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EVALUATION OF GULF MODEL NLI-5B LOG N CHANNELS FOR USE IN EBR-II

by

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ABSTRACT

The log N, intermediate-range channels, are the last three of eleven nuclear channels for EBR-II to be upgraded from the vacuum-tube type of components to all-solid-state components. Because completely solid-state channels were not available with the operating information normal for nuclear channels, an extensive preinstallation test program was carried out to provide background information for use in subsequent in-plant operation and maintenance. For reactor safety, each channel must have sufficient trouble-free preinstallation operating time to essentially assure continuous operation in-plant. The channel was evaluated to verify performance, classify possible failure modes, and determine needed modifications. With the modifications, the channels meet all critical requirements for use in EBR-II.

I. INTRODUCTION

The log N channels (for intermediate range of neutron flux) are the last three of eleven nuclear channels for EBR-II to be upgraded from the vacuum-tube type of components to all-solid-state components. These channels consist of all electronic components and interconnections from neutron-flux sensors to reactor trip circuits, inclusive. Figure 1 shows a simplified block diagram of a log N channel. Figure 2 is a schematic drawing of the channel circuits. See the Appendix for other schematic drawings. (Figures 2, 4, 5, 6, and 7 are used with the permission of the Gulf General Atomic Co).

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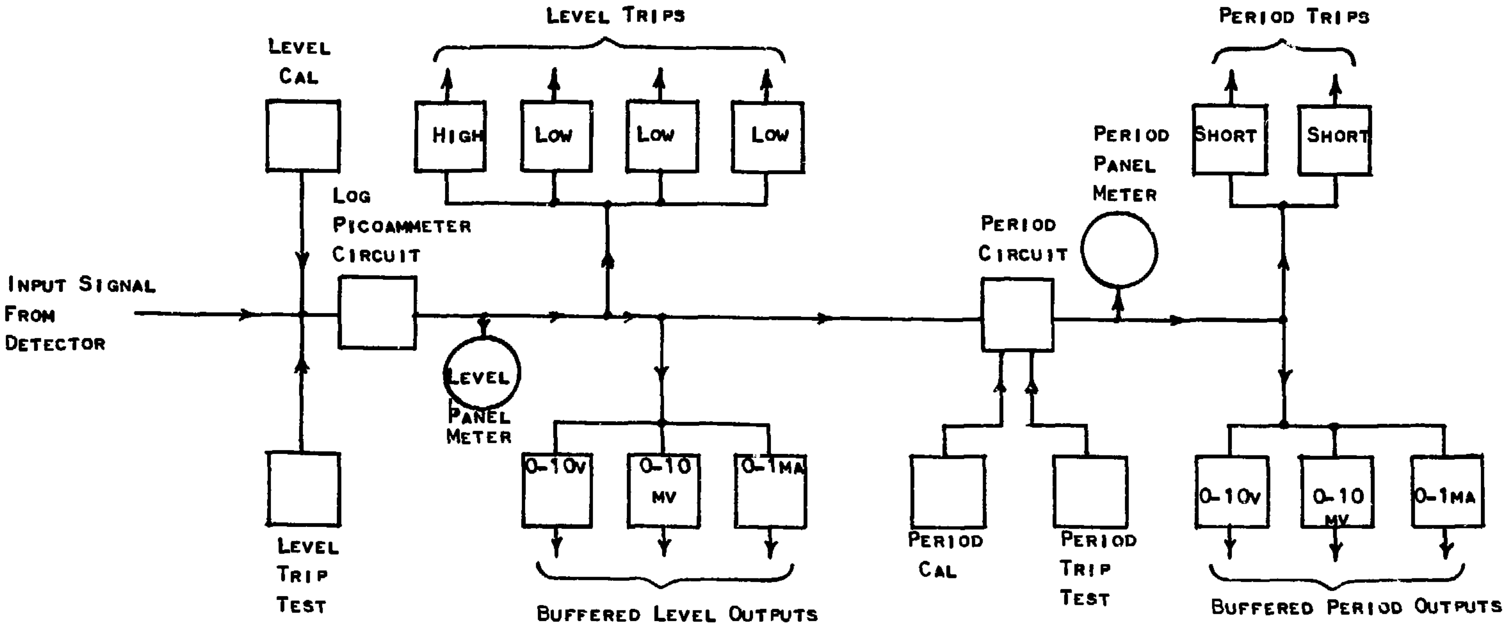


Fig. 1. Block Diagram of Chassis of Log N Channel

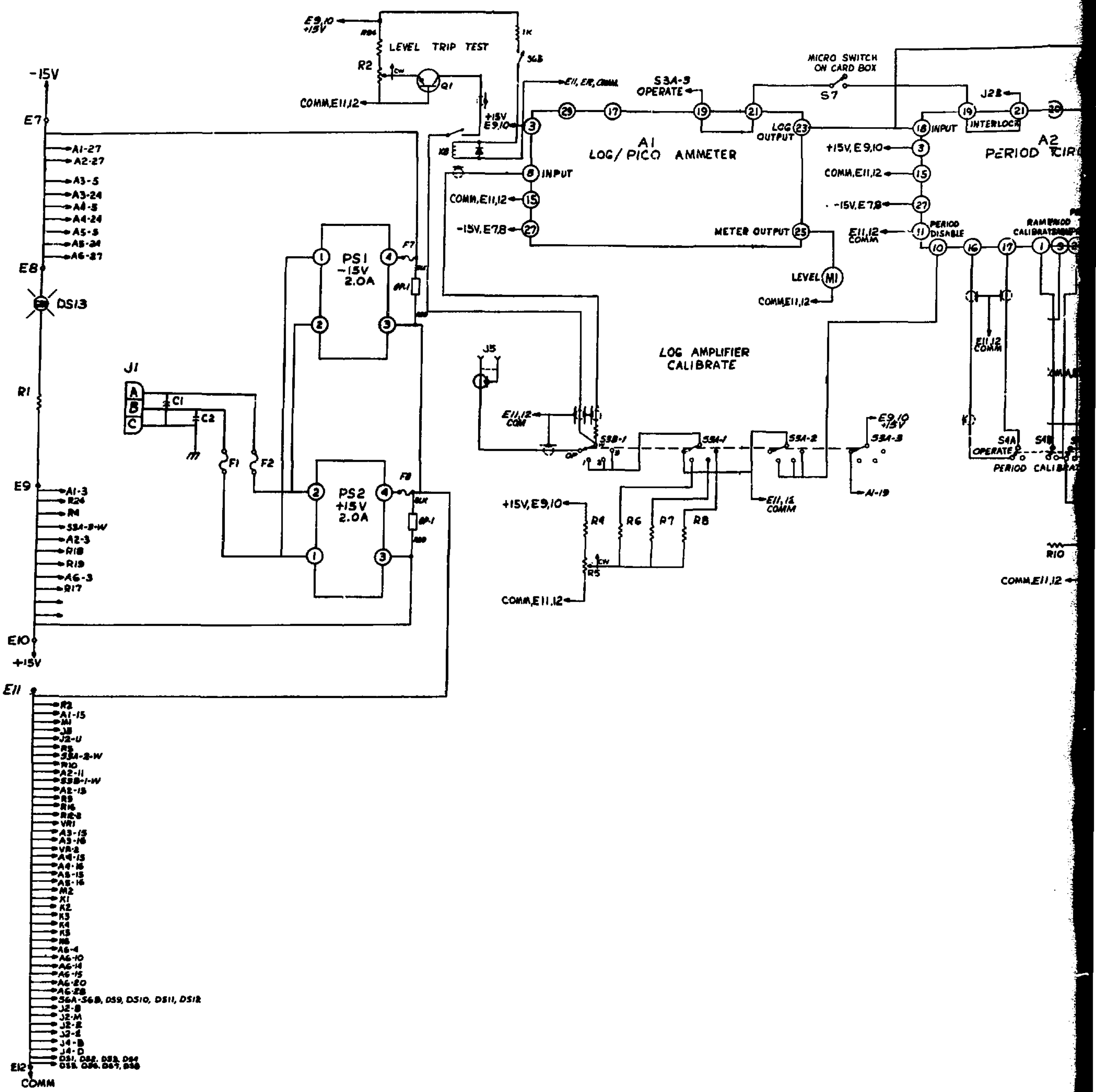
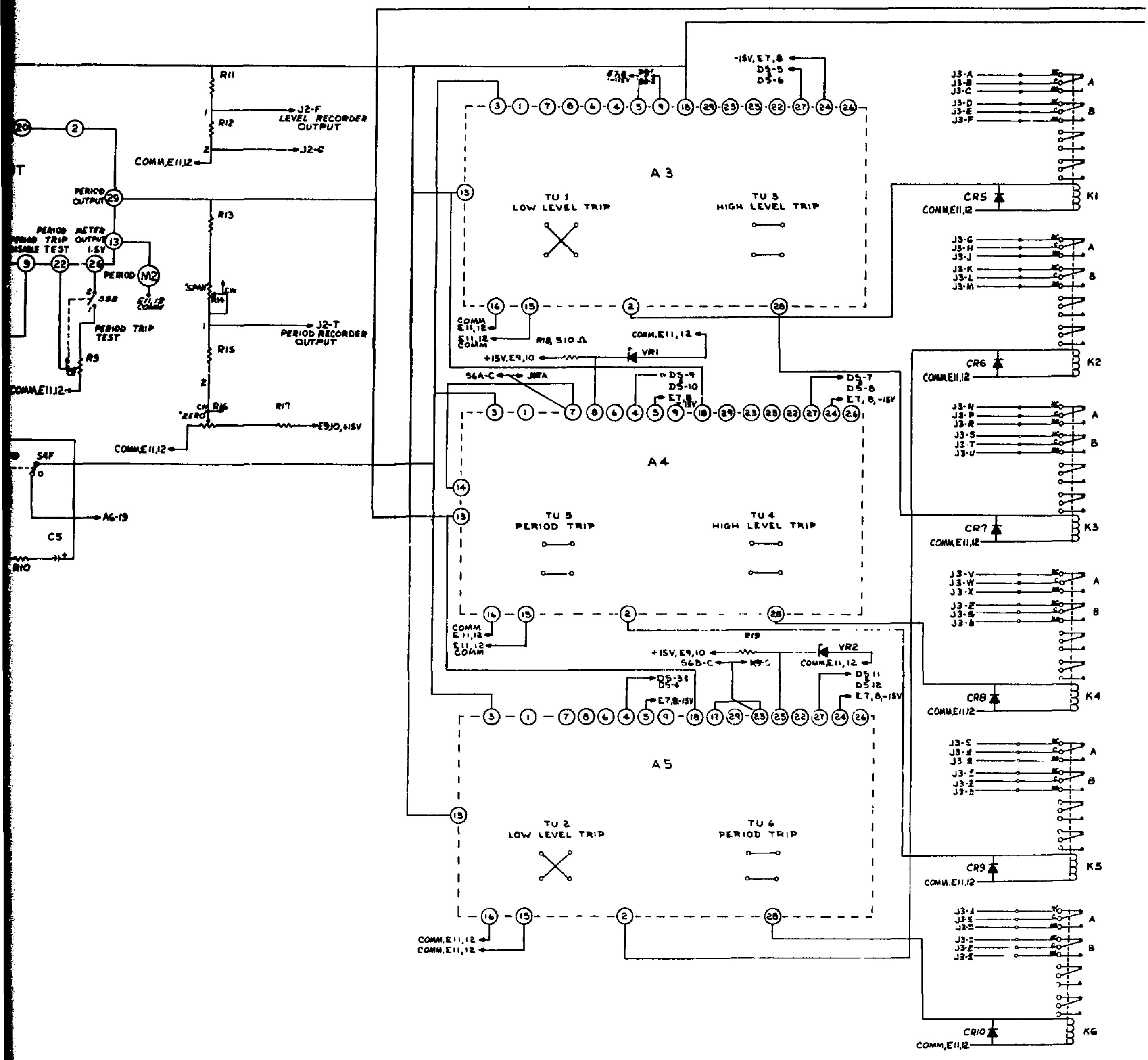


