

# **A Read-out System for the Medipix2 Chip Capable of 500 Frames per Second**

M. Maiorino<sup>1,\*</sup>, R. Martinez<sup>2</sup>, G. Pellegrini<sup>2</sup>, G. Blanchot<sup>1</sup>, M. Chmeissani<sup>1</sup>,  
J. Garcia<sup>1</sup>, M. Lozano<sup>2</sup>, C. Puigdengoles<sup>1</sup>, M. Ullan<sup>2</sup>

<sup>1</sup>IFAE – Institut de Física d'Altes Energies – UAB Campus – 08193 - Barcelona  
- Spain

<sup>2</sup>Centro Nacional de Microelectrónica – IMB-CNM-CSIC – UAB Campus –  
08193 - Barcelona - Spain

## **Abstract**

High speed X-ray imaging acquisition technique is a growing field that can be used to understand microscopic mechanism of different phenomena in biology and material science. IFAE and CNM developed a very high speed readout system, named DEMAS, for the Medipix2. The system is able to read a single Medipix2 chip through the parallel bus at a rate of 1 kHz. With a duty cycle of 50 %, the real sampling speed is 500 frames per second (fps). This implies that 1 ms is allocated to the exposure time and another millisecond is devoted to the read-out of the chip. In such configuration, the raw data throughput is about 500 Mbit/s. For the first time we present examples of acquisition at 500 fps of moving samples with X-rays working in direct capture and photon counting mode.

**Keywords:** high speed X-ray imaging, X-ray readout system, radiography.

**PACS:** 87.57.-s; 87.59.Bh; 07.05.Hd

## **1. Introduction**

Dear\_Mama (Detection of Early Markers in Mammography) [1] is a scientific collaboration funded by E.U.-funded in the framework of the FP5 programme. Its aim is

---

\* Corresponding author: Marino Maiorino, maiorino@ifae.es, +34 93 581 4249

the development of a low-dose X-ray system based on CdTe or Si detectors coupled to photon counting electronics for mammography and osteoporosis. In our system, a complete image is made of 320 single chip images; in order to limit the read out time for the whole image in one second, a very fast read out system was developed.

The detection system developed by Dear\_Mama project is based on Medipix2 [2] photon counting read-out chip. Medipix2 is an ASIC developed by Medipix Collaboration [3], based at CERN, mainly for medical imaging applications in the field of X-rays. It features a matrix of  $256 \times 256$  pixels with a pixel pitch of  $55 \mu\text{m}$ , the ideal spatial resolution for a medical imaging device. Each pixel in Medipix2 chip features a 13-bit pseudo-random counter, so that one image is made of  $13 \times 256 \times 256 = 832$  kbits. For external reading, Medipix2 provides both a serial I/O LVDS data bus and a CMOS 32-bit parallel bus, that allows fast data transfer.

The pixellated detector material is coupled to Medipix2 via a bump-bonding process. The X-ray photon is directly captured in the detector and induces electric signals that are processed and counted in the Medipix2 ASIC.

Silicon is the standard material for radiation detectors due to its low cost and wide spread availability, however since a decade CdTe has become the reference material for X-ray application due to its high Z number. Therefore, in order to maximise the detection efficiency, thick CdTe can be used as a detector, a feature that is not feasible with silicon. The high Z value of this semiconductor material is such that it shows a high absorption coefficient (AC) even for small values of the detector thickness. For example, as shown in figure 1, the AC for 20 keV photons in a Silicon detector  $800 \mu\text{m}$  thick is about 50 %, whereas for a CdTe detector only  $300 \mu\text{m}$  thick is about 97 %.

There are different high speed X-ray imaging devices in the market, but they are based on scintillation material and CCDs. X-ray direct capture and photon counting offers

very high quantum efficiency, ultra low noise, and high contrast image at low doses. Therefore, we are able to obtain high-speed movies with a microfocus X-ray tube.

In this work we will highlight the main features of the read-out system DEMAS (DEar\_Mama Acquisition System) based on the Medipix2 chip, and developed in the framework of Dear-Mama project with capability to grab 500 frames per second (fps). The present paper shows that, with the parallel readout option provided by Medipix2 chip, it is possible to design a very fast X-ray imaging camera for various imaging applications, such as material engineering, biological cellular processes, etc., where high frame rate acquisition is desirable.

## **2. DEMAS readout system**

The DEMAS system, shown in figure 2, can read the Medipix2 chip using both its transfer modes, serial LVDS and 32-bit CMOS parallel bus. The serial communication mode is based on Low Voltage Differential Signaling (LVDS), although it is a serial protocol, it uses differential signals, therefore it features a high common-mode rejection value over long distances and allows high speed communications on a single line. This serial mode was tested up to 100 MHz.

