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Charge-Sensitive Preamplifier for Use with Large Proportional Counter Arrays

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by

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James E. Swanson

*Work supported by Division of Nuclear Materials Security, AEC.

CHARGE-SENSITIVE PREAMPLIFIER FOR USE WITH LARGE PROPORTIONAL COUNTER ARRAYS

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ABSTRACT

A charge-sensitive preamplifier developed for use with large arrays of proportional counters is described. Positive feedback is utilized to essentially eliminate charge sensitivity dependence upon input capacity. The preamplifier operates from a single + 12 V power source, and its output is linear to about 4 V when operated into a 100-ohm load.

I. INTRODUCTION

A charge-sensitive, or integrating, preamplifier designed for use with large arrays of proportional counters is described in this report. Its characteristics are as follows:

a) Maximum output pulse amplitude, for negative input signals, is ~ 8 V (positive) unterminated, or ~ 4 V into 100 Ω.

b) Switch selectable charge sensitivity of 4.5×10^5 V/μcoul or 2.8×10^6 V/μcoul into a 100 Ω load.

c) The charge sensitivity is essentially independent of input capacity up to at least 5000 pF.

d) Input protected from high voltage transients.

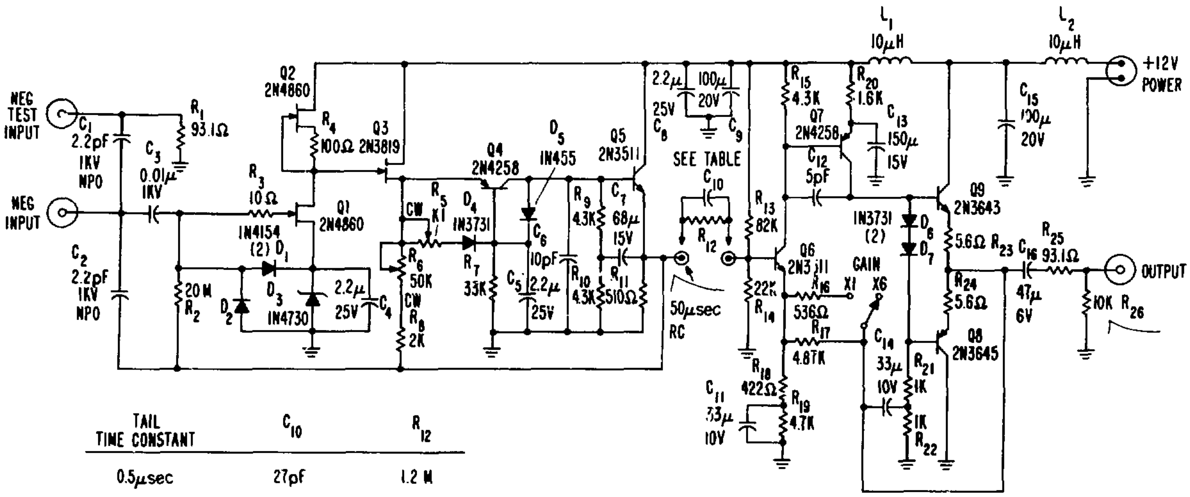
e) Output pulse decay time variable from 0.5 μs to 50 μs by means of small plug-in pulse shaping networks.

f) The preamplifier operates from a single + 12 V power source.

Although the preamplifier was designed for use with neutron detectors consisting of large proportional counter arrays[1, 2], it should prove useful in other counter applications involving high input capacitance.

II. CIRCUIT DESCRIPTION

A schematic diagram of the preamplifier is shown in Fig. 1. The charge sensitive input loop consists of Q_1-Q_5. A 2N4860 FET was chosen for Q_1 because of its very high g_m (typically 20-30 ma/V) in order to reduce the effect of input capacity on the preamplifier noise output. Q_2 is a constant current source for Q_1. Q_4 is a grounded base amplifier forming the upper half of a cascade amplifier with Q_1, with additional current gain provided by Q_3. Charge feedback is accomplished by means of the 2.2 pF capacitor, C_2, from the emitter of Q_5 to the gate of Q_1. The 20M resistor, R_2, shunting C_2 results in a pulse decay time of ~ 50 μs. Diodes D_1 and D_2 protect Q_1 from large



TAIL TIME CONSTANT	C_{10}	R_{12}
0.5μsec	27pF	1.2 M
1 μsec	56pF	510K
2 μsec	120pF	360K
5 μsec	390pF	82K
50μsec	0.5μf	NONE

Fig. 1. Preamplifier schematic diagram.

voltage transients that may occur when detector bias is suddenly applied or removed from the preamplifier input.

