Black Coatings to Reduce Stray Light

Tutorial

Bernie Outram

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Introduction

This report is a tutorial on the use of black coatings to reduce stray light. An optical system that is designed to produce an image of an object or scene is limited by three main aspects. The first is the quality of the image that the optics can provide. The second is the mechanical system that holds the optics in place within the given environmental conditions. The third is the stray light that is introduced by both the optics and the mechanical system. The stray light is the focus of this tutorial, specifically in terms of its reduction through the use of black coating.

What is Stray Light?

Stray light is the occasional photon that strikes the image plane in a fashion that is not designed for within an optical prescription. An example of this would be if you were to look through a stainless steel pipe or tube. The image can be seen, but if the image is next to a source of bright light, that light will reflect off the walls of the tube and cause interference with the intended image. Another simple example is when you have to hold your hand up to block the sun from striking you eyes, even when the image you want to see is tens of degrees away from the sun. This effect is caused by stray light.

To further narrow down what can be corrected by black coatings, the sun in the eye causing a problem is due to light being scattered by particles in the eye, and thus black coating will have no effect on this system (the eye) as is. The pipe or tube is a perfect candidate in which black coatings will provide a benefit.

Black Coating's Effect on Stray Light

When excess stray light is present in an optical system, it reduces the signal to noise ratio (SNR) which is one form of degradation of an optical system. If a mechanical or optical element can reduce the stray photons from striking the image plane, this will increase the SNR by reducing the noise. In this case, black will be defined as a surface that will significantly reduce the reflected light by method of absorption within the entire wavelength band of interest. In other words, if a lot of 6µm wavelength light strikes the sensor when the sensor is only responsive from 0.4 µm to 1.8 µm then we don't care (unless this causes thermal issues of course).

FIGURE 5.4 Notional drawings of representative cold shield designs. It is assumed that the rays enter from the left and that the gray rectangle is the focal plane. Very complex shapes are possible.
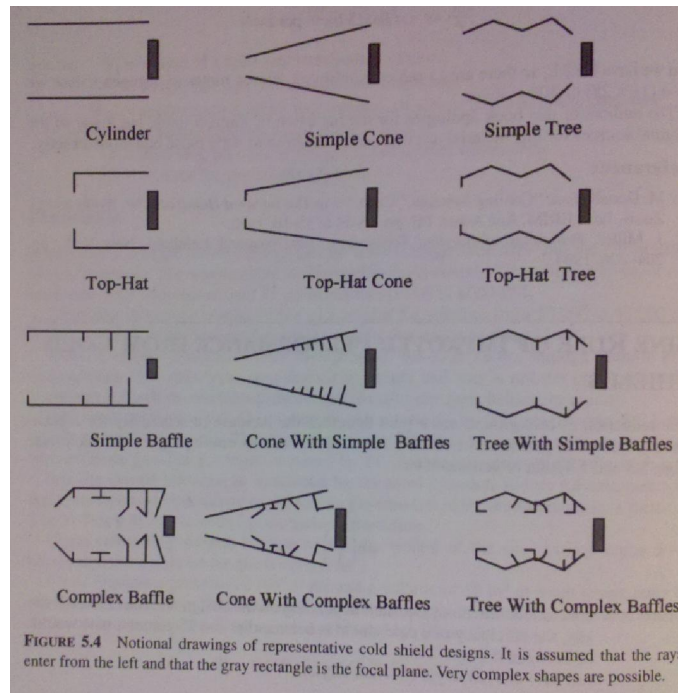
Figure 1. Baffle designs taken from "Photonics Rules of Thumb"

