Event based SWIR sensor

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ABSTRACT

Event-based imagers are an emerging class of sensors with demonstrated advantages relative to traditional imagers. Event-based vision sensors have a limited number of output bits that are only responsive to image variations, thus overcoming the speed and power constraints of the conventional imagers based on image integration. So far, event-based vision has been implemented in visible CMOS sensors. SCD has developed a new event-based VGA/10µm InGaAs sensor that is sensitive in the Visible to SWIR band (600–1700nm) thus extending the standard imaging capabilities such as day light, low-light level, see-through fog and dust. Another novelty of this sensor is that the event channel outputs in parallel to a conventional integrating fast imaging channel. Moreover, the event channel can be reconfigured to provide a fast laser pulse detection mode, which also outputs in parallel to the integrated image. The new ROIC outputs standard video at 13 bit resolution with a high frame rate of 800 frames per second and can double this rate by lowering the resolution to 11 bit. The Event channel can reach up to 25 kHz of negative, null, or positive signal and the laser channel can double this output providing a single bit detection frame up to 50 kHz. In this work, we will elaborate on the architecture, key features, and preliminary simulations of the ROIC and sensor.

Keywords: Event-based, SWIR, ALPD, InGaAs, ROIC, Machine Vision, Laser Pulse Detection, Fast Imaging

INTRODUCTION

Grabbing video frames at high frame rates is highly desirable for various imaging applications. For instance many applications, such as autonomous navigation on a spatial imaging field, collision awareness or wake-up on demand, may benefit from video imaging with fast imaging frame rates. However the conventional video imaging readout circuits present a bottleneck that practically limits video Frames Per Second (FPS) to hundreds of Hz, or support higher FPS at the expense of very low format or very high power consumption [1-2]. Event-based imaging is a new emerging imaging paradigm, which is originally inspired in the seeing characteristics of the compound eye usually found in arthropods [2]. It has been originally referred as neuromorphic imaging and its history can be tracked back to Prof. Carver Mead work during the 80s and 90s [3]. An event-based imaging sensor is focused only on variations in the pixel target thus breaks the speed bottleneck in conventional imaging.

Typically, event vision aims at machine use, such as robotics, wearables, autonomous navigation and others. In defense applications event cameras can be applied for persistent surveillance, movement detection and monitoring, object recognition and tracking. Moreover, due to its fast response, they can detect and track gun muzzle. Active defense systems may benefit from event imaging for fast response to hostile threats. Navigation systems such as defense autonomous vehicles and drones can use event imaging for movement assistance and collision avoidance and at the same time assess motion-based depth information. Adding complex neuromorphic algorithms, event vision has received increased interest in recent years for Simultaneous Location and Mapping (SLAM) [4]. Neuromorphic processing can be combined with Artificial Intelligence (AI) to perform complicated tasks such as automatic target identification. Other many processing options may enable its use to eliminate image artifacts caused by vibrations, turbulence or flow measuring.

During the last decade, we have seen the emerging of event-based and dynamic vision imagers for applications in the visible range. In most cases, these imagers are dedicated exclusively to asynchronous event-based vision without providing simultaneous and synchronous conventional image information. SCD is now developing a new product that is the first to introduce event-based imaging in the SWIR wavelength regime. Moreover, this new imager provides a simultaneous conventional high FPS image synchronized to the event-based output.

SDC event-based imager follows the line of multi-functional InGaAs/InP SWIR products that was launched in 2013 with the Cardinal 640 VGA 15µm pitch, followed by Cardinal 1280 SXGA 10µm pitch, and by Cardinal 640 Low Noise VGA

