Type HU, HU-1 and HU-4 Transformer Differential Relays

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(I) Denotes Changes since previous issue

CAUTION

Before putting relays into service, remove all blocking which may have been inserted for the purpose of securing the parts during shipment, make sure that all moving parts operate freely, inspect the contacts to see that they are clean and close properly, and operate the relay to check the settings and electrical connections.

These instructions apply to the following types of relays:

- HU
- HU-1
- HU-4

1. APPLICATION

The types HU, HU-1, and HU-4 relays are high speed relays used in the differential protection of transformers. These relays can be applied where the magnetizing inrush current to the transformer is severe.

Current transformer ratio error should not exceed 10% with maximum symmetrical external fault current flowing and the maximum symmetrical error current which is flowing in the differential circuit on external faults should not exceed 10 times relay tap setting.

The types HU, HU-1, and HU-4 relays have two, three, or four restraint transformers, respectively, and associated rows of taps. The rectified outputs of the restraint transformers of the HU and HU-1 relays are connected in parallel, and the IIT pickup of these relays is ten times the relay tap value. On the other hand, the rectified outputs of the restraint transformers of the HU-4 relay are connected in series, and the IIT-unit for this relay is set at fifteen times the tap value. Otherwise, the three relays are identical. Three-winding banks normally require the HU-1 relay, although the auto transformer application uses the HU if the tertiary is not loaded. The HU-4 is particularly applicable to protect a transformer and bus section combination. It also may be applied to three-winding transformers with one side connected to two breakers.

The HU, HU-1 and HU-4 are available with a sensitivity of either 30% or 35% times tap. The 30% sensitivity relay satisfactorily handles up to 15% mismatch (e.g., ±10% transformer tap changing plus 5% ct mismatch). The 35% sensitivity relay handles as much as 20% mismatch. See Figures 13 and 14 for a comparison of the characteristics of the two sensitivities. Any of the relays may be recalibrated in the field to obtain either characteristic.

Ordinarily the 30% sensitivity relay will suffice; however, where ct mismatch is abnormally high or where the transformer tap-changing range exceeds ±10%, this calibration may be too sensitive.

2. CONSTRUCTION

The types HU, HU-1 and HU-4 relays consist of a differential unit (DU), a harmonic restraint unit (HRU), an indicating instantaneous trip unit (IIT) and an

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

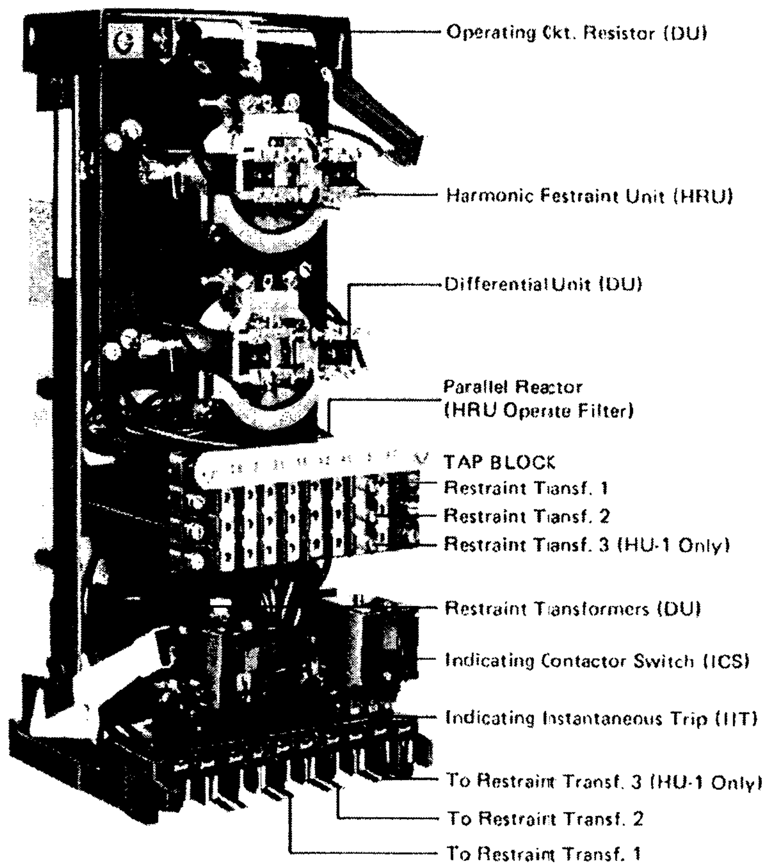


Figure 1. Type HU, HU-1 Relays (Front View)

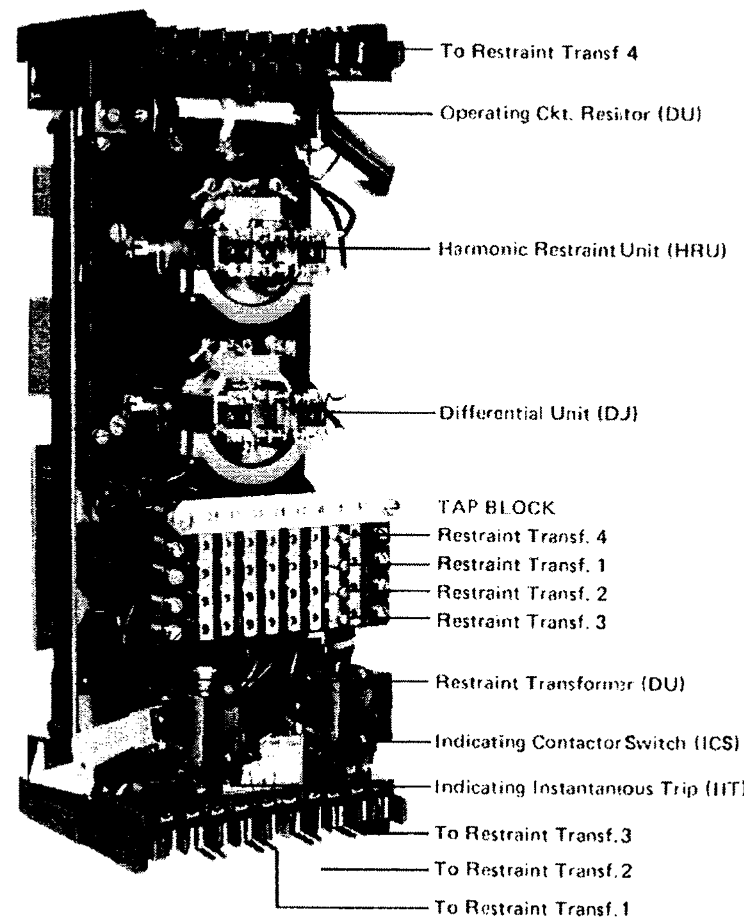


Figure 2. Type HU-4 Relay (Front View)

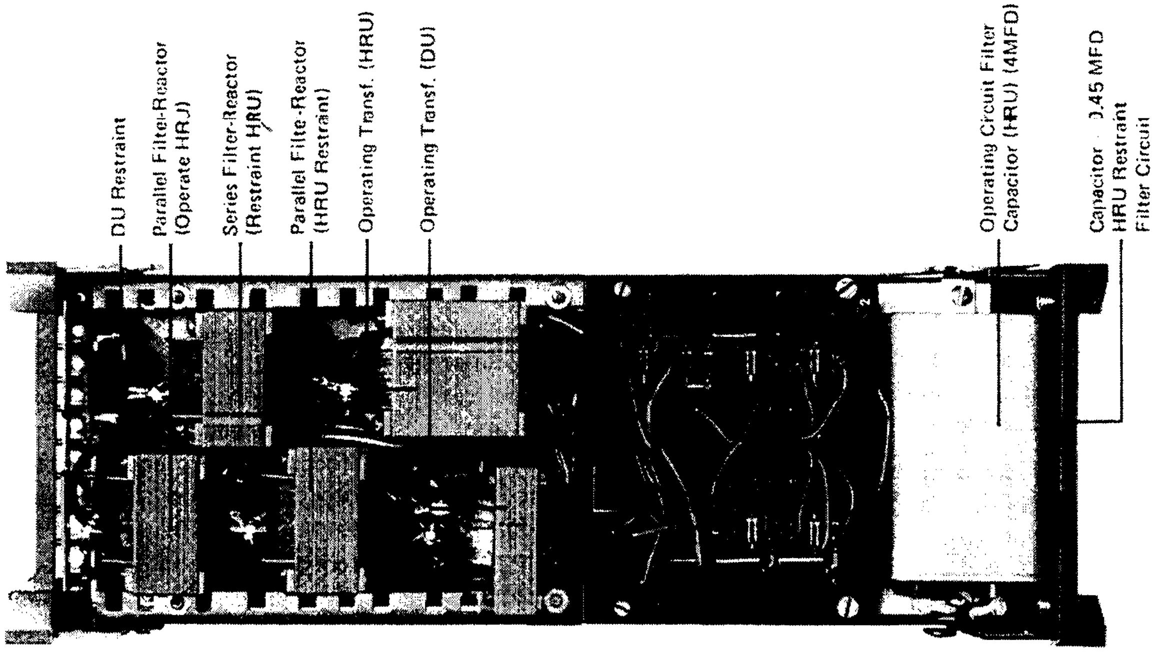


Figure 4. Type HU-4 Relays (Rear View)

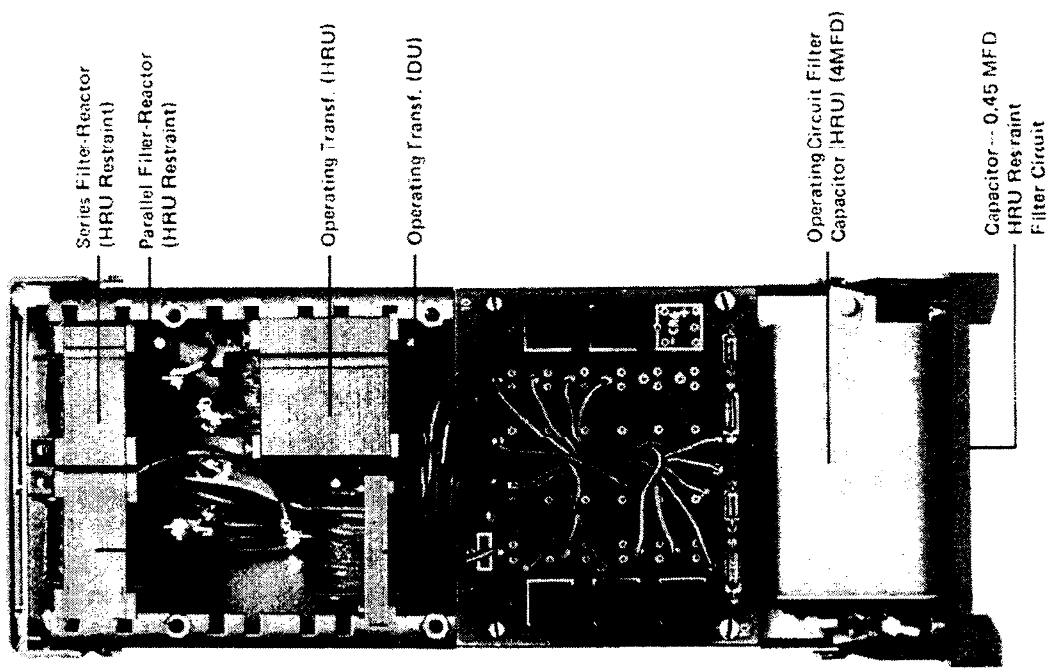


Figure 3. Type HU, HU-1 Relays (Rear View)

indicating contactor switch (ICS). The principal parts of the relays and their locations are shown in Figures 1 to 7.

2.1 Differential Unit (DU)

The differential unit of these relays consists of restraint circuits, full wave rectifiers, saturating operating transformer, and a dc polar unit.

The basic differences in the differential unit of the three relays is in the restraint circuit.

The restraint circuit of the HU-4 relay consists of four air-gap restraint transformers and four full wave rectifiers whose outputs are connected in series.

The restraint circuit of the HU-1 relay consists of three air-gap restraint transformers and three full wave rectifiers whose outputs are connected in parallel.

The restraint circuit of the HU relay consists of two air-gap restraint transformers and two full wave rectifiers whose outputs are connected in parallel.

Each of the restraint transformers and the operating transformer are provided with taps to compensate for mismatch of line current transformers. These taps are incorporated in the relay in such a manner that changing a tap on a restraint transformer automatically changes the same tap on the operating transformer.

2.2 Harmonic-Restraint Unit (HRU)

The harmonic-restraint unit of the HU relays consists of an air gap operating transformer, a second harmonic block filter, a fundamental block second harmonic pass filter, two full-wave rectifiers, indicating instantaneous trip unit, varistor, and a dc polar unit.

Taps are also incorporated in this unit to compensate for mismatch of the line current transformers. Changing a tap on the restraint transformer of the differential unit also changes the tap of this unit.

2.3 Polar Unit

The polar unit consists of a rectangular shaped magnetic frame, an electromagnet, a permanent magnet, and an armature. The poles of the crescent shaped permanent magnet bridge the magnet frame. The magnetic frame consists of three pieces joined in the rear with two brass spacers and silver solder. These non-magnetic joints represent air gaps, which are bridged by two adjustable magnetic shunts. The windings are wound around a magnetic core. The armature is fastened to this core and is free to move in the front air gap. The moving contact is connected to the free end of a leaf spring, which, in turn, is fastened to the armature.

2.4 Indicating Contactor Switch Unit (ICS)

The dc indicating contactor switch is a small clapper-type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts, completing the trip circuit. Also, during this operation, two fingers on the armature deflect a spring located on the front of the switch, which allows the operation indicator target to drop.

The front spring, in addition to holding the target, provides restraint for the armature and thus controls the pick-up value of the switch.

2.5 Indicating Instantaneous Trip Unit (IIT)

The instantaneous trip unit is a small ac operated clapper type device. A magnetic armature, to which leaf-spring mounted contacts are attached, is attracted to the magnetic core upon energization of the switch. When the switch closes, the moving contacts bridge two stationary contacts completing the trip circuit. Also, during the operation, two fingers on the armature deflect a spring located on the front of the switch which allows the operation indicator target to drop.

A core screw accessible from the top of the switch provides the adjustable pickup range.

3. OPERATION

The types HU and HU-1 relays are connected to the protected transformer as shown in Figures 10 and 11. The HU-4 is connected to the protected transformer as shown in Figure 12. In such a connection the relays operate to protect the transformer for faults internal to the differential zone of the transformer, but not for faults external to the zone. Neither do the relays operate on magnetizing inrush currents associated with energization of the transformer even though these currents may appear as an internal fault. To avoid these false operations, each unit of the relay performs a separate function. The differential unit (DU) prevents operation on an external fault. while the harmonic-restraint unit (HRU) prevent operations on magnetizing inrush currents. Hence, the operation of the relay can best be described under the headings of external fault current, internal fault currents, and magnetizing inrush currents.

3.1 External Fault Currents

The HU family of relays have a variable percentage characteristic. This means that the operating current required to close the contact of the differential unit expressed in percent of restraint varies with the magnitude of the larger restraint current in the HU and HU-1 current relays and with the sum of the restraint current in the HU-4 relays. Figures 13 and 14 illustrate these characteristics. To use these curves, divide each restraint current by the appropriate tap and enter the horizontal axis using the larger or largest restraint multiple. Then enter the vertical axis, using the difference of the restraint multiples.

With the relay connected as shown in the schematic diagram of Figure 15a, an external fault causes current to flow in the air-gap restraint transformers of the differential unit. If the line current transformers do not saturate and the correct ratio matching taps applied, no effective current flows in the operating transformer of the relay. Hence, only contact-opening torque is produced on the differential unit.

On heavy external faults where a main current transformer saturates, current flows in the operating circuit of the relay. With such a condition, the harmonic-restraint unit may or may not close its contacts, depending upon the harmonics present in the false operating current. However, operation of the relay is prevented by the variable percentage characteristic of the differential unit, since a large differential current is required to close its contacts during heavy external faults.

3.2 Internal Faults

In the case of an internal fault as shown in Figure 15b, the restraint of the differential unit is proportional to the largest restraint current flowing in the HU and HU-1 relays and to the sum of the restraint current flowing in the HU-4 relay. The sum of the restraint current flows into the operating transformer and produces an excess of operating torque, and the differential unit operates.

In the case of an internal fault fed from one source only, the fault current flows in one restraint transformer and the operating transformer. An excess of operating torque is produced on the differential unit and it operates.

Faults normally appear as an offset sine wave with a decaying dc component, and contain very few harmonics. As a result, the harmonic-restraint unit will operate during internal faults to permit tripping of the relay.

For heavy internal faults, the indicating instantaneous trip unit (IIT) will operate. Since this unit is connected to an air gap transformer, essentially only the sine wave component of an internal fault is applied to the IIT unit. The dc component of the fault is bypassed by the transformer primary.

The varistor connected across the dc side of the restraint rectifier of the harmonic restraint unit prevents excessive voltage peaks from appearing across the rectifiers. These peaks arise through transformer action of the harmonic-restraint polar-unit coils during heavy internal faults. The varistor has a large value of resistance for low voltages, while presenting a low value of resistance for high voltages. This characteristics effectively reduces the voltage spikes on heavy internal faults while not hampering performance during inrush, where the voltage is considerably lower.

3.3 Magnetizing Inrush Currents

Magnetizing inrush current waves have various wave shapes. A typical wave appears as a rectified half wave with decaying peaks. In any case, the various wave shapes are rich in harmonics with the second harmonic predominant. Since the second harmonic is always present in inrush waves and not in internal fault waves, this harmonic is used to restrain the harmonic-restraint unit during inrushes. The differential unit may or may not close its contacts, depending on the magnitude of the inrush.

