.499	146.194	92.949	154.924
125.000	116.456	134.171	110.723	141.117	101.774	153.526	95.820	163.067
130.000	120.772	139.933	114.598	147.472	104.991	160.966	98.624	171.358
135.000	125.063	145.726	118.433	153.885	108.151	168.515	101.363	179.800
140.000	129.329	151.551	122.229	160.355	111.255	176.172	104.038	188.393
145.000	133.570	157.408	125.986	166.884	114.303	183.941	106.651	197.139
150.000	137.787	163.296	129.704	173.472	117.297	191.820	109.203	206.039
155.000	141.978	169.216	133.385	180.118	120.238	199.812	111.695	215.095
160.000	146.145	175.169	137.027	186.825	123.126	207.917	114.129	224.307
165.000	150.287	181.154	140.632	193.590	125.963	216.136	116.506	233.678
170.000	154.405	187.170	144.200	200.417	128.748	224.469	118.828	243.209
175.000	158.498	193.220	147.731	207.303	131.484	232.918	121.095	252.900
180.000	162.568	199.302	151.225	214.250	134.171	241.484	123.309	262.754
185.000	166.613	205.416	154.683	221.258	136.809	250.167	125.472	272.770
190.000	170.635	211.563	158.106	228.328	139.400	258.968	127.584	282.952
195.000	174.632	217.743	161.493	235.460	141.944	267.888	129.646	293.299
200.000	178.606	223.956	164.844	242.653	144.442	276.928	131.660	303.813
205.000	182.557	230.203	168.161	249.909	146.895	286.088	133.627	314.495
210.000	186.483	236.482	171.443	257.228	149.304	295.370	135.548	325.347
215.000	190.387	242.795	174.692	264.609	151.670	304.773	137.424	336.368
220.000	194.267	249.141	177.906	272.054	153.993	314.300	139.256	347.561
225.000	198.125	255.521	181.086	279.563	156.274	323.951	141.045	358.927
230.000	201.959	261.935	184.234	287.136	158.514	333.726	142.793	370.466
235.000	205.770	268.382	187.348	294.773	160.713	343.625	144.500	382.179
240.000	209.559	274.863	190.430	302.474	162.872	353.651	146.168	394.068
245.000	213.325	281.379	193.479	310.241	164.993	363.804	147.796	406.133
250.000	217.068	287.928	196.496	318.072	167.075	374.084	149.387	418.376
255.000	220.789	294.512	199.482	325.970	169.120	384.491	150.941	430.797
260.000	224.488	301.130	202.436	333.933	171.127	395.028	152.459	443.398
265.000	228.164	307.783	205.359	341.962	173.099	405.693	153.942	456.178
270.000	231.819	314.470	208.251	350.058	175.035	416.489	155.391	469.140
275.000	235.451	321.192	211.113	358.220	176.935	427.416	156.806	482.283
280.000	239.062	327.949	213.945	366.450	178.802	438.474	158.189	495.609
285.000	242.651	334.740	216.746	374.747	180.635	449.663	159.540	509.119
290.000	246.218	341.567	219.518	383.111	182.435	460.986	160.861	522.813
295.000	249.764	348.429	222.261	391.544	184.203	472.441	162.151	536.691

CALCULATION OF BANDEDGE FREQUENCIES FOR FIRST, SECOND, THIRD AND FOURTH ORDER BANDPASS TUNERS

CC= 1500.00 PF(.00150 UF) LINE IMPED.= 300.0 OHMS CB= .100 UF

RETURN LOSS= 14.000 DB AMPLITUDE= .177 DB

	N=1		N=2		N=3		N=4	
GMF (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)	F(LOW) (KHZ)	F(HIGH) (KHZ)
300.000	253.288	355.327	224.975	400.045	185.939	484.031	163.412	550.756
305.000	256.791	362.259	227.660	408.614	187.643	495.755	164.644	565.007
310.000	260.273	369.227	230.316	417.252	189.317	507.614		
315.000	263.734	376.231	232.945	425.959	190.961	519.608		
320.000	267.174	383.271	235.545	434.736	192.576	531.739		
325.000	270.593	390.346	238.118	443.582	194.161	544.006		
330.000	273.991	397.458	240.664	452.498	195.719	556.411		
335.000	277.369	404.605	243.183	461.485	197.248	568.953		
340.000	280.726	411.789	245.674	470.542				
345.000	284.063	419.009	248.140	479.669				
350.000	287.380	426.265	250.579	488.868				
355.000	290.676	433.558	252.992	498.138				
360.000	293.952	440.888	255.380	507.480				
365.000	297.209	448.254	257.742	516.893				
370.000	300.445	455.657	260.079	526.379				
375.000	303.662	463.097	262.391	535.937				
380.000	306.859	470.574	264.678	545.568				
385.000	310.037	478.088	266.941	555.271				
390.000	313.195	485.640	269.181	565.048				
395.000	316.334	493.229	271.396	574.898				
400.000	319.454	500.855						
405.000	322.554	508.519						
410.000	325.636	516.221						
415.000	328.699	523.960						
420.000	331.743	531.738						
425.000	334.768	539.553						
430.000	337.775	547.407						
435.000	340.763	555.298						
440.000	343.733	563.228						
445.000	346.684	571.197						

SECTION 14

BYPASS CIRCUITS

Contents of Section 14

(Note: Adapted from reference [26]).

SHORT BYPASS CIRCUITS

Short bypass line tuners are used when PLC signals are to be bypassed around a bus or line discontinuity, no local drop of frequencies is required, and the physical separation of the two phase wires or coupling capacitors is 100 feet, or less. The short bypass line tuner is enclosed in a single cabinet. Figure 14-1 shows a typical connection of a short bypass line tuner around a bus.

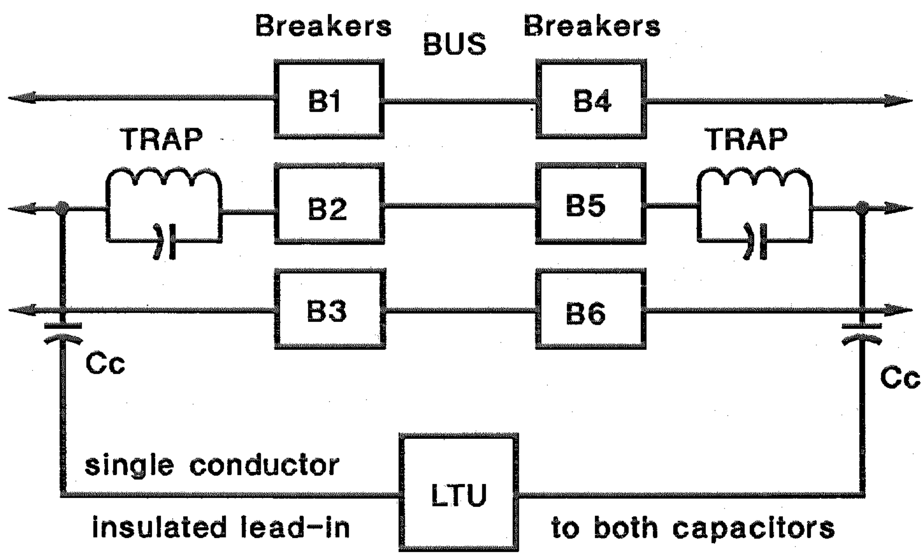


Figure 14-1. Short Bypass Connection

The PLC functions are blocked from the bus by the traps which present a high impedance at the line tuner frequency. The most simple short bypass circuit is a single tuned series circuit formed by the two coupling capacitors, or CCVT's, and the tuning inductor in the tuner cabinet. The line tuner cabinet will also contain two protector units with grounding switches, power frequency blocking capacitors, and surge protection. There are no transformers in the circuit, since both ports of the bypass line tuner are connected to the line through the coupling capacitors. The losses in the bypass line tuner are composed of the shunt loss of the line traps plus the insertion loss of the tuner.

To increase the bandwidth of the resonant short bypass line tuner a second series inductor can be added and a shunt tuned parallel circuit can be added to form a third order bandpass tuner at the line impedance. The 14 dB return loss bandwidths of the resonant and third order short bypass line tuner are given in equations 1 and 2 respectively.

$$BW(N-1) = 1.278(GMF)^2 R Cc' \quad (1)$$

$$BW(N-3) = 7.4707(GMF)^2 R Cc' \quad (2)$$

GMF = Geometric Mean Frequency(resonant frequency)
R = Line impedance
Cc' = Coupling capacitance adjusted by the power frequency blocking capacitor.

The bandwidth of the third order tuner is almost six (6) times wider than the resonant (N=1) tuner. A factor of two of this increase is the result of the series combining of the two coupling capacitors in the resonant tuner. This effectively reduces the bandwidth of the resonant tuner by a factor of two. The circuit for the resonant and wideband third order short bypass line tuners are shown in Figure 14-2 and Figure 14-3, respectively.

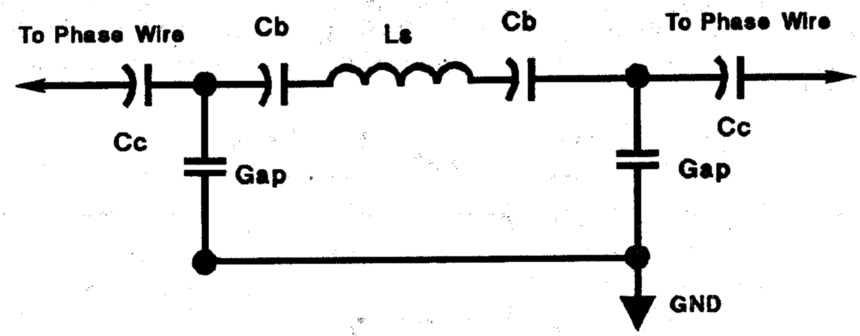


Figure 14-2. First Order Short Bypass Tuner

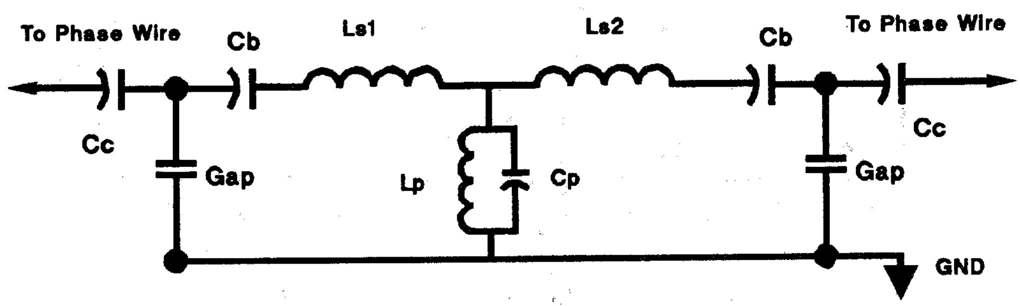


Figure 14-3. Third Order Short Bypass Tuner

INSTALLATION

The losses and bandwidth of short bypass line tuners are affected by the conductors used for lead-in conductors if these conductors result in leakage paths to ground through the insulators supporting the conductors. The lead-in conductors should be insulated, single conductor cable supported on a minimum number of insulators with clamps that do not puncture the insulation. The addition of resistive leakage paths at the supporting insulators will add to the insertion loss of the tuner and the additional shunt capacitance will reduce the bandwidth of the tuners. This additional loss will be added to the shunt loss attributed to the line traps.

LONG BYPASS TUNERS

INTRODUCTION

The situation requiring the use of a long bypass circuit occurs when a PLC signal must be passed around a discontinuity in a high voltage line where coaxial cable is needed to bridge the discontinuity because of the physical separation of the coupling capacitors. The need for routing some of the band(s) of frequencies, which are passed by the tuners, to a local station will require a coaxial connection to equipment housed indoors. The bandwidth, or frequency bands, of the local signal -called a local drop- will dictate the type of auxiliary coupling device(s) used in addition to the tuners and coupling capacitors, which are always present.

A discontinuity may be isolated by line traps. Some discontinuities, such as switches, may not be isolated, and the signal may bypass the local station altogether when the switch is closed. Without line traps a closed switch will shunt the PLC signals around the components of the bypass. Since the coupling components are permanently connected to the line, the loading at the bypass will result in a double termination and cause reflections on the line. Isolating the discontinuity with line traps will eliminate this condition and cause the circuit at the bypass to have essentially the same characteristics with the switch open or closed. A transformer, or autotransformer, should be isolated with traps since most transformers represent an unknown RF impedance, or a shunt capacitive impedance, which will interfere with the bypass circuits. The required isolation with line traps to prevent phase cancellation and interference is 20 to 25 dB across the bandwidth of the tuner and other connected coupling devices.

The long bypass circuit causes two line tuners to be connected in cascade. The return loss of the individual line tuners is reduced by at least three dB and the loss at the band edges is doubled. A wideband tuner is recommended for most bypass connections to reduce the mismatch reflections caused by cascading tuners. To reduce the mismatch effects caused by this cascading, the CCVT's or coupling capacitors and the tuners must be identical in design and tuning. These bypass line tuning devices should also match the companion devices at the ends of the lines. A resonant line tuner can be used in some cases where the value of the coupling capacitor, the frequency, and the surge(line) impedance give a wide bandwidth, and the band of frequencies required to pass between the end stations is only about one-half of the 14 dB return loss bandwidth of the individual tuners.

BYPASS TUNERS WITHOUT LOCAL DROP

The connection shown in Figure 14-4 is the most simple bypass example. The discontinuity - a switch in this example - is bridged by a coaxial cable which ties the two line tuners together at a low impedance level. This is usually the coaxial cable impedance level.

Note: Care must be exercised to guarantee that the polarity of the bypassed signal has the same instantaneous phase as the connection from A to B with the switch closed. If the discontinuity is isolated by line traps, the phase of the bypass is not a factor unless the isolation is less than 20 dB in the frequency band being used. A 180 degree phase reversing transformer must be inserted in one side of the two-way local drop circuits of Figures 14-5D, 14-6D, and 14-7D for discontinuities not isolated by line traps or where the minimum isolation is not maintained across the bandwidth in use.

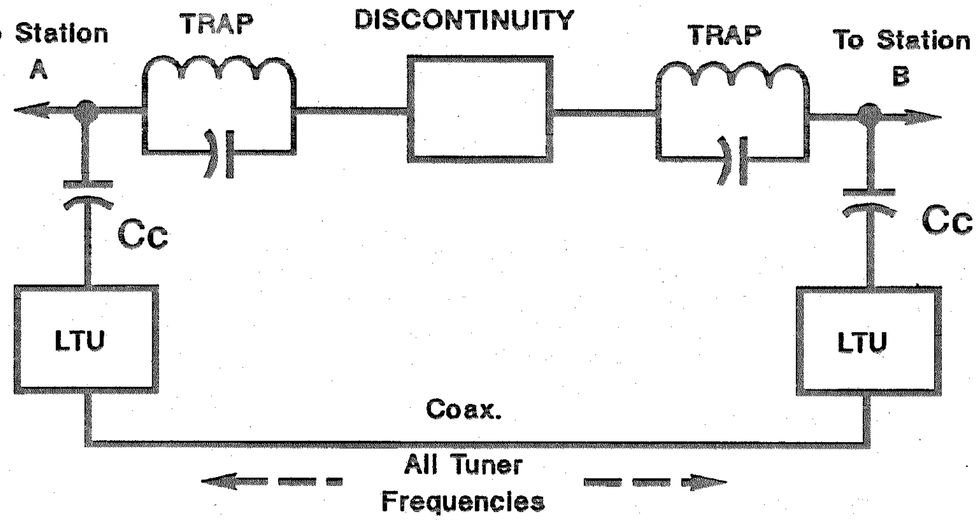


Figure 14-4. Long Bypass Installation

BYPASS WITH LOCAL DROP(S)

The local station may receive or transmit to either of the end stations by using hybrid transformers, L/C units, or branching (LP/HP) filters. The hybrid is used in applications where the band of frequencies passed by the line tuners is made available to the local station, and the local station can transmit to either, or both of the end stations. The indoor equipment may change as the application changes, but the outdoor equipment will always consist of line tuning units (LTUs) and coupling capacitors (Cc's) or CCVT's. The outdoor equipment will be shown only in Figure 14-5A, 14-6A, and 14-7A. In all other circuits it will be understood that the outdoor equipment is as shown in these figures.

HYBRID CIRCUITS FOR LOCAL DROPS

Figure 14-5A shows a circuit where the local station may receive and transmit to station B while transmissions from station A are bypassed from the local station. Communication is also maintained for all frequencies in the tuner bandwidth between the end stations.

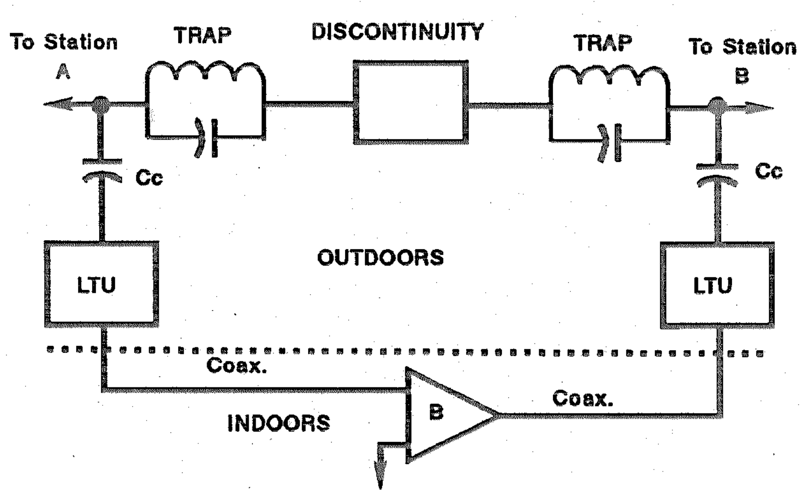


Figure 14-5A. Local Drop from Station B

The connections to the indoor equipment may be changed to allow for transmission from the local drop to station A, as shown in Figure 14-5B. Communications from Station B are bypassed at the local drop. Communications between stations A and B are maintained.

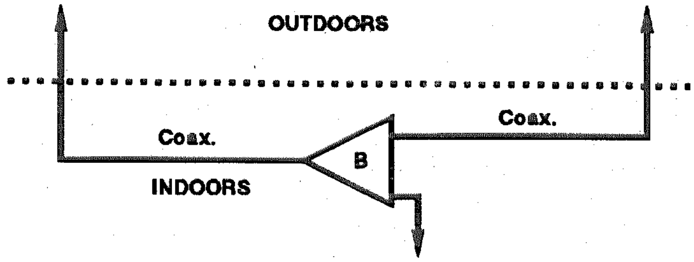


Figure 14-5B. Local Drop from Station A

Also, by using two hybrids, it is possible to have two one-way local drops, as shown in Figure 14-5C. These drops are isolated from each other and can be at different frequencies or bands of frequencies. The amount of isolation, as in all hybrid circuits, is determined by the return loss on the line side of the hybrid.

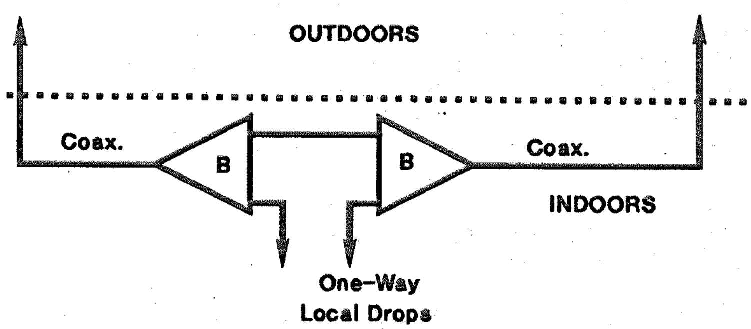


Figure 14-5C. Two One-Way Local Drops

By combining the two one-way local drops through another hybrid, it is possible to have a two-way local drop for the entire bandwidth of the line tuners. This is shown in Figure 14-5D.

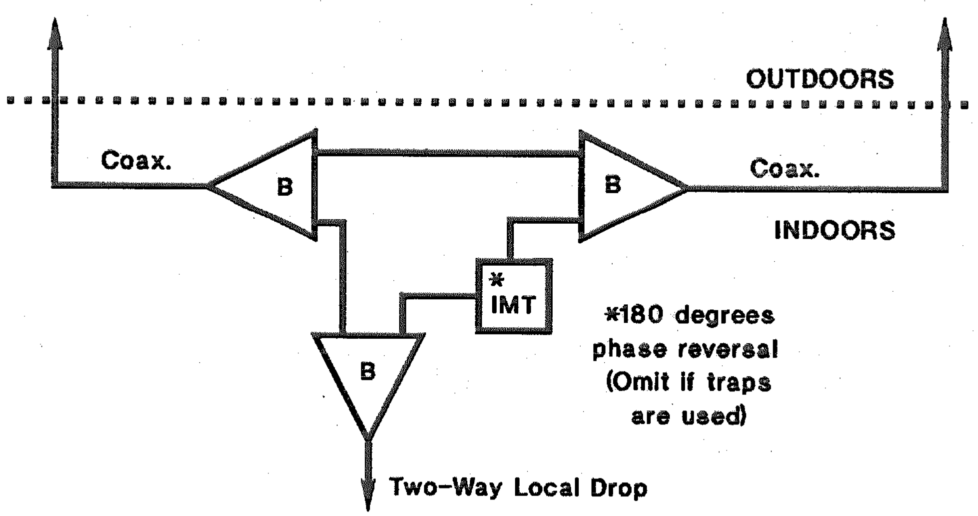


Figure 14-5D. Two-Way Local Drop

The loss, in addition to that caused by the line tuners and the shunt losses of any line traps, for hybrid bypass circuits is as shown in Table 14-1. (LD = Local Drop)

TABLE 14-1.

Figure #	Stations	Hybrid Loss
14-5A	A<—>B	3.2 dB
14-5A	B<—>LD	3.2 dB
14-5A	A<—>LD	High
14-5B	A<—>B	3.2 dB
14-5B	A<—>LD	3.2 dB
14-5B	B<—>LD	High
14-5C	A<—>B	6.4 dB
14-5C	A<—>LD#1	3.2 dB
14-5C	B<—>LD#2	3.2 dB
14-5C	A<—>LD#2	High
14-5C	B<—>LD#1	High
14-5D	A<—>B	6.4 dB
14-5D	A<—>LD	6.4 dB
14-5D	B<—>LD	6.4 dB

The loss labeled "high" is determined by the return loss of the circuit at the common hybrid connection to the line tuner(s).

L/C UNIT CIRCUITS FOR LOCAL DROPS IN BYPASS TUNERS

The loss introduced by inserting one hybrid in the signal path is 3 dB plus the loss of the transformer windings. This usually results in approximately 3.2 dB loss for each hybrid

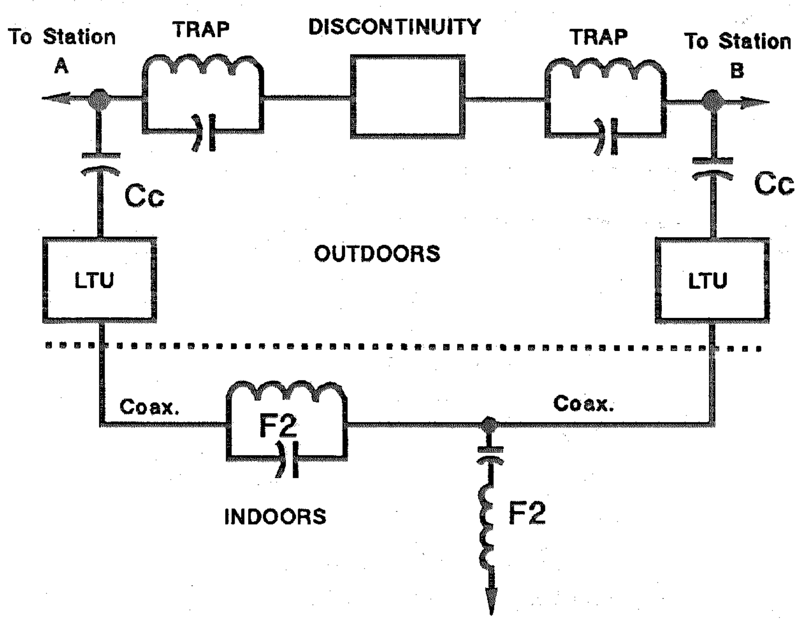


Figure 14-6A. One-Way Local Drop of F2 to B if 0.2 dB is allowed for the insertion loss of the windings. Other coupling circuits which are frequency sensitive or frequency selective result in less loss in the indoor equipment, but these sacrifice flexibility of bandwidth or bandwidth. The L/C series circuit is essentially a single frequency (function) drop. The spacing requirements for series resonant circuits must be considered and the bandwidth of the tuner must be wide enough to allow for this spacing and any frequencies on the main line connection not involved with the local drop. The indoor connections to equipment are shown in Figures 14-6A - 14-6D. The two-way local drop makes use of a hybrid. The trap (parallel L/C unit) is used to prevent double terminating the circuit between the tuners. The trap is tuned to the same frequency as the L/C series unit.

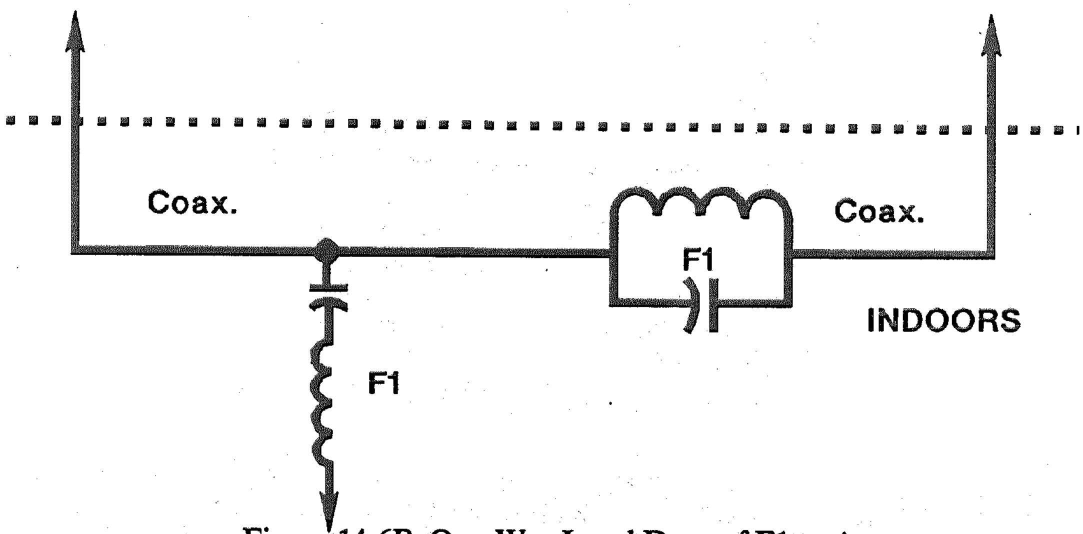


Figure 14-6B. One-Way Local Drop of F1 to A

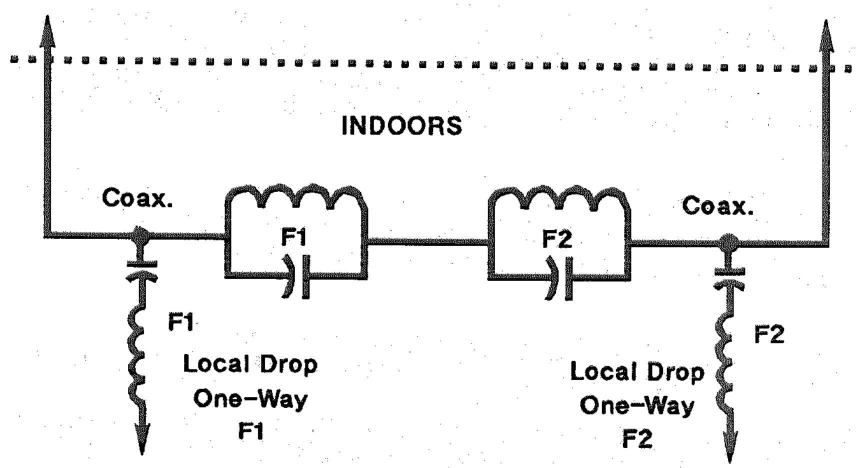


Figure 14-6C. Two One-Way Local Drops of F1 to A and F2 to B

Figure 14-6A shows a local drop circuit to communicate with station B at the frequency, F2. The inverse arrangement of Figure 14-6B allows communication between the local drop and station A at the frequency, F1. The circuit of Figure 14-6C allows both of the above. If a two-way drop is required, either at F1 or at F1 and F2, the indoor equipment connection of Figure 14-6D is one method to accomplish this with L/C units and a hybrid. If F1 and F2 are identical, then one of the traps may be removed from the diagram of Figure 14-6D.

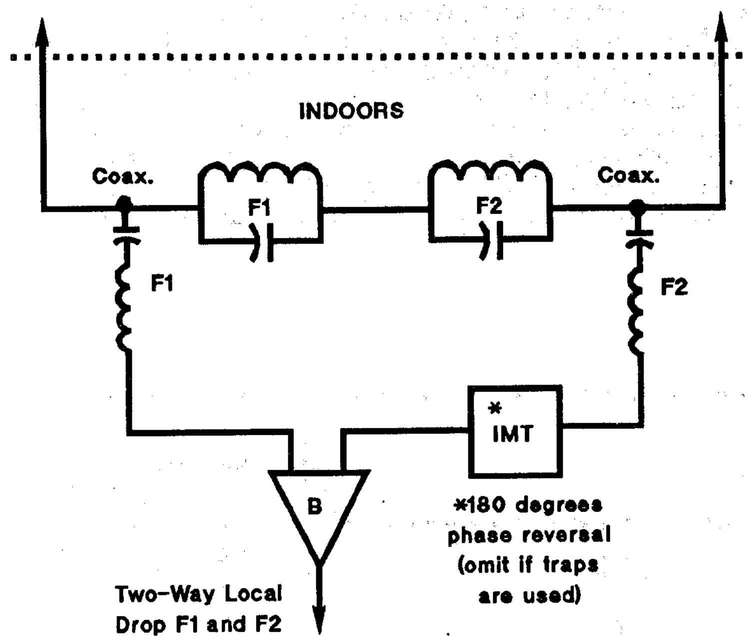


Figure 14-6D. Two-Way Local Drop of F1 and F2

The frequency of the local drop cannot be used between the end stations using L/C units for coupling at the local drop. The bandwidths of the L/C unit traps at the local drop will usually restrict the use of frequencies between stations A and B to those frequencies at least 20% above and below the local drop frequency. A 10 per cent frequency margin should be allowed for return loss reduction caused from cascading tuners. For small values of coupling capacitors, this may severely limit the application of L/C units for local drop use. (Refer to the application guidelines for series resonant circuits for spacing, power handling capability, and bandwidth requirements for L/C units. ECC-355 or in section 12 of this guide.)

