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Design and Performance of the ePix Camera System

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Abstract. A second generation camera system has been developed and built at SLAC for use in experiments at the Linac Coherent Light Source (LCLS). The system is developed around the ePix family of hybrid pixel detectors, with a focus on modularity in mechanical, electrical, and data acquisition interfaces, allowing for a versatile system that can be quickly reconfigured. The first camera is a compact, 155 mm × 52 mm × 52 mm box, with an active area of up to 35 mm × 38 mm, recording full frames of over 540 kpixel at rates in excess of 120 Hz. The camera allows fast debugging and development, providing a test bench to demonstrate features that may be required at future high repetition rate facilities.

INTRODUCTION

A second generation camera system has been developed and built at SLAC National Accelerator Laboratory for use in experiments at the Linac Coherent Light Source (LCLS) [1, 2] and other radiation sources. The system is developed around the ePix family of hybrid pixel detectors and ASICs [3], with a focus on modularity in mechanical, electrical, and data acquisition interfaces, allowing for a versatile system that can be quickly reconfigured and stacked.

The range of applications at light sources (e.g., LCLS) is broad and cannot be covered by a single detector. ePix is a platform based design [3] with multiple variants optimized for different subsets of applications. The ePix detectors will expand the range of applications covered today by the CSPAD detector providing better signal to noise ratios and/or larger dynamic range.

MECHANICAL AND THERMAL DESIGN

The first camera to be deployed is a compact, 155 mm × 52 mm × 52 mm box, with an active area of up to 35 mm × 38 mm, see Fig. 1. A limited number of connections are required to power and operate the camera: a 26-pin cable to provide power and triggers, and an optical fiber for data acquisition interfaces.

The main block is made of copper and is water cooled. The camera has one analog and one digital board mounted on either side of the main block, for a compact form factor and efficient cooling.

The detector body is fabricated out of oxygen-free electronic copper (OFE Cu) with a primary block and a cover plate brazed at one end. This brazed assembly contains a cooling channel for low conductivity water which is internal to the cooper body. The internal cooling channel is required to dissipate the heat generated from a thermoelectric Peltier element located on the adjacent side of the cover plate.

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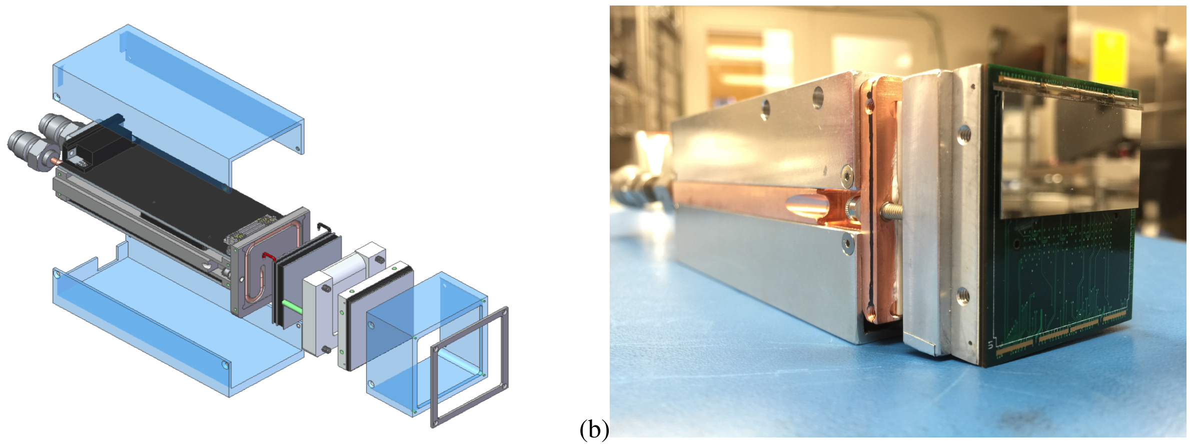


(a) (b)

FIGURE 1. (a) CAD design of the ePix camera assembly, showing central block with water cooling, Peltier element, detector module (strong-back, PCB, and hybrid pixel detector assembly) and covers. (b) Photo of an assembled ePix100 2×1 ASICs camera, vacuum compatible version, with the front cover removed to show the sensor and ASICs.

