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AI-AEC-MEMO COVER SHEET

REPORT TITLE **LOAD-SENSITIVE, LOW NOISE PULSE PREAMPLIFIER FOR USE WITH
SEMICONDUCTOR DETECTORS OF NUCLEAR RADIATION.**

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AI-AEC-MEMO 12706

(This Document Contains _____ Pages.)
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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		AI-AEC TDR NO 12706		APPROVALS <i>E. J. Jones</i>	
TECHNICAL DATA RECORD		PAGE 1 OF 9			
AUTHOR K. Langrod <i>KL</i>		DEPT & GROUP NO 737-730		DATE May 24, 1968 GO NO 7700	
TITLE Load-Sensitive, Low Noise Pulse Preamplifier for Use with Semiconductor Detectors of Nuclear Radiation		S/A NO 35431		TWR	
PROGRAM SUBACCOUNT TITLE Burnable Poison Studies		SECURITY CLASSIFICATION			
		(CHECK ONE BOX ONLY)		(CHECK ONE BOX ONLY)	
DISTRIBUTION RL Detterman C-2 IP Inglis C-5 LJ Jones SS-55 K. Langrod C-1 JP Page SS-55 JT Roberts C-1 JH Shively C-1 JH Walter C-1 WA Young C-1 TJ LaChapelle, Jr. Autonetics-547-072 (3)		AEC DOD UNCL. ☒ ☐ CONF. ☐ ☐ SECRET ☐ ☐		RESTRICTED DATA ☐ DEFENSE INFO. ☐	
		AUTHORIZED CLASSIFIER SIGNATURE DATE <i>E. J. Jones</i> 5/24/68			
STATEMENT OF PROBLEM The use of a burnable poison (e.g., Gd_2O_3) as a coating on SNAP fuel requires development of a reliable non-destructive method of determining the thickness and distribution of the poison. Absorption of α -particles by the coating (the fuel is the source) may be a suitable NDT method.					
ABSTRACT The design and construction of a novel detector preamplifier is described that has a stability of output increased by an order of magnitude, as compared with a common voltage preamplifier.					
NOTE: This is a translation, from Polish, of a paper by M. Dakowski and M. Sowinski, from the Institute for Nuclear Research in Warsaw, published in Nukleonika, 8, No. 4, pp 280-284 (1963).

I. INTRODUCTION

Methods of nuclear detection and spectroscopy by means of semiconductor devices have been developing rapidly for the past three years and require electronic instrumentation, the properties of which have been unknown until now^(1,2).

In the instruments applied to date for detection (ionization chambers, proportional counters, scintillation counters), the capacitance of the given instrument is fixed. On the other hand, the capacitance of a semiconductor detector is variable and depends on its active surface, the applied voltage, and its degree of deterioration, all of which cause changes in the amplitude of the exit pulse.

In order to eliminate detrimental changes in the pulse amplitude, the suggestion of Cottini and others^(3 - 6) was further developed relative to the application of a negative reverse voltage to the grid of the first tube through a small capacitor, C_o . This arrangement practically assures that the amplitude of the exit pulse will be independent of the capacitance of the semiconductor detector if the following condition is fulfilled:

$$k C_o \gg C_{det} \quad (1)$$

where k = amplification of the entrance level without the reverse voltage,
 C_{det} = the capacitance of the detector.

This configuration permits an increase in the stability of the detector preamplifier output by an order of magnitude, as compared with a common voltage preamplifier.

In connection with the ever increasing application of semiconductor detectors in research work in Poland, it became necessary to develop a design that would equal the best developed abroad and at the same time be made of materials obtainable at home.

II. PREAMPLIFIER CONSTRUCTION

The design developed was based on a schematic of Fairstein's preamplifier⁽³⁾. It consists (Figure 1) of a cascade with the charge voltage (Tubes L_1 , L_2), a triode with a high return voltage (L_3 , L_4), a shaper and divider, and a White repeater (cathode follower ?) at the exit tube (L_5).

