GET-6651A

# Power System Protection for Transmission Lines: Phase and Ground Distance Relays

# CONTENTS

## SUMMARY OF FEATURES

1. SLY and SLYG relays in 60-series are measuring functions only and are designed for use in factory-assembled static terminals,
2. SLY and SLYG relays in 80-series are mounted in drawout cases, and each relay has its own surge suppression, internal power supply, and contact outputs.
3. Relays are zoned-packaged; i.e. each relay provides one zone of protection for all three phases, with three separate measuring functions.
4. Phase relays use line-to-line voltage, supplemented by positive sequence voltage, for polarizing, which provides a continuous output for zero voltage phase-to-phase and double-phase-to-ground faults.
5. Ground relays use quadrature voltage for one polarizing signal, and zero sequence voltage and current for second polarizing signal. This improves performance and makes application easier.
6. Both phase and ground relays provide automatic increase in reach along R-axis, with more arc-resistance accommodation for close-in faults, as source resistance (and arc resistance) increases.

## INTRODUCTION

This publication describes the design features and application advantages of the SLY/SLYG 60/80 families of phase and ground distance relays. The SLY relays are phase relays and the SLYG relays are ground relays. The relays in the 60 series are rack-mounted for use in static protective equipments. and those in the 80 series are packaged in drawout cases. Each relay contains three measuring functions, one for each phase (ground relays) or each phase-pair (phase relays).

The basic relay designs are tripping relays with a reach-setting range that is adjustable from 0.1 to 30 ohms. Companion blocking relays are also available.

Also included in this bulletin are sections on application considerations, relay sensitivity, operating time, burden data and battery drain. Circuit diagrams for some typical relay schemes using these relays are also included.

## FEATURES

### PHASE RELAYS

The phase relays differ from other designs by having the normal line-to-line polarizing voltage supplemented by a positive sequence voltage that is in phase with the line-to-line voltage under balanced three phase conditions. This produces a “variable mho” characteristic whose diameter varies with the type of fault, the fault location, and the source impedance. The result. for phase-to-phase faults, is a characteristic with greater reach along the R-axis on a steady-state basis than the conventional mho circle, and a continuous output for a forward direction zero voltage fault. The supplementary polarizing also provides greater security against false tripping on reverse direction faults

### GROUND RELAYS

The ground relays use a second polarizing voltage, $K_0I_0Z_{R0}$-$V_0$, in addition to a quadrature polarizing voltage. The resulting characteristic provides the excellent fault resistance accommodation of a conventional quadrature polarized mho relay; prevents overreach, or incorrect directional action of the unfaulted phase mho functions, for either single line to ground or double line to ground faults; and eliminates the need for extensive calculations to determine limits on reach settings.

## SCOPE

The relays covered by this bulletin are listed below:

1. Component Relays

These relays are mounted in drawout cases and include an internal power supply, surge suppression and contact outputs.

| | |
|---|---|
| SLY81A | Phase tripping relay<br>0.1 to 4.0 ohms in short-reach relay<br>0.75 to 30 ohms in long-reach relay |
| SLY81B | Phase tripping relay with out of step blocking ($M_{0B}$)<br>0.1 to 4.0 ohms in short-reach relay<br>0.75 to 30 ohms in long-reach relay |
| SLY82 | Phase blocking relay<br>0.75 to 30 ohms reach; offset 0.1, 0.2, or 0.3 times reach setting |
| SLYG81* | Ground tripping relay<br>0.1 to 4.0 ohms in short-reach relay<br>0.75 to 30 ohms in long-reach relay<br>$K_0$ ($Z_0$/$Z_1$ compensation) settings of 2.5. 3.0,3.5,4.0,4.5 |
| SLYG82* | Ground blocking relay<br>0.75 to 30 ohms reach; offset 0.1. 0.2, or 0.3 times reach setting |

*SLYG81 and SLYG82 relays not suitable for single pole trip and reclose schemes.

2. Static Terminal Relays

These relays are measuring functions only. They are designed for use in a static terminal which includes an SSA power supply. SLA and SLAT logic units. and suitable surge suppression.

| | |
|---|---|
| SLV61A | Phase tripping relay. first zone<br>0.1 to 30 ohms reach setting range |
| SLY62A | Phase tripping relay, second zone. plus $M_{0B}$ characteristic timer<br>0.1 to 30 ohms reach setting range |
| SLY63A | Phase blocking relay<br>0.1 to 30 ohms in blocking direction, offset of 0.1, 0.2, 0.3 or 0.4 times reach setting |
| SLYG61A | Ground tripping relay, first zone<br>0.1 to 30 ohms $Z_1$, $K_0$ adjustable from 1.0 to 10.9 in 0.1 steps |
| SLYG62A | Ground tripping relay. second zone<br>0.1 to 30 ohms $Z_1$, $K_0$ adjustable from 1.0 to 10.9 in 0.1 steps |
| SLYG63A | Ground blocking relay<br>0.1 to 30 ohms reach in blocking direction. offset of 0.1, 0.2, 0.3 or 0.4 times reach setting |

**SLYG61P*** Similar to SLYGGIA except line-to-neutral polarized

**SLYG62P*** Similar to SLYG62A except line-to-neutral polarized

**SLYG63P*** Similar to SLYG63A except line-to-neutral polarized

*For use in single pole trip and reclose schemes.

LIST OF SYMBOLS

| | | |
|---|---|---|
| SLC | | Static-Line-Current Relay |
| SLY | | Static-Line-Admittance Relay |
| SLYG | | Static-Line-Admittance-Ground Relay |
| $I_A, I_B, I_C$ | = | Line Currents |
| $V_0$ | = | Zero sequence current |
| $V_{AN}, V_{BN}, V_{CN}$ | = | Line to neutral voltages |
| $V_{AB}, V_{BC}, V_{CA}$ | = | Line to line voltages |
| $V_0$ | = | Zero sequence voltage |
| $V_{AB1}$ | = | ferenced to $V_{AB}$ |
| $V_P$ | | Polarizing voltage |
| $Z_R, Z_{R1}$ | | Relay positive sequence replica impedance |
| $Z_{R0}$ | | Relay zero sequence replica impedance |
| $Z_S$ | | source inpedance |
| RF | | Fault resistance |
| $K_0$ | | Adjustable compensation factor for ratio of zero sequence to positive sequence inpedance $(Z_0/Z_1)$ of line |

## PHASE RELAYS

### PRINCIPLE OF OPERATION, SLY61 & SLY81 TRIPPING RELAYS

These relays contain single-phase mho functions that operate on the same basic principle as mho functions of conventional design. such as the SLY51 relay. In this earlier design. a mho characteristic is obtained by a phase angle measurement between an operating quantity, $IZ_R$-V, and a polarizing quantity V p. The phase angle measurement is made by checkng that these two signals are coincident for more tha n 90° indicating that the angle between the two is equal to or less than 90 °. This measurement is illustrated in Fig 1.

The I and V quantities of Fig. 1 are actually phase-pair quantities in relays designed for phase fault protection. For example. for !he A-B phase pair measuring function, I is actually $I_A$-$I_B$ and V is actually $V_{AB}$. Thoughout this section, the terms I and V will be used with the understanding that phase-pair quantities are being referred to.

Note that the polarizing voltage. VP, in Fig. 1 is the same voltage as the V in the $IZ_R$-V quantity. This produces the conventional mho characteristic of Fig. 1. which passes though the origin on the R-X diagram and which is inherently directional.

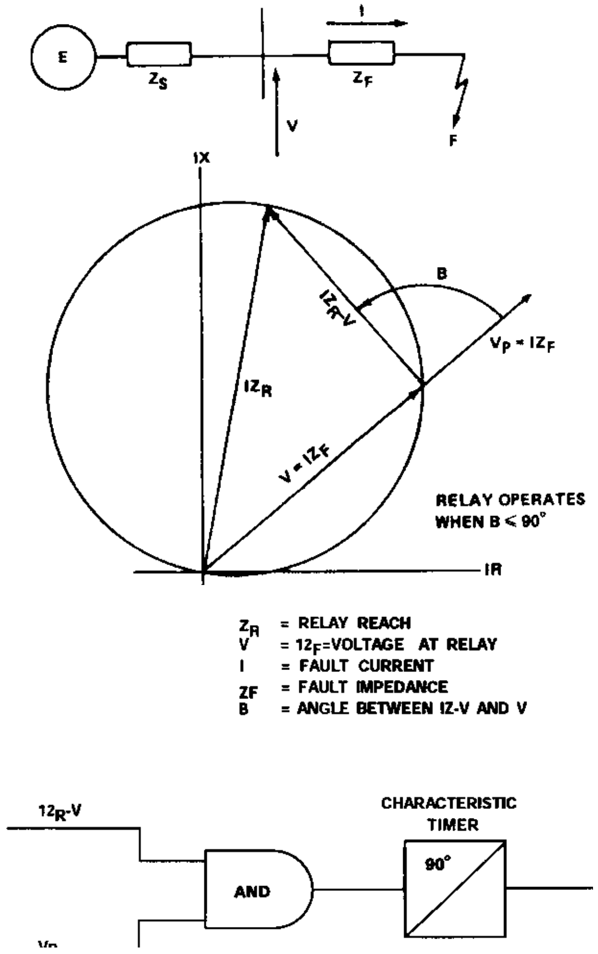


*Fig. 1. Conventional mho circle obtained by phase angle measurement*

The SLY61 and SLY81 relays use as a polarizing voltage a signal that is equal to the faulted phase-pair voltage plus a portion of the corresponding posilive sequence voltage. i.e. $V_{AB}$ + $KV_{AB1}$. The positive sequence voltage. $V_{AB1}$, is equal to and in phase with the $V_{AB}$ portion of the polarizing signal for a balanced thee-phase condition.

The resulting characteristic is a "variable mho" characteristic, as shown in Fig. 2 for one particular fault condition. Note that the polarizing voltage is not the same as $IZ_F$, as it was in Fig. 1. and that the angle 8 is still measured between $IZ_R$-V and Vp. The $KV_1$ term is not directly related to the fault current, as were all the terms in Fig. 1.

Therefore it is not possible to divide all of the terms by 1 and produce a fixed characteristic on an R-X diagram. The length of the $KV_1$ phasor, with respect to $IZ_R$ and $IZ_F$, will vary with the source impedance behind the relay, and therefore the diameter of the circle will vary also, getting larger as the source impedance increases.

It can be seen from Fig. 2 that the variable mho characteristic of the SLY61 and SLY81 relays has more reach along the R-axis than does the conventional mho circle of Fig. 1. It also indicates that a bolted zero voltage phase-to-phase fault is well within the relay characteristic.

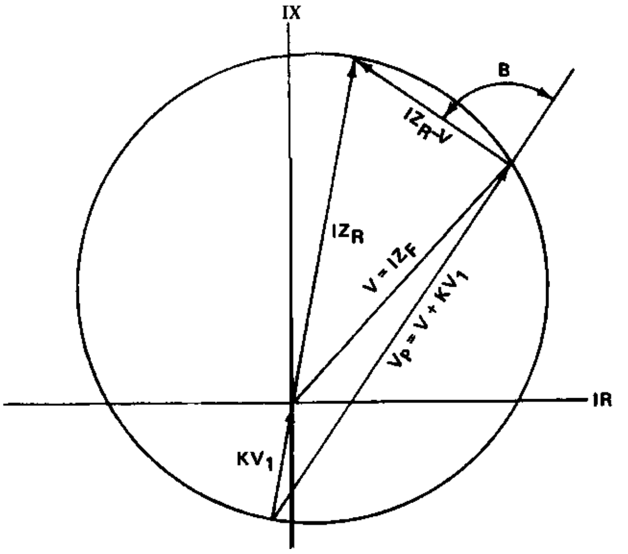
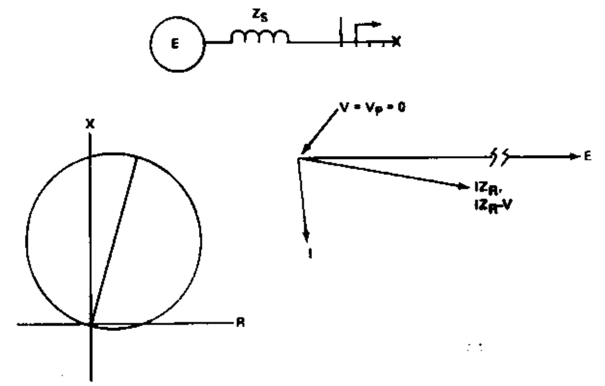


*Fig. 2. Variable mho characteristic for phase relay*

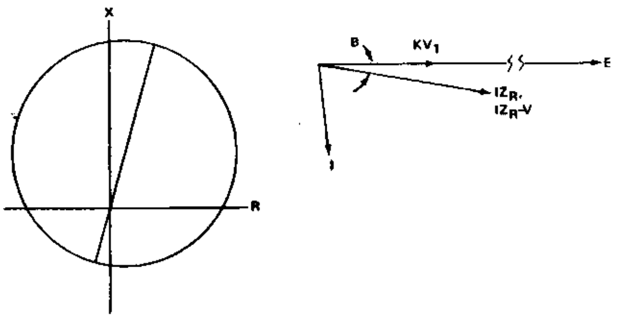
This condition is illustrated in Fig. 3. where the conventional mho function will not produce a continuous output but the variable mho will, because it has a favorable small angle (much less than 90°) between Vp and $IZ_R$-V for the zero voltage condition.

Consider now the condition of a close-in fault with arc resistance present. The faulted phase voltage present at the relay terminals is the arc-drop voltage V, which is small and is in phase with the fault current. In Fig. 4a, the angle B is less than 90° because it was assumed that the angle of the relay impedance Z is less than that of the source impedance. The arc drop voltage will remain approximately constant as the fault current decreases, and therefore the angle B will increase as I2 decreases for lower fault current levels. When the angle B exceeds 90°. the relay will not operate.

In Fig. 4b. however, the angle B is very small because of the addition of $KV_1$ to V. The IZ quantity must become very small, due to a wry large ratio of source impedance to relay reach, before IZ-V will become sufficiently leading to cause the angle B to be larger than 90° Low fault current means high fault resistance if arc drop voltage is constant. Therefore the variable mho characteristic obtained by adding $KV_1$ to the polarizing signal indicates substantially improved arc resistance accommodation compared to the conventional mho characteristic.



(a) Conventional mho characteristic



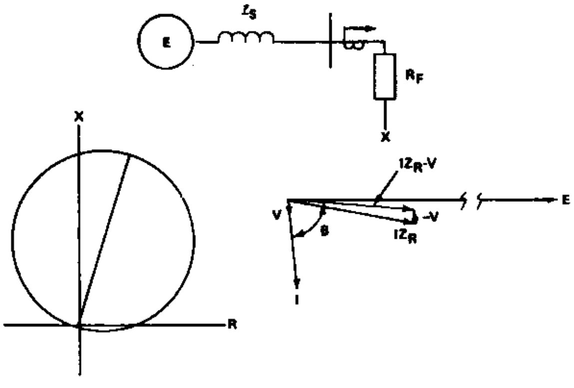
(b) Variable mho characteristic

*Fig. 3. Comparison of zero voltage phase-to-phase fault with conventional mho and variable mho characteristics*

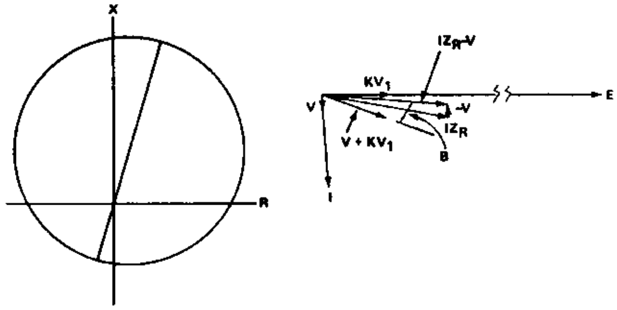
Another condition where the variable mho characteristic demonstrates improved performance is that of a reverse direction fault just behind the relay location. Fig. 5 shows the phasors for this condition, with Fig. 5a illustrating the separation angle B for the conventional mho characteristic and Fig. 5b for the variable mho characteristic. In Fig. 5a the angle is slightly more than 90°, which is a non-trip condition but with only a small margin. For certain load-flow conditions the V-phasor can swing clockwise enough to produce an output. The variable mho characteristic, on the other hand, has a much larger angle between IZ-V and VP and will not operate. Therefore it provides more security against false tripping on close-in external faults, even under load-flow conditions.

