Digital Projector Design with FRED™

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Introduction

The optical design and analysis of a digital projector light engine from the plasma fireball of the lamp through the illumination system, the spatial light modulator, and imaging system to the screen is a complicated performance feat for any design software. It is part illumination system design, part optical MEMS design, part imaging design, polarization design and analysis, color design and analysis, some scattered light analysis, and some opto-mechanical design. This is a tall order for any one piece of optical engineering software and FRED™, from Photon Engineering, is up to these tasks as we will describe to you in this white paper.

Light Source Design & Modeling

With FRED™, one has the capability to design the light source assembly by building the source opto-mechanical structure piece by piece and assigning to each piece the correct optical properties. It is important for each piece to have the correct optical properties so that each part of the opto-mechanical structure can interact with the light, by reflection, refraction, transmission, scatter, and diffraction, that is incident upon it. If one already has a mechanical design CAD model of a light source these CAD files can be imported into FRED™ and each piece is then assigned the correct optical properties. In Figure 1, we show an example of an arc lamp which has been imported as a CAD file and given the correct optical properties to each piece.

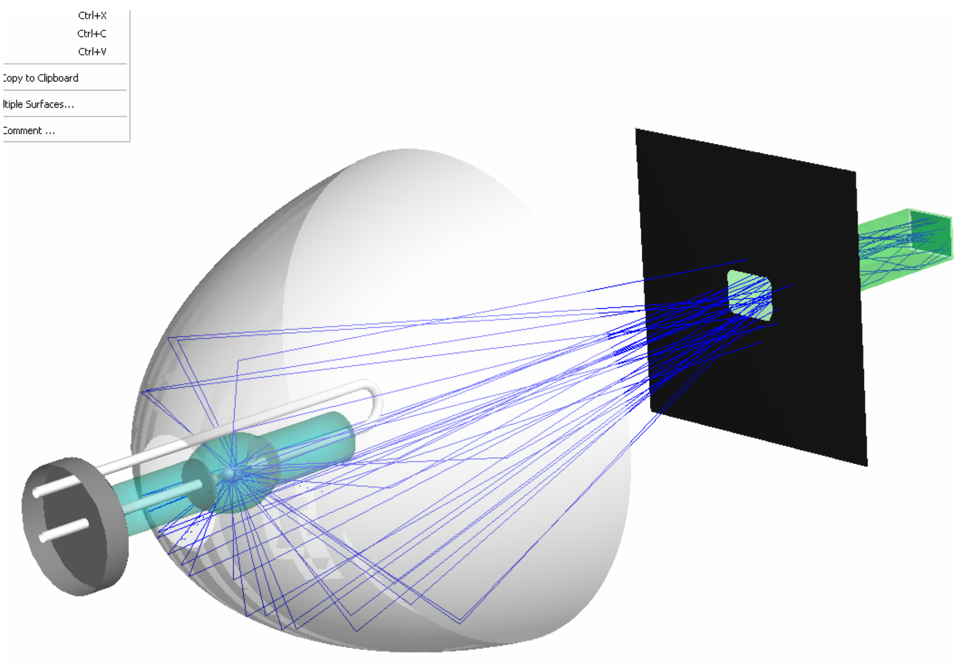

Figure 1. CAD File of Lamp and Elliptical Reflector in FRED™

If you are lucky enough to have a CAD file of the lamp and reflector from your lamp supplier then you can start you illumination design with this vendor supplied file. One large note of caution is to make sure you understand the manufacturing tolerances on the opto-mechanical structure of the lamp and model these variations in your illumination design and understand how they affect the illumination performance parameters. As you can guess most vendors will not share their manufacturing and alignment statistics so you are left to guess at them or make some informed judgments and model these yourself.

Another method of starting an illumination design is by measuring a light source assembly in a source measuring goinometer which measures the radiance of the source as a function of azimuth and elevation angles around the source. This radiance map is used to create a ray distribution file which can be imported into FRED™. The ray distribution file is a file of 1 ray to 10 billion rays which is user selectable. The rays represent the radiance of the measured light source assembly and are created on a user selectable surface or volume such as a plane, sphere, ellipse, cube, cone, cylinder, etc.

