GEK-45405G

INSTRUCTIONS

DIFFERENTIAL VOLTAGE RELAYS

TYPES

PVD21A
PVD21B
PVD21C
PVD21D

GENERAL ELECTRIC

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DIFFERENTIAL VOLTAGE RELAYS

TYPES:

PVD21A
PVD21B
PVD21C
PVD21D

DESCRIPTION

All the the Type PVD21 relays are single phase, high speed, high impedance, voltage operated relays that are designed to provide protection in bus differential schemes when used in conjunction with suitable current transformers. Typical operating times are shown in Figure 15. Three PVD relays and a lockout relay are required for combined phase and ground fault protection of a three phase bus. Four models of the relay are available as listed in Table 1.

TABLE I

	VOLTAGE UNIT (87L)	CURRENT UNIT (87H)	NO. OF THYRITE® STACKS
PVD21A	Yes	No	1
PVD21B	Yes	Yes	1
PVD21C	Yes	No	2
PVD21D	Yes	Yes	2

The PVD21C and PVD21D models of the relay include two paralleled voltage limiting Thyrite® stacks as opposed to the single stack included in the PVD21A and PVD21B models. This feature makes the PVD21C and PVD21D models better suited to those applications where high internal fault currents can be encountered. This is discussed in detail in the section on **APPLICATION** in this instruction book.

The PVD21B and PVD21D models of the relay include a high speed overcurrent unit (87H) in addition to the voltage operated unit (87L). This unit may be used to supplement the high speed voltage unit, and/or when provided with a suitable external timing device and auxiliaries, it may be used to implement breaker failure protection. This is also discussed in detail in the **APPLICATION** section.

The PVD relays are mounted in a single-end M1 size drawout case, and are provided with a single seal-in and separate targets for each unit. Outline and panel drilling dimensions for the relays are illustrated in Figure 1. Internal connections for the various models are illustrated in Figures 2 and 3.

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The external connections for the PVD21A and PVD21C relays are illustrated in Figure 4; those for the PVD21B and PVD21D relays are shown in Figure 5.

APPLICATION

The following comments on the applications of the Types PVD21A, PVD21B, PVD21C and PVD21D relays may be better appreciated if the detailed section on **OPERATING PRINCIPLES** is reviewed before proceeding. The Type PVD21 relays can be applied for bus protection in most cases where CTs having negligible leakage reactance are used. This generally includes any kind of current transformer with a toroidal core if the windings (on the tap used) are completely distributed about the core. The elementary diagram of the external connections for a typical application is shown in Figures 4 and 5.

A bus differential scheme utilizing Type PVD relays has certain advantages that simplify application considerations:

- Standard relaying-type bushing current transformers may be used
- Performance for specific applications is subject to simple calculations
- Protection is easily extended if the number of connections to the bus is increased.

The following points must be considered before a particular application is attempted:

All CTs in the bus differential circuit should have the same ratio. When adding to an existing bus, at least one CT in the new breaker should be ordered with the same ratio as the bus differential CTs in the existing breakers. If the differential circuit unavoidably includes different ratio CTs, the application may still be possible, but special attention must be given to protect against overvoltage conditions during internal faults.

If one or more of the CTs in Figures 4 or 5 are a different ratio than the others, it would appear that the simple solution would be to use the full winding of the lower ratio CTs and a matching tap on the higher ratio CTs. The high peak voltages that occur during an internal fault will be magnified by the autotransformer action of the tapped higher ratio CTs, and the peak voltages across the full winding of the higher ratio CTs may exceed the capability of the insulation in that circuit. Refer applications involving different ratio CTs to the local General Electric Sales office.

When all current transformers are of the same ratio, full windings, instead of taps, should be used. This will insure maximum sensitivity to internal faults in addition to limiting peak voltages. In any case, CT secondary leakage reactance must be negligible.

It may be possible, although not desirable, to use the differential circuit CTs jointly for other functions. The performance of the system under these conditons can be calculated by including the added burden as part of the CT lead resistance.

However, consideration must be given to the hazards of false operation due to extra connections and errors in testing the added devices. Note that the relays may trip if a CT secondary is open circuited during normal operation of the associated bus.

Thyrite® a non-linear resistance, is used in the relays to limit the voltages that can be developed across the relay during an internal fault to safe values. The magnitude of the voltage that can be developed will be a function of the total internal fault current and the characteristics of the CTs used in the differential circuit. Figure 9 illustrates the safe application limits for the PVD21A and PVD21B relays as a function of the total fault current and the knee point voltage (E_S) of the poorest CT in the circuit. If the fault current and knee point voltage are such that the intersection of these two points plots below the curve, then the application will be safe with respect to the voltage limits. Note that this curve applies for the PVD21A and PVD21B relays which have a single stack of Thyrite®. If the application of these relays does not appear to be permissible on the basis of Figure 9, it may still be permissible if the PVD21C or PVD21D relay is used. These relays have two stacks of Thyrite® connected in parallel so that significantly greater internal fault currents can be accomodated. Figure 10 may be used to determine the safe application limits for the PVD21C and PVD21D relays.

During an internal fault, current will flow in the Thyrite® stack, causing energy to be dissipated. To protect the Thyrite® from thermal damage, a contact of the lockout relay must be connected as shown in Figures 4 and 5 to short out the Thyrite® during an internal fault. The thermal limits of the Thyrite® will not be exceeded provided the relay time, plus lockout relay time, is less than four cycles.

An instantaneous overcurrent unit, 87H, is connected in series with the Thyrite® in PVD21B and PVD21D models. The 87H unit, when set with the proper pickup, may be used to supplement the voltage unit, 87L, and/or implement breaker failure protection when a suitable timing relay and other auxiliary devices are provided by the user. The required setting of the 87H unit is related to the actual setting of the 87L unit.

Figure 8 illustrates the setting to be made on 87H as a function of the 87L setting. Thus, once the voltage unit setting has been calculated, the current unit setting is easily determined.

Figure 5, which applies to the PVD21B and PVD21D relays, shows the contact of the lockout relay connected to short out the Thyrite® only. However, the 87H unit is not shorted so that the relay can continue to operate as an overcurrent function, because it will stay picked up until the fault is cleared. The 87H unit may be used to implement breaker failure protection. Device 62X can be connected as shown in Figure 5A to initiate operation of the breaker failure timer.

The curve of Figure 8, which illustrates the 87H setting as a function of the 87L setting, includes sufficient margin to insure that the overcurrent unit will not operate during an external fault. For this reason, the 87H unit will be less sensitive than the 87L unit, and it may not operate for all internal faults. However, it will pick up as soon as the lockout relay operates, provided the fault current is above the pickup setting. In those cases where the 87H unit does not pick up until the lockout relay oprates, the dropout time of 87L is sufficient to overlap the pickup time of 87H, so that a continuous input will be provided to device 62X.

If any of the bus differential CTs are protected by primary and/or secondary voltage limiting devices, such as vacuum gaps, which might be the case if the bus differential zone included shunt capacitor banks, additional considerations are necessary to ensure a reliable application. Some means must be incorporated to prevent this protective equipment from shorting the operating coils of the PVD during internal faults. Such applications may be referred to the local General Electric Sales Office.

The external connection diagrams of Figures 4 and 5 indicate that the differential junction points for the relays are located in the switchyard. For outdoor installations where there is a great distance between the breaker and the relay panel, it may be desirable to locate the differential junction in the switchyard, since the resistance of the fault CT loop may otherwise be too large (refer to the section, **CALCULATION OF SETTINGS**). Note that the cable resistance from the junction point to the relay is not included as part of the fault CT loop resistance. It is permissible to locate junction points at the panel, providing that the resulting relay setting gives the desired sensitivity.

The 87L unit should be set no higher than 0.67 times the secondary excitation voltage at ten amperes secondary excitation current (evaluated for the poorest CT in the differential circuit).

When circuit breakers are to be bypassed for maintenance purposes, or when any other atypical setup is to be made, other means than simply opening the PVD contact circuit should be used to avoid incorrect tripping. Voltages that exceed the continuous rating of the PVD may be developed with the high impedance operating coil still connected in the differential circuit. This can be avoided by removing the connection plug, or if external means are required, by short circuiting studs 4 and 5 to stud 6.

The following information must be obtained before settings are determined for a particular application:

- Determine the secondary winding resistance for all the CTs involved
- Obtain the secondary excitation curves for all the CTs involved
- Determine the resistance of the cable leads from the CTs to the differential junction point.

CONSTRUCTION

The Type PVD relays are assembled in the medium size single-end (M1) drawout case having studs at one end in the rear for external connections. The electrical connections between the relay and case studs are through stationary molded inner and outer blocks, between which nests a removable connecting plug. The inner block has the terminals for the internal connections.

Every circuit in the drawout case has an auxiliary brush, as shown in Figure 13, to provide adequate overlap when the connecting plug is withdrawn or inserted. Some circuits are equipped with shorting bars (see internal connections, Figures 2 and 3), and it is especially important that the auxiliary brush make contact on those circuits with adequate pressure to prevent the opening of important interlocking circuits, as indicated in Figure 13.

The relay mechanism is mounted in a steel framework called the cradle and is a complete unit with all leads terminated at the inner block. This cradle is held firmly in the case with a latch at both top and bottom and by a guide pin at the back of the case. The connecting plug, besides making the electrical connections between the respective blocks of the cradle and case, also locks the latch in place. The cover, which is drawn to the case by thumbscrews, holds the connecting plugs in place. The target reset mechanism is a part of the cover assembly.

The relay case is suitable for either semiflush or surface mounting on all panels up to two inches thick, and appropriate hardware is available; however, panel thickness must be indicated on the relay order to insure that the proper hardware will be included. Outline and panel drilling dimensions are shown in Figure 1.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its own source of current and voltage, or from other sources. The relay also can be drawn out and replaced by another which has been tested in the laboratory.

The relays covered by these instructions include two hinged armature type operating units: a "low-set" voltage unit, device 87L, and a "high-set" current unit, device 87H.

Device 87L is an instantaneous telephone-type voltage unit having its coil connected across the DC terminal of a full wave rectifier. In turn, the rectifier is connected to a high pass filter through an attenuator network. The 87L unit has two normally open contacts. One set of contacts is connected between terminals 7 and 8, and the other set is connected in parallel with the contacts of the seal-in unit.

Device 87H is an instantaneous overcurrent unit, mounted in the upper right hand corner, with its coil connected in series with Thyrite® resistor discs. A single set of normally open contacts is connected between terminals 9 and 10.

Hi-Seismic Seal-in Unit

A seal-in unit is mounted in the upper left corner of the relay (see Figure 3). The unit has its coil in series and its contacts in parallel with a set of normally open contacts of the 87L unit. When the seal-in unit picks up, it raises a target into view. The target latches up and remains exposed until it is released by manual operation of the reset button, which is located at the lower left corner of the relay.

RANGES

These relays are available for 60 hertz. The standard operating ranges available are given in the table below. Factors which influence the selection of the operating range are covered in the section on **CALCULATION OF SETTINGS**.

TABLE 2

87L UNIT RANGE	LINK POSITION	RANGE VOLTS	CONTINUOUS RATING VOLTS
75-500	L H	75 - 220 200 - 500	150 150

TABLE 3

87H HI-SEISMIC INSTANTANEOUS UNIT (AMPS)	LINK POSITION	**RANGE (AMPS)	CONTINUOUS RATING (AMPS)	**ONE SECOND RATING (AMPS)
2-50	L H	2 - 10 10 - 50	3.7 7.5	130

**The range is approximate, which means that the 2-10, 10-50 ampere range may be 2-8, 7-50 amperes. There will always be at least one ampere overlap between the maximum L setting and the minimum H setting. Select the higher range whenever possible, since it has the higher continuous rating.

For other ranges, consult the local General Electric Sales Office.

87L Continuous Rating

The voltage circuit included in the 87L unit has a continuous voltage rating of 150 volts RMS. Refer to the **ACCEPTANCE TESTS** section for precautions that should be taken during testing.

Contacts

The current closing rating of the contacts is 30 amperes for voltages not exceeding 150 volts. The current carrying rating is limited by the seal-in unit rating.

HI-SEISMIC TARGET AND SEAL IN UNIT

The Type PVD relay is provided with a universal target and seal in unit having 0.2 and 2.0 ampere taps as indicated in the following tabulations.

If the tripping current exceeds 30 amperes, an auxiliary relay should be used. Its connections should be such that the tripping current does not pass through the contacts or the target and seal-in coils of the protective relay.

TABLE 4
RATINGS OF THE SEAL-IN UNIT COIL

		TAP	
		0.2	2.0
DC Resistance +10%	(ohms)	8.0	0.24
Minimum Operating +0%, -25%	(amperes)	0.2	2.0
Carry Continuous	(amperes)	0.3	3.0
Carry 30 Amperes	(seconds)	0.03	4.0
Carry 10 Amperes	(seconds)	0.25	30.0
60 Hertz Impedance	(ohms)	52	0.53

BURDENS

The burdens of the 87L circuit at five amperes are:

87L Circuit:

Z (term. 5-6)	Angle	R	-jX
1678 ohms	-24^{o}	1534	680

OPERATING PRINCIPLES

All of the Type PVD relays include a high impedance voltage sensing unit (87L) that operates from the voltage produced by the differentially connected CTs during an internal fault. The relays are also provided with either one or two Thyrite® stacks (see Table 1) connected in parallel with the 87L unit to limit the voltage across the relay to safe values during internal faults. In limiting the voltage, the Thyrite® will pass significant current during internal faults, but very little current during normal operating conditions or external faults. The PVD21B and PVD21D relays are provided with an instantaneous overcurrent unit (87H) connected in series with the Thyrite®. The 87H unit is set so that it will not operate for the maximum external fault, but will operate for heavy internal faults.

