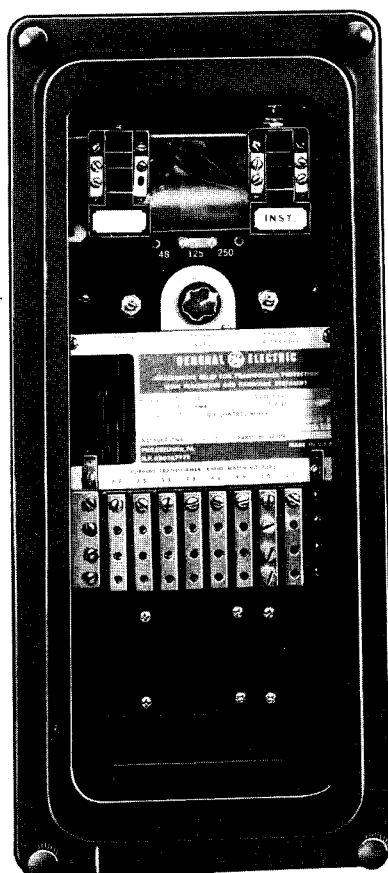




INSTRUCTIONS

TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

TYPES STD15C and STD16C



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TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

STD15C and STD16C

INTRODUCTION

Relays of the STD type are transformer differential relays provided with the features of percentage and harmonic restraint. A static decision unit controls a small telephone-type relay that provides the contact output.

Percentage restraint permits accurate discrimination between internal and external faults at high current, while harmonic restraint enables the relay to distinguish, by the difference in waveform, between the differential current caused by an internal fault, and that of transformer magnetizing inrush.

DESCRIPTION

Each Type STD relay is a single-phase unit. The Type STD15C relay is designed to be used for the protection of two-winding power transformers and has two through-current restraint circuits and one differential-current circuit.

The Type STD16C relay is designed for use with three-winding power transformers and has three through-current restraint circuits and one differential-current circuit. It may also be used for four-circuit transformer protection (see Figure 1) when only three circuits require through-current restraint, while the fourth circuit, being the weakest, needs no through-current restraint.

APPLICATION

The current transformer ratios and relay taps should be selected to obtain the maximum sensitivity without risking thermal overload of the relay or current transformer (CT), or the possibility of misoperation. Therefore, current transformer ratios in the various windings of the power transformer should be selected with the following points in mind:

1. The lower the relay tap and the lower the CT ratio selected, the higher will be the sensitivity. However, the lowest CT ratio and the lowest relay tap may not be compatible with some of the following restrictions. Where a choice is available of increasing either the CT ratio or the relay tap, it is desirable to increase the CT ratio in preference to the relay tap.

Since the relay burden is likely to be small compared to the lead burden, increasing the CT ratio tends to improve the relative performance of the CTs, as a result of reducing the maximum secondary fault current and increasing the accuracy of the CTs.

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.

To the extent required the products described herein meet applicable ANSI, IEEE and NEMA standards; but no such assurance is given with respect to local codes and ordinances because they vary greatly.

2. The CT secondary current should not exceed the continuous thermal rating of the CT secondary winding.
3. The relay current corresponding to maximum kVA (on a forced-cooled basis) should not exceed twice tap value, which is the thermal rating of the relay.
4. The CT ratios should be high enough that the secondary currents will not damage the relay under maximum internal fault conditions (refer to **RATINGS**).
5. The relay current corresponding to rated kVA of the power transformer (on self-cooled basis) should not exceed the relay tap value selected (magnetizing inrush might operate the instantaneous overcurrent unit). If the transformer under consideration does not have a self-cooled rating, the transformer manufacturer should be consulted for the "equivalent self-cooled rating"; that is the rating of a self-cooled transformer that would have the same magnetizing inrush characteristics as the transformer being considered.
6. The current transformer tap chosen must be able to supply the relay with 8 times rated relay tap current, with an error of less than 20% of the total current. If the current transformers produce an error of greater than 20% at less than 8 times tap value, the harmonic content of the secondary current may be sufficient to cause false restraint on internal faults.
7. The CT ratios should be selected to provide balanced secondary current on external faults. Since it is rarely possible to match the secondary currents exactly by selection of current transformer ratios, ratio-matching taps are provided on the relay by means of which the currents may usually be matched within 5%. When the protected transformer is equipped with load-ratio control it is obvious that a close match cannot be obtained at all points of the ratio-changing range. In this case, the secondary currents are matched at the middle of the range and the percentage differential characteristic of the relay is relied upon to prevent relay operation on the unbalanced current which flows when the load-ratio control is at the ends of the range.
8. In some applications, the power transformer will be connected to the high voltage or low voltage system through four breakers (as shown in Figure 1) as for example in a ring-bus arrangement. In this case, the CT ratios must be selected so that the secondary windings will not be thermally overloaded on load current flowing around the ring in addition to the transformer load current. It is recommended that CTs on each of the two low voltage (or high voltage) breakers be connected to a separate restraining winding to assure restraint on heavy through-fault current flowing around the ring bus.

It is not desirable to protect two parallel transformer banks with one set of differential protection, since the sensitivity of the protection would be reduced. In addition, if the banks can be switched separately, there is a possibility of false operation on magnetizing inrush to one transformer bank, causing a "sympathetic inrush" into the bank already energized. In this case, the harmonics tend to flow between the banks, with the possibility that there will be insufficient harmonics in the relay current to restrain the relay.

Typical elementary diagrams for the STD15C and STD16C are illustrated in Figures 2 and 3.

CALCULATION OF SETTINGS

METHOD

The calculations required for determining the proper relay and CT taps are outlined below. A sample calculation, for the transformer shown in Figure 4, is then given.

CURRENT TRANSFORMER CONNECTIONS

Power Transformer Connections

Delta-Wye
Wye-Delta
Delta-Delta
Wye-Wye
Delta-Zigzag with 0° phase
shift between primary and
secondary

Current Transformer Connections

Wye-Delta
Delta-Wye
Wye-Wye
Delta-Delta
Delta-Delta

DETERMINATION OF CT TURNS AND TYPE STD RELAY TAP SETTING

1. Determine the maximum line currents (Max. I) on the basis that each power transformer winding may carry the maximum forced-cooled rated kVA of the transformer.

$$\text{Max. } I_p = \frac{\text{Maximum Transformer kVA}}{\sqrt{3} \text{ (Line kV)}}$$

2. Determine the full-load rated line currents (100% I_p) on the basis that each power transformer winding may carry the full self-cooled rated kVA of the transformer, or the "equivalent" self-cooled ratings.

$$100\% I_p = \frac{100\% \text{ Transformer kVA}}{\sqrt{3} \text{ (Line kV)}}$$

Actually, this calculation does not mean that all windings will necessarily carry these maximum load currents continuously. This is only a convenient way of calculating the currents in the other windings in proportion to their voltage ratings. This is the requirement for selecting the relay tap setting so that the relay will not operate for any external fault.

3. Select CT ratios so that the secondary current corresponding to maximum I_p does not exceed the CT secondary thermal rating (5 amperes). In the case where a transformer is connected to a ring bus, for example, the CT ratio should be selected so that the CT thermal rating will not be exceeded by the maximum load current in either breaker. Also, select CT ratios so that the relay currents can be properly matched by means of the relay taps. (Highest current not more than 3 times lowest current).

For Wye-connected CTs

$$\text{Tap Current} = \frac{100\% I_p}{N}$$

For Delta-connected CTs

$$\text{Tap Current} = \frac{100\% I_p \sqrt{3}}{N}$$

where N is the number of CT secondary turns.

4. Check the matching of relay currents to relay taps, to keep the mismatch error as low as possible.

Calculate the percentage of mismatch as follows: on two-winding transformers, determine the ratio of the two relay currents and the tap values selected. The differences between these ratios, divided by the smaller ratio, is the percent of mismatch. The mismatch normally should not exceed 5%.

For three-winding transformers, the percent of mismatch error should be checked for all combinations of currents or taps.

If taps cannot be selected to keep this percentage error within allowable limits, it will be necessary to choose a different CT ratio on one or more lines, to obtain a better match between relay currents and relay taps.

5. Check to see that the sum of the relay currents that will be applied to the relay for a fault at the terminals of the power transformer is less than 220 amperes RMS for 1 second. If the period during which a fault current flows in the relay can be definitely limited to a shorter time, a higher current can be accommodated in accordance with the relation:

$$(\text{Amperes})^2 \times \text{seconds} = 48,400$$

Also check that the sum of the multiples of tap current on an internal or external fault do not exceed 150.

CURRENT TRANSFORMER RATIO ERROR

The CT ratio error must be less than 20% at 8 times relay rated tap current. This is based on the instantaneous unit being set at its normal setting, which is 8 times tap rating. If the instantaneous unit pickup is raised above this value, the 20% figure must be reduced, as described in the **CHARACTERISTICS** section.

The calculations listed below are for the worst-fault condition, as far as CT performance is concerned, which is an internal ground fault between the CT and the transformer winding, with none of the fault current supplied through the neutral of the protected transformer.

1. Determine the burden on each CT, using the following expressions:

- a. For Wye-connected CTs

$$Z = B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 1})$$

- b. For Delta-connected CTs

$$Z = 2B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 2})$$

- where B = STD relay total burden (see Table I)
- N = number of turns in bushing CT
- e = bushing CT resistance per turn, milliohms (at maximum expected temperature)
- f = bushing CT resistance per lead, milliohms (at maximum expected temperature)
- R = one-way control cable lead resistance (at maximum expected temperature)

TABLE I

Total Burden for 60 Cycle Relays

STD TAPS AMPS	8 X TAP AMPS	BURDEN OHMS (B)	MIN P.U. AMPS
2.9	23.2	0.180	0.87
3.2	25.6	0.156	0.96
3.5	28.0	0.140	1.05
3.8	30.4	0.120	1.14
4.2	33.6	0.112	1.26
4.6	36.8	0.096	1.38
5.0	40.0	0.088	1.50
8.7	69.6	0.048	2.61

2. Determine CT secondary current for 8 times tap setting.

$$I_S = 8 \times \text{STD relay tap rating}$$

(Note: For the location of fault assumed, all the fault current is supplied by one CT, so that CT current and relay current are the same, regardless of whether the CTs are connected in wye or delta.)

3. Determine secondary CT voltage required at 8 times tap setting.

$$E_{\text{sec}} = I_S Z$$

4. From excitation curve of particular tap of current transformer being used, determine excitation current I_E , corresponding to this secondary voltage, E_{sec} .

5. Determine the percent error in each CT by the expression:

$$\% \text{ error} = \frac{I_E}{I_S} \times 100$$

This should not exceed 20% of any set of CTs. If it does, it will be necessary to choose a higher tap on that set of CTs, and repeat the calculations on selection of relay taps, mismatch error, and percent ratio error.

PERCENT SLOPE SETTING

The proper percent slope required is determined by the sum of:

- a. The maximum range of manual taps and the load-ratio-control, or automatic tap changing means, in percent.
- b. The maximum percent of mismatch of the relay taps.

Set the desired percent slope by means of R3 (See Figure 6A).

The percentage slope setting selected should be greater than the ratio of maximum total error current to the smaller of the through currents. In general, if the total error current does not exceed 20%, the 25% setting is used. If it exceeds 20%, but not 35%, the 40% setting is used.

If the movable lead is used (as in Figure 1, for example) the percent slope setting should be chosen about twice as high, since the movable lead provides no restraint.

EXAMPLE (REFER TO FIGURE 4)I. Determination of CT Turns and STD Relay Tap Settings

1. Transformer and Line	A	B	C
2. Maximum $I_p = 3750/\sqrt{3}$ (Line kV)	19.7	49.5	157
3. 100% $I_p = 3000/\sqrt{3}$ (Line kV)	15.7	39.6	125
4. Assume CT turns (N)	20	20	60
5. Maximum I secondary (less than 5a)	0.98	2.47	2.62
6. 100% I secondary	0.79	1.98	2.08
7. CT connections	Delta	Wye	Delta
8. Relay Current for 100% I Sec.	1.37	1.98	3.60

Select a relay tap for one of the line currents and calculate what the currents in other lines would be if they were increased in the same ratio. If any current is greater than $\sqrt{3}$ times any other, the 8.7 tap should be chosen for it, and new ideal relay taps calculated for the other lines.

9. Ideal Relay Taps (Set C = 8.7)	3.31	4.78	8.7
10. Try Relay Taps	3.2	4.6	8.7
11. Check Mismatch Error			

Ratio of Taps on Lines B-A $\frac{4.6}{3.2} = 1.43$ Ratio of Sec. Lines Currents

$$\frac{1.98}{1.37} = 1.44$$

$$\text{Mismatch } \frac{1.44 - 1.43}{1.43} = 0.7\%$$

Ratio of Taps on Lines C-B $\frac{8.7}{4.6} = 1.89$ Ratio of Sec. Line Currents $\frac{3.60}{1.98} = 1.82$

$$\text{Mismatch } \frac{1.89 - 1.82}{1.82} = 3.8\%$$

Ratio of Taps on Lines C-A $\frac{8.7}{3.2} = 2.72$ Ratio of Sec.Line Currents $\frac{3.60}{1.37} = 2.63$

Mismatch $\frac{2.72 - 2.63}{2.63} = 3.4\%$

(All are less than 5%; therefore, mismatch error is not excessive)

12. Check that the sum of the maximum relay currents is less than 220 amps for 1 second, and therefore, short-time rating of relay is not exceeded.

II. Percent Ratio Error

ASSUME (all measured at their maximum expected temperatures)

One-way CONTROL CABLE RESISTANCE (R) = 0.284 ohms

Bushing A CT resistance per turn (e) = 4 milliohms

" B " " " (e) = 2.5 "

" C " " " " (e) = 2.3 "

Bushing A CT resistance per lead (f) = 75 milliohms

" B " " " " (f) = 52.5 "

" C " " " " (f) = 18.6 "

1. Burdens on CTs, using Equation 1 or Equation 2 from page 6.

$$a. \text{ Line A, } Z = 2 (0.156) + \frac{(20 \times 4) + (2.0 \times 75)}{1000} + 2 (.284)$$

$$= 0.312 + 0.205 + 0.568 = 1.085$$

$$b. \text{ Line B, } Z = 0.096 + \frac{(20 \times 2.5) + (2.0 \times 52.5)}{1000} + 0.568$$

$$= 0.096 + 0.138 + 0.568 = 0.80$$

$$c. \text{ Line C, } Z = 2 (0.048) + \frac{(60 \times 2.3) + (2 \times 18.6)}{1000} + 0.568$$

$$= 0.096 + 0.180 + 0.568 = 0.833$$

	A	B	C
2. Impedance, ohms	1.085	0.8	0.833
3. 8 times tap, amperes	25.6	36.8	69.6
4. Es CT voltage require (IZ)	27.8	29.4	58.0
5. I _E required, from excitation curve	1.00	50	0.5
6. % Ratio Error	3.4%	136%	0.8%

Exciting current on line B is too high; should try higher tap on CT to improve CT performance.

IA - Repeat - CT Turns and Relay Tap Setting

1. 100% I _p	15.7	39.6	125
2. Try CT turns (necessary to change C also for proper matching)	20	40	80
3. 100% I secondary	0.79	0.99	1.56
4. Relay Current	1.37	0.99	2.70
5. Ideal Relay Taps (Set C = 8.7)	4.40	3.19	8.7
6. Use Relay Taps	4.6	3.2	8.7
7. Mismatch Error is less than 5%			

IIA Repeat - Percent Ratio Error

1. Burden on CTs

Line A, $Z = 0.192 + 0.205 + 0.568 = 0.965$ Line B, $Z = 0.156 + 0.188 + 0.568 = 0.912$ Line C, $Z = 0.096 + 0.226 + 0.568 = 0.890$

2. Impedance Ohms	0.965	0.912	0.890
3. 8 times Tap, Amperes	36.8	25.6	69.6
4. E_{sec} , CT voltage required (IZ)	35.6	23.4	61.9
5. I_E required, from excitation curve	1.1	0.25	0.17
6. % of Ratio Error	3.1%	1.0%	0.3%

Percent error is less than 20%, so CT taps and relay taps are satisfactory.

III Percent Slope Setting

1. Assume load ratio control maximum range	10.0%
2. Relay tap mismatch, from IA above (Lines A-B)	4.6%

Use 25% setting 14.6%

RATINGS

MODELS 12STD15C AND 12STD16C

Continuous Rating

The through-current transformer and differential-current transformer will stand twice tap value for any combination of taps, or they will stand twice tap value if all but one of the restraint windings carry 0 current, and the full restraint current (equal to twice tap value) flows through the differential-current transformer.

Short Time Rating (Thermal)

220 amperes for 1 second, measured in the primary of any transformer of the type STD relay. Higher currents may be applied for shorter lengths of time in accordance with the following equation:

$$I^2t = 48,400$$

where I = current amperes
 t = time in seconds.

Short Time (Electrical)

For both the STD15C and STD16C the sum of the multiples of tap current fed to the relay from the several sets of current transformers should not exceed 150. These multiples should be calculated on the basis of RMS symmetrical fault current. This limitation is a result of the voltage rating of the rectifiers in the through-current restraint circuit. Note that in Figure 1 external fault current can flow through circuit breakers 52-1 and 52-2 without being limited by the transformer impedance.

TABLE II

	TARGET AND SEAL-IN UNIT		
	2.0 Amp Tap	0.6 Amp Tap	0.2 Amp Tap
DC Resistance	0.13 Ohms	0.6 Ohms	7 ohms
Carry Continuously	0.5 Amps	1.5 Amps	0.25 Amps
Carry 30 Amps for	4 Secs.	0.5 Secs.	----
Carry 10 Amps for	30 Secs	4 Secs.	0.2 Secs.

AUXILIARY RELAY CONTROL CIRCUIT

The STD15C and STD16C relays are available for use with 48, 125, and 250 DC or 48, 110 and 220 DC control voltage, depending upon the relay model. A plate with small links located on the front of the relay enables the selection of one of these voltages.

The STD relay is provided with two open contacts connected to a common output circuit. The current-closing rating of the contact is 30 amps for voltages not exceeding 250 volts. If more than one circuit breaker is to be tripped, or if the tripping current exceeds 30 amperes, an auxiliary relay must be used with the STD relay. After the breaker trips, it is necessary that the tripping circuit of these relays (STD and auxiliary) be de-energized by an auxiliary switch on the circuit breaker or by other automatic provisions. A manual reset relay is recommended and normally used.

CHARACTERISTICSPICKUP AND OPERATING TIME

The operating characteristic is shown in Figure 7. The curve for various percentage slopes shows the percent slope versus the throughcurrent flowing in the transformer. The percentage slope is a figure given to a particular slope tap setting, and indicates an approximate slope characteristic. Pickup at zero restraint is approximately 30% of tap value (see Table III). The dropout time, when the operating current is reduced to zero from any value above pickup, is less than 25 milliseconds.

Curves of the operating time of the main unit and of the instantaneous unit are shown in Figure 5, plotted against differential current. The main unit operating time includes auxiliary unit operating time.

OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are 8 times the ampere turns produced by rated tap current flowing in that tap. For example:

When only one CT supplies current, and the tap plug for the CT is in the 5 ampere tap, 40 amperes are required for pickup. This pickup value is based on the AC component of current transformer output only, since the differential-current transformer in the relay produces only a half cycle of any DC (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating on a self-cooled basis, the overcurrent unit will not pick up on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pick up, especially on small transformer banks. If this happens, it is recommended that the CT ratio or relay tap setting be increased, rather than increasing the pickup of the overcurrent unit. If the overcurrent setting must be raised, the requirements on CT error will be more stringent, in accordance with the following equation:

$$E = 20 - (2.5) (P-8)$$

where E = CT error current in percent, at pickup of the overcurrent unit
P = Pickup of overcurrent in multiples of tap setting.

PERCENTAGE DIFFERENTIAL CHARACTERISTICS

The percentage differential characteristics are provided by through-current restraint circuits. In addition to the operating circuit, which is energized by the differential current of the line current transformers, the relay is equipped with a restraining circuit that is indirectly energized by the transformer secondary currents. For the relay to operate, the current transformer secondary currents must be unbalanced by a certain minimum percentage, determined by the relay slope setting (as shown in Figure 7). This characteristic is necessary to prevent false operation on through-fault currents. High currents saturate the cores of the current transformers and cause their ratios to change, with the result that the secondary currents become unbalanced. Percentage restraint is also required to prevent operation by the unbalanced currents caused by imperfect matching of the secondary currents, as previously described under Determination of CT Turns and STD Relay Tap Settings.

HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary that establishes the required flux in the core. This current is called magnetizing inrush, and in the primary winding flows only through the current transformers. This causes an unbalance current to flow in the differential relay, which would cause false operation if means were not provided to prevent it.

Power system fault currents are of a nearly pure sine waveform, plus a DC transient component. The sine waveform results from sinusoidal voltage generation and nearly constant circuit impedance. The DC component depends on the time in the voltage cycle at which fault occurs, and upon circuit impedance magnitude and angle.

Transformer magnetizing-inrush currents vary according to the extremely variable exciting impedance resulting from core saturation. They are often of high magnitude, occasionally having an RMS value with 100% offset, approaching 16 times full-load current for worst conditions of power transformer residual flux and point-of-circuit closure on the voltage wave. They have a very distorted waveform made up of sharply peaked half-cycle loops of current on one side of the zero axis, and practically no current during the opposite half cycles. The two current waves are illustrated in Figure 8.

Any current of distorted, nonsinusoidal waveform may be considered as being composed of a DC component plus a number of sine-wave components of different frequencies; one of the fundamental system frequency, and the others, called "harmonics," having frequencies which are 2, 3, 4, 5, etc., times the fundamental frequency. The relative magnitudes and phase positions of the harmonics with reference to the fundamental determine the waveform. When analyzed in this manner, the typical fault-current wave is found to contain only a very small percentage of harmonics, while the typical magnetizing-inrush-current wave contains a considerable amount.

The high percentage of harmonic currents in the magnetizing-inrush-current wave afford an excellent means of distinguishing it electrically from the fault-current wave. In the Type STD relays, the harmonic components are separated from the fundamental component by suitable electric filters. The harmonic current components are passed through the restraining circuit of the relay, while the fundamental component is passed through the operating circuit. The DC component present in both the magnetizing-inrush- and offset-fault-current waves is largely blocked by the auxiliary differential-current transformer inside the relay, and produces only a slight momentary restraining effect. Relay operation occurs on differential-current waves in which the ratio of harmonics to fundamental is lower than a given predetermined value, for which the relay is set (e.g. an internal fault-current wave), and is restrained on differential-current waves in which the ratio exceeds this value (e.g. magnetizing-inrush-current wave).

BURDENS

Burdens are shown in Table III and IV. Burdens and minimum pickup values are substantially independent of the percent slope settings, and are all approximately 100% power factor. Figures given are burdens imposed on each current transformer at 5.0 amperes.

TABLE III

TAP SETTING AMPS	ZERO RESTRAINT PICKUP AMPS	OPERATING CIRCUIT *		RESTRAINT CIRCUIT	
		60 CYCLE RELAYS		60 CYCLE RELAYS	
		BURDEN	IMPEDANCE	BURDEN	IMPEDANCE
		VA	OHMS	VA	OHMS
2.9	0.87	3.2	0.128	1.3	0.052
3.2	0.96	2.7	0.108	1.2	0.048
3.5	1.05	2.4	0.096	1.1	0.044
3.8	1.14	2.0	0.080	1.0	0.040
4.2	1.26	1.9	0.076	0.9	0.036
4.6	1.38	1.6	0.064	0.8	0.032
5.0	1.50	1.5	0.060	0.7	0.028
8.7	2.61	0.7	0.028	0.5	0.020

* Burden of operating coil is 0 under normal conditions.
Burden of 50-cycle relay is the same or slightly lower.

TABLE IV

DC CONTROL CIRCUIT BURDEN						
RATED VOLTS	48	125	250	48	110	220
MILLIAMPS	140	105	88	140	96	80

CONSTRUCTION

Figure 6 shows the internal arrangement of the components of the STD15C relay. Refer also to the internal connection diagrams, Figures 10 and 11, which will identify the parts more completely.

CURRENT TRANSFORMERS

In the Type STD15C relay, the through-current transformer has two primary windings, one for each line-current-transformer circuit. Winding No. 1 terminates at stud 6 and winding No. 2 terminates at stud 4.

In the Type STD16C relay, there are three separate through-current transformers, each with only one primary winding, and each terminating at a separate stud, windings No. 1, No. 2 and No. 3 corresponding to studs 6, 4 and 3 in that order.

In both relays there is a differential-current transformer with one primary lead brought out to stud 5.

The primary circuit of each of these transformers is completed through a special tap block arrangement. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type STD15C or STD16C), one row for each through-current transformer winding. A tap on the differential-current transformer is connected to a corresponding tap of the through-current restraint windings by inserting tap plugs in the tap blocks.

When the STD16C relay is used on four-circuit applications, as shown in Figure 1, the fourth circuit CT is connected to stud 7, and the jumper normally connected between terminals 6 and 7 at the rear of the relay cradle should be disconnected at the terminal 6 end and reconnected to the upper row in the tap block (above the row marked winding 1), which connects it directly to the differential-current transformer in the STD relay. The terminal on the movable lead should be placed under the tap screw that gives the best current match for the current in the movable lead.

The taps permit matching of unequal line-current transformer secondary currents. The tap connections are so arranged that in matching the secondary currents, when a tap plug is moved from one position to another in a horizontal row, corresponding taps on both the differential-current transformer winding and one of the through-current transformer windings are simultaneously selected so that the percent through-current restraint remains constant.

It should be recognized that pickup current flows not only through differential-current transformer but also through one of the primary windings of the through-current transformer, producing some restraint. However, compared to the operating energy, this quantity of restraint is so small that it may be assumed to be zero.

THROUGH-CURRENT RESTRAINT CIRCUIT

A full wave bridge rectifier receives the output of the secondary of each through-current restraint transformer. In the STD16C relay, the DC outputs of all three units are connected in parallel. The total output is directed to the percent slope

rheostat (R3) located on the front of the relay. By means of adjusting the rheostat, the percent slope may be varied from 15% to 40%. The output is put through an isolating transformer, rectified, and directed to the sensitive solid state amplifier that controls the telephone-type relay.

DIFFERENTIAL-CURRENT CIRCUIT

The differential-current transformer secondary supplies 1) the instantaneous unit directly; 2) the operating (tripping) signal to the solid-state amplifier through a series-tuned circuit; and 3) the harmonic restraint isolating transformer through a parallel resonant filter. The operating and restraint currents are each rectified by a full-wave bridge prior to being supplied to the sensitive sense amplifier.

The series resonant circuit is made up of a 5 microfarad capacitor (C1) and a reactor (L1) that are tuned to pass currents of the fundamental system frequency and to offer high impedance to currents of other frequencies. Resistor R1 is connected in parallel on the AC side of the operate rectifier, and can be adjusted to give the desired amount of operate current. The output of the rectifier is applied to the operating circuit of the sense amplifier.

The parallel resonant trap is made of a 15 microfarad capacitor (C2) and a reactor (L2) that are tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. Resistor R2 is connected in parallel on the AC side of the harmonic restraint rectifier, and can be adjusted to give the desired amount of harmonic restraint. The output of the rectifier is paralleled with the through-current restraint currents and applied to the restraint circuit of the sense amplifier.

It will be evident that if the differential current applied to the relay is sinusoidal and of system frequency, it will flow mostly in the operating circuit and hence cause the relay to yield an output. If, however, the differential circuit contains more than a certain percentage of harmonics, the relay will be restrained from operating by the harmonic currents flowing in the restraint circuit.

A Thyrite^R resistor connected across the secondary of the differential-current transformer limits any momentary high-voltage peaks which may occur, thus protecting the rectifiers and capacitors from damage, without materially affecting the characteristics of the relay.

OVERCURRENT UNIT

The instantaneous unit is a hinged-armature relay with a self-contained target indicator. On extremely heavy internal fault currents, this unit will pick up and complete the trip circuit. The instantaneous unit target will be exposed, to indicate that tripping was through the instantaneous unit.

Because of saturation of the CTs and relay transformers at high fault currents, it is possible that less operating currents will be provided from the differential-current transformer than the percentage slope tap would imply, and more harmonic restraint will be provided than the actual harmonic content of the fault current would supply. As a result, under conditions of a high internal fault current, the main unit may be falsely restrained. Tripping is assured, however, by the

overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Figure 5 shows the relative levels of pickup and speed of operation of the main unit and the overcurrent unit.

MAIN OPERATING UNIT

The primary functioning unit of the STD relay is a solid-state amplifier, whose output controls a simple telephone relay. The sense amplifier is shown in Figures 10 and 11 as a large rectangle. The amplifier consists of many electronic components mounted on a printed circuit card in the top half of the relay. This printed circuit card is installed in a ten-prong printed card design socket. A schematic of this card is shown in Figure 9. This component is adjusted prior to leaving the factory, and should require no further attention.

The telephone-type relay is mounted vertically in the mid-section of the relay. It, too, has been carefully adjusted at the factory, and should require no further attention. If this small relay has been disturbed, refer to the section under **ADJUSTMENTS**.

TARGET AND SEAL-IN UNIT

There is a target and seal-in unit mounted on the top left of the relay. This unit has its coil in series and its contacts in parallel with the main contacts of the telephone-type relay. When the telephone-type relay contacts close, the seal-in unit operates, raising its target into view and sealing around the telephone-type contacts. The target of this unit will remain exposed until released by pushing a button beneath the lower left corner of the cover of the relay case.

CASE

The case is suitable for surface or semi-flush panel mounting, and an assortment of hardware is provided for either method. The cover attaches to the case, and carries the target reset mechanism for the trip indicator and instantaneous unit. Each cover screw has provision for a sealing wire.

The case has studs or screw connections at the bottom for the external connections. The electrical connections between the relay unit and the case studs are made through spring-backed contact fingers mounted in stationary molded inner and outer blocks, between which rests a removable connecting plug that completes the circuit. The outer block, attached to the case, holds the studs for the external connections, and the inner block has terminals for the internal connections.

The relay mechanism is mounted in a steel framework called the cradle, and is a complete unit, with all leads terminating at the inner block. This cradle is held firmly in the case by a latch at the top and bottom and a guide pin at the back of the case. The case and cradle are so constructed that the relay cannot be inserted in the case upside down. The connecting plug, besides making the electrical connection between the blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plug in place.

To draw out the relay unit, the cover is removed and the plug is drawn out. Shorting bars are provided in the case to short the current-transformer circuits

(see Figure 12). The latches are then released and the relay unit can be easily drawn out.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its own source of current, or from other sources. Or, the relay unit can be drawn out and replaced by another which has been tested in the laboratory.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel, will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

Reasonable care should be exercised in unpacking the relay, in order that none of the parts may be injured or the adjustments disturbed.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed, and cause trouble in the operation of the relay.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to make sure that the relay has not been damaged in shipment and that the relay calibrations are unchanged.

VISUAL INSPECTION

Check the nameplate stamping to make sure that the model number, rating and calibration range of the relay received agree with the requisition.

Remove the relay from its case and check by visual inspection that there are no broken or cracked molded parts, or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

Check the operation of the telephone-type relay and instantaneous overcurrent unit manually, to see that they operate smoothly, without noticeable friction or binds. Check the contact gap and wipe of these units, which should agree with values given in the section on **SERVICING**.

ELECTRICAL TESTS

It is recommended that the following electrical tests be made immediately upon receipt of the relay.

1. Minimum pickup of main operating unit.
2. Minimum pickup of the instantaneous overcurrent unit.
3. A single check point on the harmonic restraint characteristic.
4. A single check point on the slope characteristic curve, for the approximate slope expected to be used.

Test Equipment

In order to facilitate tests, the following test equipment is recommended:

1. Two load boxes for regulating the test currents
2. Three ammeters (two AC and one DC) for measuring the test currents
3. A test rectifier for checking the relay's response to the second harmonic. (See Figure 13.)
4. One indicating lamp
5. Two single-pole double-throw switch selectors
6. A double-pole single-throw line switch.

Check the pickup of the main unit, using the connections shown in Figure 14. During this test, the selector switches (S2 and S4) are open, and current passes through one restraint winding and the operate winding only. For example, with a relay set with a 25% slope and at the 2.9 ampere ratio-matching taps, the main unit should pick up at 30% of tap rating, $\pm 10\%$, or the pickup should be between 0.78 and 0.96 amperes. A source of DC power at rated voltage should be connected as shown in Figure 14; the indicating lamp will provide a signal, showing that the main unit has operated.

For an additional pickup test, the pickup should be 1.5 amperes, with current flowing in terminals 5 and 6 and the tap plugs in the 5 ampere tap and the 25% slope tap position. If the pickup is between 1.35 and 1.65 amperes, no adjustment should be made. The pickup of the relay has wider permissible variations than most protective relays, but due to the relay design and application, the relay accuracy is entirely adequate under all conditions, even during transformer magnetizing inrush or severe fault conditions.

With the selector switch, ST, in the A position, check the harmonic current restraint, as described in the section on **INSTALLATION PROCEDURE**.

The instantaneous overcurrent unit should be checked by passing a high current through the 5-6 terminals. The pickup should be about eight times tap rating.

Check through-current restraint, as described in the section on **INSTALLATION PROCEDURE**.

INSTALLATION PROCEDURE

TESTS

Before placing the relays in service, check the relay calibration to be used in its final location, to ensure that it is correct. The following test procedure is outlined for this purpose.

CAUTION

The Relay calibration is accomplished by adjusting resistors R1, R2 and R3. Changes made in any one of these resistors will affect the other two settings. In the event one setting is changed, the pickup, harmonic restraint, and through-current restraint adjustment procedures should be repeated until no further deviation from proper calibration is noted. Best results can be obtained if the through-current restraint adjustment is made only after the other two settings are correct.

PICKUP

The test circuit for pickup is shown in Figure 14, with S2 open. The first values given are for a 5 ampere rated relay. Those in () are for a 1 ampere rated relay. Pickup should be 1.5 (0.3) amperes with current flowing in terminals 5 and 6, and the tap plugs in the 5 (1.0) ampere position, and 25% slope tap setting. The pickup operation should be repeated several times, until two successive readings agree within 0.01 ampere with the total pickup current being interrupted between successive checks. If pickup is found to be from 1.35 to 1.65 (0.27 to 0.33), the setting should not be disturbed.

With DC control voltage applied to the proper terminals of the relay, the pickup of the telephone-type relay can be used as an indication of operation of the amplifier. This voltage may be applied as shown in Figure 15, and the indicating lamp will verify that the amplifier has produced an output signal.

Before R1 is adjusted for pickup, put a DC voltmeter (one volt scale) on pin 2 (-) and pin 8 (+) of the sense amplifier card. The pins are counted from right to left when viewed from the card socket wiring connections. Apply pickup current and adjust R1 for a voltage input to the sense amplifier card of 0.430 to 0.470 volts. If the pickup is not in limits with this setting, then adjust P1 on the sense amplifier card to obtain the proper pickup value.

HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted by means of a Test Rectifier used in conjunction with suitable ammeters and load boxes. The test circuit is as shown in Figure 15, with S2 closed to position A. Tests should be made on the 5.0 (1.0) ampere and 25% slope taps.

The analysis of a single-phase half-wave rectified current shows the presence of fixed percentages of DC, fundamental, and second harmonic components, as well as negligible percentages of all higher even harmonics. This closely approximates a typical transformer inrush current, as seen at the relay terminals, inasmuch as its principal components are DC, fundamental, and second harmonic. Although the percent second harmonic is fixed, the overall percentage may be varied by providing a path for a controlled amount of by-passed current of fundamental frequency. The by-passed current is added in phase with the fundamental component of the half-wave rectified current, and thus provides a means of varying the ratio of second harmonic current to fundamental current.

The following expression shows the relationship between the percent second harmonic, the DC component, and the by-pass current.

$$\% \text{ Second Harmonic} = \frac{0.212 I_{DC}}{0.45I_1 + 0.5I_{DC}} \times 100$$

Figure 16 is derived from the above expression. It shows the percent second harmonic corresponding to various values of by-pass current (I_1) for a constant DC set at 4.0 (0.8) amperes.

The relay is calibrated with a composite RMS current of two times tap value. When properly set, the relay will restrain with greater than 20% second harmonic, but will operate with second harmonic equal to 20% or lower. With the DC ammeter (I_2) set at 4.0 (0.8) amperes, the auxiliary relay should just begin to close its contacts with gradually increasing bypass current (I_1) at a value of 4.5-5.5 (0.9-1.1) amperes. This corresponds to 19-21% second harmonic (see Figure 16), providing a 2% tolerance at the set point to compensate for normal fluctuations in pickup. It should be noted that the current magnitude in the rectifier branch (I_2) is slightly influenced by the application of by-pass current (I_1) and should be checked to make sure it is maintained at its proper value.

If harmonic restraint is found to be out of adjustment, it may be corrected by adjusting rheostat R2. (See **CAUTION** at beginning of **INSTALLATION PROCEDURES** section.)

THROUGH-CURRENT RESTRAINT

The through-current restraint, which gives the relay the percentage differential or percent slope characteristics, is shown in Figure 7. It may be checked and adjusted using the circuit illustrated in Figure 15, with S2 closed to position B. Ammeter I_1 reads the differential current and I_3 reads the smaller of the two through-currents.

CAUTION

These currents should be permitted to flow for only a few seconds at a time, with cooling periods between tests; otherwise, the coils will be overheated.

NOTE: The percent slope tolerance is 10% of nominal, all in the plus direction. This is to ensure that the slope characteristic never falls below set point value.

In testing STD16C relays, the setting should be checked with switch S4 first in one position and then the other, thus checking all the restraint coils. With the current tap plugs in 5.0 (1.0) ampere position and the percent slope set in the 40% position, the relay should just pick up for values of the I_1 and I_3 currents indicated in Table V (VA). Repeat with the percent slope tap set in the 25% and 15% positions. If any one of these set points is found to be other than as prescribed, the adjustment may be made by adjusting R3. It should be noted that the current magnitude in the through-current branch (I_3) is slightly influenced by the application of differential current (I_1) and should be checked to make sure that it is maintained at its proper value.

TABLE V

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	30	12.0-13.2	40.0-44.0
25	30	7.5- 8.3	25.0-27.5
15	30	4.5- 5.0	15.0-16.5

TABLE VA

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	6	2.4-2.64	40-44
25	6	1.5-1.66	25-27.5
15	6	0.9-1.00	15-16.5

Any change in R3 to give the desired slope will have small effect upon minimum pickup and harmonic restraint. However, after the slope setting has once been set, any adjustment of minimum pickup will change the slope characteristics. The slope set points must then be rechecked, to make sure that they are still in accordance with Table III.

INSTANTANEOUS OVERCURRENT UNIT

This unit is located at the upper right-hand side of the relay. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at 8 times the tap rating, as described under **CHARACTERISTICS**. If the setting is incorrect, it may be adjusted by loosening the lock nut at the top of the unit and turning the cap screw until the proper pickup is obtained. **In making this adjustment, the current should not be allowed to flow for more than approximately one second at a time.**

DROPOUT OF MAIN UNIT

After the other tests are complete, check the dropout of the main unit, as described in the **ACCEPTANCE TESTS** section.

LOCATION

The location should be clean and dry, free from dust and excessive vibration, and well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Figure 18.

CONNECTIONS

Internal connection diagrams are shown in Figures 10 and 11. Typical wiring diagrams are given in Figures 1, 2 and 3 for differential applications.

