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## Raytheon's Sensing Technologies

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# High-Definition Infrared Focal Plane Arrays Enhance and Simplify Space Surveillance Sensors



Raytheon Vision Systems (RVS) has been providing light-sensing focal plane arrays for space applications for more than four decades, encompassing diverse applications, including weather data collection, space astronomy, Earth observation and missile surveillance. This extensive history of design and fabrication of high-performance focal plane arrays (FPA) for both tactical and strategic applications has allowed RVS to retain its position as one of the most technically advanced visible and infrared (IR) sensor houses in the country. The IR FPA consists of an infrared detector, which absorbs photons and generates a small voltage, and a readout integrated circuit (ROIC) that amplifies the voltage. These two components are hybridized together, with indium interconnects providing the electrical connection between each pixel in the array. Both the IR detectors and the ROIC are designed in-house at RVS' Santa Barbara, Calif., facility. The detectors are fabricated with a variety of techniques and materials to provide application-specific spectral coverage over any portion of the infrared spectrum. One particular aspect of RVS' FPA production is focused on missile surveillance for the national missile defense.

A primary mission of the national missile defense is to effectively defend the United States against ballistic missile attack. This has multiple objectives, including surveillance, tracking, targeting and intercepting ballistic missiles during boost, midcourse or terminal phases. Space-based infrared sensors provide a significant portion of the surveillance, tracking and targeting capabilities for the national missile defense. The satellite systems deploying the IR sensors have evolved over the years and have encompassed the Space Based Infrared System (SBIRS),

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Space Tracking and Satellite Surveillance (STSS) system, Overhead Non-Imaging Infrared (ONIR) system, and Alternative Infrared Satellite System (AIRSS) efforts. Raytheon has worked with each of these efforts to some degree. As sensor technology matures, each generation of satellite systems incorporates the available improvements to provide increased surveillance capabilities. Advancements made in high-definition IR FPA to recently enhance and simplify space surveillance systems are discussed here.

Traditionally, FPAs for space surveillance have necessitated scanning arrays to ensure complete theater coverage. These involve complex optics and moving components to sweep the sensor field of view across a swath of the potential path of a ballistic missile. The sensor FOV is incrementally adjusted until the entire target area has been encompassed, then the sensor is returned to the starting configuration and the scan is repeated. This scan must be completed within a timeframe adequate to detect rapidly moving missile threats. Until recently, the use of scanning arrays was the conventional approach, and it has proven effective.

Advancements in IR sensor technology have enabled increased array sizes and decreased pixel sizes to facilitate the routine production of large megapixel arrays (Figure 1). These are now attaining the technology readiness levels (TRL) necessary to be deployed in space surveillance satellites. Space surveillance systems demand

highly operable FPAs with low noise, in either traditional scanning or novel large format staring arrays, to rapidly survey large areas.

RVS has demonstrated impressive array operabilities for large format FPA in formats up to 4 megapixel (2K x 2K) arrays with either 15 or 20  $\mu\text{m}$  pixels for short wavelength and middle wavelength infrared (MWIR) detectors. MWIR response has been obtained using either InSb or HgCdTe photovoltaic detectors. These detectors exhibit excellent spectral response characteristics, including both high and uniform quantum efficiency over the spectral bands of interest. Advantages of HgCdTe typically include higher temperature operation compared to InSb, as well as the critical inherent tunable spectral response of HgCdTe, which can be readily adjusted during semiconductor growth for short, middle, or long wavelength IR response. The ROIC requires high data rates to output the data from more than four million pixels in each frame at sufficient frame rates to provide the necessary coverage.