The diagrams of Figures 4 and 5 illustrate typical external connections to the relays for use in a bus differential scheme. A conventional differential circuit is utilized, that is, the CTs associated with all of the circuits off the bus are connected in wye and paralleled on a per-phase basis. One PVD relay per phase is required to provide complete protection for the bus.

VOLTAGE UNIT (87L) - PVD21A, PVD21B, PVD21C, PVD21D

If a protection scheme utilizing a PVD relay is to perform satisfactorily, it must not trip for faults external to the zone of protection, such as at F1 in Figure 6. Since the PVD relay is a high impedance device, consider the effect of an external single line to ground fault. Figure 6 illustrates this condition for the faulted phase only. Each of the CTs associated with an infeeding circuit will produce the secondary voltage necessary to drive its secondary current through its winding and leads. The CT in the faulted circuit will produce the voltage necessary to drive the total secondary fault current through its winding and leads. If all of the CTs were to perform ideally, there would be negligible voltage developed across junction points A and D, and hence across the PVD relay. Incidentally, load flow across the bus is similar in effect to an external fault, so there will also be little voltage developed across the relay during normal operating conditions. Unfortunately, during fault conditions CTs do not always perform ideally, because core saturation can cause a breakdown in CT ratio. Such core saturation is generally accentuated by DC transients in the primary current. Any residual flux left in the core may also add to the tendency to saturate.

In the example of Figure 6, the worst condition would be realized if the CT associated with the faulted circuit saturated completely, thus losing its ability to produce a secondary voltage, while the other CTs did not saturate at all. When a CT saturates completely, its secondary impedance approaches the secondary winding resistance, provided the secondary leakage reactance is negligible. This will be the case when CTs wound on a toroidal core with completely distributed windings are used. The CTs in the infeeding circuits would then be unassisted by the fault CT and would have to produce enough voltage to force their secondary currents through their own windings and leads, as well as the windings and leads of the CT associated with the faulted circuit. As a result, a voltage will be developed across the junction points, A and D, and hence across the PVD relay. The magnitude of this voltage will simply be equal to the product of the total resistance in the CT loop circuit and the total fault current in secondary amperes, that is,

$$V_R = (R_S + 2R_L)\frac{I_F}{N} \qquad (1)$$

where:
V_R = voltage across PVD relay
R_S = CT secondary winding and lead resistance
R_L = one way cable resistance from junction point to CT
I_F = RMS value of primary fault current
N = CT ratio

Note that the factor of two, appearing with the R_L term, is used to account for the fact that all of the fault current will flow through both the outgoing cable and the return cable for single line to ground faults. If the CTs are connected as shown in Figures 4 or 5, no current will flow in the return lead for three phase faults, thus the maximum voltage developed across the PVD relays for three phase faults can be calculated as follows:

$$V_R = (R_S + R_L)\frac{I_F}{N} \qquad (2)$$

Equations (1) and (2) can be consolidated and written as follows:

$$V_R = (R_S + PR_L)\frac{I_F}{N} \qquad (3)$$

where: P = 1 for three phase faults, and 2 for single line to ground faults.

For the conditions in question, this voltage, V_R, is the maximum voltage that could possibly be developed across the PVD relay. Obviously, the CT in the faulted circuit will not lose all of its ability to produce an assisting voltage, and the CTs in the infeeding circuits may tend to saturate to some degree. In practice, the voltage developed across the relay will be something less than that calculated from equation (3) above. The effect of CT saturation is accounted for by the CT performance factor, K, used in the equation for calculating the actual voltage setting, and it is discussed further in the section **CALCULATION OF SETTINGS.**

Now consider the effect of an internal fault. In this case, all of the infeeding CTs will be operating into the high impedance PVD in parallel with any idle CTs. The voltage developed across the junction points A and D will now approach the open circuit secondary voltage that the CTs can produce. Even for a moderate internal fault, this voltage will be in excess of the value calculated for the maximum external fault as described above. Therefore, the high impedance voltage sensing unit, 87L, can be set with a pickup setting high enough so that it will not operate as the result of the maximum external fault, but will still pick up for moderate and even slight internal faults. Consequently, the relay will be selective between internal faults and external faults or load flow.

The actual equation for calculating the 87L voltage unit setting, taking CT performance and margin into account, is as follows:

$$V_R = (K)\ (1.6)\ (R_S + PR_L)\ \frac{I_F}{N} \qquad (4)$$

where: K = CT performance factor (see Figure 7)
1.6 = margin factor

All other terms are as described above.

<u>OVERCURRENT UNIT (87H) - PVD21B, PVD21D</u>

The PVD21B and PVD21D relays are similar to the PVD21A and PVD21C relays, respectively, except for the addition of the 87H unit in series with the Thyrite®. The 87H unit is set so that it will not operate on the current passed by the Thyrite® during external faults, but so that it will operate on the current passed during heavy internal faults.

During normal operating conditions, there will be little voltage developed across the PVD relay, and hence across the series combination of the Thyrite® and 87H. During external faults, the same would be true if the CTs did not saturate. Even if the CT in the fault circuit saturated completely, the maximum voltage that could be developed across the relay would be limited to the drop in the CT resistance plus the associated cable resistance. Because 87L is set at some value above the maximum expected drop, it is possible to determine the current through the Thyrite® at the 87L setting, and so determine a suitable setting for 87H to insure that it does not operate for the maximum external fault. Figure 8 illustrates the minimum safe pickup setting to be made as a function of the 87L setting with suitable margin included. Thus, once the 87L setting has been calculated, the 87H setting can be easily determined from Figure 8.

During internal faults, the CTs will attempt to drive all of the fault current through the high impedance PVD relay. As a result, the voltage will build up quite rapidly across the relay. As the voltage builds up, the nonlinear Thyrite ® will exhibit a declining resistance characteristic, so that significant current will flow through the Thyrite® and so cause 87H to operate. Because of the margin involved in setting the 87H unit, it will not be quite as sensitive as the 87L unit and it may not operate for some low level faults. It is not possible to predict at exactly what fault level the 87H unit will operate because of the numerous factors involved. However, 87H still may be used to supplement tripping by 87L with the assurance that it will at least operate for heavy internal faults. The 87H unit may also be used to implement breaker failure protection, as described in the **APPLICATION** section.

CALCULATION OF SETTINGS

The formulas and procedures described in the following paragraphs for determining relay settings assume that the relay is connected to the full windings of differentially connected CTs. Further, they assume that the secondary winding of each CT has negligible leakage reactance, and that all of the CTs have the same ratio. If these are not the conditions that exist in your application, please contact the nearest General Electric District Sales Office.

SETTING OF THE HIGH IMPEDANCE UNIT, 87L

Assuming that an external fault causes complete saturation of the CT in the faulted circuit, the current forced through this secondary by the CTs in the infeeding circuits will be impeded only by the resistance of the winding and leads. The resulting IR drop will be the maximum possible voltage which can appear across the PVD relay for that external fault. The setting of the high impedance 87L unit was described in **OPERATING PRINCIPLES**. It is expressed as follows:

$$V_R = (K)\ (1.6)\ (R_S + PR_L)\ \frac{I_F}{N} \qquad (5)$$

where:
- V_R = pickup setting of 87L unit
- R_S = DC resistance of faulted CT secondary windings and leads to housing terminal
- R_L = single conductor DC resistance of CT cable for one way run from CT housing terminal to junction point (at highest expected operating temperature)
- P = 1 for three phase faults, 2 for single phase to ground faults
- I_F = external fault current, primary RMS value
- N = CT ratio
- 1.6 = margin factor
- K = CT performance factor from Figure 7.

The calculations only need to be made with the maximum value of I_F for single phase and three phase faults. If the relay is applicable for these conditions, it will perform satisfactorily for all faults.

As previously noted in **OPERATING PRINCIPLES**, the pessimistic value of voltage determined by equation (5) for any of the methods outlined is never realized in practice. The CT in the faulted circuit will not saturate to the point where it produces <u>no</u> assisting voltage. Furthermore, the condition which caused the faulted CT core to saturate also tends to saturate the cores of the CTs in the infeeding circuits, resulting in a further decrease in voltage across the PVD relay. These effects are not readily calculated; however, extensive testing under simulated fault conditions on bushing CTs similar to those supplied in most circuit breakers manufactured in the United States, has resulted in the establishment of a so-called "performance factor," which can be determined for each application. The performance factor, K, is not a constant for a given bushing CT, but varies for each installation, depending on the value of $(R_S + PR_L)\ I_F/N$. K is readily determined from the curve of Figure 6, which is based on test data. The use of this curve is explained in SAMPLE CALCULATIONS.

The value of the 87L unit setting established by equation (5) is the minimum safe setting. Higher settings will provide more safety margin, but will result in somewhat reduced sensitivity.

The methods of utilizing equation (5) are outlined below:

<u>Method I - Exact Method</u>:

(1) Determine the maximum three phase and single phase to ground fault currents for faults just beyond each of the breakers.
(2) The value R_L is the one way cable DC resistance from the junction point to the faulted CT being considered.
(3) For each breaker in turn, calculate V_R separately utilizing the associated maximum external three phase fault current, with P = 1, and the maximum external single phase to ground fault current, with P = 2.
(4) Use the highest of the values of V_R obtained in (3) above.

<u>Method II - Simplified Conservative Method</u>:

(1) Use the maximum interrupting rating of the circuit breaker as the maximum external single phase to ground fault current.
(2) The value R_L is based on the distance from the junction point to the most distant CT.
(3) Calculate a value for V_R using P = 2.
(4) This value of V_R becomes the pickup setting.

Begin with Method II. The calculated value of V_R is determined as outlined in the paragraph, "Minimum Fault to Trip 87L." If the sensitivity resulting from the value calculated is not adequate, then Method I should be used. When the 87L pickup from Method II proves to yield an adequate sensitivity, a unique advantage is realized, since the 87L pickup setting will not require recalculation following changes in system configuration, which would result in higher bus fault magnitudes.

It is desirable for the pickup voltage of the 87L unit to plot below the knee point of the excitation curve (that is, the point on the excitation curve where the slope is 45 degrees) of all the CTs in use. However, it is permissible for the 87L pickup voltage to be higher than the knee point voltage. The maximum setting for the 87L unit is equal to the secondary excitation voltage at ten amperes secondary excitation current (evaluated for the poorest CT in the differential circuit), multiplied by 0.67.

Minimum Fault to Trip 87L Unit

After the pickup setting of the 87L unit has been established for an application, a check should be made to determine the minimum internal fault current which will just cause the unit to operate. If this value is less than the minimum internal fault current expected, the pickup setting is suitable for the application. The following expression can be used to determine the minimum internal fault current required for a particular 87L unit pickup setting:

$$I_{min} = \left[\sum_{X=1}^{n} (I)_X + I_R + I_1 \right] N \tag{6}$$

where: I_{min} = minimum internal fault current to trip 87L
n = number of breakers connected to the bus, (i.e., number of CTs per phase)
I = secondary excitation current of individual CT at a voltage equal to the pickup of 87L
I_R = current in 87L unit at pickup voltage = $V_R/1700$
I_1 = current in the Thyrite R unit at 87L pickup voltage (see Figure 11)
N = CT ratio

The values of I_1, I_2, etc., are obtained from the secondary excitation characteristics of the respective CTs. The first term in equation (6) reduces to NI if it is assumed that all CTs have the same excitation characteristic. The relay current, I_R, can be determined from the impedance of the 87L circuit, assumed to be constant at 1700 ohms. That is:

$$I_R = V_R/1700 \tag{7}$$

The current drawn by the Thyrite® unit, I_1, can be obtained from that curve in Figure 11 that applies to the relay being used.

SETTING OVERCURRENT UNIT, 87H

The required setting for the overcurrent unit, 87H, is dependent on the actual setting of the voltage unit, 87L. Figure 8, which is a plot of the 87H setting in RMS amperes versus the 87L setting in RMS volts, illustrates the relationship between these two settings. In order to determine the required 87H setting, it is only necessary to calculate the 87L setting and then enter the curve of Figure 8 at that value of voltage to read the 87H setting directly.

SAMPLE CALCULATION

The various steps for determining the settings of the PVD relay in a typical application will be explained with the aid of a worked example. Method II will be used with the following assumed parameters:

Number of breakers: five
Maximum breaker interrupting rating: 40,000 amperes
Cable resistance for longest run: 0.50 ohms at 25°C
CT Ratio: 1200/5

The characteristics for the 1200/5 CT are shown in Figure 12. The value of R_S from this figure is:

$$R_S = (0.0029)\ (240) + 0.113 = 0.809 \text{ ohms}$$

The cable resistance for the longest CT run is given at 25°C. If higher operating temperatures are expected, this must be taken into account in determining the maximum expected resistance. Resistance values of wire at 25°C, or at any temperature, t1, may be corrected to any other temperature, t2, as follows:

$$R_{t2} = [1 + P_1\ (t2 - t1)]\ R_{t1}$$

where: R_{t1} = resistance in ohms at t1, degrees Centigrade
R_{t2} = resistance in ohms at t2, degrees Centigrade
P_1 = temperature coefficient of resistance at t1

For standard annealed copper, P_1 = 0.00385 at t1 = 25°C; therefore the value of R_L at 50°C is:

$$R_L = [1 + 0.00385\ (50 - 25)]\ 0.5 = 0.548 \text{ ohms}$$

The CT performance factor, K, must next be determined. To do this, first calculate:

$$\frac{(R_S + PR_L)\ (I_F)}{(E_S)\ (N)}$$

Because Method II was selected, use P = 2. From Figure 12, E_S = 300 volts

$$\frac{[(0.809) + (2)(0.548)]\ (40{,}000)}{(300)\ (240)} = 1.06$$

From Figure 7, K = 0.7.

