Westinghouse I.L. 41.954C

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKB AND SKB-1 RELAYS AND TEST EQUIPMENT FOR TYPE TC CARRIER

INSTRUCTIONS

CAUTION: Before putting relays into service, make sure that all moving parts operate freely, inspect the contacts to see that they are clean and close properly, and operate the relay to check the settings and electrical connections.

APPLICATION

The type SKB relay is a high-speed carrier relay with static fault detectors used in conjunction with power-line carrier equipment to provide complete phase and ground fault protection of a transmission line section. Simultaneous tripping of the relays at each line terminal is obtained in less than two cycles for all internal faults within the limits of the relay settings. The relay operates on line current only, and no source of a-c line potential is required. Consequently, the relays will not trip during a system swing or out-of-step conditions. The carrier equipment operates directly from the station battery.

The type SKB-1 relay is used in distance phase-comparison carrier relaying where separate distance-type fault detectors supplement the overcurrent fault detectors of the SKB-1 relay to give improved phase-fault sensitivity. Unless otherwise stated, the following sections of this instruction leaflet apply to both the types SKB and SKB-1 relays.

The SKB relay is available with indicating contactor switches with either a 1-ampere or a 0.2/2.0-ampere rating. The 0.2/2.0-ampere rating is recommended where a lockout relay is energized or where a high resistance auxiliary tripping relay is utilized. The SKB-1 relay has a low-current operation indicator, and the trip circuit energizes an external static tripping device.

PART I

TYPE SKB AND SKB-1 RELAYS

CONSTRUCTION

The relay consists of a combination positive, negative, and zero sequence current network, a saturating auxiliary transformer, Zener clipper, high-speed type AR tripping relay unit, indicating contactor switch plus the static fault-detector circuitry which is mounted on a printed-circuit board. These components are all mounted in an FT42 Flexitest relay case.

Sequence Network

The currents from the current-transformer secondaries are passed through a network consisting of a three-winding iron-core reactor and two resistors. The zero-sequence resistor, R_0, consists of three resistor tubes tapped to obtain settings for various ground fault conditions. The other resistor R_1 is a formed single wire mounted on the rear of the relay sub-base. The output of this network provides a voltage across the primary of the saturating transformer.

The lower tap block provides for adjustment of the relative amounts of the positive, negative, and zero sequence components of current in the network output. Thus, a single relay unit energized from the network can be used as a fault detector for all types of faults.

Saturating Auxiliary Transformer

The voltage from the network is fed into the tapped primary (upper tap plate) of a small saturating transformer. This transformer and a Zener clipper connected across its secondary are used to limit the voltage impressed on the static fault detectors and the carrier control unit, thus providing a small range of voltage for a large variation of maximum to minimum fault currents. This provides high operating energy for light faults, and limits the operating energy for heavy faults to a reasonable value.

The upper tap plate changes the output of the saturating transformer, and is marked in amperes required to pick up the lower fault detector unit. For further discussion, see section entitled, SETTINGS.

SUPERSEEDES I.L. 41-954B
*Denotes changed from superseded issue.

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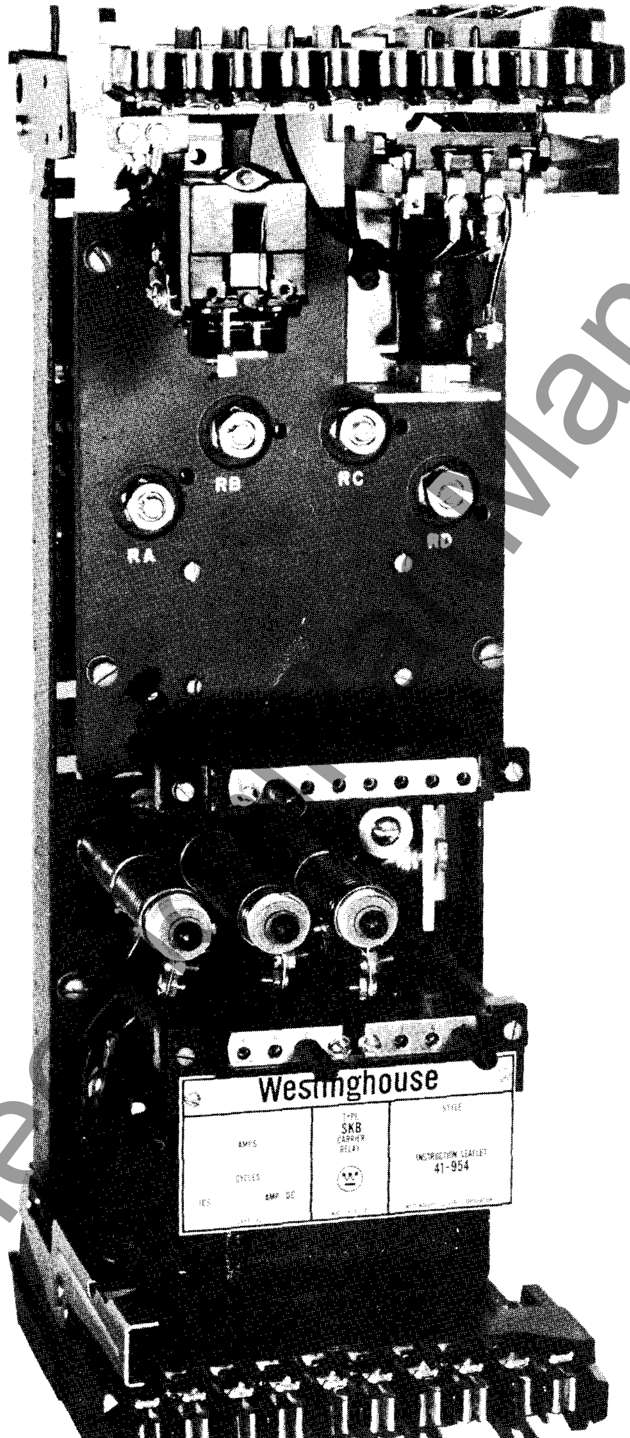


Fig. 1 Type SKB Relay – Front View

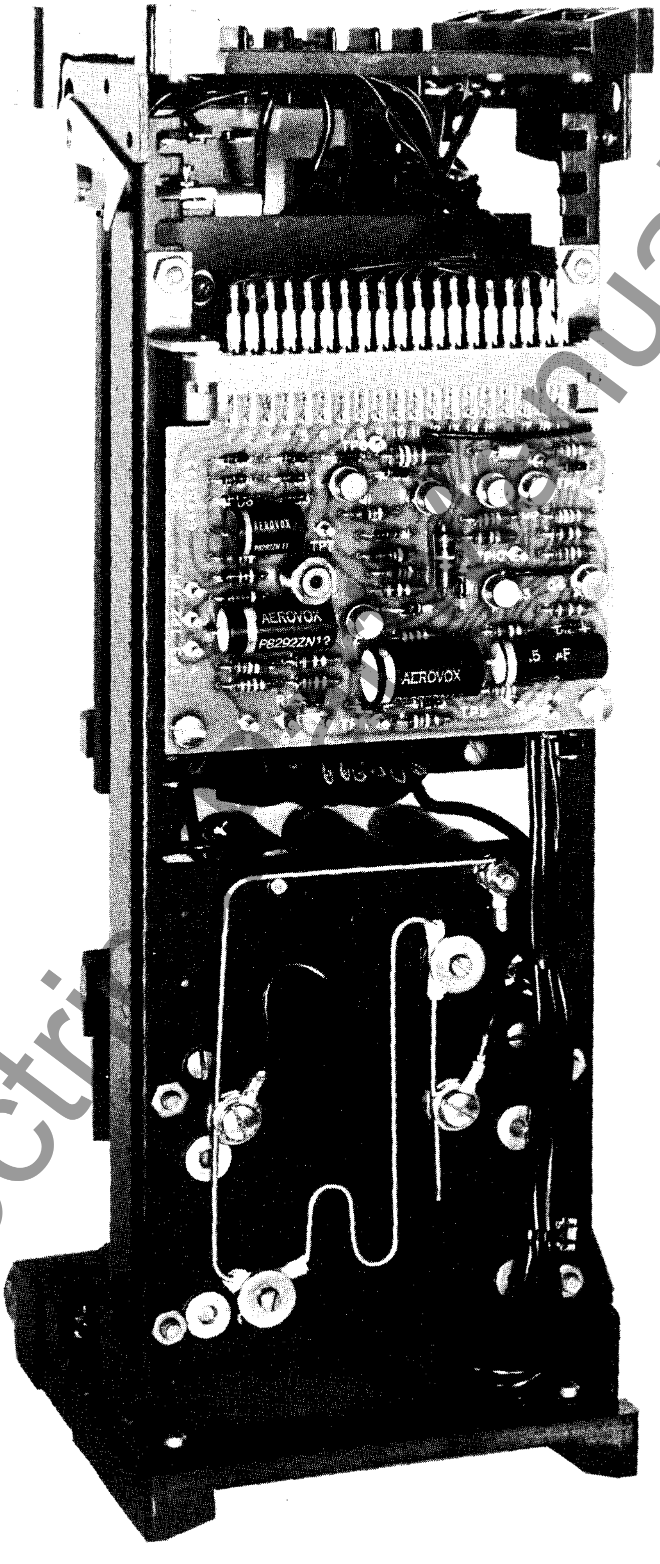


Fig. 2 Type SKB Relay – Rear View

Static Fault Detectors

The static circuitry for the two fault detectors FD1 and FD2 is mounted on a single printed circuit board on the rear of the relay chassis. Four controls for separately setting the pickup and dropout of FD1 and FD2 are mounted on a sub-panel in the chassis. The controls, with locking shafts, are adjustable from the front of the relay.

Tripping Relay

The AR tripping relay is a small high-speed attracted-armature type of unit. An insulated member, fastened to the free end of the armature, draws down four moving-contact springs to close the trip-circuit contacts when the relay coil is energized.

Indicating Contactor Switch Unit (ICS)

The d-c indicating contactor switch in the SKB relay is a small clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also during this operation, two fingers on the armature deflect a spring located on the front of the switch, which allows the the operation indicator target to drop. The target is reset from the outside of the case by a push rod located at the bottom of the cover.

The front spring, in addition to holding the target provides restraint for the armature and thus controls the pickup value of the switch. In the SKB-1 relay, the device has no contacts, and is used only as an operation indicator (OI).

OPERATION

The SKB or SKB-1 carrier relaying system compares the phase positions of the currents at the ends of a line-section over a carrier channel to determine whether an internal or external fault exists. The three-phase line currents energize a sequence network which gives a single-phase output voltage proportional to a combination of sequence components of the line current. During a fault, this single-phase voltage energizes a static control unit (TCU) which allows the transmission of carrier on alternate half-cycles of the power-frequency current. Carrier is transmitted from both line terminals in this manner, and is received at the opposite ends where it is compared with the phase position of the local sequence network output. If the local and remote half-cycle pulses are of the correct phase position for an internal fault, after a 4-millisecond delay during the half cycle in which carrier is not transmitted, tripping will be initiated through operation of the flip-flop and trip amplifier circuits in the TCU control unit. Current transformer connections to the sequence networks at the two terminals are such that carrier is transmitted on the same half cycles from both terminals during an internal fault, thus allowing tripping during the half cycles that carrier is not transmitted. However, if the fault is external to the protected line section, carrier is transmitted on alternate half cycles from opposite terminals. Thus each terminal blocks the opposite terminal during the half cycle when it is attempting to trip.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals, relay co-ordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

Since this relaying system operates only during a fault, the carrier channel is available at all other times for the transmission of other functions.

OPERATION

STATIC FAULT DETECTORS

The functional elements of the static fault detectors are shown in Fig. 3. The single-phase output of the sequence network (not shown) connects to the INPUT terminal shown at the left side of the drawing. This a-c voltage is applied to a phase-splitting network and polyphase rectifier. The resulting d-c voltage has relatively little ripple without much filtering which would slow down the fault detector operation. The d-c voltage is fed to two level detectors which determine the operating currents of FD1 and FD2. The output of FD1 level detector is amplified and provides a "normally-closed" FD1 static contact to start carrier.

The operation of FD2 is delayed about 5 milliseconds to insure coordination in setting up blocking for external faults where FD1 must operate to start carrier blocking a few milliseconds before FD2 energizes the comparison and flip-flop circuits. The output of FD2 fault detector circuit is equivalent to a "normally-open" contact.

The complete circuitry of the SKB relay is shown in Fig. 4. The sequence network, saturating transformer, phase-splitting network, and polyphase rectifier occupy the lower third of the diagram. The FD2 circuitry is in the middle portion, and the FD1 portion is in the upper part of the diagram. The type AR tripping relay is shown at the top. Fig. 5 is a simplified schematic of the SKB relay with the static fault detector circuitry omitted.

Figures 6 and 7 are the complete and simplified schematic diagrams, respectively, of the type SKB-1 relay. This relay differs from the SKB relay in the trip circuit wiring to terminals 1, 10, and 20, and in the connections from the saturating transformer tapped secondary to the input terminals 5 and 7 of the printed circuit board. The sequence network (R1, R0, and the mutual reactor) and the printed circuit board assembly for the static fault detectors for the SKB and SKB-1 relays are identical. Figure 8 shows the location of components on the printed circuit board for the static fault detectors for both the SKB and SKB-1 relays.

With reference to Fig. 4, the output voltage of the sequence network and saturating transformer is applied to a phase-splitting network (C1, R1, R2) and a polyphase rectifier (diodes D1 to D6). The d-c voltage so obtained requires a minimum of filtering (C2), and responds rapidly to a change in magnitude of the a-c output. This d-c voltage is applied to the FD1 and FD2 circuits which operate when the d-c input "signal" exceeds a predetermined value.

FD1 – Under normal line conditions (no fault), current flows from relay terminal 19 (pos. 45 v) through resistor R4 and Zener diode Z1 to negative, holding Q1 emitter at 6.8 volts positive. In transistor Q1, current flows from emitter to base, then through RA and R3 to negative, thus turning on Q1. The collector current of Q1 provides base drive to transistors Q2 and Q7, turning them on also. The voltage drop across Q7 is very low (less than 0.5 volt), thus providing the equivalent of a closed contact. When a fault occurs and the d-c input voltage to Q1 base (from the polyphase rectifier) exceeds the 6.8-volt drop across Zener diode Z1, transistor Q1 stops conducting. This removes the base current from Q2 and Q7, causing them to stop conducting, and providing the equivalent of an open contact at Q7 collector-emitter circuit.

When Q2 is cut off as just explained, its collector potential rises to about 20 volts. This further raises the potential of Q1 base through feedback resistors R6 and RB, thus holding Q1 in a non-conducting state. When the input voltage is sufficiently reduced to allow FD1 to "reset," transistors Q1, Q2, and Q7 again conduct. Resistor RA is for setting the FD1 pickup current (calibration adjustment), and the setting of RB determines the 80 per cent dropout value.

FD-2 – Under normal conditions, transistor Q3 has no base "signal" and thus is turned off (not conducting). Thus Q3 collector is at a high enough positive potential to provide base drive for transistor Q4, driving it to full conduction. With Q4 fully conducting, there is no base drive to transistor Q5. With no Q5 collector current, the base of PNP-type transistor Q6 is supplied from the 45-volt source through the drop of diode D11. Thus the Q6 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q6 in a non-conducting state, equivalent to an open contact. Zener diode Z3 is to protect transistor Q6 from external surge voltages.

When a fault causes the d-c input voltage from the adjustable resistor RC to exceed the 6.8-volt rating of Zener diode Z2, a positive bias is applied to Q3 base, causing it to conduct. In turn, Q4 stops conducting, and capacitor C5 charges up, giving a few milliseconds' time delay before Q5 and Q6 are switched to full conduction, thus "closing" FD2. The feedback resistors R13 and RD provide a 90-percent FD2 dropout ratio with "toggle" action at the dropout point.

CHARACTERISTICS

The sequence network in the relays is arranged for several possible combinations of sequence components. For most applications, the output of the network will contain the positive, negative, and zero sequence components of the line current. In this case, the taps on the upper tap plate indicate the balanced three-phase amperes which will operate the carrier-start fault detector FD1. The second fault-detector unit FD2, which supervises operation of the AR tripping relay, is adjusted to pick up at a current 25 percent above tap value. The taps available are 3, 4, 5, 6, 7, 8, and 10, for the SKB relay, and 6, 8, 10, 12, 14, 16, and 20 for the SKB-1 relay. These taps are on the primary of the saturating transformer.

For phase-to-phase faults AB and CA, enough negative sequence current has been introduced to allow the fault detector FD1 to pick up at 86% of the tap setting. For BC faults, the fault detector will pick up at approximately 50% of the tap setting.

This difference in pick-up current for different phase-to-phase faults is fundamental, and occurs because of the angles at which the positive and negative sequence components of current add together.

With the sequence network arranged for positive, negative, and zero sequence output, there are some applications where the maximum load current and minimum fault current are too close together to set the relay to pick up under minimum fault current, yet not operate under load. For these cases, a tap is available on both the SKB and SKB-1 relays which cuts the three-phase sensitivity in half, while the phase-to-phase setting is substantially unchanged. The relay then trips at 90% of tap value for AB and CA faults, and at twice tap value for three-phase faults. The setting for BC faults is 65 percent of tap value. In some cases, it may be desirable to eliminate response to positive-sequence current entirely, and operate the SKB relay on negative-plus-zero sequence current. A tap is available to operate in this manner. The fault detector FD1 picks up at about 95% of tap value for all phase-to-phase faults, but is unaffected by balanced load current or three-phase faults when using this tap.

For ground faults, separate taps are available for adjustment of the ground fault sensitivity to about 1/4 or 1/8 of the upper tap plate setting. See Table II. For example, if the upper tap plate of the SKB relay is set at tap 4, the fault detector (FD1) pick-up current for ground faults can be either 1 or ½ ampere. In special applications, it may be desirable to eliminate response to zero-sequence current. The relay is provided with a tap to allow such operation.

Trip Circuit

The main contacts of the SKB relay will safely close 30 amperes at 250 volts d-c and the seal-in contacts of the indicating contactor switch will safely carry this current long enough to trip a circuit breaker. The trip contacts of the SKB-1 relay have no seal-in device since they energize the low-current input of a static tripping relay.

Trip Circuit Constants – SKB Relay

Indicating Contactor Switch (ICS)

0.2-ampere tap, 6.5 ohms d-c resistance
2.0-ampere tap, 0.15 ohms d-c resistance
1.0-ampere tap, 0.1 ohms d-c resistance

SETTINGS – SKB RELAY

The SKB relay has separate tap plates for adjustment of the phase and ground fault sensitivities and the sequence components included in the network output. The range of the available taps is sufficient to cover a wide range of application. The method of determining the correct taps for a given installation is discussed in the following paragraphs.

In all cases, the similar fault detectors on the relays at all terminals of a line section must be set to pick up at the same value of line current. This is necessary for correct blocking during faults external to the protected line section.

Positive-Sequence Current Tap and FD2 Tap

The upper tap plate has taps of 3, 4, 5, 6, 7, 8, and 10 for the SKB relay, or 6 to 20 for the SKB-1 relay. As mentioned before, these numbers represent the three-phase, fault detector FD1 pickup currents, when the relay is connected for positive, negative and zero sequence output. The fault detector FD2 operates to allow tripping at a current value 25 percent above the fault detector FD1 setting. This 25 percent difference is necessary to insure that the carrier-start fault detectors (FD1) at both ends of a 2-terminal transmission line section pick up to start carrier on an external fault before operating energy is applied through FD2.

For a 3-terminal line, FD2 settings must be readjusted for pickup at 250 percent of FD1 setting. This is necessary to allow proper blocking when approximately equal currents flow in two terminals, and their sum flows out the third line terminal. The relay is normally shipped calibrated for 2-terminal line operation.

When the SKB is to be used on a 3-terminal line, FD2 must be recalibrated as explained in the previous paragraph, and the FD2 temperature-compensating circuit must also be changed to accomodate the new Rc (FD2 pickup) setting. This is accomplished by changing the jumper near the lower left corner of the printed circuit board (see Fig. 8) from C-2 to C-3, as shown.

The taps on the upper and lower tap plates should be selected to assure operation on minimum internal line-to-line faults, and yet not operate on normal load current, particularly if the carrier channel is to be used for auxiliary functions. The dropout current of the FD-1 fault detector is 80 percent of the pick up current, and this factor must also be considered in selecting the positive-sequence current tap and sequence component combination. The margin between load current and fault detector pick up should be sufficient to allow the fault detector to drop out after an external fault, when load current continues to flow.

Sequence Combination Taps

The two halves of the lower tap plate are for connecting the sequence network to provide any of the combinations described in the previous section. The left half of the tap plate changes the tap on the third winding of the mutual reactor and thus changes the relative amounts of positive and negative sequence sensitivity. Operation of the relay with the various taps is given in the table below.

TABLE I

COMB.	SEQUENCE COMPONENTS IN NETWORK OUTPUT	TAPS ON LOWER TAP BLOCK		FAULT DETECTOR FD1 PICK-UP △	
		LEFT HALF	RIGHT HALF	3 ϕ FAULT	ϕ - ϕ FAULT
1	Positive, Negative, Zero	C	G or H*	Tap Value	86% Tap Value (53% on BC Fault)
2	Positive, Negative, Zero	B+	G or H	2 x Tap Value	90% Tap Value (65% on BC Fault)
3	Negative, Zero	A+	G or H	——	95% Tap Value

* Taps F, G, and H are zero-sequence taps for adjusting ground fault sensitivity. See section on zero-sequence current tap.

△ Fault detector FD2 is set to pick up at 125% of FD1 for a two-terminal line, or 250% for a three-terminal line.

+ When taps A and 3, or B and 3 are used, the relay pickup currents for FD1 and FD2 will be 10 or 15 percent higher than the indicated values because of the variation in self-impedance of the sequence network and the saturating transformer.

Zero-Sequence Current Tap

The right half of the lower tap plate is for adjusting the ground fault response of the relay. Taps G and H give the approximate ground fault sensitivities as listed in Table II. Tap F is used in applications where increased sensitivity to ground faults is not required. When this tap is used, the voltage output of the network caused by zero-sequence current is eliminated.

NOTE: Because of inherent characteristics of the sequence network, there will be small variations (from the values listed in Tables I and II) in the pickup current for various phase or ground fault combinations. However, these variations will be the same from one relay to another.

TABLE II

COMB.	LOWER LEFT TAP	GROUND FAULT PICKUP	
		TAP G	TAP H
1	C	25%	12%
2	B	20%	10%
3	A	20%	10%

Examples of SKB Relay Settings

Case I

Assume a two-terminal line with current transformers rated 400/5 at both terminals. Also assume that full load current is 300 amperes, and that on minimum internal phase-to-phase faults 2000 amperes is fed in from one end and 600 amperes from the other end. Further assume that on minimum internal ground faults, 400 amperes is fed in from one end, and 100 amperes from the other end.

Positive-Sequence Current Tap

Secondary Values:

$$\text{Load Current} = 300 \times \frac{5}{400} = 3.75 \text{ amperes} \qquad (1)$$

Minimum Phase-to-Phase Fault Currents:

$$600 \times \frac{5}{400} = 7.5 \text{ amperes} \qquad (2)$$

Fault detector FD1 setting (three-phase) must be at least:

$$\frac{3.75}{0.80} = 4.7 \text{ amperes (0.80 is dropout ratio of FD-1 fault detector)} \qquad (3)$$

so that the fault detector will reset on load current.

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector FD1 setting(three-phase) must be not more than:

$$7.5 \times \frac{1}{0.866} \times \frac{1}{1.25} = 6.98 \text{ amperes} \qquad (4)$$

$$1.25 = \frac{\text{FD2 pickup}}{\text{FD1 pickup}}$$

Sequence Combination Tap

From a comparison of (3) and (4) above, it is evident that the fault detector can be set to trip under minimum phase fault condition yet not operate under maximum load. In this case, tap C on the lower left tap block would be used (see Table 1, Comb. 1) as there is sufficient difference between maximum load and minimum fault to use the full three-phase sensitivity. Current tap 6 would be used in preference to tap 5 to allow for occurrence of higher load current.

Zero Sequence Tap

Secondary Value:

$$100 \times \frac{5}{400} = 1.25 \text{ amperes minimum ground fault current.}$$

With the upper tap 6 and sequence tap C in use, the fault detector FD1 pickup currents for ground faults are as follows:

Lower right tap G–1/4 x 6 = 1.5 amp.
Minimum trip = 1.25 x 1.5 = 1.88 amp.
Lower right tap H–1/8 x 6 = 0.75 amp.
Minimum trip = 1.25 x 0.75 = 0.94 amp.

From the above, tap H would be used to trip the minimum ground fault of 1.25 amperes.

Case II

Assume the same fault currents as in Case I, but a maximum load current of 550 amperes. In this example, with the same sequence combination as in Case I, the fault detectors cannot be set to trip on the minimum internal three-phase fault, yet remain inoperative on load current. Compare equations(5) and (6). However, by connecting the network per Combination 2 on Table I, the relay can be set to trip on minimum phase-to-phase fault, although it will have only half the sensitivity to three-phase faults. This will allow operation at maximum load without picking up the fault detector, and provide high speed relaying of all except light three-phase faults.

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector tap must now be not more than:

$$7.5 \times \frac{1}{1.25} \times \frac{1}{0.9} = 6.6 \qquad (5)$$

To be sure the fault detector FD1 will reset after a fault, the minimum tap setting is determined as follows:

$$\text{Load Current} = 550 \times \frac{5}{400} = 6.9 \text{ amps} \qquad (6)$$

$$\frac{6.9}{0.80} = 8.6 \qquad (7)$$

Since the fault detector pickup current for three-phase faults is twice tap value, half the above value (Eq. 7) should be used in determining the minimum three-phase tap.

$$\frac{8.6}{2} = 4.3 \qquad (8)$$

From a comparison of (5) and (8) above, tap 5 or 6 could be used. (Continuous load current rating of relay is 10 amperes.)

With the three-phase tap 5 in use, the fault detector pickup current for ground faults will be as follows:

Tap G–1/5 x 5 = 1.0 a.
Minimum trip = 1.0 x 1.25 a. =1.25 amp.

Tap H–1/10 x 5 = 0.5 a.
Minimum trip = 1.25 x 0.5 a. =0.63 amp.

Therefore, tap H would be used to trip the minimum ground fault of 1.25 ampere with a margin of safety.

Indicating Contactor Switch (ICS) – SKB Relay

No setting is required for relays with a 1.0 ampere unit. For relays with a 0.2/2.0 ampere unit, connect the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125 or 250-volt d-c type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48-volt d-c applications set the unit in tap 2 and use a type WL relay with a S# 304C209-G01 coil, or equivalent.

SETTINGS – SKB-1 RELAY

The SKB-1 relay tap settings are made from a consideration of just maximum load current and the resetting of FD1 fault detector. The SKB-1 current taps are 6, 8, 10, 12, 14, 16, and 20. On taps 6 and C, FD1 will operate at 6 amperes, 3-phase, and reset at 80% of pickup, or 4.8 amperes. This will be adequate in most cases where maximum load current is in the order of 3 to 4 amperes, secondary values. If maximum load current is 5 amperes or slightly higher, tap 8 should be used, which will give a dropout current for FD1 or 6.4 amperes.

For most SKB-1 relay applications, where static phase-distance relays are used as phase fault detectors, taps 6-C-H are recommended. This will give a minimum trip sensitivity for phase-to-ground faults of 6 x 1/8 x 1.25 or 0.94 ampere. Taps A or B are not recommended for SKB-1 relay application.

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 vertically by means of the four mounting holes on the flange for semi-flush mounting or by means of the rear mounting studs for projection mounting. Either a mounting stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel panel mounting or to the terminal studs furnished with the relay for thick panel mounting. The terminal studs may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

ADJUSTMENT AND MAINTENANCE

CAUTION: When changing taps under load, the spare tap screw should be inserted in the new tap before removing the other tap screw.

Acceptance Tests

Since the static fault detector circuits obtain their d-c supply voltage from the associated type TC carrier set, the fault detector calibration can must easily be checked after the SKB relay and TC-TCU carrier assembly have been installed and interconnected.

NOTE: The relay current tap numbers and the FD1 and FD2 pickup and dropout current values in the Acceptance Tests and Calibration sections apply to the SKB relay. For the equivalent tap number and current value for the SKB-1 relay, double the figures given for the SKB relay.

The carrier trip circuit should be open for the following check: Set the SKB relay on taps 5, C, and H. Connect a 60-cycle test current circuit between phases A and B of the relay (terminals 5 and 7.). Connect a high-resistance d-c voltmeter between relay terminal (or test switch) 15 (pos.) and 18 (neg.). This will read approximately 20 volts when FD1 operates. Gradually increase the current. At 4.33 amperes, FD1 should operate, starting the transmission of half-cycle pulses of carrier, and the d-c voltmeter will read 20 volts.

Continue to increase the test current. At 5.41 amperes, FD2 should operate. If the R101 controls in the type TCU control unit have been set, the AR tripping unit in the SKB relay will operate. The operation of FD1 and FD2 can also be noted by observing the change in d-c voltage at the printed circuit board terminals 14 (FD1) and 15 (FD2) relative to TP4 (negative). See Table I for typical values for these voltages under standby and operating conditions.

Now back off the test current to check the dropout values. Fault detector FD2 should drop out at 90 per cent of pickup, or 4.85 amperes. The FD1 dropout is 80 per cent of pickup, or 3.46 amperes.

The fault detectors have been properly calibrated at the factory and normally will require no further adjustment. If it is found desirable to touch up the calibration, this can be done by loosening the locking nut and changing the adjustment of the appropriate control as listed at the beginning of this section. Turning RA or RC in a clockwise direction will increase the FD1 or FD2 pickup. Similarly, turning RB or RD in a clockwise direction will increase the dropout current.

The pickup and dropout calibration settings of FD1 and FD2 are made with the four controls on the SKB or SKB-1 relay subpanel, as follows:

Relay Unit	Pickup	Dropout
FD1	RA	RB
FD2	RC	RD

These four controls have slotted shafts (for screwdriver adjustment) and locking nuts which are tightened after proper adjustment.

Typical test point voltage values listed in Table I will be useful when checking the apparatus. The readings will remain fairly constant over an indefinite period unless a failure occurs. Voltages should be measured with a vacuum-tube voltmeter. To facilitate taking these voltages, a test cable is available. See Fig. 9. To use this cable, remove the SKB or SKB-1 chassis from its case. Remove the printed circuit board from the back of the relay, and insert the board end of the test cable in its place. Now plug the removed board into the receptacle at the other end of the cable. Replace the relay chassis in its case on the switchboard and close the test switches. The relay can now be energized and operated to obtain the readings in Table I. The test cable can also be used, if desired, with the printed circuit boards of the type TCU Control Unit. However, do not use these test cables in the TC transmitter where r.f. voltages are involved.

TABLE I

Note: All d-c voltages are positive with respect to negative d-c(TP4). All voltages are read with a vtvm, and in general will be within ± 10% of the values listed.

TEST POINT	$I_{SKB} = 0$	$I_{SKB} = 2$ x FD2 p.u. ¢
TP5	45.0 vdc	45.0 vdc
TP6	6.5	6.8
TP7	6.5	< 0.5
TP8	14.0	< 0.5
TP9	< 0.5	14.0
TP10	45.0	< 0.5
TP11	45	45
*Term. 14	< 0.5	20.0
*Term. 15	—	44.5
*Term. 19	< 0.5	20.0
A-C TEST POINT VOLTAGES		
TP2 to TP1 .... 18.0 vac approx.		
TP2 to TP3.................................... 17.5 vac approx.		

* On Printed Circuit Board

¢ - Test current of twice FD2 pickup for the taps used.

<0.5 - means less than 0.5

After the SKB or SKB-1 and associated relays and the carrier equipment have been installed and adjusted, the system can be checked following the procedure in Part II of this I.L. under the heading "OVERALL TEST OF COMPLETE INSTALLATION."

Routine Maintenance

All contacts should be periodically cleaned. A contact burnisher S# 182A836H01 is recommended. The use of abrasive material is not recommended because of the danger of embedding small particles in the face of the soft silver and thus impairing the contact.

The proper adjustments to insure correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer. If the adjustments have been changed, the relay taken apart for repairs, or if it is desired to check the adjustments at regular maintenance periods, the instructions below should be followed.

The performance of the phase comparison carrier relaying can be checked periodically as explained in Part III of this I.L. under the heading "TYPE SKB or SKB-1 TEST FACILITIES APPLICATION."

Calibration

Normally, there are no adjustments to be made in the sequence network. The taps on the three tubular R_0 resistors are brazed in place and cannot get out of adjustment. The two taps on the formed R1 resistor are factory settings, and should not require readjustment. However, if there is reason to suspect that the tap position has changed, the following procedure can be used to check the R1 tap settings for either the SKB or SKB-1 relay:

Remove the current tap screw (upper tap plate), and insert the tap screws in taps C and H on the lower tap plate.

Pass a single-phase current of ten amperes (SKB or SKB-1), rated frequency, through the reactor coils in series from phase B to phase C (relay terminals 7 and 9). Accurately measure the a-c voltage from phase A terminal to the upper tap plate. This voltage should be between 3.8 and 4.0 volts a-c. Now pass 10 amperes from phase A to phase B with the lower tap screw C removed. Adjust the R1 tap further from the R1 mounting screw to give a voltage drop across R1 equal to exactly one-third of the reactor drop. This voltage can be measured directly across the terminals of the resistor R1 from the mounting screw to the last tap on R1.

Note the above reading, and adjust the intermediate tap on R1 to give exactly 1/3 of the voltage obtained above for all of R1. Measure the voltage from the R1 mounting screw to the intermediate tap.

If replacement of the printed circuit board or major components necessitates a complete recalibration, proceed as follows:

1. Set relay taps on 5-C-H. (10-C-H for SKB-1)
2. Use a phase A-B test current. (double the following current values for SKB-1 relay).
3. Set RA and RC to full clockwise position.
4. Set RB and RD to mid-scale.
5. Pass 4.33 amperes through the relay (phase A to B).
6. Check the a-c voltage from TP2 to TP1 and from TP2 to TP3 with a vtvm. Adjust the small pot. R2 on the printed circuit board until these two voltages are equal.
7. Now slowly turn RA counterclockwise, with 4.33 amperes flowing, until FD1 operates.
8. Reduce the phase A-B current to check FD1 dropout. Adjust RB to get 80 percent dropout (3.46 Amperes).
9. Recheck FD1 pickup and dropout, and touch up RA and RB in that order for the correct calibration. Tighten the locknuts.
10. Similarly recalibrate FD2 using controls RC (pickup) and RD (dropout), repeating steps 7, 8, and 9 except for FD2 pickup of 5.41 amp. and dropout of 4.85 amp. Do not readjust R2.
11. For 3-terminal lines, change the printed circuit board link from C2 to C3, then calibrate FD2 for 10.82 amp. pickup and 9.7 amp. dropout.

Tripping Relay (AR)

The type AR tripping relay unit has been properly adjusted at the factory to insure correct operation, and should not be disturbed after receipt by the customer. If, however, the adjustments are disturbed in error, or it becomes necessary to replace some part in the field, use the following adjustment procedure. This procedure should not be used until it is apparent that the relay is not in proper working order, and then only if suitable tools are available for checking the adjustments.

1. Adjust the set screw at the rear of the top of the frame to obtain a 0.009-inch gap at the rear end of the armature air gap.
2. Adjust each contact spring to obtain 4 grams pressure at the very end of the spring. This pressure is measured when the spring moves away from the edge of the slot in the insulated crosspiece.
3. Adjust each stationary contact screw to obtain a contact gap of 0.020 inch. This will give 15-30 grams contact pressure.

This completes the adjustment procedure for the AR relay unit. The resistance of the AR relay coil is 100 ohms.

Indicating Contactor Switch (ICS in SKB Relay)

Close the main relay contacts and pass sufficient direct current through the trip circuit to close the contacts of the ICS. This value of current should not be greater than the particular ICS tap setting being used. The indicator target should drop freely.

Operation Indicator (OI in SKB-1 Relay)

Apply 80 percent of rated voltage across relay terminals or test switches 1 and 10. When the AR relay is operated, the orange target should drop.

There are no seal-in contacts on the operation indicator, which is a voltage-operated device.

Replacement of Printed-Circuit Board Components

If a defective resistor, capacitor, or diode is found, cut it out of the circuit by first clipping off its leads on the component side of the printed circuit board. Then turn the board over, melt the solder holding the remaining lead to the printed pad, and remove the lead with tweezers.

NOTE: For such work, a 60-watt iron with a small, clean, well-tinned tip is recommended. Use a 60-40 (tin-lead) rosin-core solder. Do not hold the iron against the printed-circuit board any longer than necessary to remove and replace the component. If the terminal hole in the board closes up with solder, use the iron to melt it, then open up the hole with a fine awl or similar tool.

Where transistors are mounted on small plastic pads, the leads cannot be clipped off. In such a case, melt the solder on one connection at a time, while gently tilting back that section of the transistor. Because of the small flexible leads, the transistor will gradually separate from the board.

Wherever possible, use a heat-sink (such as an alligator clip) on any transistor or diode being soldered. As an alternate, use a long-nosed pliers to hold the lead (being soldered) between the device and the point of soldering.

* ELECTRICAL PARTS LIST

Symbol	Description	Style	Symbol	Description	Style
C1	0.5 mfd. 200V ± 10%	187A624H11	R16	68K 1/2W ± 10%	187A641H71
C2	0.25 mfd, 200V ± 20%	187A624H02	R17	39K 1/2W ± 10%	187A641H65
C4	1.0 mfd, 200V ± 20%	187A624H04	R18	10K 1/2W ± 10%	187A641H51
C5	0.5 mfd, 200V ± 10%	187A624H11	R19	6.8K 1/2W ± 10%	187A641H47
CT	0.1 mfd, 400V.D.C.	1544920	R21	18K 1/2W ± 5%	184A763H57
D1-D7	IN459A Diode	184A855H08	R22	15K 1/2W ± 10%	187A641H55
D8-D9 D10-D12	IN457A Diode	184A855H07	R23	Type 1DO51 Thermistor, 20K at 25°C.	185A211H05
Q1	2N652A	184A638H16			
Q2-Q3	2N697	184A638H18			
Q4	2N697	184A638H18	R25	10K 1W ± 5%	187A643H51
Q5	2N699	184A638H19	R26	1K 1/2W ± 5%	629A530H32
Q6	2N4356	849A441H02	R27,R29	10K 1/2W ± 5%	629A530H56
Q7	2N697	184A638H18			
			RA	30K pot.	185A067H15
R1	2.7K 1/2W ± 5%	629A530H42	RB	200K pot.	185A067H14
R2	2.5K ± 20% 1/4W Pot	629A430H03	RC	40K pot.	185A067H16
R3,R28	20K 1/2W ± 5%	629A530H63	RD	200K pot.	185A067H14
R4	3.9K 1W ± 5%	187A643H41	RT	50 ohms, 2" tube	1340388
			RL	9.1K, ½ watt, ±5%-SKB-1 only	
R6	33K 1/2W ± 10%	187A641H63	Z1	IN957B (6.8v, 0.4w) Zener Diode	186A797H06
R7	10K 1/2W ± 5%	629A530H56			
R8	10K 1/2W ± 10%	187A641H51	Z2	IN957B (6.8v, 0.4w) Zener Diode	186A797H06
R9	10K 1/2W ± 5%	629A530H56			
R10	0.22 MEG, 1/2W ± 5%	184A763H83	Z3	IN1789 (56v, 1.0w) Zener Diode	584C434H08
R11	10K 1/2W ± 10%	187A641H51			
R12	15K 1/2W ± 10%	187A641H55	Z4	IN3686B (20v, 0.75w) Zener Diode	185A212H06
R13	33K 1/2W ± 10%	187A641H71			
R14	0.1 MEG, 1/2W ± 10%	187A641H75	ZT	IN1832C (62v, 10w) Zener Clipper	184A617H06
R15	10K 1/2W ± 10%	187A641H51			

Test Equipment

1. A-C ammeter and load box (for fault-detector calibration).
2. Vacuum-tube voltmeter for a-c and d-c measurements.
3. Cathode-ray oscilloscope (to check carrier keying and 60-cycle square-wave voltages in TCU Control Unit).
4. Test Cable

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. For components mounted on the printed circuit board, give the circuit symbol, electrical value, and style number.

ENERGY REQUIREMENTS SKB OR SKB-1 RELAY

Burdens measured at a balanced three-phase current of five amperes:

Relay Taps	Phase A		Phase B		Phase C	
	VA	Angle	VA	Angle	VA	Angle
A-F- 3	2.47	5°	0.6	0°	2.5	20°
A-H-10	3.25	0°	0.8	100°	1.28	55°
B-F-33	2.3	0°	0.63	0°	2.45	55°
B-H-10	4.95	0°	2.35	90°	0.3	60°
C-F- 3	2.32	0°	0.78	0°	2.36	50°
C-H-10	6.35	342°	3.83	80°	1.98	185°

Burdens measured at a single-phase-to-neutral current of five amperes:

Relay Taps	Phase A		Phase B		Phase C	
	VA	Angle	VA	Angle	VA	Angle
A-F- 3	2.47	0°	2.1	10°	1.97	20°
A-H-10	7.3	60°	12.5	53°	6.7	26°
B-F- 3	2.45	0°	2.09	15°	2.07	10°
B-H-10	16.8	55°	22.0	50°	12.3	38°
C-F- 3	2.49	0°	1.99	15°	2.11	15°
C-H-10	31.2	41°	36.0	38°	23.6	35°

The angles above are the degrees by which the current lags its respective voltage.

PART II – TYPE TCU CONTROL UNIT

The construction, operation, and adjustment of the type TCU Control Unit used with the SKB or SKB-1 relays are covered in separate instructions identified as I.L. 41-944.5 plus supplements, when required. The Control Unit is a part of the Type TC carrier assembly.

OVERALL TEST OF COMPLETE INSTALLATION

After the complete equipment has been installed and adjusted, the following tests can be made which will provide an overall check on the relay and carrier equipment. The phase rotation of the three-phase currents can be checked by measuring the a-c voltage across relay terminals 2 and 3 with a high resistance a-c voltmeter of at least 1000 ohms per volt. The reading obtained should be approximately 0.9 volts per ampere of balanced three-phase load current (secondary value) with relay taps 4, C and H, or taps 8-C-H for the SKB-1 relay.

The following test requires that a balanced three-phase load current of at least 1.0 ampere (secondary) be flowing through the line-section protected by the SKB relays. At both terminals of the protected line section, remove the SKB or SKB-1 relay cover and open the trip circuit by pulling the test switch blade with the red handle. Put the tap screw on the upper tap plate in the 4 tap, and on the lower ones in the C and H taps. Be sure to insert the spare tap screw before removing the connected one. Now open test switches 4 and 5 on the relay at one end of the line section (station A) and insert a current test plug or strip of insulating material into the test jack on switch 5 to open the circuit through that switch. The above operation shorts the phase A to neutral circuit ahead of the sequence filter and disconnects the phase A lead from the filter. This causes the phase B and C currents to return to the current tramsformers through the zero-sequence resistor in the filter, thus simulating a reversed phase A-to-ground fault fed from one end of the line only, As a result, both the fault detectors and tripping relay at Station A should operate. Completion of the trip circuit can be checked by connecting a small lamp (not over 10 watts) across the terminals of test switch 10. (SKB only.)

Now perform the above operations at the opposite end of the line section (station B) and momentarily open and reclose test switch 11 or momentarily depress the Test Reset push-button, if more convenient. This simulates a phase-to-ground fault external to the protected line section. The fault detectors, but not the operating unit should operate. Test switch 11 operation is required to make sure that "flip-flop" stage in the control unit is in reset position. Now open and reclose switch 11 at station A in order to reset "flip-flop" stage from previous "trip" condition. The operating unit at station A should stay open now. Restore test switches 4 and 5 at Station A to normal (closed). The line conditions now represent a phase-to-ground fault fed from Station B. only. The fault detectors at A should reset and the operating unit at B should pick up. Restore test switches 4 and 5 at Station B to normal, and all elements of the relay at Station B should reset.

The above tests have checked phase rotation, the polarity of the sequence filter output, the interconnections between the relay and the carrier set and the Phase A current connections to the relay at both stations. Phase B and C should be similarly checked by opening test switches 6 and 7 for phase B, and switches 8 and 9 for phase C. The same procedure described for Phase A is then followed.

If all the tests have been completed with satisfactory results, the test switches at both line terminals should be closed (close the trip-circuit test switch last) and the relay cover replaced. The equipment is now ready to protect the line-section to which it is connected.

PART III – TYPE SKB OR SKB-1 TEST FACILITIES APPLICATION

The test facilities provide a simple manually operated test procedure that will check the combined relay and carrier equipment. The test can be performed without the aid of instruments. The results give assurance that all equipment is in normal operating condition without resorting to more elaborate test procedures.

CONSTRUCTION

Test Switch

The type W-2 test switch is a four-position, multi-stage switch. The contact arrangement is shown in Fig. 10, and the outline and drilling plan in Fig. 11. The "on" contacts are used to complete the SKB trip circuit and the alarm circuit. These contacts are indicated in Fig. 10 by contacts C5-D5 and A1-B1. In the "Off" position, the SKB trip circuit is opened through contact C5-D5, but the alarm circuit remains closed through contact A1Z-B1Z. Two test positions to the left of the "Off" position are provided. When the switch is moved to either of these positions, the relay trip and alarm circuits are interrupted and a red alarm light is turned on by switch contacts A6-B6 and A7-B7. Moving the switch to the "Test 1" position will connect the output of the auxiliary test transformer directly to the SKB terminals number 8 and 9. Moving the switch to the "Test 2" position will connect the test transformer with a reversed polarity to the SKB relay.

For the SKB-1 relay, refer to the overall diagram which applies to the particular order for actual connections.

Auxiliary Test Transformer

The auxiliary test transformer is designed to operate from a 120-volt, 60-cycle power source. Four secondary taps numbered 1, 2, 3, and 4 are provided to vary the magnitude of the phase-C-to-ground test current approximately as follows:

TRANS TAP	RELAY TAP	
	G	H
1	3 amp.	2 amp.
2	5 amp.	4 amp.
3	7.5 amp.	5.5 amp.
4	9.5 amp.	7 amp.

The outline and drilling plan of the transformer is shown in Fig. 12.

Indicating Lamps

The red and blue indicating lamps are standard rectangular Minalites. Outline and drilling dimensions are given in Fig. 11.

ADJUSTMENT

Choose a transformer tap that will provide approximately two times the phase-to-ground current setting of the FD-2 fault detector as previously determined.

OPERATION

A multi-contact switch is provided at each line terminal which serves the dual functions of a carrier on-off switch and a test switch. This switch is arranged to apply a single-phase current to the SKB or SKB-1 relay to simulate internal and through fault conditions. Relay operation is noted by observing a blue indicating lamp connected in the SKB relay trip circuit. During the test the SKB trip circuit to the line breaker is opened and a red warning light is energized through auxiliary contacts on the test switch.

Use of the auxiliary test equipment is to be limited to provide a simplified test after the initial installation tests have been performed as described in Part II of this instruction leaflet.

The test apparatus is to be connected as shown in Fig. 10 with the auxiliary test transformers energized from 120-volt, 60-cycle power sources, at each line terminal, that are in phase with each other. The following operation procedure assumes that the same polarity is used in connecting the test transformer at each line terminal.

1. Turn the carrier test switch at both line terminals to OFF.
2. Turn the carrier test switch to TEST 1 at station A. The "A" relay should operate to transmit half cycle impulses of carrier, and trip. Tripping will be indicated by the blue light.
3. Turn the SKB test switch at Station B to TEST 1. This will simulate an internal fault fed from both line terminals. The relay at Station B will trip, and the relay at Station A will remain tripped. Tripping will be indicated by the blue lights at each line terminal Carrier will be transmitted in half cycle impulses simultaneously from each end of the line.
4. Reset the SKB test switch at Station A. The relay at Station A will reset and turn off the blue light. The relay at Station B will hold its trip contact closed, lighting the blue light.
5. Turn the SKB test switch at Station A to TEST 2. Depress Test Reset pushbutton momentarily to reset Flip-Flop stage that may have operated during switching the test switch to position 2. Operate Test Reset pushbutton at Station B to reset Flip-Flop stage from previous tripped position. Both blue lights should be off at this point, which represents an external fault.
6. Reset the test switches at both line terminals to OFF before returning to ON for normal service. Push in handle to turn in ON position.

This completes the test procedure.

Component Style Numbers

Test Transformer	S# 1338284
Type W-2 Test Switch	S# 505A742G01 for 1/8" panel mounting.
Type W-2 Test Switch	S# 505A742G02 for 1-½" panel mounting.

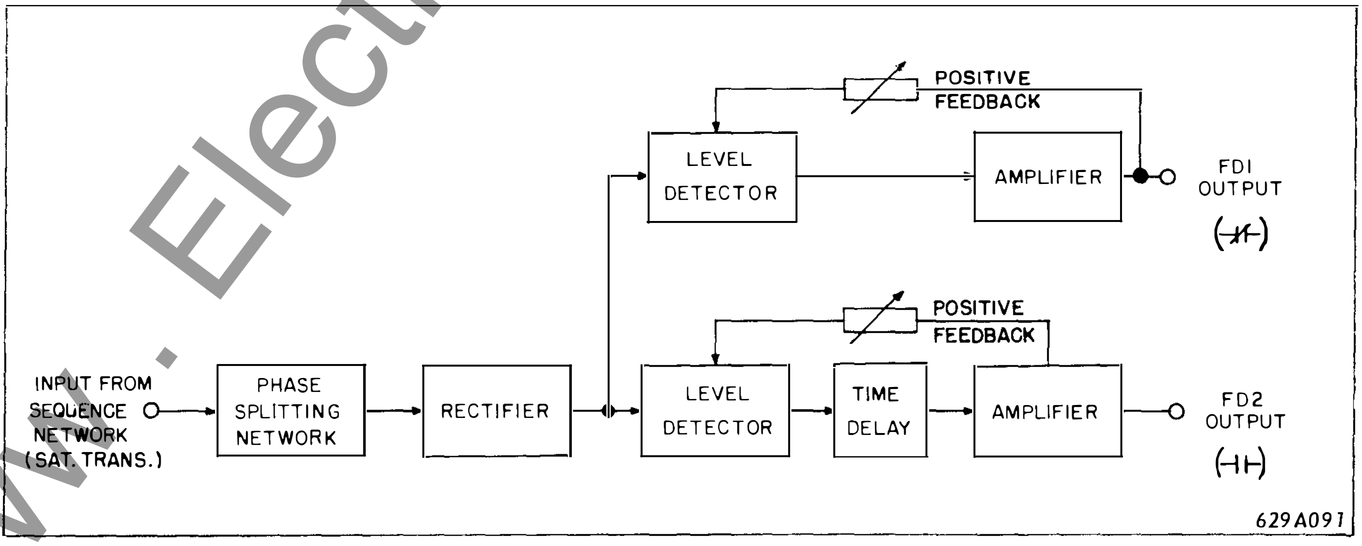
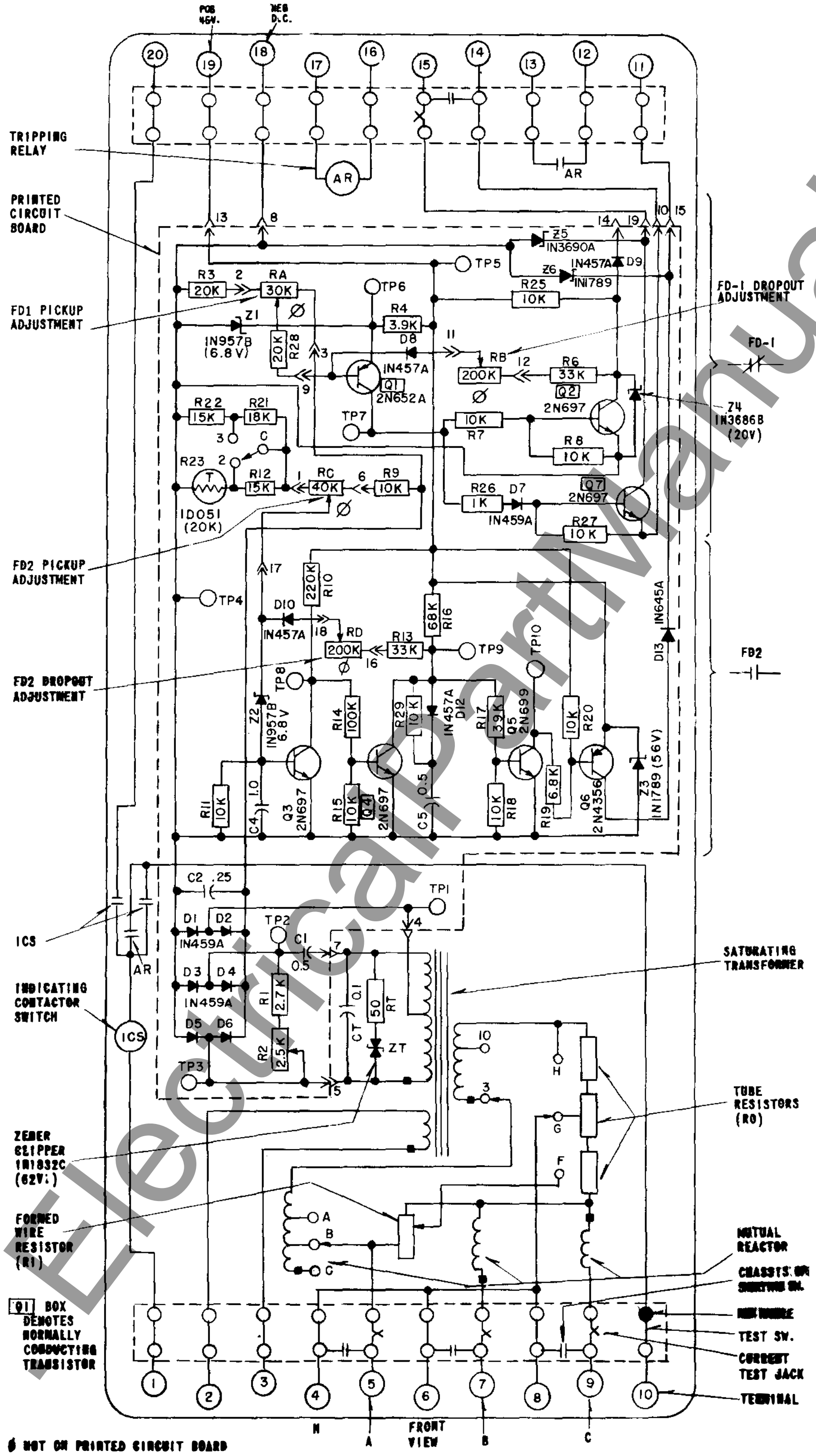


Fig. 3 Static Fault Detector Block Diagram



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* *Fig. 4 Complete Internal Schematic of SKB Relay*

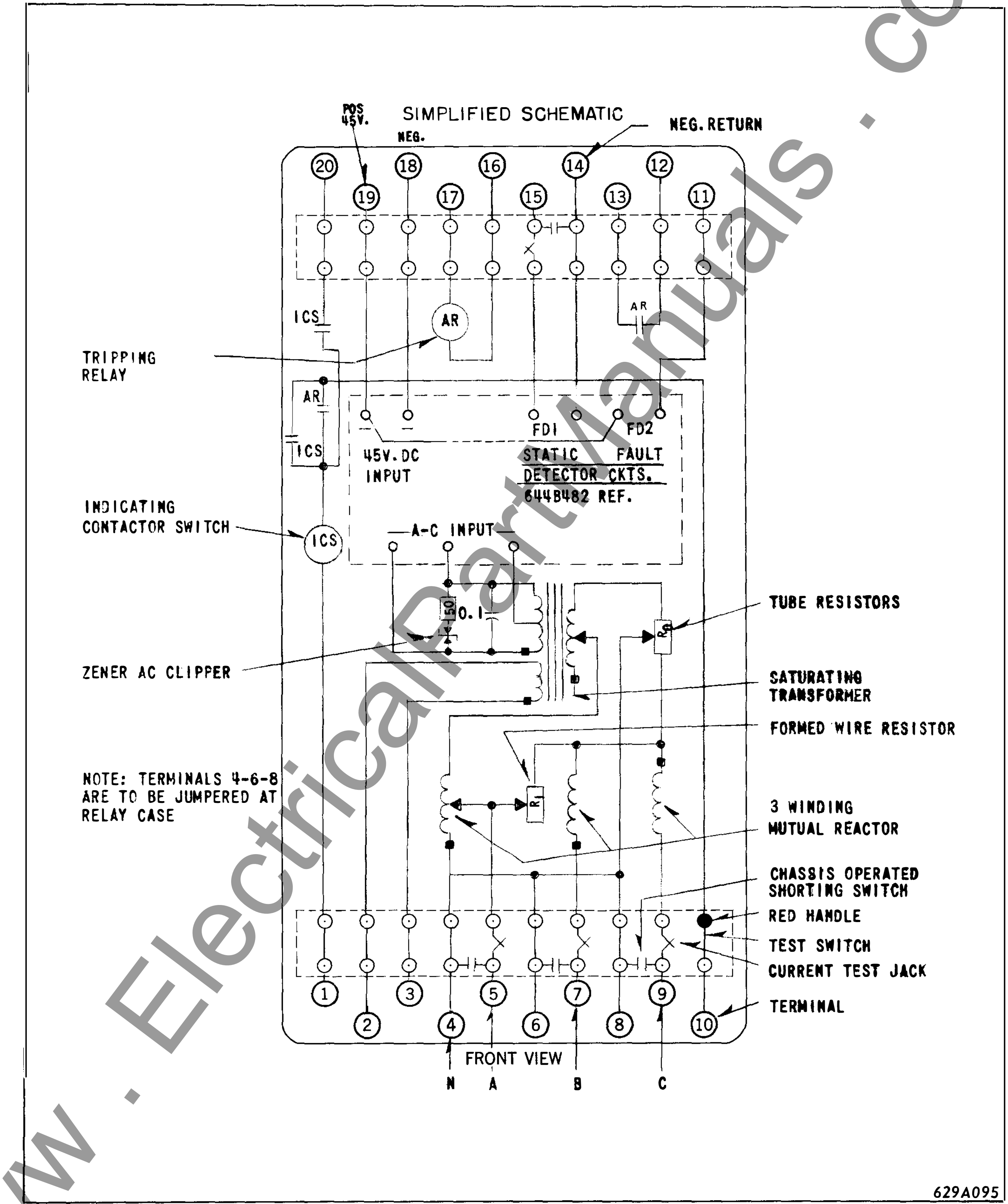
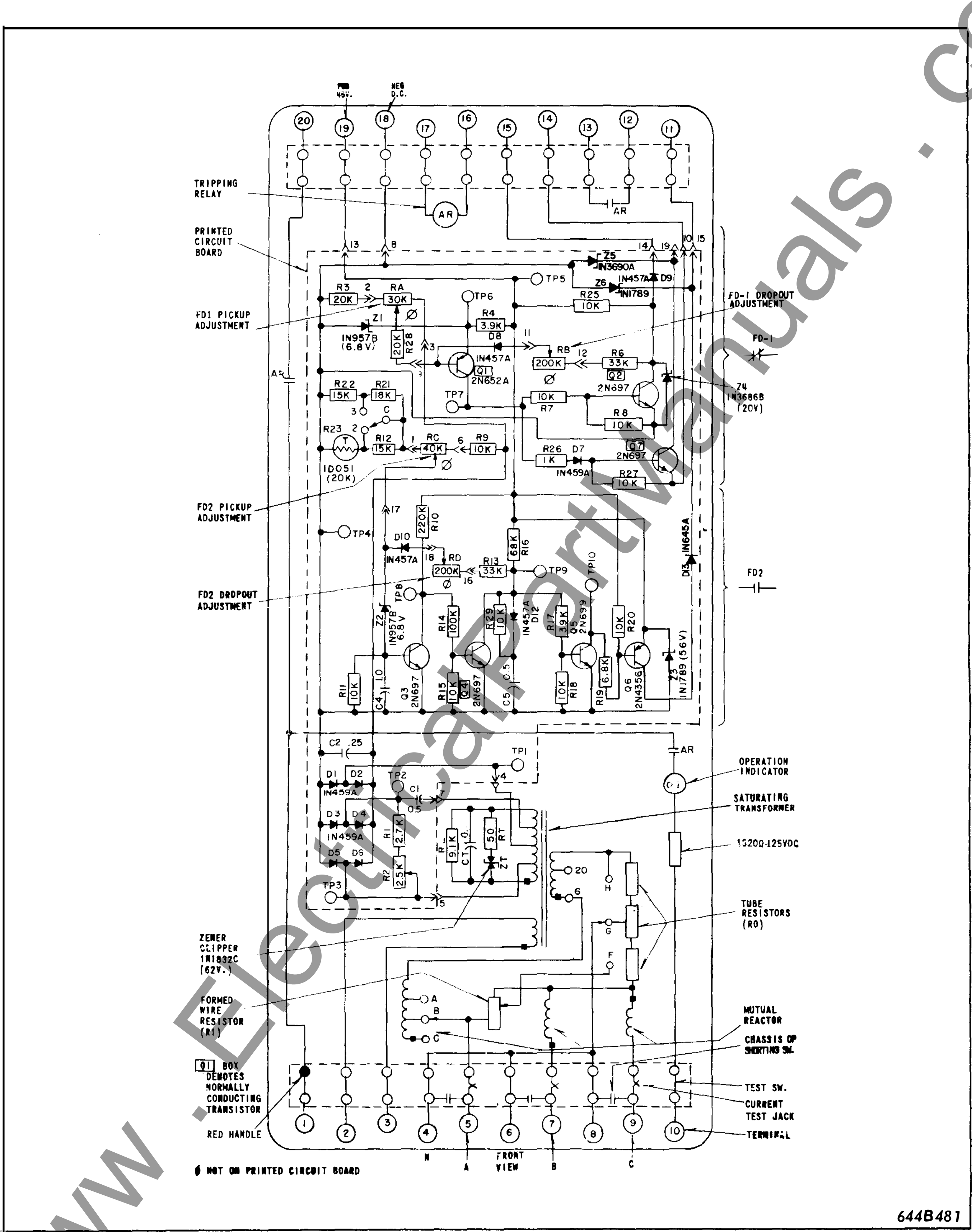


Fig. 5 Simplified Schematic — Type SKB Relay



* *Fig. 6 Complete Internal Schematic of SKB-1 Relay*

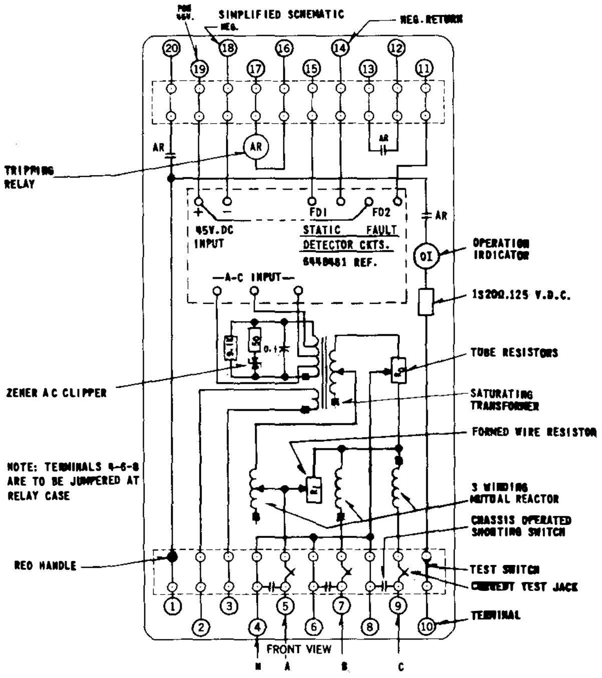
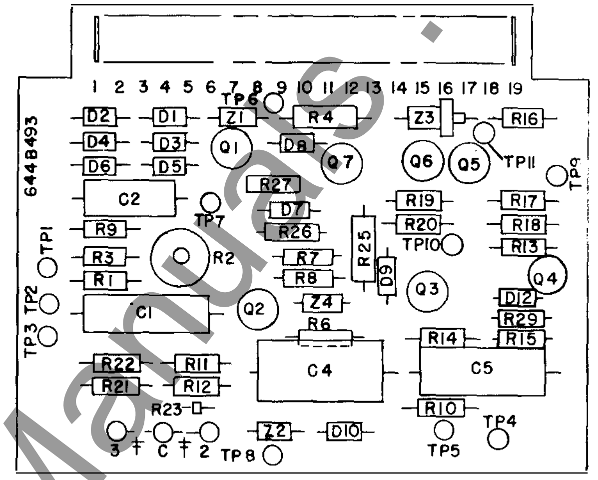
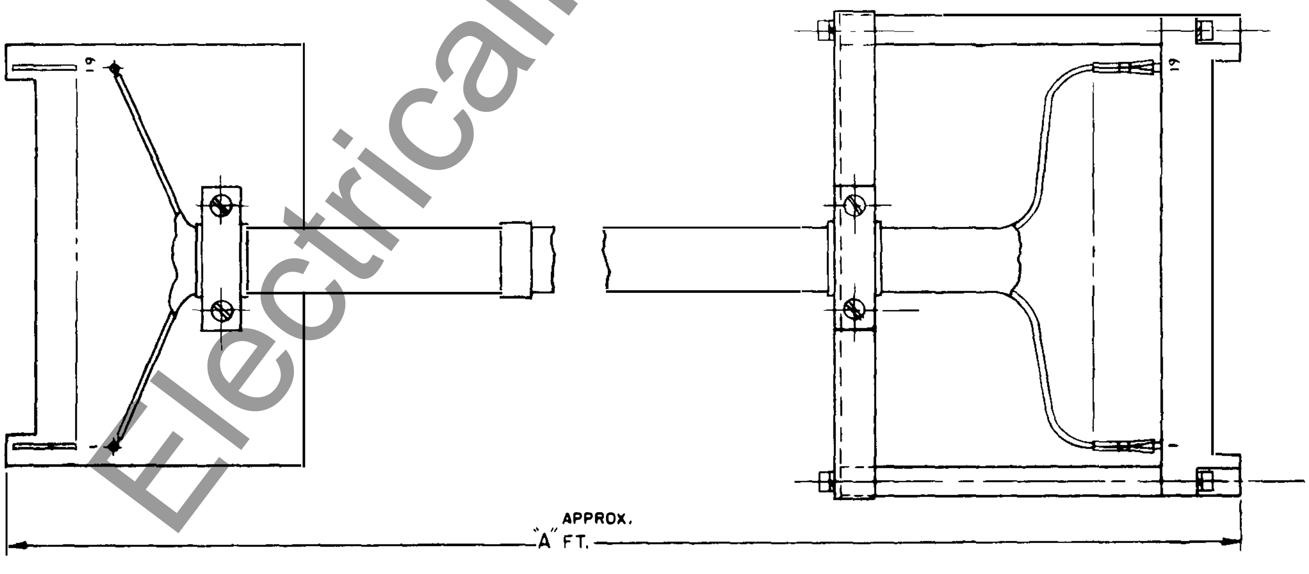


Fig. 7 Simplified Schematic — Type SKB-1 Relay

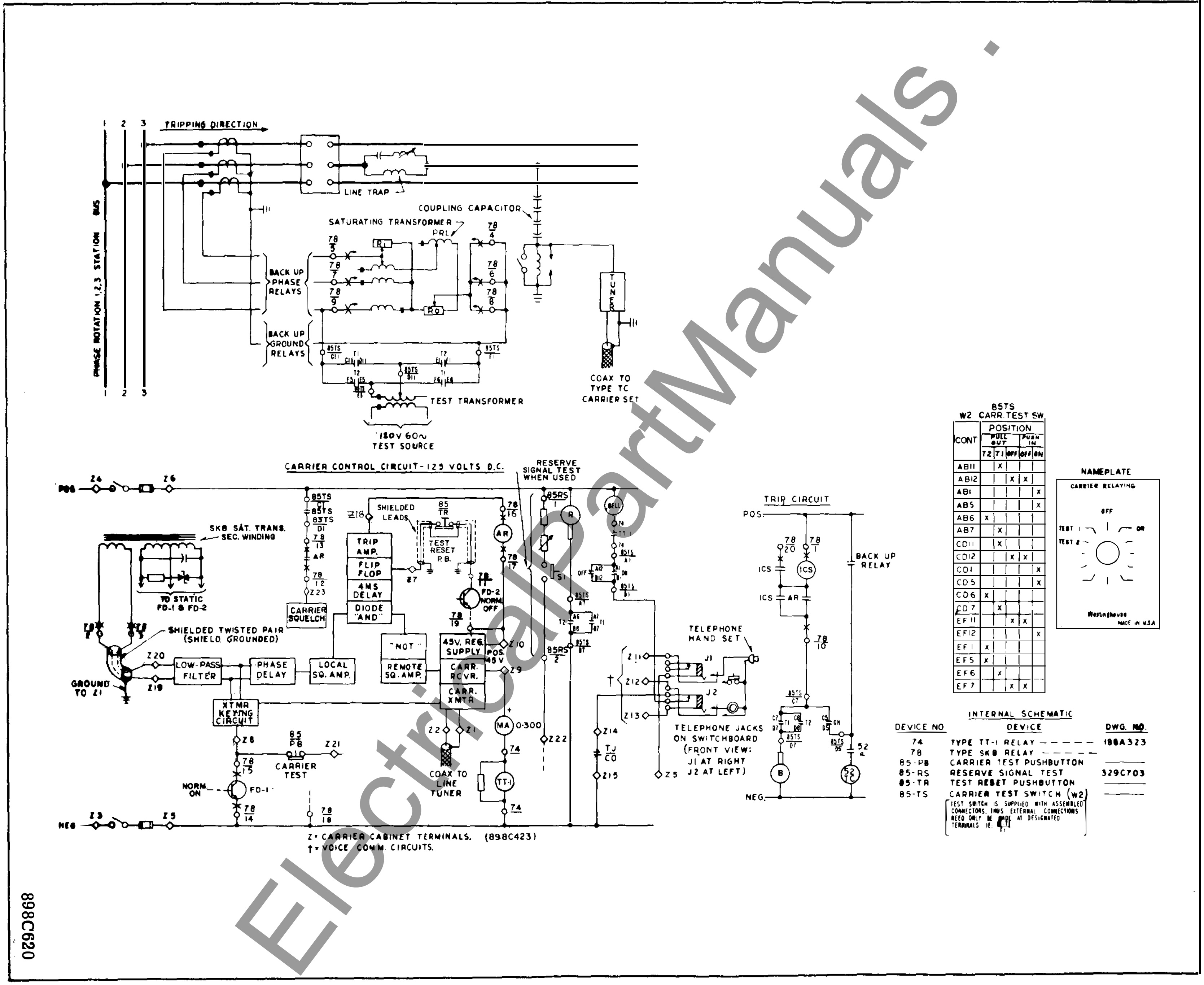


** Fig. 8 Printed Circuit Board Component Location, SKB or SKB-1 Relay*



STYLE	DIM: A
410C303G01	6 FT.
410C303G02	3 FT.

Fig. 9 Test Cable Assembly



85TS
W2 CARR. TEST SW

CONT	POSITION				
	PULL OUT			PUSH IN	
	T2	T1	OFF	OFF	ON
AB11		X			
AB12			X	X	
AB1					X
AB5					X
AB6	X				
AB7		X			
CD11		X			
CD12			X	X	
CD1					X
CD5					X
CD6	X				
CD7		X			
EF11			X	X	
EF12					X
EF1	X				
EF5	X				
EF6		X			
EF7			X	X	

INTERNAL SCHEMATIC

DEVICE NO	DEVICE	DWG. NO.
74	TYPE TT-1 RELAY	188A323
78	TYPE SKB RELAY	
85-PB	CARRIER TEST PUSHBUTTON	
85-RS	RESERVE SIGNAL TEST	329C703
85-TR	TEST RESET PUSHBUTTON	
85-TS	CARRIER TEST SWITCH (W2)	

TEST SWITCH IS SUPPLIED WITH ASSEMBLED CONNECTORS. THUS EXTERNAL CONNECTIONS NEED ONLY BE MADE AT DESIGNATED TERMINALS IE: T1

* Fig. 10 External Schematic of the SKB Relay and Test Facilities, with TT-1 Alarm Relay

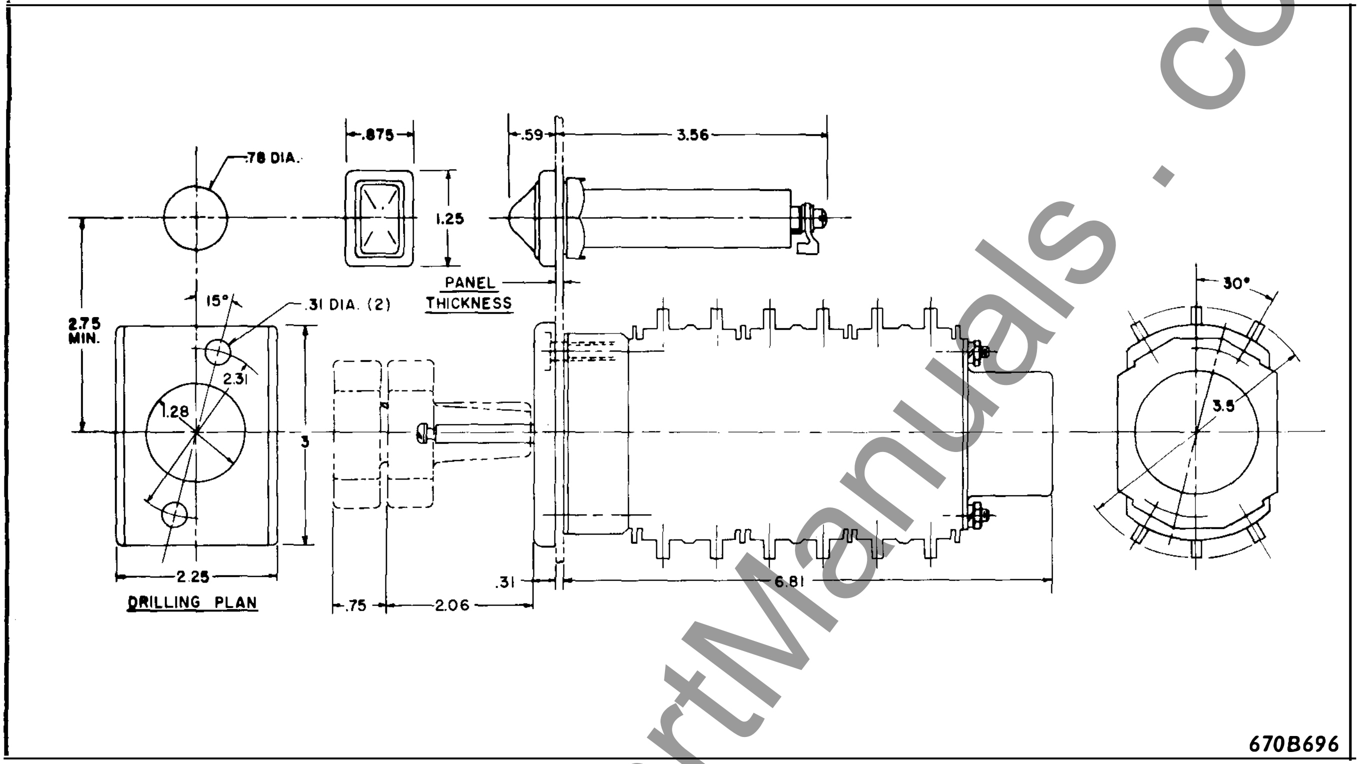


Fig. 11 Outline and Drilling Plan of the Type W-2 Test Switch and Indicating Lamps Used for SKB or SKB-1 Testing

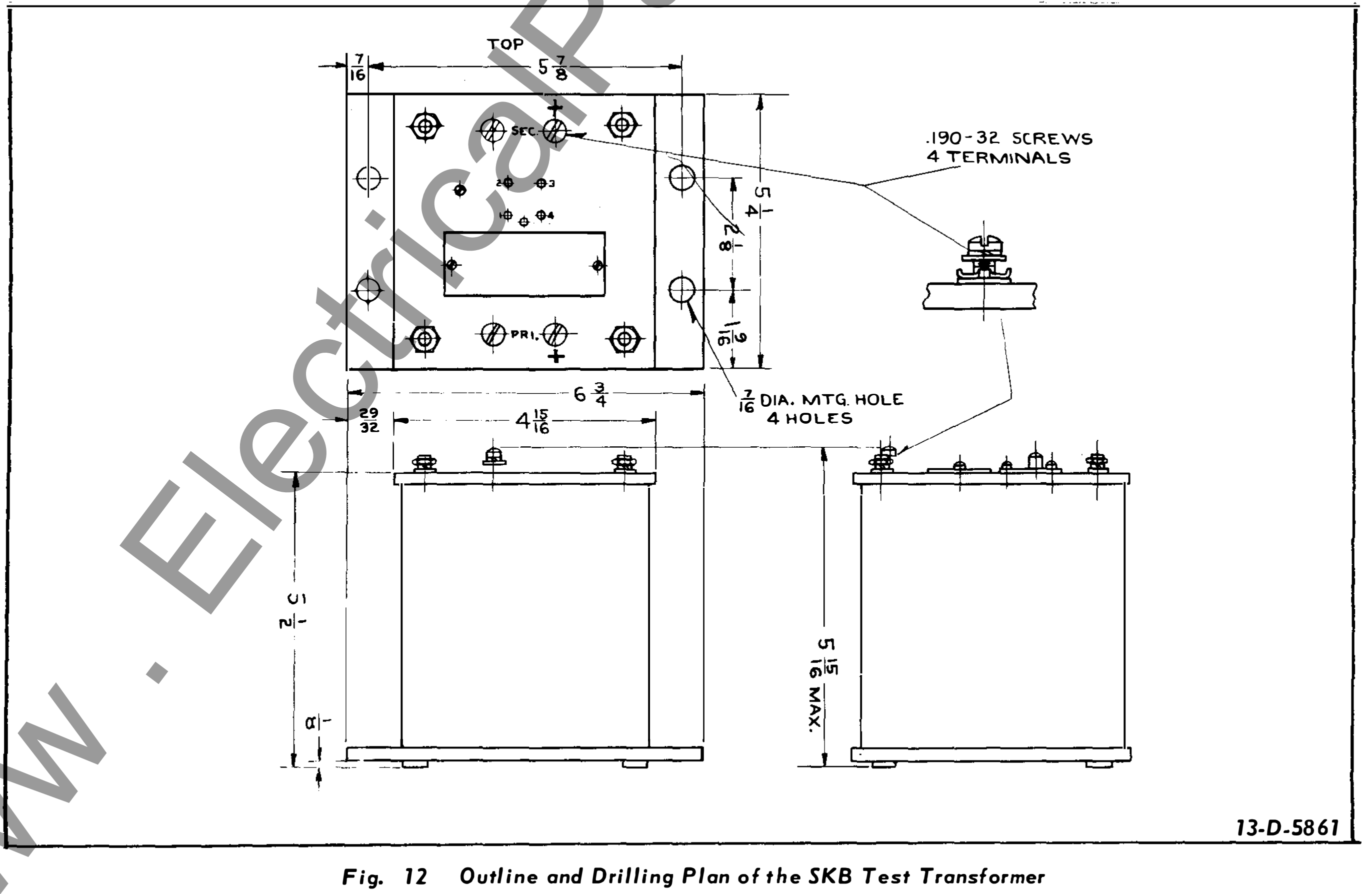


Fig. 12 Outline and Drilling Plan of the SKB Test Transformer

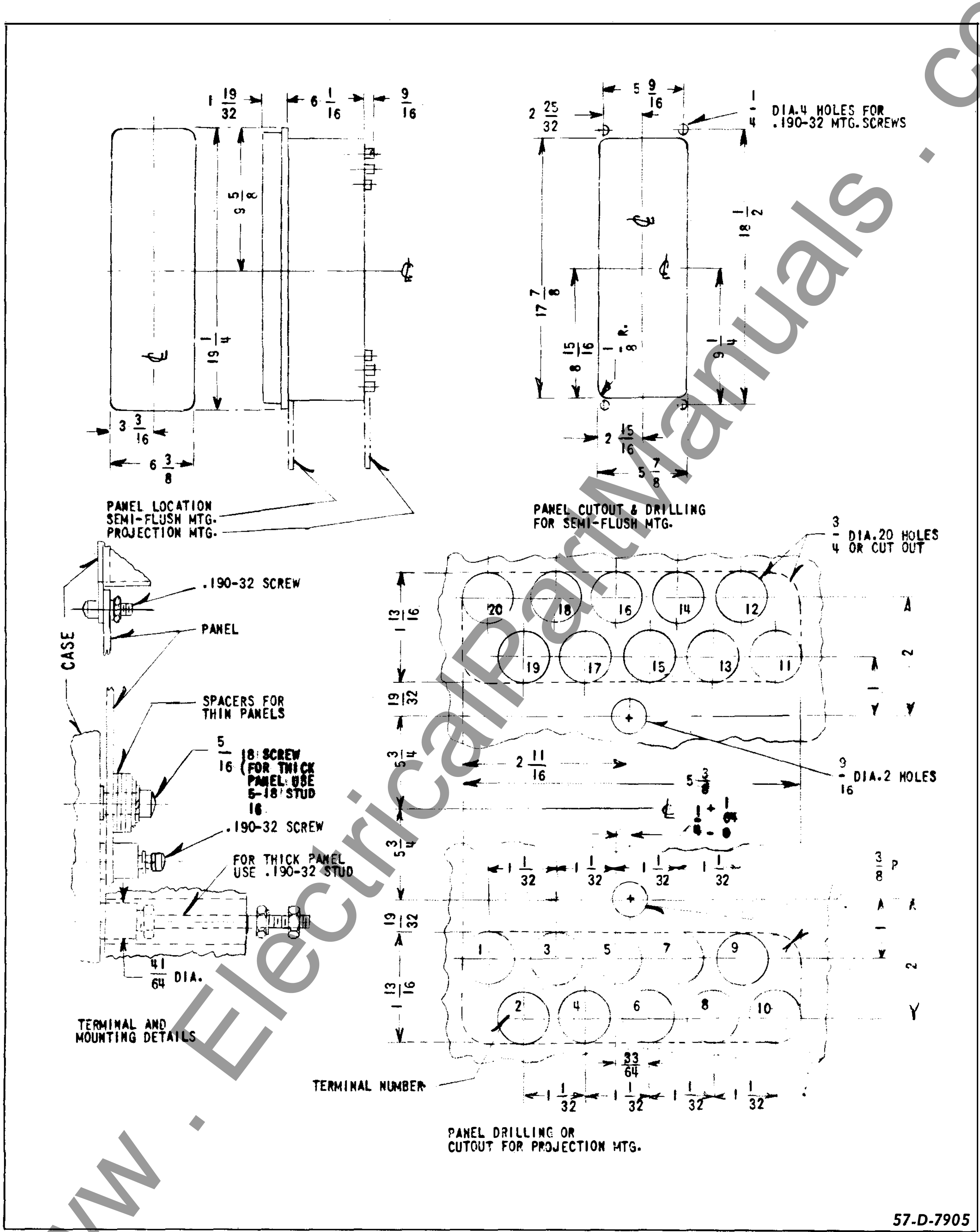


Fig. 13 Outline and Drilling Plan of the SKB or SKB-1 Relay in the FT-42 Case

WESTINGHOUSE ELECTRIC CORPORATION

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

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INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU-2 AND TYPE SKBU-21 DUAL PHASE COMPARISON RELAYS

CAUTION: It is recommended that the user of this equipment become acquainted with the information in this instruction leaflet on the system instruction leaflet before energizing the system.

For three terminal lines applications, links 1 and link 2 on amplifier and keying board must be connected C to 3. For all distance supervision relaying system, link on arming board must be open.

APPLICATION

The type SKBU-21 is a high-speed relay used in conjunction with frequency shift type channels. Simultaneous tripping of the relays at each line terminal is obtained in less than 32 milliseconds for all internal faults within the limits of the relay settings.

The system is applicable to a voice-grade pilot-wire, microwave, or carrier channel.

In contrast to the carrier blocking scheme, this is a transfer trip system; accordingly, the blocking-start function is not required.

TABLE OF CONTENTS

These instructions apply to SKBU-21 and SKBU-2 phase comparison relays for application to the following types of pilot channels.

1. TA-2 Tone Channel
2. TCF Carrier Channel

CONSTRUCTION

The phase comparison relays consist of a composite positive and negative sequence current network, a saturating transformer, three isolating transformers, a 20-volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel,

NEW INFORMATION

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8-3/4 inches high (5 rack units). The SKBU-21 relay has a second saturating transformer in addition to these components. Edge slots are provided for mounting the rack on a standard relay rack.

Sequence Network

a. SKBU-21

The sequence filter consists of a three-legged iron core reactor and a resistor. The reactor is a four-winding reactor with two primary windings and two secondary windings. The secondary windings are connected to the resistor which consists of three tube resistors and a small formed resistor. One secondary winding and the resistor is a negative sequence current filter while the other secondary winding and the resistor is a positive sequence filter.

b. SKBU-2 Relay

The sequence filter consists of a three-legged iron core reactor and a set of resistors, R_1 and R_0. The reactor has three windings: two primary and a tapped secondary winding, would on the center leg of a "F" type of lamination. The secondary taps are wired to the A, B, and C tap connections in the front of the relay (R_1 taps). Ro consists of a three tube resistors with taps wired to F, G, and H tap connections in the front of the relay. The R_0 resistor is a formed resistor associated with the tapped secondary of the reactor.

Saturating Transformer

a. SKBU-21 Relay

The voltage from the sequence network is fed into two saturating or mixing transformers. One transformer supplies a fault detector circuit and the other transformer supplies a keying circuit. Zero sequence current windings are included on the transformer.

b. SKBU-2 Relay

The voltage from the sequence network is fed into the tapped primary of a small saturating transformer. This transformer has two secondary windings. One winding supplies the fault detector circuit and the other winding supplies a keying circuit.

Isolating Transformer

Three isolating transformers are provided in the relay to isolate the dc voltages from the ac voltages. Two of the transformers are also used to energize solid-state circuit on alternate half-cycle of the power system frequency.

Power Supply

The solid-state circuits of the relays are regulated from a 20-volt supply on the relay panel. This voltage is taken from a Zener diode mounted on a heat sink. A voltage dropping resistor is provided between the source dc supply and the 20 volt regulated supply.

Printed Circuit Boards

Seven printed circuit boards are used in these relays; A fault detector board, protective relay interface board, supervision board, amplifier and keying board, arming board, output board and a relay board. The circuits of the supervision board, and the amplifier and keying boards vary with the frequency shift equipment used as a pilot channel.

All of the circuitry that is suitable for mounting on printed boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide in position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment, it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

1. FD Board (Fault Detector Board)

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, a solid-state fault detector, and a frequency verifier circuit. The controls for setting pickup (S_1) and dropout (S_2) of the fault detector are mounted on a plate in the front of the relay. This unit operates when the fault current exceeds a definite value.

The location of components on the board is shown in Fig. 3 and the schematic of the board is shown in Fig. 4.

2. Arming Board

The arming board contains AND circuits that compares pulses produced by the circuits of the amplifier and keying board. An output is obtained that is proportional to the time difference in the pulses. This board contains other logic circuits that will arm the trip output, set up the time delay of the trip output, and start transient blocking on external faults. A link is provided on this board such that the relay is armed by either solid state distance fault detectors or the SKBU fault detector. The link must be open for arming by the solid state distance fault detector only.

The location of components on the board is shown in Fig. 5 and the schematic of the board is shown in Fig. 6.

3. Ampl. and Key Board (Amplifier and Keying Board)

The amplifier and keying board contains two local squaring amplifiers, a transmitter keying circuit, and four remote squaring amplifiers. These circuits produce the pulses that are compared by the AND circuits of the arming board to determine if the fault is external or internal. Links are provided on this board to connect the relay for two or three terminal operation.

Because of the different keying requirements of the various pilot channels, this board varies with the different types of channels to which it is connected. The following table is with reference to the different figures that apply for the amplifier and keying board for the various type channels.

TYPE CHANNEL	LOCATION OF COMPONENTS	SCHEMATIC OF BOARD
TA-2	Fig. 7	Fig. 8
TCF	Fig. 9	Fig. 10

4. Output Board

The output board contains a 4-millisecond pickup and instantaneous dropout timer circuit, trip AND circuit, trip amplifier, transient blocking and unblocking circuits and two timer circuits. The trip AND operates when all the inputs to the AND circuits of the arming board are of the correct polarity and the fault detector has operated. The transient blocking circuit operates after a time delay on external faults, and the transient unblock circuit operates after a time delay on a sequential fault (external fault followed by an internal fault).

The following figures apply to this board: Fig. 11 Component Location; Fig. 12 Schematic of the Board.

5. Relay Board

The relay board contains the phase delay circuit for shifting the local signals with reference to the remote signals. It also contains a low-pass filter for the SKBU-21 relay. A Zener clipper-resistor combination is provided for protection of the solid-state circuits.

The following figures apply to this board: Fig. 13 Component Location, and Fig. 14 for the Schematic of the Board.

6. Supervis. Board (Supervision Board)

The number of circuits on this board varies with the application. However, for all applications interface circuits to the channel receivers and a 150 millisecond pickup and 0 millisecond dropout alarm timer circuit is provided on this board. The interface circuits connects the SKBU relay to the channel receiver, and the time circuit locks out to the relay for failure of the channel equipment. For tone channels a noise circuit is also provided to lockout the relay.

Because the board varies with the channel equipment, the following figures apply to the board.

TYPE CHANNEL	LOCATION OF COMPONENTS	SCHEMATIC OF BOARD
TA-2	Fig.15	Fig. 16
TCF	Fig. 17	Fig. 18

7. Pr. Inter. Board (Protective Relay Interface Board)

The protective relay board contains logic circuits to connect the distance fault detectors, and squelch relays into the phase comparison relaying system. This board contains buffer circuits, OR circuits to connect the relays into the system. A 6/0 timer circuit and a signal squelch circuit, 2.5 second alarm circuit for sustained fault detector operation are also provided on this board.

Fig. 19 shows the component location for the board and Fig. 20 shows the schematic of the board.

Card Extender

A card extender (style no. 644B315G02) is available for facilitating circuit voltage measurements or major adjustments. After withdrawing anyone of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all components and test points on the boards are readily accessible.

Test Points

Test points are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front panel of the relay for convenience in adjusting and testing the relay.

OPERATION

A. System

In phase comparison relaying, the phase positions of fault currents at the ends of a transmission line are compared over a pilot channel to determine if the fault is internal or external to the line section. When a frequency shift channel is used as the pilot channel, a dual comparison transfer trip system can be utilized. This means that the system can trip on either half-cycle of power system frequency as contrasted to a blocking scheme where tripping occurs on alternate half-cycles during the absence of a carrier signal.

a. SKBU-21 Relay

The three-phase line currents energize a sequence network in the SKBU-21 relay which produces two single-phase output voltages that are proportional to either the positive sequence current or the negative sequence current. The single-phase voltages are applied to two saturating or mixing transformers one which energizes the fault detector circuit and the other energizes the keying circuit of the SKBU-21 relay through a low-pass filter. The keying circuit shifts the frequency of the transmitter from a space frequency to a mark frequency. These frequencies are transmitted over the pilot channel to the receiver which converts the mark and space frequencies to two dc output voltages, a space output that corresponds to the space frequency and a mark output that corresponds to the mark frequency. Thus, on each half-cycle of power system frequency either a space or mark output is obtained from the receiver and applied as pulses to the remote squaring amplifiers of the SKBU-21 relay. Each of these half-cycle pulses are compared with the phase positions of each half-cycle of the voltage from the sequence network of the SKBU-21 relay at the receiver terminal. The space pulse is compared to one half-cycle of the voltage and the mark pulse to the other half-cycle. If the local and remote half-cycle pulses are of the correct phase positions for an internal fault, after a fault detector operation, 4 millisecond tripping will be initiated through operation of the trip AND and trip amplifier circuits on the output board of the relay.

b. SKBU-2 Relay

The three-phase line currents energize a sequence network in the SKBU-2 relay which produce a single-phase output voltage proportional to a combination of sequence components of the line current. This single-phase voltage energizes the primary of a saturating transformer with two secondary winding. One secondary winding energizes the fault detector circuit and the second secondary winding energizes the keying circuit of the relay through the low pass filter. The keying circuit shifts the frequency of the transmitter from a space frequency to a mark frequency. These frequencies are transmitted over the pilot channel to the tone receiver which converts the mark and space frequencies to two dc output voltage, a space output that corresponds to the space frequency and a mark output that corresponds to the mark frequency. Thus, on each half cycle of power system frequency either a space or mark output is obtained from the tone receiver and applied as pulses to the remote squaring amplifiers to the SKBU-2 relay. Each of these half cycle pulses are compared with the phase positions of each half-cycle of the voltage from the sequence network of the SKBU-2 relay at the tone receiver terminal. The space pulse is compared to one half cycle of the voltage and the mark pulse to the other half-cycle. If the local and remote half-cycle pulses are of the correct phase positions for an internal fault, after a 4 millisecond delay tripping will be initiated through operation of the trip AND and trip amplifier circuits on the output board. Current transformer connections to the sequence networks at the two line terminals are such that the space and mark pulses are in phase with their respective local pulses during an internal fault to allow tripping. However, if the fault is external to the protected line secrion, the space and mark pulses are out-of-phase with their respective local pulses and tripping does not occur.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals and relay coordination.

B. Relay

With reference to the logic diagram that applies to the particular relay, the three-phase line currents energizes a sequence filter that varies with the type relay.

A. SKBU-21 Relay

In the SKBU-21 relay, the sequence filter produces two single phase voltages: One voltage proportional to the positive sequence current, and the other voltage proportional to the negative sequence current. These voltage are applied to primary windings of two saturating transformer where they are mixed to produce two separate secondary voltages proportional to a combination of sequence components. Zero sequence windings are included on the two transformers.

B. SKBU-2 Relay

In the SKBU-2 relay, the sequence filter produces one single phase voltage proportional to a combination of sequence components. This voltage is applied to the primary winding of a saturating transformer which produces two secondary voltages.

The secondary voltages are applied to two boards:

1. Fault Detector Board
2. Relay Board

1. Fault Detector Board

With reference to the schematic dwg. of Fig. 4, the ac voltage is applied to a phase-splitting network (C52, R52, R53) and a polyphase rectifier (diodes D51 to D56). The dc voltages so obtained are applied to the fault detector circuit which operates when the dc input "signal" exceeds a predetermined value.

Fault Detector (FD)

Under normal conditions, transistor Q51, has no base "signal" and is turned off. The collector of Q51 is at a high enough positive potential to provide base drive for transistor Q52, driving it to full conduction. With Q52 fully conducting there is no base drive to transistor Q53 and Q53 is turned off. With no Q53 collector current, the base of transistor Q54 is supplied from the 20 volt source. Thus the Q54 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q54 in a non-conducting state, equivalent to an open circuit.

When a fault causes the dc input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z52, a positive bias is applied to Q51 base causing it to conduct. In turn, Q52 stops conducting, and capacitor C54 charges, giving a few milliseconds time delay before Q53 and Q54 are switched to full conduction, thus "closing" the fault detector. When the fault detector operates, a positive output is applied to the arming board at terminal 12. Resistors R66 and S2 increase the voltage to Z52 to allow the fault detector to drop out at a high dropout ratio when the ac current is reduced.

Frequency Verifier (FV)

During certain switching conditions, such as energization of a transmission line, residual currents and voltages may exist of higher frequencies than 60 hertz. The frequency verifier prevents fault detector operation when frequencies 120 hertz or higher are encountered during the switching conditions. The frequency verifier circuit consists of two functional parts: zero-crossing and commutator circuits. With reference to Fig. 4, the zero-crossing circuit consists of Q55, Q56, Q57, and Q58. The commutator circuit consists of Q59, Q60, C9, C59 and Q61.

During the positive or negative half-cycles of the output voltage from the saturating transformer, Q55 or Q57 transistors are driven into saturation by the output of the FV transformer (T3). Transistors Q56 or Q58 conduct until capacitors C56 or C57 respectively are fully charged. While either capacitor charges a voltage output in the form of very narrow pulse is developed across R76 and R78 resistors during the start of each half-cycle. This pulse triggers Q59 control switch. When transistors Q55 or Q57 are not conducting, C56 and C57 capacitors discharge respectively through D66 or D62 and the parallel combination of R73 and R74 or R69 and R70.

While Q59 is "on" its anode is only about 0.7 volts above negative, thus turning off transistor Q62 to allow capacitor C60 to start charging. However, a shorter time delay (consisting of R84, the capacitor C59 and the reference Zener diode Z54) of 4.3 milliseconds is also started. After 4.3 milliseconds of delay, the control switch Q60 fires applying the voltage of capacitor C88 across Q59 turning it off. This raises the potential of the Q59 anode to turn on Q62 to discharge C60 before the charge reaches a value to break down Z55 to turn on Q63. After the next zero-crossing pulse Q59 switch is turned on again, and the Q60 switch is turned off by capacitor C58. Transistor Q61 when turned on by the same voltage that fires the gate of Q59, discharges timing capacitor C59, thus starting the timing cycle with close to zero charge on the capacitor. If the zero crossing period of the FV voltage is less than 4.3 milliseconds, the Q61 transistor discharges the timing capacitor thus preventing the turning off of Q60 switch. This keeps Q59 switch on to allow C60 to charge to a value to break over Zener diode Z55 to turn on Q63. Turning Q63 prevents Q53 of the fault detector from turning on thereby preventing Q54 from turning on to prevent an output from the fault detector.

2. Relay Board

With reference to Fig. 14, the ac voltage from either the second saturating transformer (SKBU-21) or the second winding of the single transformer

(SKBU-2) is applied to the phase delay circuit through a low pass filter of the relay board. The low pass filter (C201, L201, C202) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R202 and R203 of the phase delay circuit. By means of capacitor C203 and variable resistor S5, the voltage across terminal 4 and 2 can be made to lag the voltage across terminal 10 and 11 by a definite amount depending on the setting of S5. Each of these two voltages are applied to separate isolating transformers.

1. Undelayed voltages to a keying transformer (T1)
2. Delayed voltages to a local transformer (T2)

A. Keying Circuit

With no ac output (Ref. Fig. 8 or 10) voltage from the sequence network, transistor Q1 has no base current. The collection of Q1 is at positive potential which allows base current to flow from positive 20 volts dc through the base of Q2 through R6 to negative. This applies negative potential to the collector of Q3 to prevent base current from flowing to Q3. Since Q2 is conducting, transistor Q3 does not conduct and the collector of Q3 is held at positive potential.

When a sinusoidal voltage is applied to the keying transformer (T1), the transformer steps up the voltage applied to terminals 2 and 8 of the amplifier and keying board. On the positive half-cycle of voltage, terminal 8 is more negative than terminal 2 and transistor Q1 does not conduct. In turn Q2 remains conducting and Q3 does not turn on. On the negative half-cycle of sine wave voltage from the keying transformer (T1) terminal 2 is more positive than terminal 8 and base current flows in Q1. This turns Q1 on which applies negative potential to the collector of Q1. Base current to transistor Q2 is stopped and Q2 stops conducting, and its collector goes to positive potential. Positive potential is thus applied to the base of Q3 through R6 to turn on Q3. When Q3 conducts, its collector is connected to negative potential. Thus on alternate half-cycles of the 60-hertz voltage from the low pass filter, Q3 turns on. By connecting Q3 through the proper interface to the channel transmitter, turning on Q3 keys the transmitter to a mark condition.

Q3 can be prevented from turning on and off by a negative signal applied to terminal 3 of the board. This is the input terminal from the signal squelch circuit of the protective relay board. With a negative input into terminal 3, Q3 will not turn on even though Q1 and Q2 are being turned on and off from the ac voltage applied to terminals 2 and 8.

B. Local Squaring Amplifiers (1 and 2)

There are two identical local squaring amplifiers in the SKBU-21 and SKBU-2 relays. One is turned on and off by the positive half-cycle of voltage from the local transformer (T2) while the other one is turned on and off by the negative half-cycle of voltage from the transformer (T2). The square wave output voltages are, therefore, functions of the ac voltage input to the amplifiers. The polarity of the outputs of the two amplifiers are such that one amplifier has an output when the other one does not when ac voltage is applied to the local transformer. With no AC signal applied to the local transformer, both local amplifiers have a positive output. (This is a blocking signal to the AND circuits of the arming board).

With reference to amplifier number 1 of either Fig. 8 or 10, with no ac input voltage, Q5 is not conducting and the collector of Q5 is at positive potential. This applies base current to transistor Q6 through R15 such that Q6 is turned on. This applies negative potential to the collector of Q6 to allow base current to flow in Q7. Q7 turns on to apply positive potential across R19. (blocking condition).

With the application of a sine wave voltage to terminals 5 and 18 of the amplifier and keying board, on the positive half-cycle of the voltage, the base of transistor Q5 is more positive than the emitter and Q5 (amplifier 1) conducts, and Q12 (amplifier 2) is turned off. On the negative half-cycle of the ac voltage, Q5 is turned off and Q12 is turned on. Therefore, Q5 is conducting on the positive half-cycle of voltage and Q12 is conducting on the negative half-cycle of ac voltage. Turning Q5 on, puts negative potential on the collector of Q5 and turns off transistor Q6. Transistor Q6 stops conducting and its potential goes to a positive potential which turns off Q7 to place a negative potential across R19. Thus the output of the squaring amplifier is a square wave voltages ranging from 0 volts dc to 20 volts dc depending upon the polarity of the voltage from the phase delay circuit.

Amplifier 2 is the same as amplifier number 1 except that its base is supplied by the opposite polarity of sine wave voltage from the squaring transformer. The output voltage from this amplifier appears across R42. By applying the same analysis of amplifier 1 to amplifier 2, the output voltage across R42 is a square wave voltage of the reversed polarity than that across R19.

C. Remote Squaring Amplifiers

As shown in Fig. 7, there are four remote squaring amplifiers in both the SKBU-2 and SKBU-21 relays. Two amplifiers connect the space outputs of two receivers to the relay while the other two amplifiers connect the mark outputs of the two receivers to the relay. For a TA-2 tone channel, space squaring amplifier 3 consists of transistors Q8 and Q9. on the amplifier and keying board in conjunction with an interface circuit of Q13 and Q1 on the supervision board. Mark remote squaring amplifier 4 consists of Q15 and Q16 on the amplifier and keying board and interface transistor Q14 and Q2 on the supervision board. For a TCF carrier channel space squaring amplifier 3 consists of Q1 on the supervision board and Q8 and Q9 on the amplifier and keying board. Mark squaring amplifier 4 consists of Q2 on the supervision board and Q15 and Q16 on the amplifier and keying board.

The remote squaring amplifiers are in one of three states:

1. Loss-of-channel state
2. Receiving space frequency only
3. Receiving alternate half-cycles of space and mark frequency

a. Tone Channel

For a loss of a tone channel, the receiver clamps its output to a mark condition. The space output from the receiver is zero with respect to the positive source. This means that transistor Q13 and Q1 (on the supervision board) are not conducting. On the amplifier and keying board, base drive to transistor Q9 is provided from positive source through R27 to negative. Q8 is turned on to provide a positive 20 volts across R123. When the channel is in service and the receiver is in a space condition, transistors Q13 and Q1 (on the supervision board) are turned on. This applies negative potential to R27. On the amplifier and keying board Q9 does not conduct and the potential of the base of transistor Q8 is raised higher than its emitter; hence, transistor Q8 stops conducting and the voltage across R23 is -20 volts. For the condition where the receiver is receiving pulses, transistors Q13 and Q1 (on supervision board) turns on and off for alternate half-cycle and the voltage across R23 is a square wave voltage varying from zero volts to a -20 volts dc. The output of the mark remote squaring amplifier is the same as the space remote amplifier except that it operates off of the mark output of the receiver. The voltage is across R43.

b. TCF Channel

For loss of a TCF carrier channel, the carrier receiver clamps its output into both a space and a mark condition. Transistor Q1 and Q2 on the supervision board turn off. This applies negative potential to the base of Q9 and Q16 (on amplifier and keying board) respectively. Transistors Q9 and Q16 turn off which applies positive potential to the base of Q8 and Q15. Negative 20 volts appears across both R23 and R43.

This voltage enables AND 1 and AND 2 to allow tripping until the AND circuits are disabled by the 150/0 timer of the supervision board.

For the condition where the receiver is receiving pulses, transistor Q1 (on supervision board) turns on and off for alternate half cycles and the voltage across R23 is a square wave voltage varying from zero volts to a -20 volts dc.

For either internal or external fault conditions the outputs of both remote squaring amplifiers are square wave voltages. Both voltages vary from zero volts to approximately -20 volts dc and are out of phase with each other; i.e., when one voltage is at zero volts the other voltage is at -20 volts.

Links are provided on the board to connect the relay for either two or three terminal lines. The connection of C to 3 on link 1 connects remote squaring amplifier 5 and AND 1 of the arming board, and link 2 (C to 3) connects remote squaring amplifier 6 to AND 2 of the arming board for three terminal operation. For two terminal operation the connection of C to 2 on the links removes the inputs of remote amplifier 5 and 6 from the AND circuits of the arming board.

3. Arming Board

The phase relationship of the outputs of the local and remote squaring amplifiers are compared by the two AND circuits of the Arming Board. One AND circuit (number 1) compares the space signal with the output from amplifier number 1. The second AND circuit (number 2) compares the mark signal with the outputs of amplifier number 2. Since the local signals are always 180 degrees out-of-phase with each other, and the remote signals are always 180 degrees out-of-phase with each other, a change in phase angle of one signal with respect to the other will provide one input to AND 3 which will activate the 4/0 timer.

A link is provided on this board for purposes of arming the relay with both distance fault detectors and the SKBU relay fault detector. Removal of the link allows arming by distance fault detector only.

A. Internal Fault Conditions

With reference to the logic drawing that applies to the particular relay for an internal fault fed from both line terminals, the output voltages of the sequence filter at one line terminal is 180 degrees out-of-phase with respect to its load current condition. This changes the polarity of Amplifier 1 and Amplifier 2 such that their outputs are in phase with the remote signals. This means that AND 1 has a half-cycle of negative voltage and that AND 2 has a half-cycle of negative voltage (not the same half-cycle). The period of each negative voltage will be 180 degrees out-of-phase with reference to each other and a negative voltage will be produced out of OR 1 of the arming board. The negative voltage is applied to AND 3 of the arming board to set-up one condition for activating the AND negative voltage from OR 1 circuit. The second condition to activate this AND is provided by arming the relay.

In either Fig. 21, 22, 23, or 24, with link connected on the arming board, arming occurs through OR 2 by either the operation of the distance fault detectors or the operation of the relay fault detector. The operation of either fault detector will apply a voltage to OR 2 of the arming board. The output voltage from OR 2 applies a positive input to the trip AND of the output board through OR 31 and a negative input into AND 3 of the arming board. AND 3 is activated and starts the 4/0 timer. Four milliseconds later, a negative input is applied to the trip AND of the output board. Since the three conditions of trip (a negative input from the 4/0 timer, a positive input from the arm lead, and a positive signal from the 18/0 timer) is fulfilled, a trip output is obtained from the relay.

For arming by the distance fault detector only, the link on the arming board must be opened. This removes the input of the SKBU relay's fault detector from OR 2 of the arming board.

B. External Fault

Under external fault conditions, the square wave voltages from the remote squaring amplifiers and the square wave voltages from the local squaring amplifiers are out-of-phase such that zero output is obtained from the AND circuits of the arming board. The output from local 1 and remote 3 are out-of-phase to prevent an output on AND 1 and the outputs from local 2 and remote 4 are out-of-phase to prevent an output on AND 2. As a result, the outputs of the AND circuits are zero, and AND 3 cannot be activated. This blocks AND 3 and the 4/0 timer can not be energized.

With a fault detector operation, an input is applied to OR 2 and OR 4 of the arming board. OR 2 will provide a positive input to the trip AND of the output board. Tripping will not occur since the 4/0 timer does not provide a negative input to the Trip AND. The input to OR 4 operation of the fault detector will provide an input to a 0/1000 timer on the Output Board. The timer negates the signal to provide a positive input to the transient block AND. With the application of the positive input from the 0/1000 timer the three conditions of transient block are fulfilled--not a negative voltage from the Trip AND; not a positive voltage from the Transient Unblock Circuit; and a negative input from the 0/1000 timer. Eighteen milliseconds later the 18/0 timer of the transient block circuit times out to provide a negative input to the Trip AND. The Trip AND is thus desensitized on the external fault to prevent undesirable operation during transients associated with power reversals on the protective line or at the clearing of an external fault.

C. Sequential Faults

If the above external fault is followed by an internal fault before the external fault is cleared, the transient unblock circuit is set up to remove the transient blocking input to the Trip AND. For the internal fault, the square wave pulses on AND 1 and AND 2 of the arming board will reverse such that a negative output is obtained from the AND circuits. This output energizes OR1 which negates the signal to a negative signal. The negative signal...

1. Provides a second input to AND 3 and the 4/0 timer times out to apply a negative input to the Trip AND.
2. Applies a negative input to the AND of the transient unblock circuit to fulfill the requirements to obtain an output from the transient unblock circuit.

As a result, a negative input is applied to the unblock timer. Twenty-five milliseconds later, the unblock timer will operate to apply a positive voltage to the block AND circuit. This resets the 18/0 block timer, which removes the positive input to the unblock timer and which resets the unblock circuit. The required three inputs are thus applied to the trip AND and a trip output is obtained from the relay. Upon operation of the relay, the 0/100 millisecond timer resets the 0/1000 transient block timer.

D. Protective Relay Operation

The phase comparison relay is armed by the distance fault detectors through a 6/0 timer on the protective relay board. The operation of the distance fault detectors applies positive potential to the board. This turns Q1 on and turns Q2 off to allow C2 to charge. Six milliseconds later the voltage on C2 reaches the breakdown of Zener diode, Z7 and base current flows into transistor Q3 to turn Q3 on. This turns on Q4 to apply a positive potential to terminal 12 of the arming board.

4. Supervision Board

The circuits on the supervision board include the interface to the channel receiver and they vary with the type of equipment used as a pilot channel. In general, though, this board contains a low signal clamp timer.

A. Low Signal Clamp (.5/150 Timer)

1. Tone Channel

With a serviceable channel either a space frequency or an alternate space-mark frequency is received from the channel equipment. With reference to a TA-2 tone channel, Q14 and Q2 of the supervision board of Fig. 16 are either turned off or turned on and off. With Q2 turned off, base current is supplied to transistor Q3 and Q3 conducts. The collector of Q3 is thus at negative potential and capacitor can not charge.

If the channel is not serviceable, the tone receiver is clamped into a mark condition and the space output is zero. Transistor Q14 conducts and transistor Q2 is turned on. Negative potential is applied to Q3 and Q3 stops conducting. Positive potential is applied to capacitor C1 through resistor R7. After a 150 millisecond time delay, capacitor C1 charges sufficiently to break down Zener diode Z1. When Z1 conducts, base drive is supplied to transistor Q4 and Q4 turns on. This connects the collector of Q4 to negative potential which allows base current to flow in transistor Q5 through R1. This turns on transistor Q5 to apply positive voltage to R12. This voltage is then applied to AND 1 and AND 2 of the arming board and to an alarm output. Applying the voltage to the AND circuits blocks tripping.

Under the condition of alternate mark and space outputs from the tone receiver, transistor Q3 is turned on and off every 8.3 milliseconds (half cycle of power system frequency). Every half cycle, capacitor C1 starts to charge but on the next half-cycle Q3 turns on to discharge capacitor C1. Since the charging time is not sufficient to allow capacitor C1 to break down Z1, transistor Q5 will not turn on to block tripping.

2. TCF Carrier Channel

With reference to the supervision board of Fig. 18 for a serviceable TCF channel Q1 and Q2 either alternately turned on and off or Q1 is turned on and Q2 is turned off. Under both conditions, base current is supplied to transistor Q3 and Q3 is turned on at all times. With Q3 turned on, C1 can not charge and Q4 is turned off.

If the channel is not serviceable, the carrier receiver is clamped into both a mark and space output. This turns on transistors Q1 and Q2 of the supervision board. Turning on the two transistors, shorts the base of Q3 to negative potential and Q3 turns off. Positive potential is applied to C1 through R12 and R13 and 150 milliseconds later, Zener diode, Z5 breaks down to allow base current to flow to Q4. Q4 turns on which provides a path through R16 for base current of Q5 to flow to negative. Q5 turns on to apply positive voltage to R17. This voltage is then applied to AND 1 and AND 2 of the arming board to block tripping. The voltage is also applied to an external alarm circuit.

B.. Noise Supervision (Tone Channel Only)

The noise supervision interface consists of transistors Q17, Q11, Q12, and associated components. under normal conditions, the output from the noise circuit of the tone channel is zero volts. As a result, transistor Q17 is not conducting and base current is not supplied to transistor Q11. Transistor Q11 is turned off and its collector is held at positive potential to prevent base current from flowing in transistor Q12 and negative voltage (across R31) is applied to AND 1 and AND 2 of the arming board.

Under noise conditions the noise circuit of the tone equipment provides a negative output with respect to positive 48 volts dc. This negative voltage allows transistor Q17 to turn on and provides base current to Q11 through resistor R27. Transistor Q11 turns on, and its collector is connected to negative potential. Base current then flows in transistor Q12 through resistor, R30, and Q12 turns on. Positive potential is applied to resistor, R31 and to terminal 5 and 11 of the supervision board. From terminal 5, the voltage is applied to AND 1 and AND 2 of the arming board to block tripping. The voltage on terminal 11 is applied to an external alarm.

5. PR INTER Board (Protective Relay Interface Board)

The protective relay board includes the interface to the protective relays as well as the auxiliary circuits associated with the protective relays. This board contains a 6/0 timer, 2500 fault detector operation timer, and a 150/10 signal squelch timer.

A. Signal Squelch Timer

When an input is applied to terminal 18 of the protective relay board, positive potential is applied to base of Q10, Q10 turns on to provide a discharge path for C8 through R41. 10 milliseconds after the input to terminal 18, C8 stops conducting and Q11 turns off to turn on Q12. Turning on Q12 applies a negative input to the keying circuit of the amplifier and keying board which keeps the keying transistor from turning on.

Upon removal of the input to terminal 18 of the protective relay board Q10 turns off to apply positive potential to C8. 150 milliseconds later Q10 turns on to turn off Q12 which removes negative potential to the keying circuit.

B. Loss-of-Potential Alarm (2500 Timer)

When arming occurs on the SKBU-21, positive potential is applied to terminal 1 and capacitor C3 of the PR INTER board from terminal 19 of the arming board. Two-and-a-half seconds later, the potential on C3 breaks down the Zener diode Z8 to allow base current to flow into Q5. This turns on Q5 which turns off Q6. Turning Q6 off applies positive potential to the base of Q7 and Q7 turns off. This removes positive potential from R26 and an external alarm is energized.