The FPA module assembly consists of the ROIC/detector hybrid mated to an adjoining motherboard with an on-board temperature sensor and two attached cables, all mounted on a supporting pedestal. An example of a space surveillance HgCdTe MWIR 2Kx2K FPA module assembly is shown in Figure 2. Primary figures of merit for IR FPA include both response and signal-to-noise ratio (SNR). A common measure of

the SNR is the noise equivalent irradiance (the minimum irradiance necessary to produce unity SNR). The FPA module in Figure 2 has achieved high operability at temperatures of 110K with 99.8 percent response operability (operable pixels exhibit response within 25 percent of the array mean) and 99.3 percent NEI operability (operable pixels exhibiting NEI within twice the array mean). This level of performance is more than sufficient for ONIR surveillance system needs.

This FPA requires motherboard electronics on two sides only, allowing it to be close butted to additional arrays on two sides. This two-side buttable capability allows up to four FPAs to be tiled together providing an effective 16-megapixel (4Kx4K) FPA with larger sensor field of view coverage. Tiling multiple IR FPA together to generate a single large format array is an option RVS has used successfully in the past for ground-based astronomy applications, with a 4x4 mosaic of 2Kx2K SWIR FPA modules creating an effective 64-megapixel FPA (Figure 3). This same tiling technique can be applied to the FPA module in Figure 2, or with recent technological advances, the manufacture of individual larger format arrays can be used to provide full continuous Earth coverage for missile surveillance systems.

Recently, RVS, working jointly with Raytheon Space and Airborne Systems independent research and development (IR&D) funding, has scaled the MWIR 2Kx2K readout integrated circuit for space surveillance up to both 2Kx4K and 4Kx4K formats to meet future system needs. Ongoing develop-

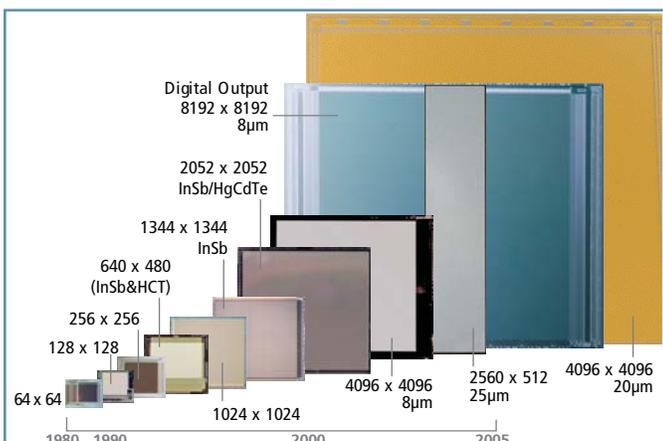


Figure 1. Progression of ROIC format at RVS over time

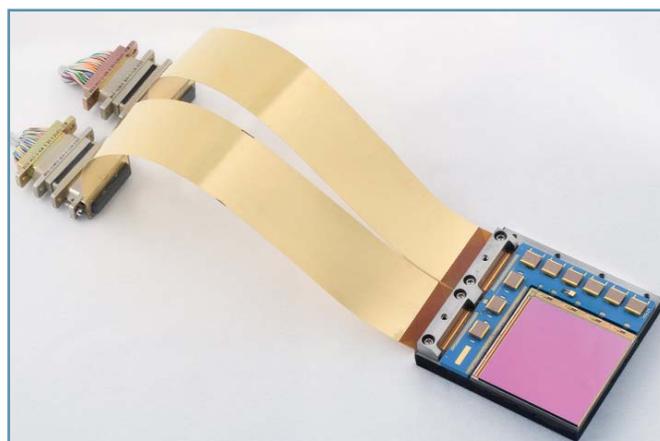


Figure 2. 2Kx2K, 20 $\mu\text{m}$  pitch MWIR FPA module assembly



Figure 3. 64-megapixel FPA composed of sixteen SWIR 2Kx2K FPA modules

ment of the technology to fabricate these increased format array sizes has focused on large area uniformity in diverse fields, including semiconductor growth, wafer and die polishing for flatness, and high-force hybridization. A single 4Kx4K ROIC die is greater than 8 cm on a side. The flatness requirements are equivalent to having a circu-

lar lake one mile in diameter with no ripples across the entire lake greater than three inches high. Dealing with this type of flatness over huge thermal ranges requires in-depth understanding of all the thermal expansion properties of the materials used. Testing has its own unique concerns for handling the massive data throughput capability. To simply output data from a 16-megapixel array at 30 Hz requires 0.5 Gbps data rates. This necessitates low inductance and capacitance wiring schemes, as well as high-speed computers with vast amounts of memory capable of storing and manipulating large arrays of data.

