Ring around the Image, A Pocket Full of Problems

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1. ABSTRACT

This paper will explore an unwanted side effect of shortwave or near infrared optimized lens assemblies operating in low light conditions. Particular attention will be paid to those designs encountering a bright source in an otherwise low light scene; i.e. those with large dynamic ranges. The impact of bright features in very low levels can produce degrading artifacts or noise and greatly hinder image quality. The aforementioned effects will be demonstrated for both the SWIR optimized lenses and their visible light counterparts. The artifacts of traditional optical and mechanical geometries and their inherent problems will also be covered as well as how one might lessen their impact on image degradation and thereby improve system sensitivity.

Keywords: SWIR, stray light, flare, light suppression, saturation, dynamic range.

2. INTRODUCTION

Shortwave infrared (SWIR) and near infrared (NIR) lens and camera packages are being utilized in many different applications. These new applications require optical designs optimized for the corresponding camera sensitivity range. These designs offer increased sensitivity and image clarity over the visible lenses commonly supplied with the NIR/SWIR cameras. NIR/SWIR cameras generally use reflected light to image a scene. This reflected light can be the source for many problems within the opto-mechanical design surrounding the optical elements of the camera lens design. Bright light sources in an otherwise low light scene can produce artifacts such as light rings and hinder image quality and sensitivity. For this effort we will focus on the basic principles of limiting the effects of the lens and mechanical components on the optical image quality.

3. SYSTEM THROUGHPUT

Optical designs optimized for the SWIR/NIR wavelengths offer increased sensitivity across the operating waveband ranges. This sensitivity can be up to four times that of an off the shelf visible lens. The normalized illumination of a NIR/SWIR lens versus a visible lens can be seen in Figure 1. The top curve shows the illumination of a NIR/SWIR optimized lens while the bottom curve shows the illumination of a

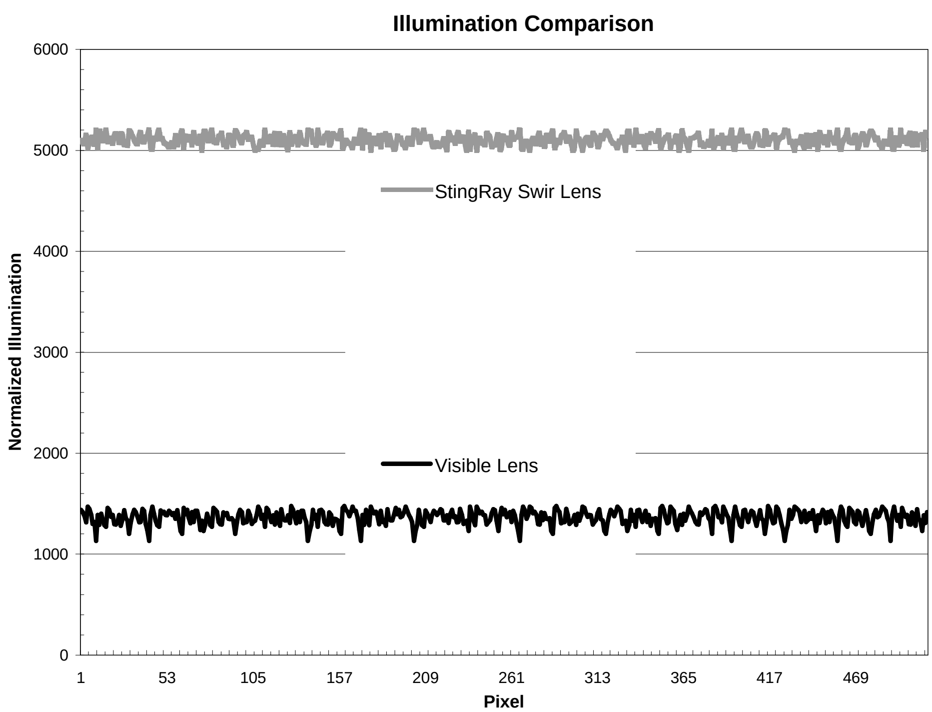

Figure 1 Illumination Comparison

visible lens across a uniformly illuminated background. The sensitivity of the NIR/SWIR camera was fixed during data collection. The transmission of a NIR/SWIR lens can be up to of ninety percent while a visible lens has an average transmission of only fifty to seventy percent of the light reaching the detector. This difference in throughput or light plays a significant role in the contribution of the mechanical surfaces on the image quality.

