Optical Short Course International

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What's "Inside The Box"?

Optics of Digital Projectors Weekly Newsletter

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TIR Prisms in Digital Projector Illumination Systems

By Michael Pate, President, OSCI

We have been looking at illumination system components and how they work in light engine illumination system designs. This week we will look at the full system design process and understand what tradeoffs are made during an illumination system design for a digital projector light engine. We will also describe some system performance criteria so that you can check your favorite light engine design against some of the best in the industry and see how yours compares.

What is a TIR Prism?

TIR is the acronym for one of the key optical principles called Total Internal Reflection. When an electromagnetic wave or ray in our case encounter a surface with a different refractive index there will be refraction of the ray based upon Snell's Law.

$$nSin\theta = n'\,Sin\theta' \qquad Where\ n\ is\ the\ refractive\ index\ and\ \theta\ is\ the\ angle\ of\ incidence$$

The unprimed quantities are before and the primed quantities are after refraction.

When the rays go from rare to dense media where n < n' the ray will almost always get into the surface, for example going from air to glass. The magnitude of the reflected or transmitted ray of course changes with angle and also depends upon the polarization especially at higher angles of incidence.

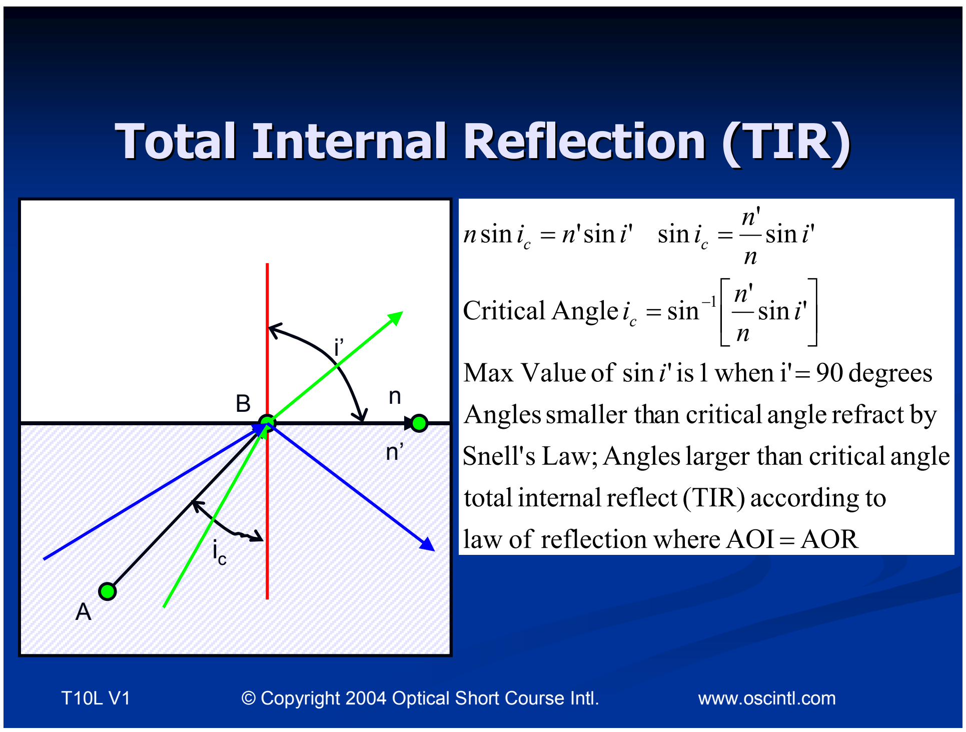

Figure 1. Total Internal Reflection
From OSCI DVD Course Top 10 Laws of Optics

You may recall that when an electromagnetic wave or ray in our case encounters an interface surface when going from dense to rare index of refraction where n' > n the ray will refract out of the dense material up to a certain angle. This angle is called the critical angle and is where the refracted angle is equal to 90 degrees. Angle of incidence above or greater than the critical angle will be 100% reflected from the surface and will obey the law of reflection. For more information about these laws see our DVD course Top 10 Laws of Optics.

