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Implementation of Digital Multiplexing for High Resolution X-ray Detector Arrays

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Abstract— **We describe and demonstrate for the first time the use of the novel Multiple Module Multiplexer (MMMIC) [1] for a 2x2 array of new electron multiplying charge coupled device (EMCCD) based x-ray detectors [2]. It is highly desirable for x-ray imaging systems to have larger fields of view (FOV) extensible in two directions yet to still be capable of doing high resolution imaging over regions-of-interest (ROI). The MMMIC achieves these goals by acquiring and multiplexing data from an array of imaging modules thereby enabling a larger FOV, and at the same time allowing high resolution ROI imaging through selection of a subset of modules in the array. MMMIC also supports different binning modes. This paper describes how a specific two stage configuration connecting three identical MMMICs is used to acquire and multiplex data from a 2x2 array of EMCCD based detectors. The first stage contains two MMMICs wherein each MMMIC is getting data from two EMCCD detectors. The multiplexed data from these MMMICs is then forwarded to the second stage MMMIC in the similar fashion. The second stage that has only one MMMIC gives the final 12 bit multiplexed data from four modules. This data is then sent over a high speed Camera Link interface to the image processing computer. X-ray images taken through the 2x2 array of EMCCD based detectors using this two stage configuration of MMMICs are shown successfully demonstrating the concept.**

I. INTRODUCTION

It is highly desirable to have flexible medical imaging systems providing high spatial resolution over a ROI and FOV large enough to encompass areas of clinical interest [3]. We demonstrate for the first time the use of a custom built Multiple Module Multiplexer Integrated circuit (MMMIC) in a two stage configuration acquiring data from a 2x2 array of EMCCD based x-ray detectors and multiplexing the data to enable a large FOV at the same time providing high spatial resolution over a region-of-interest. MMMIC also supports the use of various binning modes to provide an adjustable spatial resolution. The FOV can be further extended in two dimensions by using a greater number of MMMICs in multistage configuration for interfacing larger arrays.

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II. Design & Construction

A. MMMIC

The MMMIC is manufactured on the 0.5 µm ON-SEMI standard analog/mixed signal CMOS process through MOSIS [4]. Fig.1 shows the microphotograph of the MMMIC depicting important pin names.

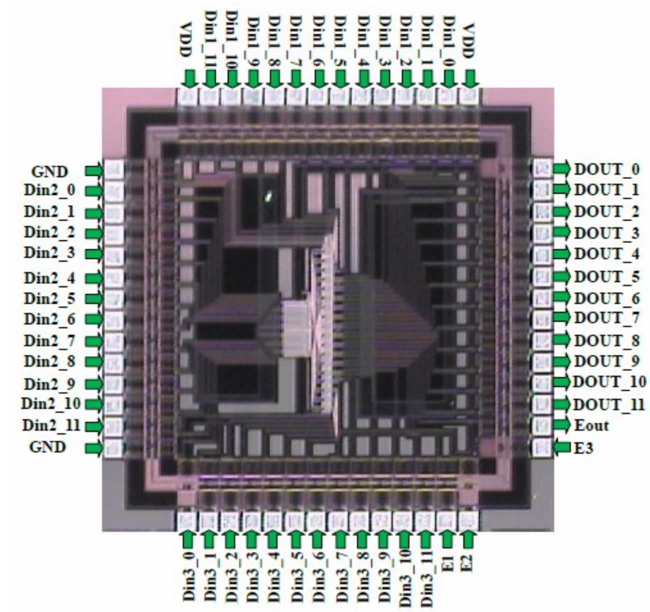


Fig.1 Microphotograph of MMMIC

Each MMMIC consist of three 12 bit input data modules M1, M2, & M3 as shown in Fig. 2. Each module has an enable signal M1_E1, M2_E2 & M3_E3 that turns ON or OFF that module.

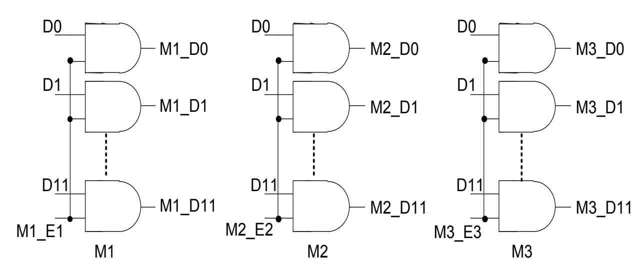


Fig. 2 Three Input modules M1, M2 & M3

Each MMMIC has an enable module consisting of three input signals E1, E2 & E3 that are used to derive signal M1_E1, M2_E2 & M3_E3 internally on chip. The enable module also generates an output enable signal Eout that is used as an input enable signal for next stage when a

MMMIC is used in a multistage configuration. Fig 3 shows the enable module.

