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EVALUATION AND PROPOSED MODIFICATION OF CANBERRA INDUSTRIES, INC., EQUIPMENT FOR NEUTRON MONITORING IN EBR-II

by

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ABSTRACT

Equipment from Canberra Industries, Inc. was the first of its kind received for application to the plant protection system (PPS) of EBR-II; therefore, the components were thoroughly tested before acceptance for this application. This report covers, in detail, testing performed, circuit-design problems identified, and corrective action taken before installation of the equipment.

I. INTRODUCTION

The objectives of the tests reported here were to measure the critical characteristics of the Canberra instrumentation; to determine its suitability for use in the fuel-element-rupture detector (FERD) and fission-gas monitor (FGM) system and as an active part of the plant protection system (PPS); and to determine necessary modifications.

II. EVALUATION

The evaluation has three parts: (1) calibration of the count-rate/high-voltage (CR/HV) monitor; (2) measurement of the time response of the equipment to a step input; and (3) fail-safe testing and analysis of the monitor.

A. Equipment

Figure 1 shows the test setup for the calibration. The following equipment was used:

1. CI Model-1418 spectroscopy amplifier, 270138.
2. CI Model-1431 SCA (single-channel analyzer), 260319.
3. CI Model-1481L/S linear-log rate meter, 27094.
4. CI Model-1608 CR/HV monitor, 202394.
5. CI Model-3002 HV power supply, 370201.
6. CI Model-1400 power supply, 3,01410.
7. Datapulse 1108 pulse generator.
8. Eldorado 1605 counter/timer.

Figure 2 shows the arrangement for the measurement of time response. The following equipment was used:

1. CI Model-1418 spectroscopy amplifier, 270138.
2. CI Model-1431 SCA (single-channel analyzer), 260319.
3. CI Model-1481L/S linear-log rate meter, 27094.
4. CI Model-1608 CR/HV monitor, 202394.
5. CI Model-1400 power supply, 3701410.
6. Datapulse 1108 pulse generator.
7. Eldorado 1605 counter/timer.
8. Keithley 160 nanovolt source.
9. Clevite-Brush 260 recorder.

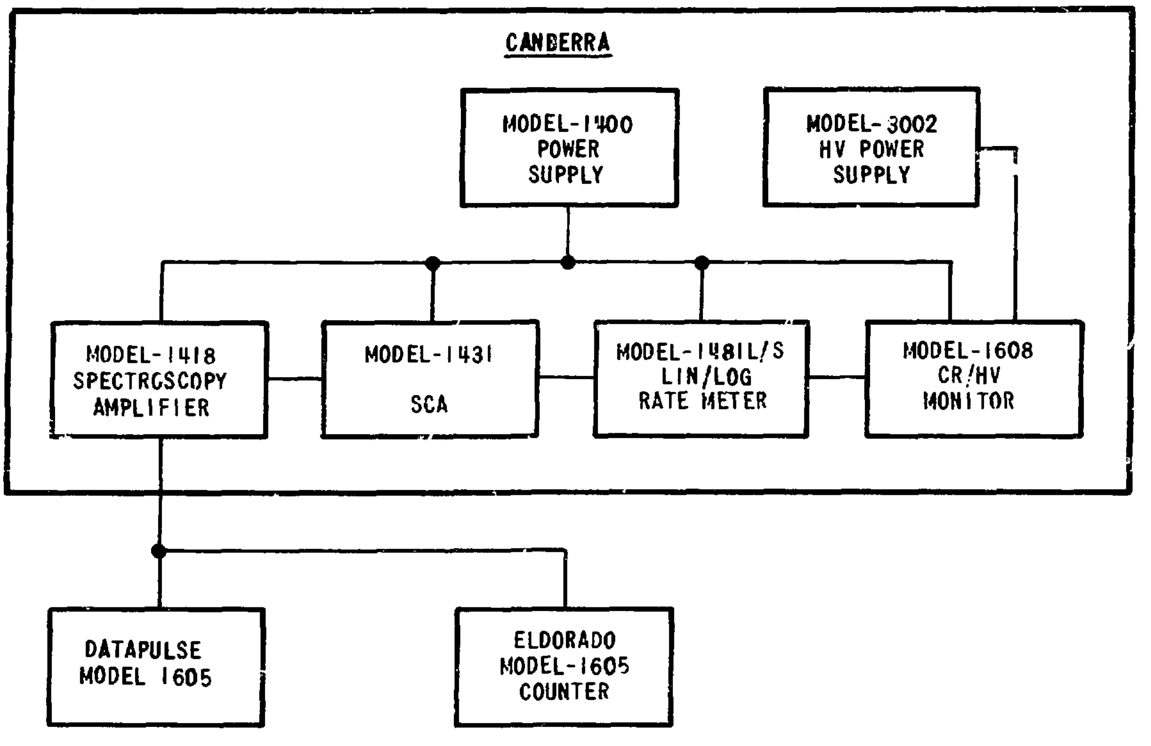


Fig. 1. Setup for Calibrating the Canberra Industries CR/HV Meter

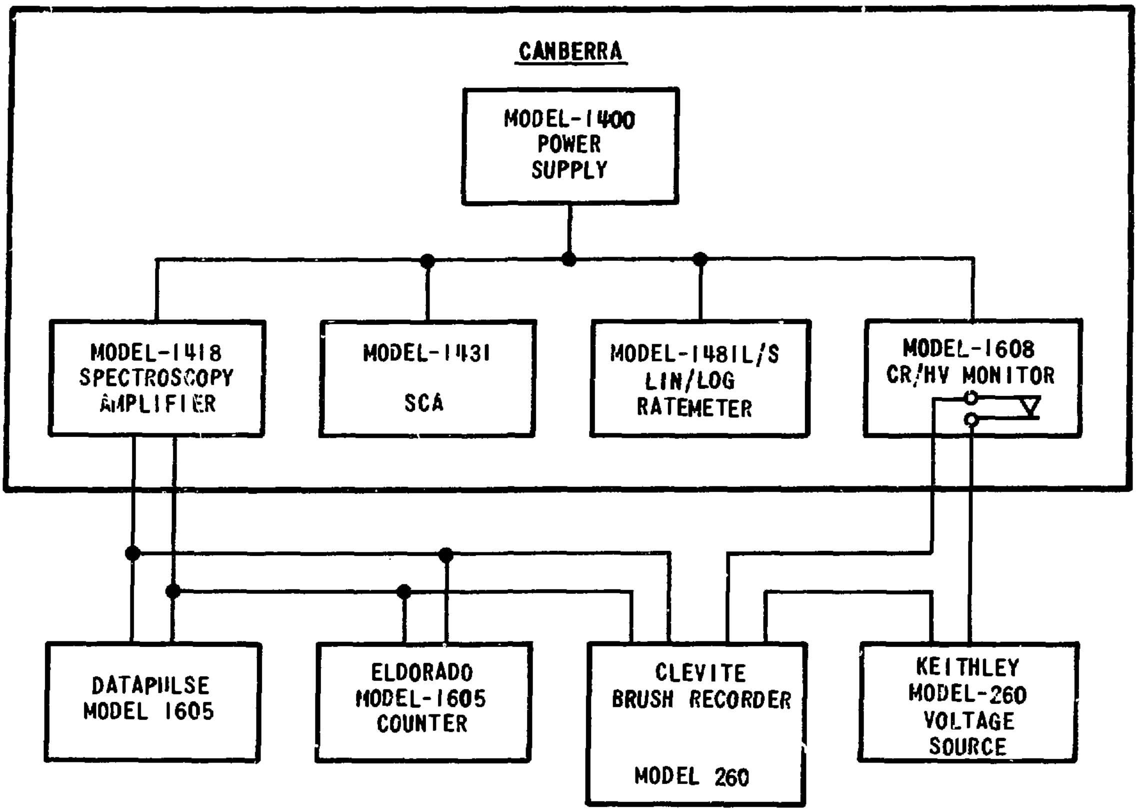


Fig. 2. Setup for Determining Time Response
of Equipment to a Step Input

B. Calibration of Count Rate and High Voltage

The count-rate calibration was determined by setting the trip point at 10% increments between and including 10 and 100% and then increasing the pulse rate until a trip occurred at each setting. The actual trip count rate was determined with the Eldorado counter. This procedure was carried out for each range of the 1481L/S rate meter, from full-scale 10 cps to full-scale 100,000 cps (5-decade ranges).

The high-voltage calibration was performed in a similar manner. The high voltage was set on the Model-3002 high-voltage power supply and the trip setting was increased until a trip occurred. The test was done at 100-V intervals at 600 - 2500 V.

A differential band, defined as the amount the count rate or high voltage (trip setting) must be changed for a tripped monitor to reset, was also investigated. A number was not recorded, however, because for both count rate and high voltage the differential band was so small as to be virtually unmeasurable with the test equipment used.

Table I shows the results of calibration. The time constant used during this run, 0.5, does not affect system calibration. The maximum error occurs between desired and actual trip on the 10^1 range. The error at this range averages 17.2%. On the remaining scales, the error is much less, averaging less than 3%.

Table II shows the calibration of the high-voltage trip monitors. With this unit, the difference between desired and actual trip is almost constant, at 10 V.

C. Time Response of Equipment

Time response of the equipment was measured by introducing a step input and recording the time required for the output to rise to 90% of its equilibrium value. This measurement was made by first setting the pulse generator at a value equivalent to 90% of full scale of the count-rate meter (e.g., 900 cps for the 10^3 scale), adjusting the trip setting, and locking it at the trip point. The pulse generator was then set to 100%

TABLE I. Calibration of Count-rate-trip Unit

Range	Trip Setting, %	Trip, cps Desired	Trip, cps Actual	Deviation from Desired Trip, %[a]
10^1	60	6.0	4.7	-21.7
	70	7.0	5.7	-18.6
	80	8.0	6.7	-16.3
	90	9.0	7.6	-15.6
	100	10.0	8.6	-14.0
10^2	10	10.0	9.7	-3.0
	20	20.0	19.4	-3.0
	30	30.0	29.4	-2.0
	40	40.0	39.3	-1.8
	50	50.0	49.4	-1.2
	60	60.0	58.6	-2.3
	70	70.0	68.4	-2.3
	80	80.0	78.6	-1.8
	90	90.0	88.0	-2.2
	100	100	98.0	-2.0
10^3	10	100	105	+5.0
	20	200	201	+0.5
	30	300	297	-1.0
	40	400	393	-1.8
	50	500	492	-1.6
	60	600	586	-2.3
	70	700	685	-2.1
	80	800	779	-2.6
	90	900	878	-2.4
	100	1000	971	-2.9

TABLE I. (contd)

Range	Trip Setting, %	Trip, cps		Deviation from Desired Trip, %[a]
		Desired	Actual	
10^4	10	1000	1070	+7.0
	20	2000	2032	+1.6
	30	3000	3002	+0.1
	40	4000	3964	-0.9
	50	5000	4932	-1.4
	60	6000	5910	-1.5
	70	7000	6868	-1.9
	80	8000	7835	-2.1
	90	9000	8800	-2.2
	100	10,000	9766	-2.3
10^5	10	10,000	10,602	+6.0
	20	20,000	20,120	+0.6
	30	30,000	29,697	-1.0
	40	40,000	39,139	-2.2
	50	50,000	48,695	-2.6
	60	60,000	58,242	-2.9
	70	70,000	67,770	-3.2
	80	80,000	77,311	-3.5
	90	90,000	86,820	-3.5
	100	100,000	96,370	-3.7

[a] % deviation from desired trip $= \frac{\text{actual trip} - \text{desired trip}}{\text{desired trip}} \times 100$

TABLE II. Calibration of High-voltage-trip Unit

Range, kV	Trip Setting, %	Trip, V Desired	Trip, V Actual	Deviation From Desired Trip, %[a]
0.5-1.5	9.0	590	600	1.69
	19.0	690	700	1.45
	29.0	790	800	1.27
	39.0	890	900	1.12
	49.1	991	1000	0.91
	59.1	1091	1100	0.83
	69.2	1192	1200	0.67
	79.2	1292	1300	0.62
	89.2	1392	1400	0.58
	99.2	1492	1500	0.54
1.5-2.5	9.0	1590	1600	0.63
	19.0	1690	1700	0.59
	29.0	1790	1800	0.56
	39.0	1890	1900	0.53
	49.0	1990	2000	0.50
	59.0	2090	2100	0.48
	69.0	2190	2200	0.46
	79.0	2290	2300	0.44
	89.0	2390	2400	0.42
	99.0	2490	2500	0.40

[a] % deviation from desired trip = $\frac{\text{actual trip} - \text{desired trip}}{\text{desired trip}} \times 100$

TABLE III. Response-time Data for Canberra Equipment

Chart No.	Pulse Freq., Hz	Trip Freq., Hz	Range	% Trip Setting	Time Const.	Chart Speed, mm/sec	90% Response Distance for, mm	90% Response Time, sec
1	100	90	10^2	92.3	0.5	125	129	1.03
2		90	10^2	92.3	2	25	129	5.16
3		90	10^2	92.3	5	5	120	24.0
4	1000	900	10^3	93.0	0.5	125	130	1.04
5		900	10^3	93.0	2	25	127	5.08
6		900	10^3	93.0	5	5	118	23.6
7	10,000	9000	10^4	92.2	0.5	125	131	1.05
8		9000	10^4	92.2	2	25	128	5.12
9		9000	10^4	92.2	5	5	119	23.8
10	10	9	10^1	92.4	0.5	125	89	0.712
11		9	10^1	92.4	2	25	115	4.60
12		9	10^1	92.4	5	5	116	23.2

of full scale. Output of the pulse generator was disabled by using the gate control, and the trip was reset. As shown in Fig. 2, two pens of the recorder were used: one was connected to the pulse-generator output to record the input of the Canberra system, and the second pen was connected to the trip relay and a voltage source so that the pen would deflect when the trip-relay contacts opened. For each measurement, the pulse generator was first enabled, then disabled after the trip occurred, and the monitor was reset.

