INSTRUCTIONS

GEK-45470

STATIC GROUND OFFSET MHO DISTANCE RELAY

TYPE SLYG53A

GENERAL ELECTRIC

CONTENTS

STATIC GROUND OFFSET MHO DISTANCE RELAY

TYPE SLYG53A

DESCRIPTION

The type SLYG53A relay is a static three-phase ground mho distance relay with provisions for offsetting its mho characteristic. The relay is used primarily to provide the carrier start function in directional comparison blocking schemes. One relay will detect all single-phase-to-ground faults that fall within its reach setting.

Three ground mho distance functions, one per phase, are included in each SLYG53A 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. The relay is packaged in one 2 rack unit case, the outline and dimensions for which are shown in Figure 9. Component locations for the relay are shown in Figure 8.

The SLYG53A relay is not intended to be used by itself, but rather as part of an equipment that provides a complete protective relaying scheme. For example, a typical directional comparison blocking scheme which employed the SLYG53A as the ground carrier start function would also include a type SLY phase tripping relay, a type SLY phase blocking relay, a type SLYG ground tripping relay, a type SLC current relay, a type SLA logic relay, a type SLAT output relay and a type SSA power supply.

The SLYG53A relay outputs are d-c 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 relay require $\pm$15V d-c which is obtained from a type SSA power supply. The internal connections are shown in Figure 7.

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 SLYG53A ground mho distance relay is used primarily to provide the carrier starting function for ground faults in directional comparison relaying schemes. In this application it is usually used with its offset characteristics, as shown in Figure 13, since when properly set this will provide more reliable coordination with the ground mho tripping function at the remote end of the protected line. The relay may also be connected to provide non-directional delayed back-up protection via a suitable timing function in the associated SLA logic relay. External connections of the a-c circuits for a typical application are shown in Figure 14.

Zero sequence current compensation is provided as an integral part of each SLYG53A relay. The compensating factor (L_0) <u>must</u> be set equal to the ratio of the zero sequence impedance totthe 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 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. The relay does not have provisions for compensating for zero sequence mutual coupling with parallel lines.

In a directional comparison blocking scheme the blocking (carrier starting) function MBG at a given terminal must be able to detect all external ground faults in back of that terminal that are within the reach of the tripping (MTG) functions at the remote terminals of the protected line. Any effects of fault resistance that may be present must also be included. If this were not so, carrier might not be started for certain external faults, a blocking signal would not be sent, and the remote MTG functions would initiate a false trip. This is illustrated in Figure 13 where the characteristics of the blocking function (MBG) at station B and the tripping function (MTG) at station A have been plotted on an R-X diagram. Note that the MBG characteristic may be a circle, or expanded circle as shown dotted, and the remote MTG may be a circle, or a lens as shown dotted, depending on line length as described in the logic description for the specific scheme.

Referring to Figure 13 it will be noted that for any external fault along or near the angle of the protected line for which the MTG function will operate at A, the MBG function at B will also operate. However, for a fault just beyond terminal B with sufficient fault resistance to plot in the shaded area, the MTG function at A is apt to operate while the MBG function at B will not. For this condition a false trip could result. An increase in either the MBG offset reach setting or its reach setting in the blocking direction, or both, would eliminate this source of trouble. With regards to the above, it should be recognized that fault resistances that are relatively large as compared to the relay settings will generally occur on short lines where increased reach settings of both the tripping and blocking functions introduce no load limiting problems. On long lines, the arc resistance tends to be smaller relative to the relay settings so that any reasonable setting of MBG will suffice.

The SLYG53A 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 of 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 carefully 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 II.

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.

RATINGS

This relay is designed for use in an environment where the air temperature outside the relay case is between -20° and +65°C.

The current circuits of this relay are rated for 5 amperes, 60 hertz for continuous duty and have a one second rating of 300 amperes. The potential circuits are rated for 69 volts, 60 hertz.

The relay requires a ±15 VDC power source which may be obtained from Type SSA50 and up power supplies.

RANGES

The SLYG53A has an adjustable reach of 0.1 to 30 ohms in the blocking direction with a selectable offset in the tripping direction of 0.0, 0.1, 0.2, 0.3 or 0.4 per unit of the reach in the blocking direction.

Current input connections of 1 and 3 ohms exist in the current circuit and 10 to 100 percent (in one percent increments) restraint taps in the voltage circuit. In addition to the current input taps, the relay has a selectable base reach multiplier of 1.0, 0.5, 0.2 or 0.1. The relay has an angle of maximum reach which can be adjusted for 60 or 75 degrees in the tripping direction (240 or 255 degrees in the blocking direction).

The relay has a zero sequence current compensation circuit with a K_0 (Z_0/Z_1) adjustment range of 1.0 to 10.9 per unit in 0.1 per unit steps.

BURDENS

The maximum potential burden per phase, measured at

9.8 volt-amperes

7.9 watts

5.9 vars

The maximum current burden per phase, measured at 5 amperes is:

Z = 0.0177 <17.25°	ohms
R = 0.0169	ohms
X = 0.00525	ohms

The maximum burden that the logic circuits present to the power supply is:

0.210 ampere to the +15 VDC supply

0.090 ampere to the -15 VDC supply

OPERATING PRINCIPLES AND CHARACTERISTICS

GENERAL

The offset mho characteristic of the SLYG53A relay is illustrated in Figure 1. This MBG characteristic is a circle that does not pass through the origin of the 1R-1X diagram. All measurements are made on a phase-to-neutral basis (V_A is compared with I_A).

The mho characteristic is obtained by converting relay currents into voltage signals (IZ), combining these IZ signals with signals proportional to the line voltage (V), and measuring the angle between the appropriate combinations to obtain the desired characteristic.

Currents are converted into IZ signals by means of transactors (TE, TG and TJ); that is, air gap reactors with secondary windings. The transactors in this equipment are tapped on the primary to obtain the current input taps (1 and 3 ohm).

The Z of the IZ quantity is the transfer impedance of the transactor, i.e. V_{OUT}/I_{IN}. The transactor secondaries have loading resistors across them. These resistors provide the desired angle between V_{OUT} and I_{IN}. This angle determines the angle of maximum reach of the relay.

The offset mho characteristic of Figure 1 is obtained by comparing the phase angle between the quantities (IZ-TV) and (IZ*+TV) where V is the phase-to-neutral voltage at the relay, I is the phase current, Z is the relay base reach in the tripping direction, Z* is the relay base reach in the blocking direction and T is the voltage restraint tap. For a circular characteristic, relay operation occurs when the angle B between (IZ-TV) and (IZ*+TV) is less than or equal to 90 degrees.

RELAY REACH

The base reach of the relay in the blocking direction (Z*) is determined by the current input tap (TB) and the base reach multiplier tap (BRM). The base reach in the blocking direction is equal to the product of the current input tap and the base reach multiplier tap, i.e.

$$Z^* = TB \cdot BRM \qquad \text{(Eq 1)}$$

As an example, assume that the relay is set on the 3 ohm current input tap with a base reach multiplier setting of 0.5. The base reach of the relay (Z*) will be (3)(0.5) or 1.5 ohms.

The base reach of the relay in the tripping direction (Z) is determined by the base reach in the blocking direction (Z*) and the per unit offset reach tap (PR). The base reach in the tripping direction is the product of the base reach in the blocking direction and the per unit offset reach, i.e.

$$Z = Z^* \cdot PR = TB \cdot BRM \cdot PR \qquad \text{(Eq 2)}$$

As an example, assume the relay is set on the 3 ohm current input tap, with a base reach multiplier of 0.5 and a per unit offset of 0.2. The base reach in the tripping direction will be (3)(0.5)(0.2) or 0.3 ohm.

The reach of the MBG function in the blocking direction at 255 degrees is given by the expression:

$$Z^*_{255} = \left(\frac{Z^*}{T}\right)\left(\frac{2 + K_0}{3}\right) \times 100 \qquad \text{(Eq 3)}$$

or

$$Z^*_{255} = \left(\frac{TB \cdot BRM}{T}\right)\left(\frac{2 + K_0}{3}\right) \times 100 \qquad \text{(Eq 4)}$$

where:

Z^*_{255} is the relay reach in the blocking direction at 255 degrees

Z^* is the relay base reach in the blocking direction

T is the voltage restraint tap in percent

K_0 is the zero sequence current compensation setting

TB is the current input tap

BRM is the base reach multiplier

The reach of the MBG function in the tripping direction at 75 degrees is given by the relationship:

$$Z_{75} = \left(\frac{Z}{T}\right)\left(\frac{2 + K_0}{3}\right) \times 100 \qquad \text{(Eq 5)}$$

or

$$Z_{75} = \left(\frac{TB \cdot BRM \cdot PR}{T}\right)\left(\frac{2 + K_0}{3}\right) \times 100 \qquad \text{(Eq 6)}$$

where:

Z_{75} is the relay reach in the tripping direction at 75 degrees

Z is the relay base reach in the tripping direction

PR is the per unit offset

K_0, TB, BRM and T as defined previously

If the 100 percent voltage restraint tap is used, the reach of the relay at the angle of maximum reach is equal to the relay base reach. If a voltage tap other than 100 percent is chosen, the relay reach is increased in inverse proportion to the voltage restraint tap as demonstrated by equations 3 through 6. For example, if the 50 percent voltage restraint tap is used, relay operation still occurs for the same voltage on the secondary of the tapped autotransformer (TA, TB, or TC); however, because the line voltage applied to the relay is twice this value, the resultant relay reach is twice the base reach.

PHASE ANGLE MEASUREMENT

The operating quantities (IZ-TV) and (IZ+TV) are fed into a filter card. This card filters out extraneous frequencies from the input quantities and produces square wave outputs. The phase relationship between these square waves is the same as that between the input quantities (IZ-TV) and (IZ*+TV). The coincidence of these square waves (coincidence is defined as having the same polarity) is determined by a coincidence logic circuit. The output of the coincidence logic circuit is a pulse whose width is equal to the coincidence of the two square waves and thereby has a direct relationship to the phase angle between the square waves. Refer to Figure 2.

The last function in the phase angle measurement circuit is a timer which measures the duration of the pulse produced by the coincidence logic. If the timer is set to pickup on a pulse of 4.17 milliseconds (90 degrees) a circular characteristic is generated. If the timer setting is less than 4.17 milliseconds, an expanded circle is generated. Refer to Figure 3. In this case the angle between (IZ-TV) and IZ*+TV) (Figure 1) is greater than 90 degrees.

ZERO SEQUENCE CURRENT COMPENSATION

Zero sequence current compensation is provided as an integral part of each relay. The compensating factor (K_0) must be set equal to the ratio of the zero sequence impedance to the positve sequence impedance of the protected line (Z_0'/Z_1').

SHAPE OF THE MBG CHARACTERISTIC

Several of the adjustments in the relay affect the shape of the MBG characteristic. The pickup setting of the characteristic timer can change the characteristic from a lens, to a circle, to an expanded circle (tomato) as the pickup delay is set for longer than 4.16 milliseconds, equal to 4.16 milliseconds, less than 4.16 milliseconds respectively. The angle of maximum reach of the relay can be adjusted for 60 or 75 degrees. The reach of the relay is affected by the relay base reach (Z, Z*) and also by the zero sequence current compensation setting (K_0). The MBG characteristic will also be affected by setting links L1 and L2 to the cable position.