Of course, any through-current transformer winding may be used for any power transformer winding, provided the taps are properly chosen.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor not less than No. 12 AWG gage copper wire, or its equivalent.

Every circuit in the drawout case has an auxiliary brush. (See Figure 12.) This is the shorter brush in the case, which the connecting plug should engage first. On every current circuit or other circuit with shorting bars, make sure the auxiliary brushes are bent high enough to engage the connecting plug or test plug before the main brushes; otherwise the CT secondary circuit may be opened where one brush touches the shorting bar before the circuit is completed from the plug to the other, main brush.

ADJUSTMENTS

TAP PLUG POSITIONINGRatio Matching Adjustment

To obtain a minimum unbalance current in the differential circuit, means are provided in the STD relay to compensate for unavoidable difference in current-transformer ratios. Taps on the relay transformer primary windings are rated 8.7 (1.74), 5.0 (1.0), 4.6 (0.92), 3.8 (0.76), 3.5 (0.7), 3.2 (0.64), and 2.9 (0.58) amperes for each line-current transformer. The tap plugs should be moved to the locations which most nearly match the expected CT currents for the same kVA assumed in each of the power transformer windings. The selection of taps should be guided by the method outlined under **CALCULATIONS**.

CAUTION

The connection plug must be removed from the relay before changing tap positions, in order to prevent open-circuiting a CT secondary. A check should be made after changing taps, to ensure that only one plug is left in any horizontal row of tap holes. Inaccurate calibration and overheating may result if more than one plug is connected to any one winding.

Unbalance Current Measurement

Unbalance current measurement is useful in checking the best tap setting when matching current-transformer ratios in the field. It is also useful in detecting errors or faults in the current transformer winding, or small faults within the power transformer itself, where the fault current is too low to operate the relay.

The type STD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provision is made for temporarily connecting a 5 V high-resistance AC voltmeter (1000 or more ohms per volt) across the secondary of the differential current transformer. This may be done by connecting the meter across terminals 8 and 9 (see Figures 10 and 11). When a perfect match of relay currents is obtained by the ratio-matching taps, the voltmeter will read 0, indicating no unbalance. If the voltmeter reads 1.5 volts or less, the unbalance current entering or leaving a given tap equals approximately 0.03 times the voltmeter reading times the tap rating. For higher voltmeter readings, the approximate unbalance current may be calculated by substituting the voltage reading and tap rating into the following equation:

$$I \text{ (unbalance)} = (0.16 \times V - 0.2) \times \text{Tap}$$

The unbalance percentage equals 100 times the unbalance current divided by the measured tap current. For a three-winding bank, this must be checked with load on at least two pairs of windings in order to ensure that the connections are correct.

The curves in Figure 17 show the approximate voltage across terminals 8 and 9 required to operate the relay, for various percent slope tap settings, and through-currents expressed as percentage of tap. To ensure a margin of safety against false operation, the unbalance voltage should not exceed 75% of that required to operate the relay for any given through-current and percent slope tap setting. This extent of unbalance may result from the relatively high error currents of low-ratio bushing CTs at low multiples of tap current.

This curve represents the STD relay characteristic. Measurement of a voltage across studs 8 and 9 which is 75% or less of the value given on the curve, does not necessarily indicate that the relay will operate at higher through-current values. This is especially true where very high through-faults may cause saturation.

Small rectifier-type AC voltmeters are suitable for the measurement of unbalance. **The voltmeter should not be left permanently connected, since the shunt current it draws reduces the relay sensitivity.**

PERCENT SLOPE SETTING

Scribe marks for 15, 25 and 40% slope settings are provided in both the STD15 and STD16 relays. It is common practice to use the 25% setting unless special connections make it advisable to use one of the others. See the corresponding heading under **CALCULATIONS** for further details.

OPERATION

TARGETS

Targets are provided for both the seal-in unit and the instantaneous overcurrent unit. In the event of an internal fault, one or both of these units will operate, depending upon the fault magnitude. This will produce a target indication of the particular unit which operates. After a fault is cleared, the target should be reset by the reset slide located at the lower left-hand corner of the relay.

DISABLING OF TYPE STD RELAY

CAUTION

When bypassing a breaker for maintenance, it will be necessary to disable the relay to prevent false tripping.

If the disabling of the relay is done by a remote switch, rather than by removing the relay connection plug, the following precautions should be taken:

1. The relay must be disabled by short-circuiting studs 8 and 9 of the relay, or by opening the trip circuit at stud 1.
2. If the CT secondaries are short-circuited as part of the disabling procedure, the trip circuit should be opened at stud 1, and studs 8 and 9 should be short-circuited first. **It is not sufficient to rely on short circuiting the CT secondaries alone, because any difference in time of shorting them may cause false tripping.**

MAINTENANCE

CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface, resembling

in effect a superfine file. The polishing action is so delicate that no scratches are left, yet corroded material will be removed rapidly and thoroughly. The flexibility of the tool insures the cleaning of the actual points of contact.

Fine silver contacts should not be cleaned with knives, files, or abrasive paper or cloth. Knives or files may leave scratches, which increase arcing and deterioration of the contacts. Abrasive paper or cloth may leave minute particles of insulating abrasive material in the contacts, and thus prevent closing.

The burnishing tool described above can be obtained from the factory.

PERIODIC TESTS

An operation test and inspection of the relay and its connections should be made at least once every six months. Tests may be performed as described under INSTALLATION TESTS, or if desired they may be made on the service taps as described in this section.

When inserting or withdrawing a test plug with U-shaped through jumpers to complete the trip circuit through the test plug, similar through jumpers should also be used on studs 8 and 9 to maintain the connections from the relay to the case. **If this is not done, there is a risk of false tripping upon inserting or withdrawing the plug.**

PICKUP

The method for checking pickup is as described under the heading **INSTALLATION TESTS** except, of course, pickup current will be different depending upon the winding (WDG) 1 service tap. Pickup may be determined as follows:

$$I_1 = 0.30 \times \text{WDG 1 Tap}$$

Of course, when checking pickup on a particular service tap, the $\pm 10\%$ expected variation still applies, the acceptable-as-found range being

$$I_1 = 9.0 \times 0.30 \times \text{WDG 1 Tap} \quad \text{to} \quad 1.10 \times 0.30 \times \text{WDG 1 Tap}$$

<u>Example</u>	WDG1 Tap	= 3.5A
	I_1	= $0.90 \times 0.30 \times 3.5$ to $1.10 \times 0.30 \times 3.5$
	I_1	= 0.94 to 1.16 amperes

HARMONIC CURRENT RESTRAINT

The procedure for checking harmonic restraint is as described under the heading **INSTALLATION TESTS**, except that the test current values must be modified as follows:

$$\begin{aligned} I_2 \text{ (DC)} &= 0.80 \times \text{WDG 1 Tap} \\ I_1 &= 0.90 \times \text{WDG 1 Tap} \quad \text{to} \quad 1.10 \times \text{WDG 1 Tap} \end{aligned}$$

In the event a suitable DC meter is not available, $I_2 \text{ (AC)} = 2.25 \times I_2 \text{ (DC)}$. (Theoretically, this conversion factor would be 2.22 if the rectifier back resistance were infinite.)

Example WDG 1 Tap = 3.5A
 I_2 (DC) = $0.80 \times 3.5 = 2.8$ amperes
 I_1 = 0.90×3.5 to 1.10×3.5
 I_2 = 3.15 to 3.85 amperes

If DC meter is not available, I_2 (AC) would in this example be
 $2.25 \times 2.8 = 6.30$ amperes.

THROUGH-CURRENT RESTRAINT

In order to check the service tap slope setting, the test current values indicated in Table IV must be modified to take into account any difference in tap settings. Furthermore, the test circuit shown in Figure 15 must be set up such that the lead from ammeter I_3 to the test plug is connected to the stud that connects to the winding with the lowest tap setting. The common lead, of course, is connected to the stud corresponding to the winding with the higher tap setting. For any combination of taps, the percent slope is given in the following equation.

$$\% \text{ Slope} = \left[\frac{T_1}{T_2} \left(\frac{I_1}{I_3} + 1 \right) - 1 \right] \times 100$$

where

T_1 = smaller tap setting
 T_2 = higher tap setting
 I_1 = differential current
 I_3 = smaller of the two through currents

Table VI, derived from the above expression, is based on a multiple of tap current of 6 times the lower tap setting for all combinations of taps except those which involve the 8.7 amp tap. For the latter case, a 4-times tap setting is used, since the total test current for a 6-times tap setting may be as high as 75.2 amperes, which is not only prohibitively high for many installations, but also may subject the relay to excessive heating.

For a given tabular value of I_3 corresponding to a given combination of winding and percent slope taps, the values of I_1 (min.) and I_1 (max.) correspond to the minimum and maximum percent slope tolerance limits given in Table III. However, for a 4-times tap setting, both the upper and the lower percent tolerance limits have been raised by a value equivalent to the difference between the true slope and the nominal slope at 4-times tap value, indicated by the percent slope characteristic curves shown in Figure 7.

Example WDG 1 Tap = 3.5 A
 Wdg 2 Tap = 5.0 A
 Slope Setting = 40%

Since WDG1 has the lower tap setting, the lead from ammeter I_3 to the test plug should be connected to stud 6, and the common lead connected to stud 4.

From Table VI

I_3 = 21.0 amps
 I_1 (min.) = 21.0 amps
 I_1 (max.) = 22.2 amps

SERVICING

Check any replacement telephone relay for mechanical operation before installation, to see that it operates smoothly and that the contacts are correctly adjusted.

With the relay de-energized, each normally-open contact should have a gap of 0.010-0.015 inch. Observe the wipe on each normally-closed contact by deflecting the stationary contact member towards the frame. Wipe should be approximately 0.005 inch.

The wipe on each normally-open contact should be approximately 0.005 inch. Check by inserting a 0.005 inch shim between the residual screw and the pole piece, and operating the armature by hand. The normally-open contacts should make before the residual screw strikes the shim.

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for the prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and complete nameplate data, including the serial number, of the relay for which the part is required. The serial number may be found stamped on the instantaneous unit in black ink. If possible, give the General Electric Company requisition number on which the relay was furnished.

Since the last edition, the equation has been changed in the section on Unbalance Current Measurement and Figure 7b has been added.

TABLE VI

TAPS	T2	2.9			3.2			3.5			3.8			4.2			4.6			5.0			8.7		
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40
T1	Currents																								
	I ₃	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	11.6	11.6	11.6
2.9	I ₁ (min)	2.6	4.3	7.0	4.6	6.6	9.5	6.7	8.8	12.0	8.8	11.1	14.5	11.6	14.1	17.9	14.3	17.1	21.2	17.1	20.1	24.6	28.7	32.2	37.4
	I ₁ (max)	2.9	4.8	7.7	5.0	7.1	10.3	7.1	9.4	12.8	9.2	11.7	15.4	12.0	14.8	18.9	14.8	17.8	22.4	17.6	20.9	25.8	29.3	33.1	38.9
	I ₃				19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	12.8	12.8	12.8
3.2	I ₁ (min)				2.9	4.8	7.7	4.9	7.0	10.2	7.0	9.3	12.7	9.8	12.3	16.1	12.5	15.3	19.4	15.3	18.3	22.8	27.5	31.0	36.2
	I ₁ (max)				3.2	5.3	8.5	5.3	7.6	11.0	7.4	9.9	13.6	10.2	13.0	17.1	13.0	16.0	20.6	15.8	19.1	24.0	28.1	31.9	37.7
	I ₃							21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	14.0	14.0	14.0
3.5	I ₁ (min)							3.1	5.2	8.4	5.2	7.5	10.9	8.0	10.5	14.3	10.7	13.5	17.6	13.5	16.5	21.0	26.3	29.8	35.0
	I ₁ (max)							3.5	5.8	9.3	5.6	8.1	11.8	8.4	11.2	15.3	11.2	14.2	18.8	14.0	17.3	22.2	26.9	30.7	36.5
	I ₃										22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	15.2	15.2	15.2
3.8	I ₁ (min)										3.4	5.7	9.1	6.2	8.7	12.5	8.9	11.7	15.8	11.7	14.7	19.2	25.1	28.6	33.8
	I ₁ (max)										3.8	6.3	10.0	6.6	9.4	13.5	9.4	12.4	17.0	12.2	15.5	20.4	25.7	29.5	35.3
	I ₃													25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	16.8	16.8	16.8
4.2	I ₁ (min)													3.8	6.3	10.1	6.5	9.3	13.4	9.3	12.3	16.8	23.5	27.0	32.2
	I ₁ (max)													4.2	7.0	11.1	7.0	10.0	14.6	9.8	13.1	18.0	24.1	27.9	33.7
	I ₃																27.6	27.6	27.6	27.6	27.6	27.6	18.4	18.4	18.4
4.6	I ₁ (min)																4.1	6.9	11.0	6.9	9.9	14.4	21.9	25.4	30.6
	I ₁ (max)																4.6	7.6	12.2	7.4	10.7	15.6	22.5	26.3	32.1
	I ₃																			30.0	30.0	30.0	20.0	20.0	20.0
5.0	I ₁ (min)																			4.5	7.5	12.0	20.3	23.8	29.0
	I ₁ (max)																			5.0	8.3	13.2	20.9	24.7	30.5
	I ₃																						34.8	34.8	34.8
8.7	I ₁ (min)																						5.5	9.0	14.2
	I ₁ (max)																						6.1	9.9	15.7

TABLE VIA

TAPS	T2	0.58			0.64			0.7			0.76			0.84			0.92			1.0			1.74		
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40
T2	Currents																								
0.58	I ₃	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	2.3	2.3	2.3	
	I ₁ (min)	0.52	0.86	1.4	0.92	1.32	1.9	1.34	1.76	2.4	1.76	2.22	2.9	2.32	2.82	3.6	2.86	3.42	4.24	3.42	4	4.92	5.74	6.44	7.48
	I ₁ (max)	0.58	0.96	1.54	1.0	1.42	2.06	1.42	1.88	2.56	1.84	2.34	3.08	2.4	2.96	3.78	2.96	3.56	4.5	3.52	4.18	5.16	5.86	6.62	7.78
0.64	I ₃				3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	2.56	2.56	2.56	
	I ₁ (min)				0.58	0.96	1.54	0.98	1.4	2	1.4	1.86	2.54	1.96	2.46	3.22	2.5	3.06	3.88	3.06	3.66	4.56	5.5	6.2	7.24
	I ₁ (max)				0.64	1.06	1.7	1.06	1.52	2.2	1.48	1.98	2.72	2.04	2.6	3.42	2.6	3.2	4.12	3.16	3.82	4.8	5.62	6.38	7.54
0.7	I ₃							4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.8	2.8	2.8		
	I ₁ (min)							0.62	1.04	1.68	1.04	1.5	2.18	1.6	2.1	2.86	2.14	2.7	3.52	2.7	3.3	4.2	5.26	5.96	7
	I ₁ (max)							0.7	1.16	1.86	1.12	1.62	2.36	1.68	2.24	3.06	2.24	2.84	3.76	2.8	3.46	4.44	5.38	6.14	7.3
0.76	I ₃										4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	3.0	3.0	3.0	
	I ₁ (min)										0.68	1.14	1.82	1.24	1.74	2.5	1.78	2.34	3.16	2.34	2.94	3.84	5.0	5.72	6.76
	I ₁ (max)										0.76	1.26	2.0	1.32	1.88	2.7	1.88	2.48	3.4	2.44	3.1	4.08	5.14	5.9	7.06
0.84	I ₃													5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.36	3.36	3.36
	I ₁ (min)													0.76	1.26	2.0	1.3	1.86	2.68	1.86	2.46	3.36	4.7	5.4	6.44
	I ₁ (max)													0.84	1.4	2.22	1.4	2.0	2.92	1.96	2.62	3.6	4.82	5.58	6.74
0.92	I ₃																5.5	5.5	5.5	5.5	5.5	5.5	3.7	3.7	3.7
	I ₁ (min)																0.82	1.38	2.2	1.38	1.98	2.88	4.38	5.1	6.12
	I ₁ (max)																0.92	1.52	2.44	1.48	2.14	3.02	4.5	5.26	6.42
1.0	I ₃																			6.0	6.0	6.0	4.0	4.0	4.0
	I ₁ (min)																			0.90	1.5	2.4	4.06	4.76	5.8
	I ₁ (max)																			1	1.66	2.64	4.18	4.94	6.1
1.74	I ₃																						7.0	7.0	7.0
	I ₁ (min)																						1.1	1.8	2.84
	I ₁ (max)																						1.22	1.98	3.14

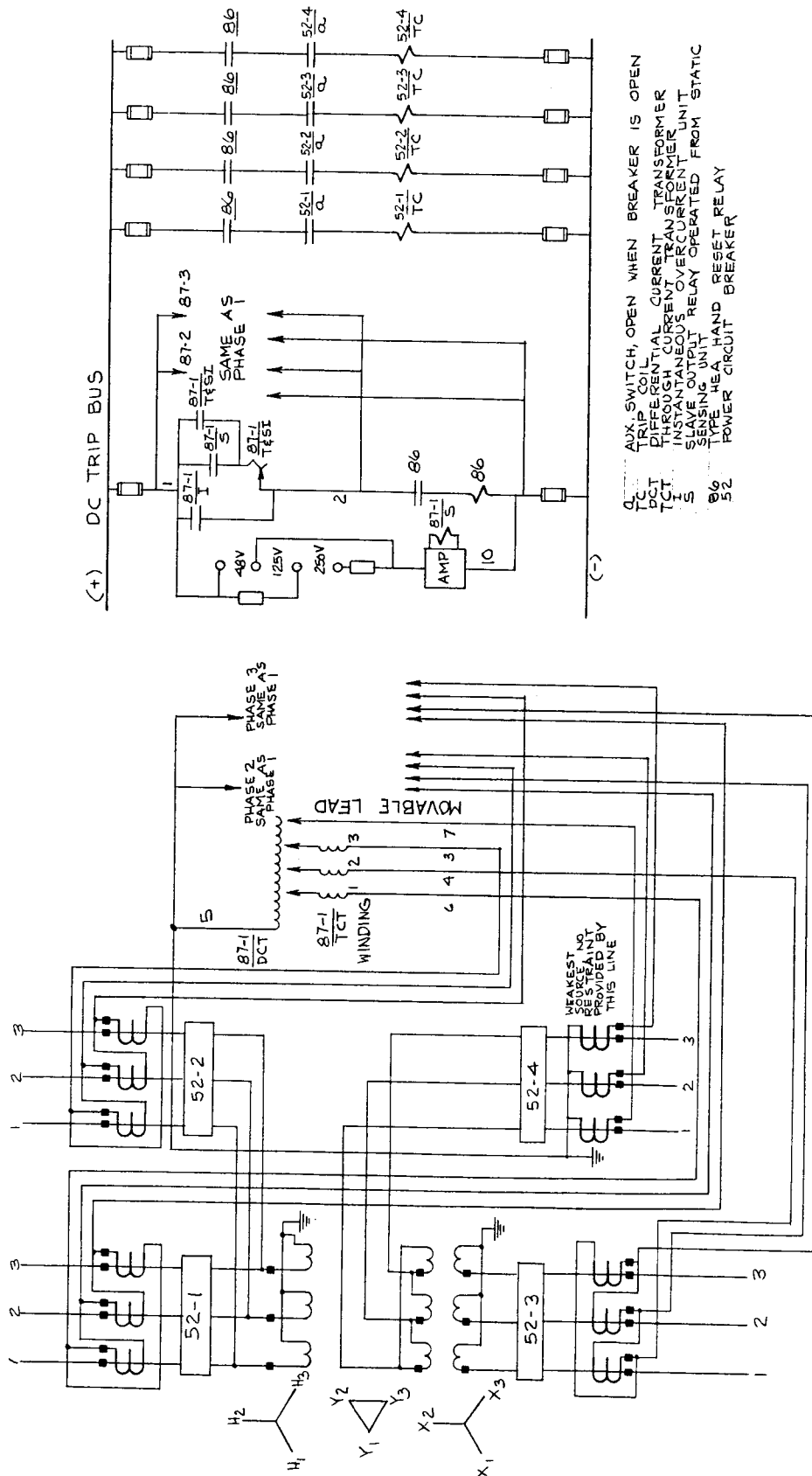


Figure 1 (0128B1982-3) Elementary Diagram for STD16C Relays for Four-Circuit Transformer Protection with Three Restraints

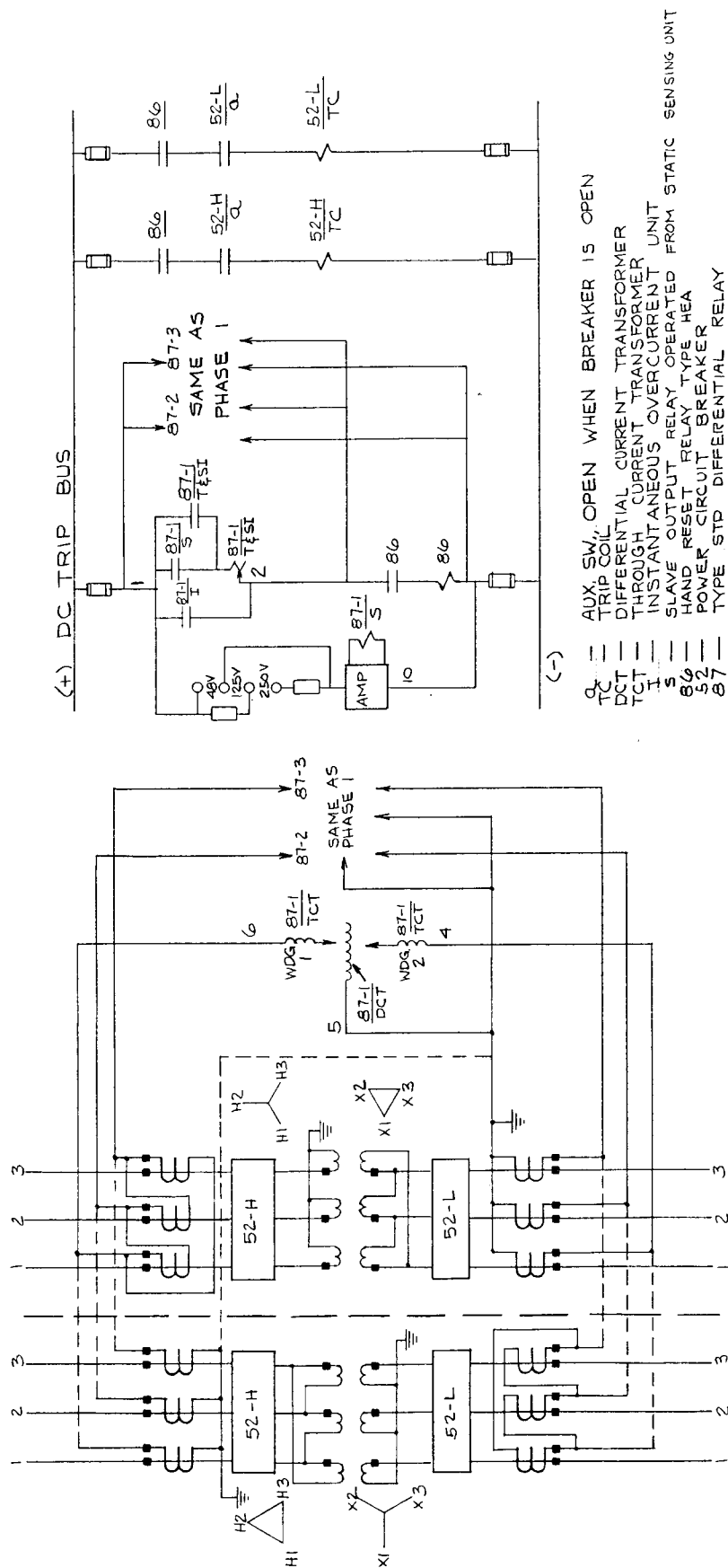


Figure 2 (0128B1981-1) Elementary Diagram for STD15C Relays
for Two-Winding Transformer Protection



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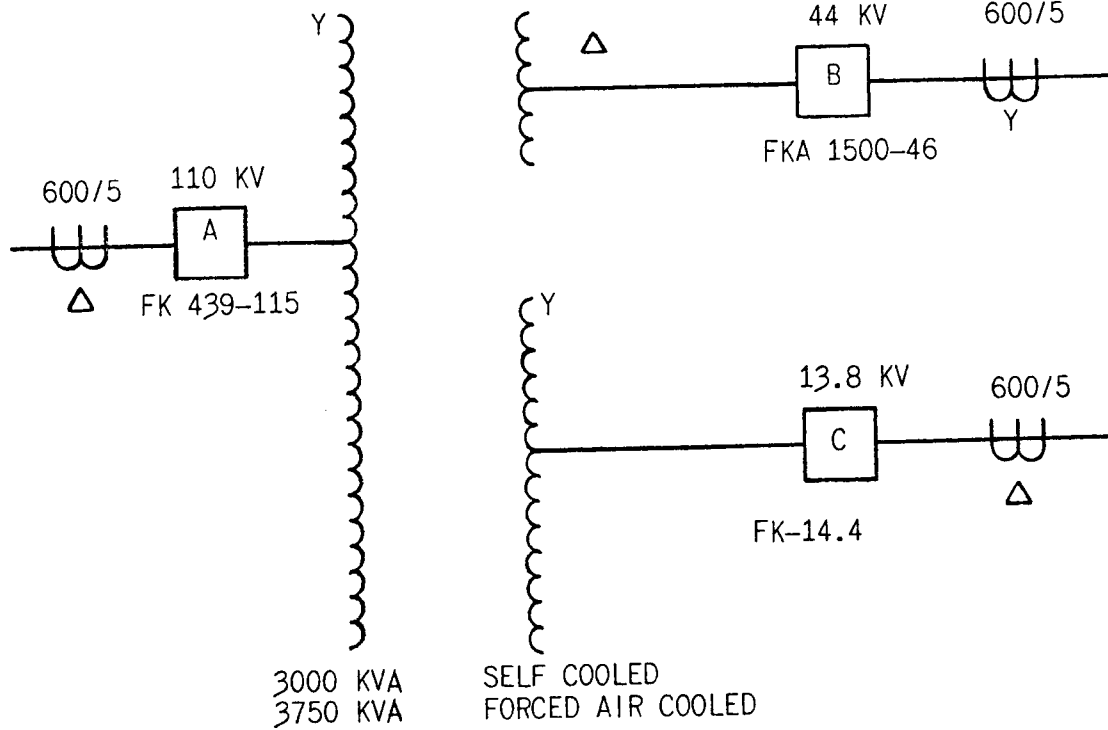


Figure 4 (0165A7601-1) Transformer Used in Sample Calculations

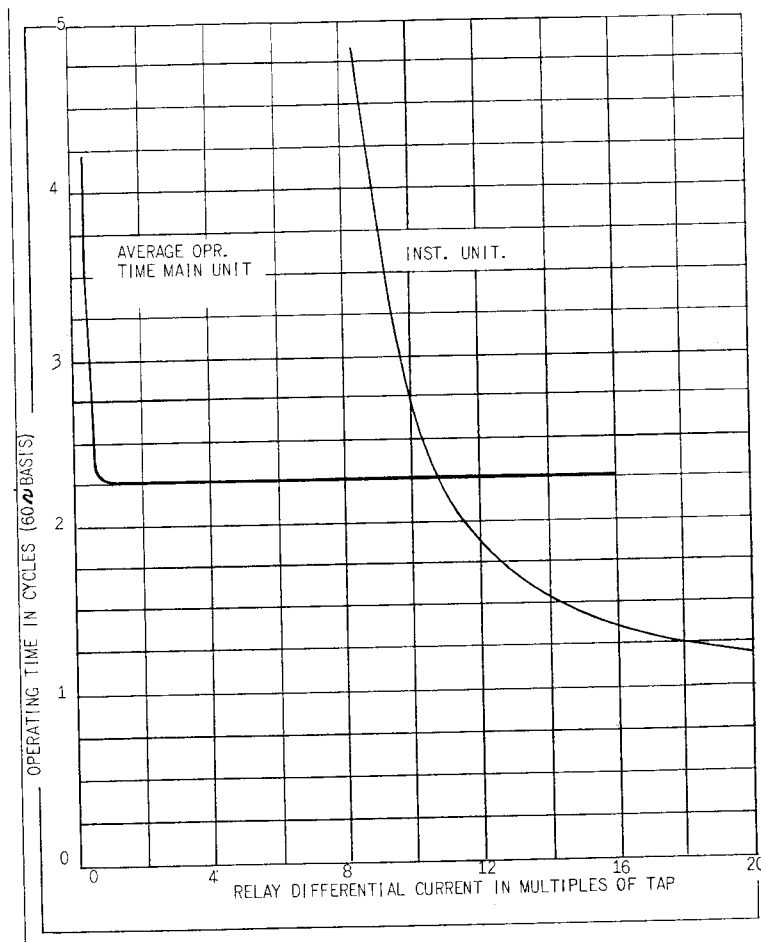


Figure 5 (0227A2503-0) Operating Speed Characteristics of the STD Relay

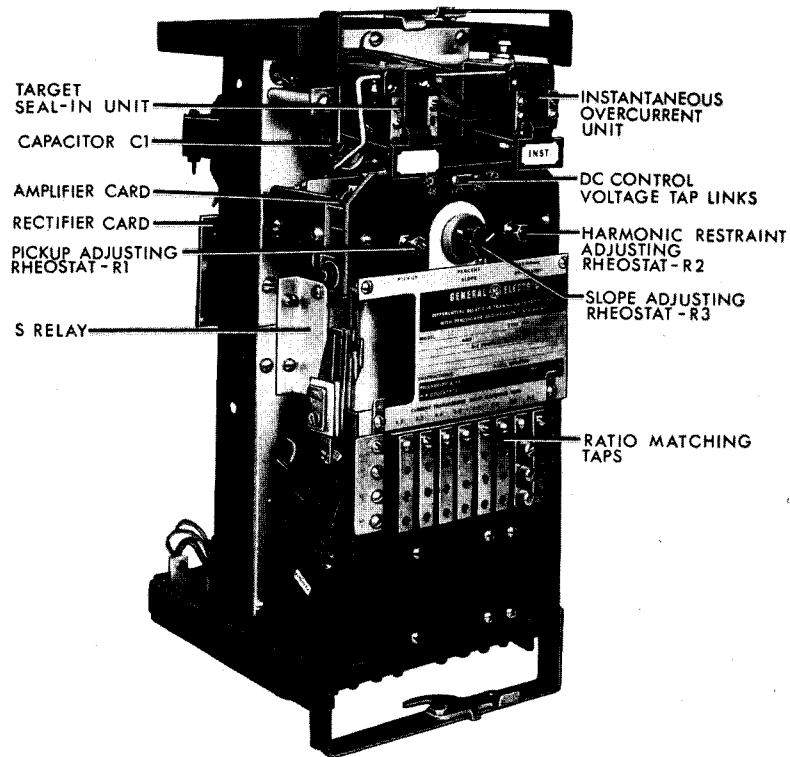


Figure 6A (8042539) Relay Type STD16C Out of Case
Approximately 3/4 Front View (Left Side)

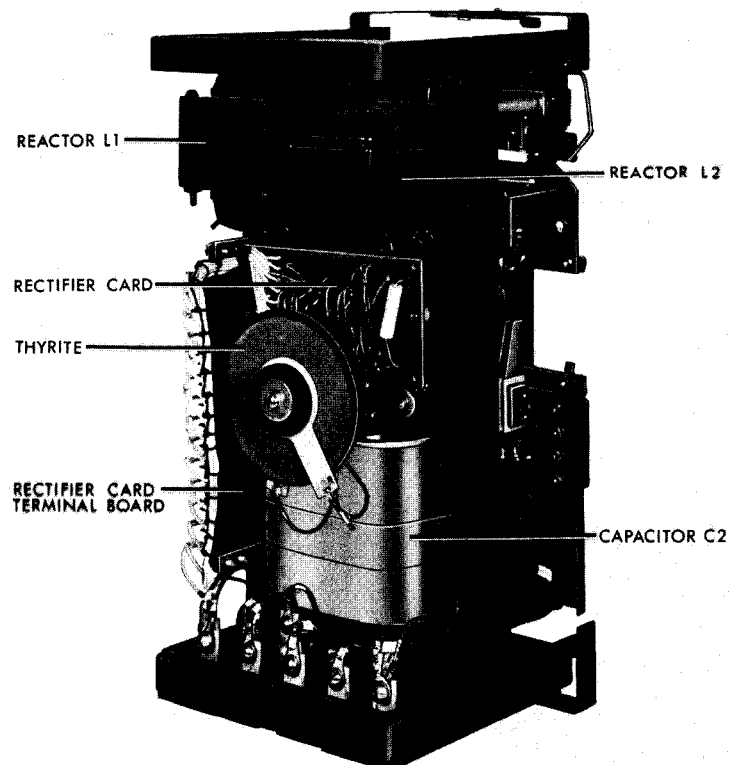


Figure 6B (8042544) Relay Type STD16C Out of Case
Approximately 3/4 Back View (Right Side)

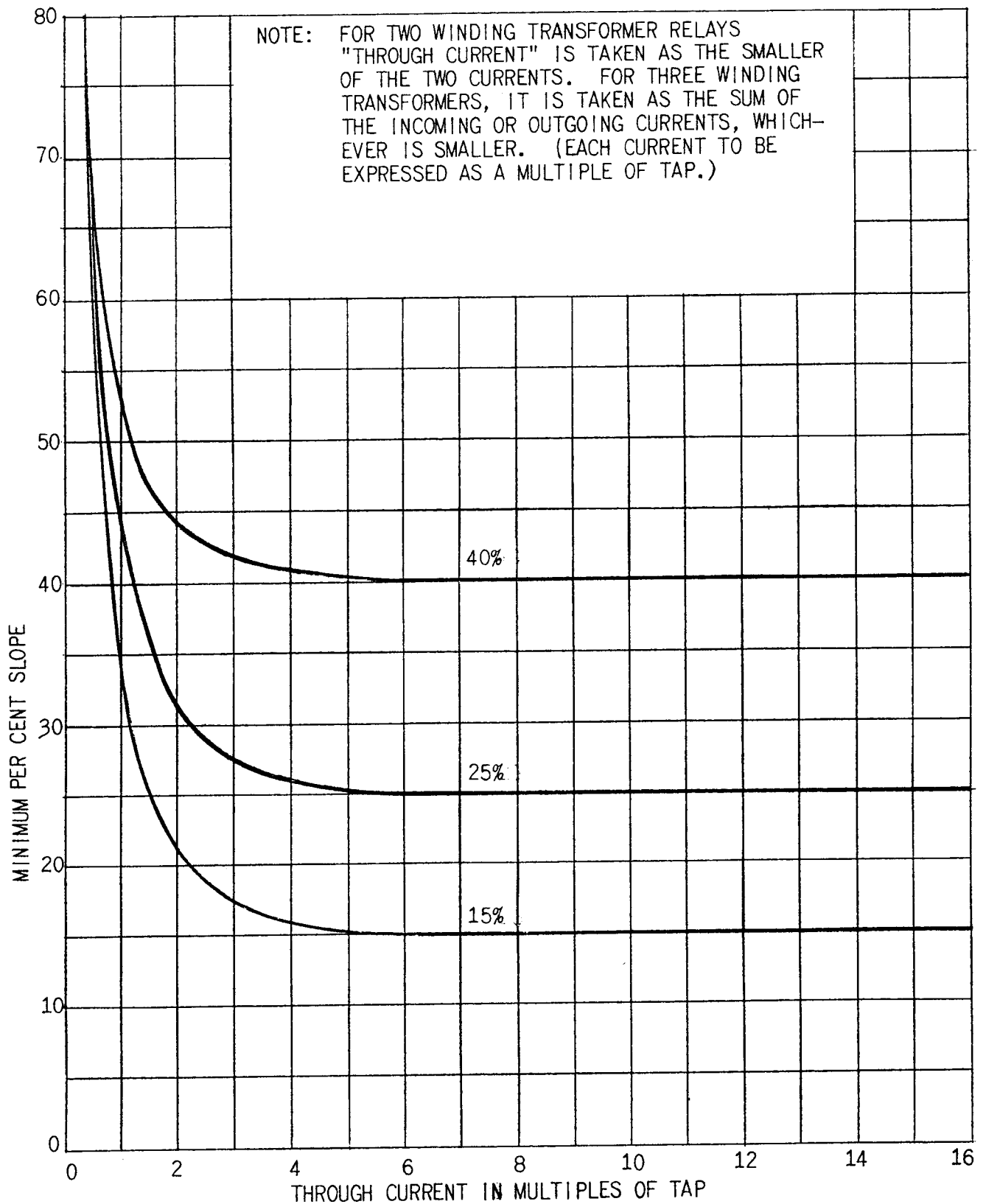


Figure 7A (0378A0588-3) Low-Current Slope Characteristics of the STD Relay

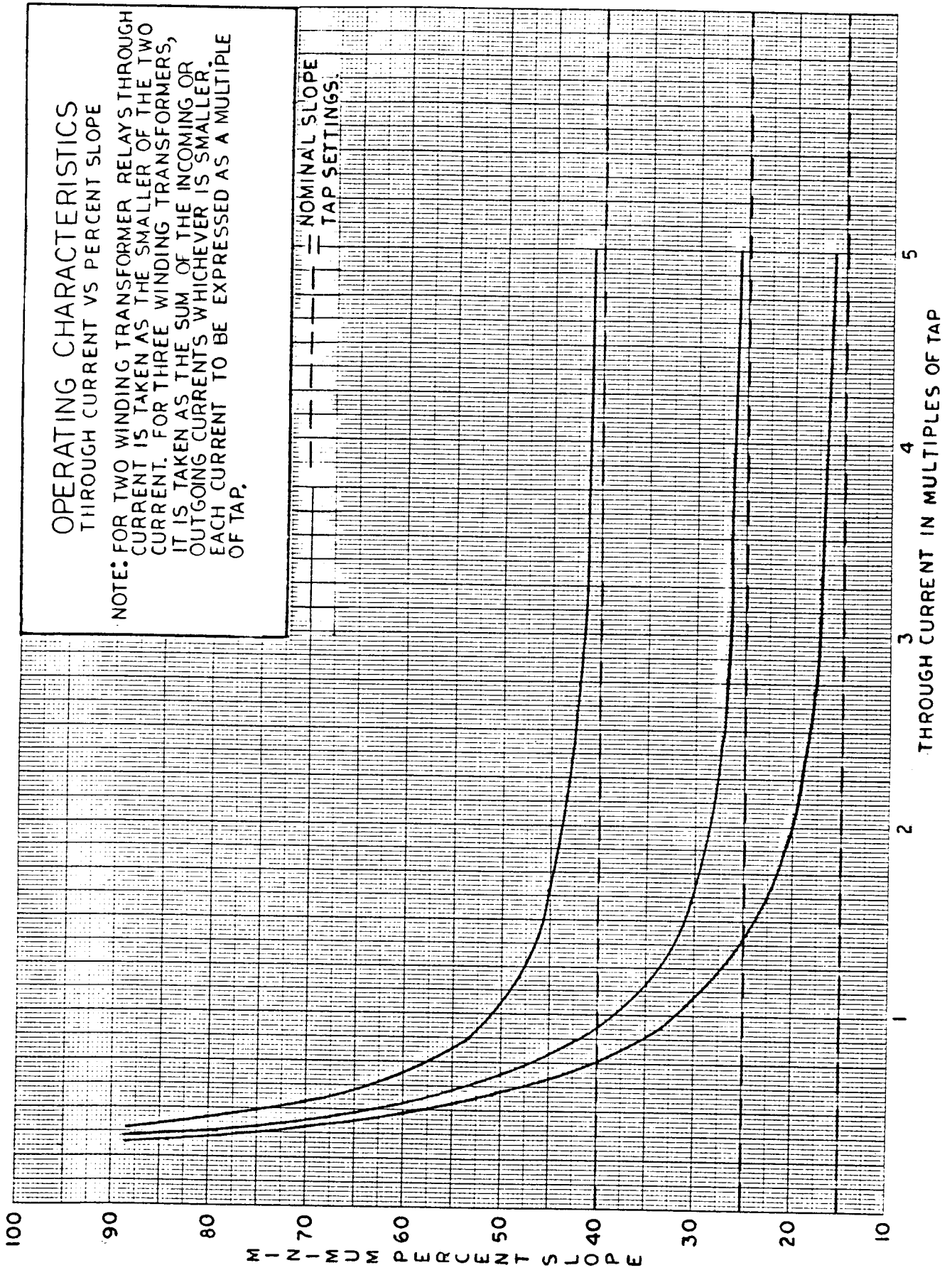
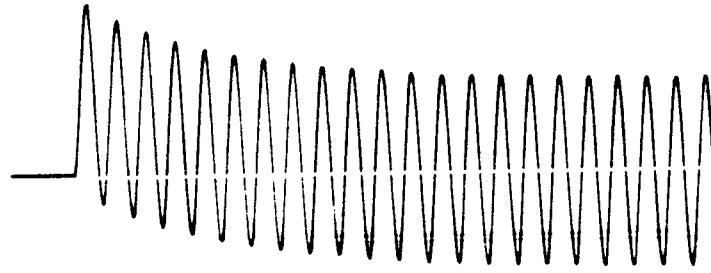
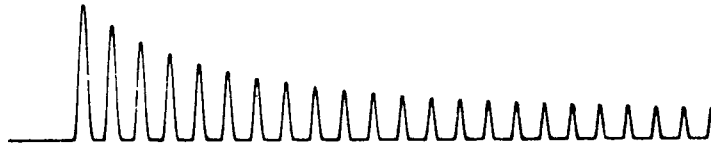


