

# Uncooled amorphous silicon TEC-less 1/4 VGA IRFPA with 25 $\mu$ m pixel-pitch for high volume applications.

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## ABSTRACT

The high level of accumulated expertise by ULIS on uncooled microbolometers TEC-less operation enables ULIS to develop 384 x 288 (1/4 VGA) IRFPA format with 25 $\mu$ m pixel-pitch especially designed for TEC-less application. This detector, while keeping all the performances and all the innovations developed on previous ULIS ROIC (NETD performance, detector configuration by serial link, low power consumption and wide electrical dynamic range ...), can be operated on a wide range of ambient temperature, with constant settings.

We present in this paper the electro-optical performances and the TEC-less capability of this device. The thermal behavior is described in detail.

**Keywords:** Uncooled microbolometer, LWIR, Amorphous silicon, IRFPA.

## 1. INTRODUCTION

From its first product in 2002 up to its large range of detector presently available, ULIS has endeavored to address its customer needs by developing ever more high-performance detectors. With pixels size ranging from 35 $\mu$ m down to 25 $\mu$ m and new breakthrough at 17 $\mu$ m, FPA size of 160 x 120 up to 1024 x 768, ULIS is offering products dedicated to a wide range of applications. On its way to provide the market with what it expects, ULIS is working on how to improve its products in terms of TEC-less abilities for any kind of applications. More precisely, we did focus on demanding application such as automotive use, where TEC-less abilities are paramount.

This paper presents our achievement on that field. Taking into account previous feedback and analyses, we have paid a special care to design the R&D component presented hereafter for TEC-less dedicated application. The main core technology has not changed but fine tuning on specific parameters has allowed a great leap toward easy-to-handle TEC-less IRFPA.

## 2. GENERAL DESCRIPTION OF THE DEMONSTRATOR

The prototype described in this paper is a 320 x 240 size IR focal plane array with a 25 $\mu$ m pixel pitch. It stems from our standard process facilities and is driven by a dedicated circuit which is very comparable with our present product line. Having in mind automotive application when we first developed this prototype, we strived to give it what car application will require in terms of size and performances and we particularly designed it to cope with large ambient temperature range and variations.

### 2.1 Architecture and readout design

Conceptually, the readout circuit is based on our standard architecture presented on Figure 1. It consists to extract the relevant information carried by one active pixel, by ditching the 'background' current using a secondary skimming bolometer. The remaining current from this balance is then integrated using a CTIA distributed column wise. The signal is then sampled and held row by row, then multiplexed to the video buffer in the analogue output mode or to the ADC in the digital one. [1]

Internal features such as ADC, CTIA gain, image windowing or flip, are selected using the serial link, a digital word that gives information to the core of the ASIC.

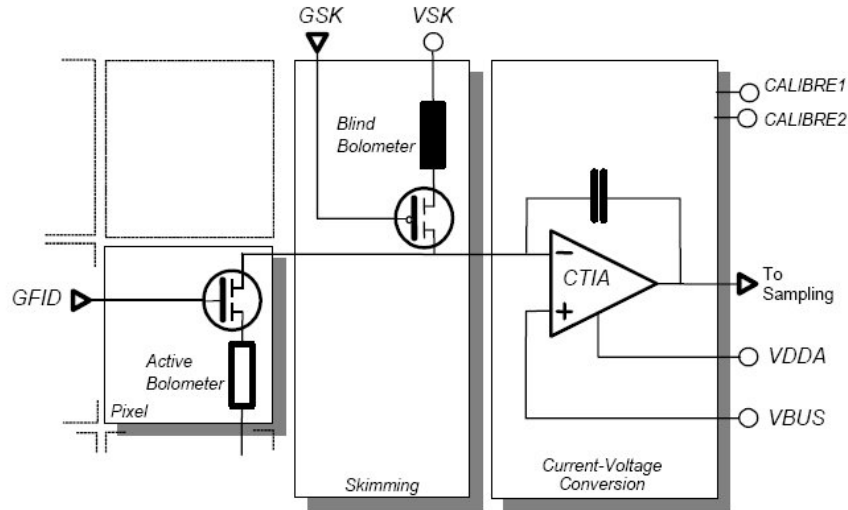


Figure 1 : Pixel Readout Architecture

Enhancing TEC-less abilities has entailed fine tuning of the balance between active and blind pixels branches. This tuning has been taken care of, as well through the electronic balance and through the bolometer process.

