Optical Short Course International

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What's "Inside The Box"?

Optics of Digital Projectors Weekly Newsletter

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Köhler Type Illumination Systems

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In last weeks issue of "In The Box", we learned about the projection condenser illumination system type and some of the illumination design tradeoffs of this system type. This week we will take a deeper look at the Köhler illumination system type system. This type of illumination system is often used in microscopes and TIR Prism digital projector light engines. Like all types of illumination systems the Köhler type illumination system has a source, condenser and field lenses, an object at the illumination plane, and a telecentric projection lens with an entrance pupil diameter and location. The function of this illumination system is to capture light from the source and provide uniform illumination at the illumination plane and fill the entrance pupil of the projection lens with an image of the source.

Overview of Köhler Illumination System

The Köhler illumination system layout is shown in Figure 1 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 to an intermediate plane where the substage iris is located. The field lens captures the light from this intermediate plane and provides collimated light at the object plane. Since light from the all of the fields overlap at the object or illumination plane the light is uniform at this location.

There are two illumination system controls in this design that are independently controllable. The first control is the iris at the substage condenser lens which controls the size of the illumination field at the object or illumination plane. The second control is the substage iris at the intermediate image plane and this controls the degree of coherence of the illumination at the object plane. The degree of coherence is related to the chief ray angle at the edge of the field in the illumination system. In a Kohler illumination system these two controls are independent and this is a unique feature of this illumination system design configuration.

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.

This general overview gives us an idea of what a Köhler illumination system looks like. Why don't we take a closer and more specific look at a digital projector light engine layout using a projection condenser illumination system.

Light Source

Currently, digital projectors use mercury and xenon arc lamps as the dominant light source for front projection systems. In the arc lamps there is a plasma arc or fire ball which emits the light we want to capture and eventually get it to the screen for viewing. These arc lamp sources are designed into elliptical or parabolic mirrors with the fireball at one foci of the mirror and we get focused light or collimated light respectively. Almost all single panel DMD light engines use an elliptical reflector with the fire ball at one foci and the entrance of the integrating rod at the second focus as shown in Figure 2.

