Beyond Omega: Next-Generation Miniature Infrared Camera

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ABSTRACT

Three years ago, Indigo Systems launched its Omega camera line, which to this day remains one of the world's smallest, lightest, lowest powered infrared cameras. The concept of a miniature thermal imager has proven very successful, and thousands of cores have been employed in a number of portable applications, including firefighting, unmanned vehicles, and handheld imagers. A common thread to these high-volume markets is their elasticity – lowering cost substantially enhances demand. Hence the motivation behind Indigo's newest miniature camera, Photon. Photon is a product family of small and mid-format sensor engines (160x128, 320x128, 320x256) specifically optimized for low cost and high volume. While it shares many of Omega's positive benefits, including remarkably small size, weight, and power, several aspects of the design contribute to it being more affordable than its fore-runner even with four times as many pixels. This paper compares the Photon design to the Omega with particular focus on those aspects affecting manufacturability and cost.

Keywords: miniature, uncooled, microbolometer, infrared, sensor engine, camera core, low cost

I. History

Almost six years ago, Indigo Systems introduced its Alpha camera[1] (Figure 1), the pioneer of the miniature infrared camera class. At that time, the small-format infrared camera (160x128) was essentially non-existent in the commercial market, and there were doubts that such a product could have any real utility. But on the contrary, the Alpha camera proved to be revolutionary, its exceptionally small size, weight, and power consumption being significant enablers in a variety of thermal-imaging applications. Three years later, Indigo launched the Omega camera[2] (Figure 2), which surpassed Alpha in practically every respect. One key difference between Alpha and Omega (which has since been renamed "Micron") is that the latter does not rely on a thermoelectric cooler (TEC), which is used in other cameras for temperature stabilization of the uncooled detector array. Eliminating the TEC was a cornerstone of Micron's reduced size, weight and power consumption. It also made near-instantaneous-on operation possible, an important advantage in many imaging applications.

Figure 1: The Alpha camera, the pioneer of Indigo's miniature camera product line.

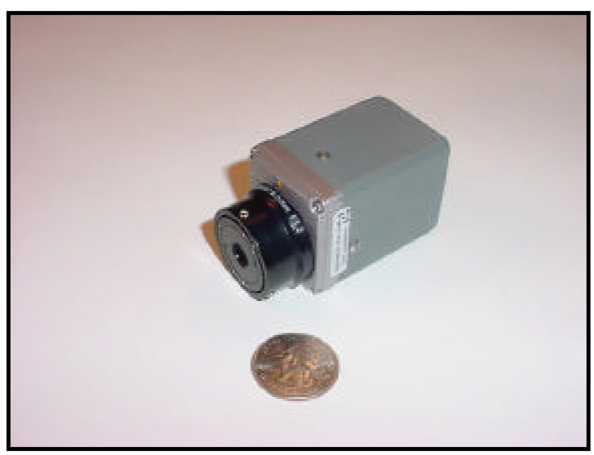

Figure 2: The Micron (Omega) camera, a technological and commercial success.

Another major difference between Alpha and Micron was the source for the focal plane array (FPA) subassembly, arguably the single most important component of any thermal imaging camera. Indigo designed Alpha's readout integrated circuit (ROIC), but the manufacture of the microbolometer array was contracted to an outside supplier. Dependence on an unreliable source for such a vital subassembly proved to be a major impediment to Alpha's commercial success – the supply of detectors simply could not keep pace with the demand for cameras. But on a positive note, the Alpha experience was a primary impetus for Indigo to establish its state-of-the-art foundry for high-volume manufacture of detector arrays[3,4]. From its inception, the microbolometer production line was designed to reliably yield in excess of one hundred thousand arrays per year via automated multi-wafer processing and tight process control. Micron was Indigo's first thermal imaging product to tap the homegrown supply of microbolometers. Now three years later, more than 9,000 Microns have been delivered into a number of commercial and military applications[5,6,7,8]. Without doubt, the investment in a dependable, dedicated supply of detector arrays has been one of the most significant reasons for the success of Micron.