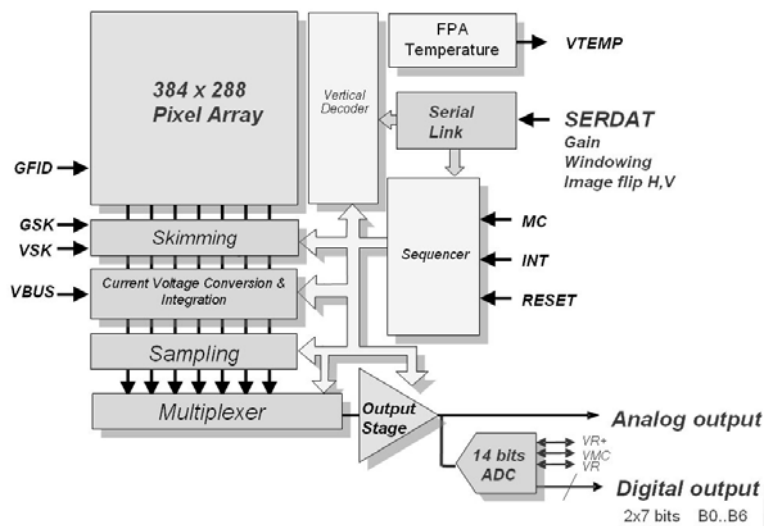


Figure 2 : Readout Circuit Block Diagram

## 2.2 Packaging

Although this study deals with a prototype, we have paid attention to mimic every aspect of a would-be-product such as the packaging. In order to anticipate what car application would require as basic container, we have chosen to use a ceramic based packaging. Throughout this study, the IR FPA was packaged in a standard low cost ceramic package without any heating or cooling device [2,3].

## 2.3 Amorphous Silicon Technology

Amorphous Silicon is the base material for ULIS Uncooled IR products. Not only is it easy-to-handle and to integrate monolithically onto silicon substrates at temperature compatible with CMOS integrated circuit, but it presents amazing properties too. In particular, when it comes to address TEC-less capabilities, Amorphous Silicon devices are coping quite well with temperature variation. Thus, amorphous silicon activation energy, which is the inherent and essential property of a-Si:H and makes it sensitive to IR flux induced temperature fluctuation, remains essentially constant throughout a large range of operational temperature (see Figure 10) and shows no spatial variation throughout pixels.

### 3. PERFORMANCES AND TEC-LESS CAPABILITY

#### 3.1 Electro-optical performances

Prior to any presentation of the temperature dependence of this new device, we hereafter present the measured performances of one detector. All electrical and electro-optical tests are carried out using f/1 optical aperture and a frame rate of 30 Hz. Responsivity is measured using two blackbodies respectively set at 293 K and 308 K.

The main characteristics are presented in this section with an ambient temperature of 303 K.

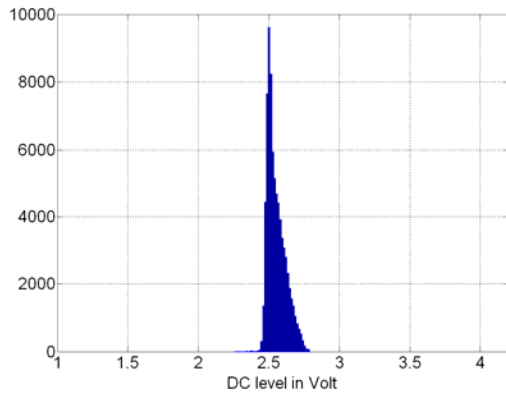


Figure 3 : Output DC level histogram @ 293 K

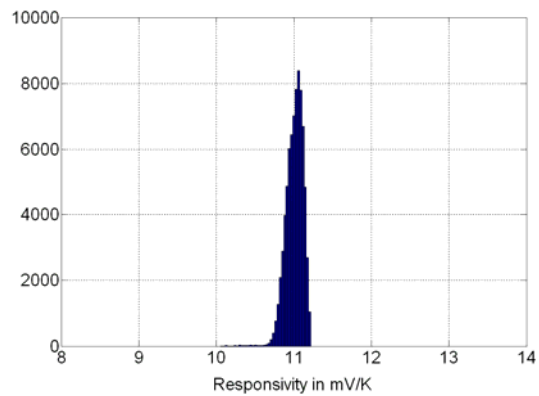


Figure 4 : Responsivity histogram

The circuit can be operated either in analog or numeric mode. Either way, performances are similar. The overall output range dynamic is 3.2V (between 1V and 4.2V). The responsivity mean value stands at 11 mV/K, hence offering a scene dynamic above 130 K for a non linear flux emission of the scene. Figures 3 and 4 show respectively, the output DC level and the histogram of responsivity for a standard component.

