ASHRA Trigger and Readout Pixel Sensors

Y. Arai[1], Y. Aita[2], T. Aoki[2], Y. Asaoka[2], T. Browder[3], C. Fukunaga[4], T. Hayashino[5], Y. Higashi[1], J. Hisano[2], W. S. Hou[6], Y. B. Hsiung[6], M. Ieiri[1], M. Jobashi[2], C. Jui[7], J. Learned[3], E. Loh[7], N. Manago[2], S. Matsuno[3], J. Matthew[7], K. Nakai[8], S. Nakamura[9], S. Ogawa[10], A. Okumura[2], S. Olsen[3], K. Sakurazawa[11], M. Sasaki[2], N. Sugiyama[12], Y. Tanaka[13], V. Vladimir[7], M. Z. Wang[6], Y. Watanabe[11], S. Yamada[2], and K. Yoshimura[1]
(1) High Energy Accelerator Research Organization, Japan, (2) Institute for Cosmic Ray Research, University of Tokyo, Japan, (3) University of Hawaii, USA, (4) Tokyo Metropolitan University, Japan, (5) Tohoku University, Japan, (6) National Taiwan University, Taiwan, (7) University of Utah, USA, (8) Tokyo University of Science, Japan, (9) Yokohama National University, Japan, (10) Toho University, Japan, (11) Tokyo Institute of Technology, Japan, (12) National Astronomical Observatory, Japan, (13) Nagasaki Institute of Applied Science, Japan

Abstract

In the All-sky Survey High Resolution Air-shower telescope (ASHRA) detector design, we newly apply the techniques matured in the other fields [1,2,4,5]. In particular, the use of solid state image sensor as a trigger and readout detector is a breakthrough to realize all-sky survey with 1 arcmin resolution with the ASHRA telescope. The conceptual design of trigger and readout sensors is described.

1. Trigger Sensor

The trigger pixel sensor has 128×128 pads, which receive electric currents amplified through Micro Channel Plate (MCP) after photoelectric conversion of incident photons. Each trigger pixel covers $0.4^\circ \times 0.4^\circ$ field of view (FOV). The night sky background in the FOV is estimated to be 0.02 pe/10ns. Since time duration of TeV γ-ray signal is about a few tenth of ns, sufficient signal to noise ratio (SNR) can be easily obtained. On the other hand, air fluorescence emitted from VHEν and EHECR takes $\sim 10\ \mu$s to pass through the FOV of each telescope. When the night sky background is accumulated for $\sim 10\ \mu$s, it reaches $\sim$20 pe/trigger pixel. Therefore, we have to incorporate “Second Level Trigger” which perform track reconstruction.

Due to the different characteristic time between Cerenkov and fluorescence, the incident light to the trigger sensor is split into two independent trigger sensors.

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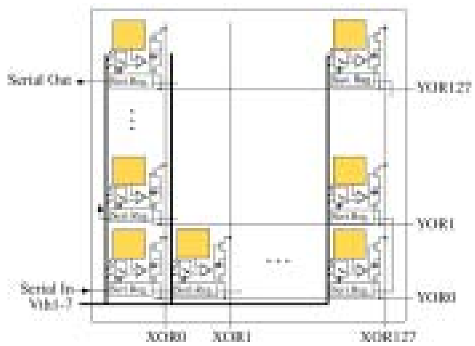

Fig. 1. A block diagram of the trigger sensor.

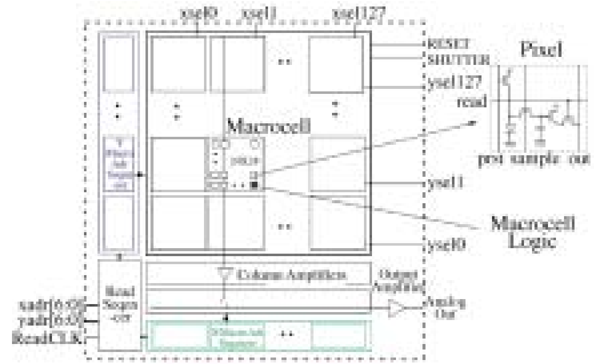

Fig. 2. A block diagram of the CMOS sensor with 2-dimensional shutter.

In order to use the same kind of trigger sensor for both purpose, threshold level of discriminator should be adjustable. The block diagram of the trigger sensor is shown in Fig. 1. The threshold level of discriminator on each pixel can be selected from 8 level (including mask bit) to compensate gain discrepancy, fluctuation of background level, and to mask strong light from something like stars. The output of discriminator is summed 128 pixels along X and Y axis by using "Wired OR" circuit. These additional circuits are implemented under the electrodes. Thus, the decrease in aperture ratio is negligible.

2. Fine Imaging Device

2.1. Requirements

To achieve 1 arcmin resolution matched with that of the ASHRA optics, more than 3000 $\times$ 3000 pixels are needed to cover the FOV of ASHRA sub-telescope. As Kodak digital camera (DCS Pro14n) has a CMOS sensor with 4500 $\times$ 3000 pixels, current technology permit the production of CMOS sensors with such fine pixels. The size of each pixel is determined by required sensitivity and fiber size of MCP-IIT and FOP (Fiber Optic Plate). The pixel size of 10 $\times$ 10 μm^2 results in the sensor size of about 35 $\times$ 35 mm^2. Because of the amplification using IIT chain, the requirement on sensitivity is not so severe that 8-bit dynamic range will be sufficient.