C. Arming Delay by Distance Fault Detectors (6/0 Timer)

The distance supervision arming is delayed by 6 milliseconds to allow time for the circuits feeding AND 1 and AND 2 to respond at fault inception. Operation of the distance fault detectors will apply positive potential to the protective relay board. This turns on Q1 which removes the base current to transistor Q2. Q2 turns off and positive potential is applied to capacitor C2. Six milliseconds later the voltage on C2 reaches a value to break down Zener diode Z7. This turns on Q3, which connects the base of Q4 to negative through resistor, R15. Q4 turns on to apply positive potential to resistor, R16 and terminal 2. From terminal 2 the voltage is applied to the arming board.

CHARACTERISTICS

A. SKBU-21 Relay

The type SKBU-21 relay is available for frequency shift channels, either tone or carrier. Taps are available to set different sensitivities of the fault detector to zero and negative sequence currents. These taps are as follows:

Negative Sequence Taps (I_2)

TAP SETTING	NEGATIVE SEQUENCE SENSITIVITY
A	None
B	0.4 Amperes
C	0.25 Amperes

Zero Sequence Taps (I_0)

TAP SETTING	ZERO SEQUENCE SENSITIVITY
F	None
G	0.2 Amperes
H	0.1 Amperes

The positive sequence response of the fault detector is greater than 7 amperes.

B. SKBU-2 Relay

Taps are available in the relay to set the sensitivity to different combinations of positive, negative, and zero sequence components of the line current. The T taps on the left hand top plate indicate the balanced three phase amperes which will operate the fault detector FD. These taps are as follows:

3, 4, 5, 6, 7, 8, and 10

For distance fault detector applications, the user should reset the SKBU-2 fault detector for a pick-up of twice tap value.

For phase-to-phase faults AB and CA, enough negative sequence current has been introduced to allow the fault detector to pick-up at 86 percent of the tap setting. For BC faults, the fault detector will pick-up at approximately 50 percent of the tap setting. This difference in pick-up current for different phase-to-phase faults is fundamental, and occurs because of the angles at which the positive and negative sequence components of current add together.

With the sequence network arranged for positive, negative and zero sequence output, there are some applications where the maximum load current and minimum fault current are too close together to set the relay to pick-up under a minimum fault current, yet not operate under load. For these cases, a tap is available on the relay which cuts the three-phase sensitivity in half, while the phase-to-phase setting is substantially unchanged. The relay then trips at 90 percent of tap value for AB and CA faults, and at twice tap value for three-phase faults. The setting for BC faults is 65 percent of tap value. In some cases, it maybe desirable to eliminate response to positive-sequence current entirely, and operate the relay on negative-plus-zero sequence current. A tap is available to operate in this manner. The fault detector picks up at tap value for all phase-to-phase faults, but is unaffected by balanced load current or three-phase faults.

For ground faults, separate taps are available for adjustment of the ground fault sensitivity to about 1/4 or 1/8 of the left-hand tap plate setting. See Table II. For example, if the left-hand tap plate of the relay is set at tap 4, the fault detector pick-up current for ground faults can be either 1 or ½ ampere. In special applications, it may be desirable to eliminate response to zero sequence current. The relay is provided with a tap to allow such operation.

The operating time of the fault detector of both the SKBU-2 and SKBU-21 is shown in Fig. 25. As shown in the figure, the fault detector has a maximum and minimum value. This is due to the point on the current wave that fault current is applied. Fig. 26 shows the operating times for different points on the fault wave for fault current at five amperes.

The keying response of the SKBU-21 relay is independent of the tap setting. Fig. 27 shows typical lengths of keying pulses with reference to a 60-hertz base of the SKBU-21 relay for different values of positive, negative, and zero sequence current.

Typical logic drawing for a tone channel is shown in Figs. 21 and 23 and for a TCF carrier channel in Figs. 22 and 24.

Operating Time	15 to 32 Milliseconds
Alarm Time	2.5 seconds for FD operation 150 Milliseconds Loss-of-Channel
Transient Block Time	16 to 20 Milliseconds

Transient Unblock Time	23 to 27 Milliseconds
Ambient Temperature Range	-20°C to 55°C
DC Drain	0.14 Amps at 48 Volts DC

Reset Time of Transient Block

1. After Fault Detector has Operated	1000 Milliseconds
2. When unblock time is utilized	Instantaneous

ENERGY REQUIREMENTS

a. SKBU-21 Relay

Burdens measured at a balanced three-phase current of five amperes.

(Independent of tap setting)

Phase A		Phase B		Phase C	
VA	ANGLE	VA	ANGLE	VA	ANGLE
8.3	106°	2.2	50°	46	0°

Burden measured at a single-phase to neutral current of five amperes.

Relay	Phase A		Phase B		Phase C	
Taps	VA	Angle	VA	Angle	VA	Angle
C-H	11.7	2.1°	9.7	1.8°	44.	2.2°
B-H	11.4	2.0°	10.3	1.8°	46	2.2°
A-H	11.1	2.0°	11.2	1.8°	48	2.2°
C-G	8.8	2.0°	7.0	1.8°	42	2.2°
B-G	8.7	2.0°	7.5	1.8°	43.5	2.2°
A-G	7.8	2.0°	8.5	1.8°	45	2.2°
C-F	6.7	2.0°	7.5	1.8°	42	2.2°
B-F	6.5	2.0°	7.2	1.8°	42	2.2°
A-F	5.8	2.0°	6.6	1.8°	43	2.2°

The angles above are the degrees by which the current lags its respective voltage.

b. SKBU-2 Relay

Burdens measured at a balanced three-phase current of five amperes.

RELAY	Phase A		Phase B		Phase C	
TAPS	VA	ANGLE	VA	ANGLE	VA	ANGLE
A-F-3	2.4	5°	0.6	0°	2.5	50°
A-H-10	3.25	0°	0.8	100°	1.28	55°
B-F-3	2.3	0°	0.63	0°	2.45	55°
B-H-10	4.95	0°	2.35	90°	0.3	60°
C-F-3	2.32	0°	0.78	0°	2.36	50°
C-H-10	6.35	342°	3.83	80°	1.98	185°

Burdens measured at a single-phase to neutral current of five amperes

RELAY	PHASE A		PHASE B		PHASE C	
TAPS	VA	ANGLE	VA	ANGLE	VA	ANGLE
A-F-3	2.47	0°	2.1	10°	1.97	20°
A-H-10	7.3	60°	12.5	53°	6.7	26°
B-F-3	2.45	0°	2.09	15°	2.07	10°
B-H-10	16.8	55°	22.0	50°	12.3	38°
C-F-3	2.49	0°	1.99	15°	2.11	15°
C-H-10	31-2	41°	36.0	38°	23.6	35°

The angles above are the degrees by which the current lags its respective voltage.

SETTINGS

A. SKBU-21

The SKBU-21 relay has separate tap plates for adjustment of the zero and negative sequence sensitivity of the fault detector. The fault-detector tap markings and pickup are:

Negative Sequence Sensitivity (I_2)

A. None
B. 0.4 Amperes
C. 0.25 Amperes

Zero Sequence Sensitivity (I_0)

F. None
G. 0.2 Amperes
H. 0.1 Amperes

Two tap plates are provided: one for I_2 and the other one for I_0.

Tap A should not be used in service since this would prevent fault detector operation for phase-to-phase faults. However, tap F may be used with either B or C since negative sequence current flows for both phase-to-phase and ground faults.

The recommended settings are tap B or C as needed for the required sensitivity, and tap F. Taps G and H have been provided for applications where the negative-sequence load flow due to series impedance unbalance may be high enough to operate FD with a tap C setting. In this case set in tap B and in tap G or H. It is not intended that taps C and H be used simultaneously due to the possibility of cancellation of the negative- and zero- sequence effects on ground faults. With a tap B setting, a tap H setting is preferred.

To summarize, the recommended setting combinations in the order of preference are:

COMBINATION	I_2 TAP	I_0 TAP
1	C	F
2	B	F
3	B	H
4	B	G

B. SKBU-2 Relay

The SKBU-2 relay has separate tap plates for adjustment of the phase and ground fault sensitivities and the sequence components included in the network output. The method of determining the correct taps for a given installation is discussed in the following paragraphs.

Sequence Combination Taps - R1 Taps

The two halves of the right-hand tap plate are for connecting the sequence network to provide combinations of sequence current response. The upper half of the tap plate or R1 taps changes the tap on the third winding of the mutual reactor and thus changes the relative amounts of positive and negative sequence sensitivity. Operation of the relay with the various taps is given in the following table.

TABLE I

COMB	SEQUENCE COMPONENTS IN NETWORK OUTPUT	TAPS ON RIGHT HAND TAP BLOCK		FAULT DETECTOR PICK-UP	
		R_1	R_0	3φ Fault	φ-φ Fault
1	Pos., Neg., Zero	C	G or H#	Tap Value	86% Tap Value (53% on BC Fault)
2	Pos., Neg., Zero	B√	G or H	2 x Tap Value	90% Tap Value (65% on BC Fault)
3	Neg., Zero	A√	G or H	--------	100% Tap Value

- Taps F, G, and H are zero-sequence taps for adjusting ground fault sensitivity. See section on zero-sequence current tap.

√ - When taps A and 3, or B and 3 are used, the relay pick-up currents for FD will be 10 to 15 percent higher than the indicated values because of the variation in self-impedance of the sequence network and the saturating transformer.

Zero Sequence Current - R_0 Taps

The lower half of the right-hand tap plate (R_0 taps) is for adjusting the ground fault response of the relay. Taps G and H give the approximate ground fault sensitivities as listed in Table II. Tap F is used in applications where increased sensitivity to ground faults is not required. When this tap is used, the voltage output of the network caused by zero-sequence current is eliminated.

NOTE: Because of inherent characteristics of the sequence network, there will be small variations (from the values listed in Tables I and II) in the pick-up current for various phase or ground fault combinations.

TABLE II

COMB.	R_1 TAP	GROUND FAULT PICK-UP PERCENT OF T TAP SETTING	
		TAP G	TAP H
1	C	25%	12%
2	B	20%	10%
3	A	20%	10%

Setting Principles

Tap C provides the best balance between 3 phase and phase-to-phase fault sensitivity. Always use this tap where distance fault detector supervision is used. Where only the SKBU-2 fault detector is used and where the full load current (maximum through any terminal) is approximately five amperes or more, tap B will provide increased phase-to-phase fault sensitivity with little or no sacrifice in 3 phase fault sensitivity. For example, if a left-hand tap (T) of 6 is needed with tap C (6C), then use a 3B setting instead.

Use tap A only where satisfactory unbalanced fault sensitivity cannot otherwise be obtained and where other protection is available for 3 phase faults, since with tap A no 3 phase fault protection is available.

In all cases provide identical response at all stations to insure adequate keying voltage from the filter for any fault detector by remote-end relays. That is, the taps should be identical with identical CT ratios, or inversely proportional to CT ratios where different.

After selecting tap C or B, pick the T tap to allow reset of the fault detector in the presence of load flow that is, fault detector pick-up should be at least 111 percent of full load current (maximum through any terminal).

Now select tap G or H for desired ground-fault sensitivity.

For distance fault detector applications, set 3C to provide the maximum sequence-filter voltage for the squaring amplifiers. The SKBU-2 current fault detector is then independently desensitized (by adjustment of S1 and S2 settings) to permit reset in the presence of full-load current. Phase faults which do not operate the SKBU-2 fault detector will be detected by the supplementary distance fault detectors.

INSTALLATION

The phase comparison relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The phase comparison relay is normally supplied as part of a relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the relay is not a part of a relaying system, the following procedure can be followed to verify that the circuits of the relay are functioning properly.

TEST EQUIPMENT

1. Oscilloscope
2. AC Current Source
3. Electronic Timer
4. AC Voltmeter
5. DC Voltmeter

ACCEPTANCE TEST

Connect the relay to the test circuit of Fig. 28 which represents the tone channel for test purposes. Fig. 29 represents the TCF carrier channel for test purposes.

1. <u>FD Pickup and Dropout</u>
    a. Set relay on taps C and H. Set SKBU-2 T tap 5.
    b. Connect a high resistance dc voltmeter across X_{22} and X_4 (neg.).
    c. Apply 60 hertz current to terminal 5 and 1 of the relay. Gradually increase the current until the voltmeter changes reading from approximately zero volts to approximately 20 volts. This is the

operating current of FD and should be 0.433 ± 5% amperes for SKBU-21 relay and 4.33 ± 5% amperes for SKBU-2 relay.

d. Gradually lower ac test current until the dc voltmeter drops to approximately zero volts. This is the dropout current of FD and should occur at 90% of the pickup current.

2. Check of Local Squaring Amplifiers

a. With all switches of test circuit open, apply 0.5 amperes ac to terminals 1 and 5 of the SKBU-21 relay, or 5 amperes ac to terminals 1 and 5 of the SKBU-2 relay.

b. Place scope probe across X12 and X4 (grd). A square wave of voltage should appear across X12 and X4 as shown in Table III.

c. Place scope probe across X15 and X4 (grd). A square wave of voltage should appear across X15 and X4 as shown in Table III.

d. If scope has two traces, connect one probe to X12 and second probe to X15. Connect grd. of scope to X4. The phase relationship of Table III should be observed.

3. Check of Keying Circuit

a. With all switches of test circuit open except A and 0.5 amperes ac applied to terminal 1 and 5 of the SKBU-21 relay, with scope check voltage across X14 and X4 (grd). (This voltage should be checked with 5 amperes into terminals 1 and 5 of SKBU-2 relay).

b. Waveform shown in Table III should be observed.

4. Check of Remote Squaring Amplifiers

a. Close switches A, B, and C of test fixture.

b. Apply 0.5 amperes ac to terminals 1 and 5 of the SKBU-21 relay, or 5 amperes ac to same terminals for SKBU-2 relay.

c. Using scope with grd. lead on X4, check waveshape of voltage across X9 and then X16. Waveforms of Table III should be observed. Also for three terminal application check waveform across X13 and X17.

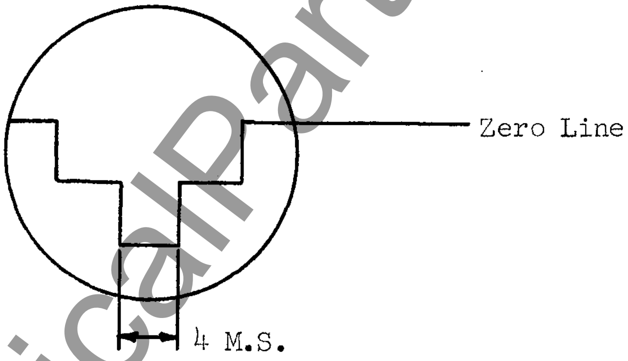
d. If scope has two traces, connect one probe to X9 and the other on X16. Connect grd. to X4. With scope set on chopped, the phase relationship to Table III **should be** observed.

5. Setting of S5 and S6

a. Set S5 to minimum resistance and S6 to maximum resistance (fully clockwise).

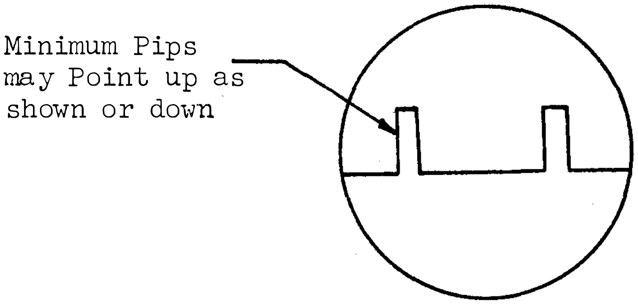
b. Set switch **L** to external fault and close switches A, B, and C of the test circuit. Apply 0.5 amperes ac to terminals 1 and 5 of the SKBU-21 relay or 5 amperes ac to same terminals of SKBU-2 relay.

c. Place scope across X10 and X2 (grd). Adjust S5 until following waveform appears on scope.



d. Adjust S6 until the relay trips. This sets the triggering of the Trip AND after a 4 millisecond delay.

e. Slowly increase S5 to obtain the following waveform. This will be with S5 at or near minimum resistance.



6. Transient Blocking Delay (18/0 and 0/1000 Timer)

   a. Connect electronic timer stop to X7 and X4 (grd). Set timer stop on negative going pulse. Relay not to be energized with ac current.

   b. Connect timer start to X3. Set timer start to positive going pulse.

   c. Close PR1 switch. Time should start and should stop between 18 and 20 milliseconds.

   d. Set timer start on a negative pulse and timer stop on a positive pulse.

   e. Open PR1 switch. Timer should start and should stop after a time delay of 980 to 1020 milliseconds.

7. Check of Transient Unblocking Circuit

   a. With electronic timer stop connected to X7 and X4 (grd), set timer stop on positive going pulse.

   b. Connect timer start to timer start contacts of switch L. Set L on external fault, and close switches A, B, C, E and F of test circuit. Set timer start on negative going pulse.

   c. Apply 0.6 amperes ac into terminal 1 and 5 of the SKBU-21 relay, or 6 amperes into terminal 1 and 5 of the SKBU-21 relay.

   d. Close switch L to internal fault, timer should start and should stop after a time delay. Time should be 22 to 28 milliseconds. If time has to be rechecked, capacitor C4 on output board should be shorted before each reading. The short should be removed from the capacitor before the reading is taken. Time can be changed by adjusting S_7 on the front panel.

8. Fast Reset Timer (0/100)

a. Connect jumper from TP4 to terminal 4 on output board.

b. Connect timer start to X11. Set timer start on positive pulse. Connect timer stop to TP6 and terminal 8 of output board. Set timer stop on positive pulse.

c. Apply 0.6 to 0.8 amperes ac into terminal 5 and out terminal 1 of SKBU-21 relay. (Apply 6 to 8 amperes ac to terminals 5 and 1 of SKBU-2 relay). (Switches A, B, C, E, F closed, H and I open and switch L on external fault position).

d.. Close switch L to internal fault position. Relay should trip and timer should start and stop in less than 2.5 milliseconds.

e. Set timer start on negative pulse and timer stop on negative pulse.

f. Close switch L to external fault position and de-energize relay. Timer should start and stop after 80 to 120 milliseconds.

g. Open all switches on test fixture, set L on external fault. Remove jumper from TP4 to terminal 4.

9. 6/0 Timer Distance Fault Detector

a. Connect timer start to timer start of PR1 switch. Set timer start on positive pulse. Connect timer stop to X3 and X4 (comm). Set timer stop on positive pulse.

b. Close PR1 switch. Timer should start and should stop after 6 to 8 milliseconds.

10 . Alarm on Relay Operation (2.5 Seconds)

a. With electronic timer stop connected to X20 and X4 (grd), set timer stop on negative going pulse.

b. Connect timer start to X3. Set timer start on positive pulse.

c. Close PR1 switch. Timer will start and should stop after 2.3 to 2.7 seconds.

d. Open PR1 switch.

11. <u>150 Timer Low Signal Clamp 1 (TCF Channel Only)</u>

a. Connect timer stop to X19 and X4 (comm). Set timer stop to positive pulse.

b. Set switch L to internal fault position.

c. Connect timer start to timer start of switch L. Set timer start to positive pulse.

d. Close switches B, C, and G. Close switch L to external fault position. Timer will start and should stop in 130 to 170 milliseconds.

e. Open switches B, C, and G. Set L on internal fault position.

12. <u>150 Timer Low Signal Clamp 2 (TCF Channel Only)</u>

a. Connect timer stop to X19 and X4 (comm). Set timer stop to positive pulse.

b. Set switch L to internal fault position.

c. Connect timer start to timer start of switch L. Set timer start to positive pulse.

d. Close switches E, F and G. Close switch L to enternal fault position. Timer will start and should stop in 130 to 170 milliseconds.

e. Open switches E, F, and G, and set L to internal fault position.

13. <u>150 Timer Low Signal Clamp 1 (TA-2 Tone Only)</u>

a. Connect timer stop to X19 and X4 (comm). Set timer stop to positive pulse.

b. Set switch L to internal fault position.

c. Connect timer start to timer start of switch L. Set timer start to positive pulse.

d. Close switches B and C. Close switch L to external fault position. Timer will start and should stop in 130 to 170 milliseconds.

e. Open switches B and C. Set L on internal fault position.

14. 150 Timer Low Signal Clamp 2 (TA-2 Tone Only)

a. Connect timer stop to X19 and X4 (comm). Set timer stop to positive pulse.

b. Set switch L to internal fault position.

c. Connect timer start to timer start of switch L. Set timer start to positive pulse.

d. Close switches E and F. Close switch L to external fault position. Timer will start and should stop in 130 to 170 milliseconds.

e. Open switches E and F and set switch L on internal fault position.

15. Signal Squelch Time (10/150)

a. Connect timer stop to X14 and X4 (comm). Set timer stop on negative pulse. Close switch A. Connect a jumper from TP1 to terminal 8 of the amplifier and keying board. This turns off Q2 to turn on Q3.

b. Connect timer start to pilot trip switch. Set timer start on positive pulse. Close switch I.

c. Close pilot trip switch. Timer will start and will stop after a 8 to 12 millisecond delay.

d. Set timer stop on negative pulse, and timer start to negative pulse.

e. Open pilot trip switch. Timer should start and stop after a time delay of 125 to 185 milliseconds.

f. Remove jumper from TP1 to terminal 8.

16. Check of Noise Circuit (Where Used)

a. Connect dc voltmeter to X18 and X4 (grd). Voltage must read zero.

b Close switch D. Voltage must rise to 20 volts. Open switch D. Voltage must change to zero volts. Close switch G. Voltage must rise to 20 volts. Open switch G.

17. Check of Frequency Verifier

a. Open all switches of test circuit.

b. Connect scope across TP60 and terminal 8 of the FD board.

c. Apply 0.5 amperes to terminal 1 and 5 of SKBU-21 relay. (Apply 5 amperes to terminal 1 and 5 on SKBU-2 relay).

d. Waveform of Fig. 31 should be observed.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram voltages of Table II should be used to isolate the circuit that is not performing correctly. The schematic of the individual board, and the voltages of Table IV should then be used to isolate the faulty component.

TABLE IV.

VOLTAGE MEASUREMENTS ON PRINTED CIRCUIT BOARDS

1) Fault Detector Board Style 5312D13G01

Test Point	I_{ac} = 0	I_{ac} = Pickup of FD
54	6.5 V DC	less than 1
55	less than 1	4.5 V DC
56	less than 1	18 to 20 V DC
Term 2	less than 1	8.6 V DC
51-52	0	7.4 volts ac (Approx.)
52-53	0	7.5 volts ac (Approx.)
53-51	0	7.4 volts ac (Approx.)
Terminal 5-6	0	15 volts ac (Approx.)
TP 57	18 volts)	Pulses see Fig. 31 for Waveform
TP 58	18 volts)	
TP 59	less than 1)	
TP 60	20 volts)	
TP 61	18 volts)	
TP 62	less than 1)	

2. Supervision Board, 202C564G01, TA-2 Tones

TEST POINT	NORMAL CONDITION	ABNORMAL CONDITION
TP1	* 48 V DC	less than 1 with loss of channel 1
Term 13	* less than 1	16 V. with loss of channel 1
TP2	* less than 1	48 V. with loss of channel 1
Term 12	* 13.5 V DC	less than 1 with loss of channel 1
TP 3	* less than 1	7 V. with loss of channel 1
Term 18	less than 1	20 V. with loss of channel 1
Term 15	less than 1	20 V. with loss of channel 1
TP4	**48 V DC	less than 1 with loss of channel 2
Term 17	** less than 1	16 V. with loss of channel 2
TP5	* less than 1	48 V. with loss of channel 2
Term 16	* 13.5 V DC	less than 1 with loss of channel 2
TP6	* less than 1	7 V. with loss of channel 2
Term 19	less than 1	20 V. with loss of channel 2
TP7	less than 1	48 V. with noise clamp
Term 5	less than 1	20 V. with noise clamp
Term 11	less than 1	20 V. with noise clamp

* Normal condition could be square wave pulses.

** Normal condition could be square wave pulses. On two terminal line application normal condition of TP4 - less than 1 and term 17 - 16 volt dc.

3. Supervision Board, 202C565G01, TCF Channel

TEST POINT	NORMAL CONDITION	ABNORMAL CONDITION
Term 13	* less than 1	less than 1 with loss of channel 1
Term 12	* 13.5 volts dc	less than 1 with loss of channel 1
TP1	* less than 1	7 V DC with loss of channel 1
Term 18	less than 1	20 V DC with loss of channel 1
Term 15	less than 1	20 V DC with loss of channel 1
Term 17	**less than 1	less than 1 with loss of channel 2
Term 16	* 13.5 Volts DC	less than 1 with loss of channel 2
TP 2	* less than 1	7 V. DC with loss of channel 2
Term 19	less than 1	20 V DC with loss of channel 2

* Normal condition could be square wave pulses.

** Normal condition could be square wave pulses. On two terminal line applications normal condition of terminal 17 is 13.5 volts dc.

4. Amplifier and Keying Style, 202C551G01 for TA-2 Tones and Style 202C540G01 for TCF

TEST POINT	NORMAL ($I_{AC} = 0$)	ABNORMAL ON I_{AC} = PICKUP OF FD
TP1	4.5 Volts	4.5 Volt pulses at FD pickup
TP2	less than 1	5.5 Volt pulses at FD pickup less than 1 with squelch
Term 6 (TA-2 Tones)	48 Volts	-12 Volt pulses at FD pickup 48 V DC with squelch
Term 6 (TCF Carrier)	less than 1	20 Volt pulses at FD pickup less than 1 with squelch
TP4	4.5 Volts	4.5 Volt pulses at FD pickup
Term 9	20 Volts	20 Volt pulses at FD pickup

4. Amplifier and Keying Style, 202C551G01 for TA-2 Tones and Style 202C540G01, for TCF (CONTINUED)

TEST POINT	NORMAL (I_{AC} = 0)	ABNORMAL ON I_{AC} = PICKUP OF FD
Term 11	less than 1 or 20 Volt pulses	20 Volts with loss of TA-2 channel 1 less than 1 with loss of TCF channel 1
Term 1	less than 1 or 16 volt pulses TA-2, 13.5 Volt pulses TCF	16 Volts with loss of TA-2 channel 1
Term 12	** less than 1 or 20 Volt pulses	20 Volts loss of TA-2 channel 2 less than 1 with loss of TCF channel 2
Term 16	** less than 1 or 16 Volt pulses TA-2, 13.5 Volts TCF	16 Volts with loss of TA-2 channel 2 less than 1 with loss of TCF channel 2
TP9	4.5 Volts	4.5 Volt pulses at FD pickup
Term 17	20 Volts	20 Volt pulses at FD pickup
Term 14	20 Volts or 20 volt pulses	less than 1 with loss of channel 1
Term 15	13.5 Volts or 13.5 Volt pulses	less than 1 with loss of channel 1
Term 10	** 20 Volts or 20 Volt pulses	less than 1 with loss of channel 2
Term 13	** 13.5 Volts or 13.5 Volt pulses	less than 1 with loss of channel 2

** Values for three terminal line applications. On two terminal line applications - Term 12 and 10 are zero volts, Term 16 16 volts TA-2 Tones, 13.5 volts TCF and Term. 13 13.5 volts dc for TA-2 tones and TCF.

5. Arming Board Style 202C509G01

TEST POINT	NORMAL $I_{AC} = 0$	ABNORMAL ON I_{AC} = PICKUP OF FD
TP1	less than 1	10 Volt pulses on internal fault * less than 1 on external fault less than 1 on loss of channel
TP2	less than 1	10 Volt pulses on internal fault * less than 1 on external fault less than 1 on loss of channel
TP3	10 Volts	* less than 1 on internal fault * 10 Volts on external fault 10 Volts on loss of channel
TP4	13.5 Volts	less than 1 at FD pickup
TP5	less than 1	13.5 Volts at FD pickup
Term 15	less than 1	20 Volts at FD pickup
TP8	20 Volts	* less than 1 on internal faults * 20 Volts on external fault 20 Volts on loss of channel

* Very narrow pulses would be observed on scope

6. Output Board Style 202C548G01

TEST POINT	NORMAL	
TP1	16	less than 1 when armed
TP2	less than 1	20 Volts when armed
TP3	20 Volts	less than 1 when armed
TP4	less than 1	20 Volts when armed
TP5		less than 1 at trip
TP6	20 Volts	less than 1 when armed
TP7	less than 1	Applies to sequential fault and is a pulse of short duration
TP8	less than 1	7 Volts 18 milliseconds after arming
TP9	18.5	7 Volts at trip
Term 13	less than 1	20 Volts at trip

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give the circuit symbol and the electrical value (ohms, mfd, etc.) and component style number.

ELECTRICAL PARTS LIST

Fault Detector Board Style 5312D13G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C51	0.1 Mfd	1544920
C52-C53-C59	0.5 Mfd	187A624H11
C54-C55	1.5 Mfd	187A508H09
C56-C57	0.02 Mfd	187A624H09
C58	0.1 Mfd	187A624H01
C60	0.22 Mfd	762A703H01
	Diodes	
D51 to D58-D70 to D73	1N457A	184A855H07
D59	1N645A	837A692H03
D60 to D69	1N4385	184A855H14
	Transistors	
Q51-Q52-Q53-Q55 Q57-Q61-Q62-Q63	2N3417	848A851H02
Q54-Q56-Q58	2N3645	849A441H01
	Switches	
Q59-Q60	2N886	185A517H03
	Resistors	
R51	50 Ohms, 5W	185A209H06
R52-R68-R71	2.7 K Ohms	629A531H42
R53 (POT)	2.5 K Ohms	629A430H03
R54-R55-R58-R62 R64-R66-R84-R89-R92	10 K Ohms	629A531H56

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Resistors	
R56-R60	100 K Ohms	184A763H75
R57	47 K Ohms	629A531H72
R59	56 K Ohms	184A763H69
R61-R87	22 K Ohms	629A531H64
R63	6.8 K Ohms	629A531H52
R65	27 K Ohms	629A531H66
R67	150 Ohms, 3W	762A679H01
R69-R73	68 K Ohms	629A531H76
R70-R74-R88	39 K Ohms	629A531H70
R72-R75-R80	2 K Ohms	836A503H33
R76-R78-R90	1 K Ohm	629A531H32
R77	5.6 K Ohm	629A531H50
R79-R86	6.2 K Ohms	629A531H51
R81	20 K Ohms	629A531H63
R82	1.5 K Ohms	836A503H30
R83-R91	470 Ohms	629A531H24
R85-R93	4.7 K Ohms	629A531H48
	Zener Diodes	
Z51	1N1832C, 62 V	184A617H06
Z52-Z55	1N957B, 6.8 V.	186A797H06
Z53	1N3688A, 24 V	862A288H01
Z54	1N759A, 12V	837A693H01

Supervision Board Style 202C564G01 TA-2 Tone Channel

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C1-C3	6.8 Mfd	184A661H10
C2-C4-C6	0.27 Mfd	188A669H05
C5	0.47 Mfd	188A669H01
	Diodes	
D1 to D7	1N645A	837A692H03
	Transistors	
Q1 to Q4, Q6 to Q9-Q11	2N3417	848A851H02
Q5-Q10-Q12	2N3645	849A441H01
Q13 to Q17	2N4356	849A441H02
	Resistors	
R1-R3-R7-R14-R16 R20-R27	47 K Ohm	629A531H72
R2-R4-R6-R9-R10-R15-R17-R19-R22-R23-R28-R29-R34-R36-R38-R40-R41-R42-R43	10 K Ohm	629A531H56
R5-R18	27 K Ohm	629A531H66
R8-R21	470 Ohm	629A531H24
R11-R24-R30	6.8 K Ohm	629A531H52
R12-R25-R31	82 K Ohm	629A531H78
R13-R26-R32	150 Ohm, 3 W	762A679H01
R33-R35-R37-R39	2 K Ohm	629A531H39
	Zener Diode	
Z1-Z3	1N957B, 6.8 Volt	186A797H06
Z2-Z4-Z5-Z6	1N3688A, 24 Volt	862A288H01
Z7	UZ5875, 75 Volt	837A693H04

Supervision Board Style 202C565G01 TCF Carrier Channel

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C1-C3	6.8 Mfd	184A661H10
C2-C4	0.27 Mfd	188A669H05
	Diodes	
D1 to D8	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q4 Q6-Q7-Q8-Q9	2N3417	848A851H02
Q5-Q10	2N3645	849A441H01
	Resistors	
R1-R2-R5-R6-R19-R20-R23-R24	4.7 K Ohm	629A531H48
R3-R7-R17-R21-R25-R35	82 K Ohm	629A531H78
R4-R8-R11-R14-R15-R22-R26-R29-R32-R33	10 K Ohm	629A531H56
R9-R10-R27-R28	27 K Ohm	629A531H66
R12-R30	47 K Ohm	629A531H72
R13-R31	470 Ohm	629A531H24
R16-R34	6.8 K Ohm	629A531H52
R18-R36	150 Ohm, 3W	762A679H01
	Zener Diodes	
Z1-Z3-Z7-Z9	1N3686B, 20 V	185A212H06
Z2-Z4-Z5-Z8-Z10-Z11	1N957B, 6.8 V	186A797H06
Z6-Z12	1N3688A, 24 V	862A288H01

Amplifier and Keying Board Style 202C551G01 TA-2 Tones

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Diodes	
D1-D3-D4-D5	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q5-Q6-Q9-Q11-Q12-Q13-Q16-Q18	2N3417	848A851H02
Q4-Q7-Q8-Q10-Q14-Q15-Q17	2N3645	849A441H01
Q19	2N699	184A638H19
	Resistors	
R1-R19-R23-R30-R42-R43-R49	82 K Ohm	629A531H78
R2-R14-R37	33 K Ohm	629A531H68
R3-R4-R6-R7-R8-R15-R16-R17-R24-R28-R31-R35-R38-R39-R40-R44-R48-R50-R54-R56	10 K Ohm	629A531H56
R5-R9-R18-R25-R27-R32-R34-R41-R45 R47-R51-R53-R55-R57	27 K Ohm	629A531H66
R12-R13-R20	68 K Ohm	629A531H76
R21-R22-R29	470 K Ohm	184A763H91
R26-R33-R46-R52	6.8 K Ohm	629A531H52
R36	220 K Ohm	184A763H83
	Zener Diodes	
Z2	UZ5875, 75 Volts	837A693H04

Amplifier and Keying Board Style 202C540G01 TCF Carrier Channel

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Diodes	
D1 to D5	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q5-Q6-Q9-Q11-Q12-Q13-Q16-Q18	2N3417	848A851H02
Q4-Q7-Q8-Q10-Q14-Q15-Q17	2N3645	849A441H01
	Resistors	
R1-R10-R19-R23-R30-R42-R43-R49	82 K Ohm	629A531H78
R2-R14-R37	33 K Ohm	629A531H68
R3-R4-R6-R7-R8-R15-R16-R17-R24-R28-R31-R35-R38-R39-R40-R44-R48-R50-R54	10 K Ohm	629A531H56
R5-R18-R25-R27-R32-R34-R41-R45-R47-R51-R53	27 K Ohm	629A531H66
R9-R26-R33-R46-R52	6.8 K Ohm	629A531H52
R11	150 Ohm 3 Watts	762A679H01
R12-R13-R20	68 K Ohm	629A531H76
R21-R22-R29	470 K Ohm	184A763H91
R36	220 K Ohm	184A763H83
	Zener Diode	
Z1	1N3688A, 24 Volts	862A288H01

Arming Board Style 202C509G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C1	.27 Mfd	188A669H05
	Diodes	
D1 to D18	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q4-Q5-Q6-Q8	2N3417	848A851H02
Q7-Q9	2N3645	849A441H01
	Resistors	
R1 to R10-R12-R14 R15-R16-R18-R19-R20-R31-R32-R37-R38	22 K Ohm	629A531H64
R11-R13-R17-R21-R24-R27-R28-R35-R36	10 K Ohm	629A531H56
R22-R25-R29	6.8 K Ohm	629A531H52
R23-R26-R33-R34-R39	27 K Ohm	629A531H66
R30	82 K Ohm	629A531H78
R40	150 Ohm, 3 W	762A679H01
	Zener Diodes	
Z1	1N3688A, 24 Volts	862A288H01

Protective Relay Board Style 202C563G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C1-C5-C7	0.047 Mfd	849A437H04
C2	0.47 Mfd	188A669H01
C3	68 Mfd	187A508H02
C4-C6	0.27 Mfd	188A669H05
C8	6.8 Mfd	184A661H10
	Diodes	
D1 to D8	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q5-Q6-Q8-Q10-Q11-Q12	2N3417	848A851H02
Q4-Q7-Q9	2N3645	849A441H01
	Resistors	
R1-R2-R3-R4-R5-R27-R28-R30-R36-R37	4.7 K Ohm	629A531H48
R6-R16-R26-R31-R35-R38	82 K Ohm	629A531H78
R8-R15-R25-R34-R40-R44	6.8 K Ohm	629A531H52
R7-R9-R10-R13-R14-R20-R21-R23-R24-R32-R33-R39-R41-R43-R46	10 K Ohm	629A531H56
R11-R22-R45	27 K Ohm	629A531H66
R12-R18	470 Ohm	629A531H24
R19	47 K Ohm	629A531H72
R29	22 K Ohm	629A531H64
R42	33 K Ohm	629A531H68
	Zener Diodes	
Z1 to Z5-Z10 to Z13-Z16	1N3686B, 20 Volts	185A212H06
Z6-Z7-Z8-Z14-Z17-Z18	1N957B, 6.8 Volts	186A797H06
Z9-Z16	1N3688B	862A288H01

Output Board Style 202C548G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C1	0.047 Mfd	849A437H04
C2	22 Mfd	184A661H16
C3	2.2 Mfd	837A241H16
C4-C12	1.5 Mfd	187A508H09
C5-C7-C10	0.22 Mfd	763A219H21
C6	4.7 Mfd	184A661H12
C8-C9	500 Mfd	187A694H03
C11	0.1 Mfd	188A669H03
	Diodes	
D1 to D11	1N645A	837A692H03
	Transistors	
Q1-Q2-Q3-Q5-Q6- Q8-Q9-Q13	2N3417	848A851H02
Q4-Q7-Q10-Q11- Q12-Q14	2N3645	849A441H01
	Resistors	
R1-R2-R32-R40-R43	4.7 K Ohm	629A531H48
R3-R48	82 K Ohm	629A531H78
R4-R7-R8-R9-R15-R17- R19-R26-R31-R34-R36- R37-R38-R41-R45-R46	10 K Ohm	629A531H56
R5-R10-R18-R22-R42-R47	6.8 K Ohm	629A531H52
R6-R24-R25	27 K Ohm	629A531H66
R11-R13	1 K Ohm	629A531H32
R12	100 Ohm	629A531H08
R14-R16-R50	15 K Ohm	629A531H60
R20	220 K Ohm	187A641H83
R21-R33-R35-R39-R44	22 K Ohm	629A531H64
R23	47 Ohm	187A290H17
R27 (Pot)	15 K Ohm	629A430H08
R28-R29	470 Ohm	629A531H24
R30	470 K Ohm	184A763H91
R49	150 Ohm, 3 Watts	762A679H01
	Zener Diodes	
Z1	1N3686B, 20 Volts	185A212H06
Z2-Z4-Z5-Z6-Z7	1N957B, 6.8 Volts	186A797H06
Z3-Z8	1N3688A, 24 Volts	862A288H01

Relay Board Style 5312D80G01 - SKBU-2
- SKBU-21

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C201-C202-C203	0.25 Mfd	187A624H02
	Resistors	
R201	50 Ohms, 5 W	185A209H06
R202-R203 (SKBU-21)	3.3 K Ohms	
R202-R203 (SKBU-2)	2.2 K Ohms	
	Filter Choke	
L201	8.5 Hy, 450 Ohms	188A460H01
	Zener Diodes	
Z201 (SKBU-21 only)	1N1828C, 43 V	629A798H14

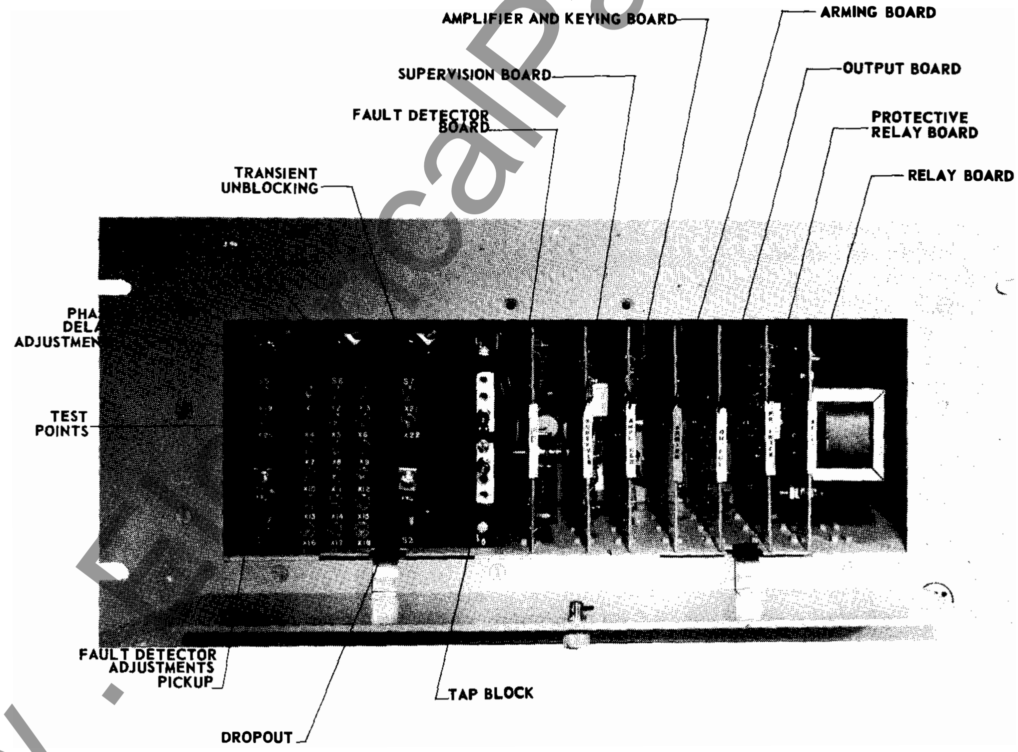


Fig. 1 Photograph (Front View).

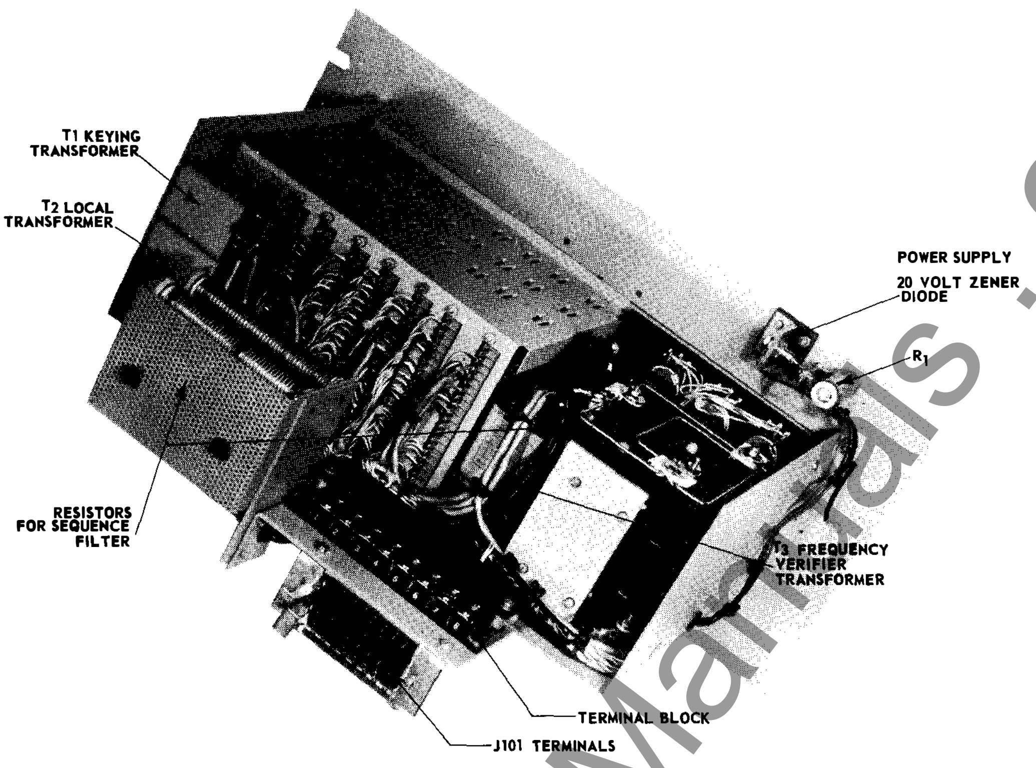


Fig. 2 Photograph (Rear View).

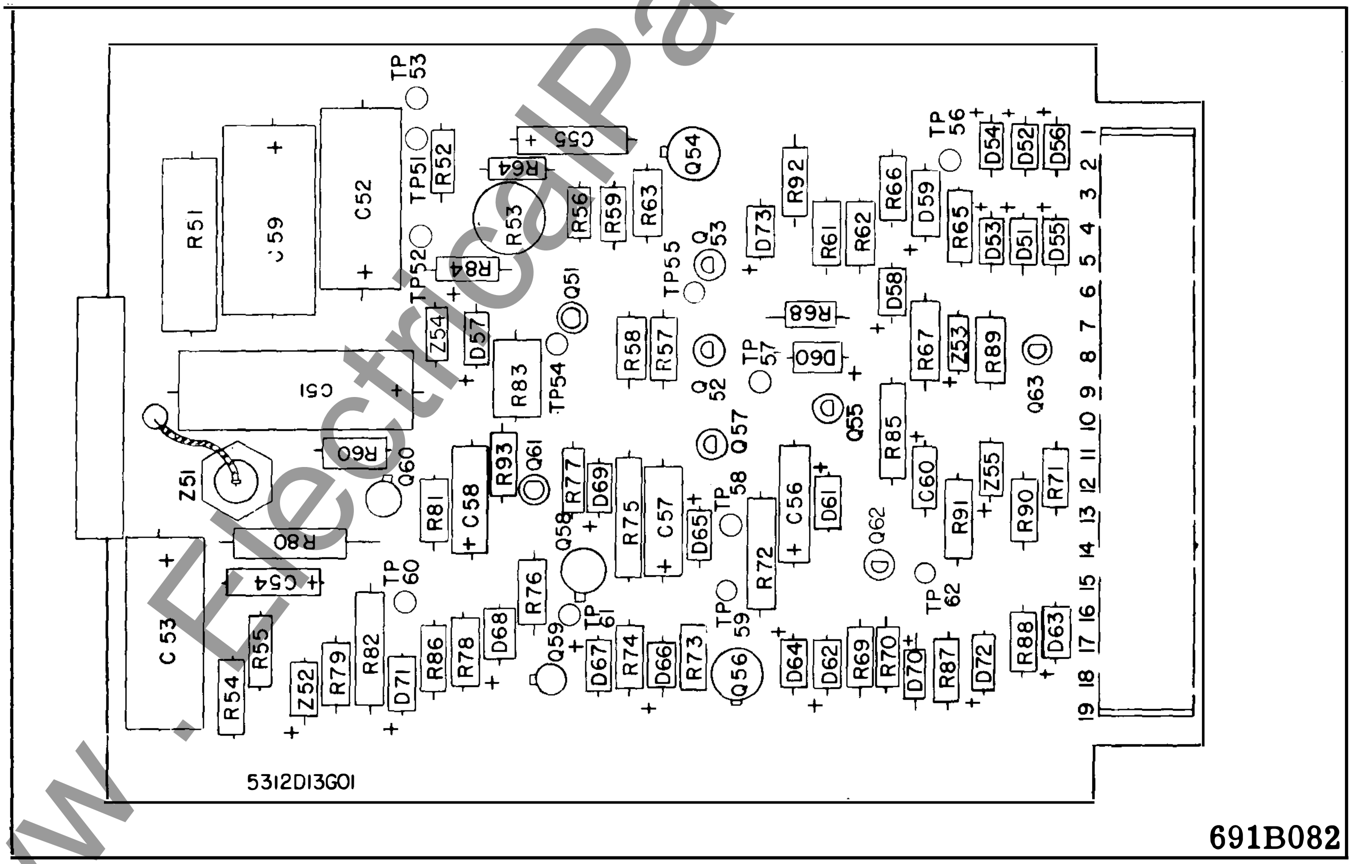


Fig. 3 Location of Components on Fault Detector Board.

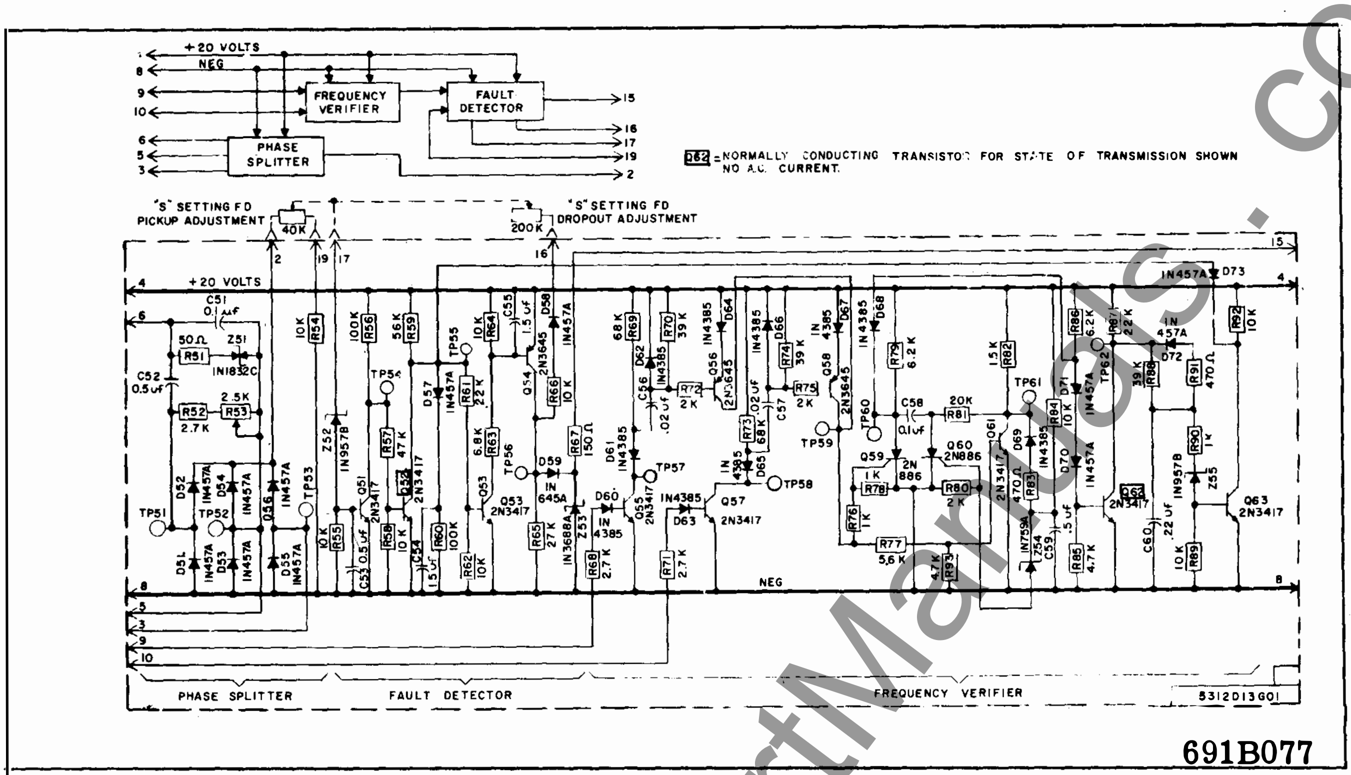


Fig. 4 Schematic of Fault Detector Board.

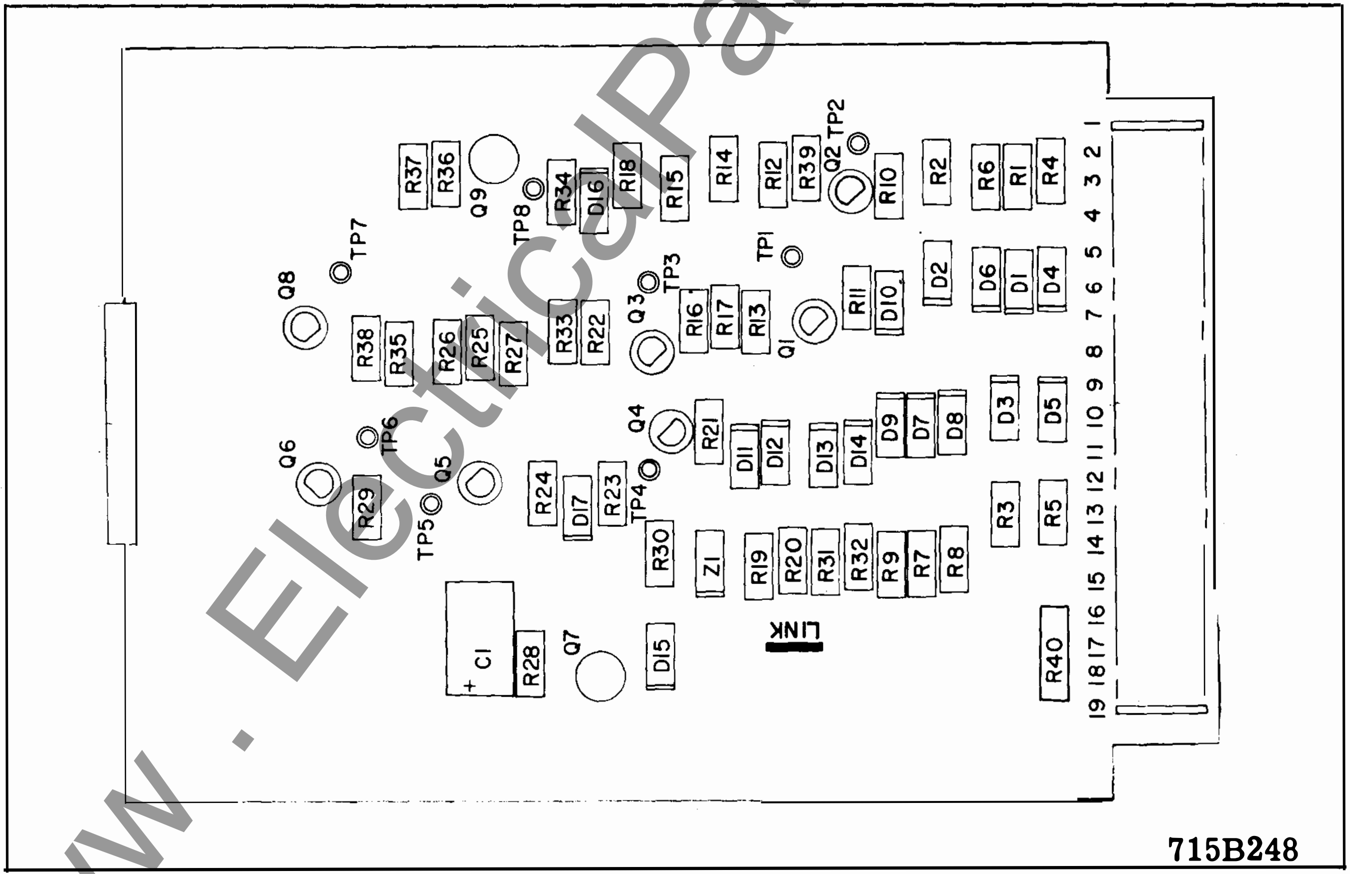
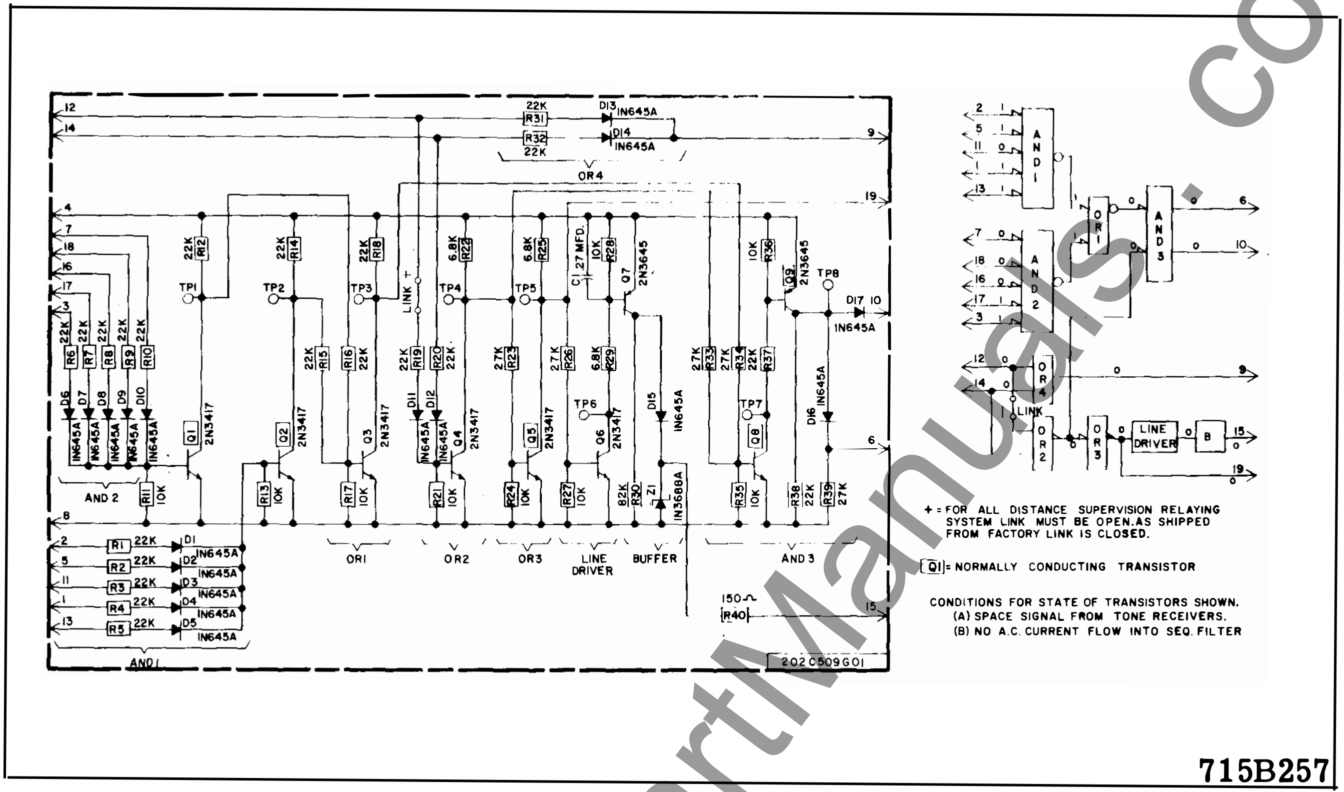


Fig. 5 Location of Components on Arming Board.



+ = FOR ALL DISTANCE SUPERVISION RELAYING SYSTEM LINK MUST BE OPEN. AS SHIPPED FROM FACTORY LINK IS CLOSED.

[Q1] = NORMALLY CONDUCTING TRANSISTOR

CONDITIONS FOR STATE OF TRANSISTORS SHOWN.
(A) SPACE SIGNAL FROM TONE RECEIVERS.
(B) NO A.C. CURRENT FLOW INTO SEQ. FILTER

Fig. 6 Schematic of Arming Board.

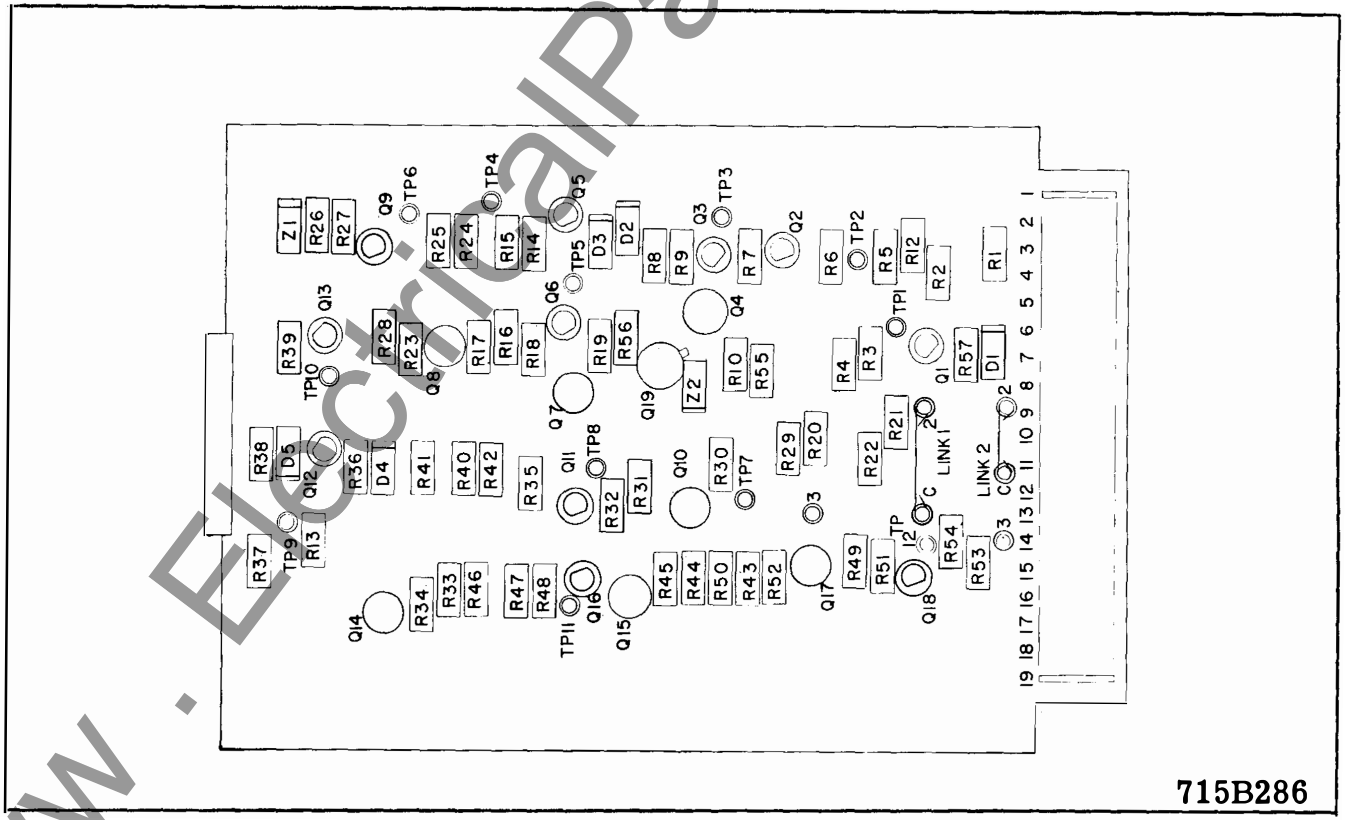


Fig. 7 Location of Components on Amplifier and Keying Board for TA-2 Tone Channel.

Q2 = TRANSISTORS ARE NORMALLY CONDUCTING.
CONDITIONS FOR STATE OF TRANSISTORS SHOWN
(1) SPACE SIGNAL BEING RECEIVED
(2) NO A.C. CURRENT FLOW INTO SEQ. FILTER
⊢ = CONNECT LINK TO PROPER TERMINAL AS SHIPPED FROM FACTORY LINK CONNECTED FOR 2 TERMINAL LINE.

VALUES OF R57

TYPE CHANNEL	K OHMS	STYLE BOARD
TA2 TONE	27	202C551G01
TA2.1 TONE	5.1	202C551G02

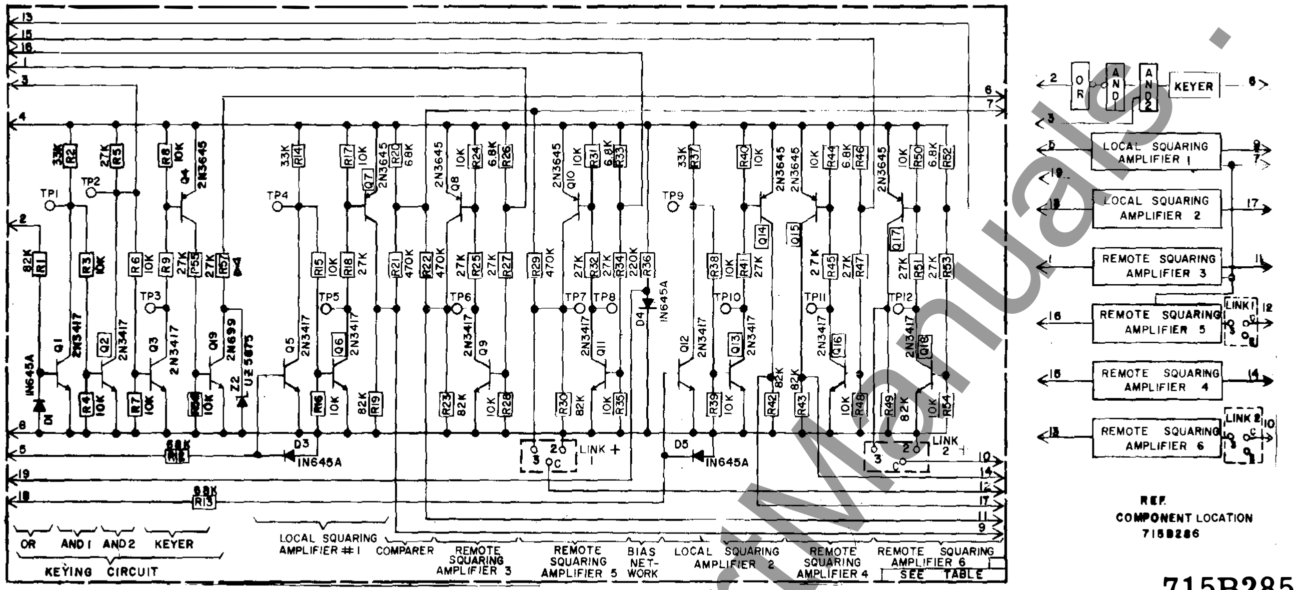


Fig. 8 Schematic of Amplifier and Keying Board for TA-2 Tone Channel.

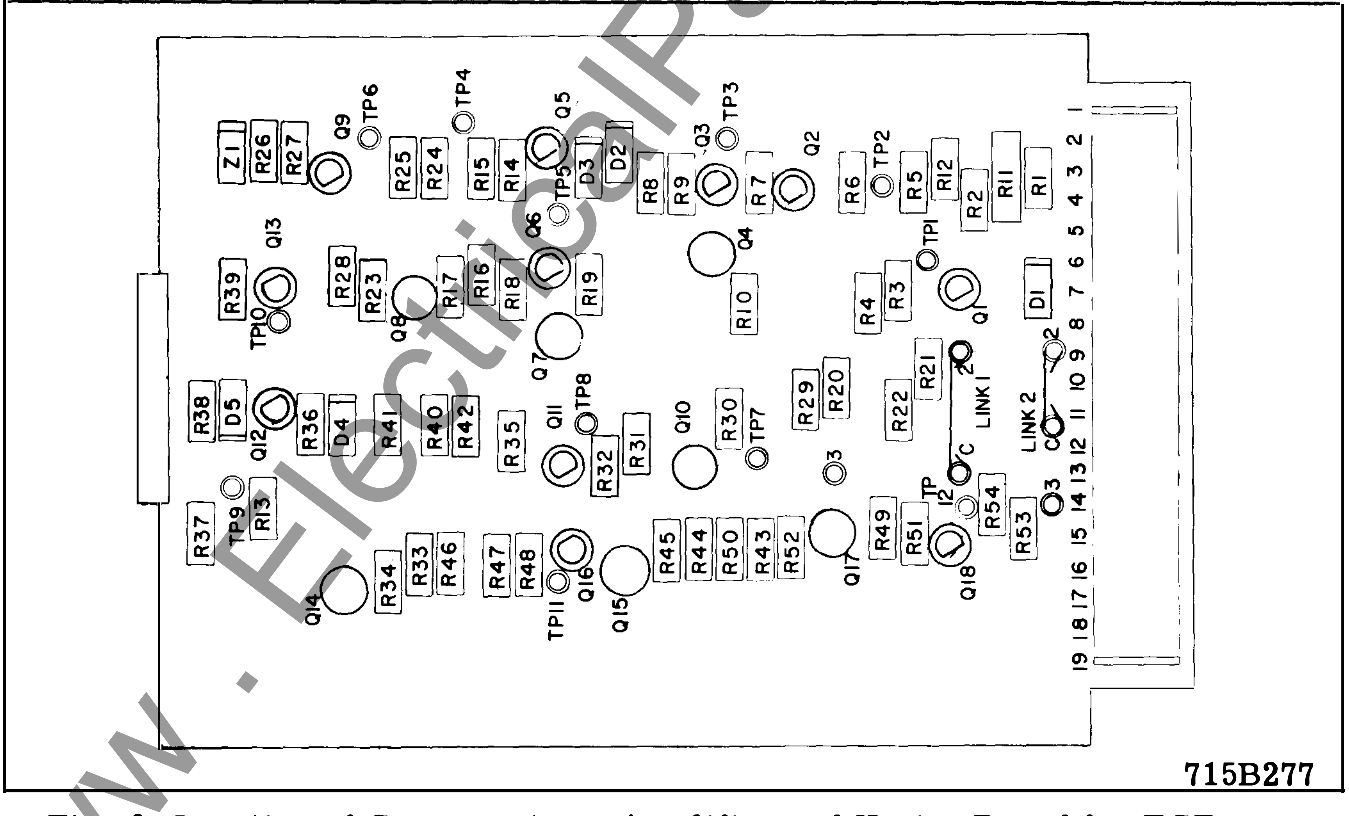


Fig. 9 Location of Components on Amplifier and Keying Board for TCF Carrier Channel.

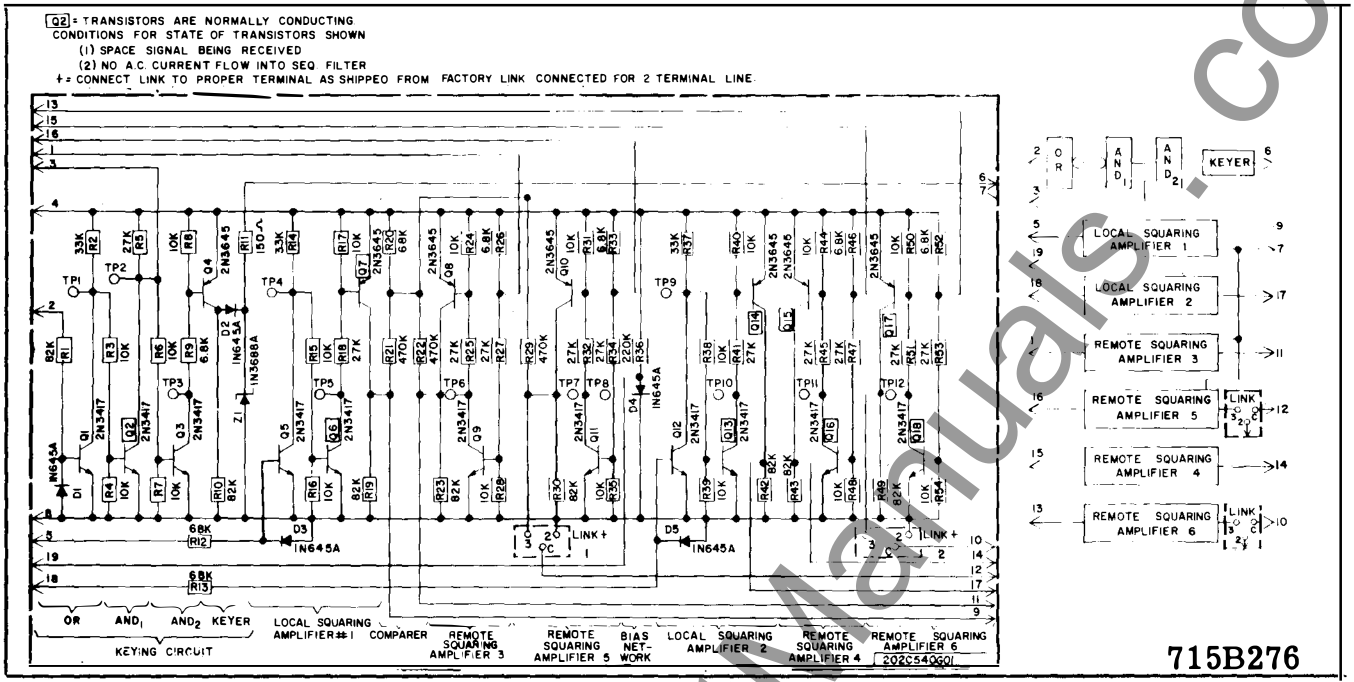


Fig. 10 Schematic of Amplifier and Keying Board for TCF Carrier Channel.

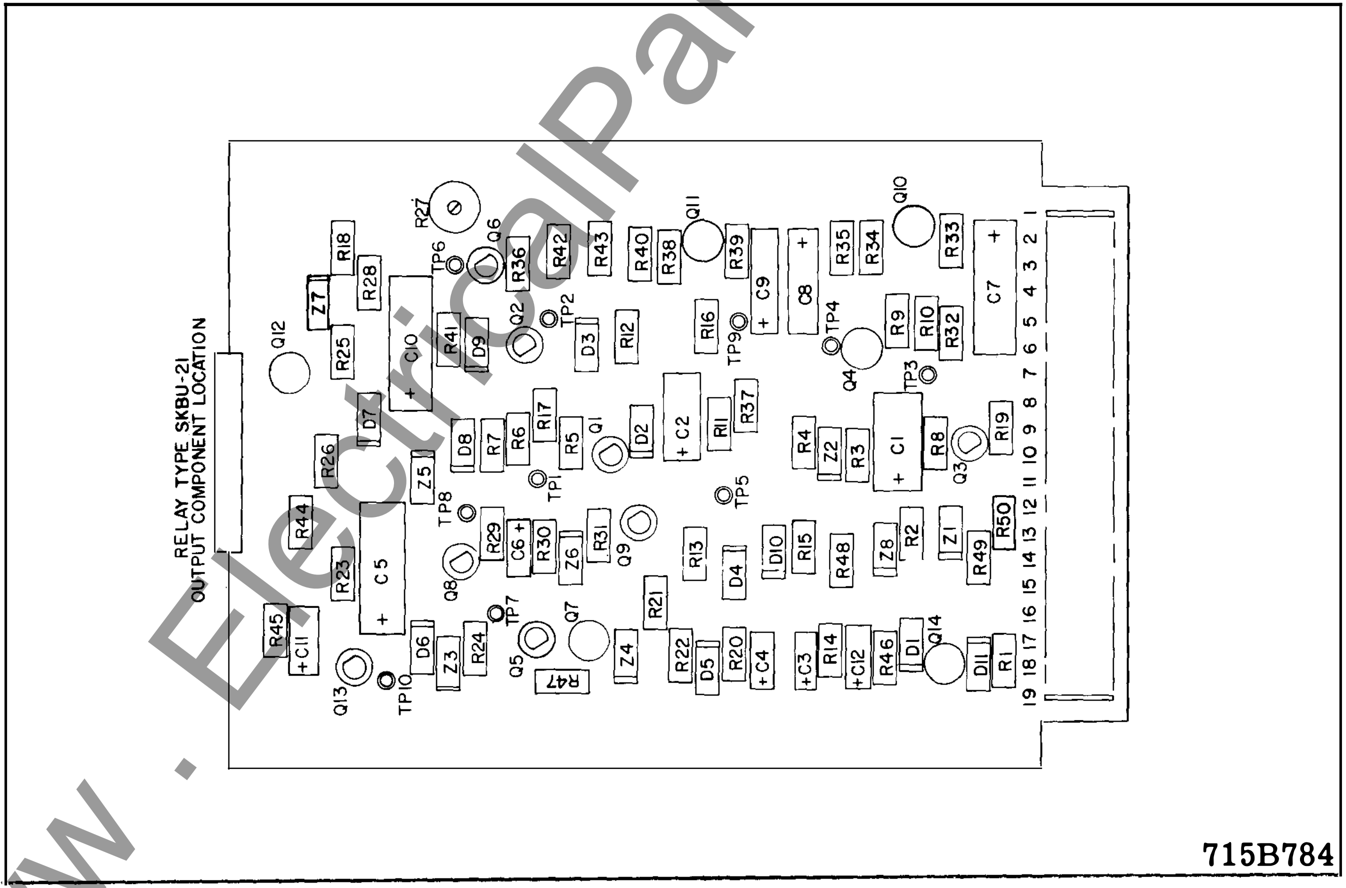


Fig. 11 Location of Components on Output Board.

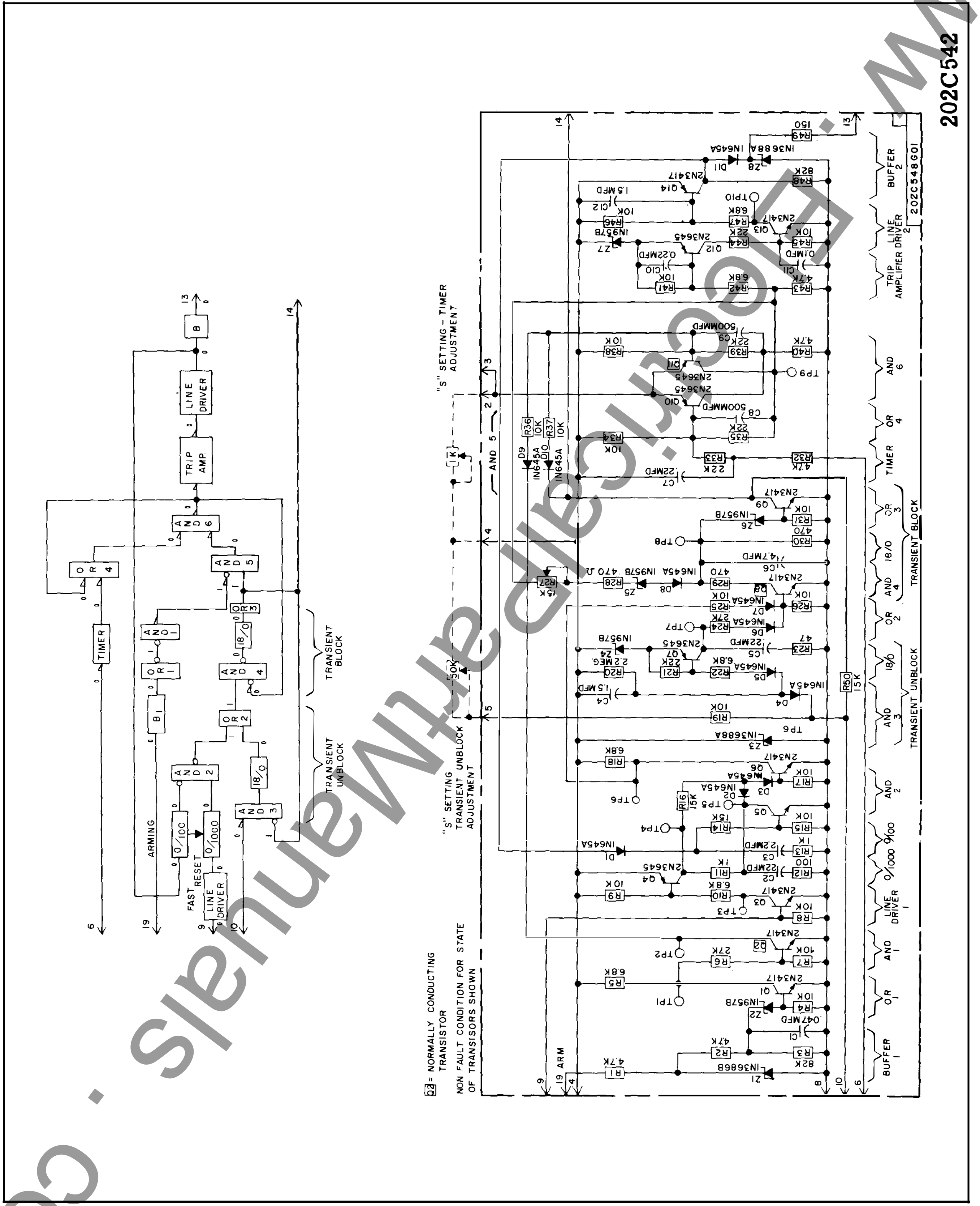


Fig. 12 Schematic of Output Board.

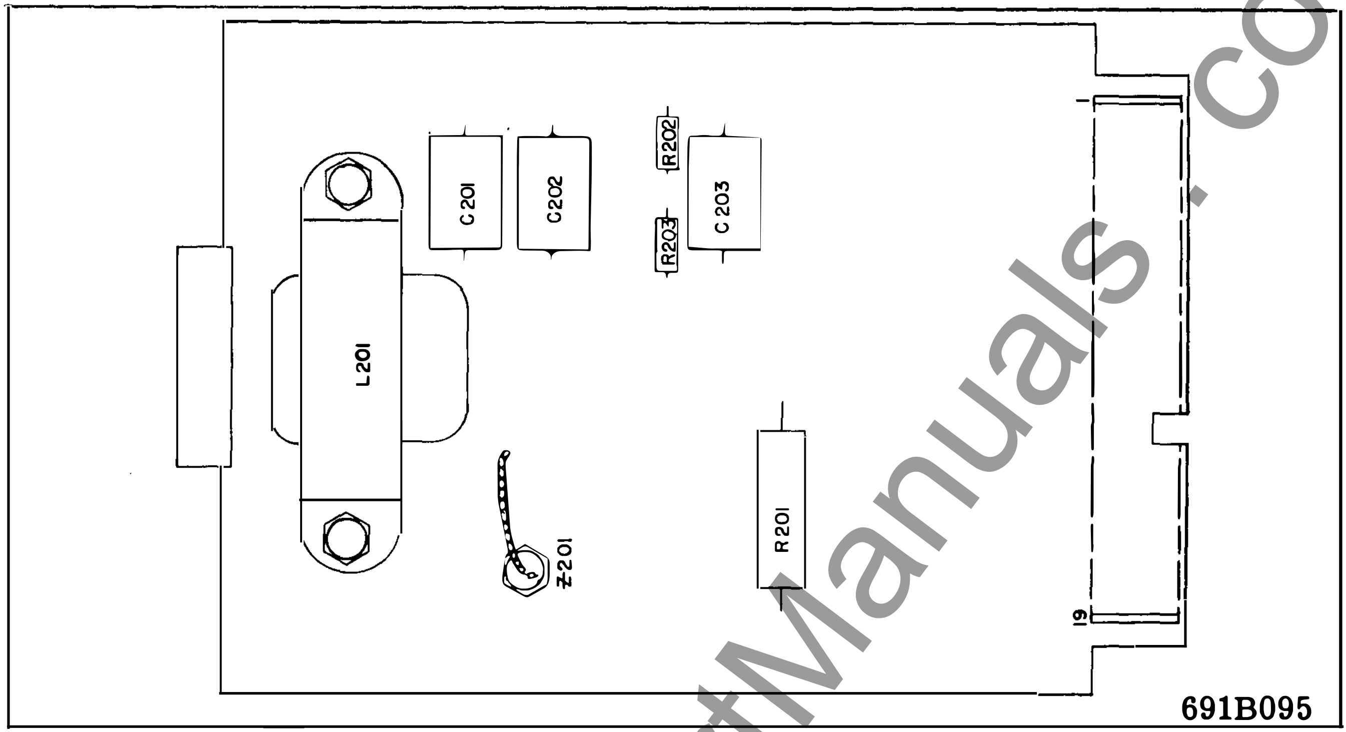


Fig. 13 Location of Components on Relay Board.

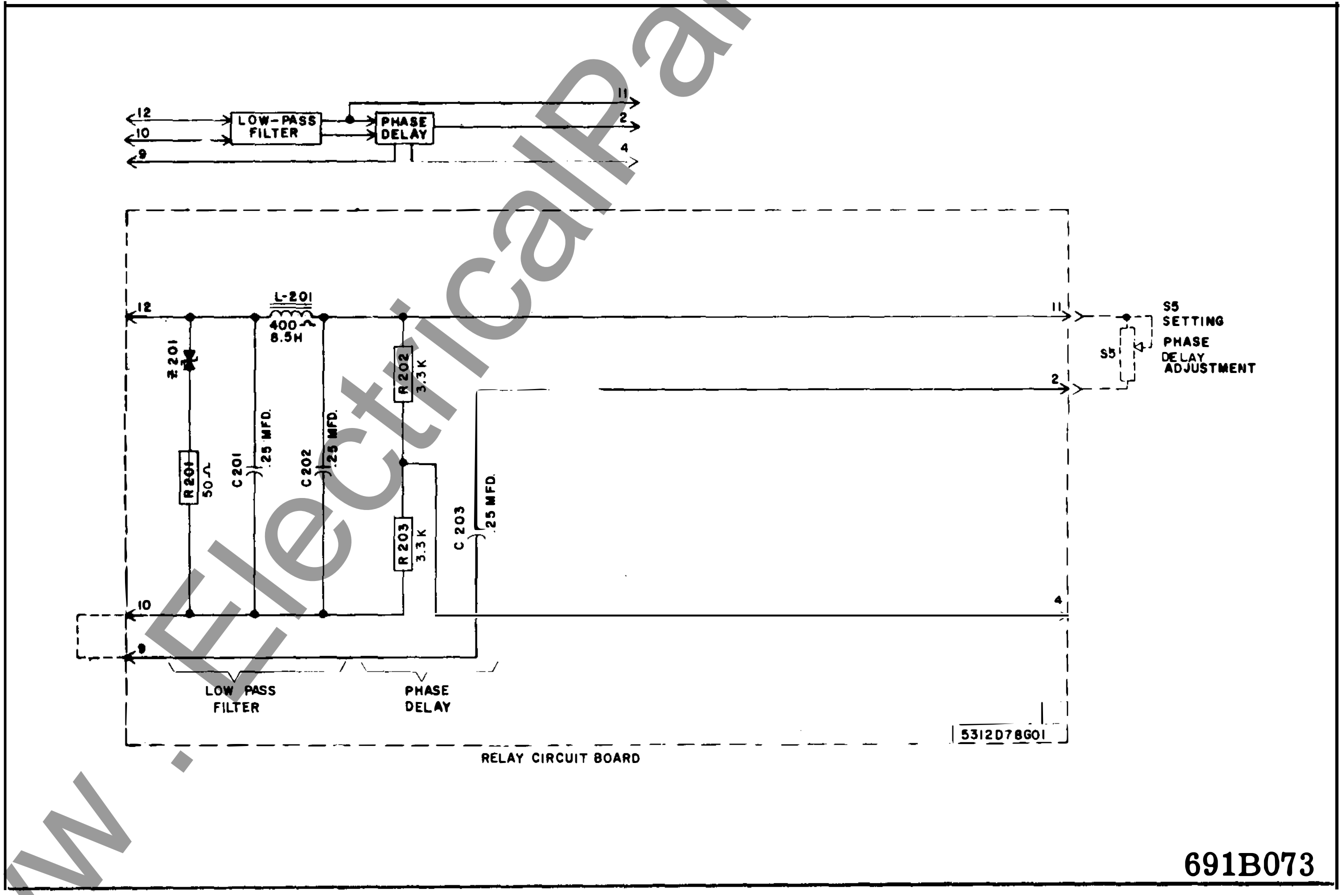


Fig. 14 Schematic of Relay Board

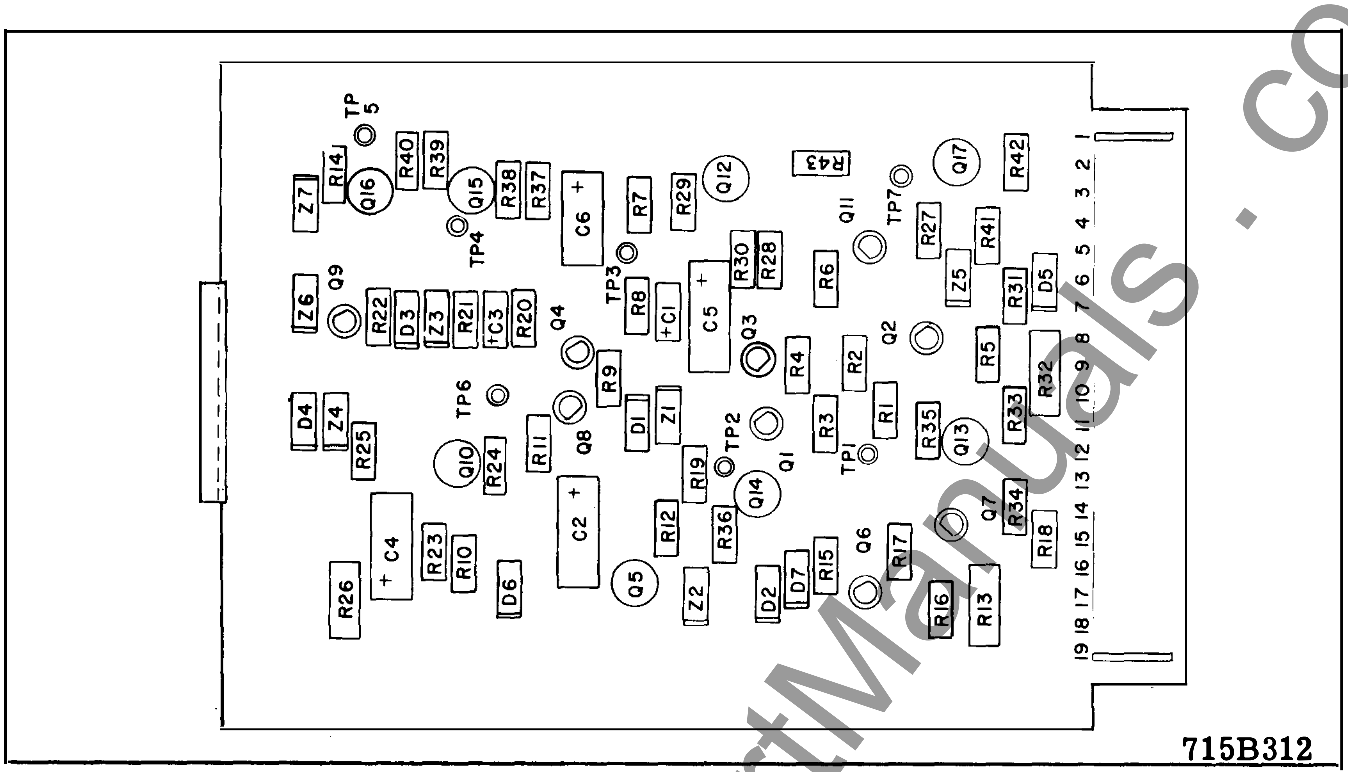


Fig. 15 Location of Components on Supervision Board for TA-2 Tone Channel.

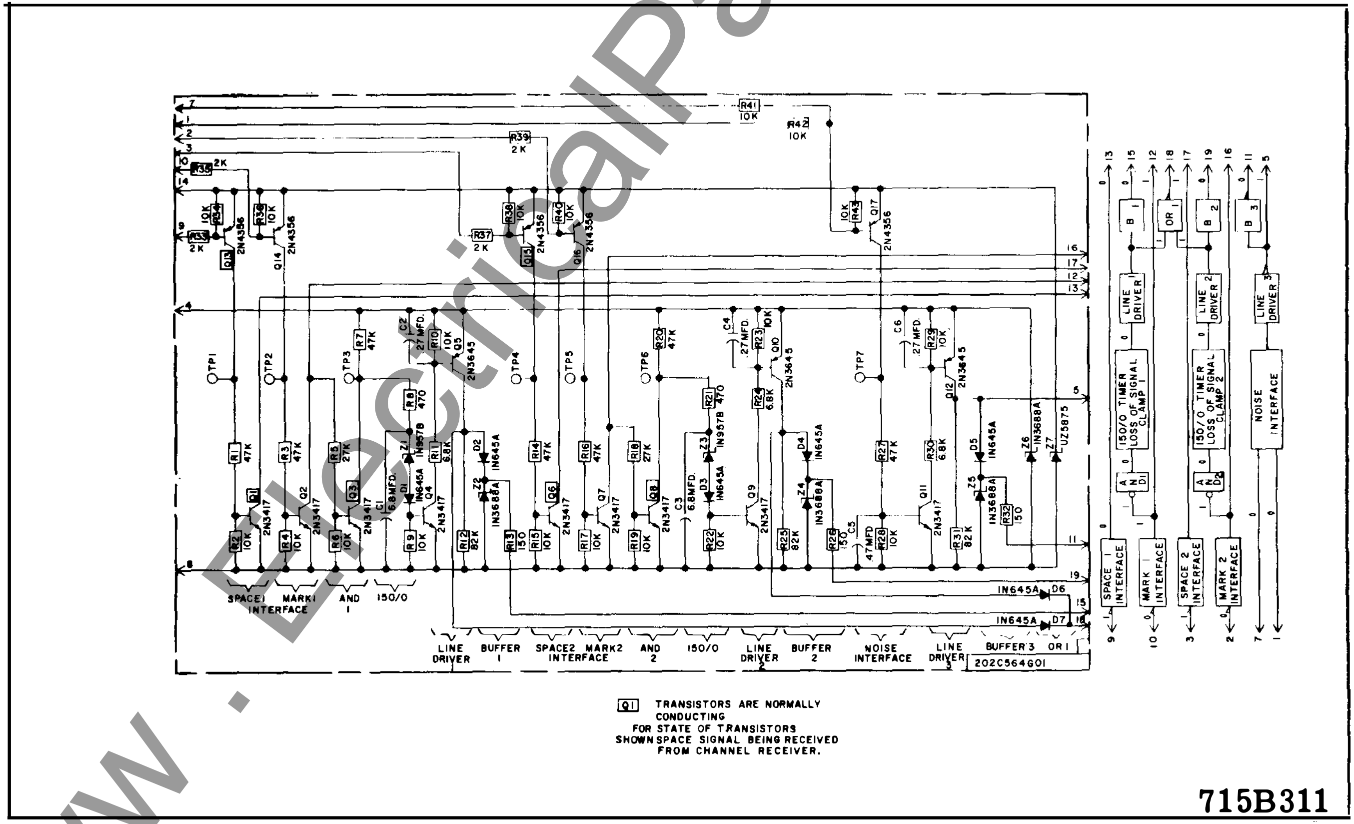


Fig. 16 Schematic of Supervision Board for TA-2 Tone Channel.

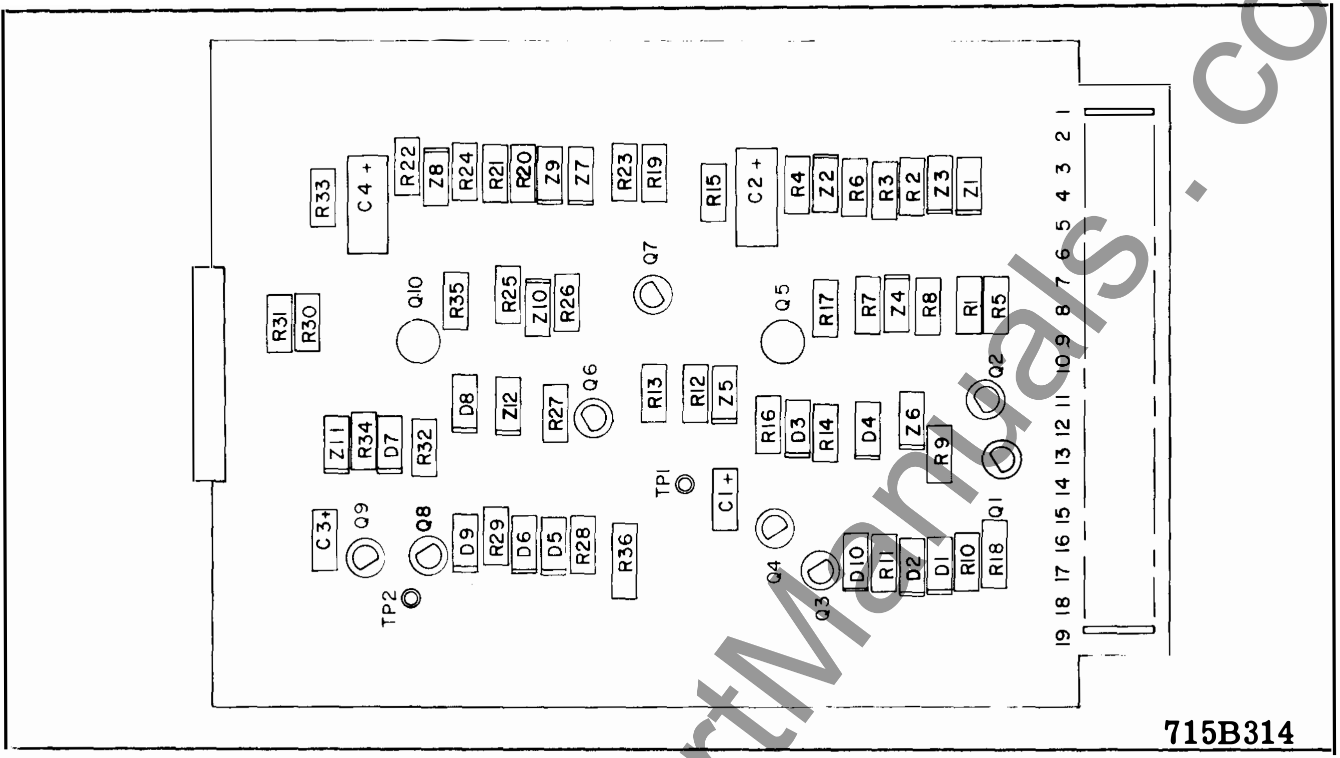


Fig. 17 Location of Components on Supervision Board for TCF Carrier Channel.

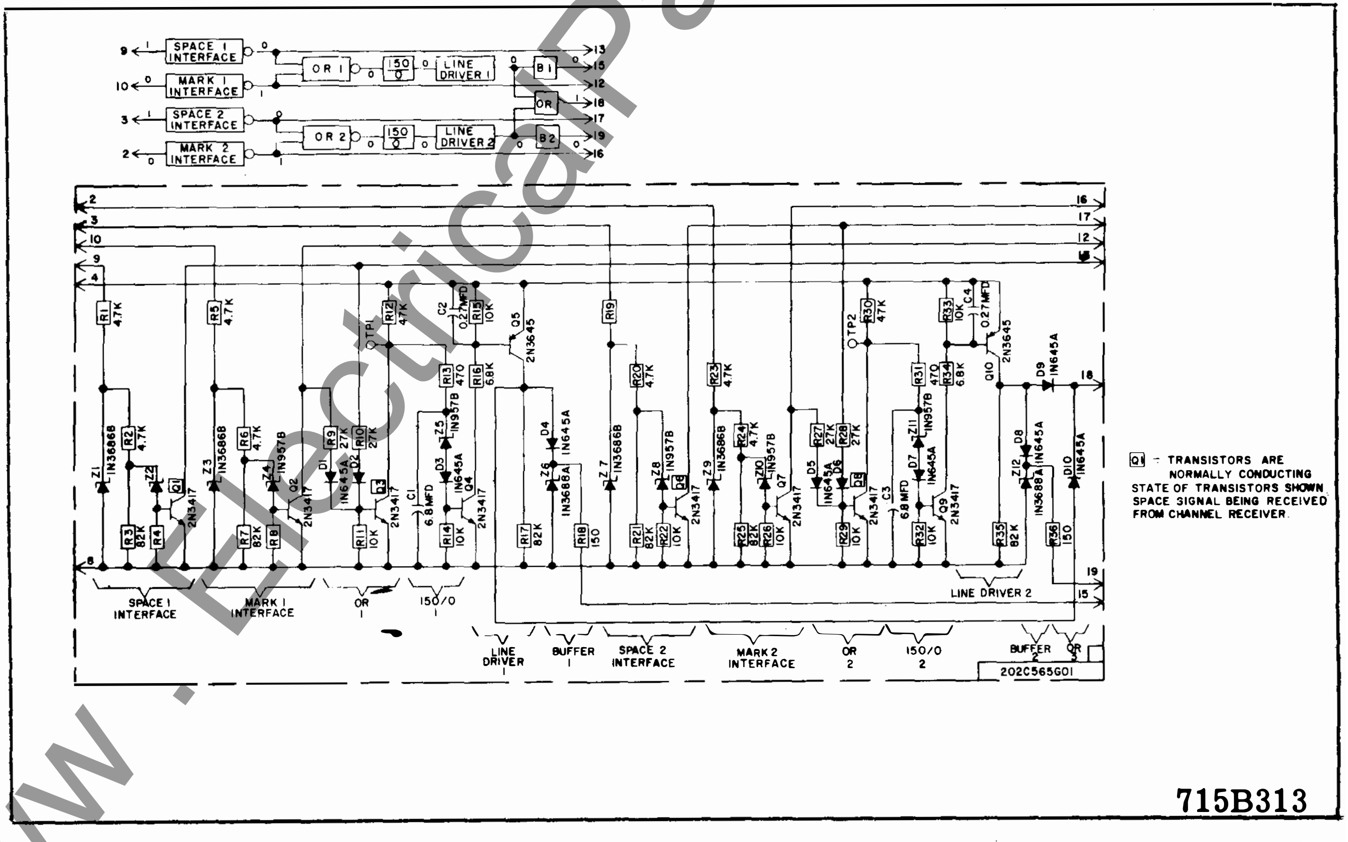


Fig. 18 Schematic of Supervision Board for TCF Carrier Channel.

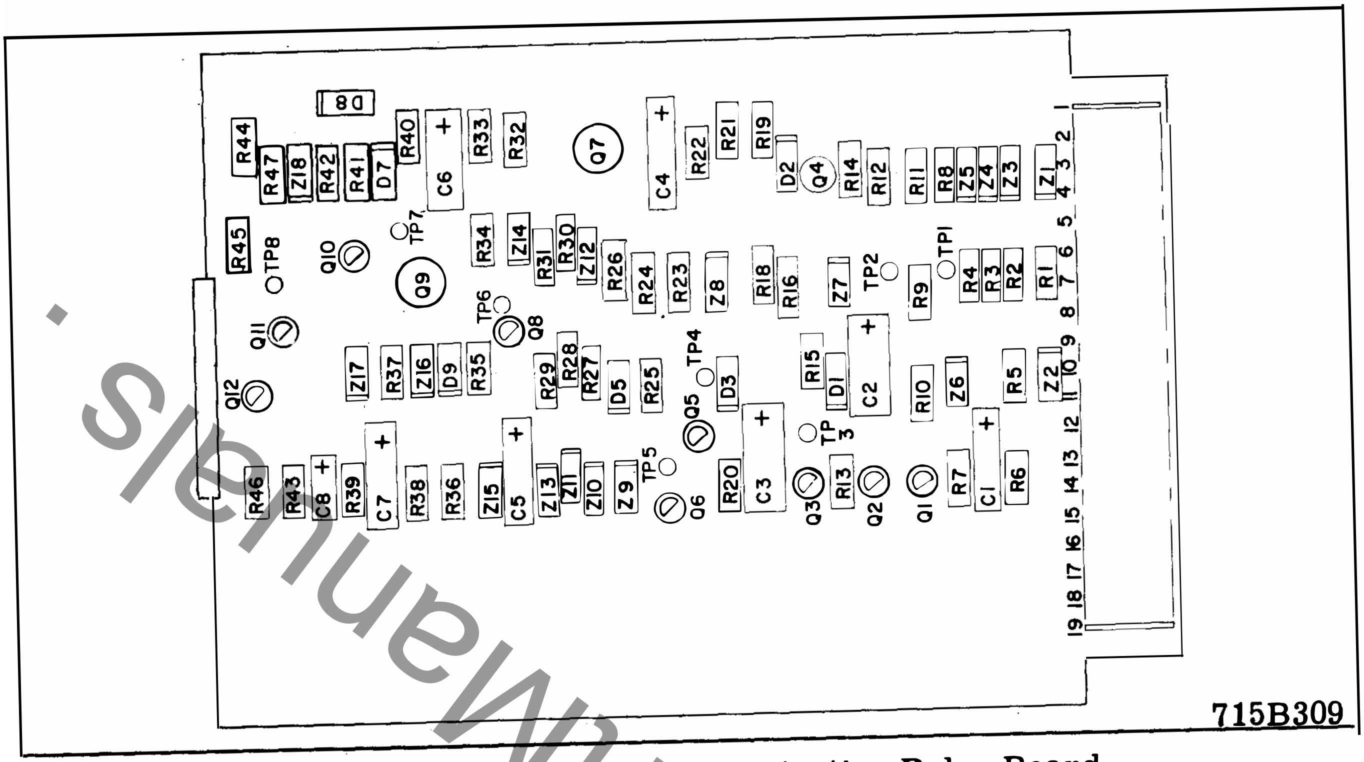


Fig. 19 Location of Components on Protective Relay Board.

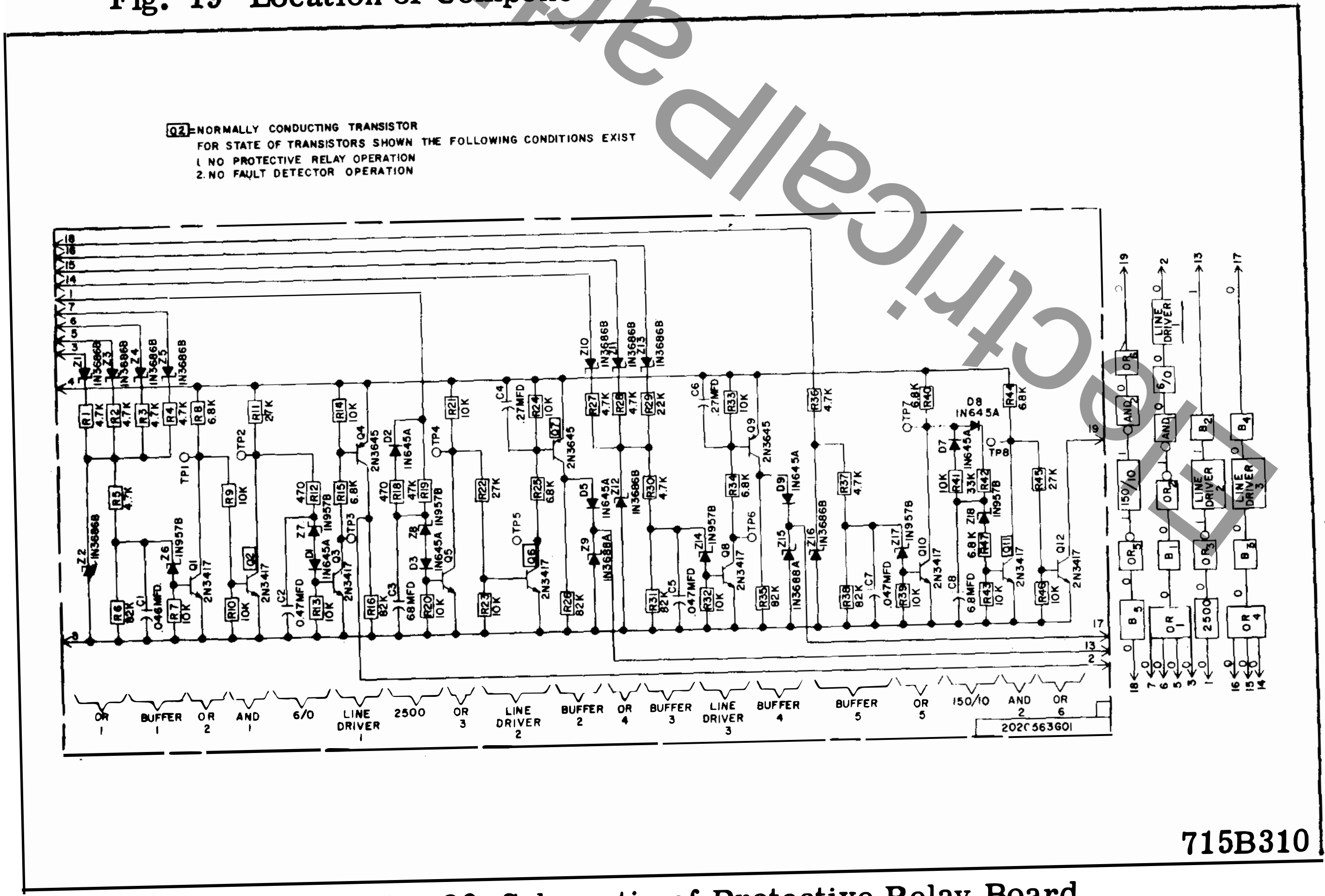


Fig. 20 Schematic of Protective Relay Board.

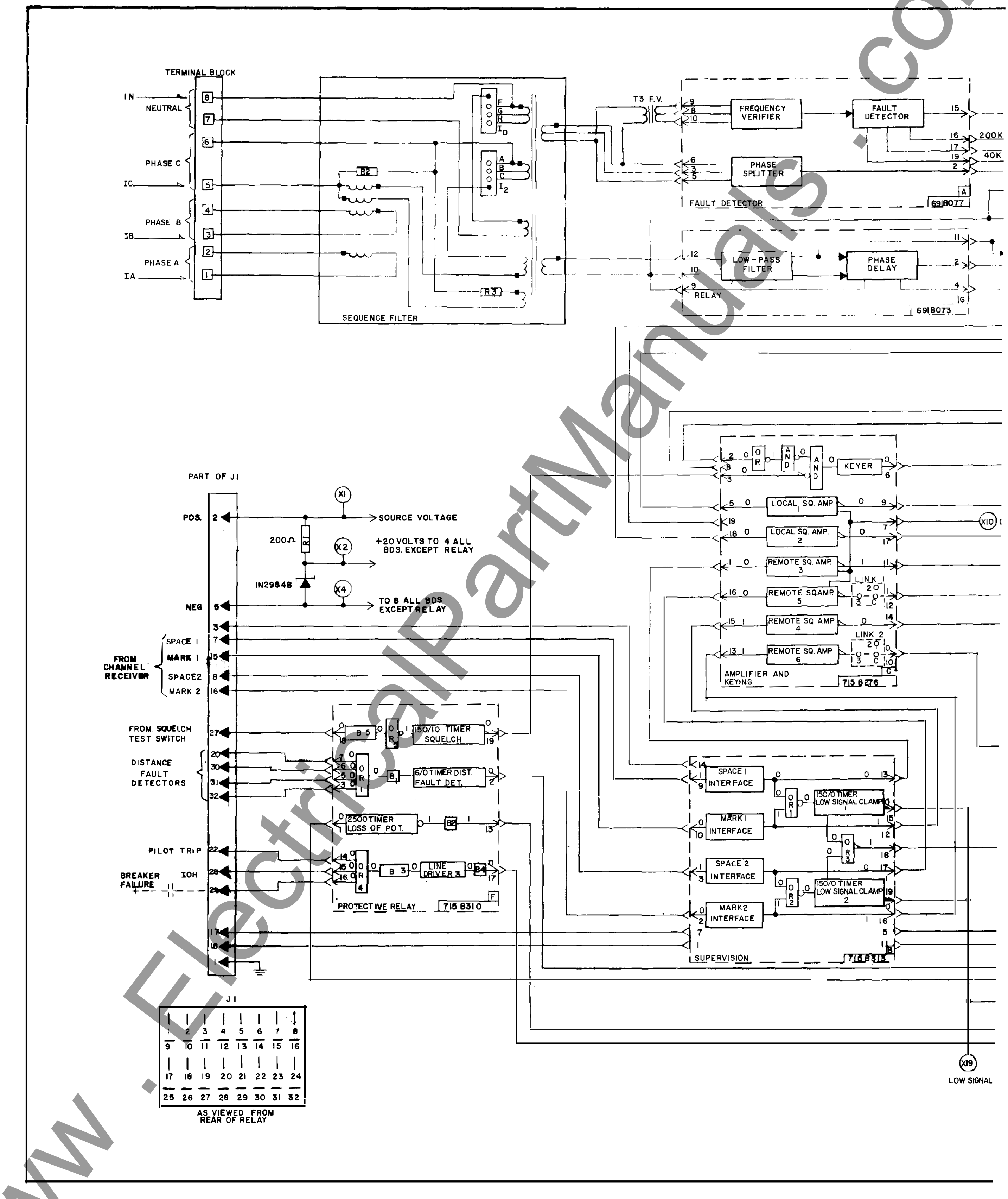
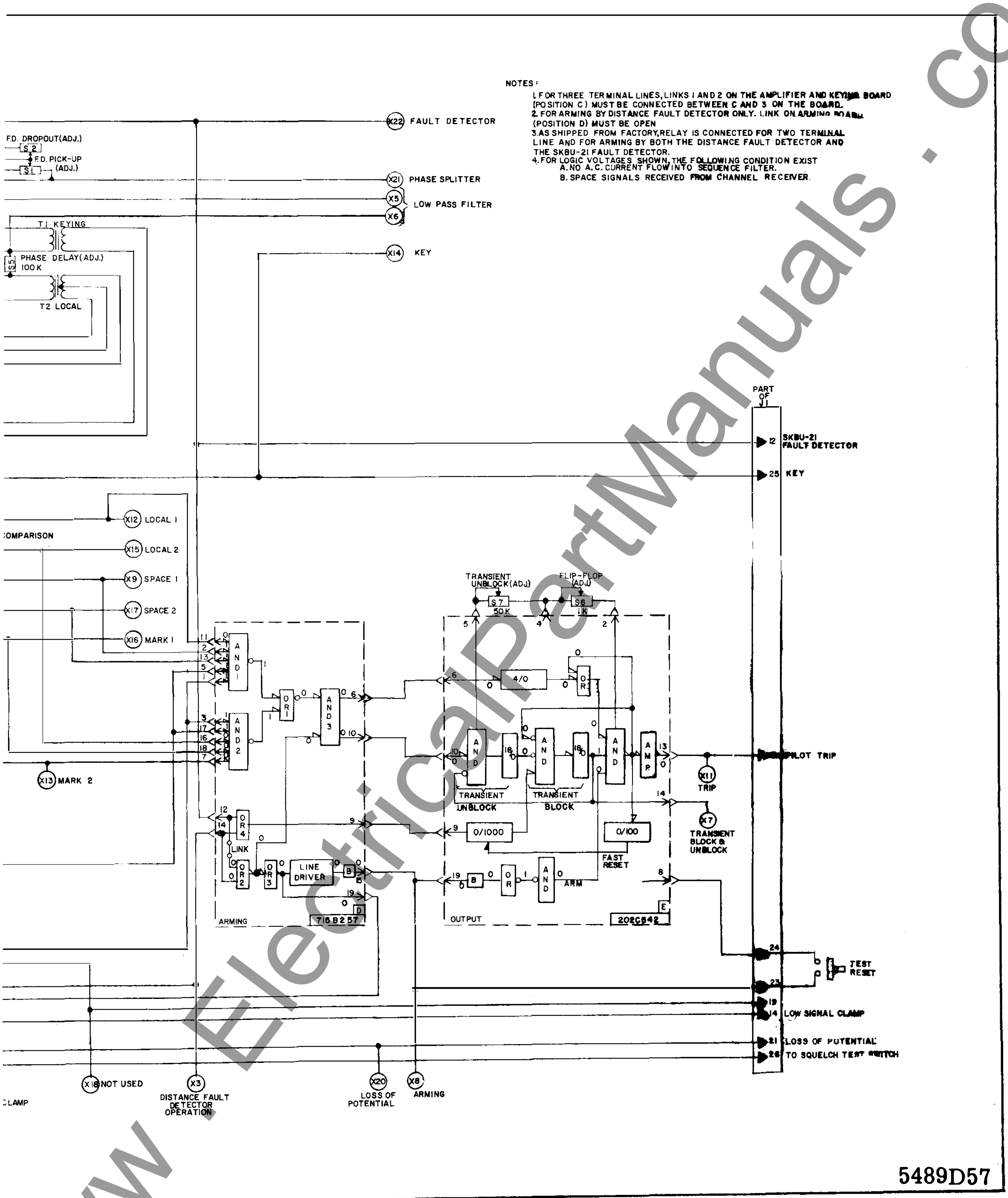


Fig. 22 Logic Diagram o



NOTES:

1. FOR THREE TERMINAL LINES, LINKS 1 AND 2 ON THE AMPLIFIER AND KEYING BOARD (POSITION C) MUST BE CONNECTED BETWEEN C AND 3 ON THE BOARD.
2. FOR ARMING BY DISTANCE FAULT DETECTOR ONLY. LINK ON ARMING BOARD (POSITION D) MUST BE OPEN
3. AS SHIPPED FROM FACTORY, RELAY IS CONNECTED FOR TWO TERMINAL LINE AND FOR ARMING BY BOTH THE DISTANCE FAULT DETECTOR AND THE SKBU-21 FAULT DETECTOR.
4. FOR LOGIC VOLTAGES SHOWN, THE FOLLOWING CONDITION EXIST
   - A. NO A.C. CURRENT FLOW INTO SEQUENCE FILTER.
   - B. SPACE SIGNALS RECEIVED FROM CHANNEL RECEIVER.

f SKBU-21 for TCF Carrier Channel.

