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NUCLEAR INSTRUMENT MODULE MAINTENANCE MANUAL

PART 15

0.1 hp DC SERVO AMPLIFIER, ORNL MODEL Q-2615

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ABSTRACT

The 0.1 hp DC Servo Amplifier is a dc power amplifier which can supply a maximum of 75 w at voltage and current limits of 25 v and 5 amp respectively. The amplifier was designed to drive a Globe Industries, Inc., type BD dc motor with a 27-v armature. In a typical application this motor is used as the servo motor to position a fission chamber in a wide-range counting-rate channel. The signal input voltage swing required for full output is +10 and -10 v.

The amplifier is packaged in a standard "3-unit" plug-in module of the ORNL modular reactor instrumentation series.

This report describes the circuit, applications, maintenance procedures, and acceptance tests for the servo amplifier.

CONTENTS

1. DESCRIPTION

1.1 General

The 0.1 hp DC Servo Amplifier (ORNL model Q-2615) is a dc power amplifier which can supply a maximum of 75 w power at voltage and current limits of 25 v and 5 amp respectively.

1.2 Construction

The 0.1 hp DC Servo Amplifier is constructed in a module 4.22 in. wide, 4.72 in. high, and 11.9 in. deep. It is a standard "3 unit" plug-in module of the Modular Reactor Instrumentation series depicted on drawings Q-2600-1 through Q-2600-5.

The four output transistors are mounted on separate heat sinks; these are supported by four rods that tie together the front and back plates of the module. The four intermediate transistors of the amplifier are mounted on smaller separate heat sinks; these are clustered on a metal plate that is supported by the four tie rods.

The input transistor and most of the other components of the amplifier are mounted on a printed circuit board near the front panel of the module.

The series limiting resistors for the output transistors are mounted on the rear plate. All decoupling resistors and capacitors are mounted on a metal plate which is supported by the four tie rods and located near the rear of the module. This metal plate also shields the amplifier from the heat dissipated in the limiting resistors.

1.3 Application

The 0.1 hp DC Servo Amplifier was designed to drive a Globe Industries, Inc., type BD dc motor with a 27-v armature. It is capable of driving this motor under all conditions from no load to blocked rotor. In one application the motor is used as the servo motor to position a fission chamber in a wide-range counting-rate channel.

1.4 Specifications

Specifications for the 0.1 hp DC servo Amplifier are:

1. Voltage gain:	3 v/v ± 10% noninverting.
2. Maximum linear output (supply voltage ± 32 v):	±28 v at no load; ±25 v with 12-ohm resistive load; and ±15 v with 3-ohm resistive load.

3.	Nonlinearity (with 12-ohm resistive load:	less than 0.1 v deviation from straight line drawn between maximum positive and negative outputs.
4.	Maximum power output:	75 w.
5.	Output impedance:	30 milliohms.
6.	Input impedance:	4700 ohms for signals not exceeding ±10 v.
7.	Input dc offset (input voltage for zero output):	negative 0.8 v.
8.	Transient response:	rise time (10 to 90%) less than 2 msec for input step.
9.	Zero drift with temperature:	less than 9 mv/°C from 0 to 50°C with output decreasing with temperature rise.
10.	Power supply requirements:	
	Voltage:	positive and negative 32 v ± 4 v.
	Current drain:	5 amp maximum.
11.	Ambient temperature range:	0 to 55°C.

2. THEORY OF OPERATION

2.1 General

The 0.1 hp DC Servo Amplifier is a dc coupled amplifier with feedback around two voltage gain stages and two cascaded emitter followers. The emitter-follower stages are complimentary NPN and PNP pairs to permit the output to swing negative and positive with respect to ground. The last emitter-follower stage is a parallel combination of two transistors to increase its power handling capabilities.

2.2 Circuit Description

Reference is made to the circuit diagram shown in Fig. 1. The input signal is applied to the base of Q1, a PNP silicon transistor. A 1-kilohm resistor R2 in series with the base limits the maximum load that is placed on the input signal in the event of any failure in the Servo amplifier. Diode D2 limits the base-to-emitter voltage on Q1 when large negative input signals are applied under blocked rotor conditions.

Negative feedback is applied to the emitter of Q1 through the resistive network R2 and R8. The feedback ratio is R3/(R3 + R8), which gives a closed-loop voltage gain of approximately 3.

