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 contractor switch as an operation indicator. Operation indication for the SP and SP-1 relays must be accomplished by auxiliary means.

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. SP and SP-1 relays are also available with "AND" logic supervision. These relays also have an additional printed circuit assembly.

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 expand the basic range of T ohms by a multiplier of $\frac{S}{1 \pm M}$. 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 and 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 capacity reactance, C3C, which are series connected and are tuned very closely to sixty hertz. 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 hertz 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 preceded by a functional group number and 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 14a 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. Figure 14b is the "AND" logic assembly used in SP and SP-1 relays.

OPERATION

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

Two distinctly different logic systems are used in the SP 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}.

The three-phase unit can be blocked by external means to prevent tripping during load conditions or system swing conditions which enter the electrical trip zone. Blocking is accomplished in single-output relays by connecting relay terminal 4 to terminal 2 (battery negative) through contacts or through a conducting transistor. Open circuit voltage at terminal 4 is not greater than 20 volts. Short circuit current out of terminal 4 is not greater than 2.5 milliamperes.

To accomplish tripping through the supervised output, terminal 19, of dual-output relays, a positive voltage of 15 V dc to 20 V dc must be applied to relay terminal 18 with negative on terminal 2. Maximum current flow into terminal 18 at 20 V dc is 1.5 milliamperes. (48 V dc may be safely applied to terminal 18 continuously. Maximum current is 6 milliamperes.).

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 $(I_A I_B)$ 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 in single-output relays can be disabled by connecting relay terminal 4 to battery negative through a swing detection means. Dual-output relays will not trip at the supervised terminal unless a "permissive signal" at 20 Vdc is applied to terminal 18.

Phase Angle Comparison Unit

Referring to Figure 10b, the phase-angle comparison unit for the phase-to-phase unit trips when current flows into the base of transistor 5Q1 through zener diode 5Z1. Such tripping current must come from the 20V bus through either transistor 1Q2 or 1Q4 located in what might be called the "operate" circuit, driven by transformer T1, is continually trying to trip the unit by supply current through 1Q2 conducts when the polarity-marked terminal of T1 is positive.

When 1Q2 conducts, a portion of the current goes through resistor 2R9. This current, I_{2R9}, may take either of two paths to the negative bus. If 2QS1 is in a conducting state, I_{2R9} passes through it directly to the negative bus. If 2QS1 is in a blocking state, I_{2R9} passes through 2D16 and then through 5Z1 to transistor 5Q1 to cause tripping. Restraint thyristor 2QS1 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 2Q1 to conduct current through 2D4, 2R5 and 2D14 to drive the base of 2Q4. 2Q4 then conducts current from the 13V bus through 2R6 to drive the gate 2QS1 into conduction. When 2QS1 conducts, it short circuits the current which might otherwise pass through 2D16 to cause tripping. Once 2QS1 begins to conduct, the gate loses control and it remains in the conducting state until the current is turned off by 1Q2. 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 1Q3 and 1Q4 conduct in an attempt to cause tripping. In the polarizing circuit, 2Q2, 2Q5 and 2QS2 seek to prevent tripping by short circuiting the current which might otherwise pass through 2D1, 5Z1 and 5Q1.

Restraint Squelch: When the operate circuit transistor 1Q2 conducts, approximately 18V is applied through diode 2D15 to back bias 2D14 and prevent 2Q4 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 1Q2. This back-biasing connection is called the restraint squelch circuit.

Restraint-Signal Detection: If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch 2QS1 and short circuit the 1Q2 current. This, of course, could cause incorrect tripping. A signal detector circuit prevents this from happening. When a useful voltage level is supplied by T2, 2Q1 and 2Q2, alternately short circuit the current which flows through 2R3 from the 20V bus. When the voltage from T2 drops too low to drive 2Q1 and 2Q2, the 2R3 current flows through 2Z2 to switch 2Q3 into conduction. This in turn drives 2Q4 through 2D8, 2R5 and 2D14 causing 2Q4 to switch 2QS1 into conduction to short circuit 2D16 and prevent tripping.

The operate circuit, driven by T1, and the polariz-circuits, driven by T2 and T3, are duals having identical circuits which operate on alternate half cycles. The restraint squelch and the restraint-signal 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 3D16 and 3D1, through 5Z2 and to 5Q3. This polarizing circuit contains a restraint squelch and a restraint-signal detector identical to those described for the T2 circuit.

SP-1 Relay: The SP-1 relay 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 restraint-signal detector from the T3 circuit. This omission reduces the accuracy of the SP-1 relay at low-voltage test levels.

Voltage Detector: Operation of the phase-angle comparison unit is based upon a comparison of the phase relation between two amplified signals. If either the a-c input signal or the d-c amplifying voltage is absent, then no phase relation can be established. Therefore, at the instant either quantity is applied, the logic does not know whether it should trip or restrain since it has no prior knowledge of phase relations. The voltage detector sends a gating pulse from 4Q2 to all restraint thyristors 2QS1,2QS2, 3QS1 and 3QS2 to block tripping long enough for the true phase-angle relation between input signals to be established. After approximately one-half cycle, 4Q2 turns on to remove the gating signal until the relay is de-energized again.

The zener diode 4Q1 monitors the d-c voltage level. If the d-c voltage drops too low for the logic to operate properly, it will cause 4Q1 to turn off and thereby send a gate signal to the restraint thyristors. This will block tripping as long as the d-c voltage is at a level which would otherwise cause an incorrect operation.

Output Circuits

SP and SP-1 Relays: Two output combinations are available. Therefore, there is an option between a dual output (where the phase-to-phase unit is separate from the three-phase unit output) and a single output (where the two use a common output circuit). The dual-output circuit is required when the three-phase unit is supervised through "AND" logic.

The basic output circuit is identical for both the phase-to-phase and the three-phase units. Consider a trip signal from the restraint thyristors which which sends current through 5Z3, 5R7 and into the base of 5Q3. This will turn on 5Q4 to give an unsupervised output at terminal 11 for the three-phase unit.

For "AND" supervision, the three-phase output is fed into the "Out-of-Step Block" printed-circuit board through 6R1 and 6Z2 into the base of transistor 6Q2. This turns 6Q2 on to short circuit part of the base drive supplied to 6Q1. The rest of the current into 6Q1 base is supplied from 6Q5 which must also turn on before 6Q1 can turn off. This means that a signal of 12V d-c or more must be supplied to terminal 18. This will cause 6Q5 to turn on. When 6Q1 turns off, it drives the 6Q3 base which allows 6Q4 to turn on and produce an output at terminal 19. The removal of either the signal at terminal 18 or the signal from the three-phase unit will cause 6Q1 to turn on and block the output at terminal 19.

Each output should supply open-circuit voltage of 15.5V d-c to 20V d-c and is capable of supplying 10 mA each.

SKD Relay:

The output of the SKD relay is a Thyristor (controlled-rectifier) TCR which is gated into conduction by a pulse transformer. The transformer is pulsed when 5Q3 turns on causing 5Q4 to conduct into an oscillator consisting of capacitor 7C1, pulse transformer TP, and unijunction transistor 7Q1. 7Q1 switches into conduction when voltage across 7C1 reaches a predetermined level. It resets after capacitor 7C1 has discharged through TP to produce a gating pulse. 7C1 then charges up again to repeat the process.

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 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 hertz. 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:

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

TAP PLATE MARKINGS

	$(T_A, T_B, \text{and } T_C)$						
.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 (TCR)

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 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:

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

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

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.
Output resistance	150 ohms
Rated output current	10 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°).

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

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:

$Z\theta$ = the ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees.

$Z = \frac{TS}{1 + M}$ = the tap plate setting 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:

A. Establish the value of $Z\theta$, as above.

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

$$Z = Z\theta\,\frac{\text{Sine } 75^\circ}{\text{Sine } \theta^\circ}$$

When θ = 75°, $Z = Z\theta$.

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

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

D. 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.

E. 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_O for a .73-21 ohm relay is 7 ohms at 60°. (Step (A).

Step (B). 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:

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

Step (C). 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 (D). 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 (E). Recheck Settings:

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

$$Z \angle 60^\circ = Z \frac{\text{Sine } 60^\circ}{\text{Sine } 75^\circ} = 7.88 \times .896 + 7.06$$

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 TB 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.

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 equivalent AC voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equivalent 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 of single-output relays 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 of single-output relays by connecting Test Point 2TP4 and Test Point 2TP9 to Printed Circuit Board Terminal 9. 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 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. $\angle -75^\circ$ 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. $\angle +105^\circ$ 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	TA (TERM'S 13-12)			TB (TERM'S 15-14)			TC (TERM'S 17-16)		
.73-21 OHM RANGE	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	3.14		-.15	.03	.06	"R" OVER "L"
	—	—	—	—	—	—	10.6	—	21.2	—	31.8		-.18	0	.06	"R" OVER "L"

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) 1.98-2.1 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 apprixímately 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 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 of 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.

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 Sine θ

    θ = the desired maximum sensitivity angle

    T = Compensator tap setting

    $10.35 = \text{a design constant} = \frac{10}{\text{sine } 75^\circ}$

		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 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:

$$\frac{\text{Sine } 75^\circ}{\text{Sine } \theta}$$

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

CFA, CFC	1. MFD	1876999
CS	0.45 MFD	1723408
C2A, C2C	1.8 MFD	14C9400H12
C3C	0.3 MFD	1724191
C4C	0.03 MFD	1725974
1C1	18 MFD	187A508H10
4C1	0.25 MFD	187A624H02
5C1	0.12 MFD	837A241H02
5C4	0.27 MFD	188A699H05

	SKD		SP		SP-1
5C2	—		0.015 MFD	187A624H10	Same
5C3, 6C2	—		0.27 MFD	188A699H05	Same
6C1, 6C3	—		0.047 MFD	849A437H04	Same
7C1	0.25 MFD	187A624H02	—		—
7C2	2 MFD	184A662H07	—		—

Diodes

SKD, SP, & SP-1 COMMON PARTS

All Blocking Diodes	CER69	188A342H06
DZP	1N2984B (20V)	762A631H01
2Z1, 5Z2	1N752A (5.6V)	186A797H12
2Z2, 4Z1	1N758 (10V)	186A797H01

	SKD		SP		SP-1
Z1 to Z4	1N2846A (200V)	184A854H08	Same	Same	—
2Z3, 3Z3	—		1N758 (10V)	186A797H01	Same
3Z2	1N758 (10V)	186A797H01	Same	Same	—
5Z1	1N758 (10V)	186A797H01	1N752A (5.6V)	186A797H12	1N752A
5Z3, 5Z4, 6Z3	—		1N3688A (24V)	863A288H01	Same
6D2	—		1N645A	Blocking Diode	Same
6Z1, 6Z4	—		1N3686B (20V)	185A212H06	Same
6Z2, 6Z5	—		1N957B (6.8V)	186A797H06	Same
7Z1	1R200 (200V)	629A369H01	—		—

Transistors

SKD, SP, & SP-1 COMMON PARTS

1Q1, 1Q3, 2Q1, 2Q2, 3Q1, 3Q2, 4Q2	2N3391	848A851H01
1Q2, 1Q4, 2Q4, 2Q5, 3Q4, 3Q5	2N1132	184A638H20
2Q3	2N679	184A638H18
5Q2	2N3645	849A441H01
5Q3	2N3417	848A851H02

	SKD		SP		SP-1
3Q3	2N679	184A638H18	Same	Same	—
5Q1, 6Q1, 6Q2, 6Q3, 6Q5	—		2N3417	848A851H02	Same
5Q4, 6Q4	—		2N3645	849A441H01	Same
7Q1	2N2647	629A435H01	—		—

TABLE VII – Continued

Resistors

SKD, SP, & SP-1 COMMON PARTS

RA, RC, RMA	1.8 KΩ	1201004
RS	10 KΩ	1730906
RAC	3550 Ω	1955270
RDC (125 VDC)	1500 Ω	1267293
RDC (48 VDC)	400 Ω	1202587
RMC	2500 Ω	05D1328H22
R3C	3 KΩ	1202954
1R1, 1R2, 2R1, 2R2, 3R1, 3R2, 4R4, 4R5	100 KΩ	184A763H75
1R3, 1R5	1 MEG Ω	184A763H99
1R4, 1R6, 2R5, 2R8, 3R5, 3R8, 2R13, 2R14, 3R13, 3R14	8.2 KΩ	184A763H49
2R3	33 KΩ	184A763H63
2R4, 3R4	22 KΩ	184A763H59
2R6, 2R10, 3R6, 3R10	2.7 KΩ	629A531H42
2R7, 2R9, 2R11, 2R12, 3R7, 3R9, 3R11, 3R12, 4R1	2.7 KΩ	184A763H37
4R2	18 KΩ	184A763H57
4R3, 4R6	27 KΩ	184A763H61
4R7	5.6 KΩ	184A763H45
5R6	56 KΩ	184A763H69
5R8	10 KΩ	629A531H56
5R9	6.8 KΩ	629A531H52

	SKD		SP		SP-1
RDC (For Dual Output Relays)		–	350 Ω	644B260H22	Same
RDC2 (For Dual Output Relays)		–	710 Ω	1267284	Same
R1, R2	500 Ω	763A129H03	Same	Same	–
3R3	33 KΩ	184A763H63	Same	Same	–
5R1, 5R2,		–	56 KΩ	184A763H69	Same
5R3		–	10 KΩ	629A531H56	Same
5R4, 6R12, 6R34, 6R35, 6R46		–	6.8 KΩ	629A531H52	Same
5R5, 6R3, 6R18		–	82 KΩ	629A531H78	Same
5R7	10 KΩ	184A763H51	56 KΩ	184A763H69	56KΩ
5R10	4.7 KΩ	184A763H43	82 KΩ	629A531H78	82KΩ
5R11, 5R12, 6R15		–	150 Ω	762A679H01	Same
6R1, 6R2, 6R17, 6R68		–	4.7 KΩ	629A531H48	Same
6R4, 6R7, 6R10, 6R13, 6R14, 6R19		–	10 KΩ	629A531H56	Same
6R5, 6R8, 6R20		–	27 KΩ	629A531H66	Same
7R1	12 KΩ	187A641H53		–	–
7R2	470 Ω	187A644H19		–	–
7R3	680 Ω	187A641H23		–	–

Thyristor

SKD, SP, & SP-1 COMMON PARTS

2QS1, 2QS2, 3QS1, 3QS2	2N884	185A517H05
TCR (SKD Relay Only)	Tripping Unit. 2N1850A 184A614H05, 500V, 60 Amperes – 80 ms Surge, 6.5 Amperes Continuous.	

Transformers & Reactors

SKD, SP, & SP-1 COMMON PARTS

SA, SC	Auto-Transformer Primary (Taps: 1, 2, 3)
T1, T2, T3	292B563G05 Coupling Transformers
TP	629A37H01 Pulse Transformer (SKD Only)
XL	Memory Circuit Reactor
XS	Center Tapped Auto-Transformer For Phase Shift Circuit.

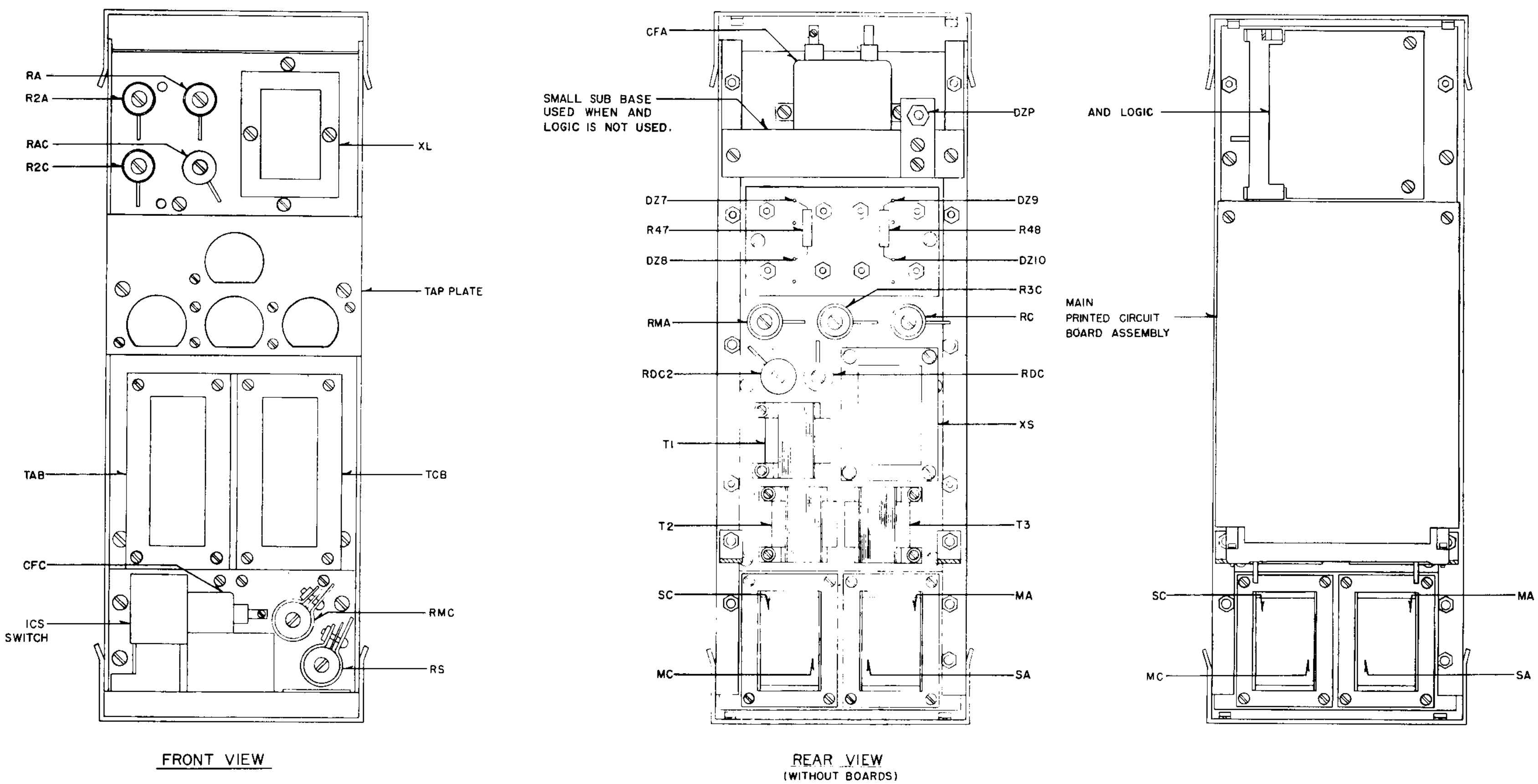

Fig. 1. Type SKD Relay Without Case.

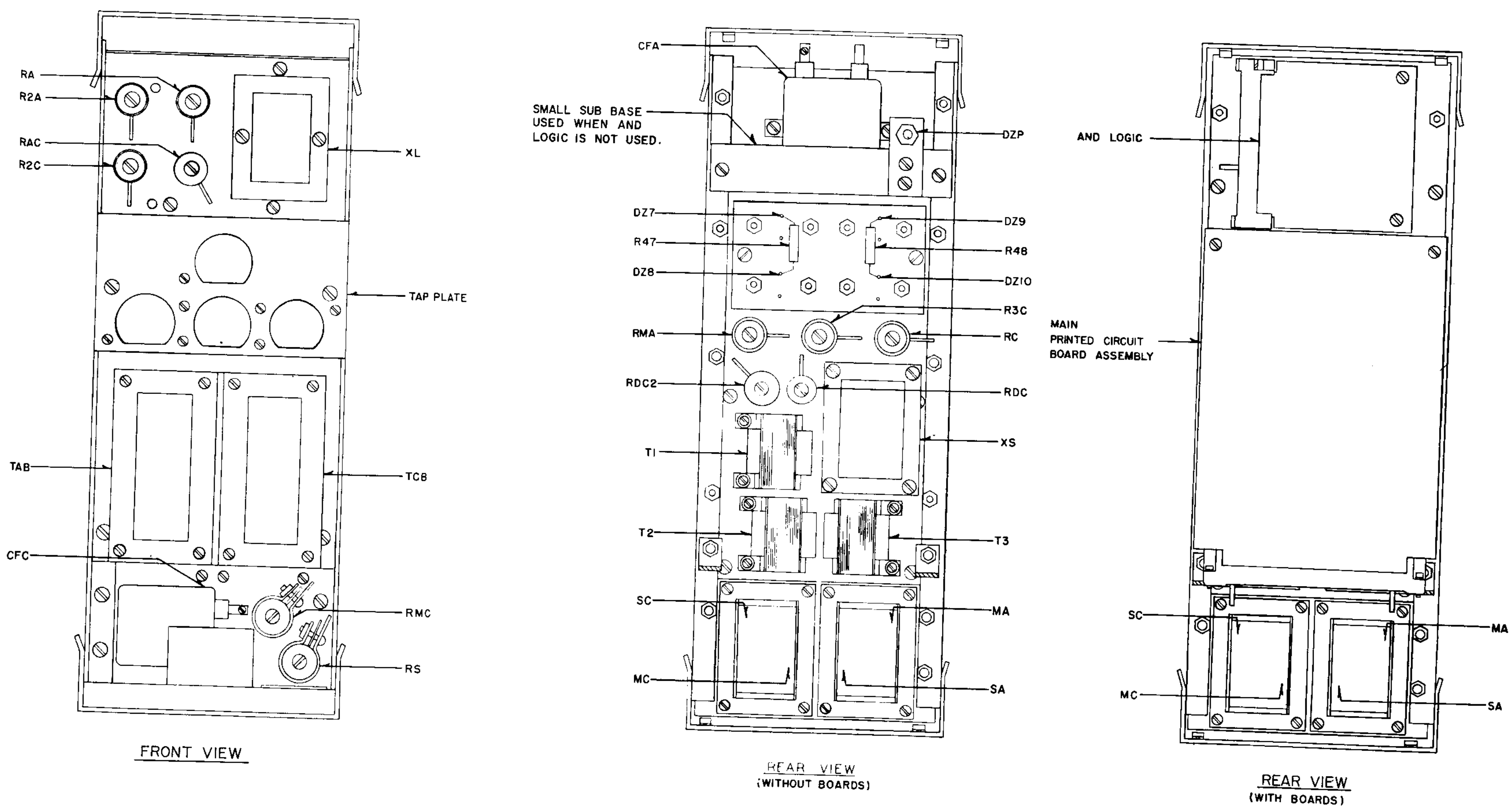

Fig. 2. Type SP Relay Without Case.

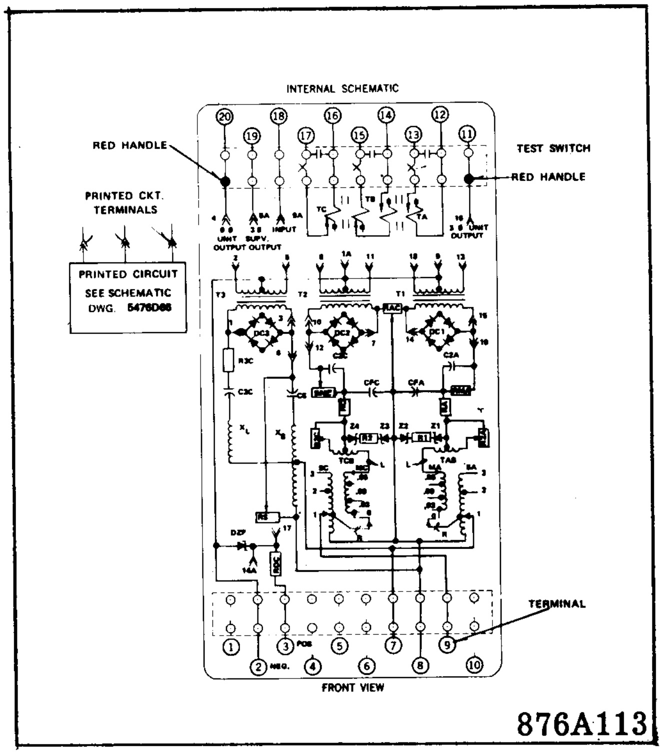

Fig. 6b. Internal Schematic of Type SP Relay with Dual Output and AND Logic in FT-42 Case.

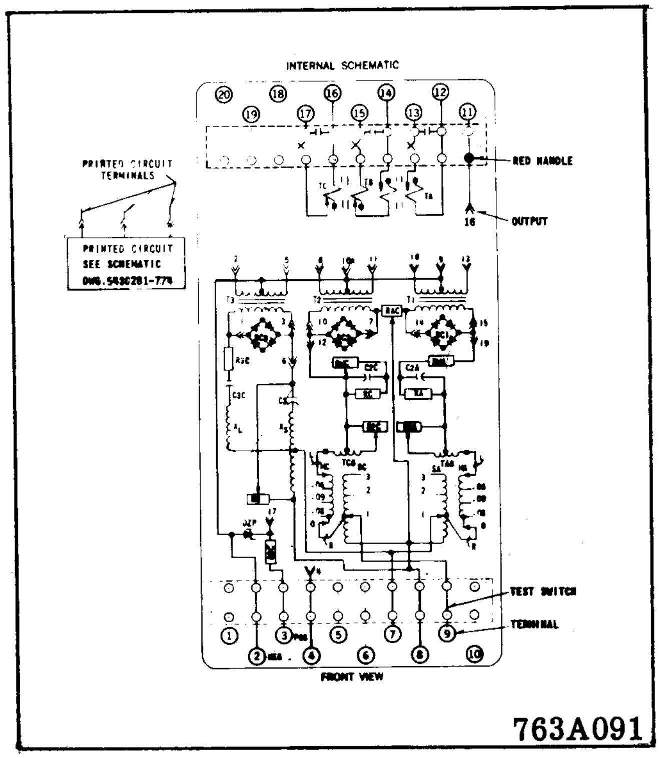

Fig. 7a. Internal Schematic of Type SP-1 Relay in Type FT-42 Case.

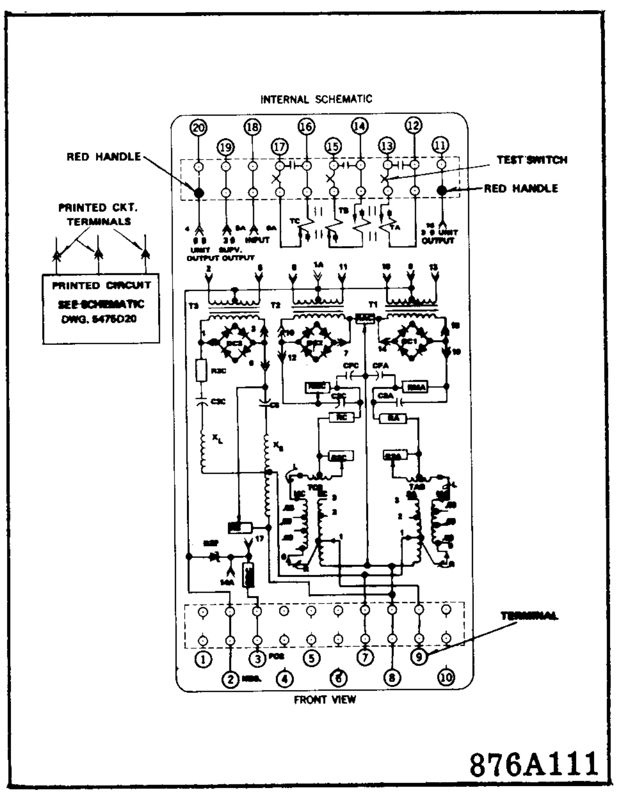

Fig. 7b. Internal Schematic of Type SP-1 Relay with Dual Output and AND Logic in Type FT-42 Case.

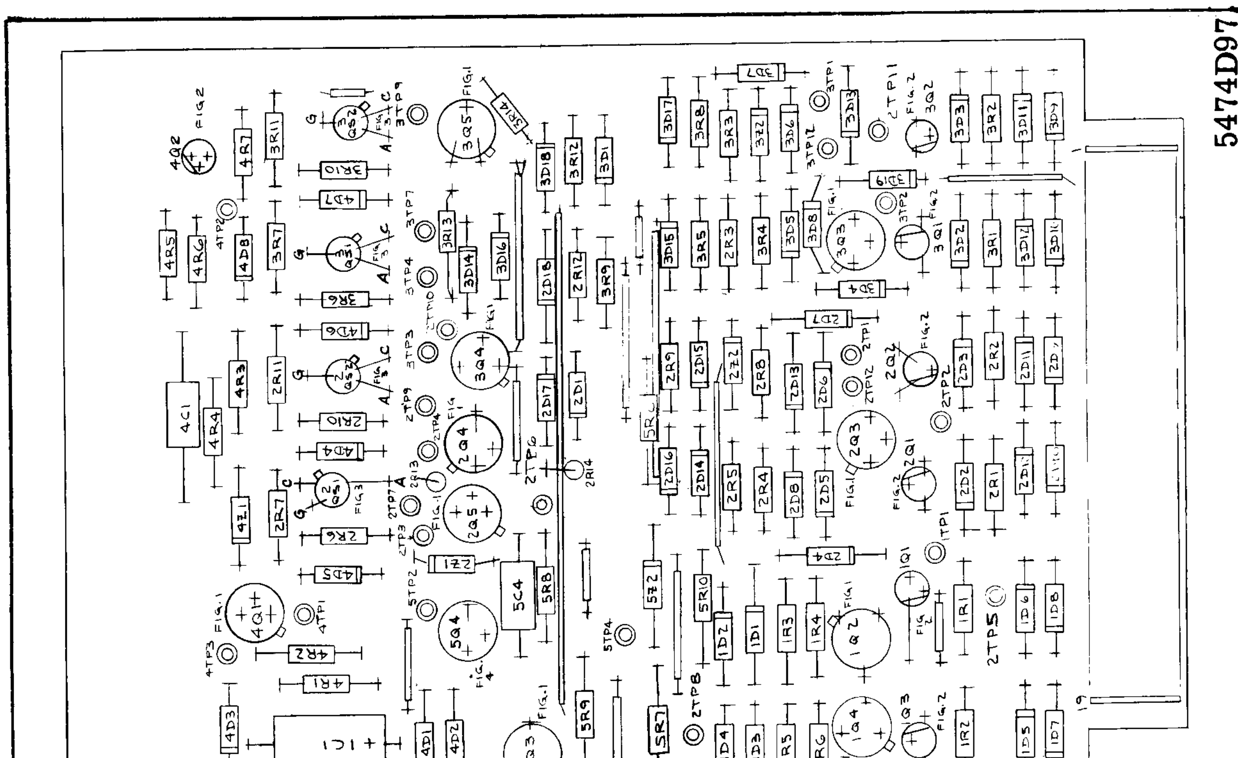

Fig. 8a. Main Printed Circuit Board Assembly for Type SKD Relay.