If the angle of maximum reach of the relay is set for 75 degrees in the tripping direction, 255 degrees in the blocking direction and L1 and L2 are set in the "Line" position, the MBG characteristic is symmetrical about the angle of maximum reach for all timer settings.

In order to plot the theoretical characteristic for this condition, convert the characteristic timer pickup setting from milliseconds to degrees using the following relationship:

$$C = 21.6\ P \qquad \text{(Eq 7)}$$

where:

C is the characteristic timer pickup setting in degrees

P is the characteristic timer pickup setting in milliseconds

Construct two diameters, one on each side of the angle of maximum reach. Refer to Figure 4. The angle between these diameters and the angle of maximum reach is given by:

$$D = 90^{o}\text{-}C \qquad \text{(Eq 8)}$$

where:

D is the angle between the diameters D1 and D2 and the angle of maximum reach

C is the characteristic timer pickup setting in degrees

Construct the perpendicular bisector of the reach at 75 degrees and 255 degrees as given by equations 3 and 5. The points at which this bisecter intersects the diameters D1 and D2 are the centers of the two circular lobes of the MBG characteristic. Use a compass to construct two circular arcs, centered at these intersections, which pass through the two ends of the maximum reach. Refer to Figure 4.

If the relay reach is set for a maximum reach angle of 60 degrees, the MBG characteristic will be asymmetrical for timer settings other than 4.16 milliseconds (90 degrees-circle). Refer to Figure 5. The reach at 75 degrees and 255 degrees remains constant when the angle of maximum reach or the timer setting is changed. The reach at these points is a function for the base reach, the voltage restraint tap and the zero sequence current compensation setting.

To construct the characteristic, draw the reach of the relay at 75 degrees and 255 degrees. Draw the angle of maximum reach at 60 degrees. Calculate C and D from equations 7 and 8 respectively. Draw two diameters (D1 and D2) D degrees on either side of the 60 degree angle of maximum reach. Construct the perpendicular bisector of the relay reach at 75 degrees and 255 degrees. The intersection of this line with diameters D1 and D2 are the centers of the two circular lobes at the MBG characteristic. Use a compass to construct two arcs, centered at these intersections, which pass through the two ends of the reach at 75 degrees. Refer to Figure 5.

When the relay is used in a cable application, the angle of the zero sequence component of the IZ quantity is shifted to 30 degrees rather than 75 degrees. In this application, the angle of maximum reach becomes a function of the zero sequence current compensation setting (K_0). The reach of the relay does not remain constant at 75 degrees as in the previous discussion. The angle of constant reach is given by the expression:

$$\theta = \tan^{-1}\left[\frac{1.932 + 0.500\ K_0}{0.519 + 0.866\ K_0}\right] \qquad \text{(Eq 9)}$$

where:

K_0 is the zero sequence current compensation setting

θ is the angle of constant reach

The reach of the relay in the forward direction at this angle is:

$$Z_C = \left(\frac{TB \cdot BRM \cdot PR}{T}\right)\left(\frac{M1}{3}\right) \times 100 \qquad \text{(Eq 10)}$$

The reach of the relay in the reverse direction at this angle is:

$$Z^{*}_C = \left(\frac{TB \cdot BRM}{T}\right)\left(\frac{M1}{3}\right) \times 100 \qquad \text{(Eq 11)}$$

M1 is a function of the zero sequence current compensation setting and is given by the expression:

$$M1 = \left[(0.520 + 0.866\ K_0)^2 + (1.932 + 0.500\ K_0)^2\right]^{1/2} \qquad \text{(Eq 12)}$$

When the angle of maximum reach is set for 75 degrees, the actual angle of maximum reach is θ. When the 60-degree setting is used, the actual angle of maximum reach is (θ - 15 degrees). To plot the theoretical characteristic for the cable application, use the procedures outlined previously with the following experience.

1) Use the angle θ in place of 75 degrees

2) Use the reach at the angle θ in place of the reach at 75 degrees

3) Use the angle (θ-15^{o}) in place of 60 degrees

CIRCUIT DESCRIPTION

The internal connections of the SLYG53A relay are shown in Figure 7. The voltage inputs are on the upper left of the diagram. The current inputs are on the lower left. The GC and GD designations refer to twelve point terminal blocks located on the rear of the unit. The component and card locations are shown in Figure 8.

The phase-to-neutral input voltages are passed through transformers (TA, TB, TC) with one percent taps on the secondary. This voltage is then fed to the processing card in location D and also into the operating circuit of one of the three filtering cards. The processing card, used in location D, develops a median polarizing voltage which is fed to the filter card.

The input phase currents are passed through transactors (TE, TG, TJ). The three resulting voltages are then fed to the processing card in location E. The zero sequence current is passed through a transactor (TL) with a variable transfer angle to account for variation between transmission lines and cables. The resulting voltage is fed to the processing card in location G which contains the zero sequence current compensation circuit. The output of the processing card is combined with the voltage derived from the phase currents on the processing card in location E to produce three phase-to-neutral IZ quantities. The Z can be changed by means of the base reach multiplier (BRM) selector located on the processing card in location E. The base reach multiplier selector sets the Z of all three IZ quantities with one adjustment. The outputs of the processing card are fed to the operating circuit of the appropriate filter card where it is added to the phase-to-neutral voltage signal to form the (IZ*+TV) quantity. The output is also fed to the processing card in location F. The per unit offset reach (PR) selector is located on this card. The output of this card is then fed to the polarizing circuit of the appropriate filter card where it is used to form the (IZ-TV) quantity.

The filter cards are used to filter the a-c signals and to produce square waves whose phase relationship is the same as between the quantities (IZ-TV) and (IZ*±TV). These two square waves are then fed into the coincidence logic circuit. The coincidence logic produces a +15 VDC output whenever the two input signals have the same polarity. The width of the pulse output of the card is proportional to the phase angle between (IZ-TV) and IZ*+TV). The pulse width is measured by the timing circuit on the timer card. The timer card produces an output whenever the fault plots within the MBG characteristic. The circuitry for all three phases is the same.

CALCULATION AND CHOICE OF SETTINGS

The calculation procedure will be illustrated by the portion of a transmission system shown in Figure 13. Assume that line No. 2 is to be protected by a directional comparison blocking scheme using power line carrier and that the SLYG53A relay to be set is located at breaker B. The general considerations for setting the MBG blocking function, and the associated MTG tripping function at remote breaker A, are given in the APPLICATION section. However, the logic description supplied with the particular scheme should be consulted for specific recommendations for that application.

For purposes of illustration it will be assumed that the MTG function at breaker A has been set to see 175 percent of the apparent impedance of the protected line, including the effects of mutual coupling with the parallel line. The equations to be used in this calculation, and their derivation, are discussed in the instruction book for the SLYG tripping relay at breaker A. The MBG function at breaker B must be set so that it outreaches the MTG function at A for all system conditions and fault locations in back of breaker B. The recommended settings for the MTG and MBG functions for various line lengths are tabulated in the logic description for the scheme in which these relays are applied.

As an example assume the following impedance values of a 75 mile, 230 kV line:

$Z_1' = 52 \angle 80^{\circ}$ ohms (pri.)

$Z_0' = 130 \angle 80^{\circ}$ ohms (pri.)

CT ratio = 1200/5

PT ratio = 2000/1

converting to secondary ohms:

$$Z_1' \text{ (sec)} = 52\left(\frac{240}{2000}\right) = 6.24 \text{ ohms}$$

$$Z_0' \text{ (sec)} = 130\left(\frac{240}{2000}\right) = 15.6 \text{ ohms}$$

The recommendations for a line in the 50 - 100 mile range in a typical logic description call for an MBG setting of 250 percent of line impedance with a per unit offset setting of 0.3. For the line in the example the MBG reach should be 2.5 x 6.24 = 15.6 ohms at 75°, assuming line angle and relay angle are approximately the same. With the 0.3 per unit offset tap, the reach of the MBG unit in the tripping direction (i.e., offset) will be approximately 4.7 ohms.

In arriving at the reach of MBG in the blocking direction (MBG*) the following settings must be made:

(a) Current input connection (T_B - 1 or 3 ohms)

(b) Base reach multiplier (BRM)

(c) Percent restraint tap setting (10-100)

The base reach in the blocking direction (Z*) will be the product of the base reach multiplier (BRM) and the base impedance (T_B) determined by the current input connection:

$$Z^* = T_B \times BRM$$

The base reach Z* should be the highest obtainable value that is less than the required reach of the MBG function in the blocking direction, in this case $15.6 \angle 75^{\circ}$ ohms. Therefore, T_B should be on the input connection that results in the 3 ohm base ohms, and BRM should be on the one tap.

The required reach of the relay in the blocking direction, $15.6 \angle 75^{\circ}$ ohms, is now obtained by the percent restraint tap setting T:

$$Z^*_{255} = \frac{Z^*}{T} \times 100$$

$$= \frac{T_B \times BRM}{T} \times 100$$

$$\text{or} \quad T = \frac{T_B \times BRM}{Z^*_{255}} \times 100$$

$$= \frac{3 \times 1}{15.6} \times 100 = 19 \text{ percent.}$$

It should be noted that in many cases it will be possible to obtain a base reach (Z*) less than the required reach setting in the blocking direction (Z^*_{255}) by using either of the two current input connections (1 or 3 ohms). It is recommended, however, that the 3 ohm base ohms connection be used whenever possible.

The zero sequence current compensation tap K_0 should be set in accordance with the relationship:

$$K_o = Z_o'/Z_1'$$

For the example:

$$K_o = \frac{130}{52} = 2.5$$

If K_o cannot be set exactly, the next higher tap value should be used. This will tend to make the function reach slightly further than the calculated setting, which is more desirable than having the function underreach.

CONSTRUCTION

The type SLYG53A 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 outline and mounting dimensions are shown in Figure 9. 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 developing three ground mho blocking characteristics. The relay has a hinged front cover and a removable top cover.

The setting of the current input tap is accomplished by the connection of the input currents to the GC terminal board on the rear of the relay. The connection points for the one and three ohm taps are shown in the table on the internal connection diagram of Figure 6.

The voltage restraint tap blocks are located on the front of the unit at the left hand side. Refer to the component location diagrams of Figure 8. The voltage restraint tap settings are made by jumpers with taper tip pins on the end. In the accessory kit accompanying each equipment there are two special tools supplied for use with these pins. One is an insertion tool and the other is an extraction tool. In order to achieve a proper connection and to prevent damage to the pins, it is essential that these tools be used. Two tap blocks are used per phase: one is for the ten percent tap and one is for the one percent tap. The voltage restraint tap setting is the sum of the one and ten percent settings.

The relay also contains printed circuit cards which are located to the right of the tap blocks. The printed circuit cards are identified by a code number such as F156, C104, T121 or P102 where F designates filter, C designates coincidence, T designates time delay, and P designates processing. The printed circuit cards plug in from the front of the unit. The pockets are identified by letter designations on "addresses" (D, E, F etc.) which appear on the guide strips in front of each pocket, on the component location diagram, on the internal connection diagram and on the printed circuit card itself.