15µm pitch [6-10]. The new imager is a multi-mode VGA 10µm pitch sensor that is sensitive in the visible to SWIR band (600 – 1700nm) providing event-based vision up to 25 kHz combined with parallel 11-13 bit integration of standard video at high frame rate. The event-based channel can be operated in parallel to the video channel as well as a separate stand-alone channel. In addition to event capabilities, the new ROIC continues the line of Laser Pulse Detection (LPD), introduced in previous SWIR products of the Cardinal family. LPD can be either Asynchronous (ALPD) or Synchronous (SLPD). ALPD works at an unprecedented fast detection rate that enables the decoding of the laser Pulse Repetition Frequency (PRF) and distinguish between different lasers in the image scenario. Therefore, we see it as the 3rd generation of ALPD based products. SLPD is also a fast mode included in previous generations that enables synchronous operation for systems having a self-generated laser. SLPD enables to detect this laser and provides a fast output that positions the laser target within the image. SCD methods for combining imaging with event and LPD are patented [11-12].

MULTI-FUNCTIONAL ROIC

The block components of the new multi-functional ROIC are shown in Fig. 1. At the front-end, the ROIC is connected to the Focal Plane Array (FPA) by the injection circuit. At this point the signal is split between an integration and a derivation (ac) path. The first one provides the conventional video imaging, while the second one is responsive to variations in the image and provides either the event-based imaging or the fast laser detection frame.

In the event-based mode, the ac path goes through two comparators with separate thresholds that output a few values indicating three possibilities. The 1st one is that the target has a positive variation; the 2nd one is that the target has a negative variation; and the 3rd one, by large the most probable one, is that the target variation is below the threshold, meaning it can be assumed constant. From the information point of view and for compression at next levels, the derivation path outputs 1.5 bits. After proper processing, the derivation path output is organized in synchronized fast output frames in a separate channel similarly to conventional video. Due to the low number of output values, the efficient processing, and the separation in an additional video path, the event FPS (eFPS) rate goes up to 25 kHz.