The increased fault resistance capability of these phase relays, due to the use of the supplementary positive sequence voltage polarizing. allows them to be recommended for short line applications where reactance relays may have been applied in the past. In general. the **SLY61A** and

SLY81A relays, when compared with reactance relays with the same Forward reach setting, will have slightly less dependability and slightly more security. Since the Fault resistance For phase-to-phase Faults is usually only the arc drop, which is well within the variable mho characteristic, this slight decrease in dependability is not significant.



(a) Conventional mho characteristic

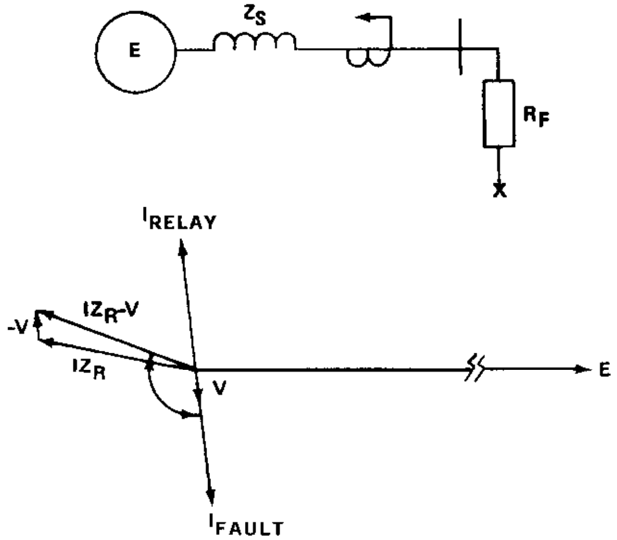


(b) Variable mho characteristic

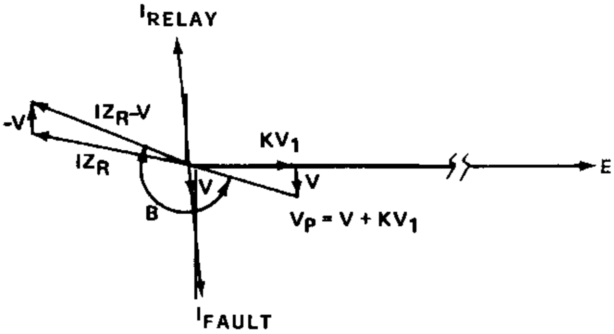
Fig. 4. Comparison of conventional and *variable* mho characteristics on *close-in phase-m-phase fault with fault resistance*

*The above* analysis applies only For line-to-line or double-line-to-ground Faults. For close-in three phase Faults all three line-to-line voltages are either zero or they consist of the arc drop between phases. There is no "healthy phase" to produce a Favorable polarizing voltage. Therefore, for three phase Faults. the effective steady-state characteristic for each phase pair is the conventional mho circle passing through the origin on an R-X diagram. The SLY61, SLY62, and SLY81 relays will produce a trip output For dose-in three phase faults on a dynamic basis (one or two cycle duration output) using memory action. The relays will not operate when closing in on a zero voltage three phase Fault if line side potential is used.

The conventional mho characteristic is also applicable when considering load flow or load swings since the memory circuit time constant is very short compared to typical pow system swing rates.



(a) Conventional mho characteristic



(b) Variable mho characteristic

Fig. 5. *Comparison of conventional and variable mho characteristic* for reverse *direction fault with fault resistance*

IF the SLY61. SLY62 and SLY81 relay characteristics are checked in a single phase test circuit the polarizing voltage will be in phase with the restraint voltage, and the test will indicate a conventional mho circle passing through the origin. In order to demonstrate the increased Fault resistance capability that results when the positive sequence component of polarizing voltage is added, it is necessary to use a test circuit which includes the 'healthy phase" voltage and a source impedance, and which maintains the proper phase relation between healthy phase and Faulted phase voltages.

## BLOCKING RELAYS, SLY63 AND SLY82

These two designs of blocking relays also use a polarizing voltage that contains a supplementary positive sequence component. Therefore they will produce a continuous output for zero voltage phase-to-phase faults even without the IZ offset normally used for that purpose.

The IZ offset quantity is included in the polarizing quantity of these relays. and it serves two purposes, depending on the type of fault. For a zero voltage three phase fault, it provides a fixed offset and insures a continuous output even though the polarizing voltage is zero. For phase-lo-phase faults. it helps to insure proper coordination of tripping and blocking relay operating times under load flow conditions by shifting the prefault voltage in the direction of the voltage at the opposite terminal. The memory action in the polarizing circuit causes the relay to remember this prefault voltage for the first few cycles after the fault occurs.

The offset in the phase blocking relays. then, is a fixed offset for three phase faults and a compensating quantity for phase-to-phase faults. The optimum setting of the offset will vary with the length of the line and the ratio of blocking relay reach to protected line length. A typical setting for the offset is 30% of the reach setting in the direction away from the protected line.

## CIRCUIT DESCRIPTION FOR PHASE RELAYS

### 1. SLY81A or SLY81B Relay

A functional block diagram of the SLY81A or SLY81B tripping relay is shown in Fig. 6. These two relays are identical except for the fact that the SLY818 contains the $M_{OB}$ function, while the SLY81A does not. This diagram shows input currents and voltages for all three phases. and coincidence logic input signals for the AB phase pair only. These signals are:

$(I_A-I_B)Z_{R1}-TV_{AB}$, where $Z_{R1}$ is base reach tap setting (ohms) and T is the percent restraint setting.

$V_{AB}+0.3\,V_{AB1}$, where $V_{AB1}$ is the positive sequence network output. in phase with $V_{AB}$.

and $C(I_A-I_B)Z_{R1}$, where C is an adjustable multiplier used to determine the sensitivity setting of this input signal.

The output of the coincidence logic is supplied to the characteristic timer (5,4/5), and the output of the timer operates the KI relay, which in turn operates the K2 output relay.

The internal connection diagram for the SLY81A or SLY818 is shown in Fig. 7. The six cards in the relay are identified as:

| | |
|---|---|
| SP | Signal Processing |
| CP | Combined Polarizing |
| OS | Operate Signal |
| CL | Coincidence Logic |
| IT | Integrating Timer |
| PS | Power Supply |

Base reach tap adjustments are made by moving adjustable leads connected to studs 1, 3, and 5 to one of three positions. These are 0.1. 0.2 and 0.4 ohms for the short-reach relay, and 0.75. 1.5 and 3.0 ohms for the long-reach relay. The potentiometer settings marked as PA, $P_B$, and PC are on the ganged precision potentiometer and are used to make the restraint voltage setting.

These relays include an overcurrent supervision function which will block operation if the fault current is not above the setting of this Function. This will provide protection against false tripping due to blown potential fuses if it is possible to choose a setting that is greater than maximum load current and less than minimum fault current. The adjustment of this Function is controlled by three potentiometers on the SP card. The range of adjustment For the various base reach taps is given below:

| Base Reach, Ohms | Range Amperes |
|---|---|
| 0.1 | 4-10 |
| 0.2 | 2-10 |
| 0.4 | I-10 |
| 0.75 | 0.52-10 |
| 1.5 | 0.23-10 |
| 3.0 | 0.13-10 |

### 2. SLY61 Relay

The internal connection diagram For the SLY61 tripping relay is shown in Fig. 8. In this diagram, card positions are shown in the lower right hand corner of the card block, and the card identification is given in Table 4.

Base reach settings are determined by the current circuit connections to the YA block on the rear of the relay. and may be further adjusted by the base reach multiplier (1.0, 0.5. 0.2, or 0.1) on the E card. The voltage restraint is adjusted by three separate pairs of tap blocks, and the D card adds the positive sequence polarizing quantity.

The $IZ_R$ and V restraint signals are added at pins 3 and 4 on the H, J. and K cards, and the polarizing voltage signals are applied to pin 6 of these three cards. The output signals on these cards are A-C signals (both polarities) but are essentially square waves because of Ihe high gain on the output amplifiers on the H. J, and K cards.

The coincidence logic cards (L, M, and N) product? an input to the corresponding integrating timer cards (P, R, or