The above procedure was performed for time constants (set on the 1481L/S rate meter) of 0.5, 2, and 5 on each range from 10 cps full scale to 10,000 cps full scale.

Data and results on response time are shown in Table III. (See Appendix B for the raw data from which Table III was constructed.) If we assume a characteristic of the form

$$CR(t) = CR_0(1 - e^{-kt}) ,$$

where CR(t) is the output of the rate meter, t = 0 at the beginning of the input, and CR_0 is the equilibrium count rate, then the following values for k are found (average overall ranges):

Time Constant	k_1, sec^{-1}
0.5	2.214
2	0.475
5	0.0974

It was determined and verified that the delay introduced by the CR/HV monitor alone is negligible when compared with the response time for the balance of the system.

D. Conclusions

Except for the 10^1 scale, the count-rate trip setting on the instrument is within 3% of the desired trip, and the high-voltage setting is always within 10 V of the desired trip. The calibration data for the CR/HV monitor can be used for exact (±0.5% or less) setting of trip points.

Time response (90%) of the equipment to a step input is a minimum of 0.712 sec (10^1 scale).

E. Fail-safe Testing

Fail-safe testing of the Canberra equipment system can be considered in three categories. The first was a thorough study of the count-rate/high-voltage monitor circuit and analysis of possible failure modes: i.e., what happens if certain failures occur. This category included performance of tests to simulate failures for approval or disapproval of the hypothesis determined by analysis. The second category of fail-safe tests was life-testing of the relays in the count-rate monitor to determine their suitability for acceptance as part of the plant protection system. The last category was a review of the system as a whole and an investigation of potential improvements.

1. Failure Simulation

The circuits of the 1608 CR/HV monitor were first thoroughly studied to determine their normal mode of operation and to hypothesize possible failure modes. Figure 3 shows that the count-rate monitor has two sections essentially identical. The exception is a potentiometer, RV6, in the lower section for balancing the sections to maintain trip at the same input level. The purpose of two sections, as shown in Fig. 3, is to prevent a "single failure", which might disable one section, from disabling the monitor as a whole. Therefore, we will discuss "single failures" that disable both sections simultaneously.

The heart of the monitor is a differential comparator, A3 or A4. (see Appendix A). This comparator operates as follows: As long as the positive input (pin 2) is at a higher potential, with respect to ground, than the negative input (pin 3), the output (pin 7) is at some positive

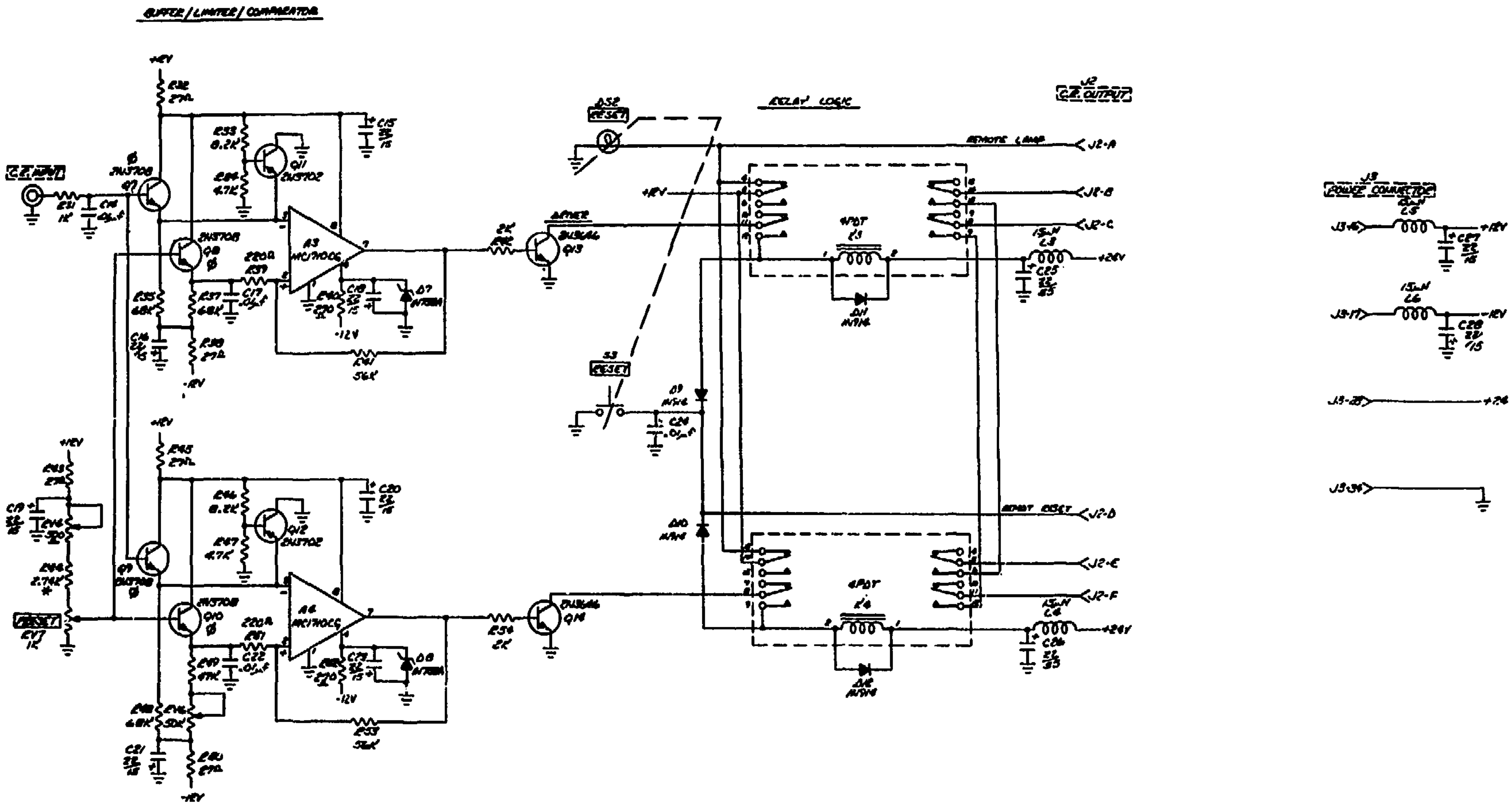


Fig. 3. Count-rate Portion of CR/HV Monitor
Courtesy, Canberra Industries, Inc.

level (around +3 V). The +3-V bias maintains the driver transistor, Q13 or Q14, in an "on" state. In this state, relay K3 or K4 is energized. The trip action, "on to off", occurs when the negative input voltage rises above the voltage of the positive input. The output of A3 or A4 goes to ground and turns off Q13 or Q14, de-energizing the relay.

For the count-rate part of the monitor (see Fig. 3), the positive input is supplied by the voltage divider, made up of R43, RV4, R44, RV7, and transistor Q8 or Q10. By adjusting RV7, the voltage at the positive input can be varied from -0.2 to +2.3 V. The negative input is supplied by the count-rate input and Q7 or Q9. As the count-rate input rises, the voltage at the negative input increases until its potential is greater than the voltage at the positive input, and the monitor trips.

Failures considered in detail were those that simultaneously affect both sections of the monitor. Since the sections are connected at the input and at the output (isolation normally provided by Q7 through Q10), this section was considered the most critical point in the circuit. In addition, the two sections share a low-voltage power supply, Model 1400.

At the input side, the following was determined: If a base-emitter short occurred on either Q7 or Q9, the negative input to A3 and A4 would be driven to the count-rate input level. If this level is lower than the bias level provided normally for the negative input, the monitor would not trip until the count-rate input level rose past the trip setting. This failure was simulated by shorting the base-emitter of Q7. With the base-emitter shorted, the count-rate input level was found to be higher than the corresponding negative-input level; therefore, the monitor tripped immediately and would not reset. This failure is in the safe direction.

The next input-related failure tested was the shorting of the base-collector of Q8 or Q10. This failure would seem to saturate Q8 and Q10 and, therefore, increase the positive input of A3 and A4 to a voltage near the supply voltage. If this increase occurred, the negative input would never exceed the positive input and, therefore, the monitor would never trip. This failure was simulated and the monitor failed safely for the following reason: As expected, the positive input voltage increased to about +8.43 V. However, it was discovered, by use of an external source, that if the positive-input level rises to 7.83 V, the output of A3 or A4 goes to ground, regardless of the signal level at the negative input. When Q8 or Q10 saturates, the positive input rises above +7.83 V and the monitor trips and will not reset. Again, the failure is in the safe direction.

Another input-related failure considered was opening of potentiometer RV7 at its ground end. This failure would, perhaps, apply a higher-than-normal potential to the bases of Q8 and Q10. However, this failure also saturates Q8 and Q10 and leads to exactly the same result as a base-collector short of Q8 or Q10, and the monitor fails safe.

The next failure considered was application of a step increase in potential to the count-rate input large enough to open the bases of Q7 and Q9. Through this action, the relay might not open in the short time required for the bases to open, but this happening was found to be very unlikely, because the response time of A3 and A4 is about 40 nanosec. Therefore, we assume, with justification, that the monitor is also fail-safe to this mode of failure.

Testing for the remaining failure potentials of the input stages is not considered necessary, because their failure mode is obvious. In fact, failures of all components in the input and preset stages were considered, and all failures except those discussed above were deemed fail-safe without testing.

In the output stages, the picture is somewhat changed and no actual testing of the system is necessary to show it. The root of the difficulty is that both relays K3 and K4, one of which must de-energize for the monitor to trip, can be reset and held closed by a single switch (S3), or a single shorted capacitor (C24). In addition, lamp DS2 energizes if either of the two relays open. Therefore, if one relay fails to open, the situation is not detected without testing the relay contacts directly. With respect to the common-reset feature, the count-rate monitor <u>is not</u> fail-safe.