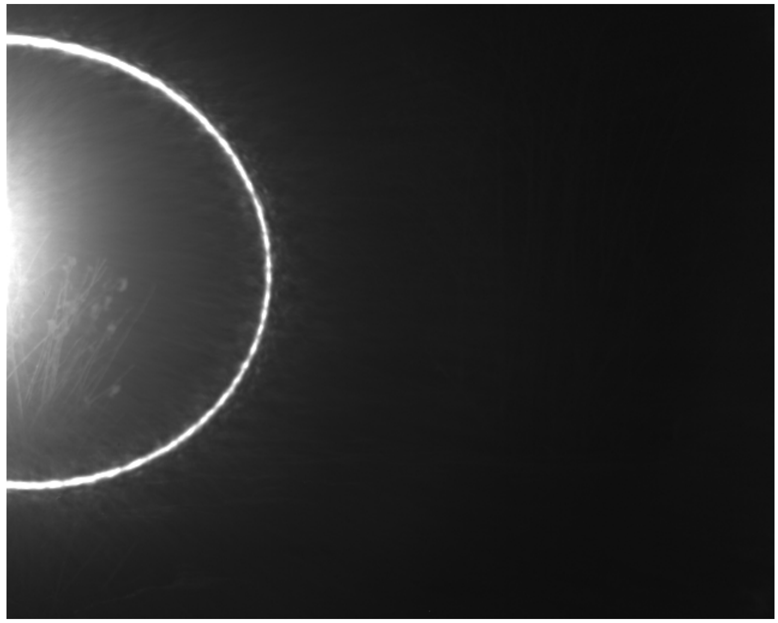

Figure 2 Ring Artifact.

NIR/SWIR lenses are typically used in low light level conditions where other detectors or cameras are not sensitive enough for the finite detail needed. When a bright light source is introduced into these low light level conditions it can have adverse effects on the imagery. One of the most common effects is a light ring caused by internal reflections inside the camera lens. Figure 2 shows one of these artifacts which is referred to as a light ring. The ring that is shown on the left hand side of the image is the effect of an out of scene high intensity light source. This light source is causing a circular internal surface to reflect the out of scene light onto the detector. The symmetry of a standard camera lens, the cylindrical housing and round optics creates the ring shape.

The goal of the camera lens designer is to reduce or eliminate these phenomena. The intensity of these artifacts can be correlated to the transmission of the lenses over these wavebands. The higher the transmission of the lens the stronger or brighter these artifacts become. These phenomena are present in off the shelf visible lenses used with NIR/SWIR detectors, but due to the decreased throughput of the lens they are not as bright or apparent in the image.

4. OPTICAL DESIGN

This section will offer optical design considerations to help in minimizing image artifacts. The first consideration is the size and shape of the lens elements can influence the stray light artifacts, they can not eliminate them alone. One method to alleviate these artifacts is to oversize the optical elements to such a degree that the out of scene light is reflected outside of the detectors active area. This is not the preferred solution as it adds to the overall size, weight, and price to the lens. Another option is to control the radii of the optical elements in such a way to minimize their contribution to the internal reflections imaged onto the detector. Highly efficient optical coatings can also help to minimize reflections and rereflections at the lens surfaces. Light that is not transmitted though the lenses are reflected elsewhere. Special attention should be paid to the coating reflectance over the operating wavebands. Another option for blocking out of scene rays is the addition of a lens hood. While this is inexpensive solution it is not always practical for the application.

