High Operating Temperature (HOT) Midwave Infrared (MWIR) 6 µm pitch Camera Core Performance and Maturity

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ABSTRACT

Leonardo DRS (DRS) has developed High Operating Temperature (HOT) HgCdTe detector material, small-pitch focal plane arrays and ultra-compact Dewar/cooler assemblies. These breakthrough technologies are integrated into a high-definition version of our micro camera core. This report provides an update on the performance, reliability and maturity of the HexaBlu® 1280 × 960, 6 µm pitch midwave camera core.

The HexaBlu® weighs <0.65 lbs., displaces <80 cm³, and achieves a Noise Equivalent Temperature Difference (NETD) of 27 mK at f/2.62 with full well at a 335 K scene. This sensitivity is complemented by a Modulation Transfer Function (MTF) within 2% of theoretical for DRS's detector architecture. Together, low NETD and high MTF enable sharp long-range imagery. The Camera Core dissipates 4.5 W and achieves cooldown in ~2.5 minutes at 25°C, while providing on-board non-uniformity correction and bad pixel replacement.

DRS predicts a mean time between failure >23,900 hours in an environment cycling between 15°C and 64°C. In ongoing accelerated life testing, the cooler has averaged over 26,700 failure free hours in a 72 hour thermal cycle, and the Dewar has averaged 100,000 failure free hours at ≥70°C ambient. Now in limited rate production, the HexaBlu® leverages 95% design commonality with the Dewar/cooler assembly in fielded systems.

Keywords: High Operating Temperature, HgCdTe, Small Pitch, Midwave Infrared, Dewar, Cooler, HexaBlu® Camera Core, High Definition, Reliability, NETD, MTF, MTBF, Accelerated Life Test

1. INTRODUCTION

Leonardo DRS has developed an ultra-compact High Definition (HD) cooled Midwave Infrared (MWIR) camera core called HexaBlu®, shown in Figure 1. This Micro Integrated Dewar/Electronics/Cooler Assembly (µIDECA) contains a 1280 x 960 format Focal Plane Array (FPA) on a 6 µm pixel pitch, with High Operating Temperature (HOT) HgCdTe detector material and ultra-compact Dewar/cooler/electronics assemblies. This self-contained camera core outputs fully-corrected HD MWIR digital video with two voltage supply inputs. It has been designed and tested for integration into space, weight and power constrained systems with demanding thermal, vibration and shock environments. Since proof of principle and initial demonstration in 2016, DRS continued to characterize and refine the camera core. The HD micro camera core leverages the benefits of the preceding Standard Definition (SD) Zafiro® micro camera core and advances the technology with an improved pixel format, pixel pitch and miniaturized electronics.

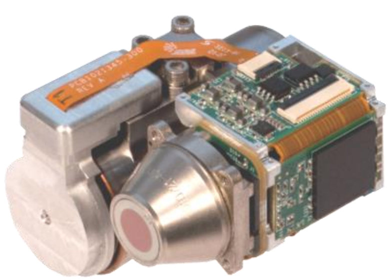

Figure 1 - HexaBlu® Micro Camera Core

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DRS set performance, Size, Weight and Power (SWaP) and durability goals for this internally funded µIDECA product family to enable a new class of compact infrared camera system serving dual-use applications. These applications include:

- Gimbal-based Intelligence, Surveillance and Reconnaissance (ISR) for military and public safety aircraft.
- Airborne mapping for wildland fire, agriculture and environmental monitoring, as well as building, energy and underground asset surveys.
- Counter-drone systems for military and non-military customers.
- Dismounted military ISR, targeting and sight systems.
- Ground-based security and surveillance of borders, ports, airports and critical infrastructure.

Figure 2 shows a timeline for the critical technology developments that enabled these products, along with camera core demonstration milestones. A sustained effort resulted in the development of key enabling technologies, including HOT HgCdTe detector material, small-pitch FPAs and ultra-compact Dewar/cooler/electronics assemblies. DRS brought these technologies together for the first time in 2010 with performance and imaging demonstrations of the industry's first MWIR µIDECA. With a 640 x 480 pixel format on a 12 µm pitch and operating at an FPA temperature ≥ 140 K, this camera core became DRS's Zafiro® product and was subsequently integrated into fielded long range dismounted and gimbal-mounted systems. In 2016, DRS extended the technology by developing an HD version of the µIDECA, with a 1280 x 960 pixel format on a 6 µm pitch and ultra-compact electronics. In the intervening time, we continued to refine, characterize and productize the HD µIDECA, which was given the product name HexaBlu®.

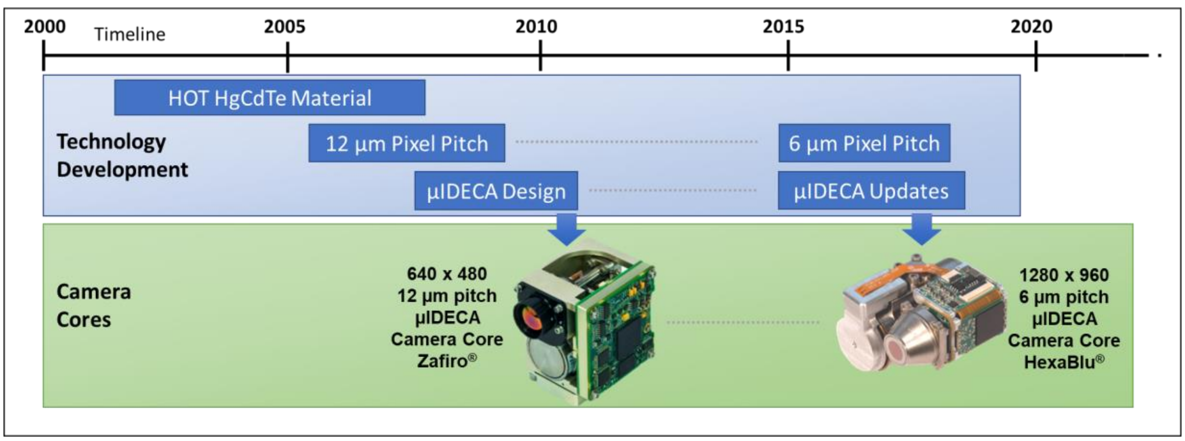


Figure 2 – Timeline of Technology and Camera Core Development

This report provides an overview on the performance, environmental test results and reliability of the HexaBlu® micro camera core, also called the HD camera core. We pull from environmental and accelerated life test results collected across all relevant DRS µIDECA camera core configurations. This includes the test results on the Zafiro® micro camera core, also called the SD camera core. The high degree of commonality between the HD and SD camera cores means test results from one configuration can apply across the micro family, within reasonable limits. Finally, we present a discussion and results from our reliability analysis under selected environmental conditions.

