# Performance of an Uncooled Camera Utilizing an SWIR InGaAs 256x256 FPA for Imaging in the 1.0 µm - 1.7 µm Spectral Band

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## ABSTRACT

The performance of an uncooled camera utilizing an InGaAs[1] Focal Plane Array (FPA) sensitive to the 1.0 - 1.7 µm IR spectrum is reported. The camera spectral sensitivity is established by the material properties of the detector array which is composed of photovoltaic detectors formed in an epitaxial layer of InGaAs with a composition which yields a lattice match with the InP substrate. The low dark current in the photovoltaic InGaAs detectors allows uncooled room temperature operation with D* above $10^{12}$ cm√Hz/W. The FPA is composed of the Sensors Unlimited $In_{0.53}Ga_{0.47}As$ photodiode array indium bump bonded to a special variant of Amber's AE173 readout circuit with reduced integration capacitance which is appropriate to $In_{0.53}Ga_{0.47}As$ detectors operating in the 1.0 - 1.7 µm spectrum. Features of the camera system include snapshot integration, variable integration time and focal plane windowing. Windowing allows readout of the full 256 x 256 array at up to 120 frames per second or readout of 128 x 128 sub array at 480 frames per second or readout of 64 x 64 sub array at 1800 frames per second. Camera output is in the form of analog video in NTSC or PAL formats and 12-bit digital output in parallel as well as serial high speed formats. A NUC processor provides a pixel by pixel gain and offset correction to image data. Uncorrected responsivity uniformity and DC uniformity of 6% - 10% sigma/mean have been observed.

## 1.0 INTRODUCTION

This paper reports the development of an uncooled infrared camera sensitive in the 1.0 - 1.7 µm region of the infrared spectrum. Development of the focal plane array was a collaborative effort between Raytheon Amber and Sensors Unlimited. The InGaAs detector arrays provided by Sensors Unlimited were fabricated in a 256x256 architecture compatible with Amber's AE173 readout chip. Radiometric data from eleven FPA's

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1. M. J. Cohen and G. H. Olsen, "Near-IR Cameras Operate at Room Temperature" Laser Focus 29. 109-113 (1993).

fabricated in this development effort are here reported. Radiometric performance is quantified in terms of quantum efficiency, uniformity of quantum efficiency, noise equivalent irradiance (NEI) and operability.

The SWIR InGaAs FPA reported here was designed to be incorporated into Amber's Radiance HS™ camera making this camera system now available in LWIR, MWIR and SWIR configurations. Performance characteristics and features of the SWIR Radiance HS™ are here reported.

## 2.0 SWIR RADIANCE HS™ CAMERA RADIOMETRIC PERFORMANCE

There has been heightened interest in recent years in the area of uncooled infrared FPA development. Progress in uncooled imagers has proceeded along several paths including microbolometer and ferroelectric technology for LWIR imaging and InGaAs and HgCdTe technology for SWIR imaging. Particular interest in uncooled SWIR imagers has been stimulated by the potential to image in the 1.0 - 1.7 µm band utilizing illumination from night glow.

The SWIR Radiance HS™ FPA consists of an InGaAs 256x256 element photovoltaic detector array hybridized via indium bump bonding to Amber's AE173-2 CMOS readout integrated circuit. The AE173-2 readout circuit is identical to the AE173-1 readout circuit used with HgCdTe and InSb detector arrays in all aspects except for the size of the integration capacitor. The AE173-2 has a signal capacity of $3\times10^6$ electrons while the signal capacity on the AE173-1 is $9\times10^6$ electrons. The smaller integration capacitor on the AE173-2 used with InGaAs detectors is appropriate to the flux levels encountered in imaging in the 1.0-1.7 µm SWIR band. All normal AE173 performance features such as snapshot integration, high speed operation, windowing and dilution are retained in the SWIR embodiment of the Radiance HS™ camera. The SWIR Radiance HS™ camera radiometric performance is established by the performance of the InGaAs/AE173 FPA. The radiometric performance specification of the Radiance HS™ SWIR is summarized in table 1 below.

Amber has demonstrated the performance of the InGaAs/AE173-2 FPA through the fabrication and test of eleven FPA assemblies. The performance of each of the eleven tested FPA's relative to the four radiometric performance specifications listed in table 1 are shown in figure 1. In the bar chart of figure 1, the data for each of the eleven FPA's is coded with its own fill pattern for the bars making it possible to determine performance on an FPA by FPA basis.