The high-voltage part of the monitor, Fig. 4, is the same circuit in principle as the count-rate part, except that the preset voltage is applied to the negative input of A1 and A2, and the high-voltage input drives

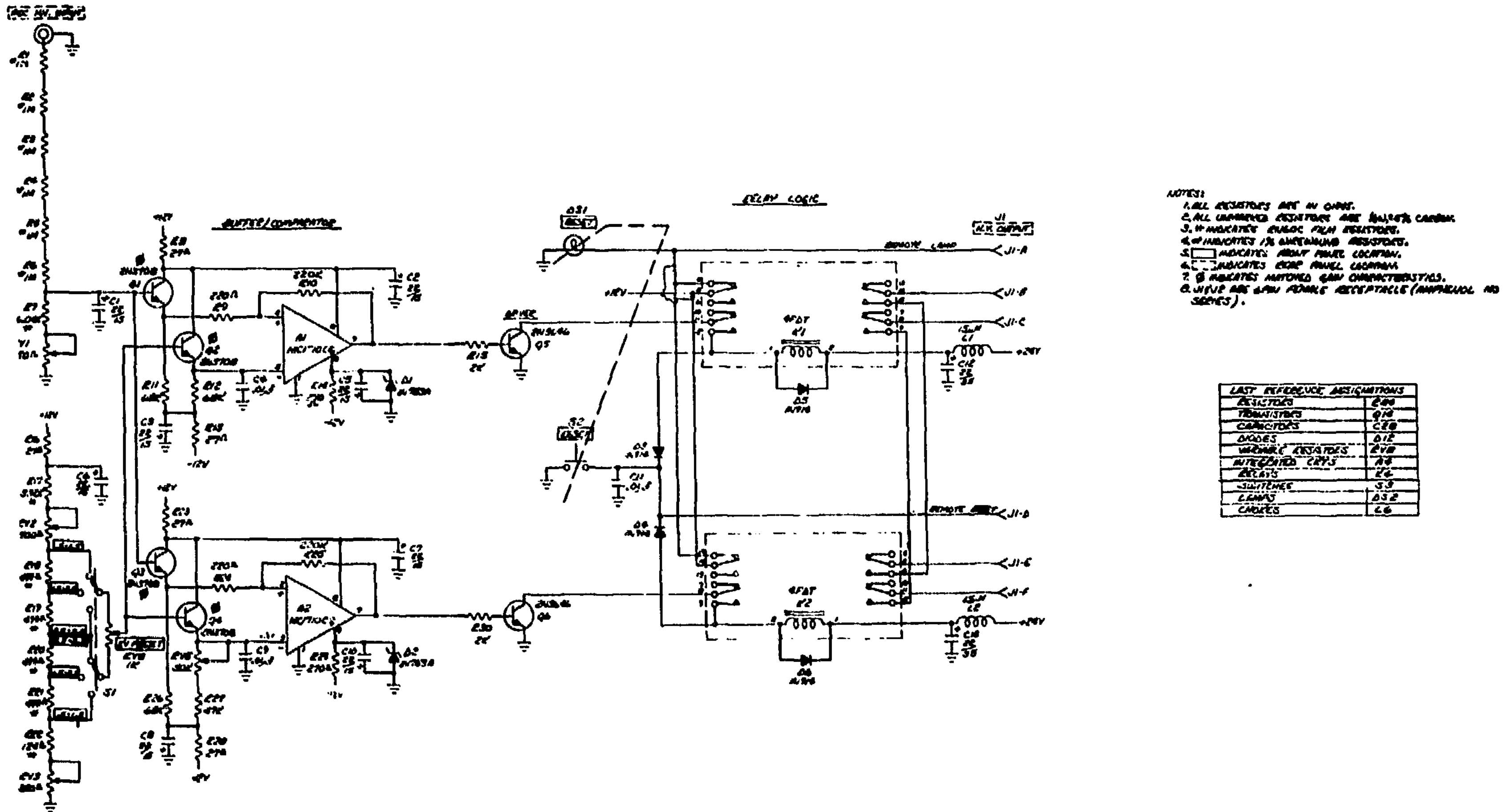


Fig. 4. High-voltage Portion of CR/HV Monitor
Courtesy, Canberra Industries, Inc.

the positive input. These changes are made to cause a trip when the high-voltage input falls, rather than rises, past a certain level, causing the positive input of A1 or A2 to be below the negative input.

One can quickly determine that a base-collector short of Q1 or Q3 is analogous to the base-collector short of Q8 or Q10, which pulls the positive input past +7.83 V and thereby causes a trip. This analogous behavior was confirmed by test.

The next failure to consider is a base-emitter short of Q2 or Q4, which might cause the negative input to be lowered and either prevent a trip or seriously change the trip point. However, as with Q7 and Q9, the potential on the base of Q2 and Q4 is higher than that of the emitter; thus a base-emitter short raises the trip point, which is the safe direction for the high-voltage part of the monitor.

The failure that appeared to be most serious was an open circuit in either R16 or R17, which would decrease the potential on the bases of Q2 and Q4 and lower the trip point. This failure was simulated by removing R16, after which the monitor would not trip. The potential on the negative input to A1 and A2 was measured at -0.5 V, clearly showing that no trip could occur without some additional failure. For an open circuit of R16, R17, or RV2, the high-voltage monitor <u>is not</u> fail-safe.

The output and relay section of the high-voltage part is identical with that of the count-rate part; therefore, the high-voltage monitor <u>is not</u> fail-safe for a shorted reset switch or capacitor.

As mentioned previously, the CR/HV monitor is supplied with low voltage (+24, +12, and -12 V) by the Canberra-1400 power supply. The last failure considered in the study was loss of each of the supply voltages. The assumption was a failure in the 1400 power supply such that the terminal, which usually supplies a given voltage, was left floating. When the + 24 V was opened, the relays immediately opened and caused a trip. When the +12 V was opened, the same result occurred and the trip would not reset. However, upon loss of the -12 V, neither the high-voltage nor the count-rate monitor tripped, and would not trip with any input. The exact cause for this result is not obvious, and correcting the condition would require a significant effort. If the -12-V supply only is open-circuited, leaving the count-rate/high-voltage monitor without that potential, the system is not fail-safe.

Another comment was mentioned earlier. If a failure occurs and disables one section, e.g., an emitter-collector short of a driver transistor, the failure might go undetected. Such a failure might be part of a "Class-4 single failure" (see IEEE publication 279), which, combined with the same failure at a later time of the other section, would render the monitor not in a fail-safe condition.

2. Testing of Relays

Category 2 is for relays K1 through K4 and their ability to operate in conjunction with a Clark relay, type PMA, 5UU4 (the type used in the plant protective system). A test was set up, as shown in Fig. 5, to determine this capability of the relays. The 15-rpm motor drove a cam and microswitches, which alternately tripped and reset the count-rate monitor. Trip and reset occurred once every 4 sec for 67.25 hr. The total number of set-reset cycles was 73,116. After completion of the test, the system was working normally. A subsequent inspection of relays K3 and K4 showed the contacts to be only slightly damaged and apparently capable of many more cycles. One set of contacts, the set that probably opened first each cycle, showed some carbon deposits, but the contact resistance was not measurably changed. The contacts of an unused relay were 67 mils (upper contact) and 41 mils (lower contact). After the test, the damaged contacts were 66 mils (upper) and 40 mils (lower); a total change of less than 2%, and perhaps none; this change indicates that contact wear from testing was very small.

3. Potential Improvements

This section describes specific improvements needed for the system, with particular emphasis on the modes of non-safe failure discussed above.

Another general observation is in order. The Canberra equipment, as put together for this test, includes no alarm for a low count rate.

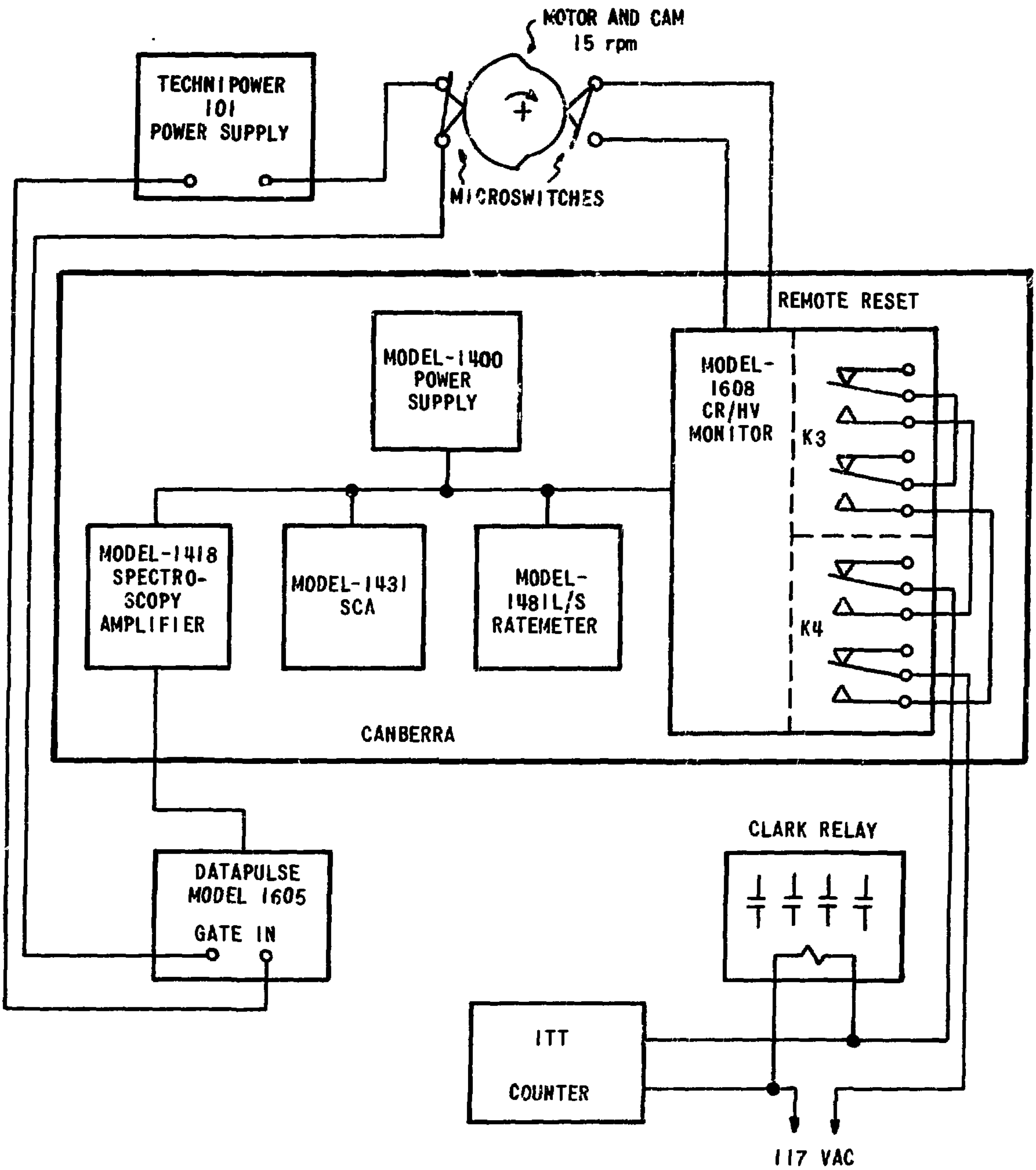


Fig. 5. Setup for Test of Relay Capabilities

Obviously, if the system failed down-scale (the count rate dropped off owing to component failure), no alarm or trip for high count rate could occur. If such a failure were to go undetected, the system would not be fail-safe for this mode of failure.

In an attempt to determine the possibility of some failure that might cause a drop or total loss of count rate, the following failures were identified, any one of which would cause such a loss:

1. Detector failure.
2. Preamplifier failure (many possible causes).
3. Amplifier failure (many possible causes).
4. Failure of a single-channel analyzer (many possible causes).

See Fig. 6 for the following:

5. Open R1.
6. Short of D2.
7. Internal failure, output of comparator A1 at ground. (See Appendix A).
8. Open base, emitter, or collector Q27.
9. Any failure of monostable multivibrators A2A, A2B, A2C, and A2D. (See Appendix A).
10. Open base, emitter, or collector Q2.
11. Open base, emitter, or collector Q4.

See Fig. 7 for the following:

12. Short of emitter-collector Q19.
13. Open R79.
14. Short of R80.

Many other failures will cause a loss of count rate. If the system fails, *it probably will fail down-scale.*

Failures 9 through 14 above affect only the linear part of the system, which is the side driving the monitor; these failures would *not* be detected automatically in the log output.

Without question, a down-scale failure of the count-rate system is possible. In fact, it is probable in the event of a failure. With the present Canberra equipment, a down-scale failure prevents the protective function (scram) from being performed, and such a failure does not cause an alarm.