2. CONFIGURATION

Figure 3 shows a detailed callout of the main sub-assemblies that make up the HexaBlu® camera core. The FPA is contained within the evacuated Dewar. The Dewar is interconnected to the cooler with a transfer tube assembly. The cooler is a balanced, linear dual-piston design with low vibration and low audible noise. Together, the cooler, transfer tube and Dewar form a closed-cycle sterling engine that "pumps" heat away from the FPA. The compact Micro Wrap Around Side Board (µWASB) Circuit Card Assembly (CCA) provides all FPA bias and timing, as well as all image correction, digital video output and user serial control. The µWASB is a rigid-flex CCA whose design allows it to be compactly integrated with the Dewar. The cooler drive CCA provides the drive signals to the cooler. It is housed under the cooler drive cover, positioned on the end of the cooler housing. The two CCAs are interconnected by a cooler drive flex cable. Both CCAs have been designed to achieve very little growth in the overall envelope of the Dewar and cooler alone.

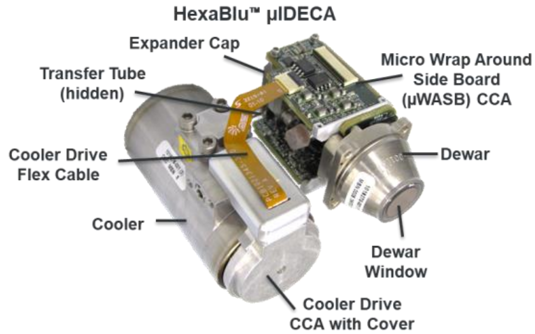


Figure 3 - HexaBlu® Camera Core Detail

Since the first demonstration of the micro camera core, several variations on the initial configuration have been built and tested. Figure 4 shows a sampling of the SD and HD camera core configurations, several of which are represented in the test results reported here. These various configurations share approximately 95% commonality in the Dewar/cooler design and components, so that environmental and life test results from any one configuration are broadly applicable across other configurations. Finally, a few of the configurations accommodate more than one spectral band option. For example, the SD camera core has MWIR mono-band and MWIR with see spot spectral band options. For the HD camera core, there are MWIR mono-band, extended Shortwave Infrared (xSWIR) mono-band, xSWIR/MWIR dual-band, and MWIR with see spot spectral band options.

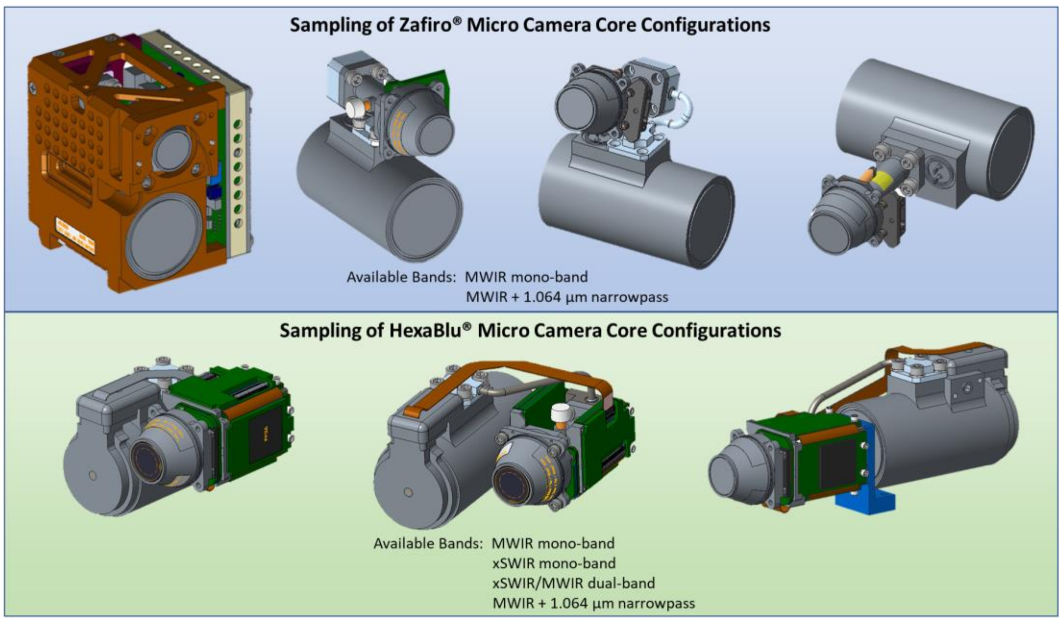


Figure 4 – Various Micro Camera Core Configurations

The qualification test results provided in this report were collected across a variety of these configurations. In addition, some of the camera cores were environmentally tested after installation in a system housing and others were tested apart from any housing.

