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CMOS-APS Detectors for Astrophysical Applications

G. Bonanno, M. Belluso, R. Cosentino, S. Scuderi

Istituto Nazionale di AstroFisica, Osservatorio Astrofisico di Catania, via S. Sofia 78, 95123 Catania, Italy e-mail: gbo@ct.astro.it

Abstract. Since three years, we have started, a research program to select a suitable detector based on the Complementary Metal Oxide Semiconductor Active Pixel Sensor (CMOS-APS) technology with a sufficient sensitive area for astrophysical applications. Thanks to the CMOS technology, the pixel addressing and the readout circuits as well as the analogue-to-digital converters are integrated into the chip. This unique characteristic makes the CMOS-APS a good candidate for a very compact, low power consumption, imager system. With time the CMOS-APS performances will become very similar to those of CCDs. Here we compare the CCD and CMOS-APS technologies and explain why, for our application, a CMOS-APS is better suited than a CCD.

Key words. Detectors – CMOS-APS – Intensified CMOS-APS – Microelectronics

1. Introduction

The CCD technology, developed more than twenty years ago and improved during these years, is well known and is appreciated in many fields for the high quantum efficiency in the visible spectral range and the low readout noise even at relatively high scan rates. The novel CMOS-APS technology is in continuous evolution, and many progresses have been made on the driving architecture and on the noise performances since the first produced APS. Current available CMOS-APS show a greater readout noise than CCDs, but improvements on noise reduction and on quantum efficiency have been announced by various silicon industries. In the very near future the only difference in favour of CCDs, will be the fill factor that, while for the CCD is 100 %, for the CMOS-APS is not higher than 60 %. However for observations where the photon flux is sufficient or in intensified photon counting systems this parameter is not very critical.

2. CMOS-APS or CCD?

As the CMOS-APS performances improve, it becomes more and more difficult to select what is the best suitable detector for a particular application. The CCD technology, developed more than twenty years ago and improved during these years, is well known and is appreciated in many fields for the high quantum efficiency in the vis-

Send offprint requests to: G. Bonanno
Correspondence to: via S. Sofia 78, 95123 Catania

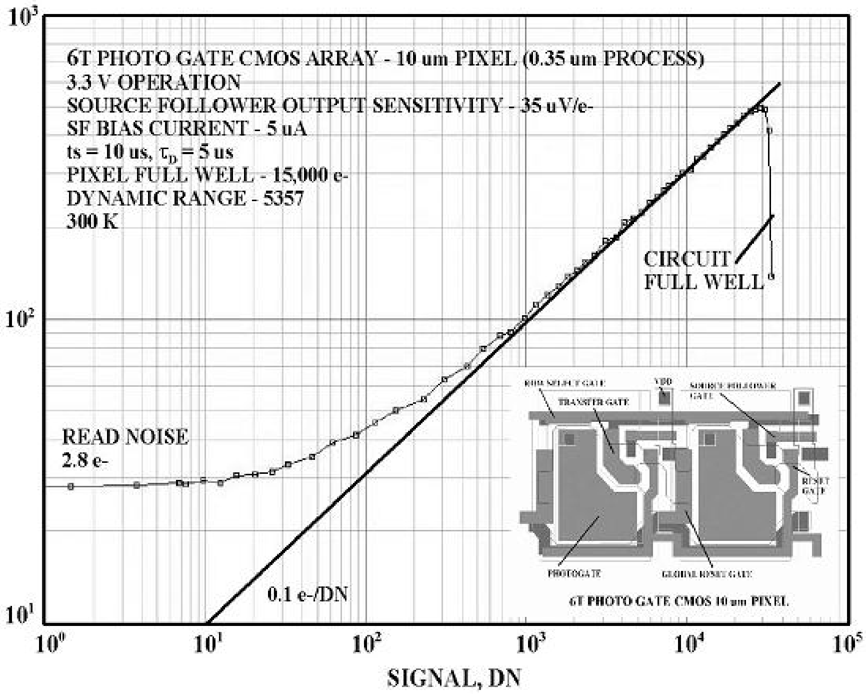

Fig. 1. Linearity and noise for a CMOS Array manufactured by Sarnof (J. Janesik). The operating conditions are also shown. As can be noted a 2.8 e- r.m.s. has been achieved.

