Design of Dual Band SWIR/MWIR and MWIR/LWIR Imagers

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ABSTRACT

Multispectral imaging is a well accepted technique for object discrimination. Hyperspectral imaging can result in highly complex optical systems that have frame rate limitations. For fast frame rate applications, dual band imaging can provide sufficient discrimination without sacrificing signal to noise ratio. The design of a fast frame rate (> 200 Hz) SWIR/MWIR and MWIR/LWIR camera is described. Two strategies for cooling the array are explored.

Keywords: Multispectral imaging, SWIR, MWIR, LWIR, Cryogenic, HgCdTe

1. DUAL BAND IMAGING

Multispectral imaging is a well accepted technique for object discrimination. [1, 2] Using this technique, manmade, organic, and inorganic objects can be identified and discriminated. Hyperspectral imaging offers further discrimination. However, this often is associated with two costs: frame rate and system complexity. The frame rate suffers from reduced power incident on the focal plane array (FPA). Hyperspectral imaging systems are often complex due to the dispersive elements required to separate the wavelengths. Dual band imaging, combining images from two significantly different spectral bands is attractive because it offers the ability to discriminate objects with a much simpler system.

The generic goal of the class of dual band imagers presented here is to provide high-speed, high resolution image capability with a wide range of features to support detection, tracking, and ranging applications. FPA's have been available to enable 10,000 frame per second (fps) at 128 x 128 resolution and 2048 x 2048 at 2 fps. In order to enable high-speed detection, tracking, and ranging, an FPA would need features such as programmable windowing, integration time offset and duration synchronization to an external event, variable gain, and multiple selectable outputs. Recently Rockwell has developed a HgCdTe FPA capable of 200 fps operation at 512 x 512 resolution with the aforementioned features. In order to exploit the capabilities of this FPA, a complete imaging system including optics, read-out electronics, cooling, and processing must be developed around the FPA. Such an imager would be valuable in both a laboratory environment and deployed in the field.

2. SYSTEM ARCHITECTURES

The goals for the Dual Band imagers under development at Surface Optics Corporation include:

- Various band combinations
- Variable region of interest (ROI)
- High SNR
- Cryogenic cooling
- Dual FPA's

The band combinations in the two designs described here include: SWIR/MWIR and MWIR/LWIR. The variable ROI is software selectable through custom drive electronics combined with the features of the Rockwell FPA. High SNR is achieved through cryogenic cooling of the HgCdTe FPA's. Two cooling systems were explored: dewar and Stirling

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cycle cooler. Two FPA's were packed in a single cryogenic housing with a common aperture room temperature objective lens.

3. CYROGENICALLY COOLED FPA

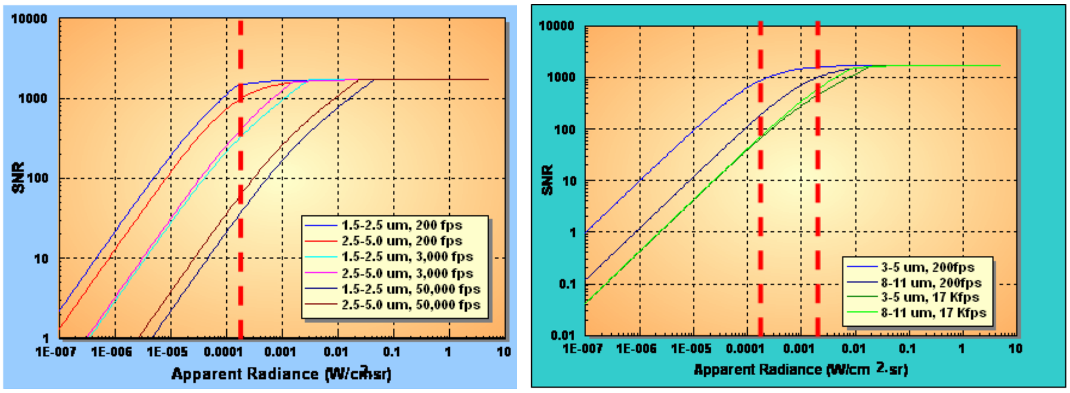

Figure 1: SNR for HgCdTe Rockwell FPA – Dashed Line Indicates 300 K Blackbody

Figure 1 shows the predicted SNR for the Rockwell FPA under various conditions. The dashed line indicates the radiance from a 300 K blackbody. Using this chart, it is clear that the 200 fps data rate has a very high SNR (> 900:1). Even for frame rates as high as 17,000 fps, the SNR is on the order of 100:1.

