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NUCLEAR INSTRUMENT MODULE MAINTENANCE MANUAL

PART 14

PULSE AMPLIFIER AND COUNT RATE METER, ORNL MODEL Q-2614

J. T. DeLorenzo

ABSTRACT

The Pulse Amplifier and Count-Rate Meter amplifies and counts pulses from a fission chamber and preamplifier such as the ORNL Model Q-2617. The module consists of a pulse amplifier, a pulse-height discriminator, a logarithmic counting-rate meter of the Cooke-Yarborough type, a linear counting-rate meter, and two calibration oscillators (10 and 10^4 counts/sec). The unit is intended primarily for reactor control applications and is packaged in a standard "4 unit" plug-in module of the ORNL Modular Reactor Instrumentation Series.

This report describes the circuit, applications, maintenance procedures, and acceptance tests for the Pulse Amplifier and Count Rate Meter.

CONTENTS

1. DESCRIPTION

1.1 General

The Pulse Amplifier and Count-Rate Meter amplifies and counts pulses from a fission chamber. The input sensitivity is such that some preamplification is required. The module consists of a pulse amplifier, a pulse-height discriminator (PHD), a logarithmic count-rate meter of the Cooke-Yarborough type, a linear count-rate meter, and two calibration oscillators (10 and 10^4 counts/sec).

1.2 Construction

The Pulse Amplifier and Count-Rate Meter is constructed in a module 5.6 in. wide, 4.72 in. high, and 11.9 in. deep. It is a standard "4 unit" plug-in module of the Modular Reactor Instrumentation series depicted on drawings Q-2600-1 through Q-2600-5.

The pulse-height discriminator and the linear and log count-rate circuits are constructed on one printed circuit board. The pulse amplifier and the two oscillators are constructed on separate boards. The pulse amplifier and discriminator count-rate boards are housed in a cadmium-plated steel compartment which covers the entire top of the module. The two boards within this compartment are shielded from each other by a cadmium-plated partition. The oscillator printed circuit board is mounted horizontally at the back end of the module beneath the compartment.

The front panel controls include a 10-turn potentiometer for the pulse-height discriminator and an 18-position switch for amplifier gain control (13 positions) and module calibration control. A BNC connector is mounted on the front panel to provide a signal for a scaler.

1.3 Application

The Pulse Amplifier and Count-Rate Meter is one element of a wide-range count-rate channel[1] for monitoring neutron flux over a ten-decade span. It amplifies pulses from a fission chamber and preamplifier assembly[2] and provides logarithmic and linear count-rate output signals. An output pulse is also provided to operate a scaler.

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[1] R. E. Wintenberg and J. L. Anderson, Trans. Am. Nucl. Soc. 3 (2), 454 (1960).

[2] D. P. Roux et al., A Miniaturized Fission Chamber and Preamplifier Assembly (Q-2617) for High-Flux Reactors, ORNL-3699 (October 1964).

The pulses from the preamplifier assembly are bipolar in shape, which eliminates the problem of duty-cycle shifts in the pulse amplifier. The pulse amplifier, however, can be used with positive unipolar pulses. Count rates up to 10^4 counts/sec of unipolar pulses 1 μsec wide can be accommodated with a resulting shift in effective pulse amplitude of less than 1%.

The logarithmic output signal is a current which drives an external, conventional operational amplifier. The output of the operational amplifier is used to operate indicators and other circuits.

The linear output signal is also a current which drives an external, conventional operational amplifier. The output of the operational amplifier is used to operate other circuits. In a wide-range counting channel, this linear signal is used as the control signal for a servo system.

1.4 Specifications

1.4.1 Pulse Amplifier

1. Gain:	90 ± 5.
2. Rise time (10% to 90%):	less than 0.07 μsec.
3. Linear pulse output (100-ohm load):	0 to +5 v.
4. Saturated output:	less than 7.5 v for pulse widths less than 0.5 μsec.
5. Attenuator control:	13-position, 100-ohm ladder type at amplifier input in 1, 1.5, 2, 3, 5, and 7 sequence.

1.4.2 Pulse-Height Discriminator

1. Range:	0.25 to +5 v with 10-turn Helipot (500 divisions).
2. Integral nonlinearity (including pulse amplifier):	less than ±0.2% of 5 v from 0.25 to 5 v at 30°C and varies less than 0.03%/°C of its 30°C value between 0 and 50°C.

1.4.3 Output Pulse for Scaler

1. Amplitude:	+3.5 v ± 0.25 v into load of 100 ohms.
2. Rise time (10% to 90%):	0.05 μsec.
3. Fall time (10% to 90%):	0.05 μsec (no output cable).
4. Pulse width:	varies with pulse amplitude in excess of PHD bias.

1.4.4 Log Count-Rate Output

1. Range: 1 to 10^5 counts/sec in 5 decades.
2. Amplitude: 0 at 1 count/sec and approx 40 μamp at 10^5 counts/sec.
3. Accuracy (at 30°C): output deviates less than ±3% from the true log reading at any point with regularly spaced input pulses.
4. Temperature effects: output deviates less than ±1% from the 30°C value for any temperature from 0 to 30°C. From 30 to 50°C, output deviates less than ±3% from the 30°C value at each point.

1.4.5 Linear Count-Rate Output

1. Range: 0 to 2.5×10^4 counts/sec.
2. Amplitude: approx 170 μamp at 10^4 counts/sec.
3. Accuracy (at 30°C): output deviates less than the equivalent of ±25 counts/sec from the true counting rate from zero to 10^4 counts/sec with regularly spaced input pulses.
4. Temperature effects: the deviation of the 10^4 counts/sec point from its 30°C value is less than 0.3%/°C from 0 to 30°C and less than 0.15%/°C from 30 to 50°C.

1.4.6 Power Requirements

1. Voltage: +25 ± 0.01 v; -25 ± 0.01 v.
2. Current drain: 75 ma from +25 v supply; 25 ma from -25 v supply.
3. Regulation: ±0.04% or better against ±10% line changes and with load changes from no load to full load.
4. Ripple: peak to peak ripple less than 0.01 v.

1.4.7 10 count/sec Oscillator

1. Stability: 30 ppm at 20°C with vertical orientation of spring balance wheel axis. 300 ppm at 20°C in any other orientation.
2. Thermal error: 11 ppm/°C from 0 to 30°C.
3. Output pulse: -11.7 v, 6 msec width, rise time (10 to 90%) is less than 20 μsec.

4. Output pulse load: 50 kilohms minimum.
5. Power supply: -12 v ± 10% at 0.15 ma average and 3-ma peak per pulse.

1.4.8 10^4 count/sec Oscillator

1. Calibration accuracy at 70°C: +0.000%; -0.004%.
2. Thermal error: -4 ppm/°C at 70°C.
3. Output pulse: 8 v peak-to-peak square wave; rise time (10 to 90%) of less than 1 μsec.
4. Output pulse impedance: 800 ohms.
5. Power supply: -12 v ± 10% at 7 ma.

1.4.9 Ambient Temperature Range

The ambient temperature range of all units is 0 to 55°C.

1.5 Applicable Drawings and Specification

The following list gives the drawing numbers (ORNL Instrumentation and Controls Division drawing numbers) and subtitles and the fabrication specification number for the Pulse Amplifier and Count-Rate Meter:

1. Q-2614-1 Circuit
2. Q-2614-2 Details (sheet 1)
3. Q-2614-3 Details (sheet 2)
4. Q-2614-4 Metalphoto Panel
5. Q-2614-5 Printed Circuit Board
6. Q-2614-6 Assembly
7. Q-2614-7 Parts List
8. Q-2614-8 Switch Assembly and Details
9. SF-246 Fabrication Specification.

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.

2. THEORY OF OPERATION

2.1 General

The following description of the Module (Fig. 1) is divided into five main groups: (1) pulse amplifier and control switch; (2) pulse-height discriminator, which includes the Schmitt trigger and emitter follower; (3) pump driver, which includes the flip-flop, Q-15 as a limiter-amplifier, and Q16 and Q17 as the complementary emitter-follower drive; (4) pump circuits, which include both the log and linear pumps; and (5) test oscillators.

2.2 Pulse Amplifier and Control Switch

The pulse amplifier design is tailored to amplify pulses of the shape shown in Fig. 2a. This pulse shape is produced by a preamplifier which double differentiates the pulses from a fission chamber with a 0.125-μsec time constant. (The second differentiation is made at a pulse transformer which terminates the balanced transmission line driven by the preamplifier.) The preamplifier has a 0.1 μsec integrating time constant.

The pulse amplifier consists of two fed-back groups which are cascaded to achieve an overall gain of nearly 100. Each group has a voltage gain of about 10. These two stages of amplification are preceded by a ladder-type attenuator, where the input impedance is a constant 100 ohms at all settings and the impedance, looking back from the amplifier input, is 50 ohms. The attenuator is part of an 18-position switch that (1) provides attenuation of the input signal in 13 positions, (2) disconnects the amplifier input from the attenuator and grounds it through 100 ohms in two "off" positions, (3) disconnects the amplifier from the attenuator and applies 10^4 counts/sec to its input, (4) disconnects the amplifier from the attenuator and applies 10 counts/sec to its input, and (5) disconnects the amplifier from the attenuator and supplies a dc voltage for application to a 5-sec period generator circuit that is external to the module. Also, in all positions other than attenuator positions, the control switch provides a dc voltage which actuates a front panel light and can be used to actuate an external alarm.

