Effective: November 1997

Supersedes I.L. I.L. 41-348.1G, Dated January 1985

Type SA-1
Generator Differential Relay

(|) Denotes Change Since Previous Issue

CAUTION

Before putting relays into service, operate the relay to check the electrical connections. Close red handle switch last when placing relay in service. Open red handle switch first when removing relay from service.

1. APPLICATION

The SA-1 relay is a three-phase high-speed relay used for differential protection of ac generators and motors. With proper selection of current transformers, the relay is unaffected by dc transients associated with asymmetrical through short-circuit conditions.

Current transformer burden in ohms should not exceed ($N_P V_{CL}$)/133; further, the burden factor, BF, should not differ by more than a 2 to 1 ratio between the two sets of ct's. The above terms are defined as:

N_P = proportion of total number of ct turns in use

V_{CL} = current transformer relaying accuracy class voltage (e.g. C400, V_{CL} = 400)

$$B_F = \frac{1000^{R_B}}{N_P V_{CL}}$$

R_B = resistance of the burden, excluding ct winding resistance

In calculating the burden, use the longest one-way lead resistance from the ct to the SA-1 for distribution transformer or resistance grounded machines. Use twice the longest one-way lead resistance for reactance grounded machines.

For example, if the 400/5 tap of a 600/5 multi-ratio ct is used, N_P = 400/600 = 0.67. If this ct has a C200 rating, V_{CL} = 200, and the burden should not exceed:

$$\frac{N_P V_{CL}}{133} = \frac{0.67 \times 200}{133} = 1.0 \text{ ohm}$$

Assuming a resistance burden of R_B = 0.5 ohms, the burden factor, BF is:

$$BF = \frac{1000^{R_B}}{N_P V_{CL}} = \frac{1000 \times 0.5}{0.67 \times 200} = 3.8$$

The other set of ct's may than have a burden factor as high as 2 x 3.8 = 7.6, or as low as 1/2 x 3.8 = 1.9.

If the other set of ct's also has a burden of 0.5 ohm, a C100, C200, or C400 rating would be satisfactory since the burden factors are 7.6, 3.8 and 1.9 respectively.

2. CONSTRUCTION

The type SA-1 relay consists of a Restraint Circuit, Operating Circuit, Sensing Circuit, Amplifier Circuit, Trip Circuit, Indicating Circuit, Surge Protection Circuit and external reactors. The principal parts of the relay and their location are shown in Figures 1 through 8.

2.1. RESTRAINT CIRCUIT

The restraint circuit of each phase consists of a center-tapped transformer, a resistor, and a full wave rectifier bridge. The outputs of all the rectifiers are connected in parallel. The parallel connection of rectifiers is a maximum voltage network. Hence, the voltage applied to the filter circuit is proportional to the phase current with the largest magnitude.

2.2. OPERATING CIRCUIT

The operating circuit consists of a transformer, a resistor, and a full wave rectifier bridge. The outputs of all the rectifiers are connected in parallel. This parallel connection of rectifiers is a maximum voltage network. Hence, the voltage applied to the filter circuit is proportional to the phase current with the largest magnitude.

2.3. SENSING CIRCUIT

The sensing circuit is connected to the output of the restraint filter circuit, the operating filter circuit and the input to the amplifier circuit.

2.4. AMPLIFIER CIRCUIT

The amplifier circuit consists of a two-transistor amplifier which controls the operation of a relaxation oscillator.

The amplifier circuit is connected to the sensing circuit such that it receives the difference in output of the restraint filter and the operating filter. Thus, the polarity of the input voltage to the amplifier depends upon the relative magnitude of the voltages appearing on the restraint and operating filters. When the voltage output of the operating filter is greater than the output voltage of the restraint filter, a voltage of a certain polarity appears across the input of the amplifier. To trigger the amplifier requires that the output voltage of the operating filter be greater than the output voltage of the restraint filter.

2.5. TRIP CIRCUIT

The trip circuit consists of a thyristor which has an anode, cathode, and a gate. The anode of the thyristor is connected to the positive side of the dc supply and the cathode of the thyristor is connected to the negative side of the dc supply through the trip coil of a breaker. The gate of the thyristor is connected to the output of the amplifier circuit through a pulse transformer.

With no gate current flowing, the thyristor acts as an open circuit to the breaker trip coil. When a gate current is applied tot he thyristor the thyristor connects the breaker trip coil to the dc supply.

2.6. INDICATING CIRCUIT

The indicating circuit is triggered by a signal from the amplifier of the relay. Under normal or non-fault conditions, the indicating circuit is turned off. When a fault is applied to the relay, the amplifier will conduct to cause a signal to flow into the indicator circuit. When the indicator circuit is triggered, the lamp will turn on. This lamp will remain lit until the indicator circuit is interrupted by resetting the micro-switch.

2.7. SURGE PROTECTION CIRCUIT

The surge protection circuit consists of two capacitors (C10 and C11) and a R-C network which is connected across the anode and cathode of the tripping thyristor to prevent the SCR from firing by a surge of voltage.

2.8. EXTERNAL REACTORS

Three reactors are mounted on a metal plate with a separate terminal strip. The reactors are of the saturable type.

3. OPERATION

The Type SA-1 relay is connected to the protected apparatus as shown in Figure 9. On external faults, current flows through the primary winding of the restraint transformers to induce a voltage on the restraint side of the sensing circuit. If the two sets of main current transformers have different performances, some current will flow out of the mid-tap of the restraint transformers to the operating transformers. This will produce a voltage on the operating side of the sensing circuit. With the relay correctly applied, sufficient restraint voltages will exist to prevent the operating voltage from triggering the amplifier.

The percentage slope characteristic of the relay limits the operating voltage on heavy external faults where the performance of the two sets of current transformers may be quite different.

On internal faults, the operating coil current is the sum of the current flowing in each of the windings of the restraint transformer and sufficient operating voltage is available to overcome the restraint voltage.

4. CHARACTERISTICS

The percentage slope curves are shown in Figures 12 and 13. It will be observed that the relay operates at 5% unbalance at 5 amperes restraint (Figure 12) to provide high sensitivity for internal faults up to full load conditions. At 60 amperes restraint, the operating current required to trip the relay is 30 amperes or 50% unbalance (Figure 13). Thus, when 60 amperes through-fault current is flowing, the output of the main current transformers may vary considerably without causing incorrect operation.

The minimum pickup of the relay is 0.14 ampere or 0.5 ampere for the desensitized version.

The operating characteristic of the desensitized SA-1 is shown in Figure 14.

The time curve of the relay is shown in Figure 15.

The frequency response characteristic of the SA-1 relay is shown in Figure 16.

5. ENERGY REQUIREMENTS

Each Restraint Circuit

Burden at 5 amperes is 0.25 VA
Continuous rating 20 amperes
1 second rating 300 amperes

Operating Circuit

The burden imposed by the operating circuit on each circuit transformer is variable because of the saturating transformer and reactors. At 0.5 amperes, it is 0.37 VA, and at 60 amperes it is 170 VA.

Continuous rating 10 amperes
1 second rating 200 amperes

Amplifier

The dc burden on the station battery is:

Volts	Milliamperes	Watts
125 dc 48 dc	55 60	6.9 2.9

6. SETTINGS

There are no taps on either transformer and, consequently, there are no settings to be made except for the choice of battery voltage level.

The 48/125 Vdc relays are normally shipped for 125 volts. For 48 Vdc applications use the mid-tap on the resistor mounted at the top of the relay. The red dot on the resistor is the common point – DO NOT REMOVE.

7. INSTALLATION

The relay should be mounted on switchboard panels or their equivalent in a location free from moisture. Mount the relay vertically by means of the four mounting holes on the flange for semi-flush 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.

The external reactor assembly should be mounted and wired per “interwiring Connection Drawing”, Figure 11.

For detailed FT case information, refer to I.L. 41-076.

8. ADJUSTMENTS AND MAINTENANCE

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.

8.1. ROUTINE TEST

The following check is recommended to insure that the relay is in proper working order. All checks can best be performed by connecting the relay per the test circuit of Figure 17. Due to high impedance of the external reactor, prior to saturation, the test circuit of Figure 17 should be used to test the relay only. The reactors can be checked by applying 0.2 amperes 60 hertz and reading the voltage drop across the reactor with a high impedance True RMS reading voltmeter. The voltage drop will be between 20 and 26 volts True RMS. For 0.4 amperes input, the reading should be between 29 and 31 volts True RMS.

1. **Minimum Trip Current** with I_R set at zero amperes, apply 0.14 ±5% (0.5 ±5% got desensitized SA-1) amperes operating current to each operating circuit of the relay. The relay should operate and the indicator lamp should light.

2. **Differential Characteristic**

   a) Apply I_R of 5 amperes and adjust the operating current until the relay operates. The relay should operate and the indicator lamp should light with an operating current of 0.25 ±5% amperes (0.71 5% for desensitized SA-1). Repeat for each phase of the relay.

   b) Apply I_R of 60 amperes and adjust the operating current until the relay operates. The relay should operate and the indicator lamp should light with an operating current of 30 ±10% amperes. Repeat for each phase of the relay. (I_R = 40 amperes and I_O = 24 ±10% for desensitized SA-1).

8.2. MAINTENANCE

All relays should be checked once a year to detect any failures which may have occurred. The tantalum capacitors C1, C2, C3, C4 and C13 may have a common mode failure characteristic and should be checked visually for symptoms of electrolyte leakage every year and replaced if necessary.

8.3. CALIBRATION

Use the following procedure for calibrating the relay if the relay adjustments have been disturbed. This procedure should not be used until it is apparent the relay is not in proper working order.

1. **Minimum Trip Current** – Connect the relay per test circuit of Figure 17 with switch K open. Adjust the operating resistor in the rear of the relay until the relay operates with IO equal to 0.14 ampere, 0.5 ampere for desensitized SA-1. **DO NOT make adjustments to the resistor unless the dc is disconnected**.

   The indicator lamp should light when the relay operates.

   Repeat for each phase of the relay.

2. **Percentage Slope Characteristic (Low Current)**. Close switch K and set I_R equal to 5 amperes and adjust the restraint resistor in the rear of the relay until the relay operates with I_o = 0.25 ±.010 amperes. **DO NOT adjust resistor with dc applied to relay**.

