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NUCLEAR INSTRUMENT MODULE MAINTENANCE MANUAL

PART 36

LOG CURRENT AND PERIOD AMPLIFIER, ORNL MODEL Q-2636

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ABSTRACT

The circuit, application, maintenance procedures, and acceptance tests for a Log Current and Period Amplifier are described. This instrument accepts a positive input current from a gamma-compensated ionization chamber and produces a voltage output that is proportional to the logarithm of the input current. In addition, the logarithmic signal is differentiated and amplified, producing another output that is proportional to the reciprocal of reactor period. The useful input current range is 10^{-12} to 3×10^{-8} amp. The zero to +10 v output is expressed in percent power over 6.5 decades from 10^{-4} to 300%.

The amplifier is packaged in a standard "four-unit" plug-in module of the ORNL Modular Reactor Instrumentation Series.

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1. DESCRIPTION

1.1 General

The Log Current and Period Amplifier accepts a positive input current from a gamma-compensated ionization chamber and produces a voltage output that is proportional to the logarithm of the input current. In addition, the logarithmic signal is differentiated and amplified, producing another output that is proportional to the reciprocal of the reactor period. The useful input current range is 10^{-12} to 3×10^{-5} amp. The zero to +10 v output is expressed in percent power over 6.5 decades from 10^{-4} to 300%. The lowest decade of current sensitivity is not normally displayed; however, the period information in this range is useful even though the output level indication is not on scale. The period output signal is actually the reciprocal of reactor period, but the panel meter is calibrated to indicate period directly on a reciprocal scale from -30 sec through infinity to +5 sec. The period output voltage signal is accurate to a positive period of about 0.6 sec before saturation is reached, making it useful for safety or control action in this range.

1.2 Construction

The Log Current and Period Amplifier is constructed in a single module 5.66 in. wide, 4.72 in. high, and 11.90 in. deep. It is a standard "four-unit" plug-in module of the Modular Reactor Instrumentation Series depicted on drawings Q-2600-1 through Q-2600-6.

The circuit is constructed on two printed circuit boards. One board containing a sensitive, low-level circuit is enclosed in a metal shield with a removable cover. The other board is unshielded. The front panel contains two meters that display percent power and reactor period, a calibrate-operate switch, and calibration adjustment screws.

1.3 Application

The Log Current and Period Amplifier, sometimes called "Log N" for neutron level, is normally used to monitor reactor power from intermediate levels through full power. Output signals proportional to reactor power and period may be used for safety and control functions. The amplifier is usually used in conjunction with a neutron-sensitive, gamma-compensated ionization chamber, but it may also be used with other detectors of suitable current range.

1.4 Specifications

1.4.1 Period

1. Output voltage range: 0 to -10 v for periods of approx. -30 sec to +0.6 sec.

2. Calibration

$$-V_{out} = 0.22 + \frac{6.70}{\text{period(sec)}} : \quad 0 \text{ v} = -30 \text{ sec}; \ -0.22 \text{ v} = \infty; \ -1.56 \text{ v} = 5 \text{ sec}; \ -6.92 \text{ v} = 1 \text{ sec}.$$

3. Meter scale: -30 through ∞ to + 5 sec.

4. Zero drift: Less than 20 mv/month.

1.4.2 Log Current

1. Output voltage

$$V_{out} = 1.543(\log_{10} I_{in} + 11): \quad 1.543 \text{ v/decade}; \ 0 \text{ v} = 10^{-11} \text{ amp}; \ 10 \text{ v} = 3 \times 10^{-5} \text{ amp}.$$

2. Scale: 10^{-4} to 300%.

3. Zero drift: less than 50 mv/month after warmup.

4. Input leakage current: less than 10^{-13} amp at 25°C.

1.4.3 General

1. Power required: ±15 v dc with regulation of ±0.1%.

2. Ambient temperature range: 0 to 55°C.

1.5 Applicable Drawings

The following list gives the drawing numbers (ORNL Instrumentation and Controls Division drawing numbers) and subtitles for the Log Current and Period Amplifier:

1. Q-2636-1 Circuit.
2. Q-2636-2 Details.
3. Q-2636-3 Metalphoto Panel.
4. Q-2636-4 Printed Circuit Boards.

5. Q-2636-5 Assembly.

6. Q-2636-6 Parts List.

7. Q-2636-7 Meter Faces.

The following list gives the drawing numbers and subtitles for the Plug-In Chassis System:

1. Q-2600-1 Assembly.

2. Q-2600-2 Details.

3. Q-2600-3 Details.

4. Q-2600-4 Details.

5. Q-2600-5 Details.

6. Q-2600-6 Details.

2. THEORY OF OPERATION

2.1 General

The Log Current and Period Amplifier consists of three basic stages. The input stage has very high input impedance and low leakage so that essentially all of the input current flows in the feedback element which is a thermionic diode. The diode, a specially selected type, is operated with reduced heater power so that cathode current is emission limited. When the diode is operated in this fashion, the anode-to-cathode voltage drop is proportional to the logarithm of anode current, which is the same as the input signal current. The input stage is an operational configuration with 100% feedback through the thermionic diode so that the stage output voltage is equal in magnitude and opposite in polarity to the diode voltage drop. The diode logarithimic characteristic produces about 170 mv/decade over the current range of 10^{-12} to 5×10^{-5} amp.

The output of the first stage is fed to a second stage which uses a conventional operational amplifier to further amplify and shift the level of the signal to produce an output of C to 10.0 v for the current range of 10^{-11} to 3×10^{-5} amp, or about 1.54 v/decade. The exact output relation is greater by $V_{out} = 1.543(\log_{10} I_{in} + 11)$.

The third stage is also an operational amplifier which is connected as a differentiator to take the derivative of the logarithimic signal and produce a signal proportional to the inverse of reactor period.

