INSTALLATION • OPERATION • MAINTENANCE

INSTRUCTIONS

SOLID STATE DISTANCE PHASE COMPARISON BLOCKING SYSTEM (TYPE AIBIA)

INTRODUCTION

This system instruction leaflet describes the overall operation of the distance phase comparison system using the SKBU-11 relay and TC power line carrier. This is a phase comparison system with distance relays supplementing the overcurrent fault detectors in the SKBU-11 relay. The distance relays perform the carrier start and carrier trip functions for three phase faults. The overcurrent fault detectors perform these functions for all unbalanced faults.

This instruction leaflet describes the basic pilot system and many of its options. The assembly drawing and schematics which are included are typical. The equipment supplied on a specific job is defined by the drawings provided for the job. Detailed descriptions of the operation, setting, and recommended maintenance for individual relays of the system are presented in the individual relay instruction leaflets.

CAUTION

Before placing the equipment in service:

1. Secure the cabinet or panel to the floor before working with the system to prevent tipping of the cabinet or panel.

2. Be sure all printed circuit bards and multi-pin connectors are well seated in their receptacles and TC crystals are in place.

3. Adjust equipment and perform tests outlined under "INSTALLATION."

4. It is recommended that before proceeding to adjust the system, one become familiar with the information in this instruction leaflet and the information in the individual relay instruction leaflets.

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*Denotes change from superseded issue.

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APPLICATION

Solid State Pilot Relay Systems

High-speed relaying is required for modern transmission lines in order to improve transient stability, permit the highest speed reclosing commensurate with arc de-ionization time and to minimize conductor damage by extending the basic principle of differential protection to line relaying. Pilot relay systems provide high-speed clearing for all internal faults and restraint for all external faults. The pilot channel provides the communication link which enables comparison of current or power flow at all line terminals.

Distance Phase Comparison Blocking System

The system described in this instruction leaflet provides high-speed detection of transmission line phase and ground faults, initiates tripping, controls reclosing of the circuit breaker(s), provides an input to the breaker failure detection logic, and refrains from operating for any fault outside of the protected line section.

Distance relays are utilized to detect three-phase faults and supplement the overcurrent fault detectors within the SKBU-11 relay. This arrangement significantly improves the sensitivity of the system response to interphase faults. Consequently, the system is particularly applicable to long lines where the minimum three-phase fault current may be relatively small. This system is suitable for three-terminal applications, unless there is a substantial outfeed current at more than one terminal for an external fault.

The determination of fault location (internal vs. external) for all faults is made on the basis of phase (angular) comparison of currents only. Therefore, the relays will not trip during a swing or out-of-step condition. For the same reason, this system is applicable on lines containing series capacitors. The carrier equipment is Type TC transmitter/receiver. The transmitter has a 10 watt power rating. The ON-OFF characteristic of the TC permits use of the channel for auxiliary functions, such as voice communication, during normal (non-fault) conditions.

The distance relays have some reverse as well as forward reach. Since the directional sensing at zero voltage is not critical (the discrimination being provided by phase comparison), this relaying system is not subject to false directional sensing due to mutual induction, and will operate when reclosing into close-in three-phase faults, with line side potential supply.

High set, direct trip (through the SRU) overcurrent elements (I_{OH}, I_{BH} and I_{CH}) within the SIU relay are always included in the distance phase comparison system. They are required to provide coverage for close-in faults which may cause incorrect phase comparison, due to adverse sequence current distribution factors or current transformer saturation. By the use of high set overcurrent control of carrier "squelch", the remote breaker may be cleared at high speed for this difficult end zone fault

These instructions contemplate the use of separate primary and secondary relaying systems, in line with local backup philosophies. Where used, backup features (such as high set overcurrent or zone 2 timer) which are incorporated in this pilot function merely as a convenient means of increasing reliability and do not constitute true secondary protection.

Application Options

Options which are available and permit the use of standard designs are:

1. Out-of-step (O-S) relaying using Type SDBU-2 relay, OS-2 logic in the SRU relay, and I_{A-OS} overcurrent supervision in the SIU relay. This scheme provides O-S blocking of reclosing, optional O-S blocking of distance relays, and optional controlled angle O-S tripping. In addition, restricted trip (ability to accommodate high load current) capability is provided by the double blinder characteristic of the SDBU-2 relay.

2. Zone 2 Timer, .1 to 1.0 Seconds or .4 to 4.0 Seconds, initiated by the carrier trip distance relay or the arming fault detector, FD-2. The timer is contained in the SRU relay.

The following non-standard options are also available:

1. Blocking reclosing for three phase faults. This requires a type SKDU-31 relay instead of the SKDU-3 for the carrier trip function, a zero sequence overcurrent unit

(I_N) in the SIU relay, and "not I_O" logic in the SRU relay. If the SDBU-2 relay is provided, the over-current unit, I_N, is not required.

2. Supervision of the distance trip relay by overcurrent fault detector unit (I_B) in the SIU relay. This will prevent false tripping due to potential circuit trouble. This application is restricted to lines with relatively high internal fault currents.

EQUIPMENT COMPLEMENT

A typical layout of components for the basic SKBU-11/TC system is shown in Fig. 4. The components listed below may be furnished in a 90" swing rack cabinet or a 90" panel. The 90" swing rack cabinet is the Type SU with a mounting space of 46 rack units. Refer to Fig. 5 for the cabinet outline. The 90" panel Type VU, has a total mounting space of 49 rack units, and Fig. 6 shows its outline dimensions.

Typical Complement

DEVICE NO.	TYPE	DESCRIPTION
78	SKBU-11	Phase comparison relay, with high sensitivity fault detectors and separate sequence filter output for keying.
50	SIU	Instantaneous overcurrent relay with I_{OH}, I_{BH} and I_{CH} units.
21P	SKDU-3	Phase distance carrier trip relay, offset mho characteristic, to detect three-phase faults.
21S	SKDU-3	Phase distance carrier start relay, offset mho characteristic, to detect three-phase faults.
95	SRU	Output and indication relay, with two thyristor trip outputs, reclosing initiation, reclose blocking, breaker failure initiation, alarms and indication.
	TC	ON-OFF power line carrier, 10 watt transmitter/receiver.

DEVICE NO.	TYPE	DESCRIPTION
	FTU	Functional test unit, consisting of: (2) FT-1 Switches, Device TCO and Device FT-1 (1) Test Transformer (1) Type W-2 Relay Test Switch, Device RST (6) Blue Lights, for SRU output indication (1) Carrier Test Pushbutton (85 PB) (1) Carrier Milliammeter, range 0 to 300 milliamperes. (1) Test Reset Pushbutton
	SPP	Surge Protective Package, Mounted Inside Cabinet

Optional Equipment

DEVICE NO.	TYPE	DESCRIPTION
21B	SDBU-2	Dual blinder relay, for out-of-step relaying and restricted tripping.
95	OS-2	Out-of-step logic for dual blinder, located in SRU.
50	I_A-OS	Overcurrent supervision for out-of-step relaying, located in SRU
2	--	Zone 2 timer, operated by Dev. 21P or FD-2, located in the SRU relay.
21P	SKDU-31	Phase distance relay, responsive only to three-phase faults and some phase to ground faults. Used instead of SKDU-3 when three-phase fault block reclosing is required.
50	I_N	Ground instantaneous overcurrent unit, located in SIU. Used with SKD-31 for "not I_0" function.
50	I_B	Phase instantaneous overcurrent unit, located in SRU. Used to supervise distance relay, Device 21P.

OPERATION

In phase comparison relaying, the relative phase positions of the fault currents at the two ends of the line section are compared over a carrier channel to determine whether the fault is within or outside the protected line section. Fault current from the line current transformers is applied to a sequence network in the SKBU-11 relay. The sequence network consists of a positive sequence current filter, a negative sequence current filter, and two mixing transformers, as shown in the system logic diagram, Fig. 1. One mixing transformer is energized by negative and zero sequence currents. This transformer operates the overcurrent fault detectors in the SKBU-11 relay: FD-1 (carrier start) and FD-2 (carrier trip, or "arming"). The other mixing transformer is energized by positive, negative and zero sequence currents. This transformer operates the carrier transmitter keying circuit and provides the local 60 Hz pulses which are compared in phase position to carrier pulses received from the remote terminal. This critical comparison of current phase angle (the key logic in all "phase comparison" systems) takes place via logic blocks "Local Squaring Amplifier", and "Remote Squaring Amplifier" and "AND-1" as shown in Fig. 1. By comparing the local pulses with those received from the remote terminal, the system determines if the fault is internal or external to the protected line section. Current transformer connections to the SKBU-11 relays of the two line terminals are such that carrier is transmitted on the same half-cycle from both terminals during an internal fault, and on alternate half cycles during an external fault. For tripping to occur, a hole must appear in the carrier signal. The hole has to be greater than 4 msec. to overcome a time delay that has been added to allow for differences in current transformer performance at opposite line terminals, mismatch in current phase angle (due to capacitive line charging current), relay coordination, and momentary interruptions in carrier caused by arcing over of protective gaps in the tuning equipment.

A phase comparison blocking system is characterized by the use of ON-OFF carrier. The carrier transmitter is normally off, which is the trip-permissive state. Therefore it is necessary to provide security by requiring high set, or relatively insensitive, fault detectors to supervise tripping (referred to as "arming") and low set, or relatively sensitive, fault detectors to start carrier. The margin between the sensitive and insensitive fault detectors provides the coordination necessary to assure that all external faults seen by the arming elements at the local terminal are seen by the starting elements at the remote terminal.

