UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION II
101 MARIETTA STREET, N.W., SUITE 2900
ATLANTA, GEORGIA 30323-0199

ELECTRICAL ENGINEERING ON-SITE INSPECTION GUIDE

SUBJECT: Concepts in Static Trip Devices

PREPARED BY: Paul J. Fillion

DATE: October 8, 1996

DISCUSSION:

The following discussion and attached diagrams present some concepts related to the operating principles for static trip devices. Static trip devices are typically used with low-voltage metal enclosed power circuit breakers to provide overcurrent protection. The discussion revolves around Brown Boveri Electric, Inc. equipment. However, the examples are instructive, and should provide a platform from which one can more readily understand static trip devices by other manufactures or static rectifier circuits in general. The discussion includes an analysis of why certain wiring errors associated with static trip devices cannot be detected by the basic primary injection test.

The two diagrams in Attachment 1 depict the circuit for an ABB/ITE static trip device. There are two sets of current transformers: power supply and current sensing. The power supply current transformers and associated diodes make the tripping function independent of external power supplies. In the current sensing circuit, when current flows in the primary circuit, a dc current (rectified ac) will flow through the resistor at the input to the pickup/timing circuit. This current causes a voltage drop across the resistor. This voltage is actually the input to the pickup/timing circuit. The pickup/timing circuit responds to the peak instantaneous voltage appearing across the input resistor.

One key to understanding how the current sensing, rectifier circuit works is realizing that certain pairs of diodes cannot conduct simultaneously. These are D3-D7, D2-D6, D1-D5 and D4-D8. Figure 1 depicts the current sensing circuit between the secondaries of the auxiliary current transformers and the pickup/timing circuit. Referring to Figure 1, diode D1 conducts during the positive half cycle of phase A current. Diode D2 conducts during the positive half cycle of phase B current. Diode D3 conducts during the positive half cycle of phase C current. The top portion of Figure 1 extends this concept, and shows the diode conduction intervals corresponding to the three phase currents when those currents are of equal magnitude and displaced by 120° (i.e. balanced).

The best way to gain insight into the voltage that appears across the input resistor for a given set of primary currents is to take a "snapshot" of current flows throughout the circuit at a given instant. Figure 2 shows the per-unit current flows when phase A current is at 90° and 150° respectively. One can see that for balanced phase currents having a per-unit peak magnitude of 1 the input resistor has a constant magnitude of 1.

Similar circuit analysis can be done for unbalanced conditions. Figure 3 depicts the current flows for a typical double line to ground fault on phases B and C. The magnitude of the primary currents are: phase A equals zero and phases B and C equal 1.7624 per-unit rms. The magnitude of the total fault current is 3.27 per-unit peak. Note that the voltage across the resistor is full wave rectified ac having a magnitude of 3.27 per-unit, which is equal to the total fault current.

Consider the ramifications of having one auxiliary current transformer connected backwards. This case, with phase A auxiliary current transformer connected backwards, is depicted in Figures 4a and 4b. Note that the peak voltage at the resistor is equal to 2 per-unit for a 1 per-unit peak primary current. Therefore, when the sensing circuit is looking at normal balanced primary current with one auxiliary current transformer connected backwards, the peak voltage at the input resistor is twice that with correct connections. This problem, however, cannot be detected with standard primary injection testing because the phases are checked one at a time using a single phase source. During the test, the pickup/timing circuit would see the correct magnitude whether a current transformer is reversed or not. Depending on the trip device set points in relation to the actual load current the trip device may not trip during normal operation even with a reversed current transformer. If accident scenario current is significantly higher than normal current, the wiring error could result in spurious tripping.

The above example demonstrates that basic primary injection testing cannot detect all possible wiring errors in static trip devices. Such wiring errors have in fact been introduced during breaker refurbishment where a quality control check was not made on the current transformer wiring due to the belief that testing would detect any errors.

Wiring errors in the power supply current transformer circuit can cause problems similar to those described above. Consider the wiring error shown in the power supply current transformers in Figure 5. With primary current flowing in all three phases, the wiring error shown results in phase A and phase B current transformers opposing each other which results in less than normal voltage being supplied to the pickup/timing circuit. With primary current flowing in only one phase such as during test conditions, the CT secondary current induced by the primary injection current is forced to flow through a CT having no primary current. This is different than the normal case, but also results in reduced voltage at the pickup/timing circuit.

Again, this problem actually occurred at a site. What was observed in the primary injection testing was that phase C tested fine, but phase A and phase B gave results a few percent outside the acceptance band (i.e. slow response). These empirical results obtained by the licensee were reproduced by an independent test laboratory. Also, the author spoke with engineers at Asea Brown Boveri, and they confirmed that a reduction from normal levels of power supply voltage would cause a shift in response time of the long-time element. Conceivably, in a different circuit with components of different ratings, a circuit having the same error would just pass the calibration check thus masking the wiring error. We do not have any information as to how the trip device having the wiring error shown in Figure 5 would respond for the case of three phase primary current.