By way of example, the requirement to pass two signals at frequencies of about 110 kHz between stations A and B along with a need to drop signals at 60 kHz and at 80 kHz would require a tuner bandwidth determined as follows:

Cascading margin will determine lower tuner bandedge:
LOWER TUNER BANDEDGE: 60kHz - 0.1 x 60 kHz = 60 - 6 = 54 kHz.

Lower edge of bypass frequency band determined by highest drop frequency:
LOWER BYPASS BANDEDGE: 80 kHz + 0.2 x 80 kHz = 96 kHz.

Cascading margin will determine upper tuner bandedge:
UPPER TUNER BANDEDGE: 110 kHz + 0.1 x 110 kHz = 121 kHz.

The bandwidth from 96 kHz to 110 kHz can be used between the two stations A and B for the two bypass signals. The tuner bandwidth required at 14 dB return loss is 54 to 121 kHz.

BRANCHING FILTER CIRCUITS FOR LOCAL DROPS

Another frequency dependent method of creating a local drop is to use branching filter indoor equipment connections. This technique allows only a low frequency (lowpass) or a high frequency (highpass) band of frequencies to be transmitted between stations A and B. The bandwidth of the tuners has to be coordinated with the passbands of the lowpass and highpass filters comprising the branching filter. (The branching filter crossover frequency could be made equal to the tuner GMF.) Branching filters are available with a 10% separation between the low frequency and high frequency passbands. The local drop can be assigned the frequencies which are not in the band of use from station A to station B. The lowpass bandwidth in the examples is the range from 30 kHz to 100 Khz. The highpass bandwidth is the range from 110 kHz to 300 kHz.

Figure 14-7A shows the local drop circuit for transmitting the lowpass frequencies (30-100 kHz) between the local drop and station A. By exchanging the lowpass and highpass filter positions, the highpass frequencies (110-300 kHz) can be used between the local drop and station A.

Figure 14-7B shows a configuration using a branching filter with the highpass frequencies (110-300 kHz) assigned between station B and the local drop. Figure 14-7C shows a configuration for two one-way local drops using branching filters. The line side of the common LP/HP connection is the branching terminal of the filter. The lowpass band of frequencies (30-100 kHz) are bypassed from the local drop. Both local drops will pass the highpass band of frequencies (110- 300 kHz). By adding a hybrid and a phase reversing transformer, the local drop can communicate with both end stations, as is shown in Figure 14-7D.

The previous example given for two local drop frequencies of 60 and 80 kHz and the requirement to bypass frequencies above 110 kHz could make use of the bypass circuits of Figure 14-7A or Figure 14-7C with the lowpass and highpass filters interchanged.

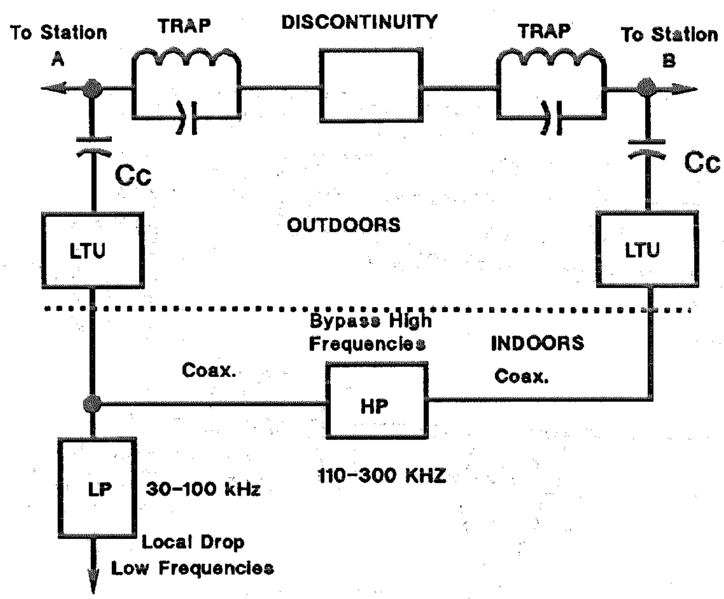


Figure 14-7A. One Way Local Drop of Low Frequencies

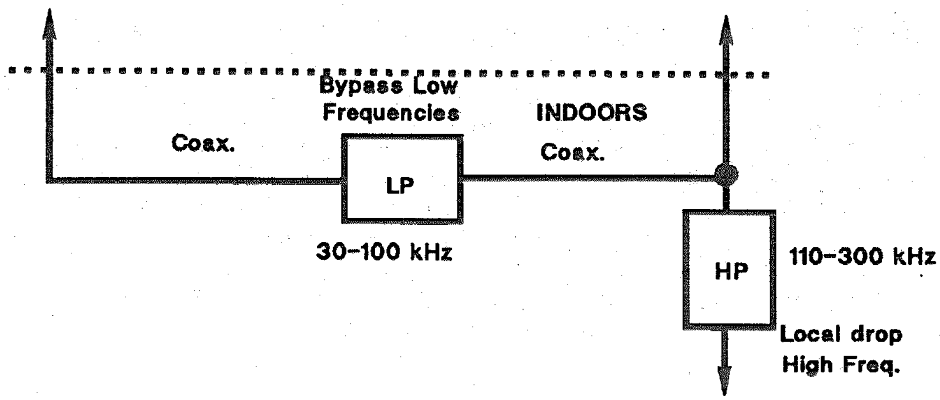


Figure 14-7B. One Way Local Drop of High Frequencies

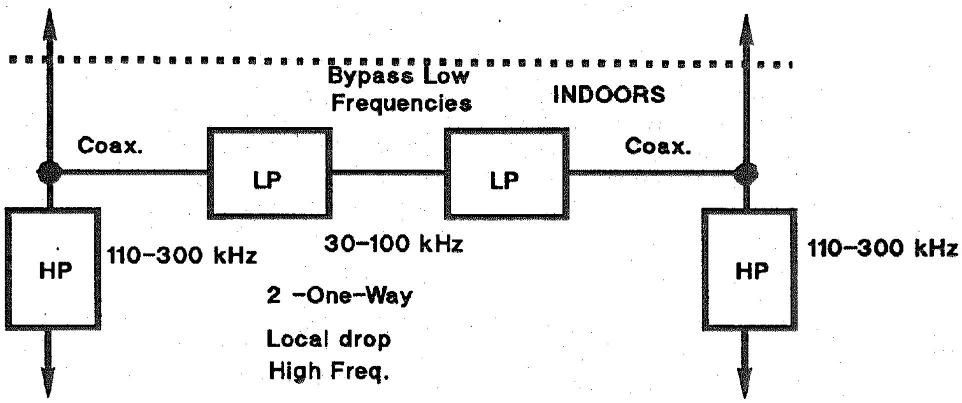


Figure 14-7C. Two One-Way Local Drops of High Frequencies

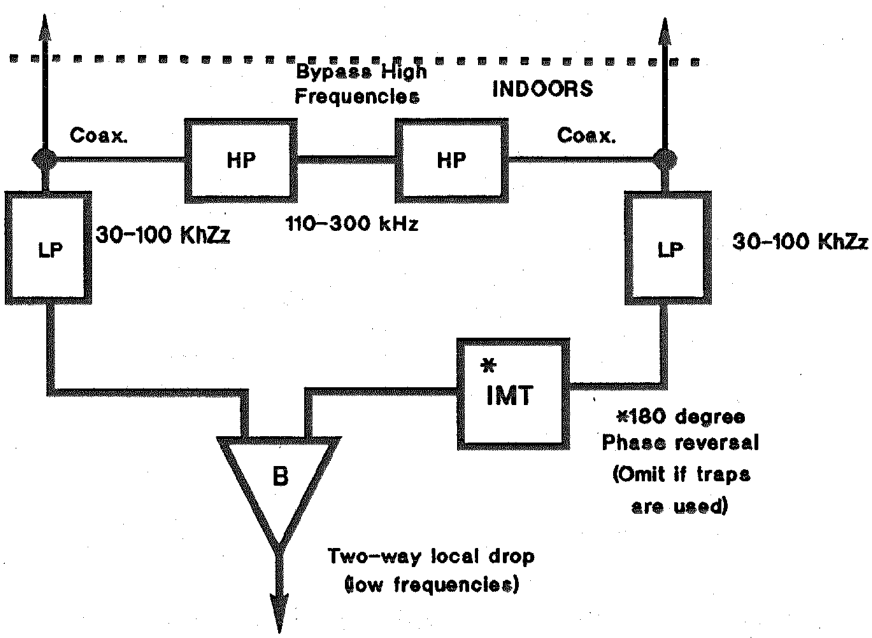


Figure 14-7D. Two-Way Local Drop of Low Frequencies

SECTION 15

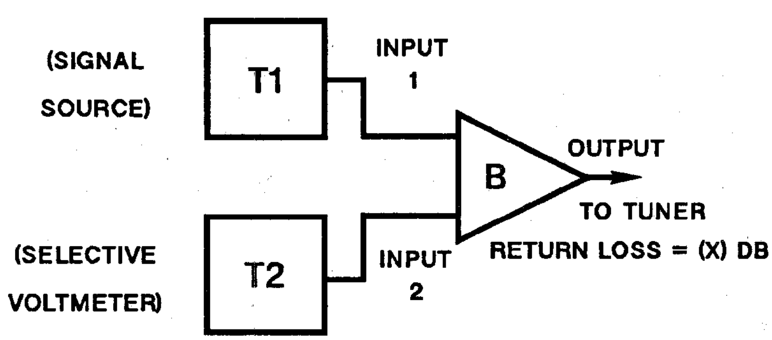
RESONANT AND WIDEBAND BANDPASS LINE TUNERS

Contents of Section 15

(Note: Adapted from reference [29]).

TWO AND THREE TERMINAL LINES AND POWER CABLES WITH LOSSES OVER 10 DB: THE HYBRID ISOLATION METHOD

Section 13, formerly Application Guide ECC-354, gave some of the theoretical aspects of bandpass line tuners. The instruction books for the various types of line tuners give several methods for tuning these devices for laboratory and field applications. LBI 35783, entitled " Power Line Carrier Line Tuning Service Notes", gives practical methods for tuner alignment. An additional method, which is closely akin to the reflected power/reflective wattmeter method, is to use the isolation provided by a balanced hybrid to optimize the tuner alignment. The primary disadvantage of the reflected power tuning method using the available transmitters is that the tuning can be done only at the transmitter frequency (or frequencies), which may not necessarily be at the geometric mean frequency (GMF) of the tuner. This frequency is the frequency at which the tuning should be optimized. Consider the circuit of Figure 15-1.



HYBRID ISOLATION TEST CIRCUIT

Figure 15-1

With two transmitters, T1 and T2, connected to the inputs of a balanced hybrid, the isolation provided by the hybrid is the loss between Input 1 and the output, plus the return loss looking into the coaxial cable going to the tuner, plus the loss from the output to Input 2. The isolation between the two transmitters is thus 6 dB plus the return loss measured at the output of the hybrid.

By substituting a 50 ohm signal generator for one of the transmitters and a selective voltmeter terminated in 50 ohms for the second transmitter, the return loss and the isolation across the hybrid can be measured. With the coax to the tuner disconnected, the voltage at the meter should be 6 dB below the generator voltage, since the return loss is zero with no line termination. With this as a reference, the return loss is the difference between the meter reading and the open circuit reading. The use of this method assumes that all transmitters on the line section have been turned off, but the equipment terminals to all tuners on the line are terminated properly. (NOTE: SEE CAUTION NOTE ON PAGE 15-14 BEFORE PROCEEDING TO PREVENT POSSIBLE FALSE TRIPS.)

If the tuner is not properly aligned, the return loss and the tuner bandwidth will not be optimized. Section 13 gives 14 dB return loss bandwidths for resonant and wideband line tuners. The return loss between these bandedge frequencies will be higher than 14 dB with the correct Impedance Matching Transformer (IMT) settings and the proper selections of inductor and capacitor values in the tuner. Some typical theoretical return loss curves for resonant and wideband second order tuners are shown in Figures 15-2 and 15-3.

The tuners shown in the curves are properly tuned and matched to a line impedance of 275 ohms using a coupling capacitor value of 2150 pF at a geometric mean frequency (GMF) of 114 kHz. The 14 dB return loss bandwidth for the resonant tuner of Figure 15-2 is from about 105 kHz to 124 kHz. The 14 db return loss bandwidth for the wideband (second order) tuner of Figure 15-3 is about 98.5 kHz to 132 kHz. The maximum return loss occurs at the GMF for both tuners, and this maximum is approached by a curve which is continuously increasing. There are no other maximums, or minimums of return loss in this band. This same shape of curve would be observed if the isolation were measured across the hybrid of Figure 15-1. (The curves of Figures 15-2 through 15-10 must have an additional 6 dB added to them to obtain the isolation that would be measured across the hybrid.) The minimum isolation in these two bands, for the tuners above, would be 20 dB (14 dB + 6 dB).

Starting with the IMT strapped to 175 ohms, and using a resonant tuner with the same requirements as above, the isolation across the hybrid provided by the return loss will resemble the curve of Figure 15-4. Remember that the total isolation is the return loss plus the six (6) dB hybrid loss. The six (6) dB must be added to all of the return loss curves to determine the selective voltmeter reading for isolation. The isolation is only 12.8 dB at the GMF (plus the 6 dB of the hybrid) because the tuner is not properly matched to the line impedance. A similar isolation (return loss) curve would be obtained if the transformer tap were set to 450 ohms. This is shown in Figure 15-5. The isolation at the GMF is about 12.5 dB for this IMT setting. The conclusion to be reached from observing the return loss curves for improper IMT settings for a resonant tuner is that, although the series inductor may be tuned to the GMF with the coupling capacitor/ 60 hZ blocking capacitor combination, the tuning is very broad and inconclusive. The IMT setting should initially be set close to the usual value of impedance expected for the voltage class of line being tuned.

Changing the tap from 175 ohms to 240 ohms changes the isolation at the GMF to 23.1 dB, as shown by the curve of Figure 15-6. As the peak of isolation (return loss) becomes more pronounced, the series inductor tuning can be optimized at the GMF. A review of Figure 15-2 with the IMT set to the value which matches the actual line impedance shows the sharpness to be expected with proper tuning of the series inductor and the proper IMT settings.

```
  FREQ(HZ)     RTN LOSS(DB)
.800000E+05  .368360E+01   *
.820000E+05  .406824E+01   *
.840000E+05  .449532E+01    *
.860000E+05  .497046E+01    *
.880000E+05  .550031E+01     *
.900000E+05  .609291E+01     *
.920000E+05  .675807E+01      *
.940000E+05  .750815E+01       *
.960000E+05  .835905E+01       *
.980000E+05  .933194E+01        *
.100000E+06  .104561E+02         *
.102000E+06  .117741E+02          *
.104000E+06  .133512E+02            *
.106000E+06  .152967E+02              *
.108000E+06  .178138E+02                *
.110000E+06  .213549E+02                   *
.112000E+06  .273157E+02                         *
.114000E+06  .419567E+02                                       *
.116000E+06  .274680E+02                         *
.118000E+06  .216578E+02                    *
.120000E+06  .182646E+02                 *
.122000E+06  .158911E+02              *
.124000E+06  .140840E+02             *
.126000E+06  .126388E+02           *
.128000E+06  .114456E+02          *
.130000E+06  .104381E+02         *
.132000E+06  .957347E+01        *
.134000E+06  .882192E+01        *
.136000E+06  .816217E+01       *
.138000E+06  .757829E+01       *
.140000E+06  .705808E+01      *
.142000E+06  .659193E+01      *
.144000E+06  .617216E+01     *
.146000E+06  .579254E+01     *
.148000E+06  .544790E+01     *
.150000E+06  .513393E+01    *
```

```
>—[ IMT ]—[ L ]—[ PROT. ]—>
   (SIMPLIFIED CIRCUIT)
```

C_c = 2.15 nF
R_L = 275 ohms
GMF = 114 kHz

(NOTE: E+05 IS POWER OF 10 MULTIPLIER: THUS 0.800000E+05 = 80000.0 HZ OR 80.000 KHZ AND 0.419567E+02 = 41.9567 DB.)

Figure 15-2. Return Loss of Resonant Line Tuner

FREQ(HZ)	RTN LOSS(DB)
.820000E+05	.426682E+01
.840000E+05	.504970E+01
.860000E+05	.593881E+01
.880000E+05	.693738E+01
.900000E+05	.804739E+01
.920000E+05	.927035E+01
.940000E+05	.106082E+02
.960000E+05	.120648E+02
.980000E+05	.136475E+02
.100000E+06	.153702E+02
.102000E+06	.172585E+02
.104000E+06	.193593E+02
.106000E+06	.217627E+02
.108000E+06	.246536E+02
.110000E+06	.284687E+02
.112000E+06	.345956E+02
.114000E+06	.492559E+02
.116000E+06	.346905E+02
.118000E+06	.287125E+02
.120000E+06	.250583E+02
.122000E+06	.223518E+02
.124000E+06	.201580E+02
.126000E+06	.182893E+02
.128000E+06	.166501E+02
.130000E+06	.151861E+02
.132000E+06	.138639E+02
.134000E+06	.126614E+02
.136000E+06	.115630E+02
.138000E+06	.105573E+02
.140000E+06	.963541E+01
.142000E+06	.879009E+01
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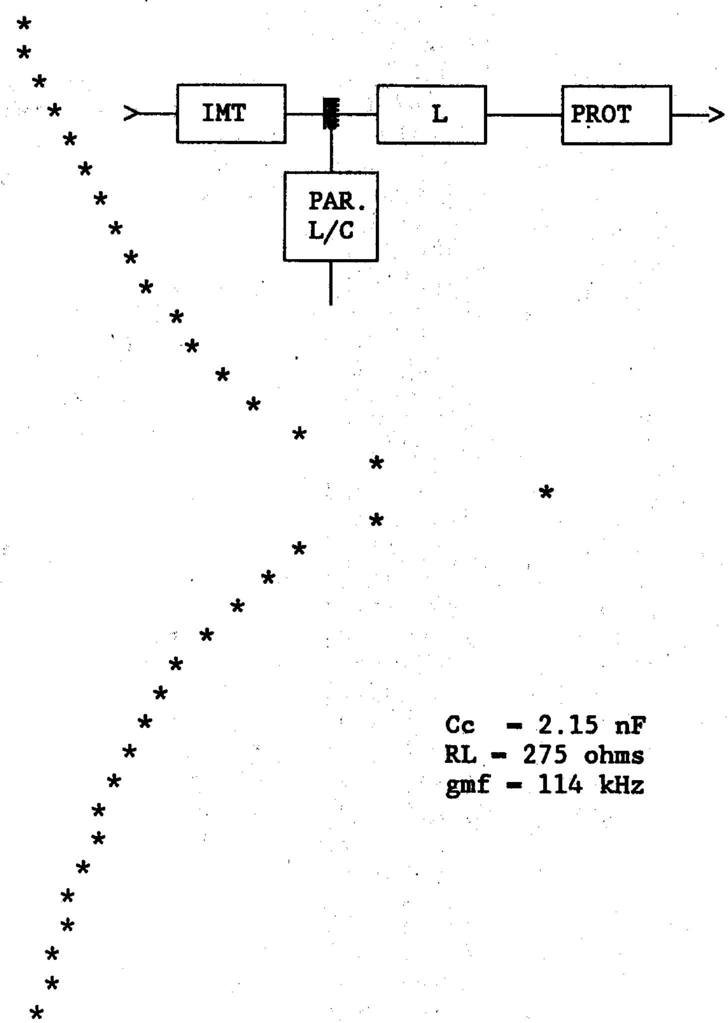
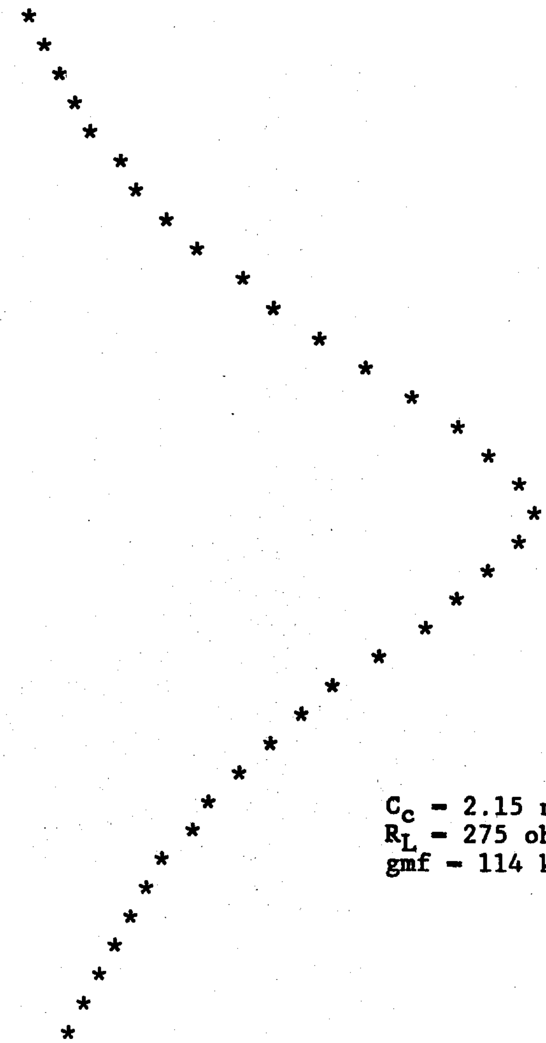


Figure 15-3. Return Loss of Wideband Second Order Line Tuner

FREQ(HZ)	RTN LOSS(DB)
.800000E+05	.258021E+01
.820000E+05	.286905E+01
.840000E+05	.319199E+01
.860000E+05	.355328E+01
.880000E+05	.395758E+01
.900000E+05	.441004E+01
.920000E+05	.491616E+01
.940000E+05	.548169E+01
.960000E+05	.611229E+01
.980000E+05	.681292E+01
.100000E+06	.758655E+01
.102000E+06	.843176E+01
.104000E+06	.933829E+01
.106000E+06	.102793E+02
.108000E+06	.112001E+02
.110000E+06	.120066E+02
.112000E+06	.125705E+02
.114000E+06	.127732E+02
.116000E+06	.125775E+02
.118000E+06	.120544E+02
.120000E+06	.113318E+02
.122000E+06	.105265E+02
.124000E+06	.971649E+01
.126000E+06	.894403E+01
.128000E+06	.822808E+01
.130000E+06	.757455E+01
.132000E+06	.698272E+01
.134000E+06	.644876E+01
.136000E+06	.596767E+01
.138000E+06	.553418E+01
.140000E+06	.514320E+01
.142000E+06	.479005E+01
.144000E+06	.447050E+01
.146000E+06	.418078E+01
.148000E+06	.391756E+01
.150000E+06	.367792E+01



C_c = 2.15 nF
R_L = 275 ohms
gmf = 114 kHz

Figure 15-4. Return Loss of Resonant Line Tuner IMT Set to 175 Ohm Tap

15

FREQ(HZ)	RTN LOSS(DB)
.800000E+05	.468365E+01
.820000E+05	.507061E+01
.840000E+05	.548417E+01
.860000E+05	.592536E+01
.880000E+05	.639496E+01
.900000E+05	.689333E+01
.920000E+05	.742013E+01
.940000E+05	.797400E+01
.960000E+05	.855202E+01
.980000E+05	.914904E+01
.100000E+06	.975667E+01
.102000E+06	.103622E+02
.104000E+06	.109475E+02
.106000E+06	.114884E+02
.108000E+06	.119553E+02
.110000E+06	.123165E+02
.112000E+06	.125442E+02
.114000E+06	.126213E+02
.116000E+06	.125469E+02
.118000E+06	.123366E+02
.120000E+06	.120172E+02
.122000E+06	.116195E+02
.124000E+06	.111728E+02
.126000E+06	.107009E+02
.128000E+06	.102216E+02
.130000E+06	.974761E+01
.132000E+06	.928688E+01
.134000E+06	.884442E+01
.136000E+06	.842294E+01
.138000E+06	.802362E+01
.140000E+06	.764667E+01
.142000E+06	.729169E+01
.144000E+06	.695786E+01
.146000E+06	.664417E+01
.148000E+06	.634951E+01
.150000E+06	.607270E+01

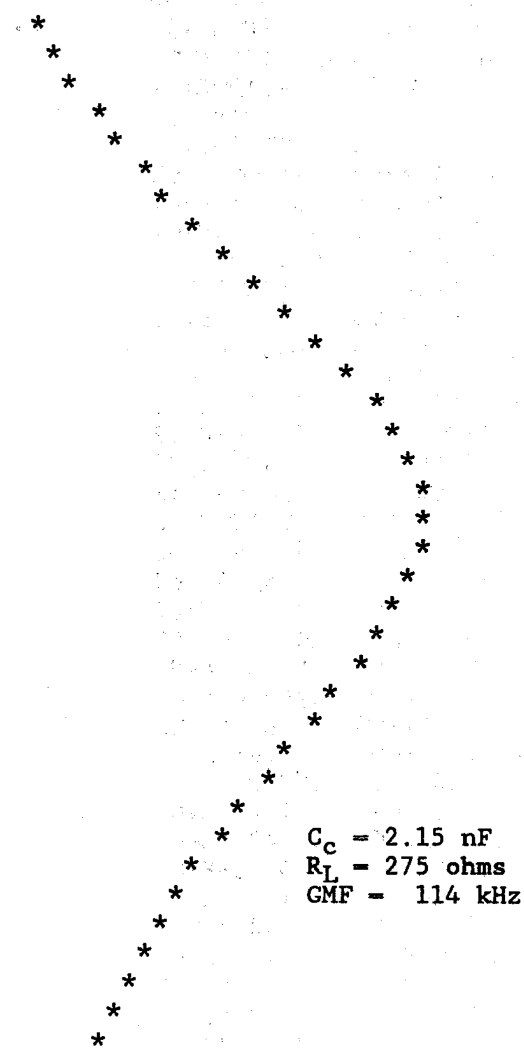


Figure 15-5: Return Loss of Resonant Line Tuner
IMT Set to 450 Ohm Tap

```
  FREQ(HZ)      RTN LOSS(DB)
.800000E+05   .333995E+01    *
.820000E+05   .369916E+01     *
.840000E+05   .409947E+01     *
.860000E+05   .454634E+01       *
.880000E+05   .504623E+01        *
.900000E+05   .560675E+01         *
.920000E+05   .623709E+01           *
.940000E+05   .694848E+01            *
.960000E+05   .775492E+01               *
.980000E+05   .867430E+01                *
.100000E+06   .973000E+01                   *
.102000E+06   .109533E+02                     *
.104000E+06   .123868E+02                        *
.106000E+06   .140883E+02                            *
.108000E+06   .161286E+02                                 *
.110000E+06   .185473E+02                                       *
.112000E+06   .210847E+02                                            *
.114000E+06   .223952E+02                                               *
.116000E+06   .211253E+02                                            *
.118000E+06   .187241E+02                                       *
.120000E+06   .164692E+02                                 *
.122000E+06   .145890E+02                              *
.124000E+06   .130379E+02                          *
.126000E+06   .117442E+02                       *
.128000E+06   .106503E+02                    *
.130000E+06   .971322E+01                   *
.132000E+06   .890185E+01                *
.134000E+06   .819283E+01               *
.136000E+06   .756846E+01              *
.138000E+06   .701500E+01            *
.140000E+06   .652161E+01           *
.142000E+06   .607957E+01           *
.144000E+06   .568181E+01          *
.146000E+06   .532248E+01         *
.148000E+06   .499672E+01         *
.150000E+06   .470042E+01       *
```

C_c = 2.15 nF
R_L = 275 ohms
GMF = 114 kHz

Figure 15-6. Return Loss of Resonant Line Tuner
IMT Set to 240 Ohm Tap

15

A similar situation exists with a wideband tuner. (The general term of "wideband tuner" usually refers to a second order bandpass tuner. However, there are other higher order bandpass line tuners which are used in systems requiring even wider tuning bandwidths. See Section 13.) The following curves show the effect of adding the parallel resonant L/C circuit on the equipment side of the resonant tuner to make a wideband second order tuner. If the parallel circuit is not tuned to the GMF, then a curve similar to that of Figure 15-7 is possible. This isolation curve would result if only the parallel circuit inductance were 20% lower than required to resonant the parallel capacitance. The value of the parallel capacitance is determined by the line impedance and the bandwidth of the tuner, and should be strapped to this value for best return loss. A method for calculating this value is given later in this discussion. (See page 15-16.)

The curve of Figure 15-8 shows the effect on the isolation (return loss) of a parallel inductance tuned 14% higher than required. The isolation is skewed above the GMF and peaks at about 26.5 dB. The series inductance and the IMT are tuned and set properly in both of these situations.

Return to Figure 15-3 for a moment. The 14 dB return loss bandwidth was from about 98.5 kHz to 132 kHz. Can the tuner be strapped to give a wider bandwidth than this? Consider the curve of Figure 15-9. This tuner was initially set for the correct settings giving the performance of Figure 15-3. The curve of Figure 15-9 shows the return loss curve with the IMT changed to the strap for 380 ohms. The return loss at the GMF is reduced to 16 dB with peaks of 24 dB at 100 kHz and 130 kHz. The 14 dB return loss points move to about 92 kHz and 140 kHz. The 14 dB return loss bandwidth is thus increased by about 14.5 kHz, but the isolation is reduced for most of the tuner bandwidth, and the insertion loss of the tuner is increased by about 0.15 dB across the entire bandwidth since the tuner is now mismatched to the line. The two-peak return loss is characteristic of the second order wideband tuner with the IMT set above the correct line impedance tap. For settings below the correct line impedance tap, the return loss, or isolation, shows only one maximum at the GMF, assuming that the resonant circuits are tuned to the GMF. This characteristic is shown in Figure 15-10. Here, the IMT was set to 175 ohms for this tuner with a actual line impedance of 275 ohms.