Each of these areas in fabrication and test of large format IR FPA has now improved to the point where the manufacture of 4Kx4K arrays is possible with minimal risk. A single eight-inch ROIC wafer from 2007 Raytheon IR&D is shown in Figure 4 containing 2Kx2K, 2Kx4K, and 4Kx4K (4-, 8-, and 16-megapixel) die. Scaling up to the 16-megapixel FPA provides larger sensor FOV and improved

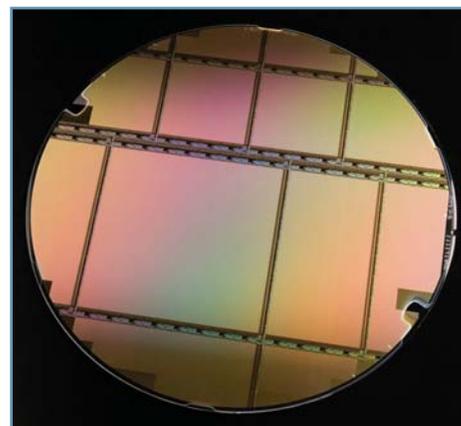


Figure 4. Eight-inch SB395 ROIC wafer with 4Kx4K, 2Kx4K and 2Kx2K die

full Earth coverage of the ballistic missile theater. Individual larger arrays are advantageous over tiling multiple smaller FPAs, and result in 100 percent coverage without the additional effort required to account for the gaps between tiled arrays.

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## ENGINEERING PROFILE



### Dr. Angelo Scotty Gilmore

Principal Infrared System Engineer  
Raytheon Network Centric Systems

Angelo Gilmore is a principal infrared system engineer in Raytheon Vision Systems (RVS). Current programs he works on include Alternative InfraRed Satellite System — a potential vehicle for ONIR to replace SBIRS HIGH. He was the program manager for this program for the last year. He also works on independent research and development efforts (IR&D) to improve the very long wavelength infrared focal plane array capabilities at RVS.

Intrigued by physics at a young age, Gilmore recalled, “I was always interested in how things work, and my father suggested I study physics to further my understanding of everyday observations.” Gilmore said. “I was fascinated by the studies, and in graduate school began researching alternative energy solutions using solar power from CdTe photovoltaic detectors.”

According to Gilmore, Raytheon Vision Systems’ infrared group has a large focus on HgCdTe photovoltaic detectors, and he sees this as a natural step from his previous experience. As an engineer, he found that his skills carried over into management, and he began leading IR&D efforts and small developmental programs.

Gilmore believes the biggest challenges facing his current programs are the compressed timelines required to transfer new technologies into viable system solutions. To help meet that challenge, he said, “Raytheon needs continuing focus on the transition from development to production in order to reduce that cycle time and more rapidly field new technologies.”

Growing up on a ranch, Gilmore developed the solid work ethic reflected in his philosophy that employees should “treat everyone as a customer, and give them the best value you can for their money, work and time.” Gilmore also believes his competitive nature has its roots in his position as the youngest of four children. “The combination of my work ethic and competitive nature has helped me excel throughout my education, and now in my career at Raytheon.”

Five years after joining Raytheon, Gilmore remains excited about his work. “Designing and developing cutting-edge technologies that will make a difference to our country’s success continually excites me,” he said, noting, “Mission Assurance is not just a catch phrase in the field, and the products we make help our soldiers succeed.”