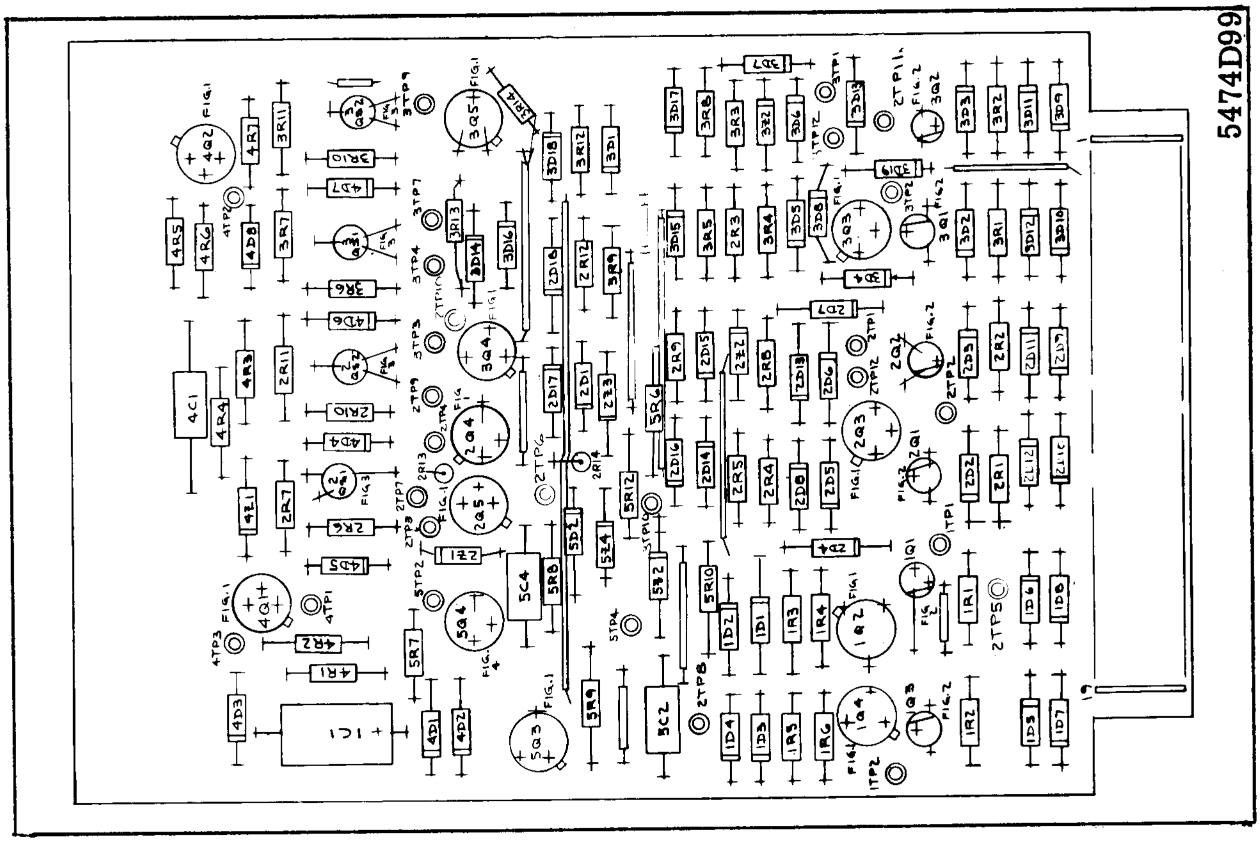

Fig. 8b. Printed Circuit Board Assembly for Type SP Relay with Single Output.

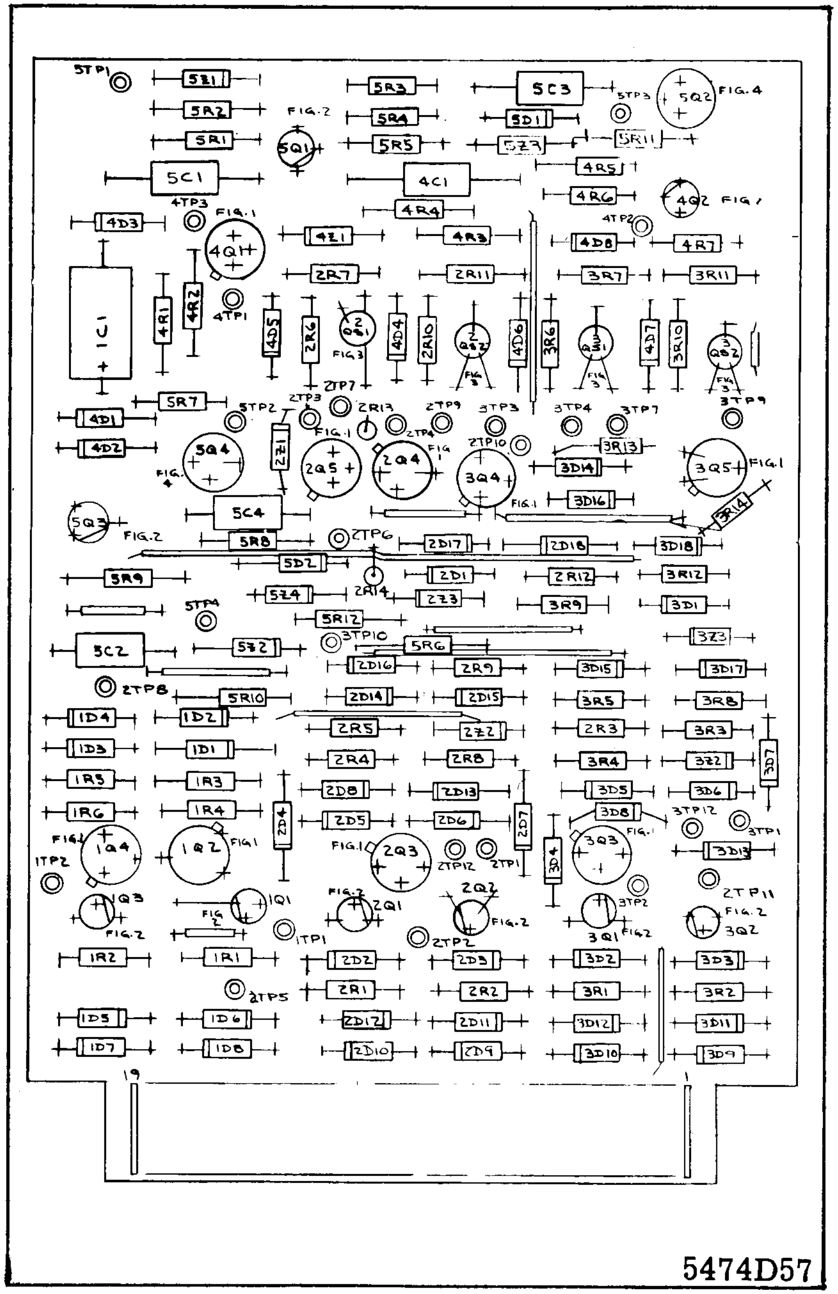

Fig. 8c. Printed Circuit Board Assembly for Type SP Relay with "AND" Supervised Dual Output.

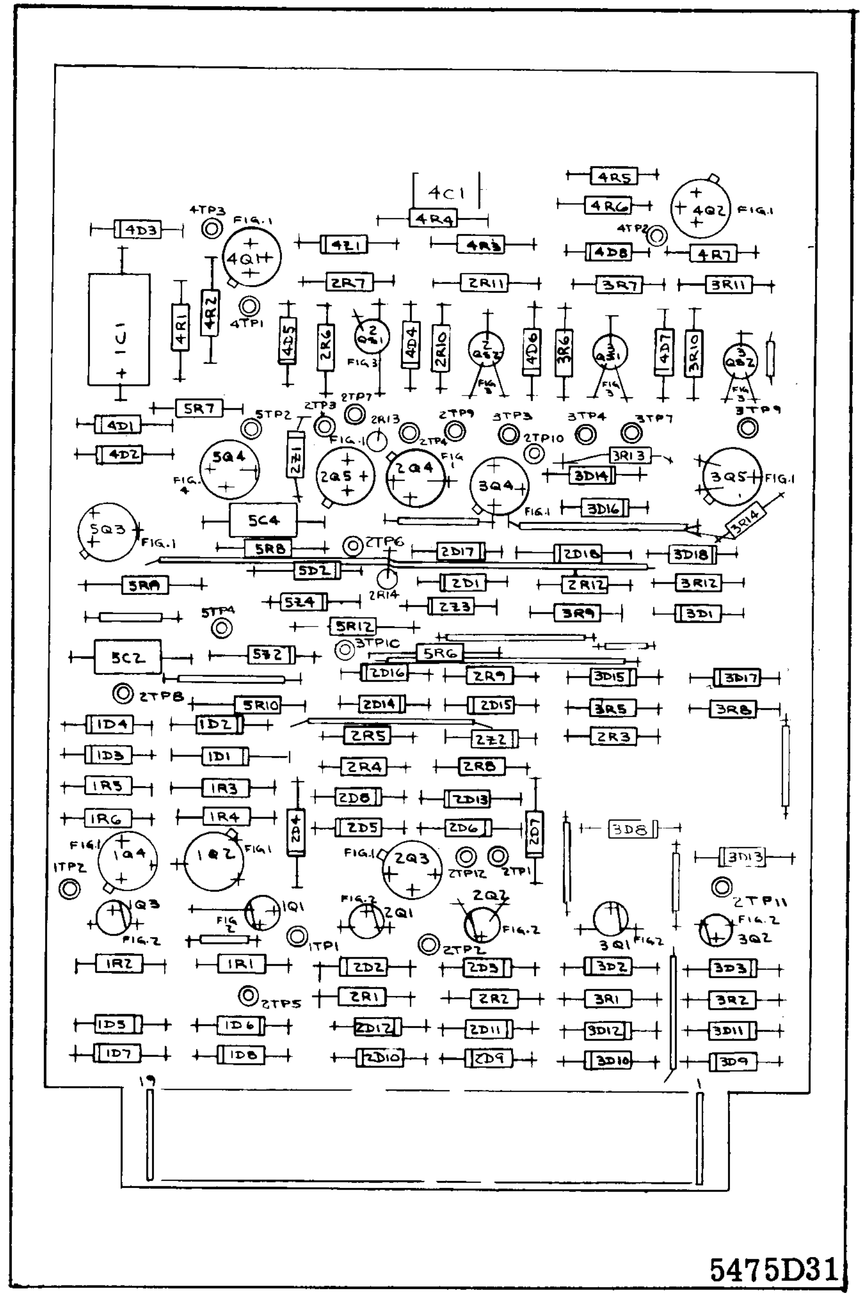

Fig. 8d. Printed Circuit Board Assembly for Type SP-1 Relay with Single Output.

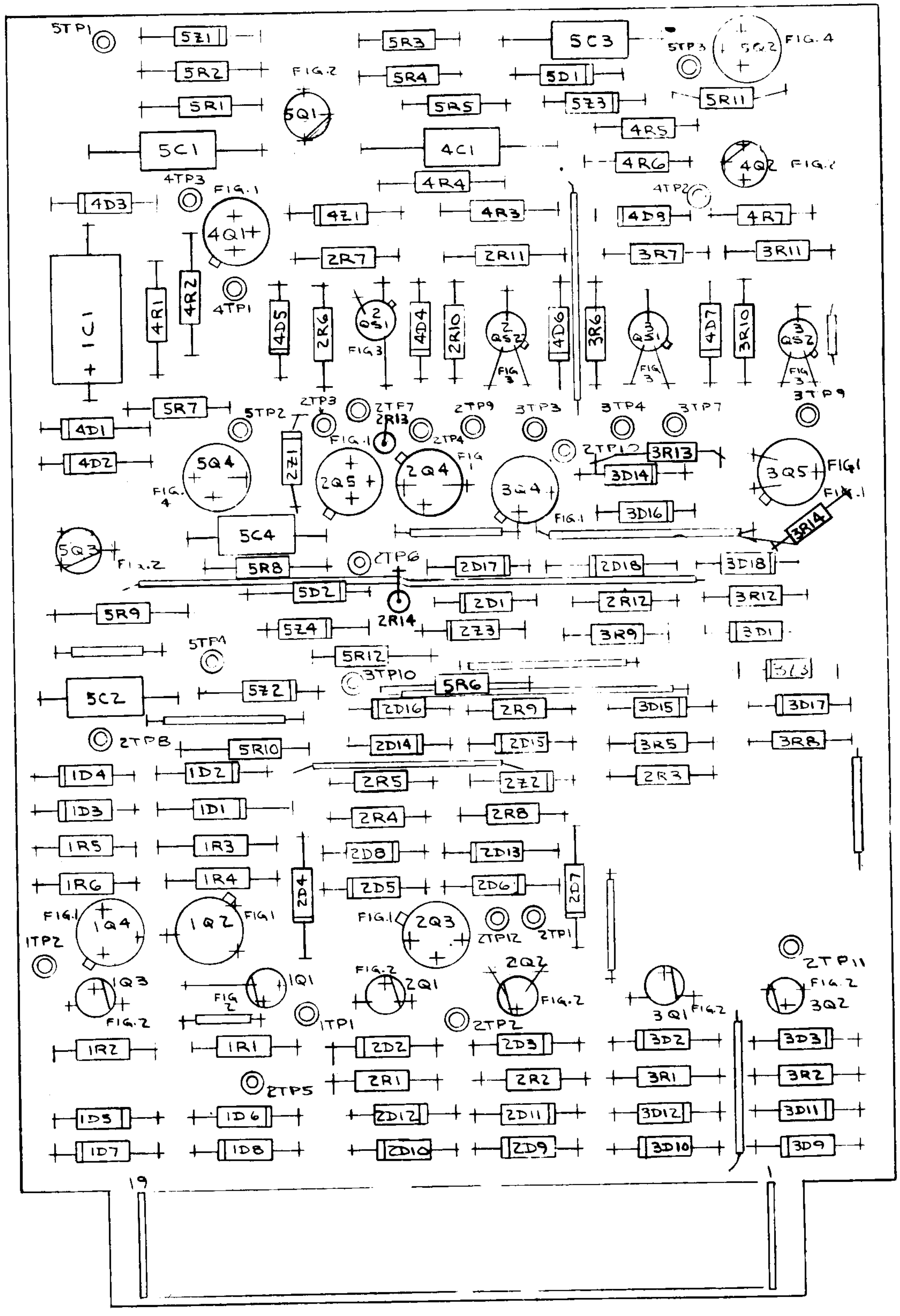

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Fig. 8e. Printed Circuit Board Assembly for Type SP-1 Relay with "AND" Supervised Dual Output.

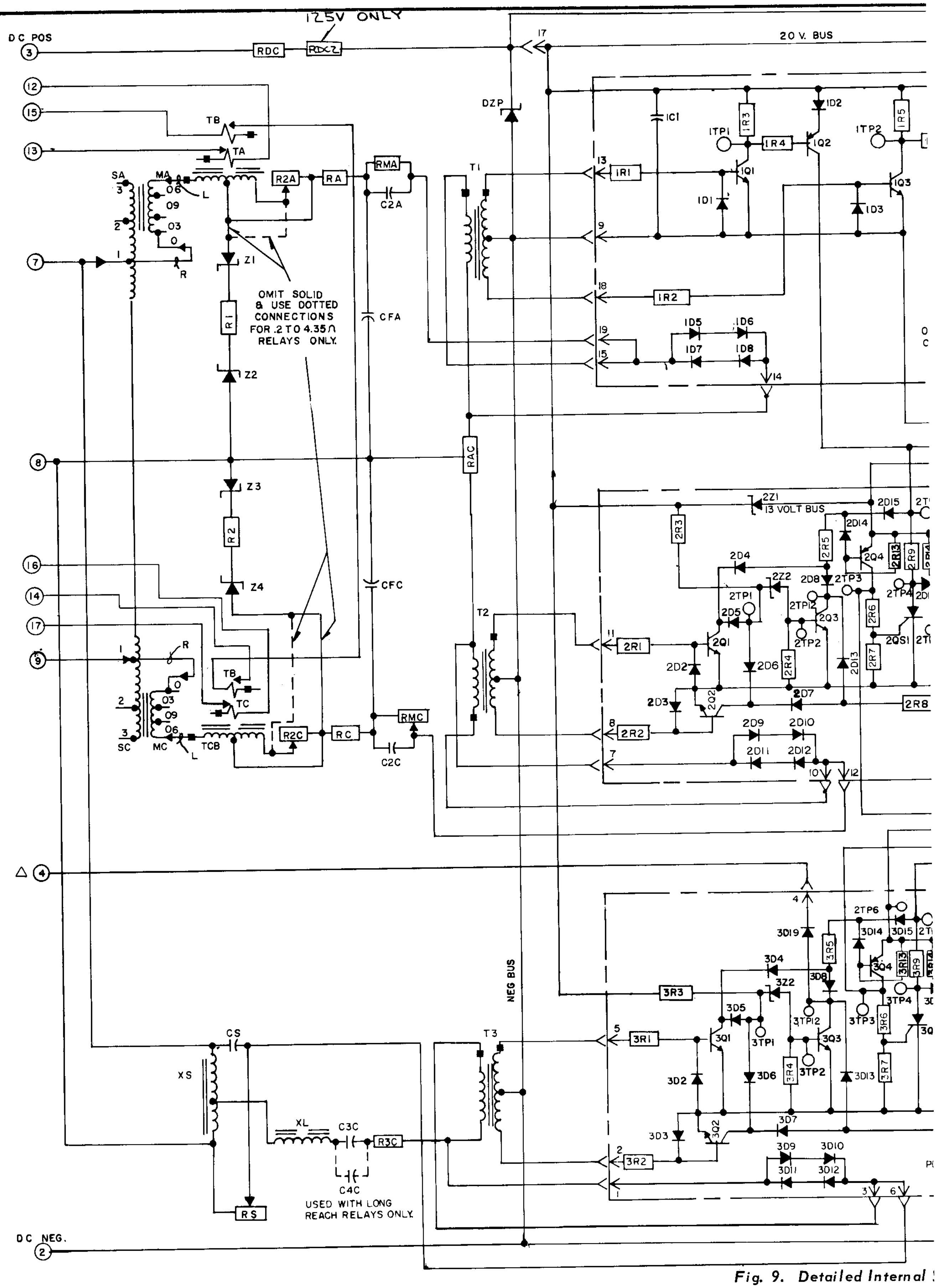
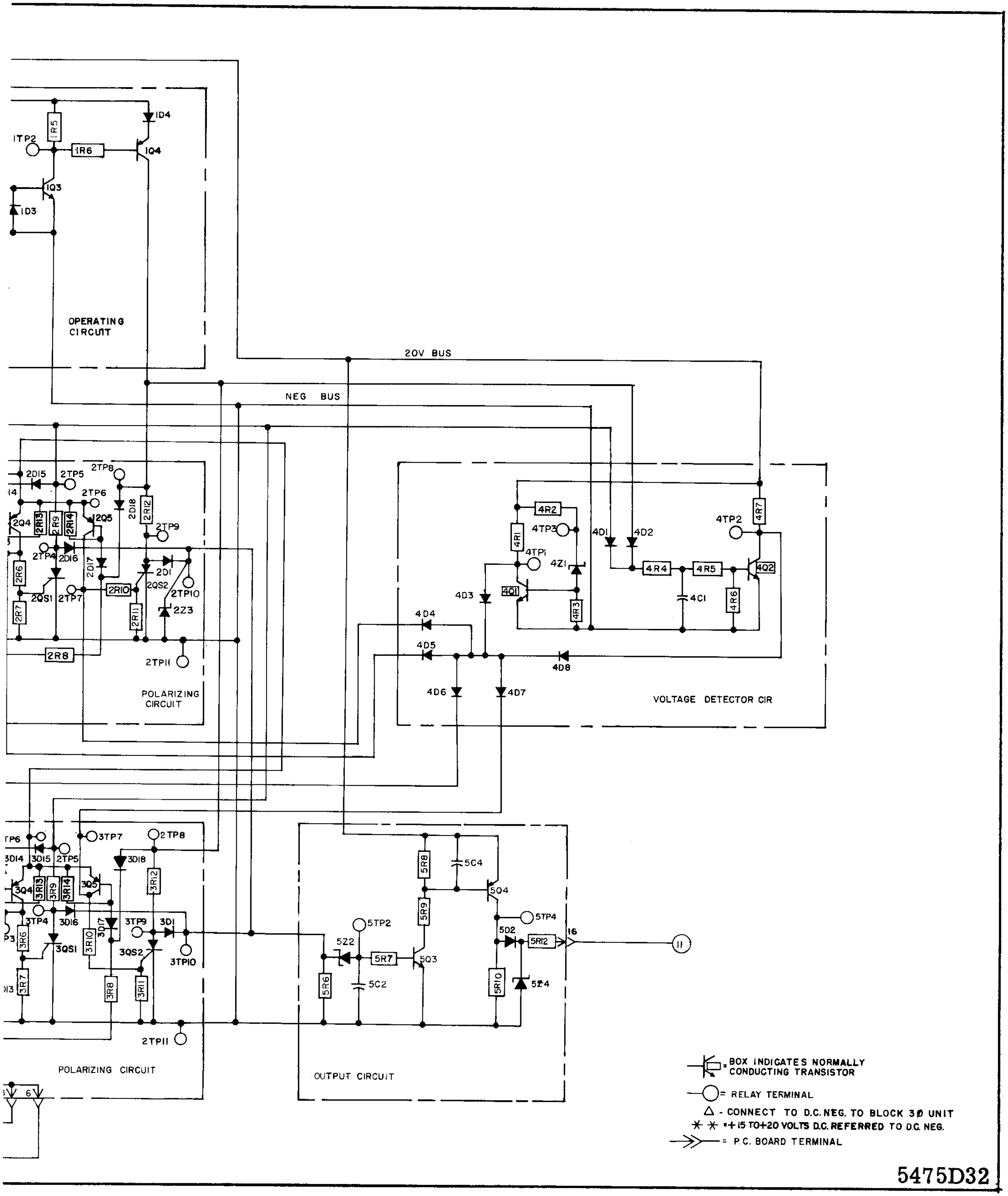
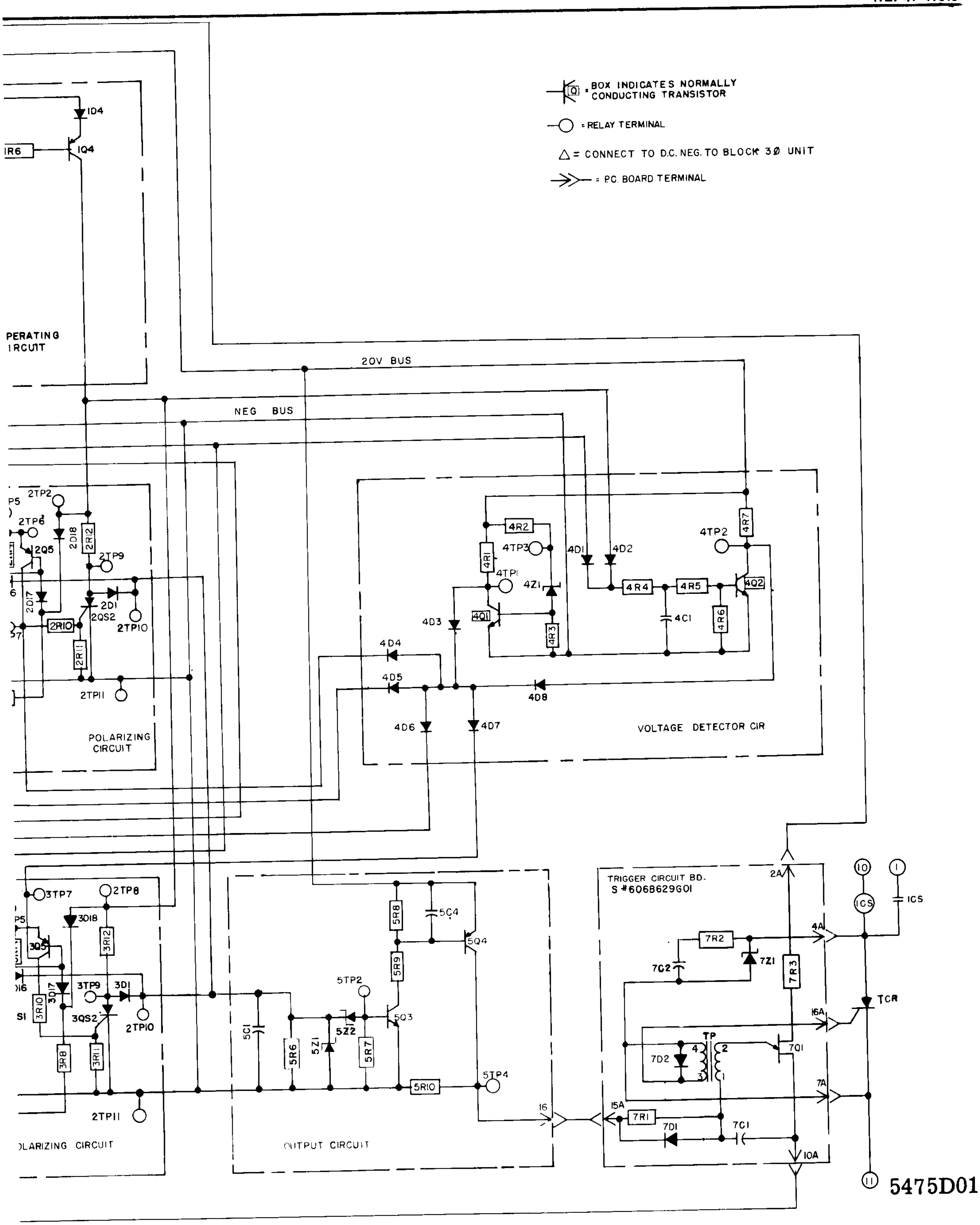


Fig. 9. Detailed Internal



rnal Schematic of SP Relay.



Schematic of SKD Relay.