FREQ(HZ)	RTN LOSS(DB)
.800000E+05	.227411E+01
.820000E+05	.275913E+01
.840000E+05	.334138E+01
.860000E+05	.403417E+01
.880000E+05	.485024E+01
.900000E+05	.580096E+01
.920000E+05	.689553E+01
.940000E+05	.813984E+01
.960000E+05	.953389E+01
.980000E+05	.110656E+02
.100000E+06	.126963E+02
.102000E+06	.143319E+02
.104000E+06	.157852E+02
.106000E+06	.167848E+02
.108000E+06	.171300E+02
.110000E+06	.168805E+02
.112000E+06	.162850E+02
.114000E+06	.155705E+02
.116000E+06	.148626E+02
.118000E+06	.142107E+02
.120000E+06	.136254E+02
.122000E+06	.131003E+02
.124000E+06	.126224E+02
.126000E+06	.121772E+02
.128000E+06	.117511E+02
.130000E+06	.113318E+02
.132000E+06	.109097E+02
.134000E+06	.104776E+02
.136000E+06	.100316E+02
.138000E+06	.957041E+01
.140000E+06	.909524E+01
.142000E+06	.860934E+01
.144000E+06	.811724E+01
.146000E+06	.762416E+01
.148000E+06	.713543E+01
.150000E+06	.665609E+01

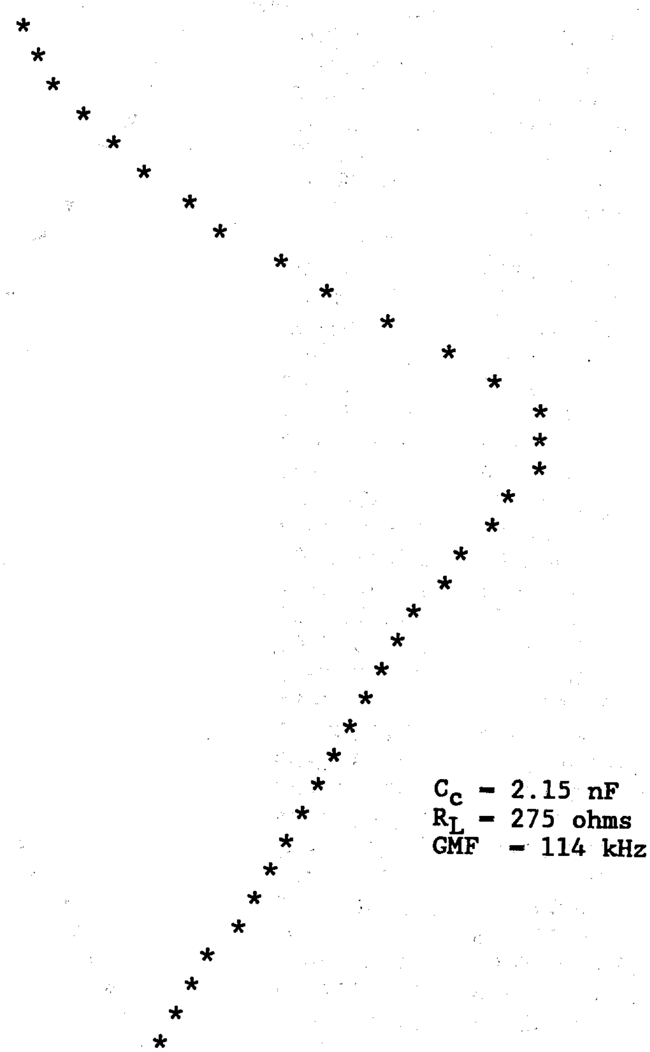


Figure 15-7. Return Loss of Wideband Second Order Tuner Parallel Inductance Set 20% Lower than Nominal

15

FREQ(HZ)	RTN LOSS(DB)
.800000E+05	.426340E+01
.820000E+05	.495031E+01
.840000E+05	.570025E+01
.860000E+05	.650605E+01
.880000E+05	.735832E+01
.900000E+05	.824618E+01
.920000E+05	.915835E+01
.940000E+05	.100845E+02
.960000E+05	.110168E+02
.980000E+05	.119518E+02
.100000E+06	.128918E+02
.102000E+06	.138465E+02
.104000E+06	.148341E+02
.106000E+06	.158825E+02
.108000E+06	.170301E+02
.110000E+06	.183281E+02
.112000E+06	.198414E+02
.114000E+06	.216403E+02
.116000E+06	.237346E+02
.118000E+06	.257507E+02
.120000E+06	.262917E+02
.122000E+06	.245008E+02
.124000E+06	.218490E+02
.126000E+06	.193586E+02
.128000E+06	.172120E+02
.130000E+06	.153735E+02
.132000E+06	.137837E+02
.134000E+06	.123939E+02
.136000E+06	.111675E+02
.138000E+06	.100776E+02
.140000E+06	.910400E+01
.142000E+06	.823123E+01
.144000E+06	.744696E+01
.146000E+06	.674121E+01
.148000E+06	.610563E+01
.150000E+06	.553304E+01

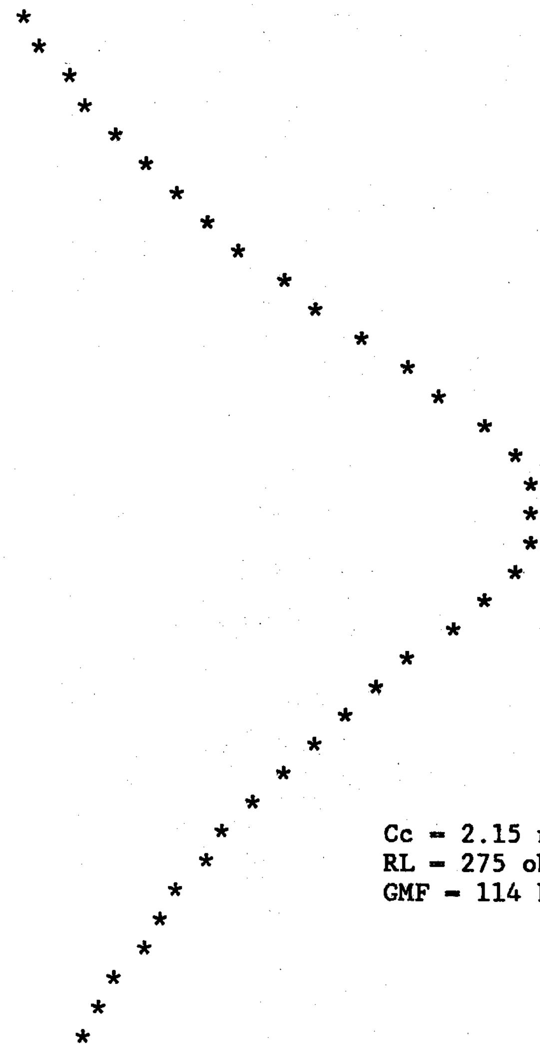
C_c = 2.15 nF
R_L = 275 ohms
GMF = 114 kHz

Figure 15-8. Return Loss of Wideband Line Tuner Parallel Inductor 14% Higher than Nominal

```
  FREQ(HZ)    RTN LOSS(DB)
.800000E+05 .403450E+01       *
.820000E+05 .500804E+01         *
.840000E+05 .619086E+01           *
.860000E+05 .761687E+01             *
.880000E+05 .932815E+01                *
.900000E+05 .113831E+02                    *
.920000E+05 .138690E+02                        *
.940000E+05 .169117E+02                             *
.960000E+05 .205908E+02                                   *
.980000E+05 .240991E+02                                         *
.100000E+06 .242848E+02                                         *
.102000E+06 .219240E+02                                     *
.104000E+06 .197774E+02                                  *
.106000E+06 .182486E+02                               *
.108000E+06 .172148E+02                             *
.110000E+06 .165557E+02                            *
.112000E+06 .161939E+02                            *
.114000E+06 .160848E+02                            *
.116000E+06 .162069E+02                            *
.118000E+06 .165569E+02                            *
.120000E+06 .171481E+02                             *
.122000E+06 .180102E+02                               *
.124000E+06 .191895E+02                                 *
.126000E+06 .207337E+02                                   *
.128000E+06 .225987E+02                                      *
.130000E+06 .242457E+02                                         *
.132000E+06 .241660E+02                                         *
.134000E+06 .220001E+02                                     *
.136000E+06 .192883E+02                                 *
.138000E+06 .168241E+02                             *
.140000E+06 .147192E+02                         *       Cc  = 2.15 nF
.142000E+06 .129279E+02                      *          RL  = 275 ohms
.144000E+06 .113918E+02                    *            GMF = 114 kHz
.146000E+06 .100635E+02                 *
.148000E+06 .890710E+01               *
.150000E+06 .789551E+01              *
```

Figure 15-9. Return Loss for Wideband Line Tuner IMT Set to 380 Ohm Tap

FREQ(HZ)	RTN LOSS(DB)
.800000E+05	.265242E+01
.820000E+05	.303264E+01
.840000E+05	.345634E+01
.860000E+05	.392564E+01
.880000E+05	.444228E+01
.900000E+05	.500762E+01
.920000E+05	.562253E+01
.940000E+05	.628717E+01
.960000E+05	.700065E+01
.980000E+05	.776031E+01
.100000E+06	.856039E+01
.102000E+06	.938997E+01
.104000E+06	.102297E+02
.106000E+06	.110473E+02
.108000E+06	.117937E+02
.110000E+06	.124029E+02
.112000E+06	.128025E+02
.114000E+06	.129374E+02
.116000E+06	.127960E+02
.118000E+06	.124159E+02
.120000E+06	.118649E+02
.122000E+06	.112135E+02
.124000E+06	.105181E+02
.126000E+06	.981720E+01
.128000E+06	.913429E+01
.130000E+06	.848228E+01
.132000E+06	.786749E+01
.134000E+06	.729224E+01
.136000E+06	.675659E+01
.138000E+06	.625937E+01
.140000E+06	.579875E+01
.142000E+06	.537263E+01
.144000E+06	.497880E+01
.146000E+06	.461506E+01
.148000E+06	.427928E+01
.150000E+06	.396943E+01



Cc = 2.15 nF
RL = 275 ohms
GMF = 114 kHz

Figure 15-10. Return Loss of Wideband Tuner
IMT Tap Set to 175 Ohms

With this background of the behavior of the return loss of the resonant and wideband (second order) line tuners, a tuning method using this characteristic can be developed. This procedure assumes that all transmitters have been turned off on the line section being optimized. Otherwise, the voltmeter may be reading a received signal and not the isolation expected. If a narrow band selective voltmeter is used, and there are no signals in the vicinity of the GMF, the presence of signals may not have adverse effects on this procedure. Recognizing and recording these signals may be required if the transmitters cannot be turned off.

Before going into the tuning method, there are situations for some systems where the tuning is not straightforward. The following section will discuss some of the techniques and considerations to use when these circumstances are encountered.

SHORT LINES, THREE-TERMINAL LINES, OVERHEAD LINE/POWER CABLE CIRCUITS

The first rule for setting up line tuners on any circuit to reduce reflections and to get the best overall end-to-end response is that all tuners: (1) are the same type ; (2) are tuned to the same GMF ; (3) use the same value of coupling capacitor, or CCVT; (4) have the same individual resonating components ; and (5) have the same bandwidth. Also, do not mix resonant and wideband line tuners on the same line section on different phase wires. The modal properties of the line will be compromised with different coupling to different phases since all signals eventually appear on all phases if the lines are long enough. (Ref. ECC-331 " Carrier Current on Transmission Lines - Modal Analysis Interpretation of Carrier Propagation.")

The application of resonant and wideband line tuners on the lines mentioned above can be a frustrating experience. The common characteristic of these circuits is a line impedance which varies with frequency, instead of having a constant value. There is not sufficient isolation between the terminals of the line for the tuning at one station to be independent of the tuning at the other station(s). The impedance observed is thus a function of the actual line impedance plus the effect of the IMT settings and reflected impedance through the tuner at the far end of the line. The tuning of line traps and the effect of bus capacitance is more critical for these lines.

For three-terminal lines which have two closely spaced stations and a remote station, the two closely spaced stations effectively double terminate the line on one end. With a line loss over 10 dB to the remote station, the remote station can usually be tuned independently of the other stations. Then, the two closely spaced stations can be optimized by treating the IMT settings as if the tuners were at the same station, which is essentially how they appear to the line. The actual distance separating the stations may be 20 or 30 miles, but the circuit distance is determined by the line loss between stations. The tuning at these two stations is done together, and the IMT settings are moved, and set to the same taps, as a first try. If there is insufficient isolation and the line impedance varies widely with frequency, the individual station IMT settings can be different since standing waves vary with absolute position on the line. If the settings are widely separated, a change of the remote end IMT tap may reduce the line impedance variations and bring the two near end settings closer together. The theoretical tuner bandwidth may not be attainable if the line impedance value is varying widely. Since the bandwidth is directly related to the line impedance, the bandwidth will be changing with frequency and a tuner response which has amplitude ripples will result.

For three-terminal lines with the tap at the midpoint, or close to the midpoint of the line, the tuner at the midpoint should be tuned to the same GMF as the other tuners with the same IMT settings close to the voltage class line impedance. The end station tuners can then be set independently if there is sufficient line loss. After the end stations are optimized, the midpoint station is tuned while observing any changes at either or both of the end stations. If the end station isolation changes with changes in the mid-point IMT, then there is not sufficient isolation between stations and both end stations should be set while observing the midpoint isolation. This could require three sets of test equipment for optimizing the tuning.

The final IMT settings may very well be a compromise favoring a station that has the most transmitters. The GMF of the individual tuners should always be the same no matter what the IMT setting.

Overhead line - power cable circuits present special problems. The most straight-forward method to avoid the standing waves caused by the cable/overhead interfaces is to trap and bypass these interfaces. A circuit of this type which has not been treated in this fashion can have widely varying impedances and standing waves depending on the loss of the end sections. A trial and error method is the best option. Short sections (in loss) of overhead line which are electrically close to a cable/overhead interface, and have not been bypassed, will have impedance variations and loss variations of dramatic proportions. The frequency selection will determine the impedance and the loss at a particular station. The use of 100 watt transmitters may be required even for fairly short sections of cable/overhead lines.

RETURN LOSS AND HYBRID ISOLATION TUNING

This procedure assumes that the hybrid being used has a minimum return loss of 30 dB in the frequency range of the tuner. To determine if this requirement is met with the hybrid, connect a 50 ohm generator and selective voltmeter, terminated in 50 ohms, to the inputs of the hybrid as if a return loss measurement were being made on a tuner. Terminate the hybrid with a 50 ohm (1%) resistor and measure the level on the voltmeter. Remove the 50 ohm termination and measure the level again. The return loss is the difference in these two readings.

CAUTION: Since the line tuner is connected to the line, any signal used in the testing and alignment will appear on the line. If signals of low level are used (< 0.1 watt) there should be very low signal levels at the receiving station. If these test levels are going to cause operation of protection circuits and equipment, the receivers should be disabled.

PRELIMINARY CHECKING OF TUNER RETURN LOSS

A preliminary reading should first be made to determine if the tuning only needs to be optimized. The circuit with the hybrid is connected to the tuner input with the ground switch closed. The measurement can be made in the equipment building on the coaxial cable from the tuner. A reference level is set on the selective voltmeter. The ground switch is then opened. The frequency is set to the GMF. The difference in the level with the switch closed and with it opened is the return loss. If this is greater than 20 dB, the tuner may only need to be optimized. If the difference is less than 10 dB, the entire tuning procedure should be followed to completely optimize the tuner. An intermediate reading between 10 and 20 dB will require a decision by the operators. Following the procedure completely will assure the best results. If one terminal on a line section requires adjustment, all line tuners on the section should be checked before and after adjustments are made, especially if the lines are short, or the line section has more than two terminals.

HYBRID ISOLATION PROCEDURE

1. Remove the coaxial connection to the tuner input, but first close the ground switch in the tuner cabinet or at the coupling capacitor or CCVT base before making any adjustments inside the tuner cabinet. (It is preferable to use the ground switch in the tuner cabinet since it will be visible at all times while the tuner is being adjusted.) The tuning slugs in the inductors can be varied with the tuner connected to the high voltage line. However, any tap changes on the IMT or removal or connection of connecting wires and capacitor straps should be made with one of these ground switches closed.

   If the tuner is a wideband second order unit, remove the connections to the parallel resonant circuit - both the ground connection and the signal (high side) connection. This circuit will be tuned and connected later.

2. Set the IMT strap to the tap closest to the line impedance for the voltage class being matched.

3. If there is a 60 Hz blocking capacitor in the tuner and it is adjustable, set it to the maximum value. This will cause the effective coupling capacitor value to be a maximum.

4. Connect a balanced 50 ohm hybrid, with a 50 ohm generator and selective voltmeter terminated in 50 ohms connected to the two inputs and the output connected to the coaxial cable input to the tuner. (This assumes that the coaxial impedance is 50 ohms.) If this impedance is other than 50 ohms, use the coaxial impedance and primary IMT setting of the tuner as a guide. Most PLC equipment in domestic (U.S.) service is either 50 ohms or 75 ohms. An additional IMT may be needed to match the hybrid to a 75 ohm coax and tuner if the hybrid cannot be strapped to match the 75 ohm tuner impedance.

5. Set the generator frequency to the tuner GMF. Check the level of the signal at the voltmeter with the cable to the tuner disconnected. This level should be 6 dB below the matched output level of the generator. A convenient level setting would be to set the generator to read -6 dBsr (scale reading) with the coax disconnected. The selective voltmeter reading would then be reading the isolation directly. Connect the coaxial cable, which usually goes to the tuner input, to the hybrid output.

6. Check the isolation at the GMF. Vary the generator frequency about the GMF to determine if the peak of isolation occurs at the GMF. If isolation increases as frequency is increased, increase the series inductance to move the peak of isolation to the GMF. If the isolation increases as the frequency is reduced, reduce the series inductance to move the isolation peak to the GMF. (Refer to the manufacturer's published information to determine the inductance and strapping of the series inductance.) If the isolation peak is not sharp and the isolation is less than 20 dB, change the IMT setting to the next higher tap. First, close the ground switch on the protector unit or in the base of the coupling capacitor. If the tap change reduces the isolation, the direction of the impedance change was incorrect, and a change in the direction of lower impedance should be tried. Continue to change taps until the isolation is maximized. For IMT's with a vernier tap, this tap should also be tried to improve the isolation.

7. After determining that the IMT tap has been optimized, the tuning of the series inductance should be checked to determine that the maximum isolation occurs at the GMF. For a resonant tuner, this completes the tuning. The tuning slug in the series inductor can be secured and all connections tightened. All connections to the tuner can be removed.

8. For a wideband (second order) tuner, the parallel resonant circuit will be resonated to the GMF before connecting it back into the circuit. Connect the 50 ohm generator to one side of the parallel L/C circuit and connect the terminated selective voltmeter to the other side of this circuit. Connect the grounds of the two instruments together, but not to the tuner. Check the strapping of the inductor and capacitor according to the manufacturer's published information.

9. These values can be calculated using the formulas given below:

$$1/Cc' = 1/Cc + 1/Cb, \qquad (1)$$

where Cc' is the effective value of the coupling capacitance, Cc is the coupling capacitor value, and Cb is the power frequency blocking capacitor value.

$$BW = Cc'(4.3875 \times RL \times (GMF)^2 \qquad (2)$$

BW is the 14 dB return loss bandwidth and RL is the assumed line impedance.

Then to calculate C1 and L1, the parallel capacitor and inductor values:

$$C1 = 0.06202/(RL \times BW) \qquad (3)$$

$$L1 = 0.02533/[C1 \times (GMF)^2] \qquad (4)$$

For the example given at the beginning of this discussion:

Cb = 0.1 uF
Cc = 0.00215 uF ; Cc' = 0.002105 uF
RL = 275 ohms
and GMF = 114 kHz.

Then,

BW = 33003.47 Hz
C1 = 6833 pF
and L1 = 285.3 uH.

Strap the parallel capacitor to the value closest to 6.83 nF (6833 pF). With the test equipment connected as previously stated, tune the inductor in this parallel circuit for a minimum voltage on the selective voltmeter at the GMF. Remove the test equipment connections to the parallel L/C circuit and reconnect the wires from the parallel L/C unit to the tuner circuit. The tuner has now been changed from a resonant tuner to a wideband, second order tuner. (See Figure 15-2. and Figure 15-3. for simplified circuit diagrams of the two tuners.)

10. Connect the test equipment to the inputs of the hybrid and check the isolation at the GMF. The isolation should be as great as for the resonant tuner circuit. Changing the tuner from a resonant tuner to a wideband tuner should not alter the match to the line. For very narrow bandwidths, the return loss may be reduced if the losses in the parallel circuit are high. For most tuners, the wideband isolation will improve. In some instances the parallel circuit may require slight adjustment to account for stray capacitance in the IMT. There also may be leakage inductance from the IMT which may affect the parallel L/C tuning. Coupling between the two inductors may also change the tuning. Tune the coils for maximum isolation at the GMF.

11. Remove all connections to the tuner, tighten all connections, and secure the tuning slugs. The reflected power test can be used to test the return loss of the system. If this test shows high reflected power, the cause must be in the terminal equipment connected to the tuner coaxial cable. The transmitter output impedance which does not match the hybrid impedance or double terminating the coax may be causes of high reflected power. The auxiliary coupling circuit should be examined to determine if there is a mismatch, loading, or double termination situation. The terminal equipment provides the load for the tuner for signals sent from the other end of the line, as well as being the driving impedance for near end signals.

    This type of test cannot be used with third and fourth order wideband bandpass line tuners, since there are multiple return loss peaks in the passband of these tuners. The instruction books for the specific tuners give alternate tuning techniques to use for these tuners.

FIELD TUNING OF TWO-FREQUENCY LINE TUNERS

CIRCUIT DESCRIPTION

The Two-Frequency line tuner will usually have a coaxial cable feeding each of the two inputs. In some cases there may be a symmetrical hybrid in the tuner cabinet and only one coaxial cable may then be necessary. The remarks of this discussion assume a two-coax input. The inputs are usually 50 ohms, and the line impedance will be in the range from 200 ohms to 400 ohms. Refer to the instruction books for these tuners for the locations of components in the outdoor cabinet. For the GE CL02 tuners, the components on the left side of the cabinet are: an IMT (impedance matching transformer); an inductor which tunes with the series combination of the power frequency blocking capacitor and the coupling capacitor to the lower frequency, called Frequency 1; a parallel L/C unit resonated to the higher frequency, called Frequency 2; and the protector unit. The parallel L/C circuit prevents power from the transmitter, connected to the IMT on the right-hand side, from appearing at the IMT input of the Frequency 1 transmitter.

The opposite tuning situation is used in the right-side circuit. The inductor is resonated with the combination of the power frequency blocking capacitor and the coupling capacitor to give a low loss path for power from the Frequency 2 transmitter to be coupled to the line. The Parallel L/C circuit prevents power from the Frequency 1 transmitter from appearing at the IMT input of the Frequency 2 transmitter.

The sequence for tuning a Two-Frequency line tuner is important. The reactance of the parallel L/C circuits at the series resonant frequencies influences the values of inductance required to tune the coupling capacitor to series resonance. The parallel L/C circuits must be tuned first.

COMPONENT VALUES FOR TWO-FREQUENCY LINE TUNERS

The capacitance of the coupling capacitor, or CCVT, determines the values of the capacitors in the parallel L/C circuits. These capacitors are usually chosen to be twice the value of the coupling capacitor. The inductance value of the series inductors is a function of the frequency spacing and the coupling capacitor value. The true coupling capacitor value is reduced by the power frequency blocking capacitor value.

Formulas for calculating the inductance values are given below.

1. $LP1 = 1.0/[2Cc(6.2832 X F1)^2]$

2. $LP2 = 1.0/[2Cc(6.2832 X F2)^2]$

3. $LS1 = [a(1 + R) - 1]/[Cc'(a - 1)(6.2832 X F1)^2]$

4. $LS2 = [b(1 + R) - 1]/[Cc'(b - 1)(6.2832 X F2)^2]$

In these formulas the following definitions apply:

LP1 is the inductance of the parallel L/C circuit tuned to the lower frequency, F1.

LP2 is the inductance of the parallel L/C circuit tuned to the higher frequency, F2.

LS1 is the inductance of the inductor unit tuned to F1.

LS2 is the inductance of the inductor unit tuned to F2.

Cc is the coupling capacitor, or CCVT, value.

Cb is the value of the power frequency blocking capacitor.

Cc' is the effective coupling capacitor value given below, and:

$a = (F1/F2)^2$; $b = (F2/F1)^2$;

$Cc' = (Cc*Cb)/(Cc + Cb)$;

$R = Cc'/2Cc$ (Note: The value of the ratio "R" may be varied to obtaim greater isolation of F1 and F2 especially for wide spacing of F1 and F2. The parallel capacitance may be equal to or less than Cc for this case. Analysis is required to select the best compromise.)

A sample tuner will show the application of the formulas.

$Cc = 0.006$ uF or $(6*10^{-9})$

Parallel capacitors $= 2Cc = 0.012$ uF or $(12*10^{-9})$

$Cb = 0.1\ uF\ or\ (100*10^{-9})$

$F1 = 100\ kHz\ or\ (100*10^{3})$; $F2 = 140\ kHz\ or\ (140*10^{3})$

The frequency ratios, "a" and "b":

$$a = (F1/F2)^2 = (100/140)^2 = 0.5102$$

$$b = (F2/F1)^2 = (140/100)^2 = 1.96$$

The effective coupling capacitor value, Cc':

$$Cc' = (Cc*Cb)/(Cc + Cb) = (6*10^{-9} *100*10^{-9})/(6*10^{-9} + 100*10^{-9})$$

$$Cc' = 5.66\ nF\ or\ (5.66*10^{-9})$$

The capacitor ratio, "R":

$$R = Cc'/2Cc = 5.66/12.0 = 0.4717$$

The parallel inductance values, LP1, and LP2:

$$LP1 = 1/[12*10^{-9}*(6.2832*100*10^{3})^{2}] = .2111\ mH$$

$$LP2 = 1/[12*10^{-9}\ (6.2832*140*10^{3})^{2}] = .1077\ mH$$

The series inductance values, LS1, and LS2:

$$LS1 = [.5102(1.4717)-1]/[5.66*10^{-9}(.5102-1)(6.2832*100*10^{3})^{2}]$$

$$LS1 = .2492/(1.094*10^{3}) = .2276\ mH$$

$$LS2 = [1.96(1.4717)-1]/[5.66*10^{-9}(1.96-1)(6.2832*140*10^{3})^{2}]$$

$$LS2 = 1.8845/(4.204*10^{3}) = .44821\ mH$$

Reference to the instruction book will show the correct strapping for capacitors and inductors depending on the model number of inductors or parallel L/C units for CLO2 tuners. Capacitor values in the stacks are all 0.01 uF for the L/C units in these tuners.

TEST PROCEDURE

A step-by-step procedure for tuning the two-frequency line tuner follows:

1. Close the ground switch on the protector unit.
2. Remove the coaxial cable connections to the inputs.
3. Connect a 50 ohm generator to the Frequency 1 input. This is the IMT on the left. Set the level of the generator to 0 dBm.
4. Connect a selective voltmeter to the other input. Terminate this meter in 50 ohms.
5. Turn off all transmitters on the line section. This applies to all transmitters which would be transmitting to this station. Also, disable the receiver outputs at all remote locations to prevent a false trip.
6. Set the frequency of the generator to Frequency 2. Open the ground switch. Tune the inductor in the parallel L/C circuit on the left side of the cabinet for minimum voltage as measured on the selective voltmeter.
7. Change the frequency of the generator to Frequency 1. Tune the inductor in the parallel L/C circuit on the right side of the cabinet for minimum voltage as measured on the voltmeter. Lock the tuning slugs on the inductors in both parallel L/C units. Close the ground switch.
8. Connect a balanced hybrid to the input of the IMT on the left side of the cabinet. This connection is made to the common output of the hybrid. Connect a 50 ohm generator to one input of the hybrid and the selective voltmeter, terminated in 50 ohms, to the other hybrid input. Terminate the IMT on the right side of the tuner cabinet with 50 ohms. Set the level of the generator to read either 0 dBm or -10 dBm on the selective voltmeter.
9. Set the frequency to Frequency 1. Open the ground switch. Tune the inductor on the left side for minimum voltage on the voltmeter. Close the ground switch and move the IMT strap to the tap lower than the present setting. Check that the voltmeter reads a lower or higher level after opening the ground switch. If the voltage increases, try the next higher tap setting by using the 10% strap. If this voltage is higher than the first setting, move the strap to the tap higher than the first setting and reset the 10% strap to the 0% position. The object is to find the tap that gives the lowest voltage reading. This is the best matched condition - or the maximum return loss. Tune the inductor on the left hand side of the cabinet each time the IMT taps are changed. Close the ground switch each time before making a strap change.
10. Connect the balanced hybrid to the IMT located on the bottom right side of the tuner. Set the frequency to Frequency 2. Set the IMT straps to the same taps as the IMT on the left side of the tuner. Tune the inductor on the right side of the cabinet for a minimum voltage reading on the meter. The IMT on the left side should be terminated with 50 ohms for this test. Open the ground switch when making all isolation or return loss readings using the hybrid.

11. This completes the tuning. Lock all tuning slugs and make sure that all straps are secured and all screws are tight.

12. If it is desired to know the amount of isolation provided by the tuner from input 1 to input 2, the test circuit of Steps 1 through 6 can be used. Before connecting the generator and voltmeter to the inputs, set up a level of 0 dB on the meter with the meter terminated in 50 ohms. After making the connections as outlined in Steps 1 through 5, set the frequency to the low frequency, or Frequency 1, and check the frequency range where the attenuation is 15 db or more. This is the usable frequency range for transmitters connected to the right hand IMT input. Set the frequency to the high frequency, or Frequency 2. Vary the frequency about Frequency 2. Check the range for which the attenuation is 15 dB or more. This is the usable range of frequencies for transmitters connected to the left hand IMT input. Some users may want a minimum of 20 dB of isolation between inputs. This range can provide a minimum of 20 dB of isolation if the return loss is 14 dB or more and a balanced hybrid is used to isolate two transmitters connected to either input of the two frequency line tuner.

CONCLUSION

The preceding discussion has given a step-by-step method for aligning resonant, wideband second order, and two-frequency line tuners. The technique used is the hybrid isolation method. Some available test equipment for measuring reflected power and SWR uses a similar technique. The instruments which are used to measure reflected power on a wideband basis are not nearly as sensitive as the hybrid isolation method. An instrument quality balanced hybrid is required to make these adjustments. The hybrid must have a return loss of at least 30 dB in the frequency range of the tuner. Some reflected power instruments can be used to measure the return loss using a selective voltmeter with the active metering circuits turned off. The voltage measured is actually a measure of the return loss. The selective voltmeter must be used to separate the GMF, being injected as the alignment frequency, from any other frequencies which may be present when the tuner is connected to the line. Wideband meters, including reflective wattmeters which do not have selective capabilities, will give incorrect readings of the reflected power, or return loss, since the reflected power is composed of all signals on the line which will pass through the line tuner passband. These signals may be those on parallel lines, adjacent line sections, or any signal coupled onto the line by any means.

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Section 16

TWO-FREQUENCY LINE TUNER BANDWIDTHS

Contents of Section 16

(Note: Adapted from reference [30]).