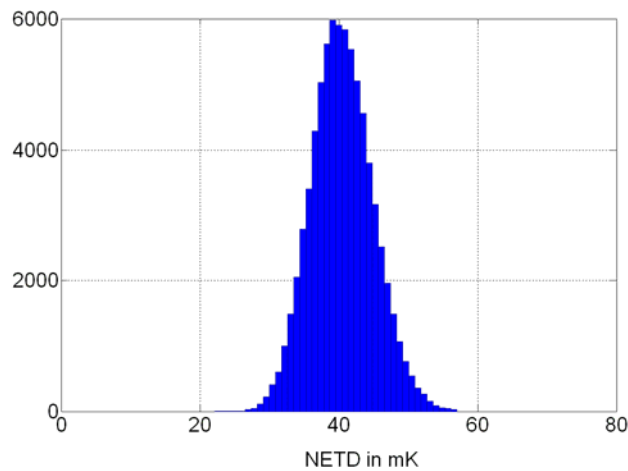


Figure 5 : NEDT histogram

The resulting mean NEDT value, @ 303 K of focal plane temperature, stands at 41mK.

Residual Fixed Pattern Noise (RFPN) for this component (not thermally stabilised) reaches 340 $\mu$ V that is to say 85 % of the RMS noise. Illustration of the RFPN and image quality is given below on Figure 6.

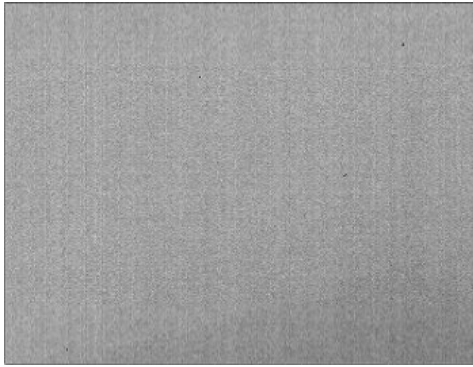


Figure 6 : RFPN map (mean value =  $340\mu\text{V}$ )



Figure 7 : 320 x 240 image of TEC-less prototype

With a NEDT as low as  $41\text{mK}$  (@  $30^\circ\text{C}$  Focal Plane Temperature), we have designed a prototype with performances representative of standard automotive component to come. Achieving TEC-less properties is then all the more challenging. Indeed, the more sensitive a detector is, the more susceptible to ambient temperature it is. The thermal constant has been measured at  $9,4\text{ ms}$ . Keeping this parameter lower than  $10\text{ ms}$  is one of ULIS commitment to ensure good image quality at video rate up to  $60\text{ Hz}$ .

### 3.2 TEC-LESS capabilities

When it comes to estimate the ability for a circuit to cope with TEC-less operation, three main criteria pop to mind.

- First of all, the DC level is to stay as constant as possible all over the temperature range. Most of all the DC level shall not reach any point of saturation of the circuit.
- Secondly, the scene dynamic is a rapidly changing variable with ambient temperature; care must be taken not to shorten it at high temperature. Dispersion of the signal and responsivity are the parameters that impact this scene dynamic.
- Finally, the TEC-less ability is estimated through the variation of NEDT along the ambient temperature range. This figure of merit of an IR detector should also stay as steady as can be with temperature.

All the measurements, hereafter presented have been performed in a thermal chamber. The circuit is not thermally stabilized by any mean. The ambient temperature range has been extended (in comparison with previous paper [3]) from down to  $-35^\circ\text{C}$  and up to  $+85^\circ\text{C}$  ( $-31^\circ\text{F}$  to  $185^\circ\text{F}$ ).