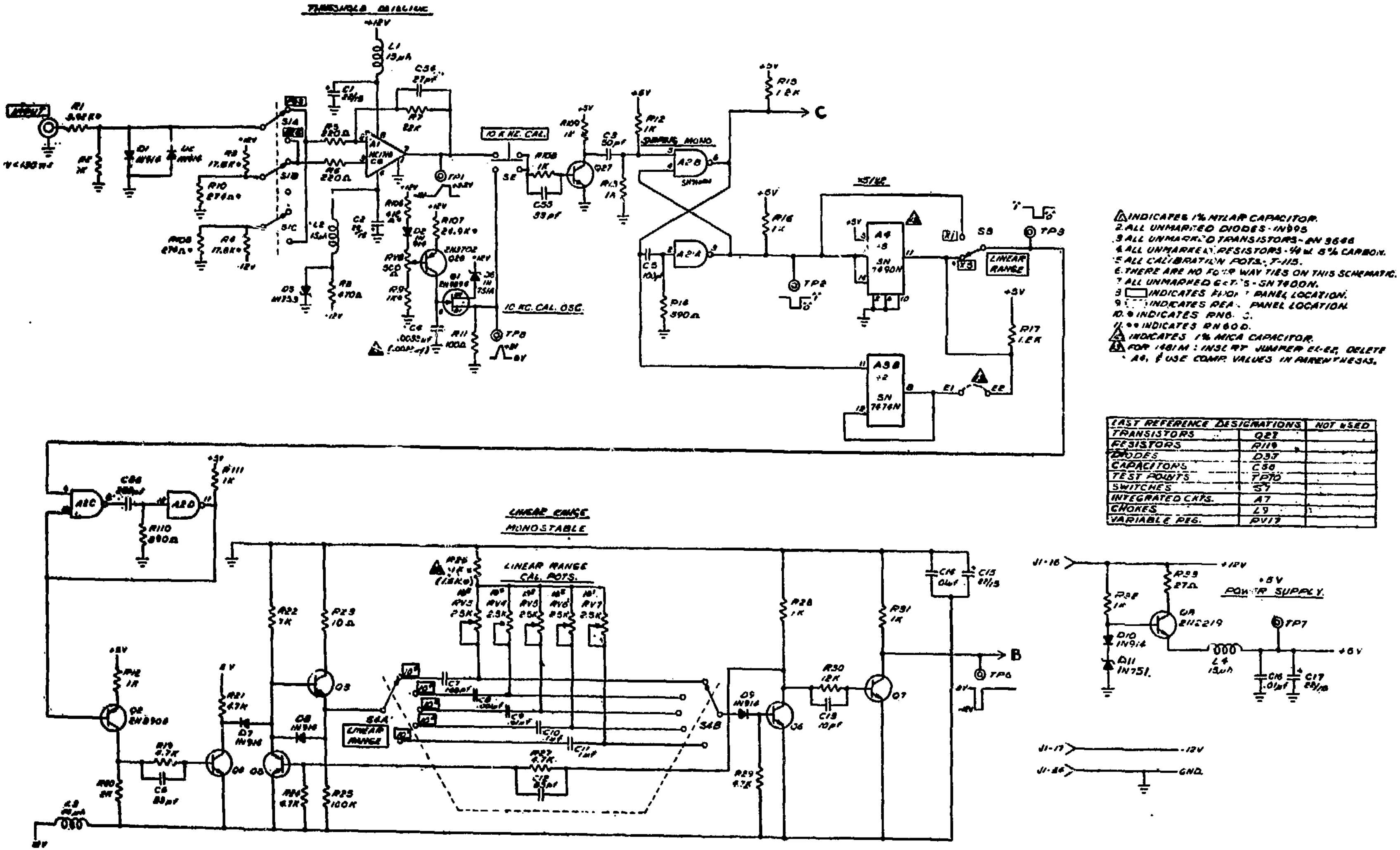


Fig. 6. Schematic of Linear-log Rate Meter, Model 1418L/S (Sheet 1)
Courtesy, Canberra Industries, Inc.

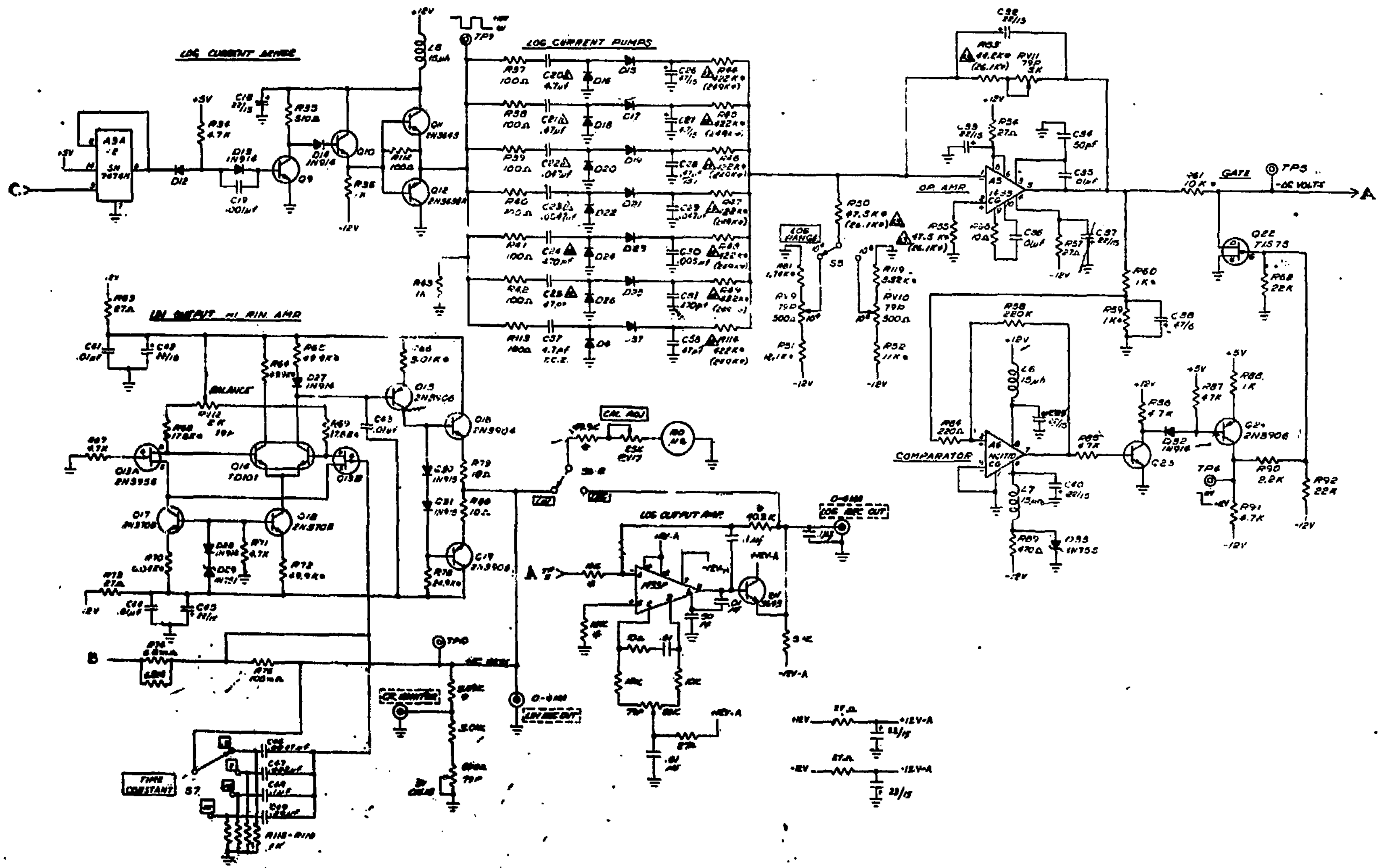


Fig. 7. Schematic of Linear-log Rate Meter, Model 1481L/S (Sheet 2)
Courtesy, Canberra Industries, Inc.

An obvious solution to this situation is to add an alarm for low count rate, which has, as its input, the same signal that goes to the alarm for high count rate. Such an alarm could probably be easily built from the high-voltage monitor discussed above, with some changes in the input-voltage divider.

Including an alarm for low count rate has another advantage. If a certain resistor (actually one of three) opens in the high-voltage monitor, the system will then fail to recognize a low high-voltage output. However, because of discrimination in the SCA, a loss of high voltage would also reduce the count rate. Therefore, the vulnerability of the high-voltage monitor to single failures is diminished, although not completely cancelled, by an independent alarm. This backup is desirable in any event, because invulnerability to single failures is almost impossible to prove in any equipment.

Probably the most severe deficiency of the existing Canberra equipment, apart from lack of a monitor for low count rate, is the reset scheme for the relays. As shown above, the count-rate monitor is not fail-safe for some failures in the relay circuitry. A very simple and effective solution is shown in Fig. 8. In this circuitry, the isolation between sections of both the count-rate and high-voltage alarms is carried out to the relays themselves. Also, an indicator light is provided for each relay so that operation of each relay can be determined independently. This arrangement immediately prevents an emitter-collector short in a driver-transistor from being undetected for longer than the periodic testing interval for the system. The circuitry in Fig. 4 also prevents a single stuck switch or shorted capacitor from preventing system operation--one of the worst problems with the present Canberra equipment.

The situation, with respect to the non-fail-safe condition, is more difficult if the -12-V supply is lost. Without more detailed analysis, it does not appear that a simple redesign of the CR/HV monitor would solve the problem; therefore a better approach probably would be to monitor the -12 V supply, and cause an alarm on loss of the supply. The possibility of a failure of the -12-V supply alone seems remote; normally the parts

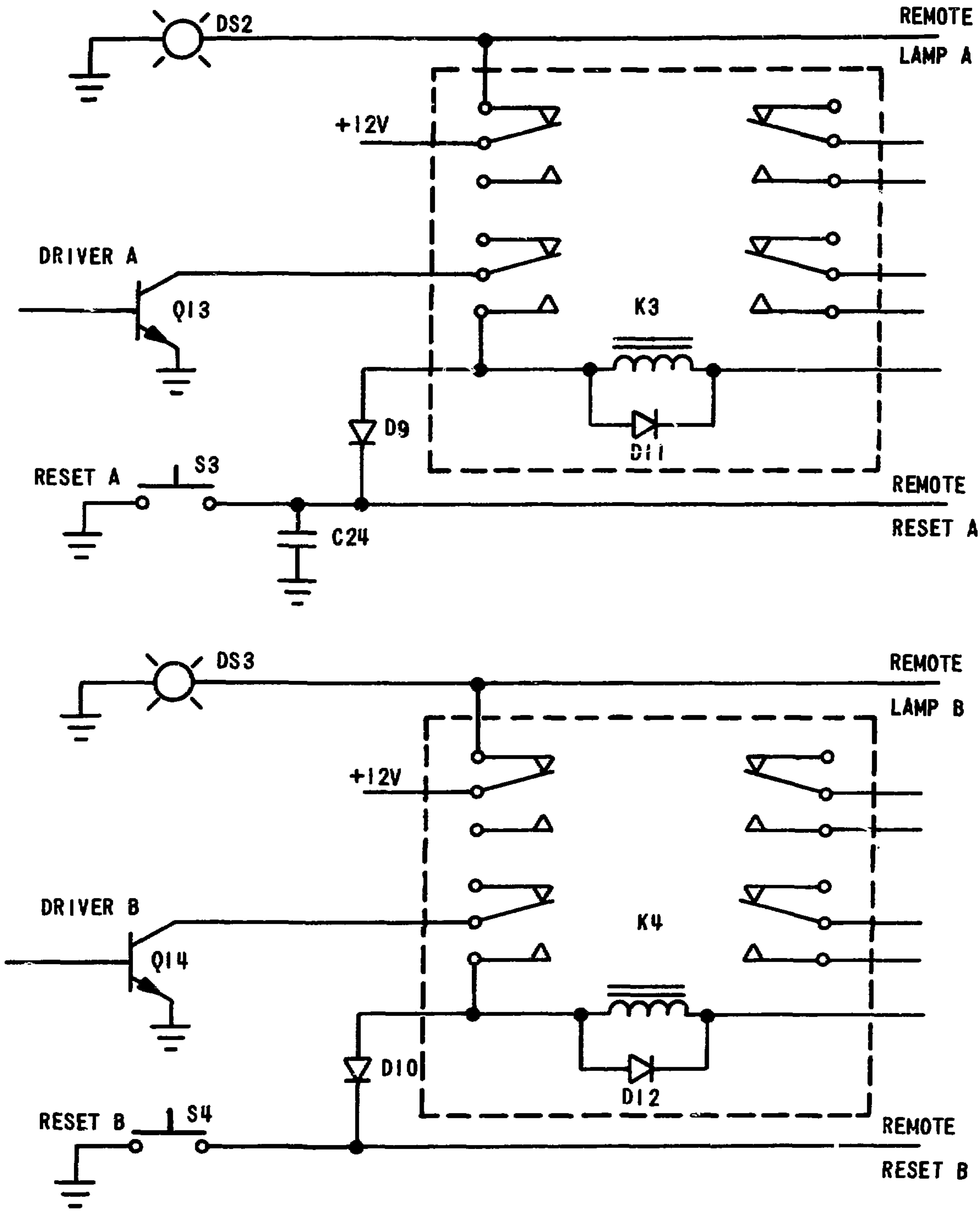


Fig. 8. Improved Relay Circuitry

of a power supply most likely to fail (transformer, rectifiers, filtering) affect the whole power supply and would then be safe in this case. Also, the loss of the 12-V supply would be detected by other parts of the system. However, only the -12-V supply might be lost, and this loss probably would go undetected until the system was checked.

