INSTRUCTIONS

GEK-49793

STATIC, THREE-PHASE DIRECTIONAL-GROUND MHO DISTANCE RELAY SLYG51C11 AND UP

POWER SYSTEMS MANAGEMENT DEPARTMENT

GENERAL ELECTRIC

PHILADELPHIA, PA.

CONTENTS

STATIC, THREE-PHASE DIRECTIONAL-GROUND MHO DISTANCE RELAY

SLYG51C11 AND UP

DESCRIPTION

The type SLYG51C11 relay is a static, three-phase directional-ground mho distance relay designed to be used in transmission-line-protection schemes. The relay will provide protection against all single phase-to-ground faults that fall within its reach setting. The relay may be used to provide the overreaching trip functions in pilot-relaying schemes or it may be used in conjunction with a suitable timing function to provide the second or third zone of protection in step-distance relaying schemes.

Three ground-mho-distance functions, one per phase, are supplied in each SLYG51C11 relay. Provision for zero sequence current compensation that does not require the use of an auxiliary CT is also included as an integral part of the relay. In addition, this relay contains provision for overcurrent supervision.

The SLYG51C11 relay is packaged in one two-rack unit case, the outline and dimensions for which are shown in Fig. 1. Component locations for the relay are shown in Fig. 2.

The SLYG51C11 relay outputs are DC logic signals that are fed into a type SLA logic relay, the circuitry for which is dependent on the overall scheme of protection. The static circuits of the SLYG51C11 relay require $\pm$15V DC which is obtained from a type SSA power supply. The internal connections for the SLYG51C11 relay are shown in Fig. 6.

The SLYG51C11 relay is not intended to be used by itself, but rather as part of a complement of equipment that forms a complete protective relaying scheme. For example, a typical directional comparison blocking scheme may be comprised of a type SLY tripping relay, a type SLY phase blocking relay, a type SLC overcurrent relay, a type SLA logic relay, a type SSA power supply and a type SLAT output relay.

For a complete description of the overall scheme in which the relay is employed, refer to the overall logic diagram and the associated logic description that is supplied with each terminal of equipment.

APPLICATION

The type SLYG51C11 relay is a static, three-phase, ground-mho-directional distance relay designed to provide the overreaching trip function in pilot-relaying schemes or the second or third zone function in step-distance schemes. Since the transient overreach of the mho functions in the SLYG51C11 relay is not sufficiently limited by design, the relay is not suited for first zone applications.

The SLYG51C11 relay is not intended to be used by itself, but rather as part of a complement of relays that forms a protective relaying scheme. The additional relays and other equipment required to complete a specific scheme are dependent on the nature of the scheme and are described in the logic description that accompanies the overall logic diagram for that particular scheme. Fig. 17 illustrates typical external connections to the SLYG51C11 relay when it is used in a directional comparison-blocking scheme.

Zero sequence current compensation is provided as an integral part of each SLYG51C11 relay. Appendix II presents a brief discussion of the effects of zero sequence current compensation and further shows that the compensation factor (K_0) <u>must</u> be set equal to the ratio of the zero sequence impedance to the positive sequence impedance of the protected line (Z'_0/Z'_1). See Appendix I for a list and definition of the symbols used throughout this book. When zero sequence current compensation is set properly ($K_0=Z'_0/Z'_1$), and if there is no mutual coupling with parallel lines, the relay will measure the positive sequence impedance of the protected line from the relay location to the fault. In general, the relay may be set with lower reach settings than would otherwise be possible had zero sequence current compensation not been used. This is beneficial on long lines where reduced reach settings will make the relay less likely to operate during maximum load or stable swing conditions. The relay does not have provisions for compensating for zero sequence mutual coupling with parallel lines. Furthermore, it is not advisable to compensate for mutual coupling because the relay may become non-directional under certain fault conditions. Because zero sequence mutual coupling will affect the apparent impedance seen by the relay under fault conditions, it must be accounted for when setting the relay. A discussion of its effects and how to account for them is given in Appendix II.

The reach setting of the SLYG51C11 relay will depend to some extent on the specific application. Consider for example pilot-relaying schemes in which overreaching trip functions are employed. These functions must be able to detect all faults on the protected line section including the effects of ground fault resistance if the scheme is to work properly. On the other hand, relays used in step distance schemes must be set to reach a certain distance and yet assure coordination with relays in the adjacent line sections. Thus, for any given equipment, the description of the scheme that accompanies the logic diagram should be consulted for specific recommendations. In general though, the following guidelines are suggested for use in setting the relays.

1. PILOT RELAYING SCHEMES

   A. Overreaching Functions - Set the voltage restraint taps (T) so that the reach of the relay will be equal to at least 125 percent and preferably 150-200 percent of the apparent impedance seen by the relay for a fault at the remote end of the line. If there is no mutual coupling with parallel lines, the apparent impedance will be equal to the positive sequence impedance of the protected line. If there is mutual coupling, take it into account only if its effect is to increase the apparent impedance.

2. STEP DISTANCE SCHEMES

   A. Zone 2 Applications - The second zone function should be set so that it does not reach beyond the Zone 1 function of any adjacent line section.

   B. Zone 3 Applications - The Zone 3 function should be set so that it does not reach beyond the Zone 2 function of any adjacent line section.

The equations to be used in making these settings are presented in Appendices II and III.

For certain system conditions the possibility exists that the function(s) associated with the unfaulted phase(s) may operate incorrectly for single line-to-ground or double line-to-ground faults in the non-tripping direction if the ohmic reach is made too large. It is possible to determine if the function will misoperate for any given ohmic reach setting and methods for doing so are given in Appendix III. However, for ohmic reach settings of 200 percent or less of the positive sequence impedance of the protected line, it is improbable that the relay will operate incorrectly. For ohmic reach settings greater than 200 percent, the user is referred to Appendix III.

In order to make the settings discussed above, it is necessary to select basic tap settings and percent restraint tap settings. In general, the sensitivity of the mho function increases as the basic tap setting is raised. Therefore, it is recommended that the highest basic tap setting that will accommodate the desired reach setting be used.

The mho functions in the SLYG51C11 relay have an adjustable angle of maximum reach of 60 to 75 degrees. The 60-degree angle will accommodate more arc resistance, hence it is useful where fault resistance can be an appreciable fraction of the protected line impedance.

The SLYG51C11 relay is applicable on any line strung on steel towers and having shield wires. The relay may be used on lines without shield wires, but in this case the tower footing resistance may contribute significantly to the total fault resistance such as to cause the impedance to plot outside the characteristic of the relay. If the relay is used on lines strung on wooden structures, with or without shield wires, it is probable that the total fault resistance will be increased considerably, thus increasing the likelihood that the impedance may plot outside the characteristic. Because the possibility exists that the impedance may plot outside the characteristic of the relay when it is used in lines without shield wires or strung on wooden towers, it is suggested that the effects of the total fault resistance be studied if the relay is to be used in these applications.

On three terminal lines, the same general considerations apply, but the application is more complex and the effects of infeed must be considered in setting the mho functions. Further discussion of three terminal line applications is provided in Appendix IV.

The preceding discussion is based on the relay being applied on transmission lines where the difference between the angles of the positive sequence impedance and the zero sequence impedance does not exceed 10 or 15 degrees. The relay may also be used on cable circuits where the angular difference may be around 40 degrees. In this case, it is necessary to move a link located on the back of the relay to the "Cable" position.

When the relay is applied in single-pole tripping and reclosing schemes, the ground mho function for each phase should be supervised by a sensitive current detector for the associated phase. Provision is made in the SLYG51C11 relays for supervision by such sensitive current detectors, usually designated as I_M functions, in an associated type SLC relay.

RATINGS

The Type SLYG51C11 relays are designed for use in an environment that the air temperature outside the relay case does not exceed 65°C.

The current circuits of the Type SLYG51C11 relay are rated at 5 amperes, 60 cycles, for continuous duty, and have a one-second rating of 300 amperes. The potential circuits are rated 120 volts, 60 cycles.

The range of adjustment of the functions in the Type SLYG51C11 relay are listed below:

MTG Tripping:

0.3 to 30 ohms at 75 degrees maximum reach setting.
0.3 to 32 ohms at 60 degrees maximum reach setting.

Base Reach Taps:

3.0, 1.5, 1.2, 0.75, 0.60, 0.30.

BURDENS

The maximum potential burden per phase measured at 120 VRMS line voltage is as follows:

0.30 Volt Amp
0.24 Watts
0.18 Vars

The maximum current burden per phase measured at five amps line current is as follows:

$Z = 0.017 \angle 40^{\circ}$
$R = 0.013$
$X = 0.011$

The maximum DC burden to the type SSA power supply is as follows:

350 ma from the +15 VDC supply
50 ma from the -15 VDC supply

OPERATING PRINCIPLES AND CHARACTERISTICS

The mho characteristic for the SLYG51C11 relay is shown in Fig. 3. The principle used to derive the electrical characteristics is illustrated in Fig. 4. The axes are "IR" and "IX". The IZ quantity is a voltage proportional to the line current obtained by passing the line current sequence components through networks consisting of current transformers and reactors. The setting of this quantity establishes the "Base Reach" of the relay. The $\overline{V}$ quantity is line voltage at the relay location, equal to IZ_F, where Z_F is the line impedance out to the fault. Comparison is between the polarizing voltage $\overline{V}$ and the operating quantity ($\overline{IZ} - \overline{V}$). The angle between these two quantities is greater than 90 degrees for faults external to the relay characteristic, and is less than 90 degrees for faults internal to the relay characteristic. For faults which cause $\overline{V}$ to terminate on the relay characteristic, the angle B is equal to 90 degrees. This is true for any angular location of $\overline{V}$, because $\overline{V}$, $\overline{IZ}$, and ($\overline{IZ} - \overline{V}$) form a right triangle for any point on the relay characteristic.

The quantities $\overline{V}$ and ($\overline{IZ} - \overline{V}$) are the relay input quantities and are converted into blocks of voltage. These blocks which come out of the F card are out of phase. These blocks are compared with each other in the C104 card. The duration of their coincidence (having opposite polarity) is measured. Blocks which are 90 degrees apart are coincident (opposite polarity) for 4.16 milliseconds. Blocks which are less than 90 degrees apart are coincident (opposite polarity) for more than 4.16 milliseconds. This is illustrated in Fig. 5.

MTG TRIPPING FUNCTION

The MTG function has a directional characteristic with the mho circle passing through the origin on an R-X diagram. See Fig. 3.

If the 100 percent voltage tap is used and K_0 is equal to 1, the phase-to-neutral reach of the relay at the angle ϕ is equal to the IZ base reach tap chosen. If a voltage tap other than 100 percent is chosen, reach is increased in inverse proportion to the voltage tap. For example, if the 50 percent voltage tap is used, relay operation still occurs for the same voltage applied to the measuring circuit, but since the actual line voltage is twice this amount, the relay reach is twice as great. The resulting mho circle has twice the reach, at any fault angle, and still passes through the origin.

Relay reach for the MTG unit at the angle of maximum reach can be calculated from the expression:

$$Z_1 = \frac{(T_B)}{(T)} \times 100$$

where

T = the restraint tap setting expressed in percent
$Z_0 = Z_1 \cos(\theta - \phi)$
ϕ = relay maximum reach angle
θ = line angle
T_B = basic minimum reach tap setting

Z_0 is the impedance the relay will see at any angle θ.

The angle of maximum reach ϕ can be set at 60 or 75 degrees by moving a link on the F162 printed circuit card.

To set the relay for the desired reach, it is necessary to first select the proper "Base Reach Tap". This tap should be the highest "Base Reach Tap" that is smaller than the desired ohmic reach. The setting of the "Base Reach Tap" is explained under the section titled CONSTRUCTION in this book. After the "Base Reach Tap" is selected the "Percent Restraint Tap" may now be chosen to produce the required relay reach.

CIRCUIT DESCRIPTION

The internal connections of the SLYG51C11 relay are shown in Fig. 6. The points on the left designated GA2 through GA7 are the voltage inputs. The points designated GA9 through GA12 and GB1 through GB12 are the current inputs.

The relay input voltage is passed through a transformer which produces a median polarized voltage. This voltage is fed directly to the filter card. The other input to the filter card is (IZ - V). The IZ component comes from the input current passing through current transformers and the secondary currents being passed through reactors to form the IZ quantity. The total IZ quantity is derived from $(I_1 + I_2)Z_1$ and from I_0Z_0. The V portion comes directly from the tapped potential transformer.

The block-block method is used for the MTG function. Blocks are formed from the (IZ - V) quantity and the polarizing voltage by means of the filter card. These blocks are then fed to the coincidence logic card where the blocks are compared on a time basis. The coincidence card will produce output blocks only when both inputs are coincident and of opposite polarity. The output blocks of the coincidence logic card are then fed to the 4/5 timer card. The characteristic of the 4/5 timer is to produce no output until the input blocks are longer in duration than 4.16 milliseconds or 90 degrees. If the timer is set to pick up at some angle other than 90 degrees, the resulting mho unit characteristic will not be a circle. Fig. 7 shows the characteristic obtained for a timer setting of 3.0 milliseconds at an angle of maximum reach of 75 degrees. Fig. 8 shows the same characteristic at an angle of maximum reach of 60 degrees. Fig. 9 shows the characteristic for a timer setting of 6 milliseconds at an angle of maximum reach of 75 degrees. Fig. 10 shows the same characteristic at an angle of maximum reach of 60 degrees. In general, the reach for a timer setting less than 90 degrees is greater than the reach for a timer setting of 90 degrees at the same fault angle. A timer setting of greater than 90 degrees will give a reach less than the reach for a timer setting of 90 degrees, again at the same fault angle.

CHOICE AND CALCULATION OF SETTINGS

The calculations to follow will be illustrated for the portion of the transmission system shown in Fig. 18. The line to be protected is line NO. 1, the relays to be set are located at breaker A and it will be assumed that the relay is being used to provide the overreaching function in a pilot-relaying scheme. General considerations for setting the relays are given in the section under APPLICATION, but the logic description supplied with a particular scheme should be referred to for specific recommendations for the given application. For purposes of illustration, it will be assumed that the relays will be set to "see" 150 percent of the apparent impedance of the protected line. The equations to be used and their derivations are presented in Appendix II. At this point, it is suggested that both Appendices I and II be studied before proceeding further.

Prior to setting the relays it will be necessary to gather certain information pertinent to the protected line. The following, assumed to be typical for the system represented in Fig. 18, illustrates the required information.

Line Parameters

$Z_1' = 24.0 \angle 79^\circ$ primary ohms

$Z_0' = 72.0 \angle 75^\circ$ primary ohms

$Z_{om} = 14.4 \angle 75^\circ$ primary ohms

CT Ratio = 600/5

PT Ratio = 1200/1

Fault Information, Acquired From a System Study

Fault at F_3

$C_0 = 0.17$

$C = 0.20$

$I_a' = 13.7$ secondary amps

$I_0' = 4.6$ secondary amps

$I_0'' = -0.88$ secondary amps based on the CT ratio of the protected line (600/5). Note that the sign of I_0'' is negative because it flows in direction opposite to that of I_0'.