ible band and the low readout noise even at relatively high scan rates. But CMOS is superior to CCD when applied to high speed applications as for example in adaptive optics, star trackers, fast video-rate readout systems. At the moment the relevant difference between CCD and CMOS is the fill factor that, while for CCD is 100 %, for CMOS-APS is not higher than 60 %. Probably the economics will drive the future imaging technologies making the CMOS a good competitor respect to the CCD, in fact the CMOS has a low fabrication cost and easy foundry access, while the CCD technology is very complex and expensive. Taking a look of the current state of art of the CMOS technology, we can assert that CMOS can compete with the CCD scientifically but major development is required. Recently at Sarnof Corporation a new device has been produced, the characterization in terms of linearity and noise is shown in figure 1. As can be noted a 2.8 e- r.m.s. has been achieved. The main reasons to select a CMOS-APS for astrophysical applications can be itemized as follow:

- APS does not require any external driving electronics, and thus avoids the complexity and power consumption of the electronic driver,
- APS has an architecture capable of higher frame rates than CCD,
- CMOS is more resistant to high energy radiation than a CCD and thus is suitable in space applications.

3. A feasible application

In astrophysical applications where usually the photon flux is very faint is prefer-

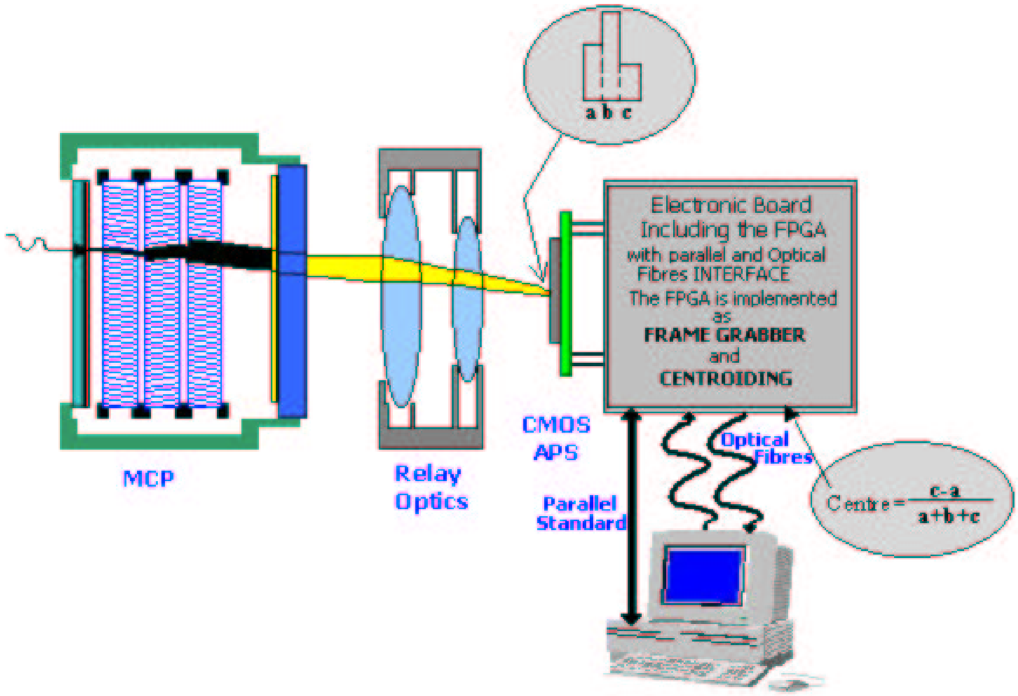

Fig. 2. Block Diagram of the CMOS-APS photon counting system

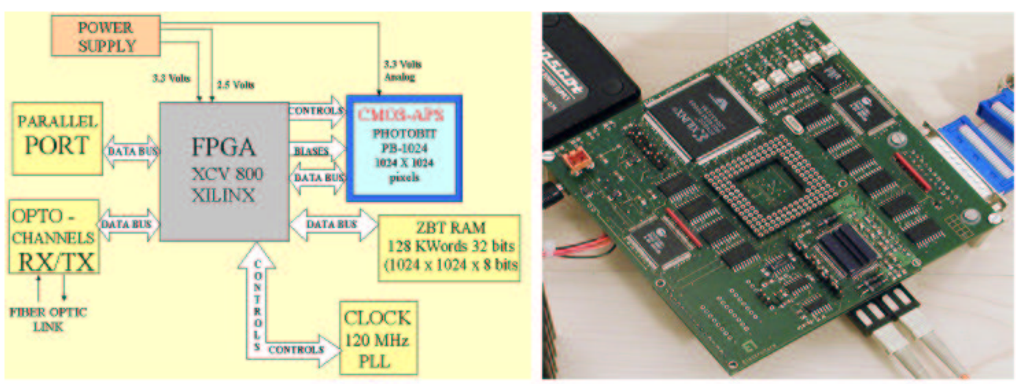

Fig. 3. Block diagram (left panel) and picture of the electronic board (right panel)

able to use photon counters that essentially are realized by coupling intensifiers Micro-Channel Plate (MCP) with image sensors (used as event position sensors) and some electronics that compute the centroid event. Intensified CCD (ICCD) or Electron bombarded CCD (EBCCD) have been manufactured for a long time now. The major limitation of such kind of devices is the low saturation level, that means a low dynamic range, due to the time required to read the image and compute the photon event position. To obtain a photon counter system capable of high count rates we developed an intensified MCP coupled with a CMOS-APS manufactured by Photobit, the PB 1024, that has an area of 1024x1024 pixels and is able to sustain a frame rate of 500 frames/s (about 10 times the TV CCD). The high frame rate is essentially due to the internal CMOS architecture that includes on chip the timing and control circuitry to treat a row at a time and 1024 -A/D converters. A block diagram of the complete system is shown in figure 2. The electrons generated in a photocathode are multiplied by the MCP, and the emerging electron cloud impinges on a phosphor screen giving a luminous spot. A relay optics re-images this spot