Development of Gigahertz Analog Memory for Front-End Electronics of Imaging Air Cherenkov Telescopes

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Abstract: The night sky light is one of the major components of the background for imaging air Cherenkov telescopes. It disturbs images of air shower, and makes both the gamma/hadron separation and the angular resolution worse. For example, The CANGAROO-III electronics consists of charge ADCs and multi-hit TDCs. In using charge ADCs, we have to delay the signal from PMTs until the trigger signal input to ADCs. Since signals from PMTs are distorted by passing through the delay line, we have to take the signal integration time longer than the distribution of Cherenkov photons, and more night sky photons are mixed to the real signal. In order to reduce this night sky photons, we are planning to replace the charge ADCs to the capacitor arrays called AMC (Analog Memory Cell). AMC consists of 512 capacitors and can record the waveform of the input signal at high sampling rate of 1 GHz. We already developed a test type of AMC chip and found that its dynamic range was more than 9 bits. Here we report on the current status of the development of AMC.

Introduction

The ground based atmospheric Cherenkov telescope observes Cherenkov light from an extented air-shower (EAS). We are developing Analog Memory Cell (AMC) for IACTs. Here we describe the preliminary results of the measurements of a linearity, a propagation delay and a readout speed.

Night Sky Background (hereafter NSB) is a major noise for Cherenkov Observation. NSB comes from all region of the sky to a pixel photon detector of IACT with a very high frequancy of 10–100 MHz, and its typical value of 6.4×10^7photons/cm^2/str/sec$(4300 - 5500\text{Å})$ is known as Jelly's value ([1]). This value varies several times in different sky region and also by the size of a mirror of the telescope. We carried out a NSB value measurement by using a 500MHz flash ADC on the CANGAROO-III telescope array. A flash ADC can record a waveform of a signal from a photo multiplier tube (PMT) and allows us to separate a NSB signal from a Cherenkov signal. An integrated NSB value in a recorded signal is pro-

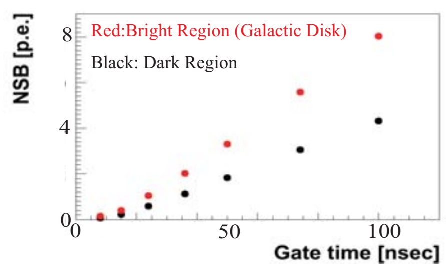

Figure 1: NSB value [p.e.] vs charge integration time [nsec]. It is possible to reduce NSB value by shortening a charge integration time.

portional to the signal integrated time as shown in Fig1.

CANGAROO-III uses charge ADCs with the charge integration time of 100 nsec. Our measurement shows that about 8 p.e. NSB is overlapped to a Cherenkov signal in the bright region. Since an arrival time of Cherenkov light from an extended

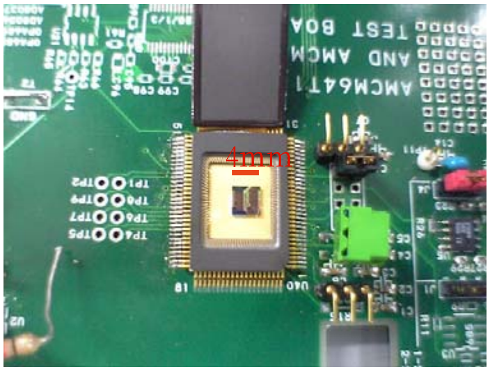

Figure 2: A photograph of AMC chip.