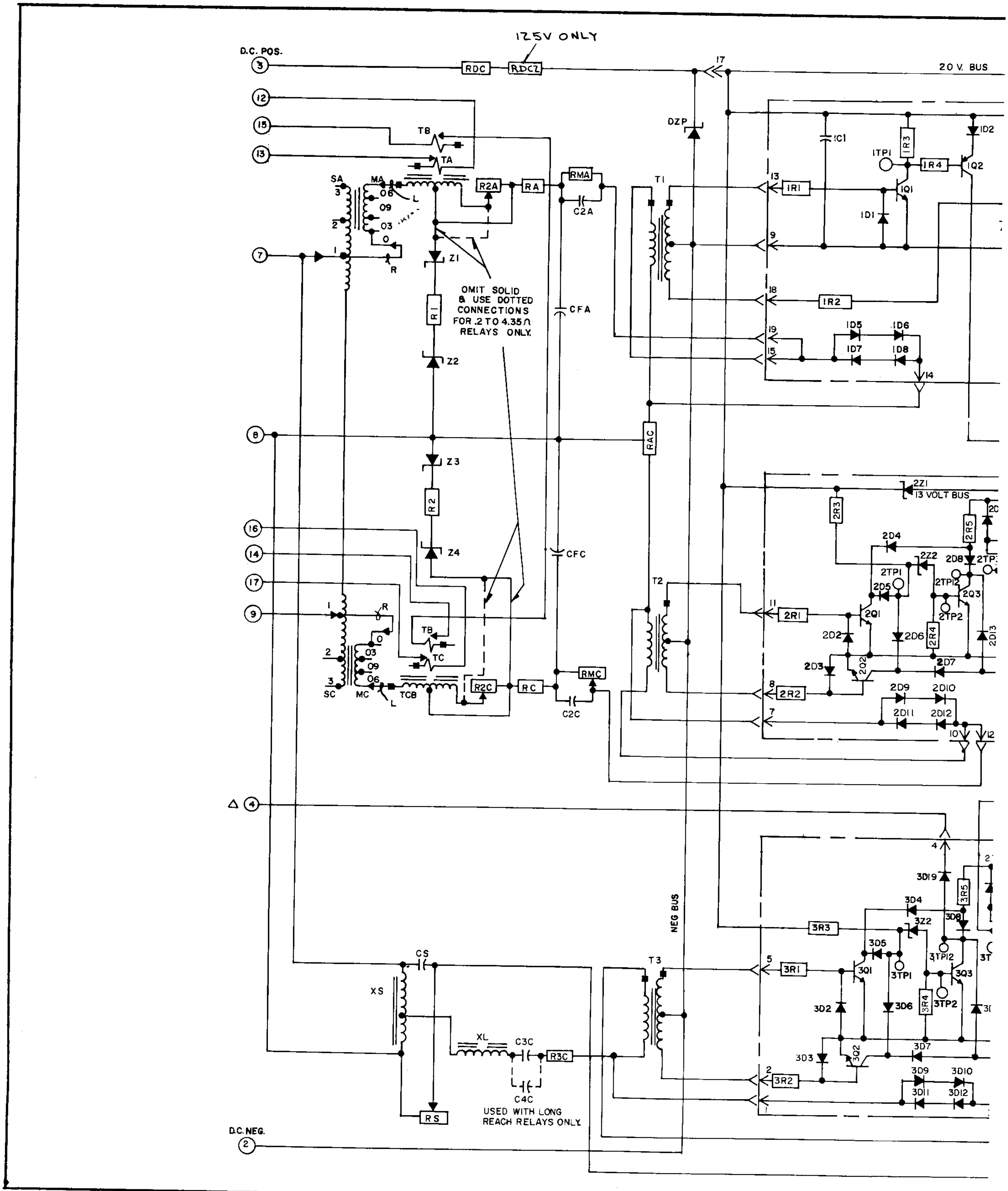


Fig. 10a. Detailed Inte

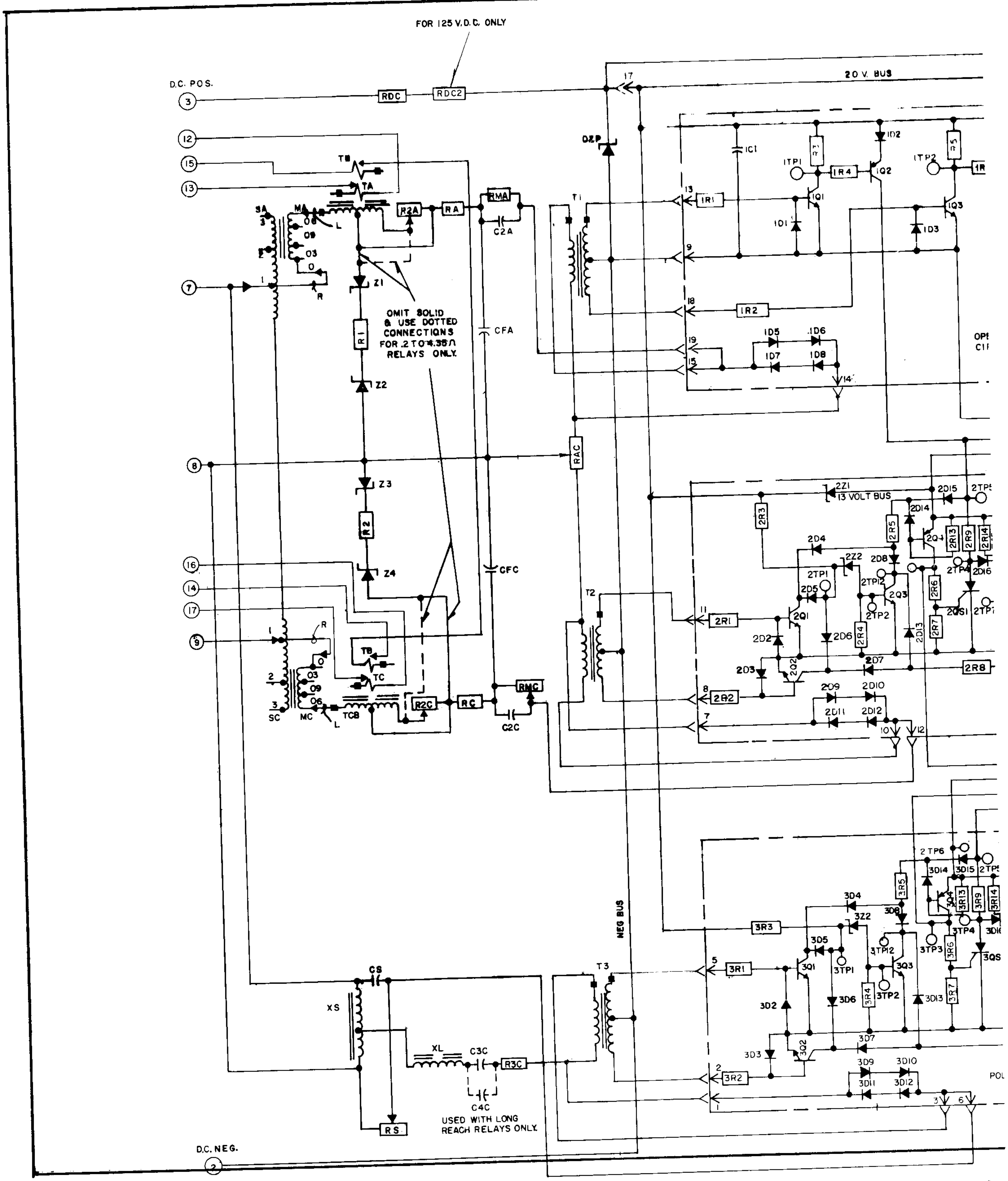
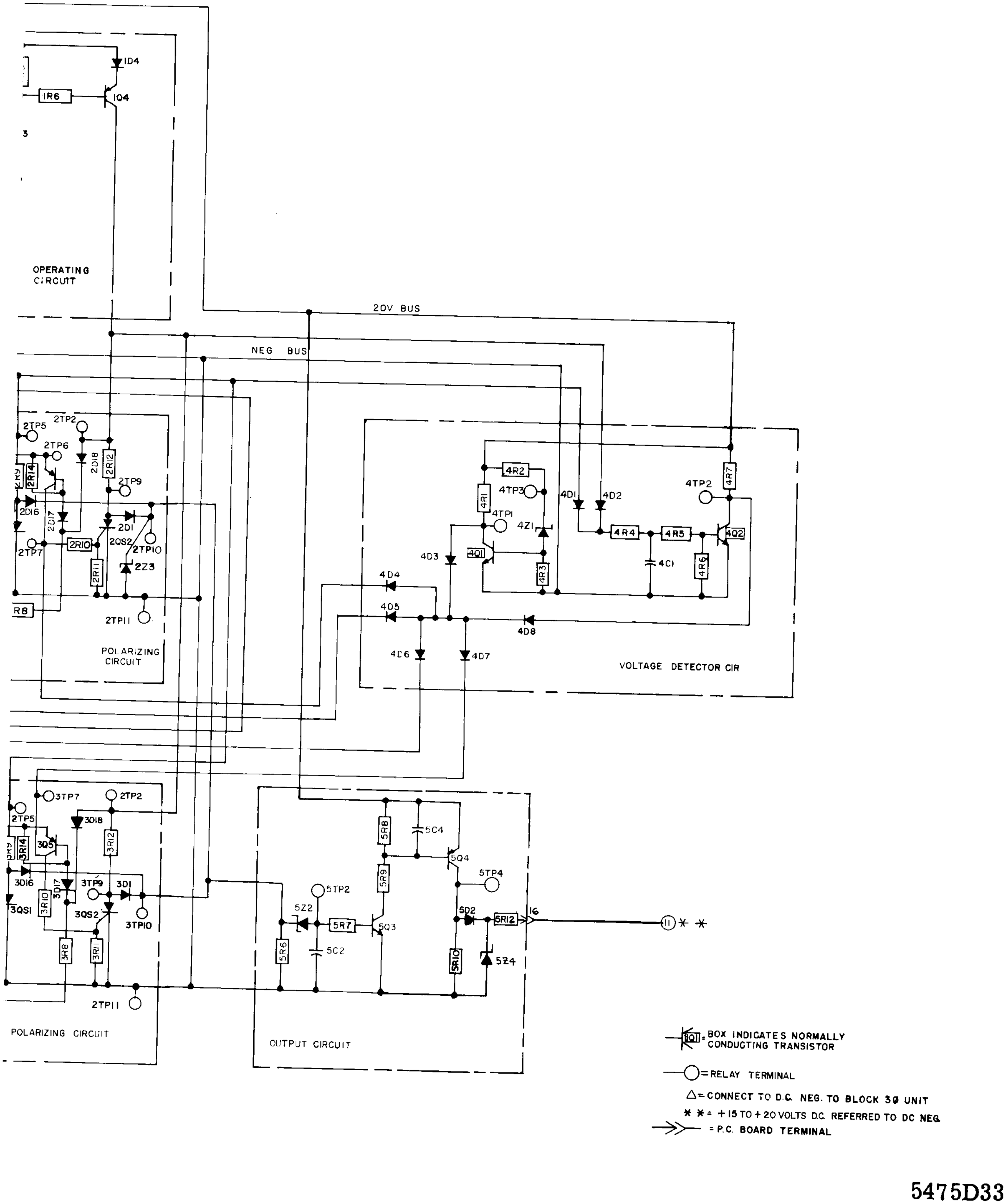
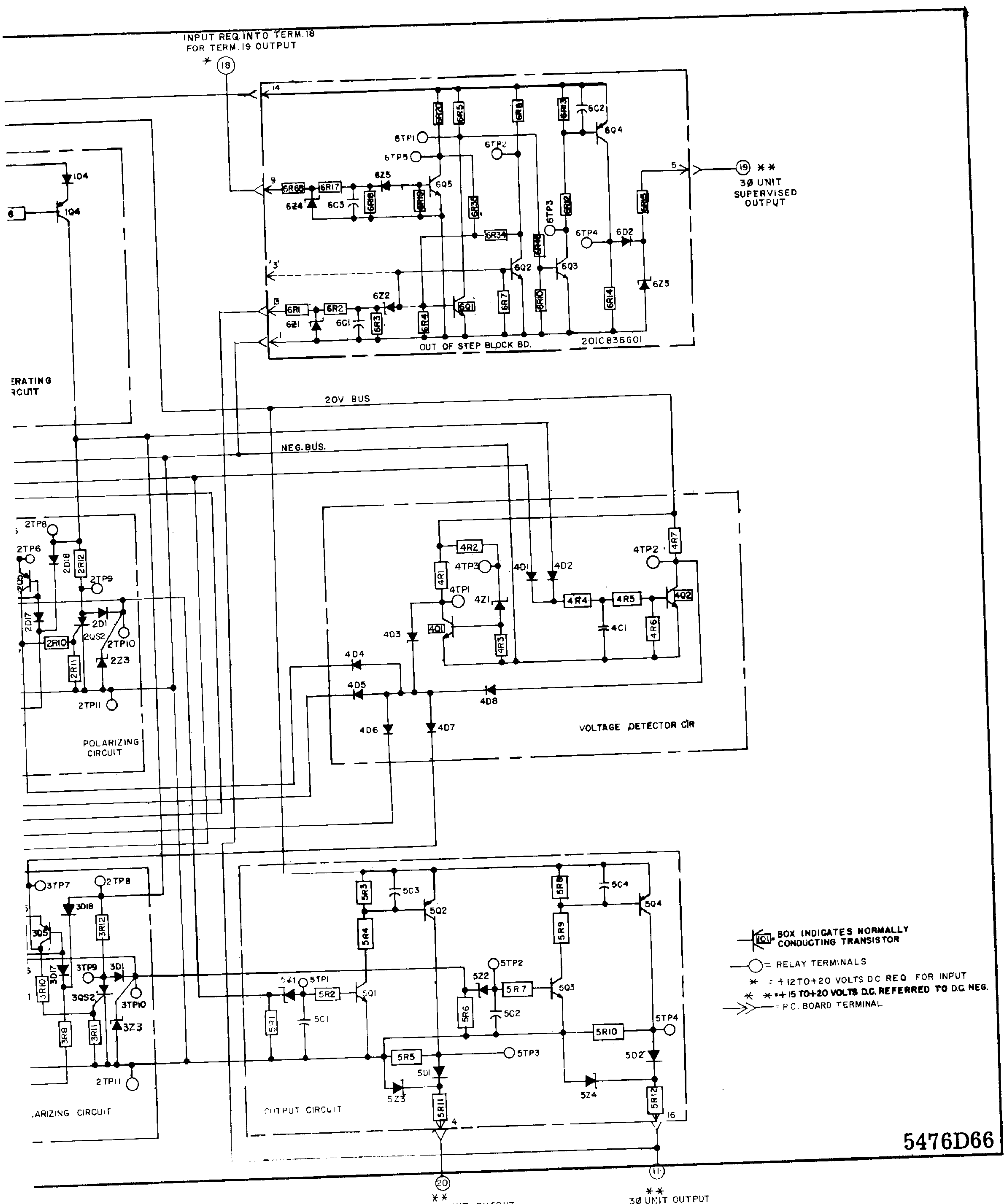


Fig. 10b. Detailed Internal Schematic of SP Relay



...ernal Schematic of SP-1 Relay.



with Dual Output and "AND" Logic.

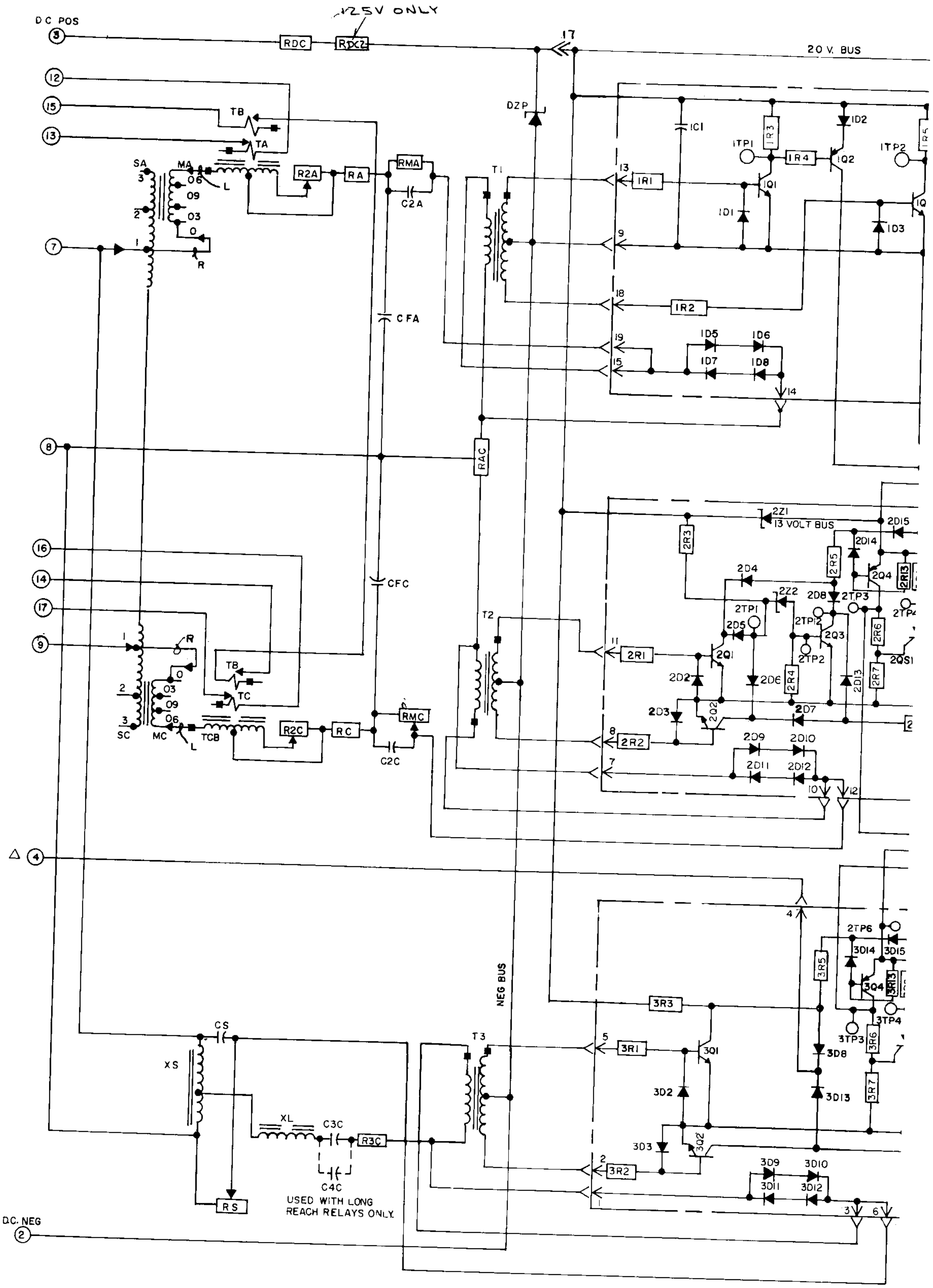


Fig. 11a. Detailed Int

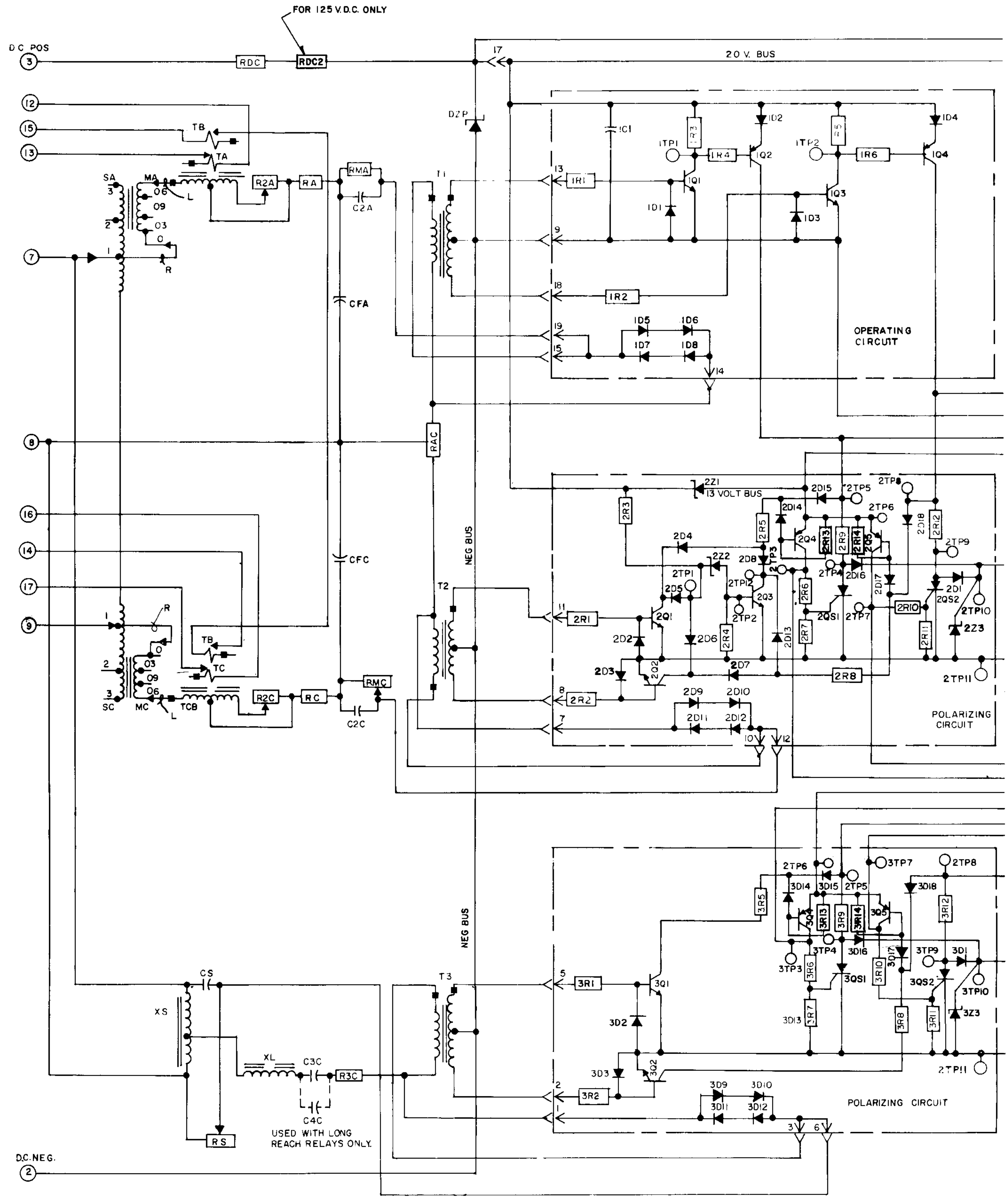


Fig. 11b. Detailed Internal Schematic of SP-1

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

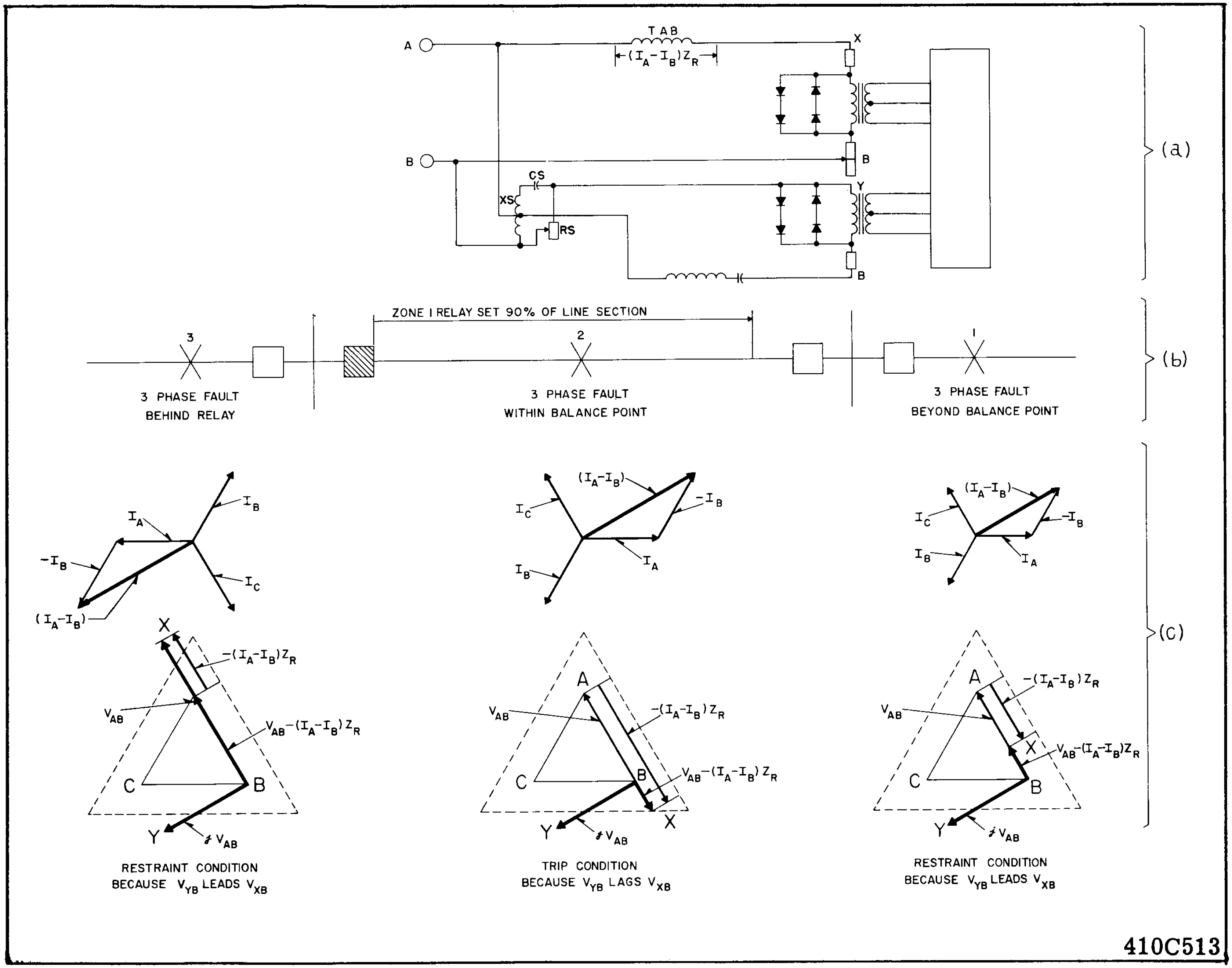
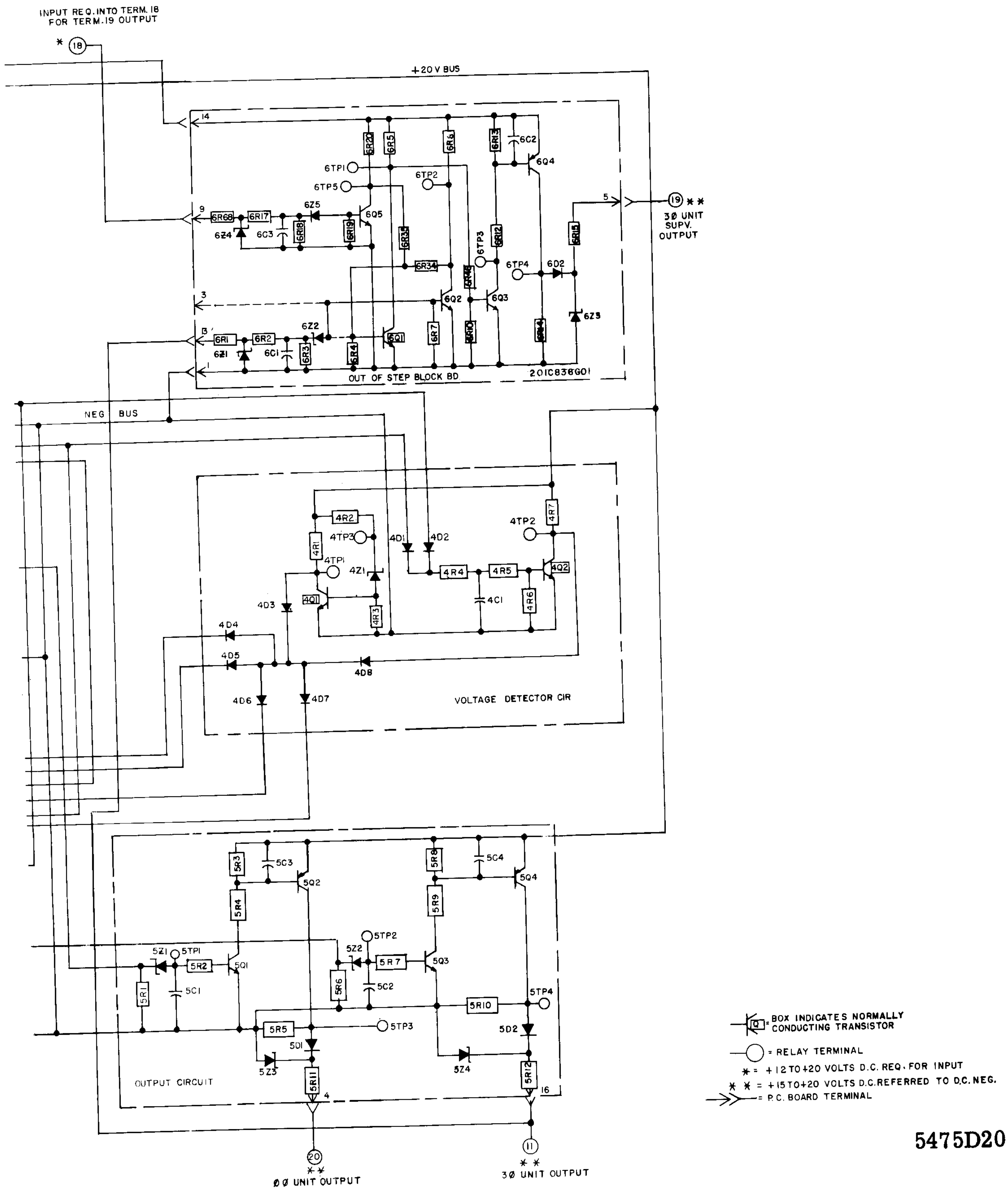
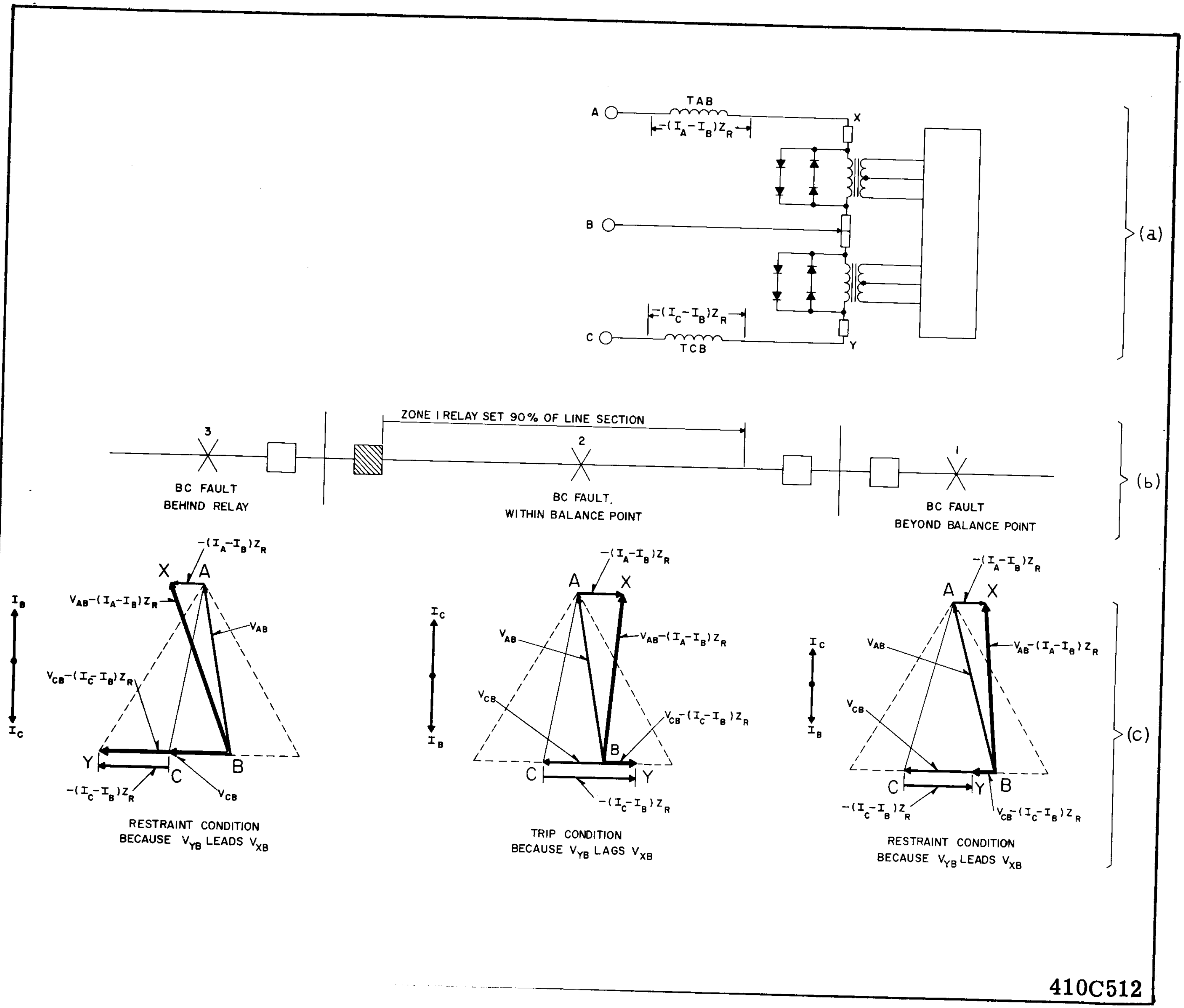
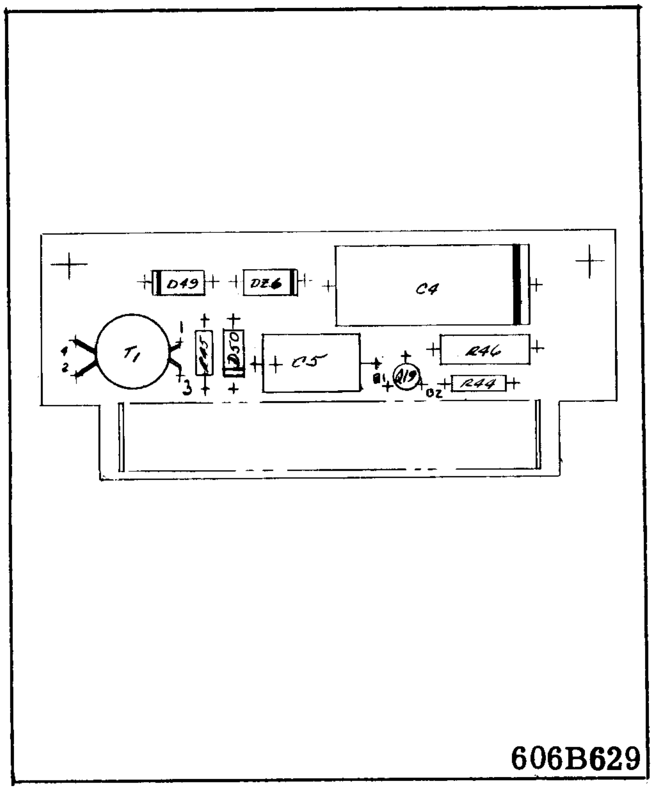


Fig. 13. Voltage and Current Conditions for the Three-Phase Unit.



Relay with Dual Output and "AND" Logic.


TAB
-(IA-IB)ZR
A
B
C
X
Y
-(IC-IB)ZR
TCB
(a)
ZONE I RELAY SET 90% OF LINE SECTION
3
BC FAULT
BEHIND RELAY
2
BC FAULT,
WITHIN BALANCE POINT
1
BC FAULT
BEYOND BALANCE POINT
(b)
IB
IC
VAB-(IA-IB)ZR
VAB
VCB-(IC-IB)ZR
VCB
RESTRAINT CONDITION
BECAUSE VYB LEADS VXB
TRIP CONDITION
BECAUSE VYB LAGS VXB
RESTRAINT CONDITION
BECAUSE VYB LEADS VXB
(c)
410C512



• *Fig. 14a. Printed Circuit Board Trigger Circuit for SKD Relay.*

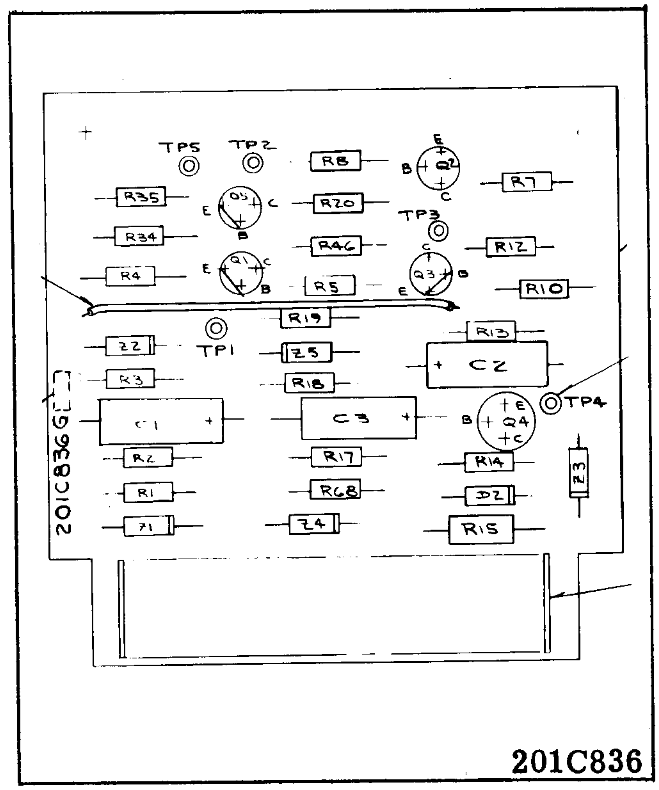


Fig. 14b. Printed Circuit Board "AND" Logic for SP and SP-1 Relays.