4. Results of Evaluation of Fail-safe Characteristics

The following conclusions are drawn from the fail-safe study:

a. Several "single failures" of the existing system, could prevent the CR/HV monitor from performing its protective function, both in the count-rate and in the high-voltage portions.

b. The relays in the CR/HV monitor appear to be compatible with the plant protective system, and a test has confirmed that the relays will operate reliably for more than 70,000 cycles of opening and closing under load.

c. Any failure in the system probably would be down-scale. If this failure were undetected, it could prevent the protection function for count rate from being carried out. For this reason and others, inclusion of a low-level alarm in the system that would bring attention to a count rate lower than the usual level is advisable.

d. A simple redesign of the relay stage of the CR/HV monitor would significantly reduce the monitor's susceptibility to single failures and would provide a convenient means of checking operation of individual relays, a feature not presently incorporated.

e. If the -12-V supply is cut off from the CR/HV monitor, the monitor will not trip. The best solution would be to include an alarm that would indicate loss or serious degradation of the -12-V supply.

f. The Canberra system is basically a well-designed unit that, with the proposed modifications or other solutions to the noted problems, should serve reliably and safely.

III. MODIFICATIONS TO IMPROVE FAIL-SAFE CHARACTERISTICS

Items c and d of the results of evaluation were considered unacceptable for use of the equipment in the plant protection system, and the following action was taken to correct for the non-fail-safe modes of failure:

A. Alarm for Low Count Rate

The alarm for low count rate was provided by adding a duplicate count-rate-trip circuit to the count-rate-trip portion of the CR/HV monitor module. The circuit is a duplicate of the existing count rate-trip circuit, except that the circuit (Fig. 9) is self-resetting and employs only one relay in its output rather than two. Interconnections are shown in Figs. 10 and 11. Basically, the circuit provides a separate alarm on low count rate and lights the count-rate reset light. The circuit is contained in a separate circuit board added internally to the CR/HV monitor. The adjustment for the low-count-rate trip is beneath a hole in the side of the module and can be set only by use of a module extender or by removing other modules of the system.

B. Modifications to Relay Stage

Wiring of the relay circuitry in the count-rate and high-voltage-trip circuits of each CR/HV, monitor has been modified so that both relays of each trip circuit must operate before the reset light will illuminate and indicate a trip. Only one relay need operate to provide one input into the two-out-of-three scram logic.