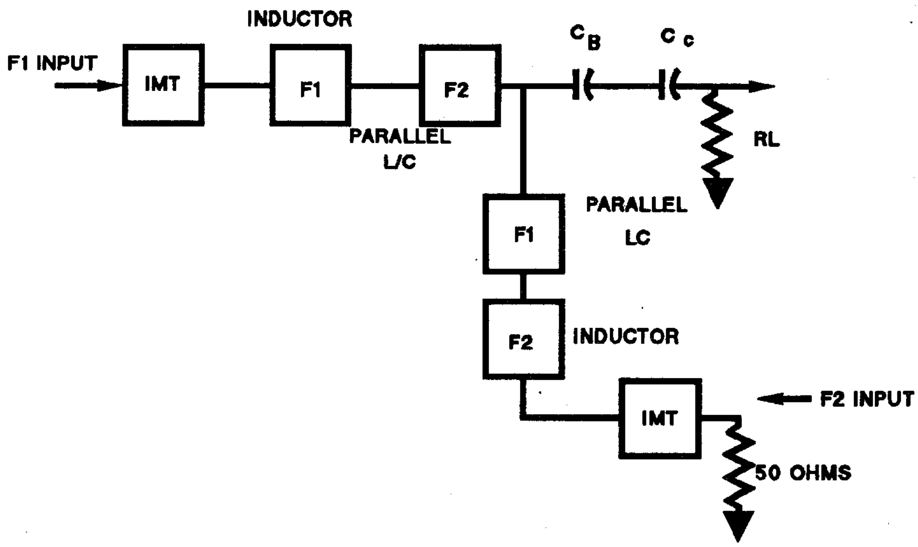
INTRODUCTION

Section 15 of this guide, formerly ECC-360, entitled " Application and Tuning of Resonant and Wideband Line Tuners", gives the formulas for the series inductances in the two-frequency tuner circuit. Before these formulas were developed, there was no analytical circuit for the two-frequency tuner. These formulas have permitted an exact analysis of this tuner, and these component values were used to design two-frequency line tuners for various values of coupling capacitance, line impedance, and for a frequency range from 35 kHz to 150 kHz. This range was used for the value of the lower frequency, which will be denoted as "F1", and for corresponding values of the upper frequency, which will be referred to as "F2". The curves for these tuners are based on a constant ratio of F2 to F1. The ratios selected are F2/F1 = 1.25 and F2/F1 = 1.40. Since an infinite number of curves for various ratios are possible, these were chosen as the limiting values where narrow bandwidths might cause matching problems if multiple frequencies were used in the two passbands.

There has been much discussion and speculation over the actual bandwidths of two-frequency line tuners. Estimates of the bandwidths have varied from "about the same" as the resonant single-frequency tuner to "much narrower" than the single-frequency tuner. The idea of a two-frequency line tuner was initially for application as the name implies - for TWO FREQUENCIES! As protection requirements have become more sophisticated for lines on which two-frequency tuners and line traps were installed, additional equipment has been added at frequencies above and below existing equipment - for dual transfer trip and for tapped lines, in particular. This has resulted in lower receive levels because of poor return loss (matching) at these frequencies and operation on the slopes of the tuners. The information presented here is intended to answer the bandwidth question for these line tuners. The curves and tables included in this application paper were prepared with the aid of an analysis program using the analytical circuit developed in Section 15. The comparison to single-frequency tuners shows that the two-frequency line tuner bandwidths may be only one-forth to one-thirteenth as wide as the resonant single-frequency tuner using the same value of coupling capacitance and line impedance. The analysis was started at F1 = 35 kHz to show the extremely narrow passbands at this frequency. Above 150 kHz the passbands are generally wide enough to accommodate most equipment combinations. Using the information contained in these curves and tables, an estimate can be made of the bandwidth of a particular application and a determination can be made if the two-frequency tuner is the correct tuner to use. Also, the 3 dB bandwidths are discussed primarily for comparison with other tuner types. In actual applications the bandwidths which should be used are the 0.2 dB to 0.5 dB bandwidths, which correspond to the 14 dB to 10 dB return loss bandwidths.

ANALYTICAL CIRCUIT OF THE TWO-FREQUENCY LINE TUNER

The circuit of Figure 16-1 was used in a general analysis computer program with typical values of "Q" used for the inductors. The inputs of the tuner were switched to obtain curves of the upper and lower passbands.



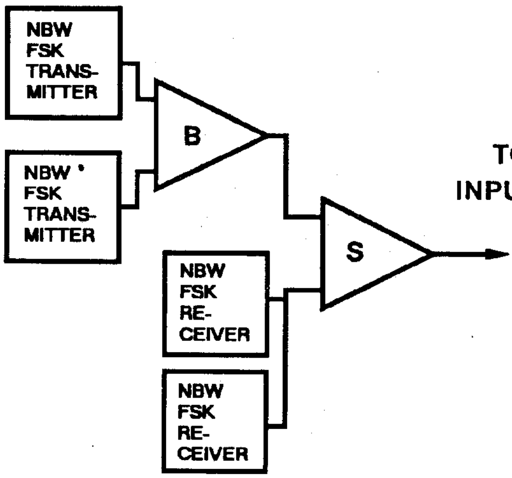
CIRCUIT FOR TWO-FREQUENCY TUNER ANALYSIS
Figure 16-1

The values of coupling capacitance chosen are 2.15 nF, 3.0 nF, and 4.70 nF for overhead line tuners. The value of 10.0 nF was selected for the one power cable circuit which was analyzed. The line impedance for the overhead lines was selected as 320 ohms. The cable impedance was chosen as 30 ohms.

The curves show the 3 dB bandedge frequencies for the lower and upper passbands. The curves for the overhead line tuners also show the 0.5 dB bandedge frequencies for the passbands where there is sufficient bandwidth to show a distinction between these bandwidths. A tabular listing of the 3.0 dB, 0.5 dB, and 0.18 dB frequencies for each selected value of coupling capacitor is included to allow expansion of the curves and to provide a basis for comparing the two-frequency tuner bandwidths with resonant tuners using the same values of line impedance and coupling capacitors. A comparison of these bandwidths will be done later.

An examination of the tabular listings of the bandedge frequencies for the various tuners will show that the values of return loss vary for the same value of attenuation. The expected values of return loss for the three chosen attenuation values should be: 3.0 dB, 10 dB, and 14 db. The listings show that there is sometimes a wide variation from these values depending on the capacitor size and the frequency of F1 and F2. These values are given for reference only. The usual relation between amplitude response and return loss does not apply for two-frequency line tuners because of the loading effect of the second branch with its termination. Most return loss values are greater than the values which would apply to single-frequency tuners or for wideband tuners for the same loss. The losses take into account the insertion loss, which can amount to up to 0.5 db for some selected values of the variables.

The problems encountered with two-frequency line tuners at low frequencies with small values of coupling capacitors can be appreciated when the bandwidth column is studied for frequencies below 100 kHz. (See Table 16-1. on page 16-28.) If dual transfer trip channels were used in the lower passband and combined through a balanced hybrid, the minimum bandwidth for narrow bandwidth FSK equipment would be 2.7 kHz. For a reasonable isolation of 20 dB, a return loss of 14 dB or more is required. (See Figure 16-2 on page 16-29.) The dual channels should be placed in the upper passband to take advantage of the somewhat wider bandwidth.



COMBINING OF EQUIPMENT FOR CONNECTION
TO TWO-FREQUENCY LINE TUNER

Figure 16-2

The bandwidths shown are for lines without reflections - where the loss between stations is greater than 10 dB and there are no taps or multi-terminal circuits. The bandwidths will be further reduced by these conditions. If the line tuners have been optimized using the procedures explained in Section 15, one alternative is to investigate the various wideband tuners of Section 13 (Formerly ECC-354) if the two-frequency tuner will not give satisfactory results. This will require changing the tuning packs in the line traps to match the tuners if wideband tuners are needed, since wideband traps are required for wideband tuners, if the entire bandpass of the wideband tuner is to be utilized. However, two-frequency tuners can be used with wideband traps.

TOTAL RESPONSE CURVES OF TWO-FREQUENCY TUNERS

Before looking at the bandwidths and bandedge frequencies of the two-frequency line tuner, the actual total response of the tuner for four combinations of the variables will show the actual frequency versus attenuation of these tuners. The first tuner selected uses a capacitor of 2.15 nF, RL = 320 ohms, F1 = 50 kHz, and F2 = 62.5 kHz. This gives the most narrow spacing of F2/F1 = 1.25.

(Refer to total response curve on page 16-9). The 15 dB blocking bandwidth of the lower frequency leg extends from about 55 kHz to 66 kHz. The 20 dB blocking bandwidth can be determined as about 56 kHz to 64 kHz for the lower passband. This is certainly wider than the passband for the upper frequency of 62.5 kHz. (See Table 16-2 on page 16-29.) For the lower passband, the response on the high frequency side shows the effect of the upper frequency leg at about 57.5 kHz. There is a peak of attenuation here before the ultimate peak at 62.5 kHz caused by the parallel L/C circuit in that branch. This first peak has a narrowing effect on the lower frequency passband.

The upper frequency passband response is shown by a separate curve on the same graph. There are no visible effects on this response from the other branch. The 20 dB blocking bandwidth is considerably more narrow. The 15 dB blocking bandwidth is considerably wider than the usable bandwidth of the lower passband at 50 kHz. (See Table 16-1 on page 16-28.)

Three other total response curves for F2/F1 = 1.4 and for capacitor values of 2.15 nF, 3.0 nF, and 4.70 nF are included for comparison to the F2/F1 = 1.25 curves at 62.5 kHz (F1 = 50 kHz.) The increase in the bandwidth is shown as the capacitance value is increased. Also, the upper passband total response shows a wide attenuation peak at about 85 kHz for the three capacitor values. The amount of attenuation at this peak is reduced as the capacitance value increases. Also, the attenuation at the first point (about 61 kHz) above the lower passband is reduced as the capacitor value increases. The blocking bandwidths at 15 dB for both branches of the two-frequency line tuner are reduced as the size of the capacitor increases. The 15 dB blocking bandwidth of the 4.70 nF two-frequency tuner at both frequencies is about the same as the 0.5 dB bandwidth. (See Tables 16-13 and 16-14 - pages 16-40 and 16-41.)

The total response curves are included to give an idea of the overall response of the individual paths of the tuner for the selected values of F2/F1 and coupling capacitor. It should be evident at this point that the response of the two-frequency tuner changes for each change of the variables, and general statements about the response behavior are possible only when one of these variables remains fixed.

Since the passband characteristics control the coupling efficiency of the tuner, the emphasis for the remainder of this discussion will be placed on these factors. The analytical circuit can be calculated and analyzed for any set of variables, and ladder analysis programs exist to do the bulk of the work. The blocking attenuation bandwidth and total responses can be calculated for any application.

TWO-FREQUENCY TUNER BANDEDGE FREQUENCY CURVES

Consult the table of contents for page numbers of the curves. The horizontal scale is the F1 axis. To find the bandedge frequencies for a ratio of F2/F1 =1.25, enter the horizontal scale at the value of F1. The dashed line through the curves, labeled "Lower Passband", is the F1 value on the vertical scale corresponding to the same value on the horizontal axis. The solid lines are the 3 dB bandedge frequencies - both upper and lower - for the lower passband. The corresponding F2 value for the F1 value selected, is denoted by the dashed line through the center of the curves labeled "Upper Passband". The 3 dB bandedge frequencies are denoted by the solid lines. The 0.5 dB bandedge frequencies are shown by the dashed lines inside the solid lines. Reference to corresponding tabular listings for each set of curves will show the location of these points on the curves.

For F2/F1 ratios between 1.25 and 1.4, a linear interpolation can be used to estimate the bandwidth, or bandedges for a particular set of frequencies. The tables give the bandwidths in kHz for the selected frequencies of F1 and F2 for the curves. The relation between frequency and bandwidth for given values of line impedance and coupling capacitance is not a constant. An examination of the curves will show what is intuitively evident: the upper bandedge of the lower bandpass about F1 is limited by the location of the frequency of the F2 trap. Likewise, the lower edge of the upper passband about F2 is limited by the frequency of the trap tuned to the F1 frequency which is in series with the series resonant circuit tuned to F2. As the capacitance of the coupling capacitor, Cc, increases, the 3 dB bandedges between F1 and F2 approach each other asymptotically, but can never cross this line. For higher F2/F1 ratios, this limit becomes less restrictive and the limiting factor becomes the value of the coupling capacitor and the line impedance considered together. This is demonstrated by the curves for the tuner designed for a power cable. The bandwidths are very narrow for the selected values of Cc and RL. The bandwidth is under 1 kHz for the majority of the useful range for cable circuitry (< 100 kHz).

As a basis for comparing bandwidths, a column has been added to the tables to show the bandwidth of a resonant single -frequency line tuner with the same values of Cc and RL and tuned to the F1 or F2 frequencies of the two-frequency tuner. These are the theoretical 3 dB, 0.5 dB, and 0.177 (labeled 0.18 db) bandwidths using the formulas and constants of ECC - 354.

On the curves for the two-frequency tuners, the 0.18 dB (0.177 dB) points were not plotted since the curves were too close to the F1 and F2 tuning frequencies to be legible. This in itself indicates the narrow bandwidths of the two-frequency tuners for reasonable return losses. Although the 3 dB bandedge curves are wide, especially for the lower passband curves for some selected frequencies, the 0.5 dB and 0.18 dB bandedge curves are closely crowded to the reference F1 and F2 lines. The bandwidths do not increase in direct proportion to the 3 dB bandwidths.

The bandwidths of the separate branches for different F2/F1 ratios are another characteristic of two-frequency tuners worth noting. Comparing the tabulated bandwidths for the 2.15 nF capacitor for F2/F1 = 1.25 at 100 kHz and 125 kHz and 0.18 dB loss shows bandwidths (see Tables 16-1 and 16-2) of 3.4 kHz and 3.8 kHz for these two frequencies. The bandwidth at 125 kHz should be at least 1.25 times greater than the 100 kHz bandwidth, or (1.25 X 3.4 kHz = 4.25 kHz). The actual bandwidth is only 3.8 kHz.

For the same parameters, but at F2/F1 = 1.4, the bandwidth at 100 kHz and 140 kHz for 0.18 dB are 4.2 and 5.7 kHz. Using the same logic, the bandwidth at 140 kHz should be 4.2 X 1.4 = 5.88 kHz when compared to the 100 kHz bandwidth. This comparison points out two variables in the two-frequency tuner. First, the bandwidth of the separate passbands increases with spacing, and second - the ratio of bandwidths approaches the ratio of F2/F1 as this ratio increases. However, as the capacitor size is increased, these generalizations no longer are true.

COMPARISON WITH RESONANT TUNER BANDWIDTHS

A comparison of the three dB bandwidths of resonant tuners to the various two-frequency tuners using the same value of coupling capacitance and line impedance shows a ratio from 4 to about 8 for the lower passband. This means that the two-frequency tuner is only one-fourth to one-eighth as wide as a comparable single-frequency tuner when comparing the lower passband of the two-frequency tuner to that of the single-frequency resonant tuner. This ratio is applicable for F2/F1 ratios of 1.25 and 1.40. The situation with the upper passband is more severe. The upper passband is only one-seventh to one-thirteenth as wide as a comparable resonant single-frequency tuner. As the frequency increases, this difference is more pronounced. At higher values of the coupling capacitor, the resonant tuner is over thirteen times wider than the two-frequency tuner upper passband at the same tuning frequency.

COMPARISON WITH WIDEBAND TUNER BANDWIDTHS

With these narrow passbands, there must be a situation where a wideband tuner of some sort will pass the entire passbands of the two-frequency tuner, as well as the band of frequencies between the upper and lower passbands. (Refer to the curves of the complete response of the two-frequency tuners.) The wideband tuner would also need to accomplish this using the same value of line impedance and the same value of coupling capacitance as the two-frequency line tuner.

A convenient point for comparison is the 100 kHz value for F1 and the corresponding value of 125 kHz for F2- a ratio of 1.25 for F2/F1. The 14 dB return loss frequency for the lower edge of the lower passband is 98.0 kHz. The corresponding 14 dB return loss (0.18 dB) point for the high edge of the upper passband is 126.8 kHz, using the small coupling capacitor value of 2.15 nF and a line impedance of 320 ohms. The tables of Section 13 (ECC-354) can be used to find bandedge frequencies for these values for different values of GMF. (The Section 13 curves are for RL=300 ohms, but these are close enough for comparison purposes.) A second order wideband tuner with a GMF of 115 kHz has 14 dB bandedge frequencies of 98.1kHz and 134.77 kHz, for a bandwidth of 36.67 kHz- all usable. This is only two (2) resonant circuits. The two-frequency tuner has four (4) resonant circuits. The third order wideband tuner will increase these bandedge frequencies to 87.96 kHz and 150.35 kHz - which is 37 kHz wider than the two frequencies- 100 kHz and 125 kHz - with which we started. The third order wideband tuner requires only three resonant circuits. These are also the 14 dB return loss frequencies for the wideband tuners.

A similar comparison can be done for the ratio of F2/F1 = 1.40 with the 2.15 nF capacitor. Using the frequencies of F1 = 100 kHz and F2 = 140 kHz for the two-frequency tuner, the 14 dB return loss frequencies are 97.7 kHz for the lower edge low passband and 142.6 kHz for the high edge upper passband edge for the two-frequency tuner. The comparable bandedge frequencies for the second order wideband tuner - from page 13-46 of Section 13 - are 101.7 kHz and 141.59 kHz, using a GMF of 120 kHz. This is not quite wide enough to pass the two bands of the two-frequency tuner. But, the third order wideband tuner will cover the range from 90.75 kHz to 158.68 kHz with 14 dB return loss. The entire range is available for expansion - not just the very narrow bands in the two-frequency tuner bands - which are 4.2 kHz about 100 kHz and 5.7 kHz at 140 kHz. (See Table 16-9 and Table 16-10 on pages 16-36 and 16-37.)

The purpose of this discussion was to show that a change to a wideband tuner might be appropriate when a poor performance by two-frequency tuners cannot be corrected. The tuning packs in the line traps would need to be changed to wide band units to match the tuner if the entire passband of the wideband tuner were to be utilized. Otherwise, the two-frequency tuning packs would be adequate for most situations.

For two-frequency tuners with very widely spaced passbands, the problem is usually not as severe, since the bandwidth of the two branches usually will increase as the separation increases. However, the individual bandwidths will never be as wide as that of a resonant single-frequency tuner. The limits of coupling capacitor size and line impedance have to be considered for widely spaced two-frequency tuners at low frequencies.

The lower coupling losses possible with a two-frequency tuner may be offset by a high reflected power because of poor return loss when multiple transmitters are coupled through the same leg of a two-frequency tuner. Hybrids used to separate transmitters in wideband coupling schemes also introduce loss. However, this loss may be compensated for in better matching and lower insertion losses for the wideband approach. The isolation between the two inputs of a two-frequency tuner is frequency dependent. This band of frequencies is very narrow, being determined by the blocking bandwidth of the parallel L/C circuit in the transmit path. Although the bandwidth of the tuners may increase, there is not a comparable increase in the isolation bandwidth. Inadequate isolation can cause intermodulation problems.

Since there are so many possible combinations of frequencies, capacitors, line impedances, and spacings for two-frequency tuners, a change to a wideband tuner with the difference in the coupling circuits will have to be studied for each case. Wideband tuning is one solution to the narrow bandwidth problem. This represents a much smaller investment than using larger coupling capacitors, or possibly doubling the number of capacitors.

The narrow bandwidth of the two-frequency cable tuner, which was used as an example, almost dictates a wideband approach instead of using two-frequency tuners. For this example, the 14 dB return loss bandwidth is less than 2 kHz at a frequency of 120 kHz, using a 10 nF capacitor.

SELECTION OF CAPACITORS IN PARALLEL RESONANT CIRCUITS

In ECC-360 and Section 15 of this guide on page 15-18, formulas are given to calculate the component values of a two-frequency line tuner. These formulas are directed towards calculating the values of the inductances in the resonant circuits. The formulas given to calculate the series inductance values which resonate with the series combination of the 60 Hz blocking capacitor and the coupling capacitor contain a ratio labeled "R". This ratio can be varied from a minimum value, which will cause the value of LS1 to go to zero, to a value which will cause the parallel capacitor value to be equal to approximately twice the coupling capacitor value, which has been used in the majority of two-frequency tuners. A value of the parallel capacitors greater than twice the coupling capacitor value is possible, but is usually not used. This formula is shown as equation (3) on page 15-18, and is rewritten below:

$$LS1 = [a(1 + R) - 1]/[C_c'(a-1)(6.2832 \times F1)^2] \qquad (3)$$

In order for LS1 to go to zero, the numerator of equation (3) must be equal to zero. As shown in section 15, the variables in the numerator have the following relationships to the tuner variables:

$R = C_c'/2C_c$ and $2C_c = C_p$

$C_c' = (C_b \times C_c)/(C_b + C_c)$ $C_b = 100\ nF$

$a = (F1/F2)^2$.

F1 is the low tuner frequency, and F2 is the high tuner frequency, and the minimum value of $F2/F1 = 1.25$.

If the numerator alone is considered, and set equal to zero, the values of "R" for this limiting case can be determined.

$$LS1 = 0.0 = [\,a\,(1 + R\,) - 1] \qquad (3a)$$

16

The value in the denominator, $2C_c$, of the ratio for R is the parallel capacitance which resonates the traps in the tuner. This is an arbitrary value which can be changed, and will be called C_p, as shown above. Solving (3a) for the ratio, R, gives:

$a(1 + R) = 1$

$1 + R = 1/a$

$$R_{min} = 1/a - 1 = (F2/F1)^2 - 1 \qquad (4)$$

Using the closest spacing for the tuner, which is F2/F1 = 1.25 gives:

$$R_{min} = (1.25)^2 - 1 = 1.5625 - 1 = 0.5625$$

$$= C_c'/C_p \text{ or } C_p = C_c'/R.$$

In the general case, the value of C_c is known. The 60 Hz blocking capacitor is 100 nF for GE tuners. C_c' can be calculated from the expression given above. As an example, assume a ratio of F2/F1 = 1.25 and a coupling capacitor value of 5 nF. Find the value of C_c' and the minimum value for C_p.

$$C_c' = (C_b \times C_c) / (C_b + C_c) = (100 \times 5)/(100 + 5)$$

$$= 4.7619 \text{ nF}.$$

The minimum value of C_p is then:

$$C_p = C_c'/ R_{min} = 4.7619/0.5625 = 8.465 \text{ nF}.$$

The ratio of C_p to C_c is also of interest. This ratio depends on the value of C_c, since the limitation for determining C_p depends on C_c', which is related to the blocking capacitor value. The value of the ratio, R_{min}, does not change for different coupling capacitor values or for different blocking capacitor values. To demonstrate the variability of the C_p to C_c ratio, consider the following: Call this ratio R_{pc} and calculate it for the present case:

$$R_{pc} = C_p/ C_c = 8.465/5.0 = 1.693.$$

For a different value of C_c = 10 nF, the value of C_c' = 9.0909 nF and C_p is calculated as before:

$$C_p = C_c' /R_{min} = 9.0909/ 0.5625 = 16.1616 \text{ nF}.$$

$$R_{pc} = C_p/C_c = 16.1616/10.0 = 1.61616.$$

This ratio increases for smaller capacitor values and decreases for larger capacitor values. A tabulation of the reciprocal of R_{min} gives the ratio of C_p to C_c', and can be used with various values of coupling capacitance and frequency ratios and is given for reference in the Table below. The relation for $1/R_{min}$ is given below:

$$1/R_{min} = C_p/C_c' = 1/[(F2/F1)^2 -1] \qquad (5)$$

Other values of this ratio can be easily calculated using equation (5).

Analysis has shown that the blocking bandwidth and attenuation of a two-frequency line tuner improves as the ratio approaches the minimum value. Since the value of LS1 tends to go to zero as R_{min} is approached, a guideline for the selection of the best compromise capacitor for the parallel trap circuits is to choose a value which is about twenty five per cent higher than the value calculated for R_{min}. For a frequency ratio of 1.25 this becomes

$R_{pc} = C_p/C_c = 1.25 / 0.5625 = 2.222.$

This value is consistent with the $2C_c$ selection for C_p which has been used for years.

F2/F1	$1/R_{min}$	F2/F1	$1/R_{min}$
1.25	1.7778	1.8	0.4464
1.30	1.4492	2.00	0.3333
1.35	1.2158	2.25	0.2462
1.40	1.0417	2.5	0.1904
1.50	0.8000	2.75	0.1524
1.60	0.6410	3.00	0.1250

For a frequency ratio F2/F1 = 1.5 the value of $C_p/C_c' = 1/R_{min} = 0.8$. A value of C_p/C_c' of 1.25 x 0.8 = 0.9 would be appropriate to give the best balance between blocking attenuation and bandwidth, and passband response. A value of $1/R_{min}$ can be calculated for any F2/F1 ratio to select the parallel capacitor value for any selected coupling capacitor.

CONCLUSION

Two-frequency tuners have very narrow bandwidths compared to resonant single-frequency tuners for both lower and upper passbands. The comparison showed ratios of from 4-to-1 to 8-to-1 for the lower passband. The situation for the upper passband is even more restrictive. These ratios were from seven to thirteen in favor of the resonant single-frequency tuner. This wide variation pointed out the possibility of using a wideband tuner in place of the two-frequency approach. For the most narrow spacing of frequencies - F2/F1 = 1.25 - the second order wideband tuner could pass the entire band from F1 to F2, giving extra flexibility for adding functions in a coupling arrangement. Reference to Section 13, "Bandpass Line Tuners", will show the tuning bandwidths possible for all available resonant and wideband line tuners.

The blocking attenuation and bandwidth of the two-frequency tuner can be improved by selecting a value of the parallel capacitors which is consistent with the ratios developed in the text. Following this approach will increase the attenuation in the blocking band and increase the blocking bandwidth to the maximum possible for the selected frequencies and coupling capacitor. This selection has very little effect on the passband responses of the two tuner branches.

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TOTAL RESPONSE CURVES, BANDEDGE FREQUENCIES AND TABULAR LISTINGS FOR SELECTED TWO-FREQUENCY LINE TUNERS

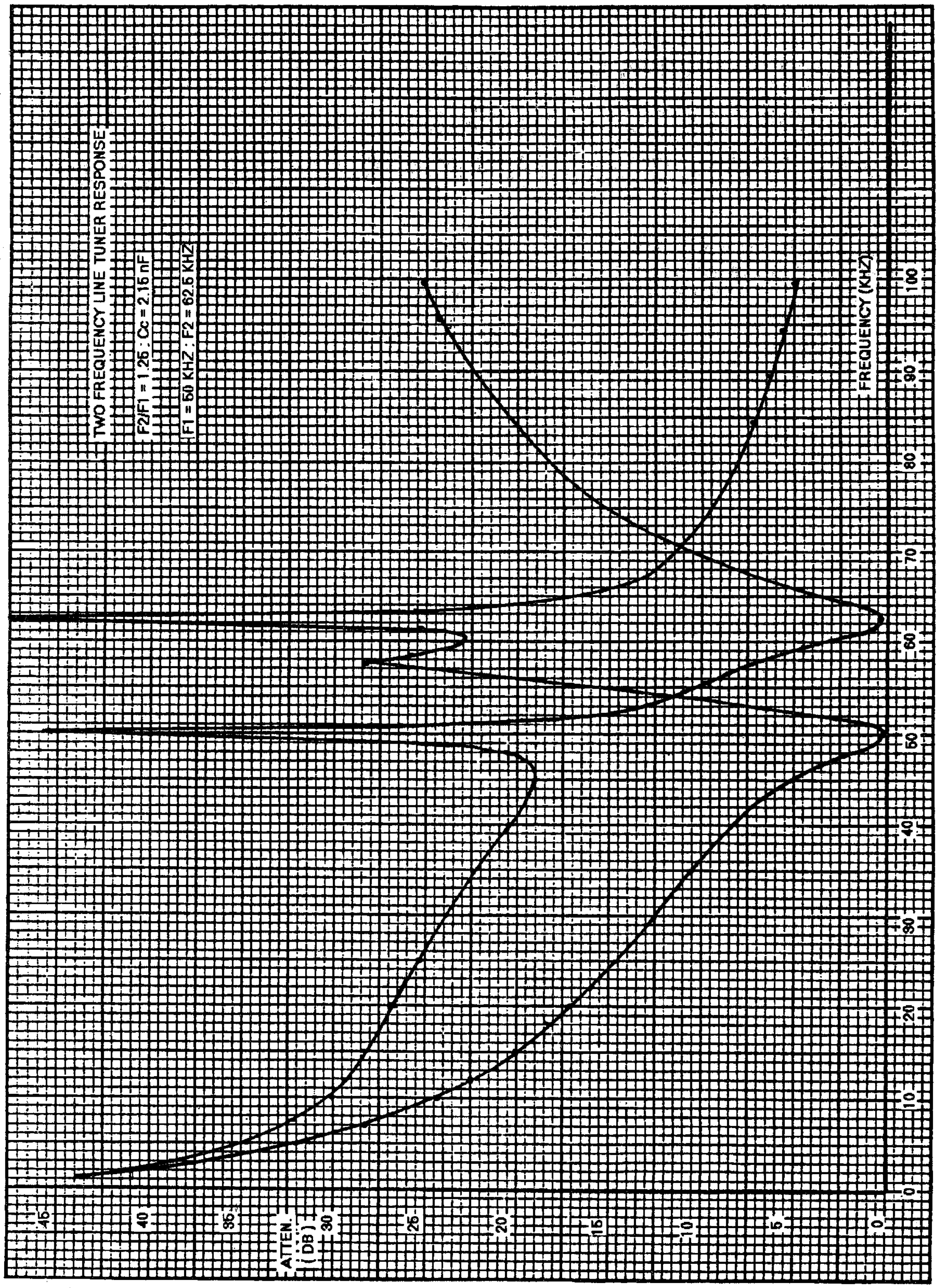

TWO FREQUENCY LINE TUNER RESPONSE
F2/F1 = 1.26 : Cc = 2.16 nF
F1 = 50 KHZ : F2 = 62.5 KHZ
FREQUENCY (KHZ)
0 10 20 30 40 50 60 70 80 90 100
ATTEN. (DB)
0 5 10 15 20 25 30 35 40 45