   The indicator lamp should light when the relay operates.

   Repeat for each phase of the relay.

   Percentage Slope Characteristic (High Current) – Set I_R equal to 60 amperes for the operating current of 30 amperes. Replace the resistor R17 if necessary. The value of R17 can be between 0 and 100 ohms. Repeat for the other two phases if necessary, replacing R18 and R19 respectively.

3. **Electrical Checkpoints** – See Table 1.

9. RENEWAL PARTS

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

10. ELECTRICAL CHECKPOINTS

Connect relay per test circuit of Figure 17. All voltage readings should be made with a high resistance voltmeter. Refer to component location of checkpoints. Voltage readings are approximate. The voltage readings “Input to Amplifier” should not be taken with relay in service.

Table 1:
(Values in Parenthesis Represent Desensitized SA-1)

CIRCUIT	PRIMARY CURRENT	PHASE	CHECKPOINTS (Typical Value)		
			TERMINAL	VALUE	FUNCTION
Operating	0.14A (0.5A)	1 2 3	2 - 7 3 - 6 4 - 5	2.5 ac 2.5 ac 2.5 ac	Input to operate rectifier Input to operate rectifier Input to operate rectifier
Sensing (Operating)	0.14A (0.5)	Any phase	+ to - 23 - 26 24 - 26 24 - 8 8 - 25 25 - 26	2.1 dc 1.85 dc 0.55 dc 0.65 dc 0.65 dc	Output to rectifier a. Output to operating sensing circuit b. Input to amplifier c. d. Output to restraint sensing circuit Ref.: a = b + c + d
	30.0A	Any phase	+ to - 24 - 26	51.0 dc	
Restraint	5.0A	1 2 3	18 - 13 17 - 14 15 - 16	6.0 ac 6.0 ac 6.0 ac	Input to restraint rectifier Input to restraint rectifier Input to restraint rectifier
Sensing (Restraint)	5.0A	Any phase	+ to - 25 - 26 25 - 8 8 - 24 24 - 26	2.1 dc 1.2 dc 0.6 dc 0.3 dc	a. Output of restraint sensing circuit b. c. Input to amplifier d. Output to operating sensing circuit Ref.: a = b + c + d
	60.0A	Any phase	+ to - 25 - 26	42.0 dc	
Amplifier	0		+ to - 27 - 8 12 - 8 10 - 8	0.7 dc 24.0 dc 24.0 dc	
	Minimum Trip Current +5%	Any phase	+ to - 27 - 8 12 - 8 21 - 8	0.5 dc 24.0 dc 10.0 dc	

**Table 2:
Electrical Part List**

Circuit Symbol		Reference	Style
Resistors	UT, UM, UB	60 Ohms, 25W	1875676
Resistors	LT, LM, LB	265 Ohms, 25W	1725542
Resistors	R14	1.8K, 40 W	187A321H06
Zener	Z2	IN2986B	629A798H03
SCR			184A614H05
Reactor	L1		1478B98G01
SA Module Style Number 408C673G01 Sub 35			
Resistor	R1	270 Ohms, 1W	184A635H06
Resistor	R2	2K, 5%	184A763H34
Resistor	R3, R4 R5	15K, 5%	184A763H55
Resistor	R6	2.7K, 5%	184A763H37
Resistor	R7	68K, 5%	184A763H71
Resistor	R8	27K, 5%	184A763H61
Resistor	R9	2.2K, 5%	184A763H35
Resistor	R10	100 Ohms, 10%	184A763H03
Resistor	R11	220 Ohms, 5%	184A763H11
Resistor	R12	680 Ohms, 5%	184A763H23
Resistor	R13	47K, 5%	184A763H67
Resistor†	R17, R18, R19	33 Ohms, 5%	187A290H13
Capacitor	C1, C2, C3, C13	25 MFD, 125V	184A637H01
Capacitor	C4	22 MFD, 35V	184A661H16
Capacitor	C5	0.5 MFD, 200V	187A624H03
Capacitor	C6	2.2 MFD, 35V	837A241H16
Capacitor	C7	2.0 MFD, 200V	187A624H05
Capacitor	C8, C9	0.47 MFD, 50V	762A680H04
Diode	D1 to D24	IN4821	188A342H16
Diode	D25, D26	IN645A	837A692H04
Zener	Z1	IN752A	186A797H12
SCR		K1149-13	184A640H13
Transistor	T1, T2	2N3417	848A851H02
Transistor	T3	2N2647	629A435H01
Transformer	TR-1		629A372H02
SPK Module Style Number 1584C21G01			
Resistor	R15	470 Ohms, 1W	187A643H19
Capacitor	C10, C11	0.01 MFD, 1.5KV	3516A36H03
Capacitor	C12	2.0 MFD, 200V	3509A33H01

† *NOTE: The values of R17, R18 and R19 are between 0 and 100 Ohms. They are determined in test.*

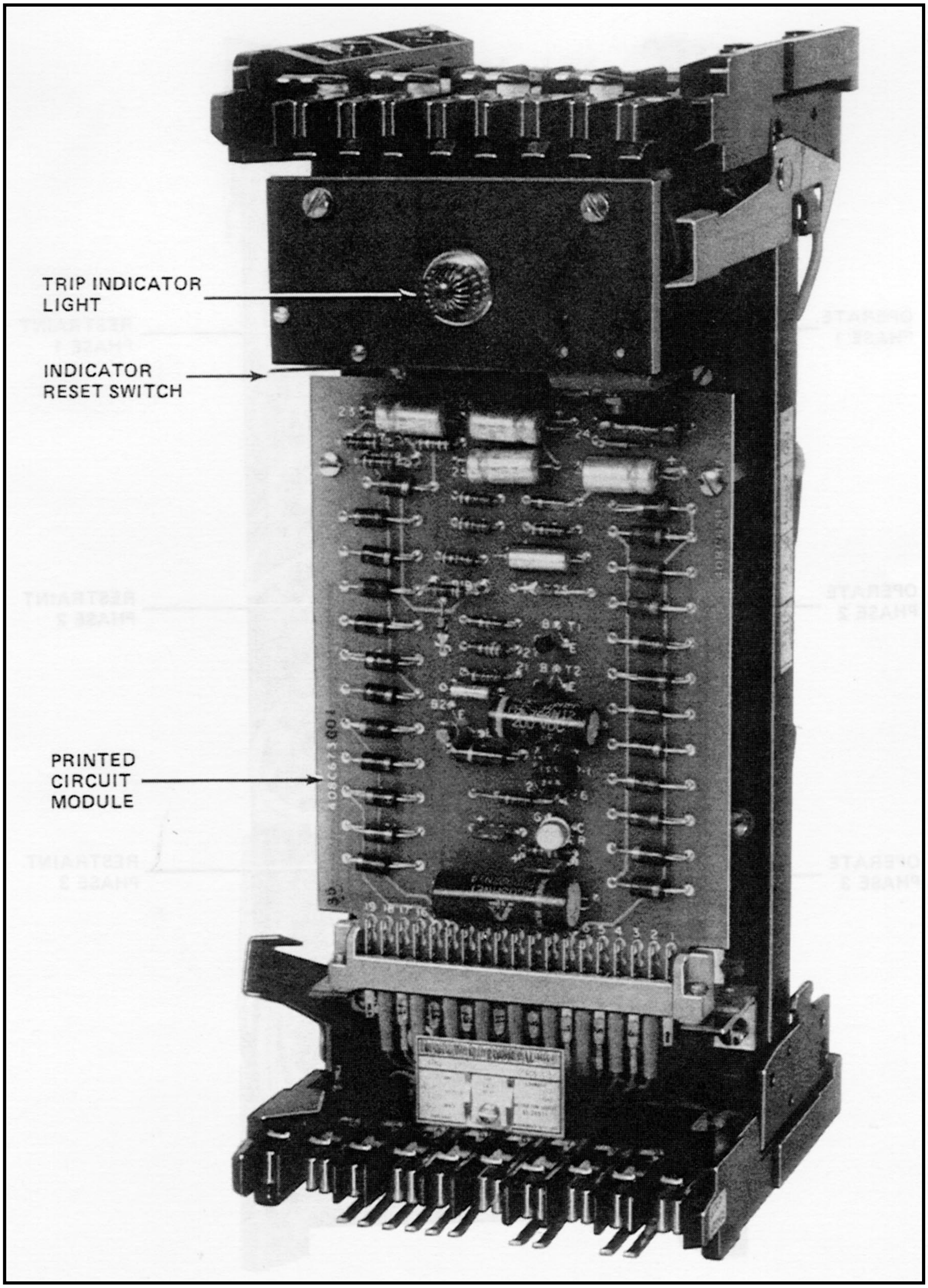


Figure 1. Type SA-1 Generator Differential Relay without Case (Front View)