Fault at F_2

$C_0 = 0.11$

$C = 0.27$

$Z_1 = 0.874 \angle 82^\circ$

$Z_0 = 1.05 \angle 78^\circ$

First convert primary ohms to secondary ohms as follows:

$$Z(sec) = Z(pri) \times \frac{\text{CT Ratio}}{\text{PT Ratio}} = Z(pri) \times \frac{600/5}{1200} = Z(pri) \times 0.1$$

$Z_1' = 2.4 \angle 79^\circ$ secondary ohms

$Z_0' = 7.2 \angle 75^\circ$ secondary ohms

$Z_{om} = 1.4 \angle 75^\circ$ secondary ohms

The following settings must be made in the SLYG51C11 relay.

1. Angle of maximum reach - set at either 60 or 75 degrees
2. Zero sequence current compensation factor, K_0, where $K_0 = K_U + K_T$: adjustable to the values shown in Table 2 under the section headed CONSTRUCTION.
3. Voltage restraint taps T: T is adjustable in one percent steps over the range of 10-109 percent.

4. Basic minimum restraint tap T_B: described in further detail under the section headed CONSTRUCTION. T_B may be set equal to 1.2K or 3K where K may be set equal to 1/4, 1/2 or 1. On that basis, the basic minimum reach taps available are 0.3, 0.6, 0.75, 1.2, 1.5 or 3.0 ohms.

In setting the angle of maximum reach, the effects of fault resistance and load flow should be considered. Because the line is relatively short, line load ability should not be a problem, therefore the angle of maximum reach will be set at 60 degrees in order to provide maximum coverage for fault resistance.

Zero sequence current compensation is described in Appendix II, where it is shown that K_o has to be set as near as possible to the ratio of Z_0'/Z_1'.

$$\text{Set } K_o = \frac{Z_o'}{Z_1'} = \frac{7.2}{2.4} = 3.0$$

From Table 2 under CONSTRUCTION, use KU = 3 and KT = 0.

If K_o can not be set exactly, the next higher tap value should be used. This will tend to make the function reach slightly farther than the desired setting, but this is more desirable than having the function underreach as would be the case if the next lower tap setting had been used.

Set the CABLE-LINE link located on the rear of the relay in the LINE position.

The following equations, derived in Appendix II, are used in determining T_B and T.

$$Z = M\left[Z_1' + \frac{I_o'' \, Z_{om}}{I_a' + (K_o - 1)\, I_o}\right] \qquad \text{II-d}$$

$$T = \frac{100\, T_B \cos(\theta - \phi)}{Z} \qquad \text{II-c}$$

where,

Z = desired reach in secondary ohms

θ = angle of maximum reach

ϕ = line angle

and all other parameters are defined in Appendix I

Equation II-d should be evaluated first. In evaluating this equation, the sign of I_o'' should first be noted. If I_o'' is negative, the second term is brackets should be neglected (see Appendix II for reason). Otherwise, take I_o'' into account. It has previously been assumed that the relay should be set to "see" 150 percent of the apparent impedance, therefore for this illustration, M = 1.5. Neglecting the term containing I_o'' and setting M = 1.5, yields,

$$Z = 1.5 \times 2.4 = 3.6 \text{ ohms} \qquad \text{II-d}$$

It has been stated that the highest available base reach tap that accomodates the desired reach should be selected, therefore select T_B = 3.0.

Equation II-d should now be evaluated using the T_B selected above.

$$T = \frac{100 \times 3.0 \times \cos(60^o - 75^o)}{3.6}$$

T = 81 percent

Because the reach has been limited to 150 percent it is highly improbable that the relay will misoperate for faults in the non-tripping direction. It is therefore unnecessary to evaluate the equations of Appendix III to determine that the maximum permissible reach has not been exceeded.

CONSTRUCTION

The Type SLYG51G11 relay is packaged in a metal enclosure designed for mounting on a 19-inch rack. The relay is two rack units high (one rack unit is 1 3/4 inches). The relay contains the magnetics and tap blocks for setting the base reach and the percent restraint. It also contains the printed circuit cards for protecting all three phases of a power system. The relay has a 90 degree hinged front cover and a removable top cover.

The tap block portion of the Type SLYG51C11 relay is located at the left of the unit. Fig. 12 shows this portion of the relay. The tap block is divided into two sections, percent restraint and base reach. These sections are identified at the top.

To set the percent restraint simply put the top MTG lead in the desired 10 percent hole and the bottom MTG lead in the desired 1 percent hole. The setting for one phase is shown in Fig. 12. It is set for 74 percent restraint.

To set the base reach for each positive and negative sequence current and also for the zero sequence current simply put the extreme right hand MTG leads and the MTGO lead in either the 1.2K or the 3K hole. This K is a ratio factor and is either 1, 1/2 or 1/4. This K factor should not be confused with K_0, which is the ratio of the zero sequence impedance to the positive sequence impedance. K is determined by the terminals that are selected for current input on the GB terminal block (positive and negative sequence currents) and the GA terminal block (zero sequence current) at the back of the relay. All base reach taps should be set the same and all values of K should be set the same. A table is given below on the internal connections diagram (Fig. 6) that shows the value of K for the given terminal block numbers. The setting for a base reach of 1.2K is shown for both the Phase 1 positive and negative sequence current and the zero sequence current in Fig. 12.

TABLE I

$I_{1, 2, 3}$	$-I_{1, 2, 3}$	K
GB1 5 9	GB4 8 12	1
GB2 6 10	GB4 8 12	1/2
GB3 7 11	GB4 8 12	1/4

$3I_0$	$-3I_0$	K
GA9	GA12	1
GA10	GA12	1/2
GA11	GA12	1/4

TABLE II

VALUES OF KU	VALUES OF KT
6	0.8
5	0.6
4	0.5
3	0.4
2	0.2
1	0.0

The base reach and percent restraint settings are made by jumpers with taper tip pins on the end. Two special tools have been supplied for these pins. One is an insertion tool and the other is an extraction tool. In order to get a proper connection and cause no damage to the pins it is important that these tools be used.

The printed circuit cards are located to the right of the tap block portion. Printed circuit cards are identified by a code number such as F162, C104, T133, etc. Each card is assigned a "position" in the relay. This position is shown on the internal connection diagram in the lower right hand corner of each card. A test card is located in the "T" poisition. Tese points are numbered 1 to 10 from top to bottom on the test card. The upper test point, TP1, is connected to relay reference. The bottom test point, TP10, is connected to the +15 VDC bus. TP2 is connected to the -15 VDC bus. The other test points are located at selected points within the logic circuitry to permit test measurement of the outputs of the various functions and facilitate signal tracing when trouble shooting.

RECEIVING, HANDLING AND STORAGE

This relay will normally be supplied as a part of a static relay equipment, mounted in a rack or cabinet with other static relays and test equipment. Immediately upon receipt of a static relay equipment it should be unpacked and examined for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

Reasonable care should be exercised in unpacking the equipment. If the equipment is not to be installed immediately, it should be stored indoors in a location that is free from moisture, dust, metallic chips, and severe atmospheric contaminants.

Just prior to final installation the shipping support bolt should be removed from each side of all relay units, to facilitate possible future unit removal for maintenance. These shipping support bolts are approximately eight inches back from the relay unit front panel. Static relay equipment, when supplied in swing rack cabinets, should be securely anchored to the floor or to the shipping pallet to prevent the equipment from tipping over when the swing rack is opened.

The Type SLYG51C11 relay contains printed circuit cards with trimmer potentiometers mounted on them. Some of these trimmer potentiometers are calibrated at the factor and sealed. These potentiometers should not be adjusted by the user.

INSTALLATION TESTS

The Type SLYG51C11 relay is usually supplied from the factory mounted and wired in a static relay equipment.

All units of a given terminal have been calibrated together at the factory and will have the same summary number on the unit nameplate.

These units must be tested and used together.

A. NECESSARY ADJUSTMENTS

The following checks and adjustments should be made by the user in accordance with the procedures given below under DETAILED TESTING INSTRUCTIONS, before the relays are put in service. Some of the following items are checks of factory calibrations and settings, or installation connections and hence do not normally require readjustment in the field. Other items cover settings or adjustments which depend on installation conditions and hence must be made on the installed equipment.

1. MTG base reach taps for positive and negative sequence currents and MTGO base reach taps for zero sequence current.

2. MTG reach by voltage tap setting.

3. The angle of maximum reach, other than 75 degrees.

4. K_0 setting on the "G" position card.

GENERAL TESTING INSTRUCTIONS

INPUT CIRCUITS

The Type SLYG51C11 relay has two terminal blocks on the rear of the unit identified as GA or GB. Both these terminal blocks are wired through the test panel in a static relay equipment where input currents and voltages can be supplied through the standard Type XLA test plug. Where other test facilities are used, input currents and voltages should be applied to test points which connect to the same GA and GB terminal points as those shown on the test circuit diagram.

Where the Type SLYG51C11 relay is supplied in a static relay equipment, reference to the job elementary will provide information concerning customer relay inputs.

OUTPUT SIGNALS

Output signals are measured with respect to the reference bus or TP1. Outputs are continuous signals of approximately +12 to +15 volts for the "ON" condition and 0-1 volts for the "OFF" condition. This output can be monitored with an oscilloscope, a portable high impedance DC voltmeter, or with the test panel voltmeter if available. To connect the test panel voltmeter, place the test lead in the proper test point pin jack and the other end in the pin jack on the test panel.

DETAILED TESTING INSTRUCTIONS

REQUIRED ADJUSTMENTS

Reach Tap Settings

The arrangement of the reach setting portion of the tap block is described under the section on CONSTRUCTION and the choice of tap settings is discussed under the section on CHOICE AND CALCULATION OF SETTINGS.

Testing mho Characteristic

The mho ground characteristic may be checked over its entire range by using the test circuit employing the phase shifter and phase angle meter shown in Fig. 13. Input connections for testing any of the phase-to-neutral characteristics should be made with Fig. 13 and Table III.

TABLE III

TEST	A	B	C	D	E	F	SHORT TERMINALS	OUTPUT
Ø1-N	GA2	GA5	GB1	GB4	GA9	GA12	GA3 to GA6 GA4 to GA7	TP6
Ø2-N	GA3	GA6	GB5	GB8	GA9	GA12	GA4 to GA7 GA2 to GA5	TP7
Ø3-N	GA4	GA7	GB9	GB12	GA9	GA12	GA2 to GA5 GA3 to GA6	TP8

By setting the current to five amperes (constant) the reach at any angle becomes a function of the settings of the base reach, the restraint taps and the value selected for K_0. Rotating the phase shifter provides a means of checking the reach on any point of the characteristic.

To obtain any points on the relay characteristic for any one of the three pahses, observe the following procedure:

(a) Set up the test circuit of Fig. 13 for the particular phase being tested. Make the AC connections according to Table III

(b) Set the test current to five amps RMS

(c) Be sure that the current limiting reactor is as high as possible in ohmic value. This assures the most harmonic-free current possible.

(d) Remove the coincidence cards (C104) of the phases not being tested. Jumper the test point outputs of these cards down to reference. Example: When testing Ø1-2, remove the C104 cards in positions "M" and "R" and jumper TP4 and TP5 to reference.

(e) Set the link at the rear of the unit in the "line" position.

(f) Set the "KU" and "KT" taps on the F162 card in the "G" position.

$$K_0 = \frac{Z_0}{Z_1} = KU + KT$$

Example: If Z_1 = 2 ohms and Z_0 = 6.4 ohms the value of K_0 would be 3.2. For this case the KU lead would be set on 3 and the KT lead on 0.2.

$$K_0 = \frac{6.4}{2} = 3.2 = 3 + 0.2 = 3.2$$

(g) Connect the instrumentation (preferably an oscilloscope) between the mho output of the phase under test and reference at TP1.

(h) Set the phase angle meter at the specific angle of interest by rotating the phase shifter.

(i) Adjust the variac until the mho function output fully picks up. Note that the point just at the verge of pickup, as read on Fig. 13 voltmeter (V) defines the relay mho characteristic.

The voltage at which the relay picks up can be expressed by:

$$V = (2 + K_0) \left(\frac{IZ}{3}\right) \frac{\cos(\alpha - \phi)}{\%\ \text{Restraint Tap}} \times 100 \qquad (2)$$

where

I = 5 amp test current
Z = base reach of the relay
Note: The base reach setting must be the same for both the positive-negative sequence portion and the zero sequence portion of the relay.
α = the angle read at the phase angle meter
ϕ = angle of maximum reach
$K_0 = \frac{Z_0}{Z_1}$ = KU + KT

Any points necessary can be obtained by simply repeating steps (h) and (i) until the characteristic is clearly defined.

An alternate method of testing the relay characteristic is shown in Fig. 14 where the R-X test combination is employed. The circuit uses the test box (102L201), test reactor (6054975) and test resistor (6158546) described in GEI-44236. Since a limited number of resistor-reactor fault impedances are available, only a few points on the relay characteristic can be checked.

Should the voltage V, at the angle of maximum reach, be different than the calculated value of V it will be necessary to perform the tests under the section titled REACH ADJUSTMENT TESTS.

PHASE ANGLE ADJUSTMENT

As stated earlier the angle of maximum reach, ϕ, can be adjusted by changing the position of the jumper on the Fig. 2 printed circuit card. The angle is typically factory set at a 75 degree angle of maximum reach. The calibration of the angle of maximum reach can be made by using the test circuit of Fig. 13. The recommended procedure is as follows:

(a) Determine what test voltage V in Fig. 13 is necessary to produce output at the relay's maximum reach angle for five amperes of current, and the particular tap setting.

The voltage V at the angle of maximum reach is

$$V = (2 + K_0) \left(\frac{IZ}{3}\right) \left(\frac{100}{\%\ \text{Restraint Tap}}\right) \qquad (3)$$

where quantities are the same as those for equation (2)

(b) Make the AC connections to the relay according to Table III. The letters A through F in Table III correspond to the letters in Fig. 13.

(c) Adjust the variac in Fig. 13 until the voltmeter reads 85 percent of the calculated voltage in equation (3).

(d) Rotate the phase shifter, holding the voltage at 85 percent of the maximum V, and record the two angles at which the output just approaches the verge of pickup.

(e) Add, algebraically, the two angles and divide the sum by two.

A preliminary test can be performed to aid in the setting of the angle of maximum reach. Apply voltage only to the relay. Apply 60 VAC to the input terminals of the phase under test. Short the voltage terminals of the other two phases. Connect a dual trace scope. Channels A and B to the F162 card, Pins 8 and 9 respectively. Move the option K jumper to the position that produces coincident square wave traces if a 75 degree angle of maximum reach is desired. If an angle of maximum reach of 60 degrees is desired change the position of the K jumper plug. This will move the channel "B" track ahead of channel "A" track by 0.69 milliseconds. Table IV shows the relationship between the difference in times and angles between the traces.

