Low SWaP 640×480/17µm Uncooled Detector and Video Core

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ABSTRACT

High performance VOx µ-Bolometer thermal detectors have been developed and manufactured by SCD for over a decade, with array formats of 384×288, 640×480, 1024×768, and pixel sizes of 25 and 17 µm. There is a strong requirement for lower Size, Weight and Power (SWaP) infrared detectors and systems, predominantly in the uncooled systems. Low SWaP is critical in battery-operated applications such as goggles and Thermal Weapon Sights (TWS).

With this approach SCD has developed a flexible, easy to deploy, high-end uncooled thermal imaging video core. The 640×480/17µm core, oriented for wide range of low SWaP applications, has a foot-print of 31×31 mm², weight of 43 grams, power consumption of 1.1 Watt, Time to Image of 3 seconds, and sub-frame video latency. The video core has two parallel digital outputs with selectable options such as BT656, Camera-Link, 8/14 bits parallel and Glue-less VGA AMOLED interface. The new video core is based on a temperature calibrated, High-Sensitive (HS) 640×480/17µm Focal Plane Array, which is packed (without TEC) in a ceramic package of 26×23 mm² dimensions.

The video core implements image processing algorithms such as Local and Global Dynamic Range Compression (DRC) and combined spatial and temporal de-noising. Shutter-less and TEC-less operation is achieved using sophisticated calibrations and image processing algorithms. The overall image is uniform, stable to temperature drifts, and with high sensitivity (NETD ≤ 32mK) and low Residual Non Uniformity (RNU).

1. INTRODUCTION AND BACKGROUND

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 device design and production, image processing algorithms and their implementation in hardware and software.

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 video cores, system integrators are relying more and more on the video 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 cores to drive their own detector and offer higher level of product integration.

"VOx Imager", SCD's new video core, is a multi-purpose, flexible, easy to deploy high-end 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 [1].

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. 640x480/17µm VOx micro-bolometer TEC-less CERAMIC PACKAGED DETECTOR

For the growing demand of Low SWaP TWS military market, SCD has developed a small ceramic package for its existing high-Sensitive (HS) 640×480/17µm Focal Plane Array. 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.

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 electrical pins.
- Utilization of an especially designed vacuum chamber and process eliminates the need for a vacuum pipe
- Removing the TEC reduce the package height.

The reduced weight compared with a metallic package is important for various applications

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.
MTTF (Vacuum Life time)	20 years @ 25deg.C ambient

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

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).

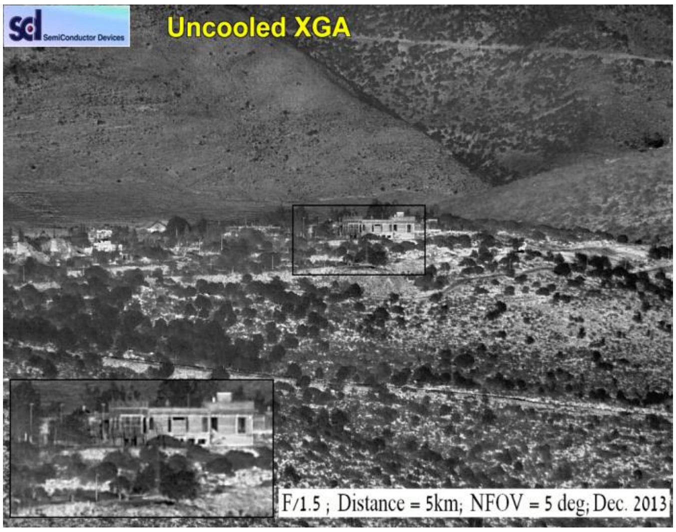

Figure 1 – Image taken by the BIRD XGA high sensitivity detector

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 [3]. The HS penalty is manifested in a longer time constant, but due to the relatively low thermal capacitance it is still below 12msec.

