INSTRUCTIONS

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Insert Booklet

STATIC MHO GROUND DISTANCE RELAYS

TYPE SLYG

POWER SYSTEMS MANAGEMENT DEPARTMENT

GENERAL ELECTRIC

PHILADELPHIA, PA.

SLYG BASIC

CONTENTS

DESCRIPTION

The Type SLYG designation covers a family of static mho ground distance relays intended for the protection of transmission lines. The SLYG relay was originally designed for use in directional comparison and distance line protection schemes employing a suitable communication channel.

A typical SLYG is packaged in two separate units:

(1) A Tap block unit containing tap blocks and other adjustments for setting the reach of the mho distance functions and overcurrent operating levels.

(2) A logic unit containing printed circuit cards, isolating transformers, option links, and push-buttons for simulating relay outputs.

Each of these units is contained in a metal enclosure designed for mounting on a 19 inch rack.

These two units contain the necessary components for detecting ground faults. Only one Type SLYG relay is required per relaying terminal. Typical mho-type directional characteristics included in a Type SLYG relay are carrier trip (MTG), lens supervision (LTG), carrier block (MB), or first and second zone tripping (MG1, OMG2). These relays may also include overcurrent supervision (G2), carrier start (G1), overcurrent direct trip (G4), or low set phase current monitoring (IMG). All of these functions are not necessarily included in every Type SLYG relay. To determine what functions are included in a specific type of SLYG, refer to the internal connection diagram for the specific relay included in the adder to this book.

Each Type SLYG relay requires a +17 volt d-c power source, with bias voltages, which can be obtained from a Type SSA power supply.

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 of a static relay equipment, it should be unpacked and examined for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

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

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 8 inches back from the relay 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.

APPLICATION

The Type SLYG static ground distance relays are applied in directional comparison pilot relaying schemes and in step distance relaying schemes for the protection of transmission lines. The functions required for these applications are as follows:

DIRECTIONAL COMPARISON PILOT RELAYING

The pilot channel in this scheme is usually power line carrier. The SLYG relay for this application would typically include three directional ground mho trip functions (MTG) for the carrier stop and trip function, three directional ground mho block functions for carrier start (MB) and a non-directional instantaneous overcurrent unit (G2) for trip supervision.

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.

STEP DISTANCE PROTECTION

Two or more steps of mho ground distance protection may be provided. The SLYG relay would typically include three directional ground mho zone 1 distance functions (MG1), and three directional ground mho zone 2 distance functions (MG2). The necessary timer may also be included or provided elsewhere. A zero sequence overcurrent fault detector would usually be included.

These relays are generally applicable on all transmission lines having ground shield wires. This is subject, of course, to the routine application checks described in the section CALCULATION OF SETTINGS in this book and in the adder book for the specific relay. The relays may also be applicable on lines which do not have shield wires. The user, however, must determine that the maximum possible ground resistance during an internal fault does not produce a net impedance as seen by the relay that falls outside of the ground mho tripping characteristic. Otherwise a failure to trip on an internal ground fault would result.

ZONE ONE MHO FUNCTIONS

The zone one ground mho functions (MG1) must be supplied with a portion (K') of the zero sequence current of the protected line section. This is necessary to reduce the apparent impedance to the fault as seen by the mho function to a value equal to the positive sequence impedance to the fault plus an error impedance introduced by the mutual effect of a parallel line if present. This is discussed in detail in Appendix II. An auxiliary compensating current transformer 367A0266G2 is used to provide this zero sequence current compensation. This CT is shown in Figure 1.

It is generally not possible to calculate to a high degree of accuracy the zero sequence impedance of the protected line nor the zero sequence mutual impedance to a parallel line. It is therefore usually necessary to limit the zone one ground mho function reach to approximately 80 percent of the protected line length. This setting must also take into account the error introduced by the mutual coupling with a parallel line if present. The zone one ground mho functions are intended for the detection of single phase to ground faults on the protected line within their reach. Thus they can provide high speed tripping of these faults without recourse to any pilot channel or other device. Since the zone one ground mho functions provide a direct tripping function, it is necessary that they have a limited transient overreach. Thus they may be applied to protect a major portion of the transmission line without the risk of false tripping on external faults.

As explained above the zone one ground mho function reach is limited to 80% of the protected line. Also the mho type of characteristic closely encircles the line impedance characteristic. The net result is that the zone one mho function accomodates a minimum of arc or ground fault resistance. An evaluation of this factor is described in Appendix II. Some zone one ground mho functions may have an adjustable angle of maximum reach over a range of 60 to 75 degrees. The 60 degree angle will accomodate more arc or fault resistance and is usually preferred for ground relays. The 75 degree angle may be used where a reduced response to load by the mho function is desirable.

OVERREACHING MHO FUNCTIONS

The overreaching ground mho functions (MTG) are used to provide the necessary tripping characteristics for a pilot relaying scheme or for zone two distance backup protection. In such applications it is not necessary that the function have a limited transient overreach since its reach is not critical as it would be in a first zone application. The MTG functions may or may not be applied with zero sequence current compensation. Refer to the adder instruction book for the specific relay being used. The overreaching ground mho functions must be set with a reach at least large enough to detect a single phase to phase ground fault anywhere in the protected line section, with margin, under all system conditions. Its reach should be at least 125%, preferably 150%, of the protected line section if at all possible.

Appendix III discusses the application of the MTG functions both with and without zero sequence current compensation. This compensation for the impedance of the protected line section makes the ground mho function better suited for use on longer transmission lines since it is possible to reduce the ground mho function reach settings and still provide adequate line coverage. The smaller ohmic reach setting reduces the possibility of the ground mho function interfering with the load carrying ability of the line.

MHO BLOCKING FUNCTIONS

The ground mho blocking functions (MB) are used in the directional comparison pilot relaying schemes for the purpose of starting carrier blocking for external single phase to ground faults. For this reason their characteristics are arranged to reach in the reverse direction, away from the protected line section as shown in Figure 2. These units will respond to a zero voltage single-phase-to-ground fault on the bus immediately behind the relay location without having any offset into the protected line section. This is so because the MB function will always employ either quadrature or median voltage polarization. Thus adequate voltage will be supplied even under zero voltage fault conditions.

MHO POLARIZATION

The ground mho functions of the SLYG may use one of a variety of polarizing voltages. The polarizing voltage is a reference voltage which is compared with an IZ-V phasor to make the distance measurement in the mho function. The types of polarizing voltages used are quadrature, median, and line-to-neutral. For a phase A relay these are shown in Figure 3. In quadrature polarization, the quadrature voltage Ebc is least likely to be affected by a single-phase-to-ground fault and will probably remain at nearly full rated value. Even for a zero voltage line-to-ground fault, ample polarizing voltage will be present and no memory action will be required.

The quadrature polarized mho function is a true mho function and has a fixed characteristic on the R-X diagram as long as the phase-to-neutral voltage restraint leads the quadrature polarizing voltage by 90 degrees. On a nearby fault with arc resistance this angle does not hold but is decreased. The result is that the mho function characteristic increases in size and its angle of maximum reach becomes less lagging and the mho function circle tips over toward the R axis. See the so called TIPPED MHO FUNCTION of Figure 4. The total effect is that the mho function can now accomodate more arc resistance in the fault. In most ground distance relay applications this is a benefit.

Median polarization provides approximately 33 percent of normal polarizing voltage on close in zero voltage line-to-ground faults. This is ample for proper operation of the function and no memory action is required. As long as the phase-to-neutral restraint voltage remains in phase with the median polarizing voltage the mho function remains a true mho function. However, a nearby fault with arc resistance again results in the function characteristic increasing in size and tipping its maximum reach angle in the direction of the R axis. More arc resistance is thus accomodated but not nearly to the degree accomodated by the quadrature polarized unit.

Phase-to-neutral polarization provides most nearly a true mho function. Since the fault voltage and the polarizing voltage are the same, memory action must be provided in the function to insure reliable operation on the close in zero voltage fault. On a steady state basis, the function will only accomodate as much arc resistance as indicated by the plot of its fixed characteristic on the R-X diagram. This is considerably less than what is accomodated by the other two types of polarization. However, under transient conditions the phase-to-neutral polarized unit will accomodate considerably more arc resistance than indicated by its R-X characteristic because of its memory action.

The type of mho function polarization used is specified in the adder book for the specific SLYG relay.

MHO FUNCTION LIMITATIONS

Under some system conditions it is possible for the ground mho function on an unfaulted phase to respond to single-phase or double-phase-to-ground faults in the non-trip direction. Since this can result in false tripping, it is necessary to limit the reach of the ground mho functions to eliminate this possibility. Appendix IV gives suitable equations for determining the maximum permissible reach that may safely be applied to the ground mho functions. Applications both with and without zero sequence current compensation are discussed. It should be noted that the evaluation of the equations of Appendix IV will vary with the type of voltage polarization used in the mho functions. Determine the type of mho function polarization in use by referring to the adder book for the specific SLYG relay. Use the appropriate curve to determine the constant K_Q as indicated in Appendix IV.

Since the overreaching mho functions will always have the larger setting, it is usually only necessary to check them by applying the calculations of Appendix IV. In some cases it may also be necessary to check the settings of the zone one mho functions. This is done by also applying the calculations of Appendix IV B including the list of zero sequence current compensation.

LENS FUNCTIONS

The lens tripping function (LTG) is usually used to supervise a mho tripping function (MTG) so as to provide a restriction of the tripping area as shown in Figure 5. In this application the operation of both MTG AND LTG are required in order to provide a trip output. Thus a suitable setting can be made without infringing on the load carrying ability of long transmission lines. Care should be exercised in applying the lens LTG function since it tends to restrict the amount of fault resistance that can be accomodated and still have the relay provide reliable tripping. The lens LTG function shown in Figure 5 is non-directional in that its characteristic includes the origin of the R-X diagram (the relay location). This arrangement provides coverage for faults with arc resistance occurring at or near the relay location.

G1 FUNCTION

The G1 is a non-directional instantaneous overcurrent function usually used to start carrier blocking in the directional comparison scheme. It should therefore be set at the minimum setting of its operating range. In any event it should never be set any higher than 75 percent of the setting of G2 at the remote end of the protected line. This will insure the proper coordination so that carrier blocking is started to properly block tripping on external faults. Since the G1 is a blocking function, setting it to operate as sensitiviely as possible simply adds to the security of the scheme against false tripping.

G2 FUNCTION

The G2 is a non-directional instantaneous overcurrent function ususally used for tripping level supervision of the MTG function. The G2 setting at one line terminal must never be less than 4/3 (1.33) times the G1 setting at the remote line terminal. The G2 pickup also must not exceed 75% of the minimum single-phase-to-ground fault current in the relay for a fault at the remote bus with the remote breaker closed.

It is desirable to set the G2 pickup as high as possible as long as it will operate for all internal line faults under all system conditions. The higher the G2 setting the less the risk of false tripping and the more secure is the overall scheme.

G4 FUNCTION

The G4 is a non-directional instantaneous overcurrent function used for direct tripping. It provides high speed direct tripping for close in heavy current faults. The G4 function must be set to operate at 125% or more of the maximum external single phase to ground fault current. Since this unit is non-directional, the heaviest fault current condition must be considered whether it be the remote bus location or on the bus immediately behind the relay.

RATINGS

Type SLYG relays are designed for use in an environment where the air temperature outside the relay case does not exceed 55^{o}C.

The current circuits of the Type SLYG relays are rated at 5 amperes, rated frequency, for continuous duty, and have a one-second rating of 300 amperes. The potential circuits are rated 120 volts, rated frequency.

OPERATING PRINCIPLES AND CHARACTERISTICS

A. GENERAL INTRODUCTION

TRANSACTOR THEORY

All distance type characteristics (Mho, Offset Mho, Lens) are obtained by measuring the phase angle between two voltages. These voltages are derived from the system voltage and the system current supplied to the relay. Inside the relay, the system current is transformed into a voltage by a transactor. A transactor is an air gap transformer which produces a secondary voltage proportional to the primary current. This voltage leads the current by an angle Ø which is determined by the amount of secondary resistance placed across the transactor. If the secondary resistance is decreased, then both the magnitude of the secondary voltage and Ø will decrease. The vector ratio of the secondary voltage to the primary current is the transfer impedance of the transactor. This impedance is labeled Z and it determines the base reach of a mho characteristic.

MHO CHARACTERISTIC

Distance type characteristics are generally plotted on a R-X diagram; but since these characteristics are determined by the angle between two voltage phasors, it is desirable to plot the characteristics on a voltage diagram in order to describe how they are derived. The voltage diagram is obtained from the impedance diagram by multiplying every point of the R-X diagram by the current supplied to the relay. Since the fault current will change as the system voltages and fault location change, the voltage diagram will contract or expand for different fault currents. However, the voltage phasors will have the same relative phase positions and magnitudes that the impedance vectors have on a R-X diagram. Because of this, any characteristic plotted on the R-X diagram will have the same shape when it is plotted on a voltage diagram.

The mho characteristics for the SLYG relays are shown in Fig. 2. The principle used to drive the electrical characteristics is illustrated in Fig. 6, using a mho unit as an example. The axis are "IR" and "IX". The $\overline{IZ}$ quantity is a voltage proportional to line current obtained by passing the line current through a transactor. The $\overline{V}$ quantity is line voltage at the relay location, equal to IZ_F with Z_F is the line impedance out to the fault. The quantity $(\overline{IZ}-\overline{V})$ is the phasor difference between these two quantities. Note that the three characteristics are drawn for the same value of $\overline{IZ}$ (Base reach tap). The greater the value of V, the more remote the fault. The angle B between V and $(\overline{IZ}-\overline{V})$ is greater than 90 degrees for a fault internal to the relay characteristic. Equal to 90° on the balance point and less than 90° for an external fault for which the relay should not operate. The quantities $\overline{V}$ and $\overline{IZ}-\overline{V}$ are the relay input quantities and are converted into blocks of voltage and the coincidence (having same polarity) are measured. Blocks which are 90° apart are coincident for less than 4.17 milliseconds. The mho function consists of a discriminator circuit to detect the coincidence of the two input quantities $\overline{V}$ and $\overline{IZ}-\overline{V}$, followed by a coincidence measurement card.

B. CURRENT FUNCTIONS

IMG CURRENT MONITORING FUNCTION

The current monitoring functions (IMG) operate from the phase currents I_1, I_2 and I_3. These functions operate on low current levels and are used to supervise the lens characteristic (LTG).

G1 CARRIER START

The carrier start function (G1) operates from the residual current $I_1 + I_2 + I_3$. This function is used to initiate the carrier signal.

G2 OVERCURRENT SUPERVISION

The G2 function also operates on residual current and is used to provide tripping level supervision of the MTG functions.

G4 DIRECT TRIP FUNCTION

The instantaneous non directional G4 function may be used to provide faster tripping on certain faults than will be realized by the associated pilot relaying scheme. Since this unit is non-directional, the heaviest fault current conditions must be considered whether it be the remote bus location or on the bus immediately behind the relay location.

C. MHO FUNCTIONS

MTG TRIPPING FUNCTION

The MTG function has a directional characteristic with the mho circle passing through the origin on an R-X diagram. See Figure 2.

The measurement principle is shown graphically in Figure 6. Comparison is between the polarizing voltage $\overline{V}$ and the operating quantity $(\overline{IZ}-\overline{V})$. The angle (C) between these two quantities is greater than 90° for faults internal to the relay characteristic, and is less than 90° for faults external to the relay characteristic. For faults which cause $\overline{V}$ to terminate on the relay characteristic, the angle C is equal to 90°. This is true for any angular location of $\overline{V}$, because $\overline{V}$, $\overline{IZ}$, and $\overline{IZ}-\overline{V}$ form a right triangle for any point on the relay characteristic.

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

Relay reach for the MTG unit at any fault angle may be calculated from the expression:

$$Z_{max} = \frac{IZ\ (Tap)}{V\ (Tap)} \times 100 \text{ (at angle } \emptyset) \quad (1)$$

where V (Tap) is the restraint tap setting expressed in %

$$\text{and } Z_\theta = Z_{max} \cos(\theta - \emptyset) \qquad \begin{matrix}\theta = \text{line angle} \\ \emptyset = \text{relay max. reach angle}\end{matrix} \quad (2)$$

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

The angle of maximum reach Ø can be adjusted by changing the load of the associate transactor.

THE MG1 FIRST ZONE MHO FUNCTION

The MG1 function has a directional characteristic with a mho circle passing through the origin of the R-X diagram. The angle of maximum reach of the Zone 1 unit is for most of the SLY relays continuously adjustable (see "adder") from 60-75 degrees. However, for first zone applications it is desirable to use the particularly true for faults close to the relay terminal. In the following discussion it will be assumed that the units are set for 60 degrees.

The first zone may be set to reach as much as 90% of the distance to the remote terminal. To set the relay for the desired reach, it is necessary to first select the proper "Base Reach Tap". This tap should be the highest "Base Reach Tap" that is smaller than the desired ohmic reach. The restraint tap setting may now be evaluated in the same fashion as already described in the MTG tripping characteristics.

THE REPLICA CIRCUIT

In the series replica circuit of the MG1 function the current transformer output provides the R component and the transactor output provides the X component of a replica of the transmission line impedance R + jX. The transactor secondaries are not loaded, but a resistor on the transformer secondaries varies the amount of the R component added and therefore determines the angle θ. Where θ is the replica angle, (see Figure 7). Since most transmission lines have impedance with angles of approximately 80°, the replica angle is factory adjusted to θ = 80°. If an angle of maximum reach of 60° is desired, $\overline{V}pol$ must be adjusted by means of the reactor X11 in the tap block unit to lead V_{1N} by 20°. Therefore, when $\overline{V}pol$ is in line with IZ', V_{1N} is at 60°. Geometrically it is shown that $\overline{V}pol$ is perpendicular to the vector quantity $(\overline{IZ}' - \overline{V}_{1N})$ for faults which cause $\overline{V}_{1N}$ to terminate on the relay characteristic (the angle C is 90°). This defines the balance point of the relay.

Referring to Figure 7b, the vector $\overline{V}_{1-N}$ plots inside the circle. By means of inductor X_1, $\overline{V}pol$ is shifted until it leads $\overline{V}_{1N}$ by 20°. The angle C_2 is greater than 90° and the impedance seen by the relay will plot inside the mho circle (internal fault). The same construction can be applied for an external fault. See Figure 7C. Construct a vector $\overline{V}_{1N}$, whose magnitude plots outside the circle. Let $\overline{V}pol$ lead $\overline{V}_{1N}$ by 20°. The angle C_3 is less than 90° and no output will be obtained from the relay. The replica angle of 80° provides the minimum transient overreach for fault occurring at any fault impedance angle, and is considered an optimum setting. Figure 8 shows the distortion of the circular mho characteristic during the transient portion of the fault.

The transfer impedance (V_{out}/I_{in}) of the transactor (or transactor-transformer combination) is the Z' of the IZ' signal. The IZ tap blocks are marked with numbers equal to this transfer impedance. This is also referred to as the base reach of a particular function and is measured in line-to-neutral ohms. It is the reach of that function, along the angle of maximum reach, when the voltage taps are in the 100% restraint position. Relay reach may be incleased by using voltage taps less than 100%.

THE MG1 FUNCTION WITH REVERSE OFFSET

The MG1 unit with reverse offset has eesentially the same construction as the forward MG1 unit with replica angle. The construction of the MG1 circle with forward reach has already been explained (see Figures 6 and 7). In addition to the quantity $\overline{IZ}_1$ with replica angle θ, in Figure 9, another quantity, $\overline{IZ}_2$, with a 90° reverse offset has been added. The voltage $\overline{IZ}_2$ has a 90° phase shift and is obtained by means of another winding on the transactor. The transactor burden is high which yields a phase shift close to 90°. Vectorial addition of the voltage $\overline{IZ}_2$ and the constructed vector $\overline{OA}$ (maximum reach without reverse offset) produces the diameter of the relay mho-circle with reverse offset.

In the tap block unit (Figure 22), the forward taps (along the protected line) are identified as MG1, and the reverse taps (away from the protected line) are identified as MG1*. This marking applies to both the IZ (base reach) and V (voltage restraint) taps. The magnitude of $\overline{IZ}_2$ is adjustable by means of the base reach taps and the MG1* vernier potentiometer. By means of the variable inductor X_{11} (see Figure 21) the polarizing voltage ($\overline{V}^*_{pol}$) can be adjusted until it leads any arbitrary applied voltage $\overline{V}_{1N}$ by 20°. The first input quantity supplied to the relay logic is $\overline{IZ}_1 - \overline{V}_{1-N}$, and the second is the $\overline{IZ}_2 + \overline{V}^*_{pol}$. Geometrically it is shown in Figure 9 that the vector quantity ($\overline{IZ}_2 + \overline{V}^*_{pol}$) is perpendicular to ($\overline{IZ}_1 - \overline{V}_{1N}$) for a fault on the relay characteristic, which again defines the balance point of the relay. If the vector $\overline{V}_{1N}$ plots inside the circle the relay will see an internal fault, and when $\overline{V}_{1N}$ plots outside the circle the relay will see an external fault as already explained in Figure 7.