In order to read in a ray distribution file in FRED™ you will need to select New, Fred Type file, and select Sources by clicking on the Sources Folder, then right click on Sources Folder and select Create A New Detailed Optical Source and you should have an input menu that looks like Figure 2 below. Next select the Position/Directions tab and from the Ray Positions section and the Type pull-down menu choose the User Defined Rays type. Now hold your mouse over any of the parameters such as X Pos or Y Pos (do not click these) right click and select Replace With Rays From a File and this will open a dialog box where you can select your ray distribution file types. Currently with Version 3.50 FRED™ supports FRED Binary and Generic Text, TracePro, Zemax, OPTICAD, LightTools, and Lucid Shape file formats (note other formats most likely fit the FRED Binary or Generic Text formats – Phone or Email Photon Engineering to make sure).

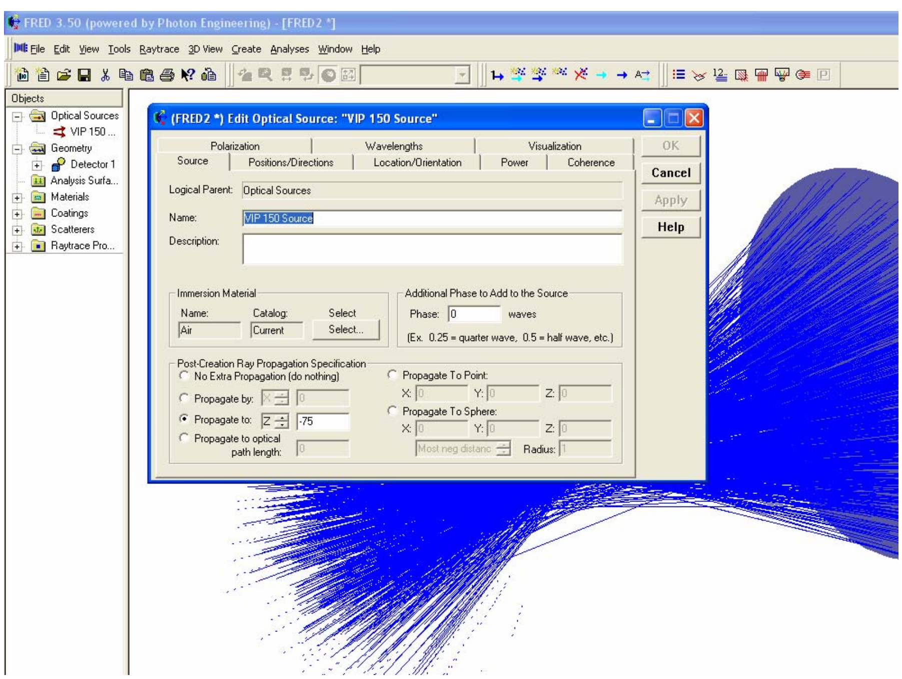

Figure 2. Create A New Detailed Optical Source Dialog

After you select your file you will be given a choice to select every ray or every nth ray and then when you hit the ok button it will read in all of the rays and you can inspect them in the dialog. This now gives you a ray distribution to start your illumination design from and you can position this source at any location like any other FRED™ element. I like to move all of the rays from the file to a particular plane in the Z direction, say to Z = -75mm, then when I trace the rays they will all appear to come from Z = -75 mm and trace in the positive Z direction as default or what ever direction I choose. This movement of the rays is done on the Source Tab in the Post-Creation Ray Propagation Specification area; in this example I choose Propagate To Z -75. In Figure 3 you can see the results of this example ray distribution file where all of the rays have been propagated to Z = -75 and are then traced to an elliptical shaped detector plane at Z = 50, I also have changed the rays to a blue color, and only traced every 10th ray for improved visualization. This ray distribution file is from a mercury arc lamp with an elliptical reflector and this is why you see the ray converting to a focus and then diverging again. It is at this focus where one would put the entrance to an integrating rod to spatially homogenize the light source.