Figure 8 illustrates the TEC-less capability in terms of DC level in two different modes. In both case, the component is operated in digital mode (ADC is powered on), however in one case biases are applied externally, in the other one the biases are generated internally. The observed scene is a uniform blackbody at ambient temperature. With external biases, the mean output level shift over a temperature range of  $110^\circ\text{C}$  is  $450\text{ mV}$  and  $320\text{ mV}$  with internal biases. The overall dynamic of the circuit is  $3.2\text{ V}$  between  $1\text{V}$  and  $4.2\text{V}$  (gray horizontal line on Figure 8 & Figure 9).

If the ambient temperature of the camera lies far from the observed scene temperature, Figure 9 shows that the output level is still within bounds of the output electric dynamic (plain line on Figure 9). On this graph, the observed temperature scene is maintained constant at  $20^\circ\text{C}$ . It is to be compared with the dotted line that gives the mean value on the array for an ambient temperature scene. However, by adjusting the only 'bias' not internally delivered by the circuit (VSK) it is possible to reduce the output variation of the DC level according to the expected scene temperature. Hence, on Figure 9, adjusting VSK from  $5.6\text{ V}$  to  $5.52\text{ V}$  (from plain line to dashed line), for a choice of mean scene temperature of  $20^\circ\text{C}$  reduces the overall variation of the DC level without affecting other parameters (NEDT, Resp ...). It proves that camera can deal with any temperature variation while looking at a rather stable scene. It is more or less what is expected in a car environment according to weather conditions and heat generation of the engine.

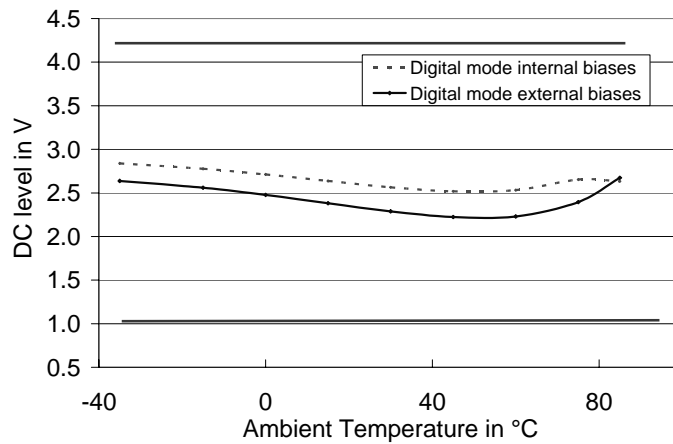


Figure 8 : Output DC level of the component versus ambient temperature (scene at variable ambient temperature)

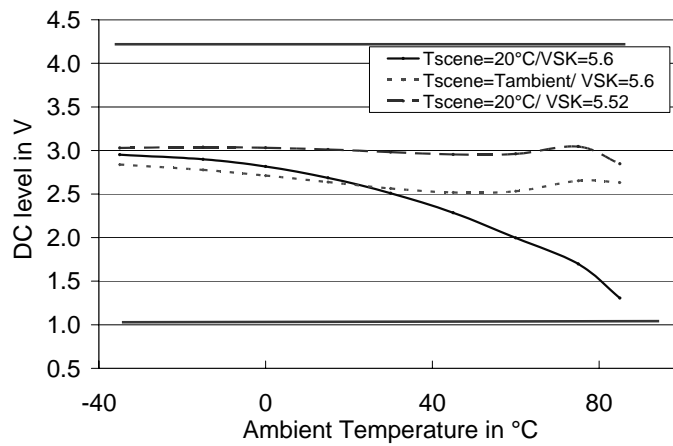


Figure 9 : Output DC level for 20°C and ambient scene temperature with internal biases

This outstanding behavior achieved on a standard read-out circuit type (no feedback correction) is made possible thanks to the exceptional feature of the amorphous silicon developed and used at ULIS. Indeed, as shown on Figure 10, the activation energy over the range of temperature is constant (variation <1% over 110°C mainly due to measurement error). Bolometers' resistances follow a simple and spatially uniform Arrhenius law and are hence predictable. It is then possible to tune the balance between active and skimming pixel bolometers and to ensure the behavior plotted on Figure 8.