RECEIVING, HANDLING AND STORAGE

These relays 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 the static relay equipment 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.

INSTALLATION TESTS

CAUTION

THE LOGIC SYSTEM SIDE OF THE D-C POWER SUPPLY USED WITH MOD III STATIC RELAY EQUIPMENT IS ISOLATED FROM GROUND. IT IS A DESIGN CHARACTERISTIC OF MOST ELECTRONIC INSTRUMENTS THAT ONE OF THE SIGNAL INPUT TERMINALS IS CONNECTED TO THE INSTRUMENT CHASSIS. IF THE INSTRUMENT USED TO TEST THE RELAY EQUIPMENT IS ISOLATED FROM

GROUND, ITS CHASSIS MAY HAVE AN ELECTRICAL POTENTIAL WITH RESPECT TO GROUND. THE USE OF A CONNECTION TO THE EQUIPMENT, SUCH AS A TEST LEAD INADVERTENTLY DROPPING AGAINST THE RELAY CASE, MAY CAUSE DAMAGE TO THE LOGIC CIRCUITRY. IT IS A GOOD TEST PROCEDURE TO CONNECT THE REFERENCE LEAD OF A TEST INSTRUMENT TO RELAY REFERENCE BEFORE CONNECTING THE SIGNAL LEAD.

GENERAL

The test points (TP1, TP2, etc.) shown on the internal connection diagram are connected to instrument test jacks on a test card in card location T. TP1 is located at the top of the card and is connected to relay reference. TP10 is located at the bottom of the card and is connected to +15 VDC. Output signals are measured with respect to the relay reference (TP1). Logic signals are approximately +15 VDC for the ON or LOGIC ONE condition, and between 0 and +1 VDC for the OFF or LOGIC ZERO condition. Filter card outputs are square waves which shift from +15V to -15V.

Any of the input/output pins on the printed circuit boards can be monitored by using the test card adapter as described in the Printed Circuit Card Instruction Book GEK-34158. The logic signals can be monitored with an oscilloscope, a portable high impedance voltmeter or the voltmeter on the equipment test panel. When the test panel meter is supplied, it will normally be connected to relay reference. Placing the test lead to the proper test point will connect the meter for testing. When time delay cards are to be adjusted or checked, an oscilloscope which can display two traces simultaneously and which has a calibrated horizontal sweep should be used.

The relay contains printed circuit cards with trimmer potentiometers mounted on them. Some of these potentiometers are factory set and sealed. These potentiometers should not be readjusted.

Before testing the relay, the trip outputs from the associated type SLAT relay should be opened to prevent inadvertent tripping of the breakers.

Input currents and voltages may be supplied to the relay through Type XLA test plugs placed in the test receptacles on the equipment test panel. Reference to the elementary diagram for the static relay equipment will provide information concerning equipment inputs. All units of a given terminal have been calibrated together at the factory and will have the same summary number on the unit nameplates. These units should be tested and used together.

NECESSARY ADJUSTMENTS

The following checks and adjustments should be made by the user in accordance with the procedures given under DETAILED TESTING INSTRUCTIONS before the relay is put into service. The necessary set points may be calculated following the procedures under CHOICE AND CALCULATION OF SETTINGS. The adjustments should be made in the order shown.

1. Base reach setting (Z, Z*)
   a) Basic ohmic tap selection (TB)
   b) Base reach multiplier selection (BRM)
   c) Per unit offset reach selection (PR)
2. Voltage restraint tap setting (T)
3. Angle of maximum reach setting.
4. Zero sequence current compensation setting (K_0)
5. Characteristic timer setting
6. Reach vernier adjustment
7. MBG characteristic plot

DETAILED TESTING INSTRUCTIONS

RELAY CURRENT INPUT CONNECTION

The current input tap (TB) is determined by the terminals to which the relay input currents are connected to the unit. The correct input terminals for the one and three ohm current input taps are given in Table I.

TABLE I

	I_A		I_B		I_C		$(I_A+I_B+I_C)$	
CURRENT TAP	IN	OUT	IN	OUT	IN	OUT	IN	OUT
1 OHM	GD8	GC4	GD9	GC6	GD10	GC8	GD11	GC10
3 OHM	GD8	GC3	GD9	GC5	GD10	GC7	GD11	GC9

The base reach multiplier selector is located on the card in location E. The adjustment is accomplished by a four position jumper block. In each position the gain of the IZ* circuit for each phase is set to the proper value of base reach multiplier. The base reach multiplier for each jumper position on the card is shown in Table II.

TABLE II

JUMPER POSITION	BASE REACH MULTIPLIER (BRM)
B	1.0
C	0.5
D	0.2
E	0.1

The per unit offset reach selector is located on the card in location F. The adjustment is accomplished by a five position jumper block. In each position the gain of the IZ circuit for each phase is set to the proper value of per unit offset reach multiplier. The per unit offset reach for each jumper position on the card is shown in Table III.

TABLE III

JUMPER POSITION	PER UNIT OFFSET REACH (PR)
A	0.0
B	0.1
C	0.2
D	0.3
E	0.4

The relay base reach in the blocking direction (Z*) is given by equation 1. The relay base reach in the tripping direction (Z) is given by equation 2.

VOLTAGE RESTRAINT TAP SETTING

The voltage restraint tap setting (T) is accomplished on tap blocks located on the front of the relay. A separate tap block is provided for each phase pair. The setting consists of a ten percent tap and a one percent tap. A restraint tap setting of 57 percent would consist of a ten percent setting of 50 and a one percent setting of 7. Only the special tools supplied with the relay should be used to change the tap setting. The reach of the relay at 255 degrees is given by equations 3 or 4. The reach of the relay at 75 degrees is given by equations 5 or 6.

ANGLE OF MAXIMUM REACH SETTING

The angle of maximum reach of the relay is set by adjusting the position of plug X on the cards in locations H, J and K. There are two positions for the jumper plug, one for a 75-degree angle of maximum reach and one for a 60-degree angle. The setting must be made on each of the three filter cards. The angle of maximum reach for each position is shown in Table IV.

TABLE IV

PLUG X SHORTING ARRANGEMENT	ANGLE OF MAXIMUM REACH
2 to 3 and 4 to 5	75^{o}
1 to 2 and 3 to 4	60^{o}

ZERO SEQUENCE CURRENT COMPENSATION SETTING

The zero sequence current compensation setting (K_0) is adjusted by means of two thumb-wheel switches mounted on the card in position G.

The upper switch (510) selects the unit value and is adjustable from 1 to 10 in integer steps. The lower switch (511) selects the tenth value and is adjustable from 0.0 to 0.9 in one tenth increments. The zero sequence current compensation setting can be read from the positions of the two switches.

The angle associated with transactor TL has two possible settings, one for use on transmission lines and one for cables. Links L1 and L2, which are located on the rear of the unit, must both be rotated to either the "Line" or "Cable" position depending upon the application.

CHARACTERISTIC TIMER SETTING

The pickup setting of the characteristic timer affects the shape of the MB characteristic. Increasing the pickup time tends to narrow the characteristic, decreasing the pickup time widens the characteristics. The reset time delay (dropout time) provides an overlap of the next half cycle measurement and provides a time delay before resetting after the input signal is removed. The inputs of the timers are +15V pulses whose width is proportional to the phase angle between (IZ-TV) and (IZ*+TV). One pulse occurs every half cycle. The outputs of the timers are DC logic signals. The timer settings are discussed in the section CHOICE AND CALCULATION OF SETTING.

The timers used for the MBG function are integrating characteristic timers. These timers are typically listed on the overall logic as T1, T2/T3 where T1 is the pickup time in milliseconds on a step d-c input, T2 is the pulse width which will cause the timer to pickup with one pulse applied per half cycle and T3 is the drop-out delay. The operation of the integrating characteristic timers is discussed in the printed circuit card instruction book, GEK-34158.

The d-c pickup (T1) and the dropout (T3) of the MBG characteristic timer may be set using the test circuit of Figure 10. Before testing the timer with this circuit, the card which normally supplies the input to the timer must be removed (refer to Table V). Opening the normally closed contact of Figure 10 causes the output to step to +15VDC after the pickup delay of the timer. To increase the pickup delay, turn the upper potentionmeter (P1) on the timer card clockwise. Closing the contact causes the timer to drop out (step to less than 1VDC) after the reset delay setting of the card. To increase the reset delay, turn the second potentionmeter (P2) clockwise. The pulse pickup mode of the timer may be observed while plotting the characteristic as described in OVERALL CHECK OF THE MBG CHARACTERISTIC. The applied voltage and current as well as the phase angle between them, can be adjusted to vary the pulse width of the timer input.

TABLE V

TIMER UNDER TEST	REMOVE CARD
P	L
R	M
S	N

OVERALL CHECK OF THE MBG CHARACTERISTIC

An overall check of the MBG characteristic can be made by applying current and voltage to the relay and plotting the MBG characteristic on a R-X (ohms) or IR-IX (voltage) diagram. This plot may be compared with a theoretical characteristic plotted following the directions given in the section SHAPE OF THE MGB CHARACTERISTIC.

RELAYS FOR TRANSMISSION LINE APPLICATIONS

The MBG characteristic may be checked using the test circuit of Figure 11 or 12. The connections for testing each of the three phases are listed in Table VI for one ohm current tap and Table VII for the three ohm current tap.

TABLE VI

PHASE	Fig 11 CONNECTION POINTS - 1 OHM TAP								
	A	B	C	D	E	F	G	H	OUTPUT
A	GD2	GD4	GD6	*	GD8	GC4	GD11	GC10	TP4
B	GD4	GD6	GD2	*	GD9	GC6	GD11	GC10	TP6
C	GD6	GD2	GD4	*	GD10	GC10	GD11	GC10	TP8

*Jumper GD3, GD5 and GD7 to Point D

TABLE VII

PHASE	Fig 11 CONNECTION POINTS - 3 OHM TAP								
	A	B	C	D	E	F	G	H	OUTPUT
A	GD2	GD4	GD6	*	GD8	GC3	GD11	GC9	TP4
B	GD4	GD6	GD2	*	GD9	GC5	GD11	GC9	TP6
C	GD6	GD2	GD4	*	GD10	GC7	GD11	GC9	TP8

*Jumper GD3, GD5 and GD7 to Point D

The following procedure should be used for each of the three phases.

a) Use the test circuit of Figure 11 or 12 and the appropriate connections from Table VI or Table VII.

b) Set the input current for 5 amperes (rms). Set the input voltage for 69 volts (rms).

c) Set the phase shifter for the angle of interest.

d) Lower the input voltage until the output (TP4, TP6 or TP8) steps to !2-!5VDC.

e) Record the voltage and angle

By varying the phase angle, the operating point voltage may be determined for the whole characteristic and plotted on polar graph paper.

The operating voltage at 75 degrees is given by the following expression:

$$V_{75} = \frac{(2 + K_O)}{3} \left(\frac{IZ}{T}\right) X \ 100 \qquad \text{(Eq. 13)}$$

where:

I is the 5 ampere test current

Z is the relay base reach in the tripping direction as given by equation 2.

T is the voltage restraint tap setting in percent.

