Evaluation of a Fabricated Charge Sensitive Amplifier for a Semiconductor Radiation Detector

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A CSA(Charge Sensitive Amplifier) was designed and fabricated for application in a radiation detection system based on a semiconductor detector such as Si, SiC, CdZnTe and etc.. A fabricated hybrid-type CSA was evaluated by comparison with a commercially available CSA. A comparison was performed by using calculation of ENC (Equivalent Noise Charge) and by using energy resolutions of fabricated radiation detectors based on Si. In energy resolution comparison, a fabricated CSA showed almost the same performance compared with a commercial one. In this study, feasibility of a fabricated CSA was discussed.

Keywords : CSA (Charge Sensitive Amplifier), ENC (Equivalent Noise Charge), Energy resolution, Semiconductor radiation detector

INTRODUCTION

In general, the roles of an electronic system for measuring energy spectrum of radiation are to extract signals produced by radiation from a detector, to amplify those and to achieve the better signal-to-noise (S/N) ratio of those through a filter circuit with an appropriate bandwidth, where it is essential not to deteriorate signal amplitudes. In the radiation detectors, signals are essentially charges produced by radiation, then it is naturally the best way to use a charge sensitive amplifier (CSA) system to extract those signals. There are two types of noise in the CSA. One is the noise which originated in nature from fluctuation of carriers in electronic device and parts. The other noise result from external sources such as switching noise from switching regulators, micro-phonics, and mechanical vibrations [1, 2]. Equivalent noise charge is the most convenient measure of system noise when designing semiconductor detector systems. However, in analyzing the individual noise contributions, the basic noise parameters-voltage and current are more useful. The combination of individual voltage and current noise contributions together with the system bandwidth yields the ENC, so it is derived, rather than a primary quantity [3].

A hybrid-type CSA for a semiconductor radiation detector was fabricated for a semiconductor radiation detector. A fabricated hybrid-type CSA was evaluated in terms of an ENC and an energy resolution. ENCs were measured with respect to calibration capacitors and shaping times of a shaping amplifier. Energy resolutions were measured with a CsI(Tl)/PIN photodiode radiation detector for gamma-rays [4]. These factors were compared with a commercially available one to study feasibility of a fabricated CSA.

EXPERIMENTS

A fabricated CSA and an evaluation board were shown in figure 1. The CSA consists of a JFET and other filter components. An equivalent circuit for an ENC measurement was composed (Fig. 2). An Ortec® 448 research pulser, a 572 shaping amplifier, and a Spectrum Master MCA were used throughout the experiments. 2 mV, 4 mV and 10 mV of pulses were fed through a 1pF capacitor. These are the same charges of 2×10^6, 4×10^6 and, 1×10^7 fC feeding. A 4.7 Ω resistor was connected in parallel for matching an impedance with a pulser. Standard deviation of an original pulse was 0.214 mV at 4 mV. Figure 3 shows pulse shapes of a fabricated CSA and a Cremat® CSA. Standard deviations were 0.328 mV and 0.531 mV, respectively, at 4 mV pulse. And these are 34.7 % and 59.7 % fluctuated from an original pulse.

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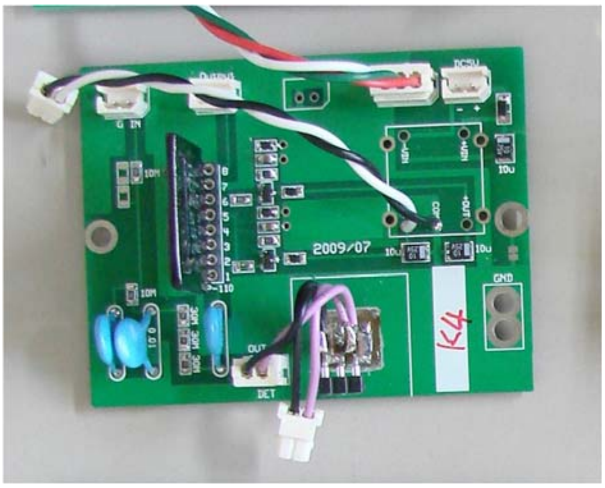

Fig. 1 The fabricated charge sensitive amplifier and the evaluation board for semiconductor radiation detector

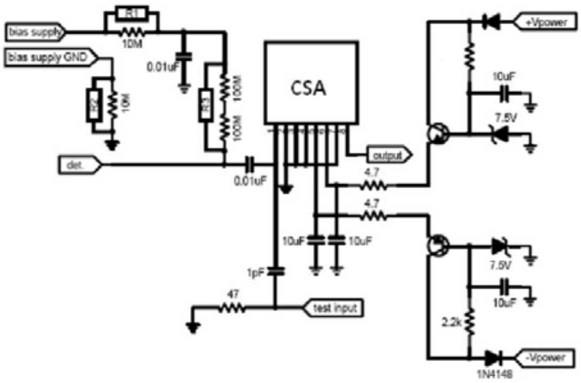

Fig. 2 Circuit diagram of a noise measurement and connection to an evaluation board.