Fig. 2. Circuits of Intermedi



-range Channel, 8 Decade (Contd. on p. 10)

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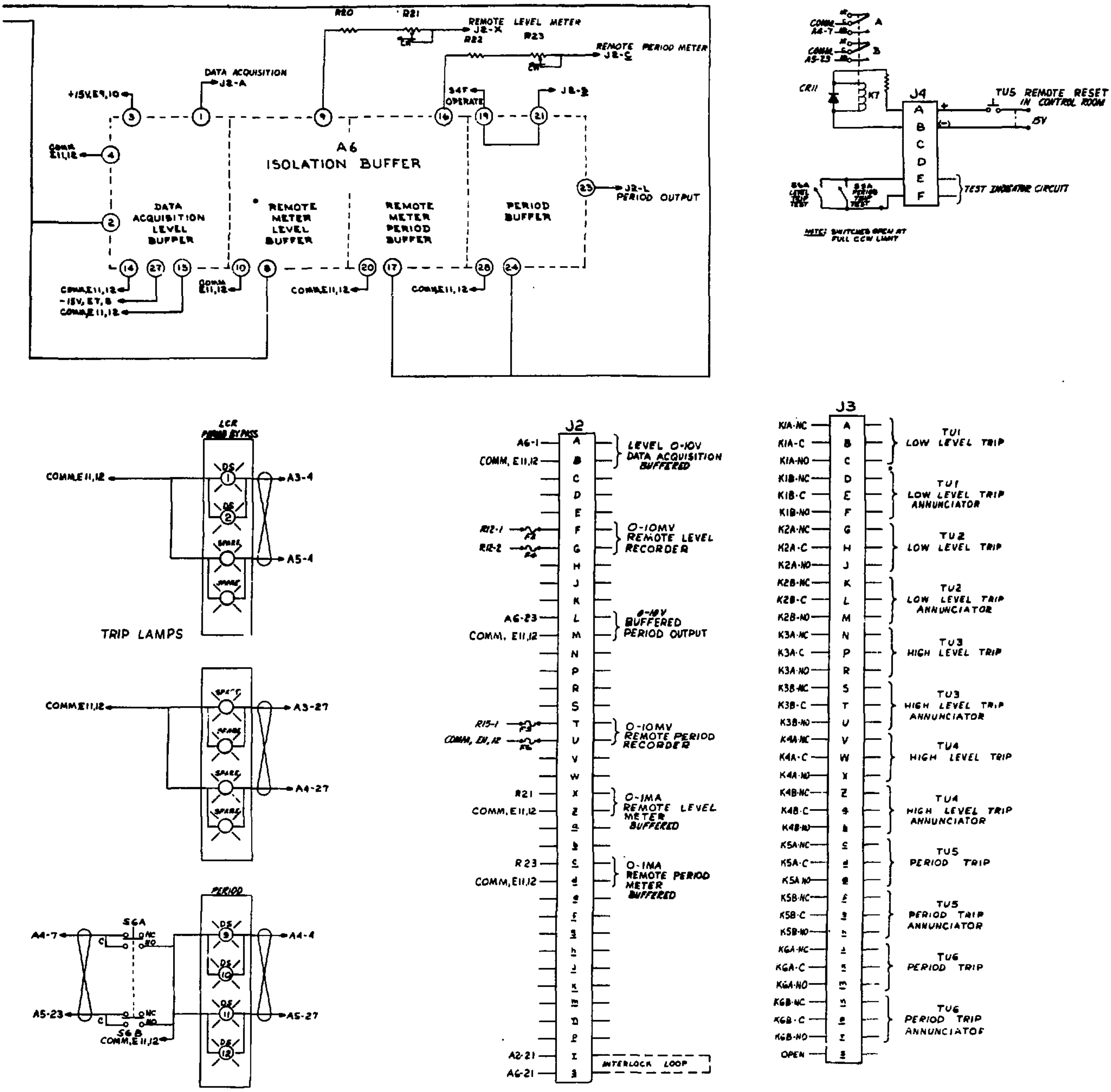


R20
R21
REMOTE LEVEL METER
J2-X
R22
R23
REMOTE PERIOD METER
J2-C
DATA ACQUISITION
J2-A
+15V,E9,10
COMM E11,12
S4F OPERATE
J2-B
A6
ISOLATION BUFFER
J2-L PERIOD OUTPUT
DATA ACQUISITION LEVEL BUFFER
REMOTE METER LEVEL BUFFER
REMOTE METER PERIOD BUFFER
PERIOD BUFFER
COMM E11,12
-15V, E7, 8
COMM E11,12
CR11
K7
J4
TU5 REMOTE RESET IN CONTROL ROOM
15V
TEST INDICATOR CIRCUIT
NOTE: SWITCHES OPEN AT FULL CCW LIMIT
LCR PERIOD BYPASS
COMM E11,12
A3-4
A5-4
TRIP LAMPS
A3-27
A4-27
PERIOD
S6A
S6B
A4-7
A5-23
A4-4
A5-27
J2
LEVEL 0-10V DATA ACQUISITION BUFFERED
0-10MV REMOTE LEVEL RECORDER
0-10V BUFFERED PERIOD OUTPUT
0-10MV REMOTE PERIOD RECORDER
0-1MA REMOTE LEVEL METER BUFFERED
0-1MA REMOTE PERIOD METER BUFFERED
INTERLOCK LOOP
A2-21
A6-21
J3
TU1 LOW LEVEL TRIP
TU1 LOW LEVEL TRIP ANNUNCIATOR
TU2 LOW LEVEL TRIP
TU2 LOW LEVEL TRIP ANNUNCIATOR
TU3 HIGH LEVEL TRIP
TU3 HIGH LEVEL TRIP ANNUNCIATOR
TU4 HIGH LEVEL TRIP
TU4 HIGH LEVEL TRIP ANNUNCIATOR
TU5 PERIOD TRIP
TU5 PERIOD TRIP ANNUNCIATOR
TU6 PERIOD TRIP
TU6 PERIOD TRIP ANNUNCIATOR
OPEN

Fig. 2 (Contd.)

Because completely solid-state channels were not available with the amount of operating information normal for nuclear channels, an extensive preinstallation test program was carried out to provide background information for use in subsequent in-plant operation and maintenance. For reactor safety, each channel must have sufficient trouble-free operating time before installation to assure essentially continuous operation in service. The evaluation testing included enough equipment operating time and manipulation of the controls and adjustments to provide conclusive information on reliability. Modifications required to make the channels suitable for use in EBR-II were evaluated.

II. TESTING

A. Initial Calibration and Drift Test

One channel was calibrated and checked out for proper operation by using the manufacturer's operation and maintenance procedures. It was then left energized for five days, with a Keithley Model 261 picoampere current source supplying an input of 1×10^{-7} A to the input of the channel. A strip-chart recorder was connected to monitor the 0-10-mV output of the remote level recorder, and provisions were made for use of a Dana Model 5600 digital voltmeter (DVM) to manually probe and monitor four of the buffered outputs. The four outputs monitored were: (1) 0-1-V period; (2) 0-1-mA remote level meter; (3) 0-10-mV remote period recorder; and (4) 0-10-V data acqusition. Data from the strip-chart recorder were recorded continuously, and manual data were recorded once each eight hours during the five-day test. Maximum drift observed during the test was 0.11% on output of the 0-10-V data acquisition. All other outputs monitored showed drifts of 0.1%. The drift figures include the effects of current source and DVM drifts. The drift figures noted were maximum deviations from start values and are not cumulative. Cumulative drift was so low as to be unmeasurable with the equipment used.

B. Measurements of Trip Time

Period trip times were recorded with an ANL-designed exponential current generator, Type 1T1-1123, and an Eldorado Model 255 time-interval meter. Tests of period trip times were conducted with input periods of 1, 5, 10, and 20 sec at each decade of input starting current (see Fig. 3). Each data point on the curves was repeated three times and an average of the three was used. Maximum nonrepeatability was about 40 msec at input or starting currents of 1×10^{-11} A and 10 msec at starting currents above 1×10^{-7} A. This variation is attributed to random noise currents inherent in the test setup. Worst-case nonrepeatability of the trip-time tests, 2.66%, occurs at an input period of 1 sec at an input current of 1×10^{-11} A.

The measured cable and chamber capacity of channel 9 is 5245 pF; thus the 8400 pF of cable capacity used in testing will provide an adequate safety margin.

C. Sensitivity to Line Voltage

To document the effects of line voltage and to verify adherence to specification, an autotransformer was used to vary the input line voltage to the test channel with a constant channel input current of 1×10^{-7} A. Three line voltages were used: 105, 120, and 135 Vac, corresponding to the lower, normal, and upper specified limits. Before data were recorded, the channel was held at each voltage for one-half hour to assure that any effects of variation with time would be included in the results. Readings of the panel meters for the channel and all data outputs, except the 0-10-V buffered period output, were taken. This output was not recorded because it is not intended to be used and its critical circuitry is identical with the 0-10-V remote-level data output, which was monitored. See Table I.

An additional test was run to determine the minimum line voltage required for operation. The line voltage was gradually lowered until any output shown in Table I deviated by more than ± 2%. As 98 Vac is approached from a higher line voltage, all outputs suddenly degrade because of a loss of regulation in one of the dc power supplies. Because a positive deviation of all level outputs is caused by lowering the line voltage, a period trip occurs if the 98-Vac point is crossed rapidly in a downward line-voltage excursion. The rate must exceed about 2 V/sec for the period trip to occur.