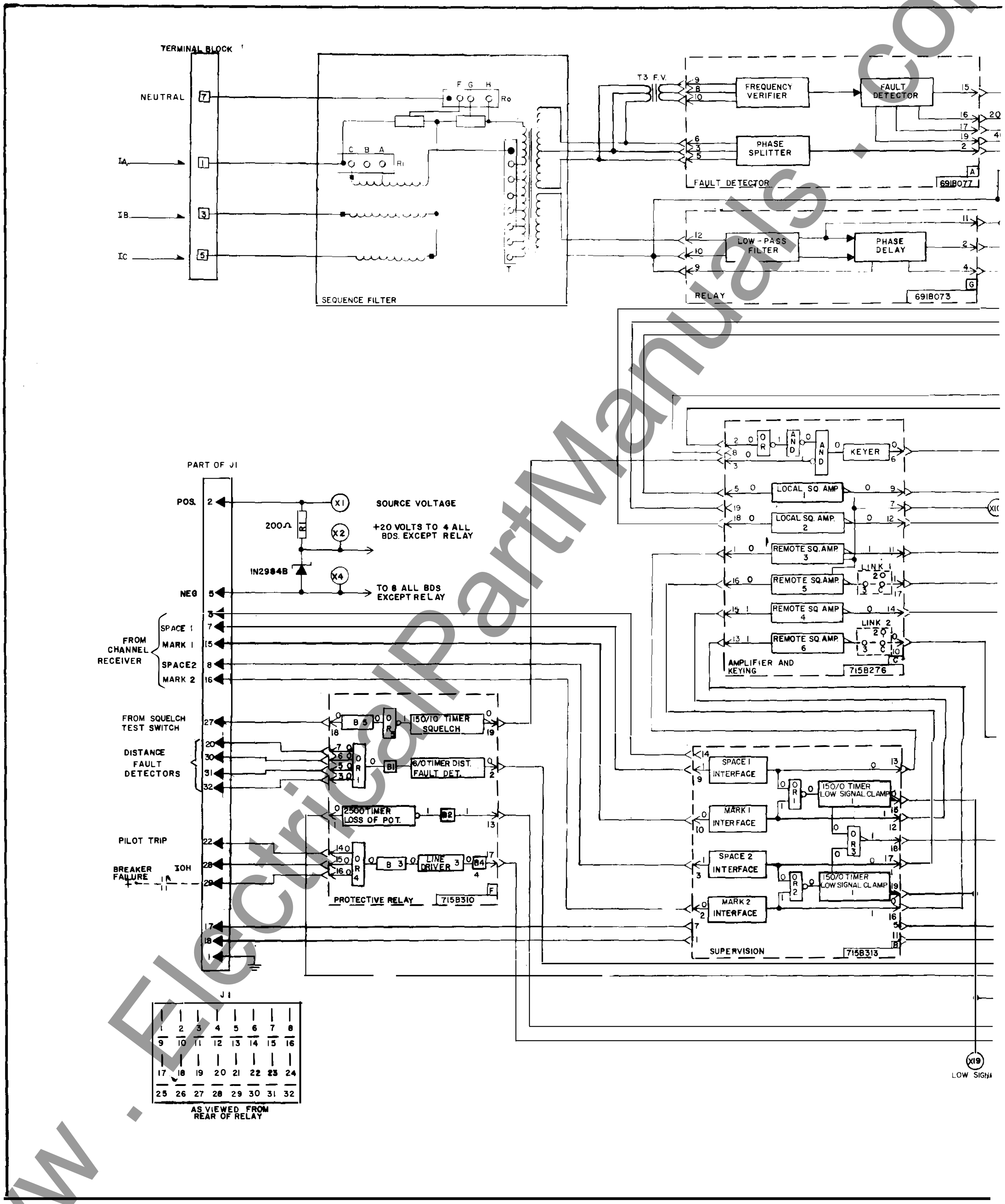
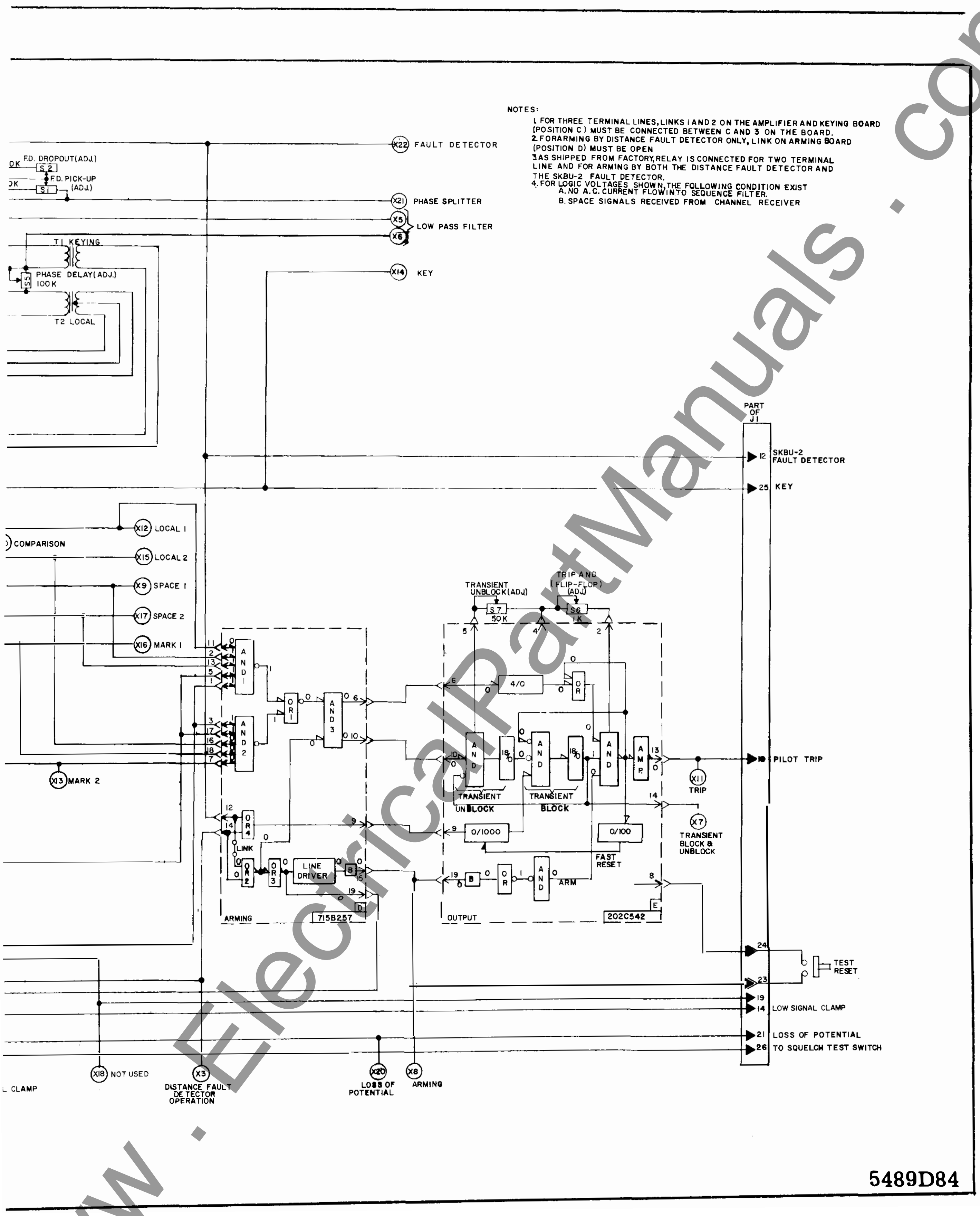


Fig. 24 Logic Diagram of S



NOTES:

1. FOR THREE TERMINAL LINES, LINKS 1 AND 2 ON THE AMPLIFIER AND KEYING BOARD (POSITION C) MUST BE CONNECTED BETWEEN C AND 3 ON THE BOARD.
2. FOR ARMING BY DISTANCE FAULT DETECTOR ONLY, LINK ON ARMING BOARD (POSITION D) MUST BE OPEN
3. AS SHIPPED FROM FACTORY, RELAY IS CONNECTED FOR TWO TERMINAL LINE AND FOR ARMING BY BOTH THE DISTANCE FAULT DETECTOR AND THE SKBU-2 FAULT DETECTOR.
4. FOR LOGIC VOLTAGES SHOWN, THE FOLLOWING CONDITION EXIST
   A. NO A.C. CURRENT FLOW INTO SEQUENCE FILTER.
   B. SPACE SIGNALS RECEIVED FROM CHANNEL RECEIVER

KBU-2 for TCF Carrier Channel.

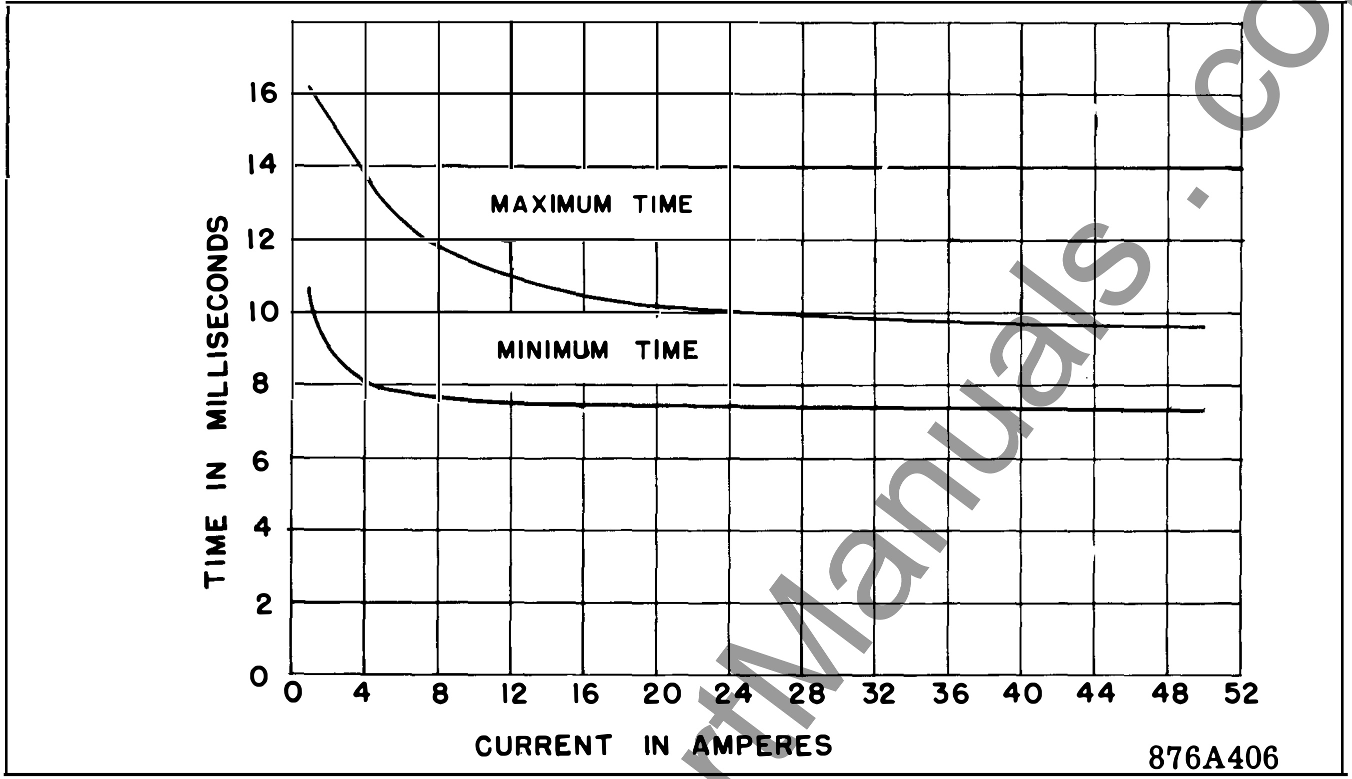


Fig. 25 Operating Times of Fault Detector of SKBU-21 Relay.

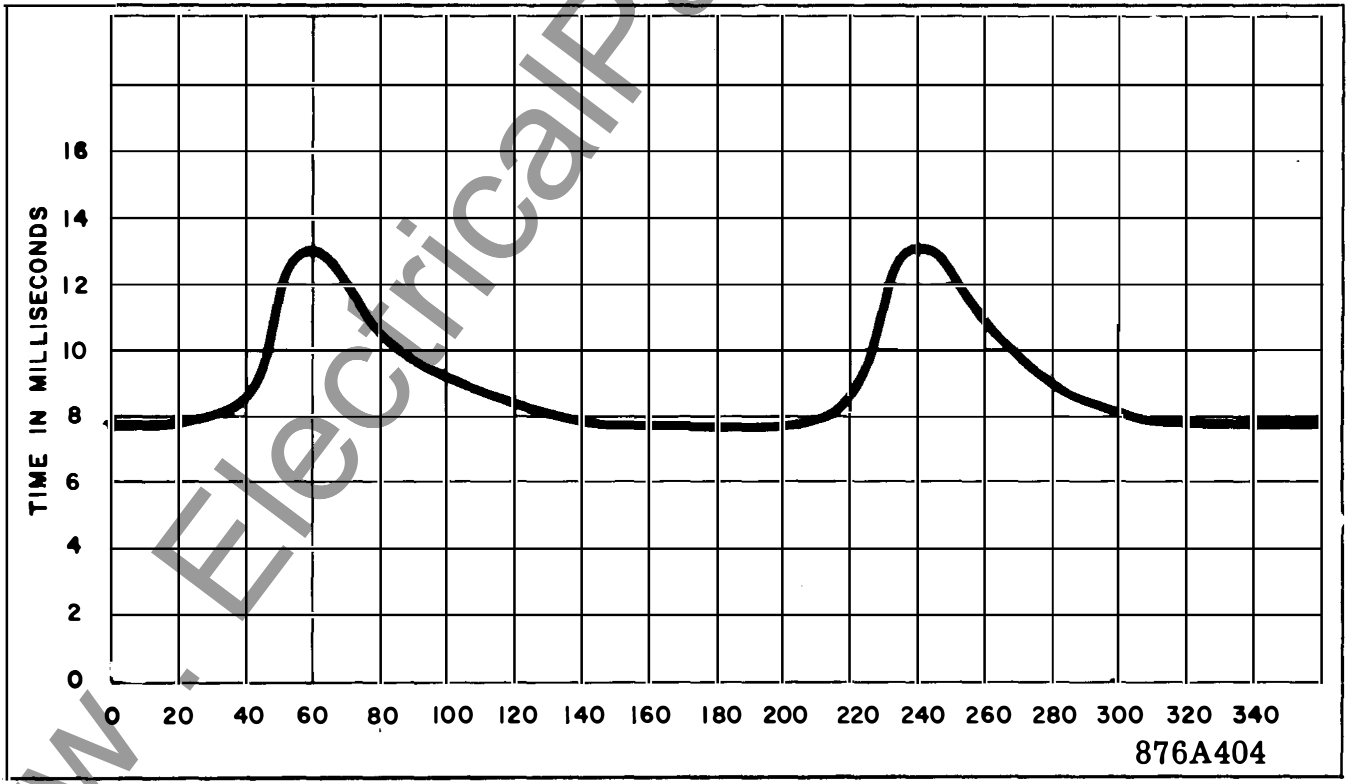


Fig. 26 Operating Times for Fault Detector of SKBU-21 Relay as a Function of Fault Incidence Angle at 5 amperes.

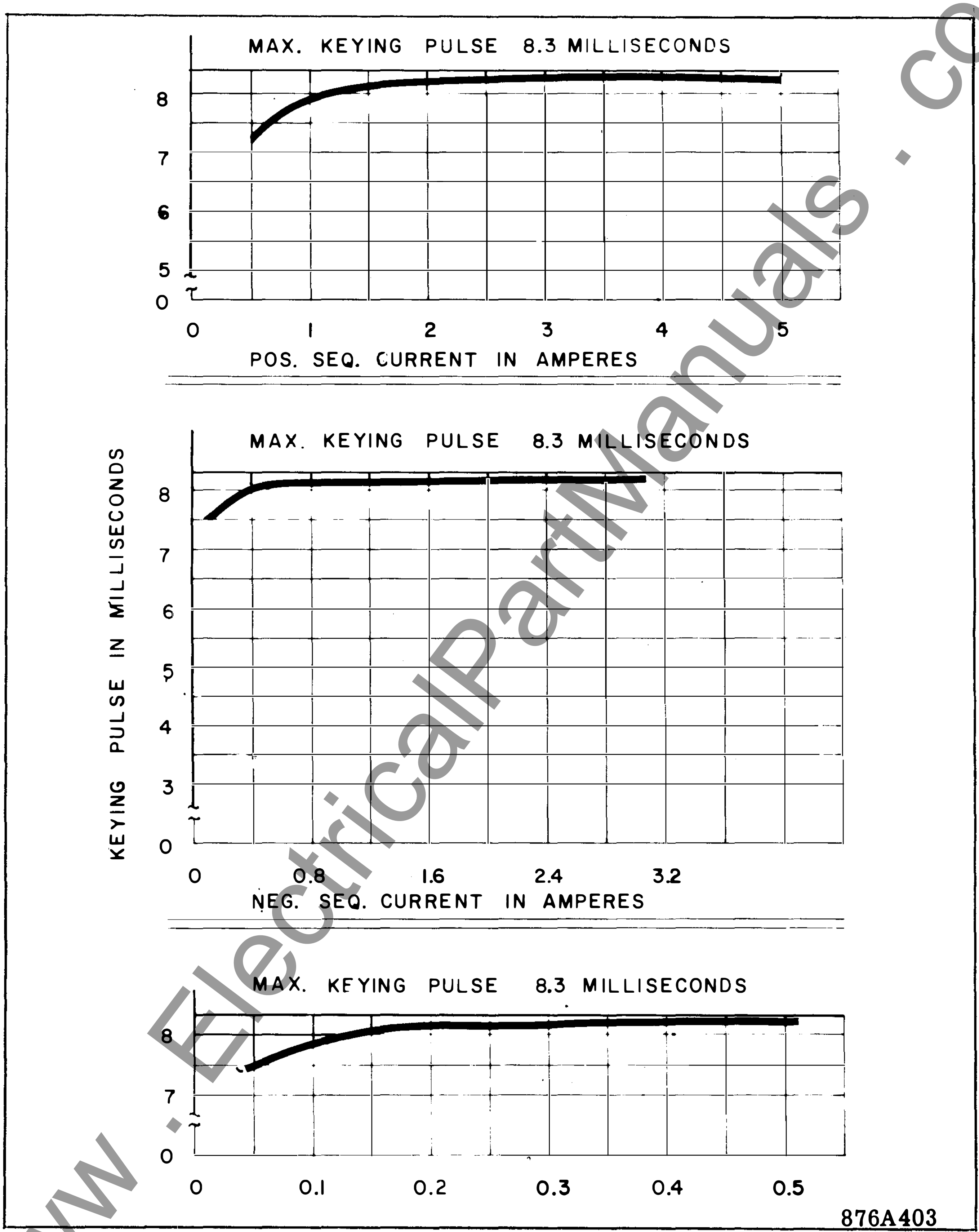


Fig. 27 Width of Keying Pulses at Different Current Levels of SKBU-21Relay.

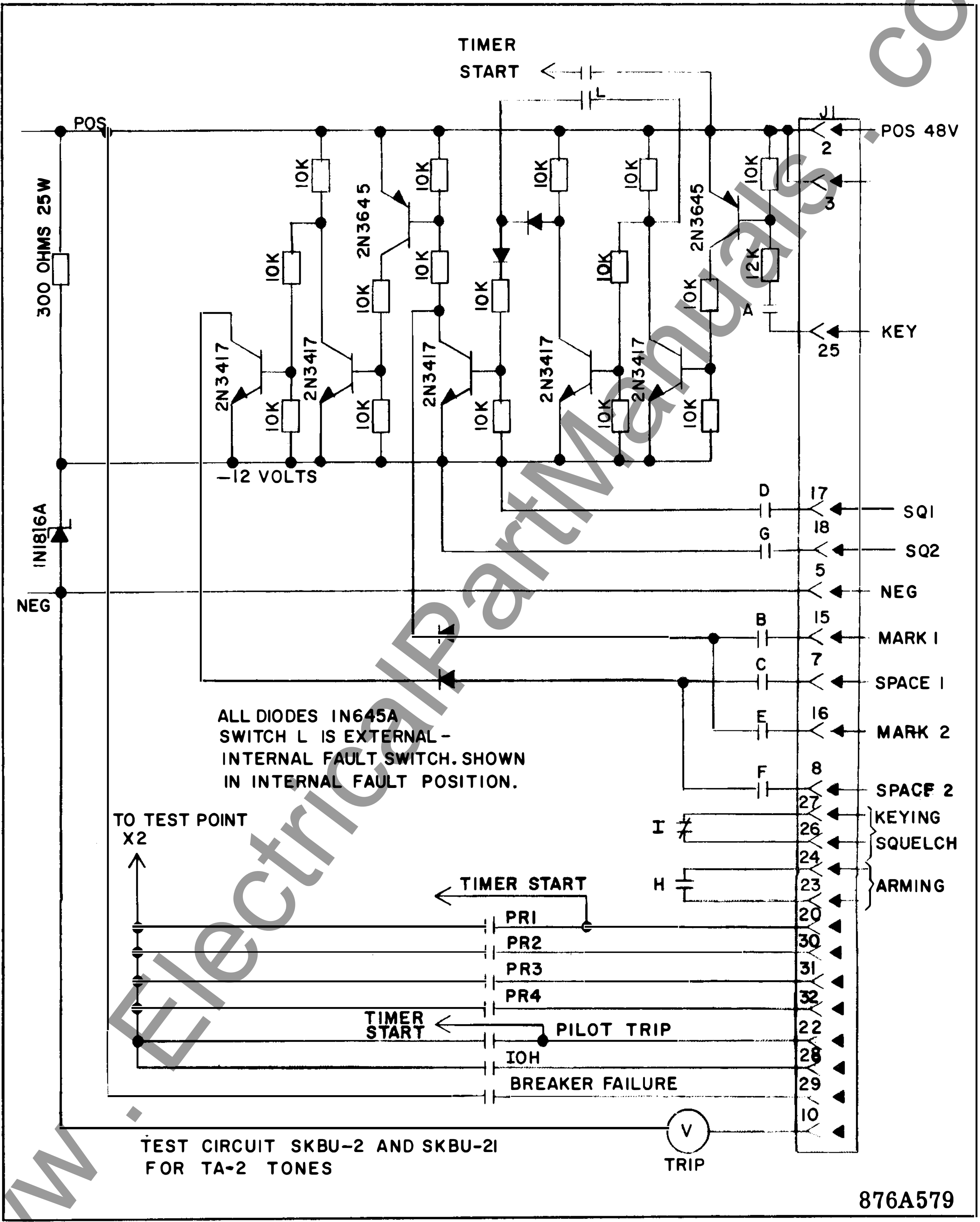
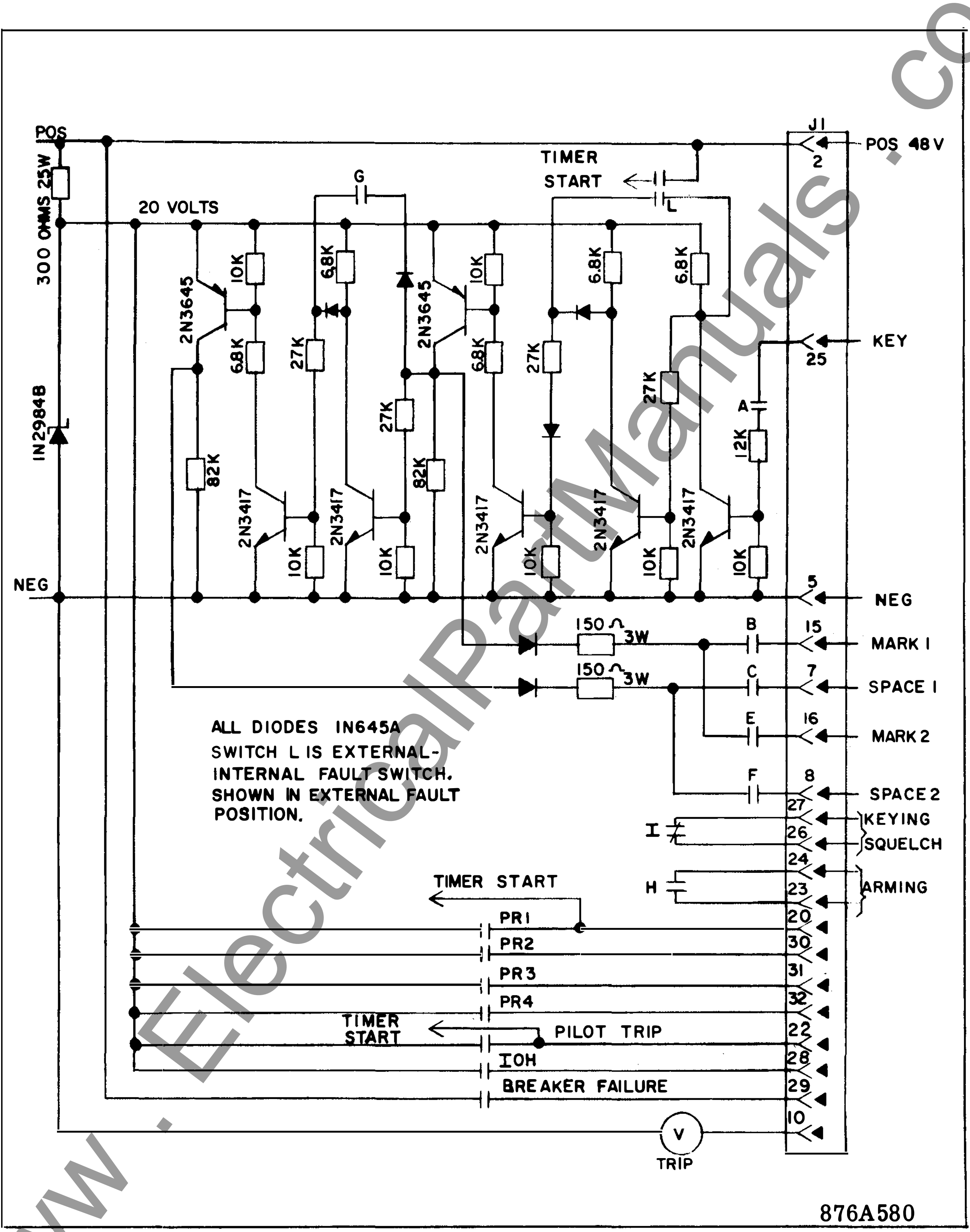
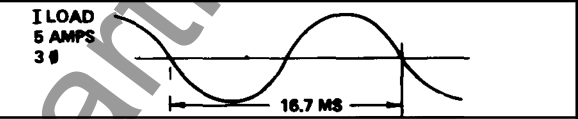
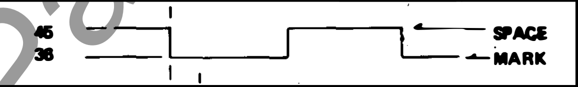
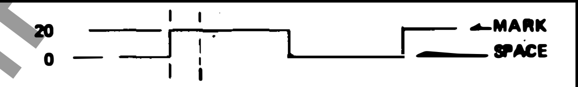
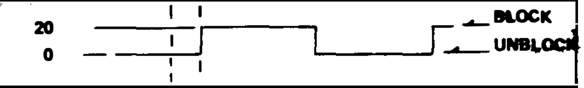
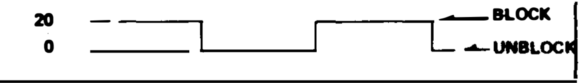
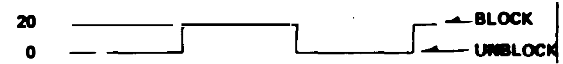
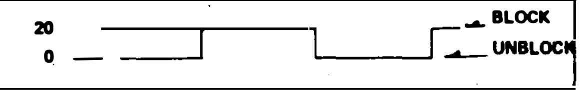


Fig. 28 Test Circuit of SKBU-21 Relay for TA-2 Tone Channel.



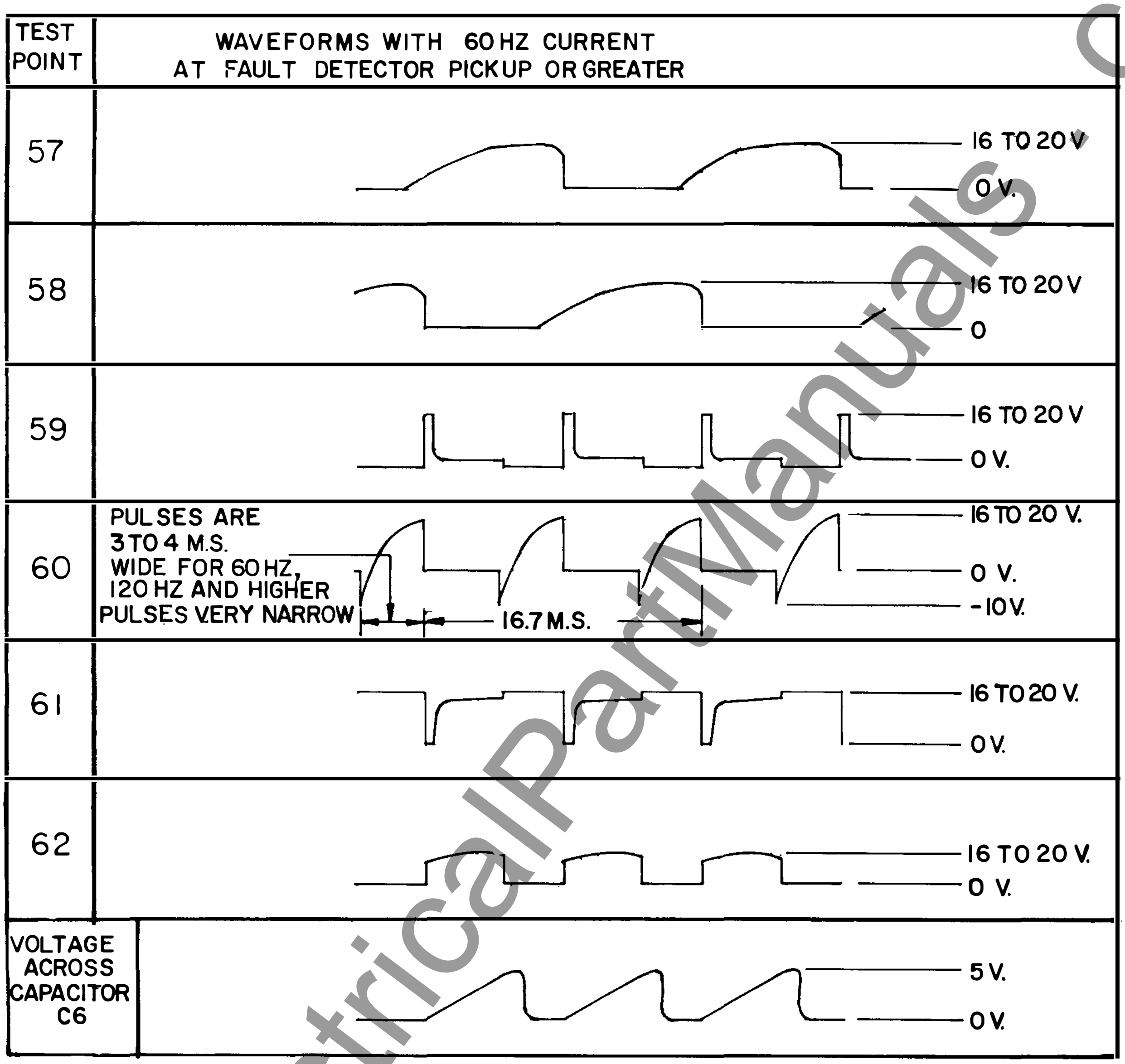
ALL DIODES IN645A
SWITCH L IS EXTERNAL-INTERNAL FAULT SWITCH.
SHOWN IN EXTERNAL FAULT POSITION.

Fig. 29 Test Circuit of SKBU-21 Relay for TCF Carrier Channel.

TEST POINT	CIRCUIT	VOLTAGE TO X4
X1	D.C. INPUT VOLTAGE	48 VOLTS D.C.
X2	REGULATED D.C.	20 VOLTS D.C.
X4	BATTERY NEGATIVE	
X7	TRANSIENT BLOCK	NORMAL 20 VOLTS OPERATE 0 VOLTS
X8	ARMING	NORMAL 20 VOLTS OPERATE 0 VOLTS
X11	PILOT TRIP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X18	NOISE (TA-2 ONLY)	NORMAL 0 VOLTS OPERATE 20 VOLTS
X3	DISTANCE FAULT DETECTOR OPERATION	NORMAL 0 VOLTS OPERATE 20 VOLTS
X19	LOSS OF SIGNAL CLAMP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X20	LOSS OF POTENTIAL	NORMAL 20 VOLTS OPERATE 0 VOLTS
X22	FAULT DETECTOR	NORMAL 0 VOLTS OPERATE 20 VOLTS
X5 TO X6(GND)	LOW PASS FILTER	
X14	KEYING TA-2 TONE CHANNEL	
X14	KEYING TCF POWER LINE CARRIER CHANNEL	
X12	LOCAL SIGNAL 1	
X9	SPACE SIGNAL 1 REMOTE 3	
X17	SPACE SIGNAL 2 REMOTE 5 (3 TERMINAL LINE)	
X15	LOCAL SIGNAL 2	
X16	MARK SIGNAL 1 REMOTE 4	
X13	MARK SIGNAL 2 REMOTE 6 (3 TERMINAL LINE)	
X10	COMPARER	
X21	PHASE SPLITTER	

715B052

Fig. 30 Table III Test Point Voltage.



715B106

Fig. 31 Frequency Verifier Waveforms at 60 Hz.

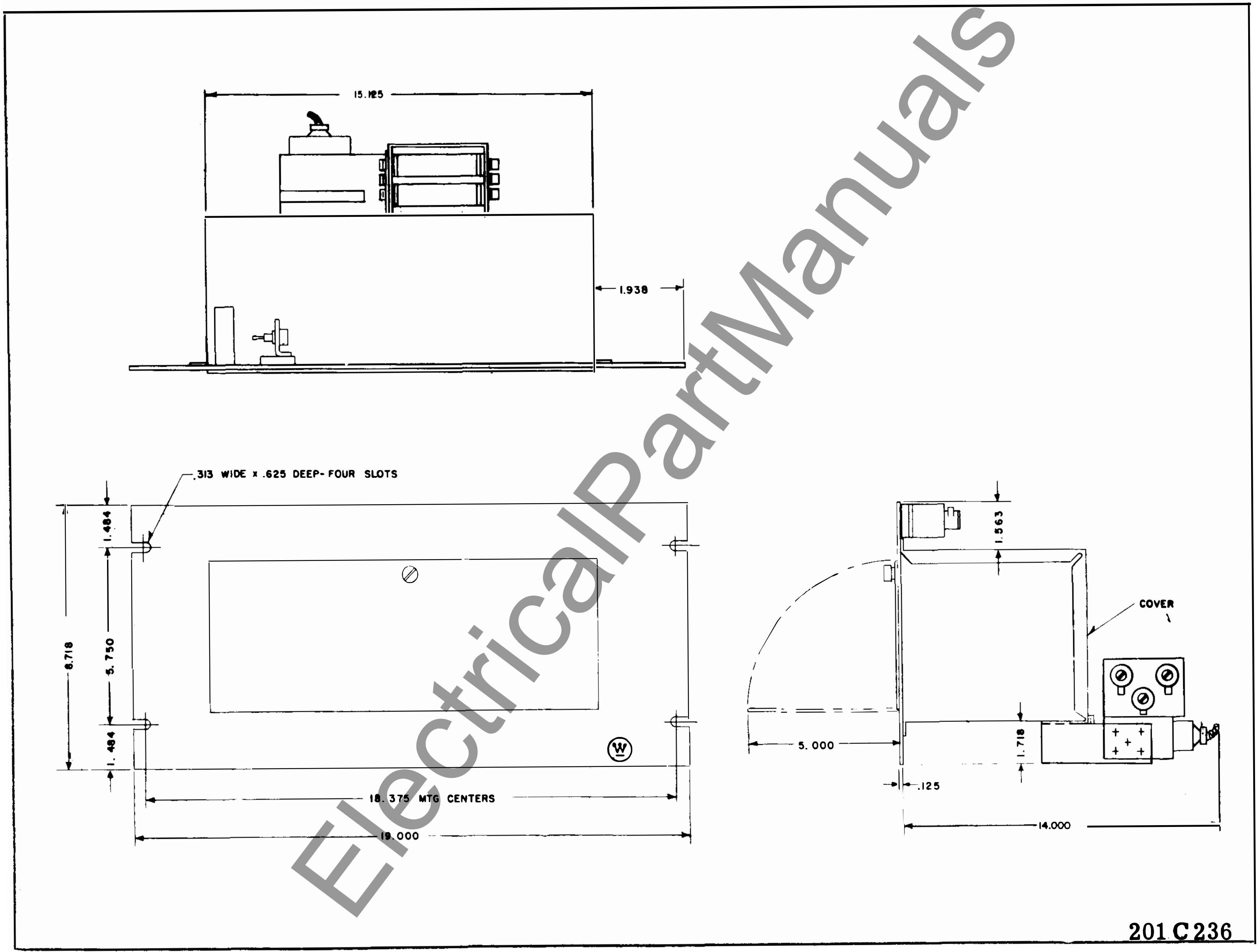


Fig. 32 Outline for the Type SKBU-21 Relay.

WESTINGHOUSE ELECTRIC CORPORATION
RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**
Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU-21 PHASE COMPARISON RELAY FOR TYPE TA-2 FREQUENCY SHIFT TONE CHANNEL

CAUTION: It is recommended that the user of this equipment become acquainted with the information in either this instruction leaflet or the system instruction leaflet before energizing the system.

If the SKBU-21 is mounted in a cabinet, it must be bolted down to the floor or otherwise secured before swinging out the equipment rack to prevent its tipping over.

APPLICATION

The type SKBU-21 is a high-speed relay used in conjunction with frequency shift type channels. Simultaneous tripping of the relays at each line terminal is obtained in less than 32 milliseconds for all internal faults within the limits of the relay settings.

The system is applicable to a voice-grade pilot-wire or microwave channel.

In contrast to the carrier blocking scheme, this is a transfer-trip system; accordingly, the blocking-start function is not required.

TABLE OF CONTENTS

These instructions apply to SKBU-21 relays for application to the following relaying systems.

1. All distance supervision
2. Distance phase comparison

CONSTRUCTION

The type SKBU-21 relay consists of a composite positive and negative sequence current network, two mixing transformers, three isolating transformers, a 20-volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel, 8-3/4 inches high (5 rack units). Edge slots are provided for mounting the rack on a standard relay rack.

Sequence Network

The sequence filter consists of a three-legged iron core reactor and a resistor. The reactor is a four-winding reactor with two primary windings and two secondary windings. The secondary windings are connected to the resistor which consists of three tube resistors and a small formed resistor. One secondary winding and the resistor is a negative sequence current filter while the other secondary winding and the resistor is a positive sequence filter.

Mixing Transformer

The voltage from the sequence network is fed into two mixing transformers. One transformer supplies the fault detector circuit and the other transformer supplies the keying circuit. These transformers and Zener clippers (mounted on printed circuit boards) connected across their secondary are used to limit the voltage impressed on the solid-state circuits, thus providing a small range of voltage for a large variation of maximum to minimum fault currents. This provides high operating energy for light fault, and limits the operating energy for heavy faults to a reasonable value.

Isolating Transformer

Three isolating transformers are provided in the relay to isolate the D.C. voltages from the A.C. voltages. Two of the transformers are also used to energize solid-state circuit on alternate half-cycle of the power system frequency.

Power Supply

The solid-state circuits of the SKBU-21 are regulated from a 20-volt supply on the relay panel. This voltage is taken from a Zener diode mounted on a heat sink. A voltage dropping resistor is provided between the source D.C. supply and the 20-volt regulated supply.

Printed Circuit Boards

Seven printed circuit boards are used in the SKBU-21 relay: A fault detector board, protective relay interface board, supervision board, amplifier and keying board, arming board, output board and a relay board. The circuits of the protective relay, and the arming board varies with the relaying system.

All of the circuitry that is suitable for mounting on printed boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide in position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment, it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

1. Fault Detector Board

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, a solid-state fault detector, and a frequency verifier circuit. The controls for setting pickup (S1) and dropout (S2) of the fault detector are mounted on a plate in the front of the assembly. This unit operates when the fault current exceeds a definite value.

The location of components on the board is shown in Fig. 3 and the schematic of the board is shown in Fig. 4.

2. Arming Board

The arming board connects the outputs of the supervision board and the fault detector board to the final output of the relay. This board contains logic circuits that will arm the trip output, set up the time delay of the trip output, and start transient blocking on external faults.

The components of this board vary with the relaying system. The schematic of the board for the distance phase comparison system is shown in Fig. 6 and the schematic of the board for the all-distance supervision system is shown in Fig. 7. The difference in the two boards is that the distance phase comparison board has an additional resistor and diode on the board. The location of components is shown in Fig. 5.

3. Amplifier and Keying Board

The amplifier and keying board contains two local squaring amplifiers, a transmitter keying circuit, two remote squaring amplifiers, and a signal squelch circuit for each line terminal. The amplifier circuits produce the pulses that are compared by the AND circuits of the arming board to determine if the fault is external or internal.

The location of components on the board is shown in Fig. 8 and the schematic of the board is shown in Fig. 9.

4. Output Board

The output board contains a 4-millisecond pickup instantaneous dropout timer circuit, trip "AND" (flip-flop circuit), trip amplifier, transient blocking and unblocking circuits. The trip AND operates when all the inputs to the AND inputs of the arming board are of the correct polarity and the fault detector has operated. The transient blocking circuit operates after a time delay on external faults, and the transient unblock circuit operates after a time delay on a sequential fault (external fault followed by an internal fault). The following figures apply to this board: Fig. 10 Component Location; Fig. 11 Schematic of the board.

5. Relay Board

The relay board contains the phase delay circuit for shifting the local signals with reference to the remote signals. It also contains a low-pass filter, and a Zener clipper-resistor combination for protection of the solid-state circuits on the relay board.

The following figures apply to this board: Fig. 12 Component Location, and Fig. 13 for the schematic of the board.

6. Supervision Board

The circuits on this board vary with the relaying system. For all applications a 150 millisecond pickup and 15 millisecond dropout alarm timer circuit and a 2.5 second alarm circuit for fault detector operation are provided on this board. The circuits on the board are utilized to lockout the SKBU-21 relay for channel failure on the channel equipment. For tone channels a noise circuit is provided to lock out the SKBU-21 relay from information supplied by the tone equipment.

Because the board varies with the noise circuit of the channel equipment, the following figures apply to the board.

Type Channel	Location of Components	Schematic of Board
TA-2 with AM Squelch	Fig. 14	Fig. 15
TA-2 with TA-3 Noise Supervision	Fig. 16	Fig. 17

7. Protective Relay Board

The protective relay board contains logic circuits to connect the distance fault detectors, and squelch relays into the phase comparison portion of the relaying system. This board contains AND circuits, circuit buffer and OR circuits to connect the relays into the system.

For a distance phase comparison system Fig. 18 shows the component location of the board and Fig. 19 shows the schematic of the board. For an all-distance supervision system, Fig. 20 shows the component location of the board and Fig. 21 shows the schematic of the board.

Card Extender

A card extender (Style No. 644B315G02) is available for facilitating circuit voltage measurements of major adjustments. After withdrawing anyone of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all components and test points on the board are readily accessible.

Test Points

Test ponts are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front of the relay for convenience in adjusting and testing the relay.

OPERATION

A. System

In phase comparison relaying, the phase positions of fault currents at the ends of a transmission line are compared over a pilot channel to determine if the fault is internal or external to the line section. When a frequency shift channel is used as the pilot channel, a dual comparison transfer-trip system can be utilized. This means that the system can trip on either half-cycle of power system frequency as contrasted to a blocking scheme where tripping occurs on alternate half-cycles during the absence of a carrier signal.

The three-phase line currents energize a sequence network in the SKBU-21 relay which produces two single-phase output voltages which are proportional to either the positive sequence current or the negative sequence current. The single-phase voltages are applied to saturating transformers one which energizes the fault detector circuit and the other energizes the keying circuit of the SKBU-21 relay. This circuit shifts the frequency of the transmitter from a space frequency to a mark frequency on alternate half-cycles of the power frequency current. These frequencies are transmitted over the pilot channel to the receiver which converts the mark and space frequencies to two D.C. output voltages, a space output that corresponds to the space frequency and a mark output that corresponds to the mark frequency. Thus, on each half-cycle of power system frequency either a space or mark output is obtained from the receiver and applied as pulses to the remote squaring amplifiers of the SKBU-21 relay. Each of these half-cycle pulses are compared with the phase positions of each half-cycle of the sine wave voltage from the sequence network of the SKBU-21 relay at the receiver terminal. The space pulse is compared to one half-cycle of the voltage and the mark pulse to the other half-cycle. If the local and remote half-cycle pulses are of the correct phase positions for an internal fault, after a fault detector operation, 4 millisecond tripping will be initiated through operation of the trip "AND" and trip amplifier circuits.

Current transformer connections to the sequence networks at the two line terminals are such that the space and mark pulses are in phase with their respective local pulses during an internal fault to allow tripping. However, if the fault is external to the protected line section, the space and mark pulses are out-of-phase with their respective local pulses and tripping does not occur.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals and relay coordination.

B. Relay

With reference to the logic diagram that applies to the particular relay, the three-phase line currents energize a sequence filter that produces two single-phase voltages: One voltage proportional to the positive sequence current, and the second voltage proportional to the negative sequence current. These voltages are applied to two mixing transformers which have zero sequence windings on them. The output of the two transformers are applied to two separate board:

1. Output from one transformer to the fault detector board.

2. Output from the second transformer to the relay board.

These transformers and a Zener clipper connected across their secondaries are used to limit the voltage impressed on the solid state circuits, thus providing a small range of voltage for a large variation of fault currents.

With reference to the schematic Dwg. of Fig. 4, the A.C. voltage from one mixing transformer is applied to a phase-splitting network (C52, R52, R53) and a polyphase rectifier (diodes D51 to D56). The D.C. voltages so obtained are applied to the fault detector circuit which operates when the D.C. input "signal" exceeds a predetermined value.

Fault Detector

Under normal conditions, transistor Q51, has no base "signal" and is turned off. The collector of Q51 is at a high enough positive potential to provide base drive for transistor Q52, driving it to full conduction. With Q52 fully conducting there is no base drive to transistor Q53 and Q53 is turned off. With no Q53 collector current, the base of transistor Q54 is supplied from the 20-volt source. Thus the Q54 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q54 in a non-conducting state, equivalent to an open circuit.

When a fault causes the D.C. input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z52, a positive bias is applied to Q51 base causing it to conduct. In turn, Q52 stops conducting, and capacitor C54 charges, giving a few milliseconds time delay before Q53 and Q54 are switched to full conduction, thus "closing" the fault detector. When the fault detector operates, a positive output is applied to the arming board at terminal 12. Resistors R66 and S2 increase the voltage to Z52 to allow the fault detector to drop out at a high dropout ratio when the A.C. current is reduced.

Frequency Verifier

During certain switching conditions, such as energization of a transmission line, residual currents and voltages may exist of higher frequencies than 60 cycles per second. The frequency verifier prevents fault detector operation when frequencies 120 cycles or higher are encountered during the switching conditions. The frequency cerfier circuit consists of two functional parts: Zero-crossing and commutator circuits. With reference to Fig. 4, the zero-crossing circuit consists of Q55, Q56, Q57, and Q58. The commutator circuit consists of Q59, Q60, C9, C59 and Q61.

During the positive or negative half-cycles of the output voltage from the saturating transformer, Q55 or Q57 transistors are driven into saturation by the output of the FV transformer. Transistors Q56 or Q58 conduct until capacitors C56 or C57 respectively are fully charged. While either capacitor charges a voltage output in the form of very narrow pulse is developed across R76 and R78 resistors during the start of each half-cycle. This pulse triggers Q59 control switch. When transistors Q55 or Q57 are not conducting,C56 and C57 capacitors discharge respectively through D66 or D62 and the parallel combination of R73 and R74 or R69 and R70.

While Q59 is "on" its anode is only about 0.7 volts above negative, thus turning off transistor Q62 to allow capacitor C60 to start charging. However, a shorter time delay (consisting of R84, the capacitor C59 and the reference Zener diode Z54) or 4.3 milliseconds is also started. After 4.3 milliseconds of delay, the control switch Q60 fires applying the voltage of capacitor C88 across Q59 turning it off. This raises the potential of the Q59 anode to turn on Q62 to discharge C60 before the charge reaches a value to break down Z55 to turn on Q63. After the next zero-crossing pulse Q59 switch is turned on again, and the Q60 switch is turned off by capacitor C58. Transistor Q61 when turned on by the same voltage that fires the gate of Q59, discharges timing capacitor C59, thus starting the timing cycle with close to zero charge on the capacitor. If the zero-crossing period of the FV voltage is less than 4.3 milliseconds, the Q61 transistor discharges the timing capacitor thus preventing the turning off of Q60 switch. This keeps Z59 switch on to allow C60 to charge to a value to break over Zener diode Z55 to turn on Q63. Turning Q63 prevents Q53 of the fault detector from turning on thereby preventing Q54 from turning on to prevent an output from the fault detector.

2. Relay Board

With reference to Fig. 13, the A.C. voltage from the second mixing transformer is applied to the phase delay circuit through a low pass filter of the relay board. The low pass filter (C201, L201, C202) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R202 and R203 of the phase delay circuit. By means of capacitor C203 and variable resistor S5, the voltage across terminal 4 and 2 can be made to lag the voltage across terminal 10 and 11 by a definite amount depending on the setting of S5. Each of these two voltages are applied to separate isolating transformers.

1. Undelayed voltages to a keying transformer (T1)

2. Delayed voltages to a local transformer (T2)

A. Keying Circuit

With no A.C. output (Ref. Fig. 9) voltage from the sequence network, base current does not flow into transistor Q103. The collector of Q103 is at positive potential which allows base current to flow from positive 20 volts D.C. through the base of Q104 through R111 and R112 to negative. This applies negative potential to the collector of Q104 to prevent base current from flowing to Q105. Since Q104 is conducting, transistor Q105 does not conduct and the collector of Q105 is held at positive potential.

When a sinusoidal voltage is applied to the keying transformer (T1), the transformer steps up the voltage applied to terminals 9 and 8 of the amplifier and keying board. On the positive half-cycle of voltage, terminal 8 is more negative than terminal 9 and transistor Q103 does not conduct. In turn, Q104 remains conducting and Q105 does not turn on. On the negative half-cycle of sine wave voltage from the keying transformer, terminal 9 is more positive than terminal 8 and base current flows into Q103. This turns Q103 on which applies negative potential to the collector of Q103. Base current to transistor Q104 is stopped and Q104 stops conducting, and its collector goes to positive potential. Positive potential is thus applied to the base of Q105 through R114 and R115 to turn on Q105. When Q105 conducts, its collector is connected to negative potential. Thus on alternate half-cycles of the 60-cycle voltage from the low pass filter, Q105 turns on. By connecting Q105 through the proper interface to the channel transmitter, turning on Q105 keys the transmitter to a mark condition.

B. Local Squaring Amplifiers (1 and 2)

There are two identical local squaring amplifiers in the SKBU-21. One is turned on and off by the positive half-cycle of voltage from the local transformer (T2) while the other one is turned on and off by the negative half-cycle of voltage from the transformer. The square wave output voltages are, therefore, functions of the A.C. voltage input to the amplifiers. The polarity of the outputs of the two amplifiers are such that one amplifier has an output when the other one does not when A.C. voltage is applied to the squaring transformer.

With reference to amplifier number 1 of Fig. 9 with no A.C. input voltage, Q106 is not conducting and the collector of Q106 is at positive potential. This applies base current to transistor Q107 through R120 and R121 such that Q107 is turned on. This applies negative potential to the collector of Q107 to allow base current to flow in Q108. Q108 turns on to apply positive potential across R125.

With the application of a sine wave voltage to terminal 6 and 19 of the amplifier and keying board, on the positive half-cycle of the voltage, the base of transistor Q106 is more positive than the emitter and Q106 (amplifier 1) conducts, and Q110 (amplifier 2) is turned off. On the negative half-cycle of the a.c. voltage, Q106 is turned off and Q110 is turned on. Therefore, Q106 is conducting on the positive half-cycle of voltage and Q110 is conducting on the negative half-cycle of A.C. voltage. Turning Q106 on, puts negative potential on the collector of Q106 and turns off transistor Q107. Transistor Q107 stops conducting and its potential goes to a positive potential which turns off Q108 to place its collector at a negative potential. Thus the output of the squaring amplifiers square wave voltages ranging from 0 volts D.C. to 20 volts D.C. depending upon the polarity of the voltage from the phase delay circuit.

Amplifier 2 is the same as amplifier number 1 except it is supplied by the opposite polarity of sine wave voltage from the local transformer (T2) at terminals 19 and 6 of the amplifier and keying board. The output voltage from the amplifier appears across R138. By applying the same analysis of amplifier 1 to amplifier 2, the output voltage across R138 is a square wave voltage of the reversed polarity than that across R125.

C. Remote Squaring Amplifiers

As shown in Fig. 9, there are two remote squaring amplifiers in the SKBU-21. One amplifier is to connect the space output of the receiver to the SKBU-21 while the other is to connect the mark output of the receiver to the SKBU-21 relay. The space squaring amplifier consists of transistor Q109 on the amplifier and keying board in conjunction with an interface circuit of Q167 on the supervision board. The mark remote squaring amplifier consists of Q113 on the amplifier and keying board and interface transistor Q165 on the supervision board.

The remote squaring amplifiers are in one of three states:

1. Loss-of-channel state
2. Receiving space frequency only
3. Receiving alternate half-cycles of space and mark frequency.

For a loss of a tone channel, the receiver clamps its output to a mark condition. The space output from the receiver is zero with respect to the positive source. This means that transistor Q167 (on the supervision board) is not conducting. Base drive to transistor Q109 is provided from positive source through R131 to negative. Q109 is turned on to provide a positive 20 volts across R129. When the channel is in service and the receiver is in a space condition, transistor Q167 is turned on. This applies source voltage through R130 and diode D106 to R131. The potential of the base of transistor Q109 is raised higher than its emitter; hence, transistor Q109 stops conducting and the voltage across R129 is -20 volts. For the condition where the receiver is receiving pulses, transistor Q167 (on supervision board) turns on and off for the same half-cycle and the voltage across R129 is a square wave voltage varying from zero volts to a -20 volts D.C.

For either internal or external fault conditions the outputs of both remote squaring amplifiers are square wave voltages. Both voltages vary from zero volts to approximately -20 volts D.C. and are out of phase with each other; i.e., when one voltage is at zero volts the other voltage is at -20 volts.

3. Arming Board

The phase relationship of the outputs of the local and remote squaring amplifiers are compared by the two AND circuits of the Arming Board. One AND circuit (number 1) compares the space signal with the output from local squaring amplifier number 1. The second AND circuit (number 2) compares the mark signal with the output of local squaring amplifier number 2. Since the local signals are always 180 degrees out-of-phase with each other, and the remote signals are always 180 degrees out-of-phase with each other, a change in phase angle of one signal with respect to the other will provide one input to AND number 3 which will activate the 4/0 timer.

A. Internal Fault Conditions

With reference to the logic drawing that applies to the relay, the output voltages from one terminal of the sequence filter is 180 degrees out-of-phase with respect to its load current condition. This changes the polarity of Amplifier 1 and Amplifier 2 such that their outputs are in phase with the remote signals. This means that AND 1 has a half-cycle of negative voltage and that AND 2 has a half-cycle of negative voltage (not the same half-cycle). The period of each negative voltage will be 180 degrees out-of-phase with reference to each other and a negative voltage will be produced out of the OR circuit of the arming board. The negative voltage is applied to AND 3 of the arming board. One condition for activating this AND is thereby set up--negative voltage from the OR circuit. The second condition to activate the AND is provided by arming the SKBU-21.

In either Fig. 22 or 23, for a distance phase comparison system, arming occurs through either the operation of the distance fault detectors or the operation of the SKBU-21 fault detector. The operation of either fault detector will apply a voltage to the ARM logic of the arming board. The output voltage from the ARM logic removes negative potential from the trip AND and applies a negative signal into AND 3 of the arming board. AND 3 is activated and starts the 4/0 timer. Four milliseconds later, a negative input is applied to the trip AND of the output board. Since the three conditions of trip (a negative input from the 4/0 timer, not a negative input from the ARM logic, and not a negative signal from the 18/0 timer) is fulfilled, a trip output is obtained from the SKBU-21 relay. For an all-distance supervision system, arming occurs through operation of the distance fault detectors only. As shown in either Fig. 24 or 25, the operation of the distance fault detector applies the voltage to the ARM logic of the arming board to activate AND 3.

B. External Fault

Under external fault conditions, the square wave voltages from the remote squaring amplifiers and the square wave voltages from the local squaring amplifiers are out-of-phase such that zero input is being received on the AND circuits of the arming board. The output from local 1 and remote 3 are out-of-phase to prevent tripping on AND 1 and the outputs from local 2 and remote 4 are out-of-phase to prevent tripping on AND 2. As a result, the outputs of these AND circuits are zero, and AND 3 cannot be activated. This blocks AND 3 and the 4/0 timer is not energized.

With fault detector operation, an input is applied to the ARM logic of the arming board. A positive input will be applied to the trip AND but tripping will not occur since the 4/0 timer is not providing a negative input to the Trip AND. Operation of the fault detector will provide an input to a 1/100 timer on the Output Board. The timer negates the signal to provide a negative input to the transient block AND. With the application of the negative input from the 0/100 timer the three conditions of transient block are fulfilled--not a negative voltage from the TRIP AND; not a negative voltage from the Transient UNBLOCK Circuit; and a negative input from the 0/100 timer. Eighteen milliseconds later the 18/0 timer of the transient block circuit times out to provide a negative input to the TRIP AND. The TRIP AND is thus desensitized to prevent undesirable operation during transients associated with power reversals on the protective line or at the clearing of an external fault.

C. Sequential Faults

If the above external fault is followed by an internal fault before the external fault is cleared, the transient unblock circuit is set up to remove the transient blocking input to the TRIP AND. For the internal fault, the square wave pulses on AND 1 and AND 2 of the arming board will reverse such that a negative output is obtained from these AND circuits. This output energizes the OR circuit which negates the signal to a negative signal. The negative signal...

1. Provides a second input to AND 3, and the 4/0 timer times out to apply a negative input to the TRIP AND.

2. Applies a negative input to the AND of the transient unblock circuit to fulfill the requirements to obtain an output from the transient unblock circuit.

As a result, a negative input is applied to the unblock timer. Eighteen milliseconds later, the unblock timer will operate to remove the negative voltage from the block AND circuit. This resets the 18/0 block timer, and removes the negative input to the AND of the unblock timer to reset the unblock. The required three inputs are thus applied to the trip AND and a trip output is obtained from the SKBU-21 relay.

D. Protective Relay Operation

The SKBU-21 relay is armed by the distance fault detectors through a 6/0 timer on the supervision board. The operation of the distance fault detectors applies negative potential to terminal 16 of the supervision board. This removes current to transistor Q157 and allows C151 to charge. Six milliseconds later the voltage on C157 reaches the breakdown of Zener diode, Z151, and base current flows into transistor Q152 to turn Q152 on. This turns on Q153 to apply a positive potential to terminal 14 of the arming board.

4. Supervision Board

The circuits on the supervision board include the auxiliary functions of the SKBU-21 relay, and they vary with the application of the relay and the type of equipment used as a pilot channel. In general, though, this board contains a low signal clamp timer and an arming timer.

A. Low Signal Clamp (.5/150 Timer)

With a serviceable channel either a space frequency or an alternate space-mark frequency is received from the channel equipment. With reference to Fig. 15 or 17, Q167 of the supervision board is either turned on or is turned off. With Q169 turned on, base current is supplied to transistor Q158 and Q158 conducts. The collector of Q158 is thus at negative potential and capacitor C155 cannot charge.

If the channel is not serviceable, the tone receiver is clamped into a mark condition and the space output is zero. Transistor Q167 does not conduct and transistor Q158 is turned off. Positive potential is applied to capacitor C155 through resistor R177. After a 150 millisecond time delay, capacitor C155 charges sufficiently to break down Zener diode Z154. When Z154 conducts, base drive is supplied to transistor Q159 and Q159 turns on. This connects the collector of Q159 to negative potential which allows base current to flow in transistor Q160 through R181. This turns on transistor Q160 to apply positive voltage to R183. This voltage is then applied to AND 2 of the arming board and to an alarm output. Applying the voltage to

AND 2 blocks tripping.

Under the conditions of alternate mark and space outputs from the tone receiver, transistor Q158 is turned on and off every 8.3 milliseconds (half-cycle of power system frequency). Every half-cycle, capacitor C155 starts to charge but on the next half-cycle Q158 turns on to discharge capacitor C155. Since the charging time is not sufficient to allow capacitor C155 to break down Z152, transistor Q159 will not turn on to block tripping.

B. Loss-of-Potential Alarm (2500 Timer)

When arming occurs on the SKBU-21, negative potential is removed from terminal 18 of the supervision board. This applies positive potential to capacitor C152. Two-and-a-half seconds later, the potential on C152 breaks down the Zener diode Z152 to allow base current to flow into Q154. This turns on Q154 which turns off Q155. Turning Q155 off applies positive potential to the base of Q156 and Q156 turns off. This removes positive potential from R170 and an external alarm is energized.

C. Arming Delay by Distance Fault Detectors (6/0 Timer)

The distance supervision arming is delayed by 6 milliseconds to allow time for the circuits feeding AND 1 and AND 2 to respond at fault inception. Operation of the distance fault detectors will apply negative potential to terminal 16 of the supervision board. This removes the base current to transistor Q151. Q151 turns off when positive potential is applied to capacitor C151. Six milliseconds later the voltage on C151 reaches a value to break down Zener diode A151. This turns on Q152, which connects the base of Q153 to negative through resistor, R158. Q153 turns on to apply positive potential to resistor, R160 and terminal 13. From terminal 13 the voltage is applied to the arming board.

D. Noise Supervision for a TA-2 Tone Channel with AM Squelch

The noise supervision interface of the SKBU-21 relay for a TA-2 tone channel with AM squelch consists of transistors Q166, Q161, Q162, and associated components. Under normal conditions, the output from the noise circuit of the tone channel is zero volts. As a result, transistor Q166 is not conducting and base current is not supplied to transistor Q161. Transistor Q161 is turned off and its collector is held at positive potential to prevent base current from flowing in transistor Q162 and negative voltage (across R158) is applied to AND 1 and AND 2 of the arming board.

Under noise conditions the noise circuit of the tone equipment provides a negative output with respect to positive 48 volts D.C. This negative voltage allows transistor Q166 to turn on and provides base current to Q161 through resistor, R187. Transistor Q161 turns on, and its collector is connected to negative potential. Base current then flows in transistor Q162 through resistor, R188, and Q162 turns on. Positive potential is applied to resistor, R190 and to terminal 5 and 1 of the supervision board. From terminal 5, the voltage is applied to AND 1 and AND 2 of the arming board to block tripping. The voltage on terminal 1 is applied to an external alarm.

The noise supervision interface of the SKBU-21 relay for a TA-2 tone channel with a TA-3 noise supervision is the same as above except Q166 is omitted.

CHARACTERISTICS

The type SKBU-21 relay is available for a frequency shift tone channel. Taps are available to set different sensitivities of the fault detector to zero and negative sequence currents. These taps are as follows:

Negative Sequence Taps (I_2)

Tap Setting	Negative Sequence Sensitivity
A	None
B	0.4 Amperes
C	0.25 Amperes

Zero Sequence Taps (I_0)

Tap Setting	Zero Sequence Sensitivity
F	None
G	0.2 Amperes
H	0.1 Amperes

The positive sequence response of the fault detector is greater than 7 amperes.

The operating time of the fault detector is shown in Fig. 24. As shown in the figure, the operating curve has a maximum and minimum value. This is due to the point on the current wave that fault current is applied. Figure 25 shows the operating times for different points on the fault wave for fault current at five amperes.

The keying response of the SKBU-21 relay is independent of the tap setting. Figure 26 shows typical lengths of keying pulses with reference to a 60-cycle base of the SKBU-21 relay for different values of positive, negative, and zero sequence current.

Operating time	15 to 32 Milliseconds
Alarm Times	2.5 seconds for FD Operation 150 Milliseconds Loss-of-Channel
Transient Block Time	18 to 20 Milliseconds
Transient Unblock Time	25 to 30 Milliseconds
Ambient Temperature Range	-20°C to 55°C
D.C. Drain	0.14 Amps. at 48 Volts D.C.
Reset Time of Transient Block	
1. After a fault detector has operated	100 Milliseconds
2. When Unblock time is Utilized	Instantaneous

ENERGY REQUIREMENTS

Burdens atbalanced three-phase currents of five amperes. (Independent of tap setting).

Phase A		Phase B		Phase C	
VA	Angle	VA	Angle	VA	Angle
8.3	106°	2.2	50°	46	0°

Burden at five amperes (single-phase to neutral current).

Relay	Phase A		Phase B		Phase C	
Taps	VA	Angle	VA	Angle	VA	Angle
C-H	11.7	2.1°	9.7	1.8°	44.[illegible]	2.2°
B-H	11.4	2.1°	10.3	1.8°	46	2.2°
A-H	11.1	2.0°	11.2	1.8°	48	2.2°
C-G	8.8	2.0°	7.0	1.8°	42	2.2°
B-G	8.7	2.0°	7.5	1.8°	43.5	2.2°
A-G	7.8	2.0°	8.5	1.8°	45	2.2°
C-F	6.7	2.0°	7.5	1.8°	42	2.2°
B-F	6.5	2.0°	7.2	1.8°	42	2.2°
A-F	5.8	2.0°	6.6	1.8°	43	2.2°

The angles above are the degrees by which the current lags its respective voltage.

SETTINGS

The SKBU-21 relay has separate tap plates for adjustment of the zero and negative sequence sensitivity of the fault detector. The fault-detector tap markings and pickup are:

Negative Sequence Sensitivity (I_2)

A. None
B. 0.4 Amperes
C. 0.25 Amperes

Zero Sequence Sensitivity (I_0)

F. None
G. 0.2 Amperes
H. 0.1 Amperes

Two tap plates are provided: one for I_2 and the other one for I_0.

Tap A should not be used in service since this would prevent fault detector operation for phase-to-phase faults. However, tap F may be used with either B or C since negative sequence current flows for both phase-to-phase and ground faults.

The recommended settings are tap B and C as needed for the required sensitivity, and tap F. Taps G and H have been provided for applications where the negative-sequence load flow due to series impedance unbalance may be high enough to operate FD with a tap C setting. In this case set in tap B and in tap G or H. It is not intended that taps C and H be used simultaneously due to the possibility of cancellation of the negative- and zero-sequence effects on ground faults. With a tap B setting, a tap H setting is preferred.

To summarize, the recommended setting combinations in the order of preference are:

Combination	I_2 Tap	I_0 Tap
1	C	F
2	B	F
3	B	H
4	B	G

INSTALLATION

The SKBU-21 relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The SKBU-21 relay is normally supplied as part of a relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the SKBU-21 relay is not a part of a relaying system, the following procedure can be followed to verify that the circuits of the SKBU-21 are functioning properly.

TEST EQUIPMENT

1. Oscilloscope
2. A.C. Current Source
3. Electronic Timer †
4. A.C. Voltmeter
5. D.C. Voltmeter

† Scope may be used for timing by connecting scope probe to timer stop points, and external trigger of scope to timer start points.

ACCEPTANCE TEST

Connect the relay to the test circuit of Fig. 27 which represents the tone channel for test purposes.

Open all test switches of the test circuit and connect a 60-cycle test current between terminals 3 and 5 of the relay. Connect terminal 2, 4, 6 and 8 of the terminal block together. Set taps I_2-C and I_0-H.

1. Filter Output

a. Connect a high resistance a-c voltmeter across X6 and X5 of the relay.

b. Pass 10 amperes, 60 cycles into terminal 5 and out terminal 3. Voltmeter should read 20 volts ± 5%.

2. FD Pickup and Dropout

a. Set relay on taps I_2-C and I_0-H.

b. Connect a high resistance D.C. voltmeter across X_{22} and X_4 (neg.)

c. Connect a 60 cycle test current to terminal 5 and 3 of the relay. Gradually increase the current until the voltmeter changes reading from approximately zero volts to approximately 20 volts. This is the operating current of FD and should be 0.433± 5% amperes.

d. Gradually lower A.C. test current until D.C. voltmeter drops to approximately zero volts. This is the dropout current of FD and should occur at 0.35 ± 5% amperes of the pickup current.

3. Check of Local Squaring Amplifiers

a. With all switches of test circuit open, apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the relay.

b. Place scope probe across X12 and X4 (grd). A square wave of voltage should appear across X12 and X4 as shown in Table I.

c. Place scope probe across X15 and X4 (grd). A square wave of voltage should appear across X15 and X4 as shown in Table I.

d. If scope has two traces, connect one probe to X12 and second probe to X15. Connect grd. of scope to X4. The phase relationship of Table I should be observed.

4. Check of Keying Circuit

a. With all switches of test circuit open and 0.6 to 0.8 amperes A.C. applied to terminal 3 and 5 of the relay, with scope check voltage across X14 and X4 (grd).

b. Waveform shown in Table I should be observed.

5. Check of Remote Squaring Amplifiers

a. Close switches A, B, and C of test fixture.

b. Apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the SKBU-21 relay.

c. Using scope with grd. lead on X4, check waveshape of voltage across X9 and then X16. Waveforms of Table I should be observed.

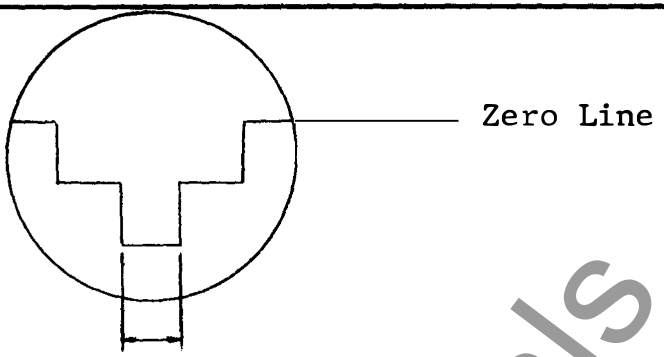
d. If scope has two traces, connect one probe to X9 and the other on X16. Connect grd. to X4. With scope set on chopped, the phase relationship of Table I should be observed.

6. Setting of S5 and S6

a. Set S5 to minimum resistance and S6 to maximum resistance (fully clockwise).

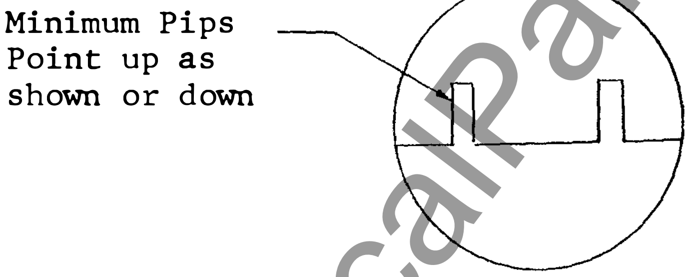
b. Set switch L to external fault and close switches A, B, and C of the test circuit. Apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the SKBU-21 relay.

c. Connect scope across X10 and X2 (grd). Adjust S5 until following waveform appears on scope.



d. Adjust S6 until the relay trips as determined by an increase in voltage across X_{11} to X_4 from zero to approximately 20 volts. This sets the triggering of the flip-flop after a 4 millisecond delay.

e. Slowly increase S5 to obtain the following waveform. This will be with S5 at or near minimum resistance.



7. Transient Blocking Delay (18/0 and 0/100 Timer)

a. Connect electronic timer stop to X7 and X4 (grd). Set timer stop on negative going pulse.

b. Connect timer start to X22. Set timer start to positive going pulse.

c. Apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the SKBU-21 relay. Measure time for voltage to drop from 20 volts to approximately zero volts. This should be between 16 and 20 milliseconds.

d. Set timer start on a negative pulse and timer stop on a positive pulse.

e. De-energize relay. Timer should start and should stop after a time delay of 80 to 135 milliseconds.

8. Check of Transient Unblocking Circuit

a. With electronic timer stop connected to X7 and X4 (grd), set timer stop on positive going pulse.

b. Connect timer start to timer start contacts of switch L. Set L on external fault, and close other switches of test circuit.

c. Apply 0.6 to 0.8 amperes A.C. into terminal 3 & 5 of the SKBU-21 relay.

d. Close switch L to internal fault, timer should start and should stop after a time delay. Time should be 16 to 20 milliseconds.

9. Loss of Channel Timer (.5/150)

a. With electronic timer stop connected to X19 and X4 (grd), set timer stop on positive pulse.

b. Connect timer start to start contacts fo switch C. Set time start to break.

c. Close switch C.

d. Open switch C. Timer should start and should stop after 130 to 170 milliseconds.

10. Alarm on Relay Operation (2.5 Seconds)

a. With electronic timer stop connected to X20 and X4 (grd), set timer stop on negative going pulse.

b. Connect timer start to X22. Set timer start on negative pulse.

c. Apply 0.6 to 0.8 amperes A.C. to terminals 3 & 5 of SKBU-21 relay.

d. Timer will start and should stop after 2.3 to 2.7 seconds.

11. Signal Squelch Time (10/150)

a. Connect timer stop to X14 and X4 (grd). Connect a jumper from TP102 to terminal 8 of the amplifier and keying board. This turns off Q104 to turn on Q105.

b. Connect timer start to switch 28. Set timer start on positive pulse. Connect timer stop on positive pulse.

c. Close switch 28. Timer will start and will stop after a 8 to 12 millisecond delay.

d. Set timer stop on negative pulse, and timer start to negative pulse.

e. Open switch 28. Timer should start and stop after a time delay of 125 to 185 milliseconds.

12. Check of Noise Circuit

a. Connect D.C. voltmeter to X17 and X4 (grd). Voltage must read zero.

b. Close switch D. Voltage must rise to 20 volts.

13. Check of Frequency Verifier

a. Open all switches of test circuit.

b. Connect scope across TP60 and terminal 8 of the FD board.

c. Apply 0.6 to 0.8 amperes to terminal 3 & 5 of SKBU-21 relay.

d. Wave form of Fig. 29 should be observed.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram voltages of Table I should be used to isolate the circuit that is not performing correctly. The schematic of the individual board, and the voltages of Table II should then be used to isolate the faulty component.

TABLE II

VOLTAGE MEASUREMENTS ON PRINTED CIRCUIT BOARDS

1) Fault Detector Board

Test Point	$I_{a.c.} = 0$	$I_{a.c.} =$ Pickup of FD
54	6.5 V. d.c.	less than 1
55	less than 1	4.5 V. d.c.
56	less than 1	18 to 20 V. d.c.
Term 2	less than 1	8.6 V. d.c.
51-52	0	7.4 volts a.c. (Approx.)
52-53	0	7.5 volts a.c. (Approx.)
53-51	0	7.4 volts a.c. (Approx.)
Terminal 5-6	0	15 volts a.c. (Approx.)
TP 57	18 volts	Pulses see Table II for Waveform
TP 58	18 volts	
TP 59	less than 1	
TP 60	20 volts	
TP 61	18 volts	
TP 62	less than 1	

2. Supervision Board

Test Point	Normal Condition	Abnormal Condition
Term 16	12	less than 1 with DFD Operation
TP151	less than 1	7 " " "
TP152	20	less than 1 " " "
Term 13	less than 1	20
Term 18	less than 1	15 with arming
TP153	15	less than 1 " "
TP154	less than 1	20 " "
Term 19	20	less than 1 " "
Term 17	*48 VDC(receiving space)	less than 1 with loss of channel
TP155	*less than 1 (receiving space)	18 with loss of channel

Supervision Board (Cont'd.)

Test Point	Normal Condition	Abnormal Condition
TP156	20(receiving space)	less than 1 with loss of channel
Term 11	less than 1	20
TP157	less than 1	46 with noise clamp
TP158	20	less than 1 with noise clamp
Term 1	less than 1	20 with noise clamp
Term 15	*less than 1	46 with loss of channel

* Normal condition could be square wave pulses

Amplifier and Keying

		Serviceable Channel
Test Point	Normal $(I_{a.c.} = 0)$	Abnormal or I_{AC} = Pickup of FD
Term 7	18	less than 1 breaker failure on trip
TP101	less than 1	8.5
Term 10	less than 1	less than 1 " " " "
TP102	5 Vdc	4.3 pulses
Term 13	less than 1	*6 volt pulses
Term 12	48 Vdc	*48 volt pulses
TP103	5 Vdc	5 volt pulses
TP104	less than 1	16 volt pulses
Term 11	20 Vdc	20 volt pulses
Term 2	20 V pulses	200 with loss of channel
TP105	5 Vdc	5 volt pulses
TP106	less than 1	16 volt pulses
Term 16	20 Vdc	20 volt pulses
Term 18	20 volt pulses	20 with loss of channel

* Non-squelch condition

Arming Board

Test Point	Normal	Internal Fault	Loss of Channel
TP251	⌿less than 1	10 V pulses	less than 1
TP252	⌿less than 1	10 V pulses	less than 1
Term 3	⌿10 volts	⌿less than 1	10 volts
TP254	⌿less than 1	17 volts D.C.	less than 1
TP255	⌿20 volts	*less than 1	20 volts
TP256	6.5 volts	less than 1	when armed
Term 19	less than 1	18 volts	when armed

⌿ Very narrow pulses would be observed on scope

* 20 Volts pulses with signal squelch from remote terminal.

Output Board

Test Point	Normal	Trip	Blocking
301	20	Applies to Sequential Fault	
302	0	" " " "	
303	2.2	12.5	less than 1
304	less than 1	less than 10	7
Board 14	20	20	less than 1
305	18.5	7	18.5
306	0	13.5	0
307	20	less than 1	20
308	0	20	0

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give the circuit symbol and the electrical value (ohms, mfd, etc.) and component style number.

ELECTRICAL PARTS LIST

Fault Detector Board Style 5312D13G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitors	
C51	0.1 Mfd	1544920
C52-C53-C59	0.5 Mfd	187A624A11
C54-C55	1.5 Mfd	187A508H09
C56-C57	0.02 Mfd	187A624H09
C58	0.1 Mfd	187A624H01
C60	0.22 Mfd	762A703H01
	Diodes	
D51 to D58-D70 to D73	1N457A	184A855H07
D59	1N645A	837A692H03
D60 to D69	1N4385	184A855H14
	Transistors	
Q51-Q52-Q53-Q55 Q57-Q61-Q62-Q63	2N3417	848A851H02
Q54-Q56-Q58	2N3645	849A441H01
	Switches	
Q59 - Q60	2N886	185A517H03

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Resistors	
R51	50 Ohms, 5W	185A209H06
R52-R68-R71	2.7K Ohms 1/2W	629A531H42
R53 (POT)	2.5K Ohms 1/2W	629A430H03
R54-R55-R58-R62 R64-R66-R84-R89-R92	10K Ohms 1/2W	629A531H56
R56-R60	100K Ohms 1/2W	184A763H75
R57	47K Ohms 1/2W	629A531H72
R59	56K Ohms 1/2W	1 4A763H69
R61-R87	22K Ohms 1/2W	629A531H64
R63	6.8K Ohms 1/2W	629A531H52
R65	27K Ohms 1/2W	629A531H66
R67	150K Ohms 3W	762A679H01
R69-R73	68K Ohms 1/2W	629A531H76
R70-R74-R88	39K Ohms 1/2W	629A531H70
R72-R75-R80	2K Ohms 1/2W	836A503H33
R76-R78-R90	1K Ohms 1/2W	629A531H32
R77	5.6K Ohms 1/2W	629A531H50
R81	20K Ohms 1/2W	629A531H63
R82	1.5K Ohms 1/2W	836A503H30
R83-R91	470 Ohms 1/2W	629A531H24
R85	4.7K Ohms 1/2W	629A531H48
	Zener Diodes	
Z51	1N1832C, 62V	184A617H06
Z52-Z55	1N957B, 6.8V	186A797H06
Z53	1N3688A, 24V	862A288H01
Z54	1N759A, 12V	837A693H01

Supervision Board Style 5315D33G01

CIRCUIT SYMBOL	DESCRIPTION			WESTINGHOUSE STYLE NUMBER
	Capacitor			
C151-C153-C157	0.47	Mfd		188A669H01
C152	68	Mfd		187A508H02
C154-C156-C158	1.5	Mfd		187A508H09
C155	6.8	Mfd		184A661H10
	Diodes			
D151-D153-D158- to D162	1N457A			184A855H07
D152-D154-D155	1N645A			837A692H03
	Transistors			
Q151-Q152-A154-A155 Q158-Q159-A161	2N3417			848A851H02
Q153-A156-Q160-Q162	2N3645			849A441H01
Q165-Q166-Q167	2N4356			849A441H02
	Resistors			
R151-R158-R168-R177 R181-R188	6.8K	Ohms	1/2W	629A531H52
R152-R153-R157-R159- R164-R165-R167-R169- R176-R180-R182-R186 R189-R200	10K	Ohms	1/2W	629A531H56
R154	470	Ohms	1/2W	184A763H19
R155-R166-R197-R201	22K	Ohms	1/2W	184A763H59
R156-R161-R178	1K	Ohms	1/2W	184A763H27
R160-R170-R183-R190	82K	Ohms	1/2W	629A531H78
R162	33K	Ohms	1/2W	184A763H63
R163	56K	Ohms	1/2W	184A763H69
R171-R184-R191	150K	Ohms	1/2W	762A679H01
R175-R187	47K	Ohms	1/2W	184A763H67
R179	39K	Ohms	1/2W	629A531H70
R198-R202	2K	Ohms	1/2W	184A763H34
	Zener Diode			
Z151-Z152-Z154	1N957B,	6.8V		186A797H07
Z153-Z155-Z157-Z159	1N3688,	24V		862A288H01
Z158	UZ5875,	75V		837A693H04

Amplifier & Keying Board Style 5314D78G01

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
	Capacitor	
C101	6.8 Mfd	184A661H21
C102	1.5 Mfd	187A508A09
	Diodes	
D101-D106-D110	1N457A	184A855H07
D102 to D105-D107-D109	1N645A	837A692H03
	Transistors	
Q101 to Q104-Q106 Q107-Q110-Q111	2N3417	848A851H02
Q105	2N699	184A638H19
Q108-Q109-Q112-Q113	2N3645	849A441H01
	Resistors	
R101-R117	6.8K Ohms 1/2W	629A531H52
R102-R106	470 Ohms 1/2W	184A763H19
R103	39K Ohms 1/2W	184A763H65
R104-R108	1K " "	184A763H27
R105-R109-R112-R113-R115-R116-R121-R122-R124-R134-R135-R137	10K " "	184A763H51
R107-R127-R130-R141	15K " "	629A531H60
R110	82K " "	629A531H78
R111-R120-R133	33K " "	184A763H63
R114-R123-R136	22K " "	184A763H59
R118	220K " "	184A763H83
R119-R132	68K " "	629A531H76
R125-R129-R138-R139	4.7K " "	184A763H43
R126-R128	470K " "	184A763H91
R127-R130-R141	47K " "	184A763H67
R131-R140	56K " "	184A763H69
	Zener Diodes	
Z101-Z102	1N957B, 6.8V	186A797H06
Z103	UZ5875, 75V	837A693H04

Arming Board Style 201C174G01 - 201C172G01

Diodes

D251 to D257-D260-D261 to D265 - D267	1N457A	184A855H07

Transistors

Q251-Q252-Q253-Q256 Q258-Q259	2N3417	848A851H02
Q257	2N3645	849A441H01

Resistors

R251 to R257-R259-R261 R262-R263-R265-R274 R277-R278-R280-R281 R287-R288	22K Ohms 1/2W	184A763H59
R258-R260-R264-R275 R276-R282-R284-R285	10K Ohms 1/2W	184A763H51
R279	27K Ohms 1/2W	629A531H66
R283-R289	12K Ohms 1/2W	184A763H53

Zener Diodes

Z251	1N3688A, 24V	862A288H01

Protective Relay Board Style 201C166G01 - 201C148G01

Capacitors

C1 to C5	.047 Mfd	849A437H04

Diodes

D1 to D5	1N645A	837A692H03
D6 to D10	1N457A	184A855H07

Transistors

Q1 to Q7-Q9	2N3417	848A851H02
Q8	2N3645	849A441H01

CIRCUIT SYMBOL	DESCRIPTION		WESTINGHOUSE STYLE NUMBER
	Resistors		
R1 (125 volt input)	68K	1W	187A643H71
R1 (48 volt input)			
R6-R21-R30=R39	27K	1/2W	184A763H01
R2-R3-R4-R8-R9			
R13-R14-R122-R23			
R31-R32-R33	4.7K	1/2W	629A531H48
R5-R10-R15-R24-R34-R38	82K	1/2W	629A531H78
R7-R11-R16-R25-R35	10K	1/2W	629A531H56
R12-R17-R26-R37	6.8K	1/2W	629A531H52
R18-R19-R27-R28	22K	1/2W	184A763H59
R20-R29-R36-R40	10K	1/2W	184A763H51
	Zener Diode		
Z1-Z3-Z5-Z7-Z9	1N3686B	20V	185A212H06
Z2-Z4-Z6-Z8-Z10	1N957B	6.8V	186A797H06
Output Board Style 201C025G01			
	Capacitors		
C301-C304-C305	4.7	Mfd	184A661H12
C302-C303-C306-C309	0.22	Mfd	762A703H01
C307-C308	0.047	Mfd	849A437H04
C310	0.10	Mfd	188A669H03
C311	1.5	Mfd	187A508H09
	Diodes		
D301 to D306-D308	1N457A		184A855H07
D307	1N645A		837A692H03
	Transistors		
Q301-Q305-Q306-Q307			
Q308	2N3645		849A441H01
Q302-Q303-Q304-Q308	2N3417		848A851H02

CIRCUIT SYMBOL	DESCRIPTION			WESTINGHOUSE STYLE NUMBER

Resistors

R301-R303-R304-R306 R310-R311-R315 R320-R323-R324 R326-R330-R335	10K	Ohms	1/2W	184A763H51
R302	2.2M	Ohms	1/2W	187A290H26
R305	47K	Ohms	1/2W	187A290H17
R307-R314-R319-R321 R325-R328	22K	"	"	184A763H59
R309-R317	1K	"	"	184A763H27
R312	470K	"	"	184A763H19
R313	470K	"	"	184A763H91
R316	15K	"	"	629A430H08
R318-R322	4.7K	"	"	184A763H43
R327	6.8K	"	"	184A763H47
R329	18K	"	"	184A763H57
R331	10K	"	"	629A531H56
R332	6.8K	"	"	629A531H52
R333	27K	"	"	629A531H66
R334	150K	"	3W	762A679H01

Zener Diodes

Z301-Z303-Z304-Z305	1N957B	186A797H06
Z306	1N3688A	862A288H01

Relay Board Style 5312D78G01

Capacitors

C201-C202-C203	0.25	Mfd	187A624H02

Resistors

R201	50 Ohms	5W	185A209H06
R202-R203	3.3K Ohms	1/2W	629A531H44

Filter Choke

L201	8.5Hy	450 Ohms	188A460H01

Zener Diodes

Z201	1N1828C	43V	629A798H14

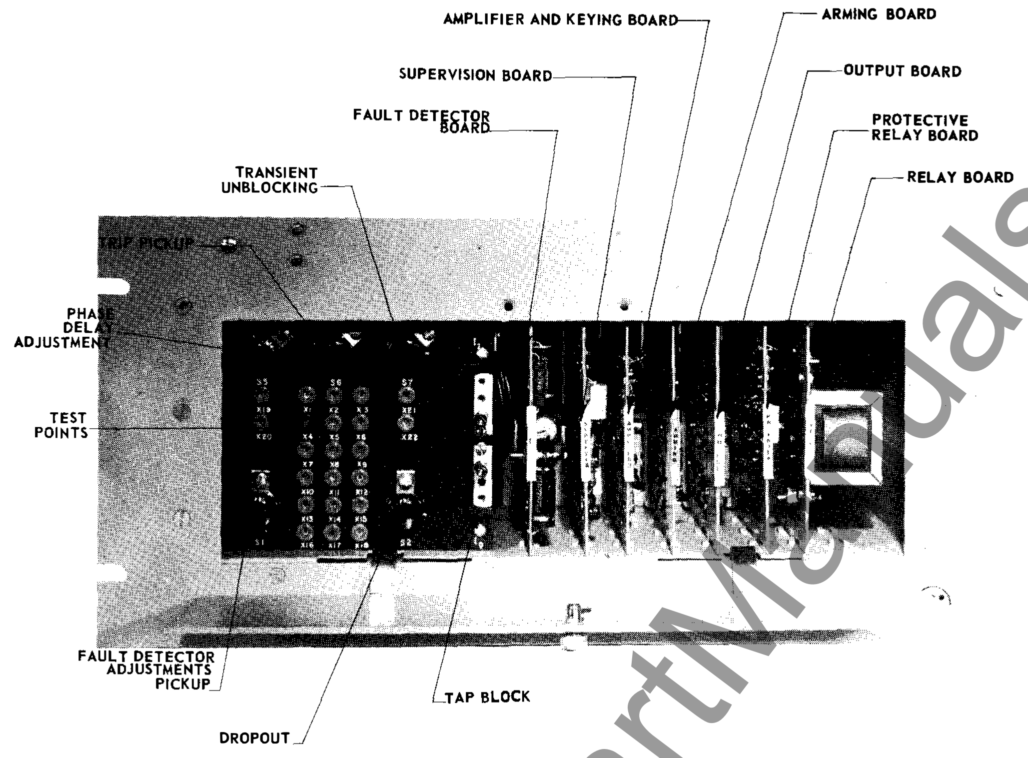


Fig. 1 Type SKBU-21 Relay (Front View)

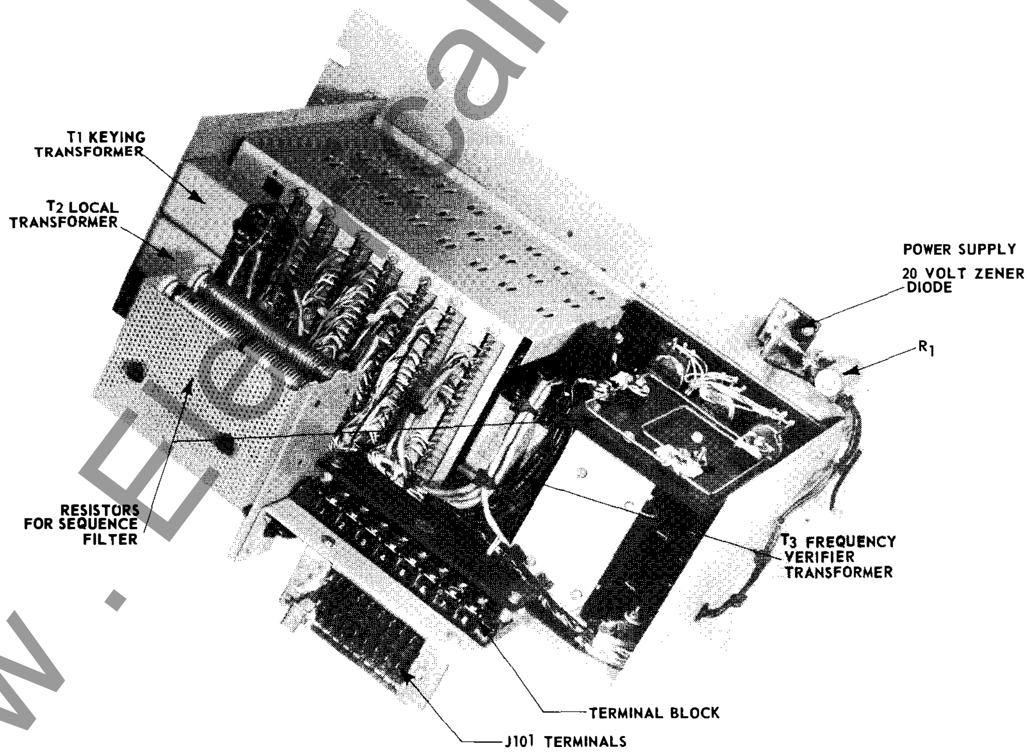


Fig. 2 Type SKBU-21 Relay (Rear View)

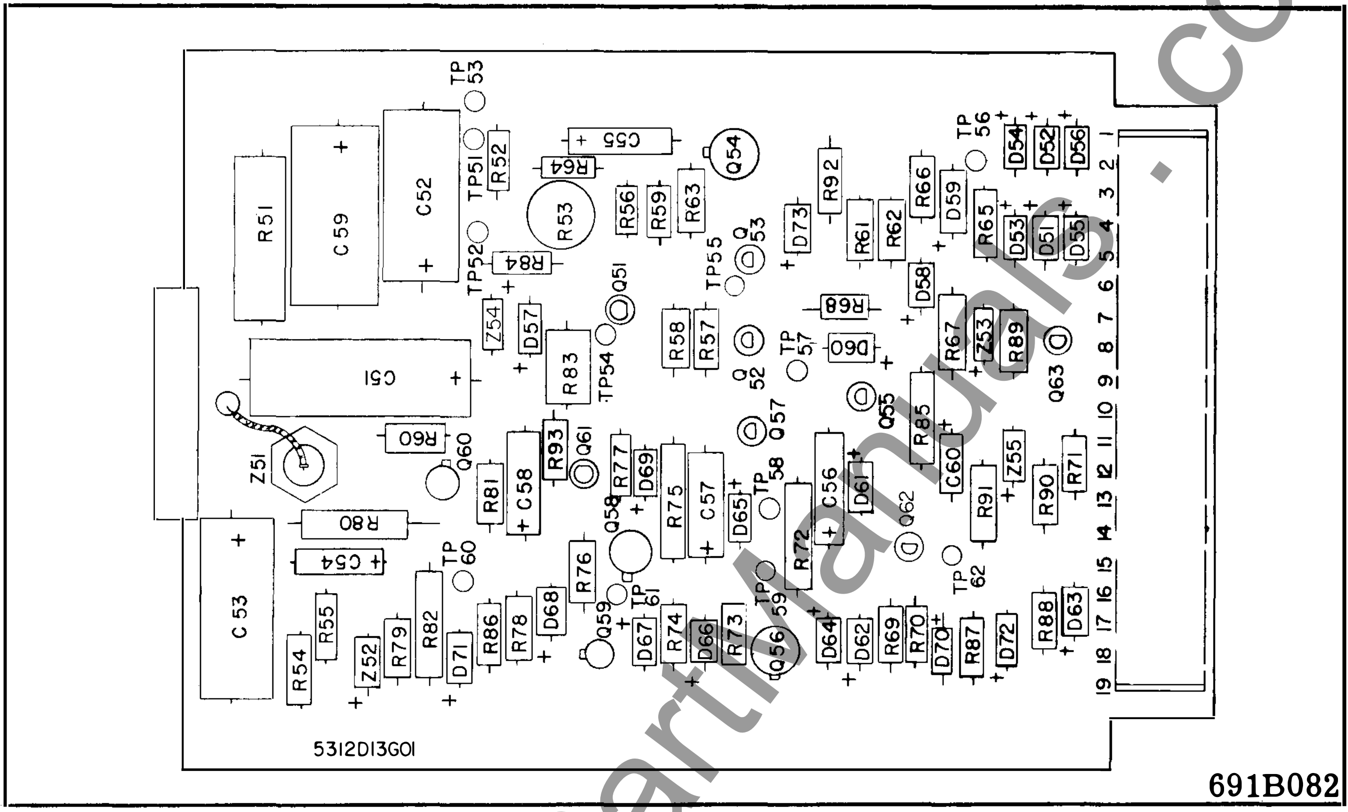


Fig. 3 Location of Components on Fault Detector Board.

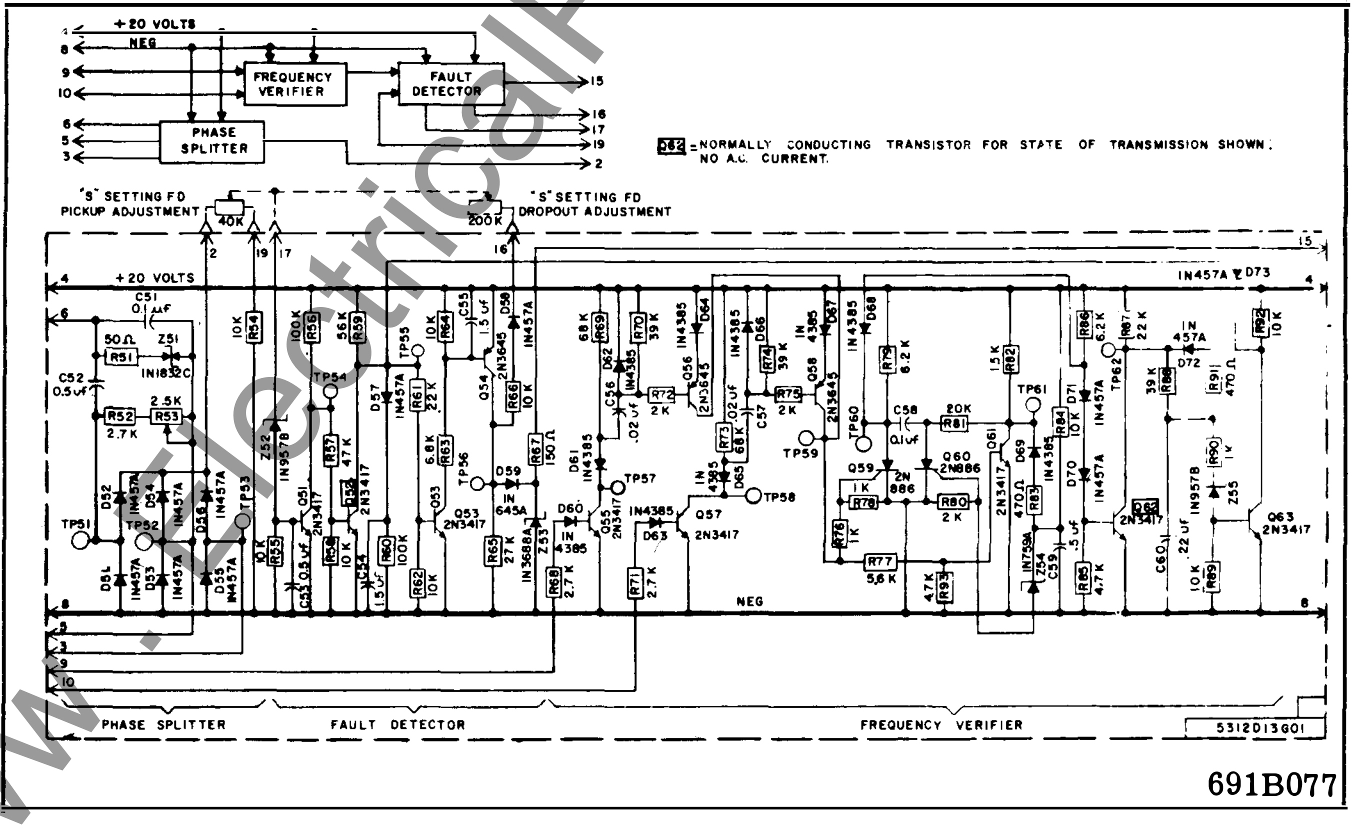


Fig. 4 Schematic of Fault Detector Board .

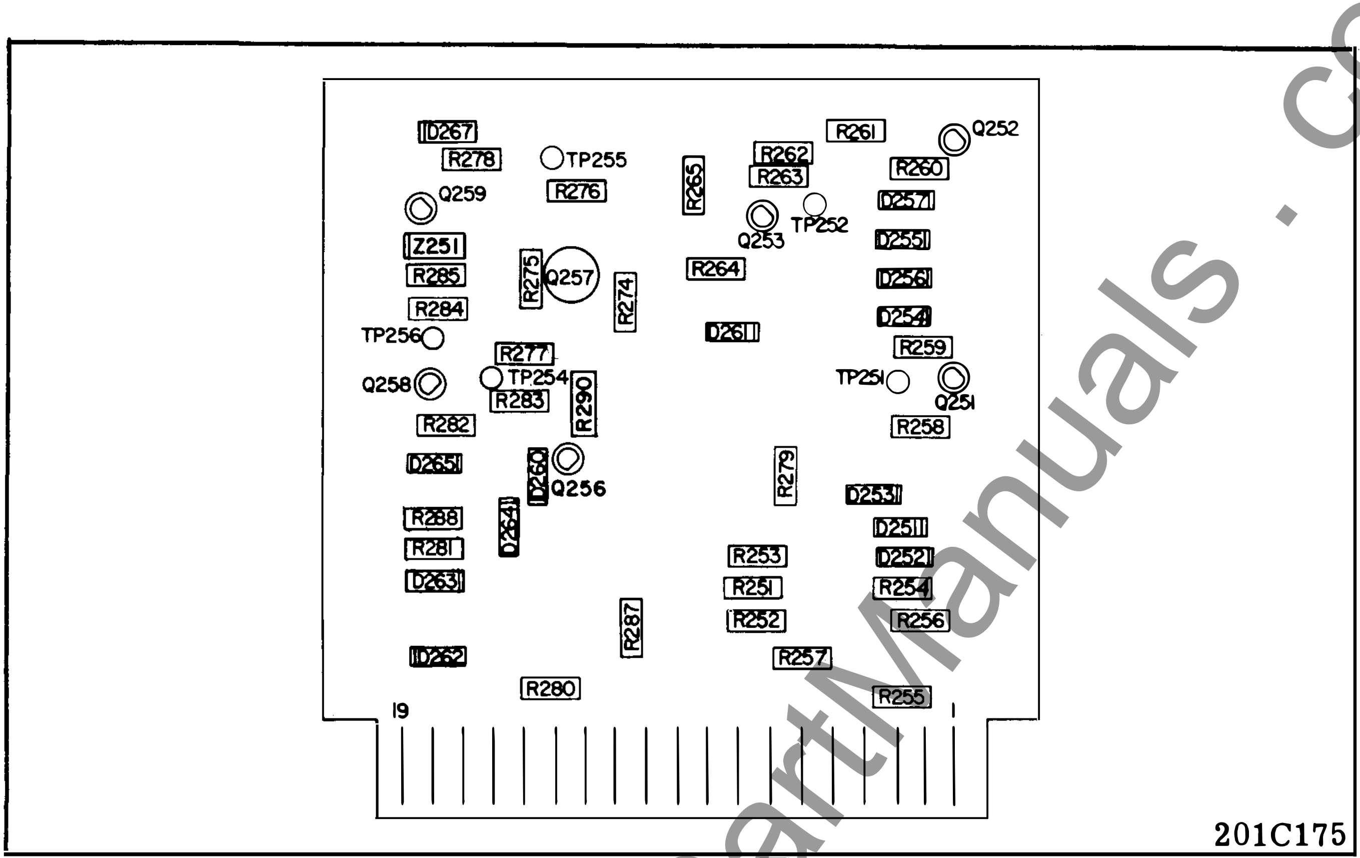


Fig. 5 Location of Components on Arming Board.

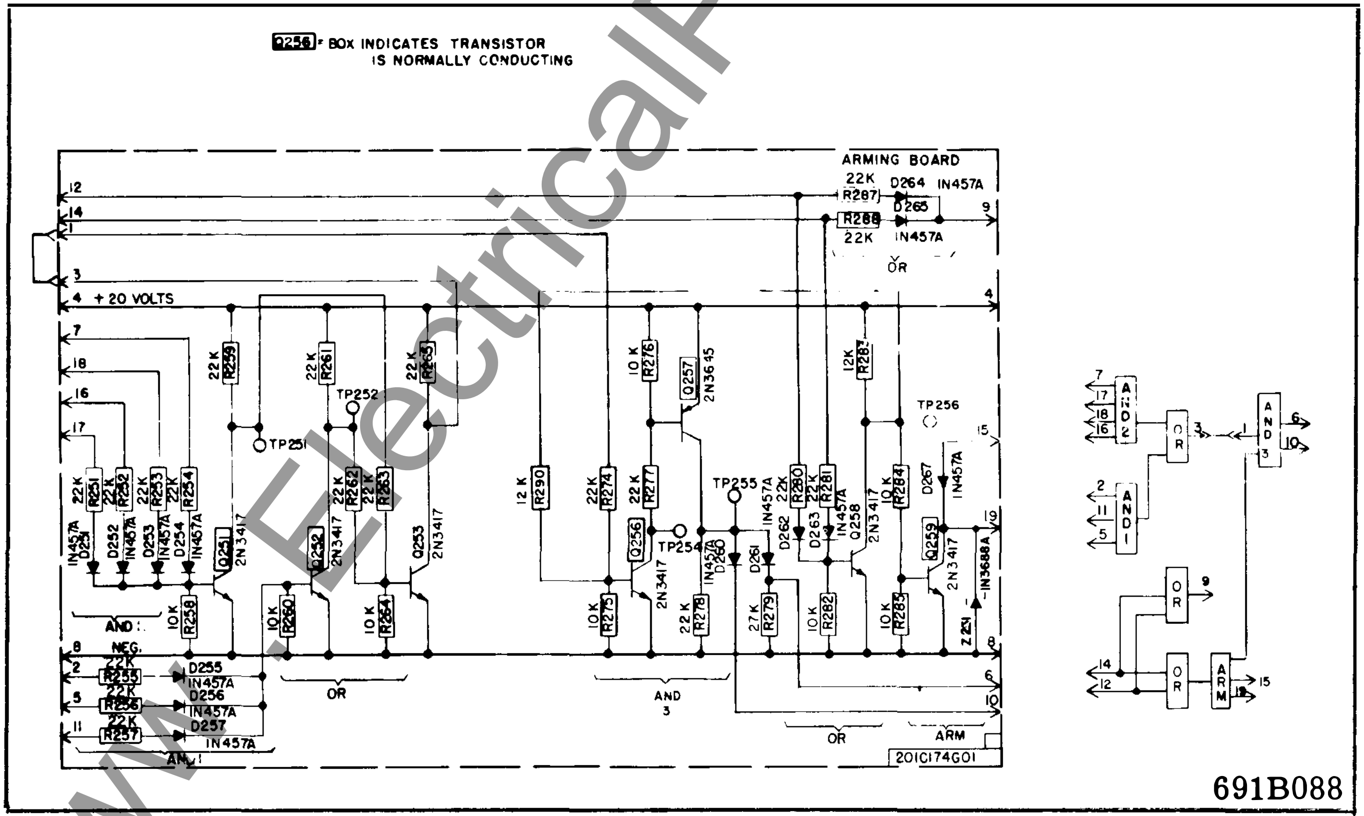


Fig. 6 Schematic of Arming Board for Distance Phase Comparison System.

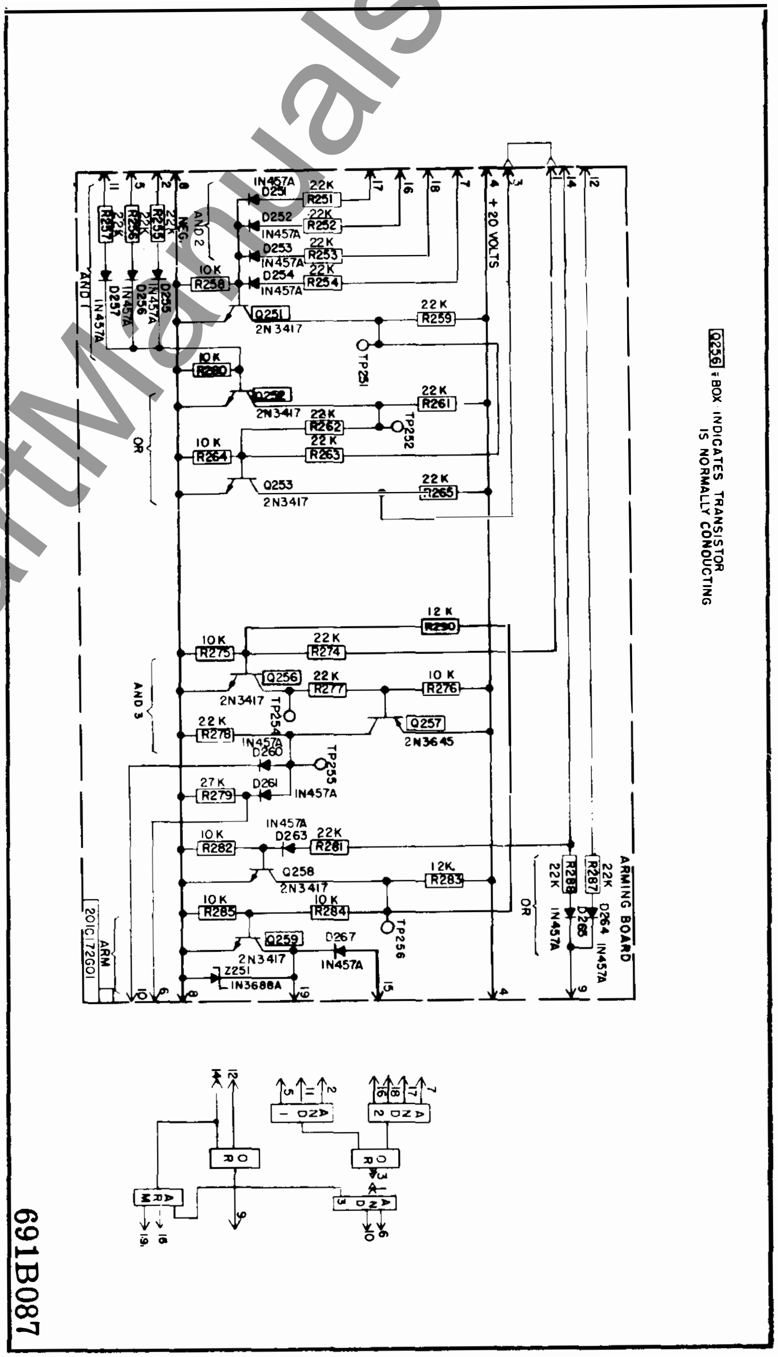


Fig. 7 Schematic of Arming Board for All Distance Supervision System.

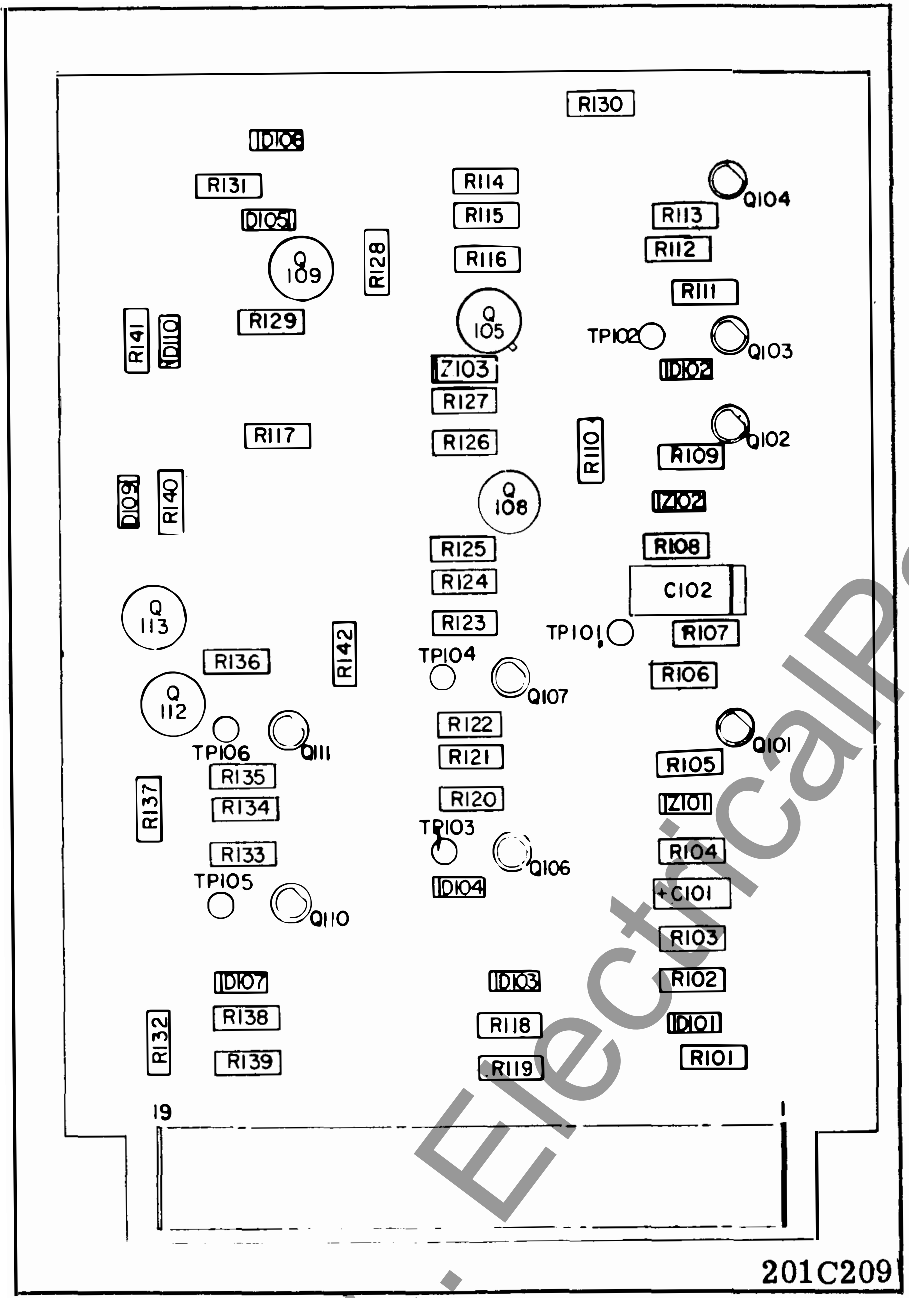


Fig. 8 Location of Components on Amplifier and Keying Board .