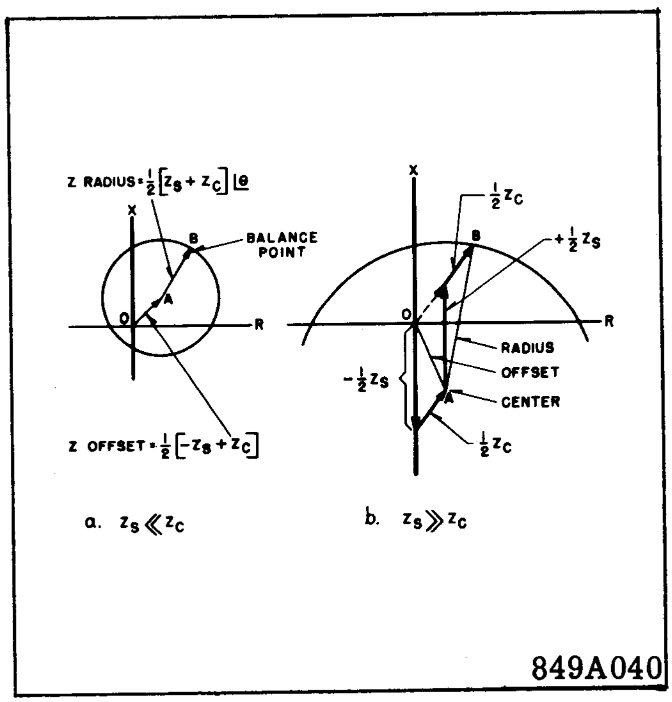


Fig. 15. Impedance Circles for Phase-to-Phase Unit in Types SKD, SP, and SP-1 Relays.

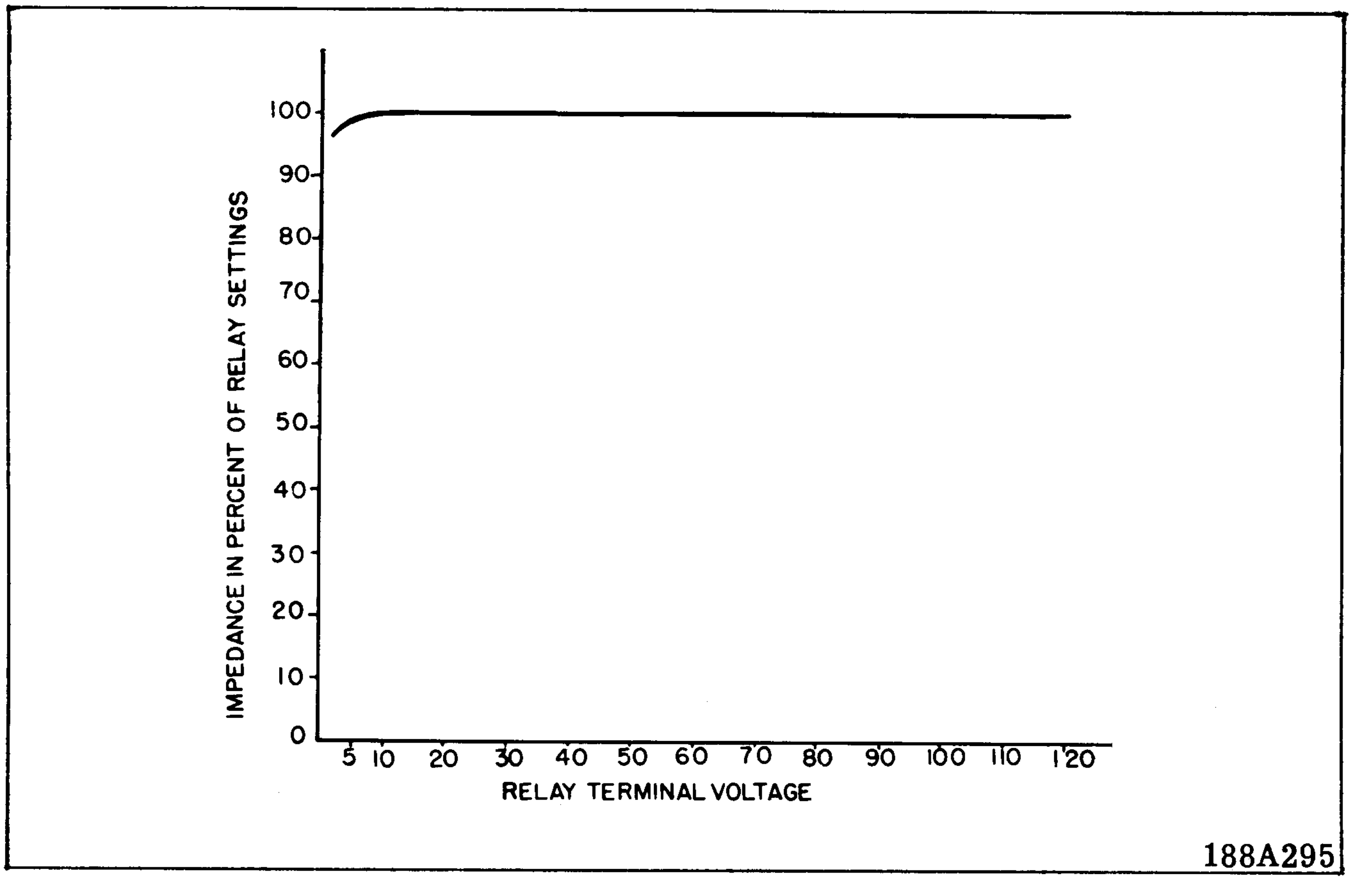


Fig. 16. Impedance Curves for Types SKD, SP, and SP-1 Relays.

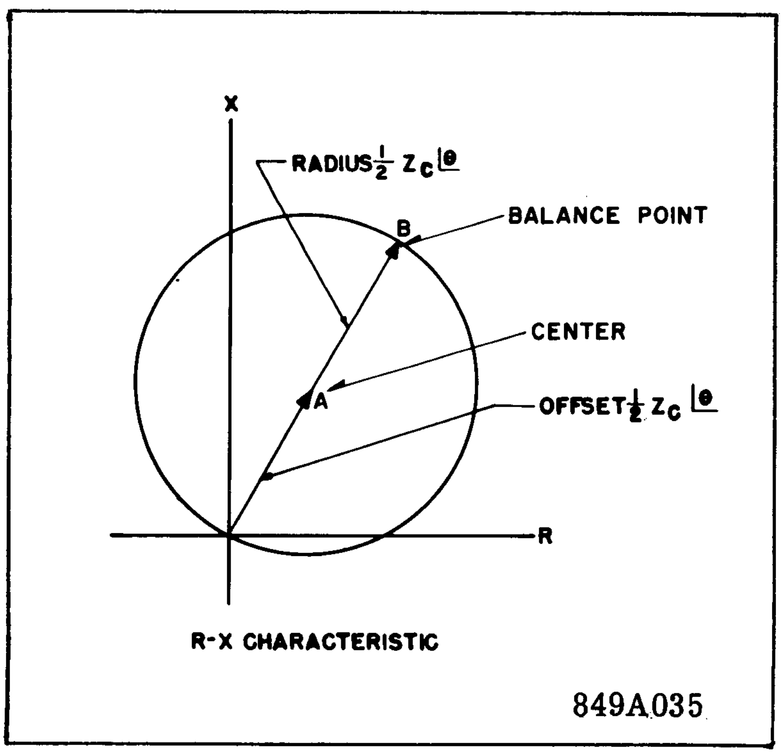


Fig. 17. Impedance Circle for Three-Phase Unit in Types SKD and SP Relays.

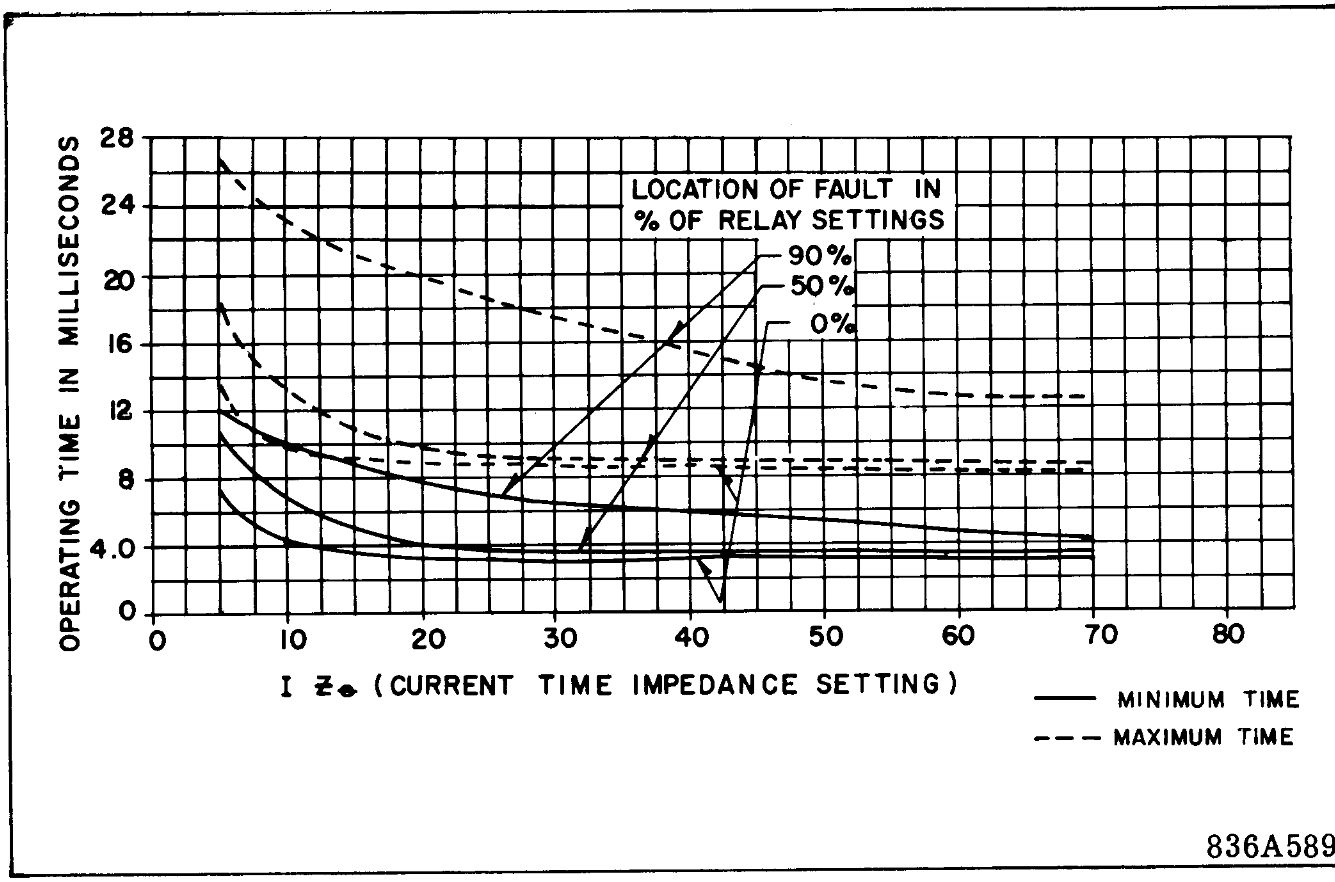
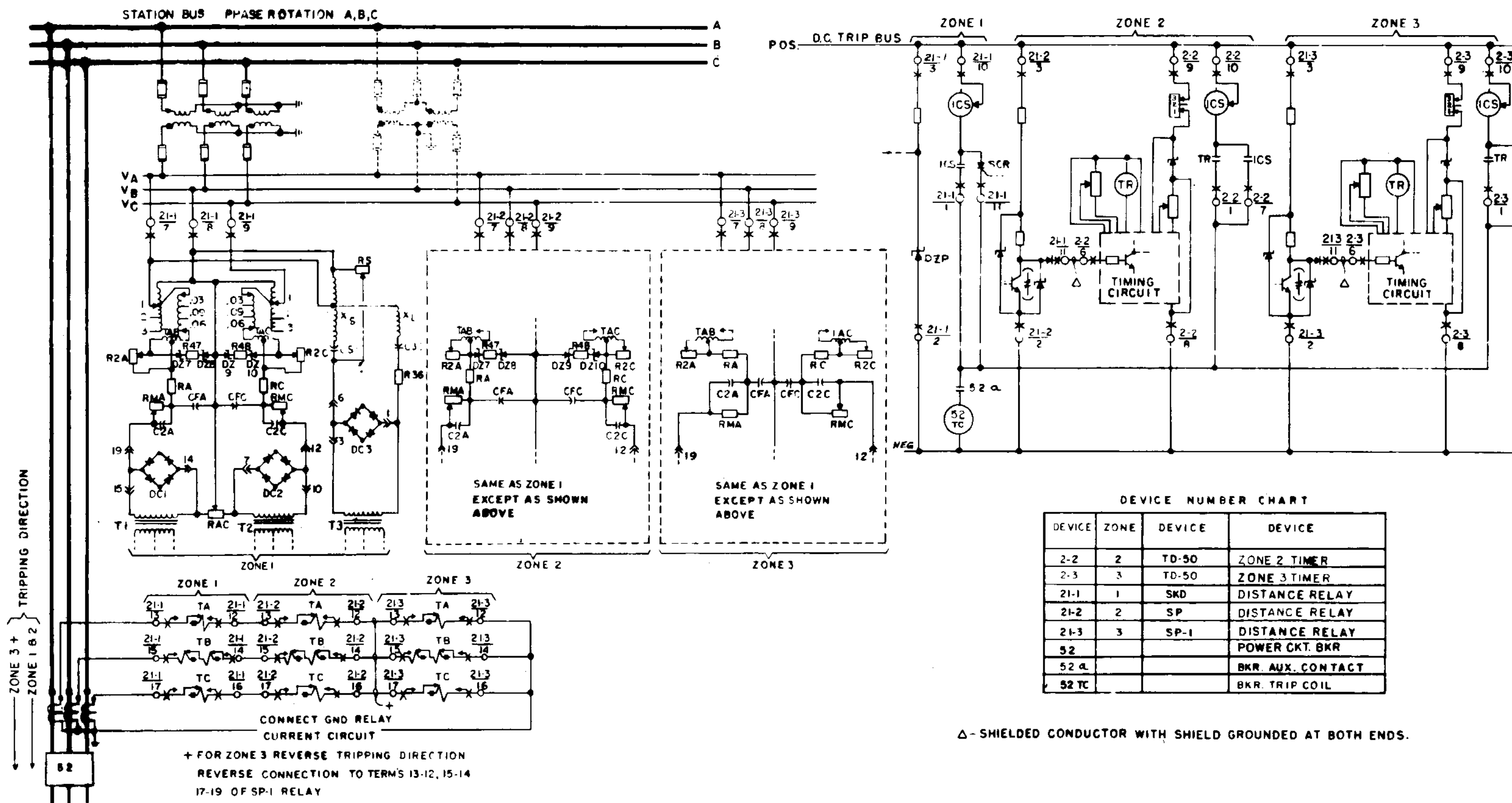


Fig. 18. Typical Operating Time Curves for SKD, SP, and SP-1 Relays. Normal Voltage Before the Fault is 120 Volts.



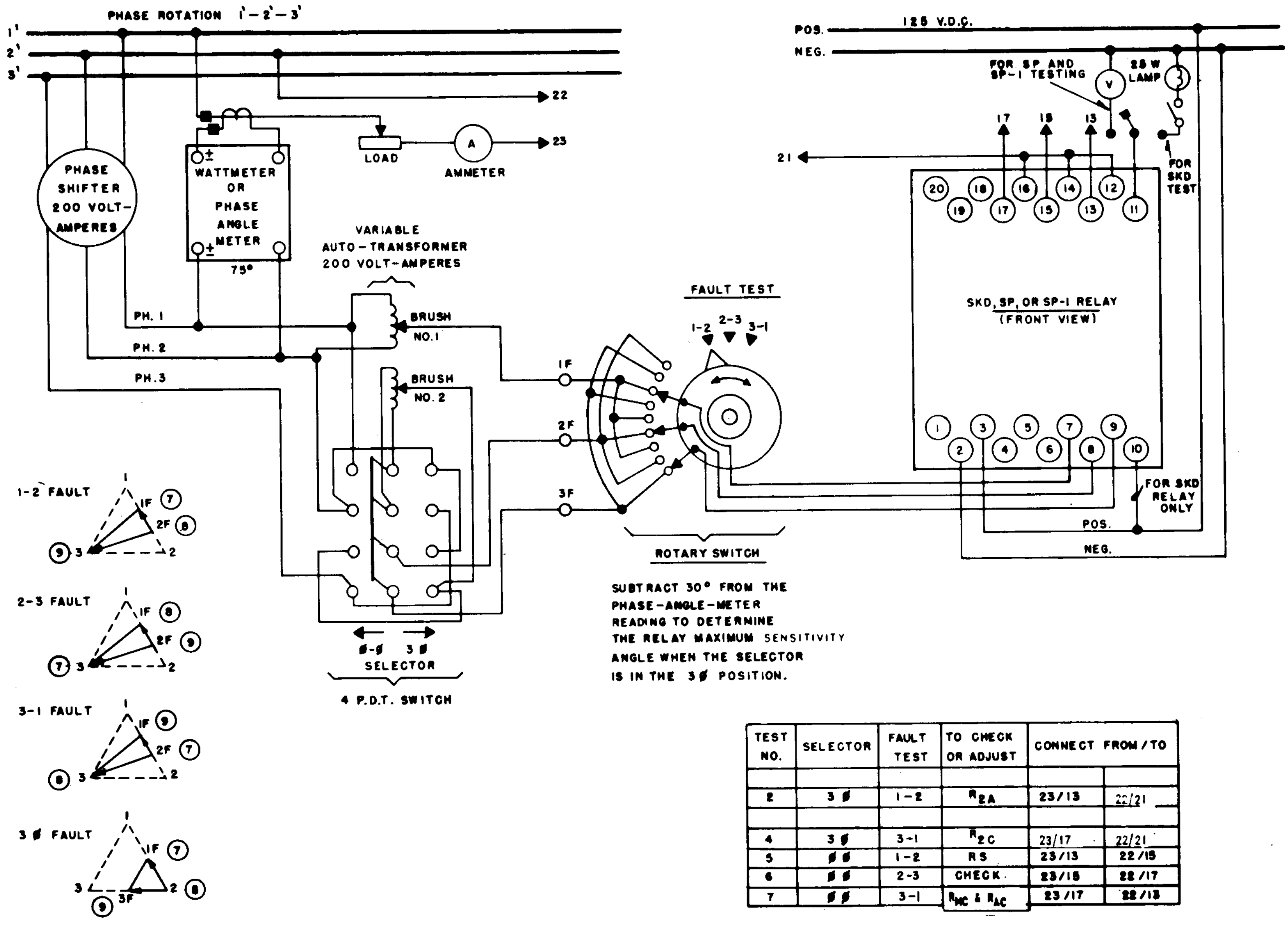
DEVICE NUMBER CHART

DEVICE	ZONE	DEVICE	DEVICE
2-2	2	TD-50	ZONE 2 TIMER
2-3	3	TD-50	ZONE 3 TIMER
21-1	1	SKD	DISTANCE RELAY
21-2	2	SP	DISTANCE RELAY
21-3	3	SP-1	DISTANCE RELAY
52			POWER CKT. BKR
52 a			BKR. AUX. CONTACT
52 TC			BKR. TRIP COIL

Δ - SHIELDED CONDUCTOR WITH SHIELD GROUNDED AT BOTH ENDS.

898C793

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	3Ø	1-2	R_{2A}	23/13	22/21
4	3Ø	3-1	R_{2C}	23/17	22/21
5	ØØ	1-2	RS	23/13	22/15
6	ØØ	2-3	CHECK	23/15	22/17
7	ØØ	3-1	R_{MC} & R_{AC}	23/17	22/13

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

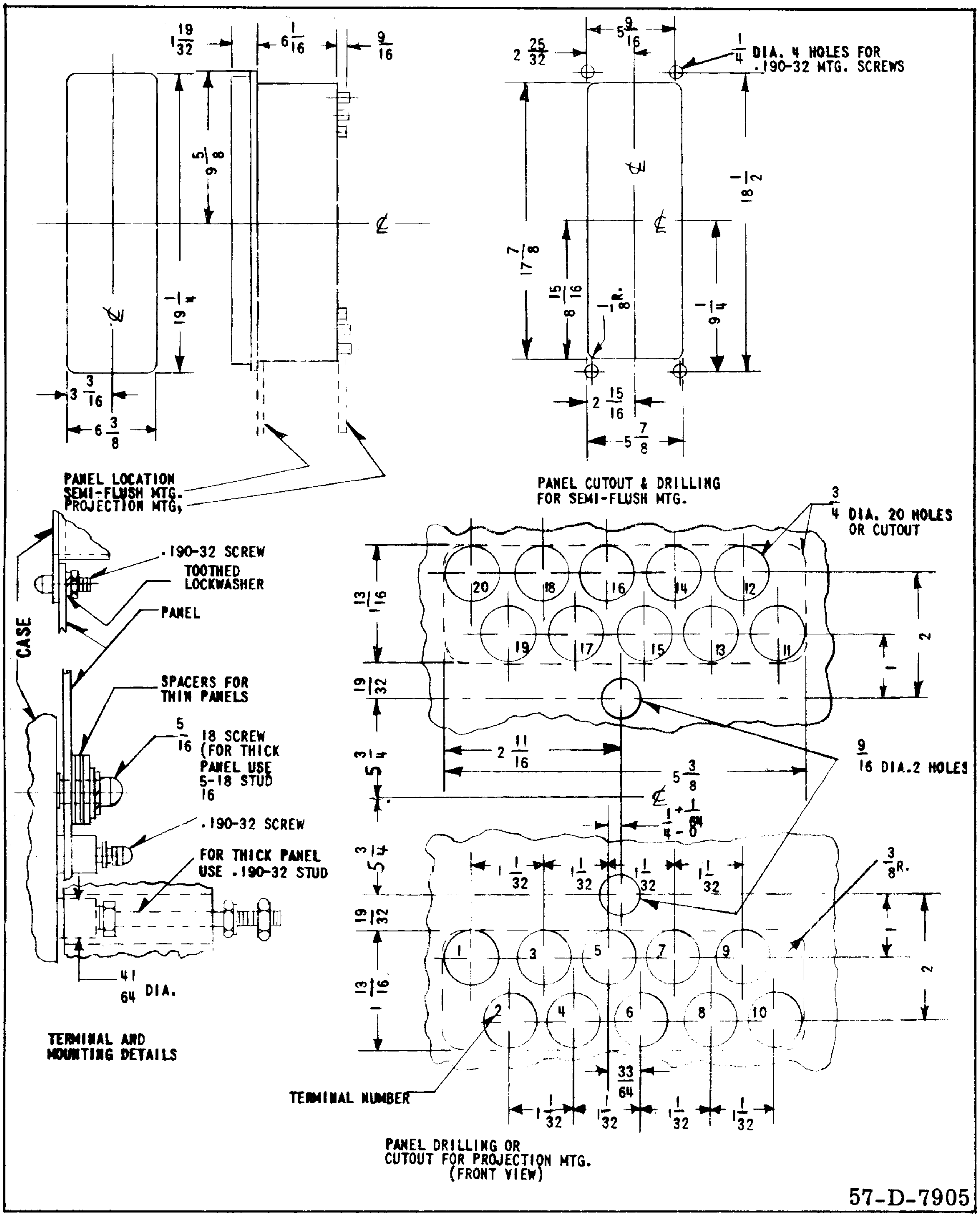


Fig. 21. Outline and Drilling Plan for Types SKD, SP, and SP-1 Relays in Type FT-42 Case.

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 contractor switch as an operation indicator. Operation indication for the SP and SP-1 relays must be accomplished by auxiliary means.

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. SP and SP-1 relays are also available with "AND" logic supervision. These relays also have an additional printed circuit assembly.

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

SUPERSEDES I.L. 41-495.5
*Denotes change from superseded issue.

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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 $\frac{S}{1 \pm M}$. 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 and 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 capacity reactance, C3C, which are series connected and are tuned very closely to sixty hertz. 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 hertz 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 preceded by a functional group number and 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 14a 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. Figure 14b is the "AND" logic assembly used in SP and SP-1 relays.

OPERATION

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

Two distinctly different logic systems are used in the SP 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}.

The three-phase unit can be blocked by external means to prevent tripping during load conditions or system swing conditions which enter the electrical trip zone. Blocking is accomplished in single-output relays by connecting relay terminal 4 to terminal 2 (battery negative) through contacts or through a conducting transistor. Open circuit voltage at terminal 4 is not greater than 20 volts. Short circuit current out of terminal 4 is not greater than 2.5 milliamperes.

To accomplish tripping through the supervised output, terminal 19, of dual-output relays, a positive voltage of 15 V dc to 20 V dc must be applied to relay terminal 18 with negative on terminal 2. Maximum current flow into terminal 18 at 20 V dc is 1.5 milliamperes. (48 V dc may be safely applied to terminal 18 continuously. Maximum current is 6 milliamperes.).

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.

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 $(I_A I_B)$ 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 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 in single-output relays can be disabled by connecting relay terminal 4 to battery negative through a swing detection means. Dual-output relays will not trip at the supervised terminal unless a "permissive signal" at 20 Vdc is applied to terminal 18.

Phase Angle Comparison Unit

Referring to Figure 10b, the phase-angle comparison unit for the phase-to-phase unit trips when current flows into the base of transistor 5Q1 through zener diode 5Z1. Such tripping current must come from the 20V bus through either transistor 1Q2 or 1Q4 located in what might be called the "operate" circuit. This circuit driven by transformer T1, is continually trying to trip the unit by supply current through 1Q2 or 1Q4. Each conducts on alternating half-cycles.

When 1Q2 conducts, a portion of the current goes through resistor 2R9. This current, I_{2R9}, may take either of two paths to the negative bus. If 2QS1 is in a conducting state, I_{2R9} passes through it directly to the negative bus. If 2QS1 is in a blocking state, I_{2R9} passes through 2D16 and then through 5Z1 to transistor 5Q1 to cause tripping. Restraint thyristor 2QS1 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 2Q1 to conduct current through 2D4, 2R5 and 2D14 to drive the base of 2Q4. 2Q4 then conducts current from the 13V bus through 2R6 to drive the gate 2QS1 into conduction. When 2QS1 conducts, it short circuits the current which might otherwise pass through 2D16 to cause tripping. Once 2QS1 begins to conduct, the gate loses control and it remains in the conducting state until the current is turned off by 1Q2. 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 1Q3 and 1Q4 conduct in an attempt to cause tripping. In the polarizing circuit, 2Q2, 2Q5 and 2QS2 seek to prevent tripping by short circuiting the current which might otherwise pass through 2D1, 5Z1 and 5Q1.

Restraint Squelch: When the operate circuit transistor 1Q2 conducts, approximately 18V is applied through diode 2D15 to back bias 2D14 and prevent 2Q4 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 1Q2. This back-biasing connection is called the restraint squelch circuit.

Restraint-Signal Detection: If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch 2QS1 and short circuit the 1Q2 current. This, of course, could cause incorrect tripping. A signal detector circuit prevents this from happening. When a useful voltage level is supplied by T2, 2Q1 and 2Q2, alternately short circuit the current which flows through 2R3 from the 20V bus. When the voltage from T2 drops too low to drive 2Q1 and 2Q2, the 2R3 current flows through 2Z2 to switch 2Q3 into conduction. This in turn drives 2Q4 through 2D8, 2R5 and 2D14 causing 2Q4 to switch 2QS1 into conduction to short circuit 2D16 and prevent tripping.

The operate circuit, driven by T1, and the polarizcircuits, driven by T2 and T3, are duals having identical circuits which operate on alternate half cycles. The restraint squelch and the restraint-signal 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 3D16 and 3D1, through 5Z2 and to 5Q3. This polarizing circuit contains a restraint squelch and a restraint-signal detector identical to those described for the T2 circuit.

SP-1 Relay: The SP-1 relay 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 restraint-signal detector from the T3 circuit. This omission reduces the accuracy of the SP-1 relay at low-voltage test levels.

Voltage Detector: Operation of the phase-angle comparison unit is based upon a comparison of the phase relation between two amplified signals. If either the a-c input signal or the d-c amplifying voltage is absent, then no phase relation can be established. Therefore, at the instant either quantity is applied, the logic does not know whether it should trip or restrain since it has no prior knowledge of phase relations. The voltage detector sends a gating pulse from 4Q2 to all restraint thyristors 2QS1,2QS2, 3QS1 and 3QS2 to block tripping long enough for the true phase-angle relation between input signals to be established. After approximately one-half cycle, 4Q2 turns on to remove the gating signal until the relay is de-energized again.

The zener diode 4Q1 monitors the d-c voltage level. If the d-c voltage drops too low for the logic to operate properly, it will cause 4Q1 to turn off and thereby send a gate signal to the restraint thyristors. This will block tripping as long as the d-c voltage is at a level which would otherwise cause an incorrect operation.

Output Circuits

SP and SP-1 Relays: Two output combinations are available. Therefore, there is an option between a dual output (where the phase-to-phase unit is separate from the three-phase unit output) and a single output (where the two use a common output circuit). The dual-output circuit is required when the three-phase unit is supervised through "AND" logic.

The basic output circuit is identical for both the phase-to-phase and the three-phase units. Consider a trip signal from the restraint thyristors which which sends current through 5Z3, 5R7 and into the base of 5Q3. This will turn on 5Q4 to give an unsupervised output at terminal 11 for the three-phase unit.

For "AND" supervision, the three-phase output is fed into the "Out-of-Step Block" printed-circuit board through 6R1 and 6Z2 into the base of transistor 6Q2. This turns 6Q2 on to short circuit part of the base drive supplied to 6Q1. The rest of the current into 6Q1 base is supplied from 6Q5 which must also turn on before 6Q1 can turn off. This means that a signal of 12V d-c or more must be supplied to terminal 18. This will cause 6Q5 to turn on. When 6Q1 turns off, it drives the 6Q3 base which allows 6Q4 to turn on and produce an output at terminal 19. The removal of either the signal at terminal 18 or the signal from the three-phase unit will cause 6Q1 to turn on and block the output at terminal 19.

Each output should supply open-circuit voltage of 15.5V d-c to 20V d-c and is capable of supplying 10 mA each.

SKD Relay:

The output of the SKD relay is a Thyristor (controlled-rectifier) TCR which is gated into conduction by a pulse transformer. The transformer is pulsed when 5Q3 turns on causing 5Q4 to conduct into an oscillator consisting of capacitor 7C1, pulse transformer TP, and unijunction transistor 7Q1. 7Q1 switches into conduction when voltage across 7C1 reaches a predetermined level. It resets after capacitor 7C1 has discharged through TP to produce a gating pulse. 7C1 then charges up again to repeat the process.

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 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 hertz. 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:

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

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			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 (TCR)

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 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:

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

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

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	18V to 21V d.c.
Output resistance	150 ohms
Rated output current	10 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:

$Z\theta$ = 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:

A. Establish the value of $Z\theta$, as above.

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

$$Z = Z\theta \frac{\text{Sine } 75°}{\text{Sine } \theta°}$$

When θ = 75°, Z = $Z\theta$.

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

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

D. 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.

E. 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_O for a .73-21 ohm relay is 7 ohms at 60°. (Step (A).

Step (B). 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:

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

Step (C). 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 (D). 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 (E). Recheck Settings:

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

$$Z \underline{/60^\circ} = Z \frac{\text{Sine } 60^\circ}{\text{Sine } 75^\circ} = 7.88 \times .896 + 7.06$$

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 TB 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.

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 equivalent AC voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equivalent 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 of single-output relays 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 current necessary to trip the phase-to-phase unit at 45° 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°.

* Go from non-trip to trip area.

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 of single-output relays by connecting Test Point 2TP4 and Test Point 2TP9 to Printed Circuit Board Terminal 9. 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 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	TA (TERM'S 13-12)			TB (TERM'S 15-14)			TC (TERM'S 17-16)		
.73-21 OHM RANGE	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	
	.205	.274	.342	.48	.615	.82	1.1	1.64	2.2	—	3.29	+.12		.09	0	
	.211	.281	.352	.493	.633	.845	1.13	1.69	2.26	—	3.38	+.09		.09	.03	
	.217	.289	.362	.506	.65	.868	1.16	1.74	2.32	—	3.48	+.06		.06	.09	
	.223	.298	.372	.521	.67	.893	1.2	1.79	2.39	—	3.58	+.03		.03	0	
	.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	
	.252	—	.42	—	.758	1.01	1.35	2.02	2.7	3.03	4.05		-.09	.03	.09	
	—	—	.435	—	—	—	1.4	—	2.8	—	4.19		-.12	0	.09	
	—	—	—	—	—	—	1.45	—	2.89	—	4.35		-.15	.03	.06	
	—	—	—	—	—	—	1.5	—	3.0	—	4.5		-.18	0	.06	

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	
	.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	
	.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	
	.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"

TABLE V

Test Voltage = 30 $V_{L\text{-}L}$

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 appriximately 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 Tests #5, #6, and #7 is:

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

where $V_{L\text{-}L}$ 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:

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

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 of 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.