TABLE IV

DESIRED ANGLE OF MAXIMUM REACH	DIFFERENCE IN TIME BETWEEN TRACES	DIFFERENCE IN DEGREES BETWEEN TRACES
75^{o}	0 MSEC	0 DEGREES
60^{o}	0.69 MSEC.	15 DEGREES

REACH ADJUSTMENT TESTS

The Type SLYG51C11 relay has two reach adjustment potentiometers. These potentiometers are P10 and P12 located on the F162 card. P10 is the reach adjustment for the positive-negative sequence portion of the relay. P12 is the reach adjustment for the zero sequence portion of the relay.

To set P10 for each phase observe the following procedures:

(a) Set up the test circuit of Fig. 13 for the particular phase being tested. Make the AC connections according to Table V.

TABLE V

TEST	A	B	C	D	E	F	SHORT TERMINALS	OUTPUT
Ø1	GA2	GA5	GB1	GB4	GB8	GB5	GA3 to GA6 GA4 to GA7	TP6
Ø2	GA3	GA6	GB5	GB8	GB12	GB9	GA4 to GA7 GA2 to GA5	TP7
Ø3	GA4	GA7	GB9	GB12	GB4	GB1	GA2 to GA5 GA3 to GA6	TP8

(b) Set the test current at 10 amps.

(c) Connect the instrumentation (preferably an oscilloscope) between the mho output of the phase under test and reference at TP1.

(d) Set the phase angle meter at the angle of maximum reach of the relay.

(e) Adjust the variac until the mho function output fully picks up. Note that the point just at the verge of pickup, as read on Fig. 13 voltmeter (V), defines the relay mho characteristic. The voltage at which the relay picks up can be expressed by:

$$V = \frac{IZ \times 100}{\% \text{ Restraint Tap}} \qquad (4)$$

where I = 10 amp test current
Z = base reach of the relay

(f) Adjust the P10 potentiometer until the pickup occurs at the calculated value of V.

To set P12 for each phase observe the following procedure:

(a) Set up the test circuit of Fig. 15 for the particular phase being tested. Make the AC connections according to Table VI.

TABLE VI

TEST	SHORT TERMINALS	A	B	C	D	OUTPUT
Ø1	GA3 TO GA6 GA4 TO GA7	GA2	GA5	GA9	GA12	TP6
Ø2	GA4 TO GA7 GA2 TO GA5	GA3	GA6	GA9	GA12	TP7
Ø3	GA2 TO GA5 GA3 TO GA6	GA4	GA7	GA9	GA12	TP8

(b) Set the test current at 10 amps.

(c) Connect the instrumentation (preferably an oscilloscope) between the mho output of the phase under test and reference at TP1.

(d) Set the phase angle meter at the angle of maximum reach of the relay.

(e) Be sure the link at the rear of the unit is in the "line" position.

(f) Adjust the variac until the mho function output fully picks up. Note that the point just at the verge of pickup, as read on Fig. 15 voltmeter (V), defines the relay mho characteristic. The voltage at which the relay picks up can be expressed by:

$$V = \frac{K_o \, IZ \times 100}{3 \times \% \text{ Restraint Tap}}$$

where I = 10 amp test current
Z = base reach of the relay
K_o = KU + KT setting on "G" position card.

(g) Adjust the P12 potentiometer until the pickup occurs at the calculated value of V.

TIMER ADJUSTMENTS AND TESTS

The following information concerns items which have been covered in factory tests. This information is supplied for use in trouble-shooting or in checking the overall performance of the Type SLYG51C11 relay.

F162 FILTER CARDS

The F162 filter cards have four potentiometers and a jumper plug located on them. By number these potentiometers are P61, P52, P10 and P12. Potentiometer P61 is for filter adjustment purposes. Potentiometer P52 is for phase shift purposes. Both these potentiometers have been set in factory test and sealed. These potentiometers should not be moved. Potentiometers, P10 and P12, are for adjusting the relay reach at the angle of maximum reach. The procedure used to set these potentiometers is described under the REACH ADJUSTMENT TESTS section. The jumper plug is used to set the angle of maximum reach, its use is described under the PHASE ANGLE ADJUSTMENT section.

T133 TIMER CARDS

The T133 timer affects the mho characteristic shape. Three potentiometers are provided for adjustment purposes. P1, the first pickup, is the top potentiometer. P2 which sets the dropout is the middle potentiometer and P3 the steady state pickup which determines the characteristic shape is on the bottom.

There are two procedures listed below to set the T133 timer. The first procedure is used if a touchup of the characteristic shape is required. The second procedure is used when the card is replaced or when the card is suspected of being incorrectly adjusted.

PROCEDURE 1 - If a plot of the characteristic is too wide or too narrow indicating an incorrect steady state pickup setting, P3 can be adjusted to obtain the correct shape. (See Figs. 7-10). However, do not change the settings of P1 or P2 during this procedure as they have no effect on the shape of the characteristic.

Procedure 2 - Note that all three potentiometers must be set in this procedure, follow the setting order shown below to obtain correct operation of the card.

To set potentiometer P1, the first pickup:

(a) Remove the C104 card of the phase pair being tested.
(b) Connect the test circuit of Fig. 16.
(c) Connect the input signal to the test point on the input of the timer being tested (TP3 for phase 1-2).
(d) Use an oscilloscope with a horizontal sweep which can be triggered externally. Connect the external trigger input to the test point on the input of the timer being tested and the vertical input to the test point on the output of the timer being tested.
(e) Set P3 fully counterclockwise.
(f) With the oscilloscope set for positive slope triggering, open the normally closed contact. The trace should step to +12 to +15 volts. Adjust P1 to obtain the pickup time specified on the Logic Diagram. Clockwise rotation will increase the pickup time delay.

To set potentiometer P2, the dropout time delay;

(a) thru (d) same as for P1.
(e) With the oscilloscope set for negative slope triggering, open the contact to allow the timer to pickup, then close the contact and the desired dropout time can be set. To increase the dropout time turn P2 clockwise.

To set potentiometer P3, the steady state pickup;

(a) Install the C104 card for the phase pair under test.
(b) Connect the AC test circuit of Fig. 13.
(c) Set the current to five amperes.
(d) Set the voltage to 25 volts.
(e) Swing the phase shifter to the point that causes a square with an ON and OFF time, as measured with an oscilloscope at the input of the timer being tested, which is the same as the pickup time to be set.
(f) Move the oscilloscope input to the output of the timer being tested and adjust P3 to the point that makes the card's output just become a continuous DC level of over 12 volts - DO NOT READJUST THE P1 AND P2 POTENTIOMETERS.
(g) Plot the characteristic using the AC test circuit of Fig. 13 and touch up the P3 setting to obtain characteristic shape desired.

CABLE TESTING

A link at the rear of the unit has been supplied so that the Type SLYG51G11 relay may be used in a "cable" application. When used in this fashion the following tests and equations apply.

PHASE ANGLE ADJUSTMENT (PRELIMINARY CALIBRATION)

(a) Apply voltage only to the relay. Apply 60 VAC to the input terminals of the phase under test. Short the voltage terminals of the other two phases.

(b) Connect a dual trace scope, channels A and B to the F162 card, pins 8 and 9 respectively of the phase under test.

(c) Position the Option K jumper plug on this card such that coincident square wave traces are obtained.

REACH ADJUSTMENT TESTS

To set pot P10 use the same procedure as that stated earlier except for step (d). Step (d) should read - Set the phase angle meter at 75 degrees.

To set pot P12 use the same procedure as that stated earlier except for step (d) and (e). Step (d) should read - Set the phase angle meter at 30 degrees. Step (e) should read - Be sure the link at the rear of the unit is in the "cable" position.

TESTING MHO CHARACTERISTIC

To obtain any points on the relay characteristic for any one of the three phases use the same procedure as that stated earlier with the following exceptions:

Step (e) - Set the link at the rear of the unit in the "cable" position.

The voltage at which the relay picks up can be expressed by:

$$V = \frac{2}{3}(IZ)\frac{\cos(\alpha - 75^o)}{\%\ \text{Restraint Tap}} \times 100 + \frac{K_o}{3}(IZ)\frac{\cos(\alpha - 30^o)}{\%\ \text{Restraint Tap}} \times 100 \qquad (6)$$

where I = five amp test current
Z = base reach of the relay (again both portions must have the same base reach)
α = the angle read at the phase angle meter
$K_o = \frac{Z_o}{Z_1} = KU + KT$

ANGLE OF MAXIMUM REACH

A plot of the relay characteristic by using the above test procedure will show the angle of maximum reach.

MAINTENANCE

PERIODIC CHECKS

For any periodic testing of the Type SLYG51C11 relay the trip coil circuit of the circuit breaker should be opened by opening the disconnect switches or other test switches provided for this purpose.

TROUBLE SHOOTING

Test points are provided at selected points in the Type SLYG51C11 relay to observe outputs if trouble shooting is necessary. The use of a card adapter will make the pins on any one card available for testing.

For the physical location of components and cards refer to Fig. 2, the component location diagram.

SPARE CARDS

The number of spare cards to carry in stock would depend on the total number of static relays, using similar cards, at the same location or serviced by the same test group. For each type of card (different code designation) a suggested minimum number of spare cards would be:

1 spare for 1 to 25 cards
2 spares for 26 to 75 cards
3 spares for 76 to 150 cards

CARD DRAWINGS

Details of the circuits of the printed circuit cards can be obtained in the printed circuit card book GEK-34158.

APPENDIX I

DEFINITION OF SYMBOLS

In the following appendices, and throughout other portions of this instruction book, the symbols used for voltages, currents, impedances, etc., are consistent. Note that all of the parameters listed below are secondary quantities based on the CT and PT ratios on the protected line terminal. Other symbols not defined here are to be defined as and where they are used.

Voltage

E_a = Phase A-to-neutral voltage

E_b = Phase B-to-neutral voltage

E_c = Phase C-to-neutral voltage

$E_{ab} = (E_a - E_b)$

$E_{bc} = (E_b - E_c)$

$E_{ca} = (E_c - E_a)$

E_{am} = Phase A-to-median (midpoint of E_{bc}) voltage

E_{bm} = Phase B-to-median (midpoint of E_{ca}) voltage

E_{cm} = Phase C-to-median (midpoint of E_{ab}) voltage

E_0 = Zero sequence phase-to-neutral voltage

E_1 = Positive sequence phase-to-neutral voltage

E_2 = Negative sequence phase-to-neutral voltage

Note that when one of these symbols is primed, such as E_a', it then represents the voltage at the location of the relay under consideration.

Current

I_a = Total phase A current in the fault.

I_b = Total phase B current in the fault.

I_c = Total phase C current in the fault.

I_0 = Total zero sequence current in the fault.

I_1 = Total positive sequence current in the fault.

I_2 = Total negative sequence current in the fault.

Note that when one of the above symbols is primed, such as I_a', or I_2', it then represents only that portion of the current that flows in the relays under consideration.

I_0'' = Zero sequence current flowing in a line that is parallel to the protected line. Taken as positive when the current flow in the parallel line is in the same direction as the current flowing in the protected line. While this current flows in the parallel line, the secondary value is based on the CT ratio at the protected line terminal under consideration.

Distribution Ratios

C = Positive sequence current distribution ratio, assumed equal to the negative sequence current distribution ratio.

C_0 = Zero sequence current distribution ratio,

$$C = \frac{I_1'}{I_1} = \frac{I_2'}{I_2} \qquad C_0 = \frac{I_0'}{I_0}$$

Impedance Reactance

Z_0 = System zero sequence phase-to-neutral impedance as viewed from the fault.

Z_1 = System positive sequence phase-to-neutral impedance as viewed from the fault.

Z_2 = System negative sequence phase-to-neutral impedance as viewed from the fault. Assume equal to Z_1.

Z_0' = Zero sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal.

Z_1' = Positive sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal.

Z_2' = Negative sequence phase-to-neutral impedance of the protected line from the relay to the remote terminal, assume equal to Z_1'.

Z_{om} = Total zero sequence mutual impedance between the protected line and a parallel circuit over the entire length of the protected line.

X_1' = Positive sequence phase-to-neutral reactance of the protected line from the relay to the remote terminal.

X_0' = Zero sequence phase-to-neutral reactance of the protected line from the relay to the remote terminal.

X_{om} = Total zero sequence mutual reactance between the protected line and a parallel line over the entire length of the protected line.

Z_L = Line impedance

Z_a = Phase A impedance for condition described.

All of the above are secondary ohms, where:

$$\text{Secondary Ohms} = \text{Primary Ohms} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

and Z_{om} and X_{om} are calculated using the CT ratio for the protected line.

Miscellaneous

T = Relay voltage restraint tap setting in percent.

K_0 = Zero sequence current compensation tap setting for the protected line; in percent, unless otherwise noted (MOD III design; $K_0 = Z_0'/Z_1'$).

K_Q = Constant depending on the ratio of Z_0/Z_1.

T_B = Relay basic minimum ohmic tap at the set angle of maximum reach.

K' = Zero sequence current compensation tap setting for the protected line: in percent, unless otherwise noted.

K'' = Zero sequence current compensation tap setting for the parallel line: in percent, unless otherwise noted.

S = Ratio of distances as defined where used.

M = Reach of mho function from the origin (relay location) in the direction of the protected line section as forward reach.

M' = Reach of mho function from the origin (relay location) away from the protected line section as reverse reach or reach in the blocking direction.

θ = Line angle.

ϕ = Angle of maximum reach
or any other lower case Greek letter (except π) = angles in degrees as defined where used.

APPENDIX II

ZERO SEQUENCE CURRENT COMPENSATION, MUTUAL COUPLING AND RELAY SETTINGS

Included in the SLYG51C11 relay are provisions for zero sequence current compensation of the mho distance functions. Zero sequence current compensation when set properly assures that the distance function will measure the positive sequence impedance of the protected line. The impedance measured by the function will also be affected by the presence of mutual coupling. For the general case, the apparent impedance seen by the mho function for a phase-A-to-ground fault at the far end of a line is as follows:

$$Z_a = \left[\frac{2C + C_0\, Z_0'/Z_1'}{2C + K_0\, C_0}\right] Z_1' + \frac{I_0''\, Z_{om}}{I_a' + (K_0 - 1)\, I_0'} + \frac{I_a\, R_a}{I_a' + (K_0 - 1) I_0} \qquad \text{II-a}$$

All terms are defined in Appendix I.