One design facet that can be overlooked is the interaction between the camera lens and the detector packaging. Internal surfaces in the camera body can also play a role in the intensity and shape of these artifacts. Light can be reflected from the camera’s supporting structure back into the lens and in turn back onto the active detector area. Attention should be paid to how the lens and camera will interact together as a system.

One last design consideration is scattering from the ground surfaces of the lenses. This is can also be a source in the aforementioned artifacts. Lens’s ground edges can appear in the imagery depending on the location of bright sources within and out of the imaged scene. The location and size of any ground edge should be considered during the design phase. In conjunction with this is coating over spray onto these surfaces can enhance the scattering on the fine ground surface. Careful attention should be paid to the size and location of the coatings applied to the clear apertures of the lenses.

Experience has shown us that the optical design's role in the degrading features from bright light sources is very minimal but the lens's physical characteristics are of significant importance. Surface treatments can remedy some of these concerns and will be discussed later in this paper.

5. OPTO-MECHANICAL DESIGN

This section will concentrate on the role the opto-mechanical package will have on any internally reflected artifacts. Reflections from mechanical surfaces can play a significant role in the image quality. These surfaces can reflect light unintentionally onto the detectors active area resulting in the bright ring shown in Figure 2. Common stray light suppression techniques such as internal threading, rough surfaces, light traps, and others can suppress inner reflections causing the artifacts projected onto the detector. The worst possible surface choice for an interior surface is a smooth bore or cylinder. Figure 3 shows a smooth bored spacer, which has proven to be the biggest contributor to the ring artifact shown in Figure 2. These types of spacers can be avoided by the method of assembly, assembly order, and the opto-mechanical design. Figure 4 shows a threaded spacer that can be used to significantly degrade the bright source artifacts. Any uneven or textured surface will also greatly attenuate the reflections seen by the imager.

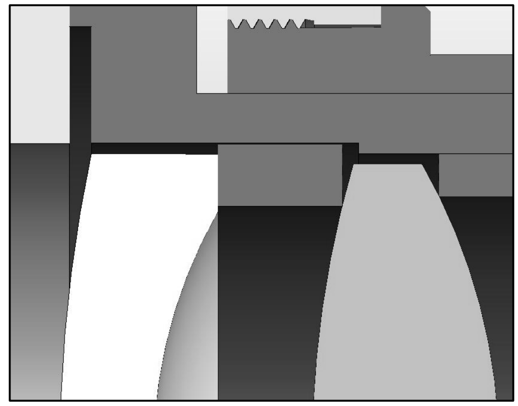

Figure 3 Smooth Lens Spacer.

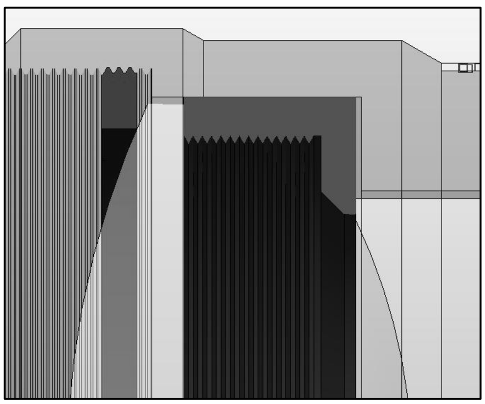

Figure 4 Threaded Lens Spacer.

While the shape of the spacers and internal surfaces are crucial it is also important to maintain a comfortable distance from the mechanical structures to the maximum cone of light being focused by the lenses. The closer the mechanical surfaces are to the cone of light the more of a factor they will play with internal reflections.

Textured surfaces that are comfortably away from the internal cone of light may not be enough to eliminate the internal reflections caused by the mechanical components. Surface treatments on top of this will help to further eliminate any internal reflections and will be discussed later in this paper.

6. MATERIAL SELECTION

This section will concentrate on the material selection for the mechanical components. Since NIR/SWIR cameras generally use reflected light to image a scene the more reflective the surfaces are the more they will contribute to the artifacts in the images.