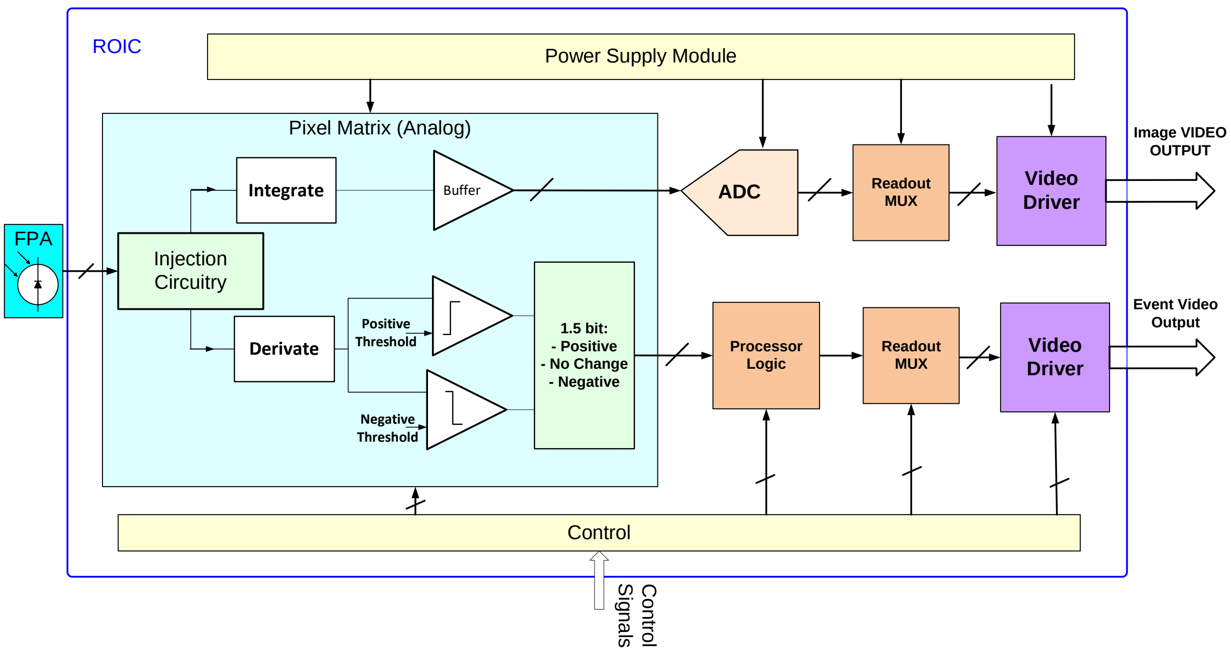

Figure 1. Multi-Functional ROIC

An additional event detection feature integrated in the new ROIC is the capability to provide fast LPD modes, either for ALPD or SLPD operation. In both ALPD and SLPD modes, the derivation path is optimized for laser event detection. Although both the fast LPD and the event modes are based on the ac component of the signal, they are not the same. The first is optimized for fast laser pulses lasting typically ~100nsec, the second for relatively slower events continuously varying at rates well below 25 kHz. Noise shaping and internal gain of the derivative path vary depending upon combination of the image with laser or event detection in order to provide optimal detection.

The integration path in the new ROIC also improves significantly the conventional imaging frame rate. The image integration can reach 800 FPS with 13 bit resolution. This relatively high frame rate is achieved disregardless the additional event capabilities integrated in the same pixel and due to the Analog to Digital Converter (ADC) improvements and column proper optimization. By reducing the output to 11 bit resolution, the rate can be doubled to 1600 FPS. These values depend upon the multi-functional mode combination; some limitations may apply depending upon the mode of operation defined.

Fig. 2 shows the floor plan of the ROIC. The overall width and height are 12.3 mm and 10.9 mm, respectively. Detection and imaging column-parallel channels are placed on top and bottom of the 640 x 512 pixel matrix, the detection channel is closer to the matrix as shown. The imaging ADC is a slope ADC that generates up to 13 bit and can be reconfigured between 11-13 bits, the ramp generator provides the reference to top and bottom of these ADCs. Digital and video are concentrated on the ROIC right side. Fast digital clocks are used for the ADC counting and fast communication that end in four JESD204B subclass-1video channels operating up to four Gbit/sec data rate.