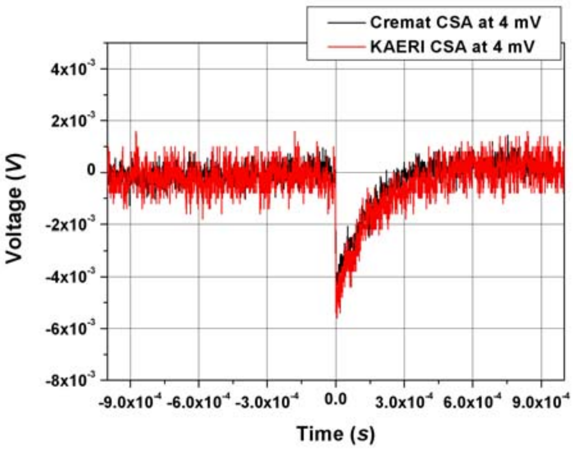

Fig. 3 Pulse shapes of a fabricated CSA and a Cremat® CSA. Fluctuations of pulses were 34.7 % and 59.7 %, respectively, compared with an original pulse.

ENCs were measured with respect to calibration capacitors instead of detectors to exclude detector's noise. ENCs were also measured with respect to shaping times of a shaping amplifier. Energy spectra in case of feeding pulses directly to a shaping amplifier were shown in figure 4. FWHM (Full-width at Half-maximum) in this case were 1.43 and 3.64 at 2 mV and 4 mV, respectively. Energy spectra in case of feeding pulses to a fabricated CSA, which was connected to a shaping amplifier, were shown in figure 5. FWHMs in this case were 9.01 and 8.68 at 2 mV and 4 mV, respectively.

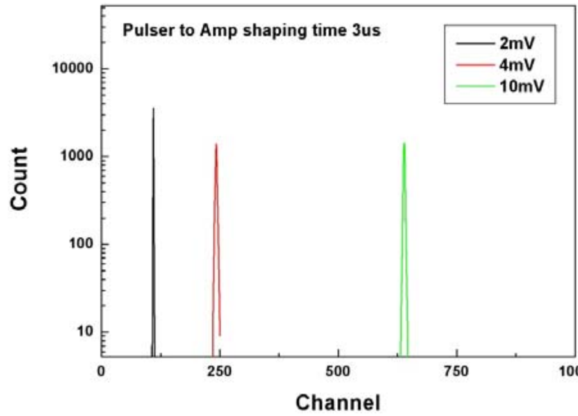

Fig. 4 Energy spectra in case of feeding pulses directly to a shaping amplifier at 3 μs shaping time. FWHM were 1.43 and 3.64 at 2 mV and 4 mV, respectively.

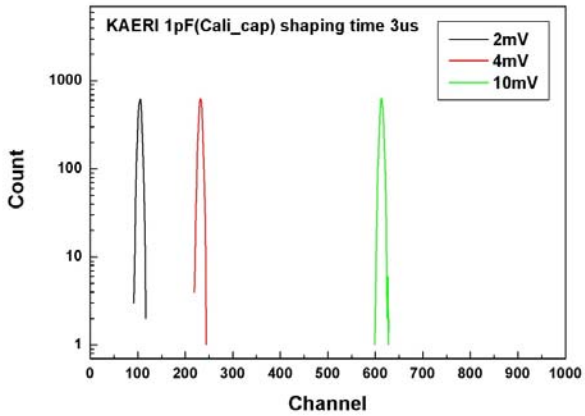

Fig. 5 Energy spectra in case of feeding pulses to a fabricated CSA, which was connected to a shaping amplifier, at 3μs shaping time. FWHMs were 9.01 and 8.68 at 2 mV and 4 mV, respectively.