It is desirable to make the open-loop gain of the charge sensitive amplifier stage large in order to reduce the dependence of charge sensitivity on input capacity. As may be easily shown[3], the output, V_o, resulting from a charge Q at the input of a charge sensitive amplifier is given by

$$V_o = -(Q/C_f)[A/(1+A+C_i/C_f], \quad (1)$$

where

A = open-loop midband amplifier gain,
C_f = feedback capacitance,
C_i = input capacitance.

For $A >> (1+C_i/C_f)$, Eq. (1) becomes

$$V_o \simeq -Q/C_f; \quad (2)$$

hence for large open-loop gain the charge sensitivity is essentially independent of input capacity. Three techniques have been used in the present design to increase the open-loop gain: 1) Q_3 provides additional gain between Q_1 and Q_4, 2) the output of the emitter follower Q_5 is bootstrapped back to the collector load of Q_4, and 3) positive feedback[4,5] is applied to the emitter of Q_4 via R_6 and R_8 from the emitter of Q_5. With the proper adjustment of R_6, the open-loop gain can be made to approach infinity. A further increase in the positive feedback will result in the amplifier appearing to operate into a negative impedance, and the charge sensitivity will increase rather than decrease with increasing input capacity. R_6 should be adjusted so that the output pulse height changes less than 5% for a given input charge when the input capacity is increased from 0 to ~ 2000 pF. An increase in pulse height with input capacity should be avoided, since with too much positive feedback the preamplifier may become unstable for certain combinations of input capacity and shunt resistance. R_5 is used to set the operating point of the input loop: it should normally be adjusted to produce the fastest output pulse rise-time at the emitter of Q_5 under conditions of high input capacity (1000 pF or greater).

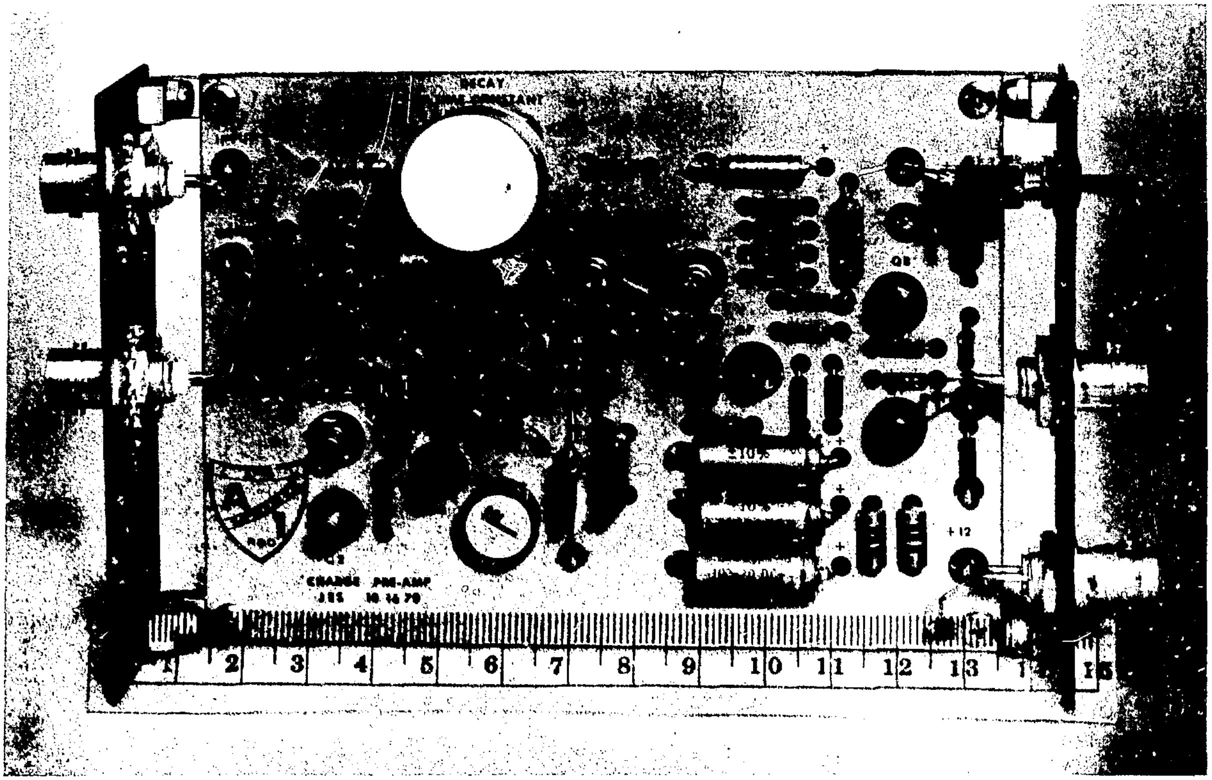


Fig. 2. Top view of completed preamplifier.