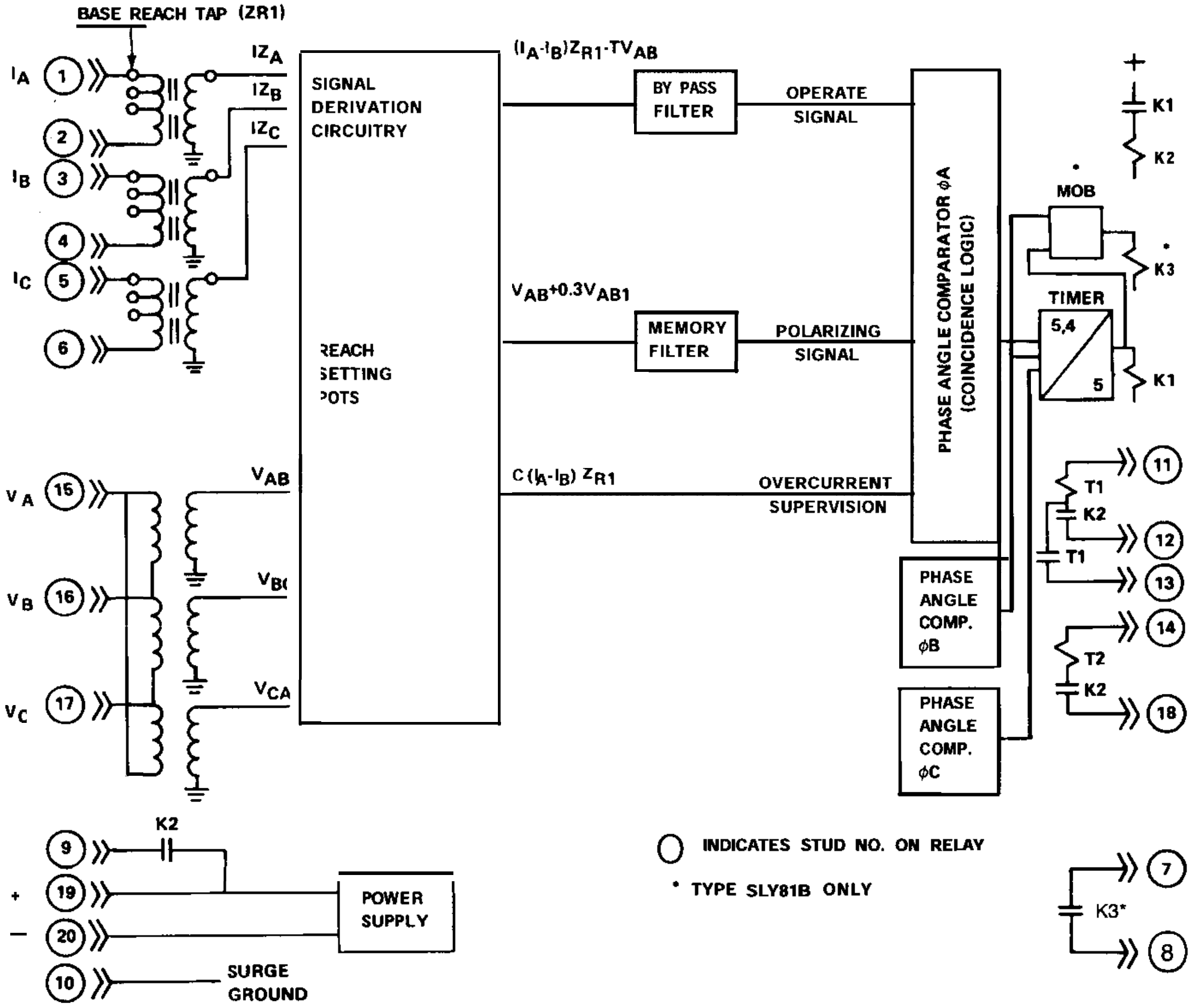


Fig. 6. Functional **Block Diagram, SLY81**

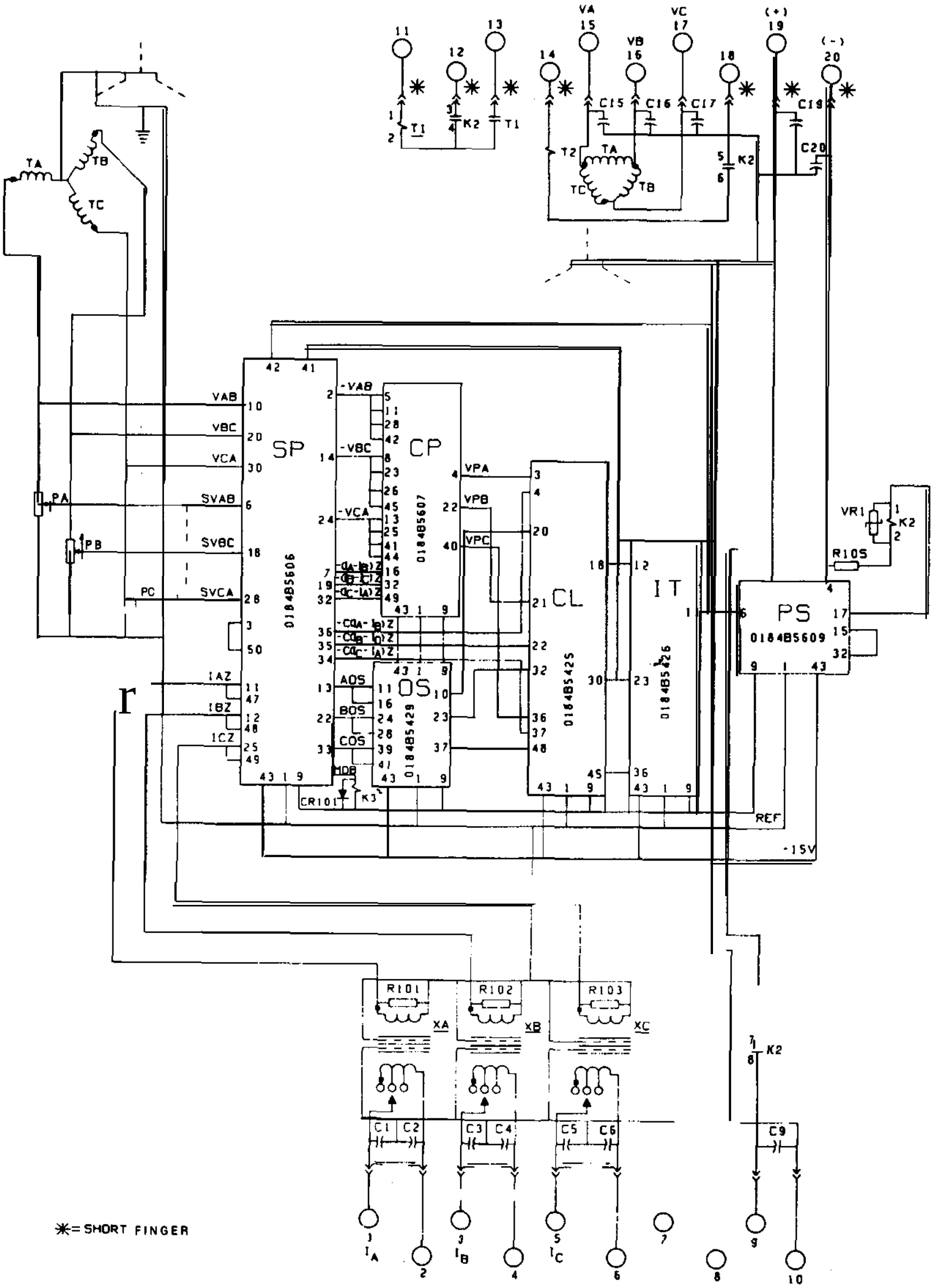
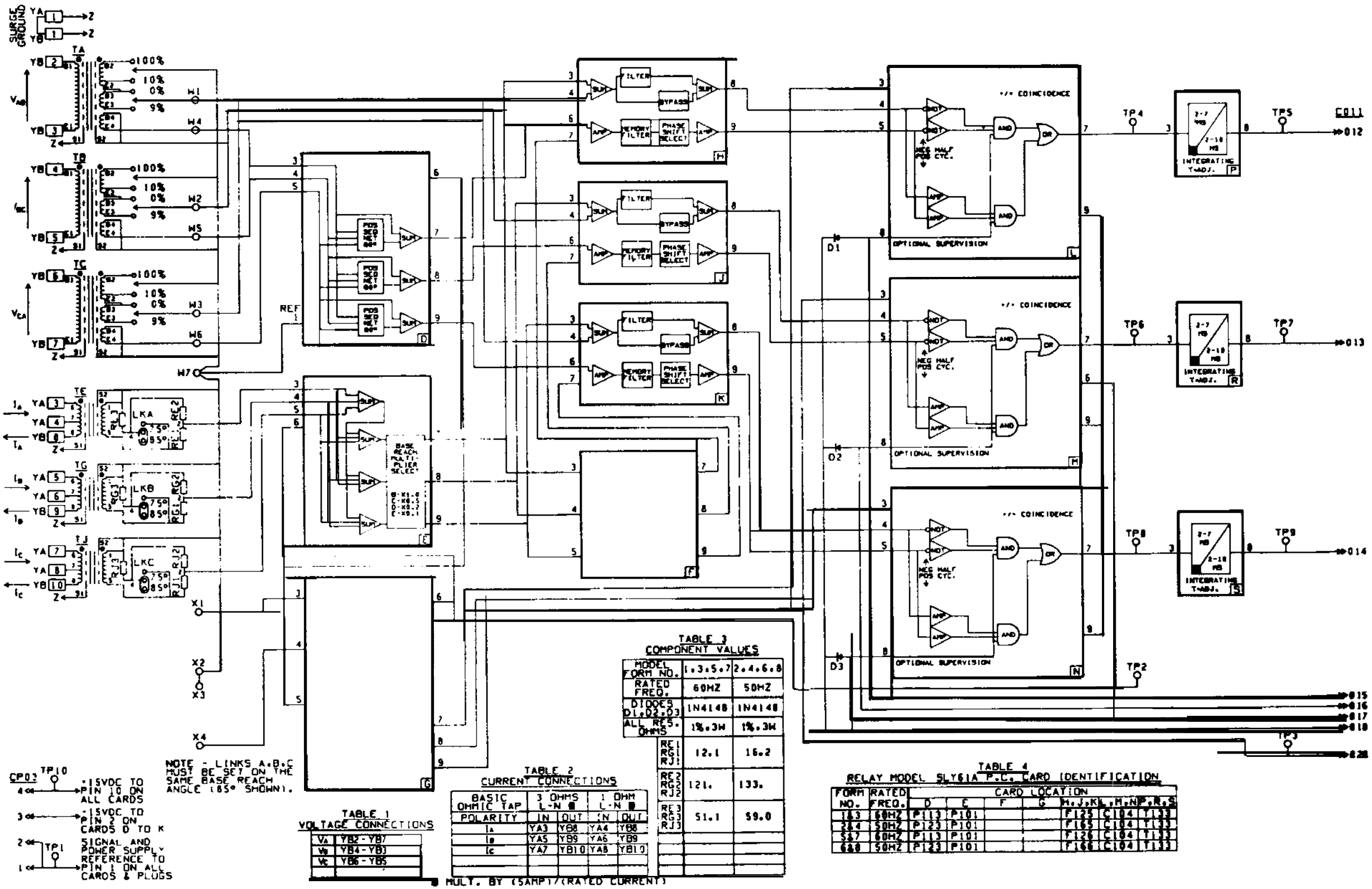


*Fig. 7.* **Internal** ***connections for*** *SL* Y81A ***Relay***



+15VDC TO PIN 10 ON ALL CARDS

-15VDC TO PIN 2 ON CARDS D TO K

SIGNAL AND POWER SUPPLY REFERENCE TO PIN 1 ON ALL CARDS & PLUGS

NOTE - LINKS A,B,C MUST BE SET ON THE SAME BASE REACH ANGLE (85° SHOWN).

TABLE 1
VOLTAGE CONNECTIONS

| | |
|---|---|
| $V_A$ | YB2 - YB7 |
| $V_B$ | YB4 - YB3 |
| $V_C$ | YB6 - YB5 |
| | |

TABLE 2
CURRENT CONNECTIONS

| BASIC OHMIC TAP | 3 OHMS L-N ■ | | 1 OHM L-N ■ | |
|---|---|---|---|---|
| POLARITY | IN | OUT | IN | OUT |
| $I_A$ | YA3 | YB8 | YA4 | YB8 |
| $I_B$ | YA5 | YB9 | YA6 | YB9 |
| $I_C$ | YA7 | YB10 | YA8 | YB10 |
| | | | | |
| | | | | |

■ MULT. BY (5AMP)/(RATED CURRENT)

TABLE 3
COMPONENT VALUES

| MODEL FORM NO. | 1,3,5,7 | 2,4,6,8 |
|---|---|---|
| RATED FREQ. | 60HZ | 50HZ |
| DIODES D1,D2,D3 | 1N4148 | 1N4148 |
| ALL RES. OHMS | 1%,3W | 1%,3W |
| RE1<br>RG1<br>RJ1 | 12.1 | 16.2 |
| RE2<br>RG2<br>RJ2 | 121. | 133. |
| RE3<br>RG3<br>RJ3 | 51.1 | 59.0 |
| | | |
| | | |
| | | |
| | | |

TABLE 4
RELAY MODEL SLY61A P.C. CARD IDENTIFICATION

| FORM NO. | RATED FREQ. | CARD LOCATION | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D | E | F | G | H,J,K | L,M,N | P,R,S |
| 1&3 | 60HZ | P113 | P101 | | | F125 | C104 | T133 |
| 2&4 | 50HZ | P123 | P101 | | | F165 | C104 | T133 |
| 5&7 | 60HZ | P113 | P101 | | | F126 | C104 | T133 |
| 6&8 | 50HZ | P123 | P101 | | | F166 | C104 | T133 |

Fig. 8. Internal connection diagram for SLY61 Relay

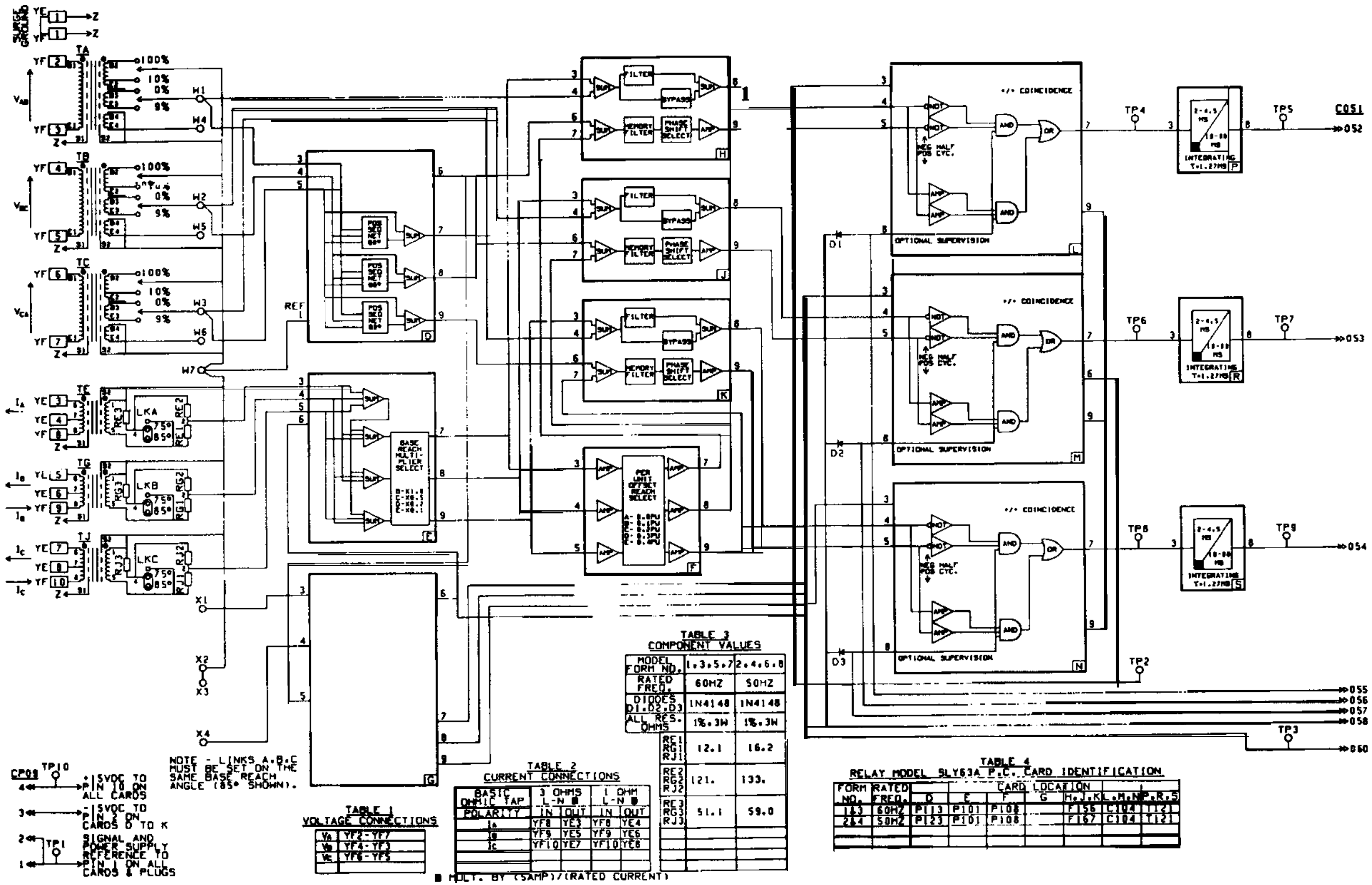


TABLE 1
VOLTAGE CONNECTIONS

| | |
|---|---|
| VA | YF2 - YF7 |
| VB | YF4 - YF3 |
| VC | YF6 - YF5 |
| | |

TABLE 2
CURRENT CONNECTIONS

| BASIC OHMIC TAP | 3 OHMS L-N ■ | | 1 OHM L-N ■ | |
|---|---|---|---|---|
| POLARITY | IN | OUT | IN | OUT |
| IA | YF8 | YE3 | YF8 | YE4 |
| IB | YF9 | YE5 | YF9 | YE6 |
| IC | YF10 | YE7 | YF10 | YE8 |
| | | | | |
| | | | | |

■ MULT. BY (5AMP)/(RATED CURRENT)

TABLE 3
COMPONENT VALUES

| MODEL FORM NO. | 1.3.5.7 | 2.4.6.8 |
|---|---|---|
| RATED FREQ. | 60HZ | 50HZ |
| DIODES D1.D2.D3 | 1N4148 | 1N4148 |
| ALL RES. OHMS | 1%.3W | 1%.3W |
| RE1<br>RG1<br>RJ1 | 12.1 | 16.2 |
| RE2<br>RG2<br>RJ2 | 121. | 133. |
| RE3<br>RG3<br>RJ3 | 51.1 | 59.0 |
| | | |
| | | |
| | | |
| | | |

TABLE 4
RELAY MODEL SLY63A P.C. CARD IDENTIFICATION

| FORM NO. | RATED FREQ. | CARD LOCATION | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D | E | F | G | H.J.K | L.M.N | P.R.S |
| 1&3 | 60HZ | P113 | P101 | P108 | | F156 | C104 | T121 |
| 2&4 | 50HZ | P123 | P101 | P108 | | F167 | C104 | T121 |
| | | | | | | | | |
| | | | | | | | | |

*Fig. 9. Internal connection diagram for SLY63A Relay*

S) when the input signals are either both positive or both negative. The width of the block at the coincidence logic output is a measure of the phase angle between $IZ_R - V$ and V.

Overcurrent supervision of the coincidence logic output (for blown fuse protection) is optional and may be either phase by phase (pins 015, 016, and 017) or a single signal input at 018. When this supervising signal is held at the reference level there is no output from the coincidence logic. When it is either a plus voltage or an open circuit condition, the coincidence logic is not blocked from operating. The phase by phase supervision is typically used in single pole trip and reclose schemes.

The setting of the integrating timer determines the shape of the relay characteristic. A setting equal to 90" (4.16 ms. at 60Hz) produces a circular characteristic.

### 3. **SLY62A** Relay

The **SLY62A** relay is similar to the **SLY61A** except that the **SLY62A** is intended for use **as an** overreaching, or second **zone** mho distance relay. The **SLY62A** provides slightly faster speed. and has more transient overreach than the **SLY61A** relay. The **SLY62A** also includes an $M_{OB}$ characteristic timer which can be used as part of an out-of-step detection scheme.

### 4. SLY82A Relay (Blocking)

The SLY82A relay is similar to the SLY81A relay except that it is designed for use as a blocking relay in a directional comparison scheme. The polarizing quantity has an 12 quantity added to it, in addition to the supple. mentary positive sequence polarizing. Reach in the blocking direction is adjustable from 0.75 to 30 ohms. and the percentage of IZ (or offset) added to the polarizing signal is adjustable to provide a choice of 10%. 26% or 30%.

The SLY82A also has a normally closed contact output for use in schemes where the opening of a normally closed contact is desirable for transmitting a blocking signal.

### 5. SLY63A Relay (Blocking)

The SLY63A relay is similar to the SLY61A except that it is designed for use as a blocking relay in a directional comparison scheme. The polarizing quantity has an IZ quantity added to it, in **addition** to the supplementary positive sequence polarizing. Reach in the blocking direction is adjustable from 0.1 to 30 ohms, and the percentage of IZ (or offset) added to the polarizing signal is adjustable to provide a choice of 10%. 20%. 30% or 40%.

## APPLICATION CONSIDERATIONS, PHASE RELAYS

### 1. Reach Setting. First Zone Relays

The SLY81 relay has a fixed maximum reach angle of 85°. The relay can be set to cover up to 90% of the line impedance for positive sequence impedance angles above 76°. and up to 85% of the line for positive sequence impedance angles above 70°. For line angles lower than 70° the reach should not exceed 90% of the reactive component of the line impedance.

The SLY61 relay has a base reach angle that is adjustable by means of links on the rear of the unit, and these may be set for either 85° or 75°. In addition, the polarizing voltage may be shifted leading by 15°. which shifts the relay characteristic clockwise by 15°. This provides two additional choices of 70° or 60° maximum reach angle. When this 15° shift is used, the reach at the maximum reach angle is increased slightly (by 3%) over the tap value.