Using an integrating sphere and filtered light source for the NIR/SWIR waveband different materials were measured for their relative illumination. These samples were measured using a NIR/SWIR detector with an optimized camera lens for this waveband. The angle of incidence for the measurements was approximately ten degrees and the background was normalized for the measurements. Figure 5 shows the normalized illumination for several different materials. The most contradictory finding was that anodized aluminum is more reflective over the NIR/SWIR wavebands than bare or unanodized aluminum. The average normalized illumination for anodized aluminum was nine hundred detector counts while unanodized aluminum was five hundred detector counts. The best untreated surface was that of black plastic which had an average normalized illumination of one hundred and eighty five detector counts. Materials that are absorptive across these wavebands are going to be the best choice of spacer materials. However, the coefficient thermal expansion characteristics of these material most be considered as they may have adverse effects on the focus and performance of the optical system.

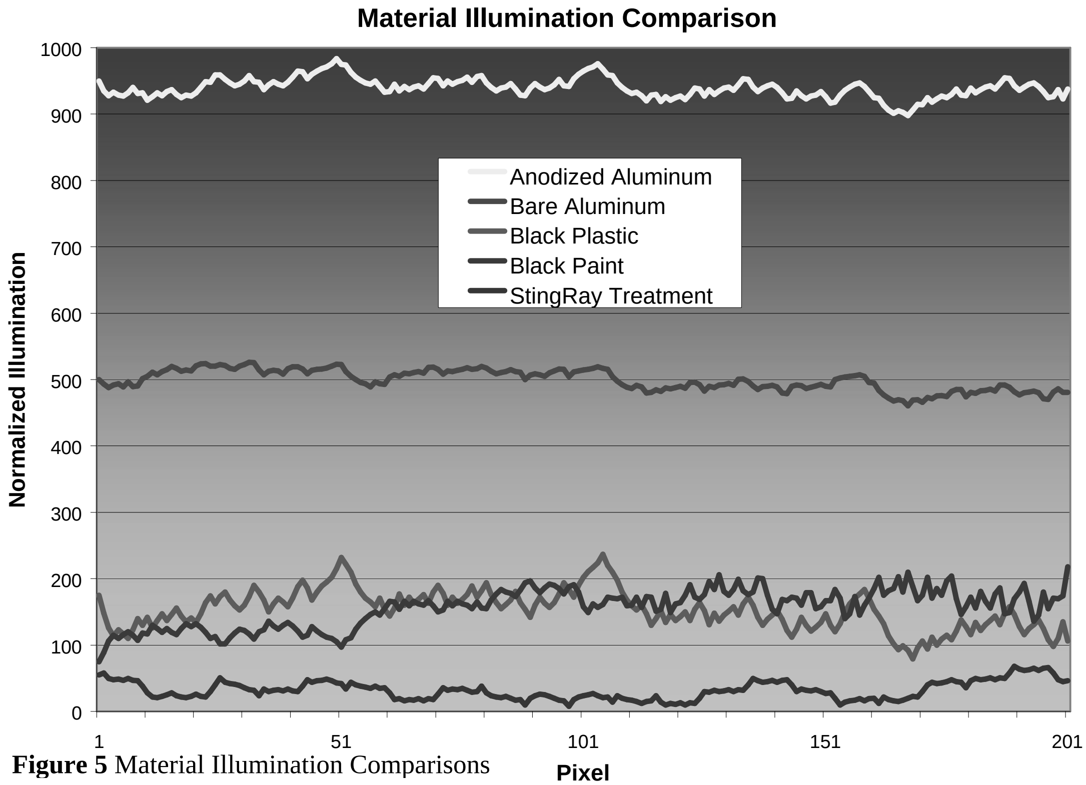

Figure 5 Material Illumination Comparisons

While material selection is critical for the performance of an optical system the surface treatments employed on these surfaces is even more important. The next section will discuss surface treatments and their effects on internal reflections.