3. PERFORMANCE

3.1 Radiometric and Functional

Table 1 is a listing of the HD camera core's radiometric and design parameters that contribute to performance. Typical HD camera core Noise Equivalent Temperature Difference (NETD) is 27 mK when setup for full well at a scene temperature of 335 K. Integration time is adjustable. This sensitivity is achieved at an FPA operating temperature of 140 K, which is made possible by our HOT HgCdTe detector material. The typical Collection Efficiency (CE) of the FPA is 0.74, where CE is the product of Quantum Efficiency (QE) and Fill Factor (FF). The HD camera core typically reaches its operating temperature in 150 s. There are three configurations, with two options for f-number and spectral band. The f/2.62 selection allows for the smallest/lightest optical design, whereas the f/2.3 selection provides slightly better resolution due to a smaller diffraction limit spot size that is optimally matched to the pixel pitch. The HD camera core has an Integrate While Read (IWR) architecture which keeps integration time from being reduced by the pixel readout time. This means that while the current frame is being integrated, the previous frame is being read out. Consequently, integration time is limited only by the frame rate.

Table 1 – HexaBlu® Camera Core Radiometric and Design Parameters

Performance Parameter	Value for HexaBlu Configuration #		
	1	2	3
Bandpass (µm)	3.4 - 4.8	3.4 - 4.15, 4.45 - 4.8 (CO_2 Notch)	
f# (1/(2*sinq))	2.62	2.62	2.30
Pixel Pitch (µm)	6		
Format (cols x rows)	1280 x 960		
Readout Mode	Integrate While Read (IWR)		
Typ. NETD (335K full well)	27		
CE (QE*FF)	0.74		
3D Noise - σ_v/σ_tvh	0.2		
3D Noise - σ_h/σ_tvh	0.2		
3D Noise - σ_vh/σ_tvh	0.5		
Noise Floor Electrons at Well (e-rms)	490		
well capacity (Me-)	4.8		
Jdark (µA/cm²)	1		
Operating Temp (K)	140		
Typ. Cooldown Time at 23°C (s)	150		
Frame Rate (Hz)	30 (60, 90 and 120 selectable)		

Table 2 lists the physical and functional parameters for the HD camera core. With a displaced volume of 80 cm³, weighing 0.65 lbs. and dissipating 4.5 W steady state at room temperature, the HD camera core has industry-leading SWaP for a cooled HD MWIR sensor. The µWASB CCA performs on-board image processing, including Non-Uniformity Correction (NUC), Bad Pixel Replacement (BPR) and Switched Median Filtering (SMF). It is also capable of inverting and/or reverting the image readout orientation, as well as windowing to preselected formats. The output digital video is formatted as Base Camera Link™ (default) or 14-bit parallel single-ended (optional). An extensive user command set enables calibration through user optics and control over user-defined operational modes.

Table 2 - HexaBlu® Physical and Functional Parameters

Physical/Functional Parameter	Value
Size (cm)	4.6 x 6.1 x 6.8 (1.8 x 2.4 x 2.7 in.)
Displaced Volume (cm^3)	80
Weight (lbs)	0.65
Input Voltage (V)	+5.0 and +14.0
Power Draw at SS (W)	4.5
Max. Power Draw at Cooldown (W)	9.0
Sensor Control	LVDS UART with large user command set
Image Processing	Non-Uniformity Correction (NUC) Bad Pixel Replacement (BPR) Switched Median Filter (SMF) Image Invert and/or Revert Windowing
Output Format	Camera Link or 14-bit parallel single-ended

The HD camera core's high sensitivity and low SWaP enable a host of battery powered and man-portable applications with long range performance.

3.2 Modulation Transfer Function (MTF)

The Modulation Transfer Function (MTF) of a sensor is a measure of how well that sensor recreates, in its output signal, the spatial detail from an input image projected onto it. Along with sensitivity, MTF is a critical sensor performance characteristic that, in concert with the optical and signal processing characteristics of the system in which it has been installed, determines system range performance. DRS's unique detector architecture offers advantages that enable MTF near the theoretical maximum. Since sensor MTF is often overlooked as a key performance parameter in sensor performance discussions, we have included an extended discussion of the modeled and measured MTF of our HD camera core.

To begin to understand why the HD camera core MTF is so well behaved, in spite of having one of the industry's smallest MWIR pixel pitches, it is helpful to understand the FPA's High Density Vertically Integrated Photodiode (HDVIP®) architecture. The HDVIP® architecture is illustrated in Figure 5 as a cross-sectional view through the Mercury Cadmium Telluride (MCT) detector layer. Following epoxy mount of the detector die onto the Read Out Integrated Circuit (ROIC), each pixel is created by etching a via through the MCT layer, down to the ROIC. The process of etching the via type-converts the p-type MCT substrate to n-type in a circular pattern around the via. The resulting circular depletion region forms an n-on-p diode junction around its perimeter. Consequently, the diode structure is cylindrical and extends through the full thickness of the MCT. This means that regardless of the depth at which a photon is absorbed, the generated free carrier will intersect a nearby junction. Another key part of the process for achieving good MTF involves choosing a junction diameter that fills the pixel pitch without shorting to adjacent pixels. The central via is then metalized to create a contact from the pixel to the underlying ROIC unit cell, while the substrate completes the return path.