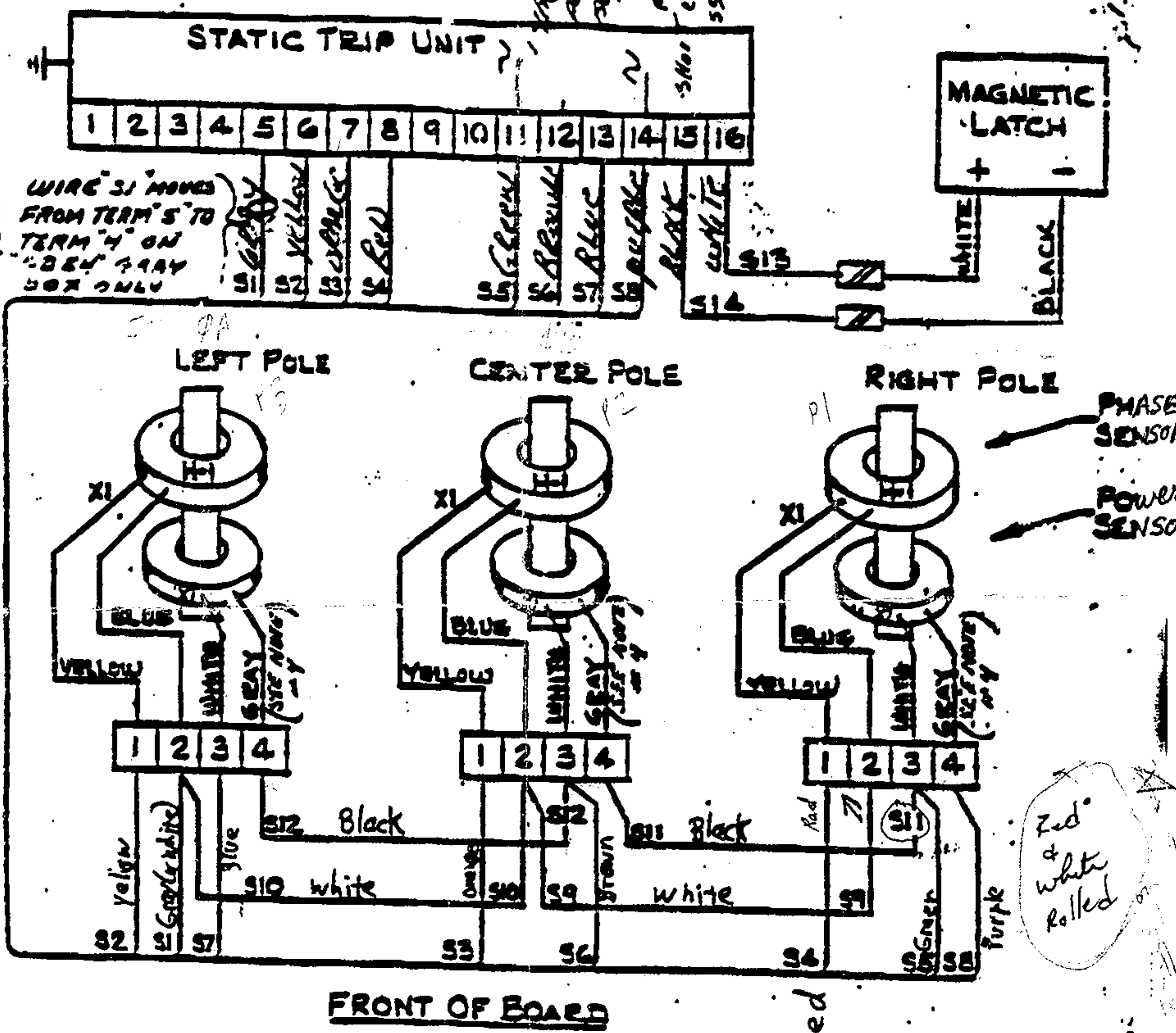
ATTACHMENT 1

Two diagrams showing the circuit and arrangement of the ABB/ITE static trip device.

BBC Brown Boveri Electric, Inc.
Manufacturer of I-T-E Electrical Power Equipment

709551

REV.	BY	CHD.	APP.	SCALE
0	M.E. Smal DATE 10-16-69	DATE	R.G.M. DATE 21 Oct. '69	NONE



FRONT OF BOARD

(Front of Breaker)

NOTES:

1. USE #18 B&S GA. WIRE (PER CABLE ASSY. EPL 709756 OR 712279)
2. COLOR CODE (COLOR CODED WIRES DO NOT REQUIRE ADDITIONAL IDENTIFIC

S1 - GRAY	S5 - GREEN	MULTICONDUCTOR CABLE
S2 - YELLOW	S6 - BROWN	
S3 - ORANGE	S7 - BLUE	
S4 - RED	S8 - PURPLE	
S13 - WHITE	S14 - BLACK	
S9 - WHITE	S11 - GREEN	JUMPER WIRES
S10 - WHITE	S12 - BLACK	