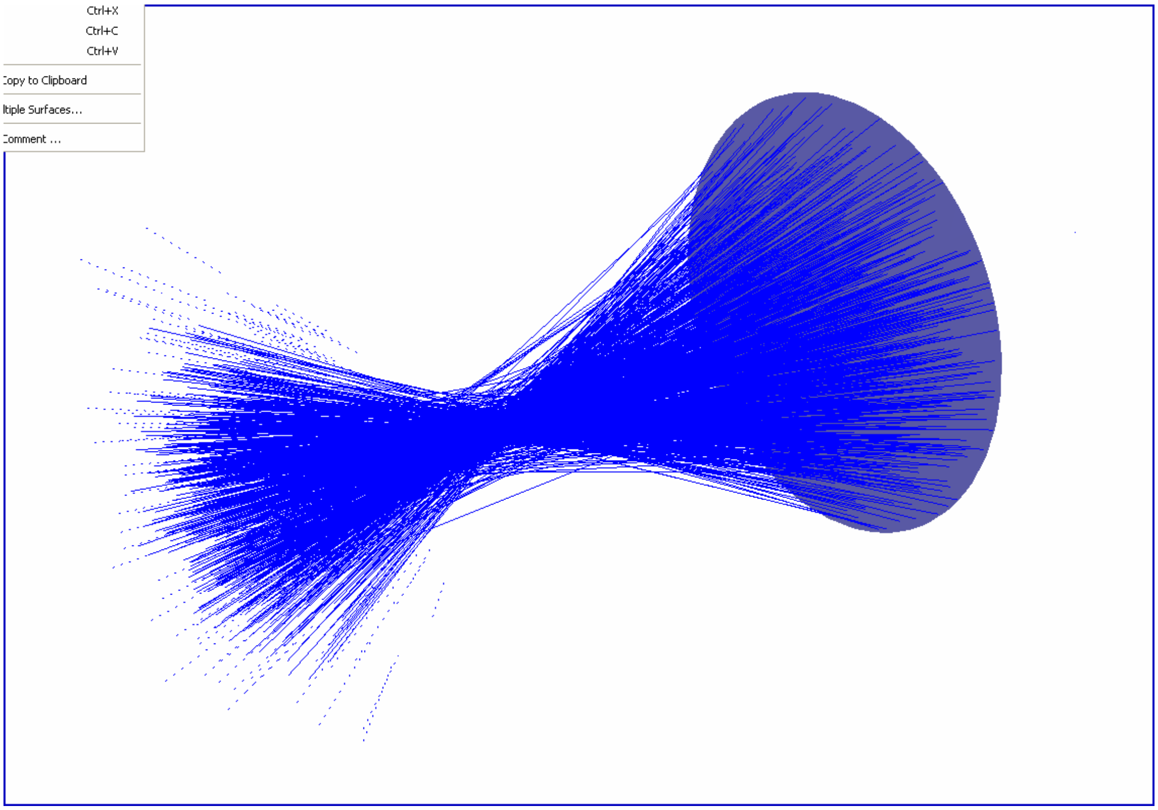

Figure 3. Ray Distribution File with Rays Moved to Z = -75 and Traced to Detector Surface

Illumination Homogenization

If we look at the spatial irradiance profile of a spot of light from a focused elliptical reflector, parabolic reflector, or most other types of light sources we will find that they have a Gaussian type spatial irradiance profile. In many illumination design specifications the requirement is for a spatially uniform irradiance profile on the illumination plane. The illumination plane is often rectangular in shape as well and most light sources have a circular collection aperture and provide a circular irradiance pattern.

Illumination homogenization or uniformization is accomplished using optical devices called integrating rods and fly's eye homogenizers. Integrating rods are also known as light pipes and work on the principle of reflection. Fly's eye homogenizer arrays work typically on refraction. The design objective for both of these devices is to provide a spatially uniform illumination pattern that is rectangular in shape at the illumination plane. In digital projector the spatial light modulator, such as the Digital Micromirror Device or DMD, LCD, or LCoS panel, is located at the illumination plane.

