320 x 240 uncooled microbolometer 2D array for radiometric applications

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SUMMARY
Uncooled infrared focal plane arrays are being developed for a wide range of thermal imaging applications. Developments are focused on the improvement of their sensitivity enabling the possibility to manufacture high performance radiometric devices with internal temperature stabilized shield to determine the input infrared flux.
We present the characterization of a new radiometric device obtained from 320 x 240 uncooled microbolometer array with f/1.4 aperture. This device is well adapted to radiometric or process control applications and moreover shows a high level of stability due to the internal temperature stabilized shield which prevents the detector from camera internal temperature shift artifacts.
Keywords: Uncooled IRFPA, 2D array, Microbolometer, Amorphous silicon, Radiometry

1. INTRODUCTION

Uncooled infrared detectors are now available for various applications. Their simple operating conditions are similar to those of CMOS Active Pixel Sensor (APS) or CCD digital camera. They have already shown their potentiality to fulfill many commercial and military applications. Nevertheless, as they are not cooled, no cold shield could be added to determine with precision the IR irradiance level. Consequently, they are very sensitive to temperature environmental conditions and camera manufacturers have to take this behavior into account to address thermographic applications by adding an internal temperature shield between the detector and the lenses.

In order to fulfill this demand, a radiometric version of our standard 320 x 240 detector has been developed. Main characteristics and performances of this new detector are detailed below.

2. RADIOMETRIC DETECTOR DEVELOPMENT

2.1. CONTEXT

Uncooled infrared detector applications need low cost detectors. Therefore the development rules were chosen to minimize the number of new sub-assemblies needed for radiometric detector manufacturing process. A design to cost procedure has been set up to develop this new detector and, as an example, infrared window, which is an expensive part of an infrared detector, has been chosen identical to the standard detector one. Taking into account the market needs, an f/1.4 detector has been developed.

2.2. PACKAGE DEVELOPMENT

The radiometric version has been designed from the standard product using the same focal plane array integrated with a temperature stabilized internal shield limiting the aperture to f/1.4 (see Figure 1). The shield aperture is positioned at 22.8 mm above focal plane. CAD tools have been used to develop the vacuum package.

The internal shield is maintained at the same temperature as the focal plane. Specific care has been taken to prevent from parasitic light reaching the sensitive area of the detector and black coating is applied on internal face of the shield while the outside is fully reflective.

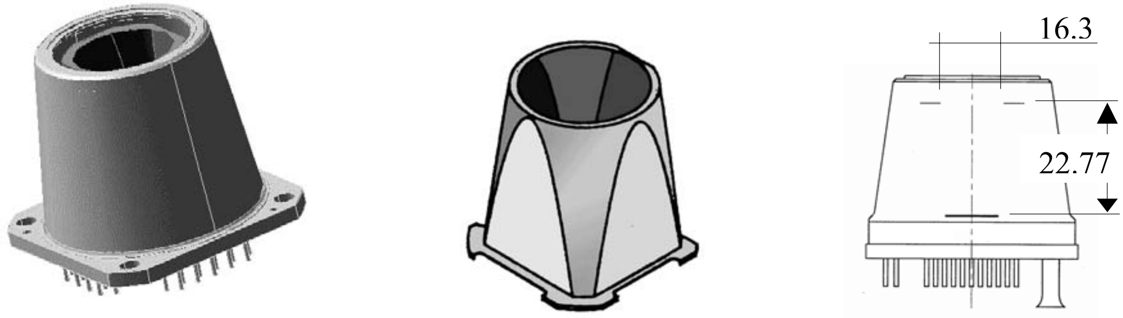

Figure 1: CAD view of package and internal shield

f/1.4 is defined for the pixel at the center of the array with a shield aperture of 16.3 mm in diameter. Consequently the lenses could be limited to small diameter enabling the manufacturing of low cost camera.