FILMED

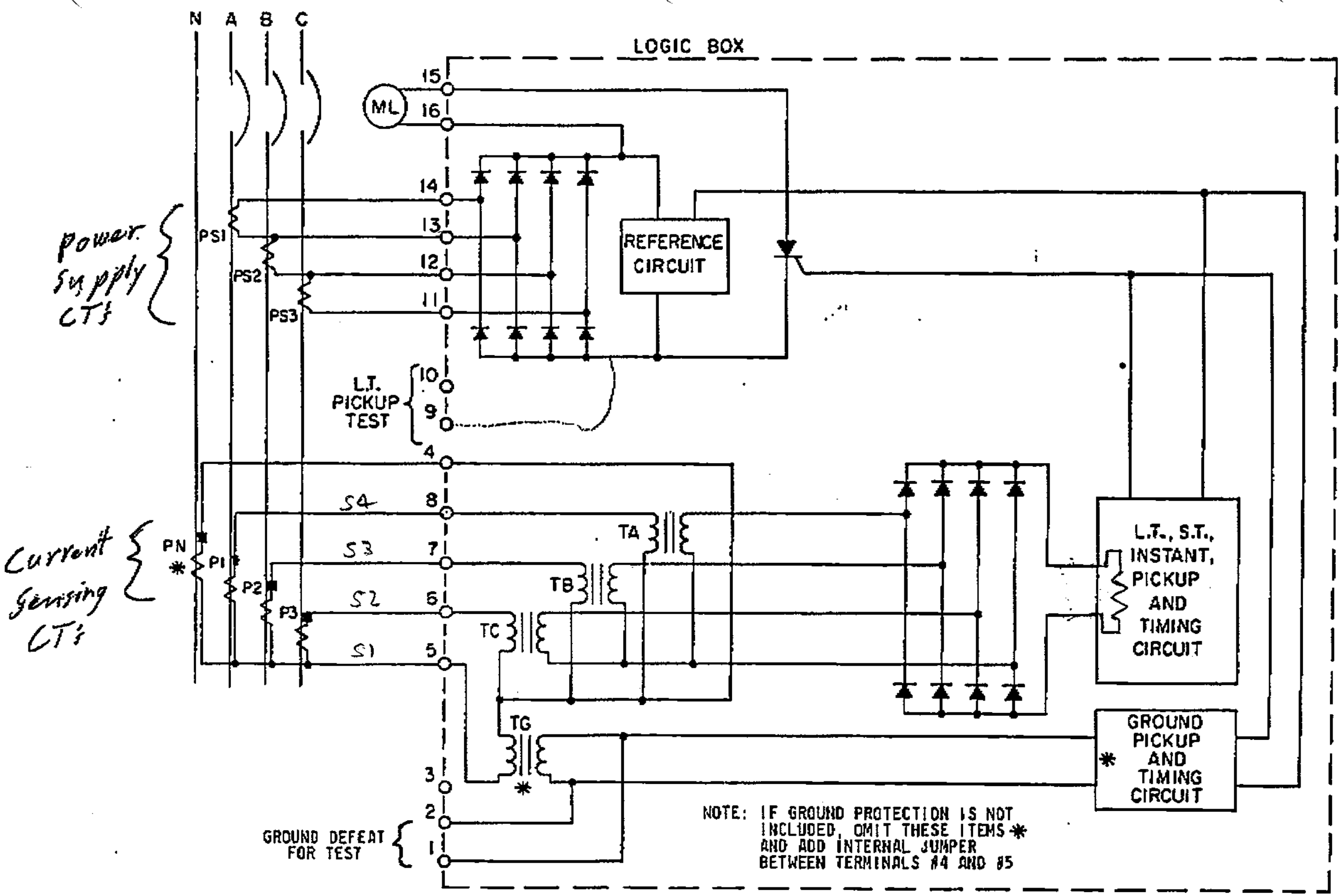
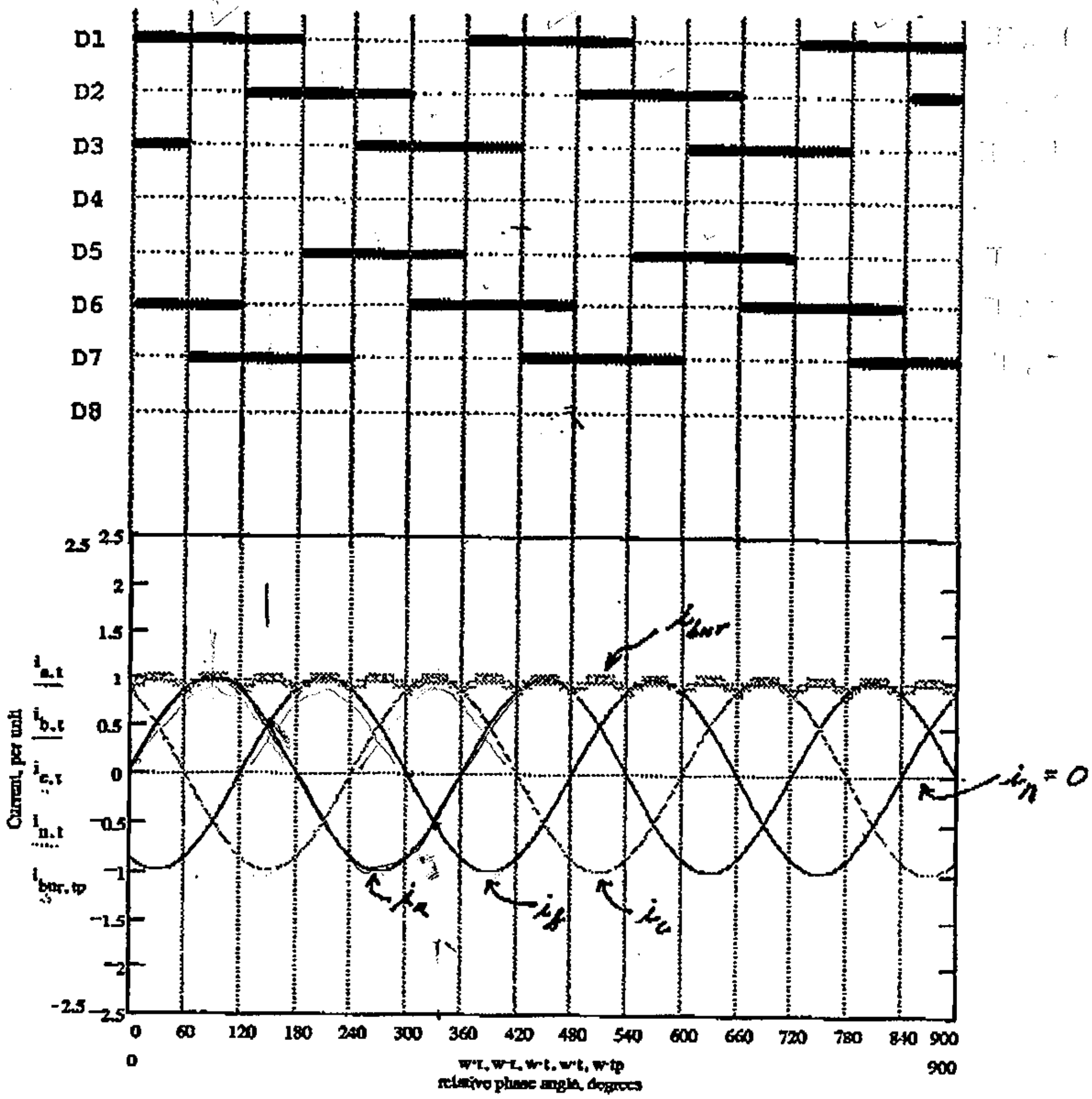