In digital projector light engines there are two main types of prisms that work on the TIR principle and they are the TIR Prism and the Philips Prism. We will take a look at both of these prisms. The TIR Prism is most often used in single panel light engines using the TI DMD and is shown below in Figures 2 & 3.

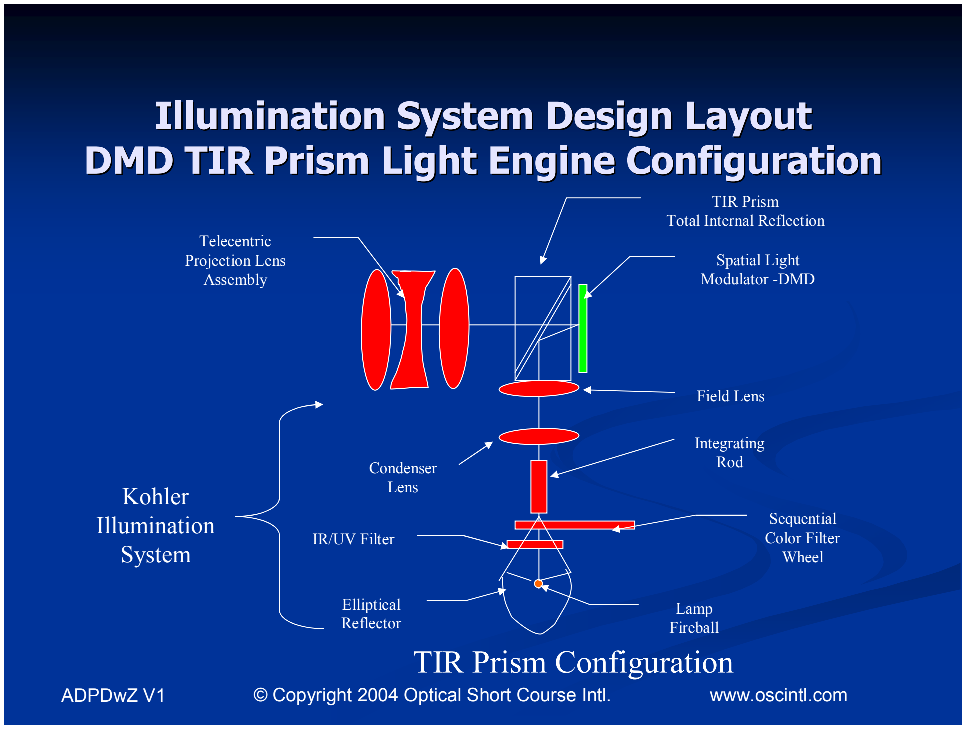

Figure 2. TIR Light Engine Layout
From OSCI Course Applied Digital Projector Design with Zemax

