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

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Abstract: Researchers 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.

Key words: Radiation, detector, op-amp, preamplifier and charge-sensitive preamplifier, resistor

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 (Knoll, 1988). 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 (Jagadish *et al.*, 2000). 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 (HAMAMATSU, 2001).

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 study. The current system has derived from study and implementation of 20 channels charge-sensitive preamplifier using eagle (Islam *et al.*, 2012) (Fig. 1):

$$\begin{aligned} & A >> \left(C_i + C_f\right)/C_f \\ & V_{out} = -AVin \\ & \quad = -A\frac{Q}{C_i + \left(A+1\right)/C_f} \\ & \quad \cong -\frac{Q}{C_f} \end{aligned} \tag{1}$$

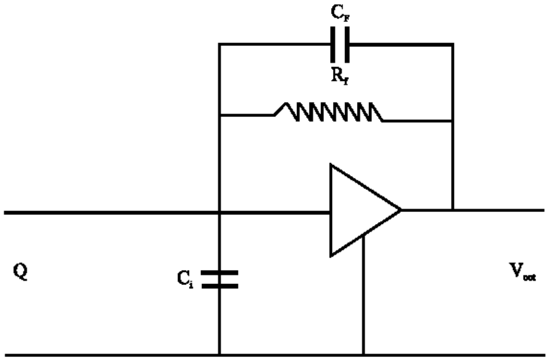

Fig. 1: Simplified diagram of the charge-sensitive preamplifier configuration

MATERIALS AND METHODS

Principle of operation: When soft X-rays or gamma rays strike, for example a Si semiconductor detector, signal

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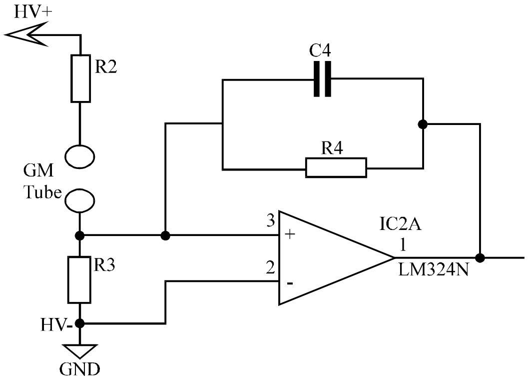

Fig. 2: Schematic diagram of the designed charge sensitive preamplifier circuit

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 Q_s are all integrated to the feedback capacitance C_f 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 (Cremat Inc., 2006). The selected operational amplifier LM324 is low-cost, short circuited protected outputs, single supply operation and four amplifiers per package (Fig. 2).

RESULTS AND DISCUSSION

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:

$$G_c = \frac{V_{out}}{Q_s}\left(=\frac{1}{C_f}\right) \tag{2}$$

In other case, researchers usually use the term called sensitivity rather than gain. Sensitivity is expressed as:

$$R_s = \frac{V_{out}}{E} = \frac{\frac{Q_s}{C_f}}{Q_s.\frac{\varepsilon}{e^-}} = \frac{e^-}{C_f}.\frac{1}{\varepsilon}\left(\text{mV / MeV}\right) \tag{3}$$

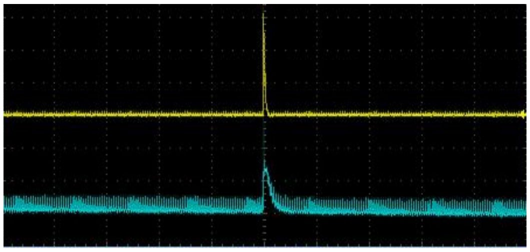

Fig. 3: Output of the charge-sensitive preamplifier

Where:
E = Particle energy (MeV)
C_f = Feedback capacitance
e^- = Elementary charge 1.6×10^{-19} coulomb
ε^- = Energy required to create one electron/hole pair

For example, when using a Si, Q_s ranges from 3.62 eV (at 300k) to 3.71 eV (at 77K). Typical R_f is of order 1-100 MΩ combined with C_f, this leads to $\tau = 1\sim100$ μ sec. Here, R_f is of only 1 MΩ combined with C_f of 10 pF, this leads to $\tau = 10$ μ sec (Fig. 3).

Noise consideration: Noise in charge sensitive pre-amplifier comes from the following three major sources:

Thermal noise of first-stage FET: Thermal noise of the first-stage FET, en_1 is given by:

$$en_1 = \sqrt{\frac{8}{3}\frac{KT}{gm}}\left(\frac{V}{\sqrt{Hz}}\right) \tag{4}$$

Where:
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:

$$in = \sqrt{2q(I_G + I_D)}\left(\frac{A}{\sqrt{Hz}}\right) \tag{5}$$

Where:
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 en_2 caused by the feedback resistance R_f is given by:

$$en_2 = \sqrt{4KTR_f}\left(\frac{V}{\sqrt{H_z}}\right) \quad (6)$$

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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