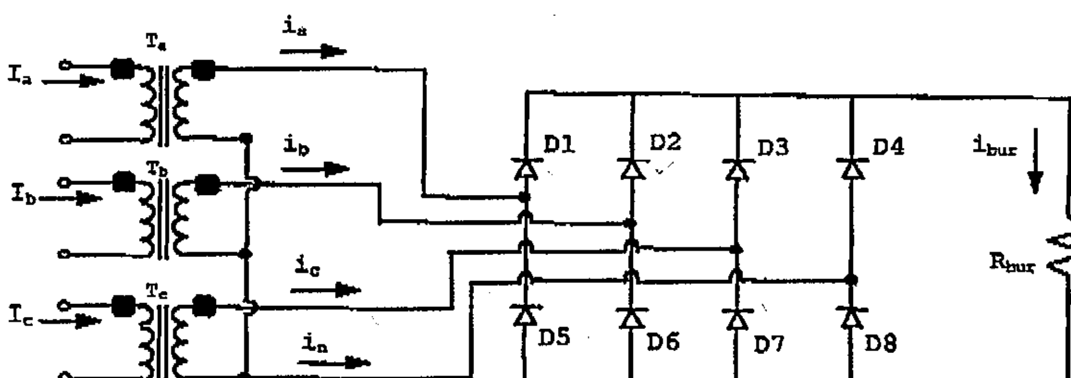
Fig. 3 — Typical Wiring Diagram of Standard 3- or 4-Wire System with Ground Fault Protection

From ABB/ITE instruction book IB-9.1.7-22, pg 9.
We don't have Ground protection components. The diode "bridges" on your drawing are re arranged, but circuit is identical.

Balanced Case (CT leads correctly connected)