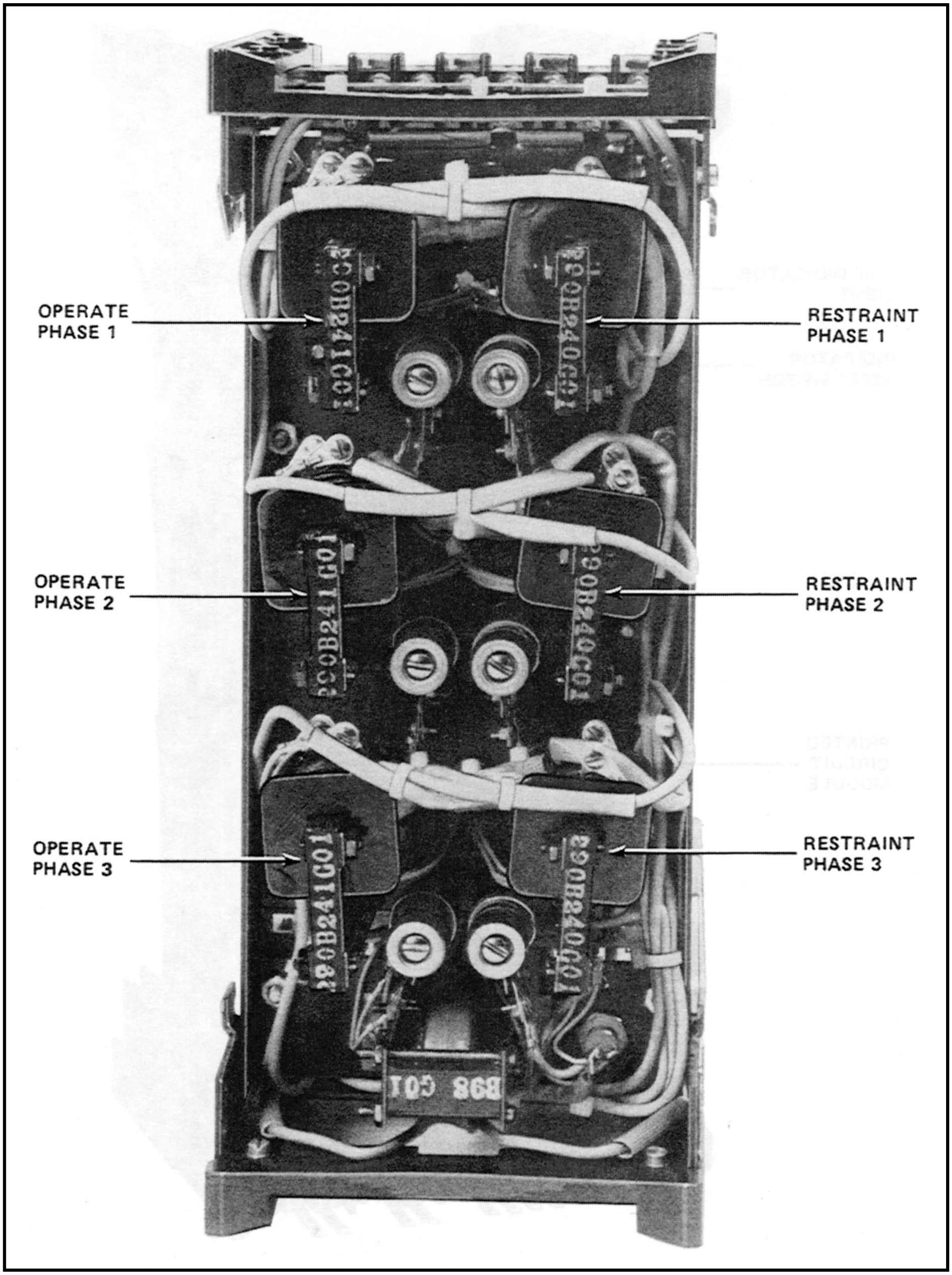
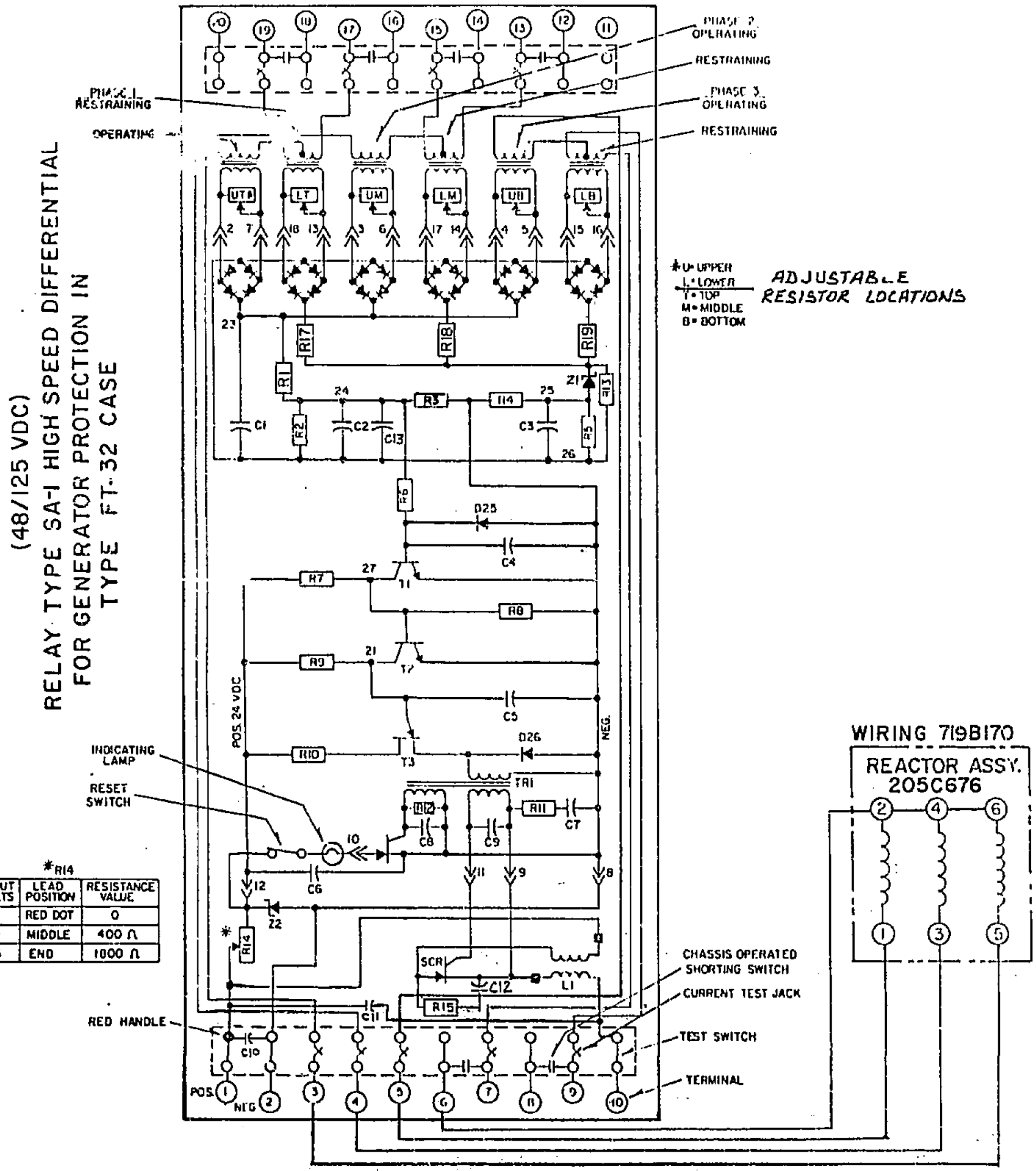


Figure 2. Type SA-1 Generator Differential Relay without Case (Rear View)