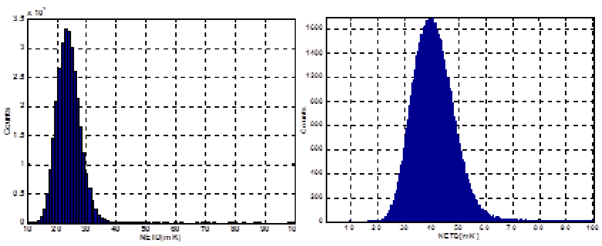

Figure 2 - Temporal NETD (F/1, 60Hz) distribution of the HS pixel detector (left) and the standard pixel detector (right)

The VGA, 17µm HS, ceramic detector is offered in three integration levels (Figure 3 from top to bottom): as a "stand-alone" detector, with proximity electronic, or as an entire video core. The ceramic package detector assembled with 30x30mm foot-print proximity electronics is fully qualified for military and industrial uses.

Prototype units of the VOx Imager video core have been released to customers for integration into their systems.

Figure 3 –VGA (640x480), 17u HS detector in a ceramic package (top caption), 17u HS ceramic detector with proximity electronics and optics (center caption), "VOx Imager" video core (bottom caption)

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

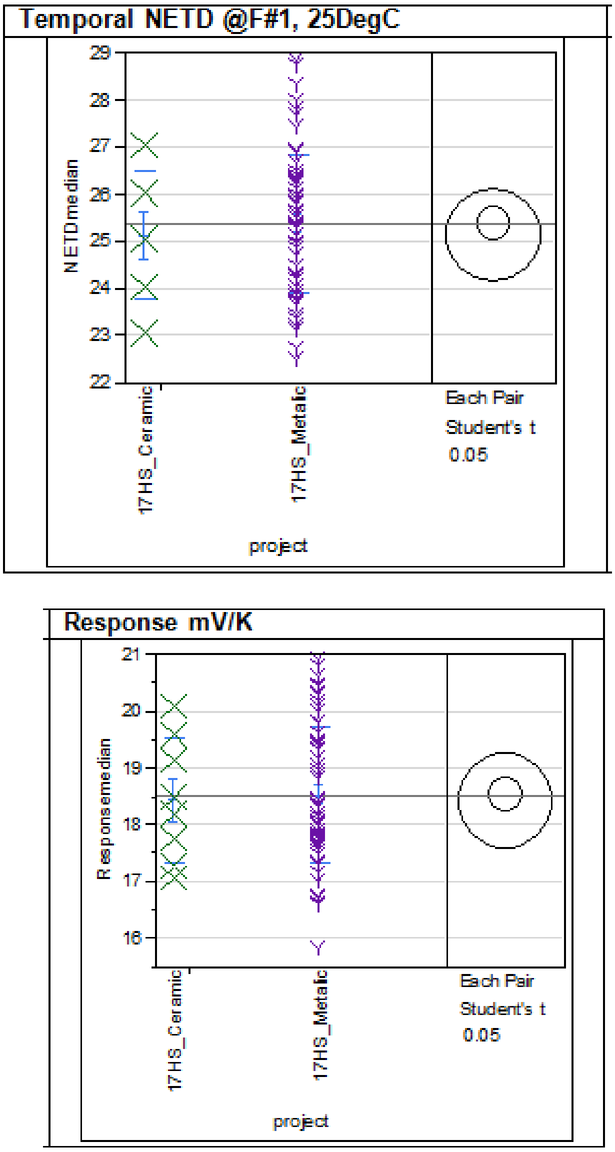

Figure 4 – Comparison of the NETD & Response for the ceramic and metallic package

3. IMAGE PROCESSING

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

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

- Fixed pattern noise: readout artifacts, pixel non-uniformity
- Noise reduction (in the spatial and temporal domains)
- Optical vignetting

This block is suitable for both automated video analysis (Machine vision) and imaging and maximizes the image quality of the 17µm detector.

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
- Graphics and Overlay
- Pseudo coloring

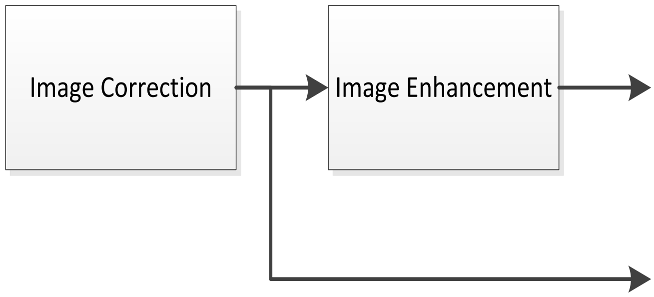

Figure 5 – "Vox Imager" image processing concept

a. 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 and spatial noise.

