

Low SWaP SWIR Cameras for Multi-Mode Applications

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ABSTRACT

This paper reviews the camera development efforts at Sensors Unlimited Inc. (SUI), a Collins Aerospace company, focused on serving multi-mode short-wavelength infrared (SWIR) applications while maintaining a low size, weight, and power (SWaP) footprint. Increasingly over the last decade, end users have looked to SWIR to support not only low-noise passive imaging, but also active illumination applications. Hence, cameras that include provisions to specifically support both modalities, passive and active imaging, have been given the moniker, “Multi-Mode.” In this work, SUI offers an overview of the passive and active imaging performance of the multi-mode cameras in its technology portfolio juxtaposing the traits of each. Finally, an outlook for future work in the area of multi-mode SWIR camera development is presented.

Keywords: SWIR, Low SWaP, Multi-Mode

1. INTRODUCTION

Collins Aerospace is a leading provider of short-wavelength infrared (SWIR) imaging products based on advanced InGaAs technology. A vertically integrated company, Collins Aerospace manufactures a range of SWIR products, including InGaAs photodiode arrays, packaged focal planes, OEM cameras and handheld imaging systems.

Over the past decade, Collins Aerospace has continued to advance its imaging capabilities beyond passive imaging and has developed the capability to support active illumination applications ranging from capturing short-duration laser pulse events to performing long range distance measurements. While these multi-mode applications have increased the complexity of the camera, Collins Aerospace simultaneously works to continue to drive down the size, weight, and power (SWaP) of the cameras in order to meet the demanding requirements of today’s systems.

This paper reviews Collins Aerospace’s most recent advancements in camera SWaP and multi-mode capabilities and provides insight into the current development work to be integrated into future imaging systems.

2. LOW SWAP MULTI-MODE TRACKING CAMERA

2.1 Overview

Collins Aerospace has recently completed development of a Low SWaP Multi-Mode Tracking (MMT) Camera. Building on the success of the current Collins Aerospace Micro-SWIR 640CSX MMT Camera, the Low SWaP MMT maintains the ability to perform simultaneous passive imaging and asynchronous laser pulse detection (ALPD), while significantly reducing power consumption and size when compared to its predecessor. A comparison of the two cameras is shown in Figure 1.

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Figure 1. Size comparison of the Micro-SWIR 640CSX MMT Camera (left) and the Low SWaP MMT Camera (right).

2.2 Passive SWIR Imagery

The Low SWaP MMT camera captures passive SWIR imagery using an Indium Gallium Arsenide (InGaAs) focal plane array (FPA). The FPA consists of a back-side illuminated InGaAs photodiode array (PDA) bonded to a silicon readout integrated circuit (ROIC), arranged as 640x512 pixels on a 15 μm pitch.

The PDA can be used in its standard form for SWIR-only applications, or substrate-thinned to extend sensitivity to shorter wavelengths. The resulting quantum efficiency is shown in Figure 2 below for cameras built with standard SWIR, NIR-SWIR, and VIS-SWIR PDA variants.

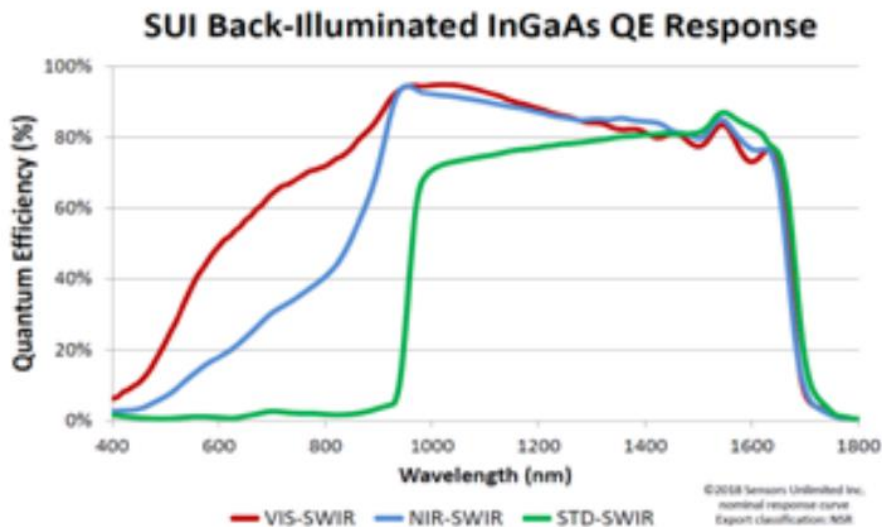


Figure 2. Quantum Efficiency of SUI SWIR, NIR-SWIR and VIS-SWIR PDAs. [1]

Within the ROIC, each pixel utilizes the Collins Aerospace-patented and optimized Buffered Gate Modulated (B-GMOD) input circuit, allowing for continually adjustable gain of the photodiode signal. All pixels in the array operate in snapshot mode and can begin integrating immediately after sampling the previous frame, allowing for near-100% duty cycle operation for applications requiring capture of short-duration events.

Within the camera electronics, the raw imagery is corrected, enhanced, and processed as needed for a given application. The image is then transmitted via a standard video protocol, such as MIPI or Camera Link.

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2.3 Asynchronous Laser Pulse Detection

In addition to passive imagery, the Low SWaP MMT camera can also detect short-duration asynchronous laser pulses. The pulse is captured by the same InGaAs photodiode array used for passive imagery but relies on independent circuitry within each pixel to detect the pulse and differentiate it from ambient light.

Separating the circuits within the pixel provides several advantages to the system. For one, it provides the capability to detect pulses of very low power relative to ambient light. Therefore, even if the pulse is not discernable in the passive imagery, it can still be detected by the pulse circuit and added to the image in post-processing.