When a magnetizing inrush wave is applied to the relay, the dc component of the wave is bypassed by the air-gap operating transformer. The other components are fed into the filter circuits. The impedance characteristics of these filters are such that the second harmonic component flows into the restraint coil of the polar unit, while the other harmonics flow into the operating coil. The polar unit will not close its contacts unless the second harmonic content is less than 15 percent of the fundamental component.

The indicating instantaneous trip unit (IIT) will not operate on inrush. The air-gap transformer will bypass the dc component of the inrush thereby reducing the magnitude of the wave applied to the IIT unit. If the inrush has an initial peak of 16 times tap-value current, the air-gap transformer will reduce this peak to approximately 8 times tap value on the secondary of the transformer.

3.4 Breaker Maintenance

Before some of the ct's are bypassed for breaker maintenance the trip circuit should be opened, as shown in Figures 9 through 12. Otherwise the false-unbalanced current will cause the relay to trip. It is not necessary to short-circuit the relay operating circuit since it has an adequate continuous-current rating. (See "Energy Requirements").

4. CHARACTERISTICS

Taps are incorporated in the HU family of relays to compensate for main current transformer mismatch. These taps are as follows: 2.9, 3.2, 3.5, 3.8, 4.2, 4.6, 5.0, 8.7.

To measure the effective unbalance, a sensitive low-reading voltmeter (5000 ohms per volts) can temporarily be connected across the operating coil resistor (at top of case). With a perfect balance, the voltmeter reading will be zero. The reading should not exceed the values indicated by the 15% mismatch curve at Figure 16 when the relay pickup is 0.30 times tap. If the amount of mismatch is measured or calculated, the measured voltage can be checked against the interpolated value from the curve. For example, assume that the larger restraint current is measured as 1.5 tap multiple and the calculated mismatch is 7%. Then, from Figure 16 the measured voltage should be approximately 1.0 volt. Use Figure 17 if the pick-up is 0.35 times tap.

Pickup of the harmonic-restraint unit and the differential unit is either 30 or 35% of tap value current. Pick up of the indicating instantaneous trip unit is 10 times tap value current for the HU and the HU-1 relay and 15 times tap value current for the HU-4.

Components of the harmonic-restraint unit are selected such that 15% second harmonic will prevent operation of the unit. This factor is adequate to prevent false operation on inrushes.

The frequency response of the HU and HU-1 60 Hz relays is shown in Figure 19 and, for the HU and HU-1 50 Hz relays is shown in Figure 28.

4.1 Trip Circuit

The main contacts will safely close 30 amperes at 250 volts dc, and the seal-in contacts of the indicating contactor switch will safely carry this current long enough to trip a circuit breaker.

The indicating contactor switch has two taps that provide a pick-up setting of 0.2 or 2 amperes. To change taps requires connecting the lead located in front of the tap block to the desired setting by means of a screw connection

5. SETTING

CAUTION

Since the tap block screw carries operating current, be sure that the screws are turned tight.

In order to avoid opening current transformer circuits when changing taps under load, the relay must be first removed from the case. Chassis operating shorting switches on the case will short the secondary of the current transformer. The taps should then be changed with the relay outside of the case and then reinserted into the case.

To set the relay, calculations must be performed as shown under "Setting Calculations". After the correct tap is determined, connections can be made to the relay transformers by placing the connector screws in the various terminal-plate holes in front of the relay. Only one tap screw should be inserted in any horizontal row of taps.

5.1 Indicating Contactor Switch (ICS)

No setting is required on the ICS unit except the selection of the 0.2 or 2.0 ampere tap setting. This selection is made by connecting the lead located in front of the tap block to the desired setting by means of the connecting screw. When the relay energizes a 125- or 250-volt dc type WL relay switch, or equivalent, use the 0.2 ampere tap; for 48 volt dc applications set relay in 2 tap and use Type WL Relay coil S#304C209G01 or equivalent.

Trip Circuit Constants
Indicating Contactor Switch (ICS)

0.2 ampere tap -	6.5 ohms dc resistance
2.0 ampere tap -	0.15 ohm dc resistance

5.2 Indicating Instantaneous Trip (IIT)

No setting is required on the indicating instantaneous trip unit. This unit is set at the factory to pickup as follows:

- HU/HU-1 Relays 10 times tap value current
- HU-4 Relay 15 times tap value current

6. SETTING CALCULATIONS

Select the ratio matching taps. There are no other settings. In order to calculate the required tap settings and check current transformer performance the following information is required.

6.1 Required Information

a. Maximum transformer power rating $(KVA)_M$

b. Maximum external fault currents

c. Line-to-Line voltage ratings of power transformer (V_H, V_I, V_L)

d. Current transformer ratios, full tap (N_T)

e. Current transformer "C" accuracy class voltage (or excitation or ratio correction factor curve)

f. One way current transformer lead resistance at 25°C (RL). When using excitation curve, include ct winding resistance.

g. Current transformer connections (wye or delta) ct secondary winding resistance, R_S.

6.2 Definitions of Terms

I_P = Primary current at $(KVA)_M$

I_R = Relay input current at $(KVA)_M$
I_{RH}, I_{RL}, I_{RI} are same as I_R except for high, low and intermediate voltage sides respectively.

I_S = ct secondary current at $(KVA)_M$

T = relay tap setting.
TH, TL, TI = are same as T except for high, low and intermediate voltage windings, respectively.

N = Number of current transformer turns that are in use.

N_P = N/NT (Proportion of total turns in use)

N_T = Current transformer ratio, full tap

V_{CL} = "C" accuracy class voltage

Z_A = Burden impedance of any devices other than the HU, HU-1, or HU-4 relays, with maximum external fault current flowing.

I_{ext} = max symmetrical external fault current in secondary RMS amperes.

Z_T = Total secondary burden in ohms (excluding current transformer winding resistance.)

6.3 Calculation Procedure

a. Select current transformer taps, where multi-ration types are used. Select a tap to give approximately 5 amperes at maximum load. This will provide good sensitivity and will produce no thermal problem to the ct., the leads, or the relay. Better sensitivity can be achieved by selecting a tap to give more than 5 amperes if a careful check is made of the ct, the leads, and the relay capability. For determining the required continuous rating of the relay, use the expected two hour maximum load, since the relay reaches final temperature in this time.

b. Calculate the relay currents, I_R. All relay currents for relay tap selection should be based on the same KVA capacity.

c. Calculate the relay current ratio(s) using the lowest current as reference.

d. Select the tap ratio as close as possible to relay current ratio from Table 1. Choose the first relay tap ratio using the largest current ratio from step 3. The other tap ratios should be determined using the lower tap from the first tap ratio as reference. I_R should not exceed relay continuous rating as defined in Energy Requirement Table.

e. Check IIT operation. The IIT pickup is ten times the relay tap value for the HU and HU-1, or 15 times tap value for the HU-4. Therefore, the maximum symmetrical error current which is flowing in the differential circuit on external fault current due to dissimilar ct saturation should not exceed 10 or 15 times relay tap.

f. Determine Mismatch

For 2 winding banks:

$$\%\,\text{mismatch} = 100\frac{\left(\frac{I_{RL}}{I_{RH}} - \frac{T_L}{T_H}\right)}{S} \quad (1)$$

where S is the smaller of the two terms, $\left(\frac{I_{RL}}{I_{RH}}\right)$ or $\left(\frac{T_L}{T_H}\right)$

For 3 winding banks:

Repeat calculation of equation (1) and apply similar equations to calculate mismatch from the intermediate to high and from and from the intermediate to low voltage windings.

Where tap changing under the load is performed the relays should be set on the basis of the middle or neutral tap position. The total mismatch, including the automatic tap change should not exceed 15% with a 30% sensitivity relay, and 20% with a 35% sensitivity relay. Note from Figures 13 and 14 that an ample safety margin exists at these levels of mismatch.

g. Check current transformer performance. Ratio error should not exceed 10% with maximum symmetrical external fault current flowing. An accurate method of determining ratio error is to use ratio-correction-factor curves (RCF). A less accurate, but satisfactory method is to utilize the ANSI relaying accuracy classification. If the "C" accuracy is used, performance will be adequate if:

$[N_P V_{c1} - (I_{ext} - 100)\, R_S] / I_{ext}$
is greater than Z_T (2)

NOTE: Let I_{ext} = 100 where maximum external fault current is less than 100A.

For wye-connected ct:

Z_T = lead resistance + relay burden + Z_A

$$= 1.13\,(R_L + \frac{0.15}{T} + Z_A)\ \text{ohms} \quad (3)$$

(R_L multiplier, 1.13, is used to account for temperature rise during faults. $\frac{0.15}{T}$ an approximation. Use 2 way lead resistance for single phase to ground fault.

For delta-connected ct:

$$Z_T = 3(1.13R_L + \frac{0.15}{T} + Z_A)\ \text{ohms}\ \dagger$$

$$= 3.4\,(R_L + \frac{0.45}{T} + 3Z_A) \quad (4)$$

h. Examples:

Refer to Tables 6 and 7 and Figure 20 for setting examples.

† The factor of 3 accounts for conditions existing during a phase fault.

Table 1
HU Relay Tap Ratios

TAP	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
2.9	1.000	1.103	1.207	1.310	1.448	1.586	1.724	3.000
3.2		1.000	1.094	1.188	1.313	1.438	1.563	2.719
3.5			1.000	1.086	1.200	1.314	1.429	2.486
3.8				1.000	1.105	1.211	1.316	2.289
4.2					1.000	1.095	1.190	2.071
4.6						1.000	1.087	1.890
5.0							1.000	1.740
8.7								1.000

7. INSTALLATION

The relays should be mounted on switchboard panels or their equivalent in a location free from dirt moisture, excessive vibration and heat. Mount the relay vertically by means of the four mounting holes on the flange for semi-flush mounting, or by means of the rear mounting stud or studs for projection mounting. Either a mounting stud or the mounting screws may be utilized for grounding the relay. The electrical connections may be made directly to the terminals by means of screws for steel-panel mounting or to the terminal studs furnished with the relay for thick panel mounting. The terminal studs may be easily removed or inserted by locking two nuts on the stud and then turning the proper nut with a wrench.

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

8. ADJUSTMENTS AND MAINTENANCE

The proper adjustments for correct operation of this relay have been made at the factory and should not be disturbed after receipt by the customer.

8.1 Performance Check

The following check is recommended to verify that the relay is in proper working order. All checks can best be performed by connecting HU and HU-1 relays per test circuit of Figure 21 and the HU-4 relay per test circuit of Figure 22. **Relays must be tested in the case.**

8.1.1 Minimum Trip Circuit.

NOTE: The moving contact of the upper polar unit (HRU) closes to the left-hand (front view) stationary contact. The moving contact of the lower polar unit (DU) closes to the right hand (front view) stationary contact.

With SPDT switch open and relay set on 5-ampere tap, apply 1.35 to 1.65 amperes for the 30% sensitivity relay and 1.6 to 1.9 amperes for the 35% sensitivity relay. The upper polar unit (HRU) should operate. The upper polar unit may operate for lower currents, but not below 1.0 ampere. This low pickup will not impair its operation on magnetizing inrush currents and should not be disturbed if it is found to be less than the lower polar unit. However, if the pickup value is considered to be too low, it should be checked after applying a polarizing current magnitude of 20 times tap value to relay terminals 3 and 7. This will cause the upper polar unit to pickup at a current of approximately 1.65 amperes.

8.1.2 Indicating Instantaneous Trip Pickup.

With switch open and relay set on the number 5 tap, apply current specified in following table to relay. Instantaneous trip should pickup and its target should drop freely:

HU/HU-1 .... 50 amperes
HU-4 .... 75 amperes

The contact gap should be approximately 0.094 inches between the bridging moving contact and the adjustable stationary contacts. The bridging moving contact should touch both stationary contacts simultaneously.

8.1.3 Indicating Contactor Switch (ICS)

Block contacts of the polar units closed. Pass sufficient direct current through the trip circuit to close the contacts of the ICS. This value of current should be not greater than the particular tap setting being used. The operation-indicator target should drop freely.

8.1.4 Differential Characteristic

a. Close switch to position 1. Set I_{ac} to zero and I_{SR} to either 28 amperes for HU/HU-1 relays or 38 amperes for HU-4 relay. Adjust I_{ac} to 20 amperes. Check the operating point for the relay by gradually adjusting I_{SR}. Operation should occur between the following limits:

Relay Type	I_{ac}	I_{LR}
HU/HU-1	20 amps	45 to 50 amps.
HU-4	20 amps.	53 to 56 amps.

b. **For 30% Sensitivity Relays:** Close switch position 1. Set I_{ac} to zero and adjust I_{SR} to either 10 amperes for HU/HU-1 relays or 6 amperes for

HU-4 relays. Increase I_{ac} to 2.8 amperes. If the lower polar unit does not operate, lower I_{SR}.

The relay should operate between the following limits:

Relay Type	I_{ac}	I_{LR}
HU/HU-1	2.8 to 2.95 amps	11.8 to 12.8 amps
HU-4	2.8 to 2.95 amps	8.0 to 9.1 amps

c. Reverse leads to restraint transformers and repeat differential test outlined in paragraphs a and b. Results should be approximately the same as obtained under these paragraphs.

d. **For 35% Sensitivity Relays:** Close switch to position 1. Set I_{ac} to zero and adjust I_{SR} to either 9 amperes for HU/HU-1 relays or 5 amperes for HU-4 relays. Increase I_{ac} to 2.8 amperes. If the lower polar unit does not operate lower I_{SR}. The lower polar unit should operate between the following limits.

Relay Type	I_{ac}	I_{LR}
HU/HU-1	2.8 to 2.95 amps	10.8 to 11.8 amps
HU-4	2.8 to 2.95 amps	7.0 to 7.8 amps

e. Reverse leads to restraint transformers and repeat differential test outlined in paragraphs a and d. Results should be approximately the same as obtained under these paragraphs.

8.1.5 Harmonic Restraint Characteristic

Close switch to position 2. Short out I_{LR} ammeter. Set I_{dc} to 4 amperes and adjust I_{ac} until upper polar unit operates. I_{ac} should read between 6.5 and 9 amperes.

As shown in Figure 23, these values of alternating current correspond to 17 percent and 14 percent second harmonic.

9. IN SERVICE TEST

Refer to the Tables 2 , 3, or 4 for different tap combinations.

All relays should be checked at least once every year or at such other time intervals as may be dictated by experience to be suitable to the particular application.

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

All checks can be performed by connecting the relay per the test circuit of Figures 21 or 22. Relays to be tested in their case.

In the HU relay, terminal 5 supplies the upper tap block and Terminal 7 supplies the lower tap block. In the HU-1, Terminal 5 supplies the first (upper) tap block, Terminal 7 supplies the second tap block and Terminal 9 supplies the lower tap block. In the HU-4, Terminal 13 supplies the first (upper) tap block, Terminal 5 supplies the second tap block, Terminal 7 supplies the third tap block and Terminal 9 supplies the lower tap block. I_{SR} should be connected to the Terminal with the lowest tap setting.

9.1 Minimum Trip

9.1.1 Lower Unit (Differential)

With S.P.D.T. switch open, the lower polar unit in a 30% relay should operate with I_{ac} between 30% and 31% of the setting of the tap block corresponding to the terminal conducting I_{LR}. For 35% relays, operation should occur between 34% and 36% of tap setting.

9.1.2 Upper Unit (Harmonic Restraint)

With S.P.D.T. switch open, the upper polar unit should operate with I_{ac} between 27% and 33% of the setting of the tap block corresponding to the terminal conducting I_{LR}. The application of a polarizing current of 20 times I_{LR} tap value current between Terminal 3 and the terminal conducting I_{LR}, will make the polar unit operate at the upper limit of the minimum trip range.

9.2 Differential Characteristics

To check the differential characteristics of a relay using any tap combination, close switch to position 1.

Tables 2, 3, and 4 give values of I_{ac} necessary to operate the relay when using a value of I_{SR} equal to 3 times tap value for all taps except the 8.7 tap. A value of I_{SR} equal to 2 times tap value was chosen for the 8.7 tap setting in order to keep the current a convenient value for testing. Table 2 refers to 30% HU relays, for 35% HU relay, values of I_{ac} will be 0.1 to 0.2 amperes higher.

Example: (for HU Relay)
Upper tap block tap 3.5
Lower tap block tap 5.0

Since the upper tap block has the smaller tap setting I_{SR} should be connected to the upper tap block or equivalently into Terminal 5 and I_{LR} should be connected into Terminal 7. From Table 2 under "Restraint" transformer: tap "Larger" = 5 and "Smaller" = 3.5 find I_{SR} which in this case is 10.5 and I_{ac} which is between 8.3 and 9.2 amps.

To check the third restraint winding on the HU-1 relay, repeat the procedure using Terminal 9 and either Terminal 5 or 7. Follow the same procedure to check the third and fourth restraint windings in the HU-4, using Terminal 9 with either Terminal 5 or 7 for the third restraint check and Terminal 13 with 5 or 7 for the fourth restraint check.

9.3 Harmonic Restraint Characteristic

Close switch to position 2. Short out I_{LR} meter. Adjust direct current until I_{dc} reads 0.8 times tap setting for the tap block corresponding to the terminal which conducted I_{LR}. Gradually increase alternating current (I_{ac}) until upper polar unit operates. I_{ac} should read between 1.3 and 1.8 times the same tap setting. Note that this test is responsive to harmonics which might be in I_{ac}. Such harmonics will result in a different operate value.

10. CALIBRATION

Use the following procedure for calibrating the relay if the relay has been taken apart for repairs or the adjustments disturbed. This procedure should not be used until it is apparent that the relay is not in proper working order. All adjustments to be done with relay inside its case. (See Section 8.1, Performance Check).

10.1 Indicating Contactor Switch

For proper contact adjustment, insert a.030"" feeler gauge between the core pin and the armature. Hold the armature closed against the core pin and gauge and adjust the stationary contacts such that they just make with the moving contact. Both stationary contacts should make at approximately the same time. The contact follow will be approximately 1/64" to 3/64".