The second communication mode is based on a parallel CMOS bus. Although the maximum communication frequency and distance values are smaller than in the LVDS case, CMOS bus provides 32 communication lines simultaneously. The presented system uses an internal clock running at 66 MHz, and therefore this is the maximum velocity that DEMAS can drive this bus. It also features a 66 MHz 32-bit local PCI Interface and can communicate data with the host PC through optical link at a 150 MBytes/s continuous transfer speed. The circuitry is controlled via a high performance Stratix FPGA. This system is used as well for Medipix2 ASIC wafer

probing, assembly characterization and for single-chip static and dynamic image acquisitions. DEMAS also includes a complete GUI software for the full control of the hardware.

Each Medipix2 frame can be read through the parallel bus in 1 ms, which represents a transfer rate of 100 Mbytes/s. The actual DEMAS on-board memory allows the capture of up to 1024 consecutive images with no delay, which corresponds to a 2 s movie at 500 fps. Nevertheless, as the transfer rate from the readout system to the PC is higher, the acquisition can be sustained until all the available memory at the PC is filled. With a duty cycle of 50 %, this speed results in a continuous acquisition rate of 500 frames per second.

### **3. High Speed Measurements**

CdTe and Si pixel detectors bump bonded to Medipix2 chip were used. Medipix2 chip is designed to operate with both negative (electrons) and positive (holes) charges, thus in our study we biased the CdTe and Si detectors to operate in electrons and hole collection mode respectively.

CdTe pixel detectors with a resistivity of  $10^9 \Omega/\text{cm}$  and a thickness of 1 mm were supplied with platinum ohmic contacts from Acrorad while high resistivity n-type silicon wafer, 800  $\mu\text{m}$  thick, were supplied from Siltronix. Silicon detectors were fabricated at IMB-CNM facilities in form of p-n diodes. Silicon detectors were always operated at full depletion voltage while CdTe were operated at +100 V.

Figure 3 shows the setup used to perform the experiment. The test bench is placed under a Hamamatsu L7901 microfocus X-ray tube that has a focal spot size of 5  $\mu\text{m}$ , a voltage range of 20 to 100 kV and a maximum current intensity of 250  $\mu\text{A}$  at 40kV. In order to

obtain the maximum radiation flux from the X-ray tube, we minimized the distance between the X-ray tube and the detector.

To perform high speed acquisitions there are few requirements that have to be met: the radiation flux must be high enough in order to have enough count-rate per image pixel; a high detection efficiency is desirable in order to detect all the incoming photons, thus increasing the signal significance over the image noise.

In order to obtain high detection efficiency, we set the maximum energy of the X-ray tube to 40 and 60 keV for silicon and CdTe respectively. The noise was kept to a low level by setting a suitable threshold value for the Medipix2 chip and controlling the temperature of the assembly via a Peltier device. The shutter signal fed to the Medipix2 during a high-speed acquisition was monitored using an oscilloscope to evaluate the actual frame grabbing speed and the resulting measured rate was 509 Hz.

To visualize the system ability in sampling fast acting phenomena, we took short movies of a high speed rotating gears with CdTe detector, and a high speed rotating binary wheel and the mechanics of a spring-driven clock (spring wheel, hairspring and pallet) with silicon detector. The image quality was good enough to see clearly the phenomenon under study. In the case of the binary wheel, a circular copper binary pattern with 256 different values was made on a Printed Circuit Board (PCB). During the acquisition, the PCB rotated at 2 rpm, and used as a tool to accurately confirm that acquisition speed was 500 fps. Finally, the mechanism of the spring wheel clock had a movement frequency of 1.5 Hz.

The subjects of the acquisitions and images of the movies are shown in figures 4, 5, and 6.

#### **4. Conclusions**

DEMAs is a high-speed readout system for the Medipix2 chip and has been developed within the framework of Dear\_Mama project. The system allows the readout of Medipix2 chip using serial and parallel buses and it includes a software package to control it. Using the parallel bus, high speed X-ray video recording at a maximum of 500 fps was achieved. The system capabilities are demonstrated via the grabbing of different X-ray videos at this speed using CdTe and silicon pixel detectors.

#### **References**

- [1] Detection of Early Markers in Mammography (Dear-Mama), EU Project n. QLK3-2001-01318, [http://xray.ifaes.es/index\\_brochure.html](http://xray.ifaes.es/index_brochure.html)
- [2] X. Llopart et al., "Medipix2, a 64k pixel readout chip with 55  $\mu\text{m}$  square elements working in single photon counting mode" IEEE Trans. Nucl. Sci. vol. 49, no. 5, pp. 2279-2283, 2002.
- [3] Medipix2 Collaboration website: [www.cern.ch/MEDIPIX](http://www.cern.ch/MEDIPIX).
- [4] C. Ponchut et al., "Evaluation of a photon-counting hybrid pixel detector array with a synchrotron X-ray source" Nucl. Inst. & Meth. A, Vol. 484, Issues 1-3, pp. 396-406.
- [5] <http://www.ifaes.es/xray/DEMAs/500fps>.