A distance phase comparison system incorporates distance relays which respond to three phase faults. These relays, Device 21S for carrier start and Device 21P for arming, supplement the overcurrent fault detectors, FD-1 and FD-2. This use of distance fault detectors greatly improves the sensitivity of the pilot system for three phase faults, from 7.5 amperes for phase comparison systems without distance relays to 1.0 amperes for the distance phase comparison system. The response to phase-to-phase faults is also improved. This is achieved by the high negative sequence content in the fault detector filter. The improvement in phase-to-phase fault sensitivity is from 3.4 amperes for phase comparison systems without distance relays to 0.8 amperes for the distance phase comparison system.

An integral part of the distance phase comparison system is the SIU high-set phase and ground unit, which is utilized to provide extra fast tripping of heavy close-in faults. This function is not optional on the distance phase comparison systems; it should be utilized in all cases.

I. Internal Faults

With reference to Figs. 1 and 3, consider the relay operation at breakers A and B for the internal fault condition. The sequence network in the SKBU-11 relay at both terminals develops sequence current quantities which energize the mixing transformers.

A. Fault Detector Mixing Transformer (T_{FD})

If the fault is unbalanced (other than 3-phase) there will be a zero and/or negative sequence component in the fault current, and the fault detector mixing transformer (T_{FD}) will have a secondary voltage output. The T_{FD} output energizes the fault detector, FD-1, to start carrier by turning off transistor Q_{164}. The T_{FD} output also operates FD-2, which is the "arming" fault detector. The arming function is essential; it provides security by supervising the phase comparison coincidence circuit, AND-4, as well as the ultimate tripping of the Flip-Flop, AND-3. As shown in Fig. 1, FD-2 is supervised by the frequency verifier circuit. The frequency verifier prevents spurious fault detector operation due to high frequencies which may be encountered during certain switching conditions, such as line energizing.

If the internal fault is three phase, the FD-1 function is performed by the carrier start distance relay, Dev. 21S, via OR-1; and the FD-2 function is performed by the carrier trip distance relay, Dev. 21P, via OR-2. The 8/0 timer prior to OR-2 provides a coordinating delay to take care of the worst case during external faults where 21P may be as much as 8 msec. faster than 21S. It also allows time for the AND-1 inputs to readjust to the post-fault conditions before allowing tripping.

B. Keying Mixing Transformer (T_K)

Transformer T_K is energized by all sequence components, and, therefore, will respond to all faults. In fact, T_K has an output due to normal load current (2.0 amperes, or more). The 60 Hz voltage output from T_K keys the TC carrier transmitter by turning keying transistor Q105 alternately on and off. As shown on Fig.s 1 & 3, the OFF state of Q105 corresponds to the ON state of the local transmitter carrier frequency. Transformer T_K also provides a local waveform which permits the phase comparison coincidence circuit, AND-1, to correctly determine the fault location. This waveform must be delayed by the "phase delay" block in order to compensate for the communication delay experienced by the remote carrier signal. After this delay, the local squaring amplifier provides the alternating square wave form shown as waveform VII on Fig. 3.

C. Received Carrier Signal

At terminal A, the half-cycle carrier signal from terminal B is received over the carrier channel and applied to the remote squaring amplifier. This circuit converts the received signal to a square wave voltage at point X9. The output at point X9 is the remote quantity to be compared with the local square wave voltage at point X12 through the AND-1 circuit. Since the fault is internal, both carrier transmitters will be turned off simultaneously (due to the current transformer connection). This means that on one-half cycle neither end will be transmitting carrier, and a half-cycle hole appears in the carrier signal. This hole produces half-cycle negative voltage at point X9 which is coincident with the half-cycle negative voltage at point X12. Since the input to the AND circuit is satisfied for one half-cycle, the output of AND-3 goes negative and a capacitor in the 4 msec. delay starts to charge. After 4 msec., the capacitor charges sufficiently to allow an input to the Flip-Flop circuit. Since the Flip-Flop was previously armed by the FD-2 unit or Device 21P, AND-3 is energized to operate the SRU tripping relay. It should be pointed out that on long lines, the hole in the carrier signal will be slightly less than one-half cycle, due to fault-current propagation time delay. The 4/0 timer provides sufficient margin to permit tripping for all except the very longest lines (over 250 miles).

The tripping Flip-Flop, AND-3, also provides a signal to operate a squelch timer, 10/150. After a 10 msec. delay, the squelch circuit operates to stop carrier, by turning on transistor Q102. The squelch circuit keeps carrier off for 150 msec. to prevent delayed tripping of breaker B due to a short burst of carrier at the time of breaker A opening. The high set overcurrent elements, Device 50HS, also operate the squelch circuit to assure high speed tripping of both terminals during worst case end zone ground faults which may cause almost all the ground current to flow from one end thereby upsetting the phase comparison coincidence circuit. The breaker failure lockout relay, Device 86BF, also operates the squelch circuit to provide a convenient form of transfer trip backup for breaker failure conditions.

II. External Faults

Consider the operation of the relaying at breakers A and B for the external fault condition of Fig. 3. For the unbalanced fault, it is assumed that fault detectors FD-1 and FD-2 operate at both A & B. For the three phase fault, it is assumed that Devices 21S and 21P operate at both terminals. Since carrier is started at both terminals, the keying transistor, Q105, controls the alternating half cycle carrier transmission, as it did for the internal fault. However, in this case there is a polarity reversal of the keying voltage at station B. This shifts the received carrier signal and remote squaring amplifier output by 180°, as shown in Fig. 3. A blocking signal is now always provided, either by the local squaring amplifier or the remote squaring amplifier, to prevent operation of the 4/0 timer. An additional blocking effect is provided by the local transmitter operating the local receiver, so that in actual practice, for a short line, the remote squaring amplifier output is nearly a continuous blocking (20 volts) signal. For long lines, a hole will appear in the remote squaring amplifier signal, and the local squaring amplifier, as phased delayed, will provide the proper blocking signal.

III. Transient Blocking

Transient blocking is included in this relaying system. Since the sequence networks and low pass filter contain reactive circuit elements, discharge of their stored energy at the clearing of an external fault might cause an incorrect relay operation. In order to prevent this, a transient blocking circuit has been added. For any fault, if trip initiation does not occur in less than 18 msec. after the flip-flop is armed, the flip-flop will be blocked from operating so that a transient pulse cannot operate it. This is done via OR-3, 0/100, and AND-4, as shown in Fig. 1. However, if an internal fault develops before the external fault is cleared, the change in phase position of the local and remote carrier pulses will cancel the transient blocking after approximately 25 msec. (transient unblocking) to allow tripping.

INSTALLATION

The assembly should be mounted in a location free from dust, excessive humidity, vibration, corrosive fumes or heat. Since the equipment is transistorized, the air temperature around the chassis must not exceed 60°C or go below -20°C.

I. Acceptance Testing

A. Relay and Carrier Acceptance

The individual relay and carrier equipment instruction leaflets should be referred to for specific acceptance tests. These tests should be performed to assure that no calibration change nor component damage has occurred in shipment. The relay tests may be performed with the relays in place by applying appropriate quantities to the Flexitest switches that have been provided. Care should be exercised that current in excess of continuous rating of the device being tested is not applied for more than a few seconds.

B. System Acceptance

After the complete equipment has been installed and the channel equipment adjusted, tests can be made to provide an overall check for the system. These tests require the following conditions:

a. Balanced three-phase load of at least 1.0 ampere (secondary) flowing in the line section protected by the SKBU-11 relay.

b. SRU output circuits disconnected by opening red handle test switches A, B, C, D, E, and F of FT-1 switch, Device TCO. (Refer to Fig. 2).

c. Device TCO switch G open to disconnect the pilot trip input to the squelch circuit.

d. SKBU-11 relay settings of I_2 = C (0.25 ampere) and I_0 = F (0). Be sure to insert the spare tap screw before removing the connected one.

The tests should be performed in the following order: Phase Rotation Check, Phase Delay and 4/0 Timer Adjustment, Polarity and Connection Check.

1. Phase Rotation Check

The phase rotation of the three-phase current can be checked by measuring the fault detector mixing transformer (T_{FD}) output, as measured at printed circuit board terminals 3 & 6 of the "fault detector" board. Transformer T_{FD} nominally contains negative and zero sequence components only, with the ratio of current required to operate FD-1 7.0/0.25 amperes or 28/1 for positive sequence vs. negative sequence. With at least 1.0 ampere (secondary) flowing to the SKBU-11 relay, measure the a-c voltage across the Fault Detector printed circuit board terminals 3 and 6. The reading obtained should be negligible (less than 1/2 volt per ampere of balanced 3-phase load). If the phase rotation is not correct, the reading will be approximately 10 volts rms per ampere.

2. Phase Delay and the 4/0 Timer Adjustment

These adjustments are made utilizing the functional test unit, FTU, provided with each system. Energize the test transformer with system potential. See the Functional Testing section for a description of Device FTU and instructions for connecting the test transformer circuit.

a. Open all red handles on the FT-1 Switch, Device TCO. This opens all critical SRU outputs (breaker trip, breaker failure initiation, reclose initiation, and reclose blocking).