onto the CMOS-APS. The APS and a high density Field Programmable Gate Array (FPGA) are located on a very compact board that is connected to a PC through a parallel interface and a fast serial connection (1.2 GBit/s) based on fibre optic. The FPGA is configured (by downloading a file via the parallel interface or via the optical fibres) to drive the APS, to readout the pixels and to make computations. The data corresponding to the coordinates of each valid event are acquired by the computer and stored in a file. To achieve a very compact and highly programmable system we used an ultra-high density (800K Gates) Field Programmable Gate Array (FPGA) to give the necessary control signals. The block diagram of the detector front-end electronics is shown in the left panel of the figure 3, while the right panel shows a picture of the electronic board. The high count rate allowed by our system is due not only to the high frame rate of the CMOS-APS but also to the fact that the FPGA hosts the centroid algorithm and makes computation while the images are acquired. A control software written in Visual C++ has been developed to drive the entire data acquisition procedure.

4. First Results

Before operating in centroid mode, we took lots of images, varying the MCP gain, the objective focus and the APS working frequency. From the analysis of the spot profile with respect to the noise level we derived the best operating conditions. Images taken at 20 MHz, 40 MHz and 50 MHz show that the noise increases with the increasing frequency, while the events are always well discriminated. The measured APS fixed pattern noise is negligible (3 - 6 ADU r. m. s.) at all readout frequencies. Another advantage of CMOS respect to the CCD is the intrinsic possibility of windowing to speed up the readout. Our system can double the count rate by simply windowing the CMOS-APS to half frame.

5. Conclusions

The CMOS-APS can be applied successfully in high speed applications. Future work have to be done to have a real competitor respect to the CCD in scientific applications. Thanks to the CMOS-APS internal architecture and to the use of an FPGA it is possible to make a very compact, powerful and highly programmable imaging system. In fact by means of a simple control software the system parameters can be easily adjusted and the FPGA can be reconfigured at any time.

We demonstrated that CMOS-APS can be used in applications where photon counters are required and an higher count rate is preferable. We measured on the tested CMOS-APS, negligible fixed pattern noise (3 - 6 ADU r.m.s.) even at 50 MHz (400 Frames/s) and concluded that the CMOS-APS used as position sensor in MCP based systems can perform better than a faster CCD and with some important advantages: compactness, simplicity, radiation hardness (good for space applications) and low power consumption.

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