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 Sine θ

    θ = the desired maximum sensitivity angle

    T = Compensator tap setting

    10.35 = a design constant = $\frac{10}{\text{sine } 75°}$

		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 current neces-
* ary 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:

$$\frac{\text{Sine } 75°}{\text{Sine } \theta}$$

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 (2TP4) and Test Point 24 (2TP9) 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

CFA, CFC	1. MFD	1876999
CS	0.45 MFD	1723408
C2A, C2C	1.8 MFD	14C9400H12
C3C	0.3 MFD	1724191
C4C	0.03 MFD	1725974
1C1	18 MFD	187A508H10
4C1	0.25 MFD	187A624H02
5C1	0.12 MFD	837A241H02
5C4	0.27 MFD	188A699H05

	SKD		SP		SP-1
5C2	—		0.015 MFD	187A624H10	Same
5C3, 6C2	—		0.27 MFD	188A699H05	Same
6C1, 6C3	—		0.047 MFD	849A437H04	Same
7C1	0.25 MFD	187A624H02		—	—
7C2	2 MFD	184A662H07		—	—

Diodes

SKD, SP, & SP-1 COMMON PARTS

All Blocking Diodes	CER69	188A342H06
DZP	1N2984B (20V)	762A631H01
2Z1, 5Z2	1N752A (5.6V)	186A797H12
2Z2, 4Z1	1N758 (10V)	186A797H01

	SKD		SP		SP-1
Z1 to Z4	1N2846A (200V)	184A854H08	Same	Same	—
2Z3, 3Z3	—		1N758 (10V)	186A797H01	Same
3Z2	1N758 (10V)	186A797H01	Same	Same	—
5Z1	1N758 (10V)	186A797H01	1N752A (5.6V)	186A797H12	1N752A
5Z3, 5Z4, 6Z3	—		1N3688A (24V)	863A288H01	Same
6D2	—		1N645A	Blocking Diode	Same
6Z1, 6Z4	—		1N3686B (20V)	185A212H06	Same
6Z2, 6Z5	—		1N957B (6.8V)	186A797H06	Same
7Z1	1R200 (200V)	629A369H01		—	—

Transistors

SKD, SP, & SP-1 COMMON PARTS

1Q1, 1Q3, 2Q1, 2Q2, 3Q1, 3Q2, 4Q2	2N3391	848A851H01
1Q2, 1Q4, 2Q4, 2Q5, 3Q4, 3Q5	2N1132	184A638H20
2Q3	2N679	184A638H18
5Q2	2N3645	849A441H01
5Q3	2N3417	848A851H02

	SKD		SP		SP-1
3Q3	2N679	184A638H18	Same	Same	—
5Q1, 6Q1, 6Q2, 6Q3, 6Q5	—		2N3417	848A851H02	Same
5Q4, 6Q4	—		2N3645	849A441H01	Same
7Q1	2N2647	629A435H01		—	—

TABLE VII – Continued

Resistors

SKD, SP, & SP-1 COMMON PARTS

RA, RC, RMA	1.8 KΩ	1201004
RS	10 KΩ	1730906
RAC	3550 Ω	1955270
RDC (125 VDC)	1500 Ω	1267293
RDC (48 VDC)	400 Ω	1202587
RMC	2500 Ω	05D1328H22
R3C	3 KΩ	1202954
1R1, 1R2, 2R1, 2R2, 3R1, 3R2, 4R4, 4R5	100 KΩ	184A763H75
1R3, 1R5	1 MEG Ω	184A763H99
1R4, 1R6, 2R5, 2R8, 3R5, 3R8, 2R13, 2R14, 3R13, 3R14	8.2 KΩ	184A763H49
2R3	33 KΩ	184A763H63
2R4, 3R4	22 KΩ	184A763H59
2R6, 2R10, 3R6, 3R10	2.7 KΩ	629A531H42
2R7, 2R9, 2R11, 2R12, 3R7, 3R9, 3R11, 3R12, 4R1	2.7 KΩ	184A763H37
4R2	18 KΩ	184A763H57
4R3, 4R6	27 KΩ	184A763H61
4R7	5.6 KΩ	184A763H45
5R6	56 KΩ	184A763H69
5R8	10 KΩ	629A531H56
5R9	6.8 KΩ	629A531H52

	SKD		SP		SP-1
RDC (For Dual Output Relays)		–	350 Ω	644B260H22	Same
RDC2 (For Dual Output Relays)		–	710 Ω	1267284	Same
R1, R2	500 Ω	763A129H03	Same	Same	–
3R3	33 KΩ	184A763H63	Same	Same	–
5R1, 5R2,		–	56 KΩ	184A763H69	Same
5R3		–	10 KΩ	629A531H56	Same
5R4, 6R12, 6R34, 6R35, 6R46		–	6.8 KΩ	629A531H52	Same
5R5, 6R3, 6R18		–	82 KΩ	629A531H78	Same
5R7	10 KΩ	184A763H51	56 KΩ	184A763H69	56KΩ
5R10	4.7 KΩ	184A763H43	82 KΩ	629A531H78	82KΩ
5R11, 5R12, 6R15		–	150 Ω	762A679H01	Same
6R1, 6R2, 6R17, 6R68		–	4.7 KΩ	629A531H48	Same
6R4, 6R7, 6R10, 6R13, 6R14, 6R19		–	10 KΩ	629A531H56	Same
6R5, 6R8, 6R20		–	27 KΩ	629A531H66	Same
7R1	12 KΩ	187A641H53		–	–
7R2	470 Ω	187A644H19		–	–
7R3	680 Ω	187A641H23		–	–

Thyristor

SKD, SP, & SP-1 COMMON PARTS

2QS1, 2QS2, 3QS1, 3QS2	2N884	185A517H05
TCR (SKD Relay Only)	Tripping Unit. 2N1850A 184A614H05, 500V, 60 Amperes – 80 ms Surge, 6.5 Amperes Continuous.	

Transformers & Reactors

SKD, SP, & SP-1 COMMON PARTS

SA, SC	Auto-Transformer Primary (Taps: 1, 2, 3)
T1, T2, T3	292B563G05 Coupling Transformers
TP	629A37H01 Pulse Transformer (SKD Only)
XL	Memory Circuit Reactor
XS	Center Tapped Auto-Transformer For Phase Shift Circuit.

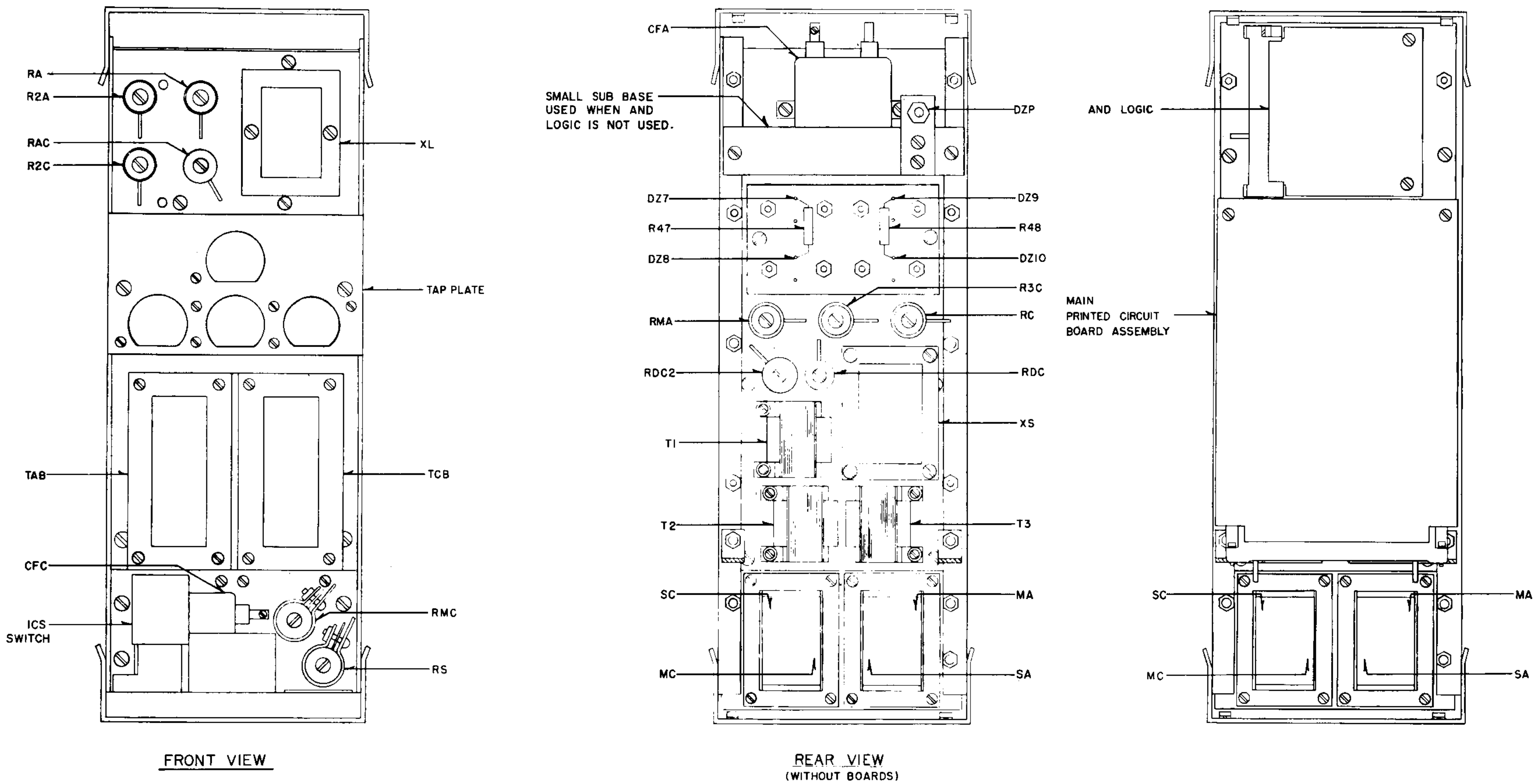


Fig. 1. Type SKD Relay Without Case.

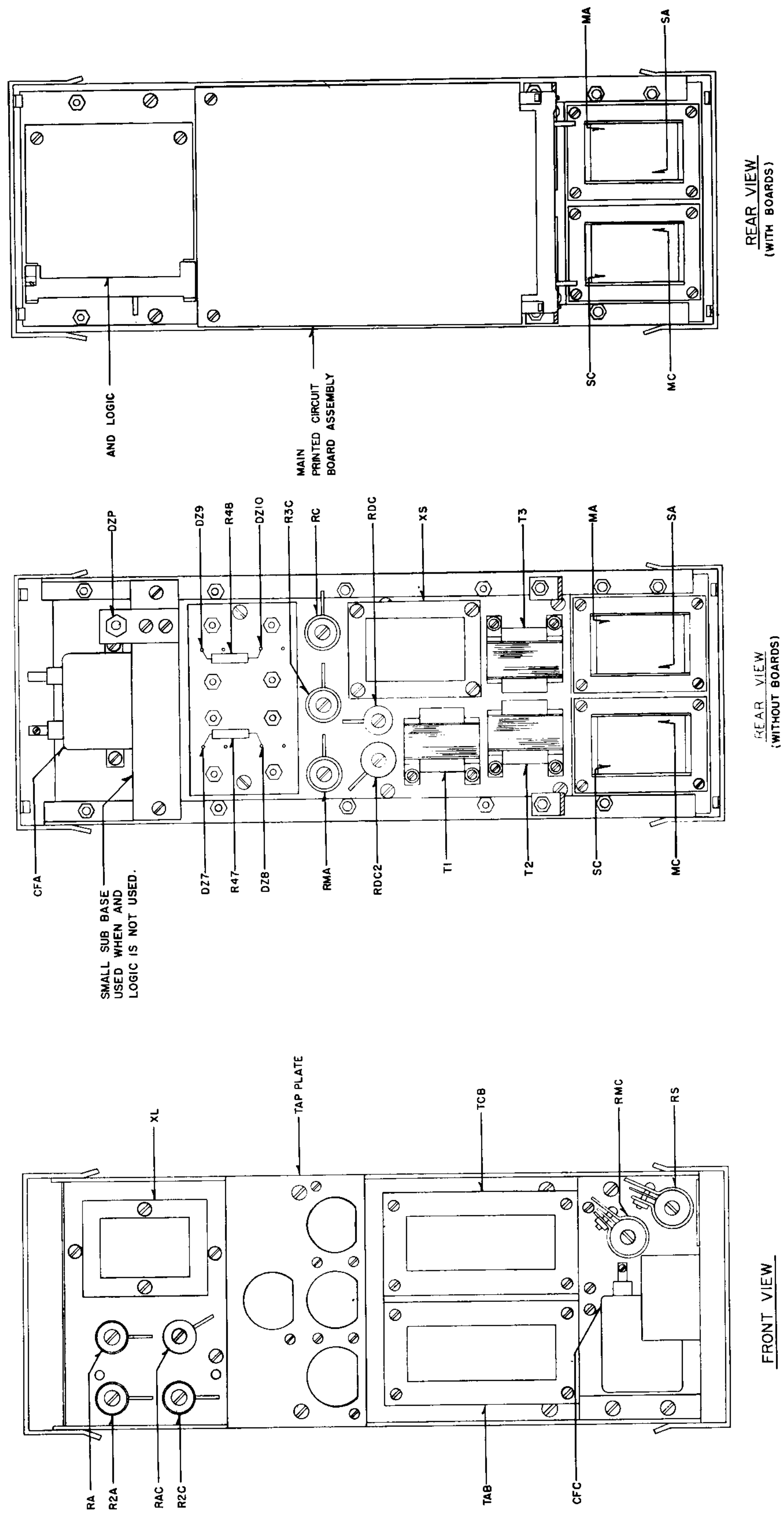


Fig. 2. Type SP Relay Without Case.

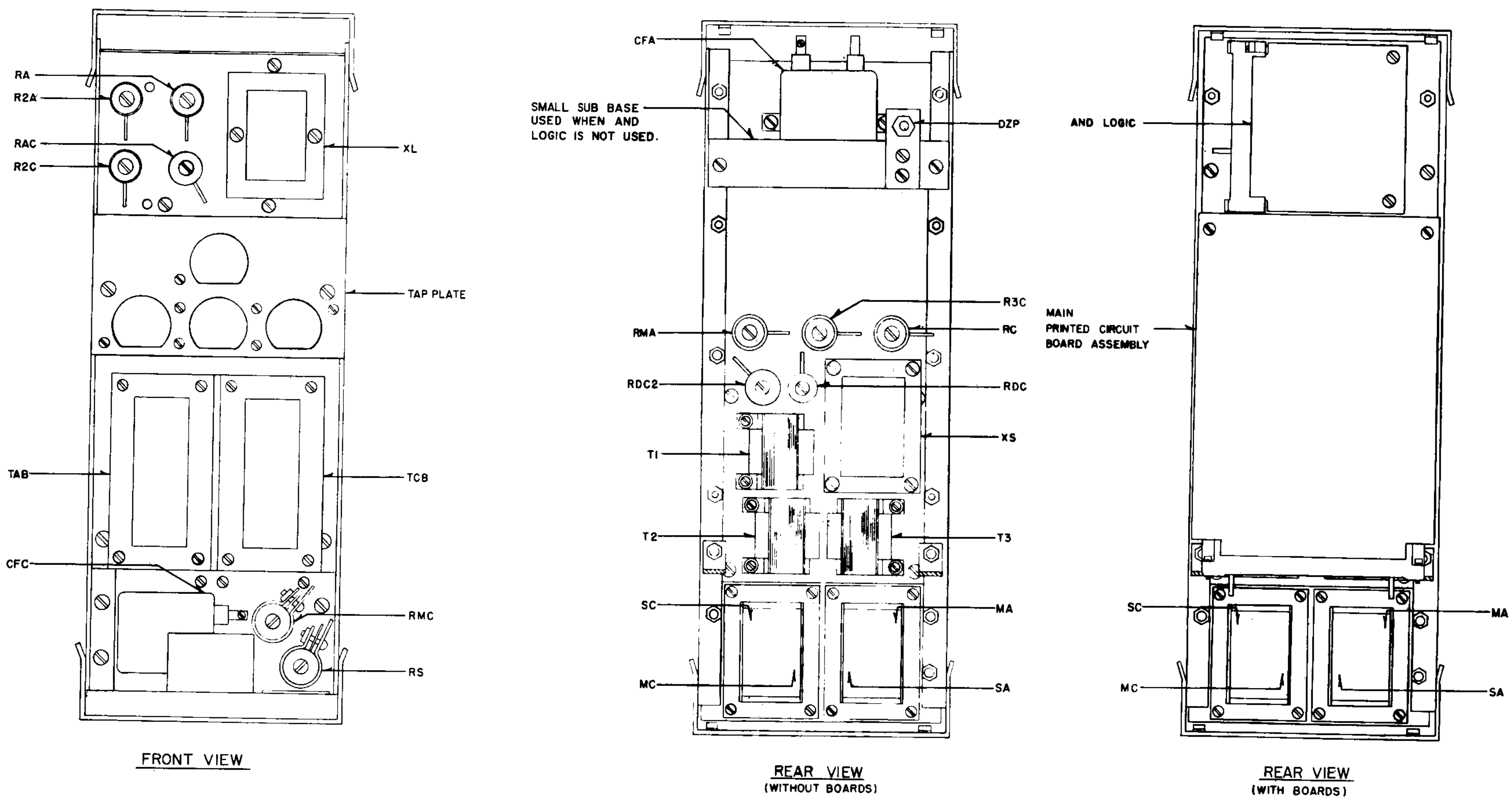


Fig. 3. Type SP-1 Relay Without Case.

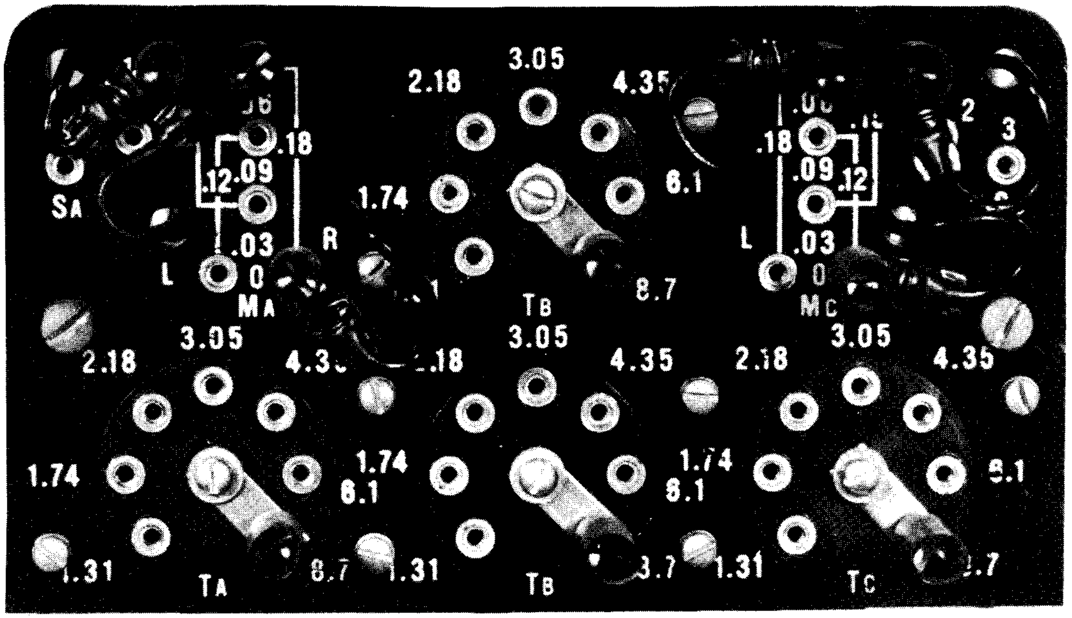


Fig. 4. Tap Plate of 30 Ohm Relay

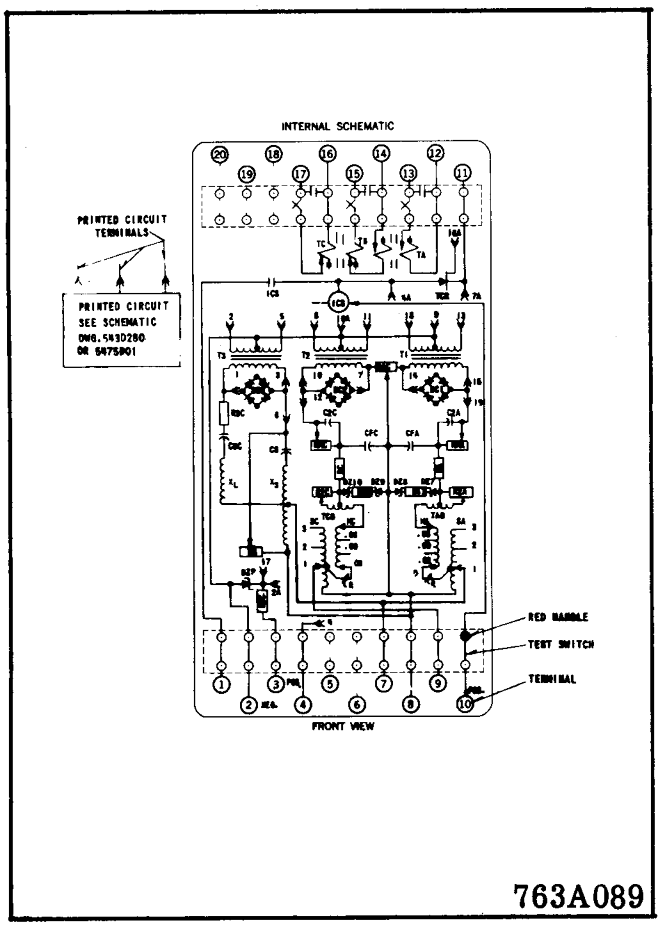


Fig. 5. Internal Schematic of Type SKD Relay in Type FT-42 Case.

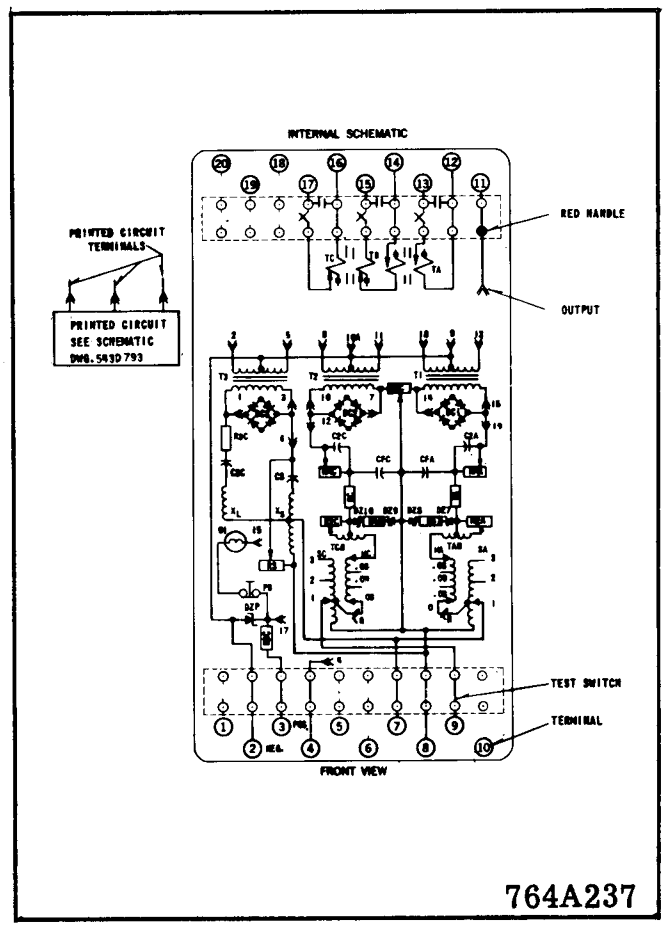


Fig. 6a. Internal Schematic of Type SP Relay in Type FT-42 Case.

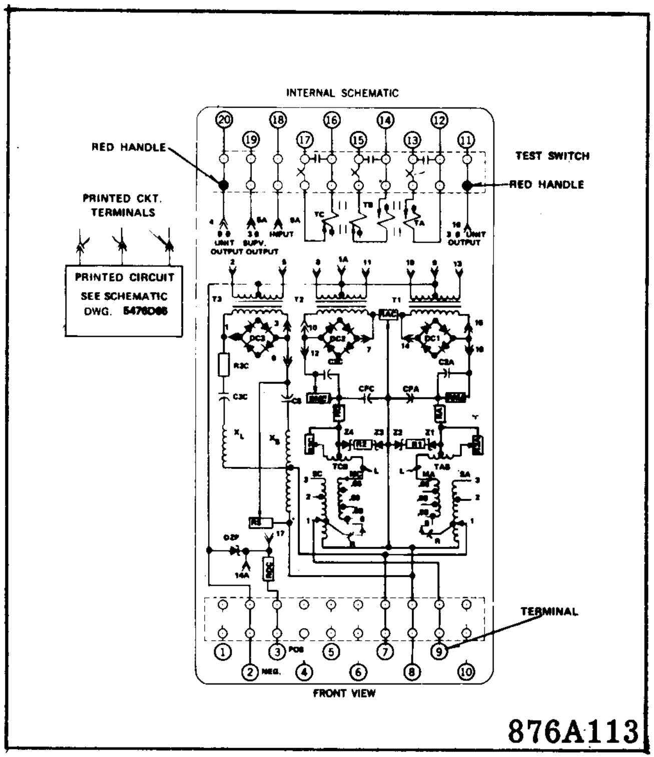


Fig. 6b. Internal Schematic of Type SP Relay with Dual Output and AND Logic in FT-42 Case.

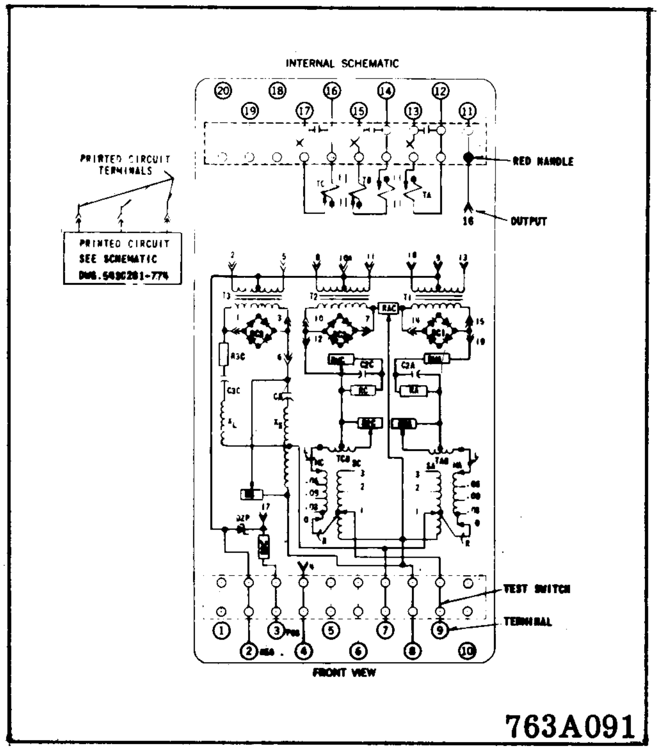


Fig. 7a. Internal Schematic of Type SP-1 Relay in Type FT-42 Case.