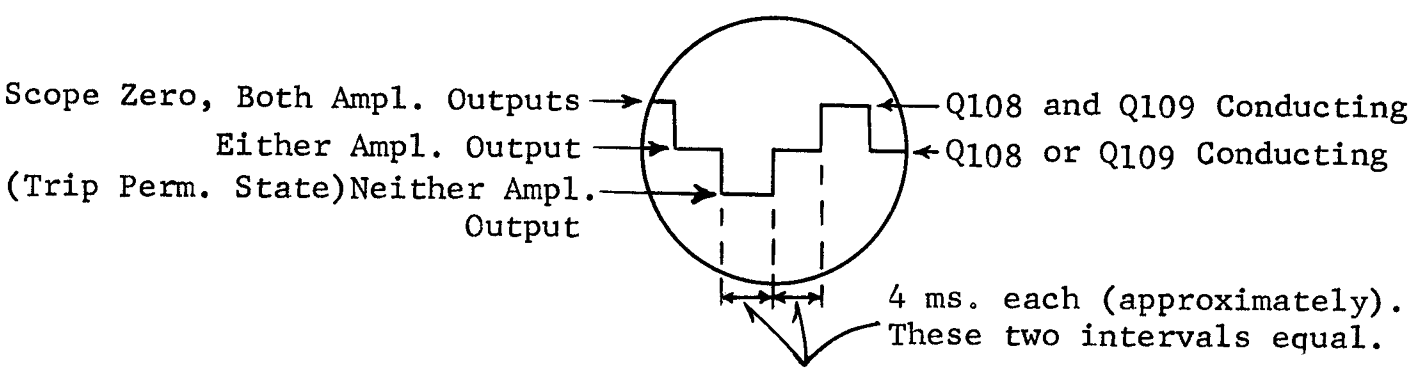
b. Open all black handles on Device FT-1; this short circuits the CT secondaries and opens potential transformer leads.

c. Remove the local transmitter crystal. This will prevent the local transmitter from operating the local receiver and thereby disturbing the phase delay adjustment.

d. Set potentiometer S5 to minimum resistance, providing minimum phase delay. Set potentiometer S6 to maximum, providing maximum pickup delay on the 4/0 timer. (Turn clockwise for minimum delay).

e. Simulate an external fault at both line terminals by placing Type W-2 switch, Device RST, at the T1 position.

f. Place cathode ray oscilloscope across test points X10 and X2 (scope shield lead). Adjust phase delay potentiometer, S5, until the following waveform is obtained:

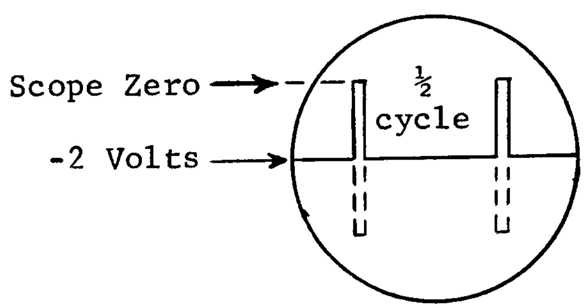


In this adjustment, the local operating voltage has been shifted 90°, or delayed 4 msec. from its normal "external fault" condition. If the scope has a linear sweep, the two indicating sections in this waveform should be of equal length (slightly over 4 msec., if the scope has a calibrated sweep). The phase relationship of this condition represents the tripping threshhold. The next adjustment will be to set the bias on the flip-flop so that it just triggers at this 90° phase setting.

g. At this point, momentarily depress the test reset pushbutton on the functional test panel to reset the flip-flop.

h. Adjust the 4/0 timer potentiometer, S6, until the SRU red breaker trip lights operate. This sets the triggering of the flip-flop after a 4 msec. delay.

i. Slowly increase S5 to obtain the following waveform. Adjust for minimum area of the pips. This will be with S5 near minimum resistance.

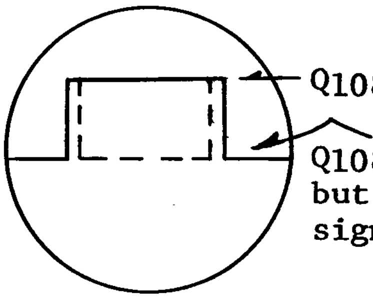


NOTE: At point of minimum area, pips may extend either up or down.

j. If it is desired to re-check the trip point, leave S6 as adjusted in "h." Depress the test reset pushbutton to reset the flip-flop. Slowly increase S5 until the flip-flop triggers. The wave form at this setting should be essentially as shown in section "f." If the triggering point is reached too soon, slightly increase S6 and repeat the foregoing check. When the adjustment of S6 is satisfactory, tighten its lock nut. NOTE: The flip-flop will not reset by simply increasing S6. Because of its toggle action provided by positive feedback, once it triggers, it will stay in that condition until arming is removed. This is most conveniently accomplished with the test reset pushbutton.

k. Reset S5 to get the wave form at step "i." Tighten S5 lock nut.

m. Replace the local transmitter crystal. The space between the two pips on the scope of step "i" or "j" will fill in, thus:



NOTE: In the foregoing adjustment, the operating voltage has been shifted 90° (4 msec. delay), then the flip-flop was set to just operate under this condition. This "calibrates" the trip point. Change in supply voltage, fault current, received signal level or ambient temperature will cause a negligible change in this trip point.

n. With the condition of step "m," depress the test pushbutton. By measuring the voltage of test point XII (20 volt is trip, 0 volts is non-trip), verify that the relay is not operating.

This completes the adjustment at one terminal. Adjust the opposite line terminal following the same procedure.

3. Polarity and Connection Check

a. Open Device FT-1 test switches D and E (Refer to Fig. 1) at one end of the line section (Station A). Next, open the current test jack in Switch E by inserting a strip of insulation. This 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 transformers through the zero sequence windings in the mixing transformers, thus simulating a phase A to ground fault fed from one end of the line only. As a result, both the overcurrent fault detector and the phase comparison logic at Station A will operate. If the SKBU-11 has a voltage output, 20 volts positive will appear at test point XII measured from test point X4 (d.c. negative), and the SRU.

b. Leaving the test connections at Station A as described above, perform the same operations at Station B. Carrier will be transmitted at both stations as evidenced by approximately 200 M.A. receiver current, but the SKBU-11 relay at Station B will not operate. Now momentarily push the test reset pushbutton at both stations. The SKBU-11 relays at neither station will operate. This test simulates a single phase to ground fault external to the protected line section.

c. At Station A restore Device FT-1 test switches D and E to normal by removing the insulation strip from Switch E and closing the handles. This simulates a phase A to ground fault fed from Station B only. The SKBU-11 at Station B will operate and the SKBU-11 at Station A will not operate. At Station B restore Device FT-1 test switches to normal. FD-1 and FD-2 will drop out to reset the SKBU-11 relay.

The above tests have checked the polarity of the sequence network output, the interconnections between the relay and the carrier set, and the phase A current connections to the relay at both stations. Phases B and C can be similarly checked by opening Device FT-1 test switches F and G for phase B and switches H and I for phase C. The same procedure described for phase A is then followed.

II. Settings

As in any blocking system, it is essential that the carrier start elements be more sensitive then the carrier trip elements. That is, any external faults seen by the remote tripping unit must also be seen by the local start unit; otherwise, undesired tripping of the remote breaker will occur. A second rule for any blocking system is that the carrier tripping elements must be sensitive enough to see all internal faults. A third rule, that pertains to phase comparison only, is that the sequence component settings in the local and remote fault detector mixing transformers must be the same. Otherwise, it is impossible to obtain proper coordination between the carrier start and carrier trip fault detectors.

A. Overcurrent Fault Detectors

Fault detectors FD-1 (carrier start) and FD-2 (arming) in the SKBU-11 relay must respond to all unbalanced faults. The SKBU-11 relay has separate tap plates for adjustment of the zero and negative sequence sensitivity of fault detector FD-1. The tap block marking and pickup for FD-1 are:

Negative Sequence Sensitivity (I_2)

Tap	Pickup
A	None
B	0.4 Amperes
C	0.25 Amperes

Zero Sequence Sensitivity (I_0)

Tap	Pickup
F	None
G	0.2 Amperes
H	0.1 Amperes

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 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 and where tap B will not provide the desired ground-fault sensitivity. In this case, set tap B and tap G or H. With a tap B setting, tap H setting is preferable to tap G so the zero-sequence effect can predominate over the negative sequence effect for ground faults.

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

The arming fault detector, FD-2, is set by selecting the proper ratio between FD-2 and FD-1. As shipped from the factory, FD-2 is set to pick up at 125% of FD-1. This ratio is correct for short lines. Long line applications, 100-miles or more, will require a higher FD-2/FD-1 ratio. This is due to the distributed capacitance effect on external ground faults causing the zero sequence and negative sequence currents to be higher in the relays remote from the fault than in the relays at the terminal close to the fault. In order to prevent false tripping on these long lines, it is recommended that FD-2 be set at 200% of FD-1. This may be done by adjusting the potentiometer S1 in the SKBU-11 relay. For three terminal lines, FD-2 should be set at 250% of FD-2.

B. Keying Sensitivity

The keying response of the SKBU-11 relay is independent of the fault detector tap settings. Fig. 7 shows typical lengths of keying pulses for different values of positive, negative and zero sequence currents.

C. Distance Fault Detectors

The distance fault detectors, Devices 21S and 21P, respond to 3 phase faults. The setting instructions which follow apply for the Type SKDU-3 relay and the Type SKDU-31 relay.

As shown in Fig. 8, Device 21P has a forward reach setting, Z_A, and a reverse reach setting, Z_C. A forward setting should be set to substantially overreach the adjacent bus, in order to assure coverage for all internal faults. A typical setting is 150% of the line secondary ohm impedance.

Where 21P operates a timer, it must not be set to overreach any adjacent line zone 1 relay. The reverse reach should be approximately 50% of the line impedance.

Device 21S should be set to overlap the remote 21P setting. Typical settings are Z_A equal to 175% of the line impedance and Z_C 75% of the line impedance. As shown in Fig. 8, these settings will produce 21S and 21P characteristics which are essentially superimposed on one another at stations I and II when plotted on a common R-X diagram. The disadvantage of reversed coverage only for 21S is illustrated in Fig. 9, wherein an out-of-step condition is shown causing a trip at both terminals.