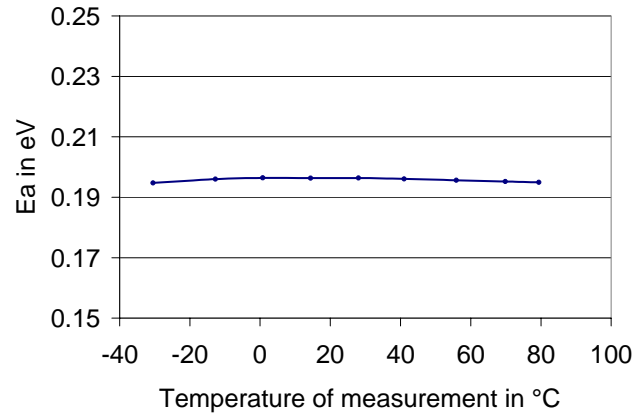


Figure 10: Measurement of the Activation Energy versus temperature of measurement.

The digital mode with internal biases is showing a lower shift in the DC output level. The internal bandgap responsible for the biases generation are not entirely immune to temperature variation. Hence between 75°C and 85°C, one of the biases is compensating for the DC level. This compensation does not hamper the responsivity or NEDT.

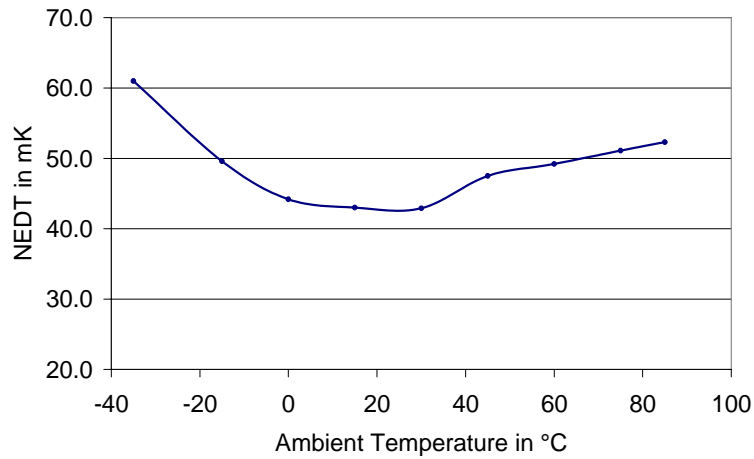


Figure 11 : NEDT variation with ambient temperature.

We have demonstrated outstanding properties with this new high volume application dedicated detector. DC level stability over ambient temperature change has improved compared to products usually afforded by ULIS [3] while securing NEDT performance (~ 40 mK). Scene dynamic stays above 100°C for ambient temperature up to 70 °C and NEDT stability is performing quite well with a total variation of 18mK over 110°C ambient temperature change.

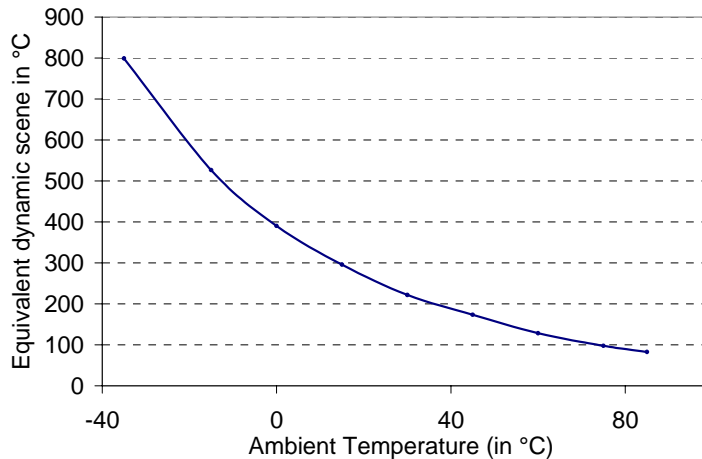


Figure 12: Equivalent dynamic scene versus ambient temperature

#### 4. CONCLUSION

ULIS has demonstrated with this development that TEC-less hardening can be controlled and improved with simple recipes without much change either in the process or with the readout circuit. Those results rely mainly on the remarkable properties stability and uniformity of amorphous silicon. This prototype has opened the way to easy-to-drive (internal biases) and TEC-less components with a very large temperature range of operation. Automotive but generally camera designer should greatly benefit from this improvement.

#### ACKNOWLEDGEMENTS

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