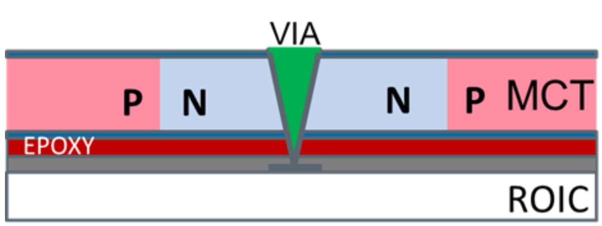
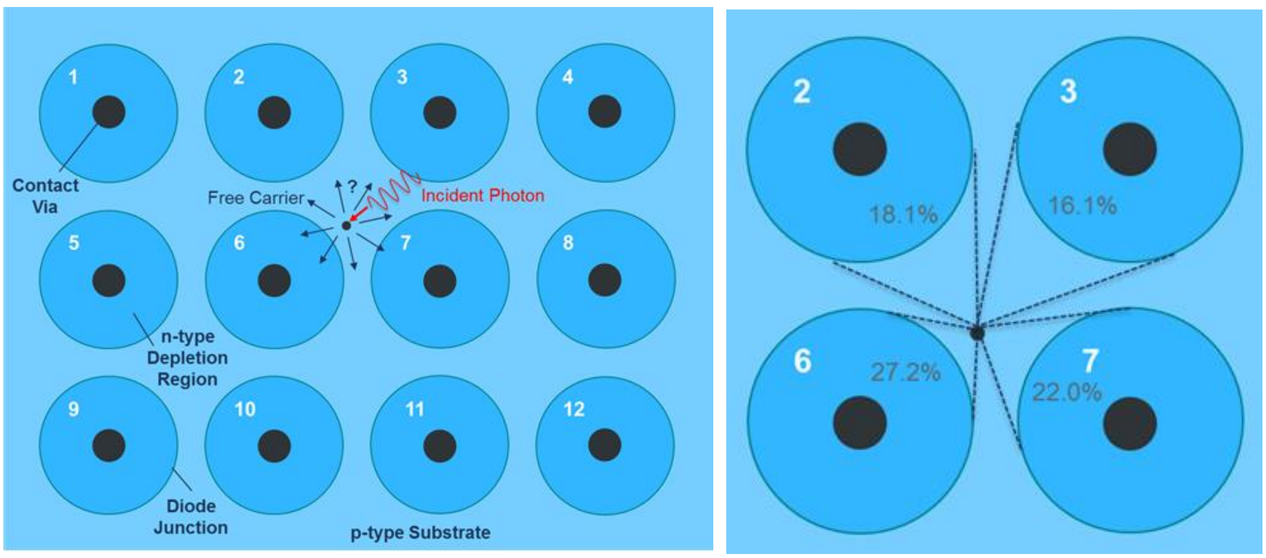


Figure 5 – Cross-section of HDVIP® Detector

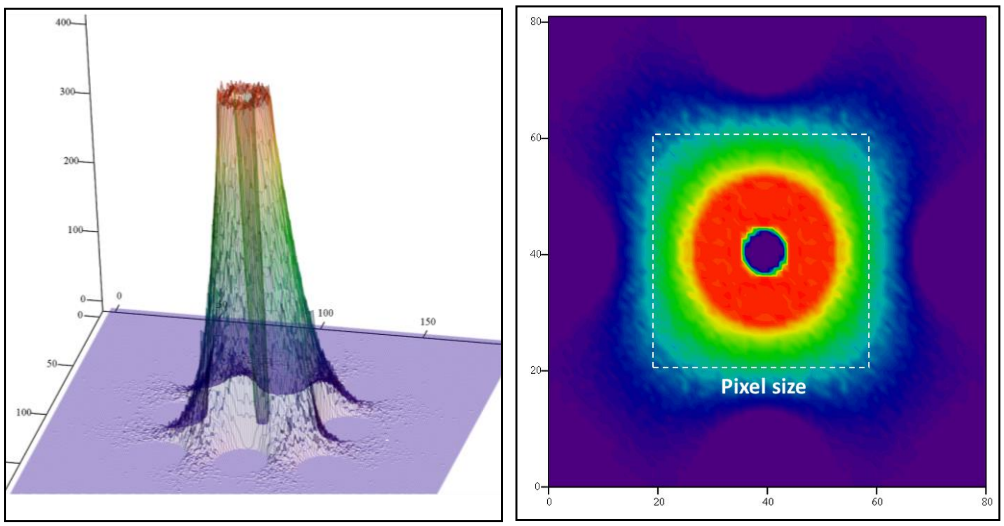
Figure 6a shows an illustration of a 4 x 3 region of pixels as viewed from the top of the FPA. The extent of the diode junctions are illustrated here for clarity, but are not actually discernable under visual inspection. The illustration represents the absorption of an incident photon in a random region between diode junctions. Note that any photon absorbed within the depletion region will create a carrier that will be immediately swept into the ROIC charge well. However, a carrier created between diode junctions can move in any direction with a diffusion length that is a function of MCT material parameters, typically 30 µm for our HOT MWIR material. Once the free carrier meets a diode junction, it is captured and collected at the ROIC well. The fact that the average direction the carrier travels is random, turns the question of which nearby pixel will collect it into an exercise in statistical probability. Geometrically, this can be approximated by calculating the angle that each diode junction subtends from the perspective of the carrier's point of origin. Figure 6b illustrates this first-order analysis by showing the probability that the carrier could intersect each of the four nearest junctions, as a ratio of the angle subtended from the carrier's point of origin to each junction relative to 360º. In this example, the carrier has a 27.2 + 22.0 + 18.1 + 16.1 = 83.4% probability of being captured by one of these four nearest pixels. This method suggests that there is a 13.3% probability of the carriers being collected by one of the next-nearest pixels (not shown), which leaves only a 3.3% probability that the carrier will travel more than 2 pixels from its point of origin.



(a) (b)

Figure 6 – Illustration of (a) 4 x 3 region of HDVIP® pixels with diode junctions and incident photon, and (b) Close-up of free carrier origin point and geometric probability of intersecting a nearest pixel

Although the geometric approximation can help us gain an intuitive understanding of why MTF is well-behaved in the HDVIP detector, DRS has developed a rigorous Monte Carlo model for MTF that accounts for the material parameters and detector structure. This model simulates minority carrier diffusion from creation to recombination given diffusion times and lengths, as well as the physical pixel geometry. This model is Monte Carlo in that the starting (seed) position and direction for the minority carriers are selected at random over the pixel area. The output of this model is shown in Figure 7a as a 3-dimensional plot of carrier collection over the pixel area and in Figure 7b as a 2-dimensional "heat" map. This collection map is then processed to generate a modeled MTF curve for the pixel. Note the presence of the via (dark blue disk) in the center of the pixel structure in Figure 7b. The heat map shows there is little collection at the contact via and very high collection in the depletion region, as expected. Notice the very low collection outside the confines of the 6 µm pixel, which is key to well behaved MTF. With fill factors that are typically 96%, the via represents a small impact to sensitivity and MTF while serving as an enabling feature for all the attendant MTF benefits of this architecture.