*R14

INPUT VOLTS	LEAD POSITION	RESISTANCE VALUE
—	RED DOT	0
48	MIDDLE	400 Ω
125	END	1000 Ω

*629A406
Sub 15*

Figure 3. Internal Schematic of Type SA-1 Relay 48/125 Vdc

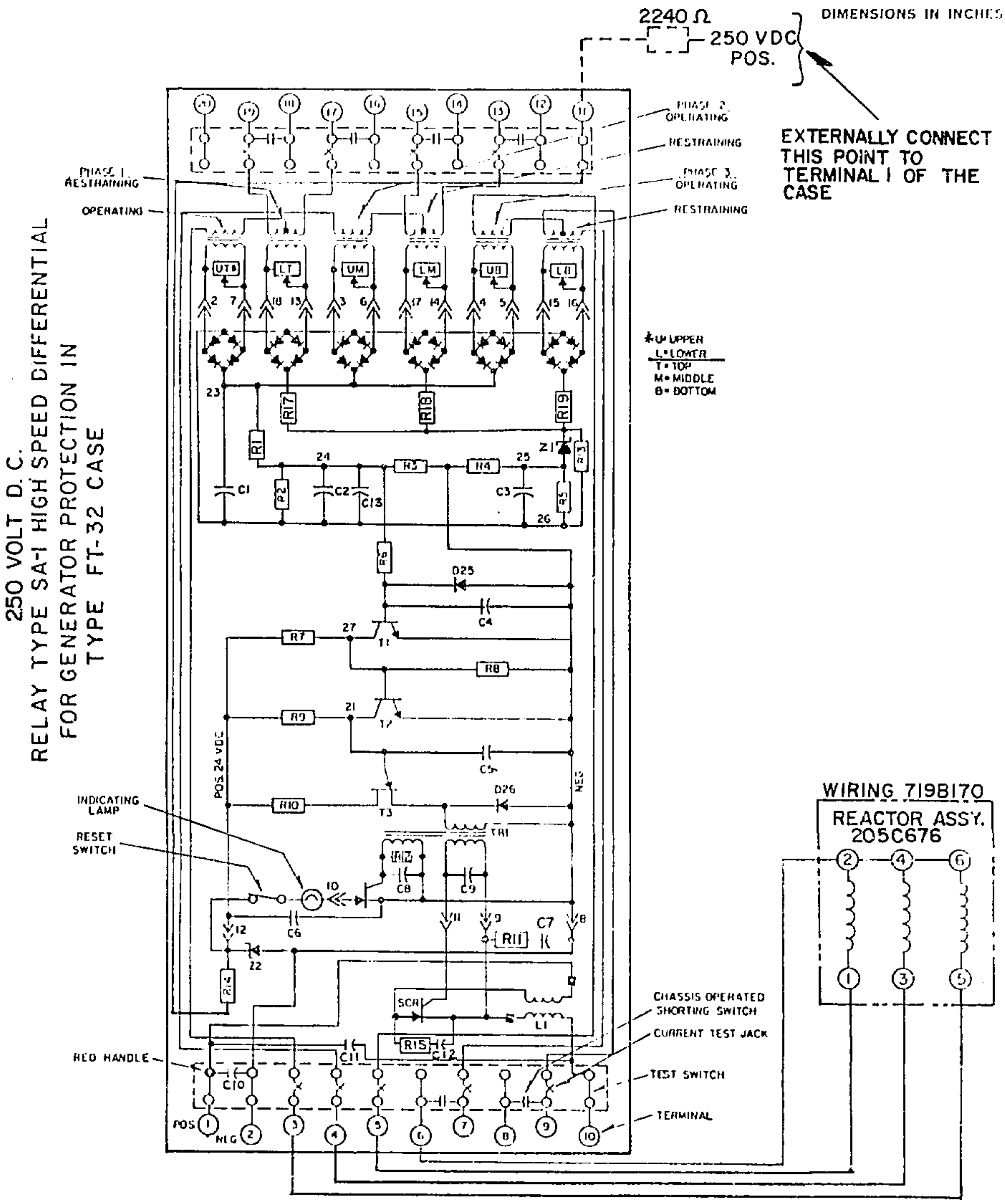
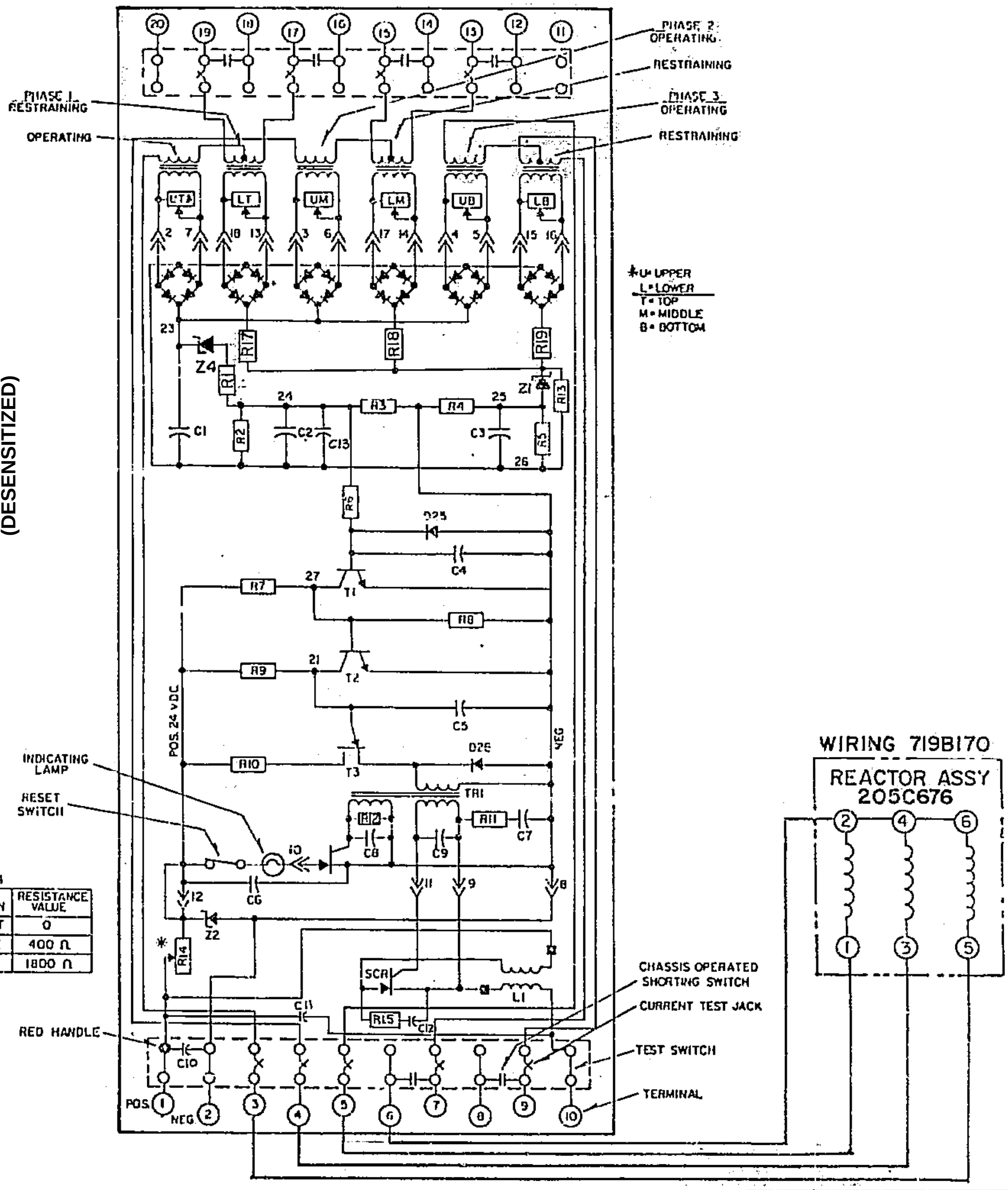


Figure 4. Internal Schematic of Type SA-1 Relay 250 Vdc

RELAY TYPE SA-1 HIGH SPEED DIFFERENTIAL
FOR GENERATOR PROTECTION IN
TYPE FT-32 CASE
(DESENSITIZED)

