A 5Mpix 5 µm 140 fps MWIR Focal Plane Array and Readout Integrated Circuit at 150K

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Abstract— A novel 5Mpix Medium Wave Infrared (MWIR) imager is presented. The imager format is 2560×2048. An XBn-InAsSb infrared Focal Plane Array (FPA) is used to enable operation at relatively high temperature(150K), and is hybridized to a CMOS Readout Integrated Circuit (ROIC). This work opens the way for new applications using low Size, Weight and Power (SWAP) cooled MWIR detectors. The pixel size is reduced to 5µm enabling relatively low cost fabrication and reducing the size of the optics required, while maintaining high quality electro-optical performance.

Keywords: Infrared, Cooled, IRFPA, ROIC, MWIR, ADC, Cryogenic, XBn-InAsSb.

I. INTRODUCTION

This work presents a novel 5Mpix 2560×2048 format, XBn-InAsSb FPA and ROIC. The XBn-InAsSb technology enables a High Operating Temperature (HOT) Medium Wave Infrared (MWIR) FPA operating at 150K [1]. This relatively high temperature relaxes the cooling system requirements, resulting in a longer lifetime cooler, detector and system in addition to the favorable impact in size and power [2]. Nowadays HOT MWIR detectors of several formats, with 15 and 10 µm pitch, are integrated in numerous electro-optical systems for many defense and commercial applications. Reducing the pixel size to 5 µm while maintaining the same electro-optical performance, namely high quantum efficiency (QE), low dark current, low cross talk (XT), and high array uniformity, is a demanding technological challenge. For the 5 micron pixel a new pixel design has been introduced that achieves low XT and peak QE, above 70%, similar to larger pitch pixels [3].

The dedicated ROIC is fabricated in an advanced node CMOS technology and introduces additional challenges. The ROIC is able to operate at cryogenic temperatures either at 77K or 150K. Special device modeling of the CMOS fabrication process at cryogenic temperature has been done in order to enable a successful VLSI implementation. A large integration capacitor needs to be integrated in a reduced area in order to achieve high well capacity. This is done without compromising XT and linearity. In addition, low power operation is critical in a cooled environment. To achieve this, a low power Direct Injection (DI) pixel readout architecture is combined with a slope Analog-Digital Converter (ADC) that achieves 13 bit resolution with an excellent Figure of Merit (FOM) [4-5].

Last but not least, video communication is largely limited in a cooled environment, the ROIC must output fast video with a reduced number of lines, resulting in a challenging requirement of more than 4Gbit/sec per video line. A high-speed JESD240B serial interface is implemented that enables the ROIC to have a very high throughput of more than 15Gbps, resulting in Frame Rates up to 140 Hz for the full matrix.

II. ROIC DESIGN

Fig. 1 shows the pixel schematics, several operation modes are integrated at the ROIC. In IR systems global shutter operation is an important requirement. In addition, the integration modes Integrate While Read (IWR) and Integrate Then Read (ITR) maximize the readout output without compromising the frame read time. An additional feature is variable gain. Low gain is achieved with full well capacity of 0.6Me- and high gain with full well capacity of 0.25Me-. A 2×2 pixel binning mode, enables SXGA (1280×1024) format, which is useful when a higher signal-to-noise ratio or higher frame rate is required. The pixels read is rolling, using a Source Follower (SF) shared by every 4 pixels. The output of the SF is converted by slope column-parallel ADCs. The pixel and ADC are required to have a linearity below 0.1% to achieve low Residual Non Uniformity (RNU) after Non-Uniformity Correction (NUC), detailed design of the ramp slope generator, pixel and ADC channel enables to meet this requirement.