One of the important features of image sensor is the readout speed. If 9 Mpixels are read out at the rate of 50 Mpixels/sec, only 5 frames can be read per second. Because almost all solid state imagers are developed for still or video use, the readout speed is at most $\sim$ 30 fps. Among sensors for high speed camera, several hundreds of fps can be achieved, but pixel resolution is limited to $\sim$ 1 Mpixel. Since the trigger rate expected in the ASHRA experiment is about 1 kHz, very fast readout scheme is required in order to keep dead time fraction as small as possible. Thus, i) parallelization of readout line and ii) random access of pixels which allows windowing of region of interest are required.

The observation time for each event in the fluorescence method is so large comparing with the night sky background rate that the 2-dimensional shutters are required. The 2-dimensional shutter is opened one by one along the AS development on the field of view of the CMOS image sensor. We need to develop this kind of CMOS image sensor, because there is no this kind of image device although a CMOS image sensor with the 1-dimensional shutters, so called "rolling shutter", is commercially available.

As described above, our imaging device needs various special properties. Considering this, CMOS sensor is very much preferable than CCDs in terms of i) easiness of development and ii) low cost. In future, there is a possibility to include the trigger function within the CMOS sensor itself.

2.2. Macrocell-structure CMOS sensor

To realize the selective imaging and readout on one CMOS image sensor chip, we have invented the CMOS image sensor with macrocell structure (Fig. 2.). The number of macrocells is 128×128 in one CMOS sensor chip. Each macrocell contains 24×24 pixels. As a result, totally 3,072×3,072 (9.4M) pixels are implemented on one CMOS image sensor. Note that one pixel per macrocell is occupied by the macrocell logic. Figure 3. shows the circuit of macrocell logic.

In the ASHRA detector, each sub-telescope uses one newly developed CMOS image sensor and each telescope uses totally four. In the trigger sensor, after adding 4 images of each sub-telescope, a coarse image of 128 × 128 pixel resolution is obtained.

The control signal and function of macrocells are shown in Table 1., and function flow chart is shown in Fig. 4. The macrocell selected by trigger signal starts exposure with **SHUTTER on** and **RESET off**. When a track extends several macrocells, mirror images will appear. In such case, it is possible to expose several macrocells at the same time by outputting plural **xsel** and **ysel**. After exposing, **yadr** signals select **Y Macro Address Sequencer**, and the sequencer outputs read signal to 24 row pixels successively when an "event trigger" is received. Output signals of the selected row are sent to **Column Amp**, and **xadr** signals select **X Macro Address Sequencer**. Then, the pixel data is in tern read by **Output Amplifier**. Assuming a readout speed of 50 Mpixels/sec, only 12 μs is spent to read all the data of one macrocell (24 × 24 pixels). Since signal routes of exposure and readout are completely independent, exposure and readout can be carried out at the same time. After the readout, or when a "event trigger" is not received, image data of the macrocell are cleared by **xsel**, **ysel**, **RESET on**, and **SHUTTER on** signals.

xsel,ysel	RESET	SHUTTER	prst	sample	captureb	status
selected	ON	ON	H	H	H	pixel clear
	OFF	ON	L	H	L	expose
	ON	OFF	H	L	unchanged	hold/readout
	OFF	OFF	L	L	unchanged	hold/readout
not selected	X	X	L	L	H	pixel clear
	X	X	L	L	L	hold/readout

Table 1. The control signal and function of macrocells.

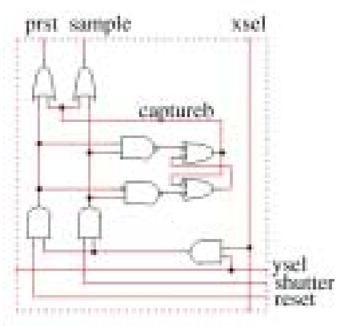

Fig. 3. Macrocell logic circuit.

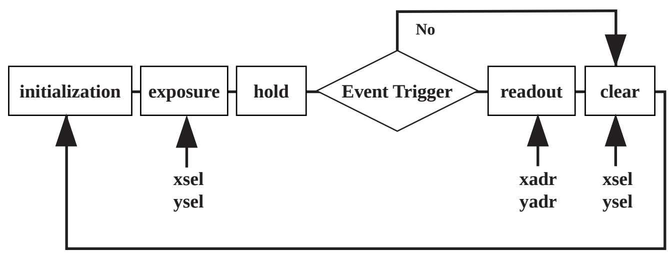

Fig. 4. Macrocell sequence.

3. Summary

Together with the Baker-Nunn optics and the image intensifier pipeline, the trigger and CMOS image sensor of ASHRA dramatically reduce the pixel cost comparing to the traditional air-fluorescence, air-Cerenkov, and water-Cerenkov detectors. As a result, ASHRA provides the advanced features of all-sky survey, 1 arcmin resolution, and simultaneous detection of air Cerenkov and fluorescence lights. This will open a new field, "Observational Particle Astrophysics" by continuously observing TeV gamma-rays, VHE-neutrinos, Knee-CR, and UHECR [6].

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