Figure 7B (0257A7985 [1]) Through-Current vs Percent Slope Characteristics of the STD Relay



TYPICAL OFFSET FAULT CURRENT WAVE



TYPICAL TRANSFORMER
MAGNETIZING INRUSH CURRENT WAVE

Figure 8 (K-6209195-0) Fault Current and Transformer Magnetizing Current Waves

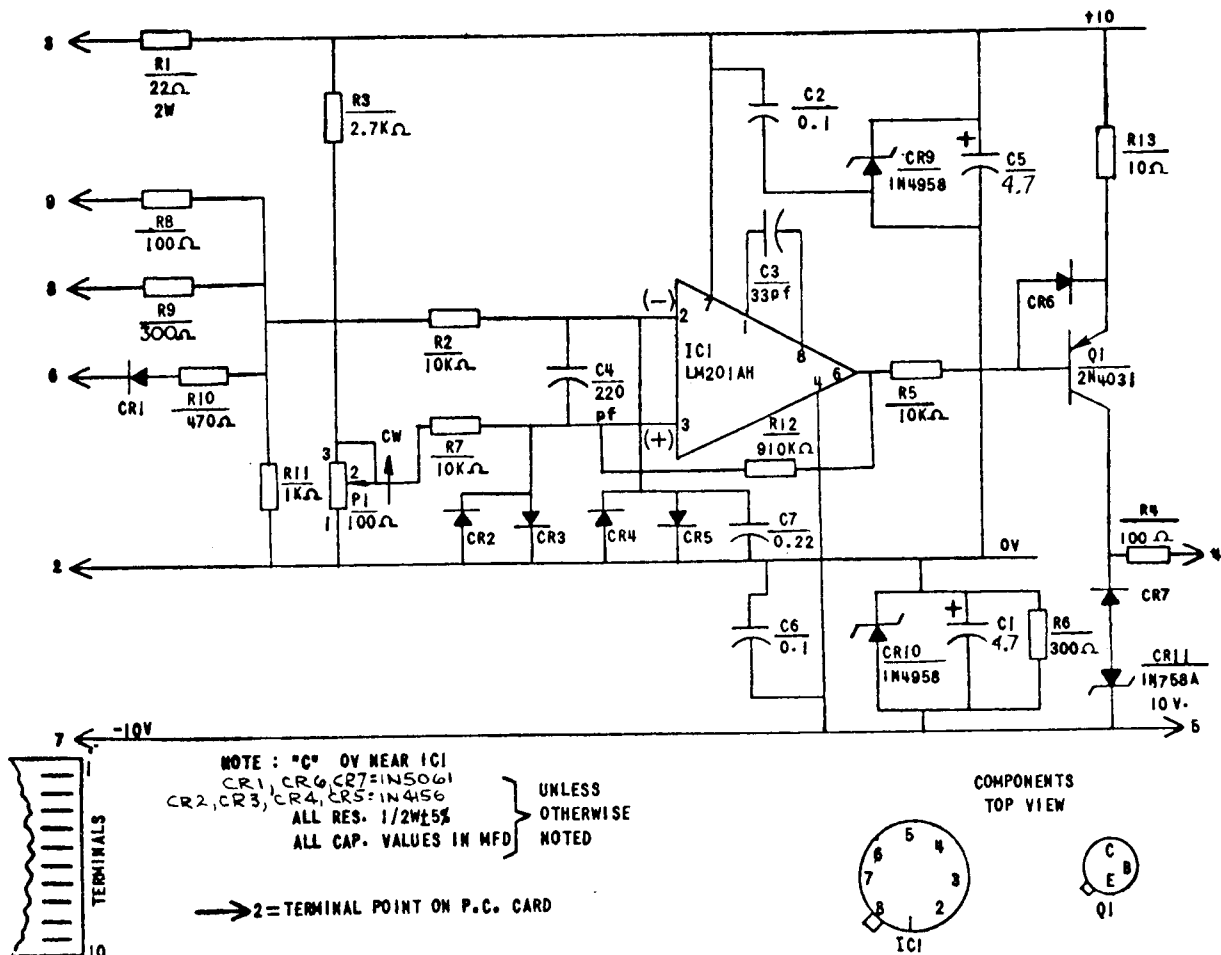


Figure 9 (0269A3039-3) Internal Connections Diagram
of Sense Amplifier Printed Circuit Board

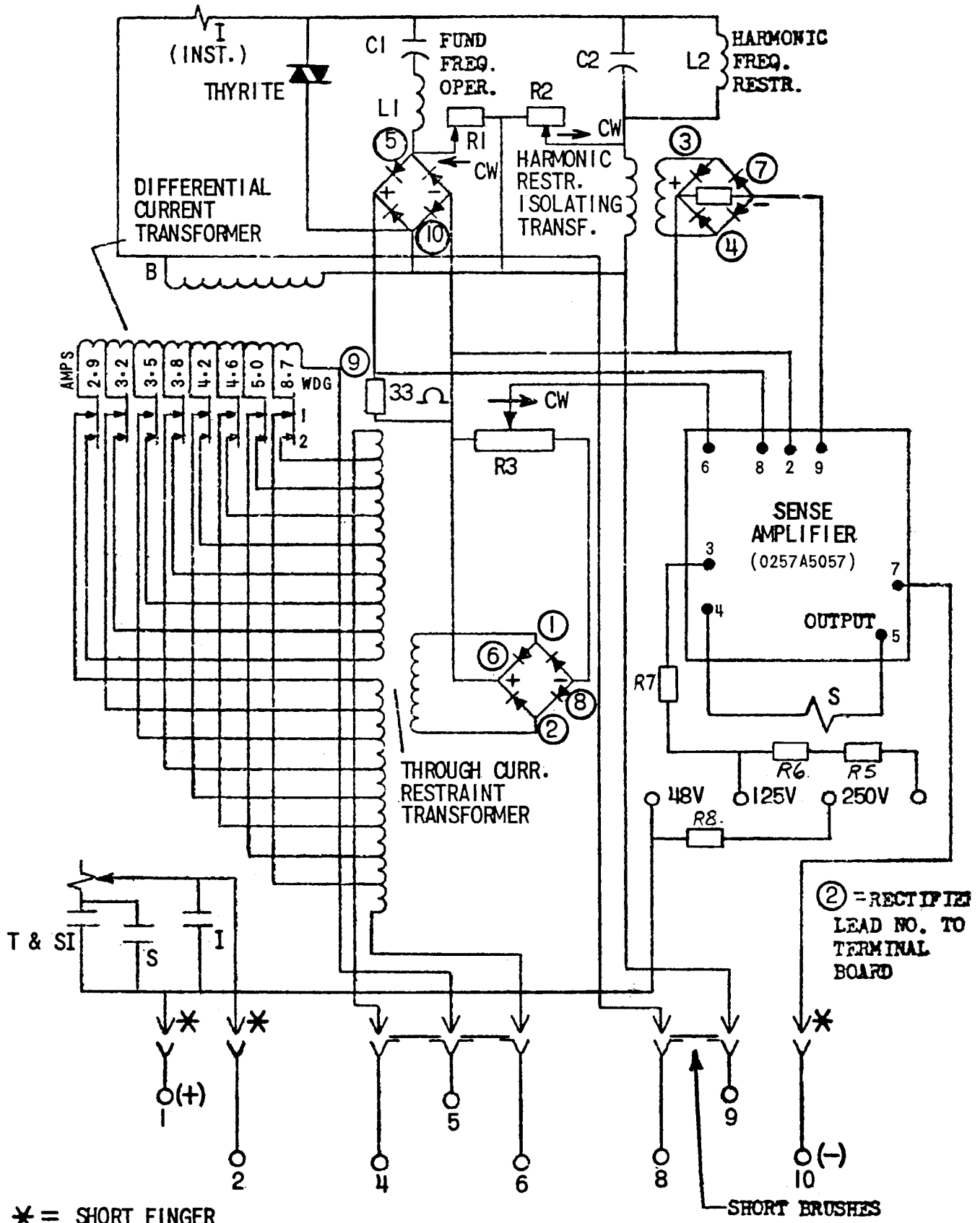


Figure 10 (0257A5026-2) Internal Connections Diagram for Relay Type STD15C

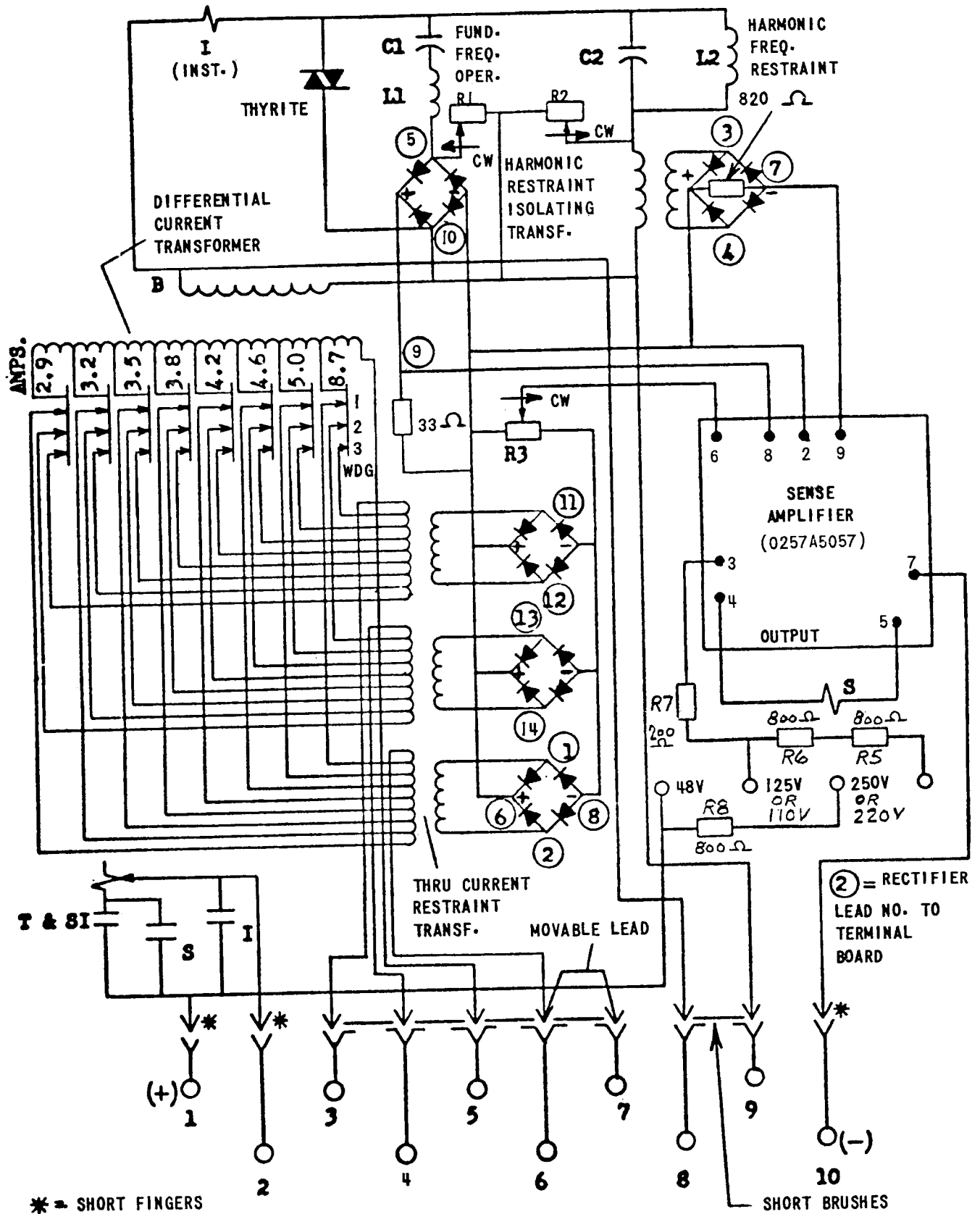
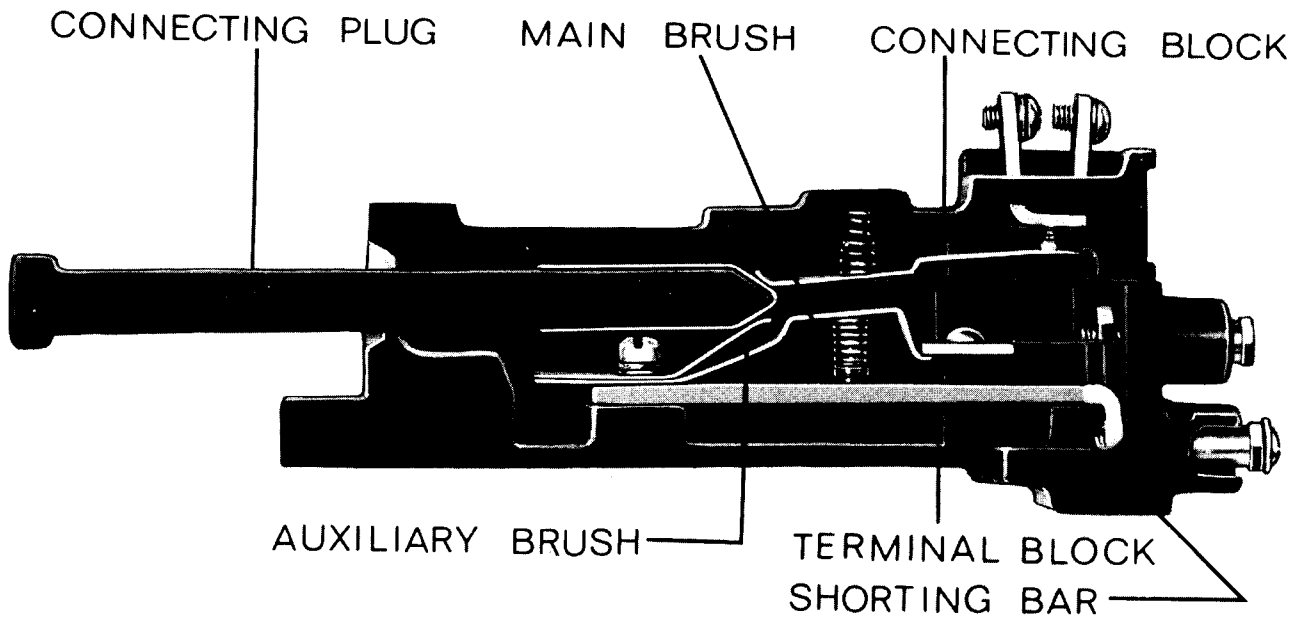


Figure 11 (0257A5027-1) Internal Connections Diagram for Relay Type STD16C



NOTE: AFTER ENGAGING AUXILIARY BRUSH CONNECTING PLUG TRAVELS $\frac{1}{4}$ INCH BEFORE ENGAGING THE MAIN BRUSH ON THE TERMINAL BLOCK

Figure 12 (8024039) Cross Section of Drawout Case Showing Position of Auxiliary Brush

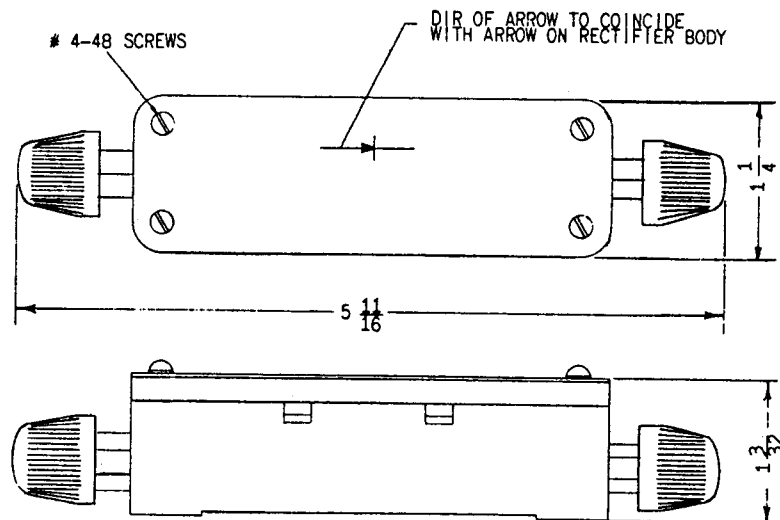
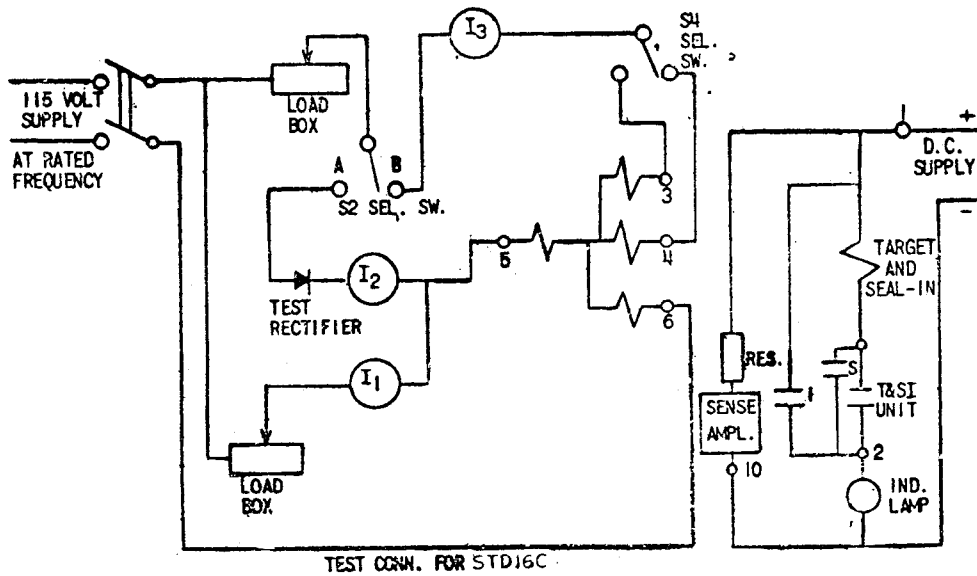
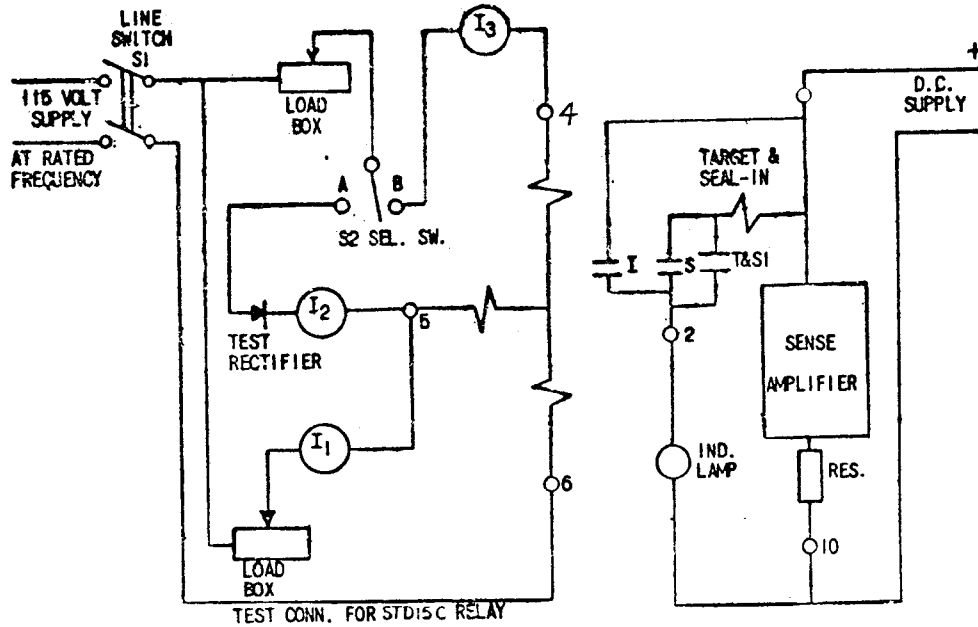


Figure 13 (0148A2994-1) Outline of Test Rectifier



LEGEND

- I = INSTANTANEOUS OVERCURRENT UNIT
- T&SI = TARGET AND SEAL-IN UNIT
- S = TELEPHONE RELAY

Figure 14 (0165B2697-1) Test Connections Diagram

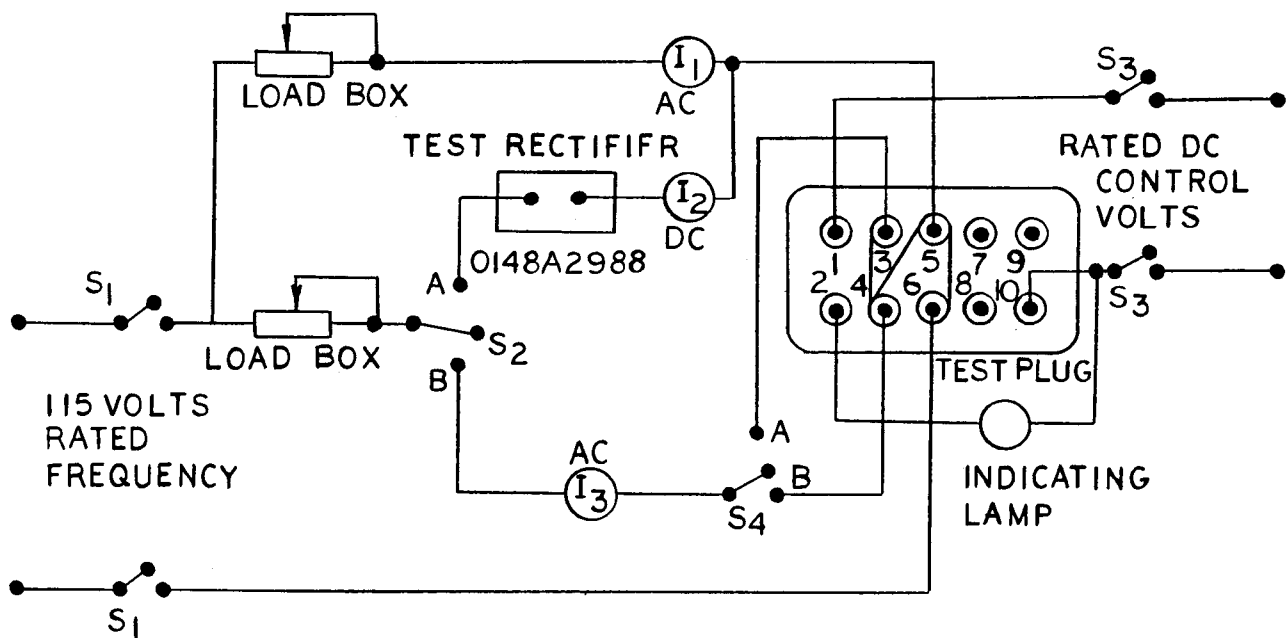
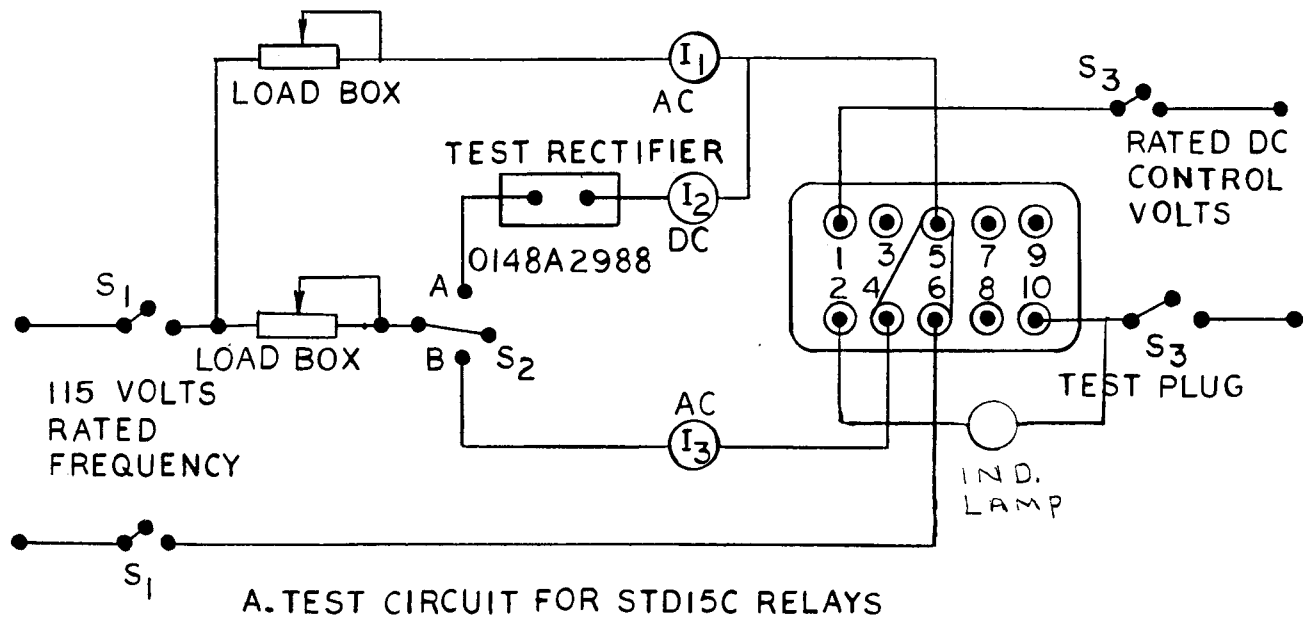


Figure 15 (0257A5054-0 Sh.1) Field Test Connections, in Case,
Using Type XLA Test Plug

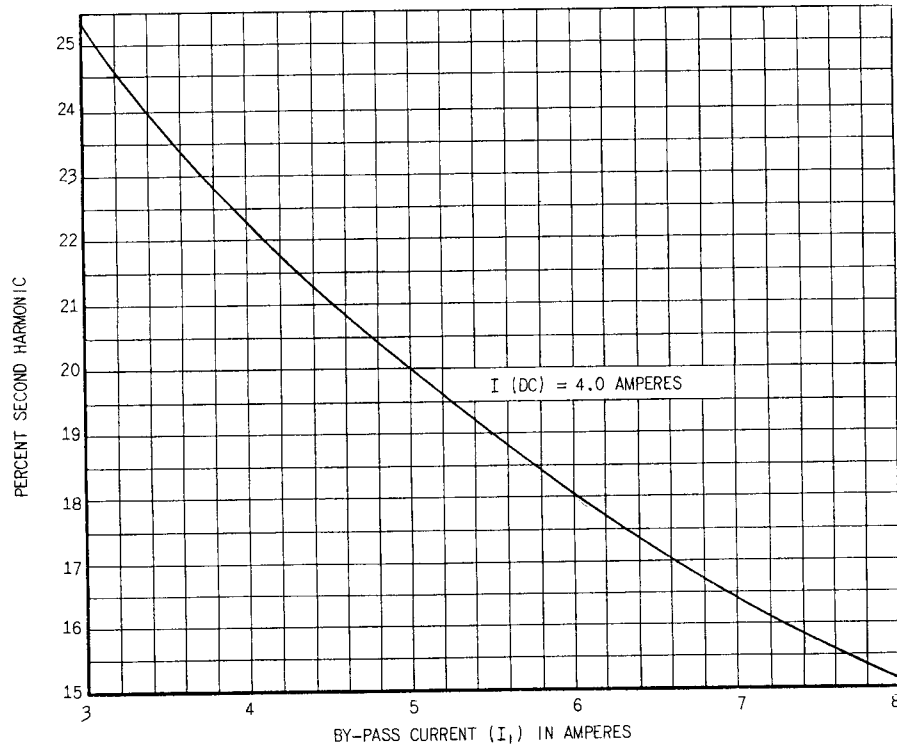


FIGURE 16 (418A 786-0) Relationship Between Second Harmonic and By-Pass Current with $I(DC)$ set at 4.0 Amperes

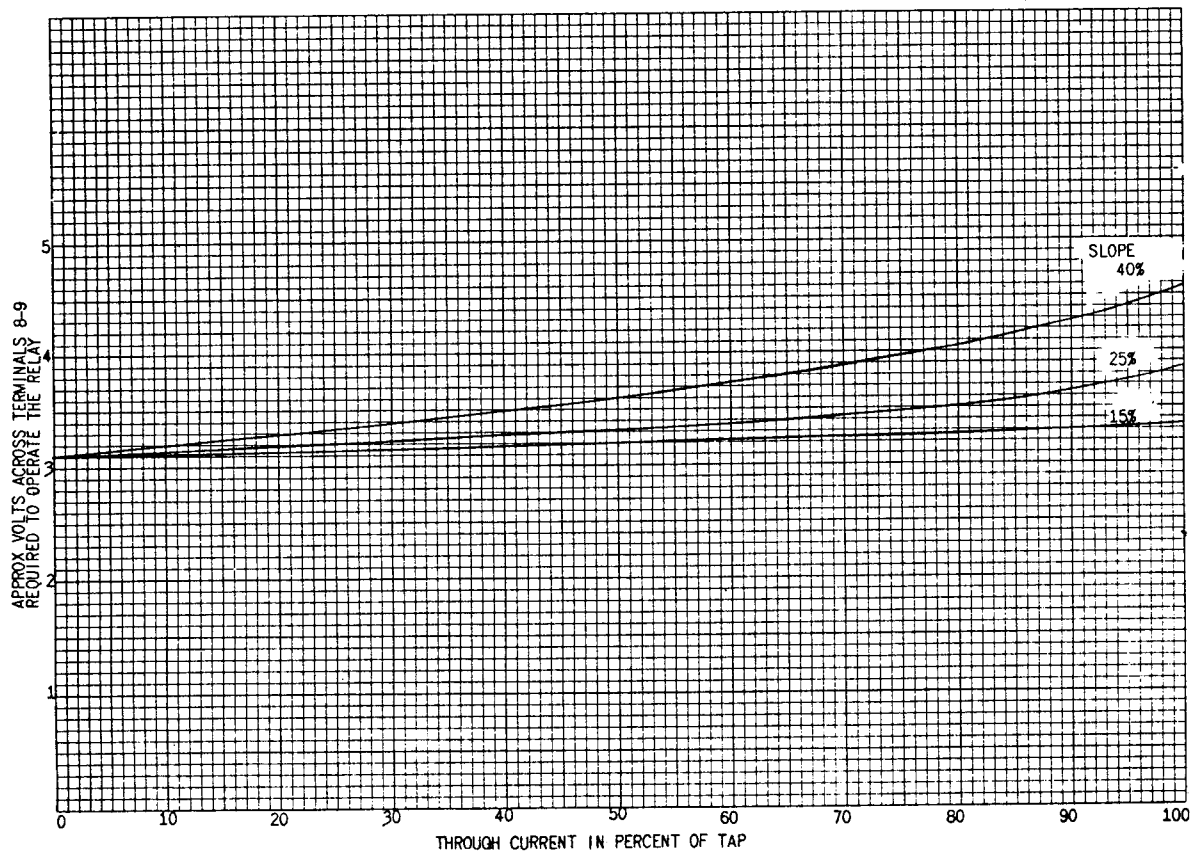


Figure 17 (0178A8111-0) Differential Voltage Operating Characteristics of Type STD Relay

GEK-45307

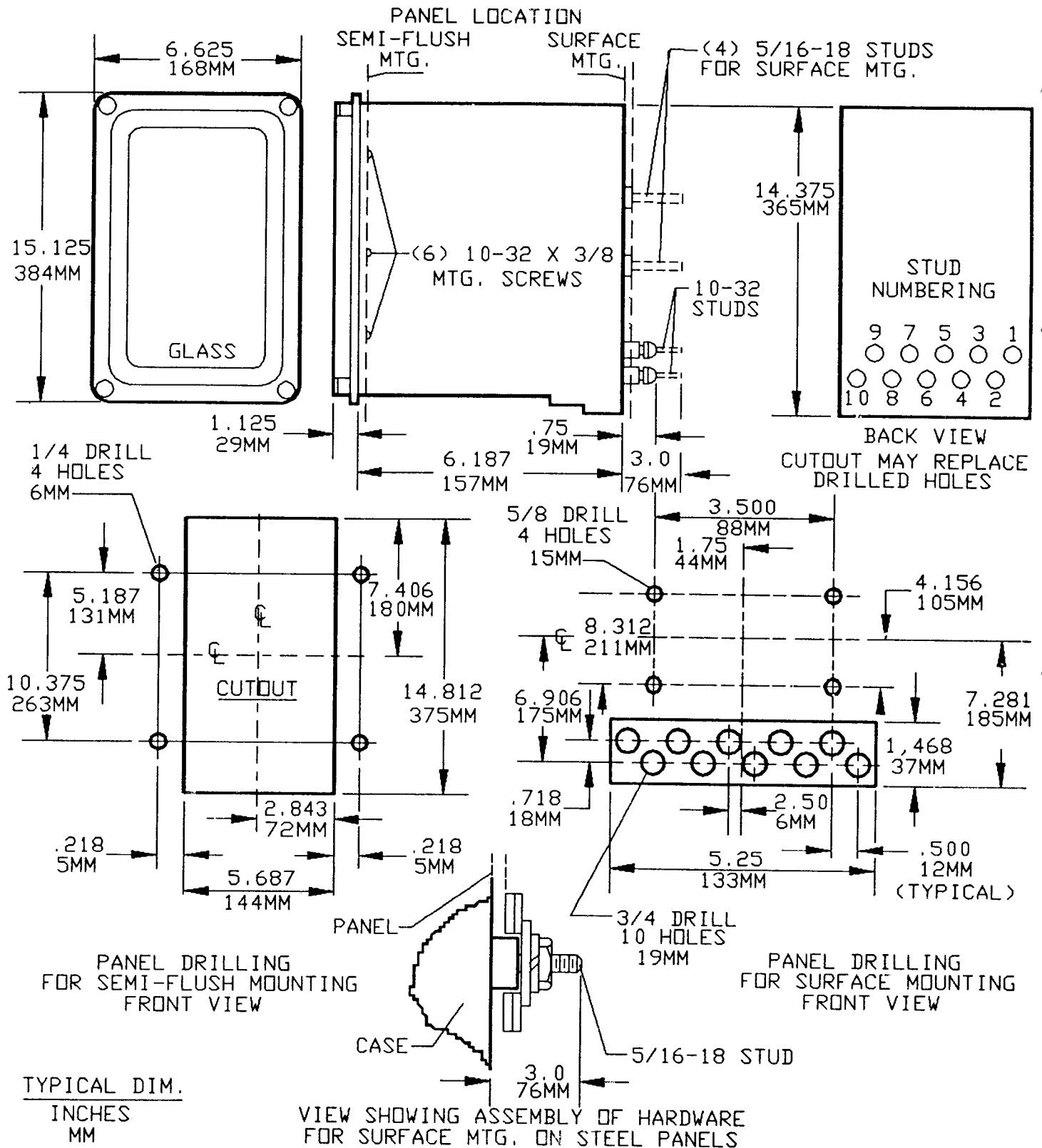


Figure 18 (K6209273-5) Outline and Panel Drilling Dimensions for Medium Single End (M1) Case of Relay Type STD

***Protection and Control
Business Department***

(6/93) (1500)

General Electric Company
205 Great Valley Parkway
Malvern, Pennsylvania 19355-1337



INSTRUCTIONS

TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

TYPES STD15C and STD16C



*GE Protection and Control
205 Great Valley Parkway
Malvern, PA 19355-1337*

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TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

STD15C and STD16C

INTRODUCTION

Relays of the STD type are transformer differential relays provided with the features of percentage and harmonic restraint. A static decision unit controls a small telephone-type relay that provides the contact output.

Percentage restraint permits accurate discrimination between internal and external faults at high current, while harmonic restraint enables the relay to distinguish, by the difference in waveform, between the differential current caused by an internal fault, and that of transformer magnetizing inrush.

DESCRIPTION

Each Type STD relay is a single-phase unit. The Type STD15C relay is designed to be used for the protection of two-winding power transformers and has two through-current restraint circuits and one differential-current circuit.

The Type STD16C relay is designed for use with three-winding power transformers and has three through-current restraint circuits and one differential-current circuit. It may also be used for four-circuit transformer protection (see Figure 1) when only three circuits require through-current restraint, while the fourth circuit, being the weakest, needs no through-current restraint.

APPLICATION

The current transformer ratios and relay taps should be selected to obtain the maximum sensitivity without risking thermal overload of the relay or current transformer (CT), or the possibility of misoperation. Therefore, current transformer ratios in the various windings of the power transformer should be selected with the following points in mind:

1. The lower the relay tap and the lower the CT ratio selected, the higher will be the sensitivity. However, the lowest CT ratio and the lowest relay tap may not be compatible with some of the following restrictions. Where a choice is available of increasing either the CT ratio or the relay tap, it is desirable to increase the CT ratio in preference to the relay tap.

Since the relay burden is likely to be small compared to the lead burden, increasing the CT ratio tends to improve the relative performance of the CTs, as a result of reducing the maximum secondary fault current and increasing the accuracy of the CTs.

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.

To the extent required the products described herein meet applicable ANSI, IEEE and NEMA standards, but no such assurance is given with respect to local codes and ordinances because they vary greatly.