The circuit shown produces a dc offset between input and output. With no input, the voltages will be shown (+2.4 v on the output and 0 v on the input). For the output to be at a zero potential, the base of the input transistor must be at a negative 0.8 v to keep Q1 in a conducting state.

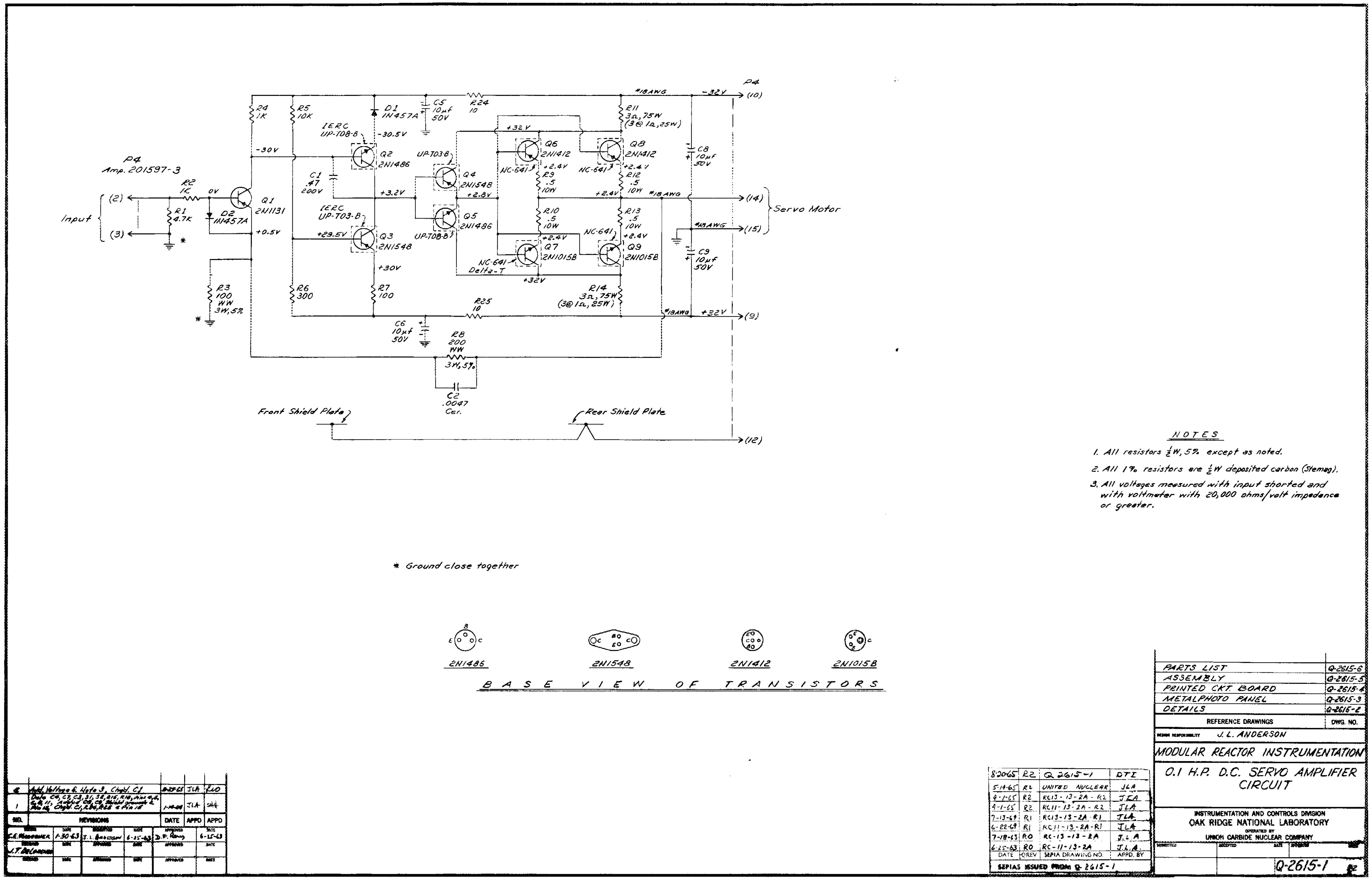

Fig. 1. 0.1 hp DC Servo Amplifier Circuit.

