Development of a High Performance Charge Sensitive Preamplifier for 3-Dimensional Radiation Imaging

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1. Introduction

During radiation therapy, the possible sources of errors in the dose delivery are incorrect patient positioning, the evolution of patient or/and tumor morphology, and treatment planning errors. In classical radiotherapy, these are taken into account by irradiating a volume slightly larger than the tumor itself. This volume is called the planning target volume, and it includes the clinical target volume and extra margins. To limit these errors, and thus reduce the margins as much as possible, patient positioning systems and position verification systems composed of X-ray imaging devices are necessary. However, radiation therapy requires beam energy levels high enough to treat tumors, and the main interactions of the incident photon are Compton scattering at such energy levels. Currently, using these characteristics of radiation, we are developing a Compton camera that can realize 3-dimensional imaging for incident beam monitoring during radiation therapy. The beam monitoring system is composed of three double-sided silicon strip detectors or CdZnTe strip detectors for photon tracking, and radiation signal conditioning circuits such as a preamplifier, shaping amplifier, and data acquisition system.

In this study, a charge sensitive preamplifier for 96-channel double sided silicon strip detectors was developed, characterized, and compared with commercial charge sensitive preamplifier known as best one.

2. Methods and Results

2.1 Preamplifier Design and Fabrication

As already well known, the preamplifier is used to match the impedance between the detector and the signal processing circuits and to amplify the detector signal generated by the incident radiation. It must amplify the detector signal with extremely low noise, high linearity, good stability, and wide bandwidth.

The charge sensitive preamplifier shown in Fig. 1 [3] was designed using commercially available operational amplifier having low noise, low power consumption, high open loop gain, high gain bandwidth product characteristics, and low input capacitance. To minimize 1/f noise at the input stage of the preamplifier that is known as a dominant noise source, a junction field effect transistor (JFET) was used at the input of the operational amplifier. Matching well with double-sided silicon strip detectors and having a high sensitivity, a low noise, a high linearity, a good operation stability, and an appropriate count rate, amounts of the feedback resistor and capacitor were optimized.

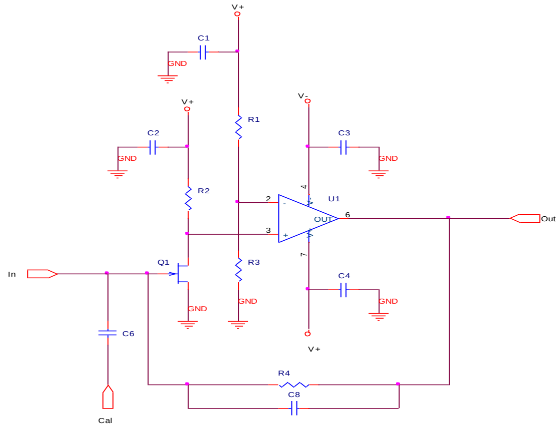

Fig. 1. Schematic of the charge sensitive preamplifier used in design. It is composed of a calibration capacitor, a JFET, an operational amplifier, a feedback RC, and others such as resistors for biasing and bypassing capacitors at power input.

To minimize noise and signal loss of the charge sensitive preamplifier, the printed circuit boards (PCBs) were designed considering placement of the devices, routing and ground plane. The PCBs of this amplifier were fabricated with 2 layer Teflon substrate, and the size is 25.4 mm × 15.2 mm.

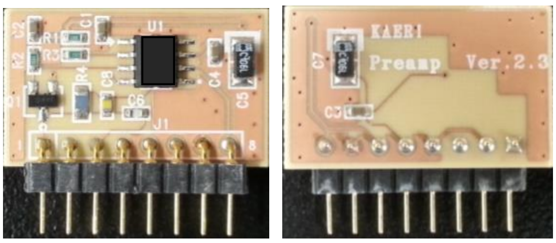

Fig. 2. The fabricated charge sensitive preamplifier that has an 8 pin connector (input, output, calibration input, positive and negative power, and common ground). The substrate of the PCBs is Teflon, and the size is 25.4 mm × 15.2 mm.