2. The CT secondary current should not exceed the continuous thermal rating of the CT secondary winding.
3. The relay current corresponding to maximum kVA (on a forced-cooled basis) should not exceed twice tap value, which is the thermal rating of the relay.
4. The CT ratios should be high enough that the secondary currents will not damage the relay under maximum internal fault conditions (refer to **RATINGS**).
5. The relay current corresponding to rated kVA of the power transformer (on self-cooled basis) should not exceed the relay tap value selected (magnetizing inrush might operate the instantaneous overcurrent unit). If the transformer under consideration does not have a self-cooled rating, the transformer manufacturer should be consulted for the "equivalent self-cooled rating"; that is the rating of a self-cooled transformer that would have the same magnetizing inrush characteristics as the transformer being considered.
6. The current transformer tap chosen must be able to supply the relay with 8 times rated relay tap current, with an error of less than 20% of the total current. If the current transformers produce an error of greater than 20% at less than 8 times tap value, the harmonic content of the secondary current may be sufficient to cause false restraint on internal faults.
7. The CT ratios should be selected to provide balanced secondary current on external faults. Since it is rarely possible to match the secondary currents exactly by selection of current transformer ratios, ratio-matching taps are provided on the relay by means of which the currents may usually be matched within 5%. When the protected transformer is equipped with load-ratio control it is obvious that a close match cannot be obtained at all points of the ratio-changing range. In this case, the secondary currents are matched at the middle of the range and the percentage differential characteristic of the relay is relied upon to prevent relay operation on the unbalanced current which flows when the load-ratio control is at the ends of the range.
8. In some applications, the power transformer will be connected to the high voltage or low voltage system through four breakers (as shown in Figure 1) as for example in a ring-bus arrangement. In this case, the CT ratios must be selected so that the secondary windings will not be thermally overloaded on load current flowing around the ring in addition to the transformer load current. It is recommended that CTs on each of the two low voltage (or high voltage) breakers be connected to a separate restraining winding to assure restraint on heavy through-fault current flowing around the ring bus.

It is not desirable to protect two parallel transformer banks with one set of differential protection, since the sensitivity of the protection would be reduced. In addition, if the banks can be switched separately, there is a possibility of false operation on magnetizing inrush to one transformer bank, causing a "sympathetic inrush" into the bank already energized. In this case, the harmonics tend to flow between the banks, with the possibility that there will be insufficient harmonics in the relay current to restrain the relay.

Typical elementary diagrams for the STD15C and STD16C are illustrated in Figures 2 and 3.

CALCULATION OF SETTINGS

METHOD

The calculations required for determining the proper relay and CT taps are outlined below. A sample calculation, for the transformer shown in Figure 4, is then given.

CURRENT TRANSFORMER CONNECTIONS

Power Transformer Connections

Delta-Wye
Wye-Delta
Delta-Delta
Wye-Wye
Delta-Zigzag with 0° phase
shift between primary and
secondary

Current Transformer Connections

Wye-Delta
Delta-Wye
Wye-Wye
Delta-Delta
Delta-Delta

DETERMINATION OF CT TURNS AND TYPE STD RELAY TAP SETTING

1. Determine the maximum line currents (Max. I) on the basis that each power transformer winding may carry the maximum forced-cooled rated kVA of the transformer.

$$\text{Max. } I_p = \frac{\text{Maximum Transformer kVA}}{\sqrt{3} (\text{Line kV})}$$

2. Determine the full-load rated line currents (100% I_p) on the basis that each power transformer winding may carry the full self-cooled rated kVA of the transformer, or the "equivalent" self-cooled ratings.

$$100\% I_p = \frac{100\% \text{ Transformer kVA}}{\sqrt{3} (\text{Line kV})}$$

Actually, this calculation does not mean that all windings will necessarily carry these maximum load currents continuously. This is only a convenient way of calculating the currents in the other windings in proportion to their voltage ratings. This is the requirement for selecting the relay tap setting so that the relay will not operate for any external fault.

3. Select CT ratios so that the secondary current corresponding to maximum I_p does not exceed the CT secondary thermal rating (5 amperes). In the case where a transformer is connected to a ring bus, for example, the CT ratio should be selected so that the CT thermal rating will not be exceeded by the maximum load current in either breaker. Also, select CT ratios so that the relay currents can be properly matched by means of the relay taps. (Highest current not more than 3 times lowest current).

For Wye-connected CTs

$$\text{Tap Current} = \frac{100\% I_p}{N}$$

For Delta-connected CTs

$$\text{Tap Current} = \frac{100\% I_p \sqrt{3}}{N}$$

where N is the number of CT secondary turns.

4. Check the matching of relay currents to relay taps, to keep the mismatch error as low as possible.

Calculate the percentage of mismatch as follows: on two-winding transformers, determine the ratio of the two relay currents and the tap values selected. The differences between these ratios, divided by the smaller ratio, is the percent of mismatch. The mismatch normally should not exceed 5%.

For three-winding transformers, the percent of mismatch error should be checked for all combinations of currents or taps.

If taps cannot be selected to keep this percentage error within allowable limits, it will be necessary to choose a different CT ratio on one or more lines, to obtain a better match between relay currents and relay taps.

5. Check to see that the sum of the relay currents that will be applied to the relay for a fault at the terminals of the power transformer is less than 220 amperes RMS for 1 second. If the period during which a fault current flows in the relay can be definitely limited to a shorter time, a higher current can be accommodated in accordance with the relation:

$$(\text{Amperes})^2 \times \text{seconds} = 48,400$$

Also check that the sum of the multiples of tap current on an internal or external fault do not exceed 150.

CURRENT TRANSFORMER RATIO ERROR

The CT ratio error must be less than 20% at 8 times relay rated tap current. This is based on the instantaneous unit being set at its normal setting, which is 8 times tap rating. If the instantaneous unit pickup is raised above this value, the 20% figure must be reduced, as described in the **CHARACTERISTICS** section.

The calculations listed below are for the worst-fault condition, as far as CT performance is concerned, which is an internal ground fault between the CT and the transformer winding, with none of the fault current supplied through the neutral of the protected transformer.

1. Determine the burden on each CT, using the following expressions:

- a. For Wye-connected CTs

$$Z = B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 1})$$

- b. For Delta-connected CTs

$$Z = 2B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 2})$$

- where B = STD relay total burden (see Table I)
- N = number of turns in bushing CT
- e = bushing CT resistance per turn, milliohms (at maximum expected temperature)
- f = bushing CT resistance per lead, milliohms (at maximum expected temperature)
- R = one-way control cable lead resistance (at maximum expected temperature)

TABLE I

Total Burden for 60 Cycle Relays

STD TAPS AMPS	8 X TAP AMPS	BURDEN OHMS (B)	MIN P.U. AMPS
2.9	23.2	0.180	0.87
3.2	25.6	0.156	0.96
3.5	28.0	0.140	1.05
3.8	30.4	0.120	1.14
4.2	33.6	0.112	1.26
4.6	36.8	0.096	1.38
5.0	40.0	0.088	1.50
8.7	69.6	0.048	2.61

- Determine CT secondary current for 8 times tap setting.

$$I_S = 8 \times \text{STD relay tap rating}$$

(Note: For the location of fault assumed, all the fault current is supplied by one CT, so that CT current and relay current are the same, regardless of whether the CTs are connected in wye or delta.)

- Determine secondary CT voltage required at 8 times tap setting.

$$E_{\text{sec}} = I_S Z$$

- From excitation curve of particular tap of current transformer being used, determine excitation current I_E , corresponding to this secondary voltage, E_{sec} .

- Determine the percent error in each CT by the expression:

$$\% \text{ error} = \frac{I_E}{I_S} \times 100$$

This should not exceed 20% of any set of CTs. If it does, it will be necessary to choose a higher tap on that set of CTs, and repeat the calculations on selection of relay taps, mismatch error, and percent ratio error.

PERCENT SLOPE SETTING

The proper percent slope required is determined by the sum of:

- The maximum range of manual taps and the load-ratio-control, or automatic tap changing means, in percent.
- The maximum percent of mismatch of the relay taps.

Set the desired percent slope by means of R3 (See Figure 6A).

The percentage slope setting selected should be greater than the ratio of maximum total error current to the smaller of the through currents. In general, if the total error current does not exceed 20%, the 25% setting is used. If it exceeds 20%, but not 35%, the 40% setting is used.

If the movable lead is used (as in Figure 1, for example) the percent slope setting should be chosen about twice as high, since the movable lead provides no restraint.

EXAMPLE (REFER TO FIGURE 4)I. Determination of CT Turns and STD Relay Tap Settings

1. Transformer and Line	A	B	C
2. Maximum $I_p = 3750 / \sqrt{3}$ (Line kV)	19.7	49.5	157
3. 100% $I_p = 3000 / \sqrt{3}$ (Line kV)	15.7	39.6	125
4. Assume CT turns (N)	20	20	60
5. Maximum I secondary (less than 5a)	0.98	2.47	2.62
6. 100% I secondary	0.79	1.98	2.08
7. CT connections	Delta	Wye	Delta
8. Relay Current for 100% I Sec.	1.37	1.98	3.60

Select a relay tap for one of the line currents and calculate what the currents in other lines would be if they were increased in the same ratio. If any current is greater than $\sqrt{3}$ times any other, the 8.7 tap should be chosen for it, and new ideal relay taps calculated for the other lines.

9. Ideal Relay Taps (Set C = 8.7)	3.31	4.78	8.7
10. Try Relay Taps	3.2	4.6	8.7
11. Check Mismatch Error			

Ratio of Taps on Lines B-A $\frac{4.6}{3.2} = 1.43$ Ratio of Sec. Lines Currents

$$\frac{1.98}{1.37} = 1.44$$

$$\text{Mismatch } \frac{1.44 - 1.43}{1.43} = 0.7\%$$

Ratio of Taps on Lines C-B $\frac{8.7}{4.6} = 1.89$ Ratio of Sec. Line Currents $\frac{3.60}{1.98} = 1.82$

$$\text{Mismatch } \frac{1.89 - 1.82}{1.82} = 3.8\%$$

$$\text{Ratio of Taps on Lines C-A } \frac{8.7}{3.2} = 2.72 \quad \text{Ratio of Sec. Line Currents } \frac{3.60}{1.37} = 2.63$$

$$\text{Mismatch } \frac{2.72 - 2.63}{2.63} = 3.4\%$$

(All are less than 5%; therefore, mismatch error is not excessive)

12. Check that the sum of the maximum relay currents is less than 220 amps for 1 second, and therefore, short-time rating of relay is not exceeded.

II. Percent Ratio Error

ASSUME (all measured at their maximum expected temperatures)

One-way	CONTROL	CABLE	RESISTANCE	(R)	=	0.284	ohms
Bushing	A	CT	resistance	per turn	(e)	=	4 milliohms
"	B	"	"	"	(e)	=	2.5 "
"	C	"	"	"	(e)	=	2.3 "
Bushing	A	CT	resistance	per lead	(f)	=	75 milliohms
"	B	"	"	"	(f)	=	52.5 "
"	C	"	"	"	(f)	=	18.6 "

1. Burdens on CTs, using Equation 1 or Equation 2 from page 6.

$$\text{a. Line A, } Z = 2 (0.156) + \frac{(20 \times 4) + (2.0 \times 75)}{1000} + 2 (.284)$$

$$= 0.312 + 0.205 + 0.568 = 1.085$$

$$\text{b. Line B, } Z = 0.096 + \frac{(20 \times 2.5) + (2.0 \times 52.5)}{1000} + 0.568$$

$$= 0.096 + 0.138 + 0.568 = 0.80$$

$$\text{c. Line C, } Z = 2 (0.048) + \frac{(60 \times 2.3) + (2 \times 18.6)}{1000} + 0.568$$

$$= 0.096 + 0.180 + 0.568 = 0.833$$

	A	B	C
2. Impedance, ohms	1.085	0.8	0.833
3. 8 times tap, amperes	25.6	36.8	69.6
4. ES CT voltage require (IZ)	27.8	29.4	58.0
5. IE required, from excitation curve	1.00	50	0.5
6. % Ratio Error	3.4%	136%	0.8%

Exciting current on line B is too high; should try higher tap on CT to improve CT performance.

IA - Repeat - CT Turns and Relay Tap Setting

1. 100% Ip	15.7	39.6	125
2. Try CT turns (necessary to change C also for proper matching)	20	40	80
3. 100% I secondary	0.79	0.99	1.56
4. Relay Current	1.37	0.99	2.70
5. Ideal Relay Taps (Set C = 8.7)	4.40	3.19	8.7
6. Use Relay Taps	4.6	3.2	8.7
7. Mismatch Error is less than 5%			

IIA Repeat - Percent Ratio Error

1. Burden on CTs

Line A, $Z = 0.192 + 0.205 + 0.568 = 0.965$ Line B, $Z = 0.156 + 0.188 + 0.568 = 0.912$ Line C, $Z = 0.096 + 0.226 + 0.568 = 0.890$

2. Impedance Ohms	0.965	0.912	0.890
3. 8 times Tap, Amperes	36.8	25.6	69.6
4. E_{sec} , CT voltage required (IZ)	35.6	23.4	61.9
5. I_E required, from excitation curve	1.1	0.25	0.17
6. % of Ratio Error	3.1%	1.0%	0.3%

Percent error is less than 20%, so CT taps and relay taps are satisfactory.

III Percent Slope Setting

1. Assume load ratio control maximum range	10.0%
2. Relay tap mismatch, from IA above (Lines A-B)	4.6%
Use 25% setting	14.6%

RATINGS

MODELS 12STD15C AND 12STD16C

Continuous Rating

The through-current transformer and differential-current transformer will stand twice tap value for any combination of taps, or they will stand twice tap value if all but one of the restraint windings carry 0 current, and the full restraint current (equal to twice tap value) flows through the differential-current transformer.

Short Time Rating (Thermal)

220 amperes for 1 second, measured in the primary of any transformer of the type STD relay. Higher currents may be applied for shorter lengths of time in accordance with the following equation:

$$I^2t = 48,400$$

where I = current amperes
 t = time in seconds.

Short Time (Electrical)

For both the STD15C and STD16C the sum of the multiples of tap current fed to the relay from the several sets of current transformers should not exceed 150. These multiples should be calculated on the basis of RMS symmetrical fault current. This limitation is a result of the voltage rating of the rectifiers in the through-current restraint circuit. Note that in Figure 1 external fault current can flow through circuit breakers 52-1 and 52-2 without being limited by the transformer impedance.

TABLE II

	TARGET AND SEAL-IN UNIT		
	2.0 Amp Tap	0.6 Amp Tap	0.2 Amp Tap
DC Resistance	0.13 Ohms	0.6 Ohms	7 ohms
Carry Continuously	0.5 Amps	1.5 Amps	0.25 Amps
Carry 30 Amps for	4 Secs.	0.5 Secs.	----
Carry 10 Amps for	30 Secs	4 Secs.	0.2 Secs.

AUXILIARY RELAY CONTROL CIRCUIT

The STD15C and STD16C relays are available for use with 48, 125, and 250 DC or 48, 110 and 220 DC control voltage, depending upon the relay model. A plate with small links located on the front of the relay enables the selection of one of these voltages.

The STD relay is provided with two open contacts connected to a common output circuit. The current-closing rating of the contact is 30 amps for voltages not exceeding 250 volts. If more than one circuit breaker is to be tripped, or if the tripping current exceeds 30 amperes, an auxiliary relay must be used with the STD relay. After the breaker trips, it is necessary that the tripping circuit of these relays (STD and auxiliary) be de-energized by an auxiliary switch on the circuit breaker or by other automatic provisions. A manual reset relay is recommended and normally used.

CHARACTERISTICSPICKUP AND OPERATING TIME

The operating characteristic is shown in Figure 7. The curve for various percentage slopes shows the percent slope versus the throughcurrent flowing in the transformer. The percentage slope is a figure given to a particular slope tap setting, and indicates an approximate slope characteristic. Pickup at zero restraint is approximately 30% of tap value (see Table III). The dropout time, when the operating current is reduced to zero from any value above pickup, is less than 25 milliseconds.

Curves of the operating time of the main unit and of the instantaneous unit are shown in Figure 5, plotted against differential current. The main unit operating time includes auxiliary unit operating time.

OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are 8 times the ampere turns produced by rated tap current flowing in that tap. For example:

When only one CT supplies current, and the tap plug for the CT is in the 5 ampere tap, 40 amperes are required for pickup. This pickup value is based on the AC component of current transformer output only, since the differential-current transformer in the relay produces only a half cycle of any DC (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating on a self-cooled basis, the overcurrent unit will not pick up on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pick up, especially on small transformer banks. If this happens, it is recommended that the CT ratio or relay tap setting be increased, rather than increasing the pickup of the overcurrent unit. If the overcurrent setting must be raised, the requirements on CT error will be more stringent, in accordance with the following equation:

$$E = 20 - (2.5) (P-8)$$

where E = CT error current in percent, at pickup of the overcurrent unit
P = Pickup of overcurrent in multiples of tap setting.

PERCENTAGE DIFFERENTIAL CHARACTERISTICS

The percentage differential characteristics are provided by through-current restraint circuits. In addition to the operating circuit, which is energized by the differential current of the line current transformers, the relay is equipped with a restraining circuit that is indirectly energized by the transformer secondary currents. For the relay to operate, the current transformer secondary currents must be unbalanced by a certain minimum percentage, determined by the relay slope setting (as shown in Figure 7). This characteristic is necessary to prevent false operation on through-fault currents. High currents saturate the cores of the current transformers and cause their ratios to change, with the result that the secondary currents become unbalanced. Percentage restraint is also required to prevent operation by the unbalanced currents caused by imperfect matching of the secondary currents, as previously described under Determination of CT Turns and STD Relay Tap Settings.

HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary that establishes the required flux in the core. This current is called magnetizing inrush, and in the primary winding flows only through the current transformers. This causes an unbalance current to flow in the differential relay, which would cause false operation if means were not provided to prevent it.

Power system fault currents are of a nearly pure sine waveform, plus a DC transient component. The sine waveform results from sinusoidal voltage generation and nearly constant circuit impedance. The DC component depends on the time in the voltage cycle at which fault occurs, and upon circuit impedance magnitude and angle.

Transformer magnetizing-inrush currents vary according to the extremely variable exciting impedance resulting from core saturation. They are often of high magnitude, occasionally having an RMS value with 100% offset, approaching 16 times full-load current for worst conditions of power transformer residual flux and point-of-circuit closure on the voltage wave. They have a very distorted waveform made up of sharply peaked half-cycle loops of current on one side of the zero axis, and practically no current during the opposite half cycles. The two current waves are illustrated in Figure 8.

Any current of distorted, nonsinusoidal waveform may be considered as being composed of a DC component plus a number of sine-wave components of different frequencies; one of the fundamental system frequency, and the others, called "harmonics," having frequencies which are 2, 3, 4, 5, etc., times the fundamental frequency. The relative magnitudes and phase positions of the harmonics with reference to the fundamental determine the waveform. When analyzed in this manner, the typical fault-current wave is found to contain only a very small percentage of harmonics, while the typical magnetizing-inrush-current wave contains a considerable amount.

The high percentage of harmonic currents in the magnetizing-inrush-current wave afford an excellent means of distinguishing it electrically from the fault-current wave. In the Type STD relays, the harmonic components are separated from the fundamental component by suitable electric filters. The harmonic current components are passed through the restraining circuit of the relay, while the fundamental component is passed through the operating circuit. The DC component present in both the magnetizing-inrush- and offset-fault-current waves is largely blocked by the auxiliary differential-current transformer inside the relay, and produces only a slight momentary restraining effect. Relay operation occurs on differential-current waves in which the ratio of harmonics to fundamental is lower than a given predetermined value, for which the relay is set (e.g. an internal fault-current wave), and is restrained on differential-current waves in which the ratio exceeds this value (e.g. magnetizing-inrush-current wave).

BURDENS

Burdens are shown in Table III and IV. Burdens and minimum pickup values are substantially independent of the percent slope settings, and are all approximately 100% power factor. Figures given are burdens imposed on each current transformer at 5.0 amperes.

TABLE III

TAP SETTING AMPS	ZERO RESTRAINT PICKUP AMPS	OPERATING CIRCUIT *		RESTRAINT CIRCUIT	
		60 CYCLE RELAYS		60 CYCLE RELAYS	
		BURDEN	IMPEDANCE	BURDEN	IMPEDANCE
		VA	OHMS	VA	OHMS
2.9	0.87	3.2	0.128	1.3	0.052
3.2	0.96	2.7	0.108	1.2	0.048
3.5	1.05	2.4	0.096	1.1	0.044
3.8	1.14	2.0	0.080	1.0	0.040
4.2	1.26	1.9	0.076	0.9	0.036
4.6	1.38	1.6	0.064	0.8	0.032
5.0	1.50	1.5	0.060	0.7	0.028
8.7	2.61	0.7	0.028	0.5	0.020

* Burden of operating coil is 0 under normal conditions.
Burden of 50-cycle relay is the same or slightly lower.

TABLE IV

DC CONTROL CIRCUIT BURDEN						
RATED VOLTS	48	125	250	48	110	220
MILLIAMPS	140	105	88	140	96	80

CONSTRUCTION

Figure 6 shows the internal arrangement of the components of the STD15C relay. Refer also to the internal connection diagrams, Figures 10 and 11, which will identify the parts more completely.

CURRENT TRANSFORMERS

In the Type STD15C relay, the through-current transformer has two primary windings, one for each line-current-transformer circuit. Winding No. 1 terminates at stud 6 and winding No. 2 terminates at stud 4.

In the Type STD16C relay, there are three separate through-current transformers, each with only one primary winding, and each terminating at a separate stud, windings No. 1, No. 2 and No. 3 corresponding to studs 6, 4 and 3 in that order.

In both relays there is a differential-current transformer with one primary lead brought out to stud 5.

The primary circuit of each of these transformers is completed through a special tap block arrangement. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type STD15C or STD16C), one row for each through-current transformer winding. A tap on the differential-current transformer is connected to a corresponding tap of the through-current restraint windings by inserting tap plugs in the tap blocks.

When the STD16C relay is used on four-circuit applications, as shown in Figure 1, the fourth circuit CT is connected to stud 7, and the jumper normally connected between terminals 6 and 7 at the rear of the relay cradle should be disconnected at the terminal 6 end and reconnected to the upper row in the tap block (above the row marked winding 1), which connects it directly to the differential-current transformer in the STD relay. The terminal on the movable lead should be placed under the tap screw that gives the best current match for the current in the movable lead.

The taps permit matching of unequal line-current transformer secondary currents. The tap connections are so arranged that in matching the secondary currents, when a tap plug is moved from one position to another in a horizontal row, corresponding taps on both the differential-current transformer winding and one of the through-current transformer windings are simultaneously selected so that the percent through-current restraint remains constant.

It should be recognized that pickup current flows not only through differential-current transformer but also through one of the primary windings of the through-current transformer, producing some restraint. However, compared to the operating energy, this quantity of restraint is so small that it may be assumed to be zero.

THROUGH-CURRENT RESTRAINT CIRCUIT

A full wave bridge rectifier receives the output of the secondary of each through-current restraint transformer. In the STD16C relay, the DC outputs of all three units are connected in parallel. The total output is directed to the percent slope

rheostat (R3) located on the front of the relay. By means of adjusting the rheostat, the percent slope may be varied from 15% to 40%. The output is put through an isolating transformer, rectified, and directed to the sensitive solid state amplifier that controls the telephone-type relay.

DIFFERENTIAL-CURRENT CIRCUIT

The differential-current transformer secondary supplies 1) the instantaneous unit directly; 2) the operating (tripping) signal to the solid-state amplifier through a series-tuned circuit; and 3) the harmonic restraint isolating transformer through a parallel resonant filter. The operating and restraint currents are each rectified by a full-wave bridge prior to being supplied to the sensitive sense amplifier.

The series resonant circuit is made up of a 5 microfarad capacitor (C1) and a reactor (L1) that are tuned to pass currents of the fundamental system frequency and to offer high impedance to currents of other frequencies. Resistor R1 is connected in parallel on the AC side of the operate rectifier, and can be adjusted to give the desired amount of operate current. The output of the rectifier is applied to the operating circuit of the sense amplifier.

The parallel resonant trap is made of a 15 microfarad capacitor (C2) and a reactor (L2) that are tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. Resistor R2 is connected in parallel on the AC side of the harmonic restraint rectifier, and can be adjusted to give the desired amount of harmonic restraint. The output of the rectifier is paralleled with the through-current restraint currents and applied to the restraint circuit of the sense amplifier.

It will be evident that if the differential current applied to the relay is sinusoidal and of system frequency, it will flow mostly in the operating circuit and hence cause the relay to yield an output. If, however, the differential circuit contains more than a certain percentage of harmonics, the relay will be restrained from operating by the harmonic currents flowing in the restraint circuit.

A Thyrite^R resistor connected across the secondary of the differential-current transformer limits any momentary high-voltage peaks which may occur, thus protecting the rectifiers and capacitors from damage, without materially affecting the characteristics of the relay.

OVERCURRENT UNIT

The instantaneous unit is a hinged-armature relay with a self-contained target indicator. On extremely heavy internal fault currents, this unit will pick up and complete the trip circuit. The instantaneous unit target will be exposed, to indicate that tripping was through the instantaneous unit.

Because of saturation of the CTs and relay transformers at high fault currents, it is possible that less operating currents will be provided from the differential-current transformer than the percentage slope tap would imply, and more harmonic restraint will be provided than the actual harmonic content of the fault current would supply. As a result, under conditions of a high internal fault current, the main unit may be falsely restrained. Tripping is assured, however, by the

overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Figure 5 shows the relative levels of pickup and speed of operation of the main unit and the overcurrent unit.

MAIN OPERATING UNIT

The primary functioning unit of the STD relay is a solid-state amplifier, whose output controls a simple telephone relay. The sense amplifier is shown in Figures 10 and 11 as a large rectangle. The amplifier consists of many electronic components mounted on a printed circuit card in the top half of the relay. This printed circuit card is installed in a ten-prong printed card design socket. A schematic of this card is shown in Figure 9. This component is adjusted prior to leaving the factory, and should require no further attention.

The telephone-type relay is mounted vertically in the mid-section of the relay. It, too, has been carefully adjusted at the factory, and should require no further attention. If this small relay has been disturbed, refer to the section under **ADJUSTMENTS**.

TARGET AND SEAL-IN UNIT

There is a target and seal-in unit mounted on the top left of the relay. This unit has its coil in series and its contacts in parallel with the main contacts of the telephone-type relay. When the telephone-type relay contacts close, the seal-in unit operates, raising its target into view and sealing around the telephone-type contacts. The target of this unit will remain exposed until released by pushing a button beneath the lower left corner of the cover of the relay case.

CASE

The case is suitable for surface or semi-flush panel mounting, and an assortment of hardware is provided for either method. The cover attaches to the case, and carries the target reset mechanism for the trip indicator and instantaneous unit. Each cover screw has provision for a sealing wire.

The case has studs or screw connections at the bottom for the external connections. The electrical connections between the relay unit and the case studs are made through spring-backed contact fingers mounted in stationary molded inner and outer blocks, between which rests a removable connecting plug that completes the circuit. The outer block, attached to the case, holds the studs for the external connections, and the inner block has terminals for the internal connections.

The relay mechanism is mounted in a steel framework called the cradle, and is a complete unit, with all leads terminating at the inner block. This cradle is held firmly in the case by a latch at the top and bottom and a guide pin at the back of the case. The case and cradle are so constructed that the relay cannot be inserted in the case upside down. The connecting plug, besides making the electrical connection between the blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plug in place.

To draw out the relay unit, the cover is removed and the plug is drawn out. Shorting bars are provided in the case to short the current-transformer circuits

(see Figure 12). The latches are then released and the relay unit can be easily drawn out.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its own source of current, or from other sources. Or, the relay unit can be drawn out and replaced by another which has been tested in the laboratory.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel, will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

Reasonable care should be exercised in unpacking the relay, in order that none of the parts may be injured or the adjustments disturbed.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed, and cause trouble in the operation of the relay.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to make sure that the relay has not been damaged in shipment and that the relay calibrations are unchanged.

VISUAL INSPECTION

Check the nameplate stamping to make sure that the model number, rating and calibration range of the relay received agree with the requisition.

Remove the relay from its case and check by visual inspection that there are no broken or cracked molded parts, or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

Check the operation of the telephone-type relay and instantaneous overcurrent unit manually, to see that they operate smoothly, without noticeable friction or binds. Check the contact gap and wipe of these units, which should agree with values given in the section on **SERVICING**.

ELECTRICAL TESTS

It is recommended that the following electrical tests be made immediately upon receipt of the relay.

1. Minimum pickup of main operating unit.
2. Minimum pickup of the instantaneous overcurrent unit.
3. A single check point on the harmonic restraint characteristic.
4. A single check point on the slope characteristic curve, for the approximate slope expected to be used.

Test Equipment

In order to facilitate tests, the following test equipment is recommended:

1. Two load boxes for regulating the test currents
2. Three ammeters (two AC and one DC) for measuring the test currents
3. A test rectifier for checking the relay's response to the second harmonic. (See Figure 13.)
4. One indicating lamp
5. Two single-pole double-throw switch selectors
6. A double-pole single-throw line switch.

Check the pickup of the main unit, using the connections shown in Figure 14. During this test, the selector switches (S2 and S4) are open, and current passes through one restraint winding and the operate winding only. For example, with a relay set with a 25% slope and at the 2.9 ampere ratio-matching taps, the main unit should pick up at 30% of tap rating, $\pm 10\%$, or the pickup should be between 0.78 and 0.96 amperes. A source of DC power at rated voltage should be connected as shown in Figure 14; the indicating lamp will provide a signal, showing that the main unit has operated.

For an additional pickup test, the pickup should be 1.5 amperes, with current flowing in terminals 5 and 6 and the tap plugs in the 5 ampere tap and the 25% slope tap position. If the pickup is between 1.35 and 1.65 amperes, no adjustment should be made. The pickup of the relay has wider permissible variations than most protective relays, but due to the relay design and application, the relay accuracy is entirely adequate under all conditions, even during transformer magnetizing inrush or severe fault conditions.

With the selector switch, ST, in the A position, check the harmonic current restraint, as described in the section on **INSTALLATION PROCEDURE**.

The instantaneous overcurrent unit should be checked by passing a high current through the 5-6 terminals. The pickup should be about eight times tap rating.

Check through-current restraint, as described in the section on **INSTALLATION PROCEDURE**.

INSTALLATION PROCEDURE

TESTS

Before placing the relays in service, check the relay calibration to be used in its final location, to ensure that it is correct. The following test procedure is outlined for this purpose.

CAUTION

The Relay calibration is accomplished by adjusting resistors R1, R2 and R3. Changes made in any one of these resistors will affect the other two settings. In the event one setting is changed, the pickup, harmonic restraint, and through-current restraint adjustment procedures should be repeated until no further deviation from proper calibration is noted. Best results can be obtained if the through-current restraint adjustment is made only after the other two settings are correct.

PICKUP

The test circuit for pickup is shown in Figure 14, with S2 open. The first values given are for a 5 ampere rated relay. Those in () are for a 1 ampere rated relay. Pickup should be 1.5 (0.3) amperes with current flowing in terminals 5 and 6, and the tap plugs in the 5 (1.0) ampere position, and 25% slope tap setting. The pickup operation should be repeated several times, until two successive readings agree within 0.01 ampere with the total pickup current being interrupted between successive checks. If pickup is found to be from 1.35 to 1.65 (0.27 to 0.33), the setting should not be disturbed.

With DC control voltage applied to the proper terminals of the relay, the pickup of the telephone-type relay can be used as an indication of operation of the amplifier. This voltage may be applied as shown in Figure 15, and the indicating lamp will verify that the amplifier has produced an output signal.

Before R1 is adjusted for pickup, put a DC voltmeter (one volt scale) on pin 2 (-) and pin 8 (+) of the sense amplifier card. The pins are counted from right to left when viewed from the card socket wiring connections. Apply pickup current and adjust R1 for a voltage input to the sense amplifier card of 0.430 to 0.470 volts. If the pickup is not in limits with this setting, then adjust P1 on the sense amplifier card to obtain the proper pickup value.

HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted by means of a Test Rectifier used in conjunction with suitable ammeters and load boxes. The test circuit is as shown in Figure 15, with S2 closed to position A. Tests should be made on the 5.0 (1.0) ampere and 25% slope taps.

The analysis of a single-phase half-wave rectified current shows the presence of fixed percentages of DC, fundamental, and second harmonic components, as well as negligible percentages of all higher even harmonics. This closely approximates a typical transformer inrush current, as seen at the relay terminals, inasmuch as its principal components are DC, fundamental, and second harmonic. Although the percent second harmonic is fixed, the overall percentage may be varied by providing a path for a controlled amount of by-passed current of fundamental frequency. The by-passed current is added in phase with the fundamental component of the half-wave rectified current, and thus provides a means of varying the ratio of second harmonic current to fundamental current.

The following expression shows the relationship between the percent second harmonic, the DC component, and the by-pass current.

$$\% \text{ Second Harmonic} = \frac{0.212 I_{DC}}{0.45I_1 + 0.5I_{DC}} \times 100$$

Figure 16 is derived from the above expression. It shows the percent second harmonic corresponding to various values of by-pass current (I_1) for a constant DC set at 4.0 (0.8) amperes.

The relay is calibrated with a composite RMS current of two times tap value. When properly set, the relay will restrain with greater than 20% second harmonic, but will operate with second harmonic equal to 20% or lower. With the DC ammeter (I_2) set at 4.0 (0.8) amperes, the auxiliary relay should just begin to close its contacts with gradually increasing bypass current (I_1) at a value of 4.5-5.5 (0.9-1.1) amperes. This corresponds to 19-21% second harmonic (see Figure 16), providing a 2% tolerance at the set point to compensate for normal fluctuations in pickup. It should be noted that the current magnitude in the rectifier branch (I_2) is slightly influenced by the application of by-pass current (I_1) and should be checked to make sure it is maintained at its proper value.

If harmonic restraint is found to be out of adjustment, it may be corrected by adjusting rheostat R2. (See **CAUTION** at beginning of **INSTALLATION PROCEDURES** section.)

THROUGH-CURRENT RESTRAINT

The through-current restraint, which gives the relay the percentage differential or percent slope characteristics, is shown in Figure 7. It may be checked and adjusted using the circuit illustrated in Figure 15, with S2 closed to position B. Ammeter I_1 reads the differential current and I_3 reads the smaller of the two through-currents.

CAUTION

These currents should be permitted to flow for only a few seconds at a time, with cooling periods between tests; otherwise, the coils will be overheated.

NOTE: The percent slope tolerance is 10% of nominal, all in the plus direction. This is to ensure that the slope characteristic never falls below set point value.

In testing STD16C relays, the setting should be checked with switch S4 first in one position and then the other, thus checking all the restraint coils. With the current tap plugs in 5.0 (1.0) ampere position and the percent slope set in the 40% position, the relay should just pick up for values of the I_1 and I_3 currents indicated in Table V (VA). Repeat with the percent slope tap set in the 25% and 15% positions. If any one of these set points is found to be other than as prescribed, the adjustment may be made by adjusting R3. It should be noted that the current magnitude in the through-current branch (I_3) is slightly influenced by the application of differential current (I_1) and should be checked to make sure that it is maintained at its proper value.

TABLE V

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	30	12.0-13.2	40.0-44.0
25	30	7.5- 8.3	25.0-27.5
15	30	4.5- 5.0	15.0-16.5

TABLE VA

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	6	2.4-2.64	40-44
25	6	1.5-1.66	25-27.5
15	6	0.9-1.00	15-16.5

Any change in R3 to give the desired slope will have small effect upon minimum pickup and harmonic restraint. However, after the slope setting has once been set, any adjustment of minimum pickup will change the slope characteristics. The slope set points must then be rechecked, to make sure that they are still in accordance with Table III.

INSTANTANEOUS OVERCURRENT UNIT

This unit is located at the upper right-hand side of the relay. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at 8 times the tap rating, as described under **CHARACTERISTICS**. If the setting is incorrect, it may be adjusted by loosening the lock nut at the top of the unit and turning the cap screw until the proper pickup is obtained. In **making this adjustment, the current should not be allowed to flow for more than approximately one second at a time.**

DROPOUT OF MAIN UNIT

After the other tests are complete, check the dropout of the main unit, as described in the **ACCEPTANCE TESTS** section.

LOCATION

The location should be clean and dry, free from dust and excessive vibration, and well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Figure 18.

CONNECTIONS

Internal connection diagrams are shown in Figures 10 and 11. Typical wiring diagrams are given in Figures 1, 2 and 3 for differential applications.

Of course, any through-current transformer winding may be used for any power transformer winding, provided the taps are properly chosen.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor not less than No. 12 AWG gage copper wire, or its equivalent.

Every circuit in the drawout case has an auxiliary brush. (See Figure 12.) This is the shorter brush in the case, which the connecting plug should engage first. On every current circuit or other circuit with shorting bars, make sure the auxiliary brushes are bent high enough to engage the connecting plug or test plug before the main brushes; otherwise the CT secondary circuit may be opened where one brush touches the shorting bar before the circuit is completed from the plug to the other, main brush.

ADJUSTMENTS

TAP PLUG POSITIONINGRatio Matching Adjustment

To obtain a minimum unbalance current in the differential circuit, means are provided in the STD relay to compensate for unavoidable difference in current-transformer ratios. Taps on the relay transformer primary windings are rated 8.7 (1.74), 5.0 (1.0), 4.6 (0.92), 3.8 (0.76), 3.5 (0.7), 3.2 (0.64), and 2.9 (0.58) amperes for each line-current transformer. The tap plugs should be moved to the locations which most nearly match the expected CT currents for the same kVA assumed in each of the power transformer windings. The selection of taps should be guided by the method outlined under **CALCULATIONS**.

CAUTION

The connection plug must be removed from the relay before changing tap positions, in order to prevent open-circuiting a CT secondary. A check should be made after changing taps, to ensure that only one plug is left in any horizontal row of tap holes. Inaccurate calibration and overheating may result if more than one plug is connected to any one winding.

Unbalance Current Measurement

Unbalance current measurement is useful in checking the best tap setting when matching current-transformer ratios in the field. It is also useful in detecting errors or faults in the current transformer winding, or small faults within the power transformer itself, where the fault current is too low to operate the relay.

The type STD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provision is made for temporarily connecting a 5 V high-resistance AC voltmeter (1000 or more ohms per volt) across the secondary of the differential current transformer. This may be done by connecting the meter across terminals 8 and 9 (see Figures 10 and 11). When a perfect match of relay currents is obtained by the ratio-matching taps, the voltmeter will read 0, indicating no unbalance. If the voltmeter reads 1.5 volts or less, the unbalance current entering or leaving a given tap equals approximately 0.03 times the voltmeter reading times the tap rating. For higher voltmeter readings, the approximate unbalance current may be calculated by substituting the voltage reading and tap rating into the following equation:

$$I (\text{unbalance}) = (0.16 \times V - 0.2) \times \text{Tap}$$

The unbalance percentage equals 100 times the unbalance current divided by the measured tap current. For a three-winding bank, this must be checked with load on at least two pairs of windings in order to ensure that the connections are correct.

The curves in Figure 17 show the approximate voltage across terminals 8 and 9 required to operate the relay, for various percent slope tap settings, and through-currents expressed as percentage of tap. To ensure a margin of safety against false operation, the unbalance voltage should not exceed 75% of that required to operate the relay for any given through-current and percent slope tap setting. This extent of unbalance may result from the relatively high error currents of low-ratio bushing CTs at low multiples of tap current.

This curve represents the STD relay characteristic. Measurement of a voltage across studs 8 and 9 which is 75% or less of the value given on the curve, does not necessarily indicate that the relay will operate at higher through-current values. This is especially true where very high through-faults may cause saturation.