Building upon Micron's success, a predictable direction for the next generation miniature camera from FLIR Systems* would have been further reduction of size, weight and power consumption. From an engineering point of view, there is certainly an appeal to push the envelope and set new standards for miniaturization. However, the real demand from the markets served by Micron (most notably firefighting and security / surveillance) is not further miniaturization but rather further cost reduction. In general, these markets are highly elastic[9]. That is, decreasing price significantly increases demand as illustrated in Figure 3. Firefighting is an excellent case in point. Just a few years ago, the high cost of thermal imaging equipment was such that it was rare to find more than one system within any given fire department. As costs have come down, one system per fire-service vehicle is becoming more realistic, and there is hope that thermal imagers will become standard issue for every firefighter in the not-too-distant future. Bearing in mind the elasticity of the markets for miniature cameras coupled with the very high capacity of Indigo's detector manufacturing facility, the development of the next-generation miniature camera at FLIR Systems has been focused on manufacturability in high volume and reducing cost. With these two items as fundamental design drivers, the trade space for defining system architecture is considerably different than when miniaturization is the primary goal.

Figure 3: Many markets served by thermal imaging are highly elastic – reducing cost significantly enhances demand. (Note: values shown are illustrative only and do not intend to represent actual market demand nor pricing.)

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*Note: FLIR Systems Incorporated acquired Indigo Systems in 2004 and quickly established the Indigo Operations Division as its center for development of miniature cameras.

II. Introduction to Photon

FLIR System's next-generation miniature camera is actually a family of thermal imagers referred to as the Photon product line. Several distinct configurations of Photon have been defined, including camera cores intended specifically for integration by original equipment manufacturers (OEMs) as well as stand-alone cameras for list sale. The primary difference between the various configurations are the array size, the optics, and the external housing (or lack thereof). The OEM configuration provides a single 30-pin surface mount (SM) connector for all external I/O. The standalone configuration provides separate connectors integrated into the rear wall of the housing for power (cylindrical plug), analog video (BNC), serial communication and digital output (DB15). Figure 4 shows both a standalone and an OEM configuration of Photon.

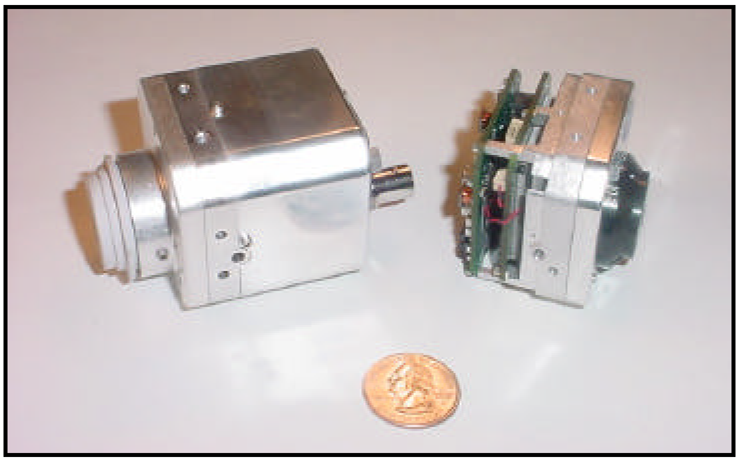

Figure 4: Standalone (left) and OEM (right) Photon configurations.

An underlying tenet of Photon's development was to maintain similar performance to Micron in all critical characteristics and improve performance where possible without significant cost impact. Certainly the largest performance benefit of Photon relative to Micron is the higher image resolution. A parameter comparison between Micron and Photon is shown in Table 1. Figure 5 is a side-by-side photo.

Table 1: Parameter comparison between Micron and Photon.

