INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKDU AND SKDU-1 COMPENSATOR DISTANCE RELAYS

APPLICATION

The type SKDU relay, Figure 1, is a polyphase compensator-type distance relay which provides a single zone of phase protection for all three phases. It has a mho circle characteristic when plotted on an R + jX diagram. Logic may be specified which can be supervised by related protective relays such as blinder or out-of-step detecting relays. The output is 15V d-c to 19V d-c and up to 0.01 ampere d-c. An auxiliary unit such as an SAR tripping relay or an SRU output package is necessary to trip a breaker or operate other electromechanical devices.

The SKDU-1 is similar to the SKDU relay and has only a slight modification which allows the three-phase fault-detecting unit to trip on current only in the event a close in fault drops the relay voltage to zero.

CONSTRUCTION

Types SKDU and SKDU-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 a-c quantities into the static network.

Either five or six printed-circuit boards are used in the static network. They are plug-in types which may be removed for tests or examination and then reinserted. They may also be plugged into a card extender, style #849A534G01, to make the test points and components accessible for in-service checking.

A hinged and removable door provides access to all adjustments and printed-circuit boards. A 24-terminal jack provides external voltage connections, and a terminal block provides current connections.

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 2. 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) ohm, (.73-21) ohm, and (1.1-31.8) ohm 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 2. 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.

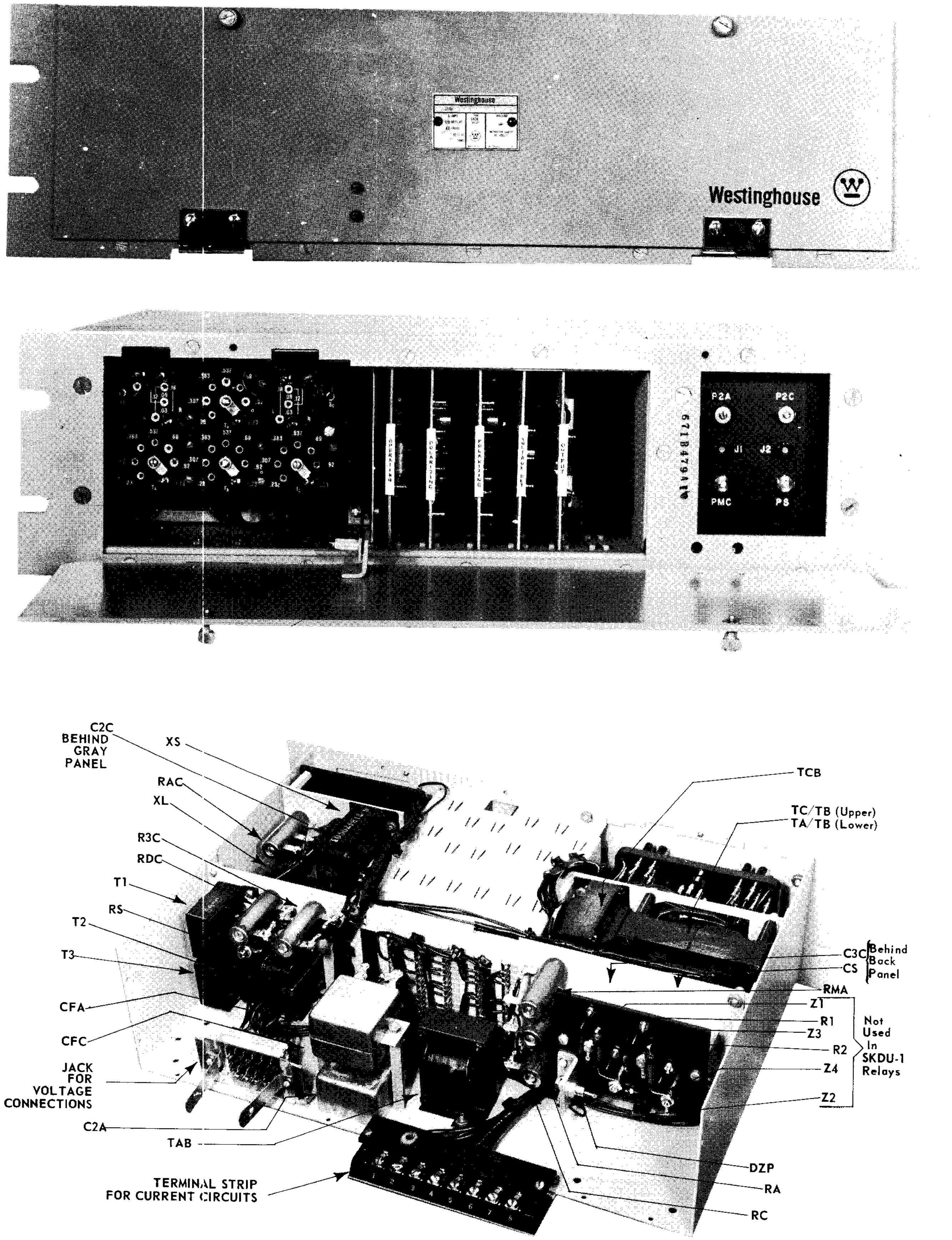


Fig. 1. Photo of Relay, Front (Door Open), Top (Cover Off)

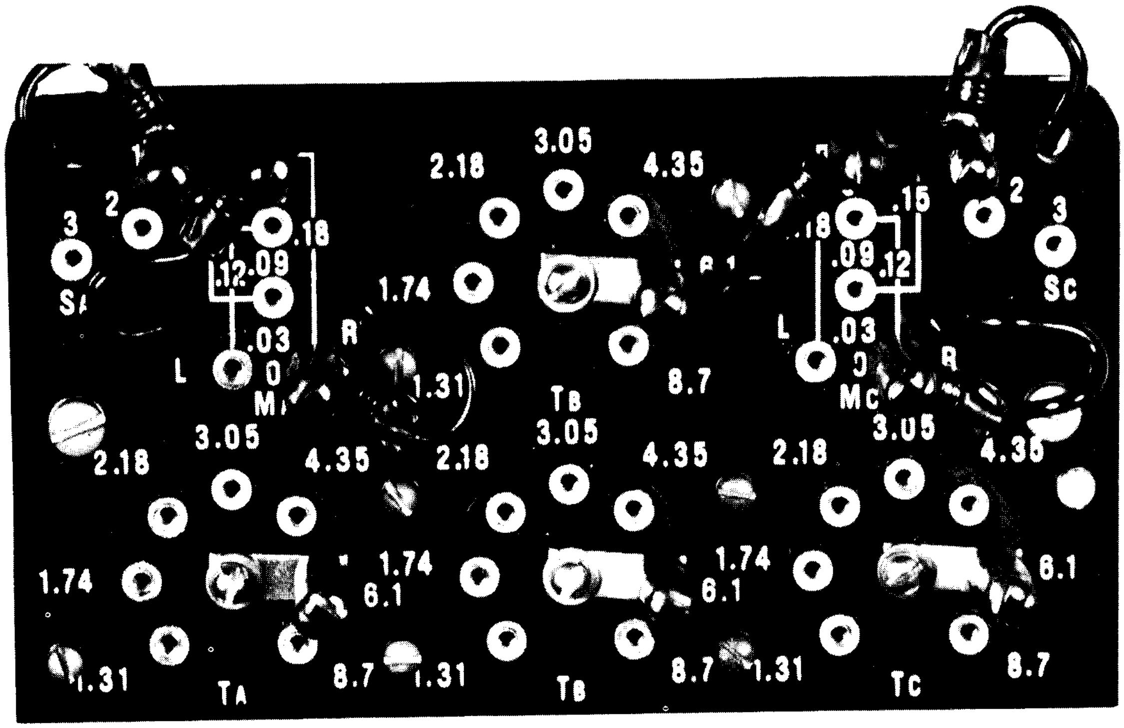


Fig. 2. Photo of Tap Plate

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 leads. The actual per unit values which appear on the tap plate between taps are 0., .03, .09 and .06.

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

Phase-Shifting Circuit

"Polarization" is the reference against which the "operate" signal is compared. Polarization for the three-phase unit is obtained by shifting the phase 1-2 voltage ahead 90°. The phase-shifting circuit consists of a center tapped auto-transformer, XS, which supplies voltage to a series-connected resistance capacitor, RS and PS, and CS respectively (Figures 3 and 4). Voltage between the resistor-capacitor junction and the auto-transformer center tap leads the applied voltage by 90°.

Memory Circuit

The memory circuit consists of a large inductive reactance, XL, and a large capacitive reactance, C3C, which are series connected and are tuned very closely to sixty 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 60 Hz 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 a-c circuits from the d-c circuits: Secondly, they amplify the clipped a-c signal by a factor of 1:8 to make the relay sensitive to low-level input signals.

Printed-Circuit Board Assemblies

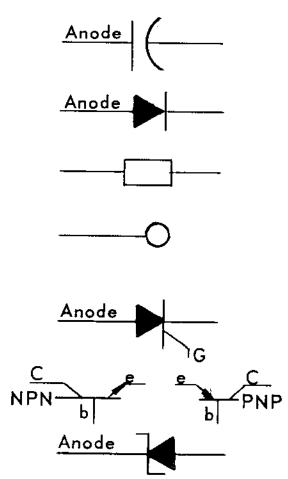
The basic relay uses five Printed Circuit Board (PCB) assemblies. The five basic PCB's are one

"operate" board, two "polarizing" boards (both are identical in the SKDU relay but are slightly different in the SKDU-1 relay), one "voltage detector" board, and one "output" board. A sixth PCB assembly is required when the output is to be supervised by additional input logic.

PCB assemblies shown in Figures 5 through 9 contain all the resistors, diodes, transistors and thyristors necessary to perform the functions of a dual-polarized phase-angle comparison unit. PCB's in Figures 10 and 11 contain "AND" logic components for external supervision.

Components on each board are identified by a letter followed by a number so that every component has an exclusive identification. Resistors are identified by the letter R followed by a number starting with 1. Where the component is shown on a schematic drawing, Figure 12, which includes more than one PCB, the component designation on the schematic is preceded by the board location number. For instance, each PCB in Figure 12 has an R6 resistor. The R6 resistor on the Voltage Detector PCB located in position 4 is designated 4R6, while R6 on the Polarizing Circuit in position 2 is designated 2R6 in Figure 12. 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 Z, transistors by Q, thyristors by QS, capacitors by C, and test points by TP. Component letter designations are listed as follows:

CAPACITOR	C
DIODE	D
RESISTOR	R
TEST POINT	TP
THYRISTOR	QS
TRANSISTOR	Q
ZENER DIODE	Z(or DZ)



Case Construction

The jack plug on the rear has 24 terminals numbered left to right and top to bottom. Thus terminal #1 is located in the upper left-hand corner when viewed from the rear, and terminal #24 is in the lower right-hand corner. Terminal #1 is connected internally to the chassis ground and may be used for grounding the connecting cable shields.

There is also an 8-terminal strip used for current terminals which is located in the right-hand side of rear when viewed from the back. The terminals are numbered from left to right.

The chassis case, cover, and front panel have electrical connections established by the use of shakeproof washers which cut through any point or protective coating to make electrical contact with the base metal. The complete relay is then grounded to the switchboard or cabinet by an external wire connection which must be made by clamping the wire under a shakeproof washer which also serves to help hold the cover in place.

The door is hinged at the bottom and is secured at the top by two captive screws. It may be opened to 90 degrees where it is stopped by a slotted strap attached to the door and also to the frame of the case. To remove the door, release the strap by either unscrewing it or unhooking it from the door and then slide the door to the right to disengage the hinges.

Printed-circuit boards are connected into the electrical circuits of the relay through 14-terminal connectors. The boards can be disengaged by a steady pull outward. Sometimes a simultaneous up-and-down motion (if there is clearance) will help free the mating connections. The boards are keyed so that they cannot be pushed home into the wrong connector although they may be replaced into the guides of the wrong position.

OPERATION

The SKDU and SKDU-1 relays both utilize identical a-c input circuits. Therefore, an explanation for the SKDU will suffice for both.

Two distinctly different logic systems are used in the SKDU 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 phase-angle comparison circuit 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 13.a. A trip condition results when V_{YB} lags V_{XB}.

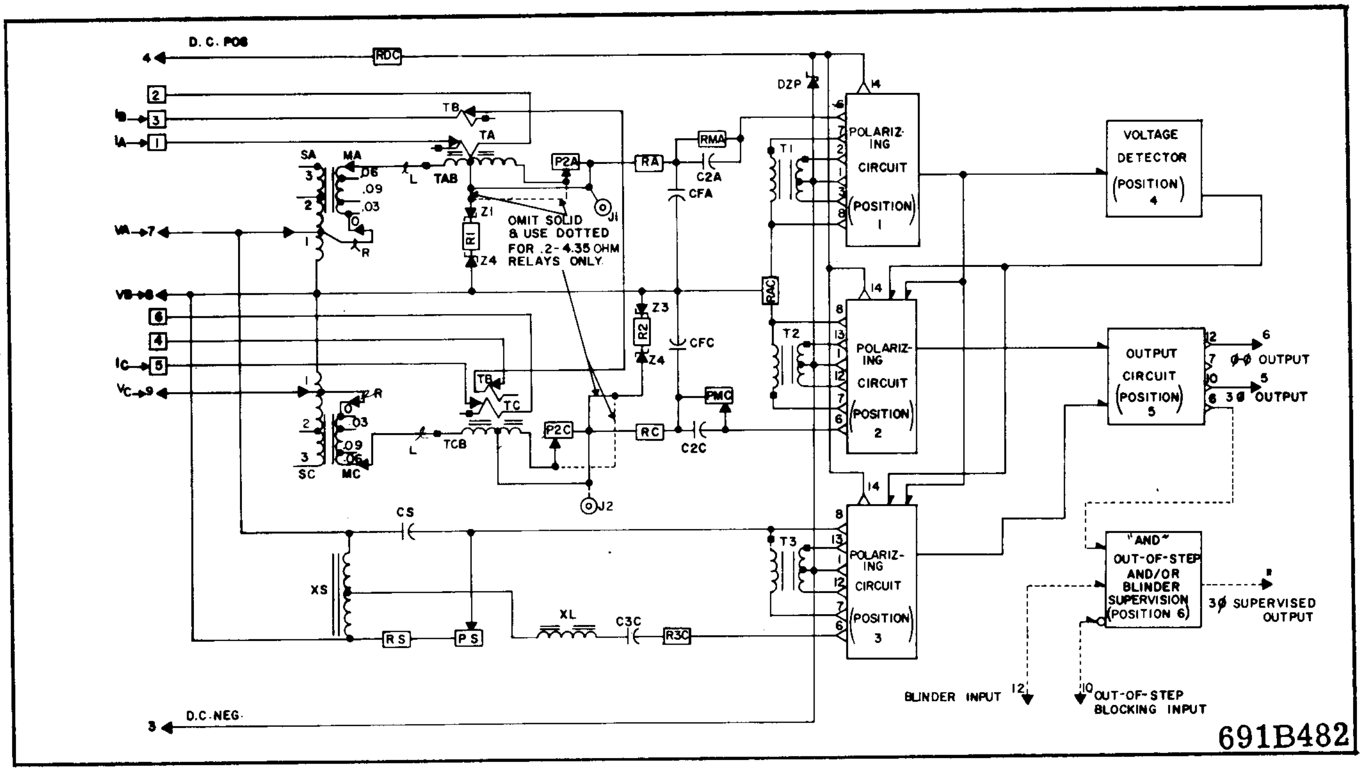


Fig. 3. SKDU Internal Schematic (showing a-c input and logic blocks)

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 13.b at point 1, it can be seen that the voltage V_{CB} is greater than the permissible minimum $(I_A - I_B)\ Z_R$ computed by compensator T_{CB}. 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 circuit 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 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 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 14.a illustrates the connections which apply to the static phase-angle comparison unit. Voltage V_{AB} is modified by the compensator output

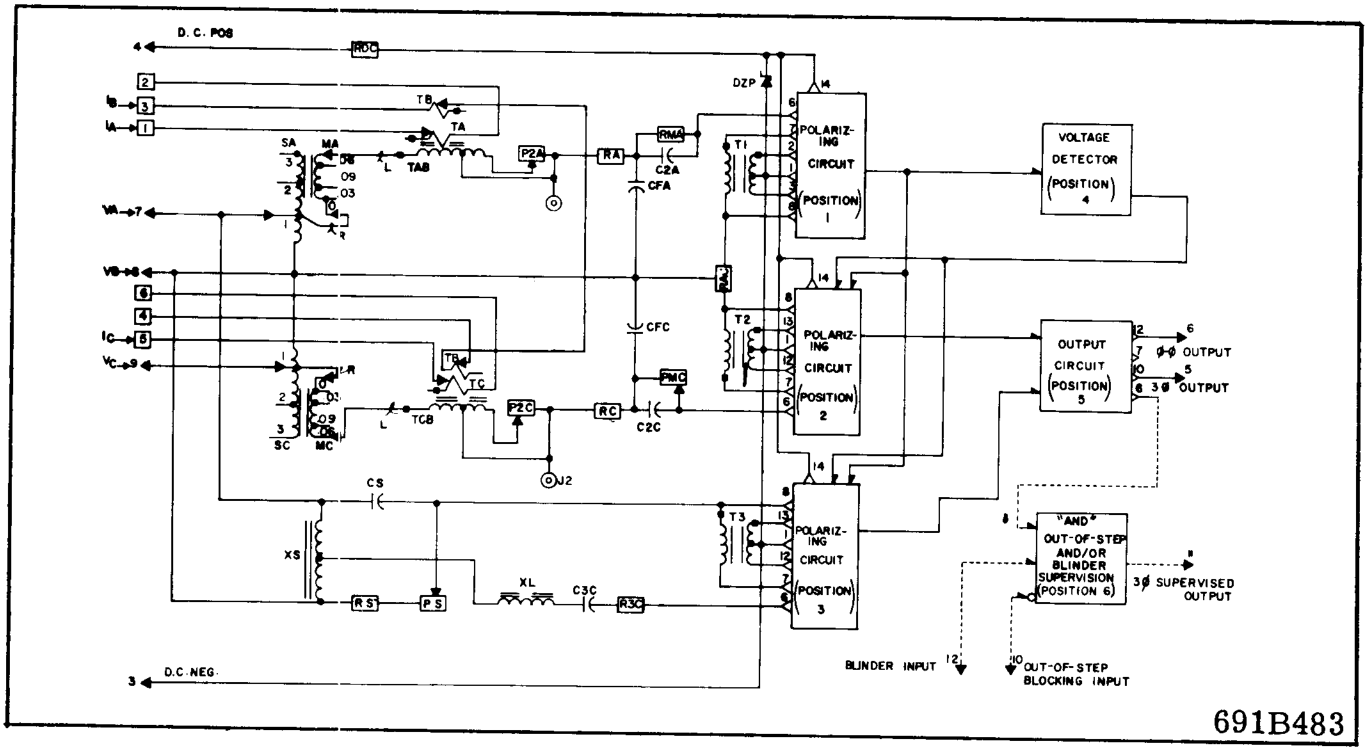


Fig. 4. SKDU-1 Internal Schematic (showing a-c input and logic blocks)

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 14.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 14.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 comparator 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 14.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 overreach 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 output can be supervised by working it into an AND logic with an out-of-step signal from an out-of-step relay.

Phase-Angle Comparison Circuit

Referring to Figure 12, the phase-to-phase angle comparison circuit trips when current flows into the

base of transistor 5Q3 through zener diode 5Z2. Such tripping current must come from the 20V bus through either transistor 1Q2 or 1Q4 located in the "operate" PCB. The operate circuit, driven by transformer T1, is continually trying to trip the unit by supplying current through 1Q2 and 1Q4 on alternative half cycles. 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 5Z2 to transistor 5Q3 to cause tripping.

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 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 the 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, 5Z2 and 5Q3.

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 Detectors: 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 restraint-signal detector circuit prevents this from happening. Under normal conditions, no voltage is allowed to develop across zener diode 2Z2 at Test Point 2TP1 because it is alternately short circuited to the negative bus by transistors 2Q1 and 2Q2 through diodes 2D5 and 2D6 respectively. When the voltage from T2 drops too low to drive 2Q1 and 2Q2, current flows from the 20-volt bus through 2R3 and 2Z2 into the base of 2Q3. With 2Q3 conducting, the bases of 2Q4 and 2Q5 are driven through diodes 2D8 and 2D13 respectively to maintain the gate drive of 2QS1 and 2QS2 respectively. Thus when the T2 voltage is near zero, thyristors 2QS1 and 2QS2 are maintained in a conducting state so that no output can develop.

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 5Z1 and 5Q1 to switch 5Q2 into conduction.

SKDU-1 Relay: The SKDU-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 SKDU-1 three-phase unit 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 4Z1 monitors the d-c voltage level. If the a-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.

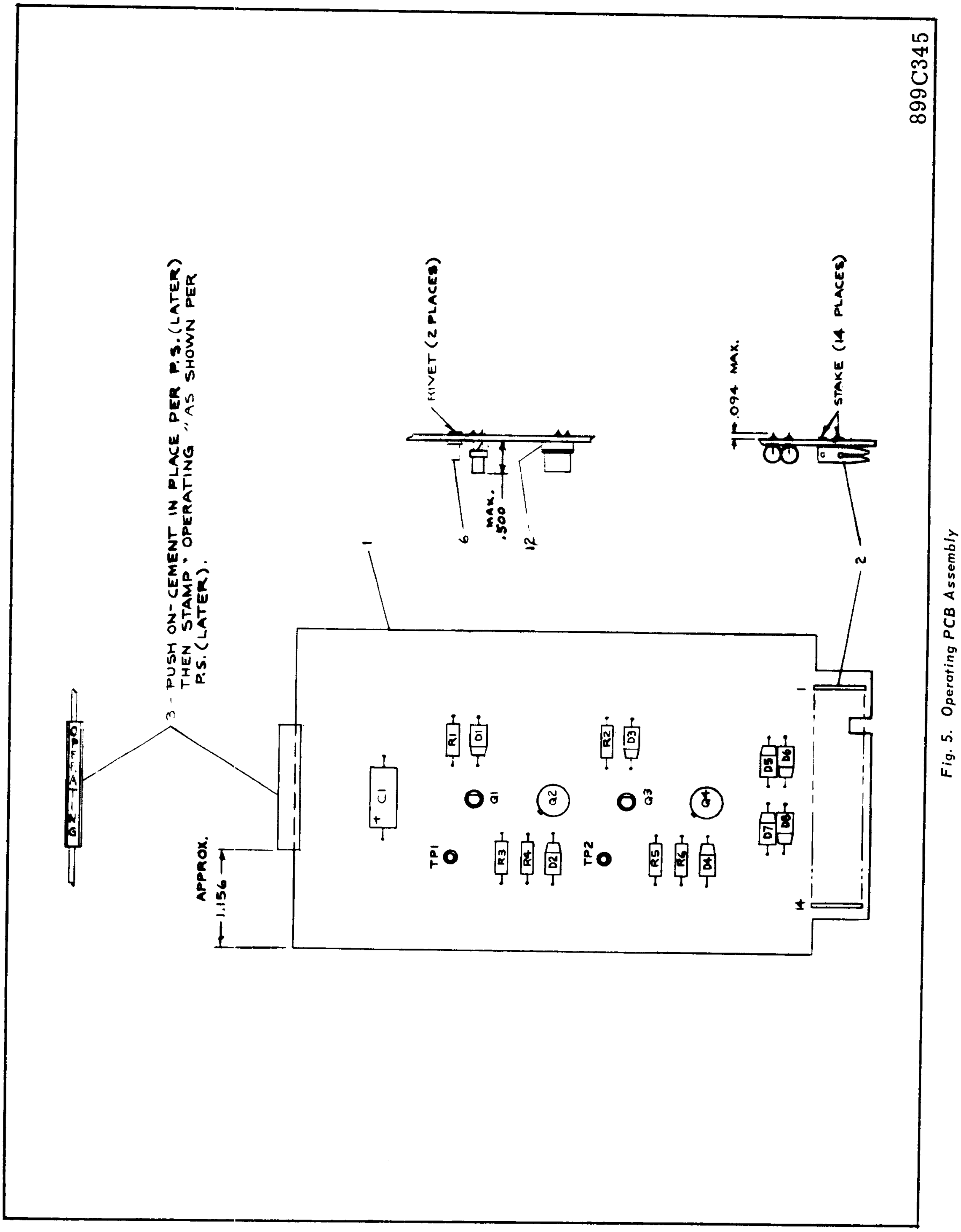


Fig. 5. Operating PCB Assembly

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 overreach due to d-c transients. Compensators basically are insensitive to d-c 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 unidirectional voltage in the secondary.

Distance Characteristic: SKDU 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 14) 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: Three-Phase Unit

The impedance curve for the three-phase unit is shown in Figure 16. This 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 voltage below which the three-phase unit probably will be disabled by the restraint-signal detector circuit is 1.5 V_{LL}.

Distance Characteristics: SKDU-1 Three-Phase Unit

The three-phase unit of the SKDU-1 relays has a characteristic circle which includes the origin. This feature results from the omission of the restraint-signal detector in the polarizing 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°.

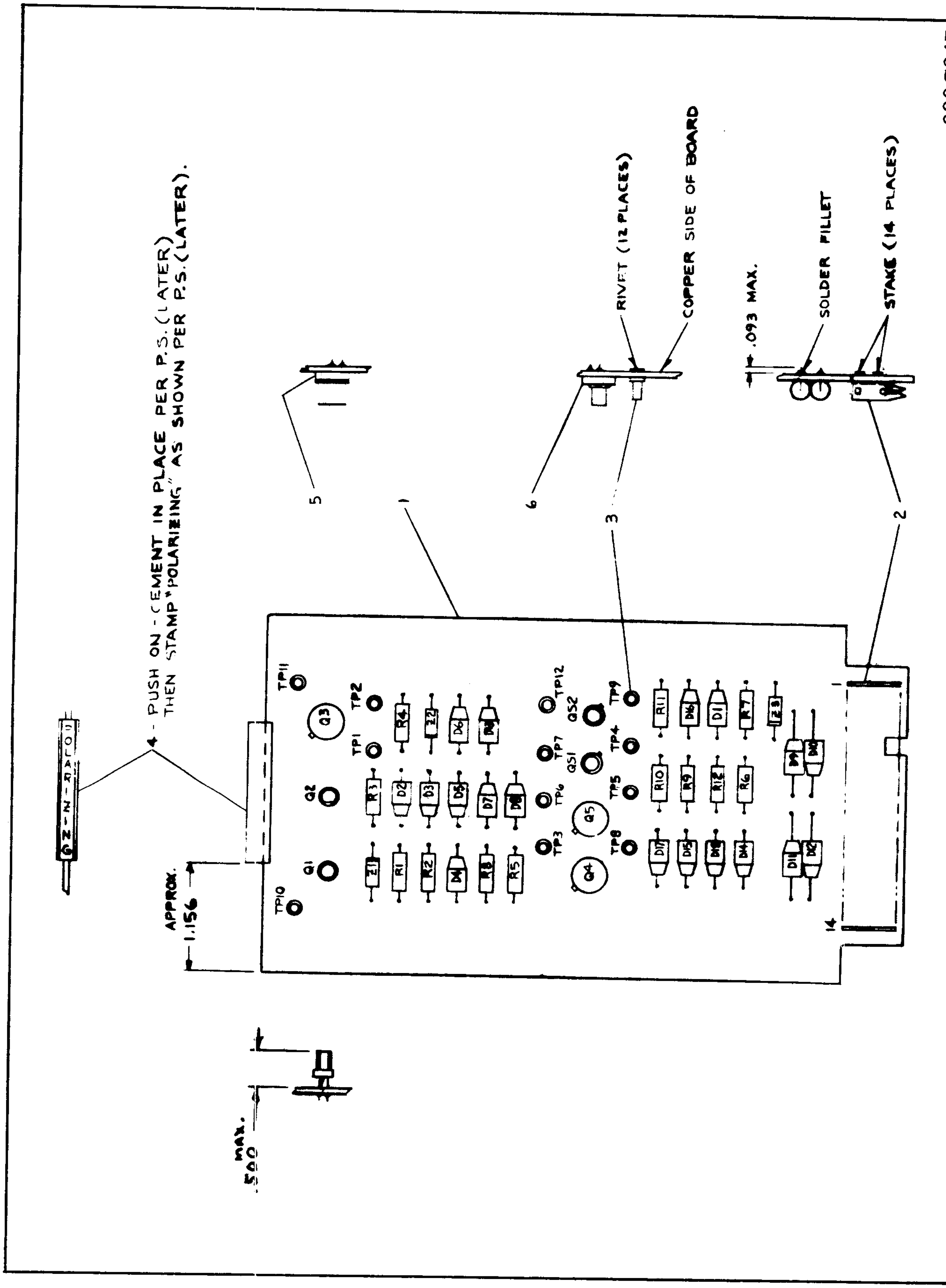


Fig. 6. Polarizing PCB Assembly for Phase-to-Phase Unit and for SKDU Three-Phase Unit

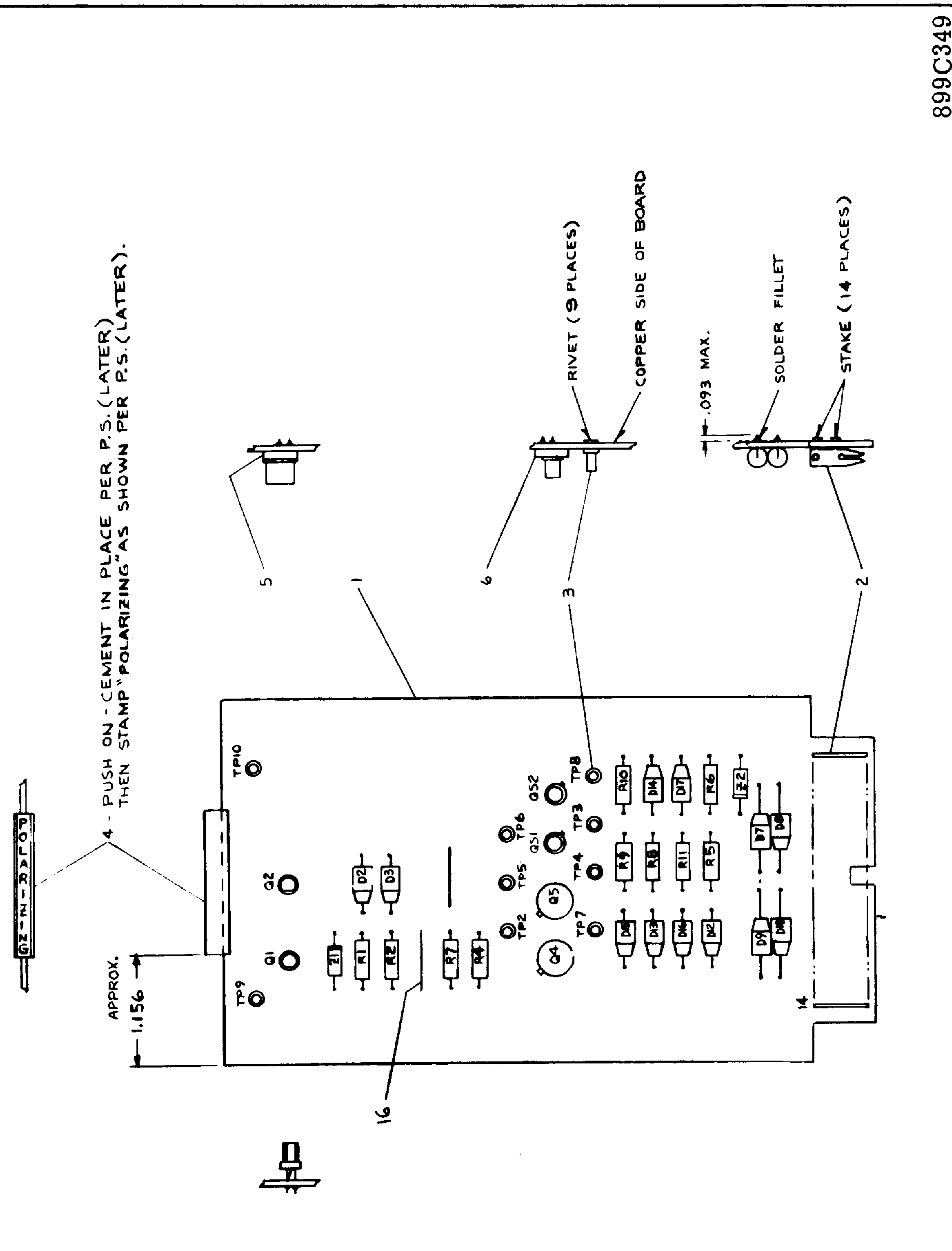


Fig. 7. Polarizing PCB Assembly for SKDU-1 Three-Phase Unit

This 90° relationship is approached if the compensator loading resistor (P2A or P2C) shown in Figures 3 and 4 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_{CB}. 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 2 are based upon a 75° compensator angle setting. If the resistors P2A and P2C are adjusted for some other maximum sensitivity angle, the nominal reach is different than indicated by the taps. The reach, Z_θ, varies with the maximum sensitivity angle, θ, as follows:

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

TAP PLATE MARKINGS

(T_A, T_B and T_C)

(0.2 to 4.35) ohms	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21) ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 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 SKDU and SKDU-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 within the relay setting.

Burden

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

Current Circuit Rating in Amperes

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

Output Circuits

Open Circuit Voltage	17V to 21V d-c
Rated Current	10 milliamperes

SETTING CALCULATIONS

Relay-reach is set on the tap plate shown in Figure 2. The tap markings are:

(T_A, T_B and T_C)

(0.2 to 4.35 ohms)	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21 ohms)	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 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 P2A and P2C. Set zone 1 reach to be 90% of the line (85% for line angles of less than 50°).

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

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V} \qquad \text{Eq. (1)}$$

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

Z_θ = The ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees. Ea. (2)

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

T = compensator tap value

S = auto-transformer primary tap value

θ = maximum sensitivity angle setting of the relay (factory setting of $\theta = 75°$).

±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.)

Z_{pri} = ohms per phase of the total line section

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

R_C = current transformer ratio

R_V = potential transformer ratio

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

1. A. Establish the value of Z_θ as above.

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

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

   when $\theta = 75°$, $Z = Z_\theta$

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

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

   B. Select from the Table "S", "T" and "M" settings. "M" column includes additional information for "L" and "R" lead settings for the specified "M" value.

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

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

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

Step 1B

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

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

Step 2A

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

Step 2B

From Table III, read off:

S = 2
T = 4.06
M = +.03

Step 2C

Recheck settings:

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

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

From Eq. (3)

which is 101.0 percent of the desired setting.

SETTING THE RELAY

The SKDU and SKDU-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.

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

Each set of compensator taps terminates in

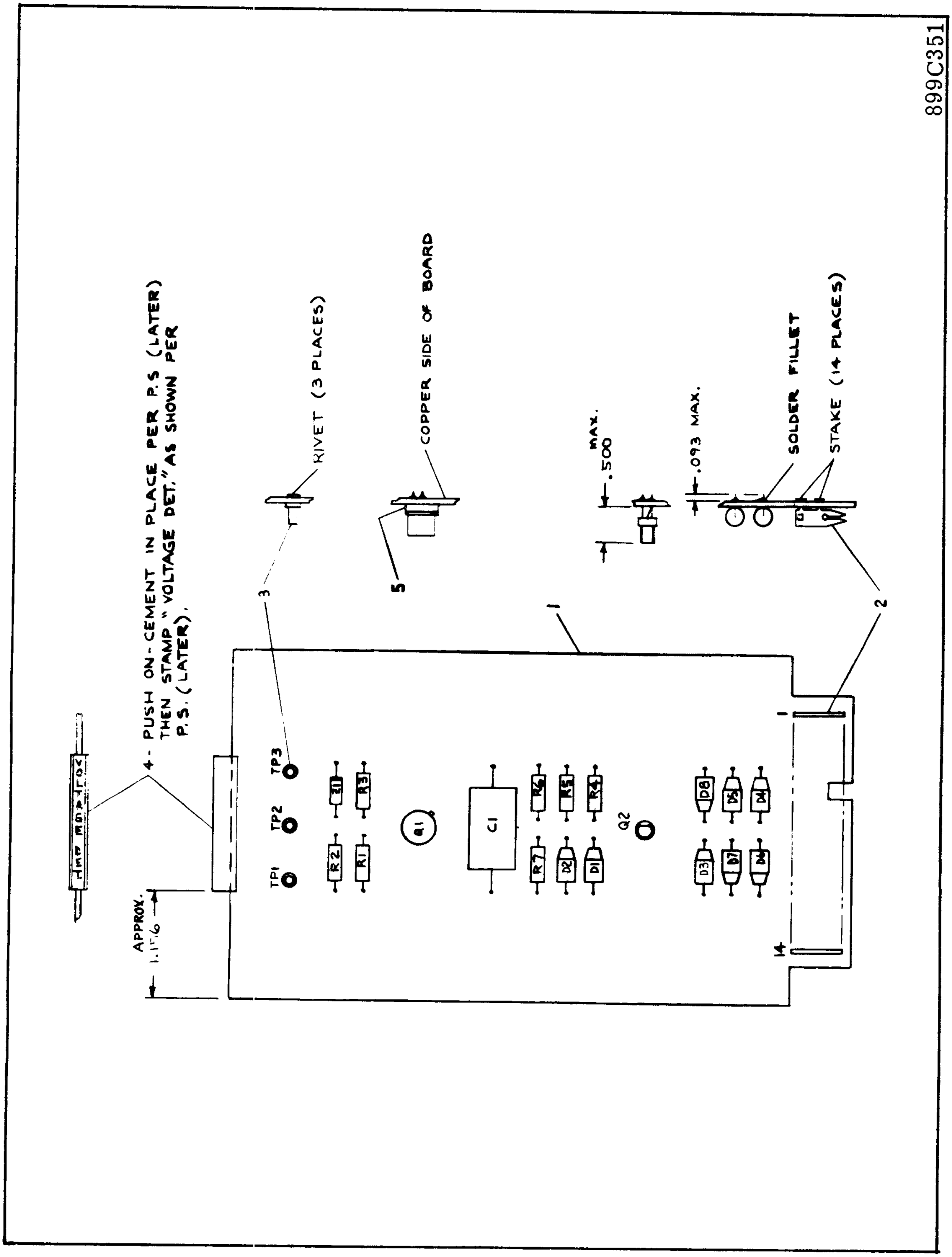


Fig. 8. Voltage Detector PCB Assembly

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

Auto-Transformer Primaries (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 2).