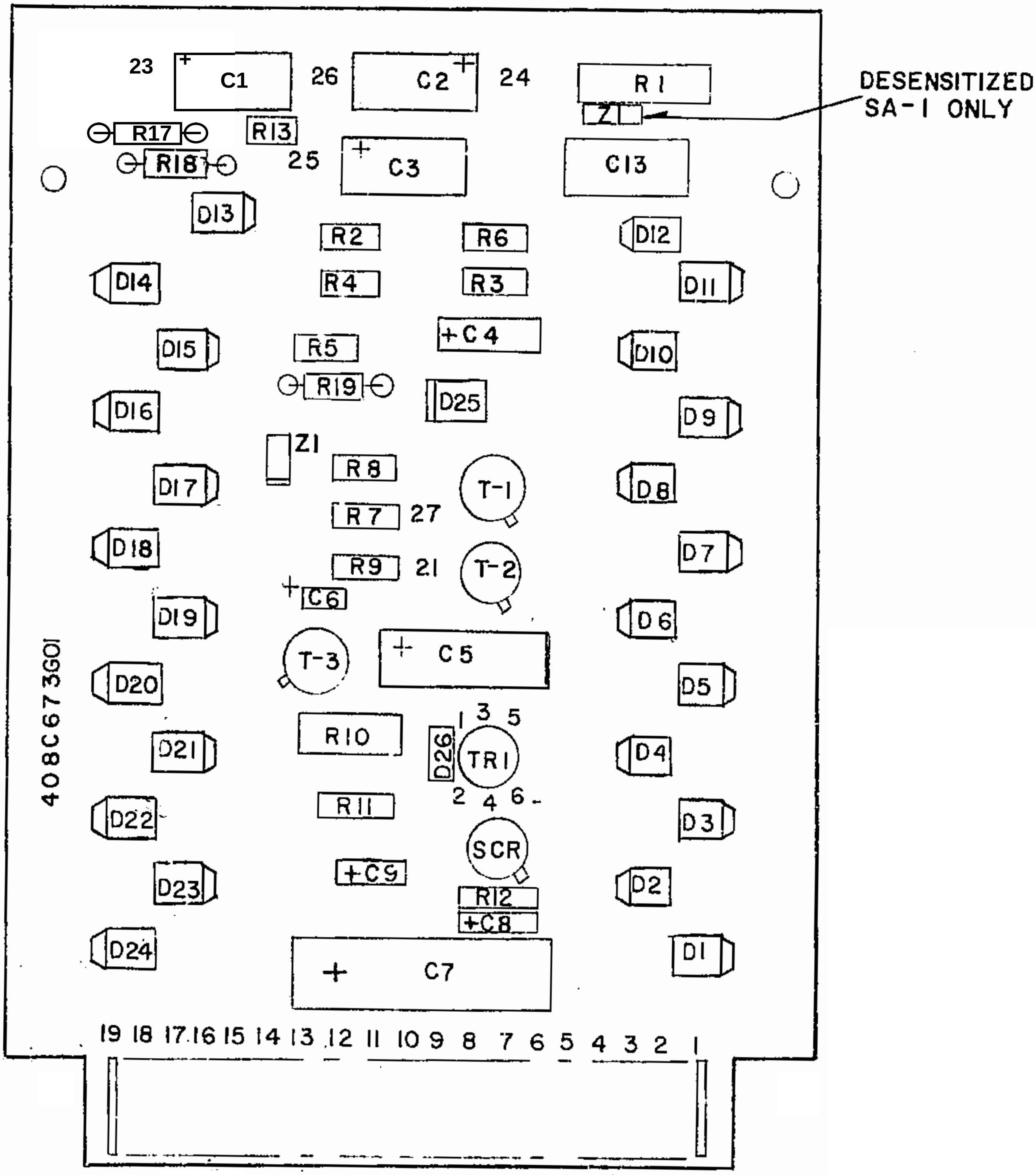


*R14

INPUT VOLTS	LEAD POSITION	RESISTANCE VALUE
—	RED DOT	0
48	MIDDLE	400 Ω
125	END	1800 Ω

877A847
Sub 8

Figure 5. Internal Schematic of Desensitized SA-1 Relay



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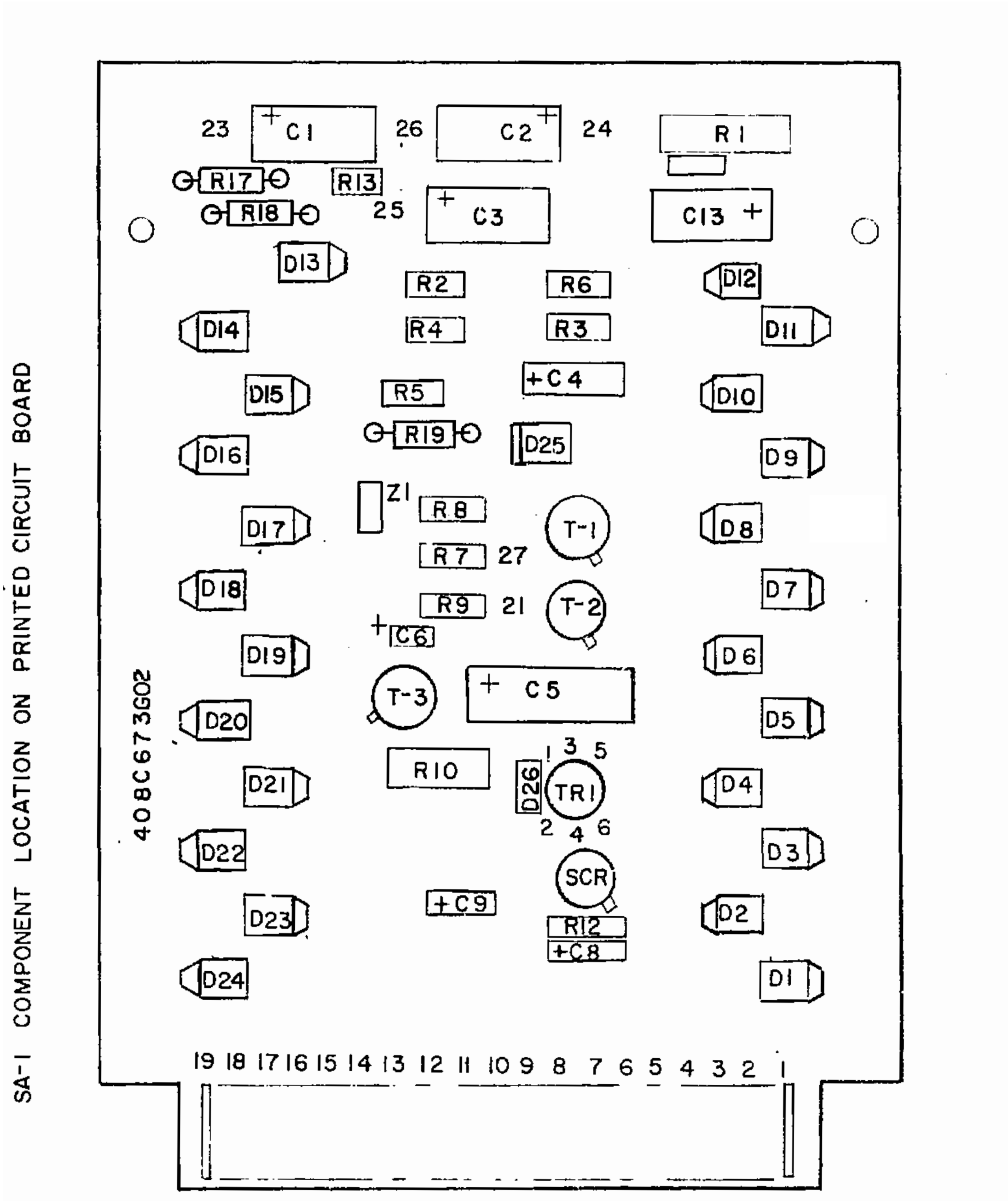
Sub 9

Figure 6. Component Location for 48/125 Vdc



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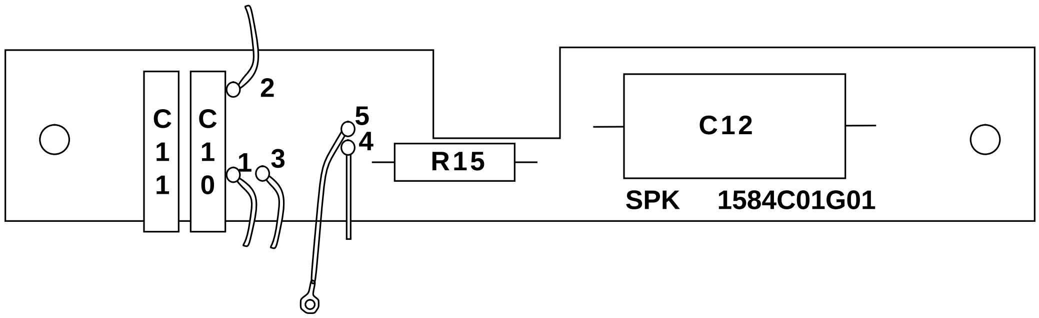
* Sub 5

Figure 7. Component Location for 250 Vdc

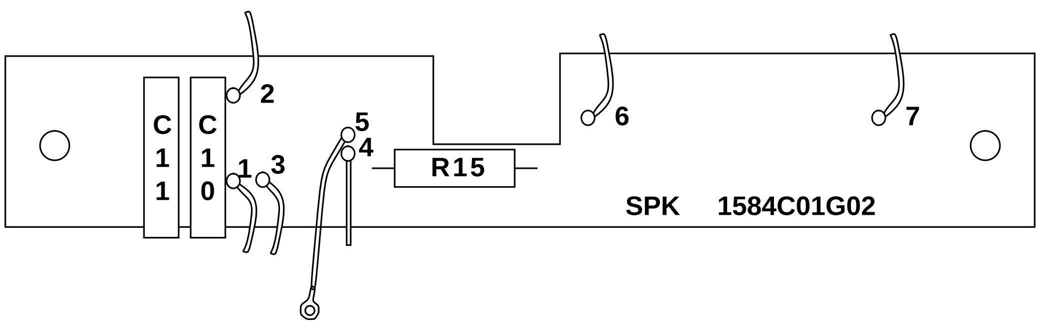
* *Denotes Change*

COMPONENT LOCATION
48/125 V



C11 & C10	.01 uf	3516A36H03
C12	2.0 uf	3509A33H01
R15	470 Ohm	187A643H19

COMPONENT LOCATION
250 V



C11 & C10	.01 uf	3516A36H03
R15	470 Ohm	187A643H19

Illustration
3532A07
Sub 2

Figure 8. Component Location of the SPK Module

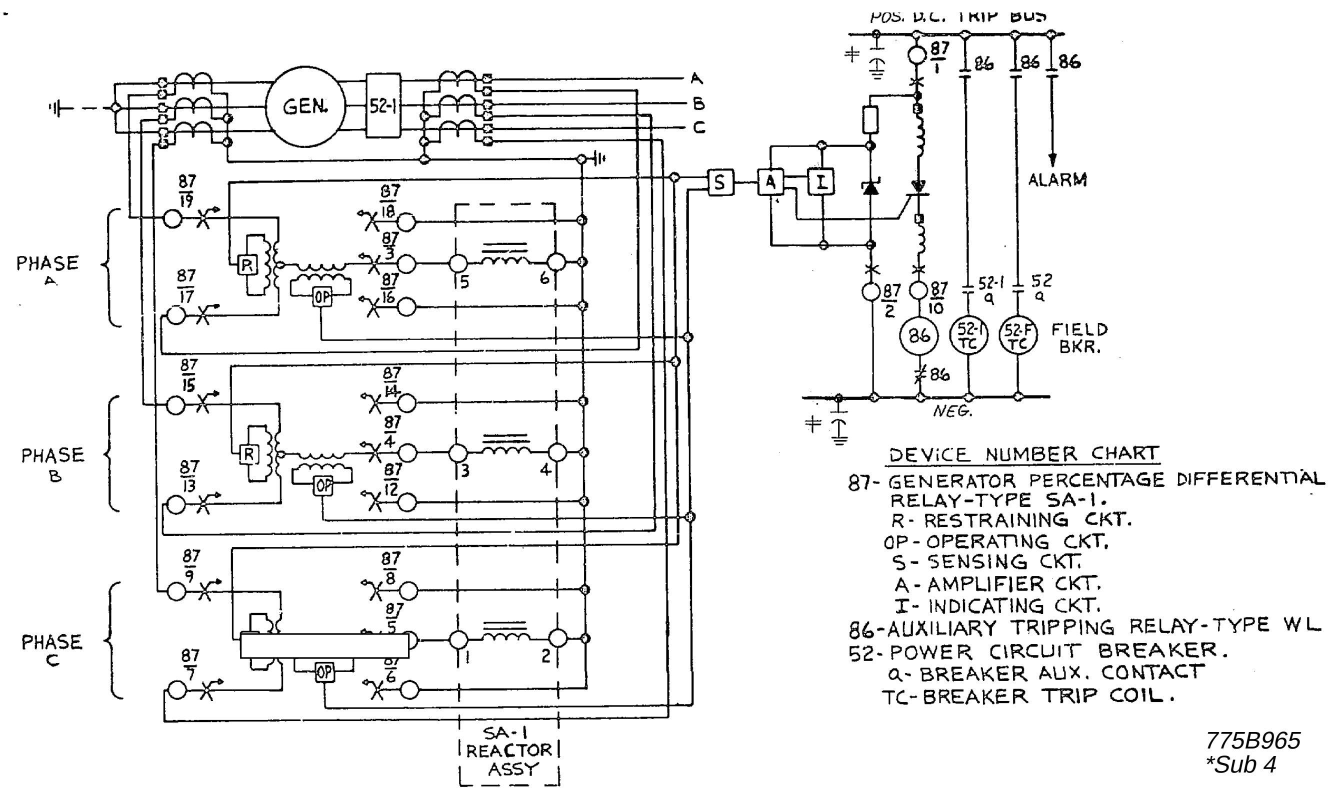


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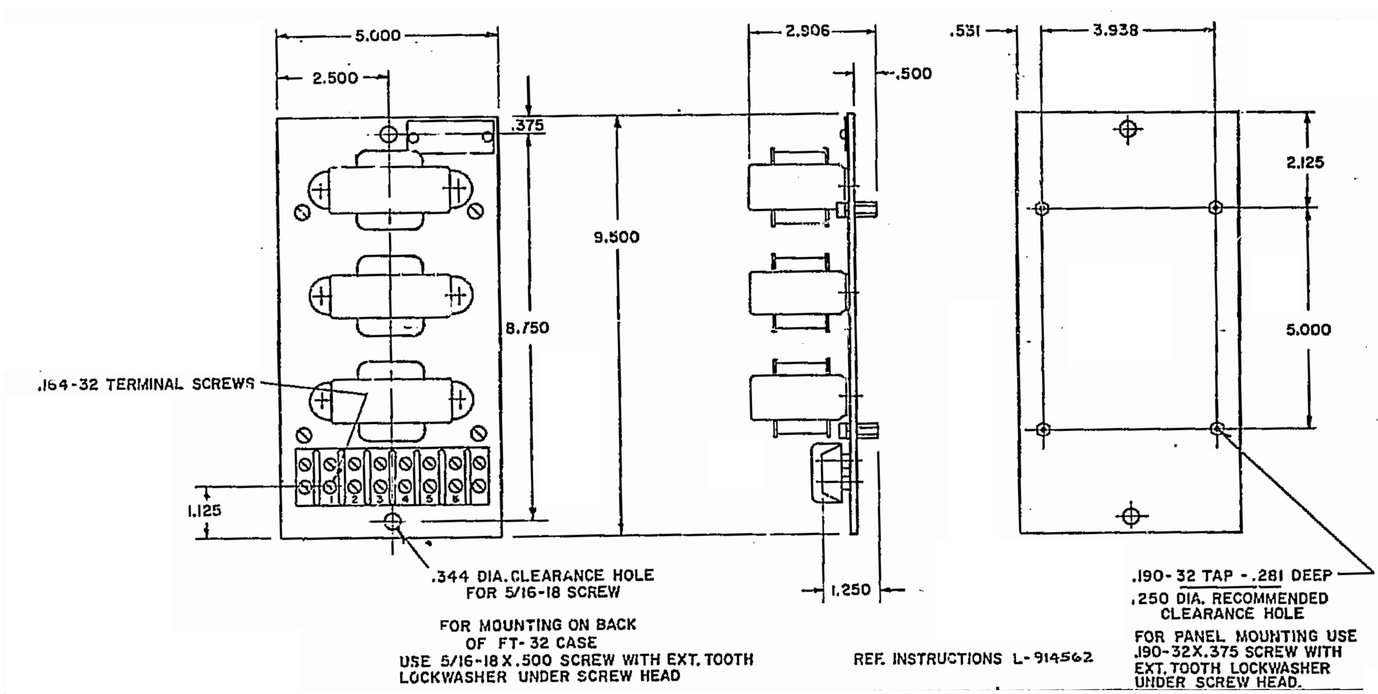
Figure 9. External Schematic of Type SA-1 Relay for Generator Protection