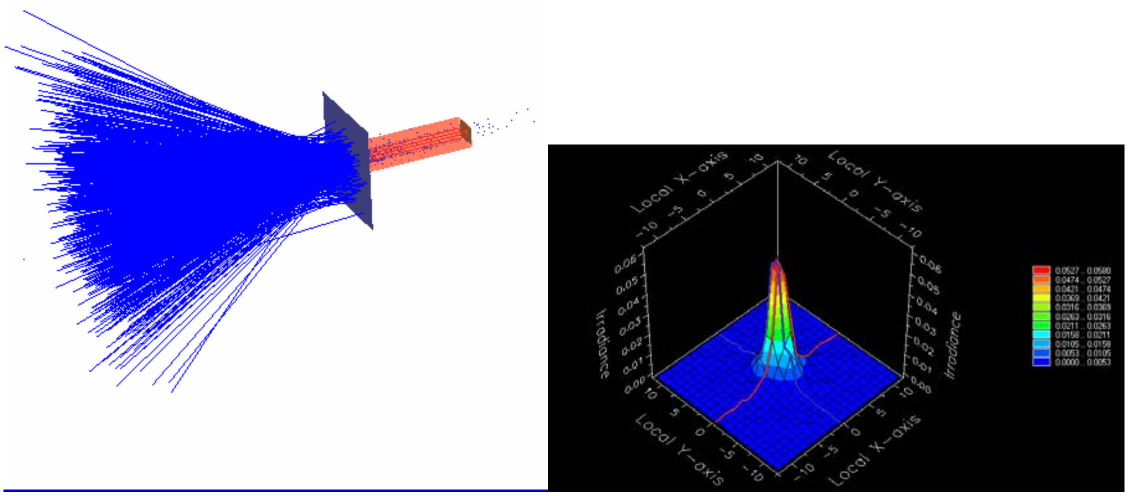

Figure 4. Irradiance at Integrating Rod Entrance Aperture is Gaussian Distribution

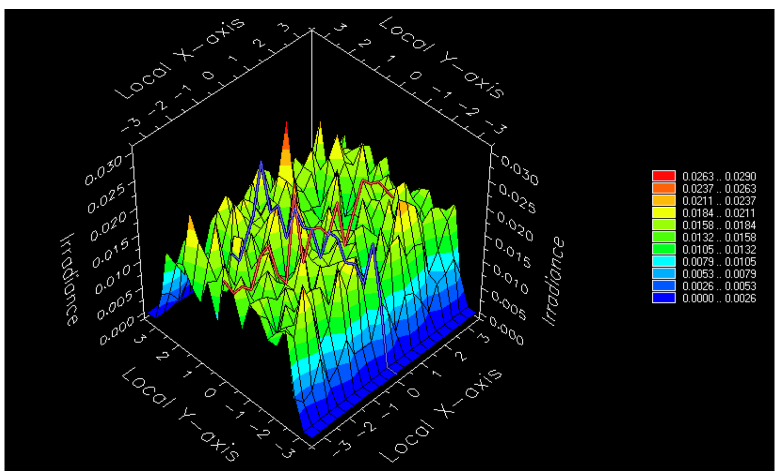

Figure 5. Uniform Spatial Distribution at Integrating Rod Exit Aperture

It is clear from Figure 4 that the spatial distribution of light at the entrance of the integrating rod is Gaussian shaped. After the light enters the hollow integrating rod (made from four front surface mirrors facing inward) and has multiple bounces that the light becomes spatially homogenized. A big part of the homogenization comes from the internal corners and skew rays being spatially relocated at the exit end of the integrating rod.

Figure 6 show a fly's eye array along with a condenser lens which is used to illuminate a transmissive LCD panel or an LCoS panel in a digital projector light engine. FRED™ has an easy input for the development of fly's eye array lenses. The first step is to input an optical surface as normal, in this case I choose to use an XY Toroidal Aspheric surface type, input the X and Y radii and aspheric coefficients, and then set the rectangular aperture size for a single element in the array. After the individual array surface has been input you right click on this surface in the objects, geometry director and choose the Edit/View Array Parameters. This will open the Array Parameters dialog box where you can input the array spacing and array display properties. This dialog is quite powerful in creating the arrayed optical surface you need for illumination system design and analysis. You can tell a particular surface is an arrayed element by the matrix icon next to the particular surface in the objects, geometry tree.