K_O is the zero sequence current compensation setting

V_{75} is the pickup voltage at 75 degrees.

The reach at 75 degrees should be within five percent of the calculated value. The pickup voltage at 75 degrees may be adjusted by P52 on the appropriate filter card. Turning P52 clockwise increases the voltage needed to pick up the MBG function.

The operating voltage at 255 degrees is given by the equation:

$$V_{255} = \frac{(2 + K_O)}{3} \left(\frac{IZ^*}{T}\right) X \ 100 \qquad \text{(Eq. 14)}$$

where:

I is the 5 ampere test current

Z* is the relay base reach in the tripping direction as given by equation 1

T is the voltage restraint tap setting in percent

K_0 is the zero sequence current compensation setting

V_{255} is the pickup voltage at 255 degrees

The reach of 255 degrees should be within five percent of the calculated value. The pickup voltage at 255 degrees may be adjusted by P10 on the appropriate filter card. Turning P10 clockwise increases the voltage needed to pick up the MBG function.

Each filter card contains two sealed factory adjusted potentiometers: P27 and P61. These potentiometers are used in setting the filter circuits used on the cards and should not be adjusted by the user.

Relays for Cable Applications

The MBG characteristic may be checked as described for transmission line applications. The test circuit of Figure 11 or 12 and the connections of Table VI or VII should be used. The reach of the relay at the angles θ and(θ+180 degrees) are given by equations 15 and 16. The angle < is given by equation 9.

$$V_e = IZ_c \qquad \text{(Eq. 15)}$$

$$V_{(\theta+18)} = IZ_c^* \qquad \text{(Eq. 16)}$$

where:

V is the pickup voltage at the angle θ

$V_{(\theta+180)}$ is the pickup voltage at the angle (θ+180)

I is the 5 ampere test current

Z_c and Z_c* are given by equations 10 and 11

PERIODIC CHECKS AND ROUTINE MAINTENANCE

Periodic Checks

The MBG functions included in the relay may be checked at periodic intervals using the procedures described in the DETAILED TESTING INSTRUCTIONS section. Cable connections between the relay and the associated Type SLA relay can be checked by observing the relay outputs at points in the SLA relay.

TROUBLE SHOOTING

In any troubleshooting equipment, it should first be established which unit is functioning incorrectly. The overall logic diagram supplied with the equipment shows the combined logic of the complete equipment and the various test points in each unit. By signal tracing, using the overall logic diagram and the various test points, it should be possible to quickly isolate the trouble.

A test adapter card (0149C7259G-2) is supplied with each static relay equipment to supplement the prewired test points on the test cards. Use of the adapter card is described in the card instruction book GEK-34158.

A dual-trace oscilloscope is a valuable aid to detailed troubleshooting, since it can be used to determine phase shift, operate and reset times as well as input and output levels. A portable dual-trace oscilloscope with a calibrated sweep and trigger facility is recommended.

SPARE PARTS

To minimize possible outage time, it is recommended that a complete maintenance program should include the stocking of at least one spare card of each type. It is possible to replace damaged or defective components on the printed circuit cards, but great care should be taken in soldering so as not to damage or bridge-over the printed circuit busses, or overheat the semi-conductor components. The repaired area should be recovered with a suitable high-dielectric plastic coating to prevent possible breakdowns across the printed busses due to moisture and dust. The wiring diagrams for the cards in the relay are included in the card book GEK-34158; the card types are shown on the component location diagram, Figure 7.

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 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.

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'.

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.

Z_L = Line impedance

Z_a = Phase A impedance for condition described.

All of the above are secondary ohms, where:

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

Miscellaneous

T = Relay voltage restraint tap setting in percent.

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

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

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

THREE-TERMINAL LINE APPLICATIONS

PILOT RELAYING SCHEMES

The ideal performance of a pilot relaying scheme for transmission line protection for either a 2-terminal or 3-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 li.. . 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 - Do not trip the 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 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 Figure 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:

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

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 $[I_a' + (K_o-1)\, I_o']$ where K_o is a per unit value. The voltage E_a' at terminal A for a fault at terminal C, Figure 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}.

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

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, or as defined in the logic description for the specific scheme. The voltage restraint tap setting will then be determined as:

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

where θ = angle of maximum reach

θ = angle of protected line

All other symbols are defined in Appendix I.

The MBG function must be set to outreach either remote MTG functions when that function is not subject to the effect of infeed, that is, when the line is operating as a 2-terminal line.

