1 Development of an ASIC for Si/CdTe detectors in a
2 radioactive substance visualizing system

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8 **Abstract**

9 We report on the recent development of a 64-channel analog front-end ASIC
10 for a new gamma-ray imaging system designed to visualize radioactive sub-
11 stances. The imaging system employs a novel Compton camera which con-
12 sists of silicon (Si) and cadmium telluride (CdTe) detectors. The ASIC is
13 intended for the readout of pixel/pad detectors utilizing Si/CdTe as detec-
14 tor materials, and covers a dynamic range up to 1.4 MeV. The readout chip
15 consists of 64 identical signal channels and was implemented with X-FAB
16 0.35 μm CMOS technology. Each channel contains a charge-sensitive ampli-
17 fier, pole-zero cancellation circuit, low-pass filter, comparator, and a sample-
18 hold circuit, along with a Wilkinson-type A-to-D converter. We observed
19 an equivalent noise charge of $\sim 500\text{ e}^-$ and noise slope of $\sim 5\text{ e}^-/\text{pF}$ (r.m.s.)
20 with power consumption of 2.1 mW per channel. The chip works well when
21 connected to Schottky CdTe diodes, and delivers spectra with good energy
22 resolution, such as $\sim 12\text{ keV}$ (FWHM) at 662 keV and $\sim 24\text{ keV}$ (FWHM) at
23 1.33 MeV.

24 **Keywords:** ASIC; Gamma ray; Si/CdTe; Analog front-end

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25 1. Introduction

26 A new gamma-ray imaging system that can visualize radioactive sub-
27 stances is urgently needed to help decontamination efforts in Fukushima.
28 The imaging system employs a Compton camera that offers many advan-
29 tages over traditional gamma cameras. Because it directly locates the source
30 by Compton reconstruction, this system needs no mechanical collimator or
31 heavy high-Z material (e.g. Pb) to cover the imaging detector in order to
32 avoid contamination by background gamma rays.

33 We have developed a novel Compton camera which consists of silicon (Si)
34 and cadmium telluride (CdTe) semiconductor detectors for the ASTRO-H
35 satellite mission scheduled for launch in 2015[1]. The original technologies
36 of low-noise silicon devices[2], high resolution Schottky CdTe diodes[3], and
37 a dedicated low-noise analog ASIC allow the tracking of low energy gamma
38 rays, thereby realizing an energy coverage of 100 keV to a few MeV[4]. By
39 employing these technologies, we have fabricated a dedicated prototype for
40 decontamination within the evacuation zone in Fukushima[6]. The prototype
41 consists of two layers of Si double-sided strip detectors and three layers of
42 CdTe double-sided strip detectors, with a detector area of 3.2×3.2 cm and
43 a strip pitch of 250 μm .

44 The system's imaging performance was reported as 3.8° (FWHM) at 662
45 keV for the angular resolution, 2.2% (FWHM) at 662 keV energy resolution,
46 and almost 2π steradian ($180^\circ \times 180^\circ$) for the FoV[5]. Hotspots correspond-
47 ing to air radiation levels of a few $\mu\text{Sv/h}$ in the evacuation zone were clearly
48 visible with an exposure of around 40-60 min[6].

49 We have recently developed a 64-channel analog front-end ASIC (KW04D64)
 50 by adopting the architecture of KW-series ASICs[7, 8, 9, 10, 11]. The ASIC
 51 employed thus far accepts signals of energies ranging from 20 keV to 1.4
 52 MeV, and is intended to acquire these gamma rays emitted directly from
 53 ^{137}Cs (662 keV), ^{134}Cs (605, 795, 802 keV) and ^{60}Co (1.17, 1.33 MeV). The
 54 camera should have a spectral resolution capable of distinguishing individual
 55 lines. Thus, energy resolution better than 3% ($\Delta E/E$) is necessary. And in
 56 terms of cooling, low power consumption of about a few mW per channel
 57 must comply with limited cooling capability.