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 lead is higher and negative (–) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Refer to Table 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.

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. $\angle -75°$ 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. $\angle +105°$ 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 TAP .73-21 OHM RANGE	CURRENT CIRCUIT IMPEDANCE AT 5 TO 100 AMPERES (V_{LL} = 120 V.)								
	TA (TERM'S 1 - 2)			TB (TERM'S 3 - 4)			TC (TERM'S 5 - 6)		
	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 and TB compensators or TB and TC.

‡ Fault current flowing into the line.

‡‡ Fault current flowing out of the line.

TABLE II

RELAY SETTINGS FOR .2-4.5 OHM RANGE RELAY

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

TABLE III

RELAY SETTINGS FOR .73-21 OHM RANGE RELAY

	"S" = 1							"S" = 2		"S" = 3		"M"		LEAD CONNECTIONS	
	T = .87	1.16	1.45	2.03	2.9	4.06	5.8	4.06	5.8	4.06	5.8	+ M	– M	"L" LEAD	"R" LEAD
"L" OVER "R"	.737	.98	1.23	1.72	2.46	3.44	4.92	—	9.85	—	14.7	+.18		.06	0
"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
	.870	1.16	1.45	2.03	2.9	4.06	5.8	8.12	11.6	—	17.4	0	0	0	0
"R" OVER "L"	.897	1.20	1.49	2.09	2.99	4.18	5.98	8.36	11.9	—	18.0		–.03	0	.03
"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

TABLE IV

RELAY SETTINGS FOR 1.1-31.8 OHM RANGE RELAY

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

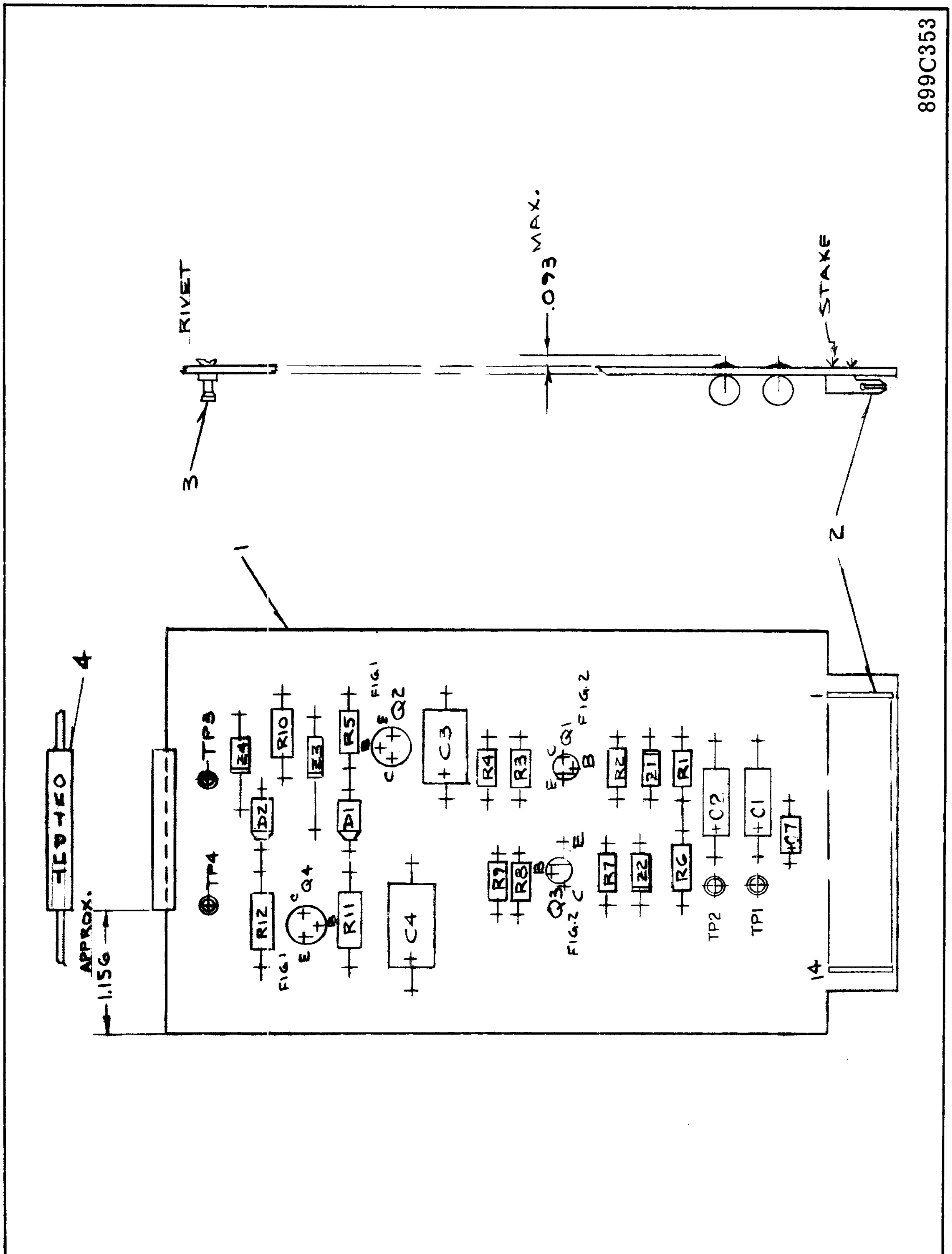


Fig. 9. Output PCB Assembly

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 P2A and P2C. Refer to Repair Calibration, parts 11 to 15, and 20, 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 four slotted holes on the front of the case. Additional support should be provided toward the rear of the relay in addition to the front panel mounting. This will protect against warping of the front panel due to the extended weight within the relay case.

EXTERNAL CONNECTIONS

Figure 19 shows the external connections for an SKDU or an SKDU-1 relay.

Current circuit connections are made to an eight-section terminal block located at the rear. Potential circuits, both a-c and d-c as well as input and output logic signal circuits, are connected through a 24-terminal jack. Connections are made by a plug on the wiring harness. The plug is inserted between two latching fingers which hook over the back of the plug to prevent an accidental loosening of the plug. The plug can be removed by spreading the two fingers apart enough to disengage the hooks from the back. The plug must be withdrawn while the fingers are spread apart.

Note that terminal number 1 is connected to the case within the relay and may be used for grounding the shields of connecting cable. The grounding connection will be broken when the plug is disconnected.

Permanent grounding of the case is accomplished by connecting a ground wire under a washer of a cover screw. These are self-tapping screws and provide excellent low-resistance contact with the case.

RECEIVING ACCEPTANCE

Acceptance tests consist of 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 a-c voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equivalent a-c ammeter.

Testing can be accomplished by use of the test connections shown in Figure 20. Tripping is indicated by a d-c voltmeter reading. At the balance point, the output may be as low as 1 volt or 2 volts 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 15 volts indicates a defective tripping output or defective logic.

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. Connect the relay for a 1-2 fault as indicated for Test #5, 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 = 30V).

3. Supply 105% 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 unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. This should be 75° ± 3°.

   The angle shifts from 75° to 70 V_{LL} to approximately 70° at 5 V_{LL}. This is a normal response of the logic and is not detrimental to the relay protection.

4. 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.

5. Repeat section 4 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.

6. Repeat the above tests 2, 3 and 4 for the three-phase unit. The current required to trip the three-phase unit should be within the limits given in Table V at the maximum sensitivity angle of 75°.

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

TABLE V

Test Voltage = 30 V_{L-L}
M Setting = +.15
S Setting = 1

RANGE	SETTING		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 3 ϕ	(100% Z - 94.7% Z) 14.0 - 14.8 Amps.
.73-21 Ohms	5.8	5.05	5,6,7 5	ϕ-ϕ 3 ϕ	(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 3 ϕ	(100% Z - 94.5% Z) 1.98 - 2.1 Amps.

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 jack terminals 2, 3, 4, 5, 6, 11 and 12 to avoid destroying components in the static network. These connections are not necessary for surge testing.

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

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

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

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

REPAIR CALIBRATION

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

7. Connect the relay for testing as shown in Figure 20. The four-pole, double-throw switch shown in the test circuit selects the type of voltage condition for a phase-to-phase or a three-phase fault, that may 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 procedures outlined below.

8. 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 "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 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.

9. 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

10. 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:	disconnected
"L" for M_A and M_C:	set for .06 (top position

A. PHASE-TO-PHASE UNIT

Maximum Sensitivity Angle Adjustment

11. Connect the relay for a 1-2 fault as indicated for Test #5. Connect a high-resistance voltmeter (2000 ohms/volt) between the "R" lead and the .03 tap position of M_A, and adjust voltages V_{1F2F} and V_{2F3F} for 30 volts.

12. Pass the current called for in Table VI for 30 volts through the T_{AB} compensator with the phase shifter set for the desired maximum sensitivity angle. Adjust potentiometer P2A for a null, or minimum reading, on the voltmeter.

13. Swing the phase shifter and adjust P2A slightly to obtain a minimum reading on the voltmeter when the phase-angle reading is at the desired maximum sensitivity angle. This adjusts the T_{AB} compensator angle.

14. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_A and jack J_1 located just below P2A. Pass 5 amperes through the compensator. The secondary voltage should be:

$$V_S = 10.35\ T \sin\theta \pm 1.5\%$$

where

θ = the desired maximum sensitivity angle

T = compensator tap setting

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

1.5% = the allowable variation from nominal

		NOMINAL 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

15. Connect the relay for Test #6. Connect the voltmeter between the "R" lead and the .03 position of M_C, and repeat steps 12 and 13 above. This adjusts the T_{CB} compensator angle with P2C.

16. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_C and jack J_2 located just below P_{2C}. With 5 amperes through the compensator, the voltage should be as listed above in step 14.

Circuit Calibration

17. Connect "R" for M_A and M_C on ".03" and "L" for M_A and M_C in the top position so that there is .15 between L and R. Connect terminals 7 and 9 together, apply 120V a-c between terminals 8 and 9, and adjust P_{MC} until the ϕ-ϕ unit just trips. At the balance point, the output detector voltmeter reading may be as low as 1V or 2V indicating that the system is only partially tripping. This is a normal balance point character-

TABLE VI

TEST NO.	VOLTS V_{1F2F}	AMPERES TO TRIP FOR $\theta = 75°$					
		.2-4.5 RANGE		.73-21 RANGE		1.1-31.8 RANGE	
		I_{min}	I_{max}	I_{min}	I_{max}	I_{min}	I_{max}
5,6,7	5.0	2.34	2.66	0.50	0.56	0.33	0.376
	30.0	14.0	14.8	2.95	3.15	1.98	2.1
	70.0	—	—	6.9	7.1	4.62	4.72

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

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

istic. However, a 5 percent increase in current should produce an output of 15 to 20 volts.

18. 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 5.0 volt level first, and adjust P_{MC} further, if necessary, to make the current trip level for Test #7 fall between the trip levels for Tests numbers 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:

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

Maximum Sensitivity Angle Check

19. Use the 30-volt condition in Table VI. Supply 103% of the current necessary to trip at the calibrated angle of maximum sensitivity and swing the phase shifter to determine the two angles, $\theta 1$ and $\theta 2$, at which the unit just trips. The maximum sensitivity angle, θ, is $\frac{\theta_1 + \theta_2}{2}$. This value should be not more than 3° different from the setting made in steps 11 to 15. The phase-to-phase unit testing is complete.

B. THREE-PHASE UNIT

Maximum Sensitivity Angle Adjustment

20. Connect the relay for a 1-2 fault as indicated for Test #5. Apply 30 V_{LL} between relay terminal 7 and 8. Supply 103% 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 maximum sensitivity angle can be set by adjusting potentiometer P_S. The angle for the three-phase unit should be the same as for the phase-to-phase unit as determined with Test #5 in step 19 above.

21. Set the phase shifter for the maximum sensitivity angle. Using only Test #5 connections, the three-phase unit should trip within the same limits as listed for the phase-to-phase unit.

22. The three-phase unit testing is complete.

C. "AND" LOGIC (When Applicable)

No calibration is required for the static logic; however, it is desirable that a functional check be made to establish that the circuits are working properly.

23. Use connections for Test #5, and apply current and voltage to trip the three-phase unit as determined by an output voltage appearing at the output terminal #5.

24. "AND and Blocking" input relays should not have an output voltage at terminal 11. Apply +20V d-c to terminal 12 with negative to the NEG. BUS, and an output should appear at terminal 11.

25. With +20V d-c on terminal 12, apply +20V d-c to the "Blocking" terminal 10 and the output should stop.

26. "Blocking" input relays should have an output at terminal 11 with the three-phase unit tripped. Apply +20V d-c to terminal 10, and the output should stop.

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.

The chassis outline is shown in Figure 21.

TABLE VII

NOMENCLATURE FOR RELAY TYPES SKDU AND SKDU-1

NOTE: The manufacturer reserves the right to change component values without prior notice.

Item	Description	Style Number
	CAPACITORS	
C2A, C2C	1.8 mfd	14C9400H12
C3C	.3 mfd	1724191
C4C	.03 mfd	1725974
CFA, CFC	1 mfd	1876999
CS	.45 mfd	1723408
DZP	Zener Regulating Diode: 20V, 10W	1N2984B
Z1, Z2, Z3, Z4	Clipping Zener Diodes: 200V, 50W	1N2846A
J_1, J_2	Test Jacks	
M_A, M_C	Auto-Transformer Secondary (between taps 0.0, .03, .09, .06)	
	POTENTIOMETERS	
P2A, P2C	1000 ohm	836A635H03
P_{MC}	2.5 K-ohm	836A635H04
P_S	5 K-ohm	836A635H05
	PRINTED CIRCUIT BOARDS	
	Operate Circuit	899C345G01
	Polarizing Circuit (2 in SKDU)	899C347G01
	Polarizing Circuit (in SKDU-1 only)	899C349G01
	Voltage Detector	899C351G01
	Output Circuit	899C353G01
	O. S. Block	201C374G01
	Blind Supervision	201C375G01
	Card Extender	849A534G01
	RESISTORS	
R_1, R_2	5 watt, 500 ohm	763A129H03
R_{3C}	25 watt, 3 K-ohm	1202954
R_A, R_C, R_{MA}	25 watt, 1.8 K-ohm	1201004
R_{AC}	25 watt, 3.55 K-ohm	1955270
R_{DC}	for 48V d-c, 25 watt, 600 ohm	1202587
R	for 125V d-c, 25 watt, 1.5 K-ohm	1267293
R_S	10 watt, 10 K-ohm, adjustable	185A925H05
S_A, S_C	Auto-Transformer Primary (Taps: 1, 2, 3)	
T_1, T_2, T_3	Coupling Transformer, Center Tapped Secondary (Step Up 1:8)	292B563G05
T_{AB}, T_{CB}	Compensator Assemblies	
X_L	Memory Circuit Reactor	606B544G02
X_S	Center Tapped Auto-Transformer for Phase Shift Circuit	671B470G01

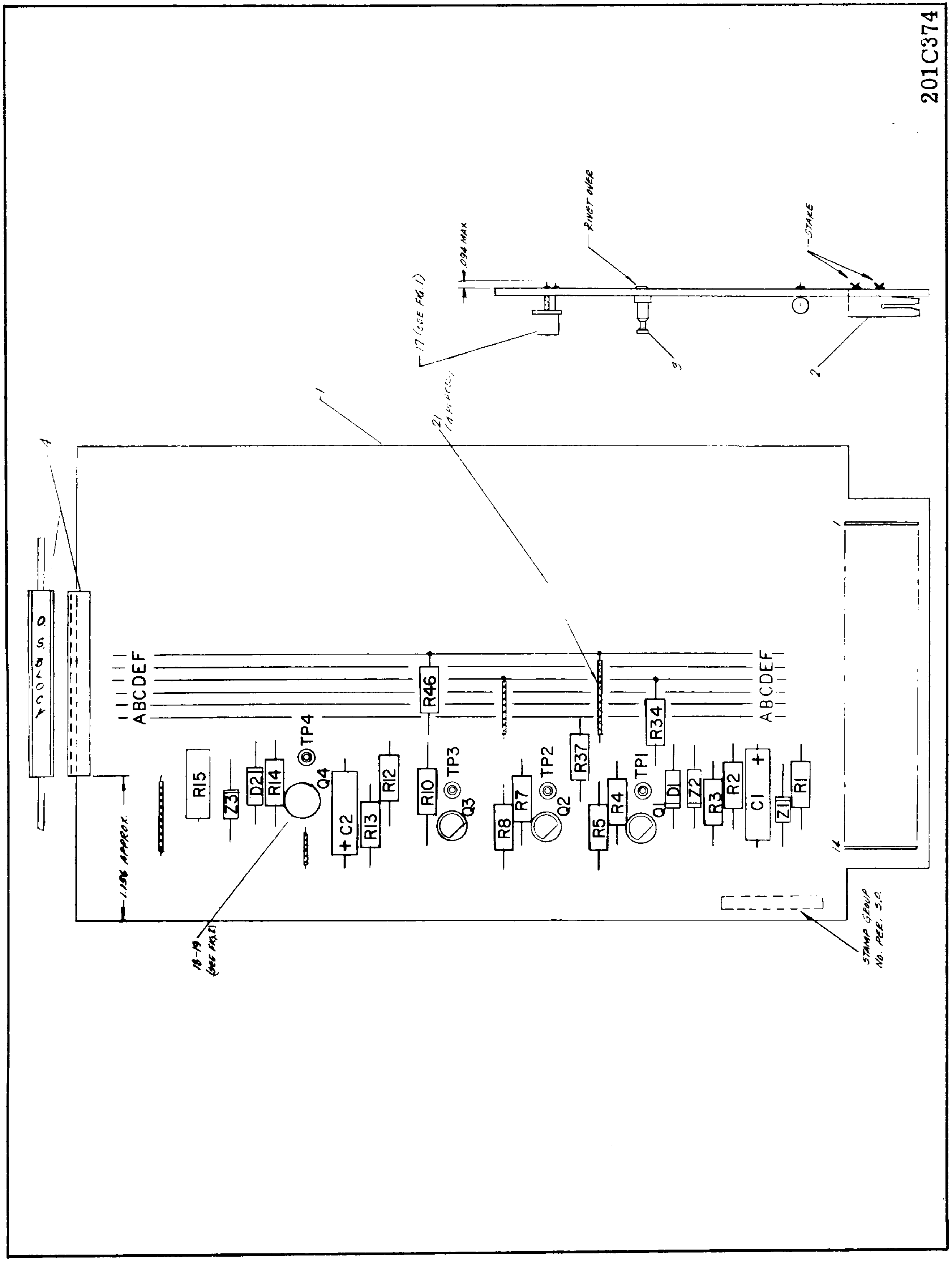


Fig. 10. Out-of-Step Blocking "AND" PCB Assembly

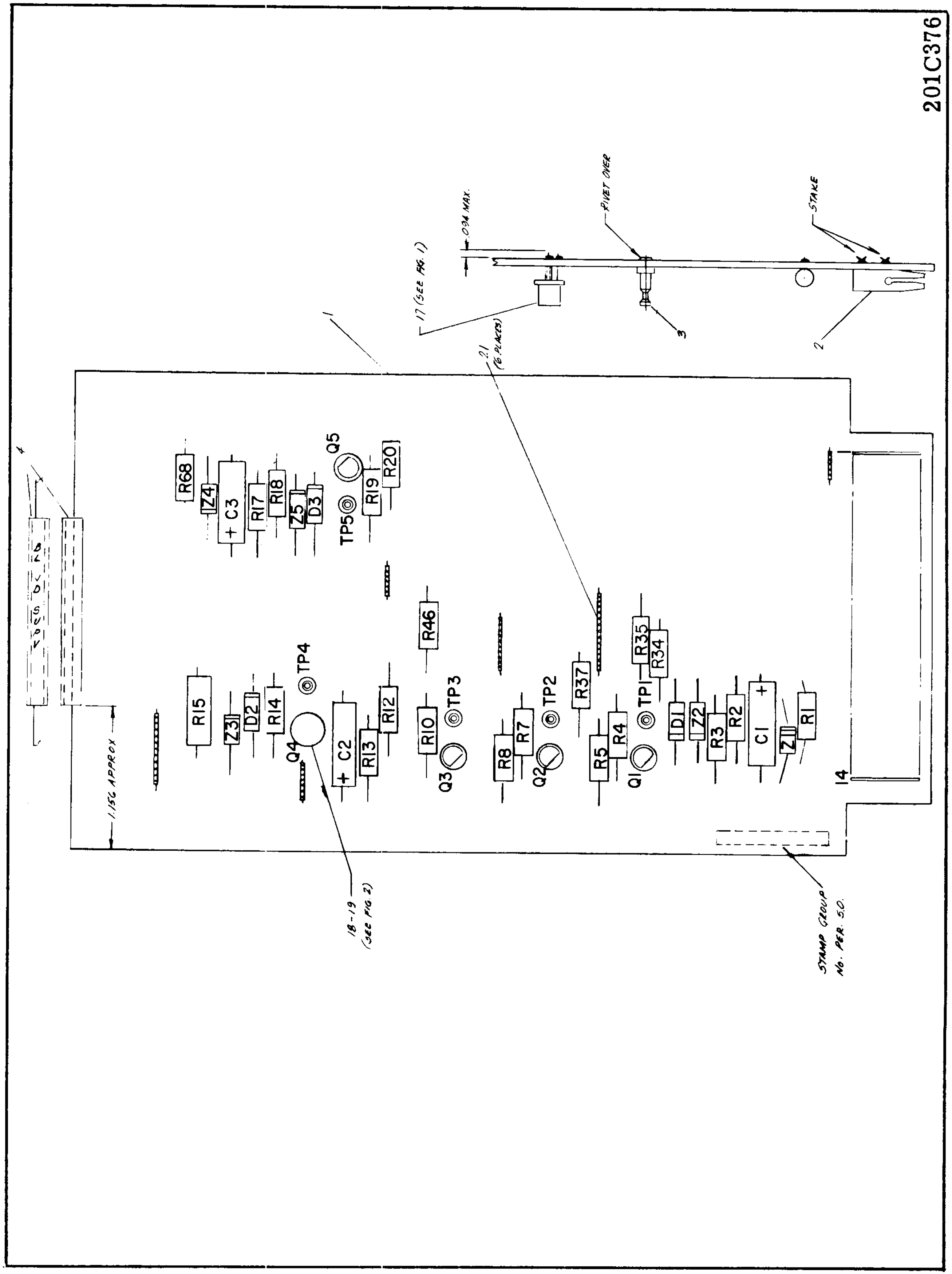


Fig. 11. Out-of-Step Blocking with Blinder Supervision "AND" PCG Supervision

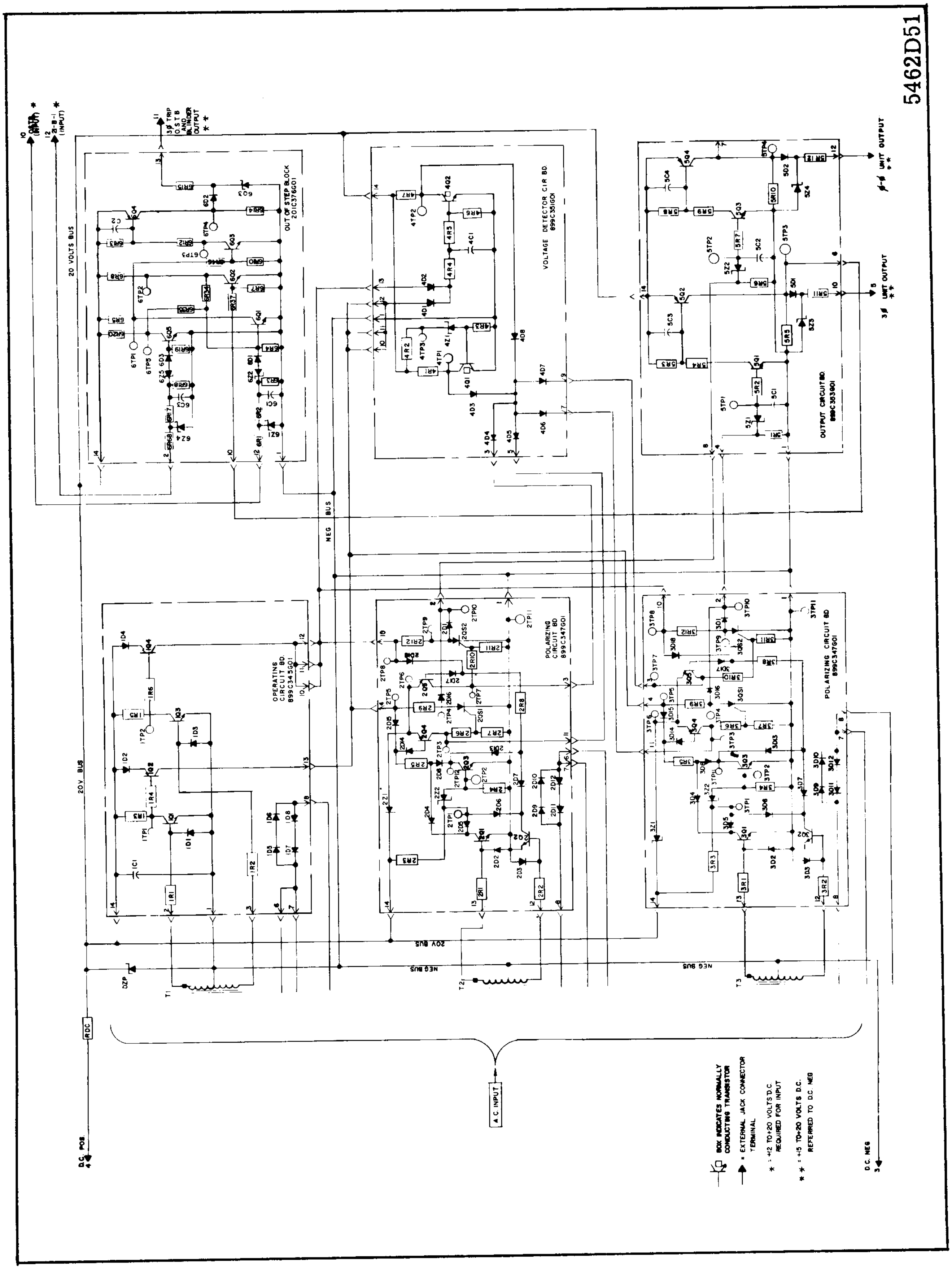


Fig. 12. SKDU D-C Schematic

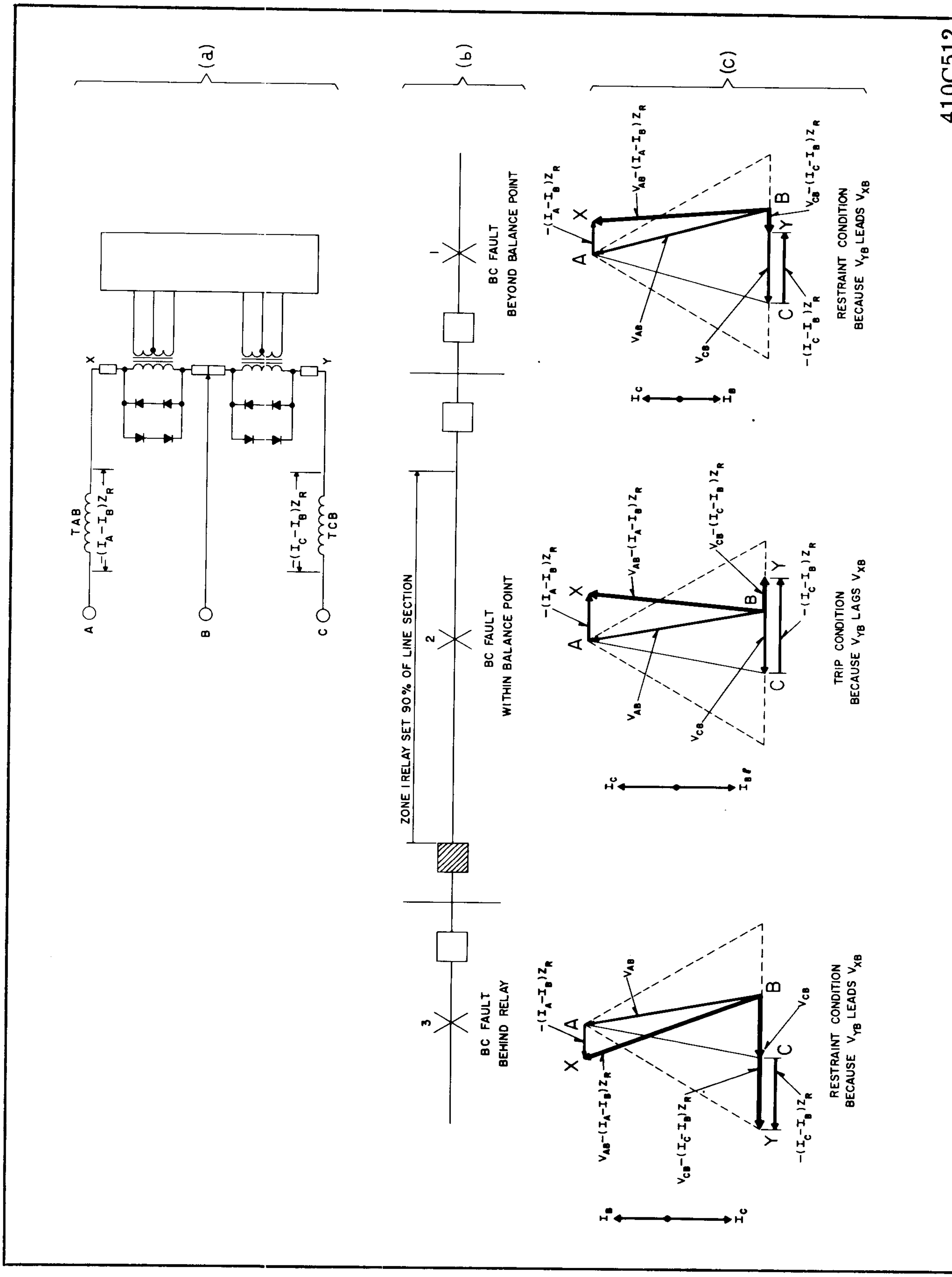


Fig. 13. Voltage and Current Conditions for the Phase-to-Phase Unit

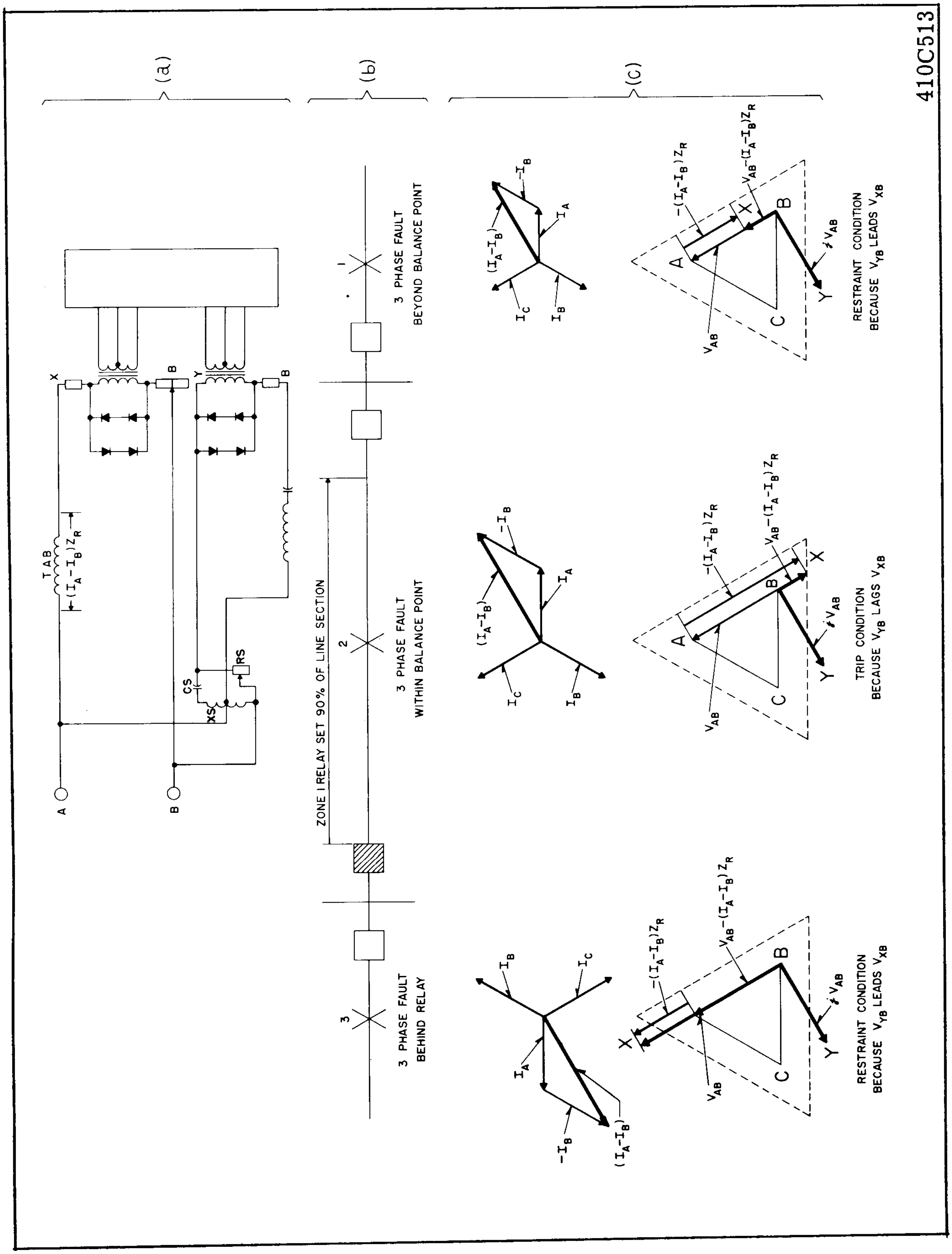


Fig. 14. Voltage and Current Conditions for the Three-Phase Unit

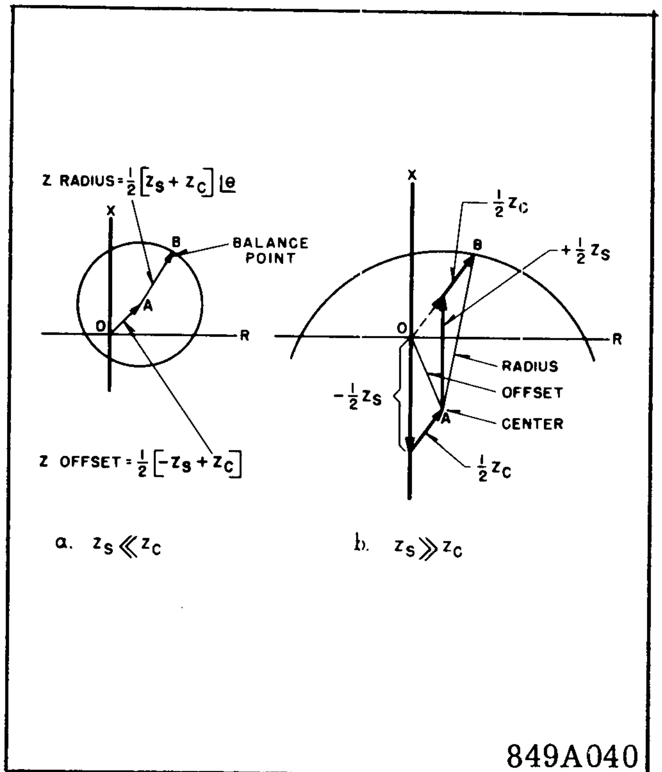


Fig. 15. Impedance Circles for Phase-to-Phase Unit in SKDU and SKDU-1 Relays

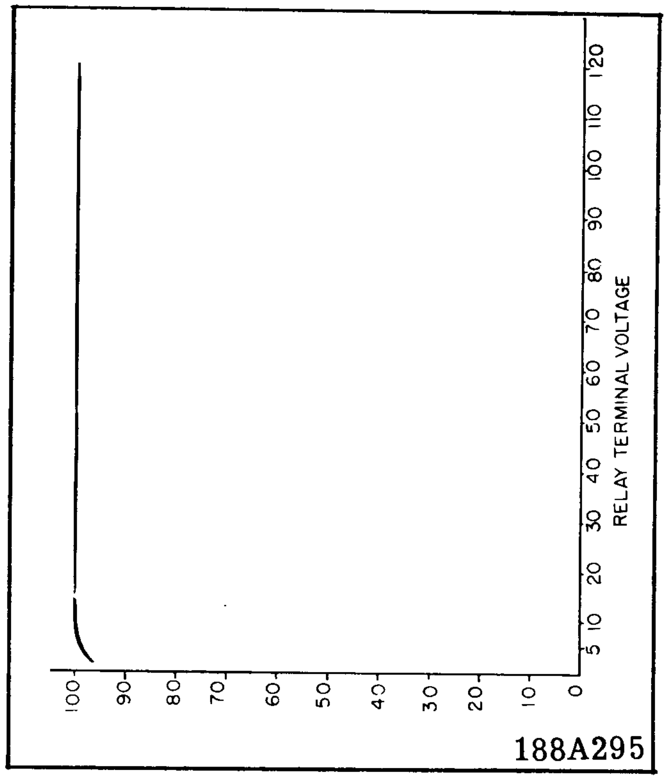


Fig. 16 Impedance Curve for Types SKDU and SKDU-1 Relays

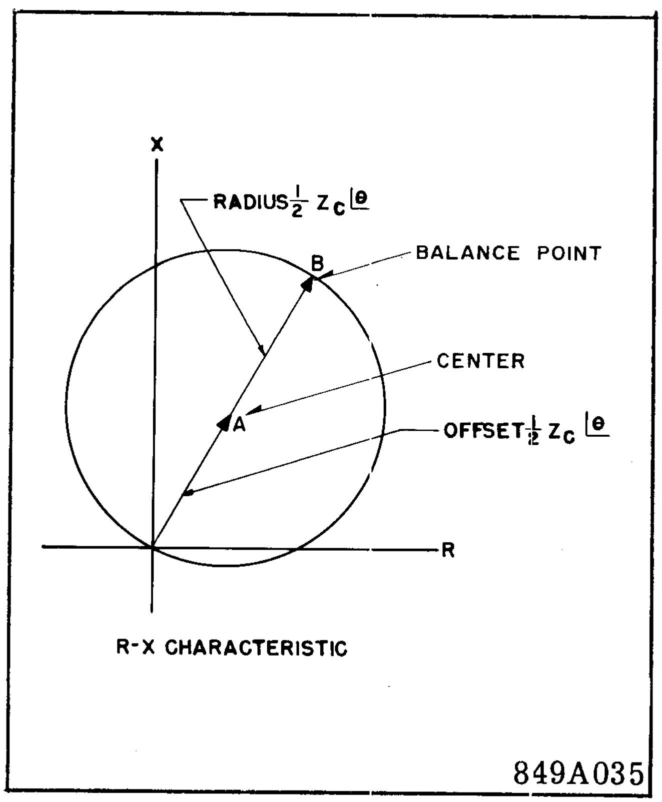


Fig. 17. Impedance Circle for Three-Phase Unit in SKDU Relays

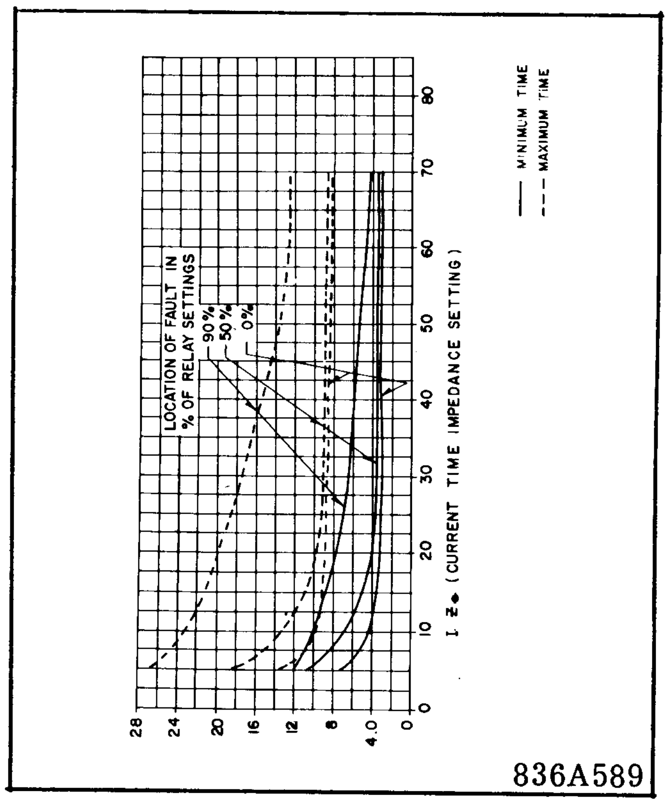


Fig. 18. Typical Operating Time Curves for SKDU and SKDU-1 Relays. Normal Voltage before the Fault is 120 Volts.