Let the voltages $\overline{V}_{1N}$ and $\overline{V}_{1N}^*$ be applied to the taps MG1 and MG1* respecitvely. The voltage restraint taps are in the 100% position for both $\overline{V}_{1N}$ and $\overline{V}_{1N}^*$ as shown in the MG1 construction in Figure 9.

THE MG2 SECOND ZONE MHO FUNCTION

The MG2 function has a directional characteristic with the mho circle passing through the origin on an R-X diagram. The measurement principle is shown graphically in Figure 6. Comparison is between the polarizing voltage $\overline{V}$ and the operating quantity ($\overline{IZ}_1$-$\overline{V}$). The angle (C) between these two quantities is less than 90° for faults external to the relay characteristic, and is greater than 90° for faults within the relay characteristic. For faults which cause V to terminate on the relay characteristic, the angle C is equal to 90°. This is true for any angular location of V, because $\overline{V}$, $\overline{IZ}_1$, and $\overline{IZ}_1$-$\overline{V}$ form a right triangle for any point on the relay characteristic.

If the 100% voltage tap is used, the reach of the relay at the angle Ø is equal to the IZ_1 "base reach tap" chosen. If a voltage tap other than 100% is chosen, relay reach is increased in inverse proportion to the voltage tap. For example, if the 50% voltage tap is used, relay operation still occurs for the same voltage applied to the measuring circuit, but since the actual line voltage is twice this amount, the relay reach is twice as great. The resulting circle has twice the reach, at any fault angle, and still passes through the origin.

The OMG2 characteristic with forward offset is a special case off the MG2 characteristic. The diameter of the OMG2 mho-circle with forward offset is obtained by the difference between the $\overline{IZ}_2$ and $\overline{IZ}_1$ quantity as shown graphically in Figure 10. Note that in the following description the quantity $\overline{IZ}_2$ and the superscript (*) do not indicate the reverse direction (away from the protected line) as was defined before.

Because $\overline{IZ}_1$ and $\overline{IZ}_2$ are both derived from the same transactor they are in phase with each other and have the same angle of maximum reach Φ. The magnitudes of $\overline{IZ}_1$ and $\overline{IZ}_2$ are determined by individual base-reach settings and the OMG2 and OMG2* vernier potentiometers. The base-reach settings $\overline{IZ}_1$ and $\overline{IZ}_2$ have to be different otherwise the OMG2 characteristic will be a point instead of a mho-circle. An arbitrary angle for the voltage vector $\overline{V}_{1N}$ is shown in Figure 10 with the magnitude terminating on the relay characteristic. The relay compares the quantities ($\overline{IZ}_1 - \overline{V}_{1N}$) and ($\overline{IZ}_2 - \overline{V}_{1N}^*$). The angle between both vector quantities will always be 90° for the case where $\overline{V}_{1N}$ terminates on the relay characteristic. For faults external to the protected line section, $\overline{V}_1$ will plot outside the circle and the angle (B) will be smaller than 90°. For faults inside the protected line section, the angle (B) will be greater than 90°.

In Figure 10, $\overline{V}_{1N}$ and $\overline{V}_{1N}^*$ are both at the 100% restraint tap. However, the characteristic developed for the $\overline{V}_{1N}^*$ ar 50% restraint makes the reach of the $\overline{IZ}_2^*$ twice as far. The diameter of the mho circle in this case is $2\overline{IZ}_{2*} - \overline{IZ}_1$. The quantities compared in the relay are again $\overline{IZ}_1 - \overline{V}_{1N}$ at 100% restraint and $\overline{IZ}_{2*} - \overline{V}_{1N}^*$ at the 50% restraint tap.

MB BLOCKING FUNCTION

The MB function is an offset mho characteristic, and its circle does not pass through the origin. This offset characteristic is obtained by adding a second $\overline{IZ}$ quantity ($\overline{IZ}_2$) to the polarizing $\overline{V}$ quantity, as shown in Figure 11. Angle measurements are made with a comparison of ($\overline{IZ}_1 - \overline{V}$) and ($\overline{IZ}_2 + \overline{V}$), and relay operation occurs when C ≧ 90° as before. The resulting characteristic is a circle with diameter = $\overline{IZ}_1 + \overline{IZ}_2$, with a forward reach = $\overline{IZ}_1$ and a reverse reach = $\overline{IZ}_2$.

The graphical illustration in Figure 11 shows that the same $\overline{V}$ is used with $\overline{IZ}_1$ and $\overline{IZ}_2$ quantities to obtain the offset characteristic. A more accurate reach setting can be obtained by adjusting the voltage used with $\overline{IZ}_1$ separately from the voltage used with $\overline{IZ}_2$. To accomplish this, separate 1% taps for the forward and reverse reach are provided, and the resulting characteristic is a circle passing through these two points and with its diameter along the transactor angle of 75°. The $\overline{IZ}_1$ and $\overline{IZ}_2$ tap settings may be the same, or they may be different.

This separate adjustment of MB forward and reverse reach is illustrated in Figure 12. In the tap block unit, the forward (along the protected line) taps are identified as MB, and the reverse (away from the protected line) taps are identified as MB*. This marking applied to both the $\overline{IZ}$ (base reach) and $\overline{V}$ (voltage) taps as already mentioned.

The inner circle on Figure 12 is the characteristic obtained with the same $\overline{IZ}$ setting (0.75 ohms) and the same $\overline{V}$ setting (100%) for MB and MB*. The outer characteristic is obtained by changing the MB voltage tap to 80% and the MB* voltage tap to 40%.

The typical MB function has 0.2, 0.75, and 3 ohm IZ taps (MB) in the forward direction and 0.75 and 3 ohm taps (MB*) in the reverse direction (see "adder" for specific relay). It has 1% voltage taps in both directions.

LTG LENS TRIPPING FUNCTION

The LTG function has a lens shaped mho characteristic with reverse offset as shown in Figure 13. The angle of maximum reach is $85^{o} \pm 5^{o}$.

The measurement principle is similar to the MG1 function with reverse offset. The comparison is still made between the quantities (IZ_1 - V) and (IZ_2 + V*); the angle C, however, is greater than 90^{o} (usually 120^{o}) in order to achieve the lens shape. The coincidence required for the LTG function is greater than 4.17 ms, typically 5.55 ms (120^{o}). The relay will therefore operate when the angle between (IZ_1 - V) and (IZ_2 + V*) is greater than 120^{o}.

A. BLOCK-BLOCK METHOD

The mho tripping functions use a block-block measuring scheme, in which both input quantities are converted into blocks of voltage, and the duration of their coincidence is measured. This is illustrated in Figure 14. The size of angle C (measured in time units) is obtained by combining these blocks in an AND circuit and measuring the duration of the output by means of a timer card. The characteristic of the timer is to produce no output until the input exceeds the pickup setting. The dropout setting determines how long the output is maintained after the input is removed. Figure 15a shows the characteristics obtained for a timer setting of 2.8 ms. Figure 15b shows the characteristic for a timer setting of 6 ms. Blocks which are 90^{o} apart are coincident for 4.17 ms. Blocks which are less than 90^{o} apart are coincident for less than 4.17 ms. The angle C measured is the angle between pts. A and B in Fig. 10. In general, the reach for a timer setting less than 4.17 ms is greater than the reach for a timer setting of 4.17 ms at the same fault angle.

The exact operating time for a given fault varies considerably with the angle of incidence of the fault and the timer setting. Figure 16 shows the operating time for a timer setting of 4.17 ms. Maximum time is 12 ms and minimum time is 4 ms based on 60 Hz steady state conditions.

B. BLOCK-SPIKE METHOD

The mho blocking function MB uses a block-spike method of measuring the angle C. A narrow spike is generated at the instant of voltage maximum in the polarized voltage wave. This is compared with a block obtained from the (IZ-V) quantity as shown in Figure 17. Coincidence of the block and spike indicates that the fault is an external one and thus, is inside the reversed mho circle. (See Fig. 1-MB). The output of the discriminator card is connected to a P/9 "pulse stretcher" which converts the spike output of the discriminator card to a continuous output signal.

Operating time for this function, shown in Figure 17 is a function of fault incidence angle and has a maximum operating time of 8.3 ms or faster than the block-block method; however, since the measurement is made instantaneously it is not as secure. Because of this, the block-spike method is not generally used as a tripping function, but is usually employed for blocking functions where high speed is desirable for fault detection and coordination.

CIRCUIT DESCRIPTION

A. GENERAL

The ground mho function of the SLYG may use one of a variety of polarizing voltages. The polarizing voltage is a reference voltage which is compared with an IZ-V phasor to make the distance measurement in the mho function. The types of polarizing voltages used are quadrature, line-to-median, and line-to-neutral. For a phase A relay, these are shown in Figure 3.

B. QUADRATURE POLARIZED A-C CURCUIT

A typical schematic representation of the a-c circuits for Phase 1 MB is shown in Figure 18. This drawing combines the parts of the circuit that are in the tap block unit with the parts in the logic unit to give a better understanding of the input signals to the logic cards. Phase 2 and Phase 3 are similar in arrangement. Input currents and voltages are identified at the left of the drawing where the numbers within the squares represent typical GA and GB terminal block numbers.

The MB card is supplied with a polarizing voltage taken directly from the relay input voltage V_{2-3} and passed through an isolating transformer. The other input to the MB card is (IZ + V), with the IZ component coming from the TB transactor, and the restraint voltage V coming from the MB tap on the autotransformer TA. The (IZ + V) voltage is limited by diode clippers on the primary of the isolating transformer feeding the MB card.

C. LINE-TO-MEDIAN POLARIZED A-C CIRCUIT

A typical schematic representation of the a-c circuits for a Phase 1 MTG is shown in Figure 19. Phase 2 and Phase 3 are similar in arrangement.

The MTG card is supplied with a polarizing voltage taken from Phase 1 to the midpoint of V_{2-3}. The other input to the MTG card is (IZ - V), with the IZ component coming from the TB transactor, and the restraint voltage V coming from the MTG tap on the autotransformer TA. The (IZ - V) voltage is limited by diode-clippers on the primary of the isolating transformer feeding the MTG card.

The block-block method, described in Section A, is used to measure the angle between the polarizing voltage and IZ-V.

D. LINE-TO-NEUTRAL POLARIZED A-C CIRCUIT

A typical schematic representation of the a-c circuits for a Phase 1 LTG with reverse offset is shown in Figure 20. Phase 2 and Phase 2 are similar in arrangement.

The LTG card is supplied with (IZ_1 - V) and (IZ_2 + V*) quantities. The (IZ_1 - V) quantity is passed through a series L-C memory circuit to allow operation for zero voltage faults. The measuring principle for the LTG is the "block-block" method described above. The forward and reverse voltage and current taps may be adjusted independently.

Figure 21 shows a typical schematic representation of the a-c circuits for a Phase 1 MG1 function with reverse offset. This function employs a memory circuit (X_{21},C_2) and a replica circuit (X_{11}). A filter (X_1, C_1) is used to eliminate unwanted harmonics. Transformer TB and transactor TC provide the IZ components. The replica angle is adjusted by the P1 potentiometer, the reach is adjusted by current taps and a vernier potentiometer (P2, P3).

CONSTRUCTION

The components of the SLYG relay are mounted in two separate containers:

(1) the tap block unit

(2) the logic unit

A. TAP-BLOCK UNIT

The tap-block unit is packaged in a metal-enclosed case which has removable front and top covers and is suitable for mounting on a standard 19" rack. The outline and mounting dimensions of the case and physical location of the components in a specific SLYG relay are included in an "adder" to this instruction book.

A typical tap-block unit contains the tap blocks for making reach settings of the mho functions. It also contains rheostats for making the maximum reach angle adjustment for the different mho characteristics. All of these adjustments are located on the front of the mounting plate of the tap-block unit, behind the hinged front panel.

There are three sets of reach setting tap blocks, one for each phase. Each set contains voltage (V) taps and current (IZ) taps.

One method of making SLYG reach tap settings is illustrated in Figure 22, which shows typical settings for the Phase 1 tap blocks. The 10% voltage taps are on the left half of the tap block arrangement, and settings are made by connecting jumpers from the fixed taps MG, LTG, and LTG*, on the center voltage tap block, to the desired 10% tap. The 1% voltage taps appear on the right half of the voltage tap blocks, and adjustment is made by connecting two jumpers on each block as shown in Figure 22. The finer adjustment, which can be adjusted up to 5% in 1% steps is either added to or subtracted from the 10% tap setting depending on the manner of connecting the two jumpers.

If the jumpers do not cross over, the difference between the two taps is the percent added to the basic 10% tap setting. If the leads are crossed, the difference is the percent subtracted from the basic 10% tap setting. In other words, settings with a second digit of 6, 7, 8, or 9 require a crossover of these jumpers and the next higher 10% tap.

Tap settings between 0 and 5% are made using taps as shown below:

PERCENT	TAPS
0	0, 0
1	0, 1
2	1, 3
3	0, 3
4	1, 5
5	0, 5

Base reach (IZ) tap settings are made as shown in Figure 22. A jumper is connected from the fixed tap position to the desired adjustable tap position. A second method is to move a knurled screw to the desired tap.

Incoming currents and voltages are supplied to the tap block unit through a screw terminal block (GA) at the rear of the unit. Output voltage signals appear at 10 point sockets at the rear of the unit which are used for interconnection with the logic unit.

B. LOGIC UNIT

The logic unit is packaged in a metal-enclosed case which has removable front and top covers and is suitable for mounting on a standard 19" rack. The outline and mounting dimensions of the case and physical location of the componets in a specific SLYG relay are included in an "adder" to this instruction book.

The SLYG logic unit contains one or two rows of printed circuit cards plus links and push buttons. Mounted behind the cards are a group of isolating transformers, some capacitros, and further auxiliary equipment.

The push buttons on the front panel simulate operation of certain relay functions.

Links on the front panel provide the means of selecting the desired modes of operation.

Printed circuit cards are identified by a code number such as A3, D6, L10, etc. where A means auxiliary, D means discriminator, L means logic, and T means time delay.

The logic unit has a test card in the T position (lower right-hand). Test points are numbered 1 to 10 from top to bottom on this card. The upper test point, TP1, is connected to the negative or reference bus of the transistor circuits, and the lower test point, TP10, is connected to the +15.6 volt bus. The other eight test points are located at selected points within the logic circuitry to permit test measurement of the outputs of the various functions, and facilitate signal tracing and trouble-shooting.

INSTALLATION TESTS

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

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

These units must be tested and used together.

A. NECESSARY ADJUSTMENTS

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

1. Mho function IZ tap setting.

2. Mho function V tap setting.

3. Position supervisory links (if used).

4. Angle of maximum reach.

Connect all interconnecting cables from the tap block to the logic units, and from the logic unit to the power supply, before beginning tests.

GENERAL TESTING INSTRUCTIONS

A. INPUT CIRCUITS

A typical SLYG tap block unit has a 10-point terminal block on the rear of the unit identified as the GA terminal block. Where the "drawout" test facility is used, this is connected to the GA block on the tap block unit by a 10-conductor cable, and input currents and voltages can be supplied through the standard Type XLA test plug. Where other test facilities are used, input currents and voltages should be applied to test points which connect to the same tap block terminal points as those shown on the test circuit diagram.

Where the SLYG is built and furnished with a terminal of Static Relaying, reference to the job elementary will provide information concerning customer relay inputs.

B. OUTPUT SIGNALS

The SLYG logic unit has a test card in the T position. This test card has 10 pin jacks mounted on the outer edge of the card and is numbered 1 to 10, from top to bottom. These jacks are the test points shown as TP1 to TP10 on the SLY logic diagram.

Output signals are measured with respect to the reference bus, or TP1, the upper jack on the test card. Outputs are continuous signals of approximately +10 to +15 volts for the ON condition, and "0" volts for the OFF condition. This output can be monitored with an oscilloscope, a portable high impedance d-c voltmeter, or with the test panel voltmeter if available. When the test panel voltmeter is available, the voltmeter negative terminal will normally be connected to the reference bus. Placing the relay test lead in the proper test point pin jack will connect the meter for testing.

Where 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.

CAUTION: IT IS A DESIGN CHARACTERISTIC OF MOST ELECTRONIC INSTRUMENTS THAT ONE OF THE SIGNAL INPUT TERMINALS IS CONNECTED TO THE INSTRUMENT CHASSIS. SINCE THE SLYG REFERENCE VOLTAGE, WHICH NORMALLY IS CONNECTED TO THE GROUND INPUT OF THE INSTRUMENT, IS NEAR THE (-) STATION BATTERY VOLTAGE LEVEL, THE INSTRUMENT CHASSIS MUST BE INSULATED FROM STATION GROUND. IF THE INSTRUMENT POWER CORD CONTAINS A THIRD LEAD, THAT LEAD MUST NOT BE CONNECTED TO STATION GROUND. HOWEVER, IF THE INPUT TO THE OSCILLOSCOPE IS A DIFFERENTIAL AMPLIFIER AND NEITHER INCOMING SIGNAL LEAD IS TIED DIRECTLY TO THE INSTRUMENT GROUND, IT IS NOT NECESSARY TO OBSERVE THE ABOVE PRECAUTIONS.

DETAILED TESTING INSTRUCTIONS

REQUIRED ADJUSTMENTS

A. REACH TAP SETTINGS

The arrangement of the reach tap blocks is described under the section on CONSTRUCTION, and the choice of tap settings is discussed under the section on CHOICE AND CALCULATION OF SETTINGS. The tap settings of a particular relay are outlined in the "adder" for that relay.

B. TESTING MHO CHARACTERISTICS

The mho characteristic may be checked over its entire range by using the test circuit employing the phase shifter and phase angle meter shown in Figure 23. Input connections for testing any of the phase-pair characteristics should be made with Figure 23. The SLYG terminal points identified by letters in

Figure 23 are identified in the adder to this book.

By setting the current greater than 3A RMS the reach at any angle becomes a function of the settings of both the base reach and restraint taps. Rotating the phase shifter provides a means of checking the reach on any point of the characteristic. Notice that as the percent value of the restraint taps decreases the phase to phase impedance increases.

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

(a) Set up the test circuit of Figure 23 for the particular phase being tested. Make the AC connections described in the adder.

(b) Set the test current greater than 3A RMS to insure a high degree of sensitivity.

(c) Be sure that the current limiting reactor is as high as possible in ohmic value (perhaps 24 ohms). This assures the most transient-free current possible.

(d) Remove the two detector cards of the phases not being tested.

(e) Connect the instrumentation (preferably an oscilloscope) between the mho function output and reference at TP1.

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

(g) Adjust the variac from zero volts until the mho-function output drops out. The output will first pick up at very low variac voltage, then reduce variac voltage until mho-function fully picks up. Note that the point just at the verge of pick-up, as read on Figure 23 voltmeter (V), defined the relay mho-characteristic.

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

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

Z = Base reach of the relay
I = 5 Ampere test current
α = The angle read at the phase angle meter

Referring to Figure 24 of this book, the angle rotates from $\alpha = \phi - 90^o$ to $\alpha = \phi + 90^o$

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

Since distance relays use impedance or reactance measurement to determine fault location, it follows that an ideal test method would be to have the relay "see" an impedance which would equal the relay reach setting. The R-X test combination has been specifically designed to accomplish this precise method of test. This method employs a test box (102L201), test reactor (6054975) and test resistor (6158546) described in GET-3474 and shown in Figure 25. The R-X test combination is highly accurate, but only has a limited number of fault impedance angles available.

C. PHASE ANGLE ADJUSTMENT

The rheostats, located on the front panel of the tap-block unit, control the angle between the transactor output voltage and input current for each of the mho-functions. The angle is typically factory adjusted for 60^o, which produces 60^o maximum reach angle of the mho characteristics.

To varify max. reach angle of 60^o, follow instructions (a) through (e) below.

In most Type SLYG's the angle of maximum reach can be adjusted up to 75^o. The calibration of the angle of maximum reach can be made by using the Test Circuit of Figure 23. The recommended procedure is as follows:

(a) Determine what test voltage V in Figure 23 is necessary to produce output at the relays maximum reach angle for the test current, and the particular tap setting.

The voltage V at the angle of maximum reach is:

$$V = \frac{IZ100}{\%\ RESTRAINT\ TAP}$$

I = test current in amps
Z = base reach tap in ohms

(b) Make the AC connections to the relay as shown in the adder

(c) Adjust the variac in Figure 23 until the voltmeter reads 85% of the calculated voltage in equation 3.

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

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

If this maximum reach angle is different from the desired angle, adjust the phase angle rheostat (on the front plate of the tap-block unit) for the particular phase involved and repeat steps (a) through (e).

An alternate method of adjusting the angle is shown in Figure 26. This method is used to set the replica angle if used. The circuit of Figure 26 applies approximately 5 amperes to the primary of the transactor and measure the output angle at the input to the discriminator card. Refer to the adder to this book for the terminal numbers identified by letters in Figure 23.

Set the voltage tap to zero for the phase being checked, so that the (IZ-V) output is IZ only. Remove the card on the phase being checked and insert a test card to gain access to the pin 5 point in the card socket. Connect a dual trace oscilloscope as shown.