Evaluation of the first term in Equation II-a will show that the term in brackets would be equal to 1.0 if K_0 is set equal to Z_0'/Z_1'. Equation II-a then reduces to

$$Z_a = \left[Z_1' + \frac{I_0''\, Z_{om}}{I_a' + (K_0-1)\, I_0'}\right] + \frac{I_a\, R_a}{I_a' + (K_0-1)\, I_c'} \qquad \text{II-b}$$

In the absence of mutual coupling, and neglecting fault resistance, the apparent impedance seen by the relay will be equal to the positive sequence impedance of the line (Z_1') if and only if $K_0 = Z_0'/Z_1'$. If K_0 is set at some other value, the apparent impedance will be somewhat different than the positive sequence line impedance. In general, the proper amount of zero sequence current compensation leads to a reduction in the apparent impedance seen by the mho distance function thereby allowing lower reach settings to be made. The zero sequence current compensation factor K_0 should be set equal to or as near as possible to the ratio of Z_0'/Z_1'. If K_0 can not be set exactly equal to Z_0'/Z_1', the next higher tap setting should be selected. This will tend to make the function reach slightly further than the desired setting, but that is more desirable than having the function underreach as would be the case if the next lower tap setting had been used.

Equation II-b shows the second term to be a function of the mutually coupled current (I_0'') from parallel line. I_0'' will be either positive, zero, or negative thus leading to an increase, no change or a decrease in the apparent impedance seen by the function. In those cases where I_0'' has a negative value, the second term inside the brackets in equation II-b and II-a should be neglected in evaluating the apparent impedance. Otherwise, the function would have a tendency to underreach and may not provide adequate coverage if the mutually coupled current were not present; i.e., if the parallel line was out of service.

The reach of the function is determined by the setting of the basic minimum reach taps T_B and the voltage restraint taps T. The voltage restraint tap setting is calculated as follows:

$$T = \frac{100 T_B \cos(\theta - \phi)}{2} \qquad \text{II-c}$$

where:

θ = Angle of maximum reach

ϕ = Angle of positive sequence impedance of the protected line

Z = Desired reach in secondary positive sequence phase-to-neutral ohms

In general, the function will be set to reach beyond the remote terminal of the line, therefore the desired reach will be somewhat larger than the apparent impedance as calculated from equation II-b; that is,

$$Z = M\left[Z_1' + \frac{I_0''\, Z_{om}}{I_a' + (K_0 - 1) I_0'}\right]$$

where:

M = margin factor

Consideration must be given to the particular application in determining the margin factor M. General considerations are given in the section under APPLICATION. For a particular application, see the logic description that accompanies the overall logic diagram for that scheme. As an example, consider an application in which it is desired to have the reach of the function be set equal to 150 percent of the apparent impedance. In that case, M = 1.5.

In the section under APPLICATION, it was noted that the highest basic reach tap that accomodates the desired reach should be used in setting the relay. In order to meet this requirement it will be necessary to determine the desired reach before equation II-c can be evaluated. The steps to be followed in setting the relay are as follows:

1. Evaluate equation II-a to determine the desired reach.

2. Select the highest basic minimum reach tap that will accomodate this reach; i.e., the highest tap available that is less than the desired reach.

3. Evaluate equation II-c to determine the voltage restraint tap setting T.

The effect of fault resistance, which is to add another error term to the equation, has not been included in the equations for determining the reach setting of the mho distance function. When the SLYG51C11 relay is applied on relatively long lines strung on steel towers and having shield wires, the characteristic of the mho functions is such that coverage for fault resistance will automatically be provided. On short lines, lines without shield wires and on lines strung on other than steel towers, it may be necessary to evaluate the effects of fault resistance to see if adequate coverage will be provided.

APPENDIX III

MAXIMUM PERMISSIBLE REACH SETTINGS

Under some conditions, it is possible during single-phase or double-phase-to-ground faults in the non-tripping direction for a mho function associated with an unfaulted phase to operate. Because this can result in a false trip, it is necessary to limit the reach setting of the ground mho function to prevent it from operating on reverse faults. In the following sections, equations are presented for determining the maximum permissible reach setting (minimum permissible tap setting) for both types of faults. Evaluation of these equations is required only if the reach setting exceeds twice the positive sequence of the protected line.

(1) Single-phase-to-ground fault

$$T = \frac{T_B K_Q \left[K_o C_o - C\right]}{Z_1} \qquad \text{III-a}$$

where

T_B = basic minimum tap

K_o = zero sequence current compensation factor = Z_0'/Z_1'

C_o = zero sequence current distribution constant

0 = positive sequence current distribution constant

Z_1 positive sequence impedance of system as viewed from the fault.

K_Q = system constant depending on ratio of system impedances Z_0/Z_1 as viewed from the fault Use curves of Figs. 19 and 20 to determine K_Q.

(2) Double-phase-to-ground faults

$$T\ min = \frac{100\ T_B \left[K_o C_o - C\right]\ Cos\ (\theta - \phi)}{3\ Z_o} \qquad \text{III-b}$$

where

θ = relay angle of maximum reach

ϕ = angle of protected line

Z_o = zero sequence system impedance as viewed from fault

All other terms are defined above.

In making the evaluations, the term in brackets $[K_o C_o - C]$ should be evaluated first. If this term is negative, it indicates no limitation to the application and no further evaluation need be made. If the term is not negative, both equations must be evaluated and the highest of the two tap values determined should be selected and some margin added. A 10 percent margin (not 10 percentage points) should be adequate. The tap setting used on the mho function should be no lower than this value nor should it be any higher than the value calculated in Appendix II, equation II-c. In any event, the mho function tap setting should never be set less than 10 percent.

APPENDIX IV

THREE TERMINAL LINE APPLICATIONS

PILOT RELAYING SCHEMES

The ideal performance of a pilot relaying scheme for transmission line protection for either a two terminal or three terminal line may be defined in very broad and simple terms as follows:

(a) Internal Faults - Trip all terminals simultaneously for any internal fault at any location with any expected distribution of currents that is possible on the system being considered. (Note that it may be impossible to meet the requirement for a simultaneous tripping of all terminals on a multi-terminal line. This is particularly true if there are external ties between source and fault terminals or if one of the terminals lacks a ground current source. In such cases some special provision must be made in order to provide simultaneous tripping).

(b) External Faults - Trip no line terminal for any external fault at any location with any expected distribution of currents that is possible on the system being considered.

In order to provide simultaneous tripping of all three line terminals, it is necessary to use reach settings on the overreaching mho functions MTG large enough to insure that all three terminals will respond for any internal fault location with all three line breakers closed. This condition must be obtained for any possible system configuration including the outage or in-service condition of adjacent lines or generating sources which affect the line under consideration. If the MTG units do not respond to some internal fault locations and conditions, there are pilot relaying schemes which will not trip at any line terminal. Care should be exercised in the choice of the pilot relaying scheme as well as the setting of the units.

The setting of the overreaching MTG functions requires the determination of the apparent impedance "seen" by the relays at a given line terminal for a fault at the second line terminal under the conditions of maximum infeed from the third line terminal. Consider the relays at terminal A of Fig. 11 and the fault at terminal C with infeed current from terminal B. The approximate apparent impedance Zapp at terminal A is given by the following:

$$Zapp = Z_{AC} + \frac{I_B}{I_A} Z_{JC}$$

A more accurate way to determine this apparent impedance would be using a system fault study. The apparent impedance would then be the line-to-neutral voltage E_a' divided by the phase current I_a'. Where zero sequence current compensation is used, I_a' would be replaced by the expression $[I_a' + (K_0 - 1) I_0']$ where K_0 is a per unit value. The voltage E_a' at terminal A for a fault at terminal C. Fig. 11, is made up of the sum of two complex components. One component is the positive, negative and zero sequence voltage drops resulting from the current contribution from terminal A through the impedance Z_{AC}. The other component is the positive, negative and zero sequence voltage drops resulting from the current contribution from terminal B through the impedance from the junction to terminal C, Z_{JC}.

$$Ea' = I_1'_A Z_1'_{AC} + I_2'_A Z_2'_{AC} + I_{oA} Z_o'_{AC} + I_1'_B Z_1'_{JC} + I_2'_B Z_2'_{JC} + I_o'_B Z_o'_{JC}$$

If the two source terminals A and B have the same positive and zero sequence current distribution ratios, the above expression could be greatly simplified. This is not usually the case, however, and it is necessary to take these factors into account.

The setting of the MTG overreaching function should be at least 1.50 times the apparent impedance Zapp. The voltage restraint tap setting will then be determined as:

$$T = \frac{100\ T_B \cos(\theta - \phi)}{1.5 \times Zapp}$$

where θ = angle of maximum reach

ϕ = angle of protected line

All other symbols are defined in Appendix I.

STEP DISTANCE PROTECTION

When the SLYG relay is applied as step distance protection on three terminal lines, special considerations need to be employed in the settings of the various functions.

A Zone Two ground mho function must be set large enough to overreach a fault at the most remote bus with all three line breakers closed. If it is not possible to set the Zone Two functions to achieve this, it is quite likely that sequential tripping will result for remote end zone internal faults. Once the Zone Two settings have been made for the conditions of maximum infeed, they should then be checked for proper coordination with adjacent line Zone Two relaying when the infeed on the protected line is zero. A Zone Three ground mho function has similar requirements for settings as the Zone Two function except for longer reach and coordination with adjacent line Zone Three relaying.

