INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKD, SP, SP-1 COMPENSATOR DISTANCE RELAYS

APPLICATION

The type SKD relay, Figure 1, is a polyphase compensator type distance relay which provides a single zone of phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to ground faults, and three-phase faults.

Types SP and SP-1 relays, Figure 2 and Figure 3 respectively, are similar to the SKD relay except they have a low-energy transistor output used to control auxiliary circuits. Characteristics of the SP-1 are slightly different in that the impedance circle of the three-phase unit includes the origin. The SKD relay has an electro-mechanical indicating contactor switch and the SP relay has a light as an operation indicator.

CONSTRUCTION

Types SKD, SP, and SP-1 relays are available in ranges of .2-4.35 ohms, .73-21 ohms, and 1.1-31.8 ohms. They consist of two air gap transformers (compensators), two tapped auto-transformers, a phase shifting circuit, a memory circuit, and three isolating transformers which couple the ac quantities into the static network. One large printed circuit assembly provides the characteristics of a dual polarized phase angle comparison unit and has a transistor output. The SKD relay has an additional small printed circuit assembly containing the trigger circuit for a thyristor (controlled-rectifier) tripping unit.

Compensator

The compensators which are designated T_{AB} and T_{CB} are three-winding air-gap transformers. There are two primary current windings, each current winding having seven taps which terminate at the tap block, Figure 4. The "T" values are marked (.23, .307, .383, .537, .69, .92, and 1.23), (0.87, 1.16, 1.45, 2.03, 2.9, 4.06, and 5.8), and (1.31, 1.74, 2.18, 3.05, 4.35, 6.1, and 8.7) for the .2-4.35 ohms, .73-21 ohms, and 1.1-31.8 ohms ranges respectively.

A voltage is induced in the secondary which is proportional to the primary tap value and the current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

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The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between current and the induced secondary voltage. The phase angle may be set for any value between 60° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum sensitivity angle of $75^\circ \pm 3^\circ$ current lagging voltage.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block Figure 4. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -18 to +18 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0., .03, .09, and .06.

The auto-transformer makes it possible to expand the basic range of T ohms by a multiplier of $\frac{S}{1 + M}$. Therefore, any relay ohm setting can be made within $\pm$ 1.5 percent from the minimum value to maximum value of a given range by combining the compensator taps T_{AB} and T_{BC} with the auto-transformer taps S_A-M_A and S_C-M_C.

Phase Shifting Circuit

"Polarization" is the reference against which the "operate" signal is compared. Polarization for the three-phase unit is obtained by shifting the phase 1-2 voltage ahead 90°. The phase shifting circuit consists of a center tapped step-up auto-transformer, XS, which supplies voltage to a series connected resistor and capacitor, RS and CS respectively (Figures 5, 6, and 7). Voltage between the resistor-capacitor junction and the auto-transformer center tap leads the applied voltage by 90°.

Memory Circuit

The memory circuit consists of a large inductive reactance, XL, and a large capacitive reactance, C3C, which are series connected and are tuned very closely to sixty cycles. In the event of a close-in fault which drops the relay terminal voltages to zero, the energy trapped in memory circuit will decay relatively slowly, while oscillating at a sixty cycle frequency. This will maintain a polarizing signal long enough for the relay to operate with an accurate reach and directional sense.

Isolating Transformers

Transformers T1, T2, and T3 serve two purposes. Firstly, they isolate the ac circuits from the dc circuit. Secondly, they amplify the clipped ac signal by a factor of 1:8 to make the relay sensitive to low level input signals.

Printed Circuit Board Assembly

The printed circuit board assembly shown in Figure 8 contains all the resistors, diodes, transistors, and silicon controlled switches necessary to perform the functions of a dual polarized phase angle comparison unit. In Figure 8, resistors are identified by the letter R followed by a number, the same combination is used to identify the same resistor in the internal schematics, Figures 9, 10 and 11. Similarly, diodes are identified by a D and the cathode (the end out of which conventional current flows) is identified by a bar across the point of an arrow. Zener diodes are identified by two letters, DZ, transistors are identified by a Q, silicon controlled switches by QS, capacitors by C, and test points by TP.

When facing the component side with terminals at the bottom, terminals are numbered from right to left starting at 1 and going through number 19. These terminal numbers are shown within brackets on the internal schematic and will be referred to as Printed Circuit Terminals, PCT, in the trouble shooting section.

Trigger Circuit for SKD

The circuit board assembly shown in Figure 14 contains triggering and protective circuitry for the tripping thyristor in the SKD relay. Components are identified the same as on the main board. Terminals are numbered in the same way as for the main board and are identified on the internal schematic by the letter A following the terminal number and both enclosed by brackets, (5A).

OPERATION

The SKD, SP, and SP-1 relays all utilize identical ac input circuits. Therefore, an explanation for the SKD will suffice for all.

Two distinctly different logic systems are used in the SKD relay. One detects all except three-phase faults and is called the phase-to-phase unit. The other system detects three-phase faults and is called the three-phase unit. Each of the two systems present two voltages to the static phase angle comparison unit which checks the phase angle relation between the two. A non-trip or restraint condition exists when V_{YB} leads V_{XB} as referred to in Figure 12.a. A trip condition results when V_{YB} lags V_{XB}.

Phase-to-Phase Unit

For phase-to-phase fault detection, the system monitors the three phase-to-phase voltages and compares them with the related I_{ZR} drops computed by the relay compensators. The compensators are set to be replica of the protected line section as seen by the secondary side and have the same relative current flowing through them as flows through the total line impedance. If a fault is external to the protected line section as shown in Figure 12.b at point 1, it can be seen that the voltage V_{CB} is greater than the permissible minimum (I_c-I_b) ZR computed by compensator TCB. The difference voltage V_{YB} shown as a heavy line still leads voltage V_{XB} and the phase angle comparison unit remains in a non-trip or restraint condition.

For a fault within the protected line section at point 2, the voltage V_{CB} is less than the permissible minimum computed by the compensator. This results in the difference voltage V_{YB} being flipped 180° so that it lags V_{XB} and causes the phase angle comparison unit to trip.

Faults behind the relay produce a restraint condition as shown for a fault at point 3. In this case the fault current polarity is the reverse of that for faults at points 1 and 2. The compensator voltage is added to V_{CB} and the resulting voltage V_{YB} leads V_{XB} to maintain the restraint condition.

For each fault illustrated in Figure 12.c, it is assumed that the angle of the protected line is 90° and that the relay is set for a maximum sensitivity angle of 90°.

The phase-to-phase unit will not trip for any balanced three-phase condition whether it be a three-phase fault, an out-of-step or swing condition, or a heavy load. For this reason, an additional circuit is provided which will detect and trip for three-phase fault.

<u>Three-Phase Unit</u>

The three-phase unit is basically a single phase unit operating from delta voltage and current. Since a three-phase fault produces nearly identical conditions in all three phases, any set of phase-to-phase voltage and current may be used to detect a three-phase fault.

Figure 13.a illustrates the connections which apply voltages to the static phase angle comparison unit. Voltage V_{AB} is modified by the compensator output voltage $(I_A-I_B)\ Z_R$ to produce voltage V_{XB}. (This is identical to the phase-to-phase unit). A polarizing voltage V_{YB} is obtained by advancing V_{AB} 90° through the phase shifting circuit. A restraint condition exists when V_{YB} leads V_{XB} and a trip condition exists when V_{YB} lags V_{XB}.

A simple diagram in Figure 13.b shows the protective zone for the three-phase unit and indicates three locations for faults which will present a different set of voltage conditions to the phase-angle comparison unit. Figure 13.c illustrates the three conditions.

For a fault at location 1, external to the protected line section, V_{AB} is greater than the permissible minimum $(I_A-I_B)\ Z_R$ computed by the compensator T_{AB}. The phase shifted polarizing voltage V_{YB} leads the difference voltage V_{XB} and a restraint condittion exists.

When a fault occurs within the protected line section such as at point 2, V_{AB} becomes smaller than the permissible minimum computed by the compensator. This results in V_{XB} being flipped 180° so that the polarizing voltage V_{YB} lags V_{XB} and the phase-angle-comparitor unit trips.

For a fault behind the relay such as at point 3, current through the relay has a polarity opposite from that for faults at points 1 and 2. The compensator voltage is added to V_{AB} so that polarizing voltage V_{YB} leads the resulting V_{XB} to maintain the restraint condition.

In Figure 13.c, it is assumed that the angle of the protected line is 90° and that the relay is set for a maximum sensitivity angle of 90°.

The three-phase unit will trip for some phase-to-phase faults and some ground faults as well as for three-phase faults. However, it will not over-reach the phase-to-phase setting for any type of fault. Note that the phase-to-phase unit and the three-phase unit use the same compensator, T_{AB}. Thus, the two units have identical reach settings. The three-phase unit may trip for an out-of-step or swing condition. To prevent such tripping, the three-phase unit can be disabled by connecting relay terminal 4 to battery negative through a swing detection means.

Phase Angle Comparison Unit

Referring to Figure 9, the phase angle comparison unit trips when current flows into the base of transistor Q9 through zener diode DZ4. Such tripping current must come from the 20V bus through either transistor Q10 or Q11 located in what might be called the "operate" circuit. The operate circuit, driven by transformer T1, is continually trying to trip the unit by supply current throgh Q10 and Q11 on alternate half cycles. Q10 conducts when the polarity marked terminal of T1 is positive.

When Q10 conducts, a portion of the current goes through resistor R24. This current, I_{R24}, may take either of two paths to the negative bus. If QS1 is in a conducting state, I_{R24} passes through it directly to the negative bus. If QS1 is in a blocking state, I_{R24} passes through D16 and then through DZ4 to transistor Q9 to cause tripping. Silicon controlled switch QS1 is located in what might be called the "polarizing" circuit of the phase-to-phase unit. This circuit is driven by transformer T2.

To prevent the operate circuit from tripping, the polarity marked terminals of T2 must go positive before the polarity terminals of T1 do. This caused Q3 to conduct current through R22 and D14 to drive the base of Q13. Q13 then conducts current from the 13V bus through R9 to gate QS1 into conduction. When QS1 conducts, it short circuits the current which might otherwise pass through D16 to cause tripping. Once QS1 begins to conduct, the gate loses control and it remains in the conducting state until the current is turned off by Q10. No tripping output can develop as long as the T2 voltage leads the T1 voltage.

The operate circuit switches for the next half cycle so that transistors Q2 and Q11 conduct in an attempt to cause tripping. In the polarizing circuit, Q4, Q14, and QS2 seek to prevent tripping by short circuiting the current which might otherwise pass through D21, DZ4, and Q9.

Restraint Squelch: When the operate circuit transistor Q10 conducts, approximately 18V is applied through diode D13 to back bias D14 and prevent Q13 from turning on. Thus a trip signal, initiated because the T1 voltage is leading, cannot be improperly interrupted when the T2 voltage goes positive. A full half cycle tripping output is therefore produced by Q10. This back biasing connection is called the restraint squelch circuit.

Voltage Detectors: If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch QS1 and short circuit the Q10 current. This, of course, could cause incorrect tripping. A voltage detector circuit prevents this from happening. Transistor Q12 is maintained in the conducting state by Q3 and Q4 alternately when a useful voltage level is supplied by T2. When conducting, Q12 short circuits current which flows through R5 from the 20V bus. When the voltage from T2 drops too low to drive Q3 and Q4, then Q12 turns off and the R5 current flows through DZ2 to switch Q7 into conduction. This in turn drives Q13 through D11, R22, and D14 causing Q13 to switch QS1 into conduction to short circuit D16 and prevent tripping.

The operate circuit, driven by T1, and the polarizing circuits, driven by T2 and T3, are duals having identical circuits which operate on alternate half cycles. The restraint squelch and the voltage detector both work into each of the duals in the same way.

Transformer T3 receives a polarizing signal from the three-phase circuit and drives a polarizing circuit which is identical to the one supplied by transformer T2. The phase angle relation between the T1 voltage and the T3 voltage is compared in the same manner as described above and tripping signals are supplied through D31 and D35, through DZ4 and to Q9. This polarizing circuit contains a restraint squelch and a voltage detector identical to those described for the T2 circuit.

SP-1 Relay: The SP-1 relays has a characteristic circle which includes the origin. That is, it will trip on current when the voltage is zero. This feature is obtained by omitting the voltage detector from the T3 circuit. This omission reduces the accuracy of the SP-1 relay at low voltage test levels.

Output Circuit

The output of the SKD relay is a Thyristor (controlled-rectifier) which is gated into conduction by a pulse transformer. The transformer is pulsed when Q9 turns on causing Q18 to conduct into an oscillator consisting of capacitor C5, pulse transformer TP, and unijunction transistor Q19. Q19 switches into conduction when voltage across C5 reaches a predetermined level. It resets after capacitor C5 has discharged through TP to produce a gating pulse. C5 then charges up again to repeat the process.

In the SP and SP-1 relays, Figures 10 and 11 respectively, Q9 turns on to short circuit current from the base of Q22 causing it to stop conducting. An output voltage subsequently develops across Q22 and appears at terminal 11 of the relay.

CHARACTERISTICS

Distance Characteristic - Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the RX diagram as shown in Figure 15, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional.

An inspection of Figure 15 indicates that the circle of the phase-to-phase unit is dependent on source impedance Zg. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-Phase Unit

A plot of relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 16. The unit will operate with the correct directional sense for zero voltage phase-to-phase faults. For this condition the product of fault current times T setting must be not less than 0.40 with rated voltage on the unfaulted phase.

The relays may be set without regard to possible over-reach due to dc transients. Compensators basically are insensitive to dc transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary.

Distance Characteristic - SKD and SP, Three Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 17. This circle is independent of source impedance. The three-phase unit is also inherently directional.

If a solid-three-phase fault should occur right at the relay location, the voltage will collapse to zero to give a balance point condition, as implied by the relay characteristic (in Figure 17) passing through the origin. When the YB voltage (Figure 13) drops to zero, the relay is unable to determine whether an internal or external fault existed. To avoid this condition, a resonant circuit causes the Y voltage to collapse gradually at a frequency of 60 cycles. This characteristic called memory action provides a reference voltage long enough to determine whether the fault is inside the protected line section or behind the relay.

Sensitivity: 3 Phase Unit

The impedance curve for the three-phase unit is shown in Figure 16.

The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above.

Distance Characteristics: SP-1, Three Phase Unit

The three-phase unit of the SP-1 relays has a characteristic circle which includes the origin. This feature results from the omission of the voltage detector in the static circuit. The unit will trip for an "IT" product of 0.40 or more when the input voltage is zero.

General Characteristics

Impedance settings in ohms reach can be made in steps of 3 percent for any range, the .2-4.35 ohm relay, the .73-21 ohm relay, and the 1.1-31.8 ohm relay. The maximum sensitivity angle, which is set for 75 degrees at the factory, may be set for any value from 60 degrees to 80 degrees. A change in maximum sensitivity angle will produce a slight change in reach for any given setting of the relay. The compensator secondary voltage output V is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R2A or R2C) shown in Figures 5, 6, and 7 is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT_{AB} or IT_{AC}. Thus, the net voltage, V, is phase-shifted to change the compensator maximum sensitivity angle. As a result of this phase shift the magnitude of V is reduced.

Tap markings in Figure 4 are based upon a 75° compensator angle setting. If the resistors R2A and R2C are adjusted for some other maximum sensitivity angle the nominal reach is different than indicated by the taps. The reach Z_θ, varies with the maximum sensitivity angle, θ, as follows:

$$Z_\theta = \frac{TS \sin \theta}{(1 + M) \sin 75^\circ}$$

TAP PLATE MARKINGS

(T_A, T_B, and T_C)

.2-4.35 Ohms	.23	.307	.383	.537	.69	.92	1.23
.73-21 Ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
1.1-31.8 Ohms	1.31	1.74	2.18	3.05	4.35	6.1	8.7

(S_A and S_C)

	1	2	3
	(M_A and M_C)		
± Values between taps	.03	.09	.06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the SKD, SP and SP-1 relays is shown by the time curves in Figure 18. The curves indicate the time in milliseconds required for the relay to provide an output for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating In Amperes

"T" TAP SETTING			CONTINUOUS S=1	S=2	S=3	1 SECOND
1.23	5.8	8.7	5.0	8.5	9.5	240
.92	4.2	6.1	6.0	10.0	10.0	240
.69	3.0	4.35	8.0	10.0	10.0	240
.537	2.2	3.05	10.0	10.0	10.0	240
.383	1.6	2.18	10.0	10.0	10.0	240
.307	1.16	1.74	10.0	10.0	10.0	240
.23	0.87	1.31	10.0	10.0	10.0	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is listed in Table 1. The potential burden and burden phase angle are based on 69.3 volts line-to-neutral applied to the relay terminals.

SKD Trip Circuit Constants

1 ampere I.C.S. 0.1 ohm dc resistance.

Thyristor Tripping Unit

The thyristor is a three-terminal semi-conductor device. In the reverse, or non-conducting direction, the device exhibits the very low leakage characteristics of a silicon rectifier. In the forward, or conducting direction, conduction can be initiated by the application of a control pulse to the control terminal or "gate". If a gate signal is not applied, the device will not conduct at below rated forward blocking voltage. With the application of a gate signal, however, the device switches rapidly to a conducting state characterized by a very low voltage drop and a high current-carrying capability. Once conduction has been initiated, the gate terminal no longer has any effect. In order to turn the unit off, the anode-cathode current must be reduced to a value less than the holding current.

It should be noted that the SKD trip circuit differs from mechanically operated contacts. A certain minimum trip current must flow before the thyristor (controlled-rectifier) will latch on. If the minimum turn on current is not established during the first millisecond after the first gate pulse is received, the unit will not latch on. However, voltage will be applied to the load for the duration of each gate pulse. Pulses are applied to the gate circuit at a rate of one every four milliseconds.

Current rating per circuit:

Ambient temperature	25°C	50°C	75°C
3 cycle duty (50 MS surge)	60A	49A	37A
5 cycle duty (83 MS surge)	54A	44A	33A
Continuous	6.5A	4.5A	3A

Trip circuit requirements:

$$\frac{V_{dc}}{R_{LOAD\ OHMS}} = .25 \text{ amp. or more}$$

$$\frac{L_{HENRYS}}{R_{LOAD\ OHMS}} = .02 \text{ or less}$$

Thyristor:

Max. forward leakage current 125°C = 8 MA dc.
  Typical at 85°C = .07 MA dc
Max. reverse leakage current 125°C = 8 MA dc.
  Typical at 85°C = .07 MA dc
Max. forward voltage drop at 10 amps. 25°C
  1.6 volts

SP and SP-1 Output Circuits

Open circuit voltage	18 V to 21 V d.c.
Short circuit current	18 to 21 milliamperes

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Figure 4. The tap markings are:

(T_A, T_B, and T_C)

.2-4.35 Ohms	.23	.307	.383	.537	.69	.92	1.23
.73-21 Ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
1.1-31.8 Ohms	1.31	1.74	2.18	3.05	4.35	6.1	8.7

(S_A and S_C)

1	2	3

(M_A and M_C)

Values between taps	.03	.09	.06

Maximum sensitivity angle, θ, is set for 75° (current lagging voltage) in the factory. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65° set θ for a 60° maximum sensitivity angle, by adjusting R2A and R2C. Set zone 1 reach to be 90% of the line (85% for line angles of less than 50°).

Calculations for setting the SKD, SP, and SP-1 relays are straight-forward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relay is:

$$Z_\theta = Z_{pri} \frac{0.9\,R_c}{R_v} \qquad \text{Eq. (1)}$$

The terms used in this formula and hereafter are defined as follows:

Z_θ = the ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees.

$$Z = \frac{TS}{1 + M} = \text{the tap plate setting} \qquad \text{Eq. (2)}$$

T = Compensator tap value

S = Auto-transformer primary tap value

θ = Maximum sensitivity angle setting of the relay (Factory setting of θ = 75°)

$\pm M$ = Auto-transformer secondary tap value. (This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads. The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Zpri = Ohms per phase of the total line section.

0.9 = The portion of the total line for which the relay is set to trip.

Rc = Current transformer ratio

Rv = Potential transformer ratio

The following procedure should be followed in order to obtain an optimum setting of the relay:

1. a) Establish the value of Z_θ, as above.
   b) Determine the tap plate value Z using the formula:

$$Z = Z_\theta \frac{\text{Sin } 75^\circ}{\text{Sin } \theta^\circ}$$

When $\theta = 75^\circ$, $Z = Z_\theta$.

2. Now refer to Table 11, Table 111, and Table 1V for the optimum tap settings.

   a) Locate a Table value for relay reach nearest the desired value Z. (It will always be within 1.5% of the desired value.)

   b) Select from the Table "S", "T" and "M" settings. "M" column includes additional information for "L" and "R" leads setting for the specified "M" value.

   c) Recheck the selected "S", "T" and "M" settings to assure the correct value of Z by using equation (2).

$$Z = \frac{ST}{1 \pm M}$$

For example, assume the desired reach, Z_0 for a .73-21 ohm relay is 7 ohms at 60°. (Step 1a).

Step (1b). The line angle of 60° requires that the relay maximum sensitivity angle be changed from a factory setting of 75° to the new value of 60°. Using equation (3), we find the corrected value for the relay tap settings:

$$Z = 7 \times \frac{\text{Sin } 75^\circ}{\text{Sin } 60^\circ} = 7.8 \text{ ohms}$$

Step (2a). In Table 111, we find nearest value to 7.8 ohms is 7.88. That is $100 \times \frac{7.88}{7.8} = 101.0$ percent of the desired reach.

Step 2b) From Table 111, read off:

$$S = 2$$
$$T = 4.06$$
$$M = +.03$$

and "L" lead should be connected over "R" lead, with "L" lead connected to "03" tap and "R" lead to tap "0".

Step (2c) Recheck Settings:

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times 4.06}{1 + .03} = 7.88 \qquad \text{From Eq. (2)}$$

$$Z \angle 60^\circ = Z \frac{\sin 60^\circ}{\sin 75^\circ} = 7.88 \times .896 + 7.06 \qquad \text{From Eq. (3)}$$

which is 101.0 percent of the desired setting.

SETTING THE RELAY

The SKD, SP, and SP-1 relays require settings for the two compensators (T_{AB} and T_{CB}), the two auto-transformer primaries (S_A and S_C) and secondaries (M_A and M_C). All of these settings are made with taps on the tap plate.

Compensator (T_{AB} and T_{CB})

Each set of compensator taps terminates in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly but not so tightly as to break the tap screw.

Auto-Transformer Primary (S_A and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 4.)

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

TABLE I

† POTENTIAL BURDEN IN VOLT-AMPERES

	TAP SETTING	PHASE A-N			PHASE B-N			PHASE C-N		
	M	VA	WATTS	VARS	VA	WATTS	VARS	VA	WATTS	VARS
I = 0	+.18	3.80	3.06	-2.26	6.40	6.38	0.45	3.1	2.38	1.99
69.3 VL-N 3Ø	0	2.98	2.38	-1.92	4.98	4.97	0.30	2.27	1.69	1.52
S = 1	-.18	2.22	1.57	-1.57	3.68	3.68	0.13	1.57	1.13	1.09
I = 0	+.18	1.47	0.80	-1.24	2.27	2.24	-0.33	0.72	0.55	0.46
69.3 VL-N 3Ø	0	1.33	0.62	-1.17	1.93	1.89	-0.37	0.55	0.42	0.36
S = 2	-.18	1.24	0.48	-1.14	1.61	1.57	-0.38	0.38	0.28	0.26
I = 0	+.18	1.22	0.44	-1.14	1.57	1.52	-0.41	0.33	0.25	0.21
69.3 VL-N 3Ø	0	1.16	0.34	-1.11	1.44	1.38	-0.40	0.25	0.19	0.16
S = 3	-.18	1.11	0.27	-1.08	1.31	1.24	-0.42	0.18	0.14	0.12
‡ 5A. ∠-75° 3Ø	+.18	1.72	1.66	-0.46	3.52	1.60	-3.14	1.30	-0.36	-1.25
69.3 VL-N 3Ø	0	1.34	1.33	-0.14	2.53	1.26	-2.19	0.83	-0.27	-0.79
S = 1	-.18	1.03	1.03	-0.07	1.68	0.89	-1.42	0.45	-0.20	-0.40
‡‡ 5A. ∠105° 3Ø	+.18	6.65	4.7	-4.70	10.3	5.75	-10.1	5.00	-1.30	-4.84
69.3 VL-N 3Ø	0	5.0	3.94	-3.08	7.90	2.04	-7.60	3.76	-0.91	-3.65
S = 1	-.18	3.46	3.14	-1.46	5.70	2.41	-5.17	2.67	-0.65	-2.59

† CURRENT BURDEN IN OHMS
(†† MAXIMUM BURDEN CONDITIONS)

S = 1, M = 0, TAP .73-21 OHM RANGE	CURRENT CIRCUIT IMPEDANCE AT 5 TO 100 AMPERES (VLL = 120 V.)								
	TA (TERM'S 13-12)			TB (TERM'S 15-14)			TC (TERM'S 17-16)		
	IMP. Z	RES. R	REAC. jX	IMP. Z	RES. R	REAC. jX	IMP. Z	RES. R	REAC. jX
.87	.019	.0188	.0026	.0356	.0349	.0068	.0162	.0159	.0031
1.16	.021	.0203	.0054	.039	.0379	.0094	.0194	.0188	.005
1.45	.026	.0243	.0093	.0432	.0411	.0133	.0206	.0189	.0068
2.03	.0344	.0295	.0177	.0569	.0507	.0257	.0294	.0252	.0152
2.9	.0514	.0382	.0344	.081	.0647	.0487	.047	.0344	.0320
4.06	.085	.0523	.067	.130	.087	.0965	.074	.0456	.0583
5.8	.153	.081	.130	.230	.129	.191	.135	.0675	.117

† Typical potential and current burden data applies for all relays and all relay ranges.

†† Maximum burden is produced by phase-to-phase fault involving TA & TB compensators or TB & TC.

‡ Fault current flowing into the line.

‡‡ Fault current flowing out of the line.

TABLE II

RELAY SETTINGS FOR .2-4.5 OHM RANGE RELAY

	"S" = 1							"S" = 2		"S" = 3		M		LEAD CONNECTIONS		
T =	.23	.307	.383	.537	.69	.92	1.23	.92	1.23	.92	1.23	+M	-M	"L" LEAD	"R" LEAD	
	.195	.26	.324	.455	.585	.78	1.04	1.56	2.08	-	3.13	+.18		.06	0	"L" OVER "R"
	.20	.267	.333	.466	.6	.8	1.07	1.6	2.14	-	3.21	+.15		.06	.03	"L" OVER "R"
	.205	.274	.342	.48	.615	.82	1.1	1.64	2.2	-	3.29	+.12		.09	0	"L" OVER "R"
	.211	.281	.352	.493	.633	.845	1.13	1.69	2.26	-	3.38	+.09		.09	.03	"L" OVER "R"
	.217	.289	.362	.506	.65	.868	1.16	1.74	2.32	-	3.48	+.06		.06	.09	"L" OVER "R"
	.223	.298	.372	.521	.67	.893	1.2	1.79	2.39	-	3.58	+.03		.03	0	"L" OVER "R"
	.23	.307	.383	.537	.69	.92	1.23	1.84	2.46	-	3.69	0	0	0	0	
	.237	.316	.395	.554	.71	.948	1.27	1.9	2.54	-	3.8		-.03	0	.03	"R" OVER "L"
	.245	-	.407	.571	.735	.978	1.31	1.96	2.62	-	3.92		-.06	.09	.06	"R" OVER "L"
	.252	-	.42	-	.758	1.01	1.35	2.02	2.7	3.03	4.05		-.09	.03	.09	"R" OVER "L"
	-	-	.435	-	-	-	1.4	-	2.8	-	4.19		-.12	0	.09	"R" OVER "L"
	-	-	-	-	-	-	1.45	-	2.89	-	4.35		-.15	.03	.06	"R" OVER "L"
	-	-	-	-	-	-	1.5	-	3.0	-	4.5		-.18	0	.06	"R" OVER "L"

TABLE III

RELAY SETTINGS FOR .73-21 OHM RANGE RELAY

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTIONS		
T =	.87	1.16	1.45	2.03	2.9	4.06	5.8	4.06	5.8	4.06	5.8	+M	-M	"L" LEAD	"R" LEAD	
	.737	.98	1.23	1.72	2.46	3.44	4.92	-	9.85	-	14.7	+.18		.06	0	"L" OVER "R"
	.755	1.01	1.26	1.76	2.52	3.53	5.04	-	10.1	-	15.1	+.15		.06	.03	"L" OVER "R"
	.775	1.03	1.29	1.81	2.59	3.63	5.18	7.26	10.3	-	15.5	+.12		.09	0	"L" OVER "R"
	.800	1.01	1.33	1.86	2.66	3.73	5.32	7.44	10.6	-	15.9	+.09		.09	.03	"L" OVER "R"
	.820	1.09	1.37	1.91	2.74	3.83	5.48	7.65	10.9	-	16.4	+.06		.06	.09	"L" OVER "R"
	.845	1.12	1.41	1.97	2.81	3.94	5.64	7.88	11.3	-	16.9	+.03		.03	0	"L" OVER "R"
	.870	1.16	1.45	2.03	2.9	4.06	5.8	8.12	11.6	-	17.4	0	0	0	0	
	.897	1.20	1.49	2.09	2.99	4.18	5.98	8.36	11.9	-	18.0		-.03	0	.03	"R" OVER "L"
	.925	-	1.54	2.16	3.09	4.32	6.18	8.65	12.3	-	18.6		-.06	.09	.06	"R" OVER "L"
	.955	-	1.59	2.23	3.19	4.47	6.38	8.93	12.7	-	19.2		-.09	.03	.09	"R" OVER "L"
	-	-	1.65	2.31	3.29	4.62	6.60	9.13	13.2	-	19.8		-.12	0	.09	"R" OVER "L"
	-	-	1.71	2.39	3.41	4.77	6.82	9.55	13.7	-	20.5		-.15	.03	.06	"R" OVER "L"
	-	-	-	-	-	-	7.08	-	14.1	14.3	21.3		-.18	0	.06	"R" OVER "L"

TABLE IV

RELAY SETTINGS FOR 1.1-31.8 OHM RANGE RELAY

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTIONS		
T =	1.31	1.74	2.18	3.05	4.35	6.1	8.7	6.1	8.7	6.1	8.7	+M	-M	"L" LEAD	"R" LEAD	
	1.11	1.47	1.85	2.58	3.68	5.16	7.37	-	14.71	-	22.1	+.18		.06	0	"L" OVER "R"
	1.14	1.51	1.89	2.65	3.78	5.30	7.56	-	15.11	-	22.7	+.15		.06	.03	"L" OVER "R"
	1.17	1.55	1.95	2.72	3.88	5.45	7.76	10.9	15.5	-	23.3	+.12		.09	0	"L" OVER "R"
	1.20	1.6	2.00	2.8	3.99	5.6	7.98	11.2	16	-	23.9	+.09		.09	.03	"L" OVER "R"
	1.23	1.64	2.06	2.87	4.10	5.75	8.20	11.5	16.4	-	24.6	+.06		.06	.09	"L" OVER "R"
	1.27	1.69	2.12	2.96	4.22	5.92	8.45	11.8	16.9	-	25.3	+.03		.03	0	"L" OVER "R"
	1.31	1.74	2.18	3.05	4.35	6.1	8.7	12.2	17.4	-	26.1	0	0	0	0	
	1.35	1.79	2.25	3.14	4.49	6.29	8.96	12.6	17.9	-	26.9		-.03	0	.03	"R" OVER "L"
	1.39		2.32	3.24	4.62	6.49	9.25	13	18.5	-	27.8		-.06	.09	.06	"R" OVER "L"
	1.44	-	2.4	3.35	4.78	6.70	9.55	13.4	19.1	-	28.7		-.09	.03	.09	"R" OVER "L"
		-	2.48	3.46	4.94	6.93	9.88	13.9	19.8	-	29.7		-.12	0	.09	"R" OVER "L"
	-	-	2.56	3.59	5.11	7.17	10.2	14.3	20.5	2.15	31.4		-.15	.03	.06	"R" OVER "L"
	-	-	-	-	-	-	10.6	-	21.2	-	31.8		-.18	0	.06	"R" OVER "L"

Auto-Transformer Secondary (M_A and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from -.18 to +.18 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L lead is higher and negative (-) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Refer to Table 11, Table 111 or Table 1V to determine the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

Line Angle Adjustment

Maximum sensitivity angle is set for $75^o \pm 3^o$ (current lagging voltage) in the factory. This adjustment need not be disturbed for line angles of 65^o or higher. For line angles below 65^o set for a 60^o maximum sensitivity angle by adjusting the compensator loading resistors R_{2A} and R_{2C}. Refer to repair calibration parts 14, 15, 22, and 23 when a change in maximum sensitivity angle is desired.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay by means of the mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case, refer to I.L. 41-076.