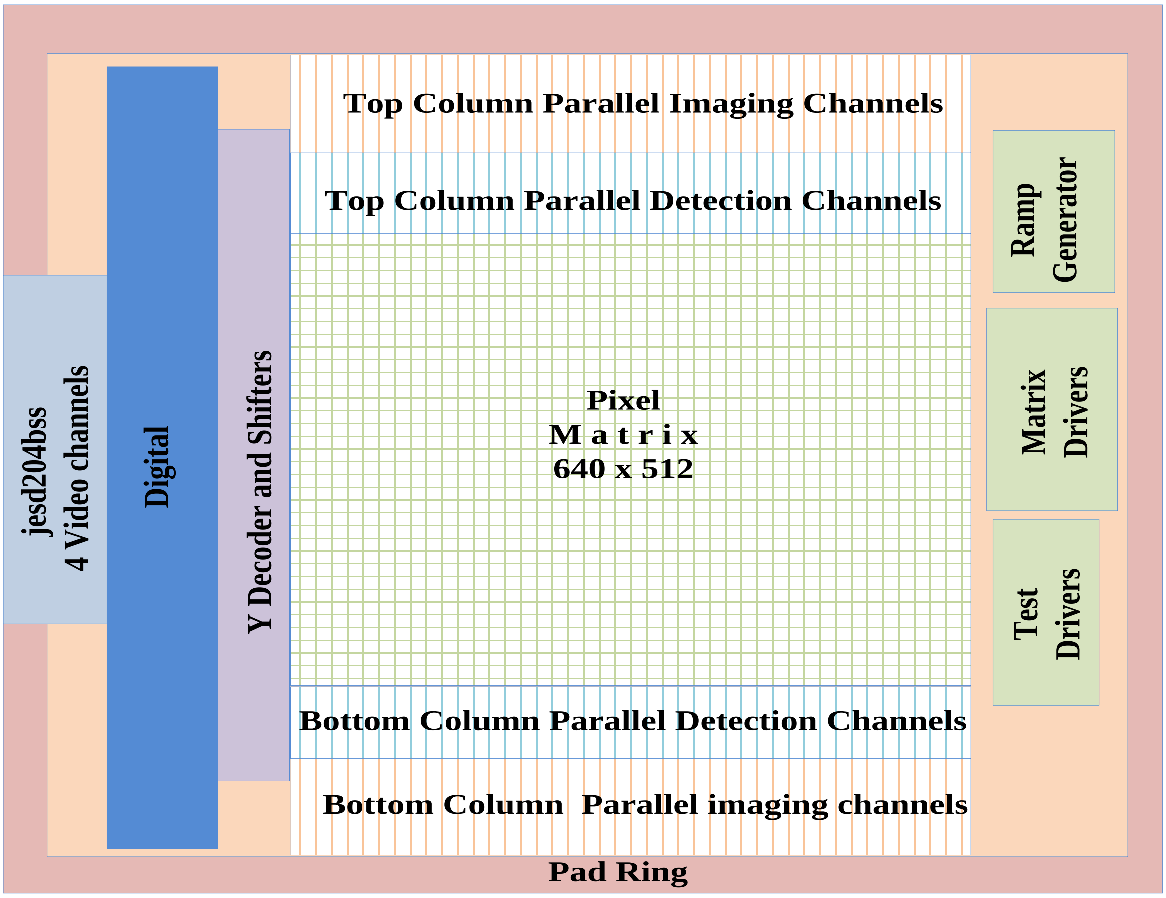

Figure 2. ROIC floor plan

MULTI-FUNCTIONAL IMAGER MAIN CHARACTERISTICS

Table 1 summarizes the main imager parameters. In the event modes the target is to achieve high-sensitivity event recognition as usually required by defense applications. In order to comply with this requirement, the main mode of event operation trade-off between sensitivity and dynamic range following a linear response. The event recognition can go down to 1500 e^-, a significant low value that when translated in percentage of the background may be below 5%. This percentage of background variation depends upon the background illumination. In some conditions, the background dependency can be a limitation, and to this end an “event-only” mode is provided that eliminates the background dependency.

In all LPD modes the high laser sensitivity is kept at a 2000 e^- minimal detection threshold with a low False Alarm Rate (FAR) below 0.3%. Internal gain and threshold are controllable in these modes to provide optimal detection. The fast frame ALPD rate of 50 kHz can provide decoding of the laser PRF, an useful characteristic in many defense applications.

Standard imaging modes provide 500ke^- Full Well Capacity (FWC) in Integration While Read (IWR) and 900ke^- Integration Then Read (ITR). The standard image FPS goes up to 800 Hz at 13 bit resolution and 1600 Hz at 11 bit resolution. A high-gain imaging mode for Low Light Level (LLL) is also provided. This mode works on 2x2 binning only (QVGA) format. At high gain the FWC is reduced to 50ke^- and the noise is reduced to 50e^- achieving a 1000:1 dynamic range.

Parameter	Units	Value	Comments
Format		640x512	
Event rate	kHz	0.5-25	Controllable
Event sensitivity	e^-	1500	Linear response
Max. capacity of event channel	e^-	±20k	Event variations only
ALPD/SLPD sensitivity	e^-	2000	At 0.3% FAR
ALPD rate	kHz	0.5-50	Controllable
ALPD duty cycle	%	100	At 500 Hz
Image capacity	ke^-	500 IWR & 900 ITR	
Image noise	e^-	150 IWR & 260 ITR	
High gain imaging FWC	ke^-	50 ITR	Low Light Level (LLL) mode
High gain imaging noise	e^-	50	Low Noise Imaging
Maximum frame rate w/o detection	kfps	800/1600	13/11 bit
Maximum frame rate with simultaneous detection	kfps	200/250	13/11 bit, Higher values depends upon mode.

