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What's "Inside The Box"?

Optics of Digital Projectors Weekly Newsletter

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Illumination Systems and Their Function

By Michael Pate, President, OSCI

Illumination systems have their roots in luminaries, reading lamps, and communication devices. Certainly signal fires, candles, and fuel oil lamps come to mind when we think of early illumination devices. These illumination systems basically radiated into almost a full sphere around the source and were not typically very efficient. Mirrors or reflectors were put behind the candles and oil lamps to increase the amount of illumination in a particular direction or illumination plane. A search for higher radiance ($W/cm^2/Sr$) sources was initiated and developed lime light and carbon arc sources. We have all heard about Thomas Edison's incessant search to find the best materials for a light bulb. This moved us from consumable sources of candle wax and fuel oil to a somewhat permanent bulb.

A jump to modern times we find mercury and xenon arc lamps as the dominant light source currently in digital projectors. These display devices are rapidly replacing the overhead projector and slide projectors, that use tungsten halogen lamps, and even film projectors at a very fast rate. We also see LED's or solid state sources coming into use in traffic signals and large venue displays and digital signage. As the light source developers seek to create sources that have higher radiance or luminance ($Lm/m^2/Sr$) illumination designers are working to develop illumination system configurations to capture more of this luminance from the source and deliver it to the illumination plane and finally to the display screen and the viewers eye.

Illumination System Types

The problem with many illumination systems is that they are not very efficient at collecting the light from the lamp and getting it to the illumination plane. We see an example of this inefficiency in Figure 1 where a candle on the left illuminates a piece of paper on the right. The candle radiates light into almost a full sphere but only a small solid angle of light is used to illuminate the paper and therefore we are wasting most of the light in this illumination system. As every illumination designer will tell you a photon is a terrible thing to waste.

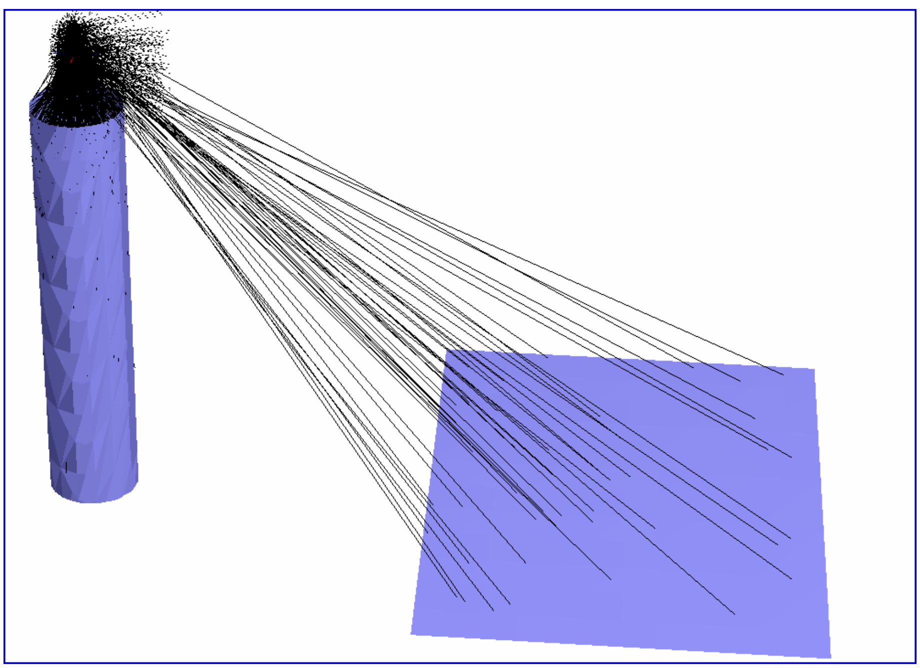

Figure 1. Candle Illuminating Paper – Simple Illumination System

After the candle came mirrors and reflectors behind the flame or light source. The mirrors were often parabolas in the case of light houses or ellipses in the case of illuminators and projectors. The idea with reflectors is to capture light from the source that is propagating in the opposite direction and reflector it in the direction of need or use. Lighthouses and signal lights have used parabolic mirrors to increase the amount of light flux reaching an observer over the bare source from 3% of the total light flux to 39% in some applications. The use of prism to make Fresnel lenses in light house optics is also well known. The Fresnel lens is used so that the shortest focal length condenser lens can be used, which means that the largest solid angle of light from the source can be collected and sent down the illumination system optical path.