4. SWIR/MWIR

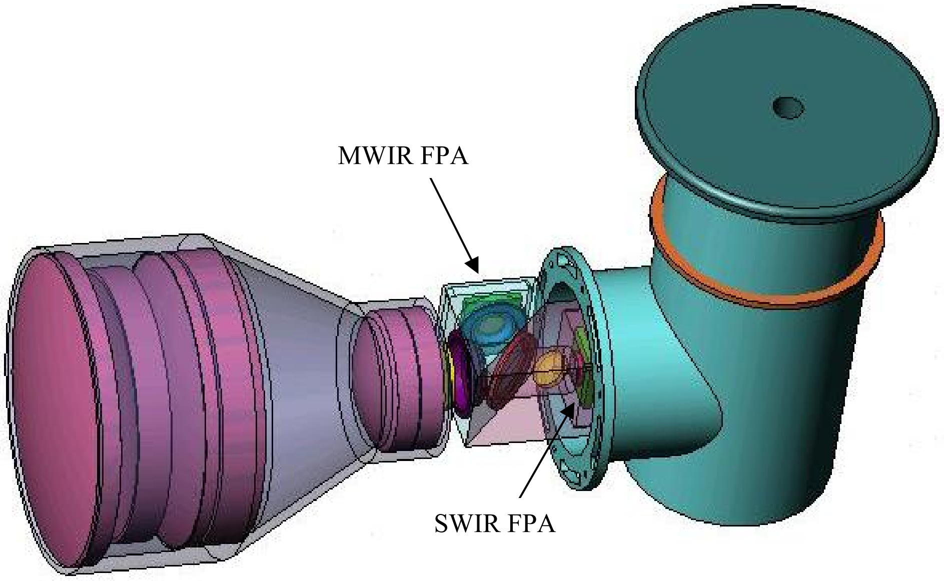

Figure 2: SWIR/MWIR Dualband Imager

A SWIR/MWIR imager was designed for use in a laboratory and field deployment. The SWIR channel covers λ = 1.5 – 3 μm and the MWIR channel covers λ = 3 – 5 μm. The optical system consists of a common objective for both SWIR and MWIR. After the last powered element, the input is separated and sent to two separate FPA's using a dichroic beamsplitter. The SWIR spectrum is transmitted through the beamsplitter while the MWIR spectrum is reflected. The dichroic beamsplitter and FPA's are cooled to cryogenic temperatures. The objective lens is at room temperature.

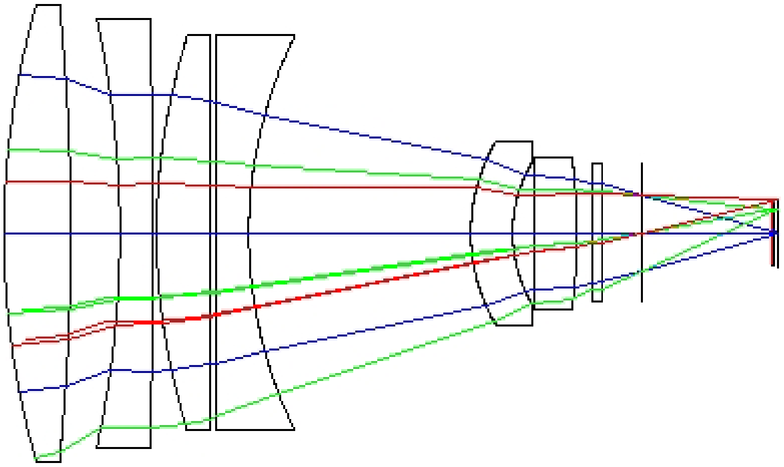

Figure 3: SWIR/MWIR F/1.9 Objective

The objective lens is a six element lens using classic IR materials including zinc selenide, silicon, and calcium fluoride. Figure 3 shows the layout of the lens. The lens is F/1.9 with an EFL of 180 mm. The back focal length is over 30 mm, allowing space for the dichroic mirror. The MTF of the objective is shown in Figure 4.