The brazement was performed with a braze alloy of 35% Au and 65% Cu. During this process a film alloy was placed between the primary block and the cover plate to ensure a solid joint was formed between the mating surfaces. Swagelok VCR glands were also brazed on the back end of the detector body.

The ePix camera was originally designed as a prototype for non-vacuum applications at SLAC National Accelerator Laboratory and was subsequently qualified for vacuum operation after performing a specific set of vacuum qualifications (hydrostatic pressure test, leak test, visual inspection, nitrogen purge, check list, etc.)

The elements that dissipate heat (front detector module, elements on the side analog and digital boards) are in thermal contact with the main block, enabling vacuum operation or stable operation in air. There is a nitrogen purge line for operation in air at low temperature (under the dew point).

ELECTRONIC DESIGN

The ePix camera is built around a pair of printed circuit boards (one analog and one digital, see Fig. 2), compatible with a large set of existing and future cameras. They share firmware and software, enabling rapid development and testing of existing and new detectors. The division of digital and ADC functionality onto separate PCBs with well-defined interfaces and mechanical footprints further allows continual staged upgrades of system components.

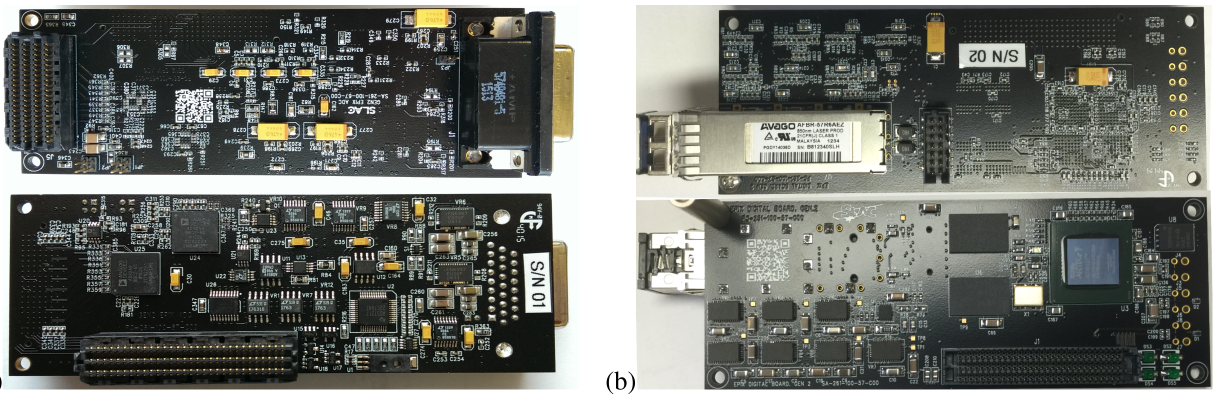
The camera and data acquisition system can record full frames of over 540 kpixel at rates in excess of 120 Hz [4]. The system supports Region of Interest (ROI) readout and can reach frame rates of over 1 kHz in this mode.

System features include: triggers that can be delivered either electrically or via optical fiber for simplified cabling and ease of setup; on-module memory allowing for buffering of ~ 500 Mpixel samples (with the Artix-7 FPGA); and firmware auto-calibration for improved ADC performance and stability. This auto-calibration self aligns the 700 Mb/s ADC serial data upon startup, which in turn relaxes design requirements on trace length matching and allows the ADCs to maintain high performance while residing on a separate PCB from the FPGA.

ONE SYSTEM, MANY CAMERAS

The ability to reuse almost all system components when developing and deploying a new type of detector with unique functionality greatly reduces the resources and time required, in some cases cutting the concept-to-deployment by a factor of two.