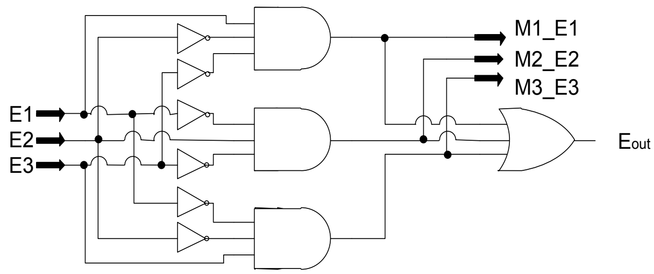


Fig.3 Enable module in MMMIC

The third part of the MMMIC is the 12 bit output module that consist of twelve 3-in-OR gates as shown in Fig. 4

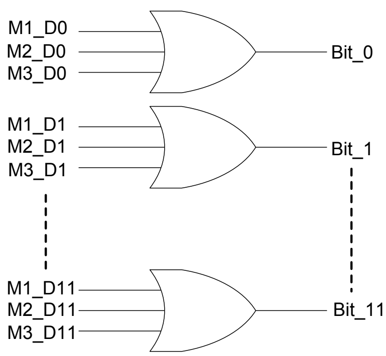


Fig. 4 The 12 bit Output module in MMMIC

The first OR gate handles the first bits M1_D0, M2_D0 and M3_D0 from each of the three input modules, the second OR gate handles the second bits M1_D1, M2_D1 and M3_D1 from each of the three input modules and so on till the twelfth OR gate which handles the twelfth bits from each of the three modules. Logic Table I given below shows all the possible cases of operation for a MMMIC.

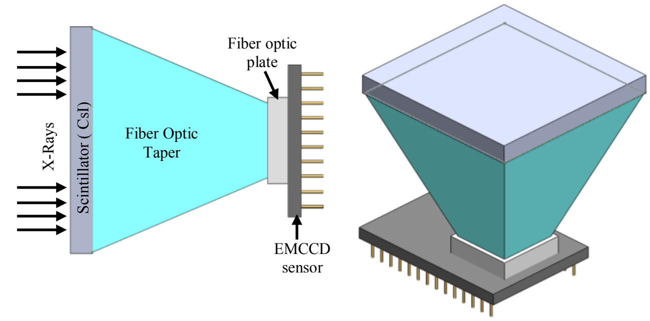
I/P Enable			O/P Enable	Modules		
E1	E2	E3	Eout	M1	M2	M3
1	0	0	1	Valid	Not Valid	Not Valid
0	1	0	1	Not Valid	Valid	Not Valid
0	0	1	1	Not Valid	Not Valid	Valid
1	1	0	0	Not Valid	Not Valid	Not Valid
1	1	1	0	Not Valid	Not Valid	Not Valid
0	0	0	0	Not Valid	Not Valid	Not Valid

Table I. Logic table for MMMIC

As we can see from the Table I, only in the cases when any of the three enable signals are ON is the data on the corresponding input modules valid or propagated to the output. Whenever any two enable signals are ON simultaneously the output module is isolated from the input modules to ensure data integrity and avoid false mixing of data from multiple modules.

B. EMCCD based detector array

As shown in Fig.5 an EMCCD based high resolution dynamic x-ray detector includes an EMCCD sensor optically bonded to a fiber optic plate (FOP) which is coupled to the



a) Side view b) Isometric view

Fig.5. EMCCD-based X-ray detector

micro-columnar scintillator phosphor, CsI(TI), using a fiber optic taper (FOT). Fig. 6 shows the 2x2 array of these EMCCD based detectors that were used to interface with the MMMICs.