D. Series Capacitor Applications

The setting criteria for series capacitor applications are illustrated with reference to Fig. 10 which shows the R-X diagram at stations A and B for a mid-line series capacitor location, with 50% compensation. It should be kept in mind that these characteristics apply only for positive sequence (3 phase faults, balanced loads, and swing conditions). The apparent line impedance and 21P and blinder characteristics are shown for the condition of series capacitors in-service (solid lines) and bypassed (dotted lines). The bypassed characteristic will apply during capacitor gap flashing. The resistive component of the line has been exaggerated to clarify the diagram.

The carrier start characteristic is a composite of the outer blinder, Device 21BO, and Device 21S. The trip characteristic is a composite of the inner blinder, Device 21BI, and Device 21P. The use of blinders, Type SDBU-2 Relay, is normally required with series capacitor applications, since the extreme line length associated with these applications implies load interference with the circular mho characteristic of Devices 21S and 21P. Also plotted on Fig. 10 is the effect of the overcurrent supervision, Device I_{A-OS}, as seen on the R-X diagram. Of course, in actual use the overcurrent device has an ohmic reach which varies with voltage level.

The trip characteristic should overreach the line section, in both forward and reverse directions, by at least 50% of the uncompensated line ohms. The carrier start characteristic should in turn overlap the remote carrier trip by approximately 25% in both forward and reverse directions with the capacitors in or bypassed. The inner blinder should be set high enough to accommodate the maximum arc resistance, as described in the blinder relay instruction leaflet. The outer blinder should be set at least 3 ohms (or 50% of the line length, whichever is greater) higher than the inner blinder unless the blinder relays are being used with out-of-step logic. In the latter case, the setting criteria of the static blinder relay instruction leaflet should be followed.

E. High-set Overcurrent Units

The high-set overcurrent units (I_{AH}, I_{CH} and I_{OH}) trip directly for close-in high-current faults. The setting of these units must be high enough to prevent tripping on reverse or remote external faults. To assure a safety margin against false tripping it is recommended that these units be set 25% higher than the maximum expected reverse current or the maximum expected remote external current, whichever is greater.

FUNCTIONAL TESTING

The phase comparison system should be tested at routine maintenance intervals to determine if the components are in working order. These terminals are provided with test equipment, Type FTU, that will check the circuits of the relays as well as the carrier equipment. Results give assurance that the equipment is in normal operating condition without resorting to more elaborate test procedures.

The design of the functional test unit is highly variable depending upon user preference and the requirements of the particular application. This instruction leaflet will assume that the simplest form of functional testing has been provided, as detailed in the equipment complement section. If the functional testing unit provided with a particular order differs from that described herein, refer to the supplementary instructions furnished with the order.

I. Components

1. Two FT-1 Switches:

   a) Device TCO. This performs the trip cutoff function by means of red handle switches which interrupt breaker trip BFI, and RI outputs. Device TCO also disables pilot trip initiated of the squelch circuit.

b) Device FT-1. The black handle switches on this device short circuit the current transformer secondaries and open the a-c potential supply.

2. Type W-2 Multi-Contact Switch (Device RST):

A multi-contact switch is provided at each line terminal to apply a single phase current from a test transformer to the SKBU-11 relay to simulate internal and external fault conditions. This switch also connects loading resistors and test lights in the tripping thyristor circuits.

3. Test Transformer:

The test transformer is designed to operate from a 120V., 60 Hz power source. Four secondary taps 1, 2, 3 & 4 are provided to vary the magnitude of the test current. Select the tap which produces 5 amperes maximum current. The test transformers at each terminal must be energized from voltages that are in phase with each other. When using the test circuit to adjust the phase delay timer, Paragraph I-B-2 of the INSTALLATION Section, it is important that the test currents at the two line terminals be in phase with each other. Therefore, check the impedance angle of the test current circuit at each terminal. If the angle differs by more than 5°, equalize the phase angle by adding resistance as required.

4. Test Lights:

Blue lights are provided to indicate breaker trip, BFI, RI, and RB outputs.

5. Carrier Test Pushbutton:

A pushbutton is provided to key the TC transmitter on.

6. Carrier Milliammeter:

Milliammeter is provided to indicate the TC receiver output current.

7. Test Rest Pushbutton:

Resets SKBU-11 Flip-Flop and verifies reset of tripping thyristors.

II. Test Procedure

CAUTION: No test should be started without the red handles on Device TCO at both stations in the OPEN position.

1. Channel Test:

   a) Push the carrier test pushbutton (85PB). Carrier should be transmitted at full power, as indicated by a reading of approximately 200 M.A. on the milliammeters.

2. Internal Fault Fed from One Line Terminal:

   a) Turn the carrier test switch (RST) to "Test 1" position at Station A. The SKBU-11 at Station A will operate, the SRU red trip lights will come on, and the blue indicating lamps (Breaker Trip, BFI and RI) will light. Carrier will be transmitted at half cycle pulses as indicated by approximately 100 milliamperes on a milliammeter. The received carrier alarm relay in the SRU will pick up. The alarm relay may be visually checked to verify operation.

   b) Close Device TCO Switch G. Carrier will be squelched off.

   c) Open Device TCO switch G.

3. Internal Fault Fed from Both Line Terminals:

   a) At Station A, leave system test switch (RST) in "Test 1" position.

   b) At Station B, turn RST to "Test 1" position. The SKBU-11 at Station B will trip and the SKBU-11 at Station A will remain tripped. Carrier will be transmitted in half cycle pulses from both stations as indicated by approximately 100 M.A. on both milliammeters. The SRU red trip lamps and the blue test lamps will light at both stations.

   c) Close Device TCO switch G at both stations. Carrier will be squelched off at both stations.

d) Open Device TCO switch G at both stations.

4. External Faults:

a) Push the FTU test reset pushbutton and at the same time at Station A, turn carrier test switch to "Test 2" position. This simulates an external fault behind station A.

b) At Station B leave test switch RST at "Test 1" position. Push the test reset pushbutton. Carrier will be transmitted from Station A and from Station B on alternate half cycles as indicated by approximately 200 M.A. on both milliammeters. The SKBU-11 relay will not operate at either station.

c) At Station B turn RST to "Test 2" position. This simulates an internal fault at both stations, causing red SRU lamps and blue test lamps to light.

d) At Station A turn RST to "Test 1" position. This simulates a remote external fault beyond Station B.

e) At both stations, push the test reset pushbutton. This will reset the SKBU-11 trip. Now, the SKBU-11 relay will not operate at either station.

5. Return to Normal:

CAUTION: In returning to normal, it is important to close the Device TCO red handles last.

Return the carrier test switch RST, to "NORM" position at both stations. Verify the reset of tripping thyristors by depressing the Test Reset Pushbutton. Close the black handle switches of Device FT-1. Close the red handle switches of Device TCO. This completes the functional test of the SKBU-11/TC relaying system.

TROUBLE SHOOTING

To troubleshoot the equipment, the functional test procedure, the schematic diagram of Fig. 1 and the wave-forms of Fig. 3 should be used to isolate the unit that is not performing correctly.

The troubleshooting procedure outlined in that unit's construction book should then be followed to locate the faulty component.

The following list will also aid in locating the trouble circuit. Follow steps listed until faulty unit is located.

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
Continuous Transmission of Carrier	Open Circuit	TC carrier transmitter (TP102 of TC Set or TPX14 of SKBU-11) TC test switch, SW. 101 85 PB. Open wiring between circuits FD-1 Transistor Q164, TPX14 to TPX4	1. Determine which terminal is transmitting signal 2. Open designated relay terminals listed under false signal. 3. Remove voice adapter 4. Short designated TP to negative 5. Short test switches (TC test switch & 85PB) 6. Check wiring between the circuits
	False Signal	78 (FD-1) 21S (SKDU-3)	
	Short Circuit	Voice Adapter	
	Blown Cabinet Fuse or Short Circuit	TC Carrier Set TP102 Carrier Squelch Carrier Keying TPX14 (SKBU-11) FD-1 or 21S (TPX16)	1. Check voltage regulator circuit on TC set. Term. 4 of TC should be pos. 45 Vdc. If not, check d-c supply to TC set. 2. Push 85PB button. If carrier is transmitted, trouble is in Carrier Control Circuit. If Carrier is not transmitted, trouble is either in the keying circuit or the squelch circuit. 3. If keying ckt. or squelch is faulty, refer to SKBU-11 Instr. Book