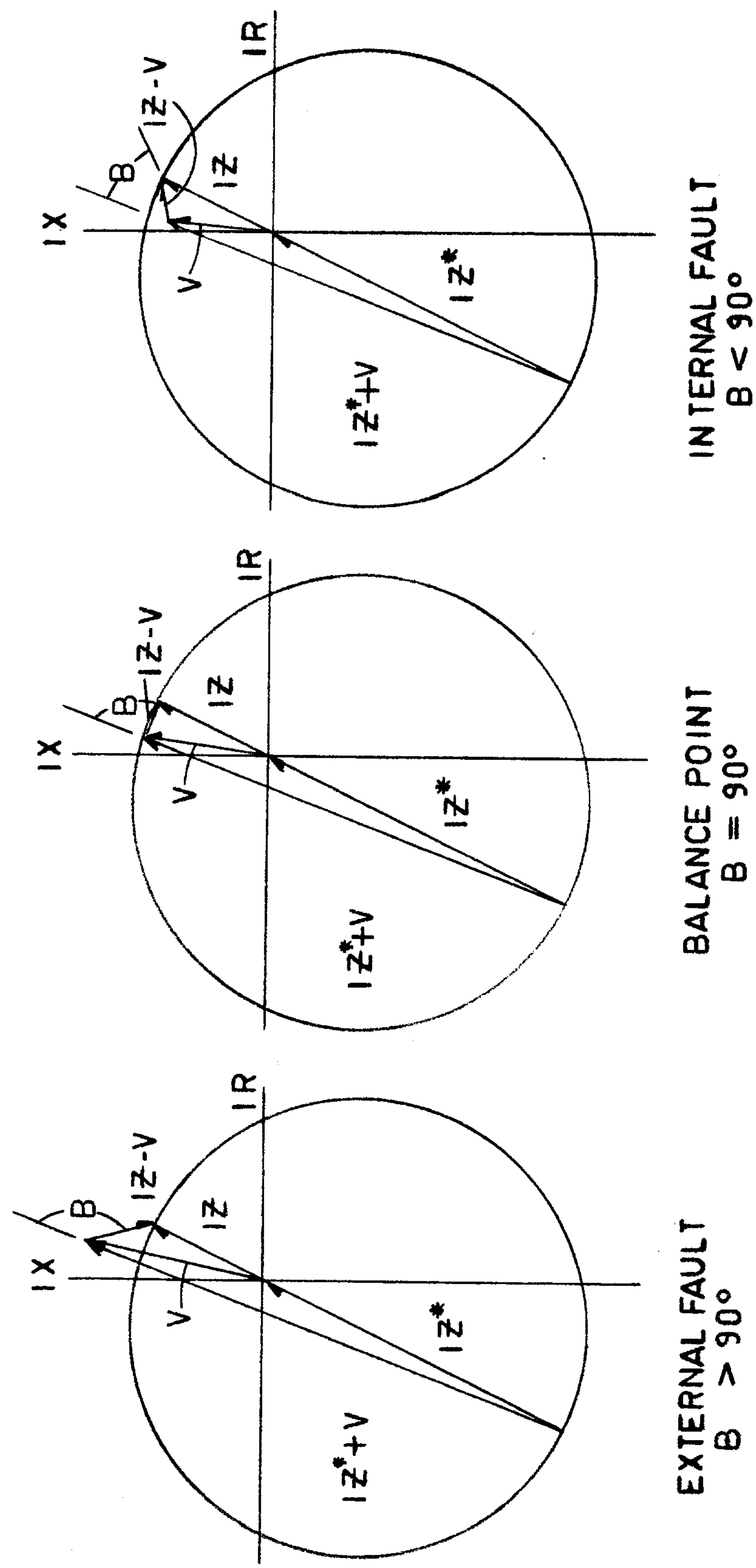


Fig. 1 (0269A3109-0) OFFSET MHO CHARACTERISTIC BY PHASE ANGLE MEASUREMENT

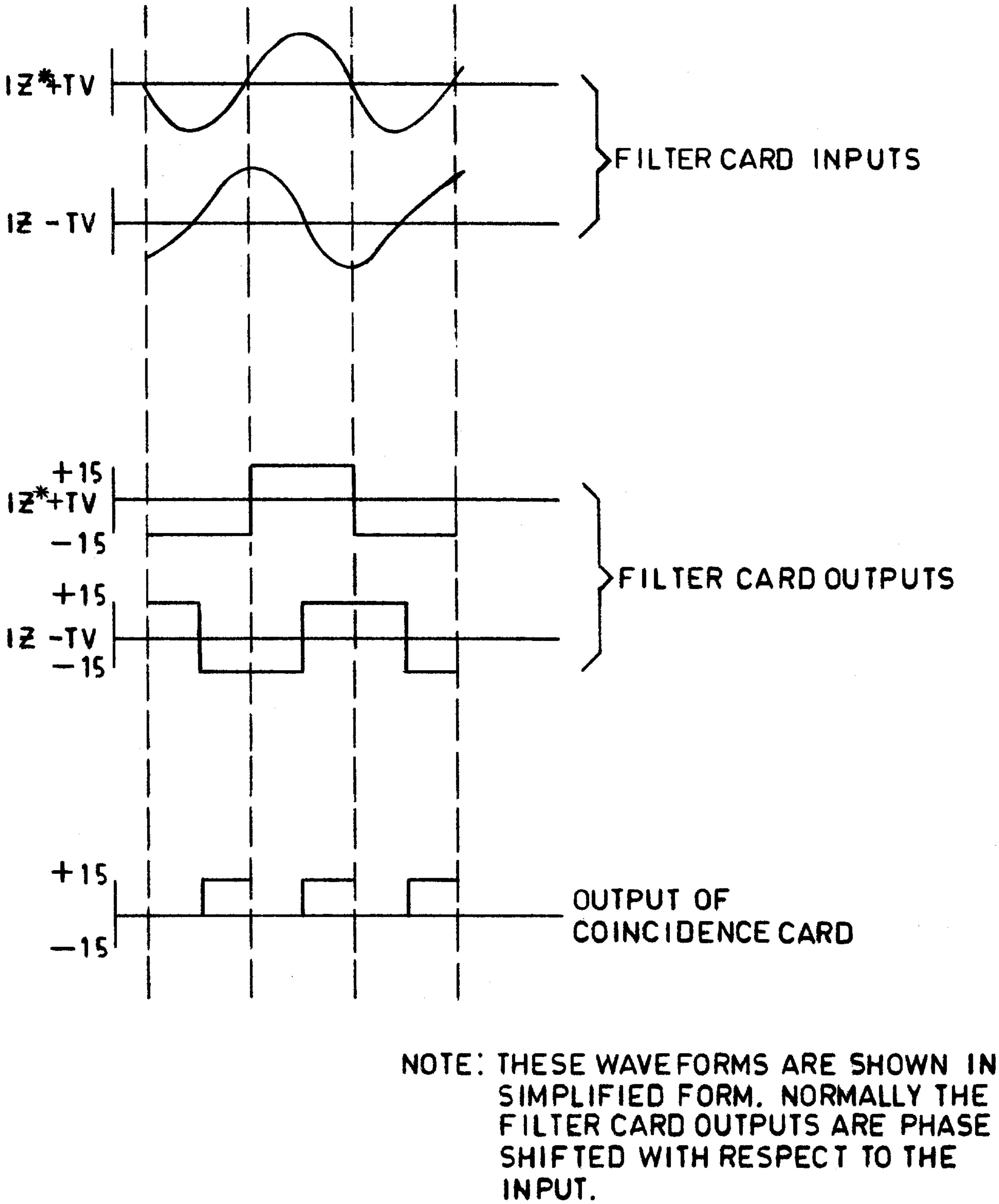


FIG. 2 (0269A3110-0) OPERATING QUANTITY WAVEFORMS

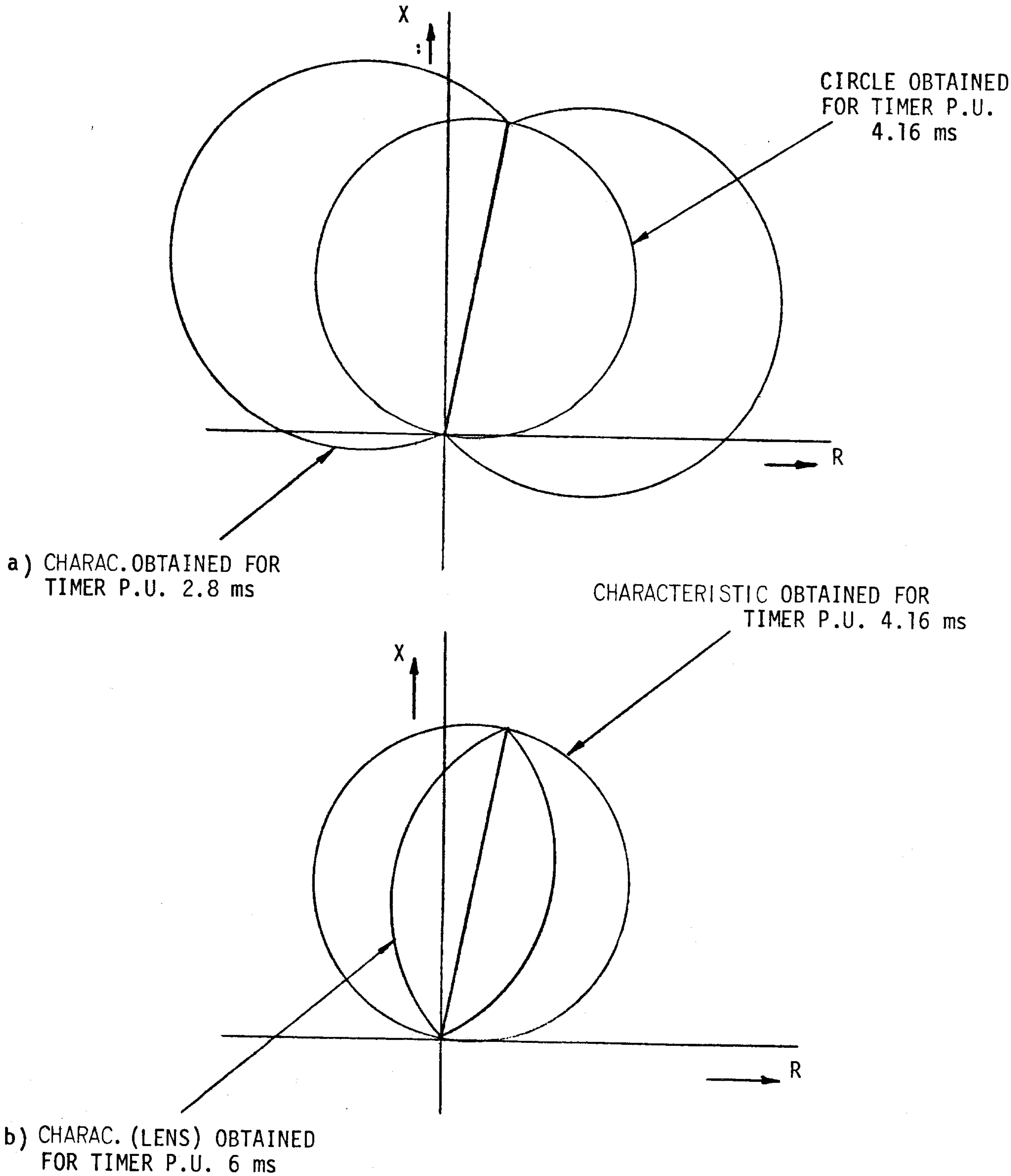
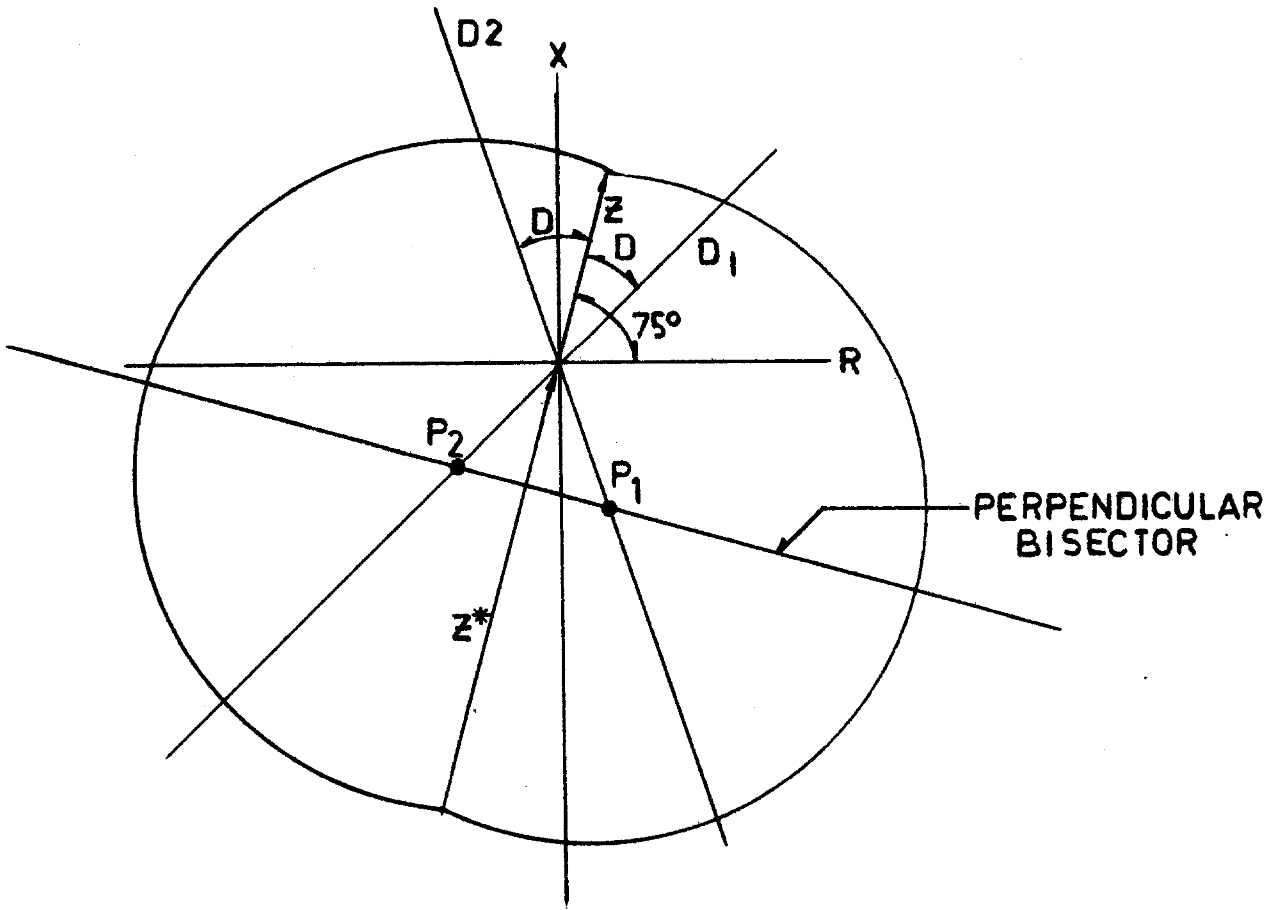
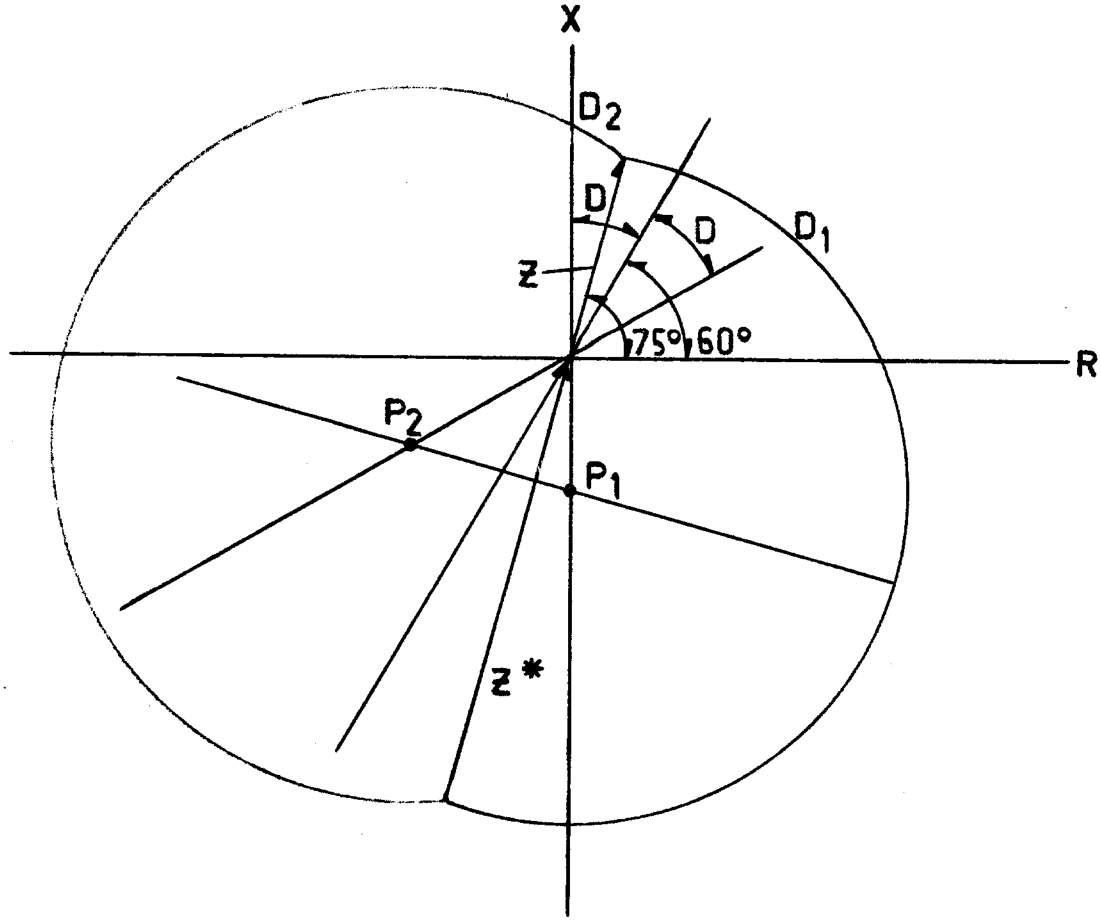