A simple cylinder baffle can have a stray light reduction of about 5 orders of magnitude or 10^5 attenuation. Two stage baffles or more complicated baffle designs can reduce the stray light by a factor or 10^8 or more. This is of course dependent on black coatings on the inside of the baffle. As a matter of having a coating being black or more reflective, that is a matter more of strategy and location. In other words, if part of the baffle design is reflect light back out of the system instead of absorb it with black coatings, then specular reflection (glossy) coating is called for. If the only way for the light to reflect is more towards the sensors, then lambertian (flat) coating with high absorbing properties is called for.
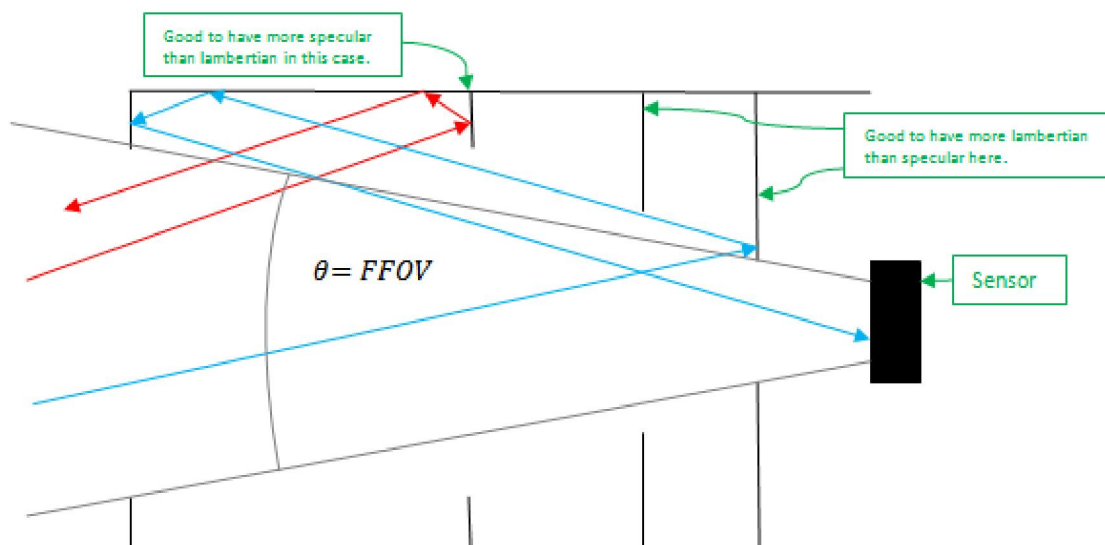

Figure 2. Effectiveness of baffle placement.

In the previous depiction of a baffle system with a simple sensor as the focal plane array, two rays of light are shown. In the red ray of light, the light strikes a baffle in which it is best to have more of a specular reflection so that the ray reflects out of the system as shown in the figure. The blue ray of light (not meant to depict blue light, just a different color to separate it from other lines on the figure) is shown to strike another baffle that if specularly reflected, would introduce stray light into the system in such a way to degrade the SNR. The effect of this happening with a lot of rays will reduce the contrast of the image or yield a false reading of light intensity at the sensor. The gist of this concept is to evaluate blade by blade what needs to be flat black and what is better suited for glossy black coatings.

There are also types of textures that can be produced on a surface (beyond what the coating produces) that will dictate mostly the type of reflection, but also to a smaller degree, the reflectivity of the surface. The following table describes the basic rule of thumb for surface texture type with their correlated reflectances.

Surface Texture	%
Dead matte	<1
Matte	1-10
Eggshell	15-20
Semi-gloss	40-50
Full gloss	>80
Mirror	>95

I found a simple list of some common black coatings along with normal absoptance from the light of the sun as well as what it's emissivity is and the ratio thereof at the web site
http://www.tak2000.com/data/finish.htm

a= solar absobtivity
e= normal emmitance
ESH=equivalent Sun Hours
Coating thickness is usually critical

NAME BLACK COATINGS	SOLAR a	NORMAL e	Ratio a/e
Anodize Black	0.88	0.88	1.00
Carbon Black Paint NS-7	0.96	0.88	1.09
Catalac Black Paint	0.96	0.88	1.09
Chemglaze Black Paint Z306	0.96	0.91	1.05
Delrin Black Plastic	0.96	0.87	1.10
Ebanol C Black	0.97	0.73	1.33
Ebanol C Black-384 ESH* UV	0.97	0.75	1.29
GSFC Black Silicate MS-94	0.96	0.89	1.08
GSFC Black Paint 313-1	0.96	0.86	1.12
Hughson Black Paint H322	0.96	0.86	1.12
Hughson Black Paint L-300	0.95	0.84	1.13
Martin Black Paint N-150-1	0.94	0.94	1.00
Martin Black Velvet Paint	0.91	0.94	0.97
3M Black Velvet Paint	0.97	0.91	1.07
Paladin Black Lacquer	0.95	0.75	1.27
Parsons Black Paint	0.98	0.91	1.08
Polyethylene Black Plastic	0.93	0.92	1.01
Pyramil Black on Beryllium Copper	0.92	0.72	1.28
Tedlar Black Plastic	0.94	0.90	1.04
Velesat Black Plastic	0.96	0.85	1.13