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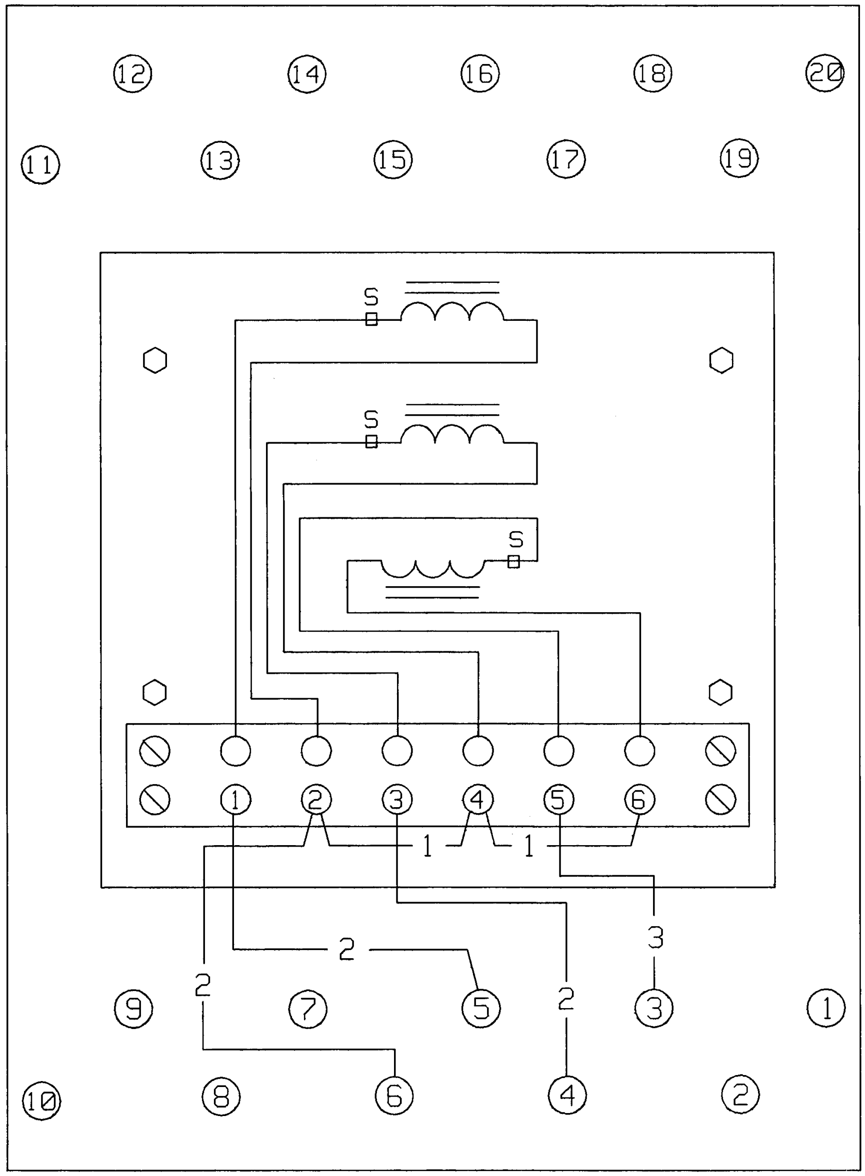
Sub 1

Figure 10. Reactor Outline

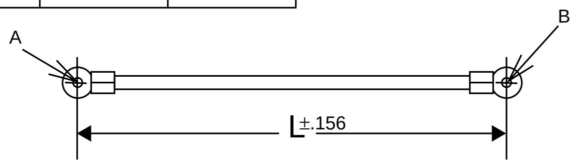


REAR VIEW OF CASE

NOTE: A - PLACE IT. 1 TO 3 IN IT. 5 FOR SHIPPING

Lead IT.	L	SCREW SIZE A	SCREW SIZE B
1	3.00	.164 - 32	.164 - 32
2	4.00	.164 - 32	.190 - 32
3	3.00	.164 - 32	.190 - 32
4	13.438	.164 - 32	.190 - 32

ITEM	PART NAME	STYLE DWG.	ITEM GR.	NOTE CODE	ENG. REF.	REQ
01	LEAD	57Z0301	616	A	63-D-653	2
02	LEAD	57Z0401	622	A	63-D-655	3
03	LEAD	57Z0301	622	A	63-D-655	1
05	BAG	836A618	H04	B	27-D-5478	1



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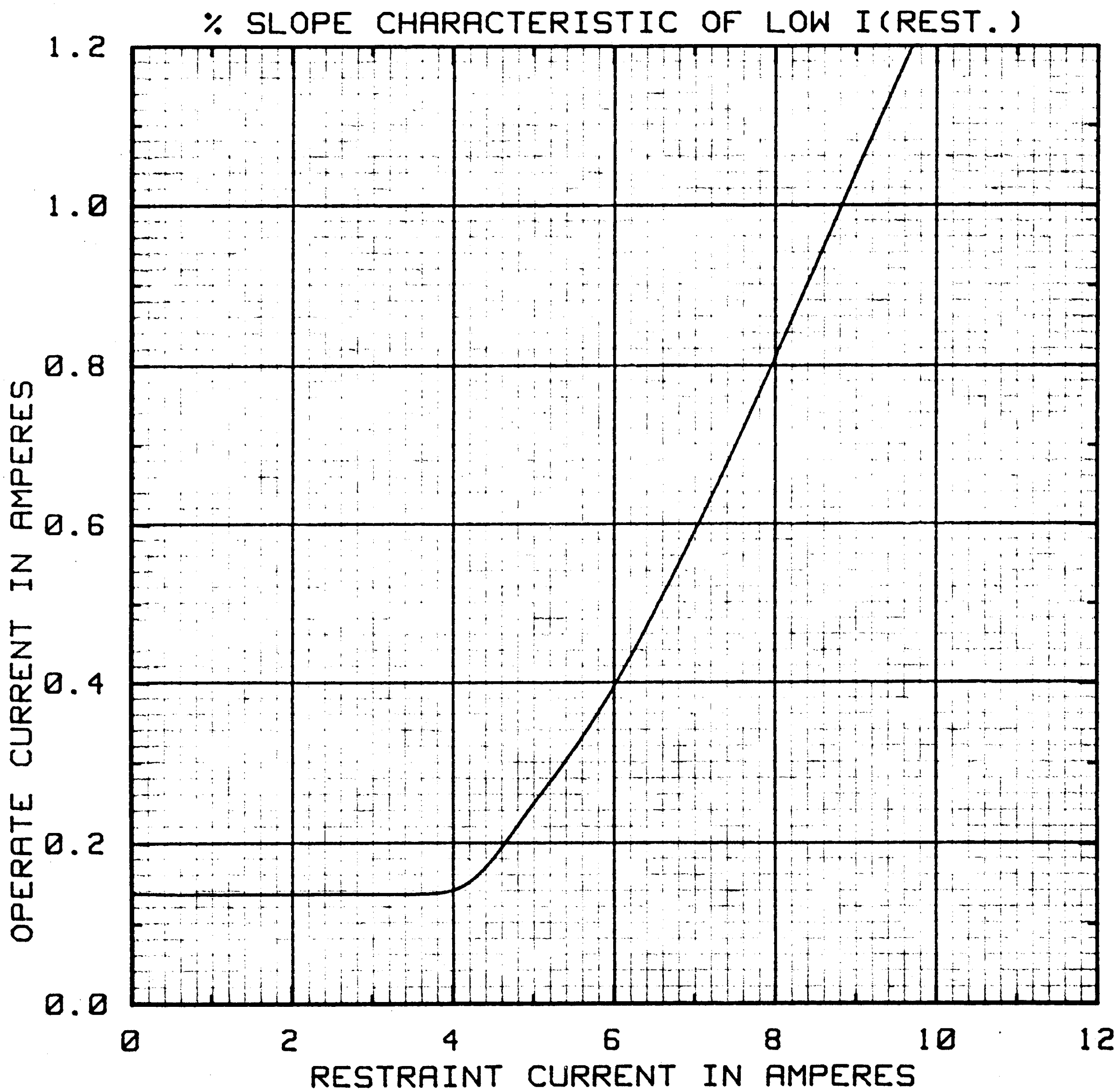
* Sub 5

