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A HYBRID, BROADBAND, LOW NOISE CHARGE PREAMPLIFIER FOR SIMULTANEOUS HIGH RESOLUTION ENERGY AND TIME INFORMATION WITH LARGE CAPACITANCE SEMICONDUCTOR DETECTOR

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Summary

A broadband and low noise charge preamplifier was developed in hybrid form, for a recoil spectrometer requiring large capacitance semiconductor detectors. This new hybrid and low cost preamplifier permits good timing information without compromising energy resolution. With a 500 pF external input capacity, it provides two simultaneous outputs : (i) the faster, current sensitive, with a rise time of 9 nsec and 2 mV/MeV on 50 Ω load, (ii) the lower, charge sensitive, with an energy resolution of 14 keV(FWHM Si) using a RC-CR ungated filter of 2 µsec and a FET input protection.

Introduction

Many circuits have been designed for the treatment of charges generated by semiconductor detectors [1]. For large capacitance (C_T = 500 pF) thin detectors, the signal amplitude delivered by voltage amplifiers is very low. The energy resolution turns much too high. The current signal, which is proportional to the collecting time, is usually very short for this type of detectors. Therefore the timing information may be obtained either through a pick-off system or, directly after the current amplifier, through a constant fraction discriminator [2]. This timing information is also given either at the output of a charge preamplifier when the rise-time is very short [3,4] or after filtering by zero-crossing detection [5]. All these techniques produce very good experimental results but also show some disadvantages. The configuration which we propose, as well as that one described by Sherman [6], allows one to obtain simultaneously timing and energy information. The faster of these, current sensitive, is a timing output. In this way, the delay time between the event and its detection is reduced to a minimum. This is of particular importance with an experiment of the recoil-spectrometer type when multi-coincidences are needed between many different types of detectors. The slower pulse is obtained from the output of the charge sensitive loop. Finally, the circuit is simple enough so as to make a hybrid design evolution possible.

Configuration of the preamplifier

The proposed configuration is presented on Figure 1. A fraction of the FET generated current is amplified by A_i. This current charges the feedback capacity C_f and gives the fast timing-signal. The voltage variation across C_f, read by the voltage amplifier A_v, provides the energy information. The response of the circuit to a short pulse of current I is as follows :

$$e_{3(t)} \simeq -\frac{\alpha I}{C_f} e^{-\frac{\alpha}{R_f C_f} t} \qquad (1)$$

for $(A_i + B_i) R_f g_m > \alpha$

A_i and B_i : current gain in e_2 and e_3

α : voltage gain of A_v

For a unit-gain (α = 1) one should consider the general case, presented on Figure 2. The total input capacity (detector, FET, parasitics) is represented by C_1. The output impedance in e_2 may be assimilated to

$$Z_o(j\omega) = \frac{R_o}{1 + j\omega R_o C_o} \qquad (2)$$

and the feedback impedance value is :

$$Z_f(j\omega) = \frac{R_f}{1 + j\omega R_f C_f} \qquad (3)$$

If one takes $A_i g_m$ constant on the whole frequency band considered, it is possible to evaluate the variations of e_2 and I_2. The voltages in e_1 and e_2 are equal to :

$$e_2(j\omega) = I(j\omega) \frac{(1 - A_i g_m Z_f) Z_o}{j\omega C_1 (Z_o + Z_f) + 1 + A_i g_m} \qquad (4)$$

these values, for a FET slope of 50 mA/V is 10 ns. The contribution of the amplifier band - width increases when C_T decreases. There - fore one obtains better results with a simulation program of the IMAG2 type (Appendix). The whole circuit is shown on Figure 4. All the cir- cuit parts are mounted on a 1" x 0.5" ceramic substrat and assembled in a 2 x 10 pin package (Figure 5).

Performances

The equivalent noise charge (CEB) of the preamplifier depends directly on the FET noise sources [8] and on the detector characteristics. For high input capacities, one may consider that the CEB is equal to :

$$(CEB)^2 = \underbrace{\frac{e^2}{2} A_f C_T^2}_{A} + \underbrace{\frac{e^2}{2} \frac{KT}{\tau} \frac{0.7}{g_{m_o}} C_T^2}_{B} + \underbrace{\frac{e^2}{4} q \tau I_{inv}}_{C} \quad (21)$$

where C_T is the total input capacity, I_{inv} the total leakage current, τ the filtering time con- stant and A_f definee the noise in 1/f. The 1/f and white noise in series, A and B are repre- sented on Figure 6 for the two types of tested transistors. Their contribution to the total noise is important. The mean measured values are respectively :

C413N $A_f = 1.6 \ 10^{-14}$ volt^2, $g_{m_o} \simeq 55$ mA/V

2N4393 $A_f = 2 \ 10^{-14}$ volt^2, $g_{m_o} \simeq 25$ mA/v

(2 FET mounted in parallel).

With A_f and g_{m_o} one can make an estim- ation of the energy resolution in terms of the detector parameters. This evaluation is very close to the results obtained with a 800 mm^2, 200 micron thick, RTC silicium detector (Figure 7). For an input capacity of 250 pF, the elec- tronic contribution is 8.5 keV FWHM and for 500 pF it reaches 13.5 keV, for a RC-CR filtering of 2 µsec. The maximum positive out- put signal is equivalent to 100 MeV referred to Si detector. The maximum negative signal level is about 25 MeV.

