

What You Should Ask Before Investing In A Shortwave Infrared (SWIR) Lens

Just because a lens is sold with a SWIR label on it does not mean it will really offer high performance.

BY MARC HANSEN

The military and industrial communities are investigating shortwave infrared (SWIR) technology for new and improved imaging solutions for a variety of challenging applications. Indium gallium arsenide (InGaAs) is a material often used for SWIR imaging due to its high quantum efficiency and low dark current. This advanced InGaAs material makes these detectors the most sensitive imagers that operate in the shortwave IR wavelength range at any given temperature. A standard InGaAs camera responds to wavelengths from about 0.9 μm to 1.7 μm , utilizing reflected radiation to produce images that resemble those from a black and white visible-response camera. Since SWIR imagers are capable of creating high contrast, high resolution imagery well beyond the visible spectrum, the performance of the cameras are often dictated by the lenses chosen for the application.

InGaAs cameras can use standard off-the-shelf visible lenses due to the fact that SWIR wavelengths readily pass through glass. This is in contrast to mid-wave IR (MWIR 3 μm - 5 μm) and long-wave IR (LWIR > 7 μm) cameras that require exotic and expensive lens materials. Even though a visible lens can produce impressive results when imaging in the SWIR, only a lens assembly designed and optimized specifically for shortwave infrared wavelengths will be able to take full advantage of the camera performance. With this newly-emerging lens market, some manufacturers have produced SWIR lenses at a premium price to capitalize on the industry's quest for higher performance.

Let the Buyer Beware

Not all SWIR lenses are the same. Testing has shown significant performance differences from one lens design to another and from one manufacturer to another. Higher price and even higher throughput in the SWIR wavelength band does not always mean better performance. This article is intended to guide and educate the user about what questions should be asked before investing in a SWIR lens, and why the correct lens purchase can make or break an application.

Most lens manufacturers will supply simulated lens performance data based on the theoretical design of the lens. Often the data supplied is a modulation transfer function, or MTF graph, a field distortion graph, or throughput calculation, etc. Unless you are a lens designer, and most SWIR camera end-users are not, MTF graphs and field distortion graphs do not give an intuitive depiction of how the lens will perform. To make things more confusing, the actual performance of the lens can deviate significantly from the theoretical design and lens manufacturers offer no specification for the tolerance of this deviation. Having to base decisions on the theoretical best performance of the lens rather than the actual performance makes selecting the right lens even more difficult.

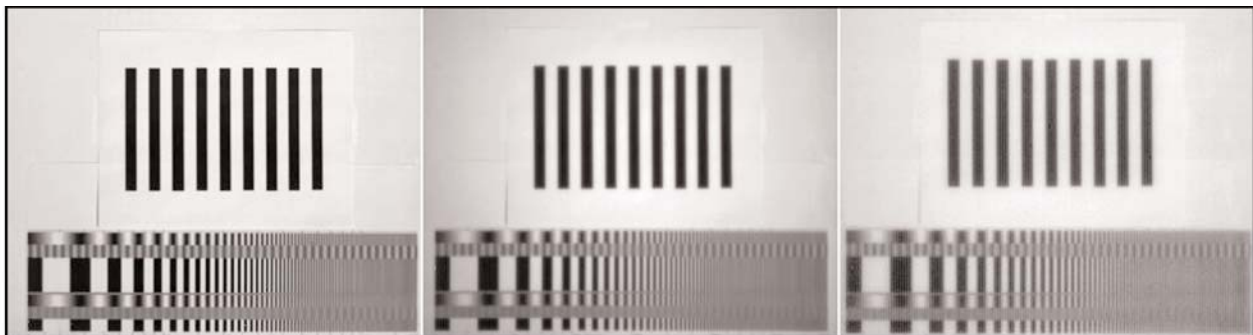


Figure 1: The SWIR-optimized SOLO 50 lens (used in the left image and available from Sensors Unlimited, Inc., part of Goodrich Corporation) has superior resolution, throughput, and uniformity. LENS B, a standard glass optics visible lens coated for high throughput in the SWIR wavelength band, is used in the center image, and LENS C, a standard glass optics visible lens with no coating, is used in the right image.