Voltage gain in the loop is obtained from Q1 and Q2. Q3 is a current source which functions as a high-impedance collector load for Q2 while still providing adequate current to drive the emitter-follower stages under all design conditions. When the servo amplifier is driving positive with respect to ground, part of the collector current of Q3 is diverted into the base of Q5. When the servo amplifier is driving negative with respect to ground, all of the Q3 collector current flows through Q2, and Q2 must be capable of handling this current plus the required drive current into the base of Q4.

Transistor Q4 and transistors Q6 and Q8 in parallel function as an emitter-follower chain; they operate when the servo amplifier is driving negative with respect to ground. Transistor Q5 and transistors Q7 and Q9 in parallel operate when the servo amplifier is driving positive with respect to ground. The transistor not operating is held in a back-biased state by the base-to-emitter voltage of its complement.

Diode D1 in the emitter of Q2 permits Q2 to be turned off "hard" when the amplifier is delivering its full positive output. Any small collector current could create a large dissipation in Q2, since Q2 will have in excess of 60 v from collector to emitter.

Capacitor C1, connected from the base to the collector of Q2, along with the collector impedance of Q1 shapes the open-loop response to improve the high-frequency stability. The total capacitance at the collector of Q1 is increased in magnitude by the Miller effect. This results in a smaller value of capacitance for the same shaping of the open-loop response. This internal time constant, coupled with the compensating effect of C2 across R8, stabilizes the amplifier over its entire range of operation with as much as 0.22 μf capacitance in shunt with the output.

The behavior of the amplifier with the step input signal is different with positive and negative input signals. With a negative input step, Q1 and Q2 are immediately driven into a higher conducting state, and the output rise time is exponential in character and is controlled primarily by the value of C2. With a positive step, Q1 and Q2 are both immediately turned off in the absence of a return signal from the feedback network. Thus, the current from Q3 flows into C1, generating a ramp until there is sufficient signal from the feedback network to return Q1 to a conducting state and thereby restore the closed loop. The output waveform under these conditions will have a ramp type leading edge.

Resistors R9 and R12 in the emitter of Q6 and Q8 tend to balance the current contribution of each transistor, even with large differences in transistor parameters such as current gain and transconductance. Resistors R10 and R13 are used for the same purpose with transistors Q7 and Q9.

Resistor R11, which is a series combination of three 1-ohm resistors, protects transistors Q6 and Q8 under severe load conditions. With a blocked rotor condition, the Globe, type BD motor will behave as a 3-ohm load, and the maximum dissipation that is possible in either parallel transistor is about 27 w. This is assuming supply voltages of ±36 v. These potentials are possible when the batteries that normally power this module are fully charged. Resistor R14 provides similar protection for transistors Q7 and Q9.

The collectors of Q4 and Q5 are connected to resistors R11 and R14 respectively. This prevents damage to these transistors under overload conditions.

3. OPERATING INSTRUCTIONS

3.1 Installation

The 0.1 hp Servo Amplifier, ORNL model Q-2615, is a module in the ORNL Modular Reactor Instrumentation 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 or unplugged with power on without damage.

3.2 Operating Controls

There are no operating controls on this module.

3.3 Connections

All connections are made through the rear connector P4 when the module is inserted.

4. MAINTENANCE INSTRUCTIONS

4.1 General

All transistor terminals and most of the circuit components are available at the top of the module and are accessible when the drawer containing the module is pulled out.

Should a failure occur, any part listed in the Replaceable Parts List, Sect. 5, may be replaced.

4.2 Periodic Maintenance

No periodic maintenance is required.

4.3 Calibration Procedure

No calibration procedured are necessary.

4.4 Trouble Shooting

If the module should fail and the cause is not apparent by visual inspection, check the module supply voltages. Both positive and negative 32 v are required. These supply voltages, derived from batteries, can range from 36 to 28 v, depending on the state of their charge. Any slight discoloring of R11 and R13 is normal, since these are high-power resistors and can operate at high dissipation levels for extended periods of time.

If the supply voltages are correct, disconnect the input and output leads and measure the voltages on the various transistors and components. Any instrument with 20,000 ohms/v impedance can be used. The voltages for this module are given on ORNL drawing Q-2615-1 and in Table 2. Note that these voltages apply to battery potentials of positive and negative 32 v.