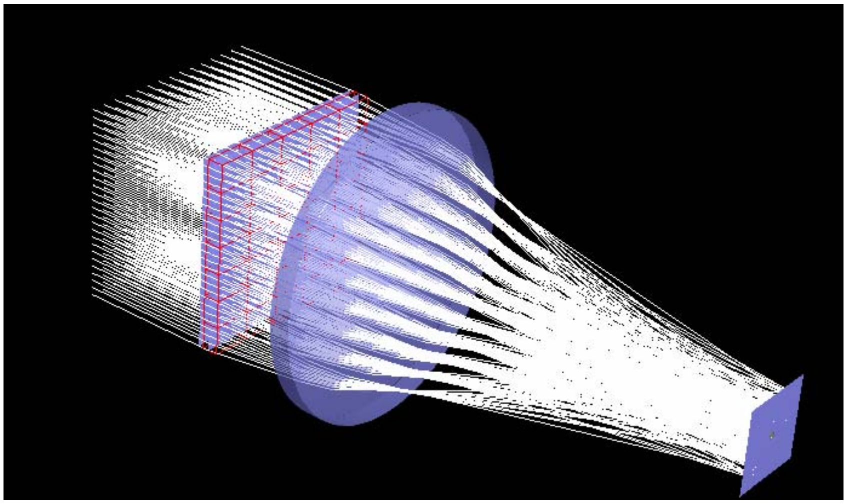

Figure 6. Fly's Eye Array Illumination System on LCD Panel

Modeling Polarization Components for LCD and LCoS Light Engines

Optical system that operate on the principle of polarization and polarization rotation such as LCD and LCoS spatial light modulator require polarization analysis of the light engine during design and analysis activities. FRED™ has the capability to model and analyze sophisticated sequential and non-sequential polarization components such as polarization conversion arrays in LCD projectors and wire grid polarizers in LCoS light engines.

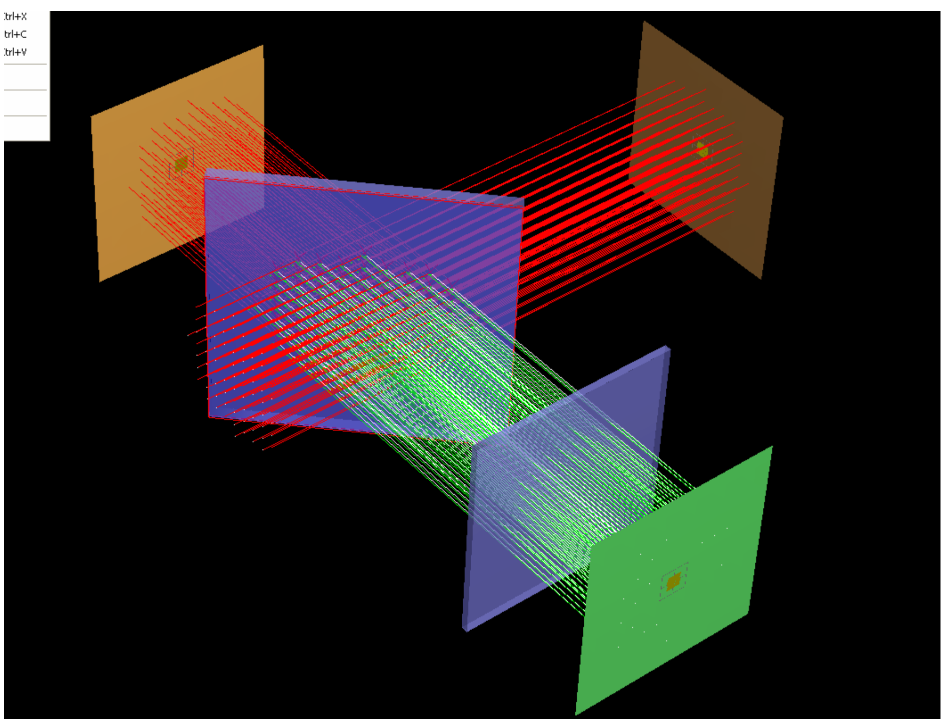

Figure 7 ProFlux™ Wire Grid Polarization Model

In Figure 7 we show a model of a wire gird polarizer such as the ProFlux™ wire grid from Moxtek. The optical performance and polarization properties were modeled in FRED™ by using what is called a General Sampled Coating type. A General Sampled Coating is created in the coating tab on the surface properties dialog and allows one to specify the reflected S and P and the transmitted S and P polarization as a function of wavelength and angle of incidence. The program interpolates between these values and uses the nearest values for wavelengths and angle outside those specified. The actual thin film coating can be used in FRED™ if the design exists.