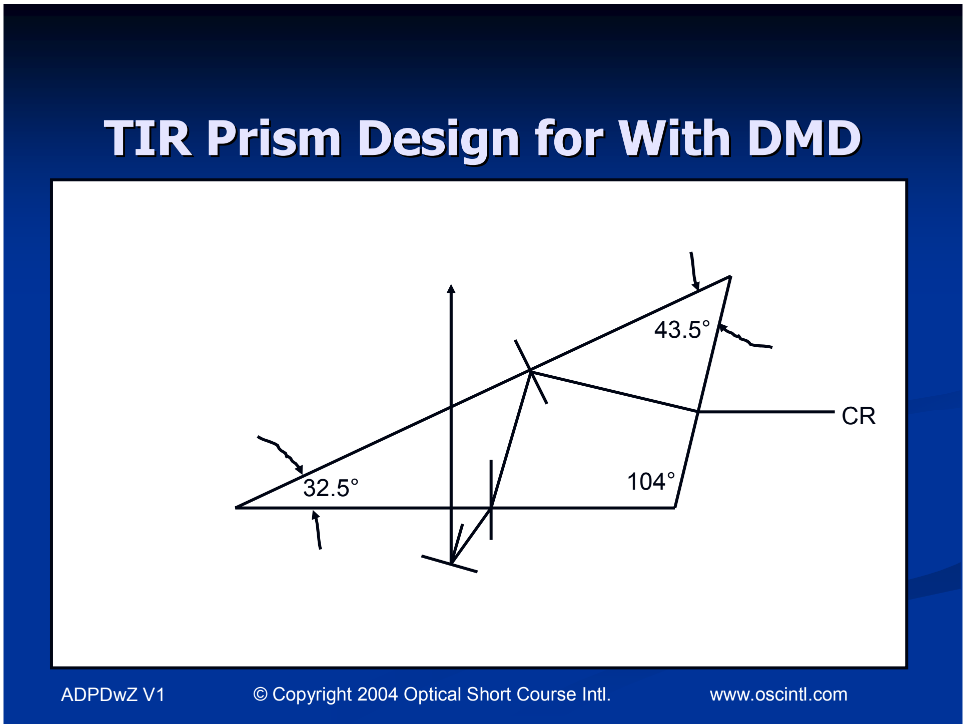

Figure 3. Lower Prism Layout and Angles
From OSCI Course Applied Digital Projector Design with Zemax

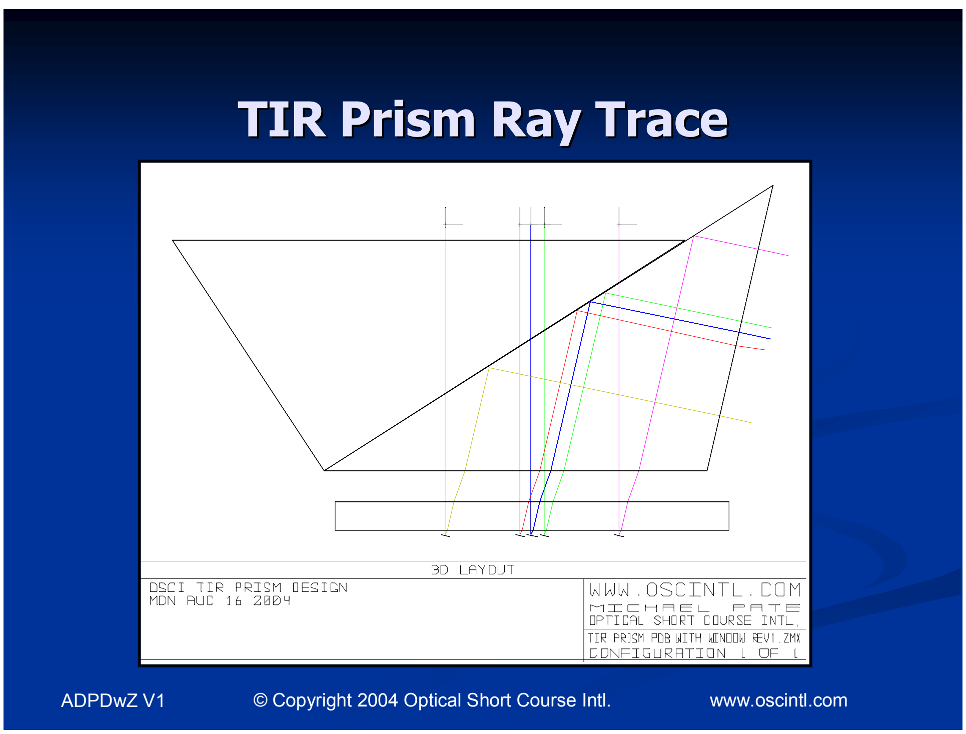

Figure 4. Full Prism Ray Trace
From OSCI Course Applied Digital Projector Design with Zemax

Transport Light to Illumination Plane

We must transport the light from the second focus of the elliptical mirror or the focal point of the objective lens with the parabolic mirror to the illumination plane. The illumination plane is where the spatial light modulator is located in a digital projector. As we learned in the previous section the irradiance is not spatially uniform at the focus of the light source mirrors and this must change so we can meet the uniformity specification of the illumination system design. We must spatially homogenize the irradiance and this is done by integrating rods and fly's eye arrays (see V1 No15 and 16).

If the light is spatially homogenized with an integrating rod the exit surface of the integrating rod can be thought of as the source and this source plane must be imaged onto the illumination plane with some magnification. If the fly's eye arrays are used the nonuniform beam from the parabolic reflector can be thought of as being spatially chopped up in an array and overlapped at the illumination plane to achieve the uniform illumination.