Table 1. Main ROIC characteristics

SIMULATIONS AND MODELING

The ROIC event channel was simulated using a MATLAB and Simulink engine. The simulation input is based upon high frame rate images taken with SCD Cardinal 640 Low Noise (LN) SWIR camera reducing the camera Region of Interest (ROI) to increase the frame rate. Some further interpolation is used to increase even further the simulated frame rate. The fast images are then passed through simulation blocks that emulate the response of the event channel. In the enclosed images, positive detection is shown as white and negative as black, constant is the grey background.

Figure 2 and 3 show two images from movies taken with a using different lenses and different backgrounds during evening hours with a base frame of 1 kHz capturing the movement of a drone at the target scenario. In the event detection mode the detection efficiency is improved because the detection is only focused on the relevant changes in the image frame with a reduced number of bits output. At a fast event frame rate (fast eFPS), the drone is distinguished from other objects by the fast movement of its propellers. This technique can prevent the false alarm created by other objects moving in the frame, like for example, birds or kites.

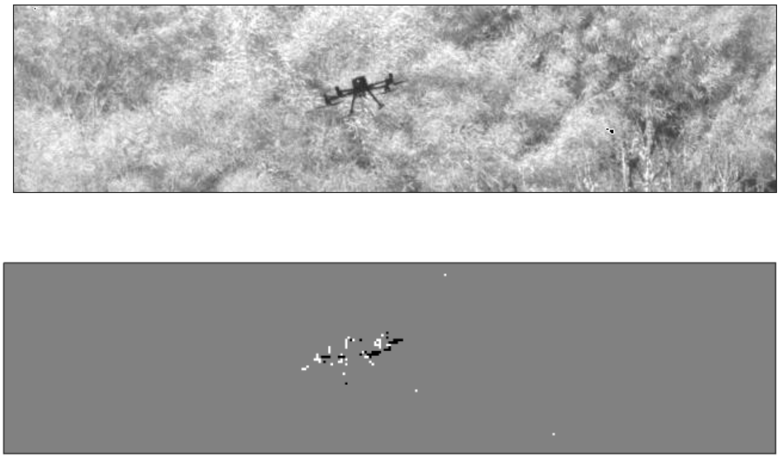

Figure 2: Top: Drone image taken with a Cardinal 640 LN camera, using a 500mm f/7 lens, at a 1kHz frame-rate. The drone is seen on a vegetation background. Bottom: The corresponding simulated event frame operating the ROIC event channel at a 10kHz frame-rate, dark and bright pixels are correspondingly negative and positive events

Figure 3: Top: Drone image taken with a Cardinal 640 LN camera, using a 50mm f/2 lens, at a 1kHz frame-rate. The drone is seen on a sky background. Bottom: The corresponding simulated event frame operating the ROIC event channel at a 10kHz frame-rate, dark and bright pixels are correspondingly negative and positive events

5. FOCAL PLANE ARRAY

The Focal Plane Array (FPA) is composed of the Event ROIC hybridized to an InGaAs diode array which is based on our legacy 10µm pitch VIS-SWIR technology. This mature technology is already embedded in thousands of delivered sensors. We chose the VGA format in order to support wide distribution low cost systems, specifically for hand-held "see spot" applications. The combination of high frequency ALPD channel superimposed on the real time image provides significant advantages for such applications.
The ROIC is currently in production and we expect to present first prototypes towards the end of 2022 and ramp-up production during 2023.

6. SUMMARY

In this paper we have presented SCD's new event-based VGA/10µm InGaAs sensor that is sensitive in the Visible to SWIR band (600–1700nm). This sensor supports simultaneously both imaging and event channels, which is a unique and novel feature. Additionally, the event channel can be reconfigured to perform Asynchronous Laser Pulse Detection (ALPD) up to 50KHz which is suitable for decoding Pulse Repetition Frequency (PRF).

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