## Figure captions

1. Absorption coefficients for various detector materials with different thicknesses.
2. Picture of the DEMAS read-out system board.
3. Experimental set used to acquire high-speed images, the picture shows the DEMAS acquisition board, the Hamamatsu microfocus X-ray tube, and the object to be filmed.
4. Picture of a rotating gear and X-ray video acquired with a CdTe pixel detector. Full video is shown in [5].
5. Circular copper binary pattern with 256 different values made on a Printed Circuit Board (PCB) and X-ray video acquired with a silicon pixel detector. Full video is shown in [5].
6. Mechanism of the spring wheel clock which has a movement frequency of 1.5 Hz and X-ray video acquired with a silicon pixel detector. Full video is shown in [5].

# FIGURES

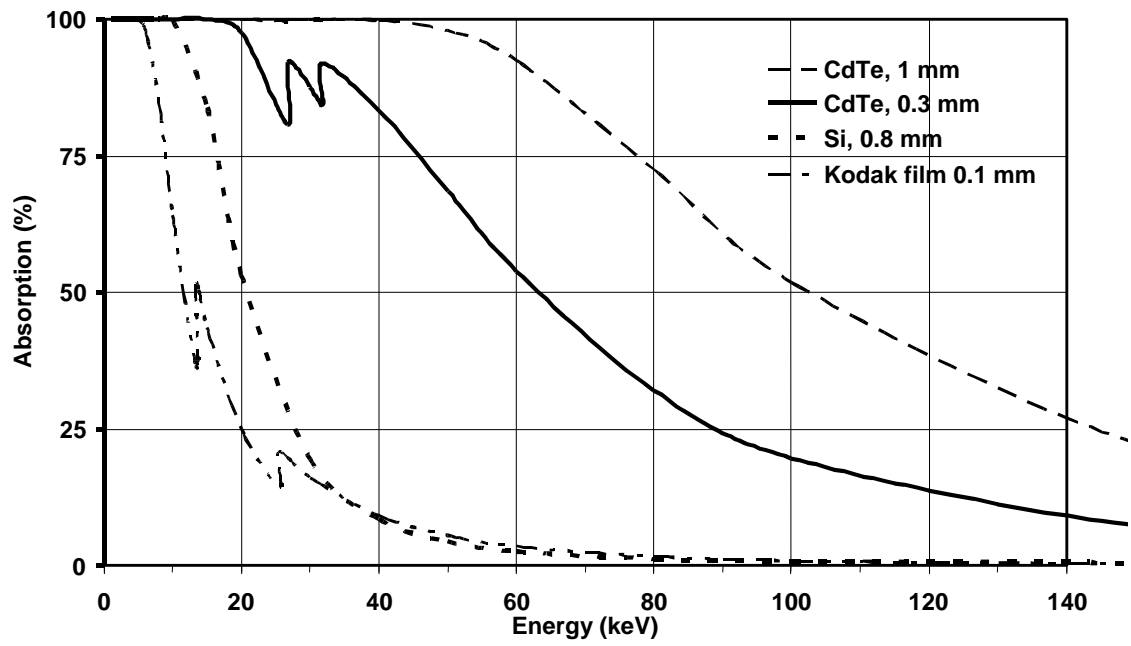


Figure 1

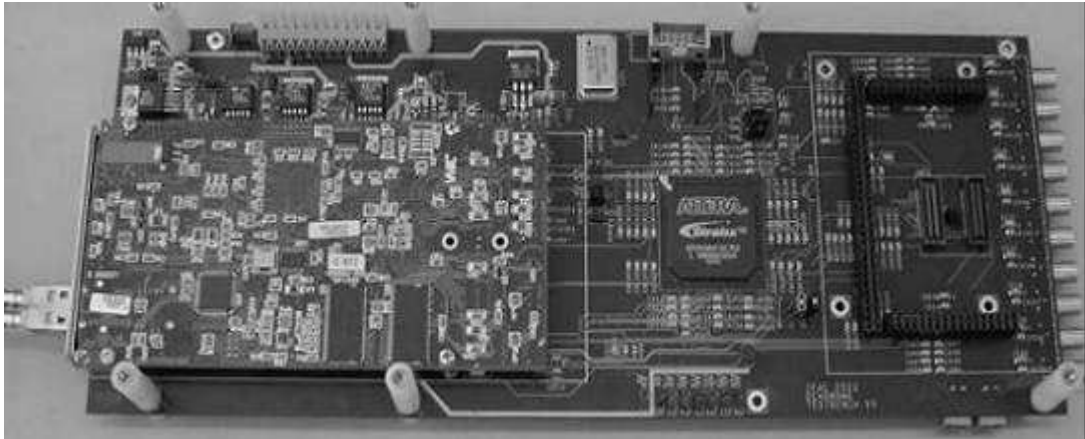


Figure 2



Figure 3

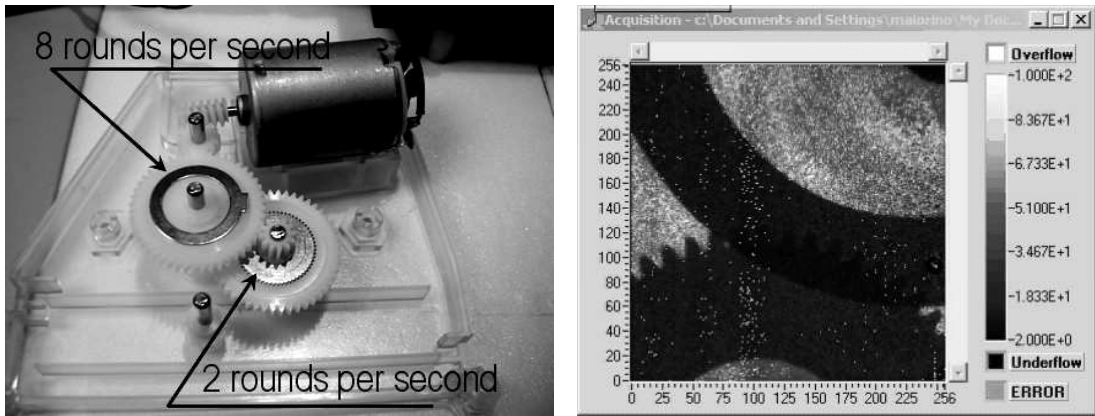


Figure 4

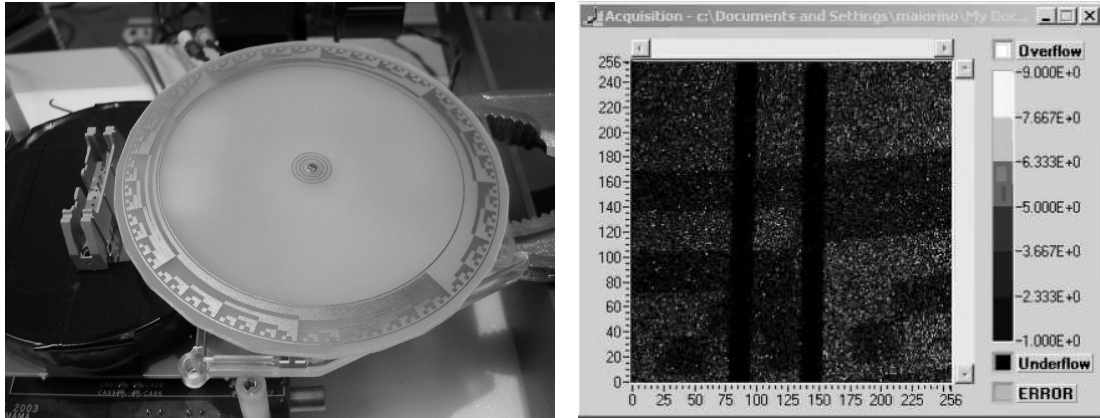


Figure 5

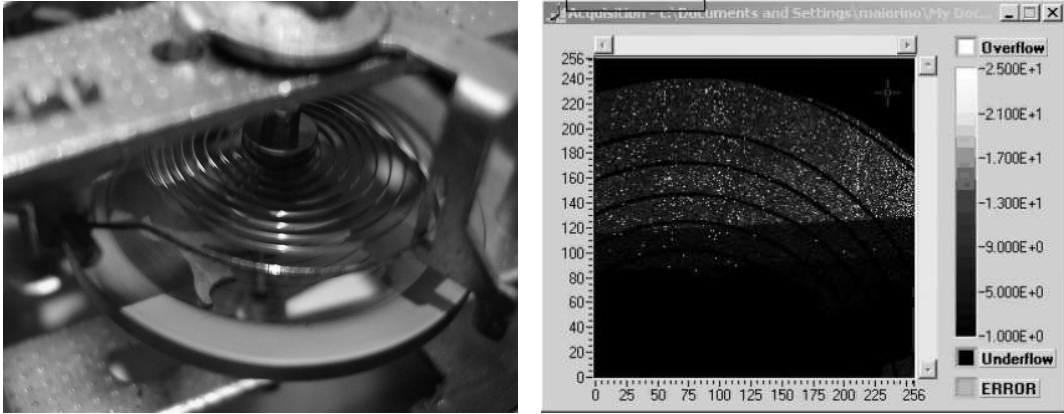


Figure 6