2.3. READOUT INTEGRATED CIRCUIT CONFIGURATION

The readout integrated circuit (ROIC) configuration is the one used for the standard product (1). Classical readout circuit architecture with a pixel pitch of 45µm has been designed using a 3.3V 0.5µm CMOS technology. The pixel implementation and readout architecture are presented on figure 2. Each detector is coupled by direct injection, and detectors operate in a pulsed bias mode to reduce substrate thermal sensitivity fluctuation. Most of the background current is suppressed by using one blind bolometer Rb for each column. The useful current from the bolometer is then integrated in a capacitive trans-impedance amplifier (CTIA) at the bottom of the column. Several integration capacitors are implemented in the feedback of the amplifier to deal with different operating conditions. The silicon technology used in our case, allows us to produce array with more than 99.5% of detector within +/- 5% peak-to-peak resistance distribution. Consequently our standard background suppression mode is efficient and allows us to obtain correct thermal sensitivity with no incidence from the readout integrated circuit noise on signal to noise ratio.

As the microbolometer is based on an electrical resistance thermometer, the responsivity closely depends on the bias VFID (see figure 2) that drives the current going through the microbolometer resistance.

Increasing the microbolometer bias VFID will increase the signal but also the pixel output voltage distribution width at the expense of a decrease of the available scene temperature dynamic range.

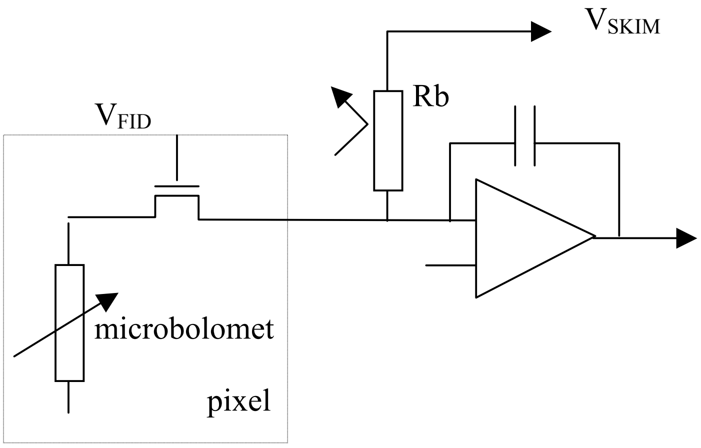

Figure 2: Schematic drawing of pixel readout architecture

3. ELECTRO-OPTICAL CHARACTERIZATION

3.1. NETD MEASUREMENTS

The detector presented here shows a RMS noise at 526 µV and a response at 3.7 mV/K. The NETD of the detector is then 143 mK for f/1.4, 300 K and this performance is constant from 30 Hz to more than 60 Hz frame rates.

Figure 3 presents the histogram of the NETD value for all the pixels of the 320x240 array, and figure 4 the NETD distribution value on the array.