Small rectifier-type AC voltmeters are suitable for the measurement of unbalance. **The voltmeter should not be left permanently connected, since the shunt current it draws reduces the relay sensitivity.**

PERCENT SLOPE SETTING

Scribe marks for 15, 25 and 40% slope settings are provided in both the STD15 and STD16 relays. It is common practice to use the 25% setting unless special connections make it advisable to use one of the others. See the corresponding heading under **CALCULATIONS** for further details.

OPERATION

TARGETS

Targets are provided for both the seal-in unit and the instantaneous overcurrent unit. In the event of an internal fault, one or both of these units will operate, depending upon the fault magnitude. This will produce a target indication of the particular unit which operates. After a fault is cleared, the target should be reset by the reset slide located at the lower left-hand corner of the relay.

DISABLING OF TYPE STD RELAY

CAUTION

When bypassing a breaker for maintenance, it will be necessary to disable the relay to prevent false tripping.

If the disabling of the relay is done by a remote switch, rather than by removing the relay connection plug, the following precautions should be taken:

1. The relay must be disabled by short-circuiting studs 8 and 9 of the relay, or by opening the trip circuit at stud 1.
2. If the CT secondaries are short-circuited as part of the disabling procedure, the trip circuit should be opened at stud 1, and studs 8 and 9 should be short-circuited first. **It is not sufficient to rely on short circuiting the CT secondaries alone, because any difference in time of shorting them may cause false tripping.**

MAINTENANCE

CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface, resembling

in effect a superfine file. The polishing action is so delicate that no scratches are left, yet corroded material will be removed rapidly and thoroughly. The flexibility of the tool insures the cleaning of the actual points of contact.

Fine silver contacts should not be cleaned with knives, files, or abrasive paper or cloth. Knives or files may leave scratches, which increase arcing and deterioration of the contacts. Abrasive paper or cloth may leave minute particles of insulating abrasive material in the contacts, and thus prevent closing.

The burnishing tool described above can be obtained from the factory.

PERIODIC TESTS

An operation test and inspection of the relay and its connections should be made at least once every six months. Tests may be performed as described under INSTALLATION TESTS, or if desired they may be made on the service taps as described in this section.

When inserting or withdrawing a test plug with U-shaped through jumpers to complete the trip circuit through the test plug, similar through jumpers should also be used on studs 8 and 9 to maintain the connections from the relay to the case. **If this is not done, there is a risk of false tripping upon inserting or withdrawing the plug.**

PICKUP

The method for checking pickup is as described under the heading **INSTALLATION TESTS** except, of course, pickup current will be different depending upon the winding (WDG) 1 service tap. Pickup may be determined as follows:

$$I_1 = 0.30 \times \text{WDG 1 Tap}$$

Of course, when checking pickup on a particular service tap, the $\pm 10\%$ expected variation still applies, the acceptable-as-found range being

$$I_1 = 9.0 \times 0.30 \times \text{WDG 1 Tap} \text{ to } 1.10 \times 0.30 \times \text{WDG 1 Tap}$$

<u>Example</u>	WDG1 Tap	= 3.5A
	I_1	= $0.90 \times 0.30 \times 3.5$ to $1.10 \times 0.30 \times 3.5$
	I_1	= 0.94 to 1.16 amperes

HARMONIC CURRENT RESTRAINT

The procedure for checking harmonic restraint is as described under the heading **INSTALLATION TESTS**, except that the test current values must be modified as follows:

$$I_2 (\text{DC}) = 0.80 \times \text{WDG 1 Tap}$$

$$I_1 = 0.90 \times \text{WDG 1 Tap} \text{ to } 1.10 \times \text{WDG 1 Tap}$$

In the event a suitable DC meter is not available, $I_2 (\text{AC}) = 2.25 \times I_2 (\text{DC})$. (Theoretically, this conversion factor would be 2.22 if the rectifier back resistance were infinite.)

Example WDG 1 Tap = 3.5A
 I_2 (DC) = $0.80 \times 3.5 = 2.8$ amperes
 I_1 = 0.90×3.5 to 1.10×3.5
 I_1 = 3.15 to 3.85 amperes

If DC meter is not available, I_2 (AC) would in this example be
 $2.25 \times 2.8 = 6.30$ amperes.

THROUGH-CURRENT RESTRAINT

In order to check the service tap slope setting, the test current values indicated in Table IV must be modified to take into account any difference in tap settings. Furthermore, the test circuit shown in Figure 15 must be set up such that the lead from ammeter I_3 to the test plug is connected to the stud that connects to the winding with the lowest tap setting. The common lead, of course, is connected to the stud corresponding to the winding with the higher tap setting. For any combination of taps, the percent slope is given in the following equation.

$$\% \text{ Slope} = \left[\frac{T_1}{T_2} \left(\frac{I_1}{I_3} + 1 \right) - 1 \right] \times 100$$

where

T_1 = smaller tap setting
 T_2 = higher tap setting
 I_1 = differential current
 I_3 = smaller of the two through currents

Table VI, derived from the above expression, is based on a multiple of tap current of 6 times the lower tap setting for all combinations of taps except those which involve the 8.7 amp tap. For the latter case, a 4-times tap setting is used, since the total test current for a 6-times tap setting may be as high as 75.2 amperes, which is not only prohibitively high for many installations, but also may subject the relay to excessive heating.

For a given tabular value of I_3 corresponding to a given combination of winding and percent slope taps, the values of I_1 (min.) and I_1 (max.) correspond to the minimum and maximum percent slope tolerance limits given in Table V. However, for a 4-times tap setting, both the upper and the lower percent tolerance limits have been raised by a value equivalent to the difference between the true slope and the nominal slope at 4-times tap value, indicated by the percent slope characteristic curves shown in Figure 7.

<u>Example</u>	WDG 1 Tap	= 3.5 A
	Wdg 2 Tap	= 5.0 A
	Slope Setting	= 40%

Since WDG1 has the lower tap setting, the lead from ammeter I_3 to the test plug should be connected to stud 6, and the common lead connected to stud 4.

From Table VI

I_3 = 21.0 amps
 I_1 (min.) = 21.0 amps
 I_1 (max.) = 22.2 amps

SERVICING

Check any replacement telephone relay for mechanical operation before installation, to see that it operates smoothly and that the contacts are correctly adjusted.

With the relay de-energized, each normally-open contact should have a gap of 0.010-0.015 inch. Observe the wipe on each normally-closed contact by deflecting the stationary contact member towards the frame. Wipe should be approximately 0.005 inch.

The wipe on each normally-open contact should be approximately 0.005 inch. Check by inserting a 0.005 inch shim between the residual screw and the pole piece, and operating the armature by hand. The normally-open contacts should make before the residual screw strikes the shim.

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for the prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and complete nameplate data, including the serial number, of the relay for which the part is required. The serial number may be found stamped on the instantaneous unit in black ink. If possible, give the General Electric Company requisition number on which the relay was furnished.

Since the last edition, the equation has been changed in the section on Unbalance Current Measurement and Figure 7b has been added.

TABLE VI

TAPS	T2	2.9			3.2			3.5			3.8			4.2			4.6			5.0			8.7		
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40
T1	Currents																								
	I ₃	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	11.6	11.6	11.6
2.9	I ₁ (min)	2.6	4.3	7.0	4.6	6.6	9.5	6.7	8.8	12.0	8.8	11.1	14.5	11.6	14.1	17.9	14.3	17.1	21.2	17.1	20.1	24.6	28.7	32.2	37.4
	I ₁ (max)	2.9	4.8	7.7	5.0	7.1	10.3	7.1	9.4	12.8	9.2	11.7	15.4	12.0	14.8	18.9	14.8	17.8	22.4	17.6	20.9	25.8	29.3	33.1	38.9
	I ₃	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	12.8	12.8	12.8
3.2	I ₁ (min)	2.9	4.8	7.7	4.9	7.0	10.2	7.0	9.3	12.7	9.8	12.3	16.1	12.5	15.3	19.4	12.5	15.3	19.4	15.3	18.3	22.8	27.5	31.0	36.2
	I ₁ (max)	3.2	5.3	8.5	5.3	7.6	11.0	7.4	9.9	13.6	10.2	13.0	17.1	13.0	16.0	20.6	15.8	19.1	24.0	15.8	19.1	24.0	28.1	31.9	37.7
	I ₃	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	14.0	14.0	14.0
3.5	I ₁ (min)	3.1	5.2	8.4	5.2	7.5	10.9	5.2	7.5	10.9	8.0	10.5	14.3	10.7	13.5	17.6	13.5	16.5	21.0	13.5	16.5	21.0	26.3	29.8	35.0
	I ₁ (max)	3.5	5.8	9.3	5.6	8.1	11.8	5.6	8.1	11.8	8.4	11.2	15.3	11.2	14.2	18.8	14.0	17.3	22.2	14.0	17.3	22.2	26.9	30.7	36.5
	I ₃	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	15.2	15.2	15.2
3.8	I ₁ (min)	3.4	5.7	9.1	3.4	5.7	9.1	6.2	8.7	12.5	6.2	8.7	12.5	8.9	11.7	15.8	11.7	14.7	19.2	11.7	14.7	19.2	25.1	28.6	33.8
	I ₁ (max)	3.8	6.3	10.0	3.8	6.3	10.0	6.6	9.4	13.5	6.6	9.4	13.5	9.4	12.4	17.0	9.4	12.4	17.0	12.2	15.5	20.4	25.7	29.5	35.3
	I ₃	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	16.8	16.8	16.8
4.2	I ₁ (min)	3.8	6.3	10.1	6.5	9.3	13.4	6.5	9.3	13.4	6.5	9.3	13.4	9.3	12.3	16.8	9.3	12.3	16.8	9.3	12.3	16.8	23.5	27.0	32.2
	I ₁ (max)	4.2	7.0	11.1	7.0	10.0	14.6	7.0	10.0	14.6	7.0	10.0	14.6	9.8	13.1	18.0	9.8	13.1	18.0	9.8	13.1	18.0	24.1	27.9	33.7
	I ₃	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	18.4	18.4	18.4
4.6	I ₁ (min)	4.1	6.9	11.0	6.9	9.9	14.4	6.9	9.9	14.4	6.9	9.9	14.4	9.9	12.9	17.6	9.9	12.9	17.6	9.9	12.9	17.6	21.9	25.4	30.6
	I ₁ (max)	4.6	7.6	12.2	7.4	10.7	15.6	7.4	10.7	15.6	7.4	10.7	15.6	10.7	13.7	18.8	10.7	13.7	18.8	10.7	13.7	18.8	22.5	26.3	32.1
	I ₃	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	20.0	20.0	20.0
5.0	I ₁ (min)	4.5	7.5	12.0	4.5	7.5	12.0	4.5	7.5	12.0	4.5	7.5	12.0	7.5	10.5	15.6	7.5	10.5	15.6	7.5	10.5	15.6	20.3	23.8	29.0
	I ₁ (max)	5.0	8.3	13.2	5.0	8.3	13.2	5.0	8.3	13.2	5.0	8.3	13.2	8.3	11.3	16.8	8.3	11.3	16.8	8.3	11.3	16.8	20.9	24.7	30.5
	I ₃	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	34.8	24.8	28.8	34.8
8.7	I ₁ (min)	5.5	9.0	14.2	5.5	9.0	14.2	5.5	9.0	14.2	5.5	9.0	14.2	9.0	12.0	17.6	9.0	12.0	17.6	9.0	12.0	17.6	25.5	29.5	35.5
	I ₁ (max)	6.1	9.9	15.7	6.1	9.9	15.7	6.1	9.9	15.7	6.1	9.9	15.7	9.9	12.9	18.8	9.9	12.9	18.8	9.9	12.9	18.8	26.3	30.3	36.3

TABLE VIA

TAPS	T2	0.58			0.64			0.7			0.76			0.84			0.92			1.0			1.74		
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40
T2	Currents																								
0.58	I ₃	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	2.3	2.3	2.3
	I ₁ (min)	0.52	0.86	1.4	0.92	1.32	1.9	1.34	1.76	2.4	1.76	2.22	2.9	2.32	2.82	3.6	2.86	3.42	4.24	3.42	4	4.92	5.74	6.44	7.48
	I ₁ (max)	0.58	0.96	1.54	1.0	1.42	2.06	1.42	1.88	2.56	1.84	2.34	3.08	2.4	2.96	3.78	2.96	3.56	4.5	3.52	4.18	5.16	5.86	6.62	7.78
0.64	I ₃				3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	2.56	2.56	2.56
	I ₁ (min)				0.58	0.96	1.54	0.98	1.4	2	1.4	1.86	2.54	1.96	2.46	3.22	2.5	3.06	3.88	3.06	3.66	4.56	3.5	6.2	7.24
	I ₁ (max)				0.64	1.06	1.7	1.06	1.52	2.2	1.48	1.98	2.72	2.04	2.6	3.42	2.6	3.2	4.12	3.16	3.82	4.8	5.62	6.38	7.54
0.7	I ₃							4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.8	2.8	2.8
	I ₁ (min)							0.62	1.04	1.68	1.04	1.5	2.18	1.6	2.1	2.86	2.14	2.7	3.52	2.7	3.3	4.2	5.26	5.96	7
	I ₁ (max)							0.7	1.16	1.86	1.12	1.62	2.36	1.68	2.24	3.06	2.24	2.84	3.76	2.8	3.46	4.44	5.38	6.14	7.3
0.76	I ₃										4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	3.0	3.0	3.0
	I ₁ (min)										0.68	1.14	1.82	1.24	1.74	2.5	1.78	2.34	3.16	2.34	2.94	3.84	5.0	5.72	6.76
	I ₁ (max)										0.76	1.26	2.0	1.32	1.88	2.7	1.88	2.48	3.4	2.44	3.1	4.08	5.14	5.9	7.06
0.84	I ₃													5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.36	3.36	3.36
	I ₁ (min)													0.76	1.26	2.0	1.3	1.86	2.68	1.86	2.46	3.36	4.7	5.4	6.44
	I ₁ (max)													0.84	1.4	2.22	1.4	2.0	2.92	1.96	2.62	3.6	4.82	5.58	6.74
0.92	I ₃																5.5	5.5	5.5	5.5	5.5	5.5	3.7	3.7	3.7
	I ₁ (min)																0.82	1.38	2.2	1.38	1.98	2.88	4.38	5.1	6.12
	I ₁ (max)																0.92	1.52	2.44	1.48	2.14	3.02	4.5	5.26	6.42
1.0	I ₃																			6.0	6.0	6.0	4.0	4.0	4.0
	I ₁ (min)																			0.90	1.5	2.4	4.06	4.76	5.8
	I ₁ (max)																			1	1.66	2.64	4.18	4.94	6.1
1.74	I ₃																								
	I ₁ (min)																						7.0	7.0	7.0
	I ₁ (max)																							1.1	1.8

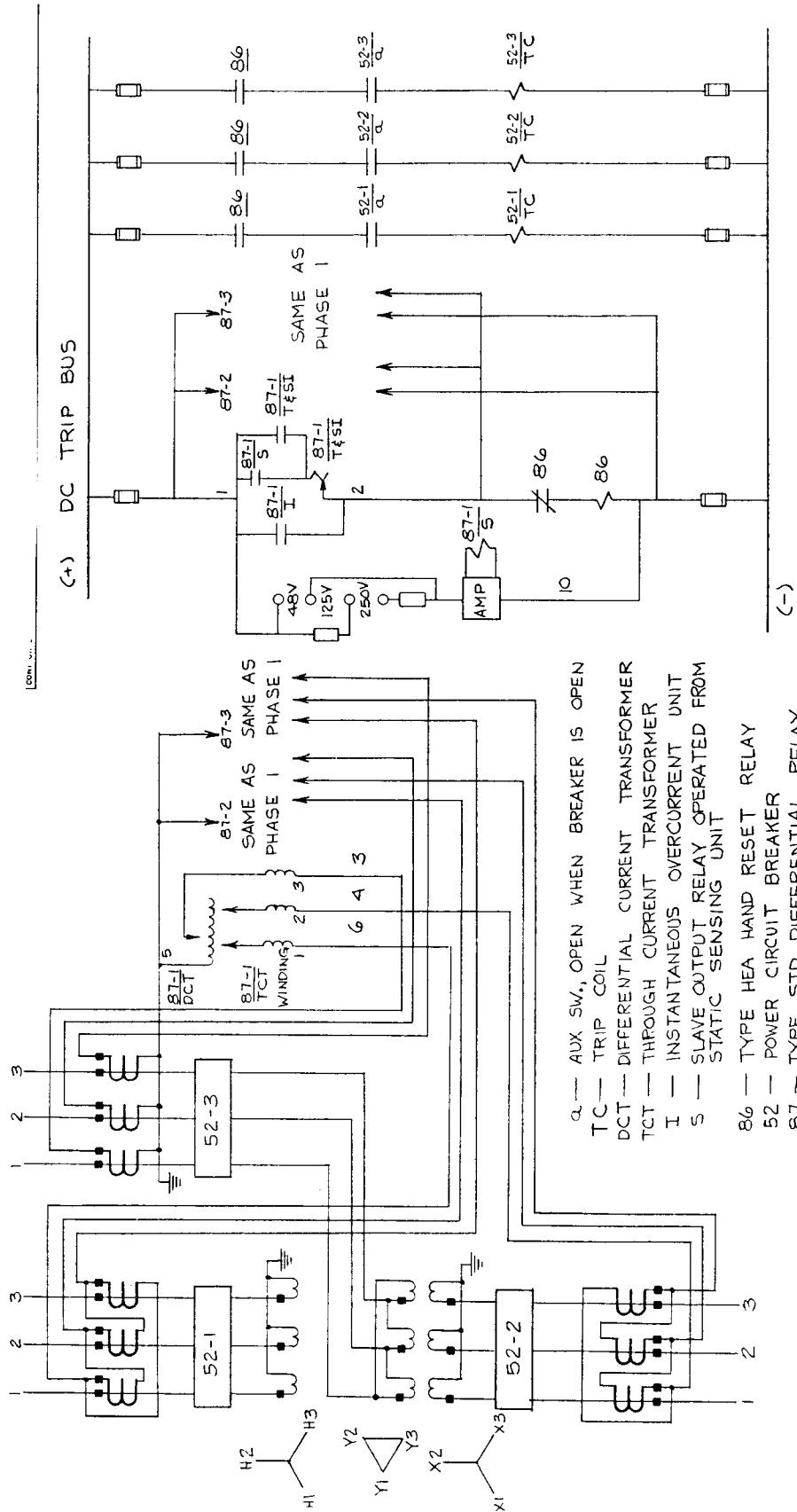


Figure 3 ((0128B1980-2) Elementary Diagram for STD 16C Relays
for Three-Winding Transformer Protection

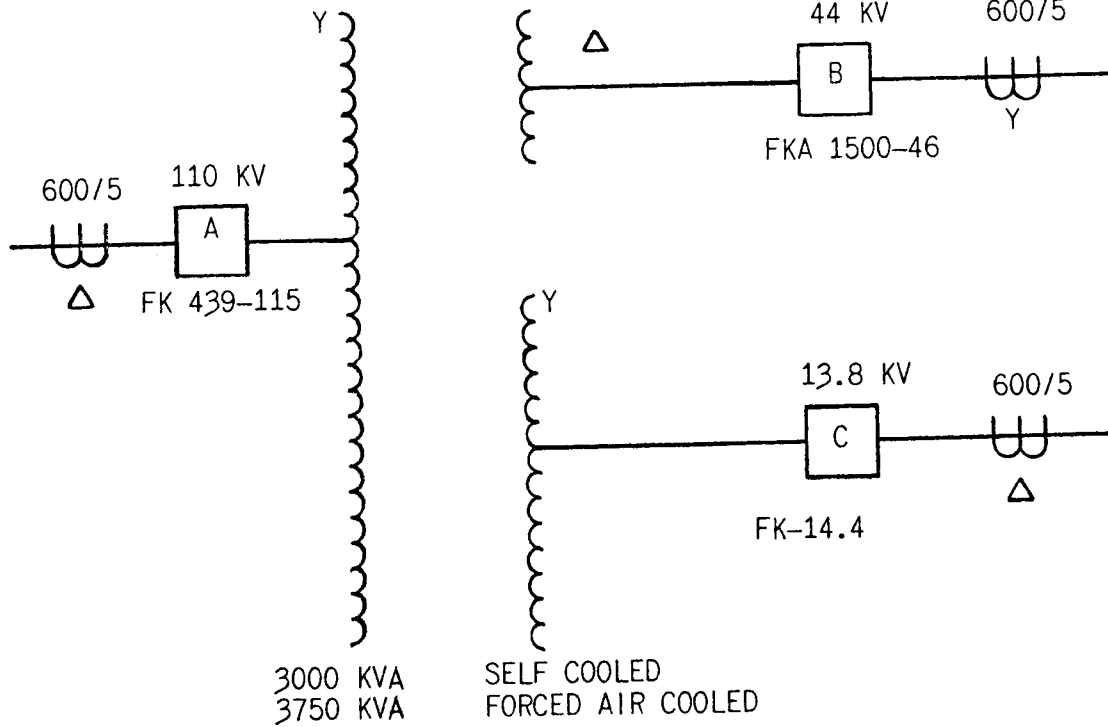


Figure 4 (0165A7601-1) Transformer Used in Sample Calculations

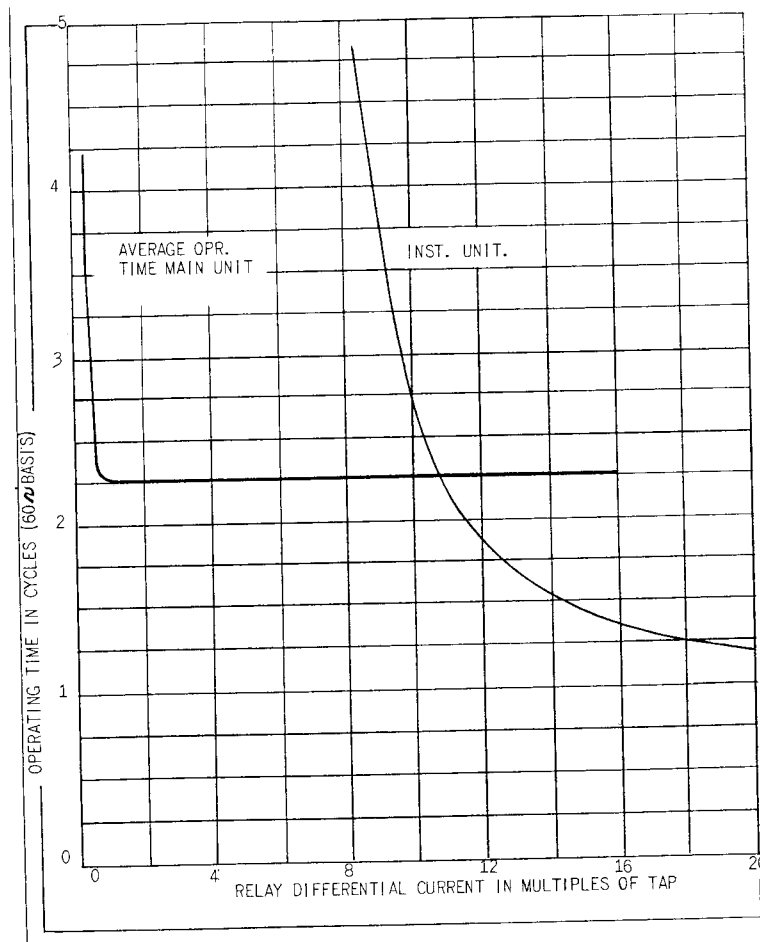


Figure 5 (0227A2503-0) Operating Speed Characteristics of the STD Relay

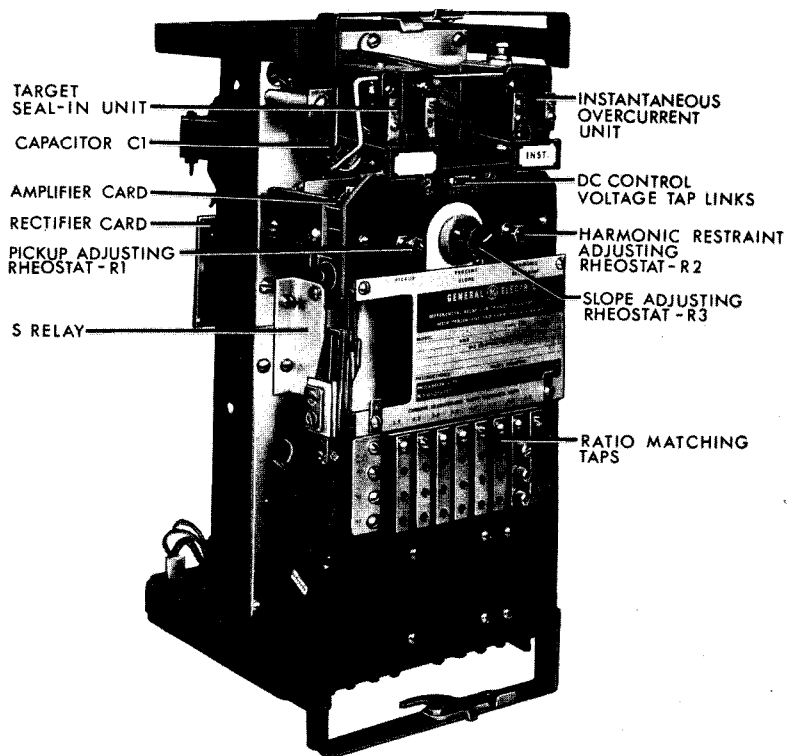


Figure 6A (8042539) Relay Type STD16C Out of Case
Approximately 3/4 Front View (Left Side)

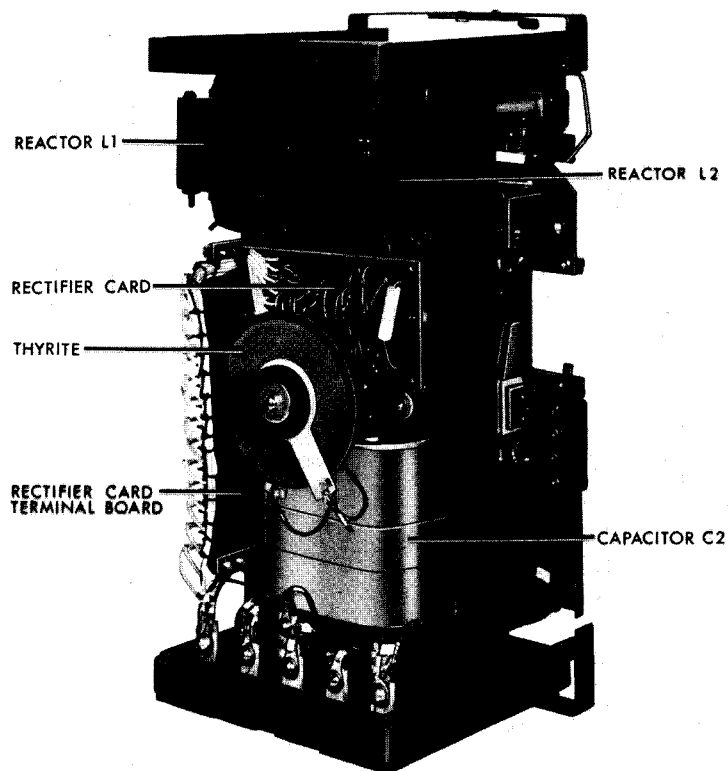


Figure 6B (8042544) Relay Type STD16C Out of Case
Approximately 3/4 Back View (Right Side)

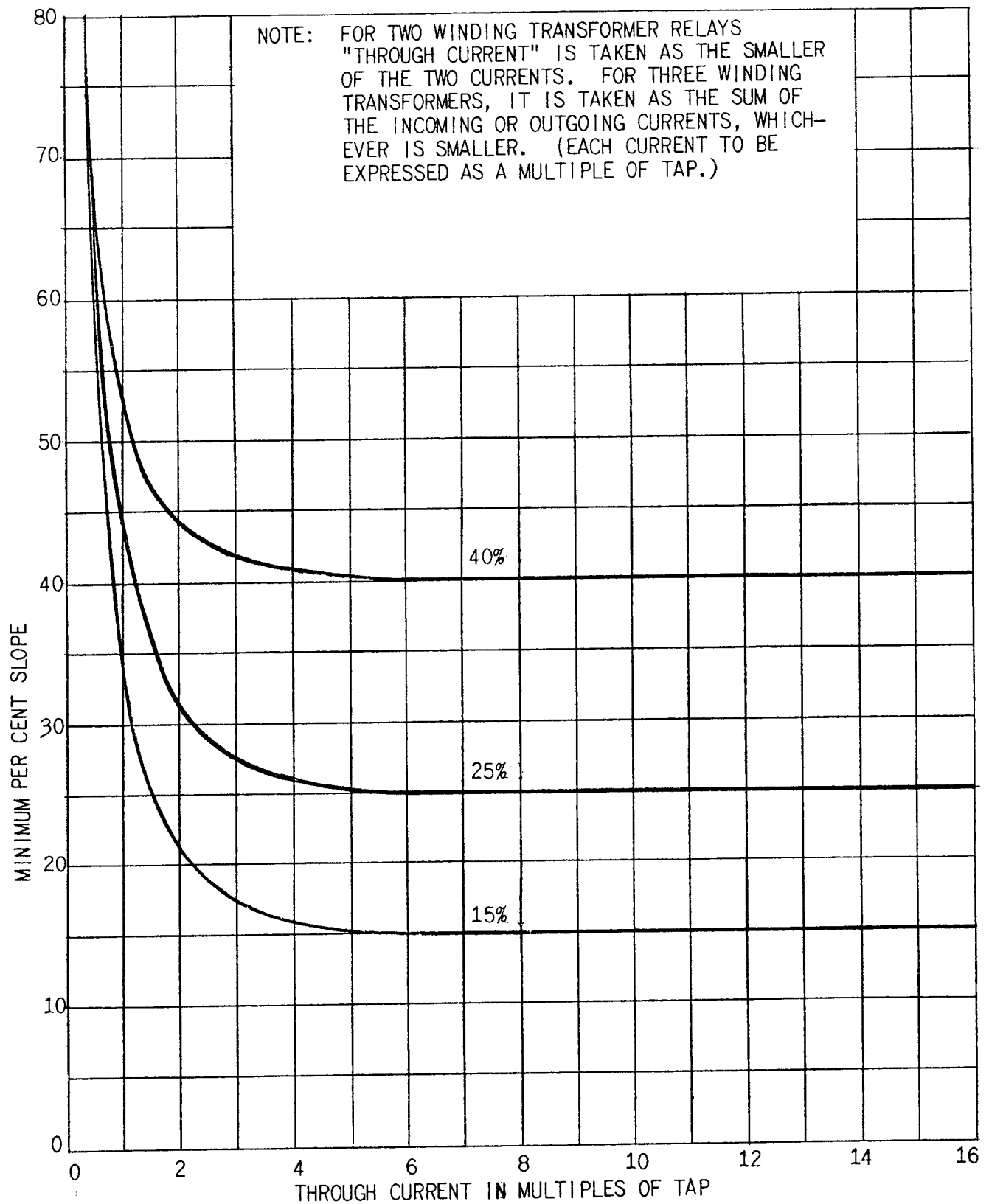


Figure 7A (0378A0588-3) Low-Current Slope Characteristics of the STD Relay

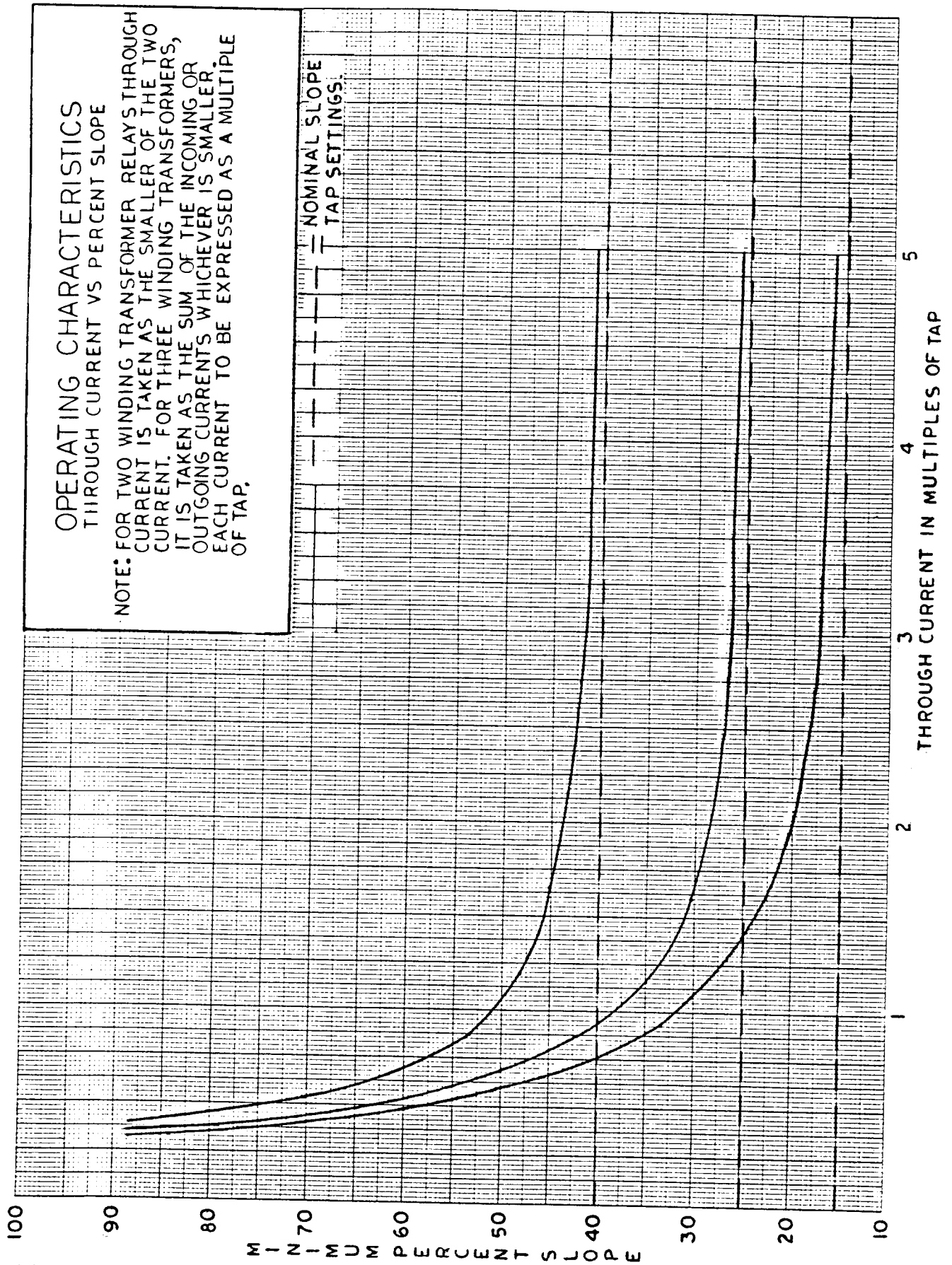
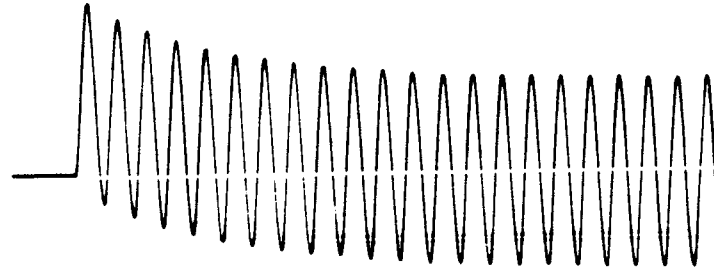
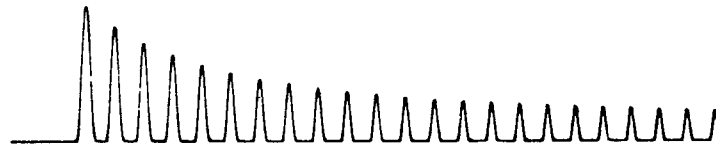


Figure 7B (0257A8579 [1]) Through-Current vs Percent Slope Characteristics of the STD Relay



TYPICAL OFFSET FAULT CURRENT WAVE



TYPICAL TRANSFORMER
MAGNETIZING INRUSH CURRENT WAVE

Figure 8 (K-6209195-0) Fault Current and Transformer Magnetizing Current Waves

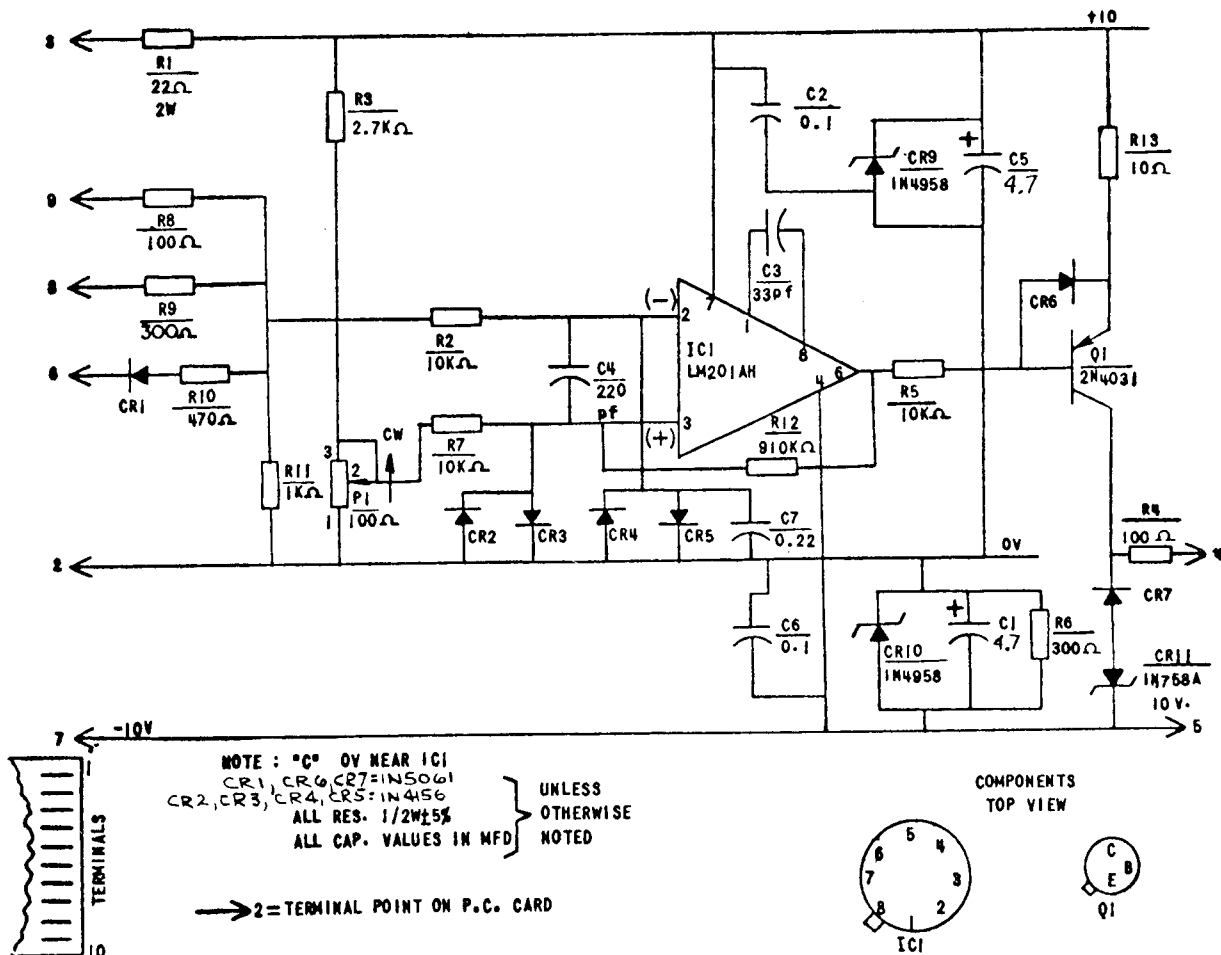


Figure 9 (0269A3039-3) Internal Connections Diagram
of Sense Amplifier Printed Circuit Board