Both fed-back groups are of identical design. Each fed-back group is a three-transistor configuration, with the first two transistors Q1 and Q2 constituting a differential pair. The output from the second collector Q2 drives the third transistor Q3, which is an emitter follower. Feedback is made from the emitter of Q3 to the base of Q2. The output signal is taken from the emitter follower, and the input signal drives the first base Q1 of the differential pair. This results in a group with an output pulse of

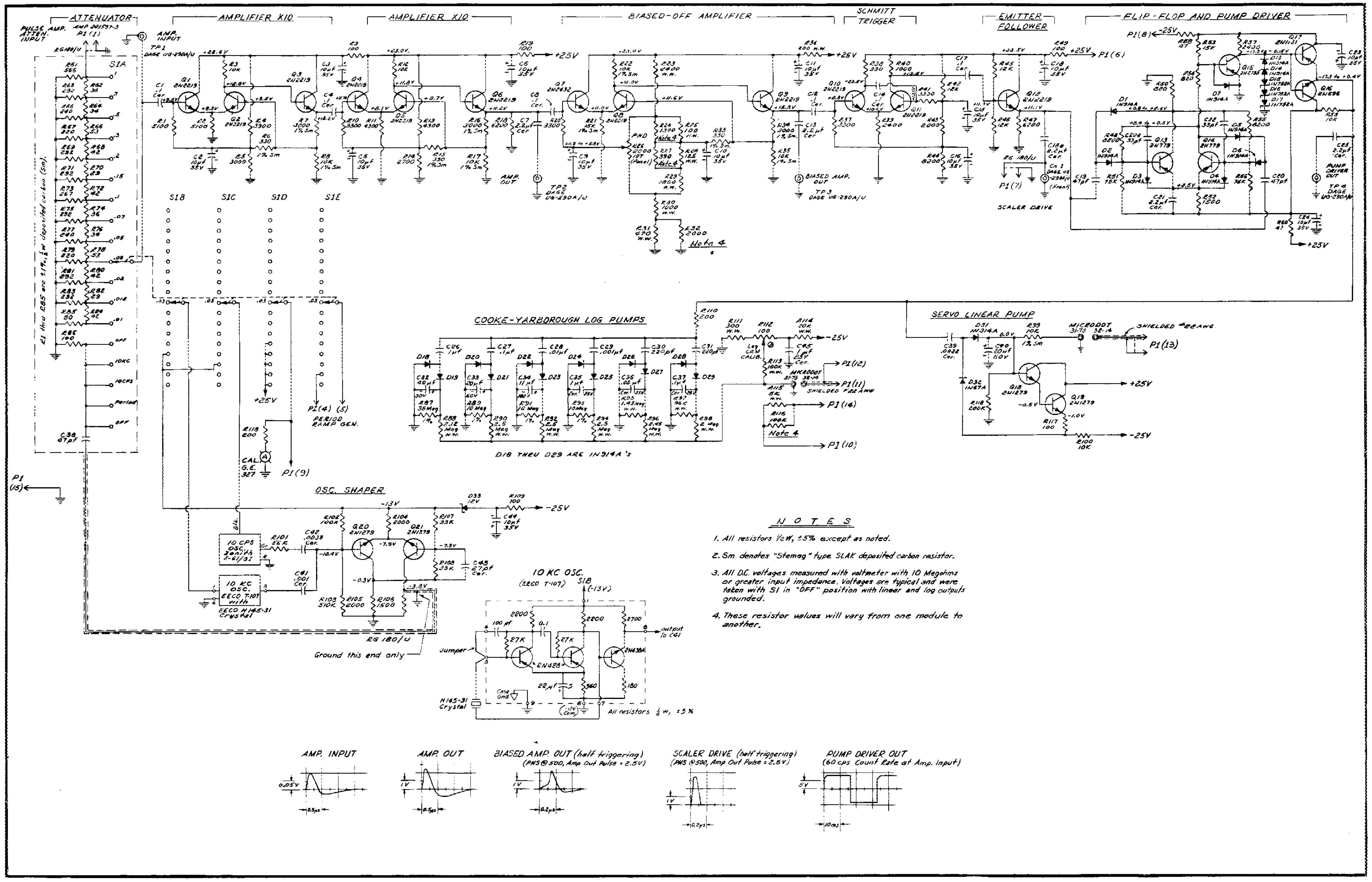

Fig. 1. Pulse Amplifier and Count-Rate Meter Circuit.

the same polarity as that of the input signal. The pulse gain of the stage is very nearly (R6 + R7)/R6, neglecting the shunting effect of R8 on R6. The measured[3] high-frequency feedback factor for the stage was 10.

The fed-back group is dc coupled and has excellent dc stability by nature of the differential input and a dc feedback factor in excess of 100. The bias in the amplifier has been selected so that both positive and negative portions of the bipolar input signal will be clipped proportionately under overload, thereby retaining its bipolar nature.

A closed-loop analysis, utilizing the hybrid-π equivalent circuit, shows that the predominant time constant is nearly $C_{ob}R7[(R_b' + R6)/R6]$, where C_{ob} and R_b' are the collector transition capacitance and base resistance of Q2 respectively.

The output impedance of the stage was computed to be 12.6 ohms.[4]

The input impedance of the stage is very nearly equal to that of the base resistor R1 of the input transistor Q1, because the emitter impedance of Q1 is R2 (5.1 kilohms) in parallel with the looking-in impedance of Q2, which is nearly 300 ohms due to the feedback to the base of Q2. Thus, with an effective emitter impedance of about 300 ohms, the impedance looking into the base of Q1 is about 30 kilohms for an h_{fe} of 100.

Capacity coupling is used to the input fed-back stage, between the two fed-back stages and on the output to the pulse-height discriminator. These coupling time-constants are in excess of 300 μsec, which is adequate to prevent further differentiation. The bipolar nature of the input signal eliminates any possible duty-cycle shifts across these capacitors.

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[3]The procedure for measurement is given by E. Fairstein, Pulse Amplifier Manual, ORNL-3348 (Oct. 26, 1962), p 20.

[4]The output impedance $R_o' = \dfrac{V \text{ (open circuit)}}{I \text{ (short circuit)}} = \dfrac{e_i(A)}{e_i\dfrac{(A)}{R_o}} = R_o\left(\dfrac{A'}{A}\right)$,

where

A = open-loop gain, 100
A' = closed-loop gain, 10
R_o = open-loop output impedance.

In this case, $R_o = r_e + \dfrac{\text{base impedance of Q3}}{h_{fe} \text{ of Q3}}$

$$= 26 + \frac{10^4}{100} = 126.$$

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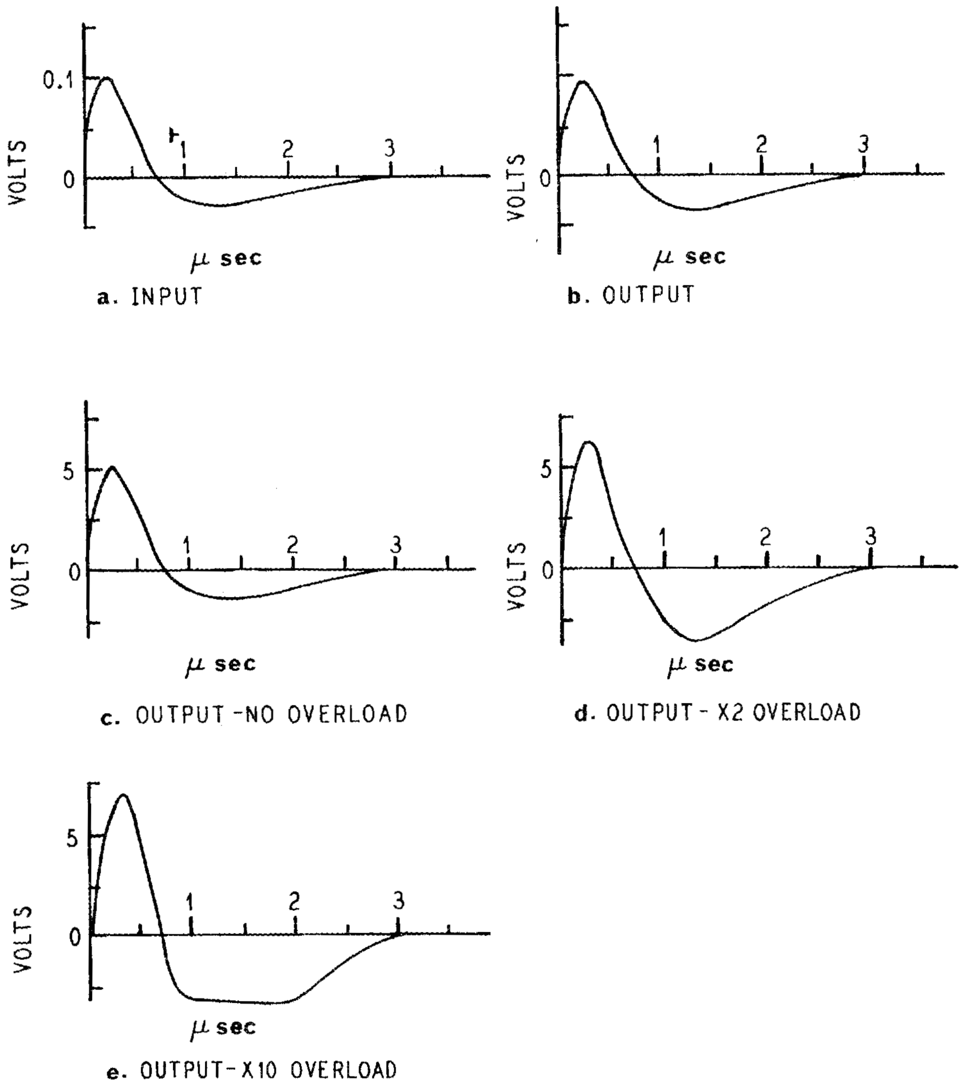

Fig. 2. Pulse Amplifier Waveforms.

2.3 Pulse-Height Discriminator

The pulse-height discriminator (PHD) is based on a biased amplifier scheme. The biased amplifier design is very similar to that used in the pulse amplifier. The PHD control potentiometer R26 has 10 turns, and the dial has 500 divisions. The position of R26 determines the differential bias that exists between the bases of Q7 and Q8. Since Q8 is conducting at any position of this potentiometer, any positive input signal applied to the base of Q7 must exceed this differential before Q7 is brought into conduction, and any portion in excess of this differential is amplified by a factor of 10.

The voltage drop across the PHD potentiometer R26 must be 5 v to achieve the full-range control of 5 v for pulse-height discrimination. The voltage can be trimmed to this value by adjusting R32. The "zero" of the PHD can be trimmed by adjusting the values of R24 and R27. Sect. 6 gives the details for these adjustments.

An ac-coupled Schmitt trigger is used to shape the pulse from the biased amplifier. The trigger sensitivity of the Schmitt is 2.5 v. A more sensitive trigger will create stability problems, even though any sensitivity changes are reduced by a factor of 10 when referred to the pulse amplitude. The sensitivity cannot be less than 0.5 v, because this is about the amplitude of "feed-through" pulses of the biased amplifier.

Another consideration for keeping the Schmitt trigger sensitivity large is to relax the bandwidth requirements of the biased-off amplifier. The triangular shaped character of the positive portion of the amplifier pulse places a bandwidth burden on the biased-off amplifier for the pulses which barely exceed the threshold level. The larger the pulse required to trigger the Schmitt, the greater the output required from the biased amplifier. These larger pulses, because of their triangular shape, will be wider at the base line and will require less bandwidth from the amplifier.

The 2.5-v sensitivity of the Schmitt trigger results in PHD potentiometer control that is ineffective below 0.25 v of pulse amplitude. This is only 5% of the 5-v full range and is considered to be only a minor limitation. Trigger sensitivites in excess of 2.5 v would result in even less usable portions of the PHD potentiometer and would not be desirable.

Transistor Q7 of the biased amplifier must have a base-to-emitter breakdown voltage greater than 5 v. The 2N2432 transistor designed for inverted chopper applications has a 15-v BV_{EBO} rating.

The pulse out of the Schmitt trigger is applied to emitter-follower Q12. The magnitude of this pulse is +3.5 v, and its width depends upon the amount that the pulse amplifier pulse exceeds the bias setting of the PHD. The emitter-follower output drives the succeeding binary stage and an external scaler. The recovery of the pulse at the emitter follower will be slow at the termination of each pulse if an unterminated cable is used to make connection to a scaler, because the charged cable will hold Q12 off and must be discharged through R47, a 6.2-kilohm resistor.