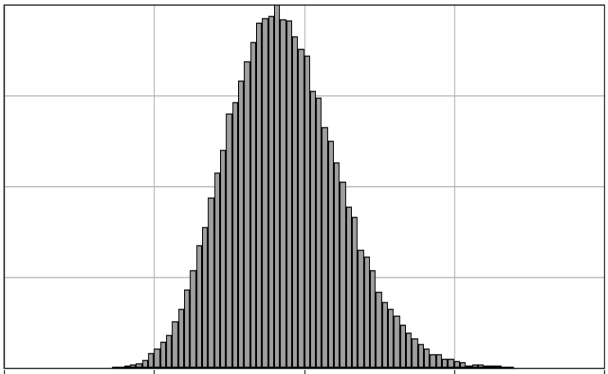

Figure 3: NETD histogram

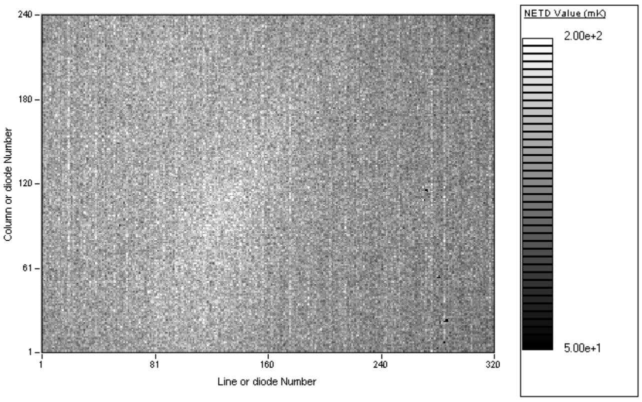

Figure 4: NETD spatial distribution on the 320x240 array

3.2. *TEMPERATURE DYNAMIC RANGE*

The scene temperature dynamic range results from the output electrical dynamic range (from 0.4V to 2.1V), minus the maximum pixel DC output signal distribution width. A rough order of magnitude for dynamic range in Kelvin is then obtained by the ratio of (A+B) in mV to the responsivity in mV/K (see figure 5).

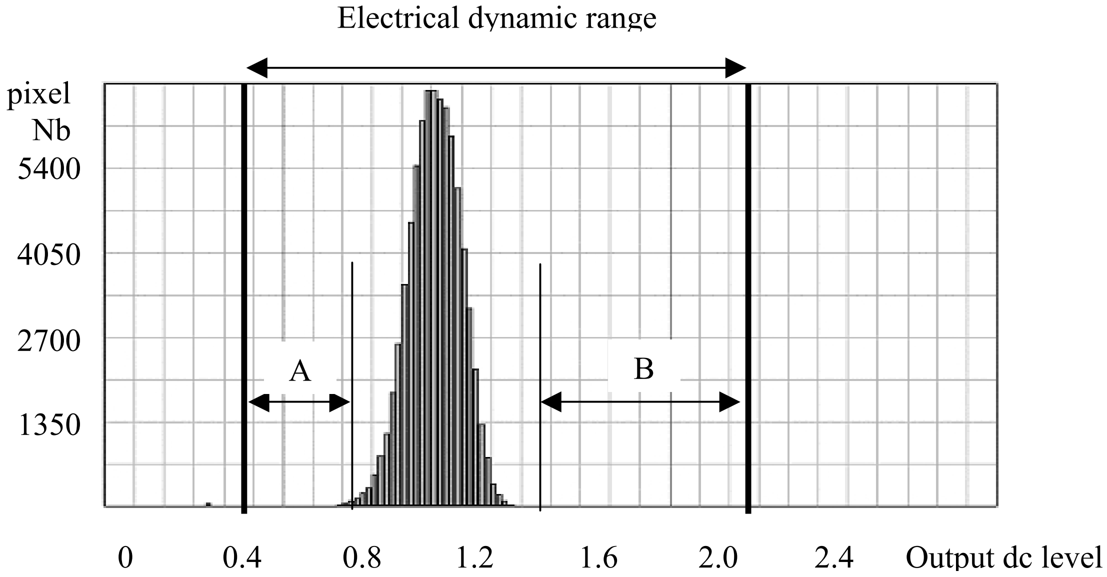

Figure 5: Output dc level distribution

A large dynamic range is measured with a bias value at V_{FID} = 1.6 V. The responsivity is then 2.47 mV/K and the values of A and B are respectively: 350 mV and 700 mV. With the precedent formula we obtain about 425 K for the available temperature dynamic range. As we can see on figure 6, there is a compromise between NETD estimation and accessible temperature dynamic range. The more the detector is biased, the better the NETD is, but the accessible dynamic temperature range is lower. Consequently, as a first approximation, the NETD increases with the dynamic temperature range and, for the detector presented here, it varies from 127 mK with 70 K of temperature dynamic range for high V_{FID} to 194 mK with 500 K of equivalent temperature dynamic range for low V_{FID}. However this behaviour is rather limited due to 1/f noise increase when high V_{FID} values are reached.