7. SURFACE TREATMENTS

This section will discuss surface treatments and their effects on the image artifacts seen in the lenses. Surface treatments in combination with the lens elements and the mechanical components are critical in eliminating the effects of stray light. Figure 2 showed an image captured with out any surface treatments employed on the lens surfaces. Surface treatments can by used to attenuate the light ring shown in Figure 2. Surface treatments can be as simple as hardware store black paint to as complicated chemically etching surfaces. The

Figure 6 Ring Artifact with Lens Surfaces Treated Only

relative illumination of flat black paint can be seen in Figure 5. Flat black paint has a relative illumination of approximately 125 counts. Figure 6 shows an image taken with a lens that only had the lenses treated. It can be seen that the light ring has nearly the same amount of a totally untreated lens shown in Figure 2. Figure 7 shows an attenuated light ring in the bottom left hand corner. The image in Figure 7 was taken with a lens that only had the mechanical surfaces treated. Finding the right surface treatment may include several factors such as ease of application, durability, low cost, availability, and lot to lot consistency. Many of the highly efficient absorptive coatings are toxic and require special considerations for application.

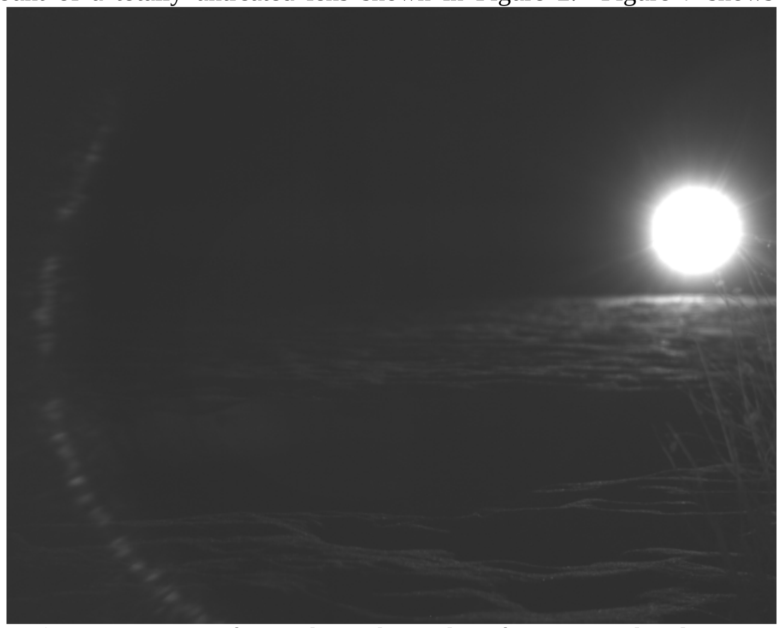

Figure 7 Ring Artifact with Mechanical Surfaces Treated Only

Materials that contain carbon are typically very successful surface treatments over the NIR/SWIR wavebands and are non-hazardous. Some readily available materials that contain carbon for surface treatments are India ink and lamp black for lens edges. Lamp black can also be mixed with paints or adhesives for adherence to mechanical surfaces. The combination of surface treatments with the optical and opto-mechanical design parameters discussed earlier can limit or control internal reflections.

8. CONCLUSION

Images were taken with four different combinations of internal treatments with a NIR/SWIR camera and a NIR/SWIR optimized lens. Figure 2 shows an image taken with a lens without any internal surface treatments. Figure 6 shows an image taken with only the ground surfaces of the lenses treated. Figure 7 shows an image with only the mechanical surface treated for reflection. Figure 8 shows an image taken with both the lens and mechanical surfaces treated for internal reflections.

Figure 8 Ring Artifact with Mechanical and Lens Surfaces Treated

The some of the parts in an optical and opto-mechanical design is central to the success of the final product. Whether it be optical design, opto-mechanical design, material selection, or surface treatments they must be considered during the design process. The impact of bright features in very low levels can produce degrading artifacts, or noise, and greatly hinder image quality. With the combination of the entire aforementioned treatments camera lenses can be manufactured that can provide high throughput and the sensitivity necessary to image even in the lowest light level conditions.