In the cascade step and at the exit of the triode a so-called "boot strap" circuit is used in order to increase the amplification (especially important in the load voltage step) and the widening of the dynamic range of linearity, occurring in the case of fission fragments in the presence of strong (of the order of 10^6 pulses/sec) radioactivity.

The best signal to noise ratio can be achieved in a design that has equal time constant differentials and integrals $\gamma_r = \gamma_c = \gamma$ (see, for example, Reference 9). Therefore, in order to assure workability with conventional amplifiers, the design as $\gamma_r = \gamma_c = \gamma$ with the following values of γ : 0.2, 0.5, 1, 2.5 and 5 sec.

The choice of the optimal time constant depends on the properties of the detector (its capacitance, current losses, and non-uniformity in charge collection) and can improve, by many multiples, the discrimination capability of the design. F. Goulding⁽⁷⁾ gives the following equation for the optimal time constant

$$\gamma_{\text{opt}} = 0.35 C_{\text{det}} / \sqrt{g L_L} \quad (2)$$

where g = mutual conductance of the input tube and L_L = the sum of the grid current of the input tube and detector leakage.

The divider is needed for the measurement of large particle energy (e.g., of fission fragments where the energy approaches 100 Mev). The White repeater assures a low output impedance matching the 75 ohm cable, and the possibility of working with a loaded coaxial cable of 10-90 meters in length.

One can easily substitute (by one soldering) the Soviet tube 6C3 η * for the input tube E83F which has been described in the literature^(3,6) as one of the best with respect to low noise. The results with this tube in our circuit are better than with the E83F.

In order to achieve high stability and assurance of proper work, long life tubes (10,000 hours) and high stability elements were chosen. Miniature metallized resistors of the Soviet type MLT increased the thermal stability of the instrumentation and diminished its dimensions.

The output coupling capacitor was chosen with the smallest possible temperature coefficient, $\sim 4.0 \times 10^{-5} \text{ }^{\circ}\text{C}$.

In order to obtain the lowest possible noise level the following steps were taken:

1. A cascade step with reduced amplifying current was used at the input.
2. The input tube was used with reduced filament current (non-glowing).
3. Resistors with a low noise coefficient were used.
4. Direct current was used for the filaments.
5. Low ripple (1.2 mv) plate voltage was used.
6. The optimal time constant, τ , was selected.

Due to the high sensitivity of the preamplifier, the noise in the main amplifier constitutes less than 0.6% of the total noise (scale for $C_{\text{det}} = 0$).

The power supply of the semiconductor detector, which is built into the preamplifier, gives a supply voltage to the detector within the limits of 0 - 200 v.

Due to the good filtering of this power supply, the noise has an unmeasurably small amplitude ($U_{\text{noise}} < 0.3 \text{ } \mu\text{v}$). The bias current flowing through the divider of the input circuit (2 ma) allows for the correct amplification for detector surfaces from the smallest to the largest ($\sim 7 \text{ cm}^2$) so far used in our laboratory.

* This is a bantam triode requiring 6 v for the heater.

Despite its high sensitivity, the preamplifier shows no tendency to oscillate if properly mounted. It is constructed from copper sheet (about 1.5 mm thick) for better cooling and to prevent parasitic voltages.

The preamplifier is protected from electromagnetic disturbances by an iron cage and iron shielding on the feed cables.

The plate supply is received from a specially constructed power supply of high stability ($\sim 0.1\%$ per day for 300 v anode voltage) and low output ripple (< 1.2 mv).

The constant filament voltage, obtained from a transistorized power supply which is Zener diode stabilized, has a variation of 5 - 10 mv and a long term stability of better than 2% per day (assuming net voltage variations of $\pm 10\%$ and temperature variations of the surroundings of $\pm 10^\circ\text{C}$).

