Synopsis of a published paper

"The Management of Stray Radiation Issues in Space Optical Systems"
Stephen M. Pompea

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Abstract

This paper describes the need to reduce stray light or stray radiation. There are a few methods that this paper goes into focusing of optical systems that go into space or near space orbits. I will focus on how this paper deals with black coatings to reduce the unwanted radiation. First I will explain what radiation is unwanted, which is similar to how the paper describes it. It doesn't describe the types of coating that are used to absorb light in much detail, but I will delve into them a little more because I place importance on this information.

Introduction

The image that an optical system produces needs to be sheltered from the noise that is not part of the image. This, if not careful, can significantly come from stray light. Stray light is an issue in any optical system. This paper describes the extra need for light, or radiation, reduction in an optical system that operates outside the protection of the earth's atmosphere. In space, radiation comes from all around the system. Some radiation permeates common materials such that the skin of the system needs perhaps several layers of protective materials and coatings. The first thing that I would inject into the stream is that if a coating is intended to block or reduce the amount of radiation within a region of wavelengths, I would call it *black* for that band.
Not only do the wavelengths of radiation that the sensor is responsive to need to be baffled and blackened, but there are wavelengths outside the sensitivity of the sensor that have other, indirect effects that degrade the SNR.

Gloss or Flat Black

When black is thought of, one often thinks of paint that is either gloss or flat or other variations in between. What does this mean in terms of what get's absorbed and what gets reflected? In optics terminology, Gloss black is considered to have more specular reflective properties while Flat is considered to have more lambertian reflective properties. To show the differences between lambertian and specular in a more visual method, I include two figure that demonstrate the difference. It should be more intuitive to imagine the benefits and detriment that each has to offer for various situations and environments.

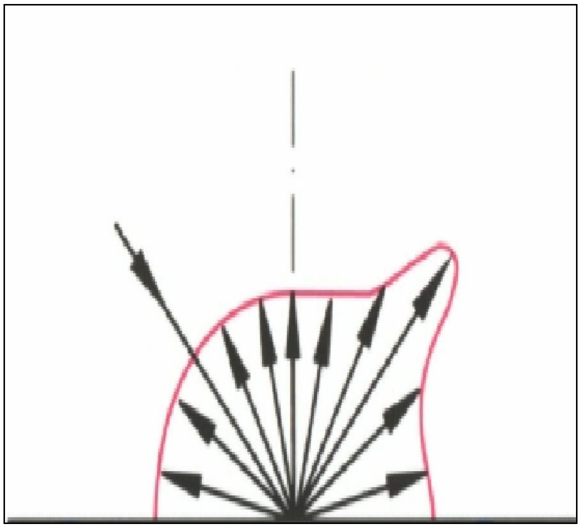

Figure 1: Lambertian reflection

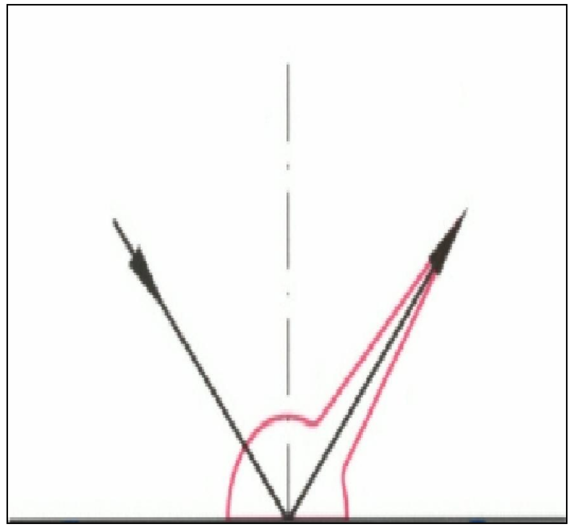

Figure 2: Specular reflection

In a perfect world, black would absorb ALL wavelengths of interest. But alas, that is not practically possible. This can be closely achieved, but at a price. Compromises must be made in any design effort to make it well, and within budget. Programs like ZEMAX, CodeV, OSLO and a few others do well with the optical design, but when stray light analysis is needed programs such as ASAP, GUERAP and APART. This paper touches slightly on the aspects of each of these and how they can analyze stray light issues. I also know of a add-on component of OSLO called “LightTools” that also does stray light analysis, but don’t know enough about it to comment about any comparison. Needless to say these applications tell about the location of a system that let light in unwontedly. They know about reflective properties of many common materials, but sometimes other coatings or material variances are used and assumptions are used which cause all sorts of errors in the results.