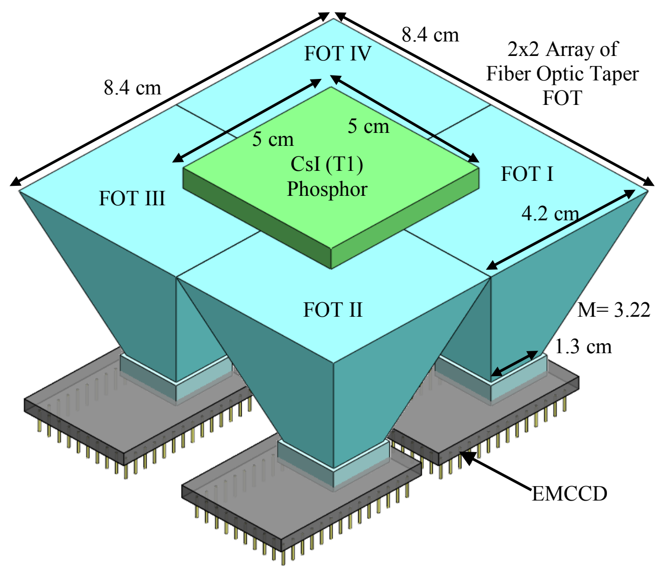


Fig. 6 The 2x2 array of EMCCD based detectors

The fused fiber optic taper array has a total field of view of 8.4 cm x 8.4 cm. The magnification ratio M for each taper in the array is 3.22 which is the ratio of the larger end of the taper (4.2 cm) to the smaller end of the taper (1.3 cm). The CsI (T1) that was used in the prototype array has a FOV of 5cm x 5cm. The EMCCD sensor used is a back-illuminated L3Vision^{TM} EMCCD sensor (CCD201-20) manufactured by e2v Technologies Ltd, UK [5]. It consists of 1024x1024 active image pixels, each 13 µm x13 µm in size providing an active image area of 13.3 x13.3 mm^2. Fig. 7 shows the actual picture of the EMCCD that was used. It has peak quantum efficiency of over 92% over the spectral response ranging from 500-600 nm. Fig. 8 shows the complete electronic assembly for 2x2 array

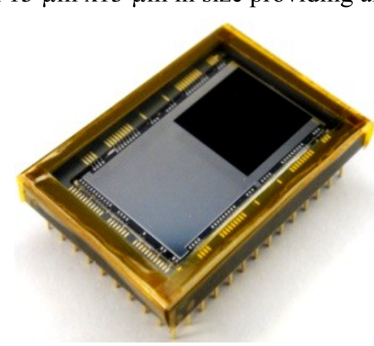


Fig.7. L3 Vision EMCCD sensor

of EMCCD based detectors that comprise headboards, driver board, FPGA board, power board and CameraLink board.

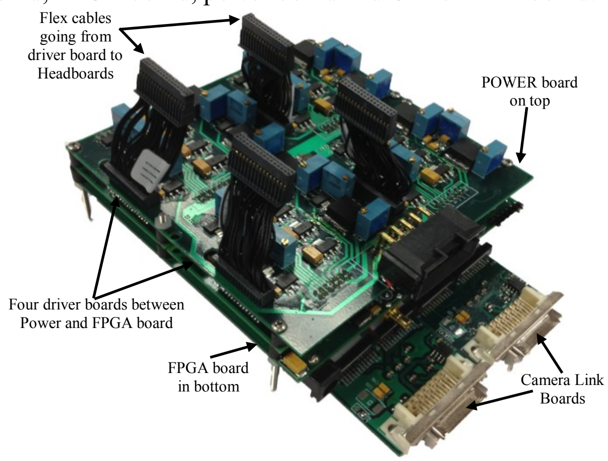


Fig.8. Complete electronic assembly for the 2x2 array

C. 2x2 Array configuration of MMMICs

As described each MMMIC is capable of acquiring data from three imaging modules in which each imaging module gives a 12-bit digital output. The innovative design of the MMMIC allows multiple chips to be cascaded to allow a greater number of modules to be connected together. Fig. 9 shows a two stage configuration of MMMIC where four modules of EMCCD based detectors in a 2x2 array are connected together.

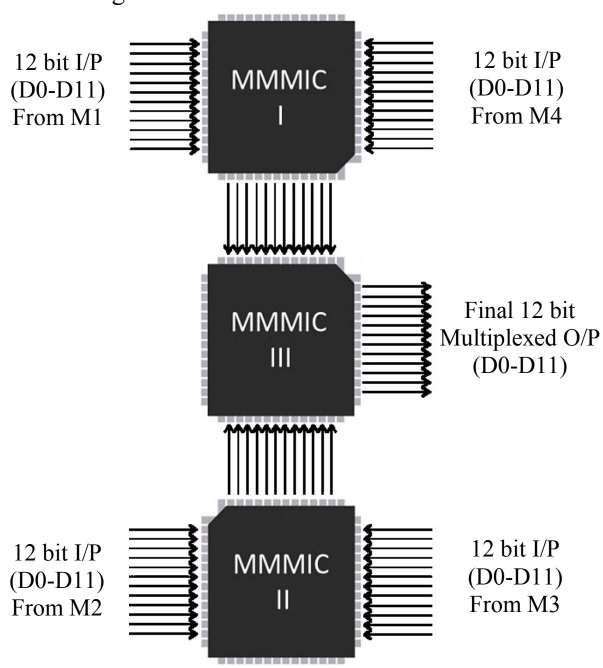


Fig. 9 Two stage configuration of 3 MMMICs for 2x2 array imaging

As shown in Fig. 9, the first stage involves MMMIC I and MMMIC II, each of them handling data from two imaging modules. MMMIC I gets the data from modules M1 and M4 while MMMIC II gets the data from modules M2 and M3. The second stage MMMIC III handles the multiplexed data from the first stage MMMICs in similar way and provides the final 12-bit multiplexed data from the four imaging modules M1, M2, M3 and M4