I have basically deduced through my experience and through comparing these two tables that the first table shows the surface type that when you use the second table's information and inject into the first's should give a closer approximation of what the reflectivity of a surface will be. Also keep in mind that the first table, that deals with the texture, mostly describes the *type* of reflection with the reflectance percentage being measured at a specular looking sensor and assuming a generic black coating otherwise being used on said textured surface.

Another way to imagine this is to visualize shining a red laser pointer from the hood ornament of a car into the eyes of the driver AFTER being reflected off of the ultra shiny gloss black paint job of a new Lamborghini. If you are in your military hummer next to this car looking directly at the hood, you won't see the laser reflecting directly into the eyes of the Lamborghini driver, who is now blind. If that same laser is reflected off of your hood (with its flat paint of olive drab color) a lot of the laser light will be absorbed before reflecting into your, and many other directions. The Lamborghini driver will see the red laser light a little bit from your hood, but you will see most of the light.

How does BRDF fit into all this?

BRDF is the Bidirectional Reflectance Distribution Function. This data tells about how much a surface behaves like a glossy surface a matte surface or somewhere in-between.
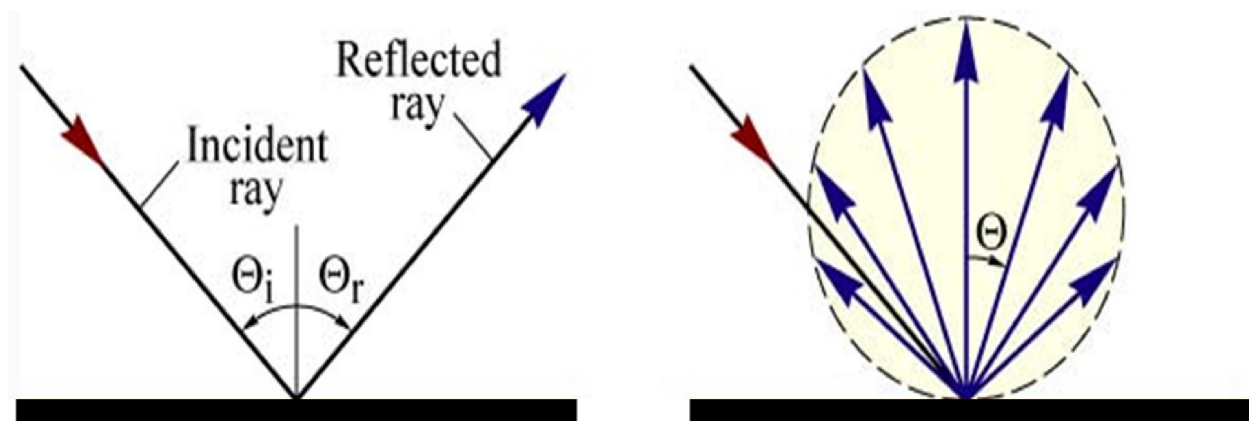
The above left figure shows a specular type reflection where the reflected light is the same angle as the incident light, but on the other side of the reflecting surface normal.

Shown on the right for a purely lambertian reflection where all the light from the incident ray is distributed such that the collection of reflected light will appear equally intense in any reflected direction. The lambertian reflection feature follows a simple mathematical law whereas the intensity of the reflected light is normalized to cos (θ from surface normal).