b. Temperature Based NUC (TBNUC)

Applies traditional gain and offset map correction to overcome detector non-uniformity. Where pout, pin 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:

$$pout(x, y) = G(x, y)pin(x, y)+Offset(x, y, T)$$

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 17 µm detector. TBNUC maintains local RNU at 2-3 times the temporal NETD.

c. 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 (Figure 6).

d. Scene-Based NUC (SBNUC)

Scene-based NUC infers and removes residual non-uniformity remaining in the 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 maintains RNU at 0.5 times the NETD and enables long term shutter-less operation (Figure 7).

e. Noise reduction (NR)

Spatio-temporal noise reduction reduces NETD by a factor of ~2. The NR algorithm uses a combination of spatial and temporal filtering according to inter-frame similarity. The algorithm preserves maximum detail while maintaining uniform noise levels across the frame (Figure 8).

f. Dynamic Range Compression (DRC)

DRC compresses the input signal to a displayable signal and enhances signal edges. 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 (Figure 9).

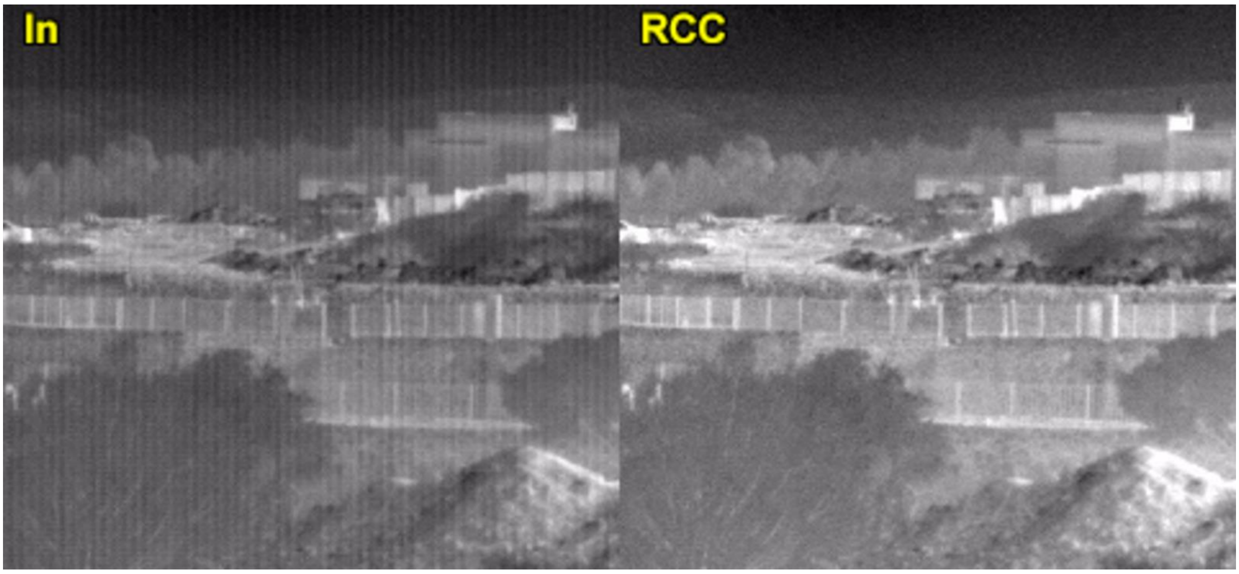

Figure 6 –Row and column correction (RCC)