(a) (b)

Figure 7 – HDVIP® Pixel Modeled Carrier Collection (a) 3D Map and (b) 2D Heat Map

The resulting modeled MTF is plotted in Figure 8 along with the measured MTF of a representative FPA. DRS measured the MTF of the FPA by photo-lithographically patterning a slanted knife-edge metal mask on top of a representative FPA. The non-uniformity corrected FPA signal was then post-processed to get the edge-spread function and then differentiated to get the line spread function. Finally, the fast Fourier transform was calculated to arrive at the measured MTF plot of Figure 8. The top curve (solid black line) represents the modeled MTF of an ideal square 6 µm pixel while the bottom curve (dashed blue line) represents the modeled MTF of the HDVIP® 6 µm pixel. The data points (dark orange diamonds) represent the measured MTF of the HDVIP® 6 µm pixel. The small difference between the modeled and measured HDVIP® detector MTF, which averages approximately 2%, is likely due to the slight difference between the modeled detector semiconductor parameters and those of the article under test. These test results confirm that the camera core's FPA is achieving MTF in close agreement with modeled predictions. It is also consistent with previously reported modeled MTF and measured crosstalk of our more demanding 5 µm pitch HDVIP® pixel, after accounting for the difference in pitch.[1]

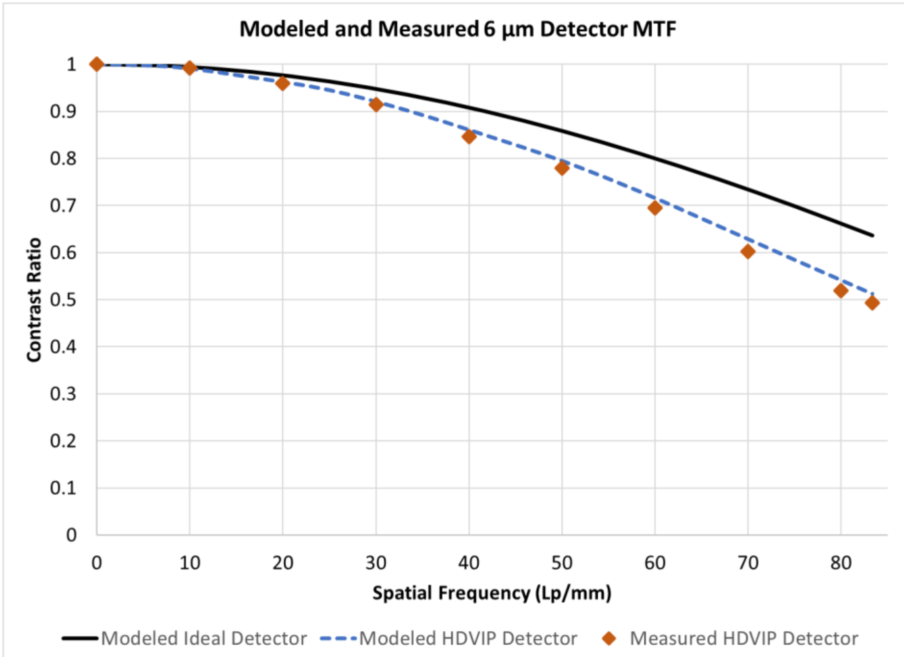


Figure 8 – Modeled and Measured MTF of 6 µm Pitch Detector

4. RELIABILITY

4.1 Environmental Tests

DRS conducted successful environmental qualification tests during multiple programs on various configurations of the micro camera core. These tests cover a wide variety of demanding environments to meet customer requirements. Some of these tests were conducted at the camera core level and some were conducted at the system level with the camera core integrated into a system enclosure. Table 3 is a summary of results for the qualification tests that have been conducted across the micro camera core family. With approximately 95% commonality in design, materials and process methods across the various configurations, the universally passing results speak well to the ruggedness of the design.

Table 3 is subdivided into ambient temperature, vibration and shock test results. The camera core operates across an ambient temperature range from -45ºC to +71ºC. Furthermore, the camera core withstands non-operational thermal shock between ambient temperatures of -40ºC and +85ºC with a 15 minute transition time. The camera core can withstand enveloped and MIL-STD-810G minimum integrity vibration profiles, with 5.52 Grms and 7.7 Grms respectively, for a duration of 1 hour. The camera core is also robust in shock environments, surviving shock levels of 40 Gpk in an 11 ms sawtooth event in all axes. Beyond this, multiple configurations of the camera core survive up to 300 Gpk shock levels to meet our most demanding shock requirements. These results confirm that the micro camera core is robust enough to qualify in a wide range of harsh environmental conditions.

Table 3 – Summary of Environmental Qualification Results Across Micro Camera Core Family

Test Description	Environment	Duration	MIL-STD Method	Level	Result
Operational Temperature	-45°C to +71°C	23 hr soak 1 hr run	---	μIDCA	Pass
Thermal Shock	-40°C to +85°C, 5 cycles	15 min. soak < 15 min. transition	---	μIDCA	Pass
Vibration	5.52 Grms in 3 axes	1 hr operation	---	μIDCA	Pass
	Minimum Integrity, 7.7 Grms in 3 axes	1 hr each axis	MIL-STD-810G, Meth. 514.6, Proc. I, Cat. 5	System	Pass
Transportation Vibration	Various vehicles, up to 5 Grms	3 hrs each axis	MIL-STD-810G, Chg 1, Meth. 514.7, Proc. I	μIDCA	Pass
	Loose Cargo - 2 axes	3 hrs each axis	MIL-STD-810G, Meth. 514.6, Proc. II, Cat. 5	System	Pass
Shock	40 Gpk in 3 axes, 3 shocks/direction/axis	11 ms sawtooth	---	μIDCA	Pass
	Up to 300 Gpk in 3 axes	SRS envelope	---	μIDCA, System	Pass
Transit Drop Shock	1 m height in softcase on 6 sides	N/A	MIL-STD-810G, Meth. 516.6, Proc. IV	System	Pass
Bench Handling	Tip on each edge, 4 drops/edge	N/A	MIL-STD-810G, Meth. 516.6, Proc. VI	μIDCA, System	Pass