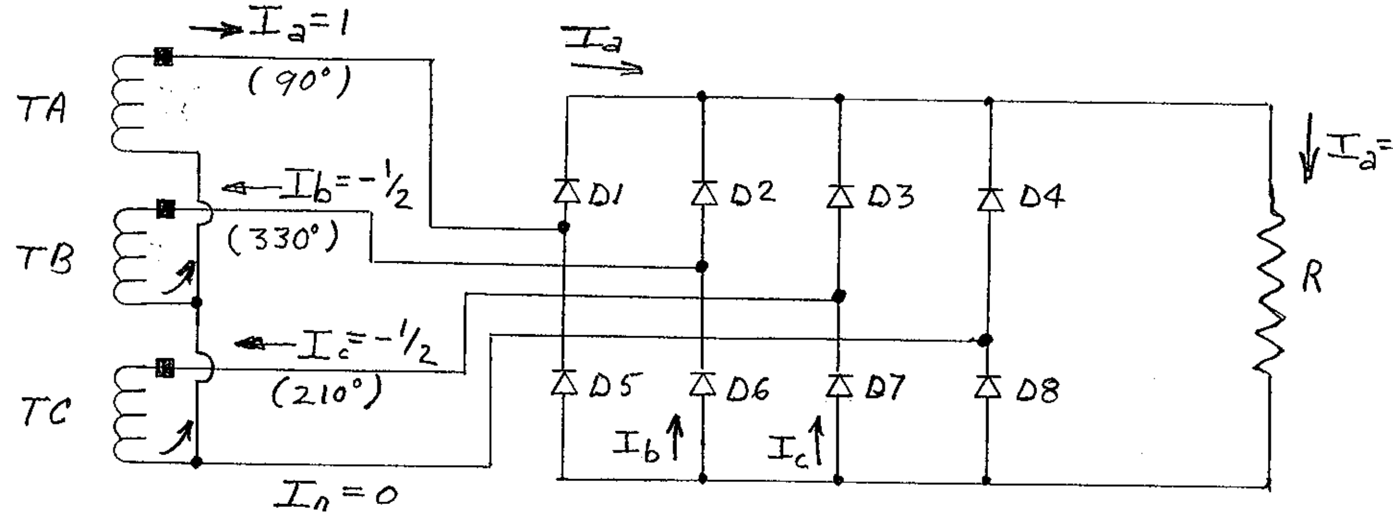
Diode Conduction Intervals



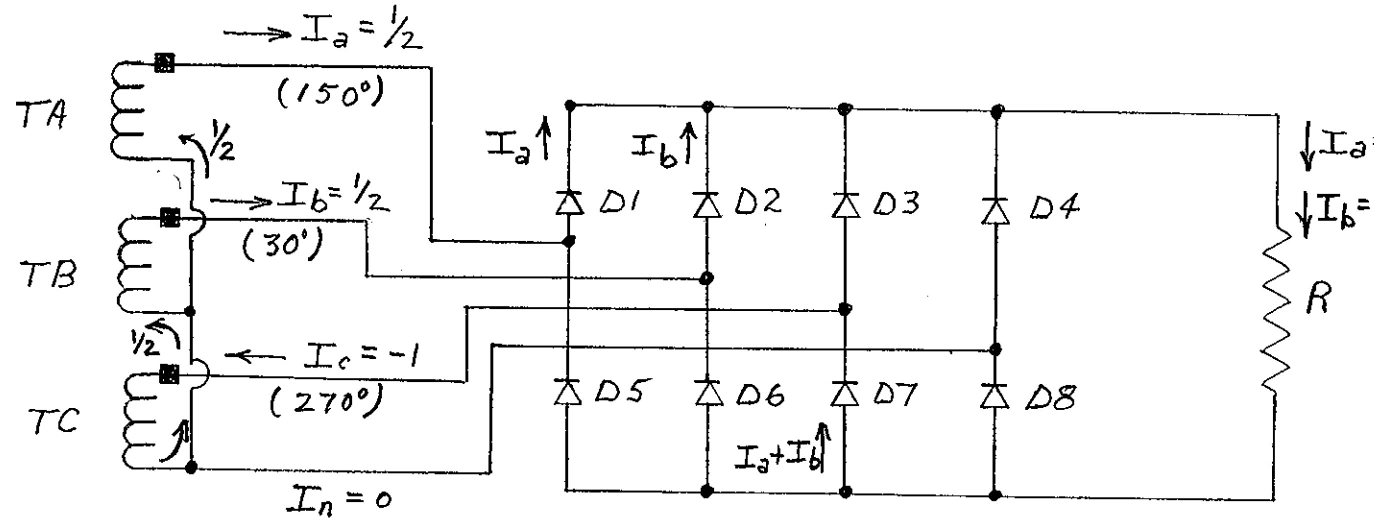


$i_n = -(i_a + i_b + i_c) = 0$

FIGURE 1



Ia @ 90°



Ia @ 150°

POWER SENSOR CIRCUIT
CORRECT CONNECTIONS
BALANCED PRIMARY CURRENT

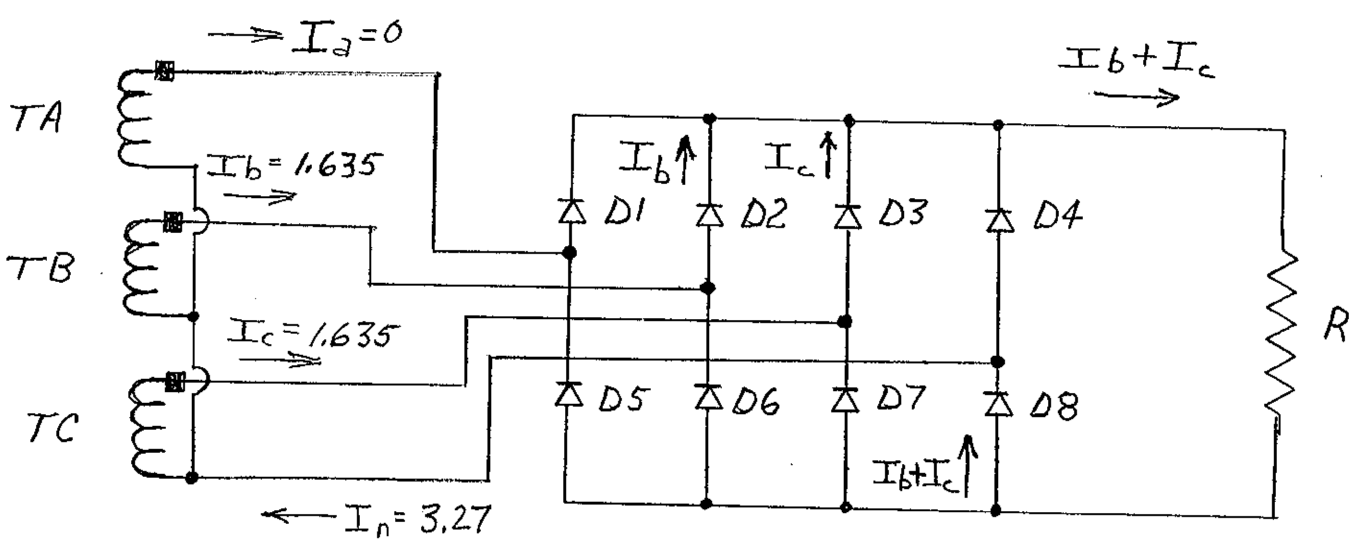
FIGURE 2

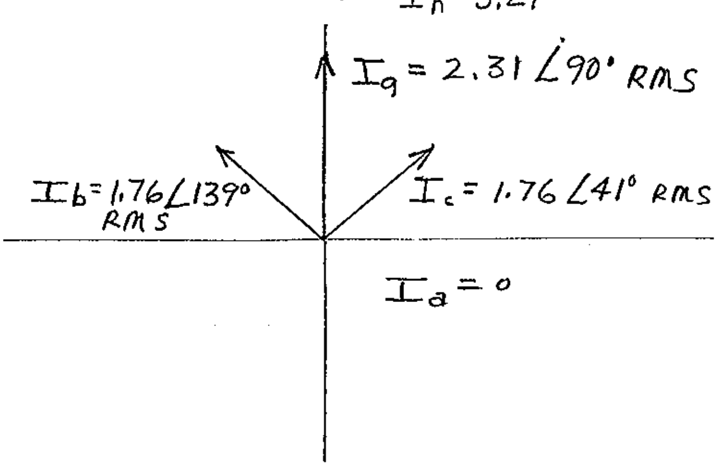
The line currents for a double line to ground fault on phases B & C are : $I_a = 0$, $I_b = 1.7624\angle 139°$ RM
$I_c = 1.7624\angle 41°$ RMS

I_b peak $= I_c$ peak $= 1.7624\sqrt{2} = 2.4924$

Total ground fault current $= 2.31\angle 90°$ RMS
I_g peak $= 2.31\sqrt{2} = 3.27$

I_g peak occurs when $I_b = 139°$ and $I_c = 41°$
$I_b \sin 139° = I_c \sin 41° = 2.4924 \times 0.6561 = 1.6352$





POWER SENSOR CIRCUIT
CORRECT CONNECTIONS
DOUBLE LINE GROUND

FIGURE 3

Phase A CT leads rolled ("Unbalanced" Case)