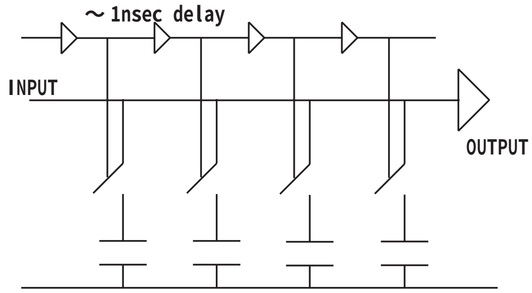

Figure 3: A schematic view of AMC chip.

air shower (EAS) distributes within about 10 nsec, the signal record time also could shorten to 10 nsec. A charge ADC, however, needs an external gate signal, and a signal delay line is needed. Because of the delay line chip, a waveform smeared, and hence we can not shorten the gate width of the ADC. We could shorten the time if we used a module which can record the waveform like a Flash ADC. Due to limits of a space, an electric power, or an economical problem, it seems difficult to use flash ADCs for an imaging air Cherenkov telescope which consists of hundreds of PMTs. The AMC is expected to solve these problems, and makes it possible to install all electronics behind the camera directly.

Figure 2 we shows our prototype AMC chip. It has a very small area of $\sim$16 mm^2 and one input channel in one chip. Its schematic view is shown in Fig3. The AMC consists of 64 capacitors and a switch in each capacitor in ASIC. A capacitor is switched off when a trigger signal is inputted to the switch. By delaying this trigger signal by delay line, each capacitor has an electric charge which reflects an input signal level at switched timing. By reading each capacitor's charges we can reconstruct the waveform of the input signal. When an external trigger signal is fed, the AMC in the current version starts waveform sampling, and record the waveform during 64 nsec with a sampling rate of 1 GHz. In the next version this sampling method will be changed to "Common Stop Mode" which stops the sampling when an external trigger is fed to the AMC.

Linearity

We developed two types of AMC and tested its linearity by varying an input signal level. Schematci views of two types are shown in Fig4. Type-I AMC has a simpler layout than that of Type-II, while Type-II doesn't need a charge transfer between a capacitor of AMC and a capacitor for signal readout. An RMS of the output level for a fixed input signal were 7.9 mV in type-I and 4.9 mV in type-II, respectively. Figure 5 shows linearities of both types of AMC as a function of the input signal level. The input signal was DC-level and both the input and the output signal levels were measured by an oscilloscope. Each output signal dispersed within only 5 mV from the fitted line. The linearity was guaranteed in the input level range from 0.5 V to 4.0 V in both type-I and type-II, so that each AMC's dynamic range is about 440 in type-I and about 710 in type-II considering the noise levels of 7.9 mV in type-I and 4.9 mV in type-II. This result shows that type-II AMC is superior to type-I AMC in the dynamic range.

Propagation Delay

A dispersion of the trigger signal timing of switches directly affects the capacitor 's charge. To evaluate this effect, we measured a propagation delay time which means a triggered time interval between each capacitor. The result is shown in Fig6. The dispersion of this propagation delay time was less than 20 % in both types of AMC and its RMS were 4.5% in type-I and 5.0% in type-II. The fluc-

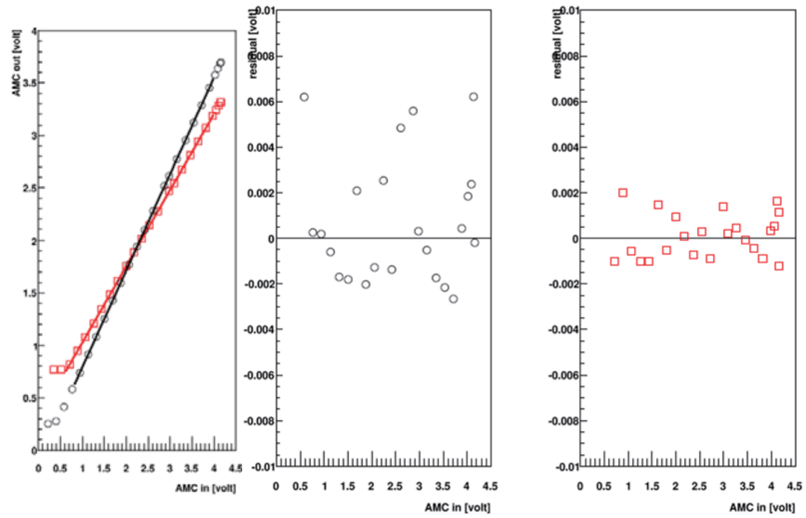

Figure 5: (Left) Relations between input levels and output levels for type-I (black line) and type-II (red line).(Middle) Dispersions from the fitted line of type-I. (Right) Dispersion of type-II.