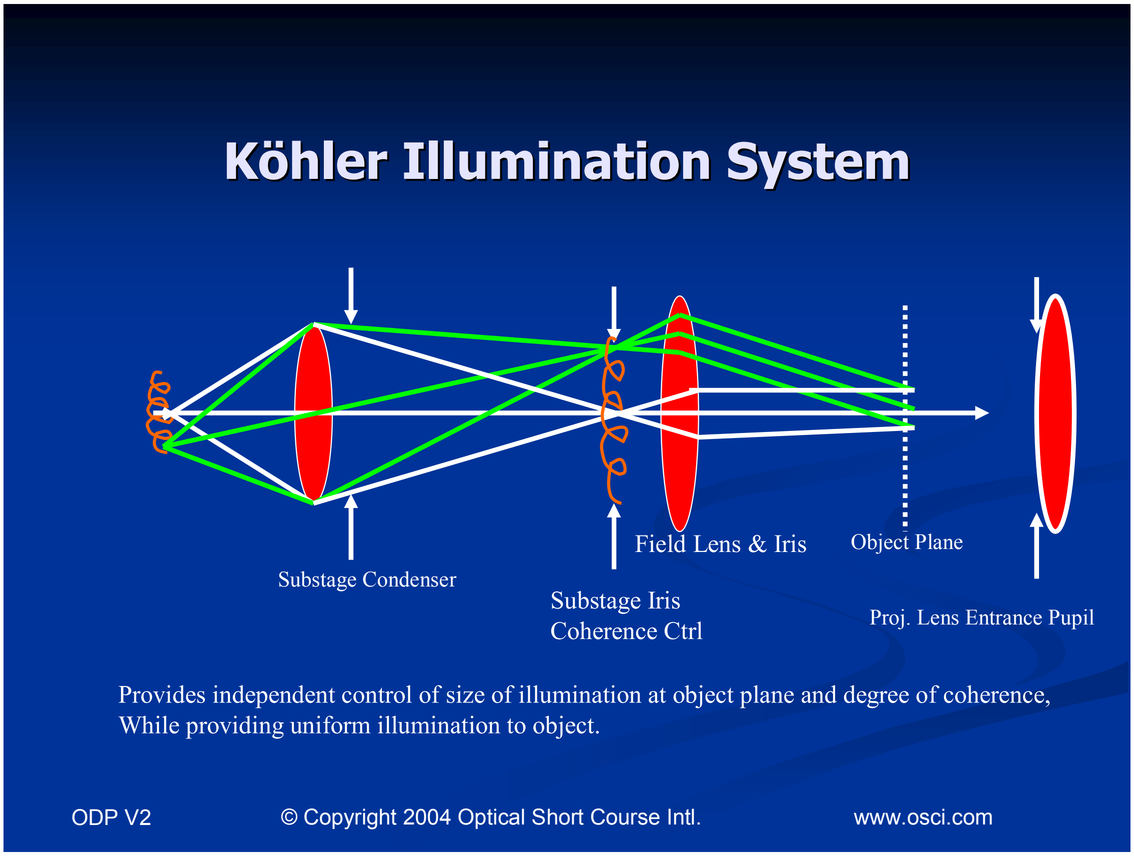

Figure 1. Köhler Illumination System Layout

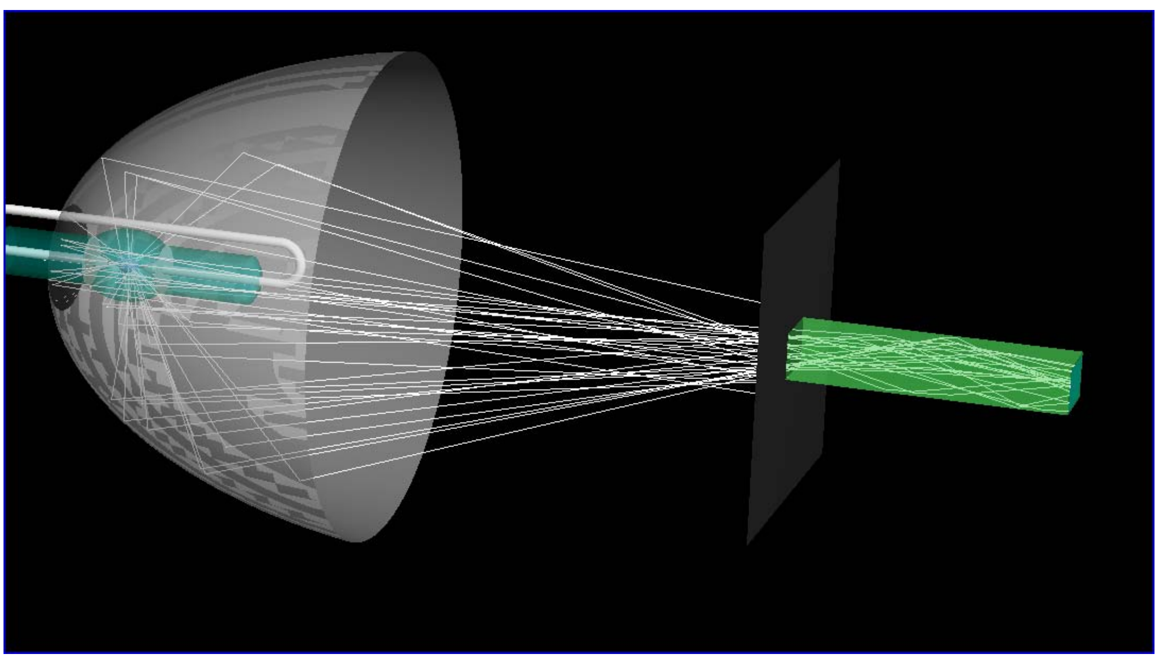

Figure 2. Elliptical Reflector: Plasma and Integrating Rod at two foci of ellipse