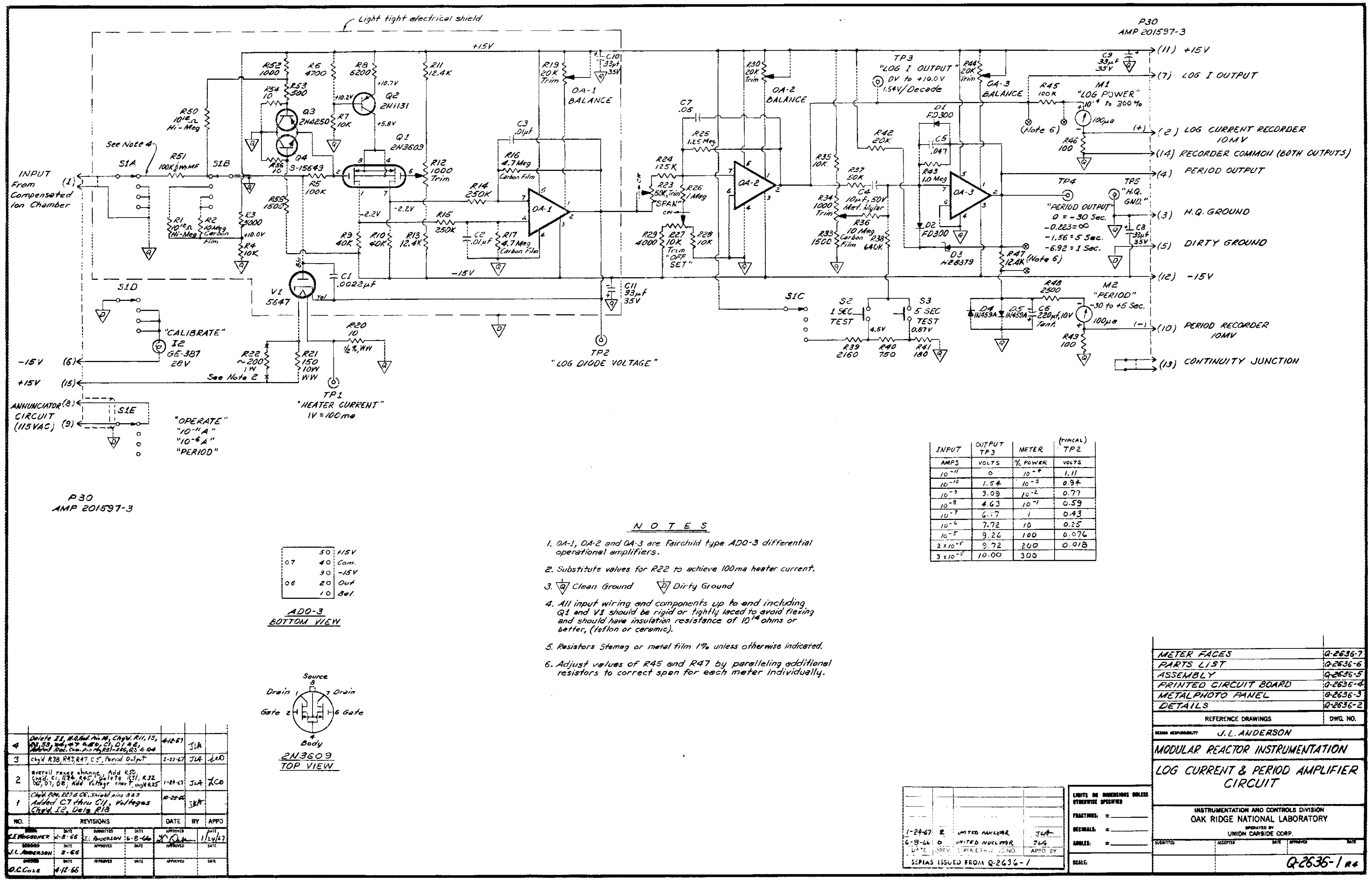
2.2 Circuit Description

The complete circuit diagram of the module is shown in Fig. 1. The input stage consists of logarithmic diode V1, transistors Q1 and Q2, and an operational amplifier OA-1. Transistors Q3 and Q4 form a protection circuit to prevent damage to Q1 during extreme transients. In the "Operate" position of the Calibrate-Operate switch S1, the input current from an ionization chamber flows through V1 to the output of amplifier OA-1, developing a voltage across V1 which is proportional to the logarithm of the input current. Voltage at the anode of V1 with respect to ground is amplified by Q1 which is a dual, insulated-gate, field-effect transistor connected as a differential amplifier. This type of transistor has a typical gate leakage current of less than 10^{-14} amp so that, even with signal currents as low as 10^{-12} amp, the error due to leakage is negligible. Transistor Q2 supplies a constant source current to Q1 for high gain and stable operation. The output of Q1 appears as a differential voltage between its drains and is further amplified by a differential operational amplifier OA-1. The output of OA-1 is connected to the cathode of V1, completing the loop. The overall loop gain of Q1 and OA-1 is about 3000. Since all of the output is fed back through V1, the high loop-gain will cause the output voltage to adjust itself until the input (anode voltage of V1) is nearly zero and the output voltage is consequently equal in magnitude to the voltage drop across V1.

The low impedance output of OA-1 drives the second stage OA-2, which provides voltage gain and level changing to produce the desired output of 0 to +10.0 v for input currents from the chamber of 10^{-11} to 3×10^{-5} amp. The characteristics of the logarithmic diode V1 vary somewhat from tube to tube and also change slowly with age. To adjust for these changes a span control R23 and an off-set control R27 are provided on the front panel. Calibration currents of 10^{-11} and 10^{-6} amp can be selected with the front-panel switch S1. The input signal lead is grounded when a calibration position is selected.

There are two significant time-constants that control the transient response of the logarithmic amplifier. Capacitor C1 across the dynamic impedance of V1 supplies an integrating, or smoothing, time-constant which varies with current level. At low currents, where the statistical fluctuations of the signal current are high, the time constant is long and the smoothing is very effective. As the signal current increases, the fluctuations decrease; but the dynamic impedance of V1 decreases at a faster rate, thereby reducing the smoothing effectiveness which results in a net increase in fluctuations at the output of OA-1. To offset this effect, a second smoothing network consisting of C7 and R25 is included at OA-2. This fixed, first-order lag has a significant effect only at high signal currents. The transient response to short periods is affected by both time constants C1-V1 and C7-R25. The values selected are compromises between adequate smoothing and satisfactory speed of response to short periods.

If the signal current should reverse or if small circuit-leakage currents are opposite to the normal signal current, V1 may become



INPUT	OUTPUT TP3	METER	(TYPICAL) TP2
AMPS	VOLTS	% POWER	VOLTS
10^{-11}	0	10^{-4}	1.11
10^{-10}	1.54	10^{-3}	0.94
10^{-9}	3.09	10^{-2}	0.77
10^{-8}	4.63	10^{-1}	0.59
10^{-7}	6.17	1	0.43
10^{-6}	7.72	10	0.25
10^{-5}	9.26	100	0.076
2×10^{-5}	9.72	200	0.018
3×10^{-5}	10.00	300	

Fig. 1. Log Current and Period Amplifier Circuit, ORNL Model Q-2636.

reverse biased and nonconducting. This effectively opens the feedback loop and allows C1 to charge up to the saturation voltage of OA-1, thus paralyzing the circuit. To prevent this a small positive bias current (5×10^{-12} amp) is inserted through R50.