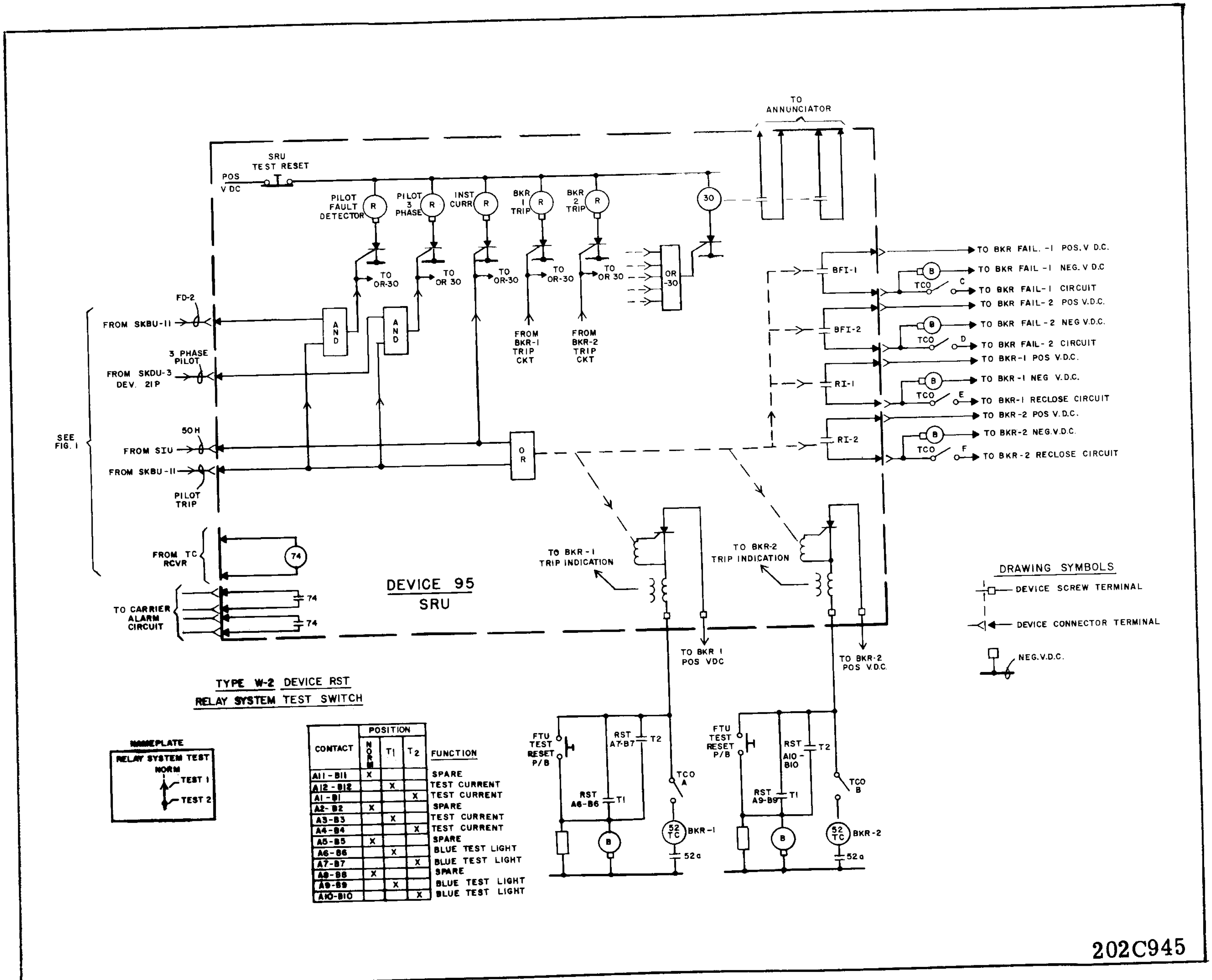
DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
Carrier Signal received at 200 MA Instead of 100 MA	Both transmitters keying on alternate half cycles Short Circuit Open Circuit	Carrier Keying Circuit TPX14 (SKBU-11) Low pass filter Phase Delay 78 TPX6 & TPX5	1. Check to see that only one transmitter is keying 2. Check a-c voltage across 78 test points X6 and X5 3. Check output of transmitter keying transistor TPX14. Should be a square wave
System Not Operating When it Should	Blown Cabinet Fuse Improper Adjustment Circuit not Armed No hole in carrier Remote terminal transmitting full carrier Short Open	TC Carrier Set S5 & S6 SKBU-11 Unit Arming Circuit 78(TPX8, TPX13, TPX18) Transient Blocking/Un-Blocking (TPX7)SKBU-11 Local Squaring Amplifier (TPX12 to TPX10)SKBU-11 Remote squaring Amplifier(TPX9) to TPX10) SKBU-11 Carrier Squelch Term. 10 of Amplifier & Keying Board SKBU-11	1. Check that cabinet power light is on. 2. Measure arming circuit voltage.Should be 20V. Short FD-2 78 TP256 on Arming Board to see if circuit will arm. 3. Check SKBU-11 test points for proper calibration as well as proper wave shapes. This will check the remote and the local squaring amplifiers. 4. Check to see that transient unblocking has worked. If note, refer to SKBU-11 Instruction Leaflet.

DESCRIPTION OF TROUBLE	POSSIBLE CAUSE	INVOLVED CIRCUITS	SUGGESTED PROCEDURE
System not Operating when it should (Cont'd.)		Transmitter Keying Ckt. (TPX14) SKBU-11 Trip Ckt., SKBU-11/SRU	5. Check transmitter keying and squelch circuits, TPX14 6. Check TPX11 for 20 volt trip output. If not present, trouble probably is in SKBU-11 relay. If present, trouble is probably in SRU relay.
System Trips when it should not	Short Spurious Pulse	Tripping Flip-Flop in SKBU-11 SRU	1. Check to see if TPX11 has trip output (20 volts). 2. Clamp lead to SRU to negative to see if it stops tripping
Intermittent Signal at SKBU-11 output (TPX11)	On-Off Signal	FD-1 and FD-2 in SKBU-11 21S & 21P	1. Determine which circuit causes trouble. 2. Check outputs with scope. Signal should not be on-off D-C. 3. Check calibration of SKBU-11

RECOMMENDED TEST EQUIPMENT

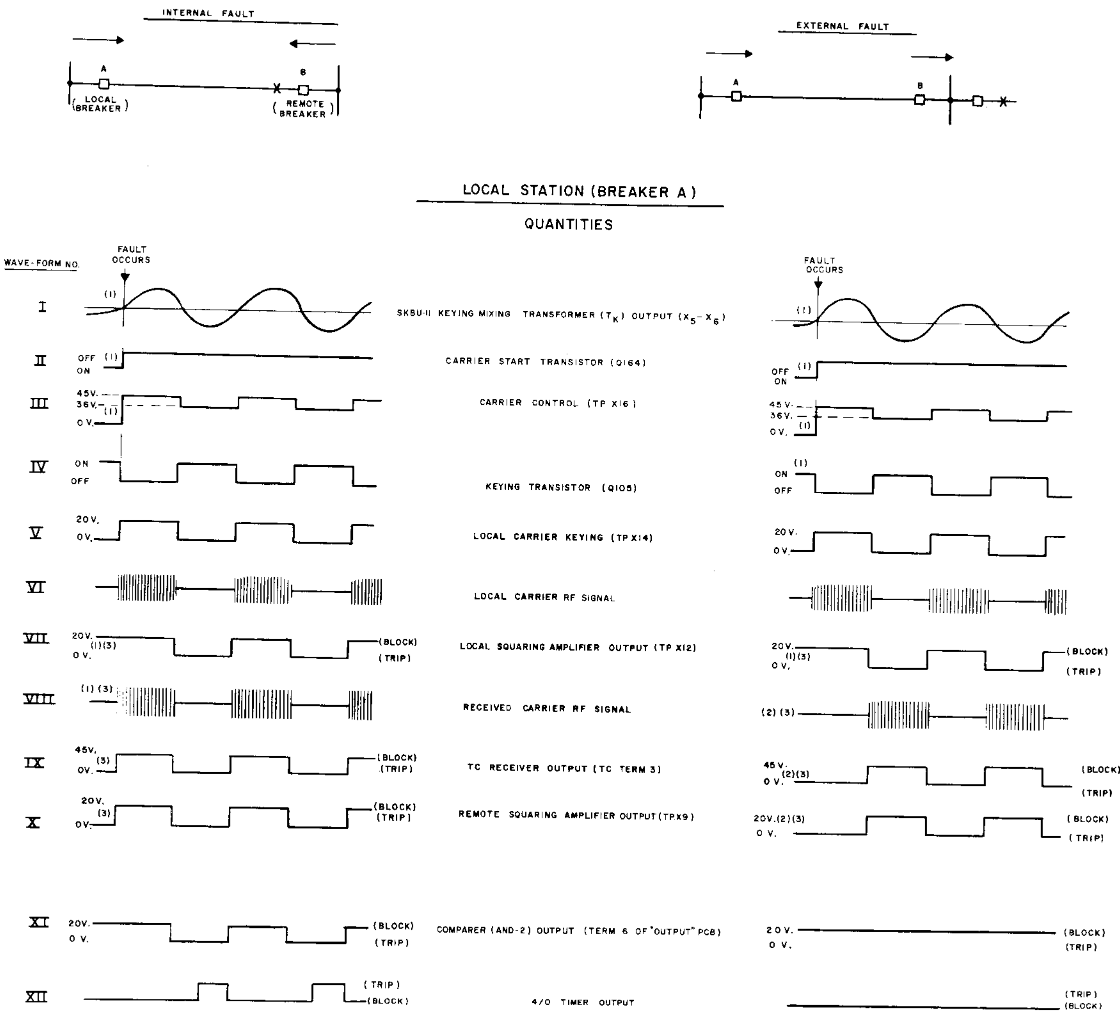
1. Oscilloscope
2. Frequency counter
3. A-C vacuum tube voltmeter
4. TCT test meter unit
5. Carrier frequency signal generator
6. Carrier frequency tuned voltmeter
7. Apparatus described in "Applied Protective Relaying" published by Westinghouse Electric Corporation, Chapter 12.

LIST OF FIGURES



CONTACT	POSITION NORM	T1	T2	FUNCTION
A11-B11	X			SPARE
A12-B12		X		TEST CURRENT
A1-B1			X	TEST CURRENT
A2-B2	X			SPARE
A3-B3		X		TEST CURRENT
A4-B4			X	TEST CURRENT
A5-B5	X			SPARE
A6-B6		X		BLUE TEST LIGHT
A7-B7			X	BLUE TEST LIGHT
A8-B8	X			SPARE
A9-B9		X		BLUE TEST LIGHT
A10-B10			X	BLUE TEST LIGHT

Fig. 2 SRU Logic Diagram for SKBU-11/TC System



NOTES

(1) THE FOLLOWING ASSUMPTIONS ARE MADE:

(a) PRE-FAULT CURRENT IS IN PHASE WITH FAULT CURRENT.