2.4 Pump Driver

The pulse from the Schmitt trigger and its emitter follower does not have the proper amplitude or the width to drive the log and linear pumps. A binary stage (also called a flip-flop) is used to further shape the pulse. The output pulse of the flip-flop is rectangular, having a width equal to the time elapsed between two successive pulses. This method of shaping automatically provides the pump circuits with wide pulses without any increase in dead-time losses. The consequent division of the pulse rate by a factor of 2 must, of course, be considered in the pump design.

The flip-flop design composed of Q13 and Q14 is a saturated type (i.e., the "on" transistor is driven into saturation) with 10^7 counts/sec resolution capabilities. When either Q13 or Q14 is "on," the other is "off." The positive pulse from the emitter follower acts to turn the "on" transistor off, and the regenerative nature of the circuit then switches the state of the flip-flop. Diodes D2 and D6 serve to steer or apply the pulse to the base of the "on" transistor. To understand how the steering is achieved, assume Q13 to be "on" and Q14 to be "off." The collector of Q13 will be near +8.5 v, and the collector of Q14 will be near ground. Diodes D6 and D5 are in series and are back biased by the difference in potential between the collector and base of Q14 (about 8.5 v). The base of Q14 is clamped to a potential slightly more positive than +8.5 v by D4. (The only purpose for D3 and D4 is to limit the back bias applied to Q13 and Q14 when they are turned off. With these diodes, the back bias can never exceed about 0.5 v.) In contrast, diodes D1 and D2, which are also in series, are only back biased by a few tenths of a volt. Thus, a positive input pulse will take the route through D2 (and to the base of the "on" transistor) in preference to through D6 because of the greater bias on D6.

Diodes D1 and D5 aid in another manner. These diodes help discharge capacitors C19 and C20, respectively, by providing a low-impedance path to C21 (a 2.2-μf capacitor) through the collector of the "on" transistor between input pulses. These capacitors will acquire some charge as the input signal proceeds to turn off the "on" transistor and, if permitted to accumulate or to not sufficiently recover, can cause a malfunction of the flip-flop.

The collector swing of Q13 and Q14 is approximately 8 v. This value is marginal to provide reliable operation of a pump circuit. Also, the pump circuit input impedance is quite low and would drastically load the flip-flop and impair its speed. Thus, some further amplification is still required and some impedance isolation is needed. It should be recognized that any amplification process must also achieve high amplitude stability to achieve good pump performance. Transistors Q15, Q17, and Q16 along with diodes D7, D13, D14, D15, D16, and D17 are used to perform this task. Diodes D7, D13 and D14 are fast-recovery conventional diodes, and diodes D15, D16, and D17 are 5.2-v Zener diodes.

Amplification with controlled amplitude is accomplished by Q15, the three fast diodes, and the three Zener diodes. The collector current of Q14 forward-biases diode D7 and turns Q15 hard "off." The collector of Q15 is caught at approximately -17 v by the series string of the three fast diodes and the three 5.2-v Zener diodes. When Q14 is turned off, D7 is released and Q15 is turned hard "on" by the base drive through R53. Thus, the collector swing of Q15 is from -17 v to essentially 0 v. The two diodes in series with the Zener diodes isolate the large capacitance of the Zener diodes from the collector of Q15, permitting fast rise and fall times. One diode is adequate for this isolation, but two diodes give better temperature compensation for diode effects on the diode pumps. The Zener diodes have a specified rating of 0.005% per $^{\circ}$C change, and the variation of the saturation voltage of Q15 is less than a few tenths of a millivolt per $^{\circ}$C.

It should be apparent that the scheme just described is one where the collector current of Q14 is sampled, rather than its collector voltage, so that amplification is not achieved in the usual sense. However, the method employed is one where no loading is placed on the flip-flop, permitting it to operate at maximum speed.

Transistors Q16 and Q17 comprise a complementary emitter-follower driving stage which applies the 17-v pulses to the pump circuits. The necessity of a complementary design over that of a single emitter follower can be explained if we momentarily include the pump circuits in the discussion. The following section will discuss the pump circuits in greater detail. The negative-going step of the 17-v pulse proceeds to charge the feed capacitors of the pump circuits (C26 through C31 for the log pumps, and C39 for the linear pump) through their respective diodes (D18, D20, D22, D24, D26, D28, and D32) to the full 17 v. On the positive-going edge of the pulse (or the return to ground), these capacitors must now be discharged quickly to 0 v to be prepared for the next pulse. This discharged path must proceed through the second diode of each pump into the smoothing capacitor or output capacitor of each pump for proper action of the pump. At this time, Q17 is biased off and cannot provide this discharge. Q17 is off, since its base is at or near ground and its emitter is at -17 v because the feed capacitor is behaving as a 17-v battery. With Q16 in the circuit as the NPN complement, it will be biased "on" and will permit the feed capacitor to discharge.

2.5 Pump Circuits

2.5.1 Logarithmic Pumps

The log pump design is composed of six pumps and is based on the earlier work of Cooke-Yarborough.[5] The dc currents from each pump are summed at the common junction of R88, R90, R92, R96, and R98 and are delivered to the summing junction of an external operational amplifier. The composite response of six pumps is shown in Fig. 3. Since the output voltage of each pump is positive, the conventional current flow will be out of these resistors. An additional current of opposite polarity is supplied through R113 and is adjustable by the "calibrate" control potentiometer R112. The gain of the external amplifier and hence the "span" of the log count-rate meter are controlled by the parallel combination of R115 and R116. For trimming purposes, the value of R116 is adjusted. Section 4 will give details for both "calibrate" and "span" adjustments. (The relationship of R115 and R116 with the external amplifier is shown in Fig. 9.) A 250-kilohm feed-back resistor for the operational amplifier and 1-kilohm resistor which forms a voltage divider network

[5] E. H. Cooke-Yarborough and E. W. Pulsford, "An Accurate Logarithmic Counting Rate Meter Covering a Wide Range," Proc. IEEE, Part II, 98, pp. 196-203 (April 1951).

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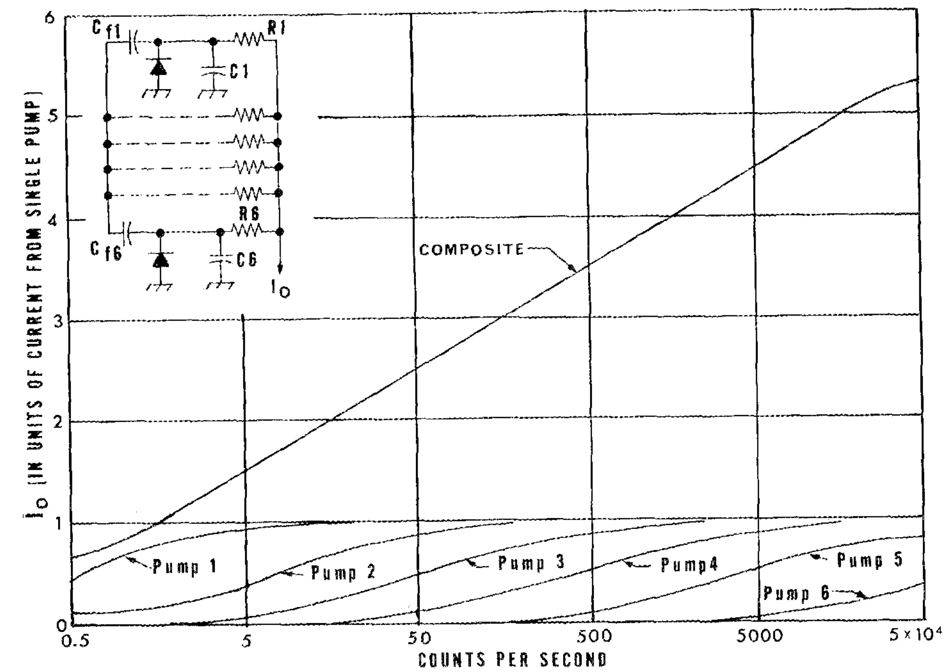

Fig. 3. Composite Response of Six Diode Pumps With Individual Pump Response, where $C_{fn} \times Rn = 0.1^{n-1} C_{f1} \times R1$.

with R115 and R116 are located at the operational amplifier. If these resistors were located in the pulse amplifier and count-rate meter module and the module were unplugged, it would open-circuit the feed-back loop on the operational amplifier and cause the operational amplifier to saturate. It is not advisable to leave these amplifiers in this state for extended periods of time.

The operation of the pump circuit was partially covered in the preceding section and will be extended here. As charge from the feed capacitor is transferred to the smoothing capacitors C32 through C37, a voltage is developed across these capacitors which causes the current flow through any shunt resistance such as R88 and R87 of the first pump. R88 is essentially returned to ground since it is tied to the summing junction (a virtual ground) of the external operational amplifier. At a steady count rate, there is an equilibrium condition established where the rate of charge, or current inflow, is equal to the current outflow, and a steady dc voltage (with superimposed statistical variation) is established across each smoothing capacitor.

The voltage on each smoothing capacitor will bear the following relationship:[6]

$$v_o = \frac{V_i nRC}{1 + nRc} ,$$

where

V_i = input pulse amplitude,
n = detector count rate divided by 2,
C = capacity of feed capacitor,
R = total shunt resistance across smoothing capacitor.

This response is shown graphically by any of the six curves in Fig. 3. For small values of n, where nRC is small compared with unity, the response is nearly linear as a function of n, the count rate. As n becomes larger, the response becomes nonlinear (appearing to be linear on a semilog plot)

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[6]The derivation is as follows:

$$v_o = i_o R,$$

where

$$i_o = \frac{\Delta Q}{\Delta t} = \frac{(V_i - v_o)C}{\frac{1}{n}} = (V_i - v_o)nC.$$

Thus

$$v_o = (V_i - v_o)nCR,$$

$$= \frac{V_i nRC}{1 + nRC} .$$

and ultimately reaches a saturation value of V_i when nRC is much greater than unity. As the count rate increases, each pump becomes successively saturated (pumps with the largest RC product saturate first), resulting in a constant output current from each pump.

The Cooke-Yarborough principle will show end effects when a limited number of pumps is used to approximate the logarithmic response. To compensate for this, the two end pumps deliver about 10% more current than the four middle pumps. This is accomplished by making the value of the feed resistors R88 and R98 smaller than that of the other four feed resistors R90, R92, R94, and R96. The values of the shunt resistors R87, R89, R91, R93, R95, and R97 are adjusted to keep the pump time-constant RC at values which differ by a factor of 10.

The value of the total shunt resistance R across each smoothing capacitor was made as small as possible while still permitting reasonable values of smoothing capacitors (i.e., values less than 100 μf). The product of the resistance and the smoothing capacitor values determines the statistical noise superimposed on the dc current. The values shown were determined by experiment on the complete wide-range counting channel. The first three time-constants involving C32, C33, and C34 were selected to keep the period noise at reasonable values while the wide-range counting channel was behaving as a straight counting instrument. The remaining three time-constants were selected to optimize the speed of response of the counting channel.