Examination of figure 1 reveals that all focal planes passed the quantum efficiency fill factor product specification, the quantum efficiency uniformity specification and the NEI specification. Two of eleven failed the operability specification obtaining 97.92 % and 97.78 % operability, the remaining nine FPA's passed all performance requirements. Overall the FPA radiometric performance was met for 82 % of the devices tested.

## 3.0 THE RADIANCE HS™ MODULAR IR CAMERA

The design of most contemporary FLIRs are strongly driven by specific end user applications. Typical system architectures are unable to accommodate expansion to larger format focal planes, utilize alternative detector materials, or provide flexible sets of user accessible image and digital data manipulation features without significant investments

Table 1. Swir Radiance Hs™ Camera Radiometric Performance Specification

| | |
|---|---|
| QE x Fill Factor | > 50 % |
| QE Uniformity | < 10% sigma/mean |
| NEI | < $6 \times 10^{10}$ photons/cm$^2$/sec |
| Operability * | >98 % |
| * An Operable Pixel Must Have: | |
| QE x Fill Factor | > 0.5 x mean |
| DC Uniformity | > 0.33 x mean<br>< 1.5 x mean |
| NEI | < 4.0 x BLIP |
| Flickering Pixel | < ± 10 x noise |

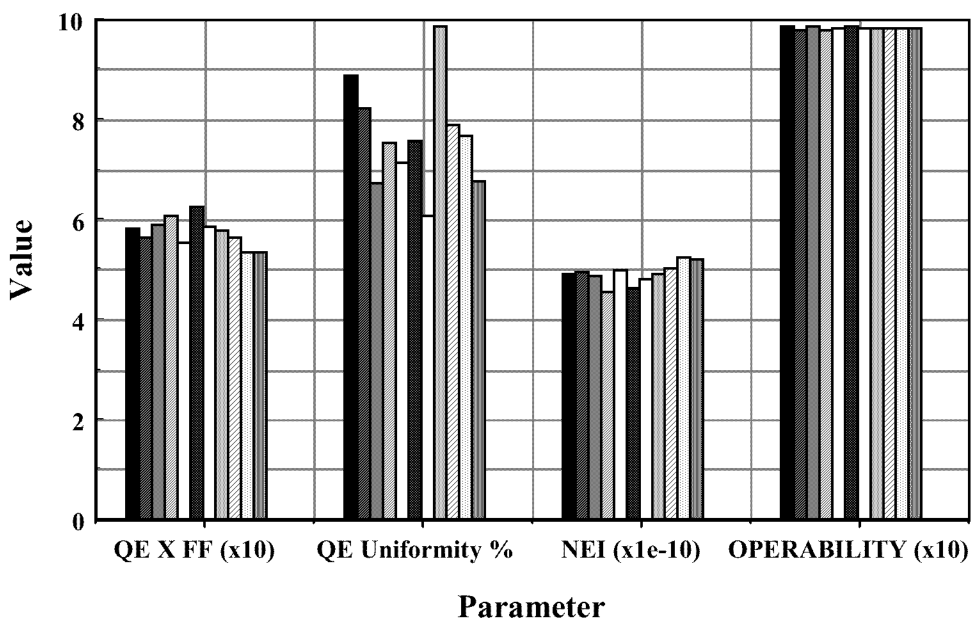


Figure 1. Radiometric Performance Of Eleven Ingaas 256x256 Fpa's

in redesign. Amber provides an innovative solution to this dilemma by offering a modular infrared camera featuring flexible hardware and software architectures designed for stand alone research and industrial instrumentation activity as well as in embedded gimbal FLIR systems applications.


Figure 2. Radiance HS™ Modular IR Camera

The standard Radiance HS™ product design, as shown in Figure 2, currently incorporates Amber's AE173 focal plane array with 256x256 detector elements and is available in either MWIR (InSb), LWIR (HgCdTe) or most recently SWIR (InGaAs) versions. The AE173 features selectable frame rates and simultaneous pixel integration, or what Amber refers to as snapshot operation. This allows stop action analysis of events as short as 2 μsec and microscanning to produce higher resolution imagery for FLIR applications. It is capable of directly imaging a scene or is compatible with high speed analog or digital recorders. Capabilities including focal plane windowing support full format (256X256) operation of the FPA at up to 120 Hz. When the FPA is operated in one of the seven standard windowed and/or diluted data output modes digital data frame rates of up to 6 Khz are achievable. A variety of specialized integration time controls are available to support the use of Radiance HS™ for ultra high speed thermographic and non-destructive test applications. The camera furnishes composite analog video in NTSC or PAL formats and 12-bit digital data output in parallel as well as serial high speed formats. Table 2 summarizes the principal camera features and parameters.