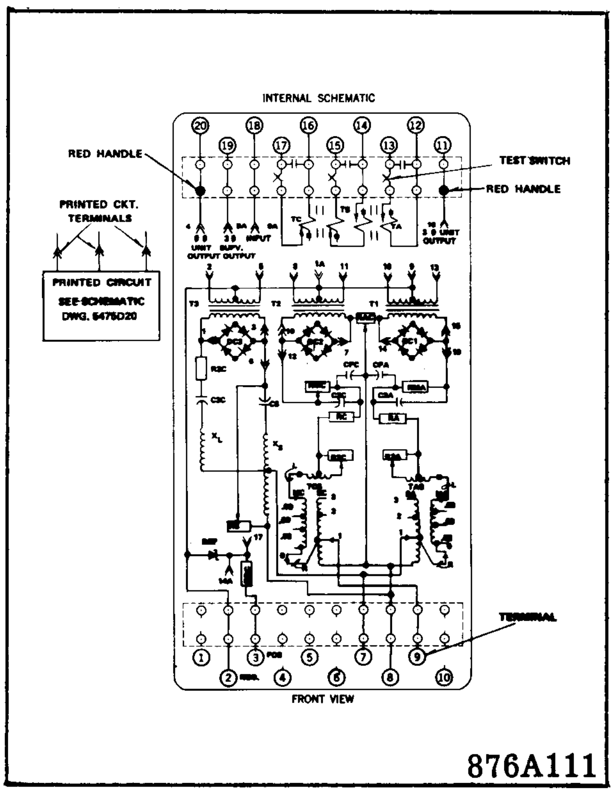
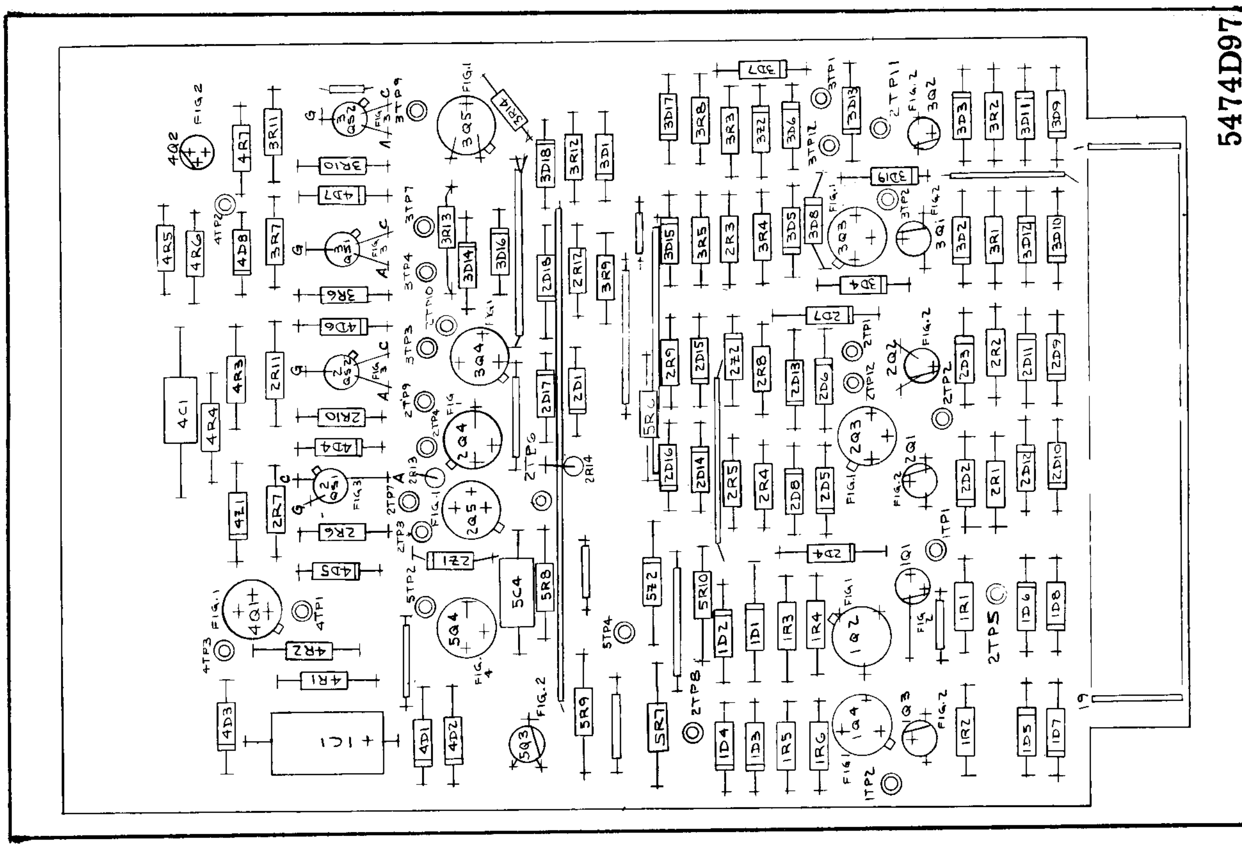
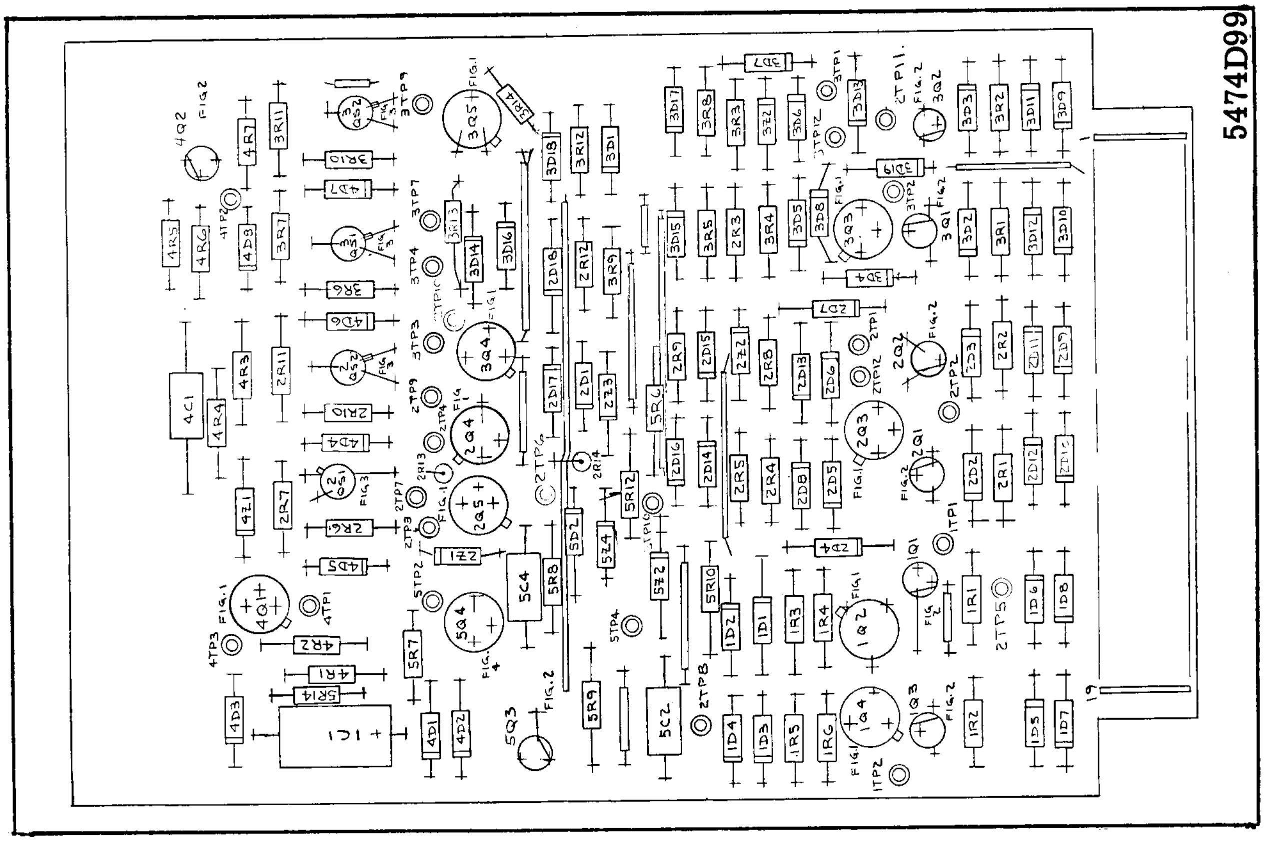


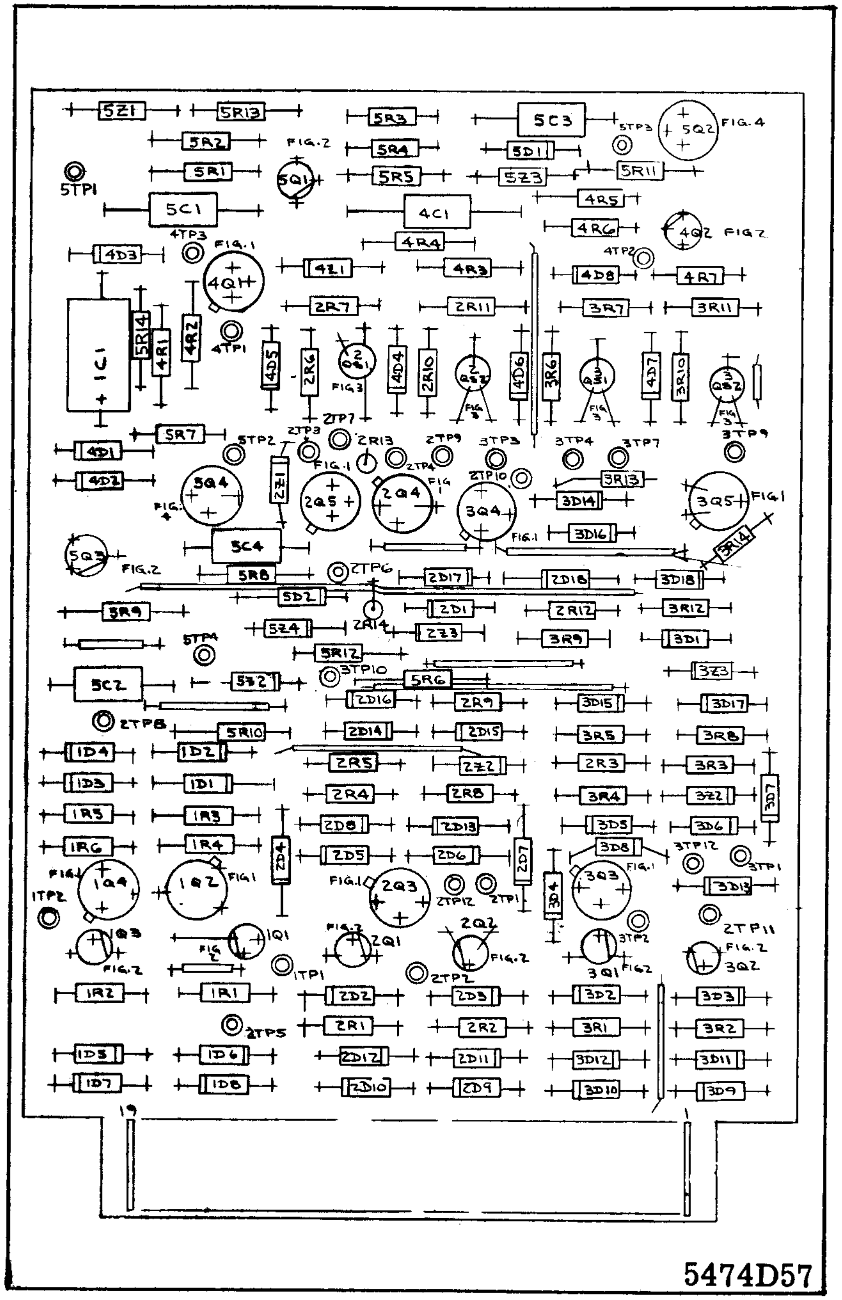
Fig. 7b. Internal Schematic of Type SP-1 Relay with Dual Output and AND Logic in Type FT-42 Case.



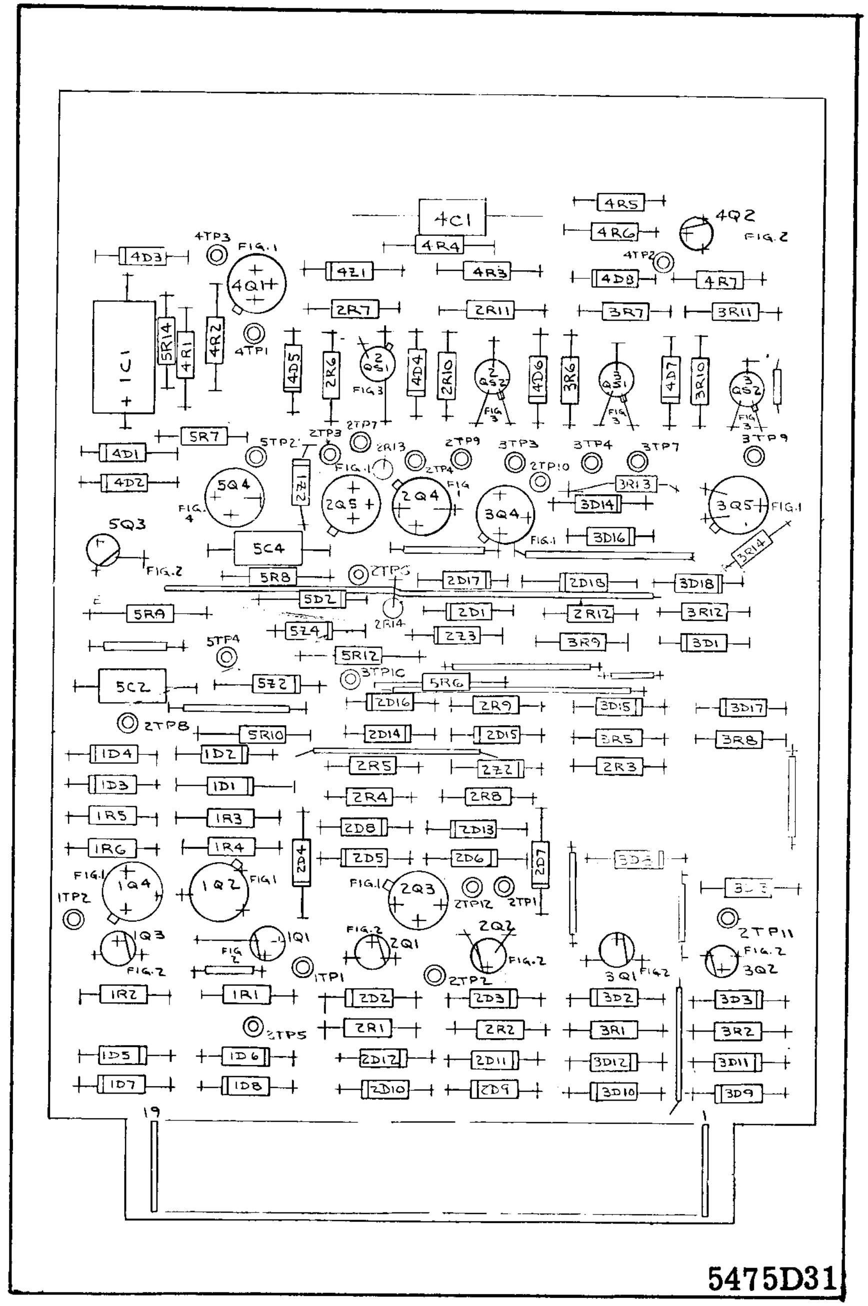
* Fig. 8a. Main Printed Circuit Board Assembly for Type SKD Relay.



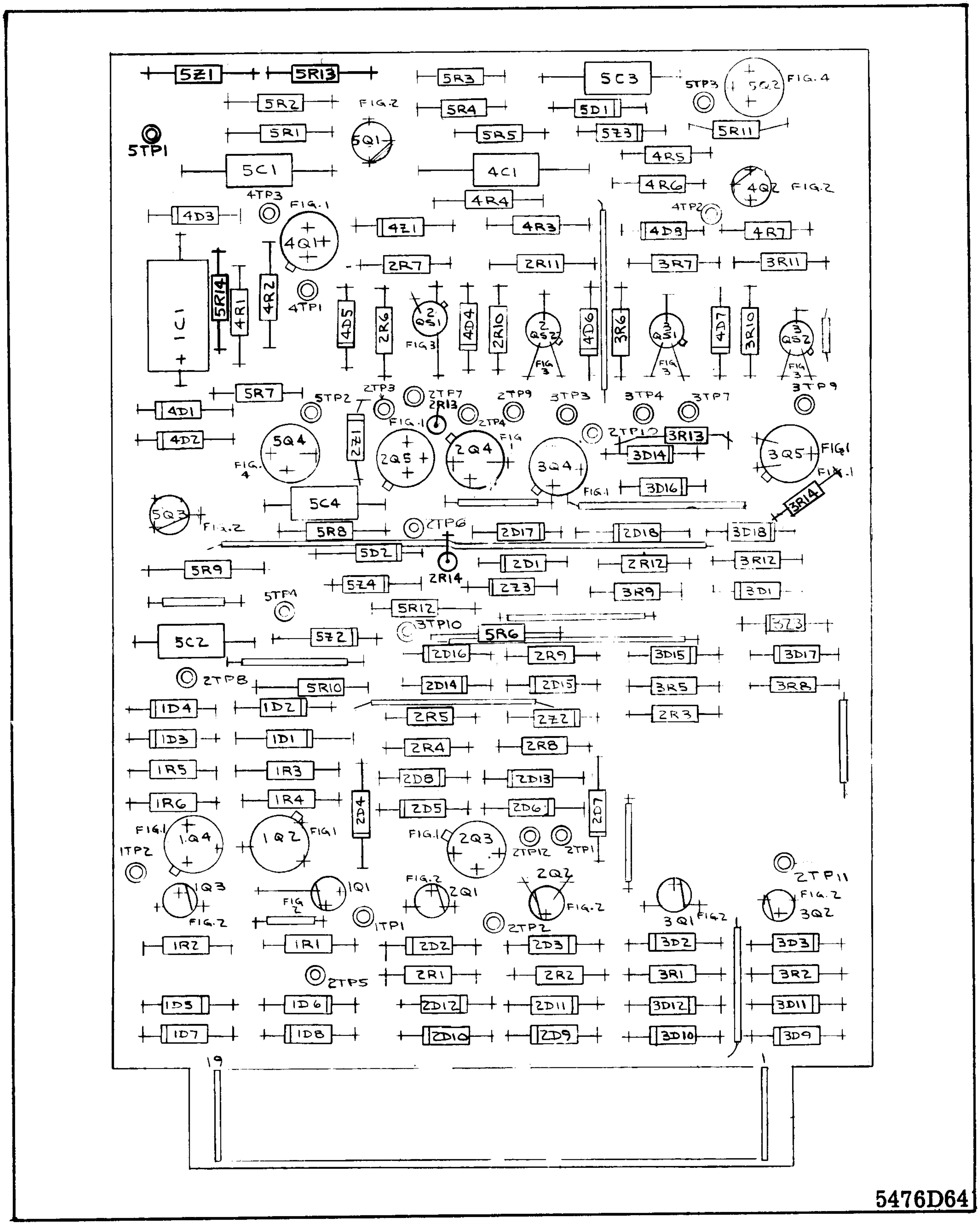
* Fig. 8b. Printed Circuit Board Assembly for Type SP Relay with Single Output.



* *Fig. 8c.* ***Printed Circuit Board Assembly for Type SP Relay with "AND" Supervised Dual Output.***

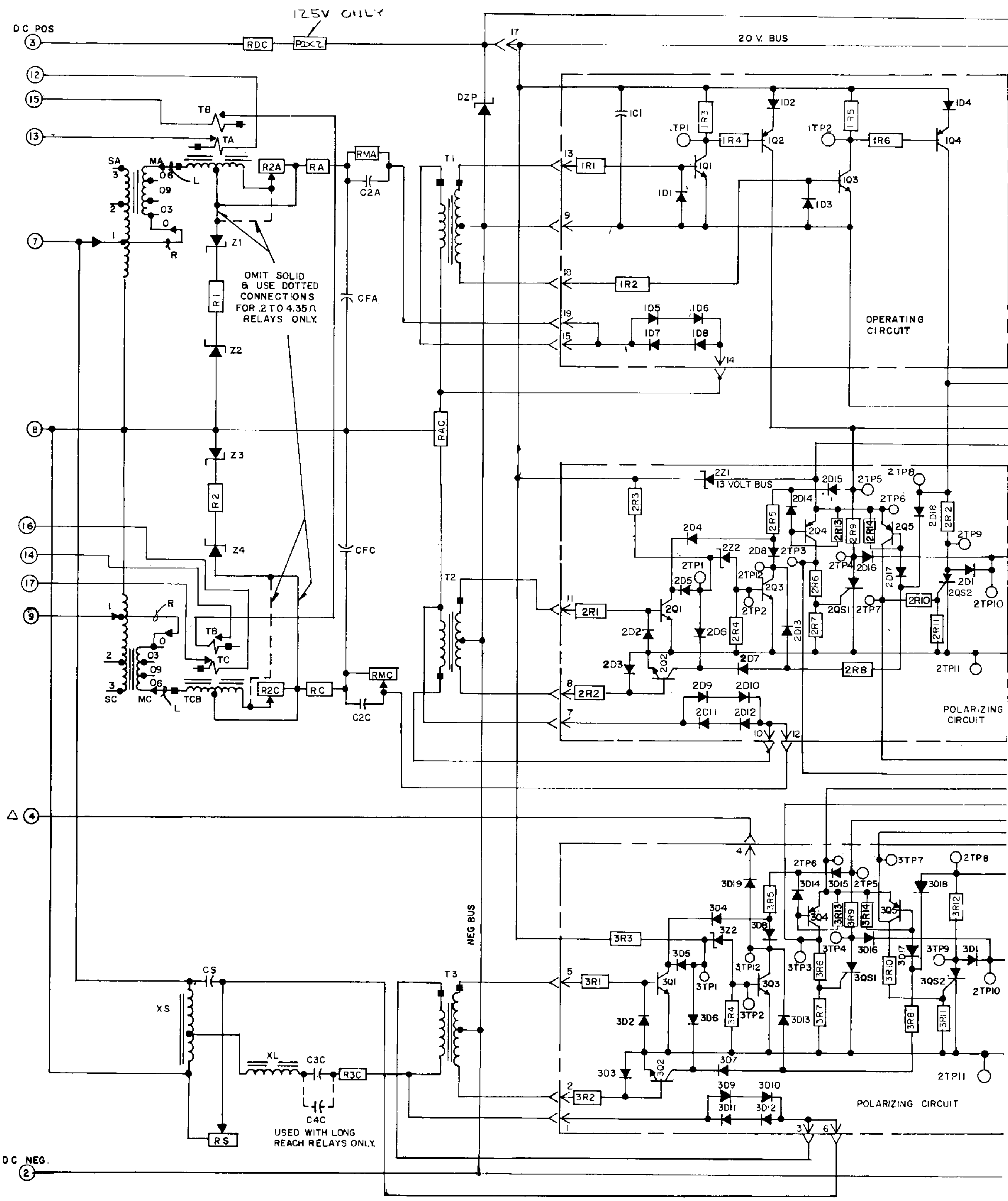


* *Fig. 8d.* ***Printed Circuit Board Assembly for Type SP-1 Relay with Single Output.***

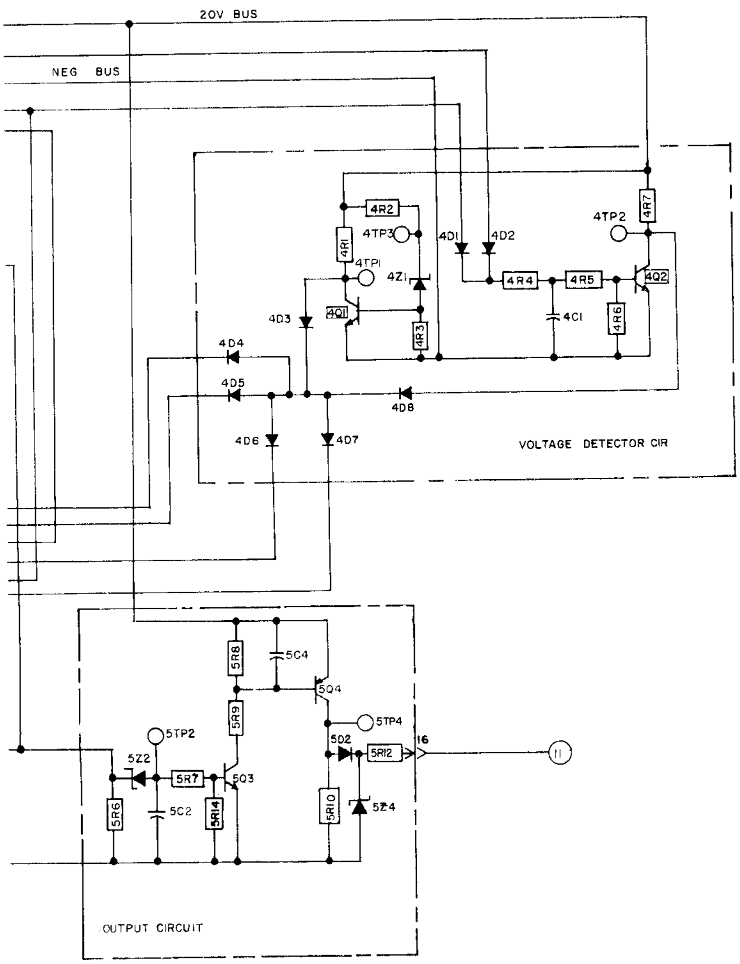


5476D64

* *Fig. 8e. Printed Circuit Board Assembly for Type SP-1 Relay with "AND" Supervised Dual Output.*



* *Fig. 9. Detailed Internal S*



RESISTOR	STYLE	REQ	REF	
2R7-2R11-3R7-3R11-2R9-2R12	184A763H37	9	2.7K	
3R9-3R12-4R1	"		"	
1R4-1R6-2R5-2R8-3R5-3R8 2R13-2R14-3R13-3R14	184A763H49	10	8.2K	
2R4-3R4	184A763H59	2	22K	
5R6	184A763H69	1	56K	
1R1-1R2-2R1-2R2-3R1-3R2-4R4 4R5	184A763H75	8	100K	
2R3-3R3	184A763H63	2	33K	
RDC (48V.D.C.-125VDC)	6448260H22	1	350Ω	
RAC	1955270	1	3550	
RDC2 125V.D.C.)	1267284	1	710Ω	
RMA	1201004	1	1.8K	
RS	1730900	1	7.1 K	
RA-RC	1201004	1	1.8K	
R3C	1202954	1	3K	
5R8-5R14	629A531H56	2	10K	
R1-R2	763A129H03	2	500Ω	
4R3-4R6	184A763H61	2	27K	
4R2	184A763H57	1	18K	
2R6-2R10-3R6-3R10	629A531H42	4	2.7K	
1R3-1R5	184A763H99	2	1MEG	
4R7	184A763H45	1	5.6K	
5R9	629A531H52	2	6.8K	
5R10	629A531H78	1	82K	
5R12	762A679H01	1	150Ω	
R2A-R2C	05D1328H22	2	900Ω	
RMC	05D1328H40	1	2500Ω	
5R7	629A531H63	1	20K	
ZENERDIODES				
5Z2-2Z1	186A797H12	2	IN752A	5.6 V.5%
DZP	762A631H01	1	IN2984B	20 V
Z1 TO Z4	184A854H08	4	IN2846A	200V10%
4Z1-2Z2-2Z3-3Z2	186A797H01		IN758	10 " "
5Z4	863A288H01	1	IN3688A	24 V
DIODES				
1D1 TO 1D8	188A342H06	56	CER 69	
2D1 TO 2D18	"		"	
3D1 TO 3D18	"		"	
4D1 TO 4D8 5D2	"		"	
CAPACITORS				
1C1	187A508H10	1	18 MFD	
C2A-C2C	14C9400H12	2	1.8 MFD	
5C4	188A699H05	1	.27 MFD	
CS	1723408	1	.45 MFD	
5C2	187A624H10	1	.015 MFD	
4C1	187A624H02	1	.25 MFD	
CFA-CFC	1876999	2	1 MFD	
C3C	18C6553H02	1	.225 MFD	
C4G	1725974	1	.03 MFD	
TRANSISTOR				
1Q1-1Q3-2Q1-4Q2-2Q2-3Q1-3Q2	848A851H01	7	2N3391	
2Q3-3Q3-4Q1	184A638H18	3	2N697	
1Q2-1Q4-2Q4-2Q5-3Q4-3Q5	184A638H20	6	2N1132	
5Q2	849A441H01	1	2N3645	
5Q3	848A851H02	1	2N3417	
TRANSFORMER				
T1-T2-T3		3	292B563G05	
SWITCH				
2QS1-2QS2-3QS1-3QS2	185A517H05	4	2N884	

= BOX INDICATES NORMALLY CONDUCTING TRANSISTOR

○ = RELAY TERMINAL

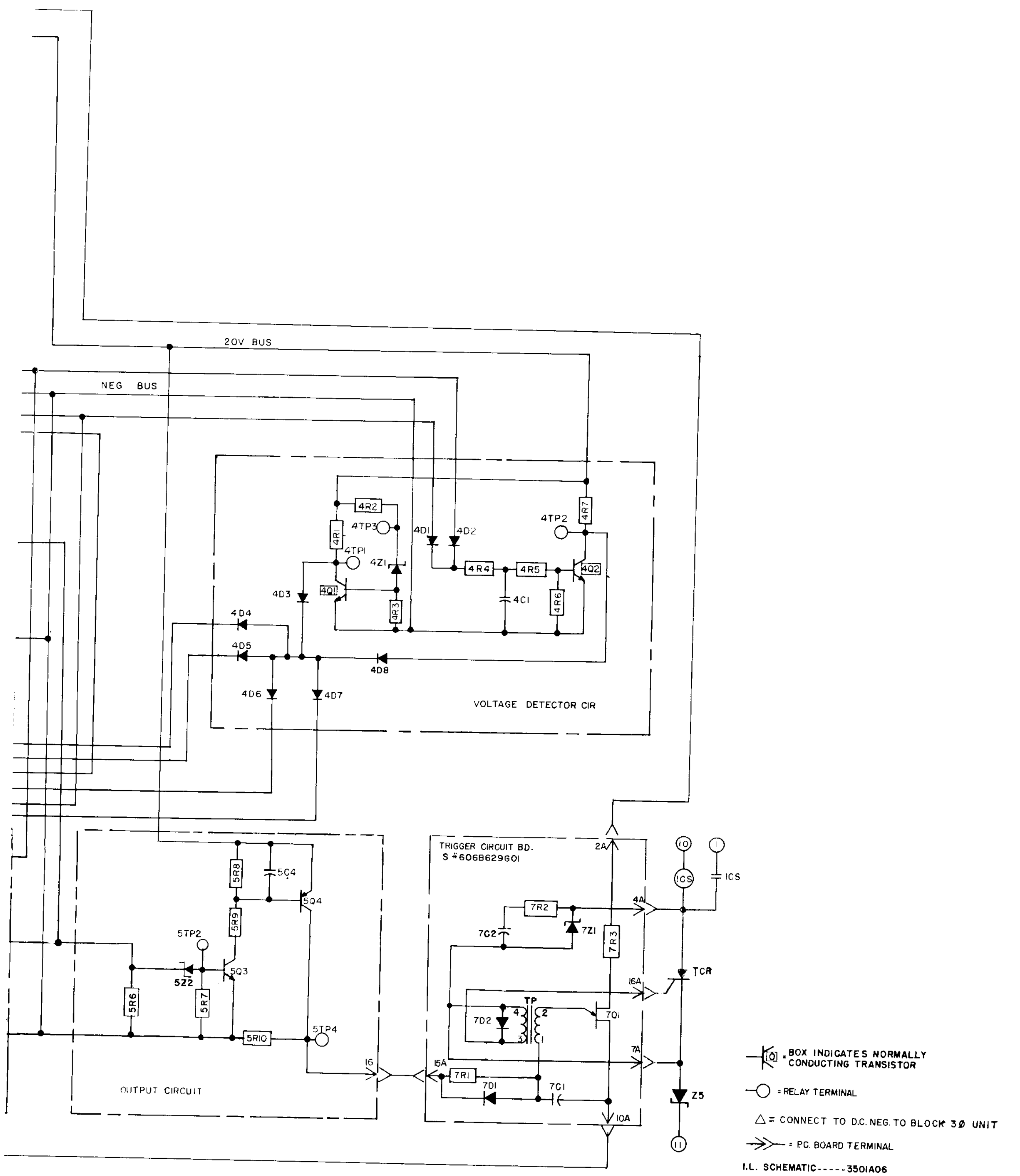
△ - CONNECT TO D.C. NEG. TO BLOCK 3Ø UNIT

✱ ✱ = +15 TO +20 VOLTS D.C. REFERRED TO D.C. NEG.

→≫— = P.C. BOARD TERMINAL

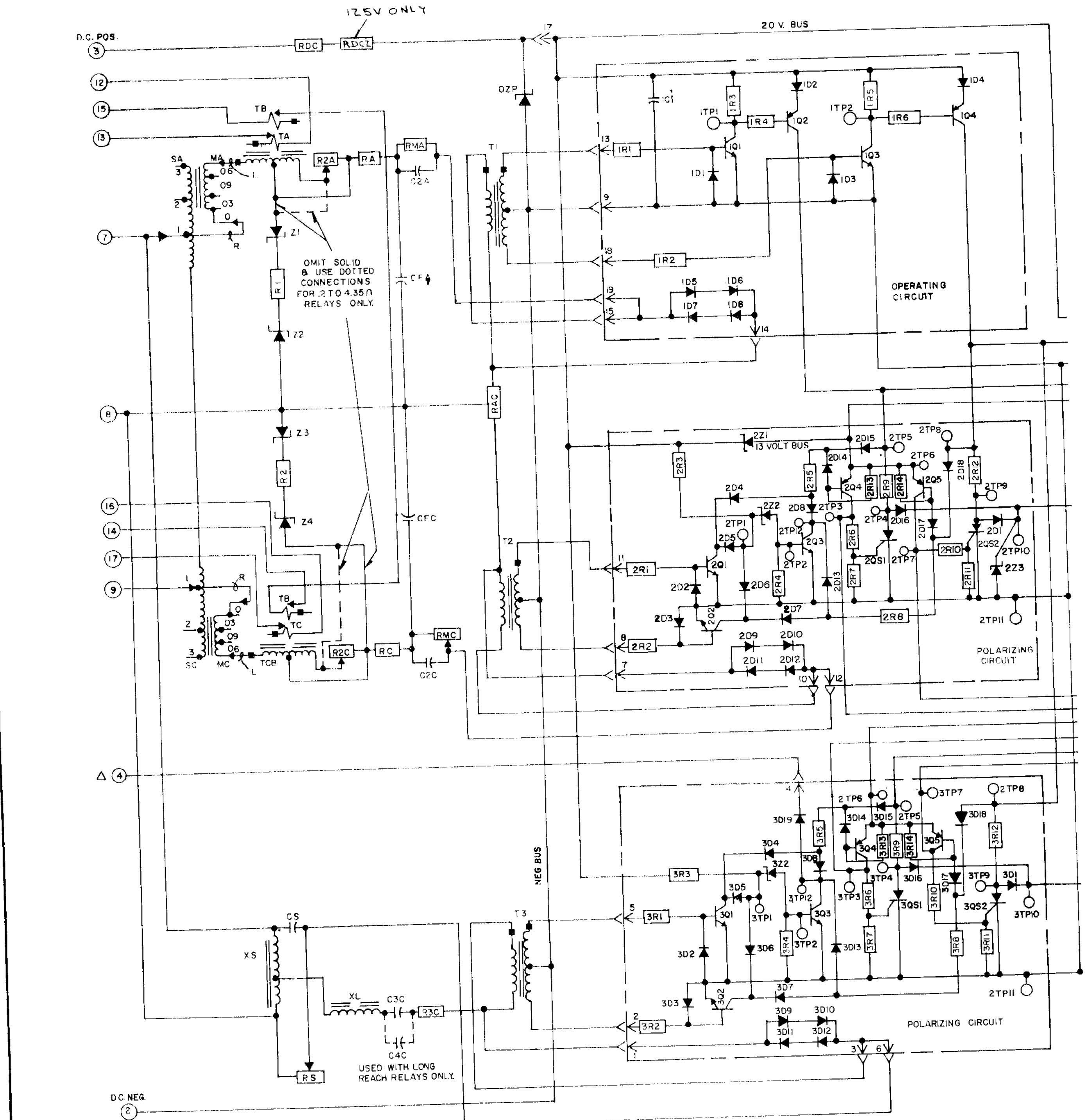
5475D32

rnal Schematic of SP Relay.