(b) FAULT OCCURS AT TK OUTPUT INSTANTANEOUS ZERO.

(c) PRE-FAULT CURRENT IS BELOW KEYING AND LOCAL SQUARING AMPLIFIER PICK-UP LEVEL (LESS THAN APPROX. 2.0 AMP).

(d) CURRENT DISTRIBUTION FACTORS ARE IDENTICAL AT STATIONS A & B FOR THE INTERNAL FAULT.

(e) THE MIXING TRANSFORMERS, CARRIER START CIRCUIT AND CARRIER CONTROL CIRCUIT PRODUCE OUTPUT IN ZERO TIME AFTER THE FAULT.

THESE ASSUMPTIONS SIMPLIFY THE WAVE-FORMS AND DO NOT AFFECT THE ANALYSIS OR PERFORMANCE IN THE GENERAL CASE.

(2) WAVE-FORMS VIII IX AND X ARE SHOWN WITH LOCAL TRANSMITTER CRYSTAL REMOVED, TO ILLUSTRATE THE EFFECT OF COMPARISON SHIFT. IN ACTUAL SERVICE, THE LOCAL TRANSMITTER ALSO KEYS THE LOCAL RECEIVER, AND THE REMOTE SQUARING AMPLIFIER OUTPUT WOULD BE CONTINUOUS 20 V. FOR THE EXTERNAL FAULT CONDITION ILLUSTRATED.

(3) FOR CLARITY, THIS FIGURE IS DRAWN WITH A PHASE DELAY TIMER SETTING OF ZERO AND NO DELAY IN THE RECEIVED CARRIER SIGNAL. IN ACTUAL SERVICE, THESE DELAYS EXIST, AND WAVE-FORMS VII VIII IX AND X LAG THE OTHER WAVE-FORMS BY SEVERAL MILLISECONDS.