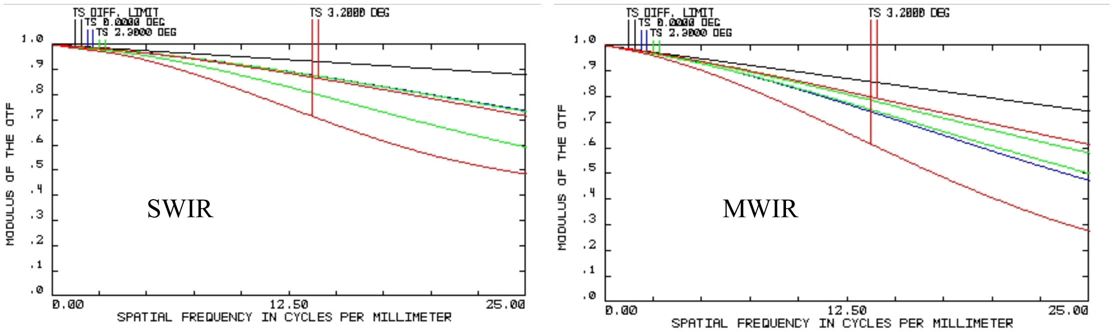

Figure 4: SWIR (left) and MWIR (right) MTF Calculations

In a system with this numerical aperture, the presence of a beamsplitter introduces astigmatism. A classic method for compensating for this aberration is the introduction of a tilted "dummy" plate (see Figure 5). Nominally, the reflected channel would be limited by the aberrations in the lens and the transmitted channel would be limited by aberrations from the objective and the contributions from the beamsplitter. Since the lens is near diffraction limited, the MWIR channel is reflected and the SWIR channel is transmitted. In this configuration, the aberrated resolution of the SWIR channel more closely matches the diffraction limited resolution of the MWIR channel (see Figure 5). Significant effort was expended designing the housing to mount the two optics. Figure 6 shows the packaging of the beamsplitter and compensator.