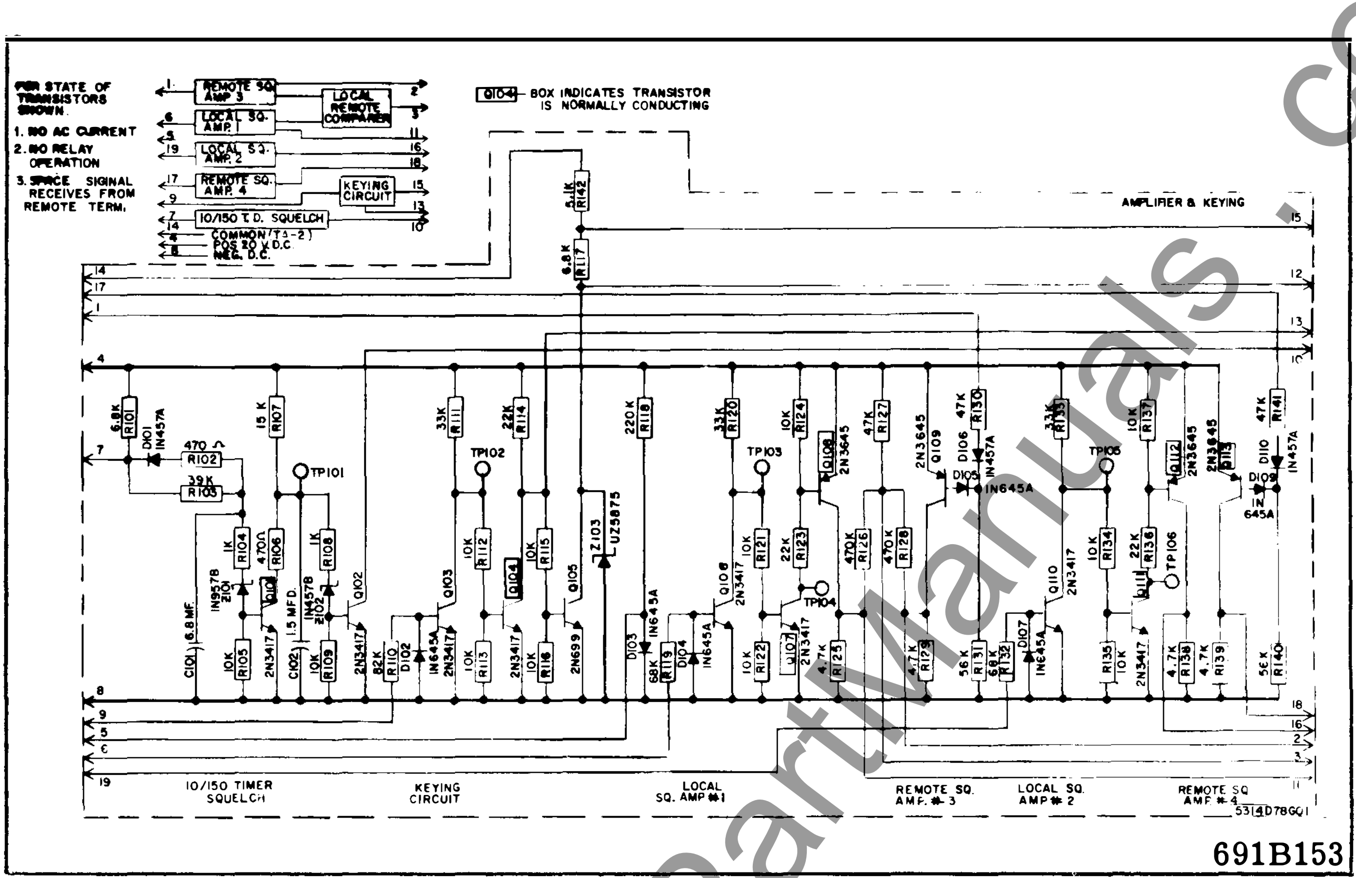


Fig. 9 Schematic of Amplifier and Keying Board.

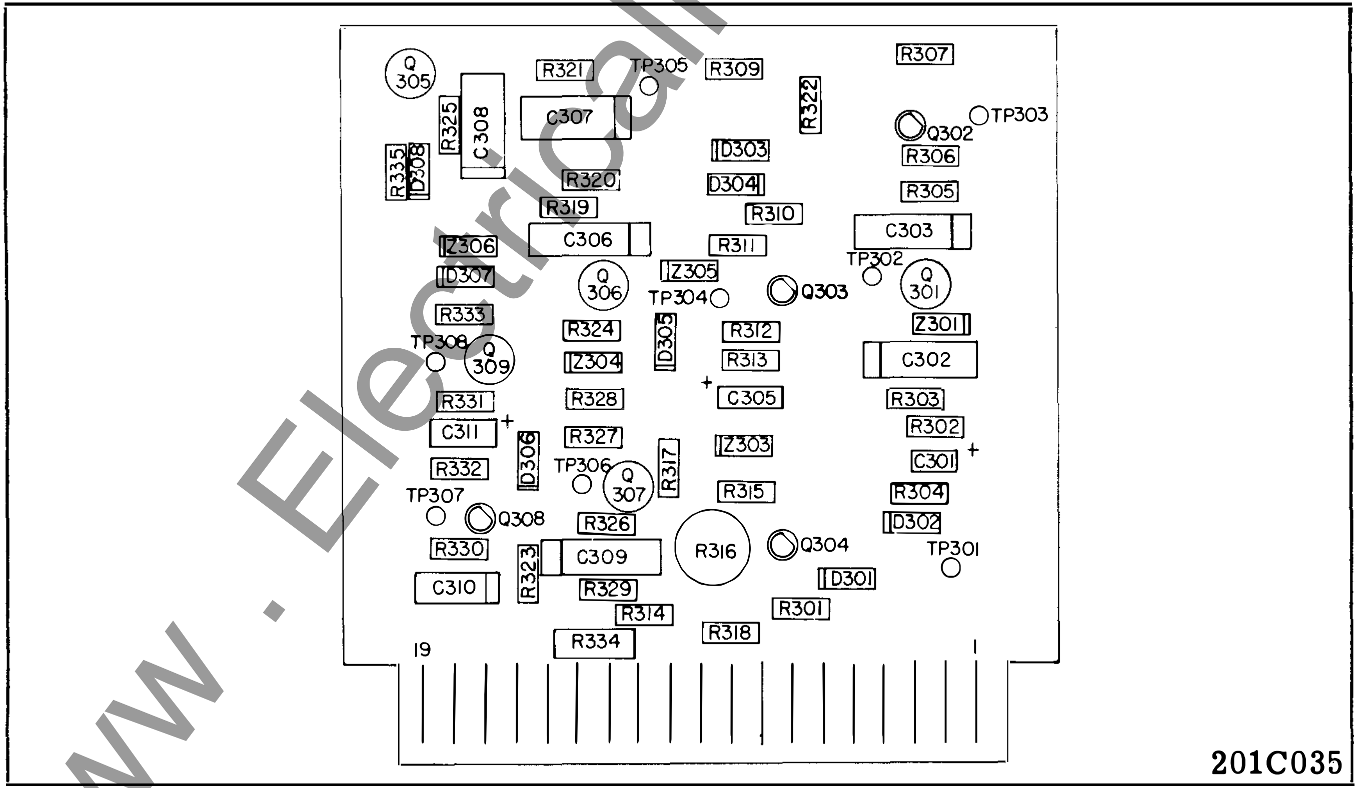


Fig. 10 Location of Components on Output Board .

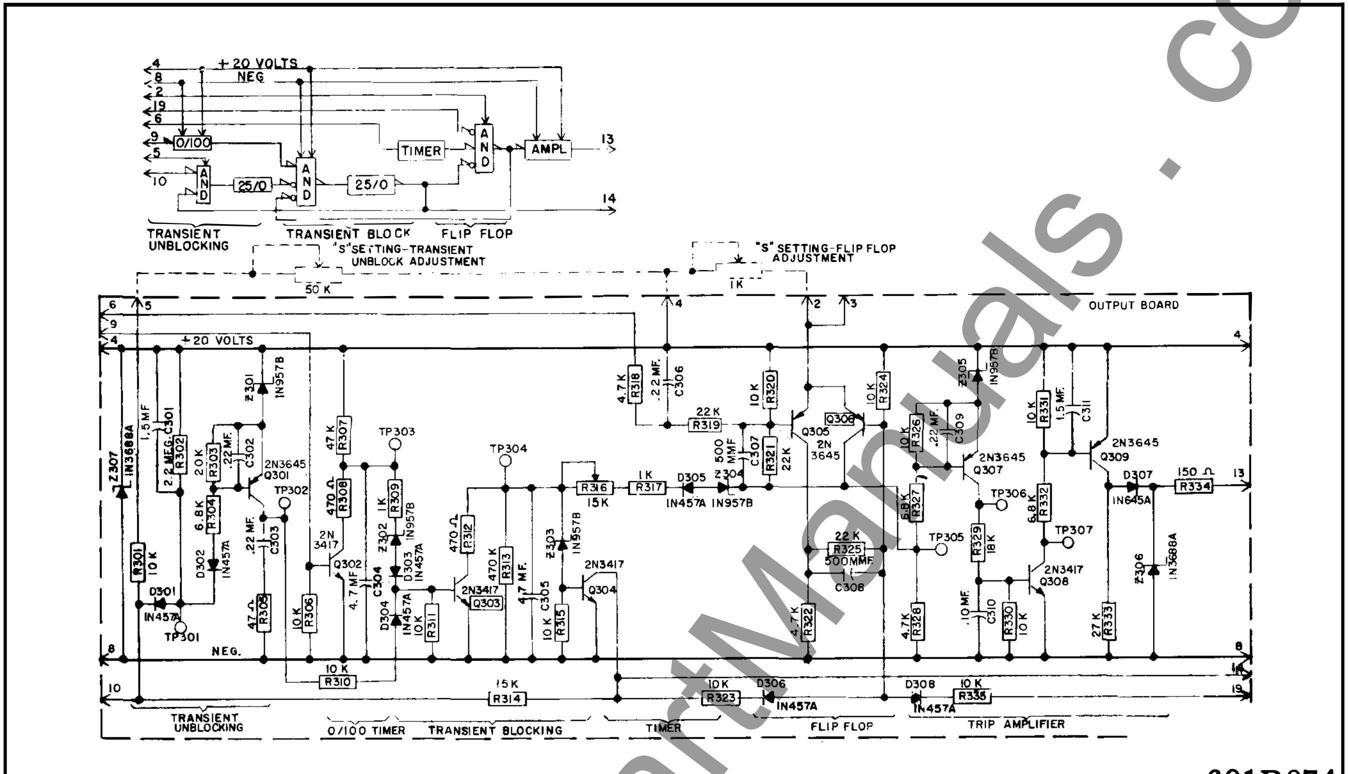


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Fig. 11 Schematic of Output Board.

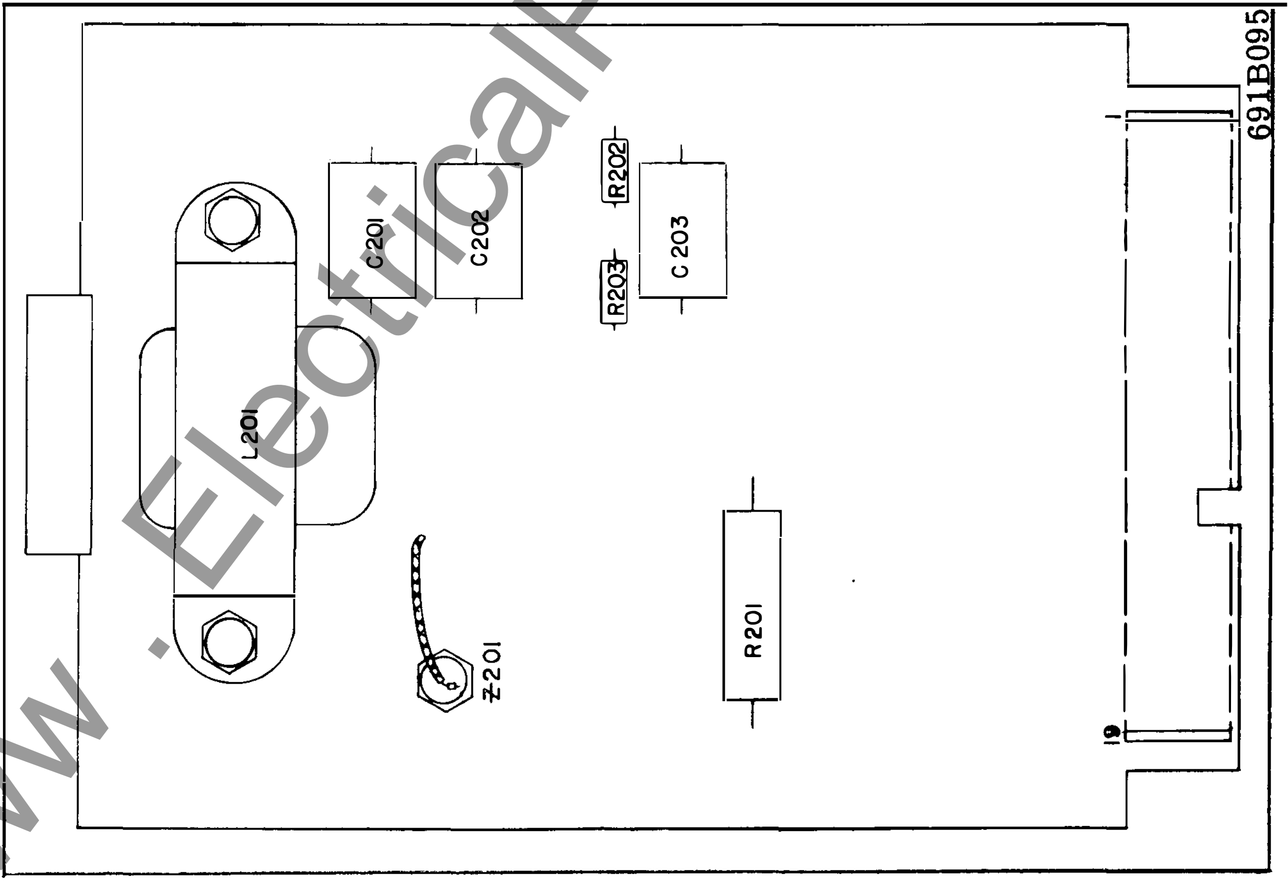

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Fig. 12 Location of Components on Relay Board.

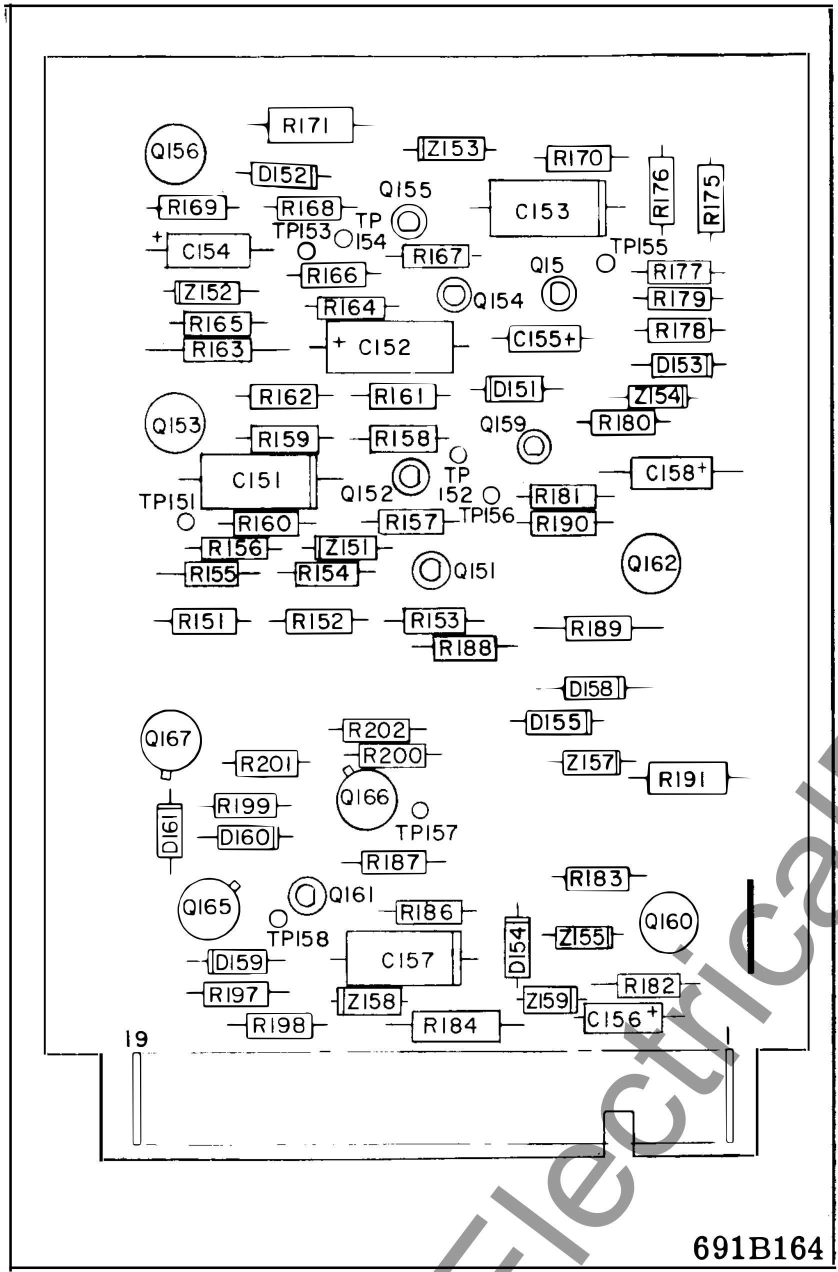


Fig. 14 Location of Components on Supervision Board for TA-2 Tone Channel with AM Squelch.

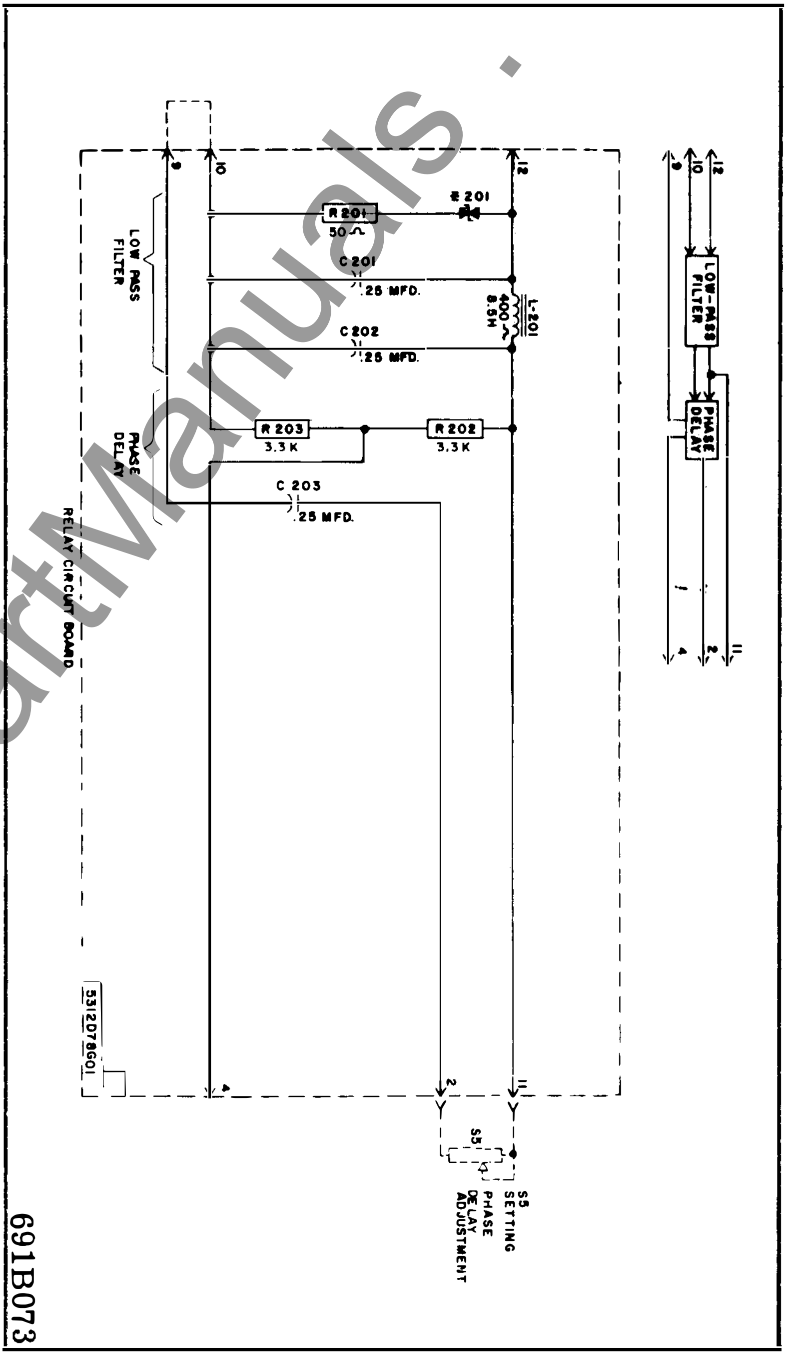


Fig. 13 Schematic of Relay Board.

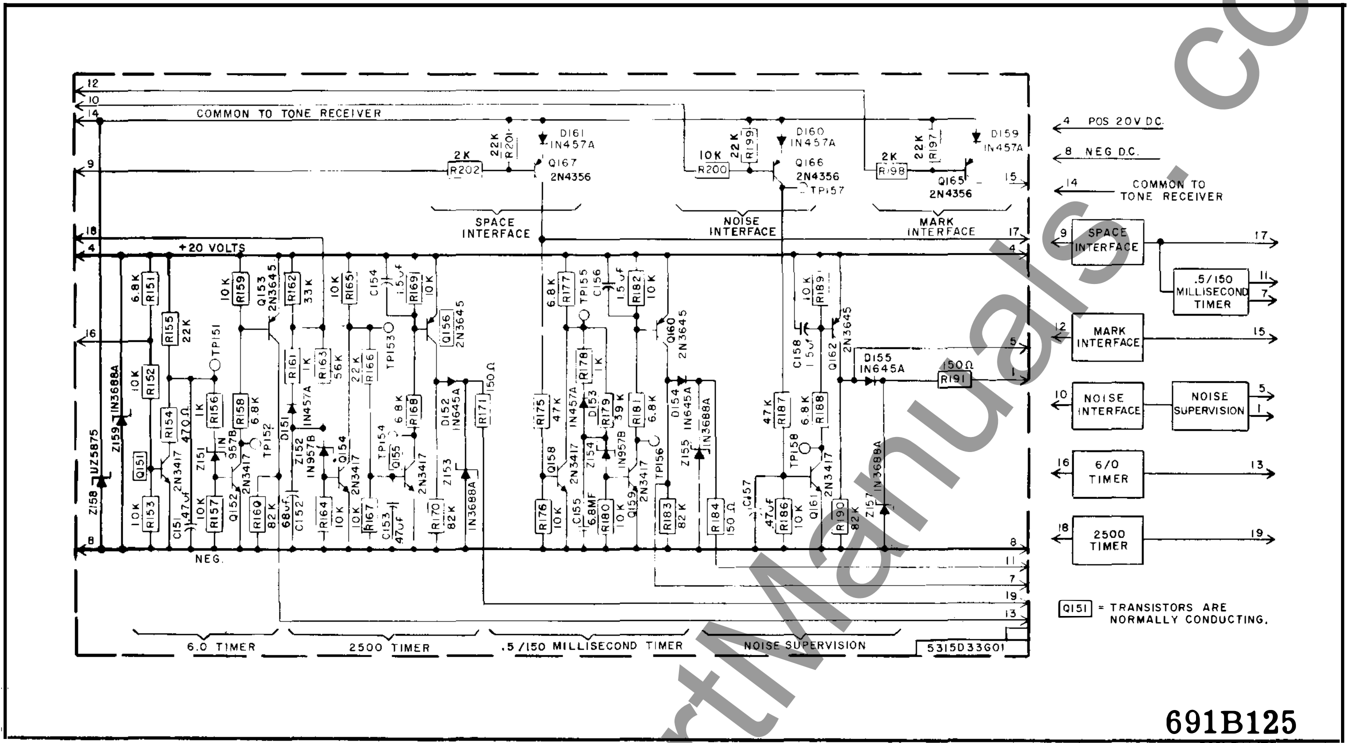


Fig. 15 Schematic of Supervision Board for TA-2 Tone Channel with AM Squelch.

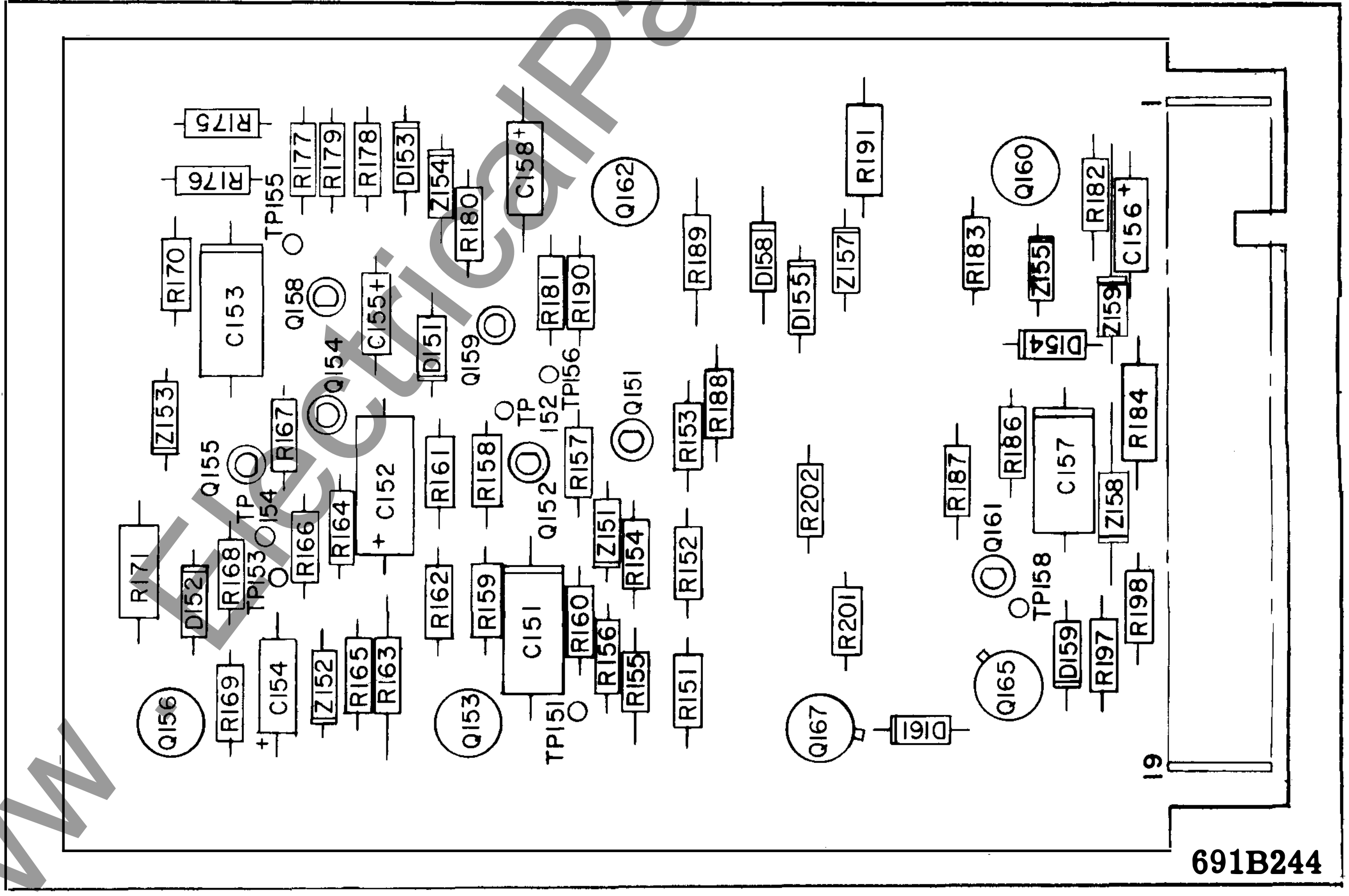


Fig. 16 Location of Components on Supervision Board for TA-2 Tone Channel with TA-3 Noise Supervision.

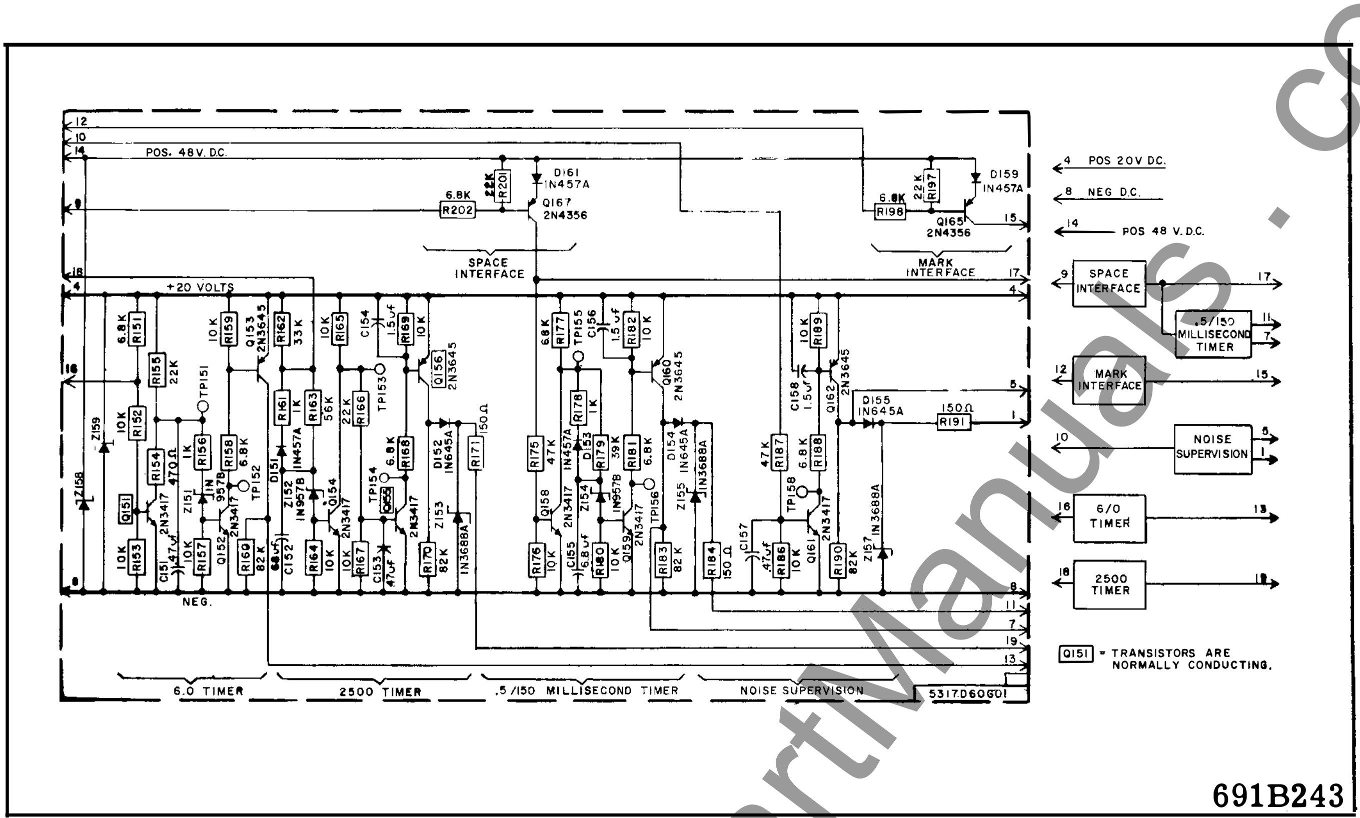


Fig. 17 Schematic of Supervision Board for TA-2 Tone Channel with TA-3 Noise Supervision.

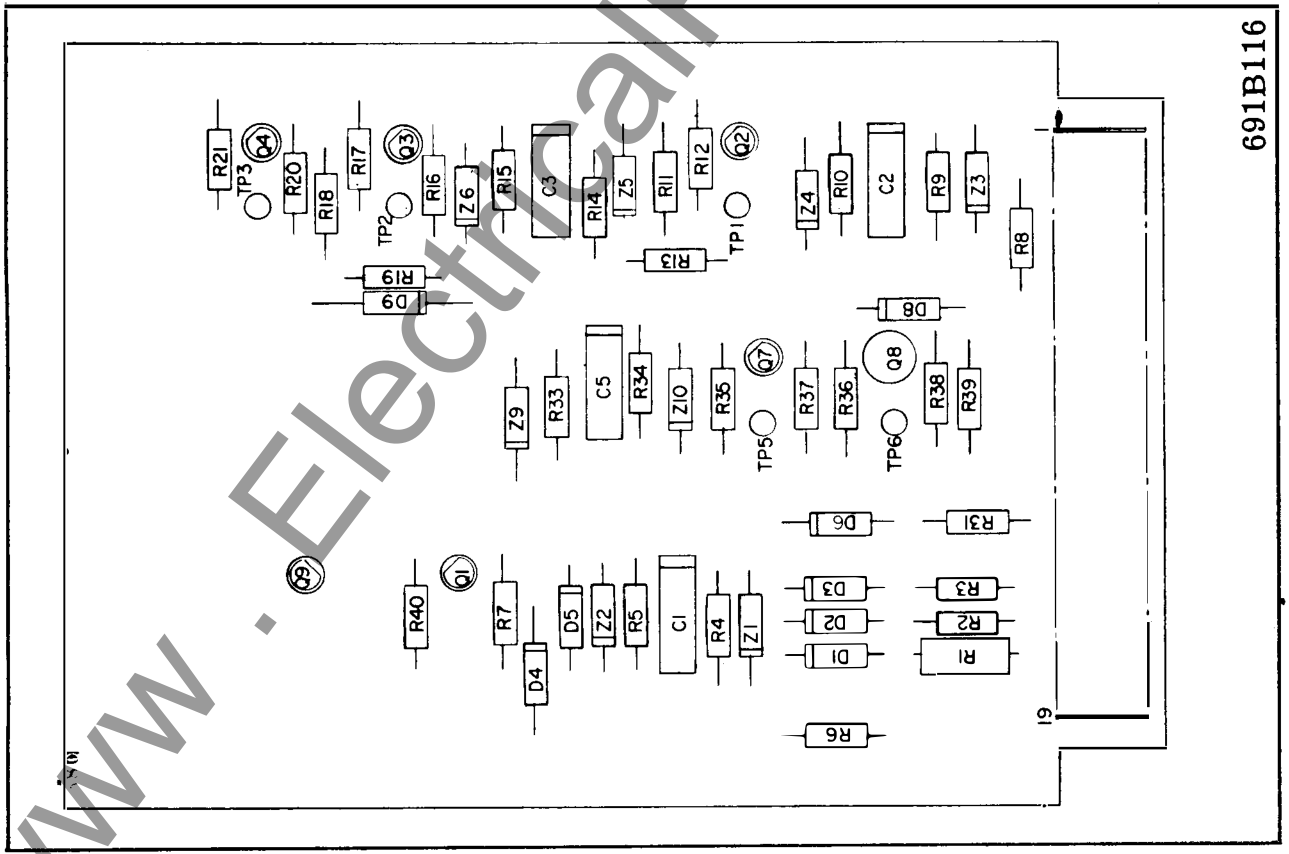


Fig. 18 Location of Components on Protective Relay Board for Distance Phase Comparison.

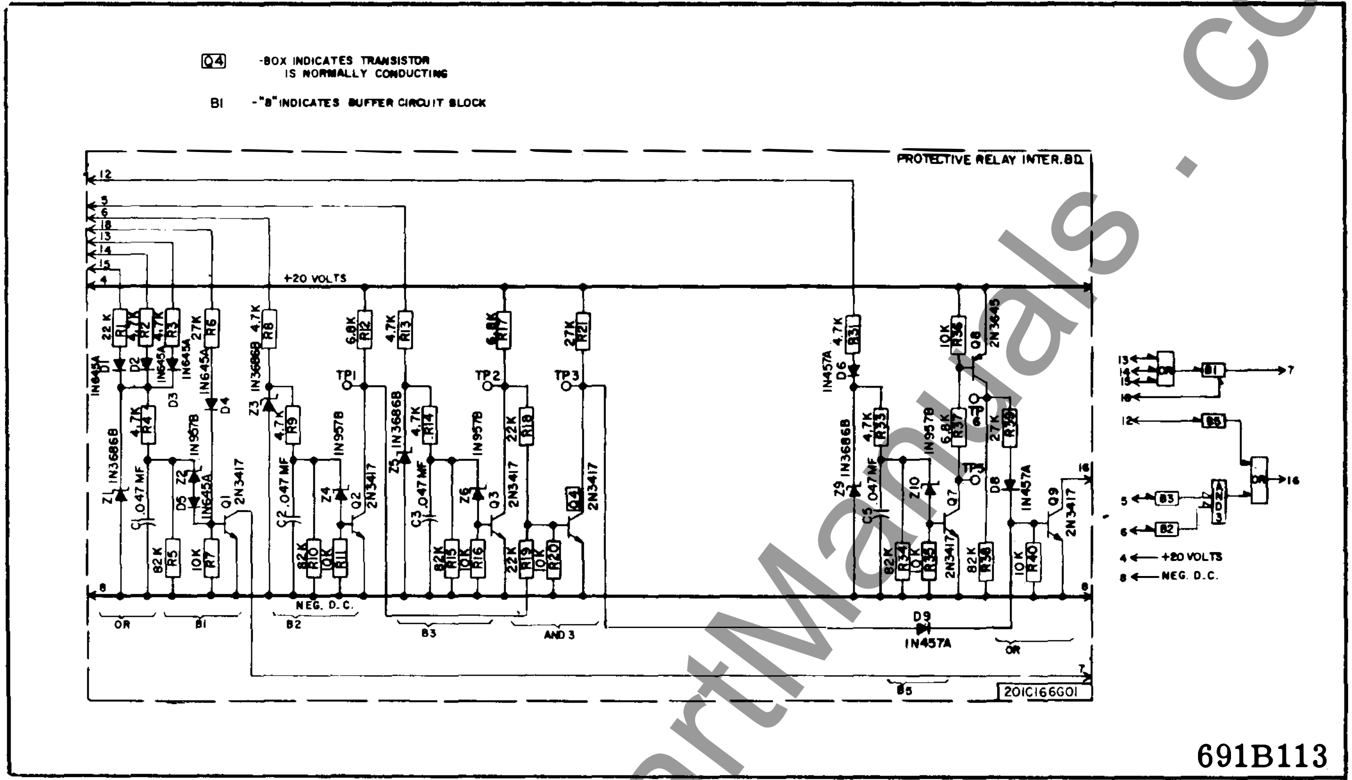


Fig. 19 Schematic of Protective Relay Board for Distance Phase Comparison System.

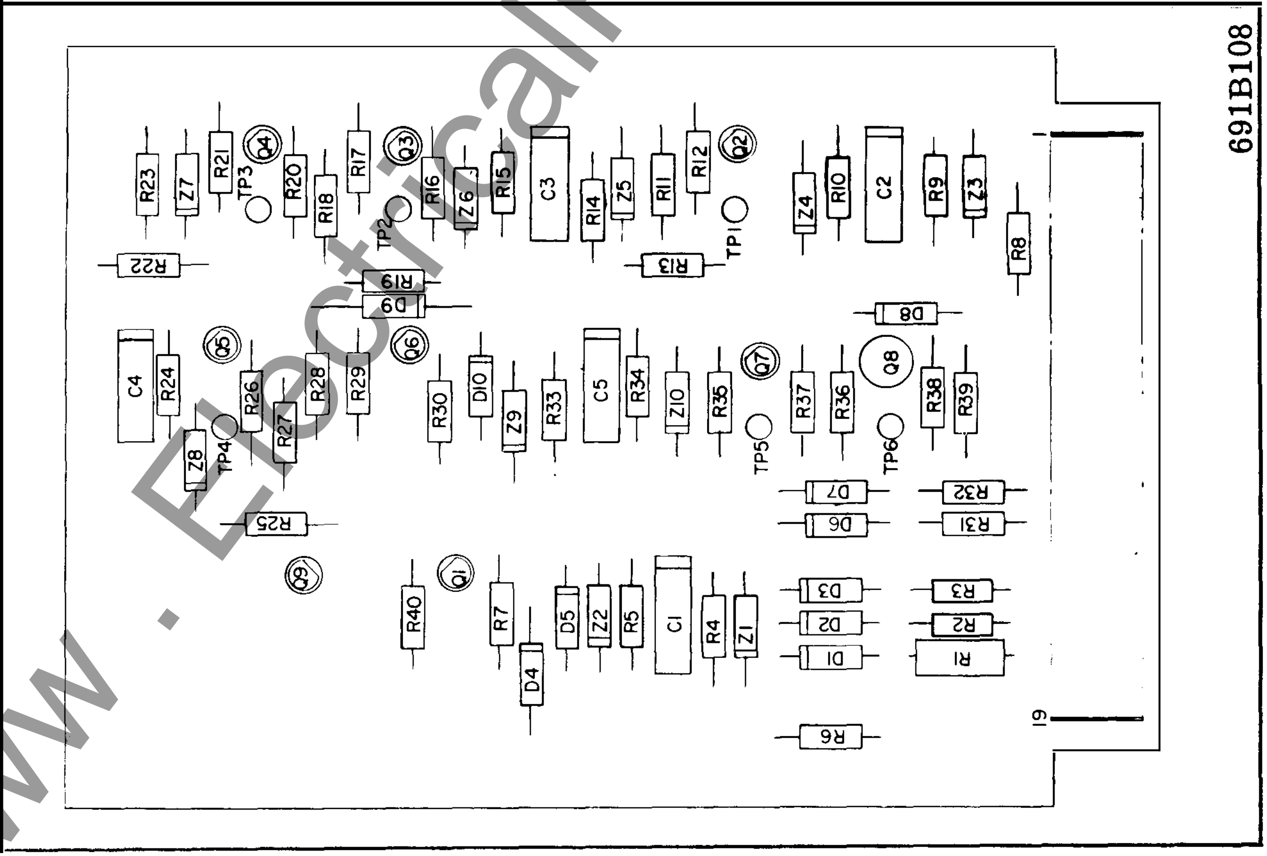


Fig. 20 Location of Components on Protective Relay Board for All Distance. Supervision System.

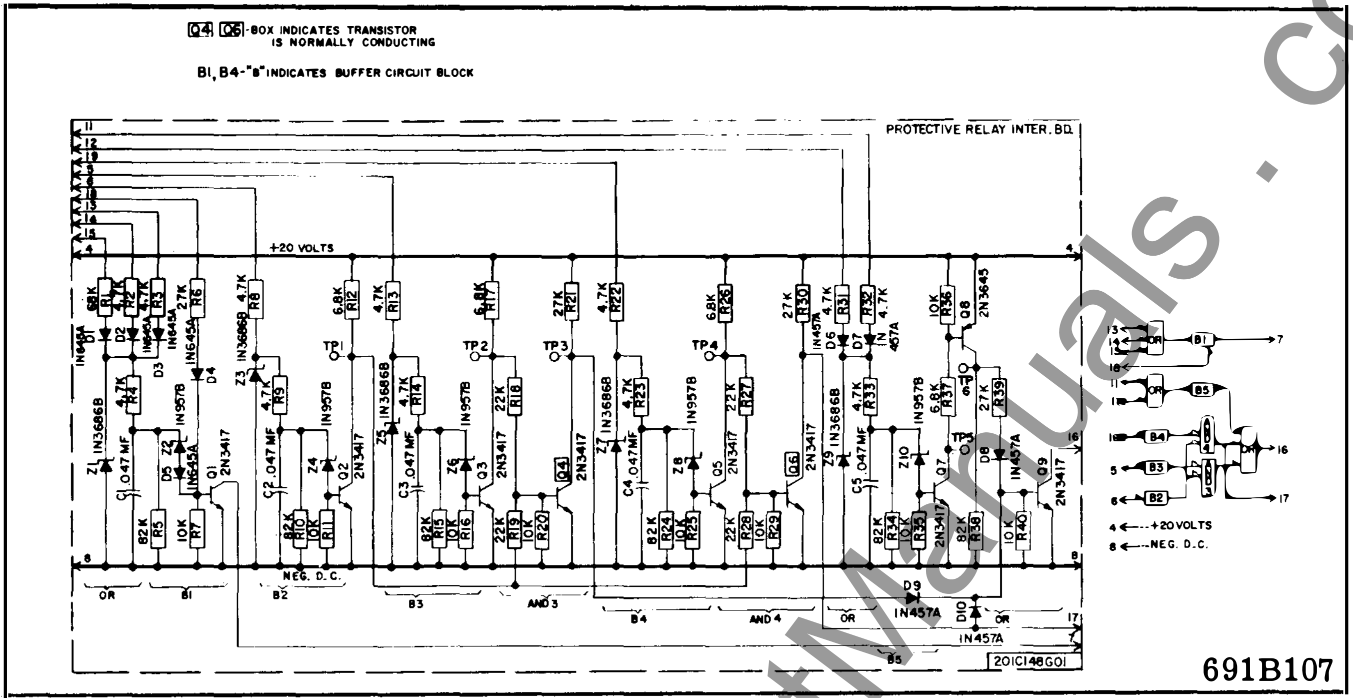


Fig. 21 Schematic of Protective Relay Board for All Distance Supervision System.

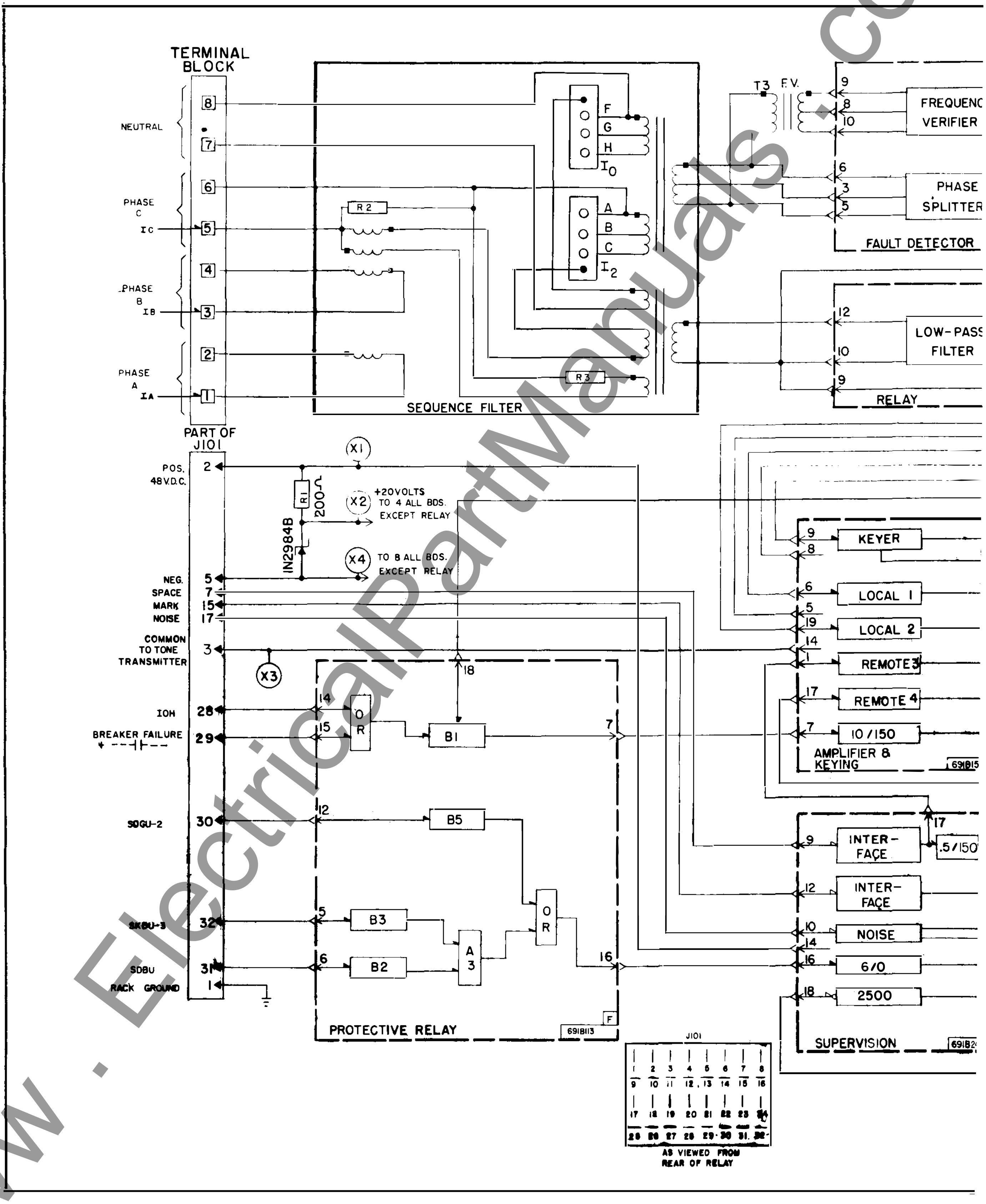
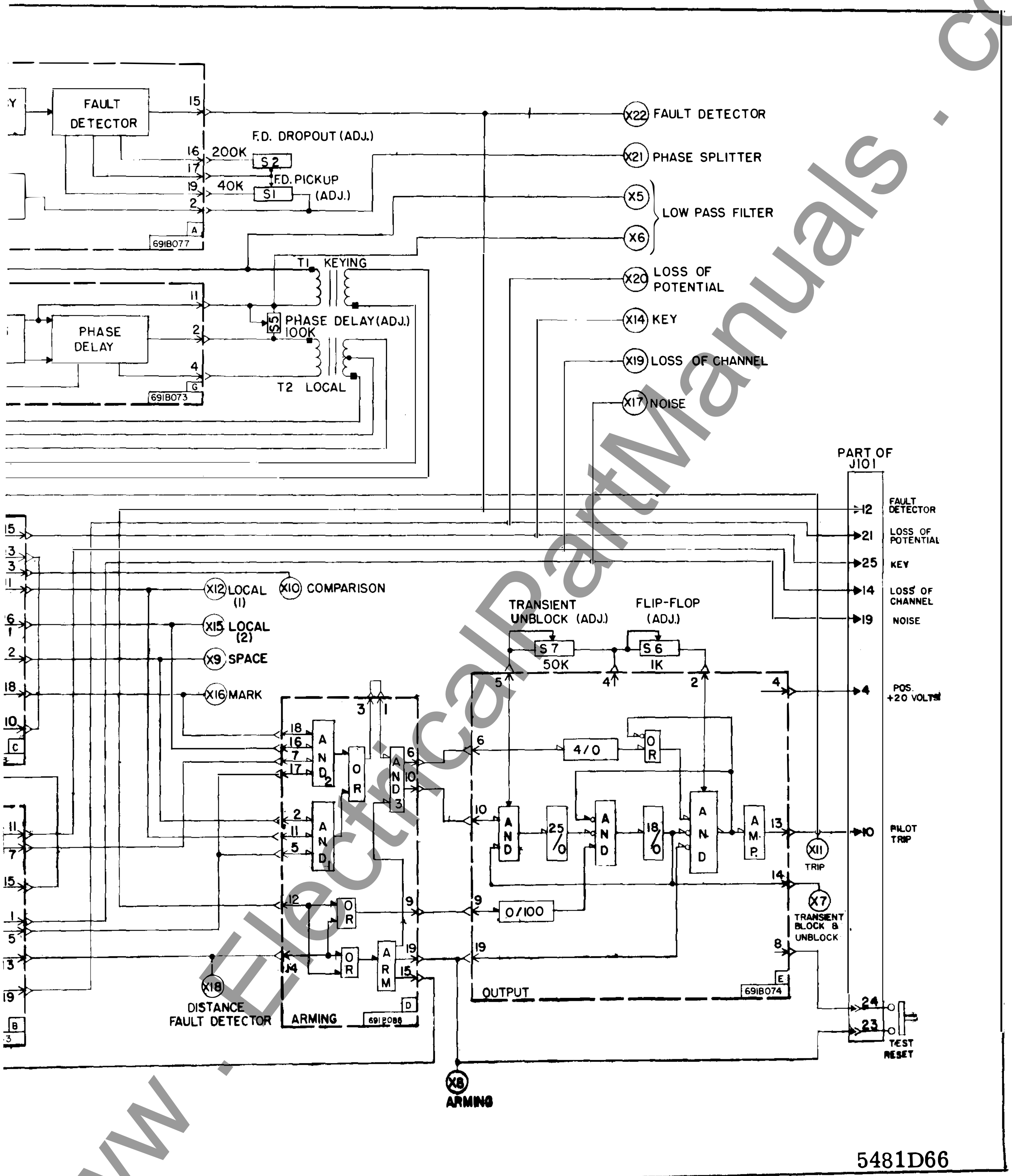


Fig. 23 Logic Diagram of SKBU-21 for Dista



nce Phase Comparison System with TA-3 Noise Supervision.

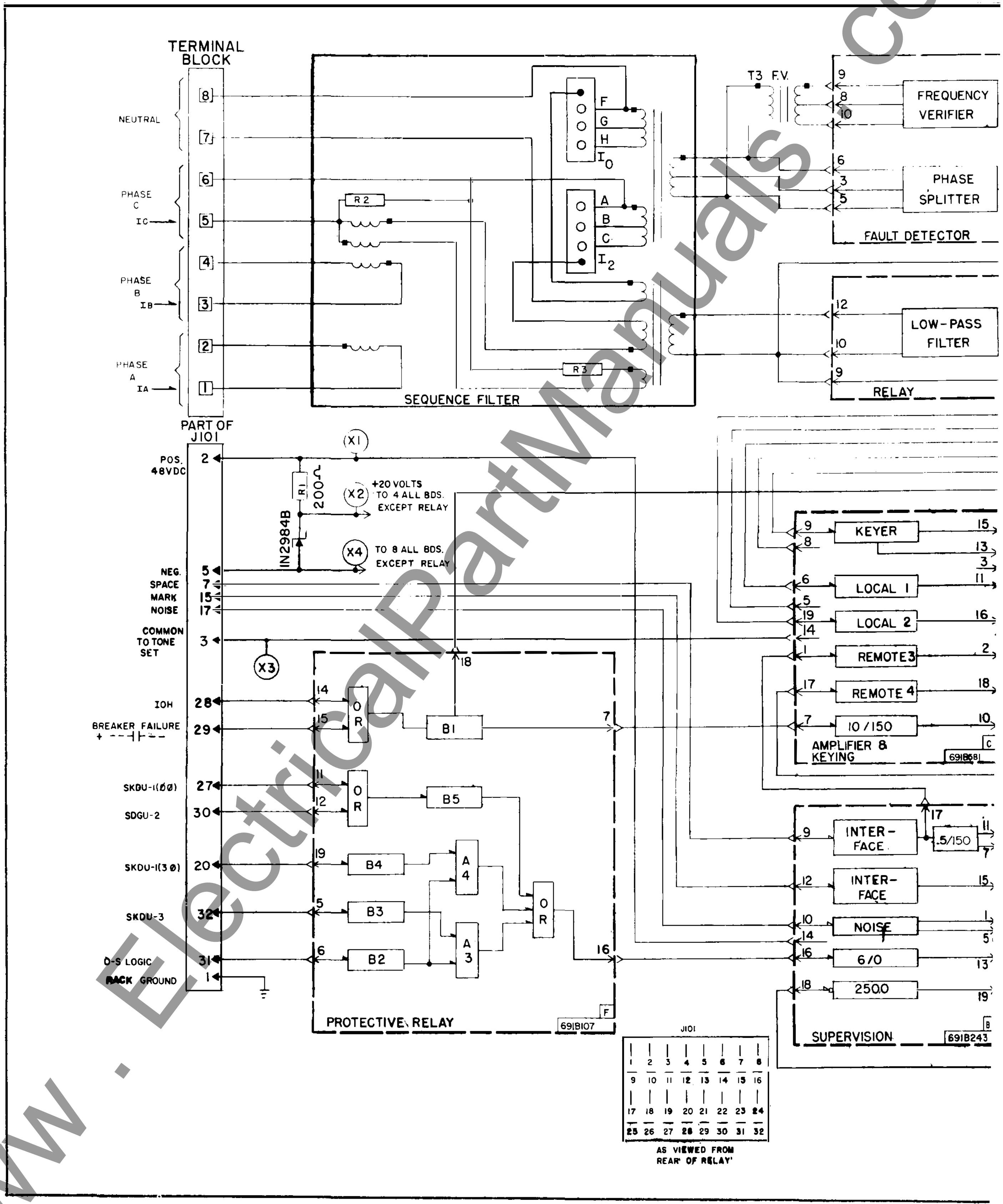
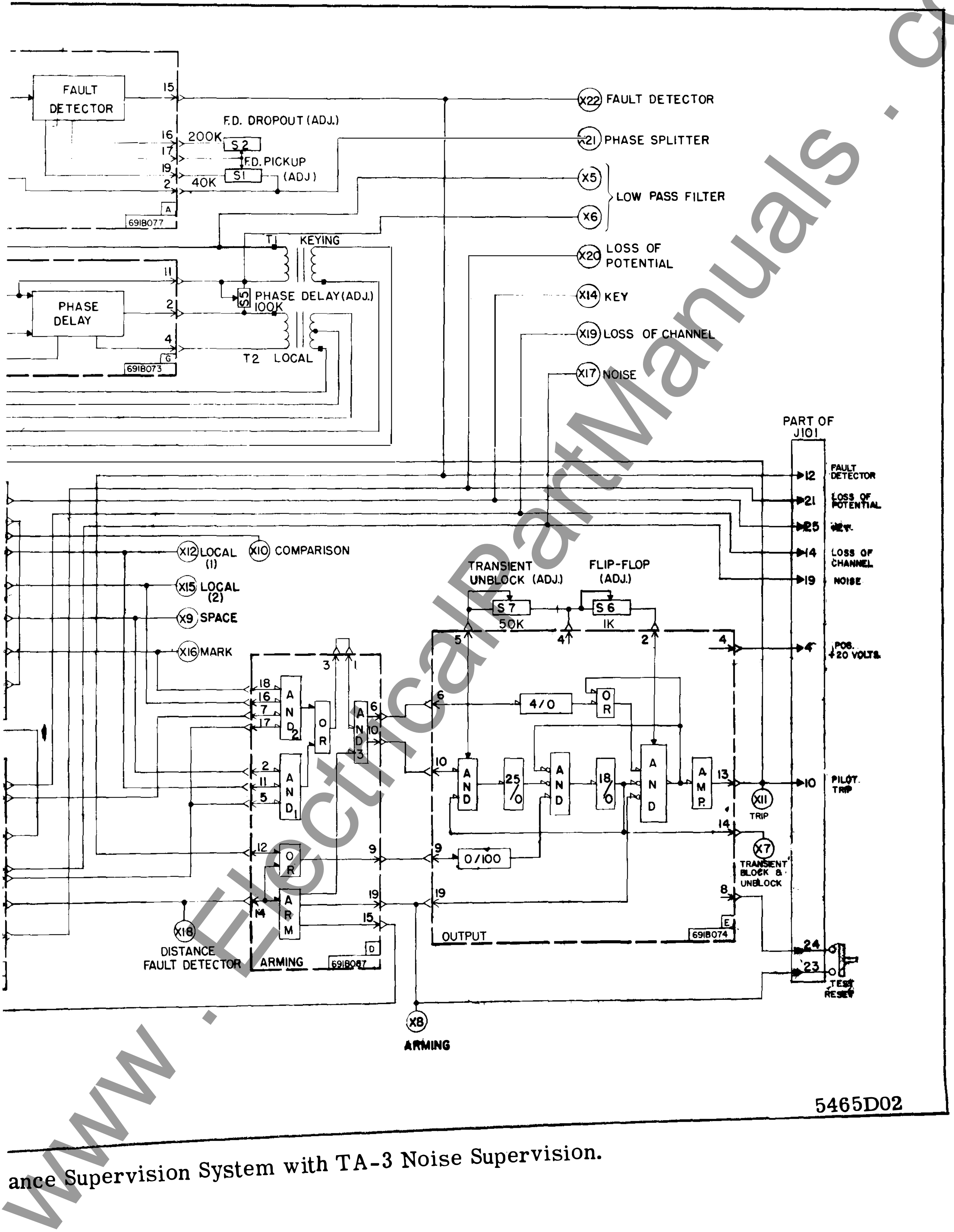


Fig. 25 Logic Diagram of SKBU-21 Relay for All Dist



ance Supervision System with TA-3 Noise Supervision.

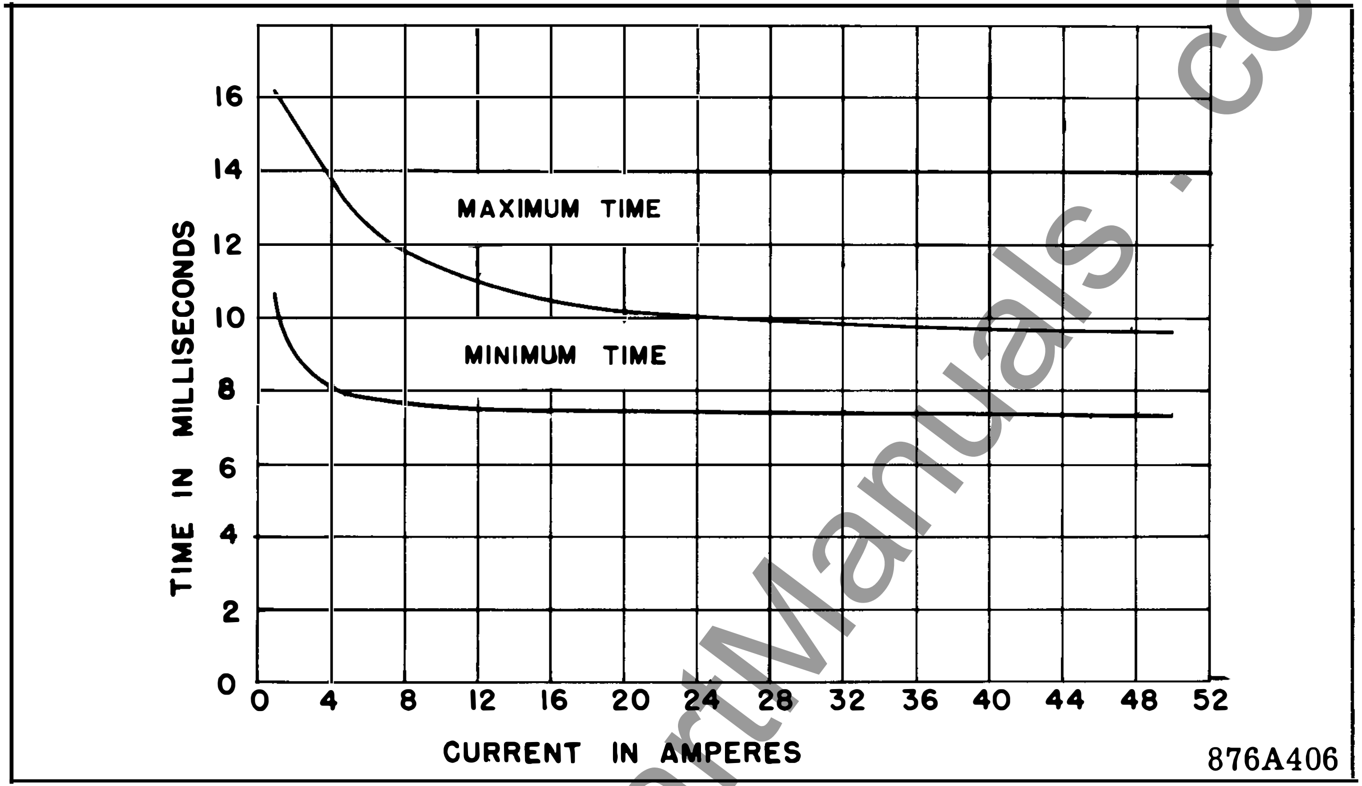


Fig. 26 Operating Times of Fault Detector of SKBU-21 Relay.

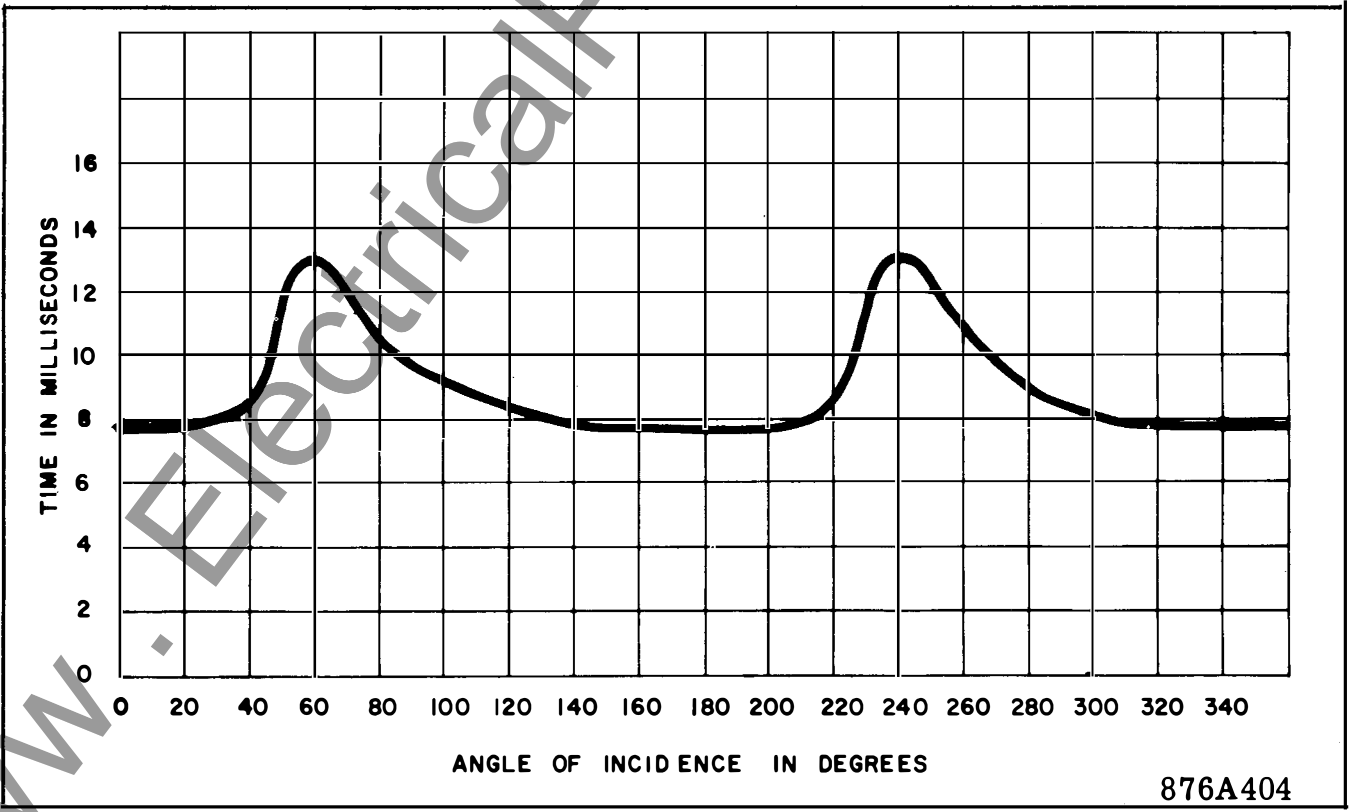


Fig. 27 Operating Times for Fault Detector of SKBU-21 Relay as A Function of Fault Incidence Angle at 5 Amperes.

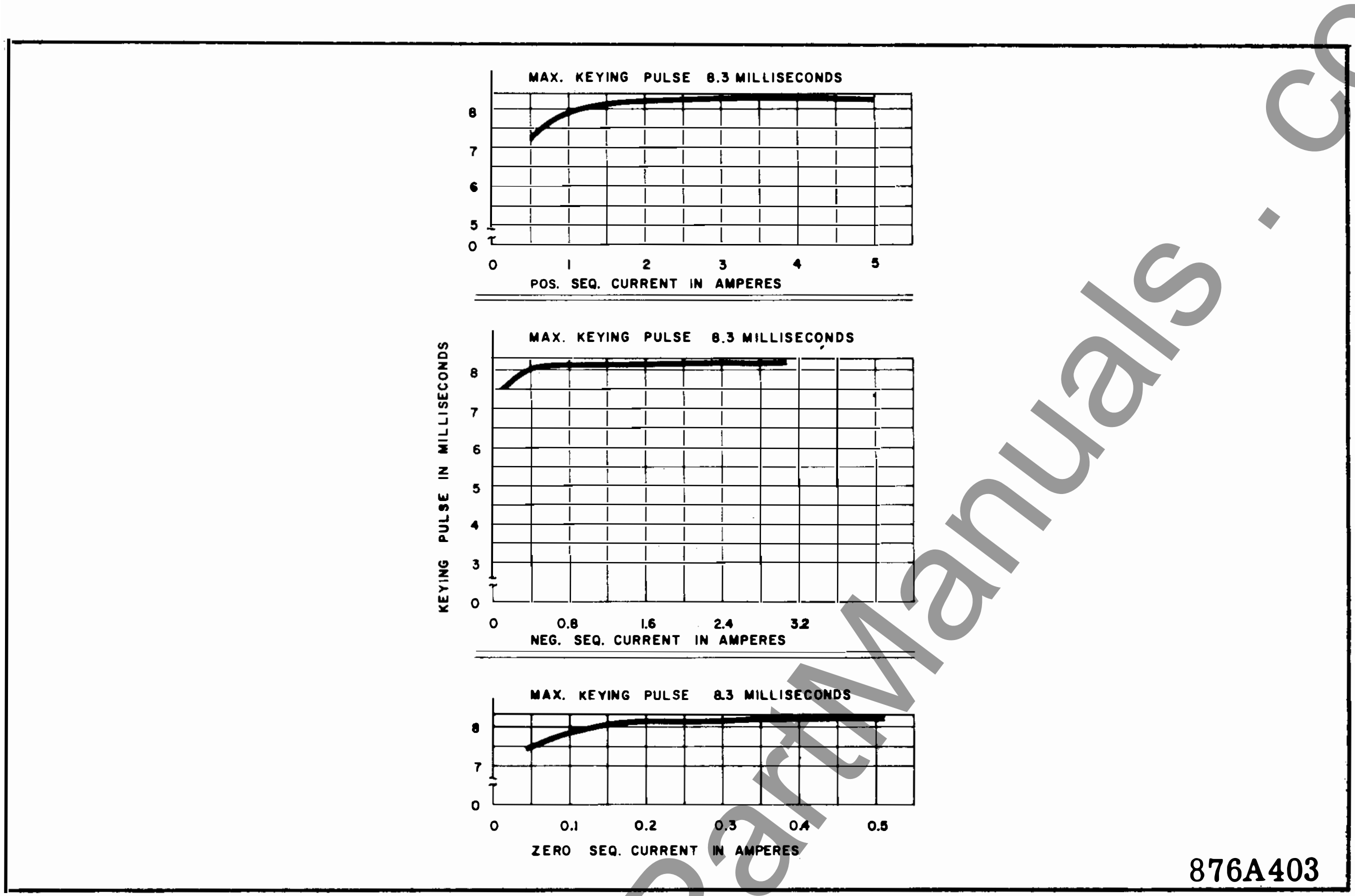


Fig. 28 Width of Keying Pulses at Different Current Levels of SKBU-21 Relay.

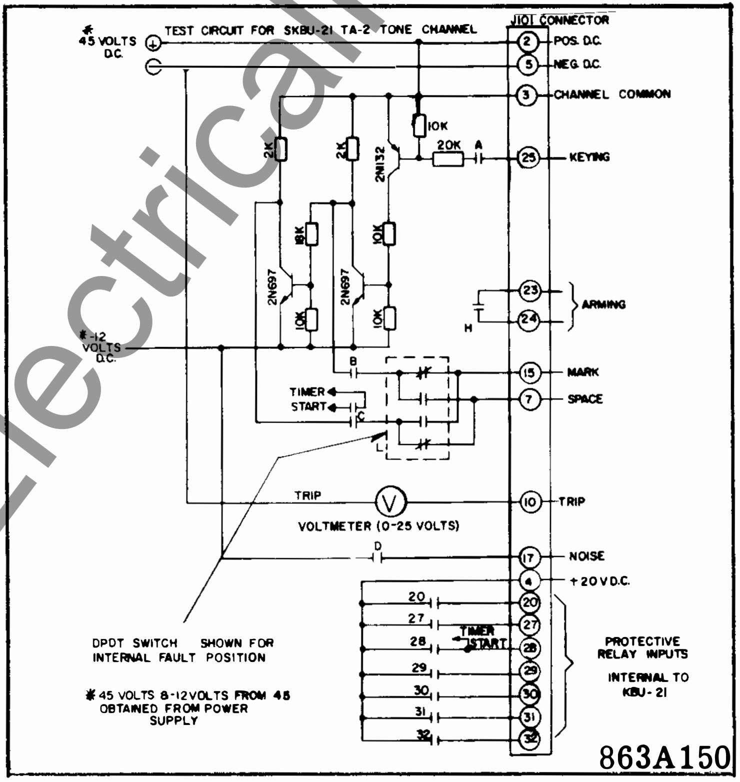
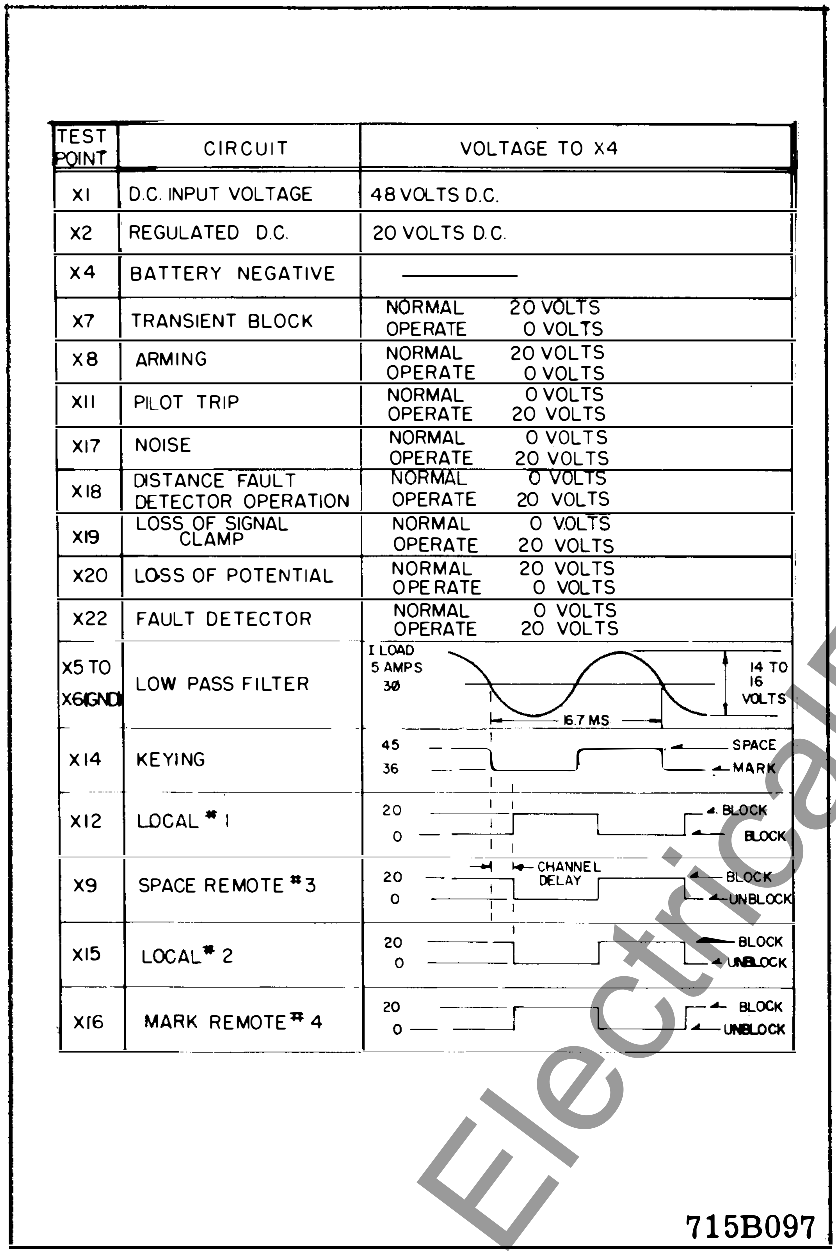


Fig. 29 Test Circuit of SKBU-21 Relay for TA-2 Tone Channel.



TEST POINT	CIRCUIT	VOLTAGE TO X4
X1	D.C. INPUT VOLTAGE	48 VOLTS D.C.
X2	REGULATED D.C.	20 VOLTS D.C.
X4	BATTERY NEGATIVE	————
X7	TRANSIENT BLOCK	NORMAL 20 VOLTS OPERATE 0 VOLTS
X8	ARMING	NORMAL 20 VOLTS OPERATE 0 VOLTS
X11	PILOT TRIP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X17	NOISE	NORMAL 0 VOLTS OPERATE 20 VOLTS
X18	DISTANCE FAULT DETECTOR OPERATION	NORMAL 0 VOLTS OPERATE 20 VOLTS
X19	LOSS OF SIGNAL CLAMP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X20	LOSS OF POTENTIAL	NORMAL 20 VOLTS OPERATE 0 VOLTS
X22	FAULT DETECTOR	NORMAL 0 VOLTS OPERATE 20 VOLTS
X5 TO X6(GND)	LOW PASS FILTER	I LOAD 5 AMPS 3Ø 14 TO 16 VOLTS 16.7 MS
X14	KEYING	45 36 SPACE MARK
X12	LOCAL # 1	20 0 BLOCK BLOCK
X9	SPACE REMOTE # 3	CHANNEL DELAY 20 0 BLOCK UNBLOCK
X15	LOCAL # 2	20 0 BLOCK UNBLOCK
X16	MARK REMOTE # 4	20 0 BLOCK UNBLOCK

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Fig. 30 Table I Test Point Voltages.

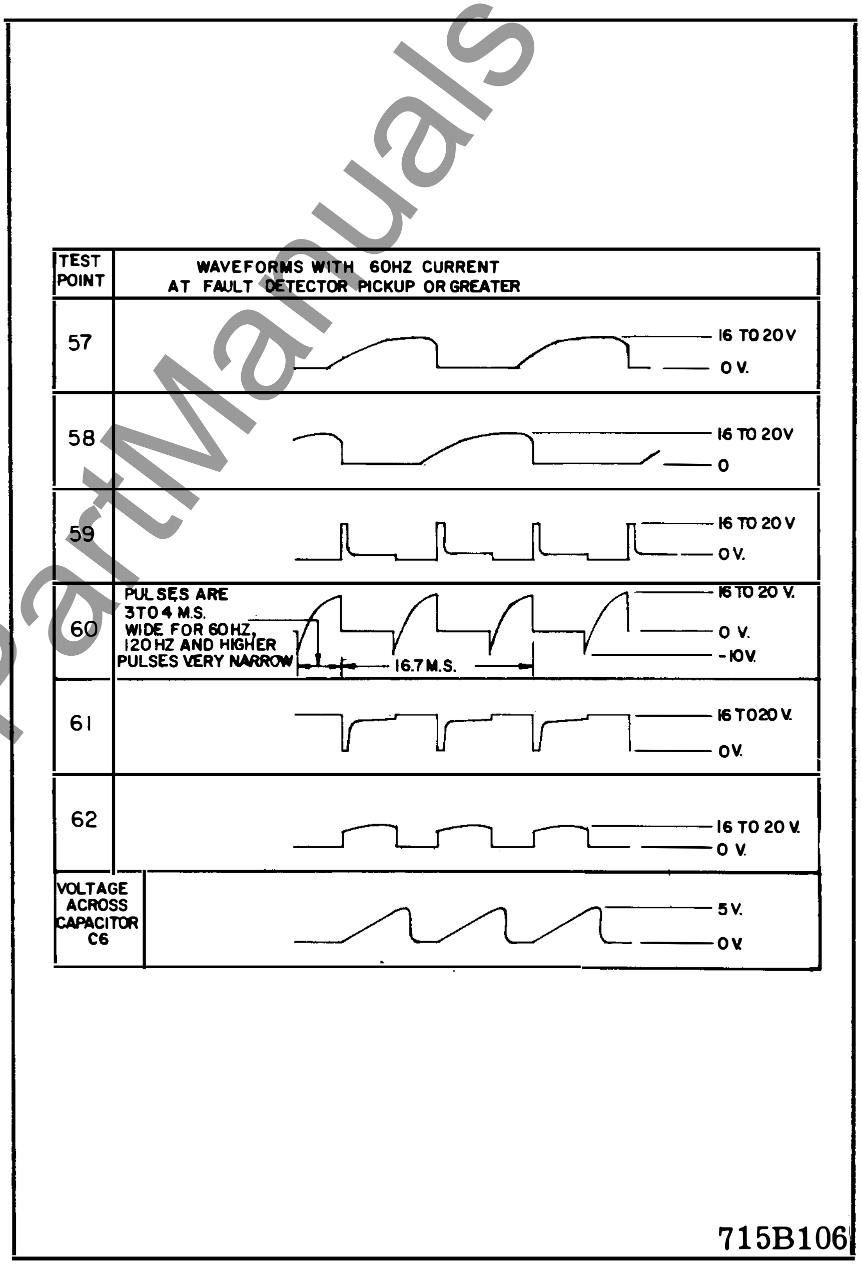

Fig. 31 Table III frequency Verifier Waveforms at $60H_z$.

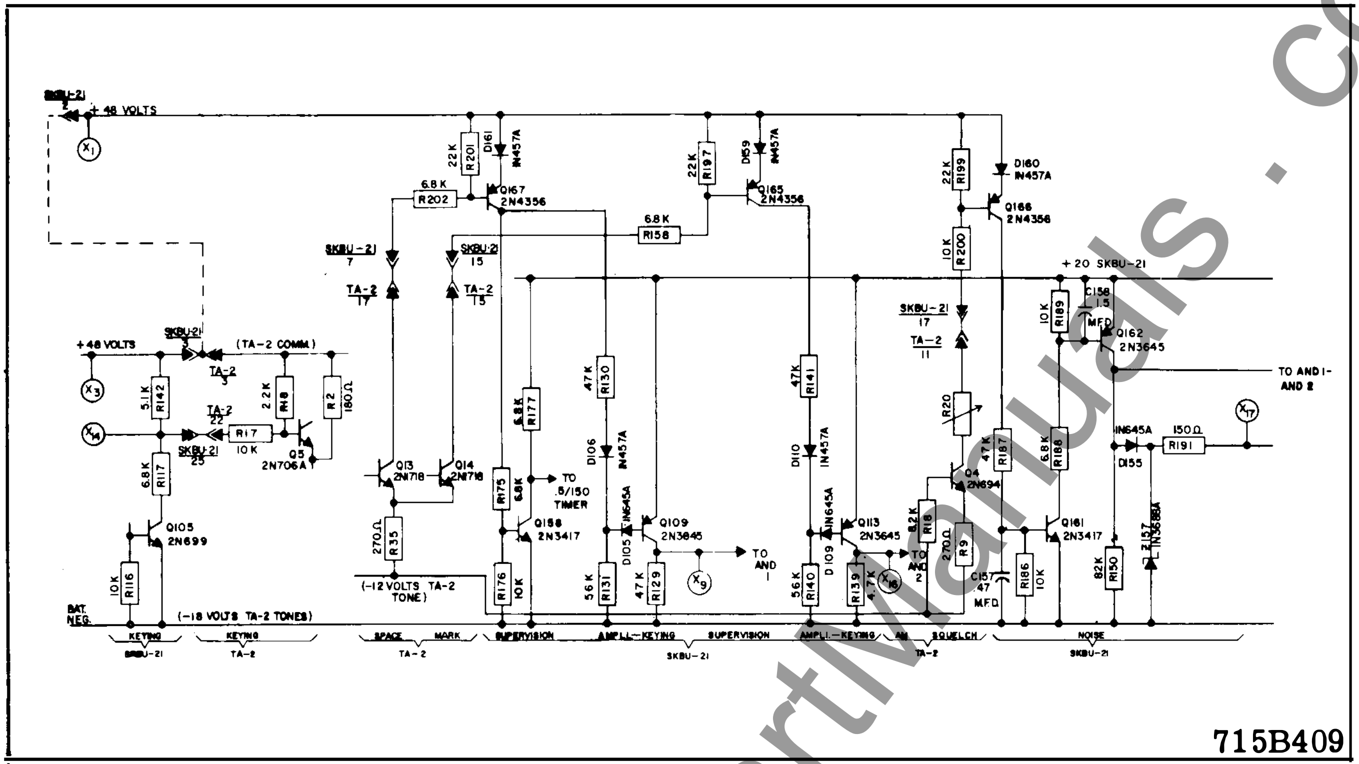

Fig. 32 Elementary Connections for SKBU-21 Relay with TA-2 Tone Channel with AM Squelch.

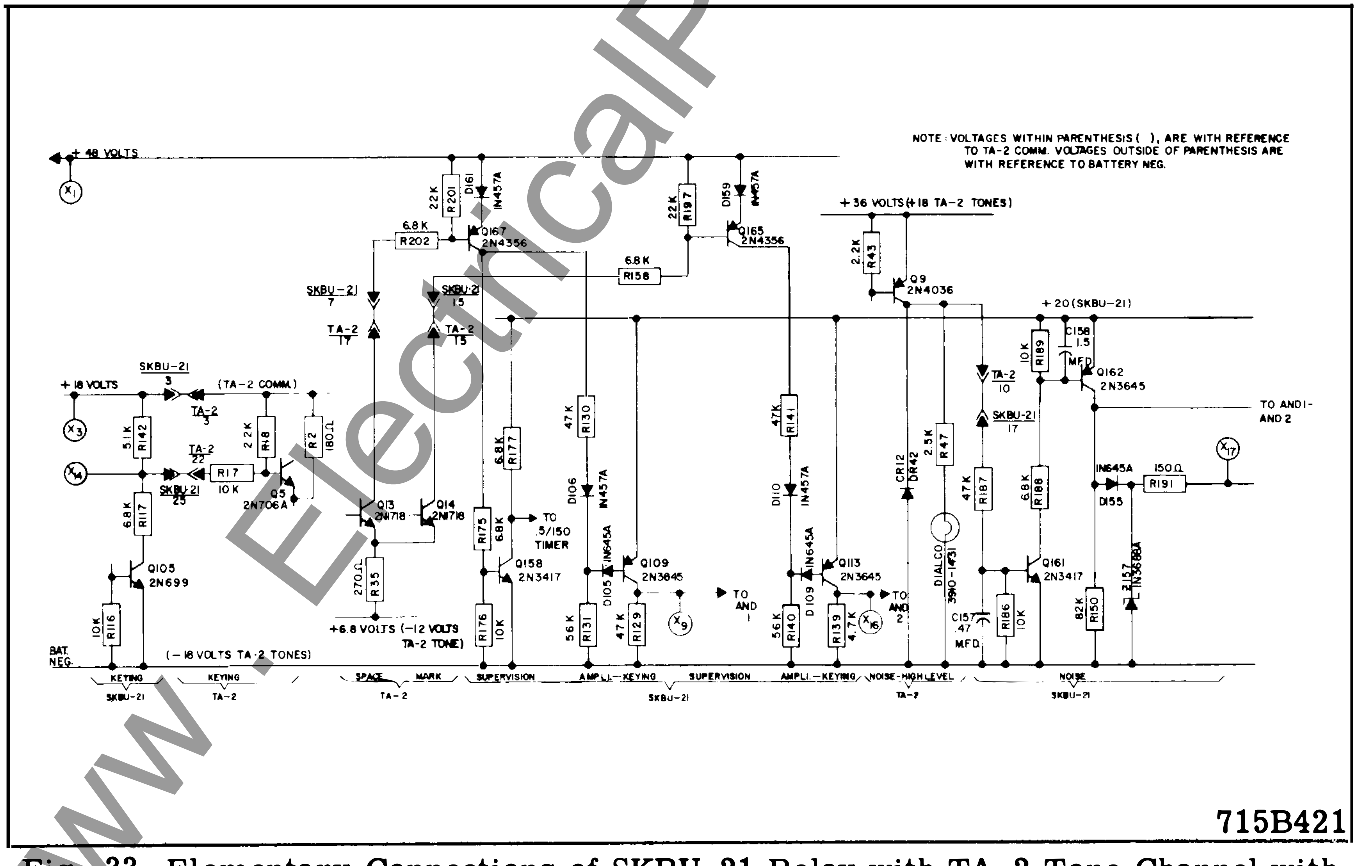

Fig. 33 Elementary Connections of SKBU-21 Relay with TA-2 Tone Channel with TA-3 Noise Supervision.

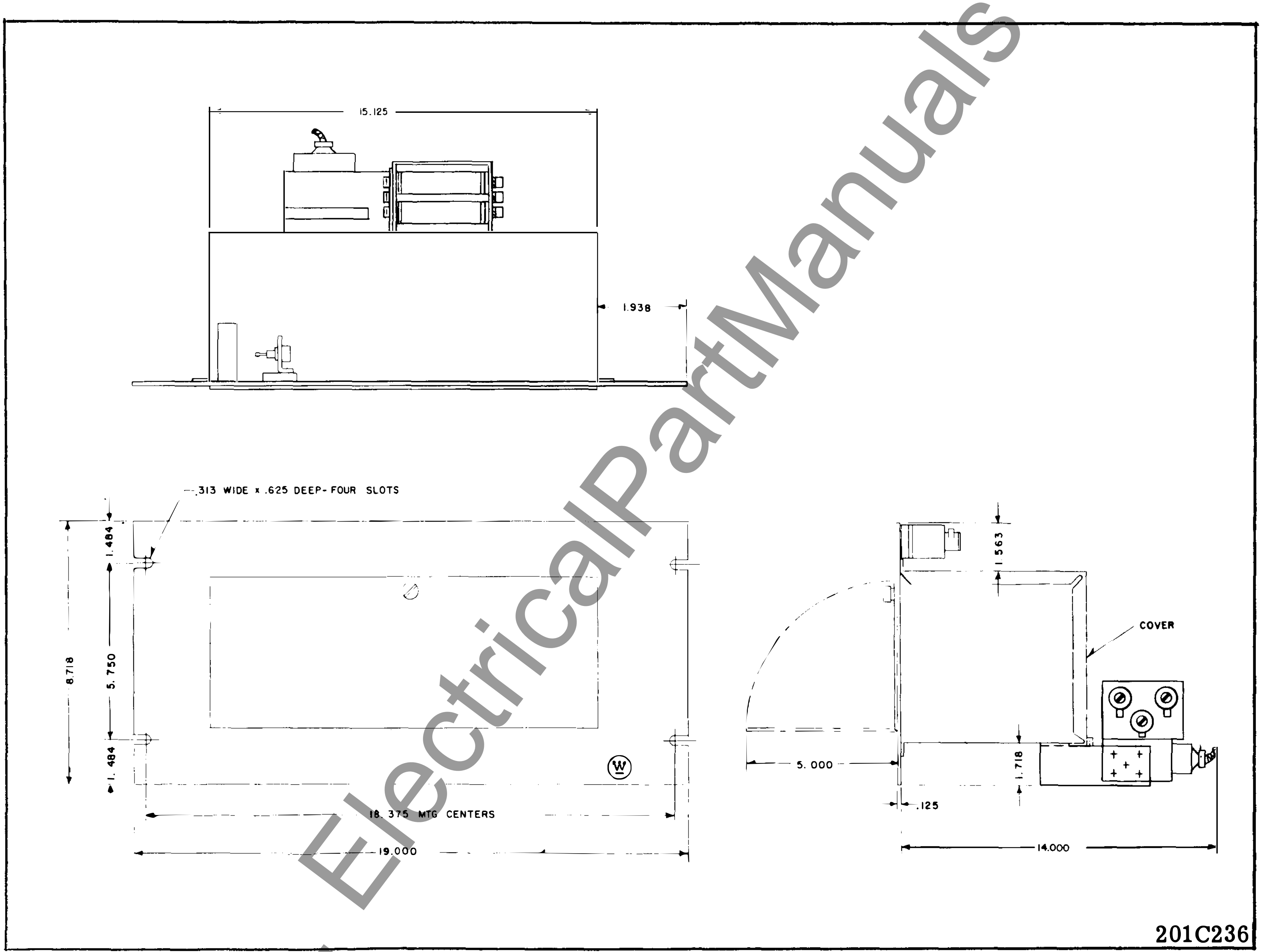

Fig. 34 Outline for the Type SKBU-21 Relay.

WESTINGHOUSE ELECTRIC CORPORATION
RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**
Printed in U.S.A.

Westinghouse I.L. 41-954.3C

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU-1 AND TYPE SKBU-11 PHASE COMPARISON RELAY FOR TC CARRIER CHANNEL

CAUTION: It is recommended that the user of this equipment become acquainted with the information in this instruction leaflet and on the system instruction leaflet before energizing the system.

Printed circuit modules should not be removed or inserted where the relay is energized. Failure to observe this precaution can result in an undesired tripping output and can cause component damage.

APPLICATION

The type SKBU-1 relay and the type SKBU-11 relay are relays used in conjunction with a type TC power line carrier set to provide complete phase and ground fault protection of a two terminal transmission line. Simultaneous tripping of the relays at each line terminal is obtained in less than twenty-five milliseconds for all internal faults within the limits of the relay settings. The relay operates on line current only, and no source of a-c line potential is required. Consequently, the relays will not trip during a swing or out-of-step conditions. The carrier equipment operates directly from the station battery.

CONSTRUCTION

The phase comparison relays consist of a composite positive and negative sequence current network, a saturating transformer, three isolating transformers, a 20-volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel, 8-3/4 inches high (5 rack units). The SKBU-11 relay has a second saturating transformer in addition to these components. Edge slots are provided for mounting the rack on a standard relay rack.

Sequence Network

a. SKBU-11*

The sequence filter consists of a three-legged iron core reactor and a resistor. The reactor is a four-winding reactor with two primary windings and two secondary windings. The secondary windings are connected to the resistor which consists of three tube resistors and a small formed resistor. One secondary winding and the resistor is a negative sequence current filter while the other secondary winding and the resistor is a positive sequence filter.

b. SKBU-1 Relay

The sequence filter consists of a three-legged iron core reactor and a set of resistors, R_1 and R_0. The reactor has three windings: two primary and a tapped secondary winding, wound on the center leg of a "F" type of lamination The secondary taps are wired to the A, B and C tap connections in the front of the relay (R_1 taps). Ro consists of a three tube resistors with taps wired to F, G and H tap connections in the front of the relay. The R_0 resistor is a formed resistor associated with the tapped secondary of the reactor.

Saturating Transformer

a. SKBU-11 Relay

The voltage from the sequence network is fed into two saturating or mixing transformers. One transformer supplies a fault detector circuit and the other transformer supplies a keying circuit. Zero sequence current windings are are included on the transformer.

b. SKBU-1 Relay

The voltage from the sequence network is fed into the tapped primary of a saturating transformer which has two secondary windings. One winding supplies the fault detector circuit and the other winding supplies a keying circuit.

Isolating Transformer

Three isolating transformers are provided in the relay to isolate the dc voltages from the ac voltages. Two of the transformers are also used to energize

SUPERSEDES I.L. 41-954.3B
*Denotes change from superseded issue.

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solid-state circuit on alternate half-cycle of the power system frequency.

Power Supply

The solid-state circuits of the relays are regulated from a 20-volt supply on the relay panel. This voltage is taken from a Zener diode mounted on a heat sink. A voltage dropping resistor is provided between the source dc supply and the 20 volt regulated supply.

Printed Circuit Boards

Seven printed circuit boards are used in these relays: A fault detector board, protective relay interface board, supervision board, amplifier and keying board, arming board, output board and a relay board. The circuits of the protective relay board vary with the relaying system.

All of the circuitry that is suitable for mounting on printed boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide in position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment, it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

1. FD Board (Fault Detector Board)

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, a solid-state fault detector, and a frequency verifier circuit. The controls for setting pickup (S_1) and dropout (S_2) of the fault detector are mounted on a plate in the front of the relay. This unit operates when the fault current exceeds a definite value.

The location of components on the board is shown in Fig. 3 and the schematic of the board is shown in Fig. 4.

2. Arming Board

The arming board connects the outputs of the supervision board and the fault detector board to the final output of the relay. This board contains logic circuits that will arm the trip output, set up the time delay of the trip output, and start transient blocking on external faults.

The location of components on the board is shown in Fig. 5 and the schematic of the board is shown in Fig. 6.

3. Amplifier and Keying Board

The amplifier and keying board contains a local squaring amplifier, a transmitter keying circuit, a remote squaring amplifier, and a signal squelch circuit for each line terminal. The amplifier circuits produce the pulses that are compared by AND circuit of the arming board to determine if the fault is external or internal.

The location of components on the board is shown in figure 7, and the schematic of the board is shown in Fig. 8.

4. Output Board

The output board contains a 4-millisecond pick-up instantaneous dropout timer circuit, trip "AND" (flip-flop circuit), trip amplifier, transient blocking and unblocking circuits. The trip AND operates when all the inputs to the AND inputs of the arming board are of the correct polarity and the fault detector has operated. The transient blocking circuit operates after a time delay on external faults, and the transient unblock circuit operates after a time delay on a sequential fault (external fault followed by an internal fault). The following figures apply to this board: Fig. 9 Component Location; Fig. 10 Schematic of the Board.

5. Relay Board

The relay board contains the phase delay circuit for shifting the local signals with reference to the remote signals. It also contains a low-pass filter for the SKBU-11 relay, a Zener clipper-resistor combination is provided for protection of the solid-state circuits.

The following figures apply to this board: Fig. 11 Component Location, and Fig. 12 for the schematic of the board.

6. Supervision Board

The supervision board contains a 8/0 timer for distance fault detector operation, a 2.5 second alarm circuit for sustained arming operation, a fault detector (FD1) and a carrier control circuit. The circuits on this board are utilized to start carrier, to alarm on an sustained arming operation, and to delay arming for distance fault detector operation.

Fig. 13 shows the component location for this board and Fig. 14 shows the schematic of the board.

7. Protective Relay Board

The protective relay board contains logic circuits to connect the distance fault detectors, and squelch relays into the phase comparison portion of the relaying system. This board contains AND circuits, buffer circuits, and OR circuits to connect the relays into the system.

Fig. 15 shows the component location for the board. Fig. 16 and 17 shows the schematic of the board.

Card Extender

A card extender (style no. 644B315G02) is available for facilitating circuit voltage measurements or major adjustments. After withdrawing anyone of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all components and test points on the boards are readily accessible.

Test Points

Test points are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front panel of the relay for convenience in adjusting and testing the relay.

OPERATION

A. System

The SKBU carrier relaying system compares the phase position of the currents at the ends of a line section over a carrier channel to determine whether an internal or external fault exists on the line section.

1. SKBU-11 Relay

The three-phase line currents energize a sequence network in the SKBU-11 relay which produces two single-phase output voltages that are proportional to either the positive sequence current or the negative sequence current. The single-phase voltages are applied to two saturating or mixing transformers, one which energizes the fault detector circuits (FD-1 and FD-2) and the other energizes the keying circuit of the SKBU-11 relay through a low-pass filter. This circuit allows the transmission of carrier on alternate half-cycles of the power frequency current. Carrier is transmitted from both line terminals and is received at the opposite ends where it is compared with the phase position of the local sequence network output. If the local and remote pulses are in an internal fault relationship and the fault detector has operated, tripping will occur 5-milliseconds later through operation of the trip "AND" and trip amplifier circuits on the output board of the relay.

2. SKBU-1 Relay

The three-phase line currents energize a sequence network in the SKBU-1 relay which produce a single-phase output voltage proportional to a combination of sequence components of the line current. This single-phase voltage energizes the primary of a saturating transformer with two secondary windings. One secondary winding energizes the fault detector circuits (FD-1 and FD-2) and the second secondary winding energizes the keying circuit of the relay through the low pass filter. This circuit allows the transmission of carrier on alternate half-cycles of the power frequency current. Carrier is transmitted from both line terminals and is received at the opposite ends where it is compared with the phase position of the local sequence network output. If the local and remote pulses are in an internal fault relationship and the fault detector has operated, tripping will occur 5-milliseconds later through operation of the trip "AND" and trip amplifier circuits on the output board of the relay.

Current transformer connections to the sequence networks at the two line terminals are such that carrier is transmitted on the same half-cycles from both terminals during an internal fault to allow tripping during the half-cycle that carrier is not transmitted.

However, if the fault is external to the protected line section, carrier is transmitted on alternate half-cycles from opposite terminals. Thus each terminal blocks the opposite terminal during the half-cycle when it is attempting to trip.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals, relay coordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

Since this relaying system operates only during a fault, the carrier channel is available at all other times for the transmission of other functions.

B. Relay

With reference to the logic diagram that applies to the particular relay, the three-phase line currents energize a sequence filter that varies with the type relay.

1. SKBU-11 Relay

In the SKBU-11 relay, the sequence filter produces two single phase voltages: One voltage proportional to the positive sequence current, and the other voltage proportional to negative sequence current. These voltages are applied to primary windings of two saturating transformers where they are mixed to produce two separate secondary voltages proportional to a combination of sequence components. Zero sequence windings are included on the two transformers.

2. SKBU-1 Relay

In the SKBU-1 relay, the sequence filter produces a single phase voltage proportional to a combination of sequence components. This voltage is applied to the primary winding of a saturating transformer which produces two secondary voltages.

* The secondary voltages are applied to two separate boards:

Voltage 1 to Fault Detector Board

Voltage 2 to Relay Board

1. Fault Detector Board

With reference to the schematic drawing of Fig. 4, the ac voltage is applied to terminals 6, 5, and 3 of the fault detector board. This voltage is then applied to a phase-splitting network (C52, R52, R53) and a polyphase rectifier (diodes D51 to D56). The dc voltages obtained from the rectifier are applied to the fault detector circuit (Q51, Q52, Q53, Q54) which operates when the dc input "signal" exceeds a predetermined value.

Fault Detector (FD-2)

Under normal conditions, transistor Q51, has no base "signal" and is turned off. The collector of Q51 is at positive potential and provides base drive to transistor Q52, driving it to conduction. With Q52 conducting there is no base drive to transistor Q53 and Q53 is turned off. This condition keeps transistor Q54 in a non-conducting state, equivalent to an open circuit.

When a fault causes the dc input voltage from the polyphase rectifier (across S_1 and R_{54}) to exceed the 6.8 volt rating of Zener diode Z52, a positive potential is applied to the base of Q51 causing it to conduct. In turn, Q52 stops conducting, and capacitor C54 charges, giving a few milliseconds time delay before Q53 and Q54 are switched to full conduction, thus "closing" the fault detector. When the fault detector operates, a positive input is applied to the arming board at terminal
* 12. The feedback path of resistors R66 and S2 increase the voltage to Z52 after the fault detector operates. This seals-in the fault detector and allows the fault detector to drop out at a high dropout ratio when the ac current is reduced.

Frequency Verifier (FV)

During certain switching conditions, such as energization of a transmission line, residual currents and voltages may exist of higher frequencies than 60 hertz. The frequency verifier prevents fault detector operation when frequencies 120 hertz or higher are encountered during the switching conditions. The frequency verifier circuit consists of two functional parts: Zero-crossing and commutator circuits. With reference to Fig. 4, the zero-crossing circuit consists of Q55, Q56, Q57 and Q58. The commutator circuit consists of Q59, Q60, C58, C59, Z54 and Q61.

During either the positive or negative half-cycles of the output voltage from the mixing transformer, Q55 or Q57 transistors are driven into saturation by the output of the FV transformer (T3). Transistors Q56 or Q58 conduct until capacitors C56 or C57 respectively are fully charged. While either capacitor charges, a voltage output in the form of very narrow pulse is developed across R76 and R78 resistors. This pulse triggers Q59 control switch. When transistors Q55 or Q57 are not conducting, C56 and C57 capacitors discharge respectively through D66 or D62 and the parallel combination of R73 and R74 or R69 and R70.

While Q59 is "on" its anode (TP60) is only about 0.7 volts above negative, thus turning off transistor Q62 to allow capacitor C60 to start charging. However, a shorter time delay (consisting of R84, capacitor C59 and the reference Zener diode Z54) of 4.3 milliseconds is also started. After 4.3 milliseconds of delay, the control switch Q60 fires applying the voltage of capacitor C58 across Q59 turning it off. This raises the potential of the Q59 anode to turn on Q62 to discharge C60 before the charge reaches a value to to break down Z55 to turn on Q63. After the next zero-crossing pulse Q59 switch is turned on again, and the Q60 switch is turned off by capacitor C58. Transistor Q61 when turned on and off by the same pulse that fires the gate of Q59, discharges timing capacitor C59, when on. This starts the timing cycle with close to zero charge on the capacitor. If the zero crossing period of the FV voltage is less than 4.3 milliseconds, the Q61 transistor discharges the timing capacitor to prevent Q60 from turning on. This keeps Q59 switch on to allow C60 to charge to a value to break down Zener diode Z55 to turn on Q63. Turning on Q63 prevents Q53 of the fault detector from turning on thereby preventing Q54 from turning on and thus prevents an output from the fault detector.

2. Relay Board

With reference to Fig. 12, the ac voltage from either the second saturating transformer (SKBU-11) or the second winding of the single transformer (SKBU-1) is applied to terminals 10 and 12 of the relay board. This voltage is then applied to the phase delay circuit through a low pass filter. The low pass filter (C201, L201, C202) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R202 and R203 of the phase delay circuit. The phase delay circuit consists of R202, R203, C203, and S5 mounted on the front panel of the relay. By means of capacitor C203 and variable resistor S5, the voltage across terminal 4 and 2 can be made to lag * the voltage across terminal 10 and 11 by a definite amount depending on the setting of S5. Each of these two voltages are applied to separate isolating transformers.

1. Undelayed voltage terminals 10 and 11 to a keying transformer (T1).
2. Delayed voltages (terminals 4 and 2) to local transformer (T2).

a. Keying Circuit

With no A.C. output (Ref. Fig. 8) voltage from the sequence network, base current does not flow into transistor Q103, from terminals 9 and 8 of the amplifier and keying board. The collector of Q103 is at positive potential which allows base current to flow from positive 20 volts D.C. to the base of Q104 through R111 and R112. This turns on Q104 to prevent base current from flowing to Q105. Since Q104 is conducting, transistor Q105 does not conduct and the collector of Q105 is held at positive potential. As a result, transistor Q105 does not conduct.

When a sinusoidal voltage is applied to the keying transformer (T1), the transformer steps up the voltage applied to terminals 9 and 8 of the amplifier and keying board. On the positive half-cycle of this voltage, terminal 8 is more positive than terminal 9 and transistor Q103 does not conduct. In turn Q104 remains conducting and Q105 does not turn on. On the negative half-cycle of sine wave voltage from the keying transformer, terminal 9 is more positive than terminal 8 and base current flows in Q103. This turns Q103 on which removes base current to transistor Q104. Q104 stops conducting, and its collector goes to positive potential. Positive potential is thus applied to the base of Q105 through R114 and R115 to turn on Q105. Thus on alternate half-cycles of the 60-hertz voltage from the low pass filter, Q105 turns on. If the carrier control circuit operates, as seen in Fig. 18, turning Q105 on and off every half cycle, shorts the input to the TC carrier set every other half cycle so that carrier is transmitted on the half cycle when Q105 is not conducting.

b. Signal Squelch Circuit

When an input is removed from terminal 7 of the amplifier and keying board, positive potential is removed from the base of Q101. Q101 turns off and a discharge path from C101 is provided through R102 and transistor Q1 of the protective relay board. Q101 stops conducting and a positive potential is applied to capacitor C102 of the amplifier and keying board. Ten milliseconds after the input to terminal 7, C102 charges sufficiently to break down Zener diode, Z102. This turns on Q102, which shorts the input of the TC carrier set to negative to prevent the transmission of carrier.

Upon removal of the input to terminal 7 of the amplifier and keying board, positive potential is applied to capacitor, C101, 150 milliseconds later C101 charges sufficiently to break down Zener diode Z101. This turns on Q101 to provide a discharge path for C102 through R106 and Q101 to negative. In turn, Q102 stops conducting to remove the short from the input of the TC carrier set.

c. Local Squaring Amplifier

The delayed voltage from the local transformer (T2) is applied to the local squaring amplifier (Q106, Q107, Q108) and a loading circuit on the amplifier and keying board of the relay. With reference to the local squaring amplifier of Fig. 8, with no ac input voltage, Q106 is not conducting and the collector of Q106 is at positive potential. This applies base current to transistor Q107 through R120 and R121 such that Q107 is turned on. This allows base current to flow in Q108. Q108 turns on to apply positive potential across R125, (blocking condition).

With the application of a sine wave voltage to terminal 6 and 19 of the amplifier and keying board, on the negative half-cycle of the voltage, the base of transistor Q106 is more positive than the emitter and Q106 (amplifier 1) conducts. On the positive half-cycle of the ac voltage, Q106 is turned off and current flows into the loading circuit. Therefore, Q106 is conducting on the negative half-cycle of ac voltage. Turning Q106 on and turns off transistor Q107. Transistor Q107 stops conducting and its collector goes to a positive potential which turns off Q108. Thus the output of the squaring amplifier is a square wave voltage ranging from 0 volts dc to 20 volts dc depending upon the polarity of the voltage from the phase delay circuit.

D. Remote Squaring Amplifier

The remote squaring amplifier consists of transistors Q109 and Q113 of the amplifier and keying board, (Ref. Fig. 8).

Under non-fault conditions, carrier is not transmitted from the remote carrier set. As a result the base of Q113 is more negative than its emitter, and Q113 conducts. This applies positive 20 volts to the base of Q109 to prevent it from turning on. Hence, Q109 is not conducting and negative voltage (with ref. to +20 volts) appears across R129, (unblocking condition).

Under fault conditions, the remote TC carrier set is keyed on and off as described under the Keying Circuit. This signal is received at the local TC carrier receiver and is converted to a square wave voltage varying in magnitude from 45 volts to 0 volt. This voltage is applied to the base of Q113 through R141 and D110. Upon application of positive 45 volts d-c to the base of Q113, the potential of the base is greater than that of the emitter and Q113 stops conducting. This removes positive potential from R139 and allows the base of Q109 to become negative with respect to the emitter. Q109 turns on to apply positive voltage (with ref. to neg.) to R129. Hence, the voltage across R129 is a square wave voltage that is developed by the voltage received from the TC receiver.

3. Arming Board (Ref. Fig. 6)

The phase relationship of the outputs of the local and remote squaring amplifiers are compared by AND 1 of the Arming Board. If the local and remote signals are out of phase with respect to each other, the AND circuit will provide one input to AND number 3 which will activate the 4/0 timer.

a. Internal Fault Conditions

With reference to the logic drawing that applies to the relay, the output voltages of the sequence filter of one relay are 180 degrees out-of-phase with respect to its load current condition. This changes the polarity of Amplifier #1 such that its output is in phase with the remote signal. This means that AND 1 has a half-cycle of negative voltage. This voltage is applied to AND 3 of the arming board to set-up one condition (negative voltage from OR-1) for activating the AND. The second condition to activate AND-3 is provided by arming the relay.

In either Fig. 19, 20, or 27, arming occurs through either the operation of the distance fault detectors or the operation of fault detector (FD2) of either the SKBU-11and SKBU-1 relays. The operation of either fault detector will apply a voltage to OR 2 of the arming board. The output voltage from OR 2 removes negative potential from the trip AND through the arm logic AND applied a negative signal into AND 3 of the arming board. AND 3 is activated and starts the 4/0 timer. Four milliseconds later, a negative input is applied to the trip AND of the output board. Since the three conditions of trip (a negative input from the 4/0 timer, not a negative input from the ARM logic, and a positive signal from the 22/0 timer) is fulfilled, a trip output is obtained from the relay.

b. External Fault

Under external fault conditions, the square wave voltage from the remote squaring amplifier and the square wave voltage from the local squaring amplifier are out-of-phase such that zero output is being obtained from AND 1 of the arming board. As a result, the output of AND 1 is zero, and AND 3 cannot be activated. This blocks AND 3 and the 4/0 timer is not energized.
With fault detector operation, an input is applied to OR-2 and OR-3 of the arming board. OR-2 will provide a positive input (not a negative input) will be applied to the trip AND but tripping will not occur since the 4/0 timer is not providing a negative input to the Trip AND. The fault detector input to OR-3 will provide an input to a 1/100 timer on the Output Board. The timer negates the signal to provide a negative input to the transient block AND. With the application of the input from the 0/100 timer the three conditions of transient block are fulfilled — not an input from the Transient UNBLOCK circuit, not a negative input from the Trip AND, and a negative input from the 0/100 timer. Twenty two milliseconds later the 22/0 timer of the transient block circuit times out to remove the positive input to the TRIP AND. The TRIP AND is thus desensitized to prevent undesirable operation during transients associated with power reversals on the protective line or at the clearing of an external fault.

c. Sequential Faults

If the above external fault is followed by an internal fault before the external fault is cleared, the transient unblock circuit is set up to remove the transient blocking input to the TRIP AND. For the internal fault, the square wave pulses on AND-1 of the arming board will reverse such that a square-wave output is obtained from AND-1. This output energizes OR-1. The negative signal provides the second input to AND-3 which:

1. Provides an input to the 4/0 timer which times out to apply a negative input to the TRIP AND.

2. Applies a square wave input every other half cycle to the AND of the transient unblock circuit to fulfill the requirements to obtain an output from the transient unblock circuit.

As a result, an input is applied to the unblock timer every other half cycle. Twenty-five milliseconds later, capacitor C301 (Ref.Fig.10) will charge such that the unblock timer will operate to apply a voltage to the block AND circuit. This resets the 22/0 block timer, and removes the input to the AND of the unblock timer to reset the unblock circuit. The required three inputs are thus applied to the Trip AND and a trip output is obtained from the relay.