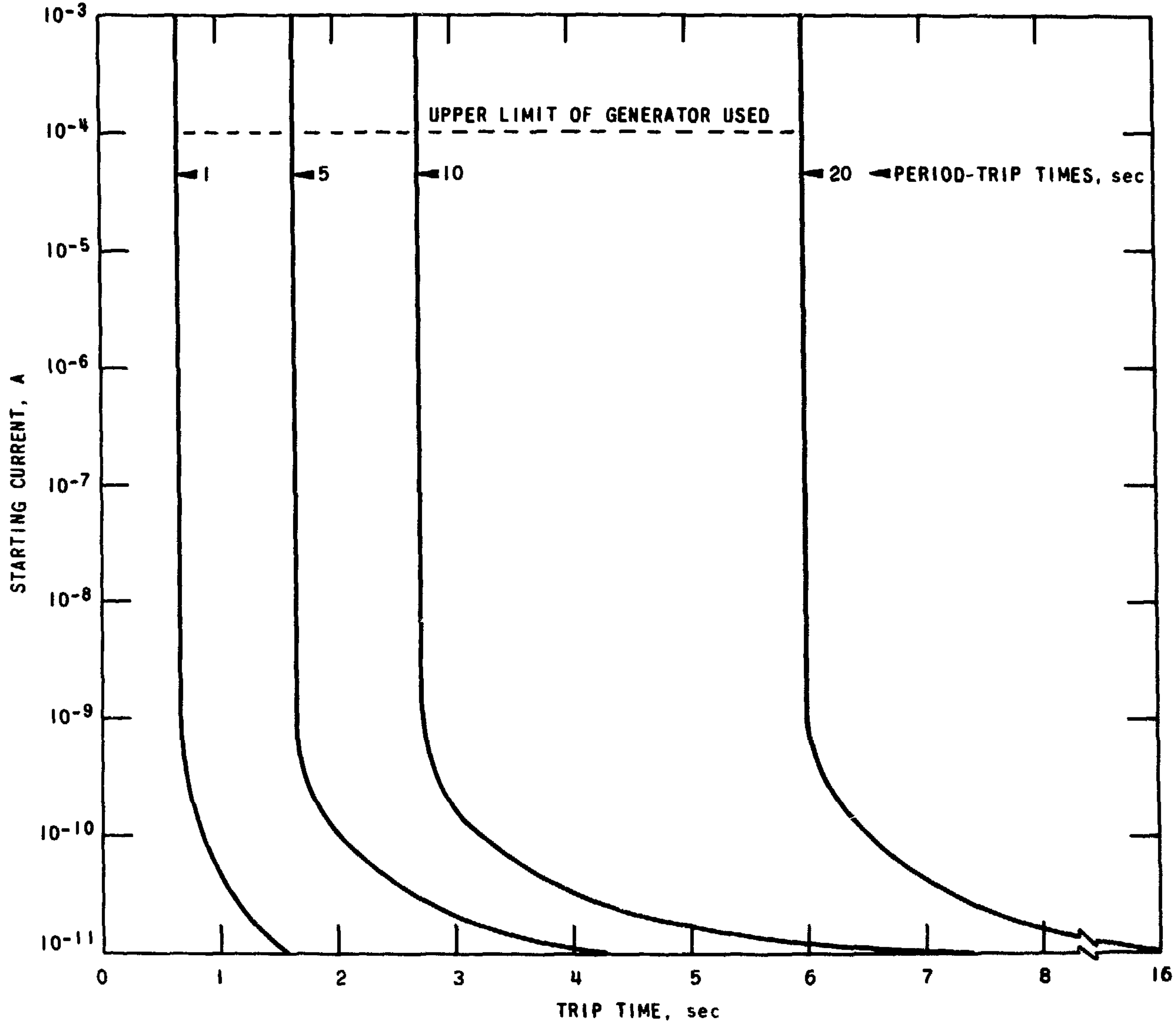


Fig. 3. Starting Current as a Function of Time for Modified

TABLE I. Line-voltage Sensitivity

	Line Voltage, Vac			Maximum Change from 120-V Value, % full scale
	120	135	105	
Level Meter Indication, A	1×10^{-7}	1×10^{-7}	1×10^{-7}	Not readable
Output of 0-1-mA Remote Level Meter, mA	0.490	0.493	0.498	+0.8
Output of 0-10-mV Remote Level Recorder, mV	4.92	4.92	4.99	+0.7
Output of 0-10-V Remote Level Data, V	4.898	4.890	4.94 ± 0.05	+1
Output of 0-1-mA Remote Period Meter, mA	0 ± 0.0004	0.0002 ± 0.0002	0 ± 0.0015	+0.1
Output of 0-10-mV Remote Period-Meter Recorder, mV	0.660	0.639	0.620	-0.4
Period-meter Indication	∞	∞	∞	Not readable

At a lower rate, a lower voltage will be reached before any trips occur. Because the trip circuits are inherently fail-safe, all trips will actuate at some voltage lower than 98 Vac, which depends on individual components in the trip circuits. Overvoltage tests were not conducted, because a separate regulator protected from overvoltage supplies each channel and is set to trip at 125 Vac.

D. Power-supply Tests

Each channel contains two Technipower Type MC-14.5-2.0 modular, regulated, short-circuit-protected dc power supplies with an MTBF* rating

*Mean time between failures.

of 50,000 hr. These supplies are adjustable from 13.0 to 16.0 Vdc at 2 A and are operated at 15 Vdc; one supplies -15 Vdc and the other supplies +15 Vdc for operation of all circuitry in the channel. The supplies are connected in series, with their common connection forming the channel electronics ground, which is isolated from chassis ground. These power supplies have current limiting but do not include overvoltage protection at the outputs. Accordingly, a modification has been made to provide protection against output overvoltage (Sec. III. C).

Testing the channels to determine the failure mode with various power-supply faults consisted of short-circuiting each supply separately and simultaneously. Also, temperature-rise tests were conducted to ascertain whether the supplies were operating within their temperature-rise specification of +65°C (see Table II).

TABLE II. Power-supply Tests[a]

Test	Result
Short Circuit of +15-Vdc Supply[b]	All trips actuate. All buffered outputs go to down-scale limits. Trip lights remain lighted.
Short Circuit of -15-Vdc Supply[b]	All buffered outputs move up scale, depending on channel input current. No trips on application of short circuit. Both period trips operate when short circuit is removed.
Short Circuit of Positive to Negative Bus[b]	All trips actuate. All buffered outputs go to zero voltage output.
Temperature Rise in Power Supply with No Trips Actuated	Equilibrium temperature for positive 15-Vdc supply is 87°F. Equilibrium temperature of negative 15-Vdc supply is 98°F.
Temperature Rise in Power Supply with All Trips Actuated	Equilibrium temperature of positive 15-Vdc supply is 94°F. Equilibrium temperature of negative 15-Vdc supply is 89°F.

[a]Ambient temperature varied between 70 and 71°F during temperature-rise tests. Each test condition was maintained for a minimum of 24 hr.

[b]The power supplies are rated by the manufacturer to withstand, without damage, a continuous short circuit at the output.

Measurements were also made to determine the amperage stress level of the power supplies. With all trips actuated, the +15-Vdc supply is loaded to about 0.6 A, the -15-Vdc supply to about 1.0 A.

E. Repeatability of Trip and Influence of Line Voltage

To determine the hysteresis, repeatability, and the influence of line voltage on the trip circuits, the following tests were conducted: The 0-10-Vdc remote-level data output was adjusted to exactly mid-scale (5.000 Vdc) by varying the input current to the channel. One of the high-level trips was then adjusted slowly downward until a trip occurred. Next, the channel input current was lowered enough to allow the trip to reset, and a gradual upward approach to the trip point was made until a trip occurred. A reading of the output voltage of the 0-10-V remote-level data was taken and compared with the original setting of 5.000 Vdc. This test was conducted with input line voltages of 105, 120, and 135 Vac to determine the effect of line voltage on trip repeatability. Also, measurements were made to determine the differential between trip and reset levels (see Table III).

TABLE III. Trip Repeatability and Differential as Functions of Line Voltage

	Line Voltage, Vac		
	105	120	135
Repeatability, % of full scale	0.02	0.03	0.05
Reset-Trip Differential (Hysteresis), % of full scale	0.10	0.11	0.12

The channels, as purchased, contained extra trip circuits that will not be used in service. The channels, as delivered, contained two low-level, two high-level, and two period trips. The low- and high-level trips are self-resetting. The period trips are latching. In service in EBR-II, the two low-level trips will be used with their output contacts in parallel to provide bypass of the log N period trips below 1 x 10^{-9} A and bypass of trips due to a high period count rate above 1 x 10^{-9} A. The high-level trips will not be used, and the indicator lamps will be removed. The two period trips will be used in a series contact arrangement. Trip-indicator windows will be re-marked "Log 'N' Period Bypass" where originally marked "Low Level Trip," and "Spare" where originally marked "High Level Trip." Removal of the trip-circuit board to completely remove the high-level trip is impossible, because three circuit boards contain all six trips, and redundant trips are not on the same printed circuit board.

F. Tests of Buffered Outputs

Six buffered outputs are available on each channel for remote period, level, and data meters and recorders. Four of these outputs are buffered by active circuitry (amplifiers), and the remaining two are buffered by passive, resistive voltage dividers. Outputs are (a) 0-10-Vdc data acquisition with buffer amplifier; (b) 0-10-mV remote level recorder with resistive buffering; (c) 0-10-Vdc remote period with buffer amplifier; (d) 0-10-mV remote period recorder with resistive buffering; (e) 0-1-mA remote level meter with buffer amplifier; and (f) 0-1-mA remote period meter with buffer amplifier.

Both types of buffered outputs were tested to meet requirements of RDT Standard C16-1T, Section 4.3.2, a and b, by using maximum ac voltage of 115 Vac, 60 Hz, and maximum dc voltage of ± 10 Vdc. Particular attention was directed to testing the resistive buffered output. Specific outputs tested were: (a) 0-10-V level data acquisition with buffer amplifier; (b) 0-10-mV remote level recorder with resistive buffering; (c) 0-10-V period with buffer amplifier; and (d) 0-1-mA remote level meter with buffer amplifier. Additionally, the output of the 0-10-mV remote period recorder was tested with ac voltages only being used.

The resistive buffering is very effective, owing to the low output impedance of the signal source ($\simeq$ 10 Ω) and high-impedance (100 kΩ) path offered to a fault voltage appearing at the output connector. Also, a 100-Ω input impedance will be offered to the fault voltage initially, because, for sustained fault voltages of over about 7 V, the 100-Ω resistor would be burned out. A modification to include a 1/8-A fuse in each lead of each resistively buffered output has been made to prevent the 100-Ω resistor from being burned out, even though tests have shown that this burning out would not degrade channel operation. The channels, as purchased, had 1/8-A fuses in the high side of each amplifier buffered output. Burnout of the 100-Ω resistor could conceivably result in an internal fire in the channel, which could render the channel inoperative. Tests on the amplifier buffered outputs have proved the design to be sound, and channel operation did not degrade at the specified test voltages. However, it has been considered remotely possible that capacitor C6 (2.0 μF, 200 V) could fail shorted. If this shorting happens and a 115-Vac fault to the output of a buffer amplifier is considered with the high side of the 115 Vac to the low or common side of the amplifier output, a short-circuit current will flow through the common wiring inside the log N channel. This current flow most likely would result in open-circuiting of some or all of the channel internal-signal ground system and a high noise level caused by the nonisolated condition of the channel-signal ground.

The buffered outputs were tested with 10 Vdc and 115 Vac, with each voltage applied in both polarities. In the ac-voltage testing, the low or ground side of the ac supply was connected to the chassis of the channel to simulate the worst possible fault conditions. In the dc-voltage tests, three ground conditions were used: (a) no ground on dc voltage; (b) positive-supply lead grounded to channel chassis; and (c) negative supply grounded to channel chassis. These conditions are referred to in the test procedure as "ground off," "reverse," and "normal," respectively. See Table IV for results of the 10-Vdc testing. Test numbers in Table IV are those marked on the original data.