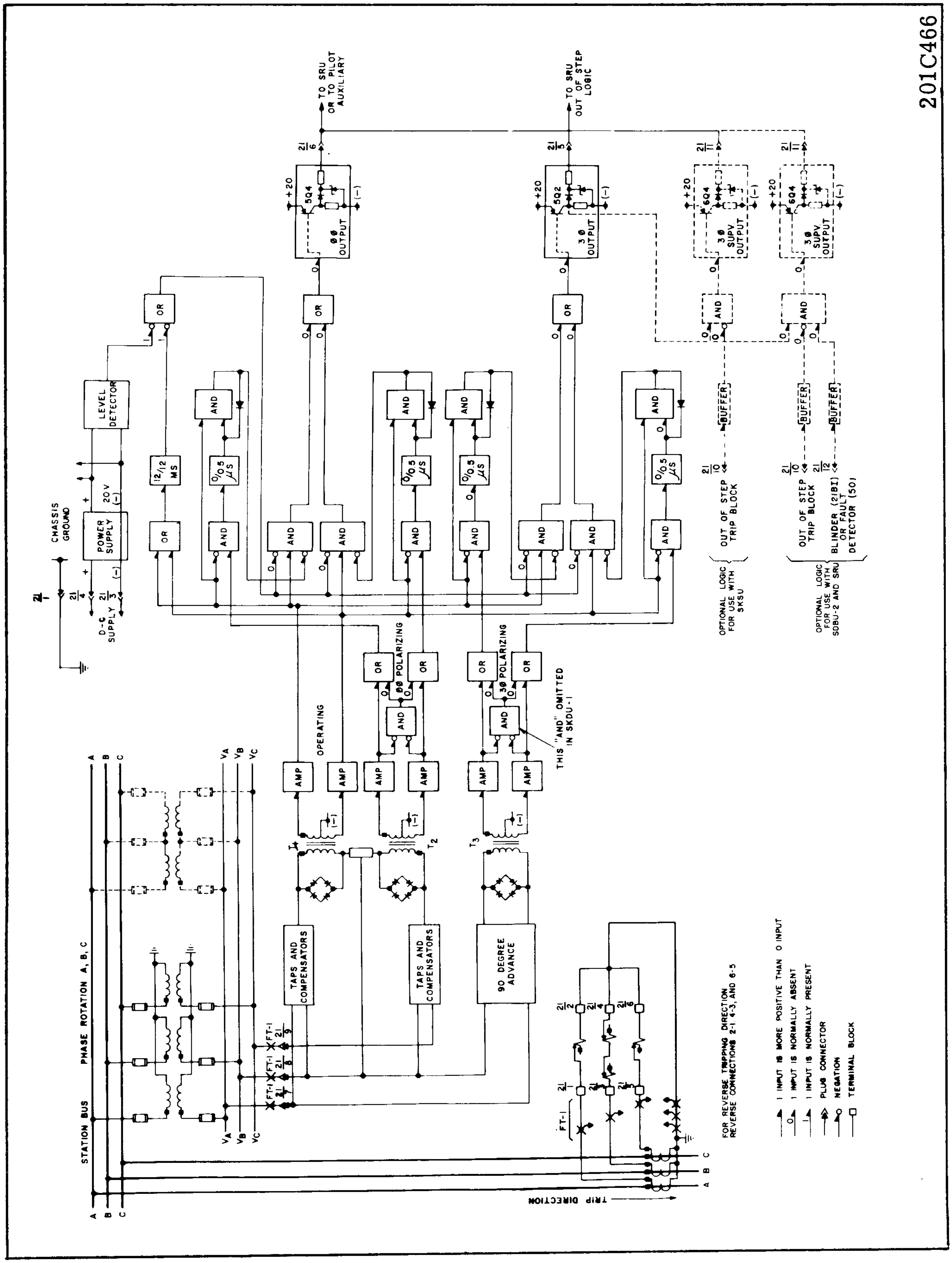
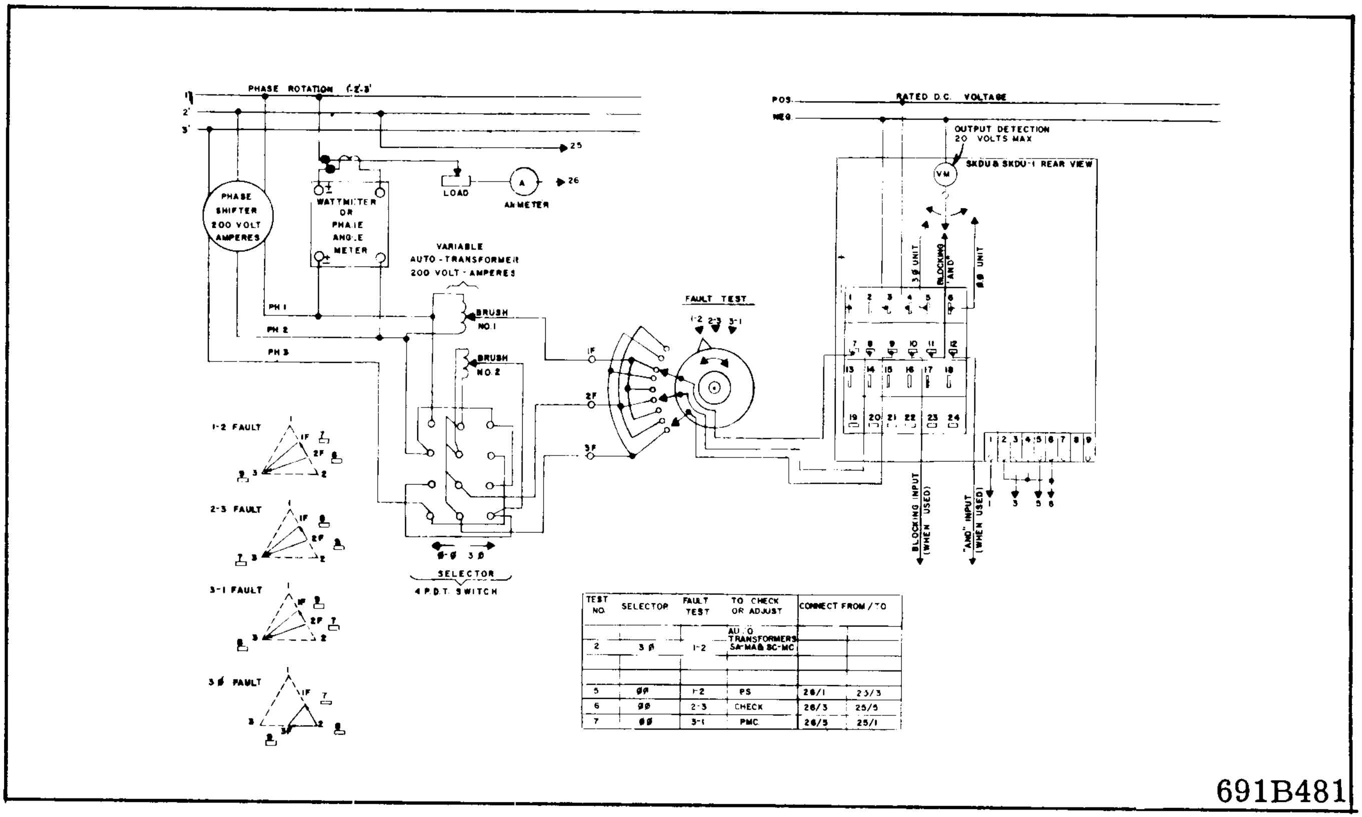


Fig. 19. External Schematic of Types SKDU and SKDU-1 Relays



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM / TO	
2	3 Ø	1-2	AUTO TRANSFORMERS SA-MA & BC-MC		
5	ØØ	1-2	PS	26/1	25/3
6	ØØ	2-3	CHECK	26/3	25/5
7	ØØ	3-1	PMC	26/5	25/1

Fig. 20. Test Connections for Types SKDU and SKDU-1 Relays

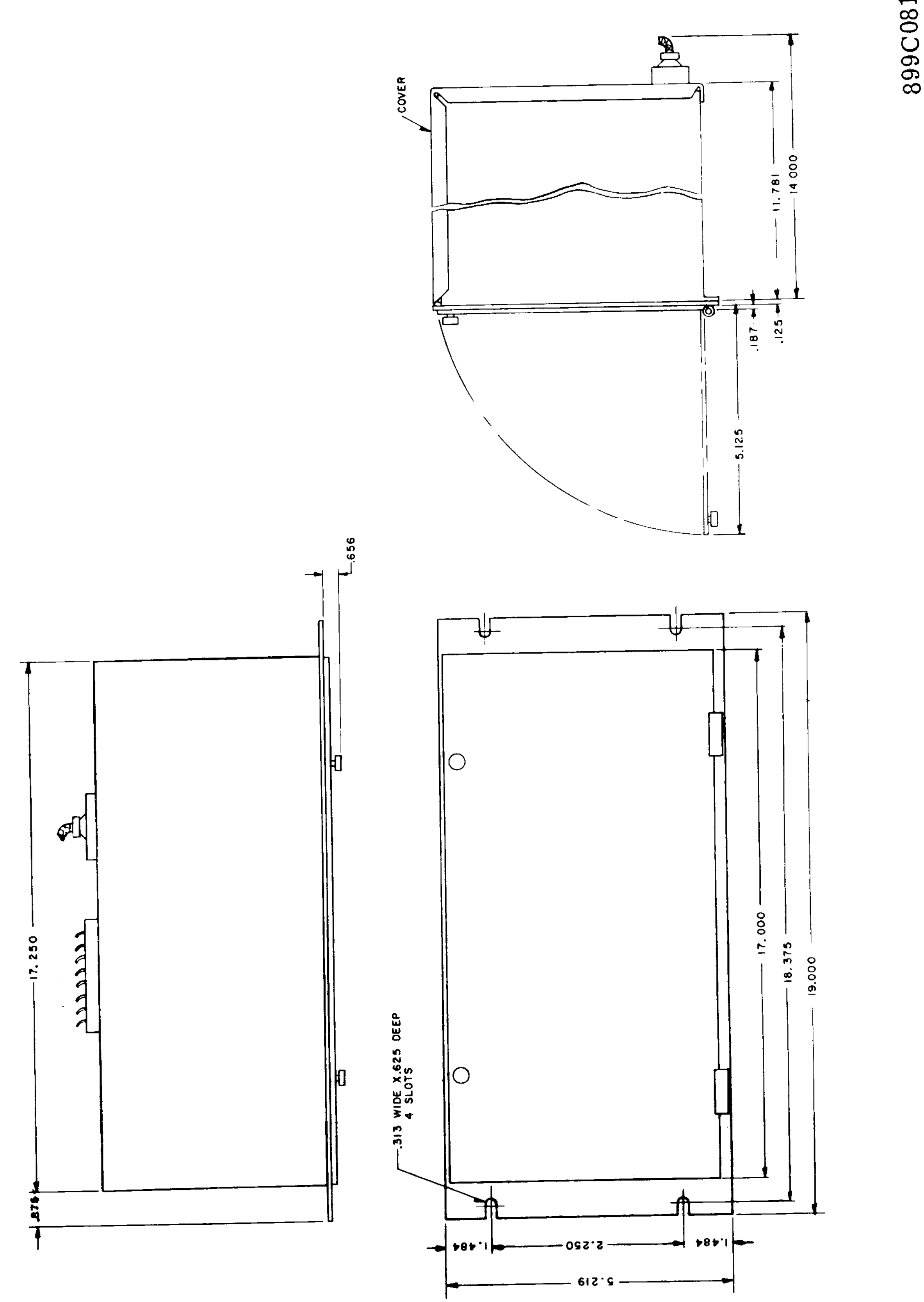


Fig. 21. Chassis Outline

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION

NEWARK, N. J.

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKDU AND SKDU-1 COMPENSATOR DISTANCE RELAYS

APPLICATION

The type SKDU relay, Figure 1, is a polyphase compensator-type distance relay which provides a single zone of phase protection for all three phases. It has a mho circle characteristic when plotted on an R + jX diagram. Logic may be specified which can be supervised by related protective relays such as blinder or out-of-step detecting relays. The output is 15V d-c to 19V d-c and up to 0.01 ampere d-c. An auxiliary unit such as an SAR tripping relay or an SRU output package is necessary to trip a breaker or operate other electromechanical devices.

The SKDU-1 is similar to the SKDU relay and has only a slight modification which allows the three-phase fault-detecting unit to trip on current only in the event a close in fault drops the relay voltage to zero.

CONSTRUCTION

Types SKDU and SKDU-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 a-c quantities into the static network.

Either five or six printed-circuit boards are used in the static network. They are plug-in types which may be removed for tests or examination and then reinserted. They may also be plugged into a card extender, style #849A534G01, to make the test points and components accessible for in-service checking.

A hinged and removable door provides access to all adjustments and printed-circuit boards. A 24-terminal jack provides external voltage connections, and a terminal block provides current connections.

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 2. 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) ohm, (.73-21) ohm, and (1.1-31.8) ohm 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 2. 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.

SUPERSEDES I.L. 41-495.1
*Denotes change from superseded issue.

EFFECTIVE MAY 1969

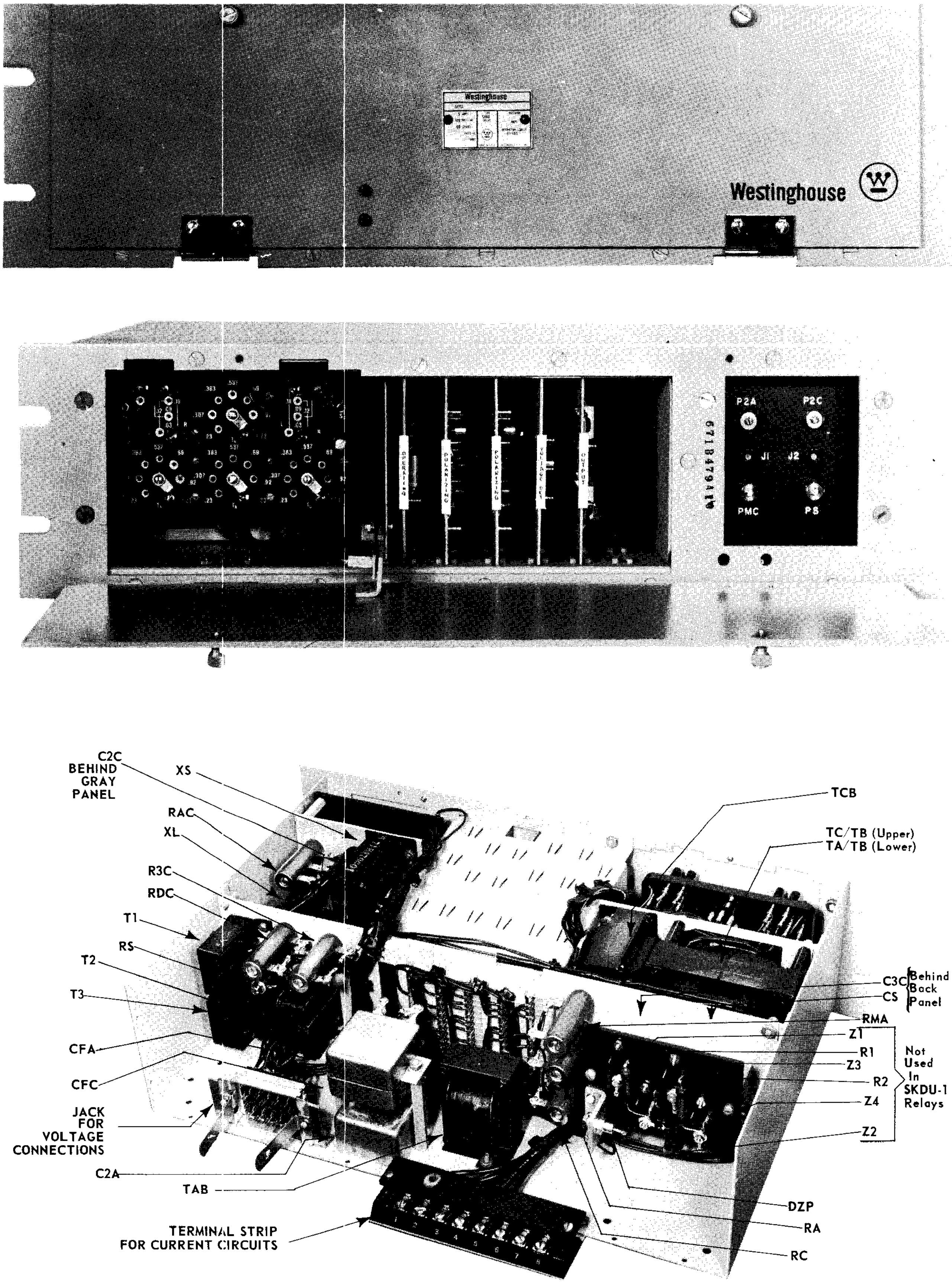


Fig. 1. Photo of Relay, Front (Door Open), Top (Cover Off)

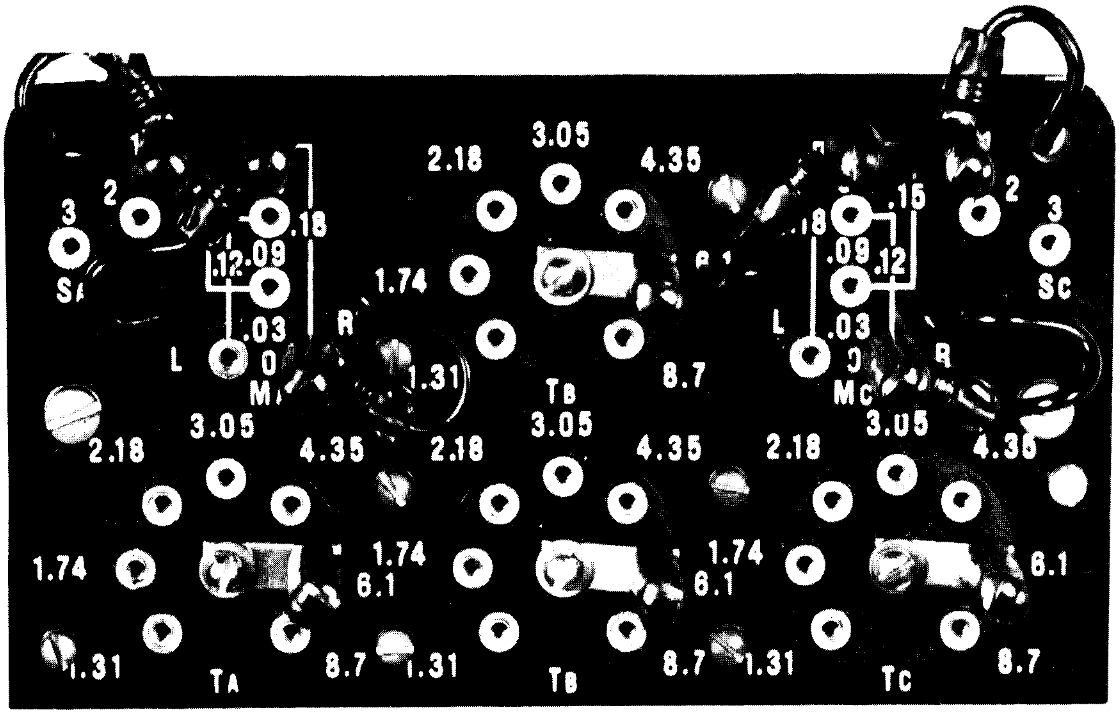


Fig. 2. Photo of Tap Plate

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 leads. The actual per unit values which appear on the tap plate between taps are 0., .03, .09 and .06.

* The auto-transformer makesit 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_{CB} with the auto-transformer taps S_A-M_A and S_C-M_C.

Phase-Shifting Circuit

"Polarization" is the reference against which the "operate" signal is compared. Polarization for the three-phase unit is obtained by shifting the phase 1-2 voltage ahead 90°. The phase-shifting circuit consists of a center tapped auto-transformer, XS, which supplies voltage to a series-connected resistance capacitor, RS and PS, and CS respectively (Figures 3 and 4). Voltage between the resistor-capacitor junction and the auto-transformer center tap leads the applied voltage by 90°.

Memory Circuit

The memory circuit consists of a large inductive reactance, XL, and a large capacitive reactance, C3C, which are series connected and are tuned very closely to sixty 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 60 Hz 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 a-c circuits from the d-c circuits. Secondly, they amplify the clipped a-c signal by a factor of 1:8 to make the relay sensitive to low-level input signals.

Printed-Circuit Board Assemblies

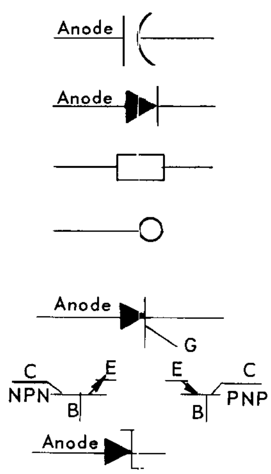
The basic relay uses five Printed Circuit Board (PCB) assemblies. The five basic PCB's are one

"operate" board, two "polarizing" boards (both are identical in the SKDU relay but are slightly different in the SKDU-1 relay), one "voltage detector" board, and one "output" board. A sixth PCB assembly is required when the output is to be supervised by additional input logic.

PCB assemblies shown in Figures 5 through 9 contain all the resistors, diodes, transistors and thyristors necessary to perform the functions of a dual-polarized phase-angle comparison unit. PCB's in Figures 10 and 11 contain "AND" logic components for external supervision.

Components on each board are identified by a letter followed by a number so that every component has an exclusive identification. Resistors are identified by the letter R followed by a number starting with 1. Where the component is shown on a schematic drawing, Figure 12, which includes more than one PCB, the component designation on the schematic is preceded by the board location number. For instance, each PCB in Figure 12 has an R6 resistor. The R6 resistor on the Voltage Detector PCB located in position 4 is designated 4R6, while R6 on the Polarizing Circuit in position 2 is designated
* 2R6. 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 Z, transistors by Q, thyristors by QS, capacitors by C, and test points by TP. Component letter designations are listed as follows:

CAPACITOR	C
DIODE	D
RESISTOR	R
TEST POINT	TP
THYRISTOR	QS
* TRANSISTOR	Q
ZENER DIODE	Z(or DZ)



Case Construction

The jack plug on the rear has 24 terminals numbered left to right and top to bottom. Thus terminal #1 is located in the upper left-hand corner when viewed from the rear, and terminal #24 is in the lower right-hand corner. Terminal #1 is connected internally to the chassis ground and may be used for grounding the connecting cable shields.

There is also an 8-terminal strip used for current terminals which is located in the right-hand side of rear when viewed from the back. The terminals are numbered from left to right.

The chassis case, cover, and front panel have electrical connections established by the use of shakeproof washers which cut through any point or protective coating to make electrical contact with the base metal. The complete relay is then grounded to the switchboard or cabinet by an external wire connection which must be made by clamping the wire under a shakeproof washer which also serves to help hold the cover in place.

The door is hinged at the bottom and is secured at the top by two captive screws. It may be opened to 90 degrees where it is stopped by a slotted strap attached to the door and also to the frame of the case. To remove the door, release the strap by either unscrewing it or unhooking it from the door and then slide the door to the right to disengage the hinges.

Printed-circuit boards are connected into the electrical circuits of the relay through 14-terminal connectors. The boards can be disengaged by a steady pull outward. Sometimes a simultaneous up-and-down motion (if there is clearance) will help free the mating connections. The boards are keyed so that they cannot be pushed home into the wrong connector although they may be replaced into the guides of the wrong position.

OPERATION

The SKDU and SKDU-1 relays both utilize identical a-c input circuits. Therefore, an explanation for the SKDU will suffice for both.

Two distinctly different logic systems are used in the SKDU 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 phase-angle comparison circuit 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 13.a. A trip condition results when V_{YB} lags V_{XB}.

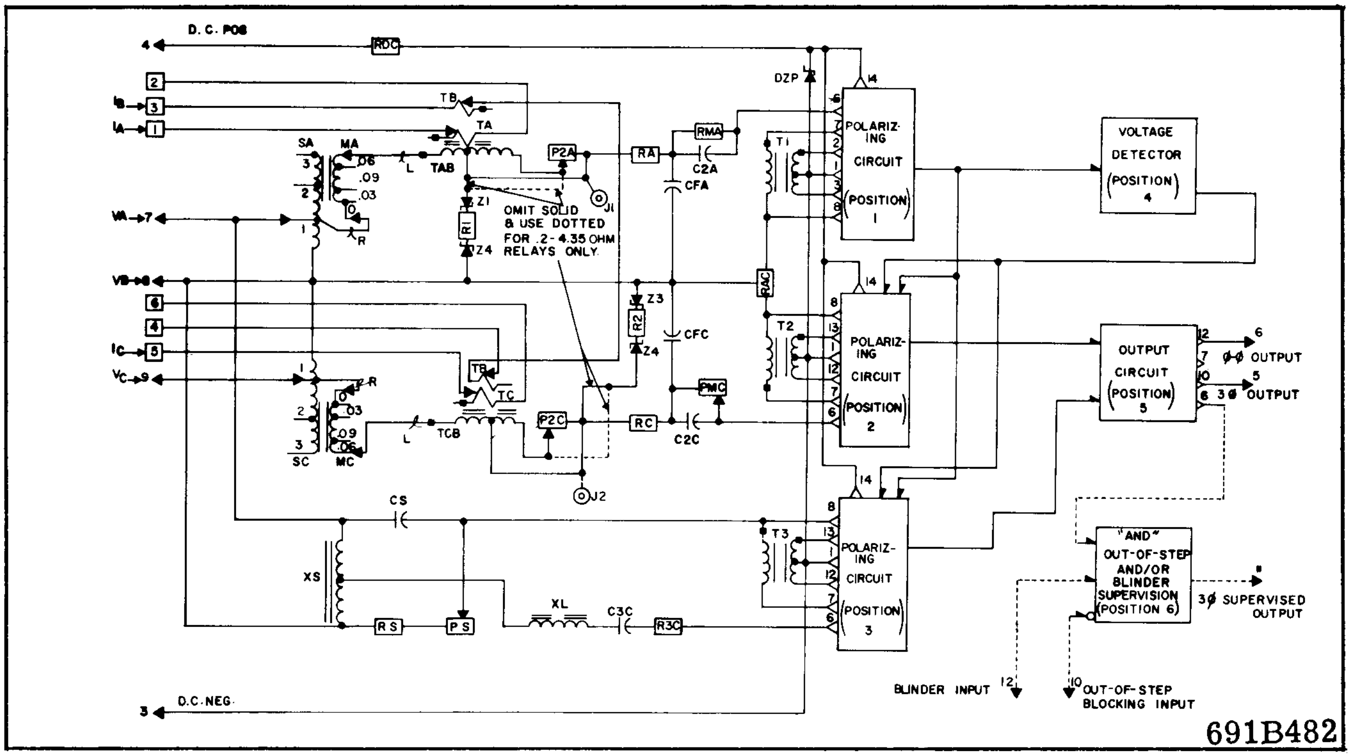


Fig. 3. SKDU Internal Schematic (showing a-c input and logic blocks)

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 $I Z_R$ 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 13.b at point 1, it can be seen that the voltage V_{CB} is greater than the permissible minimum $(I_A - I_B)\ Z_R$ computed by compensator T_{CB}. 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 circuit 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 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 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 14.a illustrates the connections which apply to the static phase-angle comparison unit. Voltage V_{AB} is modified by the compensator output

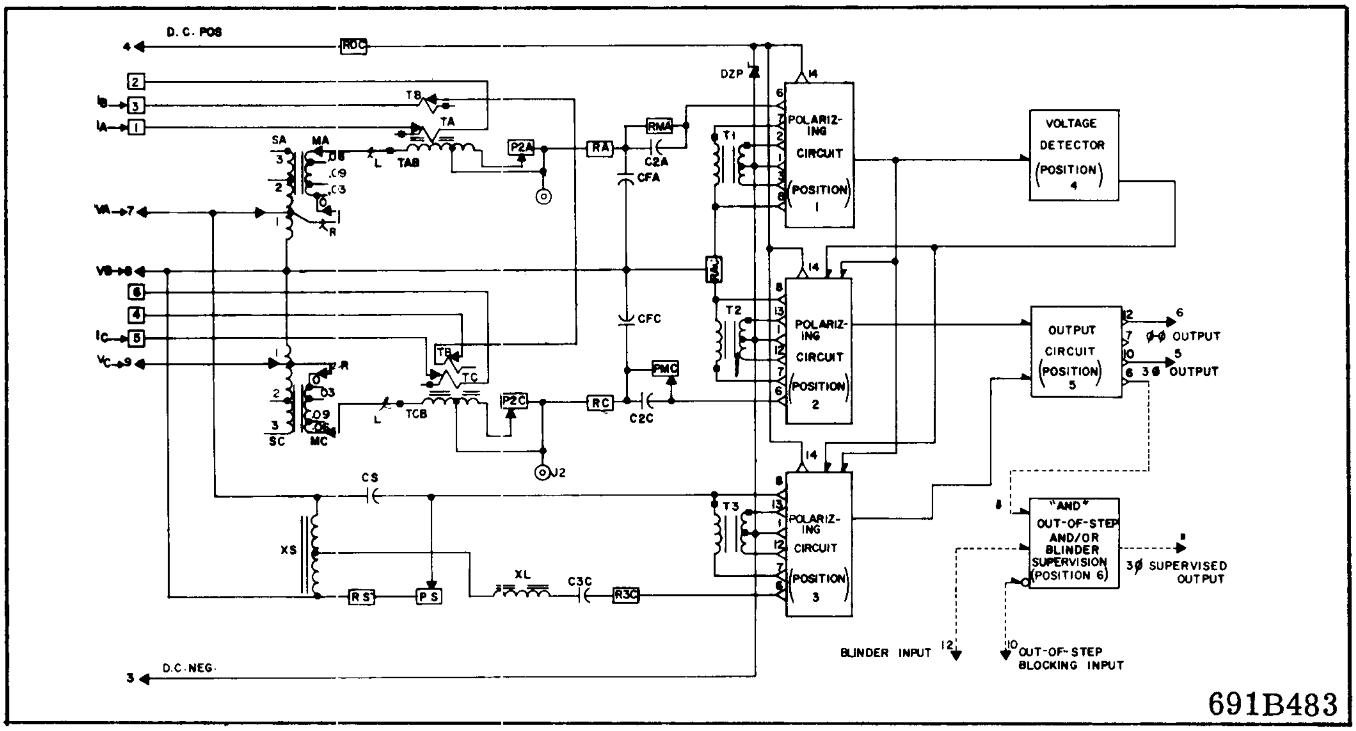


Fig. 4. SKDU-1 Internal Schematic (showing a-c input and logic blocks)

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 14.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 14.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 comparator 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 14.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 overreach 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 output can be supervised by working it into an AND logic with an out-of-step signal from an out-of-step relay.

Phase-Angle Comparison Circuit

Referring to Figure 12, the phase-to-phase angle comparison circuit trips when current flows into the

* base of transistor 5Q3 through zener diode 5Z2. Such tripping current must come from the 20V bus through either transistor 1Q2 or 1Q4 located on the "operate" PCB. The operate circuit, driven by transformer T1, is continually trying to trip the unit by supplying current through 1Q2 and 1Q4 on alternative half cycles. 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 5Z2 to transistor 5Q3 to cause tripping.

* To prevent the operate circuit from tripping, the polarity marked terminal of T2 must go positive before the polarity terminal of T1. This causes 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 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 the 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, 5Z2 and 5Q3.