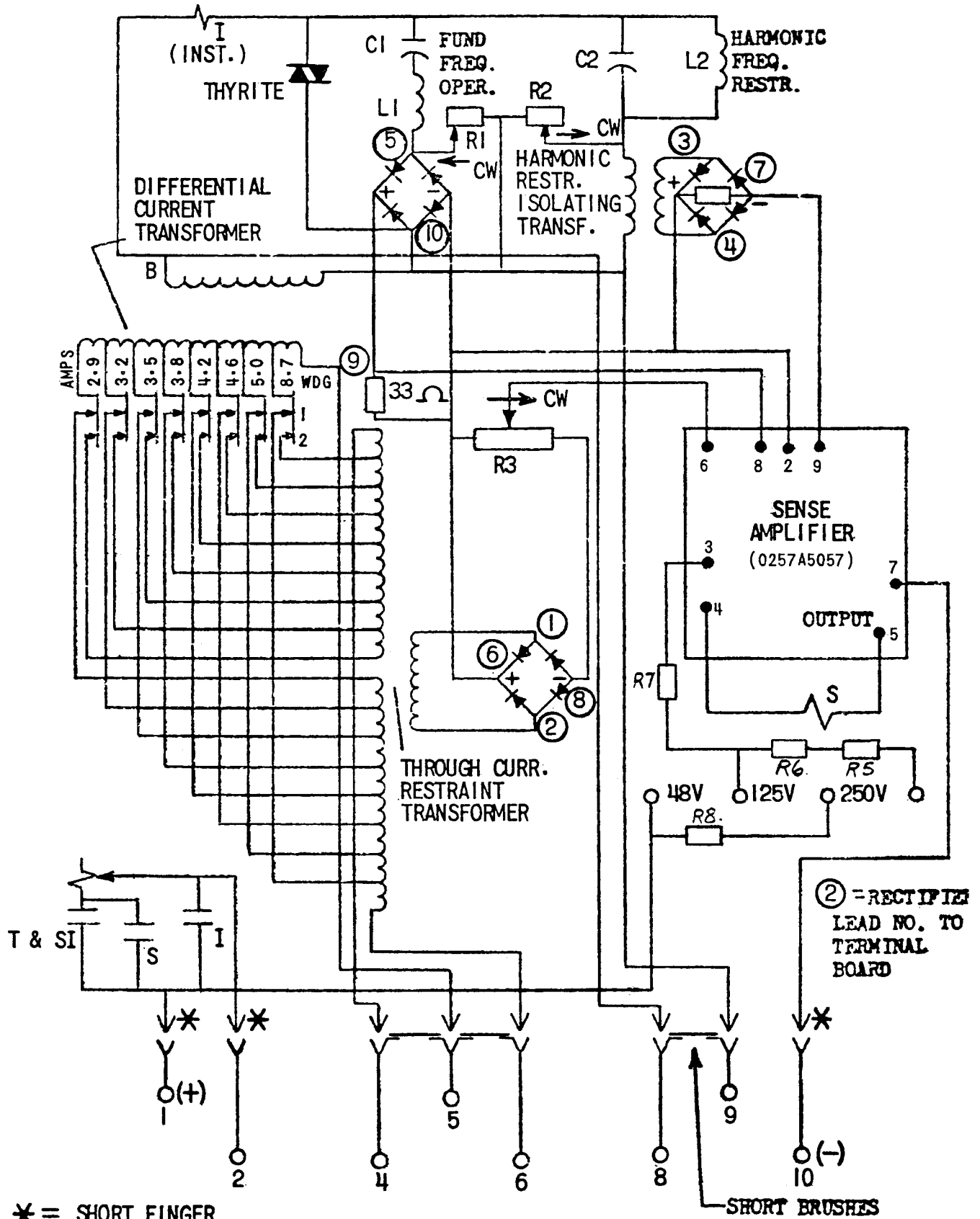


Figure 10 (0257A5026-2) Internal Connections Diagram for Relay Type STD15C

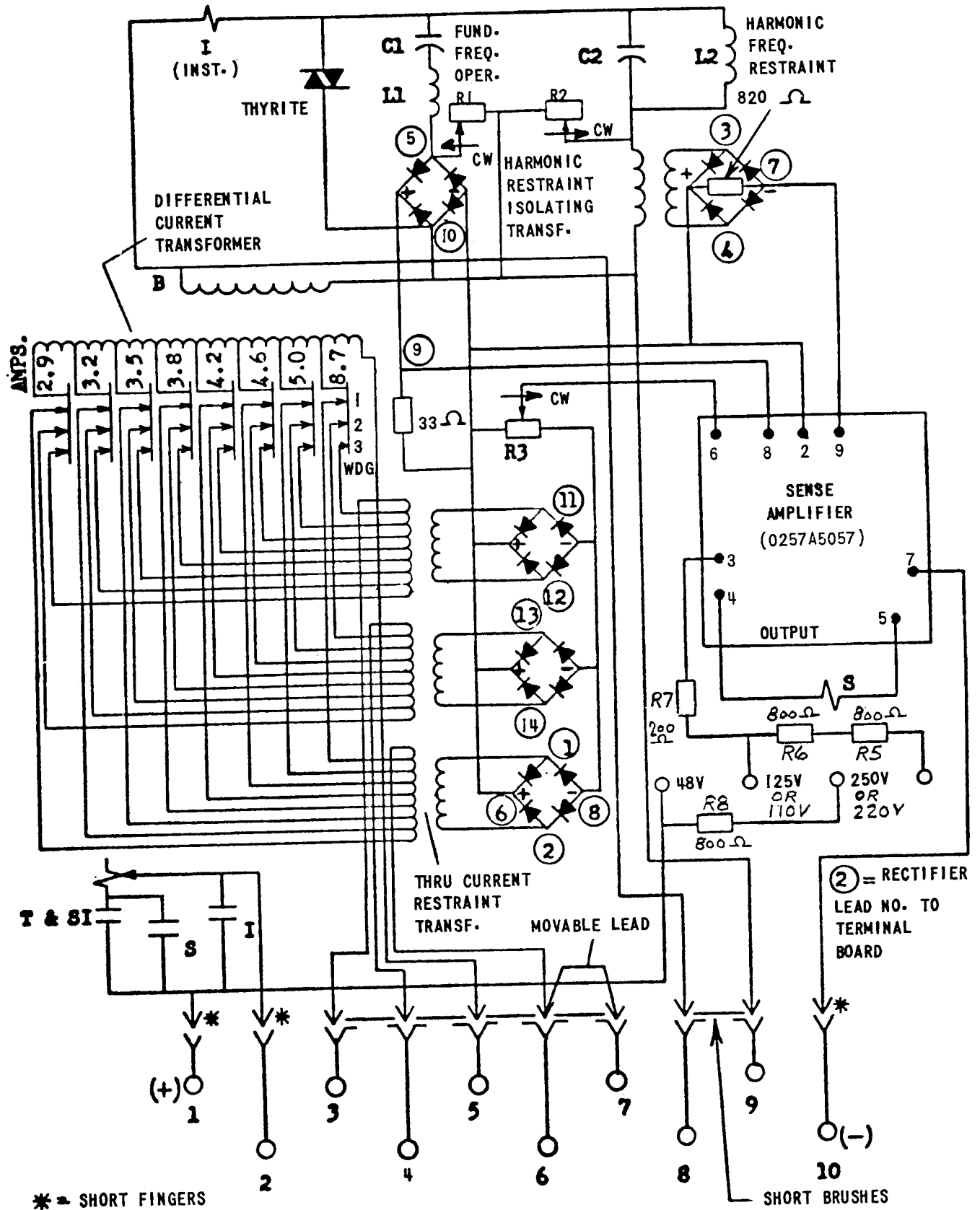
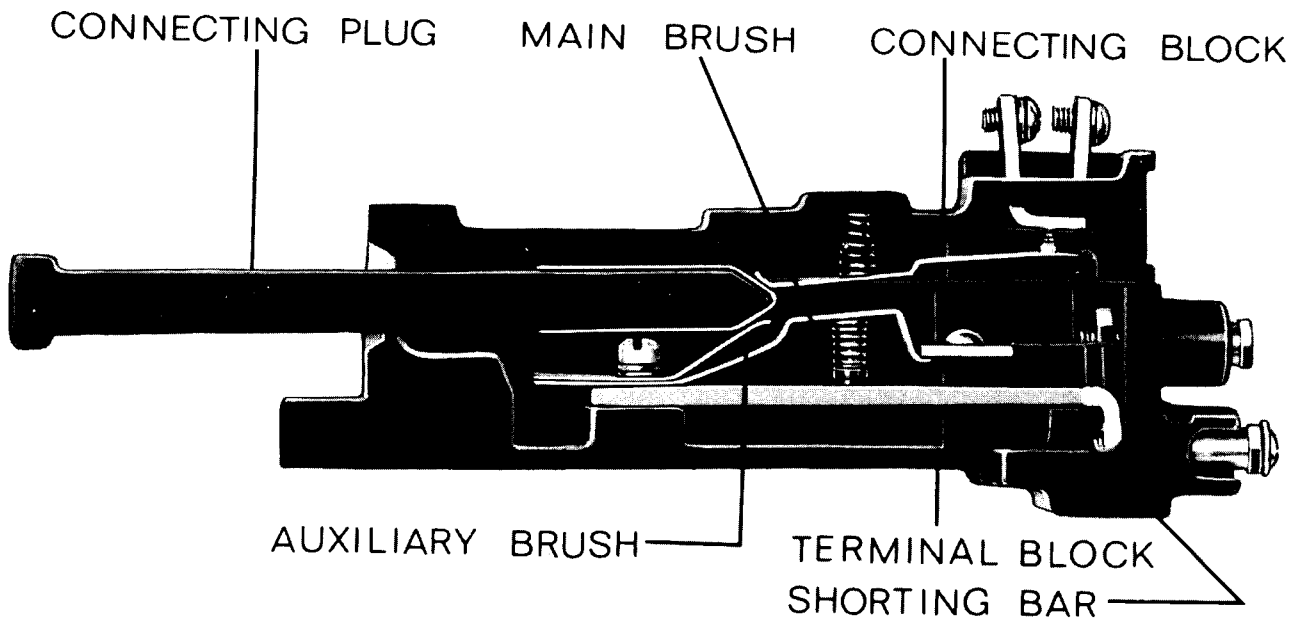


Figure 11 (0257A5027-1) Internal Connections Diagram for Relay Type STD16C



NOTE: AFTER ENGAGING AUXILIARY BRUSH CONNECTING PLUG TRAVELS $\frac{1}{4}$ INCH BEFORE ENGAGING THE MAIN BRUSH ON THE TERMINAL BLOCK

Figure 12 (8024039) Cross Section of Drawout Case Showing Position of Auxiliary Brush

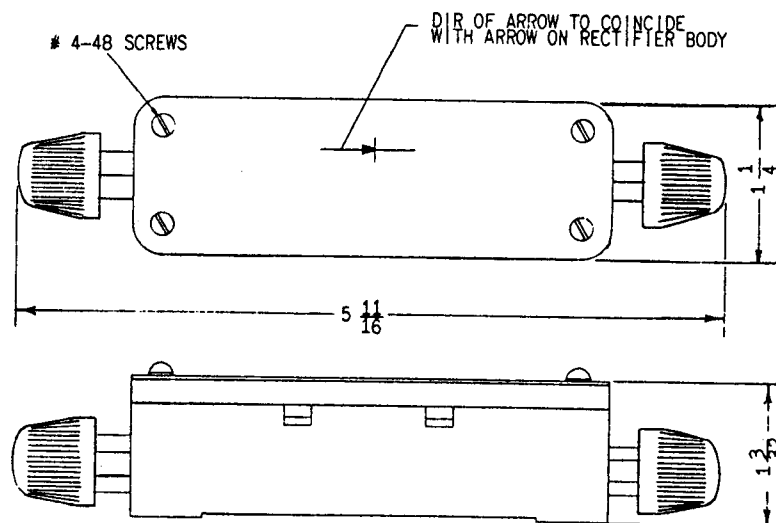
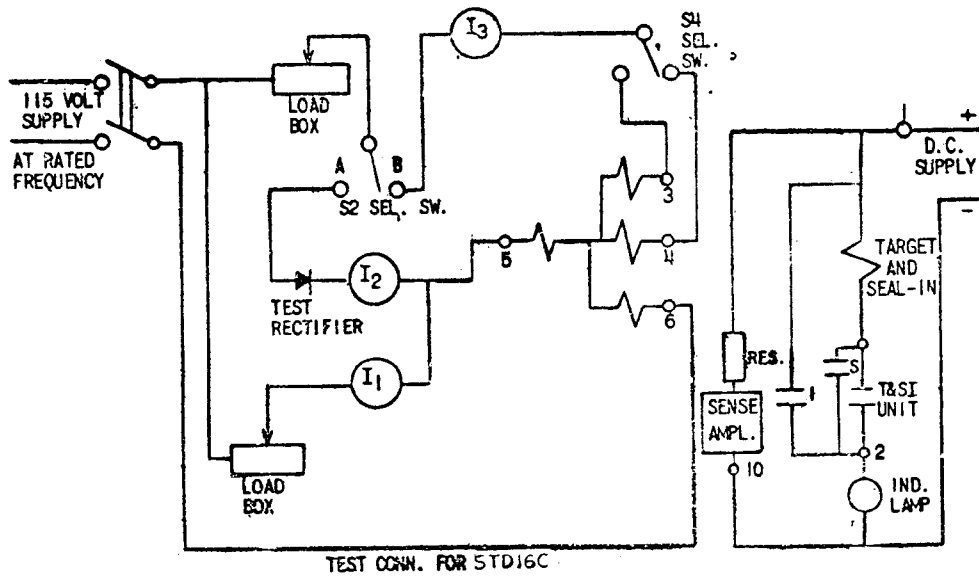
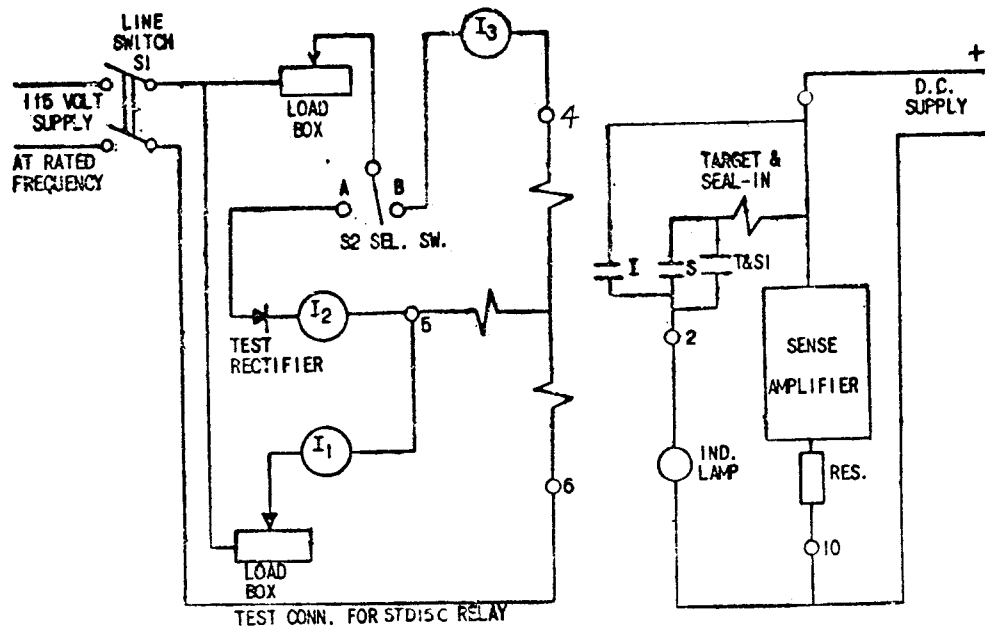


Figure 13 (0148A2994-1) Outline of Test Rectifier



LEGEND

I = INSTANTANEOUS OVERCURRENT UNIT
 T&SI = TARGET AND SEAL-IN UNIT.
 S = TELEPHONE RELAY

Figure 14 (0165B2697-1) Test Connections Diagram

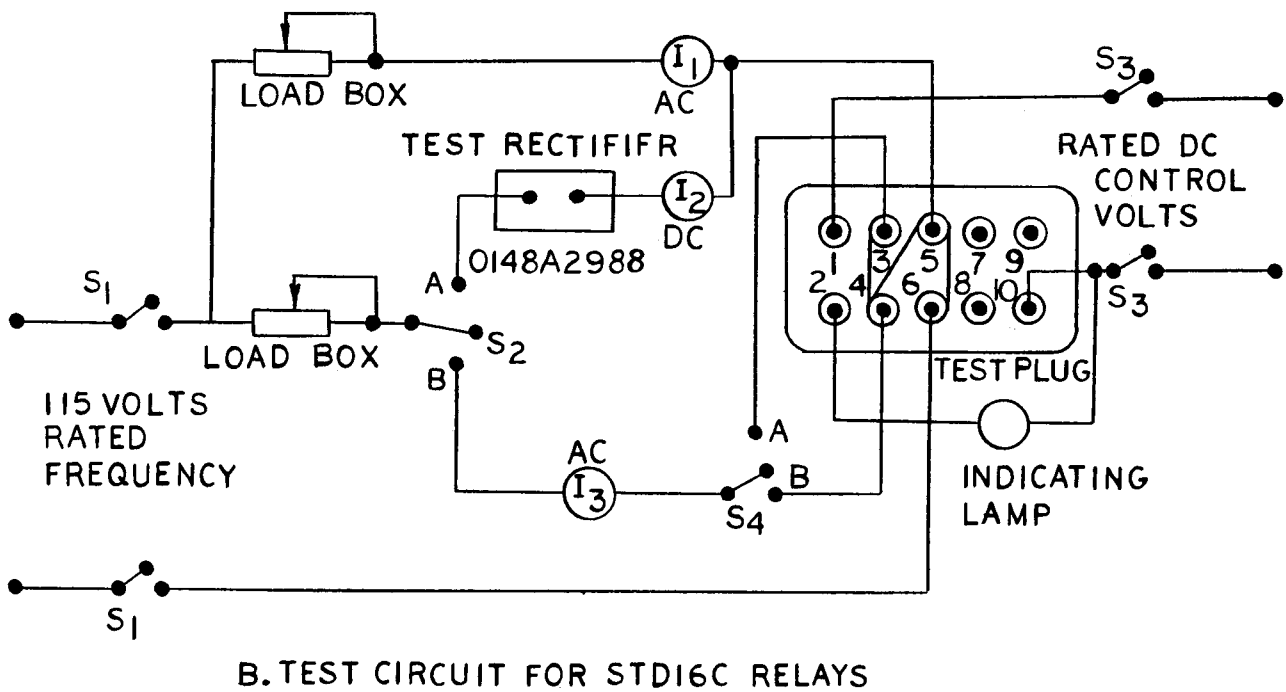
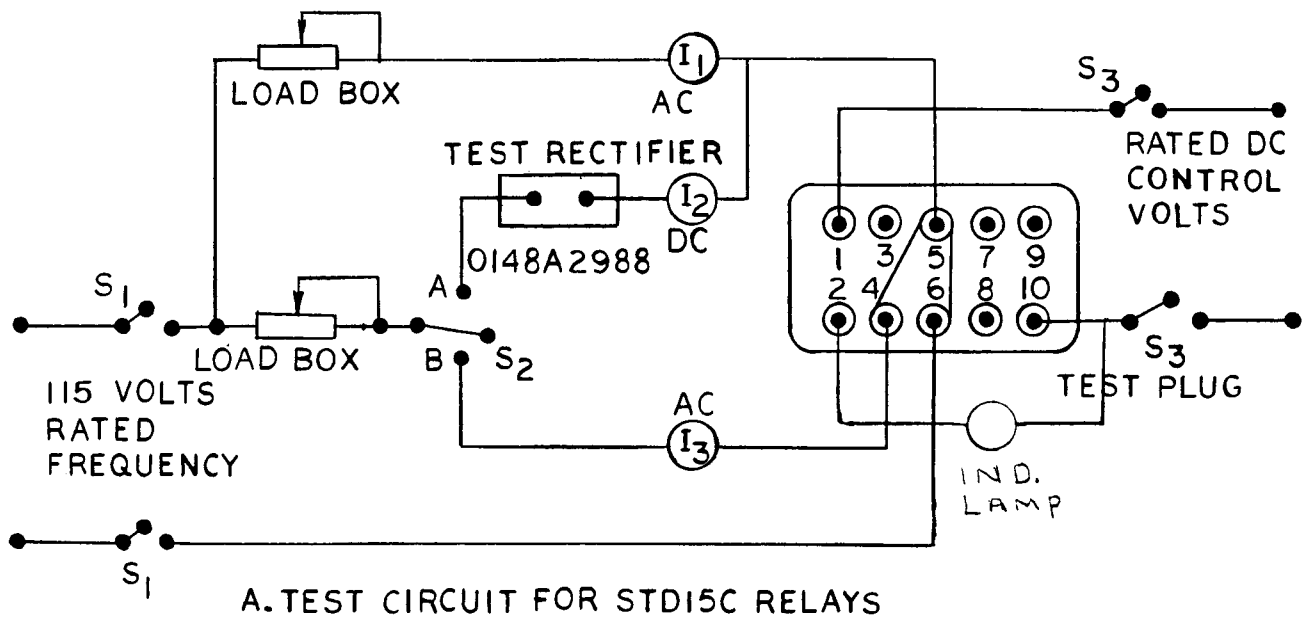


Figure 15 (0257A5054-0 Sh.1) Field Test Connections, in Case,
Using Type XLA Test Plug

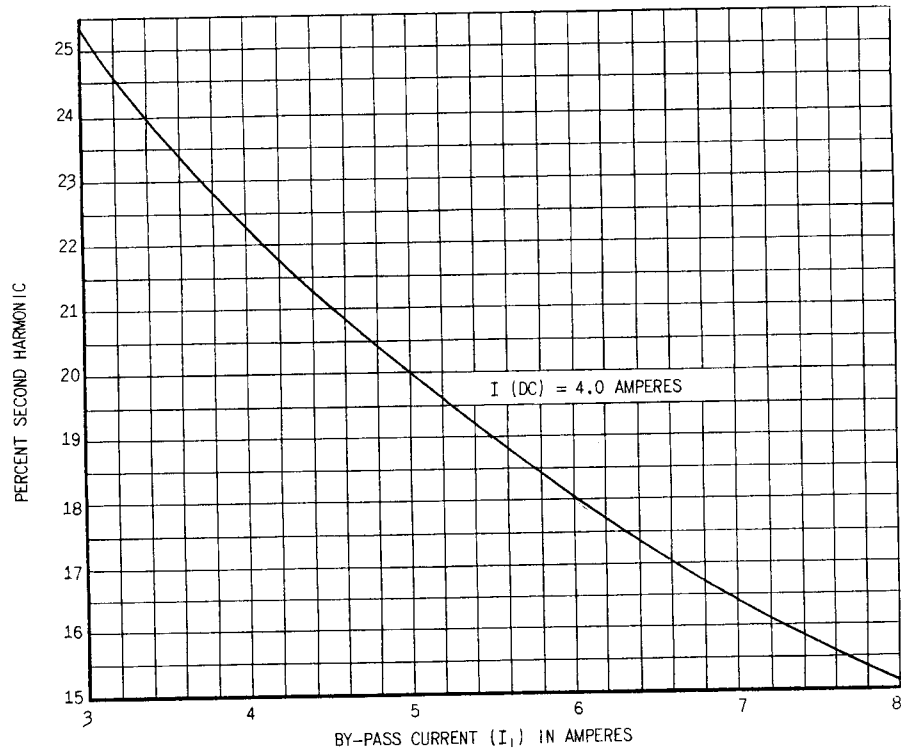


FIGURE 16 (418A 786-0) Relationship Between Second Harmonic and By-Pass Current with $I(DC)$ set at 4.0 Amperes

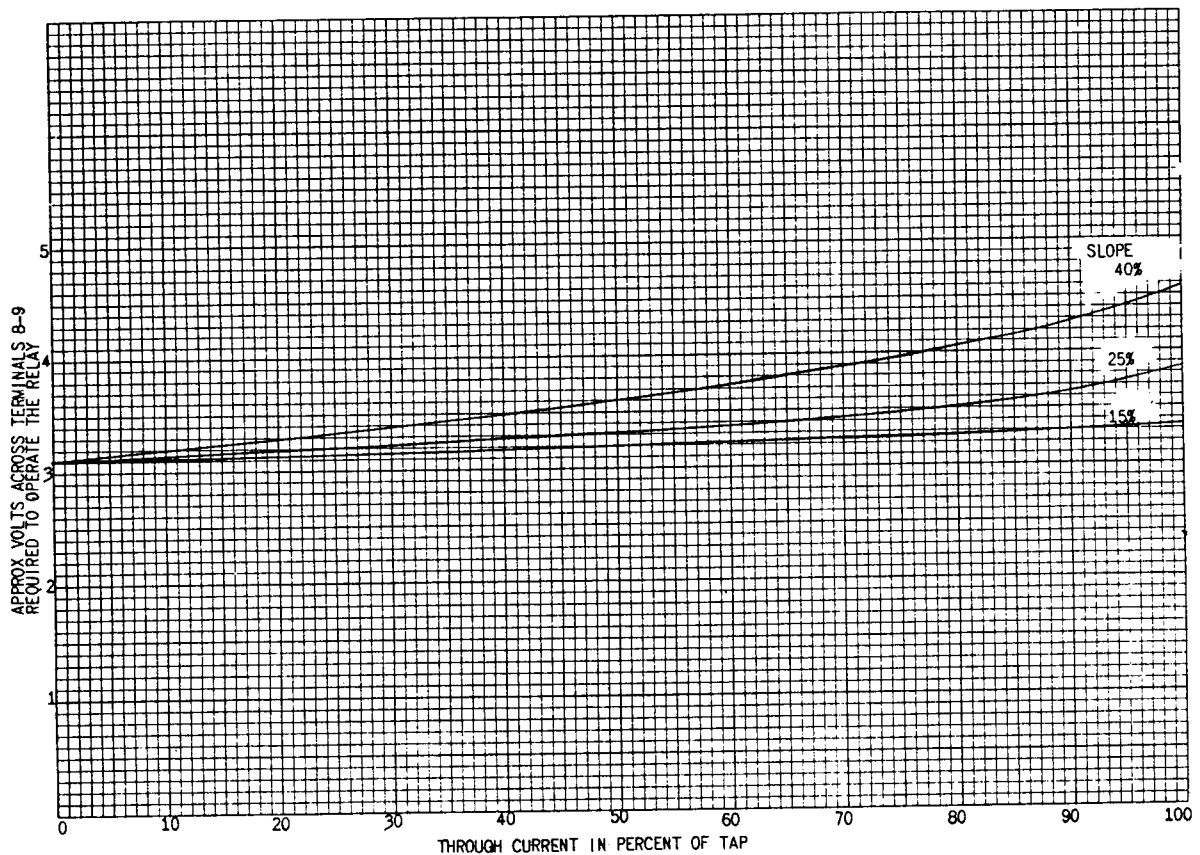


Figure 17 (0178A8111-0) Differential Voltage Operating Characteristics of Type STD Relay

GEK-45307

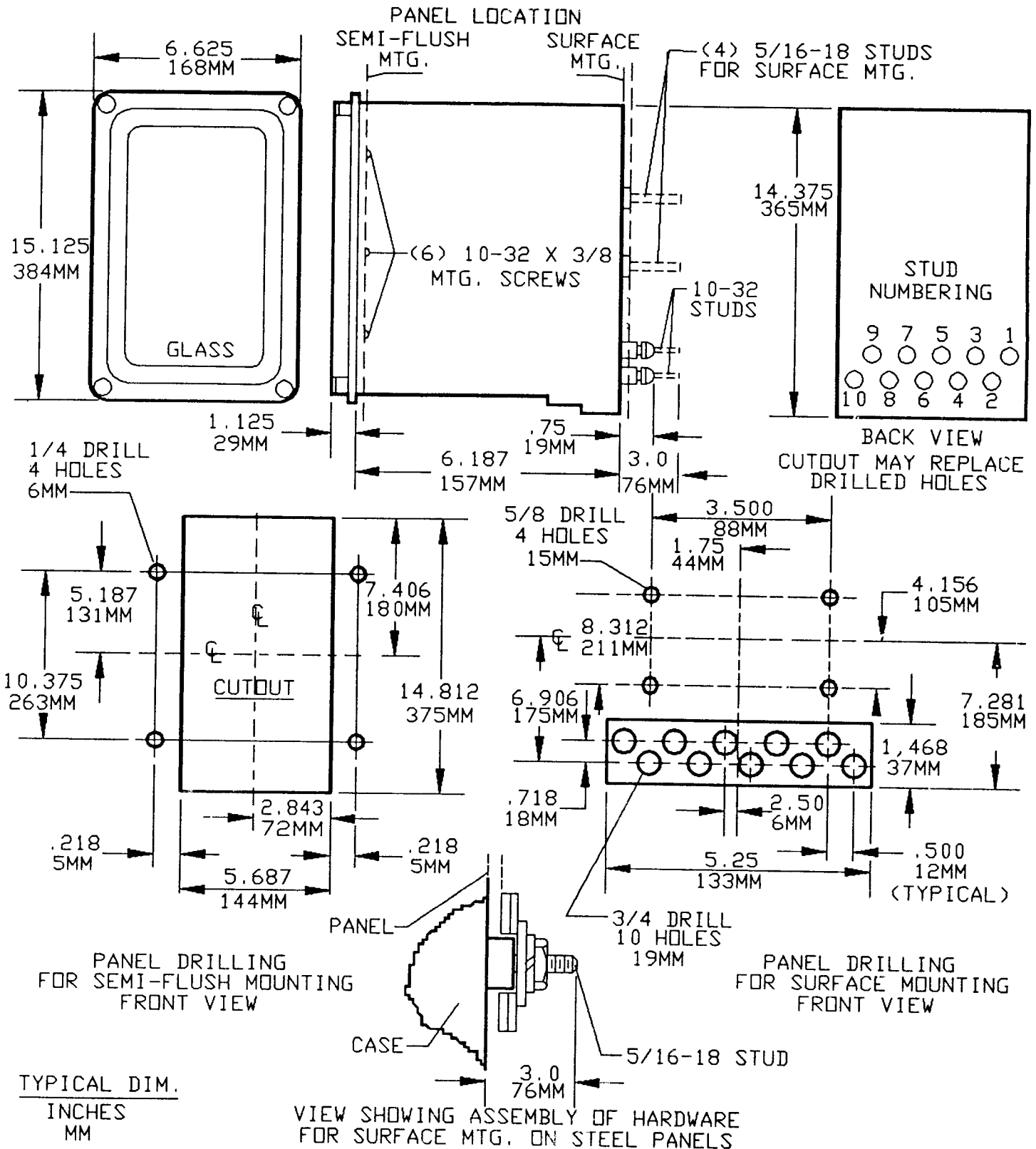


Figure 18 (K6209273-5) Outline and Panel Drilling Dimensions for Medium Single End (M1) Case of Relay Type STD

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(6/93) (1500)

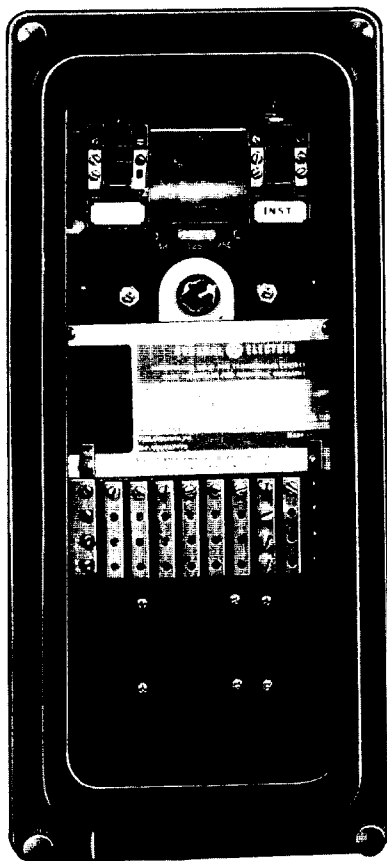
General Electric Company
205 Great Valley Parkway
Malvern, Pennsylvania 19355-1337



INSTRUCTIONS

**TRANSFORMER DIFFERENTIAL RELAYS WITH
PERCENTAGE AND HARMONIC RESTRAINT**

TYPES STD15C and STD16C



*GE Protection and Control
205 Great Valley Parkway
Malvern, PA 19355-1337*

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TRANSFORMER DIFFERENTIAL RELAYS WITH PERCENTAGE AND HARMONIC RESTRAINT

STD15C and STD16C

INTRODUCTION

Relays of the STD type are transformer differential relays provided with the features of percentage and harmonic restraint. A static decision unit controls a small telephone-type relay that provides the contact output.

Percentage restraint permits accurate discrimination between internal and external faults at high current, while harmonic restraint enables the relay to distinguish, by the difference in waveform, between the differential current caused by an internal fault, and that of transformer magnetizing inrush.

DESCRIPTION

Each Type STD relay is a single-phase unit. The Type STD15C relay is designed to be used for the protection of two-winding power transformers and has two through-current restraint circuits and one differential-current circuit.

The Type STD16C relay is designed for use with three-winding power transformers and has three through-current restraint circuits and one differential-current circuit. It may also be used for four-circuit transformer protection (see Figure 1) when only three circuits require through-current restraint, while the fourth circuit, being the weakest, needs no through-current restraint.

APPLICATION

The current transformer ratios and relay taps should be selected to obtain the maximum sensitivity without risking thermal overload of the relay or current transformer (CT), or the possibility of misoperation. Therefore, current transformer ratios in the various windings of the power transformer should be selected with the following points in mind:

1. The lower the relay tap and the lower the CT ratio selected, the higher will be the sensitivity. However, the lowest CT ratio and the lowest relay tap may not be compatible with some of the following restrictions. Where a choice is available of increasing either the CT ratio or the relay tap, it is desirable to increase the CT ratio in preference to the relay tap.

Since the relay burden is likely to be small compared to the lead burden, increasing the CT ratio tends to improve the relative performance of the CTs, as a result of reducing the maximum secondary fault current and increasing the accuracy of the CTs.

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes, the matter should be referred to the General Electric Company.

To the extent required the products described herein meet applicable ANSI, IEEE and NEMA standards; but no such assurance is given with respect to local codes and ordinances because they vary greatly.

2. The CT secondary current should not exceed the continuous thermal rating of the CT secondary winding.
3. The relay current corresponding to maximum kVA (on a forced-cooled basis) should not exceed twice tap value, which is the thermal rating of the relay.
4. The CT ratios should be high enough that the secondary currents will not damage the relay under maximum internal fault conditions (refer to **RATINGS**).
5. The relay current corresponding to rated kVA of the power transformer (on self-cooled basis) should not exceed the relay tap value selected (magnetizing inrush might operate the instantaneous overcurrent unit). If the transformer under consideration does not have a self-cooled rating, the transformer manufacturer should be consulted for the "equivalent self-cooled rating"; that is the rating of a self-cooled transformer that would have the same magnetizing inrush characteristics as the transformer being considered.
6. The current transformer tap chosen must be able to supply the relay with 8 times rated relay tap current, with an error of less than 20% of the total current. If the current transformers produce an error of greater than 20% at less than 8 times tap value, the harmonic content of the secondary current may be sufficient to cause false restraint on internal faults.
7. The CT ratios should be selected to provide balanced secondary current on external faults. Since it is rarely possible to match the secondary currents exactly by selection of current transformer ratios, ratio-matching taps are provided on the relay by means of which the currents may usually be matched within 5%. When the protected transformer is equipped with load-ratio control it is obvious that a close match cannot be obtained at all points of the ratio-changing range. In this case, the secondary currents are matched at the middle of the range and the percentage differential characteristic of the relay is relied upon to prevent relay operation on the unbalanced current which flows when the load-ratio control is at the ends of the range.
8. In some applications, the power transformer will be connected to the high voltage or low voltage system through four breakers (as shown in Figure 1) as for example in a ring-bus arrangement. In this case, the CT ratios must be selected so that the secondary windings will not be thermally overloaded on load current flowing around the ring in addition to the transformer load current. It is recommended that CTs on each of the two low voltage (or high voltage) breakers be connected to a separate restraining winding to assure restraint on heavy through-fault current flowing around the ring bus.

It is not desirable to protect two parallel transformer banks with one set of differential protection, since the sensitivity of the protection would be reduced. In addition, if the banks can be switched separately, there is a possibility of false operation on magnetizing inrush to one transformer bank, causing a "sympathetic inrush" into the bank already energized. In this case, the harmonics tend to flow between the banks, with the possibility that there will be insufficient harmonics in the relay current to restrain the relay.

Typical elementary diagrams for the STD15C and STD16C are illustrated in Figures 2 and 3.

CALCULATION OF SETTINGS

METHOD

The calculations required for determining the proper relay and CT taps are outlined below. A sample calculation, for the transformer shown in Figure 4, is then given.

CURRENT TRANSFORMER CONNECTIONS

Power Transformer Connections

Delta-Wye
Wye-Delta
Delta-Delta
Wye-Wye
Delta-Zigzag with 0° phase
shift between primary and
secondary

Current Transformer Connections

Wye-Delta
Delta-Wye
Wye-Wye
Delta-Delta
Delta-Delta

DETERMINATION OF CT TURNS AND TYPE STD RELAY TAP SETTING

1. Determine the maximum line currents (Max. I) on the basis that each power transformer winding may carry the maximum forced-cooled rated kVA of the transformer.

$$\text{Max. } I_p = \frac{\text{Maximum Transformer kVA}}{\sqrt{3} \text{ (Line kV)}}$$

2. Determine the full-load rated line currents (100% I_p) on the basis that each power transformer winding may carry the full self-cooled rated kVA of the transformer, or the "equivalent" self-cooled ratings.

$$100\% I_p = \frac{100\% \text{ Transformer kVA}}{\sqrt{3} \text{ (Line kV)}}$$

Actually, this calculation does not mean that all windings will necessarily carry these maximum load currents continuously. This is only a convenient way of calculating the currents in the other windings in proportion to their voltage ratings. This is the requirement for selecting the relay tap setting so that the relay will not operate for any external fault.

3. Select CT ratios so that the secondary current corresponding to maximum I_p does not exceed the CT secondary thermal rating (5 amperes). In the case where a transformer is connected to a ring bus, for example, the CT ratio should be selected so that the CT thermal rating will not be exceeded by the maximum load current in either breaker. Also, select CT ratios so that the relay currents can be properly matched by means of the relay taps. (Highest current not more than 3 times lowest current).

For Wye-connected CTs

$$\text{Tap Current} = \frac{100\% I_p}{N}$$

For Delta-connected CTs

$$\text{Tap Current} = \frac{100\% I_p \sqrt{3}}{N}$$

where N is the number of CT secondary turns.