Table 2. Radiance HS™ Camera Features

| | |
|---|---|
| Detector Technology (Standard Spectral Band) | InSb (3-5μm), HgCdTe (8 - 10μm) or InGaAs (1 - 1.7 μm) |
| Input Power | 18V to 32V, 50 Watts Peak |
| Analog Video Interface | NTSC or PAL, S-Video |
| Digital Data | 12 Bit Parallel and Serial Data |
| Dynamic Range | 65 dB Camera Avg. (45dB/pixel) |
| Remote Control | RS-422 or RS-232C |
| Cooling Method | Stirling Closed Cycle InSb & HgCdTe, TE stabilized InGaAs |
| NEΔT (Camera @ 23° K) | InSb <.025°K, HgCdTe<.050°K InGaAs: No Specification |
| NEI (InGaAs) | $< 6x10^{10}$ photons/$cm^2$/sec |
| Internal Video Synchronization | Standard Video or Programmable |
| External Video Synchronization | Analog (Genlock) and Digital Options |
| Outline and Mounting (Standard) | 5.1" H by 5.7" W by 6.75"L |
| Weight | ≤9 lbs (Including Standard Housing) |
| Operating Temperature (Conductively Cooled, Commercial)) | 0°C to +50°C (@ Thermal Interface) |
| Storage Temperature | -54°C to +65°C |

The Radiance HS™ camera system consists of two primary mechanical modules, the camera head and signal processing electronics. The standard camera package (Figure 2) outline and mounting dimensions are 5.67" wide, 5.10" high and 6.75" long. There are two 1/4-20 tapped holes on the base plate of the camera head chassis that are in-line with the optical centerline. The two holes are spaced 2.50" apart with the first hole located 2.00" behind the optic bayonet mount. In this configuration, conductive cooling is accomplished through the mounting base. With Amber's off-the-shelf Split-Kit these two modules may be separated without compromising system performance or functionality. Most embedded systems applications require varying degrees of separation and/or reconfiguration of the two modules and some customers choose to forgo the use of Ambers standard power supply in favor of their own internal sources.

## 4.0 SIGNAL PROCESSING ELECTRONICS

The signal processing electronics consist of three functional board level sub-assemblies; the non-uniformity correction (NUC) processor, video processor, and power. Each assembly is individually contained in its own mechanical structure that doubles as an individual board heat sink. Heat generated by the electronics is conducted through internal conductive planes to all four of the edges where it is transferred to the sinks. Board mounted connectors are used for the integration of the complete module to ensure reliability in higher vibration and shock environments by eliminating the need for internal cables and harness assemblies.

The NUC processor produces non-uniformity corrected FPA data that has had bad pixels replaced. The principal logic functions are NUC memory read and write, NUC adder and multiplier, and bad pixel replacement. Secondary functions include; power conditioning to the camera head electronics and camera head electronics command and status signal pass through, control registers and associated read back logic for coefficient table selection, as well as the data path integrity and memory Built-in-Test.

The video processor electronics provides for overall system control, normalization, and system interface as required. This includes non-volatile program, system start-up parameter, and NUC coefficient storage. In addition this board provides the capability for manual and automatic contrast and brightness control, NTSC or PAL analog video output, digital parallel data output (12-bit) and high-speed digital serial output. Video control features such as white hot/black hot image intensity conversion, pseudo color, image rotation, and digital zoom (2X, 4X) functions are also available. Analog composite video output may be configured to either NTSC or PAL standards as a factory set option. S-video chrominance and luminance outputs also provided.

The Radiance HS™ camera system electrical interface includes customer supplied raw power, a serial command and control link, and analog and serial digital video output data. The allowable DC input voltage limits are from 18 to 32 volts. Radiance HS™ uses military grade DC to DC converters. These converters are MIL-STD-704D compatible, however, if full adherence to MIL-STD-704D is required, a system power pre-conditioner would also be required.