The channel A voltage, taken across the 24 ohm tap of a 6054975 test reactor, provides a reference voltage that leads the transactor primary current by 87.5. The output voltage will be a flat-topped wave, whose zero-crossings can be compared with the reference voltage to determine the output voltage angle θ. The calibrated horizintal sweep of the oscilloscope can be used to measure time between zero-crossings, which can be converted to degrees by the constant 1 millisecond = 21.6°. The following table may be helpful in converting time measurements to angle measurements.

TABLE 1

θ	87.5 - θ	TIME
60	27.5	1.27 ms
65	22.5	1.04 ms
70	17.5	0.81 ms
75	12.5	0.58 ms

The angle θ can be changed by adjusting the phase angle rheostat, being careful to adjust the proper rheostat for the phase being checked. Turn the rheostat adjusting screw CLOCKWISE to increase the phase angle.

After this adjustment has been made, the mho characteristic should be checked, using the test circuit described above under REQUIRED ADJUSTMENTS. If the resulting maximum reach angle is not close enough to the desired maximum reach angle, the difference in degrees should be noted, and a second adjustment of the phase angle rheostat by this amount should be made to obtain the desired characteristic.

D. MB PHASE ANGLE RHEOSTAT

Since the MB function is used with MTG function, it may be desirable to adjust the MB characteristic whenever the MTG characteristics are changed. The phase shift can be checked as described in the adder. Check the MB characteristic as described above, under TESTING MHO CHARACTERISTICS.

E. OVERCURRENT FUNCTION OPERATING LEVEL

All current functions supplied in the SLYG may be set using the following procedure:

Apply current, through a variac, to the appropriate terminals of the SLYG relay and read an output at the correct test point (see relay "adder"). The output voltage is +10 to +15 volts when the unit operates. To adjust the operating level, turn the rheostat on the tap block front panel, using the appropriate rheostat for the phase pair being checked. Turn the rheostat CLOCKWISE to increase the operating level. Increase the current slowly to check the operating level. Decrease the current slowly to check the reset level.

TIMER ADJUSTMENTS AND TESTS

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

A. (4/9) COINCIDENCE MEASUREMENT CARD

These cards should not be adjusted unless a plot of the mho-characteristic indicates an improper pick-up time setting (see Figure 16) or if the reset time is too short to produce a continuous signal.

These cards should have a 4.17 millisecond delay on operate time and a 9 millisecond delay on reset time. The 4.17 millisecond time is important in making the 90° coincidence measurement and affects the shape of the mho characteristic; times longer than 4.17 milliseconds tend to narrow the characteristic and times shorter than 4.17 milliseconds tend to widen the characteristic. The 9 millisecond time is provided to overlap the next half-cycle measurement and produce a continuous DC logic signal. To check the 4/9 timers in the MT circuits, connect the test circuit used previously for checking the mho characteristic. Reduce the applied voltage until the fault condition applied to the relay within the relay characteristic.

Note that card positions, test points and card designations mentioned in the following descriptions are typical of a Type SLYG relay. For a particular relay refer to the "adder" to this instruction book.

Consider phase 1 first. Remove the MTG cards in the other phases and the 4/9 card from the AG position. Use a card adapter with the AE position card to get access to its input terminal, AE-6. Connect the input to this card to one channel of a dual trace oscilloscope and the output (TP2) to the other channel.

Typical wave shapes for this test are shown in Figure 27. The AE card receives the pin 7 output from the MTG card, and this output should be blocks greater than 4 milliseconds long, with gaps longer than 11 milliseconds. Changing the applied fault voltage changes the width of the block. The 4/9 timer should operate 4.17 milliseconds after the beginning of each pin 7 output block, and should drop 9 milliseconds after the end of the pin 7 block. If adjustments are necessary, use the potentiometer CW to increase operate time, and turn the outer potentiometer CW to increase reset time. These potentiometers can be turned approximately 20 turns for complete travel from one end to the other.

Place the card adapter in the AG position and place the AG position 4/9 card in the adapter. Repeat the procedure described above to check and adjust this card, removing now the AE position card. The input to this card is the pin 8 output from the MTG card, and appears on the opposite half-cycle to that for the pin 7 output. Replace both 4/9 cards (AE and AG) and check the TP2 output to be sure that output is continuous at pickup.

Repeat this procedure for the phase 2 and phase 3 circuits, in each case removing the MTG cards from the other two phases, and applying input current and voltage to the proper terminals for the phase pair being tested. Refer to the logic internal for each relay.

As a final check on the accuracy of the 4.17 millisecond setting, the MTG characteristic may be rechecked and compared with the desired characteristic. If half-cycle output is observed at the threshold of operation, this can be corrected by a finer adjustment of the two 4/9 timers on the phase being checked.

B. LENS (6/9) COINCIDENCE MEASUREMENT CARD

The coincidence measurement cards for the LTG function are adjusted in the same manner as the 4/9 timer cards. A time setting of 5.55 ms corresponds to a lens with an angle of 120°. This card is shown as a 6/9 timer on the unit internal.

C. (P/9) PULSE STRETCHER

The purpose of the pulse stretcher is to convert the output of the MB cards to a continuous output.

Pulses occur every 8 milliseconds (1/2 cycle) and the 9 millisecond reset time provides overlap from one pulse to the next. The reset time does not have to be exact, but it should be long enough to produce contimuous output without being excessively long.

To check the P/9 operation, connect the relay characteristic circuit of Figure 23 using the connections for phase 1. Reduce the voltage until an MB output is obtained. Reduce reset time of the P/9 card by turning the potentiometer screw CCW until gaps begin to appear in MB output. Then turn the screw CW to increase reset time until output is continuous again.

MAINTENANCE

PERIODIC CHECKS

NOTE: For any periodic testing of the SLYG, the trip coil circuit of the circuit breaker should be opened by removing one of the connections plugs in the SLA relay test and connection receptacle, or by opening other test switches provided for this purpose. Removing the connection plug (at the GA test and connection receptacle) does not open the trip circuit.

Reach of the MHO function and overcurrent operate level may be checked at periodic intervals, using the instructions under INSTALLATION TESTS. Cable connections between the SLYG and SLA relay may be checked by using push-buttons in the SLYG to produce CARRIER START and TRIP outputs. The CARR. START button should start a pilot channel blocking signal. The TRIPPING function push-button should produce a tripping output from the SLA and the appropriate target lights in the SLA. TRIP output from the SLA can be checked by an actual circuit breaker trip operation, by operating an auxiliary relay (HEA), or by energizing a resistive load (less than 3 amperes).

TRPUBLE-SHOOTING

Test points are provided at selected points in the SLYG logic unit and may be used to observe outputs if trouble-shooting is necessary. The use of a card adapter will make all the pins on any one card available for testing.

All output voltages at the test points are measured with respect to the reference bus, TP1, and under normal conditions, are less than +1 volt. When an output appears at any test point, the voltage at that point switches to a continuous ON signal (+10 to +15 volts).

For the physical location of components (transactors, transformers, etc.) refer to the "adder" for the particular relay.

SPARE CARDS

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

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

CARD DRAWINGS

Details of the circuits of the printed circuit cards can be obtained in the printed circuit card book GEK-7364.

CALCULATION OF SETTINGS

The required settings of the various functions of the SLYG relay must be determined prior to putting the relay into service. The user should refer to the instruction book adder for the particular relay involved for specific information. However, some general recommendations can be made which will apply to the more common applications of these relays. The following paragraphs relate only to two-terminal line applications. Special considerations relating to three-terminal line applications are discussed in Appendix V.

In order to illustrate the calculations required assume the application of the relay to the protection of Line No. 1 between Breakers A and B shown in Figure 28. Line No. 1 has the following characteristics:

$Z1' = 24.0 \angle 80^\circ$ primary ohms $Zo' = 72.0 \angle 75^\circ$ primary ohms

$Zom = 14.4 \angle 75^\circ$ primary ohms

CT Ratio = 600/5   PT Ratio = 1200/1

Converting primary to secondary ohms by the relation

$$Z \text{ secondary} = Z \text{ primary} \times \frac{\text{CT Ratio}}{\text{PT Ratio}}$$

$Z1' = 2.4 \angle 80$ deg $= 0.42 + j\,2.36$ secondary ohms
$Zo' = 7.2 \angle 75$ deg $= 1.86 + j\,6.95$ secondary ohms
$Zom = 1.4 \angle 75$ deg $= 0.36 + j\,1.35$ secondary ohms

All symbols are defined in Appendix I except as indicated.

ZONE ONE MHO FUNCTIONS

The settings to be made on the zone one ground mho functions are: basic minimum ohmic tap T_B, the voltage restraint tap setting T, and the protected line zero sequence current compensation factor K'. The K' setting in percent is determined by the following relation:

$$K' = \frac{X_0' - X_1'}{3X_1'} \times 100$$

All symbols are defined in Appendix I. The setting for K' is:

$$K' = \frac{6.95 - 2.36}{3\ (2.36)} \times 100 = 65 \text{ percent}$$

Since K' can only be set in 10 percent steps, set it for 60 percent. This setting will provide a slight undercompensation to shorten the function reach. This is in a conservative direction for a zone one function.

Consider the relays located at Breaker A. The zone one mho functions should be set for 80 percent of the line impedance Z_1' or $(0.8)\ 2.4 \angle 80^\circ = 1.92 \angle 80^\circ$. If a parallel line existed, the next step would be to apply Appendix II, equation II-a to determine that this zone 1 mho setting will not overreach breaker B due to the mutual effect while clearing a parallel line fault.

The mutual effect of Line 2 must also be considered. A fault current contribution over line 2 from breaker D through breakers C, A and B to fault F3 will cause the zone one ground mho functions at A to overreach. This may be evaluated using Appendix II, equation II-a. Assume a fault study yielded the following values for fault F3:

Ia' = 13.7 amperes based on 600/5 CT ratio
Io' = 4.1 amperes based on 600/5 CT ratio
Io" = 5.5 amperes based on the CT ratio of the protected line of 600/5. This current has a negative sign because Io" flows in the opposite direction in Line 2 from that in which Io' flows in Line 1.

K' = 0.6 per unit as determined previously. Substituting these values into equation II-a and neglecting arc resistance the apparent impedance is:

$$Za = Z_1' + \frac{Io''\ Zom}{Ia' + 3K'\ Io'} = 2.4 + \frac{(-5.5)\ 1.4}{13.7 + (1.8)\ 4.1} = 2.4 - 0.36$$

$Za = 2.04 \angle 80^\circ$ Since this value is greater than the 80 percent setting of zone one which is $1.92 \angle 80^\circ$ ohms, the zone one function will not overreach to respond to fault F3 on the next bus. If additional margin against this overreaching is desirable, the zone one setting should be reduced.

Assuming the setting of $1.92 \angle 80^\circ$ ohm is satisfactory, select the highest possible basic minimum tap T_B for optimum performance, in this case a 2 ohm basic minimum tap. Next, the choice of the angle of maximum reach is made, assume 60 degrees. The voltage restraint tap setting T is determined by the following relation:

$$T = \frac{100\ T_B \cos(\theta - \phi)}{Z}$$

where: ϕ = relay angle of max. reach, 60 degrees assumed.
Z = desired reach of zone 1, 1.92 ohms
θ = angle of Z, 80 degrees

$$T = \frac{100\ (2)\ \cos\ (80 - 60)}{1.92} = 98 \text{ percent}$$

OVERREACHING MHO FUNCTIONS

The overreaching mho function maximum tap setting must be determined to insure detection of a single-phase-to-ground fault at the remote bus. This should be evaluated for the relays at Breaker A on the basis of fault location F3, Figure 28. The equations of Appendix III are to be used. Assume that a system study gives the following values for these conditions:

$Co = 0.17$ $C = 0.20$ $\theta = 80$ degrees $\phi = 60$ degrees
$Ia' = 13.7$ amperes $Io' = 4.1$ amperes
$Io'' = -5.5$ amperes based on protected line CT ratio.

The negative sign of Io" current indicates the opposite direction of flow in Line 2 from that in which Io' flows in Line 1. This tends to reduce the apparent impedance as seen by the relays at Breaker A. For an overreaching mho function a negative mutual impedance effect should not be used to determine the settings since if Line 2 were out of service the mho function would then tend under reach and not provide adequate coverage.

A. WITHOUT COMPENSATION

Equation III A - a should first be used to evaluate the apparent impedance

$$Za = Z_1' + \frac{(Zo' - Z_1')\ Co}{2C + Co} + \frac{Zom\ Io''}{Ia'}$$

Not including the mutual term, this becomes:

$$Z_a = 2.4 + \frac{(7.2 - 2.4)\ (0.17)}{(0.4 + 0.17)} = 3.83 \text{ ohms}$$

Equation III A - C $$Tmax = \frac{100\ (T_B)\ \cos\ (\theta - \phi)}{1.25\ Za} = \frac{100\ (2)\ \cos\ (80 - 60)}{1.25\ (3.83)} = 39 \text{ percent}$$

B. WITH COMPENSATION

Determine the protected line zero sequence current compensation factor K' in percent by the following relation:

$$K' = \frac{X_0' - X_1'}{3X_1'} \times 100 = \frac{6.95 - 2.36}{3\ (2.36)} \times 100 = 65 \text{ percent}$$

Since K' can only be set in 10 percent steps, set it for 70 percent. This setting will provide a slight overcompensation tending to increase the function reach. This is desirable for an overreaching mho function.

Equation III B - a should next be used to evaluate the apparent impedance

$$Za = Z_1' + \frac{Zom\ Io''}{Ia' + 3K'\ Io'}$$

Since the mutual term should be excluded when Io" has a negative sign, the apparent impedance will simply be Z_1'. Equation III B - C then becomes

$$Tmax = \frac{100\ \ T_B\ \cos\ (\theta - \phi)}{1.25\ Z_1'} = \frac{100\ (2)\ \cos\ (80 - 60)}{1.25\ (2.4)} = 64 \text{ percent}$$

MHO FUNCTION LIMITATIONS

Appendix IV provides the necessary equations to determine the mho function maximum permissible reach settings (minimum tap). This will insure the non-operation of the mho functions on the unfaulted phases for ground faults in the reverse or non-trip direction. These should be evaluated for the relays at Breaker A on the basis of fault location F2, Figure 28. Assume that the mho function in this application is quadrature polarized. The value for K_Q will then be determined from the curve of Figure 32. The following quantities are determined from a system study.

$Co = 0.11$	$C = 0.27$
$Z_1 = 0.875 \quad 82^\circ$ ohms	$Z_0 = 1.05 \quad 78^\circ$ ohms
$Z_0/Z_1 = 1.2$	$K_Q = 33$

A. WITHOUT COMPENSATION

Equation IV A - a

$$T_{min} = \frac{T_B\, K_Q\, (Co - C)}{Z_1} = \frac{2\,(33)\,(0.11 - 0.27)}{0.875} = -12 \text{ percent}$$

Equation IV A - b

$$T_{min} = \frac{100\, T_B\, (Co - C)\cos(\theta - \emptyset)}{3\, Z_0} = \frac{100\,(2)\,(0.11 - 0.27)\cos(78 - 60)}{3\,(1.05)} = -9.4 \text{ percent}$$

Since both equations give values for Tmin which are negative, these equations impose no restrictions on the mho function tap setting. Thus the mho function in this case may be set for any tap setting in the range of 10 to 39 percent for proper operation. In the evaluation of equations IV A - a and IV A - b in this example it would only have been necessary to determine that the term (Co - C) is negative and thus the equations impose no restrictions. It should also be noted that the mho functions will respond to load and will measure effective load impedance. For this reason the mho function tap setting should not be made so low that it will operate on load conditions.

B. WITH COMPENSATION

Equation IV B - a

$$K' = 0.7 \text{ per unit}$$

$$T_{min} = \frac{T_B\, K_Q\, [(3K' + 1)\, Co - C]}{Z_1} = \frac{2\,(33)\,[3.1\,(0.11 - 0.27]}{0.875} = 5.3 \text{ percent}$$

Equation IV B - b

$$T_{min} = \frac{100\, T_B\, [(3K' + 1)\, Co - C]\cos(\theta - \emptyset)}{3Z_0} = \frac{200\,(0.071)\cos(78 - 60)}{3\,(1.05)} = 4.3 \text{ percent}$$

Since both equations IV B - a and - b give values for Tmin which are less than 10 percent, these equations impose no limitations on the mho function tap setting. Thus the mho function in this case may use any tap setting in the range of 10 to 64 percent for proper operation. It should be noted that the mho function will also respond to load and will measure effective load impedance. For this reason the mho function tap setting should not be made so low that it will operate on load conditions.

OTHER FUNCTIONS

Refer to the aader instruction book for the description of the specific functions included in a particular relay and how they should be applied and set.

APPENDIX I

DEFINITION OF SYMBOLS

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

Voltage

E_a = Phase A-to-neutral voltage.

E_b = Phase B-to-neutral voltage.

E_c = Phase C-to-neutral voltage.

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

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

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

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

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

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

E_o = 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_o = Total zero sequence current in the fault.

I_1 = Total positive sequence current in the fault.

I_2 = Total negative sequence current in the fault.

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

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

Distribution Ratios

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

C_o = Zero sequence current distribution ratio.

$$C = \frac{I_1'}{I_1} = \frac{I_2'}{I_2} \qquad C_o = \frac{I_o'}{I_o}$$

Impedance, Reactance

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

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

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

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

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

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

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

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

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

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

Z_a = Phase A impedance for conditions described.

All of the above are secondary ohms, where:

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

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

Miscellaneous

T = Relay voltage restaint tap setting in percent.

B, θ, Ø = Angles in degrees as defined where used.

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

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

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

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

S = Ratio of distances as defined where used.

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

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

APPENDIX II

ZONE ONE MHO FUNCTIONS

The zone one mho functions use zero sequence current compensation of the protected line. These functions therefore respond to the positive sequence impedance to the fault plus an error impedance introduced by the mutual effect of a parallel line of one is present. The following derivation explains how this is accomplished.

The phase-to-neutral voltage at the relay during a single phase-to-ground fault on phase A is E_a' and is equal to the sum of the voltage drops from the relay to the fault. For a fault at the remote terminal of a line that is paralleled for its full length by a second line, this voltage, in terms of sequence components, is:

$$E_a' = I_1'Z_1'+I_2'Z_2'+I_0'Z_0'+I_0''Z_{om}+I_aR_a$$

where I_aR_a is the drop due to arc resistance, and all other terms are as defined in Appendix I.

If we assume $Z_2'=Z_1'$, which is usually the case, and if we insert in the above equation the expression $(I_0'Z_1'-I_0Z_1')$, we have:

$$E_a'=I_1'Z_1'+I_2'Z_1'+I_0'Z_1'-I_0'Z_1'+I_0'Z_0'+I_0''Z_{om}+I_aR_a$$

$$E_a'=(I_1'+I_2'+I_0')Z_1'+I_0'(Z_0'-Z_1')+I_0''Z_{om}+I_aR_a$$

Since $(I_1'+I_2'+I_0')$ = the line current I_a',

$$E_a'=I_a'Z_1'+I_0'(Z_0'-Z_1')+I_0''Z_{om}+I_aR_a$$

$$E_a'=I_a'Z_1' + \frac{3I_0'(Z_0'-Z_1')}{3Z_1'}Z_1' + \frac{3I_0''Z_{om}Z_1'}{3Z_1'} + I_aR_a$$

$$E_a' = Z_1'\left(I_a' + \frac{3I_0'(Z_0' - Z_1')}{3Z_1'}\right) + I_0''Z_{om} + I_aR_a$$

This equation can also be written as

$$E_a' = Z_1'(I_a' + K'I_{res}') + I_0''Z_{om} + I_aR_a$$

where $K' = \frac{Z_0' - Z_1'}{3Z_1'}$ and $3I_0' = I_{res}'$, the residual current of the protected line. If the current supplied to the relay is $I_a' + K'I_{res}'$, the apparent impedance Z_a as determined by dividing the relay voltage E_a' by the relay current $I_a' + K'I_{res}'$ is as follows:

$$Z_a' = Z_1' + \frac{I_0''Z_{om}}{I_a' + 3K'I_0'} + \frac{I_aR_a}{I_a' + 3K'I_0'} \qquad \text{II-a}$$

The second term of this equation is the error impedance introduced by the mutual effect of a parallel line of one is present. This error term may add or subtract. The I_0'' current is considered positive when the current flow in the parallel line is in the same direction as the current flow in the protected line. When these currents have opposite polarities the I_0'' current is considered negative.

The error term due to the mutual impedance must be evaluated in determining the setting of the zone one ground mho units so that it will not overreach the protected line section and trip on an external fault. Consider two similar parallel lines on the same right-of-way as illustrated in Figure 29. Assume a single-phase-to-ground fault on Line B at F1 and that Breaker 3 opens promptly on zone 1 but Breaker 4 remains closed for a time. The effect of the fault current flowing down Line A and back on Line B to the fault would produce a mutual effect which would tend to cause the ground mho functions at Breaker 1 to overreach. The apparent impedance as seen by the ground mho function at Breaker 1 for fault F1 with breaker 3 open and no infeed from Station D is given by the following equation:

$$Z_a = Z_1'\left[1 + S3\left(\frac{2 + K_0 - 2K_mK_0}{2 + K_0}\right)\right] \qquad \text{II-b}$$

where: $K_o = Z_o'/Z_1'$ $K_m = Z_{om}/Z_o'$
S3 = the ratio of (distance from Breaker 4 to the fault) to (the total length of Line A or Line B)
All other symbols are defined in Appendix I

The most severe condition of overreach will occur for the larger values of K_m and K_o. On actual systems, K_o will average about 3.5 but may be as high as 7.5. K_m will generally be about 0.5 but may be as high as 0.7. An evaluation of equation II-b with the extreme ratios of K_m and K_o will show that the apparent impedance will always be greater than the zone one ground mho setting which should never exceed 80 percent of the line length.