Since the pulse detection circuit is operating independently from the imaging portion of the pixel, the pulse data can be sampled much more frequently at 1 kHz for full frame operation, and up to 20 kHz for sub-window regions. This allows for detection and decoding of laser target designators for target identification.

2.4 Size, Weight & Power Reduction

The primary objective of the Low SWaP MMT camera development was to enable SWIR imaging and ALPD capabilities in applications with demanding size and power constraints, such as battery powered systems, handheld devices, and unmanned aerial vehicles (UAVs). To that end, new developments were made in camera packaging, circuit board design, and image processing to support these goals.

The most significant improvement in overall camera size was made by reducing the total depth of the camera. To do this, the traditional multi-board stack was abandoned in favor of a single-piece rigid-flex assembly. This allowed the camera electronics to be folded into a smaller package than would be possible with typical board-to-board connectors. The independent FPA package was also transitioned to a direct-mound chip-on-board package, where the FPA is permanently bonded to the camera electronics rather than as a removable component. This resulted in a reduction of camera core depth from 21 mm on previous cameras to approximately 7 mm on the Low SWaP MMT camera (excluding optics).

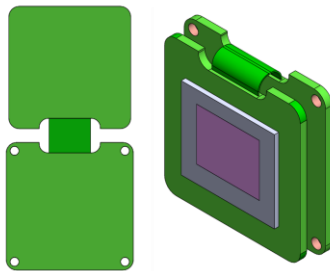


Figure 3. Low SWaP MMT Camera Rigid-flex Assembly.

The camera size was further reduced in length and width by careful selection of electronic components. Components were selected to use common power rails wherever possible to reduce power management circuitry, and the memory interface was structured to minimize the number of signals required for memory accesses. This allowed for the use of smaller, lower pin-count components, and required less circuit board real estate for routing the memory bus signals. The result is a reduction in both the width and height of the camera, from 30mm x 30mm on previous cameras to 25mm x 25mm on the Low SWaP MMT camera. Coupled with the reduction in camera depth, the overall camera volume has been reduced by approximately 75% (excluding optics).

Finally, the total camera power was reduced by several means. First, thermal management of the FPA was changed from active cooling using a thermoelectric cooler (TEC) to passive cooling. This resulted in a significant power savings, but also increased the nonuniformity of the camera due to increased FPA temperature. To compensate for this, the nonuniformity correction algorithm was modified to incorporate temperature-based corrections in addition to the

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traditional gain, offset and pixel replacement corrections. Next, the camera processor and memory devices were updated to newer, lower power technology. Historically, these devices have had to follow the trends of mainstream consumer electronics, which were often over specified for camera applications. However, the past few years have seen a number of low power, mid-range performance devices in both the processor and memory markets, that are more fitting for use in cameras and image processing. By implementing these changes, the total camera power was reduced from 3-5 Watts on previous cameras to 1.5 Watts on the Low SWaP MMT camera.

3. HIGH RESOLUTION MMT CAMERA WITH TIME OF FLIGHT RANGE SENSING

3.1 Overview

Collins Aerospace has recently completed prototype development of a high resolution MMT camera with time of flight (TOF) range sensing capabilities. The primary goal of this camera is to perform laser range finding while providing SWIR imagery of the scene and laser location within it. The camera provides passive imagery with a resolution of 1280 by 1024 pixels, asynchronous laser pulse detection with a resolution of 640 by 512 pixels, and range sensing up to 3000 m.

3.2 Range Sensing

Range sensing is performed using the Direct TOF method. In Direct TOF, a synchronized light source is used to transmit a laser pulse at the target. The camera then measures the amount of time before the pulse reflects off an object and is detected by the camera, and uses time calculate the distance of the object.

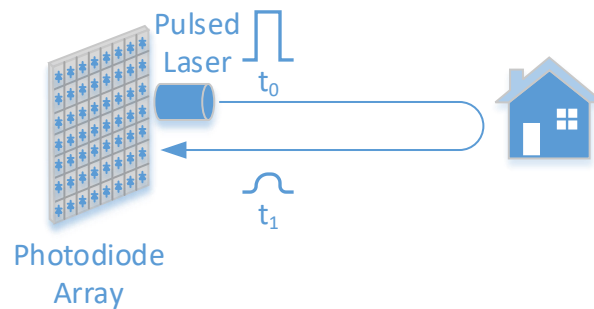


Figure 4. Direct Time of Flight measurement method.

This method has several challenges to obtaining accurate measurements. One such challenge is that differences in target reflectivity may cause slight delays in detecting the returning pulse, which would create error in the distance measurement. To reduce this error, the pixel ALPD circuit is repurposed to detect a low amplitude return pulse based on the range and reflectivity requirements for a given application.

4. MULTI-MODE FOCAL PLANE ARRAY WITH FULL FRAME TIME OF FLIGHT DEPTH SENSING

4.1 Overview

Collins Aerospace is taking the LRF capability to the next logical step and is currently developing a focal plane array capable of producing a full-frame depth sensing image. This FPA builds on the existing Direct TOF pixel but will produce a depth measurement for each pixel in the array, rather than a single-point range measurement. Future

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development will focus on building this FPA into a camera and coupling with a suitable illumination source to provide a full depth-sensing imaging system. Since the resolution and pixel pitch are similar to the previously mentioned Low SWaP MMT Camera, the FPA has the potential to be packaged into a similar low SWaP form factor. This imaging system could be used in a variety of applications where depth imagery is advantageous, such as autonomous vehicles and augmented reality systems.

5. REFERENCES

[1] Sensors Unlimited, Inc., “SUI Back-Illuminated InGaAs QE Response” 2018,
https://www.sensorsinc.com/images/uploads/documents/VIS_NIR_SWIR_FPA_TYPICAL_QE_CHART.pdf

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