To study feasibility of a fabricated CSA, energy resolutions for gamma-rays were measured with a fabricated CsI(Tl)/PIN photodiode and compared with respect to a fabricated CSA and a Cremat® CSA CR-110 [4, 5].

RESULTS AND DISCUSSION

Noises of radiation detector system can be categorized by detector's noise and electronics' noise.

Electronics' noise can be expressed by the ENC and as follows:

$$\sqrt{ENC}^2 = \sqrt{ENC_s}^2 + \sqrt{ENC_p}^2 + \sqrt{ENC_{1/f}}^2$$

$$q_n^2 = (2eI_d + 4kT/R_b + i_{na}^2)F_i T_S + (4kTR_s + e_{na}^2)F_v C^2/T_S + F_{vf}A_f C^2$$

Since radiation detectors typically convert the deposited energy into charge, the system's noise level is also expressed as equivalent noise charge Qn, which is equal to the detector signal that yields a signal-to-noise ratio of one. ENC_s means the series noise, ENC_P the parallel noise, and $ENC_{1/f}$ the 1/f noise. C is the sum of all capacitances shunting the input, F_i, F_v, and F_{vf} depend on the shape of the pulse determined by the shaper and T_S is a characteristic time. More specific explanation can be found in reference 1. A basic assembly of circuit for measuring noises in the CSA is shown in Fig. 2.

The measured ENCs in case of a Cremat® CSA and a fabricated CSA were shown in figure 6 and 7, respectively. ENCs are improved at lower calibration capacitance and at lower shaping time. To minimize electronic noise and to enhance energy resolution, detector capacitance in both cases must be low from the above results. sincreased with respect to the detector's capacitances in exponential scale from the above results. Comparison of ENC between two CSAs at 1 μs and 3 μs shaping times was shown in figure 8.

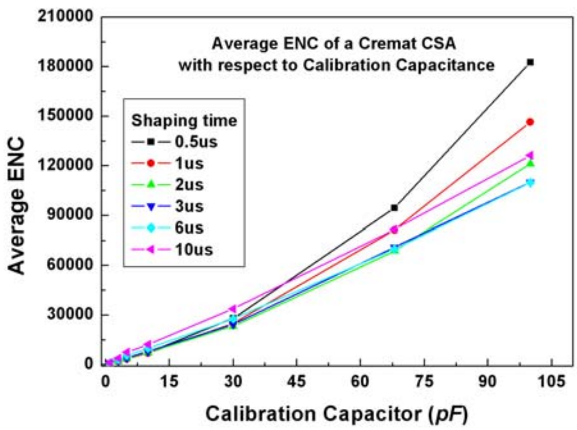

Fig. 6 The measured ENCs in case of a Cremat® CSA with respect to calibration capacitances and shaping times.

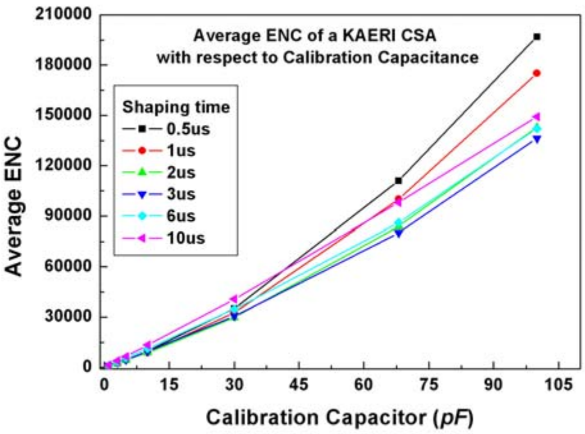

Fig. 7 The measured ENCs in case of a fabricated CSA with respect to calibration capacitances and shaping times.

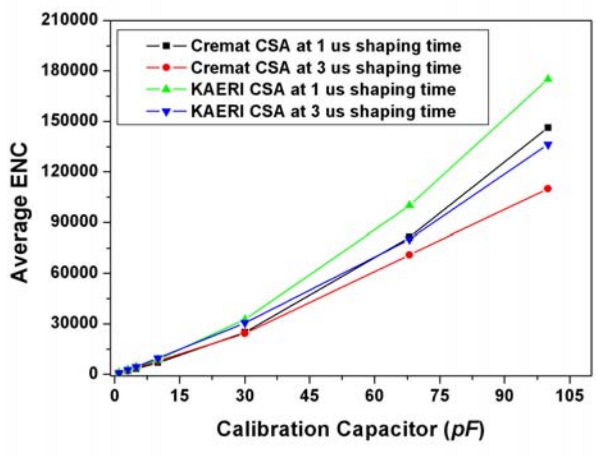

Fig. 8 Comparison of ENC between two CSAs at 1 μs and 3 μs shaping times.