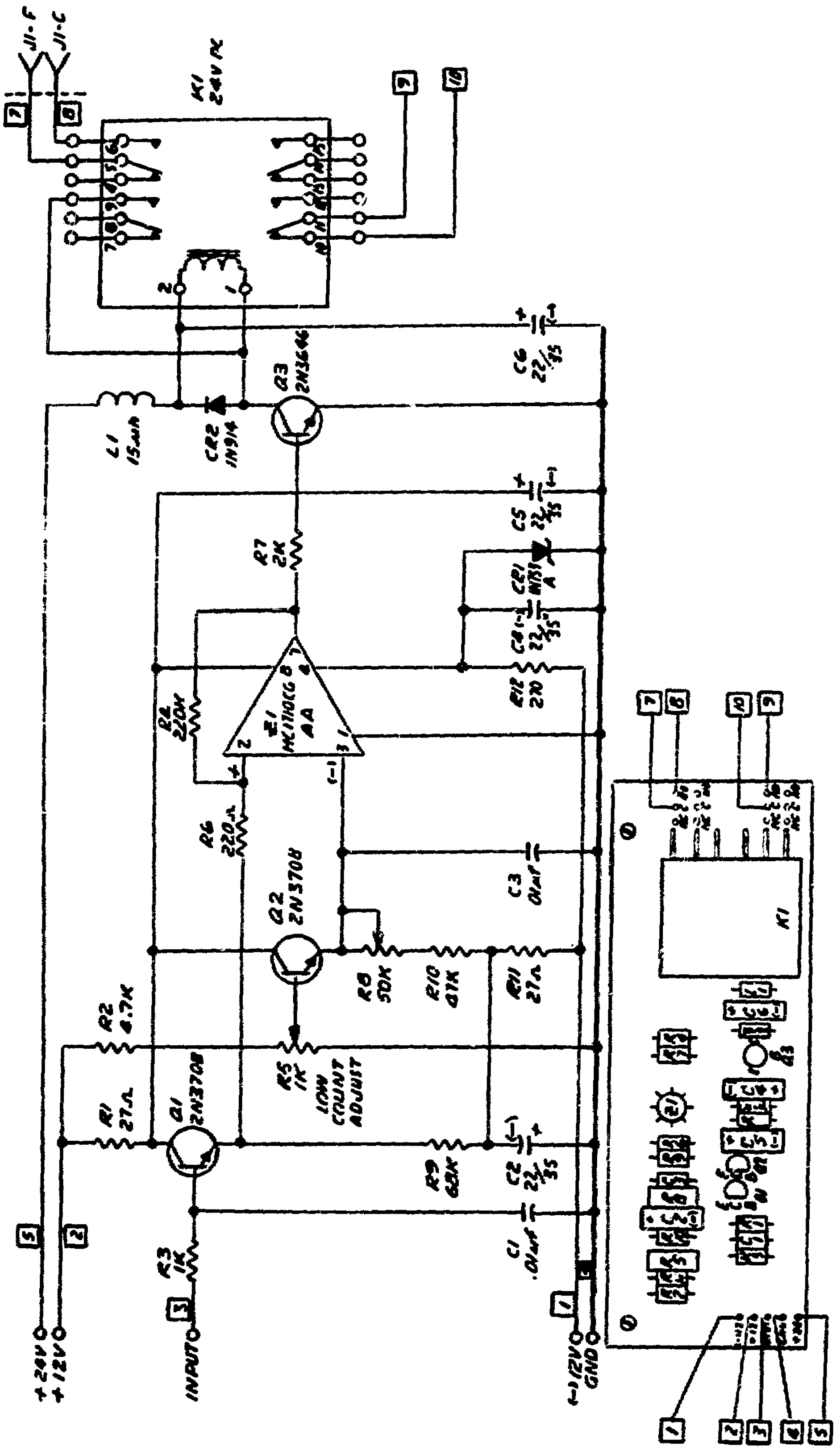


Fig. 9. Low-voltage Trip Board

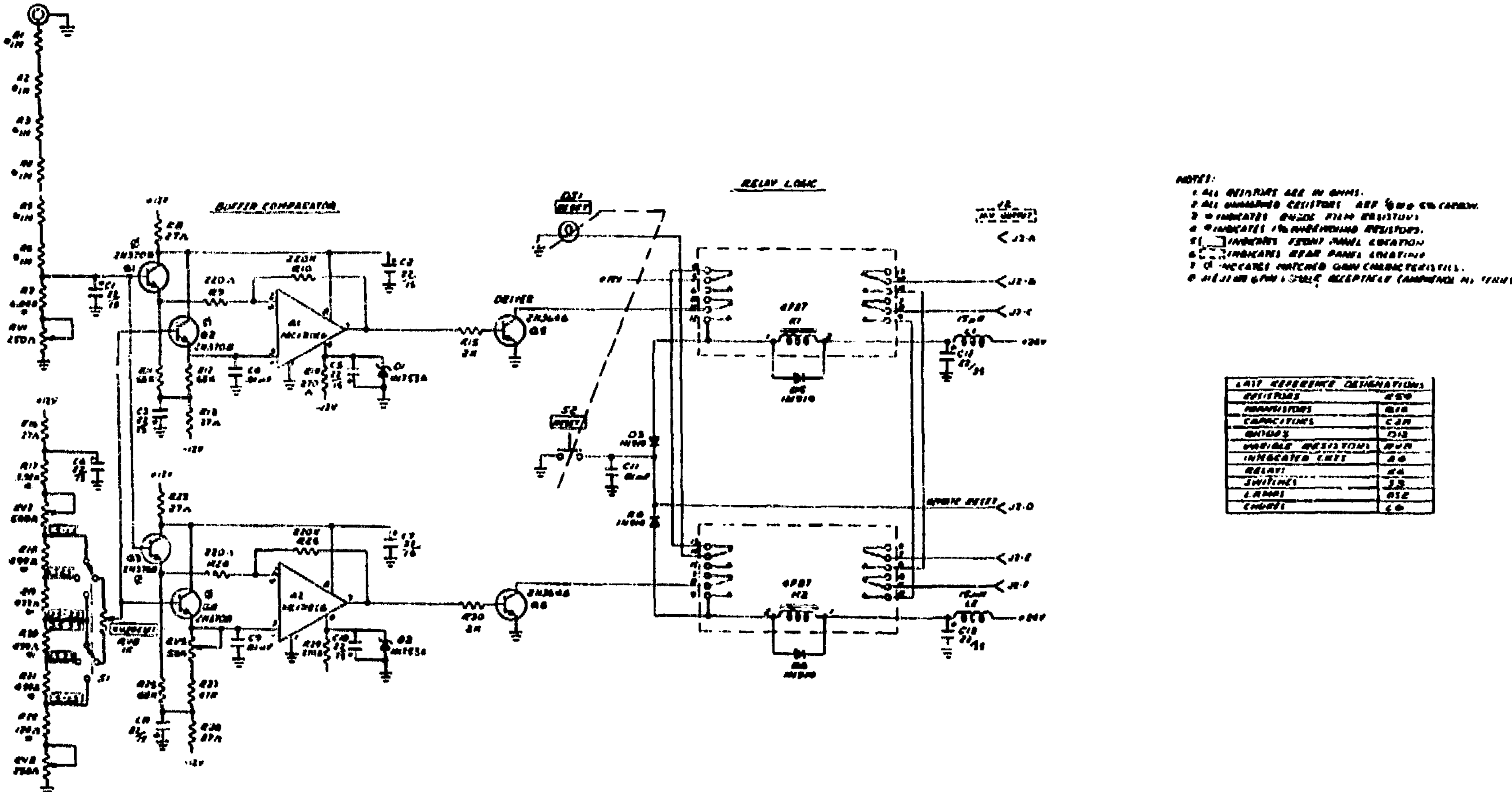


Fig. 10. Modified High-voltage Portion of Canberra Monitor, Model 608

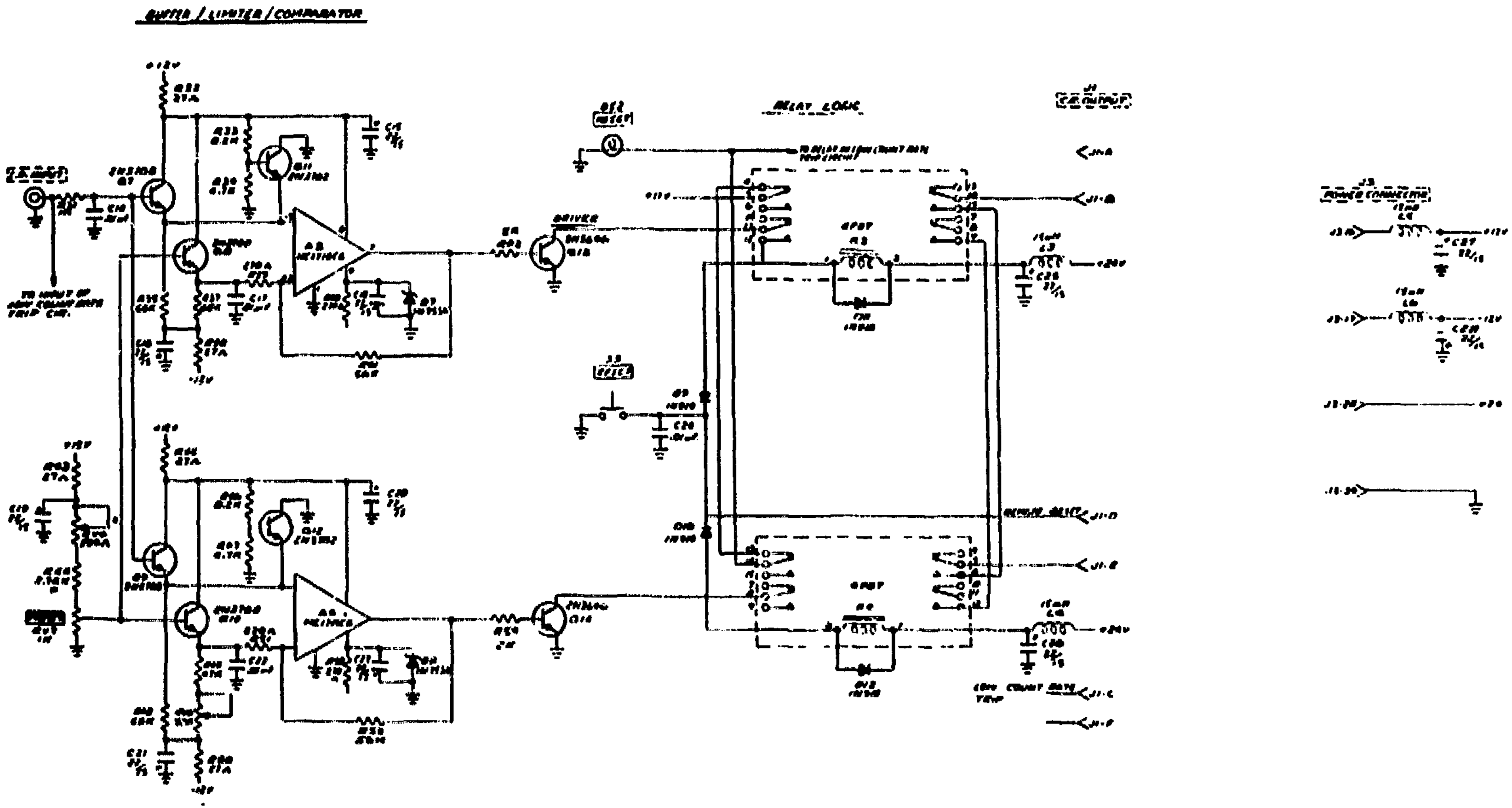


Fig. 11. Modified Count-rate Portion of Canberra Monitor, Model 1608

C. -12-V Power Supply

The -12-V power supply is actually part of the 12-V power supply, and it is very difficult for one supply to fail without the other failing. For the -12-V supply to fail, the -12 V bus must open. Monitoring this bus is not practical nor is it considered essential. The probability of bus failure is extremely remote, and any failure that would occur would most likely result from an overloading of the bus, which is fused for protection. The bus was carefully inspected and is adequate; therefore, the interlock checks performed monthly are considered adequate assurance against this failure. Because of the isolation between the three channels provided for the PPS, a common mode of failure or simultaneous failures of the -12-V supplies in two or more channels was thought to be too improbable to consider.

D. Single Failures

The "single failures" resulting from a loss (open circuit) of resistors R16, R17, and RV2, as stated in the description of testing, were reviewed and considered. The resistors are of a size adequate to provide self-protection from burnout; therefore, the probability of an open circuit occurring in more than one channel was considered too highly improbable to protect against. Here again, the monthly interlock checks will detect this failure.

IV. CONCLUSION

The Canberra equipment, modified as described above, should be suitable for inclusion in the plant protective system.

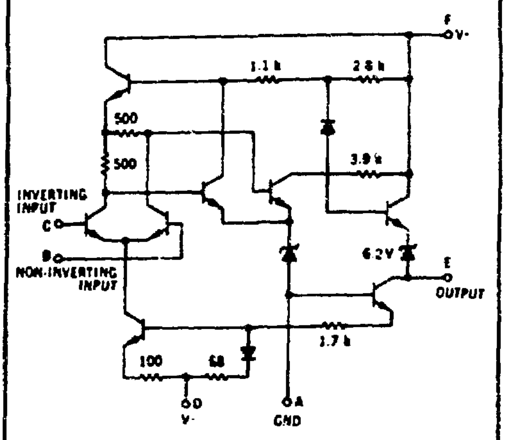
APPENDIX A

Supplementary Circuit Diagrams

. . . the MC1710 and MC1710C are identical circuits specified over different temperature ranges. These devices are differential voltage comparators for use in level detection, low-level sensing, and memory applications. Features:

- Differential Input Characteristics:
  - Input Offset Voltage = 1 mV
  - Offset Voltage Drift = 3 μV/°C
- Fast Response Time — 40 ns
- Low Output Impedance — 200 ohms
- Output Compatible with All Saturating Logic Forms — +3.2 V to −0.5 V typical

MC1710, MC1710C Available in Metal Can (G) and Flat (F) Packages (Cases 96, 72)



PIN CONNECTIONS

Schematic	A	B	C	D	E	F
"G" Package	1	2	3	4	7	8
"F" Package	1	2	3	5	6	8

MAXIMUM RATINGS (T_A = 25°C UNLESS OTHERWISE NOTED)

RATING	SYMBOL	VALUE	UNIT
Power Supply Voltage	V^+ V^-	+14 7.0	Vdc Vdc
Differential Input Signal	V_{in}	±5.0	Volts
Common Mode Input Swing	CMV_{in}	±7.0	Volts
Peak Load Current	I_L	10	mA
Power Dissipation (Package Limitation) Metal Can Derate above 25°C Flat Package Derate above 25°	P_D	 680 4.6 500 3.3	 mW mW/°C mW mW/°C
Operating Temperature Range	T_A	−55 to +125	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

TYPE	V^+ (Vdc)	V^- (Vdc)	V_{io} (mV)	A_{VOL} (V/V)	V_{OH} (Vdc)	V_{OL} (Vdc)	t_R (ns)	CMV_{in} (Vpk)	TCV_{io} (μV/°C)
MC1710	+12	−6.0	1.0	1700	3.2	−0.5	40	±6.0	3.0
MC1710C	+12	−6.0	1.5	1500	3.2	−0.5	40	±6.0	5.0

Fig. 12. Sense Amplifier and Differential Comparator
Courtesy, Motorola, Inc., Semiconductor Products Division

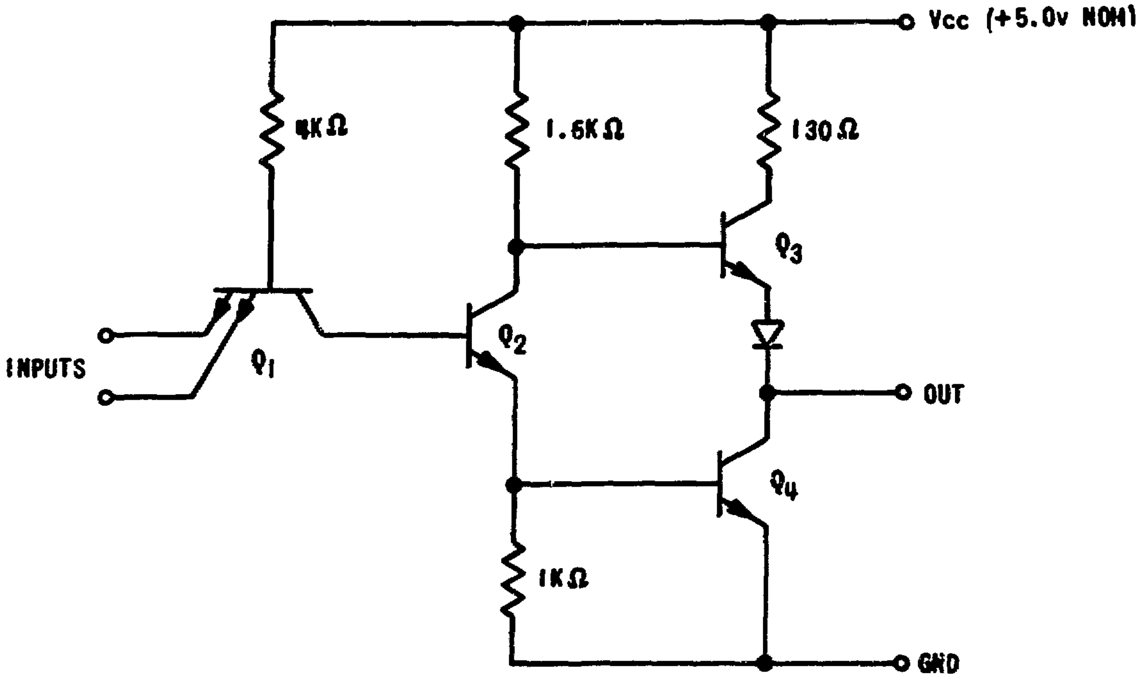
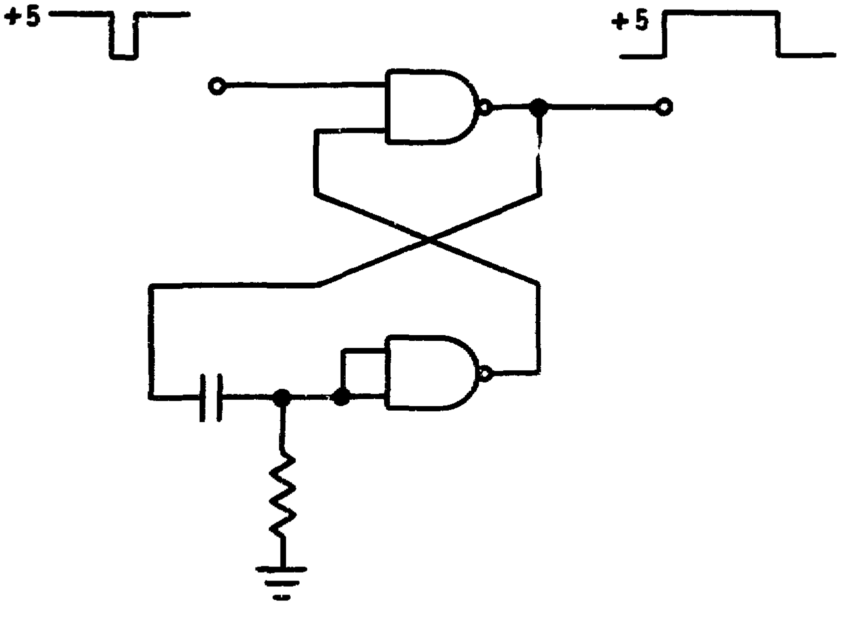