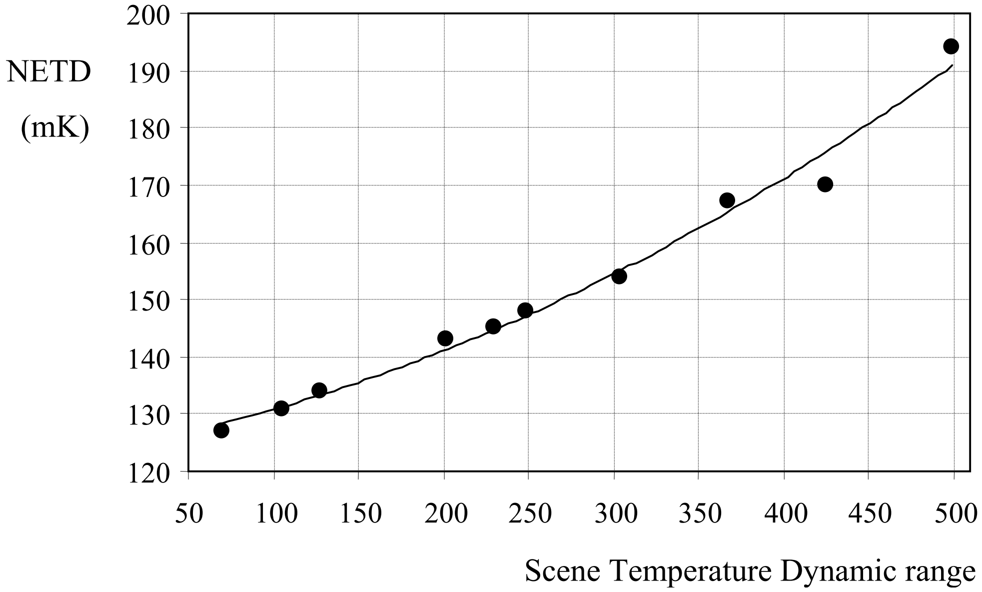

Figure 6: Accessible Scene Temperature Dynamic Range vs NETD

3.3. THERMAL STABILITY

On the other hand, and thanks to its temperature stabilized FOV shield, the detector is less sensitive to the non useful flux coming from outside of the optical field defined by the f/1.4 shield.

Figure 7 compares the standard IRFPA and the radiometric IRFPA. For this experiment, the two detectors are operated in variable environmental temperatures. The sensitivity of the standard detector to the environmental temperature is almost 20 mV/K while the radiometric detector (figure 8) is nearly not sensitive to outside temperature (only 1.3 mV/K). This leads to a simplified camera in which no thermal screen is to be added to prevent the detector operating conditions from thermal shift.

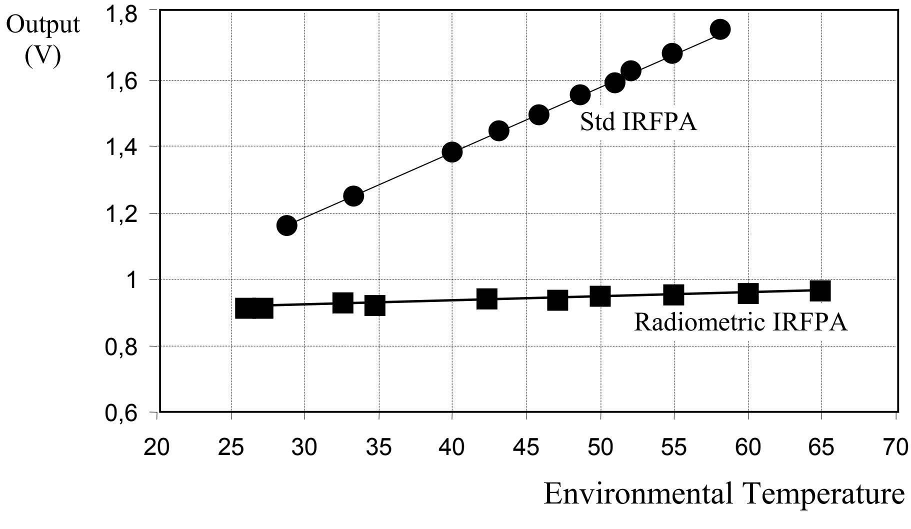

Figure 7: Environmental Temperature Sensitivity

Figure 8: Radiometric uncooled infrared detector

3.4. TEC POWER CONSUMPTION

The power consumption measurements of thermo-electric cooler have been done for two experimental conditions:

- Variable focal plane temperature and a fix ambient temperature (28°C).
- Variable ambient temperature and a fix focal plane operating temperature (30°C).