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Fig. 3 Wave Form Time Chart

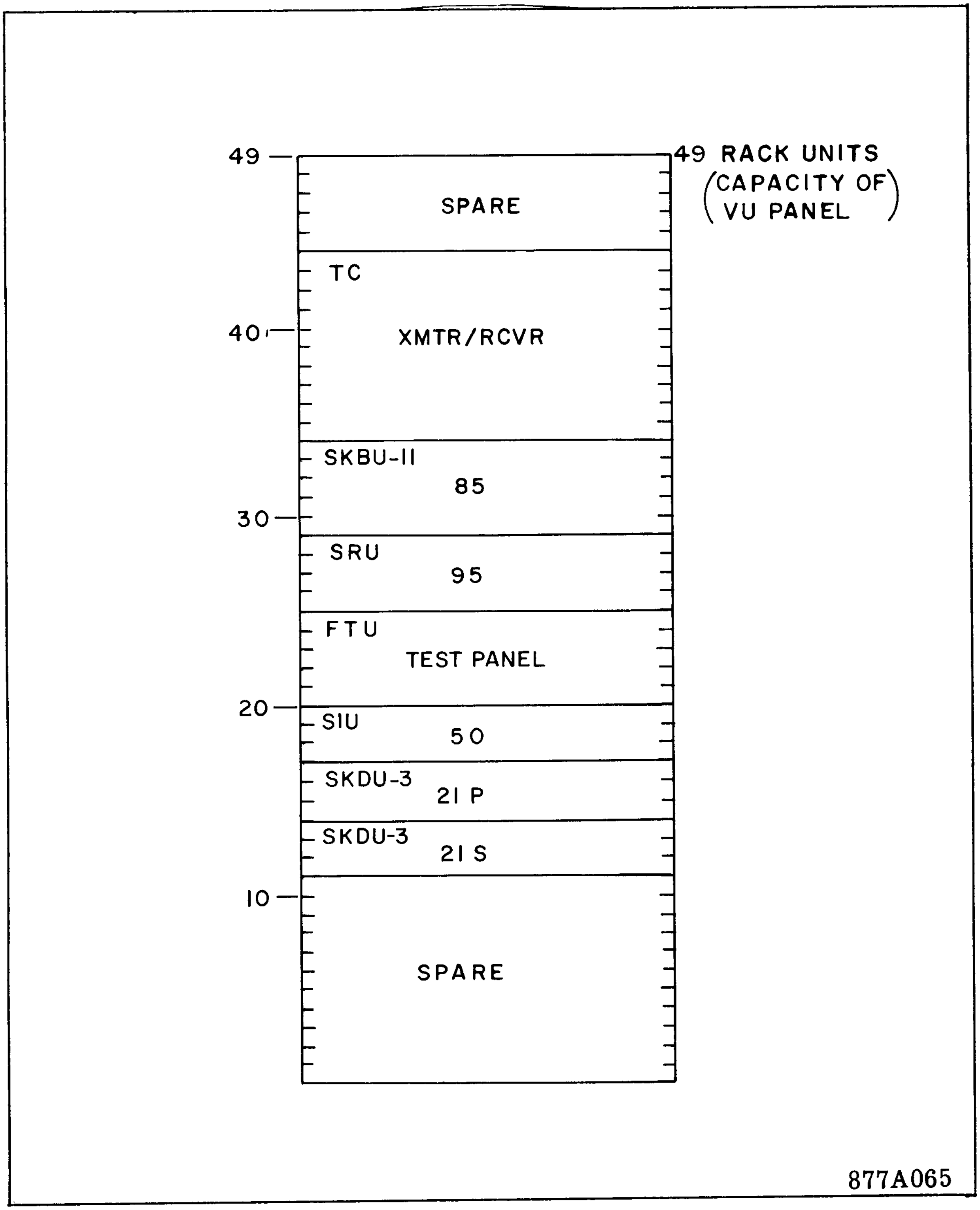


Fig. 4 Typical Layout

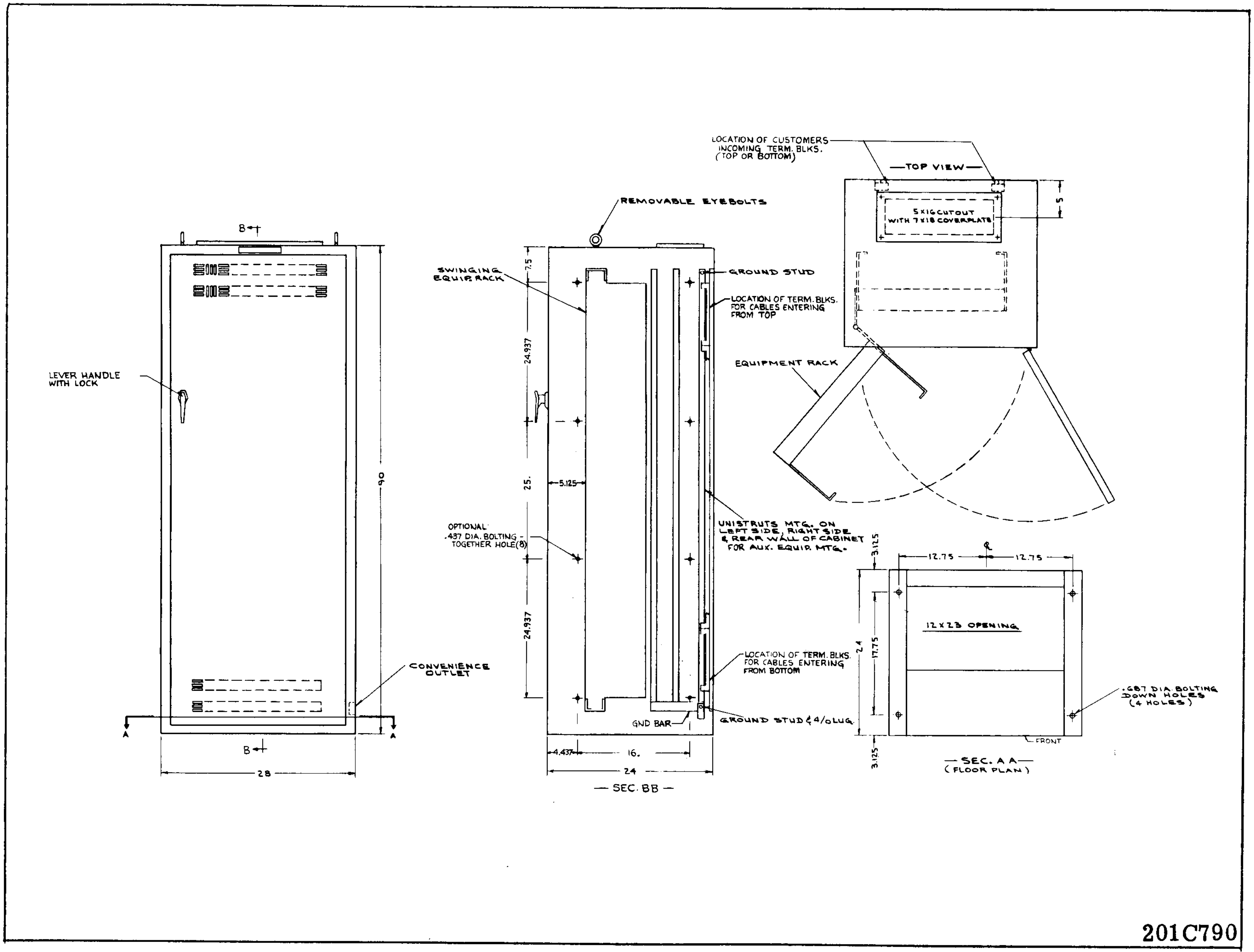
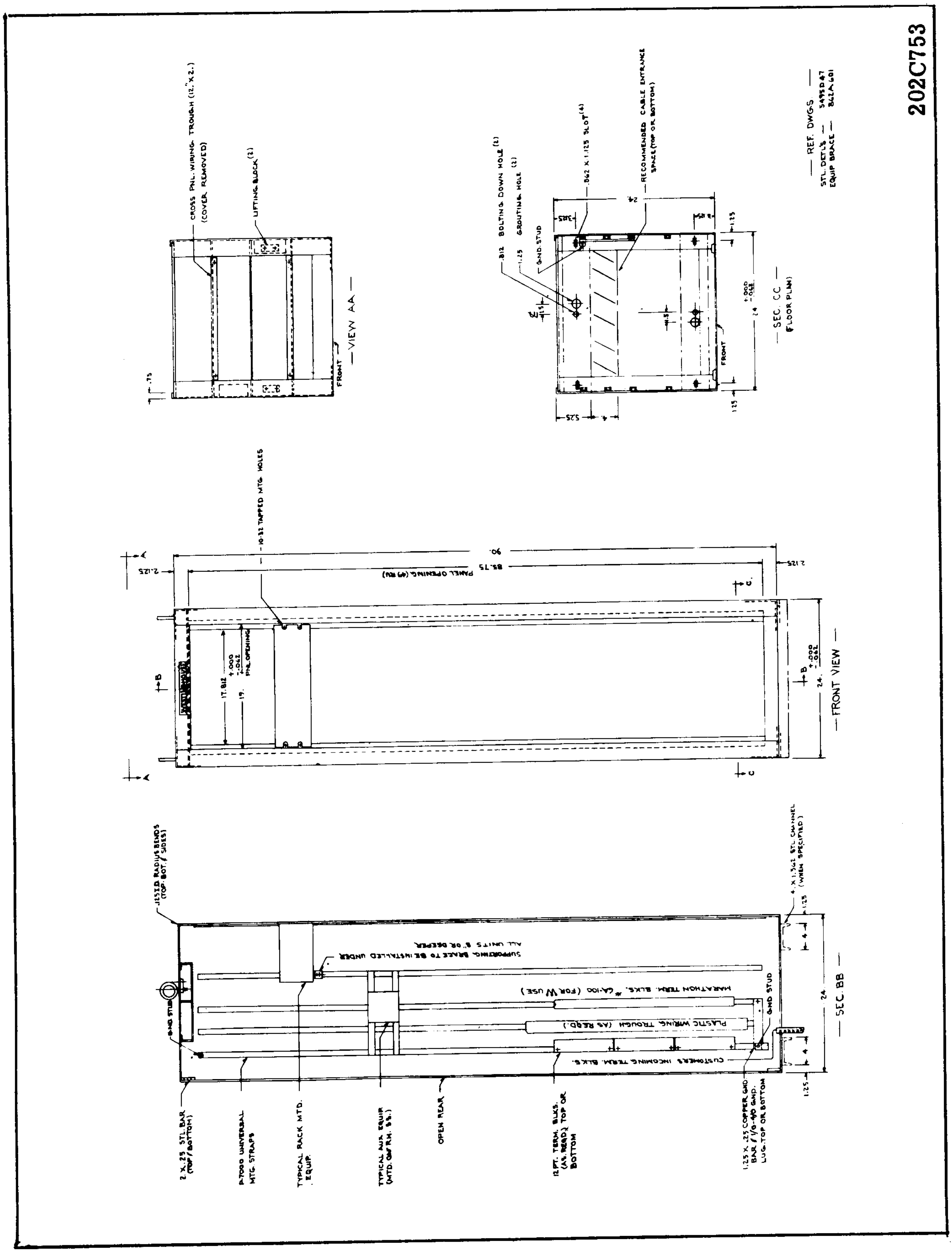