EXTERNAL CONNECTIONS

Figure 19 shows the connections for three zone protection using an SKD, and SP, and an SP-1 relay.

RECEIVING ACCEPTANCE

Acceptance tests consist of a visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires; and an electrical test to make certain that the relay measures the balance point impedance accurately.

Recommended Instruments for Testing

Westinghouse Type PC-161, Style #291B749A33 or equiv. AC voltmeter.
Westinghouse Type PA-161, Style #291B719A21 or equiv. AC ammeter.

Tripping is indicated for the SKD when the 25 watt lamp shown in Figure 20 turns on. For the SP and SP-1 relays, tripping is indicated by a voltmeter reading. At the balance point, the voltmeter reading may be as low as 1V or 2V indicating that the system is only partially tripping. This is a normal balance point characteristic. However, a 5 percent increase in current should produce an output of 15 to 20 volts. A reading of less than 12 volts indicates a defective tripping output.

Distance Units - Electrical Tests

1. Check the electrical response of the relay by using the test connections shown in Figure 20. Set T_A, T_B, and T_C for the maximum tap value: S_A and S_C for 1; M, M_A and M_C for +0.15.

2. Disable the three-phase unit by connecting relay terminal 4 to relay terminal 2.

3. Connect the relay for a 1-2 fault as indicated for Test #5 in Figure 20 and adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts. (120-45V-45V = 30 V.)

4. Supply 110% of the current necessary to trip the phase-to-phase unit at 75° and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. This should be $75^\circ \pm 3^\circ$.

5. The current required to make the phase-to-phase unit trip should be within the limits given in Table V at an angle of 75° current lag.

6. Repeat section 5 while using connections for Test #6 and Test #7. The difference in values of current that makes the unit trip for each of the three test connections should not be greater than 5% of the smallest value. Remove jumper between relay terminals 4 and 2.

7. Disable the phase-to-phase unit by connecting Test Point 23 (TP23) and Test Point 24 (TP24) to Printed Circuit Board Terminal 9 (PCB9). These points, located on the Printed Circuit Boards, are shown in Figure 8.

8. Repeat the above tests 3, 4, and 5 for the three-phase unit. The current required to trip the three-phase unit should be within the limits given in Table V at the maximum sensitivity angle of 75°.

If the electrical response is outside the limits, a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

TABLE V

TEST VOLTAGE = 30 V_{L-L}
M SETTING = +.15
S SETTING = 1

RANGE	SETTING T	SETTING OHMS	TEST NO.	UNIT	AMPERES TO TRIP AT 75° LAG
.2-4.5 OHMS	1.23	1.07	5,6,7 5	ϕ-ϕ 3ϕ	(100% Z - 94.7% Z) 14.0 - 14.8 AMPS.
.73-21 OHMS	5.8	5.05	5,6,7 5	ϕ-ϕ 3ϕ	(101% Z - 94.5% Z) 2.95 - 3.15 AMPS.
1.1-31.8 OHMS	8.7	7.57	5,6,7 5	ϕ-ϕ 3ϕ	(100% Z - 94.5% Z) 1.98 to 2.1 AMPS.

Indicating Contactor Switch (ICS in SKD only)

9. With the phase-to-phase unit tripped, pass sufficient dc current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

Distance Units

CAUTION: Before making hi-pot" tests, connect together terminals 1, 2, 3, 10, 11, and 20 to avoid destroying components in the static network.

Use connections for Tests #5, #6, and #7 of Figure 20 to check the reach of the relay. Note that the impedance measured by the 3-phase unit in Test #5 and by the phase-to-phase unit in Tests #5, #6, and #7 is:

$$Z_R = \frac{V_{L-L}}{2\, I_L}$$

where V_{L-L} is the phase-to-phase voltage, and I_L is the phase current. When in service and receiving three phase currents, the 3-phase unit response is:

$$Z_R = \frac{V_{L-L}}{\sqrt{3}\, I_L}$$

Indicating Contactor Switch (ICS in SKD only)

With either of the distance units tripped, pass sufficient dc current through the trip circuit to close the contact of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

10. Connect the relay for testing as shown in Figure 20. The four-pole double-throw switch shown in the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simulates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable auto-transformers.

Auto-Transformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 2 Test connections of Figure 20, and the procedure outlined below.

11. Set S_A and S_C on tap number 3. Set the "R" leads of M_A and M_C on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminals 8 to the #1 tap of S_A. It should be 30 volts. From 8 to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2.

12. Set S_A and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to each of the M_A taps. This voltage should be equal to 100 (1 + the sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

13. Check to see that the taps on front of the tap block are set as follows:

T_A, T_B (twice) and T_C: Set on the highest tap value. (1.23, 5.8, or 8.7)
S_A and S_C: Set on 1.
"R" for M_A and M_C: Set on ".03".
"L" for M_A and M_C disconnected.

1. PHASE-TO-PHASE UNIT

Maximum Sensitivity Angle Adjustment

14. Connect the relay for a 1-2 fault as indicated for Test No. 5. Connect a high resistance voltmeter (2000 ohms/volt) between the "L" lead of M_A and the fixed end of R2A.

15. Pass 5 amperes through the T_{AB} compensator and adjust R2A so that the secondary voltage reads:

V_s = 10.35 T Sin Θ
Θ = the desired maximum sensitivity angle
T = Compensator tap setting
10.35 = a design constant = $\frac{10}{\sin 75^\circ}$

		V_s VOLTS FOR GIVEN "T" SETTINGS		
Θ	V_s	T = 1.23	T = 5.8	T = 8.7
75°	10T	12.3	58	87
60°	8.96T	11.	52	78

16. Connect the relay for Test No. 6. Connect the voltmeter between the "L" lead of M_C and the fixed end of R2C. Pass 5 amperes through the T_{CB} compensator and adjust R2C so that the secondary voltage reads the proper value as described in section 15 above.

17. Maximum sensitivity angle has been adjusted by steps 14, 15, and 16 above. Connect "L" for M_A and M_C in the top position so that there is .15 between L and R.

18. An electrical check of the maximum sensitivity angle may be performed for each compensator after the circuit calibration in the next step (19) is completed. For the T_{AB} compensator make connections for Test No. 2. For the T_{CB} compensator, use connections for Test No. 4. Connect relay terminals 2 and 4 together to disable the three-phase unit and set voltages V_{1F2F} and V_{2F3F} for 30 volts. Supply 110% of the current necessary to trip the phase-to-phase unit at 75° and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle Θ is: $\frac{\theta_1 + \theta_2}{2}$

Note that, as indicated in the test circuit diagram, θ_1 and θ_2 values are obtained by subtracting 30° from the phase-angle-meter reading. Remove connection between terminals 2 and 4 after the completion of these checks.

Circuit Calibration

19. Connect terminals 2 and 4 together to disable the three-phase unit. Connect terminals 7 and 9 together, set resistor RAC so that the band is centered, apply 120 Vac between terminals 8 and 9, and adjust RMC until the ϕ-ϕ unit just trips. For a fine adjustment, adjust RAC until the unit just trips. At the balance point for SP and SP-1 relays, the voltmeter reading may be as low as 1v or 2v indicating that the system is only partially tripping. This is a normal balance point characteristic. However, a 5 percent increase in current should produce an output of 15 to 20 volts.

20. Connect the relay as listed in Table Vl. The phase-to-phase unit should trip within the current limits listed for the given test voltages. Check the 5 volt level first and adjust RAC further, if necessary, to make the current trip level for Test No. 7 fall between the trip levels for Test No.'s 5 and 6.

TABLE VI

TEST NO.	VOLTS V1F2F	AMPERES TO TRIP FOR $\theta = 75^{\circ}$ .2-4.5 RANGE Imin	Imax	.73-21 RANGE Imin	Imax	1.1-31.8 RANGE Imin	Imax
5,6,7	5.0	2.34	2.55	0.50	0.54	0.33	0.36
	30.0	14.0	14.8	2.95	3.15	1.98	2.1
	70.0	32.7	33.4	6.9	7.1	4.62	4.72

To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio:

$$\frac{\sin 75^{\circ}}{\sin \theta}$$

21. The phase-to-phase unit testing is complete, and the connection between terminals 2 and 4 should be removed.

11. THREE-PHASE UNIT

Maximum Sensitivity Angle Adjustment

22. Disable the phase-to-phase unit by connecting Test Point 23 (TP23) and Test Point 24 (TP24) to Printed Circuit Board Terminal 9 (PCB9).

23. Connect the relay for a 1-2 fault as indicated for Test No. 5. Apply 30 V_{LL} between relay terminals 7 and 8. Supply 110% of the current necessary to trip the three-phase unit and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. The factory setting for θ is 75°.

The maximum sensitivity angle can be adjusted by loosening the adjustable band on RS and carefully moving the band to a different setting. The angle for the three-phase unit should be the same as for the phase-to-phase unit.

24. Set the phase shifter for the maximum sensitivity angle. Using only Test No. 5 connections, the three-phase unit should trip within the same limits as listed for the phase-to-phase unit. The three-phase unit testing is complete and the connections from TP23 and TP24 to PCB9 should be removed.

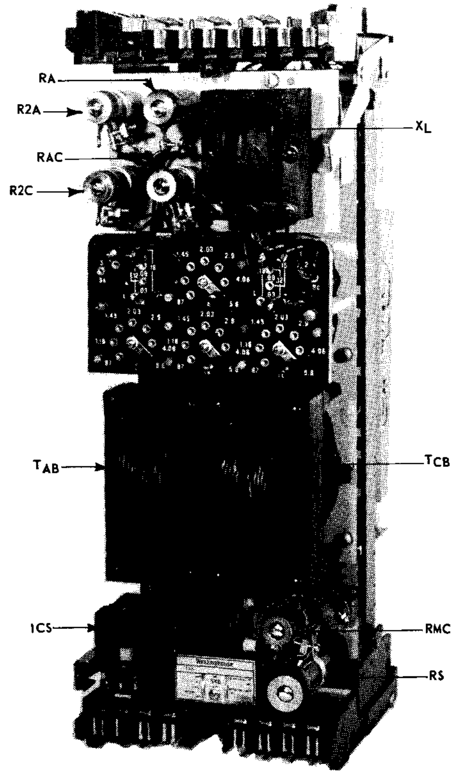
RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE VII

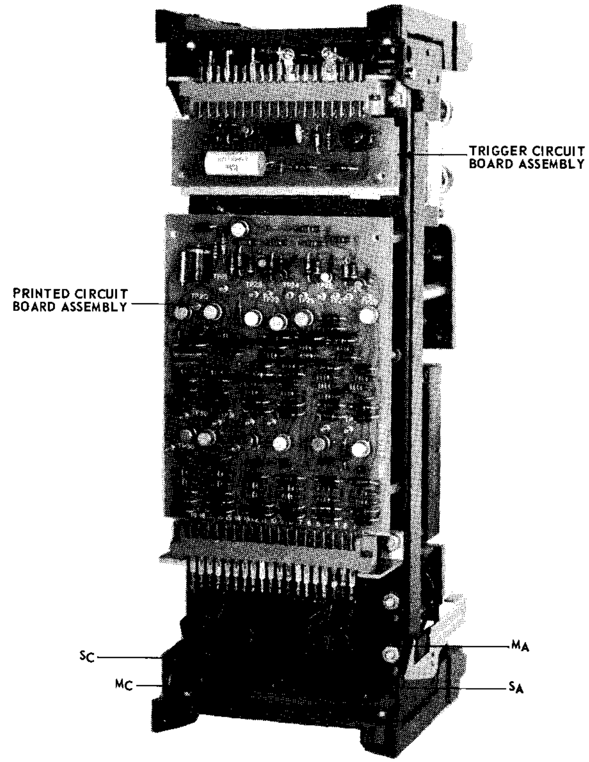
NOMENCLATURE FOR RELAY TYPES SKD, SP, and SP-1

ITEM	DESCRIPTION
C2A, C2C	1.8 MFD capcitor
C3C	0.3 MFD capacitor
CFA, CFC	1.0 MFD capacitor
CS	0.45 MFD capacitor
DC1, DC2, DC3	Clipping Diodes, 200V, 0.75 Amp.
DZ7, DZ8, DZ9, DZ10	Clipping Zener Diodes IN2846A; 200V, 50W
DZP	Zener Regulated Diode IN2984B; 20V, 10W
ICS	Indicating Contactor Switch (Type SKD Relay Only)
M_A, M_C	Auto-Transformer Secondary (Between taps 0.0; .03; .09; .06)
OI	Operation Indicator Lamp #1819 (Type SP Relay Only)
PB	Microswitch (Type SP Relay Only)
R2A, R2C	2-inch Resistor, 900 Ohms, Adjustable
R3C	2-inch Resistor, 1000 Ohms, Fixed
R47, R48	5-watt Resistor, 500 Ohms, Fixed
RA, RC, RMA	2-inch Resistor, 1800 Ohms, Fixed
RAC	3-½inch Resistor, 1000 Ohms, Adjustable
RDC	2-inch Resistor, 1500 Ohms, Fixed for 125 VDC Relays or 400 Ohms for 48 VDC
RMC	2-inch Resistor, 2500 Ohms, Adjustable
RS	2-inch Resistor, 10,000 Ohms, Adjustable
SA, SC	Auto-Transformer Primary (Taps: 1, 2, 3)
T1, T2, T3	Coupling Transformer, Center Tapped Secondary (Step Up 1:8)
TCR	Thyristor (Controlled Rectifier) 2N1850A; 500V, 60 amperes, 5 cycle surge - 6.5 amperes continuous. (Type SKD Relay Only)
XL	Memory Circuit Reactor
XS	Center Tapped Auto-Transformer for Phase Shift Circuit



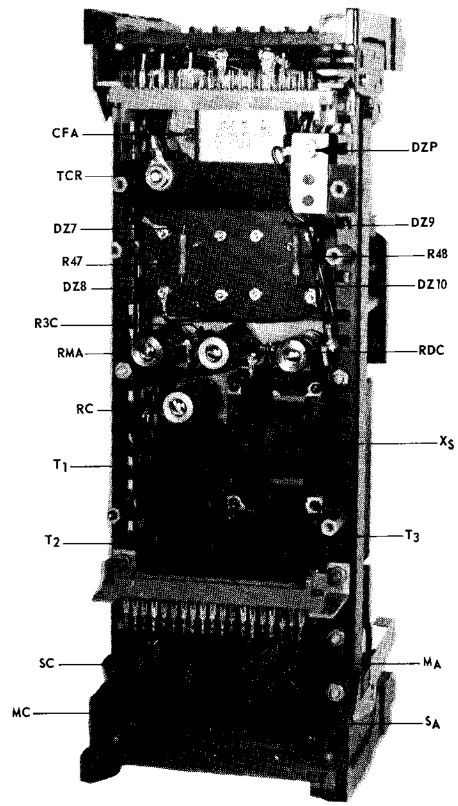
N365522

Front View



N365520

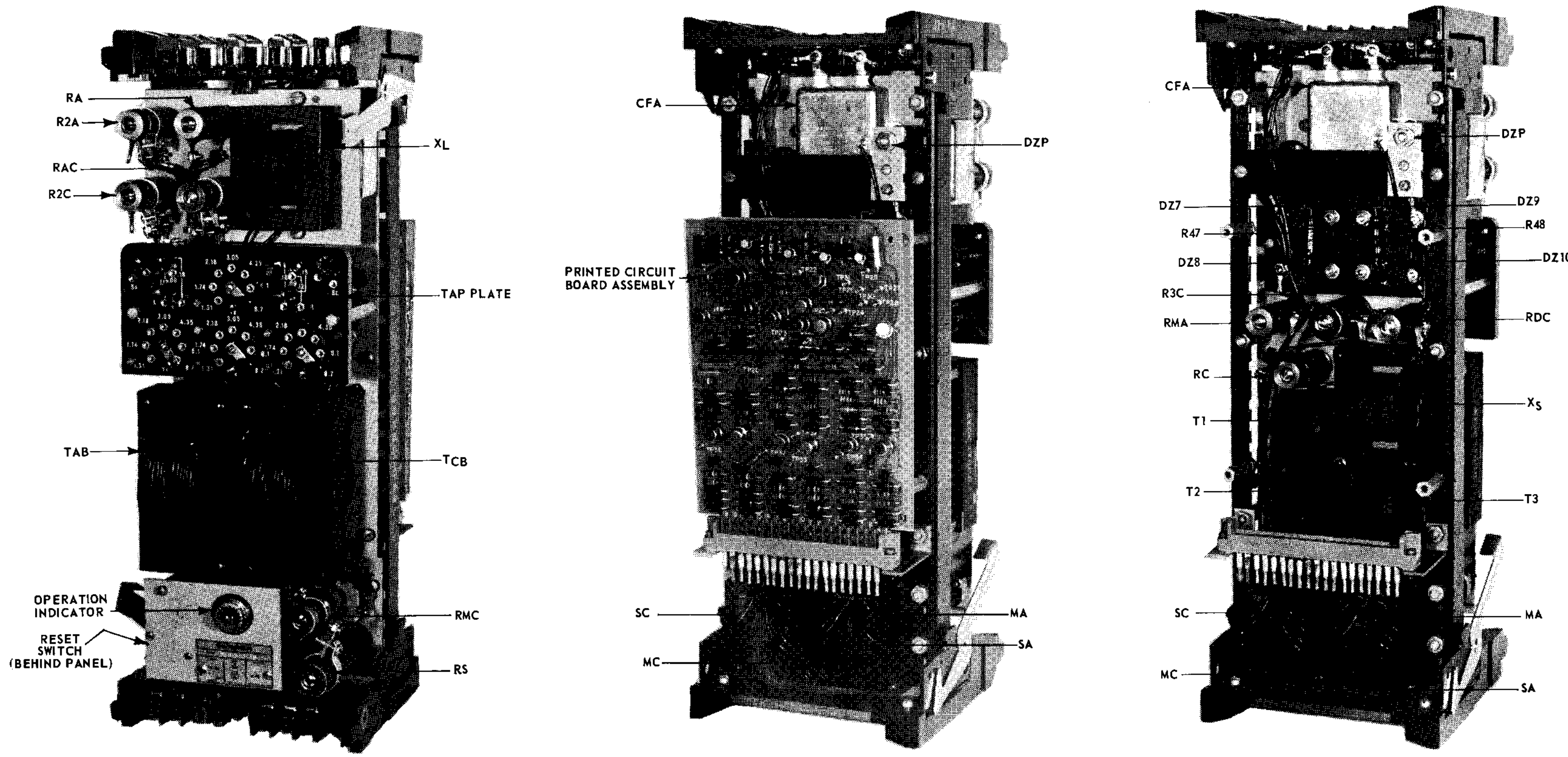
Rear View



N365526

Rear View
(Without Boards)

Fig. 1 Type SKD Relay Without Case.

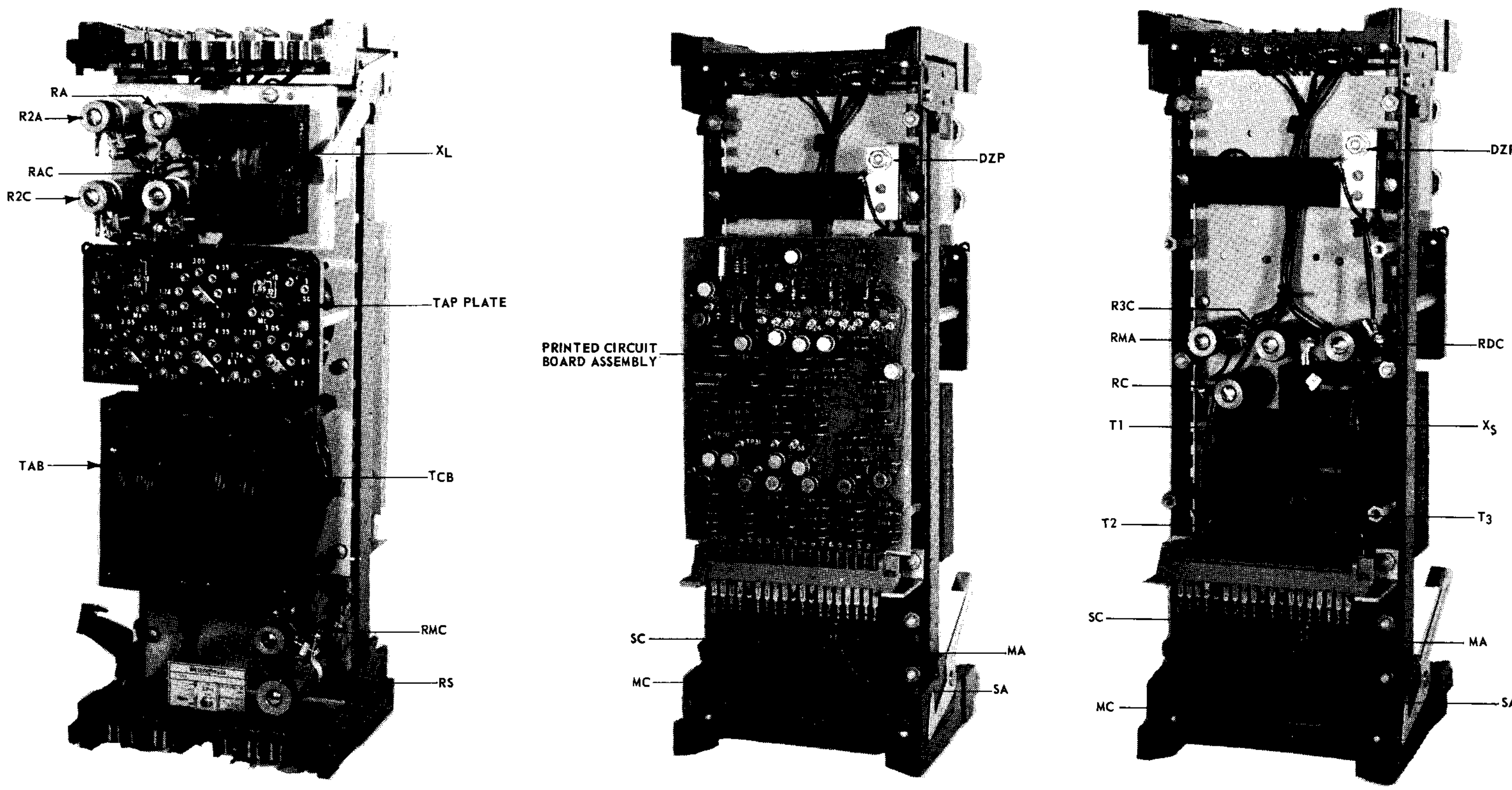


N365514
Front View

N365518
Rear View

N365519
Rear View
(Without Boards)

Fig. 2 Type SP Relay Without Case.



N365517

Front View

N365516

Rear View

N365515

Rear View
(Without Boards)

Fig. 3 Type SP-1 Relay Without Case.

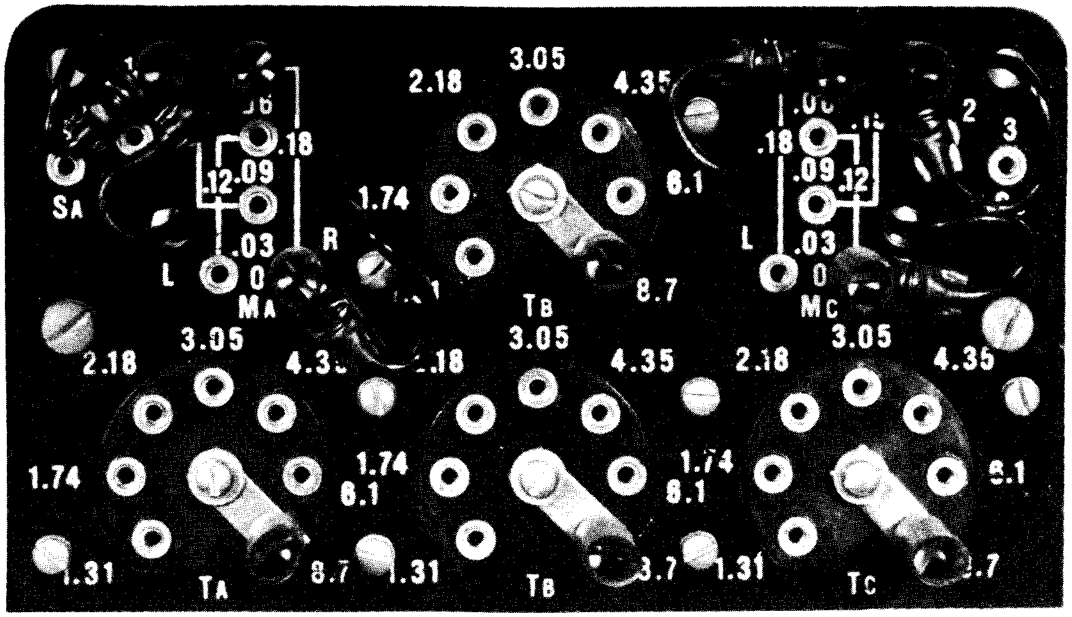


Fig. 4 Tap Plate of 30 Ohm Relay.

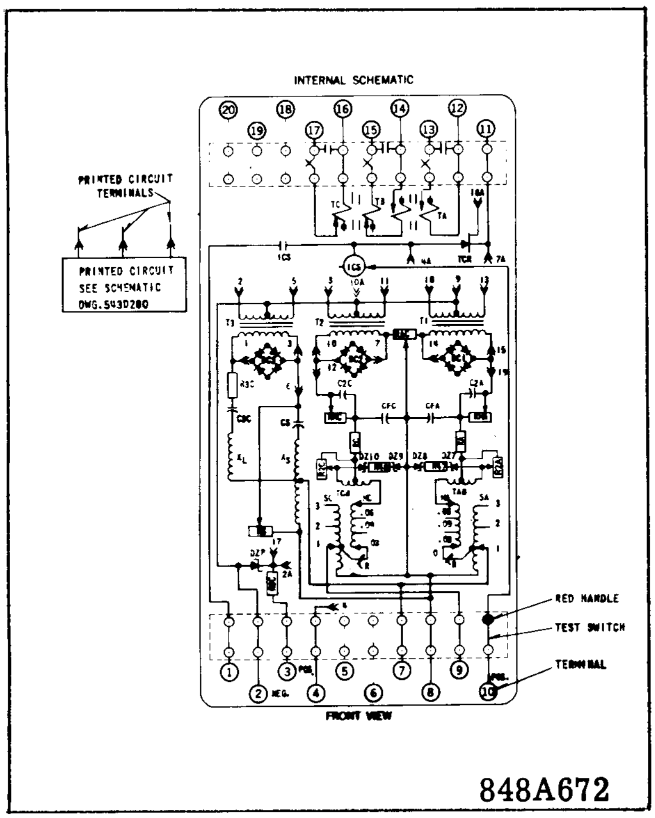


Fig. 5 Internal Schematic of Type SKD Relay in Type FT-42 Case.