During tests involving application of -10 Vdc with either normal or reverse grounding configuration, various offset effects (Table IV) were encountered in the buffered outputs. These effects have been proven to be caused by interactions in the strip-chart recorder used. If the effect had been caused by leakage through the buffered outputs back into the channel circuitry, indications would have been apparent on the channel panel metering. Also, in testing the outputs of 0-10-V-level data acquisition and remote level recorder, the effects noted on the 0-10-V remote period and 0-1-mA (0-1 V on chart) would have been offset on the strip chart in the ratio of 10:1, because the recorder channels used were both calibrated 0-1 Vdc. That

TABLE IV. Results of Tests of Buffered Output at 10 Vdc[a,b]

Test No.	Polarity	Ground Configuration	Result
10 Vdc Applied to Output Terminals of 0-10-V Level Data Acquisition			
25	+	None	No effect.
27	-	None	No effect.
28	+	Normal	No effect.
29	+	Reverse	No effect.
30	-	Normal	0-10-mV remote level output increases from 1 x 10^{-7} to ≈ 1 x 10^{-4} A. Slight increase in 0-10-V remote-period output. Slight decrease in 0-1-mA remote-level output. 0-1-mA remote-period output indicates ≈ +2000-sec period. Absolutely no change in channel panel metering. No trips.
31	-	Reverse	0-10-mV remote-level output decreases from 1 x 10^{-7} to ≈ 9 x 10^{-8} A. 0-10-V remote-period output decreases by 0.02 V. 0-10-mV remote-period output decreases by 0.5 mV. Output of 0-1-mA remote-level meter increases by 0.02 mA. 0-1-mA remote-period output indicates ≈ -1000 sec. Absolutely no change in channel panel-meter readings. No trips.
10 Vdc Applied to Output Terminals of 0-10-mV Remote Level Recorder[a]			
32-25-1	+	None	No effect.
33-27-1	-	None	No effect.
33-28-1	+	Normal	No effect.
33-29-1	+	Reverse	No effect.
33-30-1	-	Normal	No effect on 0-10-V data-acquisition output. Slight increase in 0-10-V remote-period output. 0.5-mV increase in 0-10-mV remote-period output. 0.02-mA decrease in output of 0-1-mA remote-level meter. Output of 0-1-mA remote-period meter increases by 0.02 mA. Channel panel meters unchanged. No trips.

TABLE IV. (contd)

Test No.	Polarity	Ground Configuration	Result
33-31-1	-	Reverse	No effect on 0-10-V data-acquisition output. 0-10-V remote-period output decreases by 0.02 V. 0-10-mV remote-period output decreases 0.5 mV. 0-1-mA remote-level-meter output increases by 0.02 mA. 0-1-mA remote-period meter decreases by 0.02 mA. Channel panel meters unchanged. No trips.
10 Vdc Applied to 0-10-V Buffered Period Output Terminals[b]			
33-25-2	+	None	No effect.
33-27-2	-	None	No effect.
33-28-1	+	Normal	No effect.
33-29-1	+	Reverse	No effect.
33-30-2	-	Normal	Outputs of 0-10-V level data acquisition shows 0.5-V transient at start of test. 0-10-mV remote-level output increases 3.0 mV. Output of 0-10-mV remote-period recorder shows no change. Output of 0-1-mA remote-level meter shows 0.07-mA negative transient at start of test and -0.02-mA offset during test. 0-1-mA remote-period meter shows ≈ +2000-sec period. No change in channel panel meters. No trips.
33-31-2	-	Reverse	Output of 0-10-V-level data acquisition shows 0.01-V negative transient on test completion. 0-10-mV remote-level recorder decreases 0.5 mV and shows a -2.0-mV transient at test completion. 0-10-V buffered period output shows no change. Output of 0-1-mA remote-level meter indicates 0.02 increase. 0-1-mA remote-period meter shows ≈ -1000-sec period. No change or effect on channel panel meters. No. trips.

[a]Current from the 10-Vdc test source into the output of the 0-10-mV remote-level recorder was 0.02 A during each test sequence. Both meters read the same.

[b]Current from the 10-Vdc test source into the 0-10-V buffered period output was 0.05 A during each test sequence. Both meters read the same.

this effect did not show on the recorder chart proved that interactions in the recorder were the cause. Also, during test sequences 33-30-1 and 33-31-1, the offset showed on the recorder even though the particular recorder channel was disconnected. Of particular interest in the 10-Vdc tests is that no degradation, calibration change, or failure in buffer-output components was encountered and no trips occurred during any of these tests. Output levels of each buffered output tested were checked before and after each test and no changes were found. This was expected, as the Zener diodes used in the buffer-amplifier output protective circuitry are 15-V units and would not conduct below that voltage. Voltages appreciably above 15 Vdc would result in an amplifier-output fuse being opened. Likewise, 10 Vdc across the resistively buffered outputs would result in 0.1-A current flow only if the 10-Vdc to 1-mA conversion resistors were short-circuited. Fuses in the high side of the buffer-amplifier outputs are 1/8 A, Type GJV. Those in both legs of the resistively buffered outputs are 1/8 A, Type 275.

From the results of the 10-Vdc buffer tests and the fact that no spurious trips occurred during the testing, it is concluded that, for ± 10 Vdc applied to the buffered output terminals, there will be no loss of protective functions, and spurious trips will not be a problem. Some degradation of the buffered outputs may occur, however.

Alternating-voltage tests were conducted, starting at 10 Vac and gradually increasing to 115 Vac. Each test-voltage level was applied once in each polarity. The same leg of the ac source was connected to earth ground and chassis ground of the channel during all testing. Reversal of polarity also reversed the ground configuration. During the ac-voltage buffer tests, an additional test method was instituted to determine whether the protective function was operable during each test. Also, the output of the 0-10-mV remote period recorder was tested by supplying to the channel input a 10-sec period signal and noting whether period trip could be achieved. Trip setting was 25 sec. See Table V for results of the 115-Vac testing.

TABLE V. Results of Tests of Buffered Output to 115 Vac

Test No.	Voltage, Vac	Ground Configuration	Result
		Data Acquisition at 0-10-V Level[a]	
42	10	Normal	No effect. Protective function operates properly.
44	10	Reverse	No effect noted. Protective function operates properly. 0.02-Vac envelope impressed on output of 0-1-mA remote level meter.
45	20	Normal	No effect. Protective function operates properly.
45	20	Reverse	0.04-Vac envelope impressed on output of 0-1-mA remote level meter. Protective function operates properly.
46	30	Normal	No effect. Protective function operates properly.
46	30	Reverse	No effects observed. Protective function operates properly. 0.05-Vac envelope impressed on output of 0-1-mA remote level meter.
47	40	Normal	No effect. Protective function operates properly.
47	40	Reverse	No effects observed. Protective function operates properly. 0.1-Vac envelope impressed on output of 0-1-mA remote level meter.
48	50	Normal	Failed fuse F1. Otherwise, no effect. Protective function operates properly.
48	50	Reverse	Failed fuse F1. Otherwise, no effect. Protective function operates properly.
48	115	Normal	Same as Test 48 with 50 V and normal ground.
48	115	Reverse	Same as Test 48 with 50 V and reverse ground.

TABLE V. (contd)

Test No.	Voltage, Vac	Ground Configuration	Result
			Output of 0-10-mV Remote Level Recorder[b]
49-42	10	Normal	No effect. Protective function operates properly.
49-44	10	Reverse	Fuse F5 failed. Protective function operates properly.
49-42	20	Normal	No effect. Protective function operates properly.
49-42	30	Normal	Fuse F4 failed. Protective function operates properly.
49-42	115	Normal	Fuse F4 failed. Protective function operates properly.
49-44	115	Reverse	Fuse F5 failed. Protective function operates properly.
			Output of 0-10-mV Remote Period Recorder[c]
	10	Normal	No effect. Protective function operates properly.
	10	Reverse	Failed fuse F8. Protective function operates properly.
	20	Normal	No effect. Protective function operates properly.
	30	Normal	Failed fuse F7. Protective function operates properly.
	115	Normal	Failed fuse F7. Protective function operates properly.
	115	Reverse	Failed fuse F8. Protective function operates properly.
			Output of 0-1-mA Remote Level Meter[d]
54-42	10	Normal	No effect. Protective function operates properly.

TABLE V. (contd)

Test No.	Voltage, Vac	Ground Configuration	Result
54-44	10	Reverse	Fuse in test rig failed. Protective function operates properly. Some ac noise observed on 0-10-V buffered period and 0-1-mA remote period outputs. Otherwise, no effect.
54-42	20	Normal	No effect. Protective function operates properly.
54-42	30	Normal	No effect. Protective function operates properly.
54-42	40	Normal	No effect. Protective function operates properly.
54-42	50	Normal	No effect. Protective function operates properly.
54-42	60	Normal	No effect. Protective function operates properly.
54-42	70	Normal	No effect. Protective function operates properly.
54-42	80	Normal	No effect. Protective function operates properly.
54-42	90	Normal	No effect. Protective function operates properly.
54-42	100	Normal	No effect. Protective function operates properly.
54-42	115	Normal	No effect. Protective function operates properly.
54-44	115	Reverse	Fuse in test rig failed. Protective function operated properly. Same as Test 54-44 with 10-Vac reverse ground, except that noise is of shorter duration because of quicker fuse operation at the higher voltage.

See p. 24 for footnotes of this table.

TABLE V. (contd)

[a]No tests were run between 50 and 115 Vac, because it was apparent that any increase in voltage above 50 Vac would fail fuse F1. It was, therefore, decided to use the worst case and test at 115 Vac.

[b]When a test voltage with a particular ground configuration was reached, which resulted in fuse failures, all subsequent test voltages with that ground configuration were omitted and only the 115-Vac test was made to ensure that the higher voltage did not result in an unacceptable test.

[c]These tests do not have test numbers because they were not included in the original test procedure.

[d]No reverse-ground tests were made between 10 and 115 Vac, because fuse failure occurred at 10 Vac. The 115-Vac test ensures that protective-function operation is obtained within this range.

These tests (Table V) prove conclusively that both the resistive and amplifier buffered outputs fulfill the intent of RDT Standard C16-1T, Section 4.3.2, a and b. During the application of each test voltage, a 10-sec period test signal was applied to the channel input, and a period trip was received in each test. Also, in each case, it was possible to remove the period signal and allow the channel to stabilize and manually reset the period trip while still applying the ac test voltage. No spurious trips occurred during the ac-voltage tests. Some degradation of channel output signals occurred when ac voltages were applied to the outputs, but operation of the protective function was unaffected.

In certain tests involving application of ac voltages with reverse ground configuration, a test-circuit fuse failed. This failure resulted from the test voltage appearing between the chassis ground and channel signal ground of the chassis. Since capacitor C6 is connected between these two ground systems, the current flow that caused the test-rig fuse to fail is a result of the low ac impedance of C6 in parallel with other built-in stray impedances to chassis. Two failures would be required to cause channel malfunction from a fault of this kind. First, a failure would have to occur to cause a fault voltage to appear between chassis ground and signal ground, and C6 (or ground isolation) would have to fail from overcurrent or overvoltage, or part of the channel signal wiring would have to fail from the overcurrent condition. Failure of C6 or a parallel path would result in channel malfunction if C6 fails shorted or at the instant of C6 failing open. Failure of any of the channel signal ground wiring must be considered to occur at a point in the circuit that would prevent protective action.

III. MODIFICATIONS

Some modifications to the Gulf Model NLI-5B log N channels were necessary to meet operational or fail-safe requirements.

A. Input Instability

Initial testing of the Gulf channels showed that the log-picoammeter section of the channels was unstable at input currents above about 5×10^{-4} A when tested with the simulated cable capacity required by Specification IC-002. This specification calls for the channel to operate with an input cable, 400 ft long, consisting of 25 ft of RG 115A and 375 ft of RG 149 coaxial cable. Simulated cable capacity, in the form of fixed precision capacitors, was connected across the input of the channel during all testing and was arrived at in the following manner:

25 ft of RG 115A at 29.5 pF/ft =	737.5 pF
375 ft of RG 149 at 20.5 pF/ft =	7687.5 pF
Total	8425.0 pF

The manufacturer was informed of the problem and provided parts and modification information to correct the discrepancy. This modification consists of adding a 1-kΩ resistor in series with the channel input and changing C5 on the log-picoammeter board from 100 pF to 390 pF. The modified channels have been tested with input currents up to 1×10^{-2} A with no instability.