Most materials (and coatings) aren't one or the other exclusively, but rather variations of both of these. One case where it could be more complicated is if there was a surface irregularity that had a periodicity to it that is close to the wavelength of the incident light. This is a type of diffraction grating effect. But that's really another story and most often doesn't happen to coated surfaces. If you wanted to model the expected effectiveness of a baffle design, it is best to analyze the BRDF of the specific coating applied to the specific material to be used while its accessible to be analyzed. This data can then be inputted into programs such as ASAP or other stray light modeling application software.

Contaminants and other surface flaws

Dust, lint and other airborne particles can have a significant effect on stray light if it is in the path of the field of view. As one can imagine, if dust is simply floating in space in the field of view, not only does it block a portion of light which is fairly insignificant, but also scatters light towards a direction not intended by the imaging system. If many particles are there doing the same thing it will add up to be a significant problem. A similar thing will happen when an accumulation of dust forms on a baffle system. The black coating that was once absorbing a lot of light is now being shrouded by light scattering particles of dust thereby defeating the purpose of the baffle system.

It may appear black, but…

Black anodized aluminum may be black in the visible spectrum, but is nowhere near so absorbing in the infrared spectrum. I have viewed many black anodized aluminum parts with an IR camera and it appears as though it were polished chrome. For purposes of free space optics, which use wavelengths of light in the IR of around 1.5µm, I trust my old standby Krylon Ultra-Flat Black spray paint. There's a trick to this when painting aluminum though. While black anodized aluminum isn't black in the IR, the black anodized aluminum will accept paint better than non-anodized aluminum. In other words, it's still a good idea to get aluminum anodized regardless of whether painting is to intended place or not. If not anodized paint easily peels off the aluminum.

I found a company online that claims that their anodizing process covers the IR spectrum 5 times more than conventional black anodizing. The company URL is http://www.pioneermetal.com. One thing I know about statistics is that 80% of all statistics are 50% wrong 65% of the time. Ok, that might be a dramatic exaggeration, but I was hoping to have an example tested, but they haven't sent the piece back anodized yet, so I won't berate them too harshly yet. If black anodizing was effective as other black coating types, it's advantage would be significant.

Conclusion

This tutorial report is by no means meant to be a complete guide to black coatings, but rather a guide to the basics of black coatings from one person's perspective as influenced from experience and a little research into what other people and companies are doing with it and about it. The main purpose of black coating for optical systems is to reduce light from getting to the image plane that the optical system's design hadn't intended to pass through. This is done, in the case of black coatings, through absorption. Absorption is usually most effective at angles close to the surface normal. Rays of light through glancing angles have less likelihood of being absorbed. This is where surface roughness helps, but usually doesn't totally eliminate glancing angle reflections. To reduce the glancing angle reflections from getting through, baffle geometry must be employed to deal with this in the best way possible for each individual system.
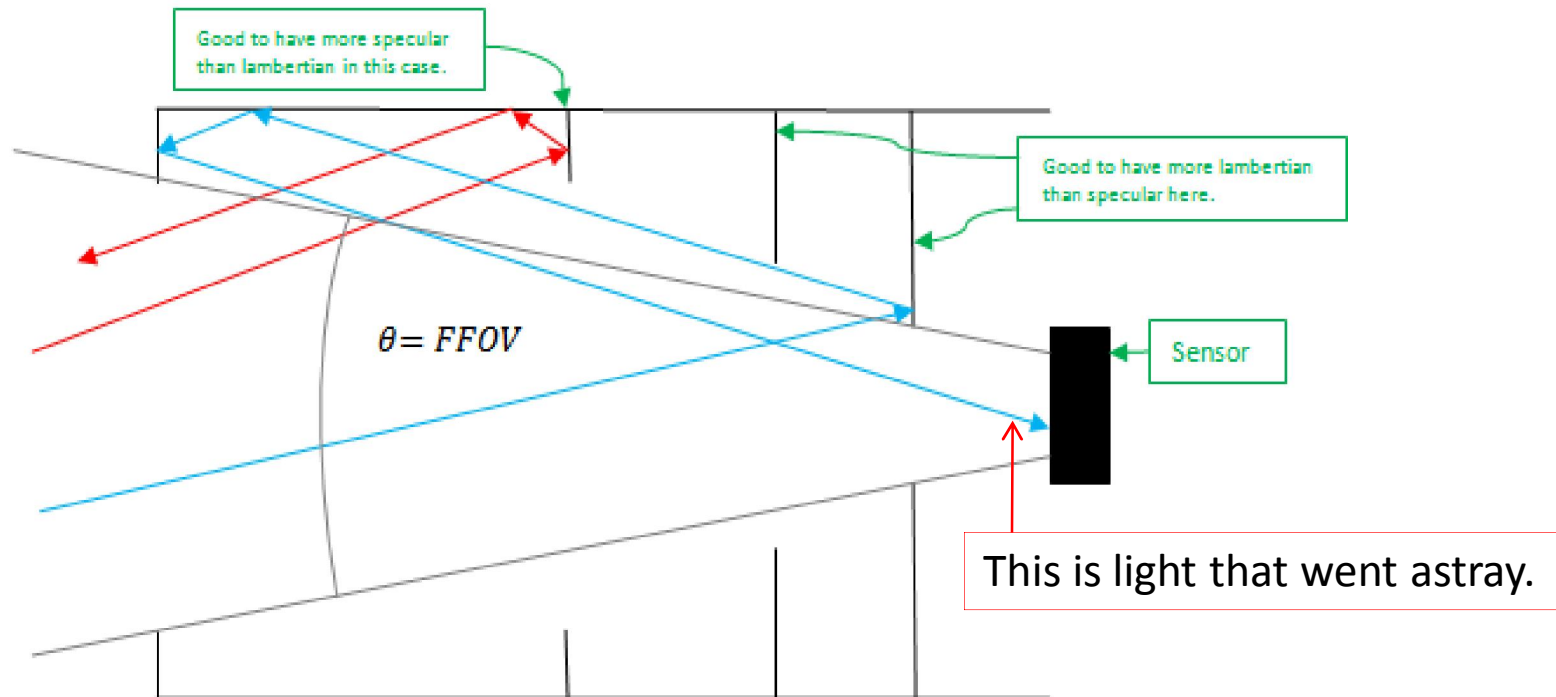
References