Using Equation (5), the appropriate relay setting is:

$$V_R = \frac{(1.6)\ (0.7)\ [0.809 + (2)\ (0.548)]\ (40{,}000)}{240}$$
$$V_R = 355 \text{ volts}$$

This value is just above the knee point (300 volts) of the CT characteristic, and well below 67 % of the voltage at ten amperes excitation, (0.67)x(590)=395 so the application is satisfactory in that respect.

Next it is necessary to determine whether the PVD21A or PVD21B, or the PVD21C or PVD21D (one versus two Thyrite® stacks) should be used. First determine the knee point voltage, E_S, for the poorest CT in the circuit. From Figure 12, E_S = 300 volts (all CTs are assumed to be identical). Assume that the maximum internal fault current is 45,000 amperes primary, which is equivalent to 188 amperes secondary. The curve of Figure 10, when entered at these coordinates (300 volts and 188 amperes), shows that the application is safe for either the PVD21C or PVD21D relays (two Thyrite® stacks). If Figure 9 were entered at the same coordinates, it would show that PVD21A or PVD21B would not be applicable.

The next step in the calculation is to determine the sensitivity of the relay to internal faults. This may be done using equation (6) as follows:

From the excitation curve of Figure 12, I at 355 volts: 0.07 amperes

From the Thyrite® curve of Figure 11, I at 355 volts: 1.1 amperes (use curve for two Thyrite® stacks)

From equation (7):

$$I_R = 355/1700 = 0.209 \text{ amperes}$$

From equation (6):

$$I_{min} = [5(0.07) + 1.1 + 0.209]\ 240$$

$$I_{min} = 398 \text{ amperes primary}$$

If the minimum internal primary fault current is above 398 amperes, the pickup setting of 355 volts is adequate.

If the instantaneous overcurrent unit will be included in the relay, then the PVD21D must be used. To determine the 87H setting, enter the curve of Figure 8 at the calculated 87L setting of 355 volts. Read the 87H setting from the scale for the PVD21D relay. For the 355 volt setting of 87L, the appropriate setting for 87H is 11.8 amperes.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Apparatus Sales Office.

Reasonable care should be exercised when unpacking the relay in order that none of the parts are damaged nor the adjustments disturbed. If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed, and cause trouble in the operation of the relay.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to insure that no damage has been sustained in shipment and that the relay calibrations have not been disturbed. These tests may be performed at the discretion of the user, since most operating companies use different procedures for acceptance and installation tests. The following section includes all applicable tests that may be performed on these relays.

VISUAL INSPECTION

Check the nameplate stamping to insure that the model number, rating and calibration range of the relay received agree with the requisition.

Remove the relay from its case and check that there are no broken or cracked molded parts, or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

Cradle and Case Blocks

Check that the fingers on the cradle and case agree with the internal connection diagram. Check that the shorting bars are in the correct position, and that each finger with a shorting bar makes contact with the shorting bar. Deflect each contact finger to insure that there is sufficient contact force available, and check that each auxiliary brush is bent high enough to contact the connection plug.

Contact 87L

The following mechanical adjustments must be checked:

1. The armature and contacts of the seal-in unit, as well as the armature and contacts of the instantaneous unit, should move freely when operated by hand. There should be at least 0.015 inch wipe on the seal-in contacts.

2. The targets in the seal-in and the instantaneous unit must come into view and latch when the armatures are operated by hand, and they should unlatch when the target release button is operated.

3. The brushes and shorting bars should agree with the internal connections diagram.

4. With the telephone relays in the de-energized position, all circuit closing contacts should have a gap of 0.015 inch, and all circuit opening contacts should have a wipe of 0.005 inch. The gap may be checked by inserting a feeler gage. Wipe can be checked by observing the amount of deflection on the stationary contact before parting the contacts. The armature should then be operated by hand, and the gap and wipe again checked as described above.

ELECTRICAL SETTING AND INSPECTION

Hi-Seismic Instantaneous Unit, 87H

Make sure the instantaneous unit link is in the correct position for the range in which it is to operate. See internal connections diagram, Figures 3 and 4, and connect as indicated in the test circuit of Figure 14A. Use the higher range whenever possible, since the higher range has a higher continuous rating.

Setting the Hi-Seismic Instantaneous Unit

The instantaneous unit has an adjustable core located at the top of the unit. To set the instantaneous unit to a desired pickup, loosen the locknut and adjust the core. Turning the core clockwise decreases the pickup; turning it counterclockwise increases it. Bring the current up slowly until the unit picks up. It may be necessary to repeat this operation until the desired pickup value is obtained. Once the desired pickup value is reached, tighten the locknut.

CAUTION: Refer to the **RATINGS** section for continuous and one second ratings of the instantaneous unit. Do not exceed these ratings when applying current to the instantaneous unit.

The range of the instantaneous unit (±10% of minimum and maximum current value) must be obtained between one-eighth (1/8) and 20 counterclockwise turns of the core from the fully clockwise position.

Hi-Seismic Target and Seal-in Unit

The target and seal-in unit has an operating coil tapped at 0.2 and 2.0 amperes. The relay is shipped from the factory with the tap screw in the lower ampere position. The tap screw is the screw holding the right had stationary contact. To change the tap setting, first remove one screw from the left-hand stationary contact and place it in the desired tap. Next remove the screw from the undesired tap and place it on the left- hand stationary contact where the first screw was removed. This procedure is necessary to prevent the right-hand stationary contact from getting out of adjustment. Screws should never be left in both taps at the same time.

TABLE 5

TAP	PICKUP CURRENT	DROPOUT CURRENT
0.2	0.15 - 0.195	0.05 or more
2.0	1.50 - 1.95	0.50 or more

87L Unit

The 87L unit can be adjusted at any voltage within the range shown on its calibration plate. Four specific calibration values, for both the high and low voltage range are shown on the plate, which correspond to the values stamped on the nameplate. The 87L unit, unless otherwise specified on the requisition, will be set at the factory to operate at its minimum pickup voltage. If the unit is to be set at some other point, the calibration marks should be used as a guide in making a rough adjustment, and the test circuit of Figure 14B should then be used to make an exact setting.

When the test plug is inserted in the relay, as depicted in Figure 14B, the current transformer secondaries are shorted by means of the link between the outer terminals 5 and 6. The adjustable test voltage is applied across terminals 5 and 6 of the relay; that is, across the voltage circuit which includes the 87L unit. Since the continuous voltage rating of the resonant circuit is only 150 volts, it is recommended that a hand-reset lockout relay be used in the test setup if the desired 87L setting is to be above this figure.

The following procedure should be followed in checking pickup of the 87L unit. Start with a test voltage considerably higher than the expected operating point. Lower the test voltage by successively smaller increments, closing the test switch at each point. The lockout relay will operate each time, protecting the resonant circuit. Eventually, a point will be reached where the 87L unit will just fail to operate. The preceding voltage value, therefore, is the pickup value of the 87L unit (within reasonable accuracy).

At the point where the 87L unit fails to pick up, the test voltage must be removed at once to prevent damage to the relay.

If the 87L unit setting is to be less than the 150 volt continuous rating, it will not be necessary to use the lockout relay. The voltmeter used must have high internal impedance.

The 87L unit operating time can be checked by using the test circuit shown in Figure 14B and measuring the time elapsed between application of the input voltage and the operation of the 87L output contacts. The times measured should be within plus three and minus seven milliseconds of the time shown in Figure 15.

Thyrite® Unit

Apply 120 volts direct current to studs 3 and 6. The current should be between 0.005 and 0.012 amperes for a single stack, and between 0.008 and 0.024 amperes for a double stack of Thyrite®. Any meter error in the voltmeter will be magnified four to five times, for example, a 3% meter error will have an effect on the current of from 12 to 15%.

INSTALLATION PROCEDURE

LOCATION AND MOUNTING

The relay should be mounted on a vertical surface in a location reasonably free from excessive heat, moisture, dust and vibration. The relay case may be grounded using at least #12 AWG gage copper wire. The outline and panel drilling dimensions for Type PVD relays are shown in Figure 1.

CONNECTIONS

Internal connections diagrams for the Type PVD21A and PVD21C, and the Type PVD21B and PVD21D relays, are shown in Figures 2 and 3, respectively. The elementary diagram of the external connections for a typical application is shown in Figure 4.

Note in Figure 4 that when the relay is installed, a connecting jumper should be placed between terminals 3 and 5, and that terminals 5 and 6 are then connected across differential junction points A and B of the several current transformers. In Figure 5, a connecting jumper should be placed across terminals 4 and 5 when the relay is installed. A shorting bar is provided between terminals 5 and 6 so that if the connection plug of the relay is withdrawn, the differential circuit will not be opened.

The midpoint between the Thyrite® stack and unit 87H is connected to terminal 3. This makes it possible to test or calibrate unit 87H without the necessity of passing high current through the Thyrite®, and makes it possible to short out the 87H coil when its operation is not necessary.

The external connections in Figure 4 indicate that the differential junction, points A and B, should be located in the switchyard. This is important in outdoor installations where the distance between the breaker and relay panel may be great, since the resistance through the fault CT loop may otherwise be too large. The junction points can be located at the panel, provided that the necessary relay setting gives the desired sensitivity.

There should be only one ground connection in the secondary circuit. When the junction points are located in the switchyard, the ground connection should be made there rather than at the panel.

The voltage limiting Thyrite® is short-time rated. The contacts of the auxiliary relay device 86 short circuits the differential circuit to protect it.

CAUTION: UNDER NO CIRCUMSTANCES SHOULD THE RELAY BE PLACED IN SERVICE WITHOUT THE THYRITE VOLTAGE LIMITING CIRCUIT CONNECTED; THAT IS, WITHOUT A JUMPER BETWEEN TERMINALS 4 AND 5. OTHERWISE, THE RELAY AND SECONDARY WIRING WILL NOT BE PROTECTED FROM HIGH CREST VOLTAGES WHICH RESULT FROM AN INTERNAL FAULT.

VISUAL INSPECTION

Repeat the items described under **ACCEPTANCE TESTS**, VISUAL INSPECTION.

MECHANICAL INSPECTION AND ADJUSTMENTS

Repeat the items described under **ACCEPTANCE TESTS**, MECHANICAL INSPECTION.

TARGET/SEAL-IN UNIT

Set the target/seal-in unit tap screw in the desired position. The contact adjustment will not be disturbed if a screw is first transferred from the left contact to the desired tap position on the right contact, and then the screw in the undesired tap is removed and transferred to the left contact.

87H AND 87L UNITS

Refer to the appropriate descriptions in **ACCEPTANCE TESTS** for the proper method of setting the 87L and 87H units.

The external trip circuit wiring to the relay, as well as the relay itself, should be checked by operating one of the relay units by hand and allowing it to trip the breaker or lockout relay. Observe that the target operates upon manual operation of the relay unit.

PERIODIC CHECKS AND ROUTINE MAINTENANCE

In view of the vital role of protective relays in the operation of a power system, it is important that a periodic test program be followed. The interval between periodic checks will vary depending upon environment, type of relay and the user's experience with periodic testing. Until the user has accumulated enough experience to select the test interval best suited to his individual requirements, it is suggested that the points listed under **INSTALLATION PROCEDURE** be checked at an interval of from one to two years.

Check the items described in **ACCEPTANCE TESTS**, both VISUAL and MECHANICAL INSPECTION. Examine each component for signs of overheating, deterioration, or other damage. Check that all connections are tight by observing that the lockwashers are fully collapsed.

CONTACT CLEANING

Examine the contacts for pits, arc or burn marks, corrosion and insulating films. A flexible burnishing tool should be used for cleaning relay contacts. This is a flexible strip of metal with an etch-roughened surface, which in effect resembles a superfine file. The polishing action of this file is so delicate that no scratches are left on the contacts, yet it cleans off any corrosion thoroughly and rapidly. The flexibility of the tool insures the cleaning of the actual points of contact. Relay contacts should never be cleaned with knives, files, or abrasive paper or cloth.

PERIODIC TEST EQUIPMENT

* A test set is available for periodic testing of PVD relays. It is intended to be mounted on the panel adjacent to the relays, and in addition to testing, it can also be used to check current transformers for open or short circuits, and incorrect wiring. This test set is more fully described in instruction book GEK-65521.

ELECTRICAL TESTS

Pickup of the 87L and 87H units should be measured and the results compared against the desired setting. If a measured value is slightly different from that measured previously, it is not necessarily an indication that the relay needs readjustment. The errors in all the test equipment are additive, and the total error of the present setup may be of opposite sign from the error present during the previous periodic test. Instead of readjusting the relay, if the test results are acceptable, no adjustment should be made. Note the deviation on the relay test record. After sufficient test data has been accumulated, it will become apparent whether the measured deviations in the setting are due to random variations in the test conditions, or are due to a drift in the relay characteristics.

THYRITE® UNIT

Repeat the test described in **ACCEPTANCE TESTS**, ELECTRICAL INSPECTION.

* Indicates revision

HI-SEISMIC INSTANTANEOUS UNIT, 87H

Check for the following:

1. Both contacts should close at the same time.

2. The backing should be so formed that the forked end (front) bears against the molded strip under the armature.

3. With the armature against the pole piece, the cross member of the "T" spring should be in a horizontal plane, and there should be at least 0.015 inch wipe on the contacts. Check by inserting a 0.010 inch feeler gage between the front half of the shaded pole with the armature held closed. The contacts should close with the feeler gage in place.