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Current Raytheon IR&D has funded the prove-in of all the key fabrication steps required for this burgeoning technology. Highlights of these recent IR&D efforts include the design and fabrication of IR FPA-specific 4Kx4K ROICs; dramatic improvements to six-inch wafer, molecular beam epitaxy grown, HgCdTe detector uniformity; and the successful generation of a mock-up 4Kx4K array, to prove in the large format hybridization process. Routine fabrication of silicon ROIC wafers at RVS has ensured the handling procedures are in place for processing wafer up to eight inches in diameter. All this work leaves only the final step of fabrication and test of an IR FPA module in the 4Kx4K array format,

planned in 2008. To the author's knowledge, this will be the largest individual IR FPA fabricated to date. Each of these key efforts acts to reduce the manufacturing risk and improve the producibility of large format infrared FPA for space surveillance.

In the future, large format staring arrays providing wide FOV coverage will replace complex scanning arrays in satellite surveillance systems. These staring arrays will eliminate the system-level moving components such as gimbals and pointing mirrors required for conventional scanning arrays. Staring arrays will prove advantageous in terms of the primary considerations for satellite systems, including size, weight, power and reliability. The incorporation of staring IR FPAs will simplify the satellite

sensor system through fewer moving components leading to drastic reductions in the system weight. Reducing the number of moving components will also make it easier to satisfy the overall system reliability requirements. The enhancements in satellite surveillance made possible by large format staring arrays include 100 percent continuous full Earth coverage at higher frame rates than prior satellite systems. Future generations of satellite surveillance sensors will take advantage of the fundamental advancements provided by Raytheon's large format staring IR FPAs to improve the nation's missile defense network capabilities. ●

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## ENGINEERING PROFILE



**David M. Filgas**  
Engineering Fellow  
Raytheon Space and Airborne Systems

David Filgas is an engineering fellow at Space and Airborne Systems. Current programs he works on include K2, NSEP, SALT, and IRAD projects related to development of laser systems for a variety of applications.

Filgas has studied lasers since college. While working for an electrical engineering degree, he undertook a junior-year internship with a large laser company, and then as a senior, became involved with a laser startup company. He has worked in the laser field ever since. "I fell in love with lasers," he said. "Looking back now, I have to chuckle when my parents remind me that my first word was 'light.'"

His prior career experiences helped Filgas build a foundation for his success after he joined Raytheon five years ago. After finishing a master's degree, he worked for a large technology company, but left after a year "to escape the big-company bureaucracy."

He then went to work for a small startup company developing the highest power solid-state industrial laser in the world at that time. "I loved being on the technological cutting edge and the experience of working in a small company," he said. "In a startup company, you have to wear a lot of hats." In addition to being the chief laser scientist, he designed system components using CAD, programmed control systems, built production lasers, installed and serviced lasers in the field, conducted sales visits, and performed laser application studies. "I think

the broad range of experiences I had working in a small company taught me to consider many larger system issues during the design process."

For Filgas, one of the most rewarding aspects of his work is being on the leading edge of technology. "There's a real satisfaction in doing things that have never been done before. We're fortunate to have jobs where we can actually turn our inventions and designs into reality."

Offering others advice for success at Raytheon, Filgas said, "I believe we can all benefit from staying involved with multiple projects. It helps avoid getting burned out on a particular program, and there are always benefits from cross-pollinating the experiences of one program with those of another."

The challenges Filgas sees in current programs hark back to his large-company experiences. "Doing fast-paced development work in a large organization like Raytheon is difficult. Developmental programs could really benefit from much more streamlined processes than we're currently using," he said, citing supply-chain delays as an example. In addition to their schedule impacts, delays impact our budgets because charge numbers tend to dwindle away while we wait for parts."

Filgas believes that streamlining processes is essential for Raytheon's mission. "If we don't develop state-of-the-art systems for our forces in a timely fashion, someone else will — and it might not be one of our allies. It being a large potential growth area for Raytheon, I believe that the laser technologies we're developing can save lives."

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