4. Check the matching of relay currents to relay taps, to keep the mismatch error as low as possible.

Calculate the percentage of mismatch as follows: on two-winding transformers, determine the ratio of the two relay currents and the tap values selected. The differences between these ratios, divided by the smaller ratio, is the percent of mismatch. The mismatch normally should not exceed 5%.

For three-winding transformers, the percent of mismatch error should be checked for all combinations of currents or taps.

If taps cannot be selected to keep this percentage error within allowable limits, it will be necessary to choose a different CT ratio on one or more lines, to obtain a better match between relay currents and relay taps.

5. Check to see that the sum of the relay currents that will be applied to the relay for a fault at the terminals of the power transformer is less than 220 amperes RMS for 1 second. If the period during which a fault current flows in the relay can be definitely limited to a shorter time, a higher current can be accommodated in accordance with the relation:

$$(\text{Amperes})^2 \times \text{seconds} = 48,400$$

Also check that the sum of the multiples of tap current on an internal or external fault do not exceed 150.

CURRENT TRANSFORMER RATIO ERROR

The CT ratio error must be less than 20% at 8 times relay rated tap current. This is based on the instantaneous unit being set at its normal setting, which is 8 times tap rating. If the instantaneous unit pickup is raised above this value, the 20% figure must be reduced, as described in the **CHARACTERISTICS** section.

The calculations listed below are for the worst-fault condition, as far as CT performance is concerned, which is an internal ground fault between the CT and the transformer winding, with none of the fault current supplied through the neutral of the protected transformer.

1. Determine the burden on each CT, using the following expressions:

- a. For Wye-connected CTs

$$Z = B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 1})$$

- b. For Delta-connected CTs

$$Z = 2B + \frac{N_e + 2f}{1000} + 2R \text{ Ohms} \quad (\text{Equation 2})$$

where B = STD relay total burden (see Table I)

N = number of turns in bushing CT

e = bushing CT resistance per turn, milliohms (at maximum expected temperature)

f = bushing CT resistance per lead, milliohms (at maximum expected temperature)

R = one-way control cable lead resistance (at maximum expected temperature)

TABLE I

Total Burden for 60 Cycle Relays

STD TAPS AMPS	8 X TAP AMPS	BURDEN OHMS (B)	MIN P.U. AMPS
2.9	23.2	0.180	0.87
3.2	25.6	0.156	0.96
3.5	28.0	0.140	1.05
3.8	30.4	0.120	1.14
4.2	33.6	0.112	1.26
4.6	36.8	0.096	1.38
5.0	40.0	0.088	1.50
8.7	69.6	0.048	2.61

- Determine CT secondary current for 8 times tap setting.

$$I_S = 8 \times \text{STD relay tap rating}$$

(Note: For the location of fault assumed, all the fault current is supplied by one CT, so that CT current and relay current are the same, regardless of whether the CTs are connected in wye or delta.)

- Determine secondary CT voltage required at 8 times tap setting.

$$E_{sec} = I_S Z$$

- From excitation curve of particular tap of current transformer being used, determine excitation current I_E , corresponding to this secondary voltage, E_{sec} .

- Determine the percent error in each CT by the expression:

$$\% \text{ error} = \frac{I_E}{I_S} \times 100$$

This should not exceed 20% of any set of CTs. If it does, it will be necessary to choose a higher tap on that set of CTs, and repeat the calculations on selection of relay taps, mismatch error, and percent ratio error.

PERCENT SLOPE SETTING

The proper percent slope required is determined by the sum of:

- The maximum range of manual taps and the load-ratio-control, or automatic tap changing means, in percent.
- The maximum percent of mismatch of the relay taps.

Set the desired percent slope by means of R3 (See Figure 6A).

The percentage slope setting selected should be greater than the ratio of maximum total error current to the smaller of the through currents. In general, if the total error current does not exceed 20%, the 25% setting is used. If it exceeds 20%, but not 35%, the 40% setting is used.

If the movable lead is used (as in Figure 1, for example) the percent slope setting should be chosen about twice as high, since the movable lead provides no restraint.

EXAMPLE (REFER TO FIGURE 4)I. Determination of CT Turns and STD Relay Tap Settings

1. Transformer and Line	A	B	C
2. Maximum $I_p = 3750/\sqrt{3}$ (Line kV)	19.7	49.5	157
3. 100% $I_p = 3000/\sqrt{3}$ (Line kV)	15.7	39.6	125
4. Assume CT turns (N)	20	20	60
5. Maximum I secondary (less than 5a)	0.98	2.47	2.62
6. 100% I secondary	0.79	1.98	2.08
7. CT connections	Delta	Wye	Delta
8. Relay Current for 100% I Sec.	1.37	1.98	3.60

Select a relay tap for one of the line currents and calculate what the currents in other lines would be if they were increased in the same ratio. If any current is greater than $\sqrt{3}$ times any other, the 8.7 tap should be chosen for it, and new ideal relay taps calculated for the other lines.

9. Ideal Relay Taps (Set C = 8.7)	3.31	4.78	8.7
10. Try Relay Taps	3.2	4.6	8.7
11. Check Mismatch Error			

Ratio of Taps on Lines B-A $\frac{4.6}{3.2} = 1.43$ Ratio of Sec. Lines Currents

$$\frac{1.98}{1.37} = 1.44$$

$$\text{Mismatch } \frac{1.44 - 1.43}{1.43} = 0.7\%$$

Ratio of Taps on Lines C-B $\frac{8.7}{4.6} = 1.89$ Ratio of Sec. Line Currents $\frac{3.60}{1.98} = 1.82$

$$\text{Mismatch } \frac{1.89 - 1.82}{1.82} = 3.8\%$$

Ratio of Taps on Lines C-A $\frac{8.7}{3.2} = 2.72$ Ratio of Sec. Line Currents $\frac{3.60}{1.37} = 2.63$
Mismatch $\frac{2.72 - 2.63}{2.63} = 3.4\%$

(All are less than 5%; therefore, mismatch error is not excessive)

12. Check that the sum of the maximum relay currents is less than 220 amps for 1 second, and therefore, short-time rating of relay is not exceeded.

II. Percent Ratio Error

ASSUME (all measured at their maximum expected temperatures)

One-way CONTROL CABLE RESISTANCE (R) = 0.284 ohms
Bushing A CT resistance per turn (e) = 4 milliohms
" B " " " (e) = 2.5 "
" C " " " (e) = 2.3 "
Bushing A CT resistance per lead (f) = 75 milliohms
" B " " " (f) = 52.5 "
" C " " " (f) = 18.6 "

1. Burdens on CTs, using Equation 1 or Equation 2 from page 6.

a. Line A, $Z = 2 (0.156) + \frac{(20 \times 4) + (2.0 \times 75)}{1000} + 2 (.284)$

$= 0.312 + 0.205 + 0.568 = 1.085$

b. Line B, $Z = 0.096 + \frac{(20 \times 2.5) + (2.0 \times 52.5)}{1000} + 0.568$

$= 0.096 + 0.138 + 0.568 = 0.80$

c. Line C, $Z = 2 (0.048) + \frac{(60 \times 2.3) + (2 \times 18.6)}{1000} + 0.568$

$= 0.096 + 0.180 + 0.568 = 0.833$

	A	B	C
2. Impedance, ohms	1.085	0.8	0.833
3. 8 times tap, amperes	25.6	36.8	69.6
4. E_S CT voltage require (IZ)	27.8	29.4	58.0
5. I_E required, from excitation curve	1.00	50	0.5
6. % Ratio Error	3.4%	136%	0.8%

Exciting current on line B is too high; should try higher tap on CT to improve CT performance.

IA - Repeat - CT Turns and Relay Tap Setting

1. 100% I_p	15.7	39.6	125
2. Try CT turns (necessary to change C also for proper matching)	20	40	80
3. 100% I secondary	0.79	0.99	1.56
4. Relay Current	1.37	0.99	2.70
5. Ideal Relay Taps (Set C = 8.7)	4.40	3.19	8.7
6. Use Relay Taps	4.6	3.2	8.7
7. Mismatch Error is less than 5%			

IIA Repeat - Percent Ratio Error

1. Burden on CTs

Line A, $Z = 0.192 + 0.205 + 0.568 = 0.965$ Line B, $Z = 0.156 + 0.188 + 0.568 = 0.912$ Line C, $Z = 0.096 + 0.226 + 0.568 = 0.890$

2. Impedance Ohms	0.965	0.912	0.890
3. 8 times Tap, Amperes	36.8	25.6	69.6
4. E_{sec} , CT voltage required (IZ)	35.6	23.4	61.9
5. I_E required, from excitation curve	1.1	0.25	0.17
6. % of Ratio Error	3.1%	1.0%	0.3%

Percent error is less than 20%, so CT taps and relay taps are satisfactory.

III Percent Slope Setting

1. Assume load ratio control maximum range	10.0%
2. Relay tap mismatch, from IA above (Lines A-B)	4.6%
Use 25% setting	14.6%

RATINGS

MODELS 12STD15C AND 12STD16C

Continuous Rating

The through-current transformer and differential-current transformer will stand twice tap value for any combination of taps, or they will stand twice tap value if all but one of the restraint windings carry 0 current, and the full restraint current (equal to twice tap value) flows through the differential-current transformer.

Short Time Rating (Thermal)

220 amperes for 1 second, measured in the primary of any transformer of the type STD relay. Higher currents may be applied for shorter lengths of time in accordance with the following equation:

$$I^2t = 48,400$$

where I = current amperes
 t = time in seconds.

Short Time (Electrical)

For both the STD15C and STD16C the sum of the multiples of tap current fed to the relay from the several sets of current transformers should not exceed 150. These multiples should be calculated on the basis of RMS symmetrical fault current. This limitation is a result of the voltage rating of the rectifiers in the through-current restraint circuit. Note that in Figure 1 external fault current can flow through circuit breakers 52-1 and 52-2 without being limited by the transformer impedance.

TABLE II

	TARGET AND SEAL-IN UNIT		
	2.0 Amp Tap	0.6 Amp Tap	0.2 Amp Tap
DC Resistance	0.13 Ohms	0.6 Ohms	7 ohms
Carry Continuously	0.5 Amps	1.5 Amps	0.25 Amps
Carry 30 Amps for	4 Secs.	0.5 Secs.	----
Carry 10 Amps for	30 Secs	4 Secs.	0.2 Secs.

AUXILIARY RELAY CONTROL CIRCUIT

The STD15C and STD16C relays are available for use with 48, 125, and 250 DC or 48, 110 and 220 DC control voltage, depending upon the relay model. A plate with small links located on the front of the relay enables the selection of one of these voltages.

The STD relay is provided with two open contacts connected to a common output circuit. The current-closing rating of the contact is 30 amps for voltages not exceeding 250 volts. If more than one circuit breaker is to be tripped, or if the tripping current exceeds 30 amperes, an auxiliary relay must be used with the STD relay. After the breaker trips, it is necessary that the tripping circuit of these relays (STD and auxiliary) be de-energized by an auxiliary switch on the circuit breaker or by other automatic provisions. A manual reset relay is recommended and normally used.

CHARACTERISTICSPICKUP AND OPERATING TIME

The operating characteristic is shown in Figure 7. The curve for various percentage slopes shows the percent slope versus the throughcurrent flowing in the transformer. The percentage slope is a figure given to a particular slope tap setting, and indicates an approximate slope characteristic. Pickup at zero restraint is approximately 30% of tap value (see Table III). The dropout time, when the operating current is reduced to zero from any value above pickup, is less than 25 milliseconds.

Curves of the operating time of the main unit and of the instantaneous unit are shown in Figure 5, plotted against differential current. The main unit operating time includes auxiliary unit operating time.

OVERCURRENT UNIT PICKUP

The overcurrent unit is adjusted to pick up when the differential current transformer ampere-turns are 8 times the ampere turns produced by rated tap current flowing in that tap. For example:

When only one CT supplies current, and the tap plug for the CT is in the 5 ampere tap, 40 amperes are required for pickup. This pickup value is based on the AC component of current transformer output only, since the differential-current transformer in the relay produces only a half cycle of any DC (offset) component present.

If ratio matching taps are chosen so that rated CT current is not greater than the tap rating on a self-cooled basis, the overcurrent unit will not pick up on magnetizing inrush. If CT currents are greater than tap rating, there is danger that the unit may pick up, especially on small transformer banks. If this happens, it is recommended that the CT ratio or relay tap setting be increased, rather than increasing the pickup of the overcurrent unit. If the overcurrent setting must be raised, the requirements on CT error will be more stringent, in accordance with the following equation:

$$E = 20 - (2.5) (P-8)$$

where E = CT error current in percent, at pickup of the overcurrent unit
P = Pickup of overcurrent in multiples of tap setting.

PERCENTAGE DIFFERENTIAL CHARACTERISTICS

The percentage differential characteristics are provided by through-current restraint circuits. In addition to the operating circuit, which is energized by the differential current of the line current transformers, the relay is equipped with a restraining circuit that is indirectly energized by the transformer secondary currents. For the relay to operate, the current transformer secondary currents must be unbalanced by a certain minimum percentage, determined by the relay slope setting (as shown in Figure 7). This characteristic is necessary to prevent false operation on through-fault currents. High currents saturate the cores of the current transformers and cause their ratios to change, with the result that the secondary currents become unbalanced. Percentage restraint is also required to prevent operation by the unbalanced currents caused by imperfect matching of the secondary currents, as previously described under Determination of CT Turns and STD Relay Tap Settings.

HARMONIC RESTRAINT CHARACTERISTICS

At the time a power transformer is energized, current is supplied to the primary that establishes the required flux in the core. This current is called magnetizing inrush, and in the primary winding flows only through the current transformers. This causes an unbalance current to flow in the differential relay, which would cause false operation if means were not provided to prevent it.

Power system fault currents are of a nearly pure sine waveform, plus a DC transient component. The sine waveform results from sinusoidal voltage generation and nearly constant circuit impedance. The DC component depends on the time in the voltage cycle at which fault occurs, and upon circuit impedance magnitude and angle.

Transformer magnetizing-inrush currents vary according to the extremely variable exciting impedance resulting from core saturation. They are often of high magnitude, occasionally having an RMS value with 100% offset, approaching 16 times full-load current for worst conditions of power transformer residual flux and point-of-circuit closure on the voltage wave. They have a very distorted waveform made up of sharply peaked half-cycle loops of current on one side of the zero axis, and practically no current during the opposite half cycles. The two current waves are illustrated in Figure 8.

Any current of distorted, nonsinusoidal waveform may be considered as being composed of a DC component plus a number of sine-wave components of different frequencies; one of the fundamental system frequency, and the others, called "harmonics," having frequencies which are 2, 3, 4, 5, etc., times the fundamental frequency. The relative magnitudes and phase positions of the harmonics with reference to the fundamental determine the waveform. When analyzed in this manner, the typical fault-current wave is found to contain only a very small percentage of harmonics, while the typical magnetizing-inrush-current wave contains a considerable amount.

The high percentage of harmonic currents in the magnetizing-inrush-current wave afford an excellent means of distinguishing it electrically from the fault-current wave. In the Type STD relays, the harmonic components are separated from the fundamental component by suitable electric filters. The harmonic current components are passed through the restraining circuit of the relay, while the fundamental component is passed through the operating circuit. The DC component present in both the magnetizing-inrush- and offset-fault-current waves is largely blocked by the auxiliary differential-current transformer inside the relay, and produces only a slight momentary restraining effect. Relay operation occurs on differential-current waves in which the ratio of harmonics to fundamental is lower than a given predetermined value, for which the relay is set (e.g. an internal fault-current wave), and is restrained on differential-current waves in which the ratio exceeds this value (e.g. magnetizing-inrush-current wave).

BURDENS

Burdens are shown in Table III and IV. Burdens and minimum pickup values are substantially independent of the percent slope settings, and are all approximately 100% power factor. Figures given are burdens imposed on each current transformer at 5.0 amperes.

TABLE III

TAP SETTING AMPS	ZERO RESTRAINT PICKUP AMPS	OPERATING CIRCUIT *		RESTRAINT CIRCUIT	
		60 CYCLE RELAYS		60 CYCLE RELAYS	
		BURDEN VA	IMPEDANCE OHMS	BURDEN VA	IMPEDANCE OHMS
2.9	0.87	3.2	0.128	1.3	0.052
3.2	0.96	2.7	0.108	1.2	0.048
3.5	1.05	2.4	0.096	1.1	0.044
3.8	1.14	2.0	0.080	1.0	0.040
4.2	1.26	1.9	0.076	0.9	0.036
4.6	1.38	1.6	0.064	0.8	0.032
5.0	1.50	1.5	0.060	0.7	0.028
8.7	2.61	0.7	0.028	0.5	0.020

* Burden of operating coil is 0 under normal conditions.
Burden of 50-cycle relay is the same or slightly lower.

TABLE IV

DC CONTROL CIRCUIT BURDEN						
RATED VOLTS	48	125	250	48	110	220
MILLIAMPS	140	105	88	140	96	80

CONSTRUCTION

Figure 6 shows the internal arrangement of the components of the STD15C relay. Refer also to the internal connection diagrams, Figures 10 and 11, which will identify the parts more completely.

CURRENT TRANSFORMERS

In the Type STD15C relay, the through-current transformer has two primary windings, one for each line-current-transformer circuit. Winding No. 1 terminates at stud 6 and winding No. 2 terminates at stud 4.

In the Type STD16C relay, there are three separate through-current transformers, each with only one primary winding, and each terminating at a separate stud, windings No. 1, No. 2 and No. 3 corresponding to studs 6, 4 and 3 in that order.

In both relays there is a differential-current transformer with one primary lead brought out to stud 5.

The primary circuit of each of these transformers is completed through a special tap block arrangement. Two or three horizontal rows of tap positions are provided (depending on whether the relay is a Type STD15C or STD16C), one row for each through-current transformer winding. A tap on the differential-current transformer is connected to a corresponding tap of the through-current restraint windings by inserting tap plugs in the tap blocks.

When the STD16C relay is used on four-circuit applications, as shown in Figure 1, the fourth circuit CT is connected to stud 7, and the jumper normally connected between terminals 6 and 7 at the rear of the relay cradle should be disconnected at the terminal 6 end and reconnected to the upper row in the tap block (above the row marked winding 1), which connects it directly to the differential-current transformer in the STD relay. The terminal on the movable lead should be placed under the tap screw that gives the best current match for the current in the movable lead.

The taps permit matching of unequal line-current transformer secondary currents. The tap connections are so arranged that in matching the secondary currents, when a tap plug is moved from one position to another in a horizontal row, corresponding taps on both the differential-current transformer winding and one of the through-current transformer windings are simultaneously selected so that the percent through-current restraint remains constant.

It should be recognized that pickup current flows not only through differential-current transformer but also through one of the primary windings of the through-current transformer, producing some restraint. However, compared to the operating energy, this quantity of restraint is so small that it may be assumed to be zero.

THROUGH-CURRENT RESTRAINT CIRCUIT

A full wave bridge rectifier receives the output of the secondary of each through-current restraint transformer. In the STD16C relay, the DC outputs of all three units are connected in parallel. The total output is directed to the percent slope

rheostat (R3) located on the front of the relay. By means of adjusting the rheostat, the percent slope may be varied from 15% to 40%. The output is put through an isolating transformer, rectified, and directed to the sensitive solid state amplifier that controls the telephone-type relay.

DIFFERENTIAL-CURRENT CIRCUIT

The differential-current transformer secondary supplies 1) the instantaneous unit directly; 2) the operating (tripping) signal to the solid-state amplifier through a series-tuned circuit; and 3) the harmonic restraint isolating transformer through a parallel resonant filter. The operating and restraint currents are each rectified by a full-wave bridge prior to being supplied to the sensitive sense amplifier.

The series resonant circuit is made up of a 5 microfarad capacitor (C1) and a reactor (L1) that are tuned to pass currents of the fundamental system frequency and to offer high impedance to currents of other frequencies. Resistor R1 is connected in parallel on the AC side of the operate rectifier, and can be adjusted to give the desired amount of operate current. The output of the rectifier is applied to the operating circuit of the sense amplifier.

The parallel resonant trap is made of a 15 microfarad capacitor (C2) and a reactor (L2) that are tuned to block fundamental frequency currents while allowing currents of harmonic frequencies to pass with relatively little impedance. Resistor R2 is connected in parallel on the AC side of the harmonic restraint rectifier, and can be adjusted to give the desired amount of harmonic restraint. The output of the rectifier is paralleled with the through-current restraint currents and applied to the restraint circuit of the sense amplifier.

It will be evident that if the differential current applied to the relay is sinusoidal and of system frequency, it will flow mostly in the operating circuit and hence cause the relay to yield an output. If, however, the differential circuit contains more than a certain percentage of harmonics, the relay will be restrained from operating by the harmonic currents flowing in the restraint circuit.

A Thyrite^R resistor connected across the secondary of the differential-current transformer limits any momentary high-voltage peaks which may occur, thus protecting the rectifiers and capacitors from damage, without materially affecting the characteristics of the relay.

OVERCURRENT UNIT

The instantaneous unit is a hinged-armature relay with a self-contained target indicator. On extremely heavy internal fault currents, this unit will pick up and complete the trip circuit. The instantaneous unit target will be exposed, to indicate that tripping was through the instantaneous unit.

Because of saturation of the CTs and relay transformers at high fault currents, it is possible that less operating currents will be provided from the differential-current transformer than the percentage slope tap would imply, and more harmonic restraint will be provided than the actual harmonic content of the fault current would supply. As a result, under conditions of a high internal fault current, the main unit may be falsely restrained. Tripping is assured, however, by the

overcurrent unit operation. Pickup is set above the level of differential current produced by maximum magnetizing inrush current. Figure 5 shows the relative levels of pickup and speed of operation of the main unit and the overcurrent unit.

MAIN OPERATING UNIT

The primary functioning unit of the STD relay is a solid-state amplifier, whose output controls a simple telephone relay. The sense amplifier is shown in Figures 10 and 11 as a large rectangle. The amplifier consists of many electronic components mounted on a printed circuit card in the top half of the relay. This printed circuit card is installed in a ten-prong printed card design socket. A schematic of this card is shown in Figure 9. This component is adjusted prior to leaving the factory, and should require no further attention.

The telephone-type relay is mounted vertically in the mid-section of the relay. It, too, has been carefully adjusted at the factory, and should require no further attention. If this small relay has been disturbed, refer to the section under **ADJUSTMENTS**.

TARGET AND SEAL-IN UNIT

There is a target and seal-in unit mounted on the top left of the relay. This unit has its coil in series and its contacts in parallel with the main contacts of the telephone-type relay. When the telephone-type relay contacts close, the seal-in unit operates, raising its target into view and sealing around the telephone-type contacts. The target of this unit will remain exposed until released by pushing a button beneath the lower left corner of the cover of the relay case.

CASE

The case is suitable for surface or semi-flush panel mounting, and an assortment of hardware is provided for either method. The cover attaches to the case, and carries the target reset mechanism for the trip indicator and instantaneous unit. Each cover screw has provision for a sealing wire.

The case has studs or screw connections at the bottom for the external connections. The electrical connections between the relay unit and the case studs are made through spring-backed contact fingers mounted in stationary molded inner and outer blocks, between which rests a removable connecting plug that completes the circuit. The outer block, attached to the case, holds the studs for the external connections, and the inner block has terminals for the internal connections.

The relay mechanism is mounted in a steel framework called the cradle, and is a complete unit, with all leads terminating at the inner block. This cradle is held firmly in the case by a latch at the top and bottom and a guide pin at the back of the case. The case and cradle are so constructed that the relay cannot be inserted in the case upside down. The connecting plug, besides making the electrical connection between the blocks of the cradle and case, also locks the latch in place. The cover, which is fastened to the case by thumbscrews, holds the connecting plug in place.

To draw out the relay unit, the cover is removed and the plug is drawn out. Shorting bars are provided in the case to short the current-transformer circuits

(see Figure 12). The latches are then released and the relay unit can be easily drawn out.

A separate testing plug can be inserted in place of the connecting plug to test the relay in place on the panel, either from its own source of current, or from other sources. Or, the relay unit can be drawn out and replaced by another which has been tested in the laboratory.

RECEIVING, HANDLING AND STORAGE

These relays, when not included as part of a control panel, will be shipped in cartons designed to protect them against damage. Immediately upon receipt of a relay, examine it for any damage sustained in transit. If injury or damage resulting from rough handling is evident, file a damage claim at once with the transportation company and promptly notify the nearest General Electric Sales Office.

Reasonable care should be exercised in unpacking the relay, in order that none of the parts may be injured or the adjustments disturbed.

If the relays are not to be installed immediately, they should be stored in their original cartons in a place that is free from moisture, dust and metallic chips. Foreign matter collected on the outside of the case may find its way inside when the cover is removed, and cause trouble in the operation of the relay.

ACCEPTANCE TESTS

Immediately upon receipt of the relay, an inspection and acceptance test should be made to make sure that the relay has not been damaged in shipment and that the relay calibrations are unchanged.

VISUAL INSPECTION

Check the nameplate stamping to make sure that the model number, rating and calibration range of the relay received agree with the requisition.

Remove the relay from its case and check by visual inspection that there are no broken or cracked molded parts, or other signs of physical damage, and that all screws are tight.

MECHANICAL INSPECTION

Check the operation of the telephone-type relay and instantaneous overcurrent unit manually, to see that they operate smoothly, without noticeable friction or binds. Check the contact gap and wipe of these units, which should agree with values given in the section on **SERVICING**.

ELECTRICAL TESTS

It is recommended that the following electrical tests be made immediately upon receipt of the relay.

1. Minimum pickup of main operating unit.
2. Minimum pickup of the instantaneous overcurrent unit.
3. A single check point on the harmonic restraint characteristic.
4. A single check point on the slope characteristic curve, for the approximate slope expected to be used.

Test Equipment

In order to facilitate tests, the following test equipment is recommended:

1. Two load boxes for regulating the test currents
2. Three ammeters (two AC and one DC) for measuring the test currents
3. A test rectifier for checking the relay's response to the second harmonic. (See Figure 13.)
4. One indicating lamp
5. Two single-pole double-throw switch selectors
6. A double-pole single-throw line switch.

Check the pickup of the main unit, using the connections shown in Figure 14. During this test, the selector switches (S2 and S4) are open, and current passes through one restraint winding and the operate winding only. For example, with a relay set with a 25% slope and at the 2.9 ampere ratio-matching taps, the main unit should pick up at 30% of tap rating, $\pm 10\%$, or the pickup should be between 0.78 and 0.96 amperes. A source of DC power at rated voltage should be connected as shown in Figure 14; the indicating lamp will provide a signal, showing that the main unit has operated.

For an additional pickup test, the pickup should be 1.5 amperes, with current flowing in terminals 5 and 6 and the tap plugs in the 5 ampere tap and the 25% slope tap position. If the pickup is between 1.35 and 1.65 amperes, no adjustment should be made. The pickup of the relay has wider permissible variations than most protective relays, but due to the relay design and application, the relay accuracy is entirely adequate under all conditions, even during transformer magnetizing inrush or severe fault conditions.

With the selector switch, ST, in the A position, check the harmonic current restraint, as described in the section on **INSTALLATION PROCEDURE**.

The instantaneous overcurrent unit should be checked by passing a high current through the 5-6 terminals. The pickup should be about eight times tap rating.

Check through-current restraint, as described in the section on **INSTALLATION PROCEDURE**.

INSTALLATION PROCEDURE

TESTS

Before placing the relays in service, check the relay calibration to be used in its final location, to ensure that it is correct. The following test procedure is outlined for this purpose.

CAUTION

The Relay calibration is accomplished by adjusting resistors R1, R2 and R3. Changes made in any one of these resistors will affect the other two settings. In the event one setting is changed, the pickup, harmonic restraint, and through-current restraint adjustment procedures should be repeated until no further deviation from proper calibration is noted. Best results can be obtained if the through-current restraint adjustment is made only after the other two settings are correct.

PICKUP

The test circuit for pickup is shown in Figure 14, with S2 open. The first values given are for a 5 ampere rated relay. Those in () are for a 1 ampere rated relay. Pickup should be 1.5 (0.3) amperes with current flowing in terminals 5 and 6, and the tap plugs in the 5 (1.0) ampere position, and 25% slope tap setting. The pickup operation should be repeated several times, until two successive readings agree within 0.01 ampere with the total pickup current being interrupted between successive checks. If pickup is found to be from 1.35 to 1.65 (0.27 to 0.33), the setting should not be disturbed.

With DC control voltage applied to the proper terminals of the relay, the pickup of the telephone-type relay can be used as an indication of operation of the amplifier. This voltage may be applied as shown in Figure 15, and the indicating lamp will verify that the amplifier has produced an output signal.

Before R1 is adjusted for pickup, put a DC voltmeter (one volt scale) on pin 2 (-) and pin 8 (+) of the sense amplifier card. The pins are counted from right to left when viewed from the card socket wiring connections. Apply pickup current and adjust R1 for a voltage input to the sense amplifier card of 0.430 to 0.470 volts. If the pickup is not in limits with this setting, then adjust P1 on the sense amplifier card to obtain the proper pickup value.

HARMONIC CURRENT RESTRAINT

The harmonic restraint is adjusted by means of a Test Rectifier used in conjunction with suitable ammeters and load boxes. The test circuit is as shown in Figure 15, with S2 closed to position A. Tests should be made on the 5.0 (1.0) ampere and 25% slope taps.

The analysis of a single-phase half-wave rectified current shows the presence of fixed percentages of DC, fundamental, and second harmonic components, as well as negligible percentages of all higher even harmonics. This closely approximates a typical transformer inrush current, as seen at the relay terminals, inasmuch as its principal components are DC, fundamental, and second harmonic. Although the percent second harmonic is fixed, the overall percentage may be varied by providing a path for a controlled amount of by-passed current of fundamental frequency. The by-passed current is added in phase with the fundamental component of the half-wave rectified current, and thus provides a means of varying the ratio of second harmonic current to fundamental current.

The following expression shows the relationship between the percent second harmonic, the DC component, and the by-pass current.

$$\% \text{ Second Harmonic} = \frac{0.212 I_{DC}}{0.45I_1 + 0.5I_{DC}} \times 100$$

Figure 16 is derived from the above expression. It shows the percent second harmonic corresponding to various values of by-pass current (I_1) for a constant DC set at 4.0 (0.8) amperes.

The relay is calibrated with a composite RMS current of two times tap value. When properly set, the relay will restrain with greater than 20% second harmonic, but will operate with second harmonic equal to 20% or lower. With the DC ammeter (I_2) set at 4.0 (0.8) amperes, the auxiliary relay should just begin to close its contacts with gradually increasing bypass current (I_1) at a value of 4.5-5.5 (0.9-1.1) amperes. This corresponds to 19-21% second harmonic (see Figure 16), providing a 2% tolerance at the set point to compensate for normal fluctuations in pickup. It should be noted that the current magnitude in the rectifier branch (I_2) is slightly influenced by the application of by-pass current (I_1) and should be checked to make sure it is maintained at its proper value.

If harmonic restraint is found to be out of adjustment, it may be corrected by adjusting rheostat R2. (See **CAUTION** at beginning of **INSTALLATION PROCEDURES** section.)

THROUGH-CURRENT RESTRAINT

The through-current restraint, which gives the relay the percentage differential or percent slope characteristics, is shown in Figure 7. It may be checked and adjusted using the circuit illustrated in Figure 15, with S2 closed to position B. Ammeter I_1 reads the differential current and I_3 reads the smaller of the two through-currents.

CAUTION

These currents should be permitted to flow for only a few seconds at a time, with cooling periods between tests; otherwise, the coils will be overheated.

NOTE: The percent slope tolerance is 10% of nominal, all in the plus direction. This is to ensure that the slope characteristic never falls below set point value.

In testing STD16C relays, the setting should be checked with switch S4 first in one position and then the other, thus checking all the restraint coils. With the current tap plugs in 5.0 (1.0) ampere position and the percent slope set in the 40% position, the relay should just pick up for values of the I_1 and I_3 currents indicated in Table V (VA). Repeat with the percent slope tap set in the 25% and 15% positions. If any one of these set points is found to be other than as prescribed, the adjustment may be made by adjusting R3. It should be noted that the current magnitude in the through-current branch (I_3) is slightly influenced by the application of differential current (I_1) and should be checked to make sure that it is maintained at its proper value.

TABLE V

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	30	12.0-13.2	40.0-44.0
25	30	7.5- 8.3	25.0-27.5
15	30	4.5- 5.0	15.0-16.5

TABLE VA

% SLOPE SETTING	AMPERES		TRUE SLOPE ($I_1/I_3 \times 100$)
	I_3	I_1	
40	6	2.4-2.64	40-44
25	6	1.5-1.66	25-27.5
15	6	0.9-1.00	15-16.5

Any change in R3 to give the desired slope will have small effect upon minimum pickup and harmonic restraint. However, after the slope setting has once been set, any adjustment of minimum pickup will change the slope characteristics. The slope set points must then be rechecked, to make sure that they are still in accordance with Table III.

INSTANTANEOUS OVERCURRENT UNIT

This unit is located at the upper right-hand side of the relay. Its setting may be checked by passing a high current of rated frequency through terminals 5 and 6. The unit should pick up at 8 times the tap rating, as described under **CHARACTERISTICS**. If the setting is incorrect, it may be adjusted by loosening the lock nut at the top of the unit and turning the cap screw until the proper pickup is obtained. **In making this adjustment, the current should not be allowed to flow for more than approximately one second at a time.**

DROPOUT OF MAIN UNIT

After the other tests are complete, check the dropout of the main unit, as described in the **ACCEPTANCE TESTS** section.

LOCATION

The location should be clean and dry, free from dust and excessive vibration, and well lighted to facilitate inspection and testing.

MOUNTING

The relay should be mounted on a vertical surface. The outline and panel drilling dimensions are shown in Figure 18.

CONNECTIONS

Internal connection diagrams are shown in Figures 10 and 11. Typical wiring diagrams are given in Figures 1, 2 and 3 for differential applications.

Of course, any through-current transformer winding may be used for any power transformer winding, provided the taps are properly chosen.

When the relay is mounted on an insulating panel, one of the steel supporting studs should be permanently grounded by a conductor not less than No. 12 AWG gage copper wire, or its equivalent.

Every circuit in the drawout case has an auxiliary brush. (See Figure 12.) This is the shorter brush in the case, which the connecting plug should engage first. On every current circuit or other circuit with shorting bars, make sure the auxiliary brushes are bent high enough to engage the connecting plug or test plug before the main brushes; otherwise the CT secondary circuit may be opened where one brush touches the shorting bar before the circuit is completed from the plug to the other, main brush.

ADJUSTMENTS

TAP PLUG POSITIONINGRatio Matching Adjustment

To obtain a minimum unbalance current in the differential circuit, means are provided in the STD relay to compensate for unavoidable difference in current-transformer ratios. Taps on the relay transformer primary windings are rated 8.7 (1.74), 5.0 (1.0), 4.6 (0.92), 3.8 (0.76), 3.5 (0.7), 3.2 (0.64), and 2.9 (0.58) amperes for each line-current transformer. The tap plugs should be moved to the locations which most nearly match the expected CT currents for the same kVA assumed in each of the power transformer windings. The selection of taps should be guided by the method outlined under **CALCULATIONS**.

CAUTION

The connection plug must be removed from the relay before changing tap positions, in order to prevent open-circuiting a CT secondary. A check should be made after changing taps, to ensure that only one plug is left in any horizontal row of tap holes. Inaccurate calibration and overheating may result if more than one plug is connected to any one winding.

Unbalance Current Measurement

Unbalance current measurement is useful in checking the best tap setting when matching current-transformer ratios in the field. It is also useful in detecting errors or faults in the current transformer winding, or small faults within the power transformer itself, where the fault current is too low to operate the relay.

The type STD relays have a special arrangement for measuring the unbalance current flowing in the differential circuit without disturbing the relay connections. Provision is made for temporarily connecting a 5 V high-resistance AC voltmeter (1000 or more ohms per volt) across the secondary of the differential current transformer. This may be done by connecting the meter across terminals 8 and 9 (see Figures 10 and 11). When a perfect match of relay currents is obtained by the ratio-matching taps, the voltmeter will read 0, indicating no unbalance. If the voltmeter reads 1.5 volts or less, the unbalance current entering or leaving a given tap equals approximately 0.03 times the voltmeter reading times the tap rating. For higher voltmeter readings, the approximate unbalance current may be calculated by substituting the voltage reading and tap rating into the following equation:

$$I (\text{unbalance}) = (0.16 \times V - 0.2) \times \text{Tap}$$

The unbalance percentage equals 100 times the unbalance current divided by the measured tap current. For a three-winding bank, this must be checked with load on at least two pairs of windings in order to ensure that the connections are correct.

The curves in Figure 17 show the approximate voltage across terminals 8 and 9 required to operate the relay, for various percent slope tap settings, and through-currents expressed as percentage of tap. To ensure a margin of safety against false operation, the unbalance voltage should not exceed 75% of that required to operate the relay for any given through-current and percent slope tap setting. This extent of unbalance may result from the relatively high error currents of low-ratio bushing CTs at low multiples of tap current.

This curve represents the STD relay characteristic. Measurement of a voltage across studs 8 and 9 which is 75% or less of the value given on the curve, does not necessarily indicate that the relay will operate at higher through-current values. This is especially true where very high through-faults may cause saturation.

Small rectifier-type AC voltmeters are suitable for the measurement of unbalance. **The voltmeter should not be left permanently connected, since the shunt current it draws reduces the relay sensitivity.**

PERCENT SLOPE SETTING

Scribe marks for 15, 25 and 40% slope settings are provided in both the STD15 and STD16 relays. It is common practice to use the 25% setting unless special connections make it advisable to use one of the others. See the corresponding heading under **CALCULATIONS** for further details.

OPERATION

TARGETS

Targets are provided for both the seal-in unit and the instantaneous overcurrent unit. In the event of an internal fault, one or both of these units will operate, depending upon the fault magnitude. This will produce a target indication of the particular unit which operates. After a fault is cleared, the target should be reset by the reset slide located at the lower left-hand corner of the relay.

DISABLING OF TYPE STD RELAY

CAUTION

When bypassing a breaker for maintenance, it will be necessary to disable the relay to prevent false tripping.

If the disabling of the relay is done by a remote switch, rather than by removing the relay connection plug, the following precautions should be taken:

1. The relay must be disabled by short-circuiting studs 8 and 9 of the relay, or by opening the trip circuit at stud 1.
2. If the CT secondaries are short-circuited as part of the disabling procedure, the trip circuit should be opened at stud 1, and studs 8 and 9 should be short-circuited first. **It is not sufficient to rely on short circuiting the CT secondaries alone, because any difference in time of shorting them may cause false tripping.**

MAINTENANCE

CONTACT CLEANING

For cleaning fine silver contacts, a flexible burnishing tool should be used. This consists of a flexible strip of metal with an etched-roughened surface, resembling

in effect a superfine file. The polishing action is so delicate that no scratches are left, yet corroded material will be removed rapidly and thoroughly. The flexibility of the tool insures the cleaning of the actual points of contact.

Fine silver contacts should not be cleaned with knives, files, or abrasive paper or cloth. Knives or files may leave scratches, which increase arcing and deterioration of the contacts. Abrasive paper or cloth may leave minute particles of insulating abrasive material in the contacts, and thus prevent closing.

The burnishing tool described above can be obtained from the factory.