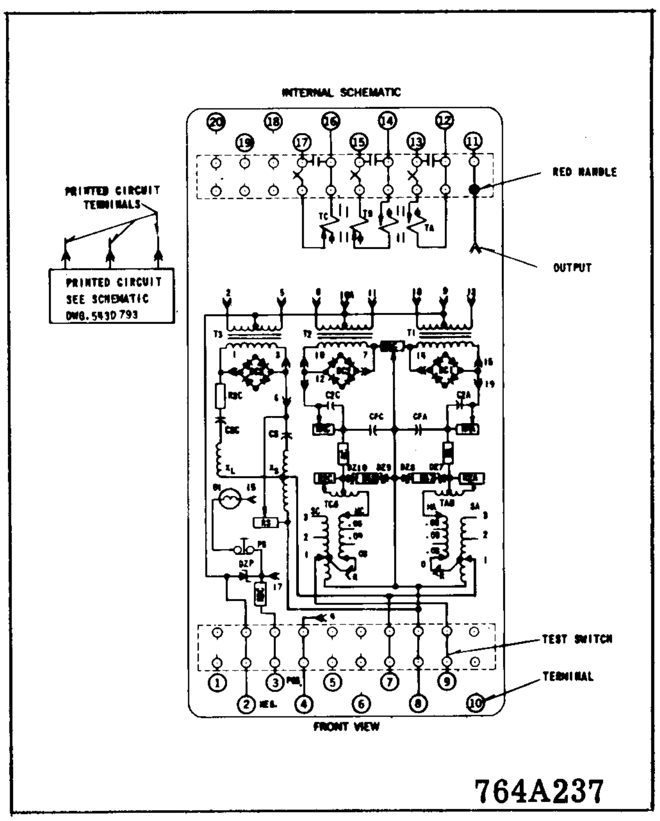
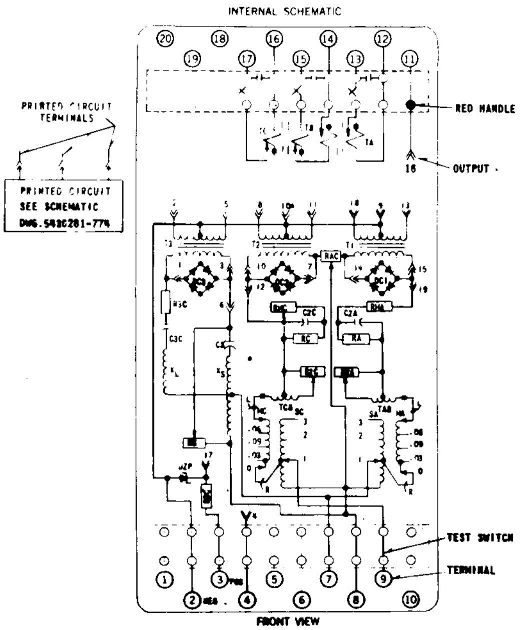
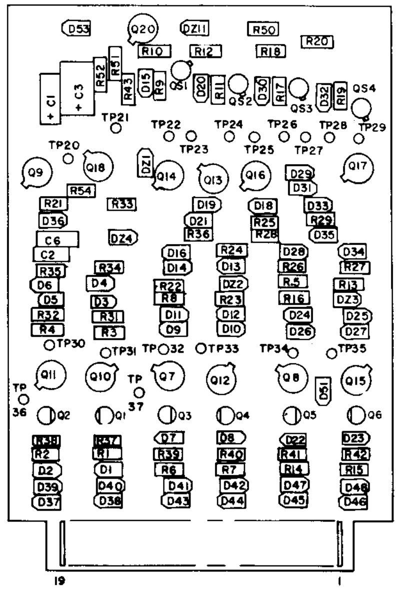


Fig. 6 Internal Schematic of Type SP Relay in Type FT-42 Case.



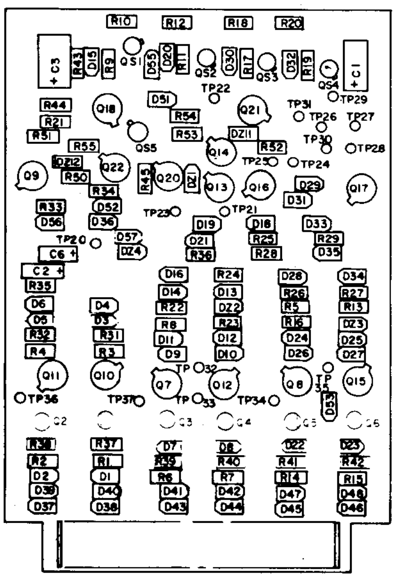
763A091

Fig. 7 Internal Schematic of Type SP Relay in Type FT-42 Case.



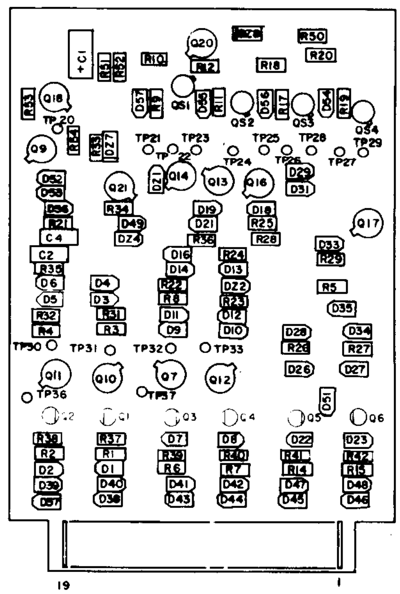
837A450

Fig. 8a Printed Circuit Board Assembly for Type SKD Relay.



837A479

Fig. 8b Printed Circuit Board Assembly for Type SP Relay.



837A478

Fig. 8c Printed Circuit Board Assembly for Type SP-1 Relay.

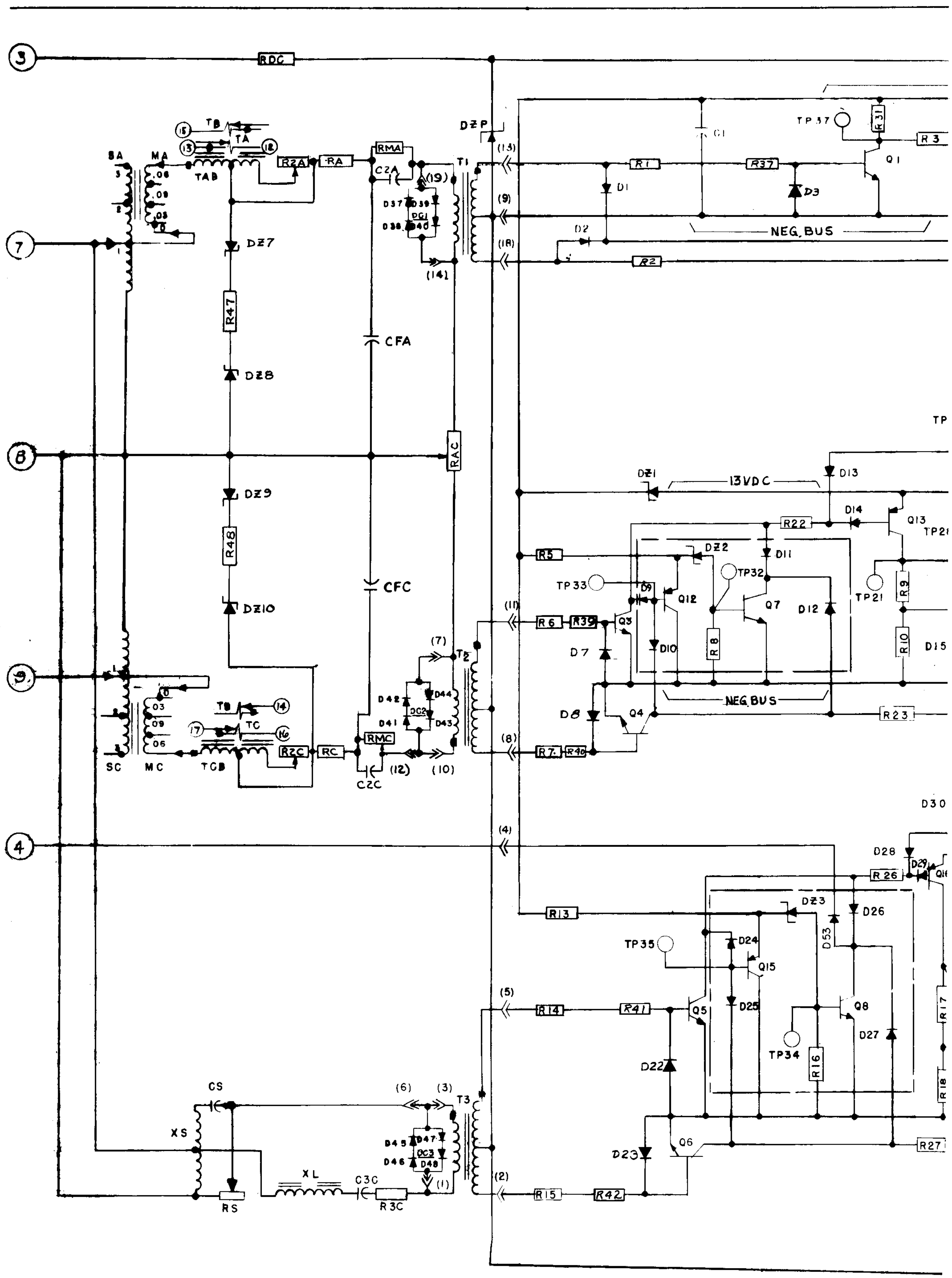
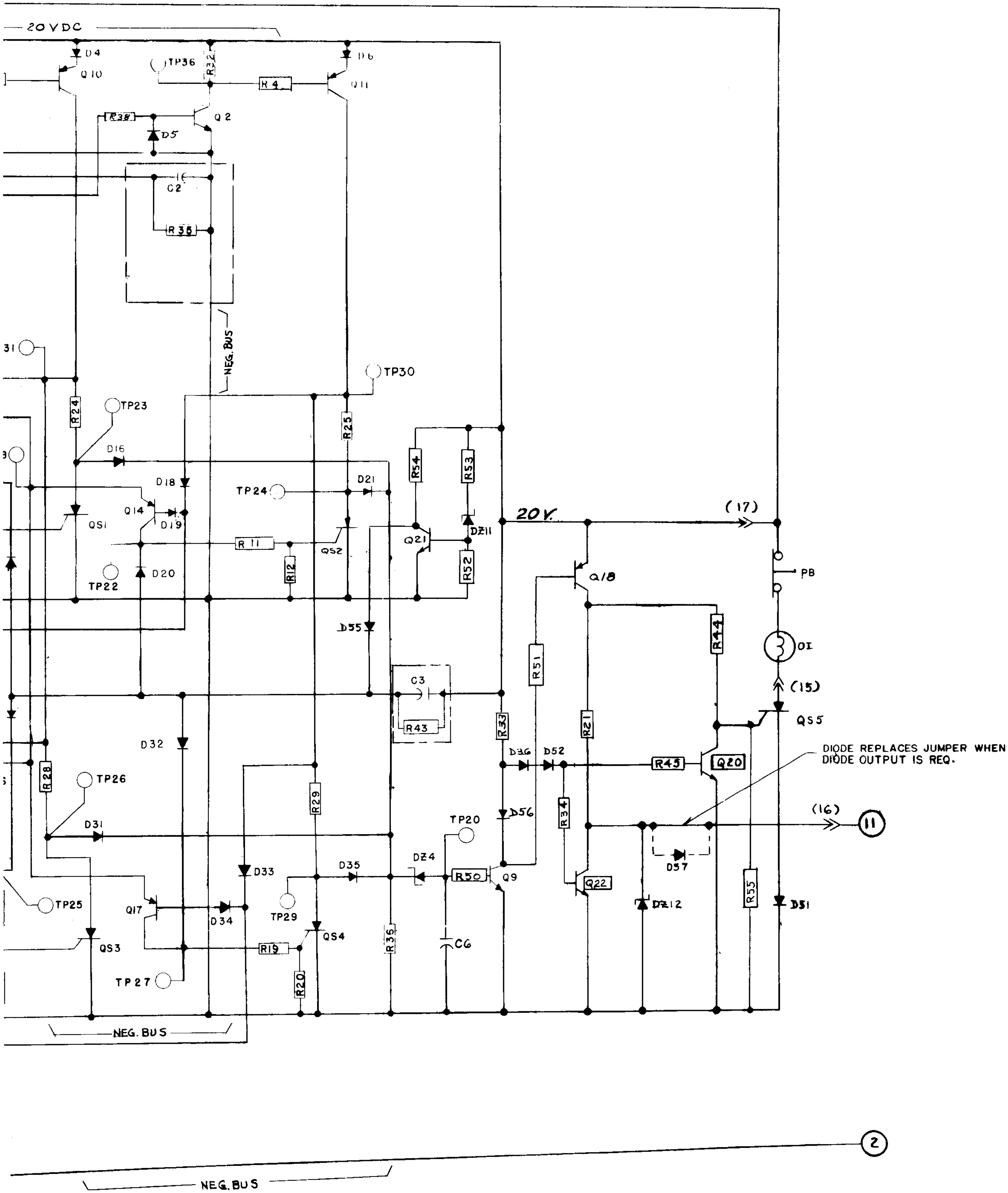


Fig. 10 Detailed Intern



543D793

al Schematic of SP Relay.

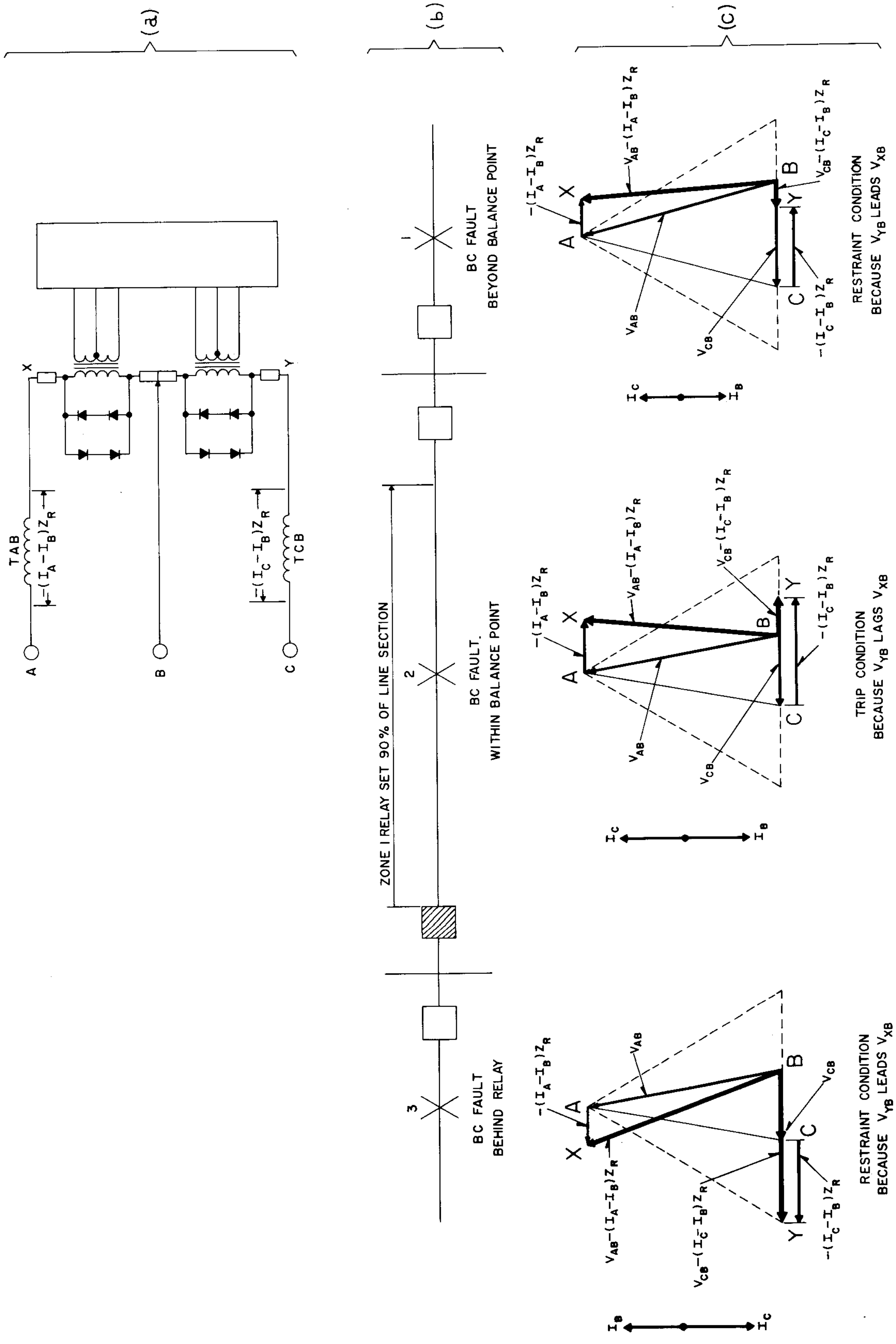


Fig. 12 Voltage and Current Conditions for the Phase-to-Phase Unit 410C512

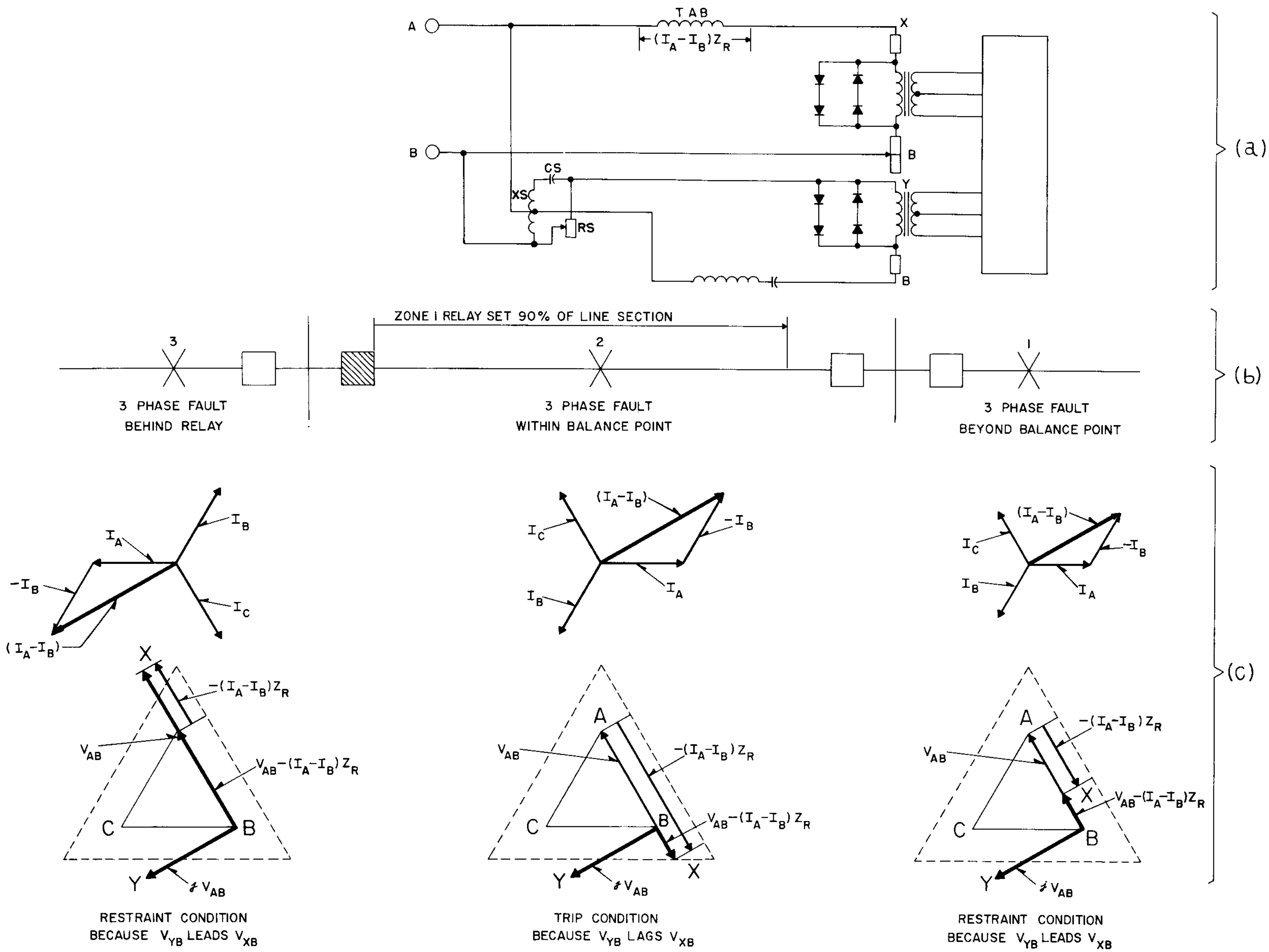


Fig. 13 Voltage and Current Conditions for the Three-Phase Unit

410C513

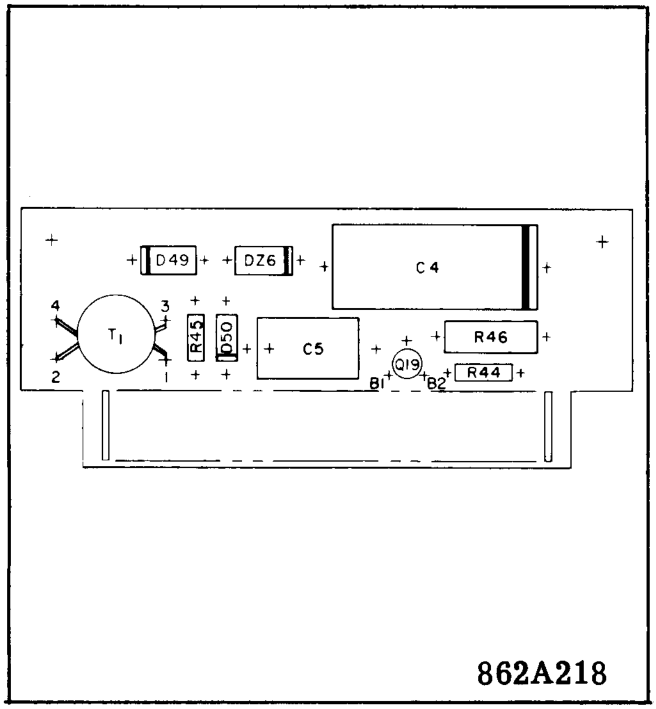


Fig. 14 Printed Circuit Board Trigger Circuit for SKD Relay.

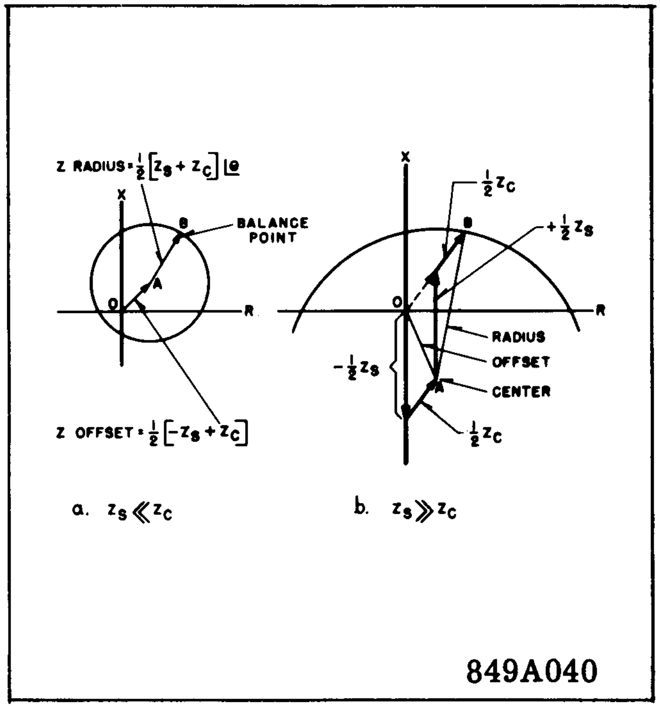


Fig. 15 Impedance Circles for Phase-to-Phase Unit in Types SKD, SP, and SP-1 Relays

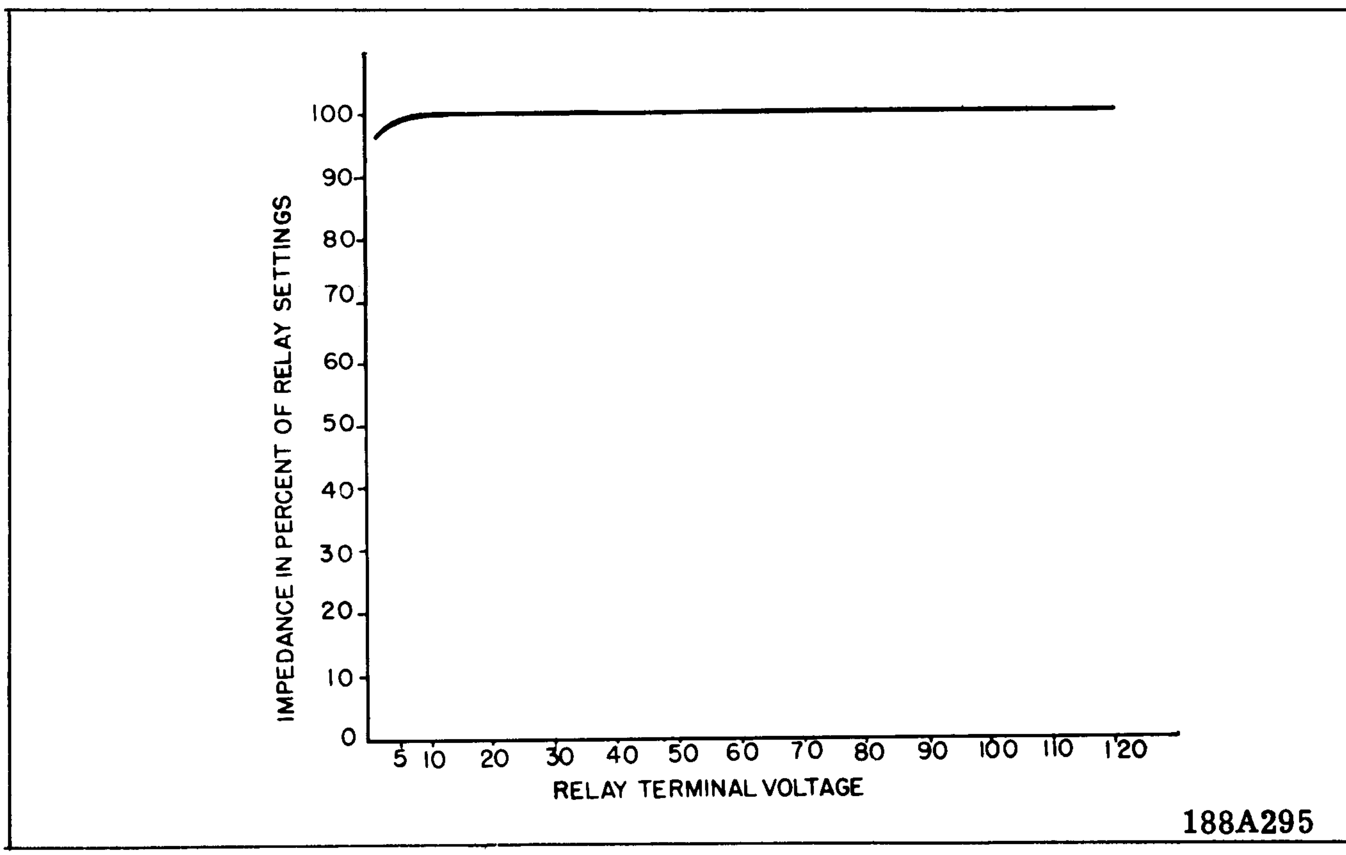


Fig. 16 Impedance Curves for Types SKD, SP, and SP-1 Relays.

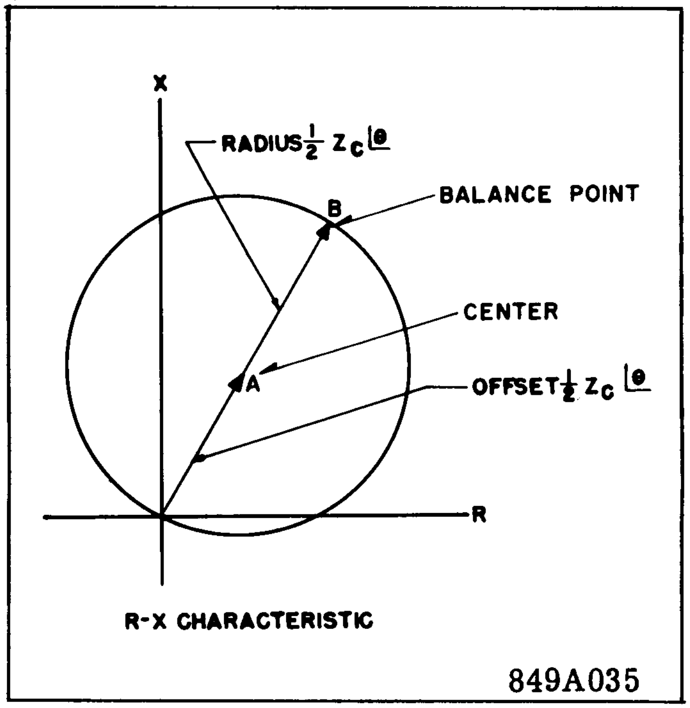


Fig. 17 Impedance Circle for Three-Phase Unit in Types SKD, SP, and SP-1 Relays.