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.

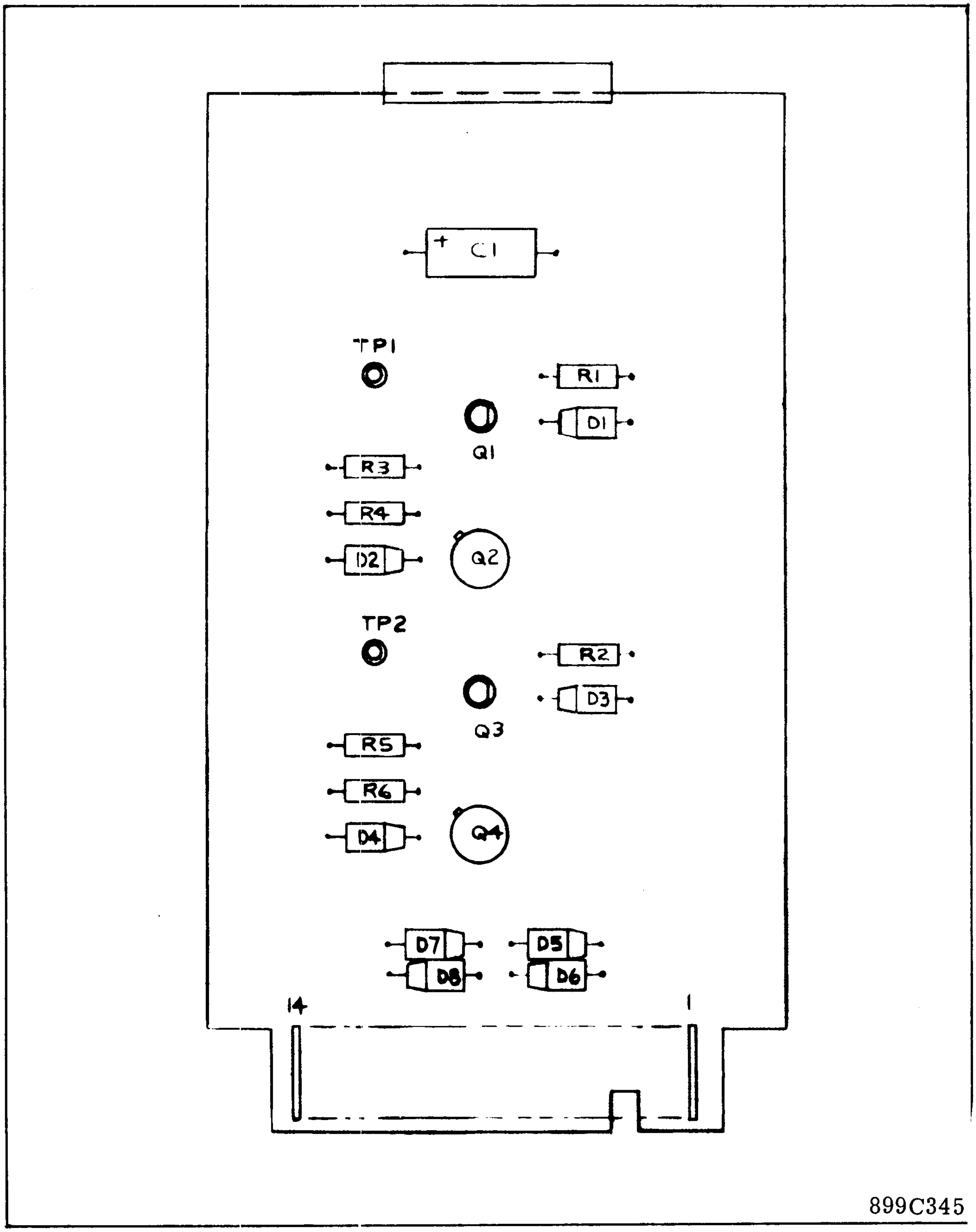
Restraint-Signal Detectors: If a condition should develop so that no polarizing voltage appears at transformer T2, then no gating signal would be available to switch 2QS1 and short circuit the 1Q2 current. This, of course, could cause incorrect tripping. A restraint-signal detector circuit prevents this from happening. Under normal conditions, no voltage is allowed to develop across zener diode 2Z2 at Test Point 2TP1 because it is alternately short circuited to the negative bus by transistors 2Q1 and 2Q2 through diodes 2D5 and 2D6 respectively. When the voltage from T2 drops too low to drive 2Q1 and 2Q2, current flows from the 20-volt bus through 2R3 and 2Z2 into the base of 2Q3. With 2Q3 conducting, the bases of 2Q4 and 2Q5 are driven through diodes 2D8 and 2D13 respectively to maintain the gate drive of 2QS1 and 2QS2 respectively. Thus when the T2 voltage is near zero, thyristors 2QS1 and 2QS2 are maintained in a conducting state so that no output can develop.

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 5Z1 and 5Q1 to switch 5Q2 into conduction.

SKDU-1 Relay: The SKDU-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 SKDU-1 three-phase unit 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 cycle, 4Q2 turns on to remove the gating signal until the relay is de-energized again.

The zener diode 4Z1 monitors the d-c voltage level. If the a-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.



* *Fig. 5. Operating PCB Assembly*

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 overreach due to d-c transients. Compensators basically are insensitive to d-c 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 unidirectional voltage in the secondary.

Distance Characteristic: SKDU 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 14) 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: Three-Phase Unit

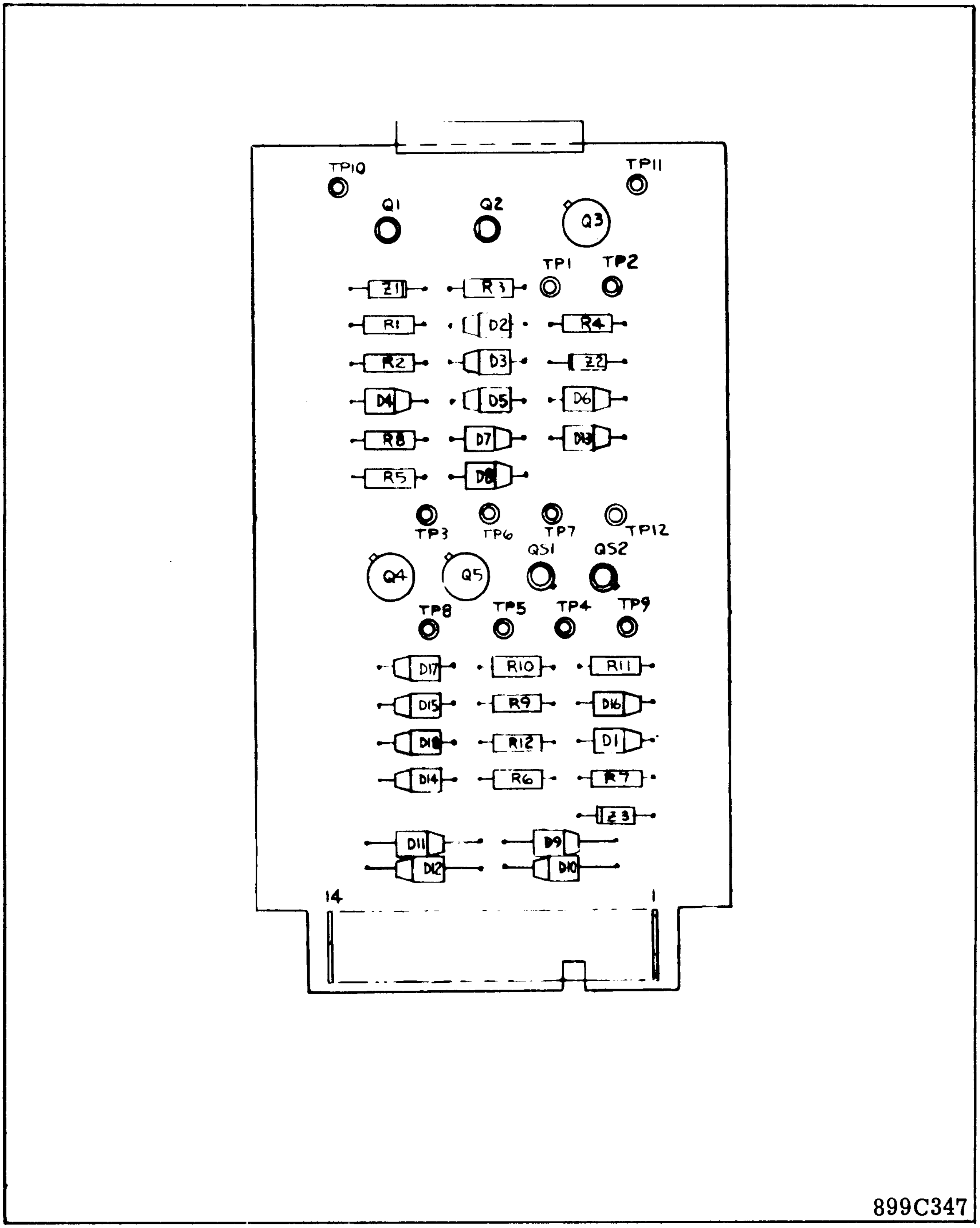
The impedance curve for the three-phase unit is shown in Figure 16. This unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. For this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

Distance Characteristics: SKDU-1 Three-Phase Unit

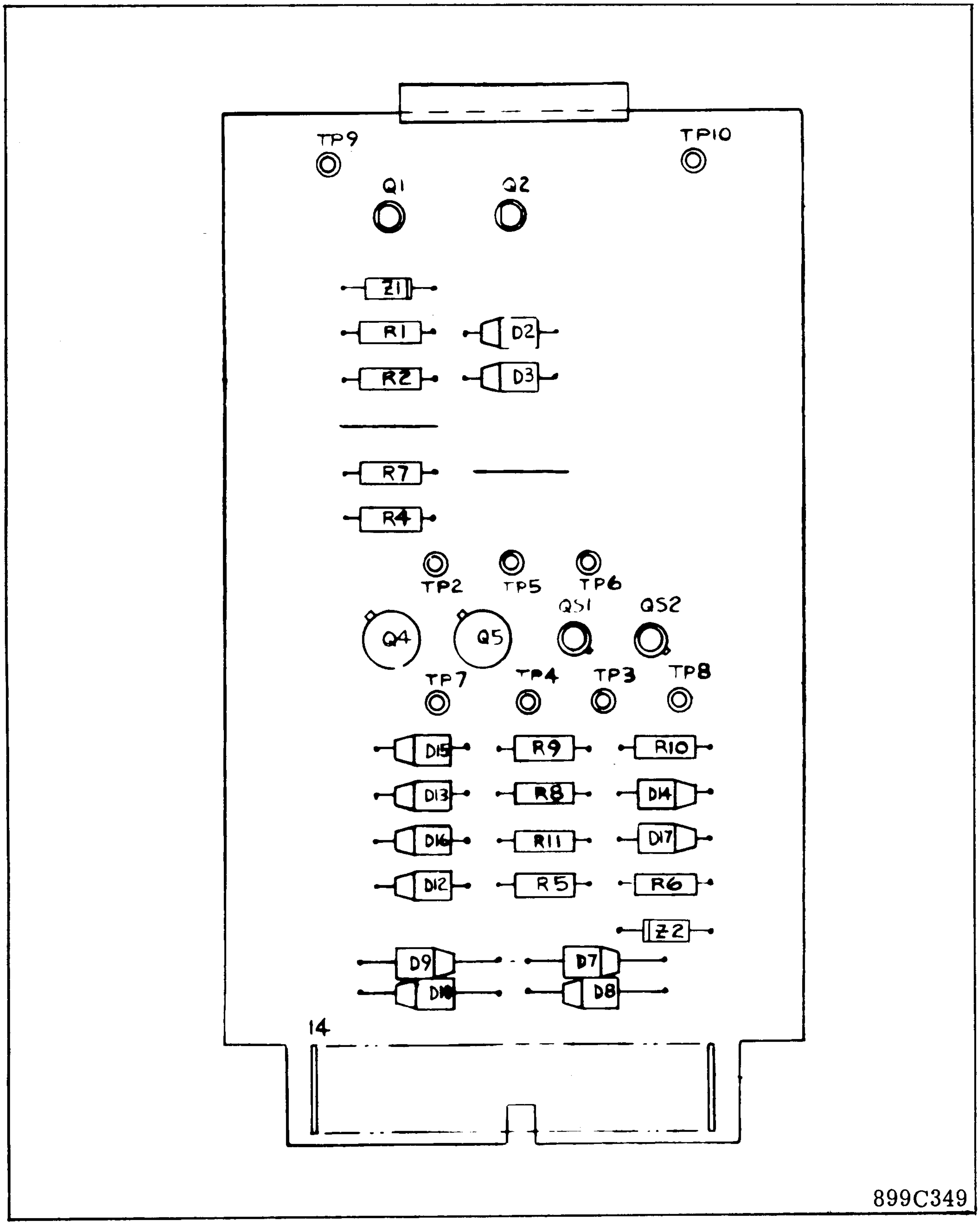
The three-phase unit of the SKDU-1 relays has a characteristic circle which includes the origin. This feature results from the omission of the restraint-signal detector in the polarizing circuit. The unit will trip for an "IT" product of 0.40 or more when the input voltage is zero.

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°.



* *Fig. 6. Polarizing PCB Assembly for Phase-to-Phase Unit and for SKDU Three-Phase Unit*



* *Fig. 7. Polarizing PCB Assembly for SKDU-1 Three-Phase Unit*

This 90° relationship is approached if the compensator loading resistor (P2A or P2C) shown in Figures 3 and 4 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_{CB}. 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 2 are based upon a 75° compensator angle setting. If the resistors P2A and P2C are adjusted for some other maximum sensitivity angle, the nominal reach is different than indicated by the taps. The reach, Z_θ, varies with the maximum sensitivity angle, θ, as follows:

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

TAP PLATE MARKINGS

(T_A, T_B and T_C)

(0.2 to 4.35) ohms	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21) ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 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 SKDU and SKDU-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 within the relay setting.

Burden

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

Current Circuit Rating in Amperes

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

Output Circuits

Open Circuit Voltage	17V to 21V d-c
Rated Current	10 milliamperes

SETTING CALCULATIONS

Relay-reach is set on the tap plate shown in Figure 2. The tap markings are:

(T_A, T_B and T_C)

(0.2 to 4.35 ohms)	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21 ohms)	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 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 P2A and P2C. Set zone 1 reach to be 90% of the line (85% for line angles of less than 50°).

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

$$Z_\theta = Z_{pri} \frac{0.9 R_C}{R_V} \qquad \text{Eq. (1)}$$

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

Z_θ = The ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees. Eq. (2)

* $Z = \frac{TS}{1 \pm M}$ = the tap plate setting

T = compensator tap value

S = auto-transformer primary tap value

θ = maximum sensitivity angle setting of the relay (factory setting of $\theta = 75°$).

±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.)

Z_{pri} = ohms per phase of the total line section

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

R_C = current transformer ratio

R_V = 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 using Eq. 1.

B. Determine the tap plate value, Z, using the formula: Eq. (3)

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

when $\theta = 75°$, $Z = Z_\theta$

Now refer to Tables II, III and 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" lead settings 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).

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

For example, assume the desired reach, Z_θ, 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:

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

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

Step E

Recheck settings:

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

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

From Eq. (3)

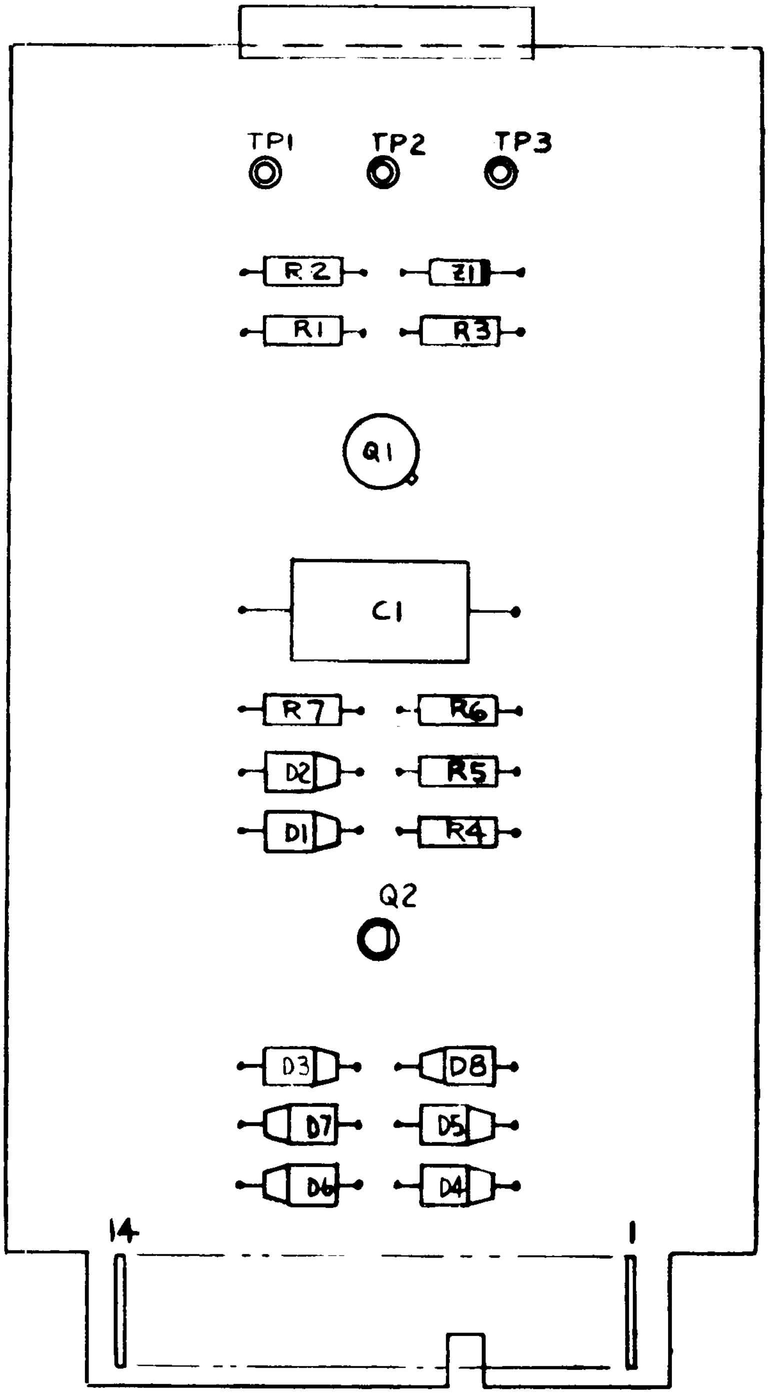
which is 101.0 percent of the desired setting.

SETTING THE RELAY

The SKDU and SKDU-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.

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

Each set of compensator taps terminates in



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* *Fig. 8. Voltage Detector PCB Assembly*

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

Auto-Transformer Primaries (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 2).

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 lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Refer to Table 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.

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 $V_{L\text{-}N}$ 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 $V_{L\text{-}N}$ 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 $V_{L\text{-}N}$ 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 $V_{L\text{-}N}$ 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 $V_{L\text{-}N}$ 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 TAP .73-21 OHM RANGE	CURRENT CIRCUIT IMPEDANCE AT 5 TO 100 AMPERES (V_{LL} = 120 V.)								
	TA (TERM'S [1] - [2])			TB (TERM'S [3] - [4])			TC (TERM'S [5] - [6])		
	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 and TB compensators or TB and 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

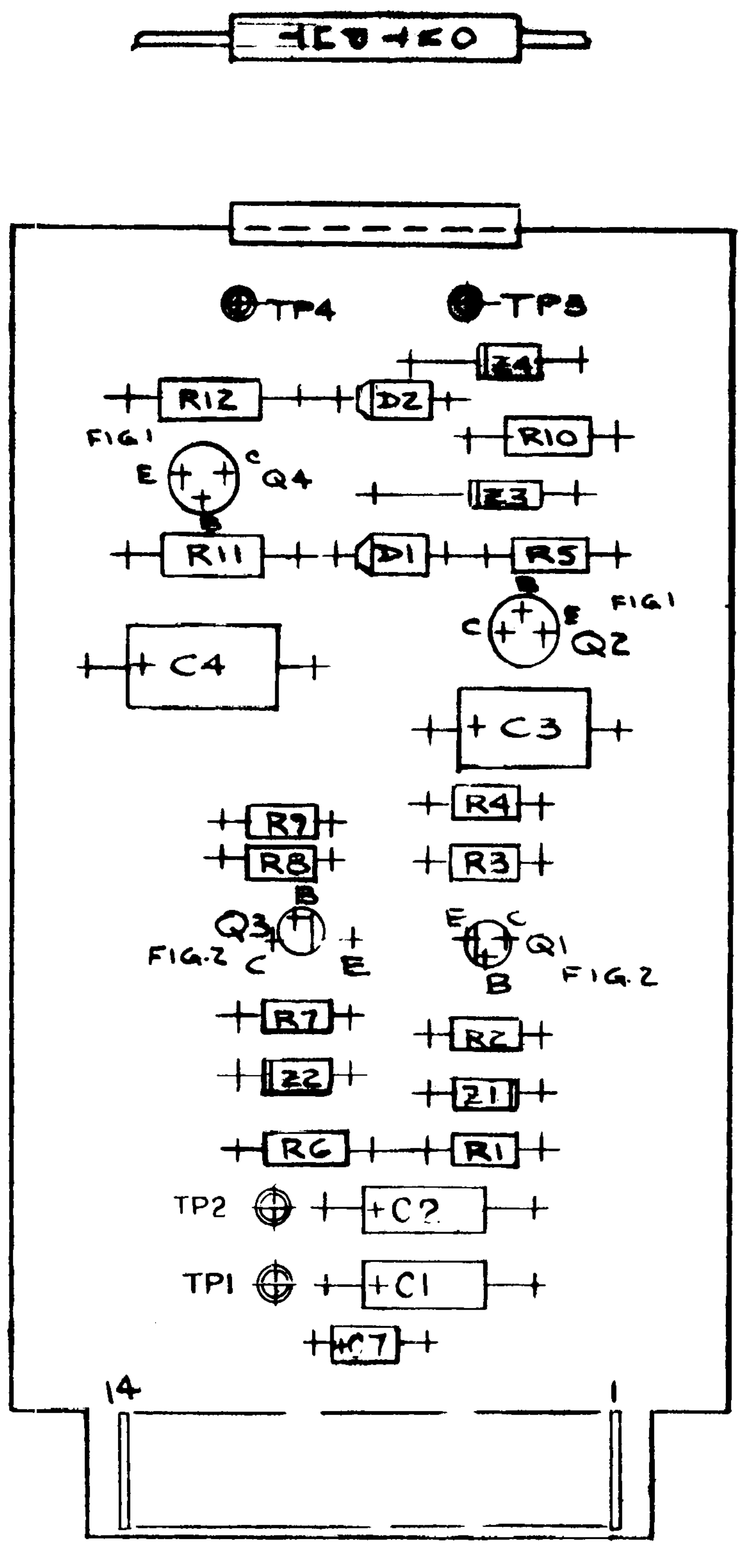
RELAY SETTINGS FOR .73-21 OHM RANGE RELAY

	"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	31.4		–.15	.03	.06	"R" OVER "L"
	–	–	–	–	–	–	10.6	–	21.2	–	31.8		–.18	0	.06	"R" OVER "L"



899C353

* *Fig. 9. Output PCB Assembly*

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 P2A and P2C. Refer to Repair Calibration, parts 11 to 15, and 20, 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 four slotted holes on the front of the case. Additional support should be provided toward the rear of the relay in addition to the front panel mounting. This will protect against warping of the front panel due to the extended weight within the relay case.

EXTERNAL CONNECTIONS

Figure 19 shows the external connections for an SKDU or an SKDU-1 relay.

Current circuit connections are made to an eight-section terminal block located at the rear. Potential circuits, both a-c and d-c as well as input and output logic signal circuits, are connected through a 24-terminal jack. Connections are made by a plug on the wiring harness. The plug is inserted between two latching fingers which hook over the back of the plug to prevent an accidental loosening of the plug. The plug can be removed by spreading the two fingers apart enough to disengage the hooks from the back. The plug must be withdrawn while the fingers are spread apart.

Note that terminal number 1 is connected to the case within the relay and may be used for grounding the shields of connecting cable. The grounding connection will be broken when the plug is disconnected.

Permanent grounding of the case is accomplished by connecting a ground wire under a washer of a cover screw. These are self-tapping screws and provide excellent low-resistance contact with the case.

RECEIVING ACCEPTANCE

Acceptance tests consist of 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 a-c voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equivalent a-c ammeter.

Testing can be accomplished by use of the test connections shown in Figure 20. Tripping is indicated by a d-c voltmeter reading. At the balance point, the output may be as low as 1 volt or 2 volts 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 15 volts indicates a defective tripping output or defective logic.

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. Connect the relay for a 1-2 fault as indicated for Test #5, 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 = 30V).

3. Supply 105% 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 unit just trips. The maximum sensitivity angle θ is $\frac{\theta_1 + \theta_2}{2}$. This should be 75° ± 3°.

* The angle shifts from 75° at 70 V_{LL} to approximately 70° at 5 V_{LL}. This is a normal response of the logic and is not detrimental to the relay protection.

4. 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.

5. Repeat section 4 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.

6. Repeat the above tests 2, 3 and 4 for the three-phase unit. The current required to trip the three-phase unit should be within the limits given in Table V at the maximum sensitivity angle of 75°.

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

TABLE V

Test Voltage = 30 $V_{L\text{-}L}$
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 3 ϕ	(100% Z - 94.7% Z) 14.0 - 14.8 Amps.
.73-21 Ohms	5.8	5.05	5,6,7 5	ϕ-ϕ 3 ϕ	(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 3 ϕ	(100% Z - 94.5% Z) 1.98 - 2.1 Amps.

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 jack terminals 2, 3, 4, 5, 6, 11 and 12 to avoid destroying components in the static network. These connections are not necessary for surge testing.

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

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

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 three-phase unit response is —

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

REPAIR CALIBRATION

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

7. Connect the relay for testing as shown in Figure 20. The four-pole, double-throw switch shown in the test circuit selects the type of voltage condition for a phase-to-phase or a three-phase fault, that may 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 procedures outlined below.

8. 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 "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 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.

9. 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

10. 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:	disconnected
"L" for M_A and M_C:	set for .06 * (top position)

A. PHASE-TO-PHASE UNIT

Maximum Sensitivity Angle Adjustment

11. Connect the relay for a 1-2 fault as indicated for Test #5. Connect a high-resistance voltmeter (2000 ohms/volt) between the "R" lead and the .03 tap position of M_A, and adjust voltages V_{1F2F} and V_{2F3F} for 30 volts.

12. Pass the current called for in Table VI for 30 volts through the T_{AB} compensator with the phase shifter set for the desired maximum sensitivity angle. Adjust potentiometer P2A for a null, or minimum reading, on the voltmeter.

13. Swing the phase shifter and adjust P2A slightly to obtain a minimum reading on the voltmeter when the phase-angle reading is at the desired maximum sensitivity angle. This adjusts the T_{AB} compensator angle.

14. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_A and jack J_1 located just below P2A. Pass 5 amperes through the compensator. The secondary voltage should be:

$$V_S = 10.35\ T \sin\theta \pm 1.5\%$$

where

θ = the desired maximum sensitivity angle

T = compensator tap setting

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

1.5% = the allowable variation from nominal

		NOMINAL 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

15. Connect the relay for Test #6. Connect the voltmeter between the "R" lead and the .03 position of M_C, and repeat steps 12 and 13 above. This adjusts the T_{CB} compensator angle with P2C.

16. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_C and jack J_2 located just below P_{2C}. With 5 amperes through the compensator, the voltage should be as listed above in step 14.

Circuit Calibration

17. Connect "R" for M_A and M_C on ".03" and "L" for M_A and M_C in the top position so that there is .15 between L and R. Connect terminals 7 and 9 together, apply 120V a-c between terminals 8 and 9, and adjust P_{MC} until the ϕ-ϕ unit just trips. At the balance point, the output detector voltmeter reading may be as low as 1V or 2V indicating that the system is only partially tripping. This is a normal balance point character-

TABLE VI

TEST NO.	VOLTS V_{1F2F}	AMPERES TO TRIP FOR $\theta = 75°$					
		.2-4.5 RANGE		.73-21 RANGE		1.1-31.8 RANGE	
		I_{min}	I_{max}	I_{min}	I_{max}	I_{min}	I_{max}
5,6,7	5.0	2.34	2.66	0.50	0.56	0.33	0.376
	30.0	14.0	14.8	2.95	3.15	1.98	2.1
	70.0	—	—	6.9	7.1	4.62	4.72

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

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

istic. However, a 5 percent increase in current should produce an output of 15 to 20 volts.

18. 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 5.0 volt level first, and adjust P_{MC} further, if necessary, to make the current trip level for Test #7 fall between the trip levels for Tests numbers 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:

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

Maximum Sensitivity Angle Check

19. Use the 30-volt condition in Table VI. Supply 103% of the current necessary to trip at the calibrated angle of maximum sensitivity and swing the phase shifter to determine the two angles, $\theta 1$ and $\theta 2$, at which the unit just trips. The maximum sensitivity angle, θ, is $\frac{\theta_1 + \theta_2}{2}$. This value should be not more than 3° different from the setting made in steps 11 to 15. The phase-to-phase unit testing is complete.

* THREE-PHASE UNIT

Maximum Sensitivity Angle Adjustment

20. Connect the relay for a 1-2 fault as indicated for Test #5. Apply 30 V_{LL} between relay terminal 7 and 8. Supply 103% 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 maximum sensitivity angle can be set by adjusting potentiometer P_S. The angle for the three-phase unit should be the same as for the phase-to-phase unit as determined with Test #5 in step 19 above.

21. Set the phase shifter for the maximum sensitivity angle. Using only Test #5 connections, the three-phase unit should trip within the same limits as listed for the phase-to-phase unit.

22. The three-phase unit testing is complete.

* "AND" LOGIC (When Applicable)

* No calibration is required to the AND logic; however, it is desirable that a functional check be made to establish that the circuits are working properly.

23. Use connections for Test #5, and apply current and voltage to trip the three-phase unit as determined by an output voltage appearing at the * output terminal 5.

24. "AND and Blocking" input relays should not have an output voltage at terminal 11. Apply +20V d-c to terminal 12 with negative to the NEG. BUS, and an output should appear at terminal 11.

25. With +20V d-c on terminal 12, apply +20V d-c to the "Blocking" terminal 10 and the output should stop.

26. "Blocking" input relays should have an output at terminal 11 with the three-phase unit tripped. Apply +20V d-c to terminal 10, and the output should stop.

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.

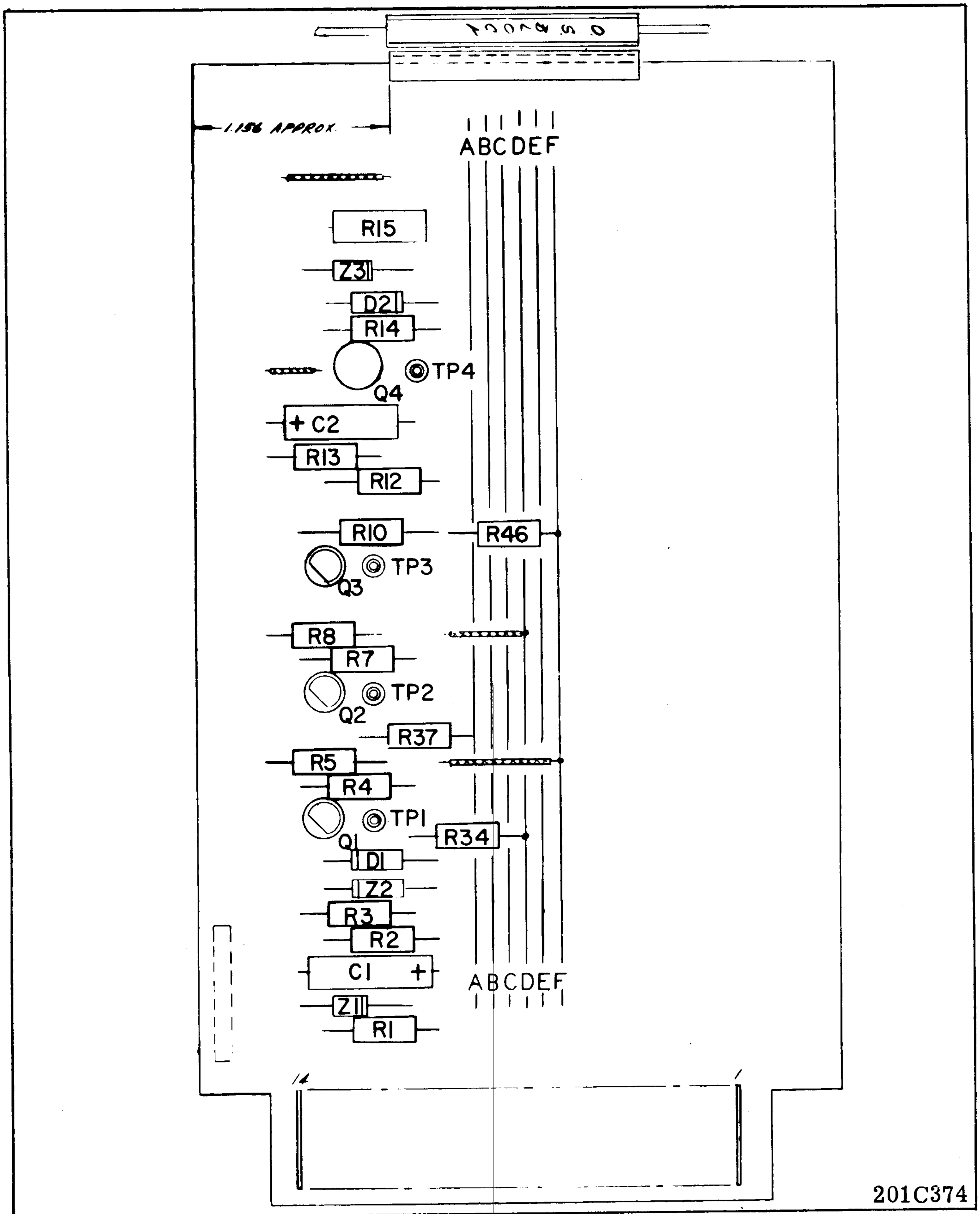
The chassis outline is shown in Figure 21.

TABLE VII

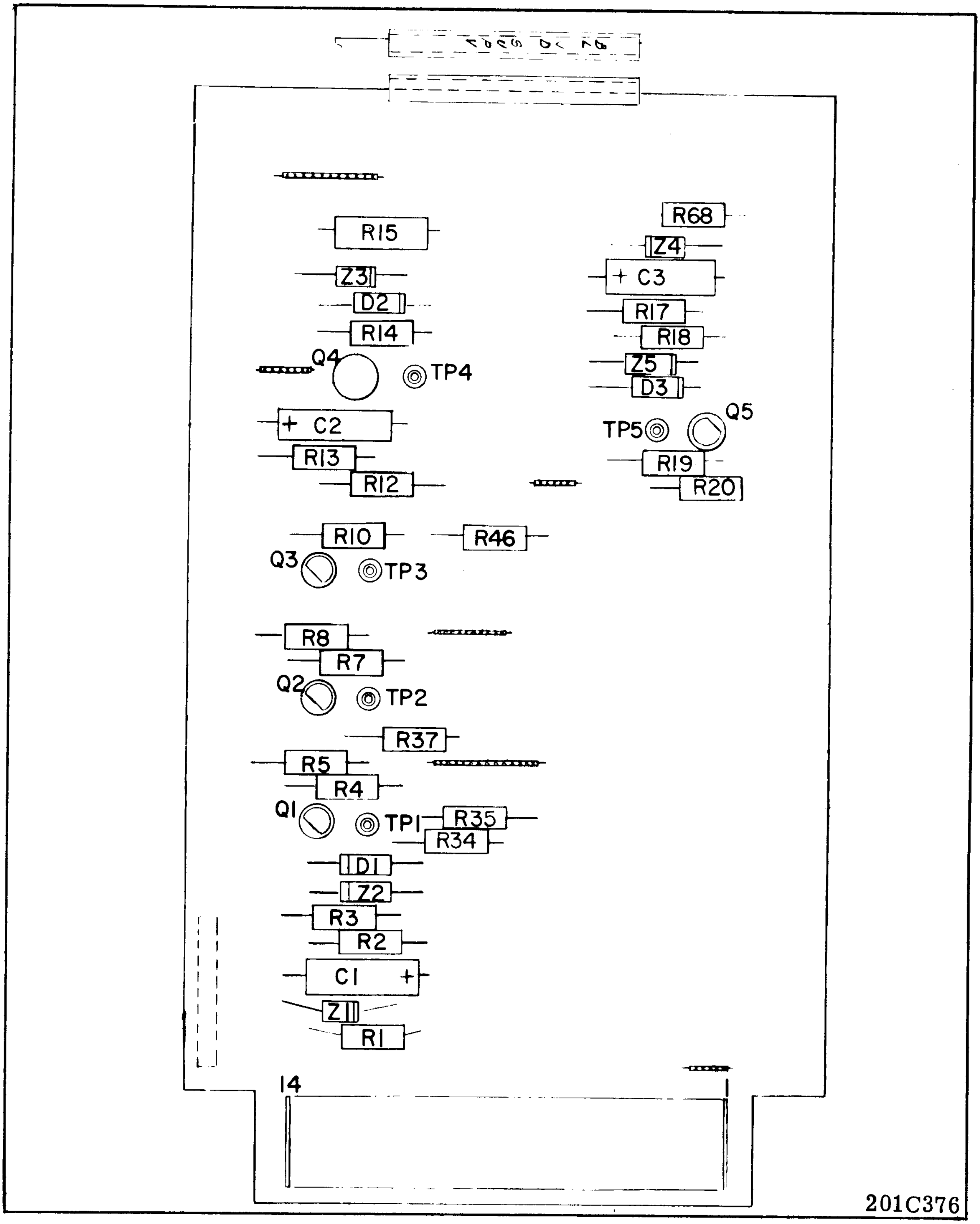
NOMENCLATURE FOR RELAY TYPES SKDU AND SKDU-1

NOTE: The manufacturer reserves the right to change component values without prior notice.