To study feasibility of a fabricated CSA, energy resolutions for gamma-rays were also measured with a fabricated CsI(Tl)/PIN photodiode and compared with a Cremat® CSA CR-110 [4, 5]. Energy resolutions for 660 keV gamma-ray were about 10.52 % and 10.28 % in respective cases. And energy resolutions for 1274.53 keV gamma-ray were about 6.31 % and 6.25 % in respective cases. A fabricated CSA showed almost the same performance in energy resolution comparison. This means noise contribution of a detector capacitance, which includes leakage current of a detector, is larger than 1/f noise term.

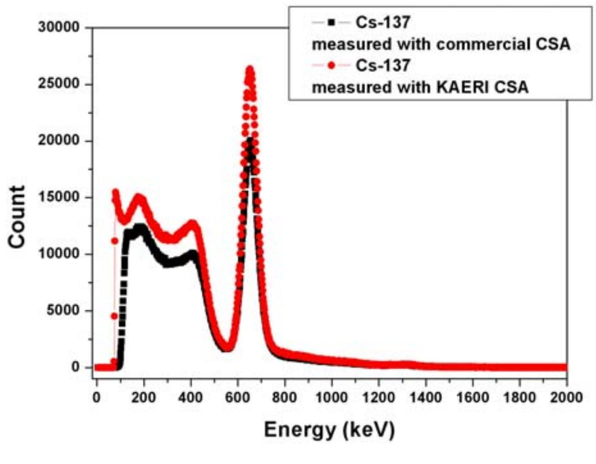

Fig. 9 Energy spectra for 660 keV gamma-ray measured with a fabricated CsI(Tl)/PIN photodiode radiation detector [4]. Measurements were performed with a fabricated CSA and a Cremat® CSA. Energy resolutions for 660 keV gamma-ray were about 10.52 % and 10.28 % in respective cases.

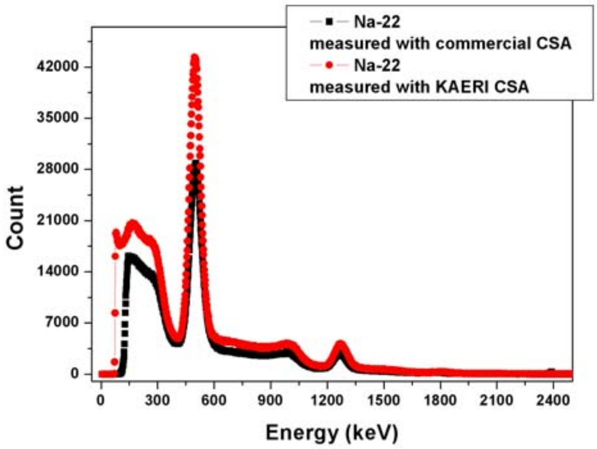

Fig. 10 Energy spectra for 1274.53 keV gamma-ray measured with a fabricated CsI(Tl)/PIN photodiode radiation detector [4]. Measurements were performed with a fabricated CSA and a Cremat® CSA. Energy resolutions for 1274.53 keV gamma-ray were about 6.31 % and 6.25 % in respective cases.

CONCLUSION

An ASIC (Application-specified Integrated Circuit) was actively developed for muti-channel radiation detectors, which have multi strip or pixel electrodes, to identify position and energy measurement of incident radiation. But ASIC still has technological drawbacks to apply to a real world. A small hybrid-type CSA is still used and applied in the present time. A hybrid-type CSA was designed and fabricated for application in a semiconductor radiation detection system in KAERI (Korea Atomic Energy Research Institute). To study the feasibility of a fabricated CSA, comparison was performed by using the calculation of an ENC (Equivalent Noise Charge) and by using energy resolutions of a CsI(Tl)/PIN photodiode radiation detectors. In energy resolution comparison, a fabricated CSA showed almost same performance compared with a commercial one. The fabricated CSA is continued to modify to the best performance. And at the same time, the fabricated CSA and the CsI(Tl)/PIN detector is tried to apply in an industrial tracer system, a gamma-ray imaging system, and an animal PET etc.

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