58 This paper presents the design and performance of the ASIC. Section 2
 59 describes the basic architecture of the ASIC and gives details of the circuit
 60 schematics. Section 3 describes the circuit properties. Section 4 gives the
 61 experimental results regarding the γ -ray spectrum measured with a CdTe
 62 diode detector. Finally, Section 5 gives a summary and future plans.

63 2. Circuit Description

Figure 1: A photograph of the 64-channel front-end ASIC (KW04D64) mounted in a QFP ceramic package.

64 The readout ASIC (KW04D64) was implemented using the X-FAB 0.35

65 μm CMOS technology with a chip size of $7.8 \times 7.1 \text{ mm}^2$. Figure 1 shows
 66 a photograph of the chip containing 64 readout channels. Each channel
 67 contains a charge-sensitive amplifier, pole-zero cancellation circuit, low-pass
 68 filter, comparator, and a sample-hold circuit, along with a Wilkinson-type
 69 analog-to-digital converter. The bonding pads for signal inputs are located
 70 on the left side. The strip pitch is $91.2 \mu\text{m}$ and the pad area is $65 \times 90 \mu\text{m}^2$.

Figure 2 shows a signal processing chain for each channel. The detector electrode is DC-coupled to an input of the charge-sensitive amplifier (CSA), while test pulses can be injected via an AC-coupling capacitor (C_{in}). The CSA is based on a folded cascade configuration and utilizes a PMOS transistor as the input transistor. The gate length and width are 1.2 and $8 \mu\text{m}$, respectively, and the M value (denoting the number of transistors arranged in parallel) is set as 180. The feedback capacitor (C_{f}) was selectable between 0.25 and 0.50 pF via a CMOS switch, dedicated for high and low gain modes, respectively. A transfer gate-type FET (R_{f}) was employed for the CSA DC feedback component. The CSA output was fed into two shaping amplifiers: a slow shaper for spectroscopy and a fast shaper for triggering. Each amplifier is composed of a pole-zero cancellation circuit (C_{dif} , R_{pz}) and a second order low-pass filter. The parameters are set as:

$$C_{\text{f}}R_{\text{f}} = C_{\text{dif}}R_{\text{pz}} \quad \text{and} \quad (1)$$

$$C_1R_1 = 4C_2R_2, \quad C_3R_3 = 4C_4R_4 \quad (2)$$

71 The peaking times are selectable between 5 and $10 \mu\text{s}$ for the slow shaper,
 72 and between 1 and $2 \mu\text{s}$ for the fast shaper. The slow shaper output is fed into
 73 the sample-and-hold (S/H) circuit, while the fast shaper output is fed into

74 a comparator with a threshold voltage of V_{TH1} . The fast shaper channel is
75 equipped with an automatic offset compensation circuit (OFFSET).

76 The Wilkinson-type analog-to-digital converter includes a comparator
77 that refers to a ramp voltage common to all the channels, and strobes dig-
78 its from a Gray-coded counter when the ramp signal exceeds the voltage of
79 S/H circuit. The digitized amplitudes are read out by external electronics,
80 e.g. Lab-VIEW system. The analog-to-digital converter includes a common
81 mode noise (CMN) detection mechanism. The CMN could be defined as the
82 median of the pedestal distribution for each event, which can be acquired
83 while the ramp signal is passing through the base-line level.

84 There are two sparse readout modes in addition to the entire read out
85 mode: one is an analog trigger mode; the other is a digital trigger mode. In
86 the analog trigger mode, one can read only from those channels whose fast
87 shapers deliver amplitudes exceeding V_{TH1} . In the digital trigger mode,
88 the A-to-D converted S/H data are corrected by the CMN, and the read out
89 condition is met if they exceed a predetermined digital threshold. The digital
90 trigger mode can be utilized to improve trigger quality by suppressing the
91 environmental interference.