Ask Questions

Over time, through the comparison of actual images to their specified performance, you can learn to intuitively understand how a lens will perform from looking at MTF or CTF graphs. Since most SWIR camera users may not have this luxury or the time to devote to this research, it's important to ask the lens manufacturer a few questions until you are familiar with the vendor and feel comfortable making a choice based on supplied specifications.

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One question is: "For what wavelength range were the optical elements of this lens assembly specifically designed?" Just because a lens is sold for the SWIR wavelength band does not mean it was originally designed for those wavelengths. Many manufacturers have taken visible lens designs and just coated them to have optimized throughput in a specific region of the spectrum, but not optimized optical performance for that region. These may be touted and advertised as "high performance", but the important question to ask here is, "High performance compared to what?"

A major challenge of lens design is to focus all of the different wavelengths of light accurately. The larger the wavelength range, the more difficult it is to avoid chromatic distortion which can result in blurring of the image. As a rule of thumb, if you're looking for a high performance lens for the SWIR wavelength range from 0.9 μm to 1.7 μm , be sure that the lens design was maximized for this wavelength range and not for a range greater than the intended use. Of course there are exceptions to every rule, but generally, lenses corrected for chromatic distortion over a larger bandwidth are usually more complex and therefore more expensive.

A comparison of 3 lenses is provided in Figure 1. All lenses are 50 mm focal length taken with the same

camera in a fixed location at the same f-number. The intensity is normalized for ease in showing the difference in resolution performance. The sharpest image, shown on the left, was taken with the Goodrich SOLO 50 lens which is a SWIR-optimized lens specifically designed for the 0.9 μm to 1.7 μm range. The center image (LENS B) was taken with a SWIR-coated lens purchased from a well-known lens manufacturer. The SWIR-coated LENS B was designed for the visible wavelength range but coated for the SWIR wavelength range to increase its throughput to market it as a "high performance" SWIR lens. The image on the right is from a standard off-the-shelf visible lens (LENS C) from a popular, consumer lens manufacturer. The superior performance of the SWIR optimized SOLO 50 lens on the left is clear.

Since a picture is worth a thousand words, ask the manufacturer to supply you with actual imagery or test data from the lens. If comparing one lens manufacturer to another, you may consider supplying them with a bar chart similar to the one shown above, and ask them to image it at a fixed distance so the test can be repeated by other lens manufacturers for comparison. This is a simple way to get an idea of how the lens will perform with regard to resolution. Many manufacturers will perform this quick test, especially considering that a single, good SWIR-optimized lens can easily cost \$5,000 or more depending on the focal length and specifications. If they decline, ask them to send whatever real imagery they can. If the vendor doesn't have a SWIR camera to take the image, then you must decide if you feel comfortable ordering a lens from a manufacturer that lacks the ability to test their own product.

Another way to compare the resolution of lenses is to image a resolution chart. A resolution chart, shown at the bottom of the images in Figure 1, has alternating black and white lines that increase in frequency from left to right as they decrease in width. In other words, the line pairs per millimeter (lp/mm) increase from left to right. This graph helps determine at what point you start to lose contrast between two distinct objects. A line profile (see Fig. 2) can be acquired from the image and displayed by plotting the intensity vs. pixel data for the row that traverses the center of the resolution chart.

Figure 2 shows the line profile of a resolution chart image taken with each of the 3 lenses previously discussed. The data was normalized for intensity since the lenses each have a different transmission. As you may expect just by visually inspecting the images in Figure 1, the SOLO 50 SWIR-optimized lens shows much more contrast at fewer lp/mm when compared to the other lenses. It is worth noting that the SWIR-coated LENS B and the visible LENS C have similar resolution even though LENS B costs more than 3 times the visible lens.