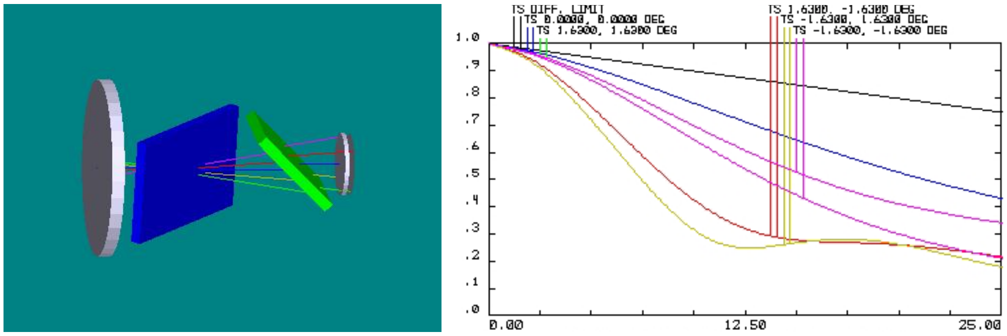

Figure 5: Beamsplitter/Compensator Configuration (right) and Associated MTF

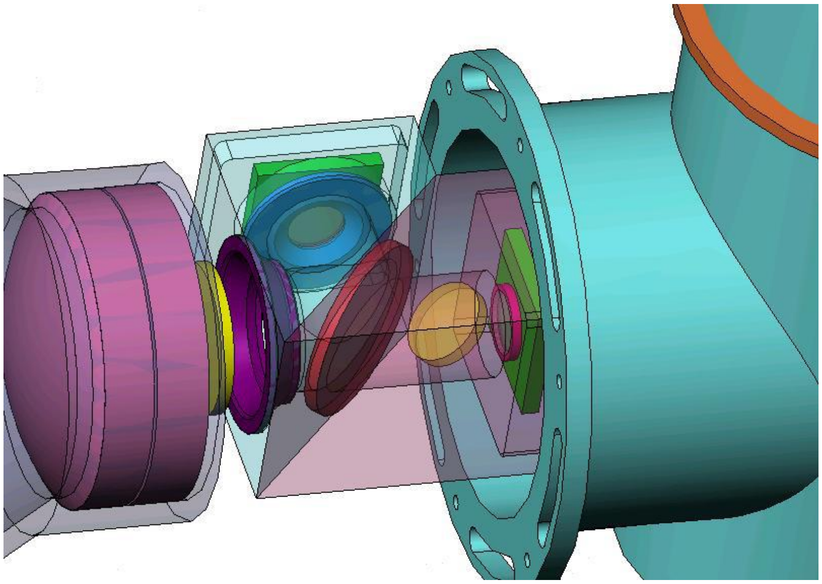

Figure 6: Beamsplitter/Compensator Detailed Packaging

5. MWIR/LWIR

A MWIR/LWIR imager was designed for use in field and operational deployment. The MWIR channel covers $\lambda = 3 - 5$ µm and the LWIR channel covers $\lambda = 8 - 11$ µm. The optical system is arranged in a fashion similar to that of the SWIR/MWIR imager: a common objective with two separate FPA's. The MWIR spectrum is transmitted through the beamsplitter while the LWIR spectrum is reflected.

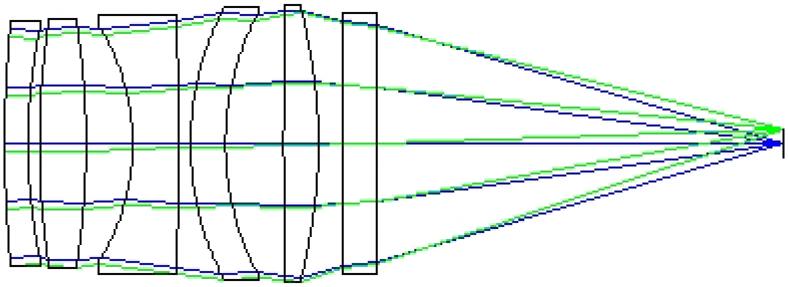

Figure 7: MWIR/LWIR F/1.9 Objective

The design of the objective lens was inspired by C. Alexay [3]. In the reference, the author describes methodology for selecting infrared compatible materials for designing achromatic lenses. This objective lens is a six element lens using IR materials including germanium, AMTIR, potassium chloride, and zinc selenide. Figure 7 shows the layout of the lens. The lens is F/1.8 with an EFL of 180 mm. The back focal length is over 30 mm, allowing space for the dichroic mirror. The MTF of the objective is shown in Figure 8.