The leakage of the smoothing capacitors and diodes D19, D21, D23, D25, D27, and D29 behaves as an additional shunt resistance across the various pump outputs. The 1N914A is specified to have a maximum leakage of 0.025 μa at a reverse bias of 20 v at 20°C. This will have negligible effect on the performance of the pumps. The electrolytic capacitors C32, C33, and C34 were purchased with a specified leakage not to exceed 0.2 μa at 25°C at a working voltage of 20 v, which is equivalent to a dc leakage resistance of 100 megohms. A reduction in leakage resistance to 50 megohms would only represent an error of 2.5% of reading over only a small range of the scale. Errors caused by leakage of the capacitors will not accumulate, because as each pump goes into saturation, its output current is only a function of pulse amplitude and the magnitude of the resistor feeding the summing junctions of the operational amplifier. In addition, any errors caused by the three electrolytic capacitors, since they apply to the pumps at the low end of the scale, are negligible at the high end.

The other critical components of the various pumps, such as the feed capacitor and output resistors, are high-quality, high-stability ±1% components, or better.

The effect of the variation of diode potentials in the pump is equivalent to a variation of the amplitude of the input pulse. The effect is such that, at higher temperatures, the input pulse appears bigger and there is greater output from the pump. More clearly, as the forward drop of D18 reduces with a temperature increase, the feed capacitor will charge to a larger voltage. Also, the forward drop across D19 is less, and more charge is transferred. The two diodes D13 and D14 in series with the three 5.2-v Zener diodes have a tendency to compensate for this. As the temperature rises, the forward drop of these two diodes will be less and will result in a reduced pulse amplitude.

2.5.2 Linear Pump

The linear pump circuit is designed to give a linear output current signal up to a value of about 170 μa for 10^4 counts/sec. This current is fed through R99, a 10-kilohm resistor, into the summing junction of an external operational amplifier. This amounts to a voltage of +1.7 v at the output of the pump.

Without any attempt (such as bootstrapping) to improve linearity, the output signal would depart from linearity by nearly 9%. This can be computed from the general count-rate expression given in the preceding section with RC = (R99) (C39) = (10^4) (0.0022) (10^{-6}) and n = 5×10^3 counts/sec. The bootstrapping circuit consisting of Q18 and Q19 serves to effectively increase the magnitude of the input pulse by an amount equal to the output dc voltage. Discounting the small drop in R117, any change in the output voltage appears at the anode of D32 and is in a direction to increase the voltage to which the feed capacitor is charged with each input pulse. Thus, the output current which without bootstrapping is

$$i_o = \frac{(V_i - v_o)C}{\frac{1}{n}} ,$$

becomes

$$i_o = \frac{[(V_i + v_o) - v_o]C}{\frac{1}{n}} ,$$

which is independent of v_o. Here all terms have the same meaning as in the preceding section.

The cascaded emitter-follower arrangement (Darlington pair) is used to raise the looking-in impedance of the bootstrapping circuit, thereby reducing its loading effect on the output voltage. The voltage drop of the base-to-emitter voltages of Q18 and Q19 plus the drop across R117 is of sufficient magnitude to ensure that D31 is sufficiently back biased during the charging time of the feed capacitor to avoid a leakage of charge from the smoothing capacitor.

Temperature effects in the linear diode pump are due primarily to changes in the two diodes D31 and D32. Variation in the forward voltages of these two diodes is compensated for by changes in input pulse amplitude in a manner as described in the preceding section. Diode leakage currents and leakage in the electrolytic smoothing capacitors are negligible, particularly since the value of the output resistor is only 10 kilohms.

Temperature effects caused by the bootstrapping scheme are small, but are not negligible. V_{be} changes of Q18 and Q19 will have a significant effect on the output. These changes will predominantly show up as a change in emitter potential of Q19 of about 4 mv/^{o}C. Only slight changes of V_{be} due to temperature are seen at the base of Q18, because the 10-kilohm base impedance of Q18 is so much smaller than the looking-in impedance of Q18. The variations at the emitter of Q19 will change the magnitude of the bootstrapping voltage with temperature. At 50^{o}C (assuming 4 mv/^{o}C), the change in bootstrapping signal from the 30^{o}C value is 120 mv, which is a change in output signal of $[0.120/(17 \times 20)]$ 100, or 0.03%/^{o}C, where 17 v is the amplitude of the input pulse. This change is in a direction to increase the output signal. If the output signal from the bootstrapped configuration had been taken from the emitter of Q19, the 0.03%/^{o}C value will be increased by an additional $[0.120/(1.7 \times 20)]100$, or 0.3%/^{o}C at 10^4 counts/sec. This occurs because the pump output voltage (1.7 v at 10^4 counts/sec) receives the full effect of the V_{be} changes.

The actual temperature drift observed on the pump operating at 10^4 counts/sec is three times worse than 0.03%/^{o}C. At 5000 counts/sec, the measured drift is more nearly 0.03%/^{o}C. The cause of the increased drift at the 10^4 count/sec rate, which nearly amounts to an additional 2 mv/^{o}C, is not definitely known.

I_{co} and the base current of Q18 will flow through R99 into the summing junction of the external amplifier and appear as signal currents. I_{co} effects will be negligible, because 0.001 μa is typical for Q18 and Q19 (NPN silicon). Temperature effects on h_{FE} are also negligible, since the base current of Q18 is only about 0.5 μa, or about 0.3% of the full-scale output. Also, the Darlington configuration will reduce the effect of the change of h_{FE} with temperature on the base current by almost $2/h_{FE}$.

2.6 Test Oscillators

2.6.1 10 count/sec Oscillator

The 10 count/sec oscillator is a Swiss-made (Zenith Model E59GJ) electromechanical oscillator which has a spring-balance wheel mounted in ruby bearings. The spring-balance wheel is driven by an electronic circuit containing two transistors and two coils. The two coils are fixed and are located coaxially above and below a permanent magnet set in the rim of the balance wheel. The axis of the magnet is parallel to the axis of rotation of the spring-balance wheel. As the magnet passes through the region between the coils, a voltage induced in one coil (the pickup coil) turns on a transistor amplifier, which has the second coil (the drive coil) as a collector load. The current in the drive coil imparts a force to the balance wheel in a direction to sustain its movement. The output pulse is taken from the collector of the amplifier transistor. The other transistor is connected as an emitter follower and provides the necessary power amplification for the signal from the pickup coil.

The oscillator produces an output pulse of the same polarity each time the magnet passes under the coils. This results in two pulses for each complete cycle. The time duration between successive pulses can differ by as much as 3 msec; however, the sum of the two intervals remains precisely at 0.1 sec (i.e., a 10 count/sec rate).

2.6.2 10^4 count/sec Oscillator

The 10^4 count/sec oscillator is crystal controlled by a 10^4 count/sec quartz crystal. The oscillator consists of an Engineered Electronics Co. (EECO) plug-in unit T-107, requiring a standard 9-pin miniature tube socket. The quartz crystal (EECO type H145-31) is mounted separately. The T-107 unit contains three transistors, two of which are used as a two-stage common emitter amplifier with feedback from the second collector to the first base through the impedance of the crystal. There is a full $360°$ phase shift, and the circuit will oscillate at a frequency which experiences neither phase shift nor appreciable attenuation through the crystal. The third transistor serves as an emitter-follower output stage.

2.6.3 Oscillator Shaper

Since the output waveforms of the 10 count/sec and the 10^4 count/sec oscillators are widely different, preshaping is required if a uniform pulse is to be applied to the pulse amplifier. Q20 and Q21 form a conventional Schmitt trigger for this purpose. Q21 is normally on and Q20 is off. The sensitivity is such that about 4 v is needed for triggering. The output pulse from the collector of Q21 is a positive pulse which is sharply differentiated by C38 and R86. The resultant pulse is about 0.1 v in amplitude. A negative pulse of about the same amplitude is obtained, but it is of the wrong polarity to trigger the pulse-height discriminator.

3. OPERATING INSTRUCTIONS

3.1 Installation

The Pulse Amplifier and Count-Rate Meter, ORNL model Q-2614, 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 with power on without damage.

3.2 Operating Controls

3.2.1 Pulse Amplifier Gain and PHD Setting

The final setting for these controls will be determined by the characteristic of the fission detector and preamplifier and by the length of transmission line from the preamplifier to the pulse amplifier. Thus, each installation will have different settings for these controls.

3.2.2 Scaler Output

A pulse signal is available to drive an external scaler. This connection can be made either on the front panel or through a coaxial insert on the rear plug-in connector. Simultaneous use of both connectors is not advised. Any interconnecting cable should be 93-ohm coaxial, and if it is more than 3 or 4 ft long, it should be terminated in its characteristic impedance.

3.2.3 Log Count-Rate "Calib" Control

This potentiometer, located inside the module, is used in conjunction with an external operational amplifier which is connected to the log output signal. This potentiometer permits the adjustment of the log count-rate meter "Calib." This adjustment, once made on the bench, need not be repeated when the module is put into service.

4. MAINTENANCE INSTRUCTIONS

4.1 General

Tests points at the top of the module are accessible when the drawer containing the module is pulled out. These test points are BNC chassis connectors, permitting a reliable means of observing pulse waveforms. BNC adapters should be used with the oscilloscope probes. If adapters are not available, short ground clips may be used, provided the connector shell is used as the ground point. Probes with X1 attenuators will slightly load some of the test points and should be used with caution. Probes with X10 attenuators are preferred. The oscilloscope should be isolated from building and power line grounds.

Many of the resistors and capacitors used in this module have been selected for high accuracy and stability. Check the Replaceable Parts List, Sect. 5, before replacing any defective component.

4.2 Periodic Maintenance

The calibration of the log count-rate meter should be checked at least once a month. This can be done with the 10 and 10^4 count/sec oscillators. The 10 count/sec test point must be given adequate time before a final reading is taken. Some slight readjustment of the "Calib" potentiometer may be necessary.

The wheel axis and bearings of the 10 count/sec oscillator should be cleaned and lubricated with high-precision oil. Once every 5 years is adequate.

4.3 Calibration

All calibration procedures and instruments required are discussed in Sect. 6.

4.4 Troubleshooting

If the cause of any failure of the module is not apparent by visual inspection, check the module for the supply voltages. Both positive 25 v and negative 25 v are required. If these are both normal, place the control switch in one of the test oscillator positions (the 10^4 count/sec oscillator is preferred). The trouble can be isolated by use of the test points. (The pulses out of the amplifier will be unipolar when driven by the test oscillator.)

The bottom of the compartment which houses all of the electronic circuits with the exception of the oscillators can be removed to gain access to the printed wiring side of the printed circuit board. The pulse amplifier section is completely enclosed, and its board must be lifted out of the compartment to gain access to the printed wiring side of its printed circuit board.