For variable focal plane temperature configuration, the measurement of TEC power consumption for a given room temperature is simply done by changing the focal plane operating temperature by driving the thermoelectric cooler with different set points. The power consumption is going up to 1100 mW for operating the focal plane at 0°C.

For variable ambient temperature, which is a normal industrial environment for radiometric applications, the detector is integrated in a small heating device therefore no measurements could be performed for temperature lower than room temperature and the initial minimum ambient temperature was 28°C. During this experiment the focal plane temperature is measured using the detector internal CTN prior power on the temperature stabilization electronics to reach a detector operating temperature of 30°C. The TEC power consumption is reaching 1 W for 60°C outside temperature.

The following figure 9 gives the power consumption for the two experimental conditions. These power consumptions are very similar to those of the standard non-radiometric detector.

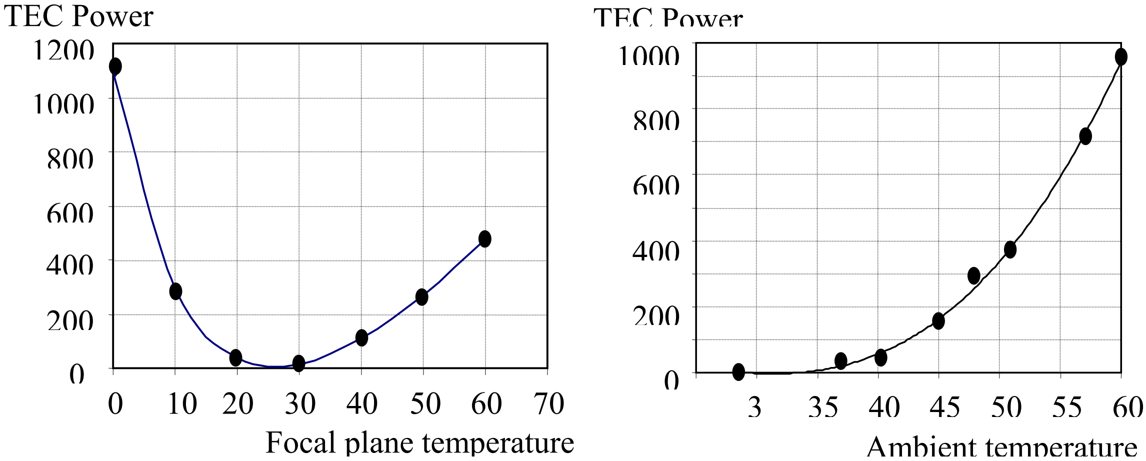

Figure 9: TEC power consumption versus focal plane operating temperature and ambient temperature

4. CONCLUSION

Uncooled infrared focal plane arrays are being developed for a wide range of thermal imaging applications. Developments are focused on the improvement of their sensitivity enabling the possibility to manufacture high performance radiometric devices with internal temperature stabilized shield to determine the input infrared flux.

We have presented the characterization of a new radiometric device derived from standard 320 x 240 uncooled microbolometer arrays but with f/1.4 field of view. This device could be used for high scene temperature dynamic range (up to 450 K). It is well adapted to radiometric or industrial process control applications. Moreover it shows a high level of stability due to the internal temperature stabilized shield that prevents the detector from camera internal temperature shift artifact.

Additional enhancements like spectral response increased to 3 to 5 µm band or f/1 limited detectors are under investigation.

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