Köhler Illumination System

The lamp assembly and the integrating rod are certainly part of the illumination system and digital projector light engine. If we study the Köhler illumination system in Figure 1 again we will consider the light source or filament to be the exit surface of the integrating rod. In this digital projector light engine illumination system design the exit of the integrating rod will be imaged into the intermediate image in the illumination system and then this image is collimated and overlapped at the spatial light modulator plane. We will have the condenser lens assembly capture the light out of the integrating rod exit surface and "optically plumb" it down the optical axis towards the intermediate image, field lens, through the unfolded total-internal-reflection (TIR) prism, and finally to the illumination plane where the spatial light modulator or DMD lies.

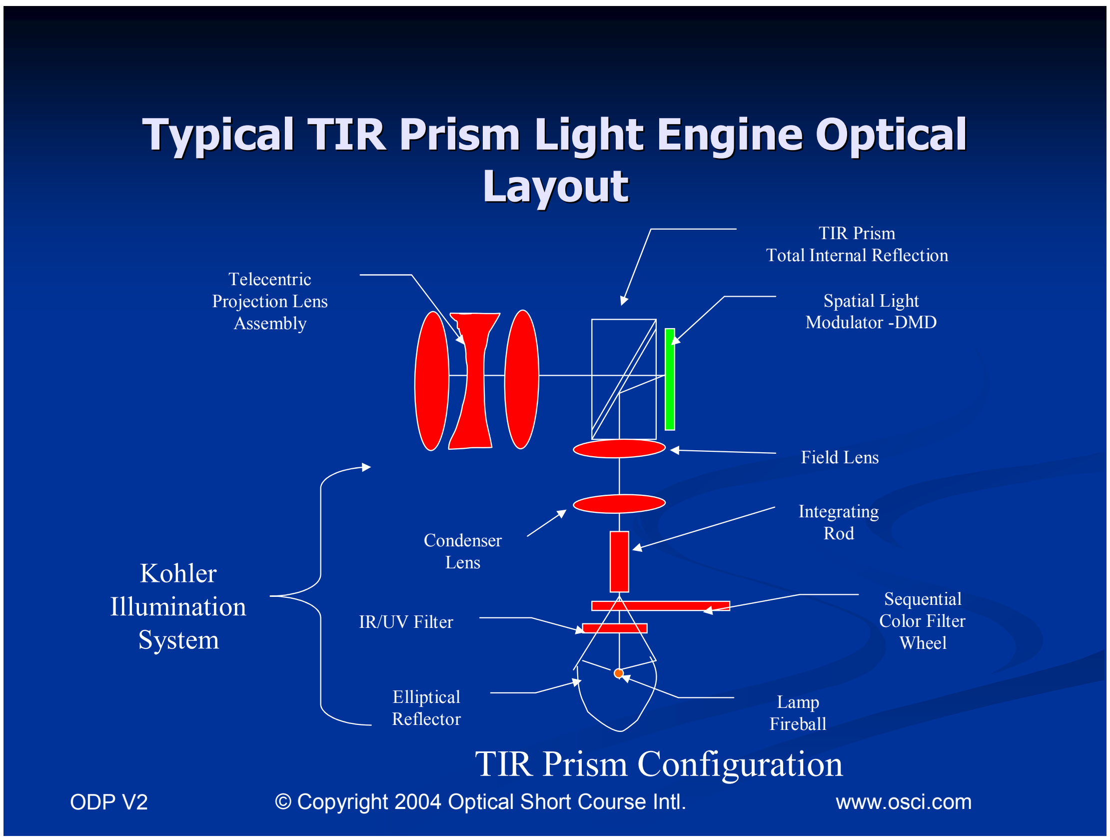

Figure 3. Digital Projector Light Engine Illumination System Layout

We can see an illumination system layout in Figure 4 using what is called perfect lenses shown in the figure as vertical lines that refract the rays passing through the lenses. On the far left we have the exit surface of the integrating rod and we can see that the perfect condenser lens captures this light and condenses it down towards the field lens. The field lens which is also shown as a perfect lens images light from the condenser lens through the unfolded TIR prism and down onto the DMD and then on towards the entrance pupil of the projection lens. You will notice that the image of the exit of the integrating rod is located at the intermediate image. The field lens collimates different field points from this intermediate image and provides overlapping images of the integrating rod exit surface at the DMD or illumination plane. The illumination system magnification is an