The noise current, at the input of the sensi- tive part of the current, measured on a frequen- cy band of 10 MHz (RMS Fluke) is 50 nA for a total input capacity C_T of 500 pF. In fact, this corresponds to the noise generated by the channel resistance :

$$\overline{I_c} = (4KT \frac{0.7}{g_{m_o}})^{1/2} C_T = \text{amp/Hz}^{1/2}$$

The amplitude and time responses are given in Figure 8, with C_T = 2.2 pF. To this end, the current is injected by a low internal impedance tension generator, with a test capaci- ty equivalent to the total input capacitance C_T.

The injection time being very short, the output amplitude as well as the rise-time depend direct- ly on the bandwidth of the amplifier and on the circuit parameters (Equation 17).

The output pulses, current and charge sen- sitive, are shown on Figure 9, for a charge injec- tion equivalent to 6.5 MeV, Si, using 500 pF external input capacitance. Figure 10 shows the same outputs obtained with the already men- tioned detector and a thoron α source (6.06 - 8.78 MeV). This allows one to appreciate the concribution of its undepleted zone resistance.

Conclusion

The performances of the described circuit easily show that significant improvement is poss- ible, in timing and energy resolution, with low cost hybrid circuit design.

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Appendix

The device models for circuit analysis programs are shown on Figure 11. With the steady-state operating conditions of current and voltage, the small signal transistor circuit mo- del parameters were determined as follows :

$r_e(\Omega) = 27/I_e$ (mA), $g_m = \frac{g}{(\beta+1)r_e}$, $gb'_e = \frac{1}{r_e(\beta+1)}$

and $Cb'_e = (1/\omega_T r_e) + C_{ib}$

rbb' can be determined from the expression of noise figure or by measuring h_{11_e} at a relative- ly high current and frequency, i.e. ,

$h_{11_e} \simeq rbb' + r_e \omega_T / \omega$

The field effect transistor paramoters are given by the manufacturer's data sheets. The circuit of Figure 4 was analyzed using simula- tion program IMAG2. The parasitic inductance and capacitance associated to the components we used were introduced into the program descrip- tion circuit. The plot of Figure 12 shows the output transient response predicted for a 1 MeV equivalent charge electronic injection by means of a 1 pF capacitor. Good agreement is obtain- ed between the predicted and experimental results.

	J_2		e_2	
	$\theta > 3\tau_m$	$\theta < \tau_m$	$\theta > 3\tau_m$	$\theta < \tau_m/3$
Rise time	$2.2\ \tau_m$	θ	θ	$2.2\ \tau_m$
Max. amplitude	$I\left(\frac{C_f+C_o}{C_f}\right)$	$I\left(\frac{C_f+C_o}{C_f}\right)(1-e^{-\theta/\tau_m})$	$\theta I/C_f$	

Table 1

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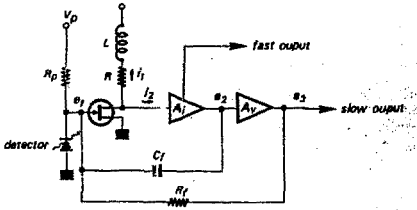

Figure 1 - Basic preamplifier stage

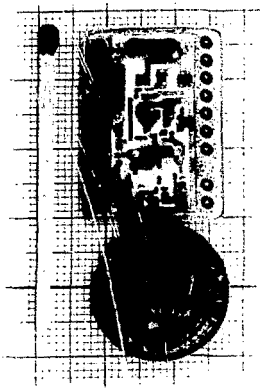

Figure 5 - Hybrid circuit photography

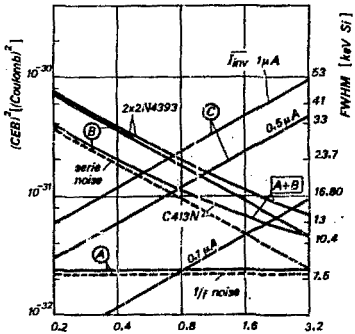

Figure 6 - Noise sources for two types FET with C_T = 500 pF

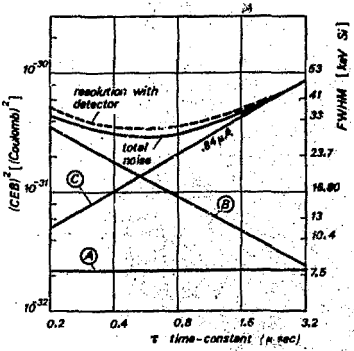

Figure 7 - Calculated total noise (A+B+C) and resolution obtained with RTC 102 detector (thoron α source)

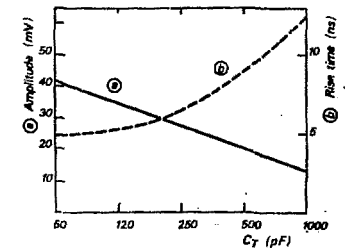

Figure 8

Plot of amplitude and time responses vs total input capitance C_T (equivalent injection : 6 MeV Si).