Transistors Q_6-Q_9 comprise the output amplifier, which is a feedback stabilized non-inverting amplifier of standard design. The output is linear to > 7 V into an open load, or ~ 4 V into a 100 Ω load for positive output pulses (negative preamplifier input). The output will saturate at about 1.5 V for negative output pulses. Signal coupling to the output stage is through a pole-zero compensation network consisting of C_{10} and R_{12}. Any output pulse decay time in the range of about 0.5 μs to 50 μs can be obtained by changing the values of C_{10} and R_{12}; values for several decay times are given in Fig. 1. The output pulse rise-time obtainable from the preamplifier will depend upon the input capacitance, increasing from < 0.1 μs for no external input capacity to about 0.5 μs for 1500 pF input capacity.

III. PREAMPLIFIER CONSTRUCTION

The preamplifier is constructed on a 5 in. x 3 11/16 in. printed circuit board and housed in a 6 in. x 4 in. x 1 3/4 in. aluminum box. A photograph of the preamplifier is shown in Fig. 2; components are identified in Fig. 3. The interstage coupling network is contained in a potted plug-in module, shown in the upper part of Fig. 2. Each module contains three coupling networks, connected between pairs of protruding pins, so that any one of three output pulse decay times may be selected by changing the position of the module in the socket mounted on the circuit board. A complete parts list is given in the Appendix.