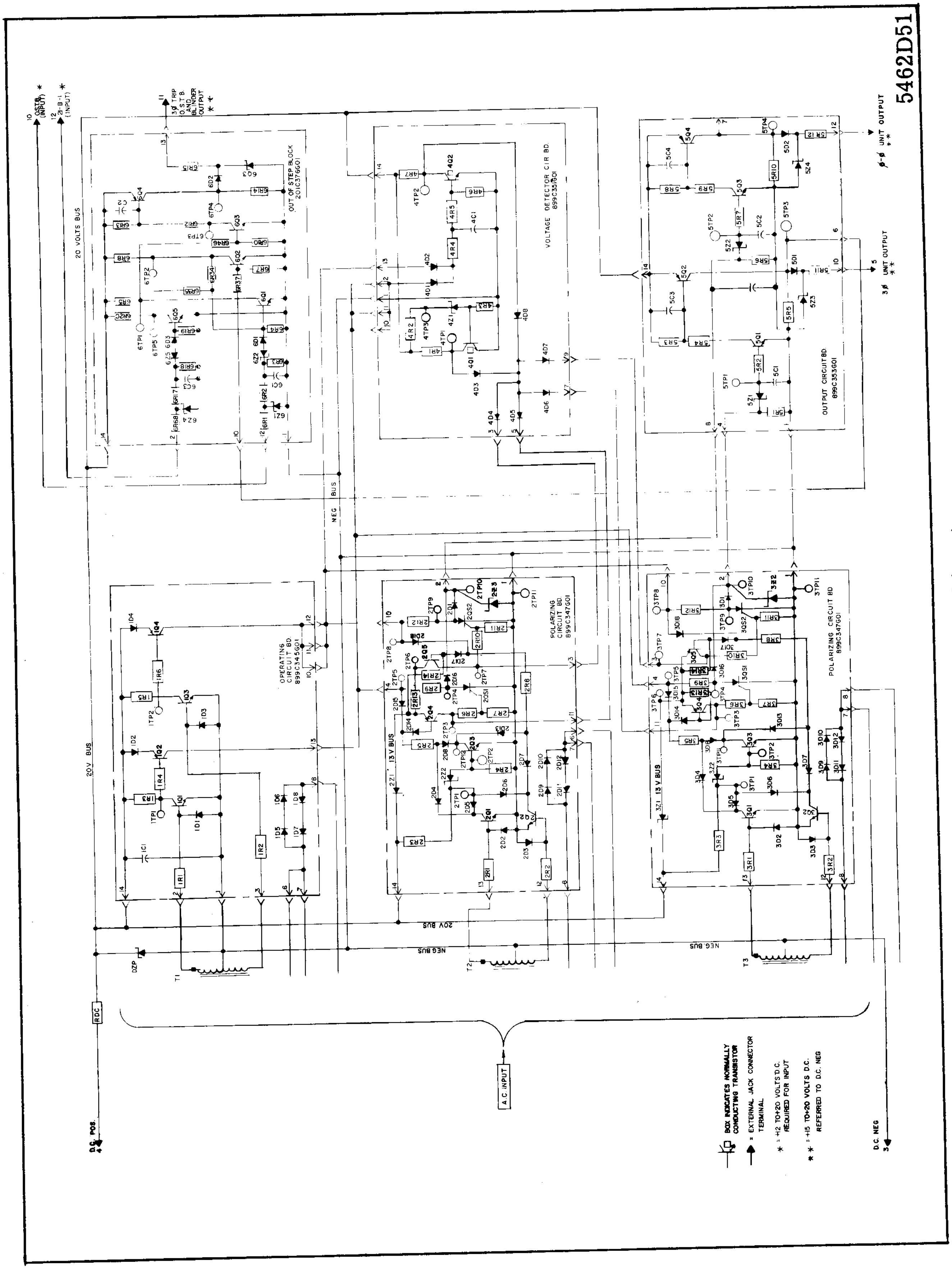
Item	Description	Style Number
	CAPACITORS	
C2A, C2C	1.8 mfd	14C9400H12
C3C	.3 mfd	1724191
C4C	.03 mfd	1725974
CFA, CFC	1 mfd	1876999
CS	.45 mfd	1723408
DZP	Zener Regulating Diode: 20V, 10W	1N2984B
Z1, Z2, Z3, Z4	Clipping Zener Diodes: 200V, 50W	1N2846A
J_1, J_2	Test Jacks	
M_A, M_C	Auto-Transformer Secondary (between taps 0.0, .03, .09, .06)	
	POTENTIOMETERS	
P2A, P2C	1000 ohm	836A635H03
P_{MC}	2.5 K-ohm	836A635H04
P_S	5 K-ohm	836A635H05
	PRINTED CIRCUIT BOARDS	
	Operate Circuit	899C345G01
	Polarizing Circuit (2 in SKDU)	899C347G01
	Polarizing Circuit (in SKDU-1 only)	899C349G01
	Voltage Detector	899C351G01
	Output Circuit	899C353G01
	O. S. Block	201C374G01
	Blind Supervision	201C375G01
	Card Extender	849A534G01
	RESISTORS	
R_1, R_2	5 watt, 500 ohm	763A129H03
R_{3C}	25 watt, 3 K-ohm	1202954
R_A, R_C, R_{MA}	25 watt, 1.8 K-ohm	1201004
R_{AC}	25 watt, 3.55 K-ohm	1955270
R_{DC}	for 48V d-c, 25 watt, 600 ohm	1202587
R	for 125V d-c, 25 watt, 1.5 K-ohm	1267293
R_S	10 watt, 10 K-ohm, adjustable	185A925H05
S_A, S_C	Auto-Transformer Primary (Taps: 1, 2, 3)	
T_1, T_2, T_3	Coupling Transformer, Center Tapped Secondary (Step Up 1:8)	292B563G05
T_{AB}, T_{CB}	Compensator Assemblies	
X_L	Memory Circuit Reactor	606B544G02
X_S	Center Tapped Auto-Transformer for Phase Shift Circuit	671B470G01



* Fig. 10. Out-of-Step Blocking "AND" PCB Assembly



* *Fig. 11. Out-of-Step Blocking with Blinder Supervision "AND" PCG Supervision*



* *Fig. 12. SKDU D-C Schematic*

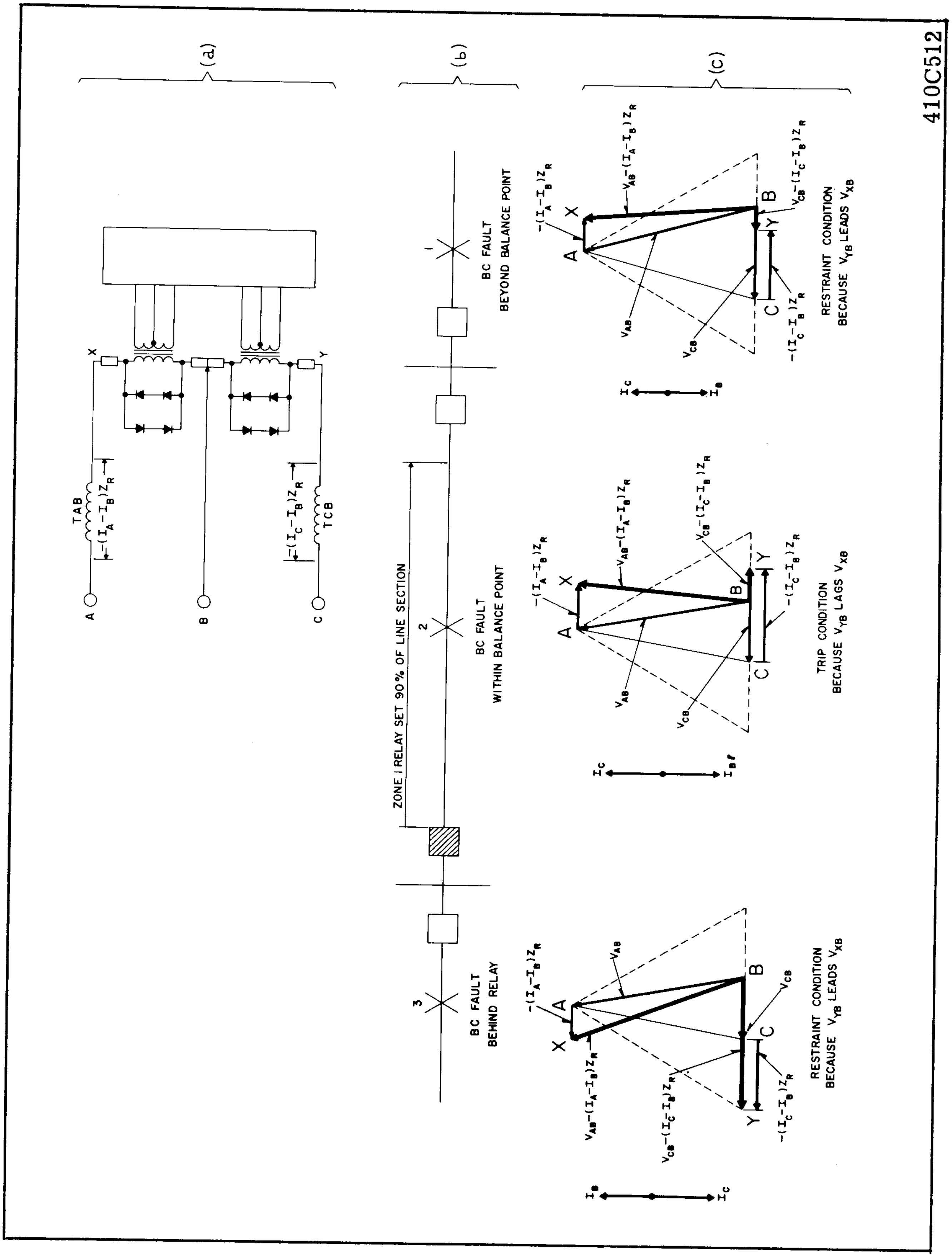


Fig. 13. Voltage and Current Conditions for the Phase-to-Phase Unit

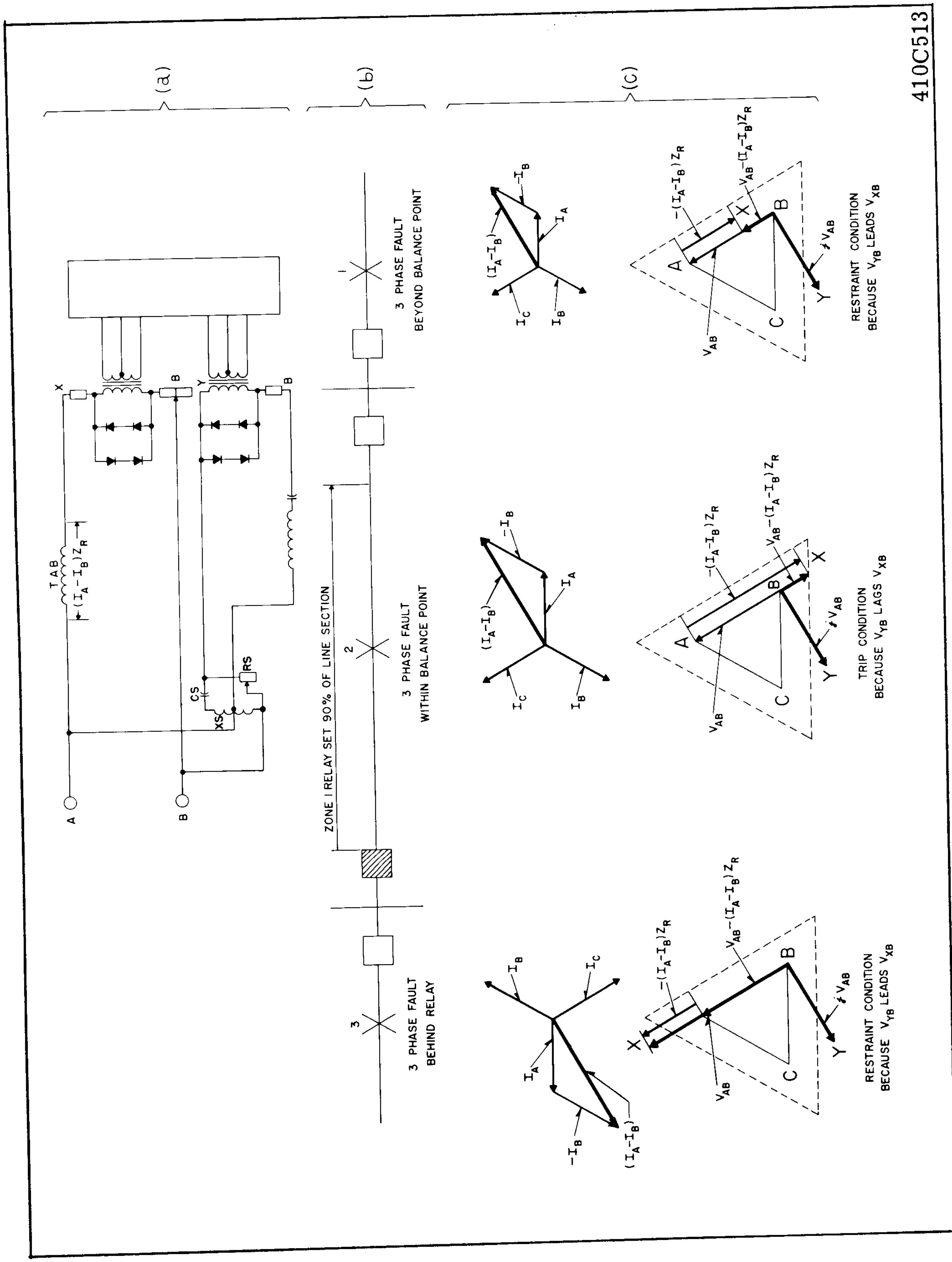


Fig. 14. Voltage and Current Conditions for the Three-Phase Unit

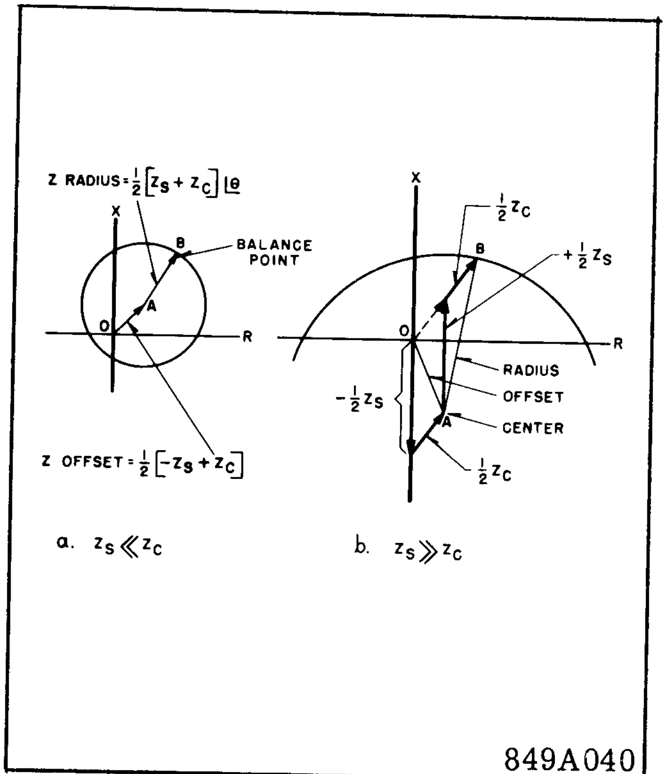


Fig. 15. Impedance Circles for Phase-to-Phase Unit in SKDU and SKDU-1 Relays

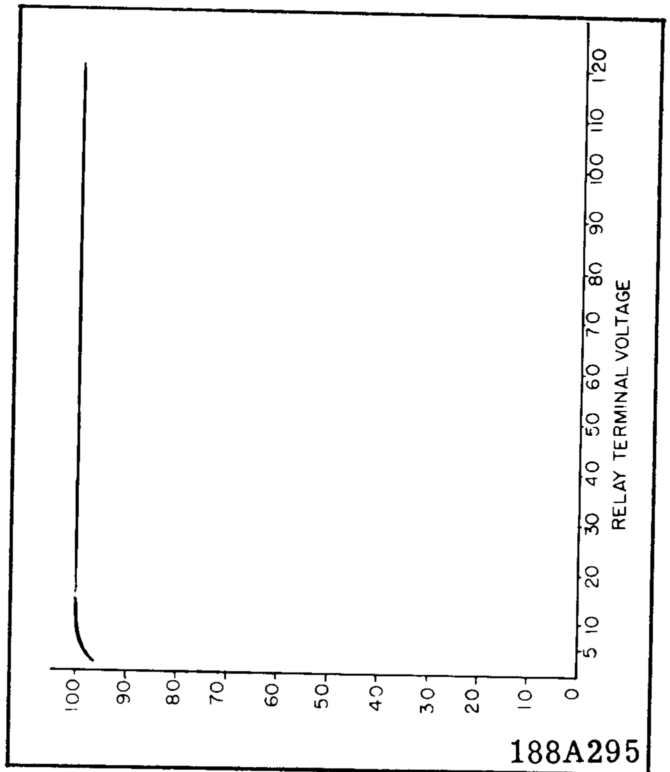


Fig. 16 Impedance Curve for Types SKDU and SKDU-1 Relays

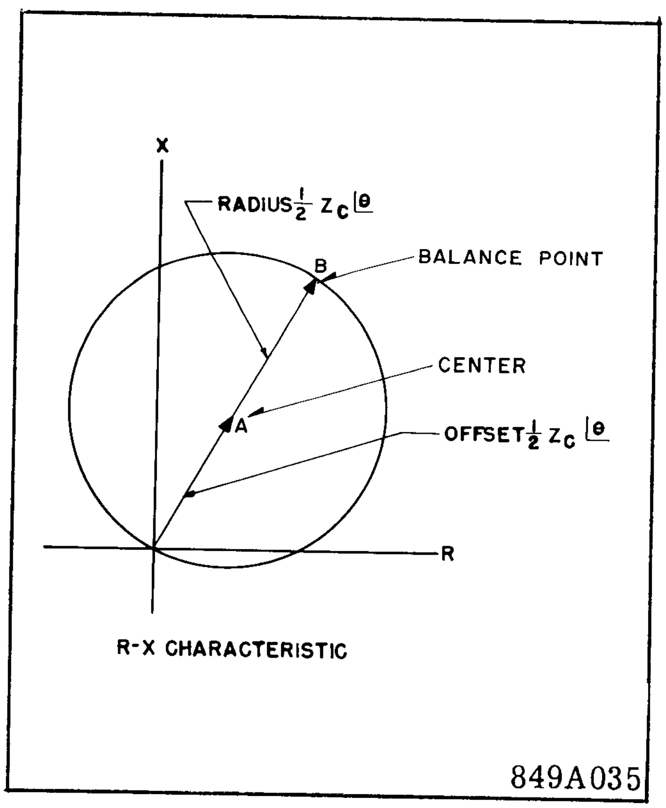


Fig. 17. Impedance Circle for Three-Phase Unit in SKDU Relays

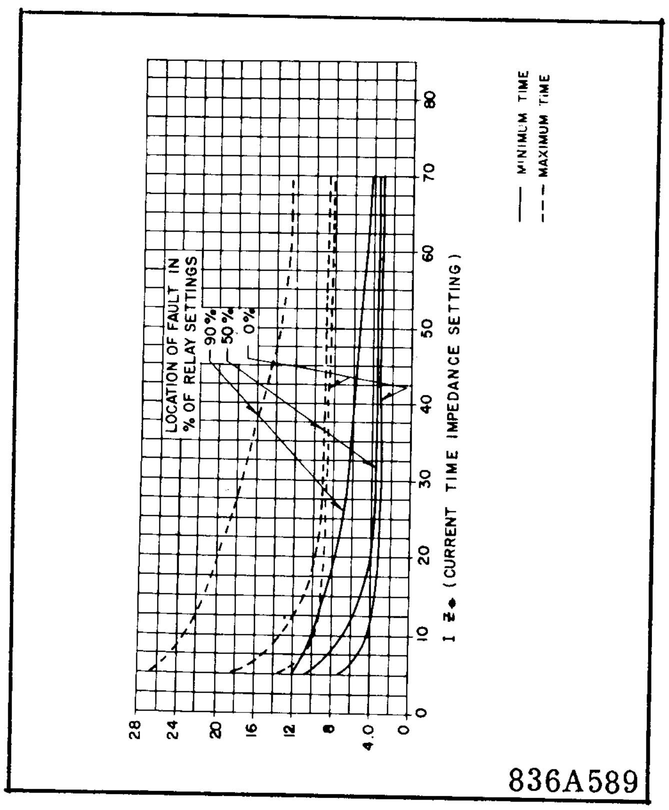
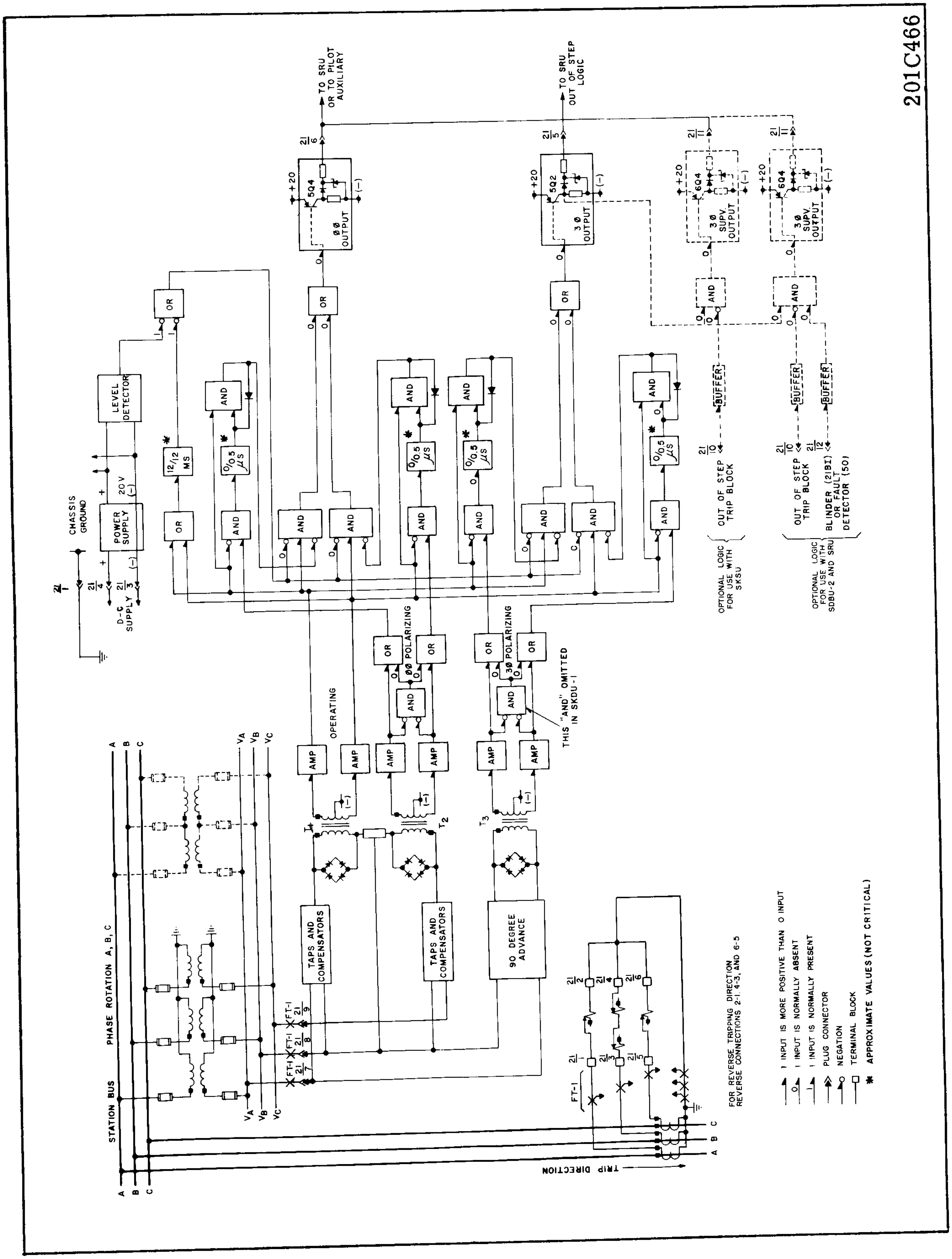
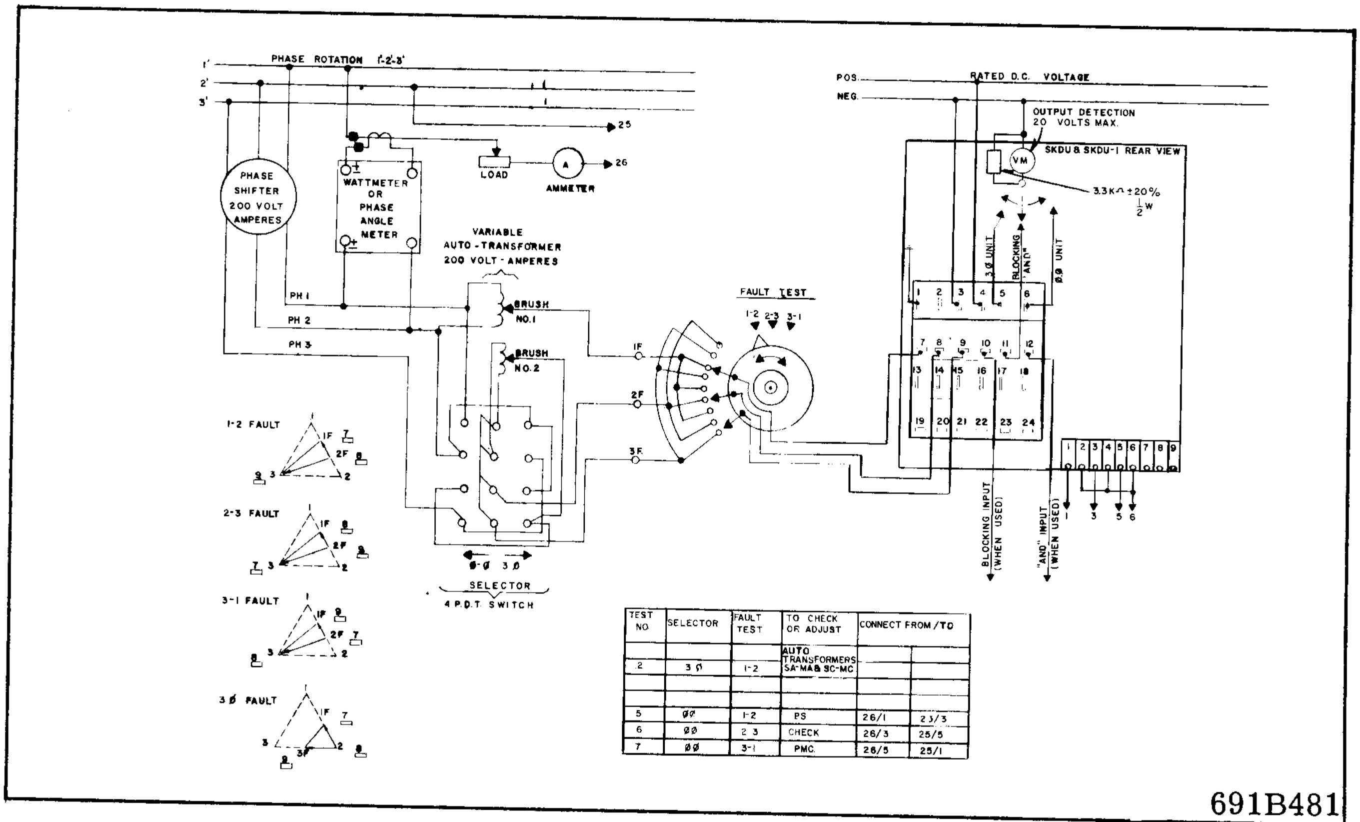


Fig. 18. Typical Operating Time Curves for SKDU and SKDU-1 Relays. Normal Voltage before the Fault is 120 Volts.



* *Fig. 19. External Schematic of Types SKDU and SKDU-1 Relays*



TEST NO	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM / TO	
2	3 Ø	1-2	AUTO TRANSFORMERS SA-MA & SC-MC		
5	ØØ	1-2	PS	26/1	23/3
6	ØØ	2 3	CHECK	26/3	25/5
7	ØØ	3-1	PMC.	26/5	25/1

* *Fig. 20. Test Connections for Types SKDU and SKDU-1 Relays*

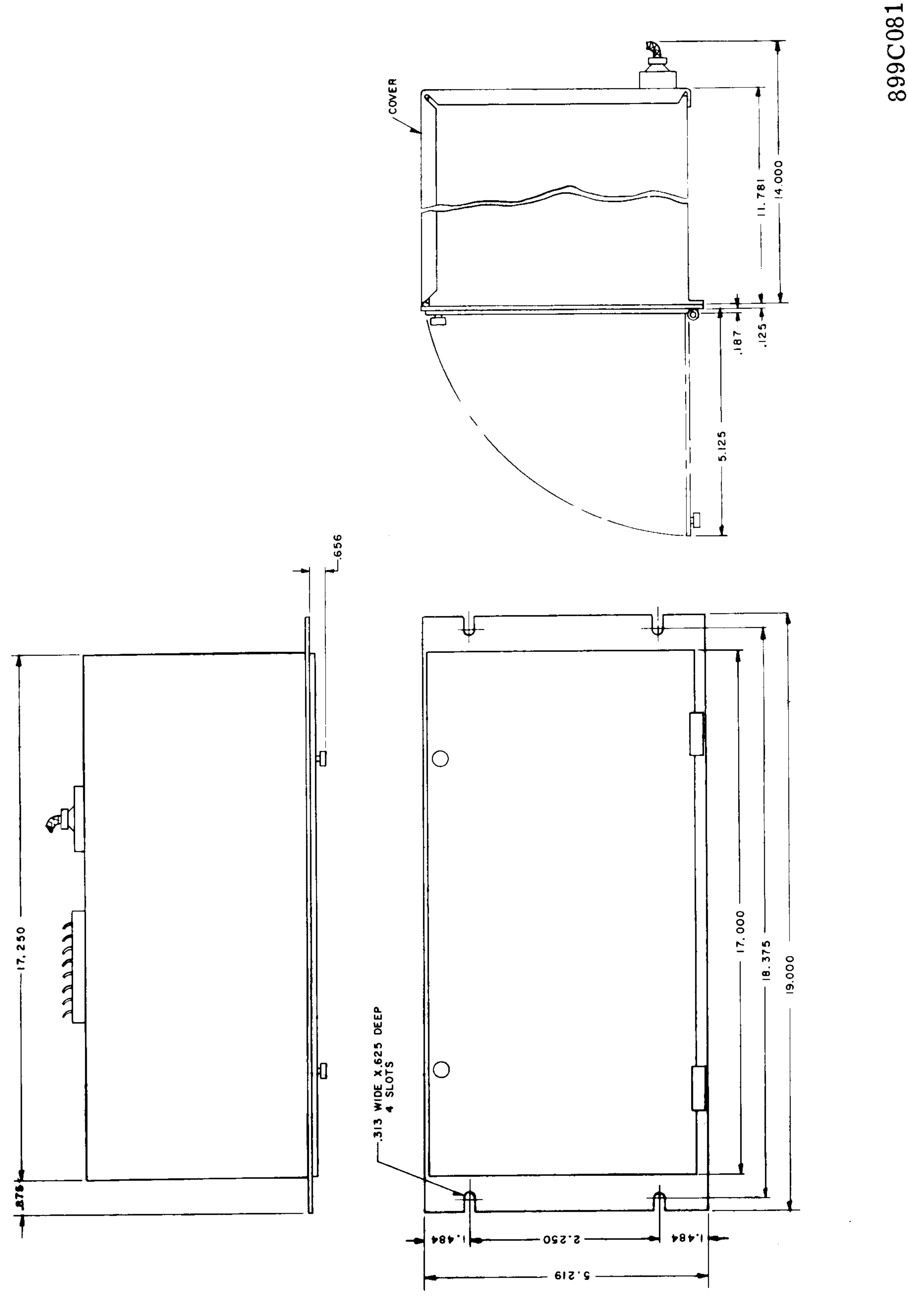


Fig. 21. Chassis Outline

WESTINGHOUSE ELECTRIC CORPORATION

RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**

Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKDU AND SKDU-1 COMPENSATOR DISTANCE RELAYS

APPLICATION

The type SKDU relay, Figure 1, is a polyphase compensator-type distance relay which provides a single zone of phase protection for all three phases. It has a ohm circle characteristic when plotted on an R + jX diagram. Logic may be specified which can be supervised by related protective relays such as blinder or out-of-step detecting relays. The output is 15V d-c to 19V d-c and up to 0.01 ampere d-c. An auxiliary unit such as an SAR tripping relay or an SRU output package is necessary to trip a breaker or operate other electromechanical devices.

The SKDU-1 is similar to the SKDU relay and has only a slight modification which allows the three-phase fault-detecting unit to trip on current only in the event a close in fault drops the relay voltage to zero.

CONSTRUCTION

Types SKDU and SKDU-1 relays are available in ranges of (.2-4.35) ohms, (.73-21) ohms and (1.1-31.8) ohms. They consists of two air-gap transformers (compensators), two tapped auto-transformers, a phase-shifting circuit, a memory circuit, and three isolating transformers which couple the a-c quantities into the static network.

Either five or six printed-circuit boards are used in the static network. They are plug-in types which may be removed for tests or examination and then reinserted. They may also be plugged into a card extender, style #849A534G01, to make the test points and components accessible for in-service checking.

A hinged and removable door provides access to all adjustments and printed-circuit boards. A 24-terminal jack provides external voltage connections, and a terminal block provides current connections.

Compensator

The compensators which are designated T_A/T_B and T_C/T_B 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 2. 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) ohm, (.73-21) ohm, and (1.1-31.8) ohm 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 $75^{\circ} \pm 3^{\circ}$ current lagging voltage.

All possible contingencies which may arise during installation, operation, or maintenance, and all details and variations of this equipment do not purport to be covered by these instructions. If further information is desired by purchaser regarding his particular installation, operation or maintenance of his equipment, the local Westinghouse Electric Corporation representative should be contacted.