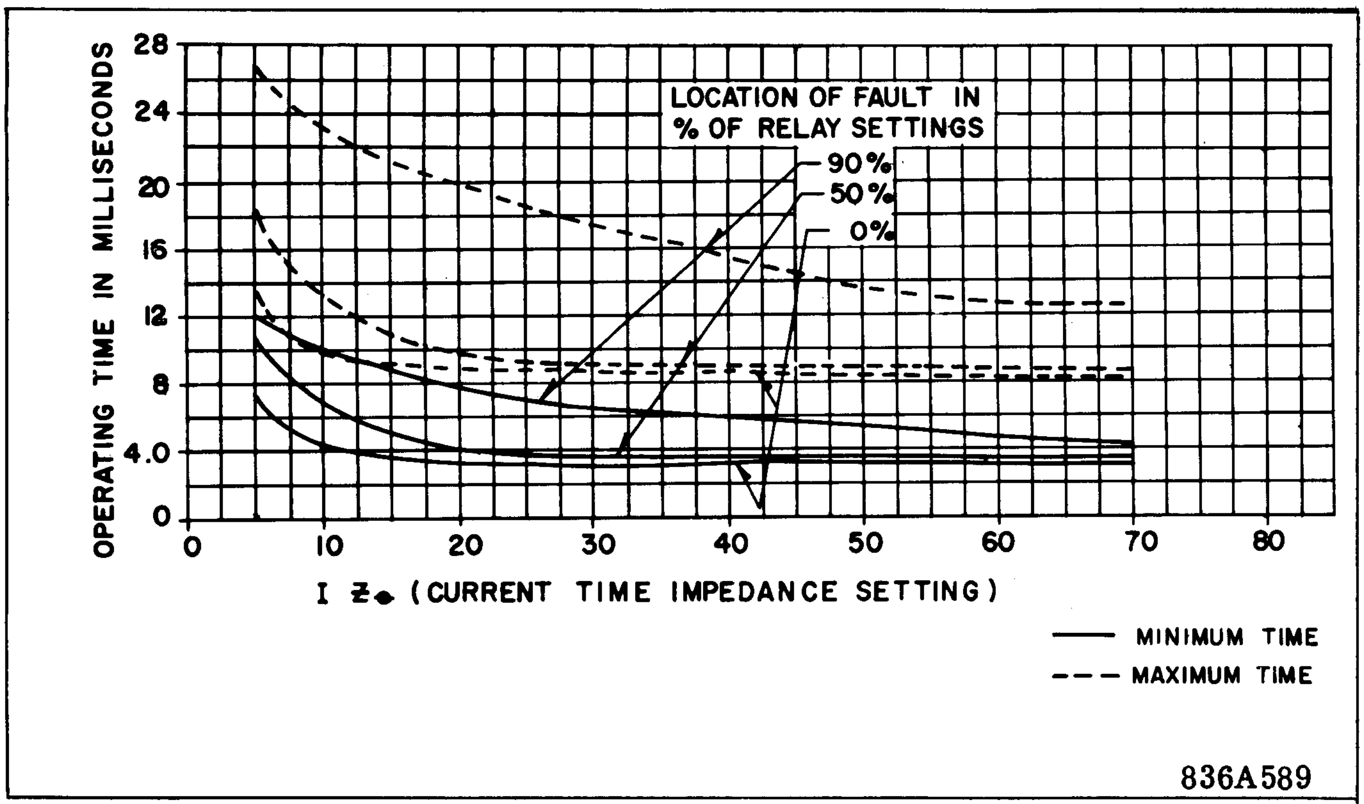


Fig. 18 Typical Operating Time Curves for SKD, SP, and SP-1 Relays. Normal Voltage before the Fault is 120 Volts.

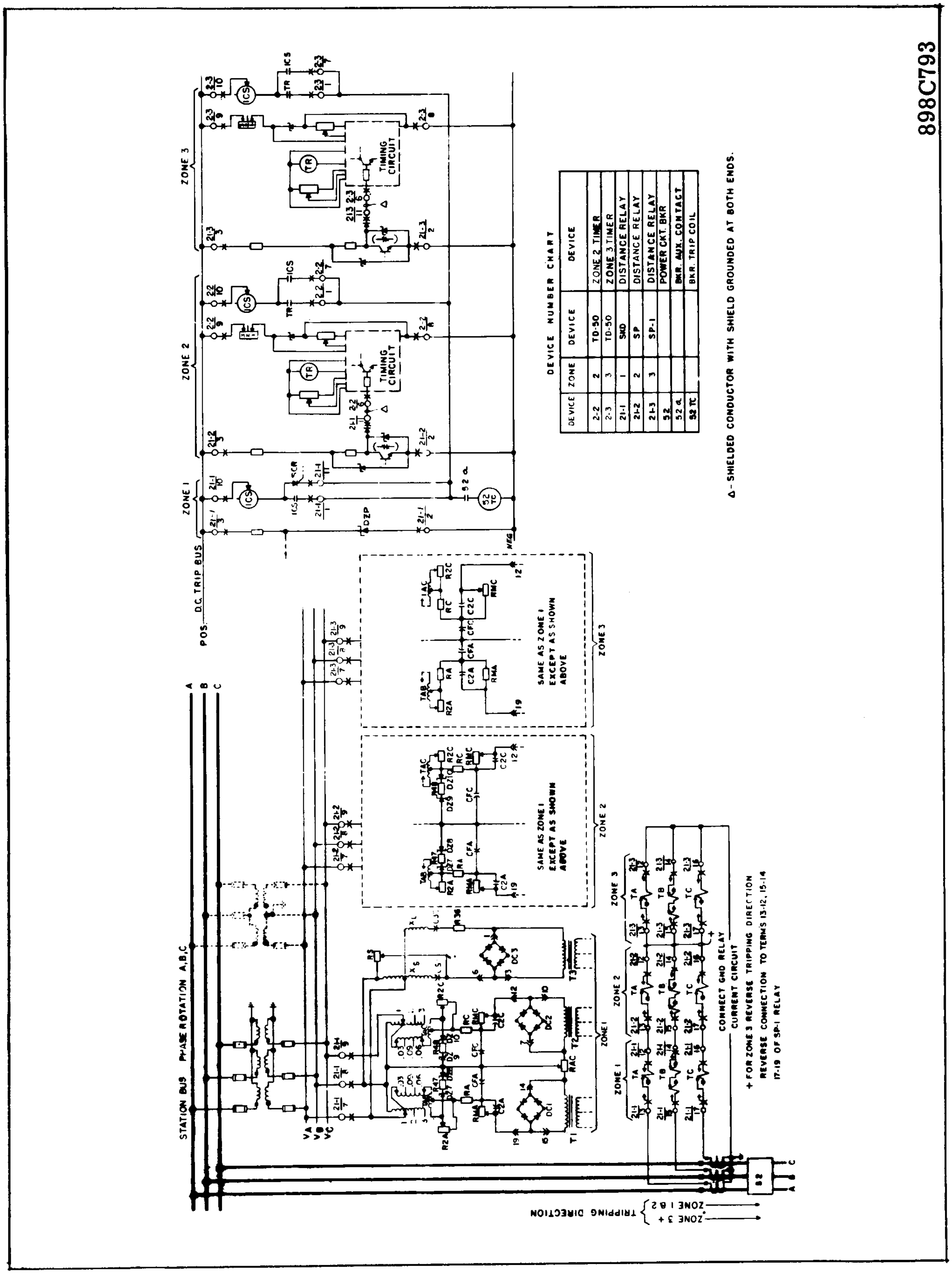
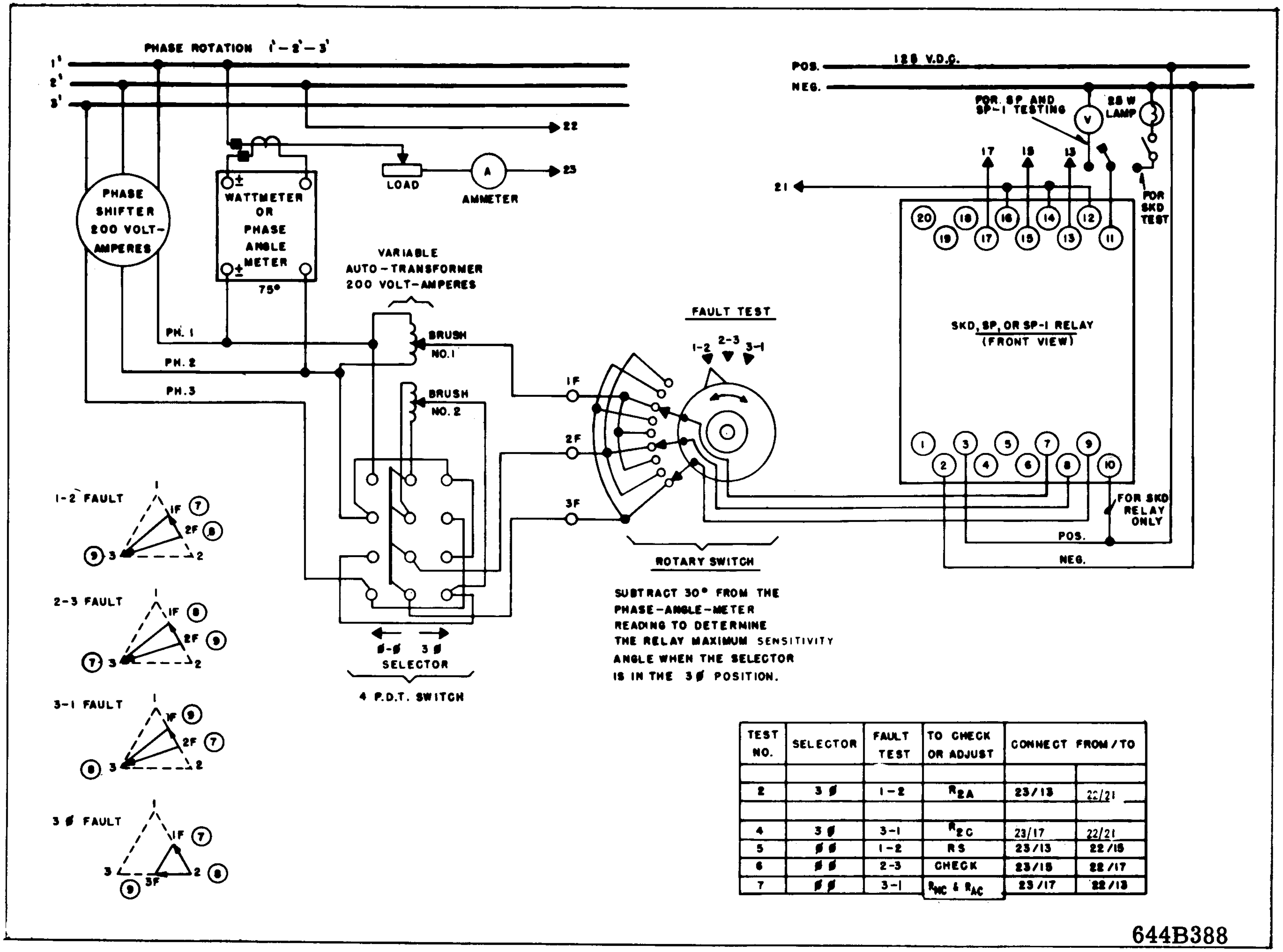


Fig. 19 External Schematic of Types SKD, SP, and SP-1 Relays.



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
2	3 Ø	1-2	R_{2A}	23/13	22/21
4	3 Ø	3-1	R_{2C}	23/17	22/21
5	Ø Ø	1-2	R S	23/13	22/15
6	Ø Ø	2-3	CHECK	23/15	22/17
7	Ø Ø	3-1	R_{NC} & R_{AC}	23/17	22/13

Fig. 20 Test Connections for Types SKD, SP, and SP-1 Relays

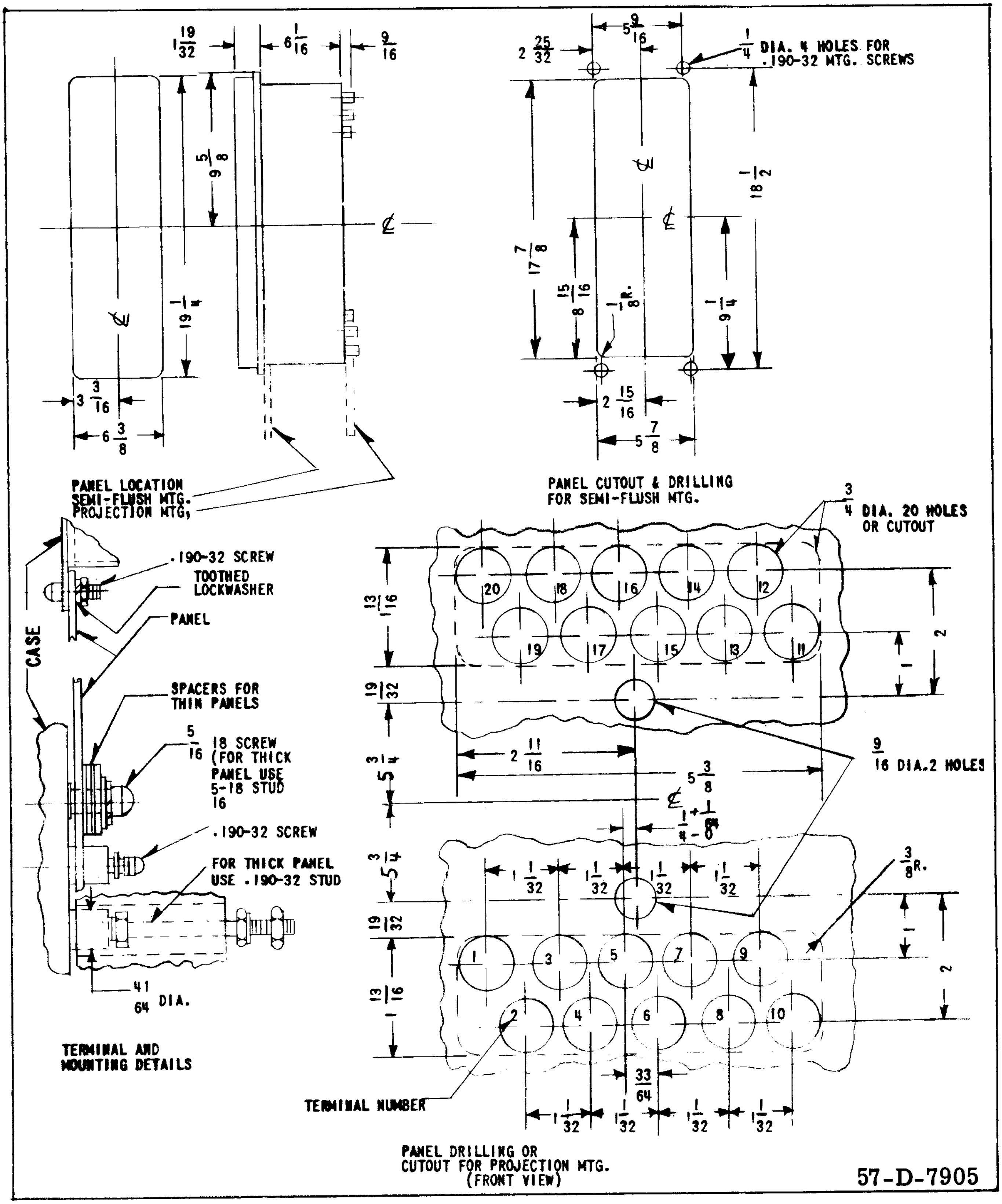


Fig. 21 Outline and Drilling Plan for Types SKD, SP, and SP-1 Relays in Type FT-42 Case.

WESTINGHOUSE ELECTRIC CORPORATION
RELAY-INSTRUMENT DIVISION
NEWARK, N. J.

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKD, SP, SP-1 COMPENSATOR DISTANCE RELAYS

APPLICATION

The type SKD relay, Figure 1, is a polyphase compensator type distance relay which provides a single zone or phase protection for all three phases. It provides instantaneous tripping for all combinations of phase-to-phase faults, two-phase-to ground faults, and three-phase faults.

Types SP and SP-1 relays, Figure 2 and Figure 3 respectively, are similar to the SKD relay except they have a low-energy transistor output used to control auxiliary circuits. Characteristics of the SP-1 are slightly different in that the impedance circle of the three-phase unit includes the origin. The SKD relay has an electro-mechanical indicating contactor switch and the SP relay has a light as an operation indicator.

CONSTRUCTION

Types SKD, SP, and SP-1 relays are available in ranges of .2-4-35 ohms, .73-21 ohms, and 1.1-31.8 ohms. They consist of two air gap transformers (compensators), two tapped auto-transformers, a phase shifting circuit, a memory circuit, and three isolating transformers which couple the ac quantities into the static network. One large printed circuit assembly provides the characteristics of a dual polarized phase angle comparison unit and has a transistor output. The SKD relay has an additional small printed circuit assembly containing the trigger circuit for a thyristor (controlled-rectifier) tripping unit.

Compensator

The compensators which are designated T_{AB} and T_{CB} are three-winding air-gap transformers. There are two primary current windings, each current winding having seven taps which terminate at the tap block, Figure 4. The "T" values are marked (.23, .307, .383, .537, .69, .92, and 1.23), (0.87, 1.16, 1.45, 2.03, 2.9, 4.06, and 5.8), and (1.31, 1.74, 2.18, 3.05, 4.35, 6.1, and 8.7) for the .2-4.35 ohms, .73-21 ohms, and 1.1-31.8 ohms ranges respectively.

A voltage is induced in the secondary which is proportional to the primary tap value and the current magnitude. This proportionality is established by the cross sectional area of the laminated steel core, the length of an air gap which is located in the center of the coil, and the tightness of the laminations. All of these factors which influence the secondary voltage proportionality have been precisely set at the factory. The clamps which hold the laminations should not be disturbed by either tightening or loosening the clamp screws.

The secondary winding has a single tap which divides the winding into two sections. One section is connected subtractively in series with the relay terminal voltage. Thus a voltage which is proportional to the phase current is subtracted vectorially from the relay terminal voltage. The second section is connected to an adjustable loading resistor and provides a means of adjusting the phase angle relation between current and the induced secondary voltage. The phase angle may be set for any value between 60° and 80° by adjusting the resistor between its minimum and maximum value respectively or for 89° by open circuiting the resistor. The factory setting is for a maximum sensitivity angle of 75° ± 3° current lagging voltage.

Auto-Transformer

The auto-transformer has three taps on its main winding, S, which are numbered 1, 2, and 3 on the tap block Figure 4. A tertiary winding M has four taps which may be connected additively or subtractively to inversely modify the S setting by any value from -18 to +18 percent in steps of 3 percent.

The sign of M is negative when the R lead is above the L lead. M is positive when L is in a tap location which is above the tap location of the R lead. The M setting is determined by the sum of per unit values between the R and L lead. The actual per unit values which appear on the tap plate between taps are 0., .03, .09, and .06.

The auto-transformer makes it possible to ex-

SUPERSEDES I.L. 41-495A
*Denotes Change From Superseded Issue.

EFFECTIVE JANUARY 1968

pand the basic range of T ohms by a multiplier of $\frac{S}{1+M}$ Therefore, any relay ohm setting can be made within ±1.5 percent from the minimum value to maximum value of a given range by combining the compensator taps T_{AB} and T_{BC} with the auto-transformer taps S_A-M_A and S_C-M_C.

Phase Shifting Circuit

"Polarization" is the reference against which the "operate" signal is compared. Polarization for the three-phase unit is obtained by shifting the phase 1-2 voltage ahead 90°. The phase shifting circuit consists of a center tapped step-up auto-transformer, XS, which supplies voltage to a series connected resistor and capacitor, RS and CS respectively (Figures 5, 6, and 7). Voltage between the resistor-capacitor junction and the auto-transformer center tap leads the applied voltage by 90°.

Memory Circuit

The memory circuit consists of a large inductive reactance, XL, and a large capacitive reactance, C3C, which are series connected and are tuned very closely to sixty cycles. In the event of a close-in fault which drops the relay terminal voltages to zero, the energy trapped in memory circuit will decay relatively slowly, which oscillating at a sixty cycle frequency. This will maintain a polarizing signal long enough for the relay to operate with an accurate reach and directional sense.

Isolating Transformers

Transformers T1, T2, and T3 serve two purposes. Firstly, they isolate the ac circuits from the dc circuit. Secondly, they amplify the clipped ac signal by a factor of 1:8 to make the relay sensitive to low level input signals.

Printed Circuit Board Assembly

The printed circuit board assembly shown in Figure 8 contains all the resistors, diodes, transistors, and silicon controlled switches necessary to perform the functions of a dual polarized phase angle comparison unit. In Figure 8, resistors are identified by the letter R followed by a number, the same combination is used to identify the same resistor in the internal schematics, Figures 9, 10 and 11. Similarly, diodes are identified by a D and the cathode (the end out of which conventional current flows) is identified by a bar across the point of an arrow. Zener diodes are identified by two letters, DZ, transistors are identified by a Q, silicon controlled switches by QS, capacitors by C, and test points by TP.

When facing the component side with terminals at the bottom, terminals are numbered from right to left starting at 1 and going through number 19. These terminal numbers are shown within brackets on the internal schematic and will be referred to as Printed Circuit Terminals, PCT, in the trouble shooting section.

Trigger Circuit for SKD

The circuit board assembly shown in Figure 14 contains triggering and protective circuitry for the tripping thyristor in the SKD relay. Components are identified the same as on the main board. Terminals are numbered in the same way as for the main board and are identified on the internal schematic by the letter A following the terminal number and both enclosed by brackets, (5A).

OPERATION

The SKD, SP, and SP-1 relays all utilize identical ac input circuits. Therefore, an explanation for the SKD will suffice for all.

Two distinctly different logic systems are used in the SKD relay. One detects all except three-phase faults and is called the phase-to-phase unit. The other system detects three-phase faults and is called the three-phase unit. Each of the two systems present two voltages to the static phase angle comparison unit which checks the phase angle relation between the two. A non-trip or restraint condition exists when V_{YB} leads V_{XB} as referred to in Figure 12.a. A trip condition results when V_{YB} lags V_{XB}.

Phase-to-Phase Unit

For phase-to-phase fault detection, the system monitors the three phase-to-phase voltages and compares them with the related I_{ZR} drops computed by the relay compensators. The compensators are set to be replica of the protected line section as seen by the secondary side and have the same relative current flowing through them as flows through the total line impedance. If a fault is external to the protected line section as shown in Figure 12.b at point 1, it can be seen that the voltage V_{CB} is greater than the permissible minimum $(I_c\text{-}I_b)$ ZR computed by compensator TCB. The difference voltage V_{YB} shown as a heavy line still leads voltage V_{XB} and the phase angle comparison unit remains in a non-trip or restraint condition.

For a fault within the protected line section at point 2, the voltage V_{CB} is less than the permissible minimum computed by the compensator. This results in the difference voltage V_{YB} being flipped 180° so that it lags V_{XB} and causes the phase angle comparison unit to trip.

Faults behind the relay produce a restraint condition as shown for a fault at point 3. In this case the fault current polarity is the reverse of that for faults at points 1 and 2. The compensator voltage is added to V_{CB} and the resulting voltage V_{YB} leads V_{XB} to maintain the restraint condition.

For each fault illustrated in Figure 12.c, it is assumed that the angle of the protected line is 90° and that the relay is set for a maximum sensitivity angle of 90°.

The phase-to-phase unit will not trip for any balanced three-phase condition whether it be a three-phase fault, an out-of-step or swing condition, or a heavy load. For this reason, an additional circuit is provided which will detect and trip for three-phase fault.

Three Phase Unit

The three-phase unit is basically a single phase unit operating from delta voltage and current. Since a three-phase fault produces nearly identical conditions in all three phases, any set of phase-to-phase voltage and current may be used to detect a three-phase fault.

Figure 13.a illustrates the connections which apply voltages to the static phase angle comparison unit. Voltage V_{AB} is modified by the compensator output voltage $(I_A\text{-}I_B)\ Z_R$ to produce voltage V_{XB}. (This is identical to the phase-to-phase unit). A polarizing voltage V_{YB} is obtained by advancing V_{AB} 90° through the phase shifting circuit. A restraint condition exists when V_{YB} leads V_{XB} and a trip condition exists when V_{YB} lags V_{XB}.

A simple diagram in Figure 13.b shows the protective zone for the three-phase unit and indicates three locations for faults which will present a different set of voltage conditions to the phase-angle comparison unit. Figure 13.c illustrates the three conditions.

For a fault at location 1, external to the protected line section, V_{AB} is greater than the permissible minimum $(I_A\text{-}I_B)\ Z_R$ computed by the compensator T_{AB}. The phase shifted polarizing voltage V_{YB} leads the difference voltage V_{XB} and a restraint condition exists.

When a fault occurs within the protected line section such as at point 2, V_{AB} becomes smaller than the permissible minimum computed by the compensator. This results in V_{XB} being flipped 180° so that the polarizing voltage V_{YB} lags V_{XB} and the phase-angle-comparitor unit trips.

For a fault behind the relay such as at point 3, current through the relay has a polarity opposite from that for faults at points 1 and 2. The compensator voltage is added to V_{AB} so that polarizing voltage V_{YB} leads the resulting V_{XB} to maintain the restraint condition.

In Figure 13.c, it is assumed that the angle of the protected line is 90° and that the relay is set for a maximum sensitivity angle of 90°.

The three-phase unit will trip for some phase-to-phase faults and some ground faults as well as for three-phase faults. However, it will not over-reach the phase-to-phase setting for any type of fault. Note that the phase-to-phase unit and the three-phase unit use the same compensator, T_{AB}. Thus, the two units have identical reach settings. The three-phase unit may trip for an out-of-step or swing condition. To prevent such tripping, the three-phase unit can be disabled by connecting relay terminal 4 to battery negative through a swing detection means.

Phase Angle Comparison Unit

Referring to Figure 9, the phase angle comparison unit trips when current flows into the base of transistor Q9 through zener diode DZ4. Such tripping current must come from the 20V bus through either transistor Q10 or Q11 located in what might be called the "operate" circuit. The operate circuit, driven by transformer T1, is continually trying to trip the unit by supply current through Q10 and Q11 on alternate half cycles. Q10 conducts when the polarity marked terminal of T1 is positive.

When Q10 conducts, a portion of the current goes through resistor R24. This current, I_{R24}, may take either of two paths to the negative bus. If QS1 is in a conducting state, I_{R24} passes through it directly to the negative bus. If QS1 is in a blocking state, I_{R24} passes through D16 and then through DZ4 to transistor Q9 to cause tripping. Silicon controlled switch QS1 is located in what might be called the "polarizing" circuit of the phase-to-phase unit. This circuit is driven by transformer T2.

To prevent the operate circuit from tripping, the polarity marked terminals of T2 must go positive before the polarity terminals of T1 do. This caused Q3 to conduct current through R22 and D14 to drive the base of Q13. Q13 then conducts current from the 13V bus through R9 to gate QS1 into conduction. When QS1 conducts, it short circuits the current which might otherwise pass through D16 to cause tripping. Once QS1 begins to conduct, the gate loses control and it remains in the conducting state until the current is turned off by Q10. No tripping output can develop as long as the T2 voltage leads the T1 voltage.

The operate circuit switches for the next half cycle so that transistors Q2 and Q11 conduct in an attempt to cause tripping. In the polarizing circuit, Q4, Q14, and QS2 seek to prevent tripping by short circuiting the current which might otherwise pass through D21, DZ4, and Q9.

Restraint Squelch: When the operate circuit transistor Q10 conducts, approximately 18V is applied through diode D13 to back bias D14 and prevent Q13 from turning on. Thus a trip signal, initiated because the T1 voltage is leading, cannot be improperly interrupted when the T2 voltage goes positive. A full half cycle tripping output is therefore produced by Q10. This back biasing connection is called the restraint squelch circuit.

Voltage Detectors: If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch QS1 and short circuit the Q10 current. This, of course, could cause incorrect tripping. A voltage detector circuit prevents this from happening. Transistor Q12 is maintained in the conducting state by Q3 and Q4 alternately when a useful voltage level is supplied by T2. When conducting, Q12 short circuits current which flows through R5 from the 20V bus. When the voltage from T2 drops too low to drive Q3 and Q4, then Q12 turns off and the R5 current flows through DZ2 to switch Q7 into conduction. This in turn drives Q13 through D11. R22, and D14 causing Q13 to switch QS1 into conduction to short circuit D16 and prevent tripping.

The operate circuit, driven by T1, and the polarizing circuits, driven by T2 and T3, are duals having identical circuits which operate on alternate half cycles. The restraint squelch and the voltage detector both work into each of the duals in the same way.

Transformer T3 receives a polarizing signal from the three-phase circuit and drives a polarizing circuit which is identical to the one supplied by transformer T2. The phase angle relation between the T1 voltage and the T3 voltage is compared in the same manner as described above and tripping signals are supplied through D31 and D35, through DZ4 and to Q9. This polarizing circuit contains a restraint squelch and a voltage detector identical to those described for the T2 circuit.

SP-1 Relay: The SP-1 relays has a characteristic circle which includes the origin. That is, it will trip on current when the voltage is zero. This feature is obtained by omitting the voltage detector from the T3 circuit. This omission reduces the accuracy of the SP-1 relay at low voltage test levels.

Output Circuit

The output of the SKD relay is a Thyristor (controlled-rectifier) which is gated into conduction by a pulse transformer. The transformer is pulsed when Q9 turns on causing Q18 to conduct into an oscillator consisting of capacitor C5, pulse transformer TP, and unijunction transistor Q19. Q19 switches into conduction when voltage across C5 reaches a predetermined level. It resets after capacitor C5 has discharged through TP to produce a gating pulse. C5 then charges up again to repeat the process.

In the SP and SP-1 relays, Figures 10 and 11 respectively, Q9 turns on to short circuit current from the base of Q22 causing it to stop conducting. An output voltage subsequently develops across Q22 and appears at terminal 11 of the relay.