In the **SLY61** it is recommended that the 95° angle should be used for line angles greater than 80°. and that the 75" angle should be used for angles of 80° and below. The suggested reach setting is 90% of the line for positive sequence line angles of 65° and above. For line angles below 65° the reach should not exceed 90% of the reactive component of the line impedance.

The 15° phase shift is normally not used but can be an advantage in special applications.

### 2. Reach Setting, Second Zone Relays

The choice of the second zone reach setting will be affected by the application. For example, if the relay is used in a stepped distance scheme. its reach will have to be coordinated with first zone distance relays in adjacent lines, so as not to reach farther than those first zone relays.

On the other hand. if the primary purpose of the second zone relay is to determine direction of fault current flow in a directional comparison scheme, the reach may be set considerably longer than the protected line in order to obtain faster speed for remote line-end faults and for more fault resistance capability. However. longer reach settings introduce the possibility of misoperation due to heavy load transfer. or swing conditions, and therefore the reach setting chosen will be a compromise between better performance and more security.

Another way to improve the security is to use a lens instead of a circular characteristic. This is accomplished by increasing the characteristic timer setting. The MT function uses an integrating timer. where the duration of a single pulse to cause an output is greater than the duration of a steady state pulse to cause an output. A setting of 4.2 ms (at 60 Hz) for the steady state pulse produces a circular characteristic.

The following values of reach setting as a percentage of line length, and of characteristic timer settings. are typical directional comparison second zone settings. These are based on an assumption that the maximum load flow under non-emergency conditions is not greater than twice the surge impedance loading of the line. The characteristic timer settings are for 60 Hz applications.

| Line *Length* *Miles* | *Reach* *% of Line* | *Characteristic Timer (ms)* *First Pulse* | *steady state* |
|---|---|---|---|
| 0-50 | 200 | 5.5 | 4.2 |
| 50100 | 175 | 6.6 | 4.2 |
| 100-150 | 150 | 6.6 | 4.8 |
| 150-200 | 135 | 6.0 | 6.6 |
| 200-300 | 125 | 6.5 | 6.6 |

### 3. Overcurrent Supervision

The overcurrent supervision function in the SLY91 relay should be set above maximum load current and below minimum fault current, if possible, to provide protection against false tripping due to loss of potential (blown fuses).

In the SLY61 relay, overcurrent supervision may be provided at the coincidence logic in the SLY61 or at an AND function in the associated SLA relay. The latter method is used in the example shown in Fig. 24.

### 4. $M_{OB}$ Characteristic

The SLY62 relay contains the $M_{OB}$ characteristic timer, which produces a tomato-shaped characteristic with the same forward reach as the MT characteristic. The setting of the $M_{OB}$ characteristic timers will normally be based on load flow and power swing studies.

The SLY818 relay contains the complete $M_{OB}$ function, including the characteristic timer as well as the timer used to indicate that the apparent impedance is inside $M_{OB}$ but outside of MT for a fixed time. An appropriate setting of this second timer is usually between two and four cycles. The SLY818 also has en option whereby $M_{OB}$ will block tripping with the "OSR" plug in one position and will not block tripping for the other position. In either case. there is an OSB contact output available for use in an external control circuit.

## GROUND RELAYS

### PRINCIPLE OF OPERATION OF SLYG61 AND SLYG81 RELAYS

The basic operating principle of these relays is that of a quadrature polarized ground distance relay with a variable mho characteristic. The distance measurement is made by a phase angle measurement between the operating voltage $(IZ_R-V)$ and the polarizing voltage $(V_P)$. Additional inputs are used to improve the security of the relay. The most significant additional input is a second polarizing signal. which is a zero sequence voltage signal $(V_0)$, supplemented by an $I_0Z_{R0}$ component.

Both relays use a fourth input. $I_0Z_{R0}$, but it is introduced in a different manner in the two relay types. In the SLYG61 relay, there is provision for introducing an SLC relay level detector output to supervise the coincidence logic card. In the SLYG81 relay, the $I_0Z_{R0}$ signal is used as a fourth input to the coincidence logic card. In both cases, this $I_0Z_{R0}$ supervision provides a degree of security if potential is lost on one phase with load transfer over the line.

To illustrate the variable mho characteristic that is effective for single phase to ground faults, consider first the interaction of the IZ-V and $V_P$ voltages. Refer to Fig. 10. The polarizing voltage is the opposite phase-to-phase voltage shifted leading by 90° and consequently it is not affected by the fault current flowing. Therefore it is in phase with the phase-to-neutral voltage at the source (assuming no load flow). The polarizing voltage, then. is also equal to the IZ drop from the source to the relay location plus the IZ drop from the relay to the fault. This produces the characteristic as shown in Fig. 10.

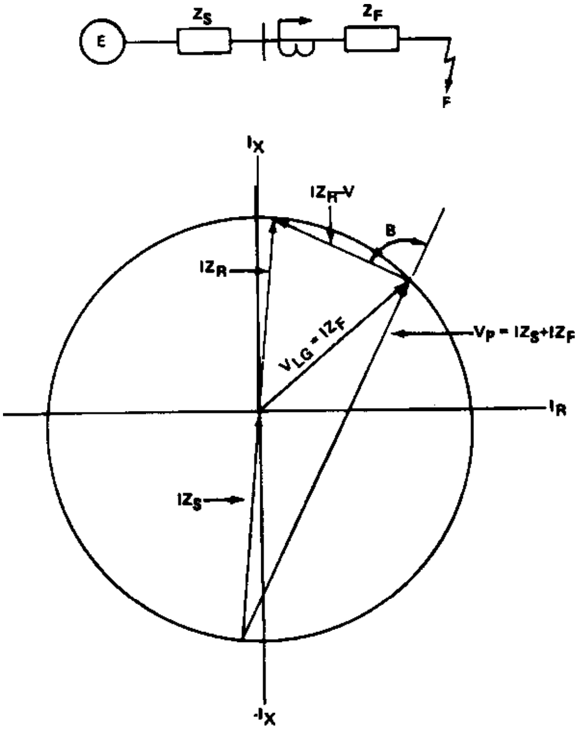
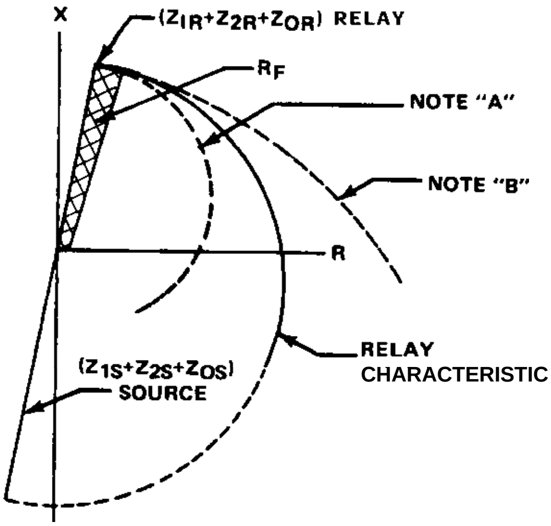


*Fig. 10. Variable mho characteristic of quadrature~ polarized ground distance relay (SLVG61 or SLVG81)*

Since the diameter of this characteristic is equal to the sum of the relay reach ($Z_R$) and the source impedance ($Z_S$), this diameter will vary as the source impedance varies. This is illustrated in Fig. 11. The effective resistance (RF) due to arc-drop also varies directly with source impedance, which provides an automatic adjustment of the circle diameter to the fault resistance. RF in Fig. 11 is three times the actual RF because the impedances are plotted as the sum of the sequence components.

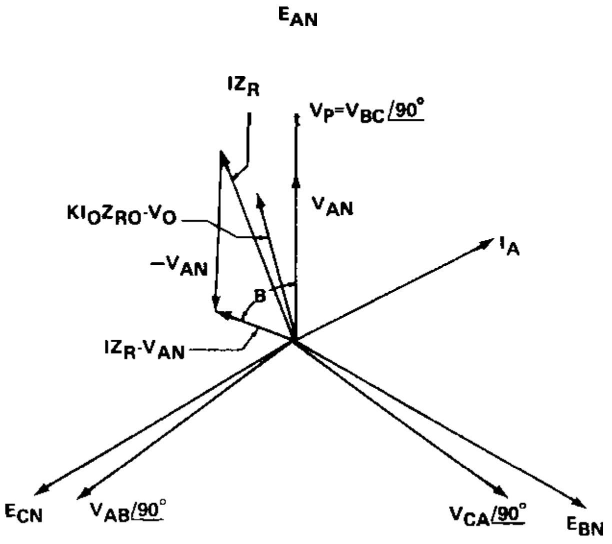
Although this characteristic is shown extending below the R-axis, this does not mean that it operates for reverse direction faults. The minus-X area for the variable mho characteristic applies to forward direction capacitive faults but not to reverse direction inductive faults.

The effect of the second polarizing quantity is to prevent operation of the unfaulted phases on a single line to ground fault. and to prevent overreach of the leading phase on a double line to ground fault. which can happen with a simple quadrature polarized relay with fault resistance present.



NOTES:
A. SMALLER SOURCE IMPEDANCE
B. LARGER SOURCE IMPEDANCE

*Fig. 11. Variable mho characteristic, effect of change in source impedance*



NOTE: $E_{AN}$, $E_{BN}$ AND $E_{CN}$, ARE SOURCE VOLTAGES

*Fig. 12. Phasor diagram for phase A to ground fault. no load*

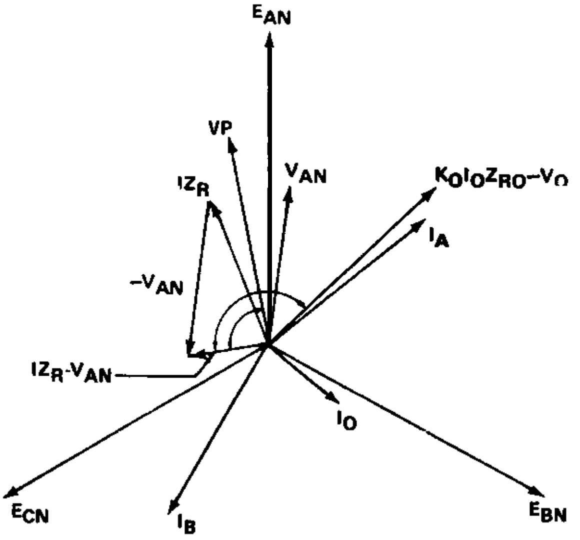


*Fig. 13. Phasor diagram for ABG fault, showing input signals for A-phase unit*

Fig. 12 illustrates the phase relations of the three A-phase input signals for an A-G fault with fault resistance so that IA lags EAN by 60°. The fault location is at approximately 9096 of the relay reach so that $IZ_R$ is 1.25 times $V_{AN}$. Note that the second polarizing quantity lies between Vp and $IZ_R-V_{AN}$, and therefore it does not restrict the operation of the phase A unit for this AG fault. Note also that this second polarizing voltage is more than 90° away from the polarizing voltages of the B and C phase units. and this provides additional security against their operation for an AG fault.

Fig. 13 illustrates the phase relations of the three A-phase input signals for an ABG fault beyond the reach setting of the relay and with fault resistance. This is the condition which causes overreach of the leading phase measuring function with a simple quadrature polarized relay. Note in the figure that the angle between $IZ_R-V_{AN}$ and $K_0 I_0 Z_{R0}-V_0$ is greater than 90° (a non-operate condition) and that the angle between Vp and $IZ_R-V_{AN}$ is less than 90° (an operate condition). This illustrates how the second polarizing signal ($K_O I_O Z_{RO} - V_O$) prevents overreach for this fault condition.

Because of the large reach along the R-axis that results from the variable mho characteristic. these relays are recommended for short line applications where reactance relays may have been applied in the past. In addition. these relays provide greater security against overreaching for conditions of high resistance ground faults in combination with heavy load flow. This condition can cause the apparent impedance seen by a reactance relay to fall within its characteristic for a fault beyond the reach setting of the relay. For a more detailed description of this condition. see IEEE paper F78 743-7. *"Design Considerations in the Development of a New Ground Distance Relay,"* by Wilkinson. Mathews and Keeney (GER 3089).

If the SLYG61 and SLYG81 relay characteristics are checked in a test circuit where all three voltages are phase-shifted together, the result will be a mho circle that passes through the origin. In order to demonstrate the increased fault resistance capability of these relays, they must be checked in a test circuit which includes the effect of source impedance and which produces the proper phase relation between polarizing and restraint voltages.

## CIRCUIT DESCRIPTION FOR GROUND RELAYS

### 1. SLYG81 Relay

A functional block diagram of the SLYG81A tripping relay is shown in Fig. 14. This diagram shows input currents and voltages for all three phases, and coincidence logic signals for phase A only. These signals are:

| | |
|---|---|
| $(I_A - I_O)Z_{R1} + K_O I_O Z_{RO} - TV_{AN}$ | *operate* signal. where $K_O$ is a compensating factor for the $X_O/X_1$ ratio of the protected line. and T is the percent restraint setting. |
| $V_{BC}\underline{/90^\circ}$ | No. 1 polarizing signal. |
| $CK_O I_O Z_{RO} - V_O$ | No. 2 polarizing signal, where C is 0.5. |
| $I_O Z_{RO}$ | Current supervision signal. |

In the operate signal, $I_O$ is subtracted from IA so that $(I_1 + I_2)$ is multiplied by $Z_{R1}$, and $K_O I_O$ is multiplied by $Z_{RO}$. This permits a different impedance angle for $Z_{R1}$ and $Z_{RO}$. The available $K_O$ settings are 2.5, 3.0, 3.5, 4.0, or 4.5.

The three line to neutral voltages are reduced by means of a three gang precision potentiometer to produce the restraint voltage portion of the operating signal, (IZ-V).

In the second polarizing signal, $V_O$ is obtained from a broken delta connection inside the relay.

The coincidence logic card receives the four input signals listed above and produces an output block when all four card inputs are positive or all four are negative.

Fig. 15 is an internal connection diagram for the SLYG81A relay. The six cards in the relay are identified as:

| | |
|---|---|
| SP | Signal Processing |
| QP | Quadrature Polarizing |
| OS | Operate Signal |
| CL | Coincidence Logic |
| IT | Integrating Timer |
| PS | Power Supply |

Base reach lap settings are made by moving adjustable leads connected to studs 1, 3, 5, and 8 to one of three positions. 0.1, 0.2 or 0.4 ohms for the short-reach relay, and 0.75. 1.5. or 3.0 ohms for the long-reach relay. The potentiometer settings marked as PA, $P_B$, and PC are on the ganged precision potentiometer. The $K_O$ setting is made by moving a jumper plug on the SP card to one of the available $K_O$ settings, which are 2.5, 3.0, 3.5, 4.0 and 4.5.

### 2. SLYG82 Relay (Blocking)

The SLYG82 relay is similar to the SLYG81 relay in basic design but has two changes in the input signals to the coincidence logic card. The No. 1 polarizing signal has an IZ quantity added to the quadrature polarizing voltage, and the No. 2 polarizing quantity is $(-V_O)$ only

### 3. SLYG61A Relay

The SLYG61A relay is designed for first-zone applications. The internal connection diagram for the SLYG61A relay is shown in Fig. 16. In this diagram, card locations are shown in the lower right hand comer of the card block, and the card-identification is given in Table 4.

Base reach settings (either 3 ohms or 1 ohm) are determined by the current connections to the GA terminal block on the back of the relay. and may be further adjusted by the base reach multiplier (1.0, 0.5, 0.2, or 0.1) on the E card. The voltage restraint is adjusted by three separate pairs of tap blocks, and the D card develops the quadrature polarizing voltage for each phase. The maximum reach impedance angle can be changed by 10° by means of links A, B, C and D.