III. PREAMPLIFIER PROPERTIES

The overall sensitivity of the preamplifier is given by

$$S = 1.33 \times 10^{13} \text{ V/coul} = 0.25 \text{ V/Mev} \quad (3)$$

For the minimum input capacitance the noise with the 6C37 tube is equivalent to 4.3 kev and with the E83F tube to 4.5 kev. These correspond to the following charges: $Q_e = 8.1 \times 10^{-17}$ and 8.5×10^{-17} coulombs and $N_e = 500$ and 525 electrons, respectively, for 4.3 and 4.5 kev.

In the accessible world literature, only Fairstein's results are better ($f = 3.5$ kev); others ^(7,8,10) report f varying from 5 to 12 kev for minimum input capacitances.

The dependence of noise on the input capacitance is shown in Figure 2. Our results (for tubes E83F and 6C37) are shown as solid lines and Fairstein's ⁽³⁾ (for tubes E83F and 417A) as dashed lines. At higher detector capacitances the noise reaches a minimum at large time constants (2 - 5 μs). For small capacitances and small detector loss currents, the optimum moves in the direction of higher frequencies ($\gamma = 0.5 \mu\text{s}$). The long term stability of the preamplifier is better than 0.5% per day.

It should be noted that this preamplifier can also be adapted to detectors of constant capacitance in cases where the connection between the detector and the preamplifier must be made by a long coaxial (high capacitance) cable.

The preamplifier, together with the amplifier, have been working for the last couple of months in our laboratory and performs very well. With its help, the semiconductor detectors developed at Institute II, by Dr. Chwaszczewska have achieved the excellent resolving power of about 16 kev (0.18%) for α -particles of 8.78 Mev.

The precision of the measurements is limited by the stability of the main amplifier and by the multichannel analyzer. The possibility of continuous control of the sensitivity of the circuit is assured by Input II, where a standard pulse can be applied through the small capacitor from a pulse generator.

At present, a high stability, step-type amplifier with an amplification factor of 20 (after pulse reception) has been constructed. This will permit the investigation of particular regions of the pulse shape and will thus increase the discrimination capability of our 100-channel pulse height analyzer, "Raduga", by a factor of 20. This amplifier has proportionally decreased the influence of the instability of the analyzer on the measurement of the stability of the amplifiers.

IV. METHOD OF MEASURING PREAMPLIFIER NOISE

The most meaningful measurement of noise depends on its expression by the discrimination capability, f . The relation between this factor and the equivalent charge can be expressed by the equation

$$f(\text{kev}) = 5.3 \times 10^{16} Q_e (\text{coul}) \quad (4)$$

where $f(\text{kev})$ corresponds to the full width at half maximum (f.w.h.m.), expressed in kev, and $Q_e (\text{coul})$ is the effective value of noise expressed in coulombs.

In order to eliminate the subjective factors in the measurement of noise and to increase the accuracy of its measurement, a circuit represented by the block diagram of Figure 3 was used. G is a pulse generator which produces fast rise-time pulses with stable and accurately measurable amplitude (of the order of millivolts); R is $\sim 100 \Omega$; C_1 is ~ 1 pF; C_{det} represents the capacitance of the detector; Q is the charge preamplifier; W is the pulse amplifier; and A is the pulse height analyzer.

Noise, Q_e , is determined by measuring

- The charge at the input of the preamplifier = $Q(\text{coul})$
 $= V_{gen} C_1$
- The pulse amplitude at the amplifier input, $A(V)$.
- The total width at half-maximum (haziness due to the internal noise of the preamplifier and amplifier), $f_v(V)$.

$$Q = Qf_v / 2.35 A = V_{gen} C_1 f_v / 2.35 A \quad (5)$$

in which the factor 2.35 is derived from the calculation of the root-mean-square from the total width.

The formula for the noise value, expressed as discrimination capability of the system, is derived from the above relations:

$$f = 22.5(f_v/A) V_{gen} C_1 \quad (6)$$

where $f = \text{kev}$; $f_v = \text{v}$; $V_{gen} = \text{mv}$; and $C_1 = \text{pF}$.

Received: November 8, 1962

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NO. AI-AEC-TDR 12706

DATE 5/24/68

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