If the results are critical, a prototype can be made and subjected to testing of radiation from outside the field of view. The optics don’t have to be made or inserted for this test to get a good analysis, but where the optics would go, something should be placed to block all the light. This way the sensor can see only what’s not supposed to be there. Also, if the amount of stray light is acceptable, this reading will give an indication of how to deal with a calibration coefficient or dark subtraction. The paper describes this in terms of a stray light study called the Point Source Normalized Irradiance Transmittance (PSNIT). This is done with the application software mentioned. It is important and cost effective to model the optical system on a computer first. This gives a baseline of trouble spots and where to place the baffles. The prototype is made if the data is more critical like if it is being sent to orbit and can’t be easily adjusted or modified later. The following table in the paper describes the pros and cons of the basics that I refer to here.

TABLE I

Comparison of "*build and test*" approach to "*system analysis*" approach (adapted from Breault, 1994).

Build and Test Approach Strengths	Build and Test Approach Weaknesses	Analysis Approach Strengths	Analysis Approach Weaknesses
Real BRDFs	Questions about accuracy of results & experimental setup	Answers are congruent with models	Programmer error a possibility
Real, assembled system performance	If first model fails, then what?	Redesign is easy in early stages	Modeling limitations
Misalignments included	What improvements are to be made?	Very informative	BRDFs of samples only
	Expense of creating model	Less expensive than hardware model	Expense of creating analytic model
	Expense of "marching army" at late program stage	Done early in program	

Table 1 from "The Management of Stray Radiation Issues in Space Optical Systems" by Stephen M. Pompea

Many of the optical systems have noise caused by many subsystems. There are many forms of noise directly from the environment. The various subsystems themselves, while tying to reduce noise in one form may introduce noise in other forms. At some point, in this case, a decision must be made to either have a product that is very complicated and takes a highly skilled person just to set it up and calibrate it or to make it a little simpler but put up with a little noise. The noise level should be negligible compared to the signal of interest. If there is any gray scaling that needs to be considered, there must be greater and greater SNR. With a good SNR (usually more than 10 to 1 at a minimum), the system can reasonably yield an accurate report of an image.

Another example of dealing with stray radiation I mentioned was dark reading subtraction. The paper describes the dark reading relatively easy to deal with if it was fairly uniform intensity. If it is a complex distribution across the focal plane, as shown in the figure from the paper, it is difficult to accurately subtract. I would say this is the case especially since space systems often have unpredictable sources of light and their scattered patterns are even more unpredictable. As a result there will always be some level of unknown values of pixel intensities.