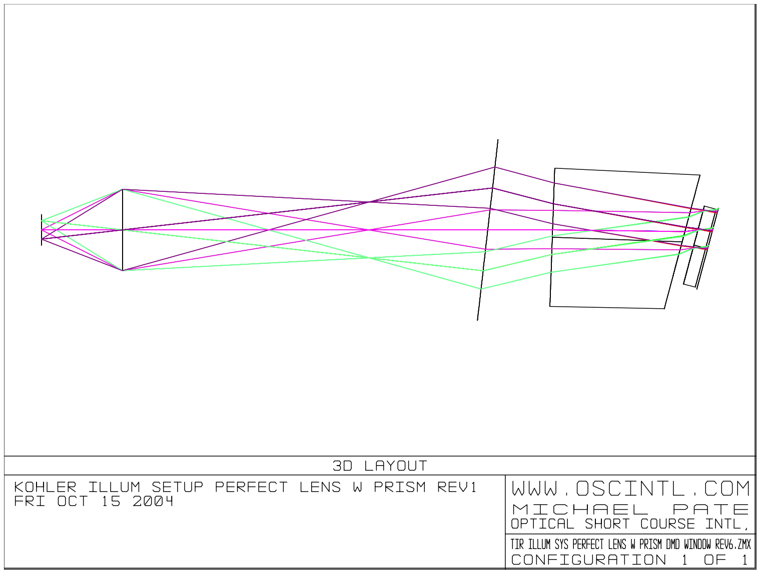

Figure 4. Projection Condenser Layout with Zemax

important design parameter for this projection condenser illumination system design. We don't want to over fill the illumination plane and waste light or under fill and have a missing part of the object or DMD not illuminated for display on the screen. The magnification in the illumination system is a function of the condenser lens and field lens focal lengths and their spacing, the integrating rod size, and the DMD size.

Because the light at the exit of the integrating rod is spatially uniform, as we learned in a previous edition of "In The Box", the illumination at the DMD is also spatially uniform as required. In this TIR Prism type light engine with the Köhler illumination system we will typically have an object side telecentric projection lens assembly. We will describe projection lenses and telecentricity in a future edition of "In The Box". What is important for this edition is that you know that the projection lens entrance pupil lies at or behind the illumination plane or DMD plane. This will ensure that all of the illumination fields from the integrating rod, condenser, and field lens will get into the telecentric projection lens assembly and onto the screen.

The next steps in this light engine design would be to perform a detailed optical design of the condenser lens assembly, the field lens assembly, TIR Prism, and finally the telecentric projection lens assembly. We know from this illumination design layout with perfect lenses what the required focal length and apertures are as well as the airspaces between the lenses so we can proceed with our detailed lens design. We would also check the illumination system magnification and illumination uniformity at the illumination plane or DMD. Finally, we would design our projection lens assembly with our entrance pupil axial position and our diameter. If we did not like some of our condenser lens, field lens, TIR Prism, or telecentric projection lens first order optical properties, we would redesign the layout before we started a detailed optical design of the system.

Summary

We have seen this week how one can start with an illumination design layout and then perform a system layout of the illumination system. This system layout design of an illumination system lets us understand the first order properties of the optical design layout so that we can understand what our system will look like before we start the detailed design of the system. Finally, we discussed the next steps in the detailed optical design and illumination design of this single panel DMD light engine design using a Köhler illumination system.

Next week we will take a look at some more illumination design issues and components. So stay tuned and keep looking for your weekly dose of "<u>In The Box</u>" to understand the optics of digital projectors.