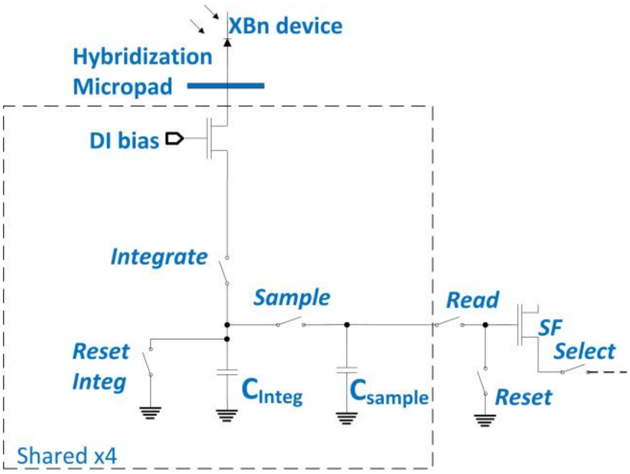


Fig. 1. Pixel Schematics

The overall readout noise is 90e$^-$ at high gain and 160e$^-$ at low gain, providing a dynamic range of 69dB and 71dB, respectively. The resolution of the ADC can be adjusted at 11-13 bit, at full frame the maximum rate is 140fps and can be increased up to 400fps with proper setting of frame format and resolution.

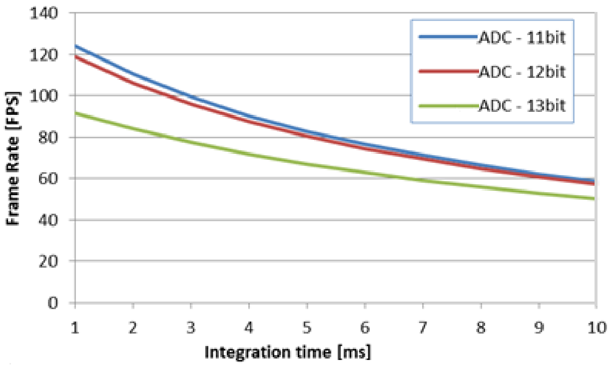


Fig. 2. ADC Frame Rate vs. Integration Time at ITR

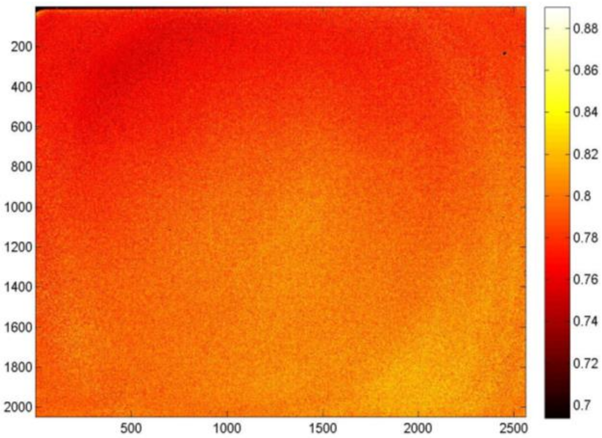
Detector parameter	Value
Format	2560 × 2048
Pixel size	5 μm
Resolution	11- 13 bit
Full Well Cap. (high/low gain)	250ke$^-$/650ke$^-$
Readout noise (high/low gain)	90e$^-$/160e$^-$
Max. Frame rate full resolution	140 fps
Linearity	< 0.1%
Binning	2×2
Shutter	Global
Read modes	ITR & IWR
Max. Power consumption	400mW

Table I. ROIC main parameters

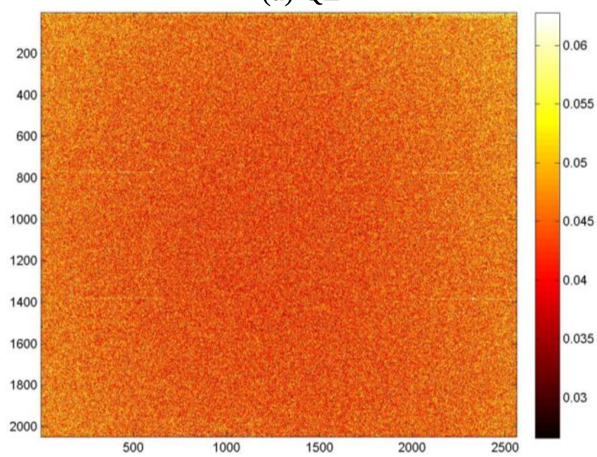
When running ITR the frame rate can be significantly increased reducing ADC resolution from 13bit to 12bit, with a low penalty on image performance, and enabling 80 fps with a 5msec integration. Other trade-offs are configurable, the overall power consumption of the imager at full frame maximum rate is 400mW, and can be reduced to half when running at 60fps with 12 bit resolution. Table I summarizes the ROIC main characteristics.