D. Setup & Data Acquisition

Fig. 10 shows the experimental setup that was used during testing the use of MMMICs in a two stage configuration for a 2x2 array of EMCCD based detectors. The 2x2 array of detectors was inserted in front of the standard flat panel detector on a Toshiba Infinix C-arm Gantry.

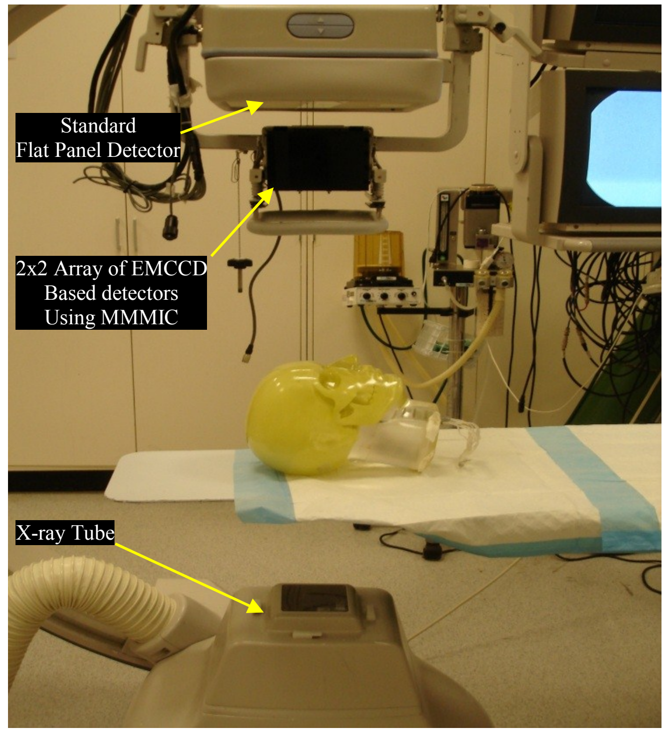


Fig. 10 Experimental setup to test MMMIC for 2x2 array

Fig. 11 shows the data acquisition scheme for the 2x2 array of EMCCD based detectors using the two stage configuration of MMMICs. The trigger from the Toshiba Infinix x-ray machine goes to the 2x2 array of EMCCD camera. All the four modules start acquiring the x-ray images simultaneously and the 12 bit data from all modules is multiplexed using MMMICs and is sent over a high speed Camera Link interface to an image acquisition board (NI PCIe-1430 from National Instruments, Inc.[6]). The CameraLink standard provides a fast interface for high resolution and high speed cameras with data rates up to 2 Gbit/s. This acquisition board is located in the PCI express slot of the processing computer. The software platform LabVIEW (National Instruments, Austin, TX) is used to control the camera as well as acquire and process the image.

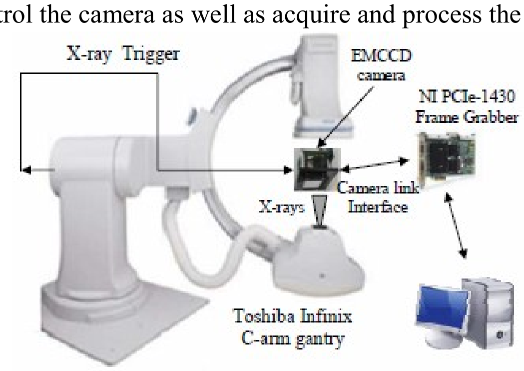


Fig.11. Data acquisition scheme for the prototype detector

III. RESULTS & DISCUSSION

Fig. 12 shows the x-ray image of a lead line pair phantom taken through a 2x2 array using MMMIC.A zoomed version of Fig.12 showing high resolution of 8 line pairs per mm is shown in Fig. 13. Another x-ray image of a scale measuring in centimeters with embedded lead numbers is shown in Fig. 14. The x-ray technique parameters during the experiment were 50kV, 100 mA, and 10 mSec