4. Supervision Board (Ref. Fig. 14)

The circuits on the supervision board include the auxiliary functions of the relay, and they include a detector (FD-1), carrier control circuit and timer circuit.

a. Fault Detector 1 (FD-1) (Q161, Q162)

Under normal conditions, transistor Q161, has no base "signal" and is turned off. The collector of Q161 is at positive potential and no collector current flows. This keeps transistor Q162 in a non-conducting state, equivalent to an open circuit.

* When a fault causes the dc input voltage from the polyphase rectifier (of the FD Board) across S3 and R185 to exceed the 6.8 volt rating of Zener diode Z156, a positive input is applied to the base of Q161 base causing it to conduct. In turn, Q162 is switched to conduction, thus "closing" the fault detector. When the fault detector operates, a positive input is applied to the carrier control circuit. The feedback path of resistors R191 and S4 increase the voltage to Z156 after the fault detector operates. This seals in the fault detector and allows the fault detector to drop out at a high dropout ratio when the ac is reduced.

B. Carrier Control Circuit (Q163, Q164)

Under normal conditions Q163 is not conducting and base drive is supplied to Q164. As shown in Fig. 18, the emitter of Q164 is connected to negative dc. The collector of Q164 is connected to positive 45 volts dc of the TC set through R142 of the amplifier and keying board. Normally Q164 is conducting. When either FD1 or the distance carrier start relay operate, base drive is supplied to Q163. Q163 turns on and shorts the base of Q164 to negative. Q164 turns off to raise the potential of point A of Fig. 18. This starts the transmission of carrier.

c. Arming Delay By Distance Fault Detectors (8/0 Timer) (Q151, C151, Z151, Q152, Q153)

The distance supervision arming is delayed by 8 milliseconds to allow time for the AND of the arming board to respond at fault inception. Operation of the distance fault detectors will remove base current to transistor Q151. Q151 turns off, and positive potential is applied to capacitor C151. Eight milliseconds later the voltage on C151 reaches a value to break down Zener diode Z151. This turns on Q152, which connects the base of Q153 to negative through resistor, R158. Q153 turns on to apply positive potential to resistor R160 and terminal 13. From terminal 13 the voltage is applied to the arming board.

d. Sustained Arming Alarm (2500 Timer) (C152, Z152, Q154 to Q156)

When arming occurs, positive potential is applied to terminal 18 and capacitor C152 from terminal 15 of the arming board. Two-and-one-half seconds later, the potential on C152 breaks down the Zener diode Z152 to allow base current to flow into Q154. This turns on Q154 which turns off Q155. Turning Q154 off applies positive potential to the base of Q156 and Q156 turns off. This removes positive potential from R170 and an external alarm is energized.

CHARACTERISTICS

A. SKBU-11 Relay

Taps are available in the SKBU-11 relay to set different sensitivities of the fault detector (FD-1) to zero and negative sequence currents. These taps are as follows:

NEGATIVE SEQUENCE TAPS (I_2)

TAP SETTING	NEGATIVE SEQUENCE SENSITIVITY
A	None
B	0.4 Amperes
C	0.25 Amperes

Zero Sequence Taps (I_0)

TAP SETTING	ZERO SEQUENCE SENSITIVITY
F	None
G	0.2 Amperes
H	0.1 Amperes

The second fault detector unit (FD-2) which supervises arming is adjusted to pick up at a current 125 per cent greater than FD-1. By means of the S_1 adjustment, the pick up of FD-2 can be increased to 250 per cent greater than FD-1.

The positive sequence response of the fault detector is greater than 7 amperes.

B. SKBU-1 Relay

Taps are available in the relay to set the sensitivity of FD-1 to different combinations of positive, negative and zero sequence components of the line current. The T taps on the left hand tap plate indicate the balanced three phase amperes which will operate the fault detector FD-1. These taps are as follows:

3, 4, 5, 6, 7, 8 and 10

The second fault detector unit (FD-2) which supervises arming is adjusted to pickup at a current 125 percent greater than FD-1. By means of the S_1 adjustment, the pickup of FD-2 can be increased to 250 percent greater than FD-1.

For distance fault detector applications, the user should reset the SKBU-1 fault detector for a pick-up of twice the tap value by means of the S_3 setting.

Positive and Negative Sequence Current - R1 Taps

The upper half of the right hand tap plate or R1 taps changes the number of turns on the third winding of the mutual reactor. This reproportions the components of the sequence filter which changes the positive and negative sequence sensitivity of the fault detector. Operation of the fault detector (FD-1) with the various taps is given in the following table:

TABLE I

COMB.	SEQUENCE COMPONENTS IN NETWORK OUTPUT	TAPS ON RIGHT HAND TAP BLOCK		FAULT DETECTOR (FD-1) PICK-UP †	
		R_1	R_0 #	3ϕ FAULT	$\phi\phi$ FAULT θ
1	Pos., Neg., Zero	C	G or H	Tap Value	86% Tap Value (53% on BC Fault)
2	Pos., Neg., Zero	B	G or H	2 x Tap Value	90% Tap Value (65% on BC Fault
3	Neg., Zero	A	G or H	–	100% Tap Value

— Taps F, G and H are zero-sequence taps for adjusting ground fault sensitivity, See section on zero-sequence current tap.

* † — When taps A and 3, or B and 3 are used, FD-1 will pickup 10 to 15 per cent higher than the above values because of the variation in self-impedance of the sequence network and the saturating transformer.

θ — Fault detector FD-2 is set to pick-up at 125 per cent of FD-1 for a two terminal line, or 250 per cent of FD-1 for a three terminal line.

Zero Sequence Current – R_0 Taps

The lower half of the right-hand tap plate (R_0 taps) is for setting the response of the relay to ground faults. Taps G and H give the approximate ground fault sensitivities listed in Table II. Tap F is used in applications where no response to zero sequence current is required. When this tap is used, the voltage output of the network caused by zero-sequence current is eliminated.

NOTE: Because of inherent characteristics of the sequence network, there will be small variations (from the values listed in Tables I and II) in the pick-up current for various phase or ground fault combinations.

TABLE II

COMB.	R_1 TAP	GROUND FAULT PICK-UP	PERCENT OF T TAP SETTING
		TAP G	TAP H
1	C	25%	12%
2	B	20%	10%
3	A	20%	10%

C. SKBU-1 and SKBU-11 Relay

The operating time of the fault detectors of both the SKBU-1 and SKBU-11 is shown in Fig. 21. As shown in the figure, the fault detector has a maximum and minimum value. This is due to the point on the current wave that fault current is applied. Fig. 22 shows the operating times for different points on the fault wave for fault current at five amperes.

The keying response of the SKBU-11 relay is independent of the tap setting. Fig. 23 shows typical lengths of keying pulses with reference to a 60-hertz base of the SKBU-11 relay for different values of positive, negative, and zero sequence current. Fig. 28 shows the response of the SKBU-1. (These curves apply with FD-1 picked up)

The keying voltage across $X_5 - X_6$ of the SKBU-11 Relay with reference to phase A positive, negative and zero sequence currents is given by:

$$V = 2.7\, I_{a1} \underline{\angle -125°} + 11.8\, I_{a2} \underline{\angle 120°} + 31\, I_{a0} \underline{\angle -75°}$$

This voltage is measured with currents into the odd number terminals except for zero sequence which is with current into the even terminals. X_5 is polarity terminal. 25 volts is maximum voltage obtainable from $X_5 - X_6$.

The keying voltage across $X_5 - X_6$ of the SKBU-1 Relay with reference to phase A positive, negative, and zero sequence currents is given by:

$$V = K_1 I_{a1} + K_2 I_{a2} + K_0 I_{a0}$$

the values of K_1, K_2 and K_0 vary with tap settings and are given in the following table:

* CONSTANT	TAP SETTING	VALUE
K_1	A – F G H	0 0
K_1	B – F G H	$\frac{1.24}{T} \underline{\angle -130°}$
K_1	C – F G H	$\frac{2.47}{T} \underline{\angle -155°}$
K_2	A – F G H	$\frac{4.35}{T} \underline{\angle 55°}$
K_2	B – F G H	$\frac{5.3}{T} \underline{\angle 40°}$
K_2	C – F G H	$\frac{5.9}{T} \underline{\angle 20°}$
K_0	A – H	$\frac{73}{T} \underline{\angle 50°}$
K_0	B – H	$\frac{73}{T} \underline{\angle 40°}$
K_0	C – H	$\frac{61.5}{T} \underline{\angle 25°}$
K_0	A – G	$\frac{41}{T} \underline{\angle 50°}$
K_0	B – G	$\frac{41}{T} \underline{\angle 40°}$
K_0	C – G	$\frac{34}{T} \underline{\angle 20°}$
K_0	A,B,C – F	0

This voltage is measured with currents into the odd number terminals. X_5 is polarity terminal.

Operating Time .... 15 to 32 Milliseconds
Alarm .... 2.5 seconds for FD operation
.... 150 Milliseconds Loss-of-Channel
Transient Block Time .... 22 to 25 Milliseconds
Transient Unblock Time ...... 23 to 27 Milliseconds

Ambient Temperature Range .... -20 C to 55 C

DC Drain .... 0.14 Amps at 48 Volts DC

Reset Time of Transient Block ....

1. After Fault Detector has Operated

.... 100 Milliseconds

2. When unblock time is utilized

.... Instantaneous

ENERGY REQUIREMENTS

A. SKBU-11 Relay

Burdens measured at a balanced three-phase current of five amperes. (Independent of tap setting).

PHASE A		PHASE B		PHASE C	
VA	ANGLE	VA	ANGLE	VA	ANGLE
8.3	106°	2.2	50°	46	0°

Burden measured at a single-phase to neutral current of five amperes.

RELAY TAPS	PHASE A		PHASE B		PHASE C	
	VA	ANGLE	VA	ANGLE	VA	ANGLE
C-H	11.7	2.0°	9.7	1.8°	44.0	2.2°
B-H	11.4	2.0°	10.3	1.8°	46.0	2.2°
A-H	11.1	2.0°	11.2	1.8°	48.0	2.2°
C-G	8.8	2.0°	7.0	1.8°	42.0	2.2°
B-G	8.7	2.0°	7.5	1.8°	43.5	2.2°
A-G	7.8	2.0°	8.5	1.8°	45.0	2.2°
C-F	6.7	2.0°	7.5	1.8°	42.0	2.2°
B-F	6.5	2.0°	7.2	1.8°	42.0	2.2°
A-F	5.8	2.0°	6.6	1.8°	43.0	2.2°

B. SKBU-1 Relay

Burdens measured at a balanced three-phase current of five amperes.

RELAY TAPS	PHASE A		PHASE B		PHASE C	
	VA	ANGLE	VA	ANGLE	VA	ANGLE
A-F-3	2.4	5°	0.6	0°	2.5	50°
A-H-10	3.25	0°	0.8	100°	1.28	55°
B-F-3	2.3	0°	0.63	0°	2.45	55°
B-H-10	4.95	0°	2.35	90°	0.3	60°
C-F-3	2.32	0°	0.78	0°	2.36	50°
C-H-10	6.35	342°	3.83	80°	1.98	185°

Burdens measured at a single-phase to neutral current of five amperes.

RELAY TAPS	PHASE A		PHASE B		PHASE C	
	VA	ANGLE	VA	ANGLE	VA	ANGLE
A-F-3	2.47	0°	2.1	10°	1.97	20°
A-H-10	7.3	60°	12.5	53°	6.7	26°
B-F-3	2.45	0°	2.09	15°	2.07	10°
B-H-10	16.8	55°	22.0	50°	12.3	38°
C-F-3	2.49	0°	1.99	15°	2.11	15°
C-H-10	31.2	41°	36.0	38°	23.6	35°

The angles above are the degrees by which the current lags its respective voltage.

CONTINUOUS RATINGS: The continuous rating of the SKBU-1 is 10 amperes and the continuous rating of the SKBU-11 is 7 amperes. The two second overload rating of the SKBU-1 is 150 amp. phase and 125 amp. ground while the two second rating of the SKBU-11 is 125 amp. phase and ground.

SETTINGS

If settings in between taps are desired, the tap screw should be set in the next lowest tap. S_1 and S_3 should then be adjusted for the desired pickup value. Dropout should be readjusted by means of S_2 and S_4.

A. SKBU-11

The SKBU-11 relay has separate tap plates for adjustment of the zero and negative sequence sensitivity of the fault detector (FD-1). The fault detector tap markings and pickup are:

Negative Sequence Sensitivity (I_2)

A. None

B 0.4 Amperes

C. 0.25 Amperes

Zero Sequence Sensitivity (I_0)

F. None

G. 0.2 Amperes

H. 0.1 Amperes

Two tap plates are provided: one for I_2 and the other one for I_0.

Tap A should not be used in service since this would prevent fault detector operation for phase-to-phase faults. However, tap F may be used with either B or C since negative sequence current flows for both phase-to-phase and ground faults.

The recommended settings are tap B or C as needed for the required sensitivity, and tap F. Taps G and H have been provided for applications where the negative-sequence load flow due to series impedance unbalance may be high enough to operate FD with a tap C setting. In this case, set in tap B and in tap G or H. It is not intended that taps C and H be used simultaneously due to the possibility of cancellation of the negative-and zero-sequence effects on ground faults. With a tap B setting, a tap H setting is preferred.

To summarize, the recommended setting combinations in the order of preference are:

COMBINATION	I_2 TAP	I_0 TAP
1	C	F
2	B	F
3	B	H
4	B	G

For a long two-terminal line, FD2 should be set at 250 per cent of FD1. As shipped from the factory, FD2 is set to pickup at 125 per cent.

B. SKBU-1 Relay

The SKBU-1 relay has separate tap plates for adjustment of the phase and ground fault sensitivities and the sequence components included in the network output. The method of determining the correct taps for a given installation is discussed in the following paragraphs.

Setting Principles

Tap C provides the best balance between three phase and phase-to-phase fault sensitivity. Always use this tap where distance fault detector supervision is used. Where only the SKBU-1 fault detector is used and where the full load current (maximum through any terminal) is approximately five amperes or more, tap B will provide increased phase-to-phase fault sensitivity with little or no sacrifice in three phase fault sensitivity. For example, if a left-hand tap (T) of 6 is needed with tap C (6C), then use a 3B setting instead.

NOTE: From Table I, pickup will be 4.15 amp. for tap 3B and 5.40 amp. for tap 6C for ϕa to ϕb fault, 3ϕ pickup is 6 amperes on tap 6C and 6.1 amp. on 3B.

Use tap A only where satisfactory unbalanced fault sensitivity cannot otherwise be obtained and where other protection is available for three phase faults, since with Tap A no three phase fault protection is available.

In all cases provide identical response at all stations to insure proper phase comparison and adequate keying for any fault detected by remote-end relays. To accomplish this, the letter taps (A, B, C, F, G, H) should be identical at all stations. Also, the taps should be identical with identical CT ratios, or inversely proportional to CT ratios where different.

After selecting tap C or B, pick the T tap to allow reset of the fault detector in the presence of load flow. That is, fault detector pick-up
* should be at least 111 per cent of full load current (maximum through any terminal).

Now select tap G or H for desired ground-fault sensitivity.

For distance fault detector applications, set 3C to provide the maximum sequence-filter voltage for the squaring amplifiers. The SKBU-1 current fault detector FD-2 is then independently desensitized (by adjustment of S1 and S2 settings) to permit reset in the presence of full-load current. Phase faults which do not operate the SKBU-1 fault detector will be detected by the supplementary distance fault detectors.

Examples of SKBU-1, Relay Settings

CASE I

Assume a two-terminal line with current transformers rated at 400/5 at both terminals. Also assume that full load current is 300 amperes, and that on minimum internal phase-to-phase faults, 2000 amperes is fed in from one end and 600 amperes from the other end. Further assume that on minimum internal ground faults, 400 amperes is fed in from one end, and 100 amperes from the other end.

a. Positive Sequence Current Tap

Secondary Values:

$$\text{Load Current} = 300 \times \frac{5}{400} = 3.75 \text{ amperes} \qquad (1)$$

Minimum Phase-to-Phase Fault Currents:

$$600 \times \frac{5}{400} = 7.5 \text{ amperes} \qquad (2)$$

Fault detector FD-1 setting (three phase) must be at least:

$$\frac{3.75}{0.90} = 4.18$$ amperes (0.90 is dropout ratio of FD-1. Setting will insure that the fault detector will reset on load current) (3)

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector FD-1 setting from Table I must not be more than: (based on a three phase fault:

$$7.5 \times \frac{1}{0.86} \times \frac{1}{1.25} = 6.93 \text{ amperes} \qquad (4)$$

$$1.25 = \frac{\text{FD-2 Pickup}}{\text{FD-1 Pickup}}$$

Sequence Combination Tap

From a comparison of (3) and (4) above, it is evident that the fault detector can be set to trip under minimum phase fault condition yet not operate under maximum load. In this case, tap C would be used (see Table I, Comb. 1) as there is sufficient difference between maximum load and minimum fault to use the full three-phase sensitivity. Current tap 6 would be used in preference to tap 5 to allow for occurrence of higher load current.

Zero Sequence Tap

Secondary Value:

$$100 \times \frac{5}{400} = 1.25$$ amperes minimum ground fault current.

With T tap 6 and R1 tap, the fault detector pickup currents for ground faults (See Table II) are as follows:

Tap G .25 × 6 = 1.5 ampere (FD-1)
Minimum Trip = 1.25 × 1.5 ampere = 1.8 amp. (FD-2)

Tap H .12 × 6 = 0.72 ampere (FD-1)
Minimum Trip = 1.25 × 0.75 = 0.90 ampere (FD-2)

From the above, tap H would be used to trip for a minimum ground fault of 1.25 amperes.

CASE II

Assume the same fault currents as in Case I, but a maximum load current of 550 amperes. In this example, with the same sequence combination as in Case I, the fault detectors cannot be set to trip on the minimum internal three-phase fault, yet remain inoperative on load current. (Compare equations (5) and (6).) However, by connecting the network per combination 2 on Table I, the relay can be set to trip on minimum phase-to-phase fault, although it will have only half the sensitivity to three-phase faults. This will allow operation at maximum load without picking up the fault detector, and provide high speed relaying of all except light three-phase faults.

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector tap must now be not more than:

$$* \; 7.5 \times \frac{1}{1.25} \times \frac{1}{.90} = 6.67 \text{ amperes} \qquad (5)$$

To be sure the fault detector FD-1 will reset after a fault, the minimum tap setting is determined as follows:

$$\text{Load Current} = 550 \times \frac{5}{400} = 6.9 \text{ amperes} \qquad (6)$$

$$* \; \frac{6.9}{0.90} = 7.7$$ amps. (.90 is dropout ratio of FD-1) (7)

Since from Table I, Comb. 2, the fault detector pickup current for three-phase faults is twice tap value, half the above value (Eq. 7) should be used in determining the minimum three-phase tap.

$$\frac{7.7}{2} = 3.86 \qquad (8)$$

From a comparison of (5) and (8) above, tap 5 or 6 could be used. (Continuous load current rating of relay is 10 amperes).

With the three-phase tap 5 in use, the fault detector pickup current for ground faults will be as follows:

Tap G = .2 × 5 = 1.0 ampere (FD-1)
Minimum Trip = 1.0× 1.25 = 1.0 ampere (FD-2)

Tap H = .1 × 5 = 0.5 ampere (FD-1)
Minimum Trip = 1.25 × 0.5a. = 0.63 ampere (FD-2)

Therefore, tap H would be used to trip the minimum ground fault of 1.25 ampere with a margin of safety.

INSTALLATION

The phase comparison relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The phase comparison relay is normally supplied as part of a relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the relay is not part of a relaying system, the following procedure can be followed to verify that the circuits of the relay are functioning properly.

TEST EQUIPMENT

1. Oscilloscope
2. AC Current Source
3. Electronic Timer
4. AC Voltmeter
5. DC Voltmeter

ACCEPTANCE TEST

Connect the relay to the test circuit of Fig. 24 which represents the TC carrier channel for test purposes. On SKBU-11 relays, jumper terminals 2 to 4 to 6 to 8.

If the test fixture is not available, the remote pulses can be obtained from the SKBU keying circuit. This is accomplished by jumpering various circuits of the relay together as follows: (Note: These instructions apply where no external connections are made to the J101 block).

1. Apply either 48 volts dc or 45 volts dc to J101-2 (pos.) and J101-5 (neg.). An alternate connection is to X_1 and X_4. Also connect positive 45 volts dc to either X_3 or J101-3.
2. Jumper J101-5 to J101-6. An alternate connection is terminal 3 to terminal 8 on the supervision board. This connects the carrier control to negative.
3. Jumper J101-13 to J101-14. An alternate connection is terminal 6 of the supervision board to terminal 15 of the amplifier and keying board. This connects the carrier control circuit to positive 45 volts dc through R142 of the amplifier and keying board.
4. Jumper J101-25 to J101-7. An alternate connection is terminal 12 to terminal 17 of the amplifier and keying board. This connects the keying circuit to the remote squaring amplifier.
5. Short resistor R141 on the amplifier and keying board. This is necessary to allow the remote squaring amplifier to work from a lower voltage input than normal. Normally 45 volts dc is applied to J101-17. In this test circuit, approximately 24 volts dc is applied to J101-17.
6. Connect one pole of a DPST switch from terminal 17 to terminal 1 of the amplifier and keying board. This is switch L of the following tests and enables internal-external fault tests to be performed on the relay. External fault position is with the switch closed. Internal fault position is with the switch open. This switch removes a stage from the remote squaring amplifier to reverse the polarity of the remote pulses.

With the jumpers added as per the above information, the transistor circuits are connected together as shown in figure 29.

If the above connections are utilized to test the relay, the reference to closing switches A, B, C, and D should be ignored.

The following tests are with reference to the relay as received. If a recalibration of the circuits is desired, the recalibration can best be obtained by setting S1, S2, S4 and S5 to counterclockwise limit, S6, S3 and S7 to clockwise limit, and R316 on output board to the middle of its range.

1. FD-1 Pickup and Dropout

a. Set relay on taps C and H. Set SKBU-1 T tap 5.

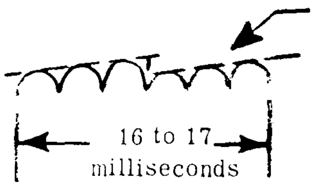
b. Connect a high resistance dc voltmeter across X_{16} and X_4 (neg.).

c. Apply 60 hertz current to terminal 1 and 3 of the relay. Gradually increase the current until the voltmeter changes reading from approximately zero volts to approximately 20 volts. This is the operating current of FD-1 and should be 0.433 ± 5% amperes for SKBU-11 relay and 4.33 ± 5% amperes for SKBU-1 relay.

d. Gradually lower ac test current until the dc voltmeter drops to approximately zero volts. This is the dropout current of FD-1 and should occur at .389 to .395 amperes for SKBU-11 and 3.89 to 3.95 amperes for SKBU-1.

e. Adjustment of pickup and dropout is made by S3 and S4 respectively.

f. If the output of the fault detector is erratic at pickup, R35 on the fault detector should be adjusted such that the following waveform should appear across X_{15} to X_4.



peaks should be nearly equal or, if not, rising slightly to the right.

2. FD-2 Pickup and Dropout

a. With relay set on taps $I_2 = C$, $I_0 = H$, connect a high resistance voltmeter to X_{13} and X_4 (neg.).

b. With a 60 hertz test current connected to terminal 1 and 3 of the relay, gradually increase the current until the voltmeter charges reading from approximately zero volts to approximately 20 volts. This is the operating current of FD-2 and should be between 0.514 to 0.568 amperes for SKBU-11 and 5.14 to 5.68 amperes for SKBU-1.

c. Gradually lower the ac test current until the dc voltmeter drops to approximately zero volts. This is the dropout current of FD-2 and should occur at between 0.461 to 0.509 amperes for SKBU-11 and 4.61 to 5.09 amperes for SKBU-1.

3. Check of Local Squaring Amplifiers

a. With all switches of test circuit open, apply 0.6 to 0.8 amperes ac to terminals 1 and 3 of the SKBU-11 relay, or 6 to 8 amperes ac to terminals 1 and 3 of the SKBU-1 relay.

b. Place scope probe across X12 and X4 (grd). A square wave of voltage should appear across X12 and X4 as shown in Fig. 25.

4. Check of Keying Circuit

a. With all switches of test circuit open and 0.6 to 0.8 amperes ac applied to terminal 1 and 3 of the SKBU-11 relay, with scope check voltage across X14 and X4 (grd). (This voltage should be checked with 6.0 to 8.0 amperes into terminals 1 and 3 of SKBU-1 relay).

b. Waveform shown in Fig. 25 should be observed.

5. Check of Remote Squarin g Amplifiers

a. Close switches A, B and C of test fixture.

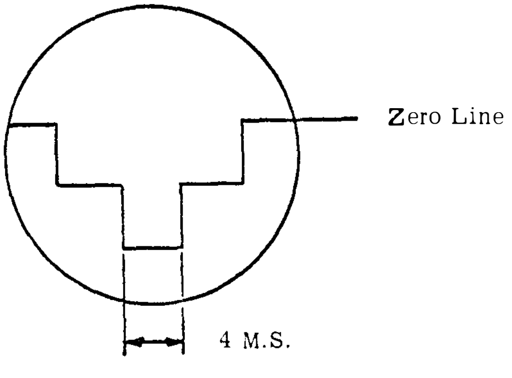
b. Apply 0.6 to 0.8 amperes ac to terminals 1 and 3 of the SKBU-11 relay, or 6 to 8 amperes ac to same terminals for SKBU-1 relay.

c. Using scope with grd. lead on X4, check waveshape of voltage across X9. Waveforms of Fig. 25 should be observed.

6. Setting of S5 and S6

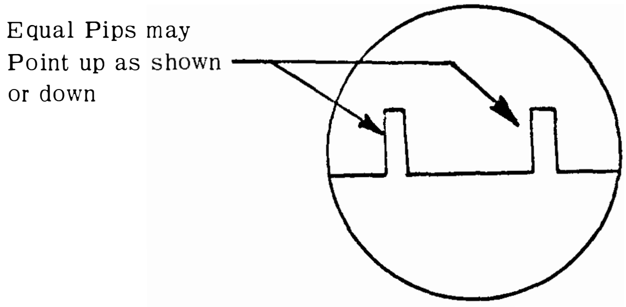
a. With S5 set to minimum resistance (fully counter-clockwise) and S6 to maximum resistance (fully clockwise), (set L on external fault) close switches A, B and C of the test circuit. Apply 0.6 to 0.8 amperes ac to terminals 1 and 3 of the SKBU-11 relay or 6 to 8 amperes ac to same terminals of SKBU-1 relay. Open and close switch D.

b. Place scope across X10 and X4 (grd). Adjust S5 until following waveform appears on scope.



c. Adjust S6 until the relay trips. This sets the triggering of the Trip AND after a 4 millisecond delay.

d. Slowly change S5 to obtain the following waveform. This will be with S5 at or near minimum resistance.



e. Close and open switch D, and slowly turn S5 until the relay operates. Waveform should be the same as in step 6. If necessary, readjust S6 and repeat step d and e.

7. Transient Blocking Delay (22/0 and 0/100 Timer)

a. Connect electronic timer stop to X7 and X4 (grd). Set timer stop on negative going pulse. Relay not to be energized with ac current.

b. Connect timer start to X18. Set timer start to positive going pulse.

c. Close switch A and switch 31. Close switch 32. (Represents 20 volt input to terminals 3 and 19 of protective relay board). Timer should start and should stop between 22 and 25 milliseconds. If necessary, adjust R316 on output board to obtain timing.

d. Set timer start on a negative pulse and timer stop on a positive pulse.

e. Open switch.32. (Represents removal of 20 volt input to terminal 5 of the protective relay board) Timer should start, and should stop after a time delay of 80 to 135 milliseconds.

8. 8/0 Timer Distance Fault Detector

a. Connect timer start to terminal 16 of supervision board. Set timer start on positive pulse. Connect timer stop to X18 and X4 (comm). Set timer stop on positive pulse.

b. Close switch 31. Close switch 32. (represents 20 volt input to terminals 3 and 19 of protective relay board). Timer should start and should stop after 6 to 8 milliseconds.

9. Sustained Arming Alarm (2.5 Seconds)

a. With electronic timer stop connected to X17 and X4 (grd), set timer stop on negative going pulse.

b. Connect timer start to X18, Set timer start on positive pulse.

c. Close switch 31 and then switch 32. (Represents 20 volt input to terminals 3 and 19 of protective relay board). Timer will start and should stop after 2.3 to 2.7 seconds.

d. Open switch 31 and 32.

10. Check of Transient Unblocking Circuit

a. With electronic timer stop connected to X7 and X4 (grd), set timer stop on positive going pulse.

b. Connect timer start to timer start contacts of switch A. Set timer start on negative pulse. If DPST switch "L" of test circuit of Fig. 29 is used, connect second pole of switch to +20 volts to trigger timer.

c. Close switch A and apply 0.6 to 0.8 amperes ac into terminal 1 and 3 of the SKBU-11 relay. (6 to 8 amperes into 1 and 3 of SKBU-1)

d. Open switch A, timer should start and should stop after a time delay. Time should be 22 to 28 milliseconds. Recheck approximately 10 times in order to take an average of 10 readings. To recheck time, it will be necessary to close SW-A and reset relay with SW-D If test circuit of Fig. 29 is used, close switch "L" to internal fault position. Timer should start and stop after a time delay of 22 to 28 milliseconds. Take average of 10 readings.

11. Recheck steps 6, 7 and 10. Readjust S6, R316, and S7 if necessary.

12. Signal Squelch Time (10/150)

a. Connect timer stop to X14 and X4 (grd). Open switch C.

b. Connect timer start to switch 28. Set timer start on positive pulse. Connect timer stop on positive pulse.

c. Close switch 28. Timer will start and will stop after a 8 to 12 millisecond delay.

d. Set timer stop on negative pulse, and timer start to negative pulse.

e. Open switch 28. Timer should start and stop after a time delay of 125 to 185 milliseconds.

13. Check of Frequency Verifier

a. Open all switches of test circuit.

b. Connect scope across TP60 and terminal 8 of the FD board.

c. Apply 0.6 to 0.8 amperes to terminal 1 and 3 of SKBU-11 relay. (Apply 6.0 to 8.0 amperes to terminal 1 and 3 of SKBU-1 relay)

d. Waveform of Fig. 26 should be observed.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram voltages of Fig. 25 should be used to isolate the circuit that is not performing correctly. The schematic of the individual board, and the voltages of Table III should then be used to isolate the faulty component.

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give circuit symbol and the electrical value (ohms, mfd., etc.) and component style number.

TABLE III

VOLTAGE MEASUREMENTS ON PRINTED CIRCUIT BOARDS

FAULT DETECTOR BOARD

Test Point	$I_{a.c.} = 0$	$I_{a.c.}$ = Pickup of FD
TP54	6.5 V. d.c.	less than 1
TP55	less than 1	4.5 V. d.c.
TP56	less than 1	18 to 20 V. d.c.
Term. 2	less than 1	8.6 V. d.c.
51-52	0	7.4 volts a.c. (Approx.)
52-53	0	7.5 volts a.c. (Approx.)
53-51	0	7.4 volts a.c. (Approx.)
Term. 5-6	0	15 volts a.c. (Approx.)
TP 57	18 volts	
TP 58	18 volts	
TP 59	less than 1	Pulses See Fig. 26 for Waveform
TP 60	20 volts	
TP 61	18 volts	
TP 62	less than 1	

SUPERVISION BOARD

Test Point	Normal Condition	Abnormal Condition
Term. 16	12	less than 1 with DFD▲Operation
TP151	less than 1	7 with DFD Operation
TP152	20	less than 1 with DFD Operation
Term. 13	less than 1	20
Term. 18	less than 1	15 with sustained arming
TP153	15	less than 1 with sustained arming
TP154	less than 1	20 with sustained arming
Term. 19	20	less than 1 with sustained arming
Term. 10	less than 1	6.8 volts d.c.
TP158	20	less than 1
Term. 1	less than 1	20
Term. 15	6	20
Term. 6	less than 1	20

▲DFD = distance fault detector

AMPLIFIER AND KEYING

Test Point	Normal ($I_{a.c.} = 0$)	Serviceable Channel ● Abnormal or ▲ I_{AC} = Pickup of FD
Term. 7	18	● less than 1 breaker failure or trip
TP101	less than 1	● 8.5 breaker failure or trip
→ Term. 10	less than 1	● less than 1 breaker failure or trip
TP102	5 Vdc	▲ 4.3 V pulses
Term. 13	less than 1	▲⌿ 6 volt pulses
→ Term. 12	less than 1	▲⌿ 20 volt pulses

AMPLIFIER AND KEYING (Continued)

Test Point	Normal ($I_{a.c.} = 0$)	Serviceable Channel Abnormal or I_{AC} = Pickup of FD
TP103	5 Vdc	▲ 5 volt pulses
TP104	less than 1	▲ 16 volt pulses
Term. 11	20 Vdc	▲ 20 volt pulses
Term. 2	0 V	▲ 20 volt pulses
Term. 18	20 V	▲ 6 volt pulses (Ref. +20V)
Term. 17	0 Volts	▲ 45 volt pulses

⌿ Non-squelch condition

● Abnormal

▲ I_{ac} = FD pickup

⋈ Terminal 10 and 12 connected together.

ARMING BOARD

Test Point	External Fault	Internal Fault
TP252	⌿ less than 1	10 V pulses
Term. 3	⌿ 10 volts	10 V pulses
T TP254	⌿ less than 1	20 V pulses
TP255	⌿ 20 volts	20 V pulses
# TP256	less than 1	less than 1
# Term. 19	18 volts	18 volts

⌿ Very narrow pulses would be observed on scope.

With $I_{ac} = 0$ (Unarmed condition)
TP256 – 6 volts, Term. 19 – 0 volts.

OUTPUT BOARD

Test Point	Normal	Trip	Blocking
301	20	Applies to Sequential Fault	
302	0	Applies to Sequential Fault	
303	2.2	12.5	less than 1
304	less than 1	less than 10	7
Board 14	20	20	less than 1
305	18.5	7	18.5
306	0	13.5	0
307	20	less than 1	20
308	0	20	0

ELECTRICAL PARTS LIST

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
FAULT DETECTOR BOARD Style 5312D13G01		
Capacitors		
C51	0.1 Mfd	1544920
C52-C53-C59	0.5 Mfd	187A624A11
C54-C55	1.5 Mfd	187A508H09
C56-C57	0.02 Mfd	187A624H09
C58	0.1 Mfd	187A624H01
C60	0.22 Mfd	762A703H01
Diodes		
D51 to D58-D70 to D73	1N457A	184A855H07
D59	1N645A	837A692H03
D60 to D69	1N4385	184A855H14
Transistors		
Q51-Q52-Q53-Q55-Q57-Q61-Q62-Q63	2N3417	848A851H02
Q54-Q56-Q58	2N3645	849A441H01
Switches		
Q59-Q60	2N886	185A517H03
Resistors		
R51	50 Ohms, 5W	185A209H06
R52-R68-R71	2.7K Ohms ½W	629A531H42
R53 (POT)	2.5K Ohms ½W	629A430H03
R54-R55-R58-R62-R64-R66-R84-R89-R92	10K Ohms ½W	629A531H56
R56-R60	100K Ohms ½W	184A763H75
R57	47K Ohms ½W	629A531H72
R59	56K Ohms ½W	184A763H69
R61-R87	22K Ohms ½W	629A531H64
R63	6.8K Ohms ½W	629A531H52
R65	27K Ohms ½W	629A531H66
R67	150 Ohms 3W	762A679H01
R69-R73	68K Ohms ½W	629A531H76
R70-R74-R88	39K Ohms ½W	629A531H70
R72-R75-R80	2K Ohms ½W	836A503H33
R76-R78-R90	1K Ohms ½W	629A531H32
R77	5.6K Ohms ½W	629A531H50
R79-R80	6.2K Ohms ½W	629A531H51
R81	20K Ohms ½W	629A531H63
R82	1.5K Ohms ½W	836A503H30
R83-R91	470 Ohms ½W	629A531H24
R85-R93	4.7K Ohms ½W	629A531H48

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
FAULT DETECTOR BOARD (Continued)		
Zener Diodes		
Z51	1N1832C, 62V	184A617H06
Z52-Z55	1N957B, 6.8V	186A797H06
Z53	1N3688A, 24V	862A288H01
Z54	1N759A, 12V	837A693H01
SUPERVISION BOARD Style 5315D34G01		
Capacitor		
C151-C153-C157	0.47 Mfd	188A669H01
C152	68 Mfd	187A508H02
C154-C158	1.5 Mfd	187A508H09
Diodes		
D151-D157-D162	1N457A	184A855H07
D152-D155-D156	1N645A	837A692H03
Transistors		
Q151-Q152-Q154-Q155-Q161-Q163-Q164	2N3417	848A851H02
Q153-Q156-Q162	2N3645	849A441H01
Resistors		
R151-R158-R168-R188-R194	6.8K Ohms ½W	629A531H52
R152-R153-R157-R159-R164-R165-R167-R169-R186-R189-R191-R193-R196	10K Ohms ½W	629A531H56
R154	470 Ohms ½W	184A763H19
R166-R192	22K Ohms ½W	184A763H59
R156-R161	1K Ohms ½W	184A763H27
R160-R170-R190	82K Ohms ½W	629A531H78
R155-R162	33K Ohms ½W	184A763H63
R163	56K Ohms ½W	184A763H69
R171	150 Ohms 3W	762A679H01
R195	2.7K Ohms ½W	184A763H37
R185	47K Ohms ½W	184A763H67
Zener Diode		
Z151-Z152-Z156	1N957B, 6.8V	186A797H06
Z153	1N3688A, 24V	862A288H01
Z158	UZ5875, 75V	837A693H04

ELECTRICAL PARTS LIST (Continued)

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
AMPLIFIER & KEYING BOARD Style 5314D77G01		
Capacitor		
C101	6.8 Mfd	184A661H21
C102	1.5 Mfd	187A509H09
Diodes		
D101-D110 to D113	1N457A	184A855H07
D102 to D105-D107 to D109	1N645A	837A692H03
Transistors		
Q101 to Q107	2N3417	848A851H02
Q108-Q109-Q113	2N3645	849A441H01
Resistors		
R101	6.8K Ohms ½W	629A531H52
R102-R106	470 Ohms ½W	184A763H19
R103	39K Ohms ½W	184A763H65
R104-R108	1K Ohms ½W	184A763H27
R105-R109-R112 to R116-R121-R122-R124-R130	10K Ohms ½W	184A763H51
R107	15K Ohms ½W	629A531H60
R110	82K Ohms ½W	629A531H78
R111-R120	33K Ohms ½W	184A763H63
R118	220K Ohms ½W	184A763H83
R119-R132	68K Ohms ½W	629A531H76
R123-R139	22K Ohms ½W	184A763H59
R125-R129	4.7K Ohms ½W	184A763H43
R126-R128	470K Ohms ½W	184A763H91
R127-R141	47K Ohms ½W	184A763H67
R140	56K Ohms ½W	184A763H69
R142	1K Ohms 5W	763A129H07
Zener Diodes		
Z101-Z102	1N957B, 6.8V	186A797H06
Z103	1N3688A, 24 V	862A288H01
Z104	1N748A 3.9V	186A797H13

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
ARMING BOARD Style 201C170G01		
Diodes		
D255-D257-D260-D261-to D265-D267	1N457A	184A855H07
Transistors		
Q252-Q253-Q256-Q258-Q259	2N3417	848A851H02
Q257	2N3645	849A441H01
Resistors		
R255-R257-R261-R262-R265-R274-R277-R278-R280-R281-R287-R288	22K Ohms ½W	184A763H59
R260-R264-R275-R276-R282-R284-R285	10K Ohms ½W	184A763H51
R279	27K Ohms ½W	629A531H66
R283-R290	12K Ohms ½W	629A531H58
Zener Diodes		
Z251	1N3688A, 24V	862A288H01
PROTECTIVE RELAY BOARD Style 201C165G01 – 201C476G01		
Capacitors		
C1 to C4	.047 Mfd	849A437H04
Diodes		
D1 to D5-D9	1N645A	837A692H03
Transistors		
Q1 to Q6-Q9	2N3417	848A851H02
Resistors		
R1 (125 volt input)	68K 1W	187A643H71
R1 (48 volt input)	22K ½W	184A763H59

ELECTRICAL PARTS LIST (Continued)

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
PROTECTIVE RELAY BOARD (Continued)		
Resistors (Continued)		
R2-R3-R4-R8-R9-R13-R14-R122-R23	4.7K ½W	629A531H48
R5-R10-R15-R24-R34	82K	629A531H78
R6-R21-R30-R39	27K ½W	184A763H01
R7-R11-R16-R20-R25-R29-R40	10K ½W	629A531H56
R12-R17-R26	6.8K ½W	629A531H52
R18-R19-R27-R28	22K ½W	184A763H59
Zener Diode		
Z1-Z3-Z5-Z7	1N3686B, 20V	185A212H06
Z2-Z4-Z6-Z8	1N957B, 6.8V	186A797H06
OUTPUT BOARD Style 201C025G02		
Capacitors		
C301	1.0 Mfd	837A241H15
C302-C303-C306-C309	0.22 Mfd	762A703H01
C304-C305	4.7 Mfd	184A661H12
C307-C308	500 Mmfd	187A694H03
C310	0.10 Mfd	188A669H03
C311	1.5 Mfd	187A508H09
Diodes		
D301 to D306-D308	1N457A	184A855H07
D307	1N645A	837A692H03
Transistors		
Q301-Q305-Q306-Q307-Q309	2N3645	849A441H01
Q302-Q303-Q304-Q308	2N3417	848A851H02
Resistors		
R301-R303-R304-R306-R310-R311-R314-R315-R320-R323-R324-R326-R330-R335	10K Ohms ½W	184A763H51

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
OUTPUT BOARD (Continued)		
Resistors (Continued)		
R302	220K Ohms ½W	187A641H83
R305	47 Ohms ½W	187A290H17
R307	47K Ohms ½W	184A763H67
R308 – R312	470 Ohms ½W	184A763H19
R309 – R317	1K Ohms ½W	184A763H27
R313	470K Ohms ½W	184A763H91
R316 (Pot.)	15K Ohms ½W	629A430H08
R318 – R322 – R323	4.7K Ohms ½W	184A763H43
R319 – R321 – R325	22K Ohms ½W	184A763H59
R327	6.8K Ohms ½W	184A763H47
R329	18K Ohms ½W	184A763H57
R331	10K Ohms ½W	629A531H56
R332	6.8K Ohms ½W	629A531H52
R333	27K Ohms ½W	629A531H66
R334	150 Ohms 3 W	762A679H01
Zener Diode		
Z301 to Z305	1N957B, 6.8V	186A797H06
Z306 - Z307	1N3688A, 24 V	862A288H01
RELAY BOARD Style 5312D78G01 – SKBU-11 Style 5312D80G01 – SKBU-1		
Capacitors		
C201-C202-C203	0.25 Mfd	187A624H02
Resistors		
R201 ▲	50 Ohms 5W	185A209H06
R202-R203 (SKBU-11)	3.3K Ohms ½W	629A531H44
R202-R203 (SKBU-1) ●	2.2K Ohms ½W	187A641H35
Filter Choke		
L201	8.5Hy 450 Ohms	188A460H01
Zener Diodes		
Z201 ▲	1N1828C 43V	629A798H14

▲SKBU-11 only ●Typical Value – Resistors selected for proper loading of low pass filter.

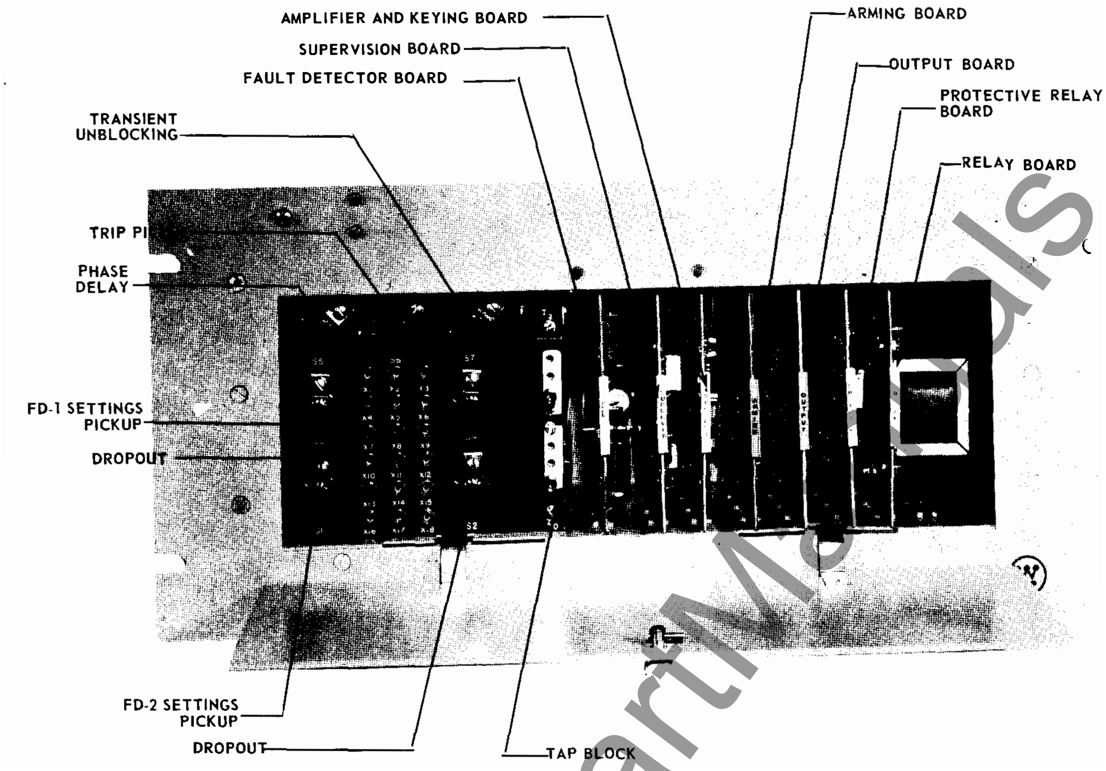


Fig. 1. Photograph (Front View) SKBU-11 Relay SKBU-1 Has a Second Tap Block "T".

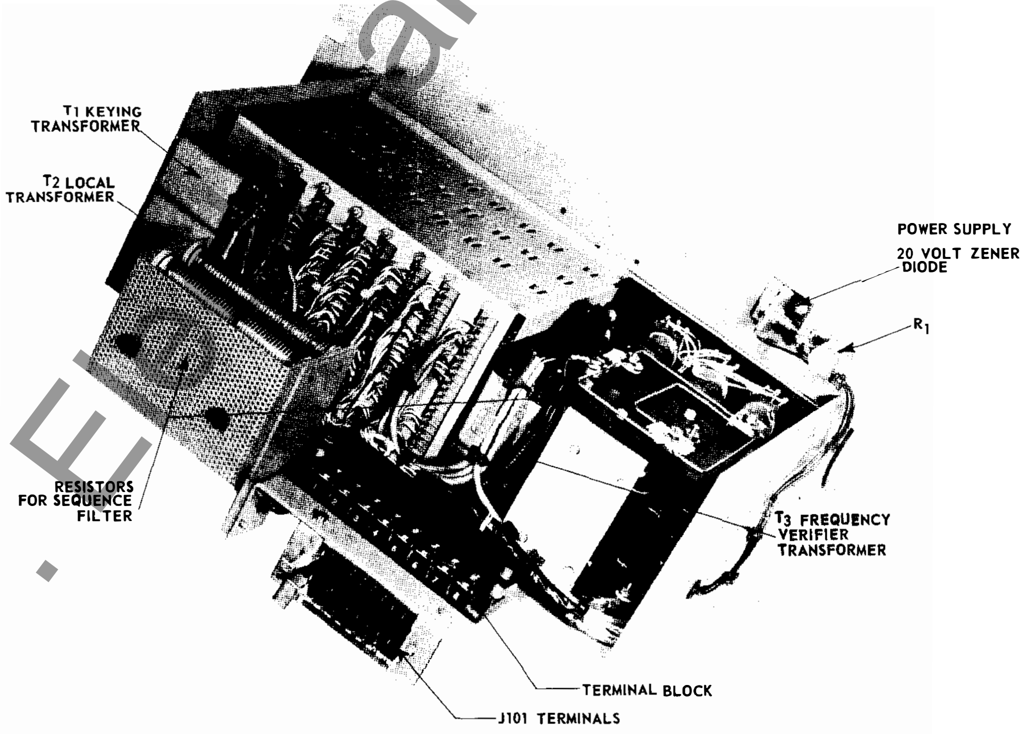


Fig. 2. Photograph (Rear View) SKBU-11 Relay

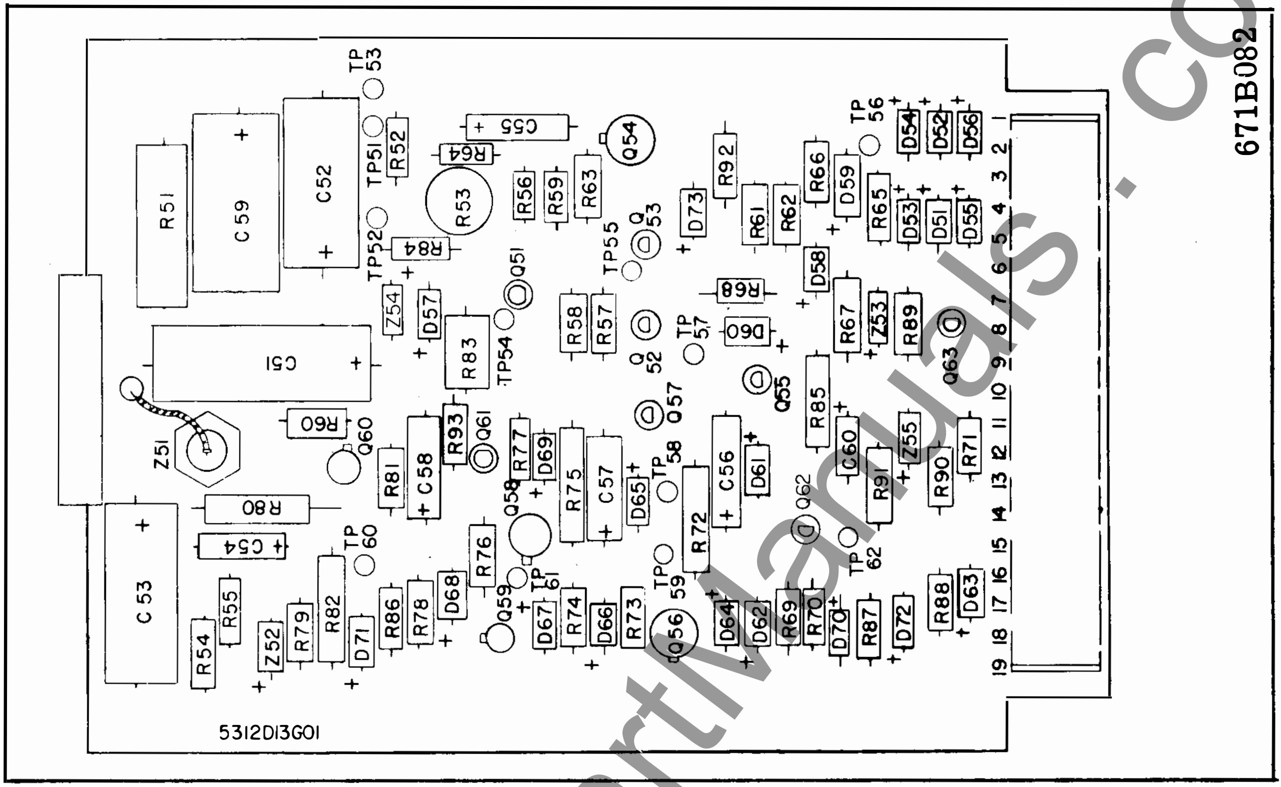


Fig. 3. Location of Components on Fault Detector Board.

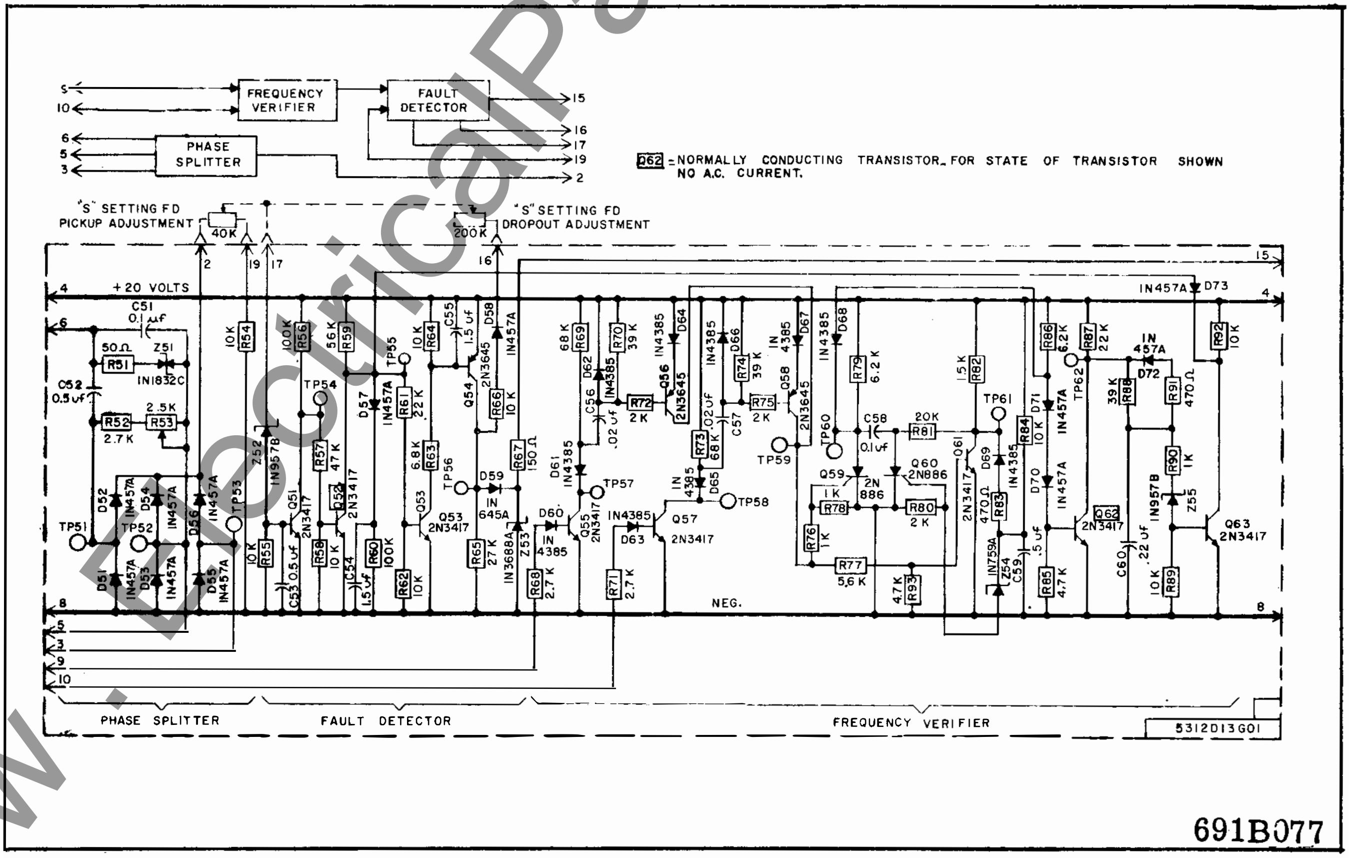


Fig. 4. Schematic of Fault Detector Board.

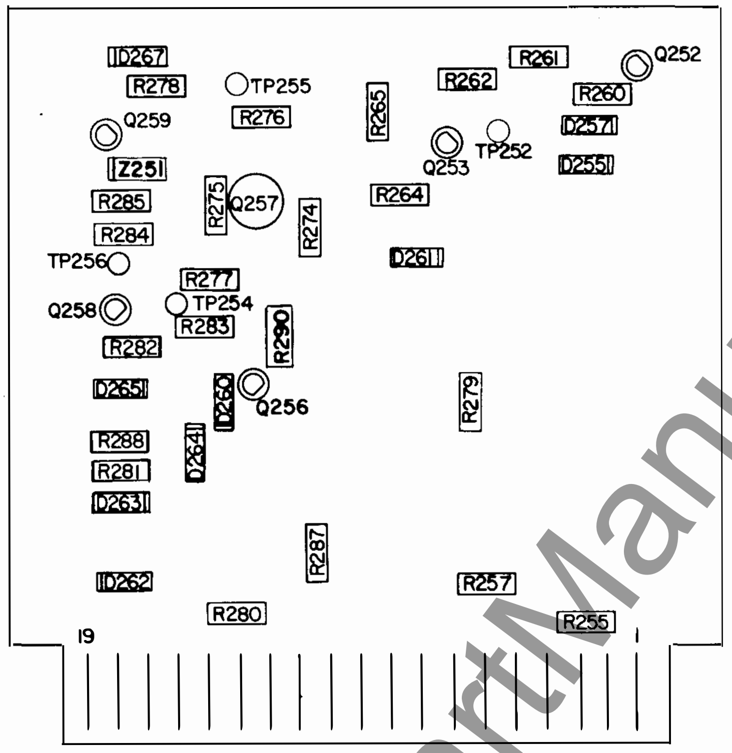


Fig. 5. Location of Components on Arming Board

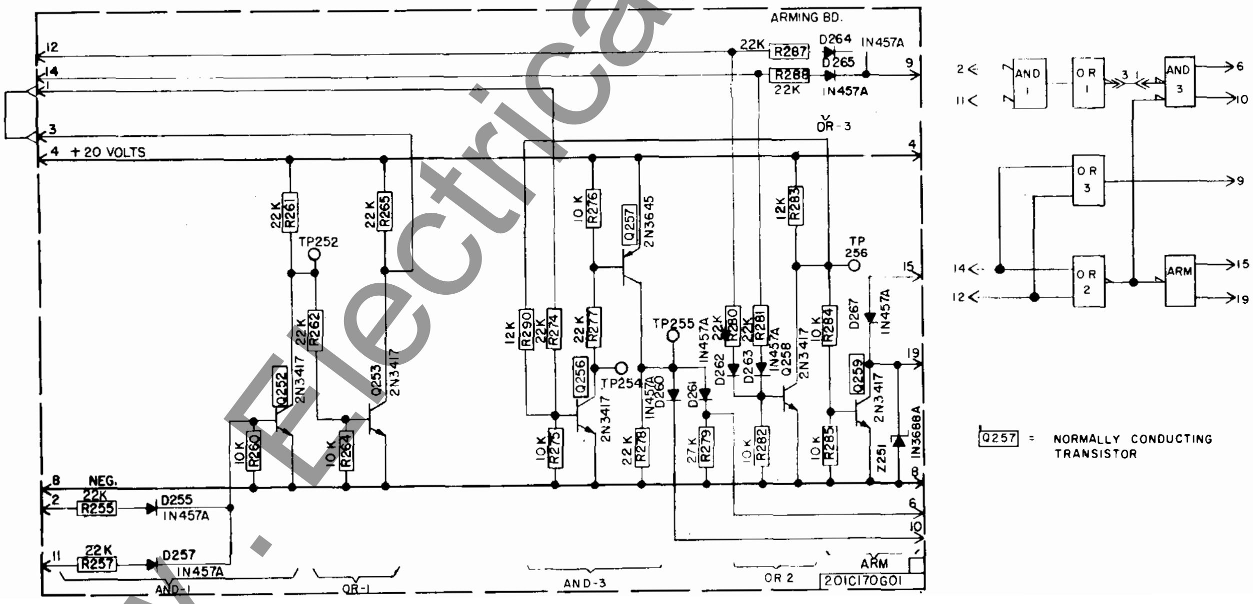


Fig. 6. Schematic of Arming Board

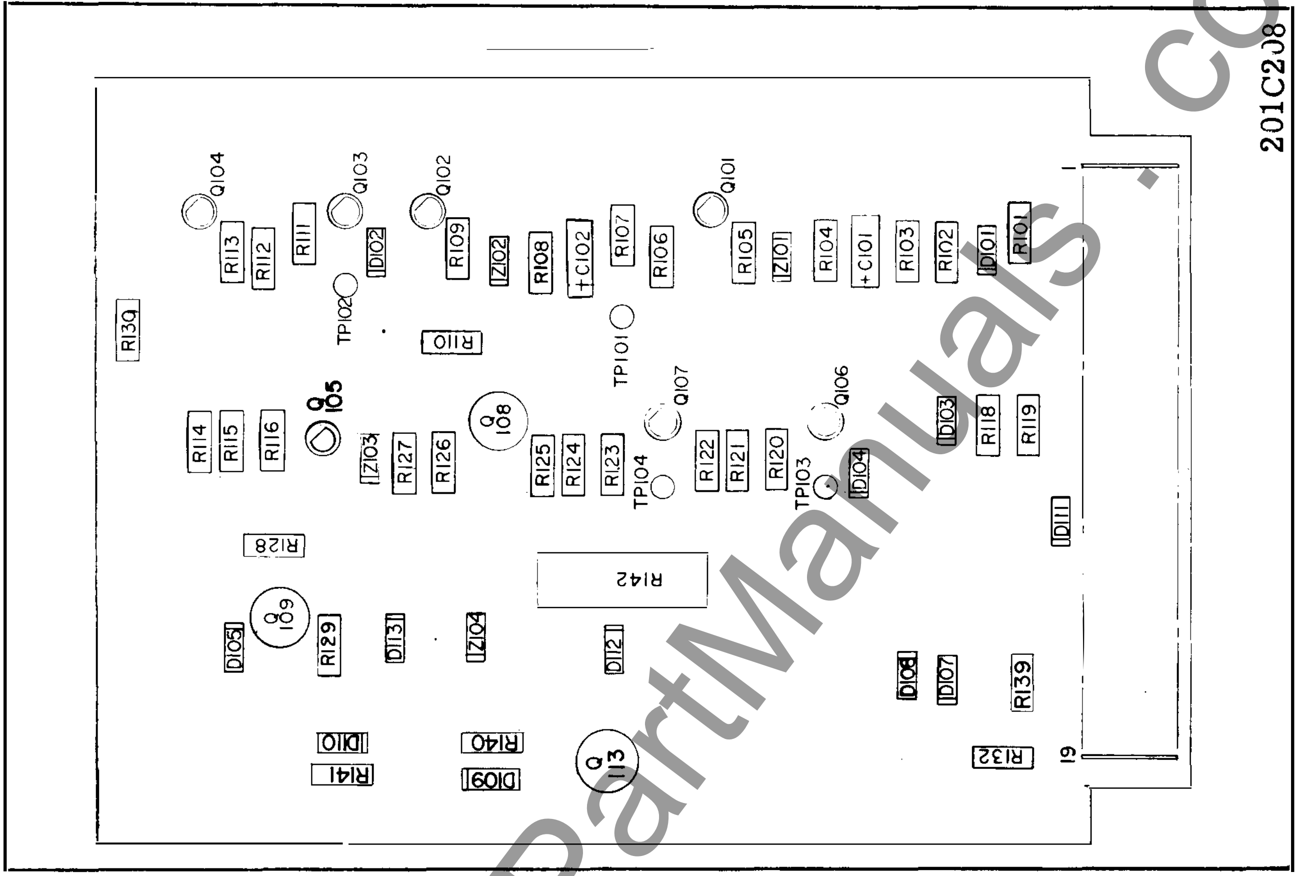


Fig. 7. Location of Components on Amplifier and Keying Board.

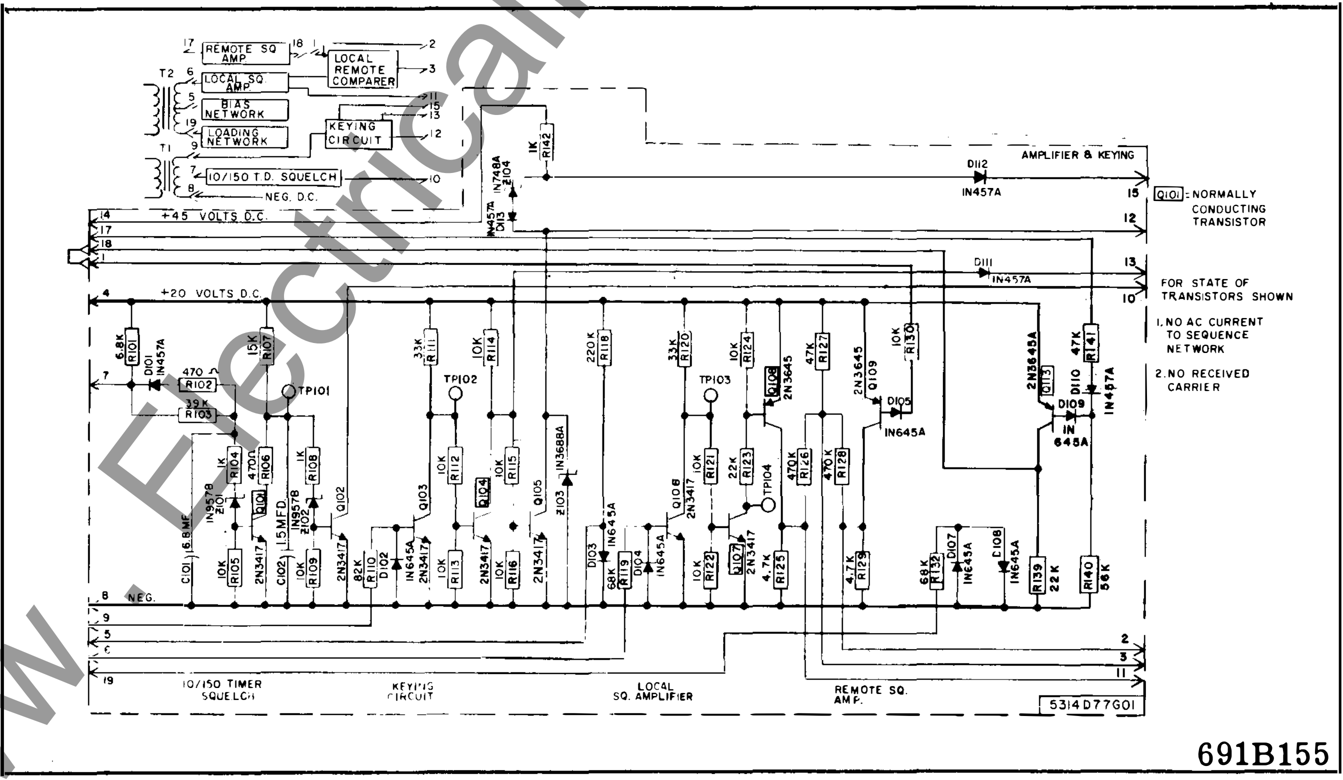


Fig. 8. Schematic of Amplifier and Keying Board.

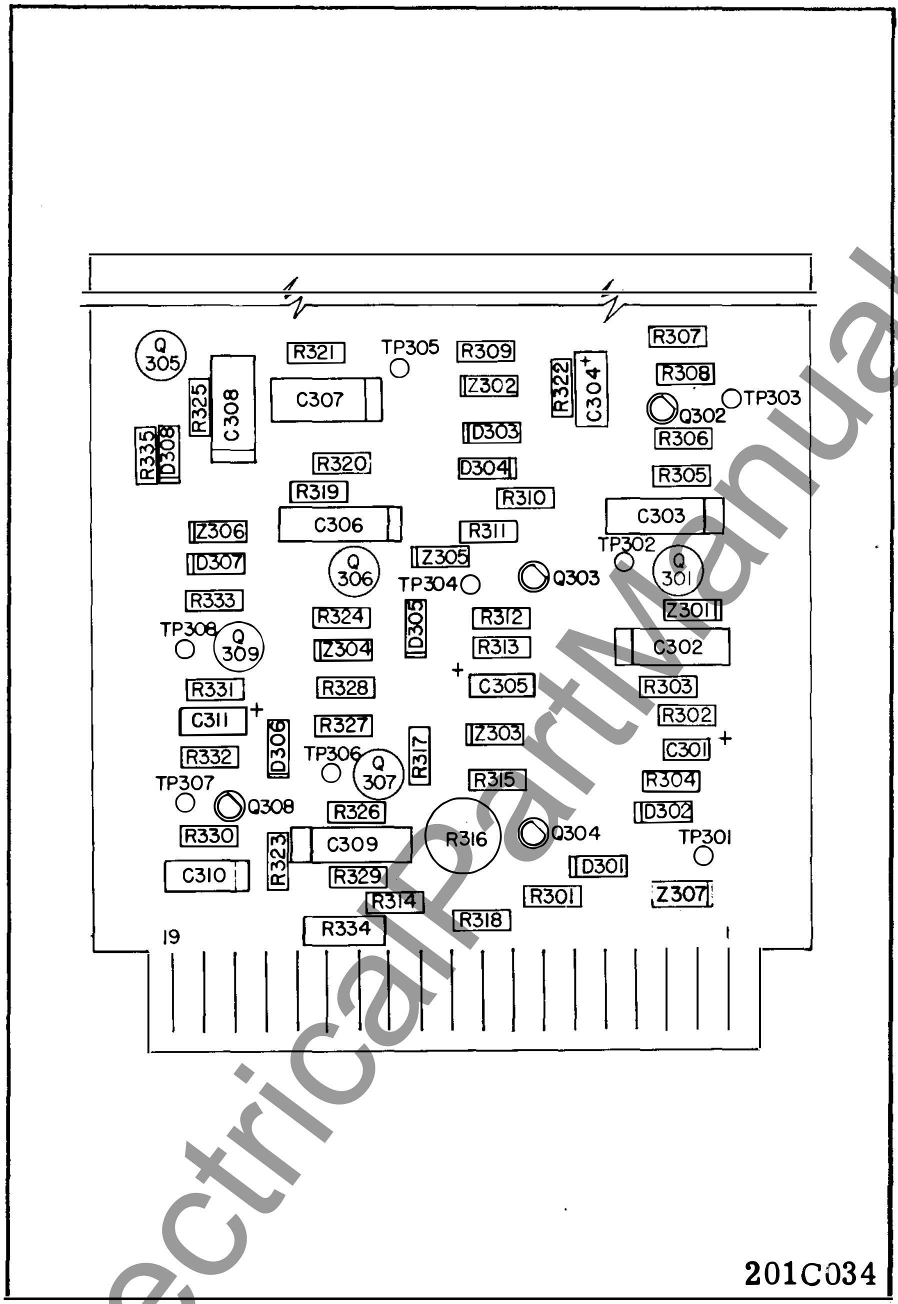
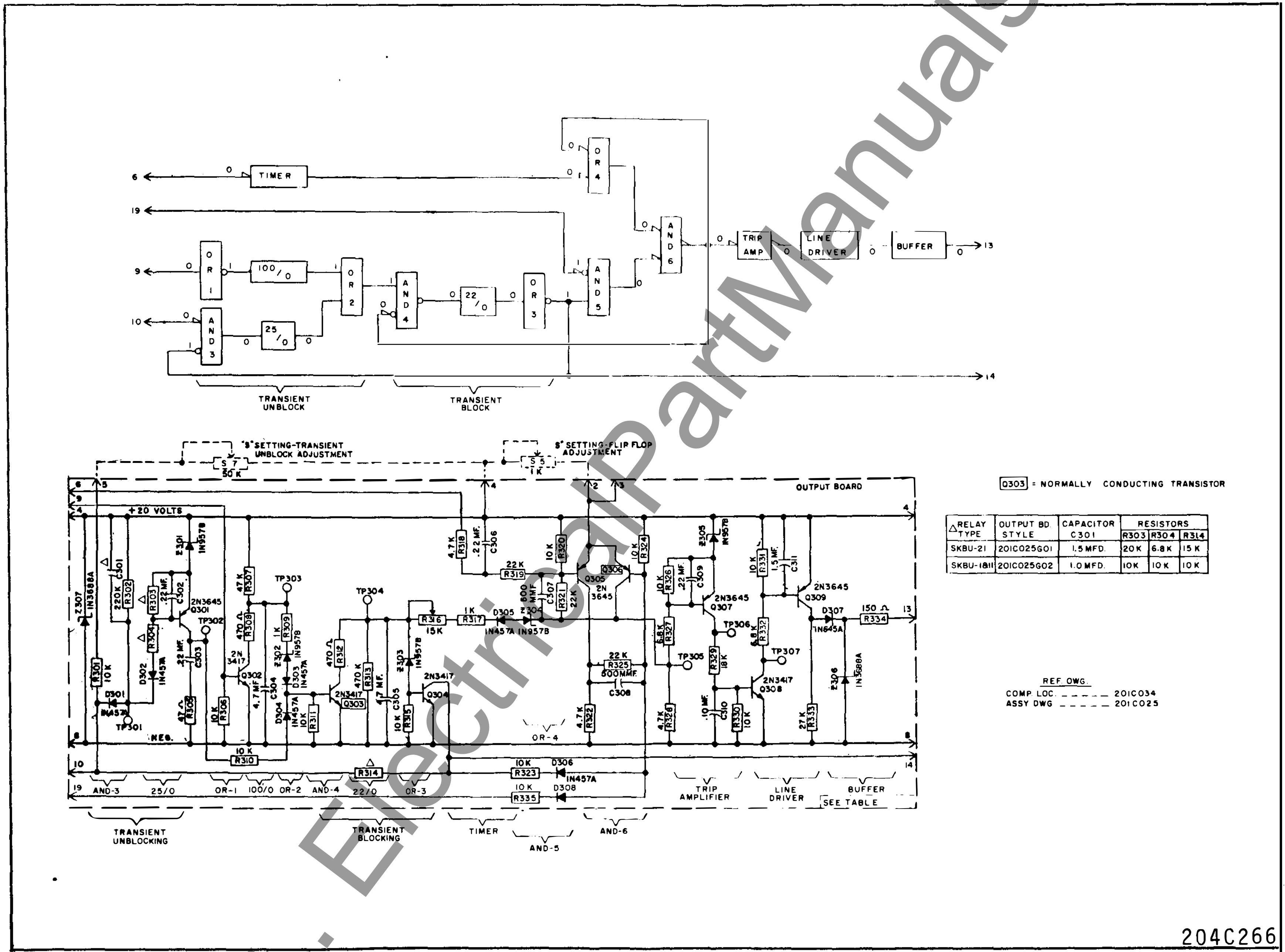


Fig. 9. Location of Components on Output Board.



△RELAY TYPE	OUTPUT BD. STYLE	CAPACITOR C301	RESISTORS		
			R303	R304	R314
SKBU-21	201C025G01	1.5 MFD.	20 K	6.8 K	15 K
SKBU-1&11	201C025G02	1.0 MFD.	10 K	10 K	10 K

Fig. 10. Schematic of Output Board.

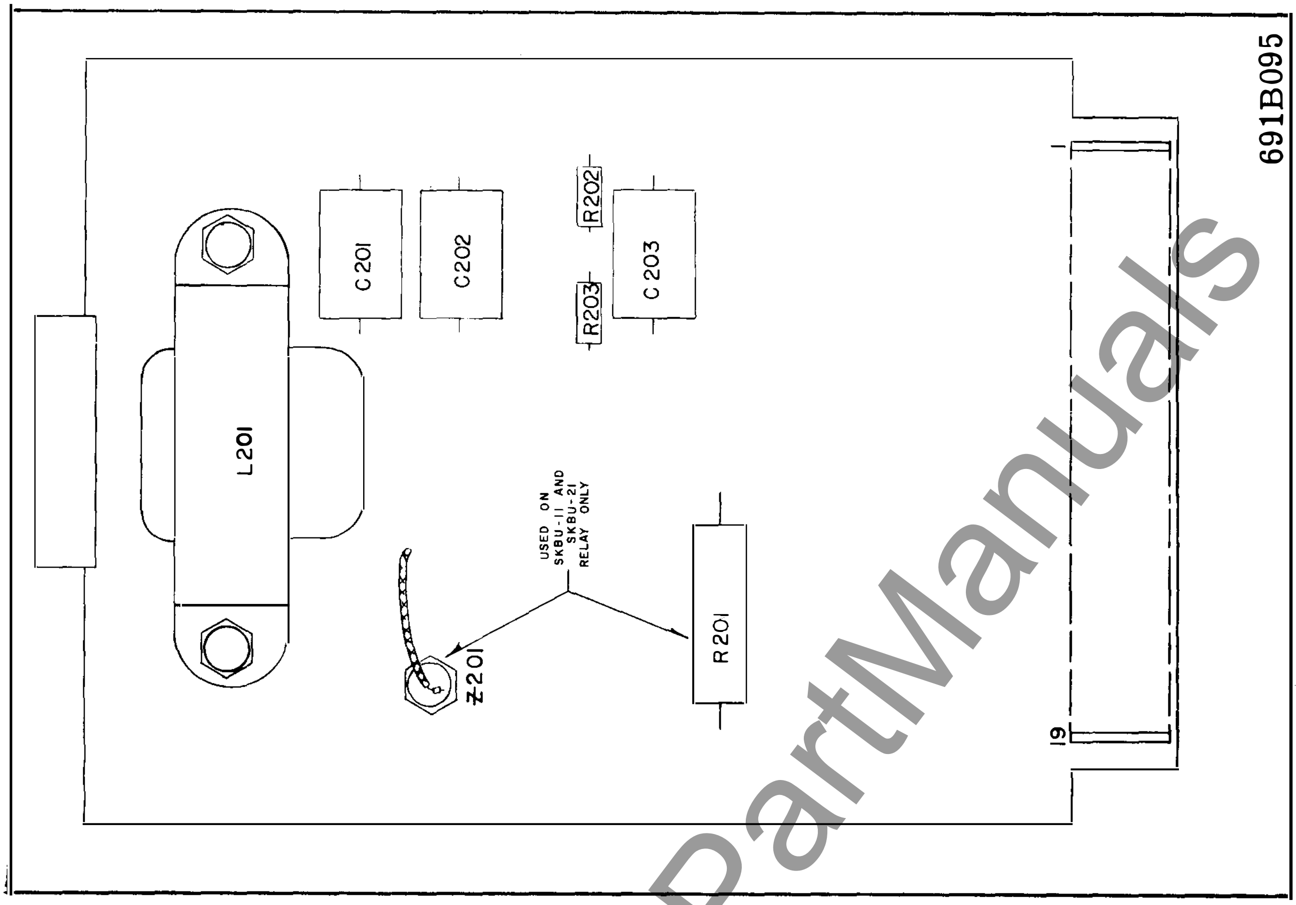


Fig. 11. Location of Components on Relay Board.

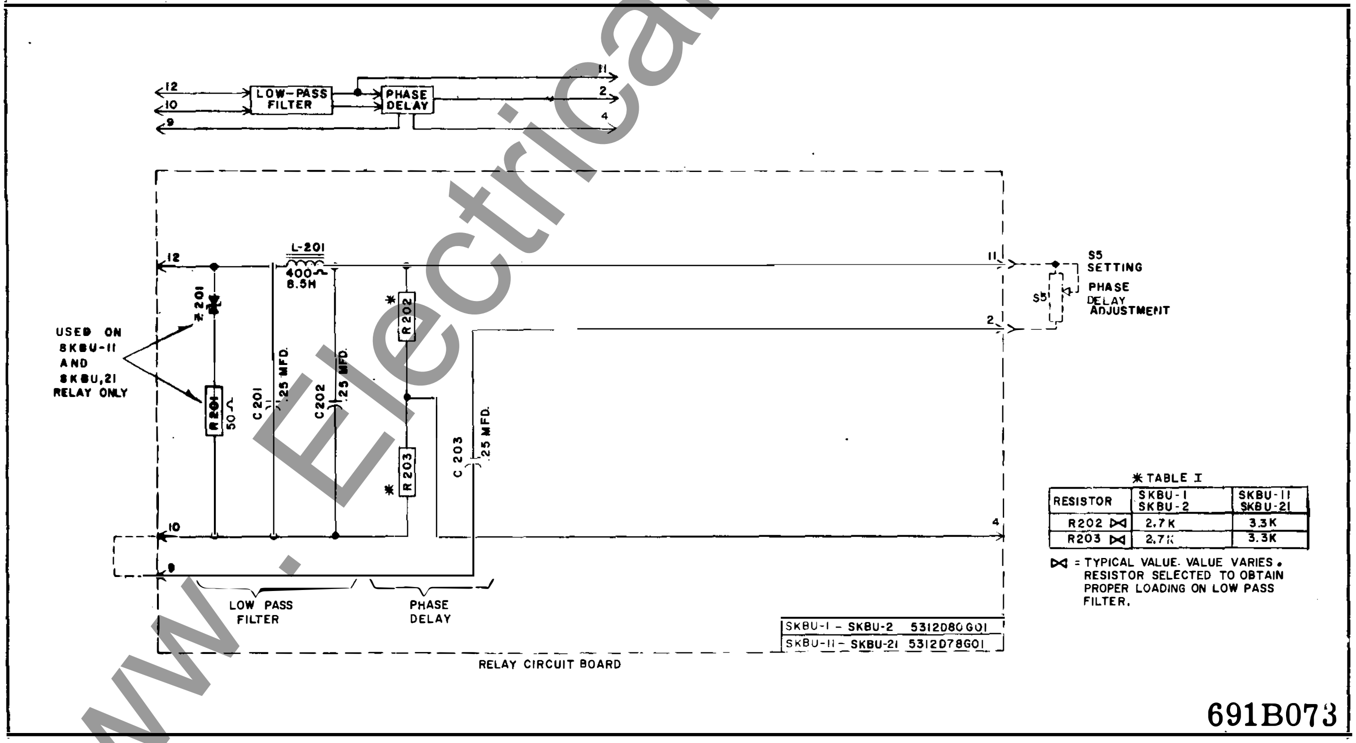


*TABLE I

RESISTOR	SKBU-1 SKBU-2	SKBU-11 SKBU-21
R202 ⋈	2.7K	3.3K
R203 ⋈	2.7K	3.3K

⋈ = TYPICAL VALUE. VALUE VARIES. RESISTOR SELECTED TO OBTAIN PROPER LOADING ON LOW PASS FILTER.

Fig. 12. Schematic of Relay Board.

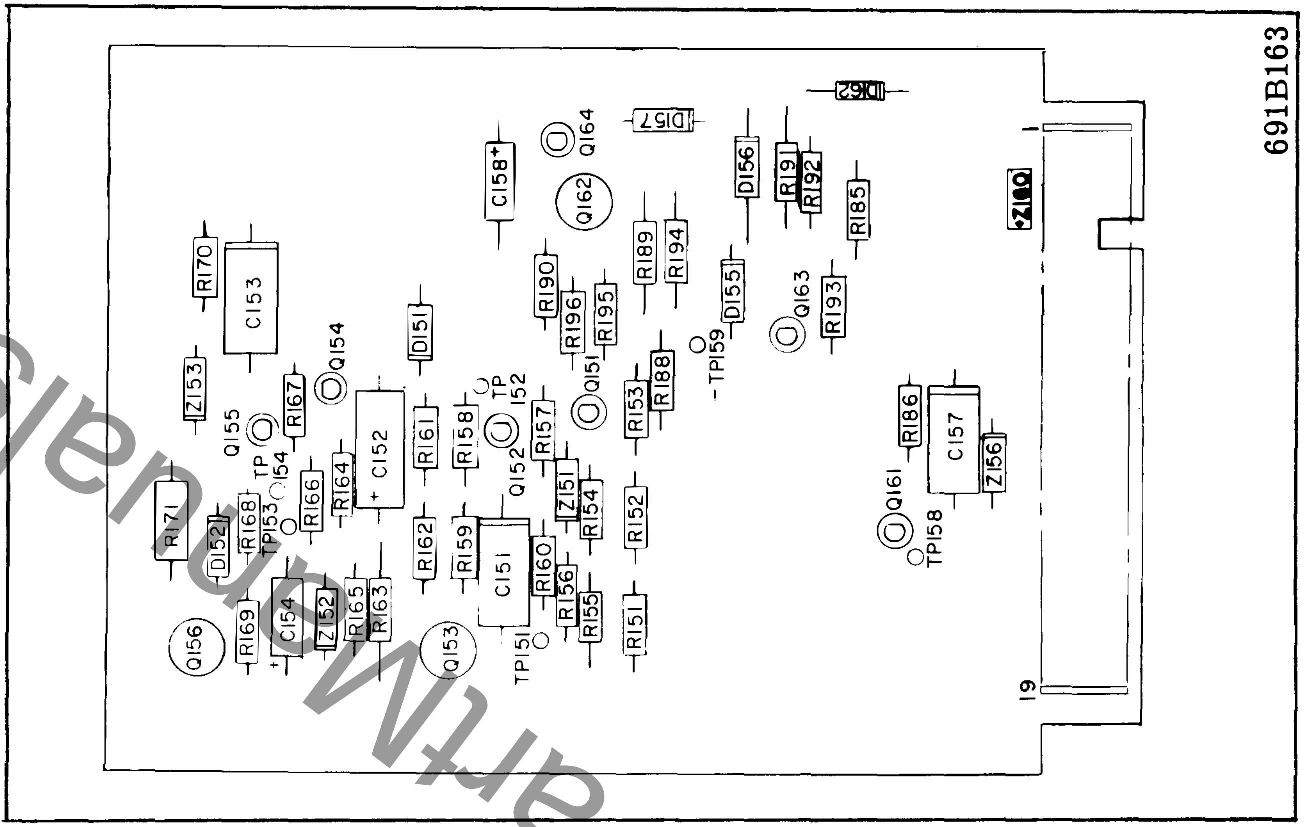


Fig. 13. Location of Components on Supervision Board.

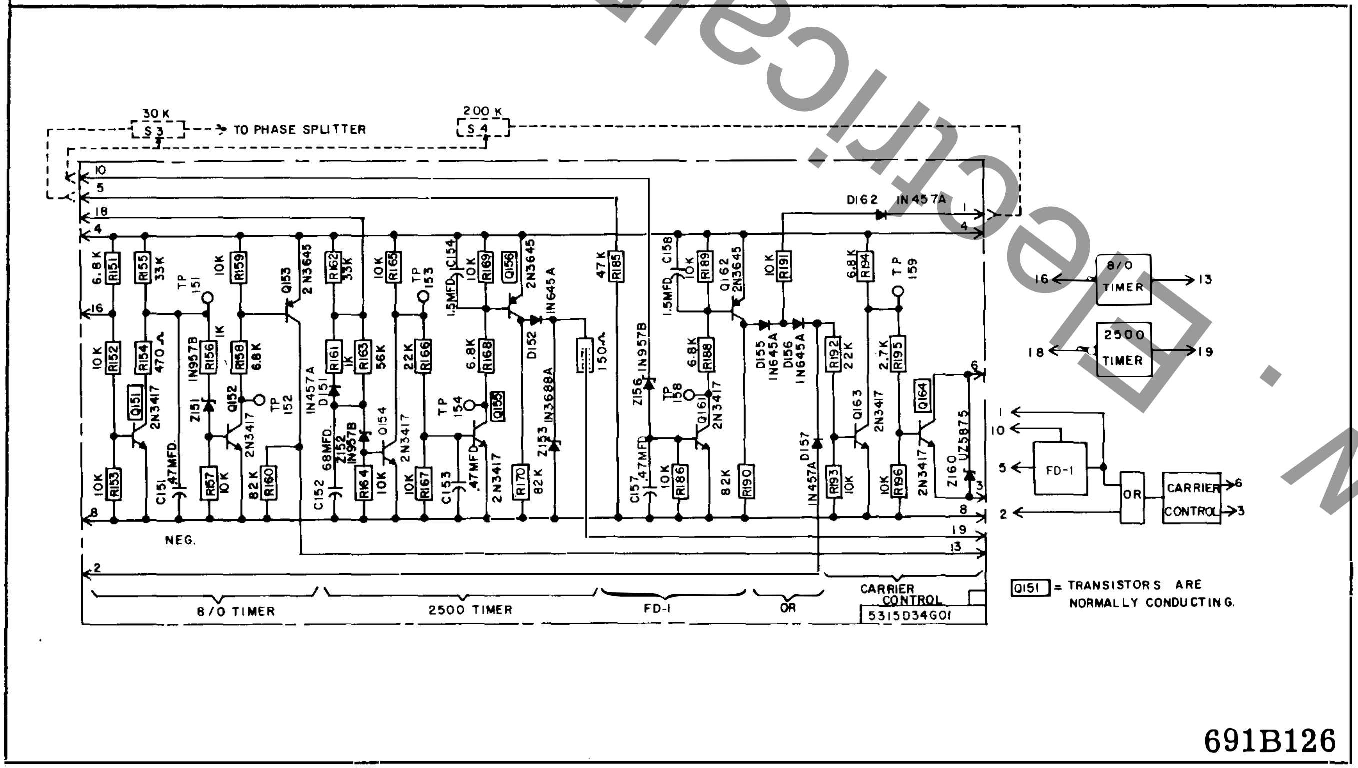


Fig. 14. Schematic of Supervision Board.

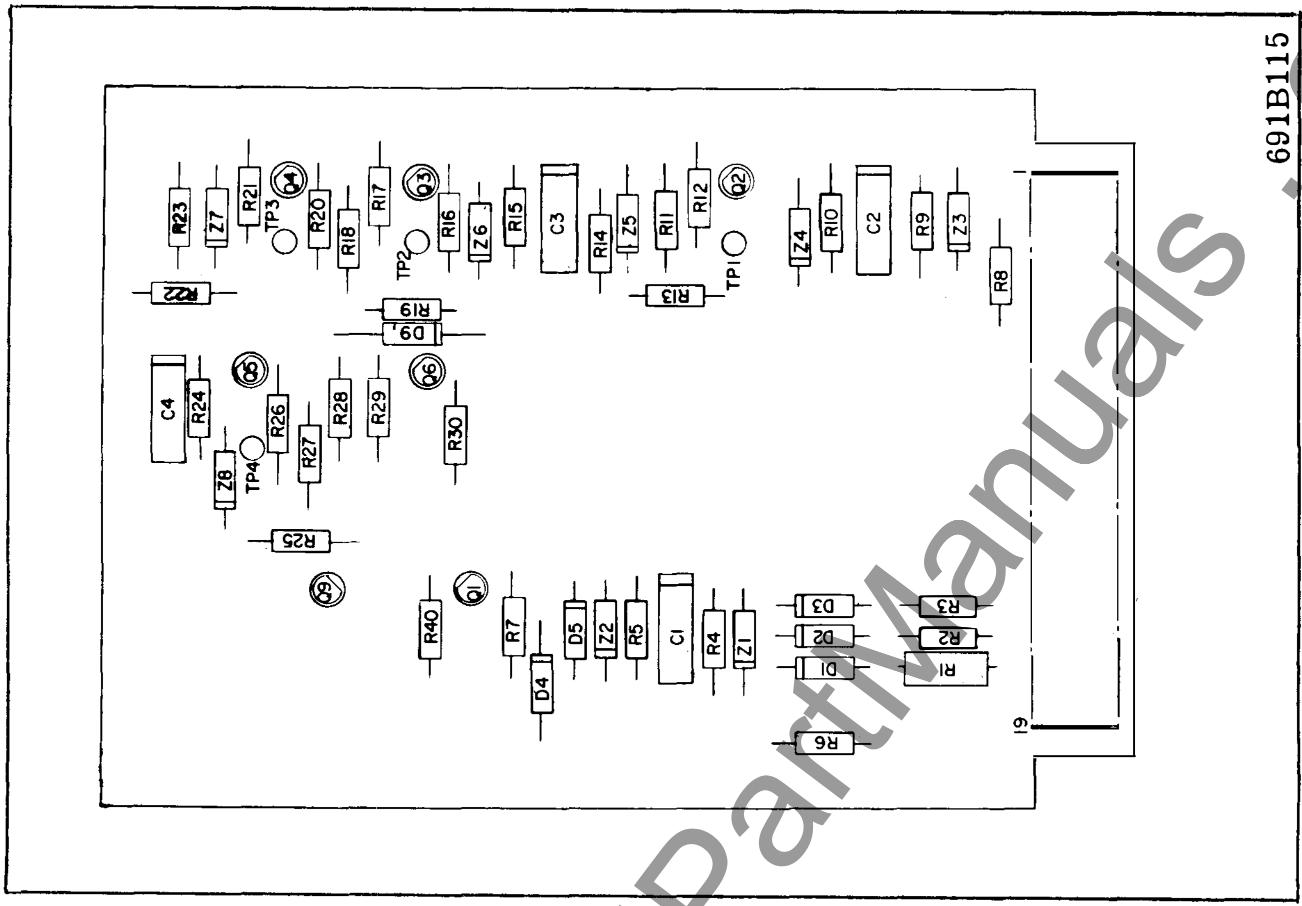


Fig. 15. Component Location on Protective Relay Board.

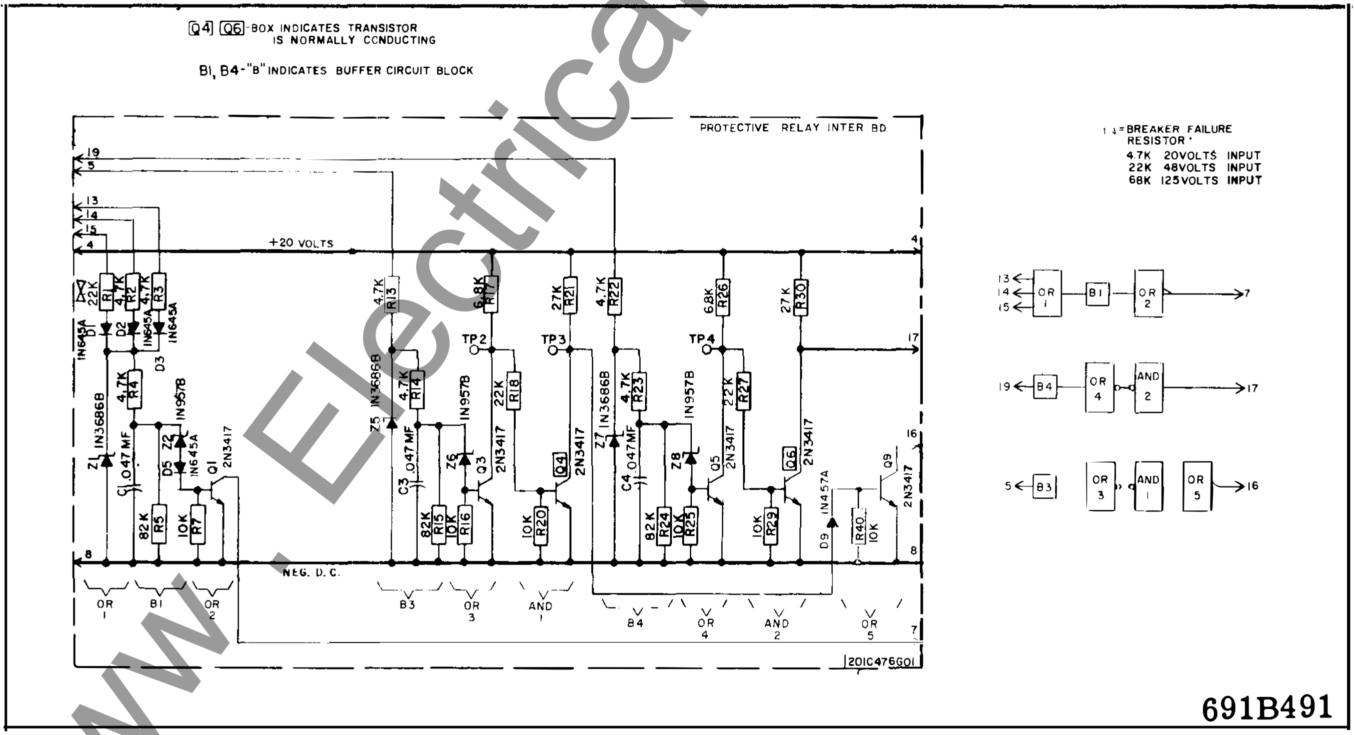


Fig. 16. Schematic of Protective Relay Board for Distance Phase Comparison System.

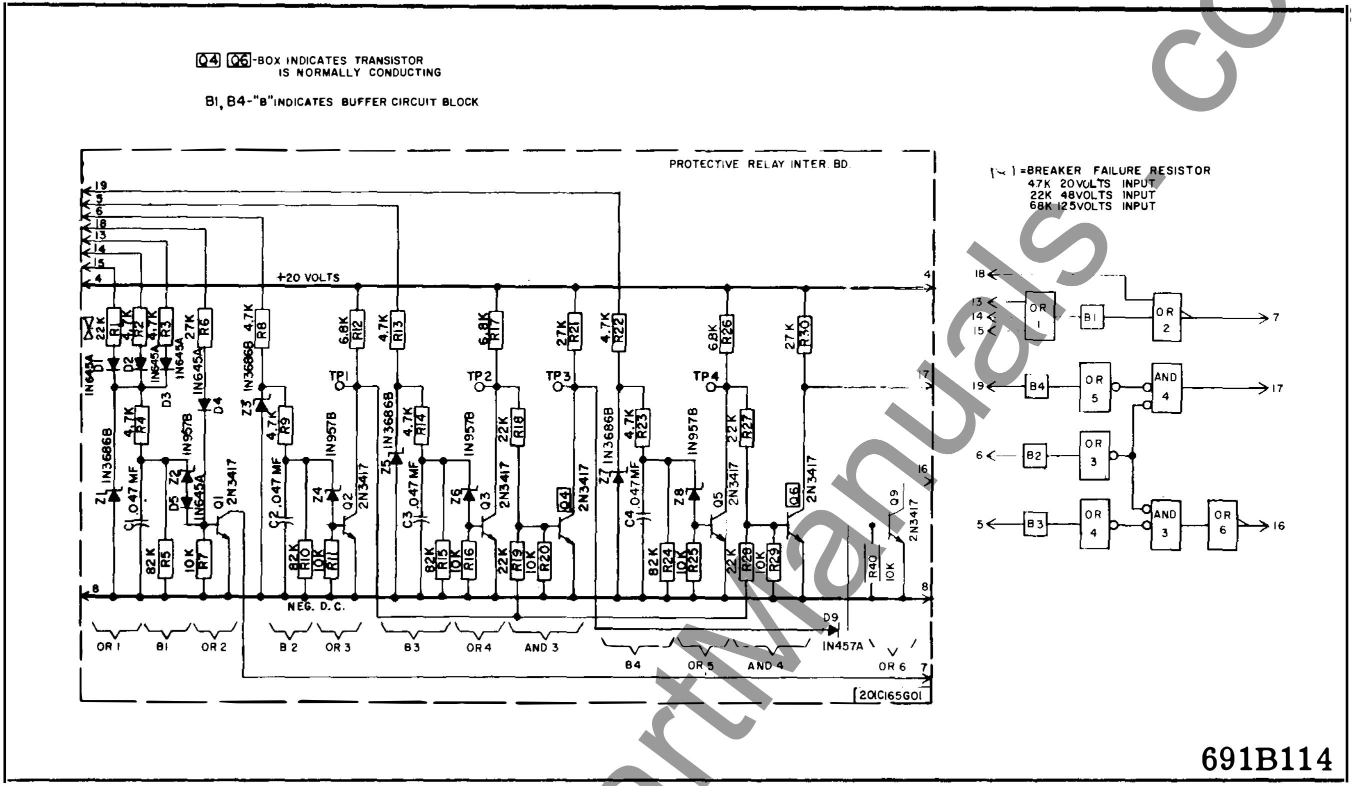


Fig. 17. Schematic of Protective Relay Board for Distance Phase Comparison System with Blinder Control.

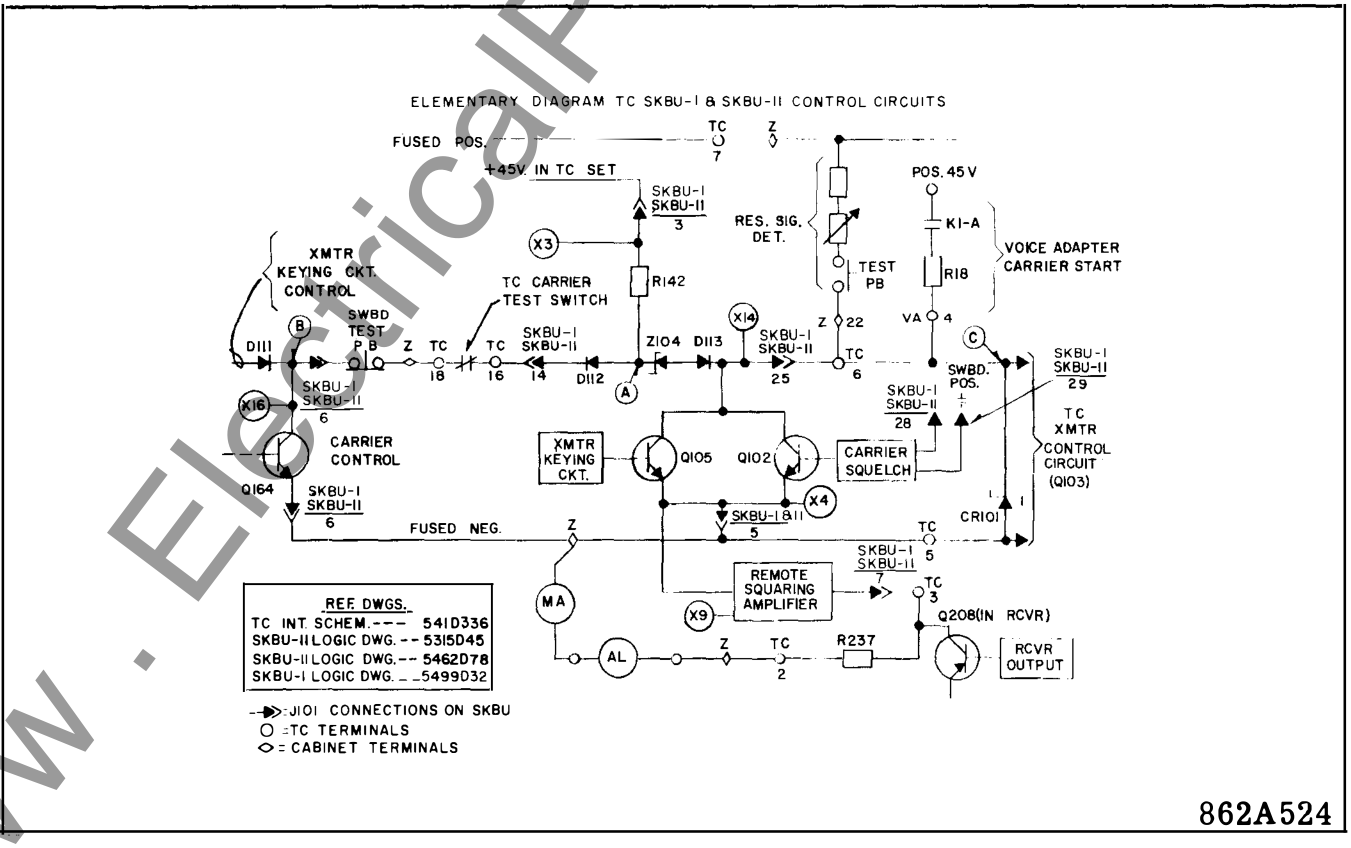


Fig. 18. Elementary Connection of TC SKBU-11.

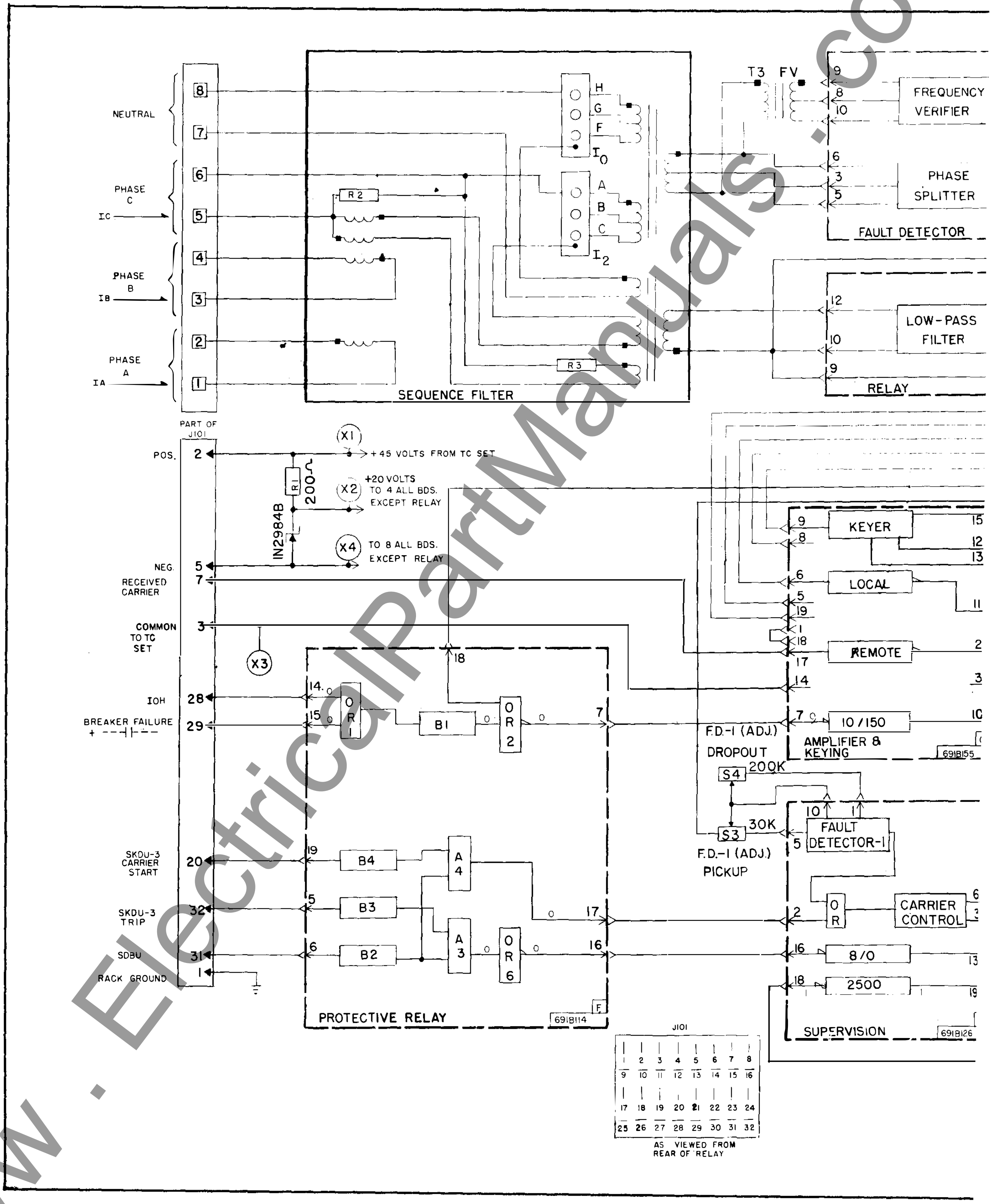
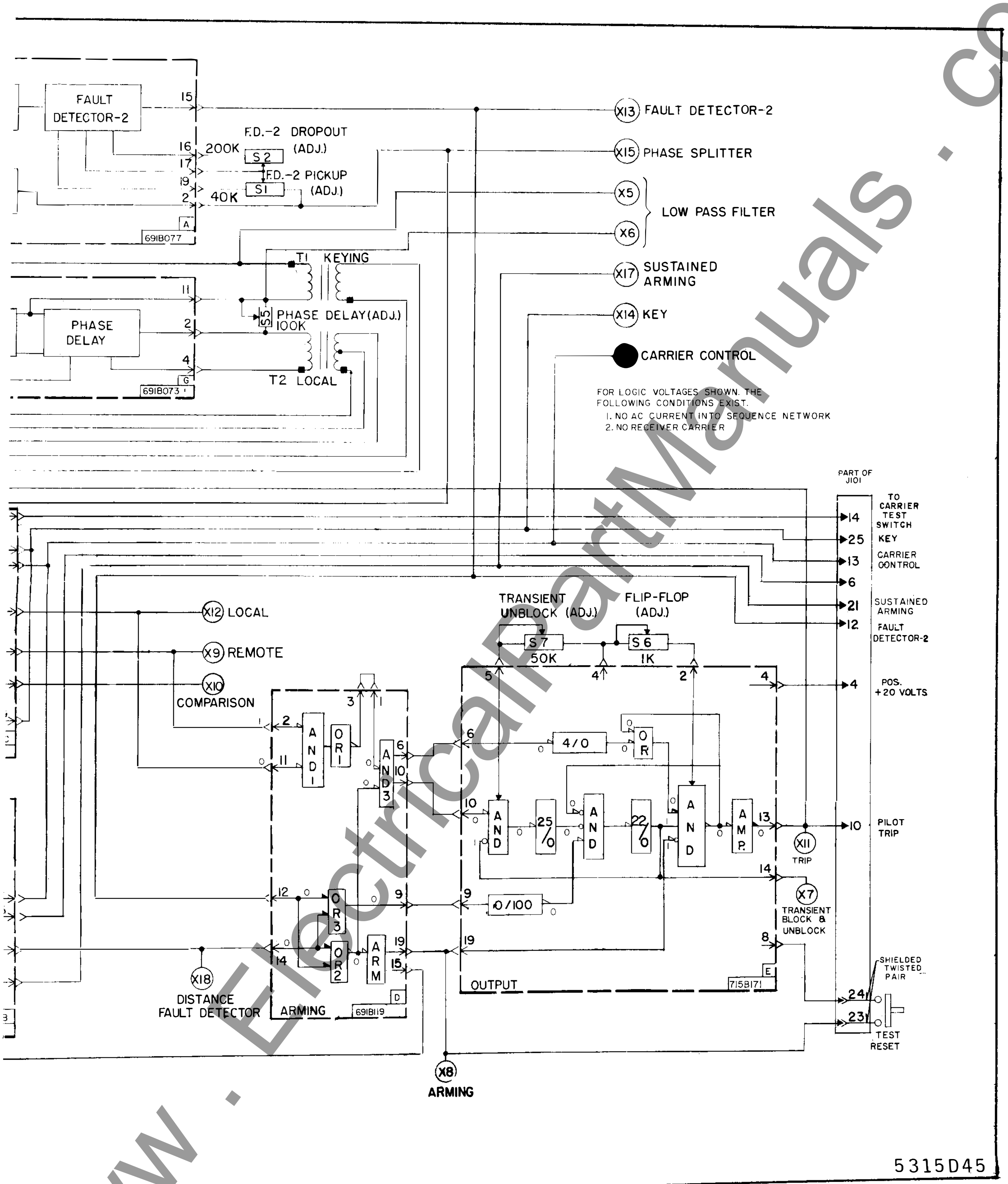


Fig. 20. Logic Diagram of SKBU-11 Relay



r Distance Phase Comparison System with Blinder Control.

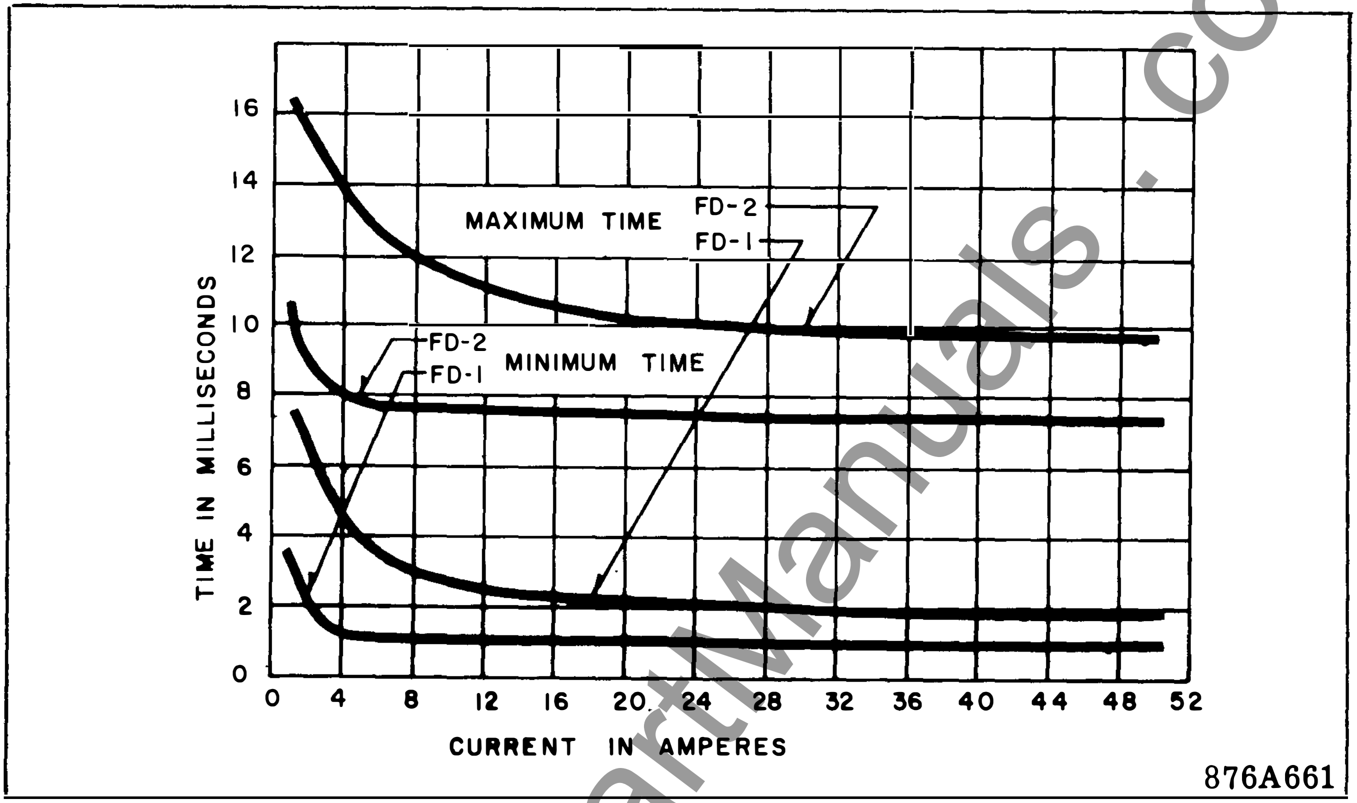


Fig. 21 Operating Times of Fault Detectors of SKBU-1 and SKBU-11 Relay

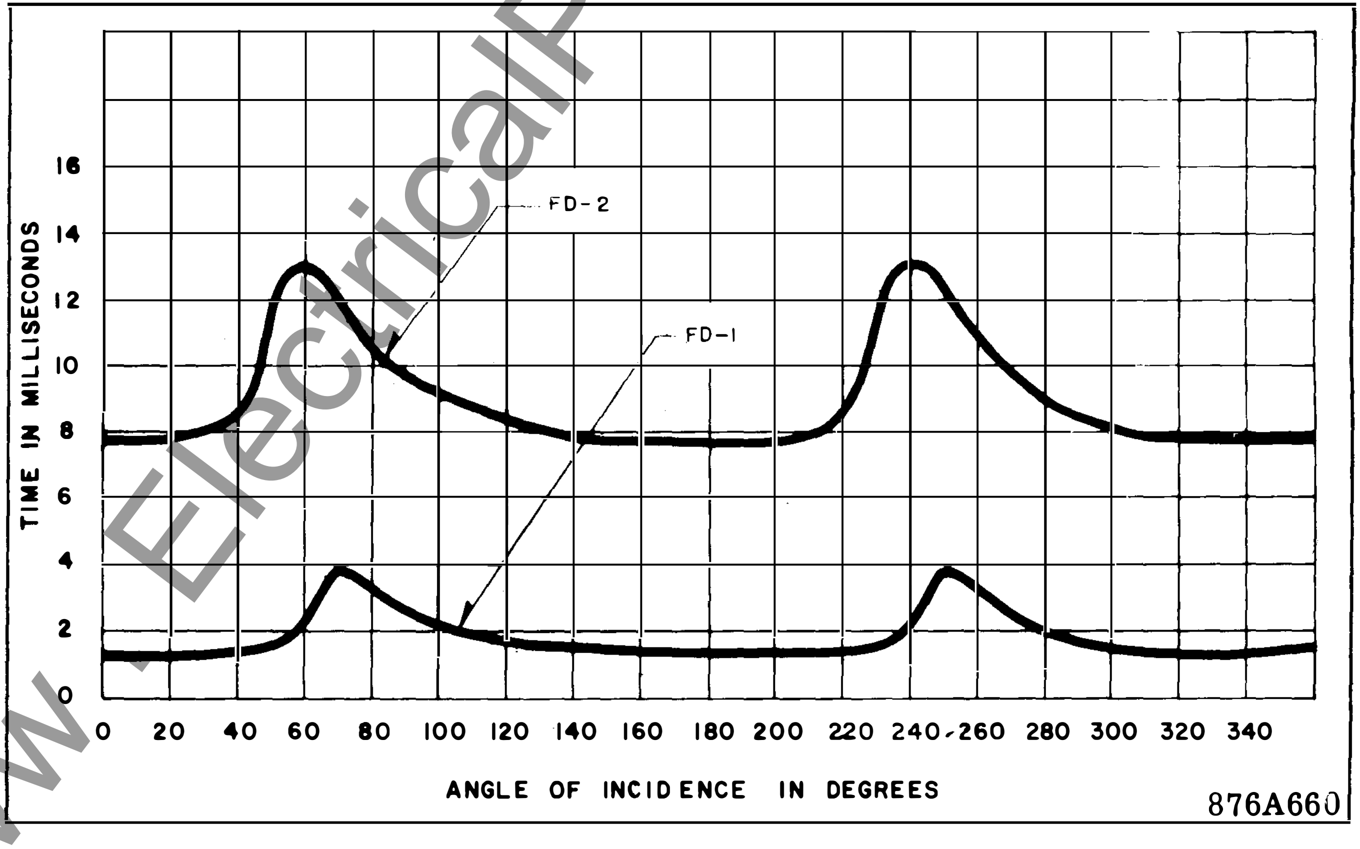


Fig. 22. Operating Time of Fault Detectors of SKBU-1 and SKBU-11 Relay as a function of Fault Incidence Angle at 5 Amperes.

