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Design and Development of a Charge-Sensitive Preamplifier for Nuclear Pulse Processing

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Abstract
Authors attempt to describe a Charge-Sensitive Preamplifier for fast Pulse Processing. The charge sensitive preamplifier uses a capacitor in place of the feedback resistor. The input capacitance of this circuit is $C_{in} = AC_f$, where A is the open-loop gain of the op-amp. If the op-amp gain is high enough that $C_i << C_{in}$, the external capacitance can be neglected. The charge Q is stored onto the feedback capacitor C_f, producing an output pulse of height $V= -Q/C_f$ independent of the detector and stray capacitances. Since there is a high voltage on the detector electrode, the amplifier input is connected to the cathode of the GM detector through a ground full-up Resistor.

Keywords: Radiation, Detector, Op-amp, Preamplifier and Charge-Sensitive Preamplifier.

1. Introduction

The preamplifier’s function is to terminate the capacitance quickly and therefore to maximize the signal-to-noise ratio. It also serves as an impedance matcher, presenting high impedance to the detector to minimize loading, while providing a low impedance output to drive succeeding components [1]. Solid-state strip detectors based on Ge or CdZnTe, both good spatial resolution and excellent energy resolution; require compact, low-noise electronics with a high number of channels [2]. Charge Sensitive preamplifier used for detection of soft X-ray and low to high energy gamma rays with high gain, low noise, excellent integration linearity, high-speed rise time and high temperature stability, etc. has been presented [3].

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A charge sensitive preamplifier with high gain, low noise and very fast rise time for G-M tubes and many scintillation counter applications, Q is sufficiently large so that a fairly large voltage is produced by integrating this charge pulse across the summed capacitance represented by the detector, connector cable, and input of the recording circuitry has been proposed in this paper. The current system has derived from Study and Implementation of 20 channels charge-sensitive preamplifier using Eagle [4].

$$A >> \left(Ci + Cf\right)/Cf$$
$$Vout = -AVin$$
$$Vout = -A\frac{Q}{Ci + (A+1)/Cf} \qquad (1)$$
$$Vout \cong -\frac{Q}{Cf}$$

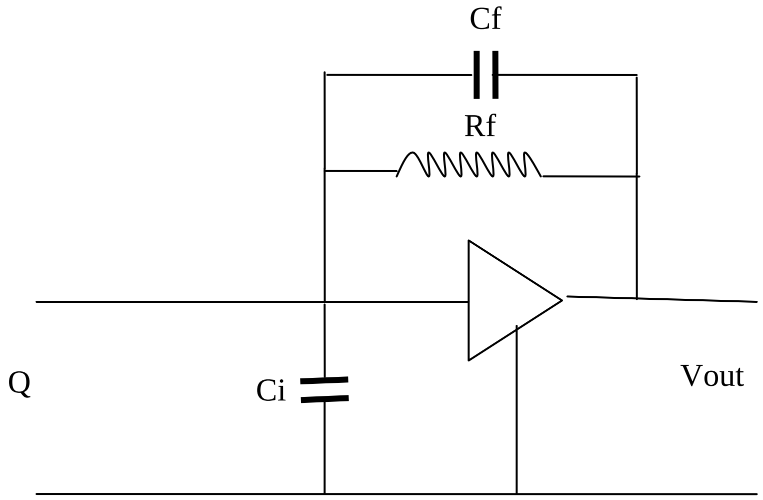

Fig. 1: Simplified diagram of the charge-sensitive preamplifier configuration.

2. Principle of Operation

When soft X-rays or gamma rays strike for example a Si semiconductor detector, signal charge pulses are generated, with amplitude according to the particle energy. Due to this charge generation, the input end potential of the charge amplifier rises and at the same time, a potential with reverse polarity appears at the output end. However because the amplifier's open-loop gain is sufficiently large, the output-end potential works through the feedback loop so as to make the input-end potential zero instantaneously. As a result, the signal charge pulses Qs are all integrated to the feedback capacitance Cf and then output as voltage pulses. The output signal rise time for charge sensitive preamplifiers is determined by the charge collection time. The exponential decay time is determined by the feedback time constant for the preamplifier. The amplitude represents the energy of the detected radiation [5, 6]. The selected operational amplifier LM324 is low-cost, short circuited protected outputs, single supply operation and four amplifiers per package [7].

