Low-SWaP Shutterless Uncooled Video Core by SCD

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ABSTRACT

Over the last decade SCD has established a "state of the art" VOx µ-Bolometer product line. The market demands for low SWaP (Size, Weight and Power) uncooled engines is steadily growing, where low SWaP is especially critical in battery-operated applications such as goggles and Thermal Weapon Sights (TWS). In this approach, SCD has developed a low-SWaP, shutter-less uncooled video core, with a foot-print of 31x31mm and sub Watt power consumption. The video core contains a temperature calibrated, High Sensitivity (HS) 640x480 17µm pitch detector (NETD ≤ 32mK @ 30Hz, F/1), packaged in a new TEC-less ceramic package (26x23mm). The video core contains superior image processing algorithms including: local and global Dynamic Range Compression (DRC), and spatial and temporal de-noising algorithms providing low NETD and stable and low Residual Non Uniformity (RNU) video image.

Keywords: VOx technology, Video Core, 17 µm pitch, SWaP, Shutter-Less

1. INTRODUCTION

SCD has been designing and manufacturing uncooled VOx µ-Bolometer detectors since 2002 and in mass production since 2006. During the last decade SCD has invested substantial resources in order to provide "cutting edge" technology to its customers. This includes proprietary CMOS read out IC, MEMS production, image processing algorithms and mass-production infra-structure.

Over the last decade, uncooled detectors have become increasingly embedded in a variety of commercial and military systems and applications. Due to the large effort required for designing and manufacturing of high quality uncooled camera cores, system integrators are relying more and more on the camera core or “video engine” instead of a stand-alone detectors, as the basic component of their system. Consequentially, most of the uncooled detectors manufacturers have been adapting this market trend and invested substantial efforts in developing video engines to drive their own detector and offer higher level of product integration.

"VOx Imager" , SCD's new video engine, is a multi-purpose, easy to deploy video core, suited for battery operated military applications and systems such as thermal weapon sights (TWS) and goggles, where low SWaP (Size, Weight and Power) and a superb image quality, is mandatory [3].

The first part of this paper is devoted to 17 µm pitch VGA TEC-Less detector, with a ceramic package and high-sensitivity NETD of 32mK (at F/1, 60Hz). In the second part we present the image processing algorithms that we have implemented in order to operate the detector in TEC-less & SHUTTER-less modes. The last part is devoted to the video core "VOx Imager" product and its capabilities.

2. 640-17 IR VOX CERAMIC PACKAGED DETECTOR

For the growing demand of Low SWaP TWS military market, SCD has developed a small ceramic package for its existing uncooled BIRD 17µm VGA detector. Apart from reducing the cost and power, the goal was to encapsulate the detector into a 31x31 video engine, while maintaining high standard of image quality and withstanding the harsh environment of TWS applications (high intensity shocks in the vicinity of 500g for 0.5ms & 750g for 0.8ms). Typical specification requirements are shown in Table 1.

PARAMETER	PERFORMANCE
Temporal NETD @ F/1, 60Hz, 25degC	<32mK
Intra scene dynamic range	>50 ºK
Size (mm^3)	26x23x5.1 (8.6 with pins)
Weight	8 ±0.5 gr
Power	<220mW (low power mode)
Operational & storage temp.	- 40ºC to +85ºC
Mechanical shocks	1800 half-sine 500g, 0.8msec shocks. (300 shocks in each direction).
MTTF (Vacuum Life time)	20 years @ 25deg.C ambient

Table 1 – VGA (640x480), 17u HS detector - Typical performance

Special attention was devoted to size and weight reduction. The reduction was achieved by several means: Transformation to a ceramic package allows for lower pitch between the pins. We have also eliminated the need for a vacuum pipe utilizing an especially designed vacuum chamber. The package height was reduced as well due to the elimination of the TEC. The reduced weight compared with a metallic package is important for various applications.

Over recent years, special effort was devoted to the improvement of the temporal NETD or SNR of the 17μm pitch pixel. This was achieved via pixel architecture and process modifications, and the outcome is the 17μm High Sensitive (HS) pixel. The HS detector (in XGA format [2]) was integrated into a demonstration camera with 200mm focal length and F/1.5 optics. A representative image is shown in Figure 1. The combination of an exceptionally small IFOV of 85μRad and system temporal NETD of roughly 55mK enables the detection of a human target at a fairly large distance (~5km).