SUPERSEDES I.L. 41-495.1E DATED SEPTEMBER 1977

EFFECTIVE JANUARY 1984

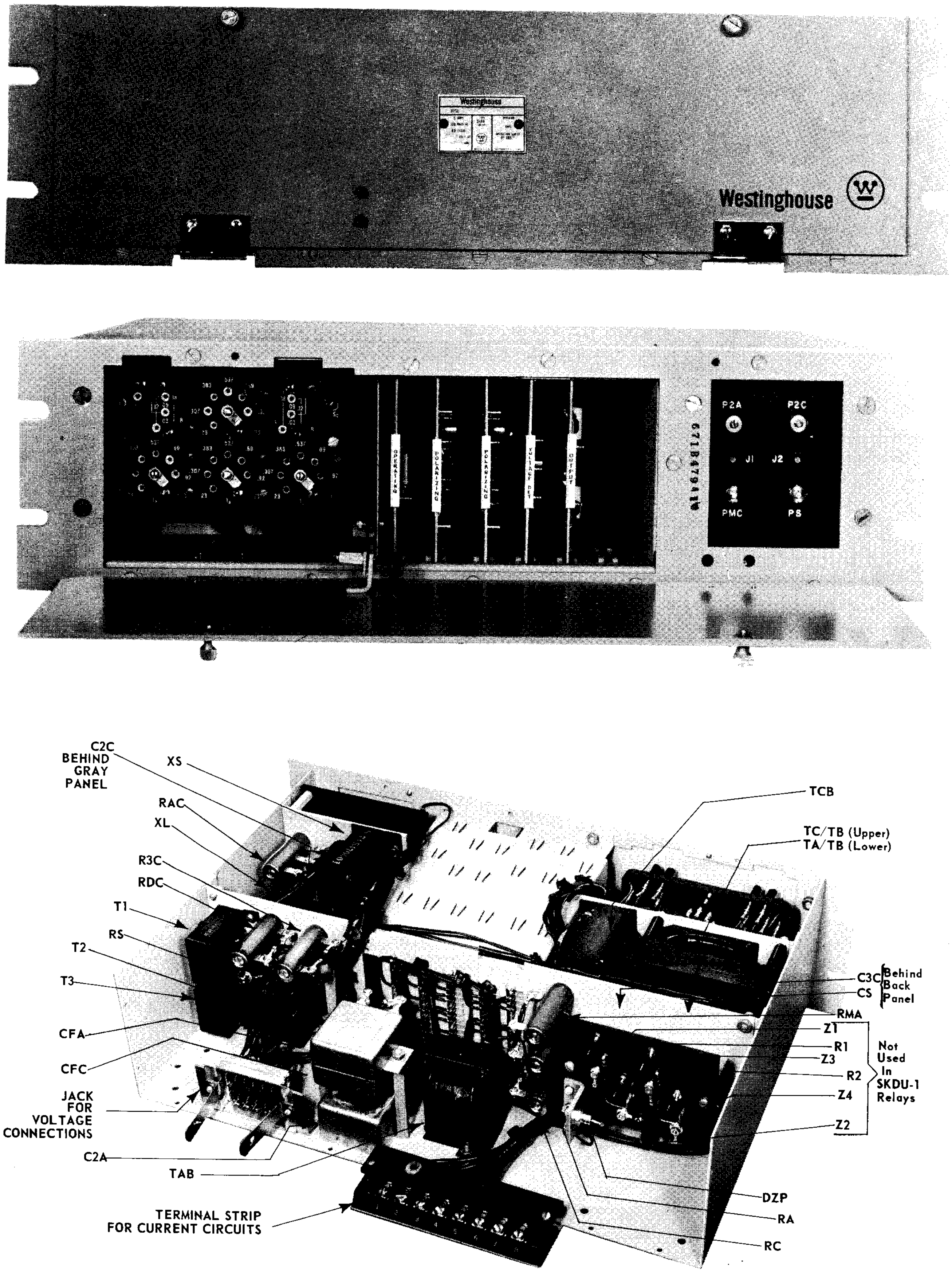


Fig. 1. Photo of Relay, Front (Door Open), Top (Cover Off)

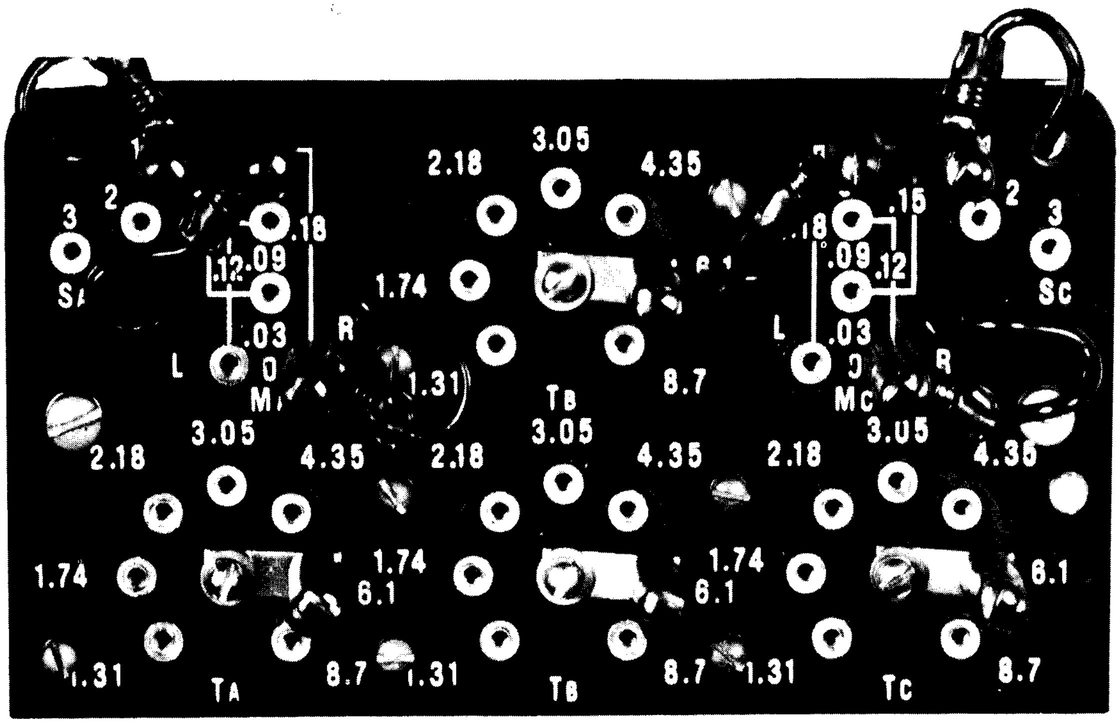


Fig. 2. Photo of Tap Plate

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 2. 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 leads. 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_{CB} with the auto-transformer taps S_A-M_A and S_C-M_C.

Phase-Shifting Circuit

"Polarization" is the reference against which the "operate" signal is compared. Polarization for the three-phase unit is obtained by shifting the phase 1-2 voltage ahead 90°. The phase-shifting circuit consists of a center tapped auto-transformer, XS, which supplies voltage to a series-connected resistance capacitor, RS and PS, and CS respectively (Figures 3 and 4). Voltage between the resistor-capacitor junction and the auto-transformer center tap leads the applied voltage by 90°.

Memory Circuit

The memory circuit consists of a large inductive reactance, XL, and a large capacitive reactance, C3C, which are series connected and are tuned very closely to sixty 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 60 Hz 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 a-c circuits from the d-c circuits. Secondly, they amplify the clipped a-c signal by a factor of 1:8 to make the relay sensitive to low-level input signals.

Printed-Circuit Board Assemblies

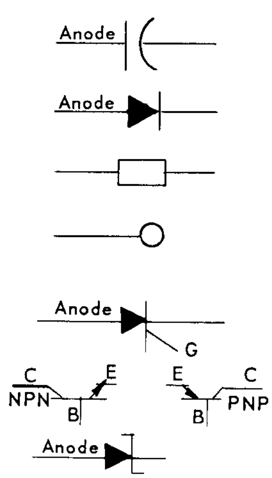
The basic relay uses five Printed Circuit Board (PCB) assemblies. The five basic PCB's are one

"operate" board, two "polarizing" boards (both are identical in the SKDU relay but are slightly different in the SKDU-1 relay), one "voltage detector" board, and one "output" board. A sixth PCB assembly is required when the output is to be supervised by additional input logic.

PCB assemblies shown in Figures 5 through 9 contain all the resistors, diodes, transistors and thyristors necessary to perform the functions of a dual-polarized phase-angle comparison unit. PCB's in Figures 10 and 11 contain "AND" logic components for external supervision.

Components on each board are identified by a letter followed by a number so that every component has an exclusive identification. Resistors are identified by the letter R followed by a number starting with 1. Where the component is shown on a schematic drawing, Figure 12, which includes more than one PCB, the component designation on the schematic is preceded by the board location number. For instance, each PCB in Figure 12 has an R6 resistor. The R6 resistor on the Voltage Detector PCB located in position 4 is designated 4R6, while R6 on the Polarizing Circuit in position 2 is designated 2R6. 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 Z, transistors by Q, thyristors by QS, capacitors by C, and test points by TP. Component letter designations are listed as follows:

CAPACITOR	C
DIODE	D
RESISTOR	R
TEST POINT	TP
THYRISTOR	QS
TRANSISTOR	Q
ZENER DIODE	Z (or DZ)



Case Construction

The jack plug on the rear has 24 terminals numbered left to right and top to bottom. Thus terminal #1 is located in the upper left-hand corner when viewed from the rear, and terminal #24 is in the lower right-hand corner. Terminal #1 is connected internally to the chassis ground and may be used for grounding the connecting cable shields.

There is also an 8-terminal strip used for current terminals which is located in the right-hand side of rear when viewed from the back. The terminals are numbered from left to right.

The chassis case, cover, and front panel have electrical connections established by the use of shakeproof washers which cut through any point or protective coating to make electrical contact with the base metal. The complete relay is then grounded to the switchboard or cabinet by an external wire connection which must be made by clamping the wire under a shakeproof washer which also serves to help hold the cover in place.

The door is hinged at the bottom and is secured at the top by two captive screws. It may be opened to 90 degrees where it is stopped by a slotted strap attached to the door and also to the frame of the case. To remove the door, release the strap by either unscrewing it or unhooking it from the door and then slide the door to the right to disengage the hinges.

Printed-circuit boards are connected into the electrical circuits of the relay through 14-terminal connectors. The boards can be disengaged by a steady pull outward. Sometimes a simultaneous up-and-down motion (if there is clearance) will help free the mating connections. The boards are keyed so that they cannot be pushed home into the wrong connector although they may be replaced into the guides of the wrong position.

OPERATION

The SKDU and SKDU-1 relays both utilize identical a-c input circuits. Therefore, an explanation for the SKDU will suffice for both.

Two distinctly different logic systems are used in the SKDU 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 phase-angle comparison circuit 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 14a. A trip condition results when V_{YB} lags V_{XB}.

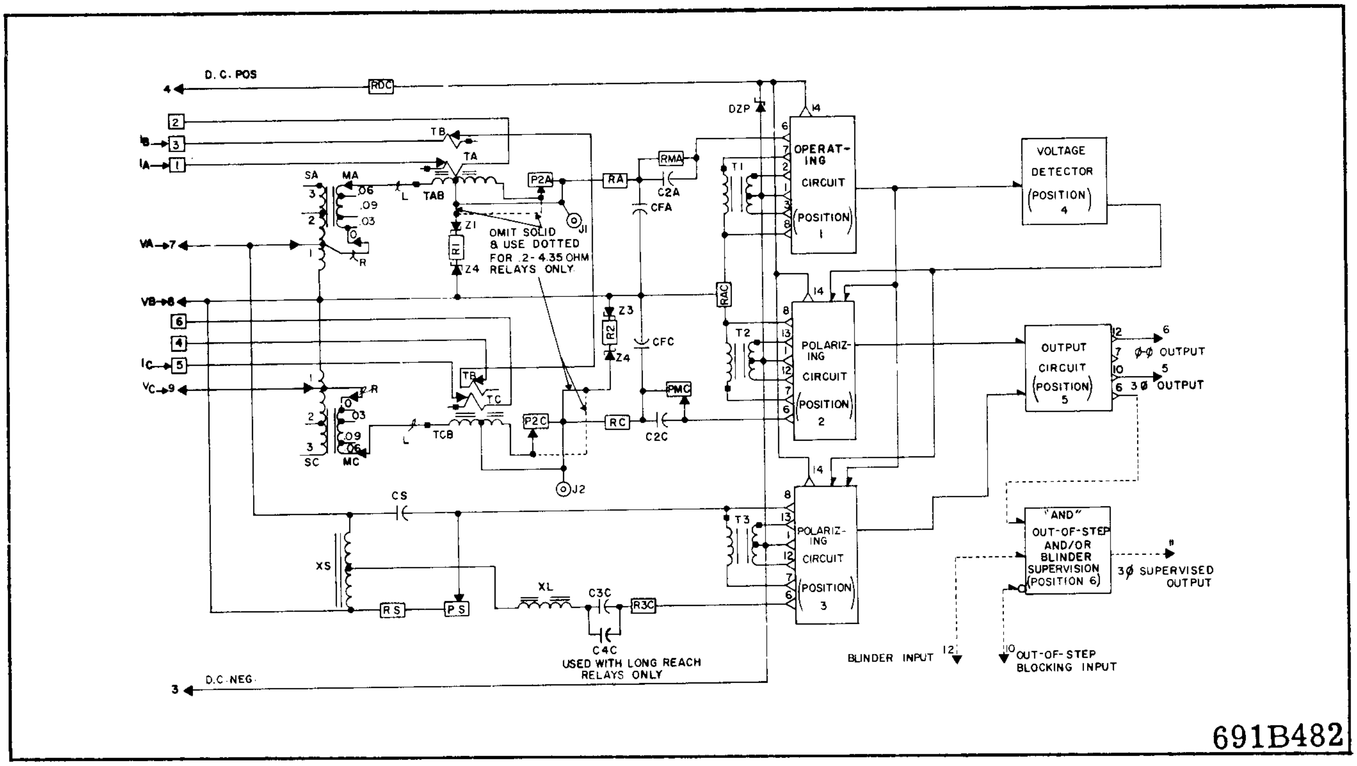


Fig. 3. SKDU Internal Schematic (showing a-c input and logic blocks)

Phase-to-Phase Unit

For phase-to-phase fault detection, the system monitors the three phase-to-phase voltages compensated 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 14b at point 1, it can be seen that the voltage V_{CB} is greater than the permissible minimum $(I_A - I_B)\ Z_R$ computed by compensator T_{CB}. 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 circuit 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 14c, 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 15a illustrates the connections which apply to the static phase-angle comparison unit. Voltage V_{AB} is modified by the compensator output

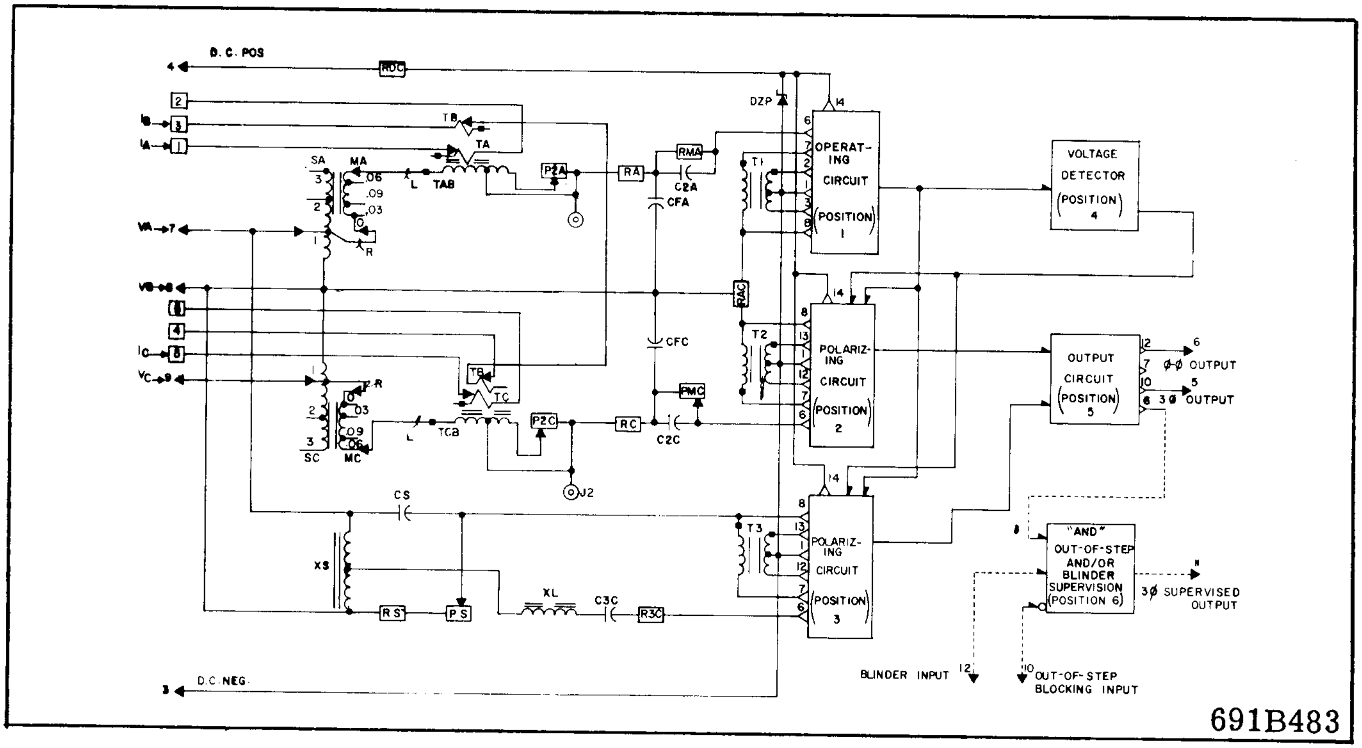


Fig. 4. SKDU-1 Internal Schematic (showing a-c input and logic blocks)

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 15b 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 14.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 comparator 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 15c, 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 overreach 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 output can be supervised by working it into an AND logic with an out-of-step signal from an out-of-step relay.

Phase-Angle Comparison Circuit

Referring to Figure 13, the phase-to-phase angle comparison circuit trips when current flows into the

base of transistor 5Q3 through zener diode 5Z2. Such tripping current must come from the 20V bus through either transistor 1Q2 or 1Q4 located on the "operate" PCB. The operate circuit, driven by transformer T1, is continually trying to trip the unit by supplying current through 1Q2 and 1Q4 on alternative half cycles. 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 5Z2 to transistor 5Q3 to cause tripping.

To prevent the operate circuit from tripping, the polarity marked terminal of T2 must go positive before the polarity terminal of T1. This causes 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 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 the 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, 5Z2 and 5Q3.

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 Detectors: 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 restraint-signal detector circuit prevents this from happening. Under normal conditions, no voltage is allowed to develop across zener diode 2Z2 at Test Point 2TP1 because it is alternately short circuited to the negative bus by transistors 2Q1 and 2Q2 through diodes 2D5 and 2D6 respectively. When the voltage from T2 drops too low to drive 2Q1 and 2Q2, current flows from the 20-volt bus through 2R3 and 2Z2 into the base of 2Q3. With 2Q3 conducting, the bases of 2Q4 and 2Q5 are driven through diodes 2D8 and 2D13 respectively to maintain the gate drive of 2QS1 and 2QS2 respectively. Thus when the T2 voltage is near zero, thyristors 2QS1 and 2QS2 are maintained in a conducting state so that no output can develop.

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 5Z1 and 5Q1 to switch 5Q2 into conduction.

SKDU-1 Relay: The SKDU-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 SKDU-1 three-phase unit 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 cycle, 4Q2 turns on to remove the gating signal until the relay is de-energized again.

The Zener diode 4Z1 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.

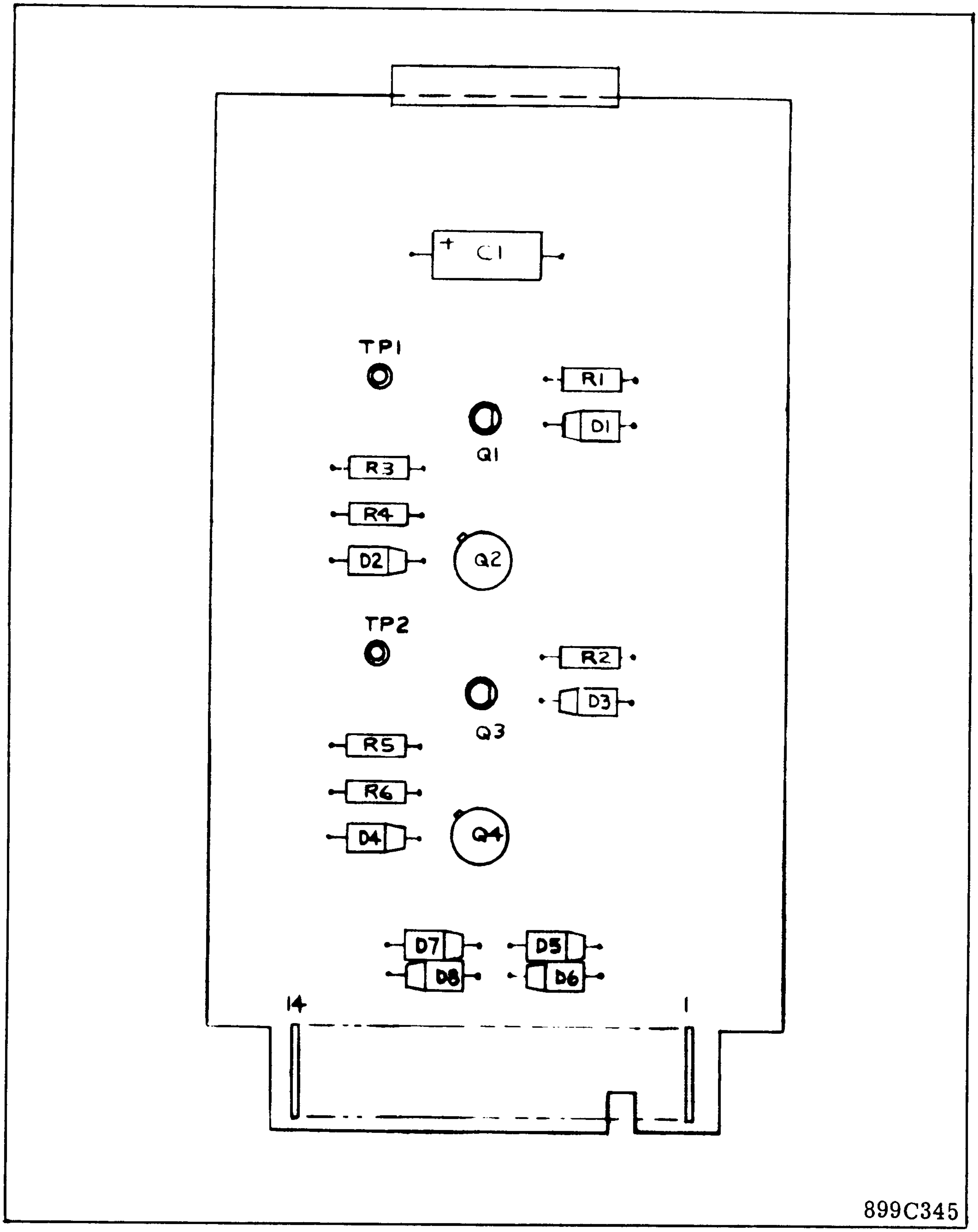


Fig. 5. Operating PCB Assembly

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 16, 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 16 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 17. 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 overreach due to d-c transients. Compensators basically are insensitive to d-c 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 unidirectional voltage in the secondary.

Distance Characteristic: SKDU Three-Phase Unit

The three-phase unit has a characteristic circle which passes through the origin as shown in Figure 18. 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 18) passing through the origin. When the YB voltage (Figure 15) 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: Three-Phase Unit

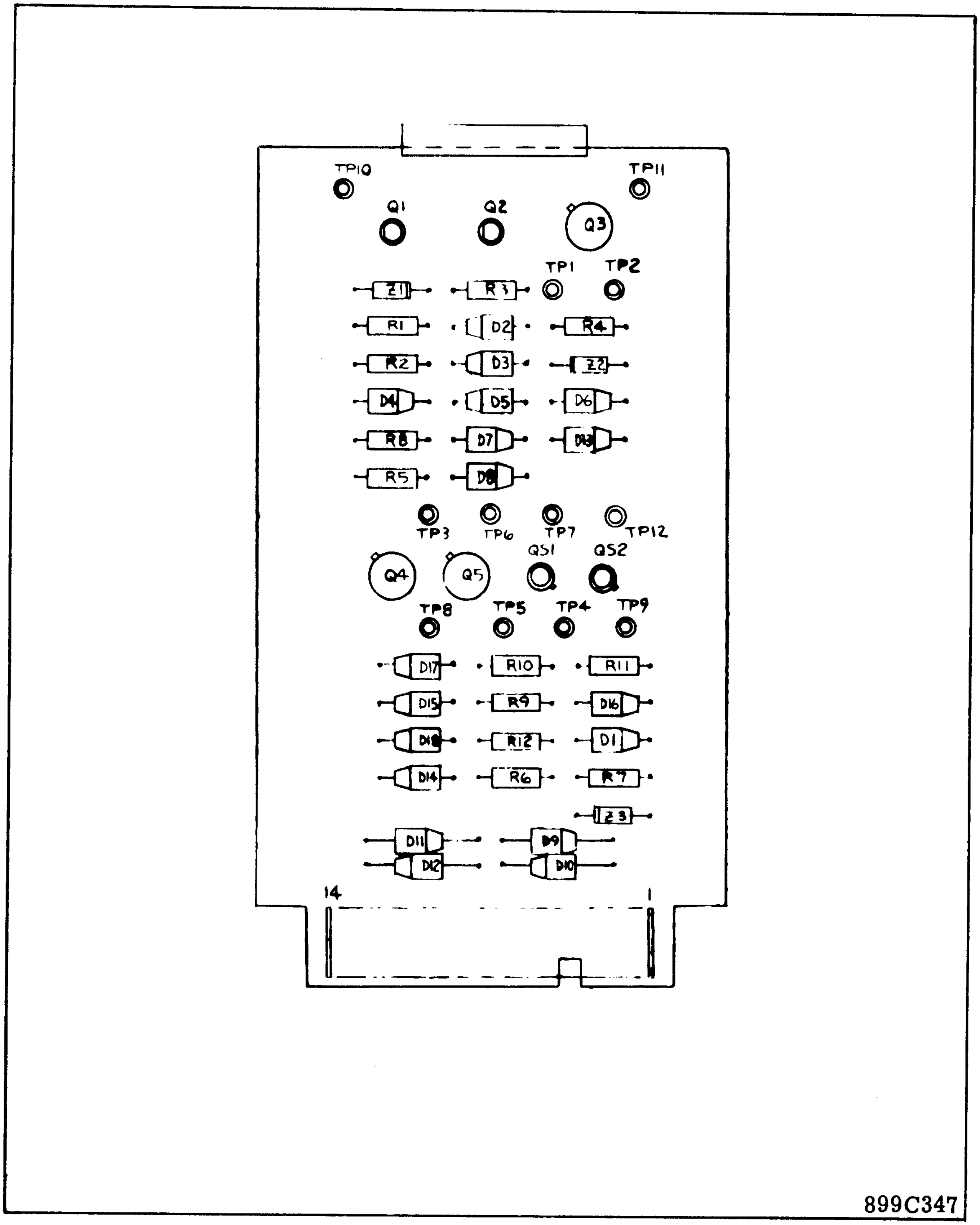
The impedance curve for the three-phase unit is shown in Figure 16. This unit will operate with the correct directional sense for zero voltage three-phase faults when normal voltage exists at the relay terminals prior to the fault. This operation occurs due to memory action as described above. For this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

Distance Characteristics: SKDU-1 Three-Phase Unit

The three-phase unit of the SKDU-1 relays has a characteristic circle which includes the origin. This feature results from the omission of the restraint-signal detector in the polarizing 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°.



✪ *Fig. 6. Polarizing PCB Assembly for SKDU-1 Phase-to-Phase Unit and for SKDU Phase-to-Phase and Three-Phase units.*

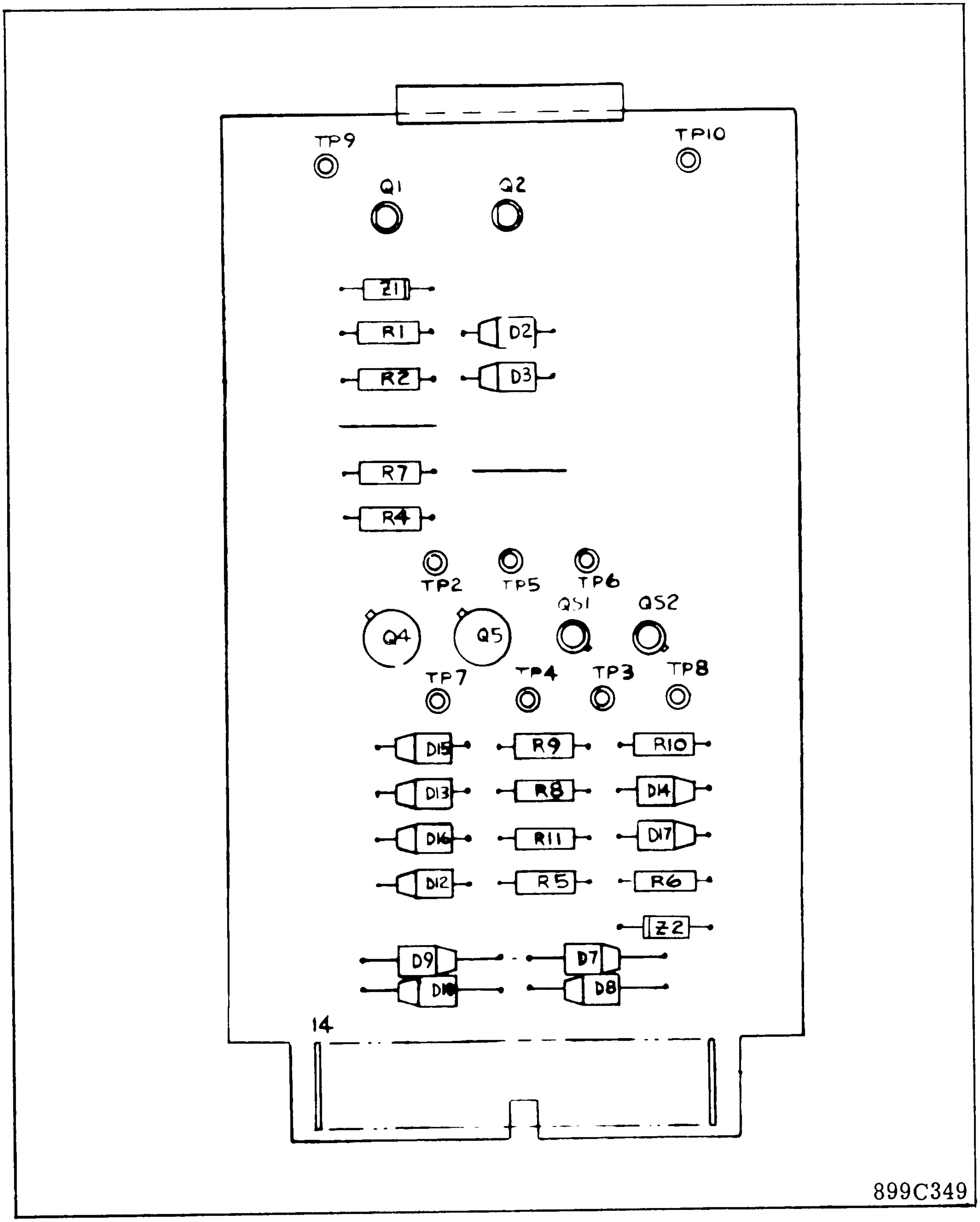


Fig. 7. Polarizing PCB Assembly for SKDU-1 Three-Phase Unit

This 90° relationship is approached if the compensator loading resistor (P2A or P2C) shown in Figures 3 and 4 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_{CB}. 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 2 are based upon a 75° compensator angle setting. If the resistors P2A and P2C are adjusted for some other maximum sensitivity angle, the nominal reach is different than indicated by the taps. The reach, Z_θ, varies with the maximum sensitivity angle, θ, as follows:

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

TAP PLATE MARKINGS

(T_A, T_B and T_C)

(0.2 to 4.35) ohms	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21) ohms	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 31.8) ohms	1.31	1.74	2.18	3.05	4.35	6.1	8.7

(S_A and S_C)

	(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 SKDU and SKDU-1 relays is shown by the time curves in Figure 19 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 within the relay setting.

Burden

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

Current Circuit Rating in Amperes

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

Output Circuits

DC-Burden	70 mA at 48, 120V.d.c.
Open Circuit Voltage	17V to 21V d-c
Rated Current	10 milliamperes

SETTING CALCULATIONS

Relay-reach is set on the tap plate shown in Figure 2. The tap markings are:

(T_A, T_B and T_C)

(0.2 to 4.35 ohms)	.23	.307	.383	.537	.69	.92	1.23
(0.73 to 21 ohms)	.87	1.16	1.45	2.03	2.9	4.06	5.8
(1.1 to 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 P2A and P2C. Set zone 1 reach to be 90% of the line (85% for line angles of less than 50°).

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

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

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

Z_θ = The ohmic reach of the relay in secondary ohms when the maximum sensitivity angle is set for θ degrees. Eq. (2)

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

T = compensator tap value

S = auto-transformer primary tap value

θ = maximum sensitivity angle setting of the relay (factory setting of $\theta = 75°$).

±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.)

Z_{pri} = ohms per phase of the total line section

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

R_C = current transformer ratio

R_V = 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 using Eq. 1.

B. Determine the tap plate value, Z, using the formula: Eq. (3)

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

when $\theta = 75°$, $Z = Z_\theta$

Now refer to Tables II, III and 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" lead settings 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).

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

For example, assume the desired reach, Z_θ, 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:

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

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

Step E

Recheck settings:

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

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

From Eq. (3)

which is 101.0 percent of the desired setting.

SETTING THE RELAY

The SKDU and SKDU-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.

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

Each set of compensator taps terminates in

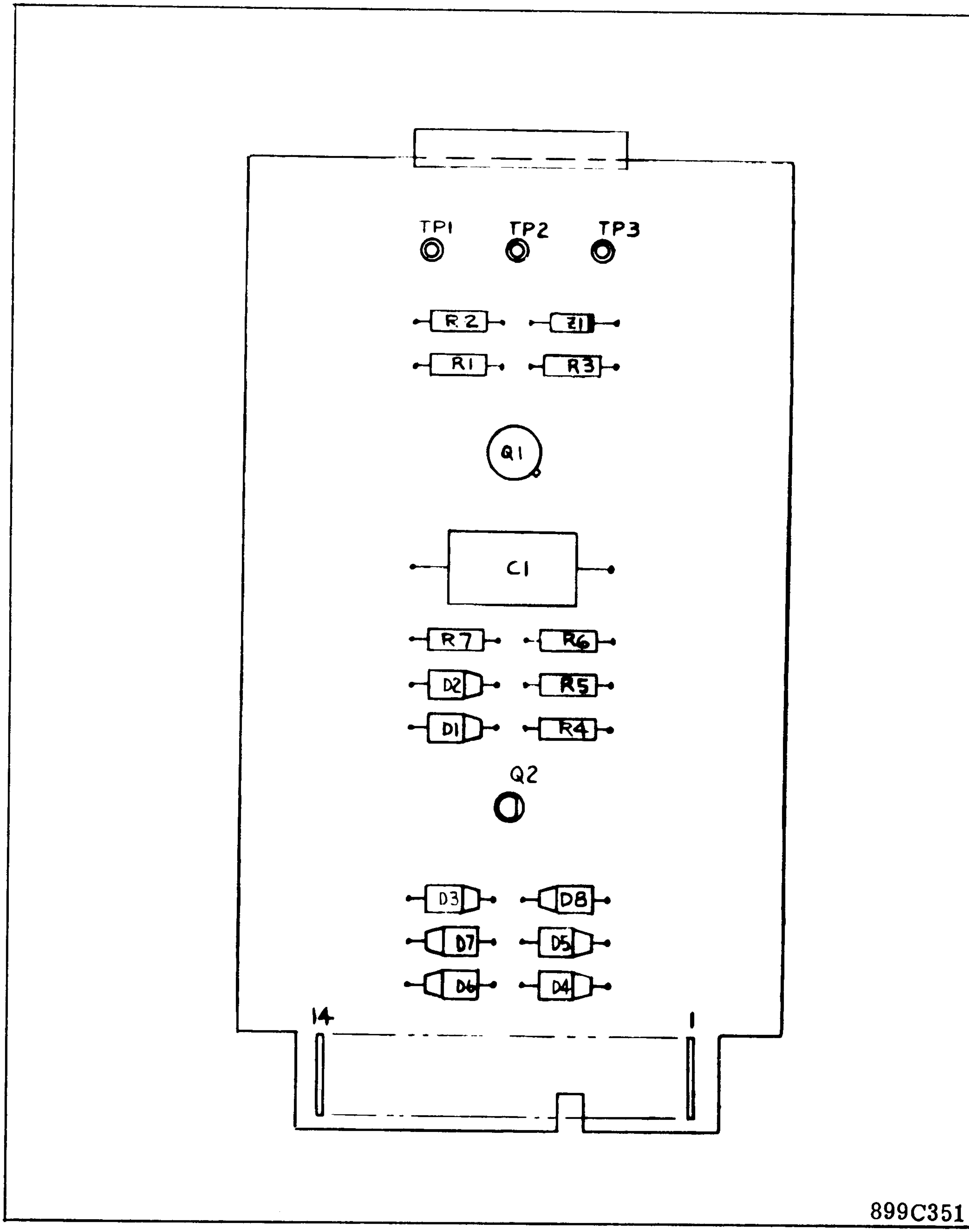


Fig. 8. Voltage Detector PCB Assembly

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

Auto-Transformer Primaries (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 2).

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 lead is higher and negative (−) if the R lead is higher.

An "M" setting may be made in the following manner. Remove the connector screws so that the L and R leads are free. Refer to Table 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.