FRED™ can do polarization analysis of systems by specifying the polarization of the light source in the polarization tab of the light source properties dialog box. The detectors can be used to perform a polarization analysis to understand orientation and combined with an irradiance analysis the magnitude of the polarization.

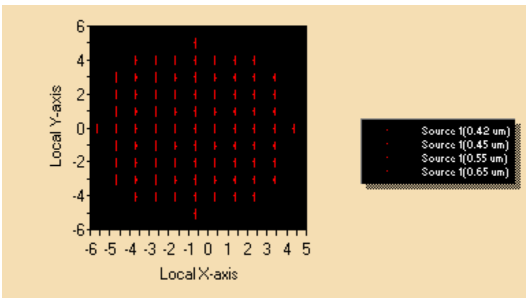

Figure 8 Reflected Detector Polarization

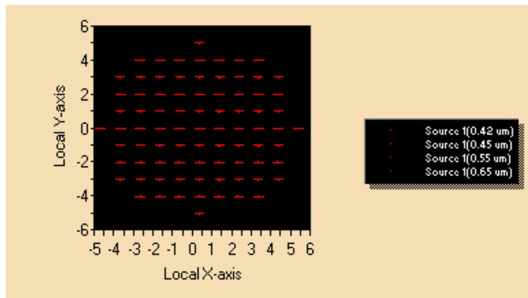

Figure 9 Transmitted Detector Polarization

In Figure 10 we show a layout of an LCoS light engine. In this engine we can see the dichroic split into the blue and yellow (red + green) channels and the red/green split further down the

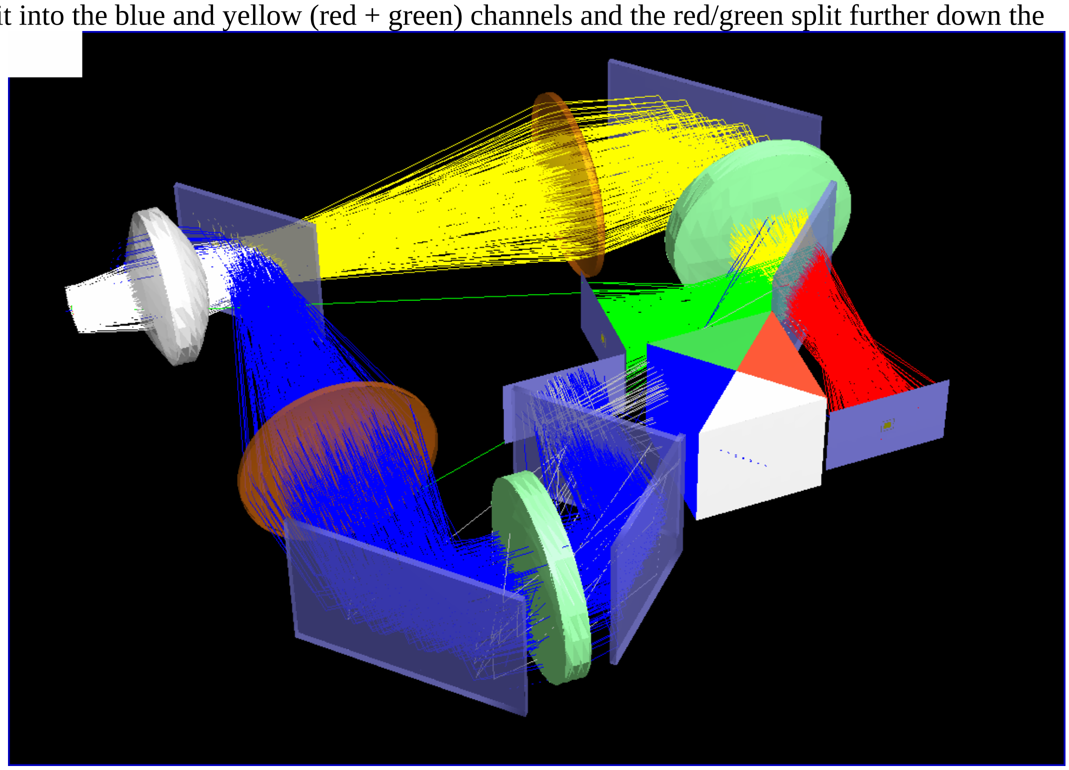

Figure 10. LCoS Light Engine Illumination Module with Wire Grid Polarizer

optical path. We can see the field and relay lenses in each path, these lenses are similar and so in the visualization properties they have been shaded the same color in FRED™ to signify similarity. Only one wire grid polarization has been shown in the blue channel for clarity. After reflection from the LCoS spatial light modulators the light will reflect from the wire grid polarizer and enter into the x-cube type prism for recombination and delivery to the projection lens assembly (not shown for clarity).