Figure 16-3

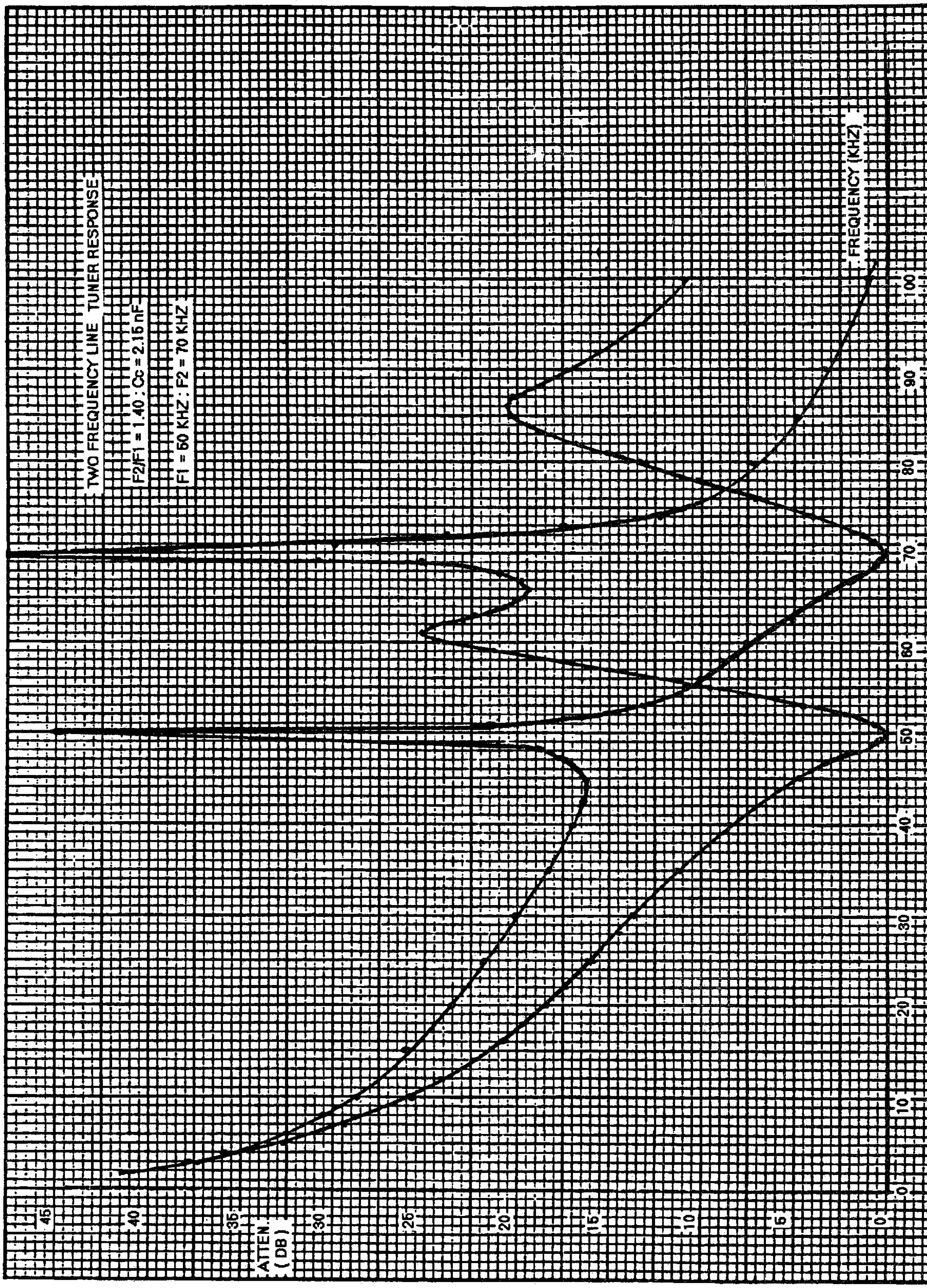

TWO FREQUENCY LINE TUNER RESPONSE
F2/F1 = 1.40 ; Cc = 2.15 nF
F1 = 50 KHZ ; F2 = 70 KHZ
FREQUENCY (KHZ)
0
10
20
30
40
50
60
70
80
90
100
ATTEN. (DB)
0
5
10
15
20
25
30
35
40
45

Figure 16-4

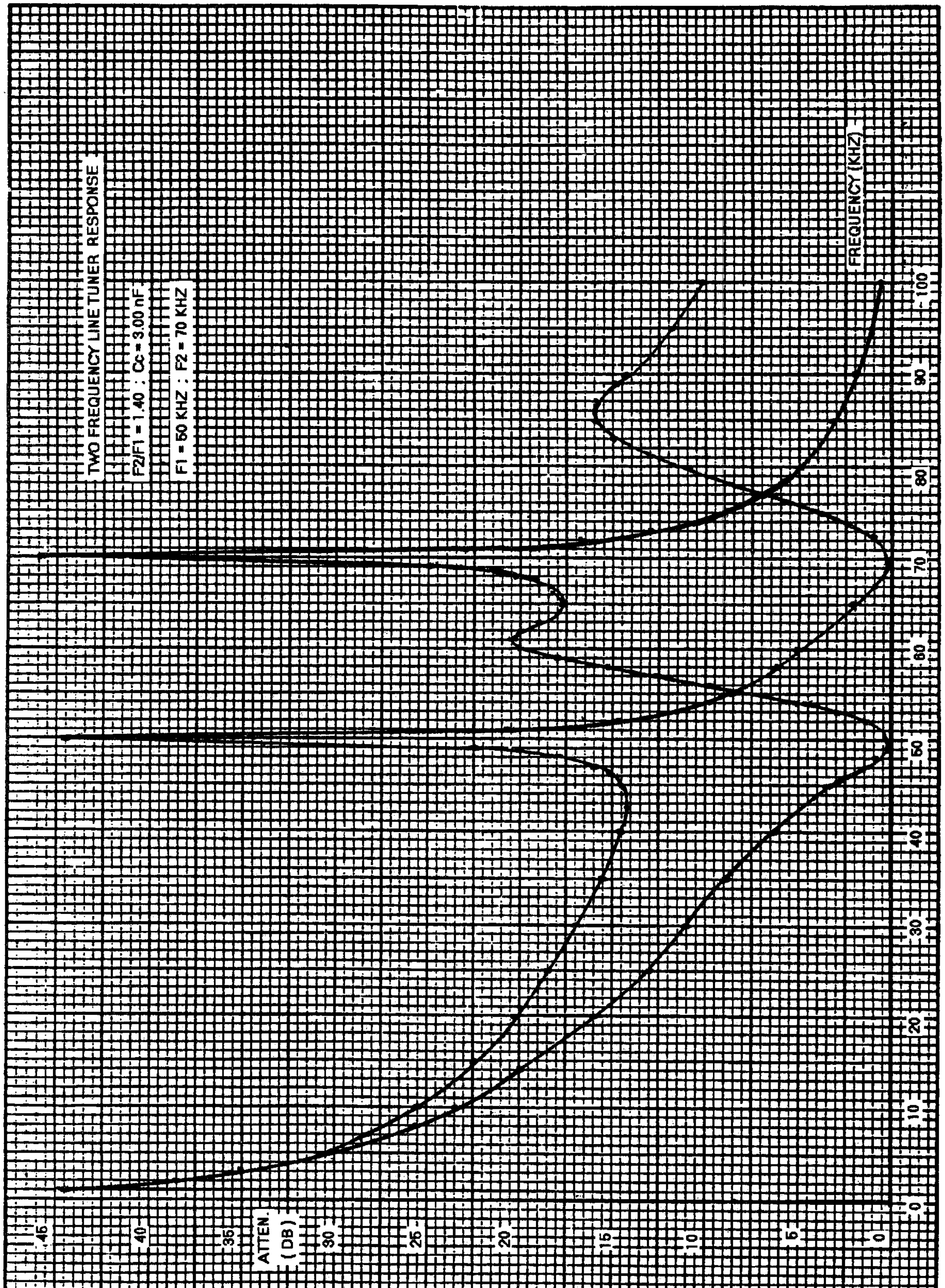

TWO FREQUENCY LINE TUNER RESPONSE
F2/F1 = 1.40 : Cc = 3.00 nF
F1 = 50 KHZ : F2 = 70 KHZ
FREQUENCY (KHZ)
0 10 20 30 40 50 60 70 80 90 100
ATTEN. (DB)
45 40 35 30 25 20 15 10 5 0

Figure 16-5

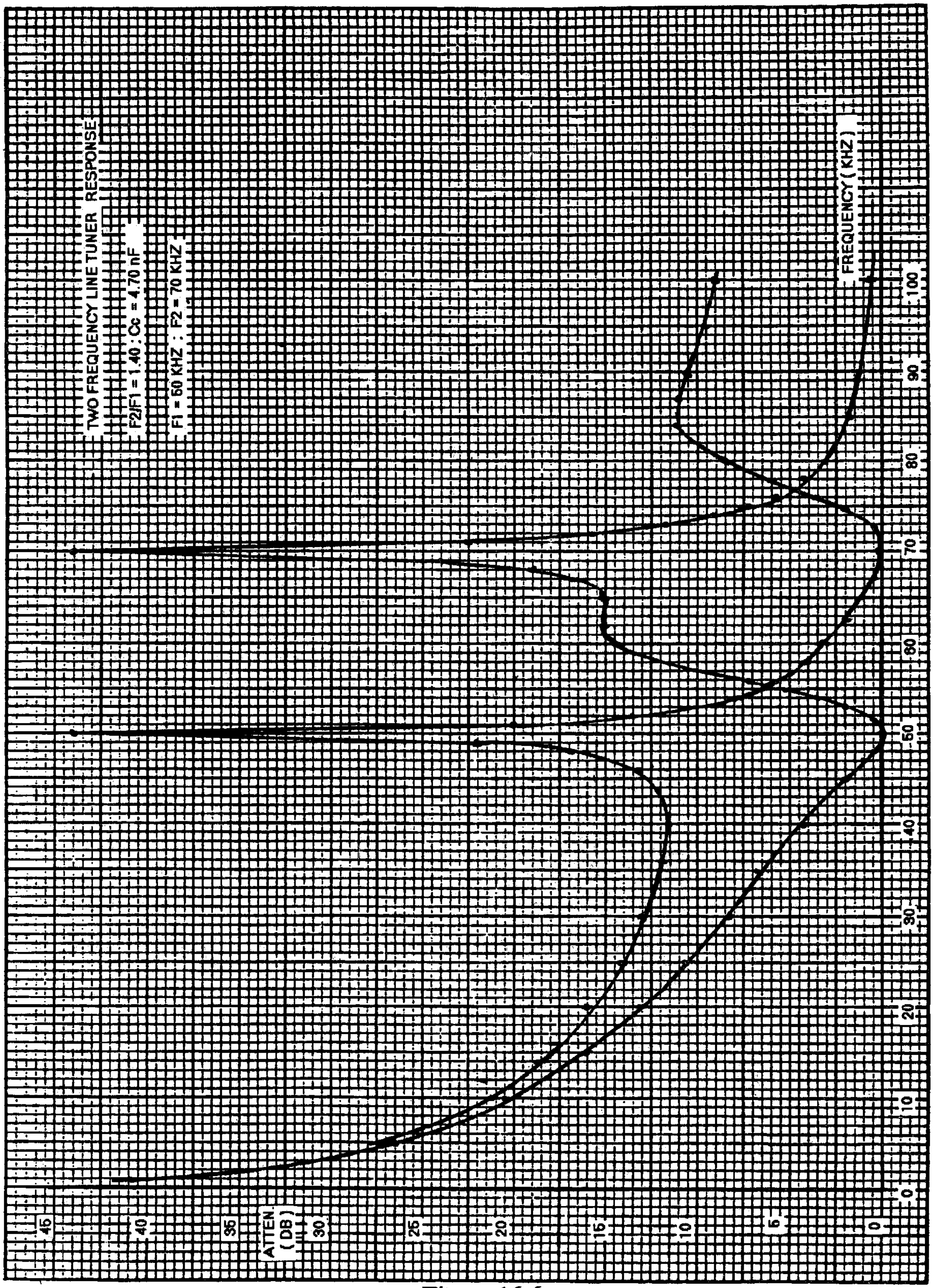

TWO FREQUENCY LINE TUNER RESPONSE
F2/F1 = 1.40 : Cc = 4.70 nF
F1 = 60 KHZ : F2 = 70 KHZ
FREQUENCY (KHZ)
0
10
20
30
40
50
60
70
80
90
100
ATTEN. (DB)
45
40
35
30
25
20
15
10
5
0

Figure 16-6

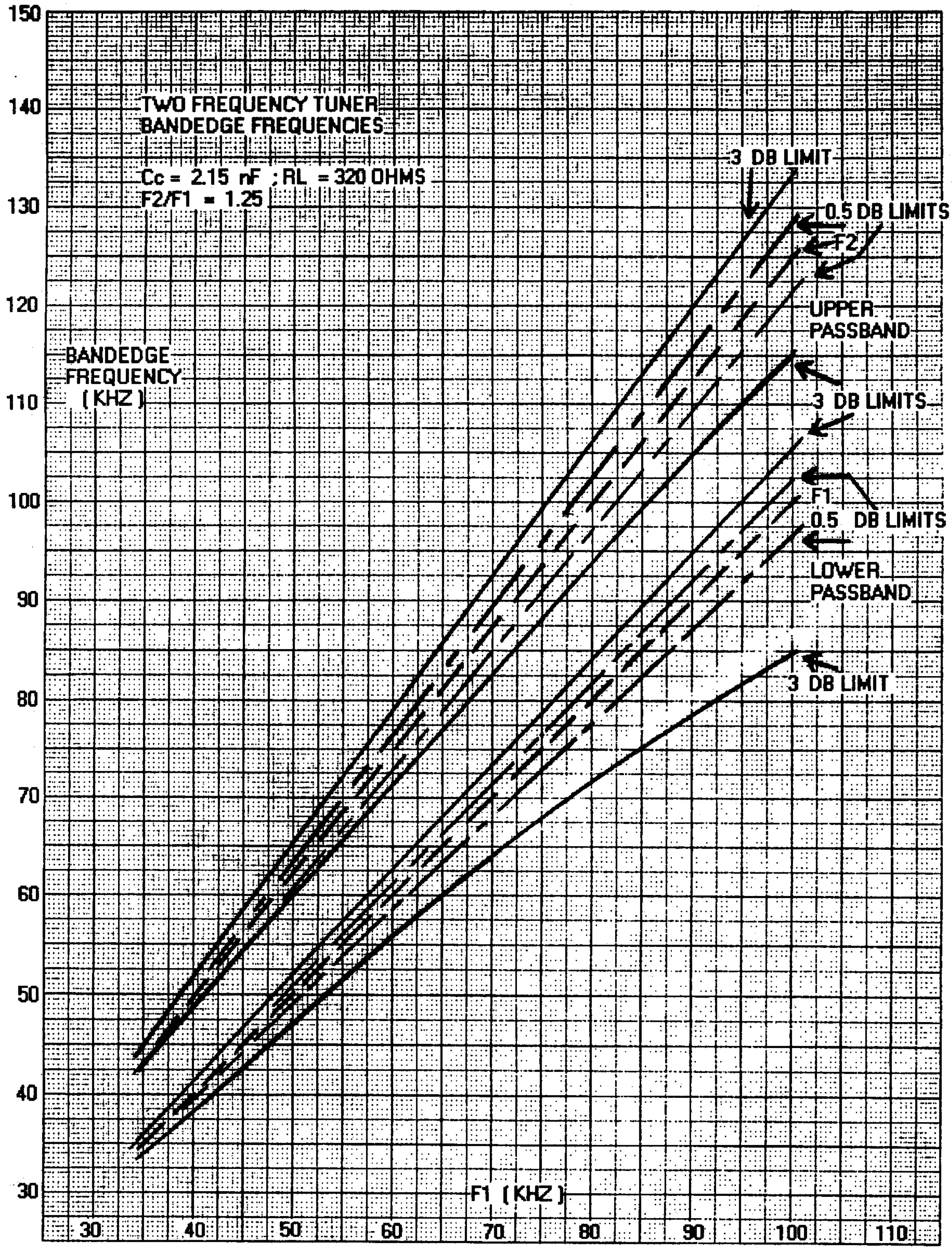

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 2.15 nF ; RL = 320 OHMS
F2/F1 = 1.25
3 DB LIMIT
0.5 DB LIMITS
F2
UPPER PASSBAND
3 DB LIMITS
F1
0.5 DB LIMITS
LOWER PASSBAND
3 DB LIMIT
BANDEDGE FREQUENCY (KHZ)
F1 (KHZ)
150
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100
110

Figure 16-7

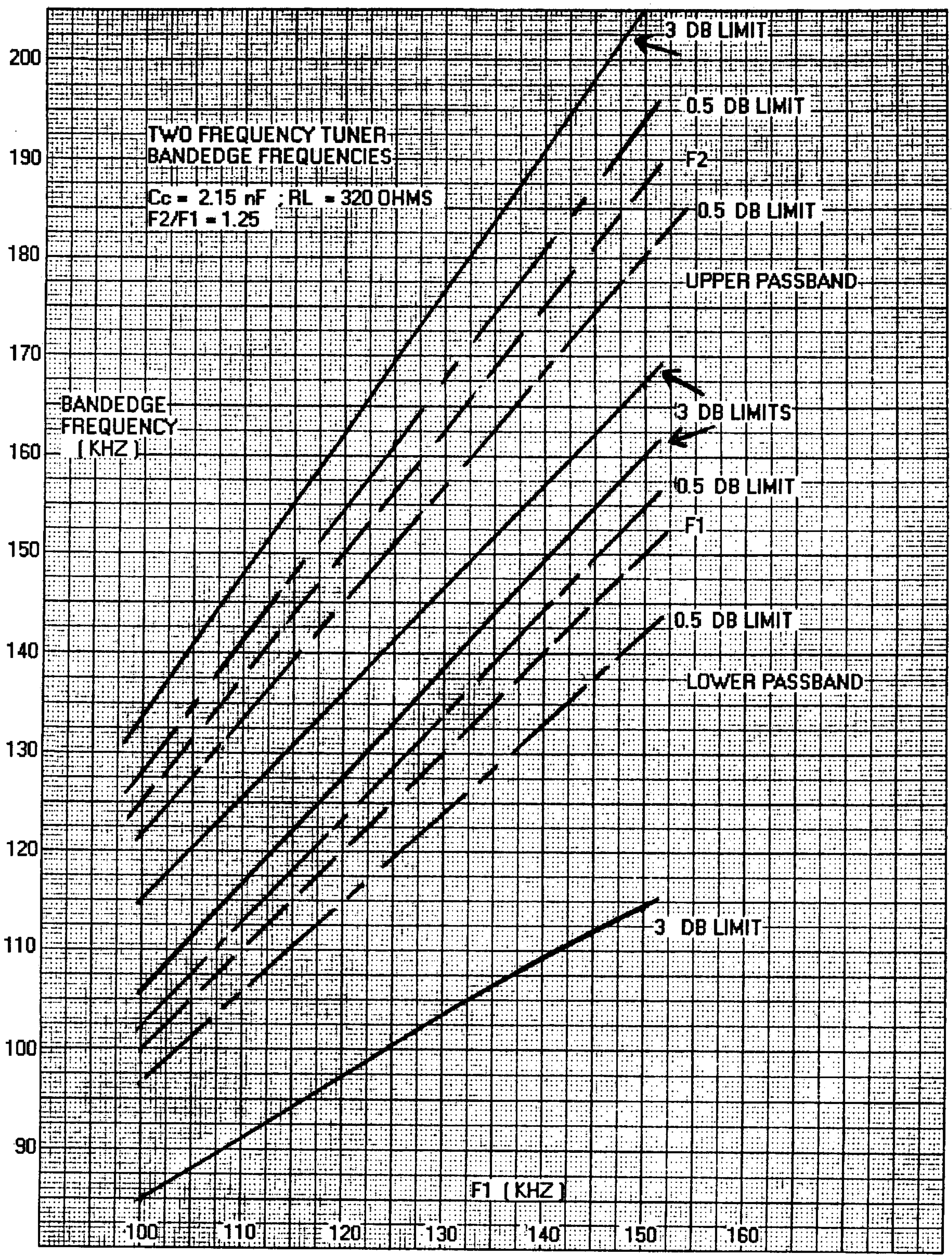


Figure 16-8

16

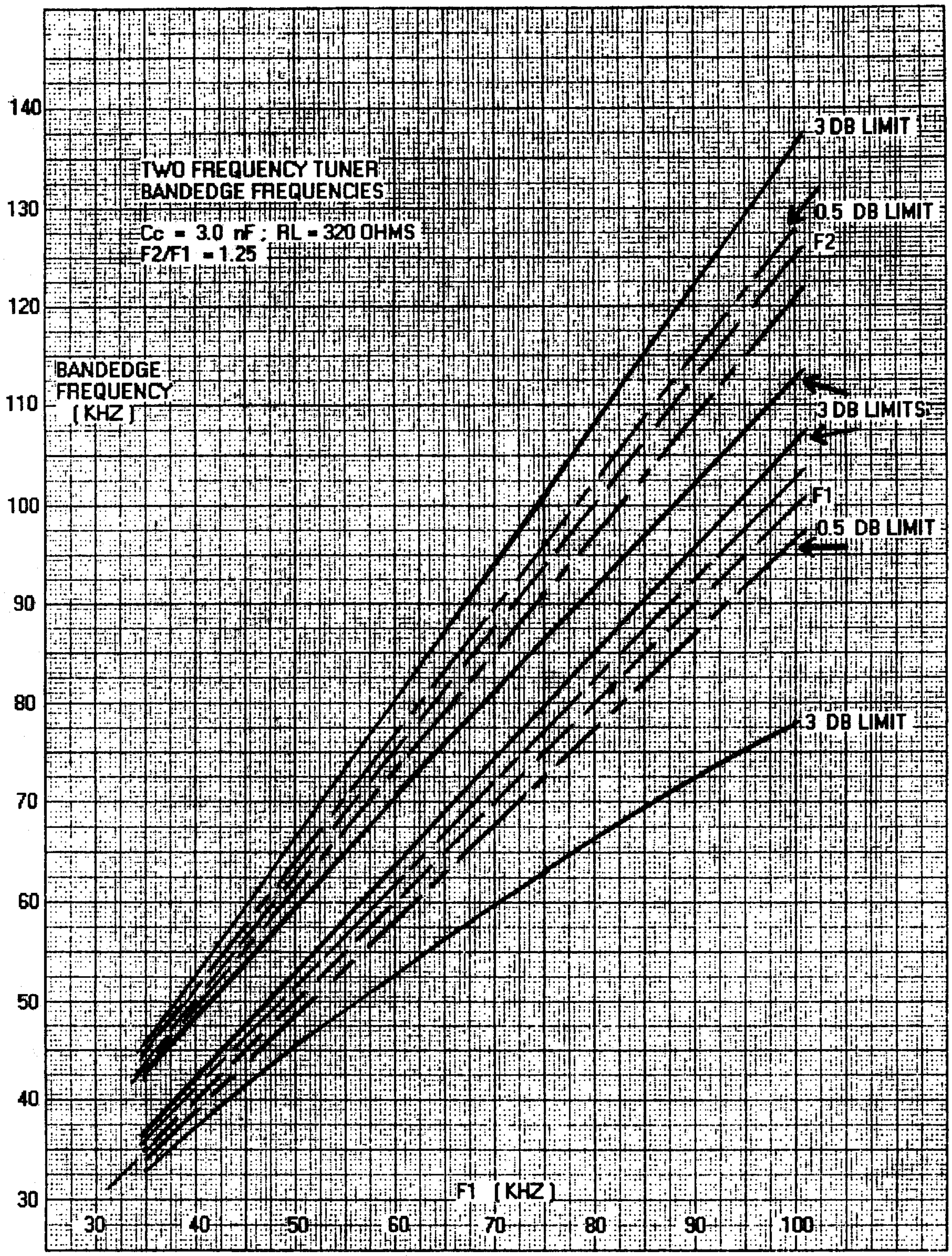

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 3.0 nF ; RL = 320 OHMS
F2/F1 = 1.25
BANDEDGE
FREQUENCY
(KHZ)
3 DB LIMIT
0.5 DB LIMIT
F2
3 DB LIMITS
F1
0.5 DB LIMIT
3 DB LIMIT
F1 (KHZ)
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100

Figure 16-9

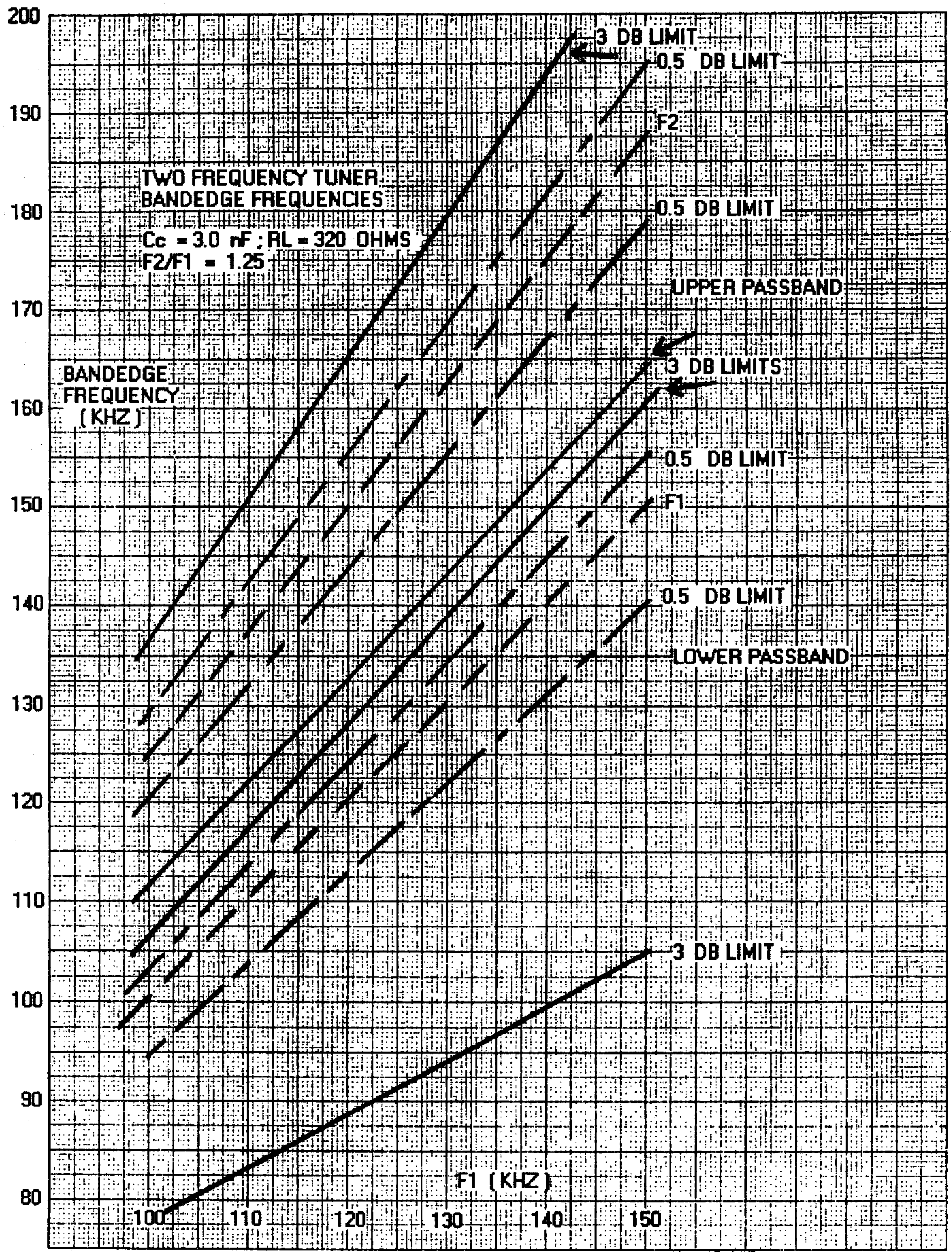

TWO FREQUENCY TUNER BANDEDGE FREQUENCIES
Cc = 3.0 nF ; RL = 320 OHMS
F2/F1 = 1.25
BANDEDGE FREQUENCY (KHZ)
3 DB LIMIT
0.5 DB LIMIT
F2
0.5 DB LIMIT
UPPER PASSBAND
3 DB LIMITS
0.5 DB LIMIT
F1
0.5 DB LIMIT
LOWER PASSBAND
3 DB LIMIT
F1 (KHZ)
200
190
180
170
160
150
140
130
120
110
100
90
80
100
110
120
130
140
150

Figure 16-10

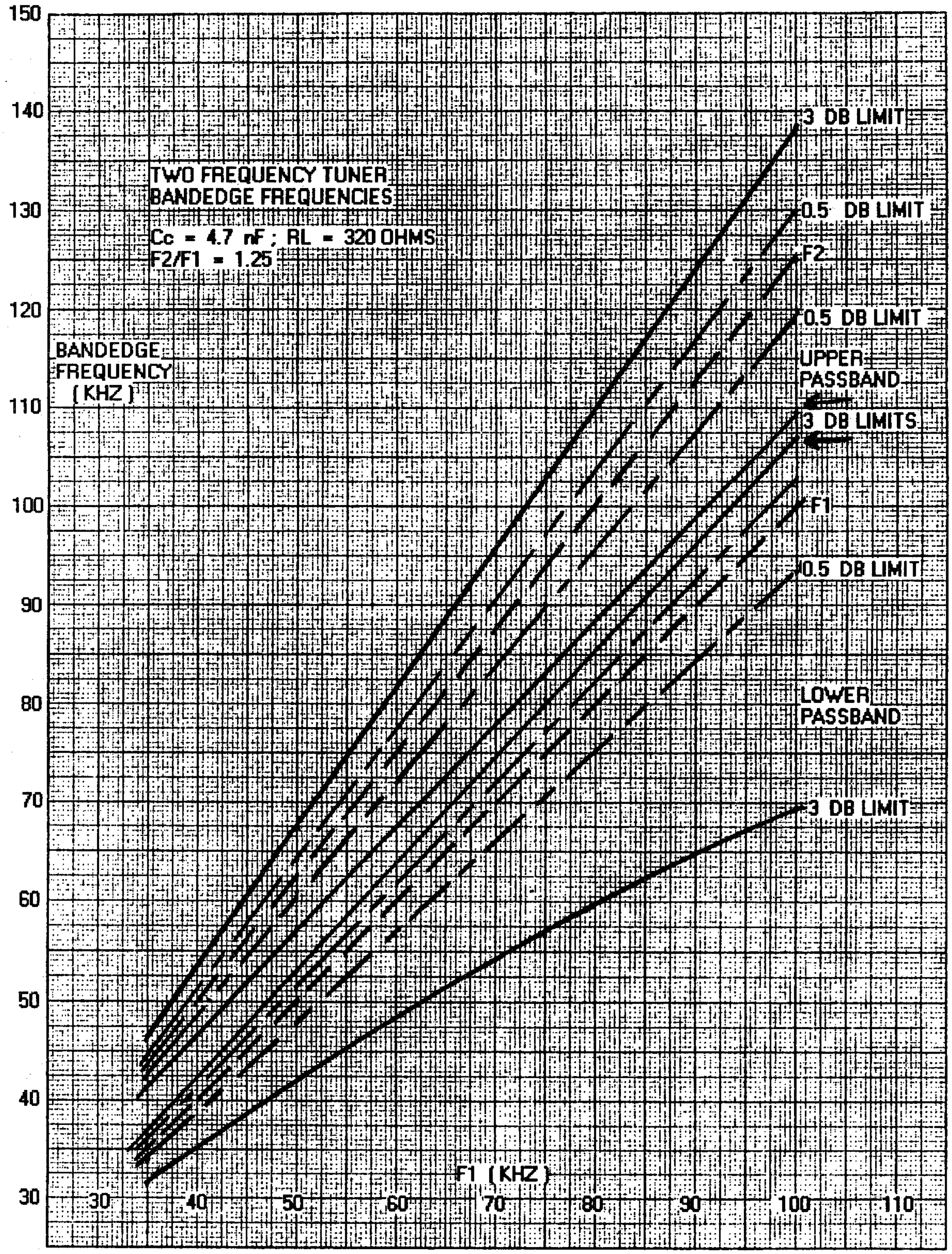

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 4.7 nF ; RL = 320 OHMS
F2/F1 = 1.25
BANDEDGE
FREQUENCY
(KHZ)
3 DB LIMIT
0.5 DB LIMIT
F2
0.5 DB LIMIT
UPPER
PASSBAND
3 DB LIMITS
F1
0.5 DB LIMIT
LOWER
PASSBAND
3 DB LIMIT
F1 (KHZ)
150
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100
110