Figure 11. Relay and Reactor Interconnection

* *Denotes Change*



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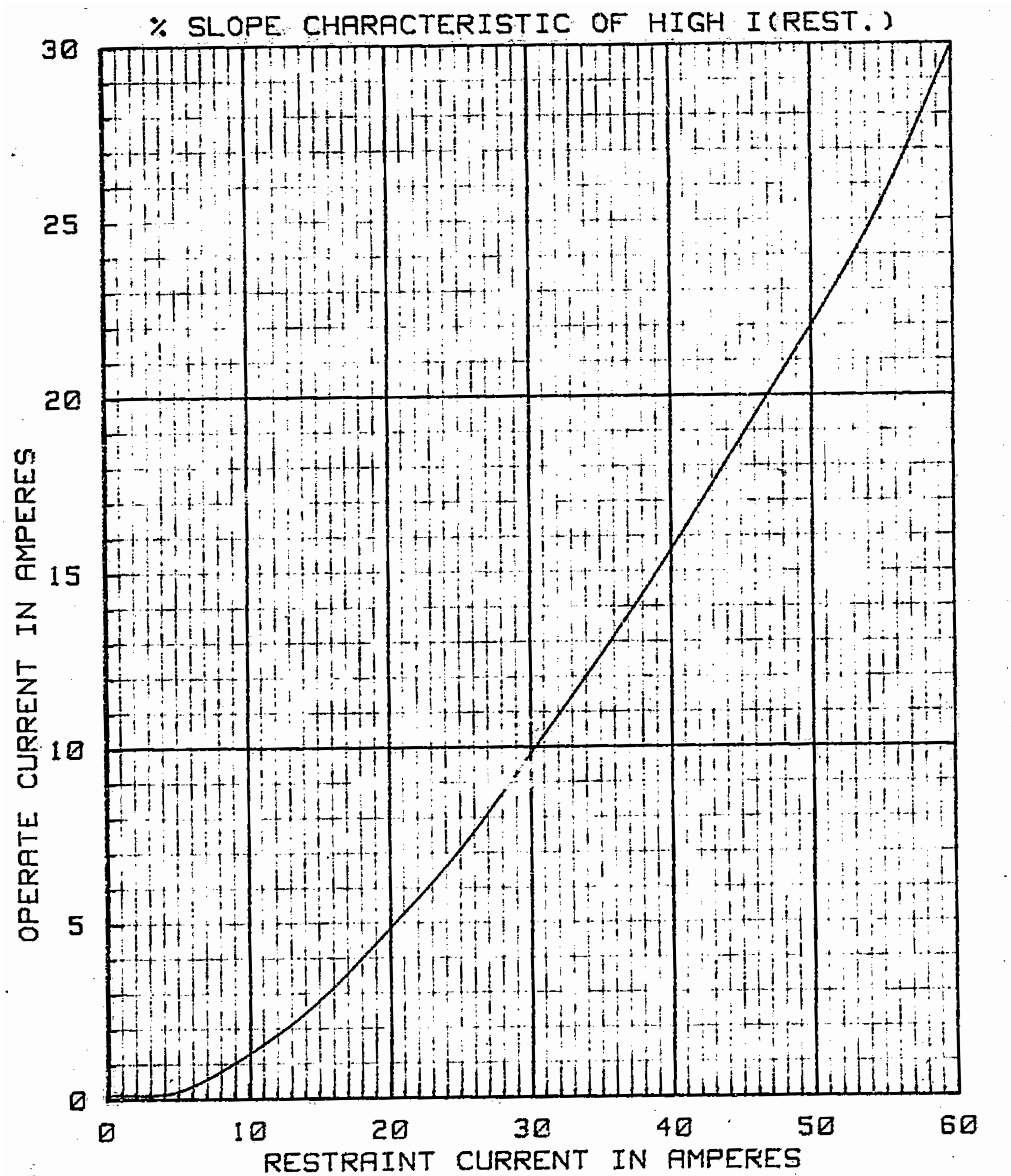
Sub 2

Figure 12. Percentage Slope characteristic at Low Value of Restraint Current



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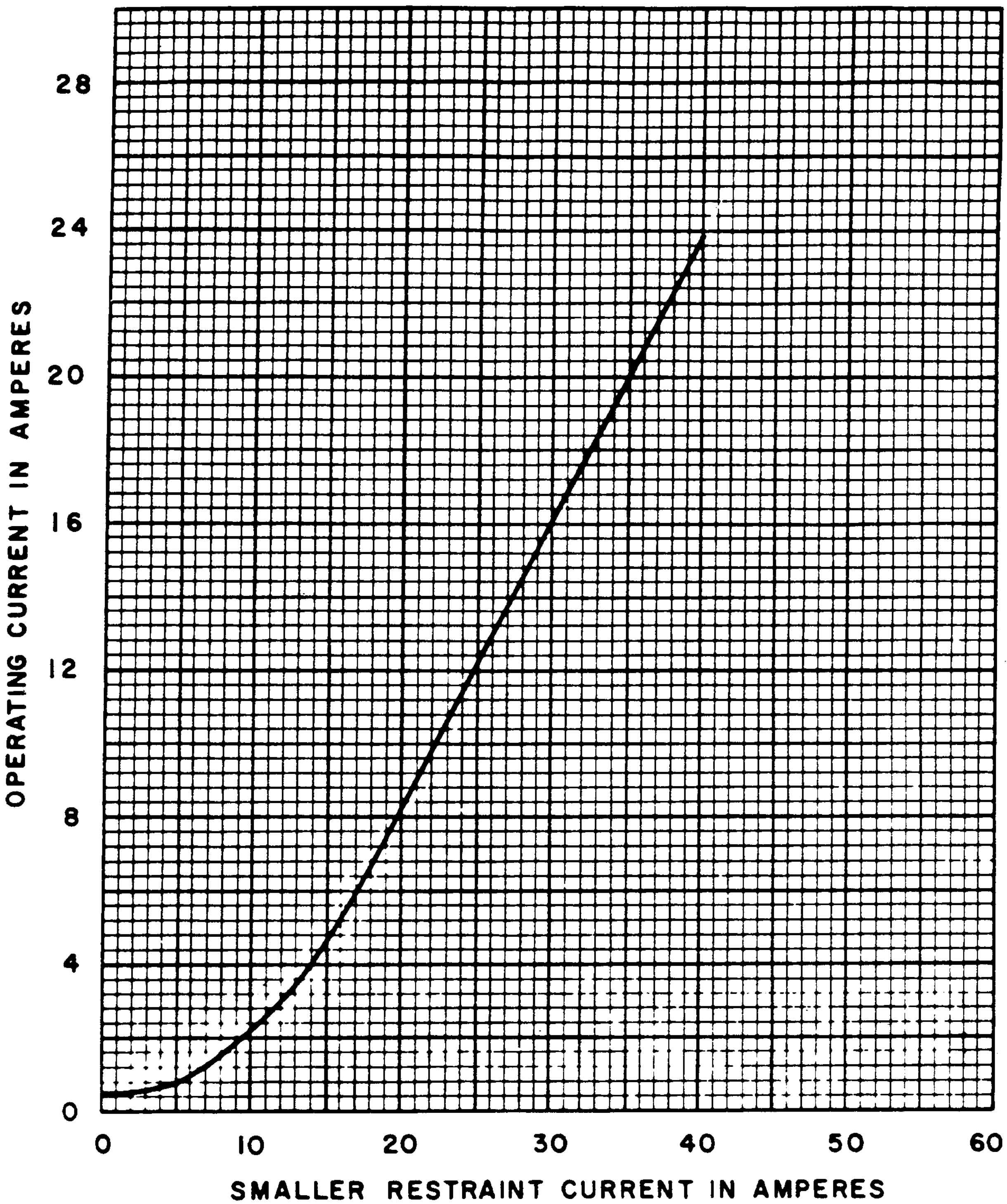
Sub 3

Figure 13. Percentage Slope Characteristic at High Value of Restraint Current



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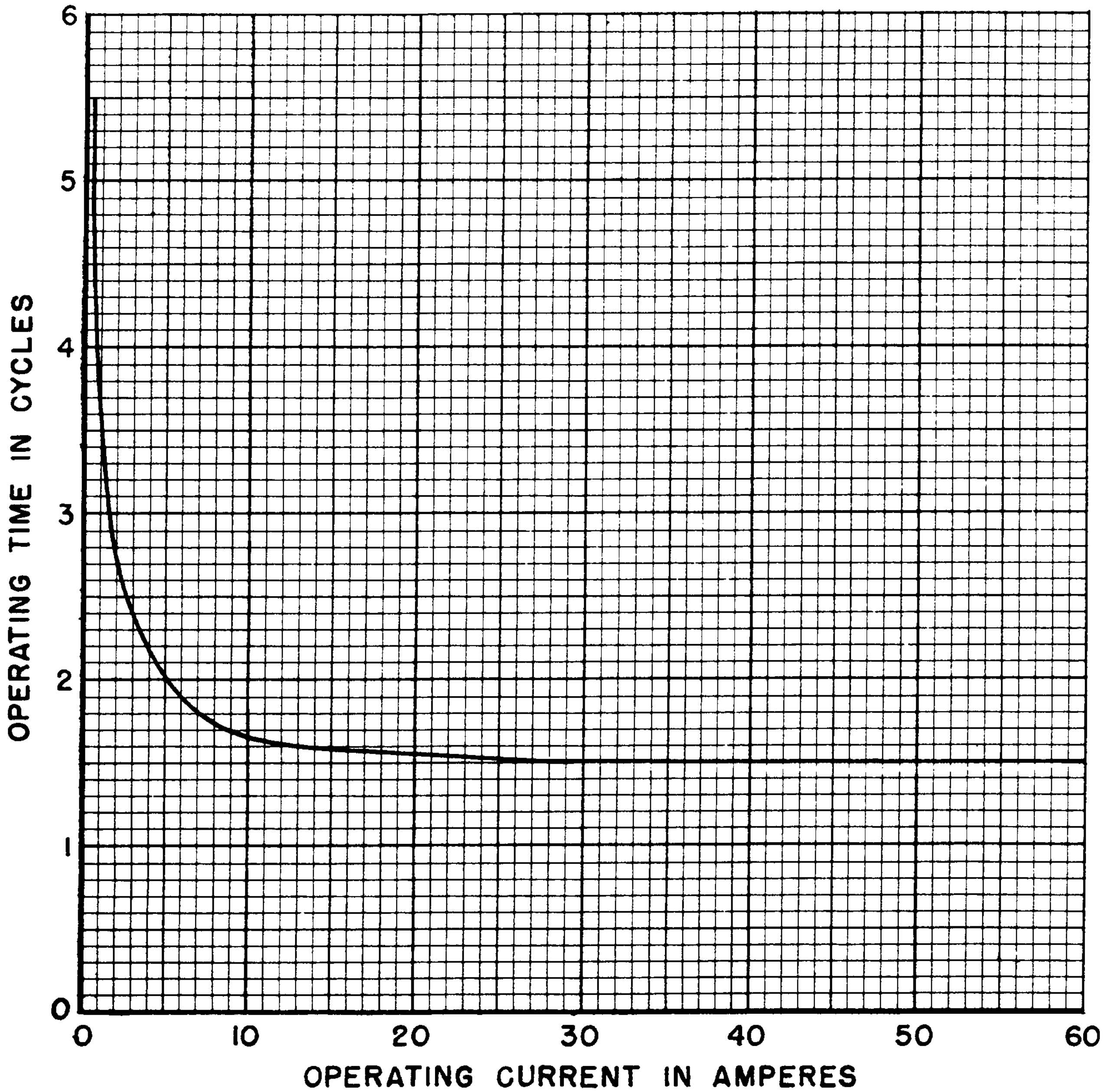
Sub 1