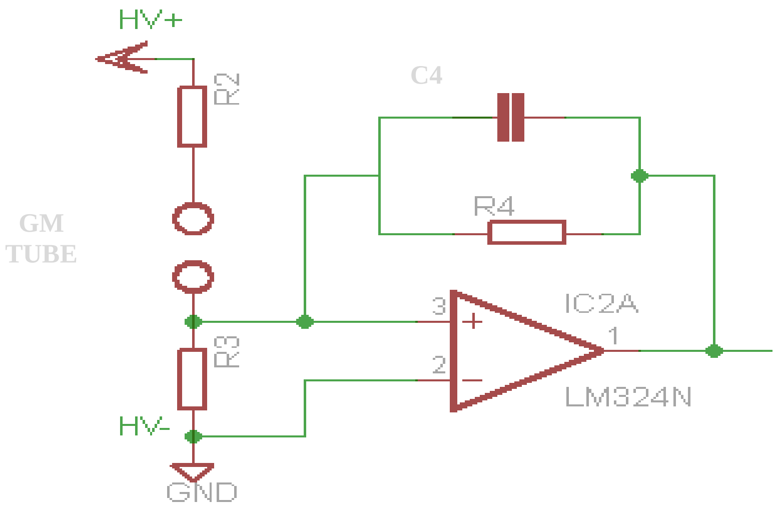

Fig.2: Schematic diagram of the Designed Charge Sensitive Preamplifier Circuit.

3. Results and Analysis

3.1: Gain:

Gain of a charge amplifier is given in one of two ways: The "Charge Gain" G_c is given by V/coulomb or V/pico coulomb

$$G_c = \frac{V_{out}}{Q_s} (= \frac{1}{C_f}) \qquad (3.1.1)$$

In other case we usually use the term called "sensitivity" rather than "gain". Sensitivity is expressed as

$$R_s = \frac{V_{out}}{E} = \frac{\frac{Q_s}{C_f}}{Q_s \cdot \frac{\varepsilon}{e^-}} = \frac{e^-}{C_f} \cdot \frac{1}{\varepsilon} (mV/MeV) \qquad (3.1.2)$$

E: particle Energy (MeV)

C_f: Feedback capacitance

e^- : Elementary Charge 1.6 $\times 10^{-19}$ coulomb

є: Energy required to create one electron/hole pair. For example, when using a Si, Qs ranges from 3.62 eV (at 300k) to 3.71eV (at 77K)

Typical R_f is of order 1 to 100 MΩ combined with Cf , this leads to τ = 1 ~ 100 μs. Here, R_f is of only 1MΩ combined with C_f of 10 pF, this leads to τ = 10 μs.

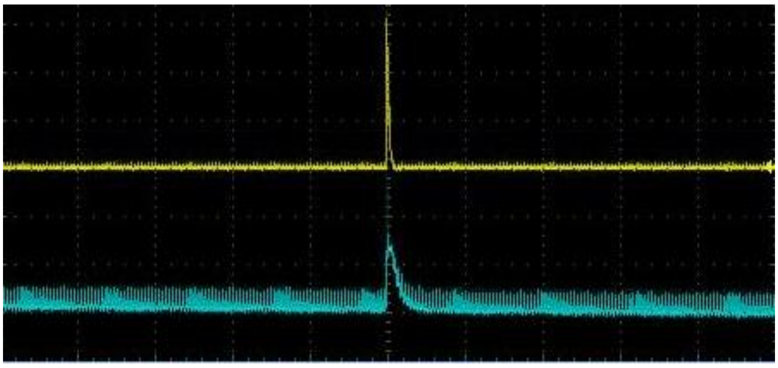

Fig.4: Output of the charge-sensitive preamplifier

3.2: Noise Consideration:

Noise in charge sensitive preamplifier comes from the following three major sources:

- **Thermal noise of first-stage FET**

Thermal noise of the first-stage FET, en1, is given by

$$en_1 = \sqrt{\frac{8}{3}\frac{KT}{gm}}\left(V/\sqrt{Hz}\right) \qquad (3.2.1)$$

K: Boltzmann constant

T: Absolute temperature

gm: Mutual conductance of of first-stage FET

- **Shot noise caused by gate current of first-stage FET and dark current of detector**

The shot noise in is given by

$$in = \sqrt{2q(I_G + I_D)}\left(A/\sqrt{Hz}\right) \qquad (3.2.2)$$

q: Elementary charge

I_G: Gate leakage current of first-stage FET

I_D: Dark current of detector

- **Thermal noise caused by feedback resistance**

The thermal noise en2 caused by the feedback resistance Rf is given by

$$en_2 = \sqrt{4KTR_f}\left(V/\sqrt{Hz}\right) \qquad (3.2.3)$$

4. Conclusion

The designed device has been tested repeatedly with several counting situations. The device is capable of handling any type of detector like GM or Scintillation is the special feature. The performance was found very satisfactory. The device is cheap and reliable in operation. The device can be used for environmental radiation monitoring and health hazards detecting instruments.

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