HI-SEISMIC TARGET AND SEAL-IN UNIT

Check steps 1 and 2 as described in the paragraph above for the instantaneous unit. To check the wipe of the seal-in unit, insert a 0.010 inch feeler gage between the plastic residual bump of the armature and the pole piece with the armature held closed. The contacts should close with the feeler gage in place.

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for the prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and catalog numbers as shown in Renewal Parts Bulletin GEF-4543.

Since the last edition, the paragraph on the Thyrite® unit in the **ACCEPTANCE TEST** ELECTRICAL SETTING AND INSPECTION section has been revised.

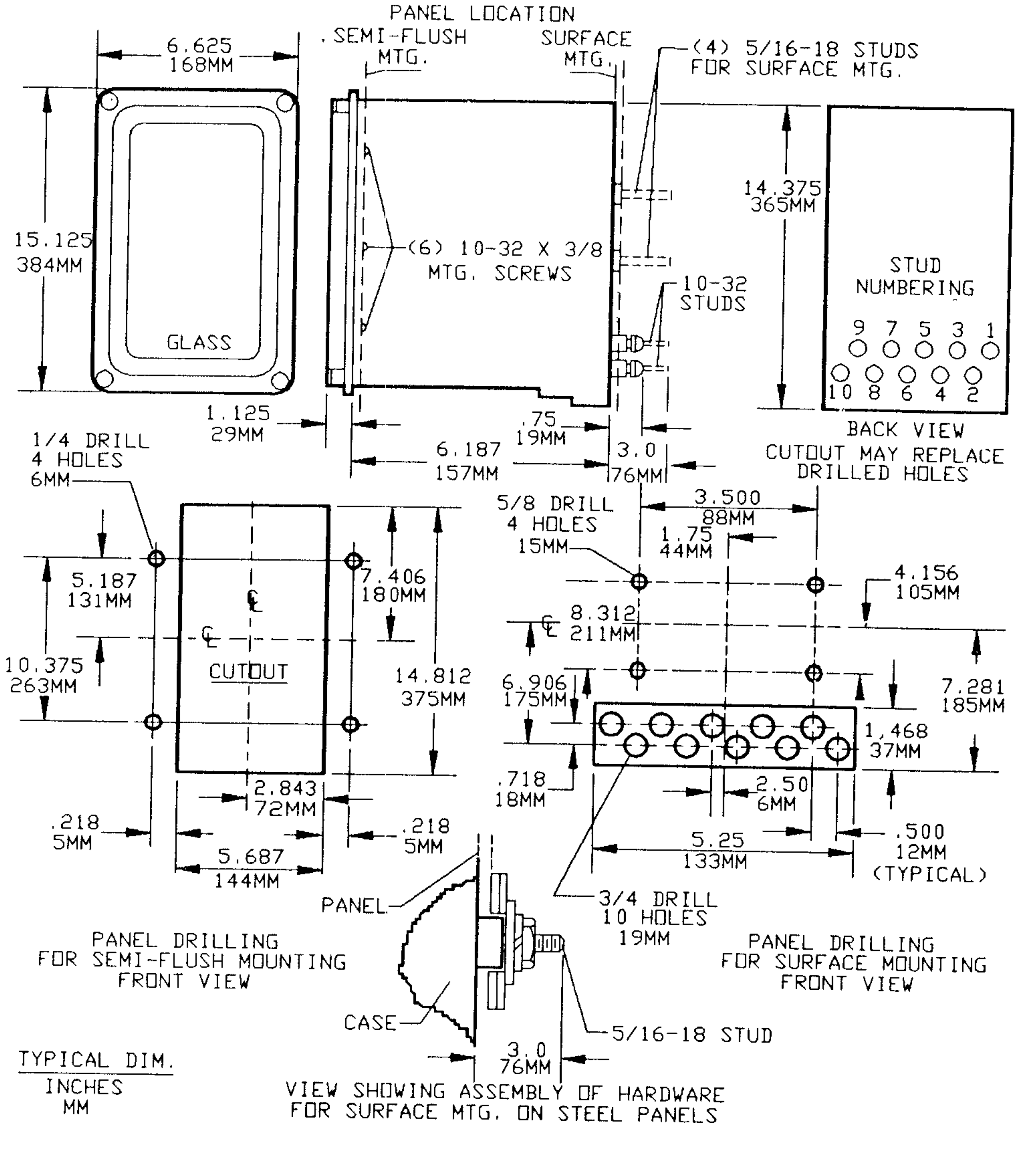


Figure 1 (K-6209273-5) Outline and Panel Drilling Dimensions for an M1 Case

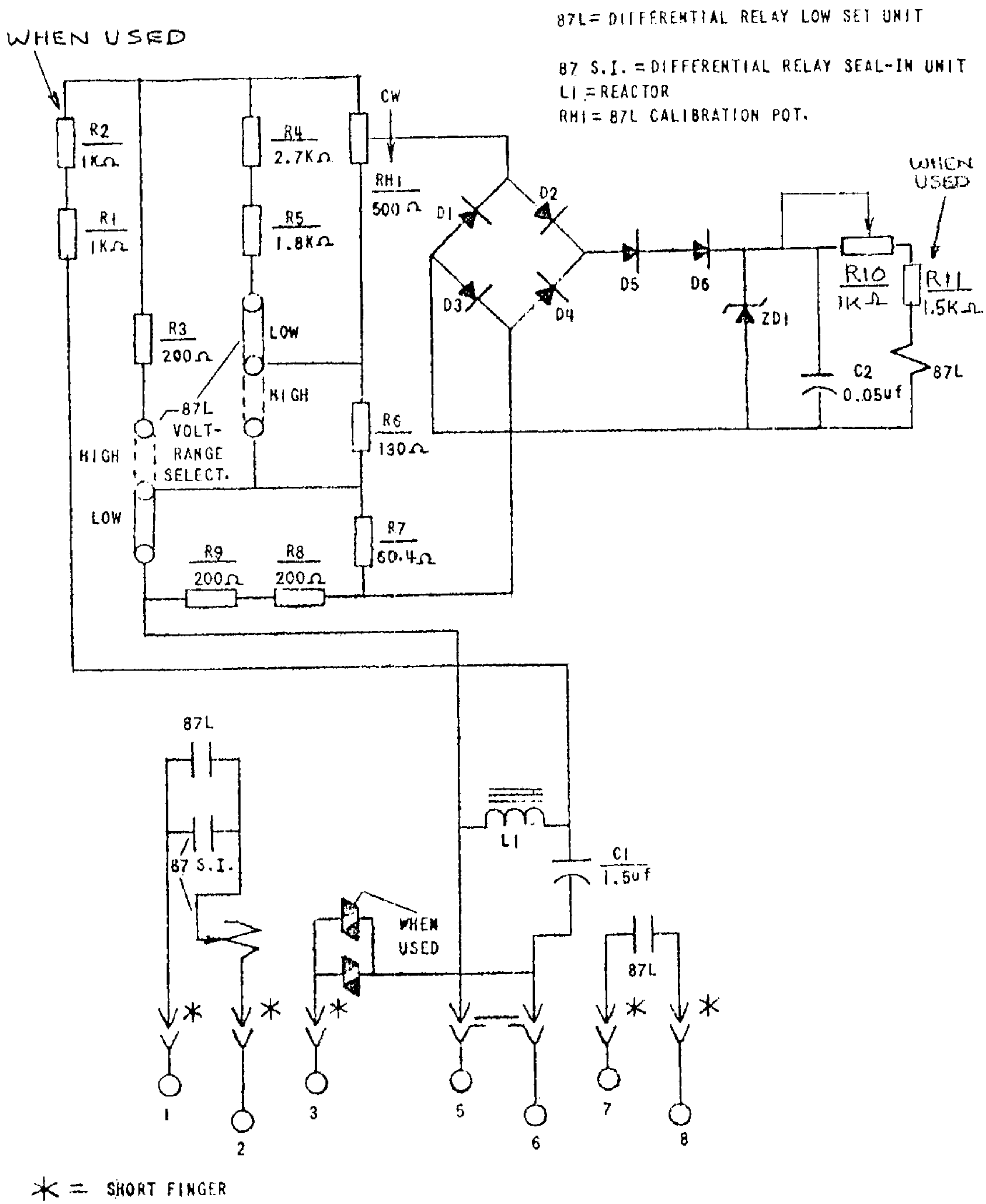


Figure 2 (0257A8374-3) Internal Connections for
Type PVD21A and Type PVD21C Relays

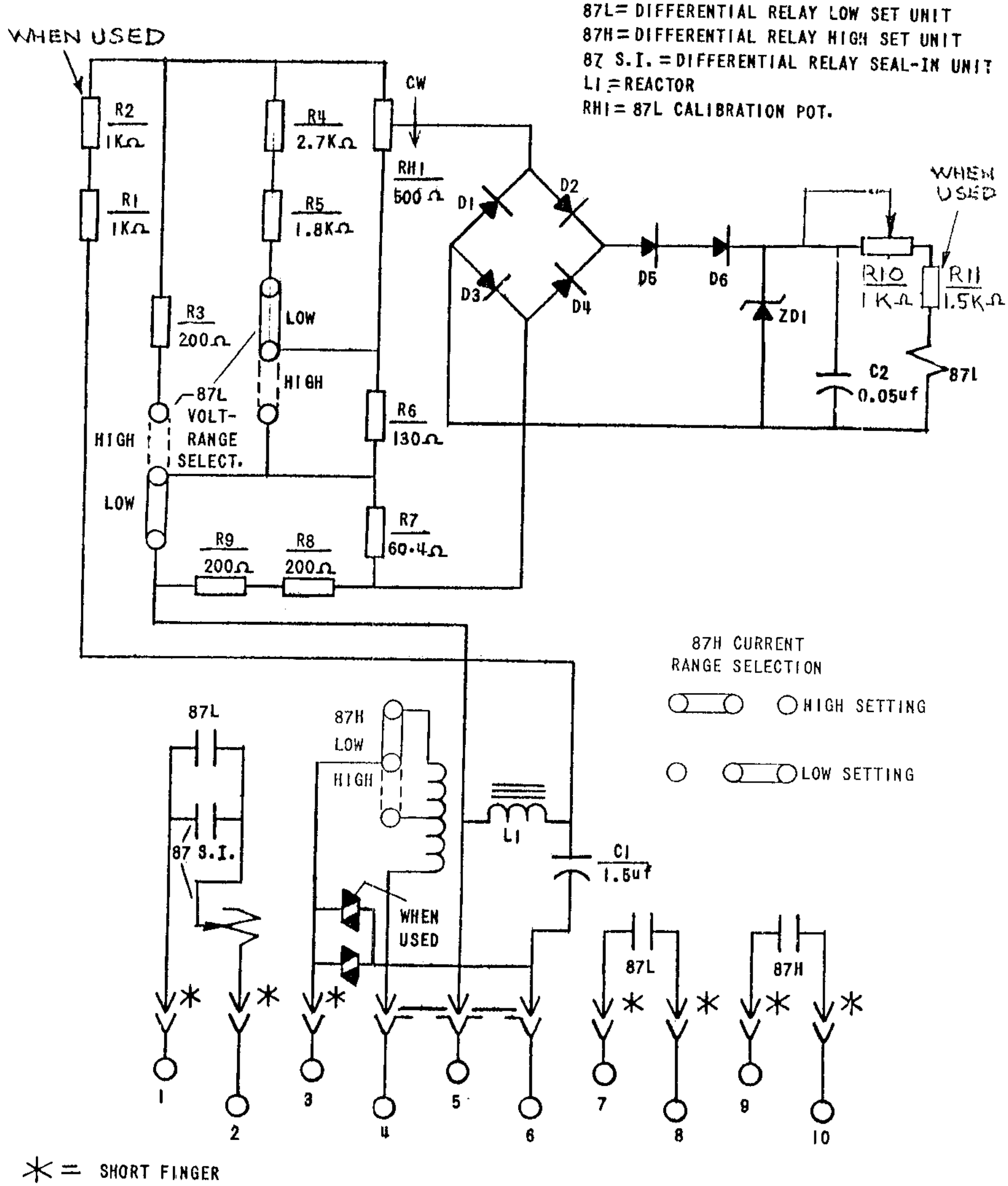


Figure 3 (0257A8387-3) Internal Connections for
Type PVD21B and Type PVD21D Relays