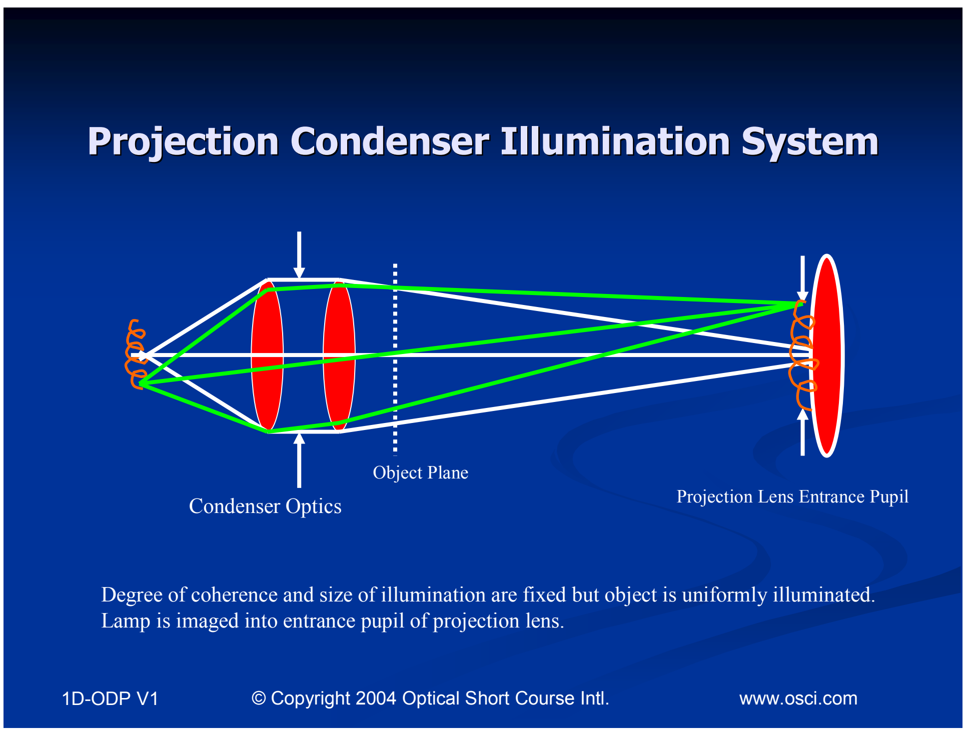

Figure 2. Projection Condenser Illumination System Layout

As a refresher I have included Figure 2 and 3 of the two main types of illumination systems from In The Box enewsletter volumes 18 and 19. If we were using an integrating rod to achieve the spatial uniformity the exit of the integrating rod would be the source shown on the left of each of these illumination system types. As we learned previously it is the job of the condenser lens assembly to capture the light from the source and get it moving down on the optical axis toward the illumination plane.