The ePix x-ray hybrid pixel detectors are built on the ePix platform [3], a modular and easy to adapt platform for particular detection requirements. Each new member of the family utilizes the same serial interface for configuration and slow-control of the ASIC, and only slightly modified interfaces for triggering and data collection. This allows the



(a) (b)

FIGURE 2. Photographs of the two central PCBs of the ePix camera. (a) The analog board includes a DB26 connector for bringing in power and triggering signals, two 16-channel, 65 Msps, 14-bit ADCs, voltage regulation, and high density board-to-board connectors to provide interfaces to the camera head and to the digital card. (b) The digital board is outfitted with an Artix-7 FPGA for system control, data collection, processing, and interfacing to back-end data acquisition systems. Data can optionally be buffered using 8 Gb of DDR3 memory. Back-end communication is performed via a pluggable SFP module using PGP, a custom protocol developed at SLAC.

TABLE 1. Overview of CSPAD and ePix detectors

	CSPAD low / high gain	**ePix100**	**ePix10k**	**ePixS**
Summary	currently deployed	low noise	high dynamic range	spectroscopic
Mode of Operation	2 gains, fixed	1 gain	2 gains, auto-ranging	1 gain
Range (8 keV photons)	350 / 2700	100	10 000	10
Pixel size	$110\,\mu m \times 110\,\mu m$	$50\,\mu m \times 50\,\mu m$	$100\,\mu m \times 100\,\mu m$	$500\,\mu m \times 500\,\mu m$
ASIC pixel array size	185×194	352×384	176×192	10×10
ASIC noise (e^- r.m.s.)	300 e^- / 1000 e^-	50 e^-	120 e^-	8 e^-

majority of system components (analog and digital PCBs, flex cable, and housing) to remain unchanged. Only the ASIC carrier board and the firmware must be changed, allowing the camera to be completely reconfigured in minutes.

This modular system has allowed rapid testing and validation of new ASICs, including ePix100, ePix10k, and ePixS. An overview is provided in Table 1.

- **CSPAD** [5] is currently the principal detector used for the LCLS hard X-ray experiments [2]. It is built around the CSPAD 1.5 ASIC, with 185×194 pixels ($110\,\mu m \times 110\,\mu m$), and 2 ASICs flip-chip bonded to one sensor. These sensor assemblies are used in 140 kpixel, 560 kpixel and 2.3 Mpixel cameras [2].
- **ePix100** [6, 7, 8] is a low noise (under 60 e^- r.m.s.) ASIC, see Fig. 3 (a), with 352×384 pixels ($50\,\mu m \times 50\,\mu m$), and 2×2 ASICs flip-chip bonded to one gapless sensor per ePix camera (resulting in a 704×768 pixels camera). This will be typically used in wavelength-dispersive spectrometers and x-ray photo correlation spectroscopy [2]. ePix100 has a 5 times higher signal to noise ratio than the CSPAD.
- **ePix10k** [9, 10] is a high dynamic range ASIC with 2 gains and auto-switching, allowing photon counting. The dynamic range is 10 000 8 keV photons, see Fig. 3 (b). The noise is under 120 e^- r.m.s.
  The ePix10k features 176×192 pixels per ASIC ($100\,\mu m \times 100\,\mu m$), and 2×2 ASICs flip-chip bonded to one gapless sensor per ePix camera (resulting in a 352×384 pixels camera). This will be typically used in high dynamic range applications like x-ray diffraction and pump-probe experiments [2]. ePix10k has a 2 times higher signal to noise ratio than the CSPAD and a 4 times larger dynamic range.
- **ePixS** [11] is a spectroscopic x-ray detector with a low noise (under 10 e^- r.m.s.) and 10×10 pixels per ASIC ($500\,\mu m \times 500\,\mu m$), used for energy-dispersive spectroscopy and low occupancy photon counting (full range of 80 keV) at pulsed sources, see Fig. 4.

In addition, the ePix family is continuing to grow with new members, e.g., Tixel, cPix[2].