The ground mho function must never be compensated for the mutual effect resulting from a parallel line. If such compensation is used it could cause the incorrect operation of the ground mho function upon the occurrence of a close-in fault on a line behind the relay location.

The last term of equation II-a is an error impedance introduced by the arc resistance of the fault. The angle of this error impedance will likely be zero degrees (parallel to the R axis) as contrasted to the highly lagging angles of the positive sequence impedance Z_1' and the mutual impedance Z_{om}. If the arc resistance is a significant factor compared to the positive sequence impedance of the line, its effect on the ground mho function settings must be evaluated. Too large an arc resistance on an internal fault could cause the total impedance to the fault to plot outside of the characteristic of the ground mho function. Thus proper tripping of the mho function would not be obtained.

APPENDIX III

OVERREACHING MHO FUNCTIONS

As mentioned in the APPLICATION section, certain types of SLYG relays covered by this basic instruction book include a provision for zero sequence current compensation of the overreaching mho functions while others do not. Even though a particular model of SLYG has provision for this compensation, its use is optional and hence the necessary auxiliary current transformer may or may not be included on a particular application. Therefore the following discussion is presented in two parts:

A. relays WITHOUT zero sequence current compensation
B. relays WITH zero sequence current compensation

In all parts of this duscussion all voltages, currents and impedances are in terms of secondary quantities based in the CT and PT ratios of the protected line section.

III A - WITHOUT COMPENSATION

For a phase-A-to-ground fault at the remote end of the protected line, the apparent impedance, Z_a, as seen by the ground mho function on the faulted phase is given for the general case by the following equation:

$$Za = Z_1' + \frac{(Z_0' - Z_1')\,Co}{2C + Co} + \frac{Z_{om}\,I_0''}{Ia'} \qquad \text{III A - a}$$

The symbols are defined in Appendix I.

The reach setting of the mho functions must be large enough to detect a single-phase-to-ground fault at the remote end of the protected line with margin. The setting of the voltage restraint tap T of the mho function to provide the required reach of the protected line angle can be determined by the following:

$$T = \frac{100\, T_B \cos(\theta - \phi)}{Z} \qquad \text{III A - b}$$

where: Z = desired reach at protected line angle
θ = protected line angle in degrees
∅ = mho function angle of maximum reach in degrees
See Appendix I for all other symbols.

Resolving equation III A - a for a single phase to ground fault where $Z_0' = Z_1'$ and there is no mutual impedance with a parallel line, the apparent impedance Za seen by the mho function will be equal to Z_1'. This same condition is obtained on a three phase fault since positive sequence quantities only are present. However, for a more typical condition where Z_0' and Z_1' are not equal and where there is also zero sequence mutual impedance with a parallel line, the apparent impedance seen by the mho function for a single phase to ground fault will be as shown in equation III A - a.

It is thus obvious that the apparent impedance is larger than just the positive sequence impedance Z_1'. In effect the reach of the mho function over the protected line section will be foreshortened. Written in general terms and providing for an overreach margin of 25 percent, equation III A - b becomes:

$$T\,max = \frac{100\, T_B \cos(\theta - \phi)}{1.25\left[Z_1' + \frac{(Z_0 - Z_1')\,Co}{2C + Co} + \frac{Z_{om}\,I_0''}{Ia'}\right]} \qquad \text{III A - c}$$

or

$$T\,max = \frac{100\, T_B \cos(\theta - \phi)}{1.25\, Za}$$

where: Tmax = maximum permissible voltage restraint tap setting

If the solution to equation III A - c yields a tap setting for Tmax greater than 100 percent, even the shortest reach setting for the minimum basic tap T_B in use will insure that the mho function reaches at least to the remote bus with a 25 percent margin. If it is desired to increase the mho function reach further beyond the rmeote bus, then a lower tap setting will, of course, be required.

If there is no zero sequence mutual impedance with a parallel line in the installation, then the last term of equation III A - a is zero. The expression for the apparent impedance then becomes:

$$Za = Z_1' + (Z_0' - Z_1') \frac{Co}{2C + Co} \qquad \text{III A - d}$$

It is obvious that the distribution ratios C and Co have an influence on the apparent impedance. For example, on an application where $Z_0' = 3Z_1'$, the situation with single end feed where C = Co = 1 results in the following:

$$Za = Z_1' + (3Z_1' - Z_1') \frac{1}{2 + 1} = Z_1' + 2/3\, Z_1' = 1.67\, Z_1'$$

Thus, to insure that the mho function will reach to the far end of the line with the remote breaker open, it must have a reach setting equal to 1.67 Z_1' plus desired margin. On the other hand, with both line breakers closed and the zero sequence current distribution ratio Co much greater than the positive sequence ratio C, the required reach setting will be longer. For example, if C = 0.3 and Co = 0.8 for a fault at the remote bus, and again Zo' = 3 Z_1', the apparent impedance Za is 2.15 Z_1'.

The user must determine the apparent impedance seen by the relay for a fault at the remote bus under the most unfavorable combination of distribution ratios considered possible for the application. The limitations of the maximum permissible tap setting as determined from equation III A - C will insure operation for this remote fault. It is apparent that in some instances, especially on long lines, the required settings of the mho functions may be too large to be practical. Use of the zero sequence current compensation feature, if provided, described in Appendix III B should then be considered.

If there is zero sequence mutual impedance present between the protected line and another line, the last term in the denominator of equation III A - C must be included in the calculations. If the mutual impedance results from the proximity of the protected line with several other circuits the term in question becomes a summation as follows:

$$\frac{1}{I_a'} \left(\sum Z_{om}\, I_o'' \right) \qquad \text{III A - e}$$

Note that in this summation the direction of the zero sequence current flow of Io" in each of the parallel circuits must be considered.

III B - WITH COMPENSATION

Zero sequence current compensation of the mho function is accomplished by adding a portion of the residual current of the protected line section, K'Ires' or $3K'I_0'$, to the normal phase current, I_a', supplied to the function. The net result is to eliminate the middle term of the right hand side of equation III A - a. Thus, for a phase-A-to-ground fault at the remote end of the protected line, the apparent impedance Za, as seen by a ground mho function with compensation is given by the following equation:

$$Za = Z_1' + \frac{Zom\ Io''}{Ia' + 3K'Io'} \qquad \text{III B - a}$$

Note that K' is in per unit in this equation. The K' factor is the compensating transformer tap setting - usually given in percent. It is defined as follows:

$$K = \left(\frac{Xo' - X_1'}{3X_1'} \right) X\ 100 \text{ percent} \qquad \text{III B - b}$$

It is apparent from equation III B - a that the zero sequence current compensation has the effect of reducing the apparent impedance Za seen by the faulted phase relay. Thus a shorter reach setting can be used with assurance that the mho function will see a fault at the remote end of the protected line section. If there is no zero sequence mutual impedance present, the apparent impedance, Za, will be equal to Z_1'. The equation for the maximum permissible voltage restraint tap setting with compensation is as follows:

$$Tmax = \frac{100\ T_B \cos(\theta - \emptyset)}{1.25 \left[Z_1' + \dfrac{Z_{om}\ I_o''}{I_a' + 3K'I_0'} \right]} \qquad \text{III B - C}$$

where: θ = protected line angle in degrees
$\emptyset$ = mho function angle of maximum reach in degrees
K' = compensation setting in per unit

APPENDIX IV

MAXIMUM PERMISSIBLE REACH SETTINGS

Under some system conditions it is possible during single-phase or double-phase-to-ground faults in the non-tripping direction for a mho function associated with an unfaulted phase to operate. Since this can result in a false trip, it is necessary to limit the reach setting of the ground mho function to prevent them from operating on such reverse faults. In the following sections equations are given for determining the maximum permissible reach setting (minimum permissible voltage restraint tap setting) for both types of ground faults. Since some types of SLYG relays have provisions for zero sequence current compensation, the discussion is given in two parts:

A - relays WITHOUT zero sequence current compensation

B - relays WITH zero sequence current compensation

In both parts of this dicussion all voltages, currents and impedances are in terms of secondary quantities based on the CT and PT ratios of the protected line section.

IV A - WITHOUT COMPENSATION

(1) SINGLE-PHASE-TO-GROUND FAULTS

In order to avoid false tripping on external single phase to ground faults, it is necessary to limit the reach of the ground mho functions by keeping the restraint tap setting T higher than the value determined as Tmin in equation IV A - a. Evaluate this equation for single-phase-to-ground faults on the bus immediately behind the relay location or as Fault F2 for relays located at Breaker A, Figure 27.

$$Tmin = \frac{T_B \quad K_Q \; (Co - C)}{Z_1} \qquad \text{IV A - a}$$

where: K_Q = system constant depending upon the ratio of system impedances Z_O/Z_1 as seen from the fault. Use the curves of Figure 30 or 31 for median polarized mho functions. Use the curves of Figure 32 for quadrature polarized mho functions. Make a direct substitution of the value of K_Q obtained from the curves into equation IV A - a.

For phase to neutral polarized mho functions evaluate the following two equations IV A - b and IV A - c and use the curves of Figures 33 and 34 to determine the system constants K_p and K_q.

$$Tmin = \frac{T_B \; K_P \; (Co - C)}{Z_1} \qquad \text{IV A - b}$$

$$Tmin = \frac{T_B \; K_q \; (Co - C)}{Z_1} \qquad \text{IV A - c}$$

Refer to the adder instruction book to determine what type of mho function polarization is employed for the specific SLYG relay to be used.

(2) DOUBLE-PHASE-TO-GROUND FAULTS

In order to avoid false tripping on external double phase to ground faults it is necessary to limit the reach settings of the ground mho functions by keeping the restraint tap setting, T, higher than the value determined as Tmin in equation IV A - d. Evaluate this equation for the same conditions as equation IV A - a. The system sequence components and current distribution ratios are independent on the type of fault

$$Tmin = \frac{100T_B \quad (Co - C) \quad COS\;(\theta - \emptyset)}{3Zo} \qquad \text{IV A - d}$$

where: θ = angle of Z_O, the system zero sequence impedance

$\emptyset$ = maximum reach angle of the mho function

All other symbols are defined in Appendix I.

After evaluation of equations IV A - a or IV A - b and - c and equation IV A - d. The highest of the tap values determined should be selected and then some margin such as 10 percent of the selected value should be added. The tap setting used on the mho function should be no lower than this value nor should it be any higher than the Tmax determined in Appendix III equation III A - c. For the equations in Appendix IVA if a negative value for Tmin is obtained, it signifies that the equation offers no limitation to the setting. In any event, the mho function tap should never be less than 10 percent. When evaluating the equations, the first step should be the evaluation of the term (Co - C). If this term is negative for all the system operating conditions for the fault at F2, no further calculations need be made.

IV B - WITH COMPENSATION

For relays having zero sequence current compensation the same calculations must be made as described in the foregoing section IVA. The equations used, however, are modified by the current compensation factor as shown.

(1) SINGLE-PHASE-TO-GROUND FAULTS

For median and quadrature polarization

$$T_{min} = \frac{T_B K_Q \left[(3K' + 1)\, Co - C\right]}{Z_1} \qquad \text{IV B - a}$$

where: K' = per unit zero sequence current compensation setting. Use curves of Figures 30, 31, or 32 to determine constant K_Q.

For phase-to-neutral polarization

$$T_{min} = \frac{T_B K_p \left[(3K' + 1)\, Co - C\right]}{Z_1} \qquad \text{IV B - b}$$

$$T_{min} = \frac{T_B K_q \left[(3K' + 1)\, Co - C\right]}{Z_1} \qquad \text{IV B - c}$$

Use curves of Figure 33 and 34 to determine the values of Kp and Kq.

(2) DOUBLE-PHASE-TO-GROUND FAULTS

$$T_{min} = \frac{100\, T_B \left[(3K' + 1)\, Co - C\right] \cos(\theta - \phi)}{3Z_0} \qquad \text{IV B - d}$$

After evaluation of the equations of IV B, the highest of the two tap values determined should be selected and them some margin should be added. A 10 percent margin (not 10 tap percentage points) should be adequate. The tap setting used on the mho function should be no lower than this value nor should it be any higher than the Tmax determined in Appendix III, equation B - c. For the equations in Appendix IV B if a negative value for Tmin is obtained, it signifies that the equation offers no limitation to the setting. In any event, the mho function tap setting should never be less than 10 percent. When evaluating the equations, the first step should be the evaluation of the term (3K' + 1) Co - C. If this is negative for all the system operating conditions for the fault at F2, no further calculations need to be made.

APPENDIX V

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 line. This is particularly true if there are external ties between source and fault terminals or of one of the terminals lacks a ground current source. In such cases some special provision must be made in order to provide simultaneous tripping).

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

In order to provide simultaneous tripping of all three line terminals, it is necessary to use reach settings on the overreaching mho functions MTG large enough to insure that all three terminals will respond for any internal fault location with all three line breakers closed. This condition must be obtained for any possible system configuration including the outage or in-service condition of adjacent lines or generating sources which affect the line under consideration. If the MTG units do not respond to some internal fault locations and conditions, there are pilot relaying schemes which will not trip at any line terminal. Care should be exercised in the choice of 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 Figure 35 and the fault at terminal C with infeed current from terminal B. The approximate apparent impedance Zapp at terminal A is given by the following:

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

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 ($I_a' + 3K' Io'$) where K' is a per unit value. The voltage E_a' at terminal A for a fault at terminal C, Figure 35, 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 form terminal B through the impedance from the junction to terminal C, Z_{JC}.

$$Ea' = I_1'A\, Z_1'_{AC} + I_2'_A\, Z_2'_{AC} + I_o'A\, Z_o'_{AC} + I_1'_B Z_1'_{JC} + I_2'_B Z_2'_{JC} + I_o'B\, Z_o'_{JC}$$

If the two source terminals A and B has 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 1.25 times the apparent impedance Zapp. The voltage restraint tap setting will then be determined as:

$$T = \frac{100\ T_B}{1.25 \times Zapp} \quad \cos(\theta - 60)$$

where θ = angle of apparent impedance
60 = assumed angle of maximum reach
All other symbols defined in Appendix I.

STEP DISTANCE PROTECTION

When the SLYG relay is applied as step distance protection on three terminal lines, special considerations need to be employed in the settings of the various functions. The zone one ground mho functions are instantaneous tripping functions and must be set so as to not operate on any external fault.

Therefore, the MG1 setting at any given line terminal must not exceed 80 percent of the distance to the nearest remote line terminal with the breaker open at the other remote terminal.