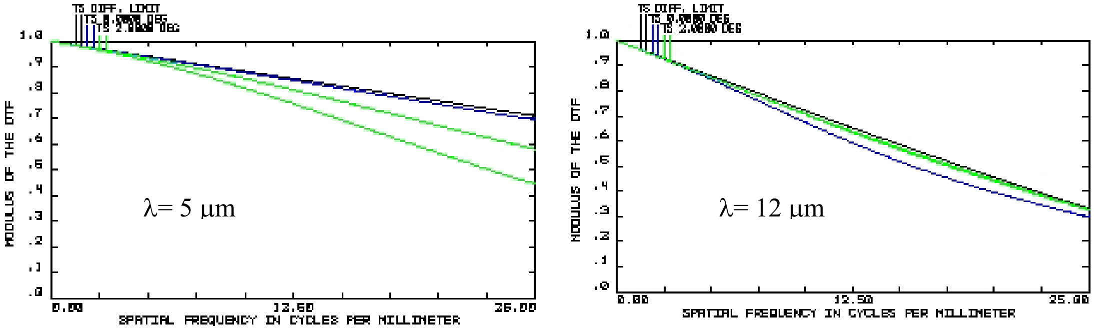

Figure 8: MWIR (left) and LWIR (right) MTF Calculations

The goal of this system was to produce a support field and operational deployment. As such, mass and the time required to cool the system to operational temperature is a critical performance parameter. The cooling time for this system was required to be less than 15 minutes from room temperature to 77 K. In order to achieve this goal, a Stirling cycle cooler was used instead of a dewar and the mass of the cooled portion of the instrument was reduced.

The cryocooler chosen for this application was a Sunpower CryoTel. The cooler has a 10W cooling capacity. The mass of the cryogenic section of the SWIR/MWIR was 400 gm. Lightweighting this design reduced the mass to 200 gm. However, at this mass, the time to cool the system was still too long. As a consequence, the design was changed to remove the compensator plate to reduce the overall volume that must be cooled. With this design change, the mass was reduced to 80 gm and the cool down time was estimated at less than 10 minutes.

By removing the compensator plate, the beamsplitter would introduce astigmatism to the transmitted channel. There were three parameters explored to reduce the impact of the astigmatism:

1. Apply a toroidal surface to the backside of the beamsplitter to correct for astigmatism,
2. Select a material with an appropriate index of refraction to minimize the aberrations,
3. Reduce the thickness of the beamsplitter to minimize the aberrations.

Adding a toroidal surface to the backside of the beamsplitter to correct for astigmatism was ineffective. In order to provide this type of correction, the thickness of the beamsplitter would need to be increased dramatically.

The index of refraction of the beamsplitter has an impact on the magnitude of the aberration. Intuitively, an index of n = 1 would produce no aberrations. An index of infinity would also produce no aberrations. Therefore, there must be at least one index where the aberrations are maximized and there must be other choices that would minimize the aberrations. An optical model was constructed to explore this parameter. A series of real and fictitious materials were used to compute the relationship between index of refraction and wavefront error (WFE). The results are shown in Figure 9.

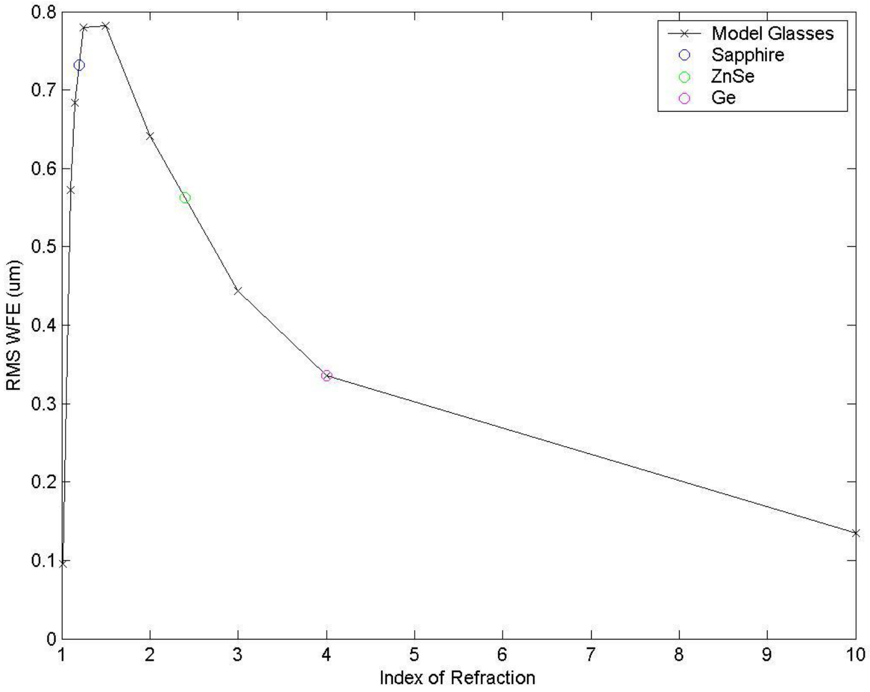

Figure 9: WFE from Beamsplitter as a Function of Index of Refraction

The fictitious (model) glasses indicate that the worst choise is close to n = 1.5 with steady improvement with increasing index. Three materials are shown for comparison: sapphire, zinc selenide, and germanium. Germanium, having the highest index, performed the best.