Fig. 13. Gate Schematic: SN7400N-T1



TRUTH TABLE - NAND

A	B	O
F	F	T
F	T	T
T	F	T
T	T	F

Fig. 14. TTL Monostable: Schematic and Truth Table

APPENDIX B

Charts of Time-response Test

CHART NO. 1

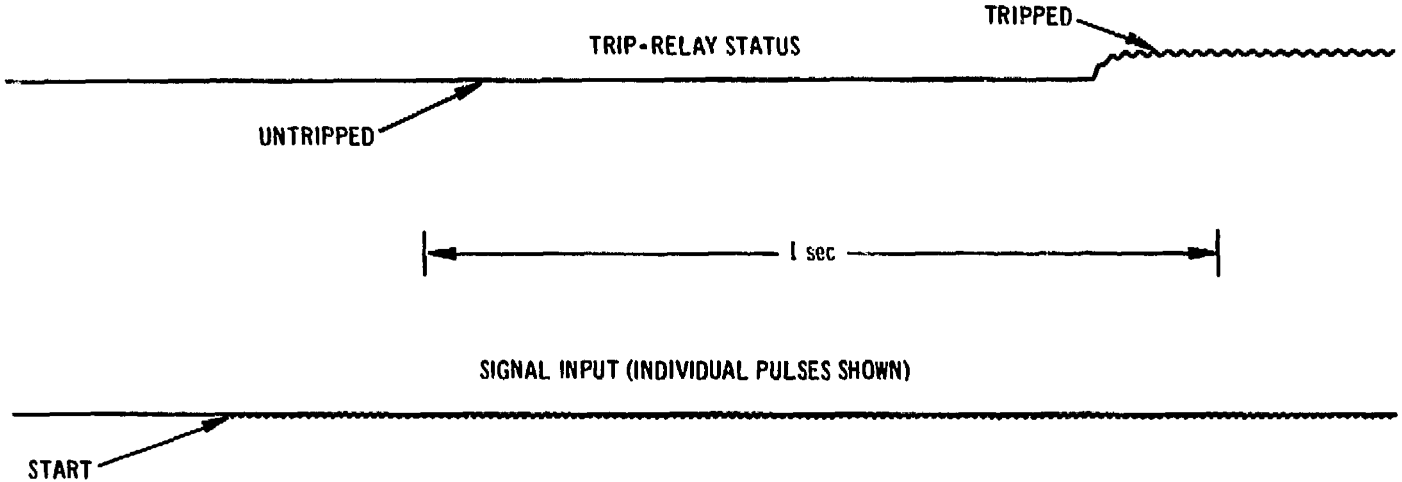
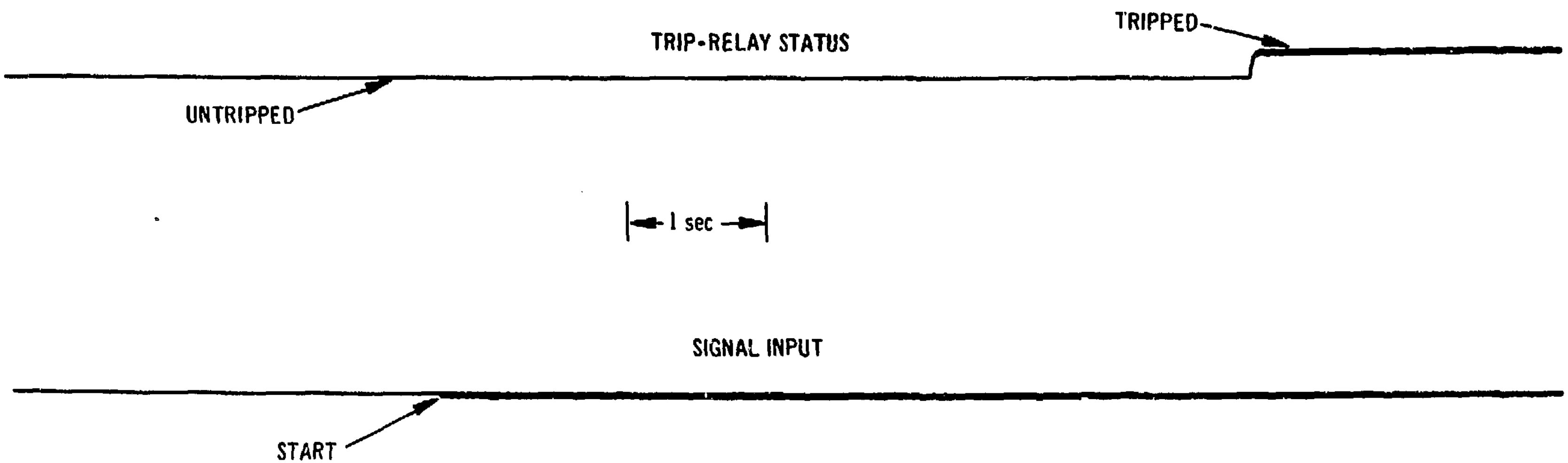


CHART NO. 2



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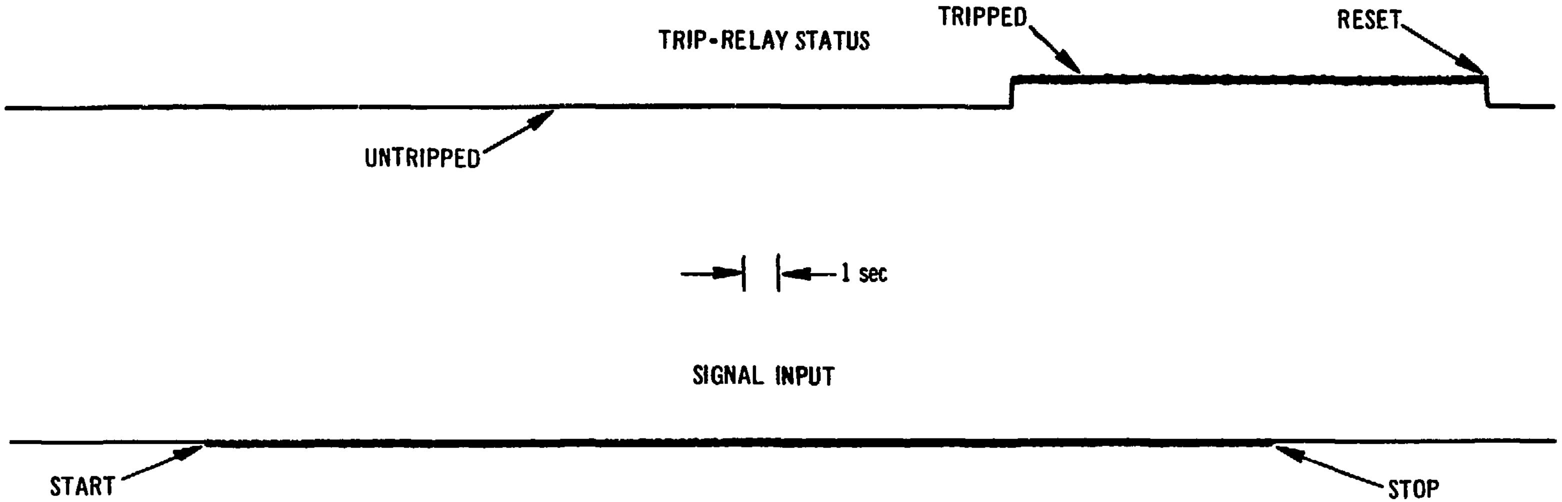

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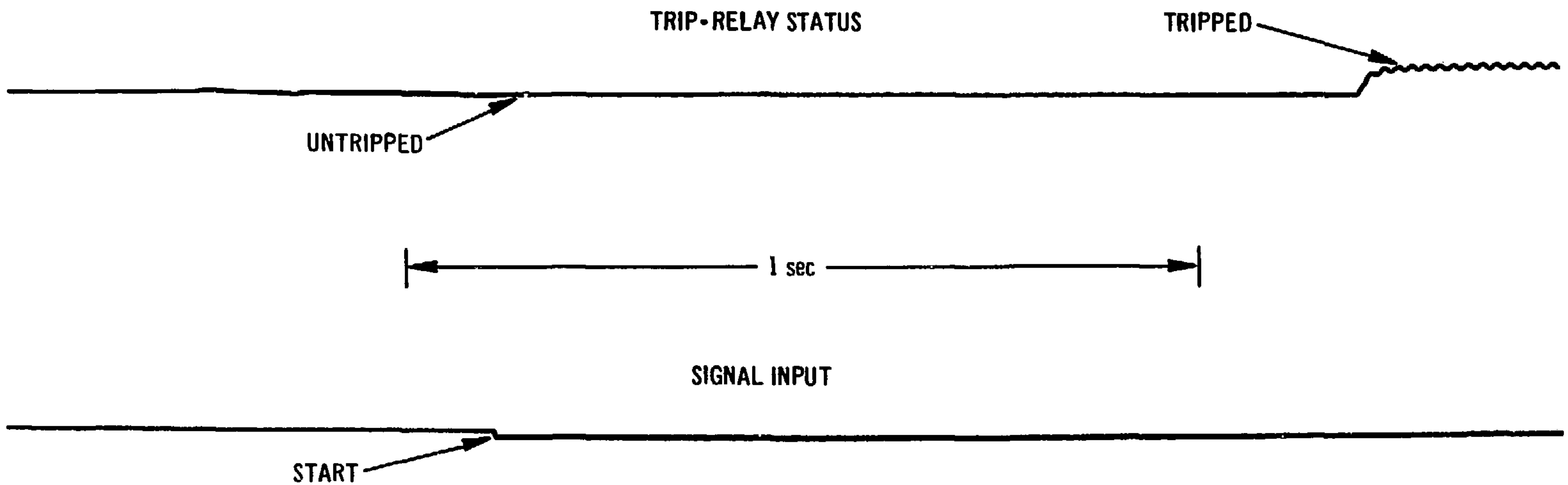
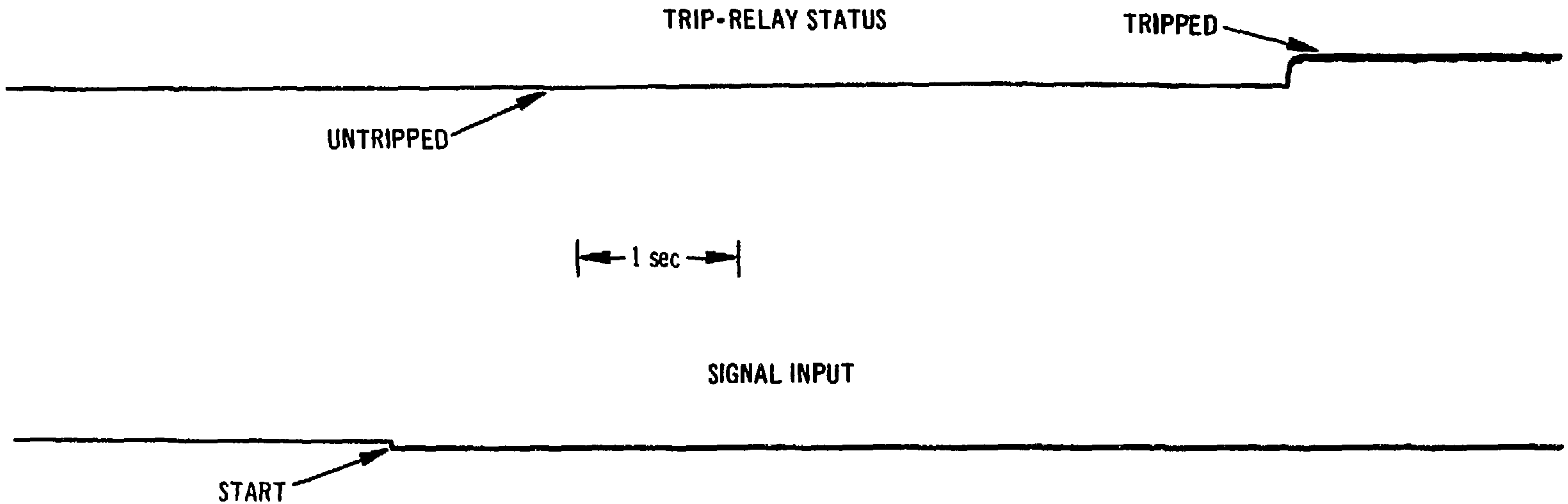


CHART NO. 5



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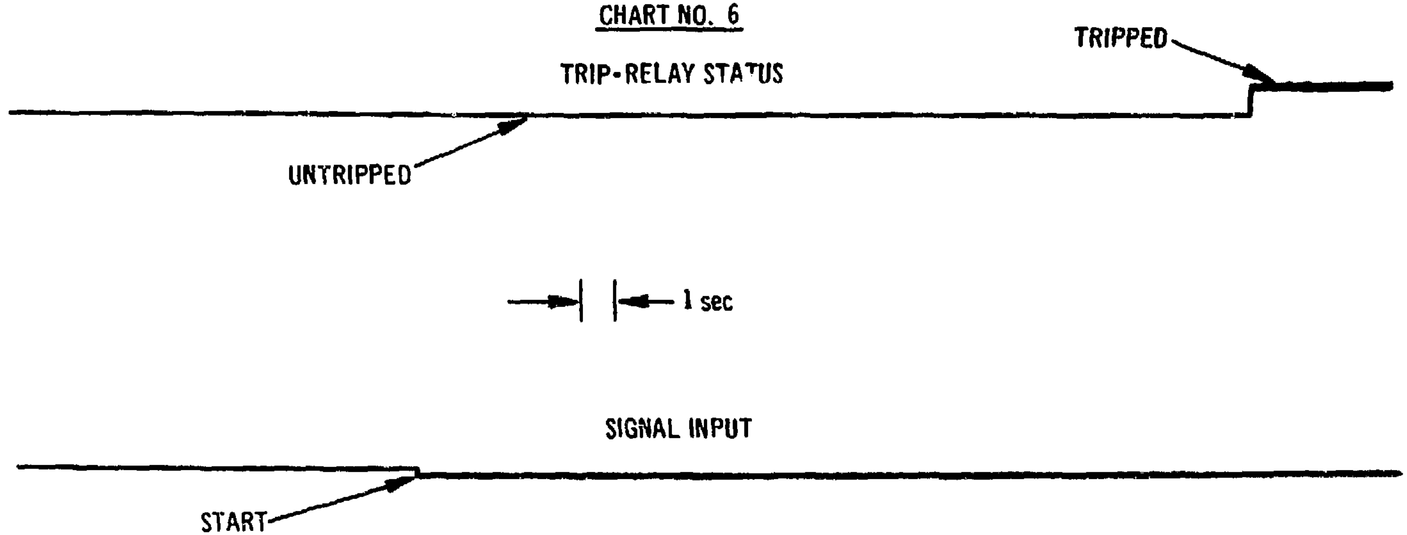