10.2 Polar Units

10.2.1 Contacts

NOTE: In adjusting either the stationary contact or backstop, the screw in the elongated holes of the assemblies should be loosened, not removed, during the adjustment procedure.

a. Upper Unit (HRU)

Place a 0.065 to 0.070 inch feeler gauge between the right hand (front view) pole face and the armature. This gap should be measured near the front of the right hand pole face. Bring up the right hand (front view) backstop until it just makes with the moving contact. Tighten the screw in the elongated hole of the backstop and remove gauge. Place a 0.046 feeler gauge between the moving contact and the stationary on the left hand (front view) side of the polar unit. Bring up the stationary contact until it just makes with the gauge. Tighten mounting screw in the elongated hole of the stationary and remove gauge.

b. Lower Unit (DU)

Place a 0.065 to 0.070 inch feeler gauge between the left hand (front view) pole face and the armature. This gap should be measured near the front of the right hand pole face. Bring up the left hand (front

TABLE 2

Tap Combination Currents
30% AND 35% HU and HU-1 Relay

Restraint Transformer Tap	Larger	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
Smaller	CURRENT IN AMPERES								
2.9	I_{SR}	8.7	8.7	8.7	8.7	8.7	8.7	8.7	5.8
	I_{AC}(Min.)	2.6	3.7	5.0	5.8	7.8	9.0	10.4	16.2
	I_{AC}(Max.)	2.8	4.0	5.5	6.4	8.6	10.0	11.6	17.9
3.2	I_{SR}		9.6	9.6	9.6	9.6	9.6	9.6	6.4
	I_{AC}(Min.)		2.7	4.0	4.9	6.9	8.1	9.6	15.7
	I_{AC}(Max.)		3.1	4.4	5.4	7.6	9.0	10.6	17.3
3.5	I_{SR}			10.5	10.5	10.5	10.5	10.5	7.0
	I_{AC}(Min.)			3.0	3.8	5.7	6.9	8.3	14.5
	I_{AC}(Max.)			3.3	4.2	6.3	7.7	9.2	16.1
3.8	I_{SR}				11.4	11.4	11.4	11.4	7.6
	I_{AC}(Min.)				3.2	5.2	6.5	7.9	14.1
	I_{AC}(Max.)				3.6	5.7	7.2	8.7	16.0
4.2	I_{SR}					12.6	12.6	12.6	8.4
	I_{AC}(Min.)					3.5	4.7	6.2	12.9
	I_{AC}(Max.)					3.9	5.2	6.9	14.2
4.6	I_{SR}						13.8	13.8	9.2
	I_{AC}(Min.)						3.9	5.3	12.4
	I_{AC}(Max.)						4.3	5.9	13.7
5.0	I_{SR}							15.0	10.0
	I_{AC}(Min.)							4.3	11.6
	I_{AC}(Max.)							4.8	12.9
8.7	I_{SR}								17.4
	I_{AC}(Min.)								5.0
	I_{AC}(Max.)								5.5

TABLE 3

Tap Combination Currents
30% HU-4 Relay

Restraint Transformer Tap	Larger	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
Smaller	CURRENT IN AMPERES								
2.9	I_{SR}	8.7	8.7	8.7	8.7	8.7	8.7	8.7	5.8
	I_{AC}(Min.)	3.9	5.2	6.7	7.6	9.8	11.3	13.8	18.9
	I_{AC}(Max.)	4.3	5.8	7.4	8.4	10.8	12.5	14.4	20.9
3.2	I_{SR}		9.0	9.6	9.6	9.6	9.6	9.6	6.4
	I_{AC}(Min.)		4.3	5.9	6.8	9.0	10.5	12.2	18.4
	I_{AC}(Max.)		4.8	6.5	7.6	10.0	11.6	13.5	20.3
3.5	I_{SR}			10.5	10.5	10.5	10.5	10.5	7.0
	I_{AC}(Min.)			4.7	5.7	7.9	9.3	10.9	17.3
	I_{AC}(Max.)			5.2	6.3	8.7	10.2	12.0	19.2
3.8	I_{SR}				11.4	11.4	11.4	11.4	7.6
	I_{AC}(Min.)				5.1	7.4	8.8	10.5	17.1
	I_{AC}(Max.)				5.6	8.2	9.7	11.6	18.9
4.2	I_{SR}					12.6	12.6	12.6	8.4
	I_{AC}(Min.)					5.5	6.9	8.6	15.5
	I_{AC}(Max.)					6.1	7.7	9.5	17.1
4.6	I_{SR}						13.8	13.8	9.2
	I_{AC}(Min.)						6.1	7.8	15.2
	I_{AC}(Max.)						6.8	8.6	16.8
5.0	I_{SR}							15.0	10.0
	I_{AC}(Min.)							6.7	14.6
	I_{AC}(Max.)							7.4	16.1
8.7	I_{SR}								17.4
	I_{AC}(Min.)								8.0
	I_{AC}(Max.)								8.8

TABLE 4

Tap Combination Currents
35% HU-4 Relay

Restraint Transformer Tap	Larger	2.9	3.2	3.5	3.8	4.2	4.6	5.0	8.7
Smaller	CURRENT IN AMPERES								
2.9	I_{SR}	8.7	8.7	8.7	8.7	8.7	8.7	8.7	5.8
	I_{AC}(Min.)	3.9	5.3	6.8	7.7	9.9	11.4	13.1	19.0
	I_{AC}(Max.)	4.3	5.8	7.5	8.5	10.9	12.6	14.5	21.0
3.2	I_{SR}		9.6	9.6	9.6	9.6	9.6	9.6	6.4
	I_{AC}(Min.)		4.4	5.9	6.9	9.1	10.5	12.2	18.5
	I_{AC}(Max.)		4.8	6.5	7.6	10.1	11.6	13.5	20.5
3.5	I_{SR}			10.5	10.5	10.5	10.5	10.5	7.0
	I_{AC}(Min.)			4.8	5.7	7.9	9.3	10.9	17.4
	I_{AC}(Max.)			5.4	6.3	8.8	10.3	12.1	19.3
3.8	I_{SR}				11.4	11.4	11.4	11.4	7.6
	I_{AC}(Min.)				5.2	7.4	8.9	10.5	17.3
	I_{AC}(Max.)				5.7	8.2	9.8	11.6	19.2
4.2	I_{SR}					12.6	12.6	12.6	8.4
	I_{AC}(Min.)					5.6	7.0	8.7	15.8
	I_{AC}(Max.)					6.2	7.8	9.6	17.2
4.6	I_{SR}						13.8	13.8	9.2
	I_{AC}(Min.)						6.2	7.9	15.2
	I_{AC}(Max.)						6.8	8.7	16.8
5.0	I_{SR}							15.0	10.0
	I_{AC}(Min.)							6.8	14.9
	I_{AC}(Max.)							7.5	16.5
8.7	I_{SR}								17.4
	I_{AC}(Min.)								8.4
	I_{AC}(Max.)								9.0

view) backstop until it just makes with the moving contact. Tighten the screw in the elongated hole of the backstop and remove gauge. Place a 0.065 to 0.070 feeler gauge between the moving contact and the stationary contact on the right (front view) side of the polar unit. Bring up the stationary contact until it just makes with the gauge. Tighten mounting screw in the elongated hole of the stationary contact and remove gauge.

10.2.2 Minimum Trip Current

a. Harmonic Restraint Unit (HRU)

Connect the relay per test circuit of Figure 21 or Figure 22 according to type. With the switch open pass I_{ac} = 20 times tap value current into the relay. This current should be applied for a very short period of time and it should be suddenly interrupted. Adjust right hand shunt on upper polar unit until it trips with I_{ac} = 33% of tap value amperes. Lower I_{ac} gradually to 15% of tap value current and adjust left-hand shunt until unit resets. Repeat these steps, if necessary, until the unit operates at 33% or slightly lower of tap value current immediately following the application of 20 times tap value current and until the unit resets at a value of current 15% of tap value or greater. After the dropout has been measured, the unit should pickup at 25% or higher of tap value current.

On the application of the high polarizing current the upper polar unit will be biased in the restraining direction and pickup will be greater than the nominal value of 30% of tap value current on the first application of pickup current. If the circuit is de-energized and pickups measured again, the pickup current will be less than before. However, pickup will be stable after the second application of pickup current. If 20 times tap value current is applied again, the pickup immediately after applying this current will be high. However, measuring the pickup the second time will show that the pickup is again reduced. The variation between these pickups will be between 25% and 33% of tap value current.

The filter circuits are charged by the application of this heavy polarizing current and upon the removal of the current, these circuits will discharge their energy. The element will be biased in the restraining direction because the restraint coil has approximately 7 times the number of turns as the operating coil. Upon the application of pickup current, the operating ampere turns will be greater than the restraint ampere turns and the bias will be removed.

If a lower biasing current is used instead of 20 times tap value current, the pickup of the upper unit will be less than before for the first application of pickup current. Pickup will be further reduced with the second application of pickup current, but the current will be stable after this energization. However, this value of pickup will be lower than the limits of 25% and 33% of tap value current. This is in the direction of making the sensitivity of the polar unit lower than 30%, but does not impair the performance of the unit on inrush currents.

b. Differential Unit (DU)

Set the adjustable resistor at top of the relay in the approximate center of its range. Open the switch and pass I_{ac} = 20 times tap value current. This current should be applied for a very short period of time and it should be suddenly interrupted. Adjust left hand shunt of lower polar unit until it trips with I_{ac} = 30% of tap value amperes. Lower I_{ac} gradually to 15% of tap value current and adjust left-hand shunt until unit resets. If polar unit resets before 15% of tap value current, no adjustments are necessary to the left-hand shunt. Repeat these steps until the lower polar unit will pickup at 30% of tap value current and reset for values of tap value current greater than 15%.

10.2.3 Indicating Instantaneous Trip Unit (IIT)

For HU and HU-1 relays, open switch and pass I_{ac} = 10 times tap value current. Adjust core of the instantaneous trip unit until it picks up. Its target should drop freely. Follow the same procedure for the HU-4 relays except pass I_{ac} = 15 times tap.

The contact gap should be approximately 0.094 inches between the bridging moving contact and the adjustable stationary contacts. The bridging contact should touch both the stationary contacts simultaneously.

10.2.4 Harmonic-Restraint Unit (HRU)

Close switch to position 2. Short out I_{LR} ammeter. Adjust direct current until I_{dc} reads 0.8 times tap setting. Gradually increase alternating current until upper polar unit operates with I_{ac} reading between 1.3 and 1.8 times tap setting. The percent second harmonic in the wave may be derived by the use of the formula:

$$\%\ \text{second harmonic} = \frac{47 I_{dc}}{I_{ac} + 1.11 I_{dc}}$$

This formula is plotted in curve form in Figure 23 for I_{dc} = 4 amperes.

10.2.5 Percentage Slope Characteristics (DU)

Close switch to position 1. Set I_{ac} to zero for all relays and I_{SR} either to 5.5 times tap value current for the HU/HU-1 relays or 6.9 times tap value current for the HU-4 relays. Then adjust I_{ac} to 4 times tap value current for all relays.

Adjust resistor at top of relay until polar until operates. The lower polar unit should operate between the following values:

Relay Type	Iac	ILR
HU/HU-1	4 times tap value current	10 to 9 tap value current
HU-4	4 times tap value current	11.2 to 10.6 tap value current

For HU relays, interchange lead position to terminals 5 and 7 and repeat the above test. Also repeat test for HU-1 relay with I_{LR} to terminal 9 and for HU-4 relay with I_{LR} to terminals 9 and 13.

Trip condition can best be determined by holding I_{ac} at 4 times tap value current and varying I_{SR}. If I_{SR} is too low the contacts will be closed when the currents are first applied. Hence, I_{LR} should be increased until the contacts open and then decreased until contacts close.

The adjustment of the resistor will have some effect on the pickup of the unit. Hence, polarize and recheck the pickup. If necessary readjust shunts to obtain a pickup of 30% of tap value current and drop-out of 15% or greater of tap value current. If shunts are changed, check to see that above readings are obtained on the higher restraint currents. If necessary readjust resistor and repeat procedure until the unit operates within the specified limits.

Apply I_{ac} =.56 times tap value for all relays and vary I_{SR} until lower polar unit operates. The lower polar unit should operate between the following limits:

Relay Type	I_{LR}
HU/HU1	2.56 to 2.24 times tap value current
HU-4	1.82 to 1.54 times tap value current

10.2.6 Calibration (35%-Sensitivity Relays)

The differential unit (DU), should first be calibrated as outlined under Section 10, Calibration. Next the right hand shunt of the lower polar unit should be turned in until the relays operate at the following values of current.

Relay Type	Iac	I_{LR}
HU/HU-1	.45 times tap	1.64 times tap value current
HU-4	.56 times tap	1.5 times tap value current

This changes the percentage slope curve of the relay to that shown by the 35 percent sensitivity curve of Figure 14. Pickup of the relay is increased from 30% to approximately 35% of the tap value current and the curve is changed at low values of restraint current. At large values of restraint current the percentage slope characteristics is essentially the same as shown in Figure 13.

As shown in Figure 14, the margin of safety between the relay calibration for a 35% sensitivity and the 20% mismatch curve is the same as that of the relay calibrated for a 30% sensitivity and the 15% mismatch curve. This margin of safety is also shown in the voltage differential characteristics of Figure 17 for the 35 percent sensitivity relay.

10.2.7 Electrical Checkpoints

The following electrical checkpoints may be used to assist in troubleshooting if the relay will not calibrate using the above calibration procedure. The values listed are approximate for current production and might change due to a minor change in design or a change in components. However, periodic checks of a given relay should reproduce very closely the same values produced when the relay was new.

10.2.7.1 Differential Unit (DU)

a. Restraint Circuit

Apply two times tap-value current successively to each restraint transformer. This is done by connecting leads to a tap screw and to terminals 5, 7, 9 (HU-1 only) and 13 (HU-4 only) in turn. The ac voltage across the appropriate restraint rectifier bridge using a high resistance voltmeter (5000 ohms per volt) should be within the range given in Table 5.

Location of the appropriate bridges is shown in Figure 24 for HU and HU-1 relays and in Figure 25 for the HU-4 relays.

b. Operating Circuit

Apply 30 percent tap-value current to terminal 3 and tap screw. Using a high-resistance voltmeter, the ac voltage across the operating coil bridge and the ac voltage output of the operating transformer (top two coil terminals) should be within the range given in Table 5.

10.2.8 Harmonic Restraint Unit (HRU)

Apply 30 percent tap-value current to terminal 3 and a tap screw. The voltages obtained by using a high resistance ac voltmeter should be within the range given in Table 5. (Refer to Figure 24 or Figure 25 for bridge location depending on relay type.)

10.2.9 Diode Check

Check for open or shorted diodes using the electrical checkpoints of Table 5.

11. RENEWAL PARTS

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

TABLE 5

	Voltage Range	
Rated Frequency	**50 Hz**	**60 Hz**
DU Restraint Circuit		
HU and HU-1	1.78-2.03	2.10-2.40
HU-4	3.16-3.60	3.55-4.05

	Voltage Range HU/HU-1/HU-4	
Rated Frequency	**50 Hz**	**60 Hz**
DU Operating Circuit		
Operate Coil Bridge	2.17–2.69	2.50–3.10
Operate Transformer	2.40–4.75	3.60–7.00
HRU		
1. Output of operate transformer (top coil terminals)	3.98–4.89	3.90–4.80
2. 4 MFD capacitor (HRU Operate)	2.41–3.33	2.27–3.13
3. .45 MFD capacitor (HRU Restraint)	2.89–3.97	3.20–4.40
Rectifier Bridges		
4. Operating	1.87–2.88	1.95–3.00
5. Restraint	<1.2	<1.0
6. Series-Filter Reactor	<1.0	<0.5

TABLE 6

TWO-WINDING TRANSFORMER CALCULATIONS

(See Figure 20)

	LOW	HIGH
1. Select ct Ratio		
$I_p = \frac{(KVA)_M}{(KV)\sqrt{3}} =$	$\frac{20,000}{12.4\sqrt{3}} = 930$ Amps	$\frac{20,000}{69\sqrt{3}} = 167$ Amp
Select ratio	1000/5 (N = 200)	200/5 (N = 40)
2. Calculate Relay Current:		
$I_s = \frac{I_P}{N} =$	$\frac{930}{200} = 4.65$ Amp	$\frac{167}{40} = 4.18$ Amp
$I_R =$	$I_{RL} = 4.65\sqrt{3} = 8.05$ Amp	$I_{RH} = 4.18$ Amp
3. Calculate Current Ratio:	$\frac{I_{RL}}{I_{RH}} = \frac{8.05}{4.18} = 1.93$	
4. Select Tap Ratio from Table 1:	$\frac{T_L}{T_H} = \frac{8.7}{4.6} = 1.890$	
I_R > relay continuous rating	No	No
5. Check IIT Operation Max. Symmetrical error current > 10 times relay tap	No	
6. Determine Mismatch: % Mismatch = $100\frac{\left(\frac{I_{LR}}{I_{RH}} - \frac{T_L}{T_H}\right)}{\frac{T_L}{T_H}} =$	$100\frac{\left(\frac{8.05}{4.18} - \frac{8.7}{4.6}\right)}{\frac{8.7}{4.6}} =$ $100\frac{(1.92 - 1.89)}{1.89} = 1.6\%$	
7. Check ct Performance		
$Z_T =$	$3.4\left(R_L + \frac{0.45}{T}\right) =$ $3.4(0.4) + \frac{0.45}{8.7} = 1.36 + 0.05 =$ 1.41 ohms	$1.13\left(R_L + \frac{0.15}{T}\right) =$ $1.13\left(04 + \frac{0.15}{4.6}\right) = 0.45 + 0.03 =$ 0.48 ohms
$N_P = \frac{N}{N_T} =$	$\frac{200}{240} = 0.833$	$\frac{40}{120} = 0.333$
$\frac{(N_p V_{CL})}{100} =$	$\frac{0.833(200)}{100} = 1.67$	$\frac{0.333(200)}{100} = 0.67$
$\left(N_P \frac{V_{CL}}{100}\right) > Z_T$	Yes	Yes
Conclusion:	$T_L = 8.7$ 30% sensitivity Relay is adequate	$T_H = 4.6$