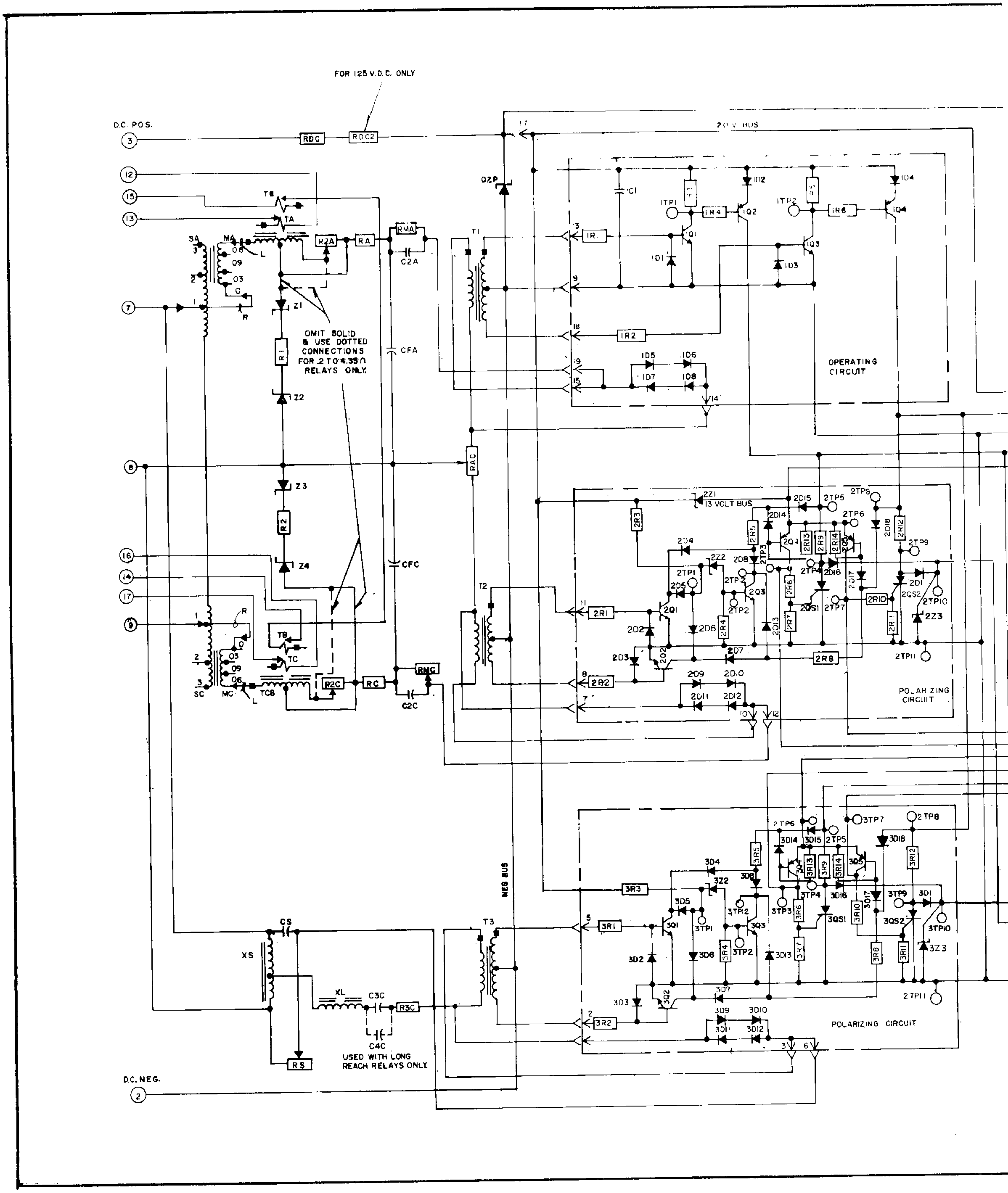


5475D01

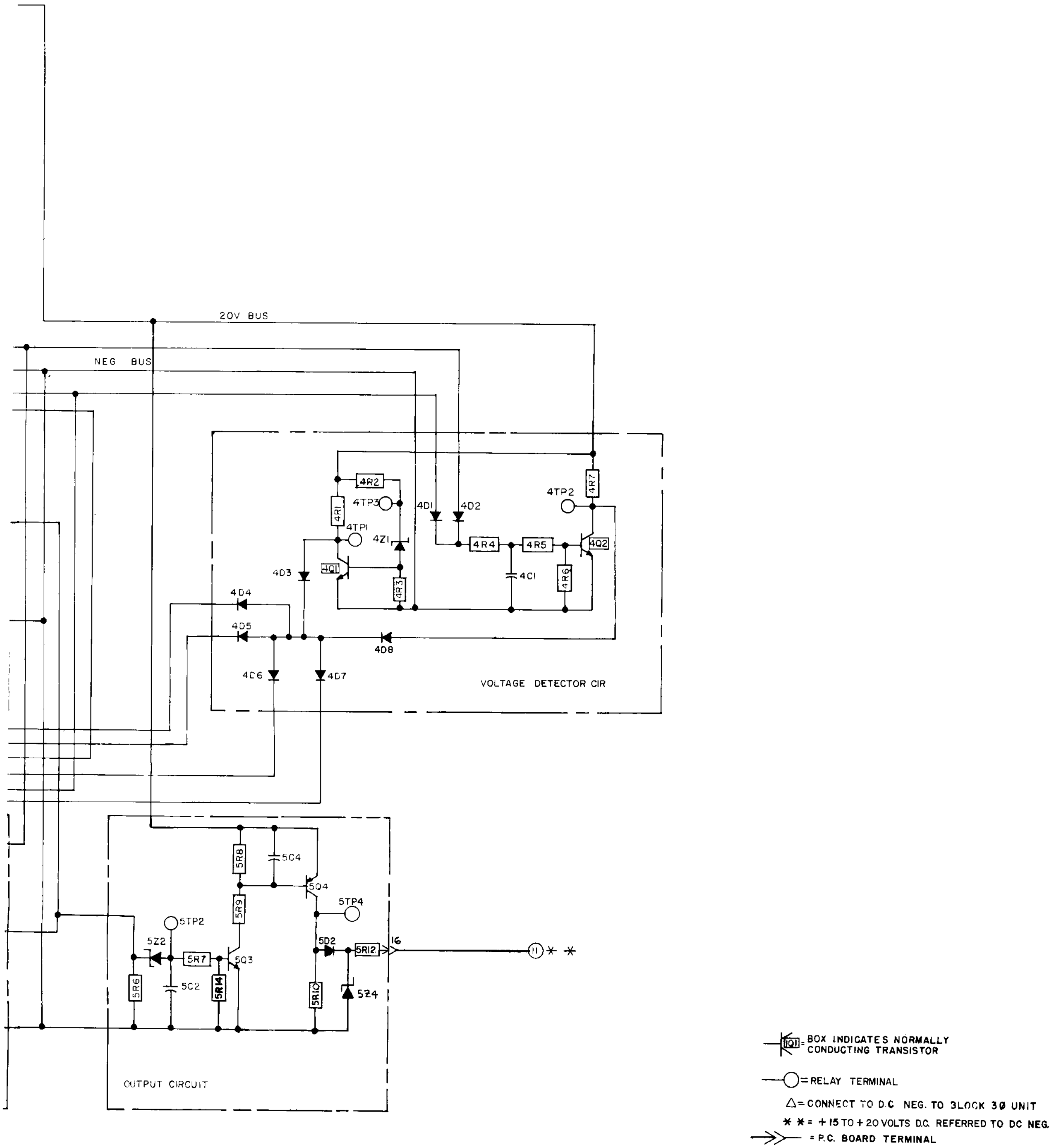
'chematic of SKD Relay.



*** Fig. 10a. Detailed Inte**

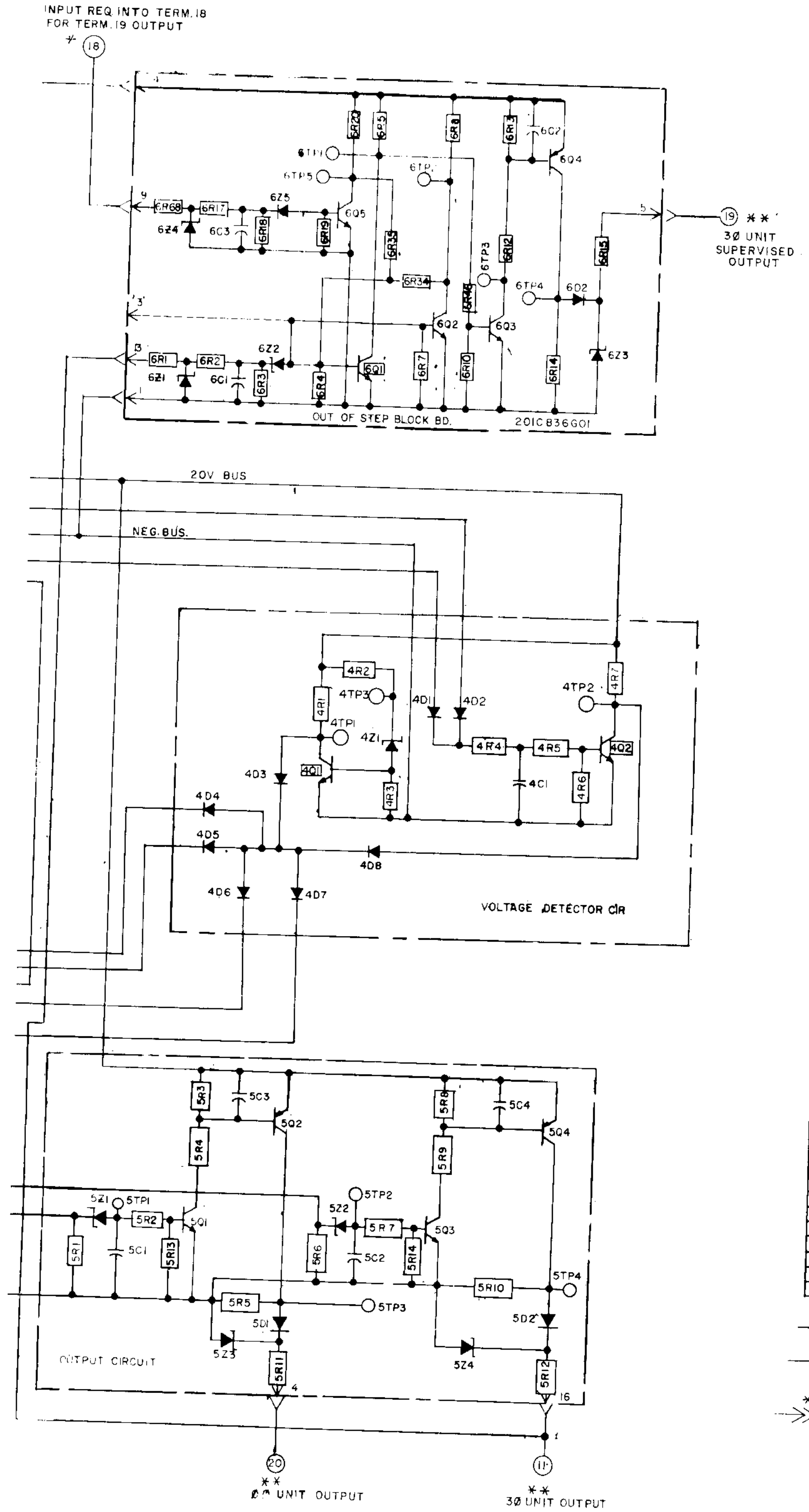


* *Fig. 10b. Detailed Internal Schematic of SP Relay wi*



5475D33

Internal Schematic of SP-1 Relay.



RESISTOR	STYLE	REQ	REF	
2R7-2R11-3R7-3R11-2R9-2R12	184A763H37	9	2.7K	
3R9-3R12-4R1	"		"	
1R4-1R6-2R5-2R8-3R5-3R8 2R13-2R14-3R13-3R14	184A763H49	10	8.2K	
2R4-3R4	184A763H59	2	22K	
5R1- 5R6	184A763H69	2	56K	
1R1-1R2-2R1-2R2-3R1-3R2-4R4 4R5	184A763H75	8	100K	
2R3-3R3	184A763H63	2	33K	
RDC 48 & 125V	644B260H22	1	350Ω	48VDC
RAC	1955270	1	3550	
RDC2 125V	1267284	1	710Ω	125VDC
RMA	1201004	1	1.8K	
RS	1730906	1	10K	
RA-RC	1201004	1	1.8K	
R3C	1202954	1	3K	
5R3-5R8-5R13-5R14	629A531H56	4	10K	
R1-R2	763A129H03	2	500Ω	
4R3-4R6	184A763H61	2	27K	
4R2	184A763H57	1	18K	
2R6-2R10-3R6-3R10	629A531H42	4	2.7K	
1R3-1R5	184A763H99	2	1MEG	
4R7	184A763H45	1	5.6K	
5R4-5R9 6R12-6R34-6R35-6R46	629A531H52	6	6.8K	
5R5 5R10 6R3 6R18	629A531H78	4	82K	
6R1 6R2 6R17 6R68	629A531H48	4	4.7K	
6R15	762A679H01	1	150Ω	
6R4 6R7 6R10 6R13 6R14 6R19	629A531H56	6	10K	
6R5 6R8 6R20	629A531H66	3	27K	
R2A R2C	05D1328H22	2	900Ω	
RMC	05D1328H40	1	2500Ω	
5R11-5R12	762A679H01	1	150Ω	
5R2-5R7	629A531H63	2	20K	
ZENER DIODES				
5Z1 5Z2-2Z1	186A797H12	3	1N752A	5.6V 5%
6Z2 6Z5	186A797H06	2	1N957B	6.8V "
DZP	762A631H01	1	1N2984B	20V "
Z1 TO Z4	184A854H08	4	1N2846A	200V 10%
4Z1-2Z2-2Z3-3Z2-3Z3	186A797H01	5	1N758	10 V "
5Z3 5Z4 6Z3	863A288H01	3	1N3688A	24 V "
6Z1 6Z4	185A212H06	2	1N3686B	
DIODES				
1D1 TO 1D8 2D1 TO 2D18	188A342H06	56	CER 69	
3D1 TO 3D3 3D9 TO 3D12	"		"	
3D15 TO 3D18	"		"	
4D1 TO 4D8 5D2	"		"	
6D2	"		"	
	837A692H03	1	1N645A	
CAPACITORS				
1C1	187A508H10	1	18 MFD	
C2A-C2C	14C9400H12	2	1.8 MFD	
5C3 5C4 6C2	188A699H05	3	.27 MFD	
CS	1723408	1	.45 MFD	
5C1 5C2	187A624H10	1	.015 MFD	
4C1	187A624H02	1	.25 MFD	
CFA-CFC	1876999	2	1 MFD	
C3C	1724191	1	0.3 MFD	
C4C	1725974	1	.03 MFD	
6C1 6C3	849A437H04	2	.047 MFD	
TRANSISTOR				
1Q1-1Q3-2Q1-4Q2-2Q2-3Q1-3Q2	848A851H01	7	2N3391	
2Q3-3Q3-4Q1	184A638H18	3	2N697	
1Q2-1Q4-2Q4-2Q5-3Q4-3Q5	184A638H20	6	2N1132	
5Q2 5Q4 6Q4	849A441H01	3	2N3645	
5Q3 5Q1 6Q1 6Q2 6Q3 6Q5	848A851H02	6	2N3417	
TRANSFORMER				
T1-T2-T3	292B563G05	3		
SWITCH				
20S1-20S2-30S1-30S2	185A517H05	4	2N884	

[box symbol] = BOX INDICATES NORMALLY CONDUCTING TRANSISTOR

○ = RELAY TERMINALS

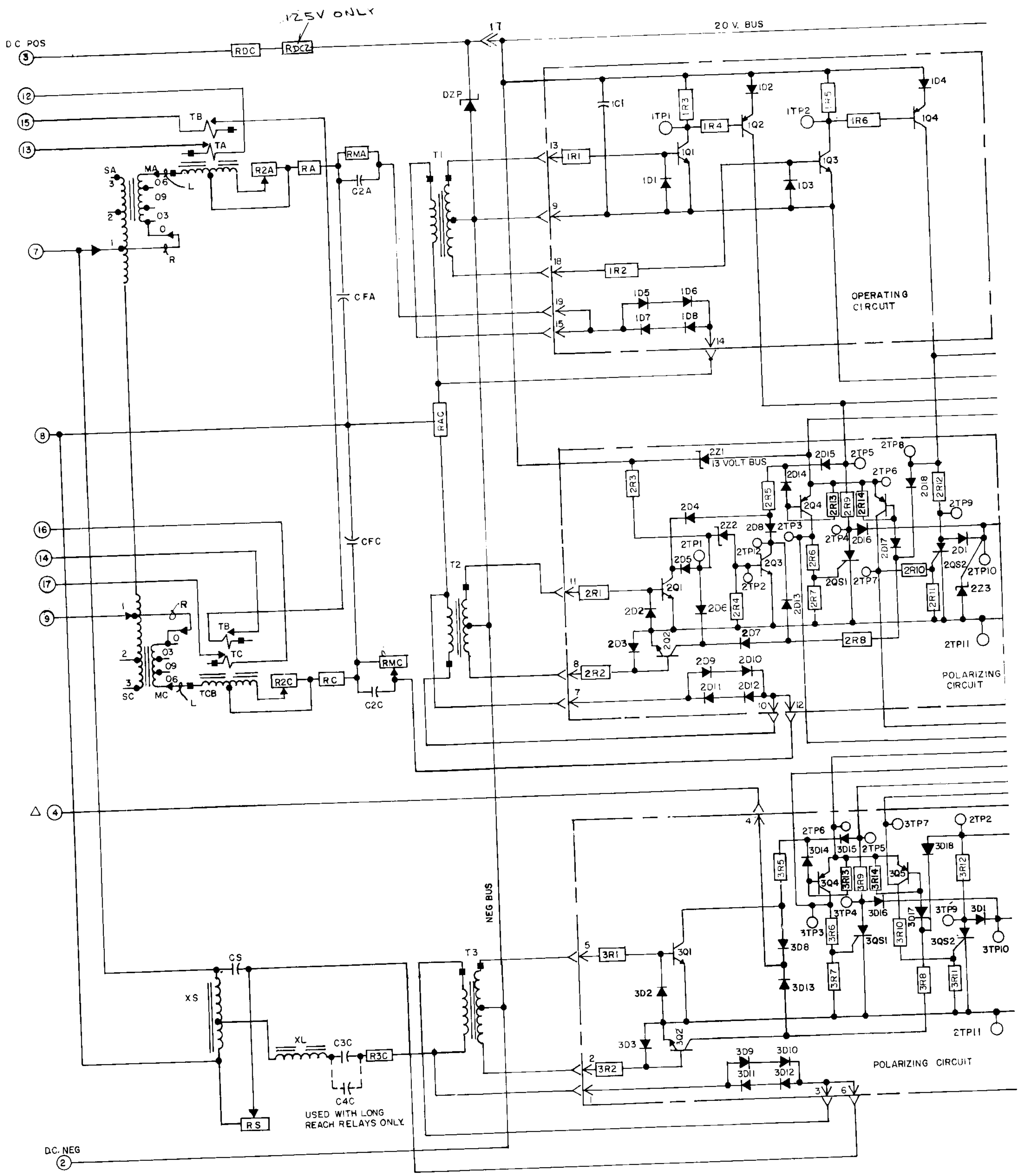
* = +12 TO +20 VOLTS DC REQ FOR INPUT

** = +15 TO +20 VOLTS D.C. REFERRED TO DC NEG.

>> = P.C. BOARD TERMINAL

5476D66

th Dual Output and "AND" Logic.



*** *Fig. 11a. Detailed***

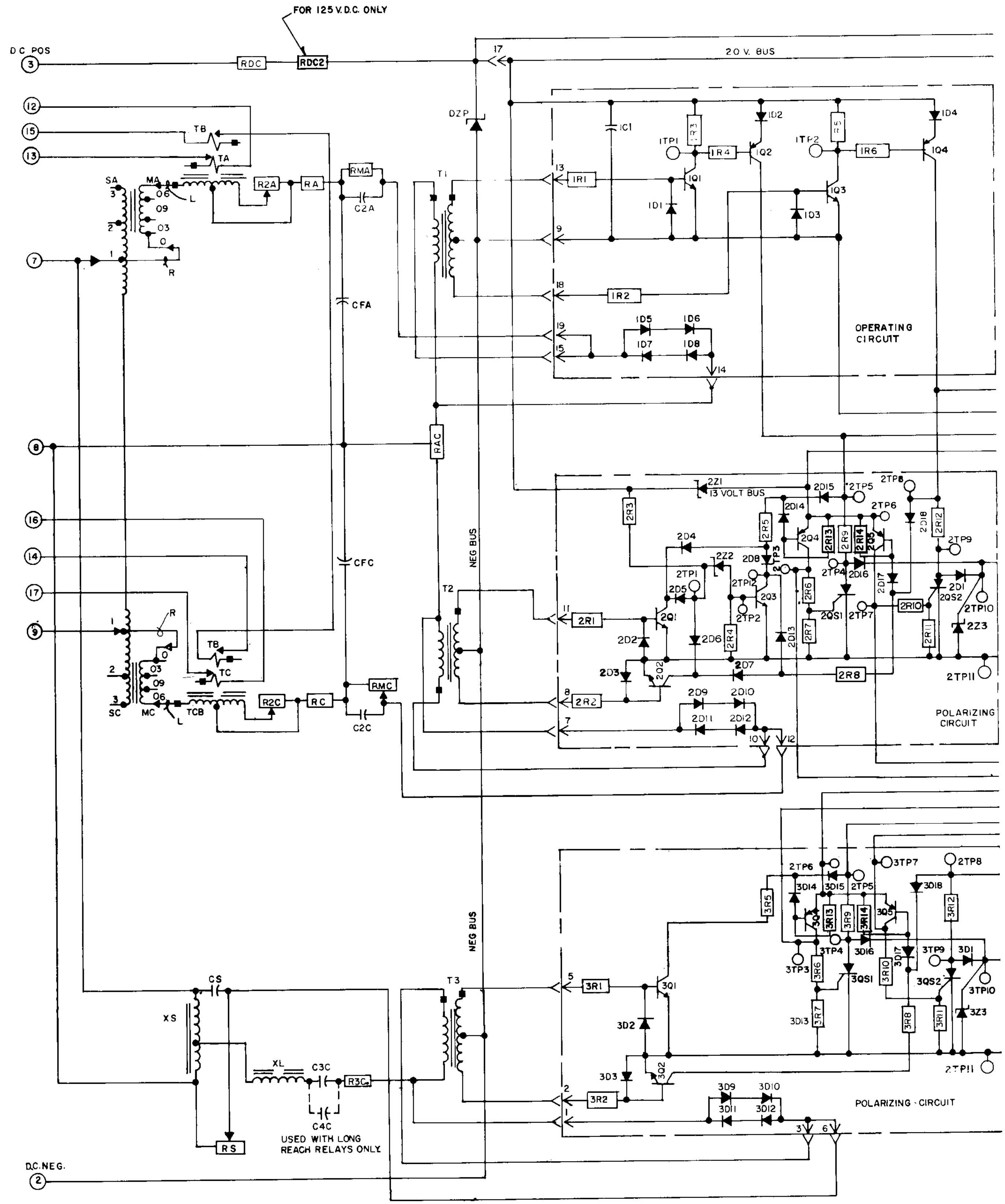
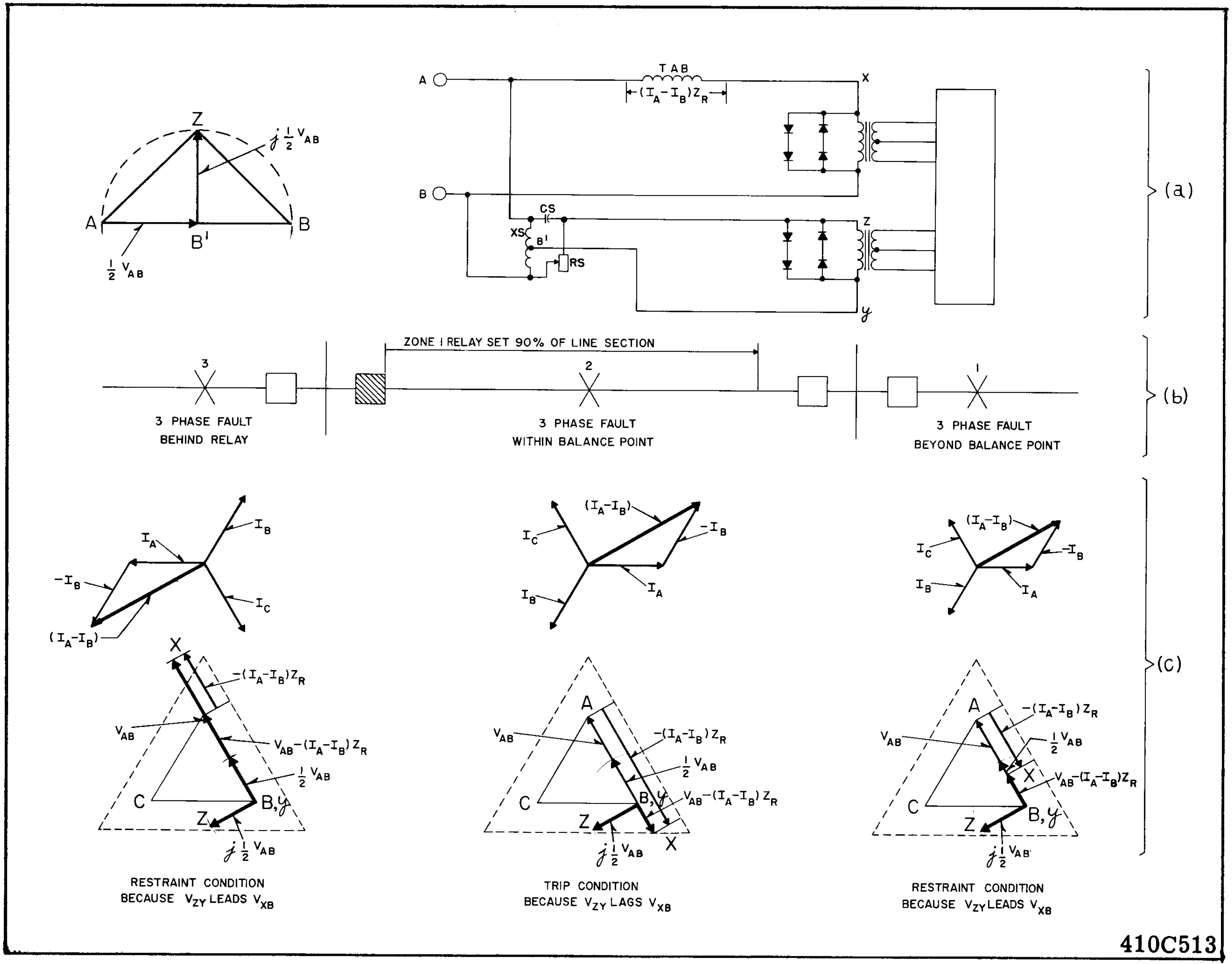
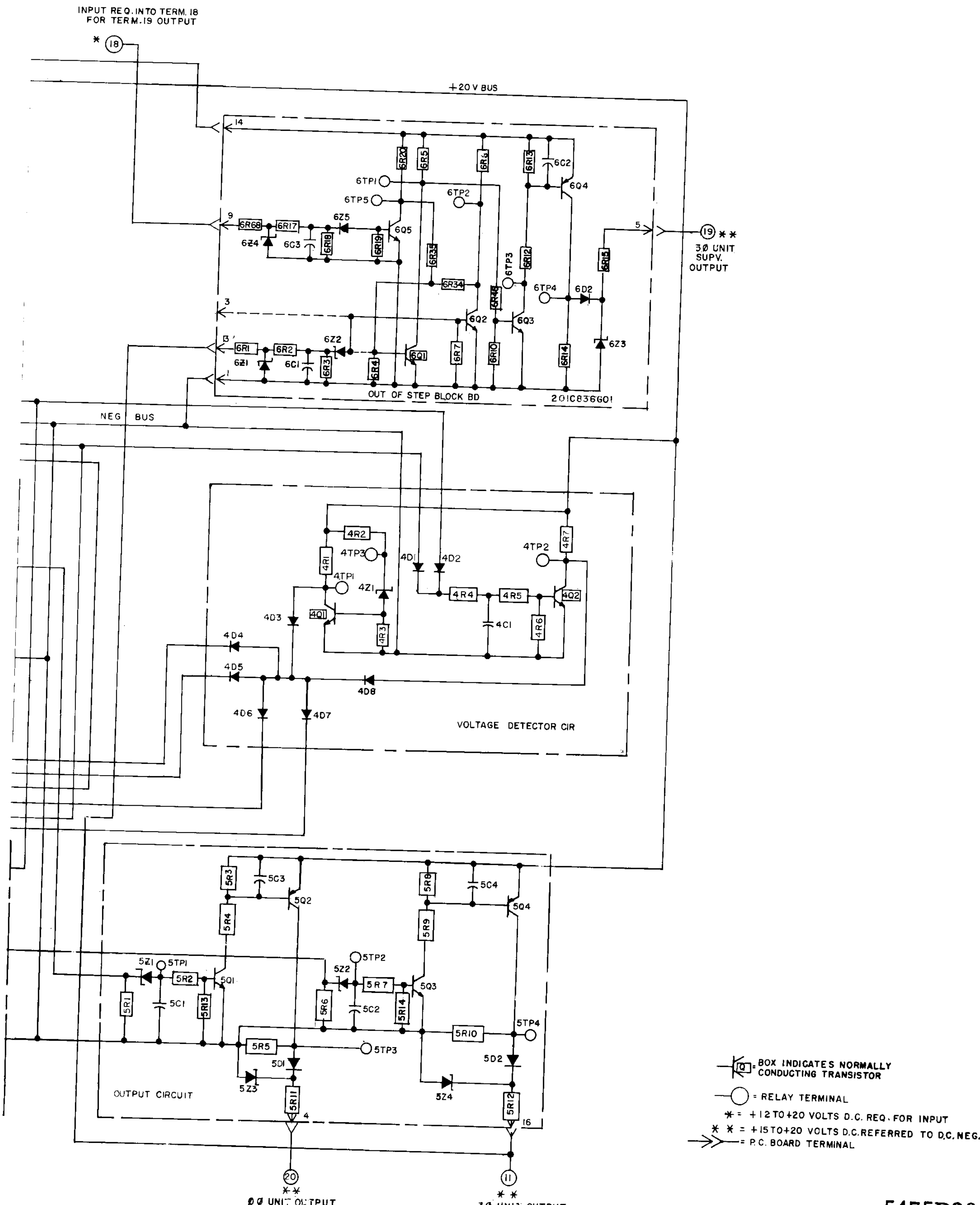


Fig. 11b. Detailed Internal Schematic of SP-1

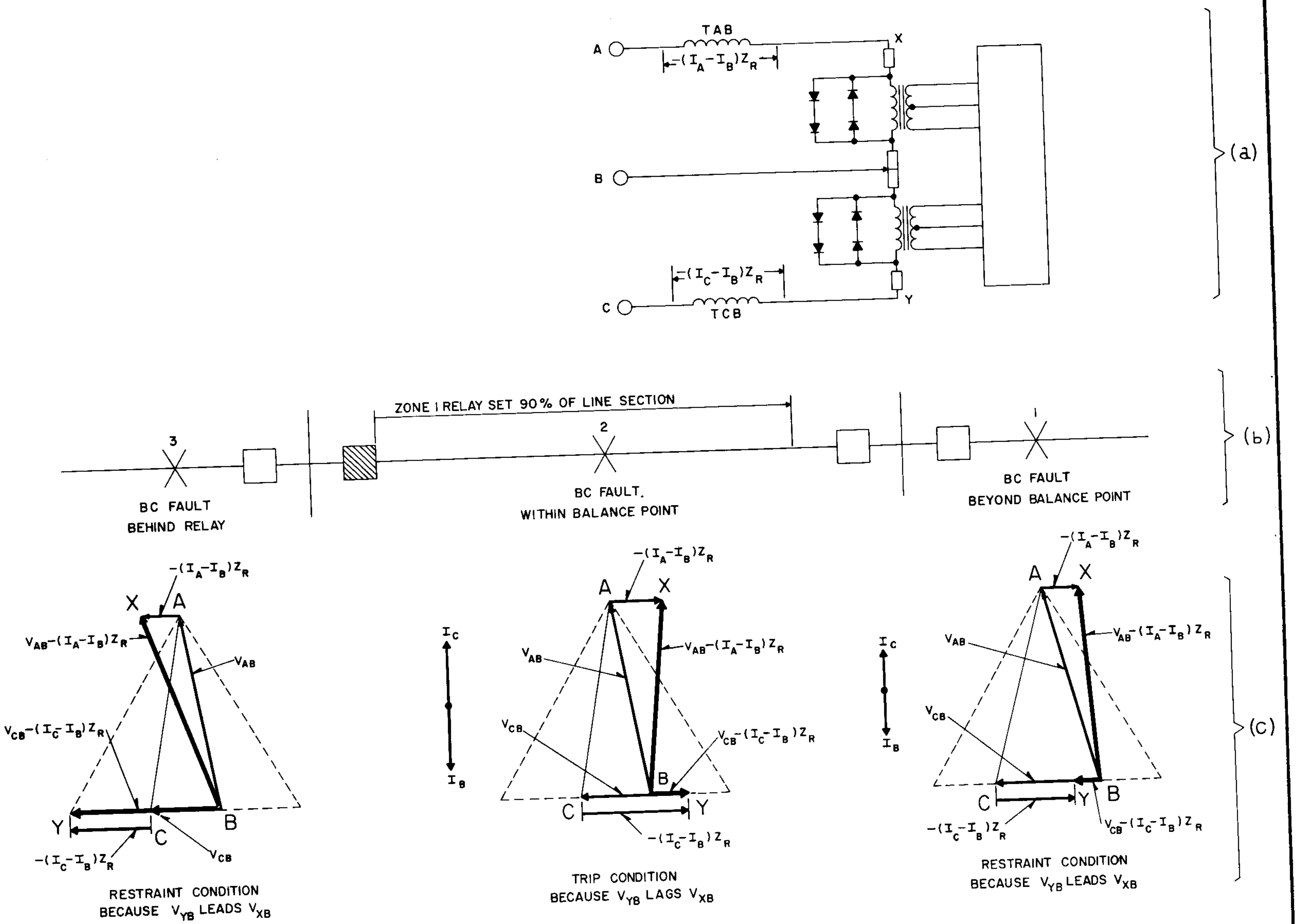
Fig. 12. Voltage and Current Conditions for the Phase-to-Phase Unit.