4.2 Accelerated Life Tests

DRS designed HexaBlu® for high reliability. Following initial development of the micro-Dewar, DRS embarked on an accelerated life testing regimen to measure vacuum integrity under stressing ambient temperature conditions. Vacuum integrity is a key measure of Dewar health. To measure vacuum quality and thereby forecast a Dewar lifetime as the vacuum quality degrades, a total of six test articles were split between soaking at constant 70ºC and 80ºC ambient temperatures. At regular intervals, the test articles are removed from the oven to undergo heat load testing. The results of this ongoing test are shown in Figure 9. Heat load testing is performed to determine the efficacy of the vacuum in each Dewar, by measuring the boil-off rate of Liquid Nitrogen (LN2) poured into a cavity behind the Dewar. The flow rate of the gas boiling off the LN2 provides a measure of vacuum integrity. The better the vacuum, the lower the flow rate of the nitrogen gas. If flow rate increases through the course of the life testing, we can use this information to extrapolate a Dewar lifetime in hours. Understanding Dewar life is important in achieving compliance to demanding reliability requirements. We consider end of Dewar life to be the time at which the vacuum has degrade to a point where the cooler can no longer cooldown or maintain the target FPA operating temperature within the allowed time and power budget.

As can be seen in Figure 9, the boil-off flow rate of all Dewars has been stable since the accelerated life test was started over 11 years and 6 months ago. This amounts to more than 100,000 hours per Dewar of high temperature exposure. It is interesting to see the measurement trend drop slightly after the first two years as the Dewar's internal getter does its job, absorbing trace contaminants left behind after the Dewar was sealed. After this the trend is flat, with the exception of a few datapoints affected by test station interconnectivity to the temperature sensor. Since none of the Dewars have failed, or even exhibited a boil-off rate trending higher, it is not yet possible to extrapolate a Dewar lifetime. However, Dewars tested to-date have demonstrated a lifetime greater than ten years under the qualification test environmental conditions.

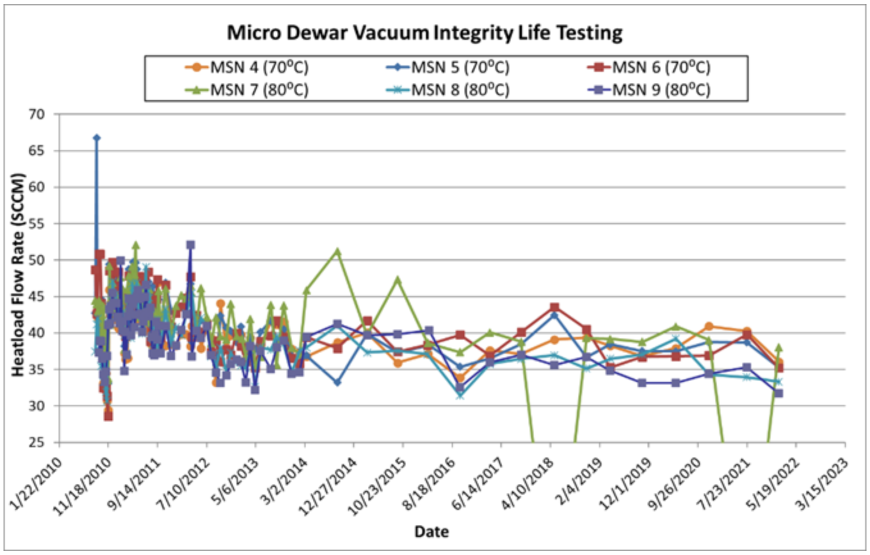


Figure 9 – Ongoing Dewar Accelerated Life Test Results

DRS also initiated accelerated life testing of one of the first SD micro camera core configurations. This life testing is separate from the Dewar-only life testing explained above, in that it tests the cooler and Dewar together. Figure 10 shows the 72-hour temperature cycle that runs constantly on two test articles between +52ºC and -32ºC with no failures to date. At each temperature setting, the test articles undergo multiple start and stop cycles, with cooldown time and steady state power measured each time.