TABLE 7

THREE–WINDING TRANSFORMER CALCULATIONS

(See Figure 20)

	HIGH	INTERMEDIATE	LOW
1. Select ct Ratio: $I_P = \frac{(KVA)_M}{(KV)\sqrt{3}} =$	$\frac{40,000}{161\sqrt{3}} = 143$ Amp	$\frac{40,000}{69\sqrt{3}} = 334$ Amp	$\frac{10,000}{12.4\sqrt{3}} = 465$Amp
Select Ratio	400/5 (N = 80)	600/5 (5N = 120)	1000/5 (N = 200)
2. Calculate Relay Current: $I_S = \frac{I_P}{N} =$	$\frac{143}{80} = 1.79$ Amp	$\frac{334}{120} = 2.78$Amp	$\frac{465}{200} = 2.33$ Amp
I_R(At 40 MVA) =	$I_{RH} = 1.79\sqrt{3}$ = 3.10 Amp	$I_{RI} = 2.78\sqrt{3}$ = 4.82 Amp	$I_{RL} = \frac{40}{10}(2.33)$ = 9.32 Amp.
3. Calculate Current Ratios:		$\frac{I_{RI}}{I_{RH}} = \frac{4.82}{3.10} = 1.55$	$\frac{I_{RL}}{I_{RH}} = \frac{9.32}{3.10} = 3.01$
4. Select Tap Ratio from Table 1:		$\frac{T_I}{T_H} = \frac{4.6}{2.9} = 1.586$	$T_L = \frac{8.7}{2.9} = 3.00$
I_R > relay continuous rating	No	No	No
5. Check IIT Operation Max. symmetrical error current > 10 times relay tap.	No	No	No
6. Determine Mismatch: % Mismatch	$100\frac{\left(\frac{I_{RH}}{I_{RI}} - \frac{T_H}{T_I}\right)}{\frac{T_H}{T_I}} =$	$100\frac{\left(\frac{I_{RI}}{I_{RL}} - \frac{T_I}{T_L}\right)}{\frac{I_{RI}}{I_{RL}}} =$	$100\frac{\left(\frac{I_{RL}}{I_{RH}} - \frac{T_L}{T_H}\right)}{\frac{T_L}{T_H}} =$
	$100\frac{\left(\frac{3.10}{4.82} - \frac{2.9}{4.6}\right)}{\frac{2.9}{4.6}} =$	$100\frac{\left(\frac{4.82}{9.32} - \frac{4.6}{8.7}\right)}{\frac{4.82}{9.32}} =$	$100\frac{\left(\frac{9.32}{3.10} - \frac{8.7}{2.9}\right)}{\frac{8.7}{2.9}} =$
	$100\left(\frac{0.643 - 0.630}{0.630}\right) =$	$100\left(\frac{0.517 - 0.529}{0.517}\right) =$	$100\left(\frac{3.01 - 3.00}{3.00}\right) =$
	2.1%	-2.3%	0.33%

(TABLE 7 cont'd)

THREE-WINDING TRANSFORMER CALCULATION

7. Check ct Performance			
$Z_T =$	$3.4R_L + \frac{0.45}{T} =$	$3.4R_L + \frac{0.45}{T} =$	$1.13R_L + \frac{0.15}{8.7} =$
	$3.4(0.5) + \frac{0.45}{2.9} =$	$3.4(0.5) + \frac{0.45}{4.6} =$	$1.13(0.5) + \frac{0.15}{8.7} =$
	$1.7 + 0.16 =$	$1.7 + 0.10 =$	$0.57 + 0.02 =$
	<u>1.86 ohms</u>	<u>1.80 ohms</u>	<u>0.59 ohms</u>
$N_p = \frac{N}{N_T} =$	$\frac{80}{240} = 0.333$	$\frac{120}{120} = 1.0$	$\frac{200}{240} = 0.833$
$\frac{(N_p V_{CL})}{100} =$	$\frac{800(0.333)}{100} = 2.67$	$\frac{200(1.0)}{100} = 2.0$	$\frac{200(0.833)}{100} = 1.67$
$(\frac{N_p V_{CL}}{100}) > Z_T$	Yes	Yes	Yes
<u>Conclusion:</u>	<u>$T_H = 2.9$</u>	<u>$T_I = 4.6$</u>	<u>$T_L = 8.7$</u>
	Requires 35% Sensitivity Relay Since (LTC + M) > 15%		

TABLE 8
ENERGY REQUIREMENTS
FOR HU, HU-1, and HU-4

Burden of Each Restraint Circuit

		Power Factor Angle θ		volt amperes † at tap value current		volt amperes † at 8 times tap value current		volt amperes † at 20 times tap value current	
Tap	Continuous Rating	HU	HU-4	HU	HU-4	HU	HU-4	HU	HU-4
2.9	10	71	83	.88	.80	50	31	191	150
3.2	12	70	79	.89	.80	51	31	198	155
3.5	13	66	75	.90	.81	51	32	203	157
3.8	14	65	73	.91	.81	53	32	220	166
4.2	15	58	69	.91	.82	53	33	235	171
4.6	16	57.5	65	.91	.83	55	33	248	186
5.0	18	52.5	66	.92	.86	59	35	280	202
8.7	22	30	48	1.28	1.20	94	59	422	396

Burden of Operating Circuit

		Power Factor Angle θ		volt amperes † at tap value current		volt amperes † at 8 times tap value current		volt amperes † at 20 times tap value current	
Tap	Continuous Rating	HU	HU-4	HU	HU-4	HU	HU-4	HU	HU-4
2.9	10	35	32	2.26	2.18	76	89	487	483
3.2	12	34	31	2.30	2.23	78	92	499	509
3.5	13	33	30	2.30	2.19	81	95	504	512
3.8	14	33	30	2.30	2.27	83	98	547	543
4.2	15	31	29	2.30	2.19	84	100	554	546
4.6	16	30	29	2.40	2.33	88	104	598	598
5.0	18	29	28	2.50	2.37	92	106	640	610
8.7	22	23	23	3.18	3.09	132	156	850	904

Note: Values for HU relay apply to HU-1 relays.

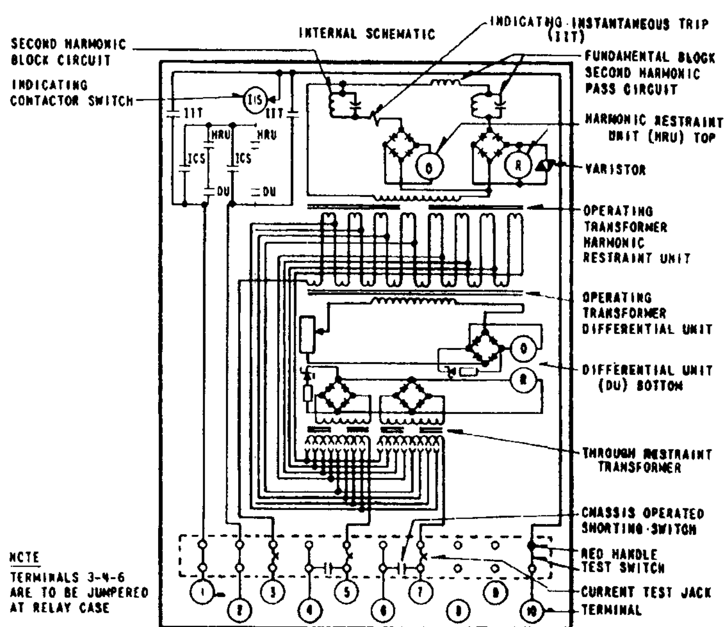
θ Degrees current lags voltage at tap value current.

† Voltages taken with Rectox type voltmeter.

Thermal rating

One second - 300 amperes

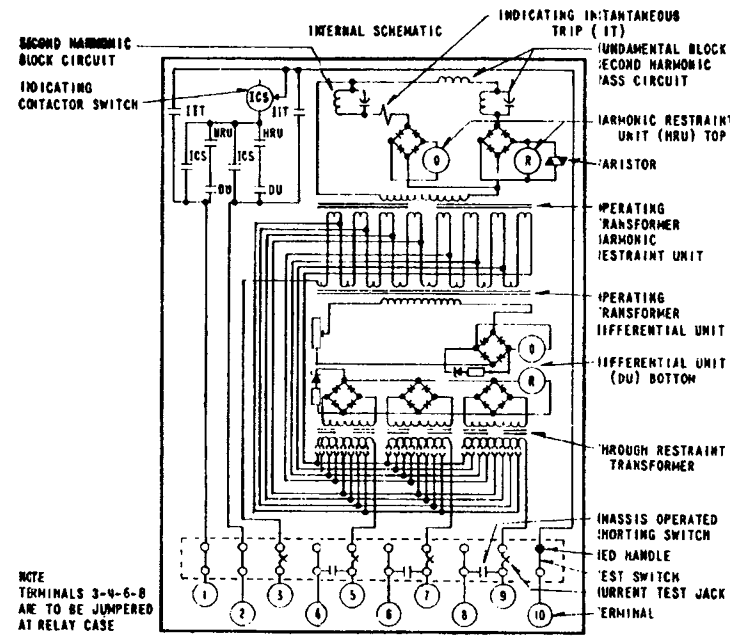
Thermal capacities for short times other than one second may be calculated on the basis of time being inversely proportional to the square of the current.



TERMINAL	TAP CONNECTION
5	TOP
7	BOTTOM

Sub 4
185A036

Figure 5. Internal Schematic of the Type HU Relay in FT-31 Case. For Single Trip Relays the Circuit Associated with Terminal 2 is Omitted.



TERMINAL	TAP CONNECTION
5	TOP
7	MIDDLE
9	BOTTOM

Sub 4
185A037

Figure 6. Internal Schematic of the Type HU-1 Relay in FT-31 Case. For Single Trip Relays the Circuit Associated with Terminal 2 is Omitted.

* Denotes Change

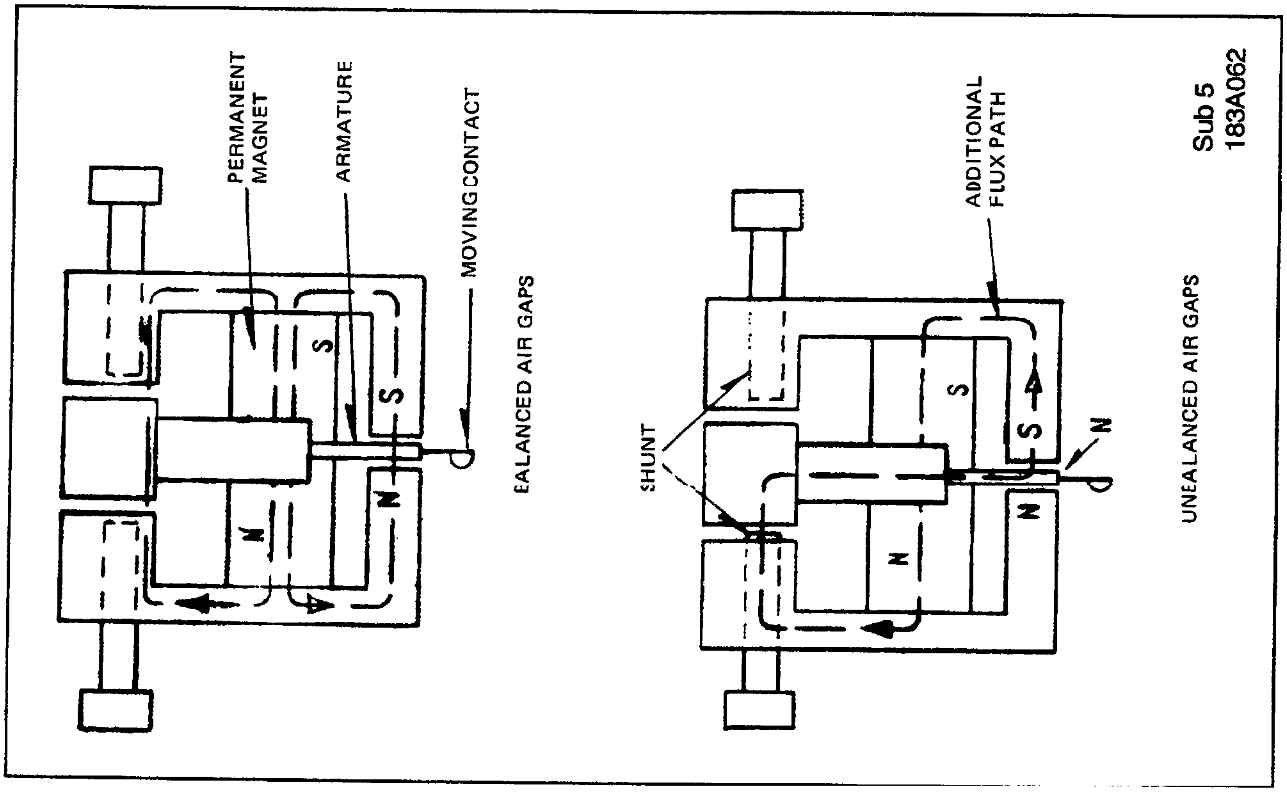


Figure 8. Polar Unit Permanent Magnet Flux Paths.

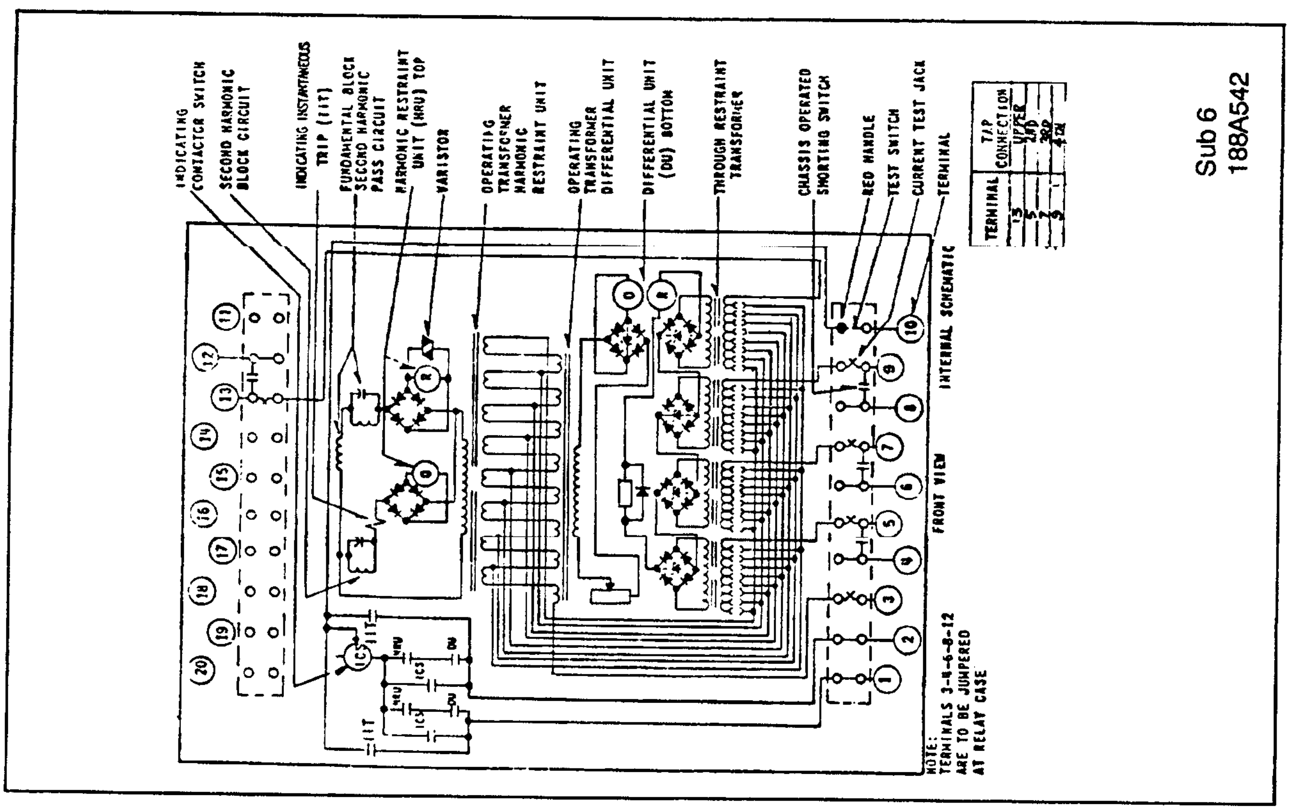


Figure 7. Internal Schematic of the Type HU-4 Relay in FT-42 Case.