A more modern optical system that has both an illumination system and an imaging system in one instrument is the microscope and lithography systems. Microscopes illuminated the object to be viewed from below the object if it was transparent or from the top if it was opaque. If the object was opaque and the object needed to be illuminated from the top then efficient optical system design required that part of the optics be used for both illumination and imaging.

Old School Illumination System

In Figure 1 we see one of the original illumination system configurations that were used in film projectors and slide projectors. This type of illumination system is called Abbe illumination. Abbe illumination is characterized by imaging the source, shown as a curly orange line in at the left of the figure, onto the object or film plane. We can see the enlarged image of the source on the object plane. The condenser lens optics collects light from the source and image it to the object plane. The projection lens images the light

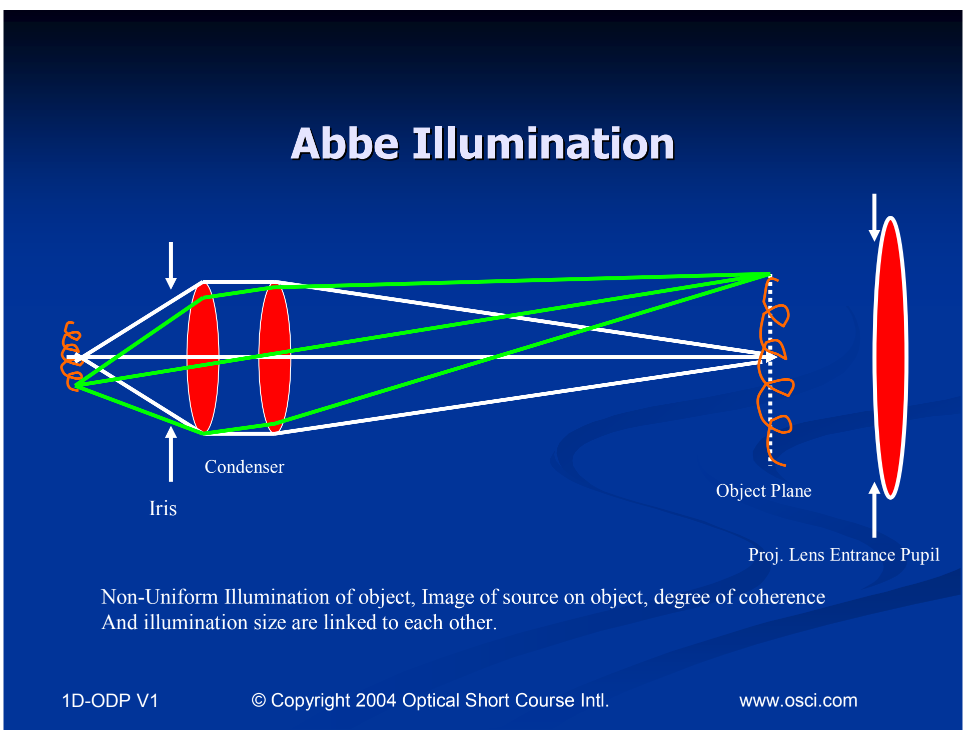

Figure 2. Abbe Illumination

From the object onto the projection screen for viewing. There is often an elliptical mirror to the left of the light source filament. The elliptical mirror is used to capture light that is emitted away from the condenser lens and reflect is back towards the filament. These mirrors are often slightly tilted so that the image of the source just passes the original filament and enters the condenser lens for collection and delivery to the object plane.