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 69.3 V_{L-N} 3ϕ S = 1	+.18 0 −.18	3.80 2.98 2.22	3.06 2.38 1.57	−2.26 −1.92 −1.57	6.40 4.98 3.68	6.38 4.97 3.68	0.45 0.30 0.13	3.1 2.27 1.57	2.38 1.69 1.13	1.99 1.52 1.09
I = 0 69.3 V_{L-N} 3ϕ S = 2	+.18 0 −.18	1.47 1.33 1.24	0.80 0.62 0.48	−1.24 −1.17 −1.14	2.27 1.93 1.61	2.24 1.89 1.57	−0.33 −0.37 −0.38	0.72 0.55 0.38	0.55 0.42 0.28	0.46 0.36 0.26
I = 0 69.3 V_{L-N} 3ϕ S = 3	+.18 0 −.18	1.22 1.16 1.11	0.44 0.34 0.27	−1.14 −1.11 −1.08	1.57 1.44 1.31	1.52 1.38 1.24	−0.41 −0.40 −0.42	0.33 0.25 0.18	0.25 0.19 0.14	0.21 0.16 0.12

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

S = 1 M = 0 TAP .73-21 OHM RANGE	CURRENT CIRCUIT IMPEDANCE AT 5 TO 100 AMPERES (V_{LL} = 120 V.)								
	TA (TERM'S [1] – [2])			TB (TERM'S [3] – [4])			TC (TERM'S [5] – [6])		
	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 and TB compensators or TB and TC.

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	"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	
	1.17	1.55	1.95	2.72	3.88	5.45	7.76	10.9	15.5	–	23.3	+.12		.09	0	
	1.20	1.6	2.00	2.8	3.99	5.6	7.98	11.2	16	–	23.9	+.09		.09	.03	
	1.23	1.64	2.06	2.87	4.10	5.75	8.20	11.5	16.4	–	24.6	+.06		.06	.09	
	1.27	1.69	2.12	2.96	4.22	5.92	8.45	11.8	16.9	–	25.3	+.03		.03	0	
	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	
	1.44	–	2.4	3.35	4.78	6.70	9.55	13.4	19.1	–	28.7		–.09	.03	.09	
	–	–	2.48	3.46	4.94	6.93	9.88	13.9	19.8	–	29.7		–.12	0	.09	
	–	–	2.56	3.59	5.11	7.17	10.2	14.3	20.5	2.15	31.4		–.15	.03	.06	
	–	–	–	–	–	–	10.6	–	21.2	–	31.8		–.18	0	.06	

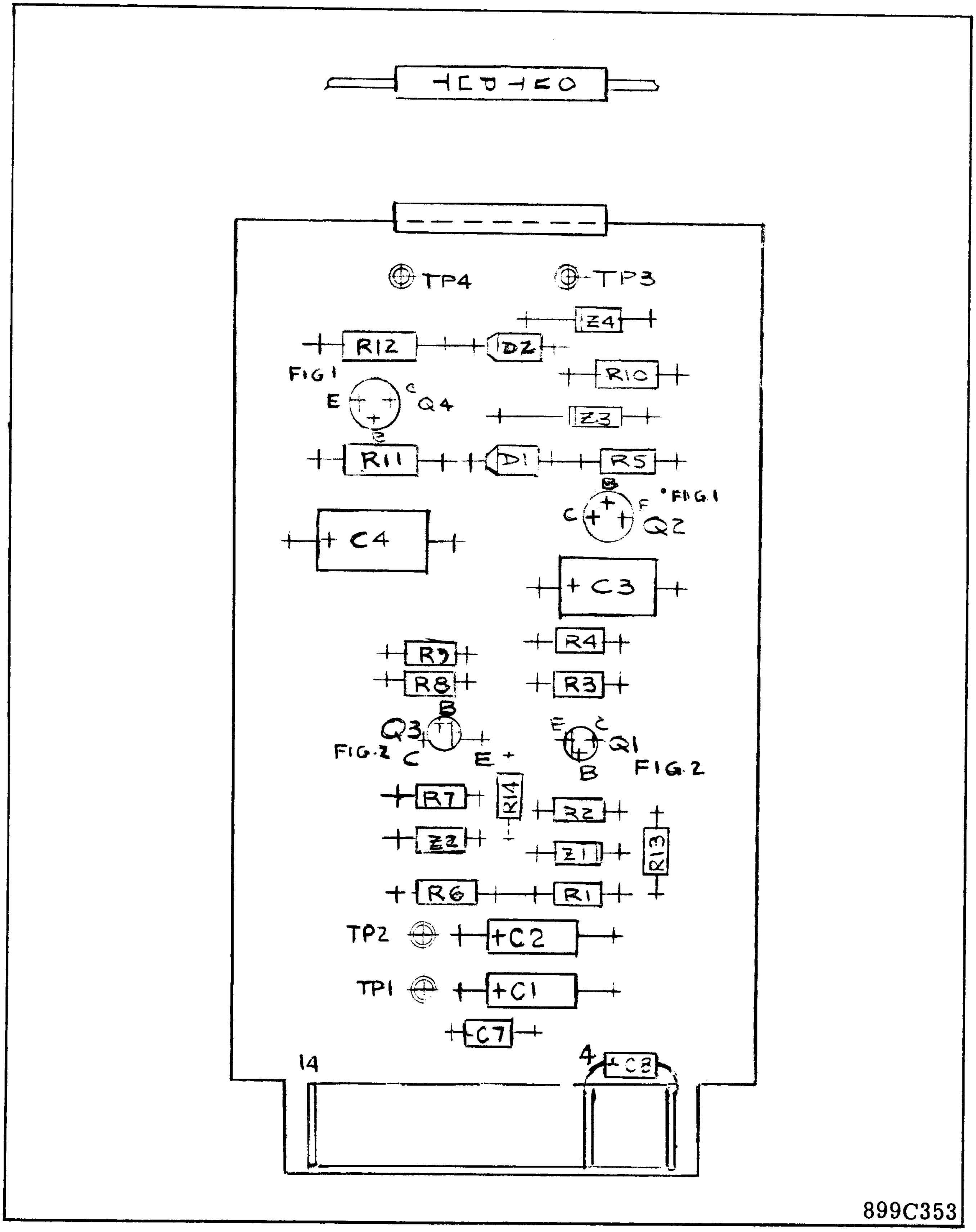


Fig. 9. Output PCB Assembly

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 P2A and P2C. Refer to Repair Calibration, parts 11 to 15, and 20, 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 four slotted holes on the front of the case. Additional support should be provided toward the rear of the relay in addition to the front panel mounting. This will protect against warping of the front panel due to the extended weight within the relay case.

EXTERNAL CONNECTIONS

Figure 20 shows the external connections for an SKDU or an SKDU-1 relay.

Current circuit connections are made to an eight-section terminal block located at the rear. Potential circuits, both a-c and d-c as well as input and output logic signal circuits, are connected through a 24-terminal jack. Connections are made by a plug on the wiring harness. The plug is inserted between two latching fingers which hook over the back of the plug to prevent an accidental loosening of the plug. The plug can be removed by spreading the two fingers apart enough to disengage the hooks from the back. The plug must be withdrawn while the fingers are spread apart.

Note that terminal number 1 is connected to the case within the relay and may be used for grounding the shields of connecting cable. The grounding connection will be broken when the plug is disconnected.

Permanent grounding of the case is accomplished by connecting a ground wire under a washer of a cover screw. These are self-tapping screws and provide excellent low-resistance contact with the case.

RECEIVING ACCEPTANCE

Acceptance tests consist of 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 a-c voltmeter.

Westinghouse Type PA-161, Style #291B719A21 or equivalent a-c ammeter.

Testing can be accomplished by use of the test connections shown in Figure 21. Tripping is indicated by a d-c voltmeter reading. At the balance point, the output may be as low as 1 volt or 2 volts indicating that the system is only partially tripping. This is a normal balance point characteristic. However, a 20 percent increase in current should produce an output of 15 to 20 volts. A reading of less than 15 volts indicates a defective tripping output or defective logic. For best indication use oscilloscope.

Distance Units – Electrical Tests

1. Check the electrical response of the relay by using the test connections shown in Figure 21. 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. Connect the relay for a 1-2 fault as indicated for Test #5, 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 = 30V).

3. Supply of the current necessary to trip the phase-to-phase unit at 45° and swing the phase shifter to determine the second angle θ_2, at which unit just trips. The maximum sensitivity angle θ is $\frac{45 + \theta_2}{2}$. This should be 75° ± 3°. The angle shifts from 75° at 70 V_{LL} to approximately 70° at 5 V_{LL}. This is a normal response of the logic and is not detrimental to the relay performance.

4. 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.

5. Repeat section 4 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.

6. Repeat section 2 for the three-phase unit. The current required to trip the three-phase unit should be within the limits given in Table V at the maximum sensitivity angle of 75°.

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

TABLE V

Test Voltage = 30 V_{L-L}
M Setting = +.15
S Setting = 1

RANGE	SETTING		TEST NO.	UNIT	AMPERES TO TRIP AT 75° LAG Δ
	T	OHMS			
.2-4.5 Ohms	1.23	1.07	5,6,7 5	φ-φ 3 φ	(100% Z - 94.7% Z) 14.0 - 14.8 Amps.
.73-21 Ohms	5.8	5.05	5,6,7 5	φ-φ 3 φ	(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 3 φ	(100% Z - 94.5% Z) 1.98 - 2.1 Amps.

Δ for relays recalibrated for 60° multiply current value by $\frac{\sin 75}{\sin 60} = 1.11$

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 jack terminals 2, 3, 4, 5, 6, 11 and 12 to avoid destroying components in the static network. These connections are not necessary for surge testing.

Use connections for tests 5, 6 and 7 of Figure 21 to check the reach of the relay. Note that the impedance measured by the three-phase unit in Test #5 and by the phase-to-phase unit in tests 5, 6 and 7 is —

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

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

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

REPAIR CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed. Use test points shown in Fig. 23 for reference.

7. Connect the relay for testing as shown in Figure 21. The four-pole, double-throw switch shown in the test circuit selects the type of voltage condition for a phase-to-phase or a three-phase fault, that may 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 21 and the procedures outlined below.

8. 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 "L" leads. Adjust the voltages V_{1F2F} and V_{2F3F} for 90 volts. Measure the voltage from terminal 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.

9. 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

10. 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:	disconnected
"L" for M_A and M_C:	set for .06 (top position)

A. PHASE-TO-PHASE UNIT

Maximum Sensitivity Angle Adjustment

11. Connect the relay for a 1-2 fault as indicated for Test #5. Connect a high-resistance voltmeter (2000 ohms/volt) between the "R" lead and the .03 tap position of M_A, and adjust voltages V_{1F2F} for 30 volts.

12. Pass the current called for in Table VI for 30 volts through the T_{AB} compensator with the phase shifter set for the desired maximum sensitivity angle. Adjust potentiometer P2A for a null, or minimum reading, on the voltmeter.

13. Swing the phase shifter and adjust P2A slightly to obtain a minimum reading on the voltmeter when the phase-angle reading is at the desired maximum sensitivity angle. This adjusts the T_{AB} compensator angle.

14. Connect the relay for Test #6. Connect the voltmeter between the "R" lead and the .03 position of M_C, and repeat steps 12 and 13 above. This adjusts the T_{CB} compensator angle with P2C.

15. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_C and jack J_2 located just below P_{2C}. With 5 amperes through the compensator, the voltage should be as listed above in step 14.

16. The compensator output can be checked by connecting the voltmeter between the "L" lead of M_A and jack J_1 located just below P2A. Pass 5 amperes through the compensator. The secondary voltage should be:

$$V_S = 10.35 \text{ T Sin } \theta \pm 1.5\%$$

where

θ = the desired maximum sensitivity angle

T = compensator tap setting

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

1.5% = the allowable variation from nominal

		NOMINAL 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

Circuit Calibration

17. Connect "R" for M_A and M_C on ".03" and "L" for M_A and M_C in the top position so that there is .15 between L and R. Connect terminals 7 and 9 together, apply 120V a-c between terminals 8 and 9, and adjust P_{MC} until the ϕ-ϕ unit just trips. At the balance point, the output detector 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.

TABLE VI

TEST NO.	VOLTS V_{1F2F}	AMPERES TO TRIP FOR $\theta = 75°$ ‡					
		.2-4.5 RANGE		.73-21 RANGE		1.1-31.8 RANGE	
		I_{min}	I_{max}	I_{min}	I_{max}	I_{min}	I_{max}
5,6,7	5.0	2.34	2.66	0.50	0.56	0.33	0.376
	30.0	14.0	14.8	2.95	3.15	1.98	2.1
	70.0	—	—	6.9	7.1	4.62	4.72

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

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

18. Connect the relay per Fig. 21 for voltages listed in Table VI. The phase-to-phase unit should trip within the current limits listed for the given test voltages. Check the 5.0 volt level first, and adjust P_{MC} further, if necessary, to make the current trip level for Test #7 fall between the trip levels for Tests numbers 5 and 6.

Maximum Sensitivity Angle Check

19. Use test connection #5 supply 30-volt. Supply the current necessary to fully trip at the 45° angle and swing the phase shifter to determine the second angle θ_2 at which the unit just trips.

The maximum sensitivity angle, θ, is $\frac{45 + \theta_2}{2}$.

This value should not be more than 5° different from the setting made in steps 11 to 15. The phase-to-phase unit testing is complete. True maximum sensitivity angle is the angle adjusted by null method. Repeat using test connections #6 and #7.

THREE-PHASE UNIT

Maximum Sensitivity Angle Adjustment

20. Connect the relay for a 1-2 fault as indicated for Test connection #5. Apply 30 V_{LL} between relay terminal 7 and 8. The current necessary to trip the three-phase unit at 45° lag and swing the phase shifter to determine the second angle θ_2 at which the unit just trips. The maximum sensitivity angle, θ, is $\frac{45 + \theta_2}{2}$.

The maximum sensitivity angle can be connected by adjusting potentiometer P_S.

21. Set the phase shifter for the maximum sensitivity angle. Using only Test #5 connections, the three-phase unit should trip within the same limits as listed for the phase-to-phase unit.
22. The three-phase unit testing is complete.

"AND" LOGIC (When Applicable)

No calibration is required to the AND logic; however, it is desirable that a functional check be made to establish that the circuits are working properly.

23. Use connections for Test #5, and apply current and voltage to trip the three-phase unit as determined by an output voltage appearing at the output terminal 5.
24. "AND and Blocking" input relays should not have an output voltage at terminal 11. Apply +20V d-c to terminal 12 with negative to the N G. BUS, and an output should appear at terminal 11.
25. With +20V d-c on terminal 12, apply +20V d-c to the "Blocking" terminal 10 and the output should stop.
26. "Blocking" input relays should have an output at terminal 11 with the three-phase unit tripped. Apply +20V d-c to terminal 10, and the output should stop.

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.

The chassis outline is shown in Figure 22.

TABLE VII

NOMENCLATURE FOR RELAY TYPES SKDU AND SKDU-1

NOTE: The manufacturer reserves the right to change component values without prior notice.

ITEM	DESCRIPTION	STYLE NUMBER
	CAPACITORS	
C2A, C2C	1.8 mfd	14C9400H12
C3C	.3 mfd	1724191
C4C	.03 mfd	1725974
CFA, CFC	1 mfd	1876999
CS	.45 mfd	1723408
	RESISTORS	
R_1, R_2	5 watt, 500 ohm	763A129H03
R_3	25 watt, 3 K-ohm	1202954
R_A, R_C, R_{MA}	25 watt, 1.8 K-ohm	1201004
R_{AC}	25 watt, 3.55 K-phm	1955270
R_{DC}	for 48V d-c, 25 watt, 600 ohm	1202587
R_{DC}	for 125V d-c, 25 watt, 1.5 K-ohm	1267293
R_S	10 watt, 10 K-ohm, adjustable	185A925H05
	POTENTIOMETERS	
P2A	1000 ohm	836A635H03
PMC	2.5 K-ohm	836A635H04
PS	5 K-ohm	836A635H05
	DIODES	
ZP	Zener Regulating Diode: 20V, 10W	1N2984B
Z1, Z2, Z3, Z4	Clipping Zener Diodes: 200V, 50W	1N2846A
	TRANSFORMERS REACTORS	
S_A	Auto Transformer	
S_C	Auto Transformer	
$M_A M_C$	Auto Transformer Secondary (Between Taps: 0.0, .03, .09, .06)	
X_S	Center Tapper Auto Transformer for phase shift circuit	671B470G01
T_1	Coupling Transformer, Center Tapped Secondary (Set Up 1:8)	201C480G06
T_2	Coupling Transformer, Center Tapped Secondary (Set Up 1:8)	201C480G07
T_3	Coupling Transformer, Center Tapped Secondary (Set Up 1:8)	201C480G08
X_L	Memory Circuit Reactor	606B544G02
T_A/T_B T_C/T_B	Compensator Assemblies	
	PRINTED CIRCUIT BOARD	
	Operate Circuit	899C345G01
	Polarizing Circuit (2 in SKDU)	899C347G01
	Polarizing Circuit (in SKDU-1 only)	899C349G01
	Voltage Detector	899C351G01
	Output Circuit	899C353G01
	O.S. Block	201C347G01
	Blind Supervision	201C376G01
	Card Extender	849A534G01
J_1, J_2	Tests Jacks	

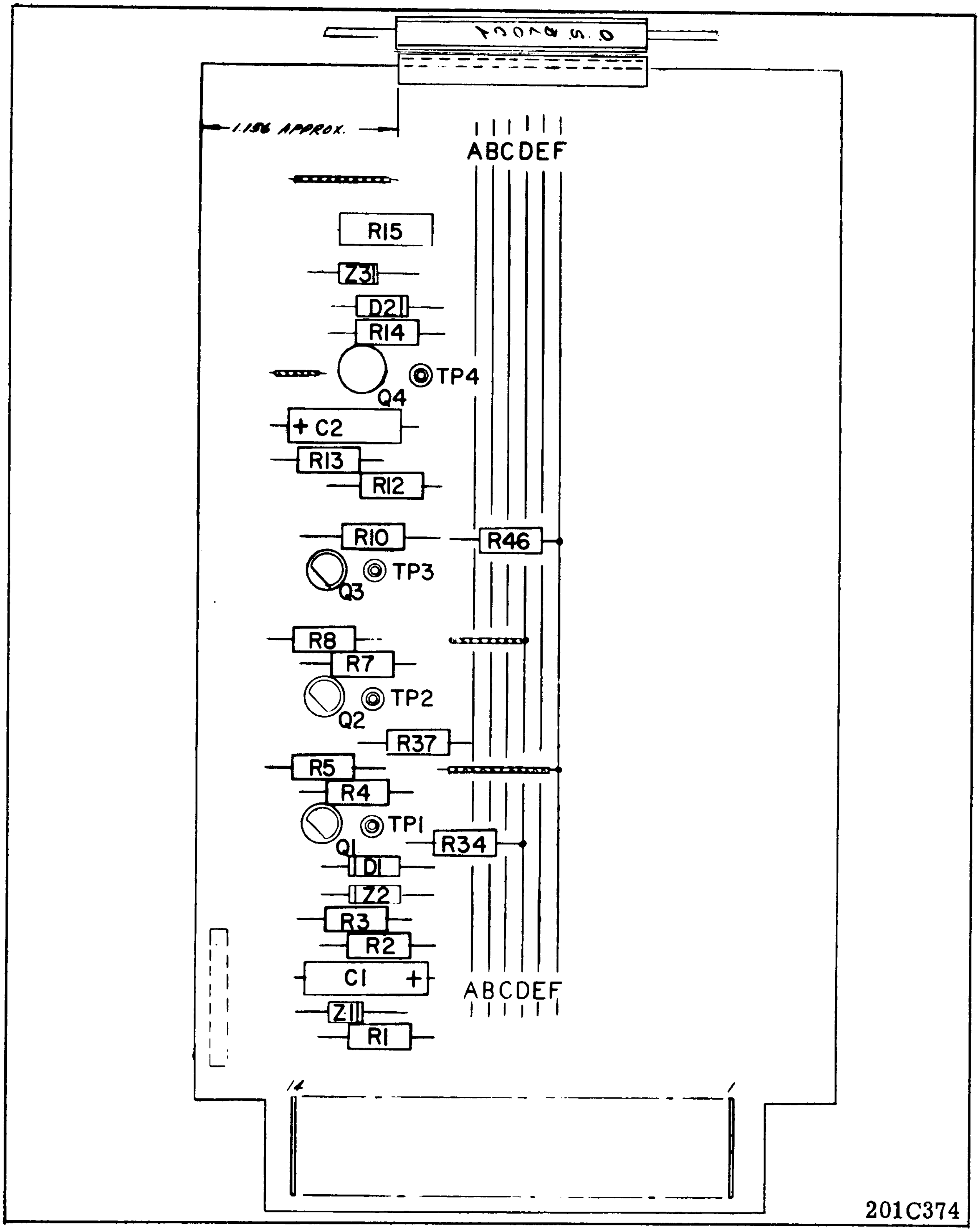


Fig. 10. Out-of-Step Blocking "AND" PCB Assembly

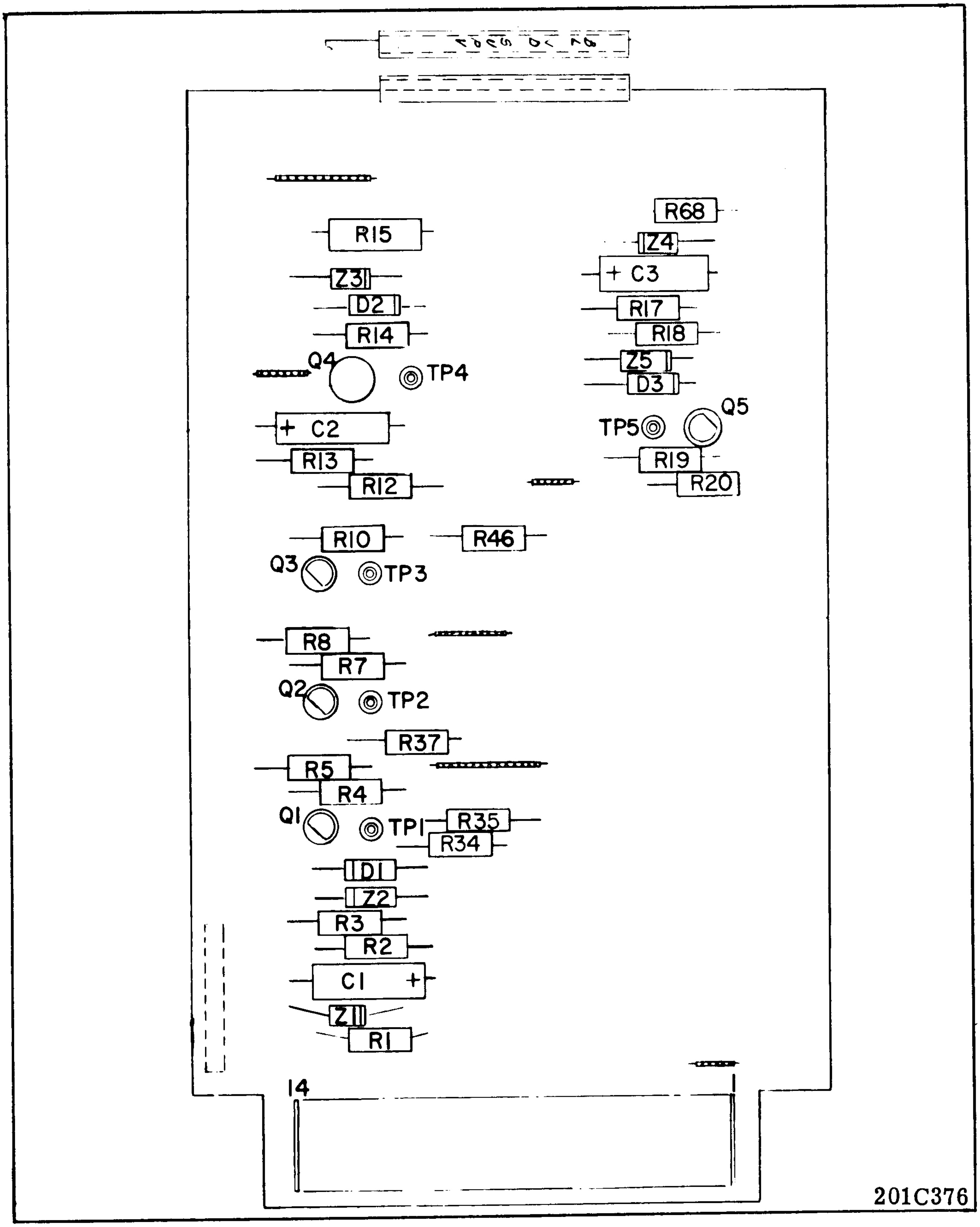


Fig. 11. Out-of-Step Blocking with Blinder Supervision "AND" PCG Supervision

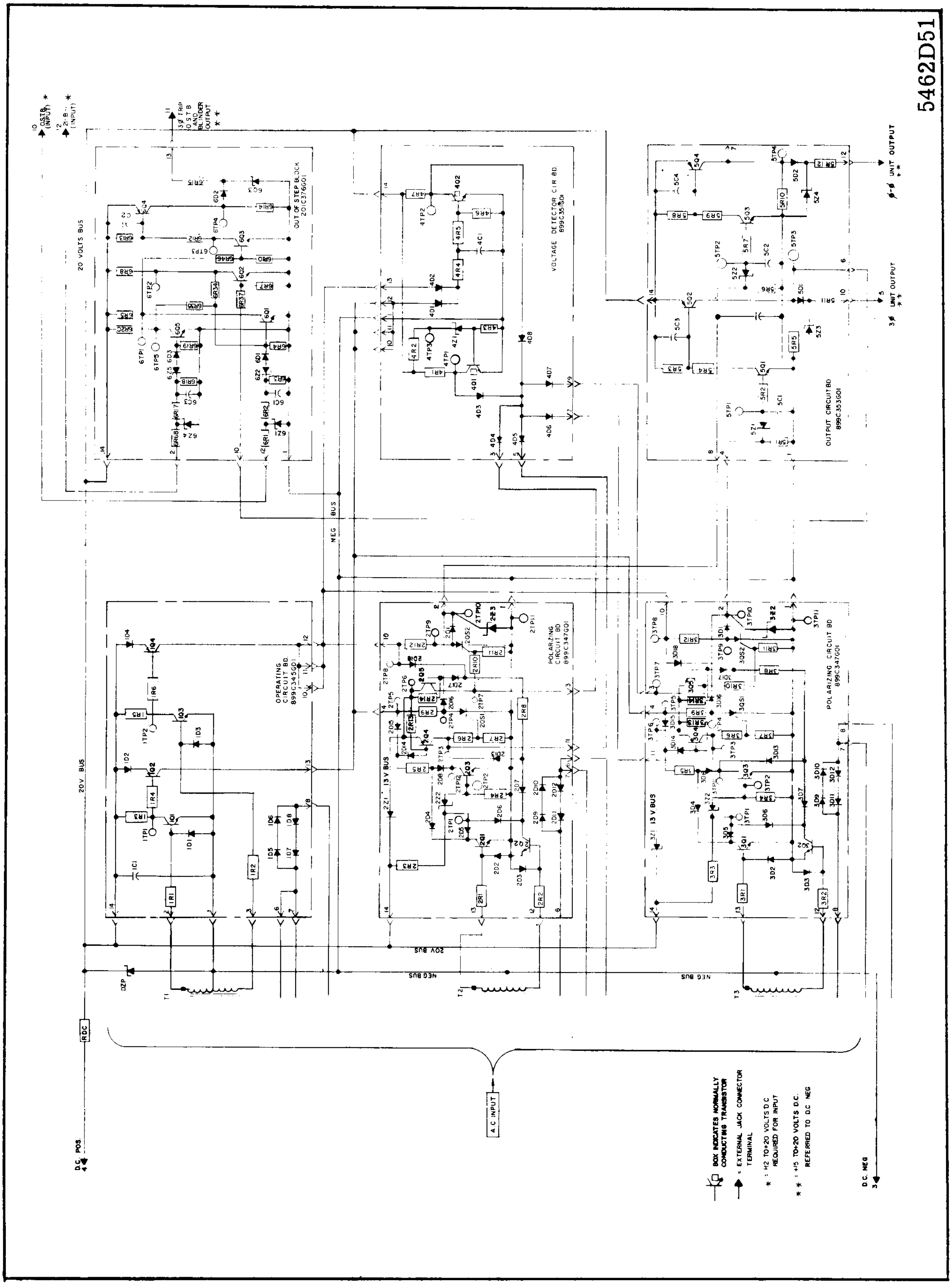


Fig. 12. SKDU-1 Internal Schematic.

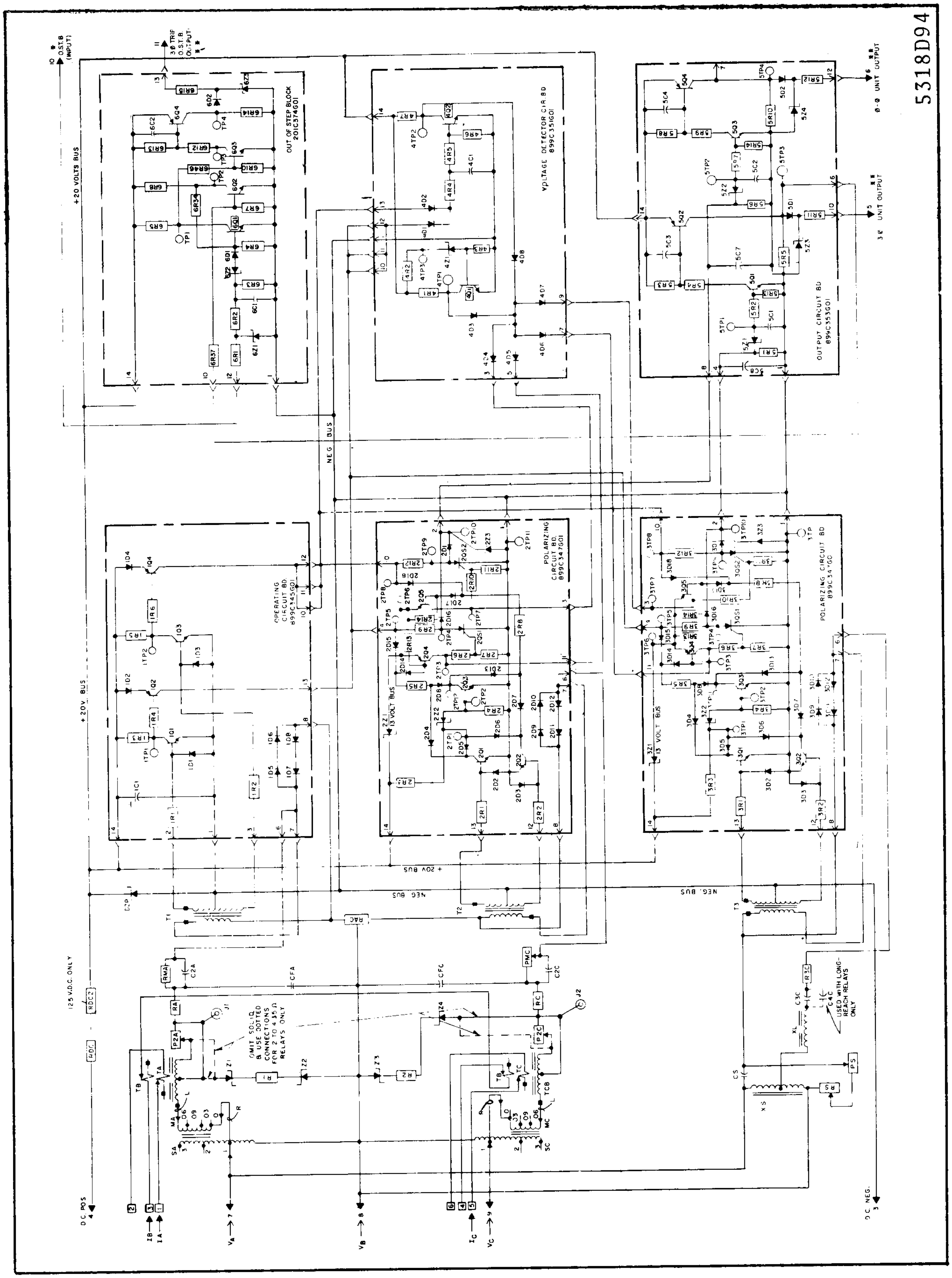


Fig. 13. SKDU Internal Schematic with Out-of-Step Block.