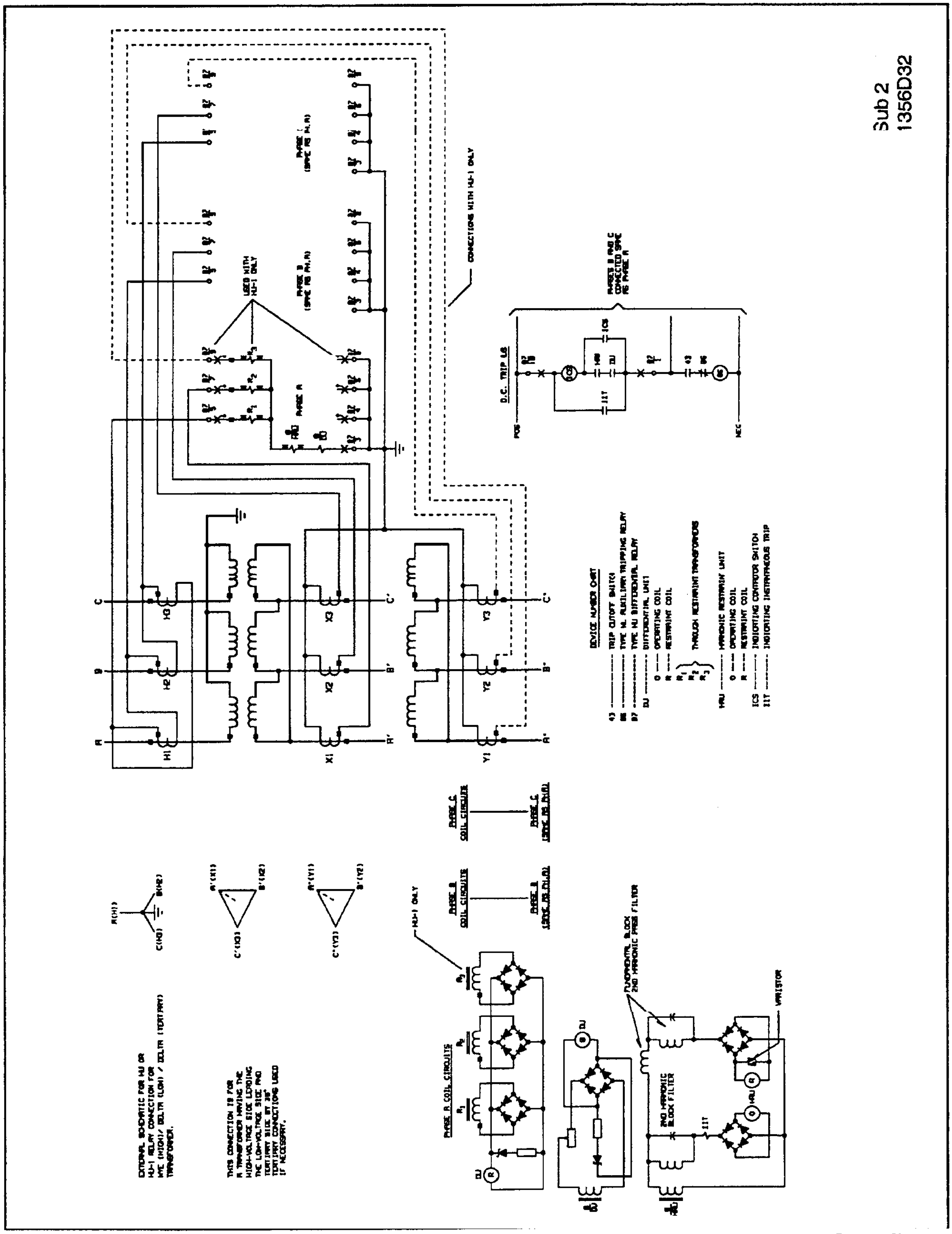


*Figure 9. External Schematic of HU Connections for a Wye (High) Delta (Low) Transformer.

* Denotes Change

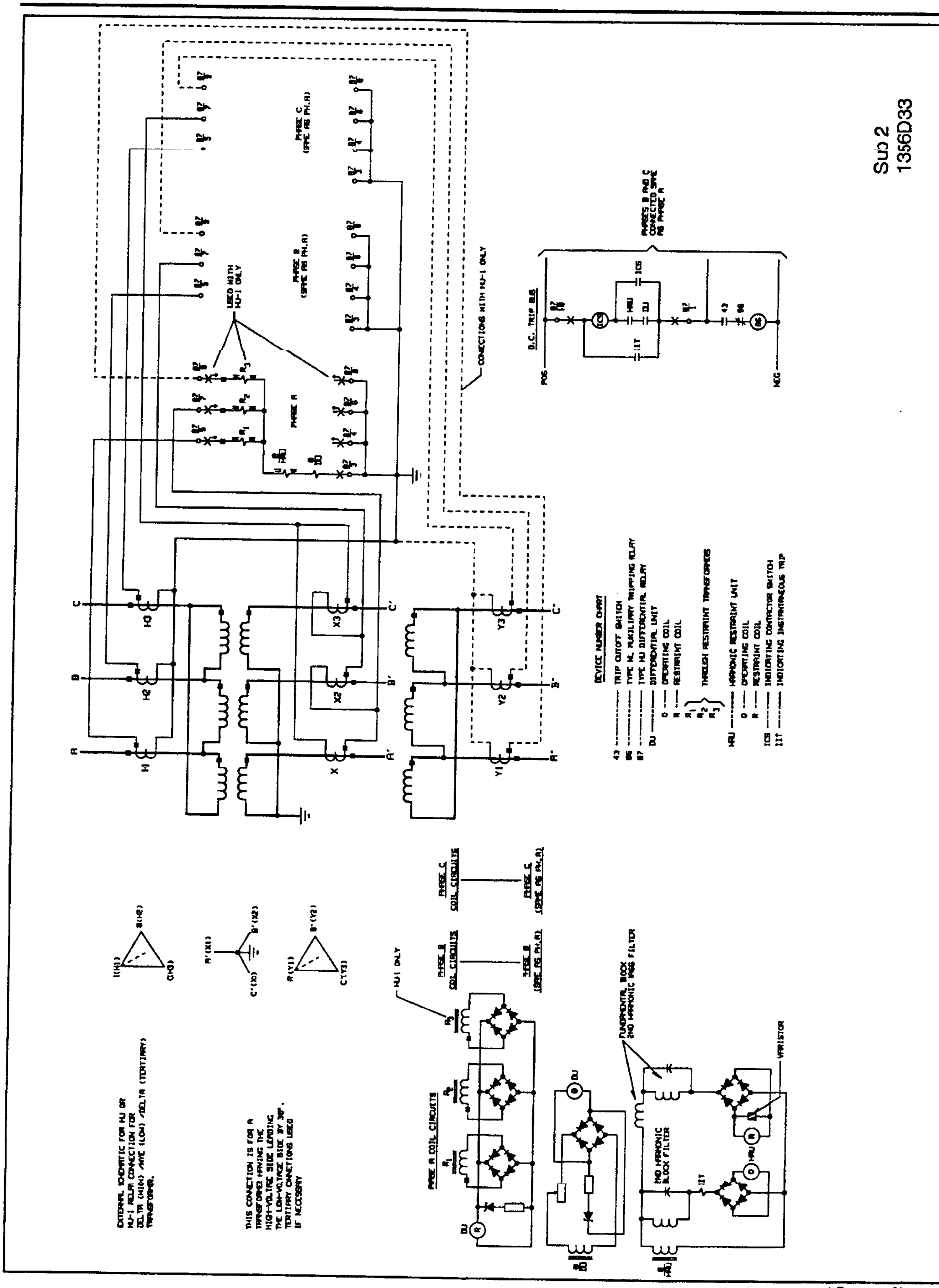


*Figure 10. External Schematic of HU Connections for a Delta (High)/Wye (Low) Transformer.

* Denotes Change

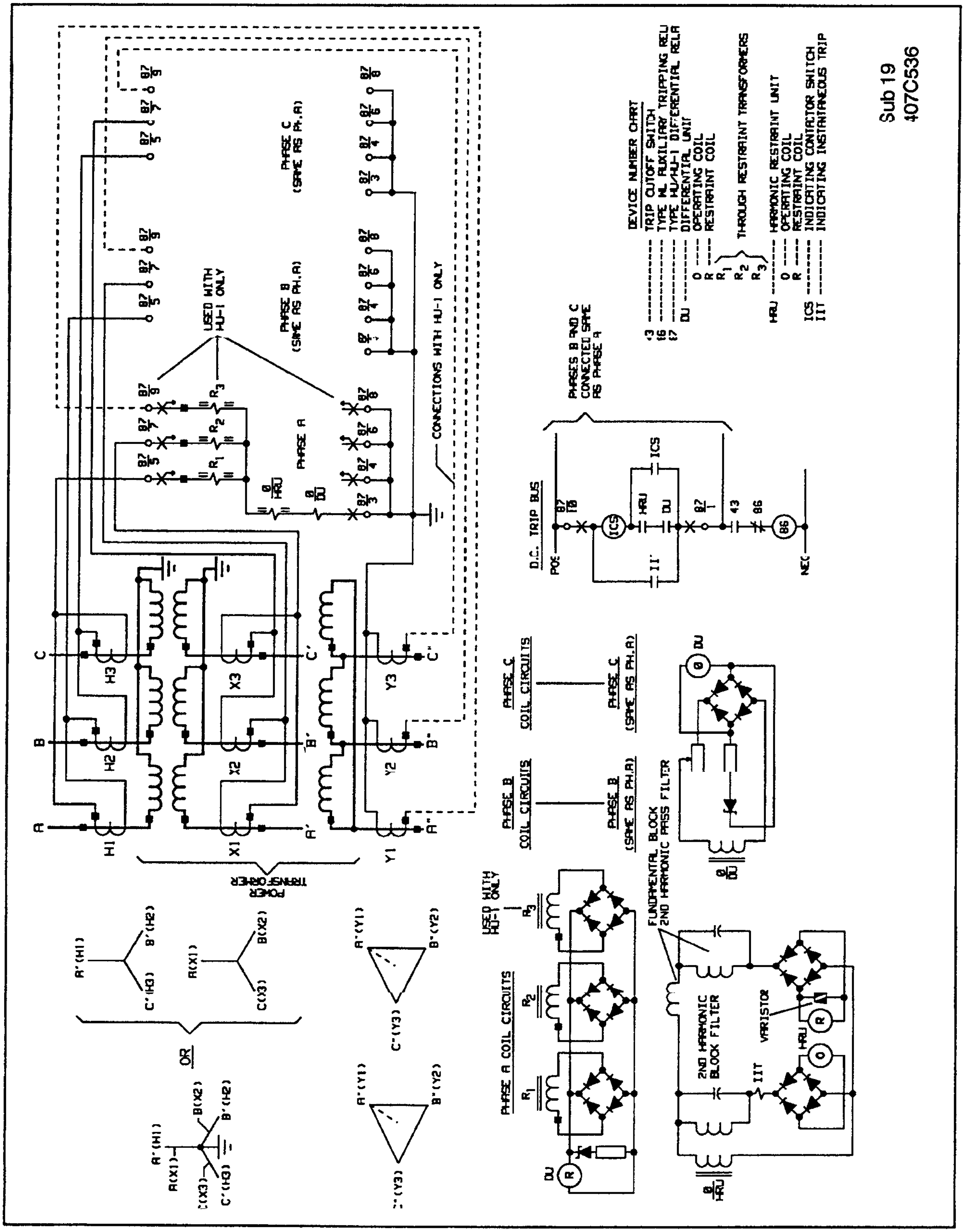


Figure 11. External Schematic of the Type HU and HU-1 Relays.

* Denotes Change

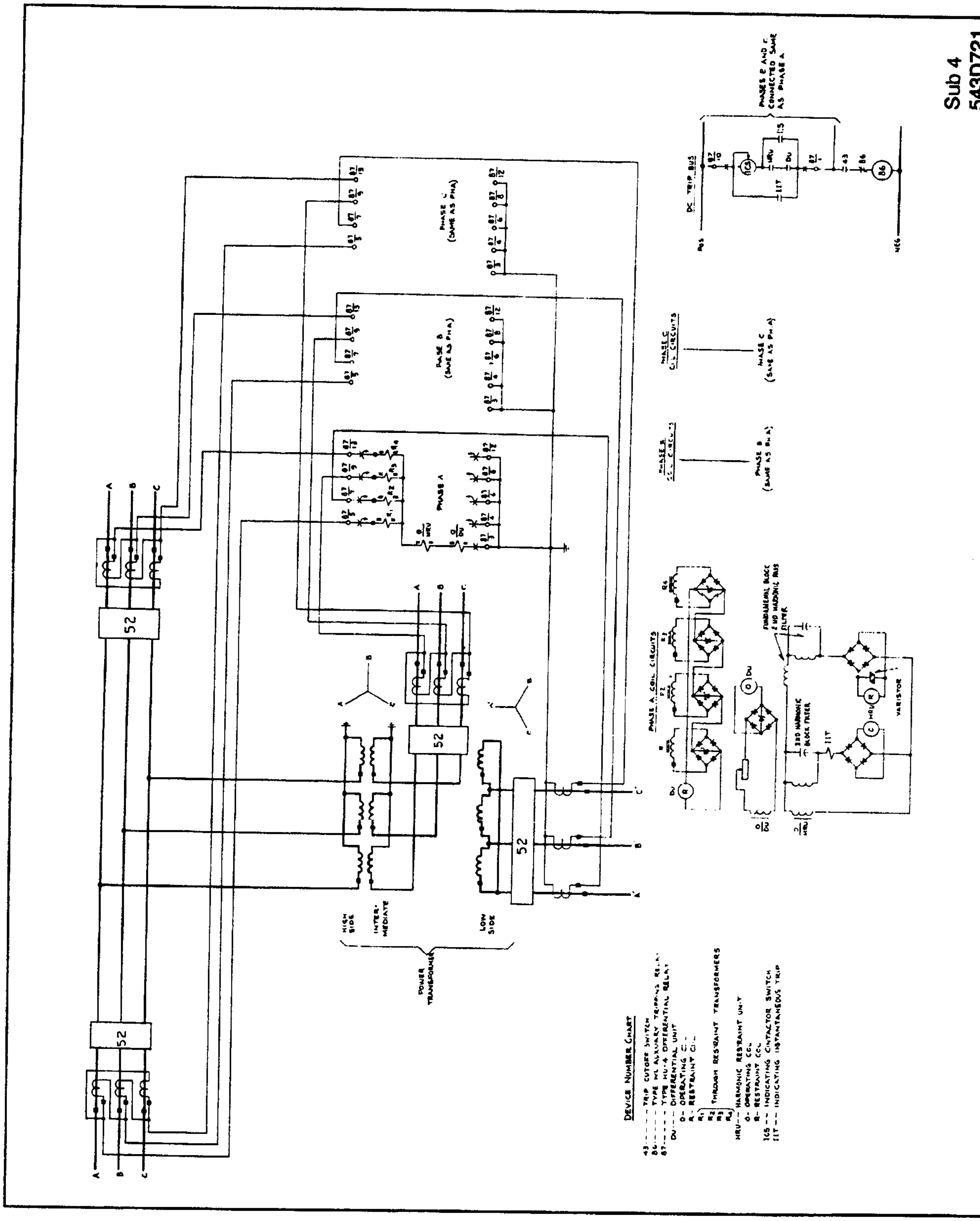


Figure 12. Typical External Schematic of the Type HU-4 Relay

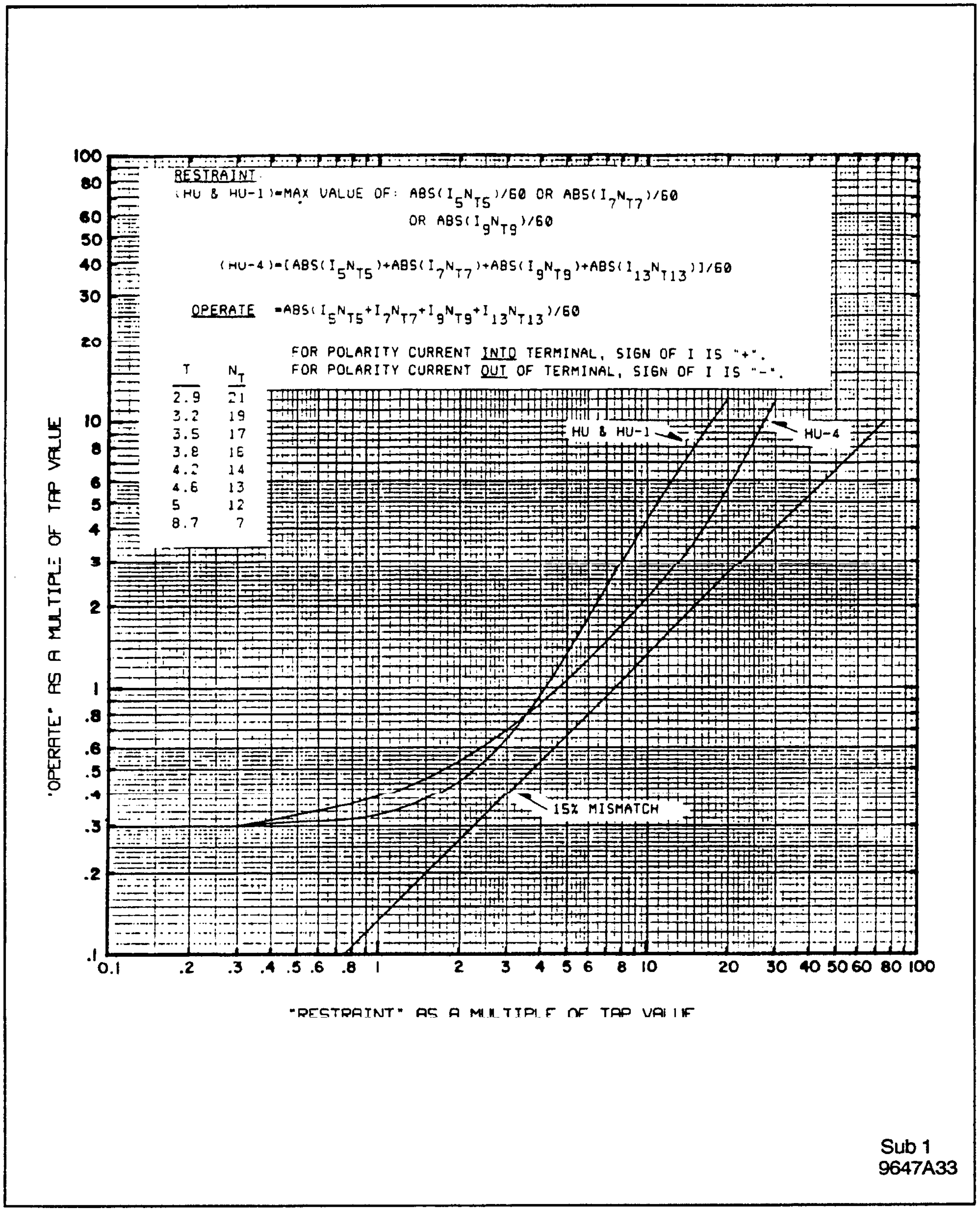


Figure 13. HU, HU-1 and HU-4 Differential Characteristics (30% Sensitivity).