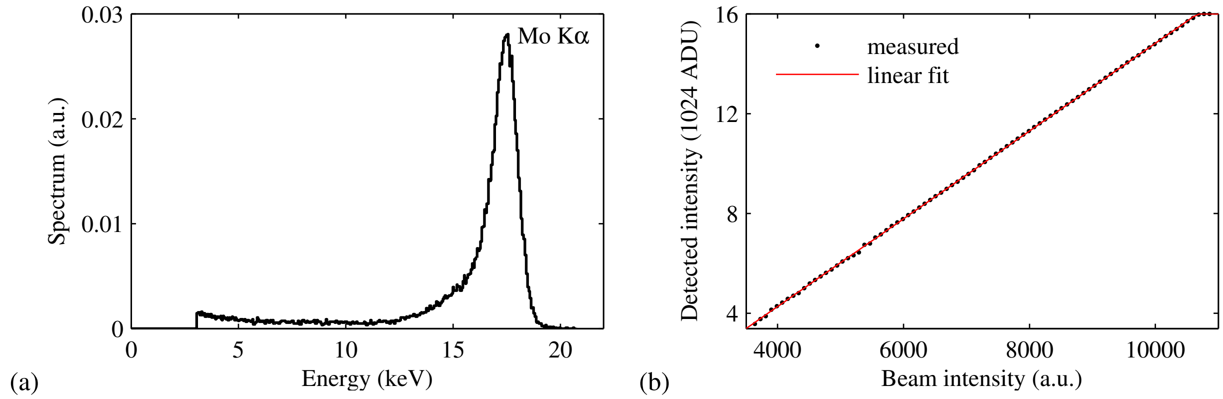


FIGURE 3. (a) ePix100 spectrum, demonstrating low noise operation with 17.4 keV illumination (Mo Kα line). (b) ePix10k has a high dynamic range of ~ 10 000 8 keV photons/pixel with good linearity.

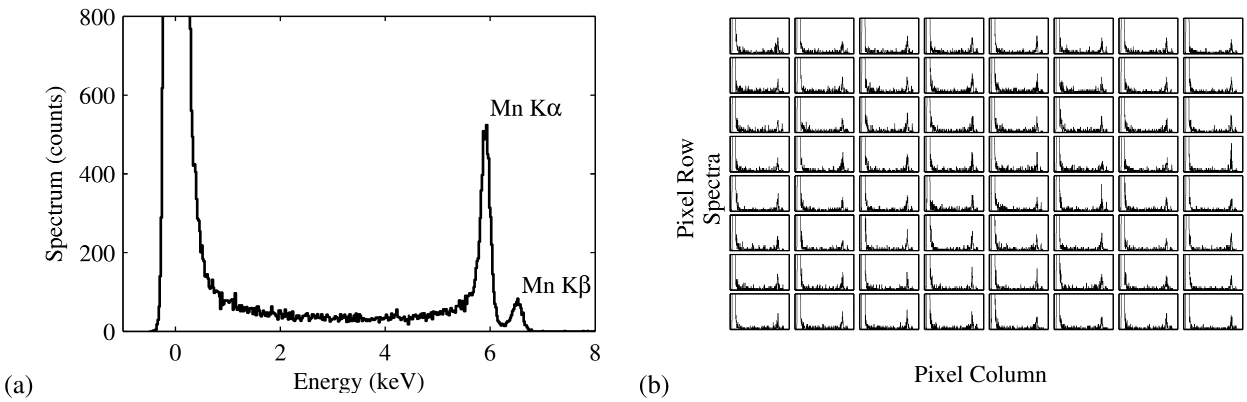


FIGURE 4. (a) ePixS spectrum obtained over all pixels using an Fe55 source, generating characteristic Mn Kα (5.9 keV) and Mn Kβ (6.5 keV) photons, showing the low noise operation. (b) Shows the same data separated in individual pixels.

CONCLUSIONS

The ePix camera is built around a pair of printed circuit boards which are compatible with a large class of existing and future cameras. They share firmware and software, enabling rapid development of new detectors built on the ePix platform. ePix cameras have a common thermal-mechanical package. Currently, 3 novel detector types are supported: ePix100, ePix10k, and ePixS. Two more detector types are anticipated soon: Tixel and cPix[2].

When developing a new suite of detectors for an operating facility the time from concept to deployment has a direct and critical impact on the science program. Use of this ePix camera system, which is common across different types of detectors, allows a high research and development velocity and hence a deeper and wider science reach for the LCLS and potentially other facilities.

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