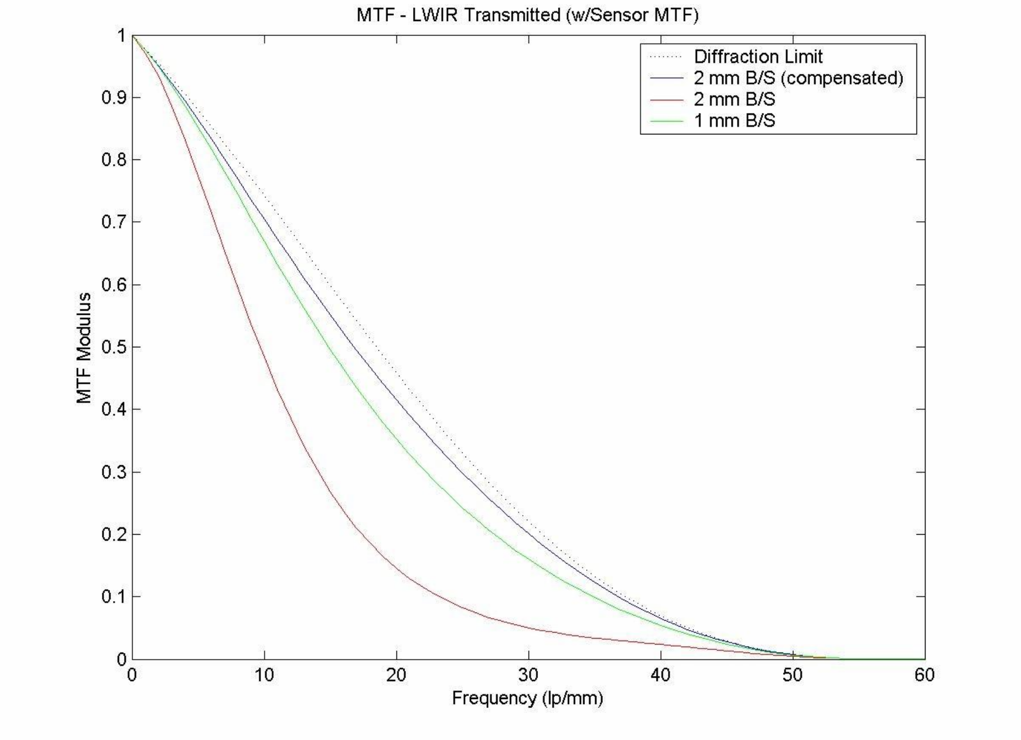

Figure 10: WFE from Beamsplitter as a Function of Thickness

Finally, the thickness of the beamsplitter was used as a tradeoff parameter. Increasing the thickness would make the beamsplitter more robust and stiff in the presence of vibration. A thinner beamsplitter would cool quicker and reduce aberrations. Figure 10 shows the impact of changing the thickness of the beamsplitter. The diffraction limit is shown for reference. The 2 mm thickness beamsplitter with a compensating plate is close to the diffraction limit. The 1 mm thick beamsplitter without compensator is very close to the compensated beamsplitter while the uncompensated 2 mm thick beamsplitter has less than adequate performance.

4. SUMMARY

In summary, the designs for two dual band imagers were reviewed. These instruments were designed for very rapid frame rates using an FPA with hardware selectable ROI. Cryogenic cooling of the FPA was required in order to support the SNR and frame rate requirements. Two options for achieving cryogenic temperatures was described: dewar and Stirling cycle cooler. The design and performance of fast, achromatic objectives was summarized. Tradeoffs in beamsplitter design and astigmatic compensator design were also reviewed.

5. REFERENCES

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