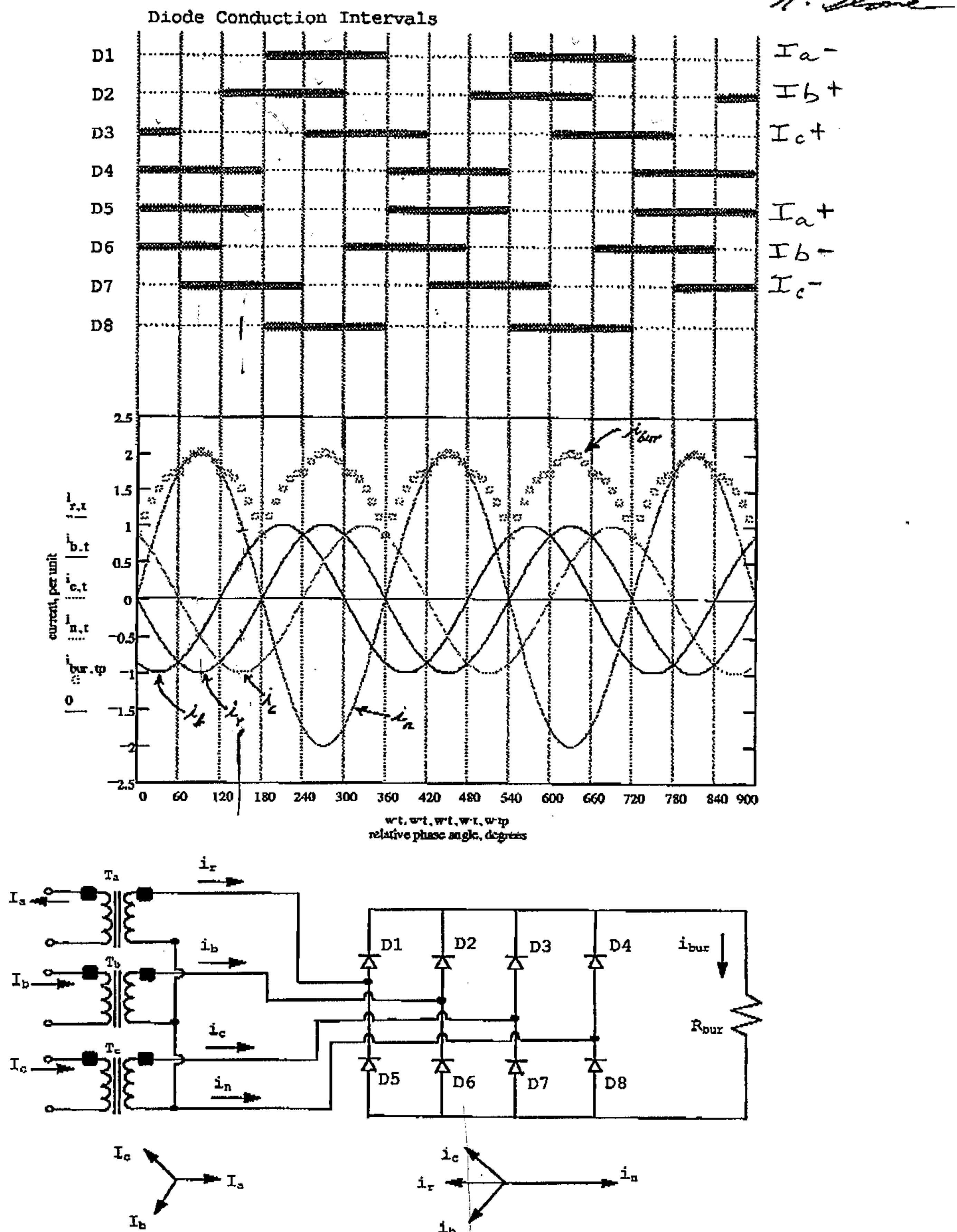
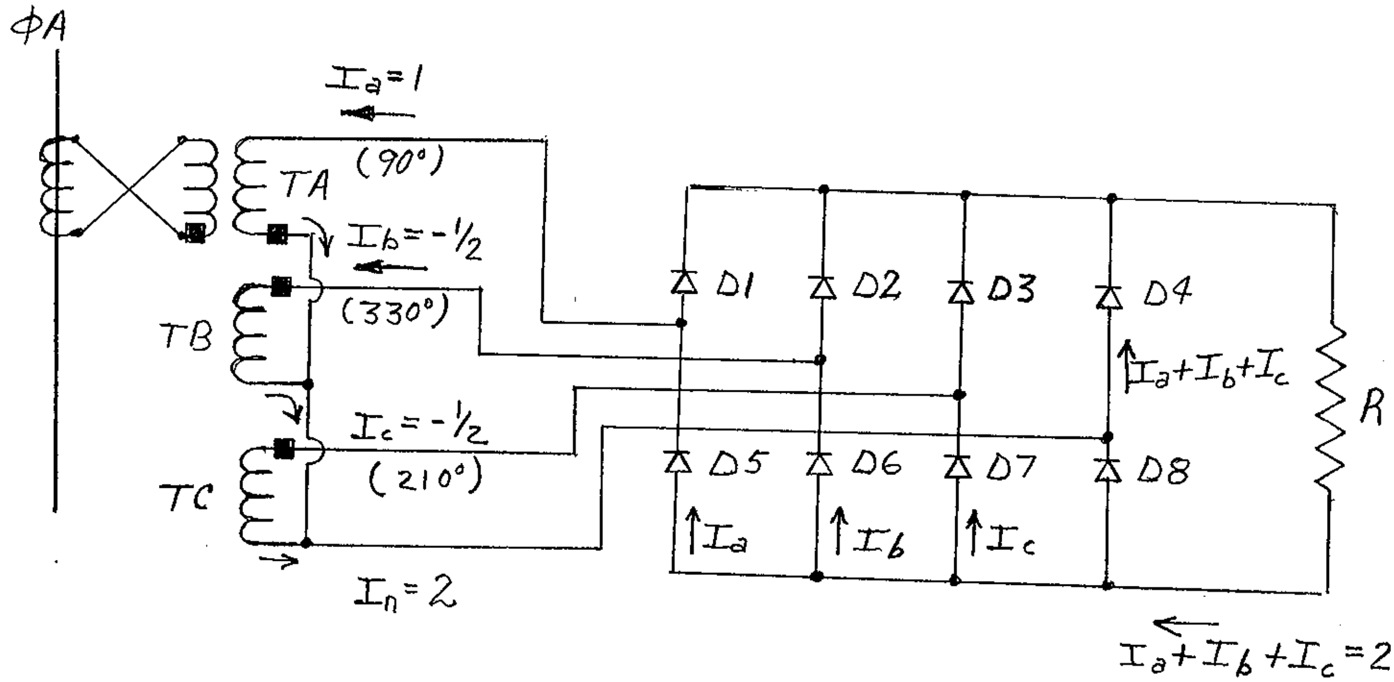