CHARACTERISTICS

Distance Characteristic – Phase-to-Phase Unit

This unit responds to all phase-to-phase faults and most two-phase-to-ground faults. It does not respond to load current, synchronizing surges, or out-of-step conditions. While a characteristic circle can be plotted for this unit on the RX diagram as shown in Figure 15, such a characteristic circle has no significance except in the first quadrant where resistance and reactance values are positive. A small portion of the fourth quadrant, involving positive resistance values and negative reactance values, could have some significance in the event that the transmission line includes a series capacitor. The portion of the circle in the first quadrant is of interest because it describes what the relay will do when arc resistance is involved in the fault. The phase-to-phase unit operating on an actual transmission system is inherently directional.

An inspection of Figure 15 indicates that the circle of the phase-to-phase unit is dependent on source impedance Z_S. However, the circle always goes through the line balance point impedance. The reach at the compensator (and line) angle is constant, regardless of the system source impedance. The broadening out of the characteristic circle with a relatively high source impedance gives the phase-to-phase unit the advantageous characteristic that for short lines, it makes a greater allowance for resistance in the fault. Stated another way, the characteristics approach that of a reactance relay more and more closely as the line being protected becomes shorter and shorter with respect to the source impedance back of the relaying location.

Sensitivity: Phase-to-Phase Unit

A plot relay reach, in percent of tap block setting, versus relay terminal voltage is shown in Figure 16. The unit will operate with the correct directional sense for zero voltage phase-to-phase faults. For this condition the product of fault current times T setting must be not less than 0.40 with rated voltage on the unfaulted phase.

The relays may be set without regard to possible over-reach due to dc transients. Compensators basically are insensitive to dc transients which attend faults on high-angle systems. The long time-constant of a high-angle system provides a minimum rate of change in flux-producing transient current with respect to time, and therefore induces a minimum of uni-directional voltage in the secondary.

Distance Characteristic – SKD and SP, Three Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 17. This circle is independent of source impedance. The three-phase unit is also inherently directional.

If a solid-three-phase fault should occur right at the relay location, the voltage will collapse to zero to give a balance point condition, as implied by the relay characteristic (in Figure 17) passing through the origin. When the YB voltage (Figure 13) drops to zero, the relay is unable to determine whether an internal or external fault existed. To avoid this condition, a resonant circuit causes the Y voltage to collapse gradually at a frequency of 60 cycles. This characteristic called memory action provides a reference voltage long enough to determine whether the fault is inside the protected line section or behind the relay.

Sensitivity: 3 Phase Unit

The impedance curve for the three-phase unit is shown in Figure 16. The unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. For this condition, the product of fault current times T setting must be not less than 0.40. The minimum steady state voltage below which the three-phase unit probably will be disabled by the voltage detector circuit is 1.5 V_{L-L}.

Distance Characteristics: SP-1, Three Phase Unit

The three-phase unit of the SP-1 relays has a characteristic circle which includes the origin. This feature results from the omission of the voltage detector in the static circuit. The unit will trip for an "IT" product of 0.40 or more when the input voltage is zero.

General Characteristics

Impedance settings in ohms reach can be made in steps of 3 percent for any range, the .2-4.35 ohm relay, the .73-21 ohm relay, and the 1.1-31.8 ohm relay. The maximum sensitivity angle, which is set for 75 degrees at the factory, may be set for any value from 60 degrees to 80 degrees. A change in maximum sensitivity angle will produce a slight change in reach for any given setting of the relay. The compensator secondary voltage output V is largest when V leads the primary current, I, by 90°. This 90° relationship is approached, if the compensator loading resistor (R2A or R2C) shown in Figures 5, 6, and 7 is open-circuited. The effect of the loading resistor, when connected, is to produce an internal drop in the compensator, which is out-of-phase with the induced voltage, IT_{AB} or IT_{AC}. Thus, the net voltage, V, is phase-shifted to change the compensator maximum sensitivity angle. As a result of this phase shift the magnitude of V is reduced.

Tap markings in Figure 4 are based upon a 75° compensator angle setting. If the resistors R2A and R2C are adjusted for some other maximum sensitivity angle the nominal reach is different than indicated by the taps. The reach Z_θ, varies with the maximum sensitivity angle, θ, as follows:

$$Z_\theta = \frac{TS \sin \theta}{(1 + M) \sin 75°}$$

TAP PLATE MARKINGS

	(T_A, T_B, and T_C)						
.2-4.35 Ohms	.23	.307	.383	.537	.69	.92	1.23
.73-21 Ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
1.1-31.8 Ohms	1.31	1.74	2.18	3.05	4.35	6.1	8.7

	(S_A and S_C)		
	1	2	3
	(M_A and M_C)		
± Values between taps	.03	.09	.06

TIME CURVES AND BURDEN DATA

Operating Time

The speed of operation for the SKD, SP and SP-1 relays is shown by the time curves in Figure 18. The curves indicate the time in milliseconds required for the relay to provide an output for tripping after the inception of a fault at any point on a line within the relay setting.

Current Circuit Rating in Amperes

"T" TAP SETTING			CONTINUOUS			1 SEC.
			S = 1	S = 2	S = 3	
1.23	5.8	8.7	5.0	8.5	9.5	240
.92	4.2	6.1	6.0	10.0	10.0	240
.69	3.0	4.35	8.0	10.0	10.0	240
.537	2.2	3.05	10.0	10.0	10.0	240
.383	1.6	2.18	10.0	10.0	10.0	240
.307	1.16	1.74	10.0	10.0	10.0	240
.23	0.87	1.31	10.0	10.0	10.0	240

Burden

The burden which the relays impose upon potential and current transformers in each phase is listed in Table 1. The potential burden and burden phase angle are based on 69.3 volts line-to-neutral applied to the relay terminals.

SKD Trip Circuit Constants

1 ampere I.C.S. 0.1 ohm dc resistance.

Thyristor Tripping Unit

The thyristor is a three-terminal semi-conductor device. In the reverse, or non-conducting direction, the device exhibits the very low leakage characteristics of a silicon rectifier. In the forward, or conducting direction, conduction can be initiated by the application of a control pulse to the control terminal or "gate". If a gate signal is not applied, the device will not conduct at below rated forward blocking voltage. With the application of a gate signal, however, the device switches rapidly to a conducting state characterized by a very low voltage drop and a high current-carrying capability. Once conduction has been initiated, the gate terminal no longer has any effect. In order to turn the unit off, the anode-cathode current must be reduced to a value less than the holding current.

It should be noted that the SKD trip circuit differs from mechanically operated contacts. A certain minimum trip current must flow before the thyristor (controlled-rectifier) will latch on. If the minimum turn on current is not established during the first millisecond after the first gate pulse is received, the unit will not latch on. However, voltage will be applied to the load for the duration of each gate pulse. Pulses are applied to the gate circuit at a rate of one every four milliseconds.

Current rating per circuit:

Ambient temperature	25°C	50°C	75°C
3 cycle duty (50 MS surge)	60A	49A	37A
5 cycle duty (83 MS surge)	54A	44A	33A
Continuous	6.5A	4.5A	3A

Trip Circuit requirements:

$$\frac{Vdc}{R_{\text{LOAD OHMS}}} = .25 \text{ amp. or more}$$

$$\frac{L_{\text{HENRYS}}}{R_{\text{LOAD OHMS}}} = .02 \text{ or less}$$

Thyristor:

Max. forward leakage current 125°C = 8 MA dc.
Typical at 85°C = .07 MA dc

Max. reverse leakage current 125°C = 8 MA dc.
Typical at 85°C = .07 MA dc

Max. forward voltage drop at 10 amps. 25°C
1.6 volts

SP and SP-1 Output Circuits

Open circuit voltage	18V to 21V d.c.
Short circuit current	18 to 21 milliamperes

SETTING CALCULATIONS

Relay reach is set on the tap plate shown in Figure 4. The tap markings are:

	(T_A, T_B, and T_C)						
.2-4.35 Ohms	.23	.307	.383	.537	.69	.92	1.23
.73-21 Ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
1.1-31.8 Ohms	1.31	1.74	2.18	3.05	4.35	6.1	8.7

(S_A and S_C)

1	2	3

	(M_A and M_C)		
Values between taps	.03	.09	.06

Maximum sensitivity angle, θ, is set for 75° (current lagging voltage) in the factory. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65° set θ for a 60° maximum sensitivity angle, by adjusting R2A and R2C. Set zone 1 reach to be 90% of the line (85% for line angles of less than 50°).

$$Z_\theta = Zpri \frac{0.9\ Rc}{Rv} \qquad \text{Eq. (1)}$$

The terms used in this formula and hereafter are defined as follows:

Calculations for setting the SKD, SP, and SP-1 relays are straight-forward and apply familiar principles. Assume a desired balance point which is 90 percent of the total length of line. The general formula for setting the ohms reach of the relay is:

Z_θ = the ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees.

$$Z = \frac{TS}{1+M} = \text{the tap plate setting} \qquad \text{Eq. (2)}$$

T = Compensator tap value

S = Auto-transformer primary tap value

θ = Maximum sensitivity angle setting of the relay (Factory setting of θ = 75°)

±M = Auto-transformer secondary tap value. (This is a Per Unit value and is determined by the sum of the values between the "L" and the "R" leads.The sign is positive when "L" is above "R" and acts to lower the Z setting. The sign is negative when "R" is above "L" and acts to raise the Z setting).

Zpri = Ohms per phase of the total line section.

0.9 = The portion of the total line for which the relay is set to trip.

Rc = Current transformer ratio

Rv = Potential transformer ratio

The following procedure should be followed in order to obtain an optimum setting of the relay:

1. a. Establish the value of Z_θ, as above.

   b. Determine the tap plate value Z using the formula:

$$Z = Z_\theta \frac{\sin 75°}{\sin \theta°}$$

When θ = 75°, $Z = Z_\theta$.

2. Now refer to Table II, Table III, and Table IV for the optimum tap settings.

   a. Locate a Table value for relay reach nearest the desired value Z. (It will always be within 1.5% of the desired value.)

   b. Select from the Table "S", "T", and

"M" settings. "M" column includes additional information for "L" and "R" leads setting for the specified "M" value.

c. Recheck the selected "S", "T" and "M" settings to assure the correct value of Z by using equation (2).

$$Z = \frac{ST}{1 + M}$$

For example, assume the desired reach, Z_O for a .73-21 ohm relay is 7 ohms at 60°. (Step 1a).

Step (1b). The line angle of 60° requires that the relay maximum sensitivity angle be changed from a factory setting of 75° to the new value of 60°. Using equation (3), we find the corrected value for the relay tap settings:

$$Z - 7 \times \frac{\text{Sin } 75°}{\text{Sin } 60°} = 7.8 \text{ ohms}$$

Step (2a). In Table III, we find nearest value to 7.8 ohms is 7.88. That is $100 \times \frac{7.88}{7.8} = 101.0$ percent of the desired reach.

Step (2b). From Table III, read off:

$$S = 2$$
$$T = 4.06$$
$$M = +.03$$

and "L" lead should be connected over "R" lead, with "L" lead connected to "03" tap and "R" lead to tap "0".

Step (2c). Recheck Settings:

$$Z = \frac{ST}{1 \pm M} = \frac{2 \times 4.06}{1 + .03} = 7.88 \qquad \text{From Eq. (2)}$$

$$Z \angle 60° = Z \frac{\text{Sin } 60°}{\text{Sin } 75°} = 7.88 \times .896 + 7.06$$

From Eq. (3)

which is 101.0 percent of the desired setting.

SETTING THE RELAY

The SKD, SP, and SP-1 relays require settings for the two compensators (T_{AB} and T_{CB}), the two auto-transformer primaries (S_A and S_C) and secondaries (M_A and M_C). All of these settings are made with taps on the tap plate.

Compensator (T_{AB} and T_{CB})

Each set of compensator taps terminates in inserts which are grouped on a socket and form approximately three quarters of a circle around a center insert which is the common connection for all of the taps. Electrical connections between common insert and tap inserts are made with a link that is held in place with two connector screws, one in the common and one in the tap. There are two T_B settings to be made since phase B current is passed through two compensators. A compensator tap setting is made by loosening the connector screw in the center. Remove the connector screw in the tap end of the link, swing the link around until it is in position over the insert for the desired tap setting, replace the connector screw to bind the link to this insert, and retighten the connector screw in the center. Since the link and connector screws carry operating current, be sure that the screws are turned to bind snugly but not so tightly as to break the tap screw.

Auto-Transformer Primary (S_A and S_C)

Primary tap connections are made through a single lead for each transformer. The lead comes out of the tap plate through a small hole located just below or above the taps and is held in place on the tap by a connector screw. (Figure 4.)

An "S" setting is made by removing the connector screw, placing the connector in position over the insert of the desired setting, replacing and tightening the connector screw. The connector should never make electrical contact with more than one tap at a time.

TABLE I

† POTENTIAL BURDEN IN VOLT-AMPERES

	Tap Setting	Phase A-N			Phase B-N			Phase C-N		
	M	VA	Watts	Vars	VA	Watts	Vars	VA	Watts	Vars
I = 0	+.18	3.80	3.06	-2.26	6.40	6.38	0.45	3.1	2.38	1.99
69.3 V_{L-N} 3φ	0	2.98	2.38	-1.92	4.98	4.97	0.30	2.27	1.69	1.52
S = 1	-.18	2.22	1.57	-1.57	3.68	3.68	0.13	1.57	1.13	1.09
I = 0	+.18	1.47	0.80	-1.24	2.27	2.24	-0.33	0.72	0.55	0.46
69.3 V_{L-N} 3φ	0	1.33	0.62	-1.17	1.93	1.89	-0.37	0.55	0.42	0.36
S = 2	-.18	1.24	0.48	-1.14	1.61	1.57	-0.38	0.38	0.28	0.26
I = 0	+.18	1.22	0.44	-1.14	1.57	1.52	-0.41	0.33	0.25	0.21
69.3 V_{L-N} 3φ	0	1.16	0.34	-1.11	1.44	1.38	-0.40	0.25	0.19	0.16
S = 3	-.18	1.11	0.27	-1.08	1.31	1.24	-0.42	0.18	0.14	0.12
‡5A. ∠75° 3φ	+.18	1.72	1.66	-0.46	3.52	1.60	-3.14	1.30	-0.36	-1.25
69.3 V_{L-N} 3φ	0	1.34	1.33	-0.14	2.53	1.26	-2.19	0.83	-0.27	-0.79
S = 1	-.18	1.03	1.03	-0.07	1.68	0.89	-1.42	0.45	-0.20	-0.40
‡‡5A. ∠105° 3φ	+.18	6.65	4.7	-4.70	10.3	5.75	-10.1	5.00	-1.30	-4.84
69.3 V_{L-N} 3φ	0	5.0	3.94	-3.08	7.90	2.04	-7.60	3.76	-0.91	-3.65
S = 1	-.18	3.46	3.14	-1.46	5.70	2.41	-5.17	2.67	-0.65	-2.59

† CURRENT BURDEN IN OHMS

(†† MAXIMUM BURDEN CONDITIONS)

S = 1 M = 0	CURRENT CIRCUIT IMPEDANCE AT 5 TO 100 AMPERES (V_{L-L} = 120V.)								
TAP .73-21 OHM RANGE	TA (TERM'S 13-12)			TB (TERM'S 15-14)			TC (TERM'S 17-16)		
	Imp. Z	Res. R	Reac. jX	Imp. Z	Res. R	Reac. jX	Imp. Z	Res. R	Reac. jX
.87	.019	.0188	.0026	.0356	.0349	.0068	.0162	.0159	.0031
1.16	.021	.0203	.0054	.039	.0379	.0094	.0194	.0188	.005
1.45	.026	.0243	.0093	.0432	.0411	.0133	.0206	.0189	.0068
2.03	.0344	.0295	.0177	.0569	.0507	.0257	.0294	.0252	.0152
2.9	.0514	.0382	.0344	.081	.0647	.0487	.047	.0344	.0320
4.06	.085	.0523	.067	.130	.087	.0965	.074	.0456	.0583
5.8	.153	.081	.130	.230	.129	.191	.135	.0675	.117

† Typical potential and current burden data applies for all relays and all relay ranges.

†† Maximum burden is produced by phase-to-phase fault involving TA & TB compensators or TB & TC.

‡ Fault current flowing into the line.

‡‡ Fault current flowing out of the line.

TABLE II

Relay Settings For .2-4.5 Ohm Range Relay

	"S" = 1							"S" = 2		"S" = 3		M		LEAD CONNECTIONS		
T =	.23	.307	.383	.537	.69	.92	1.23	.92	1.23	.92	1.23	+M	-M	"L" LEAD	"R" LEAD	
	.195	.26	.324	.455	.585	.78	1.04	1.56	2.08	—	3.13	+.18		.06	0	"L" OVER "R"
	.20	.267	.333	.466	.6	.8	1.07	1.6	2.14	—	3.21	+.15		.06	.03	"L" OVER "R"
	.205	.274	.342	.48	.615	.82	1.1	1.64	2.2	—	3.29	+.12		.09	0	"L" OVER "R"
	.211	.281	.352	.493	.633	.845	1.13	1.69	2.26	—	3.38	+.09		.09	.03	"L" OVER "R"
	.217	.289	.362	.506	.65	.868	1.16	1.74	2.32	—	3.48	+.06		.06	.09	"L" OVER "R"
	.223	.298	.372	.521	.67	.893	1.2	1.79	2.39	—	3.58	+.03		.03	0	"L" OVER "R"
	.23	.307	.383	.537	.69	.92	1.23	1.84	2.46	—	3.69	0	0	0	0	
	.237	.316	.395	.554	.71	.948	1.27	1.9	2.54	—	3.8		-.03	0	.03	"R" OVER "L"
	.245	—	.407	.571	.735	.978	1.31	1.96	2.62	—	3.92		-.06	.09	.06	"R" OVER "L"
	.252	—	.42	—	.758	1.01	1.35	2.02	2.7	3.03	4.05		-.09	.03	.09	"R" OVER "L"
	—	—	.435	—	—	—	1.4	—	2.8	—	4.19		-.12	0	.09	"R" OVER "L"
	—	—	—	—	—	—	1.45	—	2.89	—	4.35		-.15	.03	.06	"R" OVER "L"
	—	—	—	—	—	—	1.5	—	3.0	—	4.5		-.18	0	.06	"R" OVER "L"

TABLE III

Relay Settings For .73-21 Ohm Range Relay

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTIONS	
T =	.87	1.16	1.45	2.03	2.9	4.06	5.8	4.06	5.8	4.06	5.8	+M	-M	"L" LEAD	"R" LEAD
"L" OVER "R"	.737	.98	1.23	1.72	2.46	3.44	4.92	—	9.85	—	14.7	+.18		.06	0
	.755	1.01	1.26	1.76	2.52	3.53	5.04	—	10.1	—	15.1	+.15		.06	.03
	.775	1.03	1.29	1.81	2.59	3.63	5.18	7.26	10.3	—	15.5	+.12		.09	0
	.800	1.01	1.33	1.86	2.66	3.73	5.32	7.44	10.6	—	15.9	+.09		.09	.03
	.820	1.09	1.37	1.91	2.74	3.83	5.48	7.65	10.9	—	16.4	+.06		.06	.09
	.845	1.12	1.41	1.97	2.81	3.94	5.64	7.88	11.3	—	16.9	+.03		.03	0
	.870	1.16	1.45	2.03	2.9	4.06	5.8	8.12	11.6	—	17.4	0	0	0	0
"R" OVER "L"	.897	1.20	1.49	2.09	2.99	4.18	5.98	8.36	11.9	—	18.0		-.03	0	.03
	.925	—	1.54	2.16	3.09	4.32	6.18	8.65	12.3	—	18.6		-.06	.09	.06
	.955	—	1.59	2.23	3.19	4.47	6.38	8.93	12.7	—	19.2		-.09	.03	.09
	—	—	1.65	2.31	3.29	4.62	6.60	9.13	13.2	—	19.8		-.12	0	.09
	—	—	1.71	2.39	3.41	4.77	6.82	9.55	13.7	—	20.5		-.15	.03	.06
	—	—	—	—	—	—	7.08	—	14.1	14.3	21.3		-.18	0	.06

TABLE IV

Relay Settings For 1.1-31.8 Ohm Range Relay

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTIONS		
T =	1.31	1.74	2.18	3.05	4.35	6.1	8.7	6.1	8.7	6.1	8.7	+M	-M	"L" LEAD	"R" LEAD	
	1.11	1.47	1.85	2.58	3.68	5.16	7.37	—	14.71	—	22.1	+.18		.06	0	"L" OVER "R"
	1.14	1.51	1.89	2.65	3.78	5.30	7.56	—	15.11	--	22.7	+.15		.06	.03	"L" OVER "R"
	1.17	1.55	1.95	2.72	3.88	5.45	7.76	10.9	15.5	—	23.3	+.12		.09	0	"L" OVER "R"
	1.20	1.6	2.00	2.8	3.99	5.6	7.98	11.2	16	—	23.9	+.09		.09	.03	"L" OVER "R"
	1.23	1.64	2.06	2.87	4.10	5.75	8.20	11.5	16.4	—	24.6	+.06		.06	.09	"L" OVER "R"
	1.27	1.69	2.12	2.96	4.22	5.92	8.45	11.8	16.9	—	25.3	+.03		.03	0	"L" OVER "R"
	1.31	1.74	2.18	3.05	4.35	6.1	8.7	12.2	17.4	—	26.1	0	0	0	0	
	1.35	1.79	2.25	3.14	4.49	6.29	8.96	12.6	17.9	—	26.9		-.03	0	.03	"R" OVER "L"
	1.39		2.32	3.24	4.62	6.49	9.25	13	18.5	—	27.8		-.06	.09	.06	"R" OVER "L"
	1.44	—	2.4	3.35	4.78	6.70	9.55	13.4	19.1	—	28.7		-.09	.03	.09	"R" OVER "L"
	.	—	2.48	3.46	4.94	6.93	9.88	13.9	19.8	—	29.7		-.12	0	.09	"R" OVER "L"
	—	—	2.56	3.59	5.11	7.17	10.2	14.3	20.5	2.15	3.14		-.15	.03	.06	"R" OVER "L"
	—	—	—	—	—	—	10.6	—	21.2	—	31.8		-.18	0	.06	"R" OVER "L"

Auto-Transformer Secondary (M_A and M_C)

Secondary tap connections are made through two leads identified as L and R for each transformer. These leads come out of the tap plate each through a small hole, one on each side of the vertical row of "M" tap inserts. The lead connectors are held in place on the proper tap by connector screws.

Values for which an "M" setting can be made are from -.18 to +.18 in steps of .03. The value of a setting is the sum of the numbers that are crossed when going from the R lead position to the L lead position. The sign of the "M" value is determined by which lead is in the higher position on the tap plate. The sign is positive (+) if the L is higher and negative (-) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Refer to Table II, Table III or Table IV to determine the desired "M" value. Neither lead connector should make electrical contact with more than one tap at a time.

Line Angle Adjustment

Maximum sensitivity angle is set for 75° ±3° (current lagging voltage) in the factory. This adjustment need not be disturbed for line angles of 65° or higher. For line angles below 65° set for a 60° maximum sensitivity angle by adjusting the compensator loading resistors R_{2A} and R_{2C}. Refer to repair calibration parts 14, 15, 22, and 23 when a change in maximum sensitivity angle is desired.

INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt, moisture, excessive vibration and heat. Mount the relay by means of the mounting stud for the type FT projection case or by means of the four mounting holes on the flange for the semi-flush type FT case. Either the stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal stud furnished with the relay for thick panel mounting. The terminal stud may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

For detail information on the FT case, refer to I.L. 41-076.

EXTERNAL CONNECTIONS

Figure 19 shows the connections for three zone protection using an SKD, an SP, and an SP-1 relay.

RECEIVING ACCEPTANCE

Acceptance tests consist of a visual inspection to make sure there are no loose connections, broken resistors, or broken resistor wires; and an electrical test to make certain that the relay measures the balance point impedance accurately.

Recommended Instruments For Testing

Westinghouse Type PC-161, Style #291B749A33 or equiv. AC voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equiv. AC ammeter.

Tripping is indicated for the SKD when the 25 watt lamp shown in Figure 20 turns on. For the SP and SP-1 relays, tripping is indicated by a voltmeter reading. At the balance point, the voltmeter reading may be as low as 1V and 2V indicating that the system is only partially tripping. This is a normal balance point characteristic. However, a 5 percent increase in current should produce an output of 15 to 20 volts. A reading of less than 12 volts indicates a defective tripping output.

Distance Units – Electrical Tests

1. Check the electrical response of the relay by using the test connections shown in Figure 20. Set T_A, T_B, and T_C for the maximum tap value: S_A and S_C for 1; M, M_A and M_C for +0.15.
2. Disable the three-phase unit by connecting relay terminal 4 to relay terminal 2.
3. Connect the relay for a 1-2 fault as indicated for Test #5 in Figure 20 and adjust the voltage between PH.1 and 1F and between PH.2 and 2F for 45 volts each so that the resultant voltage V_{1F2F} equals 30 volts. (120-45V-45V + 30 V.)
4. Supply 110% of the current necessary to trip the phase-to-phase unit at 75° and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. This should be 75° ± 3°.
5. The current required to make the phase-to-phase unit trip should be within the limits given in Table V at an angle of 75° current lag.

6. Repeat section 5 while using connections for Test #6 and Test #7. The difference in values of current that makes the unit trip for each of the three test connections should not be greater than 5% of the smallest value. Remove jumper between relay terminals 4 and 2.

7. Disable the phase-to-phase unit be connecting Test Point 23 (TP23) and Test Point 24 (TP24) to Printed Circuit Board Terminal 9 (PCB9). These points, located on the Printed Circuit Boards, are shown in Figure 8.

8. Repeat the above tests 3, 4, and 5 for the three-phase unit. The current required to trip the three-phase unit should be within the limits given in Table V at the maximum sensitivity angle of 75°.

TABLE V

Test Voltage = 30 V_{L-L}

M Setting = +.15

S Setting = 1

Range	Setting		Test No.	Unit	Amperes to Trip At 75° Lag
	T	Ohms			
.2- 4.5 Ohms	1.23	1.07	5,6,7 5	ϕ-ϕ 3ϕ	(100% Z - 94.7% Z) 14.0 - 14.8 Amps
.73-21 Ohms	5.8	5.05	5,6,7 5	ϕ-ϕ 3ϕ	(101% Z - 94.5% Z) 2.95 - 3.15 Amps
1.1-31.8 Ohms	8.7	7.57	5,6,7 5	ϕ-ϕ 3ϕ	(100% Z - 94.5% Z) 1.98 - 2.1 Amps

If the electrical response is outside the limits, a more complete series of test outlined in the section titled "Calibration" may be performed to determine which component is faulty or out of calibration.

Indicating Contactor Switch (ICS in SKD Only)

1. With the phase-to-phase unit tripped, pass sufficient dc current through the trip circuit to close the contacts of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

The contact gap should be approximately 0.047" for the 0.2/2.0 ampere unit and 0.070" for the 1.0 ampere unit between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

ROUTINE MAINTENANCE

The relays should be inspected periodically, at such time intervals as may be dictated by experience, to insure that the relays have retained their calibration and are in proper operating condition.

Distance Units

CAUTION: Before making hi-pot" tests, connect together terminals 1, 2, 3, 10, 11, and 20 to avoid destroying components in the static network.

Use connections for Test #5, #6, and #7 of Figure 20 to check the reach of the relay. Note that the impedance measured by the 3-phase unit in Test #5 and by the phase-to-phase unit in Tests #5, #6, and #7 is:

$$Z_R + \frac{V_{L-L}}{2\, I_L}$$

where V_{L-L} is the phase-to-phase voltage, and I_L is the phase current. When in service and receiving three phase currents, the 3-phase unit response is:

$$Z_R = \frac{V_{L-L}}{3\, I_L}$$

Indicating Contactor Switch (ICS in SKD Only)

With either of the distance units tripped, pass sufficient dc current through the trip circuit to close the contact of the ICS. This value of current should be not less than 1.0 ampere nor greater than 1.2 amperes for the 1 ampere ICS. The current should not be greater than the particular ICS tap setting being used for the 0.2-2.0 ampere ICS. The operation indicator target should drop freely.

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed.

10. Connect the relay for testing as shown in Figure 20. The four-pole double-throw switch shown in

the test circuit selects the type of voltage condition, for a phase-to-phase or a three-phase fault, that will be applied to the relay voltage terminals. The rotary switch switches the fault voltage to various terminals and thereby simuates any combination of phase-to-phase faults without the tester having to change connections or readjust the phase shifter and variable autotransformers.

Auto-Transformer Check

Auto-transformers may be checked for turns ratio and polarity by using the No. 2 Test connections of Figure 20, and the procedure outlined below.

11. Set S_A and S_C on tap number 3. Set the "R" leads of M_A and M_C on 0.0 and disconnect all the "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminals 8 to the #1 tap of S_A. It should be 30 volts. From 8 to the #2 tap of S_A should be 60 volts. The voltage should read 30 volts from 8 to S_C = 1 and 60 volts from 8 to S_C = 2.

12. Set S_A and S_C on 1 and adjust V_{1F2F} and V_{2F3F} for 100 volts. Measure the voltage drop from terminal 8 to each of the M_A taps. This voltage should be equal to 100 (1 + the sum of values between R and the tap being measured). Example: 100 (1 + .03 + .06) = 109 volts.

Check the taps of M_C in the same manner. Transformers that have an output different from nominal by more than 1.0 volt probably have been damaged and should be replaced.

Distance Unit Calibration

13. Check to see that the taps on front of the tap block are set as follows:

    T_A, T_B (twice) and T_C: Set on the highest tap value. (1.23, 5.8, or 8.7)

    S_A and S_C: Set on 1.

    "R" for M_A and M_C: Set on ".03".

    "L" for M_A and M_C disconnected.