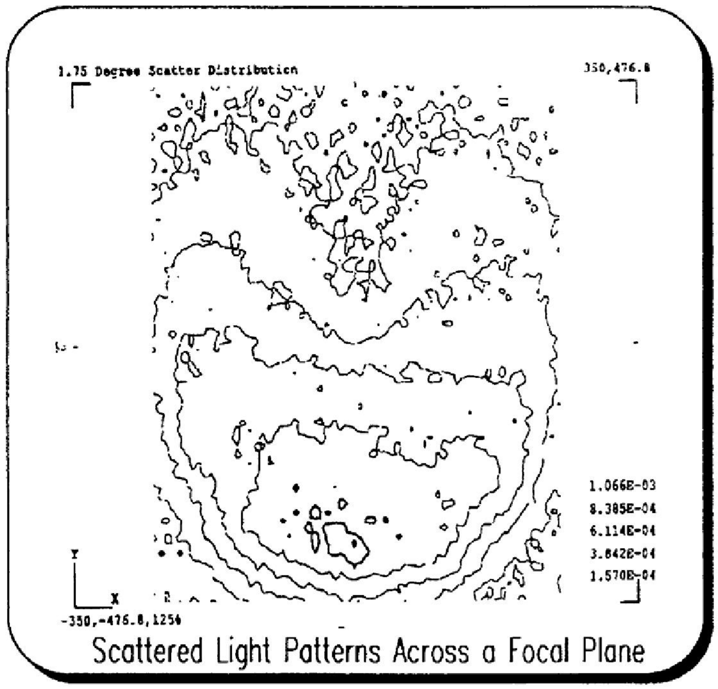

Fig. 3. If scattered light was a uniform, constant value across a focal plane array, it could be subtracted. However, most stray light paths gives a non-uniform distribution of excess irradiance that varies with the nature and angle of the source. This non-uniform distribution is difficult to subtract as it is difficult to fully characterize.

Types of black coatings

Black coatings come in many forms. There are paints, thin films, chemical etchings, anodizing dyes and others. The type of coating used depends greatly on how good the stray light reduction needs to be, what wavelength of radiation needs to be absorbed, and how much money can be thrown at the system for this purpose. Out of personal experience, I have noticed that most black anodized aluminum, while good in the visible spectrum, is very reflective in the infrared especially around 1.5µm range. For this, I've found that Krylon flat black works great.

The determination of where in the spectrum a coating is black is also valuable to make something a blackbody radiator for space borne system temperature control. Instead of convection cooling like one would find surrounding the final amplifier of a radio transmitter, radiative heat transfer takes place using a black surface exposed to "dark" region of space. For space systems, the coating usually needs to be characterized using the Bidirectional Reflectance Distribution Function (BRDF). This method basically tells how much light gets reflected in a range of directions when the light source is goes through a range of directions from the normal of the surface that has a particular coating.

The black body radiation feature has a dark side to it (so to speak). If there are parts inside the system that a sensor, that is sensitive to thermal radiation, that are exposed to such temperatures that cause it to radiate, the noise level of the imaging sensor goes up. This level goes up in proportion to the temperature; following plank's law.

Black paint is very good to reduce reflections of unwanted radiation, but there is a lot of paint that can't handle the space environment or the optical systems can't handle the black paint. The temperature variations, for starters, are more than most paints can handle and they deteriorate quickly. Then there's outgassing that introduces problems and can deposit on other optical surfaces.

Issues to look at when determining black coating

The book asserts that the determination of stray light reduction should be looked at early and often throughout the design process. The earliest that this issue is looked at, the lower impact it will have once it is realized that it needs to be looked at due to stray light **being** a problem. If there is a baffle to reduce stray light that the radiation is going to hit a surface close to normal of the surface, flat black is the better choice to use. If the radiation will cause a glancing bounce on a surface the location that it bounces to will determine the need for flat or glossy black. If the reflected angle is out of the system, use glossy since a lot of the photons will reflect and there will be less lambertian scatter in this case. If the reflected angle will be toward the sensor or other undesirable direction, use flat black, but also consider using a rough surface to increase the reflected scatter as well as increase the number of possible reflections that will take place thereby increase the chances that instead of a reflection, the photon will be absorbed by the coating.

Conclusion

Much of what Stephen M. Pompea told about in this paper I agree with and support by my experience. I added a few points to it in probably due to new techniques and technologies since the paper was written. The space optics systems that I know of currently are being looked at with much focus on stray radiation and baffle systems. I have heard many costumers talk about the importance they place on stray light reduction especially considering the importance of the various missions that these systems are involved with and also largely due to the cost of them.

References

1. Stephen M. Pompea "The Management of Stray Radiation Issues in Space Optical Systems", Kluwer Academic Publishers, Provided by the NASA Astrophysics Data System
2. Figure 1 and Figure 2 taken from: http://www.coleparmer.com/techinfo/techinfo.asp?htmlfile=PortableGlossMeasurement.htm&ID=573, November 2009