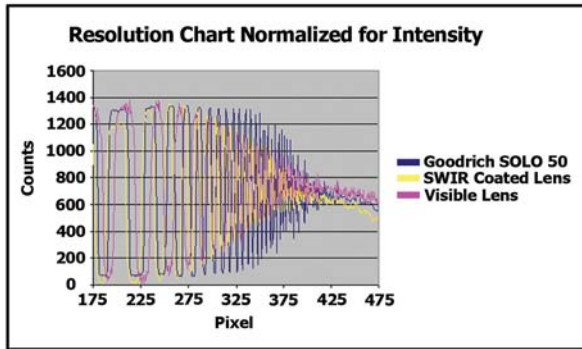


Figure 2. Line profile for 3 different lenses imaging a resolution chart. The SWIR-optimized SOLO 50 lens outperforms the SWIR-coated LENS B and the visible-response LENS C.

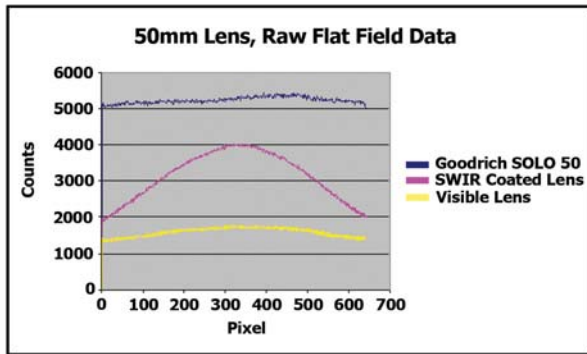


Figure 3. Background-subtracted, flat-field-response line profile of three different lenses. The throughput and flatness across the image plane is superior for the SOLO 50 lens which was optically designed for SWIR wavelengths.

To show the performance difference of these three lenses, an image of a flat field was acquired to compare throughput as a function of the distance (to the left or right) from the center optical axis. Figure 3 shows the raw data taken with each lens of a flat, uniform target illuminated with a broadband light source. The difference in throughput between the SWIR-optimized SOLO 50 lens, the SWIR-coated LENS B, and the visible LENS C is obvious. The graph shows how LENS B does have higher

throughput than the visible lens but the flat field response is poor since the intensity significantly changes from the center of the lens moving outward. The SWIR-coated LENS B will produce an image that is bright in the center and becomes darker as you move from the center of the image. At the center of the image, the SOLO 50 lens has a transmission 1.3 times that of the SWIR-coated LENS B and 3 times that of the visible LENS C while having a more uniform response across the full field.

As the data shows, LENS B performs like a visible-response lens with higher throughput but significantly less flat field uniformity. The resolution of this lens, even though it is marketed as a "high performance" SWIR lens, is plagued with chromatic distortion. Chromatic distortion can also significantly affect a lens' ability to image well in low-light-level scenarios. A point source of light will be smeared over a few pixels when using the SWIR-coated LENS B while a truly high-performance SWIR-optimized lens will have a more accurate focus, creating a higher contrast image with a better signal-to-noise ratio.

It's important when choosing the right SWIR lens for your application that you ask questions and acquire imagery of the same scene or use a bar graph or resolution chart to compare the lenses for your imaging task. And remember this - just because a lens is sold with a SWIR label on it does not mean it will really offer high performance.

For more information on SWIR-optimized lenses and SWIR camera systems, please visit: www.sensorsinc.com.



Marc Hansen, applications engineer for Sensors Unlimited Inc., part of Goodrich Corporation, has over seven years of experience studying spectral phenomena in the fields of optical imaging, spectroscopy, and mechano-optical systems. He is now concentrating his research in the near infrared

(NIR) and short wave infrared (SWIR) spectral regions to support the development of future InGaAs detector applications.

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