Specification	Micron	Photon
Image size	160x128	320x128* 320x256
NETD	< 50 mK (f/1.2) (35 mK normalized to f/1)	< 65 mK (f/1.3) (38 mK normalized to f/1)
Max. scene temp. ? High-sense mode ? High-temp mode	 ? 135C ? 450C	 ? 160C ? 560C
Size** (height x width x length)	37 mm x 34 mm x 47 mm (1.5" x 1.4" x 1.8")	50 mm x 50 mm x 45 mm (2.0" x 2.0" x 1.8")
Weight**	75 g (0.17 lbs)	95 g (0.21 lbs)
Power Consumption	< 1.5 W	< 1.5W
Operating Temp. Range	-20C to +80C -40C to +55C	-40C to +85C

* can be windowed to 160x128
** excluding lens assembly

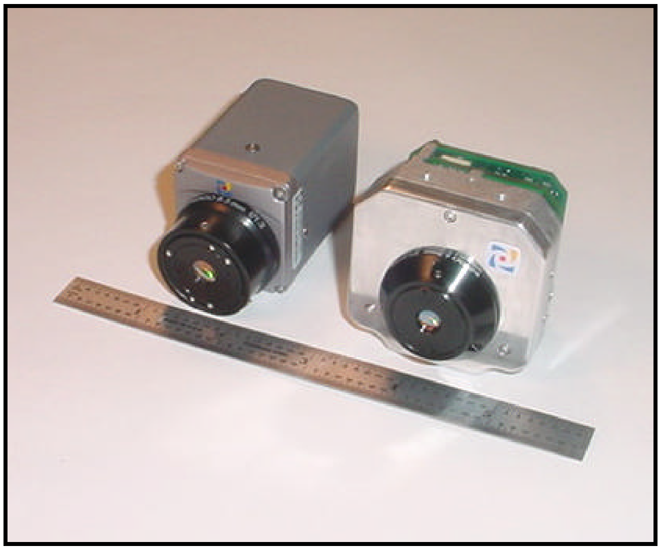

Figure 5: Micron (left) and Photon (right) miniature camera cores.

III. Cost Drivers

The paragraphs below describe aspects of the Photon design that differ from Micron, focusing specifically on system trades most influenced by manufacturability and cost as design drivers.

FPA / Vacuum Package. The component of a thermal imager that arguably exerts the most influence on total system cost and performance is the FPA. It is significant that Photon can provide four times as many pixels as Micron without increasing cost, and several aspects of the FPA and vacuum package design are largely responsible for this accomplishment:

- Pixel pitch has been reduced from 51 microns to 38 microns. Reducing pixel size produces a smaller detector array and hence the ability to print more die per wafer. While even smaller microbolometers are in use elsewhere in the industry (e.g., 25 microns), achieving reasonable fill-factor with such a pixel requires in some cases a more complicated dual-level structure that would have led to lower yield and higher cost.
- As a result of microbolometer processing improvements, Photon's 38 μm pixel provides sensitivity comparable to Micron's 51 μm pixel. This significant achievement means that Photon is not required to use larger, more expensive lens assemblies to maintain noise-equivalent temperature difference (NETD).
- More signal processing has been moved onto the ROIC, reducing the cost of system electronics as well as the number of I/O pins on the vacuum package.
- Individual vacuum feedthroughs have been eliminated by a design incorporating a multi-level ceramic base that provides the I/O connections to the FPA.
- A new assembly line has been developed to accommodate a robust, high-throughput batch process wherein numerous vacuum packages are built and tested in parallel.
- TEC-less operation has been improved, providing better image uniformity and improving margins against image-quality requirements.

Figure 6 shows the Micron and Photon vacuum packages side-by-side.

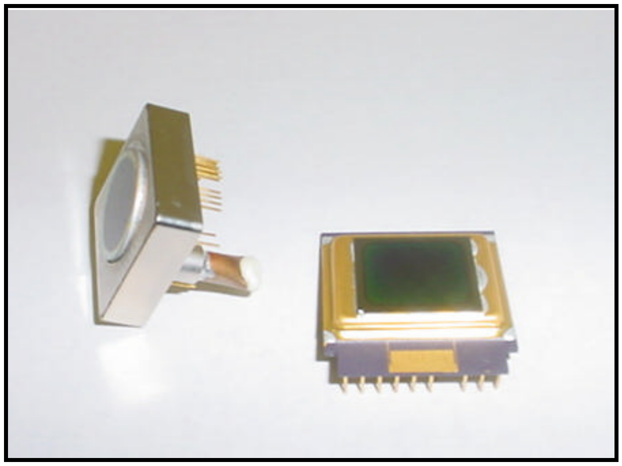

Figure 6: Micron (left) and Photon (right) vacuum packages. The Photon package design is optimized for high-volume manufacture.