The output of OA-2, which is a voltage proportional to the logarithm of the input current, is differentiated by OA-3 and its associated network. Capacitor C4 and resistor R43 form the principal network. R37 limits the maximum gain of the circuit, and C5 provides smoothing to prevent unnecessary response to noise. Diode D1 limits the response to short negative periods, and D2 and D3 prevent overdriving the amplifier with short positive periods to allow fast recovery. Two test signals equivalent to 1 sec and 5 sec periods can be injected with pushbuttons S2 or S3 when the "Period" position is selected on the front-panel calibration switch S1. These tests are intended for checking the response of external circuits driven by the period signal.

The Log Current and Period Amplifier is commonly used with ionization chambers that require polarizing voltages of 300 v or more. During reactor excursions that greatly exceed the normal full scale of the instrument, the transient input voltage may exceed the rating for Q1 and destroy it. Similar damage could occur if the instrument were plugged in when a charge exists on the chamber cables. Transistors Q3 and Q4 guard against such damage by limiting the maximum voltage at the input gate of Q1 to about ±0.7 v. The transistors are connected in a reverse-biased, inverted, complementary configuration so that their leakage currents will be small and nearly equal. This results in very small net leakage from the emitters of Q3 and Q4 to the gate of Q1—typically less than 10^{-12} amp. When the input voltage begins to rise, one or the other of the transistors will become forward biased and limit the voltage to the P-N junction voltage of approximately 0.7 v. Current is limited by series resistor R5.

3. OPERATING INSTRUCTIONS

3.1 Installation

The Log Current and Period Amplifier is a module in the ORNL Modular Reactor Instrumentation Series. Like the other modules of the series, it has standard connectors and dimensions and has a pin- and hole-code on the rear plate so that the module will not be inserted in a wrong location in a drawer. The module is installed by placing it in its proper location, inserting the module firmly, and tightening the thumb screw. The module may be plugged in with power on without damage provided the front panel switch S1 is not in the "Operate" position.

3.2 Operating Controls

3.2.1 Percent Power Panel Meter

The front-panel power meter M1 is calibrated in percent power from 10^{-4} to 300%. This corresponds to an input current of 10^{-11} to 3×10^{-5} amp and an output voltage at pin 7 and test point 3 of 0 to +10.0 v, or 1.543 v/decade logarithmic.

3.2.2 Period Panel Meter

The period panel meter M2 is calibrated to indicate reactor period from -30 to +4 sec. This corresponds to a voltage output at pin 4 and test point 4 of 0 to -1.52 v. Infinite period is electrically offset to -0.22 v. The voltage output has a greater range than the panel meter and will respond accurately to periods of about 0.6 sec before saturation is reached. The equation for the period output voltage calibration curve is

$$- V_{out} = 0.22 + \frac{6.70}{\text{period (sec)}} .$$

3.2.3 Calibration Controls

Calibration can be accomplished with the built-in test signals and front-panel controls provided. Calibration switch S1 has four positions. In the "Operate" position the input signal is connected to the amplifier for normal operation. With S1 in the "10^{-11}A" position, the input signal is grounded and a steady current of 10^{-11} amp is applied to the input. The power meter M1 should indicate 10^{-4}%. With S1 in the "10^{-6}A" position, a current of 10^{-6} amp is applied to the input and the power meter M1 should indicate 10%. Calibration adjustments R23 and R27, labeled "Span" and "Offset" respectively, are adjusted to accomplish these conditions. With S1 in the "Period" position, a steady current of 10^{-6} amp is also applied and a period test circuit is enabled. The period tests are actuated by pushbuttons S2 and S3 located on the top of the module. These tests inject the equivalent of 1- and 5-sec periods respectively. The calibration of the period circuits is fixed, and these tests are intended to test trip circuits actuated by the period output signal rather than the period circuit itself.

3.2.4 Zero Adjustments

There are five trimming, or zero, adjustments: R12, R19, R30, R34, and R44. These are located on the printed circuit boards and require adjustment only if the transistors or operational amplifiers are replaced.

3.2.5 Test Points

Five test points are located so as to be accessible from the top of the module. These are normally used only for maintenance checks or recalibration after component replacement. The points are:

TP1	heater current of V1	1 v = 100 ma.
TP2	log diode voltage	see Fig. 1.
TP3	log current output	see Fig. 1.
TP4	period output	$-V_{out} = 0.22 + \frac{6.70}{\text{period(sec)}}$.
TP5	HQ ground.	