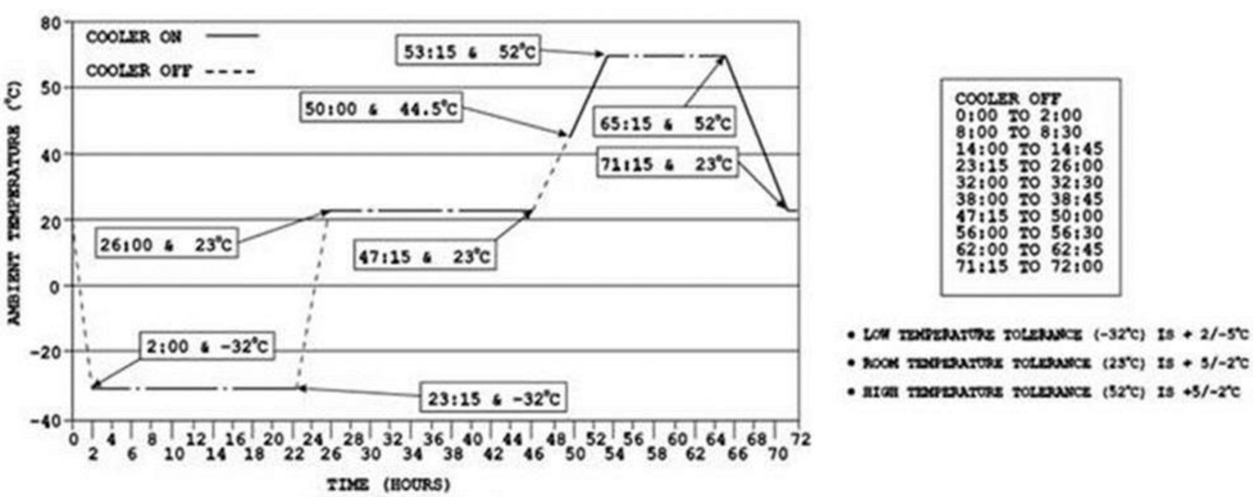


Figure 10 – Micro Cooler Accelerated Life Test Ambient Temperature Profile

Figure 11 is a plot of steady state cooler power collected during the ongoing accelerated life tests. Steady state power is measured each time the test articles complete cooldown to the FPA operating temperature. At each ambient temperature, the long-term trend in cooler power over time remains essentially flat. The discontinuities in the plot reflect occasional test station malfunctions or measurement limitations over this extended time period that are unrelated to cooler function. Cooler power tends to increase significantly as a cooler approached end of life. The lack of an increasing trend over time means we are not able to estimate a cooler life prediction from the data to date. Therefore, we conclude that neither cooler under test is nearing end of life. The two test articles have accumulated 26,523 hours and 26,972 hours of run time, respectively.

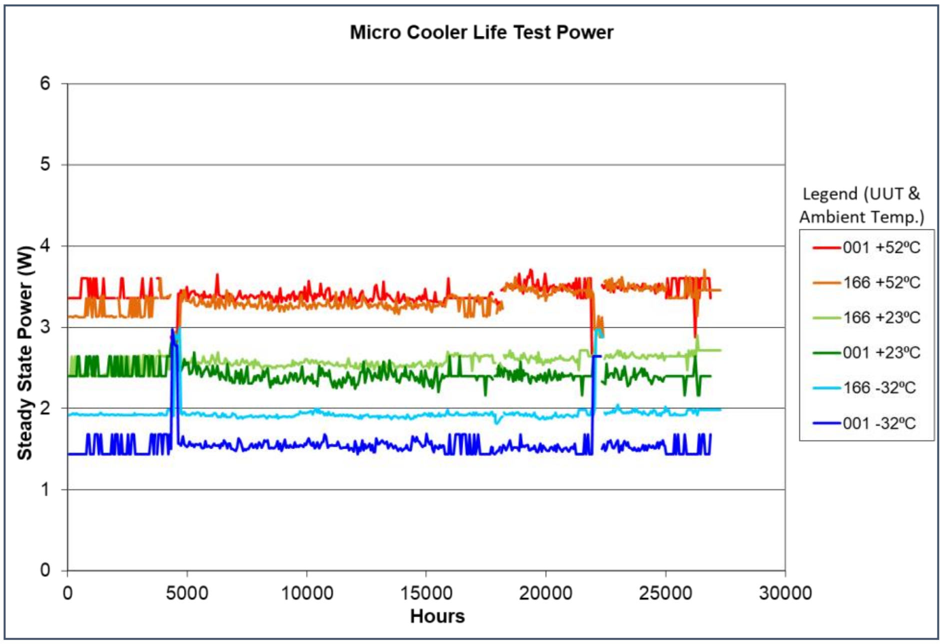


Figure 11 – Ongoing Cooler Accelerated Life Test Results - Steady State Power

4.3 MTBF

DRS conducted a reliability analysis on one of the HD micro camera core configurations to estimate the Mean Time Between Failures (MTBF) and Failure Rate (FR) of the camera core. The analysis consists of failure rate modeling using Parametric Technology Corporation's (PTC) prediction module in Windchill Quality Systems (WQS). PCT's prediction module was used in combination with MIL-HDBK-217 FN2 Ground Mobile environment (GM) and an ambient temperature range from 15ºC to 64ºC. This also accounts for the effects of self-heating in the electronics.

The reliability analysis consists of using empirical and test data to predict the FR of each major sub-assembly in the camera core. For the CCAs, the reliability prediction was generated using the MIL-HDBK-217 FN2 part stress analysis method on all components in each CCA's Bill of Materials (BOM). Without failure or performance degradation reported for the Dewar and cooler sub-assemblies, we decided to use the $\chi 2$ statistics with a 60% confidence interval to estimate the Dewar and cooler MTBF.

The environment applied to each temperature was set to Ground Mobile (GM), as defined in MIL-HDBK-217 FN2. This environment adds a stress level to the components of the camera core to account for the various vibrations and shocks experienced in ground mobile operations. Table 4 lists the calculated FR and MTBF of the complete camera core assembly. This reliability analysis yields a camera core MTBF >23,900 hours against the selected environmental conditions. Given that accelerated life testing is ongoing with no sign of end-of-life, we expect the MTBF calculation to continue increasing for some period.

Table 4 – HexaBlu® Camera Core MTBF and FR

Description	Failure Rate (FR)	Mean Time Between Failures (MTBF)	Calculation Method
HexaBlu® Assembly	**<4.18E-05**	**>23,900**	**PTC's Prediction module in Windchill**

Based on the accelerated life test results provided in this report, the reliability analysis concludes that the cooler sub-assembly has an MTBF only slightly lower than the µWASB CCA, as supported by 6 years of accelerated life testing with no failures or measurable performance degradation. The Dewar sub-assembly has an MTBF slightly higher than the cooler drive CCA, based on the fact there have been no failures or measurable degradation in over 11.5 years of Dewar accelerated life testing. The high Dewar MTBF is a consequence of the duration of the failure-free life testing and the constant ambient temperatures (70ºC and 80ºC), which are much higher than the temperature range used in the reliability analysis (+15ºC to +64ºC with duty cycle). Based on this reliability analysis, we conclude that the camera core assembly MTBF supports customer applications with long operational life requirements in similarly demanding environments.