Spatial Light Modulators

The spatial light modulator is the device in a digital projector where the digital image is created. The spatial light modulator is illuminated with spatially uniform light from the illumination system and if the particular pixel in the modulator panel is supposed to be turned on it will reflect or transmit light through the projection lens to the viewing screen. There are three main types of spatial light modulators: DMD, LCD, and LCoS. The Digital Micromirror Device works on reflection and it has an array of small mirrors as the name denotes. The Liquid Crystal Display and the Liquid Crystal on Silicon work on polarization with the LCD working in transmission and the LCoS working in reflection.

To model these types of spatial light modulators in FRED™ we need to create a single element of the modulator array by designing a mirror or polarization cell. After we create the single element mirror or polarization cell we can then use the array command and array the element with the correct spatial orientation in the array. The polarization modulators are typically used on axis where their array surface is perpendicular to the optical axis of the spatial light modulator. In the case of a DMD in some light engine configurations the optical axis of the illumination system is incident at a compound angle to the modulator surface. This compound angle can be input to the array surface as well as the proper mirror tilt angle of + or – 10 or 12 degrees.

Let's take a look at a DMD mirror array design example. The individual micro mirrors are 14 microns square (I know they are 13.68 but what is a couple of 100 nanometers among friends) on a 14 micron pitch in both the X and Y directions. We can create a New Mirror in the geometry tree and give the mirror 7 micron semi-apertures in each direction, you need to go into the advanced button and change the mirror aperture shape to a rectangle from the default elliptical. If you want the modulator to have a tilt with respect to the optical axis of the illumination system you would input that in this window. The DMD tilts along an axis that connect two opposite corners of the mirror and this tilt is input by putting a Rotation about X, Y, and Z axis.

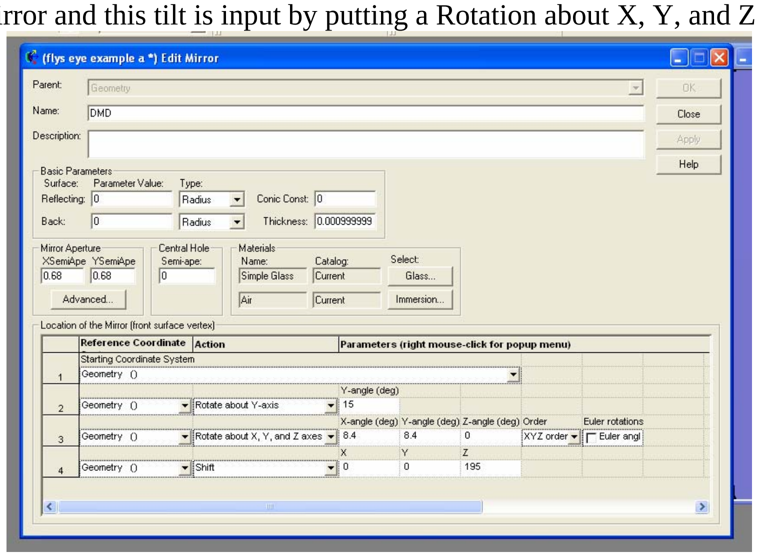

Figure 11. Mirror Input Menu for DMD Mirror

After one mirror is input you can also go into the coating/material tab and change the color of the rays upon reflection to help with the visualization. You might want to make the mirror aperture very large for easy visualization during the initial design and then shrink it to actual size later in the development process. After the mirror has been created and verified you can array the mirror to the size of array that you want. I prefer to work with smaller subsection of the whole array initially, like a 10 x 10 or 20 x 20 section. In Figure 12 we show a 10 x 10 array of micro mirrors, note the whole array has been tilted with respect to the optical axis of the illumination system.