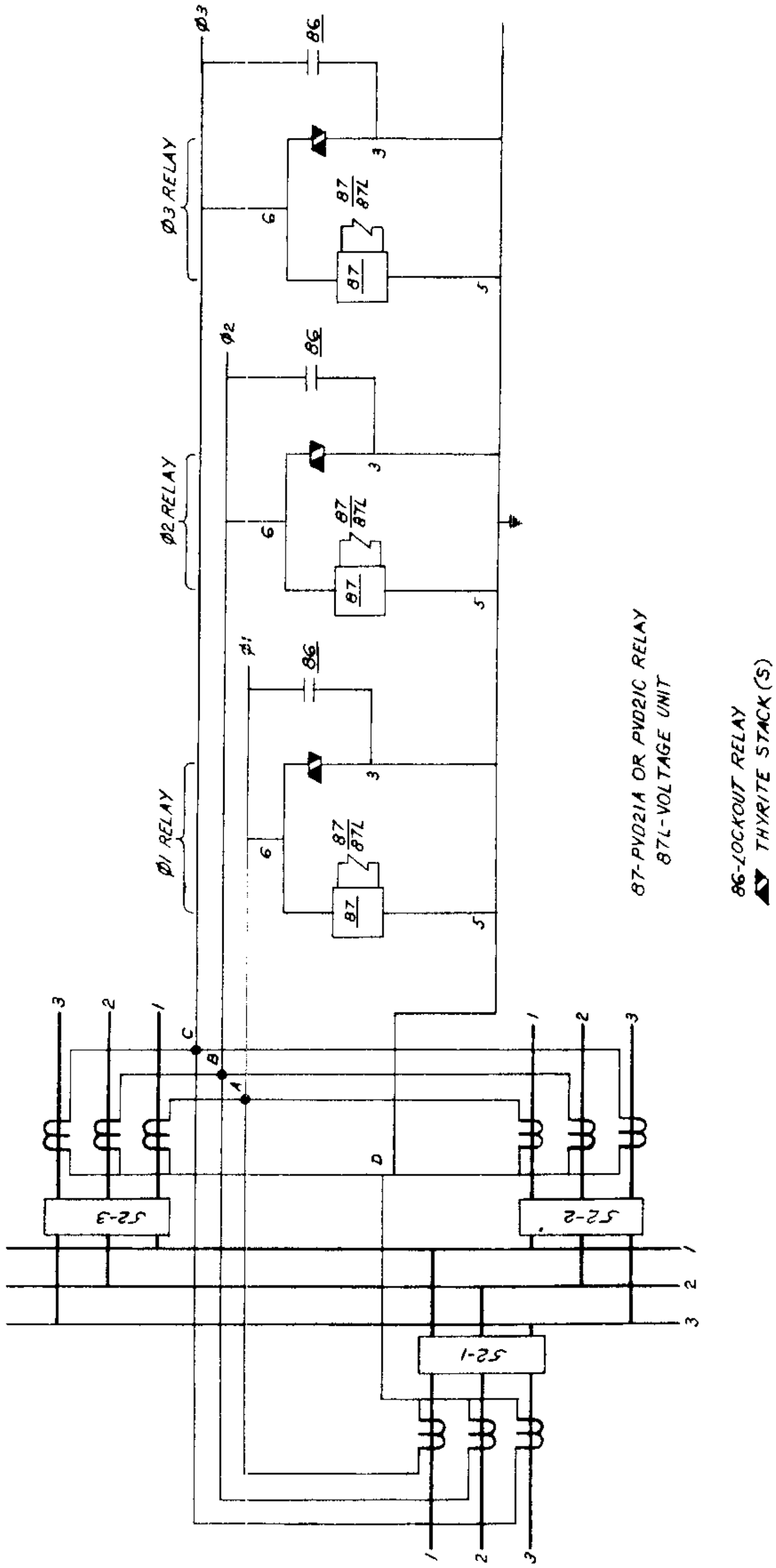


Figure 4 (0108B8928-0, Sh. 1) External AC Connections for Type PVD21A or Type PVD21C Relays

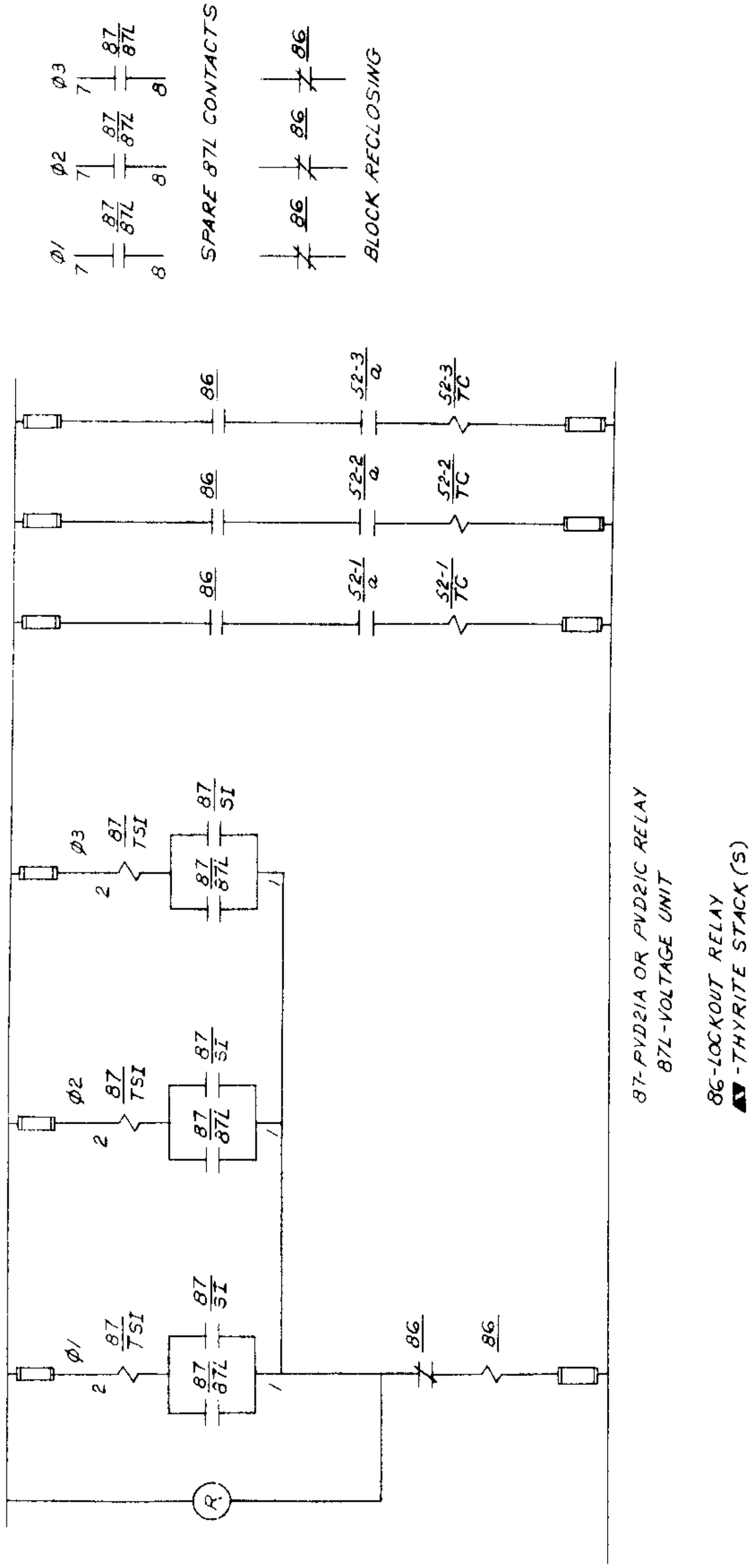


Figure 4A (0108B8928-0, Sh. 2) External DC Connections for Type PVD21A or Type PVD21C Relays

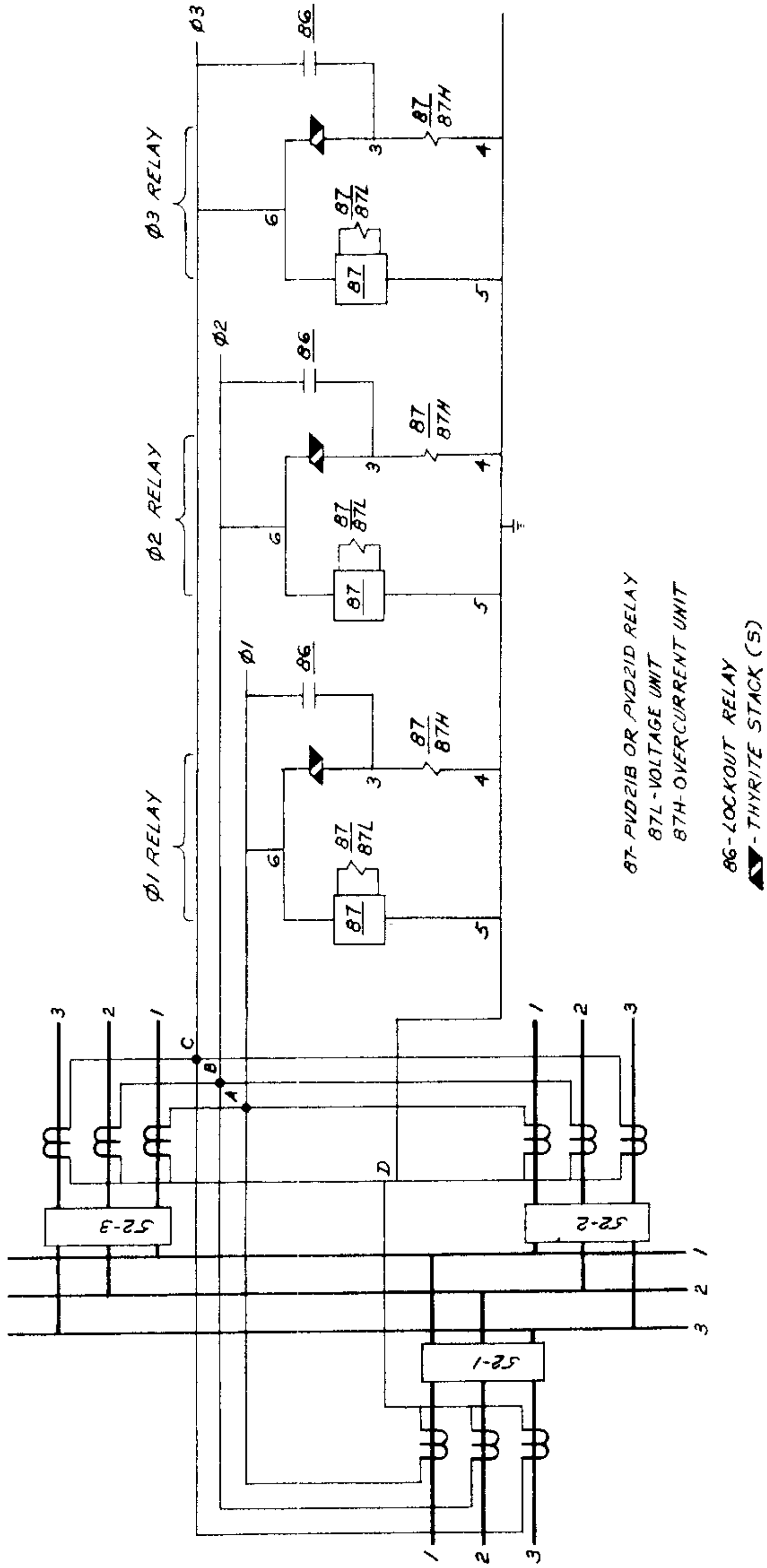


Figure 5 (0108B8929-0, Sh. 1) External AC Connections for Type PVD21B or Type PVD21D Relays