5. REPLACEABLE PARTS LIST

A description and an ORNL Stores number for replaceable parts are given in Table 1. A complete parts list is given on ORNL drawing Q-2615-6.

Table 1. Replaceable Parts List

Part No.	ORNL Stores No.	Description
C5, C6, C8, C9	06-804-3710	Capacitor, 10 mf, -10 to +100%, 50 v dcw, Sprague No. 40D193A2, with clear insulating sleeve.
C1	06-812-0908	Capacitor, 47 mf, ±10%, 200 v dcw, metalized paper, clear plastic insulating sleeve, Sprague No. 121P47492S4.
C2	06-802-0405	Capacitor, 0.0047 mf, ±20%, 1000 v dcw, ceramic, disc, Sprague No. 29C262.
R11, R14	06-934-0669	Resistor, 1 ohm, ±10%, 25 w, adjustable, ww, Ohmite "Dividohm."
R9, R10, R12, R13		Resistor, 0.5 ohms, ±3%, 10 w, ww, Dale Electronics, type PH-10.
R3	06-993-6230	Resistor, 100 ohms, ±5%, 3 w, ww, axial leads, Ohmite code 7/16-A-54-F.
R8	06-933-6240	Resistor, 200 ohms, ±5%, 3 w, ww, axial leads, Ohmite code 7/16-A-54-F.

Table 1. (continued)

Part No.	ORNL Stores No.	Description
R24, R25		Resistor, 10 ohms, ±5%, 1/2 w, A-B.
R7		Resistor, 100 ohms, ±5%, 1/2 w, A-B.
R6		Resistor, 300 ohms, ±5%, 1/2 w, A-B.
R2, R4		Resistor, 1000 ohms, ±5%, 1/2 w, A-B.
R1		Resistor, 4700 ohms, ±5%, 1/2 w, A-B.
R5		Resistor, 10 kilohms, ±5%, 1/2 w, A-B.
D1, D2	06-995-5820	Diode, silicon, 1N457A, Electrical Industrial Assoc.
Q1	06-996-1710	Transistor, silicon, PNP, Type 2N1131, Texas Instruments.
Q2, Q5		Transistor, silicon, NPN, Type 2N1486, Silicon Transistor Corp.
Q3, Q4		Transistor, germanium, PNP, Type 2N1548, Motorola.
Q7, Q9		Transistor, silicon, NPN, Type 2N1015B, Silicon Transistor Corp.
Q6, Q8	06-996-1983	Transistor, germanium, PNP, Type 2N1412, Motorola.

6. ACCEPTANCE TEST PROCEDURE

6.1 Test Equipment

The following test equipment is required.

1. A multimeter, Triplett Model 630.
2. A vacuum tube, dc voltmeter, with full-scale ranges of 0.1, 0.3, 1.0, 10, 30, and 100 v. The accuracy should be ±1% of full scale on all ranges. The input impedance should be in excess of 10 megohms on all ranges. A Hewlett-Packard model 425A or a Dynamics model 1362 is recommended.
3. An oscilloscope, Tektronix 541 with type L or type CA plug-in. Type L is preferred because of its greater sensitivity.
4. A transistor tester, Tektronix type 575 Transistor-Curve Tracer with type 175 High-Current Adapter.

5. Two unregulated power supplies, +32 v, -32 v, 10 amp.

6. A dc voltage source adjustable from 0 to ±10 v with less than 10 ohms impedance and less than 5 mv rms ripple. A Hewlett-Packard model 721A power supply is recommended.

7. Two wire-wound power resistors, 3 and 12 ohms, ±10%, 100 w.

8. A capacitor, 0.22 mf, ±10%, 50 v.

6.2 General Test Procedures

Prior to any testing, all transistors should be checked for current amplification h_{FE} and collector saturation current I_{CBO}. Because of the high current requirements of all the transistors, with the exception of one, the Tektronix type 575 Transistor-Curve Tracer with the Type 175 High-Current Adapter is required. All transistors that do not fall within the ranges specified in Table 2 should be rejected.

Extreme caution should be employed in checking these transistors with the above equipment. Apply just enough collector-to-emitter voltage to obtain the data required. Careless use of the transistor tester may result in permanent damage to costly transistors.