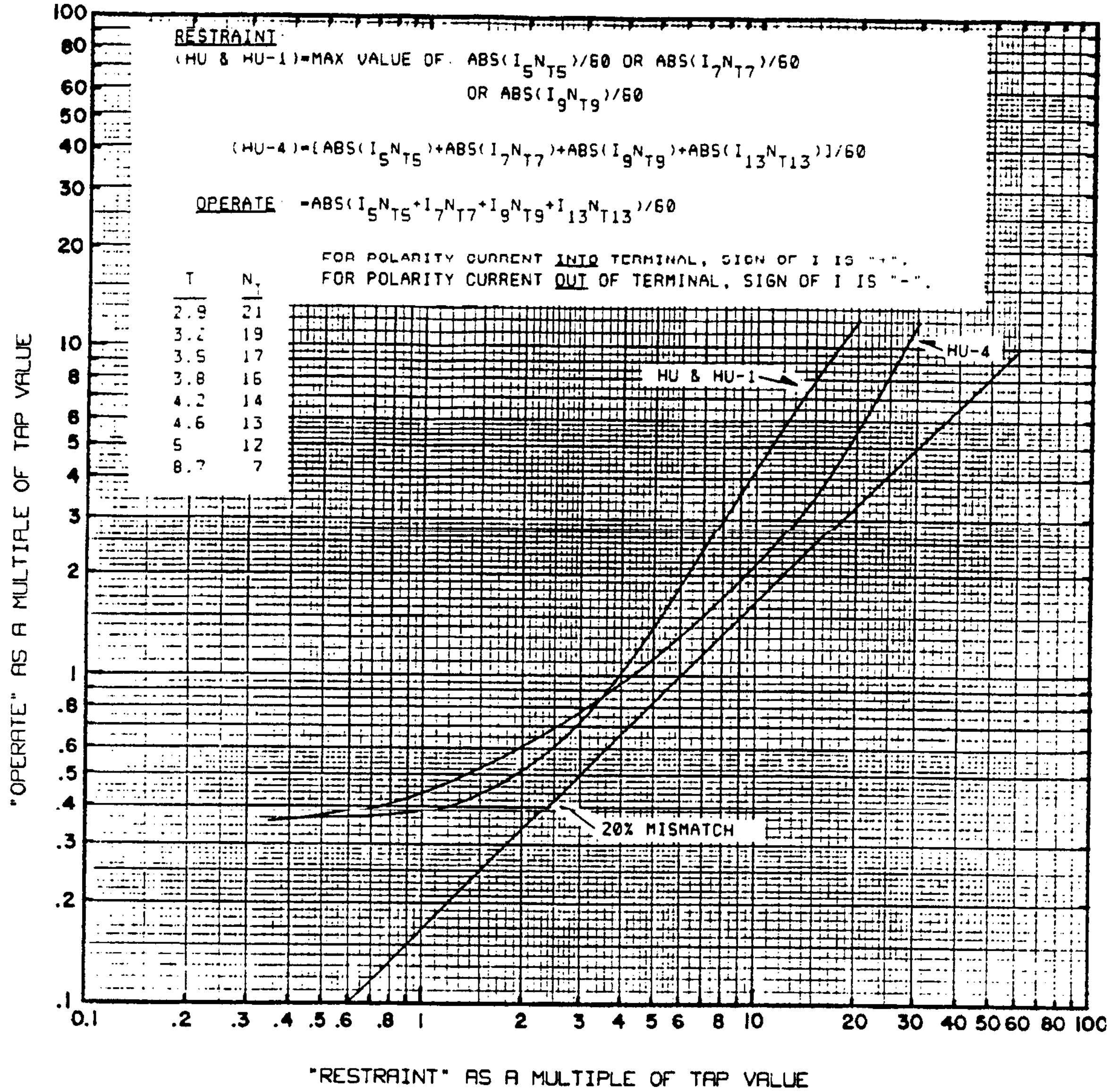


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Figure 14. HU, HU-1 and HU-4 Differential Characteristics (35% Sensitivity).

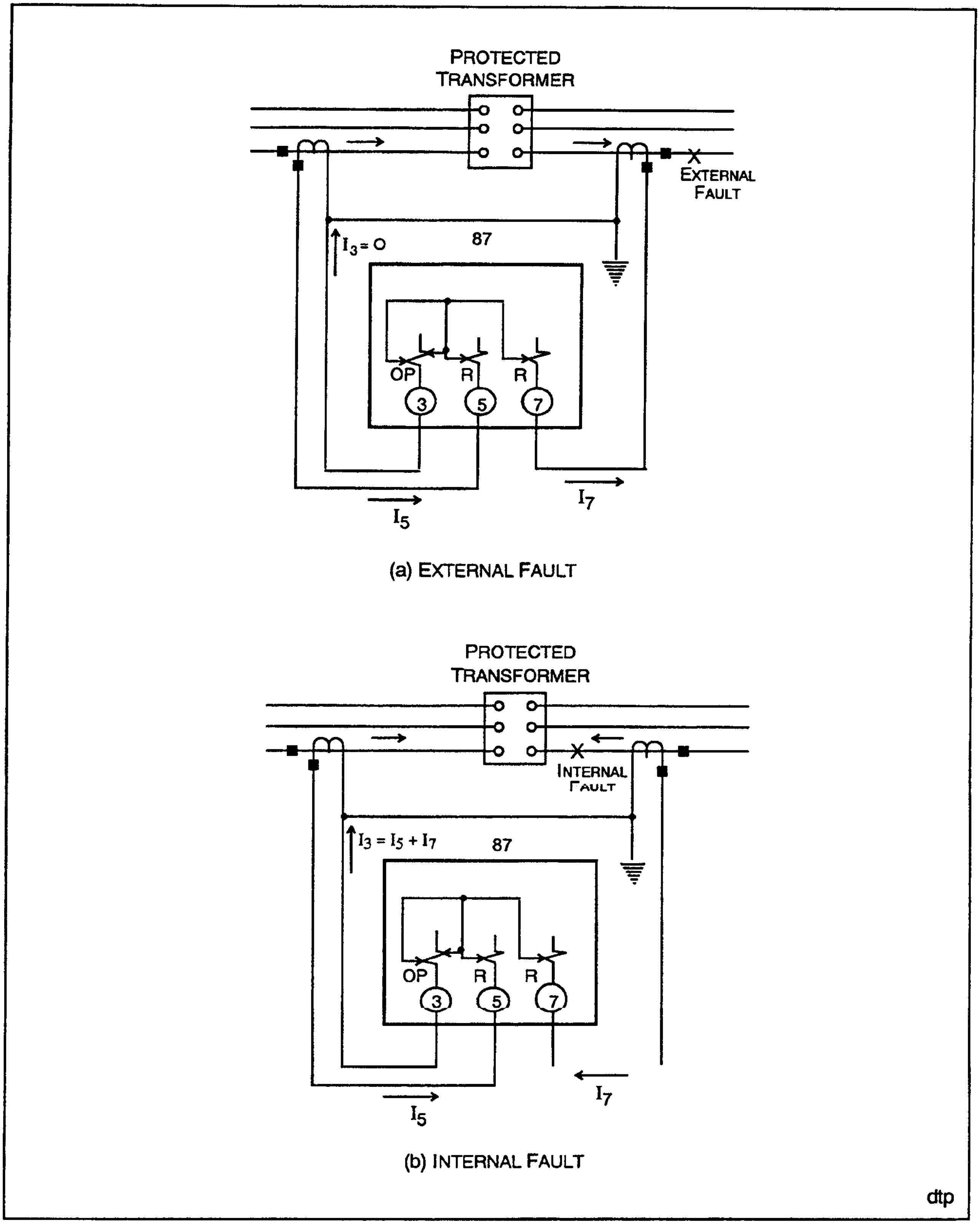

Figure 15. Simplified Schematic of the Type HU Relay with Current Distribution for (a) External Fault (b) Internal Fault.

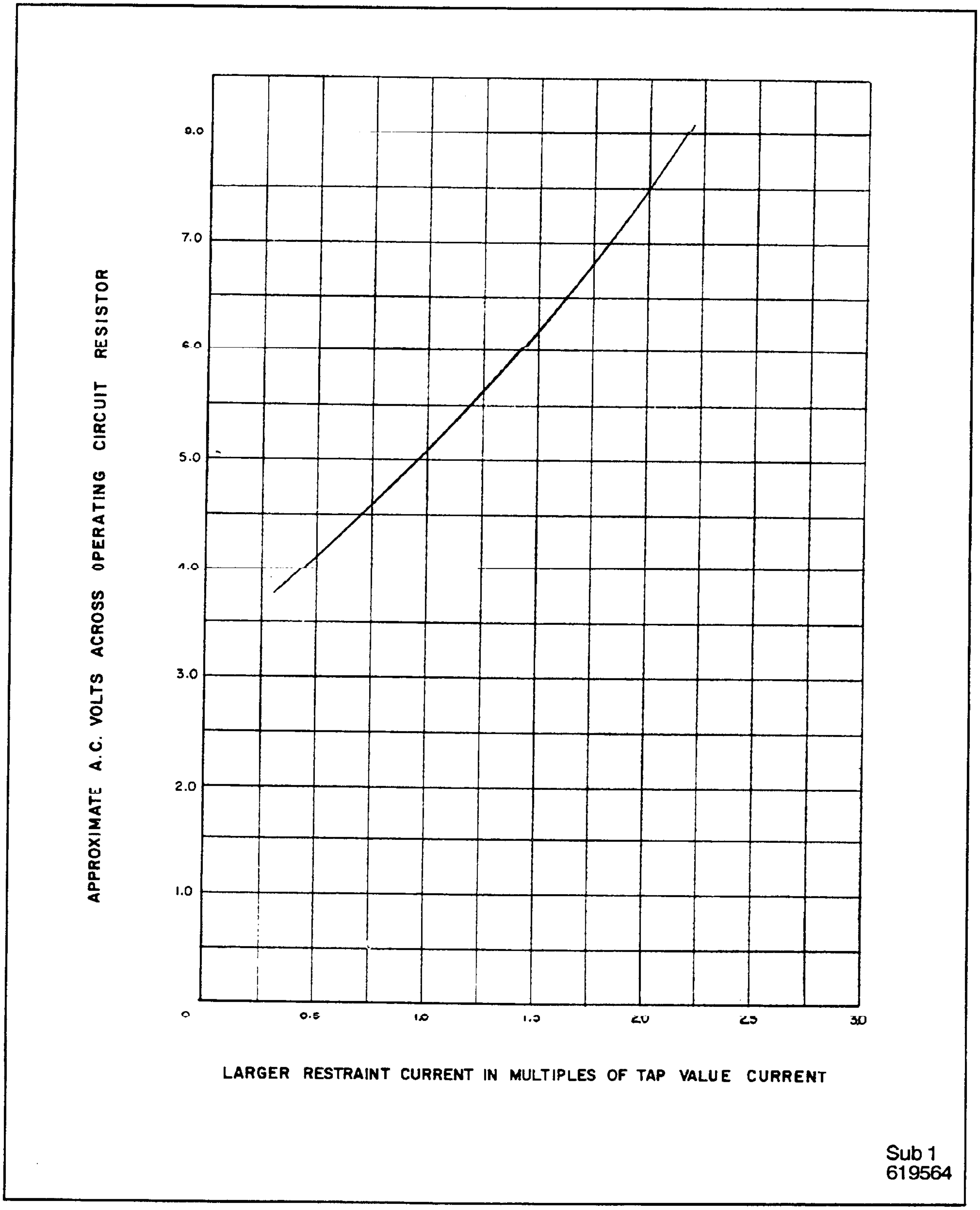

Figure 16. Differential Voltage Characteristic of the DU Unit of the HU-4 Relay with 0.30 Times Tap Pickup.

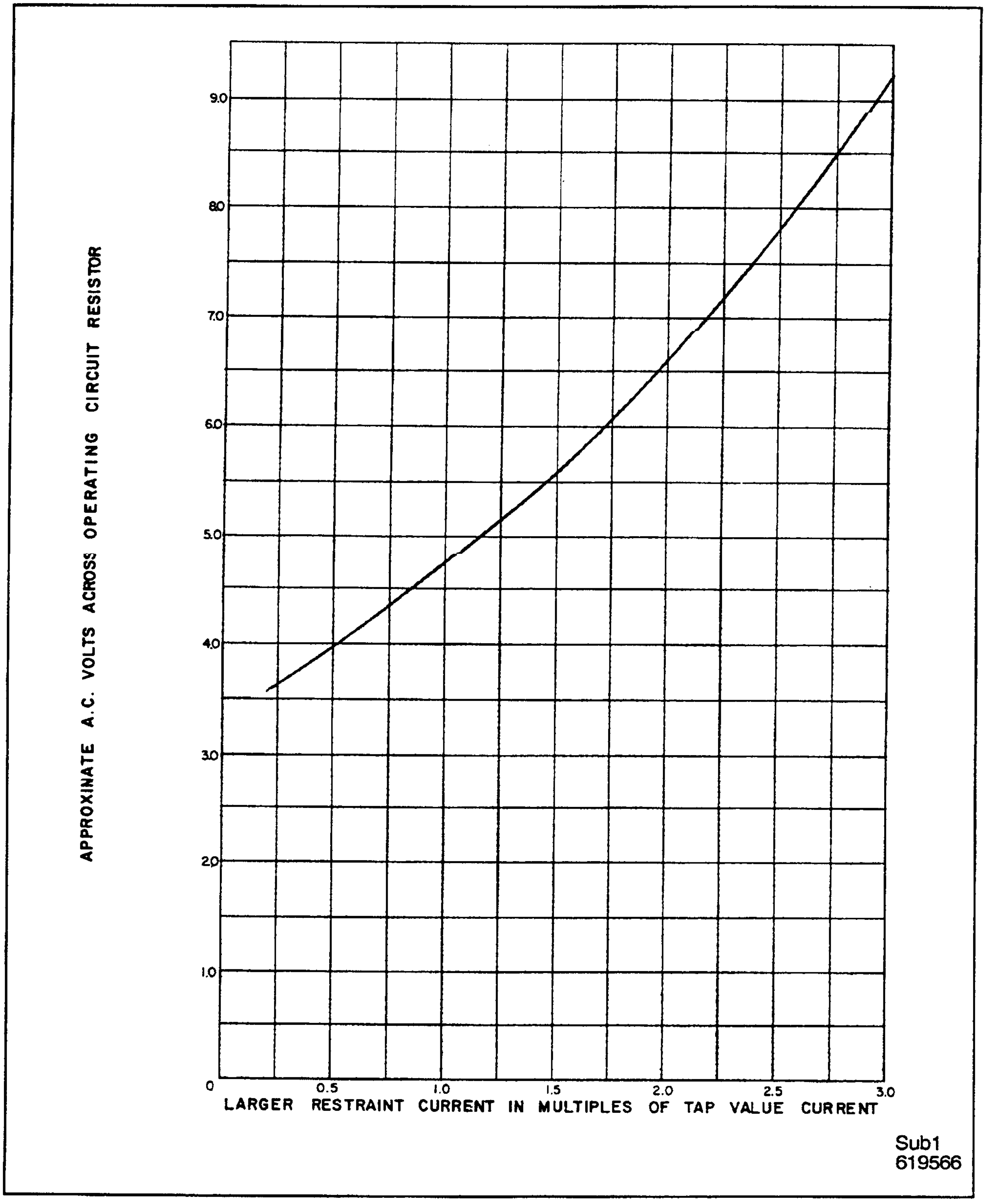

Figure 17. Differential Voltage Characteristic of the DU Unit of the HU-4 Relay with 0.35 Times Tap Pickup.

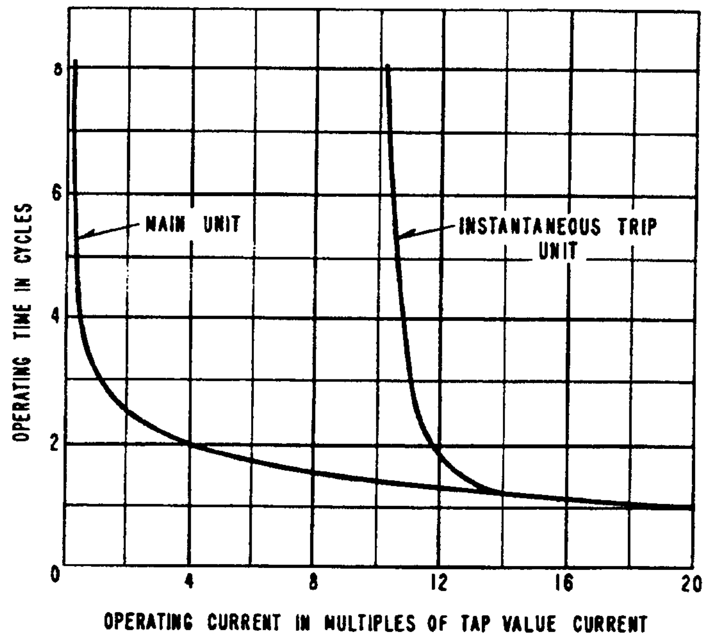

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Figure 18. Typical Tripping Time Characteristic.