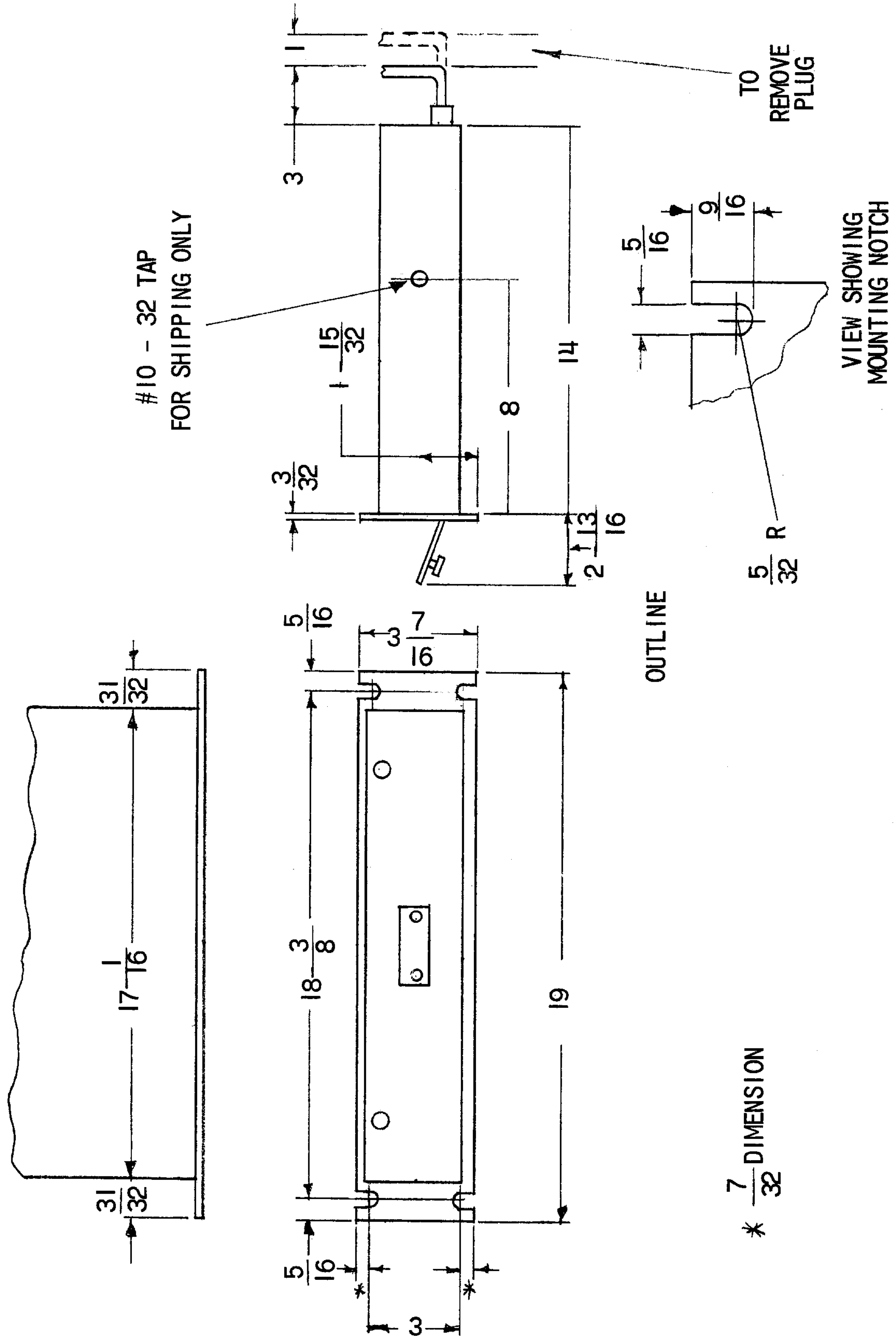

Fig. 1 (0227A2036-0) SLYG51C11 OUTLINE AND MOUNTING DIMENSIONS

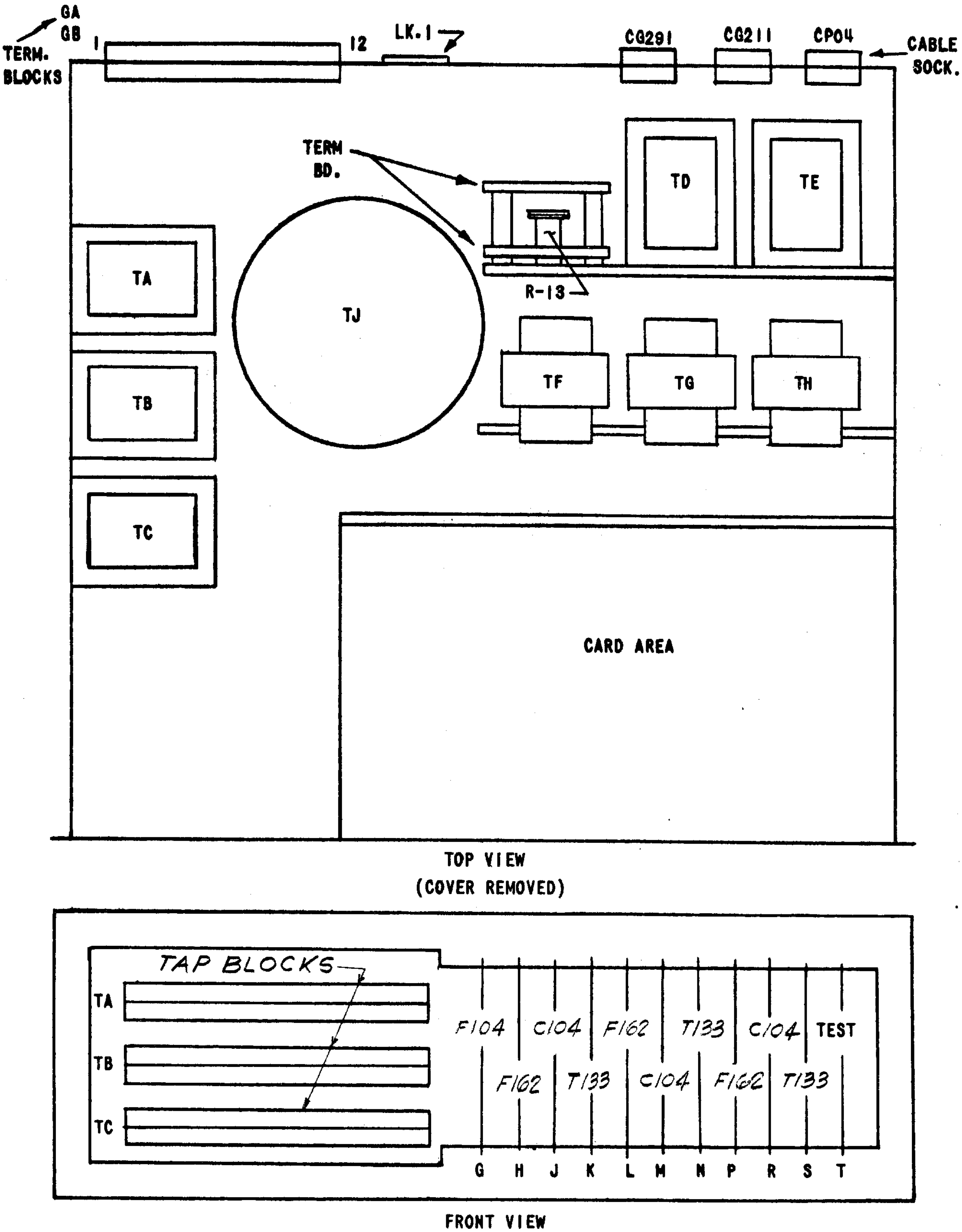

Fig. 2 (0269A3123-0) SLYG51C11 COMPONENT LOCATION DIAGRAM

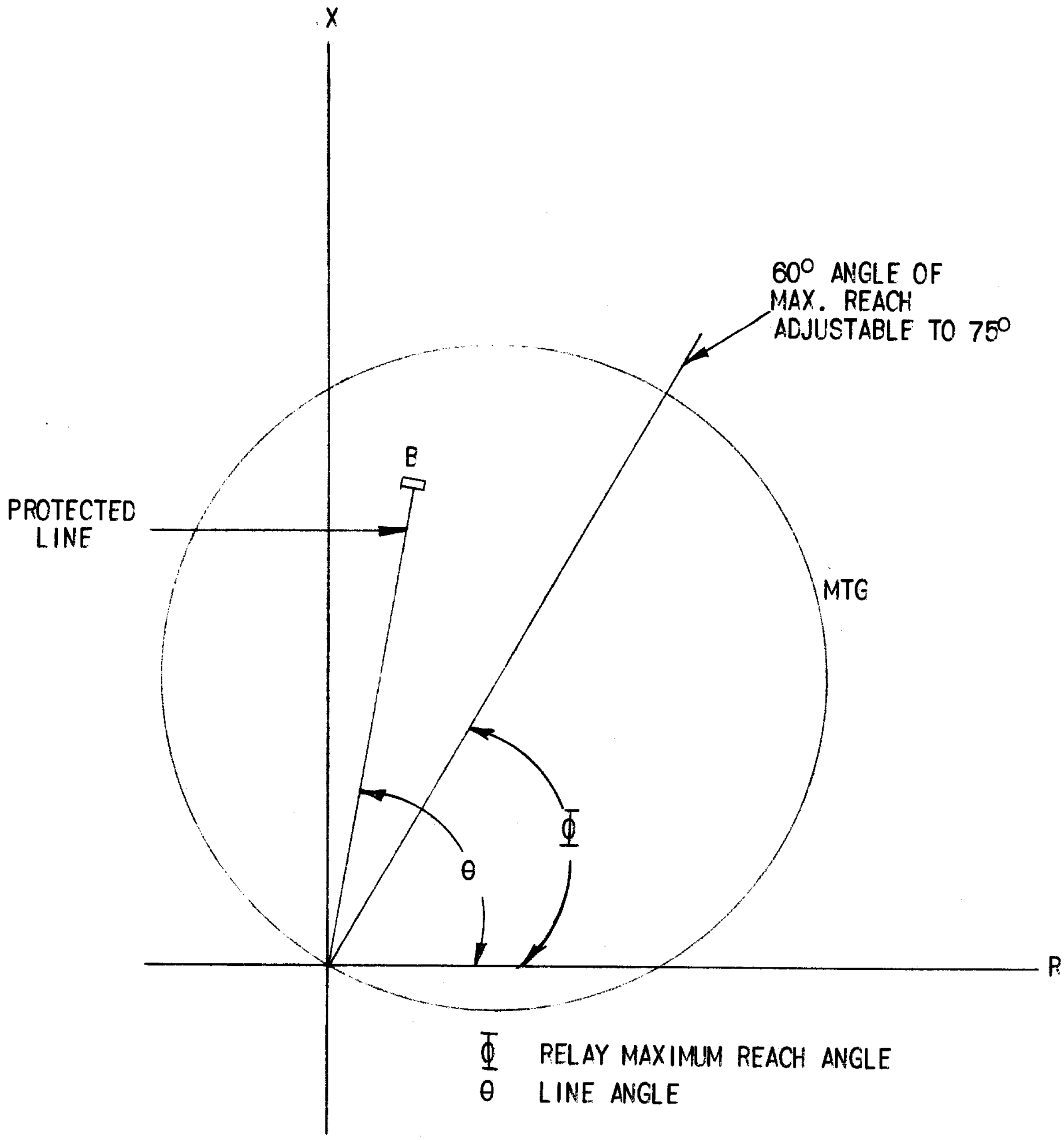

Fig. 3 (0227A2106-0) TYPICAL MTG CHARACTERISTIC-SLYG51C11 RELAY

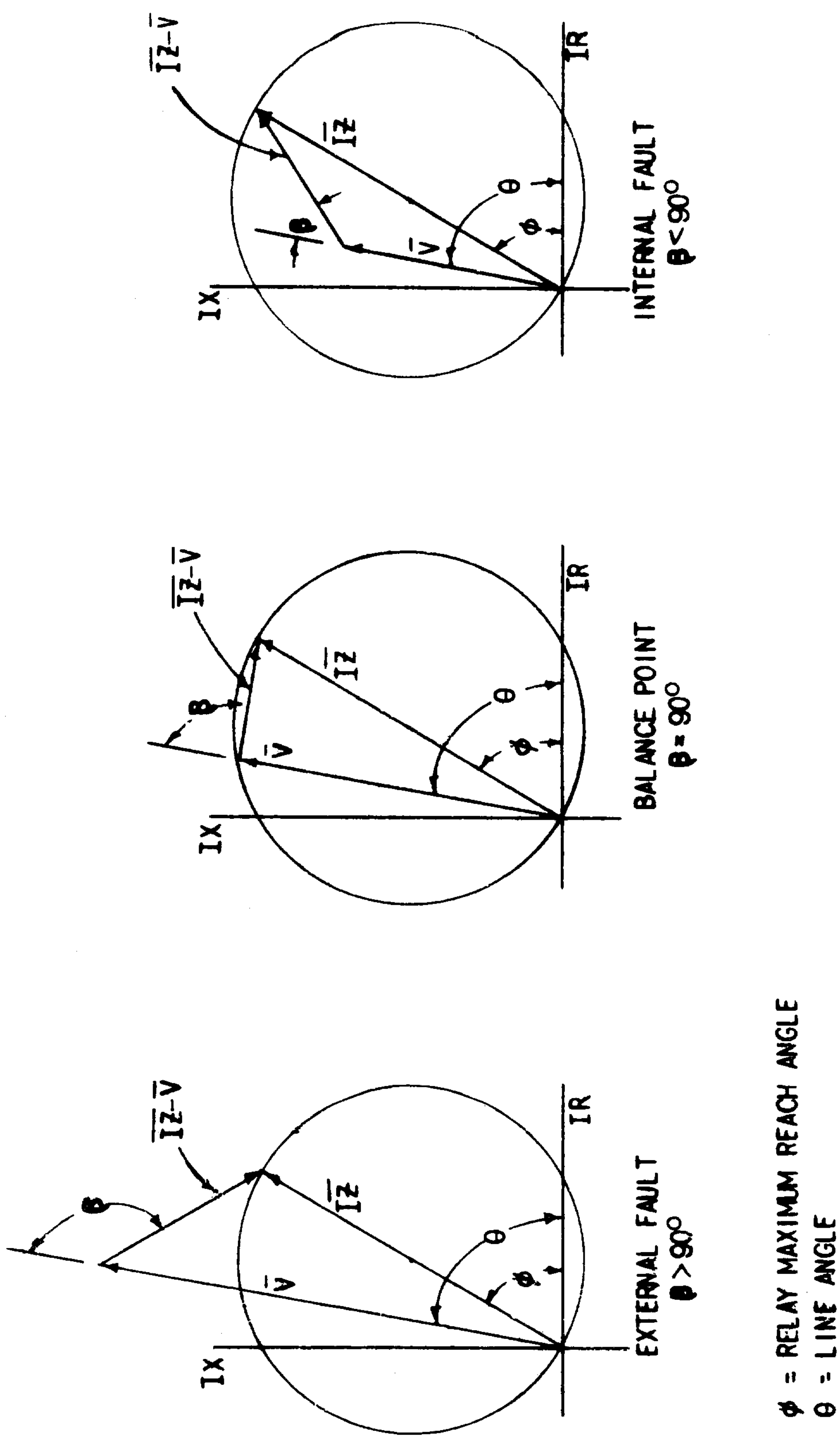

Fig. 4 (0227A2090-0) MHO CHARACTERISTIC BY PHASE ANGLE MEASUREMENT

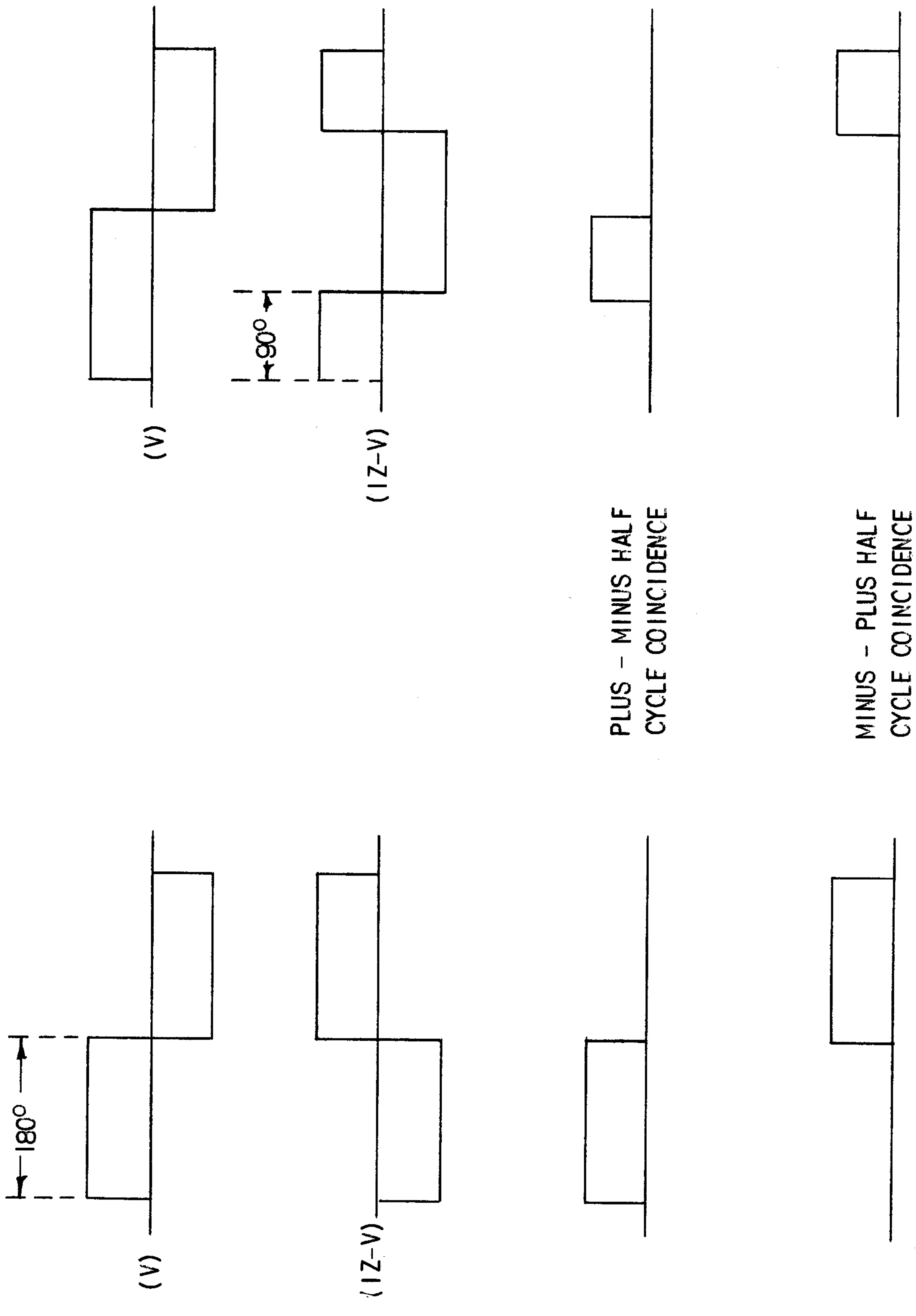

Fig. 5 (0227A2105-0) MTG MEASUREMENT PRINCIPLES

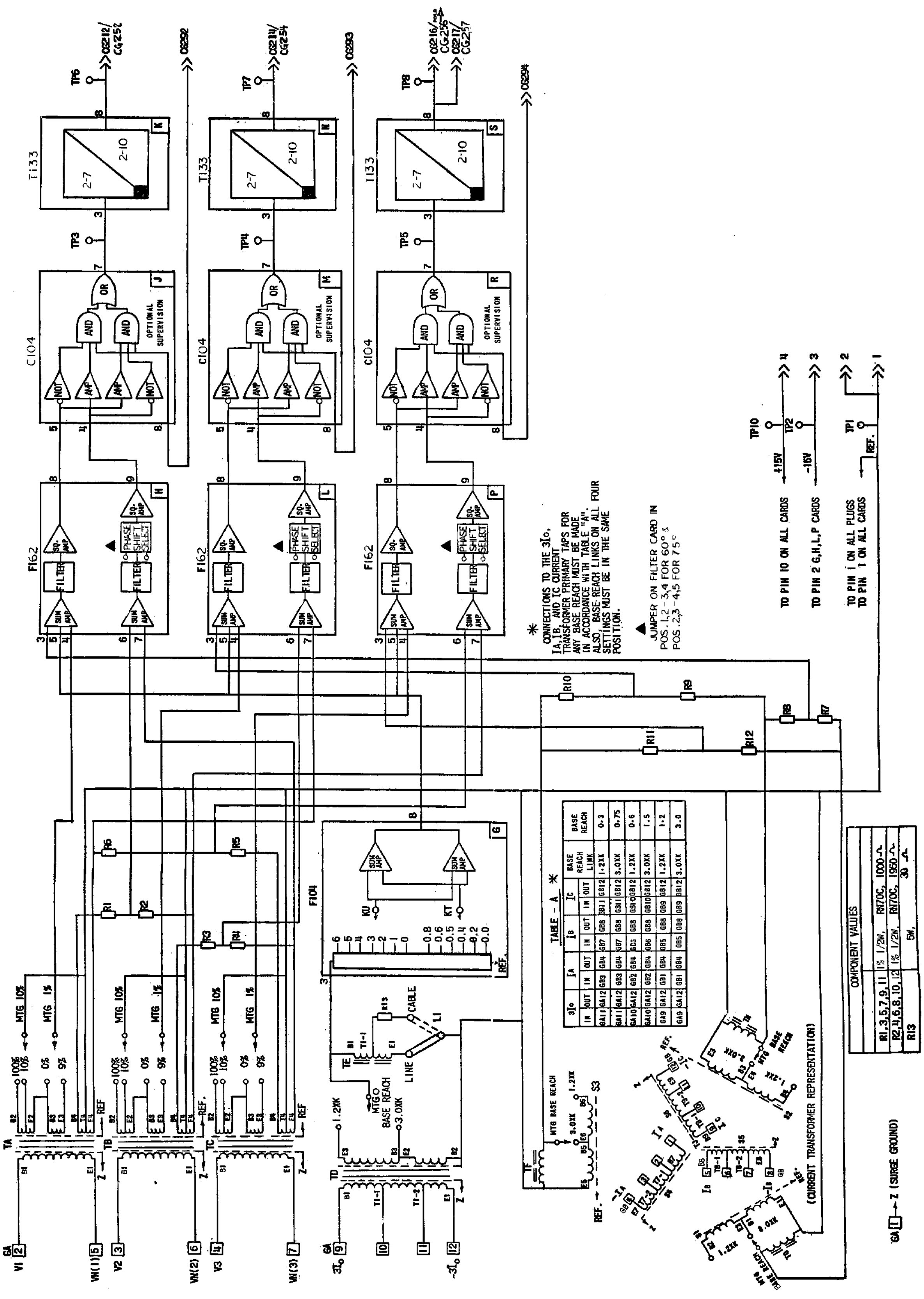