III. MEASUREMENTS

Figure 3 shows the measured quantum efficiency and NETD at 70% well fill. The mean value of the quantum efficiency is approximately 80% and above 70% for all pixels. The NETD mean value is 45mK. Table II summarizes main Integrated Detector Cooler Assembly (IDCA) parameters. The XBn material is open to sensing at 1.7-4.2 µm spectral window. NUC tables are used to compensate for sensor non-uniformity, a two-point NUC algorithm is used typically at 10-85% Well Fill. Linearity and non-uniformities result in RNU of 0.06%.



(a) QE

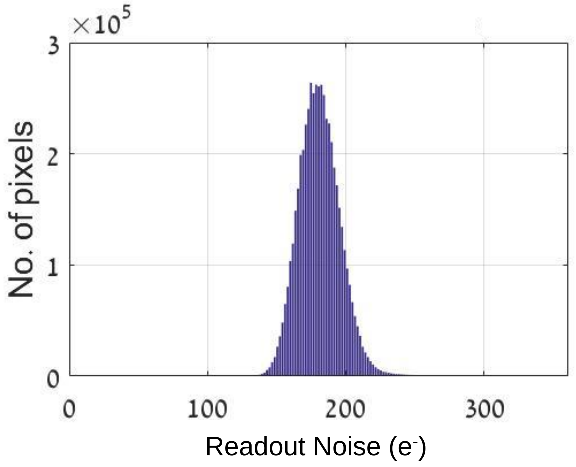


(b) NETD at 70% Well Fill [K]

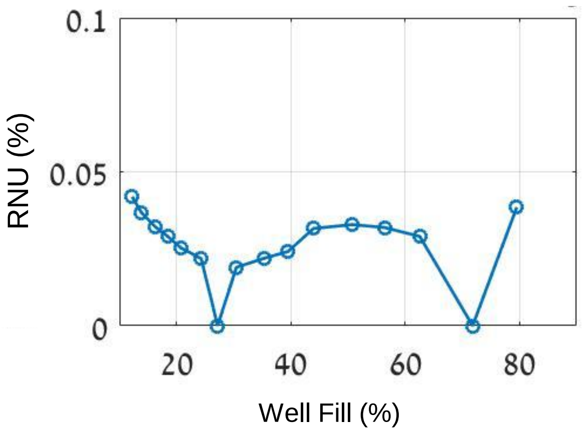
Fig. 3. Quantum Efficiency and NETD

Fig. 4 (a) shows the measured readout noise histogram at low gain and operating at IWR mode. Fig 4 (b) show the measured RNU at 30%-70% NUC correction, the RNU values are measured as a percentage of the maximum well fill. Fig. 5 shows a microphotograph of the ROIC and its main design blocks, the chip size is 16x12 mm^2.

Fig. 6 shows the image capabilities of this imager compared to previous generations, using the same sensing material but different format, pixel pitch and ROICs. For the same Field of View (FOV) the difference in details from the image are evident to the bare eye. In Fig. 7, a 10X digital zooming on the far region of the image show that road traffic is distinguishable from 25km distance without the need of additional optics. At the same capture this road traffic is only slightly discoverable at 1280x1024 format and completely unseen at 640x512 format.



(a)



(b)

Fig. 4. (a) Low gain Readout noise and (b) RNU

Detector parameter	Value
FPA spectral band	1.7 - 4.2 μm
Quantum Efficiency	> 70%
Dark current	200 fA at 150K
NETD	45 mK at 70% WF
Global RNU	0.06% of DR
Cooler	Stirling rotary cooler optimized to 150K
Cooler power consumption	4 W at 23°C
Video output	4 channel
Size	$88 \times 71 \times 68\ mm^3$
Weight	360g