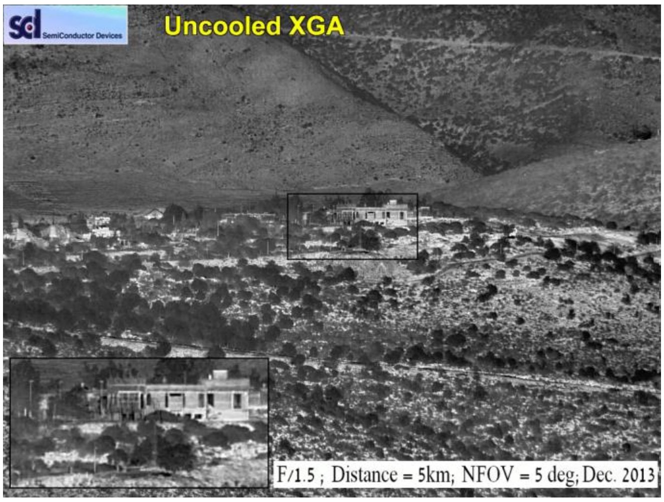

Figure 1 – Image taken by the BIRD XGA high sensitivity detector

In Figure 2 we demonstrate the temporal NETD distribution measured for F/1 optics at the frame rate of 60Hz. The peak of the distribution is around 23mk for the HS version and 40mk for the standard detector version respectively [1]. The HS penalty is manifested in a longer time constant, but due to the relatively low thermal capacitance it is still below 12msec.

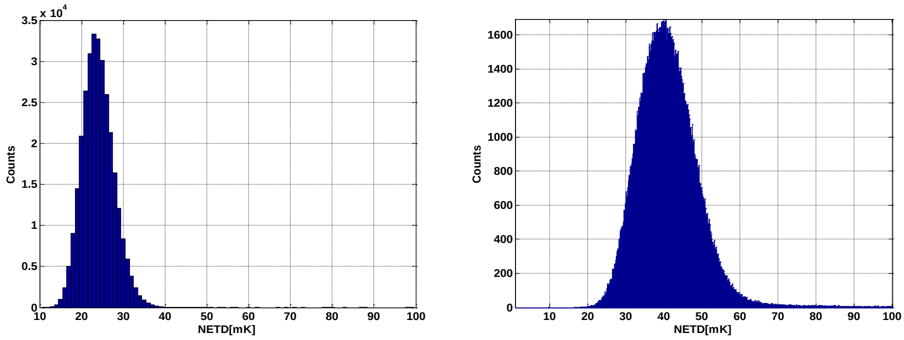

Figure 2 - Temporal NETD (F/1, 60Hz) of the HS version (left) and the standard version (right)

The VGA, 17um HS, ceramic detector is offered in three integration levels (Figure 3 from left to right): as a "stand-alone" detector, with proximity electronic or as an entire video core. So far we have successfully completed initial tests on the ceramic package detector assembled with 30x30mm foot-print proximity electronics. This is a major milestone in SCD's program to release a complete miniaturized video engine operated in TEC-less & SHUTTER-less modes. Qualification and field test are in expected to be completed by mid-2015.

Figure 3 – SCD BIRD, VGA (640x480), 17u HS detector in a ceramic package (left caption), 17u HS ceramic detector with proximity electronic and optics (center caption), "VOx Imager" video core (right caption)

Figure 4 shows a statistical analysis of the NETD and response comparing between detectors with 17µm HS VGA FPA in a TEC-less ceramic and a metallic packages. It shows that the radiometric performances of the detector with ceramic package are at least as good as with TEC based metallic package.

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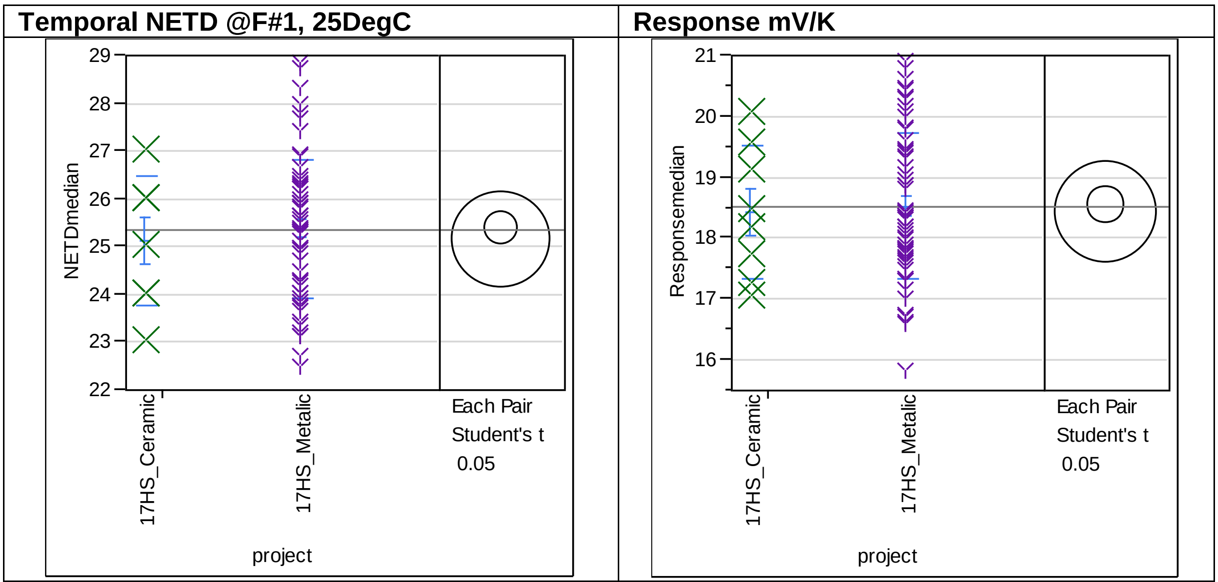