5. IMAGERY

A sampling of HD micro camera core imagery is provided in Figures 12a through 15b, collected during the daytime and nighttime with two different camera cores. These video frames show the effects of high sensitivity combined with well-behaved MTF, revealing fine detail. Both camera cores were matched to 220 mm focal length objective lens assemblies that produced a 2.0º Horizontal Field-of-View (HFOV). Figures 12a, 12b and 13a show daytime imagery, and Figure 12b is a nighttime view, looking across Baltimore harbor.

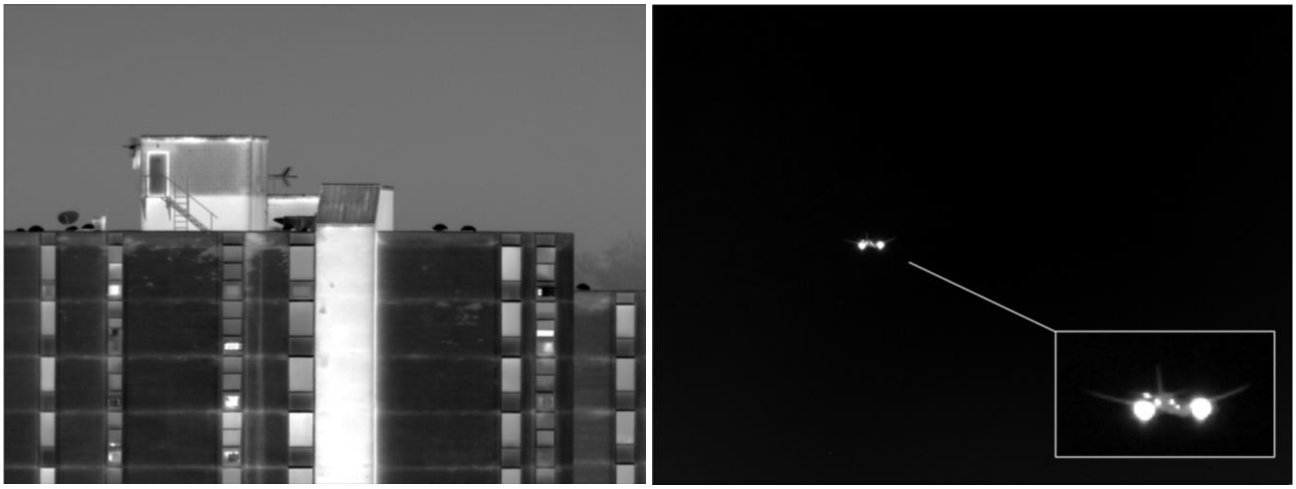
(a) (b)

Figure 12 – HD Camera Core Images, Baltimore, MD, 16 April 2019, early evening before sunset

(a) (b)

Figure 13 – HD Camera Core Images, Baltimore, MD, 16 April 2019, (a) evening before sunset and (b) nighttime

Figures 14a – 15b show a sampling of nighttime video frames collected in Dallas. Under these conditions of lower temperature nighttime viewing, the HD camera core reveals ample sensitivity and resolution to see fine detail at distance.



(a) (b)

Figure 14 – HD Camera Core Images, Dallas, TX, 22 March 2019, early morning before sunrise

(a) (b)

Figure 15 – HD Camera Core Images, Dallas, TX, 22 March 2019, early morning before sunrise

6. CONCLUSIONS

This report provided an update on the performance and reliability of DRS's HexaBlu® HD micro camera core. Since its initial proof of principle and demonstration in 2016, DRS has continued to characterize and refine the HD camera core design. It includes an FPA with a 1280 x 960 pixel format on a 6 µm pitch that is sensitive to the MWIR spectral band. The HD camera core leverages the established reliability of the Zafiro® SD micro camera core that preceded it, owing to the high degree of commonality in Dewar/cooler parts and processes. The HD camera core achieves an NETD of 27 mK at f/2.62 and a measured MTF that is within 2% of the theoretical for the detector architecture. This sensitivity and resolution are achieved in a form factor displacing 80 cm^3, weighing 0.65 lbs. and dissipating 4.5 W steady state at room temperature ambient.

We itemized a comprehensive list of the environmental qualification tests conducted across several different configurations of the HD and SD camera cores. These configurations passed all qualification tests. The camera core can operate across an ambient temperature range from -45ºC to +71ºC, and it can survive non-operational thermal shock between -40ºC and +85ºC with a 15 minute transition. The camera core can withstand a vibration profile at 5.52 Grms for 1 hour in each axis, as well as the MIL-STD-810G minimum integrity vibration profile at 7.7 Grms for 1 hour in each axis. Multiple camera core configurations have also been qualified against environmental requirements with up to 300 Gpk shock levels.

DRS conducted a reliability analysis using industry standard tools and methods for a defined set of environmental conditions. Ongoing accelerated life testing on early versions of the camera core's Dewar and cooler fed the reliability analysis and reveal no failures or performance degradations. Dewar vacuum integrity has been maintained through 11.5 years of continuous exposure to 70ºC and 80ºC ambient temperatures, which is > 100,000 hours per test article. Cooler function has been maintained through an average of >26,700 operating hours per test article in ambient temperatures cycling between -32ºC and +52ºC. The reliability analysis gives an HD camera core MTBF of 23, 900 hours in ambient temperatures cycling between 15ºC and 64ºC.

These tests and analyses confirm the HD camera core's ability to survive harsh environmental conditions with long operational life in a compact form factor. In addition, the measured NETD and MTF are in close agreement with modeled predictions. The resulting imaging performance is reflected in the daytime and nighttime video frames included in this report. This demonstrated ruggedness and high performance make the HexaBlu® camera core suitable for a wide variety of applications with demanding environmental, packaging and performance requirements.

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