The $K_O$ selection, which is adjustable from 1.0 to 10.9 in 0.1 steps, is on the G card, as is the $T_O$ selection. which may be either 0.0, 0.1, 0.2, 0.3. or 0.4.

The IZ and -V restraint signals are added at pins 3 and 4 on the H, J, and K cards, and the polarizing voltage signals

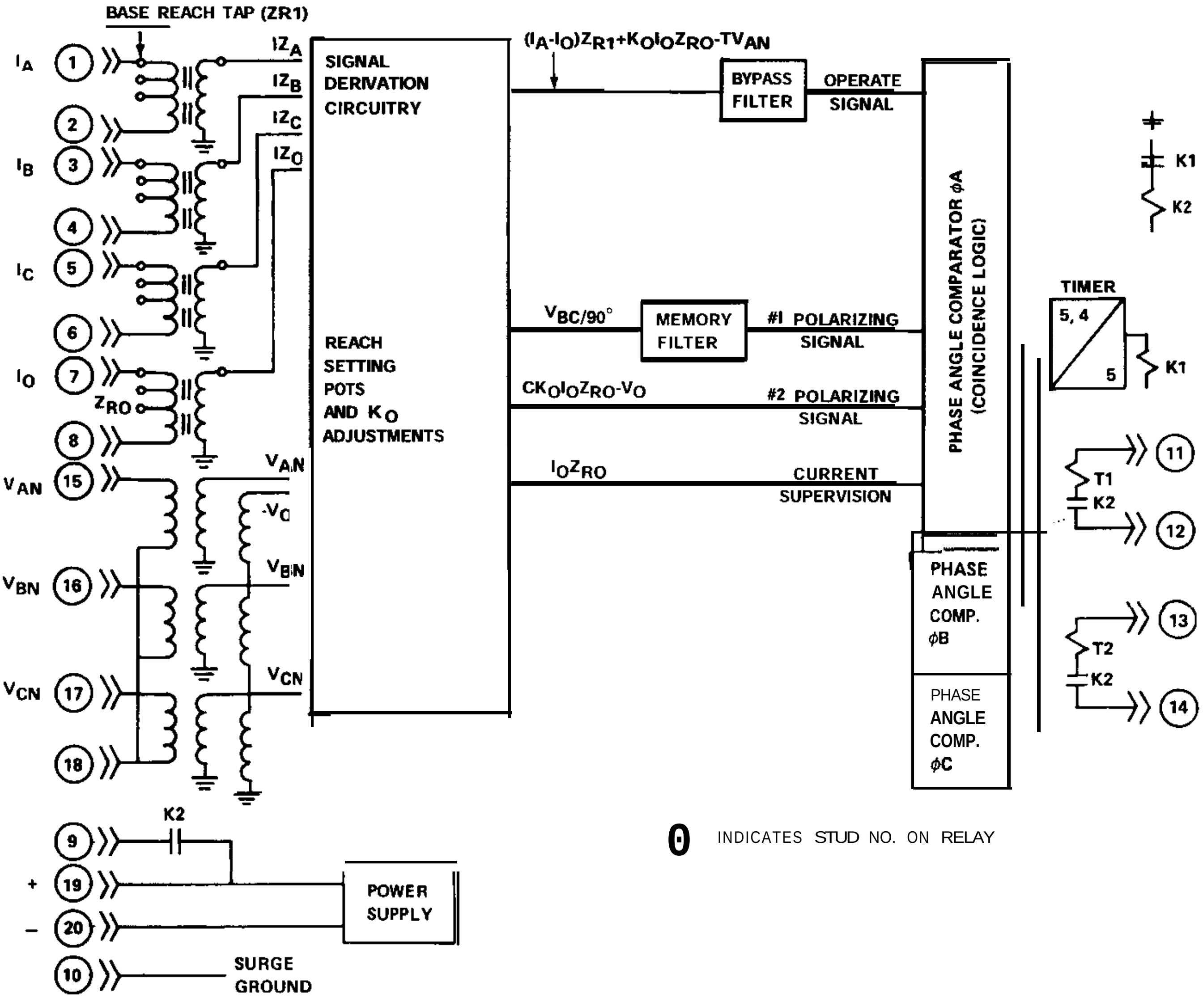
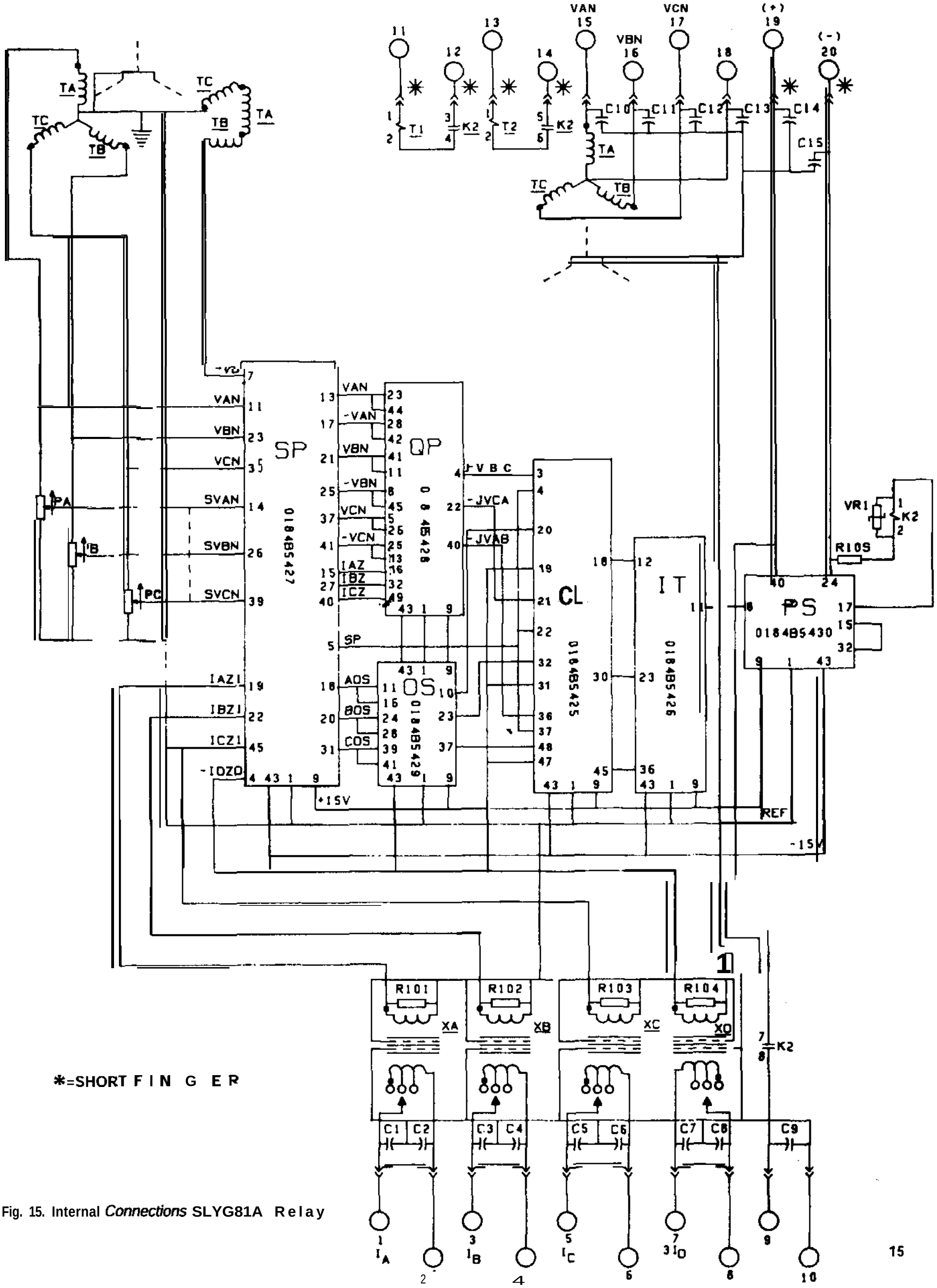
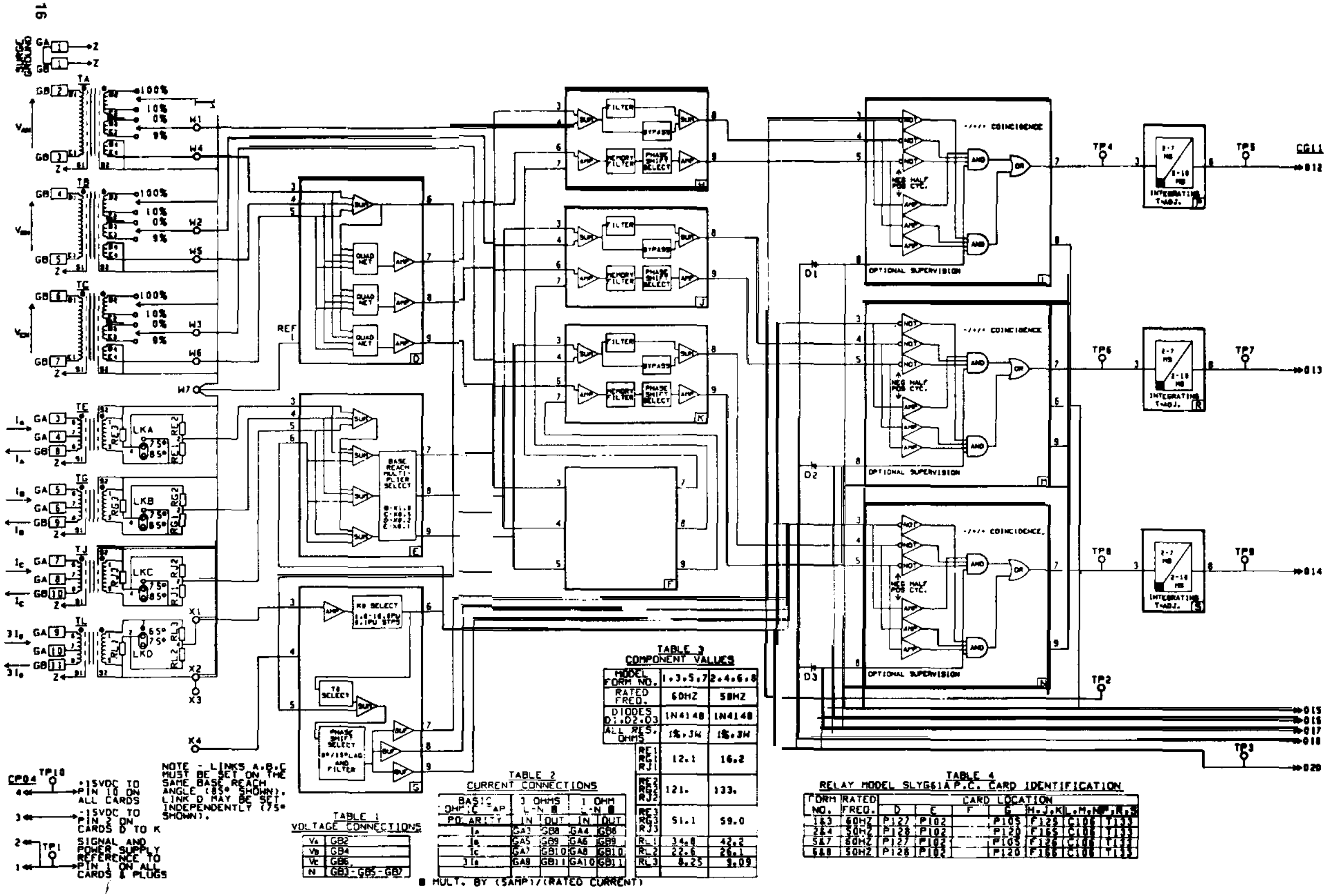


Fig. 14. SLYG81A *Functional* Block Diagram



✱=SHORT FINGER

Fig. 15. Internal *Connections* SLYG81A Relay



CP04
TP10

4 +15VDC TO PIN 10 ON ALL CARDS

3 -15VDC TO PIN 2 ON CARDS D TO K

2, 1 TP1 SIGNAL AND POWER SUPPLY REFERENCE TO PIN 1 ON ALL CARDS & PLUGS

NOTE - LINKS A,B,C MUST BE SET ON THE SAME BASE REACH ANGLE (85° SHOWN). LINK D MAY BE SET INDEPENDENTLY (75° SHOWN).

TABLE 1
VOLTAGE CONNECTIONS

| | |
|---|---|
| $V_A$ | GB2 |
| $V_B$ | GB4 |
| $V_C$ | GB6 |
| N | GB3 - GB5 - GB7 |

TABLE 2
CURRENT CONNECTIONS

| BASIC OHMIC TAP | 3 OHMS L-N ■ | | 1 OHM L-N ■ | |
|---|---|---|---|---|
| POLARITY | IN | OUT | IN | OUT |
| $I_A$ | GA3 | GB8 | GA4 | GB8 |
| $I_B$ | GA5 | GB9 | GA6 | GB9 |
| $I_C$ | GA7 | GB10 | GA8 | GB10 |
| $3I_0$ | GA9 | GB11 | GA10 | GB11 |

■ MULT. BY (5AMP)/(RATED CURRENT)

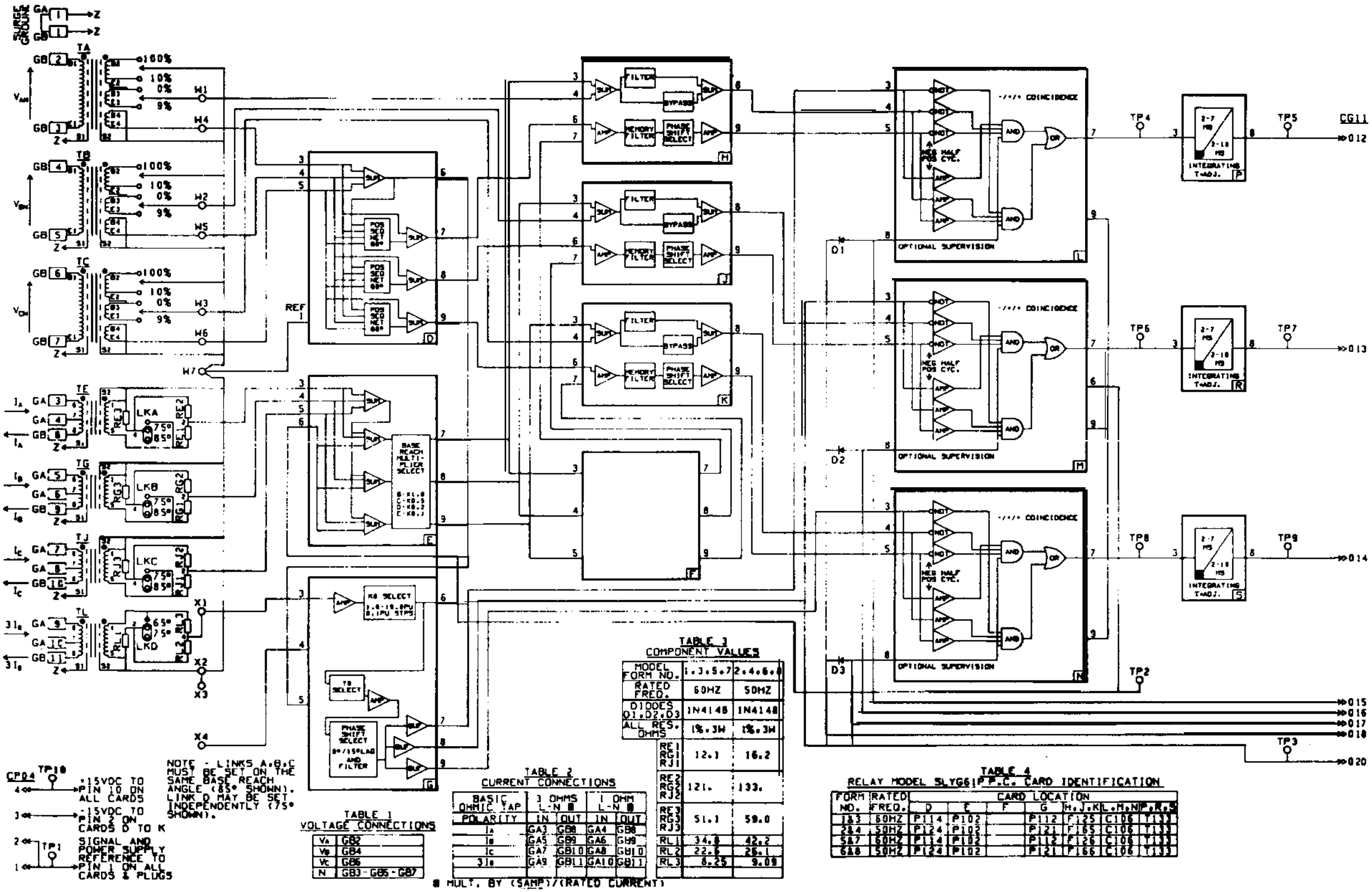
TABLE 3
COMPONENT VALUES

| MODEL FORM NO. | 1,3,5,7 | 2,4,6,8 |
|---|---|---|
| RATED FREQ. | 60HZ | 50HZ |
| DIODES D1,D2,D3 | 1N4148 | 1N4148 |
| ALL RES. OHMS | 1%,3W | 1%,3W |
| RE1<br>RG1<br>RJ1 | 12.1 | 16.2 |
| RE2<br>RG2<br>RJ2 | 121. | 133. |
| RE3<br>RG3<br>RJ3 | 51.1 | 59.0 |
| RL1 | 34.8 | 42.2 |
| RL2 | 22.6 | 26.1 |
| RL3 | 8.25 | 9.09 |