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



Relay with Dual Output and "AND" Logic.



(a)
A
B
C
TAB
TCB
X
Y
$-(I_A-I_B)Z_R$
$-(I_C-I_B)Z_R$
(b)
ZONE I RELAY SET 90% OF LINE SECTION
3
2
1
BC FAULT BEHIND RELAY
BC FAULT. WITHIN BALANCE POINT
BC FAULT BEYOND BALANCE POINT
(c)
$-(I_A-I_B)Z_R$
$V_{AB}-(I_A-I_B)Z_R$
V_{AB}
$V_{CB}-(I_C-I_B)Z_R$
V_{CB}
$-(I_C-I_B)Z_R$
I_B
I_C
RESTRAINT CONDITION BECAUSE V_{YB} LEADS V_{XB}
TRIP CONDITION BECAUSE V_{YB} LAGS V_{XB}
RESTRAINT CONDITION BECAUSE V_{YB} LEADS V_{XB}
410C512

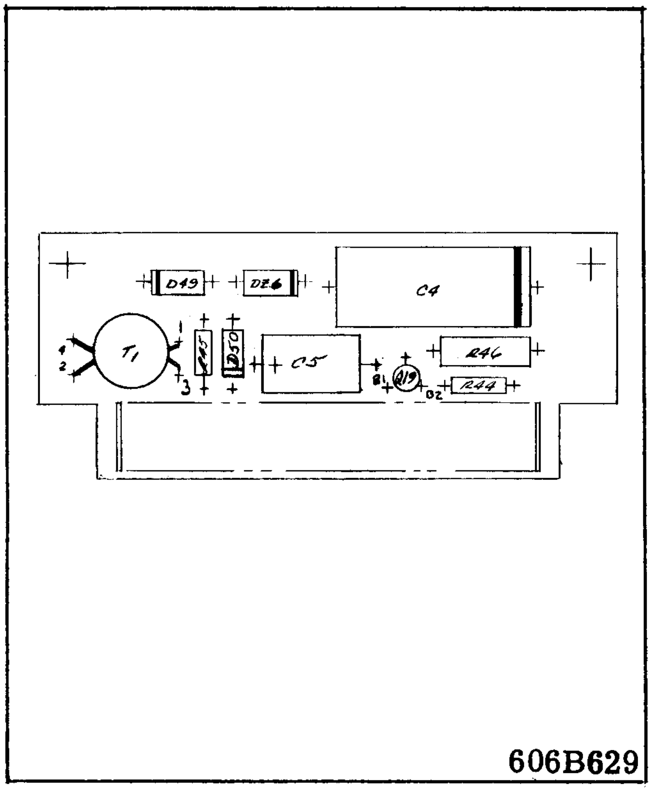


Fig. 14a. Printed Circuit Board Trigger Circuit for SKD Relay.

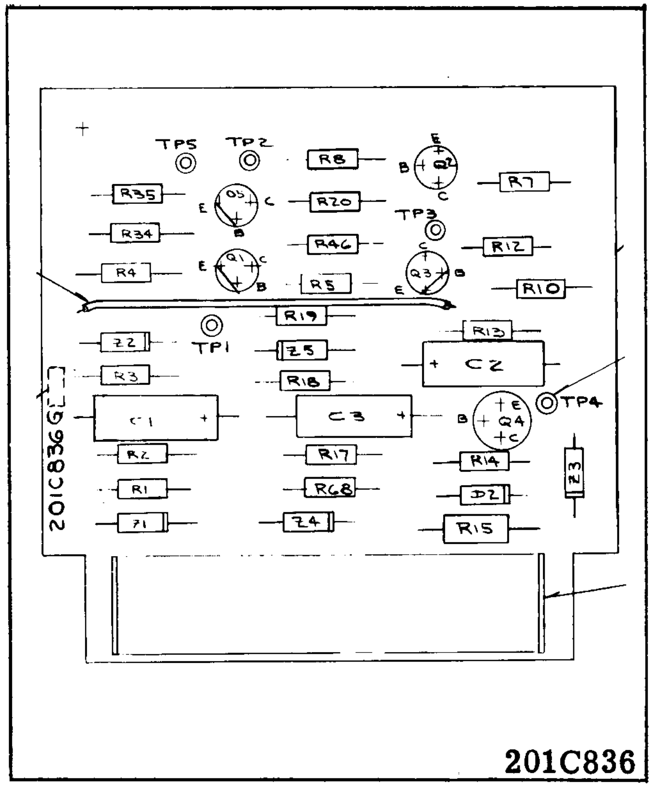


Fig. 14b. Printed Circuit Board "AND" Logic for SP and SP-1 Relays.

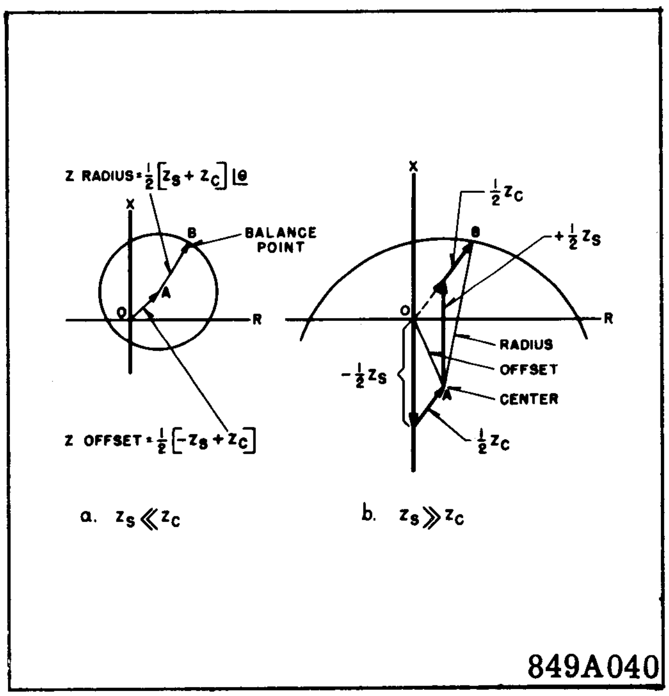


Fig. 15. Impedance Circles for Phase-to-Phase Unit in Types SKD, SP, and SP-1 Relays.

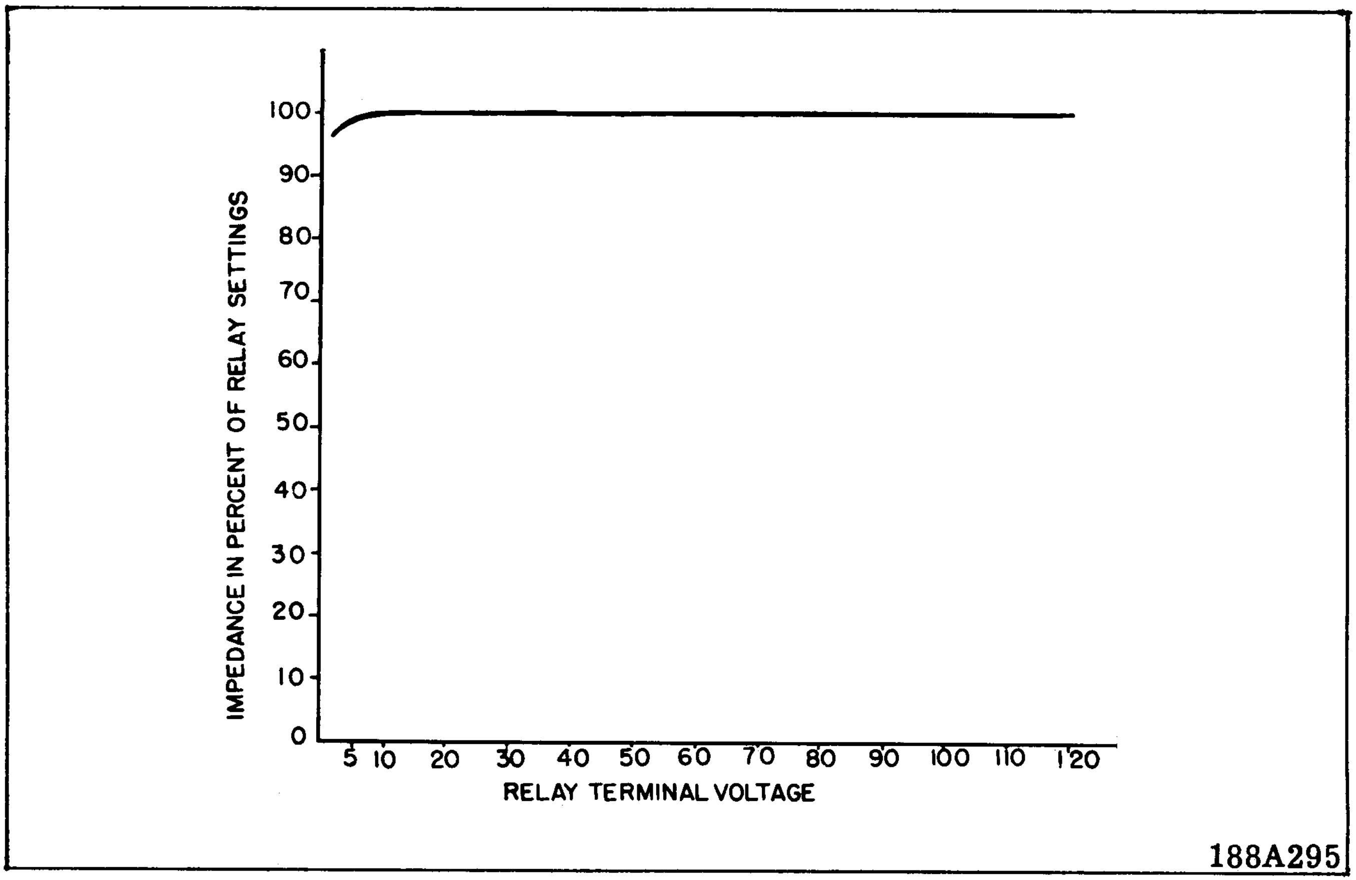


Fig. 16. Impedance Curves for Types SKD, SP, and SP-1 Relays.

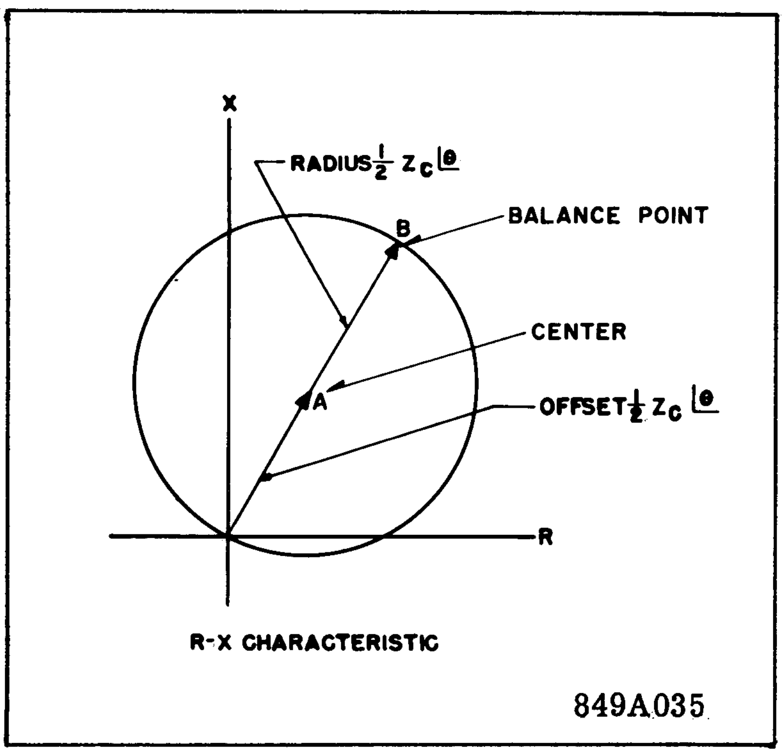


Fig. 17. Impedance Circle for Three-Phase Unit in Types SKD and SP Relays.

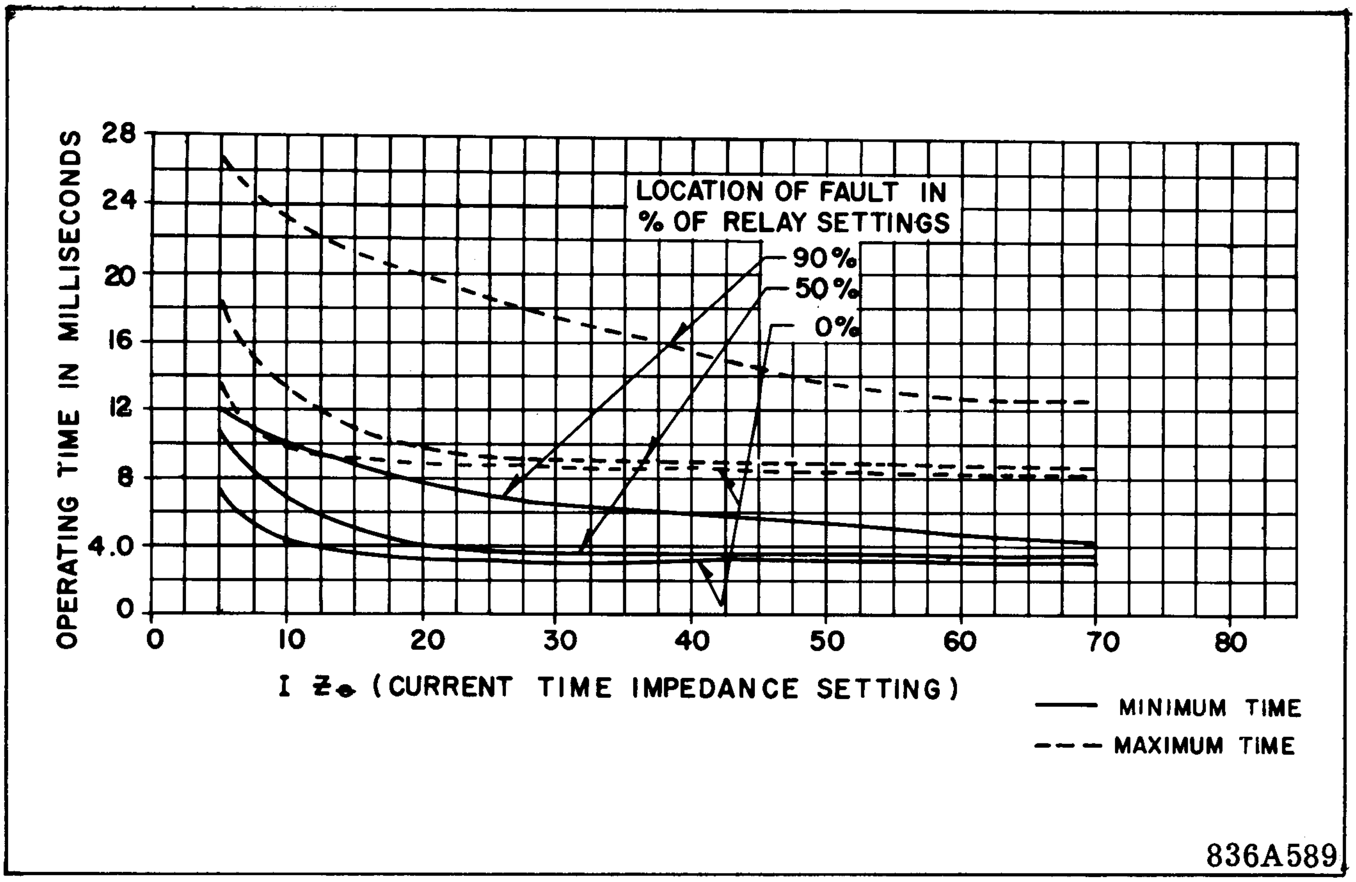
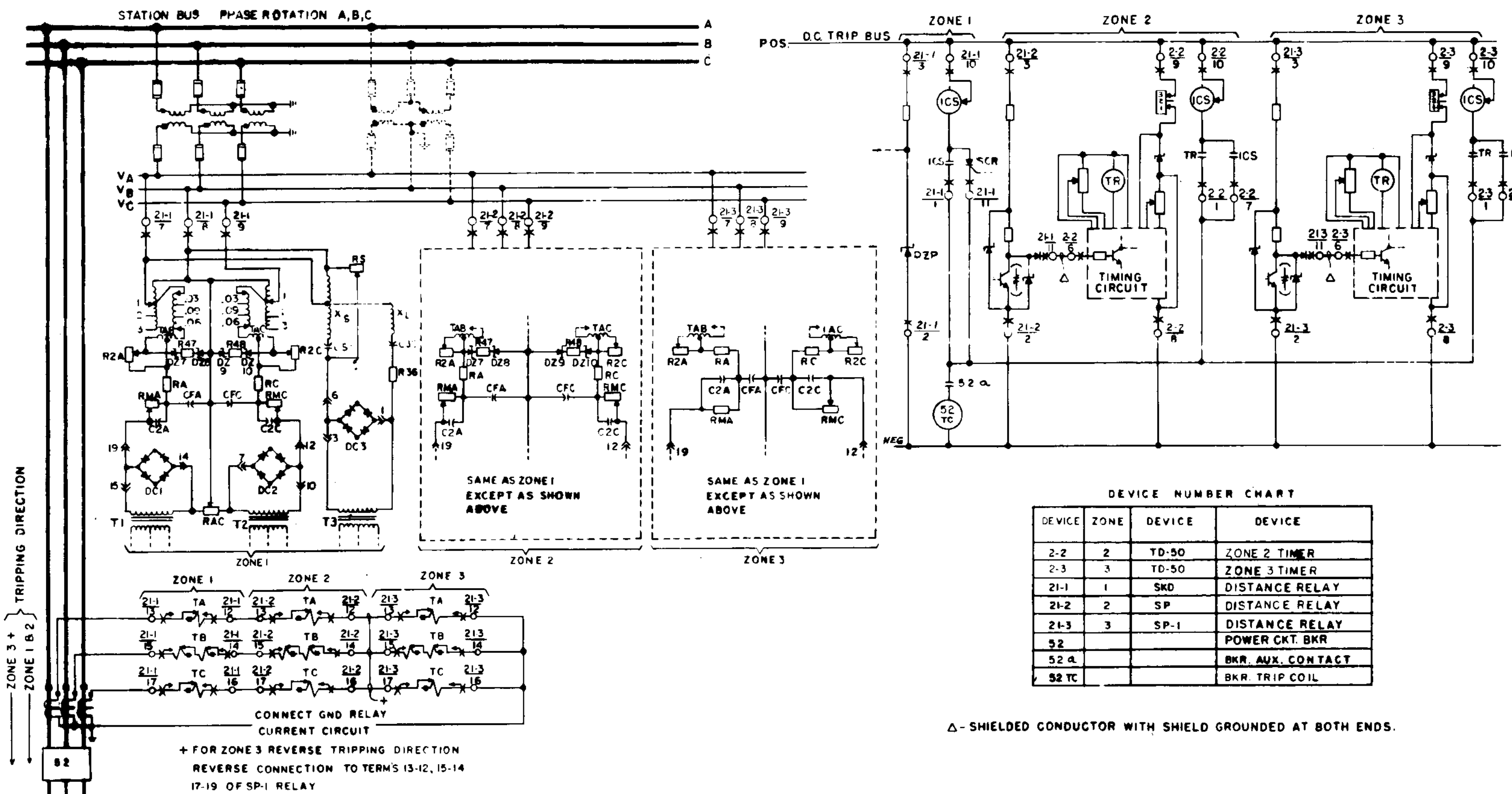


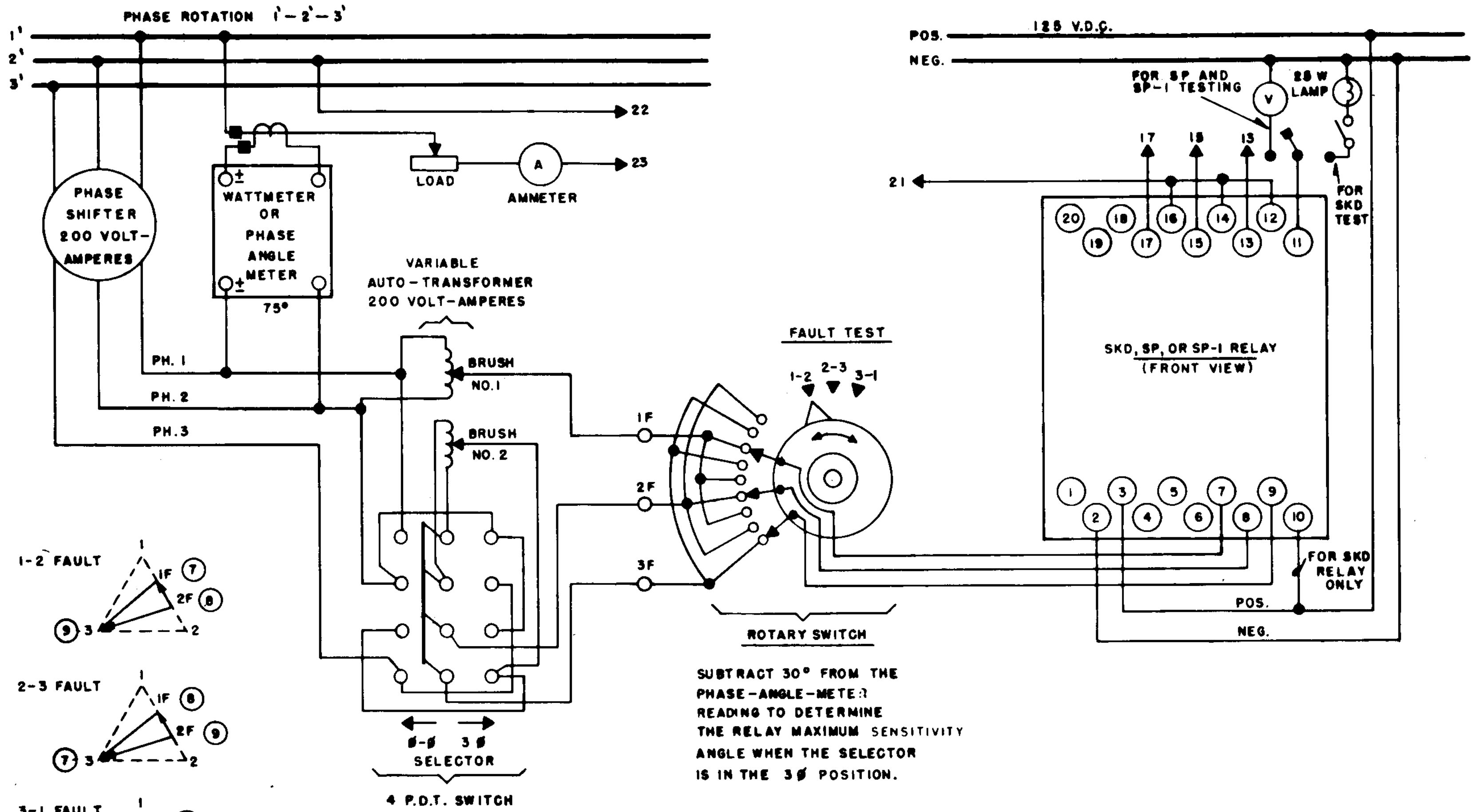
Fig. 18. Typical Operating Time Curves for SKD, SP, and SP-1 Relays. Normal Voltage Before the Fault is 120 Volts.



DEVICE NUMBER CHART

DEVICE	ZONE	DEVICE	DEVICE
2-2	2	TD-50	ZONE 2 TIMER
2-3	3	TD-50	ZONE 3 TIMER
21-1	1	SKD	DISTANCE RELAY
21-2	2	SP	DISTANCE RELAY
21-3	3	SP-1	DISTANCE RELAY
52			POWER CKT. BKR
52 a			BKR. AUX. CONTACT
52 TC			BKR. TRIP COIL

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	3ϕ	1-2	R_{2A}	23/13	22/21
4	3ϕ	3-1	R_{2C}	23/17	22/21
5	ϕϕ	1-2	RS	23/13	22/15
6	ϕϕ	2-3	CHECK	23/15	22/17
7	ϕϕ	3-1	R_{HC} & R_{AC}	23/17	22/13

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

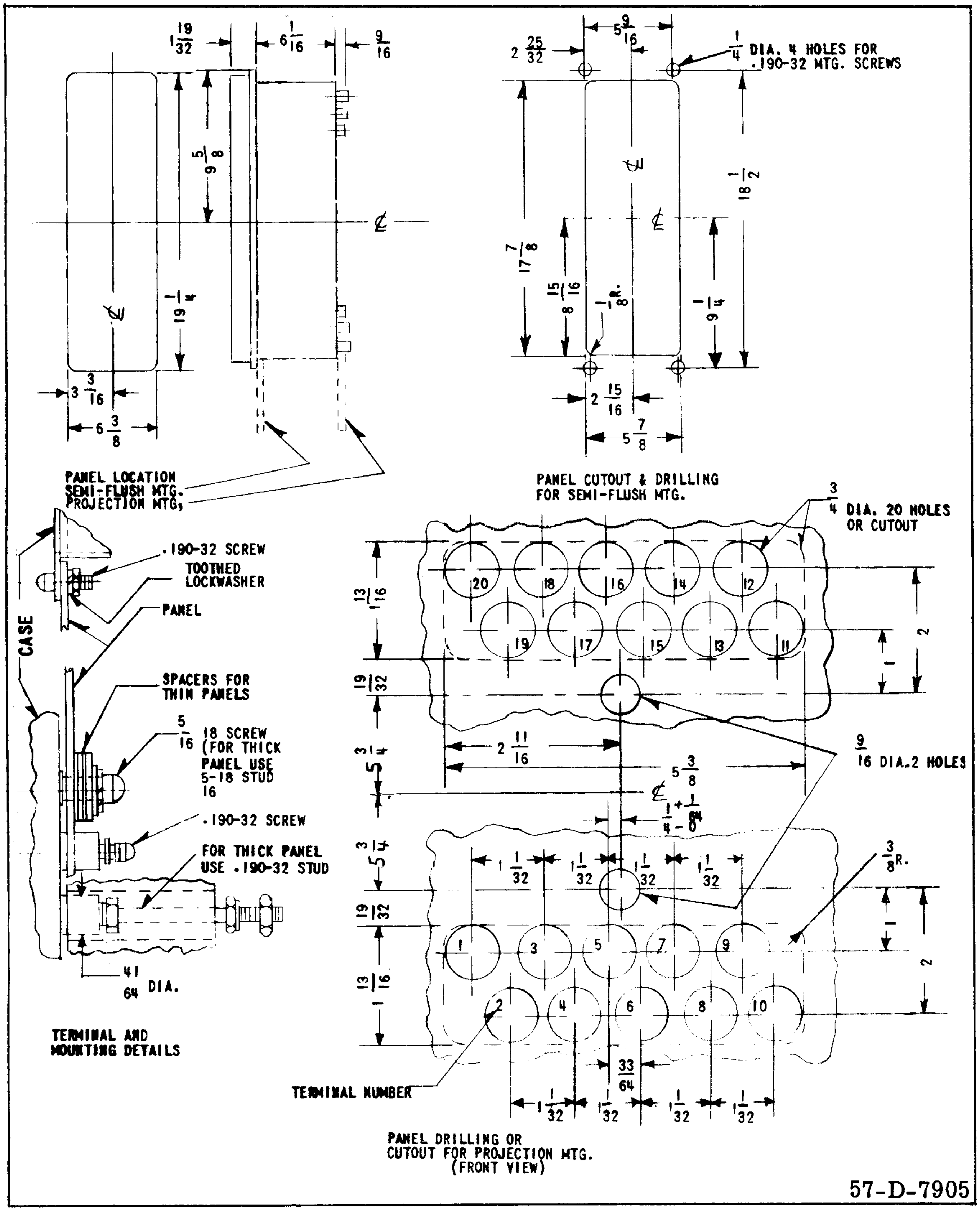

Fig. 21. Outline and Drilling Plan for Types SKD, SP, and SP-1 Relays in Type FT-42 Case.