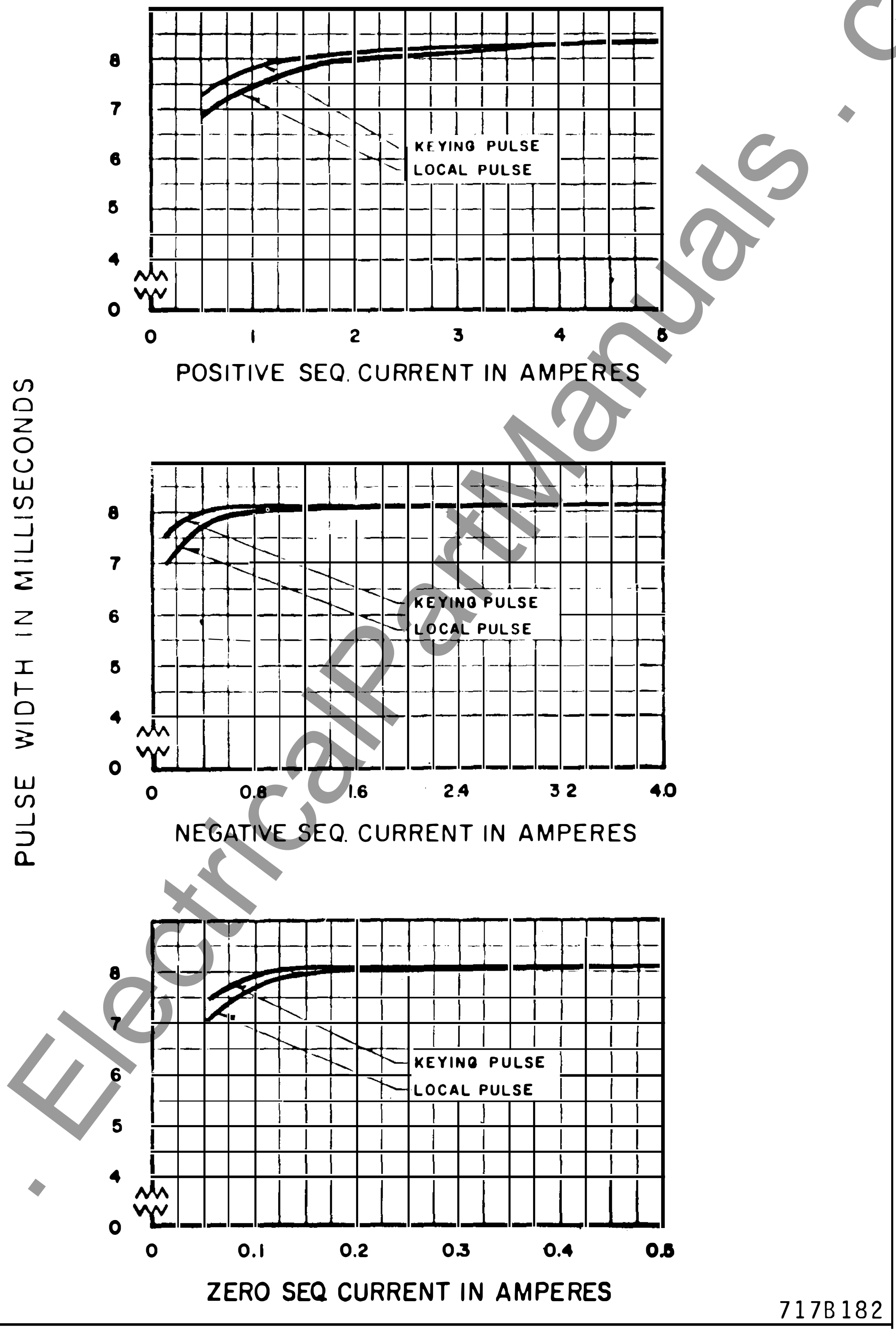


Fig. 23. Width of Keying Pulses at Different Current Levels of SKBU-11 Relay. (Phase Delay Setting S5 at minimum.)

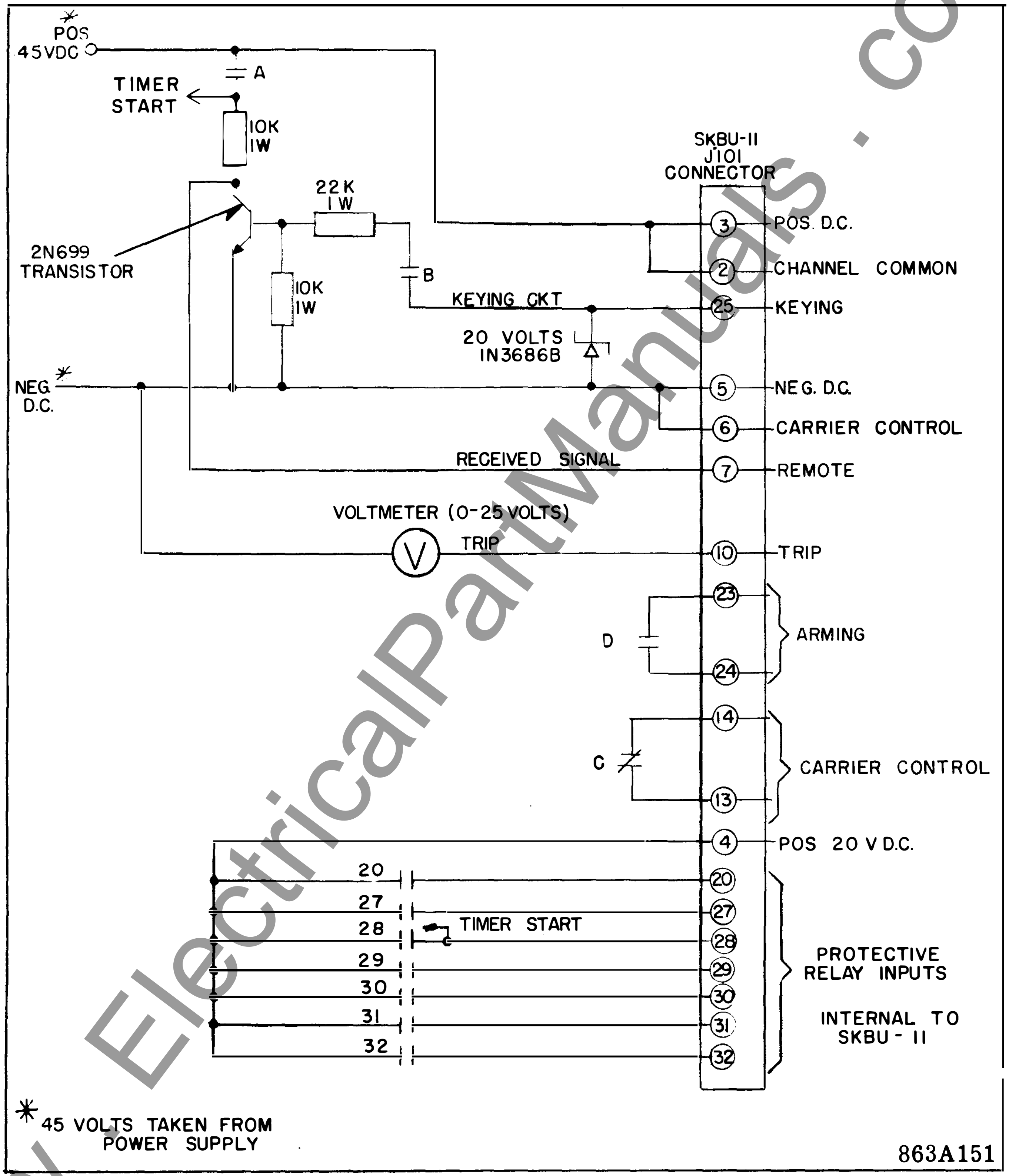


Fig. 24. Test Circuit of SKBU-1 and SKBU-11 Relays.

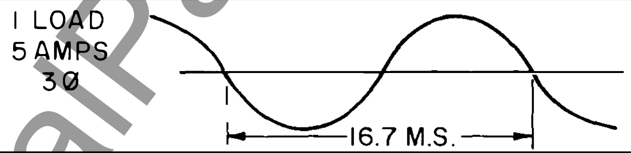
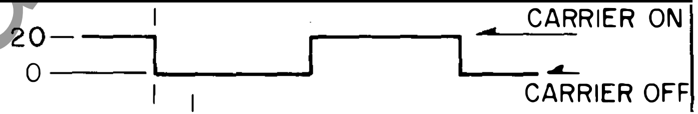
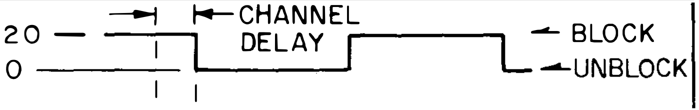
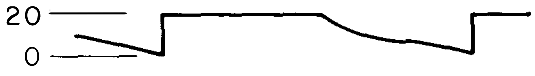
TEST POINT	CIRCUIT	VOLTAGE TO X4
X1	D.C. INPUT VOLTAGE	48 VOLTS D.C.
X2	REGULATED D.C.	20 VOLTS D.C.
X3	COMMON T.C.	45 VOLTS D.C.
X4	BATTERY NEGATIVE	———————
X7	TRANSIENT BLOCK	NORMAL 20 VOLTS OPERATE 0 VOLTS
X8	ARMING	NORMAL 20 VOLTS OPERATE 0 VOLTS
X11	PILOT TRIP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X13	FAULT DETECTOR	NORMAL 0 VOLTS OPERATE 20 VOLTS
X17	SUSTAINED ARMING	NORMAL 20 VOLTS OPERATE 0 VOLTS
X18	DISTANCE FAULT DETECTOR OPERATION	NORMAL 0 VOLTS OPERATE 20 VOLTS
X5 TO X6(GND)	LOW PASS FILTER	
X14	KEYING	
X12	LOCAL	
X9	REMOTE	
X16	CARRIER CONTROL	

Fig. 25. Test Point Voltages.

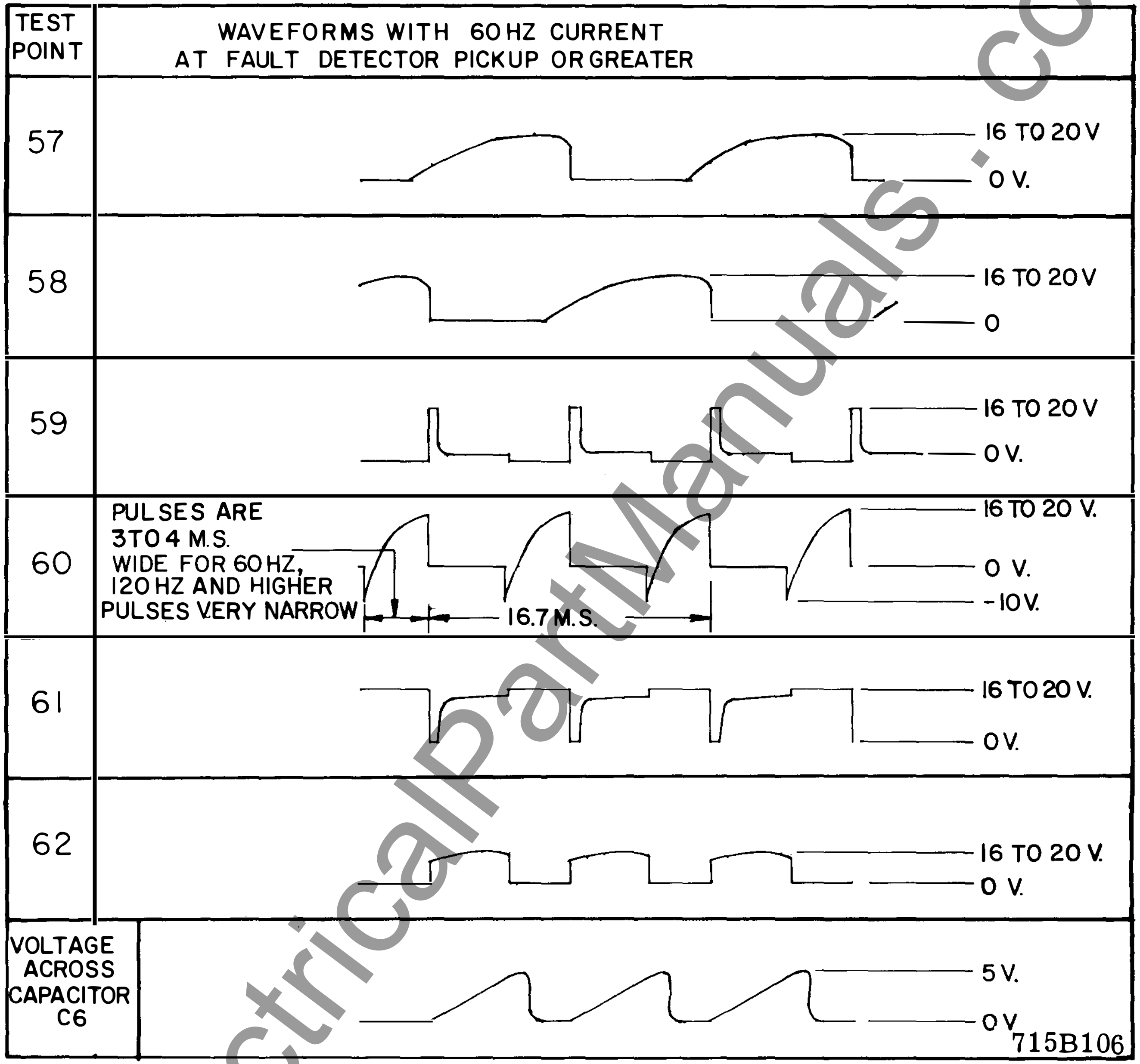


Fig. 26. Frequency Verifier Waveforms at 60 Hz.

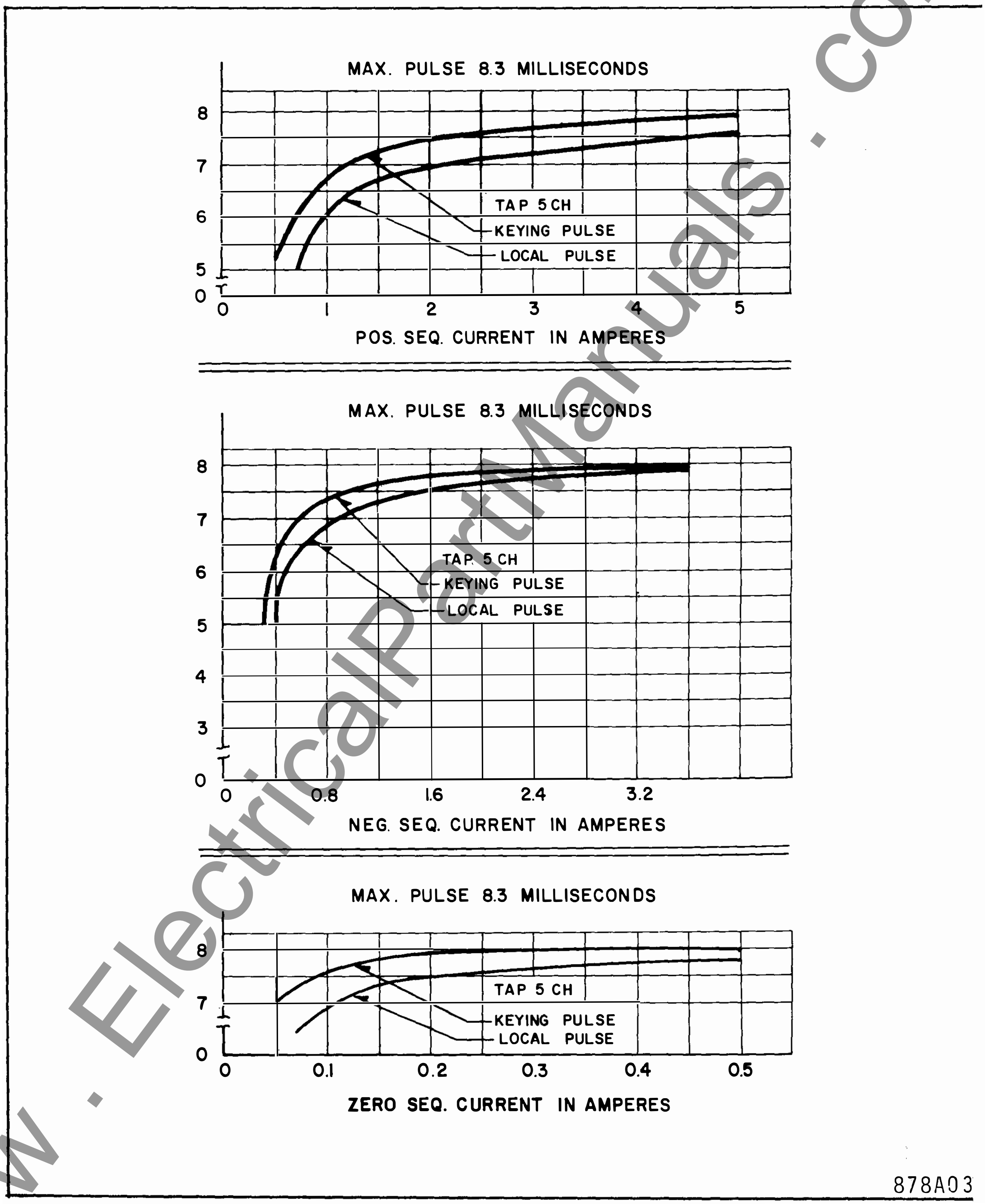


Fig. 28. Width of Keying Pulses at Different Current Levels of SKBU-1 Relay

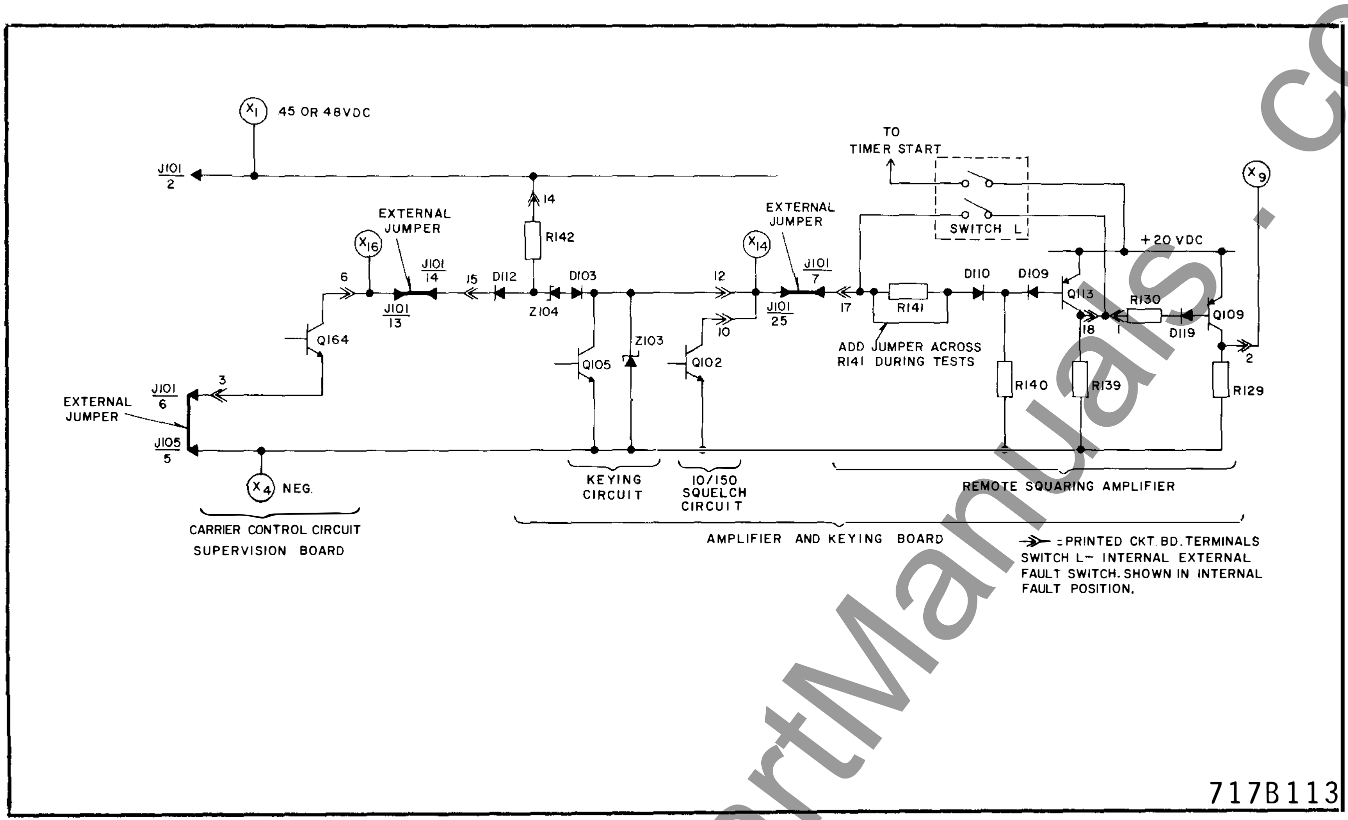


Fig. 29. Inter Connection Diagram of Test Connections to Obtain Remote Pulses from Keying Circuit

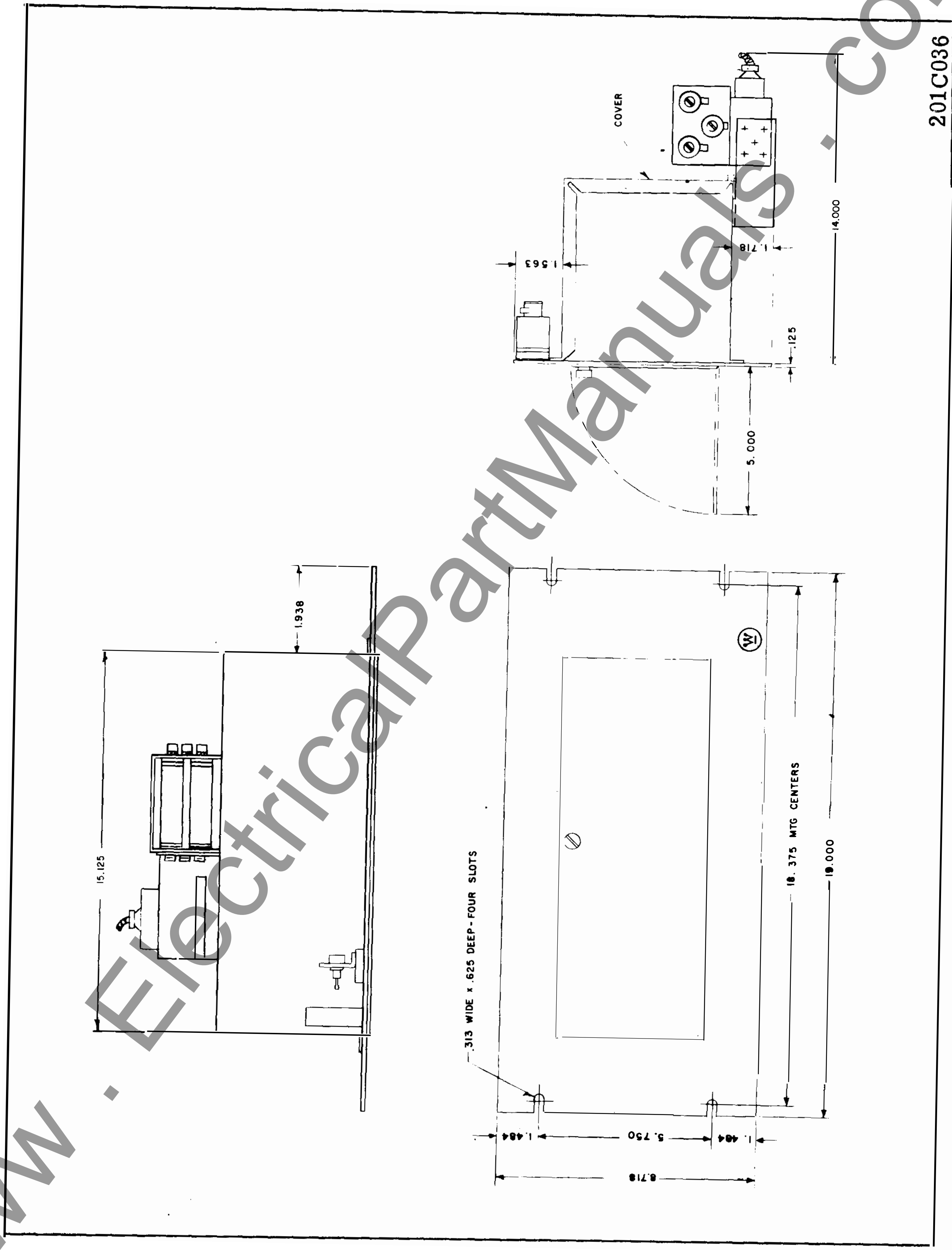


Fig. 30. Outline for Type SKBU-11 Relay

WESTINGHOUSE ELECTRIC CORPORATION
RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**
Printed in U.S.A.

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU-11 PHASE COMPARISON RELAY FOR TC CARRIER CHANNEL

CAUTION: It is recommended that the user of this equipment become acquainted with the information in either this instruction leaflet or the system instruction leaflet before energizing the relay system. If the SKBU-11 relay is mounted in a cabinet, the cabinet must be bolted down to the floor or otherwise secured before swinging out the equipment rack to prevent its tripping over.

APPLICATION

The type SKBU-11 relay is a high speed carrier relay used in conjunction with a type TC power line carrier set to provide complete phase and ground fault protection of a two terminal transmission line. Simultaneous tripping of the relays at each line terminal is obtained in less than twenty-five milliseconds for all internal faults within the limits of the relay settings. The relay operates on line current only, and no source of a-c line potential is required. Consequently, the relays will not trip during a swing or out-of-step conditions. The carrier equipment operates directly from the station battery.

CONSTRUCTION

The type SKBU-11 relay consists of a composite positive and negative sequence current network, two mixing transformers, three isolating transformers, a 20-volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel, 8¾ inches high (5 rack units). Edge slots are provided for mounting the rack on a standard relay rack.

Sequence Network

The sequence filter consists of a three-legged iron core reactor and a resistor. The reactor is a four-winding reactor with two primary windings and two secondary windings. The secondary windings are connected to the resistor which consists of three tube resistors and a small formed resistor. One secondary winding and the resistor is a negative sequence current filter while the other secondary winding and the resistor is a positive sequence filter.

Mixing Transformer

The voltage from the sequence network is fed into two mixing transformers. One transformer supplies the fault detector circuit and the other transformer supplies the keying circuit. These transformers and Zener clippers (mounted on printed circuit boards) connected across their secondary are used to limit the voltage impressed on the solid-state circuits, thus providing a small range of voltage for a large variation of maximum to minimum fault currents. This provides high operating energy for light fault, and limits the operating energy for heavy faults to a reasonable value.

Isolating Transformer

Three isolating transformers are provided in the relay to isolate the D.C. voltages from the A.C. voltages. Two of the transformers are also used to energize solid-state circuit on alternate half-cycle of the power system frequency.

Power Supply

The solid-state circuits of the SKBU-11 are regulated from a 20-volt supply on the relay panel. This voltage is taken from a Zener diode mounted on a heat sink. A voltage dropping resistor is provided between the source D.C. supply and the 20-volt regulated supply.

Printed Circuit Boards

Seven printed circuit boards are used in the SKBU-11 relay: A fault detector board, protective relay interface board, supervision board, amplifier and keying board, arming board, output board, and a relay board. The circuits of the protective relay board vary with the relaying system.

All of the circuitry that is suitable for mounting on printed boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide in position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment, it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

1. Fault Detector Board

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, a solid state fault detector, and a frequency verifier circuit. The controls for setting pickup (S1) and dropout (S2) of the fault detector are mounted on a plate in the front of the assembly. This unit operates when the fault current exceeds a definite value.

The location of components on the board is shown in Fig. 3 and the schematic of the board is shown in Fig. 4.

2. Arming Board

The arming board connects the outputs of the supervision board and the fault detector board to the final output of the relay. This board contains logic circuits that will arm the trip output, set up the time delay of the trip output, and start transient blocking on external faults.

The location of components on the board is shown in Fig. 5 and the schematic of the board is shown in Fig. 6.

3. Amplifier and Keying Board

The amplifier and keying board contains a local squaring amplifier, a transmitter keying circuit, a remote squaring amplifier, and a signal squelch circuit for each line terminal. The amplifier circuits produce the pulses that are compared by the AND circuit of the arming board to determine if the fault is external or internal.

The location of components on the board is shown in figure 7, and the schematic of the board is shown in Fig. 8.

4. Output Board

The output board contains a 4-millisecond pickup instantaneous dropout timer circuit, trip "AND" (flip-flop circuit), trip amplifier, transient blocking and unblocking circuits. The trip AND operates when all the inputs to the AND inputs of the arming board are of the correct polarity and the fault detector has operated. The transient blocking circuit operates after a time delay on external faults, and the transient unblock circuit operates after a time delay on a sequential fault (external fault followed by an internal fault). The following figures apply to this board: Fig. 9 Component Location; Fig. 10 Schematic of the Board.

5. Relay Board

The relay board contains the phase delay circuit for shifting the local signals with reference to the remote signals. It also contains a low-pass filter, and a Zener clipper-resistor combination for protection of the solid-state circuits on the relay board.

The following figures apply to this board: Fig. 11 Component Location, and Fig. 12 for the schematic of the board.

6. Supervision Board

The supervision board contains a 8/0 timer for distance fault detector operation, a 2.5 second alarm circuit for an arming operation, a fault detector (FD1) and a carrier control circuit. The circuits on this board are utilized to start carrier, to alarm an arming operation, and to delay arming for distance fault detector operation.

Fig. 13 shows the component location for this board and Fig. 14 shows the schematic of the board.

7. Protective Relay Board

The protective relay board contains logic circuits to connect the distance fault detectors, and squelch relays into the phase comparison portion of the relaying system. This board contains AND circuits, buffer circuits, and OR circuits to connect the relays into the system.

Fig. 15 shows the component location for the board. Fig. 16 and 17 shows the schematic of the board.

Card Extender

A card extender (Style No. 644B315G02) is available for facilitating circuit voltage measurements or major adjustments. After withdrawing anyone of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all components and test points on the boards are readily accessible.

Test Points

Test points are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front panel of the relay for convenience in adjusting and testing the relay.

OPERATION

A. System

The SKBU-11 carrier relaying system compares the phase position of the currents at the ends of a line section over a carrier channel to determine whether an internal or external fault exists on the line section. The three-phase line currents energize a sequence network which produces two single-phase output voltages which are proportional to either the positive sequence current or the negative sequence current. The single phase voltages are applied to saturating transformers one of which energizes the fault detector (FD^2) circuit and the other energizes the keying circuit of the SKBU-11 relay. This circuit allows the transmission of carrier on alternate half-cycles of the power frequency current. Carrier is transmitted from both line terminals and is received at the opposite ends where it is compared with the phase position of the local sequence network output. If the local and remote half-cycle pulses are of the correct phase position for an internal fault, after a 4 millisecond delay during the half-cycle in which carrier is not transmitted, tripping will be initiated through operation of the trip "AND" and trip amplifier circuits.

Current transformer connections to the sequence networks at the two line terminals are such that carrier is transmitted on the same half-cycles from both terminals during an internal fault to allow tripping during the half-cycle that carrier is not transmitted. However, if the fault is external to the protected line section, carrier is transmitted on alternate half-cycles from opposite terminals. Thus each terminal blocks the opposite terminal during the half-cycle when it is attempting to trip.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals, relay coordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

Since this relaying system operates only during a fault, the carrier channel is available at all other times for the transmission of other functions.

B. Relay

With reference to the logic diagram that applies to the particular relay, the three-phase line currents energize a sequence filter that produces two single-phase voltages: One voltage proportional to the positive sequence current, and the other voltage proportional to the negative sequence current. These voltages are applied to two mixing transformers which have zero windings on them. The output of the two transformers are applied to two separate boards:

1. Output from one transformer to the fault detector board.

2. Output from the second transformer to the relay board.

1. Fault Detector Board

With reference to the schematic Dwg. of Fig. 4, the A.C. voltage from one mixing transformer is applied to a phase-splitting network (C52, R52, R53) and a polyphase rectifier (diodes D51 to D56). The D.C. voltages so obtained are applied to the fault detector circuit which operates when the D.C. input "signal" exceeds a predetermined value.

Fault Detector 2 (FD-2)

Under normal conditions, transistor Q51, has no base "signal" and is turned off. The collector of Q51 is at a high enough positive potential to provide base drive for transistor Q52, driving it to full conduction. With Q52 fully conducting there is no base drive to transistor Q53 and Q53 is turned off. With no Q53 collector current, the base of transistor Q54 is supplied from the 20-volt source. Thus the Q54 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q54 in a non-conducting state, equivalent to an open circuit.

When a fault causes the D.C. input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z52, a posibias is applied to Q51 base causing it to conduct. In turn, Q52 stops conducting, and capacitor C54 charges, giving a few milliseconds time delay before Q53 and Q54 are switched to full conduction, thus "closing" the fault detector. When the fault detector operates, a positive input is applied to the arming board at terminal 12. Resistors R66 and S2 increase the voltage to Z52 to allow the fault detector to drop out at a high drop-out ratio when the A.C. current is reduced.

Frequency Verifier

During certain switching conditions, such as energization of a transmission line, residual currents and voltages may exist of higher frequencies than 60 cycles per second. The frequency verifier prevents fault detector operation when frequencies 120 cycles or higher are encountered during the switching conditions. The frequency verifier circuit consists of two functional parts: Zero-crossing circuit consists of Q55, Q56, Q57, and Q58. The commutator circuit consists of Q59, Q60, C9, C59 and Q61.

During the positive or negative half-cycles of the output voltage from the saturating transformer, Q55 or Q57 transistors are driven into saturation by the output of the FV transformer. Transistors Q56 or Q58 conduct until capacitors C56 or C57 respectively are fully charged. While either capacitor charges a voltage output in the form of very narrow pulse is developed across R76 and R78 resistors during the start of each half-cycle. This pulse triggers Q59 control switch. When transistors Q55 or Q57 are not conducting, C56 and C57 capacitors discharge respectively through D66 or D62 and the parallel combination of R73 and R74 or R69 and R70.

While Q59 is "on" its anode is only about 0.7 volts above negative, thus turning off transistor Q62 to allow capacitor C60 to start charging. However, a shorter time delay (consisting of R84, the capacitor C59 and the reference Zener diode Z54) of 4.3 milliseconds is also started. After 4.3 milliseconds of delay, the control switch Q60 fires applying the voltage of capacitor C88 across Q59 turning it off. This raises the potential of the Q59 anode to turn on Q62 to discharge C60 before the charge reaches a value to break down Z55 to turn on Q63. After the next zero-crossing pulse Q59 switch is turned on again, and the Q60 switch is turned off by capacitor C58. Transistor Q61 when turned on by the same voltage that fires the gate of Q59, discharges timing capacitor C59, thus starting the timing cycle with close to zero charge on the capacitor. If the zero crossing period of the FV voltage is less than 4.3 milliseconds, the Q61 transistor discharges the timing capacitor thus preventing the turning off of Q60 switch. This keeps Q59 switch on to allow C60 to charge to a value to break over Zener diode Z55 to turn on Q63. Turning Q63 prevents Q53 of the fault detector from turning on thereby preventing Q54 from turning on to prevent an output from the fault detector.

2. Relay Board

With reference to Fig. 12, the A.C. voltage from the second mixing transformer is applied to the phase delay circuit through a low pass filter (C201, L201, C202) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R202 and R203 of the phase delay circuit. By means of capacitor C203 and variable resistor S5, the voltage across terminal 4 and 2 can be made to lag the voltage across terminal 10 and 11 by a definite amount depending on the setting of S5. Each of these two voltages are applied to separate isolating transformers.

1. Undelayed voltages to a keying transformer (T1)
2. Delayed voltages to a local transformer (T2)

A. Keying Circuit

With no A.C. output (Ref. Fig. 8) voltage from the sequence network, base current does not flow into transistor Q103. The collector of Q103 is at positive potential which allows base current to flow from positive 20 volts D.C. through the base of Q104 through R111 and R112 to negative. This applies negative potential to the collector of Q104 to prevent base current from flowing to Q105. Since Q104 is conducting, transistor Q105 does not conduct and the collector of Q105 is held at positive potential.

When a sinusoidal voltage is applied to the keying transformer (T1), the transformer steps up the voltage applied to terminals 9 and 8 of the amplifier and keying board. On the positive half-cycle of voltage, terminal 8 is more negative than terminal 9 and transistor Q103 does not conduct. In turn Q104 remains conducting and Q105 does not turn on. On the negative half-cycle of sine wave voltage from the keying transformer, terminal 9 is more positive than terminal 8 and base current flows in Q103. This turns Q103 on which applies negative potential to the collector of Q103. Base current to transistor Q104 is stopped and Q104 stops conducting, and its collector goes to positive potential. Positive potential is thus applied to the base of Q105 through R114 and R115 to turn on Q105. When Q105 conducts, its collector is connected to negative potential. Thus on alternate half-cycles of the 60-cycle voltage from the low pass filter, Q105 turns on. If the carrier control circuit operates, as seen in Fig. 18, turning Q105 on and off every half cycle, shorts the input to the TC carrier set every other half cycle so that carrier is transmitted on the half cycle when Q105 is not conducting.

B. Local Squaring Amplifier

The shifted voltage from the local transformer (T2) is applied to the local squaring amplifier and a loading circuit on the amplifier and keying board of the SKBU-11 relay. With reference to the local squaring amplifier of Fig. 8 with no A.C. input voltage, Q106 is not conducting and the collector of Q106 is at positive potential. This applies base current to transistor Q107 through R120 and R121 such that Q107 is turned on. This applies negative potential to the collector of Q107 to allow base current to flow in Q108. Q108 turns on to apply positive potential across R125.

With the application of a sine wave voltage to terminal 6 and 19 of the amplifier and keying board, on the positive half-cycle of the voltage, the base of transistor Q106 is more positive than the emitter and Q106 (amplifier 1) conducts. On the negative half-cycle of the a.c. voltage, Q106 is turned off and current flows into the loading circuit. Therefore, Q106 is conducting on the positive half-cycle of A.C. voltage. Turning Q106 on, puts negative potential on the collector of Q106 and turns off transistor Q107. Transistor Q107 stops conducting and its potential goes to a positive potential which turns off Q108 to place its collector at a negative potential. Thus the output of the squaring amplifiers square wave voltages ranging from 0 volts D.C. to 20 volts D.C. depending upon the polarity of the voltage from the phase delay circuit.

C. Remote Squaring Amplifier

Under non-fault conditions, carrier is not transmitted from the remote carrier set. As a result the base of Q113 is more negative than its emitter, and Q113 conducts. This applies positive 20 volts to the base of Q109 to prevent it from turning on. Hence, Q109 is not conducting and negative voltage appears across R129.

Under fault conditions, the remote TC carrier set is keyed on and off as described under the Keying Circuit. This signal is received at the local TC carrier receiver and is converted to a square wave voltage varying in magnitude from 45 volts to 0 volt. This voltage is applied to the base of Q113 through D110 and R141. Upon application of positive 45 volts d-c to the base of Q113, the potential of the base is greater than that of the emitter and Q113 stops conducting. This removes positive potential from R139 and allows the base of Q109 to become negative with respect to the emitter. Q109 turns on to apply positive voltage to R129. Hence, the voltage across R129 is a square wave voltage that is developed by the voltage received from the TC receiver.

3. Arming Board

The phase relationship of the outputs of the local and remote squaring amplifiers are compared by an AND circuit of the Arming Board. If the local and remote signals are out of phase with respect to each other, the AND circuit will provide one input to AND number 3 which will activate the 4/0 timer.

A. Internal Fault Conditions

With reference to the logic drawing that applies to the relay, the output voltages from one terminal of the sequence filter is 180 degrees out-of-phase with respect to its load current condition. This changes the polarity of Amplifier #1 such that its output is in phase with the remote signal. This means that the AND has a half-cycle of negative voltage. The negative voltage is applied to AND 3 of the arming board. One condition for activating this AND is thereby set up – negative voltage from AND circuit. The second condition to activate the AND is provided by arming the SKBU-11.

In either Fig. 19 or 20, arming occurs through either the operation of the distance fault detectors or the operation of the SKBU -11 fault detector (FD2). The operation of either fault detector will apply a voltage to the ARM logic of the arming board. The output voltage from the ARM logic removes negative potential from the trip AND applies a negative signal into AND 3 of the arming board. AND 3 is activated and starts the 4/0 timer. Four milliseconds later, a negative input is applied to the trip AND of the output board. Since the three conditions of trip (a negative input from the 4/0 timer, not a negative input from the ARM logic, and not a negative signal from the 18/0 timer) is fulfilled, a trip output is obtained from the SKBU-11 relay.

B. External Fault

Under external fault conditions, the square wave voltage from the remote squaring amplifier and the square wave voltage from the from the local squaring amplifier are out-of-phase such that zero input is being received on the AND circuit of the arming board. As a result, the output of the AND circuit are zero, and AND 3 cannot be activated. This blocks AND 3 and the 4/0 timer is not energized.

With fault detector operation, an input is applied to the ARM logic of the arming board. A positive input will be applied to the trip AND but tripping will not occur since the 4/0 timer is not providing a negative input to the Trip AND. Operation of the fault detector will provide an input to a 1/100 timer on the Output Board. The timer negates the signal to provide a negative input to the transient block AND. With the application of the input from the 0/100 timer the three conditions of transient block are fulfilled – not a negative voltage from the Transient UNBLOCK Circuit; and a negative input from the 0/100 timer. Eighteen milliseconds later the 18/0 timer of the transient block circuit times out to provide a negative input to the TRIP AND. The TRIP AND is thus desensitized to prevent undesirable operation during transients associated with power reversals on the protective line or at the clearing of an external fault.

C. Sequential Faults

If the above external fault is followed by an internal fault before the external fault is cleared, the transient unblock circuit is set up to remove the transient blocking input to the TRIP AND. For the internal fault, the square wave pulses on the AND circuit of the arming board will reverse such that a square-wave output is obtained from the AND circuit. On the negative half cycle this output energizes AND 3 which negates the signal to a negative signal. The negative signal....

1. Provides an input to the 4/0 timer which times out to apply a negative input to the TRIP AND.
2. Applies a square wave input every other half cycle to the AND of the transient unblock circuit to 'fulfill the requirements to obtain an output from the transient unblock circuit on every other half cycle.

As a result, a negative input is applied to the unblock timer every other half cycle. Twenty-five milliseconds later, capacitor C301 will charge such that the unblock timer will operate on the negative to remove the negative voltage from the block AND circuit. This resets the 18/0 block timer, and removes the negative input to the AND of the unblock timer to reset the unblock. The required three inputs are thus applied to the trip AND and a trip output is obtained from the SKBU-11 relay.

D. Protective Relay Operation

The SKBU-21 relay is armed by the distance fault detectors through a 8/0 timer on the supervision board. The operation of the distance fault detectors applies negative potential to terminal 16 of the supervision board. This removes current to transistor Q157 and allows C151 to charge. Six milliseconds later the voltage on C157 reaches the breakdown of Zener diode, Z151, and base current flows into transistor Q152 to turn Q152 on. This turns on Q153 to apply a positive potential to terminal 14 of the arming board.

4. Supervision Board

The circuits on the supervision board include the auxiliary functions of the SKBU-11 relay, and they include a detector (FD-1), carrier control circuit and timer circuit.

A. Fault Detector 1 (FD-1)

Under normal conditions, transistor Q161, has no base "signal" and is turned off. The collector of Q161 is at positive potential and no collector current flows. With no Q161 collector current flows. With no Q161 collector current, the base of transistor Q162 is supplied from the 20-volt source. Thus the Q162 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q162 in a non-conducting state, equivalent to an open circuit.

When a fault causes the D.C. input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z156, a positive bias is applied to Q161 base causing it to conduct. In turn, Q162 is switched to full conduction, thus "closing" the fault detector. When the fault detector operates, a positive output is applied to the carrier control circuit. Resistors R191 and S2 increase the voltage to Z156 to allow the fault detector to drop out at a high dropout ratio when the A.C. current is reduced.

B. Carrier Control Circuit

Under normal conditions Q163 is not conducting and base drive is supplied to Q164. As shown in Fig. 18, the emitter of Q164 is connected to negative D.C. The collector of Q174 is connected to positive 45 volts D.C. of the TC set through R142 of the amplifier and keying board. Normally Q164 is conducting. When either FD1 or the distance fault detector operate, base drive is supplied to Q163. Q163 turns on and shorts the base of Q164 to negative. Q164 turns off to raise the potential of point A of Fig. 18. This starts the transmission of carrier.

C. Arming Delay By Distance Fault Detectors (8/0 Timer)

The distance supervision arming is delayed by 8 milliseconds to allow time for the AND of the arming board to respond at fault inception. Operation of the distance fault detectors will apply negative potential to terminal 16 of the supervision board. This removes the base current to transistor Q151. Q151 turns off once positive potential is applied to capacitor C151. Eight milliseconds later the voltage on C151 reaches a value to break down Zener diode Z151. This turns on Q152, which connects the base of Q153 to negative through resistor, R158. Q153 turns on to apply positive potential to resistor, R160 and terminal 13. From terminal 13 the voltage is applied to the arming board.

CHARACTERISTICS

Taps are available in the SKBU-11 relay to set different sensitivities of the fault detector (FD-1) to zero and negative sequence currents. These taps are as follows:

NEGATIVE SEQUENCE TAPS (I_2)

Tap Setting	Negative Sequence Sensitivity
A	None
B	0.4 Amperes
C	0.25 Amperes

ZERO SEQUENCE TAPS (I_0)

Tap Setting	Zero Sequence Sensitivity
F	None
G	0.2 Amperes
H	0.1 Amperes

The second fault detector unit (FD-2) which supervises arming is adjusted to pick up at a current 25 per cent greater than FD-1. By means of the S_1 adjustment the pick up of FD-2 can be increased to 100 per cent greater than FD-1.

The positive sequence response of the fault detector is greater than 7 amperes.

The operating time of the fault detectors is shown in Fig. 21. As shown in the figure, the operating curve has a maximum and minimum value. This is due to the point on the current wave that fault current is applied. Figure 22 shows the operating times for different points on the fault wave for fault wave for fault current at five amperes.

The keying response of the SKBU-11 relay is independent of the tap setting. Figure 23 shows typical lengths of keying pulses with reference to a 60-cycle base of the SKBU-11 relay for different values of positive, negative, and zero sequence current.

Typical logic drawings are shown in Fig. 19 and in Fig. 20.

Operating Time:	15 to 32 Milliseconds
Alarm Time:	2.5 Seconds for FD Operation
Transient Block Time:	18 to 20 Milliseconds
Transient Unblock Time:	22 to 28 Milliseconds
Ambient Temperature Range:	−20°C to 55°C
D.C. Drain:	0.14 Amps. at 48 Volts D.C.
Reset Time of Transient Block:	1. After Fault Detector has operated: 100 Milliseconds 2. When Unblock time is Utilized: Instantaneous

ENERGY REQUIREMENTS

Burdens at balanced three-phase current of five amperes. (Independent of tap setting).

Phase A		Phase B		Phase C	
VA	Angle	VA	Angle	VA	Angle
8.3	106°	2.2	50°	46	0°

Burden at five amperes (single-phase to neutral current).

	Phase A		Phase B		Phase C	
Relay Taps	VA	Angle	VA	Angle	VA	Angle
C-H	11.7	2.1°	9.7	1.8°	44.0	2.2°
B-H	11.4	2.1°	10.3	1.8°	46.0	2.2°
A-H	11.1	2.0°	11.2	1.8°	48.0	2.2°
C-G	8.8	2.0°	7.0	1.8°	42.0	2.2°
B-G	8.7	2.0°	7.5	1.8°	43.5	2.2°
A-G	7.8	2.0°	8.5	1.8°	45.0	2.2°
C-F	6.7	2.0°	7.5	1.8°	42.0	2.2°
B-F	6.5	2.0°	7.2	1.8°	42.0	2.2°
A-F	5.8	2.0°	6.6	1.8°	43.0	2.2°

The angles above are the degrees by which the current lags its respective voltage.

SETTINGS

The SKBU-11 relay has separate tap plates for adjustment of the zero and negative sequence sensitivity of fault detector (FD1). The tap markings and pickup for FD-1 are:

Negative Sequence Sensitivity (I_2)

A. None
B. 0.4 Amperes
C. 0.25 Amperes

Zero Sequence Sensitivity (I_0)

F. None
G. 0.2 Amperes
H. 0.1 Amperes

Two tap plates are provided: one for I_2 and the other for I_0.

Tap A should not be used in service since this would prevent fault detector operation for phase-to-phase faults. However, tap F may be used with either B or C since negative sequence current flows for both phase-to-phase and ground faults.

The recommended settings are tap B or C as needed for the required sensitivity, and tap F. Taps

G and H have been provided for applications where the negative-sequence load flow due to series impedance unbalance may be high enough to operate FD-1 with a tap C setting. In this case set in tap B and in tap G or H. It is not intended that taps C and H be used simultaneously due to the possibility of cancellation of the negative-and zero-sequence effects on ground faults. With a tap B setting, a tap H setting is preferred.

To summarize, the recommended setting combinations in the order of preference are:

Combination	**I_2 Tap**	**I_0 Tap**
1	C	F
2	B	F
3	B	H
4	B	G

For a long two-terminal line, FD2 should be set at 200 per cent of FD-1. As shipped from factory, FD2 is set to pick up at 125 per cent of FD1.

The SKBU-11 relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The SKBU-11 relay is normally supplied as part of a relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the SKBU-11 relay is not a part of a relaying system, the following procedure can be followed to verify that the circuits of the SKBU-11 are functioning properly.

◆ TEST EQUIPMENT

1. Oscilloscope
2. A.C. Current Source
3. Electronic Timer ≁
4. A.C. Voltmeter
5. D.C. Voltmeter

≁ Scope may be used for timing, by connecting scope probe to timer stop points, and external trigger of scope to timer start.

ACCEPTENCE TEST

Connect the relay to the test circuit of Fig. 24 which represents the carrier channel for test purposes.

Open all test switches of the test circuit and connect a 60-cycle test current between terminals 3 and 5 of the relay. Connect terminal 2, 4, 6 and 8 of the terminal block together. Set taps I_2-C and I_0-H.

1. Filter Output

a. Connect a high resistance a-c voltmeter across X6 and X5 of the relay.

b. Pass 10 amperes, 60 cycles into terminal 5 and out terminal 3. Voltmeter should read 20 volts ± 5%.

2. FD-1 Pickup and Dropout

a. Set relay on taps I_2-C and I_0-H.

b. Connect a high resistance D.C. voltmeter across X_{16} and X_4 (neg.).

c. Connect a 60 cycle test current to terminal 5 3 of the relay. Gradually increase the current until the voltmeter changes reading from approximately 20 volts. This is the operating current of FD and should be 0.433 ± 5% amperes.

d. Gradually lower A.C. test current until the D.C. voltmeter drops to approximately zero volts. This is the dropout current of FD and occur at 0.35 ± 5% amperes of the pickup current.

3. FD-2 Pickup and Dropout

a. With relay set on taps $I_2 = C$, $I_0 = H$, connect a high resistance voltmeter to X_{13} and X_4 (neg.).

b. With a 60 cycle test current connected to terminal 5 and 3 of the relay, gradually increase the current until the voltmeter charges reading from approximately zero volts to approximately 20 volts. This is the operating current of FD-2 and should be 0.541 ± 5% amperes.

c. Gradually lower the A.C. test current until the D.C. voltmeter drops to approximately zero volts. This is the dropout current of FD2 and should occur at 0.485 to 50% amperes.

4. Check of Local Squaring Amplifiers

a. With all switches of test circuit open, apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the relay.

b. Place scope probe across X12 and X4 (grd). A square wave of voltage should appear across X12 and X4 as shown in Table I.

5. Check of Keying Circuit

a. With all switches of test circuit open and 0.6 to 0.8 amperes A.C. applied to terminal 3 and 5 of the relay, with scope check voltage across X14 and X4 (grd.).

b. Waveform shown in Table 1 should be observed.

6. Check of Remote Squaring Amplifiers

a. Close switches A, B, and C of test fixtures.

b. Apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the relay.

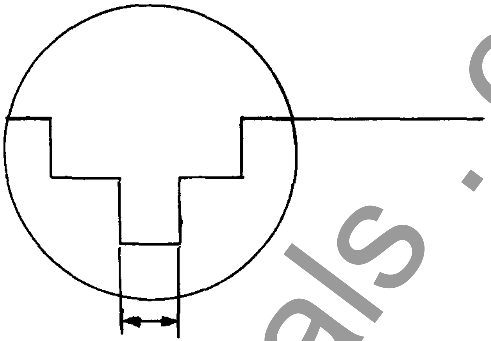
c. Using scope with grd. lead on X4, check waveshape of voltage across X9. Waveforms of Table I should be observed.

7. Setting of S5 and S6

a. Set S5 to minimum resistance and S6 to maximum resistance (fully clockwise).

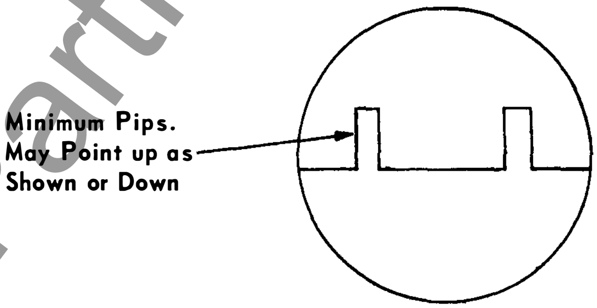
b. Close switches A, B, and C of the test circuit. Apply 0.6 to 0.8 amperes A.C. to terminals 3 and 5 of the SKBU-11 relay.

c. Connect scope across X10 and X2 (grd). Adjust S5 until following waveform appears on scope.



d. Adjust S6 until the relay trips as determined by an increase in voltage across X11 to X4 from zero to approximately 20 volts. This sets the triggering of the trip AND after a 4 millisecond delay.

e. Slowly increase S5 to obtain the following waveform. This will be with S5 at or near minimum resistance.



8. Transient Blocking Delay (18/0 and 0/100 Timer)

a. Connect electronic timer stop to X7 and X4 (grd). Set timer stop on negative going pulse.

b. Connect timer start to X18. Set timer start to positive going pulse.

c. Close switch A and switch 31. Close switch 32 and measure time for voltage to drop from 20 volts to approximately zero volts. This should be between 18 and 20 milliseconds.

d. Set timer start on a negative pulse and timer stop on a positive pulse.

e. Open switch 32, timer should start and should stop after a time delay of 80 to 132 milliseconds.

9. Check of Transient Unblocking Circuit

a. With electronic timer stop connected to X7 and X4 (grd), set timer stop on positive going pulse.

b. Connect timer start to timer start contacts of switch A. Set timer start on negative pulse.

c. Close switch A and apply 0.6 to 0.8 amperes A.C. into terminal 3 and 5 of the SKBU-11 relay.

d. Open switch A timer should start and should stop after a time delay. Time should be 22 to 28 milliseconds. Recheck approximately 10 times in order to take an average of 10 readings. To recheck time, it will be necessary to close SW-A and reset relay with SW-D. Also short between terminal 4 and TP301 on output board between reading. This assumes that C302 is completely discharged.

10. Alarm on Relay Operation (2.5 Seconds)

a. With electronic timer stop connected to X17 and X4 (grd), set timer stop on negative going pulse.

b. Connect timer start to X18. Set timer start on negative pulse.

c. Close switch 31 and then switch 32. Timer will start and should stop after 2.3 to 2.7 seconds.

11. Signal Squelch Time (10/150)

a. Connect timer stop to X14 and X4 (grd). Remove "supervise" board for tests.

b. Connect timer start to switch 28. Set timer start on positive pulse. Connect timer stop on positive pulse.

c. Close switch 28. Timer will start and will stop after a 8 to 12 millisecond delay.

d. Set timer stop on negative pulse, and timer start to negative pulse.

e. Open switch 28. Timer should start and stop after a time delay of 125 to 185 milliseconds.

12. Check of Frequency Verifier

a. Open all switches of test circuit.

b. Connect scope across TP60 and terminal 8 of the FD board.

c. Apply 0.6 to 0.8 amperes to terminal 3 and 5 of SKBU-11 relay.

d. Wave form of Fig. 26 should be observed.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram voltages of Table I should be used to isolate the circuit that is not performing correctly. The schematic of the individual board, and the voltages of Table II should then be used to isolate the faulty component.

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give the circuit symbol and the electrical value (ohms, mfd, etc.) and component style number.

TABLE II

VOLTAGE MEASUREMENTS ON PRINTED CIRCUIT BOARDS

FAULT DETECTOR BOARD

Test Point	$I_{a.c.} = 0$	$I_{a.c.}$ = Pickup of FD
54	6.5 V. d.c.	less than 1
55	less than 1	4.5 V. d.c.
56	less than 1	18 to 20 V. d.c.
Term. 2	less than 1	8.6 V. d.c.
51-52	0	7.4 volts a.c. (Approx.)
52-53	0	7.5 volts a.c. (Approx.)
53-51	0	7.4 volts a.c. (Approx.)
Term. 5-6	0	15 volts a.c. (Approx.)
TP 57	18 volts	
TP 58	18 volts	
TP 59	less than 1	Pulses See Table III For Waveform
TP 60	20 volts	
TP 61	18 volts	
TP 62	less than 1	

SUPERVISION BOARD

Test Point	Normal Condition	Abnormal Condition
Term. 16	12	less than 1 with DFD Operation
TP151	less than 1	7 with DFD Operation
TP152	20	less than 1 with DFD Operation
Term. 13	less than 1	20
Term. 18	less than 1	15 with arming
TP153	15	less than 1 with arming
TP154	less than 1	20 with arming
Term. 19	20	less than 1 with arming
Term. 10	less than 1	6.8 volts d.c.
TP158	20	less than 1
Term. 1	less than 1	20
Term. 159	6	20
Term. 6	less than 1	20

AMPLIFIER AND KEYING

Test Point	Normal ($I_{a.c.} = 0$)	Serviceable Channel
		Abnormal or I_{AC} = Pickup of FD
Term. 7	18	less than 1 breaker failure on trip
TP101	less than 1	8.5 breaker failure on trip
Term. 10	less than 1	less than 1 breaker failure on trip
TP102	5 Vdc	4.3 V pulses
Term. 13	less than 1	⌿ 6 volt pulses
Term. 12	48 Vdc	⌿ 48 volt pulses

AMPLIFIER AND KEYING (Continued)

Test Point	Normal ($I_{a.c.} = 0$)	Serviceable Channel
		Abnormal or I_{AC} = Pickup of FD
TP103	5 Vdc	5 volt pulses
TP104	less than 1	16 volt pulses
Term. 11	20 Vdc	20 volt pulses
Term. 2	20 V pulses	200 with loss of channel
TP105	5 Vdc	5 volt pulses
TP106	less than 1	16 volt pulses
Term. 16	20 Vdc	20 volt pulses
Term. 18	20 volt pulses	20 with loss of channel

⌿ Non-squelch condition

ARMING BOARD

Test Point	Normal	Internal Fault	Loss of Channel
TP251	⌿ less than 1	10 V pulses	less than 1
TP252	⌿ less than 1	10 V pulses	less than 1
Term. 3	⌿ 10 volts	⌿ less than 1	10 volts
TP254	⌿ less than 1	17 volts D.C.	less than 1
TP255	⌿ 20 volts	# less than 1	20 volts
TP256	6.5 volts	less than 1	when armed
Term. 19	less than 1	18 volts	when armed

⌿ Very narrow pulses would be observed on scope.

20volts pulses with signal squelch from remote terminal.

OUTPUT BOARD

Test Point	Normal	Trip	Blocking
301	20	Applies to Sequential Fault	
302	0	Applies to Sequential Fault	
303	2.2	12.5	less than 1
304	less than 1	less than 10	7
Board 14	20	20	less than 1
305	18.5	7	18.5
306	0	13.5	0
307	20	less than 1	20
308	0	20	0

ELECTRICAL PARTS LIST

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
FAULT DETECTOR BOARD Style 5312D13G01		
Capacitors		
C51	0.1 Mfd	1544920
C52-C53-C59	0.5 Mfd	187A624A11
C54-C55	1.5 Mfd	187A508H09
C56-C57	0.02 Mfd	187A624H09
C58	0.1 Mfd	187A624H01
C60	0.22 Mfd	762A703H01
Diodes		
D51 to D58-D70 to D73	1N457A	184A855H07
D59	1N645A	837A692H03
D60 to D69	1N4385	184A855H14
Transistors		
Q51-Q52-Q53-Q55-Q57-Q61-Q62-Q63	2N3417	848A851H02
Q54-Q56-Q58	2N3645	849A441H01
Switches		
Q59-Q60	2N886	185A517H03
Resistors		
R51	50 Ohms, 5W	185A209H06
R52-R68-R71	2.7K Ohms ½W	629A531H42
R53 (POT)	2.5K Ohms ½W	629A430H03
R54-R55-R58-R62-R64-R66-R84-R89-R92	10K Ohms ½W	629A531H56
R56-R60	100K Ohms ½W	184A763H75
R57	47K Ohms ½W	629A531H72
R59	56K Ohms ½W	184A763H69
R61-R87	22K Ohms ½W	629A531H64
R63	6.8K Ohms ½W	629A531H52
R65	27K Ohms ½W	629A531H66
R67	150K Ohms 3W	762A679H01
R69-R73	68K Ohms ½W	629A531H76
R70-R74-R88	39K Ohms ½W	629A531H70
R72-R75-R80	2K Ohms ½W	836A503H33
R76-R78-R90	1K Ohms ½W	629A531H32
R77	5.6 Ohms ½W	629A531H50
R81	20K Ohms ½W	629A531H63
R82	1.5K Ohms ½W	836A503H30
R83-R91	470 Ohms ½W	629A531H24
R85	4.7K Ohms ½W	629A531H48

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
FAULT DETECTOR BOARD (Continued)		
Zener Diodes		
Z51	1N1832C, 62V	184A617H06
Z52-Z55	1N957B, 6.8V	186A797H06
Z53	1N3688A, 24V	862A288H01
Z54	1N759A, 12V	837A693H01
SUPERVISION BOARD Style 5315D34G01		
Capacitor		
C151-C153-C157	0.47 Mfd	188A669H01
C152	68 Mfd	187A508H02
C154-C158	1.5 Mfd	187A508H09
Diodes		
D151-D156-D157-D162	1N457A	184A855H07
D152-D155	1N645A	837A692H03
Transistors		
Q151-Q152-Q154-Q555-Q161-Q163-Q164	2N3417	848A851H02
Q153-Q156-Q162	2N3645	849A441H01
Resistors		
R151-R158-R168-R188-R194	6.8K Ohms ½W	629A531H52
R152-R153-R157-R159-R164-R165-R167-R169-R186	10K Ohms ½W	629A531H56
R189-R191-R193-R196-R154	470 Ohms ½W	184A763H19
R155-R166-R192	22K Ohms ½W	184A763H59
R156-R161	1K Ohms ½W	184A763H27
R160-R170-R190	82K Ohms ½W	629A531H78
R162	33K Ohms ½W	184A763H63
R163	56K Ohms ½W	184A763H69
R171	150K Ohms 3W	762A679H01
R195	2.7K Ohms ½W	184A763H37
Zener Diode		
Z151-Z152-Z156	1N957B, Y.8V	186A797H07
Z153	1N3668, 24V	862A288H01
Z158	UZ5875, 75V	837A693H04

ELECTRICAL PARTS LIST (Continued)

AMPLIFIER & KEYING BOARD Style 5314D77G01

Capacitor

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
C101	6.8 Mfd	184A661H21
C102	1.5 Mfd	187A508A09

Diodes

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
D101-D106-D110 to D113	1N457A	184A855H07
D109	1N645A	837A692H03

Transistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
Q101 to Q107	2N3417	848A851H02
Q108-Q109-Q113	2N3645	849A441H01

Resistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
R101	6.8K Ohms ½W	629A531H52
R102-R106	470 Ohms ½W	184A763H19
R103	39K Ohms ½W	184A763H65
R104-R108	1K Ohms ½W	184A763H27
R105-R109-R112 to R116-R121-R124-R130	10K Ohms ½W	184A763H51
R107	15K Ohms ½W	629A531H60
R110	82K Ohms ½W	629A531H78
R111-R120	33K Ohms ½W	184A763H63
R118	220K Ohms ½W	184A763H83
R119-R132	68K Ohms ½W	629A531H76
R123-R139	22K Ohms ½W	184A763H59
R125-R129	4.7K Ohms ½W	184A763H43
R126-R128	470K Ohms ½W	184A763H91
R127-R141	47K Ohms ½W	184A763H67
R140	56K Ohms ½W	184A763H69

Zener Diodes

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
Z101-Z102	1N957B, 6.8V	186A797H06
Z103	1N3688, 24V	862A288H01

ARMING BOARD Style 201C170G01

Diodes

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
D255-D257-D260-D261- to D265-D267	1N457A	184A855H07

Transistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
Q252-Q253-Q256- Q258-Q259	2N3417	848A851H02
Q257	2N3645	849A441H01

Resistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
R255-R257-R261-R262-R265-R274-R277-R278-R280-R281-R287-R288	22K Ohms ½W	184A763H59
R260-R264-R275-R276-R282-R284-R285	10K Ohms ½W	184A763H51
R279	27K Ohms ½W	629A531H66
R283-R289	12K Ohms ½W	184A763H53

Zener Diodes

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
Z251	1N3688A, 24V	862A288H01

PROTECTIVE RELAY BOARD
Style 201C165G01 – 201C476G01

Capacitors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
C1 to C5	.047 Mfd	849A437H04

Diodes

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
D1 to D5	1N645A	837A692H03
D6 to D10	1N457A	184A855H07

Transistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
Q1 to Q7-Q9	2N3417	848A851H02
Q8	2N3645	849A441H01

Resistors

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
R1 (125 volt input)	68K 1W	187A643H71
R1 (48 volt input) R6-R21-R30-R39	27K ½W	184A763H01

ELECTRICAL PARTS LIST (Continued)

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
PROTECTIVE RELAY BOARD (Continued)		
Resistors (Continued)		
R2-R3-R4-R8-R9-R13-R14-R122-R23-R31-R32-R33	4.7K ½W	629A531H48
R5-R10-R15-R24-R34-R38	82K	629A531H78
R7-R11-R16-R25-R35	10K ½W	629A531H56
R12-R17-R26-R37	6.8 ½W	629A531H52
R18-R19-R27-R28	22K ½W	184A763H59
R20-R29-R36-R40	10K ½W	184A763H51
Zener Diode		
Z1-Z3-Z5-Z7-Z9	1N3686B 20V	185A212H06
Z2-Z4-Z6-Z8-Z10	1N957B 6.8V	186A797H06
OUTPUT BOARD Style 201C025G02		
Capacitors		
C301	.47 Mfd	188A669H01
C302-C303-C306-C309	0.22 Mfd	762A703H01
C304-C305	4.7 Mfd	184A661H12
C307-C308	0.047 Mfd	849A437H04
C310	0.10 Mfd	188A669H03
C311	1.5 Mfd	187A508H09
Diodes		
D301 to D306-D308	1N457A	184A855H07
D307	1N645A	837A692H03
Transistors		
Q301-Q305-Q306-Q307-Q308	2N3645	849A441H01
Q302-Q303-Q304-Q308	2N3417	848A851H02
Resistors		
R301-R303-R304-R306-R310-R311-R315-R320-R323-R324-R326-R330-R335	10K Ohms ½W	184A763H51

CIRCUIT SYMBOL	DESCRIPTION	WESTINGHOUSE STYLE NUMBER
OUTPUT BOARD (Continued)		
Resistors (Continued)		
R302	2.2 Ohms ½W	187A290H26
R305	47K Ohms ½W	187A290H17
R307-R314-R319-R321-R325-R328	22K Ohms ½W	184A763H59
R309-R317	1K Ohms ½W	184A763H27
R312	470K Ohms ½W	184A763H19
R313	470K Ohms ½W	184A763H91
R316	15K Ohms ½W	629A430H08
R318-R322	4.7K Ohms ½W	184A763H43
R327	6.8K Ohms ½W	184A763H47
R329	18K Ohms ½W	184A763H57
R331	10K Ohms ½W	629A531H56
R332	6.8K Ohms ½W	629A531H52
R333	27K Ohms ½W	629A531H66
R334	150K Ohms ½W	762A679H01
Zener Diode		
Z301-Z303-Z304-Z305	1N957B 68V	186A797H06
Z306	1N3688A 24V	862A288H01
RELAY BOARD Style 5312D78G01		
Capacitors		
C201-C202-C203	0.25 Mfd	187A624H02
Resistors		
R201	50 Ohms 5W	185A209H06
R202-R203	3.3K Ohms ½W	629A531H44
Filter Choke		
L201	8.5Hy 450 Ohms	188A460H01
Zener Diodes		
Z201	1N1828C 43V	629A798H14

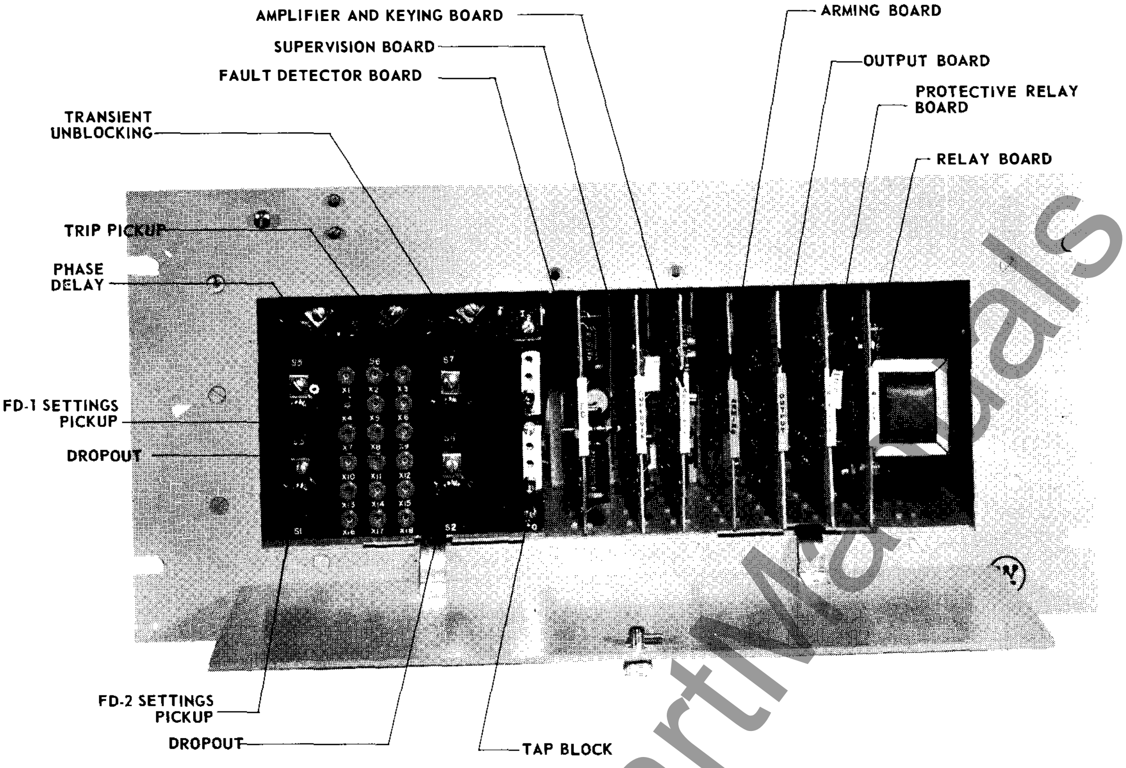


Fig. 1. Photograph (Front View)

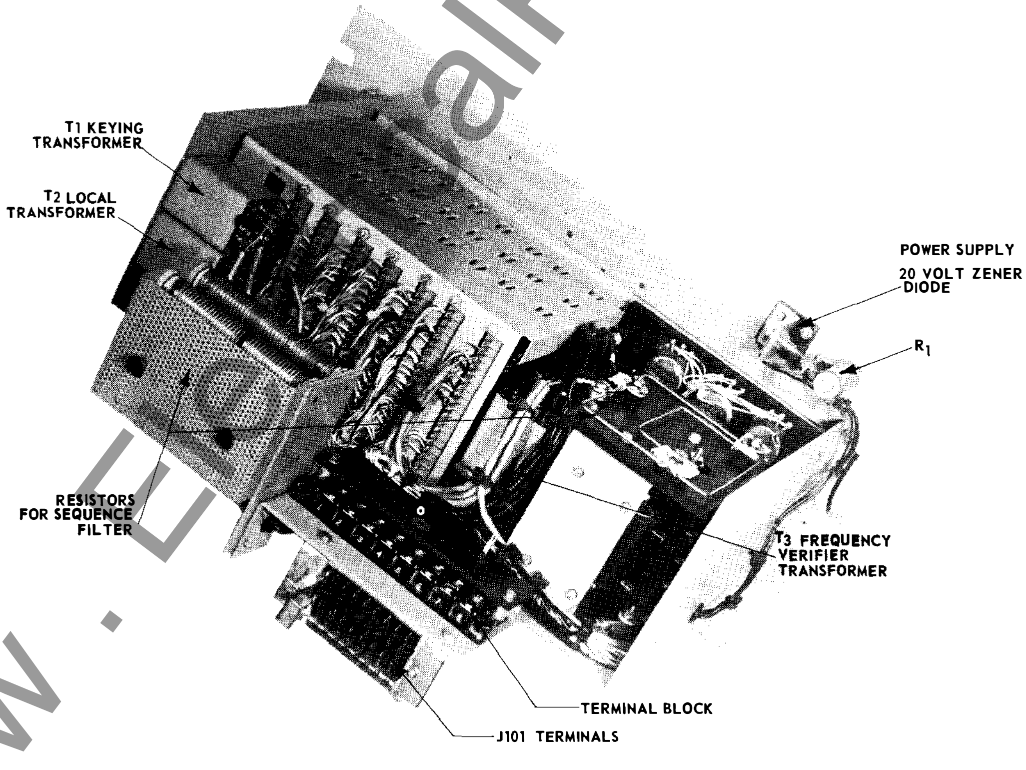


Fig. 2. Photograph (Rear View)

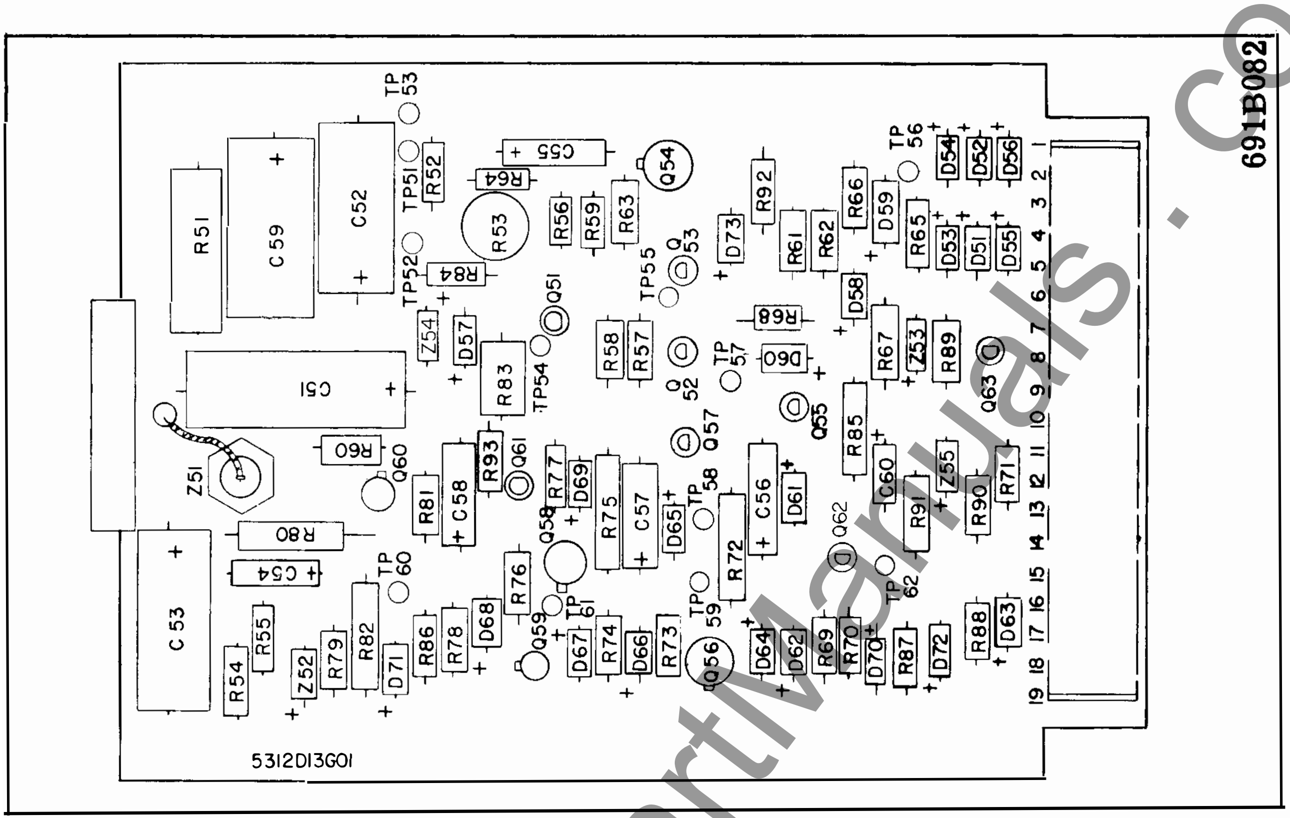


Fig. 3. Location of Components on Fault Detector Board.

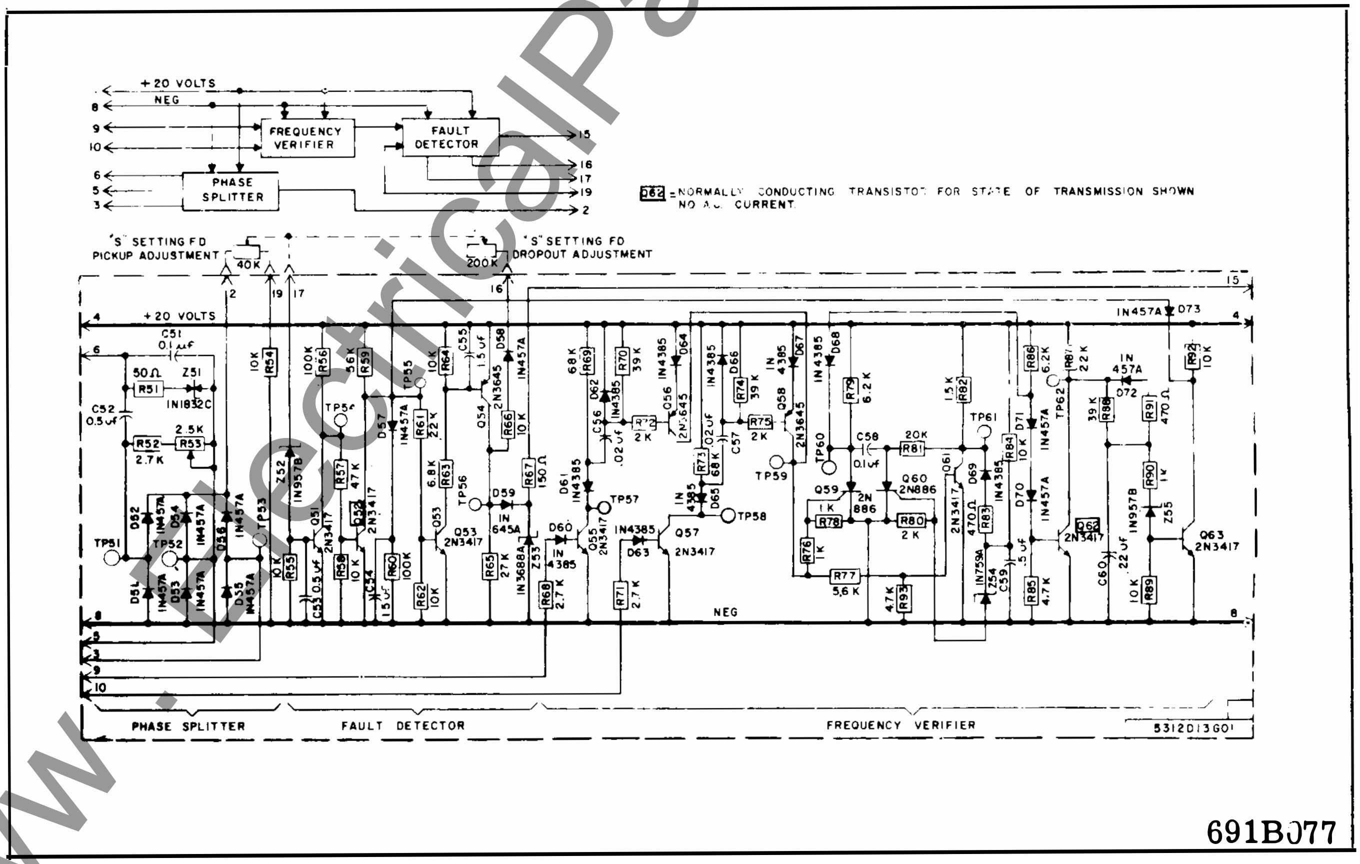


Fig. 4. Schematic of Fault Detector Board.

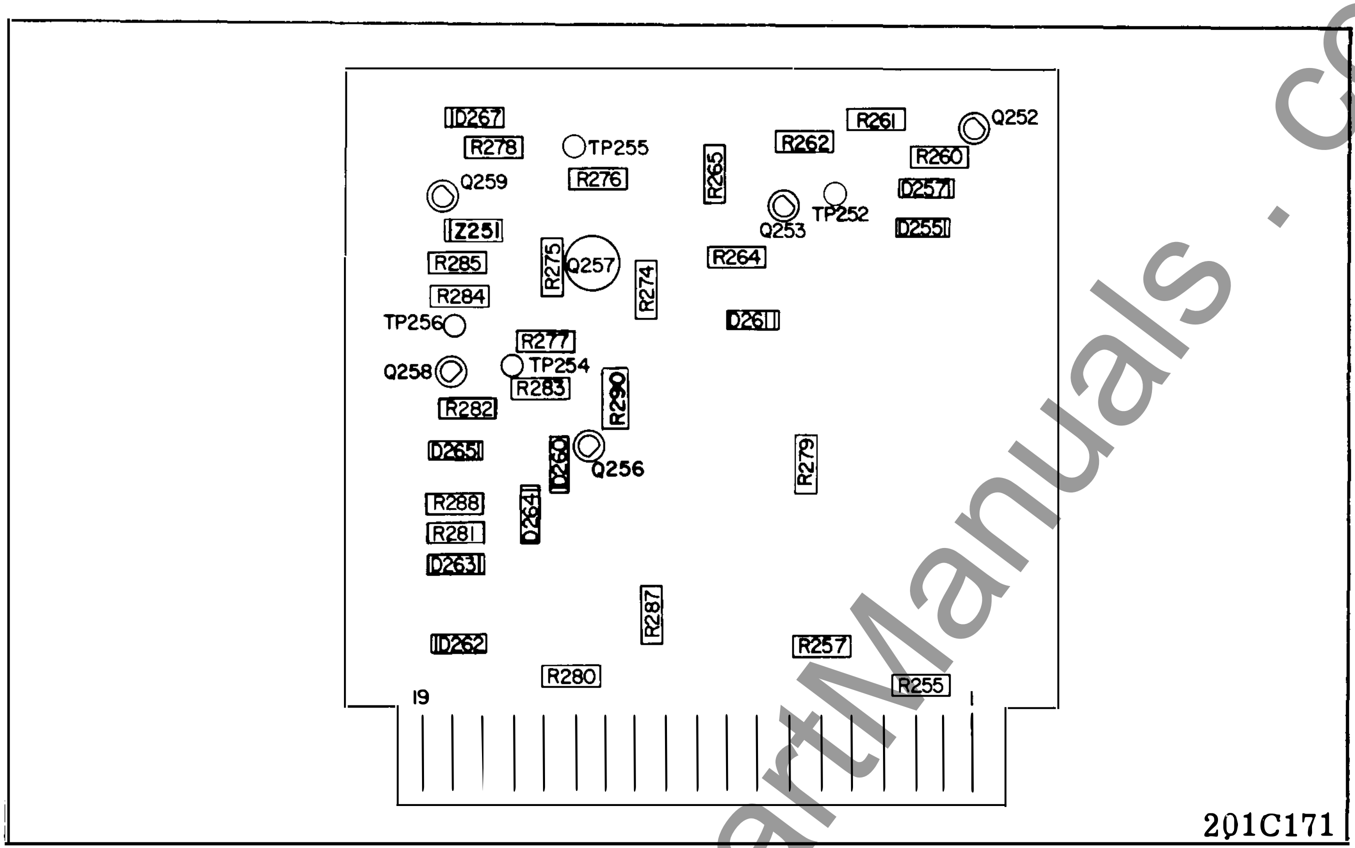


Fig. 5. Location of Components on Arming Board

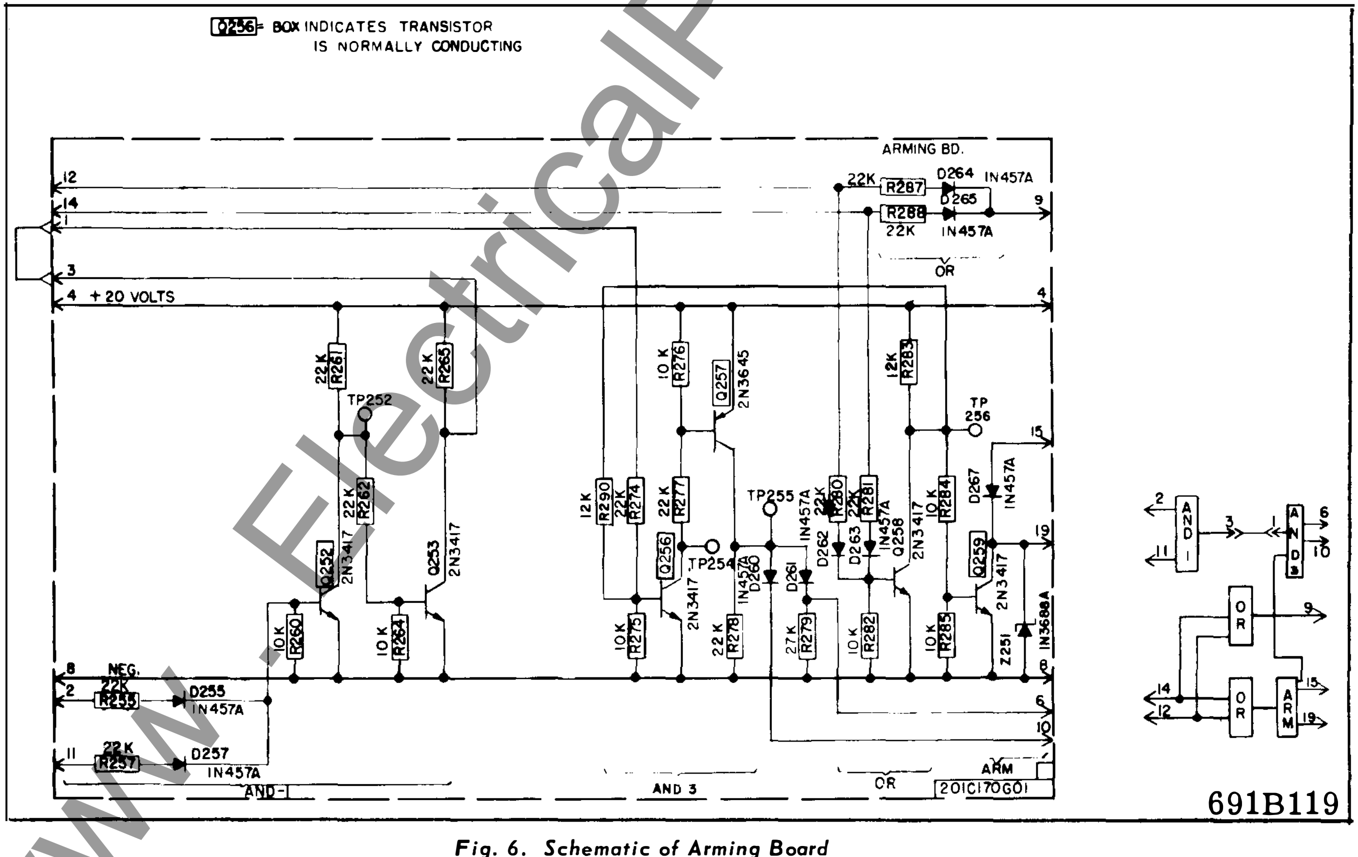


Fig. 6. Schematic of Arming Board

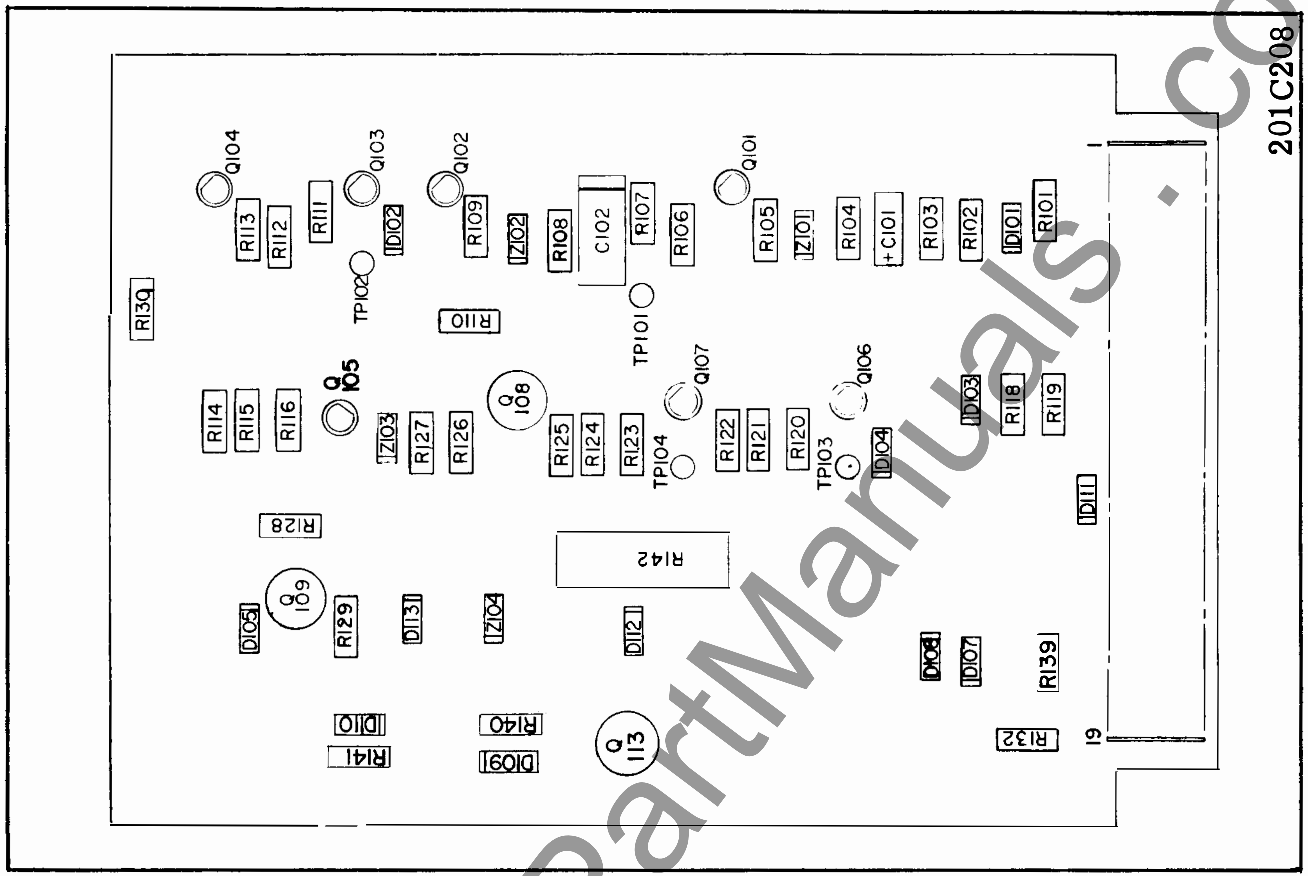


Fig. 7. Location of Components on Amplifier and Keying Board.

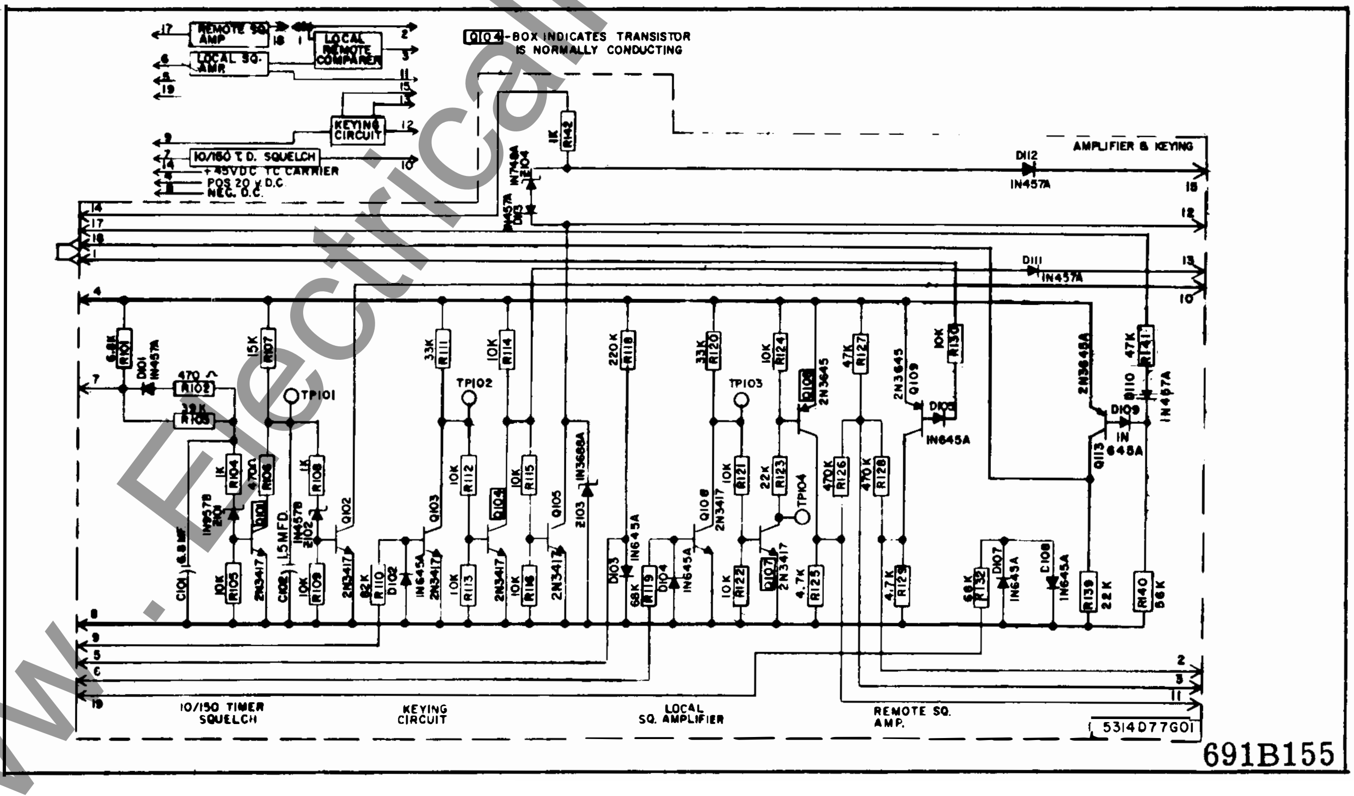


Fig. 8. Schematic of Amplifier and Keying Board.

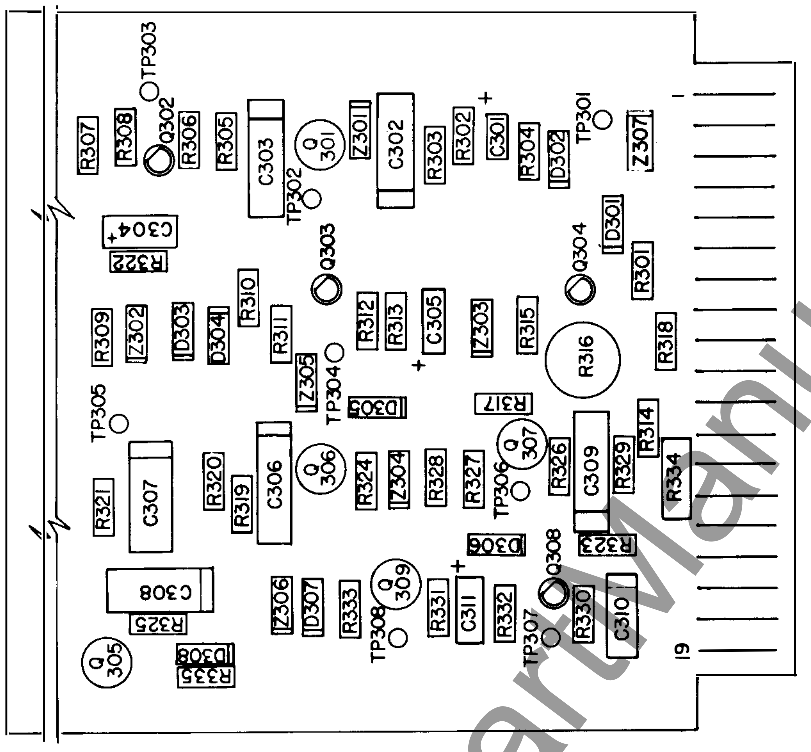


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Fig. 9. Location of Components on Output Board.

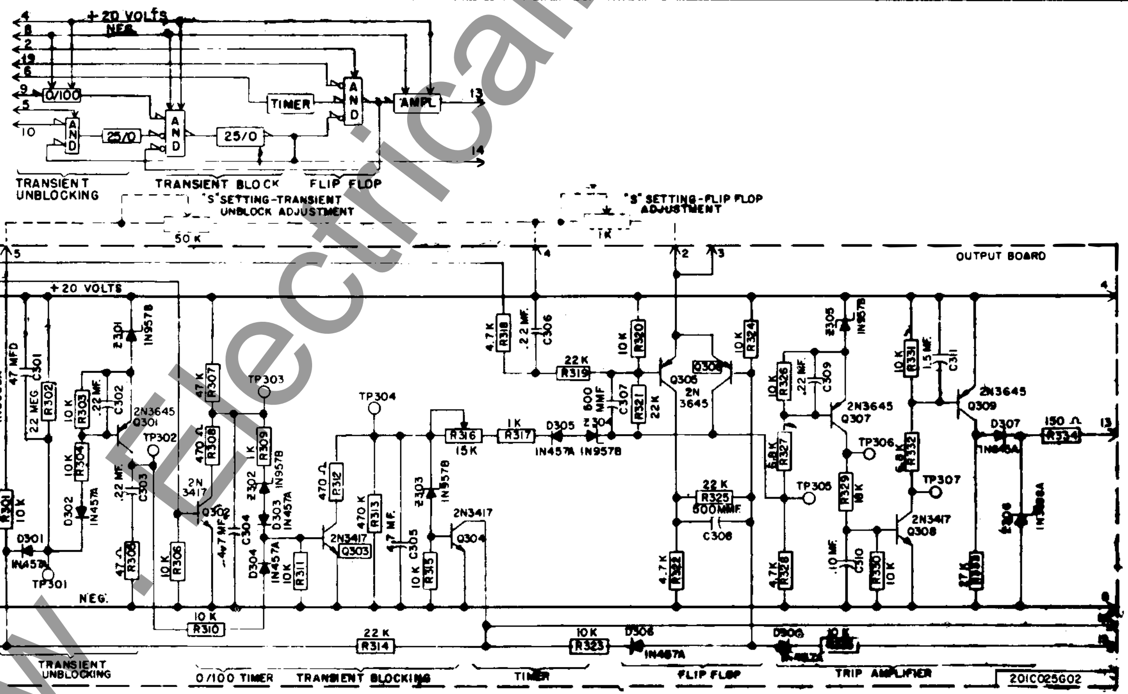

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Fig. 10. Schematic of Output Board.

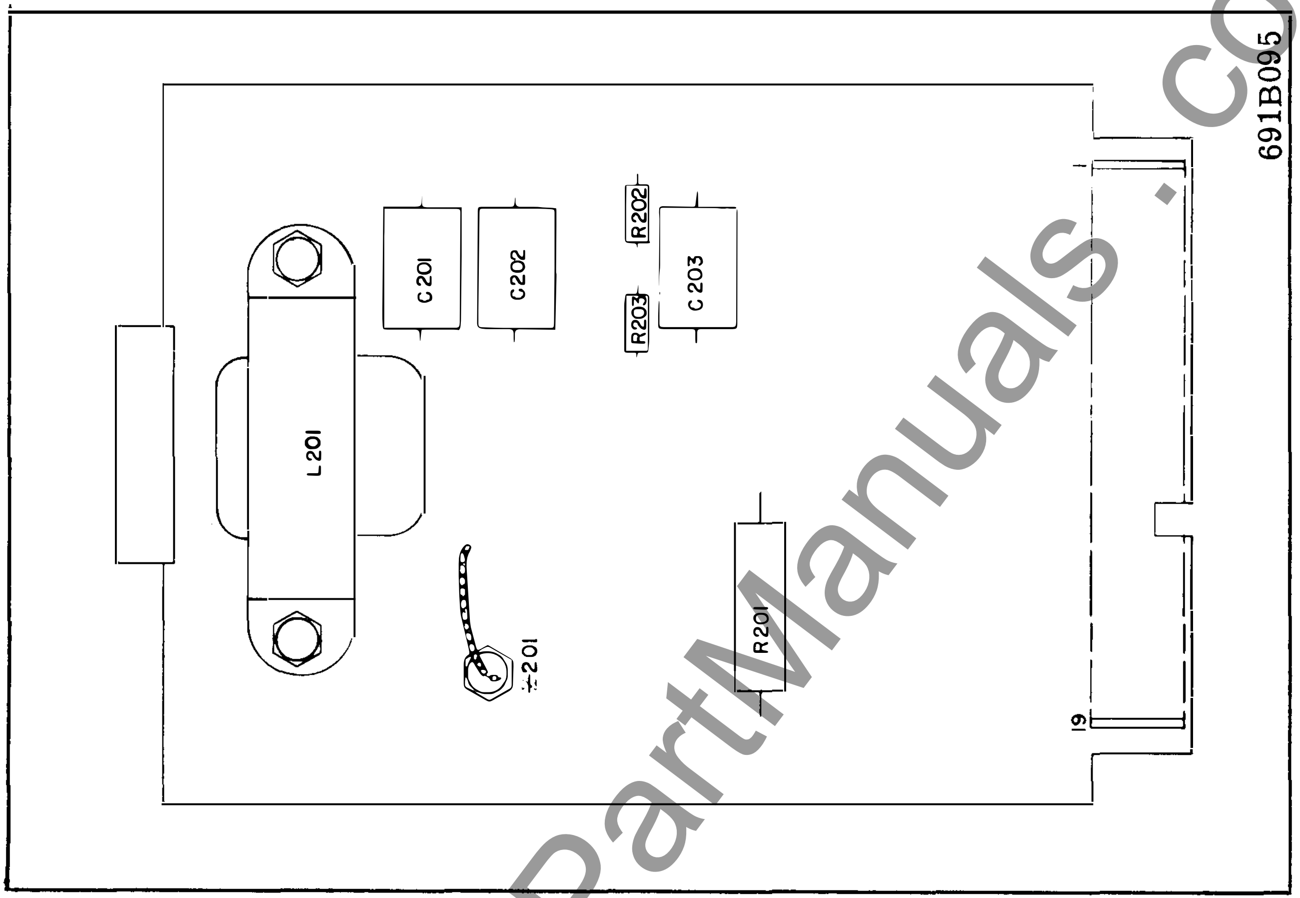


Fig. 11. Location of Components on Relay Board.

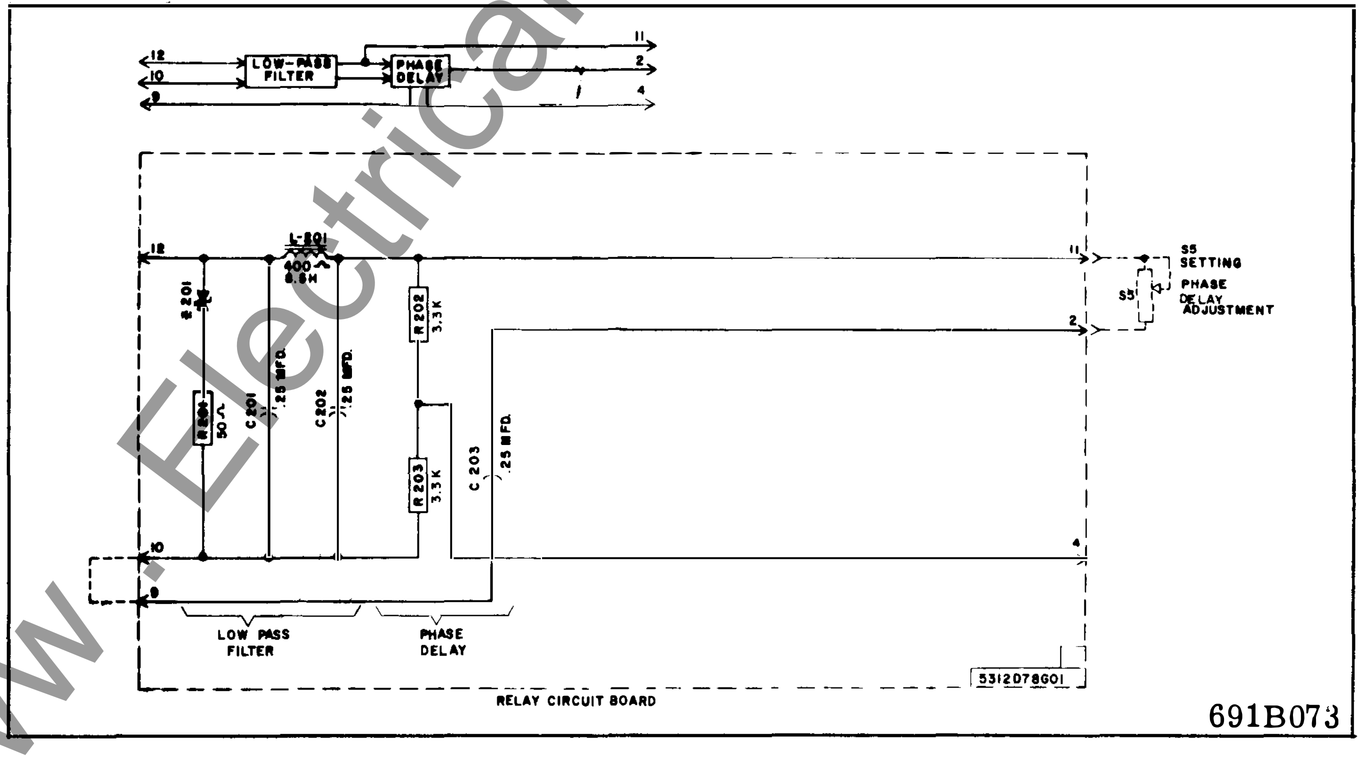


Fig. 12. Schematic of Relay Board.

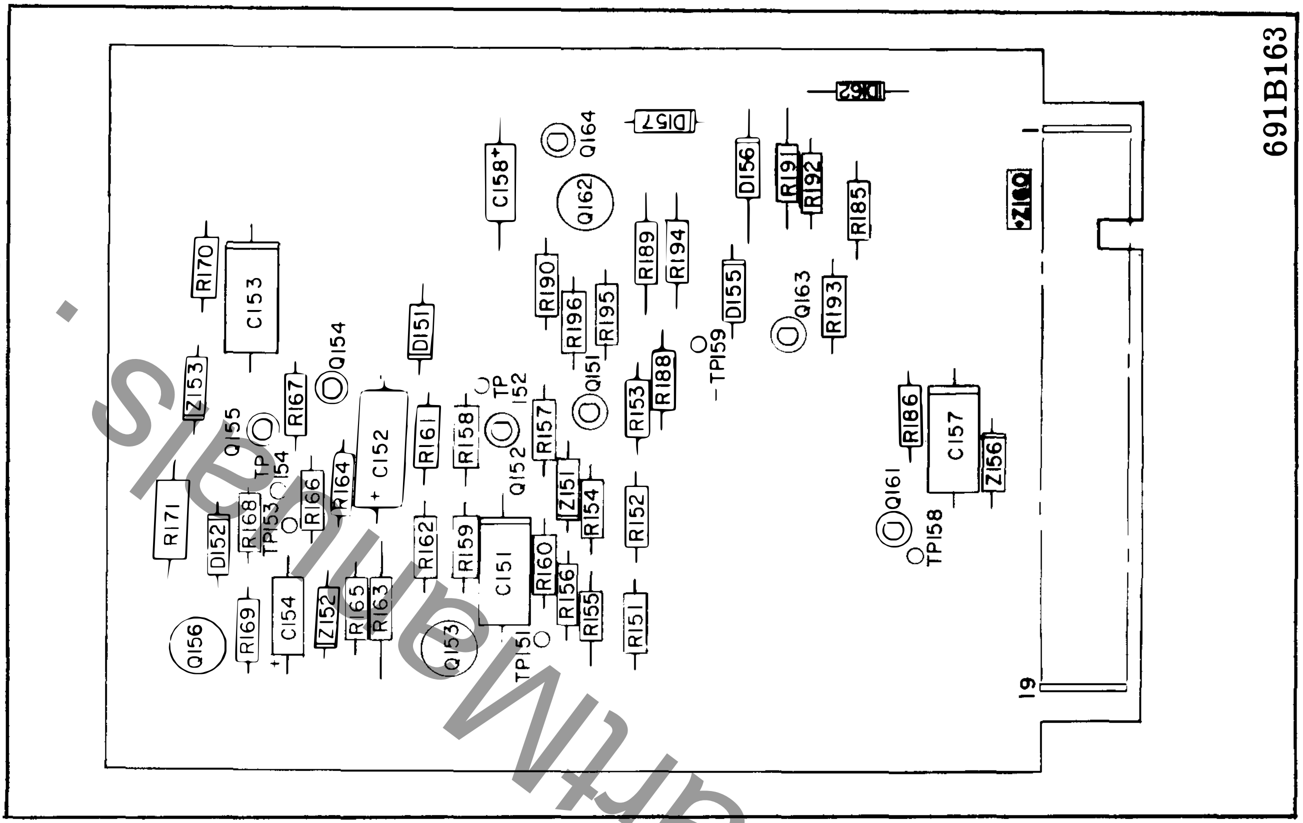


Fig. 13. Location of Components on Supervision Board.