If any transistor requires replacement, Table 2 in Sect. 6 should be checked.

4.5 Voltage Chart

See Table 3 in Sect. 6.

5. REPLACEABLE PARTS LIST

A description and an ORNL Stores number for all replaceable parts are given in Table 1.

Table 1. Replaceable Parts List

Part No.	ORNL Stores No.	Description
C43	06-807-3465	Capacitor, 27 pf, ±5%, 500 v dc w, sil. mica, Elmenco No. DM-15-270.
C19, C20 C38	06-807-3480	Capacitor, 47 pf, ±5%, 500 v dc w, sil. mica, Elmenco No. DM-15-470.
C30, C31		Capacitor, 220 pf, ±1%, 500 v dc w, sil. mica, Elmenco No. DM-15-221.
C29		Capacitor, 0.001 mf, ±1%, 500 v dc w, sil. mica, Elmenco No. DM-16-102.
C28		Capacitor, 0.01 mf, ±1%, 500 v dc w, sil. mica, Elmenco No. DM-30-103.
C20a, C22	06-802-0300	Capacitor, 33 pf, ±10%, 1000 v dc w, ceramic, disc, Sprague No. 20C198.
C41	06-802-0390	Capacitor, 1000 pf, ±10%, 1000 v dc w, ceramic, disc, Sprague No. 29C151A1.
C39	06-802-0395	Capacitor, 0.0022 mf, ±20%, 1000 v dc w, ceramic, disc, Sprague No. 20C162.
C42	06-802-0400	Capacitor, 0.0033 mf, ±20%, 1000 v dc w, ceramic, disc, Sprague No. 20C162.
C36	06-802-0086	Capacitor, 0.047 mf, ±20%, 25 v dc w, ceramic, monolithic, Sprague No. 3C15.
C35, C45	06-802-0090	Capacitor, 1 mf, ±20%, 25 v dc w, ceramic, monolithic, Sprague No. 5C13.
C7, C13, C18a, C21, C25	06-802-0091	Capacitor, 2.2 mf, ±20%, 25 v dc w, ceramic, monolithic, Sprague No. 5C15.
C1, C4, C8, C12, C14, C17, C17	06-802-0087	Capacitor, 0.1 mf, ±20%, 25 v dc w, ceramic, monolithic, Sprague No. 3C21.
C2, C3, C5, C6, C9, C10, C11, C15, C16, C18, C23, C24, C44	06-816-3240	Capacitor, 10 mf, ±10%, 35 v dc w, tantalum, Sprague No. 150D106X9035R2.
C27		Capacitor, 0.1 mf, ±1%, 100 v dc w, metalized film, Dearborn No. MPIF104E1.

Table 1 (continued)

Part No.	ORNL Stores No.	Description
C26		Capacitor, 1 mf, ±1%, 100 v dc w, metalized film, Dearborn No. MPIF105E1.
		Capacitor, tantalum electrolytic for derating to 20 v dc w, leakage current shall be less than 0.2 μa from 10°C to 45°C, leakage current shall not exceed 0.2 μa after 10,000 hours operation at 45°C and rated working voltage. Capacitance shall not vary more than 10% of rated value at 25°C over 10°C to 45°C, Sprague Electric Co. The following values are specified at 25°C:
C32		40 mf, ±10%, 30 v dc w.
C33, C40		20 mf, ±10%, 60 v dc w.
C34		11 mf, ±10%, 100 v dc w.
R26		Potentiometer, 2000 ohms, ±3%, linearity ±0.1%, 10 turn, 1.5 w at 40°C, 1/4 in. shaft, 3/8-32 bushing, Helipot model No. 7216R2KL.1.
R112		Potentiometer, 100 ohms, ±20%, 0.25 w at 70°C, printed wiring mounting, A-B type FP101M.
R87		Resistor, 35 megohms, ±1%, 1 w, carbon film, Pyroseal Construction, Pyrofilm type PT70.
R89, R91, R93	06-932-0370	Resistor, 10 megohm, ±1%, 1/2 w, carbon film, Texas Instr. Inc., type CDH 1/2S.
		The following wire-wound precision resistors to be temperature aged at 150°C for 48 hours. Final resistance value to be within tolerance when measured at 25°C. Standard lead spacing:
R28		Resistor, 125 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R25		Resistor, 100 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R36		Resistor, 200 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R111		Resistor, 300 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R31		Resistor, 470 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R30		Resistor, 1000 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R29		Resistor, 1800 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R23		Resistor, 2400 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.

Table 1 (continued)

Part No.	ORNL Stores No.	Description
R115		Resistor, 5000 ohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R114		Resistor, 20 kilohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R97		Resistor, 96 kilohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R113		Resistor, 110 kilohms, ±1/2%, 0.25 w, at 125°C, Daven type 1350.
R95		Resistor, 1.32 megohm, ±1/2%, 0.40 w, at 125°C, Daven type 1358.
R98		Resistor, 2 megohms, ±1/2%, 0.40 w, at 125°C, Daven type 1358.
R88		Resistor, 2.12 megohms, ±1/2%, 0.40 w, at 125°C, Daven type 1358.
R96		Resistor, 2.45 megohms, ±1/2%, 0.40 w, at 125°C, Daven type 1358.
R90, R92, R94		Resistor, 2.5 megohms, ±1/2%, 0.40 w, at 125°C, Daven type 1358.
		The following carbon film resistors are Stemag type SLAK, double high-temperature varnish impregnated. Vendor: H.E. Priester Corp., Scarsdale, N.Y.
R70, R82		Resistor, 29 ohms, ±1%, 1/2 w, carbon film.
R64, R76		Resistor, 34 ohms, ±1%, 1/2 w, carbon film.
R62, R74		Resistor, 36 ohms, ±1%, 1/2 w, carbon film.
R68, R72, R80, R84		Resistor, 42 ohms, ±1%, 1/2 w, carbon film.
R66, R78		Resistor, 53 ohms, ±1%, 1/2 w, carbon film.
R85	06-932-0043	Resistor, 80 ohms, ±1%, 1/2 w, carbon film.
R67, R79		Resistor, 220 ohms, ±1%, 1/2 w, carbon film.
R65, R77	06-932-0061	Resistor, 240 ohms, ±1%, 1/2 w, carbon film.
R73		Resistor, 267 ohms, ±1%, 1/2 w, carbon film.
R63, R69, R71, R75, R81, R83		Resistor, 292 ohms, ±1%, 1/2 w, carbon film.
R6, R15, R33	06-932-0071	Resistor, 330 ohms, ±1%, 1/2 w, carbon film.
R61		Resistor, 566 ohms, ±1%, 1/2 w, carbon film.
R7, R16, R34	06-932-0123	Resistor, 3000 ohms, ±1%, 1/2 w, carbon film.

Table 1 (continued)

Part No.	ORNL Stores No.	Description
R8, R17, R22, R35, R99	06-932-0147	Resistor, 10 kilohms, ±1%, 1/2 w, carbon film.
R21	06-932-0151	Resistor, 15 kilohms, ±1%, 1/2 w, carbon film.
R58, R60		Resistor, 47 ohms, ±5%, 1/2 w, Allen-Bradley.
R9, R19, R49, R86, R109, R117		Resistor, 100 ohms, ±5%, 1/2 w, A-B.
R110		Resistor, 200 ohms, ±5%, 1/2 w, A-B.
R38		Resistor, 330 ohms, ±5%, 1/2 w, A-B.
R27		Resistor, 390 ohms, ±5%, 1/2 w, A-B.
R50, R54		Resistor, 820 ohms, ±5%, 1/2 w, A-B.
R40		Resistor, 1000 ohms, ±5%, 1/2 w, A-B.
R24		Resistor, 1300 ohms, ±5%, 1/2 w, A-B.
R52, R106		Resistor, 1500 ohms, ±5%, 1/2 w, A-B.
R43, R104, R105, R32		Resistor, 2000 ohms, ±5%, 1/2 w, A-B.
R39, R57		Resistor, 2400 ohms, ±5%, 1/2 w, A-B.
R14		Resistor, 2700 ohms, ±5%, 1/2 w, A-B.
R5		Resistor, 3000 ohms, ±5%, 1/2 w, A-B.
R20, R10, R37, R41		Resistor, 3300 ohms, ±5%, 1/2 w, A-B.
R4		Resistor, 3900 ohms, ±5%, 1/2 w, A-B.
R11, R13		Resistor, 4300 ohms, ±5%, 1/2 w, A-B.
R1, R2		Resistor, 5100 ohms, ±5%, 1/2 w, A-B.
R18, R47		Resistor, 6200 ohms, ±5%, 1/2 w, A-B.
R44, R48, R55		Resistor, 8200 ohms, ±5%, 1/2 w, A-B.
R3, R12, R59, R100		Resistor, 10 kilohms, ±5%, 1/2 w, A-B.
R42, R45, R46		Resistor, 12 kilohms, ±5%, 1/2 w, A-B.
R53		Resistor, 15 kilohms, ±5%, 1/2 w, A-B.
R107, R108		Resistor, 33 kilohms, ±5%, 1/2 w, A-B.
R101		Resistor, 47 kilohms, ±5%, 1/2 w, A-B.
R51, R56		Resistor, 75 kilohms, ±5%, 1/2 w, A-B.
R102, R116		Resistor, 100 kilohms, ±5%, 1/2 w, A-B.

Table 1 (continued)

Part No.	ORNL Stores No.	Description
R118		Resistor, 200 kilohms, ±5%, 1/2 w, A-B.
R103		Resistor, 510 kilohms, ±5%, 1/2 w, A-B.
Q1, Q2, Q3, Q4, Q5, Q6, Q8, Q9, Q10, Q11, Q12	06-996-1998	Transistor, NPN, silicon, type 2N2219, Motorola.
Q7	06-996-2010	Transistor, NPN, silicon, type 2N2432, Texas Instr., Inc.
Q13, Q14	06-996-1640	Transistor, PNP, germanium, type 2N779A, Philco.
Q16	06-996-1610	Transistor, NPN, silicon, type 2N696, Texas Instr., Inc.
Q18, Q19, Q20, Q21	06-996-1880	Transistor, NPN, silicon, type 2N1279, G.E.
Q17	06-996-1710	Transistor, PNP, silicon, type 2N1131, Texas Instr., Inc.
Q15		Transistor, PNP, germaniu, type 2N2795, Sprague.
		Module, generator, timing pulse, 10 pps, 12 v, model E-61/GI, Zenith Watch Mfg., Ltd., Le Locle, Switzerland.
D1, D2, D3, D4, D5, D6, D7, D13, D14, D18, D19, D20, D21, D22, D23, D24, D25, D26, D27, D28, D29, D31	06-995-6280	Diode, silicon, type 1N914A, Texas Instr., Inc.
D32	06-995-5280	Diode, germanium, type 1N67A, Hughes.
D15, D16, D17	06-995-6230	Diode, Zener, type 1N752A, 5.6 v ±5%, Motorola.
D33	06-995-6286	Diode, Zener, type 1N963B, 12 v ±5%, Motorola.
	06-881-4182	Dial, 15 turn, 7/8 in. diam, for 1/4 in. shaft, 3/8-32 bushing, Helipot model 2607.
		Oscillator, crystal controlled, 10 kc ±0.005% at 70°C, ambient range 0°C to 50°C, output 8 v peak-to-peak square wave with less than 1 μsec rise time, less than 5 ppm/°C drift over ambient range, EECO model T107, Engineered Electronics Co.