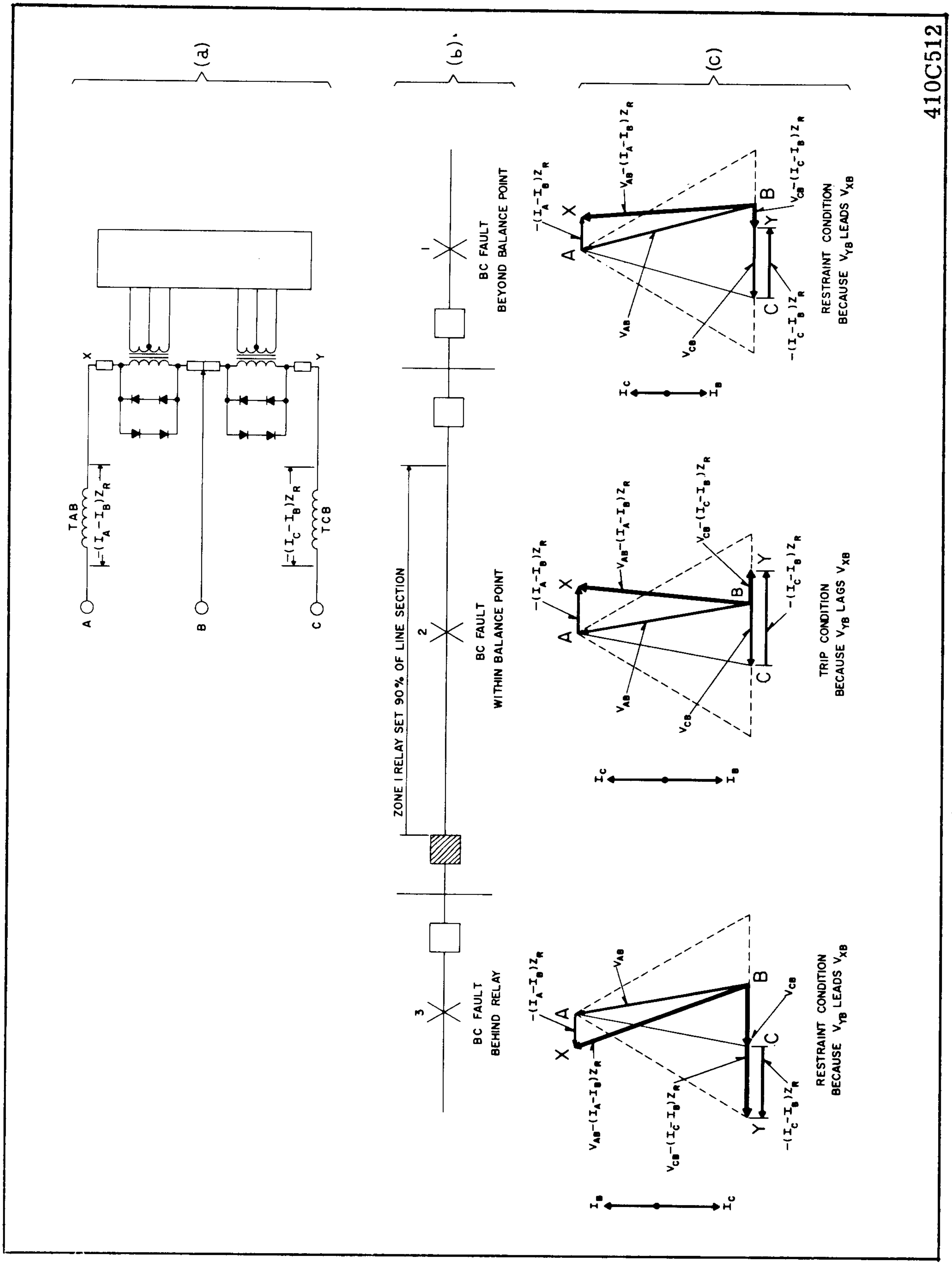


Fig. 14. Voltage and Current Conditions for the Phase-to-Phase Unit

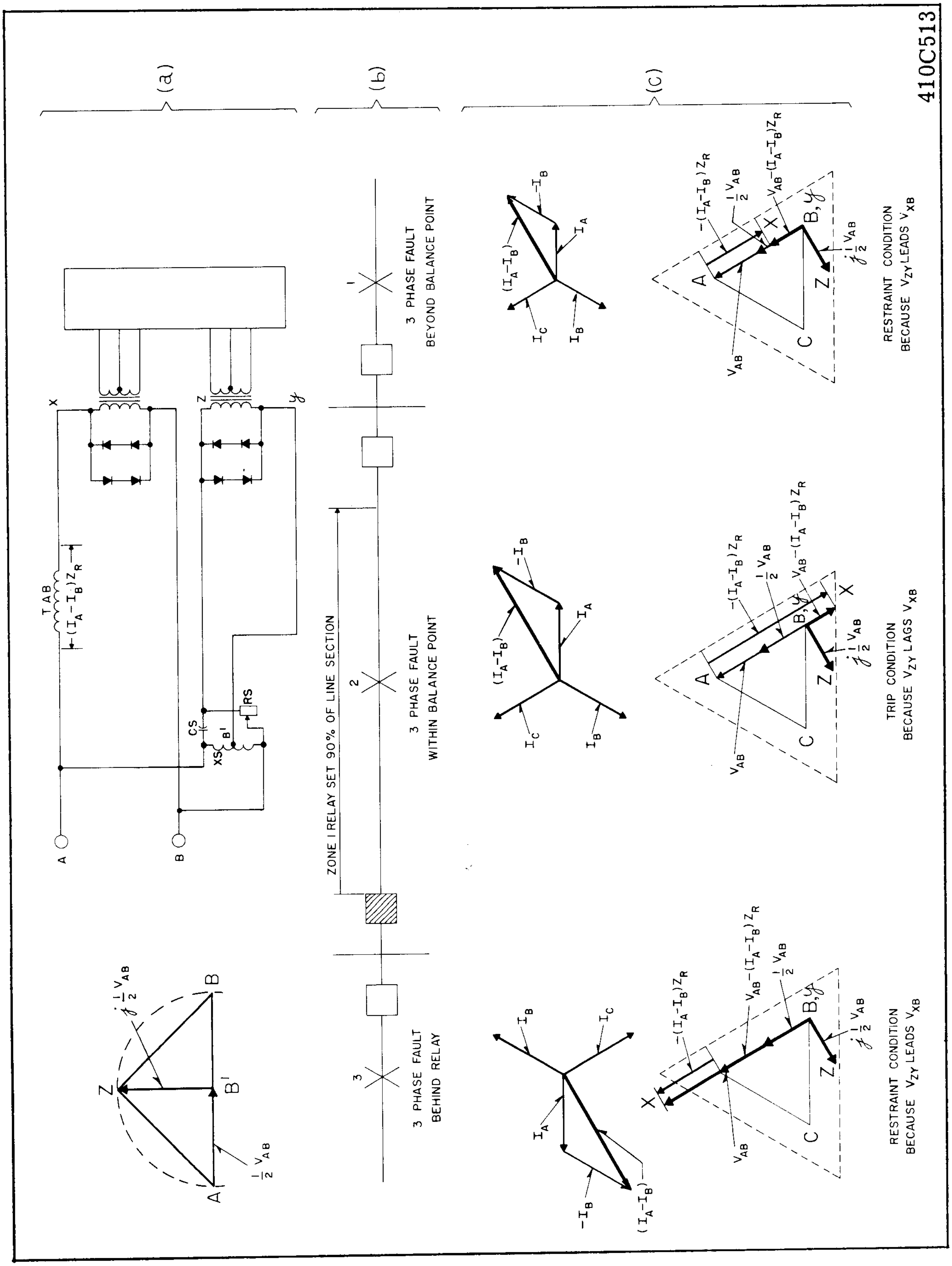


Fig. 15. Voltage and Current Conditions for the Three-Phase Unit

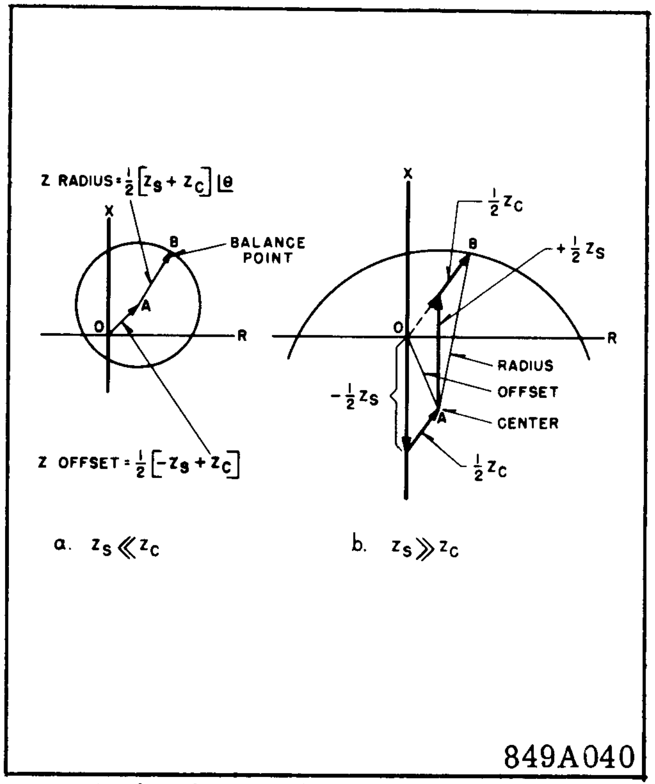


Fig. 16 Impedance Circles for Phase-to-Phase Unit in SKDU and SKDU-1 Relays

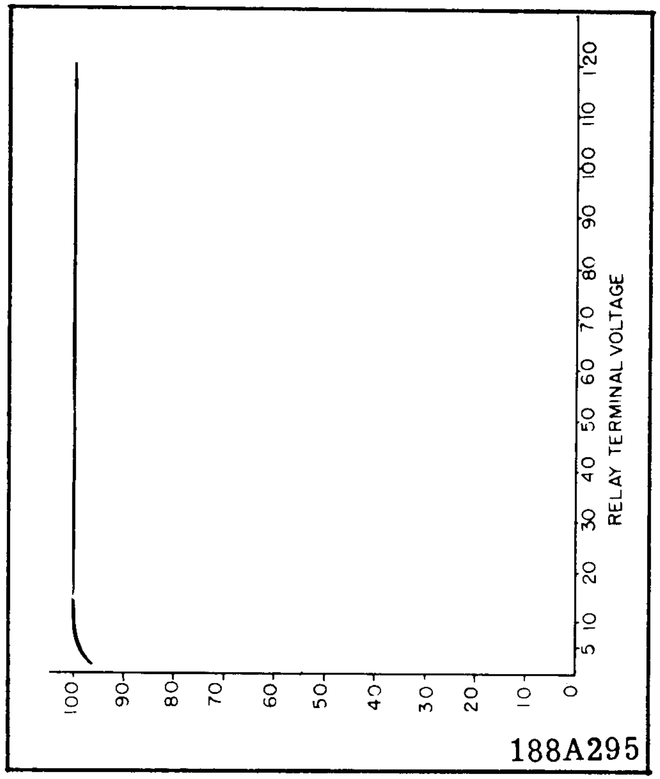


Fig. 17. Impedance Curve for Types SKDU and SKDU-1 Relays

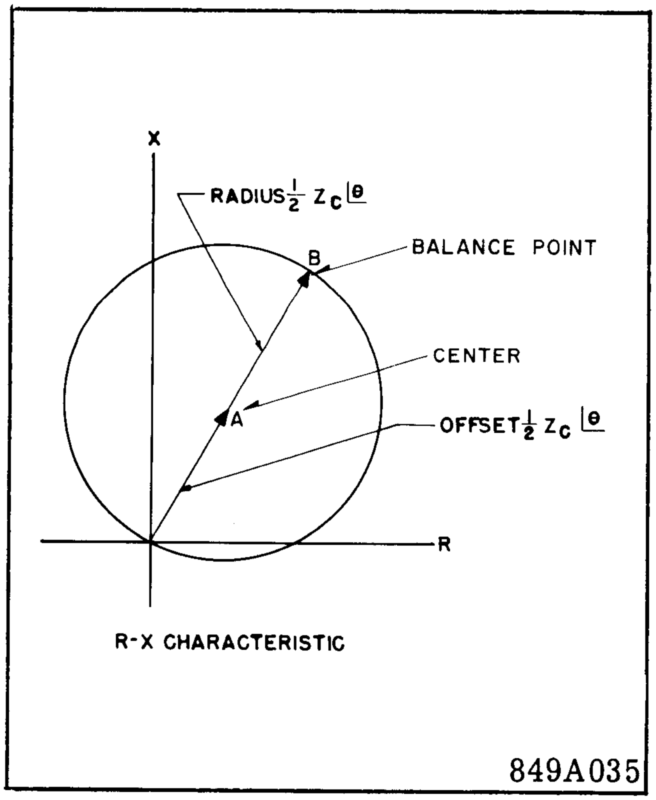


Fig. 18. Impedance Circle for Three-Phase Unit in SKDU Relays

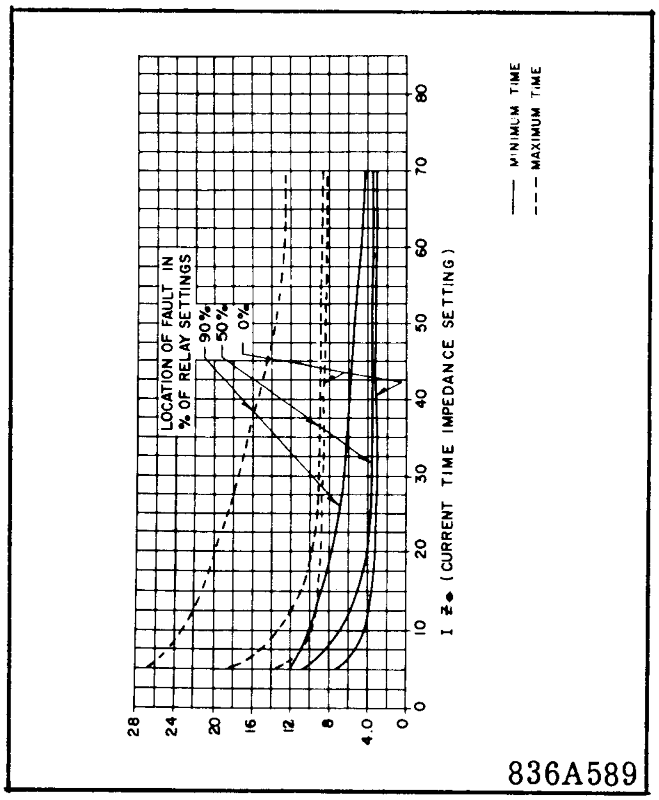


Fig. 19. Typical Operating Time Curves for SKDU and SKDU-1 Relays. Normal Voltage before the Fault is 120 Volts.

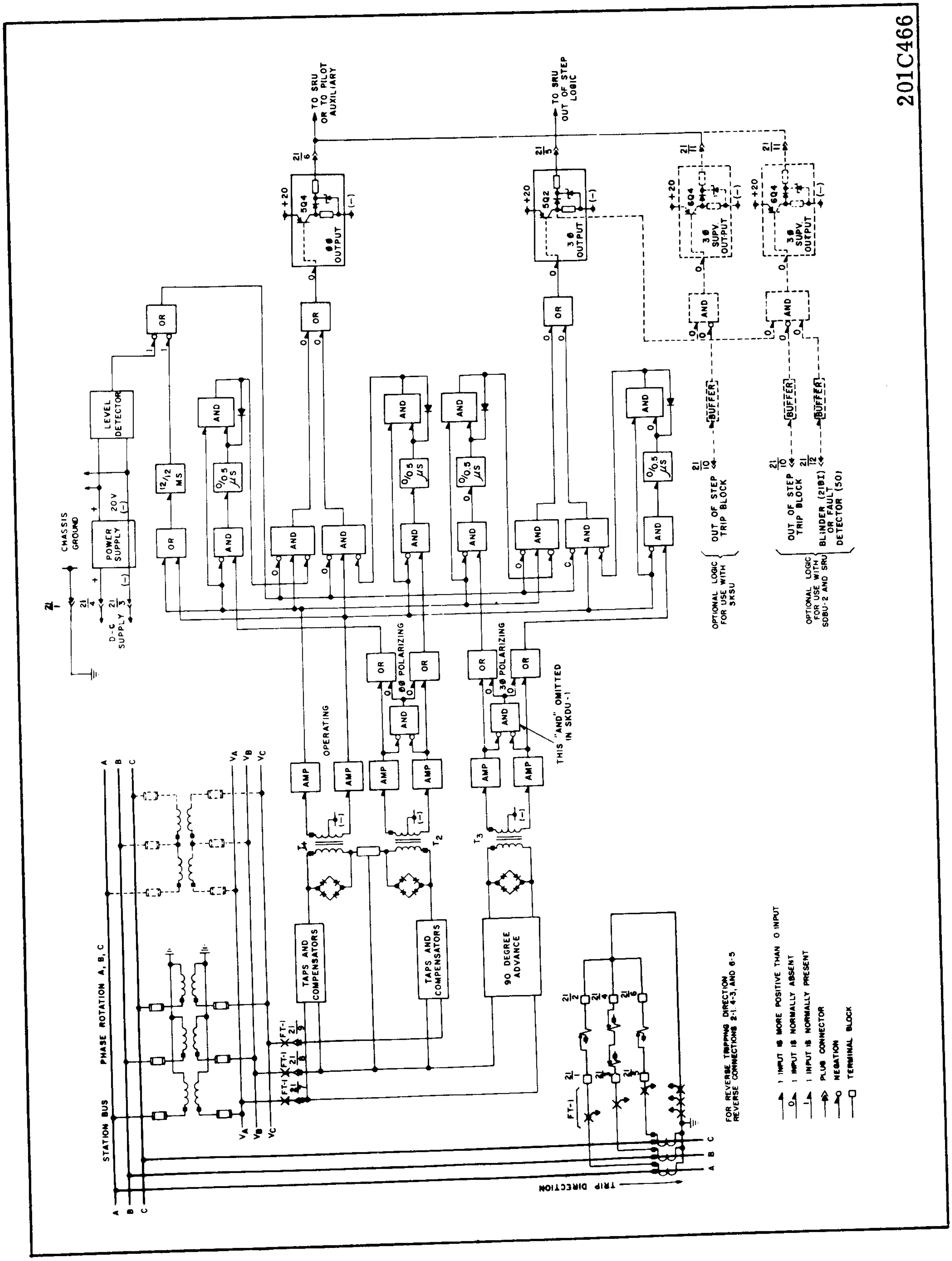
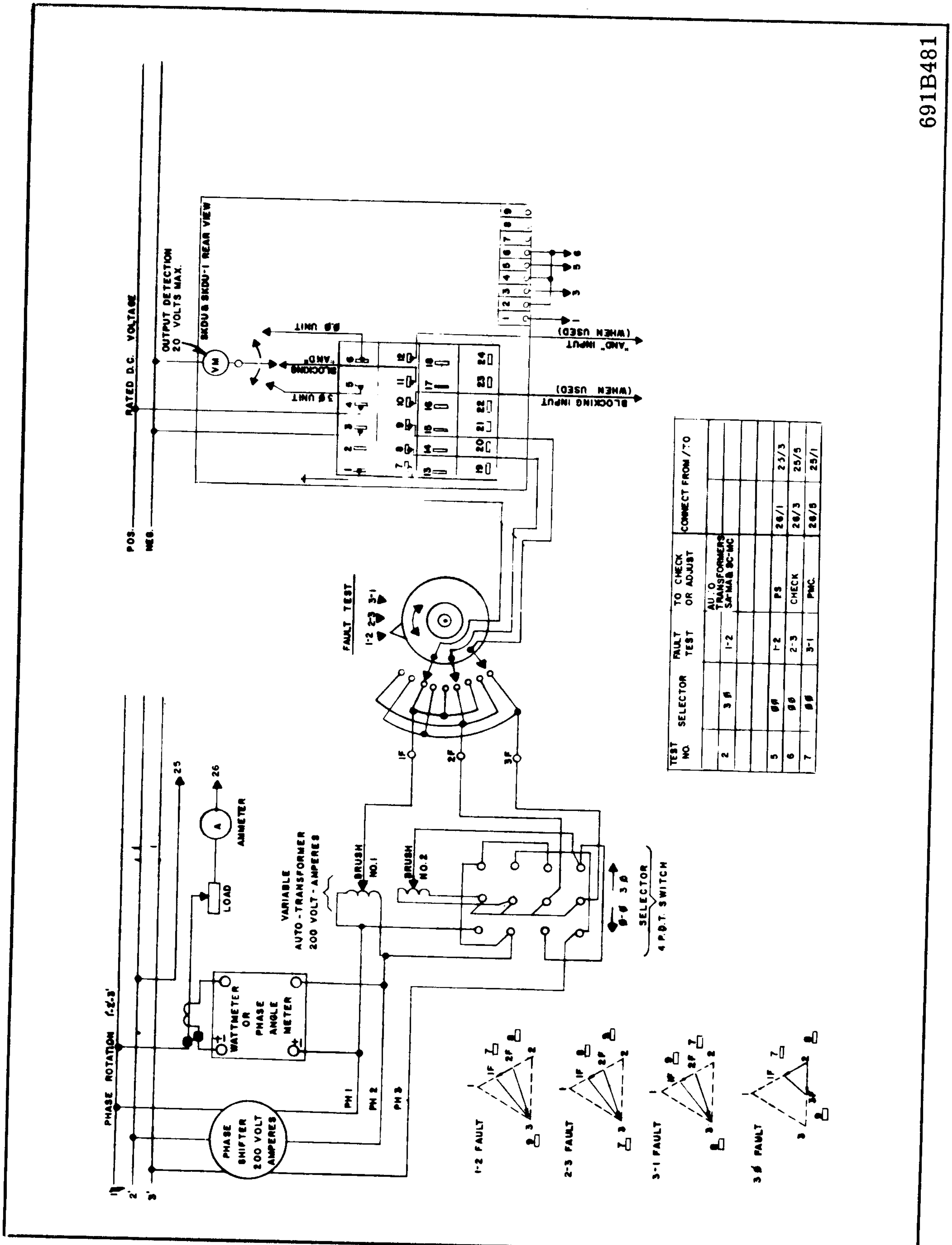


Fig. 20. External Schematic of Types SKDU and SKDU-1 Relays



TEST NO.	SELECTOR	FAULT TEST	TO CHECK OR ADJUST	CONNECT FROM/TO	
2	3 ø	1-2	AUTO TRANSFORMERS SA-MA & SC-MC		
5	øø	1-2	PS	26/1	25/3
6	øø	2-3	CHECK	26/3	25/5
7	øø	3-1	PMC	26/5	25/1

Fig. 21. Test Connections for Types SKDU and SKDU-1 Relays

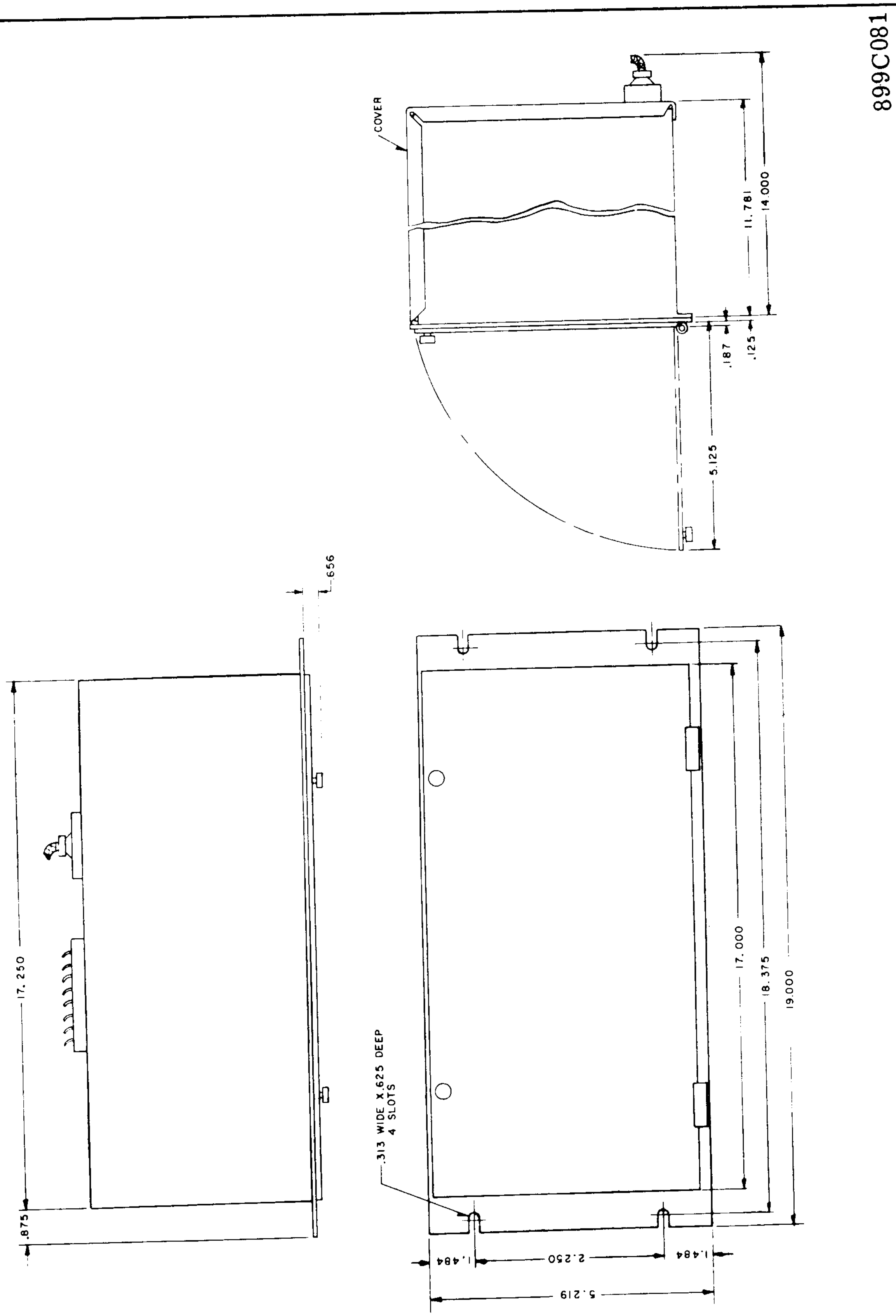
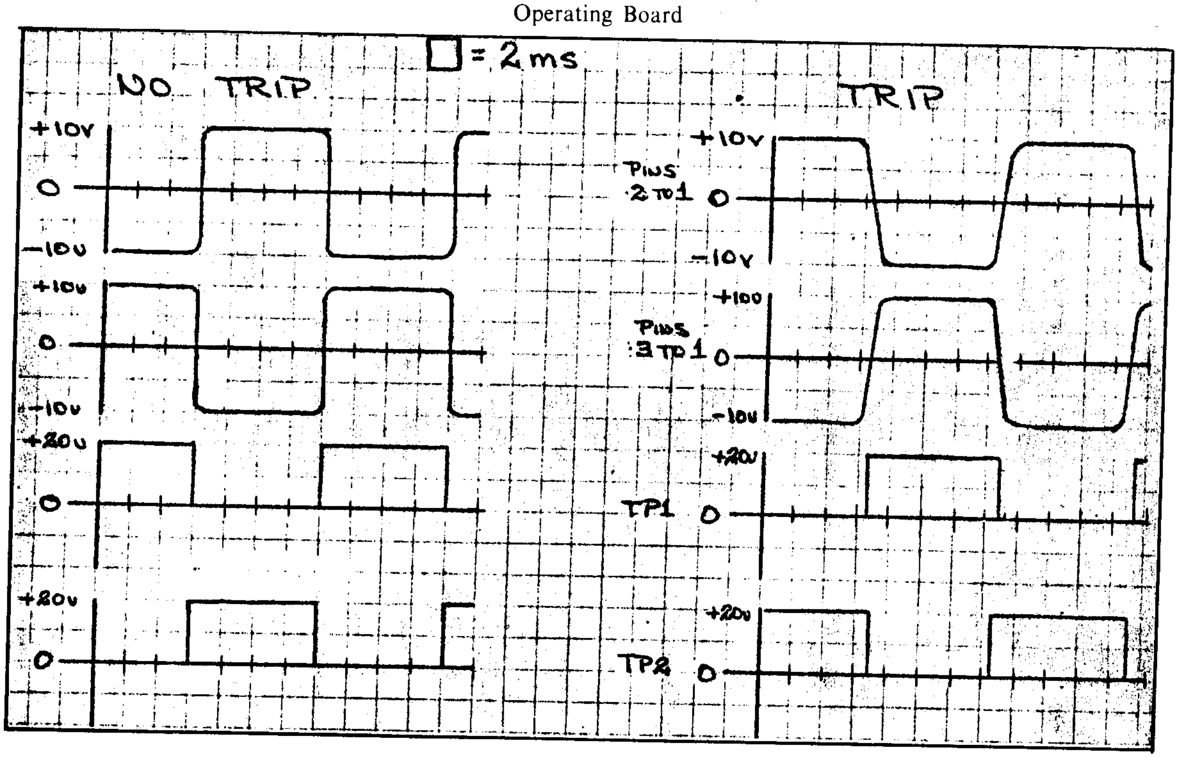


Fig. 22. Chassis Outline

Operating Board



Polarizing Board (3Ø unit)

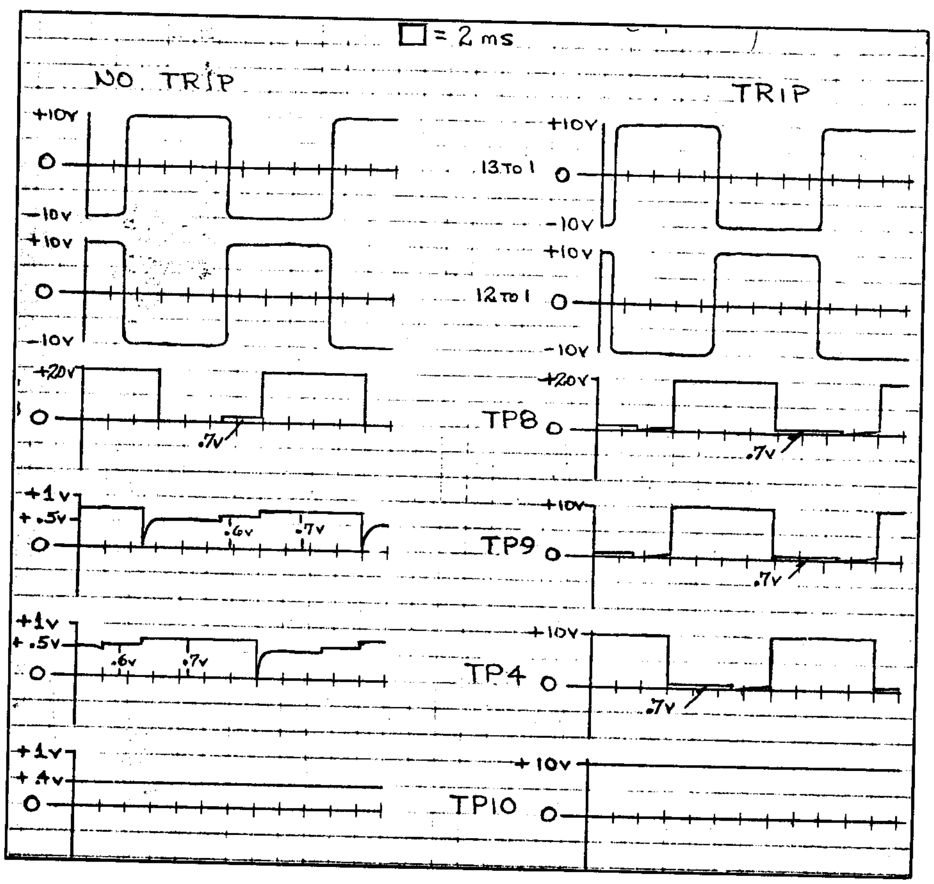


Fig. 23a & 23b Test Points

Polarizing Board (ØØ unit)

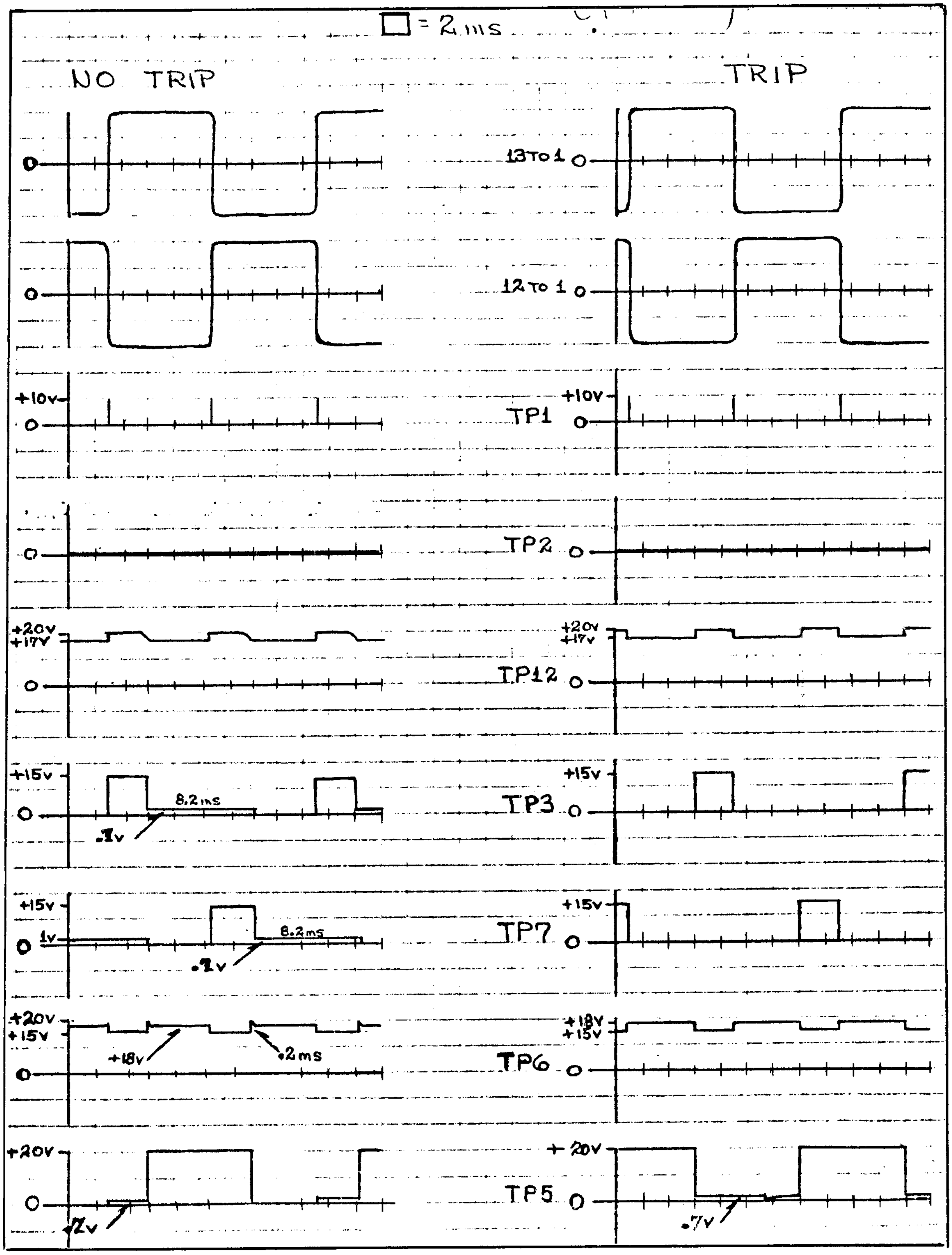
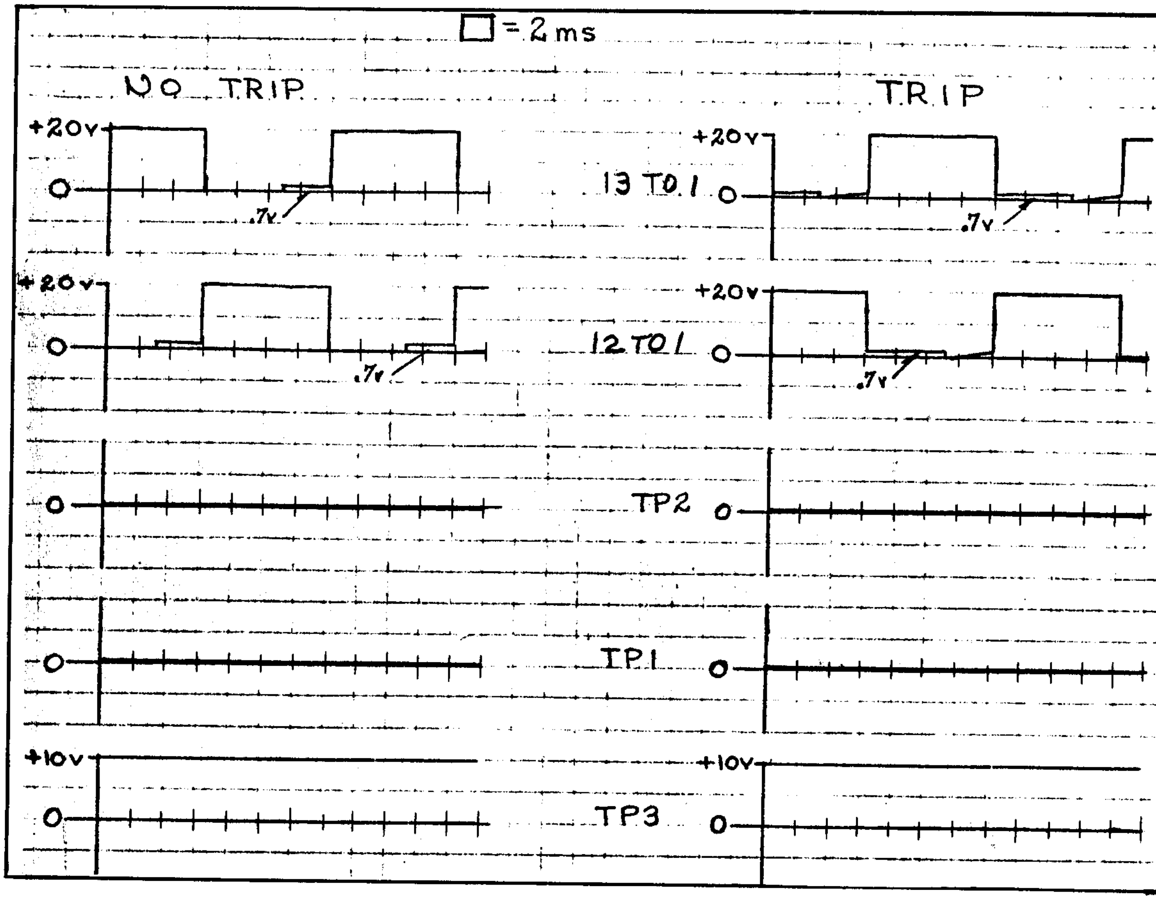


Fig. 23c Test Points

Voltage Detector Board



Output Board

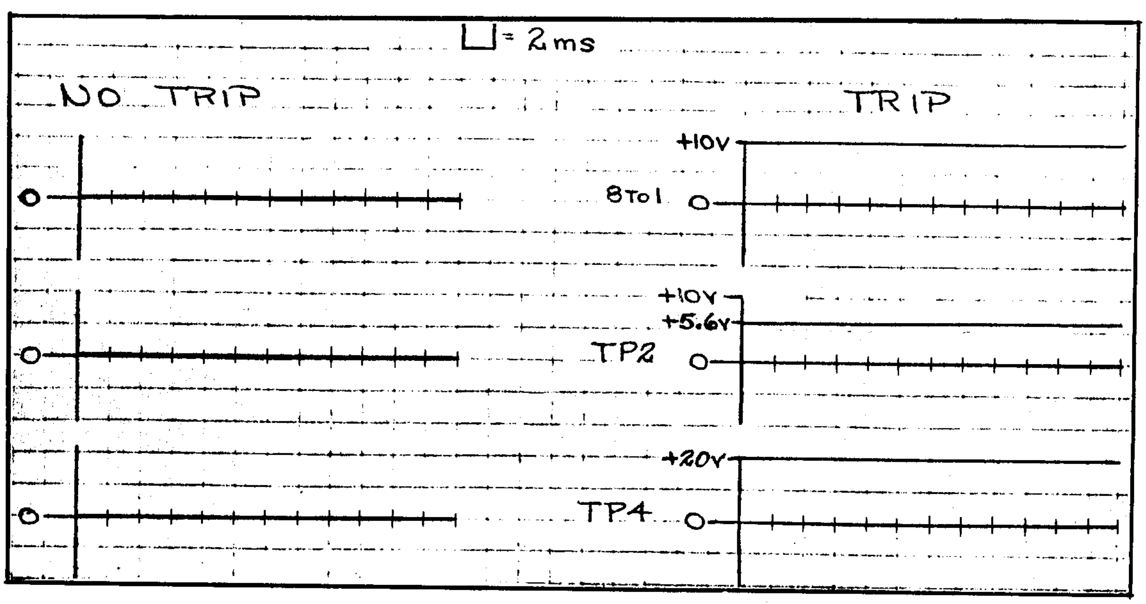


Fig. 23d and 23e Test Points

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