92 **3. Circuit Properties**

93 To evaluate the circuit properties, the ASIC was placed in a QFP ceramic
94 package. The package was held in a burn-in socket mounted on a test board.
95 An interface with a computer was established using a National Instruments
96 PCI-7833R board containing a reconfigurable FPGA and analog-to-digital
97 converters. Lab-VIEW software tools were used to control the readout se-

114 The circuit linearity was also investigated for both high and low gain
 115 modes ($C_f=0.25$ pF and $C_f=0.50$ pF, respectively). Figure 4 shows the results
 116 for a typical channel. The output voltage is in the range between 0 to 900
 117 mV, and covers a dynamic range up to 1.4 MeV in high gain mode.

Figure 3: Equivalent noise charge (ENC) against input capacitance in high gain mode. The solid line show results from SPICE simulation. Blue squares indicate the measured raw data; red circles indicate common mode subtracted noise.

Figure 4: Linearity curves for high and low gain mode. Red crosses indicate high gain mode; Blue squares indicate low gain mode.

118 4. Performance test with a Schottky CdTe Diode

119 In the performance verification test, we connected the ASIC to a CdTe
 120 detector. The detector is based on a high-quality single CdTe crystal manu-

Figure 5: Setup for the spectral measurements with a Schottky CdTe diode detector.

121 factured by ACRO RAD of Japan. With the use of indium (In) and platinum
 122 (Pt) for the anode electrode and cathode electrode, respectively, this device
 123 works as a Schottky diode. This device has lower leakage current than that
 124 of ohmic detectors and allows higher bias voltages to be applied, leading to
 125 almost full charge collection[12]. Moreover, the cathode electrode is covered
 126 by a guard ring to reduce the detector's leakage current[13]. The CdTe de-
 127 tector is 3.45×3.45 mm in size and 1 mm in thickness, and is surrounded
 128 by a guard ring 1mm in width.

129 Since spectral performance depends on the leakage current and detec-
 130 tor capacitance, the leakage current must be measured before connection to
 131 the ASIC. Positive voltages were applied to the indium electrode using a
 132 high-voltage sourcemeter(Keithley 2410). As a result, the measured leakage
 133 current was 1.5 nA with a bias voltage of 1000 V at -15°C , and the detector
 134 capacitance was 2.5 pF.

135 Figure 5 shows the setup for the spectral measurements. An electric
 136 wire of about 1 cm is used for connection between the active area of the
 137 cathode electrode and the DIP socket mounted on the test board. The DIP
 138 socket is wired to the QFP socket pins corresponding to CSA input. We

139 obtained gamma ray spectra of radioactive sources ^{137}Cs (in Figure 6) and
 140 ^{60}Co (in Figure 7) with $C_f=0.25$ pF and in self-trigger mode at an operating
 141 temperature of -15°C with a bias voltage of 1000 V. The energy resolution
 142 is 12 keV (FWHM) for a gamma ray of 662 keV and 24 keV (FWHM) for a
 gamma ray of 1.33 MeV.

Figure 6: Spectrum of ^{137}Cs with the ASIC connected to a Schottky CdTe diode in high gain mode.

Figure 7: Spectrum of ^{60}Co with the ASIC connected to a Schottky CdTe diode in high gain mode. This is obtained under the same conditions as for the spectrum of ^{137}Cs

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144 **5. Summary & Future Plans**

145 We developed a 64-channel analog front-end ASIC for a new gamma-ray
146 imaging system designed to visualize radioactive substances. We observed an
147 equivalent noise charge of $\sim 500\text{ e}^- + 5\text{ e}^-/\text{pF}$ (r.m.s.) with power consump-
148 tion of 2.1 mW per channel. The chip works well when connected to Schottky
149 CdTe diodes, and obtained spectra with good energy resolution, such as ~ 12
150 keV (FWHM) at 662 keV and ~ 24 keV (FWHM) at 1.33 MeV. The large
151 difference in ENC between the simulation and the experimental data is con-
152 sidered as due to an improper layout of the power lines. An improved version
153 is now being fabricated and will be delivered soon.

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