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

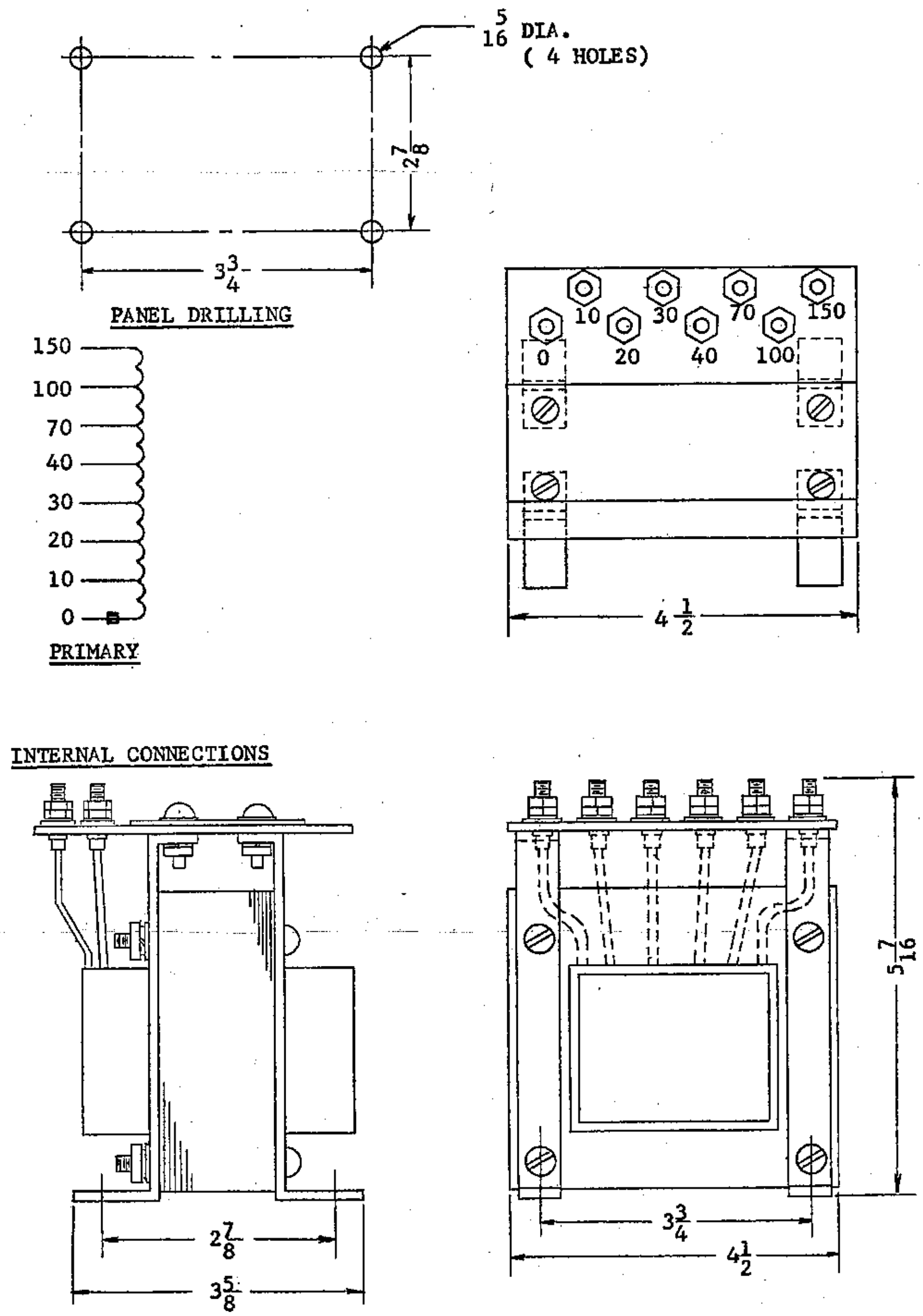


FIG. 1 (0207A5465-0) Auxiliary Compensating CT - 0367A0266 G-2

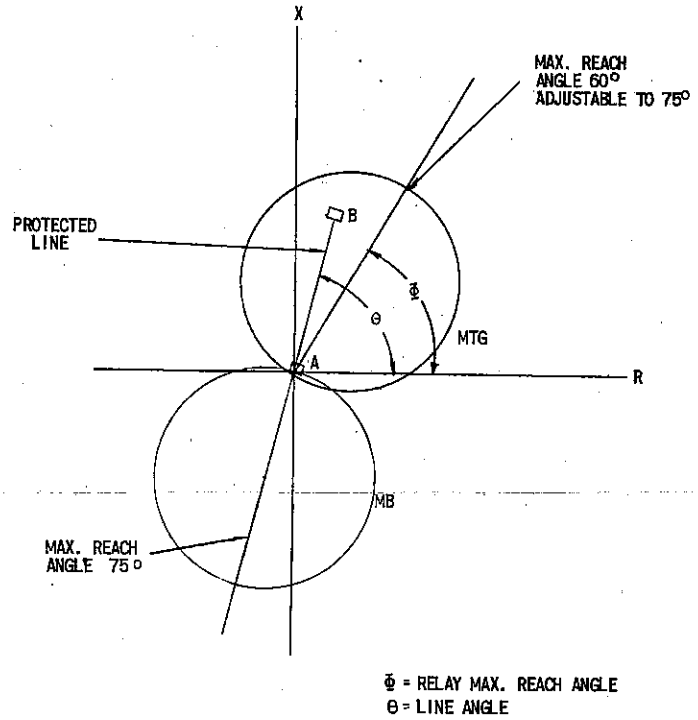


FIG. 2 (0227A2556-1) Typical Mho Characteristics

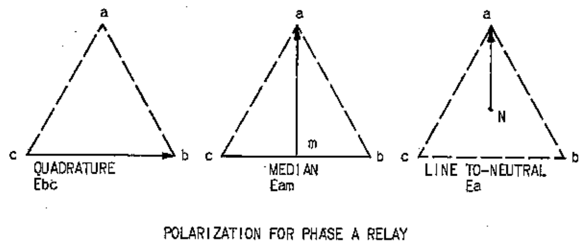


FIG. 3 (0227A2529-0) Types Of Voltage Polarization For Ground Mho Functions

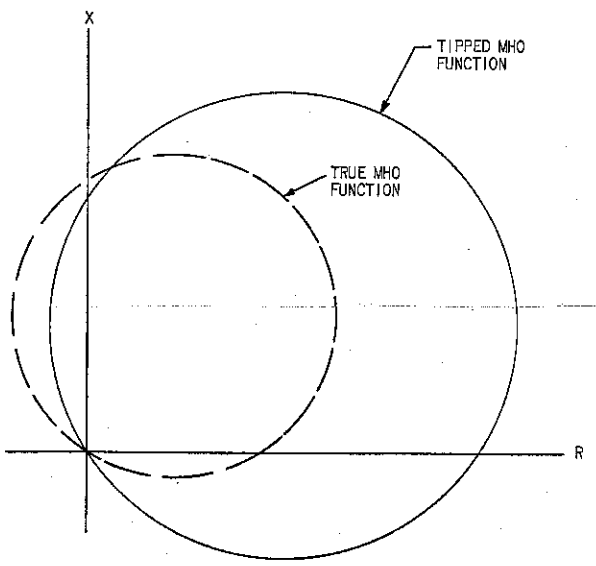


FIG. 4 (0227A2531-0) **Typical** Mho Function Characteristic

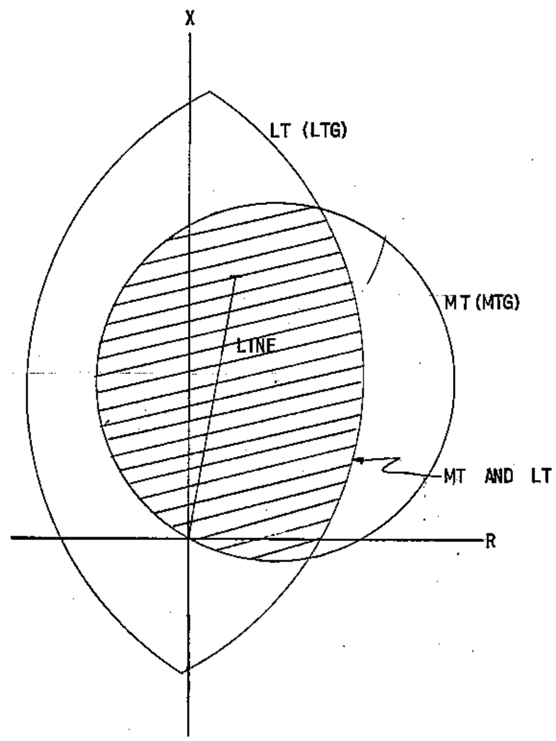


FIG. 5 (0227A2461-2) Lens **And Mho** Function Combination

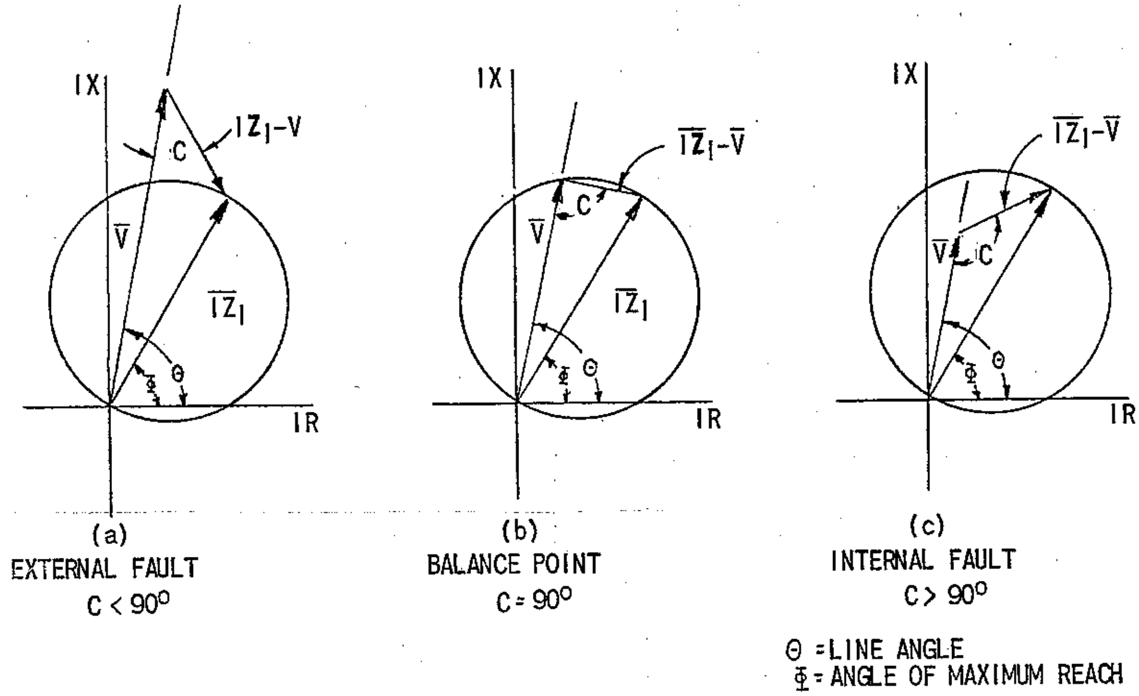


FIG. 6 (0227A2549-0) Mho Characteristics By Phase Angle Measurement

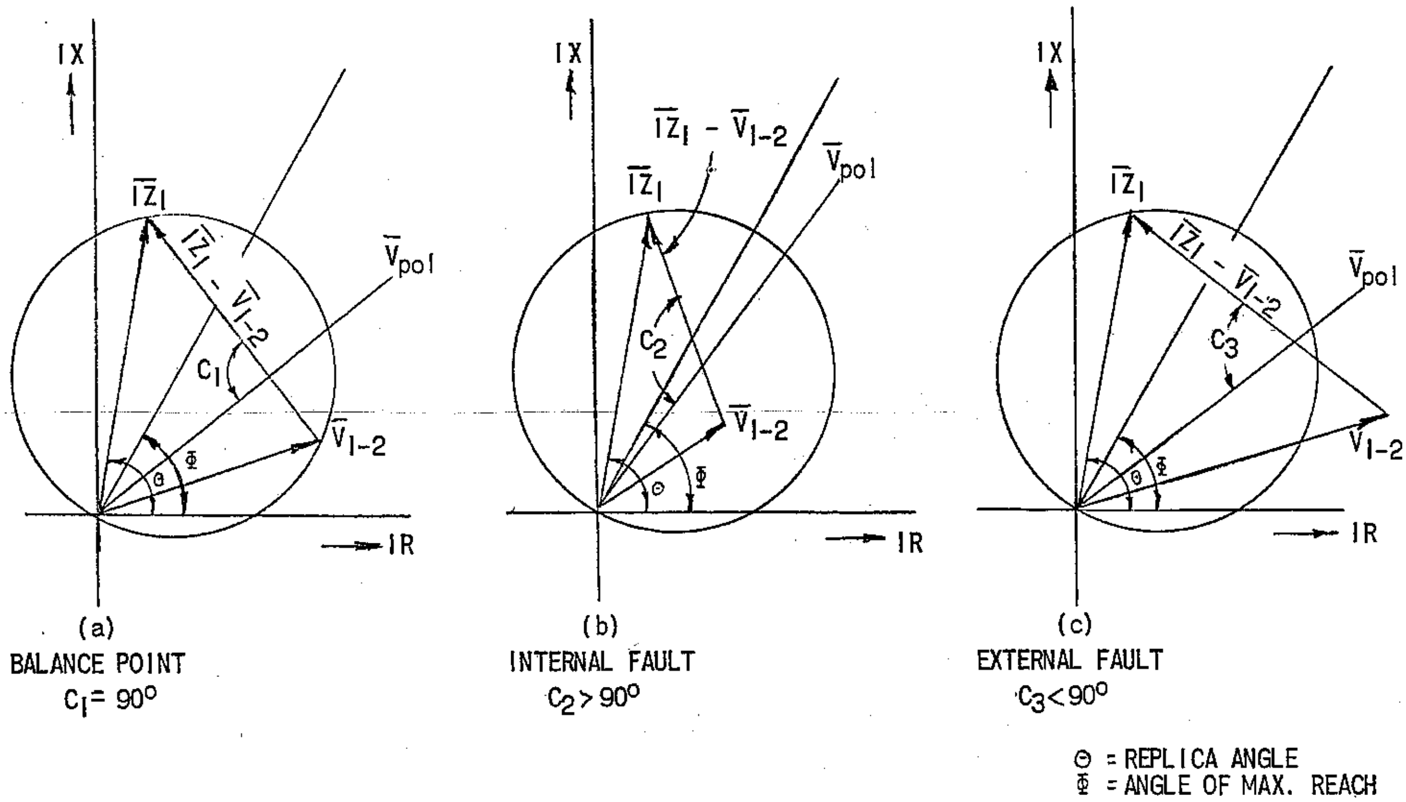


FIG. 7 (0227A2555-0) Mho Unit With Replica Angle

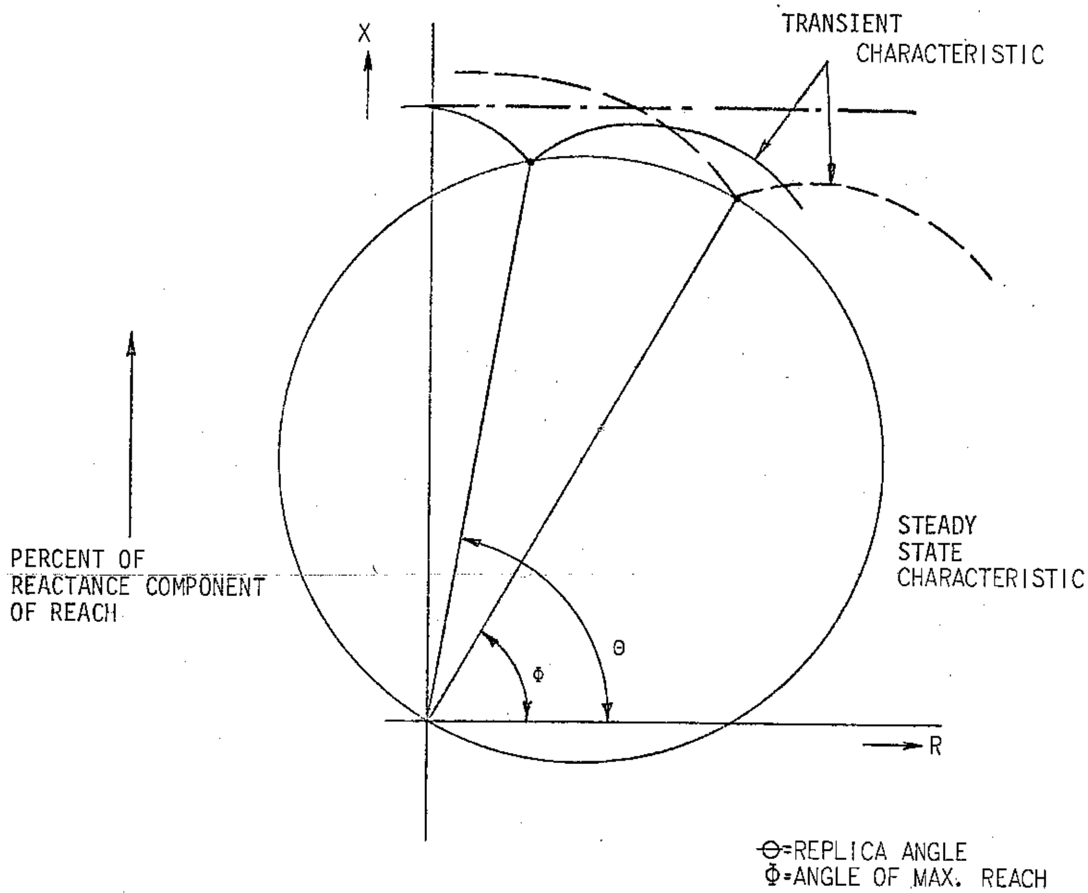


FIG. 8 (0226A7031-0) Mho Function Transient Overreach

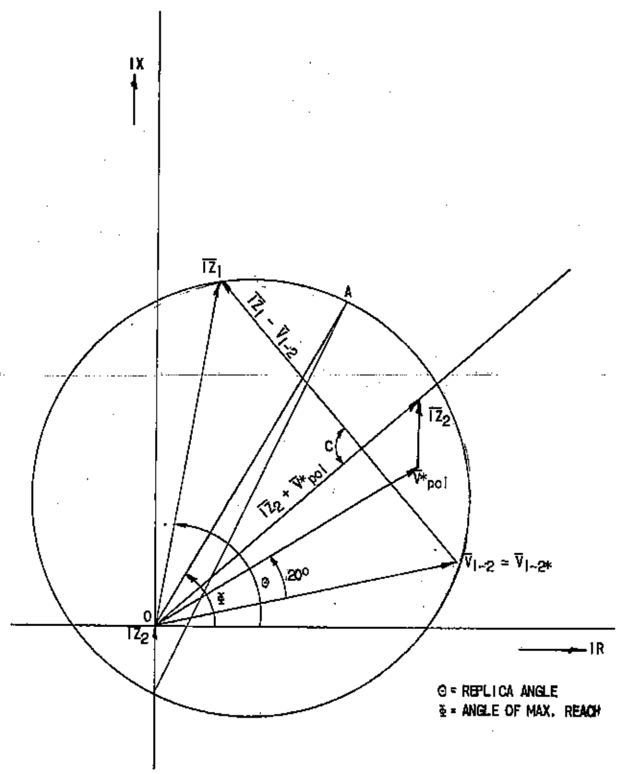


FIG. 9 (0227A2562-0) Mho Function With Replica And Reverse Offset

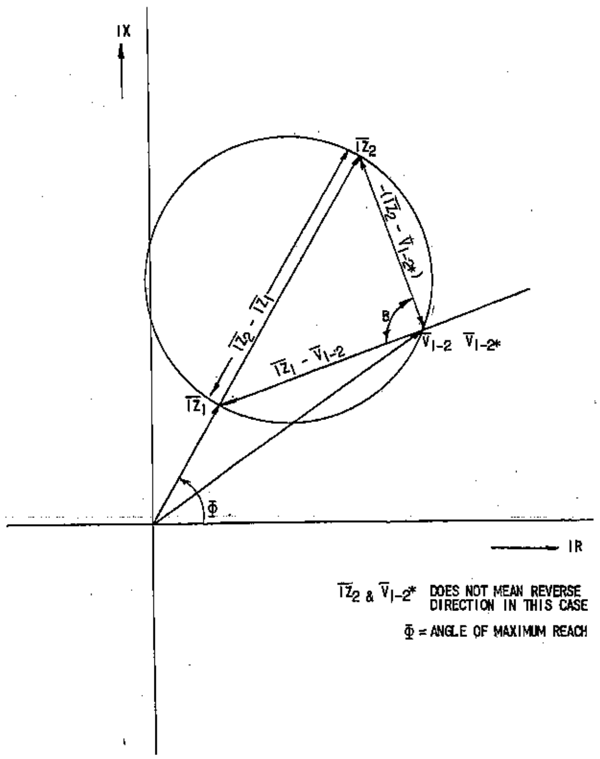


FIG. 10 (0227A2548-0) Mho Function With Forward Offset

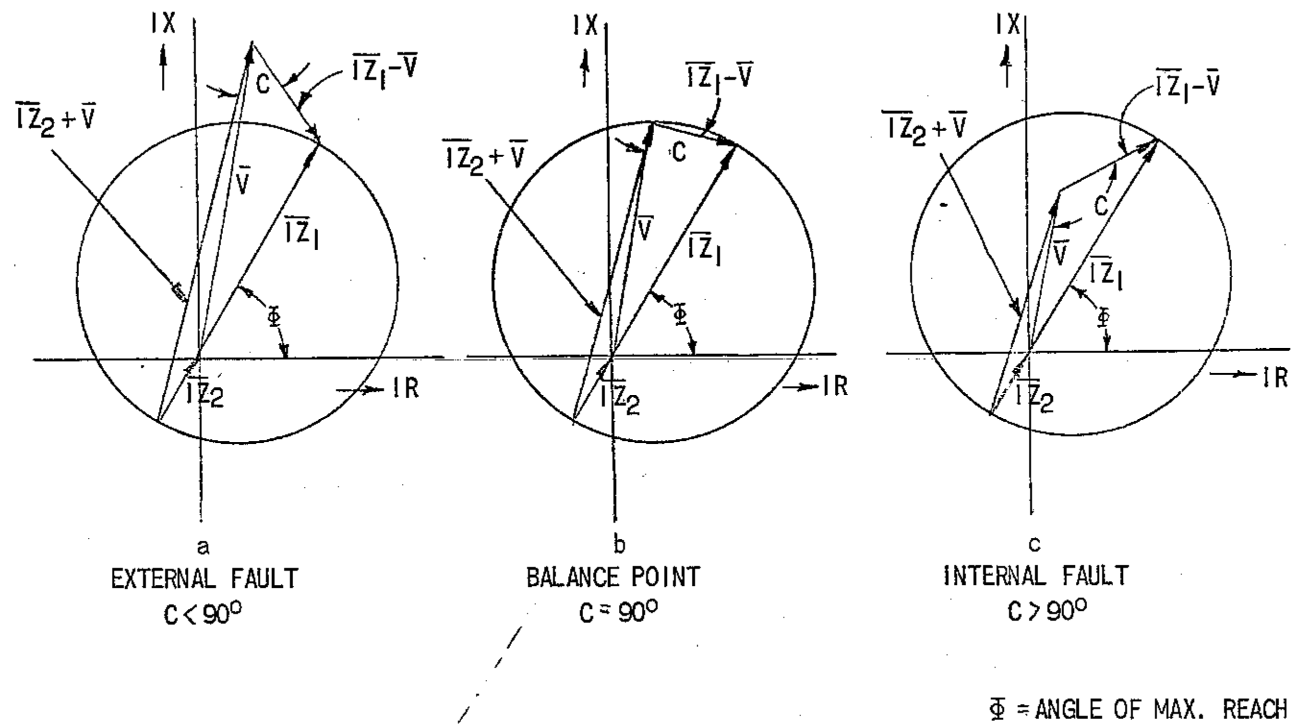