I. PHASE-TO-PHASE UNIT

Maximum Sensitivity Angle Adjustment

14. Connect the relay for a 1-2 fault as indicated for Test No. 5. Connect a high resistance voltmeter (2000 ohms/volt) between the "L" lead of M_A and the fixed end of R2A.

15. Pass 5 amperes through the T_{AB} compensator and adjust R2A so that the secondary voltage reads:

    V_S = 10.35 T Sin θ
    θ = the desired maximum sensitivity angle
    T = Compensator tap setting
    10.35 = a design constant = $\frac{10}{\sin 75°}$

		V_S VOLTS FOR GIVEN "T" SETTINGS		
θ	V_S	T = 1.23	T = 5.8	T = 8.7
75°	10T	12.3	58	87
60°	8.96T	11.	52	78

16. Connect the relay for Test No. 6. Connect the voltmeter between the "L" lead of M_C and the fixed end of R2C. Pass 5 amperes through the T_{CB} compensator and adjust R2C so that the secondary voltage reads the proper value as described in section 15 above.

17. Maximum sensitivity angle has been adjusted by steps 14, 15, and 16 above. Connect "L" for M_A and M_C in the top position so that there is .15 between L and R.

18. An electrical check of the maximum sensitivity angle may be performed for each compensator after the circuit calibration in the next step (19) is completed. For the T_{AB} compensator make connections for Test No. 2. For the T_{CB} compensator, use connections for Test No. 4. Connect relay terminals 2 and 4 together to disable the three-phase unit and set voltages V_{1F2F} and V_{2F3F} for 30 volts. Supply 110% of the current necessary to trip the phase-to-phase unit at 75° and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle θ is: $\frac{\theta_1 + \theta_2}{2}$.

Note that, as indicated in the test circuit diagram, θ_1 and θ_2 values are obtained by subtracting 30° from the phase-angle-meter reading. Remove connection between terminals 2 and 4 after the completion of these checks.

Circuit Calibration

19. Connect terminals 2 and 4 together to disable the three-phase unit. Connect terminals 7 and 9 together, set resistor RAC so that the band is centered, apply 120 Vac between terminals 8 and 9, and adjust RMC until the ϕ-ϕ unit just trips. For a fine adjustment, adjust RAC until the unit just trips. At the balance point for SP and SP-1 relays, the voltmeter reading may be as low as 1v or 2v indicating that the system is only partially tripping. This is a normal balance point characteristic. However, a 5 percent increase in current should produce an output of 15 to 20 volts.

20. Connect the relay as listed in Table VI. The phase-to-phase unit should trip within the current limits listed for the given test voltages. Check the 5 volt level first and adjust RAC further, if necessary, to make the current trip level for Test No. 7 fall between the trip levels for Test No.'s 5 and 6.

    To determine the limits of current when θ is not equal to 75°, multiply the nominal values tabulated above by the ratio:

$$\frac{\sin 75°}{\sin \theta}$$

21. The phase-to-phase unit testing is complete, and the connection between terminals 2 and 4 should be removed.

II. THREE-PHASE UNIT

Maximum Sensitivity Angle Adjustment

22. Disable the phase-to-phase unit by connecting Test Point 23 (TP23) and Test Point 24 (TP24) to Printed Circuit Board Terminal 9 (PCB9).

23. Connect the relay for a 1-2 fault as indicated for Test No. 5. Apply 30 V_{LL} between relay terminals 7 and 8. Supply 110% of the current necessary to trip the three-phase unit and swing the phase shifter to determine the two angles, θ_1 and θ_2 at which the unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. The factory setting for θ is 75°.

    The maximum sensitivity angle can be adjusted by loosening the adjustable band on RS and carefully moving the band to a different setting. The angle for the three-phase unit should be the same as for the phase-to-phase unit.

24. Set the phase shifter for the maximum sensitivity angle. Using only Test No. 5 connections, the three-phase unit should trip within the same limits as listed for the phase-to-phase unit. The three-phase unit testing is complete and the connections from TP23 and TP24 to PCB9 should be removed.

RENEWAL PARTS

Repair work can be done most satisfactorily at the factory. However, interchangeable parts can be furnished to the customers who are equipped for doing repair work. When ordering parts, always give the complete nameplate data.

TABLE VI

Test No.	Volts V1F2F	Amperes To Trip For θ = 75°					
		.2-4.5 Range		.73-21 Range		1.1-31.8 Range	
		Imin	Imax	Imin	Imax	Imin	Imax
5,6,7	5.0	2.34	2.55	0.50	0.54	0.33	0.36
	30.0	14.0	14.8	2.95	3.15	1.98	2.1
	70.0	32.7	33.4	6.9	7.1	4.62	4.72

TABLE VII

NOMENCLATURE FOR RELAY TYPES SKD, SP, AND SP-1

Note: Manufacturer Reserves the Right to Change Comparative Values Without Prior Notice.

Capacitors

	SKD, SP, SP-1 COMMON PARTS	
C1	18 MF	187A508H10
C2	1.5 MF	187A508H09
C3C	.3 MF	1724191
CS	.45 MF	1723408
CFA, CFC	1 MF	1876999

	SKD		SP		SP-1	
C3	.25 MF	187A624H02	.25 MF	187A624H02	—	
C5	.25 MF	187A624H02	—		—	
C4	2 MF	184A662H07	—		.015 MF	187A624H10
C2A, C2C	1.8 MF	14C9400H12	1.8 MF	14C9400H12	.8 MF	14C9400H15
C6	.015 MF	187A624H10	.015 MF	187A624H10	—	

Diode

	SKD, SP, SP-1 COMMON PARTS	
Blocking All Diodes	CER 69	188A342H06
DZ1, DZ2	1N957B	186A797H06
DZ4	1N752A	186A797H12
DZP	1N2984B	762A631H01

	SKD		SP		SP-1	
DZ6	1R200	629A369H01	—		—	
DZ3	1N957B	187A797H06	1N957B	186A797H06	—	
DZ7	1N2846A	184A854H08	1N2846A	184A854H08	1N3686B	185A212H06
DZ8	1N2846A	184A854H08	1N2846A	184A854H08	1N758	186A797H01
DZ9, DZ10	1N2846A	184A854H08	1N2846A	184A854H08	—	
DZ11	1N758	186A797H01	1N758	186A797H01	—	
DZ12	—		1N3686B	185A212H06	—	

ICS	Indicating Contactor Switch (Type SKD Relay Only)
M_A, M_C	Auto-Transformer Secondary (Between taps 0.0; .03; .09; .06)
OI	Operation Indicator Lamp #1819 187A133H03 (Type SP Relay Only)
PB	Microswitch (Type SP Relay Only) 184A611H01

Transistors

	SKD, SP, SP-1 COMMON PARTS	
Q1 to Q6	2N3391	848A851H01
Q7 to Q9, Q20	2N697	184A638H18
Q10 to Q18	2N1132	184A633H20

TABLE VII (Cont.)

	SKD		SP		SP-1	
Q19	2N2647	629A435H01	–		–	
Q21	–		2N697	184A638H18	2N697	184A638H18
Q22	–		2N697	184A638H18	–	

Thyristors

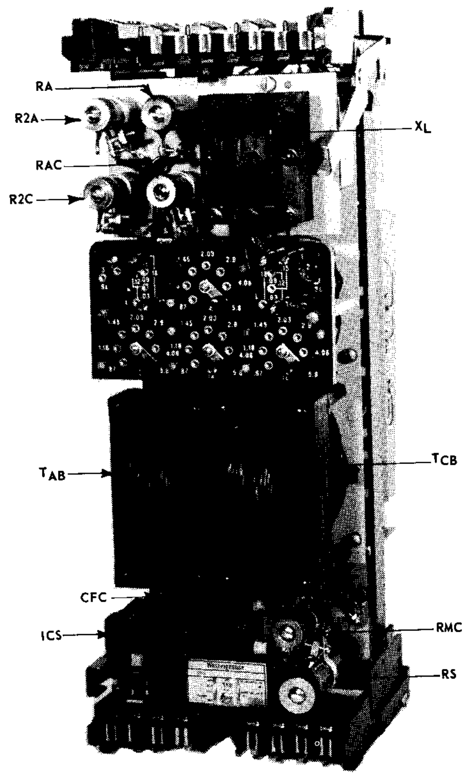
	SKD, SP, SP-1 COMMON PARTS	
QS1 to QS4	2N884	185A517H05
QS5	2N1881	184A640H08 (SP Relay Only)

Resistors

	SKD, SP, SP-1 COMMON PARTS	
R1, R2, R6, R7	120K	184A763H77
R3, R4, R22, R33, R26, R27	8.2K	184A763H49
R5	33K	184A763H63
R8	22K	184A763H59
R9, R11, R17, R19	2.7K	629A531H42
R10, R12, R15, R18, R20	2.7K	184A763H37
R24, R25, R28, R29	2.7K	184A763H37
R31, R32	1MEG	184A763H99
R35	220K	184A763H83
R36	56K	184A763H69
R37, R38, R39, R40	100K	184A763H73
R41, R42	100Ω	184A763H03
R2A, R2C	900Ω	05D132H22
R3C	1K	1202588
RA, RC	1.8K	1201004
RAC	3500Ω	05D1328H74
RDC (125 VDC)	1500Ω	1267293
(48 VDC)	400Ω	1202587
RMA	1.8K	1201004
RMC	2500Ω	5D1328H40
RS	10K	1730906

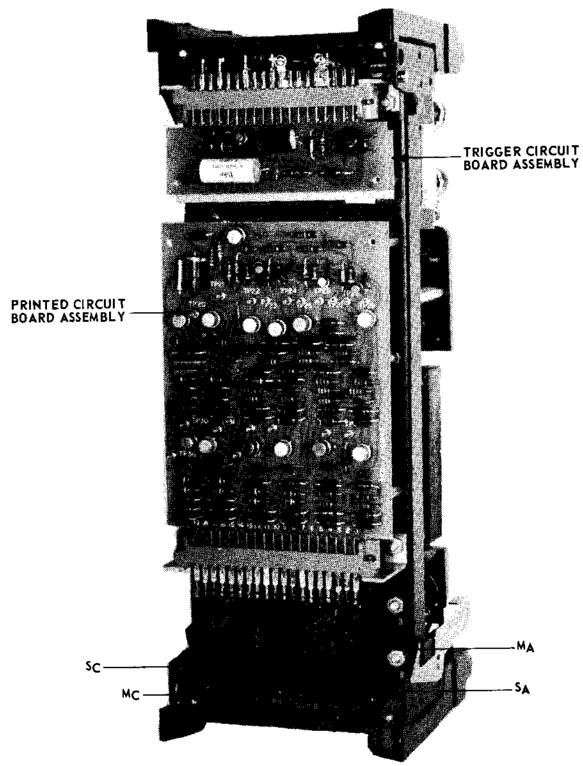
	SKD		SP		SP-1	
R13	33K	187A763H63	33K	184A763H63	–	
R16	22K	184A763H59	22K	184A763H59	–	
R21	4.7K	184A763H43	1K	184A763H27	1K	184A763H27
R33	22K	184A763H59	6.8K	184A763H47	22K	184A763H59
R34	4.7	184A763H43	1.5K	184A763H31	22K	184A763H59
R44	680Ω	184A763H23	10K	184A763H51	–	
R45	12K	184A763H53	1.5K	184A763H31	–	
R46	470Ω	184A644H19	–		–	
R47, R48	500Ω	763A129H03	500Ω	763A129H03	–	
R50	27K	184A763H61	56K	184A763H69	27K	184A763H61
R51	18K	184A763H57	22K	184A763H59	18K	184A763H57
R43	1MEG	184A763H99	1MEG	184A763H99	–	
R52	2.7K	184A763H37	27K	184A763H61	2.7K	184A763H37
R53	–		18K	184A763H57	22K	184A763H59
R54	56K	184A763H69	2.7K	184A763H37	56K	184A763H69
R55	–		1K	184A763H27	–	

SA, SC	Auto-Transformer Primary (Taps: 1, 2, 3)
T1, T2 T3	292B563G05 229B563G02 Coupling Transformers
TP	629A372H01 Pulse Transformer (SKD Only)
TCR	Thyristor (Controlled Rectifier) 2N1850A 184A614H05 500V, 60 Amperes, 5 Cycle Surge-6.5 Amperes Continuous. (Type SKD Relay Only)
XL	Memory Circuit Reactor
XS	Center Tapped Auto-Transformer For Phase Shift Circuit.



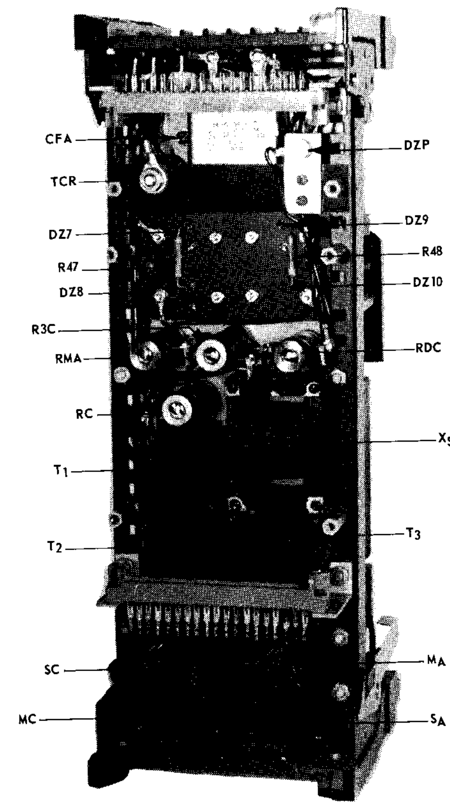
N365522

Front View



N365520

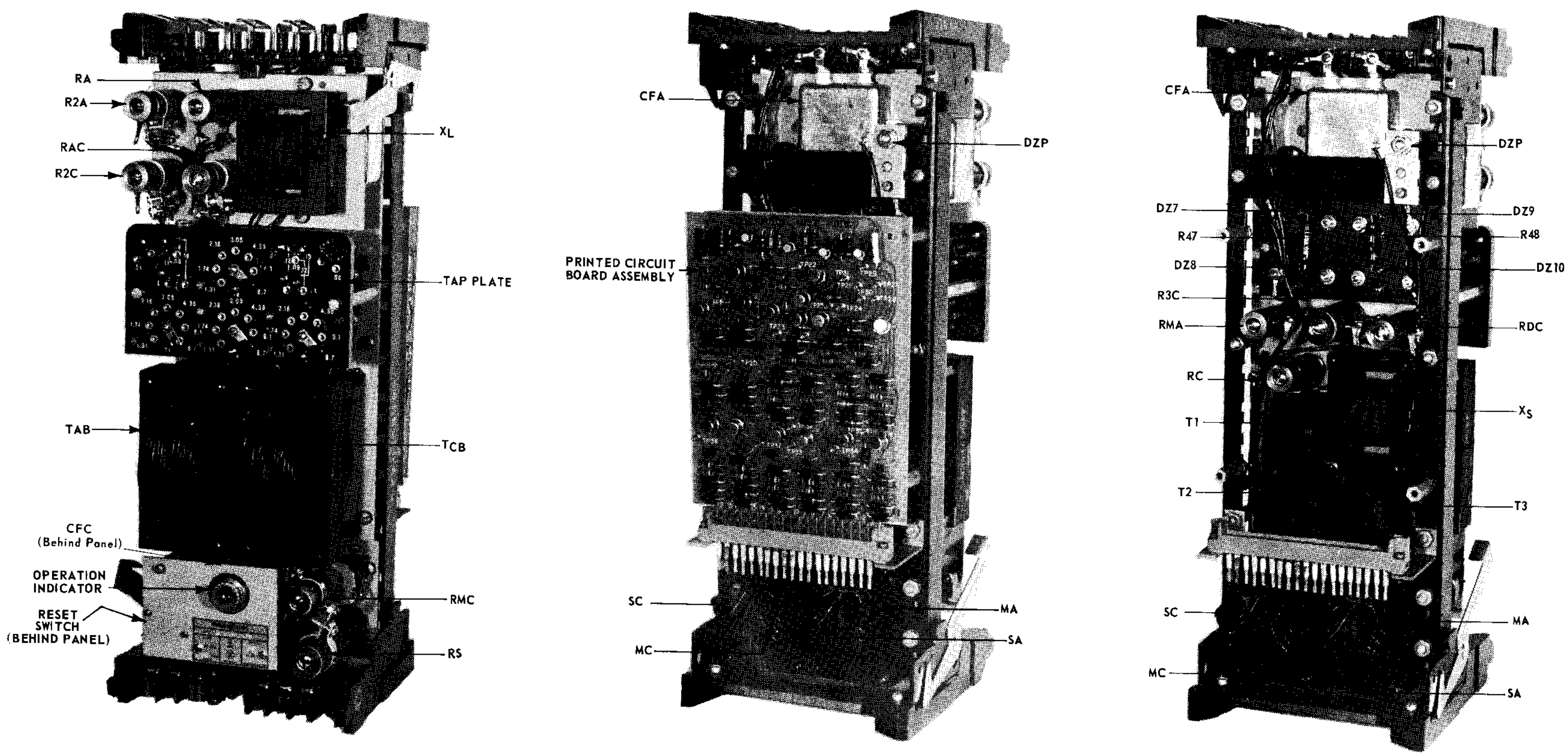
Rear View



N365526

Rear View
(Without Boards)

Fig. 1. Type SKD Relay Without Case.

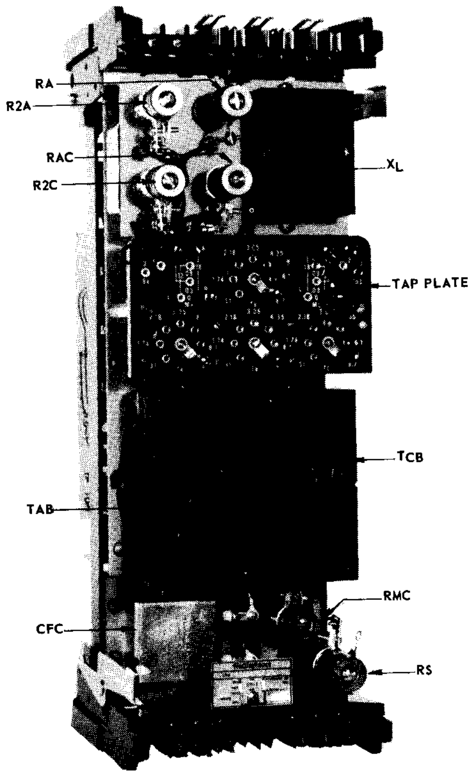


N365514
Front View

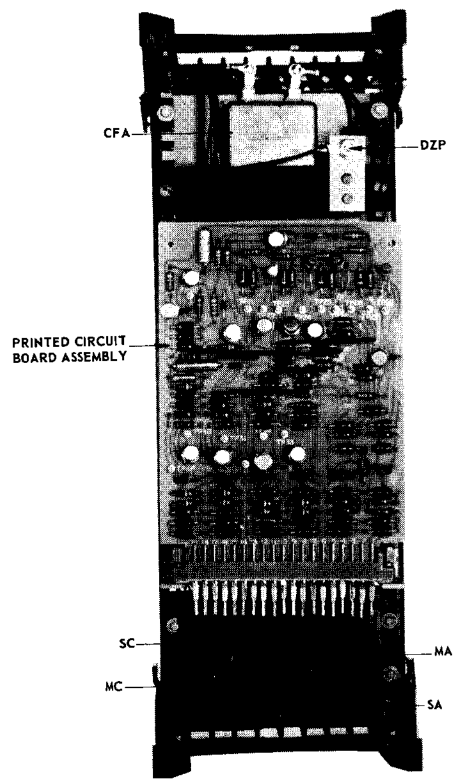
N365518
Rear View

N365519
Rear View
(Without Boards)

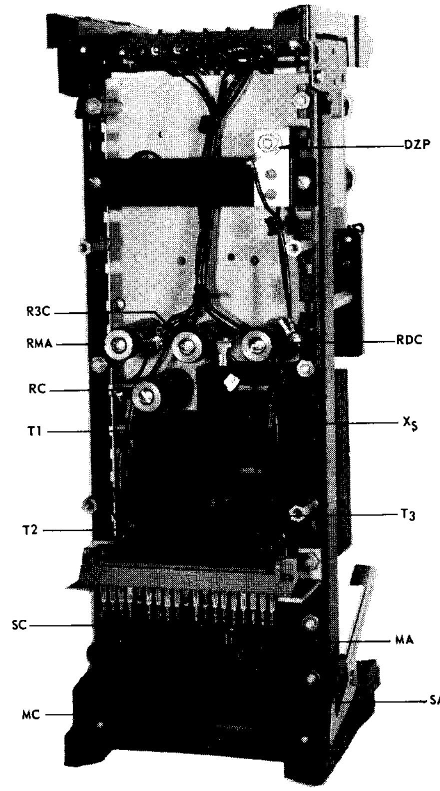
Fig. 2. Type SP Relay Without Case.



Front View



Rear View



Rear View (Without Boards)

Fig. 3 Type SP-1 Relay Without Case.

Fig. 3. Type SP-1 Relay Without Case.

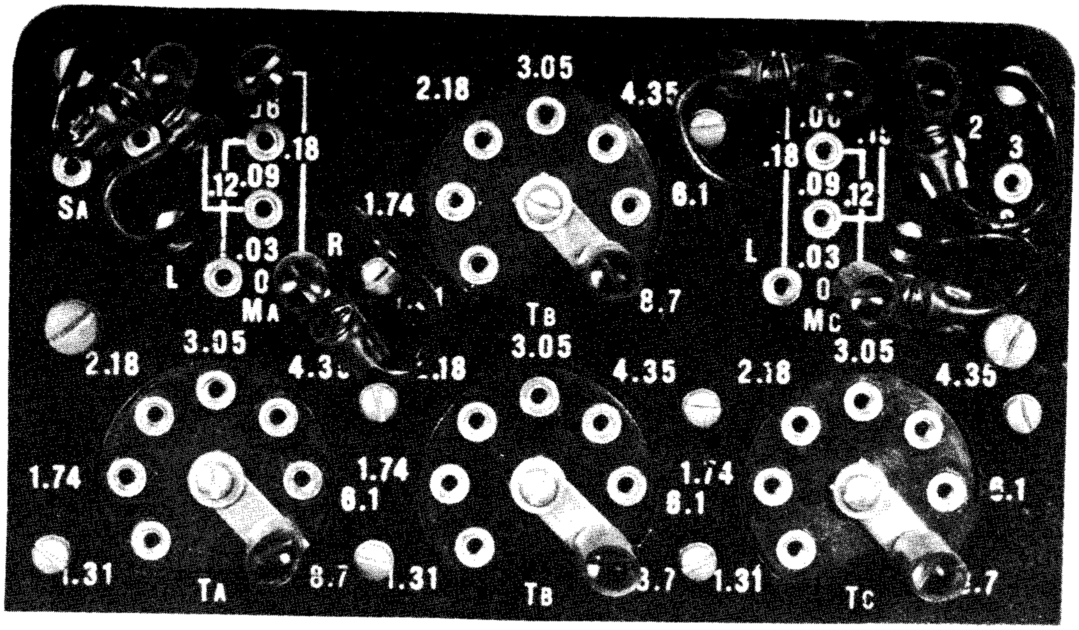


Fig. 4. Tap Plate of 30 Ohm Relay

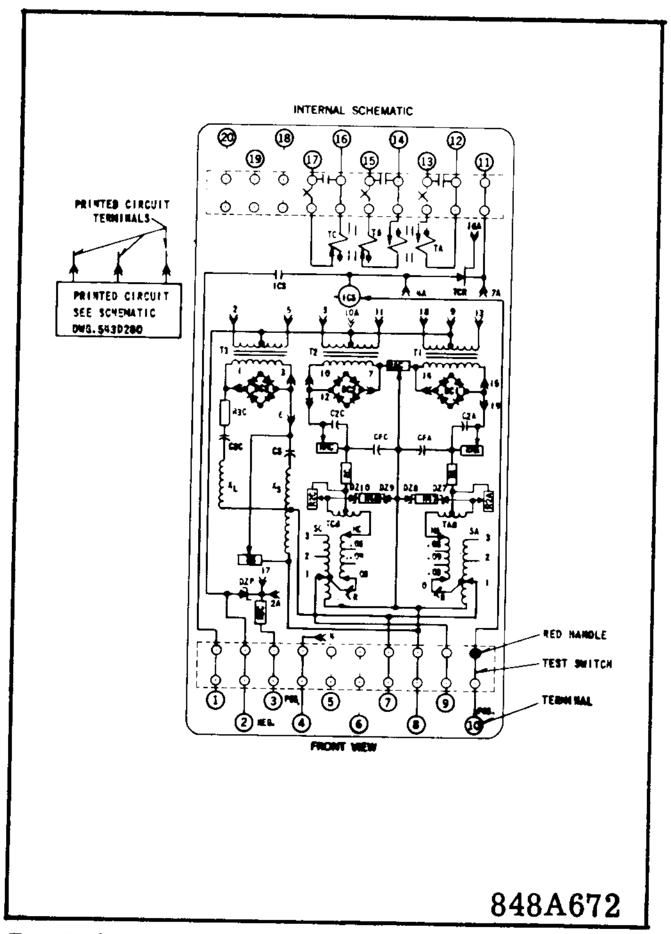


Fig. 5. Internal Schematic of Type SKD Relay in Type FT-42 Case.

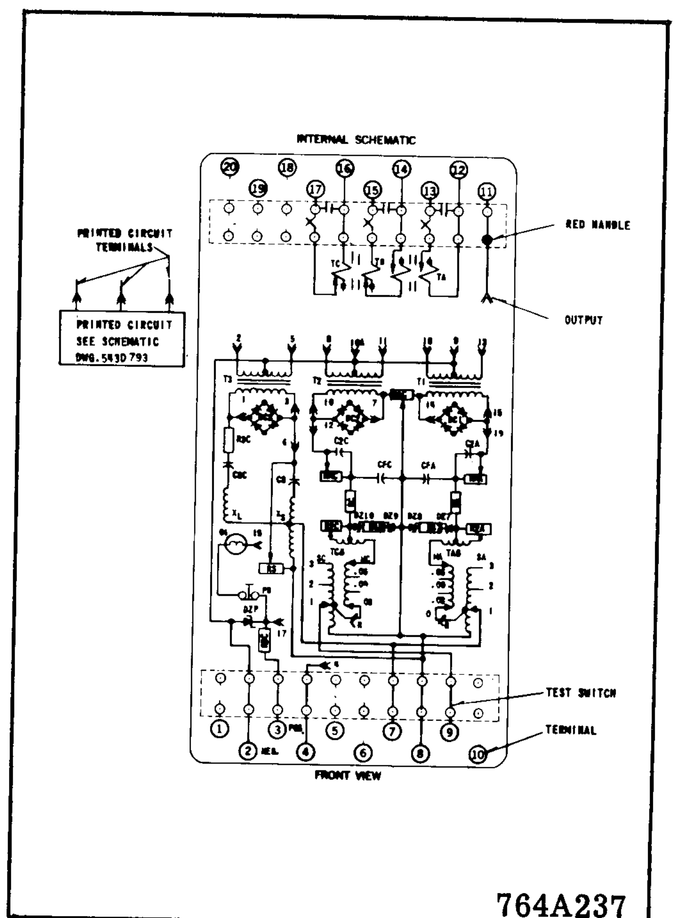


Fig. 6. Internal Schematic of Type SP Relay in Type FT-42 Case.

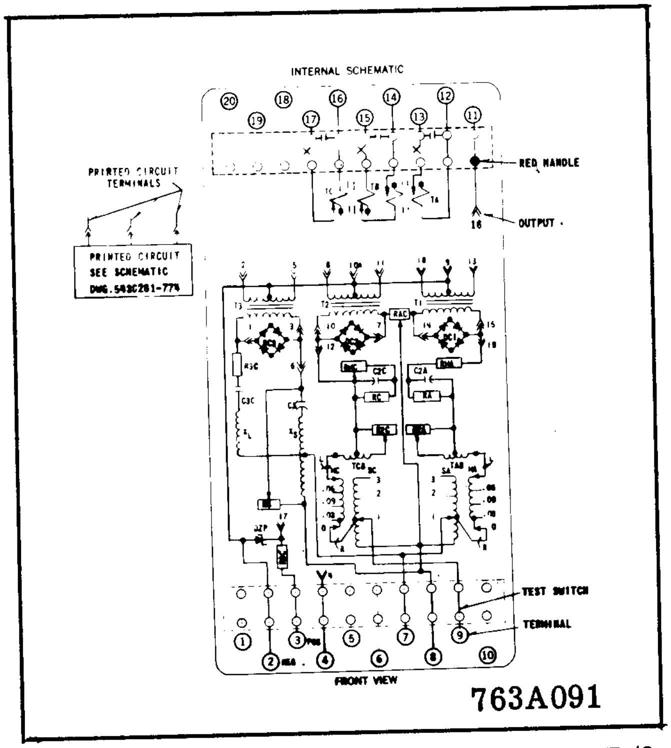


Fig. 7. Internal Schematic of Type SP Relay in Type FT-42 Case.