B. Minimum Input Current

During initial testing of the channels, if the input current into the channel fell below the lower limit of the channel range of 1×10^{-11} A, random noise response was sufficient to cause repeated spurious period trips. Trip setting of the period trip was 25 sec, as required by EBR-II operating limits. To eliminate spurious trips, a modification was made to provide the input of the channel with a minimum input current of about 1×10^{-11} A. The channel input contains an adjustable current generator, which is front-panel controlled for setting level trips. By providing a 10-Ω potentiometer in series between the channel common bus and the common end of R2 in the level-trip test circuit, a constant input current of 1×10^{-11} A can be obtained. This added potentiometer, R2A, is adjustable through a hole in the bottom plate. The level-trip test circuit is not temperature-compensated, and input-current drift results in a time-varying current between about 8×10^{-12} and 2×10^{-11} A when initially adjusted to 1×10^{-11} A. This result is acceptable because the input current from a typical EBR-II detector after extended reactor shutdown is about 1×10^{-10} A. Error introduced by this modification at 1×10^{-9}A input current for the worst case is 2% of linear scale, which is not readable on a log scale.

C. Protection from Power-supply Overvoltage

The Gulf log N channels receive all operating power from two Technipower Model MC-14.5-2.0 dc power supplies, one furnishing -15 Vdc and the other +15 Vdc. These supplies are of the sealed, modular type and include limitation on internal short-circuit currents but no protection for the channel electronics against a voltage-regulation failure in one or both power supplies. According to the manufacturer of the supplies, the worst-case regulation failure would result in an output voltage of 1.8 times nominal supply output. This voltage would be: $1.8 \times 14.5 = 26.1$ Vdc at worst-case failure. Voltages of this level would result in abnormal channel operation and eventual, if not immediate, failure of the channel. Accordingly, overvoltage protection has been provided by modification of the power-supply system. A Technipower Model OP-1 overvoltage protector has been installed on each power supply. This unit consists basically of a silicon-controlled rectifier (SCR) across the supply output, with an adjustable voltage-trip level. When the unit trips at the preset level, the SCR short circuits the power-supply output, and the power supply goes into its current-limiting mode. A voltage-regulation failure of the supply may also cause failure of the current-limiting feature. Therefore, a 2-A fuse has been included between each power supply and the overvoltage protector and channel electronics. Trip level of the overvoltage protectors are set at the manufacturer's recommended setting of 30% above operating voltage, or 19.5 Vdc.

D. Trip-circuit Differential

As supplied, the channels contained high- and low-level trips with from 1/2 to 1 decade of input level between trip and reset points. The period trips were supplied with very low trip-reset differential (0.12% maximum by test). For the channels to be an exact functional replacement for the channels originally in service in EBR-II, all trips, whether self-resetting or latching type, must trip and reset or be resettable at the same point as nearly as possible. To this end, all trip circuits in the new channels have been modified for minimum trip-reset differential by replacing R9 and R59 on each trip circuit board with a 1.13-mΩ, 1% resistor. With this change, the only differences between the various trip circuit boards is the jumpers at points A, B, C, and D, which determine whether the trip operates on increasing or decreasing signal. Original resistor values, in kΩ, are: Board A3, R9 = 6.65, R59 = 402; board A4, R9 = 1.113, R59 = 402; and board A5, R9 = 6.65, R59 = 1.13.

E. Trip-indicator Lamp Markings

In the EBR-II installation only two trip functions are used: (1) LCR period/log N period bypass, which is a low-level trip of the self-resetting type with trip point at 1×10^{-9} A; and (2) period trip, which is a latching type with trip set at 25 sec. Each new channel, as supplied, contains two low-level trips, two high-level trips, and two period trips. The two high-level trips will not be used. Their trip setting will be adjusted to maximum level, the panel lamps will be removed from the indicator, and the indicator windows will be marked "SPARE." The two low-level trips will be used to provide the log N period bypass below 1×10^{-9} A with the two relay outputs in parallel. The indicator windows will be marked "Log 'N' Period Bypass."

F. Front-panel Control Interlocks

Four controls on the channel front panel can affect channel operation: level "Operate-Calibrate," level "Trip Test," period "Operate-Calibrate," and period "Trip Test" controls. The two "Operate-Calibrate" controls are interlocked such that moving either or both controls from the "Operate" position actuates all trips. However, operation of either or both "Trip Test" controls results in no indication of nonoperational status. Accordingly, a spare switch on the level "Trip Test" control, which is closed only at the extreme counterclockwise position of the control, and a similar switch added to the period "Trip Test" control have been incorporated into a parallel circuit to provide control-room annunciation when either or both controls leave the full counterclockwise or "Operate" position. This circuit has been made available at pins E and F of channel rear connector J4. This modification duplicates a similar function on the original log N channels.

G. Buffered Output

A 1/8-A fuse has been added to each signal lead of both resistively buffered outputs (remote 0-10-mV period and level recorders). These fuses prevent burnout of resistors R15 and R16 for buffered period output, and R12 for buffered level output in the event of an external fault that would place a high potential across these resistors. Burnout of the resistors does not cause channel failure, but it may start a fire, which must be considered capable of causing channel failure. The common lead fuse also protects capacitor C6 if an ac fault should cause ac voltage between common and chassis ground of the resistively buffered output.

IV. CONCLUSION

The channels, with the modifications mentioned in Sec. III, meet all critical requirements for use in the EBR-II system. See the Appendix for a tabulation of individual component-failure considerations.

APPENDIX

Fail-safe Considerations

1. Introduction

Individual component-failure modes are listed, along with the consequence of each failure in terms of individual channel operation. For hermetically sealed electronic modules, no attempt is made to list individual internal component failures. Instead, failure of these modules is considered with regard to gross failures and their effect on channel operation. Not all components are considered--only those which would cause or could possibly cause degradation of the channel protective function. Considerations are divided into six sections and each section includes the circuitry included on one circuit board, chassis, or subsystem. The sections are as follows:

A. Power Supply
B. Circuit-board Assembly of Log Picoammeter
C. Circuit-board Assembly of Period Circuit
D. Circuit-board Assembly of Bistable Trip
E. Circuit-board Assembly of Isolation Buffer Amplifier
F. Chassis-mounted Components and Miscellaneous

For individual components, certain failure modes are not considered because their occurrence is extremely unlikely--short-circuited failures of resistors and open-circuit failure of transistors.

Certain circuit features are not used in the ANL model, and components in these circuits are not considered unless they have a possible failure mode that could affect the protective functions of the channel.

2. Results

Possible component failures and their results are shown in Table VI.

TABLE VI. Results of Component Failure

Component and Failure	Result
Power Supply (see Fig. 2)	
(1) Positive 15-V supply fails in regulation with maximum voltage output. (Maximum voltage = 1.8 x nominal = 1.8 x 14.5 V = 26.1 Vdc, according to manufacturer's information.)	Overvoltage protector operates, short circuiting supply. Trip relays trip. Fail-safe.
(2) Positive 15-V supply fails to zero output.	Trip relays trip. Fail-safe.
(3) Negative 15-V supply fails in regulation with maximum voltage output.	Overvoltage protector operates, short circuiting supply. All channel metering and buffered outputs go to maximum. No trips. Not fail-safe.
(4) Negative 15-V supply fails to zero output.	Same as (3).
(5) Failure (1), plus failure of current-limiting feature.	Fuse F8 opens. Trip relays trip. Fail-safe.
(6) Failure (3), plus failure of current-limiting feature.	Fuse F7 opens. All channel metering and buffered outputs go to maximum. No trips. Not fail-safe.
(7) Short circuit between +15 V and -15 V buses.	All trips trip. Fail-safe.
(8) Fuse F7 fails open.	Same result as (6).
(9) Fuse F8 fails open.	Same result as (5).
(10) Fuse F1 or F2, or both, fail open.	All trips trip. Fail-safe.
Circuit-board Assembly of Log Picoammeter (see Fig. 4)	
(1) A2 output zero, or output shorted to common.	No period trips and none possible. LCR period/log N bypass trip bypasses log N period trip. Negative period. Level outputs indicate less than 1×10^{-11} A. Not fail-safe.

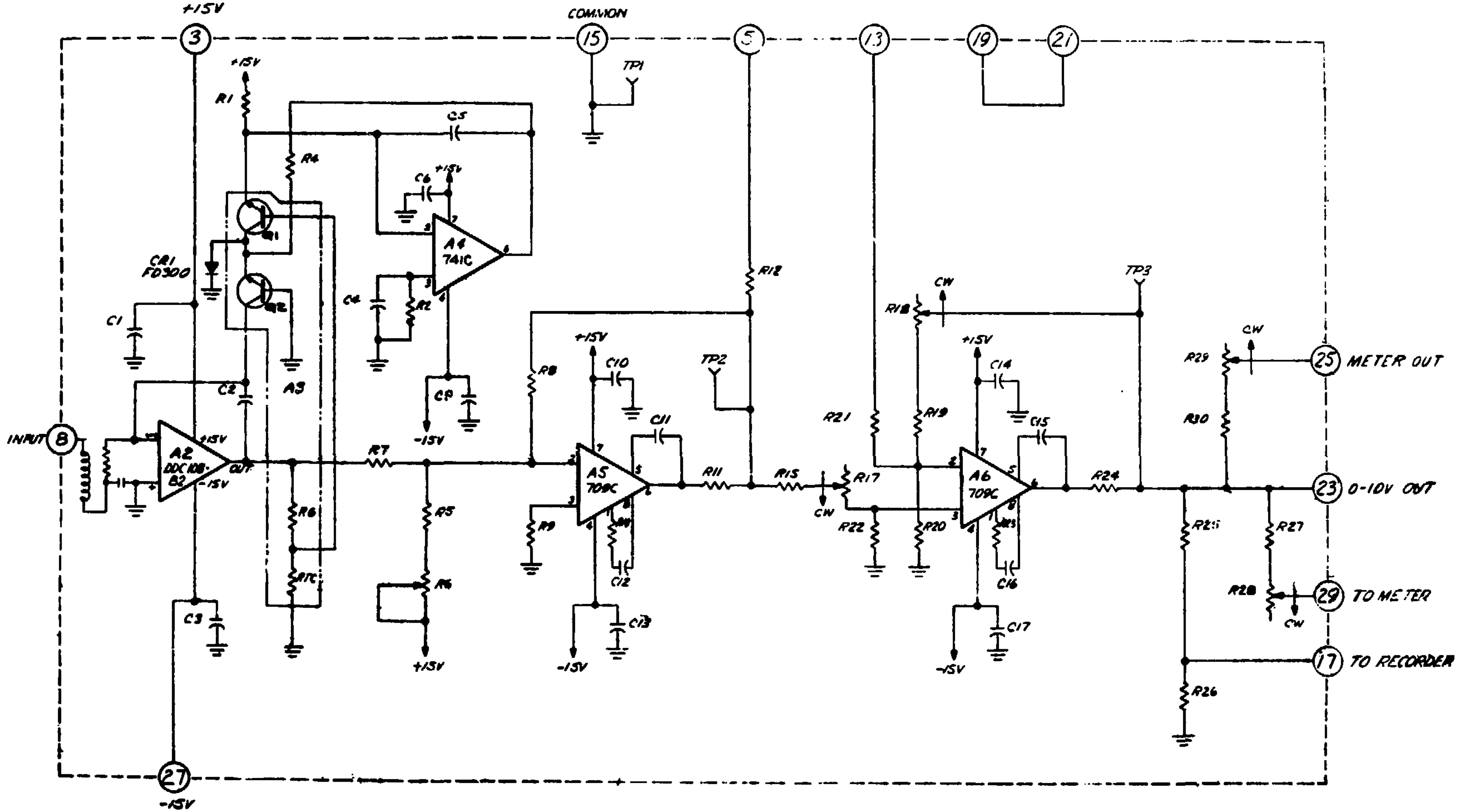


Fig. 4. Circuit-board Assembly of Log Picoammeter

TABLE VI. (contd).