Figure 14. Percentage Slope Characteristic of High Value Restraint Current for Desensitized SA-1 Relay



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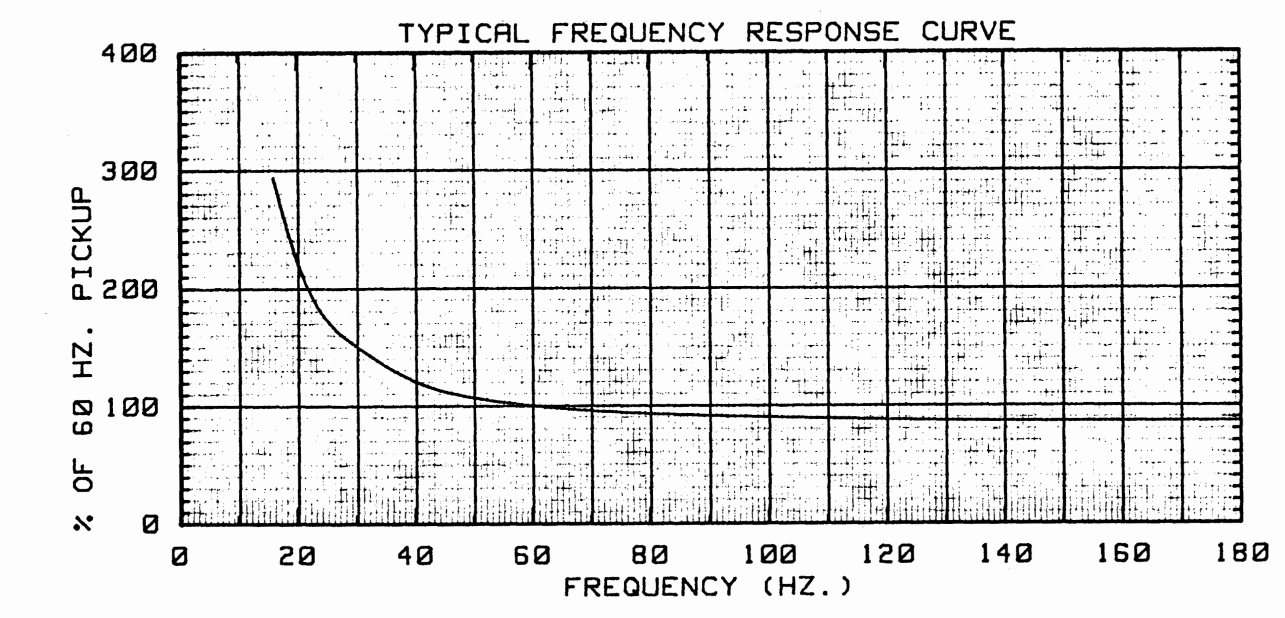
Sub 1

Figure 15. Typical Operation Time Characteristic



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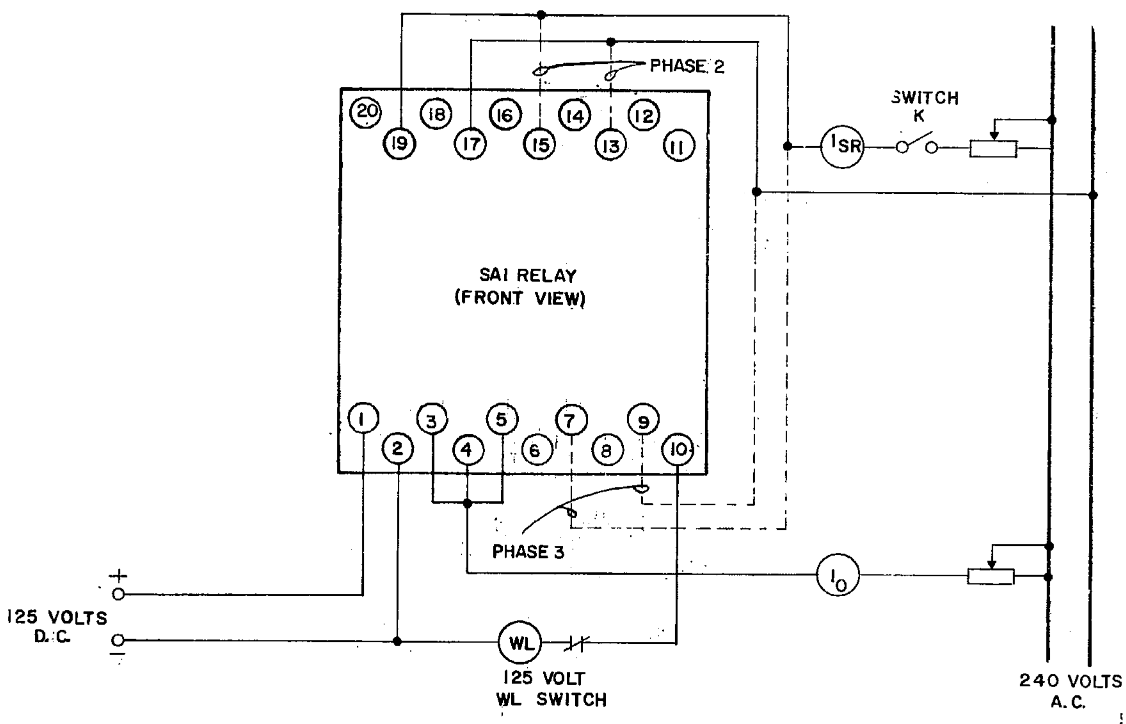
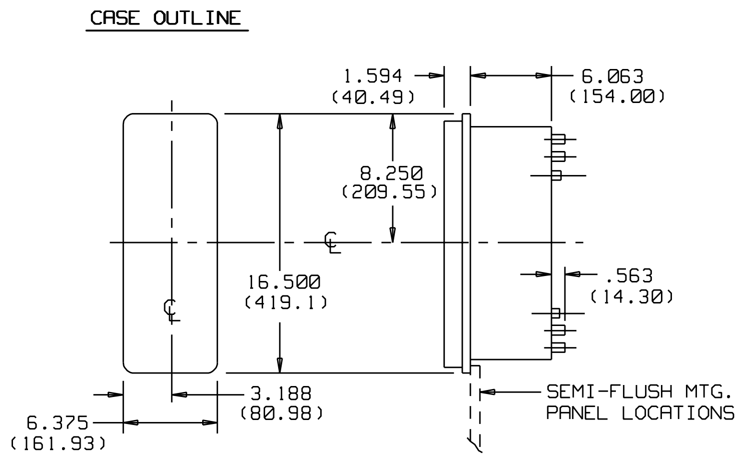
Sub 2

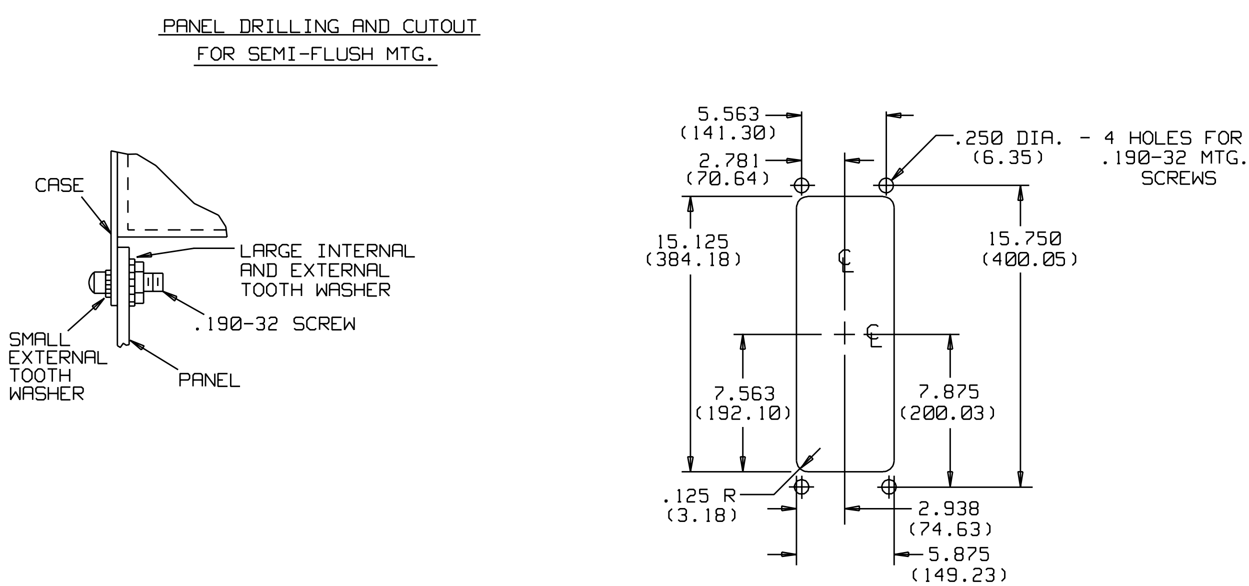
Figure 16. Typical Frequency Response Curve



184A864
Sub 4

Figure 17. Typical Frequency Response Curve





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* Sub 4

Figure 18. Outline and Drilling Plan for the Type SA-1 Relay in Type FT-32 Case

***** *Denotes Change*

NOTES

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