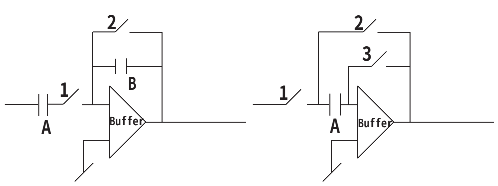

Figure 4: Schematic views of two types of AMC; (Left)Type-I and (Right)Type-II. A capacitor ”A” is a same capacitor as shown in figure 3. In type-I, after transferring a charge on the capacitor ”A” to the capacitor ”B” by switching the switch ”1” on, the charge on the capacitor ”B” is read out. In type-II, instead of the charge transfer, after switching the switch ”2” on, the charge is read out.

	Type-I	Type-II
Linearity	0.5–4.0 V	0.5–4.0 V
Noise (RMS)	7.9 mV	4.9 mV
Dynamic Range	8–9 bit	9–10 bit
jitter (RMS)	0.036 nsec	0.040 nsec
Readout freq.	250 kHz	2 MHz

Table 1: Results of measurements of Type-I & Type-II AMC.

turation of output signals from every capacitor due to the propagation delay jitter is very small.

Readout Speed

Output signals from both of AMCs are synchronized with an external clock signal. A readout speed depends on a frequency of this signal. We measured the maximum readout speed as keeping the linearity of the output level within 5mV. The maximum frequency is 300 kHz in type-I and 2 MHz in type-II. This frequency is too fast to read out all amount of the charge in the capacitor, and then the linearity becomes bad. This read out speed is limited by a band width of operational amplifier on the AMC chip. Type-II AMC is superior to type-I in the readout speed. This is because that type-II doesn't need the charge transfer, while type-I needs it.

Conclusion

We developed two types of AMC in order to install it to an IACT. Both of these consist of 64 capacitors and can record a waveform for about 64 nsec at a sampling rate of 1 GHz. Type-I has a simpler lay-

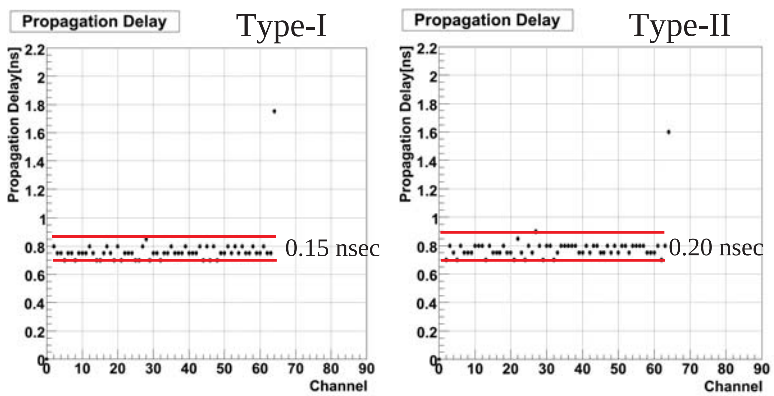

Figure 6: Intervals of the trigger signal between every capacitor for type-I (left) and type-II (right).

out and is easier to produce, while type-II doesn't need the charge transfer for the signal readout and is expected to have a better linearity and a faster readout speed. From our measurements, Type-II AMC is superior to Type-I AMC in both the linearity and the readout speed. Its dynamic range was achieved to be 9–10 bit and maximum readout frequency reached 2 MHz. Those values are already enough to use in some IACTs. However in IACT of the next generation which have a larger mirror than 10 m diameter and more PMTs [3][4], more dynamic range and faster readout are needed. We are now developing a new version of the type-II AMC chip which have an improved layout and much lower noise level.

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