Table 1 (continued)

Part No.	ORNL Stores No.	Description
		Crystal, 10 kc, for T-107 oscillator, in MC-13A holder, EECO model No. H-145-31, Engineered Electronics Co.
I1	06-916-2576	Lamp, incandescent, 28 v at 40 ma, type 327, G.E.

6. ACCEPTANCE TEST PROCEUDRES

6.1 Test Instruments and Components

The following test equipment is required:

1. A multimeter, Triplett model 630.
2. An oscilloscope, Tektronix 541 with type L or type CA plug-in. Type L is preferred because of greater sensitivity.
3. A digital, direct-current voltmeter, differential input, five digit, 0.01% accuracy with 100 μv resolution on the most sensitive range, automatic range change, input impedance of 10 megohms at balance. A Cubic, model V-85 voltmeter is recommended.
4. A direct current, vacuum tube voltmeter, Hewlett-Packard, model 425A, or Dynamics, model 1362. The Dynamics voltmeter is preferred because it has a greater input sensitivity and it can be completely isolated from power mains in battery operation mode.
5. A pulse generator, mercury relay, ORNL model Q-1212C or Q-1212D.
6. A pulse generator, crystal controlled, ORNL model Q-2167 or equivalent.
7. A transistor tester, current amplification measured at 1 kc, collector saturation current measured with a 50-μa meter with 25 small divisions. A Baird-Atomic, model KT-1 tester is recommended.
8. A power supply, positive 25 v, negative 25 v, 0.05% regulation for line and load changes, less than 0.01 v peak to peak ripple. Either Harrison Laboratory Twin Voltage Supply, model 800A-2 or an ORNL Model Q-2619 Regulator is recommended.
9. A resistance bridge, 1% accuracy from 10 ohms to 100 kilohms.
10. An operational amplifier, dual, chopper stabilized with all required power supplies. An ORNL, model Q-2605-1 amplifier is recommended.
11. Resistors, ±0.5%, 250, 1, and 10 kilohms.
12. Potentiometers, composition, carbon, 2 w, linear, 5 and 100 kilohms.
13. A potentiometer, wire-wound, 4 w, linear, 200 ohms ±1%. A General Radio, type 301-A potentiometer is recommended (selected for 1% tolerance).
14. A capacitor, ceramic, ±20%, 25 v, 0.22 mf.
15. A capacitor, metallized paper, ±20%, 10 v, 50 mf.

6.2 General Test Procedures

6.2.1 Transistor Testing

Prior to any testing, all transistors should be checked for current amplification h_{FE} and collector saturation current I_{CBO}. The Baird-Atomic, model KT-1 tester or its equivalent is recommended. This instrument uses a 1-kc signal for measurement of h_{FE}. All transistors that do not fall within the ranges specified in Table 2 should be rejected. The operating voltages of the various transistors should be observed to avoid damage from excessive dissipation. Ohmmeters should not be used for checking transistors, because the allowable reverse base-emitter voltage may be exceeded for many transistor types.

Table 2. Transistor Characteristics

	Current Amplification			Collector Saturation Current		
Transistor	V_{CE} (v)	I_C (ma)	h_{FE}	V_{CB} (v)	I_E[1]	I_{CBO}
2N2219 (NPN)	+7.5	1	75 to 200	+7.5	0	No indication
2N2432 (NPN)	+7.5	1	50 to 200	+7.5	0	No indication
2N1279 (NPN)	+7.5	1	50 to 200	+7.5	0	No indication
2N1131 (PNP)	-7.5	5	20 to 60	-7.5	0	Less than 1 μa
2N696 (NPN)	+7.5	5	20 to 60	+7.5	0	Less than 1 μa
2N779 (PNP)	-4.5	5	75 to 150	-4.5	0	Less than 1 μa
2N2795 (PNP)	-7.5	5	50 to 100	-7.5	0	Less than 1 μa

[1]Emitter open.

Connect the +25 v and -25 v supplies to the module. Both supplies should be of similar construction such that the turn-on transients are approximately the same. Connect the module to the power mains so that they can be turned on with one power switch. The Harrison Twin Voltage Supply, model 800A-2, is very convenient for this application. Adjust the supply voltage outputs to within ± 10 mv of the 25-v value. The digital voltmeter should be used for this measurement.

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

6.2.2 Pulse Shaping Network

In the tests of amplifier gain and linearity, a pulse shaping network shown in Fig. 4 must be interposed between the ORNL model Q-1212 mercury pulser and the amplifier input. This network shapes the generator pulse to where it closely conforms to the pulse that normally is transmitted by the preamplifier and its associated pulse transformer. The shaped pulse will be double differentiated as shown in Fig. 2a. With the transformer connected as shown, a negative pulse is required from the pulser to give the correct output polarity. The network attenuates the generator pulse by almost a factor of five, and if one wishes to use the pulser pulse-height selector dial as a convenient representation of pulse amplitude, it must be normalized to some integral number of pulse height (1 v is very convenient) at the output end of the shaper.

Resistor R1 terminates the pulser output. C1 spoils the pulse rise time, and C2 in conjunction with R2 and the reflected secondary load resistor of 100 ohms, acts as the first differentiator. The second differentiation is accomplished by the primary inductance of the transformer and its associated shunt resistance. R2 also serves to dampen a tendency of the primary to produce another zero-crossing following the second half of the double-differentiated pulse.

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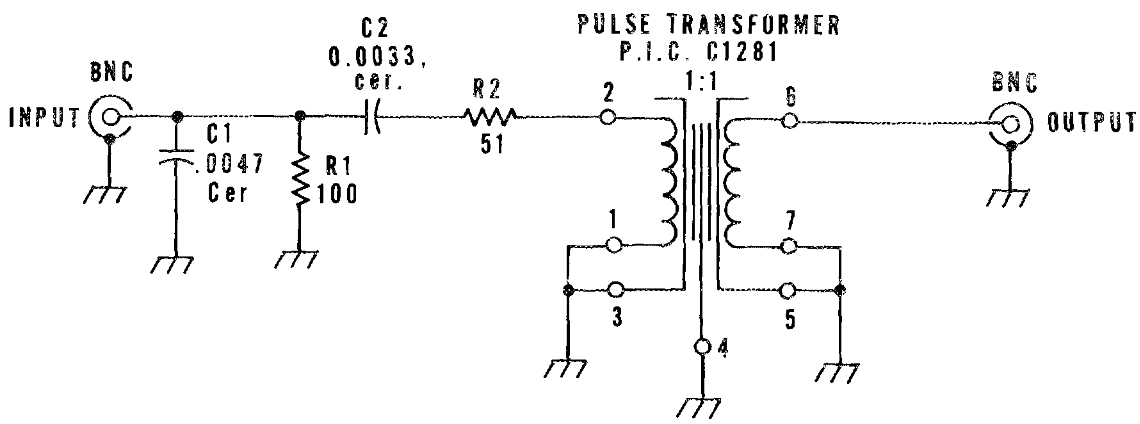

Fig. 4. Pulse-Shaping Network for Testing Module Q-2614.

6.3 Transistor Voltage Chart

All measurements in Table 3 were made with supply voltages adjusted to +25.00 ± 0.01 v and -25.00 ± 0.01 v with switch S1 in the "off" position and with both linear and log outputs grounded. Voltages shown in Table 3 were measured with a 5-digit voltmeter. A Triplett, model 630 VOM can be used with less accuracy.

Transistors Q13, Q14, Q15, Q16, and Q17 can have two values depending on the state of the flip-flop.

Table 3. Transistor Voltage Chart

Transistor No.	Emitter (v)	Base (v)	Collector (v)
Q1, 2N2219	+9.3	+9.9	+22.9
Q2, 2N2219	+9.3	+9.9	+13.4
Q3, 2N2219	+12.8	+13.4	+22.9
Q4, 2N2219	+8.2	+8.8	+23.5
Q5, 2N2219	+8.2	+8.8	+12.0
Q6, 2N2219	+11.4	+12.0	+23.5
Q7, 2N2432	+11.1	+11.8 to +6.8	+23.6
Q8, 2N2219	+11.1	+11.7	+16.2
Q9, 2N2219	+15.6	+16.2	+23.6
Q10, 2N2219	+10.0	+8.5	+24.2
Q11, 2N2219	+10.0	+10.7	+19.8
Q12, 2N2219	+11.5	+12.1	+24.2
Q13, 2N779A	+8.8/+8.5	+9.3/+8.1	+0.8/+8.4
Q14, 2N779A	+8.8/+8.5	+8.5/+9.0	+8.7/+0.4
Q15, 2N2795	0.0	+0.7/-0.3	-17.1/-0.1
Q16, 2N696	-16.4/+0.5	-17.1/-0.1	+24.4
Q17, 2N1131	-16.4/+0.5	-17.1/-0.1	-24.3
Q18, 2N1279	-0.5	0.0	+25.0
Q19, 2N1279	-1.1	-0.5	+25.0
Q20, 2N1279	-7.9	-10.4	-0.4
Q21, 2N1279	-7.9	-7.2	-3.7

6.4 Amplifier Gain and Overload

Figure 5 shows the equipment for testing amplifier gain and overload. The power ground of the positive supply is used (the ground of the negative supply may also be used) as the power ground of the test setup. This will be maintained throughout all tests.

6.4.1 Amplifier Gain

Turn the amplifier attenuator switch to the X1 position. Temporarily connect an oscilloscope to the amplifier input connector. Adjust the normalize control on the pulser for a 1-v output pulse as measured with the oscilloscope for a maximum setting of pulser pulse-height and with all attenuator switches in the "down" position, i.e., no attenuation.

Connect the oscilloscope to the amplifier output connector with the "X10" probe. Adjust the pulser pulse-height and attenuator switches until a 1.0-v pulse is observed; note the settings. Calculate the amplitude of the input pulse to the amplifier and compute the amplifier gain. It should be approximately 90. A deviation of ±5% is acceptable.