TABLE 4
RELAY MODEL SLYG61A P.C. CARD IDENTIFICATION

| FORM NO. | RATED FREQ. | CARD LOCATION | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D | E | F | G | H,J,K | L,M,N | P,R,S |
| 1&3 | 60HZ | P127 | P102 | | P105 | F125 | C106 | T133 |
| 2&4 | 50HZ | P128 | P102 | | P120 | F165 | C106 | T133 |
| 5&7 | 60HZ | P127 | P102 | | P105 | F126 | C106 | T133 |
| 6&8 | 50HZ | P128 | P102 | | P120 | F166 | C106 | T133 |

*Fig. 16. Internal connection diagram for SLYG61A relay*



CP04
TP10
4 +15VDC TO PIN 10 ON ALL CARDS
3 -15VDC TO PIN 2 ON CARDS D TO K
2 TP1
1 SIGNAL AND POWER SUPPLY REFERENCE TO PIN 1 ON ALL CARDS & PLUGS

NOTE - LINKS A,B,C MUST BE SET ON THE SAME BASE REACH ANGLE (85° SHOWN). LINK D MAY BE SET INDEPENDENTLY (75° SHOWN).

TABLE 1
VOLTAGE CONNECTIONS

| | |
|---|---|
| $V_A$ | GB2 |
| $V_B$ | GB4 |
| $V_C$ | GB6 |
| N | GB3 - GB5 - GB7 |

TABLE 2
CURRENT CONNECTIONS

| BASIC OHMIC TAP | 3 OHMS L-N ■ | | 1 OHM L-N ■ | |
|---|---|---|---|---|
| POLARITY | IN | OUT | IN | OUT |
| $I_A$ | GA3 | GB8 | GA4 | GB8 |
| $I_B$ | GA5 | GB9 | GA6 | GB9 |
| $I_C$ | GA7 | GB10 | GA8 | GB10 |
| $3I_0$ | GA9 | GB11 | GA10 | GB11 |

■ MULT. BY (SAMP)/(RATED CURRENT)

TABLE 3
COMPONENT VALUES

| MODEL FORM NO. | 1,3,5,7 | 2,4,6,8 |
|---|---|---|
| RATED FREQ. | 60HZ | 50HZ |
| DIODES D1,D2,D3 | 1N4148 | 1N4148 |
| ALL RES. OHMS | 1%, .3W | 1%, .3W |
| RE1<br>RG1<br>RJ1 | 12.1 | 16.2 |
| RE2<br>RG2<br>RJ2 | 121. | 133. |
| RE3<br>RG3<br>RJ3 | 51.1 | 59.0 |
| RL1 | 34.8 | 42.2 |
| RL2 | 22.6 | 26.1 |
| RL3 | 8.25 | 9.09 |

TABLE 4
RELAY MODEL SLYG61P P.C. CARD IDENTIFICATION

| FORM NO. | RATED FREQ. | CARD LOCATION | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | D | E | F | G | H,J,K | L,M,N | P,R,S |
| 1&3 | 60HZ | P114 | P102 | | P112 | F125 | C106 | T133 |
| 2&4 | 50HZ | P124 | P102 | | P121 | F165 | C106 | T133 |
| 5&7 | 60HZ | P114 | P102 | | P112 | F126 | C106 | T133 |
| 6&8 | 50HZ | P124 | P102 | | P121 | F166 | C106 | T133 |

*Fig. 17. Internal connection diagram for SLYG61P relay*

are applied to pin 6 of these cards. The output signals on these cards are A-C signals (both polarities) but are essentially square waves because of the high gain of the output amplifiers on the H, J, and K cards.

The second polarizing quantity. $T_O$ KG $I_O Z_{RO} - V_O$ is introduced at pin 3 of the coincidence logic cards, which requires that all three inputs must be of the proper relative polarity to produce an output block at pin 7.

The coincidence logic also provides for optional supervision through the pin 8 input on the card. For example. an $I_O$ level detector in an SLC relay can be connected through cable lead 018 to block an output if the zero sequence current is below the $I_O$ level detector setting.

The setting of the integrating timer determines the shape of the relay characteristic. A setting equal to 90° (4.16 ms. at 60Hz) produces a circular characteristic.

### 4. SLYGGIP Relay

The SLYGGIP relay is similar to the SLYG61A relay except that the No. 1 polarizing quantity is tine-to-neutral plus K times positive sequence voltage. instead of quadrature polarizing. and the No. 2 polarizing quantity is $I_O Z_{RO}$. This relay is intended for single-pole tripping applications, and this change is made to prevent misoperation on one of the faulted phases while one pole is open.

### 5. SLYG62A Relay

The SLYG62A relay is designed for second-zone tripping applications. It is similar to the SLYG61A relay except for a change in the filter design on the H, J, and K position cards.

### 6. SLYG62P Relay

The SLYG62P relay is designed for second-zone application in single-pole tripping and reclosing schemes. It is similar to the SLYG61P relay except for a change in the filter design on the H, J, and K position cards.

### 7. SLYG63A Relay (Blocking)

The SLYG63A relay is similar to the SLYG62A relay except that the No. 1 polarizing quantity has an IZ signal added to it.

The No. 2 polarizing circuit has provision for an $I_O Z_{RO}$ quantity to supplement the $(-V_O)$ quantity, but it is recommended that a setting of $T_O$ equal to zero should be used on blocking relays so that the second polarizing quantity is $(-V_O)$ only.

### 8. SLYG63P Relay (Blocking)

The SLYG63P relay is similar to the SLYG62P relay except that the No. 1 polarizing quantity has an IZ signal added to it.

The No. 2 polarizing circuit has provision for an $I_O Z_{RO}$ quantity to supplement the $(-V_O)$ quantity, but it is recommended that a setting of $T_O$ equal to zero should be used on blocking relays so that lhe second polarizing quantity is $(-V_O)$ only.

## APPLICATION CONSIDERATIONS, GROUND RELAYS

### 1. Reach Setting, First Zone Relays

The positive sequence reach of the SLYGGI or the SLYG81 relays can be set for values up to 65% of the line impedance if the angle of the positive sequence is 75° or more and ii the reach does not have to be reduced due to zero sequence mutual impedance effects as described below.

The SLYG81 relay has a fixed positive sequence maxi. mum reach angle of 8S°. For lines where the positive sequence impedance angle is less than 76°. the reactance component of the line impedance should be used to establish the positive sequence reach.

The SLYGGI relay provides a choice of 85° or 7S° positive sequence and 75° or 65° zero sequence maximum reach angles. For lines that are less than 100 miles long, these guidelines are suggested for choosing the maximum reach angle: (a) for positive sequence, use 85° tap for angles above 80° and 75° tap for angles below 80'; (b) for zero sequence. use 75° tap for angles above 70° and use 65° tap for angles below 70°. For lines where the positive sequence impedance angle is less than 65°, the reactive component of the line impedance should be used to establish the positive sequence reach.

The SLYGGI relay also has available a 15° leading phase shift of the polarizing voltage, which would produce an additional 15° clockwise shift of the relay characteristic. This additional phase shift is used only for specific load-flow conditions where such a shift would provide an advantage.

The zero sequence base reach is determined by the combination of the $Z_{RO}$ tap setting and the $K_O$ setting. Usually the $Z_{RO}$ setting will be the same as the $Z_{R1}$ setting, and variations in zero sequence reach will be made by changing KD. Il there is no mutual coupling to a parallel line, the $K_O$ setting should match the $Z_0/Z_1$ ratio of the line impedance. If there is mutual coupling. the reach setting should be reduced to avoid overreach. See the sec. tion below on mutual impdance.

### 2. Reach Setting, Second Zone Relays

Second zone relays should be set to reach beyond the remote terminal of the line with substantial margin. If there is mutual coupling from a parallel line, the zero sequence base reach may have to be increased as described in the section below on mutual impedance. IF there is no parallel line, the setting of $K_O$ should be approximately the same as the $Z_0/Z_1$ ratio of the protected line.

IF the second zone relay is used with a timer For second zone delayed tripping, the amount of overreach beyond the remote terminal will very likely have to be limited to provide coordination with backup relays on adjacent lines. IF the second zone relay is used only in a pilot scheme, the Forward reach may be increased to obtain more Fault resistance coverage, keeping in mind the Fact that both the source impedance and the Forward reach setting determine the diameter of the no-load characteristic. For more details on Fault resistance coverage. see IEEE paper No. F78 743-7. *"'Design Considerations in the Development of a New Ground Distance Relay"* by Wilkinson. Mathews and Keeney (GER 3089).

The Following values of reach setting as a percentage of line length, and characteristic timer settings, are typical values. As the line length increases, the amount of overreach is decreased, and the operating time settings of the characteristic timer increase. The characteristic timer setting values are For 60 Hz applications.

| *Line Length* | *Reach* | *Characteristic Timer (msj* | |
|---|---|---|---|
| *Miles* | *% of Line* | *First Pulse* | *Steady State* |
| *0-SO* | *ZOO* | *5.6* | *4.2* |
| *50-100* | *775* | *5.5* | *4.2* |
| *100-150* | *150* | *6.0* | *4.8* |
| *150-200* | *135* | *6.0* | *5.5* |
| *200-300* | *125* | *6.5* | *5.8* |

### *3. Mutual Impedance Considerations in Pilot Schemes*

The SLYG61 and SLYG81 relays do not contain any circuits For zero sequence mutual impedance compensation. The decision not to provide this compensation was based on the Fact that such compensation is not effective for a parallel line that is open and grounded at both ends. There. Fore the effect of the mutual impedance should be taken into account when choosing the zero sequence reach setting of the relay.

The zero sequence reach of these relays is determined by the base reach tap. $Z_{RO}$, the $K_O$ compensation setting, and Ihe restraint tap T. Usually the $Z_{RO}$ setting will be the same as $Z_{R1}$ (positive sequence base reach) and the T setting will be determined by the desired positive sequence reach. Therefore the only independent adjustment of zero sequence reach is the $K_O$ setting. The discussion below is aimed at choosing this setting.

In the examples given below, it is assumed that $Z_O$ of the protected line is 3 ohms and that $Z_M$ is 1.5 ohms. The First two conditions are For parallel lines tied together at both ends. and the next two are For lines connected together at one end only.

(a) *First zone relays, both ends common*

The worst case as Far as overreach is concerned would be that of the parallel line out of service and grounded at both ends. The current coupled into the parallel line reduces the apparent impedance of the protected line. The apparent zero sequence impedance is $Z_O\left(1-\frac{Z_M^2}{Z_O^2}\right)$.

For example. if $Z_O = 3$ and $Z_M = 1.5$, then the apparent impedance equals 3(1-2.25/g) or 2.25 ohms. The zero sequence apparent impedance, therefore, is 2.25/3.0 or *75%* of the actual impedance, and the zero sequence reach of the relay should be pulled back to 75% of the reach that would be used if there were no mutual effect.

(b) *Second zone reach, both ends common*

The condition to be considered here is that of the parallel line in service. The apparent impedance For the protected line in this case is $Z_O\left(1+\frac{Z_M^2}{Z_O}\right)$, or using the typical Figures given above, Z apparent = 3 (1 + 1.5/3.0) = 3 (1.5) = 4.5 ohms. Therefore 4.5 ohms instead of 3 ohms should be used as the zero sequence impedance of the line in calculating a second zone reach setting.

(c) *First zone reach, one end common*

*In* this case it is assumed that the current in the parallel line will flow in the opposite direction to that in the protected line and that it will be less than that in the protected line. It is necessary to calculate or assume a ratio between the currents in the two lines. IF we let the current in the protected line be $I_O$ and that in the parallel line $I_O'$ then

$$z \text{ apparent} = Z_O\left(1-\frac{I_O'Z_M}{I_OZ_O}\right)$$

With the same typical values used above. and assuming $(I_O'/I_O) = 0.8$. Z = 3 (1 – 0.8 x 1.5/3) = 3 (0.60) = 1.80 ohms. Therefore the zero sequence reach should be reduced in the ratio of 1.80/3.0 ohms.

It should be noted that the positive sequence and zero sequence reach may be set independently within the limits of the $K_O$ adjustment range. IF a calculation under this particular condition requires a greater reduction in $Z_O$ reach than can be obtained by the available $K_O$ adjustment. then the positive sequence reach should be reduced until the desired $Z_0$ reach is obtained.

(b) *Second zone reach. one end common*

If two parallel lines are permanently isolated at one end, the second zone reach setting et the common end should be based on the zero sequence impedance of the line. because the parallel line out of service gives the highest impedance. The second zone setting at the isolated end *is* $Z_0$

apparent $= Z_0 \left(1 + \frac{I_0' Z_M}{I_0 Z_0}\right)$

where $I_0$ and $I_0'$ are the currents in the protected and the parallel lines respectively.

However, if the lines could be temporarily connected, es by a bus tie breaker, for-example. then the second zone settings should be based on the calculations in paragraph (b) above.

(e) First zone *reach, both ends isolated*

For this condition, the situation which would cause overreach would be the parallel line out of service and grounded et both ends. Therefore the zero sequence reach setting should be based on the calculation in paragraph (a) on previous page.

(f) Second zone reach, *both ends isolated*

If the two parallel lines are completely isolated et each end so that there is no fault current flow in the parallel line for a fault on the protected line. the impedance to be used as a basis for the second zone setting would be the zero sequence of the line with no correction for mutual impedance effects.