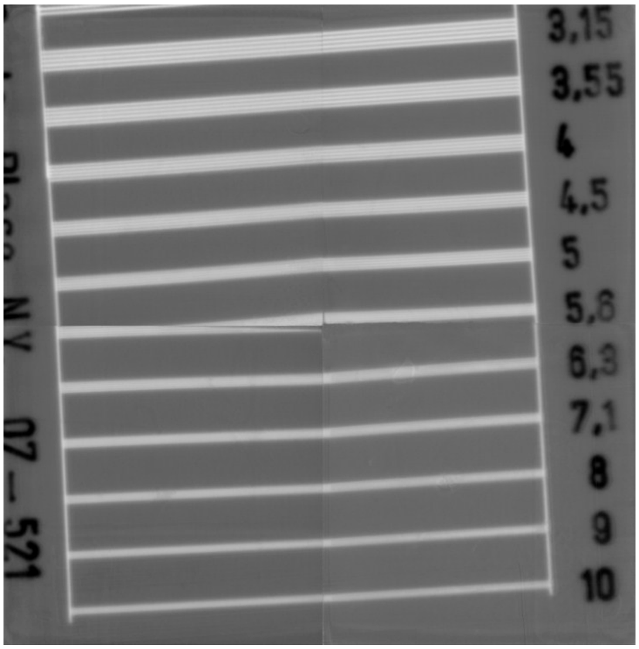


Fig.12. X-ray image of a lead line pair phantom

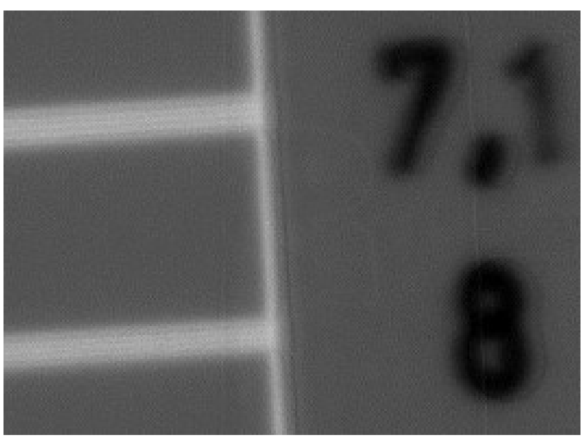


Fig.13. Zoomed view showing high resolution of 8 line pairs/mm

The difference in the image luminosities between four image modules is because of the inherent differences in the EMCCDs due to manufacturing. The image discontinuities visible at inner boundaries is caused by image mismatching during image reregistration of four modules to form a single image as well some geometric distortions caused by mechanical placement of EMCCDs with respect of the fused fiber optic taper array. All these imperfections can be corrected at hardware and software level and is not described here since it is beyond the scope of this paper.

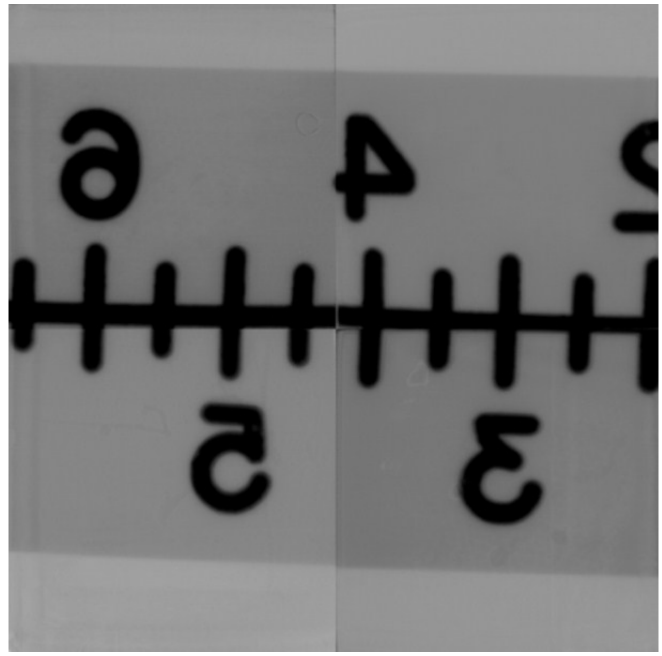


Fig.14. X-ray image of centimeter scale with embedded lead numbers.

CONCLUSION

In this paper we have described the design and demonstrated the first ever use of the MMMIC to acquire data from a 2x2 array of EMCCD based x-ray detectors using a multistage configuration. This configuration enables MMMIC to handle data from even larger arrays thereby further increasing the field of view. The selective enabling of any module in the array and support for different binning modes allows MMMICs to support ROI imaging and adjustable high spatial resolution

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