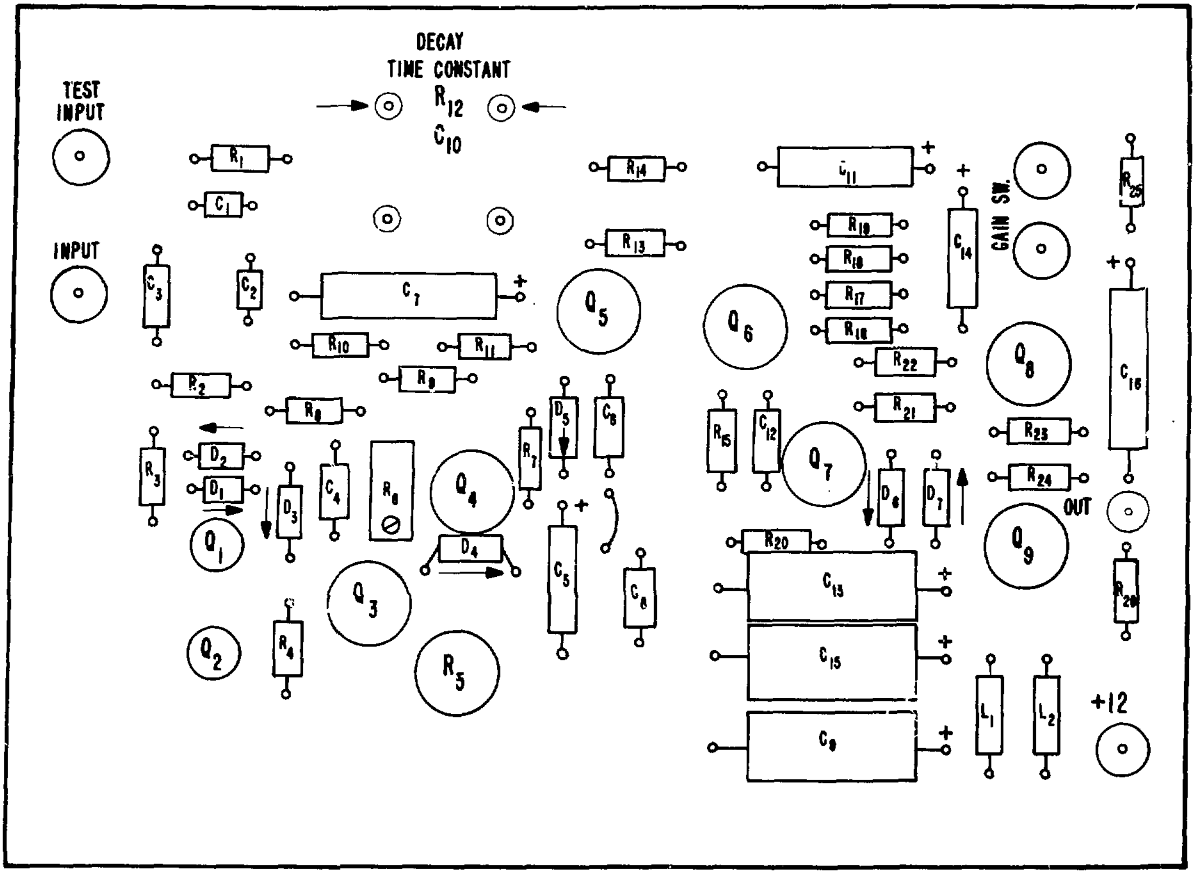


Fig. 3. Component layout. Refer to Fig. 1 or the Appendix for component values.

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3. See, for example, R. L. Chase, Nuclear Pulse Spectrometry (McGraw-Hill, New York, 1961) Ch. 2.

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APPENDIX

ELECTRICAL PARTS LIST

Circuit Reference	Description
C_1, C_2	Capacitor, ceramic disc, NPO, 2.2 pF, 1 kV.
C_3	Capacitor, ceramic disc, .01 μF, 1 kV.
C_4, C_5, C_8	Capacitor, ceramic, 2.2 μF, 25 V.
C_6	Capacitor, silvered mica, 10 pF.
C_7	Capacitor, tantalum, 68 μF, 15 V.
C_9, C_{15}	Capacitor, tantalum, 100 μF, 20 V.
C_{10}	Capacitor, silvered mica or ceramic*
C_{11}, C_{14}	Capacitor, tantalum, 33 μF, 10 V.
C_{12}	Capacitor, silvered mica, 5 pF.
C_{13}	Capacitor, tantalum, 150 μF, 15 V.
C_{16}	Capacitor, tantalum, 47 μF, 6 V.
D_1, D_2	Diode, silicon, 1N4154.
D_3	Diode, silicon zener, 1N4730.
D_4, D_6, D_7	Diode, silicon, 1N3731.
D_5	Diode, germanium, 1N455.
L_1, L_2	Inductor, 10 μH.
Q_1, Q_2	Transistor, silicon, N-channel field effect, 2N4860.
Q_3	Transistor, silicon N-channel field effect, 2N3819.
Q_4, Q_7	Transistor, silicon PNP, 2N4258.
Q_5, Q_6	Transistor, silicon NPN, 2N3511.
Q_8	Transistor, silicon, PNP, 2N3645.
Q_9	Transistor, silicon NPN, 2N3643.
R_1, R_{25}	Resistor, metal film, 1%, 93.1 ohm, 1/8 W.
R_2	Resistor, composition, 5%, 20M, 1/8 W.
R_3	Resistor, metal film, 1%, 10 ohm, 1/8 W.
R_4	Resistor, composition, 5%, 100 ohm, 1/8 W.
R_5	Potentiometer, 1-turn trimmer, cermet, 1K.
R_6	Potentiometer, 20-turn trimmer, cermet, 50K.
R_7	Resistor, composition, 5%, 33K, 1/8 W.
R_8	Resistor, composition, 5%, 2K, 1/8 W.
R_9, R_{10}, R_{15}	Resistor, composition, 5%, 4.3K, 1/8 W.
R_{11}	Resistor, composition, 5%, 511 ohm, 1/8 W.
R_{12}	Resistor, composition or metal film*
R_{13}	Resistor, composition, 5%, 82K, 1/8 W.
R_{14}	Resistor, composition, 5%, 22K, 1/8 W.
R_{16}	Resistor, metal film, 1%, 536 ohm, 1/8 W.
R_{17}	Resistor, metal film, 1%, 4.87K, 1/8 W.

ELECTRICAL PARTS LIST (cont)

Circuit Reference	Description
R_{18}	Resistor, metal film, 1%, 422 ohm, 1/8 W.
R_{19}	Resistor, composition, 5%, 4.7K, 1/8 W.
R_{20}	Resistor, composition, 5%, 1.6K, 1/8 W.
R_{21}, R_{22}	Resistor, composition, 5%, 1K, 1/8 W.
R_{23}, R_{24}	Resistor, composition, 5%, 5.6 ohm, 1/8 W.
R_{26}	Resistor, composition, 5%, 10K, 1/8 W.

* Value determined by pulse decay time desired. See table in Fig. 1.