FIG. 11 (0227A2557-0) Offset Mho Characteristic

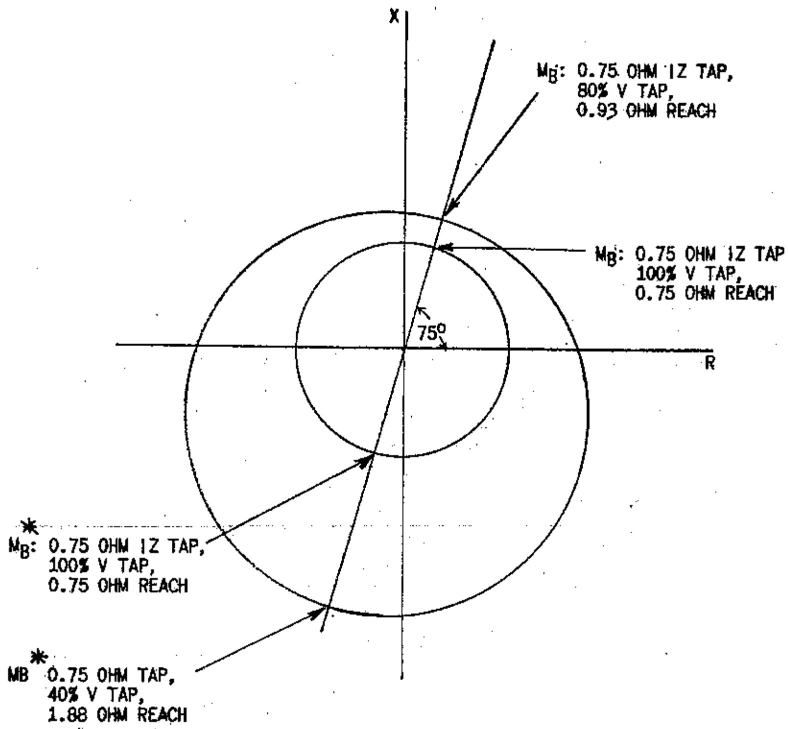


FIG. 12 (0178A7022-0) MB Offset Mho Characteristic

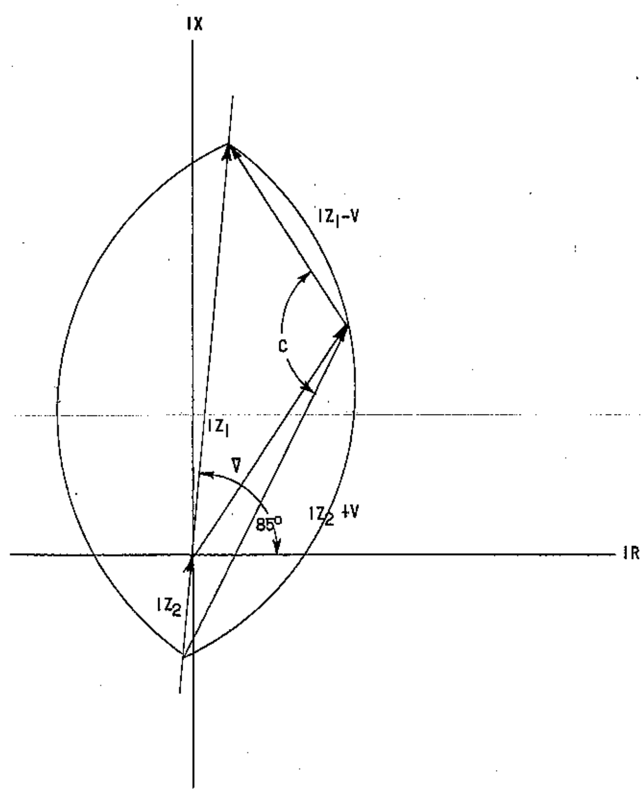


FIG. 13 (0227A2558-1) LTG Functional With Reverse Offset

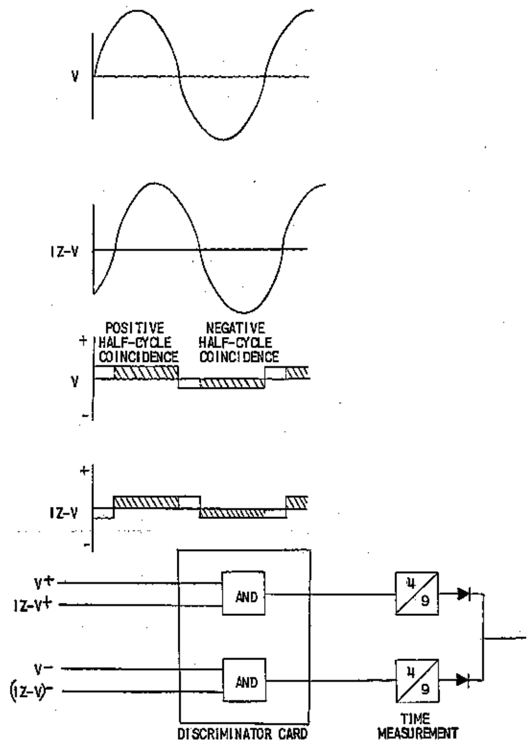


FIG. 14 (0227A2561-0) Coincidence Measurement By Block-Block Method

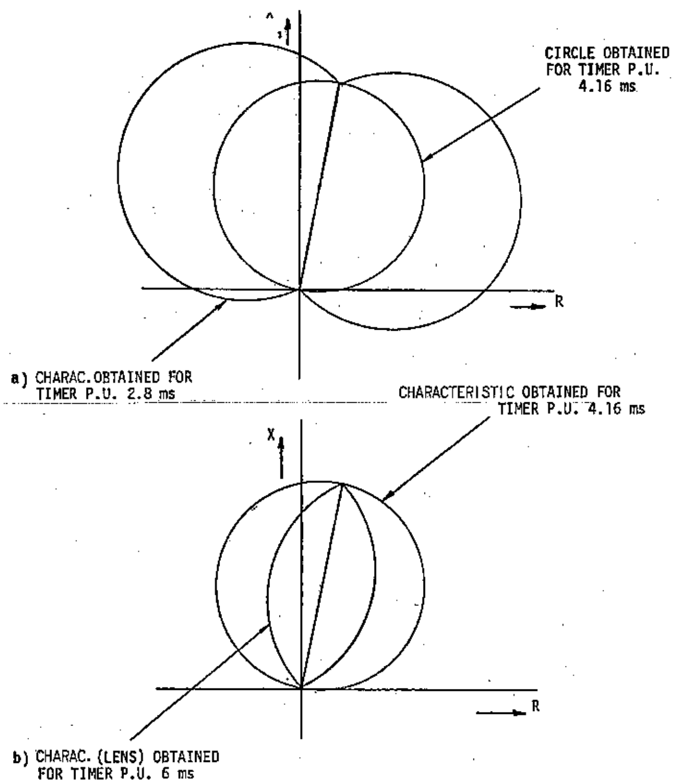


FIG. 15 (0226A7034-0) Mho Operating Characteristic Variation With Coicidence Timer Setting

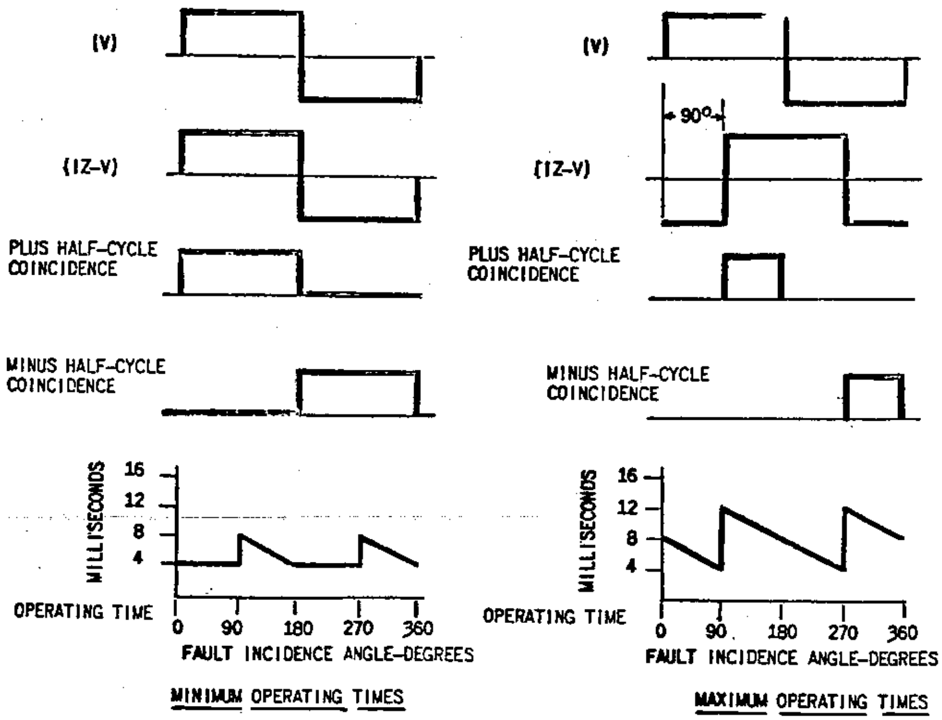


FIG. 16 (0178A7021-0) Mho Measurement Operating Time Characteristics

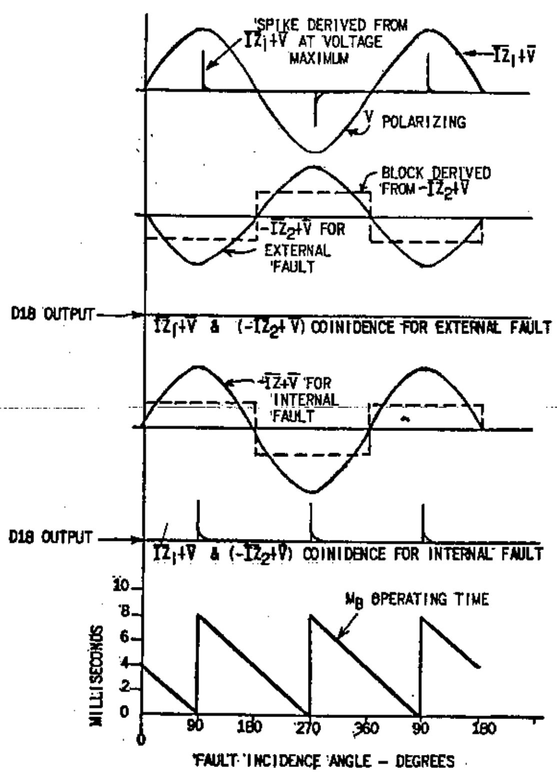


FIG. 17 (0178A7025-2) Coincidence Measurement By Block-Spike Method

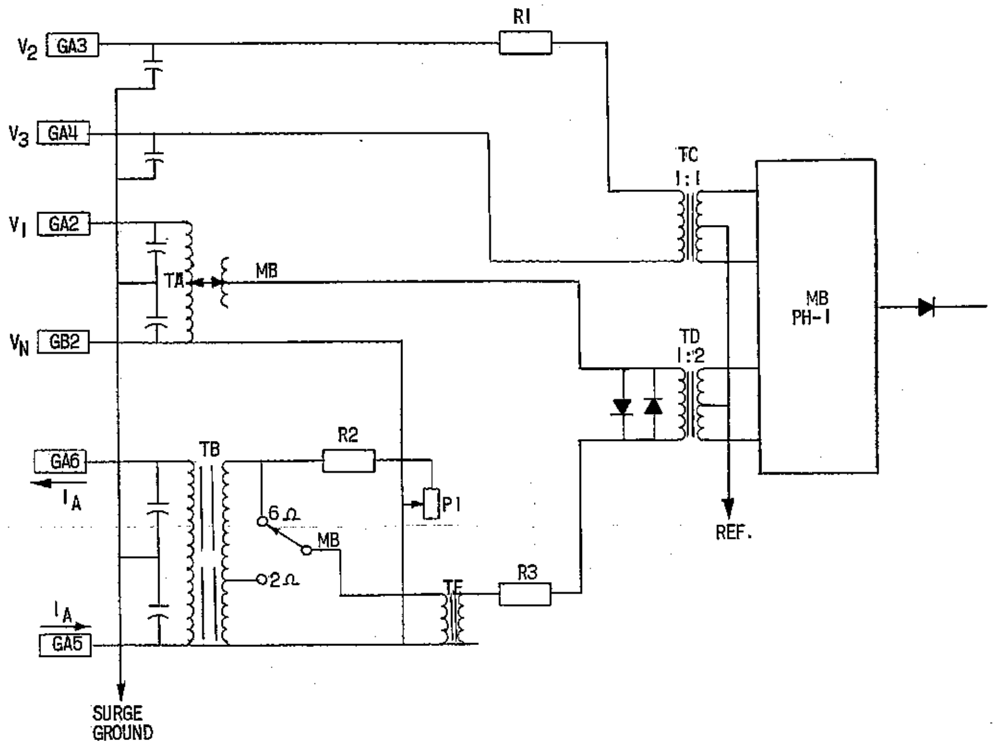


FIG. 18 (0227A2552-0) Typical MB Circuit (Quadrature Polarized)

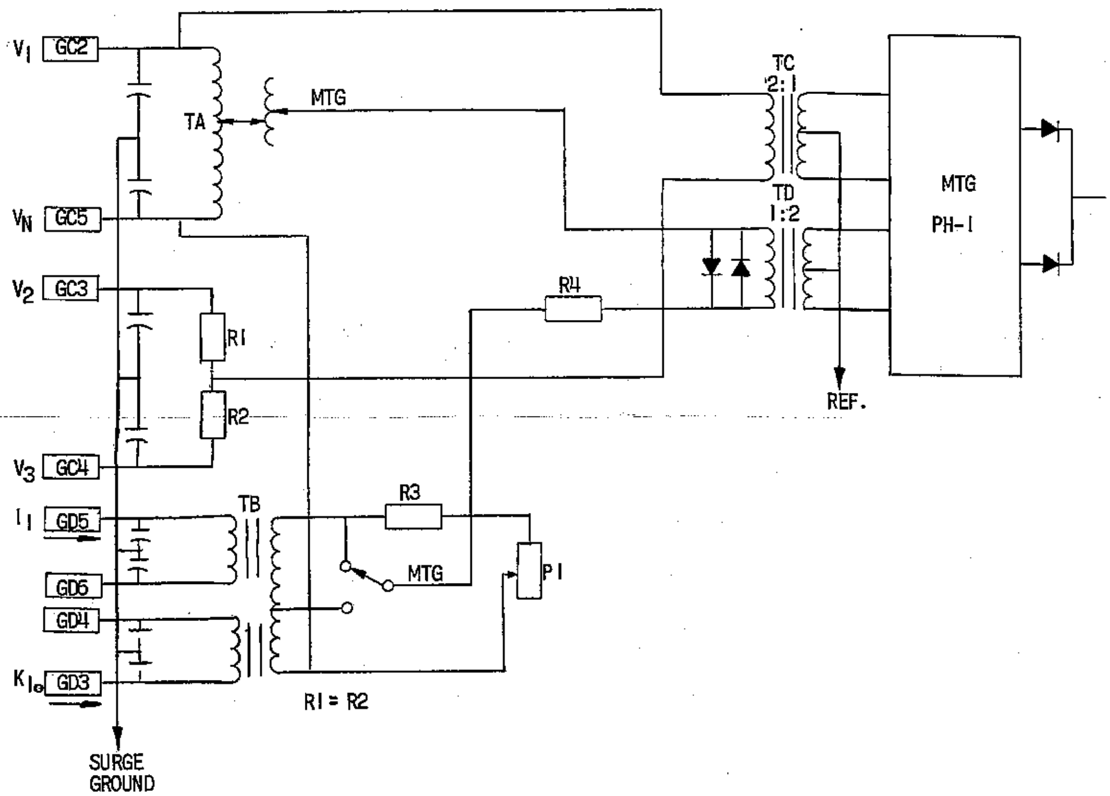


FIG. 19 (0227A2551-0) Typical MTG Circuit (Line-To-Median Polarized)

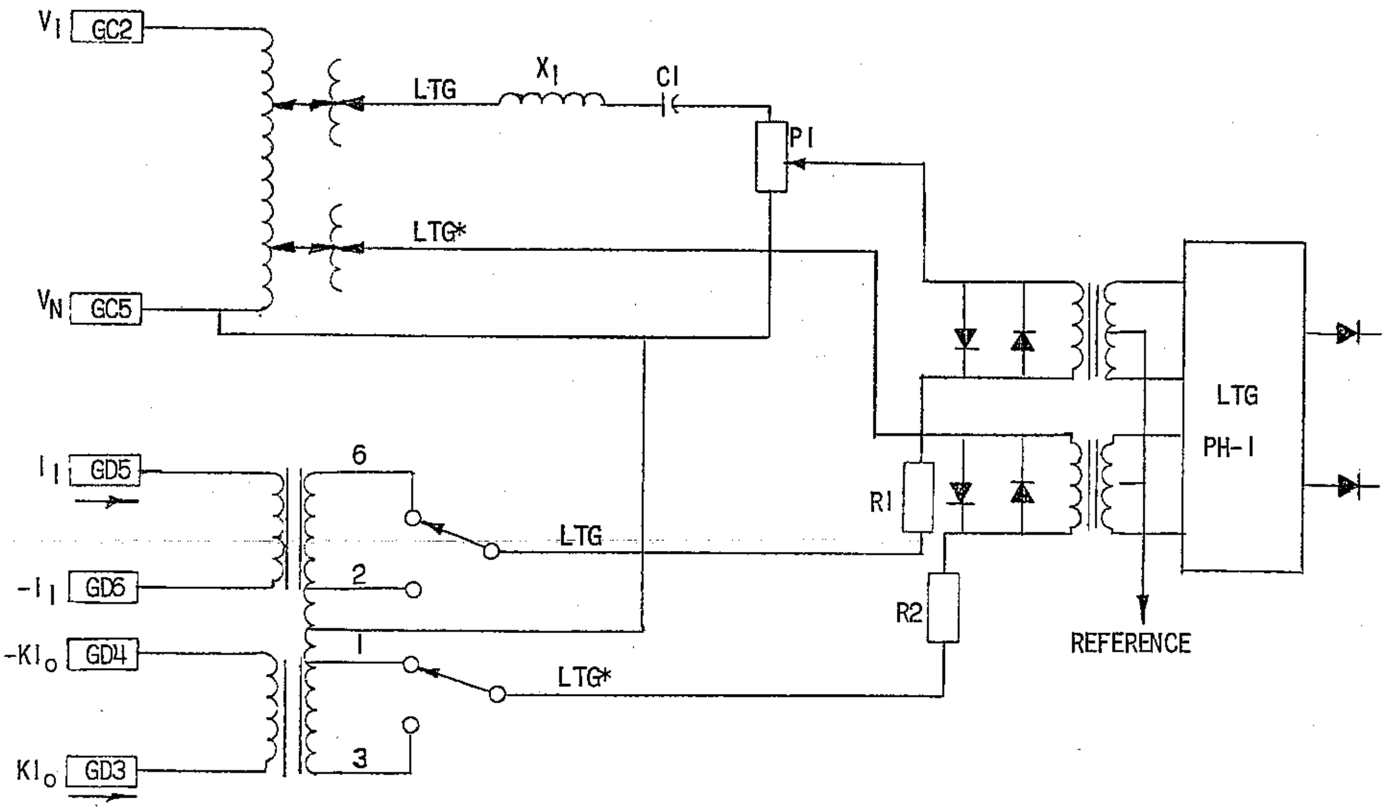


FIG. 20 (0227A2559-0) Typical LTG Circuit (Line-To-Neutral Polarized)

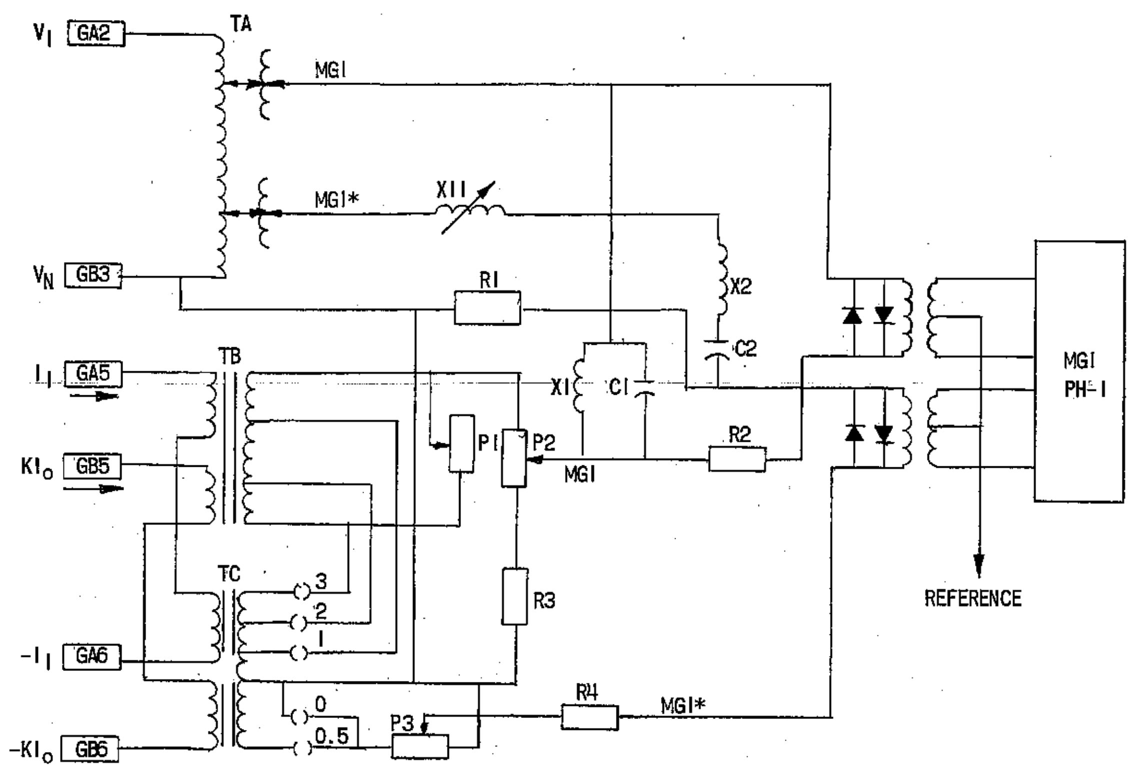
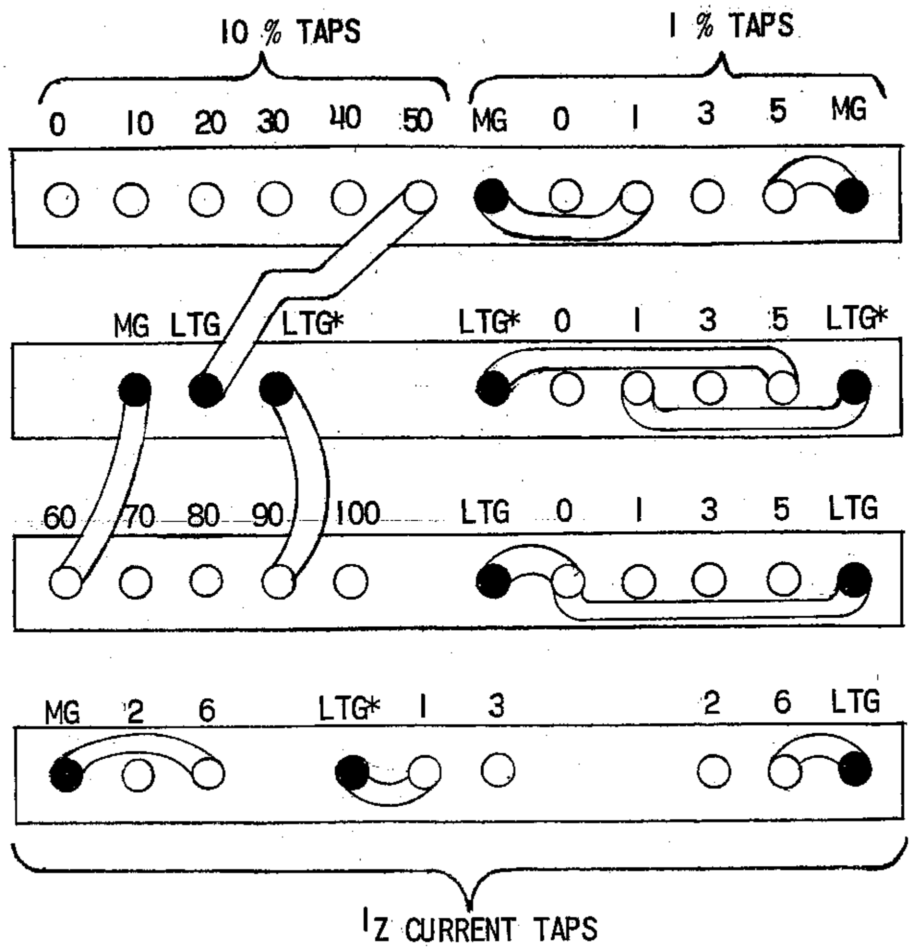