PERIODIC TESTS

An operation test and inspection of the relay and its connections should be made at least once every six months. Tests may be performed as described under INSTALLATION TESTS, or if desired they may be made on the service taps as described in this section.

When inserting or withdrawing a test plug with U-shaped through jumpers to complete the trip circuit through the test plug, similar through jumpers should also be used on studs 8 and 9 to maintain the connections from the relay to the case. **If this is not done, there is a risk of false tripping upon inserting or withdrawing the plug.**

PICKUP

The method for checking pickup is as described under the heading **INSTALLATION TESTS** except, of course, pickup current will be different depending upon the winding (WDG) 1 service tap. Pickup may be determined as follows:

$$I_1 = 0.30 \times \text{WDG 1 Tap}$$

Of course, when checking pickup on a particular service tap, the $\pm 10\%$ expected variation still applies, the acceptable-as-found range being

$$I_1 = 9.0 \times 0.30 \times \text{WDG 1 Tap} \quad \text{to} \quad 1.10 \times 0.30 \times \text{WDG 1 Tap}$$

<u>Example</u>	WDG1 Tap	= 3.5A
	I_1	= $0.90 \times 0.30 \times 3.5$ to $1.10 \times 0.30 \times 3.5$
	I_1	= 0.94 to 1.16 amperes

HARMONIC CURRENT RESTRAINT

The procedure for checking harmonic restraint is as described under the heading **INSTALLATION TESTS**, except that the test current values must be modified as follows:

$$I_2 (\text{DC}) = 0.80 \times \text{WDG 1 Tap}$$

$$I_1 = 0.90 \times \text{WDG 1 Tap} \quad \text{to} \quad 1.10 \times \text{WDG 1 Tap}$$

In the event a suitable DC meter is not available, $I_2 (\text{AC}) = 2.25 \times I_2 (\text{DC})$. (Theoretically, this conversion factor would be 2.22 if the rectifier back resistance were infinite.)

Example WDG 1 Tap = 3.5A
 I_2 (DC) = $0.80 \times 3.5 = 2.8$ amperes
 I_1 = 0.90×3.5 to 1.10×3.5
 I_1 = 3.15 to 3.85 amperes

If DC meter is not available, I_2 (AC) would in this example be
 $2.25 \times 2.8 = 6.30$ amperes.

THROUGH-CURRENT RESTRAINT

In order to check the service tap slope setting, the test current values indicated in Table IV must be modified to take into account any difference in tap settings. Furthermore, the test circuit shown in Figure 15 must be set up such that the lead from ammeter I_3 to the test plug is connected to the stud that connects to the winding with the lowest tap setting. The common lead, of course, is connected to the stud corresponding to the winding with the higher tap setting. For any combination of taps, the percent slope is given in the following equation.

$$\% \text{ Slope} = \left[\frac{T_1}{T_2} \left(\frac{I_1}{I_3} + 1 \right) - 1 \right] \times 100$$

where

T_1 = smaller tap setting
 T_2 = higher tap setting
 I_1 = differential current
 I_3 = smaller of the two through currents

Table VI, derived from the above expression, is based on a multiple of tap current of 6 times the lower tap setting for all combinations of taps except those which involve the 8.7 amp tap. For the latter case, a 4-times tap setting is used, since the total test current for a 6-times tap setting may be as high as 75.2 amperes, which is not only prohibitively high for many installations, but also may subject the relay to excessive heating.

For a given tabular value of I_3 corresponding to a given combination of winding and percent slope taps, the values of I_1 (min.) and I_1 (max.) correspond to the minimum and maximum percent slope tolerance limits given in Table V. However, for a 4-times tap setting, both the upper and the lower percent tolerance limits have been raised by a value equivalent to the difference between the true slope and the nominal slope at 4-times tap value, indicated by the percent slope characteristic curves shown in Figure 7.

<u>Example</u>	WDG 1 Tap	= 3.5 A
	Wdg 2 Tap	= 5.0 A
	Slope Setting	= 40%

Since WDG1 has the lower tap setting, the lead from ammeter I_3 to the test plug should be connected to stud 6, and the common lead connected to stud 4.

From Table VI

I_3 = 21.0 amps
 I_1 (min.) = 21.0 amps
 I_1 (max.) = 22.2 amps

SERVICING

Check any replacement telephone relay for mechanical operation before installation, to see that it operates smoothly and that the contacts are correctly adjusted.

With the relay de-energized, each normally-open contact should have a gap of 0.010-0.015 inch. Observe the wipe on each normally-closed contact by deflecting the stationary contact member towards the frame. Wipe should be approximately 0.005 inch.

The wipe on each normally-open contact should be approximately 0.005 inch. Check by inserting a 0.005 inch shim between the residual screw and the pole piece, and operating the armature by hand. The normally-open contacts should make before the residual screw strikes the shim.

RENEWAL PARTS

Sufficient quantities of renewal parts should be kept in stock for the prompt replacement of any that are worn, broken or damaged.

When ordering renewal parts, address the nearest Sales Office of the General Electric Company. Specify the name of the part wanted, quantity required, and complete nameplate data, including the serial number, of the relay for which the part is required. The serial number may be found stamped on the instantaneous unit in black ink. If possible, give the General Electric Company requisition number on which the relay was furnished.

Since the last edition, the equation has been changed in the section on Unbalance Current Measurement and Figure 7b has been added.

TABLE VI

TAPS	T2	2.9			3.2			3.5			3.8			4.2			4.6			5.0			8.7		
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	
T1 Currents																									
2.9	I ₃	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	11.6	11.6	11.6
	I ₁ (min)	2.6	4.3	7.0	4.6	6.6	9.5	6.7	8.8	12.0	8.8	11.1	14.5	11.6	14.1	17.9	14.3	17.1	21.2	17.1	20.1	24.6	28.7	32.2	37.0
	I ₁ (max)	2.9	4.8	7.7	5.0	7.1	10.3	7.1	9.4	12.8	9.2	11.7	15.4	12.0	14.8	18.9	14.8	17.8	22.4	17.6	20.9	25.8	29.3	33.1	38.1
3.2	I ₃				19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	12.8	12.8	12.8
	I ₁ (min)				2.9	4.8	7.7	4.9	7.0	10.2	7.0	9.3	12.7	9.8	12.3	16.1	12.5	15.3	19.4	15.3	18.3	22.8	27.5	31.0	36.1
	I ₁ (max)				3.2	5.3	8.5	5.3	7.6	11.0	7.4	9.9	13.6	10.2	13.0	17.1	13.0	16.0	20.6	15.8	19.1	24.0	28.1	31.9	37.0
3.5	I ₃							21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	14.0	14.0	14.0
	I ₁ (min)							3.1	5.2	8.4	5.2	7.5	10.9	8.0	10.5	14.3	10.7	13.5	17.6	13.5	16.5	21.0	26.3	29.8	35.0
	I ₁ (max)							3.5	5.8	9.3	5.6	8.1	11.8	8.4	11.2	15.3	11.2	14.2	18.8	14.0	17.3	22.2	26.9	30.7	36.1
3.8	I ₃										22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	15.2	15.2	15.2
	I ₁ (min)										3.4	5.7	9.1	6.2	8.7	12.5	8.9	11.7	15.8	11.7	14.7	19.2	25.1	28.6	33.8
	I ₁ (max)										3.8	6.3	10.0	6.6	9.4	13.5	9.4	12.4	17.0	12.2	15.5	20.4	25.7	29.5	34.8
4.2	I ₃													25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	25.2	16.8	16.8	16.8
	I ₁ (min)													3.8	6.3	10.1	6.5	9.3	13.4	9.3	12.3	16.8	23.5	27.0	32.2
	I ₁ (max)													4.2	7.0	11.1	7.0	10.0	14.6	9.8	13.1	18.0	24.1	27.9	33.1
4.6	I ₃																		27.6	27.6	27.6	27.6	18.4	18.4	18.4
	I ₁ (min)																		4.1	6.9	11.0	6.9	9.9	14.4	21.9
	I ₁ (max)																		4.6	7.6	12.2	7.4	10.7	15.6	22.5
5.0	I ₃																					30.0	30.0	30.0	20.0
	I ₁ (min)																					4.5	7.5	12.0	20.3
	I ₁ (max)																					5.0	8.3	13.2	20.9
8.7	I ₃																								34.8
	I ₁ (min)																								5.5
	I ₁ (max)																								6.1

TABLE VIA

TAPS	T2	0.58			0.64			0.7			0.76			0.84			0.92			1.0			1.74	
	Slopes	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25	40	15	25
T2	Currents																							
0.58	I ₃	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	2.3	2.3	
	I ₁ (min)	0.52	0.86	1.4	0.92	1.32	1.9	1.34	1.76	2.4	1.76	2.22	2.9	2.32	2.82	3.6	2.86	3.42	4.24	3.42	4	4.92	5.74	6.44
	I ₁ (max)	0.58	0.96	1.54	1.0	1.42	2.06	1.42	1.88	2.56	1.84	2.34	3.08	2.4	2.96	3.78	2.96	3.56	4.5	3.52	4.18	5.16	5.86	6.62
0.64	I ₃				3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	2.56	2.56	
	I ₁ (min)				0.58	0.96	1.54	0.98	1.4	2	1.4	1.86	2.54	1.96	2.46	3.22	2.5	3.06	3.88	3.06	3.66	4.56	5.3	6.2
	I ₁ (max)				0.64	1.06	1.7	1.06	1.52	2.2	1.48	1.98	2.72	2.04	2.6	3.42	2.6	3.2	4.12	3.16	3.82	4.8	5.62	6.38
0.7	I ₃							4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	2.8	2.8	
	I ₁ (min)							0.62	1.04	1.68	1.04	1.5	2.18	1.6	2.1	2.86	2.14	2.7	3.52	2.7	3.3	4.2	5.26	5.96
	I ₁ (max)							0.7	1.16	1.86	1.12	1.62	2.36	1.68	2.24	3.06	2.24	2.84	3.76	2.8	3.46	4.44	5.38	6.14
0.76	I ₃										4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	3.0	3.0	
	I ₁ (min)										0.68	1.14	1.82	1.24	1.74	2.5	1.78	2.34	3.16	2.34	2.94	3.84	5.0	5.72
	I ₁ (max)										0.76	1.26	2.0	1.32	1.88	2.7	1.88	2.48	3.4	2.44	3.1	4.08	5.14	5.9
0.84	I ₃													5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.36	3.36	
	I ₁ (min)													0.76	1.26	2.0	1.3	1.86	2.68	1.86	2.46	3.36	4.7	5.4
	I ₁ (max)													0.84	1.4	2.22	1.4	2.0	2.92	1.96	2.62	3.6	4.82	5.58
0.92	I ₃																5.5	5.5	5.5	5.5	5.5	5.5	3.7	3.7
	I ₁ (min)																0.82	1.38	2.2	1.38	1.98	2.88	4.38	5.1
	I ₁ (max)																0.92	1.52	2.44	1.48	2.14	3.02	4.5	5.26
1.0	I ₃																			6.0	6.0	6.0	4.0	4.0
	I ₁ (min)																			0.90	1.5	2.4	4.06	4.76
	I ₁ (max)																			1	1.66	2.64	4.18	4.94
1.74	I ₃																						7.0	7.0
	I ₁ (min)																						1.1	1.8
	I ₁ (max)																						1.22	1.98

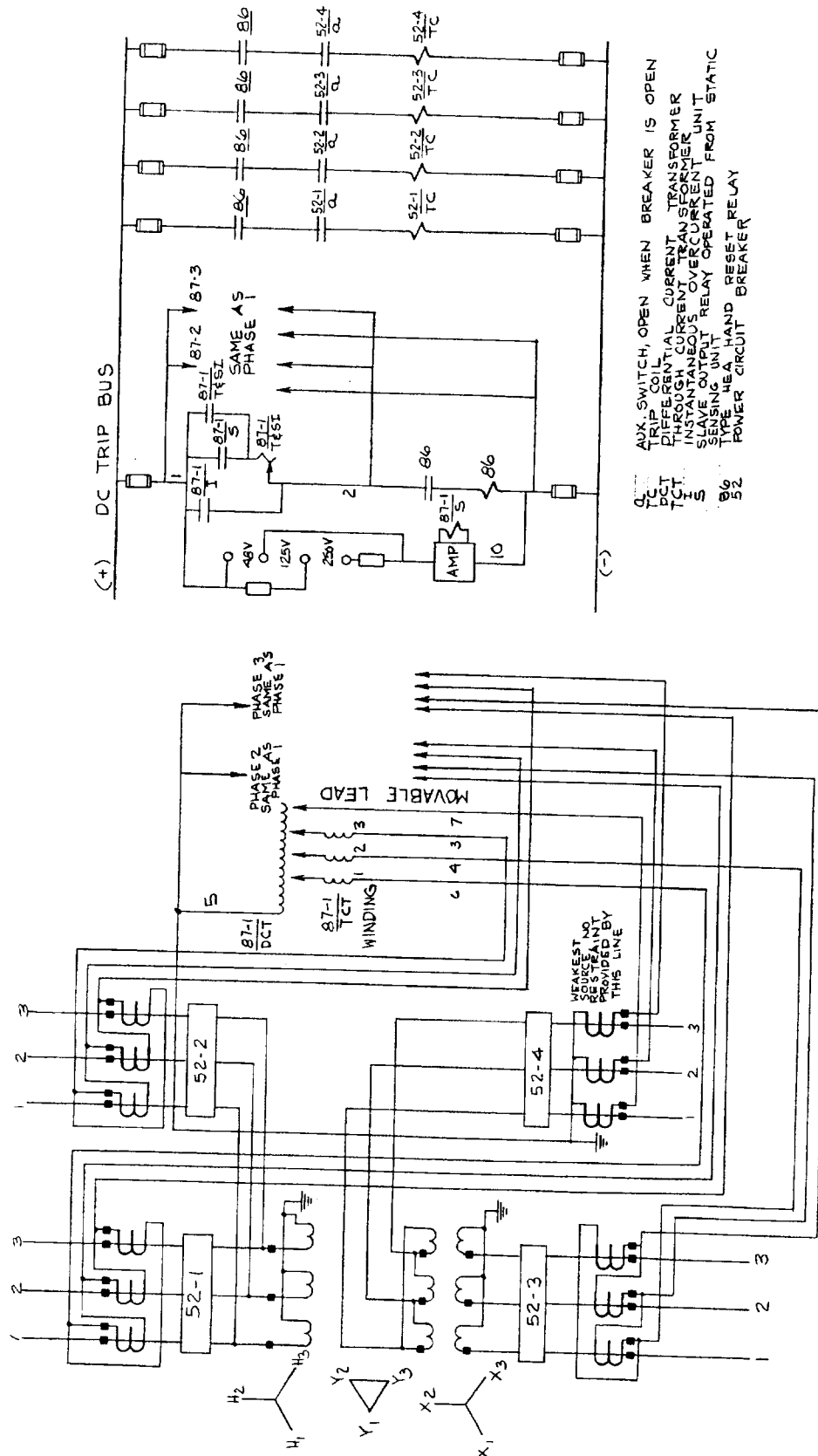


Figure 1 (0128B1982-3) Elementary Diagram for STD16C Relays for Four-Circuit Transformer Protection with Three Restraints

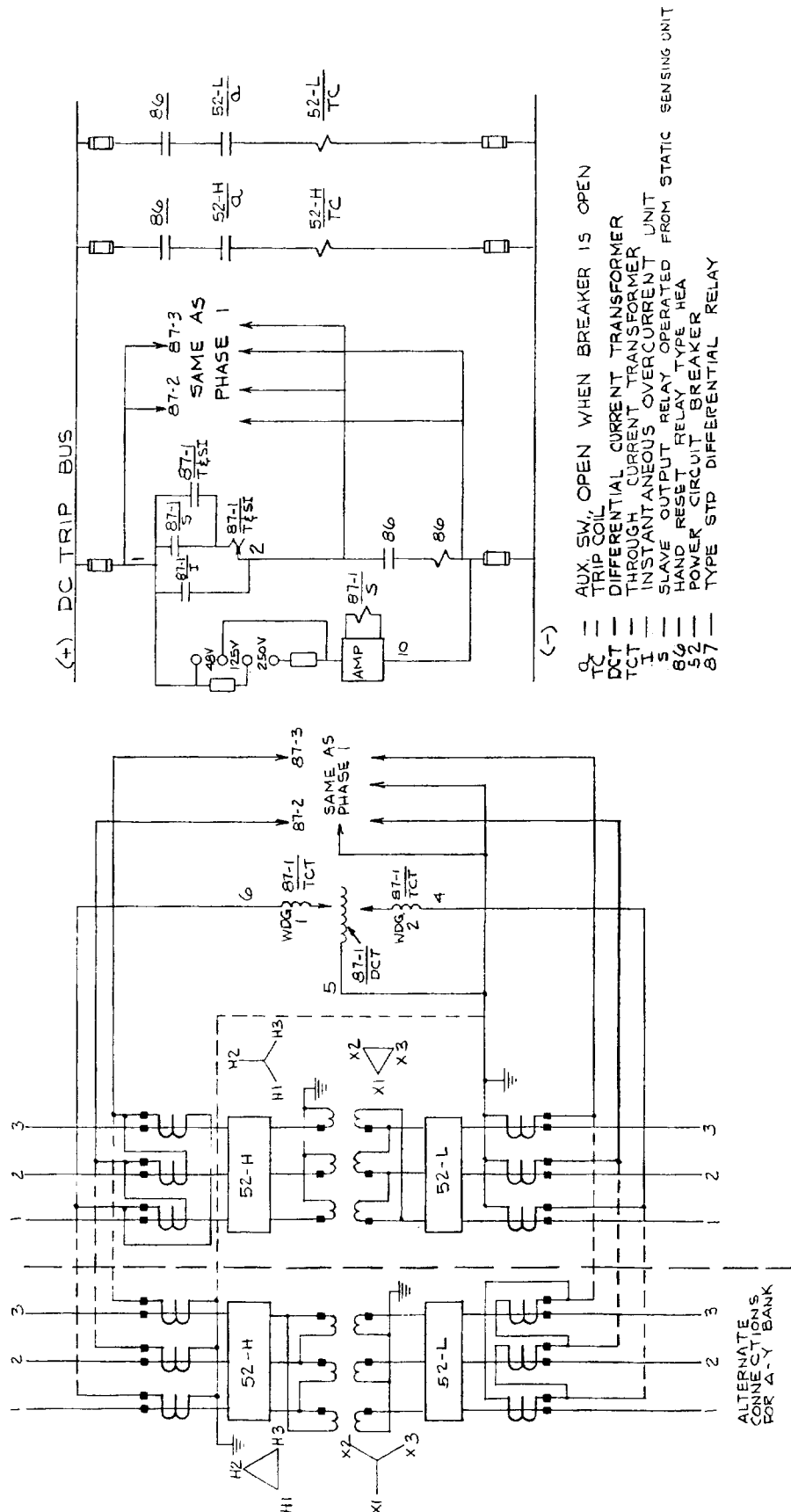


Figure 2 (0128B1981-1) Elementary Diagram for STD15C Relays for Two-Winding Transformer Protection

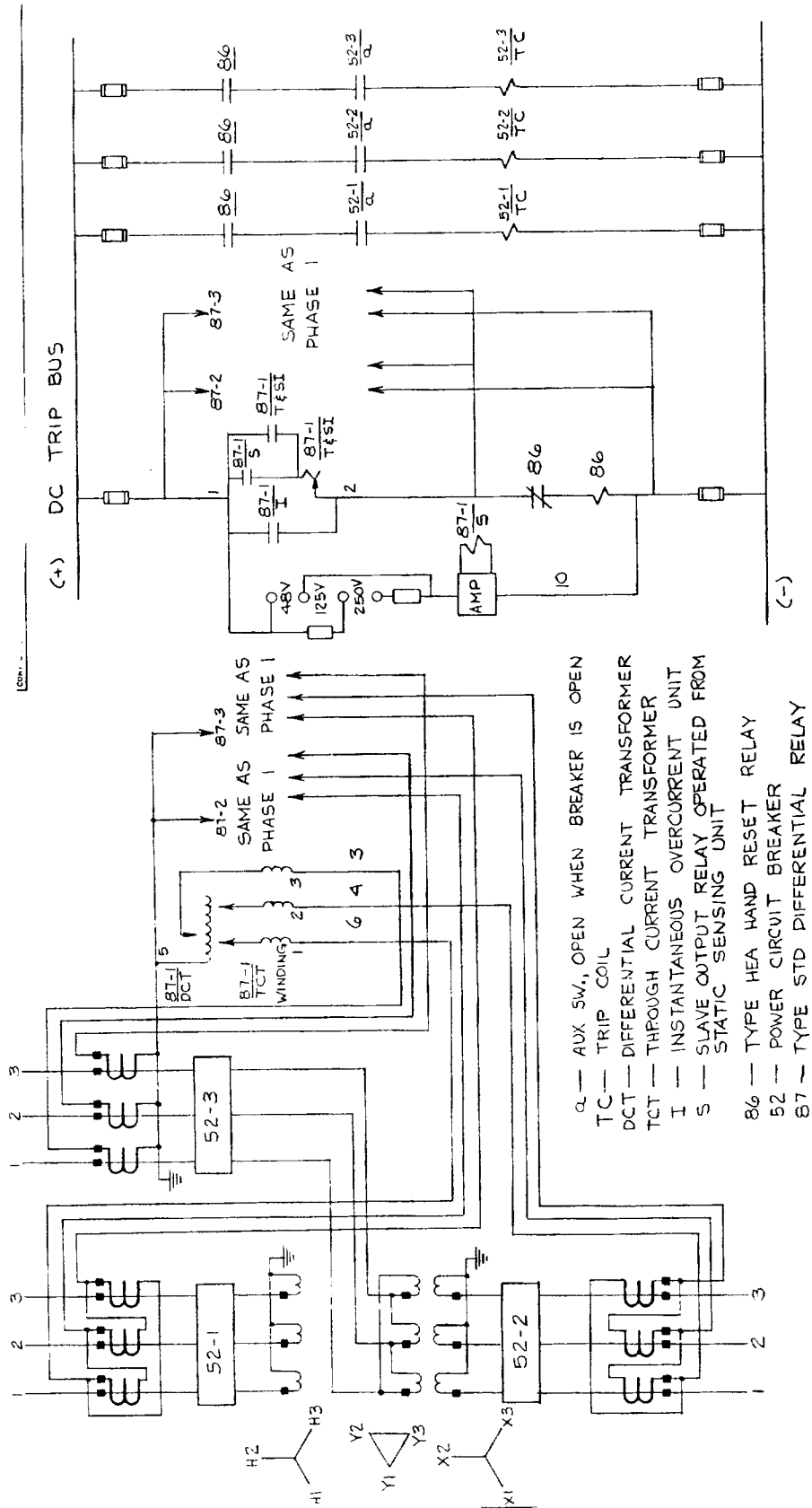


Figure 3 ((0128B1980-2) Elementary Diagram for STD 16C Relays for Three-Winding Transformer Protection

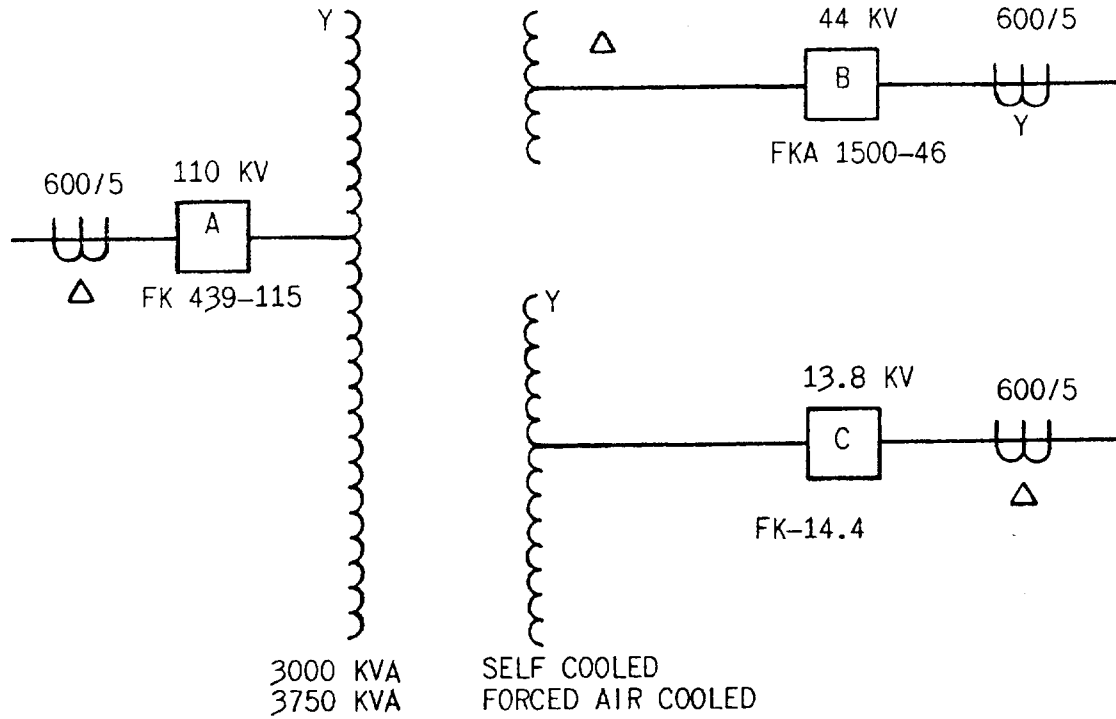


Figure 4 (0165A7601-1) Transformer Used in Sample Calculations

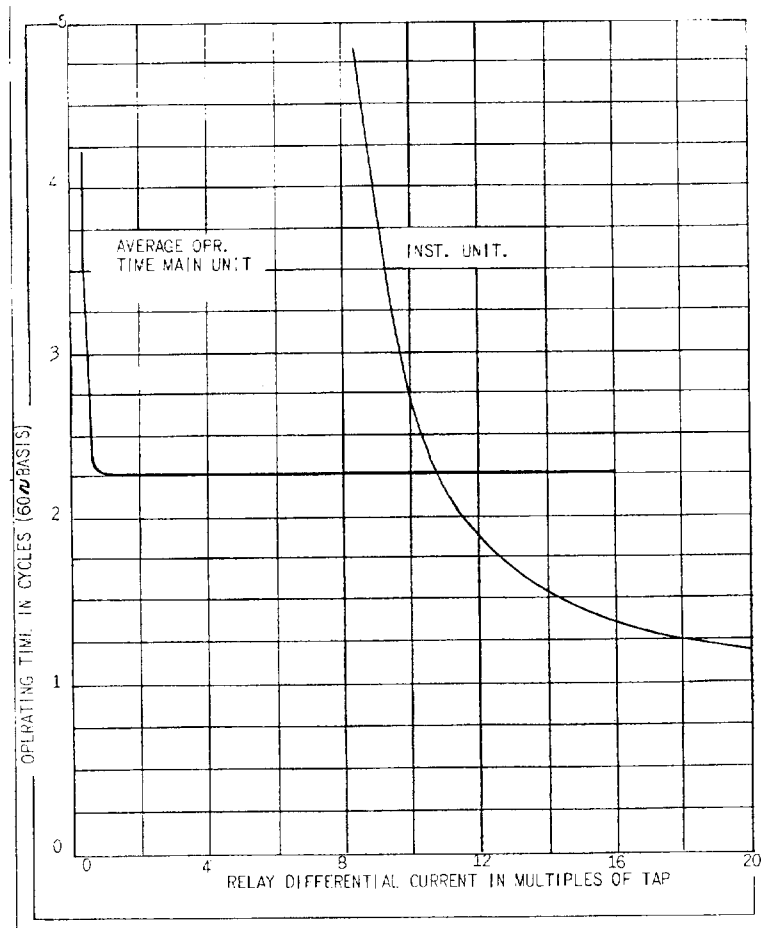


Figure 5 (0227A2503-0) Operating Speed Characteristics of the STD Relay

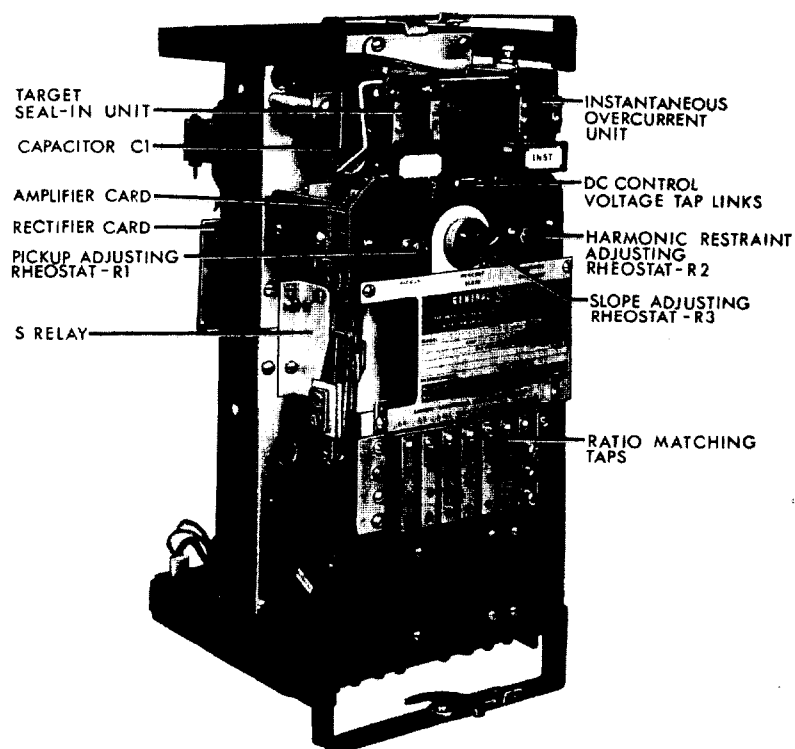


Figure 6A (8042539) Relay Type STD16C Out of Case
Approximately 3/4 Front View (Left Side)

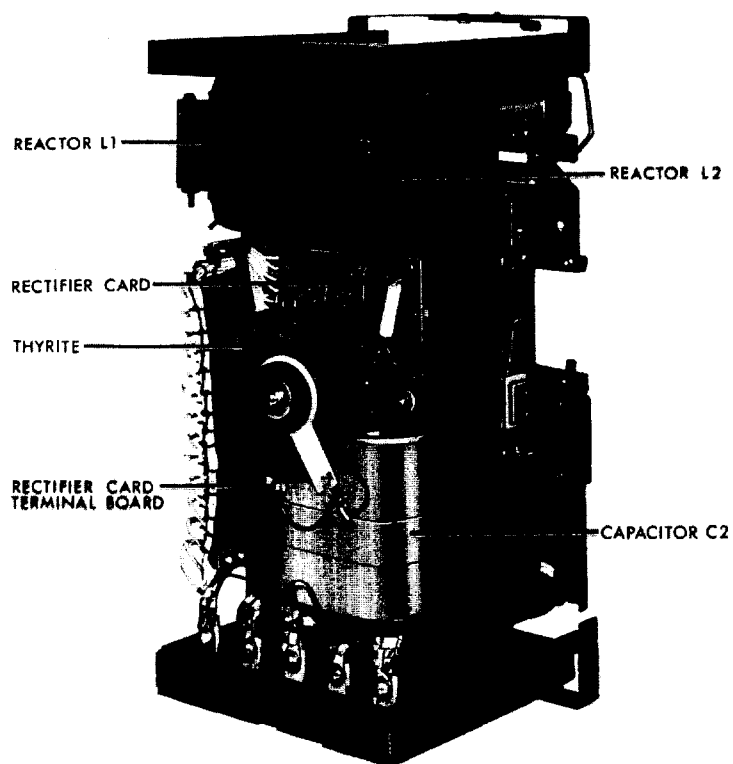


Figure 6B (8042544) Relay Type STD16C Out of Case
Approximately 3/4 Back View (Right Side)

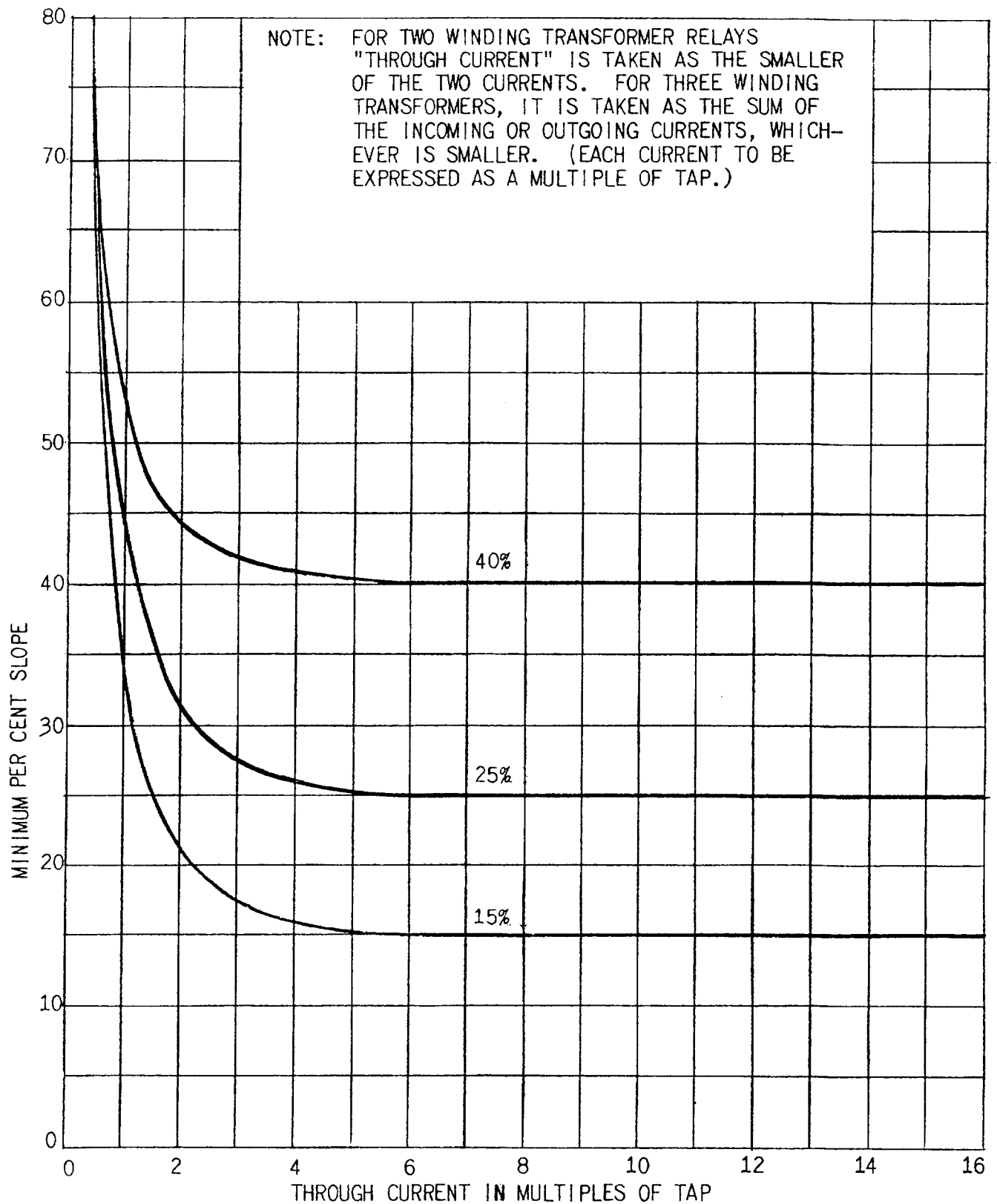


Figure 7A (0378A0588-3) Low-Current Slope Characteristics of the STD Relay

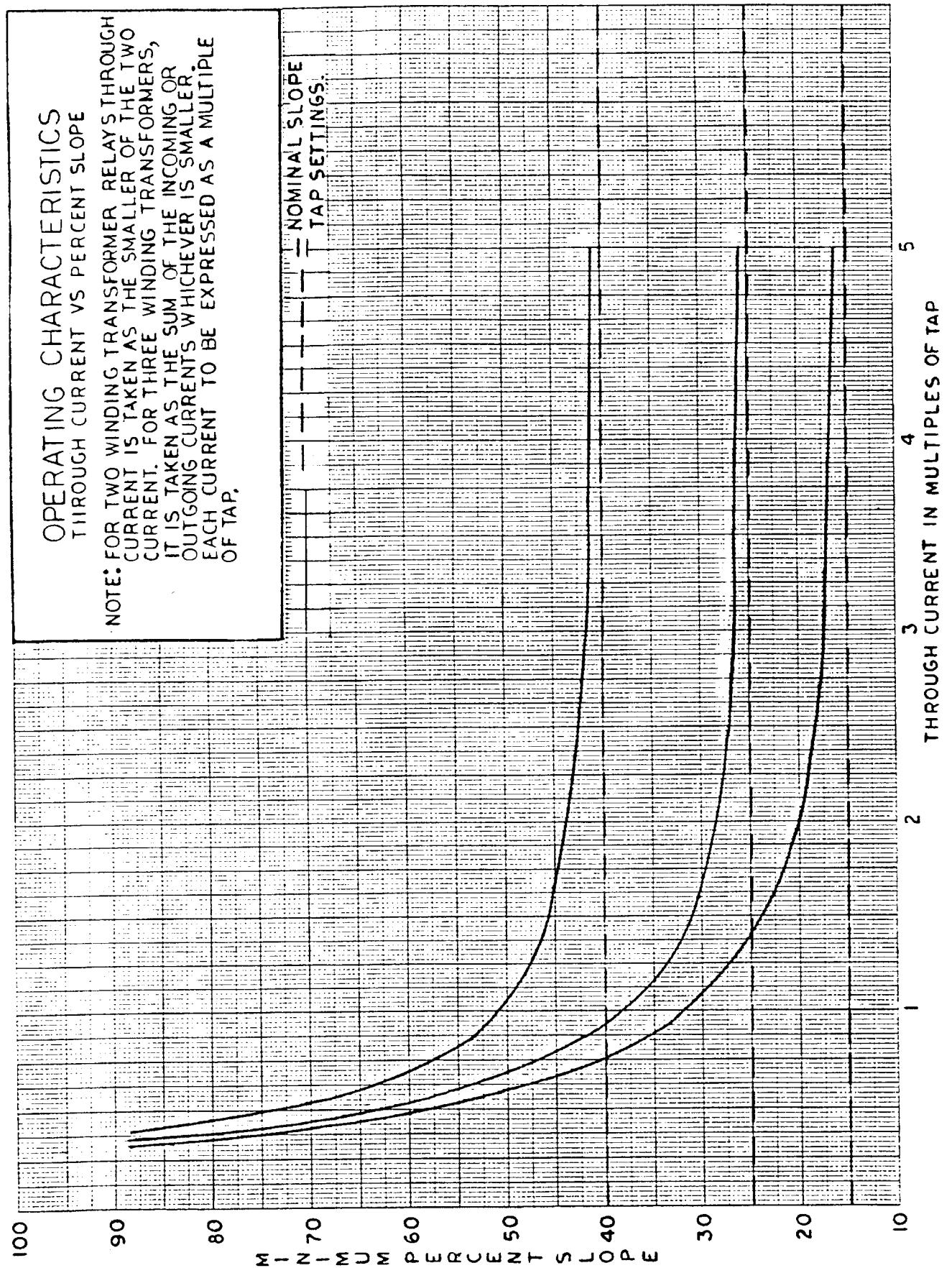


Figure 7B (0257A8579 [1]) Through-Current vs Percent Slope Characteristics of the STD Relay