Fig. 3 (0226A7034-0) MHO CHARACTERISTIC VARIATIONS WITH PICKUP TIME SETTING



P = 2.78 MS
C = 21.6 X 2.78 = 60°
D = 90-60 = 30°
P_1, P_2 : CENTER OF CIRCULAR ARCS

Fig. 4 (0269A3111-0) PLOTTING THE MBG CHARACTERISTIC AT 75 DEGREE ANGLE OF MAXIMUM REACH



P 2.78 MS
C 21.6 X 2.78 = 60°
D 90-60 = 30
P_1 P_2 CENTER OF CIRCULAR ARC

Fig. 5 (0269A3112-0) PLOTTING THE MBG CHARACTERISTIC AT 60 DEGREE ANGLE OF MAXIMUM REACH

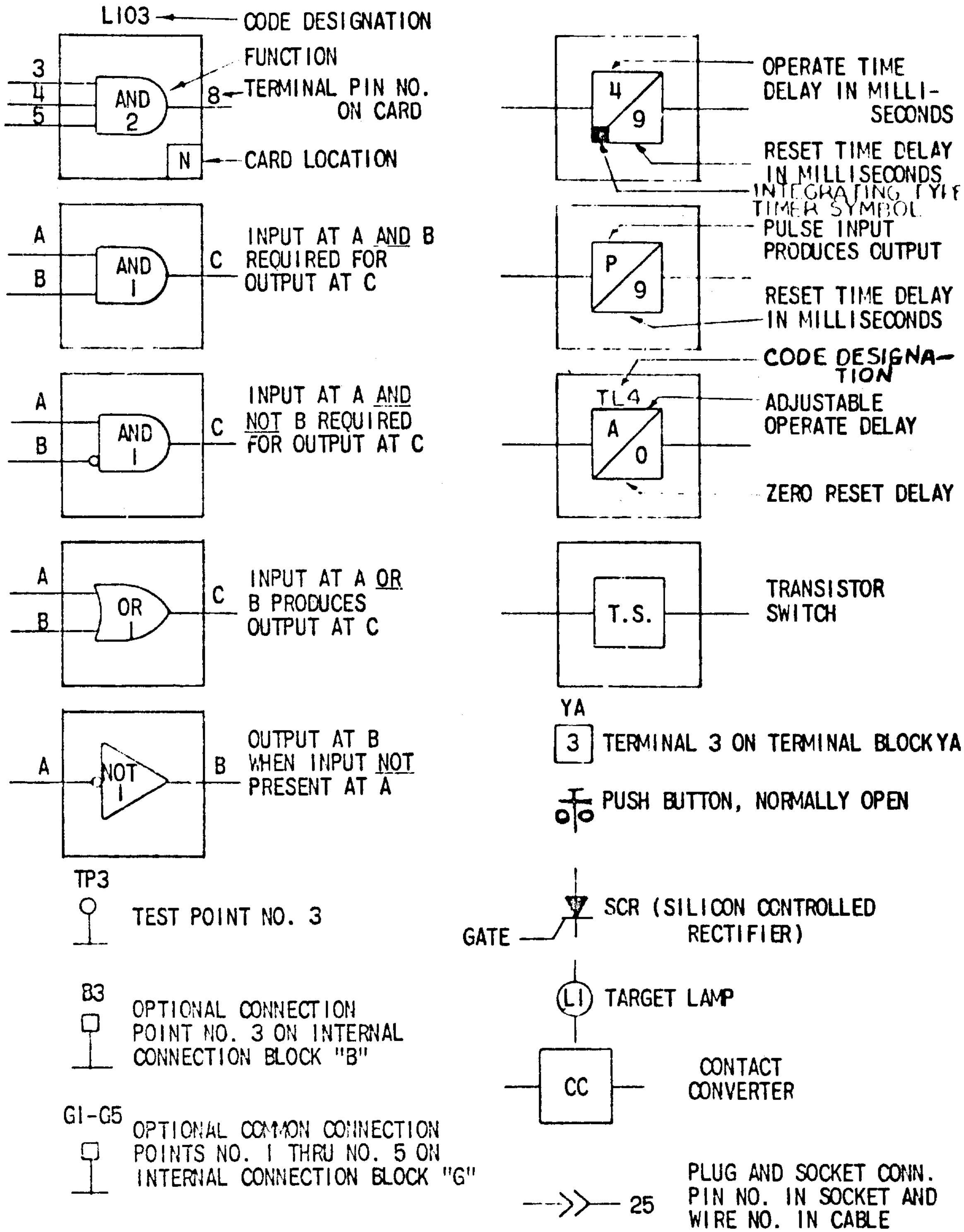


Fig. 6 (0227A2047-1) INTERNAL DIAGRAM LEGEND