There are a few problems with this early type of illumination system. The first is that the illumination at the illumination plane (film plane in a film projector) is not uniform. We will see an image of the filament at the illumination plane. If the film gets jammed in the film advance mechanism then the hot image will burn a hole in the film as it sits there with the filament imaged onto the static film. In certain illumination system it is important to be able to independently adjust the size of the illumination plane and the degree of coherence of the illumination. The size of the illumination plane is set by the film gate opening at the object plane. The degree of coherence of the illumination can be thought of as the marginal ray angle from an axial point on the source.

By studying figure 2. it should be clear that the condenser lens iris diaphragm controls the marginal ray height and along with the condenser lens focal length controls the marginal ray angle into the object plane. If we want to decrease the degree of coherence we can decrease the condenser lens iris diaphragm and thus decrease the marginal ray angle at the object plane. It is also important that all of the light from the object is able to just fill the entrance pupil of the projector lens assembly so that this light can make it to the screen for illumination purposes. Abbe illumination systems are not used in modern optical instruments as other types of illumination system have better engineering tradeoffs.

Projection Condenser Illumination Systems

The projection condenser illumination system layout is shown in Figure 3 below. We can see the light source on the left represented by a coiled filament. The light from the source is collected by a condenser lens assembly and is imaged into the projection lens entrance pupil. The object is shown close to the condenser lens assembly. In practice the object is located between the condenser lens assembly and the projection lens entrance pupil. It is often located closer to the condenser lens because the illumination is more uniform at this location than closer to the projection lens entrance pupil. There are often opto-mechanical constraints like fold mirrors, mechanical or optical beam interferences that keep one from locating the object plane in the most desirable location.

The size of the field at the illumination plane is controlled by the projection lens entrance pupil diameter. The degree of coherence is again controlled by the condenser lens iris diaphragm. The benefits of the projection condenser are that the object plane or illumination plane is uniformly illuminated and it is a shorter optical path between light source and projection lens assembly. The projection condenser illumination system is often used in digital projector light engines.

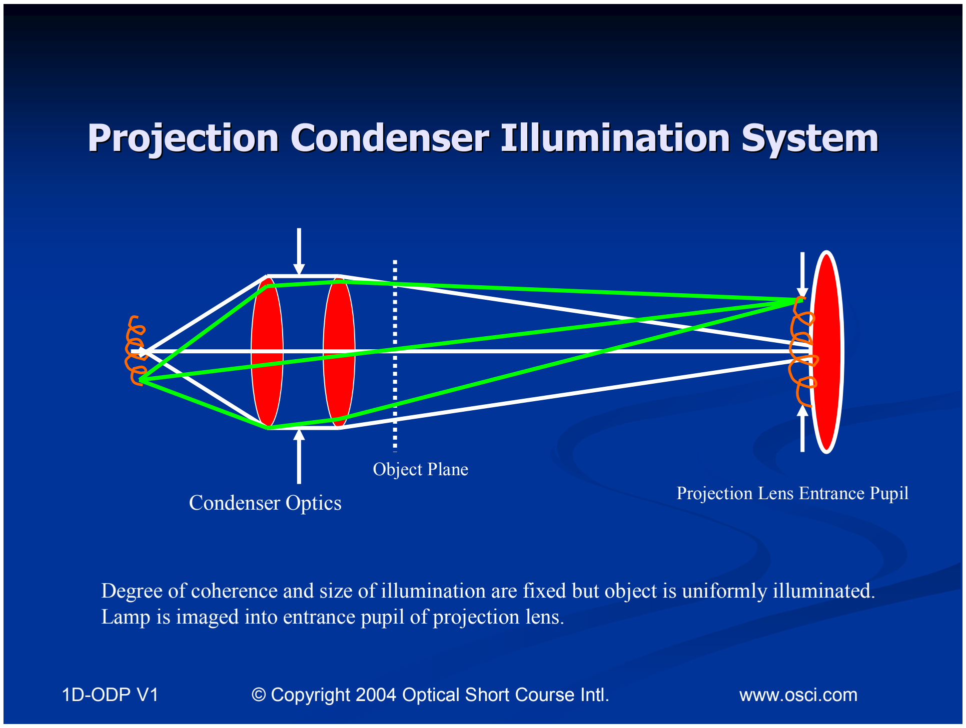

Figure 3. Projection Condenser Illumination System Layout

Köhler Illumination System

In Figure 4 we see the optical layout of the Köhler Illumination system. This system has some unique differences from the previous two illumination systems that we have just looked at previously. There is an intermediate image between the condenser lens and the field lens. The light coming into the illumination plane is collimated. There are also two separate iris diaphragms, one at the condenser lens to control the size of the illumination at the object, and another at the field lens to control the degree of coherence.