Figure 16-11

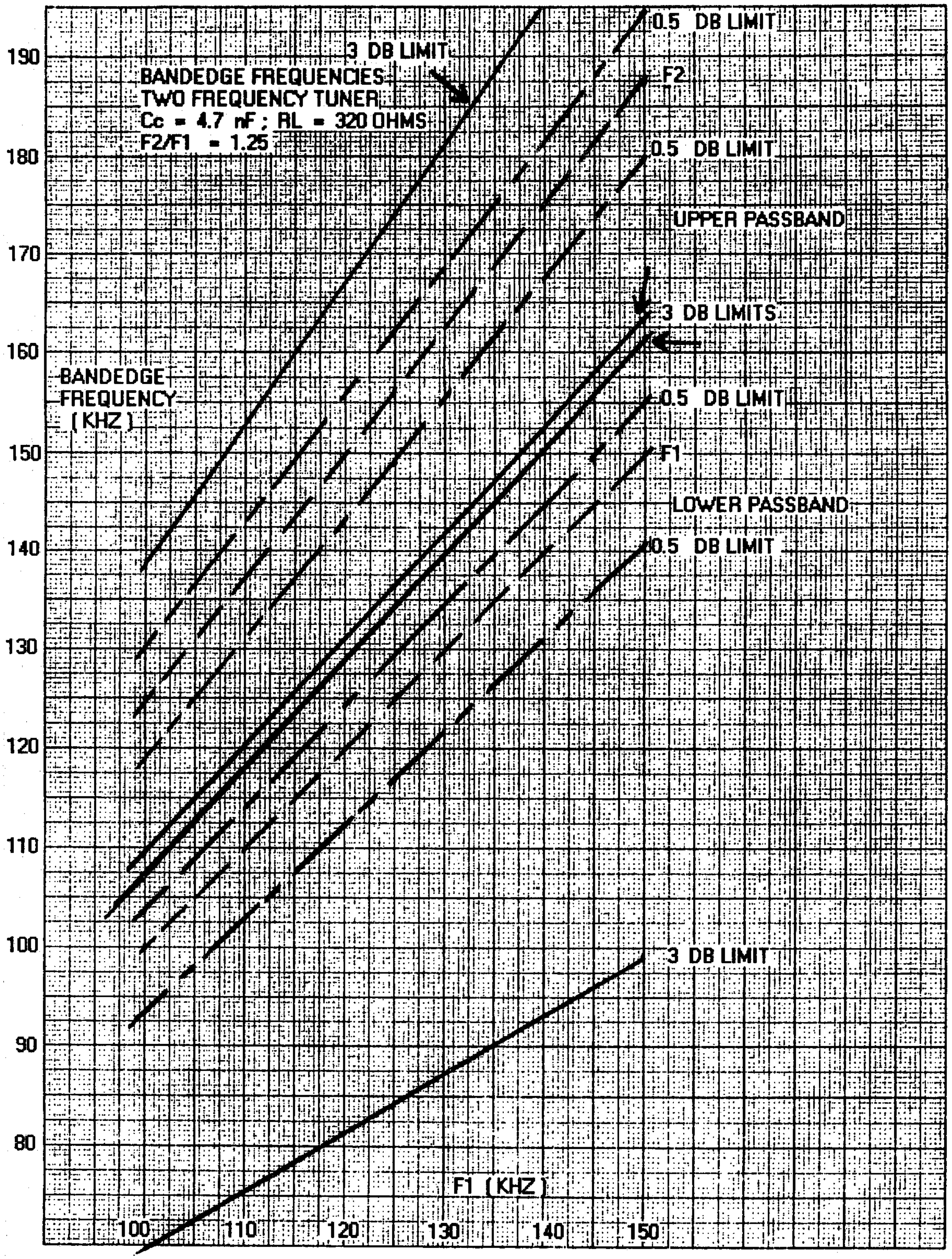

BANDEDGE FREQUENCIES
TWO FREQUENCY TUNER
Cc = 4.7 nF ; RL = 320 OHMS
F2/F1 = 1.25
3 DB LIMIT
0.5 DB LIMIT
F2
0.5 DB LIMIT
UPPER PASSBAND
3 DB LIMITS
0.5 DB LIMIT
F1
LOWER PASSBAND
0.5 DB LIMIT
3 DB LIMIT
BANDEDGE FREQUENCY (KHZ)
F1 (KHZ)
190
180
170
160
150
140
130
120
110
100
90
80
100
110
120
130
140
150

Figure 16-12

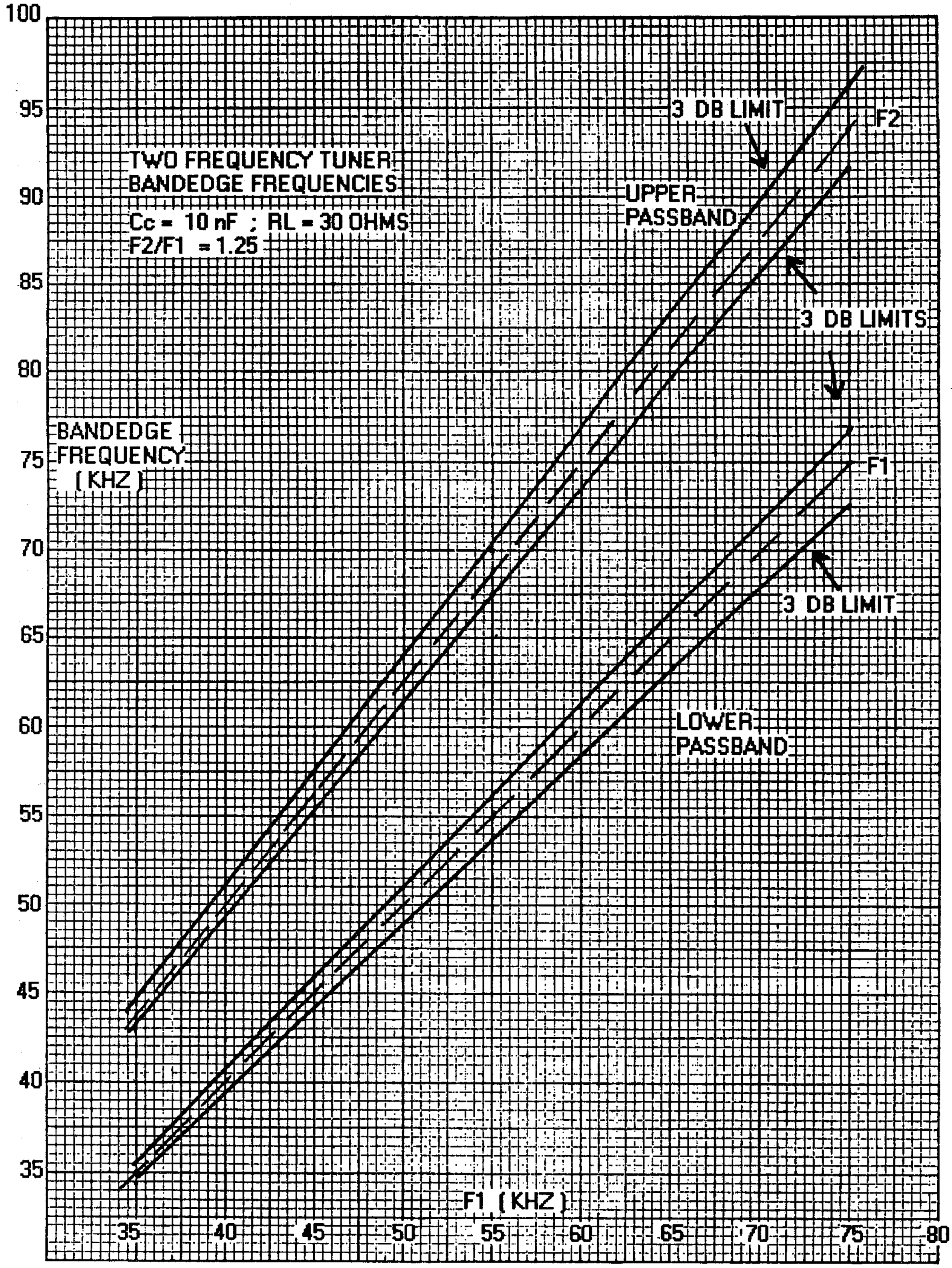
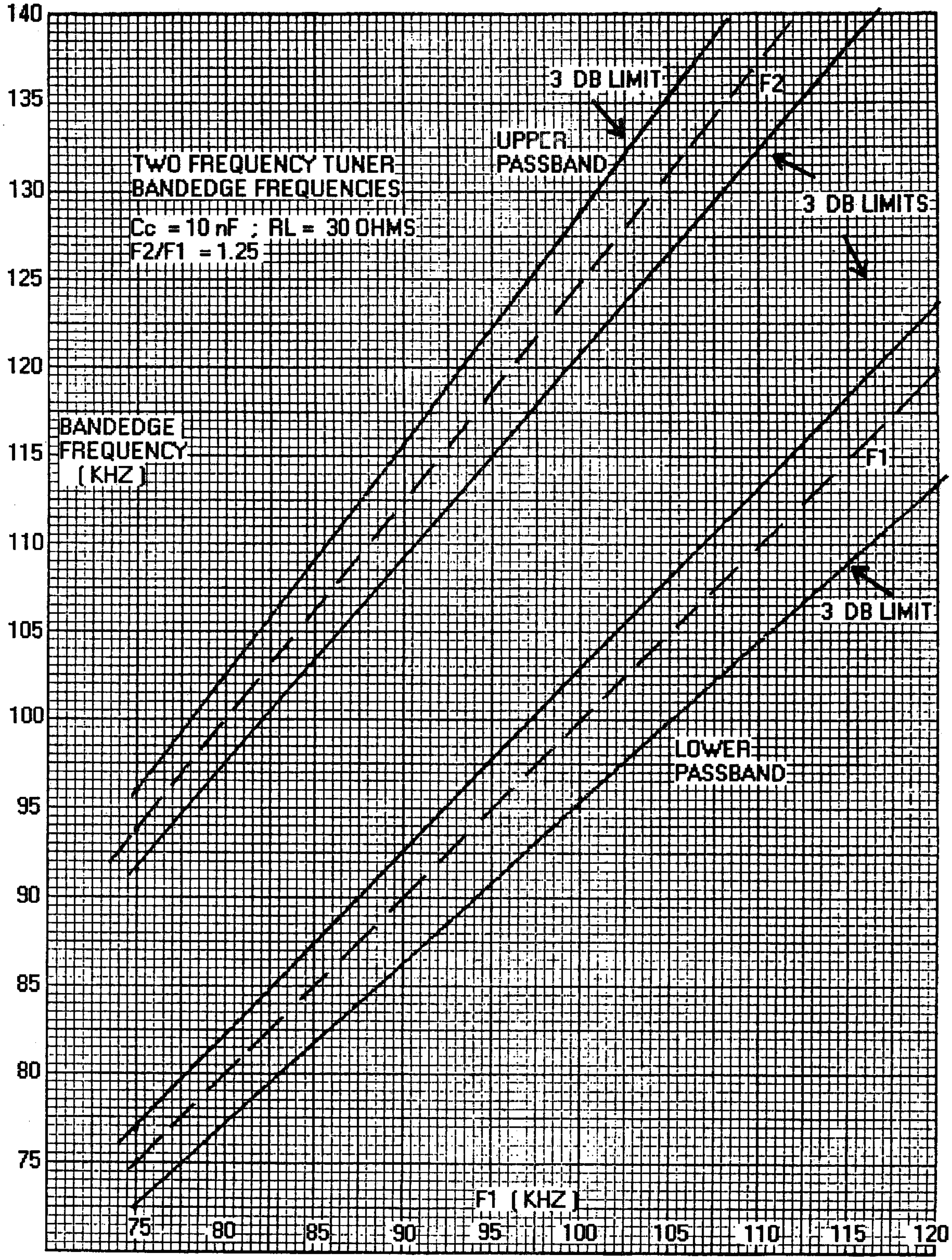

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 10 nF ; RL = 30 OHMS
F2/F1 = 1.25
3 DB LIMIT
F2
UPPER PASSBAND
3 DB LIMITS
F1
3 DB LIMIT
LOWER PASSBAND
BANDEDGE FREQUENCY (KHZ)
F1 (KHZ)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
35
40
45
50
55
60
65
70
75
80

Figure 16-13



3 DB LIMIT
F2
UPPER PASSBAND
TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 10 nF ; RL = 30 OHMS
F2/F1 = 1.25
3 DB LIMITS
BANDEDGE FREQUENCY (KHZ)
F1
3 DB LIMIT
LOWER PASSBAND
F1 (KHZ)
140
135
130
125
120
115
110
105
100
95
90
85
80
75
75
80
85
90
95
100
105
110
115
120

Figure 16-14

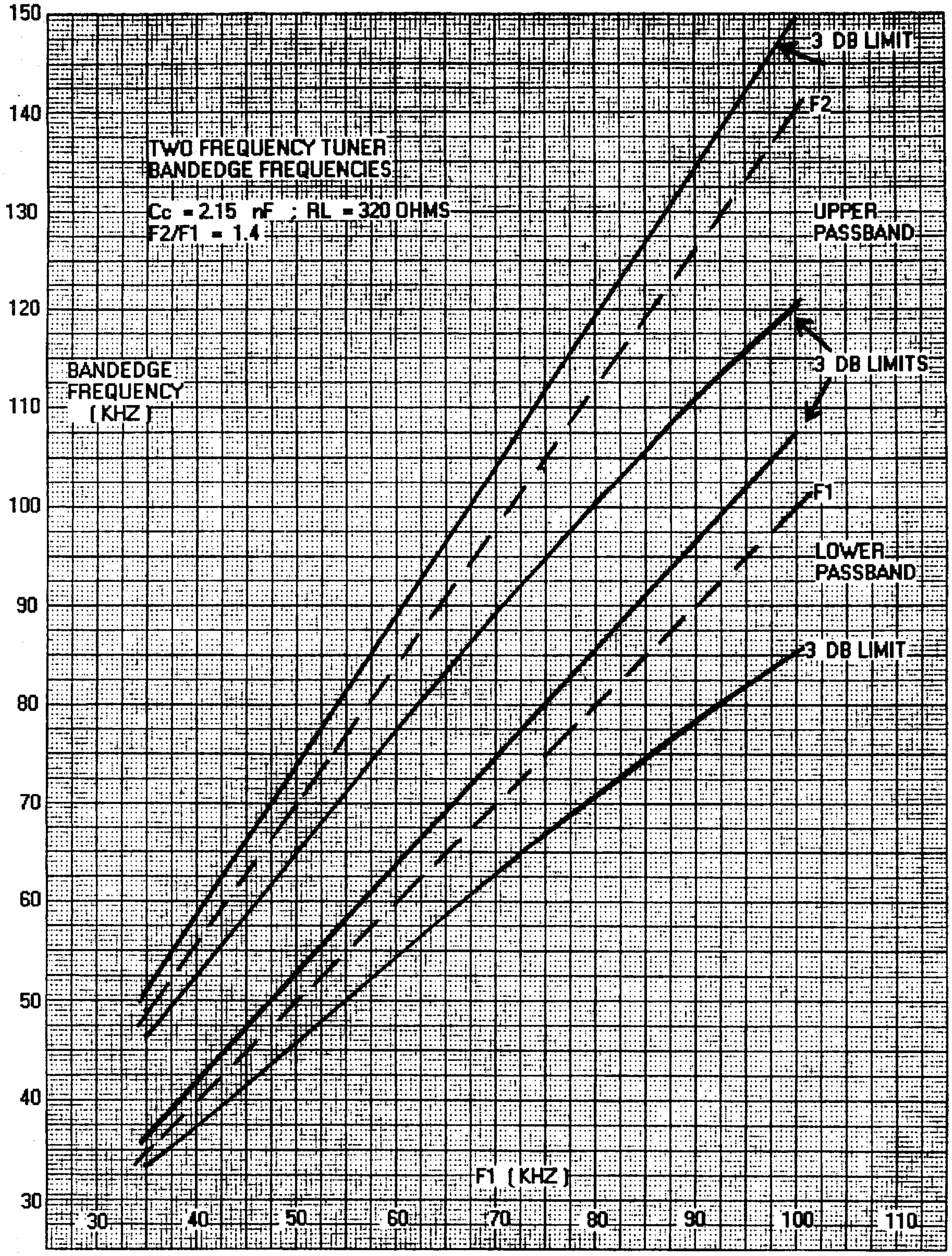

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 2.15 nF ; RL = 320 OHMS
F2/F1 = 1.4
BANDEDGE
FREQUENCY
(KHZ)
F1 (KHZ)
3 DB LIMIT
F2
UPPER
PASSBAND
3 DB LIMITS
F1
LOWER
PASSBAND
3 DB LIMIT
150
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100
110

Figure 16-15

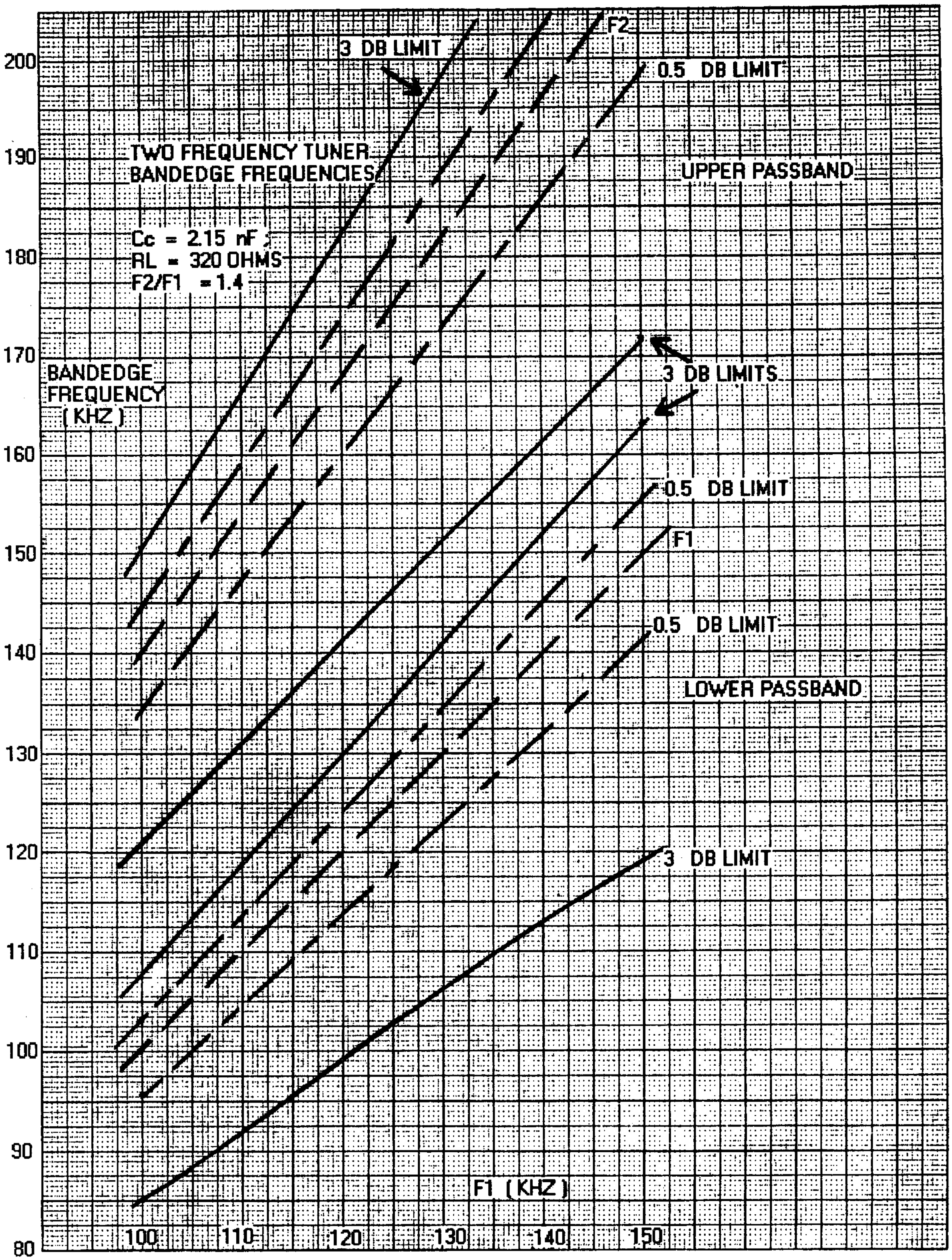

F2
3 DB LIMIT
0.5 DB LIMIT
TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
UPPER PASSBAND
Cc = 2.15 nF ;
RL = 320 OHMS
F2/F1 = 1.4
BANDEDGE
FREQUENCY
(KHZ)
3 DB LIMITS
0.5 DB LIMIT
F1
0.5 DB LIMIT
LOWER PASSBAND
3 DB LIMIT
F1 (KHZ)
200
190
180
170
160
150
140
130
120
110
100
90
80
100
110
120
130
140
150

Figure 16-16

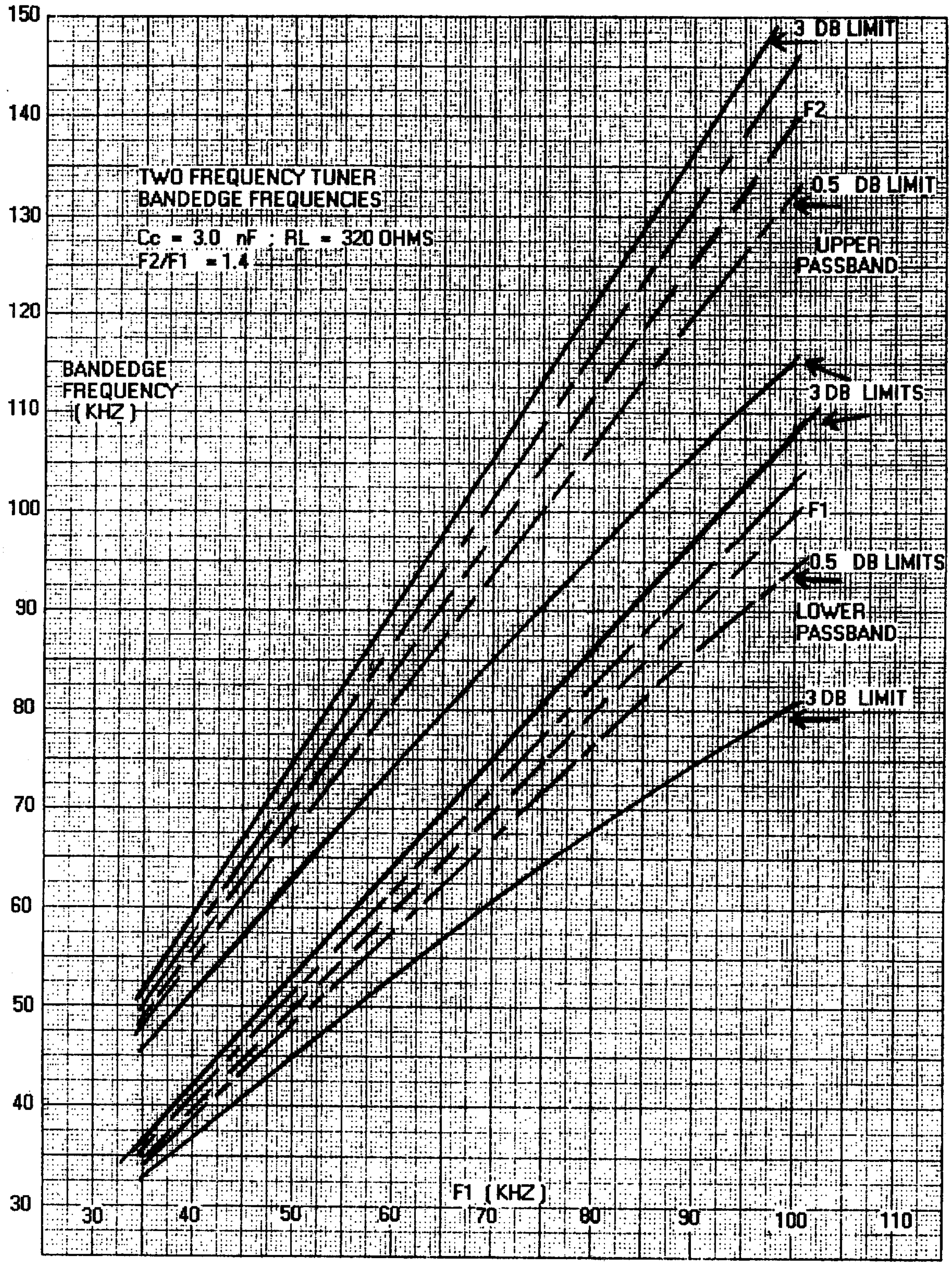

3 DB LIMIT
F2
0.5 DB LIMIT
UPPER
PASSBAND
3 DB LIMITS
F1
0.5 DB LIMITS
LOWER
PASSBAND
3 DB LIMIT
TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 3.0 nF ; RL = 320 OHMS
F2/F1 = 1.4
BANDEDGE
FREQUENCY
(KHZ)
F1 (KHZ)
150
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100
110

Figure 16-17

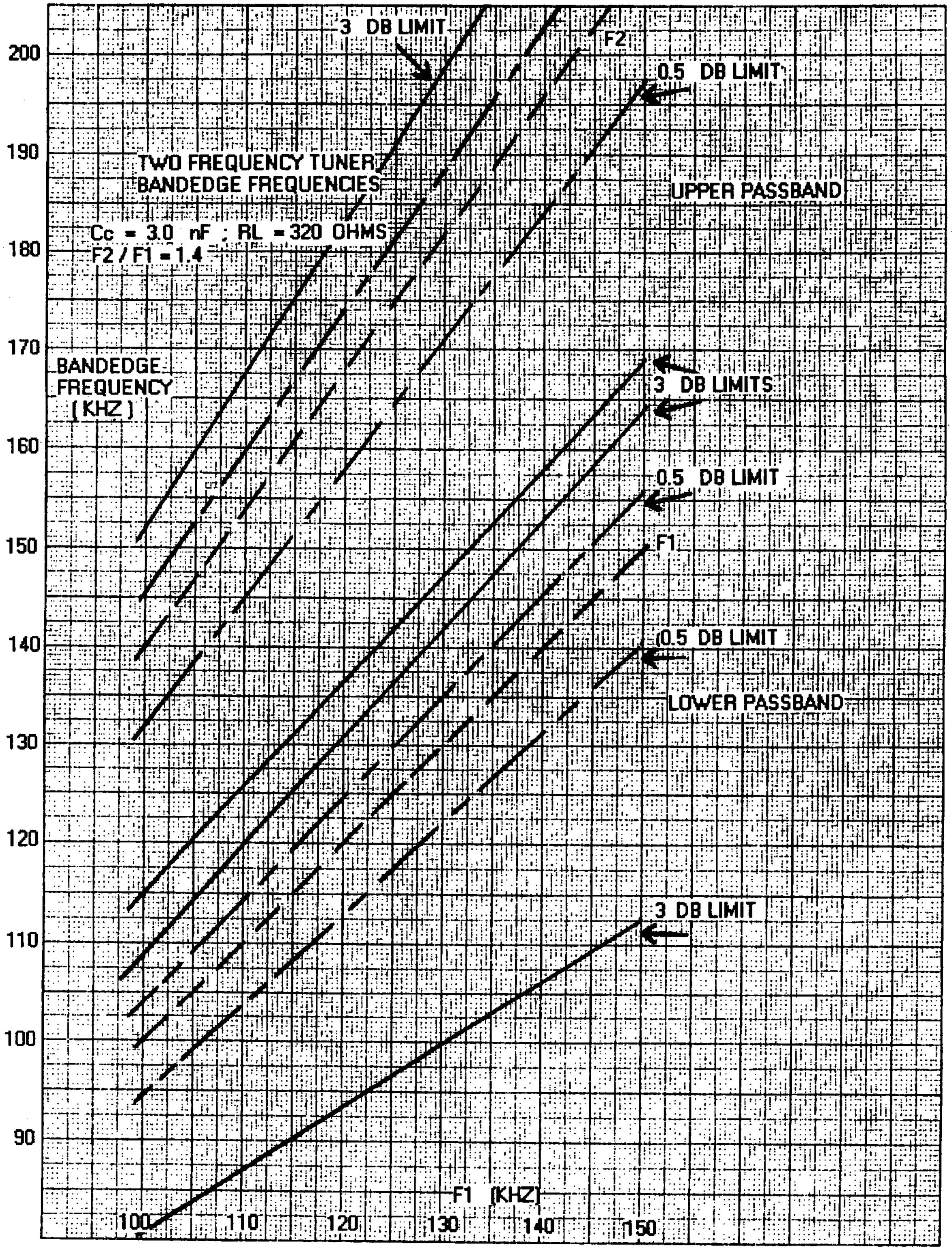

3 DB LIMIT
F2
0.5 DB LIMIT
TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
UPPER PASSBAND
Cc = 3.0 nF ; RL = 320 OHMS
F2 / F1 = 1.4
BANDEDGE
FREQUENCY
(KHZ)
3 DB LIMITS
0.5 DB LIMIT
F1
0.5 DB LIMIT
LOWER PASSBAND
3 DB LIMIT
F1 (KHZ)
200
190
180
170
160
150
140
130
120
110
100
90
100
110
120
130
140
150