Fig. 5 SU Cabinet Outline



* Fig. 6 VU Panel Outline

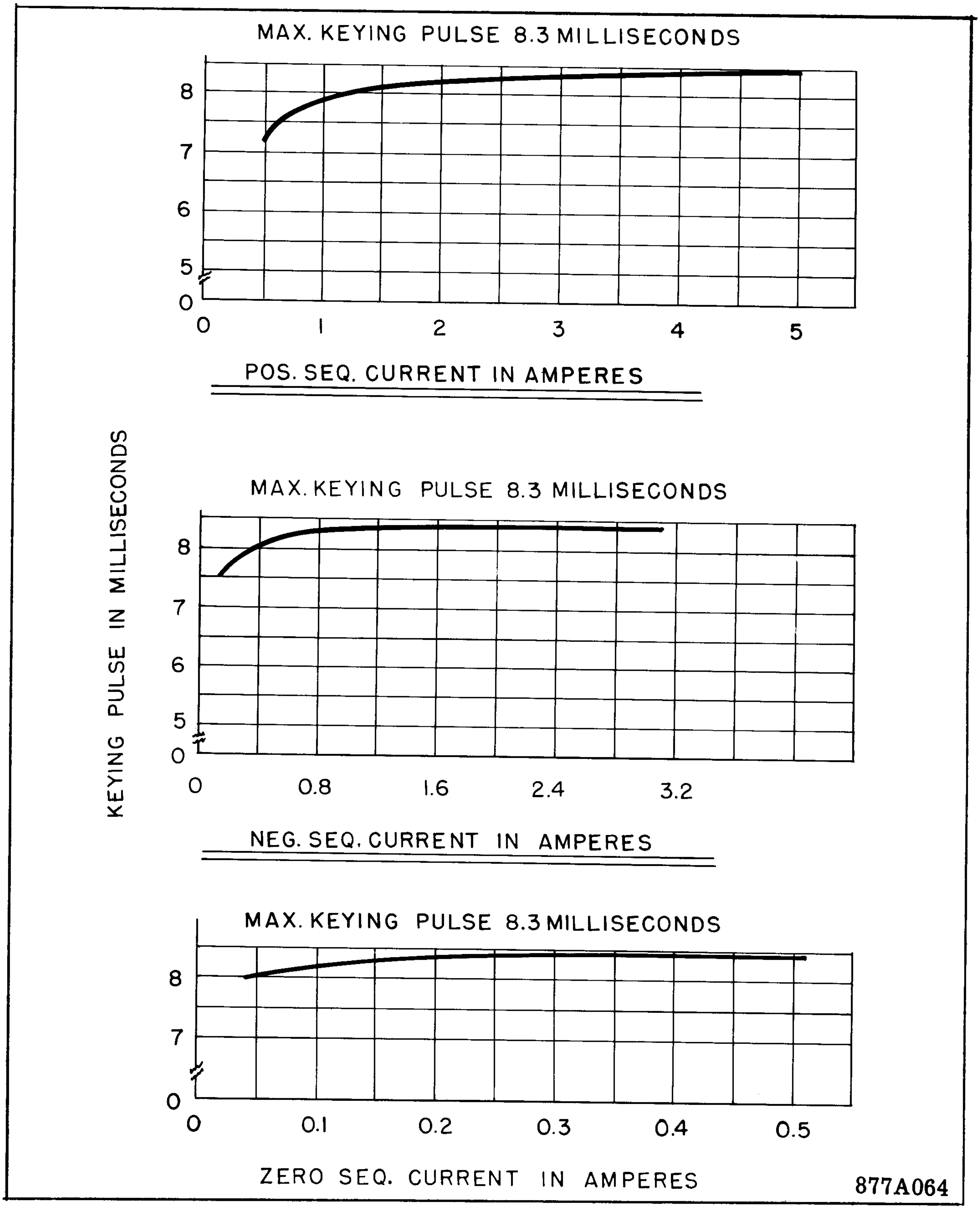


Fig. 7 SKBU-11 Keying Pulses

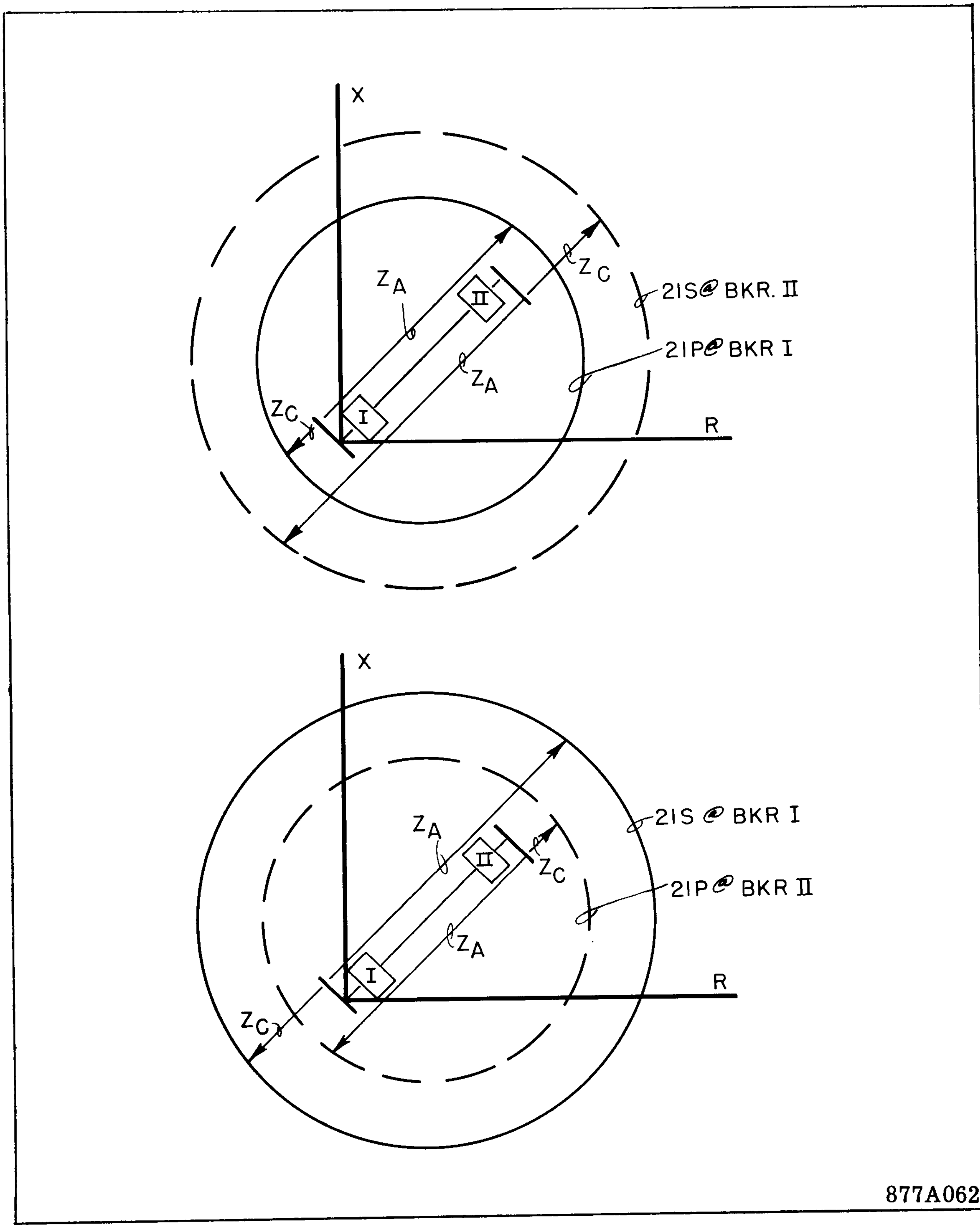


Fig. 8 Recommended Distance Relay Settings.

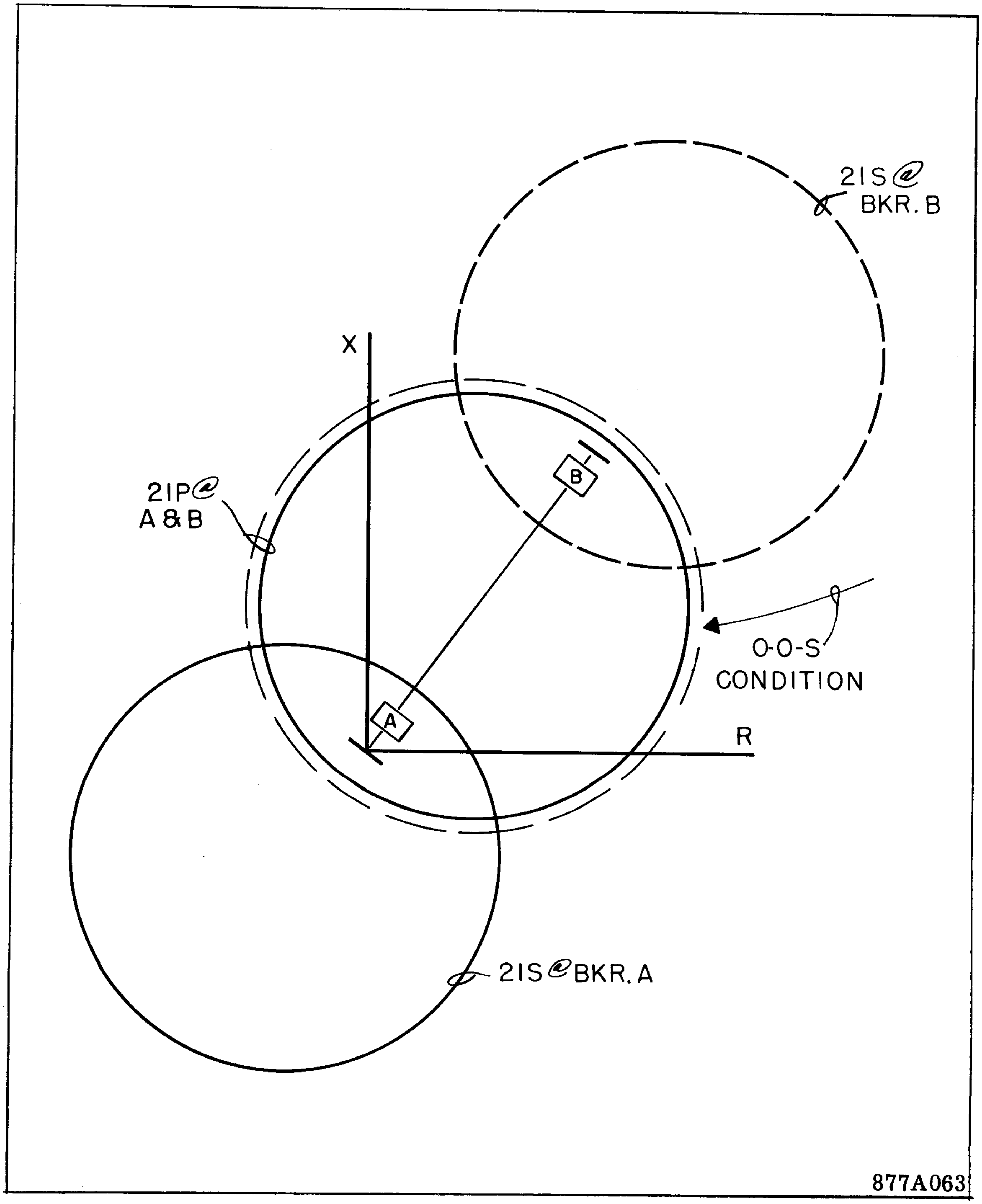


Fig. 9 Incorrect Distance Relay Settings.

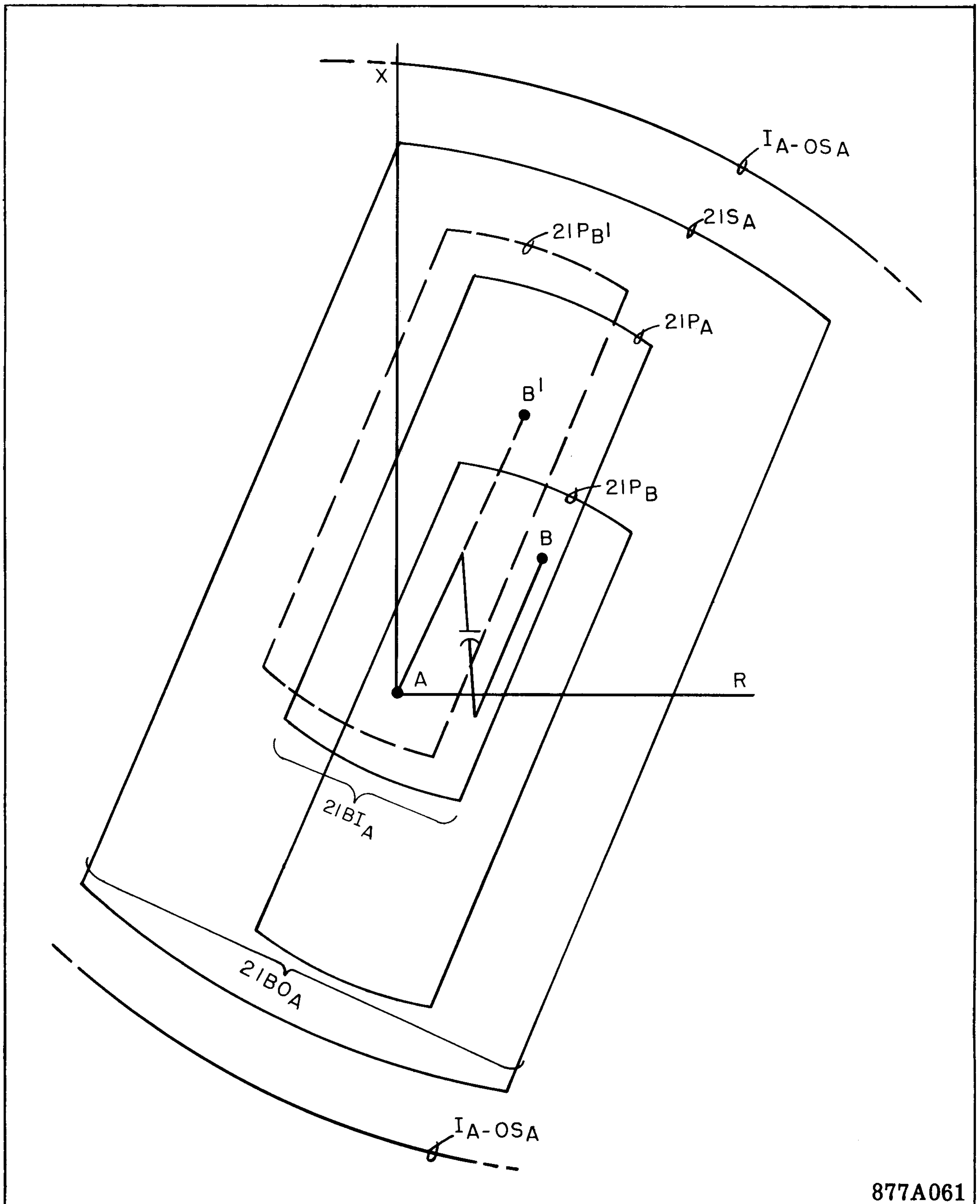


Fig. 10 Distance Relay Settings for Series Capacitor Applications.

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