3.3 Connections

All connections are made through the rear connector P30 when the module is inserted.

3.4 Operating Procedures

Except for occasional recalibration to correct for drift of the log diode characteristics, no special operating procedures are required. The instrument may be switched to the operate position and left there for all normal reactor operations.

3.4.1 Ionization Chamber

The Log Current and Period Amplifier is normally used with a gamma-compensated ionization chamber to supply its input signal current. The type of chamber, required polarizing voltages, and method of compensation adjustment will vary widely with installation. It is important for satisfactory performance of the log current amplifier that the chamber not be overcompensated where the polarity of the signal current might reverse.

3.4.2 Current Calibration

After power is applied to the circuit, approximately 1 hour is required for the logarithmic diode to reach temperature equilibrium. The calibration procedure is as follows:

1. Turn the calibrate switch S1 to the "10^{-6} A" position and adjust the "Offset" control R27 until the percent power meter M1 indicates 10% or until the voltage at TP3 is 7.72 v.

2. Turn S1 to the "10^{-11}A" position and wait 15 sec or more until the period meter M2 has returned to exactly "∞." If M1 indicates more than 10^{-4}% (10^{-4}% corresponds to 0 v at TP3), adjust the "Span" control R23 counterclockwise one or two turns or until M2 indicates 10^{-4}%. If M2 indicates less than 10^{-4}%, adjust the "Span" control clockwise. The two controls interact, and the "10^{-6}A" calibration point will now be shifted.

3. Turn S1 to the "10^{-6}A" position and repeat step 1.

4. Repeat step 2, making a smaller adjustment of the "Span" control.

5. It might be necessary to repeat steps 1 through 4 several times to achieve precise calibration. After an initial calibration it will usually be found that subsequent drift can be corrected by adjustment of the "Offset" control alone.

3.4.3 Period Calibration

The procedure for period calibration is as follows:

1. Switch the calibrate switch S1 to the "Period" position. On the top of the module, press the "5 sec" pushbutton S3. Period meter M2 should indicate 5 sec, and the voltage at TP4 should be -1.56 v.

2. Release S3 and press the "1 sec" pushbutton S2. M2 should now indicate off scale, and the voltage at TP4 should be -6.92 v.

These tests are intended primarily to test circuits external to the module such as trip comparators. No adjustments are necessary.

3.4.4 Zero Adjustments

Five trimming controls are provided on the circuit boards for initial amplifier adjustments. These controls should require adjustment only after component replacement. The adjustment procedure is described in Sect. 4, Maintenance Instructions.

3.5 Precautions

When the calibration switch S1 is turned to "Calibrate" positions, short periods will be indicated by the panel meter M2 and by the voltage output. There are no internal provisions for inhibiting these short period signals during calibration, and calibration should not be attempted during reactor operation unless these signals can be tolerated.

A contact is provided through pins 8 and 9 of the rear connector to annunciate when S1 is in any position other than "Operate."

4. MAINTENANCE INSTRUCTIONS

4.1 General

This module is designed to operate continuously with a minimum of maintenance and adjustment. Zero adjustments and voltage test points are accessible from the top when the module is inserted in its drawer. Should a failure occur, any part listed in the parts list, ORNL drawing Q-2636-6, may be replaced.

4.2 Periodic Maintenance

Except for calibration as described in Sect. 3.4, Operating Procedures, no regular maintenance is required.

4.3 Alignment

Several adjustments are provided to permit compensation for normal manufacturing variations in components. These adjustments need be made only at initial acceptance or when components are replaced.

4.3.1 Instruments Required

The following instruments are required:

1. Power supplies for normal operation: ±15 v ±0.1% regulated at approximately 200 ma.

2. A multirange dc voltmeter with 0.1% or better accuracy, 50 mv full scale to 50 v full scale.

3. A current source adjustable from 10^{-11} to 3 x 10^{-5} amp with an accuracy of ±2% above 10^{-10} amp and ±5% below 10^{-10} amp. Since the input terminal voltage of the amplifier is always near zero, a voltage source adjustable from 1 to 10 v and suitable series multiplier resistors may be used.

4.3.2 Alignment Procedure

The alignment procedure is as follows:

1. Energize the amplifier in a location such that all adjustments are accessible. Ensure that the power supply voltages are ±15 v ± 15 mv. Turn the calibration switch S1 to the "10^{-11}A" position and let the instrument warm up for at least 15 min for the circuit to reach temperature equilibrium.