Component and Failure	Result
(2) A2 fails with full negative output.	Period trips trip. Level outputs to full scale. Period outputs indicate less then 10-sec period. Fail-safe.
(3) A2 fails with full positive output.	Same as (1).
(4) A2 noisy.	Period trips when rise time and peak negative-going signal level exceed trip level. Otherwise, random period indications not exceeding period trip setpoint. Level excursions would be nearly unreadable before trip occurred. Fail-safe.
(5) CR1 short circuit.	Loss of log-picoammeter function. Positive period indication and level increase. Period trips. Fail-safe.
(6) CR1 open circuit.	No effect, unless electrical noise generated by failure is sufficient to cause period trip. Possible loss of temperature compensation.
(7) RTC fails open.	Decreased gain in picoammeter, with resulting decrease in level and negative period indication. Not fail-safe.
(8) Resistor RG fails open.	Increased gain in picoammeter, with resulting increase in level and positive period indication. Period trips if failure is sudden. Otherwise, period trip is made more sensitive and level readings are high. Fail-safe.
(9) Q1 shorted collector to emitter.	Period trip due to interrupted feedback loop and positive current to input. Fail-safe.
(10) Q1 collector-to-base short.	Period trips. Level makes step change to higher level. Fail-safe.

TABLE VI. (contd)

Component and Failure	Result
(11) Q1 emitter-to-base short.	Negative period indication. Level makes a step change to lower level. Low-level trip. No period trips and none possible. Not fail-safe.
(12) Q2 collector-to-emitter short.	Period trips. Loss of log function. Level makes a step change to higher level. Fail-safe.
(13) Q2 collector-to-base short.	Depends on balance of individual A2 operational amplifier and circuit components. Not fail-safe.
(14) Q2 collector-to-base short.	Depends on balance of individual A2 operational amplifier and circuit components. Not. fail-safe.
(15) Q2 emitter-to-base short.	Period trips. Loss of log function. Level makes a step change to higher level. Fail-safe.
(16) R4 failure open.	Period trips. Loss of reference current in log circuit. Level makes a step change to higher level. Fail-safe.
(17) C5 failure shorted.	Period trips. Loss of reference current in log circuit. Level makes a step change to higher level. Fail-safe.
(18) R2 fails open.	Period trips. Level makes a step change to higher level. Fail-safe.
(19) C4 fails shorted.	Negative period indication. Level makes a step change to a lower value. Not fail-safe.
(20) C4 fails open.	Possible oscillation in reference supply or increased noise susceptibility, resulting in a period trip. Fail-safe.
(21) C5 fails open.	Oscillation and noise, resulting in a possible period trip. Fail-safe.
(22) A4 output zero, or output shorted to common.	Period trips. Level makes a step change to higher value. Fail-safe.

TABLE VI. (contd)

Component and Failure	Result
(23) A4 fails with full negative output.	Same as (22).
(24) A4 fails with full positive output.	Same as (19).
(25) A4 fails noisy.	Same as (4).
(26) R7 fails open.	Period trips trip. Level reading increases to full scale. Fail-safe.
(27) R5 fails open.	Level reading decreases. Negative period. Will respond to input signal after initial transient. Provisionally fail-safe.
(28) R6 fails open.	Same as (27).
(29) R9 fails open.	Negative period. No period trips and none possible. Not fail-safe.
(30) R8 fails open.	Period trips. Level increases to higher level. Erratic under some conditions because of high gain resulting in A5. Fail-safe.
(31) R10 fails open.	Noise generated in channel. Depending on individual units, any of three results can happen: (1) period trips, (2) negative period with no period trips and none possible, and (3) no effect. Not fail-safe.
(32) C12 fails shorted.	Period trips. Level reading increases. Fail-safe.
(33) C12 fails open.	Same as (31).
(34) C11 fails shorted.	Level signal decreases because of loss of gain in A5. Negative period. Protective function inoperative. Not fail-safe.
(35) C11 fails open.	Period trips from noise. No effect on some units. Fail-safe.

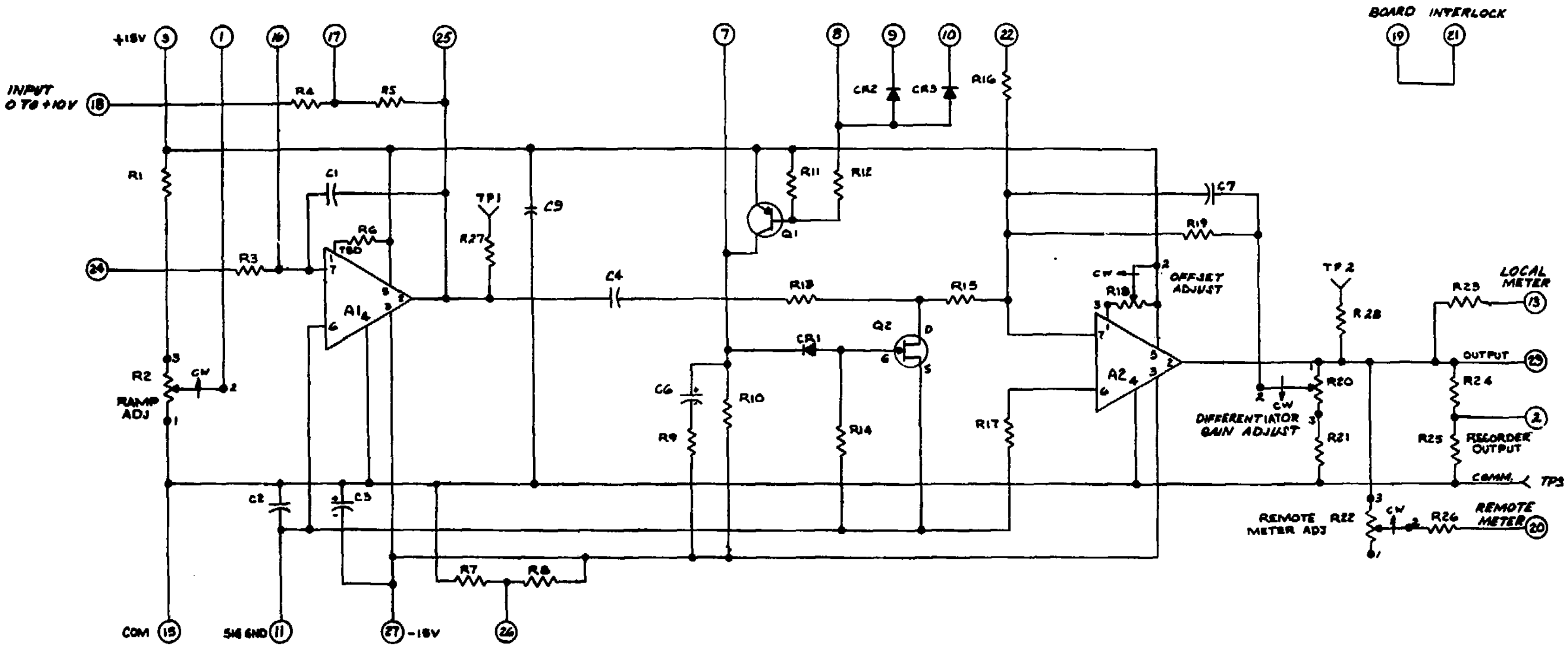
TABLE VI. (contd)

Component and Failure	Result
(36) R11 fails open.	Loss of protective function, along with loss of level signal. Negative period and level signal goes to very low level. Not fail-safe.
(37) R15 fails open.	Same as (35).
(38) R17 fails open.	Same as (35).
(39) R22 fails open.	Same as (32).
(40) R20 fails open.	Same as (34).
(41) R19 fails open.	Same as (30).
(42) R18 fails open.	Same as (30).
(43) R24 fails open.	Same as (35).
(44) R23 fails open.	Same as (31).
(45) C16 fails shorted.	Same as (32).
(46) C16 fails open.	Same as (31).
(47) C15 fails shorted.	Same as (34).
(48) C15 fails open.	Same as (35).
(49) R24 fails open.	Negative period. Level falls to zero. Loss of protective function. Not fail-safe.
(50) R30 or R29 fails open.	Loss of readout of local channel level meter. No effect on protective function.

Failure of any of the above components is extremely unlikely to be due to continued operation, as the voltage and current stress levels in the log-picoammeter circuit are at least one decade, and in some cases even more, below the component design levels. Any failures will be due to "infant mortality" of new parts or from external causes that cause operation outside of normal.

TABLE VI. (contd)

Component and Failure	Result
Circuit-board Assembly of Period Circuit (see Fig. 5)	
(1) R4 fails open.	Loss of protective function. Negative period. Not fail-safe.
(2) R5 fails open.	Period trips. Fail-safe.
(3) C1 fails shorted.	Reduced period-trip sensitivity, i.e., requires shorter period, about 12.5 sec to trip rather than 25 sec. Not fail-safe.
(4) C1 fails open.	No effect. This capacitor is used during period calibration check only.
(5) R6 fails open.	Period trips. This resistor controls offset, and opening it allows amplifier to offset toward the negative output, which is equivalent to increased level. Fail-safe.
(6) A1 fails with output zero or shorted.	Negative period. No period trips and none possible. Not fail-safe.
(7) A1 fails with full negative output.	Period trips. Negative output at A1 is equivalent to increasing level. Fail-safe.
(8) A1 fails with full positive output.	No period trips and none possible. Loss of protective function. Not fail-safe.
(9) A1 fails noisy.	Period trips as soon as negative-going noise peak exceeds rate for period trip setting. Fail-safe.
(10) C4 fails shorted.	Increased period sensitivity, i.e., trip will occur at periods much longer than original trip setting.
(11) C4 fails open.	Loss of protective function. No trips and none possible. Not fail-safe.



NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL RESISTANCE IS IN OHMS
2. ALL RESISTORS ARE 1/4W, 5%
3. A1 - BURR BROWN 3307/12C
4. A2 - BURR BROWN 3307/12C

- RESISTOR SELECTED FOR MINIMUM OFFSET VOLTAGE.
- CONNECTED TO OPERATE - CALIBRATE SWITCH.
- CONNECTED TO BISTABLE TEST POTENTIOMETER.

Fig. 5. Circuit-board Assembly of Period Circuit

TABLE VI. (contd).

	Component and Failure	Result
(12)	Q1 shorted collector to emitter.	Protective function disabled. Not fail-safe.
(13)	Q1 collector-to-base short.	Protective function disabled. Not fail-safe.
(14)	Q1 emitter-to-base short.	No effect on normal channel operation. However, it will be impossible to check period or level calibration without causing a period trip.
(15)	R13 fails open.	Loss of protective function. No period trips and none possible. Not fail-safe.
(16)	CR1 fails shorted.	No effect. Period bypass for period and level calibration checks not possible.
(17)	CR1 fails open.	Same as (16).
(18)	R10 fails open.	Same as (16).
(19)	R14 fails open.	Same as (16).
(20)	Q2 shorted drain to source.	Loss of protective function. Not fail-safe.
(21)	Q2 drain-to-gate short.	Period trips. Negative potential applied to input of A2 causes output to go positive, indicating a positive period. Fail-safe.
(22)	Q2 source-to-gate short.	Same as (16).
(23)	R15 fails open.	Loss of protective function. No trips and none possible. Not fail-safe.
(24)	R17 fails open.	Same as (23).
(25)	R18 fails open on amplifier pin No. 1 end.	Temporary loss of protective function, depending on built-in offset of A2. After new offset is stabilized, protective function will operate. Provisionally not fail-safe.