In addition to the 320x256 FPA, there is a 320x128 array that is intended primarily for specialty applications of Photon which don't require standard 4:3 aspect ratio. This array is packaged in the same vacuum package as the mid-format array and is a drop-in replacement for it. The alternative array size is particularly suited for security and surveillance systems wherein the video from two separate cameras is displayed on the same video monitor. Systems employing a widescreen display could also benefit from such an aspect ratio. Photon provides a mode in which the 320x128 image is cropped to the central 160x128. This supports lower resolution systems and Micron replacement applications.

Electronics. The system electronics employed on Micron consist of a folded, four-panel flex/rigid circuit card and a "backplane" card that provides additional interconnections between the panels (Figure 6). The advantage of this approach is that it is incredibly compact, providing an electronics "cube" measuring 33 mm x 33 mm x 38 mm (1.3" x 1.3" x 1.5"). However, the flex/rigid serpentine is appreciably more expensive than a traditional circuit card stack using SM connectors for board mating. Consequently, Photon electronics are instead partitioned on two circuit cards each measuring 45 mm x 45 mm (x 20 mm when mated) (1.8" x 1.8" x 0.8"). These are interconnected by a single 40-pin SM connector. For the standalone configuration, a third circuit card provides fan-out of the electrical I/O to standard connectors. The system architecture and component selection were highly optimized for cost, with the most expensive component being less than $30 in volume. Figure 7 shows both the Micron and Photon electronics assemblies side-by-side.

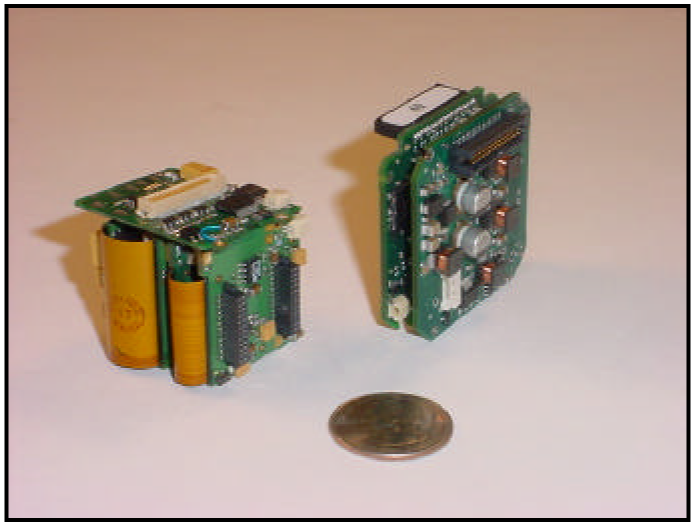

Figure 7: Micron (left) and Photon (right) system electronics.

Like Micron, the Photon electronics provides analog video in either NTSC or PAL format. The digital video channel uses the same protocol as Micron, making Photon backward-compatible with Micron accessory equipment (e.g., Ethernet module, Firewire module) and data-acquisition equipment. Two digital output channels are provided so that pre-AGC (14-bit) and post-AGC data (8-bit) can be acquired simultaneously. This supports applications wherein it is necessary to post-process the raw data (e.g., a tracker module) while also displaying or storing the contrast-enhanced data. An RS232 interface provides complete control of all camera functions. Also, Photon includes 3 undefined spare pins tied directly to the internal camera logic. These can be customized for OEM applications. For example, these pins can be tied to push-buttons that are used to control specific camera functions, such as video polarity or on-demand shutter correction.

Optics. As listed in Table 2, multiple lens assemblies are available for Photon, including narrow, medium, and wide field of view (FOV) options. For OEM applications that require custom lens design, FLIR Systems has an excellent working relationship with a number of external lens suppliers as well as in-house design and manufacturing capability.