2. Remove the inside shield cover, and with clip leads, connect pin 1 and pin 7 of Q1 to HQ ground. Adjust trimmer R19, the OA-1 balance, until the voltage from TP-2, "Log Diode Voltage," to HQ ground is 0 v ± 5 mv. Remove the clip leads.

3. With a clip lead, short circuit capacitor C1. Adjust trimmer R12 (labeled "zero") until the voltage at TP2 is 0 v ± 5 mv. Remove the clip leads and replace the inside shield cover.

4. With a clip lead, short circuit the junction of R23 and R24 to HQ ground. With another clip lead, short circuit the junction of R26 and the wiper of R27 to HQ ground. Adjust trimmer R3, the OA-2 balance, until the voltage from TP3, "Log I Output," to HQ ground is 0 v ± 5 mv. Remove the clip leads.

5. With a clip lead, short circuit TP3, "Log I Output," to HQ ground. With another clip lead, short circuit the junction of R36 and R34 to HQ ground. With a third clip lead, short circuit the junction of R38 and S2, S3 to HQ ground. Adjust trimmer R44, the OA-3 balance, until the voltage from TP4, "Period Output," to HQ ground is 0 v ± 5 mv. Remove the clip leads.

6. Switch S1 to the "10^{-6} A" position and adjust trimmer R34 until "Period Output" at TP4 is -0.223 ± 0.010 v. Check that the panel meter indicates "∞."

7. Connect the voltmeter from TP1, "Heater Current," to HQ ground. The voltage should be between 1.12 and 1.18 v. If necessary, substitute other values for R22 until the voltage falls within this range.

8. Wait about 0.5 hour after the last adjustment of V1 heater current, and then calibrate as described in Sect. 3.4.2, "Current Calibration."

9. Connect the current source to the input, and measure the output at TP3 for input currents from 10^{-11} to 3×10^{-5} amp and compare them with the values listed in Table 1. The measured values should agree with the tabulated values within ±5%.

Table 1. Test Point Values for Input Currents From 10^{-11} to 3×10^{-5} Amp

Input Current (amp)	Voltage at TP3 (v)	Meter Reading (%)	Typical Voltage at TP2 (v)
10^{-11}	0	10^{-4}	1.11
10^{-10}	1.54	10^{-3}	0.94
10^{-9}	3.09	10^{-2}	0.77
10^{-8}	4.63	10^{-1}	0.59

Table 1 (continued).

10^{-7}	6.17	1	0.43
10^{-6}	7.72	10	0.25
10^{-5}	9.26	100	0.076
2×10^{-5}	9.72	200	0.018
3×10^{-5}	10.00	300	-

10. Disconnect the current source and measure the voltage at TP3. The voltage should be between -0.5 and -2.0 v. Allow several minutes for the voltage to reach steady state.

11. If the measurements of steps 9 and 10 are not within specification, it may be necessary to increase or decrease V1 heater current by 5 or 10%. If the specification still cannot be met, replace V1 and repeat the alignment procedure beginning at step 6.

4.4 Trouble Shooting

The transistors in the module are plugged into sockets and are easily replaced. However, great care should be exercised when Q1 is replaced, since the body charge of a person handling the transistor may be sufficient to damage it. This can be avoided by grounding the body to the module while handling Q1. Special care should be used when working near the log diode V1 and Q1 to avoid smearing rosin, fingerprints, or other contaminants on these high-impedance, low-leakage circuits. Soldering should be done carefully to avoid damage to the printed circuit boards and components.

5. PARTS LIST

A description and an ORNL Stores number for all component parts are given in ORNL drawing Q-2636-6.

6. ACCEPTANCE TEST PROCEDURE

The acceptance test procedure is as follows:

1. Make a visual inspection of the module to make sure that the circuit is correct and that all connections are satisfactory.

2. Complete the Alignment Procedure, Section 4.3, and Current and Period Calibration, Sections 3.4.2 and 3.4.3. If the "Span" and "Offset"

controls have insufficient adjustment range, it may be necessary to replace V1.

3. After satisfactory completion of alignment and calibration procedures, check for proper operation of the overcurrent protection circuit by applying +300 v dc to the input terminal for a few seconds. While the voltage is applied, the log current meter should peg upscale and remain until the voltage is removed. Immediately after removal of the voltage, recheck calibration. The calibration may be shifted slightly because of the shock to the log diode, but should be within ±20% of a decade. After about 5 min again recheck the calibration. The circuit should now have recovered to within ±5% of a decade of the original calibration.

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