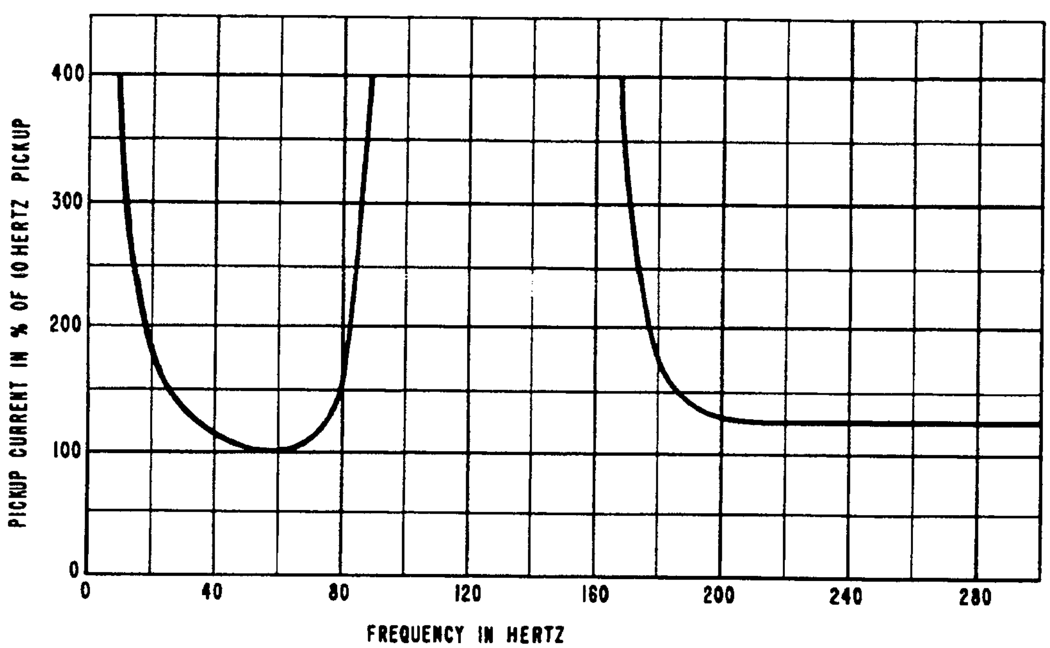

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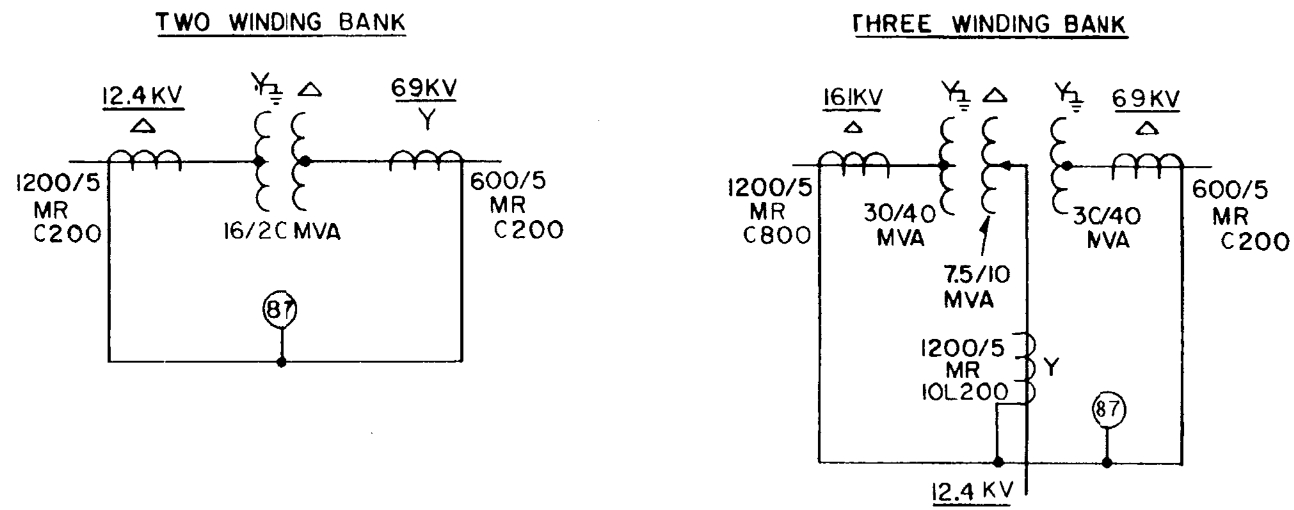
Figure 19. Typical Frequency Response of the HU and HU-1 Relays (60 Hertz).



TWO WINDING BANK

LOW	HIGH
$(KVA)_M$ = 20,000	$(KVA)_M$ = 20,000
$(KVA)_S$ = 16,000	$(KVA)_S$ = 16,000
V_L = 12,400 VOLTS	V_H = 69,000
N_T = 240 TURNS	N_T = 120
V_{CL} = 200 VOLTS	V_{CL} = 200
R_L = 0.4 OHMS	R_L = 0.4
DELTA CT	WYΞ CT
$I_{ext} \leq$ 100A	

THREE WINDING BANK

HIGH	INTERMEDIATE	LOW
$(KVA)_M$ = 40,000	$(KVA)_M$ = 40,000	$(KVA)_M$ = 10,000
$(KVA)_S$ = 30,000	$(KVA)_S$ = 30,000	$(KVA)_S$ = 7,500
V_H = 161,000	V_I = 69,000	V_L = 12,400
N_T = 240	N_T = 120	N_T = 240
V_{CL} = 800	V_{CL} = 200	V_{CL} = 200
R_L = 0.5	R_L = 0.5	R_L = 0.5
DELTA CT	DELTA CT	WYE CT
$I_{ext} \leq$ 100A		

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Figure 20. Example for Setting Calculaions.

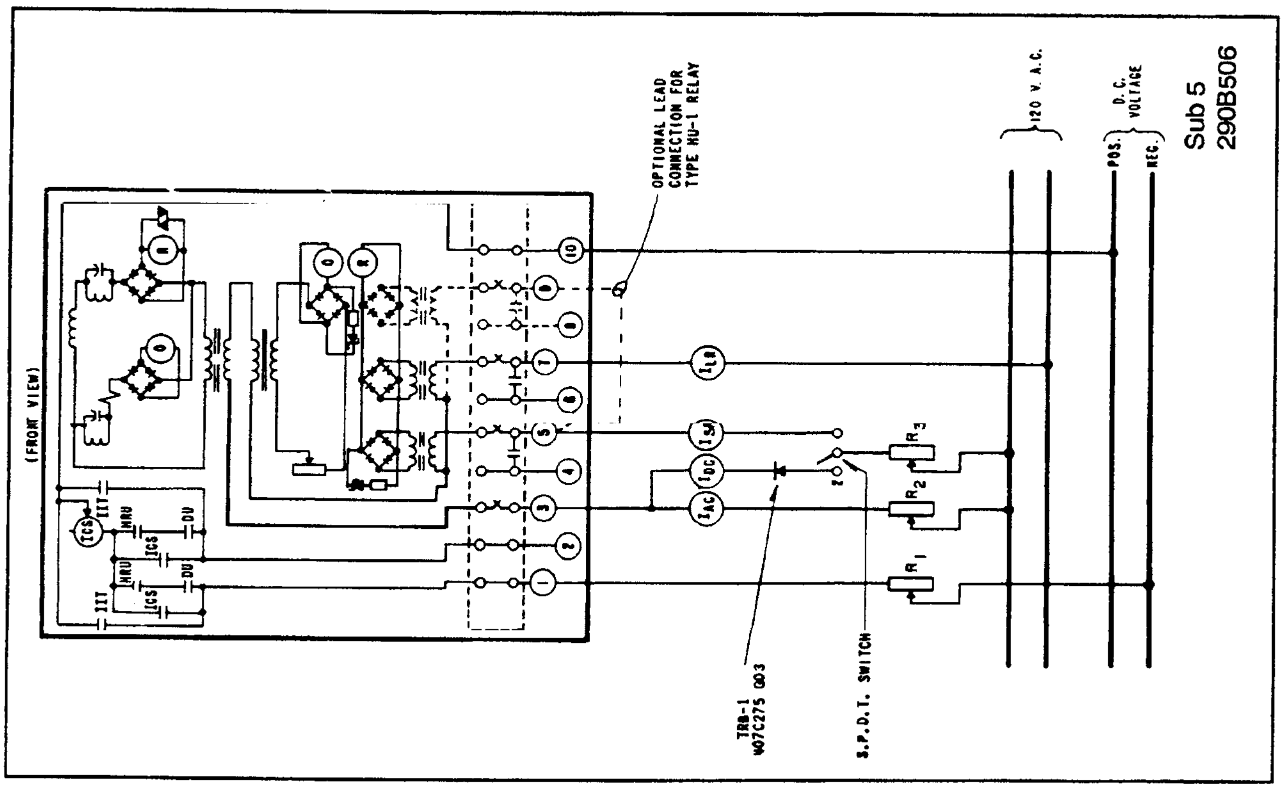

Figure 21. Test Circuit of the HU and HU-1 Relays.

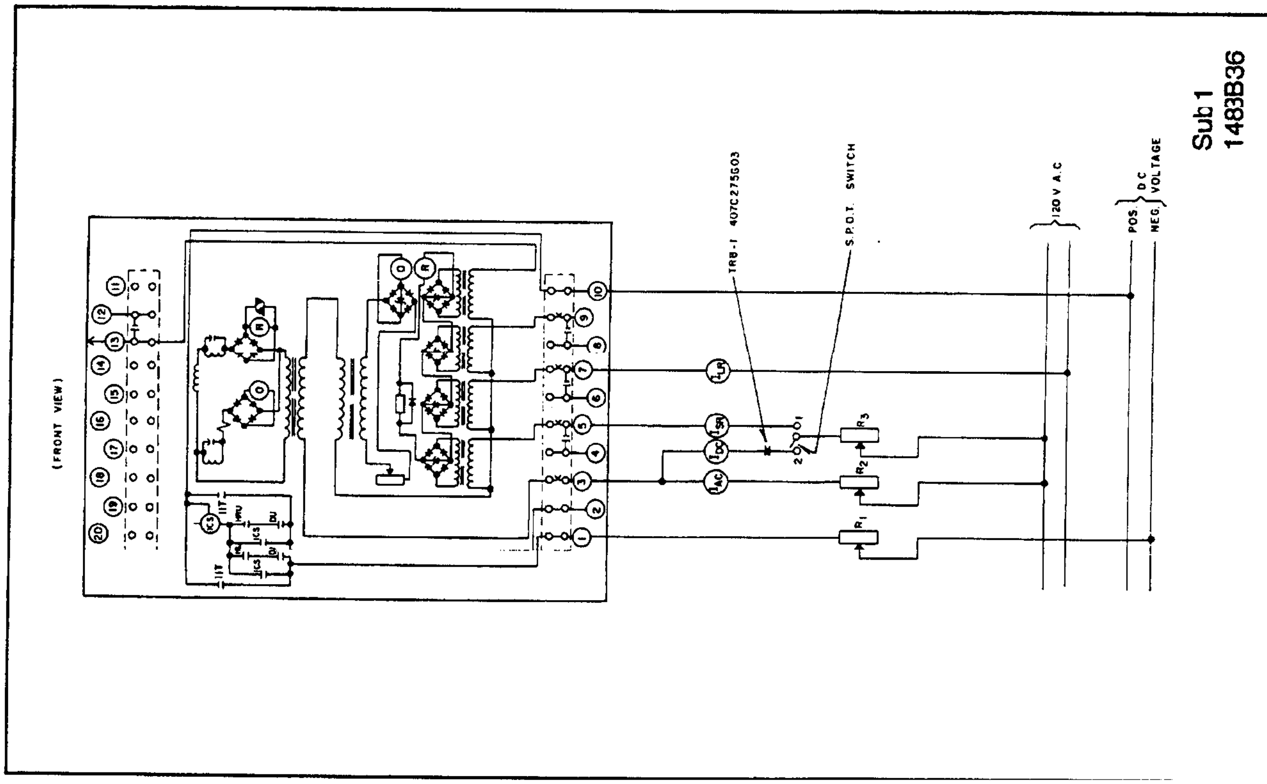

Figure 22. Test Circuit of the HU-4 Relay.

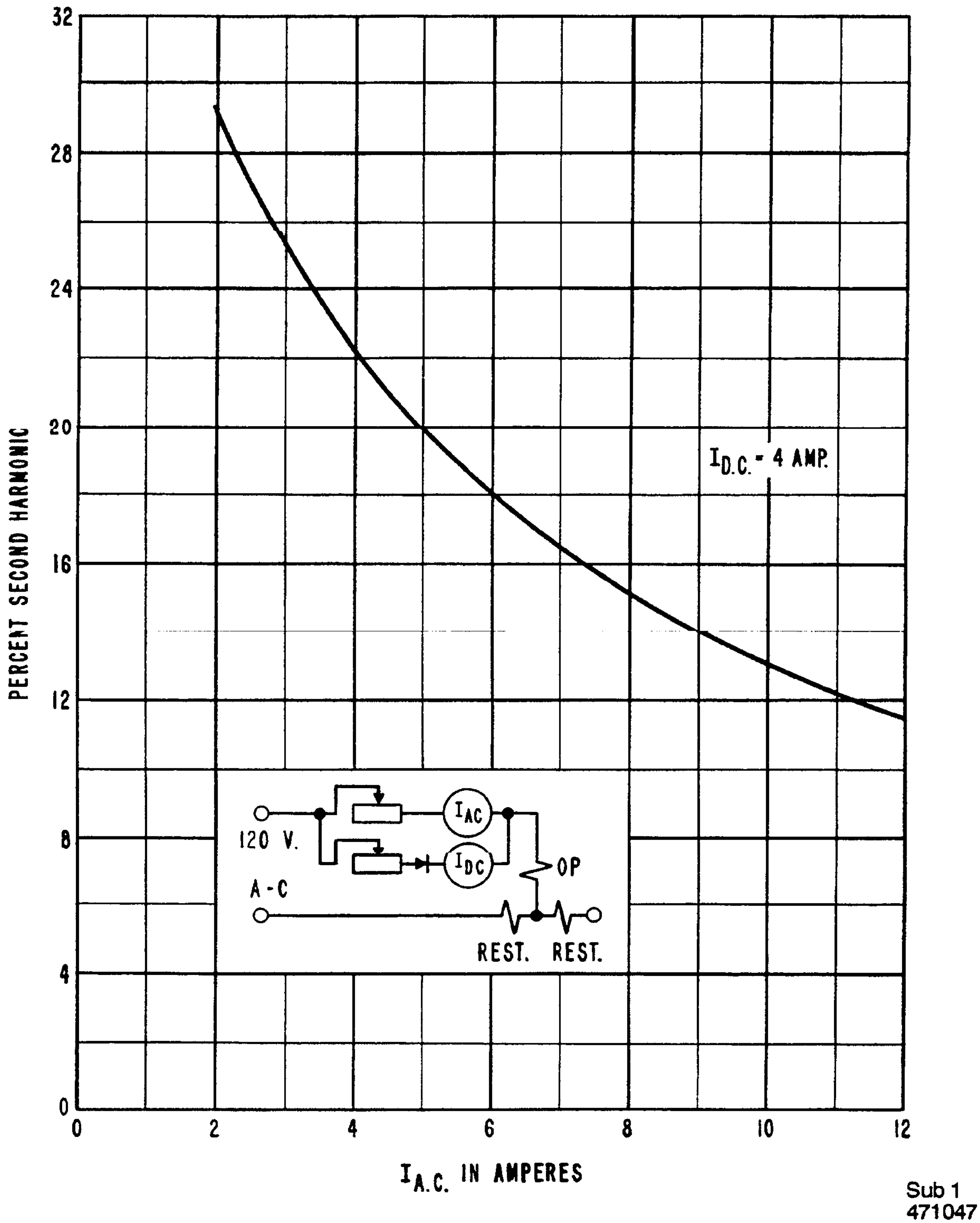

Figure 23. Variation of Second Harmonic Content of Test Current

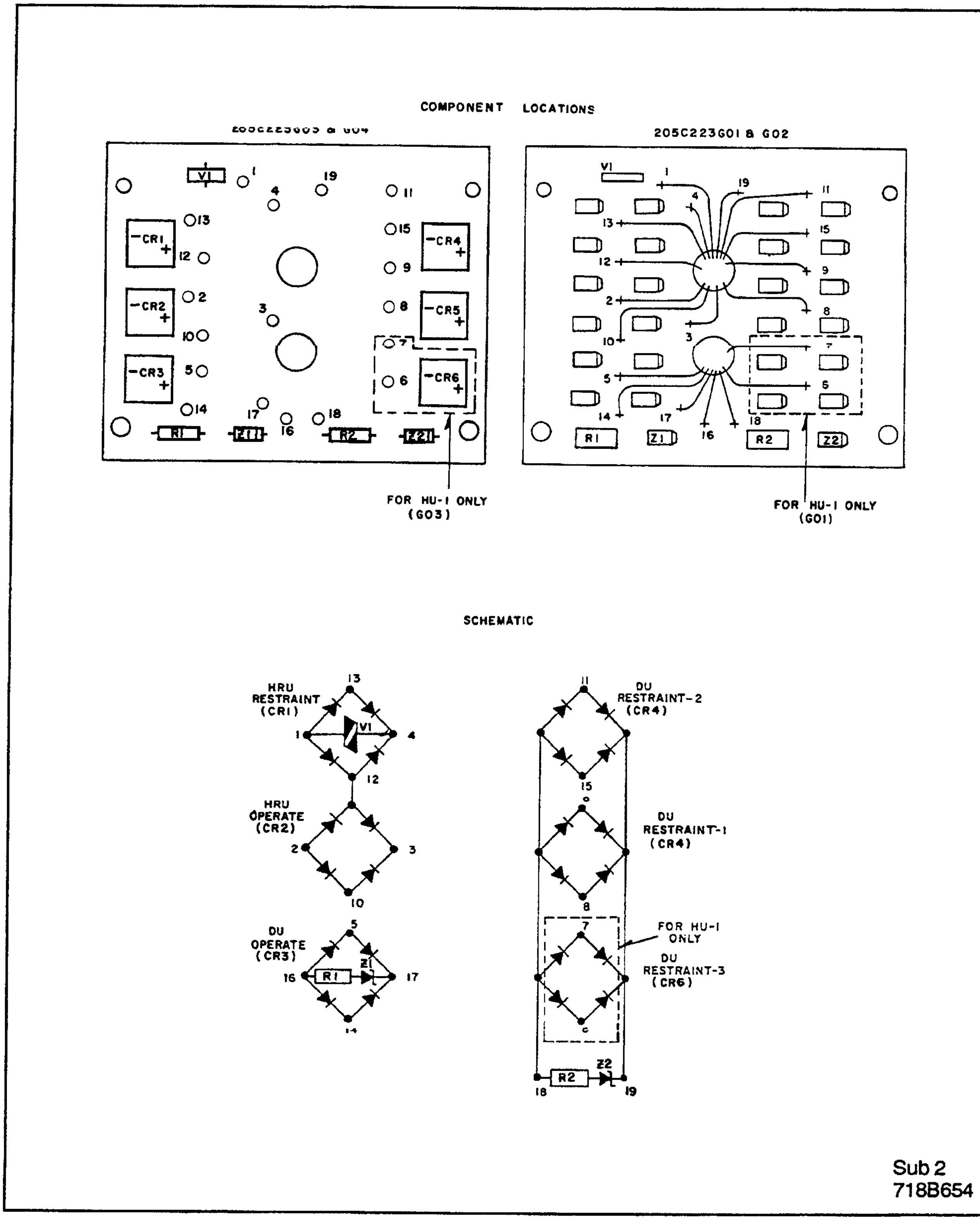

Figure 24. HU, HU-1, Diode Board Module—Component Location.