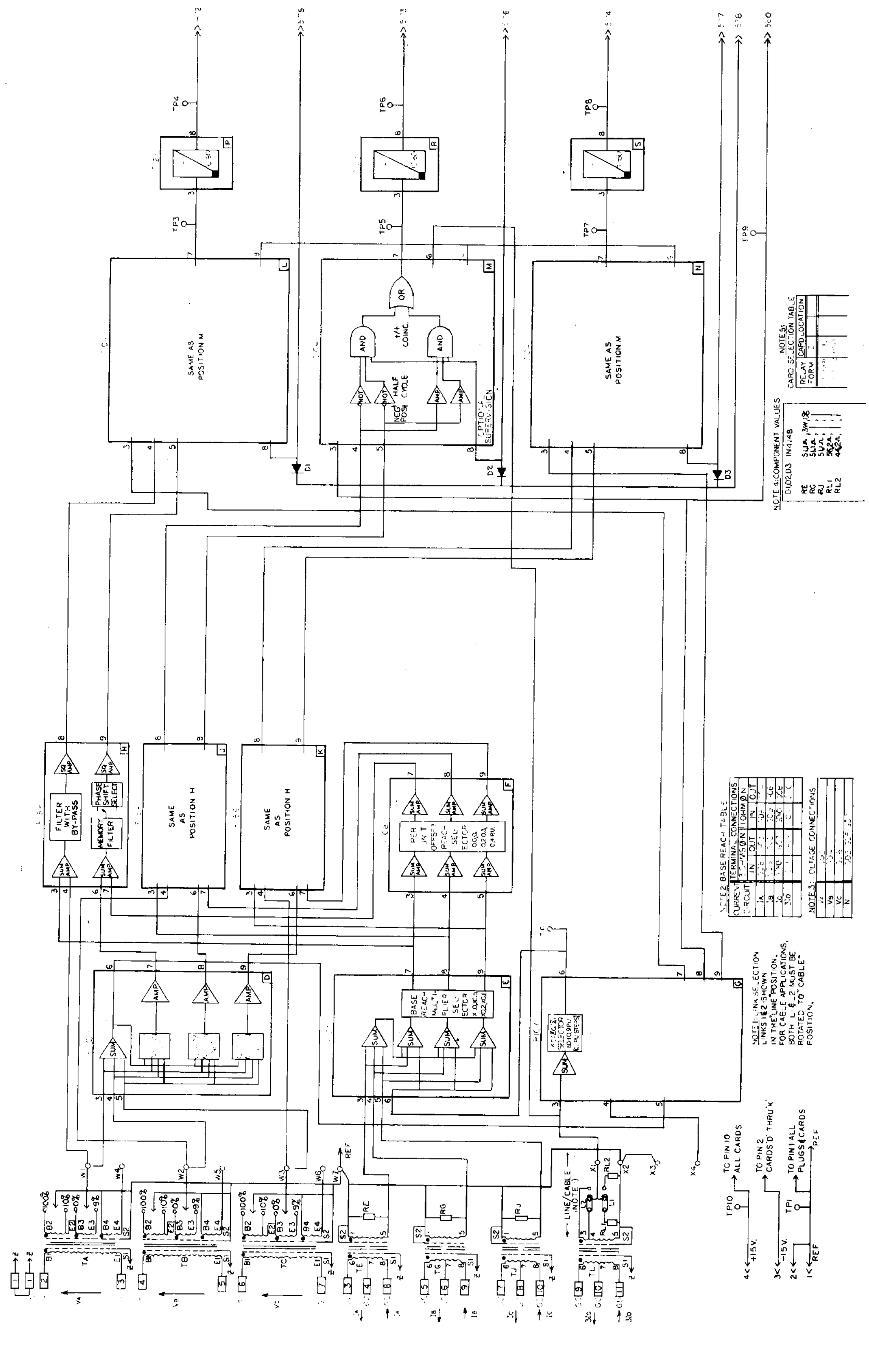


Fig. 7 (0136D1465-1) INTERNAL CONNECTIONS FOR THE SLYG53A RELAYS

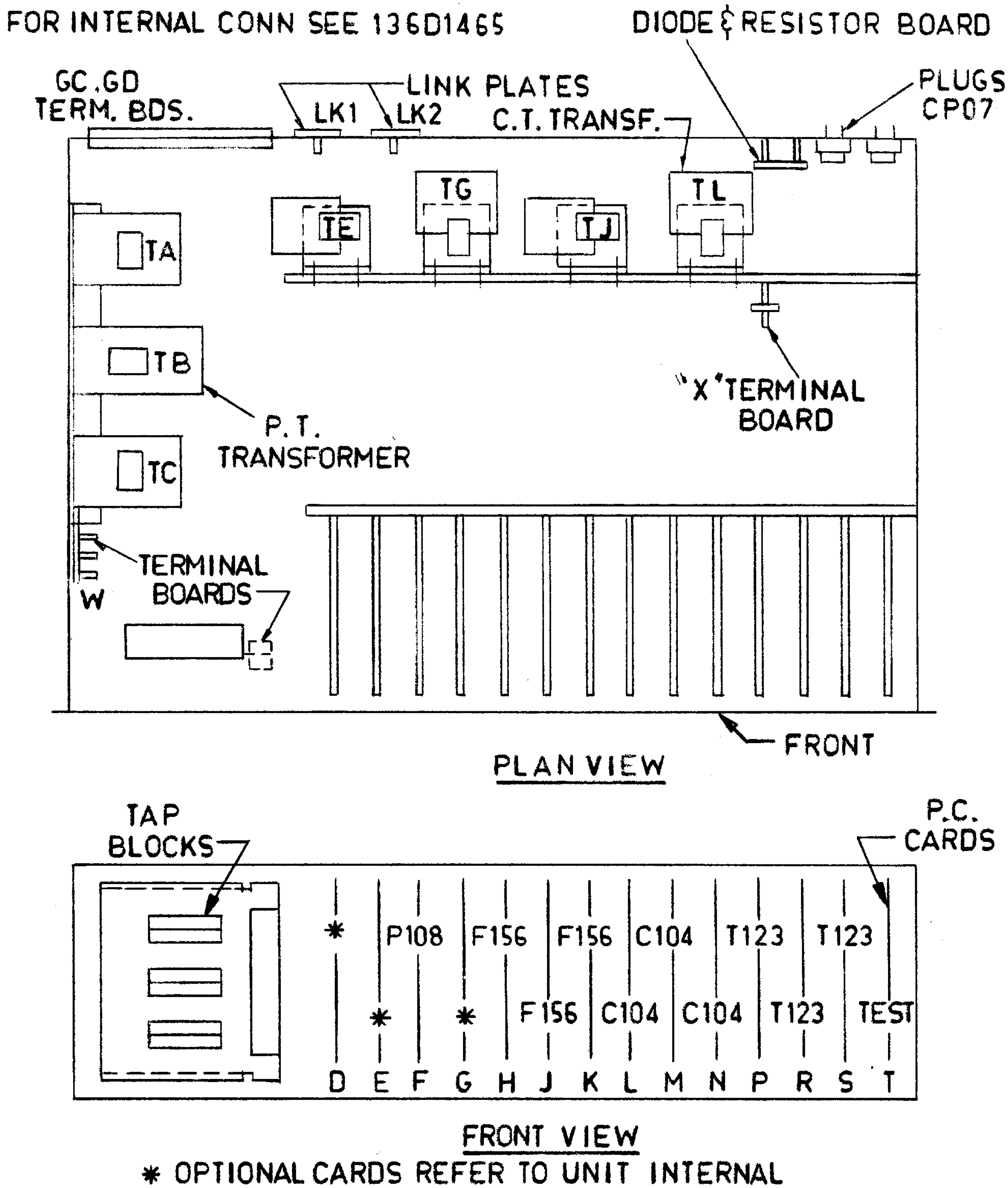


Fig. 8 (0269A3108-0) COMPONENT LOCATION DIAGRAM FOR THE SLYG53A RELAY

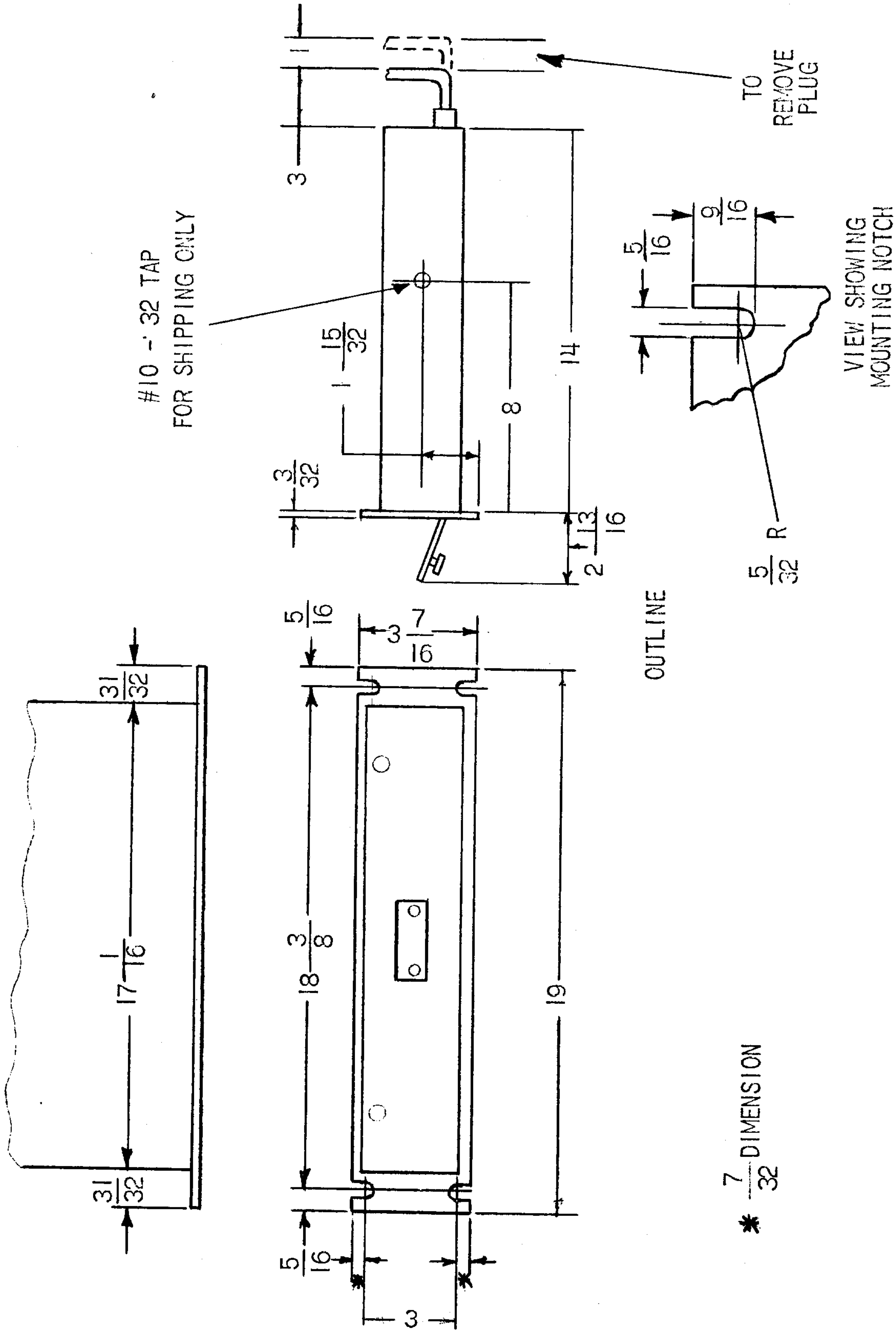
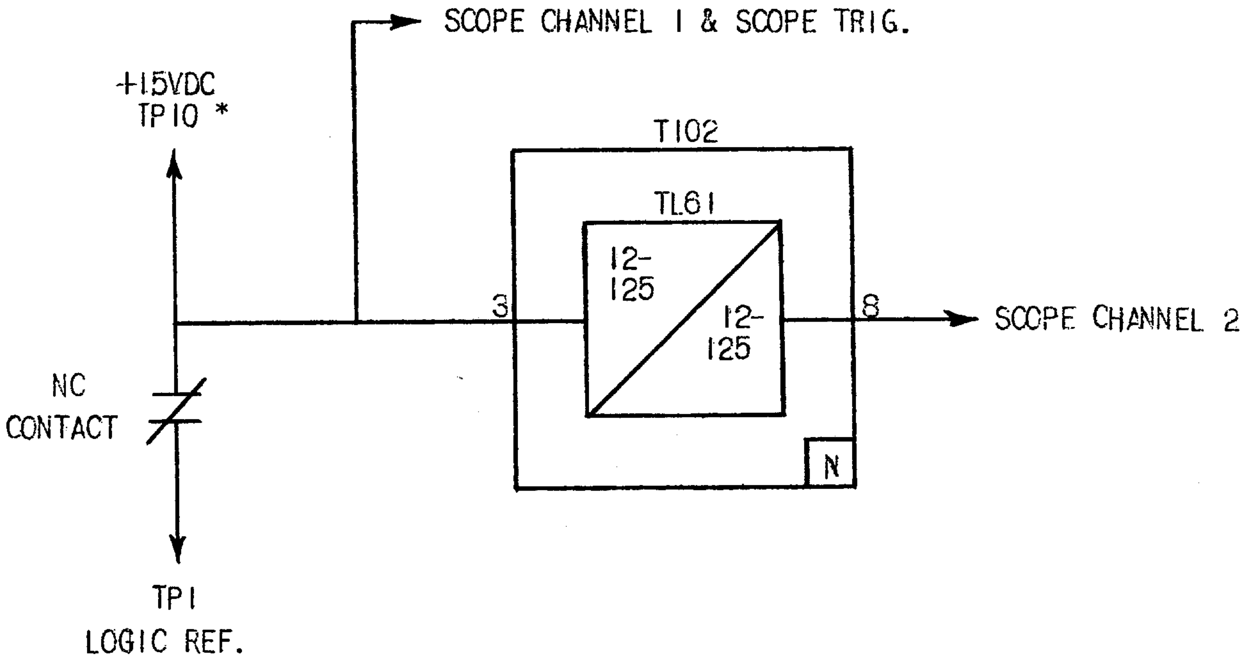


Fig. 9 (0227A2036-0) OUTLINE AND MOUNTING DIMENSIONS FOR THE SLYG53A RELAY



* THE 15VDC SIGNAL AT PIN 10 HAS A CURRENT LIMITING RESISTOR MOUNTED ON THE TEST CARD.