TABLE VI. (contd)

Component and Failure	Result
(26) C7 fails open.	Possible period trip due to nois susceptibility. Otherwise, no effect. Fail-safe.
(27) C7 fails shorted.	Loss of trip function due to extremely low gain of A2 resultin from this failure. Fail-safe.
(28) R19 fails open.	Period trip due to noise susceptibility of A2 with this failure Fail-safe.
(29) A2 fails with output zero or shorted.	Loss of protective function. No period trips and none possible. Not fail-safe.
(30) A2 fails with full negative output.	Negative period indication. Loss of protective function. No peric trips and none possible. Not fail-safe.
(31) A2 fails with full positive output.	Period trips. Fail-safe.
(32) A2 fails noisy.	Period trips. Same as (9).
(33) R20 fails open on amplifier output end.	Period trips due to high gain and noise. Fail-safe.
(34) R20 fails open on common end.	Reduced period sensitivity, i.e., shorter period required to trip than original trip setting. Not fail-safe.
(35) R21 fails open.	Same as (34).
(36) R23 fails open.	Loss of readout of local panel-mounted period meter. Fail-safe.

<u>Circuit-board Assembly of Bistable Trip</u>

(see Fig. 6)

Component and Failure	Result
(1) R1 fails open.	Nonlatching operation. This applies to period trips only. Provisionally not fail-safe.

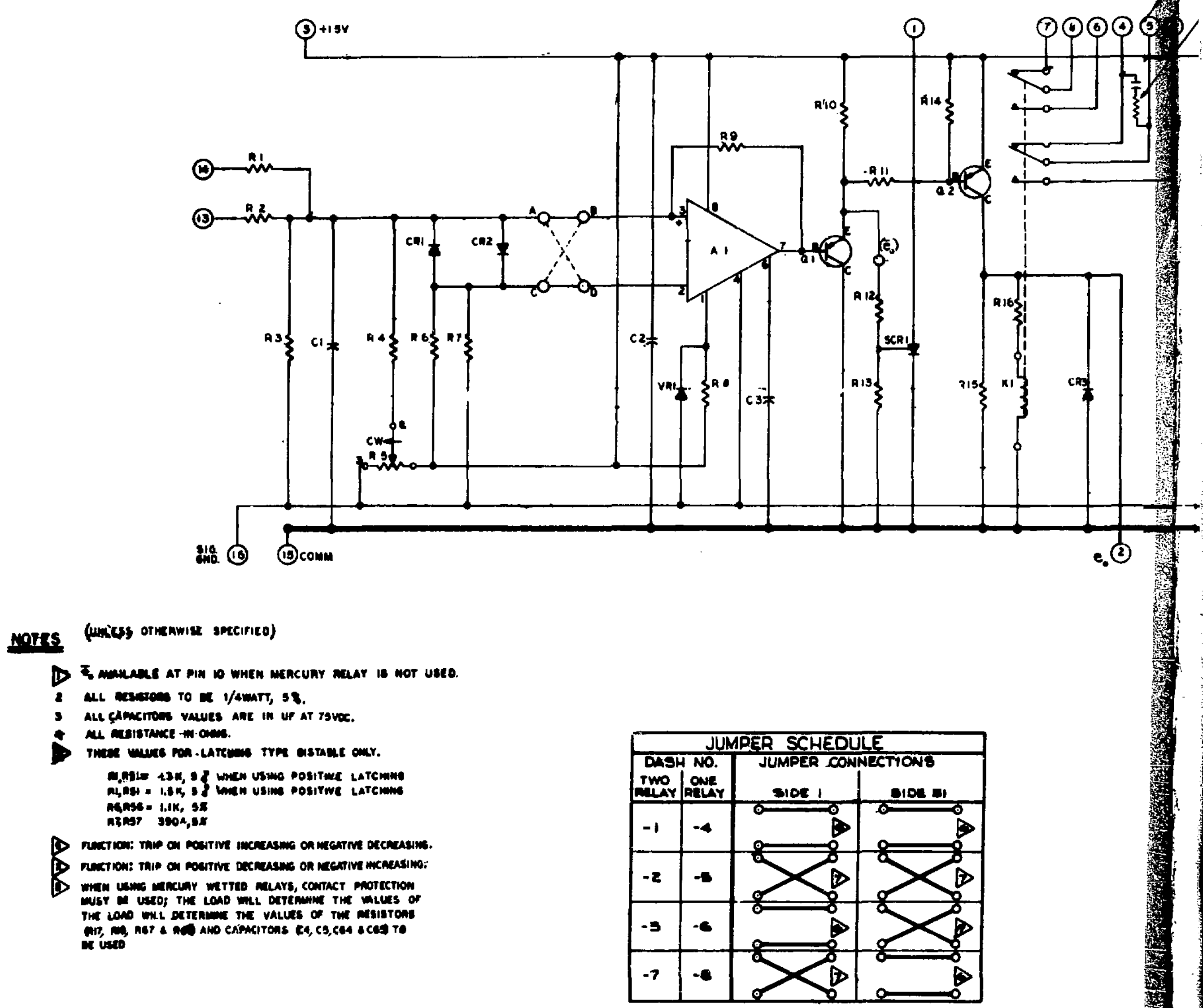


Fig. 6. Circuit-board Assembly of Bistable Trip

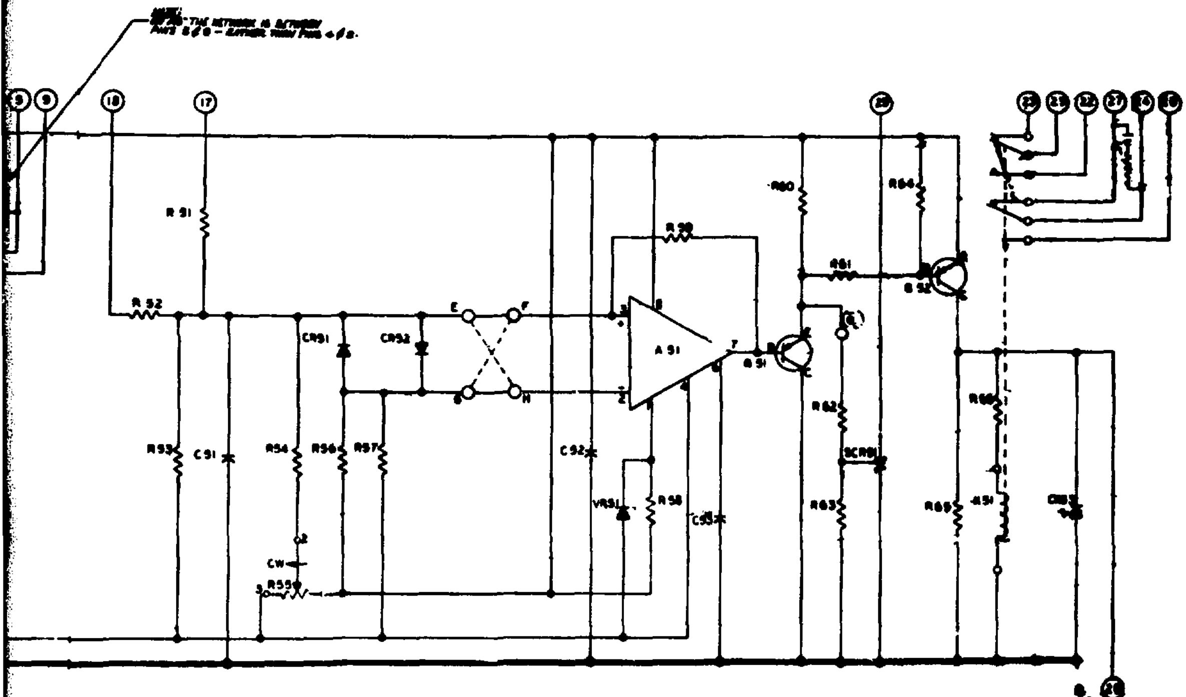

R 51
R 52
R53
C 51
R54
R56
R57
CR51
CR52
CW
R55
C 52
VR51
R 58
C53
R 59
A 51
Q 51
R60
R61
R62
R63
R64
SCR51
Q 52
R65
R66
K51
CR53

TABLE VI. (contd)

Component and Failure	Result
(2) R2 fails open.	(a) Loss of protective function in high-level trip, such as period trip. Not fail-safe.
	(b) Trips in low-level trip, such as the log N period bypass. Fail-safe.
(3) R3 fails open.	(a) Reduces the trip level by two for a high-level trip, such as period trip, i.e., longer period will cause trip. Fail-safe.
	(b) Increases trip level by two for a low-level trip. Not fail-safe.
(4) C1 fails shorted.	(a) For high-level trip, no trips and none possible. Not fail-safe.
	(b) For low-level trip, trips at failure. Fail-safe.
(5) C1 fails open.	Increases noise susceptibility. Either type would tend to trip easier. Fail-safe.
(6) R5 fails open at signal ground.	Trip level reduced for either type.
	(a) For high level, fail-safe.
	(b) For low level, not fail-safe.
(7) R5 fails open at R8 end.	Trip level raised for either type.
	(a) For high level, not fail-safe.
	(b) For low level, fail-safe.
(8) R4 or wiper of R5 fails open.	Trip level increased for either type.
	(a) For high level, not fail-safe.
	(b) For low level, fail-safe.

TABLE VI. (contd)

Component and Failure	Result
(9) CR1 fails open.	No loss of protective function. However, subsequent failure of A1 may result in loss of protective function after negative transient into the bistable. Fail-safe.
(10) CR1 fails shorted.	Loss of protective function. Not fail-safe.
(11) CR2 fails open.	Same as (9), except subsequent failure occurs with positive transient. Fail-safe.
(12) CR2 fails shorted.	Same as (10).
(13) R6 fails open.	(a) Loss of protective function for low-level trips only. Not fail-safe.
	(b) No effect for high-level trips. Fail-safe.
(14) R7 fails open.	(a) Loss of protective function for high-level trips only. Not fail-safe.
	(b) No effect for low-level trips. Fail-safe.
(15) VR1 fails shorted.	(a) Trip level for high-level trips reduces. Fail-safe.
	(b) Trip level for low-level trips reduces. Not fail-safe.
(16) VR1 fails open.	(a) Trip level raises for high-level trips. Not fail-safe.
	(b) Trip level raises for low-level trips. Fail-safe.
(17) R8 fails open.	Loss of protective function. Not fail-safe.
(18) A1 fails with output zero or shorted.	Loss of protective function. Output of amplifier must go positive to operate trips. Not fail-safe.

TABLE VI. (contd)

	Component and Failure	Result
(19)	A1 fails with full negative output.	Same as (18).
(20)	A1 fails with full positive output.	Trip operates at failure. Fail-safe.
(21)	A1 fails noisy.	Trip sensitivities increase for both types. Fail-safe.
(22)	R9 fails open.	Same as (21). Also may trip immediately, depending on individual amplifier and electrical noise. Fail-safe.
(23)	Q1 collector-to-emitter short.	Loss of protective function. No trips and none possible. Not fail-safe.
(24)	Q1 collector-to-base short.	Same as (23).
(25)	Q1 emitter-to-base short.	Trip operates at failure. Fail-safe.
(26)	R10 fails open.	Same as (25).
(27)	R14 fails open.	No immediate effect, but could cause Q2 failure eventually.
(28)	Q2 collector-to-emitter short.	No trip and none possible. Not fail-safe.
(29)	Q2 collector-to-base short.	No trip and none possible. Not fail-safe.
(30)	Q2 emitter-to-base short.	Trip operates at failure. Not possible to reset. Fail-safe.
(31)	R15 fails open.	No effect.
(32)	R16 fails open.	Trip operates at failure. Fail-safe.
(33)	K1 coil fails open.	Same as (32).
(34)	K1 coil fails shorted.	Same as (32).