Figure 16-18

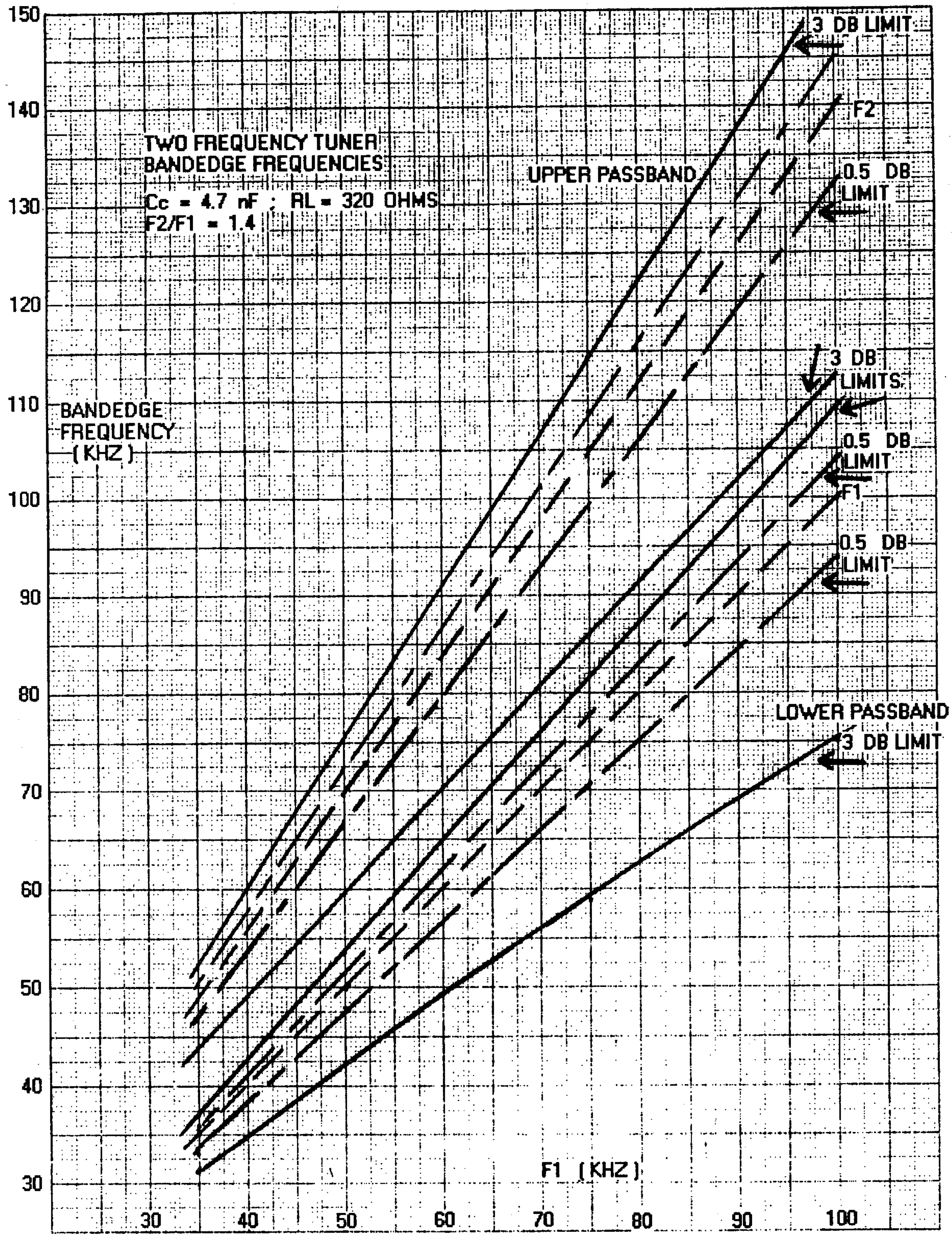

TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 4.7 nF ; RL = 320 OHMS
F2/F1 = 1.4
UPPER PASSBAND
3 DB LIMIT
F2
0.5 DB LIMIT
3 DB LIMITS
0.5 DB LIMIT
F1
0.5 DB LIMIT
LOWER PASSBAND
3 DB LIMIT
BANDEDGE FREQUENCY (KHZ)
F1 (KHZ)
150
140
130
120
110
100
90
80
70
60
50
40
30
30
40
50
60
70
80
90
100

Figure 16-19

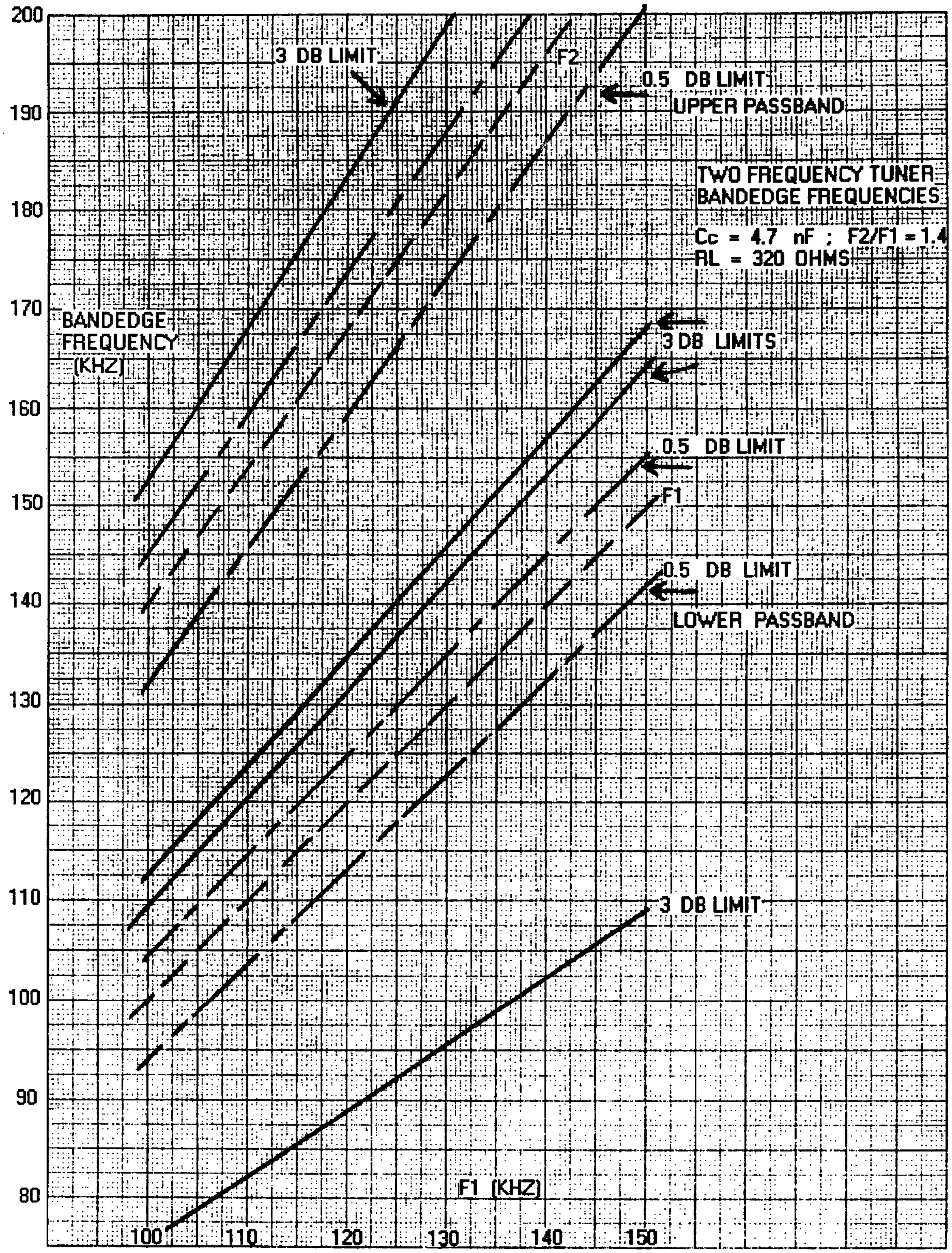

3 DB LIMIT
F2
0.5 DB LIMIT
UPPER PASSBAND
TWO FREQUENCY TUNER
BANDEDGE FREQUENCIES
Cc = 4.7 nF ; F2/F1 = 1.4
RL = 320 OHMS
BANDEDGE
FREQUENCY
(KHZ)
3 DB LIMITS
0.5 DB LIMIT
F1
0.5 DB LIMIT
LOWER PASSBAND
3 DB LIMIT
F1 (KHZ)
200
190
180
170
160
150
140
130
120
110
100
90
80
100
110
120
130
140
150

Figure 16-20

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TABULAR LISTINGS OF BANDEDGE FREQUENCIES FOR TWO-FREQUENCY LINE TUNERS

TABLE 16-1.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER

F2/F1 = 1.25 ; C_c = 2.15 NF ; R_L = 320 OHMS
(LOWER PASSBAND)

F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.02	33.59	2.370	10.368
	.50	10.20	34.60	.740	3.620
	.18	13.49	34.74	.480	2.110
	.18	14.25	35.22		
	.50	10.62	35.34		
	3.00	3.20	35.96		
50.0	3.00	3.11	46.92	4.880	21.159
	.50	9.51	49.08	1.640	7.389
	.18	13.76	49.48	.940	4.306
	.18	14.68	50.42		
	.50	10.05	50.72		
	3.00	3.49	51.80		
75.0	3.00	3.38	67.25	10.800	47.608
	.50	9.79	72.90	3.600	16.624
	.18	13.20	73.70	2.300	9.688
	.18	13.94	76.00		
	.50	10.33	76.50		
	3.00	3.49	78.55		
100.0	3.00	3.87	85.00	20.600	84.636
	.50	10.10	96.20	6.200	29.555
	.18	14.56	98.00	3.400	17.223
	.18	15.87	101.40		
	.50	10.90	102.40		
	3.00	3.71	105.60		
125.0	3.00	4.61	100.40	32.300	132.245
	.50	10.72	119.20	9.400	46.180
	.18	14.68	121.80	5.400	26.911
	.18	15.57	127.20		
	.50	10.89	128.60		
	3.00	4.08	132.70		
150.0	3.00	5.62	114.20	45.800	190.433
	.50	11.49	142.00	12.500	66.499
	.18	15.17	145.50	7.500	38.753
	.18	15.81	153.00		
	.50	11.84	154.50		
	3.00	4.34	160.00		

TABLE 16-2.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
$F2/F1 = 1.25$; $C_c = 2.15$ NF ; $R_L = 320$ OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
43.75	3.00	3.07	42.520	2.470	16.200
	.50	9.64	43.320	.850	5.657
	.18	13.94	43.500	.490	3.297
	.18	14.26	43.990		
	.50	9.81	44.170		
	3.00	3.08	44.970		
62.5	3.00	3.12	60.000	4.950	33.061
	.50	9.66	61.625	1.750	11.545
	.18	13.73	61.975	1.025	6.727
	.18	14.10	63.000		
	.50	9.61	63,375		
	3.00	3.12	64.950		
93.75	3.00	3.33	88.150	10.900	74.387
	.50	9.84	91.800	3.850	25.976
	.18	14.04	92.600	2.250	15.137
	.18	14.31	94.850		
	.50	10.29	95.650		
	3.00	3.29	99.050		
125.0	3.00	3.68	115.000	19.000	132.245
	.50	10.21	121.600	6.600	46.180
	.18	14.40	123.000	3.800	26.912
	.18	15.03	126.800		
	.50	10.29	128.200		
	3.00	3.51	134.000		
156.25	3.00	4.26	141.050	28.550	206.663
	.50	10.66	151.000	10.200	72.156
	.18	14.85	153.200	5.800	42.049
	.18	15.25	159.000		
	.50	10.35	161.200		
	3.00	3.74	169.600		
187.5	3.00	4.85	166.800	38.500	297.552
	.50	11.33	180.100	14.000	103.905
	.18	15.55	183.300	8.000	60.552
	.18	15.59	191.300		
	.50	10.91	194.100		
	3.00	4.10	205.300		

16

TABLE 16-3.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER

F2/F1 = 1.25 ; C_c = 3.00 NF ; R_L = 320 OHMS
(LOWER PASSBAND)

F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.06	32.90	3.350	14.347
	.50	9.76	34.40	1.100	5.010
	.18	12.77	34.60	.750	2.920
	.18	12.91	35.35		
	.50	9.87	35.50		
	3.00	3.19	36.25		
50.0	3.00	3.34	45.40	6.850	29.281
	.50	9.64	48.70	2.250	10.225
	.18	14.14	49.30	1.250	5.958
	.18	14.99	50.55		
	.50	10.15	50.95		
	3.00	3.43	52.25		
75.0	3.00	3.96	63.20	16.100	65.882
	.50	10.07	72.00	4.900	23.006
	.18	14.39	73.40	2.800	13.407
	.18	14.93	76.20		
	.50	10.20	76.90		
	3.00	3.71	79.30		
100.0	3.00	5.12	78.00	28.400	117.123
	.50	10.92	94.80	8.800	40.899
	.18	15.45	97.40	4.400	23.834
	.18	16.16	101.80		
	.50	11.23	103.00		
	3.00	4.27	106.40		
125.0	3.00	6.81	91.40	42.350	183.005
	.50	12.31	117.50	11.500	64.905
	.18	15.98	121.00	6.500	37.241
	.18	16.87	127.50		
	.50	12.19	129.00		
	3.00	4.62	133.75		
150.0	3.00	8.95	105.00	55.800	263.528
	.50	13.31	140.00	15.200	92.024
	.18	17.29	145.00	8.200	53.628
	.18	17.52	153.20		
	.50	12.55	155.20		
	3.00	5.25	160.80		

TABLE 16-4.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.25 ; C_c = 3.00 NF ; R_L = 320 OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
43.75	3.00	3.13	42.050	3.35	22.418
	.50	9.61	43.150	1.20	7.828
	.18	13.89	43.400	.80	4.562
	.18	13.86	44.100		
	.50	9.56	44.350		
	3.00	3.17	45.400		
62.5	3.00	3.23	59.000	6.80	45.751
	.50	9.83	61.300	2.40	15.976
	.18	14.13	61.800	1.40	9.310
	.18	14.04	63.200		
	.50	9.69	63.700		
	3.00	3.25	65.800		
93.75	3.00	3.79	86.000	14.700	102.941
	.50	10.27	91.100	5.200	35.947
	.18	15.03	92.300	3.000	20.948
	.18	14.20	95.300		
	.50	10.11	96.300		
	3.00	3.57	100.700		
125.0	3.00	4.57	111.750	24.430	183.005
	.50	11.02	120.400	8.800	63.972
	.18	15.38	122.400	5.000	37.241
	.18	15.36	127.400		
	.50	10.66	129.200		
	3.00	3.99	136.000		
156.25	3.00	5.35	137.800	34.450	285.946
	.50	12.27	149.400	12.850	99.972
	.18	16.34	152.400	7.200	58.190
	.18	16.29	159.600		
	.50	11.25	162.250		
	3.00	4.39	172.250		
187.5	3.00	6.08	164.400	43.600	411.762
	.50	14.20	178.600	16.200	143.787
	.18	18.25	182.800	9.000	83.794
	.18	17.12	192.800		
	.50	12.41	194.800		
	3.00	4.93	208.000		

16

TABLE 16-5.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.25 ; C_c = 4.70 NF ; R_L = 320 OHMS (LOWER PASSBAND)					
F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.41	31.450	5.190	22.113
	.50	9.76	34.025	1.675	7.722
	.18	14.23	34.475	.925	4.500
	.18	15.25	35.400		
	.50	10.26	35.700		
	3.00	3.51	36.640		
50.0	3.00	4.06	41.900	10.940	45.129
	.50	10.21	47.975	3.325	15.759
	.18	14.55	48.925	1.850	9.184
	.18	15.42	50.775		
	.50	10.61	51.300		
	3.00	3.89	52.840		
75.0	3.00	6.16	56.300	23.725	101.540
	.50	11.64	70.700	6.650	35.457
	.18	15.84	72.800	3.700	20.663
	.18	16.23	76.500		
	.50	11.80	77.350		
	3.00	4.58	80.025		
100.0	3.00	9.34	69.750	37.450	180.510
	.50	13.58	93.400	10.000	63.036
	.18	17.35	96.600	5.500	36.735
	.18	17.77	102.100		
	.50	12.84	103.400		
	3.00	5.35	107.200		
125.0	3.00	13.18	84.000	50.300	282.050
	.50	15.47	116.600	12.570	98.493
	.18	19.07	120.800	6.900	57.398
	.18	18.68	127.700		
	.50	13.72	129.350		
	3.00	6.09	134.300		
150.0	3.00	6.83	99.200	62.000	406.160
	.50	16.94	140.800	14.200	141.830
	.18	20.46	145.400	7.600	82.653
	.18	20.00	153.000		
	.50	14.74	155.000		
	3.00	6.83	161.200		

TABLE 16-6.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.25 ; C_c = 4.70 NF ; R_L = 320 OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
43.75	3.00	3.35	41.125	5.070	34.552
	.50	9.95	42.850	1.775	12.065
	.18	14.48	43.240	1.010	7.031
	.18	14.52	44.250		
	.50	9.96	44.625		
	3.00	3.32	46.200		
62.5	3.00	3.86	57.125	10.075	70.513
	.50	10.42	60.700	3.500	24.623
	.18	15.05	61.500	2.000	14.349
	.18	14.72	63.500		
	.50	10.33	64.200		
	3.00	3.59	67.200		
93.75	3.00	5.14	82.950	19.860	158.650
	.50	11.95	89.950	7.100	55.402
	.18	16.67	91.750	4.000	32.286
	.18	15.68	95.750		
	.50	11.38	97.050		
	3.00	4.29	102.810		
125.0	3.00	6.17	109.400	29.100	282.050
	.50	14.62	119.000	10.950	98.493
	.18	18.55	121.850	5.950	57.398
	.18	17.50	127.800		
	.50	12.39	129.950		
	3.00	5.09	138.500		
156.25	3.00	7.02	136.250	37.850	440.710
	.50	18.27	148.850	13.400	153.900
	.18	20.88	152.250	7.550	89.684
	.18	18.71	159.800		
	.50	13.88	162.250		
	3.00	5.83	174.100		
187.5	3.00	7.79	163.300	46.050	634.620
	.50	20.70	179.500	14.900	221.621
	.18	22.66	183.100	8.400	129.880
	.18	19.91	191.800		
	.50	14.87	194.400		
	3.00	6.52	209.350		

TABLE 16-7.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
$F2/F1 = 1.25$; $C_c = 10.0$ NF ; $R_L = 30$ OHMS (LOWER PASSBAND)					
F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.02	34.470	0.970	4.198
	.50	9.27	34.825	0.345	1.466
	.18	12.88	34.895	.200	0.854
	.18	14.12	35.090		
	.50	9.77	35.160		
	3.00	3.24	35.440		
45.0	3.00	3.18	44.140	1.560	6.940
	.50	9.47	44.710	0.540	2.422
	.18	13.24	44.825	0.325	1.412
	.18	14.13	45.150		
	.50	10.12	45.250		
	3.00	3.54	45.700		
55.0	3.00	3.29	53.771	2.295	10.367
	.50	9.56	54.700	0.670	3.620
	.18	13.50	54.745	0.475	2.110
	.18	14.28	55.220		
	.50	10.11	55.370		
	3.00	3.44	56.000		
75.0	3.00	3.62	72.600	4.120	19.278
	.50	9.68	74.200	1.440	6.732
	.18	13.18	74.500	0.900	3.923
	.18	14.42	75.400		
	.50	10.55	75.640		
	3.00	3.73	76.720		
100.0	3.00	4.13	95.690	7.120	34.272
	.50	10.52	98.700	2.360	11.968
	.18	14.54	99.240	1.380	6.974
	.18	15.49	100.620		
	.50	10.55	101.060		
	3.00	4.13	102.810		
120.0	3.00	4.57	113.600	10.200	49.352
	.50	10.92	118.180	3.320	17.233
	.18	15.34	119.000	1.860	10.043
	.18	15.77	120.860		
	.50	11.05	121.500		
	3.00	4.43	123.800		

TABLE 16-8.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
$F2/F1 = 1.25$; $C_c = 10.0$ NF ; $R_L = 30$ OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
43.75	3.00	3.13	43.225	1.045	6.560
	.50	9.29	43.560	.375	2.291
	.18	13.60	43.645	.205	1.335
	.18	13.93	43.850		
	.50	9.46	43.935		
	3.00	3.13	44.270		
56.25	3.00	3.16	55.390	1.700	10.844
	.50	9.63	55.950	0.600	3.787
	.18	13.51	56.070	0.360	2.207
	.18	13.36	56.430		
	.50	9.52	56.555		
	3.00	3.18	57.090		
68.75	3.00	3.29	67.500	2.470	16.199
	.50	9.72	68.310	0.870	5.656
	.18	14.07	68.500	0.500	3.296
	.18	14.03	69.000		
	.50	9.83	69.180		
	3.00	3.30	69.970		
93.75	3.00	3.51	91.470	4.480	30.122
	.50	10.09	92.970	1.560	10.518
	.18	14.21	93.290	0.920	6.130
	.18	14.15	94.210		
	.50	9.98	94.530		
	3.00	3.48	95.950		
125.0	3.00	3.90	121.040	7.700	53.550
	.50	10.43	123.660	2.620	18.700
	.18	14.67	124.220	1.540	10.897
	.18	14.74	125.760		
	.50	10.57	126.780		
	3.00	3.79	128.740		
150.0	3.00	4.28	144.140	10.840	77.112
	.50	10.82	148.140	3.640	26.927
	.18	14.92	148.900	2.160	15.692
	.18	15.10	151.060		
	.50	10.84	151.780		
	3.00	4.05	155.240		

TABLE 16-9.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.40 ; C_c = 2.15 NF ; R_L = 320 OHMS (LOWER PASSBAND)					
F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.10	33.330	2.940	10.368
	.50	9.52	34.450	1.050	3.620
	.18	13.95	34.690	.590	2.110
	.18	14.37	35.280		
	.50	9.89	35.480		
	3.00	3.21	36.270		
50.0	3.00	3.25	46.000	6.430	21.159
	.50	9.30	48.825	2.175	7.389
	.18	12.93	49.275	1.375	4.306
	.18	13.12	50.650		
	.50	9.50	51.000		
	3.00	3.27	52.430		
75.0	3.00	3.65	66.900	12.850	47.608
	.50	10.08	72.550	4.390	16.624
	.18	14.54	73.650	2.470	9.688
	.18	15.19	76.120		
	.50	10.40	76.940		
	3.00	3.63	79.750		
100.0	3.00	4.24	85.450	22.000	84.636
	.50	10.59	95.800	7.450	29.555
	.18	14.99	97.700	4.200	17.223
	.18	15.34	101.900		
	.50	10.54	103.250		
	3.00	3.99	107.450		
125.0	3.00	5.05	102.600	32.650	132.245
	.50	12.20	118.750	10.750	46.180
	.18	15.41	121.550	6.150	26.911
	.18	15.88	127.700		
	.50	11.22	129.500		
	3.00	4.42	135.250		
150.0	3.00	6.09	119.000	44.100	190.433
	.50	11.92	141.600	14.200	66.499
	.18	16.23	145.500	8.000	38.753
	.18	16.48	153.500		
	.50	11.78	155.800		
	3.00	4.86	163.100		

TABLE 16-10.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.40 ; C_c = 2.15 NF ; R_L = 320 OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
49.0	3.00	3.09	46.800	4.040	20.321
	.50	9.61	48.260	1.420	7.096
	.18	14.05	48.580	.800	4.135
	.18	14.61	49.380		
	.50	9.83	49.680		
	3.00	3.19	50.840		
70.0	3.00	3.25	65.460	8.040	41.472
	.50	9.77	68.500	2.820	14.482
	.18	14.29	69.160	1.590	8.439
	.18	14.83	70.750		
	.50	10.10	71.320		
	3.00	3.36	73.500		
105.0	3.00	3.62	94.400	17.600	93.312
	.50	10.13	101.650	6.150	32.584
	.18	14.46	103.100	3.540	18.989
	.18	14.94	106.640		
	.50	10.36	107.800		
	3.00	3.69	112.000		
140.0	3.00	4.29	120.900	29.950	165.888
	.50	10.76	134.200	10.300	57.928
	.18	15.40	136.900	5.700	33.758
	.18	15.80	142.600		
	.50	10.95	144.500		
	3.00	4.18	150.850		
175.0	3.00	5.10	146.000	43.800	259.200
	.50	12.74	166.400	14.800	90.513
	.18	15.99	170.300	8.400	52.747
	.18	16.40	178.700		
	.50	11.71	181.200		
	3.00	4.72	189.800		
210.0	3.00	5.84	171.900	56.800	373.249
	.50	12.89	198.300	19.700	130.338
	.18	17.04	203.800	11.100	75.956
	.18	16.82	214.900		
	.50	12.25	218.000		
	3.00	5.26	228.700		

TABLE 16-11.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.40 ; C_c = 3.00 NF ; R_L = 320 OHMS (LOWER PASSBAND)					
F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.16	32.60	4.000	14.347
	.50	9.70	34.25	1.350	5.010
	.18	14.53	34.60	.800	2.920
	.18	13.94	35.40		
	.50	10.51	35.60		
	3.00	3.44	36.60		
50.0	3.00	3.50	45.00	8.000	29.281
	.50	10.03	48.50	2.700	10.225
	.18	15.07	49.20	1.500	5.958
	.18	14.80	50.70		
	.50	10.40	51.20		
	3.00	3.56	53.00		
75.0	3.00	4.43	64.00	16.600	65.882
	.50	10.75	71.80	5.600	23.006
	.18	14.94	73.20	3.200	13.407
	.18	15.75	76.40		
	.50	10.92	77.40		
	3.00	4.13	80.60		
100.0	3.00	5.57	80.60	28.000	117.123
	.50	11.36	94.50	9.200	40.899
	.18	15.56	97.00	5.500	23.834
	.18	15.24	102.50		
	.50	11.62	103.70		
	3.00	4.64	108.50		
125.0	3.00	7.17	96.60	39.700	183.005
	.50	12.50	117.40	12.600	64.905
	.18	16.43	120.80	7.400	37.241
	.18	16.49	128.20		
	.50	12.29	130.00		
	3.00	5.27	136.30		
150.0	3.00	8.97	112.70	51.300	263.528
	.50	13.73	140.70	15.300	92.024
	.18	17.72	145.00	8.800	53.628
	.18	17.59	153.80		
	.50	13.25	156.00		
	3.00	5.89	164.00		

TABLE 16-12.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.40 ; C_c = 3.00 NF ; R_L = 320 OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
49.0	3.00	3.20	45.900	5.500	28.121
	.50	9.88	48.000	1.900	9.820
	.18	13.86	48.400	1.100	5.723
	.18	14.57	49.500		
	.50	10.08	49.900		
	3.00	3.31	51.400		
70.0	3.00	3.50	63.500	11.00	57.390
	.50	10.26	68.000	3.75	20.041
	.18	13.86	68.750	2.25	11.679
	.18	13.12	71.000		
	.50	10.27	71.750		
	3.00	3.50	74.500		
105.0	3.00	4.40	90.000	23.250	129.129
	.50	10.88	100.500	8.500	45.092
	.18	15.18	102.500	4.500	26.278
	.18	15.86	107.000		
	.50	11.42	108.500		
	3.00	5.09	113.250		
140.0	3.00	6.51	115.000	37.000	229.562
	.50	14.17	132.000	13.500	80.163
	.18	17.96	136.000	7.000	46.716
	.18	17.89	143.000		
	.50	13.28	145.500		
	3.00	5.71	152.000		
175.0	3.00	7.10	142.000	49.000	358.691
	.50	16.40	164.500	17.000	125.255
	.18	17.96	169.500	9.500	72.994
	.18	17.89	179.000		
	.50	13.28	181.500		
	3.00	5.71	191.000		
210.0	3.00	7.10	169.000	60.600	516.514
	.50	16.40	197.500	20.500	180.367
	.18	19.62	203.500	11.500	105.111
	.18	18.39	215.000		
	.50	15.40	218.000		
	3.00	6.20	229.600		

TABLE 16-13.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER

$F2/F1 = 1.40$; $C_c = 4.70$ NF ; $R_L = 320$ OHMS
(LOWER PASSBAND)

F1 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
35.0	3.00	3.62	31.250	5.900	22.113
	.50	10.24	33.900	1.975	7.722
	.18	14.48	34.350	1.125	4.500
	.18	15.44	35.500		
	.50	10.56	35.875		
	3.00	3.66	37.150		
50.0	3.00	4.45	42.350	11.450	45.129
	.50	10.70	47.800	3.805	15.759
	.18	15.09	48.800	2.200	9.184
	.18	15.26	51.000		
	.50	11.04	51.600		
	3.00	4.10	53.800		
75.0	3.00	6.57	59.000	22.600	101.540
	.50	12.19	70.700	7.200	35.457
	.18	16.13	72.600	4.200	20.663
	.18	16.51	76.800		
	.50	12.05	77.900		
	3.00	5.05	81.600		
100.0	3.00	9.27	75.200	34.100	180.510
	.50	14.02	94.000	10.000	63.036
	.18	18.08	96.800	5.600	36.735
	.18	18.12	102.400		
	.50	13.26	104.000		
	3.00	5.98	109.300		
125.0	3.00	11.81	92.000	44.800	282.050
	.50	15.36	117.700	12.200	98.493
	.18	19.07	121.000	7.000	57.398
	.18	18.87	128.000		
	.50	14.23	129.900		
	3.00	6.82	136.800		
150.0	3.00	13.41	109.000	55.250	406.160
	.50	16.26	142.000	13.500	141.830
	.18	20.29	145.800	7.500	82.653
	.18	19.89	153.300		
	.50	15.11	155.500		
	3.00	7.44	164.250		

TABLE 16-14.

TABLE OF BANDWIDTH FREQUENCIES FOR TWO-FREQUENCY TUNER					
F2/F1 = 1.40 ; C_c = 4.70 NF ; R_L = 320 OHMS (UPPER PASSBAND)					
F2 (KHZ)	ATTEN. (DB)	RETURN LOSS (DB)	FREQUENCY (KHZ)	BANDWIDTH (KHZ)	BW RESONANT TUNER (KHZ)
49.0	3.00	3.65	44.060	8.140	43.341
	.50	10.17	47.450	2.840	15.135
	.18	14.48	48.120	1.630	8.820
	.18	15.06	49.750		
	.50	10.39	50.290		
	3.00	3.73	52.200		
70.0	3.00	4.54	59.700	15.75	88.452
	.50	11.15	67.000	5.25	30.887
	.18	15.51	68.350	3.00	18.000
	.18	15.92	71.350		
	.50	11.35	72.250		
	3.00	4.39	75.450		
105.0	3.00	6.16	85.400	28.800	199.020
	.50	13.51	99.000	9.900	69.497
	.18	17.87	102.000	5.400	40.500
	.18	17.33	107.400		
	.50	12.75	108.900		
	3.00	5.56	114.200		
140.0	3.00	7.28	112.500	40.300	353.810
	.50	16.81	132.000	13.200	123.550
	.18	20.25	136.000	7.100	72.000
	.18	19.06	143.100		
	.50	14.07	145.200		
	3.00	6.55	152.800		
175.0	3.00	8.24	140.200	50.800	552.820
	.50	18.63	166.000	15.000	193.050
	.18	21.48	170.300	8.300	112.500
	.18	20.16	178.600		
	.50	15.26	181.000		
	3.00	7.39	191.000		
210.0	3.00	8.95	168.100	61.000	796.070
	.50	18.78	200.600	16.000	277.990
	.18	22.13	205.200	8.800	162.000
	.18	20.64	214.000		
	.50	15.95	216.600		
	3.00	7.98	229.100		

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SECTION 17

HIGHPASS LINE TUNERS

Contents of Section 17

INTRODUCTION

Highpass line tuners find limited application on high voltage transmission lines since the lower limit of the frequency range which can be successfully coupled depends for the most part on the size of the coupling capacitor. Assuming that the surge impedance of the power transmission line is 300 ohms, nominal, the lowest frequency which can be passed with an attenuation of 0.5 dB, is shown in Table 1. This limitation of the frequency range for high voltage lines is a disadvantage for highpass line tuners. The wide band of frequencies above the low frequency limit cannot be matched with a complementary blocking impedance of a line trap. The noise bandwidth of the highpass tuner also makes the coupling susceptible to wideband noise either from switching or from corona or weather related disturbances. Because of the limit on the lower passband frequency which depends on the coupling capacitor value and the line impedance, highpass line tuners are not used for power cable applications.