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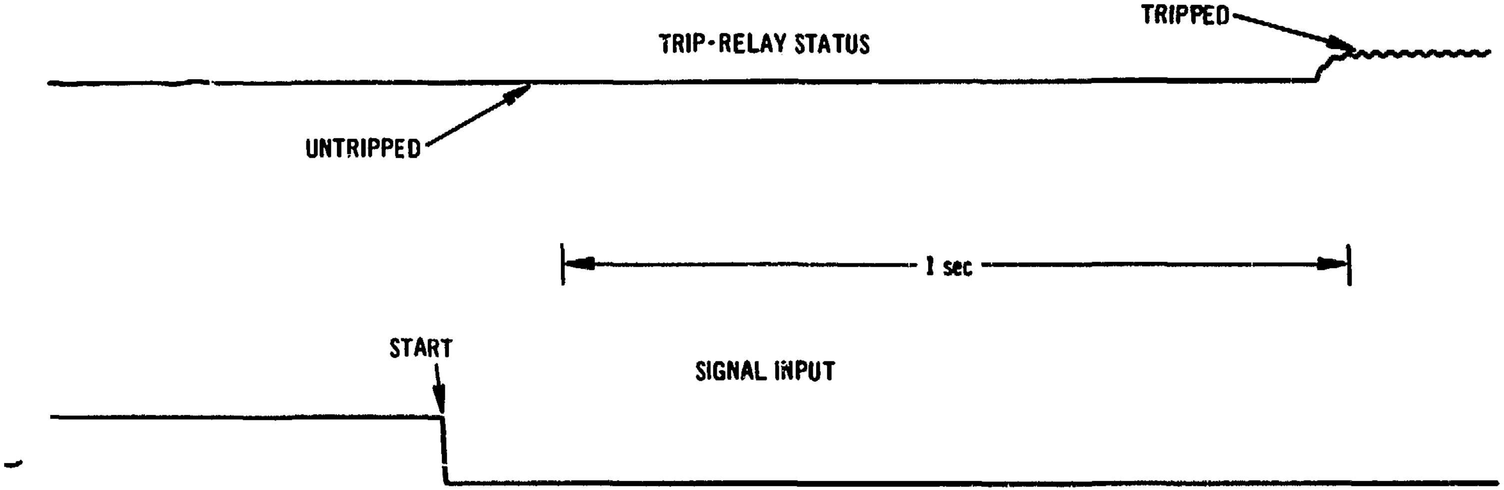

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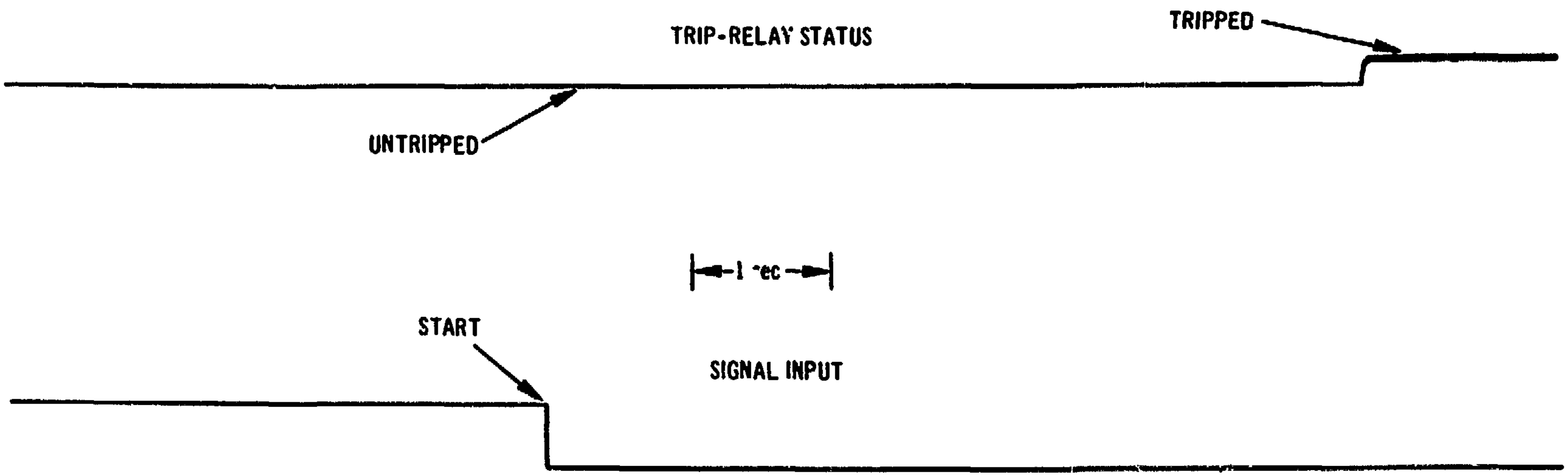

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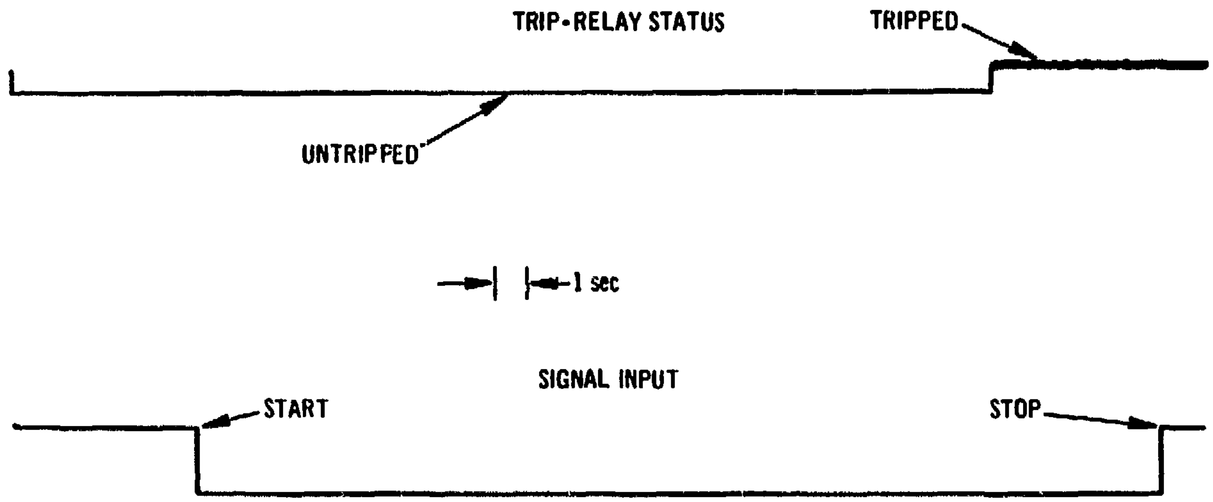
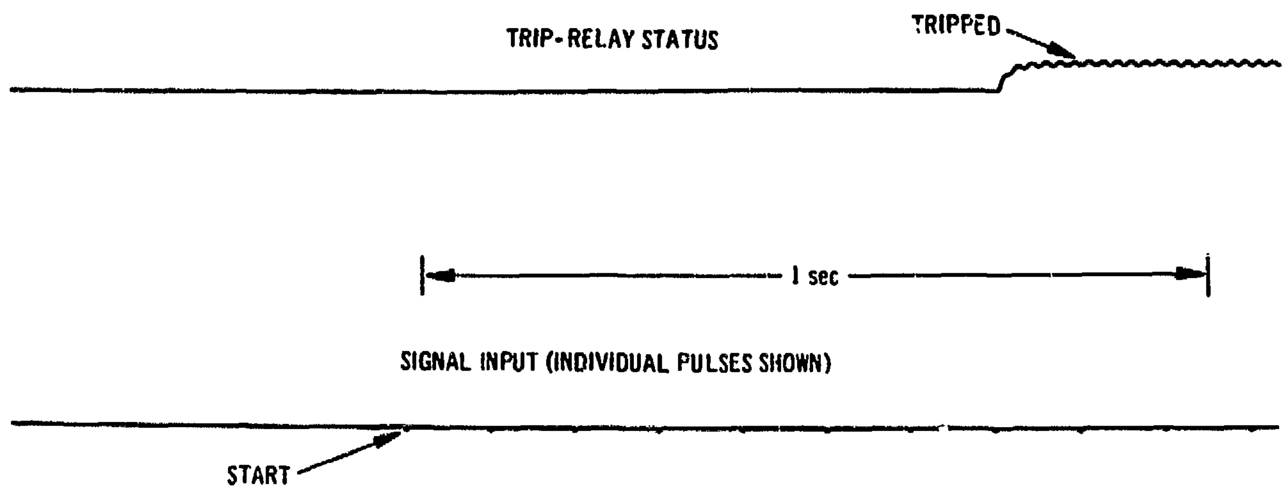


CHART NO. 10



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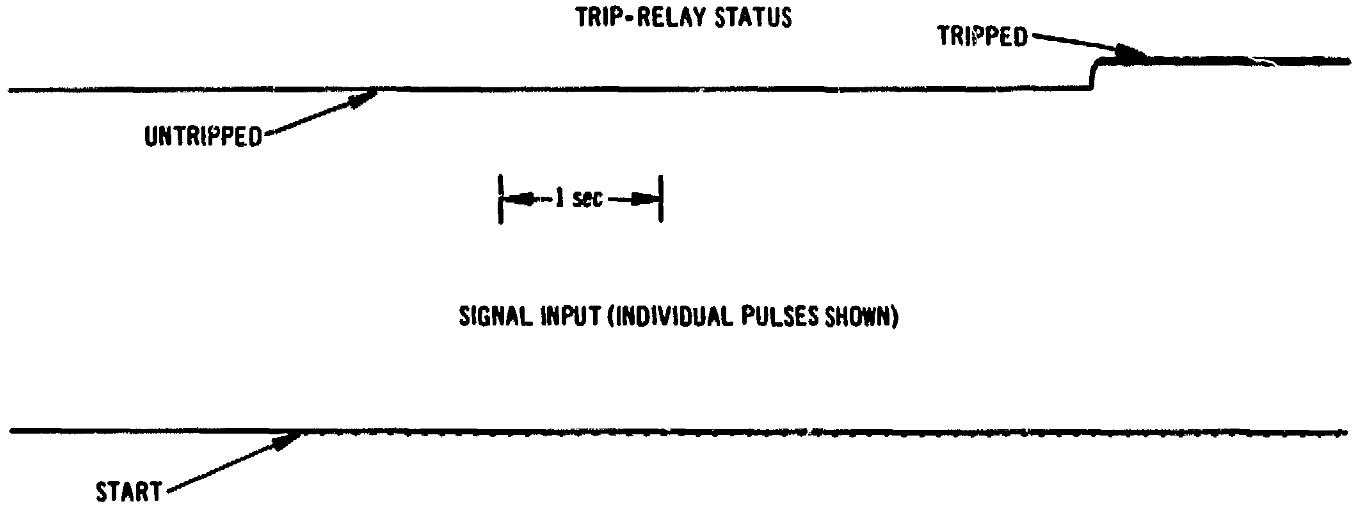

CHART NO. 12