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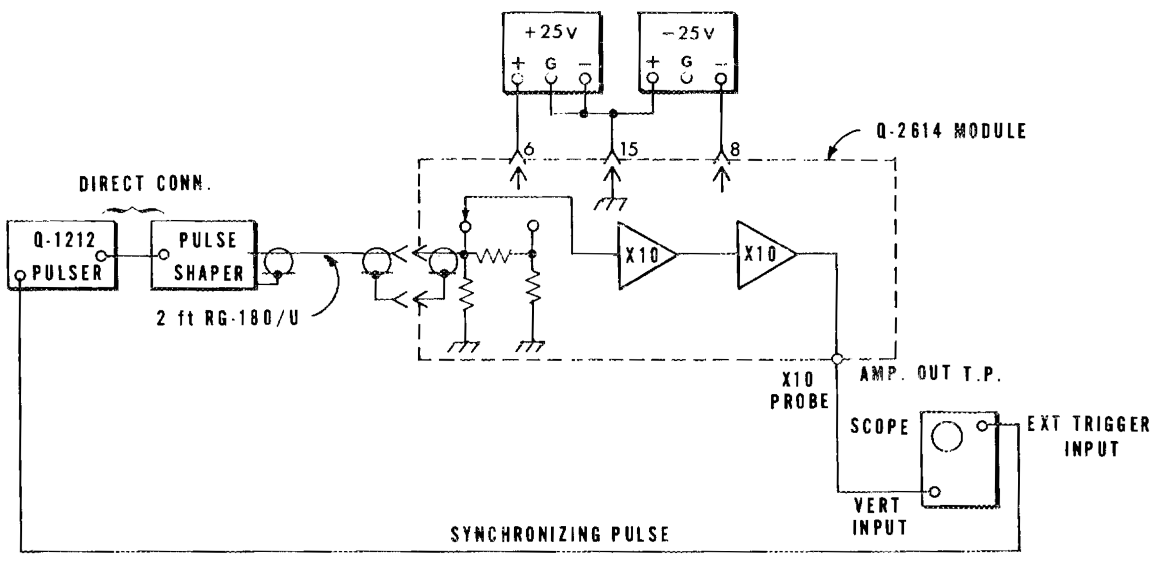

Fig. 5. Equipment for Testing Amplifier Gain and Overload.

6.4.2 Amplifier Attenuator Calibration

With the pulser normalized as above, successively adjust the amplifier attenuator switch from the "X1" position to the "X.01" position. At each position, adjust the pulser pulse-height and attenuator switches to keep the output pulse from the amplifierat 1 v. The product of the pulser setting and the amplifier attenuator setting must not vary more than ±2% at all positions. Do not use any setting of the pulser where the pulse-height reading is less than 100 divisions.

6.4.3 Amplifier Overload

Set the amplifier gain to the "X1" position and adjust the pulser until a 5-v output signal is observed at the output of the amplifier. Observe the waveform. Double the generator output and observe the waveform. Increase the generator output another factor of five and observe the output waveform. Compare these three waveforms with those shown in Fig. 2c, 2d, and 2e.

6.5 Adjustment and Measurement of Integral Linearity of Amplifier and Discriminator

Figure 6 shows a diagram of the equipment for this test. The procedure to be followed is taken from the Pulse Amplifier Manual,[3] Sect. 1.3.5, p. 10.

The linear count-rate meter, which is already a part of the Q-2614 module, is used to measure the half-triggering point (htp). One minor modification is required in the linear count-rate meter circuit. Temporarily shunt C39 with a 0.22-μf ceramic capacitor. This increases the output of the circuit so that enough current is available at the frequency of the pulser to be indicated on the 60-μa range of a Triplett multimeter.

When the pulse-height discriminator is correctly adjusted, the voltage drop across the pulse-height discriminator potentiometer R26 is 5.000 ± 0.005 v. This voltage (which determines the span of the discriminator) can be varied by changing the value of R32, which shunts R31. For the adjustment procedure to be outlined below, R32 should be disconnected at the terminal post at one end and a 5-kilohm carbon composition resistor (set at about mid-range) should be temporarily connected across R31. Also, so that the curve of pulse height vs the setting of the pulse-height selector will pass through zero when extrapolated, another adjustment must be made. This involves R25 shunted by R24, and R28 shunted by R27. These shunts, and the way they are adjusted, make the four-resistor network behave like a 200-ohm potentiometer. For the adjustment procedure, they should be temporarily disconnected and replaced by a 200-ohm potentiometer (±1 ohm overall resistance).

To temporarily remove these resistors, remove the jumper that connects the junction point of R24 and R25 to R23. Then remove the jumper that connects the junction point of R27 and R28 to R29. Then, temporarily connect the 200-ohm potentiometer between R23 and R29 (CW to R23, CCW to R29). The slider of the potentiometer is connected to the positive side of C10. These changes will result in the network shown in Fig. 7.

With the slider of the 200-ohm potentiometer somewhere near the mid-range, adjust the 5-kilohm potentiometer until 5.000 ± 0.005 v is observed across the PHD potentiometer R26. Use the digital voltmeter for this reading.

Check the mechanical zeros of the pulser pulse-height dial and amplifier PHD dial. With both controls in their counterclockwise (CCW) position, the dial reading should indicate less than half of a small division. At the full CCW position, the output of the pulser pulse-height potentiometer (A4 test point) should be no more than 3 mv. At the full CCW position, the voltage from the slider to the CCW terminal of the amplifier PHD potentiometer should be less than 5 mv.

Set the amplifier attenuator to the "X1" position and perform the following steps:

1. Set the PHD potentiometer of the amplifier and the pulse-height potemtiometer of the pulser to 500 divisions.
2. Adjust the pulser normalize potentiometer and attenuator switches until the half-triggering point (htp) is observed on the multimeter. A reading of about 600 on the normalize potentiometer with the X2 and X10 switch in the "up" position is typical.
3. Set the pulser pulse-height potentiometer to 250.0 and adjust the amplifier PHD until the htp is indicated. If these two dial readings do not agree, note the difference in readings and which side of the 250.0 mark the amplifier PHD potentiometer indicated the htp. Set the amplifier PHD dial to a point on the other side of the 250.0 mark such that the difference between the new reading and 250.0 is one-half the previously noted error. (Example: With the pulser set at 250.0, a typical amplifier PHD reading at the htp might be 240. The error is 10 divisions. Set the amplifier PHD dial to 255.)
4. Adjust the 200-ohm potentiometer until the htp is again established. At this point it will be necessary to recheck the voltage drop across the amplifier PHD potentiometer since there is some inter-reaction. If this is not found to be 5 ± 0.005 v, readjust the 5-kilohm potentiometer until it is re-established. Repeat all four steps until the amplifier PHD reading corresponds to the pulser reading at both the 500.0 and 250.0 dial marks.

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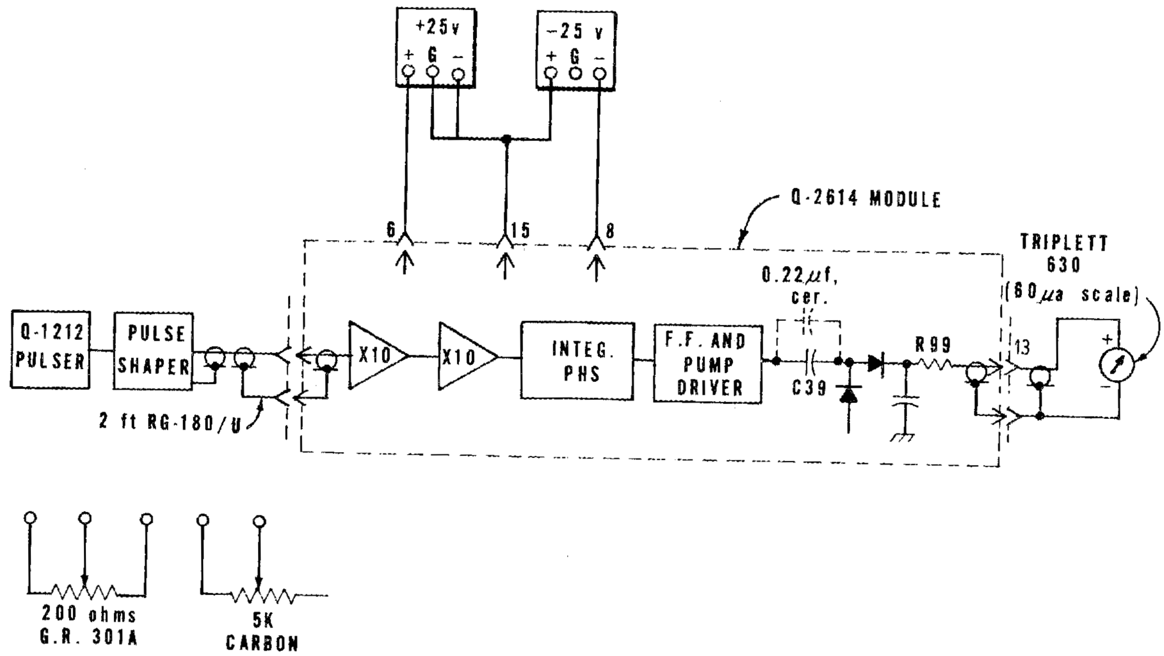

Fig. 6. Equipment for Testing Amplifier and Pulse-Height Discriminator Integral Linearity.

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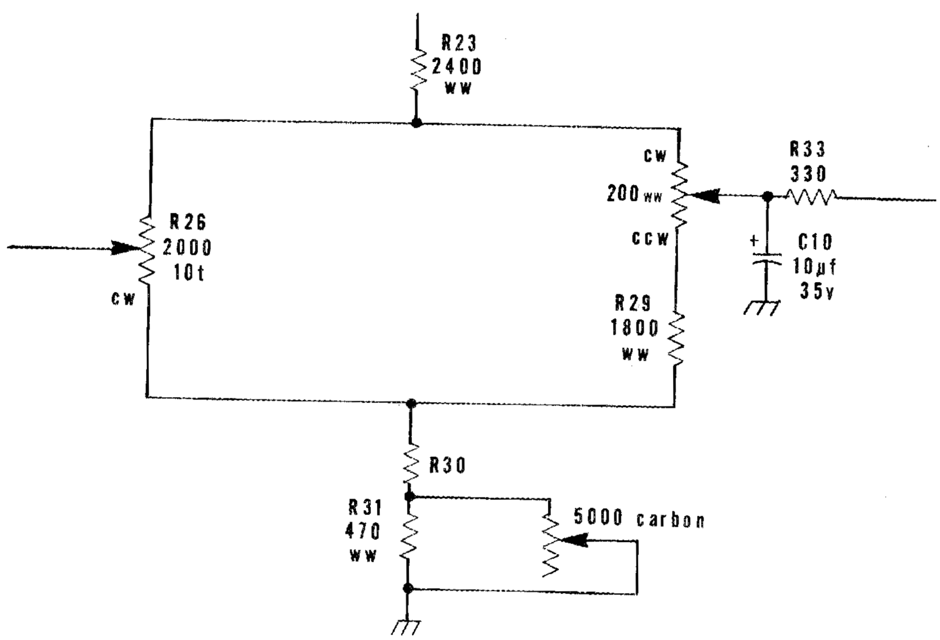

Fig. 7. Setup for Adjustment of Pulse-Height Discriminators.