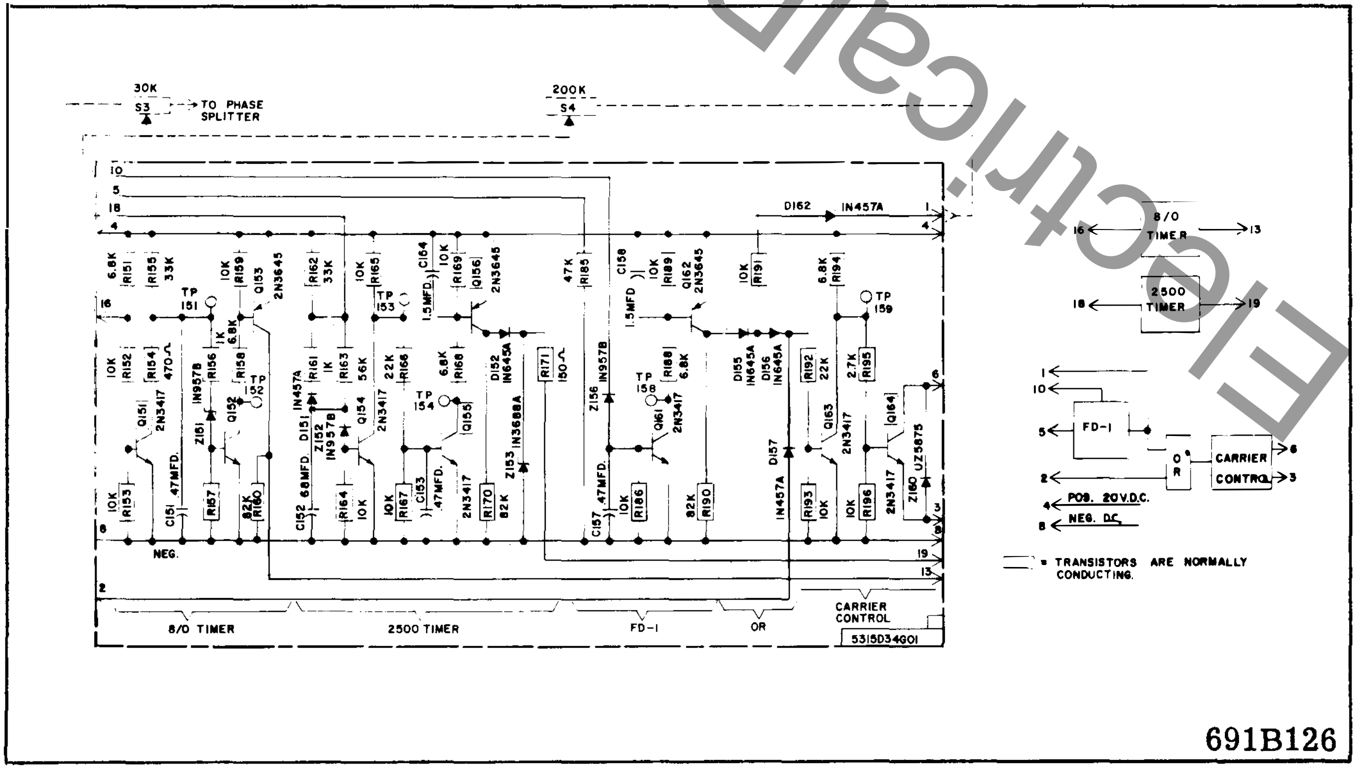


Fig. 14. Schematic of Supervision Board.

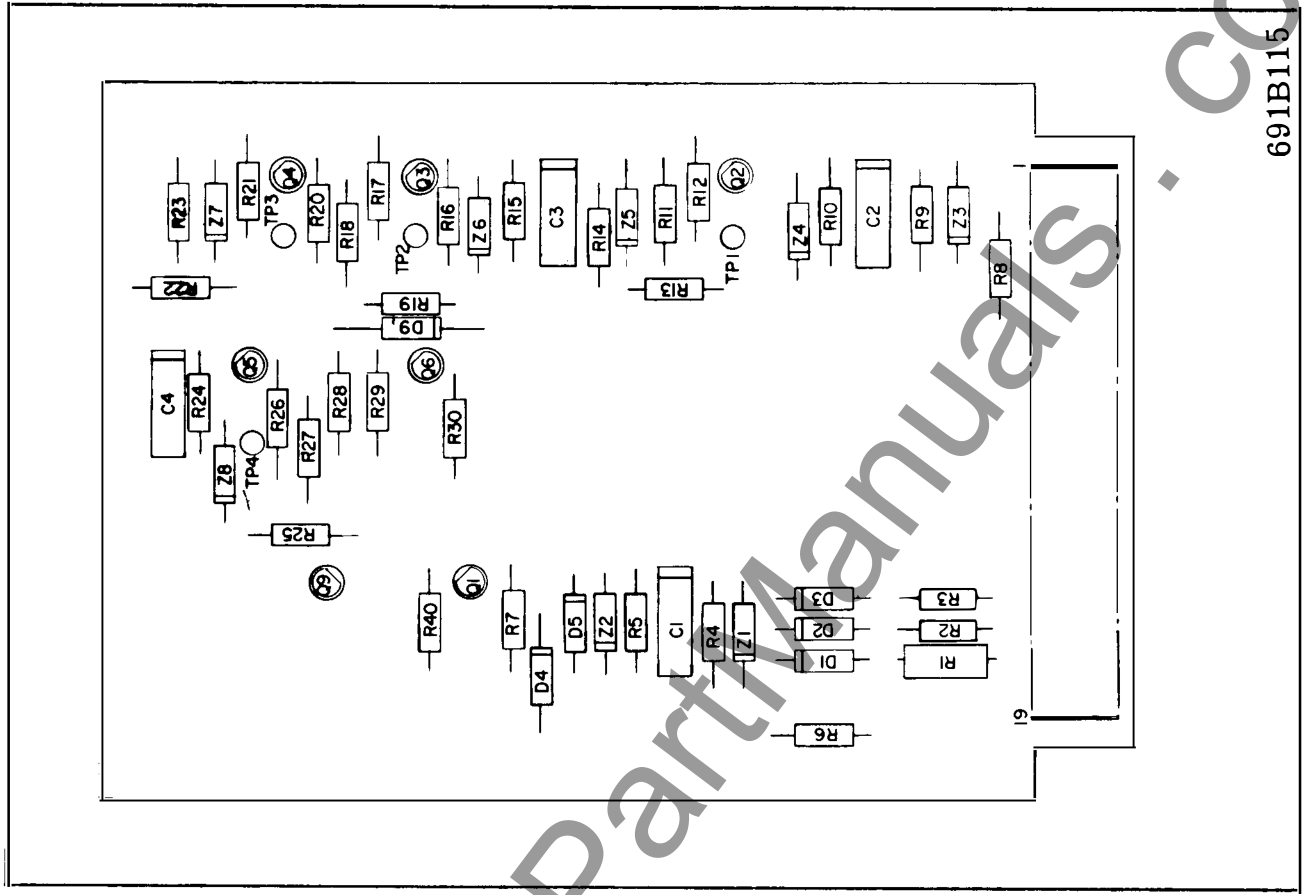


Fig. 15. Component Location on Protective Relay Board.

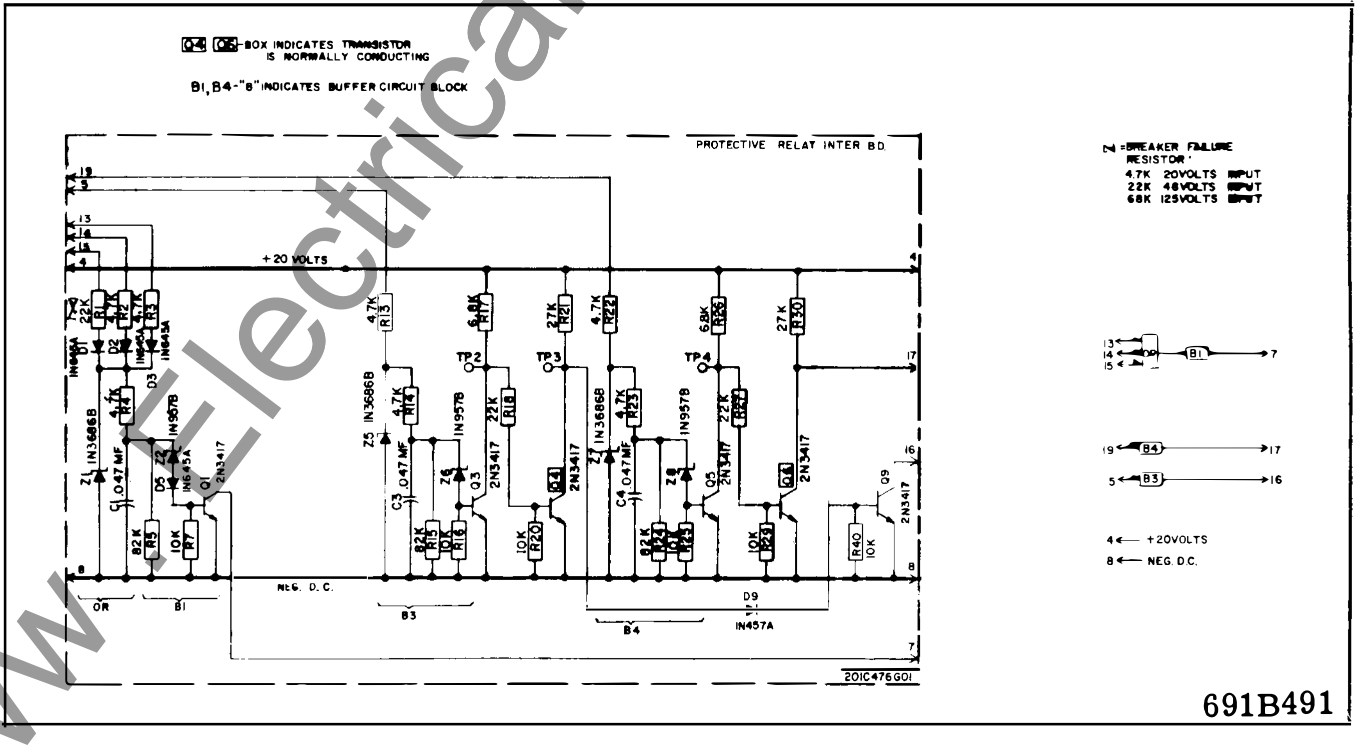


Fig. 16. Schematic of Protective Relay Board for Distance Phase Comparison System.

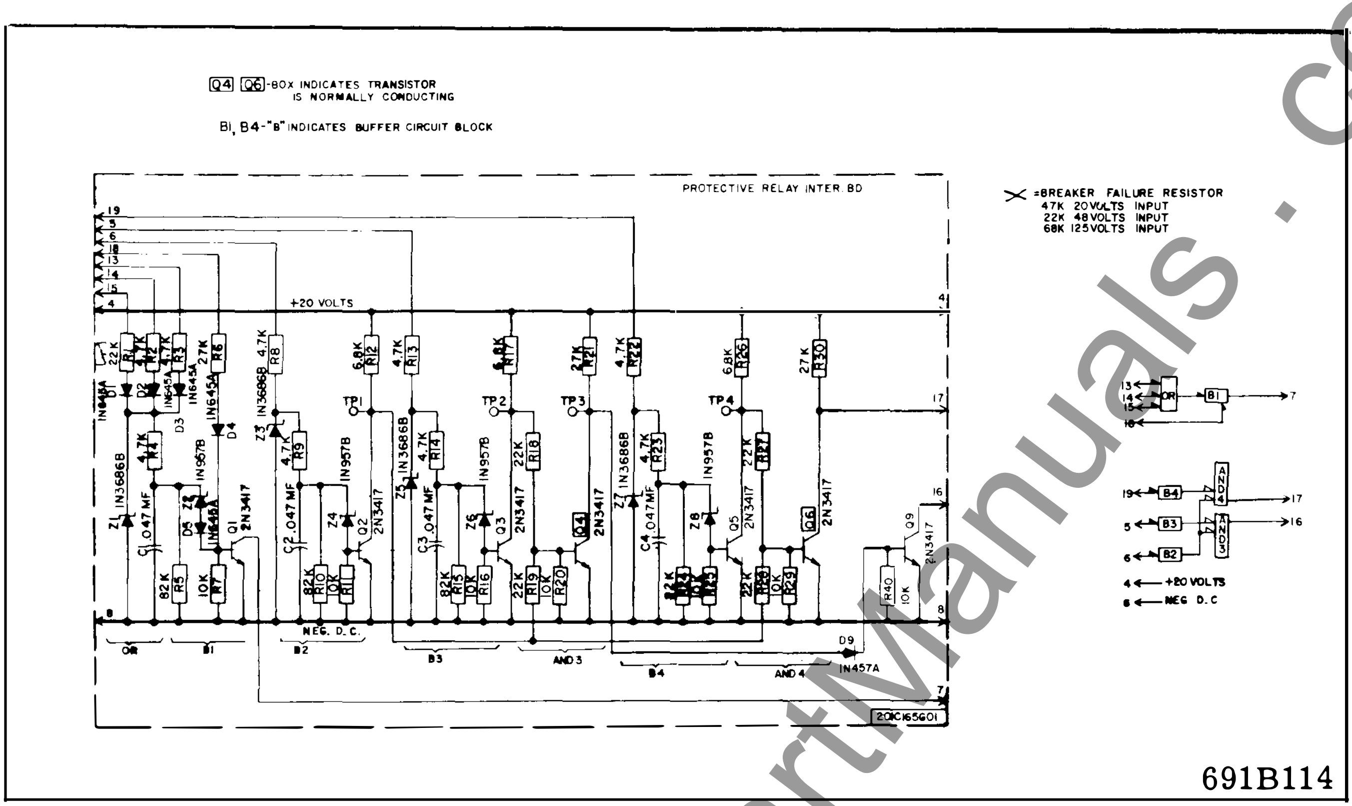


Fig. 17. Schematic of Protective Relay Board for Distance Phase Comparison System with Blinder Control.

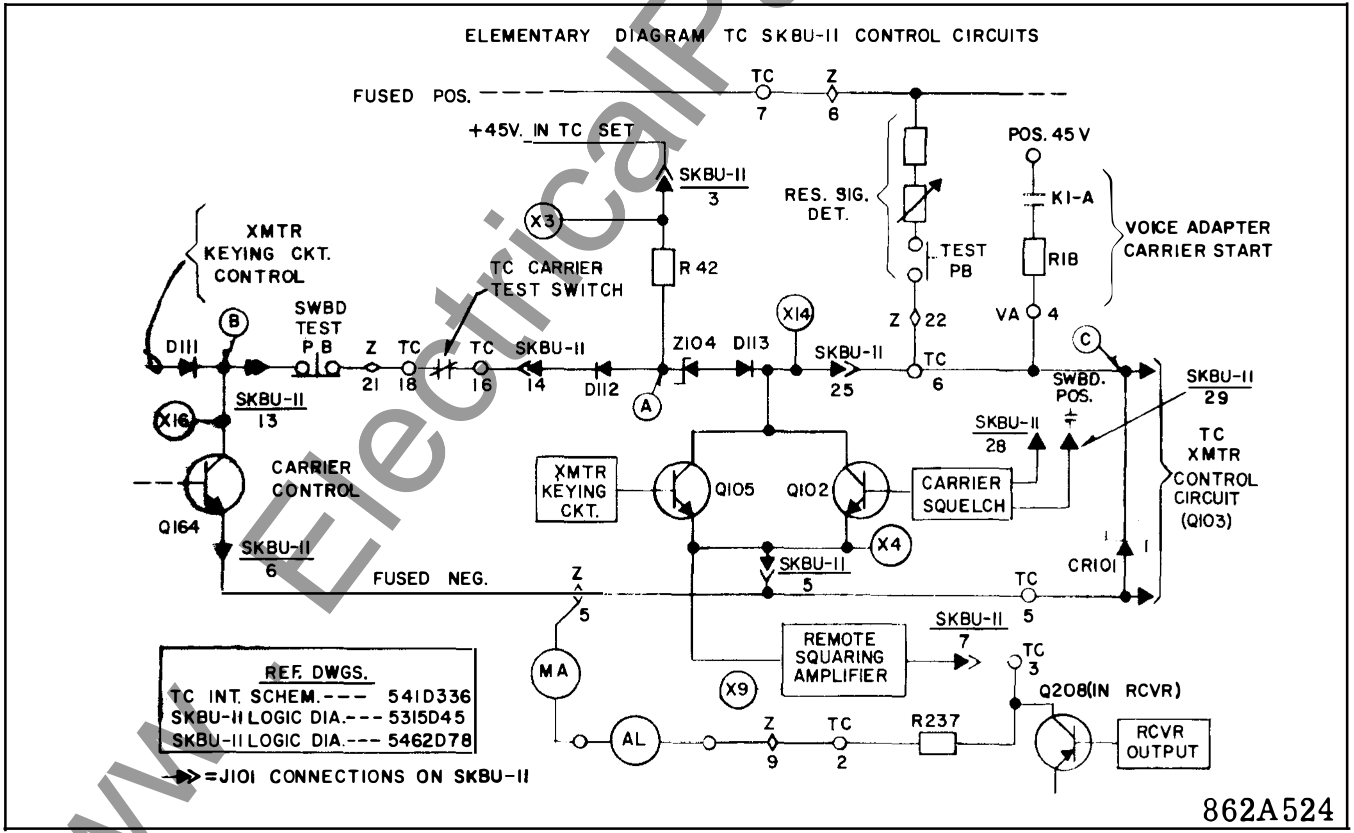


Fig. 18. Elementary Connection of TC SKBU-11.

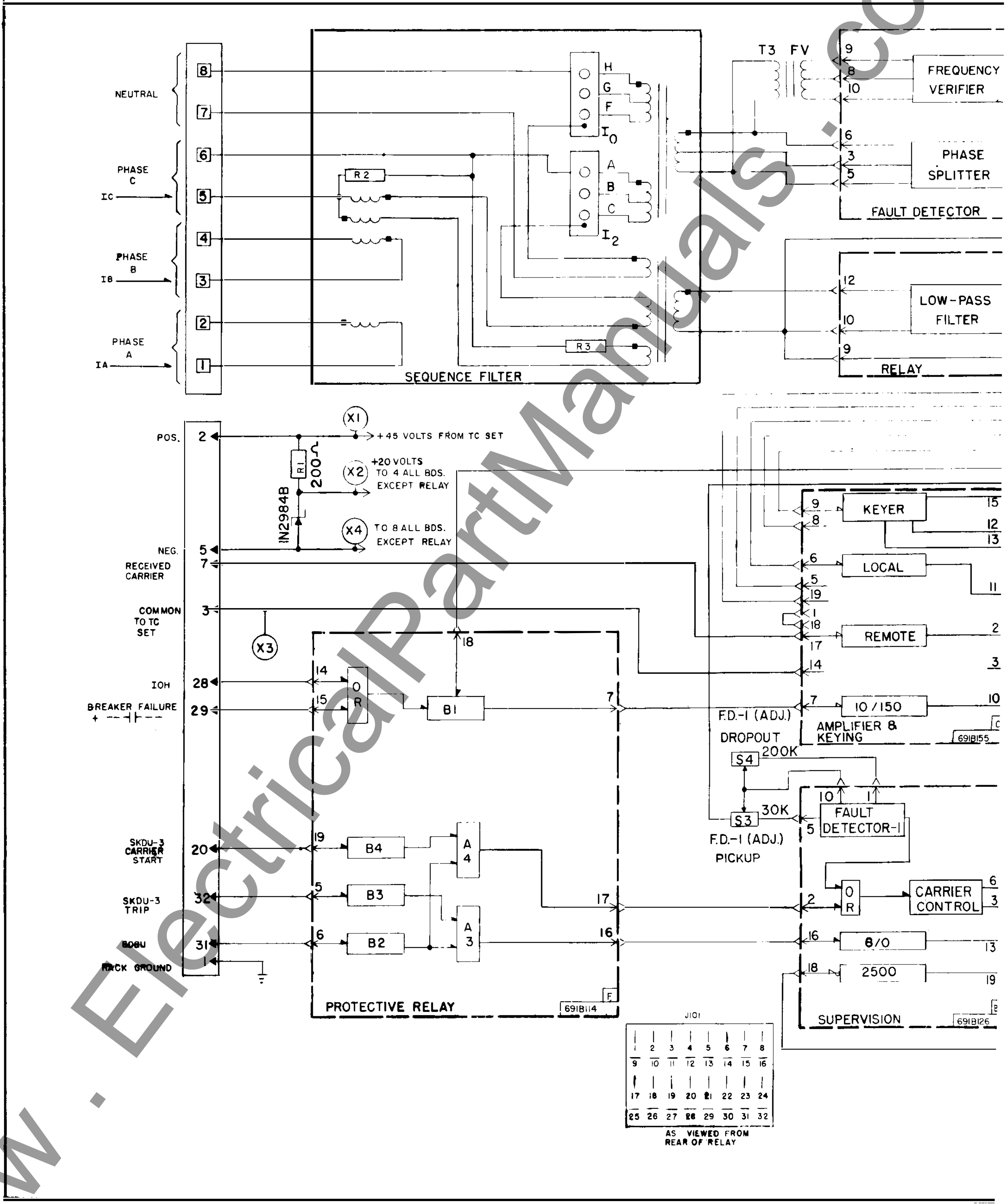
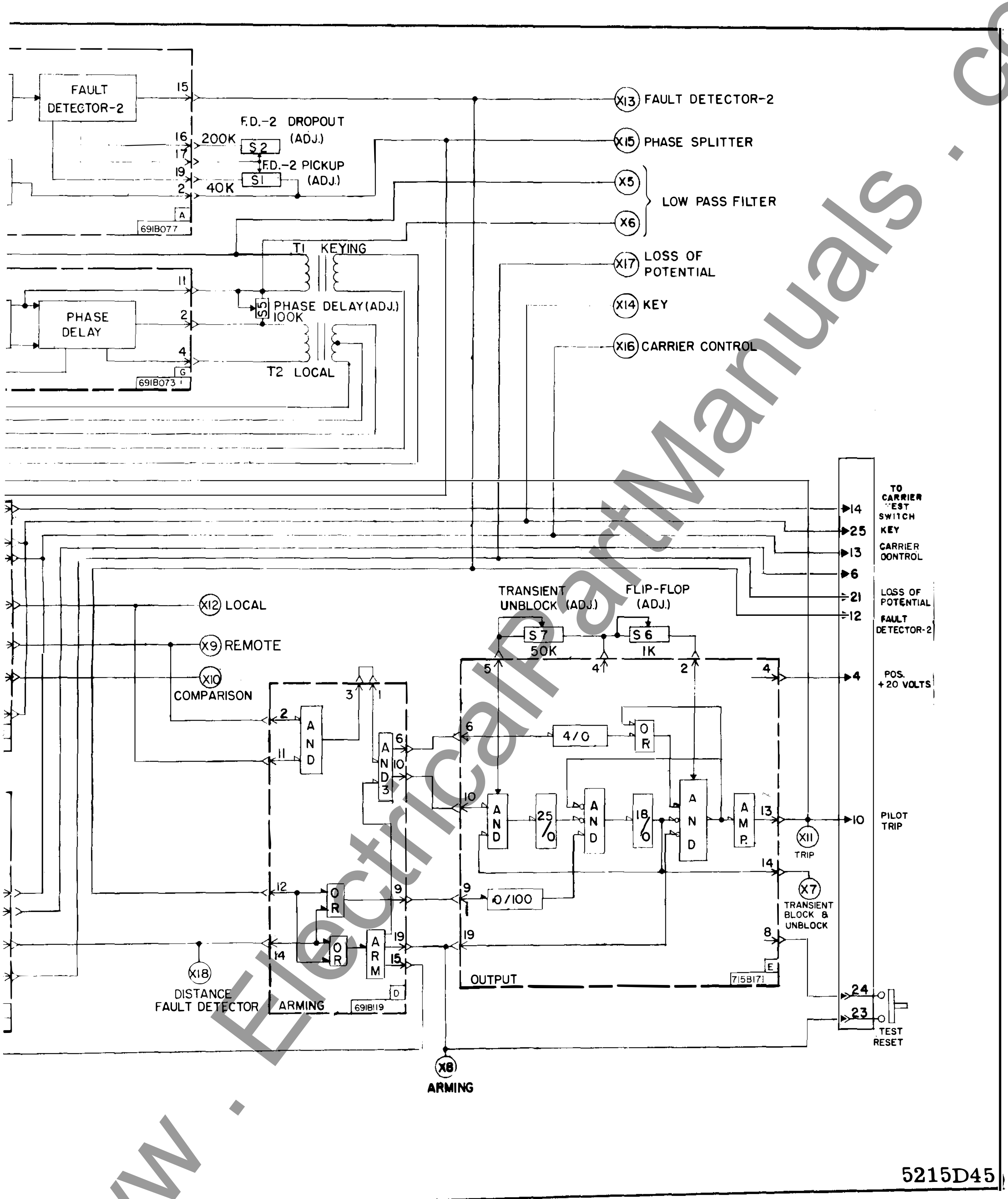


Fig. 20. Logic Diagram of SKBU-11 Relay fo



· Distance Phase Comparison System with Blinder Control.

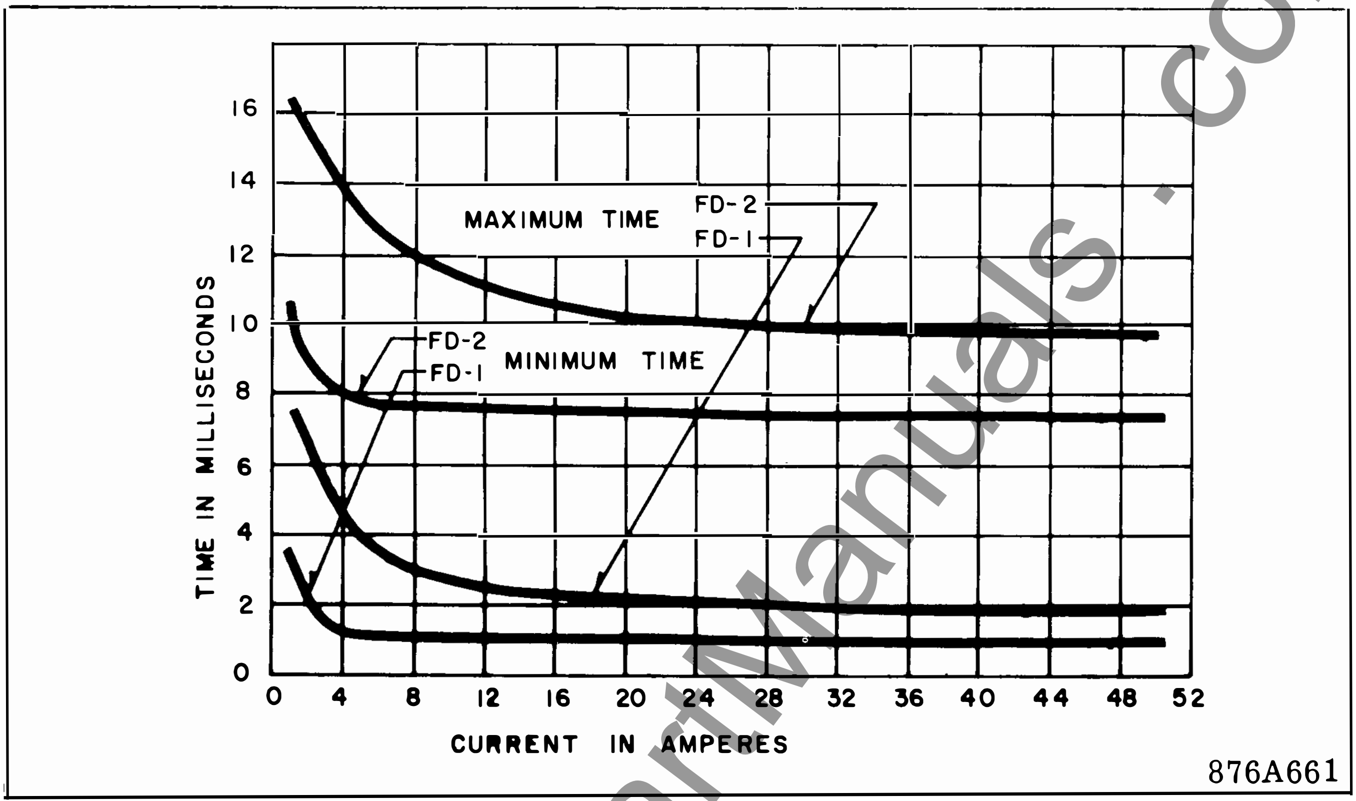


Fig. 21. Operating Times of Fault Detectors of SKBU-11 Relay.

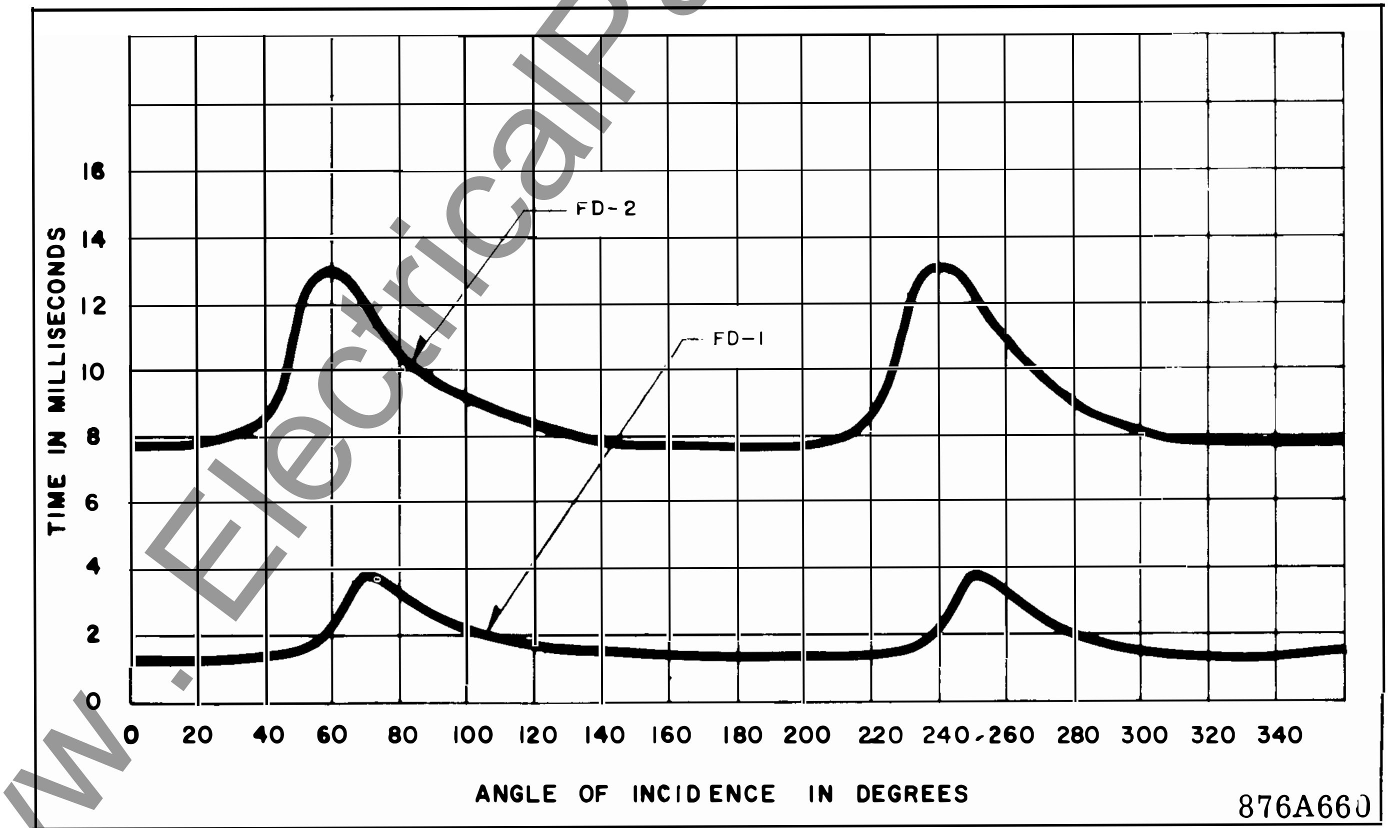


Fig. 22. Operating Time of Fault Detector of SKBU-11 Relay as a function of Fault Incidence Angle at 5 Amperes.

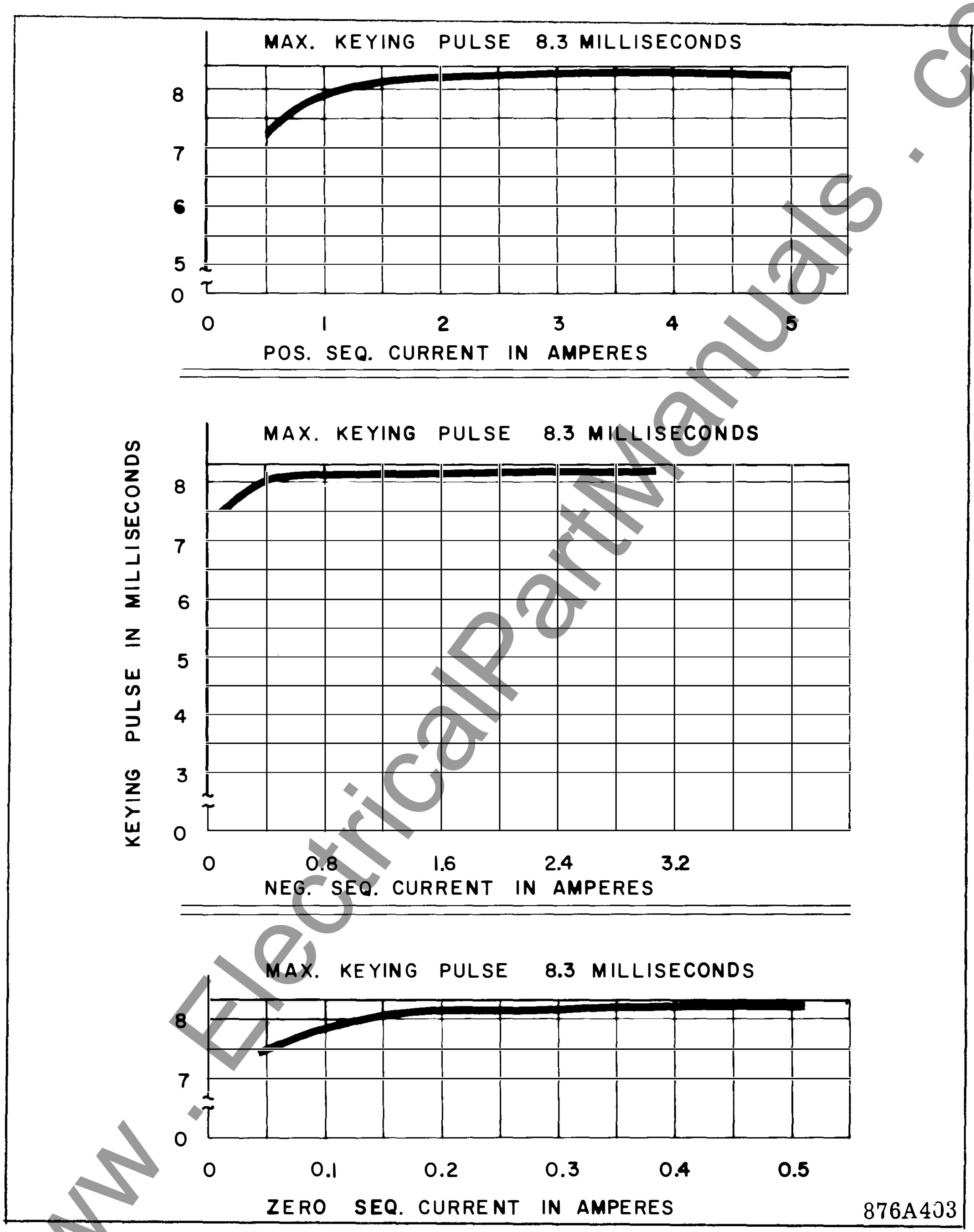


Fig. 23. Width of Keying Pulses at Different Current Levels of SKBU-11 Relay.

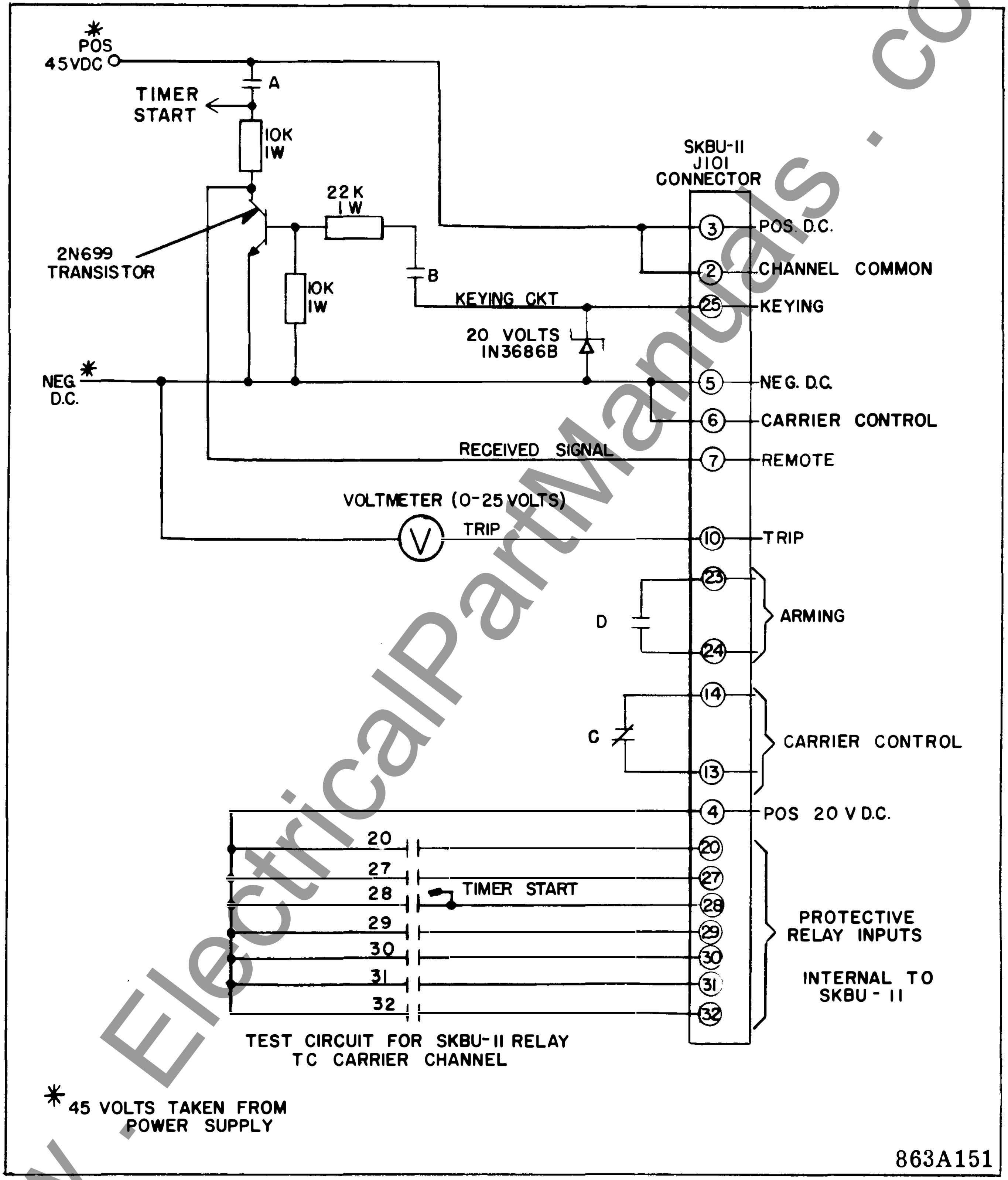


Fig. 24. Test Circuit of SKBU-11 Relay.

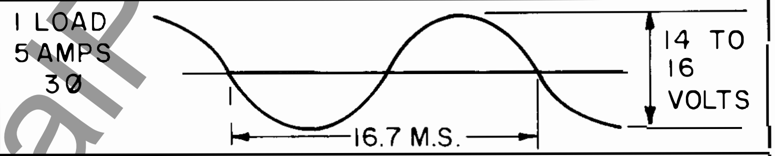
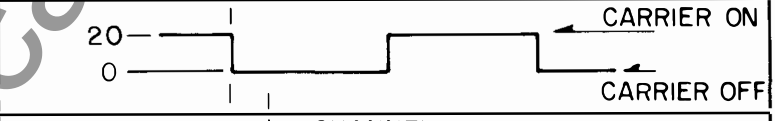
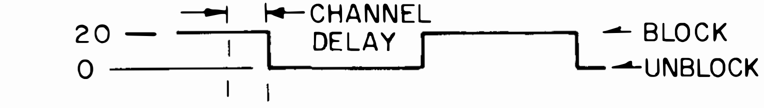
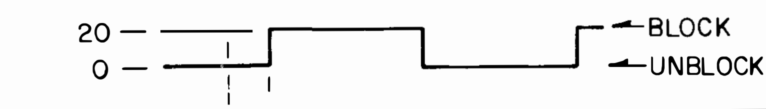
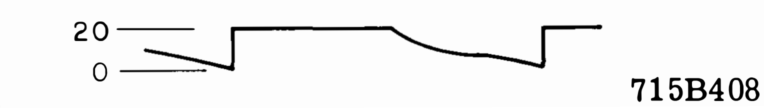
TEST POINT	CIRCUIT	VOLTAGE TO X4
X1	D.C. INPUT VOLTAGE	48 VOLTS D.C.
X2	REGULATED D.C.	20 VOLTS D.C.
X3	COMMON T.C.	45 VOLTS D.C.
X4	BATTERY NEGATIVE	———————
X7	TRANSIENT BLOCK	NORMAL 20 VOLTS OPERATE 0 VOLTS
X8	ARMING	NORMAL 20 VOLTS OPERATE 0 VOLTS
X11	PILOT TRIP	NORMAL 0 VOLTS OPERATE 20 VOLTS
X13	FAULT DETECTOR	NORMAL 0 VOLTS OPERATE 20 VOLTS
X17	LOSS OF POTENTIAL	NORMAL 20 VOLTS OPERATE 0 VOLTS
X18	DISTANCE FAULT DETECTOR OPERATION	NORMAL 0 VOLTS OPERATE 20 VOLTS
X5 TO X6(GND)	LOW PASS FILTER	
X14	KEYING	
X12	LOCAL	
X9	REMOTE	
X16	CARRIER CONTROL	

Fig. 25. Table I Test Point Voltages.

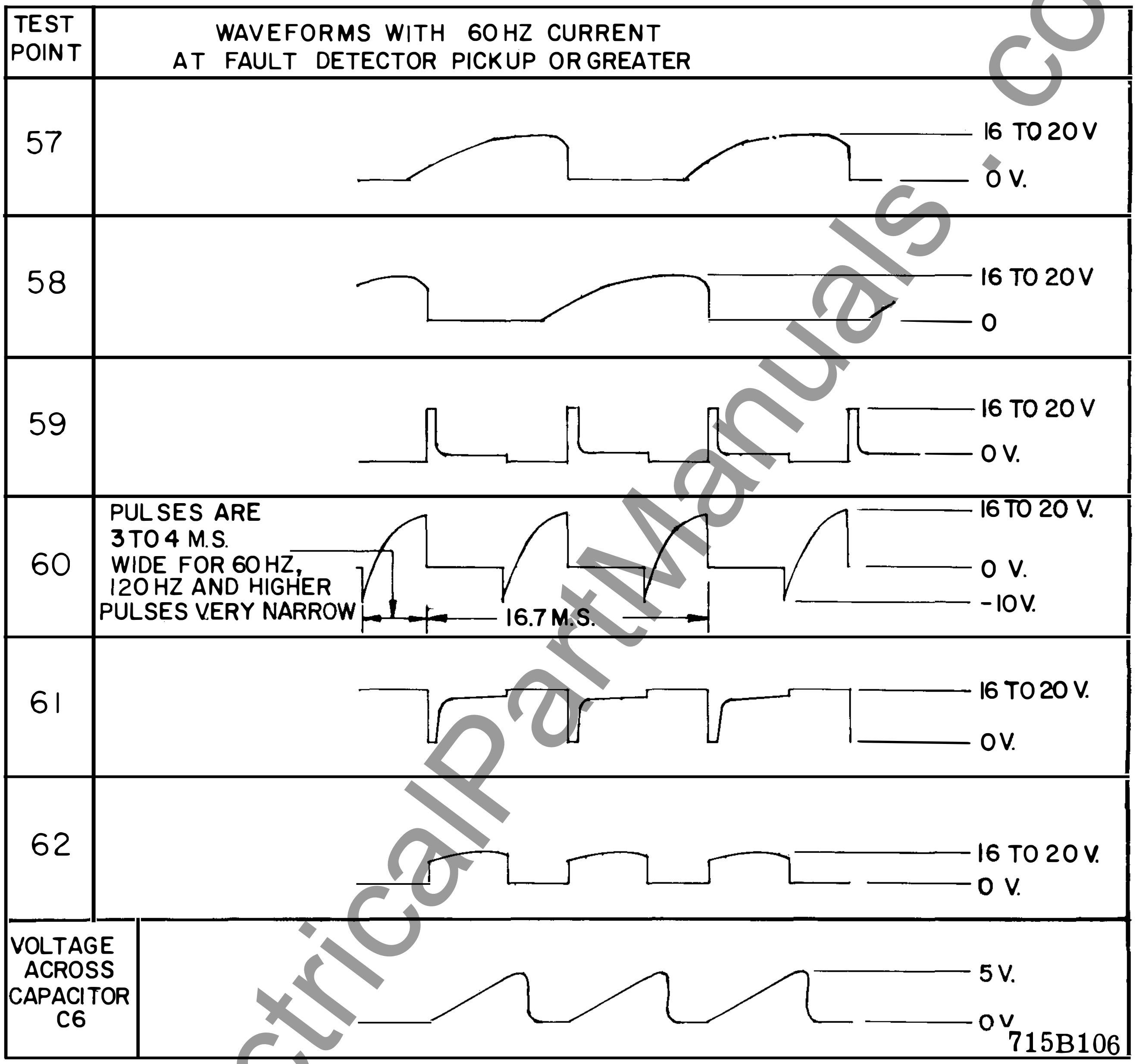


Fig. 26. Table III Frequency Verifier Waveforms at 60 Hz.

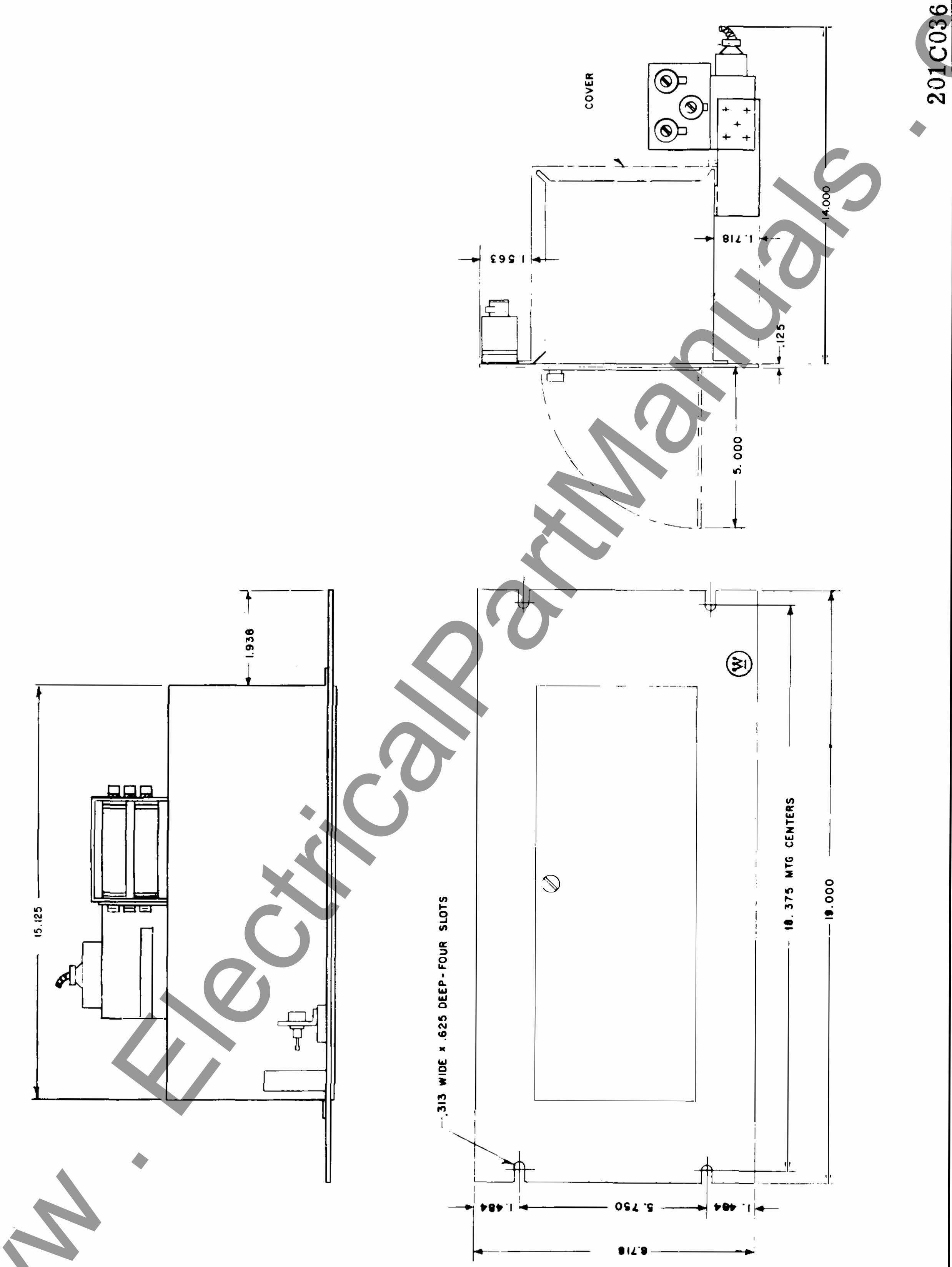


Fig. 27. Outline for Type SKBU-11 Relay.

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Westinghouse I.L. 41-954.2A

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU PHASE COMPARISON RELAY FOR TYPE TA-2 FREQUENCY SHIFT TONE CHANNEL

CAUTION: It is recommended that the user of this equipment become acquainted with the information in this instruction leaflet before energizing the carrier system.

If the SKBU relay is mounted in a cabinet, it must be bolted down to the floor or otherwise secured before swinging out the equipment rack to prevent its tipping over.

APPLICATION

The type SKBU relay is a high-speed relay used in conjunction with a type TA-2 frequency shift tone channel. Simultaneous tripping of the relays at each line terminal is obtained in less than two cycles for all internal faults within the limits of the relay settings.

The system is applicable to a voice-grade pilot-wire or microwave channel. The maximum propagation delay which can be tolerated is 3.5 msec. for two terminal lines and 2 msec. for three terminal lines.

In contrast to the carrier blocking scheme, this is a transfer-trip system; accordingly, the blocking-start function is not required.

CONSTRUCTION

The type SKBU relay consists of a combination positive, negative, and zero sequence current network, a saturating transformer, a 20 volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel, 8¾ inches high (5 rack units). Edge slots are provided for mounting the rack on a standard relay rack. The components are connected as shown in the internal schematic of figures 1 and 2.

SEQUENCE NETWORK

The sequence filter consists of a three-legged iron core reactor and a set of resistors, R_1 and R_0. The reactor has three windings: two primary and a tapped secondary winding, wound on the center leg of a "F" type of lamination. The secondary taps are wired to the A, B, and C tap connections in the front of the relay (R_1 taps). R_0 consists of three tube resistors with taps wired to F, G, and H tap connections in the front of the relay. The R_0 resistor is a formed resistor associated with the tapped secondary of the reactor.

SATURATING TRANSFORMER

The voltage from the network is fed into the tapped primary of a small saturating transformer. This transformer and a Zener clipper (on a printed circuit board) connected across its secondary are used to limit the voltage impressed on the solid static circuits, thus providing a small range of voltage for a large variation of maximum to minimum fault currents. This provides high operating energy for light faults, and limits the operating energy for heavy faults to a reasonable value.

POWER SUPPLY

The SKBU relay operates from two regulated voltages, 45 volts d.c. and 20 volts d.c. The 20 volt supply is taken from a Zener diode mounted on a heat sink at the top of the relay. An external voltage regulator supplies 45 volts d.c. to the SKBU. A separate voltage regulator for the TA-2 frequency shift tone set is provided on this external regulator.

PRINTED CIRCUIT BOARDS

Six printed circuit boards are used in the SKBU relay; fault detector board, supervision board, amplifier and keying board, "AND" board, output board, and a relay board. The circuits of the supervision, amplifier and keying, and "AND" boards varies with the application.

All of the circuitry that is suitable for mounting on printed circuit boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide

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*Denotes change from superseded issue.

EFFECTIVE AUGUST 1968

into position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment, it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

1. Fault Detector Board

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, and a static fault detector. The controls for setting pickup (S1) and dropout (S2) of the fault detector are mounted on a plate in the front of the assembly. This unit operates when the fault current exceeds a definite value.

2. "AND" Board

The "AND" board contains resistors and diodes. The number of diodes on the board varies with the application. An output is obtained from this circuit when all inputs are at negative potential.

3. Amplifier and Keying Board

The amplifier and keying board contains two local squaring amplifiers, a transmitter keying circuit, and two remote squaring amplifiers for each line terminal. These circuits produce the pulses that are compared by the "AND" circuits to determine if the fault is external or internal.

4. Output Board

The output board contains a 4 millisecond pickup and instantaneous dropout timer circuit, flip-flop circuit, trip amplifier, transient blocking and unblocking circuit. The circuits on this board operates when all the inputs to the "AND" board are at negative potential and the fault detector has operated.

5. Relay Board

The relay board contains the phase delay circuit for shifting the local signals with reference to the remote signals. This board also contains the final tripping unit (AR) and the alarm unit (AL) of the SKBU relay. The phase delay circuit is utilized to compensate for the delay of the channel equipment.

6. Supervision Board

The number of circuits on this board varies with the application. For all applications a 25 millisecond pickup and 2 millisecond dropout alarm timer circuit, a "NOT" AM squelch circuit, and a 2.5 second alarm circuit for fault detector operation are provided on this board. The circuits on the board are utilized to lockout the SKBU relay for channel failure, and noise conditions on the channel equipment. Where static distance fault detectors are used, an OR circuit is provided on this board to connect these fault detectors into the phase comparison system.

CARD EXTENDER

A card extender (Style No. 644B315G02) is available for facilitating circuit voltage measurements or major adjustments. After withdrawing any one of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all components and test points on the boards are readily accessible.

TEST POINTS

Test points are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front panel of the relay for convenience in adjusting and testing the relay.

OPERATION

A. SYSTEM

In phase comparison relaying, the phase positions of fault currents at the ends of a transmission line are compared over a pilot channel to determine if the fault is internal or external to the line section. When a tone or microwave channel is used as the pilot channel, the channel is separate from the protected line and a dual comparison transfer-trip system can be utilized. This means that the system can trip on either half cycle of the power system frequency as contrasted to a carrier channel where tripping occurs on alternate half-cycles during the absence of a carrier signal.

The three-phase line currents energize a sequence network in the SKBU relay which produces a single-phase output voltage proportional to a combination of sequence components of the line current. This single-phase voltage energizes the keying circuit of the SKBU relay to shift the frequency of the tone transmitter on alternate half-cycles of the power frequency current. The tone transmitter is shifted from a space frequency to a mark frequency. These frequencies are transmitted over the pilot channel to the tone receiver which converts the mark and space frequencies to two d.c. output voltages, a space output that corresponds to the space frequency and a mark output that corresponds to the mark frequency. Thus, on each half cycle of power system frequency either a space or mark output is obtained from the tone receiver and applied as pulses to the remote squaring amplifiers of the SKBU relay. Each of these half cycle pulses are compared with the phase positions of each half-cycle of the sine wave voltage from the sequence network of the SKBU relay at the tone receiver terminal. The space pulse is compared to one half cycle of the voltage and the mark pulse to the other half-cycle. If the local and remote half-cycle pulses are of the correct phase positions for an internal fault, after a 4 millisecond delay tripping will be initiated through operation of the flip-flop and trip amplifier circuits.

Current transformer connections to the sequence networks at the two line terminals are such that the space and mark pulses are in phase with their respective local pulses during an internal fault to allow tripping. However, if the fault is external to the protected line section, the space and mark pulses are out-of-phase with their respective local pulses and tripping does not occur.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals and relay co-ordination.

B. RELAY

With reference to either Figs. 1 or 2, the three phase line currents energize a sequence filter which gives a single phase output voltage proportional to a combination of sequence components of the line currents. This single phase output voltage is applied as inputs to two boards from the secondary of the saturating transformer:

1. Fault Detector Board (Phase Splitter Circuit)
2. Relay Board (Phase Delay Circuit)

1. Fault Detector Board

The a.c. voltage is applied to a phase-splitting network (C_{52}, R_{54}, R_{53}) and a polyphase rectifier (diodes D_{51} to D_{56}). The d.c. voltages so obtained requires a minimum of filtering (C_{53}) and responds rapidly to a change in magnitude of the a.c. output. This d.c. voltage is applied to the fault detector circuit which operates when the d.c. input "signal" exceeds a predetermined value.

Fault Detector

Under normal conditions, transistor Q_{51}, has no base "signal" and is turned off. The collector of Q_{51} is at a high enough positive potential to provide base drive for transistor Q_{52}, driving it to full conduction. With Q_{52} fully conducting there is no base drive to transistor Q_{53} and Q_{53} is turned off. With no Q_{53} collector current, the base of diode type transistor Q_{54} is supplied from the 45 volt source through the drop of D_{58}. Thus the Q_{54} emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q_{54} in a non-conducting state, equivalent to an open circuit. Zener diode Z_{53} is to protect transistor Q_{54} from external surge voltages.

When a fault causes the d.c. input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z_{52}, (through R_{55}, and S_1) a positive bias is applied to Q_{51} base causing it to conduct. In turn, Q_{52} stops conducting, and capacitor C_{55} charges, giving a few milliseconds time delay before Q_{53} and Q_{54} are switched to full conduction, thus "closing" the fault detector. The feedback resistors, R_{60} and S_2 provide a 90 percent dropout ratio with "toggle" action at the dropout point.

When the fault detector operates, positive 45 volts d.c. is applied to the output board at terminal 18. This 45 volts is applied to the flip-flop circuit at terminal 19 and to the transient blocking circuit through Zener diode Z_{302}. Thus, the fault detector arms the flip-flop and energizes the transient blocking of the SKBU relay.

2. Relay Board

The a.c. voltage from the saturating transformer is also applied to the relay board to the phase delay circuit through a low pass filter of the relay board. The low pass filter (C_{251}, L_{251}, C_{252}) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R_{251} and R_{252} of the phase delay circuit. By means of capacitor C_{253} and variable resistor S5, the voltage across terminal 4 and 2 can be made to lag the voltage across terminal 10 and 4 by a definite amount depending on the setting of S5. These voltages are applied to the amplifier and keying board of the SKBU relay.

1. Undelayed voltages to the keying circuit.
2. Delayed voltage to two local squaring amplifiers.

A. Keying Circuit

With no a.c. output voltage from the sequence network, transistor Q_{102} has no base signal. The collector of Q_{102} is at negative potential which allows base current to flow from positive 20 volts d.c. through the base of Q_{103} through R_{103} and R_{102} to negative. This applies positive 20 volts to the collector of Q_{103} to prevent base current from flowing to Q_{104}. Since Q_{104} is not conducting, transistor Q_{105} does not conduct and the collector of Q_{105} is held at positive potential. As a result, the voltage across R_{111} is zero with respect to positive 45 volts d.c. (terminal 14). Thus, the voltage applied to the tone transmitter is zero and the transmitter is not keyed. (Ref. Fig. 5).

When a sinusoidal voltage is applied to transistor Q_{102} from terminal 4 and 9 of the relay board, on the positive half cycle of voltage, terminal 9 is more positive than terminal 4 of the amplifier and keying board and Q_{102} does not conduct. However, on the negative half cycle of sine wave voltage, terminal 9 is more negative than terminal 4 and base current flows in Q_{102}. This turns Q_{103} off which in turn puts negative potential on R_{105}. When Q_{105} conducts its collector is connected to negative potential, and a negative voltage (with respect to positive 45 volts) appears across R_{111}. Thus, on alternate half cycles of the 60 cycle voltage from the low pass filter, a negative voltage appears across R_{111}. This voltage keys the tone transmitter to a mark condition.

B. Local Squaring Amplifiers (1 and 2)

There are two local squaring amplifiers in the SKBU relay. The square wave output voltages are functions of the a.c. voltage input to the amplifiers. The polarity of the outputs of the two amplifiers are such that one amplifier has an output when the other one does not.

With reference to amplifier number 1, with no a.c. input voltage Q_{107} is not conducting and R_{113} is at negative potential. As a result, the base of Q_{108} and Q_{110} is at a lower potential than the emitter of the transistors. Base current for both transistors flows from positive 20 volts through R_{114} and R_{113} to negative and both transistors conduct. With Q_{110} turned on, positive 20 volts appears across R_{117}.

With the application of a sine wave voltage to terminal 4 and 19 of the amplifier and keying board, on the positive half cycle of the voltage the base of transistor is more positive than the emitter and Q_{107} does not conduct. On the negative half cycle of sine wave voltage, the base is more negative than the emitter and Q_{107} conducts. Turning Q_{107} on applies positive 20 volts to R_{113} to cause Q_{108} to turn off. This causes Q_{110} to turn off such that negative potential is applied to R_{117}. Hence, on alternate half cycles of sine wave voltage, negative voltage appears across R_{117}. The voltage across this resistor is thus a square wave voltage ranging from 20 volts d.c. to zero volts d.c. depending upon the polarity of the voltage from the phase delay circuit.

Amplifier 2 is the same as amplifier number 1 except for the additional stage of Q_{120}. The output voltage from the amplifier appears across R_{140}. By applying the same analysis of amplifier 1 to amplifier 2, the output voltage across R_{140} is a square wave voltage of the reversed polarity than that across R_{117}.

3. Remote Squaring Amplifiers

For two terminal lines there are two remote squaring amplifiers in the SKBU relay. One amplifier is to connect the space output of the tone receiver to the SKBU while the other is to connect the mark output of the tone receiver to the SKBU. The space squaring amplifier consists of transistor Q_{151} on the supervision board, and Q_{111} on the Amplifier and Keying board. The Mark remote squaring amplifier consists of Q_{119} and Q_{120} on the Amplifier and Keying board.

The remote amplifiers are in one of three states:

1. Loss of channel state
2. Receiving space frequency only
3. Receiving alternate half cycles of space and mark frequency.

For a loss of channel, the tone receiver clamps its output to a mark condition. The space output from the tone receiver is zero with respect to positive 45 volts. This means that transistor Q_{151} is not conducting. Base drive to transistor Q_{111} is provided from positive 45 volts through R_{122} to negative. Q_{111} is turned on to provide a positive 20 volts across R_{121}. When the channel is in service and the receiver is in a space condition, transistor Q_{151} turns on. This applys positive 45 volts through resistor R_{123} and diode D_{102} to R_{122}. The potential of the base of transistor Q_{111} is raise higher than its emitter. Hence, transistor Q_{111} stops conducting and the voltage across R_{121} is zero. For the condition where the tone receiver is receiving pulses, transistor Q_{151} turns on and off every half cycle of power system frequency. Transistor Q_{111} turns on and off for the same half cycle and the voltage across R_{121} is a square wave voltage varying from 20 volts to zero.

The output of the mark remote squaring amplifier is the same as the space remote amplifier except that it operates off of the mark output of the tone receiver. The voltage is across R_{142}.

For either internal or external fault conditions the outputs of both remote squaring amplifiers are square wave voltages. Both voltages vary from zero volts to approximately 20 volts and are out of phase with each other, i.e., when one voltage is at zero volts the other voltage is at 20 volts.

4. AND Circuits

There are two AND circuits for comparing the phase relationship of the outputs of the local and remote squaring amplifiers. One AND circuit compares the Space signal with the output from amplifier number 1. The second AND circuit compares the Mark signal with the output of amplifier number 2. Since the local signals are always 180 degrees out of phase with each other and the remote signals are always 180 degrees out of phase with each other, a change in phase angle of one signal with respect to the other will allow one AND to trip.

Other inputs are shown into the AND circuits and these inputs are to clamp the SKBU in a non-operative state for noise conditions, and loss of signal.

The other AND circuits shown in the Fig. 2 are for the purpose of energizing the transient unblocking circuit under the condition of an external fault followed by an internal fault.

5. Output

A. 4/0 Millisecond Time Delay

The 4/0 time delay consists of R_{315}, C_{305}, R_{317}, R_{318}, and R_{319}. The charging path to negative for capacitor C_{305} is either through D_{215} and R_{201} or through D_{216} and R_{202} of the AND circuit. By maintaining a constant twenty volts on terminal 6 of the output board Capacitor C_{305} can not charge up and keeps base of Q_{305} of the flip-flop at positive potential.

Under external fault conditions, the square wave voltages from the remote squaring amplifiers and the square wave voltages from the local squaring amplifiers are out of phase such that a continuous 20 volts (positive signal) is received at terminal 6 of the output board. The output from local 1 and remote 3 are out of phase to prevent tripping on AND #1 and the outputs from local 2 and remote 4 are out of phase to prevent tripping on AND #2. C_{305} does not charge and transistor Q_{305} can not turn on.

Under internal fault conditions, the output voltage from one terminal of the sequence filter is 180 degrees out of phase with respect to its external fault polarity. This changes the polarity of amplifier #1 and amplifier #2 such that their outputs are in phase with the remote signals. This means that AND #1 has a half cycle of negative voltage and that AND #2 has a half cycle of negative voltage. The period of each negative voltage will be 180 degrees out of phase with each other. Capacitor C_{305} will charge up on the first negative voltage regardless if it is AND #1 or AND #2. After a calibrated time delay of 4 milliseconds, the voltage across C_{305}, which is applied to the base-emitter of transistor Q_{305} in the flip-flop circuit is sufficient to allow Q_{305} to conduct.

B. Flip-Flop

The flip-flop circuit consists of transistors Q_{305} and Q_{306} and associated components. Under normal conditions, transistor Q_{305} is in a non-conducting state, and transistor Q_{306} is fully conducting. The base of transistor Q_{306} is held well below its emitter potential by means of the voltage divider consisting of resistors R_{325}, R_{326}, D_{305}, and R_{327}. With this bias, transistor Q_{306} is held in saturation and the flip-flop is desensitized so that even if transistor Q_{305} turns on, transistor Q_{306} does not turn off. This desensitizing circuit is an arrangement to prevent inadvertent operation of the flip-flop in the presence of surges on the d-c system. As long as Q_{306} is conducting, its collector is at high enough positive potential such that transistor Q_{307} in the tripping amplifier cannot turn on.

Upon the occurrence of an internal fault, positive 45 volts d-c is applied from Q_{54} (FD) to terminal 18 of the Output board. This removes the desensitizing bias from transistor Q_{306} by making the potential of the junction of resistor R_{327} and diode D_{305} greater than the 20 volt supply for the flip-flop circuit. When this occurs, there is no current flow through resistor R_{326} and diode D_{305}, and the flip-flop is now "armed" or in a ready condition for a tripping operation. Since the pulses from the "AND" circuit are in phase, after a 4 millisecond delay, the potential across capacitor C_{305} is sufficient to cause Q_{305} to conduct. This immediately causes operation of the flip-flop, turning off transistor Q306. When Q_{306} is no longer conducting, the potential of the junction of R_{329} and R_{328} drops to a relatively low value. When this occurs, there is sufficient voltage across the base-emitter circuit of transistor Q_{307} in the trip amplifier to cause it to turn on.

C. Trip Amplifier

When transistor Q_{307} is turned on by operation of the flip-flop, base current flows from positive 20 volts through Z_{305}, the emitter-base junction of Q_{307}, and the resistors R_{328} and R_{329} to negative. The collector current of transistor Q_{307} flows through R_{330} and the base-emitter junction of output transistor Q_{308}. The collector of Q_{308} is connected to positive 45 volts d-c through R_{253} and the AR coil of the relay board. Collector current thus flows from positive 45 volts d-c through the AR coil, R_{253} to transistor Q_{308}, hence, the AR operates to trip the breaker.

D. Transient Blocking

When Q54 (FD) turns on, positive 45 volts is applied to terminal 18 of the output board, and energizes the transient blocking circuit. Base current is supplied to transistor Q_{302} through resistor, R_{305}, and Zener diode, Z_{302}. Transistor, Q_{302}, turns on to connect the base of transistor, Q_{303}, to negative. Q_{303} stops conducting and capacitor C_{303} starts to charge. When the charge on capacitor C_{303} is sufficient to cause the breakdown to Zener diode Z_{303}, it turns on transistor Q_{304}. This provides a conducting path from the base circuit of transistor Q_{306} in the flip-flop, diode D_{304}, the resistor R_{324}, and the collector emitter circuit of transistor Q_{304} to negative. This occurs after a time delay of 20 to 30 milliseconds and provides a path to apply a "desensitizing" bias to transistor Q_{306} in the flip-flop. Thus, the transient blocking circuit allows 20 to 30 milliseconds after the operation of FD for the flip-flop to operate and energize the output of the relay. If tripping does not occur in this time, as during an external fault, the operation of the transient blocking circuit desensitizes the flip-flop to prevent undesirable operation during 'transients associated with power reversals on the protective line or at the clearing of an external fault. The transient blocking circuit is cancelled either by FD resetting or by the operation of the transient unblocking circuit.

E. Transient Unblocking

If an internal fault occurs before an external fault is cleared, high speed tripping is obtained. The square wave output from the local and remote squaring amplifiers change from an out-of-phase condition to an in-phase condition. As a result, negative potential is applied to the transient unblocking circuit at terminal 9 of the Output board. Zener diode Z_{301} breaks down and base current flows through Z_{301}, emitter-base of Q_{301}, resistor R_{303}, diode D_{302}, and D_{301}, resistor R_{130}, and through the conducting transistor, Q_{304}, to negative. Transistor Q_{301} turns on to apply positive potential to resistor, R_{309}. Base current then flows through resistor R_{309}, to turn on transistor Q_{303}. Capacitor, C_{303}, will be rapidly discharged to remove the potential from the base of transistor, Q_{304}. Transistor Q_{304} turns off to interrupt the desensitizing circuit from the base of transistor Q_{306}. When this happens, the flip-flop will then be able to operate to provide an input to the trip amplifier.

6. Supervision Board

The circuits on the supervision board includes the auxiliary functions of the SKBU relay. The circuits on this board varies depending on the application of the relay. In general though, this board contains a loss of channel timer, relay operation timer, and noise clamp.

A. Loss of Channel (25/1.5 Timer)

With a serviceable channel either a space frequency or an alternate space mark frequencies are received from the tone equipment. Under this condition, Q_{151} of the supervision board is either turned on or is turned on and off. With Q_{151} turned on, base current is supplied to transistor Q_{152} and transistor Q_{152} conducts. The collector of Q_{152} is thus at negative potential and capacitor C_{151} can not charge.

If the channel is not serviceable, the tone receiver is clamped into a mark condition and the space output is zero. Transistor Q_{151} does not turn on under this condition and base drive is not supplied to transistor Q_{152}. Transistor Q_{152} turns off to apply positive potential to capacitor C_{151} through resistor R_{157}. After a 25 millisecond time delay, capacitor C_{151} charges sufficiently to breakdown Zener diode Z_{151}. When Z_{151} breaksdown, base drive is supplied to transistor Q_{153} and Q_{153} turns on. This connects the collector of Q_{153} to negative potential which allows base current to flow in transistor Q_{154} through R_{159}. This turns on transistor to apply positive voltage to R_{163}. This voltage is then applied to both AND circuits to lockout the SKBU relay and to the Alarm circuit. Base current is supplied to transistor Q_{165} through D_{164} and resistor, R_{190}. This turns on transistor Q_{165}, which connects its collector to negative potential. As a result, the base drive to transistor Q_{166} is shorted to negative and transistor Q_{166} turns off. Turning Q_{166} off interrupts coil current to the A1 coil on the relay board and the alarm drops out to close its contacts.

Under the condition of alternate mark and space outputs from the tone receiver, transistor Q_{151} is turned on and off every 8.3 milliseconds (half cycle of power system frequency). Every half cycle, capacitor C_{151} starts to charge but on the next half cycle Q_{152} turns on to discharge capacitor C_{151}. The charging time is not sufficient to allow capacitor C_{151} to breakdown Z_{151}.

B. Fault Detector Operation (2.5 Second Timer)

When the fault detector operates, positive 45 volts d.c. is applied to the base of transistor Q_{163} through diode D_{159} and resistor R_{184}. This turns on transistor Q_{163} to apply negative potential to the emitter of Q_{163}. This shorts the base current into transistor Q_{164} and turns Q_{164} off and capacitor C_{153} starts charging through resistor R_{191}. After 2.5 seconds, the voltage on C_{153} reaches a value to breakdown Z_{153}. This puts base current into transistor Q_{165} to turn Q_{165} on. The base drive to transistor Q_{166} is shorted to negative and Q_{166} turns off. This interrupts the coil current to the alarm unit to cause this unit to drop out and close its contacts.

C. Noise

The AM squelch interface of the SKBU relay consists of transistors, Q_{167}, Q_{168}, Q_{169} and associated components. Under normal conditions, the output from the AM squelch of the tone channel is zero. As a result, transistor Q_{167} is not conducting and base current is not supplied to transistor Q_{168}. Transistor Q_{168} is turned off and its collector is held at positive potential to prevent base current from flowing in transistor Q_{169}. Q_{169} is turned off and negative voltage (across R_{204}) is applied to the AND circuits under this condition.

Under noise conditions, the AM squelch of the tone equipment provides a negative output with respect to positive 45 volts d.c. This negative voltage allows transistor Q_{167} to turn on and provide base current to transistor Q_{168} through resistor R_{200}. This turns transistor Q_{168} on and connects its emitter to negative potential. Base current then flows in transistor Q_{169} through R_{202} to negative and Q_{169} turns on. This applys positive potential to resistor R_{204} to provide positive noise voltage to the AND circuits. This positive input locksout the SKBU relay until the condition of the channel equipment are normal.

D. Static Distance Fault Detectors

Where static distance fault detectors are used to supplement the SKBU relay, these fault detectors are connected into the SKBU relay through diodes D_{153}, D_{154}, and D_{155}. The circuit used in this connection consists of transistors Q_{159}, Q_{160}, Q_{161}, Q_{162} and associated components.

Under normal conditions the static relay shorts the base of transistor Q_{159} to negative. Q_{159} does not conduct and its collector is at positive potential. Base current is then applied to transistor Q_{160} through resistor R_{177} and Q_{160} turns on. With Q_{160} turned on, the base of Q_{161} is at negative potential and transistor Q_{161} does not conduct. Since Q_{161} is in a non-conducting state, transistor Q_{162} has no base drive and is not conducting.

When a static distance fault detector operates, base drive is applied to transistor Q_{159} through resistor R_{174}. Transistor Q_{159} turns on to short the input to the base of transistor Q_{160}. Transistor Q_{160} turns off to allow base drive into Q_{161} through resistor R_{180}. Transistor Q_{161} turns on to connect the base of transistor Q_{162} to negative through resistor R_{181}. Transistor Q_{162} then turns on and 45 volts d.c. is applied to the 2.5 second alarm timer and the arming circuit of the SKBU relay.

CHARACTERISTICS

The sequence network in the relay is arranged for several possible combinations of sequence components. For most applications, the output of the network will contain the positive, negative and zero sequence components of the line current. In this case, the T taps on the left-hand tap place indicate the balanced three phase amperes which will operate the fault detector FD. The taps available are 3, 4, 5, 6, 7, 8, and 10 and are on the primary of the saturating transformer. For distance fault detector applications, the user should reset the fault detector for a pick-up of twice tap value.

For phase-to-phase faults AB and CA, enough negative sequence current has been introduced to allow the fault detector to pick-up at 86 percent of the tap setting. For BC faults, the fault detector will pick-up at approximately 50 percent of the tap setting. This difference in pick-up current for different phase-to-phase faults is fundamental, and occurs because of the angles at which the positive and negative sequence components of current add together.

With the sequence network arranged for positive, negative and zero sequence output, there are some applications where the maximum load current and minimum fault current are too close together to set the relay to pick-up under a minimum fault current, yet not operate under load. For these cases, a tap is available on the SKBU relay which cuts the three-phase sensitivity in half, while the phase-to-phase setting is substantially unchanged. The relay then trips at 90 percent of tap value for AB and CA faults, and at twice tap value for three-phase faults. The setting for BC faults is 65 percent of tap value. In some cases, it may be desirable to eliminate response to positive-sequence current entirely, and operate the SKBU relay on negative-plus-zero sequence current. A tap is available to operate in this manner. The fault detector picks up at tap value for all phase-to-phase faults, but is unaffected by balanced load current or three-phase faults.

For ground faults, separate taps are available for adjustment of the ground fault sensitivity to about 1/4 or 1/8 of the left-hand tap plate setting. See Table II. For example, if the left-hand tap plate of the SKBU relay is set at tap 4, the fault detector pick-up current for ground faults can be either 1 or ½ ampere. In special applications, it may be desirable to eliminate response to zero sequence current. The relay is provided with a tap to allow such operation.

Operating Time:	12 to 20 Milliseconds
Alarm Time:	2.5 Seconds for Relay Operation 25 Milliseconds for Loss of Channel
Transient Blocking Time:	20 to 30 Milliseconds
Transient Unblocking Time:	20 to 30 Milliseconds
Ambient Temperature Range:	−20°C to +50°C
Drain on Regulator:	0.27a. at 45 V. D.C.
Dimensions:	Panel Height 8¾ Inch or 5 Rack Units Panel Width 19 Inch

ENERGY REQUIREMENTS

Burdens measured at a balanced three-phase current of five amperes.

	PHASE A		PHASE B		PHASE C	
Relay Taps	VA	Angle	VA	Angle	VA	Angle
A-F-3	2.4	5°	0.6	0°	2.5	50°
A-H-10	3.25	0°	0.8	100°	1.28	55°
B-F-3	2.3	0°	0.63	0°	2.45	55°
B-H-10	4.95	0°	2.35	90°	0.3	60°
C-F-3	2.32	0°	0.78	0°	2.36	50°
C-H-10	6.35	342°	3.83	80°	1.98	185°

Burdens measured at a single-phase to neutral current of five amperes.

	PHASE A		PHASE B		PHASE C	
Relay Taps	VA	Angle	VA	Angle	VA	Angle
A-F-3	2.47	0°	2.1	10°	1.97	20°
A-H-10	7.3	60°	12.5	53°	6.7	26°
B-F-3	2.45	0°	2.09	15°	2.07	10°
B-H-10	16.8	55°	22.0	50°	12.3	38°
C-F-3	2.49	0°	1.99	15°	2.11	15°
C-H-10	31.2	41°	36.0	38°	23.6	35°

The angles above are the degrees by which the current lags its respective voltage.

SETTINGS

The SKBU relay has separate tap plates for adjustment of the phase and ground fault sensitivities and the sequence components included in the network output. The range of the available taps is sufficient to cover a wide range of applications. The method of determining the correct taps for a given installation is discussed in the following paragraphs.

In all cases, the similar fault detectors on the relays at both terminals of a line section must be set to pick-up at the same value of line current. This is necessary for correct blocking during faults external to the protected line section.

SEQUENCE COMBINATION TAPS

The two halves of the right-hand tap plate are for connecting the sequence network to provide any of the combinations described in the previous section. The upper half of the tap plate or R_1 taps changes the tap on the third winding of the mutual reactor and thus changes the relative amounts of positive and negative sequence sensitivity. Operation of the relay with the various taps is given in the table on the next page.

TABLE I

COMB.	SEQUENCE COMPONENTS IN NETWORK OUTPUT	TAPS ON RIGHT HAND TAP BLOCK		FAULT DETECTOR PICK-UP	
		R_1	R_0	3ϕ FAULT	$\phi-\phi$ FAULT
1	Pos., Neg., Zero	C	G or H #	Tap Value	86% Tap Value (53% on BC Fault)
2	Pos., Neg., Zero	B ⌿	G or H	2 x Tap Value	90% Tap Value (65% on BC Fault)
3	Neg., Zero	A ⌿	G or H	—	100% Tap Value

— Taps F, G, and H are zero-sequence taps for adjusting ground fault sensitivity.

See section on zero-sequence current tap.

⌿ — When taps A and 3, or B and 3 are used, the relay pick-up currents for FD will be 10 to 15 percent higher than the indicated values because of the variation in self-impedance of the sequence network and the saturating transformer.

POSITIVE-SEQUENCE CURRENT TAP

The left-hand tap plate, T, has taps of 3, 4, 5, 6, 7, 8, and 10, which represent the three-phase, fault detector pick-up currents, when the relay is connected for positive, negative and zero sequence output. For distance fault detector applications, the user should reset the SKBU fault detector for a pick-up of twice tap value.

The T, R_0, and R_1 taps should be selected to assure operation on minimum internal line-to-line faults, and yet not operate on normal load current, particularly if the carrier channel is to be used for auxiliary functions. The dropout current of the fault detector is 90 percent of the pick-up current, and this factor must also be considered in selecting the positive-sequence current tap and sequence component combination. The margin between load current and fault detector pick-up should be sufficient to allow the fault detector to dropout after an external fault, when load current continues to flow.

ZERO-SEQUENCE CURRENT TAP – R_0 TAPS

The lower half of the right-hand tap plate (R_0 taps) is for adjusting the ground fault response of the relay. Taps G and H give the approximate ground fault sensitivities as listed in Table II. Tap F is used in applications where increased sensitivity to ground faults is not required. When this tap is used, the voltage output of the network caused by zero-sequence current is eliminated.

NOTE: Because of inherent characteristics of the sequence network, there will be small variations (from the values listed in Tables I and II) in the pick-up current for various phase or ground fault combinations.

TABLE II

Comb.	R_1 Tap	Ground Fault Pick-Up	Percent of T Tap Setting
		TAP G	TAP H
1	C	25%	12%
2	B	20%	10%
3	A	20%	10%

SETTING PRINCIPLES

Tap C provides the best balance between 3 phase and phase-to-phase fault sensitivity. Always use this tap where distance fault detector supervision is used. Where only the SKBU fault detector is used and where the full load current (maximum through any terminal) is approximately five amperes or more, tap B will provide increased phase-to-phase fault sensitivity with little or no sacrifice in 3 phase fault sensitivity. For example, if a left-hand tap (T) of 6 is needed with tap C (6C), then use a 3B setting instead.

Use tap A only where satisfactory unbalanced fault sensitivity cannot otherwise be obtained and where other protection is available for 3 phase faults, since with tap A no 3 phase fault protection is available.

In all cases provide identical response at all stations to insure adequate keying voltage from the filter for any fault detector by remote-end relay. That is, the taps should be identical with identical CT ratios, or inversely proportional to CT ratios where different.

After selecting tap C or B, pick the T tap to allow reset of the fault detector in the presence of load flow that is, fault detector pick-up should be at least 111 percent of full load current (maximum through any terminal).

Now select tap G or H for desired ground-fault sensitivity.

For distance fault detector applications, set 3C to provide the maximum sequence-filter voltage for the squaring amplifiers. The SKBU current fault detector is then independently desensitized (by adjustment of S1 and S2 settings) to permit reset in the presence of full-load current. Phase faults which do not operate the SKBU fault detector will be detected by only the supplementary distance fault detectors (not part of SKBU relay).

EXAMPLE

Assume a two-terminal line with current transformers rated 400/5 at both terminals. Also assume that full load current is 300 amperes, and that on minimum internal phase-to-phase faults 2000 amperes is fed in from one end and 600 amperes from the other end. Further assume that on minimum internal ground faults, 400 amperes is fed in from one end, and 100 amperes from the other end. No distance fault detectors are employed.

POSITIVE-SEQUENCE CURRENT TAP

Secondary Values:

$$\text{Load Current} = 300 \times \frac{5}{400} = 3.75 \text{ amperes} \qquad (1)$$

Minimum Phase-to-Phase Fault Currents:

$$600 \times \frac{5}{400} = 7.5 \text{ amperes} \qquad (2)$$

Fault detector setting (three phase) must be at least:

$\frac{3.75}{0.9} =$ 4.7 amperes 0.9 is dropout ratio of fault detector fault so that the fault detector will reset on load current. (3)

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector pick-up (three-phase) must be not more than:

$$7.5 \times \frac{1}{0.87} = 8.7 \text{ amperes} \qquad (4)$$

SEQUENCE COMBINATION TAP

From a comparison of (3) and (4) above it is evident that the fault detector can be set to trip under minimum phase fault conditions and yet not operate under maximum load. From (3) we can select tap 5 (T). In this case, also select tap C (R_1). However, if more margin is desired over load current, instead of setting 6C, use 3B for improved phase-to-phase fault sensitivity.

ZERO SEQUENCE TAP

Secondary Value:

$$100 \times \frac{5}{400} = 1.25 \text{ amperes minimum ground fault fault current}$$

With T, tap 3 and R1, Tap 8 in use, the fault detector pick-up currents for ground faults are as follows:

Tap G 0.2 x 6 = 1.2 ampere

Tap H 0.1 x 6 = 0.6 ampere

From the above, tap H would be used to trip the minimum ground fault of 1.25 amperes.

INSTALLATION

The SKBU relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The SKBU relay is normally supplied as part of a relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the SKBU relay is not a part of a relaying system, the following procedure can be followed to verify that the circuits of the SKBU relay are functioning properly.

TEST EQUIPMENT:

1. Oscilloscope
2. A.C. Current Source
3. Electronic Timer
4. A.C. Voltmeter
5. D.C. Voltmeter

ACCEPTANCE TEST

Connect the relay to the test circuit of Fig. 6 which represents the tone channel for test purposes.

Open all test switches of the test circuit and connect a 60 cycle test current between terminals 3 and 4 of the relay. Set relay taps on C and H and remove T tap screw.

1. FILTER OUTPUT

a. Connect a high resistance a-c voltmeter across common of T tap block and the common of Ro tap block.

b. Pass 3.44 amperes, 60 cycles into terminal 3 and out terminal 4 of relay. Voltmeter should read between 0.75 volts and 0.85 volts a-c.

2. FD PICK-UP AND DROPOUT

a. Set relay taps 5, C and H. Open all switches of test circuit.

b. Connect a high resistance d-c voltmeter across X22 and X4 (Neg.)

c. Apply 60 cycle current to terminals 3 and 4 of the relay. Gradually increase the current until the voltmeter changes reading from approximately zero volts to approximately 20 volts. This is the operating current of FD and should be 4.33 ± 5% amperes.

d. Gradually lower a-c test current until the d-c voltmeter drops to approximately zero volts. This is the dropout current of FD and should occur at 90% of the pick-up current.

3. CHECK OF LOCAL SQUARING AMPLIFIERS

a. With all switches of test circuit open, apply 5 amperes a.c. to terminals 3 and 4 of the relay.

b. Place scope probe across X12 and X4 (grd). A square wave of voltage should appear across X12 and X4 as shown in Table III.

c. Place scope probe across X15 and X4 (grd). A square wave of voltage should appear across X15 and X4 as shown in Table III.

d. If scope has two traces, connect one probe to X12 and second probe to X15. Connect grd. of scope to X4. The phase relationship of Table III should be observed.

4. CHECK OF KEYING CIRCUIT

a. With all switches of test circuit open and 5 amperes a.c. applied to terminal 3 and 4 of the relay, with scope check voltage across X14 and X4 (grd).

b. Waveform shown in Table III should be observed.

5. CHECK OF REMOTE SQUARING AMPLIFIERS

a. Close switches A, B, and C of test fixture. (If three terminal application E and F should also be closed).

b. Apply 5 amperes a.c. to terminals 3 and 4 of the SKBU relay.

c. Using scope with grd. lead on X4, check waveshape of voltage across X9 and then X11. (For three terminal lines, check X16 and X13 also). Waveforms of Table III (Fig. 7) should be observed.

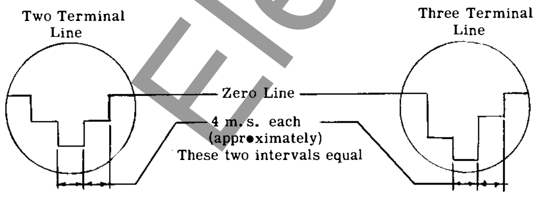
d. If scope has two traces, connect one probe to X9 and the other on X11. Connect grd. to X4. With scope set on chopped, the phase relationship of Table III should be observed. (For three terminal lines the phase relationship of X16 and X13 should be observed).

6. SETTING OF S5 AND S6

a. Set S5 to minimum resistance and S6 to maximum resistance (fully clockwise).

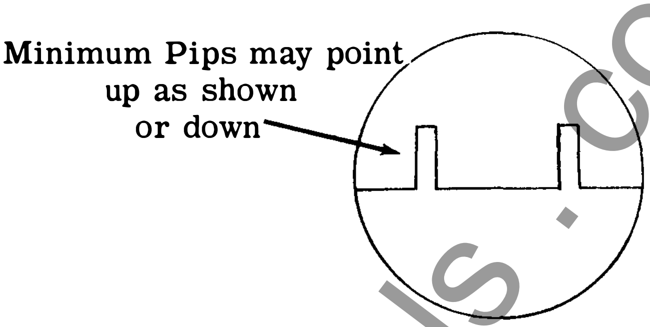
b. Set switch L to external fault and close switches A, B, and C of the test circuit. Apply 5 amperes a.c. to terminals 3 and 4 of the SKBU relay. (Switches E and F should be closed on three terminal applications.)

c. Place scope across X10 and X2 (grd). Adjust S5 until following waveform appears on scope.



d. Close switch H and adjust S6 until AR trips. This sets the triggering of the flip-flop after a 4 millisecond delay.

e. Slowly increase S5 to obtain the following waveform. This will be with S5 at or near minimum resistance.



7. TRANSIENT BLOCKING DELAY

a. Connect electronic timer stop to X7 and X4 (grd). Set timer stop on negative going pulse.

b. Connect timer start to timer start contacts of switch H. Set timer to make.

c. Apply 5 amperes a.c. to terminals 3 and 4 of the SKBU relay.

d. Close switch H (all other switches should be open). Measure time for voltage to drop from 20 volts to approximately zero volts. This should be between 20 to 30 millisecond. Take average of ten readings.

8. CHECK OF TRANSIENT UNBLOCKING CIRCUIT

a. With electronic timer stop connected to X7 and X4 (grd), set timer stop on positive going pulse.

b. Connect timer start to timer start contacts of switch C. Set L on internal fault, and open other switches of test circuit.

c. Apply 5 amperes a.c. into terminal 3 and 4 of the SKBU relay. Close switch A.

d. Close switch H and then switches E and F for a three terminal line. After a short pause, close switches B and C simultaneously. Timer should start and should stop after a time delay.

e. Check timing several times by first closing switch H, pausing to let transient blocking to occur, and then closing switch B and C. Time should be 20 to 30 milliseconds. Measure average of 10 trials.

9. LOSS OF SIGNAL TIMER

a. With electronic timer stop connected to X20 and X4 (grd), set timer stop on positive pulse.

b. Connect timer start to start contacts of switch C. Set time start to break.

c. Close switch C. Alarm relay should pick-up.

d. Open switch C. Timer should start and should stop after 23 to 27 milliseconds.

e. If a three terminal application repeat above except use X18 and switch F for timing function.

10. ALARM ON RELAY OPERATION (2.5 Seconds)

a. With electronic timer stop connected to X20 and X4 (grd), set timer on positive going pulse.

b. Connect timer start to contacts of switch H. Set timer start on break.

c. Apply 5 amperes a.c. to terminals 3 and 4 of SKBU relay.

d. Close switch H. Timer will start and should stop after 2.3 to 2.7 seconds.

11. CHECK OF PROTECTIVE RELAY INTERFACE CIRCUIT (Where Used)

a. Connect d.c. voltmeter across X8 and X4 (neg). Voltage should be 9 to 15 volts.

b. Close switches A, B, C, H of test circuit. Set L on internal fault. (On these terminal line applications close E and F also).

c. Close switch I of test circuit.

1. Voltage should change to approximately 20 volt.
2. AR relay wire operate.
3. Alarm relay should drop out after a time delay.
4. Repeat step C except wire switches J and K. Some results should occur. Only one switch either I, J, or K should be closed at a time.

12. CHECK OF AM SQUELCH CIRCUIT

a. Connect d.c. voltmeter across X17 and X4 (neg). Should read zero volts.

b. Close switches A, B, C, and H of test circuit. For three terminal application close switches E and F also. Set L on internal fault.

c. Close switch D. Voltage should change to 20 volts.

d. Apply 5 amperes a.c. to terminal 3 and 4 of the relay. AR relay should not operate.

e. Open switch D. AR relay will operate.

f. For three terminal line repeat steps C, D, and E except use switch G.

ROUTINE MAINTENANCE

All contacts should be periodically cleaned. A contact burnisher S#182A836H01 is recommended. The use of abrasive material is not recommended because of the danger of embedding small particles in the face of the soft silver and thus impairing the contact.

CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs. The relay should be connected to the test circuit of Fig. 6.

1. SEQUENCE FILTER

To calibrate the sequence filter, the top cover must be removed and the following procedure used: Remove the T tap screw and insert the tap screws in tap C and H of the R_1 and R_0 taps. Pass a single-phase current of 10 amperes, rated frequency through the reactor coils in series from phase B to phase C (relay terminals 4 and 5). Accurately measure the a-c voltage from terminal 3 to the common of the T tap plate. This voltage should be between 3.7 and 4.1 volts. Now pass 10 amperes from terminal 3 to terminal 4 with tap screw C removed, and connect voltmeter from terminal 3 to the right-hand (front R_0 view) adjustable point of the formed resistor. Adjust this point to give a voltage equal to exactly one-third of the reactor drop. Note the above reading, and adjust the intermediate tap of formed resistor to give exactly 2/3 of the voltage obtained above for all of formed resistor. Measure this voltage from terminal 3 to the intermediate tap.

2. PHASE SPLITTER

If replacement of the fault detector board or major component on the board necessitates a complete recalibration, proceed as follows:

a. Set relay taps 5-C-H.

b. Set S1 to full clockwise position.

c. Set S2 to mid-scale.

d. Pass 4.33 amperes through relay terminal 3 to terminal 4.

e. On fault detector board, check the a-c voltage from TP51 to TP52 and from TP52 to TP53 with a VTVM. Adjust the small pot. R53 on the fault detector board until these two voltages are equal.

f. Close all switches of test circuit and connect VTVM across X22 and X4 (Neg.).

g. Slowly turn S1 counterclockwise, with 4.33 amperes flowing, until FD operates as indicated by a change in voltage reading from approximately zero volts to 45 volts d-c.

h. Reduce the a-c current to check FD dropout. Adjust S2 to obtain 90 percent dropout (3.89 amperes). Dropout is indicated by a change in voltage reading from approximately 45 volts to 0 volts.

i. Recheck FD pick-up and dropout, and touch up S1 and S2 in that order for the correct calibration. Tighten the locking device.

3. TRIPPING RELAY (AR)

The type AR tripping relay unit has been properly adjusted at the factory to insure correct operation and should not be disturbed after receipt by the customer. If, however, the adjustments are disturbed in error, or it becomes necessary to replace some part in the field, use the following adjustment procedure. This procedure should not be used until it is apparent that the AR unit is not in proper working order, and then only if suitable tools are available for checking the adjustments.

a. Adjust the set screw at the rear of the top of the frame to obtain a 0.009 inch gap at the rear end of the armature air gap.

b. Adjust each contact spring to obtain 4 grams pressure at the very end of the spring. This pressure is measured when the spring moves away from the edge of the slot in the insulated crosspiece.

c. Adjust each stationary contact screw to obtain a contact gap of 0.020 inch. This will give 15-30 grams contact pressure.

4. CHECK OF SOLID-STATE CIRCUITS

Perform test listed under "Acceptance" tests to verify that the SKBU relay is functioning correctly.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram of either Fig. 3 or 4, voltages of Table III, should be used to isolate the circuit that is not performing correctly. The schematic of either Fig. 1 or 2, and the voltages of Table IV should then be used to isolate the faulty component.

TABLE IV

VOLTAGE MEASUREMENTS OF PRINTED CIRCUIT BOARD

1. FAULT DETECTOR BOARD

D-C Voltages – positive with respect to negative d-c (terminal 8 of board).

Test Point	$I_{a.c.} = 0$	$I_{a.c.} = 2 \times FD_{p.u.}$
Terminal 14	45.0 V. D.C.	45.0 V. D.C.
TP 56	14.5	less than 1
TP 57	less than 1	14.5
TP 58	45	less than 1
Terminal 15 FD	less than 1	45
TP 52 – TP 51	less than 1	18 V. A.C. approx.
TP 52 – TP 53	less than 1	17.8 V. A.C. approx.

2. AMPLIFIER AND KEYING

D-C Voltages – positive with respect to negative (terminal 8 of board).

Test Point	Normal	Fault
Terminal 4	20	20
TP 101	20	10
TP 102	20.3	19.8
TP 103	less than 1	10
Terminal 3	less than 1	9.8

3. OUTPUT BOARD

D-C Voltages – positive with respect to negative (terminal 8 of board).

Test Point	Normal	Fault
TP 302	19.5	19.0
TP 301	10	8.5
Terminal 14	20	19.0

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give the circuit symbol and the electrical value (ohms, mfd, etc.) and component style No.

ELECTRICAL PARTS LIST

Circuit Symbol	Description	Westinghouse Style No.
FAULT DETECTOR BOARD		
	Capacitor	
C51	0.10 MFD	1544920
C52-C55	0.5	187A624H11
C53	0.25	187A624H02
C54	1.5	187A508H09
	Diodes	
D51 to D56	1N459A	184A855H08
D57 to D59	1N457A	184A855H07
	Transistors	
Q51-Q52	2N697	184A638H18
Q53	2N699	184A638H19
Q54	2N2043	184A638H21
	Resistors	
R51	50 Ohm, 5W	185A209H06
R53	2.5K Ohm, Pot.	629A430H03
R54	2.7K Ohm, ½W	629A530H42
R55-R73-R78	10K Ohm, ½W	629A530H56
R60	12K Ohm, ½W	184A763H53
R61	.22 Meg. Ohm, ½W	184A763H83
R62-R64-R68	10K Ohm, ½W	187A641H51
R63	.1 Meg. Ohm, ½W	187A641H75
R65	68K Ohm, ½W	187A641H71
R66	100K Ohm, ½W	184A763H75
R67	39K Ohm, ½W	187A641H65
R69	1K Ohm, ½W	187A641H27
R70	6.8K Ohm, ½W	187A641H47
	Zener Diodes	
Z51	1N1832C	184A617H06
Z52	1N957B	186A797H06
Z53	1N1789	584C434H08
SUPERVISION BOARD		
	Capacitor	
C151-C152	4.7 MFD	184A661H12
C153	68 MFD	187A508H02
	Diodes	
D151 to D166	1N457A	184A855H07
	Transistors	
Q151-Q155-Q162-Q167	2N2043	184A638H21
Q152-Q153-Q156-Q157-Q163-Q165-Q168	2N697	184A638H18
Q154-Q158-Q169	2N1132	184A638H20
Q159-Q160-Q164	2N696	762A585H01
Q161-Q166	2N699	184A638H19

ELECTRICAL PARTS LIST (Cont.)

Circuit Symbol	Description	Westinghouse Style No.
SUPERVISION BOARD (Cont.)		
Resistors		
R151-R153-R155-R156-R160-R161-R164-R166-R167-R171-R173-R176-R179-R183-R186-R192-R194-R196-R197-R199-R203	10K Ohm, ½W	184A763H51
R152-R162-R182-R189-R198	1K Ohm, ½W	184A763H27
R154-R158-R165-R169-R201	47K Ohm, ½W	184A763H67
R157-R168	5.6K Ohm, ½W	184A763H45
R163-R172-R204	4.7K Ohm, ½W	184A763H43
R159-R170	18K Ohm, ½W	184A763H57
R179-R175-R173-R187-R191	33K Ohm, ½W	184A763H63
R177-R180-R181-R202	20K Ohm, ½W	184A763H58
R184-R200	100K Ohm, ½W	184A763H75
R185	68K Ohm, ½W	184A763H71
R188	30K Ohm, ½W	184A763H62
R190	51K Ohm, ½W	184A763H68
R193	12K Ohm, ½W	184A763H53
R195	3.3K Ohm, ½W	184A763H39
Zener Diode		
Z151-Z152	1N957B	186A797H06
Z153	1N3686B	185A212H06
AMPLIFIER AND KEYING BOARD		
Diode		
D101 to D107	1N457A	184A855H07
Transistors		
Q101 to Q104-Q106 to Q118-Q120-Q122	2N652A	184A638H16
Q105	2N697	184A638H18
Q119-Q121	2N2043	184A638H21
Resistors		
R101-R112-R122-R126-R128-R139-R144	100K Ohm, ½W	187A641H75
R102	150K Ohm, ½W	184A763H79
R103	33K Ohm, ½W	187A641H63
R104	68K Ohm, ½W	187A641H71
R105	27K Ohm, ½W	187A641H61
R106-R117-R121-R125-R138-R142-R146	4.7K Ohm, ½W	187A641H43
R107-R108-R135-R136-R137	10K Ohm, ½W	187A641H51
R109	3.3K Ohm, ½W	184A763H39
R110	6.8K Ohm, ½W	187A641H47
R11	5K Ohm, ½W	184A763H44
R113-R129	180K Ohm, ½W	187A641H81
R114-R115-R130-R131	22K Ohm, ½W	187A641H59
R116-R119-R132	47K Ohm, ½W	187A641H67
R118-R120-R124	470K Ohm, ½W	187A641H91
R123-R127-R140-R145	39K Ohm, ½W	187A641H65
R133-R134	15K Ohm, ½W	187A641H55
R141-R143	1K Ohm, ½W	187A641H27
AND BOARD		
Diode		
D204 to D232	1N457A	184A855H07
Resistors		
R203	22K Ohm, ½W	184A763H59
R201-R202	47K Ohm, ½W	184A641H67

ELECTRICAL PARTS LIST (Cont.)

Circuit Symbol	Description	Westinghouse Style No.
	OUTPUT BOARD	
C301	1.5 MFD	187A508H09
C302	0.25 MFD	187A624H02
C303	3.0 MFD	188A293H06
C304-C306	0.05 MFD	187A624H08
C305	0.22 MFD	188A293H02
	Diodes	
D301-D304-D305-D306	1N457A	184A855H07
D302-D303	1N91	182A881H04
	Tronsistor	
Q301-Q305-Q306-Q307	2N652A	184A638H16
Q302-Q303-Q304	2N697	184A638H18
Q308	2N699	184A638H19
	Resistors	
R301-R303-R309-R310-R313-R324-R325	10K Ohm, ½W	187A641H51
R302	120K Ohm, ½W	187A641H77
R304	47K Ohm, ½W	187A640H17
R305	8.2K Ohm, ½W	187A641H49
R306-~~R11~~5-R322	4.7K Ohm, ½W	187A641H43
R307-R331	2.2K Ohm, ½W	187A641H35
R308-R320	6.8K Ohm, ½W	187A641H47
R311	470 Ohm, ½W	187A641H19
R312	470K Ohm, ½W	187A641H91
R314	22K Ohm, ½W	184A763H59
R316-R321-R323	22K Ohm, ½W	187A641H59
R317-R328-R332	5.6K Ohm, ½W	184A763H45
R318	15K Ohm, ½W	187A641H55
R319	Thermistor 1D101	185A211H04
R326-R329	4.7K Ohm, ½W	184A763H43
R327	6.8K Ohm, ½W	184A763H47
R330	1.5K Ohm, ½W	187A641H31
	Zener Diode	
Z301-Z303-Z305	1N957B	186A797H06
Z302	1N965B	186A797H08
Z304	1N960B	186A797H10
Z306	1N1789	584C434H08
	RELAY BOARD	
	Capacitors	
C251-C252-C253	0.25 MFD	187A624H02
	Resistors	
R251-R252	2.2 Ohms, ½W	187A641H35
R253	800 Ohms, 3W	184A859H06
	Filter-Choke	
L251	8.5 HY, 400 Ohm	188A460H01
	Alarm	
AR	Telephone Relay	408C062H07
	Trip	
AR	AR Unit (2NC-2NC)	408C845G09

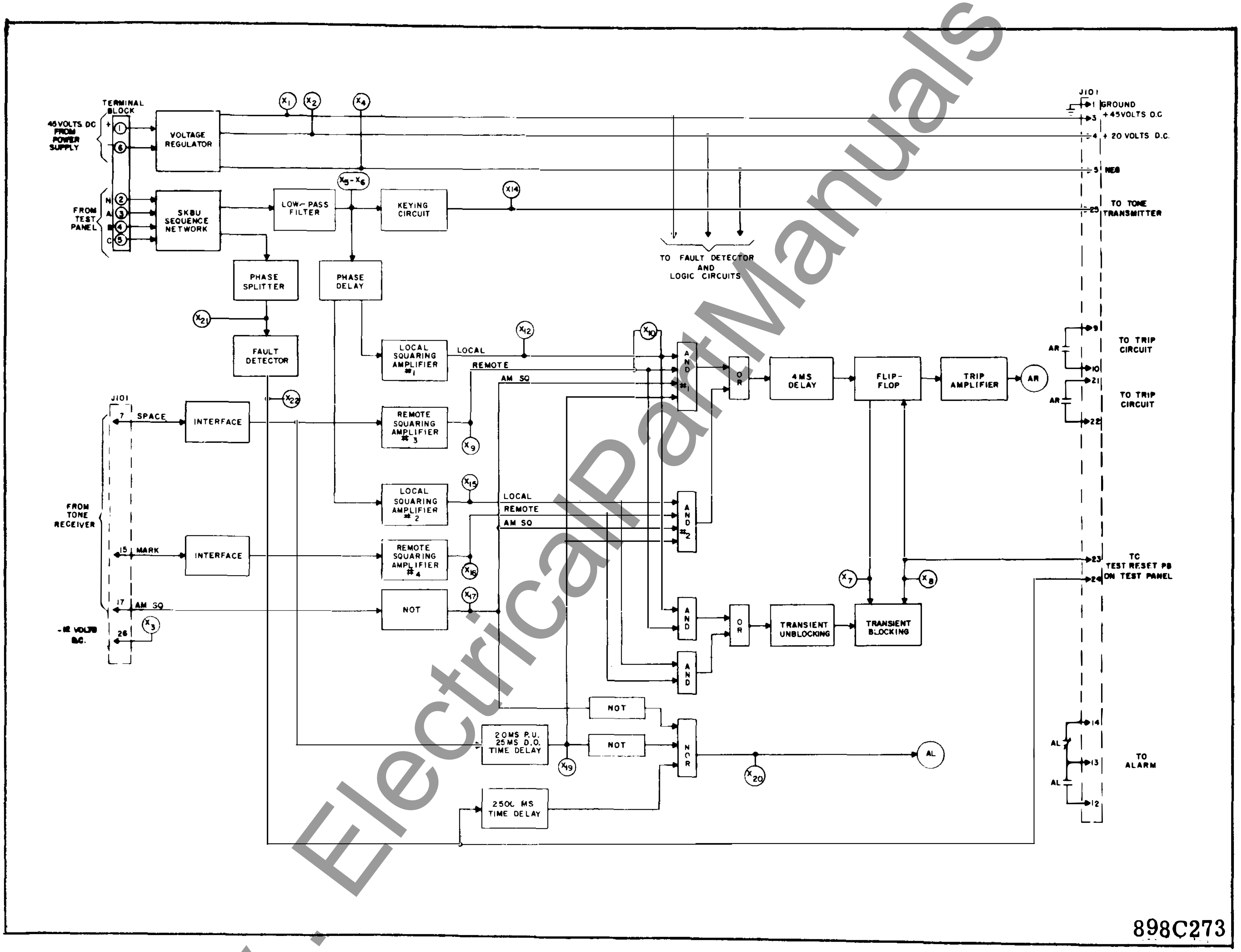


Fig. 1. Logic Diagram of SKBU Relay for Two Terminal Line

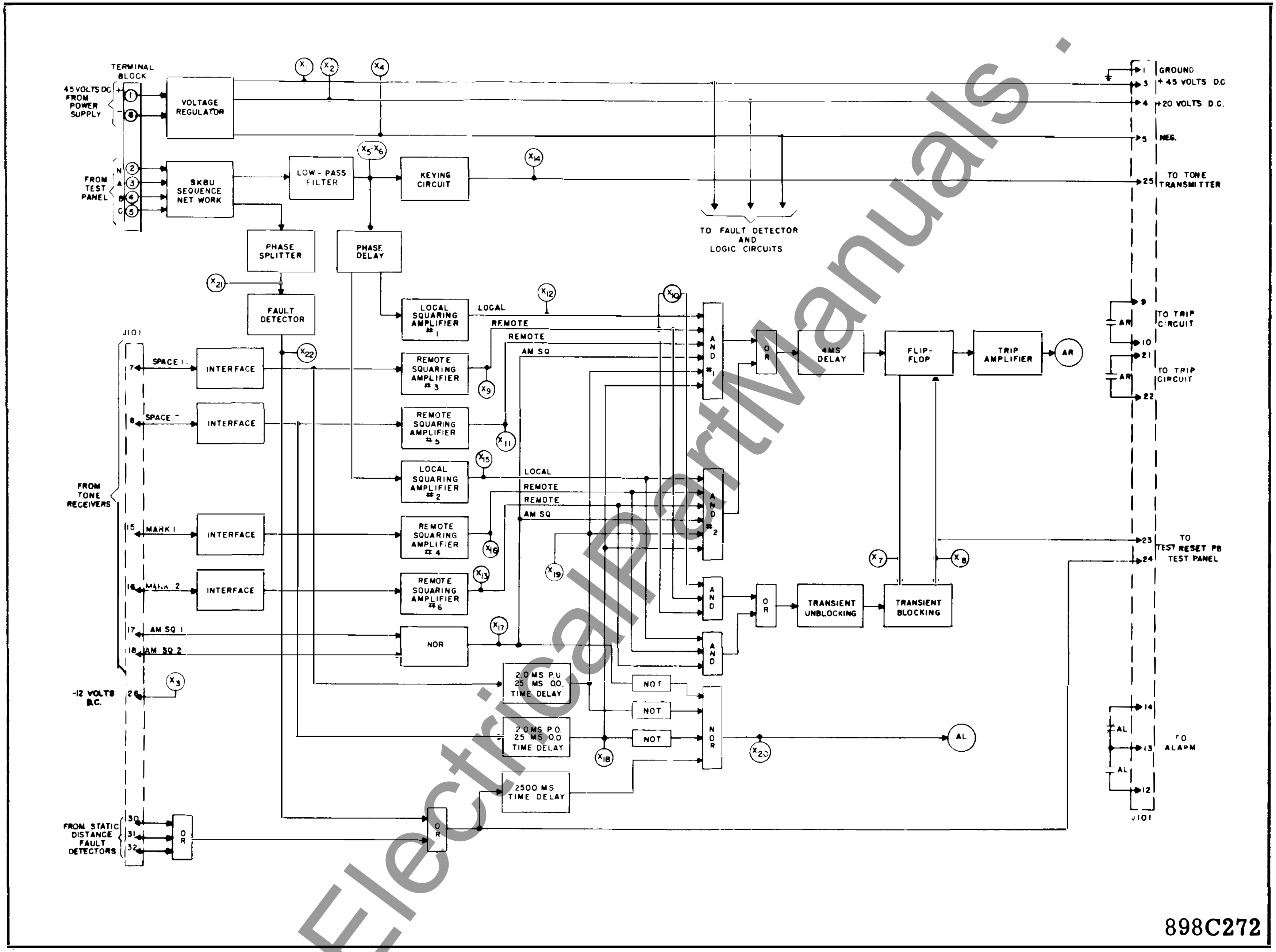


Fig. 2. Logic Diagram of SKBU Relay for Three Terminal Line with Distance Fault Detectors.