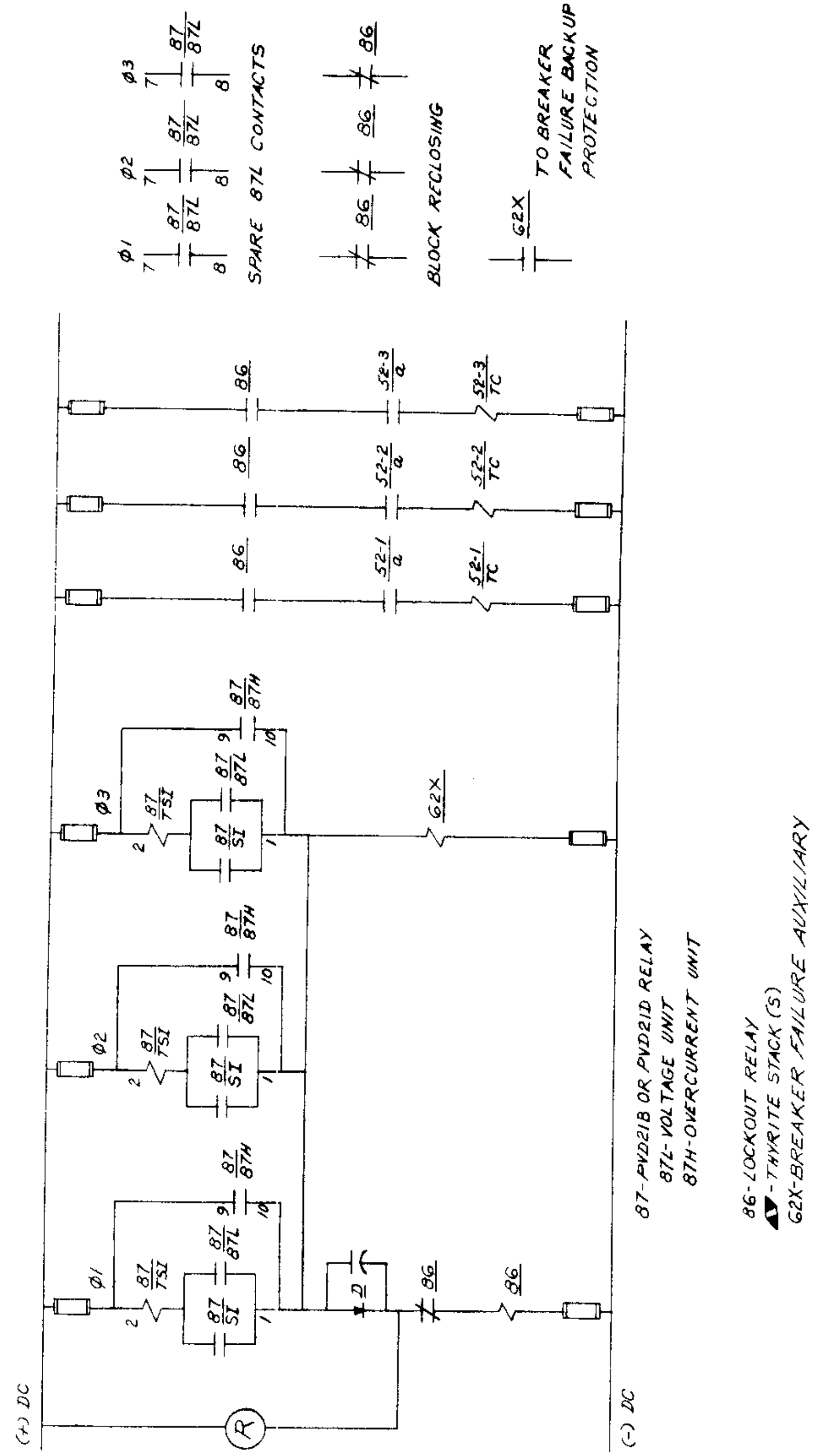
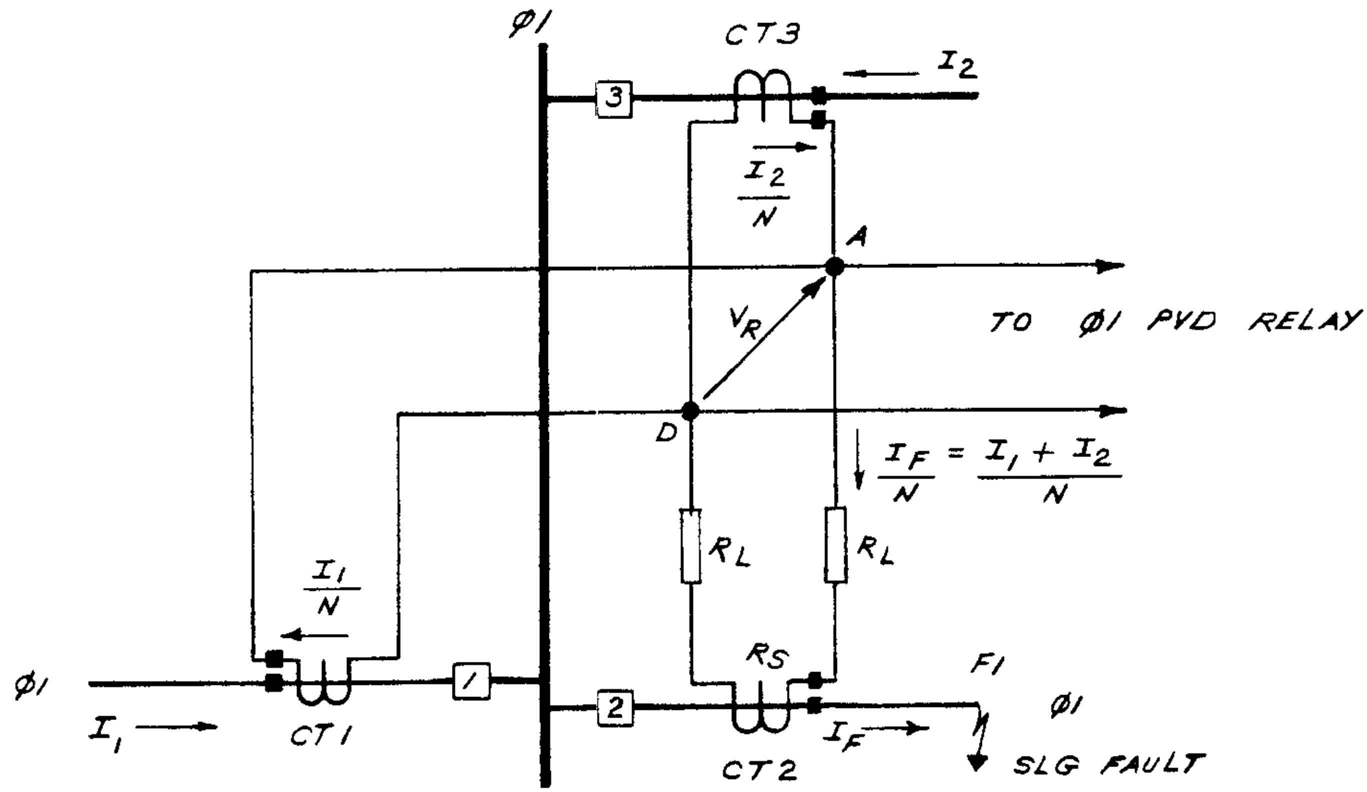


Figure 5A (0108B8929-0, Sh. 2) External DC Connections for Type PVD21B or Type PVD21D Relays



NOTE: CT2 ASSUMED TO BE COMPLETELY SATURATED

R_S = CT SEC. WINDING RESISTANCE PLUS ANY LEAD RESISTANCE

R_L = CABLE RESISTANCE FROM JUNCTION POINT TO CT

I_F = RMS VALUE OF PRIMARY CURRENT

N = CT RATIO

V_R = VOLTAGE ACROSS PVD

Figure 6 (0257A8389-0) Simplified Circuit Illustrating the Effect of Single Line to Ground Faults on the Type PVD Relay

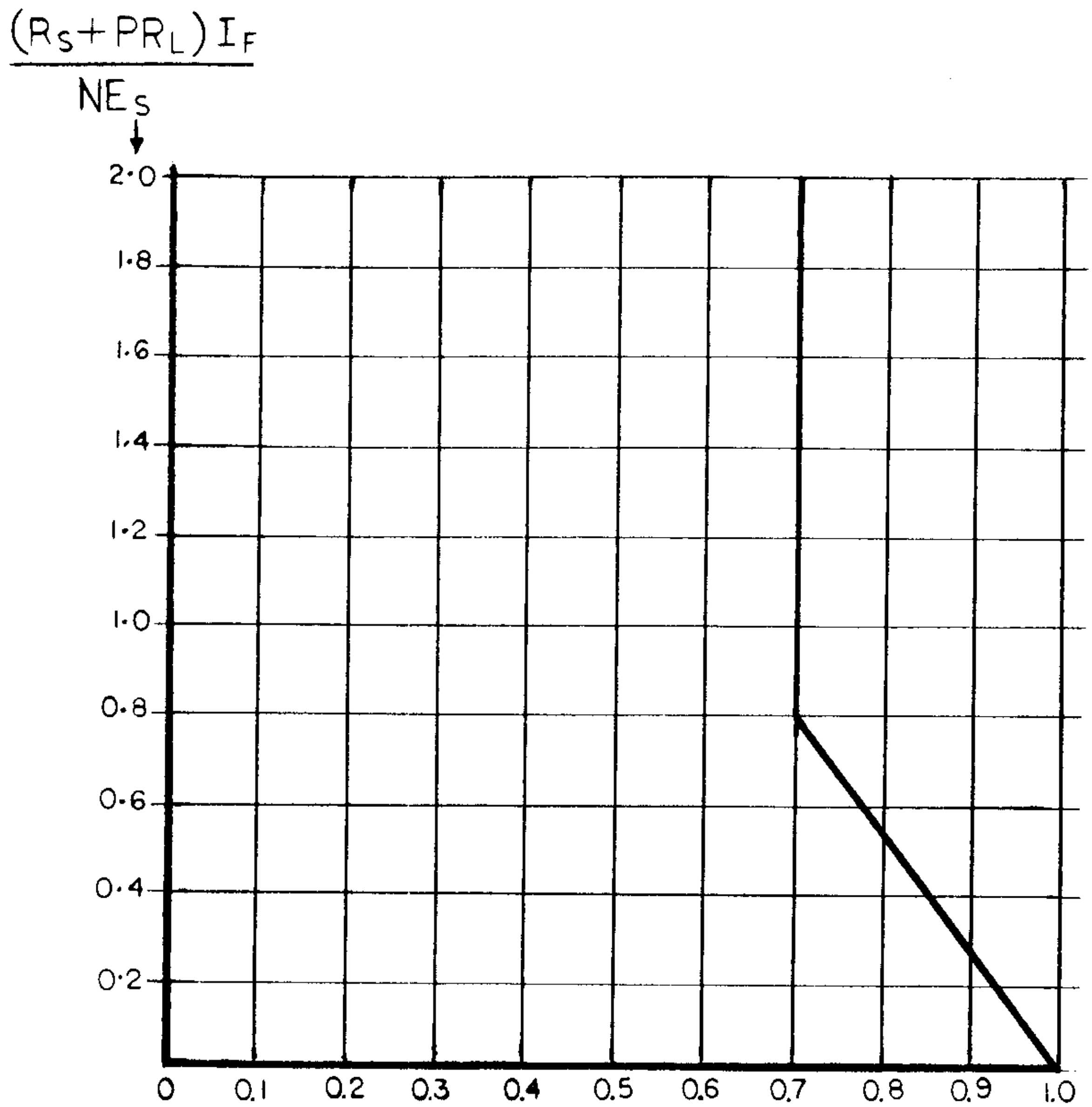


Figure 7 (0257A8586-1) CT Performance Factor, K, for Type PVD21 Relays

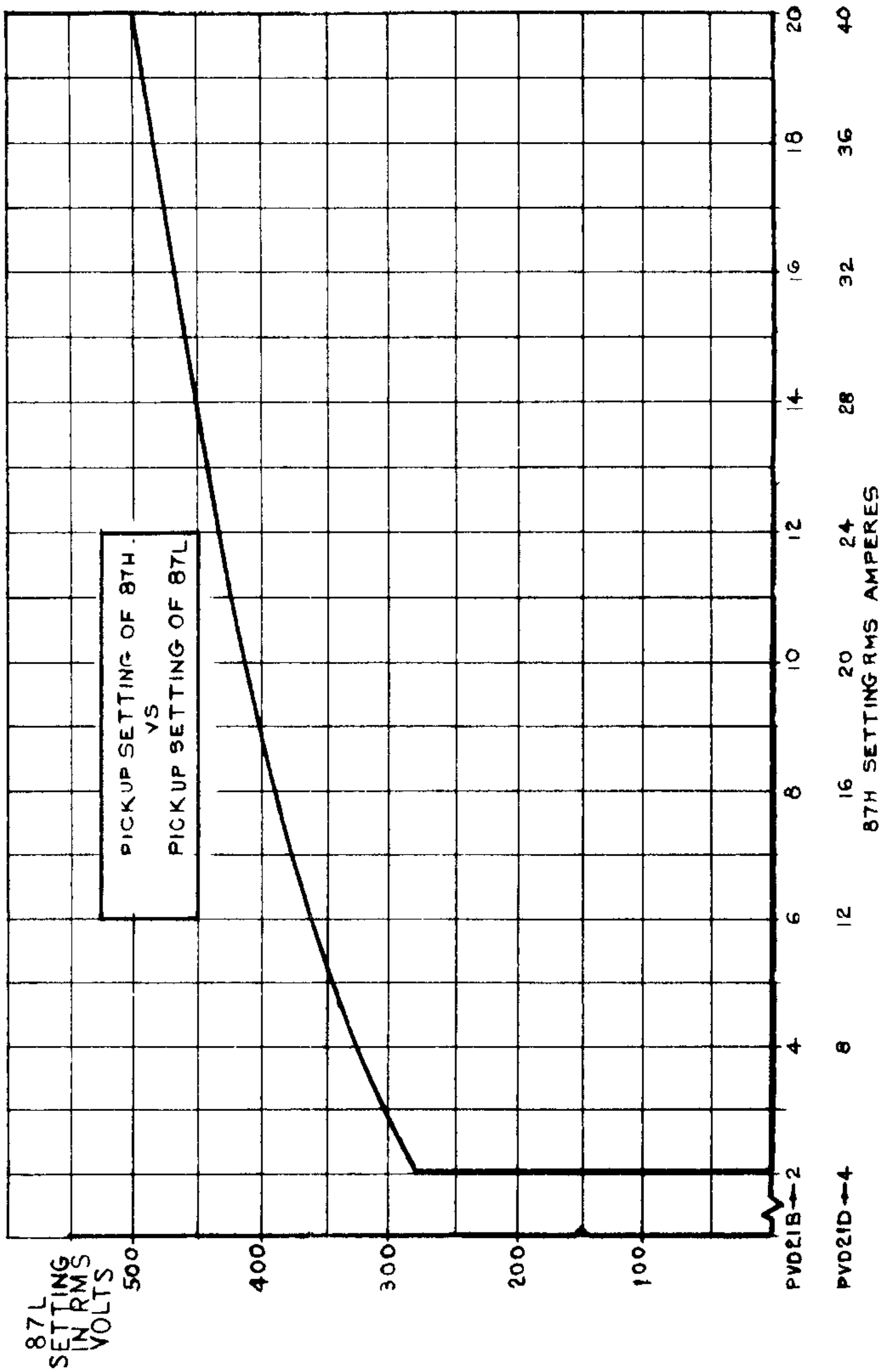


Figure 8 (0257A8587-1) Curve for Obtaining 87H Setting as a Function of 87L Setting