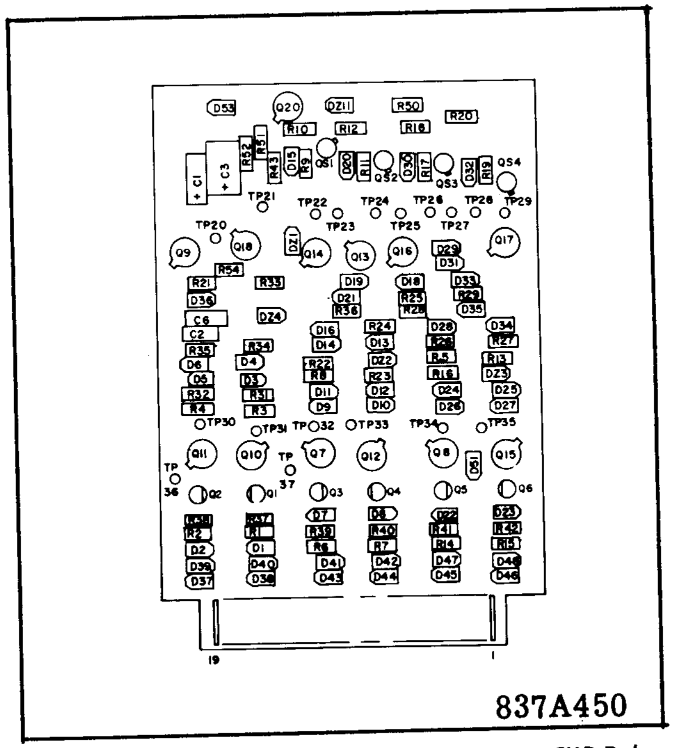


Fig. 8a. Printed Circuit Board Assembly for Type SKD Relay.

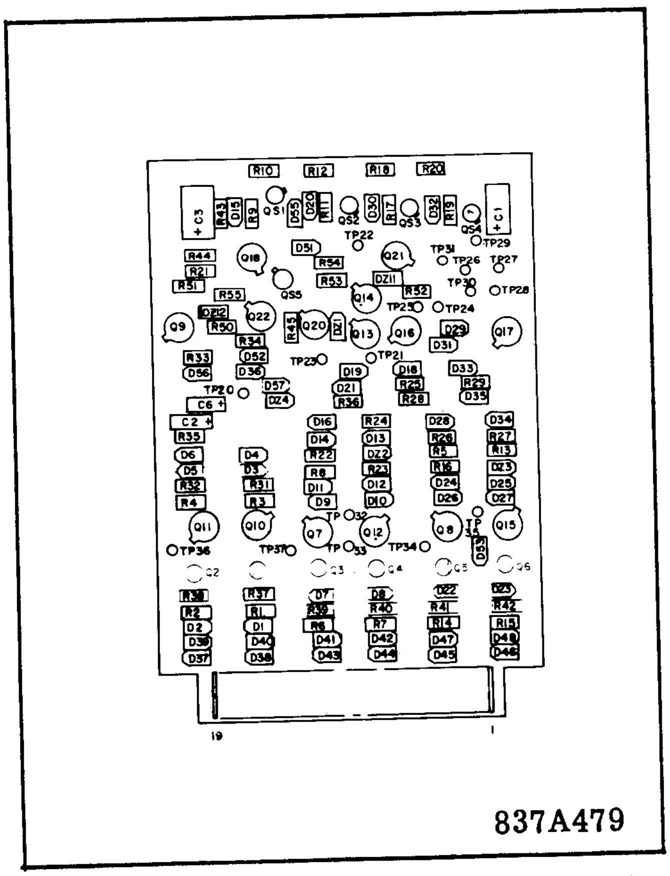


Fig. 8b. Printed Circuit Board Assembly for Type SP Relay.

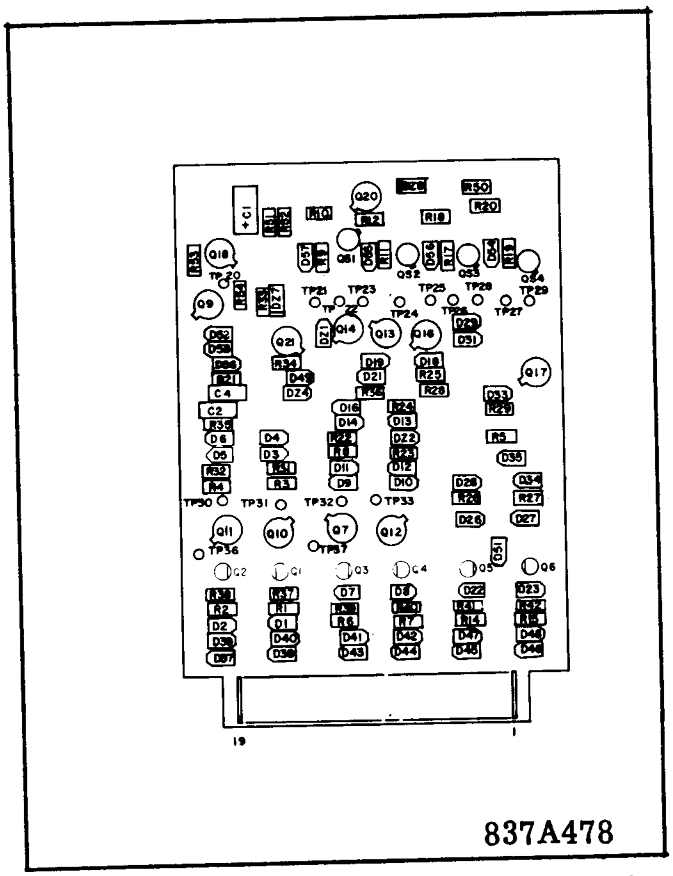


Fig. 8c. Printed Circuit Board Assembly for Type SP-1 Relay.

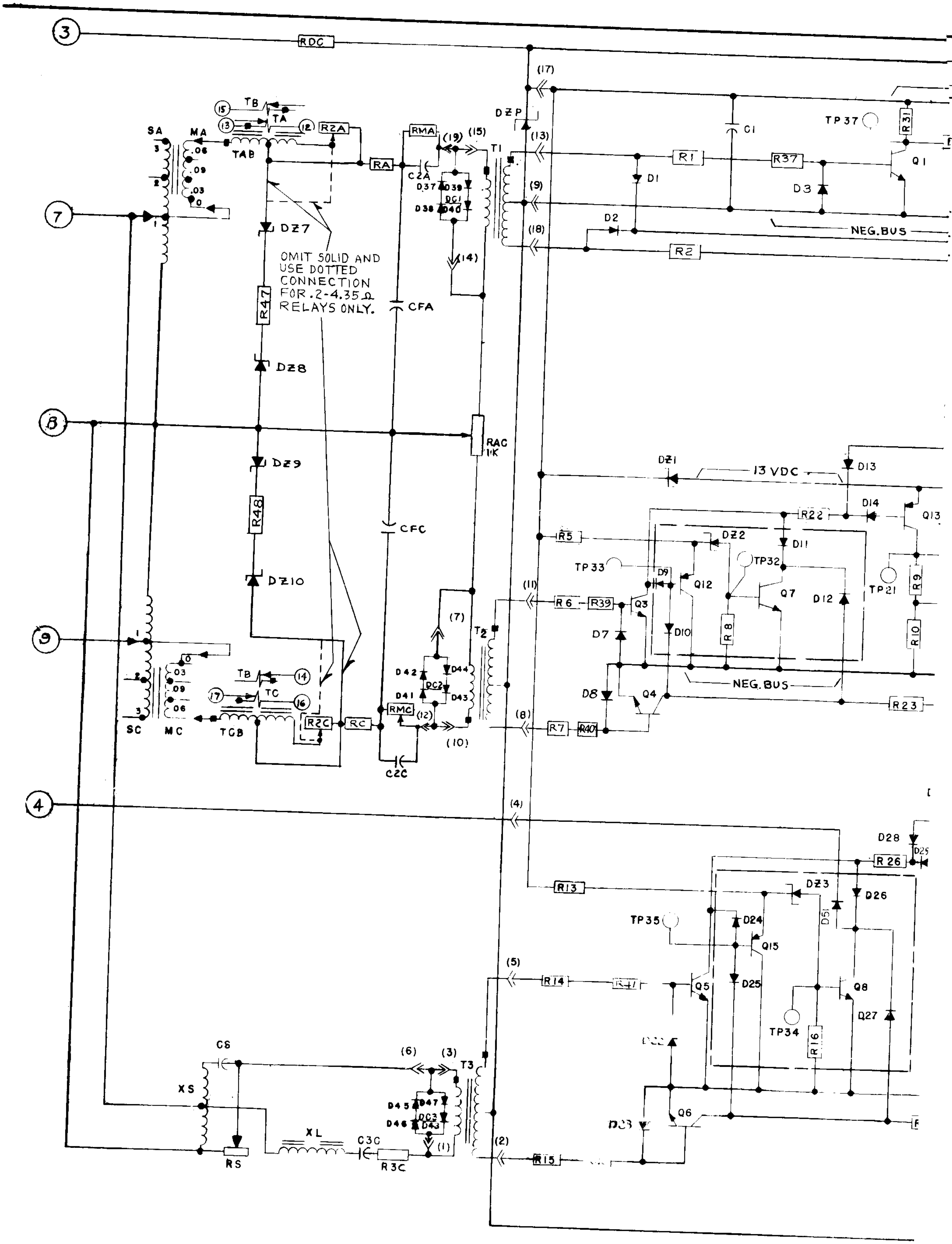
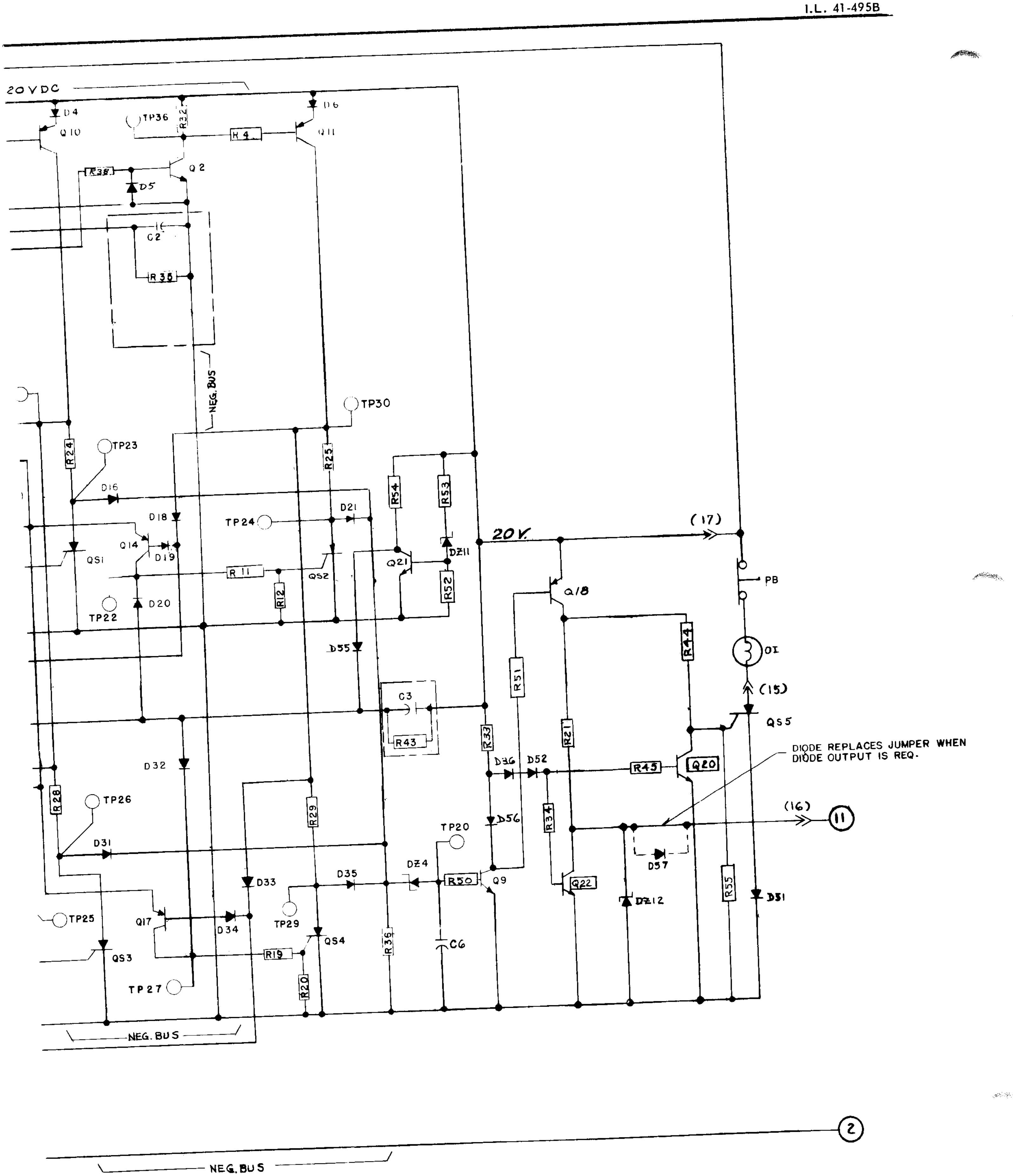
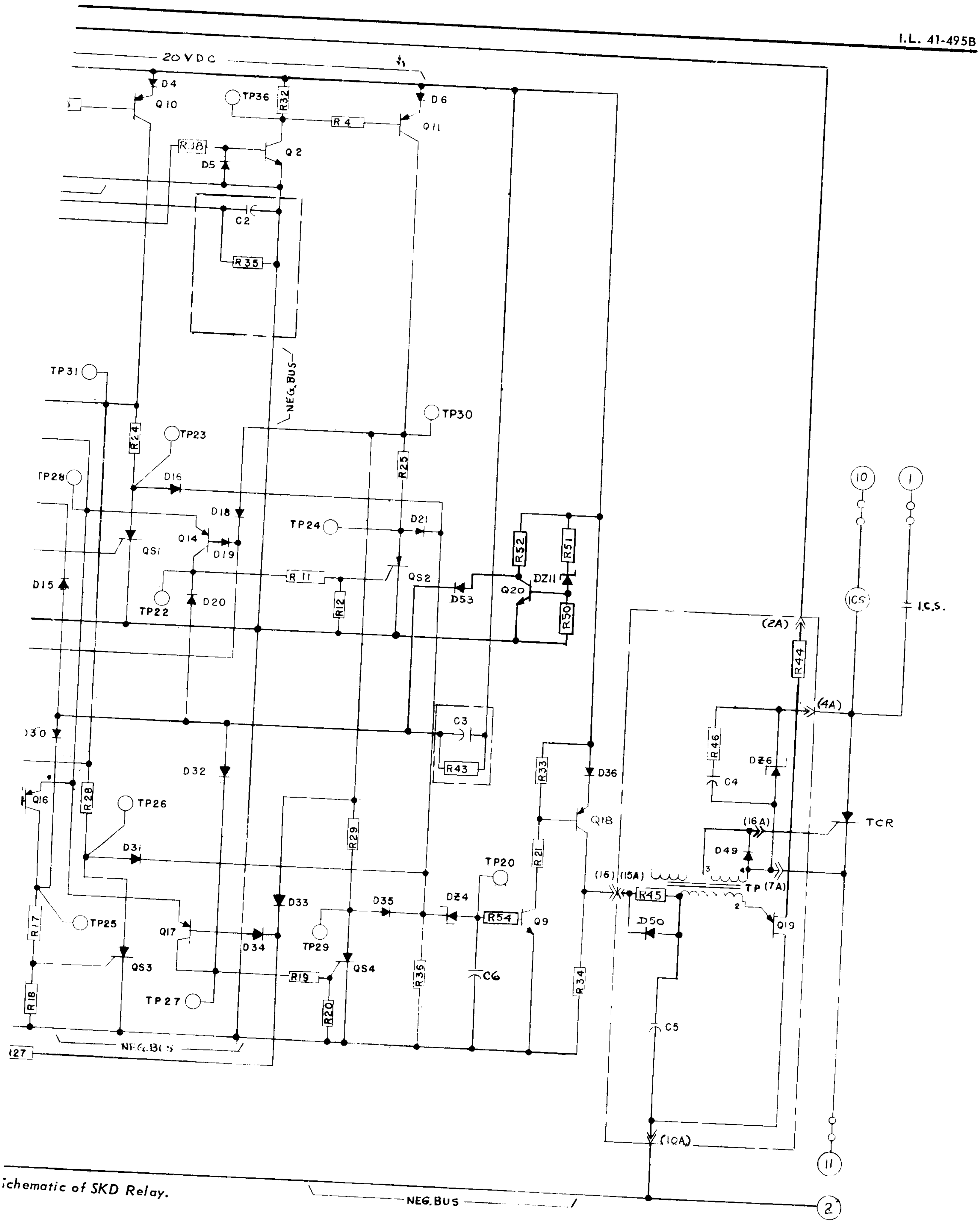


Fig. 9. Detailed Internal S



al Schematic of SP Relay.



Schematic of SKD Relay.

543D280

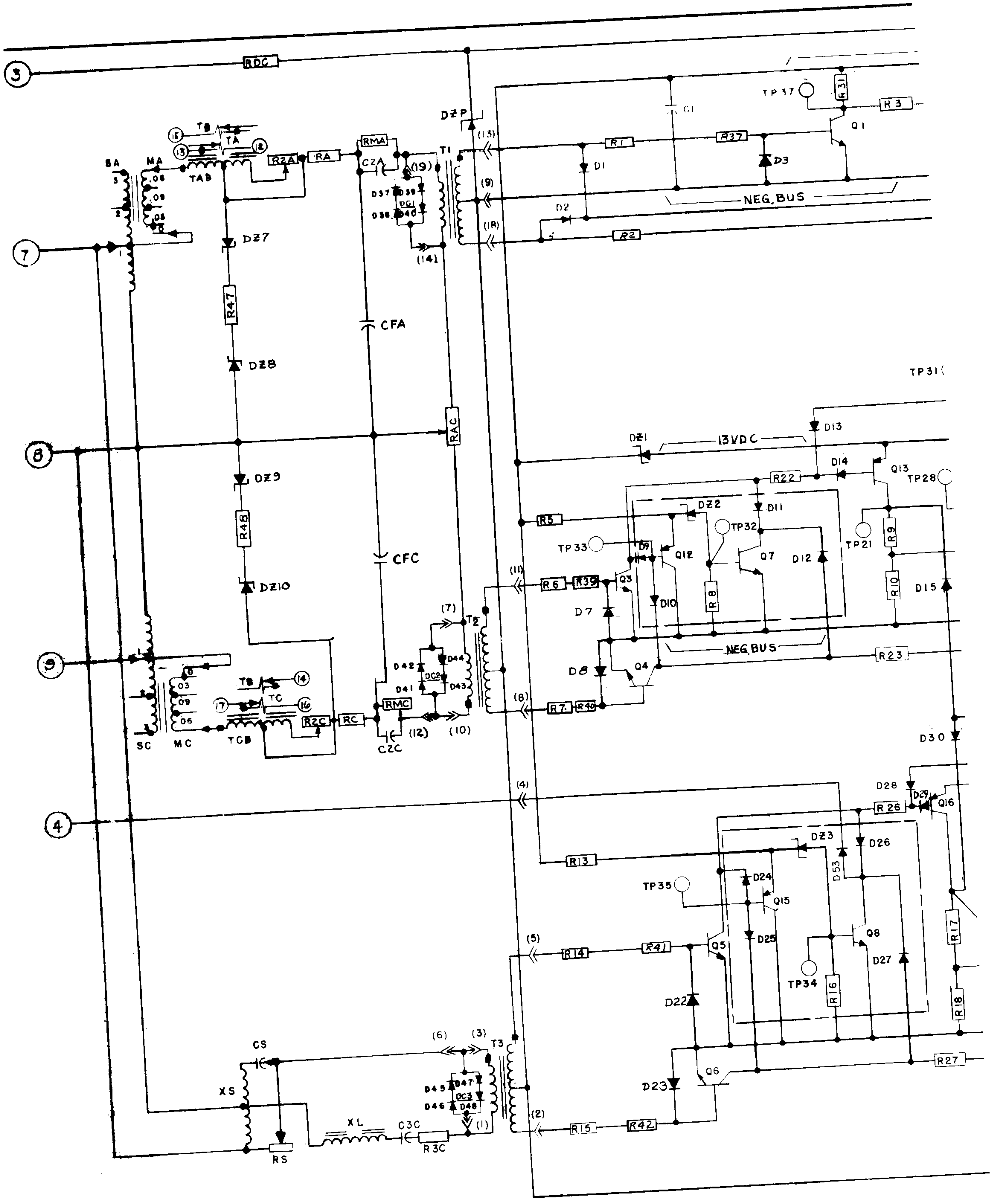


Fig. 10. Detailed Intern

543D793

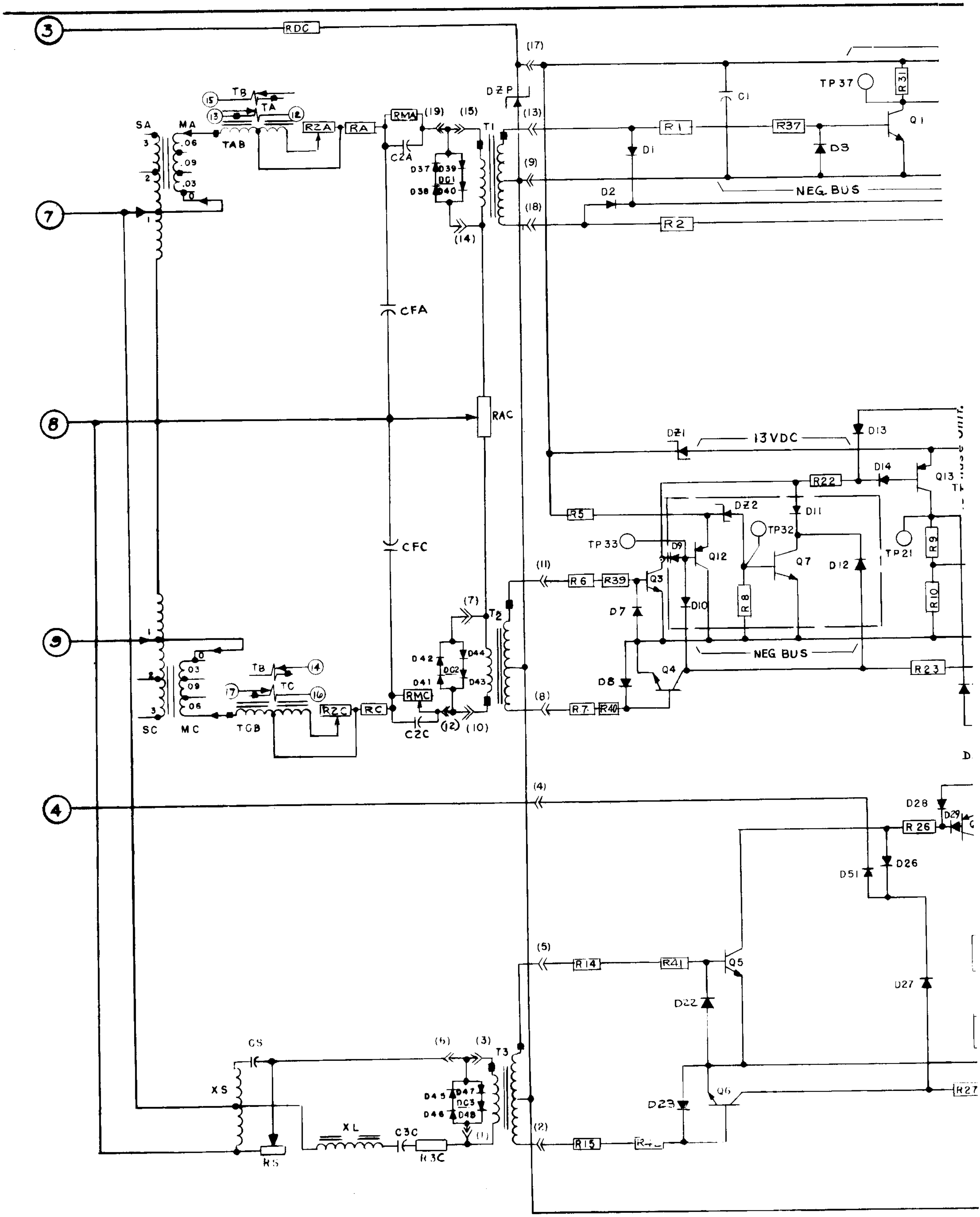


Fig. 11. Detailed Internal Sc

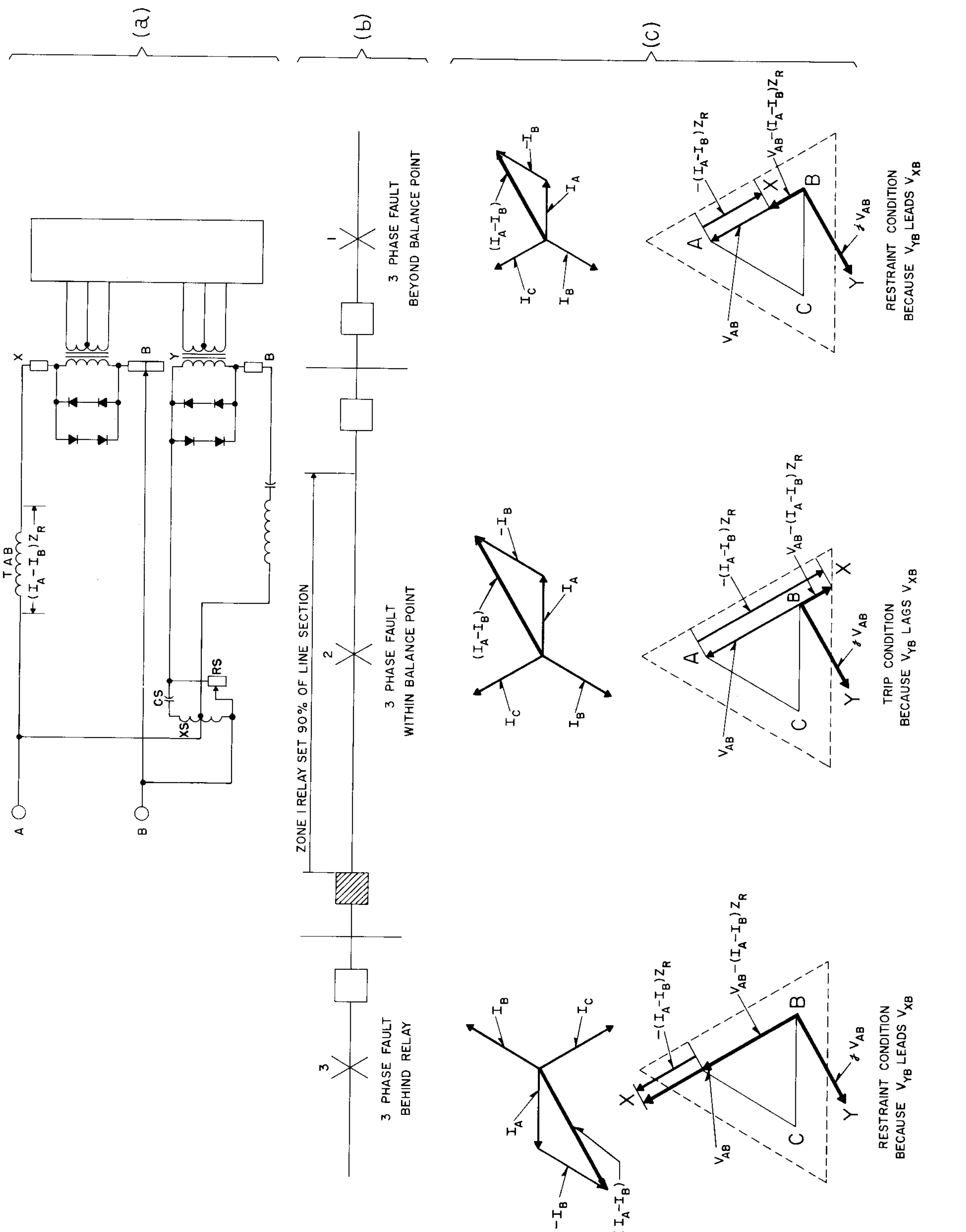
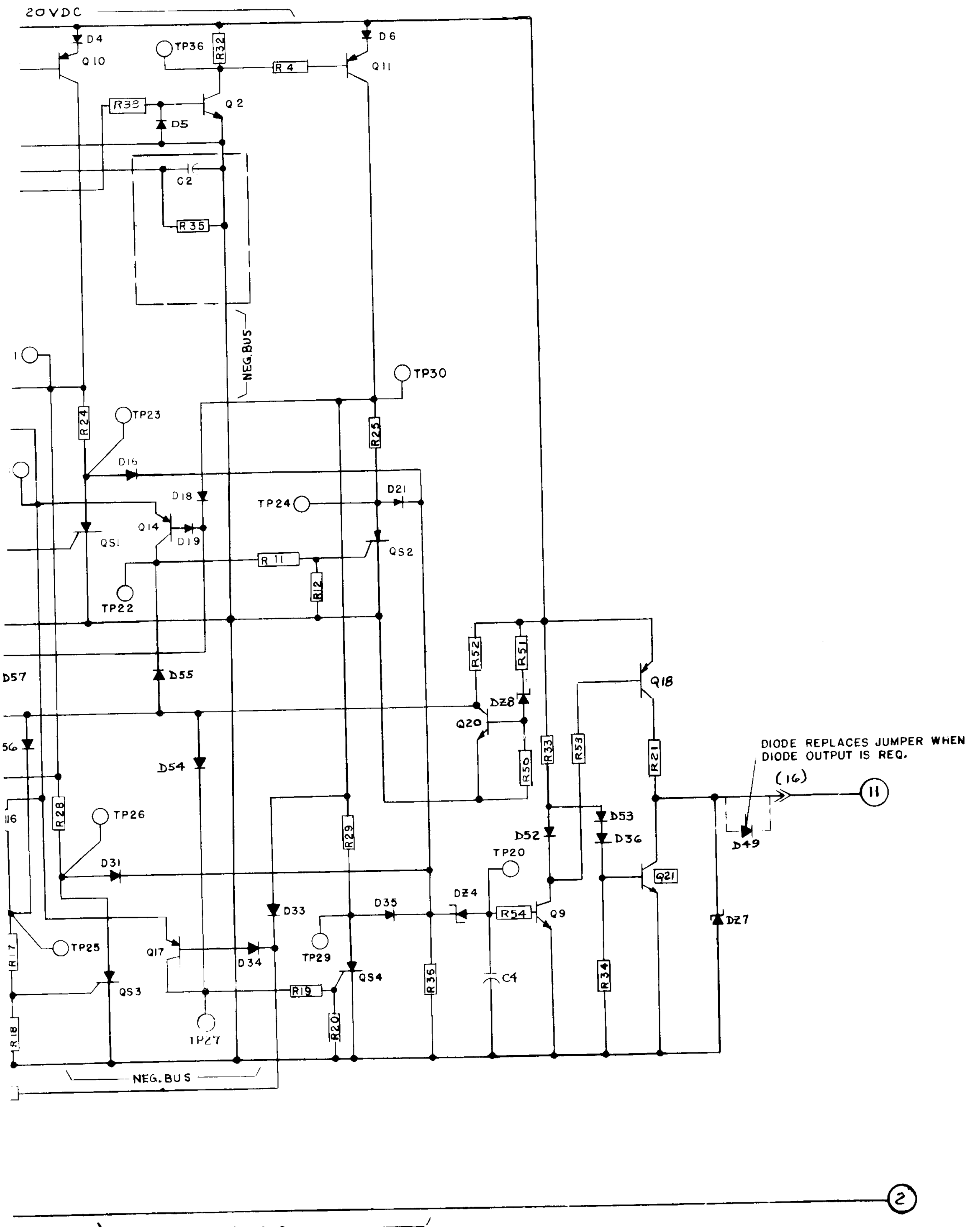
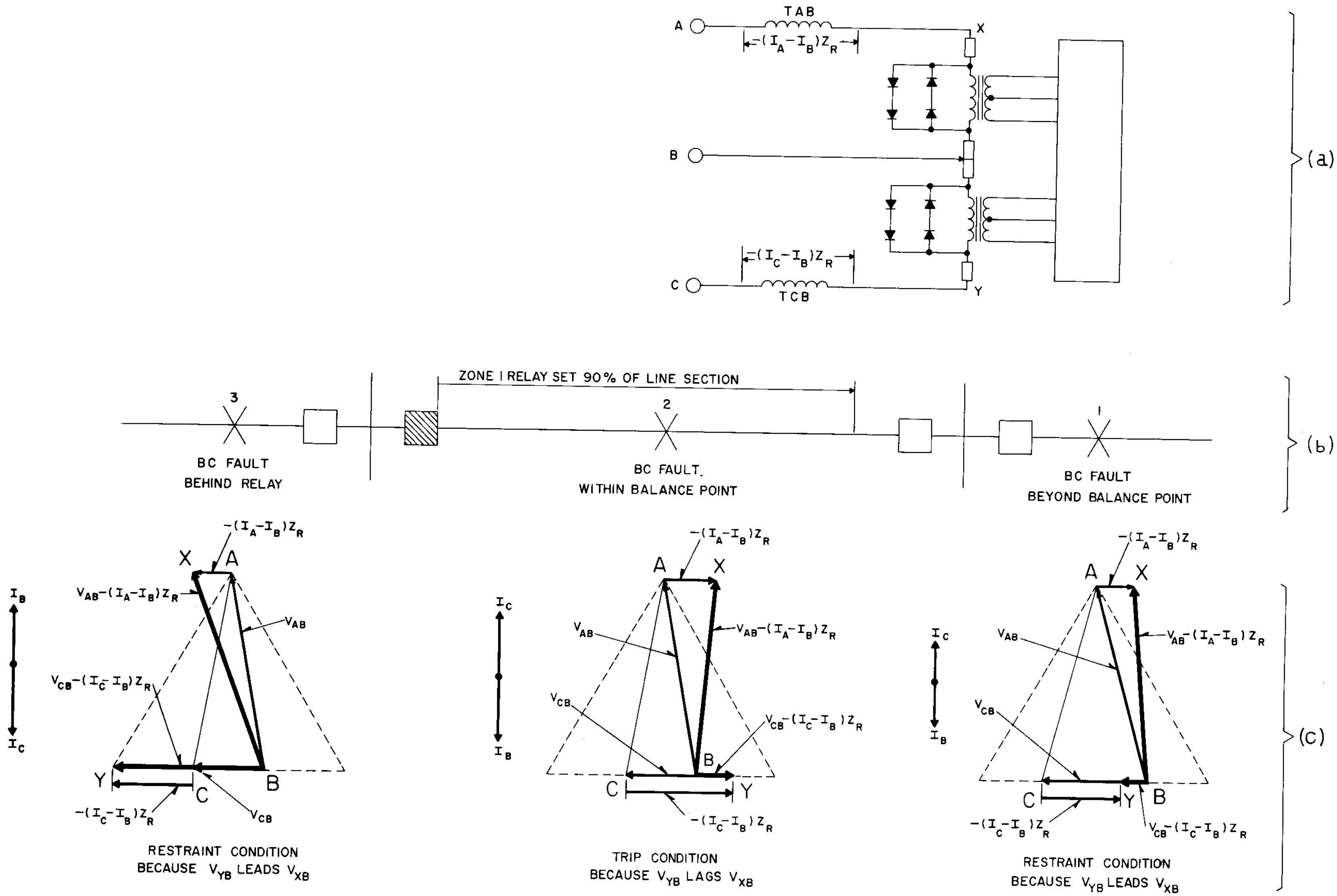