Table II. FPA and IDCA main parameters

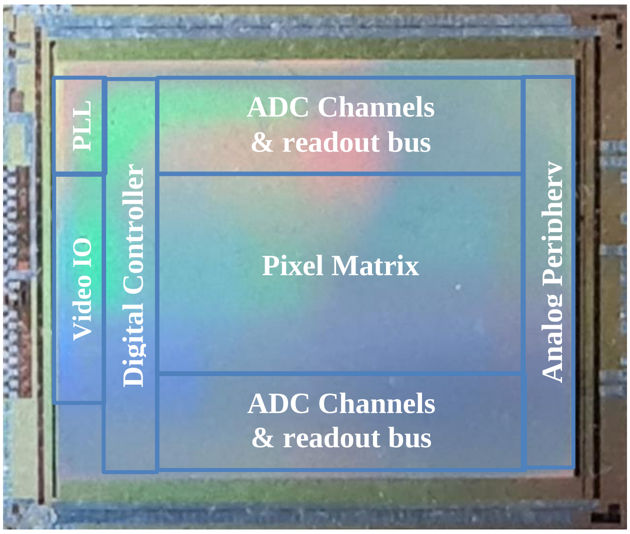


Fig. 5. ROIC microphotograph and main design blocks

The quality of the image opens the possibilities for several commercial uses besides the direct application in security and night vision. In modern smart agriculture thermal imaging can be used to determine the quality of the growing plants, another application is gas leak detection that exploits the fact that many volatile gasses absorb in the MWIR spectrum and are clearly seen in this wavelength range. In addition MWIR can provide wild fire detection, Infrared Search and Track (IRST), and other long range imaging applications

Fig. 6. Comparison of the view of Haifa Port in 3 formats: (1) SPARROW 640x512 at bottom right (2) BB1280 1280x1024 at top right and (3) This imager CRANE 2560x2048 on the left

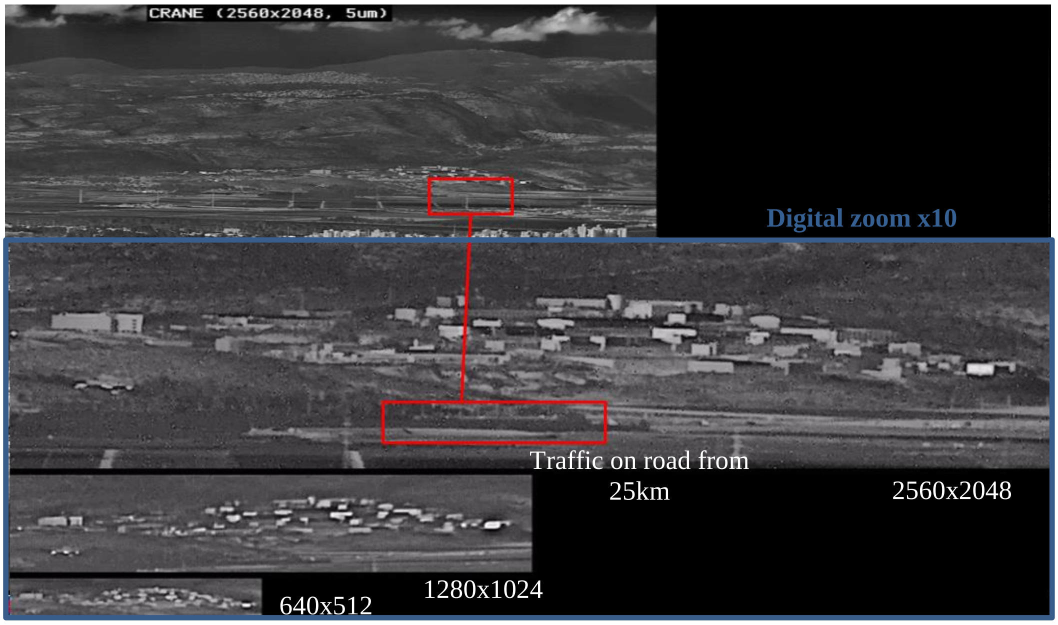


Fig. 7. Comparison of the zooming capabilities with different formats and pixels. From 25km. distance, with the 5Mpix imager and with digital zoom x10, the road traffic is recognized.

IV. Summary

This works presented a low SWAP 5Mpix XBn MWIR imager as well as its main ROIC design blocks, characteristics and performance. The IRFPA has a low dark current at 150K that relaxes the cooling requirements, and is hybridized to a CMOS ROIC. The measurements demonstrate the high imager performance, which enables to see large FOV with fine image details from a long distance. The imager opens the way for new applications such as persistent surveillance, IRST, gas leakage, wild fire detection and many others

V. Acknowledgments

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VI. References

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