1. *Photonics Rules of Thumb* by Friedman, Miller, 2004
2. http://www.tak2000.com/data/finish.htm#Black
3. *Materials* and Design by Ashby and Johnson 2002
4. *http://www.pioneermetal.com/finsishes/optical_black.php*, 2009

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Presentation for OPTI 521
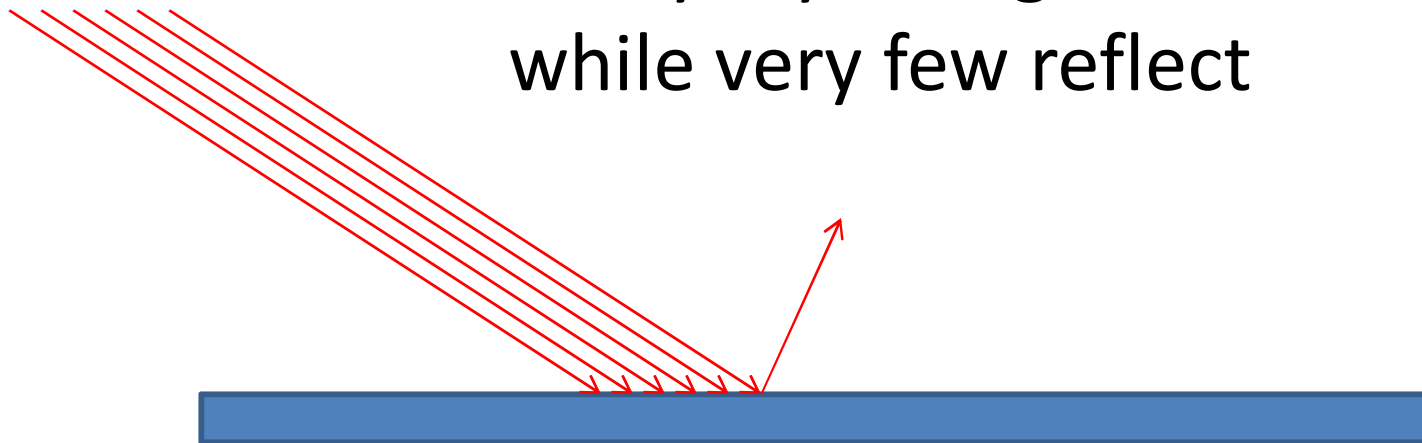
University of Arizona