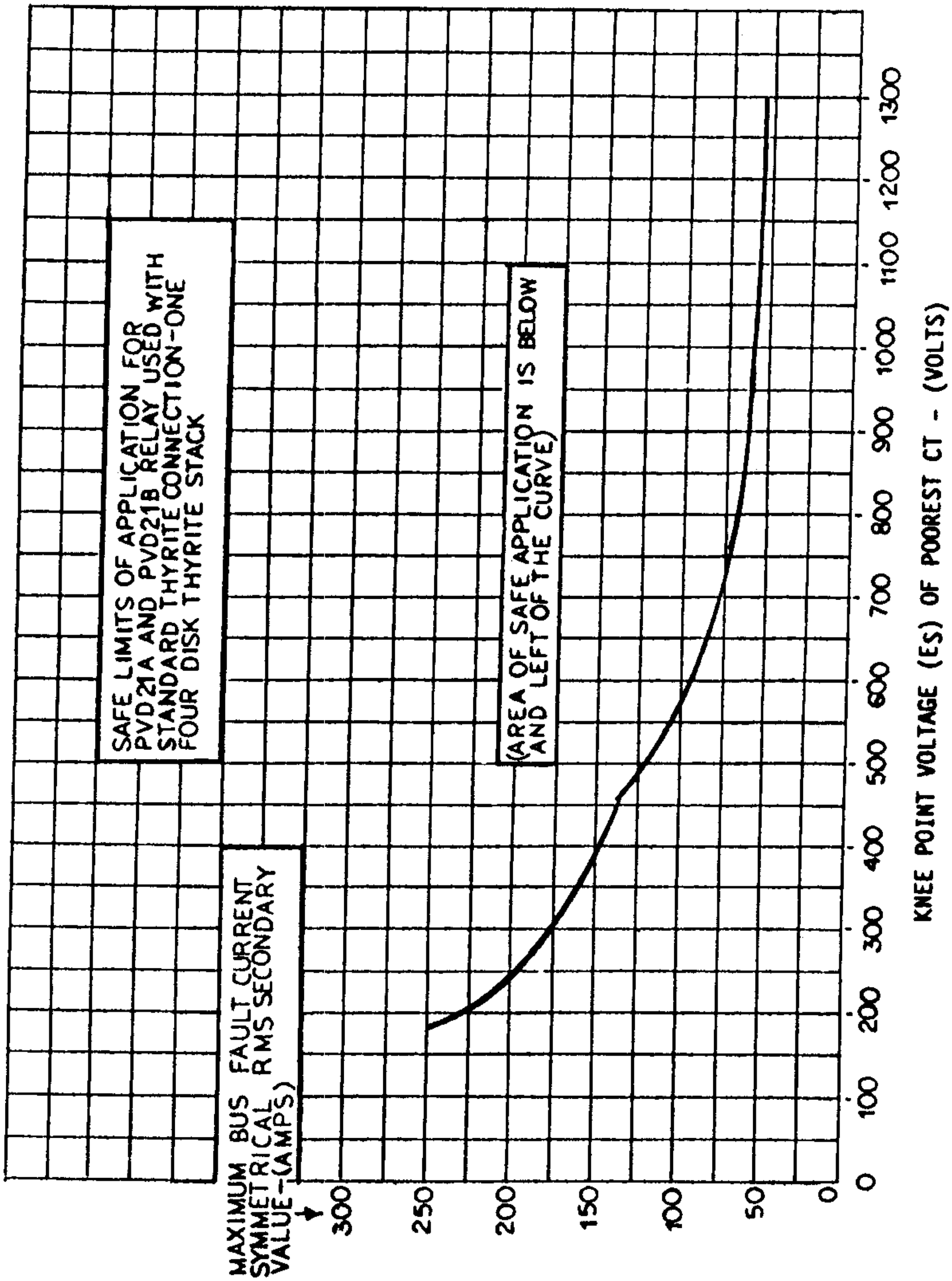


Figure 9 (0257A8588-2) Safe Application Limits for Type PVD21A or Type PVD21B Relays (One Thyrite® Stack)

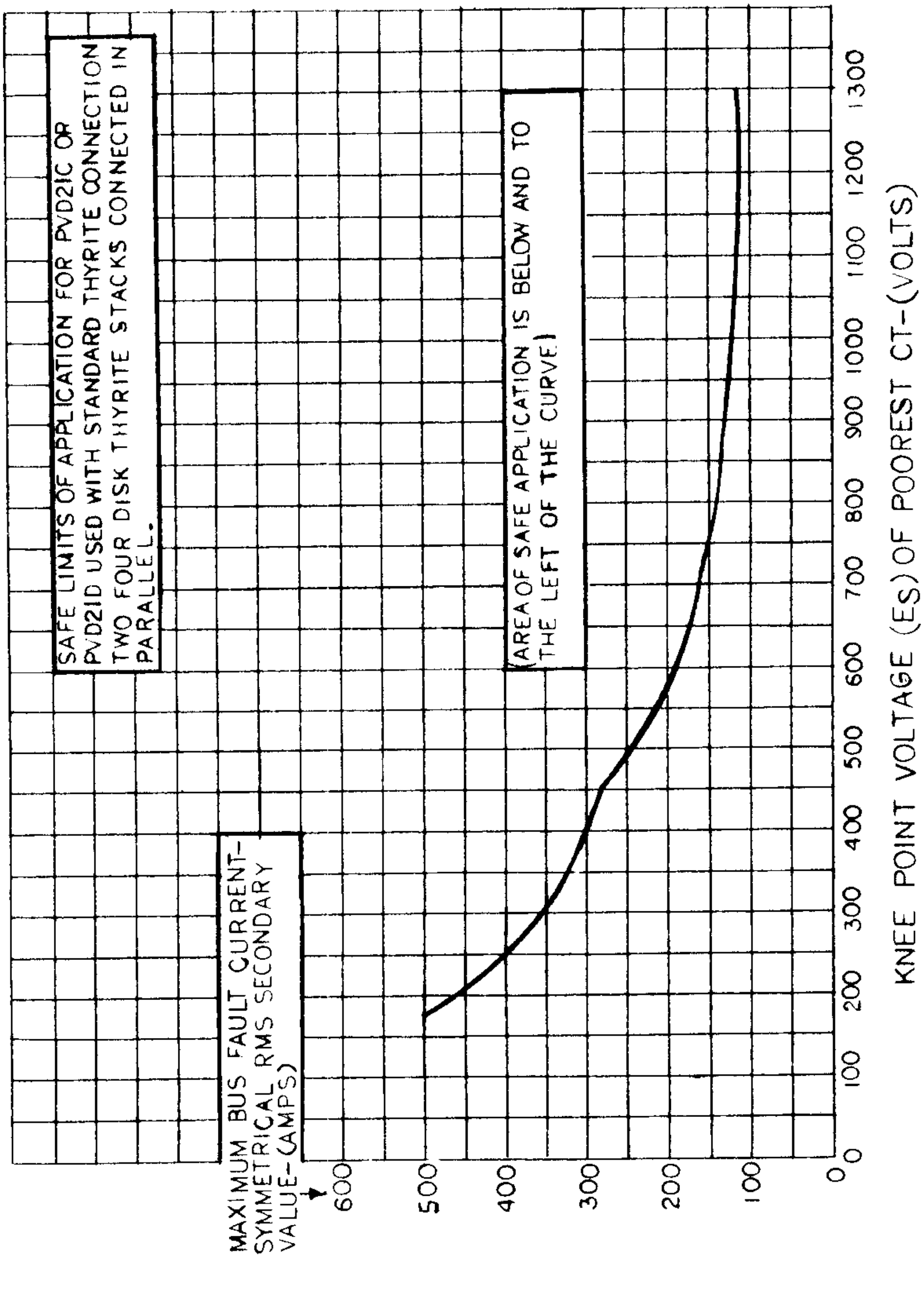


Figure 10 (0257A8590-1) Safe Application Limits for Type PVD21C or Type PVD21D Relays (Two Thyrite® Stacks)

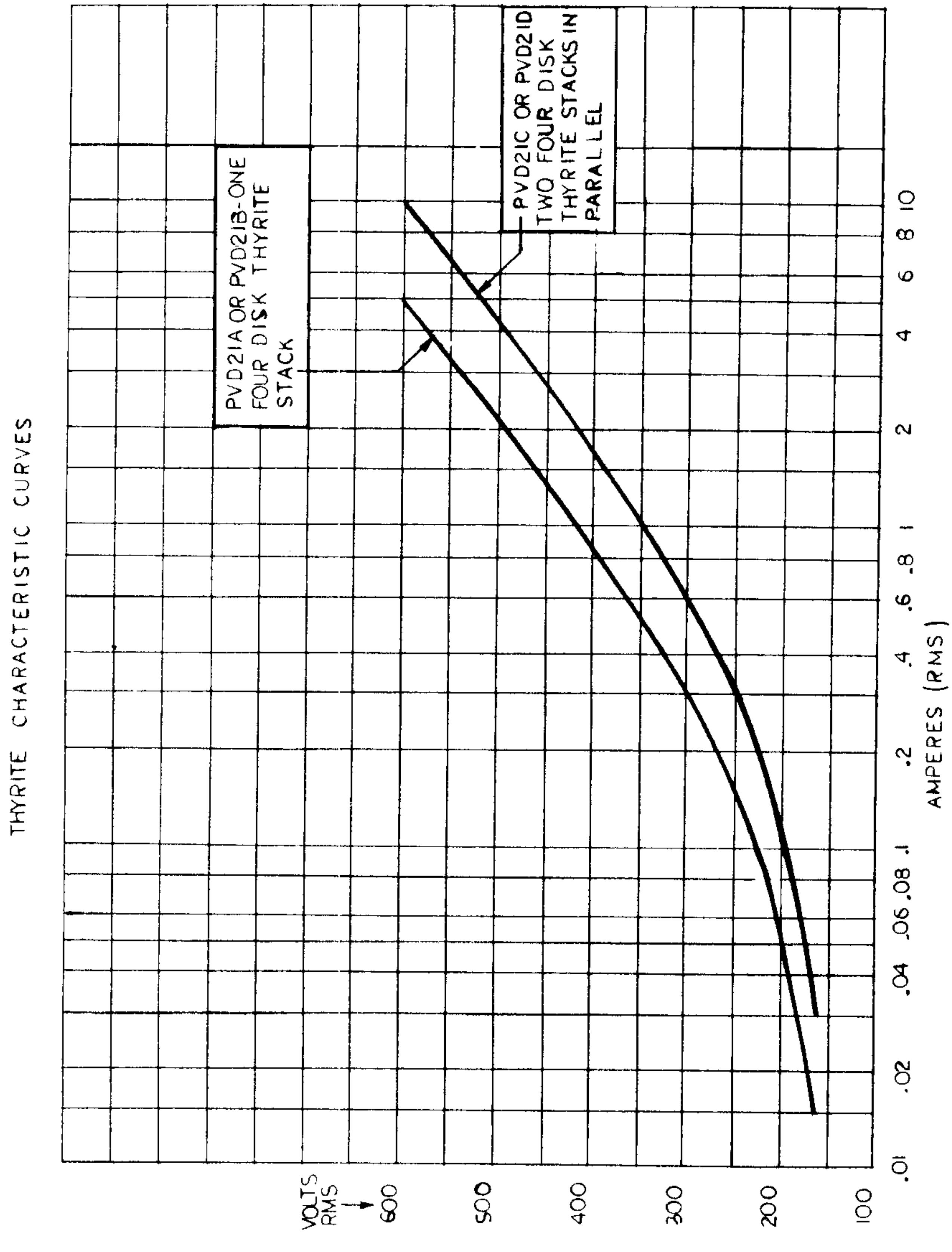


Figure 11 (0257A8589-1) Thyrite® Volt-Ampere Characteristics

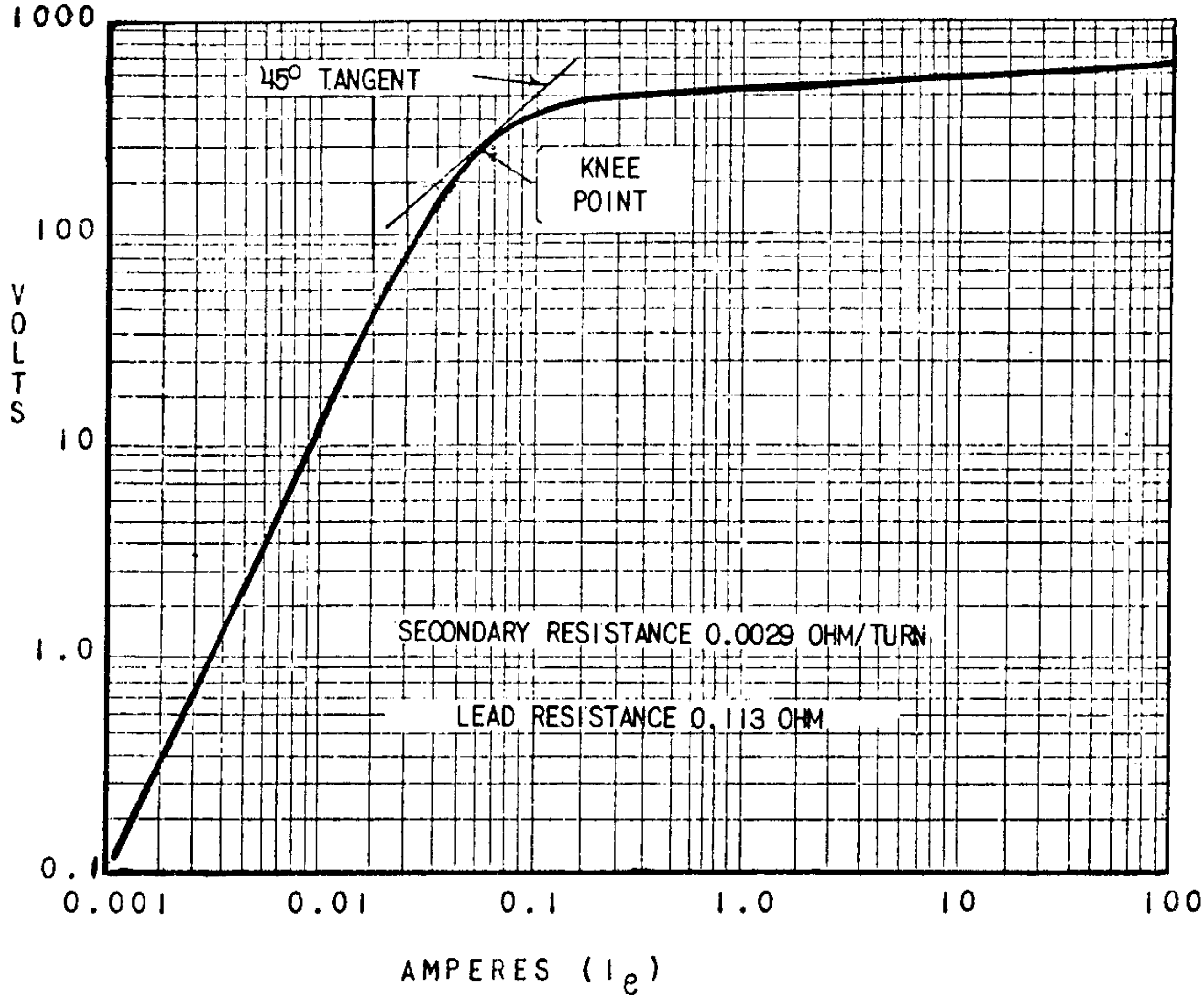


Figure 12 (0246A3799-1) Typical Secondary Excitation Characteristic for Bushing Type Current Transformer