Fig. 6 (0152C8507-0) INTERNAL CONNECTIONS DIAGRAM OF SLYG51C11 RELAY

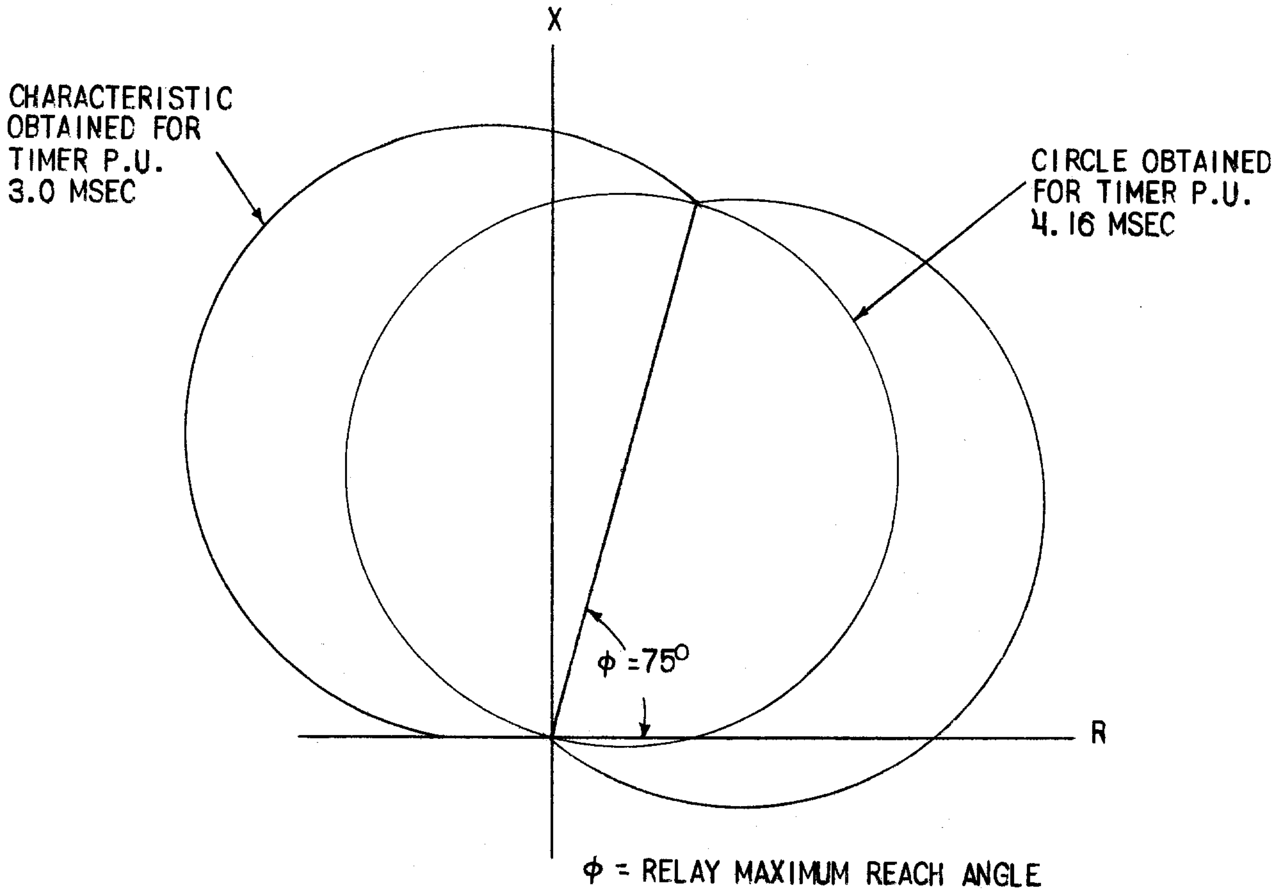

Fig. 7 (0227A2093-0) MHO OPERATING CHARACTERISTICS AT 75 DEGREE ANGLE OF MAXIMUM REACH WITH VARIATIONS IN PICKUP TIMER SETTINGS

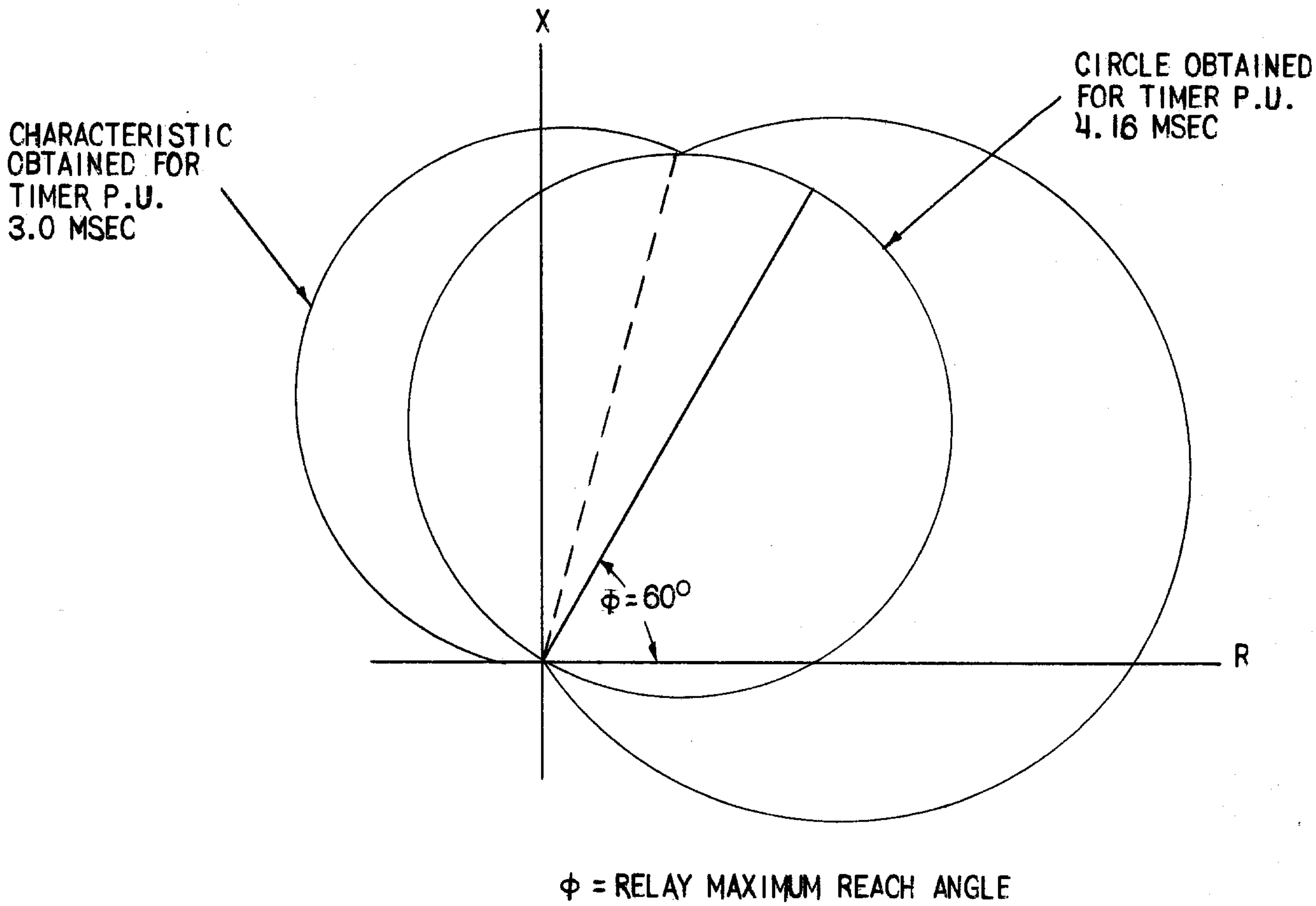

Fig. 8 (0227A2094-0) MHO OPERATING CHARACTERISTICS AT 60 DEGREE ANGLE OF MAXIMUM REACH WITH VARIATIONS IN PICKUP TIMER SETTINGS

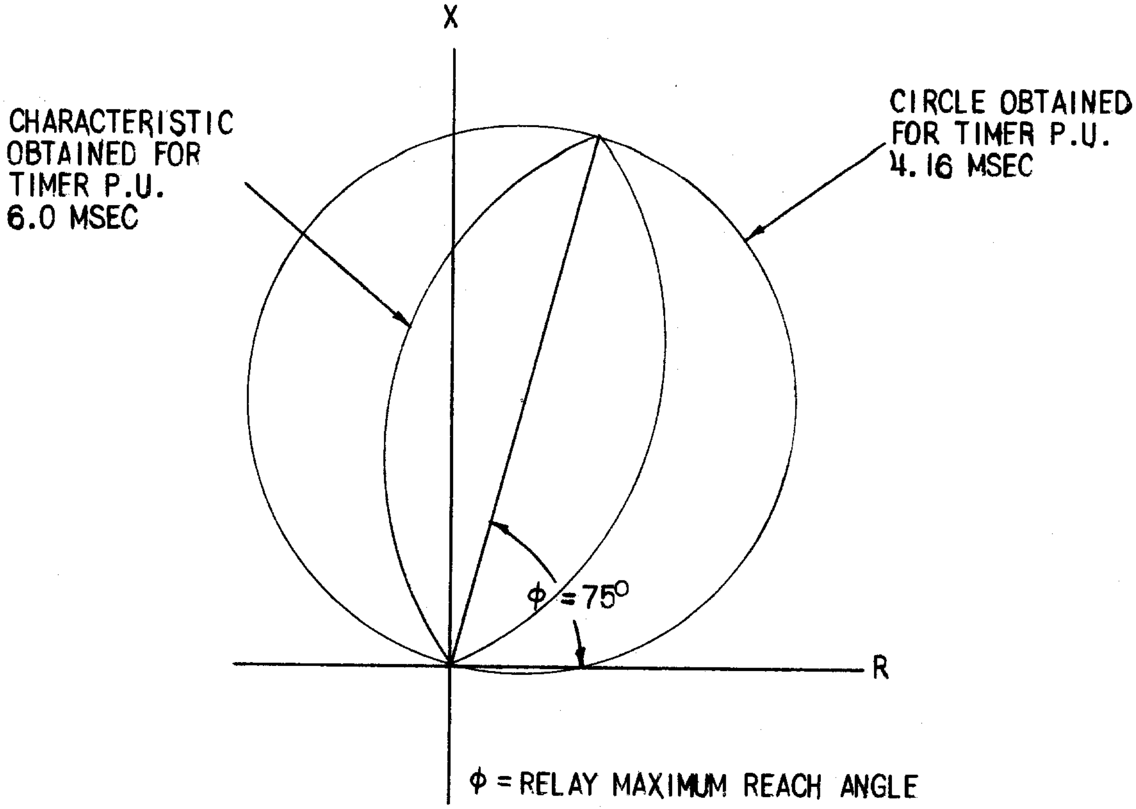

Fig. 9 (0227A2095-0) MHO OPERATING CHARACTERISTICS AT 75 DEGREE ANGLE OF MAXIMUM REACH WITH VARIATIONS IN PICKUP TIMER SETTINGS