Table 2. Transistor Test Data

Transistor	V_{CE} (v)	Current Amplification I_C	h_{FE}	V_{CB} (v)	Collector Saturation Current[a] I_{CBO}
2N1412 (PNP)	-2	5.0 amp	25 - 50	-2	<200 μa
2N1548(PNP)	-2	3.0 amp	75 - 150	-80	<2 ma
2N1486(NPN)	+4	0.75 amp	35 - 100	+30	<15 μa
2N1015B(NPN)	+4	2.0 amp	10 - 25	+50	< 1 μa
2N1131(PNP)	-10	5 ma	15[b]	-30	<1 μa

[a] With emitter open.

[b] Minimum.

Connect the +32 v and -32 v supplies to the module. Connector pins 9, 10, and 15 are the +32 v, -32 v, and ground terminals respectively. If the supplies are of the adjustable type, preadjust them to the 32-v value to within 0.25 v before connecting them to the module.

Permit at least a 15-min warmup for the module, power supplies, and test instruments before making any measurements.

6.3 Transistor Voltage Chart

All transistor voltage measurements should be made with the supply voltages adjusted to 32 ± 0.25 v and with the input to the amplifier (pins 2 and 3) shorted. All voltages shown in Table 3 were measured with the VTVM. A Triplett model 630 multimeter can be used with less accuracy.

Table 3. Transistor Voltage Chart

Transistor No.	Emitter (v)	Base (v)	Collector (v)
Q1, 2N1131	+0.5	0	-30.0
Q2, 2N1486	-30.5	-30.0	+3.2
Q3, 2N1546	+30.0	+29.5	+3.2
Q4, 2N1548	+2.8	+3.2	-32.0
Q5, 2N1486	+2.8	+3.2	+32.0
Q6, 2N1412	+2.4	+2.8	-32.0
Q7, 2N1015B	+2.4	+2.8	+32.0
Q8, 2N1412	+2.4	+2.8	-32.0
Q9, 2N1015B	+2.4	+2.8	+32.0

6.4 Amplifier Linearity and Transient Response

Figure 2 shows the equipment for testing the amplifier linearity. The Triplett meter is not needed for these tests; R_L is a 12-ohm, 100-w resistor. Note the use of the power ground of the positive supply (the ground of the negative supply may also be used) as the power ground of the test setup. This is to be maintained throughout all tests.

6.4.1 Linearity

1. Adjust the input voltage from 0 to +10 v and record the input and output voltages at the 0, +0.5, +2.0, +4.0, +6.0, +8.0, and +10.0 v points. Also record the value of the input and output voltages when the amplifier begins to limit.

2. Reverse the input voltage and adjust from 0 to -10 v and record the input and output voltages at the 0, -0.5, -2.0, -4.0, -6.0, -8.0, and -10.0 v points. Also record the value of the input and output voltages where the amplifier begins to limit.