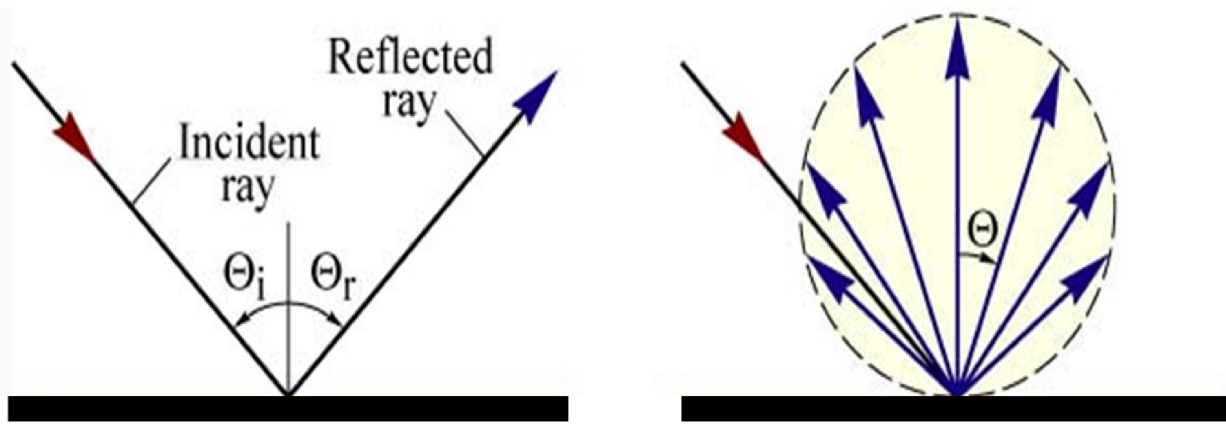# Introduction

- ## What is Stray Light?

What do black surfaces do to stray light?

Many rays of light strike
while very few reflect

Deeper black = More absorption

Glossy or Matte?

Depending on where the surface is, one of these two types of reflection is desirably.
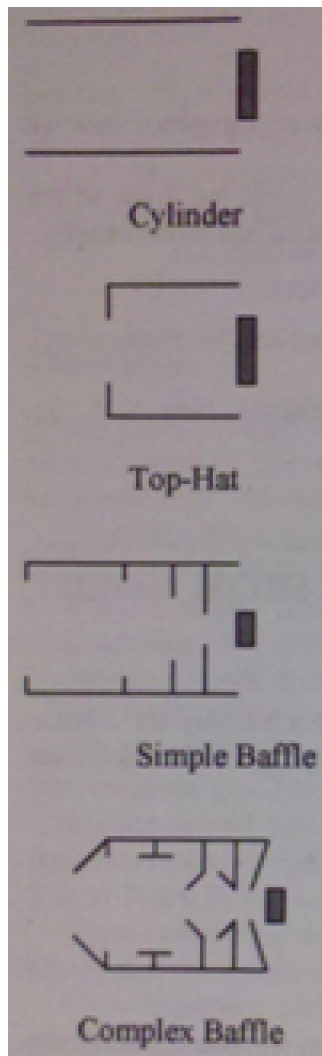
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Full gloss	>80
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Summary

Cylinder

Top-Hat

Simple Baffle

Complex Baffle

Depending on your SNR needs, you may need more detailed and complex baffle design

Questions?

Presenter: Bernie Outram

Scoring for OPTI 521 presentations

Name (of Attendee)	Big picture before details	Clear explanations	Use of visual aids	Clear, loud speech	Engage the audience	Effective use of time	Overall
Tom Love	5	4	4	5	3	5	5
Victu Potru	5	5	4	4	4	5	5

Scoring:
5 : Excellent   4: Pretty good   3: Okay   2: Could be better   1 : Pretty weak   0 : Didn't even try