2.2 Experimental Results

To evaluate the performance of a developed charge sensitive preamplifier such as rising time, falling time, sensitivity, and noise, test pulses having 50 mV amplitude, very short rising time, and sufficiently long falling time were applied to the calibration input of the preamplifier through a capacitor of 1 pF. As a result of measurements, the rising time, the falling time, and the amplitude of the preamplifier output are 155 nsec, 255 μsec, and 212 mV, respectively shown in Fig. 3 and 4.

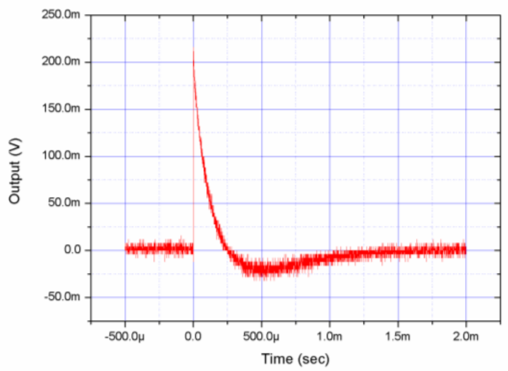

Fig. 3. Output of the developed charge sensitive preamplifier to the 50 mV input calibration pulse through 1 pF capacitor. The measured falling time is 255 μsec.

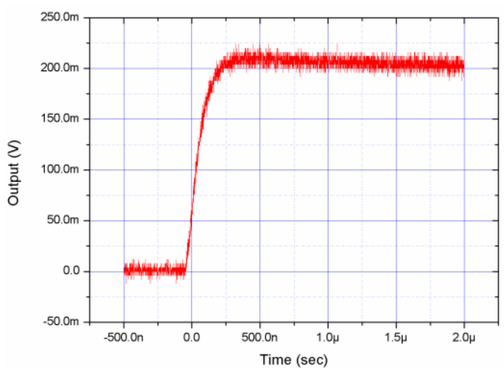

Fig. 4. Output of the developed charge sensitive preamplifier to the 50 mV input calibration pulse through 1 pF capacitor. The measured rising time is 155 nsec.

From the relationship $G=V_o/Q_i$, where G is the sensitivity, V_o the measured output voltage, and Q_i the applied input charge of the preamplifier, the calculated sensitivity of the preamplifier is 4.12 mV/fC. To measure the noise of the charge sensitive preamplifier, the simple spectroscopy was performed. The output of the preamplifier was connected to a shaping amplifier assuming that the noise of shaping amplified can be neglected, and its output was recorded in the form of a spectrum using Multi Channel Analyzer (MCA). Through the measured spectrum, the Full Width at Half Maximum (FWHM), that is the noise of the total measurement system, can be acquired. Since the amplitude of the pulse injected into the preamplifier is known, the FWHM can be converted to Equivalent Noise Charge (ENC). From the measured spectrum datum, the calculated ENC of the developed preamplifier is 161 electrons RMS.

The measurement of the linearity for the preamplifier was performed adjusting the amplitude of the precision pulse generator. From 10.0 in the dial of the generator down to 0.5, the amplitude of the output pulse of the charge sensitive preamplifier for every value of the dial was measured and registered. From the measured results, it can be known that the developed preamplifier has a very good linearity performance shown in Fig. 5.

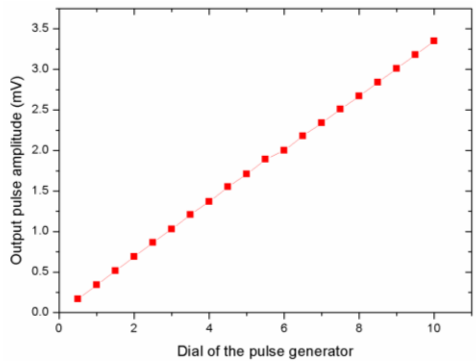

Fig. 5. Linearity of a charge sensitive preamplifier referred to the dial of the precision pulse generator.

3. Conclusions

In the same manner used in developed preamplifier, the sensitivity and noise measurements were performed for eV Products' charge sensitive preamplifier eV 5093 and compared with the developed preamplifier. As a result, the sensitivity and ENC were 3.44 mV/fC and 152 electrons RMS, respectively, and it is shown that the sensitivity of the developed preamplifier is better and the noise is comparable. Therefore, it is thought that the developed preamplifier can replace the excellent preamplifier produced by foreign companies such as eV Products, Amptek, and Cremat.

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