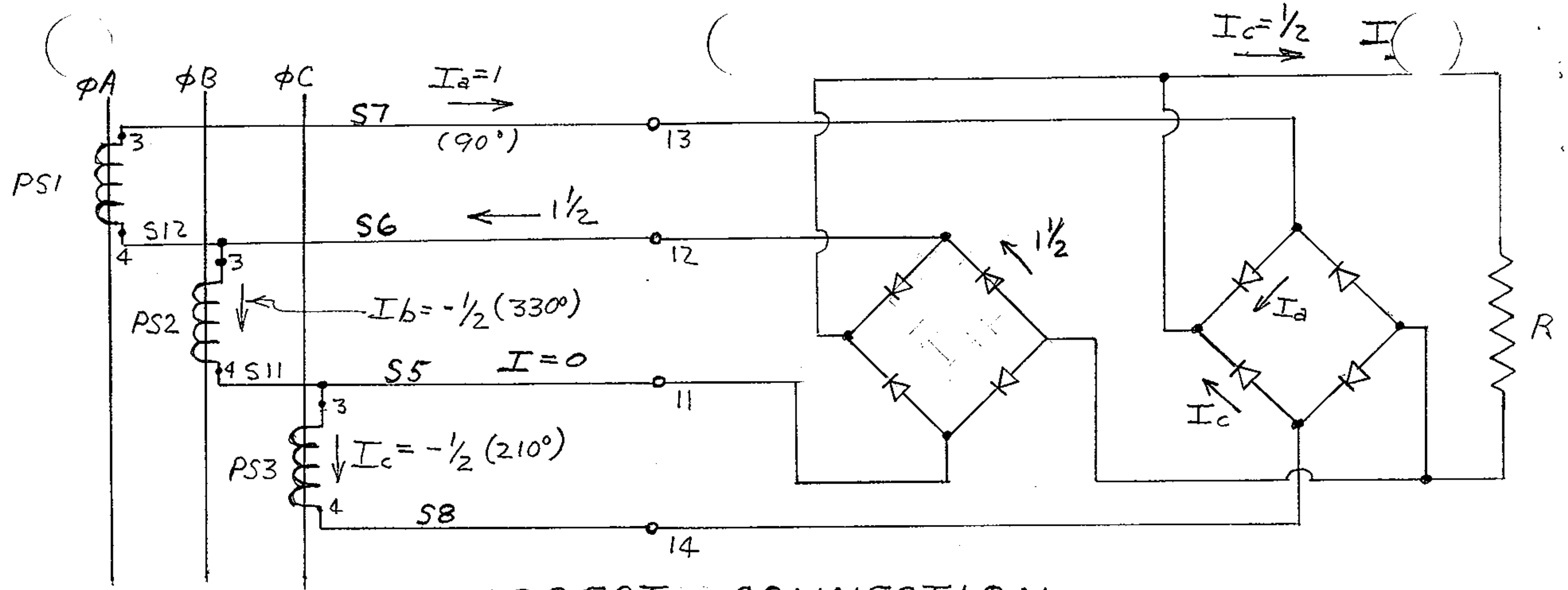
FIGURE 4a



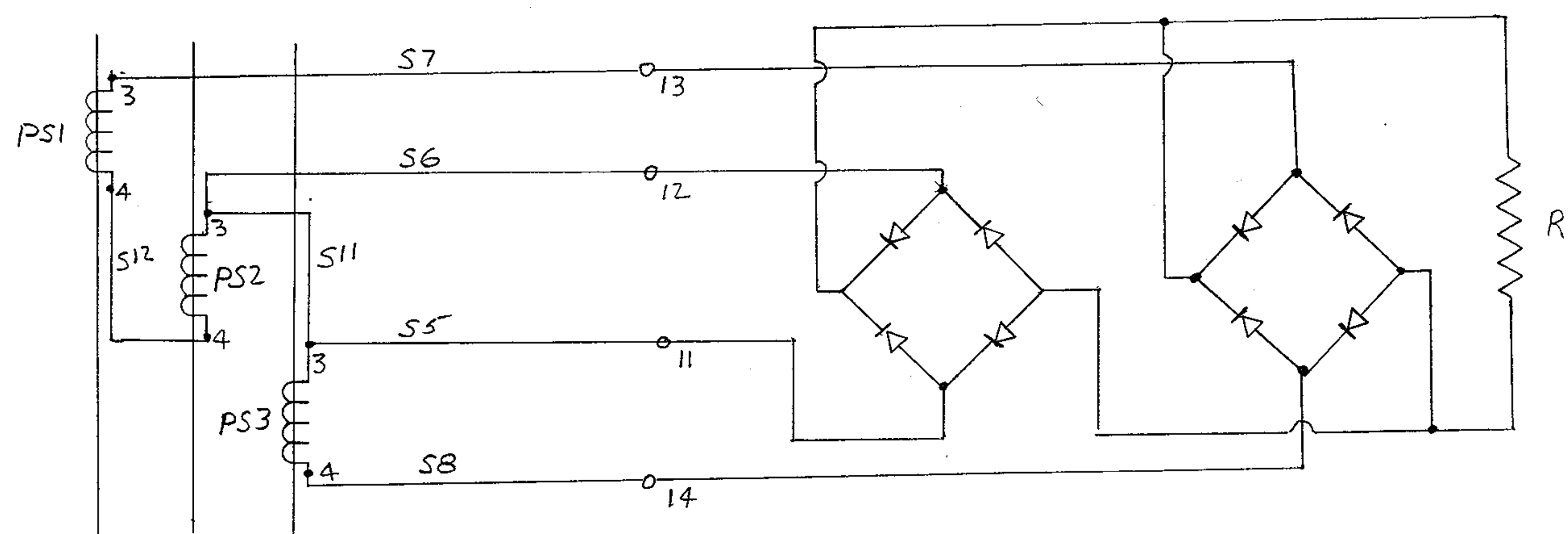
I_a @ 90°

POWER SENSOR CIRCUIT
ΦA CT CONNECTED BACKWARDS
BALANCED PRIMARY CURRENT

FIGURE 4b



CORRECT CONNECTION



WRONG CONNECTION

POWER SUPPLY CIRCUIT

FIGURE 5