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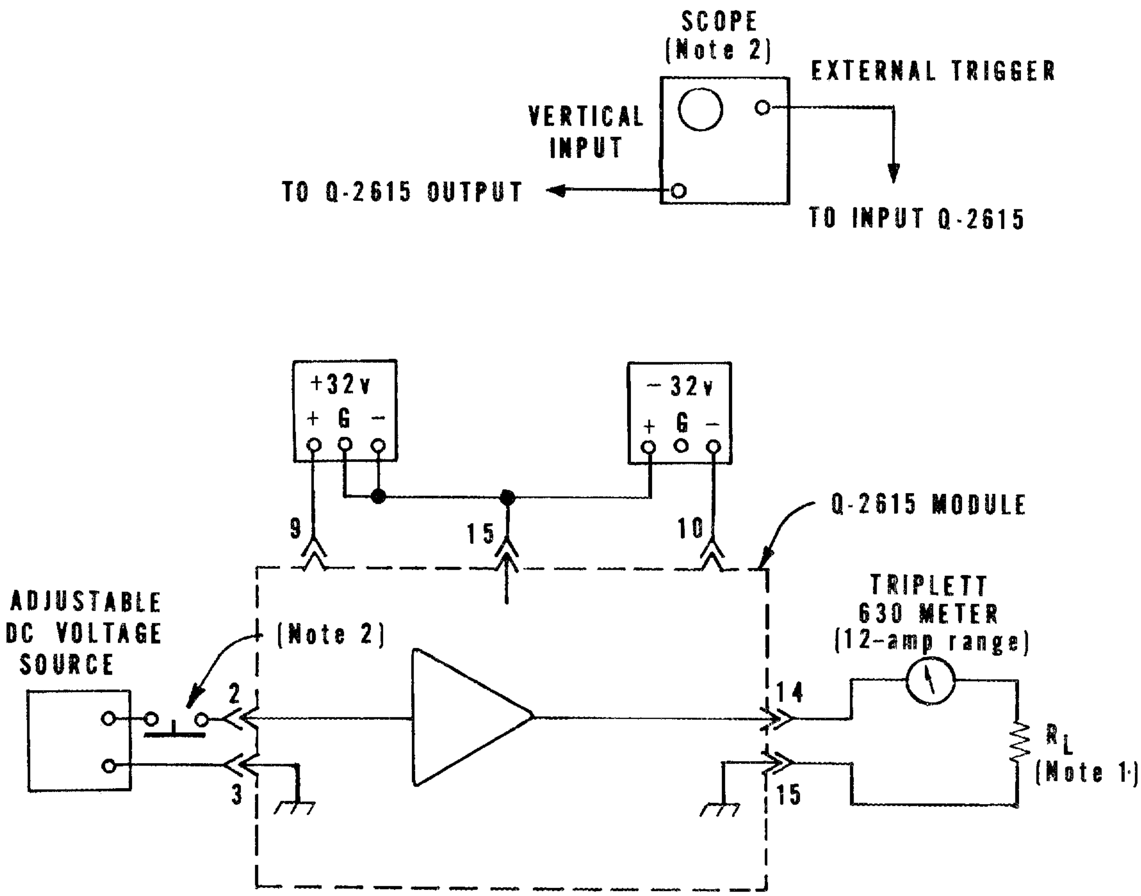

Fig. 2. Equipment for Testing 0.1 hp DC Servo Amplifier, ORNL Model Q-2615.

3. The VTVM should be used for all measurements. Plot the data recorded, and draw a best straight line through the data points. No point between ±25 v should be more than 0.1 v (output) from the line. The line will not pass through the origin.

6.4.2 Transient Response

Adjust the input voltage to approximately +2.0 v. Connect an oscilloscope across the 12-ohm load resistor. Operate the pushbutton switch in series with an adjustable dc voltage source at a rate of about 1 or 2 cps.

The rise times (10% to 90%) of the pulses observed on the oscilloscope should be between 0.5 and 2 msec with negligible overshoot. It may be necessary to externally trigger the scope from the pulses applied to input of the amplifier to obtain a good, clear trace.

The character of the output transient is different for positive and negative input steps: with negative input steps, the transient has an exponential front edge; with positive input steps, the transient has a ramp-type front edge.

6.5 Resistive Loading Effect

The 12-ohm load resistor was replaced with a 3-ohm (100 w) resistor. The equipment for making this test is shown in Figure 2.

1. Monitor the current to the 3-ohm load with the Triplett model 630 multimeter and the voltage across the load with the VTVM. Starting from zero, increase the input voltage slowly until 5 amp is indicated by the Triplett meter. The voltage across the load resistor should be approximately 15 v. Inspect the module for excessive heating or abnormal discoloring of components. Three of the wirewound resistors mounted on the back-plate of the module will become very hot (each resistor will be dissipating about 25 w at this point). Continue to increase the input signal to 10 v. There should be little change in output voltage or current. Return the input voltage to zero.

2. Reverse the input voltage and the Triplett meter polarity. Slowly increase the input voltage until 5 amp is again indicated by the Triplett meter. The voltage across the load resistor should be about 15 v. Inspect the module for excessive heating or abnormal discoloring of components. Three of the wire-wound resistor (not the same three as checked above) mounted on the back-plate of the module will become very hot (each resistor will be dissipating about 25 w at this point.

3. Continue to increase the input signal to 10 v. There should be little change in output voltage or current. Return the input voltage to zero.

6.6 Capacitance Loading Effect

The load resistor is replaced by a 0.22-mf capacitor. The equipment for making this test is shown in Fig. 2. The Triplett meter is not used.

Connect an oscilloscope with at least a 0.05-v/cm sensitivity across the output of the amplifier. Vary the input voltage slowly from 0 to +10 v. Observe if any oscillations are present; there should be none. Vary the input voltage slowly from 0 to -10 volts. Again observe if any oscillations are present; there should be none.

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