FIG. 21 (0227A2560-0) Typical MG1 Circuit (Line-To-Neutral Polarized With Replica Circuit)



TAP SETTINGS ILLUSTRATED ABOVE

FUNCTION	VOLTAGE	CURRENT	REACH
MG	60 + 4 = 64	6 OHMS	9.4 OHMS
LTG	50 + 0 = 50	6 OHMS	12.0 OHMS
LTG*	90 - 4 = 86	1 OHM	1.6 OHMS

1% VOLTAGE TAPS:

IN-LINE, ADD TO 10% TAP

CROSSED OVER, SUBTRACT FROM 10% TAP

LEGEND: ● FIXED TAP: ROUND HEAD SCREW
○ ADJUSTABLE TAP: KNURLED HEAD SCREW

FIG. 22 (0227A2550-1) Typical SLYG Tap Block Connections

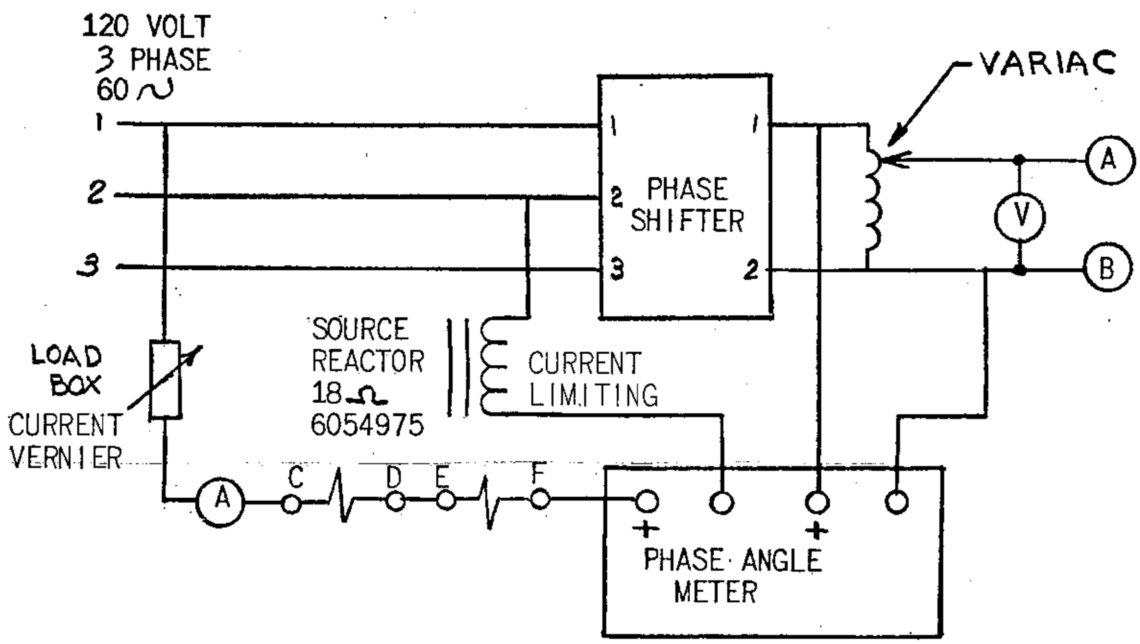


FIG. 23 (0178A7029-3) Phase Shifter Test Circuit

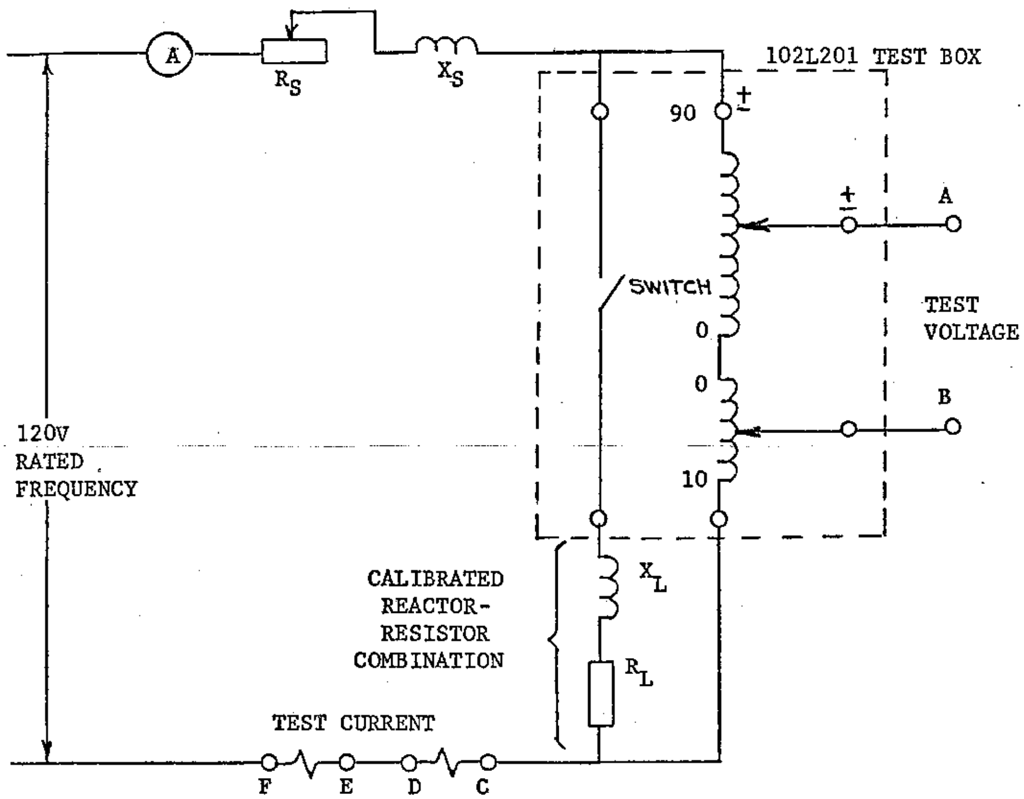


FIG. 24 (0178A7028-3) Test Circuit For Characteristic Check Using Test Box, Test Reactor And Test Resistor

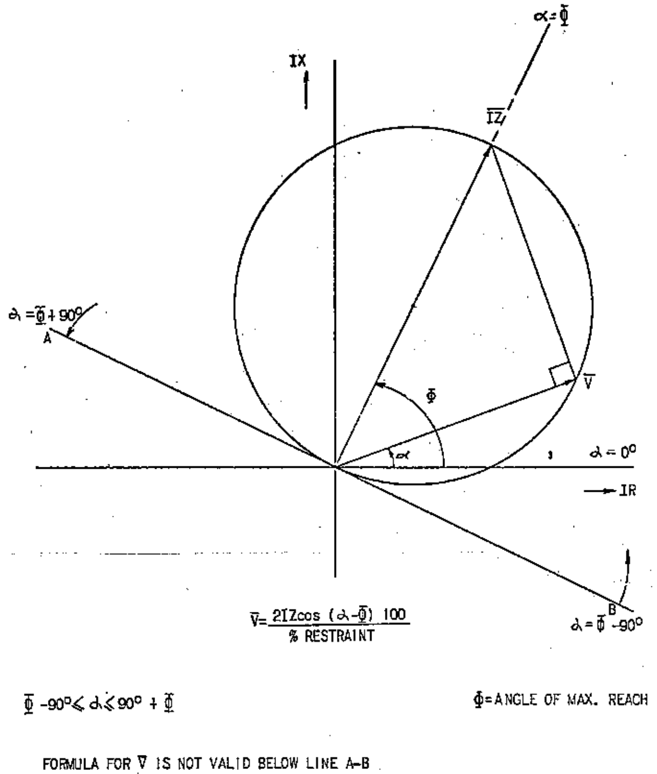


FIG. 25 (0226A7046-2) Measurement Of Mho Characteristic

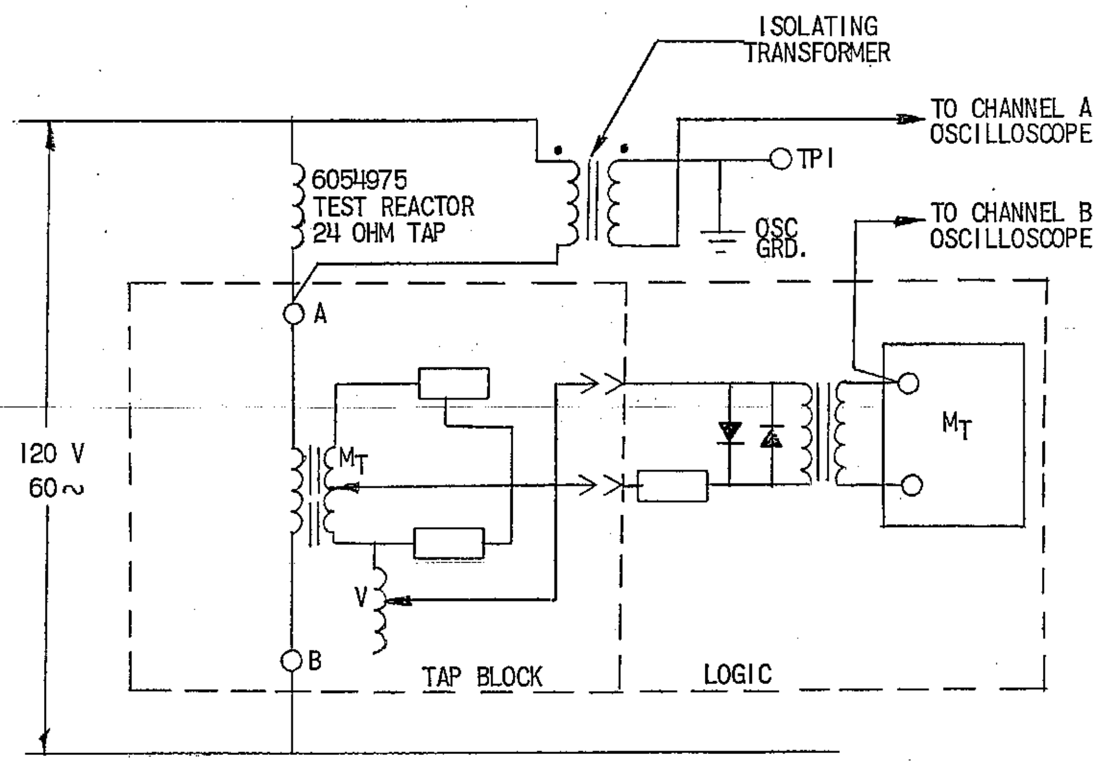


FIG. 26 (0227A2553-0) Test Circuit For Phase Angle Adjustment

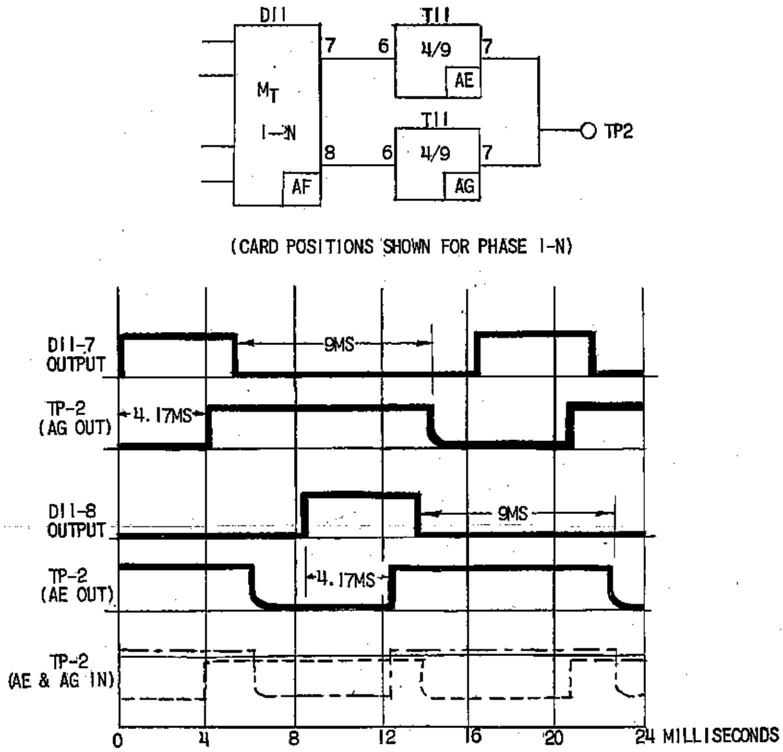


FIG. 27 (0227A2554-0) Test Conditions For 4/9 Timer

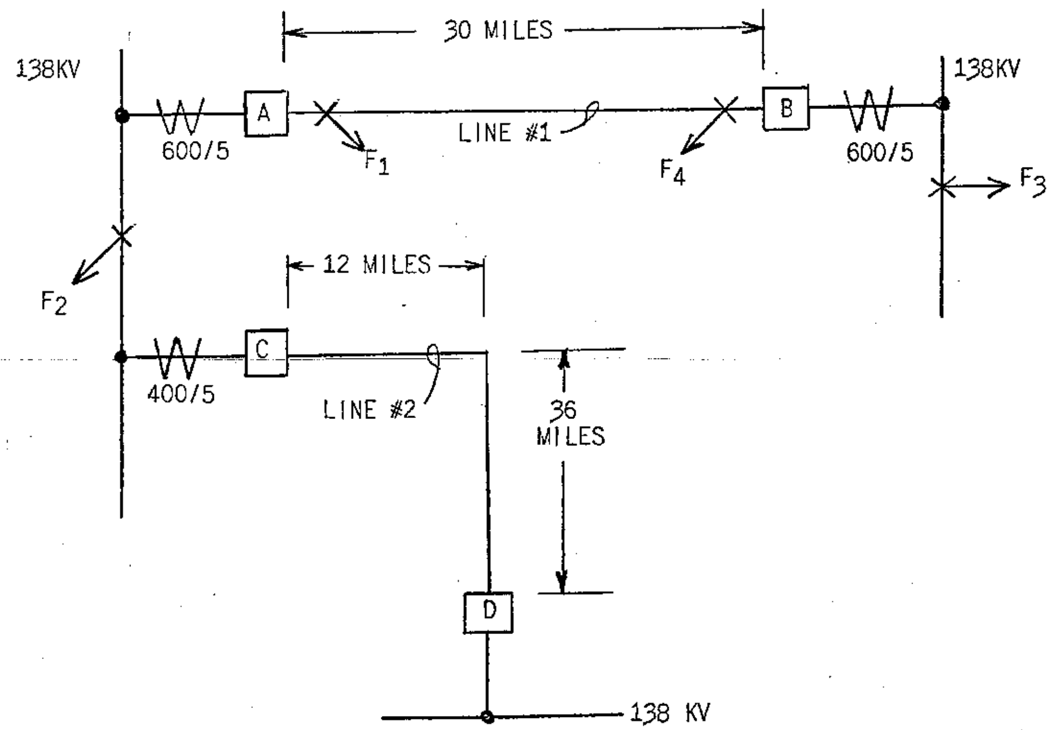


FIG. 28 (0165A7622-0) Examples Of Power Transmission System

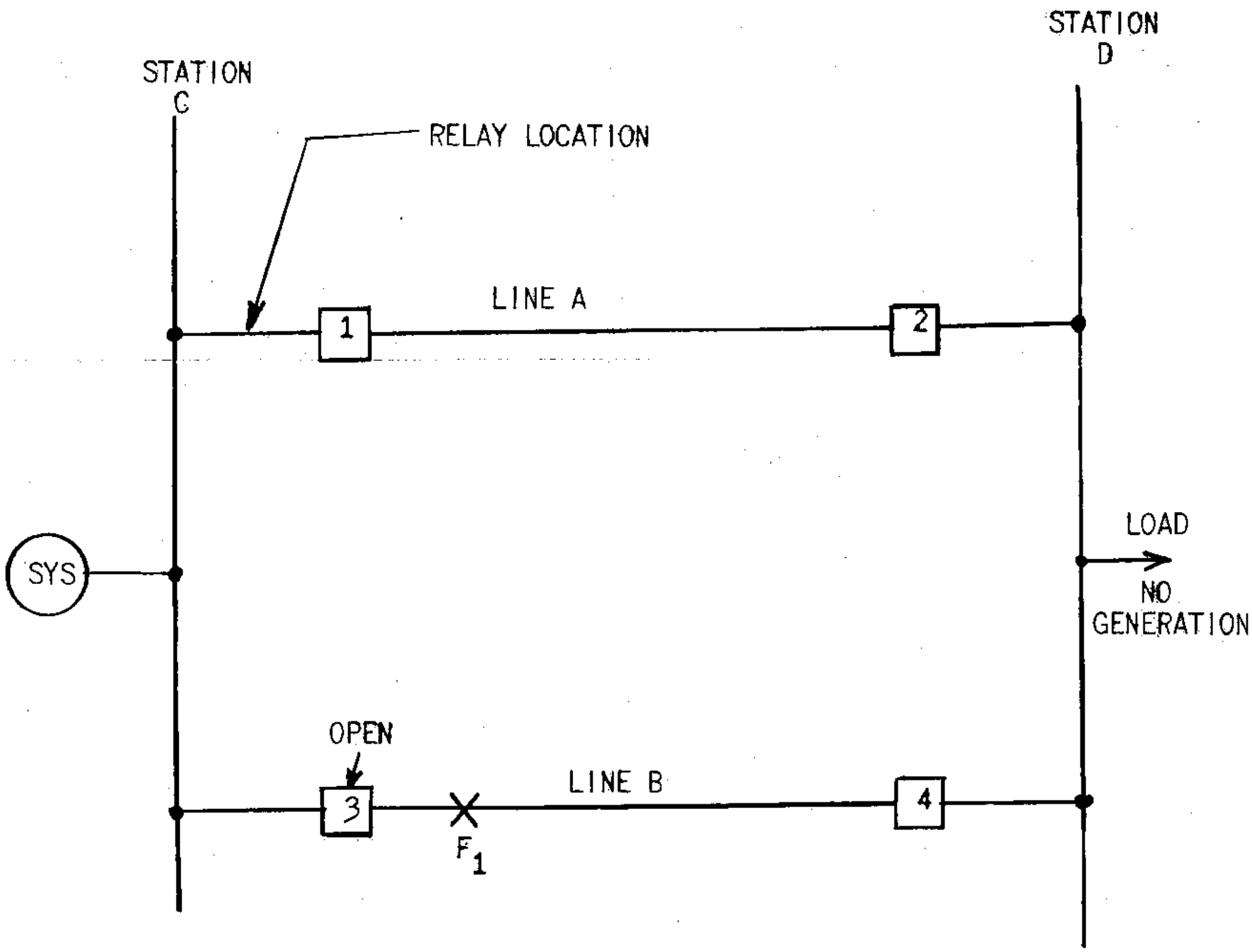


FIG. 29 (0165A7621-0) Parallel Transmission Lines

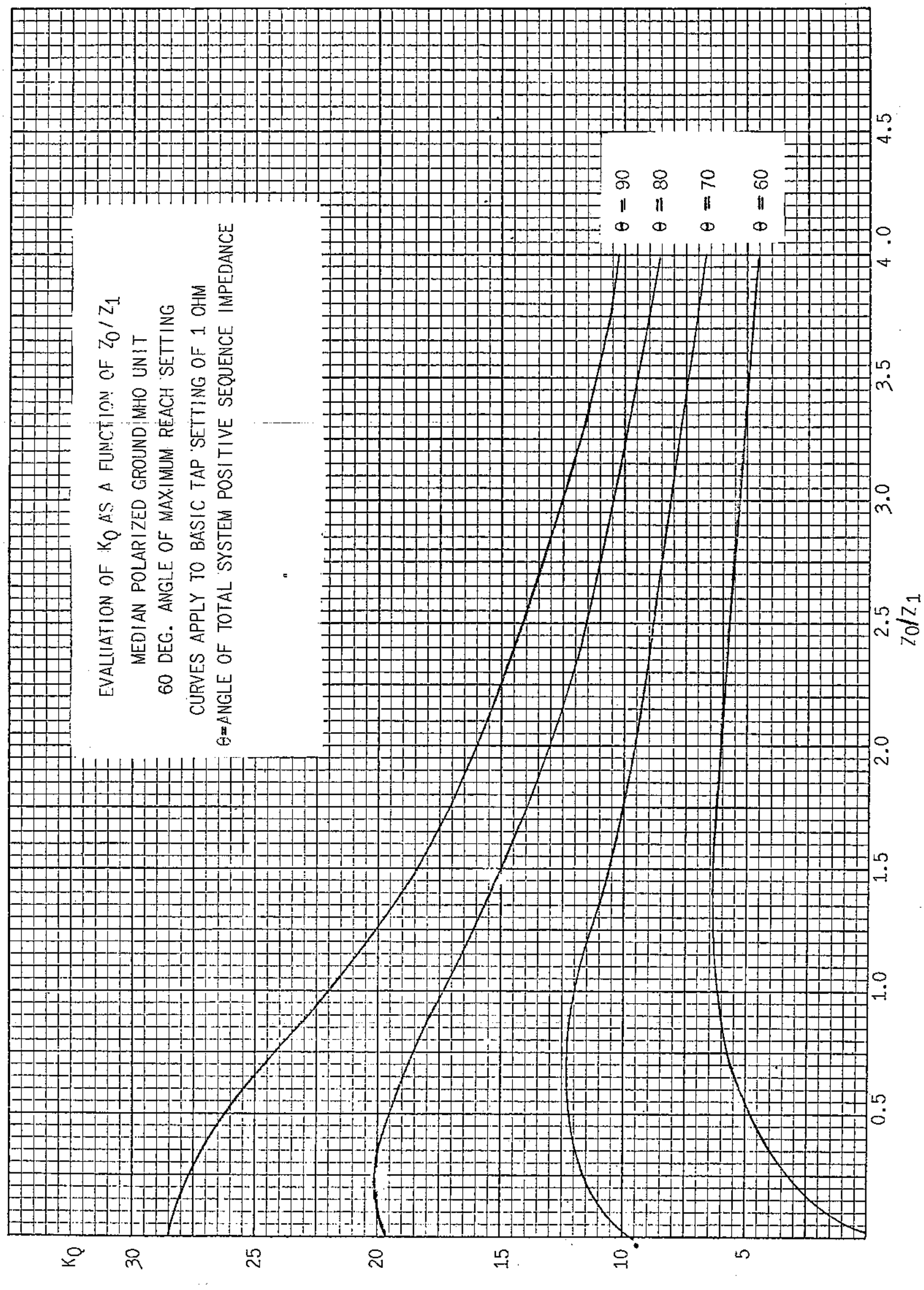


FIG. 30 (0226A6904-1) Evaluation Of K_Q Median Polarization (60°)