In the Köhler Illumination System layout we have uniform illumination at the illumination plane. The condenser lens assembly performs the same job as usual to collect the light from the source and image it down stream. The function of the field lens is to collimate the image of the source and provide uniform illumination at the object or illumination plane and also to get the light into the projection lens entrance pupil. In Köhler Illumination systems the projection lens is often object side telecentric which means that the entrance pupil lies at infinity or far behind the object plane.

Because of the intermediate image plane and the field lens the Köhler Illumination system is often a longer optical system than the previous two illumination systems. Because the projection lens is object side telecentric this means that the diameter of the individual optical elements in the projection lens assembly will be larger in diameter. With the two iris diaphragms there is independent control of the size of the illumination field and the degree of partial coherence.

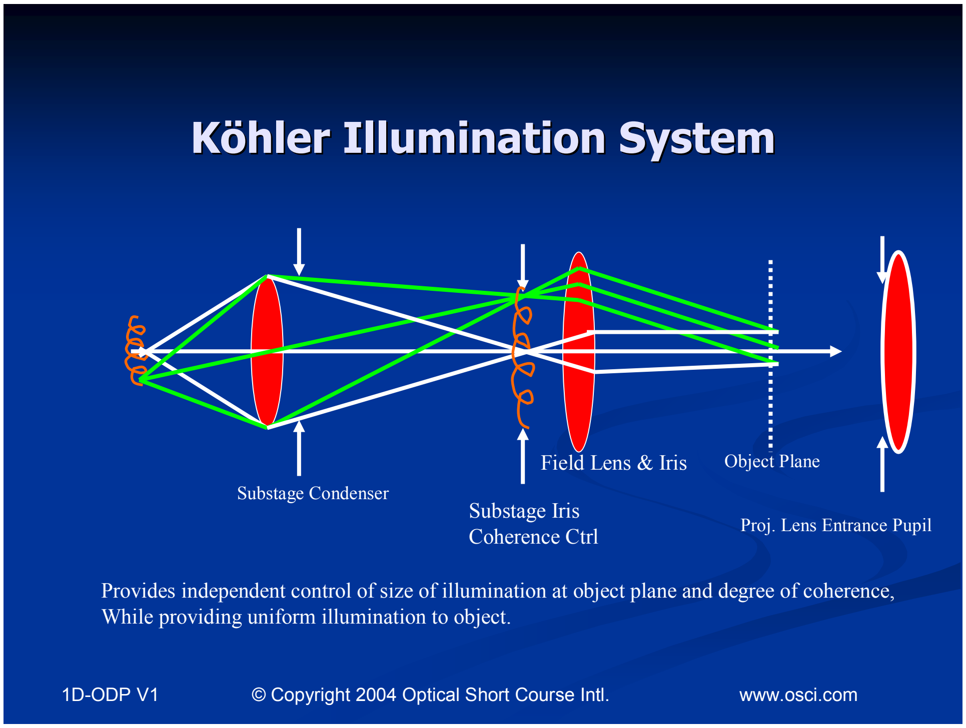

Figure 4. Kohler Illumination System Layout

Summary

In the next few issues we will start to look at the general illumination system layout configurations and determine how they can be detailed in design to work with digital projector light engines. We will look at light source coupling to the condenser lens assemblies and also using integrating rods and fly's eye integrators. We will also look at TIR prisms and understand how to design them and how they work in illumination system designs. So stay tuned and keep looking for your weekly dose of In The Box to understand the optics of digital projectors.