Fig. 10 (0246A7987-0) TIMER TEST CIRCUIT

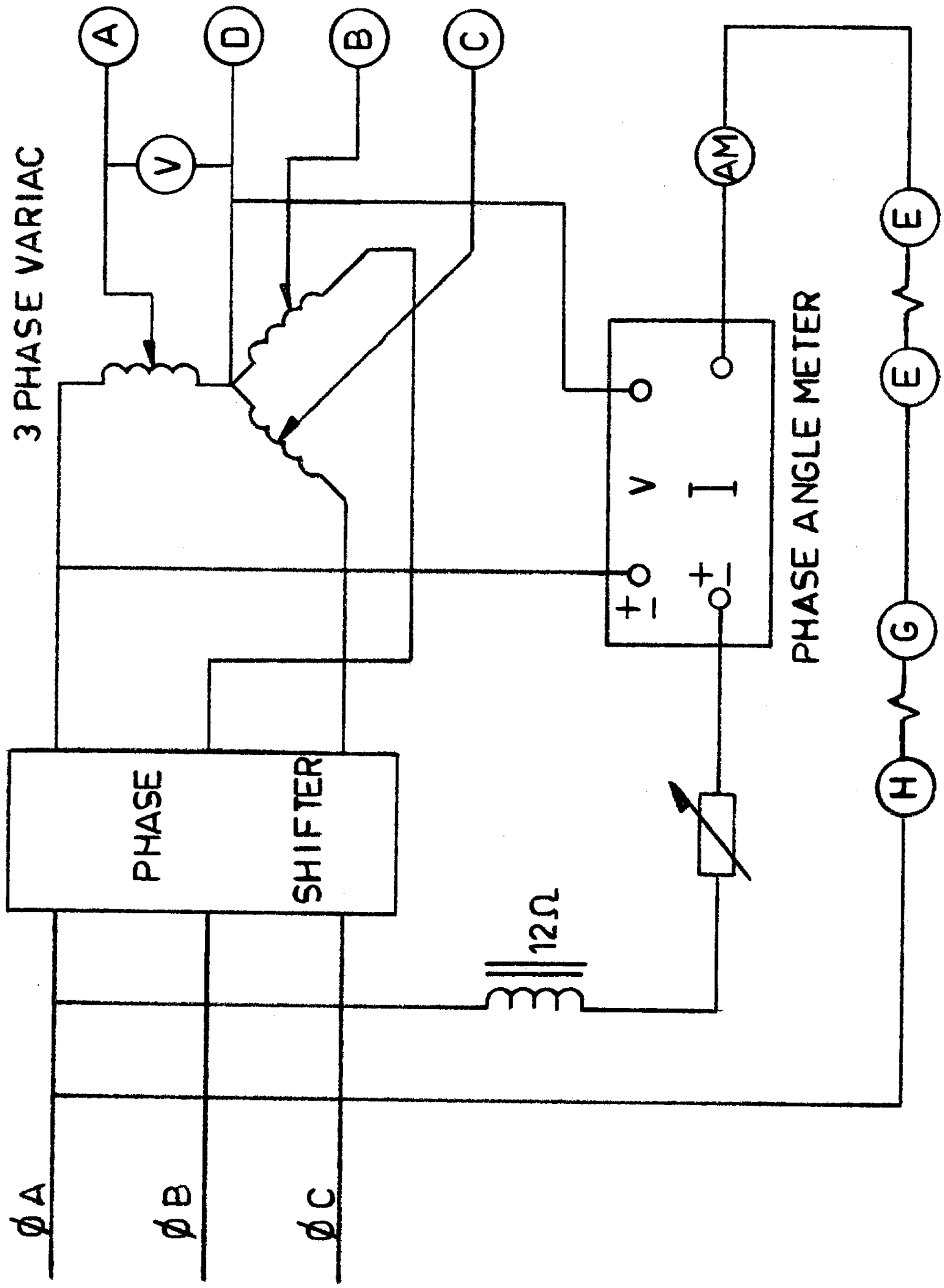


Fig. 11 (0269A3114-0) TEST CIRCUIT FOR SLYG53A RELAYS USING A THREE PHASE VARIAC

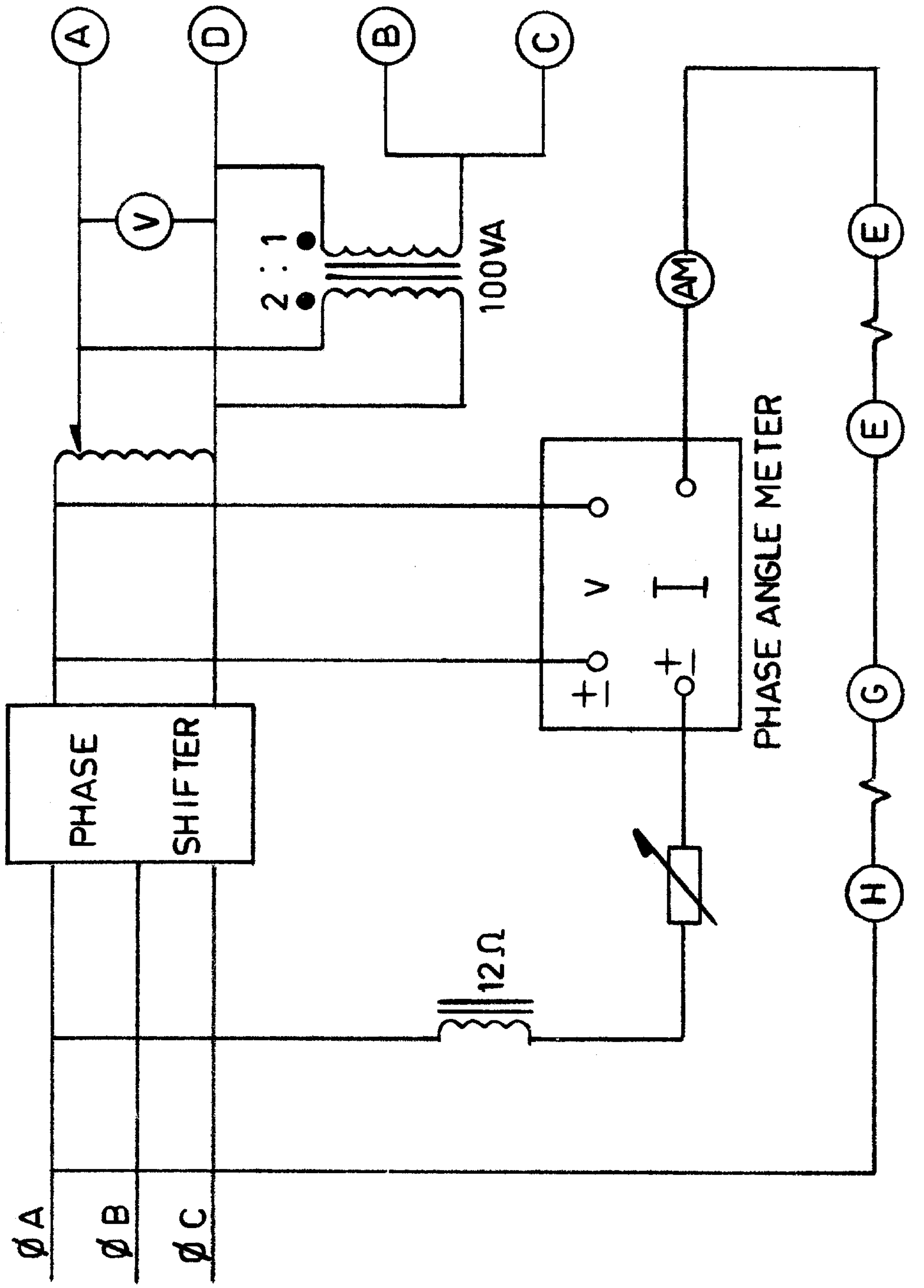


Fig. 12 (0269A3113-0) TEST CIRCUIT FOR SLYG53A RELAYS USING A SINGLE PHASE VARIAC

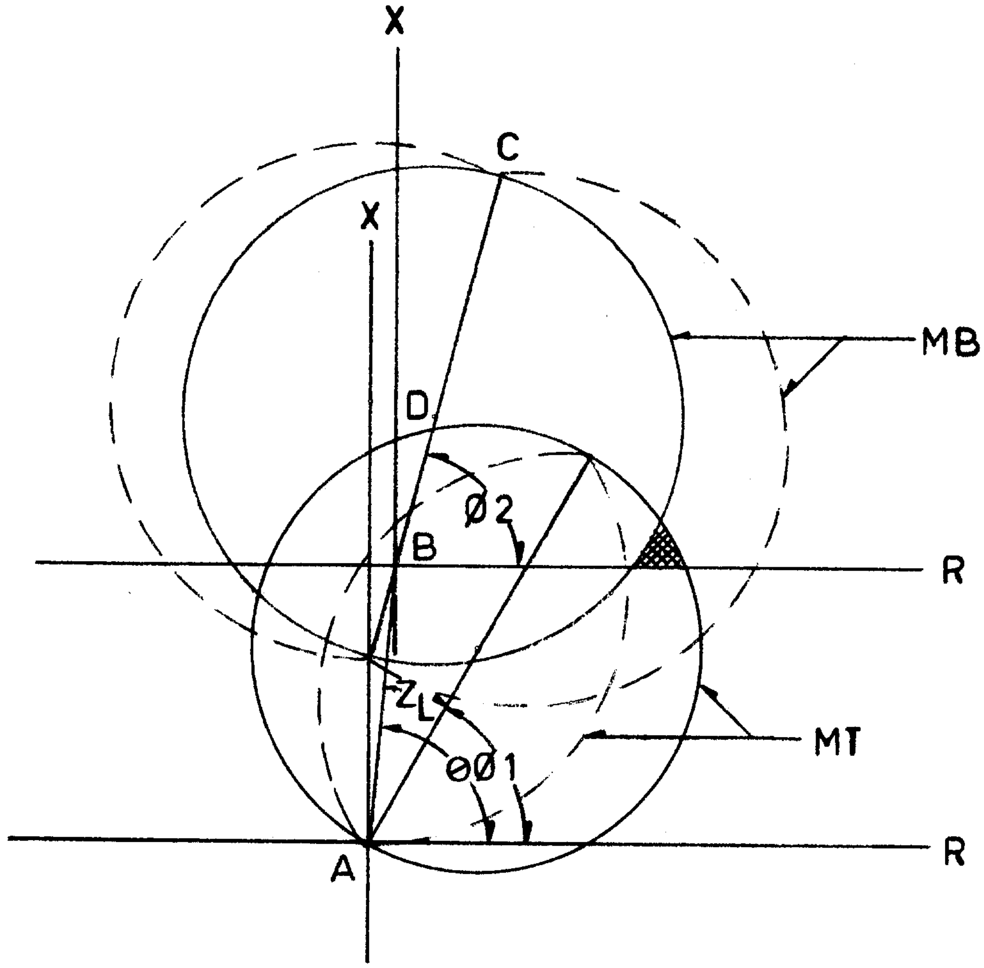


Fig. 13 (0269A3120-0) R-X DIAGRAM SHOWING RELATIONSHIP OF MTG AND MBG IN DIRECTIONAL COMPARISON SCHEMES

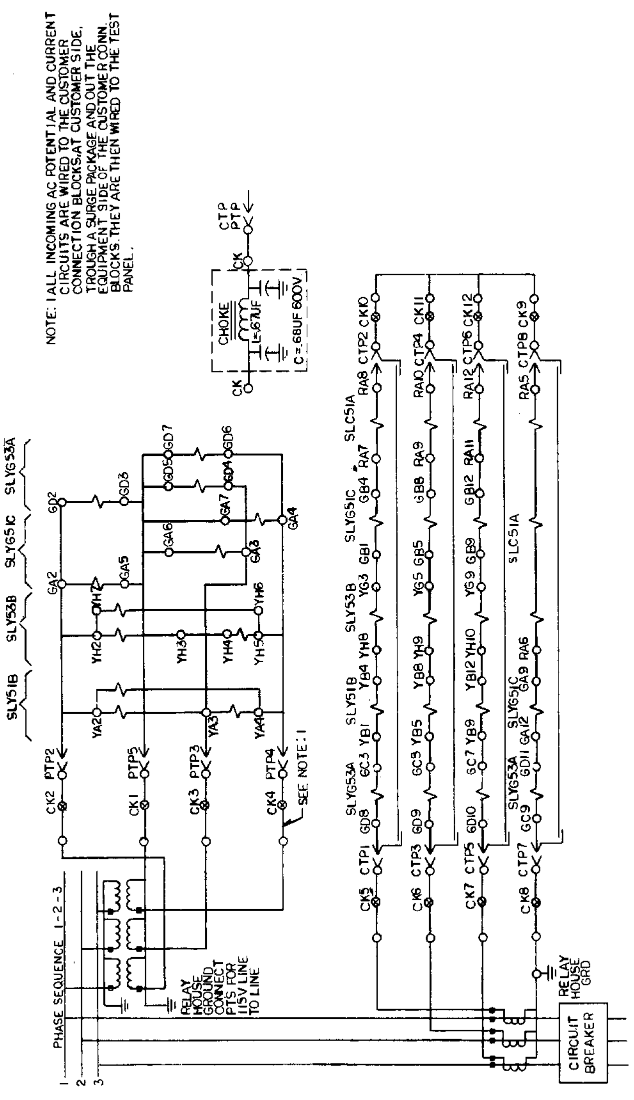


Fig. 14 (0188B9706-0) TYPICAL AC EXTERNAL CONNECTIONS FOR THE SLYG53A

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