TABLE VI. (contd)

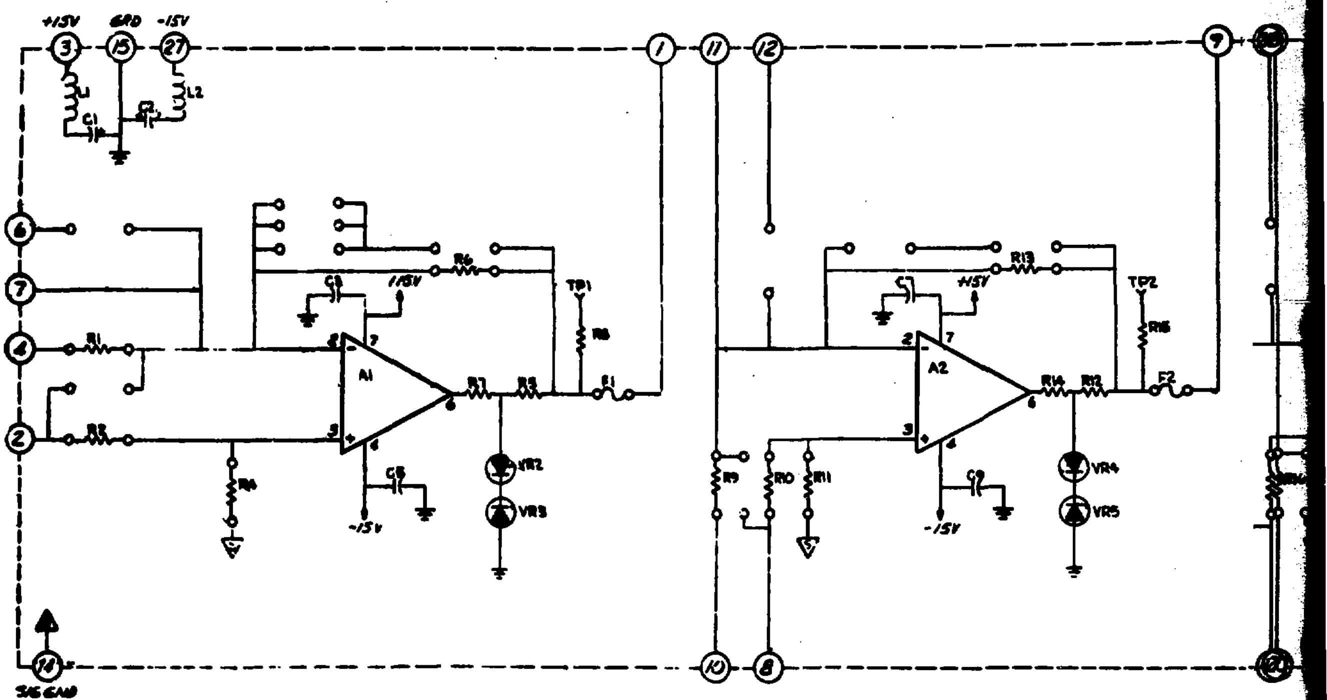
Component and Failure		Result
(35)	CR3 fails open.	Possible noise generation and failure of Q2 on subsequent trip operation. CR3 failing open does not affect operation by itself.
(36)	CR3 fails shorted.	Trip operates at failure. Fail-safe.

In any modes of failure for the bistable trip circuit that are not fail-safe, the two low-level, nonlatching trips to be used in EBR-II will be operated with contacts in parallel and designated as "Log 'N' Period Bypass" (above trip point of 1×10^{-9} A). Likewise, the two high-level, latching trips to be used will be operated with normally open contacts in series and will be designated "Period Trip" (trip setting, 25 sec).

Circuit-board Assembly of Isolation Buffer Amplifier

(see Fig. 7)

(1)	L1 fails open.	Loss of amplifier buffered outputs. No effect on channel operation.
(2)	L2 fails open.	Same as (1).
(3)	R1, R9, R16, or R23 fails open.	Loss of buffered output on buffer involved. Output falls to near zero. No effect on channel.
(4)	R2, R10, R17, or R24 fails open.	Same as (3).
(5)	R4, R11, R18, or R25 fails open.	Same as (3).
(6)	A1, A2, A3, A4 fails with output zero or shorted.	Same as (3).
(7)	A1, A2, A3, or A4 fails with full negative output.	Buffered output of buffer involved goes negative. No effect on channel.
(8)	A1, A2, A3 or A4 fails with full positive output.	Same as (7), except output positive.
(9)	A1, A2, A3, or A4 fails noisy.	Buffered output involved noisy. No effect on channel.



+15V
GRD
-15V
3
15
27
L1
C1
C2
L2
1
11
12
9
6
7
4
2
R1
R2
R4
R6
C3
+15V
A1
R7
R5
TP1
R8
F1
VR2
VR3
C5
-15V
R9
R10
R11
C7
+15V
R13
A2
R14
R12
TP2
R15
F2
VR4
VR5
C8
-15V
14
SIG GND
10
8

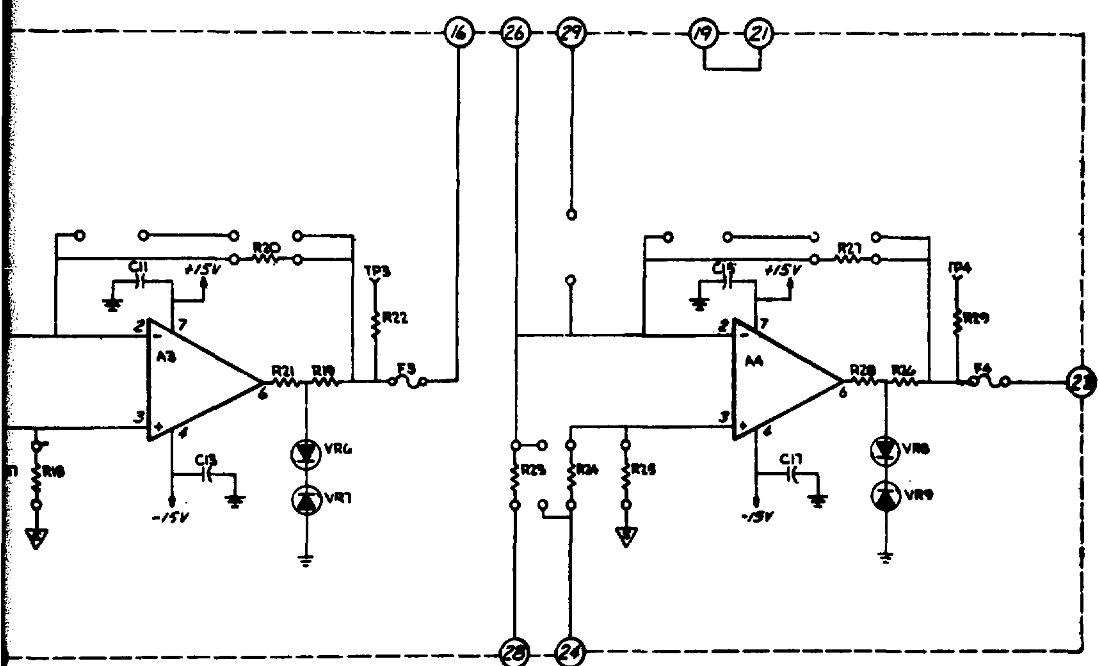


Fig. 7. Circuit-board Assembly of Isolation Buffer Amplifier

2

TABLE VI. (contd)

	Component and Failure	Result
(10)	A1, A2, A3 or A4 fails with shorted input (pins 2 to 3).	No effect on channel. Output loss on buffer concerned. 20-kΩ load presented to channel causes no loading problem.
(11)	A1, A2, A3, or A4 fails with one side of input grounded (pin 2).	Same as (10), except that 10-kΩ load presented to channel is still not significant.
(12)	A1, A2, A3, or A4 fails with input pin 3 grounded.	Same as (11).
(13)	R6, R13, R20, or R27 fails open.	Buffered output involved driven full scale or extremely noisy. No effect on channel.
(14)	R7, R14, R21, or R28 fails open.	Buffered output involved goes to zero. No effect on channel.
(15)	R5, R12, R19, or R26 fails open.	Same as (14).
(16)	VR2, VR4, VR6, or VR8 fails shorted.	Buffered output prevented from going negative. In the EBR-II model, negative outputs are not encountered. No effect. With this failure, negative-going faults to the buffered output would cause failure of fuse F1, F2, F3, or F4 at about 18 V.
(17)	VR3, VR5, VR7, or VR9 fails shorted.	Same as (16), except for positive limitation and failure of fuses at positive-applied 18 V.
(18)	VR2, VR4, VR6, or VR8 fails open.	No effect on channel or buffered output. However, voltage faults to buffered outputs will not fail fuses, and failure of buffer amplifier could result with fault application.
(19)	VR3, VR5, VR7, or VR9 fails open.	Same as (18).
(20)	F1, F2, F3, or F4 fails open.	Loss of buffered output involved. No effect to channel.

TABLE VI. (contd)

Component and Failure	Result
Chassis-mounted Components and Miscellaneous (see Fig. 2)	
(1) R1 fails open.	Complete channel failure. No indication; no trips, and none possible. Extremely improbable since maximum current is 1 x 10^{-3} A. Not fail-safe.
(2) R24 fails open.	No effect on channel. However, tests level source inoperable.
(3) R2 fails open on +15-V end.	Same as (2).
(4) R2 fails open on common end, or R2A fails open.	Period trips as level test source supplies current to input. Level reading makes step change to full scale. Fail-safe.
(5) Q1 collector-to-emitter short.	Negative period indication. Level falls to low value, depending on resistance of emitter-to-collector short. Not fail-safe.
(6) Q1 collector-to-base short.	Same as (5).
(7) Q1 emitter-to-base short.	Same as (2).
(8) C5 fails shorted.	Disables period trip. Loss of protective function. Not fail-safe.
(9) R16 fails open on common end.	No effect. Series resistance of R17 and R13 too great for +15-V supply to affect output of period circuit. However, effect would be in safe direction. Fail-safe.
(10) C6 fails open.	Increases noise susceptibility of channel slightly. No effect on protective function.
(11) C6 fails shorted.	Same as (10), except noise susceptibility higher.
(12) R18 or R19 fails open.	Loss of latching function on period trip bistable concerned.

TABLE VI. (contd)

Component and Failure	Result
(13) VR1 or VR2 fails open.	No immediate effect.
(14) VR1 or VR2 fails shorted.	Loss of latching function on period trip bistable concerned.
(15) CR5, CR6, CR7, CR8, CR9, or CR10 fails open.	No effect. These diodes are used for reverse voltage-transient suppression on deenergizing the associated relays and are paralleled by identical diodes at each bistable.
(16) CR5, CR6, CR7, CR8, CR9, or CR10 fails shorted.	Relay associated with shorted diode deenergizes, providing operation of protective function. Fail-safe.
(17) Relay K1, K2, K3, K4, K5, or K6 fails shorted or open.	Relay concerned fails to tripped conditions, providing operation of protective function. Fail-safe.