Fig. 13. Voltage and Current Conditions for the Three-Phase Unit.



hematic of *SP-1 Relay.*

543D774



410C512

Fig. 12. Voltage and Current Conditions for the Phase-to-Ph

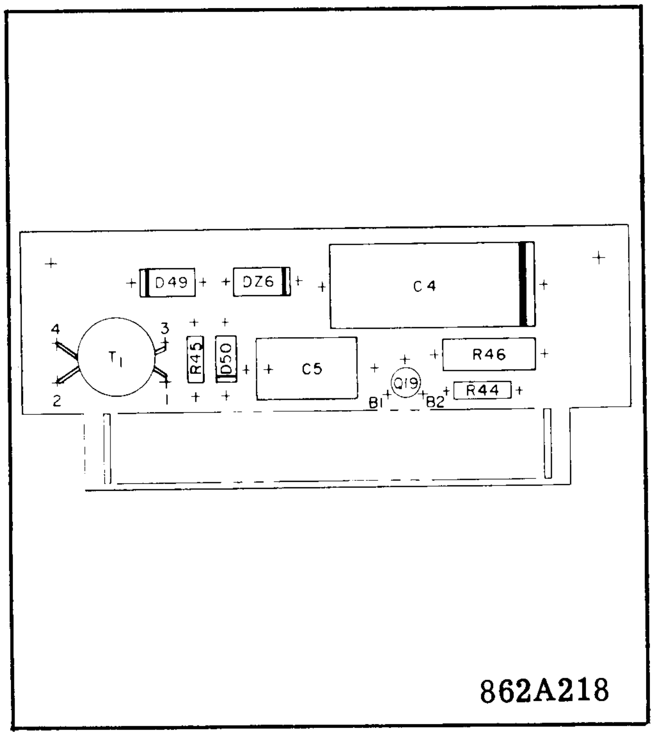


Fig. 14. Printed Circuit Board Trigger Circuit for SKD Relay.

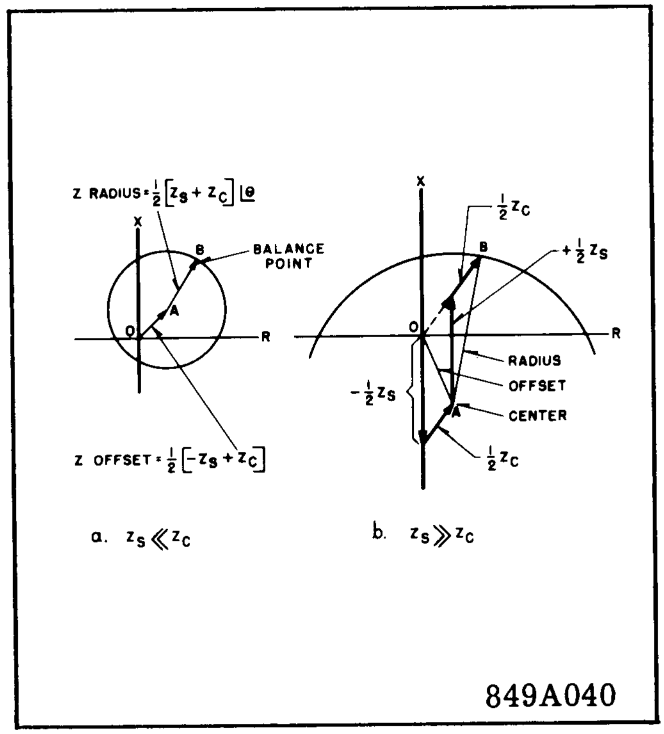


Fig. 15. Impedance Circles for Phase-to-Phase Unit in Types SKD, SP, and SP-1 Relays.

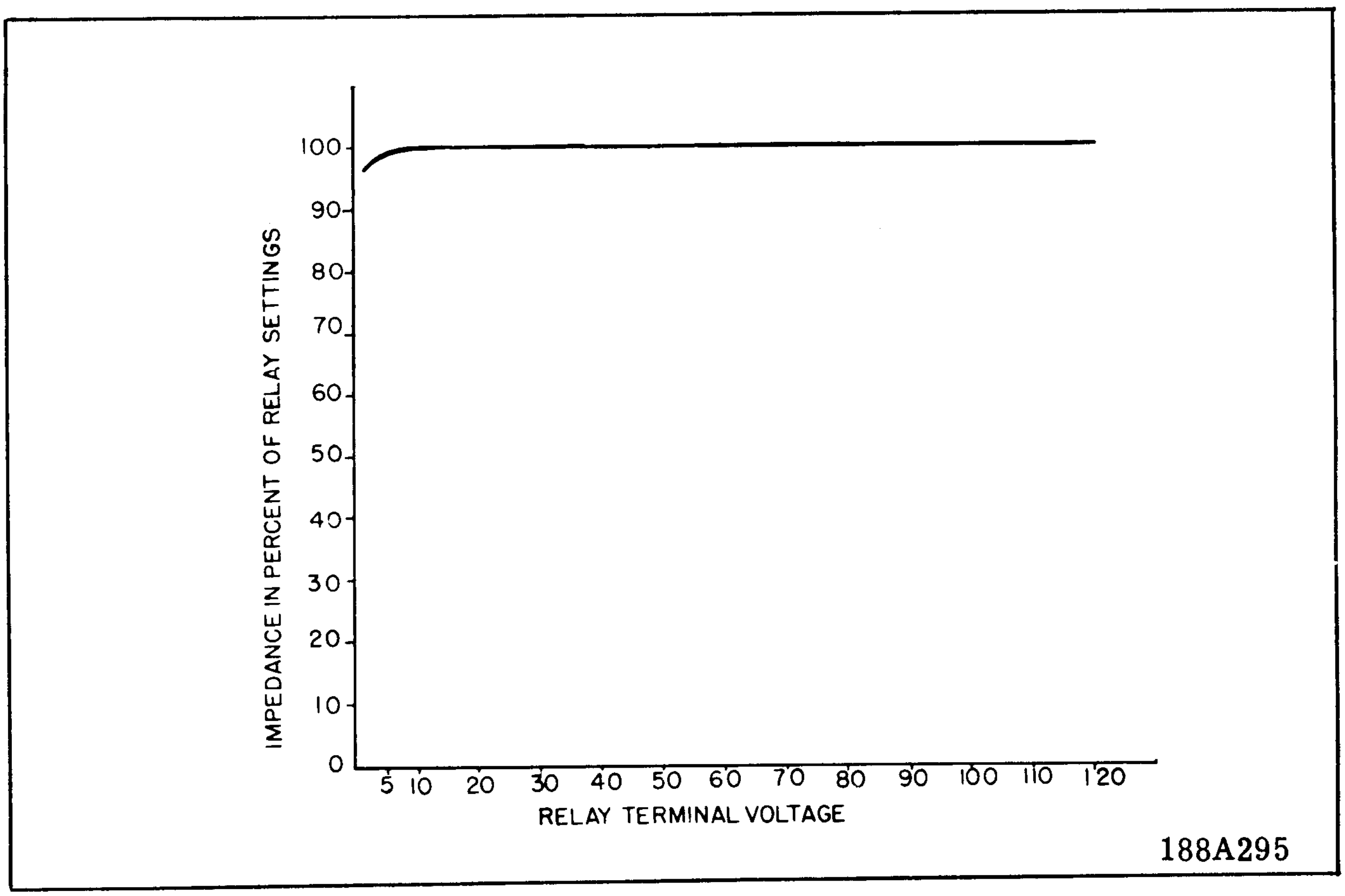


Fig. 16. Impedance Curves for Types SKD, SP, and SP-1 Relays.

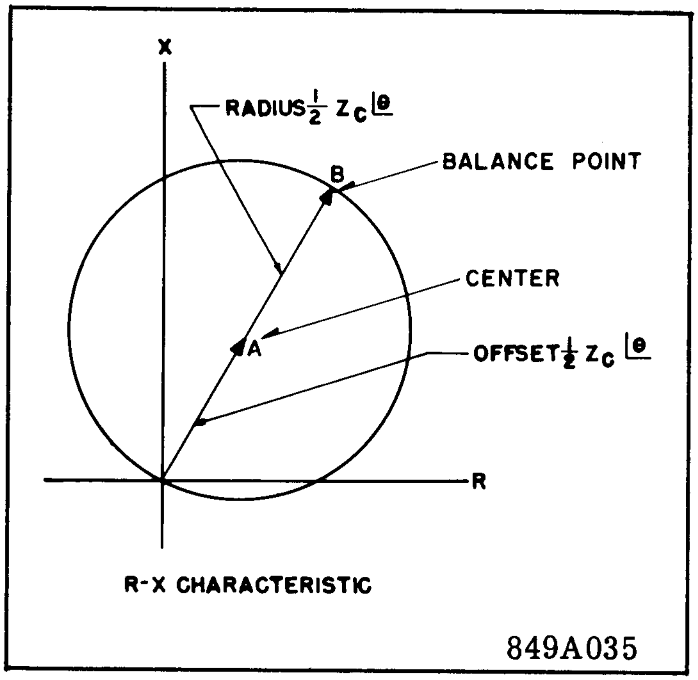


Fig. 17. Impedance Circle for Three-Phase Unit in Types SKD and SP Relays.

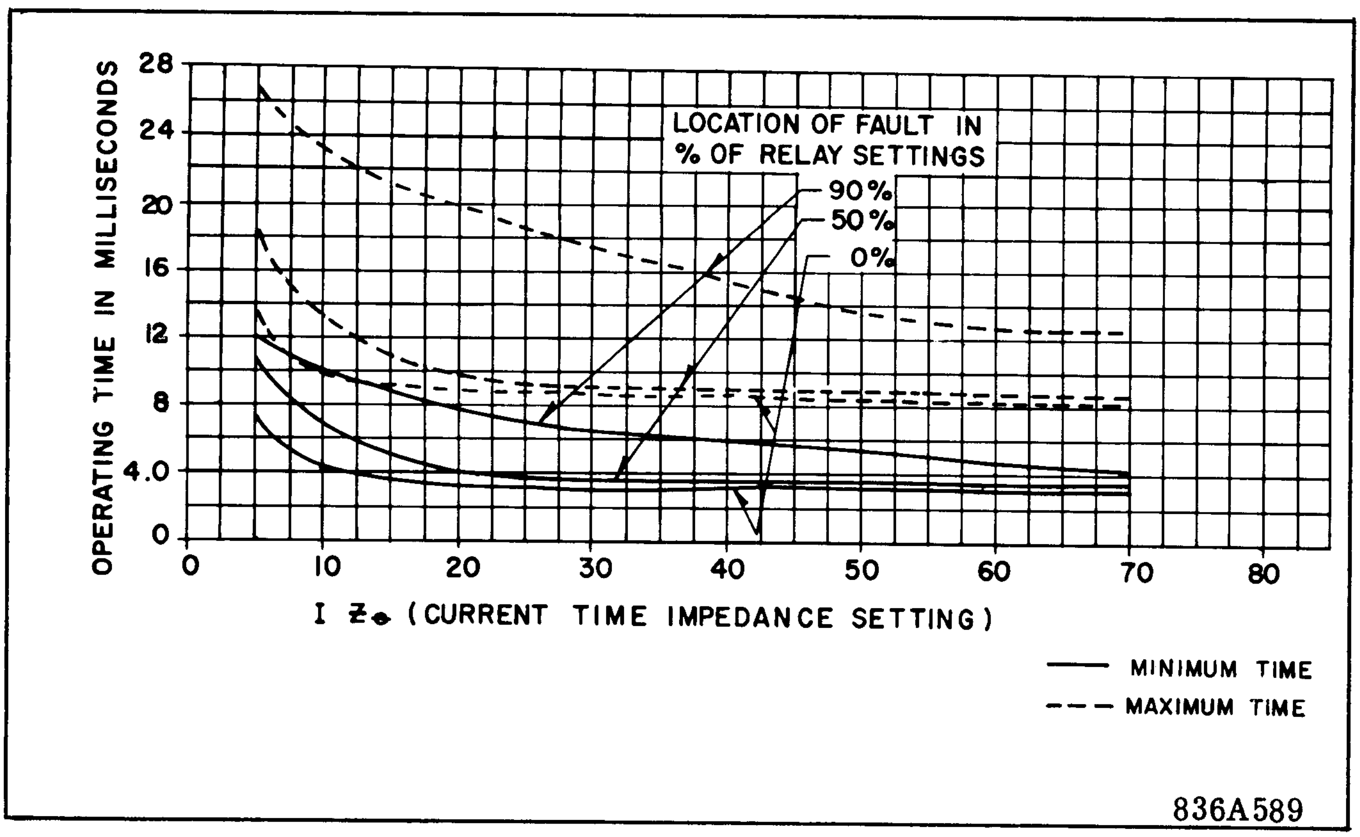


Fig. 18. Typical Operating Time Curves for SKD, SP, and SP-1 Relays. Normal Voltage Before the Fault is 120 Volts.

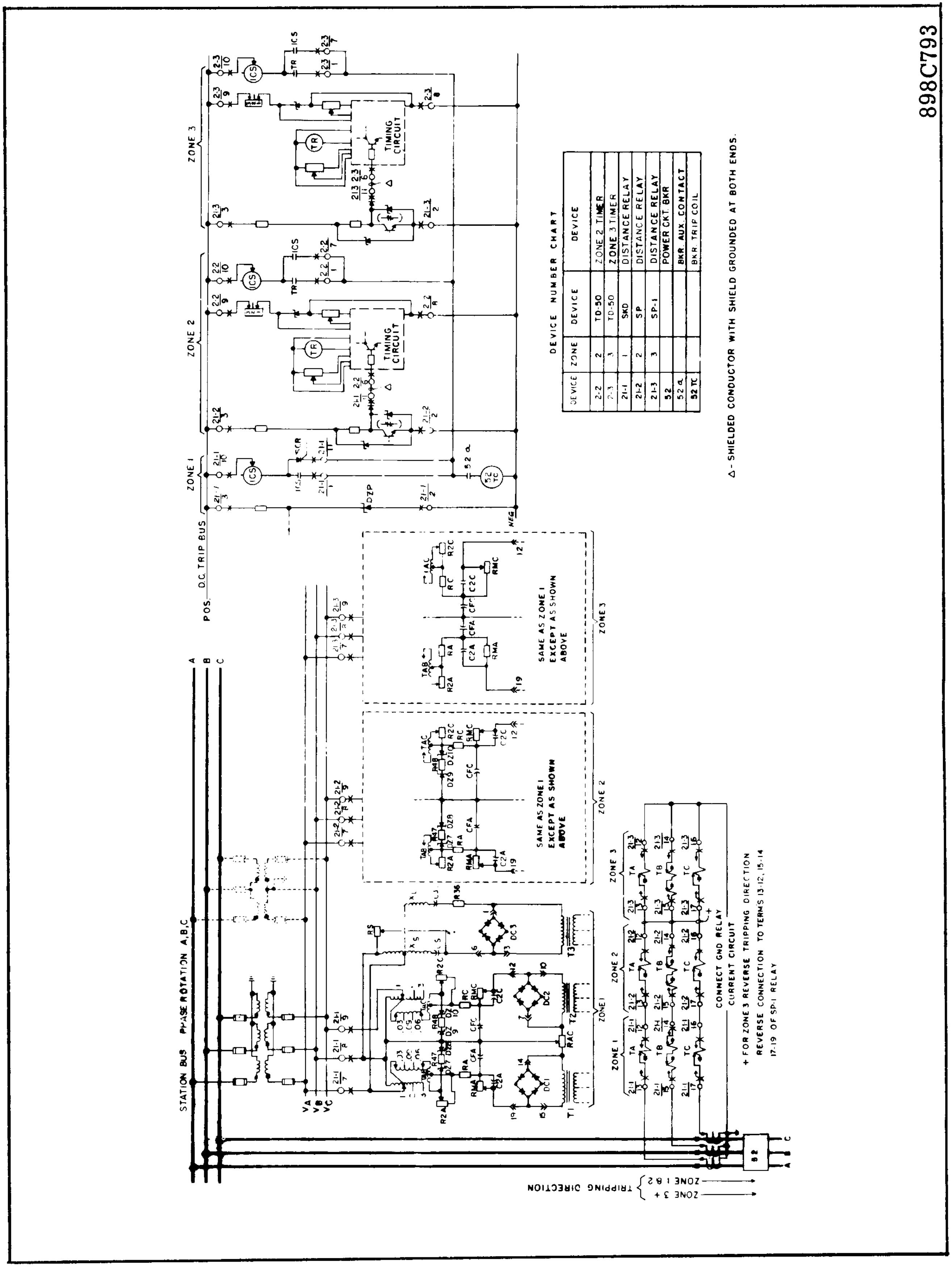
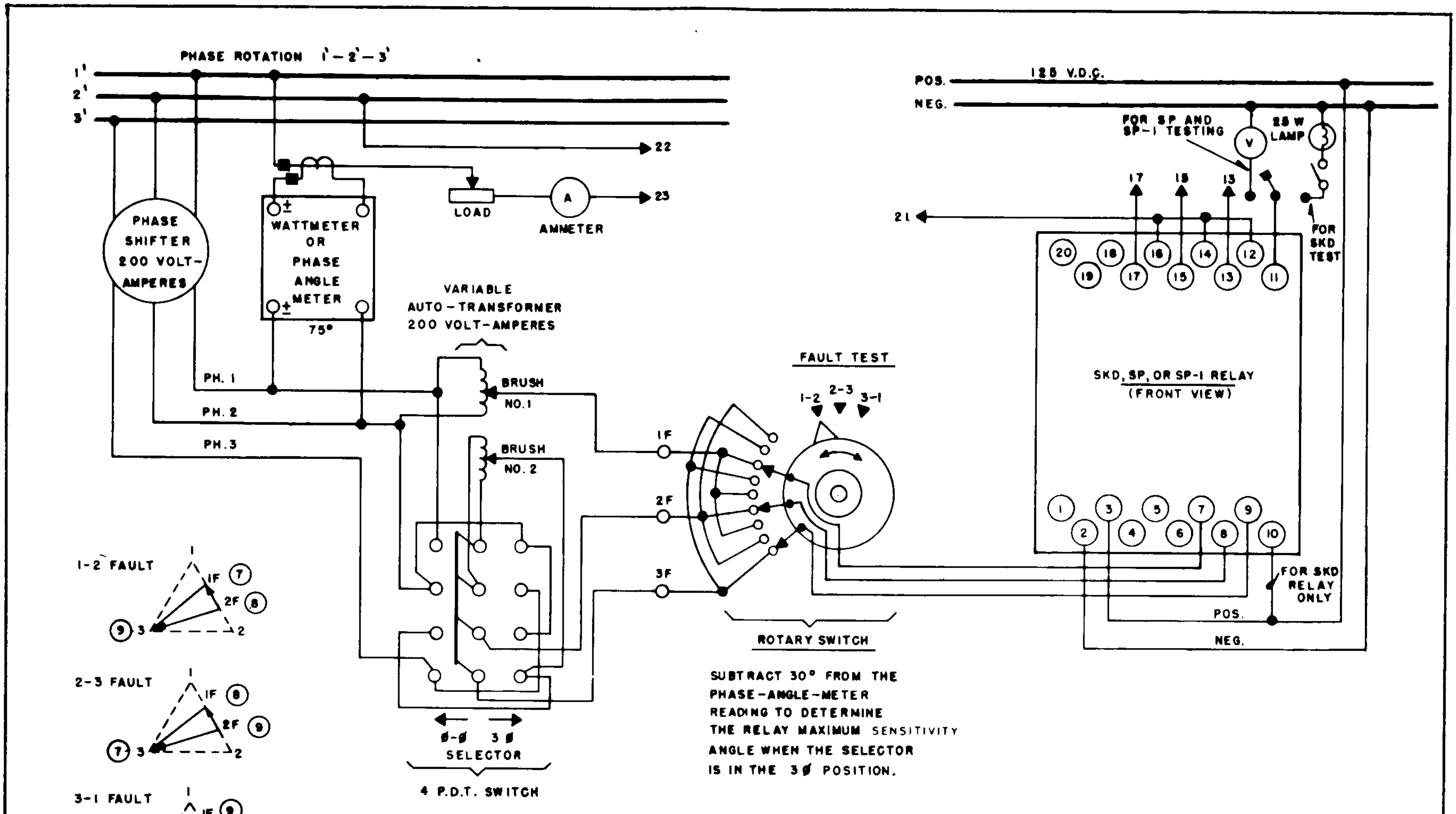


Fig. 19. External Schematic of Types SKD, SP, and SP-1 Relays.



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
2	3 Ø	1-2	R_{2A}	23/13	22/21
4	3 Ø	3-1	R_{2C}	23/17	22/21
5	Ø Ø	1-2	RS	23/13	22/15
6	Ø Ø	2-3	CHECK	23/15	22/17
7	Ø Ø	3-1	R_{MC} & R_{AC}	23/17	22/13

Fig. 20. Test Connections for Types SKD, SP, and SP-1 Relays.

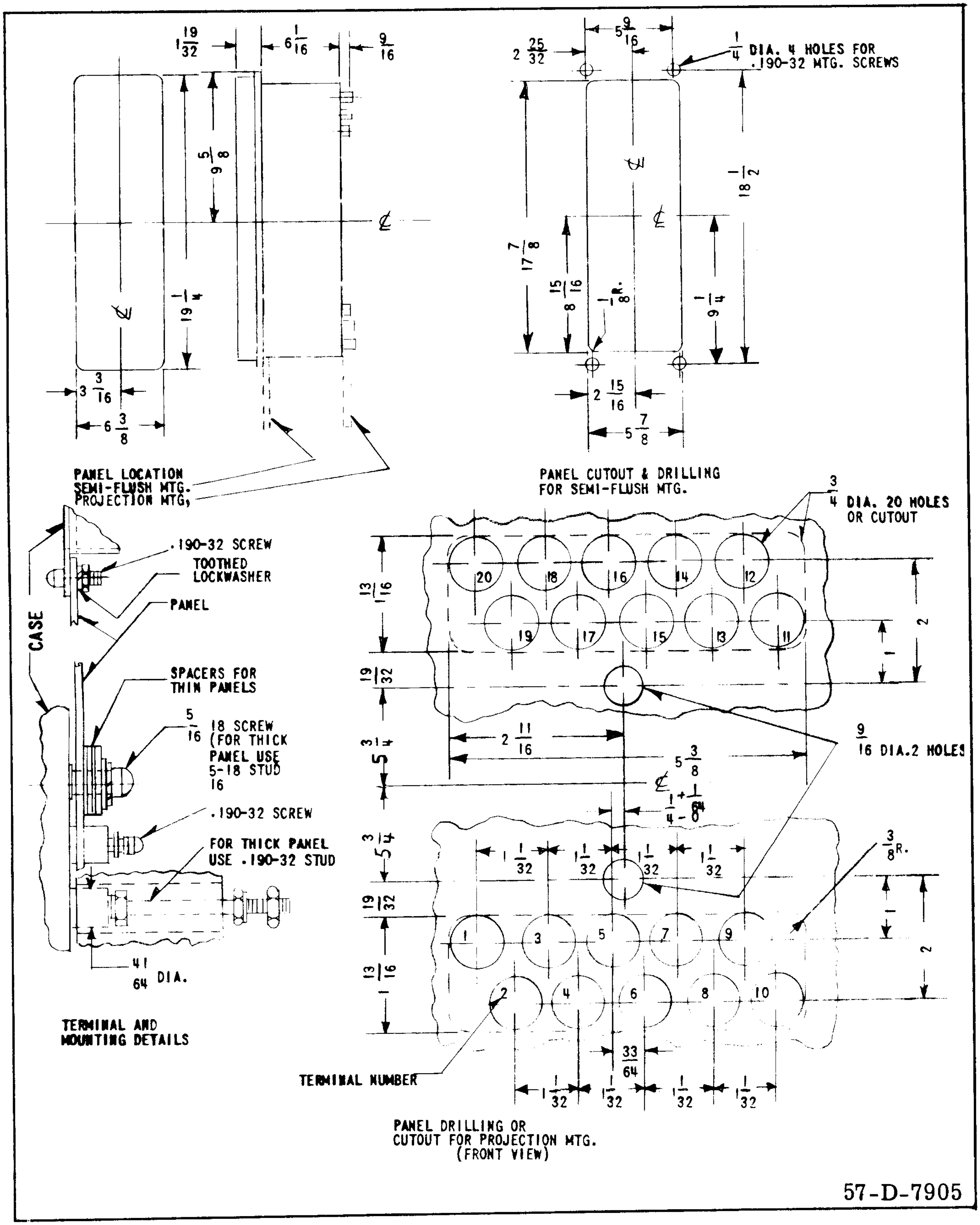


Fig. 21. Outline and Drilling Plan for Types SKD, SP, and SP-1 Relays in Type FT-42 Case.

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