(g) *Coordination wilh other relays*

If the second zone relays in the pilot scheme energize second zone timers for backup protection, then the second zone settings should also be checked for the system condition which yields the minimum apparent impedance in the line to see if this setting coordinates with first zone relays in adjacent lines. It may be necessary to use a compromise setting.

## RELAY SENSITIVITY

### OPERATING CIRCUIT SENSITIVITY

The sensitivity of the operating circuit can be defined as the lowest value of fault current that can be detected with. out exceeding a specified error of distance measurement. In mho distance relays, this is usually stated for a fault et the maximum reach angle of the relay, and the error commonly used is 10%. In other words. the actual relay reach will be no less then 90% of the reach setting at the stated current level.

The current sensitivity value is a function of the base reach tap (in the 90 series) or the base reach setting (in the 60 series) and is not affected by the restraint tap used.

In the data presented below, the basic sensitivity is given for a reduced reach, or pullback, error of 10%. In addition equations are given so that the sensitivity can be calculated for other values of reach error.

1. Phase Relays

The current sensitivity for each relay **type,** based on 10% reach error. is a constant $I_\phi Z_{R1}$ value, as given below, for phase-to-phase and 3-phase faults, where $I_\phi$ is phase current and $Z_{R1}$ is base reach ohms:

| | φ-φ | 3φ |
|---|---|---|
| SLY61 | 1.0 | 1.15 |
| s LY62 | 0.7 | 0.81 |
| SLY63 | 0.7 | 0.91 |
| SLY81 | 0.6 | *0.92* |

The actual current sensitivity can be determined by dividing the base reach ohms into the $I_\phi Z_{R1}$ value. For example, for the SLY61 relay, with a base reach of 3 ohms. and considering phase-to-phase faults. $I_\phi = 0.33$ amperes; with a base reach of 1 ohm, $I_\phi = 1$ ampere; and with a base reach of 0.1 ohm, $I_\phi = 10$ amperes.

The current sensitivity for other values of reach error can be calculated fmm the following equation. using the AB phase measuring unit es an example:

$$(I_A - I_B) Z_{R1} = \frac{A}{P}$$

where A is a constant es given below, and P is the reach error in per unit (0.2 for 20% error).

A = 0.2 for SLY61
A = 0.14 for SLY62 and 63
A = 0.16 for SLY81 and 82

2. Ground Relays

The calculation of current sensitivity for ground distance relays is more complex because it is affected by the ratio of zero sequence current to positive sequence current and by the value of $K_0$.

The basic current sensitivity values given below, in terms of $I_\phi Z_{R1}$, assume that the reach error is 10%. that $I_\phi = 3I_0$ that $K_0 = 3$. and that $Z_{R1} = Z_{R0}$.

| | $I_\phi Z_{R1}$ |
|---|---|
| SLYG61A,61 P | 1.20 |
| SLYG62A, 82P | 0.84 |
| SLYG63A, 83P | 0.84 |
| SLYG81, 82 | 0.98 |

The actual current sensitivity can be determined by dividing the base reach ohms into the $I_\phi Z_{R1}$ value. For example, For the SLYG61 relay, with a base reach of 3 ohms, $I_\phi$ = 0.4 amperes; with a base reach of 1 ohm, $I_\phi$ = 1.2 amperes; and with a base reach of 0.1 ohm, $I_\phi$ = 12 amperes.

The general equation below can be used to calculate sensitivity For other values of reach error and For other combinations of $I_\phi, I_O, K_O, Z_{R1}$ and $Z_{RO}$.

$$(I_\phi - I_O)Z_{R1} + K_O I_O Z_{RO} = \frac{A}{P}$$

where A is a constant as given below, and P is the reach error in per unit (0.2 For 20% error).

A = 0.2 For SLYG61
A = 0.14 For SLYG62 and 63
A = 0.18 For SLYG81 and 82

### POLARIZING CIRCUIT SENSITIVITY

For phase tripping relays, the voltage polarizing circuit sensitivity is 1% of rated voltage, or 1.2 volts For 120 volts rating. This is significant only For three-phase Faults.

For the quadrature polarized ground tripping relays (SLYG61A, SLYG62A, and SLYG81A) the sensitivity is 10% of the line-to-line quadrature voltage, or 12 volts For a 120 volt rating.

For the line-to-neutral polarized ground tripping relays (SLYG61P and SLYG62P) the sensitivity is 1% of rated voltage.

The sensitivity of the No. 2 polarizing signal in the ground tripping relays is 0.050 volts For the SLYG61 and SLYG82 relays and is 1.25 volts in the SLYG81 relay.

The sensitivity of the $I_O Z_{RO}$ input to the SLYG81 relay is $3I_O = 0.6/Z_{RO}$.

## OPERATING TIME CURVES

Operating time curves For some typical applications are shown in Figs. 19 through 23. The line lengths referred to are on a 500kV system with 2000/5 CT ratio.

The times shown in these curves are average times as Far as variation of operating time where incidence angle is concerned. The operating times For the SLY81A and SLYG81A relays include 4 ms pickup time of the output relay.

The inverse shape of these time curves. which is most apparent For the First zone relays, is due to the non-linear Filtering used in the $IZ_R - V$ operating circuit This filtering is most effective for faults near the reach setting of the relay. and prevents overreach due to CVT errors and other transients. For close-in Faults, the Filtering effect is effectively bypassed, so that high speed operation is attained.

## RELAY BURDEN

1. Potential Circuits

All data are burden per phase at rated voltage

| | Watts | Vars | Volt-Amps |
|---|---|---|---|
| SLY61.62,63 | 0.26 | 0.20 | 0.35 |
| SLY81, 82 | 0.20 | 0.35 | 0.46 |
| SLYG61,62,63 | 0.10 | 0.07 | 0.12 |
| SLYG81, 82 | 0.17 | 0.10 | 0.20 |

2. Current Circuits

The data below are For 5A, 80 Hz, expressed in ohms

| | R | $X_L$ | Z |
|---|---|---|---|
| SLY61,62,63 | ,025 | .003 | ,026 |
| SLY81.82 | .024 | ,014 | .028 |
| ● SLYG61, 62.63 | .025 | .003 | ,026 |
| ● ‘SLYGBI, 82 | ,026 | ,015 | ,030 |

‘These values are for either phase or residual circuit
*‘These values are For one phase circuit plus residual circuit

## BATTERY DRAIN VALUES

SLY81, 82. 83. SLYG61. 82, 83: 0.250A From +15V and 0.120A From -15V

SLY81, 82, SLYG81, 82 – Steady state: 0.2 amperes at 48V, 0.09 amperes at 125V
Tripping duty: 0.32 amps at 48V, 0.18 amps at 128V

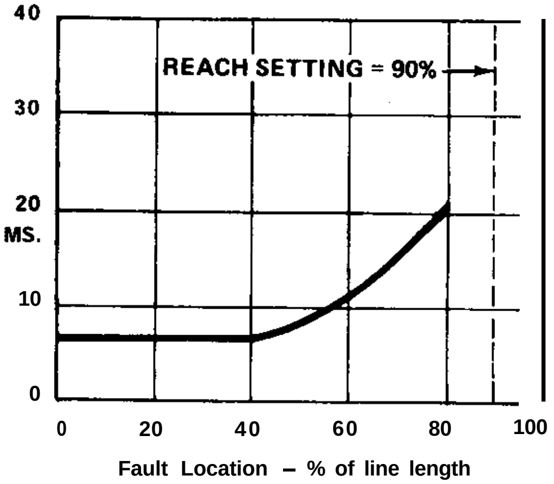


*Fig. 18. SLY61A first zone relay average operating time 75 mile line, 25 mile source*

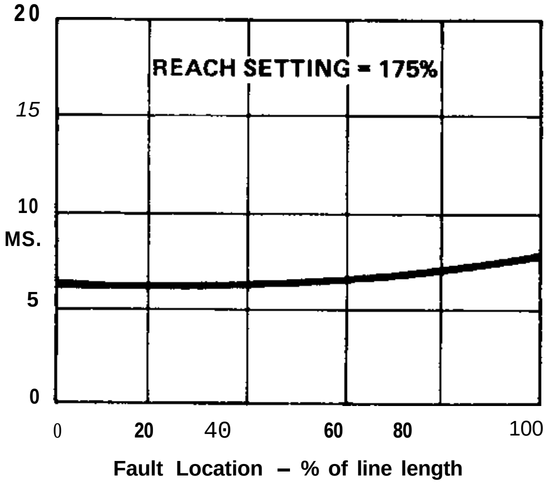


*Fig. 19. SLY62A second zone relay average operating time 75 mile line, 25 mile source*

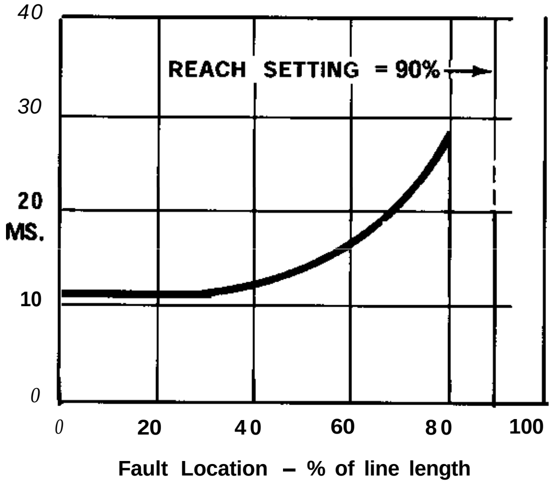


*Fig. 20. SLY81A first zone relay average operating time 100 mile line, 25 mile source*

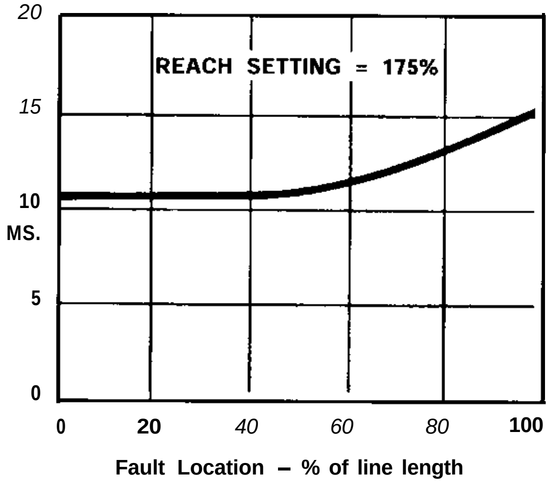


*Fig. 21. SLY81A second zone relay average operating time 700 mile line, 25 mile source*

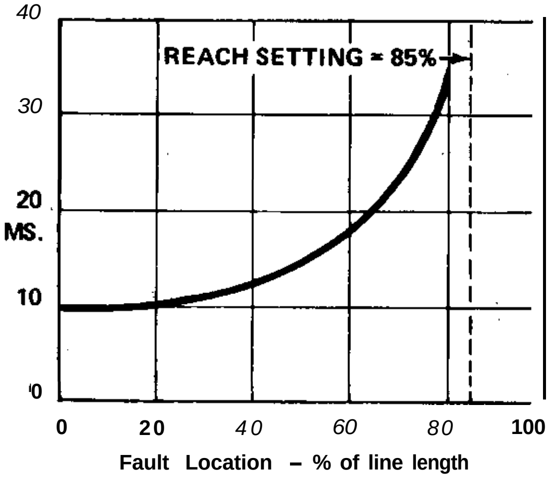


*Fig 22. SLYG81A first zone relay average operating time 100 mile line, 25 mile source*

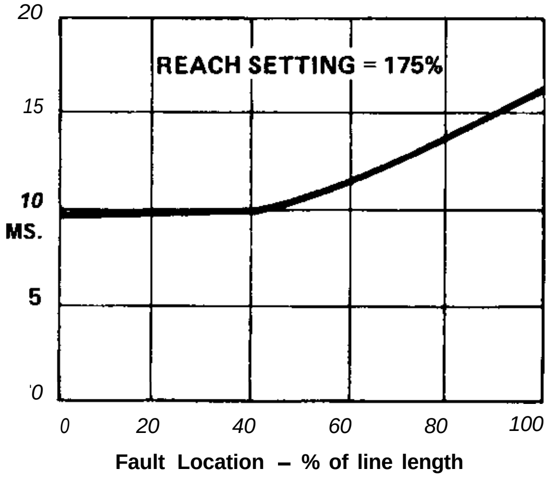


*Fig. 23. SLYG81A second zone relay average operating time 100 mile line. 25 mile source*

## RELAY SCHEMES

These relays may be used in a number of different schemes, including step-distance protection without a pilot channel. or directional comparison with a pilot channel. Directional comparison includes blocking schemes and permissive tripping schemes, and may be used with ON-OFF power line carrier, frequency shift power line carrier, or microwave channels. Direct trip functions may be included as part of the schemes.

Three typical schemes are shown in Figs. 24. 25, and 26. A legend of logic diagram symbols is shown in Fig. 24A.

Figure 24 is a simplified logic diagram showing the SLY62, SLY63, SLYG62 and SLC51 relays in a directional comparison blocking scheme using Type CS26 OFF-ON power line carrier. This scheme uses overcurrent carrier starting (G1) for all faults involving ground, and distance relay carrier start (MB) for phase faults.

In this scheme, for external ground faults. MTG at one end of the line will see the fault in the tripping direction and will operate to stop carrier transmission from that end via OR-7 and the NOT input to AND-6. At the other end. MTG will not operate. and the blocking carrier transmission will continue. blocking the end where MTG has operated.

For external phase faults. carrier is transmitted only from the end closest to the fault, where MB, and not MT. has operated. This sends a blocking signal to the remote end. where MT has operated. and prevents it from tripping.

For internal ground faults, MTG (and/or MT) at both ends will operate to stop carrier transmission and to produce a pilot trip output. For internal phase faults. the design of MT and MB is coordinated so that MT is always faster than MB for those fault locations that are within the MB steady-state characteristic. Therefore carrier transmission is either stopped or prevented for all internal faults.

Another feature of this scheme is transient blocking. which prevents incorrect tripping on the clearing of an external fault. The method of providing transient blocking is different for phase and ground relay operation. as described below.

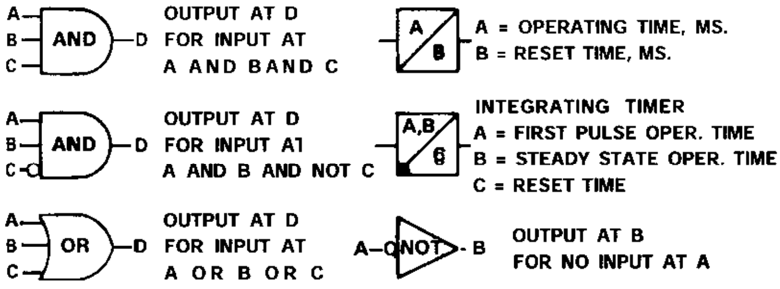
For external phase faults, where MB operates and MT does not. the output of MB is continued for 30 ms after the fault is cleared. This 30 ms reset time prevents the tripping functions from initiating a pilot trip, and prevents carrier from being stopped during that period.

For external ground faults. G1 at each end will start carrier. apply the NOT input to AND-16 to block pilot tripping, and energize timer TL-4 via AND-5. Timer TL-4 will operate in 25 ms, before the external fault is cleared. When the fault is cleared and G1 resets, TL-4 output is extended for 35 ms by the reset delay of TL-4. If the fault was on a parallel line, and clearing of one end caused a reversal of the direction of fault current flow over the line, MTG at one end may operate before MTG has reset at the other end. and transient blocking will prevent false tripping for this condition.

Figure 25 is a simplified logic diagram for a permissive tripping scheme using the SLY62 and SLYG62 relays. Either MT or MTG key the transmitter to send permission to the opposite terminal. and they also provide a local trip signal to AND-3. A trip output is obtained when there is a local trip signal and a receiver output signal at AND-3 for more than 2 ms.