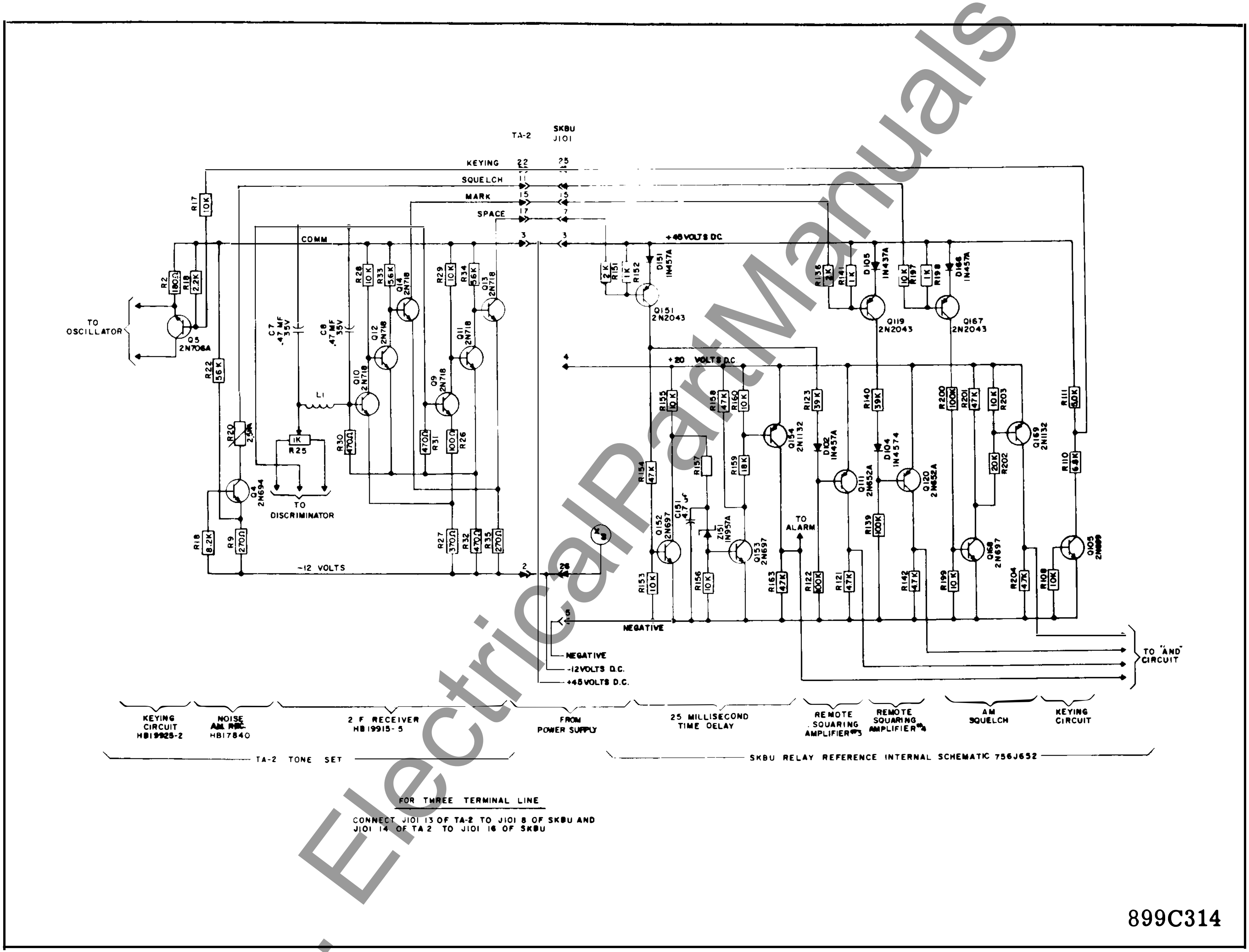
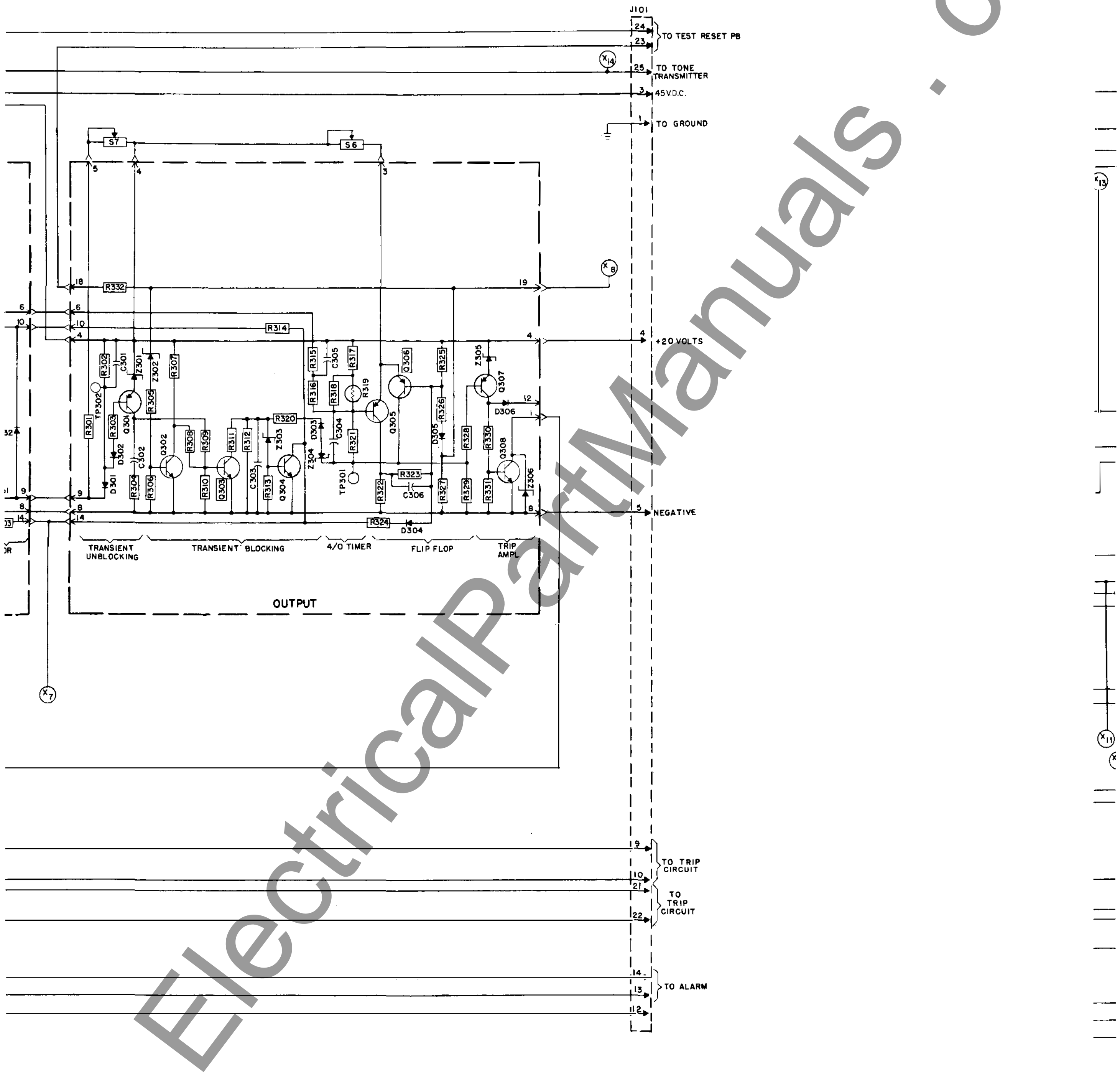


Fig. 3. Elementary Connections of TA-2 Tone Channel to SKBU Relay


J101
24
23
TO TEST RESET PB
X14
25
TO TONE TRANSMITTER
3
45 V.D.C.
1
TO GROUND
S7
S6
5
4
3
X8
X13
18
R332
19
6
10
R314
4
+20 VOLTS
R302
C301
Z301
Z302
R307
R315
C305
R317
Q306
R325
Z305
Q307
TP302
Q301
R305
R316
R318
R319
Q305
R326
12
D306
1
R301
R303
R320
C304
D303
D305
R328
R330
Q308
32
D302
C302
Q302
R308
R309
R311
R312
Z303
R321
Q303
C303
Z304
Q304
TP301
R323
R322
C306
R327
R329
R331
Z306
D301
R304
R306
R310
R313
9
8
14
R324
D304
NEGATIVE
TRANSIENT UNBLOCKING
TRANSIENT BLOCKING
4/0 TIMER
FLIP FLOP
TRIP AMPL
OUTPUT
X7
X11
9
10
TO TRIP CIRCUIT
21
22
TO TRIP CIRCUIT
14
13
12
TO ALARM

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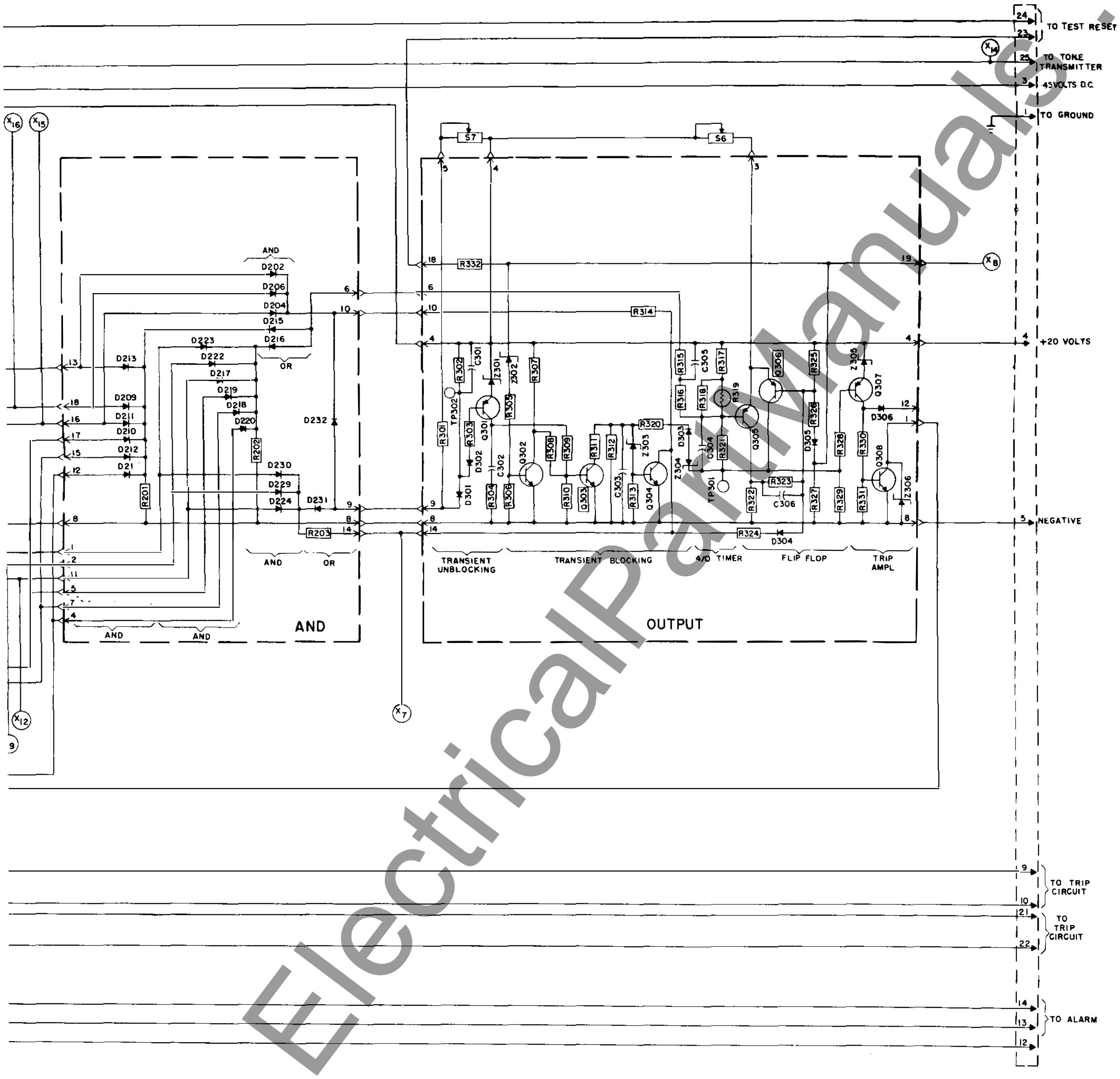

TO TEST RESET PB
TO TONE TRANSMITTER
45VOLTS D.C.
TO GROUND
+20 VOLTS
NEGATIVE
TO TRIP CIRCUIT
TO TRIP CIRCUIT
TO ALARM
S7
S6
R332
R314
AND
OR
AND
AND
AND
OR
AND
OUTPUT
TRANSIENT UNBLOCKING
TRANSIENT BLOCKING
4/0 TIMER
FLIP FLOP
TRIP AMPL
D202
D206
D204
D215
D216
D223
D222
D217
D219
D218
D220
D213
D209
D211
D210
D212
D21
D230
D229
D224
D231
D232
R201
R202
R203
R301
R302
R303
R304
R305
R306
R307
R308
R309
R310
R311
R312
R313
R315
R316
R317
R318
R319
R320
R321
R322
R323
R324
R325
R326
R327
R328
R329
R330
R331
C301
C302
C303
C304
C305
C306
Q301
Q302
Q303
Q304
Q305
Q306
Q307
Q308
Z301
Z302
Z303
Z304
Z305
Z306
D301
D302
D303
D304
D305
D306
TP301
TP302
X16
X15
X14
X8
X7
X12

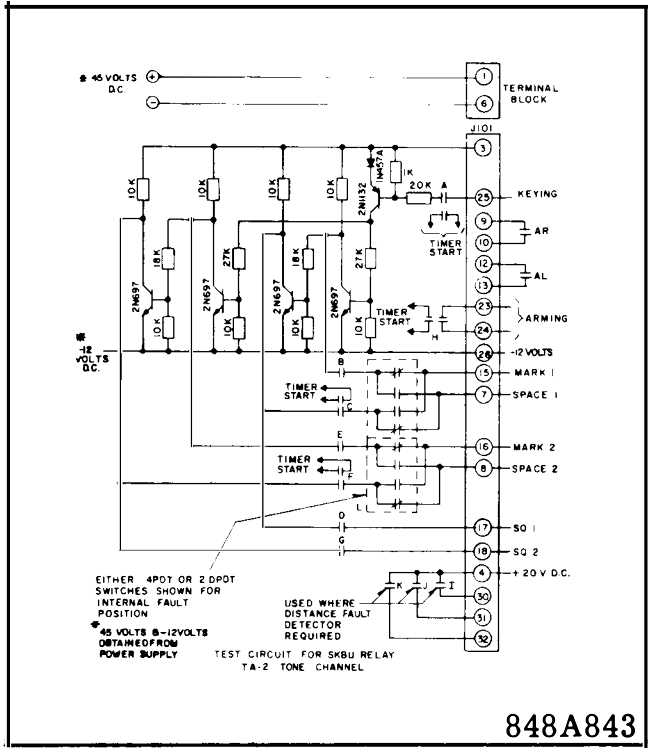

Fig. 6. Test Circuit of SKBU Relay.

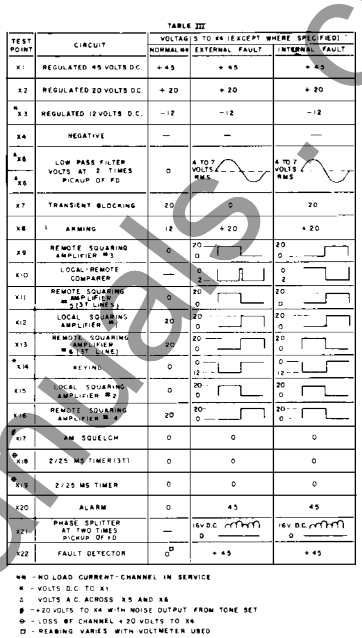

TABLE III

TEST POINT	CIRCUIT	VOLTAGES TO X4 (EXCEPT WHERE SPECIFIED)		
		NORMAL **	EXTERNAL FAULT	INTERNAL FAULT
X1	REGULATED 45 VOLTS D.C.	+ 45	+ 45	+ 45
X2	REGULATED 20 VOLTS D.C.	+ 20	+ 20	+ 20
*X3	REGULATED 12 VOLTS D.C.	− 12	− 12	− 12
X4	NEGATIVE	—	—	—
ΔX5 ΔX6	LOW PASS FILTER VOLTS AT 2 TIMES PICKUP OF FD	0	4 TO 7 VOLTS RMS	4 TO 7 VOLTS RMS
X7	TRANSIENT BLOCKING	20	0	20
X8	ARMING	12	+ 20	+ 20
X9	REMOTE SQUARING AMPLIFIER #3	0	20 0	20 0
X10	LOCAL-REMOTE COMPARER	—	0 2	0 2
X11	REMOTE SQUARING AMPLIFIER #5 (3T LINES)	0	20 0	20 0
X12	LOCAL SQUARING AMPLIFIER #1	20	20 0	20 0
X13	REMOTE SQUARING AMPLIFIER #6 (3T LINE)	20	20 0	20 0
*X14	KEYING	0	0 12	0 12
X15	LOCAL SQUARING AMPLIFIER #2	0	20 0	20 0
X16	REMOTE SQUARING AMPLIFIER # 4	20	20 0	20 0
ØX17	AM SQUELCH	0	0	0
⊖X18	2/25 MS TIMER (3T)	0	0	0
⊖X19	2/25 MS TIMER	0	0	0
X20	ALARM	0	45	45
X21	PHASE SPLITTER AT TWO TIMES PICKUP OF FD	—	16V D.C 0	16V D.C. 0
X22	FAULT DETECTOR	0□	+ 45	+ 45

** - NO LOAD CURRENT-CHANNEL IN SERVICE
* - VOLTS D.C. TO X1
Δ VOLTS A.C. ACROSS X5 AND X6
Ø - +20 VOLTS TO X4 WITH NOISE OUTPUT FROM TONE SET
⊖ - LOSS OF CHANNEL + 20 VOLTS TO X4
□ - READING VARIES WITH VOLTMETER USED

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Fig. 7. Table III, Voltage of SKBU Relay.

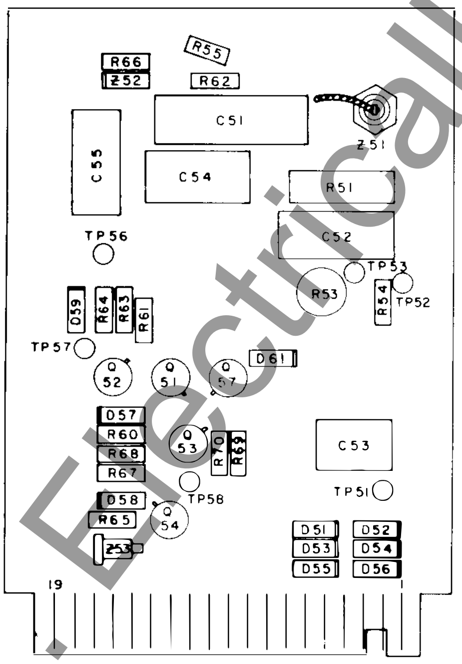


Fig. 8. Component Location on Fault Detector Printed Circuit Board for Type SKBU Relay.

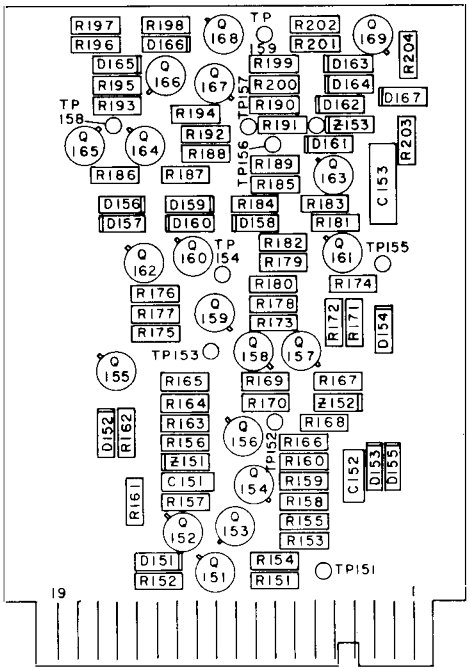


Fig. 9. Component Location on Supervision Printed Circuit Board for Type SKBU Relay.

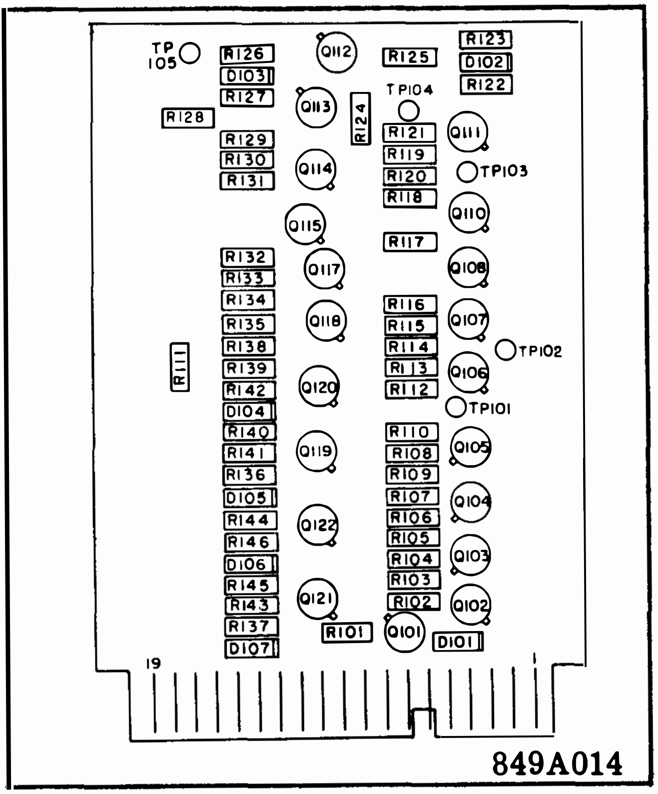


Fig. 10. Component Location on Amplifier and Keying Printed Circuit Board for Type SKBU Relay.

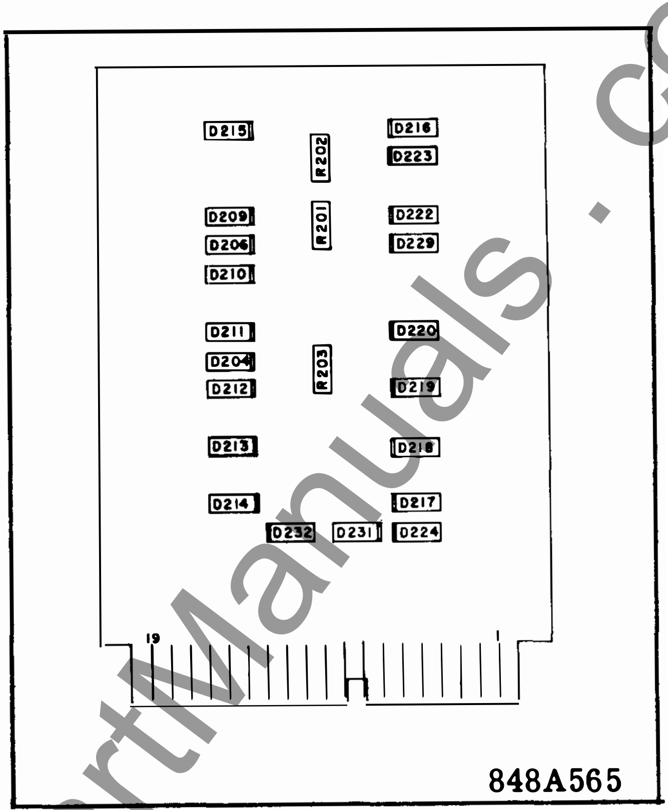


Fig. 11. Component Location on AND Printed Circuit Board for Type SKBU Relay.

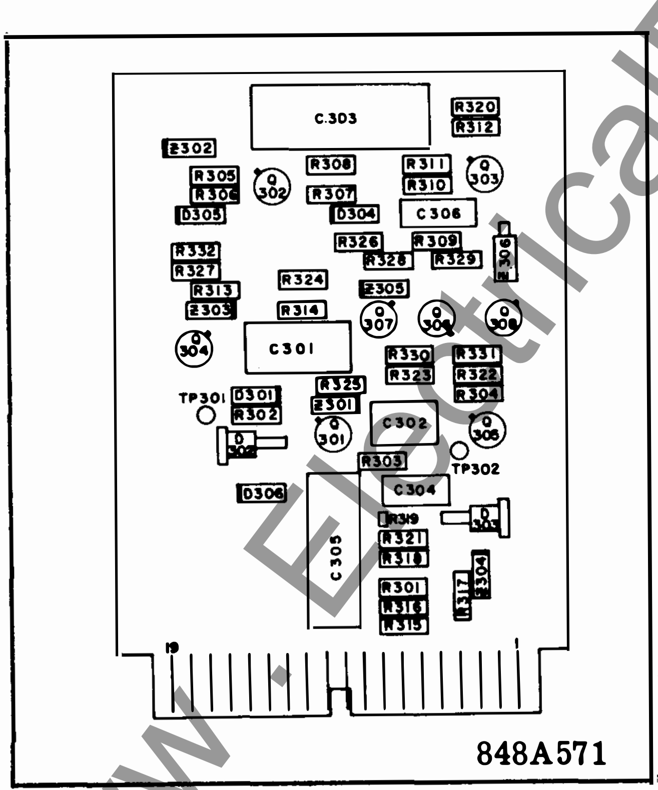


Fig. 12. Component Location on Output Printed Circuit Board for Type SKBU Relay.

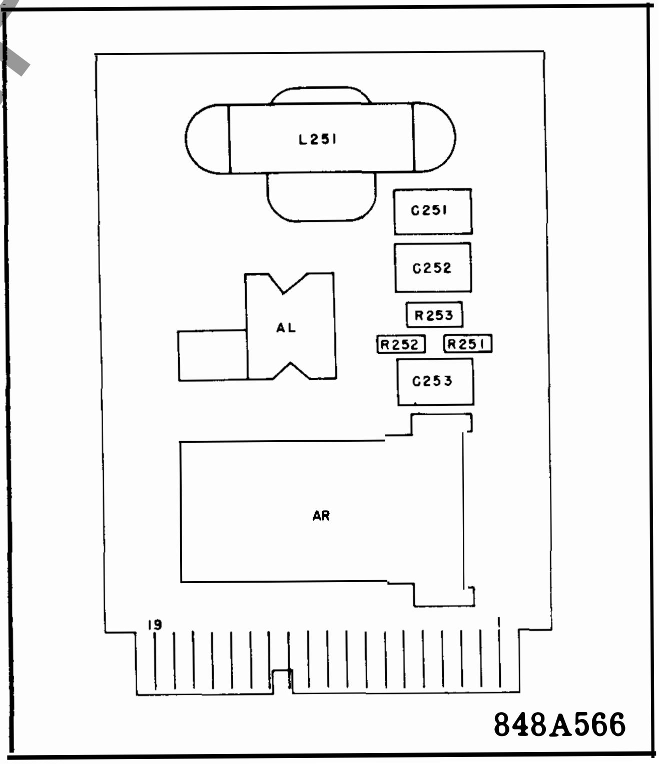
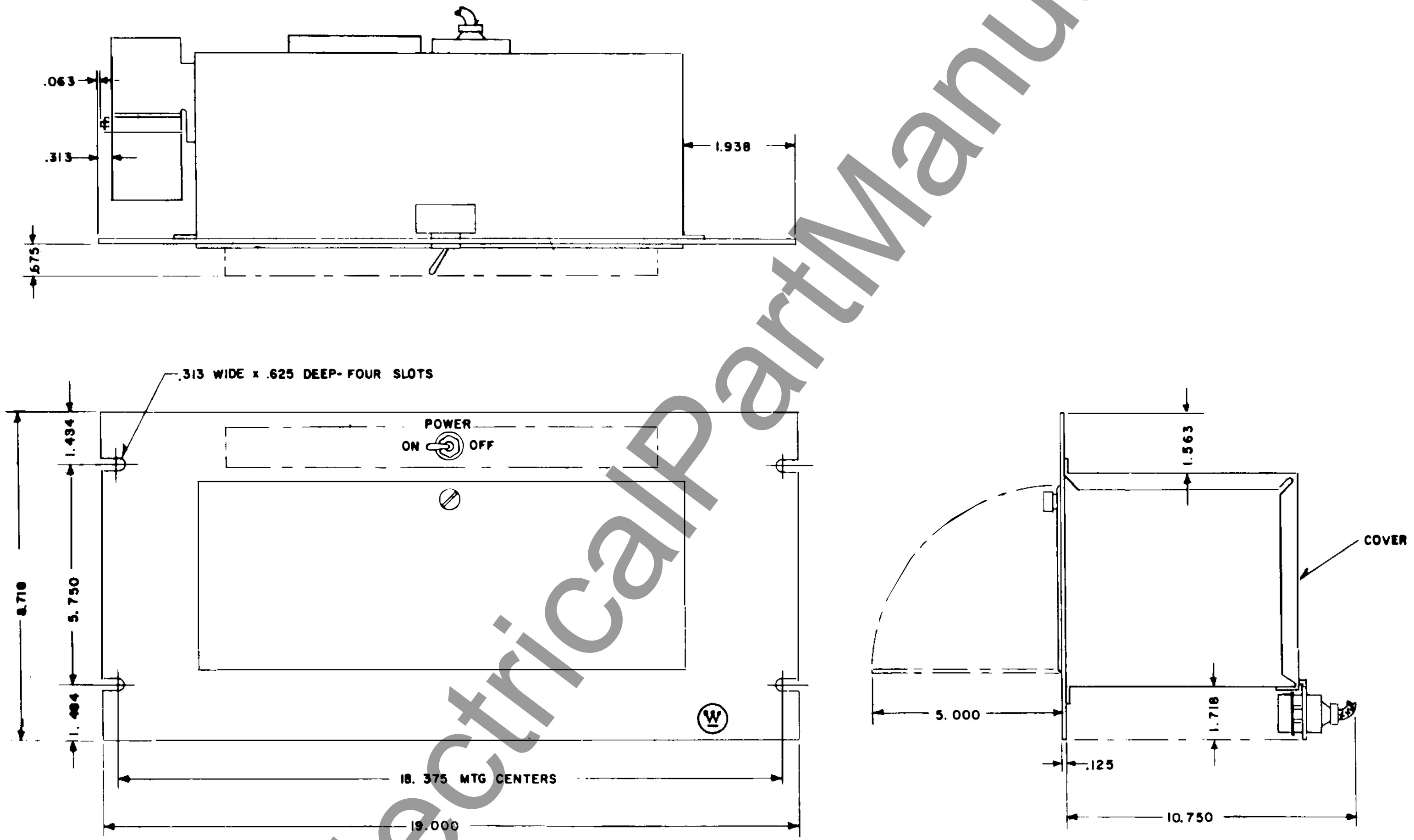


Fig. 13. Component Location on Relay Printed Circuit Board for Type SKBU Relay.



898C261

Fig. 14. Outline and Drilling Plan for Type SKBU Relay.

WESTINGHOUSE ELECTRIC CORPORATION
RELAY-INSTRUMENT DIVISION **NEWARK, N. J.**
Printed in U.S.A.

Westinghouse I. L. 41-954.1A

INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

TYPE SKBU PHASE COMPARISON RELAY FOR TYPE TC CARRIER CHANNEL

CAUTION: It is recommended that the user of this equipment become acquainted with the information in this instruction leaflet before energizing the carrier system. If the SKBU relay is mounted in a cabinet, the cabinet must be bolted down to the floor or otherwise secured before swinging out the equipment rack to prevent its tipping over.

APPLICATION

The type SKBU relay is a high speed carrier relay used in conjunction with a type TC power line carrier set to provide complete phase and ground fault protection of a two terminal or three terminal transmission line. Simultaneous tripping of the relays at each line terminal is obtained in less than twenty-five milliseconds for all internal faults within the limits of the relay settings. The relay operates on line current only, and no source of a-c line potential is required. Consequently, the relays will not trip during a swing or out-of-step conditions. The carrier equipment operates directly from the station battery.

CONSTRUCTION

The type SKBU relay consists of a combination positive, negative and zero sequence current network, a saturating transformer, a 20-volt power supply, and printed circuit boards mounted on a standard 19-inch wide panel, 8-3/4 inches high (5 rack units). Edge slots are provided for mounting the rack on a standard relay rack. The location of these components is shown in Figures 1 and 2. The components are connected as shown in the internal schematics of Figures 3 and 4.

Sequence Network

The sequence filter consists of a three-legged iron core reactor and a set of resistors, R1 and R0. The reactor has three windings: two primary and a tapped secondary winding, wound on the center leg of a "F" type of lamination. The secondary taps are wired to the A, B, and C tap connections in the front of the relay (R1 taps). R0 consists of three tube resistors with taps wired to F, G, and H tap connections in the front of the relay. The R1 resistor is a formed resistor associated with the tapped secondary of the reactor.

SUPERSEDES I. L. 41-954.1
*Denotes change from superseded issue.

EFFECTIVE AUGUST 1968

Saturating Transformers

The voltage from the network is fed into the tapped primary of a small saturating transformer. This transformer and a Zener clipper (on a printed circuit board) connected across its secondary are used to limit the voltage impressed on the solid state circuits, thus providing a small range of voltage for a large variation of maximum to minimum fault currents. This provides high operating energy for light faults, and limits the operating energy for heavy faults to a reasonable value.

Printed Circuit Boards

The number of boards varies with the application of the SKBU relay but in general consists of four printed circuit boards mounted in the order given (left to right-front view); a fault detector board, an amplifier and keying board, an output board, and a trip board. All of the circuitry that is suitable for mounting on printed circuit boards is contained in an enclosure that projects from the rear of the front panel and is accessible by opening a hinged door on the front of the panel. The printed circuit boards slide into position in slotted guides at the top and bottom of each compartment and the board terminals engage a terminal block at the rear of the compartment. Each board and terminal block is keyed so that if a board is placed in the wrong compartment it cannot be inserted into the terminal block. A handle on the front of each board is labeled to identify its function in the relay.

(1) Fault Detector Board

The fault detector board contains a resistor-Zener diode combination, a phase splitting network, and two solid state fault detectors (FD-1 and FD-2). The controls for setting pickup (S1 for FD-2, S3 for FD-1) and dropout (S2 for FD-2, S4 for FD-1) of the fault detectors are mounted on the plate in the front of the assembly.

(2) Amplifier and Keying Board

The amplifier and keying board contain a local squaring amplifier, a remote squaring amplifier, an "AND" circuit, and a transmitter keying circuit. A carrier squelch circuit is also located on the board.

(3) Output Board

The output board contains a 4 millisecond pickup and instantaneous dropout, timer circuit, flip-flop circuit, trip amplifier, transient blocking and unblocking circuit.

(4) Trip Board

The trip board contains the phase delay circuit for shifting the local signal with reference to the remote signal. This board also contains the final tripping output of the SKBU.

(5) Card Extender

A card extender (Style No. 644B315G02) is available for facilitating circuit voltage measurements or major adjustments. After withdrawing any one of the circuit boards, the extender is inserted in that compartment. The board then is inserted into the terminal block on the front of the extender. This restores all circuit connections, and all components and test points on the boards are readily accessible.

Test Points
Test points are located on each printed circuit board for the major components on the board. Complete circuit test points are wired to the front panel of the relay for convenience in adjusting and testing the relay.

OPERATION

A. System

The SKBU carrier relaying system compares the phase position of the currents at the ends of a line section over a carrier channel to determine whether an internal or external fault exists on the line section. The three-phase line currents energize a sequence network which produces a single-phase output voltage proportional to a combination of sequence components of the line current. During a fault, this single-phase voltage energizes the keying circuit to allow the transmission of carrier on alternate half-cycles of the power frequency current. Carrier is transmitted from both line terminals in this manner, and is received at the opposite ends where it is compared with the phase position of the local sequence network output. If the local and remote half-cycle pulses are of the correct phase position for an internal fault, after a 4 millisecond delay during the half cycle in which carrier is not transmitted, tripping will be initiated through operation of the flip-flop and trip amplifier circuits. Current transformer connections to the sequence networks at the two terminals are such that carrier is transmitted on the same half cycles from both terminals during a internal fault to allow tripping during the half cycle that carrier is not transmitted. However, if the fault is external to the protected line section, carrier is transmitted on alternate half cycles from opposite terminals. Thus each terminal blocks the opposite terminal during the half cycle when it is attempting to trip.

The four-millisecond delay previously mentioned is added to allow for differences in current transformer performance at opposite line terminals, relay coordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

Since this relaying system operates only during a fault, the carrier channel is available at all other times for the transmission of other functions.

B. Relay

With reference to either Figs. 3 or 4, the three phase line currents energize a sequence network which gives a single phase output voltage proportional to a combination of sequence components of the line current. This single phase output voltage is applied as inputs to two boards from the secondary of the saturating transformer.

1) Fault Detector Board (Phase Splitter Circuit)
2) Relay Board (Phase Delay Circuit)

1) Fault Detector

The a-c voltage is applied to a phase splitting network (C52, R54, R53) and a polyphase rectifier (diodes D51 to D56). The d-c voltage so obtained requires a minimum of filtering (C53) and responds rapidly to a change in magnitude of the a-c output. This d-c voltage is applied to two fault detector circuits which operate when the d-c input "signal" exceeds a predetermined value.

a. Fault Detector 1 (FD-1)

Under normal line conditions (no fault), current flows from positive 45 volts d-c through resistor R72 and Zener diode Z54 to negative, holding Q55 emitter at 6.8 volts positive. In transistor Q55, current flows from emitter to base, then through S3 and R71 to negative, thus turning on Q55. The collector current of Q55 provides base drive to transistors Q56 and Q57, turning them on also. The voltage drops across Q56 and Q57 are very low (about 0.5 volts), thus providing the equivalent of a closed contact. When a fault occurs, the d-c voltage from the polyphase rectifier is applied to S3 and R71. When this voltage exceeds the 6.8 volt drop across Zener diode Z54, transistor Q55 stops conducting. This removes the base current from Q56 and Q57, causing them to stop conducting, and providing the equivalent of an open circuit. With reference to Figure 7, this open circuit removes negative potential at point A and allows the potential at point C to become 20 volts. This increase in voltage at point C starts transmission of carrier.

When Q56 is cut off, its collector potential rises to about 20 volts. This also further raises the potential of Q55 base through feedback resistors R75 and S4, thus holding Q55 in a non-conducting state. When the input voltage (from the polyphase rectifier) is reduced, FD1 "resets" to allow transistors Q55, Q56 and Q57 to conduct. Resistor S3 is for setting the FD1 pickup current (calibration adjustment), and the setting of S4 determines the 80 percent dropout value.

b. Fault Detector 2 (FD-2)

Under normal conditions, transistor Q51 has no base "signal" and is turned off. The collector of Q51 is at a high enough positive potential to provide base drive for transistor Q52, driving it to full conduction. With Q52 fully conducting there is no base drive to transistor Q53. With no Q53 collector current, the base of PNP-type transistor Q54 is supplied from the 45 volt source through the drop of D58. Thus, the Q54 emitter is normally at a slightly lower potential than its base. This condition keeps transistor Q54 in a non-conducting state, equivalent to an open circuit. Zener diode Z3 is to protect transistor Q54 from external surge voltages.

When a fault causes the d-c input voltage from the polyphase rectifier to exceed the 6.8 volt rating of Zener diode Z52, (through R55, and S1) a positive bias is applied to Q51 base causing it to conduct. In turn, Q52 stops conducting, and capacitor C55 charges up, giving a few milliseconds time delay before Q53 and Q54 are switched to full conduction, thus "closing" FD2. The feedback resistors R60 and S2 provide a 90 percent FD2 dropout ratio with "toggle" action at the dropout point.

When FD-2 operates, positive 45 volts d-c is applied to the output board at terminal 18. This 45 volts is applied to the flip-flop circuit at terminal 19 and to the transient blocking circuit through Zener diode Z302. Thus, FD2 will "arm" the flip-flop and energize transient blocking of the SKBU relay.

2. Relay Board

The a-c voltage from the saturating transformer is also applied to the phase delay circuit through a low-pass filter of the relay board. The low-pass filter (C251, L251, C252) removes the harmonics from this voltage and applies a voltage that is essentially sinusoidal in waveform to R251 and R252 of the phase delay circuit. By menas of capacitor C253 and variable resistor S5, the voltage across terminals 4 and 9 can be made to lag the voltage across terminal 10 and 11 by a definite amount depending on the setting of S5. These two voltages are applied to the amplifier and keying board of the SKBU relay.

a) Undelayed Voltage to the Keying Circuit
b) Delayed Voltage to the Local Squaring Amplifier

a. Keying Circuit

Under normal conditons transistor Q102 is turned off. The collector of Q102 is at negative potential which allows base current to flow from positive 20 volts d-c through the base of transistor Q103, through R104 and R102 to negative. Transistor Q103 conducts and positive 20 volts is applied to the collector of Q103 to prevent base current from flowing in Q104. Since Q104 is not conducting, transistor Q105 does not conduct and the collector of Q105 is held at positive potential.

When a fault occurs, sinusoidal voltage is applied to transistor Q102 from terminals 4 and 10 of the relay board. On the positive half cycle, terminal 12 is more positive than terminal 4 of the amplifier and keying board, and Q102 does not conduct. However, on the negative half cycle of sine wave voltage, terminal 12 is more negative than terminal 4 and base current flows in Q102. This turns Q102 on and applies positive 20 volts to R102. This turns Q103 off which in turn puts negative potential on R106. Q104 then conducts to allow base current to flow into Q105. When Q105 conducts, its collector is connected to negative potential. Thus, the collector of Q105 is connected to negative on alternate half cycles of the 60-cycle voltage from the low pass filter. If FD-1 is not conducting, as seen from Fig. 7, turning Q105 on and off every half cycle, shorts the input to the TC carrier set every other half cycle so that carrier is transmitted on the half cycle when Q105 is not conducting.

b. Local Squaring Amplifier
The shifted voltage from the phase delay circuit is applied to the local squaring amplifier of the SKBU relay. Under non-fault conditions, Q108 is not conducting and R115 is at negative potential. As a result, the base of Q109 and Q111 is at a lower potential than the emitter of the transistors. Base current for both transistors flows from positive 20 volts through R116 and R115 to negative and both transistors conduct. With Q111 turned on, positive 20 volts is applied to R119 which is applied to R129 and R130 through D111 and D109 respectively. This voltage is the input to the AND circuit from the local signal and is the quantity to be compared with the signal from the remote terminal to determine if a fault is internal or external.

Under fault conditions, a sine wave of voltage is applied from emitter to base of transistor Q108. On the positive half cycle the base of transistor Q108 is more positive than the emitter and Q108 does not conduct. On the negative half cycle of sine wave voltage, the base is more negative than the emitter and Q108 conducts. Turning Q108 on applies positive 20 volts to R115 to cause Q109 to turn off. This causes Q111 to turn off such that negative potential is applied to R119. Hence, on alternate half cycles of sine wave voltage, negative voltage appears across R119 to apply negative voltage to R129 and R130 through D111 and D109 respectively. The voltage across the resistor is thus a square wave voltage varying from 20 volts d-c to 0 volt d-c dependent upon the polarity of the voltage from the phase delay circuit.

3. Remote Squaring Amplifier
Under non-fault conditions, carrier is not transmitted from the remote carrier set. As a result the base of Q113 is more negative than its emitter, and Q113 conducts. This applies positive 20 volts to the base of Q112 to prevent it from turning on. Hence, Q112 is not conducting and negative voltage appears across R123. This voltage is applied to R129 and R130 through D112 and D110 respectively, and allows the voltage across these resistors to remain at negative potential.

Under fault conditions, the remote TC carrier set is keyed on and off as described under the Keying Circuit. This signal is received at the local TC carrier receiver and is converted to a square wave voltage varying in magnitude from 45 volts to 0 volt. This voltage is applied to the base of Q113 through D108 and R128. Upon application of positive 45 volts d-c to the base of Q113, the potential of the base is greater than that of the emitter and Q113 stops conducting. This removes positive potential from R124 and allows the base of Q112 to become negative with respect to the emitter. Q112 turns on to apply positive voltage to R123. Hence, the voltage across R123 is a square wave voltage that is developed by the voltage received from the TC receiver. This voltage is applied to R129 and R130 through D112 and D110.

4. 4/0 Milliseconds Time Delay

The 4/0 time delay consists of R315, C305, R316, R317, R318, and R319. Under non-fault conditions, a continuous positive 20 volts is received from the local squaring amplifier at terminal 6 of the output board. This prevents capacitor C305 from charging and keeps the base of Q305 of the flip-flop at positive potential.

Under external fault conditions, the square wave voltage from the remote squaring amplifier and the square wave voltages from the local squaring amplifier are out of phase, such that a continuous 20 volts is received at terminal 6 of the Output board. C305 does not charge, and transistor Q305 cannot turn on.

Under internal fault conditions, the square wave voltages from the squaring amplifiers are in phase. Hence, for one-half cycle, negative voltage appears at terminal 6 of the Output board. This allows C305 to charge through resistors R315 and R129 to negative. After a calibrated time delay of 4 milliseconds, the voltage across C305, which is applied to the base-emitter circuit of transistor Q305 in the flip-flop circuit is sufficient to allow Q305 to conduct.

5. Flip-Flop

The flip-flop circuit consists of transistors Q305 and Q306 and associated components. Under normal conditions, transistor Q305 is in a non-conducting state, and transistor Q306 is fully conducting. The base of transistor Q306 is held well below its emitter potential by means of the voltage divider consisting of resistors R325, R326, D305, and R327. With this bias, transistor Q306 is held in saturation and the flip-flop is desensitized so that even if transistor Q305 turns on, transistor Q306 does not turn off. This desensitizing circuit is an arrangement to prevent inadvertent operation of the flip-flop in the presence of surges on the d-c system. As long as Q306 is conducting, its collector is at a high enough positive potential such that transistor Q307 in the tripping amplifier cannot turn on.

Upon the occurrence of an internal fault, positive 45 volts d-c is applied from Q54 (FD-2) to terminal 18 of the Output board. This removes the desensitizing bias from transistor Q306 by making the potential of the junction of resistor R327 and diode D305 greater than the 20 volt supply for the flip-flop circuit. When this occurs, there is no current flow through resistor R326 and diode D305, and the flip-flop is now "armed" or in a ready condition for a tripping operation. Since the pulses from the "AND" circuit are in phase, after a 4 millisecond delay, the potential across capacitor C305 is sufficient to cause Q305 to conduct. This immediately causes operation of the flip-flop, turning off transistor Q306. When Q306 is no longer conducting, the potential of the junction of R329 and R328 drops to a relatively low value. When this occurs, there is sufficient voltage across the base-emitter circuit of transistor Q307 in the trip amplifier to cause it to turn on.

6. Trip Amplifier

When transistor Q307 is turned on by operation of the flip-flop, base current flows from positive 20 volts through Z305, the emitter-base junction of Q307, and the resistors R328 and R329 to negative. The collector current of transistor Q307 flows through R330 and the base-emitter junction of output transistor Q308. The collector of Q308 is connected to positive 45 volts d-c through R253 and the AR coil of the relay board. Collector current thus flows from positive 45 volts d-c through the AR coil, R253 to transistor Q308, hence, the AR operates to trip the breaker. In case of a voltage output from the SKBU relay, transistor Q252 turns on to provide 20 volts output to the next device.

7. Carrier Squelch

When the SKBU relay operates as a result of an internal fault, positive potential is applied to the squelch circuit of the amplifier and keying board. Ten milliseconds after positive potential is applied, capacitor C101 charges sufficiently to allow base current to flow to transistor Q106. Transistor Q106 turns on to short the carrier start lead to negative (ref. Fig. 7). Carrier is then turned off and will remain off for approximately 150 milliseconds after the SKBU resets to prevent delayed tripping of the remote breaker due to a short burst of carrier at the instant of the local breaker opening.

8. Transient Blocking

When Q54 (FD-2) turns on, positive 45 volts is applied to terminal 18 of the output board, and energizes the transient blocking circuit. Base current is supplied to transistor Q302 through resistor, R305, and Zener diode, Z302. Transistor, Q302, turns on to connect the base of transistor, Q303, to negative. Q303 stops conducting and capacitor C303 starts to charge. When the charge on capacitor C303 is sufficient to cause the breakdown of Zener diode Zener diode Z303, it turns on transistor Q304. This provides a conducting path from the base circuit of transistor Q306 in the flip-flop, diode D304, the resistor R324, and the collector emitter circuit of transistor Q304 to negative. This occurs after a time delay of 20 to 30 milliseconds and provides a path to apply a "desensitizing" bias to transistor Q306 in the flip-flop. Thus, the transient blocking circuit allows 20 to 30 milliseconds after the operation of FD-2 for the flip-flop to operate and energize the output of the relay. If tripping does not occur in this time, as during an external fault, the operation of the transient blocking circuit desensitizes the flip-flop to prevent undesirable operation during transients associated with power reversals on the protective line or at the clearing of an external fault.

The transient blocking circuit is cancelled either by FD-2 resetting or by the operation of the transient unblocking circuit.

9. Transient Unblocking

If an internal fault occurs before an external fault is cleared, high speed tripping is obtained. The square wave output from the local and remote squaring amplifier changes from an out-of-phase condition to an in-phase condition. As a result, negative potential is applied to the transient unblocking circuit at terminal 9 of the Output board. Zener diode Z301 breaks down and base current flows through Z301, emitter-base of Q301, resistor R303, Diode D302, and D301, resistor R130, and through the conducting transistor, Q304, to negative. Transistor Q301 turns on to apply positive potential to resistor, R309. Base current then flows through resistor R309, to turn on transistor Q303. Capacitor, C303, will be rapidly discharged to remove the potential from the base of transistor, Q304. Transistor Q304 turns off to interrupt the desensitizing circuit from the base of transistor Q306. When this happens, the flop-flop will then be able to operate to provide an input to the trip amplifier.

CHARACTERISTICS

The sequence network in the relay is arranged for several possible combinations of sequence components. For most applications, the output of the network will contain the positive, negative and zero sequence components of the line current. In this case, the T taps on the left-hand tap place indicate the balanced three phase amperes which will operate the carrier-start fault detector (FD-1). The taps available are 3, 4, 5, 6, 7, 8, and 10 and are on the primary of the saturating transformer. The second fault-detector unit (FD-2), which supervises operation of tripping, is adjusted to pick up at a current 25 percent above tap value.

For phase-to-phase faults AB and CA, enough negative sequence current has been introduced to allow the fault detector FD-1 to pick up at 86 percent of the tap setting. For BC faults, the fault detector will pick up at approximately 50 percent of the tap setting. This difference in pickup current for different phase-to-phase faults if fundamental, and occurs because of the angles at which the positive and negative sequence components of current add together.

With the sequence network arranged for positive, negative and zero sequence output, there are some applications where the maximum load current and minimum fault current are too close together to set the relay to pickup under a minimum fault current, yet not operate under load. For these cases, a tap is available on the SKBU relay which cuts the three-phase sensitivity in half, while the phase-to-phase setting is substantially unchanged. The relay then trips at 90 percent of tap value for AB and CA faults, and at twice tap value for three-phase faults. The setting for BC faults is 65 percent of tap value. In some cases, it may be desirable to eliminate response to positive-sequence current entirely, and operate the SKBU relay on negative-plus-zero sequence current. A tap is available to operate in this manner. The fault detector picks up at tap value for all phase-to-phase faults, but is unaffected by balanced load current or three-phase faults.

For ground faults, separate taps (Ro) are available for adjustment of the ground fault sensitivity to about 1/4 or 1/8 of the left-hand tap plate setting. See Table II. For example, if the SKBU relay is set at T, tap 4, the fault detector (FD-1) pickup current for ground faults can be either 1 or 1/2 ampere. In special applications, it may be desirable to eliminate response to zero sequence current. The relay is provided with a tap to allow such operation.

Operating Time	12 to 20 milliseconds
Transient Blocking Time	20 to 30 milliseconds
Transient Unblocking Time	20 to 30 milliseconds
Squelch Time	150 milliseconds
Ambient Temperature Range	-20°C to 55°C
Output Voltage (where used)	20 milliamperes at 20 volts d-c
Drain on 45 volt Power Supply of TC Set:	
Non-Trip Condition	60 MA
Trip Condition (with AR output)	100 MA
Trip Condition (with voltage output)	80 MA
Dimensions:	
Panel Height	8-3/4 inches or 5 rack unit
Panel Width	19 inches

ENERGY REQUIREMENTS

Burdens measured at a balanced three-phase current of five amperes.

Relay	Phase A		Phase B		Phase C	
Taps	VA	Angle	VA	Angle	VA	Angle
A-F-3	2.4	5°	0.6	0°	2.5	50°
A-H-10	3.25	0°	0.8	100°	1.28	55°
B-F-3	2.3	0°	0.63	0°	2.45	55°
B-H-10	4.95	0°	2.35	90°	0.3	60°
C-F-3	2.32	0°	0.78	0°	2.36	50°
C-H-10	6.35	342°	3.83	80•	1.98	185°

Burdens measured at a single-phase to neutral current of five amperes.

Relay Taps	Phase A VA	Phase A Angle	Phase B VA	Phase B Angle	Phase C VA	Phase C Angle
A-F-3	2.47	0°	2.1	10°	1.97	20°
A-H-10	7.3	60°	12.5	53°	6.7	26°
B-F-3	2.45	0°	2.09	15°	2.07	10°
B-H-10	16.8	55°	22.0	50°	12.3	38°
C-F-3	2.49	0°	1.99	15°	2.11	15°
C-H-10	31.2	41°	36.0	38°	23.6	35°

The angles above are the degrees by which the current lags its respective voltage.

SETTINGS

The SKBU relay has separate tap plates for adjustment of the phase and ground fault sensitivities and the sequence components included in the network output. The range of the available taps is sufficient to cover a wide range of applications. The method of determining the correct taps for a given installation is discussed in the following paragraphs.

In all cases, the similar fault detectors on the relays at both terminals of a line section must be set to pickup at the same value of line current. This is necessary for correct blocking during faults external to the protected line section.

Sequence Combination Taps

The two halves of the right-hand tap plate are for connecting the sequence network to provide any of the combinations described in the previous section. The upper half of the tap plate or R1 taps changes the tap on the third winding of the mutual reactor and thus changes the relative amounts of positive and negative sequence sensitivity. Operation of the relay with the various taps is given in the table below.

TABLE I

Comb.	Sequence Components in Network Output	Taps on Right Hand Tap Block		Fault Detector FD-1 Pickup	
		R1	Ro	3Ø Fault	Ø-Ø Fault ~~0~~
1	Pos., Neg., Zero	C	G or H#	Tap Value	86% Tap Value (53% on BC Fault)
2	Pos., Neg., Zero	B †	G or H	2 x Tap Value	90% Tap Value (65% on BC Fault)
3	Neg., Zero	A †	G or H	--------	100% Tap Value

- Taps F, G, and H are zero-sequence taps for adjusting ground fault sensitivity.

See section on zero-sequence current tap.

-0- - Fault detector FD-2 is set to pickup at 125% of FD-1 for a two-terminal line, or 250% for a three-terminal line.

/ - When taps A and 3, or B and 3 are used, the relay pickup currents for FD-1 and FD-2 will be 10 to 15 percent higher than the indicated values because of the variation in self-impedance of the sequence network and the saturating transformer.

Positive-Sequence Current Tap and FD-2 Tap

The left-hand tap plate, T, has taps of 3, 4, 5, 6, 7, 8, and 10 which represent the three-phase, fault detector FD-1 pickup currents, when the relay is connected for positive, negative and zero sequence output. The fault detector FD-2 closes its contact to allow tripping at current value 25 percent above the fault detector FD-1 setting. This 25 percent difference is necessary to insure that the carrier-start fault detectors (FD-1) at both ends of a 2-terminal transmission line section pickup to start carrier on an external fault before operating energy is applied through FD-2.

For a 3-terminal line, there is a provision on the printed circuit board for changing the temperature compensation when calibrating FD-2 to pickup at 250% of FD-1 setting. This is necessary to allow proper blocking on 3-terminal lines when approximately equal currents are fed in two terminals, and their sum flows out the third terminal of the line. The relay is shipped connected for 2-terminal line service. For a 3-terminal line, the jumper on the FD board must be changed to c-3, and FD-2 must be recalibrated for 250% of FD-1.

The T, Ro, and Rl taps should be selected to assure operation on minimum internal line-to-line faults, and yet not operate on normal load current, particularly if the carrier channel is to be used for auxiliary functions. The dropout current of the FD-1 fault detector is 80 percent of the pickup current, and this factor must also be considered in selecting the positive-sequence current tap and sequence component combination. The margin between load current and fault detector pickup should be sufficient to allow the fault detector to dropout after an external fault, when load current continues to flow.

Zero-Sequence Current Tap - Ro Taps

The lower half of the right-hand tap plate (Ro taps) is for adjusting the ground fault response of the relay. Taps G and H give the approximate ground fault sensitivities as listed in Table II. Tap F is used in applications where increased sensitivity to ground faults is not required. When this tap is used, the voltage output of the network caused by zero-sequence current is eliminated.

NOTE: Because of inherent characteristics of the sequence network, there will be small variations (from the values listed in Tables I and II) in the pickup current for various phase or ground fault combinations.

TABLE II

Comb.	R1 Tap	Ground Fault Pickup Percent of T Tap Setting	
		Tap G	Tap H
1	C	25%	12%
2	B	20%	10%
3	A	20%	10%

Examples of SKBU Relay Settings

CASE I

Assume a two-terminal line with current transformers rated 400/5 at both terminals. Also assume that full load current is 300 amperes, and that on minimum internal phase-to-phase faults 2000 amperes is fed in from one end and 600 amperes from the other end. Further assume that on minimum internal ground faults, 400 amperes is fed in from one end, and 100 amperes from the other end.

Positive Sequence Current Tap

Secondary Values:

$$\text{Load Current} = 300 \times \frac{5}{400} = 3.75 \text{ amperes} \tag{1}$$

Minimum Phase-to-Phase Fault Currents:

$$600 \times \frac{5}{400} = 7.5 \text{ amperes} \tag{2}$$

Fault detector FD-1 setting (three phase) must be at least:

$$\frac{3.75}{0.80} = 4.7 \text{ amperes (0.80 is dropout ratio of FD-1 fault so that the fault detector will reset on load current)} \tag{3}$$

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector FD-1 setting (three-Phase) must be not more than:

$$7.5 \times \frac{1}{0.866} \times \frac{1}{1.25} = 6.98 \text{ amperes}$$

$$1.25 = \frac{\text{FD-2 Pickup}}{\text{FD-1 Pickup}} \tag{4}$$

Sequence Combination Tap

From a comparison of (3) and (4) above, it is evident that the fault detector can be set to trip under minimum phase fault condition yet not operate under maximum load. In this case, tap C would be used (see Table I, Comb. 1) as there is sufficient difference between maximum load and minimum fault to use the full three-phase sensitivity. Current tap 6 would be used in preference to tap 5 to allow for occurrence of higher load current.

Zero Sequence Tap

Secondary Value:

$$100 \text{ x } \frac{5}{400} = 1.25 \text{ amperes minimum ground fault current}$$

With T, tap 6 and R1, tap C in use, the fault detector FD-1 pickup currents for ground faults are as follows:

Tap G $\quad 1/4 \text{ x } 6 = 1.5$ ampere
Minimum Trip = $1.25 \text{ x } 1.5$ ampere

Tap H $\quad 1/8 \text{ x } 6 = 0.75$ ampere
Minimum Trip = $1.25 \text{ x } 0.75 = 0.94$ ampere

From the above, tap H would be used to trip the minimum ground fault of 1.25 amperes.

CASE II

Assume the same fault currents as in Case I, but a maximum load current of 550 amperes. In this example, with the same sequence combination as in Case I, the fault detectors cannot be set to trip on the minimum internal three-phase fault, yet remain inoperative on load current. Compare equations (5) and (6). However, by connecting the network per combination 2 on Table I, the relay can be set to trip on minimum phase-to-phase fault, although it will have only half the sensitivity to three-phase faults. This will allow operation at maximum load without picking up the fault detector, and provide high speed relaying of all except light three-phase faults.

In order to complete the trip circuit on a 7.5 ampere phase-to-phase fault, the fault detector tap must now be not more than:

$$7.5 \text{ x } \frac{1}{1.25} \text{ x } \frac{1}{0.9} = 6.6 \text{ amperes} \qquad (5)$$

To be sure the fault detector FD-1 will reset after a fault, the minimum tap setting is determined as follows:

$$\text{Load Current} = 550 \text{ x } \frac{5}{400} = 6.9 \text{ amperes} \qquad (6)$$

$$\frac{6.9}{0.80} = 8.6 \qquad (7)$$

Since the fault detector pickup current for three-phase faults is twice tap value, half the above value (Eq. 7) should be used in determining the minimum three-phase tap.

$$\frac{8.6}{2} = 4.3 \qquad (8)$$

From a comparison of (5) and (8) above, tap 5 or 6 could be used. (Continuous load current rating of relay is 10 amperes.)

With the three-phase tap 5 in use, the fault detector pickup current for ground faults will be as follows:

Tap G 1/5 x 5 = 1.0 ampere
Minimum Trip = 1.0 x 1.25 a. = 1.25 ampere

Tap H 1/10 x 5 = 0.5 ampere
Minimum Trip = 1.25 x 0.5 a. = 0.63 ampere

Therefore, tap H would be used to trip the minimum ground fault of 1.25 ampere with a margin of safety.

INSTALLATION

The SKBU relay is generally supplied in a cabinet or on a relay rack as part of a complete assembly. The location must be free from dust, excessive humidity, vibration, corrosive fumes, or heat. The maximum temperature around the chassis must not exceed 55°C.

ADJUSTMENTS AND MAINTENANCE

NOTE: The SKBU relay is normally supplied as part of a carrier relaying system, and its calibration should be checked after the system has been installed and interconnected. Details are given in the instructions of the assembly. The assembly instructions and not the following instruction should be followed when the relay is received as an integral part of the relaying system.

In those cases where the SKBU relay is not a part of a relaying system, the following procedure can be followed to verify that the circuits of the SKBU relay are functioning properly.

Test Equipment:

1. Oscilloscope
2. A.C. Current Source
3. Electronic Timer
4. A.C. Voltmeter
5. D.C. Voltmeter

Acceptance Test

Connect the relay to the test circuit of Fig. 8 which represents the TC carrier channel for test purposes.

Open all test switches of the test circuit and connect a 60 cycle test current between terminals 3 and 4 of the relay. Set relay taps on C and H and remove T tap screw.

1. Filter Output

a. Connect a high resistance a-c voltmeter across common of T tap block and the common of Ro tap block.

b. Pass with 3.44 amperes, 60 cycles into terminal 3 and out terminal 4 of relay. Voltmeter should read between 0.75 volts and 0.85 volts a-c.

2. FD-1 Pickup and Dropout

a. Set relay taps 5, C, and H. Close all switches of test circuit.

b. Connect a high resistance d-c voltmeter across X14 and X3 (Neg.)

c. Apply 60 cycle current to terminals 3 and 4 of the relay. Gradually increase the current until the voltmeter changes reading from approximately zero volts to approximately 20 volts. This is the operating current of FD-1 and should be 4.33 ± 5% amperes.

d. Gradually lower a-c test current until the d-c voltmeter drops to approximately zero volts. This is the dropout current of FD-1 and should occur at 80% of the pickup current.

3. FD-2 Pickup and Dropout

a. With the current test leads connected as in the FD-1 test, connect the voltmeter across X13 and X3 (Neg.)

b. Gradually raise a-c current until voltmeter reads approximately 45 volts. This should be 5.41 ± 5% amperes.

c. Gradually lower a-c test current until the d-c voltage reading drops to zero volts. This is dropout of FD-2 and should occur at 90% of pickup current.

4. Check of Local Squaring Amplifier

a. Open switches A, B, C, D, and E of test circuit.

b. Place scope across X10 and X3 (GRD). Apply 5 amperes a-c to terminals 3 and 4 of relay.

c. A square wave voltage should appear across X10 and X3 with the waveshape of Table III.

5. Check of Keying Circuit

a. Open all switches of test circuit and apply 5 amperes a-c to terminals 3 and 4 of the relay.

b. With scope check voltage across X11 and X3 (GRD). Waveform should be a square wave as shown in Table III.

c. Close switches A, B, C, and D. No change should be noted in waveform across X11 and X3 (GRD).

6. Check of Remote Squaring Amplifier

a. Close switches A, B, and C of the test circuit.

b. Apply 5 amperes a-c to terminals 3 and 4 of the SKBU relay.

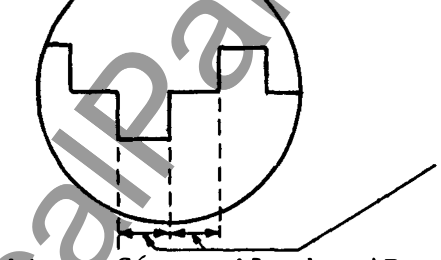
c. Put scope across X9 and X3 (GRD). A square wave of voltage should be obtained (see Table III).

7. Setting of S5 and S6

a. Set S5 to minimum resistance and S6 to maximum resistance (fully clockwise).

b. With switches A, B, and C of the test circuit closed, apply 6 amperes a-c to terminals 3 and 4 of the SKBU relay.

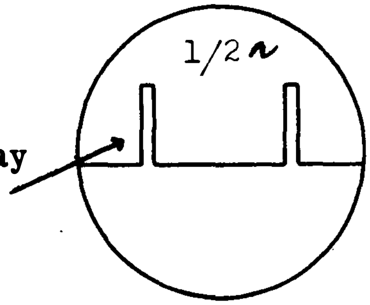
c. Place scope across X12 and X2 (GRD). Adjust S5 until following waveform is obtained.



4 ms. each (approximately) These two intervals equal

d. Close switch D and adjust S6 until the AR trips. In the case of a voltage output SKBU relay, place d-c voltmeter across X16 and X3. Tripping is indicated by a change in voltage from 0 to 20 volts. This sets the triggering of the flip-flop after a 4 millisecond delay. Recheck pickup by moving 55 minimum, opening and closing switch D and then adjusting S5 until AR operates. It may be necessary to readjust S6 to obtain AR tripping on waveform of step c.

e. Slowly increase S5 to obtain the following waveform. Adjust for minimum area of the pips. This will be with S5 near minimum resistance.



* Minimum Pips may point up as shown or down

8. Check of Transient Blocking

a. Connect electronic timer stop to X7 and X3 (GRD). Set timer stop on negative going pulse.

b. Connect timer start to timer start contacts of switch D. Set timer start to make.

c. With switches A, B, and C open, apply 6 amperes a-c to terminals 3 and 4 of the SKBU relay.

d. Close switch D and measure time for voltage to drop from 20 volts to approximately zero volts. This should be between 20 to 30 milliseconds. Take average of ten readings.

9. Check of Transient Unblocking Circuit

a. With electronic timer stop connected to X7 and X3 (GRD), set timer stop on positive going pulse. Also connect a-c voltmeter across X7 and X3 (NEG.)

b. Connect timer start to timer start contacts of switch A.

c. Apply 6 amperes a-c to terminal 4 and 3 of the SKBU relay, and close switches A, B, C, and D of test circuit. Closing switch D sets up transient blocking as can be seen by a change in voltage from 20 volts d-c to 0 volt d-c.

d. Open switch A and measure time for voltage to change from approximately zero volt to 20 volts. Time should be 20 to 30 milliseconds. Measure average of 10 trials. For each trial it will be necessary to close switch A and then open switch D. Switch D should then be closed and A opened to measure the unblocking time.

10. Check of Carrier Squelch Circuit

a. Connect timer stop across X11 and X3 GRD. Set timer stop on negative pulse.

b. Connect timer start. Set timer start to make.

c. Open switch C. Approximately 20 volts should appear across X11 and X3.

d. Close switch E and measure time for voltage to disappear. This should be 8 to 12 milliseconds.

e. Set timer stop on positive pulse and timer start on break.

f. Measure time for voltage to reappear by opening switch E. Time should be 120 to 180 milliseconds.

ROUTINE MAINTENANCE

All contacts should be periodically cleaned. A contact burnisher S#182A836H01 is recommended. The use of abrasive material is not recommended because of the danger of embedding small particles in the face of the soft silver and thus impairing the contact.

CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs. The relay should be connected to the test circuit of Fig. 8.

1. Sequence Filter

To calibrate the sequence filter, the top cover must be removed and the following procedure used: Remove the T tap screw and insert the tap screws in tap C and H of the Rl and Ro taps. Pass a single-phase current of 10 amperes, rated frequency through the reactor coils in series from phase B to phase C (relay terminals 4 and 5). Accurately measure the a-c voltage from terminal 3 to the common of the T tap plate. This voltage should be between 3.7 and 4.1 volts. Now pass 10 amperes from terminal 3 to terminal 4 with tap screw C removed, and connect voltmeter from terminal 3 to the right-hand (front Ro view) adjustable point of the formed resistor. Adjust this point to give a voltage equal to exactly one-third of the reactor drop. Note the above reading, and adjust the intermediate tap of formed resistor to give exactly 2/3 of the voltage obtained above for all of formed resistor. Measure this voltage from terminal 3 to the intermediate tap.

2. Phase Splitter

If replacement of the fault detector board or major component on the board necessitates a complete recalibration, proceed as follows:

a. Set relay taps 5-C-H.

b. Set S1 and S3 to full clockwise position.

c. Set S2 and S4 to mid-scale.

d. Pass 4.33 amperes through relay terminal 3 to terminal 4.

e. On fault detector board, check the a-c voltage from TP51 to TP52 and from TP52 to TP53 with a VTVM. Adjust the small pot. R53 on the fault detector board until these two voltages are equal.

f. Close all switches of test circuit and connect VTVM across X14 and X3 (Neg.)

g. Slowly turn S3 counterclockwise, with 4.33 amperes flowing, until FD-1 operates as indicated by a change in voltage reading from approximately zero volts to 20 volts d-c.

h. Reduce the a-c current to check FD-1 dropout. Adjust S4 to obtain 80 percent dropout (3.46 amperes). Dropout is indicated by a change in voltage reading from approximately 20 volts to 0 volt.

i. Recheck FD-1 pickup and dropout, and touch up S3 and S4 in that order for the correct calibration. Tighten the locking device.

j. Similarly recalibrate FD-2 using controls S1 (pickup) and S2 (dropout), repeating steps g, h, and i, except for FD-2 pickup of 5.41 amperes and dropout of 4.85 amperes. Pickup is measured using X13 and X3 (negative) and is indicated by a change in voltage reading from a low voltage to 45 volts.

3. Tripping Relay (AR)

The type AR tripping relay unit has been properly adjusted at the factory to insure correct operation and should not be disturbed after receipt by the customer. If, however, the adjustments are disturbed in error, or it becomes necessary to replace some part in the field, use the following adjustment procedure. This procedure should not be used until it is apparent that the AR unit is not in proper working order, and then only if suitable tools are available for checking the adjustments.

a. Adjust the set screw at the rear of the top of the frame to obtain a 0.009 inch gap at the rear end of the armature air gap.

b. Adjust each contact spring to obtain 4 grams pressure at the very end of the spring. This pressure is measured when the spring moves away from the edge of the slot in the insulated crosspiece.

c. Adjust each stationary contact screw to obtain a contact gap of 0.020 inch. This will give 15-30 grams contact pressure.

4. Check of Solid-State Circuits

Perform tests listed under "Acceptance" tests to verify that the SKBU relay is functioning correctly.

TROUBLE SHOOTING PROCEDURE

To trouble shoot the equipment, the logic diagram of either Fig. 5 or 6, voltages of Table III, should be used to isolate the circuit that is not performing correctly. The schematic of either Fig. 3 or 4, and the voltages of Table IV should then be used to isolate the faulty component.

TABLE IV

VOLTAGE MEASUREMENTS OF PRINTED CIRCUIT BOARD

1. Fault Detector Board

D-C Voltages - positive with respect to negative d-c (terminal 8 of board).

Test Point	I=0	I=2 x FD-2 p.u.
Terminal 14	45.0 VDC	45.0 VDC
TP 54	6.6	6.8
TP 55	6.6	less than 1
TP 56	14.5	less than 1
TP 57	less than 1	14.5
TP 58	45	less than 1
Terminal 13 FD-1	less than 1	20
Terminal 15 FD-2	less than 1	45
TP 52 - TP 51	less than 1	18 VAC Approximately
TP 52 - TP 53	less than 1	17.8 VAC Approximately

2. Amplifier and Keying

D-C Voltages - positive with respect to negative (terminal 8 of board).

Test Point	Normal	Fault
Terminal 4	20	20
TP 101	20	10
TP 102	20.3	19.8
TP 103	less than 1	10
Terminal 3	less than 1	9.8

3. Output Board

D-C Voltages - positive with respect to negative (terminal 8 of board):

Test Point	Normal	Fault
TP 302	19.5	19.0
TP 301	10	8.5
Terminal 14	20	19.0

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 the repair work. When ordering parts, always give the complete nameplate data. For components mounted on the printed circuit board, give the circuit symbol and the electrical value (ohms, mfd, etc.).

ELECTRICAL PARTS LIST

Fault Detector Board

Circuit Symbol	Description	Westinghouse Style Number
	Capacitor	
C51	0.10 MFD	15449220
C52-C55	0.5	187A624H11
C53	0.25	187A624H02
C54	1.0	187A624H04
	Diodes	
D51 to D56 - D61	1N459A	184A855H08
D57 to D60 - D62	1N457A	184A855H07
	Transistors	
Q51-Q52-Q56-Q57	2N697	184A638H18
Q53	2N699	184A638H19
Q54	2N2043	184A638H21
Q55	2N652A	184A638H16
	Resistors	
R51	50 Ohm, 5W	185A209H06
R52	9.1K Ohm, 1/2W	187A763H50
R53	2.5K Ohm, Pot.	629A430H03
R54	2.7K Ohm, 1/2W	629A530H42
R55-R73-R78	10K Ohm, 1/2W	629A530H56
R56-R58	15K Ohm, 1/2W	187A641H55
R57	18K Ohm, 1/2W	184A763H57
R59	Thermistor 1D05N	185A211H05
R60-R65	68K Ohm, 1/2W	187A641H71
R61	.22 Meg. Ohm, 1/2W	184A763H83
R62-R64-R68-R74	10K Ohm, 1/2W	187A641H51
R63	.1 Meg. Ohm, 1/2W	187A641H75
R66	470K Ohm, 1/2W	184A763H91
R67	39K Ohm, 1/2W	187A641H65
R69	1K Ohm, 1/2W	187A641H27
R70	6.8K Ohm, 1/2W	187A641H47
R71	20K Ohm, 1/2W	629A530H63
R72	3.9K Ohm, 1W	187A643H41
R75	33K Ohm, 1/2W	187A641H63
R76	10K Ohm, 1W	187A643H51
R77	1K Ohm, 1/2W	629A530H43
	Zener Diodes	
Z51	In1832C	184A617H06
Z52-Z54	1N957B	186A797H06
Z53	1N1789	584C434H08
Z55	1N3686B	185A212H06

ELECTRICAL PARTS LIST

Amplifier and Keying

Circuit Symbol	Description	Westinghouse Style Number
	Capacitor	
C101	39 MFD	187A508H04
	Diodes	
D101-D102-D104-D106 to D112	1N457A	184A855H07
D103	1N91	182A881H04
	Transistors	
Q101 to Q104 Q107 to Q113	2N652A	184A638H16
Q105-Q106	2N697	184A638H18
	Resistors	
R101-R103-R114-R127	100K Ohm, 1/2W	187A641H75
R102	150K Ohm, 1/2W	184A763H79
R104	33K Ohm, 1/2W	187A641H63
R105	68K Ohm, 1/2W	187A641H71
R106	27K Ohm, 1/2W	187A641H61
R107-R119-R123	4.7K Ohm, 1/2W	187A641H43
R108-R109-R126	10K Ohm, 1/2W	187A641H51
R110	3.3K Ohm, 1/2W	184A763H39
R111	5.6K Ohm, 1/2W	187A641H45
R112	1.2K Ohm, 1/2W	184A763H29
R113	330 Ohm, 2W	185A207H15
R115	180K Ohm, 1/2W	187A641H81
R116-R117-R130	22K Ohm, 1/2W	187A641H59
R118-R121-R129	47K Ohm, 1/2W	187A641H67
R120-R122	470K Ohm, 1/2W	187A641H91
R124-R125	15K Ohm, 1/2W	187A641H55
R128	39K Ohm, 1/2W	187A641H65
	Zener Diode	
Z101	1N748A	186A797H13

Output Board

	Capacitors	
C301	1.0 MFD	187A624H04
C302	0.25 MFD	187A624H02
C303	3.0 MFD	188A293H06
C304-C306	0.05 MFD	187A624H08
C305	0.22 MFD	188A293H02
	Diodes	
D301-D304-D305-D306	1N457A	184A855H07
D302-D303	1N91	182A881H04

ELECTRICAL PARTS LIST

Output Board (continued)

Circuit Symbol	Description	Westinghouse Style Number
	Transistor	
Q301-Q305-Q306-Q307	2N652A	184A638H16
Q302-Q303-Q304	2N697	184A638H18
Q308	2N699	184A638H19
	Resistors	
R301-R303-R309-R310-R313-R324-R325	10K Ohm, 1/2W	187A641H51
R302	120K Ohm, 1/2W	187A641H77
R304	47 Ohm, 1/2W	187A640H17
R305	8.2K Ohm, 1/2W	187A641H49
R306-R315-R322	4.7K Ohm, 1/2W	187A641H43
R307-R331	2.2K Ohm, 1/2W	187A641H35
R308-R320	6.8K Ohm, 1/2W	187A641H47
R311	470 Ohm, 1/2W	187A641H19
R312	470K Ohm, 1/2W	187A641H91
R316-R321-R323	22K Ohm, 1/2W	187A641H59
R317-R328-R332	5.6K Ohm, 1/2W	184A763H45
R318	15K Ohm, 1/2W	187A641H55
R319	Thermistor 1D101	185A211H04
R326-R329	4.7K Ohm, 1/2W	184A763H43
R327	6.8K Ohm, 1/2W	184A763H47
R330	1.5K Ohm, 1/2W	187A641H31
	Zener Diodes	
Z301-Z303-Z305	1N957B	186A797H06
Z320	1N965B	186A797H08
Z304	1N960B	186A797H10
Z306	1N1789	584C434H08
Relay Board		
	Capacitors	
C251-C252-C253	0.25 MFD	187A624H02
	Resistors	
R251-R252	2.2K Ohm, 1/2W	187A641H35
R253	800 Ohm, 3W	184A859H06
	Filter Choke	
L251	8.5HY, 400 Ohm	188A460H01
	Trip	
AR		408C845G09

Where a voltage output is required, the AR relay is omitted and the following additional parts are located on the board.

ELECTRICAL PARTS LIST

Relay Board (continued)

Circuit Symbol	Description	Westinghouse Style Number
	Capacitors	
C254	0.25 MFD	187A624H02
	Diodes	
D251-D252	1N457A	184A855H07
D253	CER-69	188A342H06
	Transistors	
Q251-Q252	2N398A	184A638H12
	Resistors	
R253,R256	1K Ohm, 1/2W	184A763H27
R254	2.2K Ohm, 3W	184A859H15
R255	330 Ohm, 3W	184A859H14
R257	10K Ohm, 1/2W	184A763H51
R259	2.25K Ohm, 3W	184A636H03
	Zener Diode	
Z251	1N3686B	185A212H06

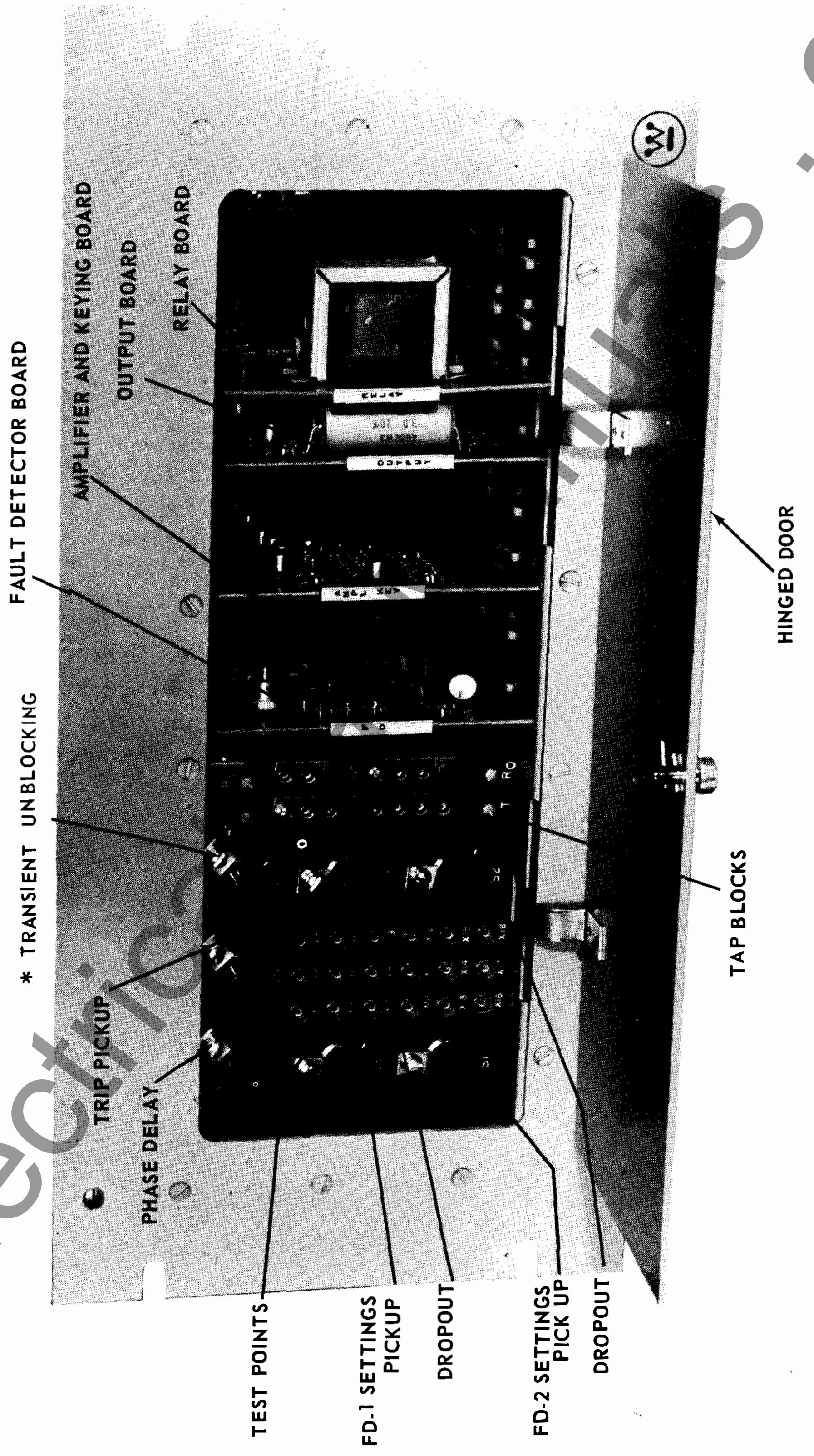


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Fig. 1 Type SKBU Phase Comparison Relay (Front View)

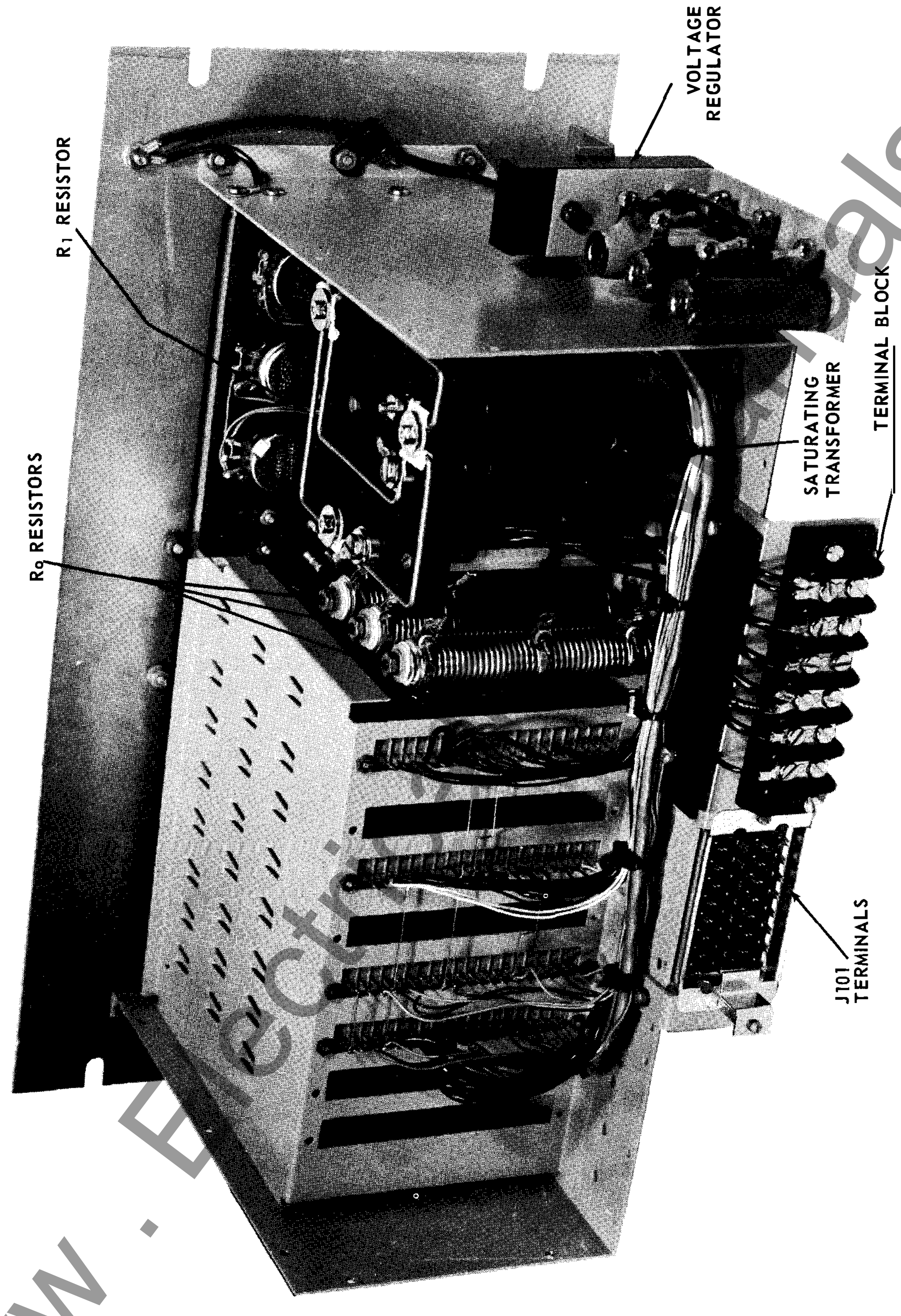

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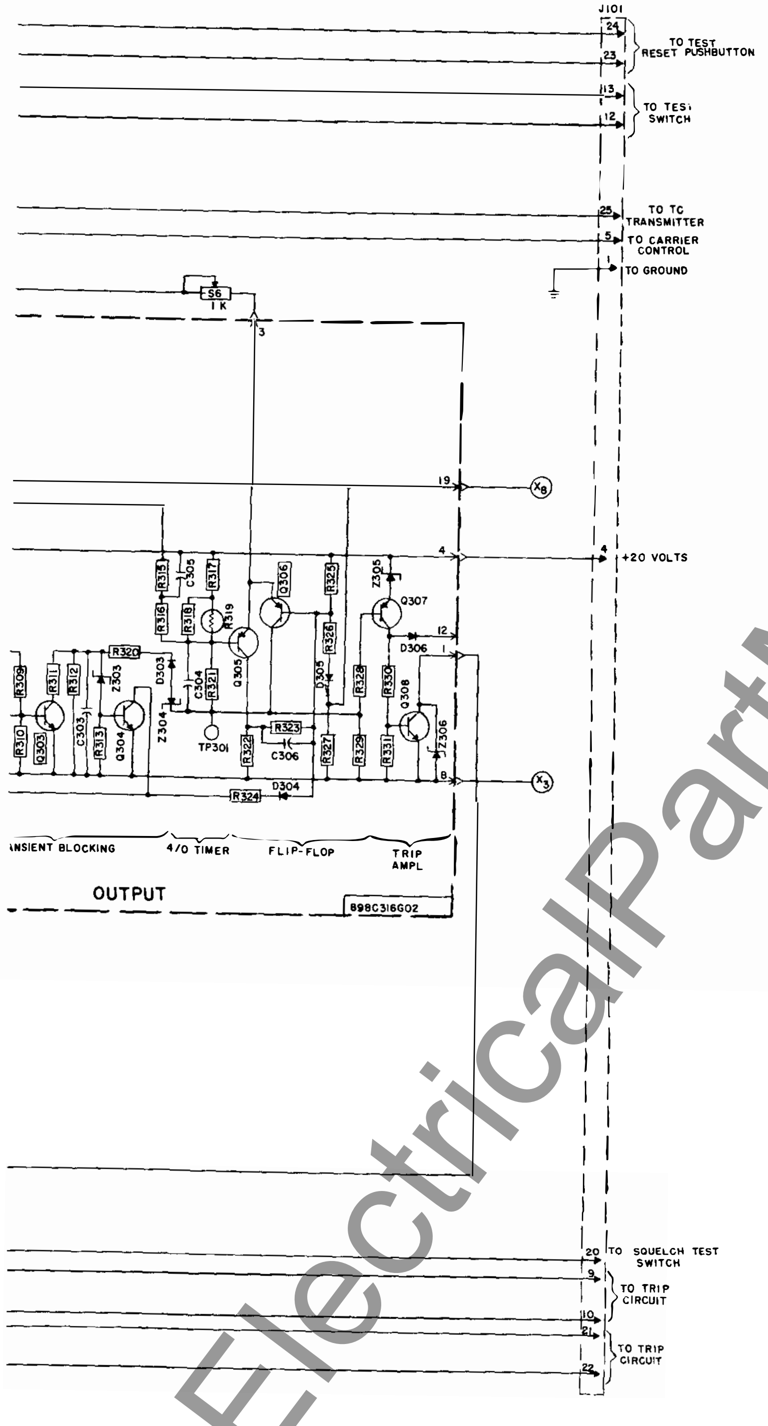
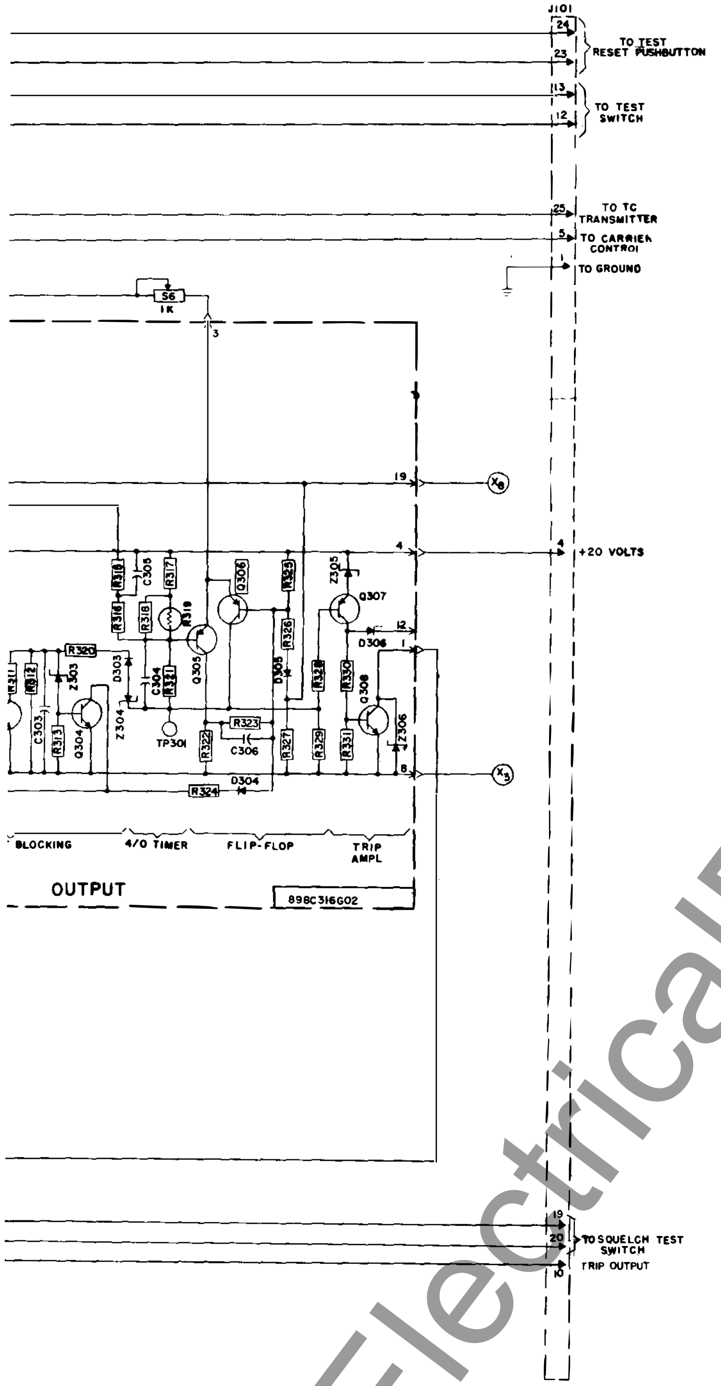
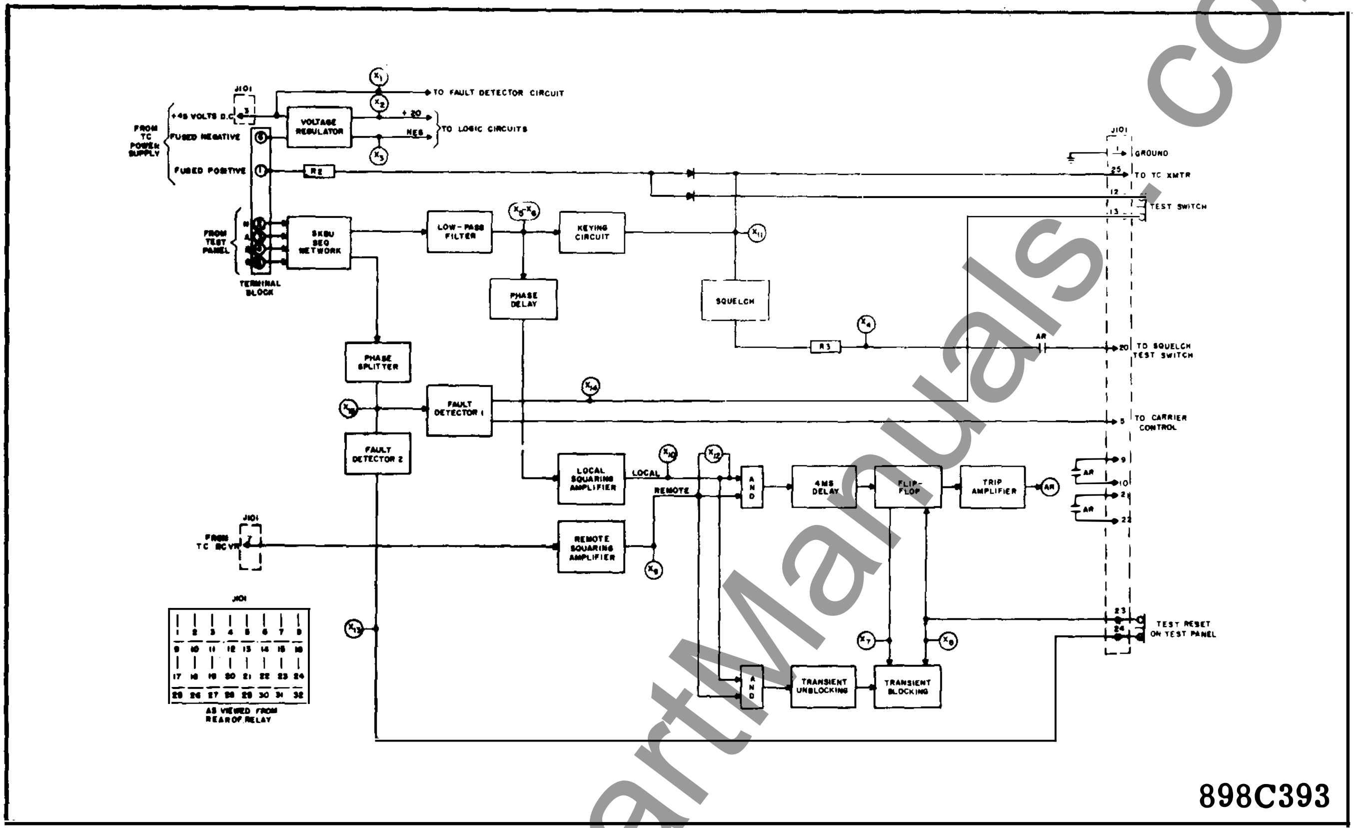
Fig. 2 Type SKBU Phase Comparison Relay (Rear View)


J101
24
23
TO TEST RESET PUSHBUTTON
13
12
TO TEST SWITCH
25
TO TC TRANSMITTER
5
TO CARRIER CONTROL
1
TO GROUND
S6
1K
3
19
X8
4
+20 VOLTS
R315
C305
R317
Q306
R325
Z305
Q307
R316
R318
R319
Q305
R326
12
D306
1
R309
R311
R312
R320
Z303
D303
C304
R321
D305
R328
R330
Q308
R310
Q303
C303
R313
Q304
Z304
TP301
R322
R323
C306
R327
R329
R331
Z306
8
X3
R324
D304
ANSIENT BLOCKING
4/0 TIMER
FLIP-FLOP
TRIP AMPL
OUTPUT
898C316G02
20
TO SQUELCH TEST SWITCH
9
TO TRIP CIRCUIT
10
21
TO TRIP CIRCUIT
22

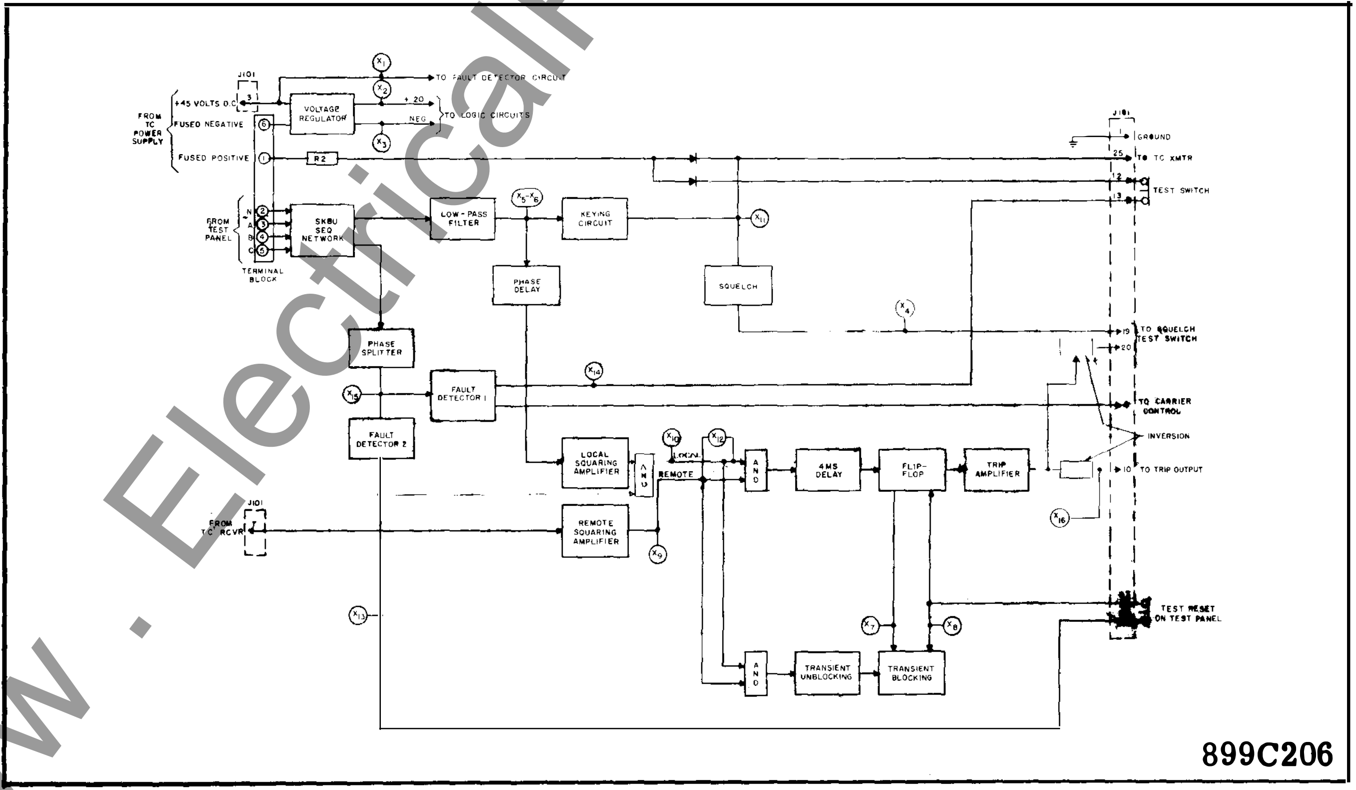
756J654


J101
24
23
TO TEST RESET PUSHBUTTON
13
12
TO TEST SWITCH
25
TO TC TRANSMITTER
5
TO CARRIER CONTROl
1
TO GROUND
S6
1K
3
19
4
+20 VOLTS
R318
C305
R317
Q306
R325
Z305
Q307
R316
R318
R319
Q305
R326
12
D306
1
R311
R312
R320
Z303
D303
C304
R321
D305
R328
R330
Q308
C303
R313
Q304
Z304
TP301
R323
R322
C306
R327
R329
R331
Z306
8
R324
D304
BLOCKING
4/0 TIMER
FLIP-FLOP
TRIP AMPL
OUTPUT
898C316G02
19
20
TO SQUELCH TEST SWITCH
TRIP OUTPUT
10

756J704



* **Fig. 5** Logic Diagram of the Type SKBU Relay with an AR Output



* **Fig. 6** Logic Diagram of the Type SKBU Relay with a Voltage Output

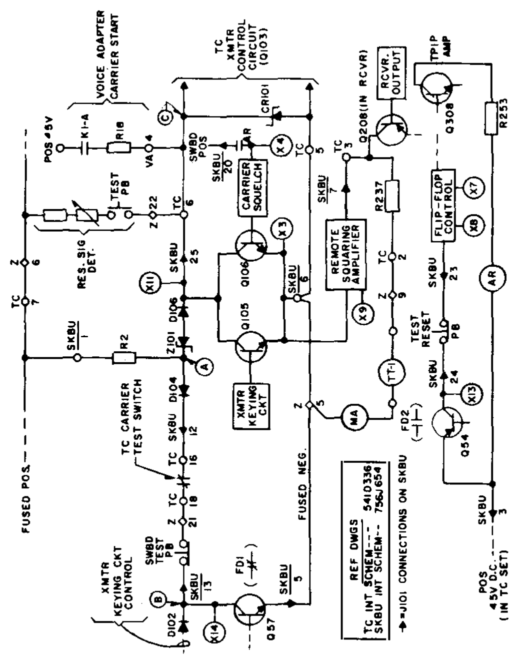


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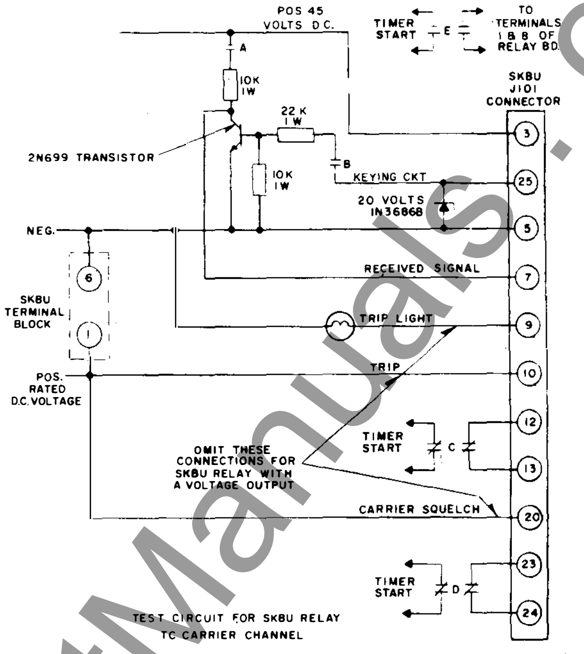
Fig. 7 Elementary Connections of TC SKBU Control Circuits



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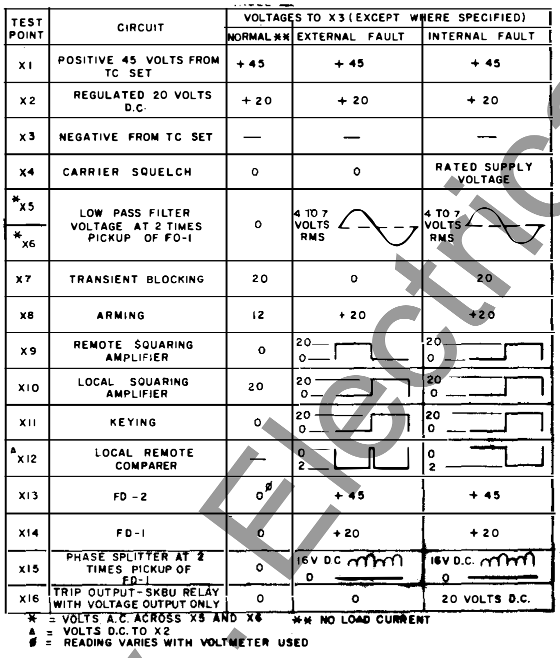
* Fig. 8 Test Circuit of SKBU Relay



TEST POINT	CIRCUIT	VOLTAGES TO X3 (EXCEPT WHERE SPECIFIED)		
		NORMAL **	EXTERNAL FAULT	INTERNAL FAULT
X1	POSITIVE 45 VOLTS FROM TC SET	+ 45	+ 45	+ 45
X2	REGULATED 20 VOLTS D.C.	+ 20	+ 20	+ 20
X3	NEGATIVE FROM TC SET	—	—	—
X4	CARRIER SQUELCH	0	0	RATED SUPPLY VOLTAGE
*X5 *X6	LOW PASS FILTER VOLTAGE AT 2 TIMES PICKUP OF FD-1	0	4 TO 7 VOLTS RMS	4 TO 7 VOLTS RMS
X7	TRANSIENT BLOCKING	20	0	20
X8	ARMING	12	+ 20	+20
X9	REMOTE SQUARING AMPLIFIER	0	20 0	20 0
X10	LOCAL SQUARING AMPLIFIER	20	20 0	20 0
X11	KEYING	0	20 0	20 0
^X12	LOCAL REMOTE COMPARER	—	0 2	0 2
X13	FD - 2	0^ø	+ 45	+ 45
X14	FD-1	0	+ 20	+ 20
X15	PHASE SPLITTER AT 2 TIMES PICKUP OF FD-1	0	16V D.C 0	16V D.C. 0
X16	TRIP OUTPUT-SKBU RELAY WITH VOLTAGE OUTPUT ONLY	0	0	20 VOLTS D.C.

* = VOLTS A.C. ACROSS X5 AND X6 ** NO LOAD CURRENT
▲ = VOLTS D.C. TO X2
ø = READING VARIES WITH VOLTMETER USED

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* Fig. 9 Table III, Voltages of SKBU Relay

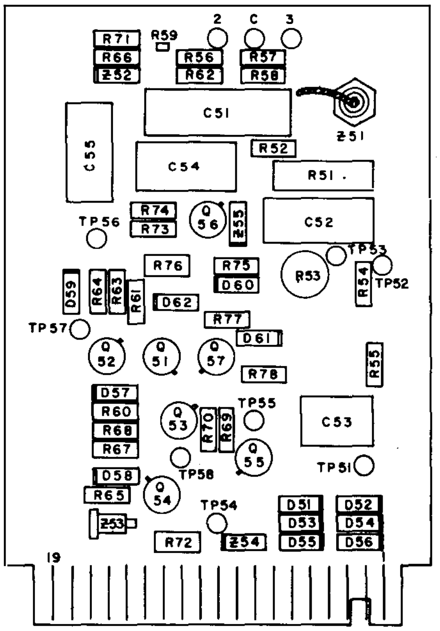

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Fig. 10 Component Location on Fault Detector Printed Circuit Board for Type SKBU Relay

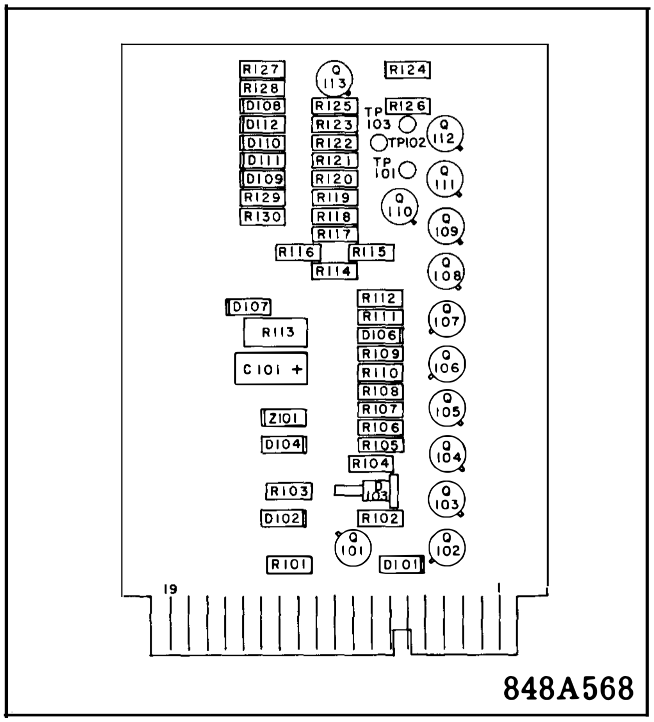


Fig. 11 Component Location on Amplifier and Keying Printed Circuit Board for Type SKBU Relay

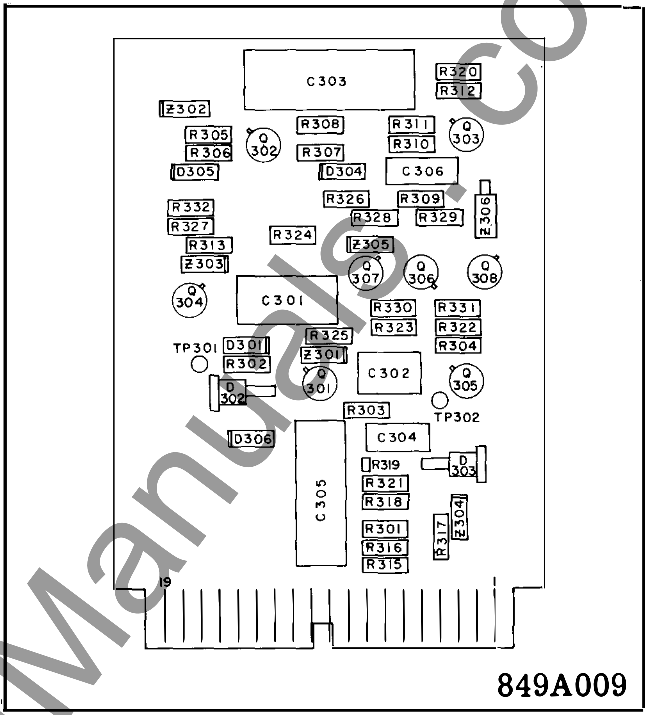


Fig. 12 Component Location on Output Printed Circuit Board for Type SKBU Relay

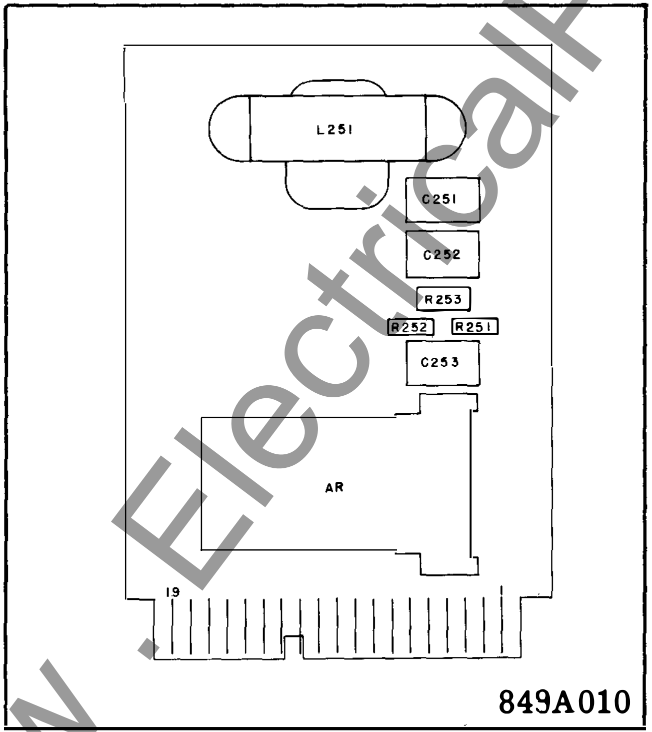


Fig. 13 Component Location on Relay Printed Circuit Board with an AR Output for Type SKBU Relay

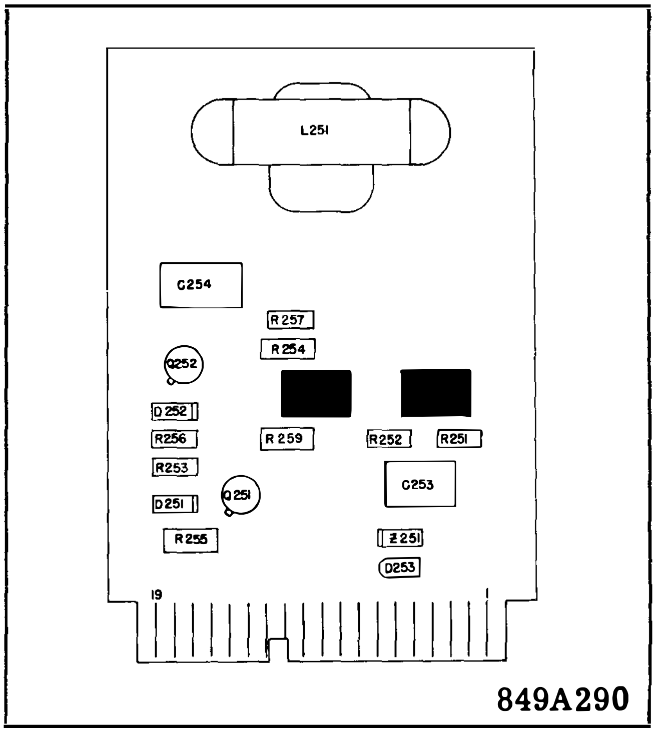
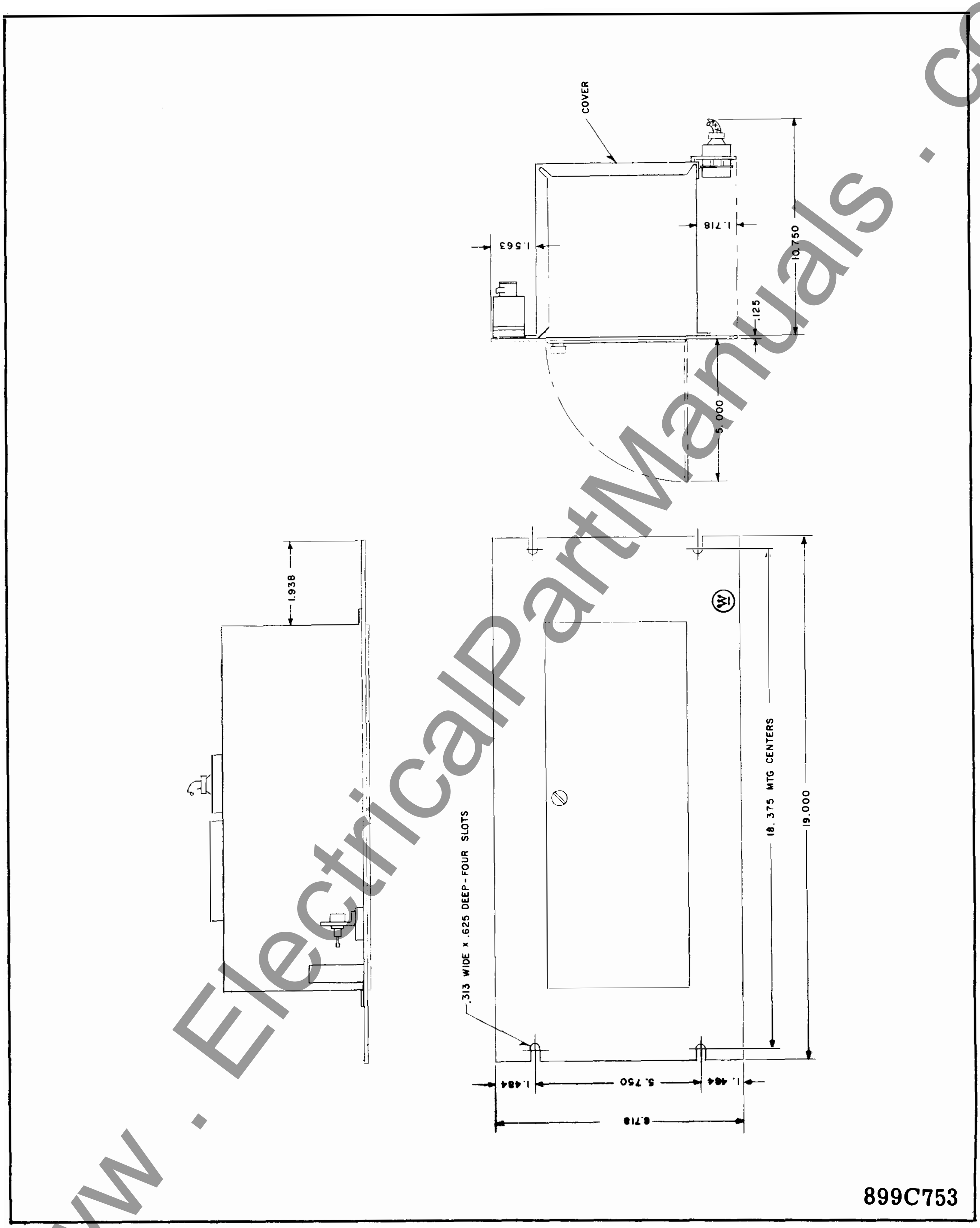


Fig. 14 Component Location on Relay Printed Circuit Board with a Voltage Output for Type SKBU Relay



* Fig. 15 Outline and Drilling Plan for Type SKBU Relay

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