Table 2: Standard lens options for Photon.

Focal length (mm)	FOV (degrees)	F/#	Manufacture
14.3	50 x 40	1.3	DPT
19	35 x 29	1.4	Molded
35	20 x 15	1.4	DPT
140	5.0 x 4.0	1.4	DPT

The 19mm lens assembly listed in Table 2 uses molded elements made of chalcoginate glass. In high volume, molded optics are a cheaper alternative to traditional diamond-point turned (DPT) germanium assemblies as a result of both the high-rate manufacturing process as well as the lower cost of the bulk material.

Software / Signal Processing. Photon provides all the system modes and features provided by the Micron camera, including:

- Automatic dynamic range control: The camera automatically selects between two different integration times depending upon scene content. One setting provides higher sensitivity while the other allows hotter objects to be imaged.
- Spot meter: The approximate temperature imaged by the center 4 pixels is computed and displayed (and/or provided as status via the serial interface).
- Isotherm: Pixels imaging scene temperatures higher than specified threshold values are colored in shades of yellow or red.
- Image orientation control: The image can be flipped horizontally or vertically to compensate for optics inversion or fold mirrors.

The same AGC algorithms used in Micron are available with Photon, as well as several new options for enhancing the image display. A region of interest (ROI) can be defined such that AGC is optimized within a subset of the field of view. Color palettes can be specified for OEM applications that require full-color video output, such as thermography.

OEM customers of miniature camera cores often require custom symbol overlays on the video output signal. For example, firefighting cameras typically show a spot-meter with temperature scale superimposed on the thermal imagery. In security and surveillance applications, it is often necessary to overlay target range, compass heading, and/or other status data. To support these applications, Photon provides a generic, full-color overlay capability for customized symbology. This capability provides the OEM customer with considerable freedom to define arbitrary icons, text, and other graphics to be placed anywhere on the video image. Additionally, a user-defined splash screen (e.g. product and/or company logo) can be optionally displayed at start-up.

Photon provides a digital zoom feature in which any 160x120 portion of the array is expanded (via bilinear interpolation) on the analog output channel. The zoom window can be panned vertically and horizontally in real-time. This feature enhances magnification for applications where performance may be limited by display size.

Calibration & Test. FLIR Systems' patented approach to TEC-less operation entails calibration over the operating temperature range. Additionally, image quality and other performance parameters are verified on every unit at multiple temperatures. From the onset of the Photon development process, a parallel effort was focused on optimizing the calibration/test equipment and processes for high-rate production. In addition to incorporating lessons-learned from the Micron production line, the Photon calibration/test system includes the following upgrades:

- The number of cameras included in each calibration/test cycle has been substantially increased to provide higher production capacity.
- The calibration/test timeline has been optimized to allow multiple calibration cycles to be executed per shift. This also translates into significant capacity increase.

- The calibration/test process has been made more robust and completely automated, requiring minimal operator support. Automatic failure reporting and built-in diagnostics have been incorporated into the production line to improve dispositioning and rework of failed units.
- An improved database for automatic collection and review of calibration/test data drives a statistical process control (SPC) system for on-going process monitoring and improvement.
- A barcode system has been installed to support a robust, paperless traveler methodology suited for high-volume production.

IV. Summary

FLIR Systems' next-generation miniature infrared camera has been specifically optimized for high-volume, low-cost applications of thermal imaging. With several OEM-friendly features, including generic symbol overlay, spare customizable I/O pins, numerous AGC options, and numerous lens options, the Photon core is easily integrated into a higher-level system. Additionally, it is available as a stand-alone module with standard I/O connectors and an enclosure. Photon's small size, weight, and power consumption provide it will utility in largely the same applications as Micron – firefighting, security and surveillance (handheld, fixed site, and vehicle-mounted), portable thermography, machine vision, etc. The improved resolution and comparable sensitivity translates to better image quality in these applications. The emphasis on high-rate manufacturability and cost reduction has the potential to substantially increase demand in these elastic markets.

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