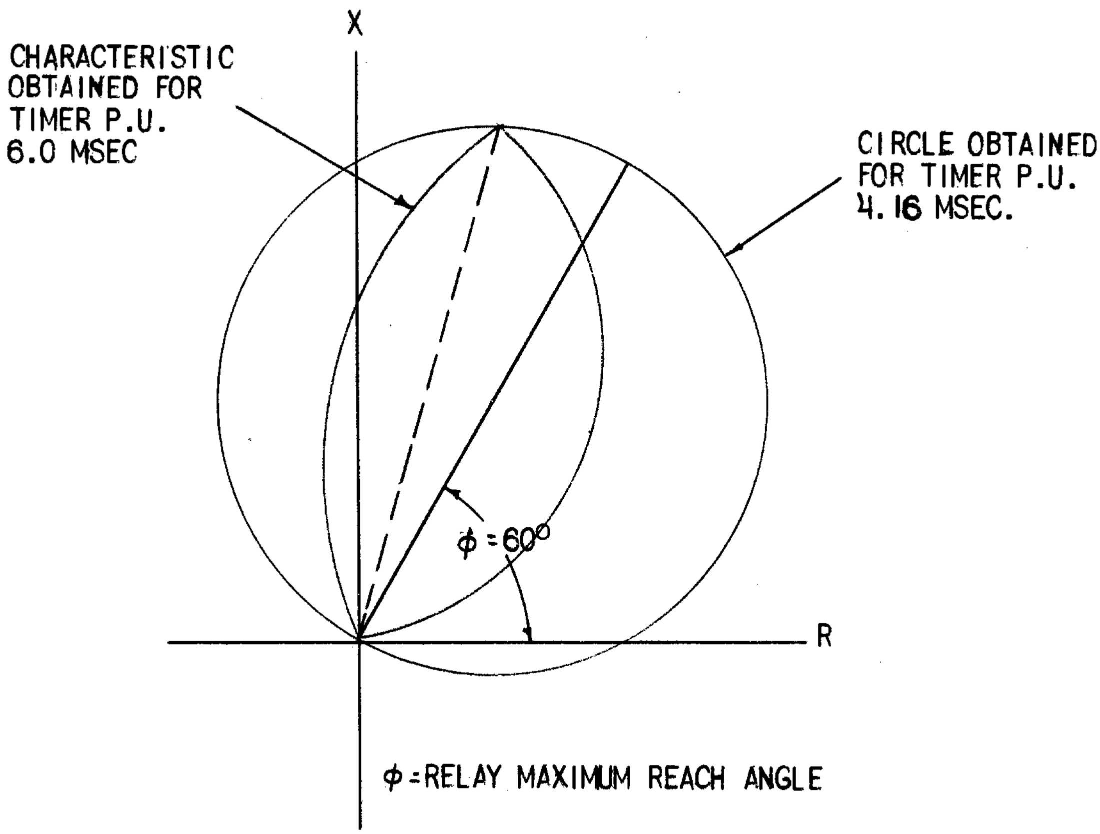

Fig. 10 (0227A2096-0) MHO OPERATING CHARACTERISTICS AT 60 DEGREE ANGLE OF MAXIMUM REACH WITH VARIATIONS IN PICKUP TIMER SETTING