Level	Num.	NETD Mean	NETD Std	Response Mean	Response Std Dev
17HS_Ceramic	8	25.1	1.3	18.4	1.1
17HS_Metalic	62	25.4	1.4	18.5	1.2

Figure 4 – Comparison of the NETD & Response for the ceramic and metallic package

3. IMAGE PROCESSING

The "Vox Imager" image processing is divided into two main blocks: Image correction and image enhancement as shown in Figure 5:

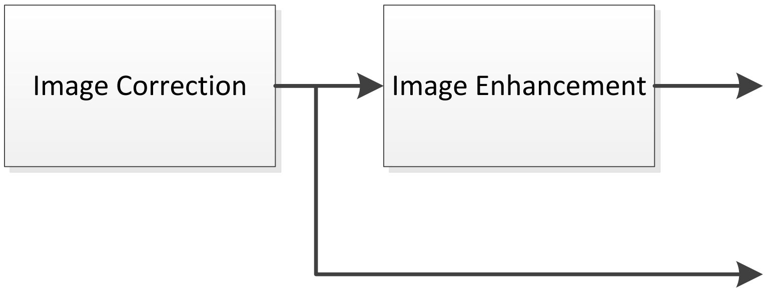

Figure 5 – "Vox Imager" image processing concept

The image correction block eliminates detector-level artifacts such as:

- Fixed pattern noise: readout artifacts, pixel non-uniformity
- Temporal noise
- Image vignetting

This block is suitable for both automated video analysis and for human users and maximizes the image quality of the 17u BIRD.

Image enhancement is an optional block that improves the perceived image for a human observer, and converts the image to the dynamic range of the display. The processing includes:

- Dynamic Range Compression (DRC)
- Edge enhancement
- Digital zoom

The Image Correction block

The "VOx Imager" image correction pipe employs a series of algorithms to reduce residual non-uniformity (RNU), starting with coarse corrections that can be modeled analytically or that have specific shape or pattern. Remaining RNU is reduced by inferring patterns using heuristics, and blind source separation techniques. Noise reduction eliminates remaining temporal noise.

1. Temperature Based NUC (TBNUC)

Applies traditional gain and offset map correction to overcome detector non-uniformity. Where p_{out}, p_{in} and $G(x, y)$ are the corrected pixel signal, raw pixel signal, and pixel gain correction respectively, and x,y are the coordinates of the pixel.

$$p_{out}(x, y) = G(x, y)p_{in}(x, y)+Offset(x, y, T)$$

However, offset is determined using an analytic temperature-dependent model. By measuring temperature and applying the model, TEC-less operation is possible. TBNUC compensates for temperature measurement drift using NUC RNU statistics collected from dedicated sections of the BIRD 17u detector. TBNUC maintains local RNU at 2-3 temporal NETD.

2. Row and Column Correction (RCC)

Row and column correction estimates and corrects detector readout pattern non-uniformities and residual non-uniformities along rows and columns. Patterns are extracted from scene data robustly without affecting scene content (shown in Figure 6).

Figure 6 –Row and column correction (RCC)

3. Scene-Based NUC (SBNUC)

Scene-based NUC infers and removes residual non-uniformity remaining in image after TBNUC and RCC. The algorithm extracts the non-uniformity map from scene data, using a blind source-separation method that relies on motion. SBNUC enables long term Shutter-less operation.

4. Noise reduction (NR)

Spatial-temporal noise reduction will reduce the NETD by factor of ~2. VOXI NR selects between spatial and temporal filtering according to inter-frame similarity. The algorithm preserves maximum detail while maintaining uniform noise levels across frame.