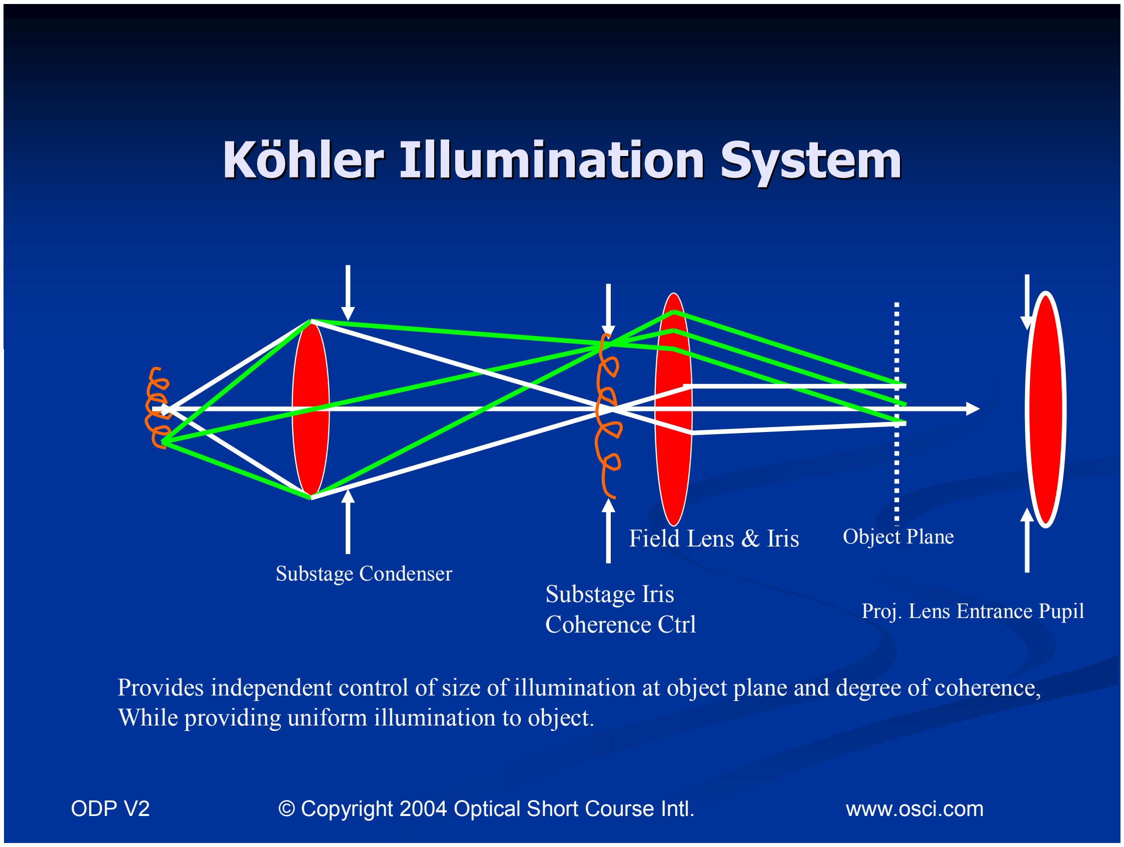

Figure 3. Köhler Illumination System Layout

If we consider the exit surface of the integrating rod our surrogate light source we will need to consider the size of this exit surface and the size of the spatial light modulator. One of the major illumination system design constraints is the illumination system magnification from the integrating rod exit to the spatial light modulator. Another constraint is the illumination system f/number that the spatial light modulator is illuminated with, as spatial light modulators can only use light within a certain f/number and angles below. Any angles in an illumination cone higher than the usable angles will be wasted light as they will not be transmitted through the system.

The illumination system f/number starts with the lamp reflector and gets maintained in the integrating rod, because these are just flat mirrors that do not change the angle out from the angle in, and flows through to the condenser lens and field lens to the illumination plane. All of these systems must play together as interdependent subsystem of the overall illumination system design. In addition to the magnification and f/number interaction there is also the overall length from source to illumination plane as well as optical element diameter limits, optical element f/number limits, system volume, spatial light modulator overfill ratios, along with illumination plane uniformity and symmetry requirements, not to mention system efficiency specifications. Yes this system does sound over constrained doesn't it? Better call a professional illumination designer to solve this problem and make the correct system design tradeoffs.

Illumination Plane Specifications

The illumination plane is where the spatial light modulators are located in digital projector light engines. At this plane we often have system illuminance level specifications as well as illuminance and color uniformity and symmetry. The illumination plane specifications are important because this is where the object will be located that the projection lens assembly projectors onto the viewing screen. The properties of the object are imaged or projected with high fidelity onto the viewing screen. The better the projection lens assembly design the higher fidelity image we will see on the viewing screen. Of course the projection lens assembly will have some affect on the image quality as will the properties of the object or spatial light modulator.

Summary

The illumination system design steps have been laid out and discussed. We have seen how starting with the bulb reflector and marching down the illumination system optical path many of the design parameters are interrelated. We have seen how the limiting angles in each part of the illumination system can affect the light engine illumination system efficiency. The many interrelated factors of illumination system design tradeoffs have been discussed and presented as well as a key criterion of how to compare light engine efficiencies.

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 "In The Box" to understand the optics of digital projectors. If you enjoy increasing your knowledge about digital projector optics please tell a friend about this e-newletter, your referral is the kindest compliment we can get to show your appreciation.