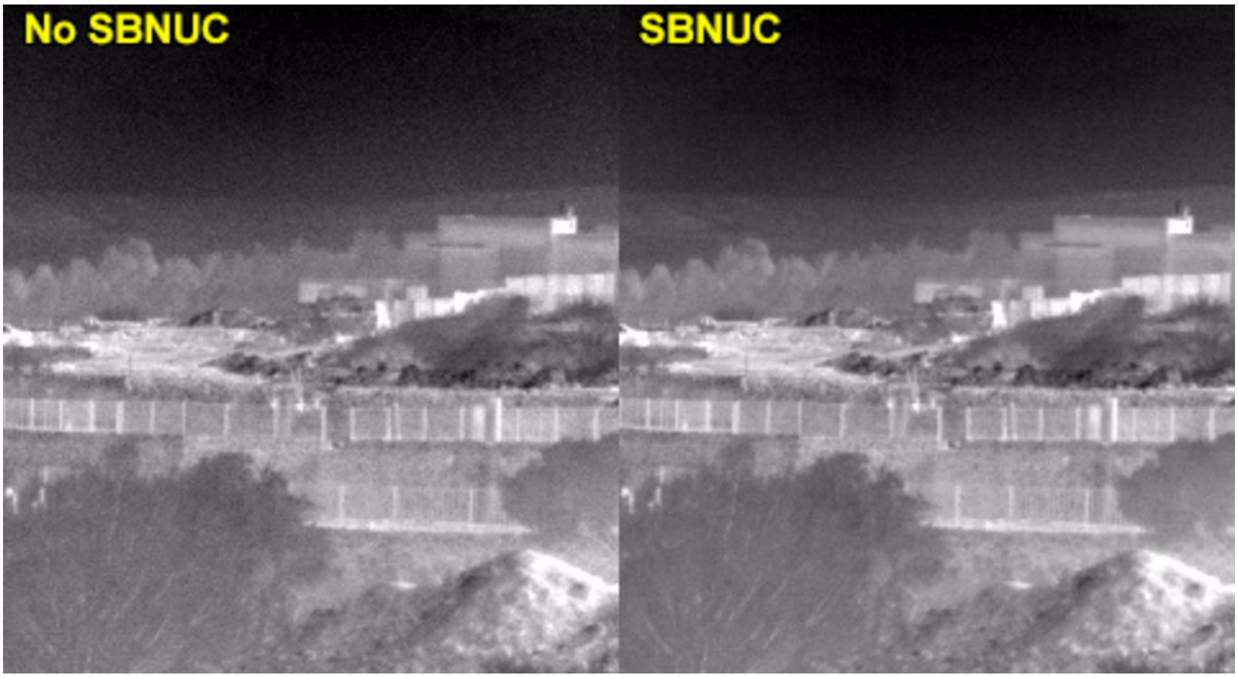

Figure 7 – Scene-based NUC removal of residual fixed-pattern

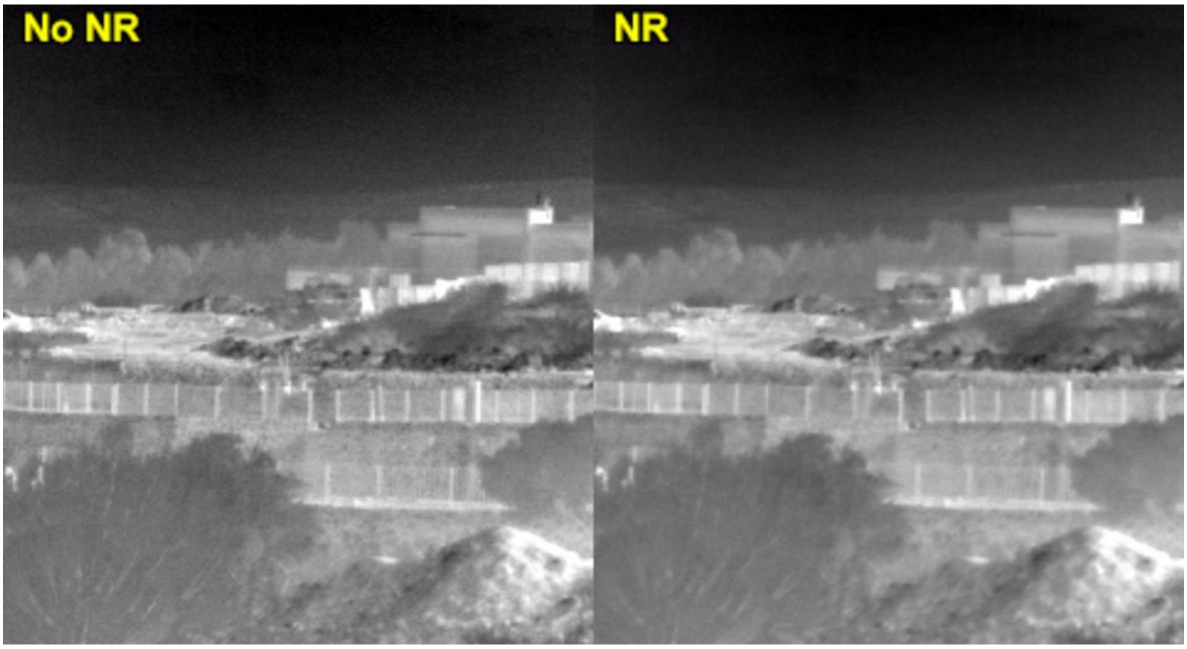

Figure 8 – Noise reduction

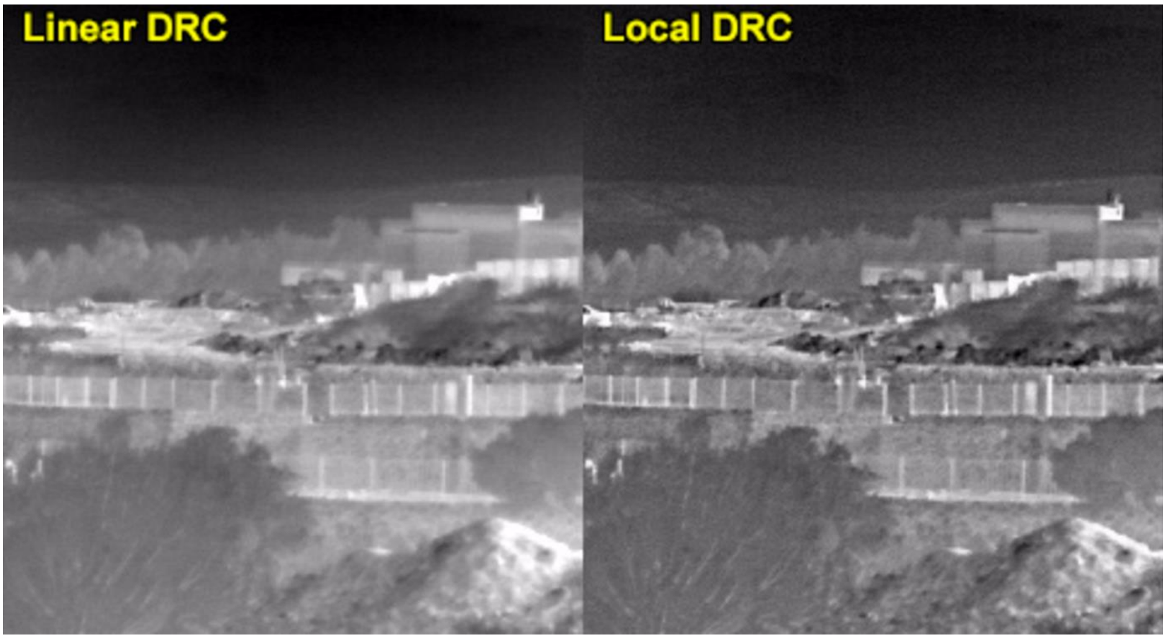

Figure 9 –Global and local dynamic range compression

4. VOx Imager – Video Core

The "VOx Imager" is a VOx based long-wave infrared (LWIR: 8 - 14 microns) video core built around SCD's high-Sensitive (HS) 640×480/17µm micro-bolometer detector. Its typical specifications are summarized in Table 12.

The "VOx Imager" is a miniature uncooled imaging video core without lens (as shown in the bottom Figure 3). The size is just 31x31x29.7 mm³ weight 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 core that provides the best solution for most applications is highly desirable. It simplifies system design and reduces cost due to commonality. Such a core 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).

Some of the key futures of the "VOx Imager" product:

a. 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%.

b. Digital Output Data Channel

The "VOx Imager" provides two video channels simultaneously, a parallel video channel and Camera-Link 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 BT656 protocol, a parallel LVCMOS protocol or an AMOLED Display mode.

c. 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.

d. 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.

e. 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.

f. 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.

g. Graphics, overlay and Color

The "VOx Imager" provide the user toolkit which allow the user to create its own graphic and text to be presented on the video display. In addition it allows the user to select color pallets to pseudo color the graphics and the video itself.

h. 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
Sensitivity	NETD < 35mK @ F/1,30Hz
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
Weight	43 grams
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" video core

5. Summary

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

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

6. ACKNOWLEDGEMENTS

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7. References

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