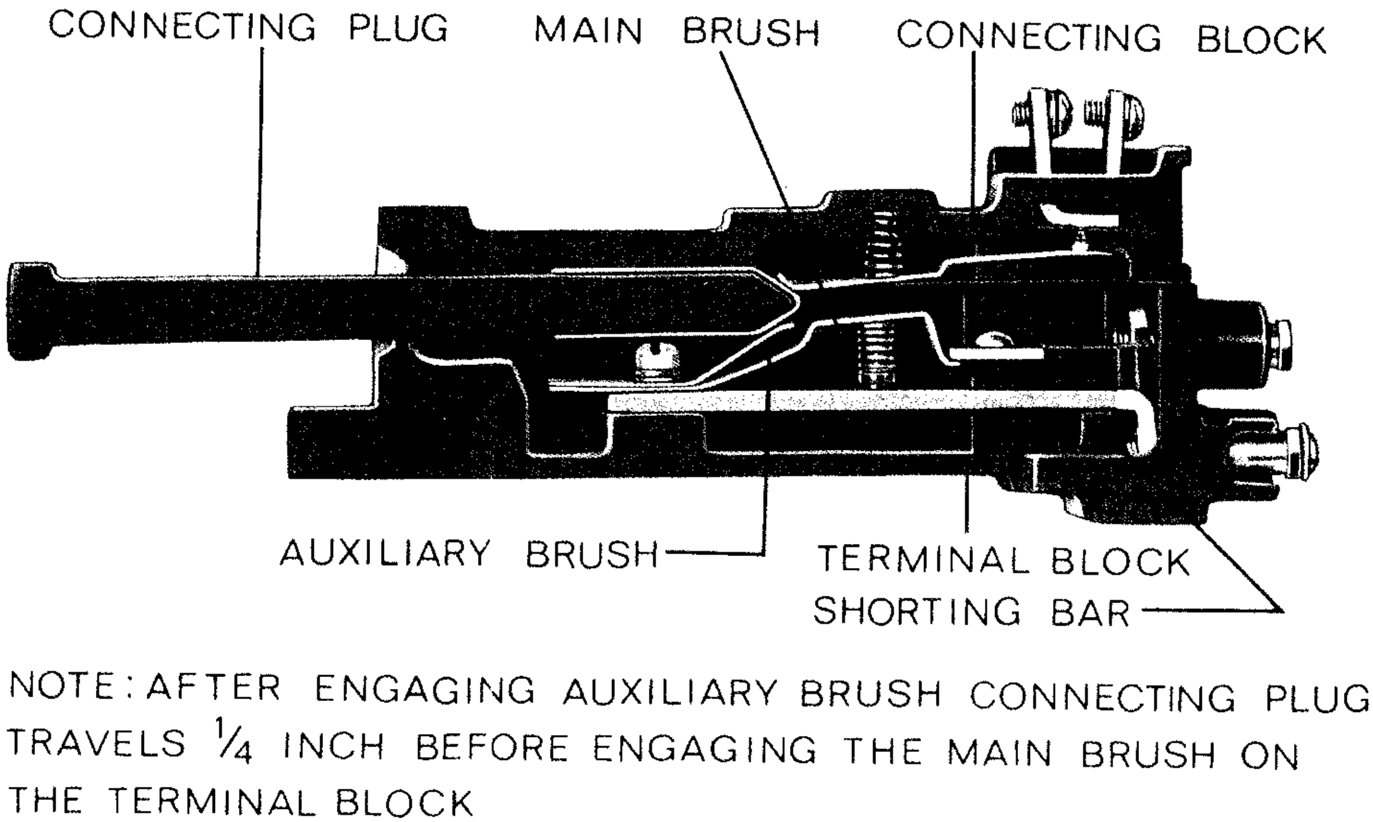
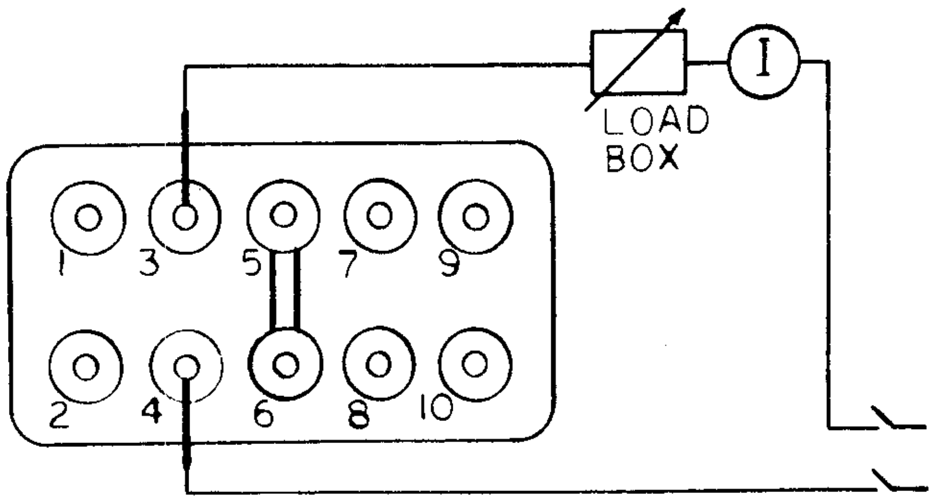
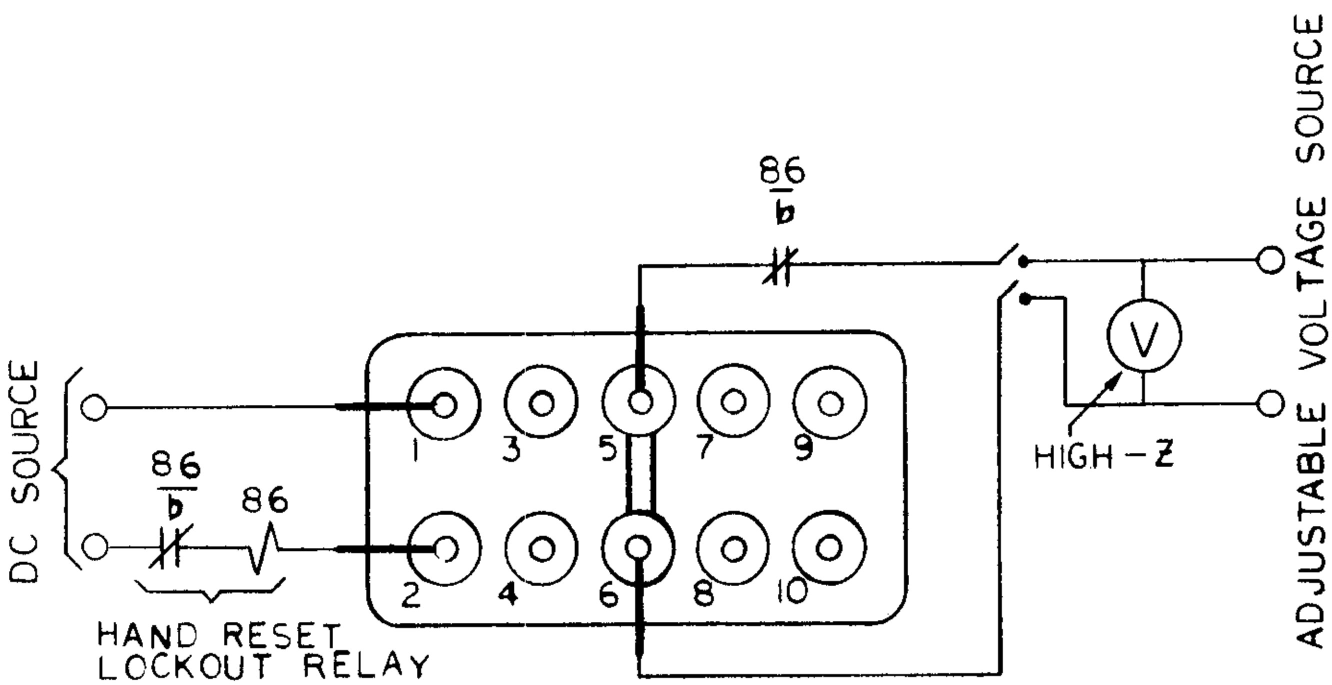


Figure 13 (8025039) Cross Section of Drawout Case Showing Position of Auxiliary Brush and Shorting Bar



TEST CIRCUIT FOR SETTING 87H



TEST CIRCUIT FOR SETTING 87L

WARNING — WHEN USING A XLA12A TEST PLUG, INSTALL SHORTING BAR ACROSS TERMINALS 5 AND 6 BEFORE INSERTING TEST PLUG.

NOTE — ABOVE TEST FIGURES SHOW XLA12 TEST PLUG

Figure 14 (0269A3025-0) Test Circuit Connections

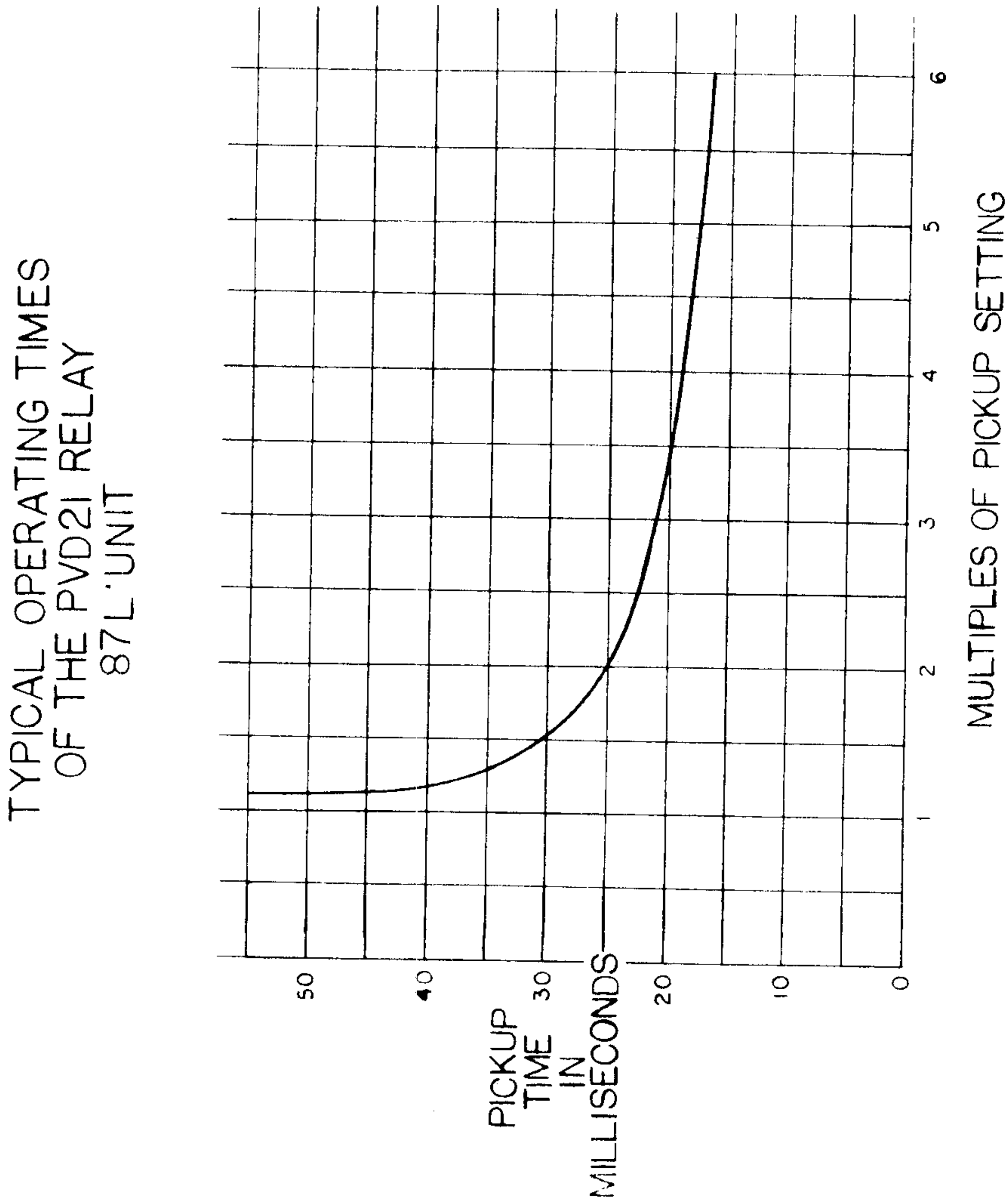


Figure 15 (0269A1798-1) Typical Operating Times for the Type PVD21 Relay, 87L Unit