TABLE 1

Coupling Capacitor (UF)	Cutoff Frequency (KHZ)
0.01	44.6
0.005	89.2
0.0025	178.4
0.001	446.0

INSULATED SHIELD WIRE COUPLERS

One method which has been used to gain additional channels for various communications over the power transmission system has been the use of appropriate couplers to use the shield wires as conductors of RF signals. The frequency range which can be coupled begins at about 12 kHz and extends to 300-400 kHz. The attenuation of RF signals on the shield wire may limit the high frequency end of the useful spectrum. Insulated Shield Wire (ISW) circuits can be either a single conductor or a two conductor installations. The line tuner consists of an impedance matching transformer, a highpass tuner consisting of a series capacitance element, a shunt inductance element, and a protective unit containing: (1) a power frequency blocking capacitor, (2) a spark gap, (3) a ground switch, and (4) a drain coil. This line tuner is connected to the ISW coupler consisting of a coupling capacitor; a drain coil which will pass a continuous current up to 100 amperes at the power frequency; a lightning arrestor; and a heavy duty ground switch. The ISW drain coil is the line-type component of this coupling circuit.

The material of the shield wires has a marked effect on the attenuation in the shield wire circuit. Also, dual shield wires have less loss because of the modal propagation of signals coupled to the wires. Since the insulation of the wires from the towers is of the order of 10 kv, the wires are essentially at ground potential as far as lightning strikes are concerned. The breakdown of the insulation during thunder/lightning storms limits the use of ISW channels to non-critical applications. Voice, SCADA, data, and non-protection channels have been used successfully over ISW facilities.

The icing of the conductors and the transpositions required for power frequency considerations must be considered when applying channels to ground wires. The individual shield wires must be grounded at each station by the ISW coupler through the drain coil. This is generally done at the entrance to the substation. Grounding of the shield wires at the entrances to the substation will usually allow frequencies to be repeated on each ISW line section, or certainly after one line section.

Figure 17-1 shows the circuit diagram of a single insulated shield wire coupler and the line tuner which is used to match the carrier equipment to the ISW impedance. The tuning units in the line tuning assembly are the same type units found in line tuners for high voltage cables and for overhead lines. The special components are all contained in the ISW drain coil assembly. These dain coils are usually encapsulated coils which must be handled by heavy lifting equipment. These assemblies are mounted on a special frame near the location where the ISW enters the substation.

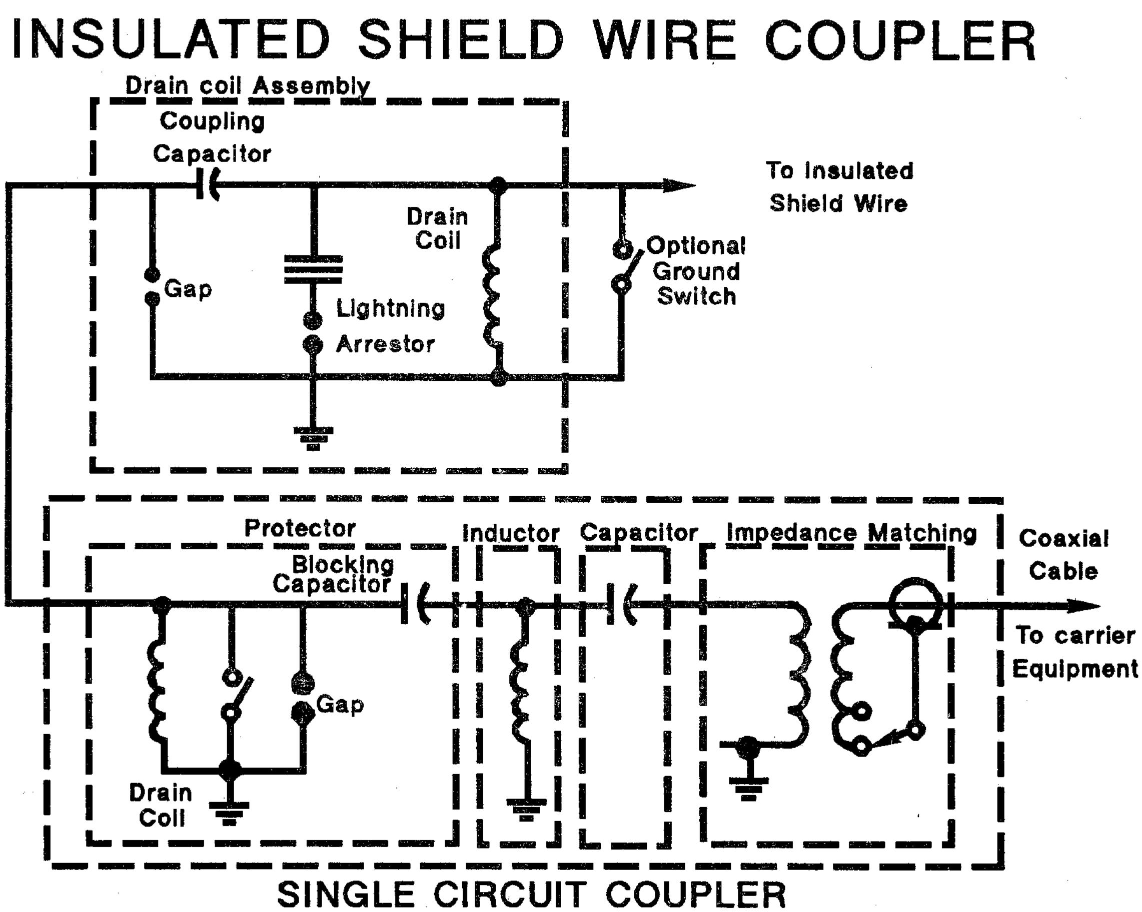

Figure 17-1. Coupling Circuit for Single Circuit ISW Coupler

Figure 17-2 shows the physical location of two ISW drain coil assemblies. One of the assemblies terminates the ISW on the end of one line section while the second is used to terminate the line section at the other side of the substation.

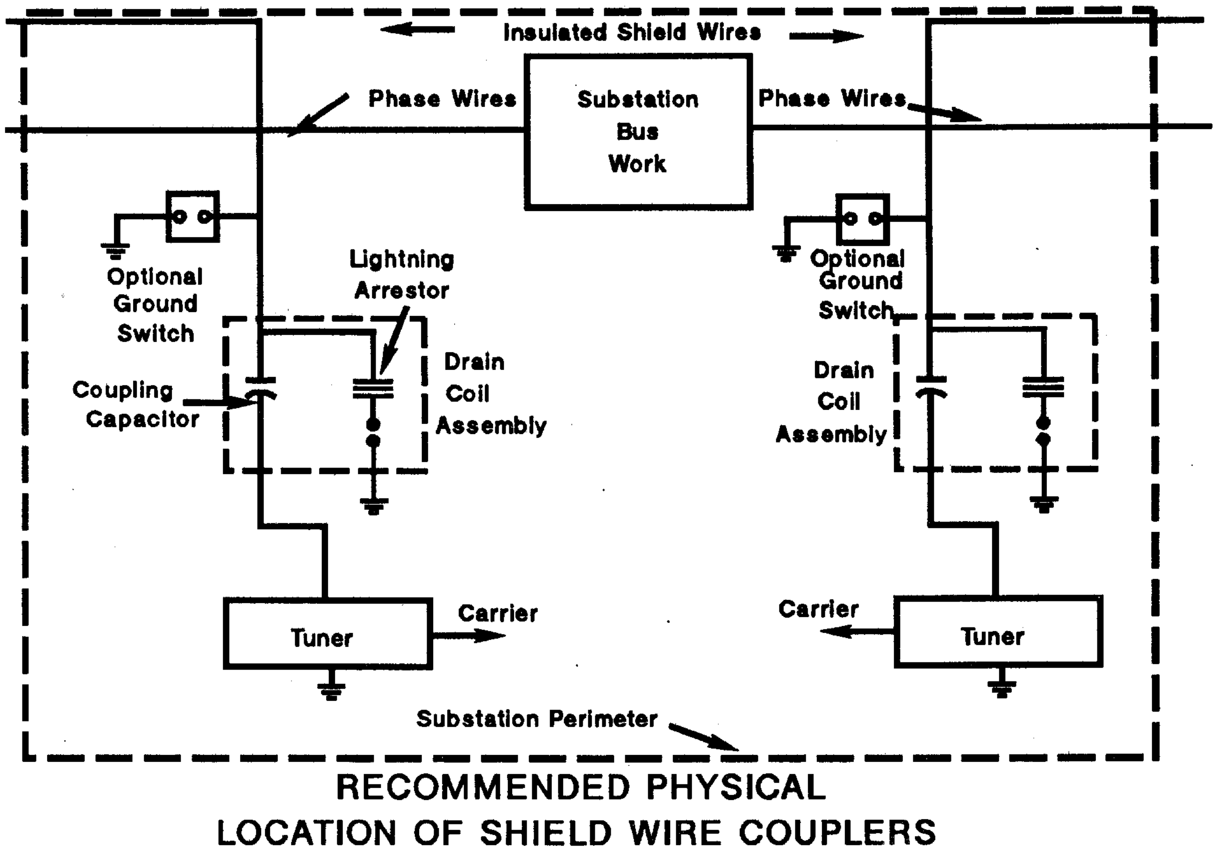

Figure 17-2. Location of ISW Couplers in Substation Yard

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SECTION 18

Appendix A

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Appendix B
GLOSSARY

Amplitude modulation: The process of varying the amplitude of a continuous high-frequency wave (known as the carrier) in direct relation to the amplitude variations of the signal to be transmitted.

Amplitude modulated wave: A wave whose envelope contains components similar to the wave form of the signal to be transmitted.

Attenuation: A general term used to denote a decrease in magnitude of a transmitted signal from one point to another. It may be expressed as a ratio or, by extension of the term, in decibels (dB).

Audio frequency or audio tone frequency: A frequency between 20 and 20,000 Hz.

Automatic frequency control (AFC): A self-acting compensating circuit that maintains the carrier oscillator output within narrow limits of the assigned frequency.

Automatic gain control (AGC): A self-acting feedback circuit that maintains a constant signal level, within the range of the AGC circuit.

Automatic load control: A control system in which raise-and-lower impulses from a suitable controller are transmitted by carrier to influence the governor adjustment of one or more generators.

Auxiliary unit: The chassis unit used with a carrier transmitter or receiver to adapt the carrier channel to a specific purpose.

Back-to-back repeater: The process of repeating a signal at line frequencies with no local drop. The receiver output is connected to the transmitter input; the transmitter being at a frequency different from that of the receiver.

Bandwidth: The range of frequencies within the limits of a band, generally taken to be the two frequencies (f_1 and f_2 in Figure 18-1) that are attenuated 3 dB below the average level of the band. Used to define the limit of such devices as filters, voice channels and power amplifiers. The wider the bandwidth, the faster the channel for teleprotection purposes. A wideband channel is also more susceptible to noise interference. The bandwidth may also be specified or measured in terms of a minimum return loss value, which is usually in the range of 10 to 14 decibels. (See Return loss.)

Baseband repeater: The process of repeating a signal at the baseband level (one stage of demodulation). The signal is remodulated and transmitted at a different frequency.

Balancing network: An arrangement of impedances connected to one branch of a hybrid to match the impedance of the line connected to the opposite branch.

Beating: The linear addition or subtraction of two frequencies, which produce a third frequency pulsating in amplitude.

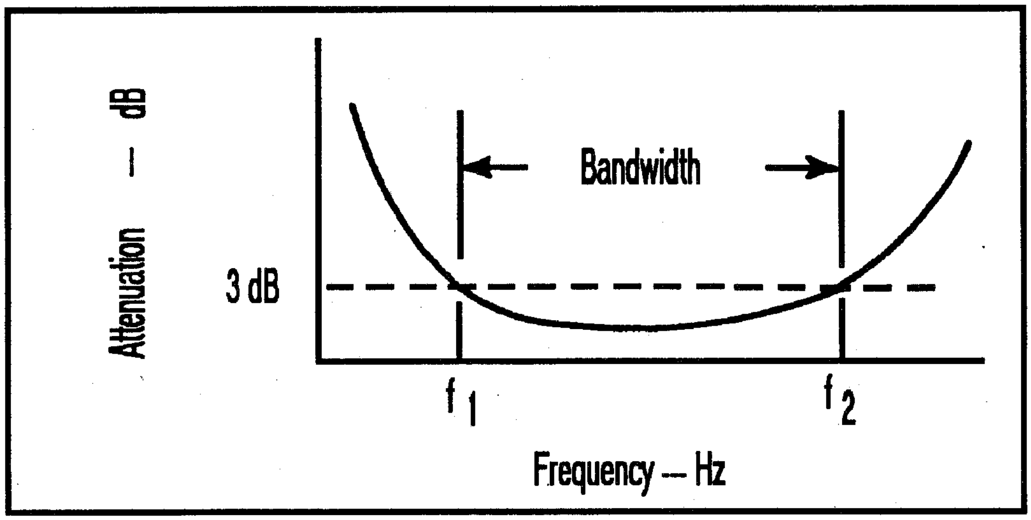


Figure 18-1. Bandwidth

Beat note: The third frequency produced by beating.

Bypass: The act of removing the carrier signal from one line and reinserting the same signal onto a second line. Bypass is necessary to get around a power bus, open disconnect, or other discontinuity.

Carrier channel: All elements that make up a complete PLC circuit between two or more points, including both the carrier apparatus and the power lines.

Carrier-current choke coil: A reactor frequently connected in series between the potential tap of the coupling capacitor and potential device transformer unit, to present a low impedance to 60 Hz power current and a high impedance to carrier frequency current. Its purpose is to limit the loss of carrier-frequency energy through the potential-device circuit.

Carrier-current drain coil: A reactor connected between the carrier-current lead and ground, to present a low impedance to the flow of power current and a high impedance to carrier-frequency current. Its purpose is to prevent high voltage at power frequency from being impressed on the carrier-current lead, and to limit the loss of carrier-frequency energy to ground.

Carrier-current lead-in: The connection from the coupling capacitor to the PLC equipment or line tuner.

Carrier-current grounding switch and gap: A protective gap for limiting the voltage impressed on the carrier-current lead-in and the line tuner (if used); and a switch which, when closed, solidly grounds the carrier equipment for maintenance or adjustment without interrupting either high-voltage line or potential-device operation.

Carrier frequency: The frequency generated by the carrier transmitter and impressed, with or without modulation, onto the power line.

Carrier signaling: A carrier-frequency tone transmitted on each voice channel for control functions and dial signaling.

Carrier system: Usually refers to all the interconnected carrier terminals using the same carrier frequency.

Carrier terminal: All of the PLC apparatus of one channel located at one station or location.

Channel: A specific band of frequencies assigned for a particular purpose (e.g., tone channel, voice channel or carrier channel).

Channel blocking: Presence of a signal blocks tripping of a protective relay.

Channel modem: That part of the SSB multiplex equipment which provides the first stage of modulation (channel) carrier modulated by external signal, voice, tone, etc.), for transmission, and the final stage of demodulation for reception.

Channel tripping: Presence of a signal causes tripping of a protective relay.

Characteristic impedance: The ratio of an applied potential difference to the resultant current at the point where the potential difference is applied, when the transmission line is of infinite length.

Common equipment: Carrier equipment that is common to two or more channels (carrier generation, group, etc.).

Compandor: A pre-emphasis device which compresses the audio signal level at the transmitter into a narrower range nearer the maximum level. At the receiver, an expandor reverses this process. This allows the signal to be transmitted at nearer maximum level and provides a significant signal-to-noise improvement in the speech signal.

Coupling capacitor: The assembly used to isolate the carrier-current equipment from the high-voltage line, and also to couple the carrier signal to and from the power line.

Crosstalk: The energy transferred to an adjacent channel when a test tone is inserted in a channel at normal signal level.

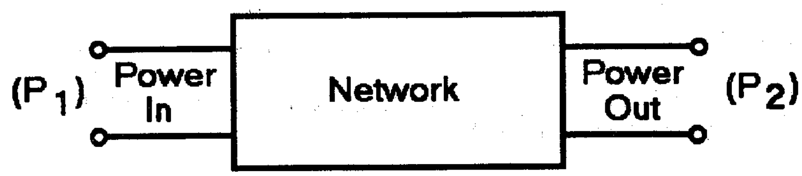
Coupling capacitor voltage transformer: A coupling capacitor with a transformer network, usually mounted in the base of the coupling capacitor, to obtain potential indication for synchronizing, relaying, etc. The coupling capacitor can also perform the usual carrier coupling function.

Cutoff frequency: That frequency at which the signal is attenuated 3 dB below the average level of the band. This frequency may also correspond to a value of attenuation much less than 3 dB and may be assigned a minimum return loss value.

Decibel (dB): Logarithmic ratio of two powers. Expresses gain or loss without reference to absolute quantities. It is used to express coupling losses, system losses and the overall performance of a system.

dBA: Weighted noise power in dB referred to 3.16 pico-watts (-85 dBm) which is 0 dBA.

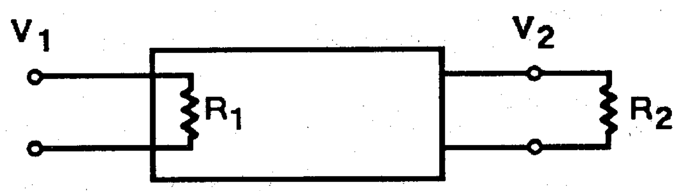
POWER RATIO



$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

Figure 18-2

VOLTAGE RATIO



$$dB = 10 \log_{10} \left(\frac{V_2^2 / R_2}{V_1^2 / R_1} \right)$$

$$= 20 \log_{10} \frac{V_2}{V_1} + 10 \log_{10} \frac{R_1}{R_2}$$

$$= 20 \log_{10} \frac{V_2}{V_1} \text{ if } R_1 = R_2$$

Figure 18-3

dBm and dBsr (dB scale reading): A reference to an absolute power and impedance. This impedance is 600 ohms and the power is one milliwatt.

$$\text{dBm} = 10 \log_{10}\{[V^2/600]/0.001\} = 10 \log_{10}[p/ 0.001]$$

Correction factor for reference impedance other than 600 ohms is:

$$\text{dB} = 10 \log_{10}[600/R_2]$$

The scale correction factors are:

R_2 (ohms)	dBm
50	dBsr + 10.8
75	dBsr + 9
150	dBsr + 6
600	dBsr + 0
1000	dBsr - 2.2

dBm0: Expresses a level referenced to a system test tone level. -10 dBm0 expresses a level 10 dB below the system test tone.

Dbrn: Decibels above reference noise. -90 dBm corresponds to 0 dBrn.

Dependability: The ability of a teleprotection channel to always permit or induce tripping a line when required to do so.

Dial signaling: Denotes a type of telephone signaling in which pulse trains are transmitted to a receiving terminal to operate automatic line-selection equipment.

Duplex: As applied to power line carrier, a system of communication in which transmission and reception are carried on without manual switching between the talking and listening periods. Similar to the operation of public telephone systems.

Echo: A signal that is reflected from some point, or points, in a circuit because of impedance mismatch, and returns to its originating point with sufficient magnitude and delay to be distinctly recognized.

"E" lead: The incoming control lead on a carrier channel, which is controlled by the "M" lead on the opposite end.

Four-wire circuit: A two-way circuit using two paths so arranged that the electric waves are transmitted in one direction by one path and in the other direction by the other path.

Four-wire terminating set: A hybrid arrangement by which four-wire circuits are converted to a two-wire basis for interconnection with other two-wire circuits.

Frequency range: An assigned frequency band employed for the application of power line carrier or audio tones. For PLC, this is nominally 30-500 kHz. Audio tones nominally use 300-3400 Hz voice-grade circuits.

Frequency-shift-keyed (FSK) carrier: A method of transmitting different control or indicating impulses by shifting the transmitted carrier frequency upward or downward. Corresponding relay (or solid-state switching) circuits in the receiver operate when they distinguish a frequency shift.

Frequency modulation: The process by which the frequency of a continuous high-frequency wave (carrier) is varied in direct relation to the amplitude of the signal transmitted.

Frequency-modulated wave: A wave whose frequency has been varied in direct relation with the amplitude of the signal transmitted.

Harmonic: A sinusoidal wave whose frequency is an integral multiple of a fundamental frequency.

High-pass filter: A filter designed to pass all frequencies above a certain predetermined cutoff frequency, and attenuate all frequencies below.

Hybrid: A bridge type circuit, or connecting device, that provides impedance matching between certain circuits, and isolation between others.

Hybrid balance: A simple hybrid has four sets of terminals, one connected to a two-wire line, two connected to the send and receive of a four-wire line, and one connected to a network designed to simulate the impedance of the two-wire line. The degree to which the two-wire line impedance is simulated is known as hybrid balance.

Impedance-matching transformers: A device for tying together lead-in circuits of different impedances or lengths.

In-band signaling: Signaling which utilizes frequencies within the voice, or intelligence, band of a channel.

Interface: The physical and electrical requirements for interconnecting two equipments or systems.

Interference: Any unwanted frequency or surge, regardless of duration, which causes a noticeable effect in the output circuit of a receiver.

Keyed carrier: A method of transmitting control or indicating pulses by turning the carrier on and off. Also referred to as AM or ON-OFF carrier.

Leakage: Loss of carrier energy due to an excessive number of insulators, high-shunt capacitance, inadequate or dirty insulators, or poor dielectric properties of the insulation.

Leased facilities: Services leased from a public telephone company for the exclusive use of the power company for communication, pilot relaying, control, telemetering or indication.

Line coupling: The coupling capacitors, line tuning, line traps and lead-in circuits which together provide a suitable connection between the power line and the carrier transmitter-receiver assembly.

Line differential relaying (same as pilot relaying): A form of protective relaying whereby conditions at the end terminals of a line section are compared through a high-speed teleprotection channel to locate a fault on the power system and clear it with minimum disturbance.

Line trap: A series inductance shunted by a tuning capacitor, inserted in series with the power line to reduce the loss of carrier energy and variations in line attenuation caused by switching or faults in the line beyond the trap.

Line tuning unit: A chassis unit or module containing adjustable tuning inductance and/or capacitance, and may also contain drainage and surge-protective devices and grounding switches. Also the unit may be an impedance-matching transformer for matching the impedance of the carrier equipment to that of the transmission line. A hybrid may also be a line tuning unit for interconnecting tuners.

Line tuner: An assembly, usually in an outdoor cabinet, containing one or more line-tuning units.

Local drop: A point where one or more channels of a multichannel system terminates (drops) between the end terminals of the system.

Local Traffic: Any and all communications which originate at any one station.

Lower sideband: The frequency, or group of frequencies, located below the carrier, produced by a modulation process.

Loss-pass filter: A filter designed to pass all frequencies below a certain predetermined cutoff frequency, and attenuate all frequencies above.

"M" lead: The control lead extending from the carrier channel to the telephone exchange or applicable control device. It is to control the outgoing signaling, which in turn controls the remote "E" lead.

Minimum frequency spacing: The minimum allowable frequency difference between adjacent channel center frequencies. This spacing can refer to the same type of equipment , or to different types of equipment.

Modulation: The combining of some lower frequency, usually speech or audio tones, with the fundamental carrier frequency.

Multiplex: A means of transmitting two or more signals over the same medium simultaneously.

Multiplex channel: A carrier channel which provides two or more services.

Noise: Any extraneous sound or interference signal which interferes with a desired signal.

Noise level: The strength of the extraneous noise; usually measured in decibels or dBm.

Offhook: The condition existing in a telephone circuit when the receiver, or handset, is removed from its cradle.

Onhook: The condition existing in a telephone circuit when the receiver, or handset, is resting in its cradle.

Operating margin: The amount that line attenuation and/or noise can increase before the received signal level falls to the point where intelligibility is poor or the receiver sensitivity is exceeded.

Operating Range: The total permissible attenuation between transmitter output and receiver input for average noise conditions which give the maximum operating range of the channel.

Out-of-band signaling: Signaling which utilizes frequencies within the bandwidth of the channel modem, but outside the voice frequency band.

Party line: A subscriber line serving two or more subscribers.

Phase-to-ground coupling: Line coupling made to only one conductor of the power line, utilizing ground return.

Phase-to-phase coupling: Line coupling made between two different conductors of the same power line.

Pilot: A carrier frequency transmitted for the purpose of frequency lock or automatic gain control regulation.

Pilot signal: A signal used in conjunction with protective relaying, either on wire line, carrier, or microwave.

Power line carrier (PLC): The art of applying low voltage, high-frequency energy directly to high voltage power lines or shield wires for the purpose of providing various forms of communications. Carrier frequencies generally used are in the range of 30-500 kHz.

Power output: Usually refers to the unmodulated carrier output in watts at the transmitter output terminals.

Preferential service: A feature of some dial-telephone carrier assemblies which permit designated extension lines to break into a conversation while another extension of the same terminal is in use.

Private automatic exchange (PAX): A fully automatic dial telephone exchange.

Private branch exchange (PBX): A telephone switchboard having provision for manual interconnection of telephone wires and carrier channels.

Rack unit: The term used with rack-and-panel assemblies to indicate the usable height provided by a standardized supporting rack. One rack unit is equal to 1-3/4 inches (44.45 mm).

Receiver assembly: A complete assembly, usually in an enclosing cabinet, containing a carrier-receiver unit, auxiliary circuits, protective units, etc.

Receiver unit: A standard chassis unit containing only a basic carrier receiver.

Reflection: A phenomenon resulting from impedance mismatch and, in carrier applications, sometimes caused by tapped or dead-ended lines that are not equipped with line traps at their junction with the main circuit

Return loss: A measure of the dissimilarity between two impedances, being equal to the number of decibels that correspond to the scalar value of the reciprocal of the reflection coefficient, and hence expressed by the formula

$$\text{Return Loss} = 20 \log_{10} \frac{Z_a + Z_b}{Z_a - Z_b}$$

Security: The ability of a teleprotection channel to never cause or permit tripping of a line section when not required.

Selectivity: The performance of an apparatus (such as a carrier receiver) with respect to the acceptance of a desired frequency, or band of frequencies, to the exclusion of undesired frequencies.

Sensitivity: The minimum input required by a device to enable it to perform its function properly.

Signal-to-noise ratio (SNR): The signal level (in dBm) minus the noise level (in dBm), resulting in a value expressed in dB. To provide an intelligible signal, the received signal must have an adequate SNR. The minimum SNR differs for different types of channel equipment and functions.

Simplex: A system of carrier communication in which a manual switch, usually a button switch on the handset, is pressed during transmission to cut out the receiver and turn on the transmitter.

Single-sideband suppressed carrier: The modulation process which results in the partial, or complete, elimination of the carrier and all components of one sideband.

Speed of Operation: Speed of operation (Figure 18-4) includes the channel speed (excluding propagation time), receiver output device, and the tripping device. It represents the elapsed time from the keying of the transmitter to the closing of the tripping device.

Sub-Multiplexing: The practice of putting more than one signal in one channel.

Supervisory control: A system of control which provides both selective control and automatic indication of the condition or position of a number of devices located at a distant point.

Telemetering: A system of measuring at a distant point the varying changes that take place in a locally measured quantity such as voltage, current, etc.

Test tone: A tone used for making measurements and adjustments in the 600-ohm audio portion of a circuit. Its level is one milliwatt (0 dBm) with a frequency of 1000 Hz, and is applied at the zero-transmission level reference point.

Transmitter assembly: A complete assembly, usually in an enclosing cabinet, containing a carrier transmitter unit, auxiliary and protective circuits, etc.

Transmitter unit: A standard chassis unit containing only a basic carrier transmitter.

Transmitter-receiver assembly: A complete assembly, usually in an enclosing cabinet, containing both a transmitter unit and a receiver unit, plus all necessary auxiliary circuits.

Trunk: A telephone circuit connecting two telephone exchanges not at the same location.

Trunk-line carrier channel: A specific type of GE carrier telephone channel employing two-frequency carrier equipment designed to provide services equivalent to a trunk.

Two-wire circuit: A two-way circuit in which the send and receive audio signals travel along the same electrical circuit.

Upper sideband: The frequency or group of frequencies, located above the carrier, produced by a modulation process.

Wavelength: The distance between successive peaks of the same polarity in a wave.

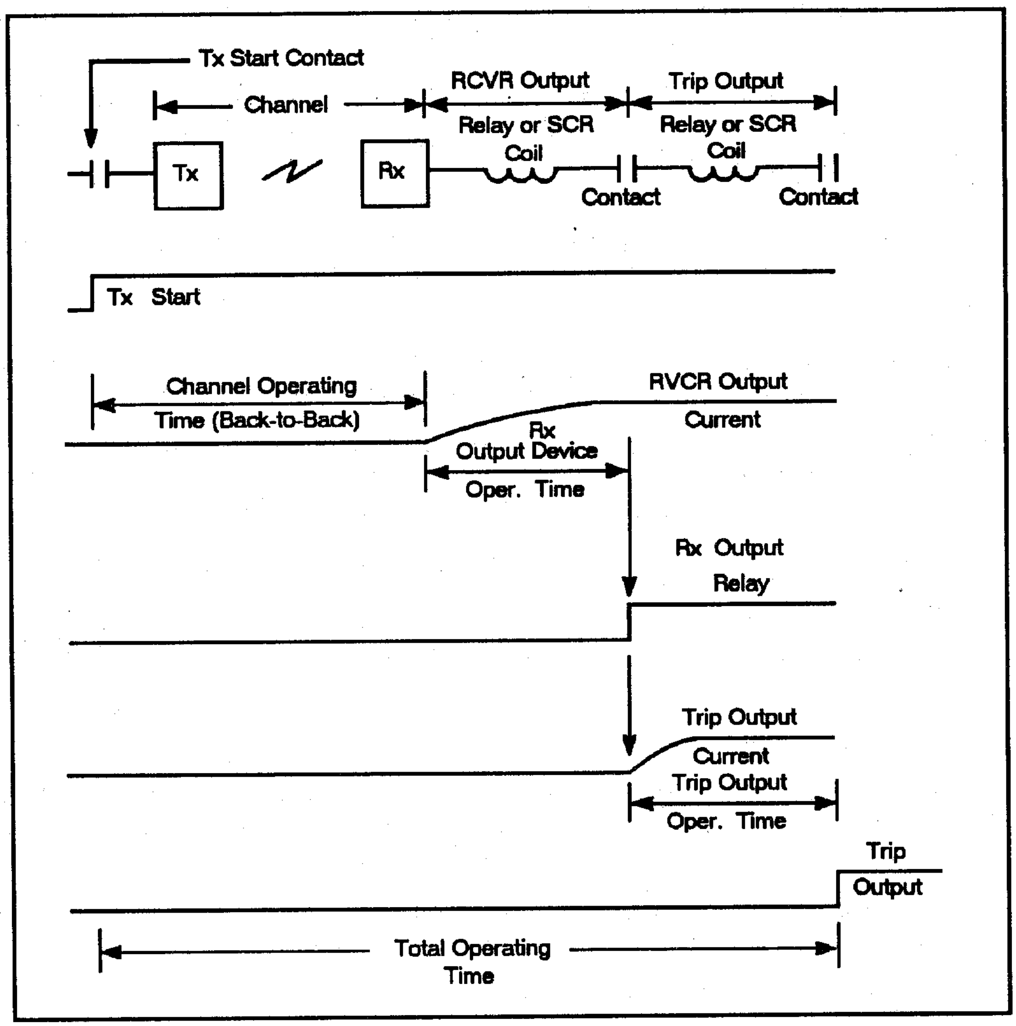


Figure 18-4. Speed of Operation

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