Image Enhancement - Dynamic Range Compression (DRC)

DRC compresses the input signal to a displayable signal. Compression is locally adaptive and ensures maximum contrast enhancement, regardless of input dynamic range variability. The enhancement is adaptive to scene content and has provisions for preventing overstretching (shown in Figure 7).

Figure 7 –Global and local dynamic range compression

4. VOX IMAGER – VIDEO CORE

The "VOx Imager" is a VOx based long-wave infrared (LWIR - 8 - 14 microns) video camera core built around SCD 17 μm pixel pitch micro-bolometer detector. Typical specification requirements are summarized in Table 12.

The "VOx Imager" is a miniature uncooled imagine video engine without lens (shown in Figure 3 - right). The body is just 31x31x29.7 mm^3 in size, weighing as little as 43 grams and dissipating less than 1.1 Watts of power. Hence it is ideally suited for applications where size, weight and power requirements are of key concern and importance.

A "general purpose" video engine that provides the best solution for most applications is highly desirable. It simplifys system design and reduces cost due to commonality. Such an engine should be flexible enough to adapt its configuration and performance to a broad set of requirements.

The "VOx Imager" will be offered with several add-on boards and a lens mount that fits for a variety of "off the shelf" lenses. It will also be available as a "front end electronics" plus detector for customers wishing to use their own proprietary processing electronics and algorithms. All versions will be fully calibrated for TEC-less & Shutter-less operation. The calibration data is stored in a serial-communication non-volatile flash memory (which resides on the proxy card).

Key futures of the "VOx Imager" product:

I. Power Supply

The "VOx Imager" can be biased by a single 5V voltage source or dual voltage sources, 5V & (1.8 to 3.3V). By using the dual source configuration the power consumption can be reduced by almost 10%.

II. Digital Output Data Channel

The "VOx Imager" provides two video channels simultaneously, a parallel video channel and LVDS video channel, where the LVDS channel can be disabled to save power consumption. The parallel video channel is field-configured to provide data via BT.656 protocol, a CMOS protocol or an AMOLED Display mode.

III. Configurable Discrete I/O Pins

The "VOx Imager" provides up to 8 signals referred to as discrete I/O pins that can each be field-configured to provide a specified functionality. The function assigned to each discrete I/O pin is defined by a control file. Some of the potential signals that can be assigned to the discrete I/O pins are: Black hot/white hot, activated external shutter, Digital zoom, etc.

IV. Frame Synchronization Interface

The "VOx Imager" provides the option of transmitting or receiving a frame-synchronization pulse on EXT_SYNC. This feature provides the capability to synchronize frame start between two cores, one configured as master and the other configured as slave, or to synchronize the device with a different camera.

V. Communication Channel

The "VOx Imager" provides an asynchronous serial interface, RS232, up to 921,600 baud/sec configurable and logic level of 3.3V LVCMOS.

VI. Aux 14 bit Video Input Interface

The "VOx Imager" supports dual sensor mode, second parallel video input channel. It accepts an external 14 bit data with Hsync and Vsync, this information can be toggled at the output with the main output data. For example a daytime or SWIR camera video output can be hooked to this port.

VII. Shock Resistance

The "VOx Imager" is designed as shock resistant video engine, and it exhibits no damage or permanent degradation after exposure to shock pulses along any axis with magnitude / duration as 500g (0.5 msec half-sine).

PARAMETER	**Performance**
Detector Technology	17 μm, VOx Microbolometer
Video format resolution	VGA, 640 x 480
Exceptional image quality	NETD < 35mK @ F/1,30Hz
Low Power Consumption	< 1.1 [Watt]
Main digital video output	Configurable: OLED support / BT.656 / Parallel LVCMOS 8/14 bit
Second digital video output	Camera Link (simultaneously with the main output)
Shutter-less, TEC-less operation	Yes
Light-weight	43 grams
Small Form Factor	31x31x29.7 mm
Latency	Sub frame
Overlay graphics	Text/Reticles
Time to Image	< 3 seconds
Operation temperature	-40°C to +71°C
Storage Temperature	-40°C to +85°C

Table 2 – Key Features of the "VOx Imager"

5. SUMMARY

In this paper we have presented the "VOx Imager", a "State of the Art" micro-bolometer VO_x uncooled and miniaturized video engine operating in TEC-less & Shutter-less modes. The detector consists of the High Sensitivity (HS) 17µm pitch VGA FPA embedded in a compact ceramic TEC-less packages. We have also described in detail the image processing algorithms that were implemented in the video core.

This video engine is targeting a wide range of applications, from medium-performance with low Size, Weight and Power (SWaP) constraints, up to high-performance cameras.

ACKNOWLEDGEMENTS

The development of the detector was supported by the Israeli Ministry of Defense (IMoD).

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