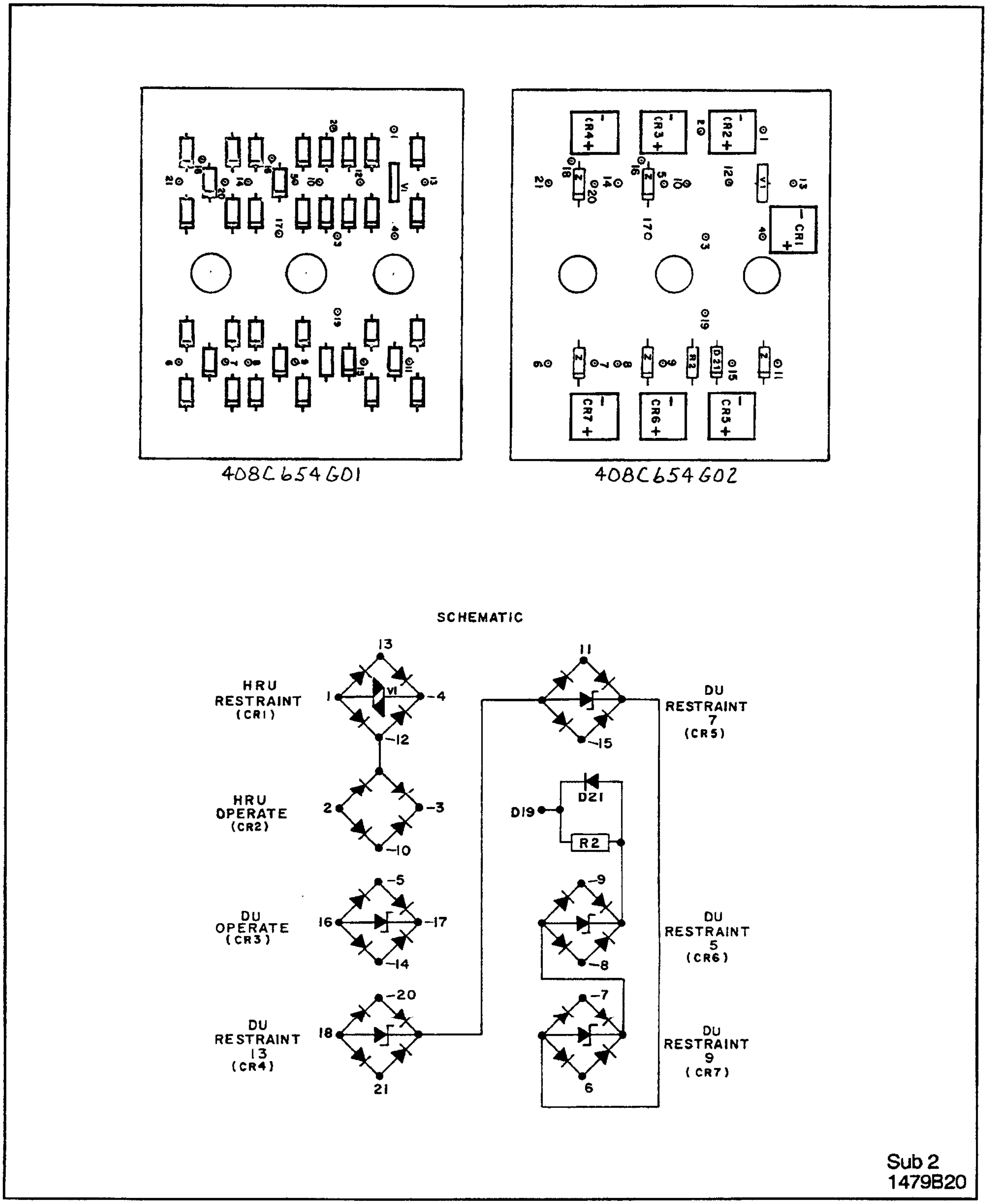

Figure 25. HU-4 Component Location.

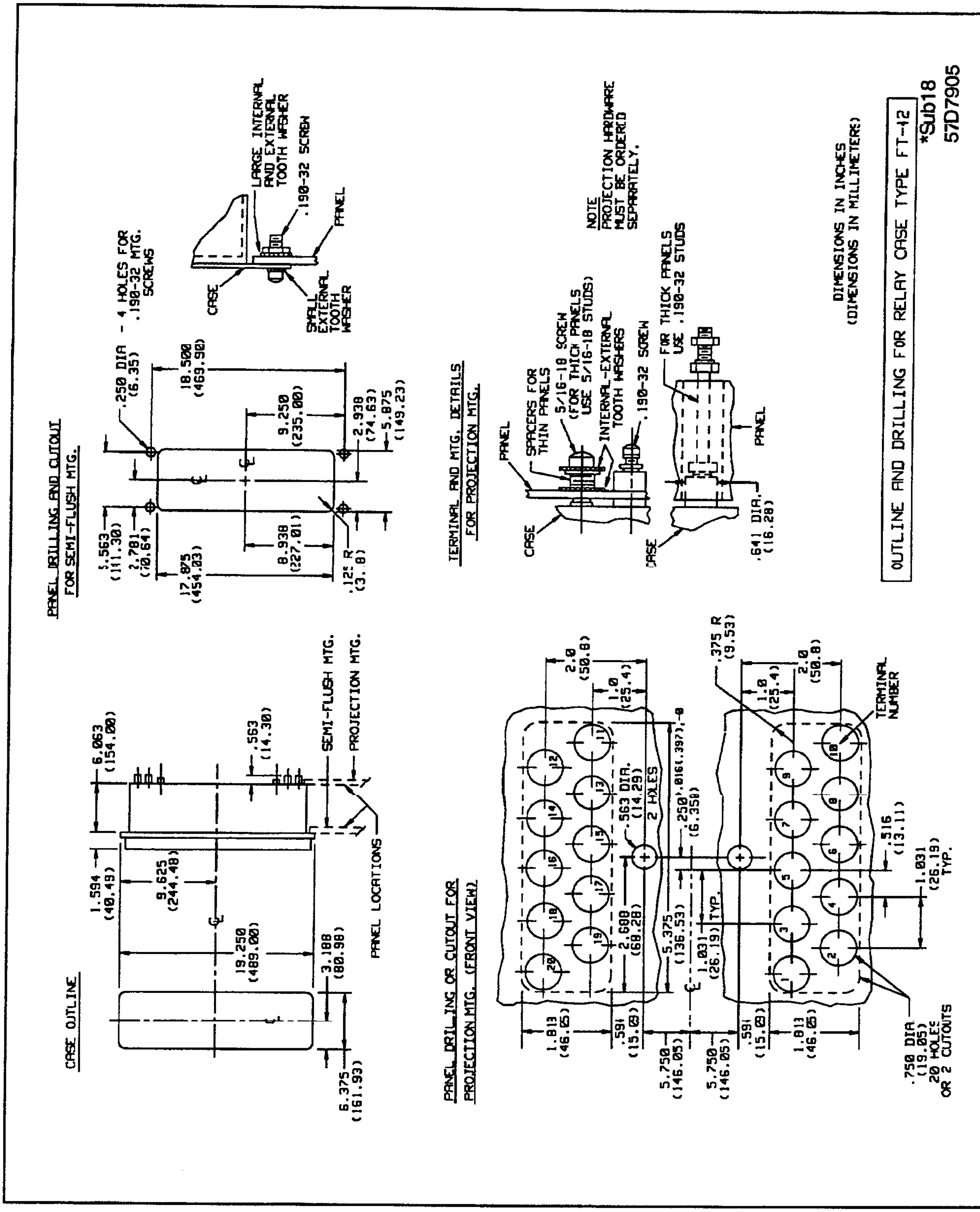

Figure 26. Outline and Drilling Plan of the HU-4 in the FT-42 Case.

* Denotes Change

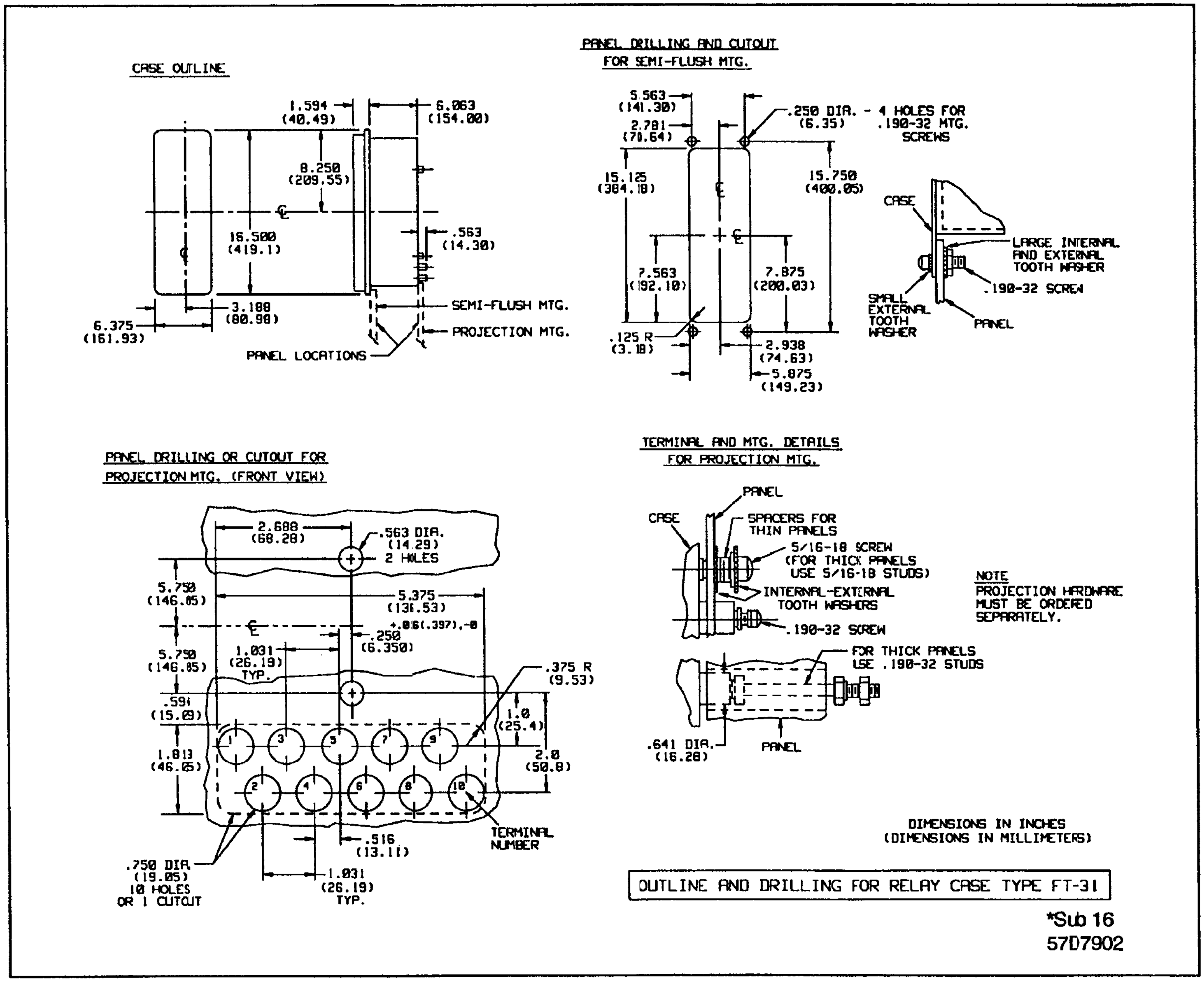

Figure 27. Outline and Drilling Plan of the Type HU and HU-1 Relays in the FT-31 Case.

* Denotes Change

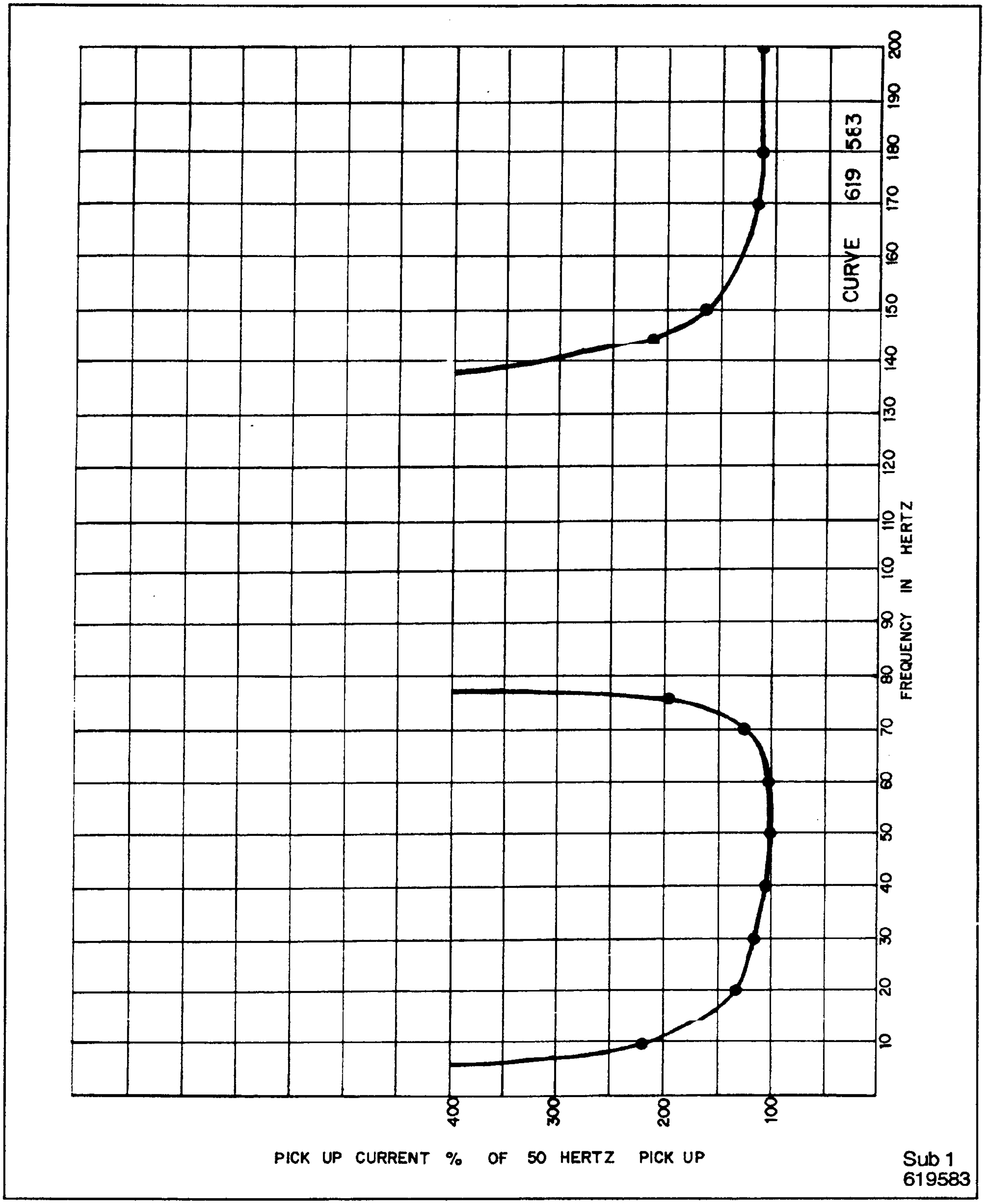

Figure 28. Typical Frequency Response of the HU and HU-1 Relays (50 Hertz).

MY NOTES

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ABB Inc.

4300 Coral Ridge Drive
Coral Springs, Florida 33065

Telephone: +1 954-752-6700
Fax: +1 954-345-5329

www.abb.com/substation automation