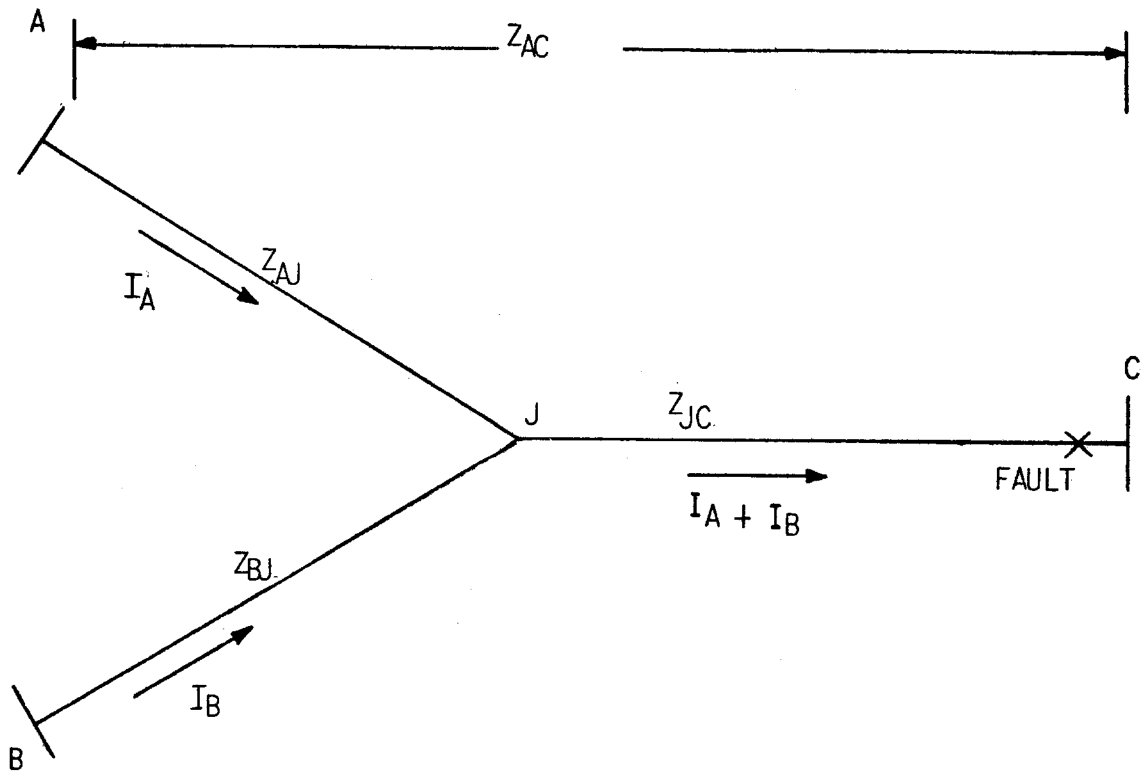

Fig. 11 (0227A2530-0) THREE TERMINAL LINE APPLICATION

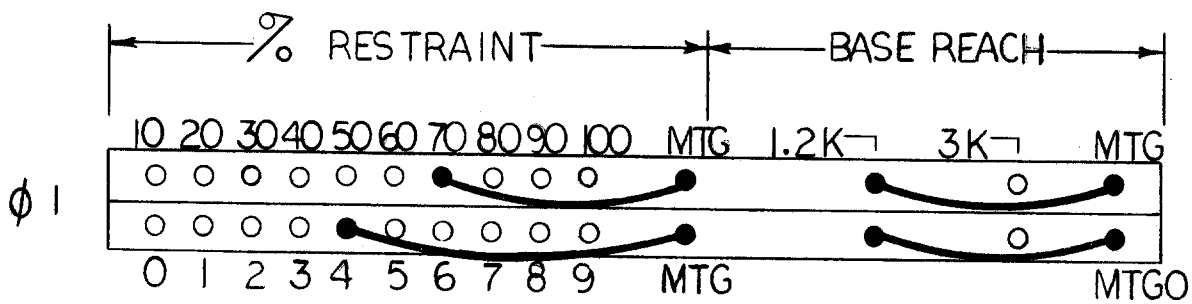

Fig. 12 (0227A2133-0) TYPICAL SLYG51C11 TAP BLOCK CONNECTIONS

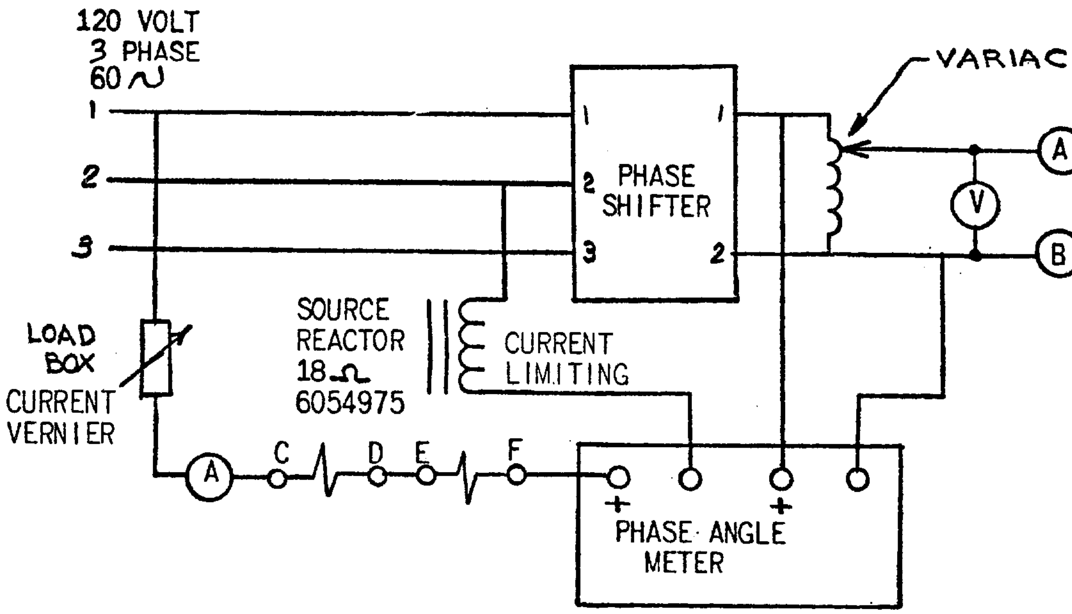

Fig. 13 0178A7029-3) PHASE SHIFTER TEST CIRCUIT

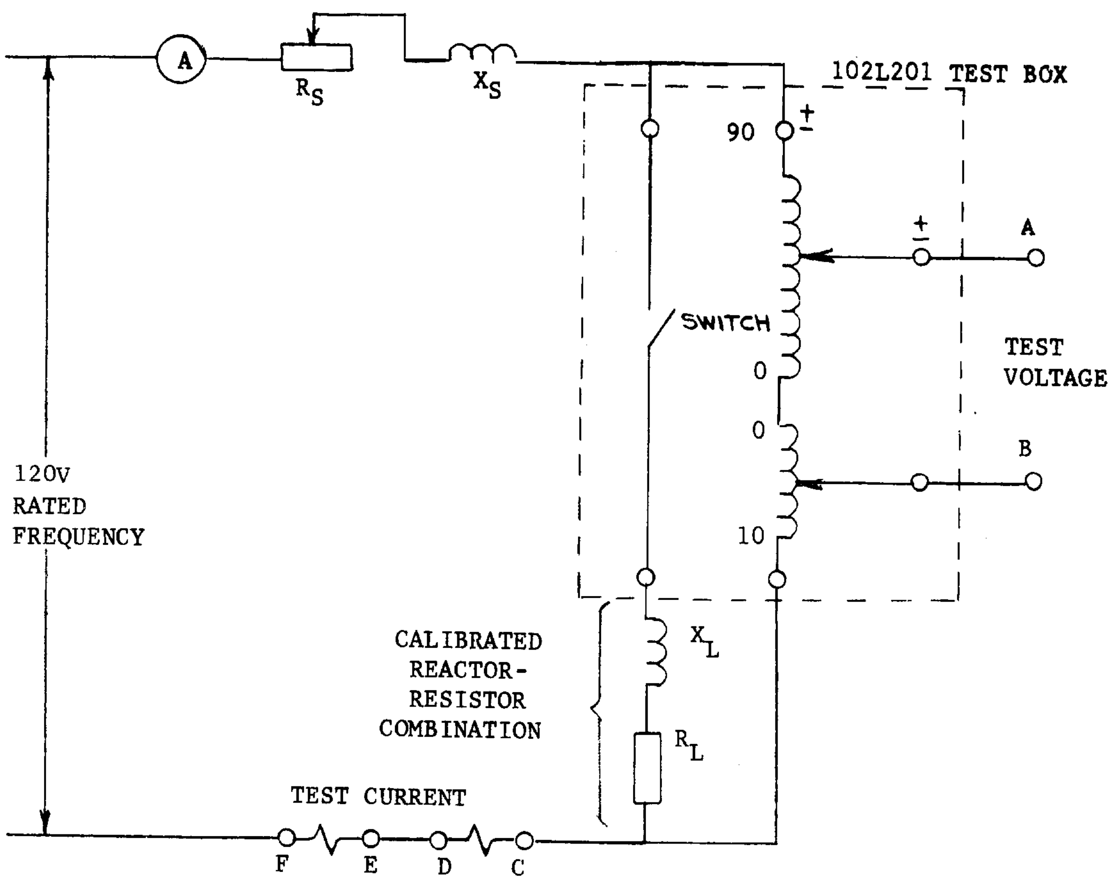

Fig. 14 (0178A7028-3) TEST CIRCUIT FOR CHARACTERISTIC CHECK USING TEST BOX, TEST REACTOR AND TEST RESISTOR METHOD

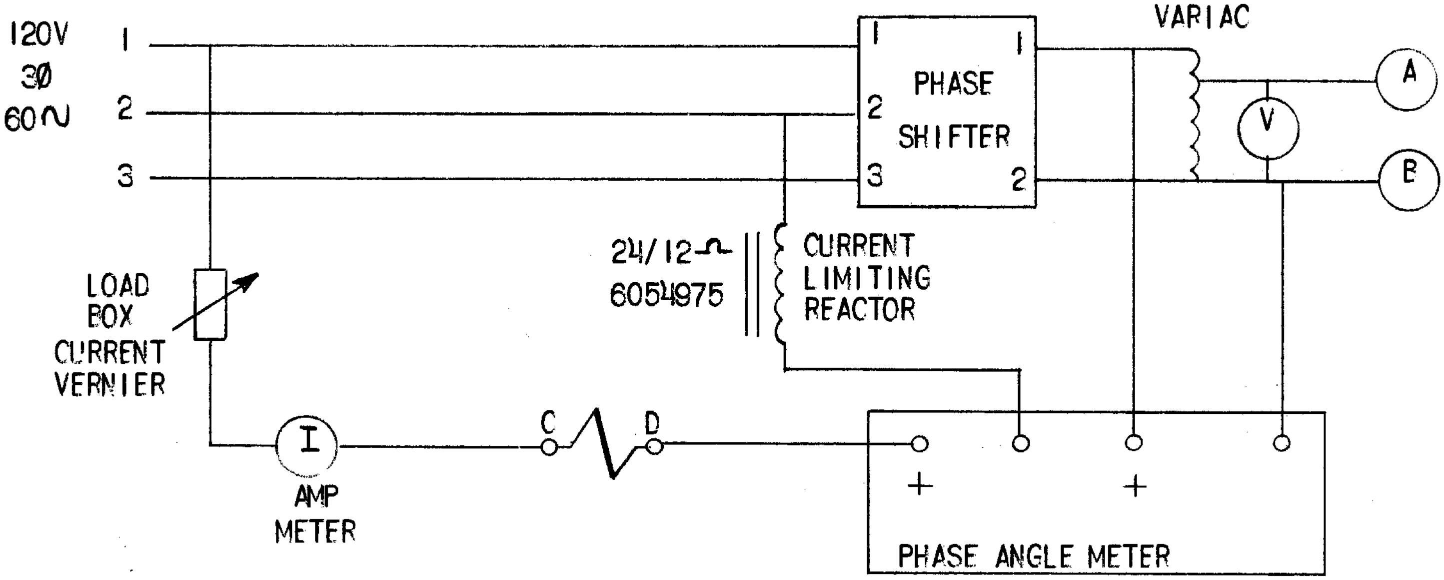

Fig. 15 (0227A2104-0) PHASE SHIFTER TEST CIRCUIT

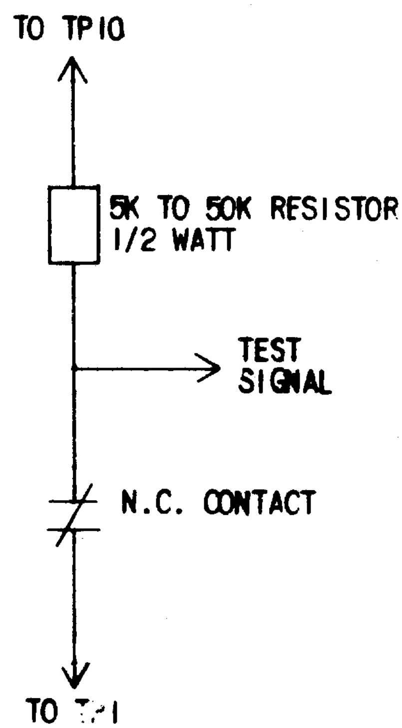

Fig. 16 (0227A2098-0) TEST CIRCUIT FOR TIMER CARD

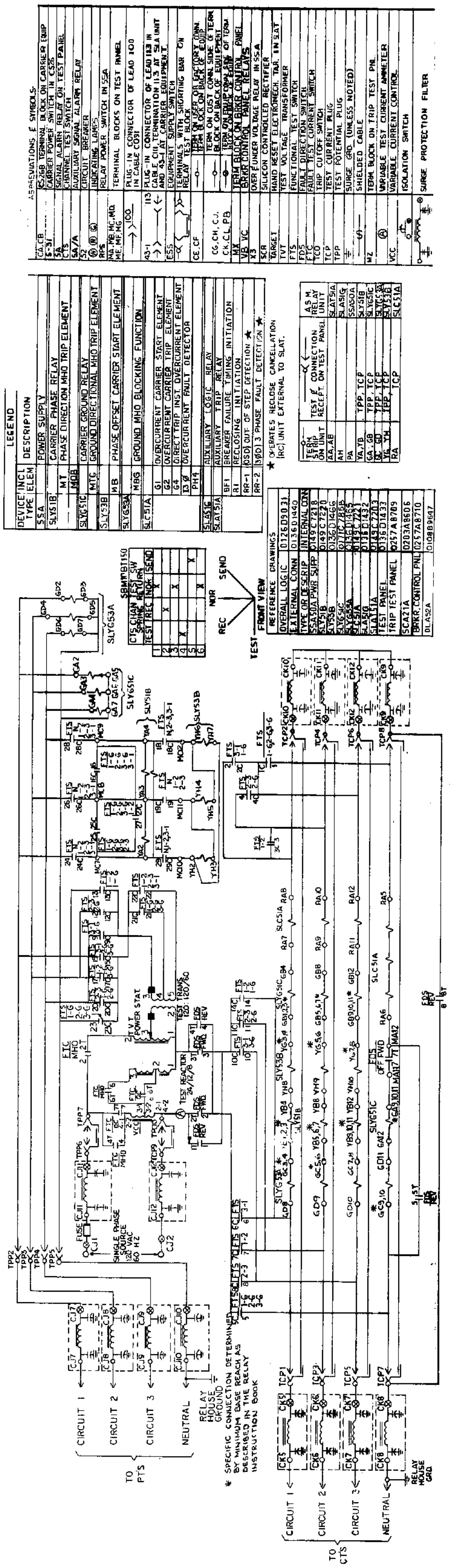

Fig. 17 (0124B8172-4 Sh. 1) TYPICAL EXTERNAL CONNECTIONS DIAGRAM

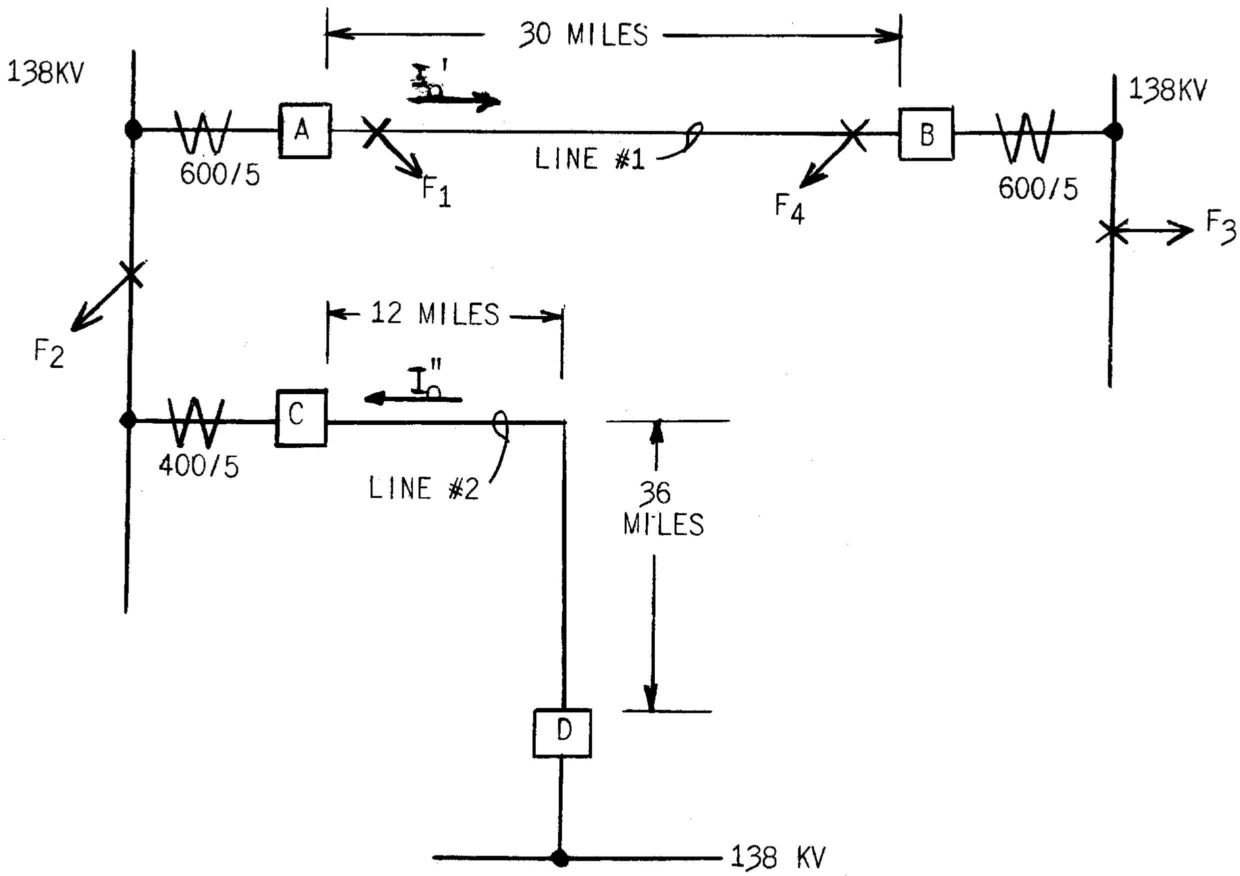

Fig. 18 (0165A7622-1) EXAMPLE OF POWER TRANSMISSION SYSTEM

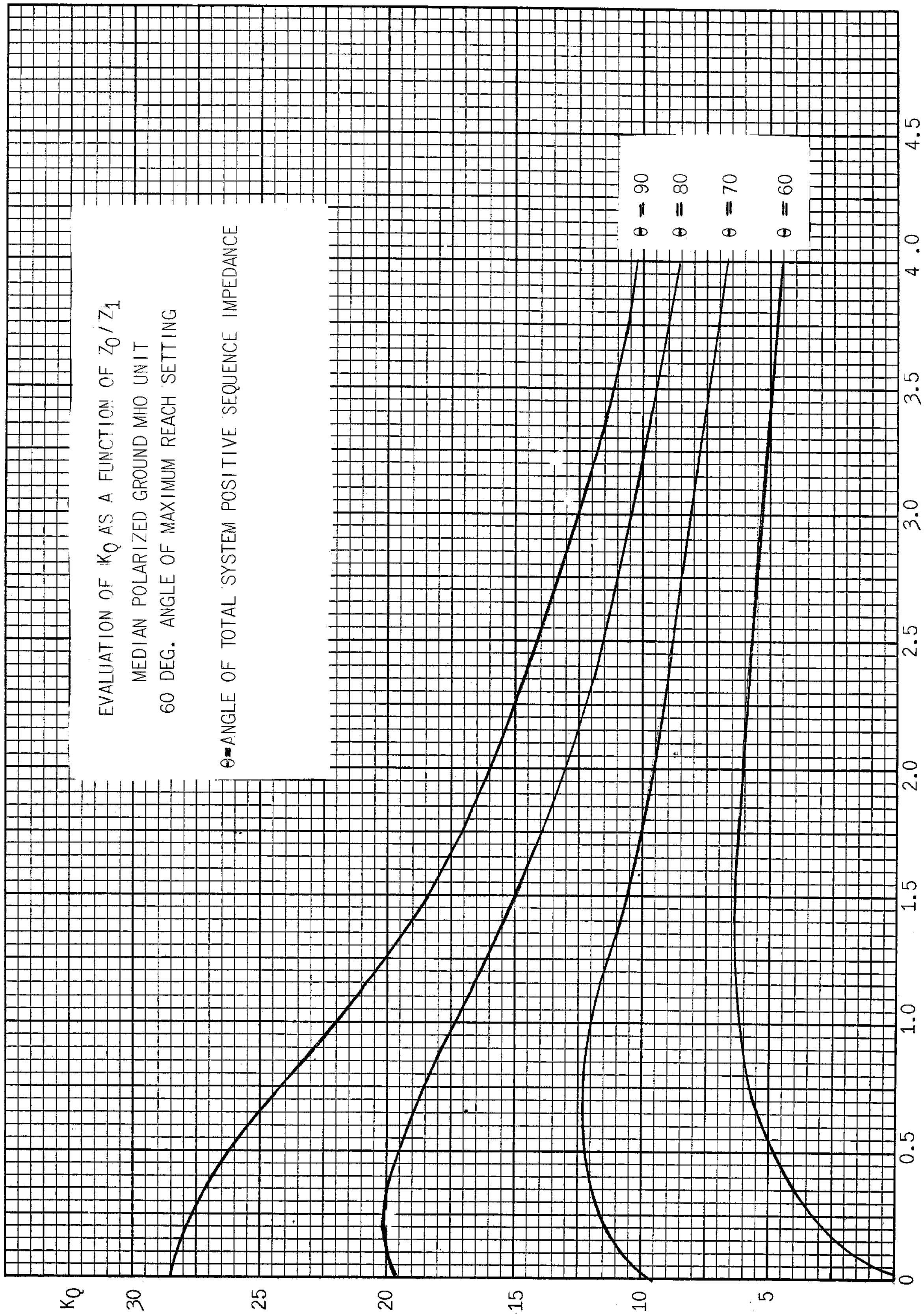

Fig. 19 (0226A6904-2) EVALUATION OF KQ MEDIAN POLARIZATION (60 DEGREES)

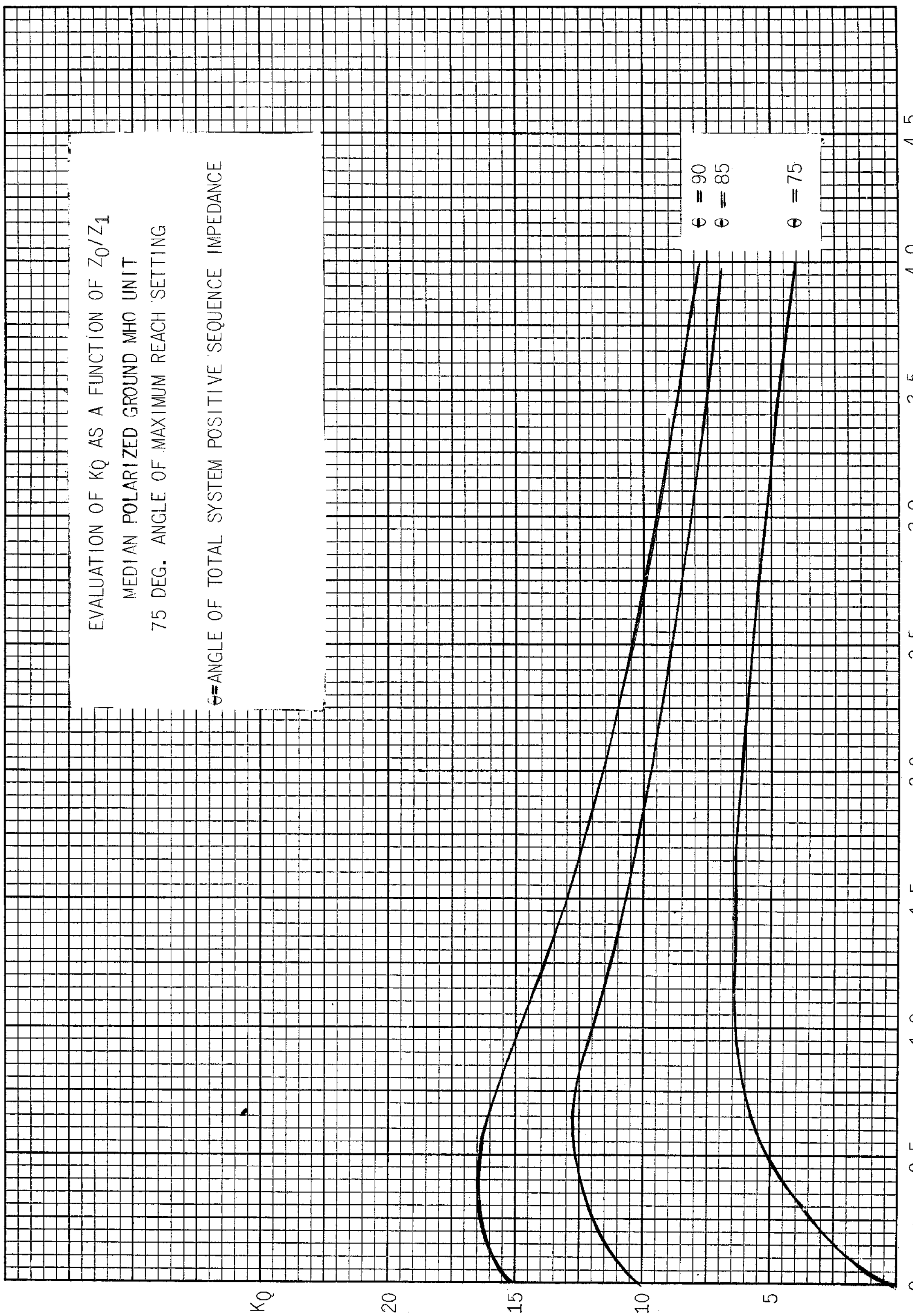

Fig. 20 (0226A6905-2) EVALUATION OF KQ MEDIAN POLARIZATION (75 DEGREES)

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