An additional feature of this particular scheme is the repeat (or echo) keying of the transmitter via TL-3. AND-O. and AND-13 if the breaker is open at one end of the line. This permits tripping via the pilot protection when closing into a faulted line.

Figure 26 is an elementary diagram for a two zone stepped distance relaying scheme using the SLY81 and SLYG81 relays. This permits direct tripping and reclose initiation for the first zone relays, and delayed tripping for faults detected by the second zone relays.



**MB** – Mho blocking function, phase relay
**MT** – Mho tripping function, phase relay
**MTG** – Mho tripping function, ground relay
**G1** – Low set zero sequence current level detector
**G2** – Zero sequence current level detector
**I3$\phi$** – Level detector responding to $I_{ab}$, $I_{bc}$, or $I_{ca}$

*Fig. 24A. Legend for logic diagrams of Figs. 24 & 25*

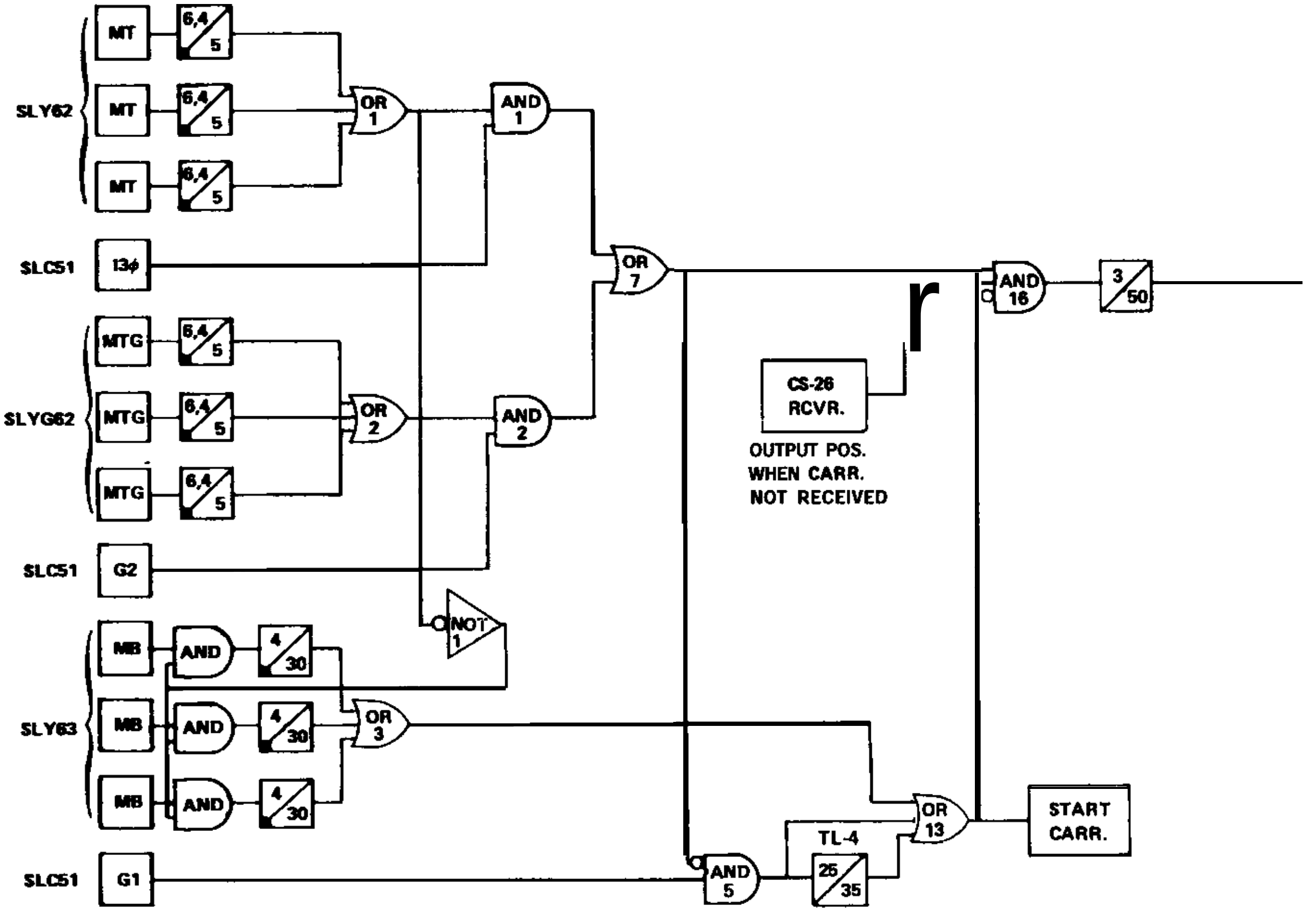


*Fig. 24. Simplified logic diagram for blocking scheme with type CS26 power line carrier*

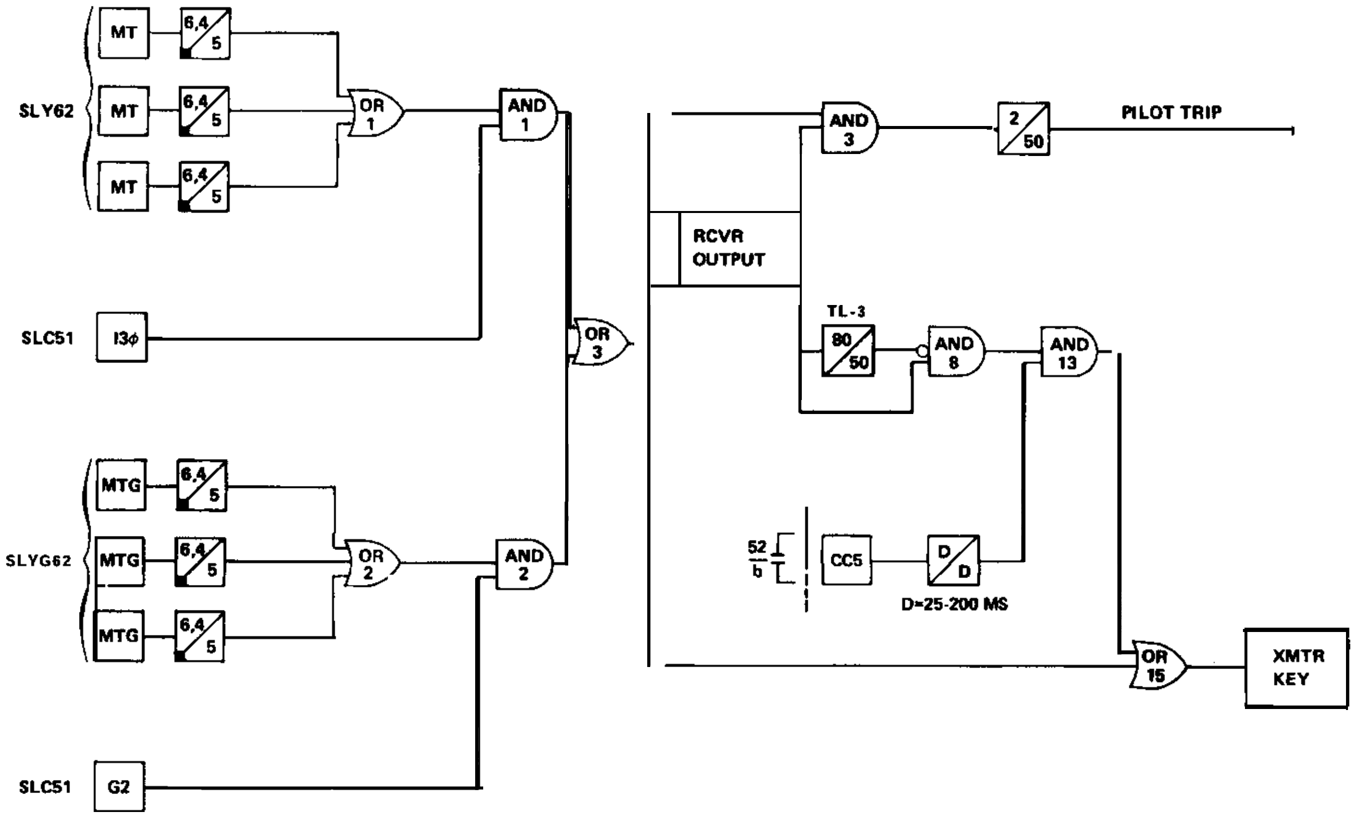
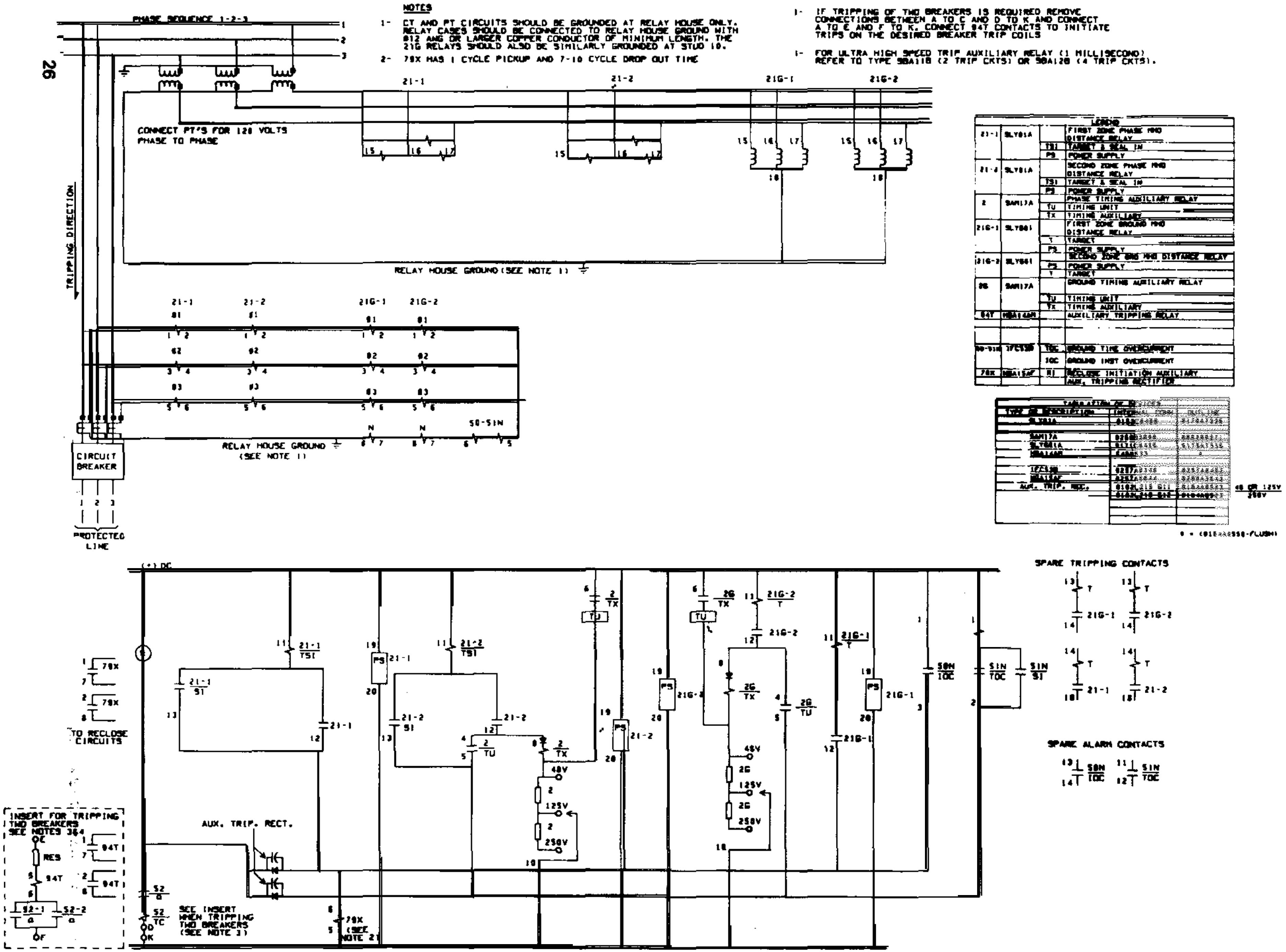


*Fig. 25. Simplified logic diagram for permissive overreaching tipping scheme with SLY62, SLYG62, and SLC51*



NOTES

1- CT AND PT CIRCUITS SHOULD BE GROUNDED AT RELAY HOUSE ONLY. RELAY CASES SHOULD BE CONNECTED TO RELAY HOUSE GROUND WITH #12 AWG OR LARGER COPPER CONDUCTOR OF MINIMUM LENGTH. THE 21G RELAYS SHOULD ALSO BE SIMILARLY GROUNDED AT STUD 10.

2- 78X HAS 1 CYCLE PICKUP AND 7-10 CYCLE DROP OUT TIME

1- IF TRIPPING OF TWO BREAKERS IS REQUIRED REMOVE CONNECTIONS BETWEEN A TO C AND D TO K AND CONNECT A TO E AND F TO K. CONNECT 94T CONTACTS TO INITIATE TRIPS ON THE DESIRED BREAKER TRIP COILS

1- FOR ULTRA HIGH SPEED TRIP AUXILIARY RELAY (1 MILLISECOND) REFER TO TYPE SBA11B (2 TRIP CKTS) OR SBA12B (4 TRIP CKTS).

| LEGEND | | | |
|---|---|---|---|
| 21-1 | SLY81A | | FIRST ZONE PHASE MHO DISTANCE RELAY |
| | | TSI | TARGET & SEAL IN |
| | | PS | POWER SUPPLY |
| 21-2 | SLY81A | | SECOND ZONE PHASE MHO DISTANCE RELAY |
| | | TSI | TARGET & SEAL IN |
| | | PS | POWER SUPPLY |
| 2 | SAM17A | | PHASE TIMING AUXILIARY RELAY |
| | | TU | TIMING UNIT |
| | | TX | TIMING AUXILIARY |
| 21G-1 | SLYG81 | | FIRST ZONE GROUND MHO DISTANCE RELAY |
| | | T | TARGET |
| | | PS | POWER SUPPLY |
| 21G-2 | SLYG81 | | SECOND ZONE GND MHO DISTANCE RELAY |
| | | PS | POWER SUPPLY |
| | | T | TARGET |
| 2G | SAM17A | | GROUND TIMING AUXILIARY RELAY |
| | | TU | TIMING UNIT |
| | | TX | TIMING AUXILIARY |
| 94T | HGA14AM | | AUXILIARY TRIPPING RELAY |
| | | | |
| | | | |
| 50-51N | IFC53B | TOC | GROUND TIME OVERCURRENT |
| | | IOC | GROUND INST OVERCURRENT |
| 78X | HGA15AF | RI | RECLOSE INITIATION AUXILIARY |
| | | | AUX. TRIPPING RECTIFIER |

| TABULATION OF DEVICES | | |
|---|---|---|
| TYPE OR DESCRIPTION | INTERNAL CONN. | [illegible] |
| SLY81A | [illegible] | [illegible] |
| | | |
| SAM17A | [illegible] | [illegible] |
| SLYG81A | [illegible] | [illegible] |
| HGA14AM | [illegible] | [illegible] |
| | | |
| IFC53B | [illegible] | [illegible] |
| HGA15AF | [illegible] | [illegible] |
| AUX. TRIP. REC. | [illegible] | [illegible] 48 OR 125V |
| | [illegible] | [illegible] 250V |

*Fig. 26.* Elementary diagram, two zone phase and ground distance line protection with ground overcurrent backup