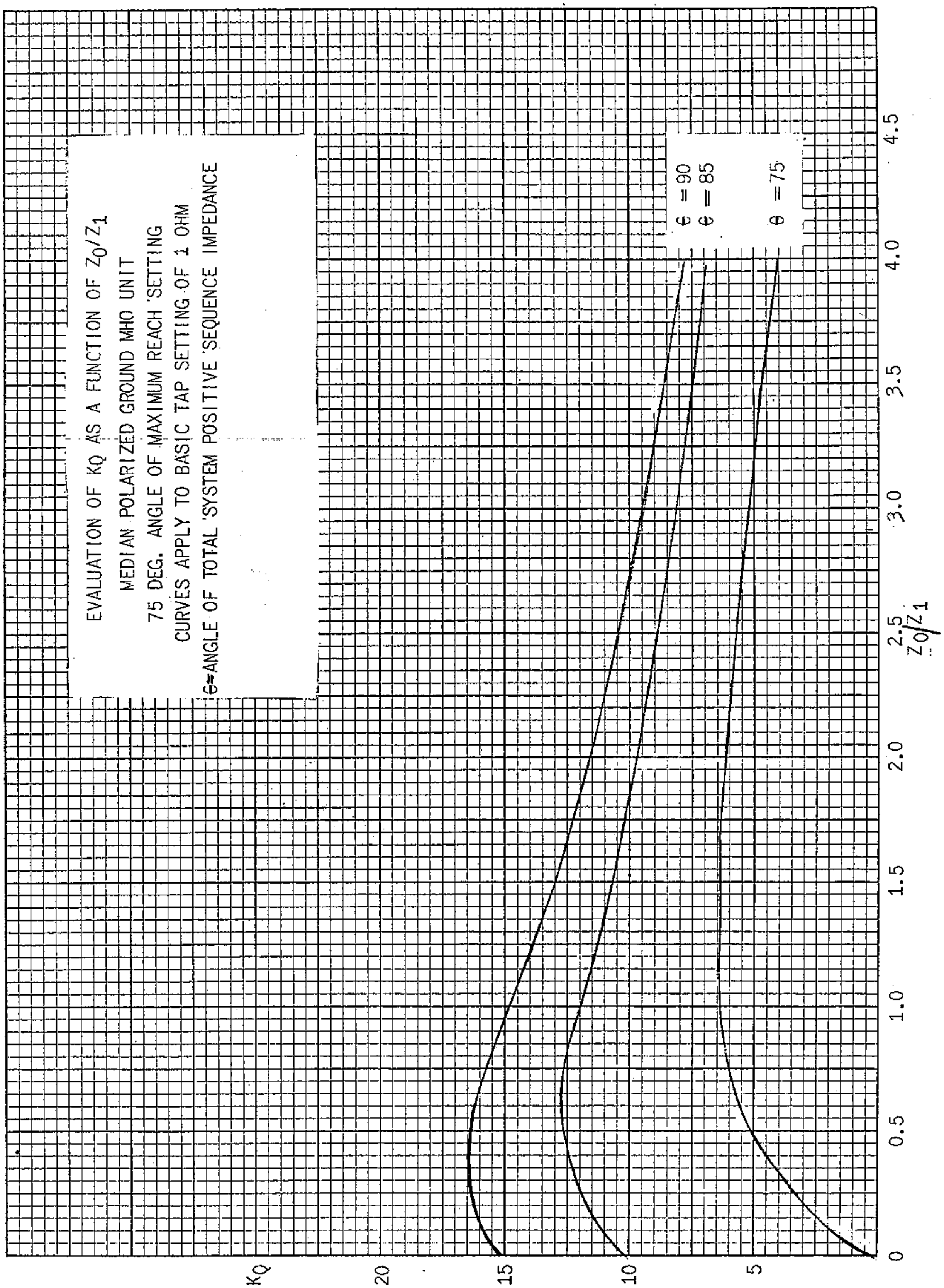


FIG. 31 (0226A6905-1) Evaluation Of K_Q Median Polarization (75^0)

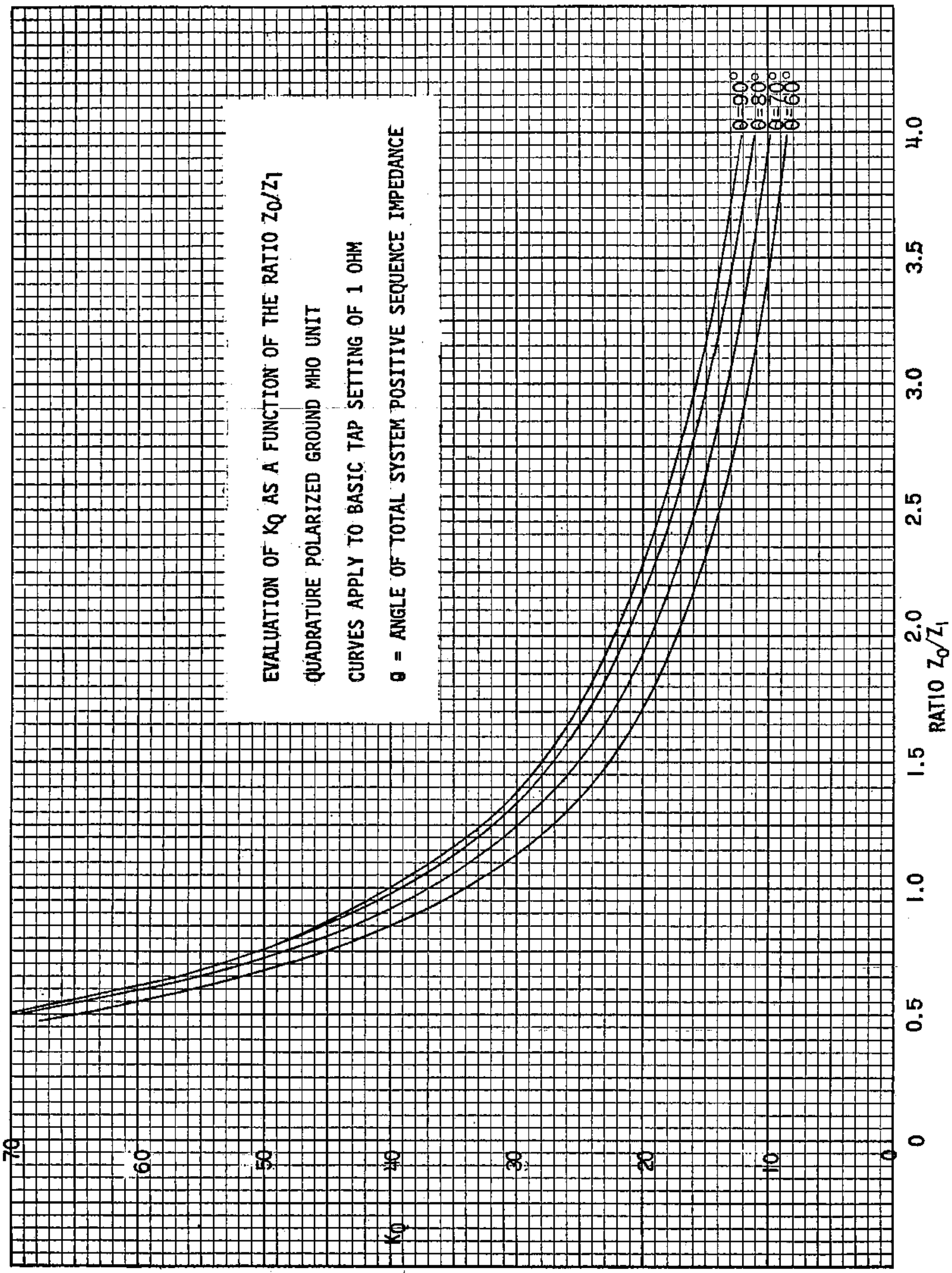


FIG. 32 (0227A2411-0). Evaluation Of K_Q Quadrature Polarization

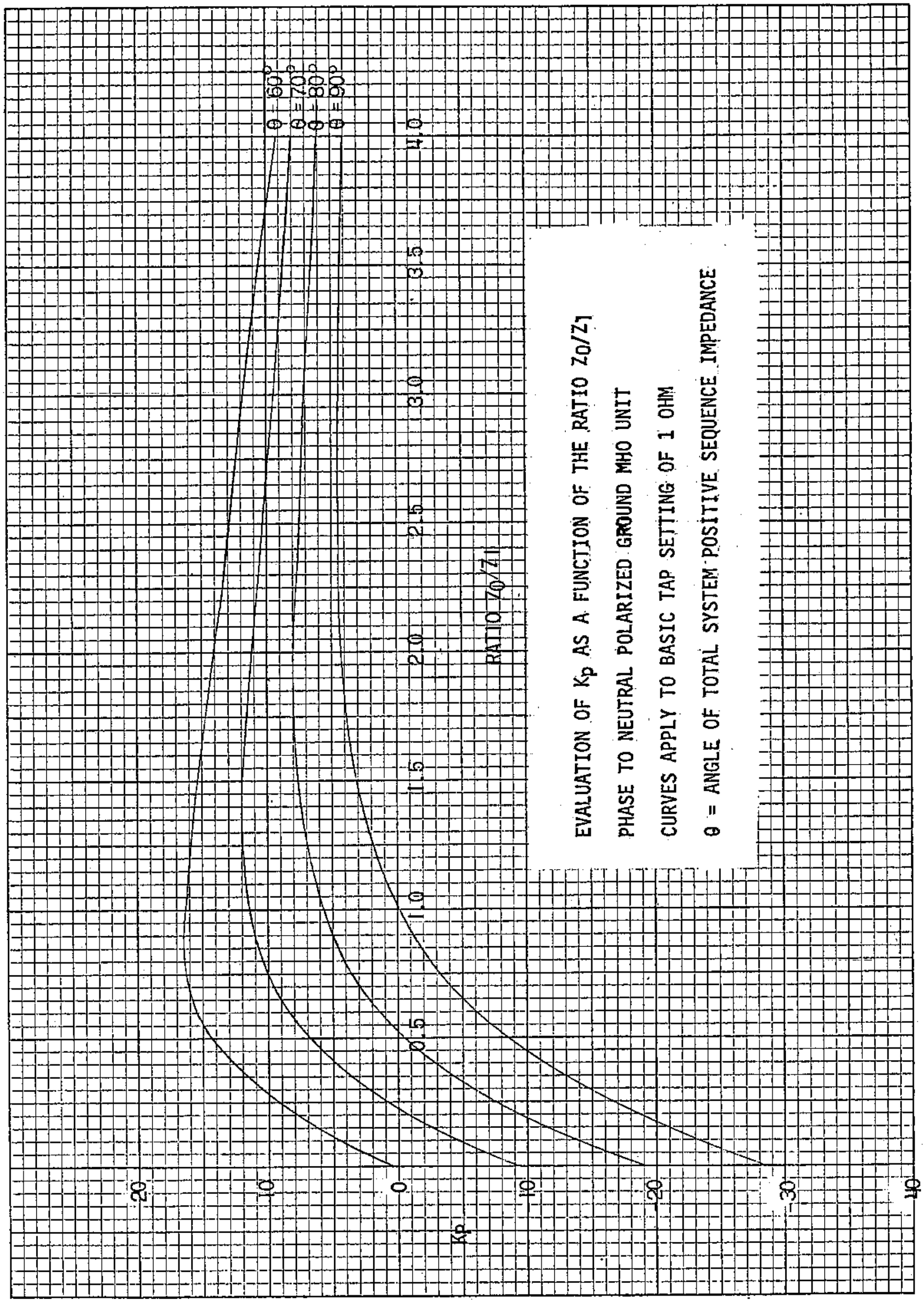


FIG. 33 (0227A2413-0) Evaluation Of K_p Phase-To-Neutral Polarization

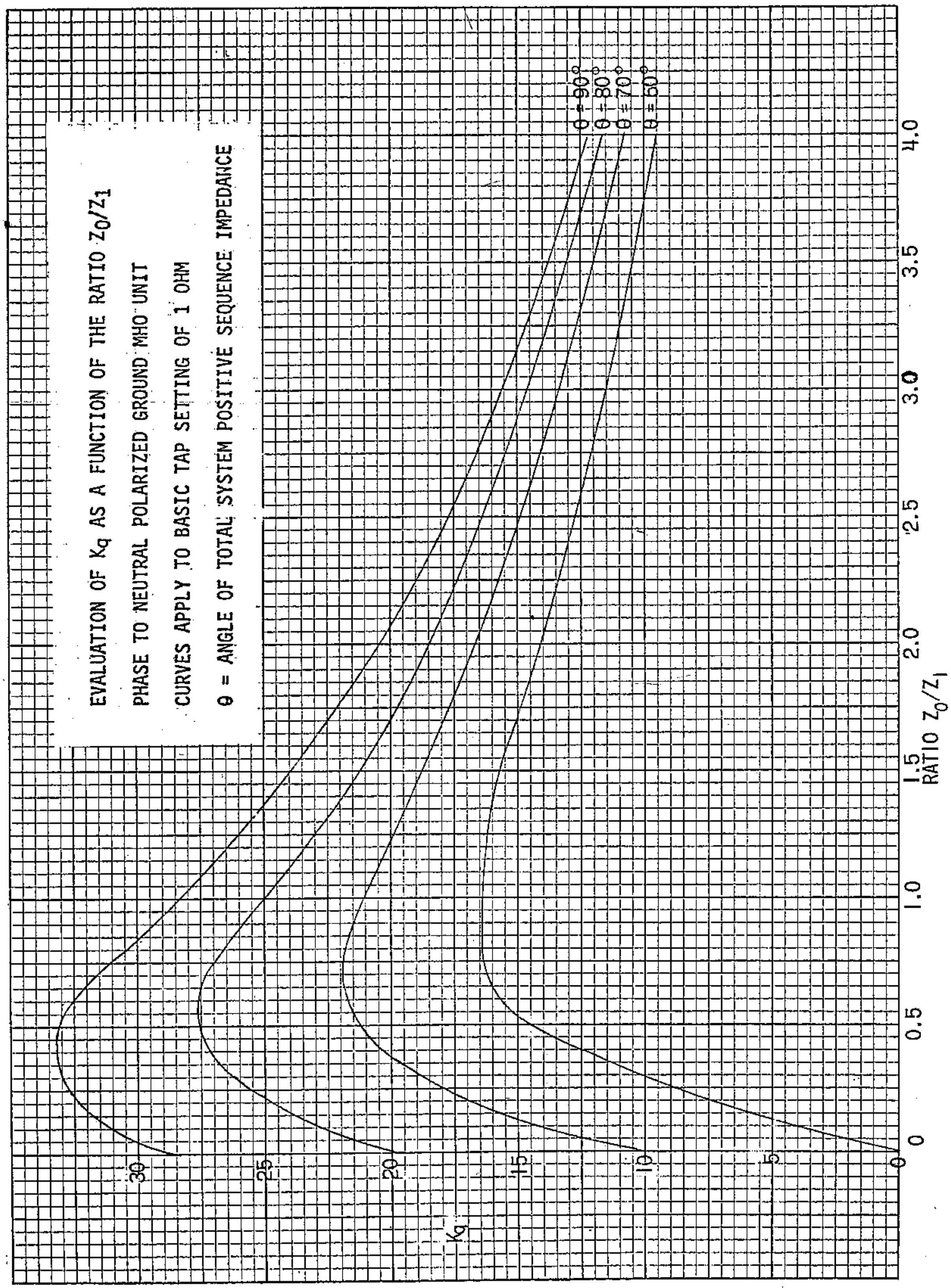


FIG. 34 (0227A2412-0) Evaluation Of K_Q Phase-To-Neutral Polarization

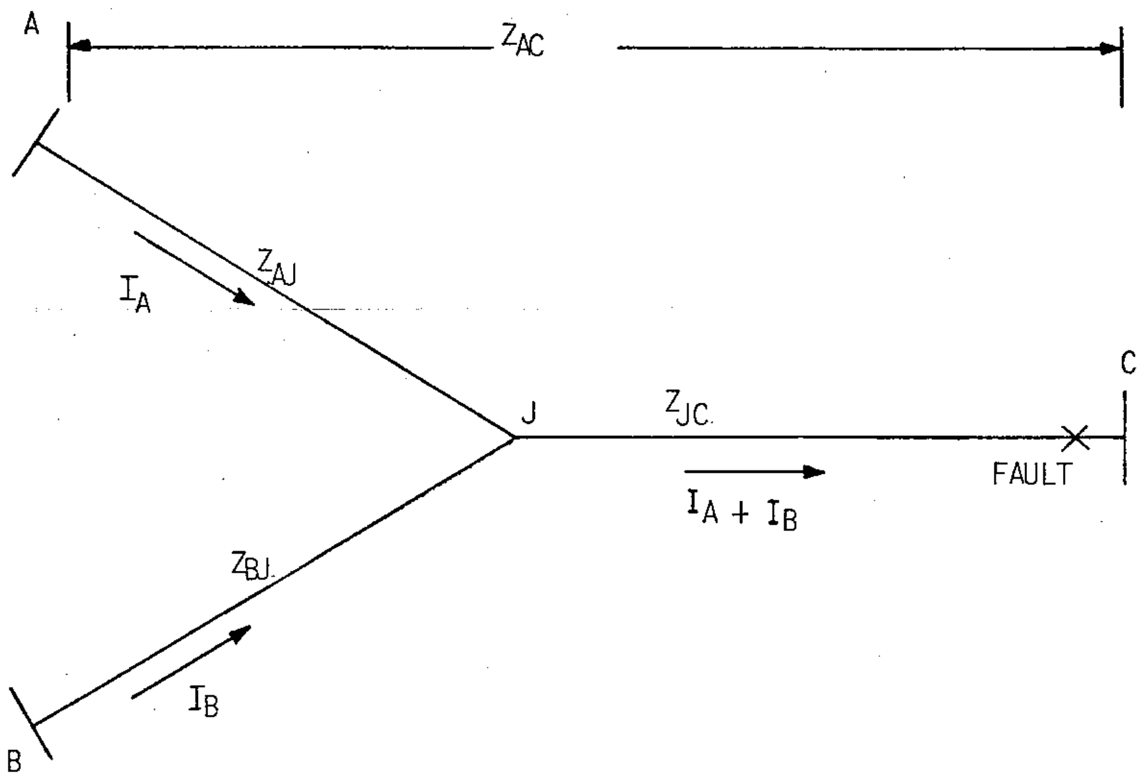


FIG. 35 (0227A2530-0) Three Terminal Line Configuration

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