Turn off the module power supplies and carefully remove the 5-kilohm and 200-ohm potentiometers without moving the sliders. Bridge the 5-kilohm potentiometer and select the nearest 5% composition carbon, 1/2-w resistor and put in shunt with R31. This resistor should not be less than three times the value of R31. Bridge either side of the 200-ohm potentiometer to the slider. Select the nearest 5%, composition carbon, 1/2-w resistors, which when placed in shunt with R25 (100 ohms) and R28 (125 ohms) will give the correct total resistance. Once again, the shunting carbon resistors should not be less than three times the value of the wire-wound resistors. Be careful not to overheat the carbon shunt resistors while they are being installed.

The linearity data may now be taken. Set the amplifier PHD dial to the various settings (50.0, 100.0, 200.0, 250.0, 300.0, 400.0, 500.0, 600.0, 700.0, 800.0, 900.0, and 1000.0) and adjust the pulser dial at each setting for the htp. Record the pulser dial values and plot the difference observed as a function of amplifier PHD setting. A typical curve is shown in Fig. 8. Remove the 0.22-µf ceramic capacitor from C39 before continuation of testing and adjusting.

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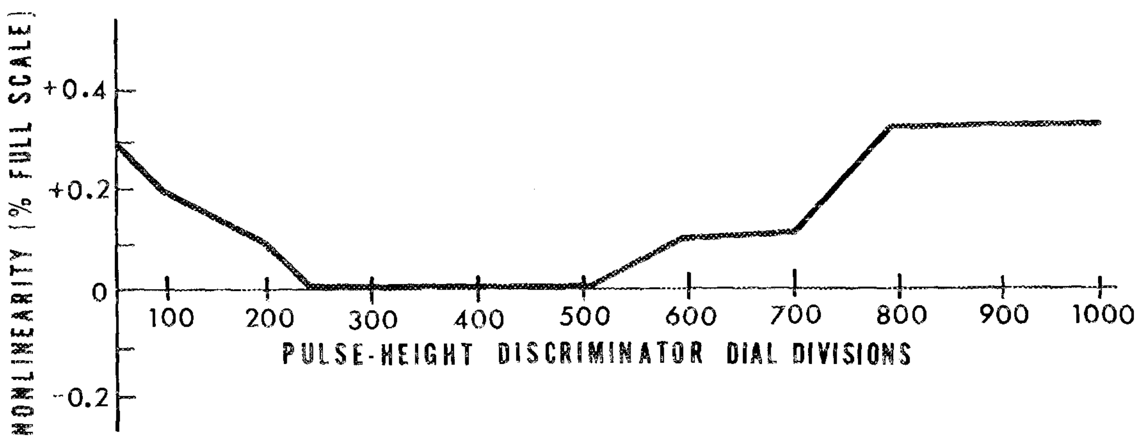

Fig. 8. Typical Pulse Amplifier and Discriminator Integral Nonlinearity Curve.

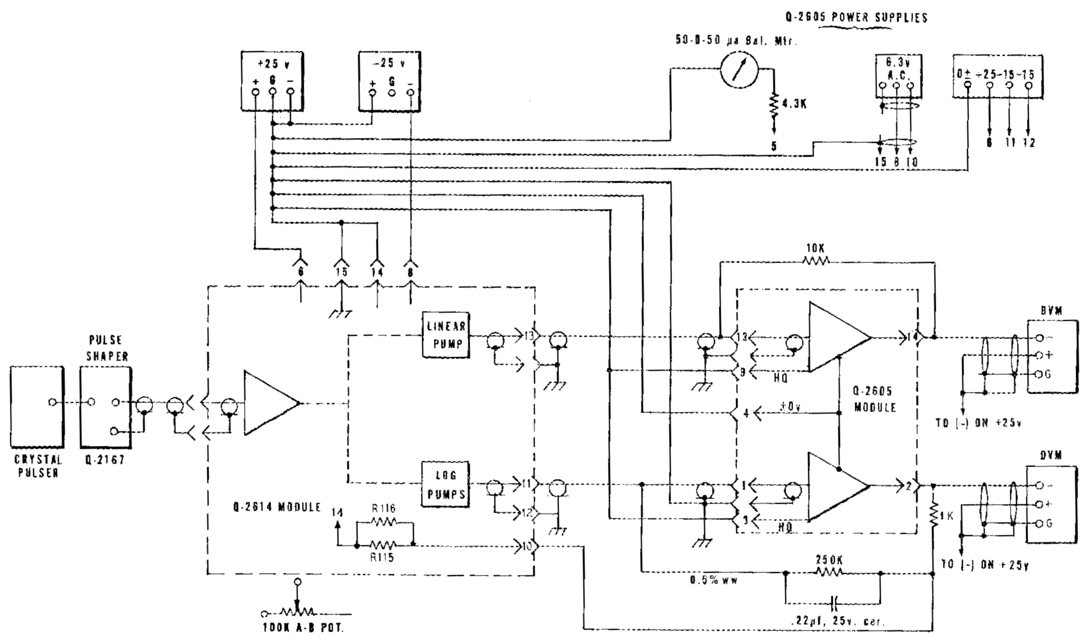

Fig. 9. Equipment for Testing Calibration of Log and Linear Count-Rate Meters.

6.6 Adjustment and Measurement of the Logarithmic and Linear Count-Rate Meter

Figure 9 shows the equipment for testing the calibration of the log and linear count-rate meter section of the Q-2614 module. For all testing the crystal-controlled pulse generator (Q-2167) should be set on fast rise time and 300 μsec decay time. Use the 0.5-v attenuated output.

Note the grounding in Fig. 9. It is important that the common ground for all dc supplies associated with the Q-2605 operational amplifiers and the ground and shield of the digital voltmeter be tied to the common ground of the +25 v and -25 v supplies of the Q-2614 module. The power ground of one of these supplies (-25 v or +25 v) should be made the power ground for the entire system. All other components should be isolated from power ground.

A small resistor (1 to 5 kilohms) in series with the digital voltmeter may be needed to decouple the "hot" voltmeter lead from the circuit to prevent the Q-2605 operational amplifier from oscillating. Before any data are recorded or any adjustments are made, the output of the Q-2605 amplifier should be checked to see that oscillation does not exist.

Prior to any testing, the Q-2605 amplifier must be checked for balance. This is done by connecting a 50-μa meter with a center-scale zero as shown in Fig. 9.

6.6.1 Log Count-Rate Meter

The adjustment of the log count-rate meter is as follows. Remove R116 from its terminal posts and temporarily connect a 100-kilohm potentiometer (adjusted to maximum value) across R115.

Set the pulser to 10 counts/sec. Adjust the amplifier gain and PHD until the module is providing pulses for the pump circuits. This can be determined by observing the pump-driver output connector (TP4). Square-wave pulses should be observed with an amplitude of 17.1 v ± 0.5 v. An improperly compensated oscilloscope probe will cause the waveform to appear to have a drooping or rising shape. The digital voltmeter at the output of the Q-2605 amplifier should be indicating close to -2 v. Adjust the output to read -2.000 ± 0.005 v with the "calibrate" potentiometer R112. At the 10-count/sec rate, the response of the pumps is slow. Make sure that the 10-count/sec reading has stabilized before making any adjustments. Two to three minutes should be adequate.

Set the pulser to 10^4 counts/sec. Adjust the 100-kilohm carbon potentiometer until the output is 8.000 ± 0.005 v. At this rate the response of the pumps is much faster, and not as much time is needed for stabilization; 30 sec is adequate.

Reset the pulser to 10 counts/sec and repeat the entire procedure until the instrument tracks at both the 10 and 10^4 count/sec points.

Remove the 100-kilohm potentiometer and bridge it. Replace it with the nearest ±5%, 1/2-w, carbon resistor. The value of this resistor should not be less than three times the value of R115. Install the resistor, taking care not to overheat it. Make the following calibration at the frequencies indicated in Table 4. The permissible error at each point is ±3%.

At frequencies less than 10 counts/sec, the fluctuation of the output voltage will make it difficult to obtain a good reading. It may be necessary to increase the size of the capacitor in shunt with the 250-kilohm wire-wound feedback resistor of the Q-2605 amplifier to 50 mf to smooth the signal. A good-quality metallized paper capacitor can be used. If there is still appreciable fluctuation, an average of the high and low readings will be acceptable.

6.6.2 Linear Count-Rate Meter

There are no adjustments associated with the linear count-rate meter.

Table 4. Log Count Rate Meter Calibration Chart

Pulser Frequency, f (counts/sec)	Output Voltage (v)	True Output Voltage ($v=2\log_{10}f$)	Deviation from True Output[1] (v)	Error[2] (In % of reading)
(1)	(2)	(3)	(4)	(5)
10^5		-10.000		
5×10^4		9.398		
2.5×10^4		8.796		
1.25×10^4		8.194		
10^4		8.000		
5×10^3		7.398		
2.5×10^3		6.796		
1.25×10^3		6.194		
10^3		6.000		
500		5.398		
250		4.796		
125		4.194		
100		4.000		
50		3.398		
25		2.796		
12.5		2.194		
10		2.000		
5		1.398		
2.5		0.796		
1.25		0.194		
0.75		+0.250		

[1]Column 2 minus column 3.

[2]Error $= \dfrac{\text{deviation (column 4)}}{\text{true output voltage (column 3)}} \times 100.$

With the pulser set at 10^4 counts/sec, the output from the operational amplifier should be 1.75 ± 0.1 v. With 0 counts/sec the output should be ±10 mv.

A calibration should be made at the frequencies indicated in Table 5. The true output voltage is calculated from a straight line drawn from zero through the 10^4 count/sec reading. The permissible error is the equivalent of ±25 counts/sec at each point.

Table 5. Linear Count-Rate Meter Calibration Chart

Pulser Frequency, f (counts/sec)	Output Voltage (v)	True Output Voltage	Deviation from True Output[1] (v)	Error[2] (% of reading)
(1)	(2)	(3)	(4)	(5)
0				
10^3				
1.25×10^3				
2.5×10^3				
5×10^3				
10^4				
1.25×10^4				
2.5×10^4				

[1]Column 2 minus column 3.

[2]Error $= \dfrac{\text{deviation (column 4)}}{\text{true output voltage (column 3)}} \times 100.$

6.7 10 and 10^4 count/sec Oscillator Calibration

Figure 9 describes the test equipment for calibration of the 10 and 10^4 count/sec oscillators. The crystal pulser is not needed. It is assumed that the procedure for adjustment and measurement of the log count rate meter has been followed as outlined in Sect. 6.6.

Set the amplifier attenuator switch to the 10 count/sec position. The amber "Calibrate" lamp will turn on. The output voltage of the operational amplifier connected to the log pumps should indicate 2 v ± 10 mv. Allow at least 3 min for stabilization. Rotate the amplifier PHD potentiometer from 50 to 1000 divisions. The output voltage should remain constant.

Set the amplifier attenuator switch to the "10 kc" position. The amber "Calibrate" lamp will remain on. The output voltage of the operational amplifier should indicate 8 ± 10 mv. Rotate the amplifier PHD potentiometer from 50 to 1000 divisions. The output voltage should remain constant.

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