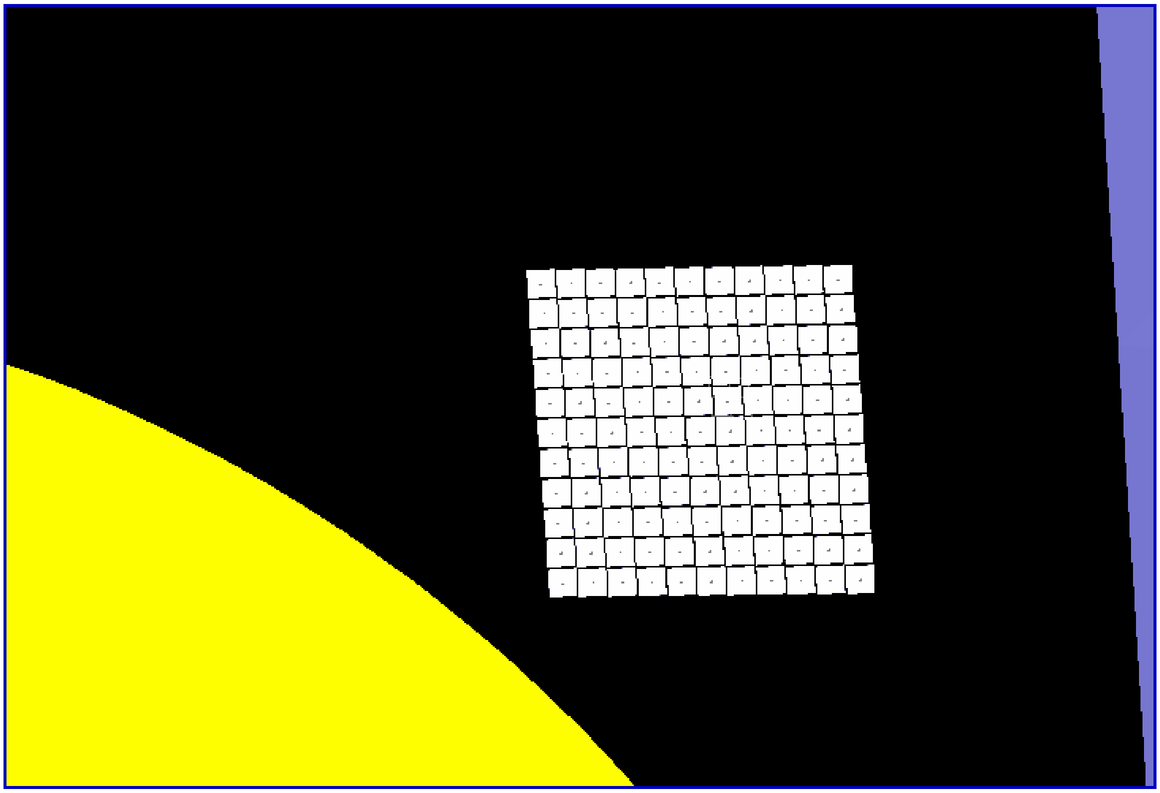

Figure 12. View of 10x10 Subsection of DMD Mirror Array

In Figure 13 below, you can see the incoming rays from the illumination system in white and the reflected rays from the micro mirror arrays in red. The rays leaving the micro mirror array are either going into the projector lens assembly and onto the screen or if the mirror are tilted to the off state the rays will go into the beam dump.

In addition to the illumination system and imaging system design and analysis FRED™ can also be used to investigate the scattered light and stray light analysis which reduces the image contrast on the viewing screen. The stray light and scattered light analysis capabilities of FRED™ will be discussed in another white paper.

Conclusion

FRED™ from Photon Engineering has the capability to design and develop all types of digital projector light engines, LCD, LCoS, and DMD. FRED™ can start with a measured ray distribution model, a CAD model, or a individually built light source model and perform an illumination design and analysis to capture and deliver the light to the modulator. The program has the capability to model and analyze the illumination system performance including coating, polarization conversion components, wire grid polarizers, fly's eyes arrays, dichroic coatings, as well as spherical and aspheric lenses and mirrors. The detectors help perform spatial uniformity and color uniformity calculations to understand how well your illumination system and imaging system will project uniform illumination and color onto the screen.

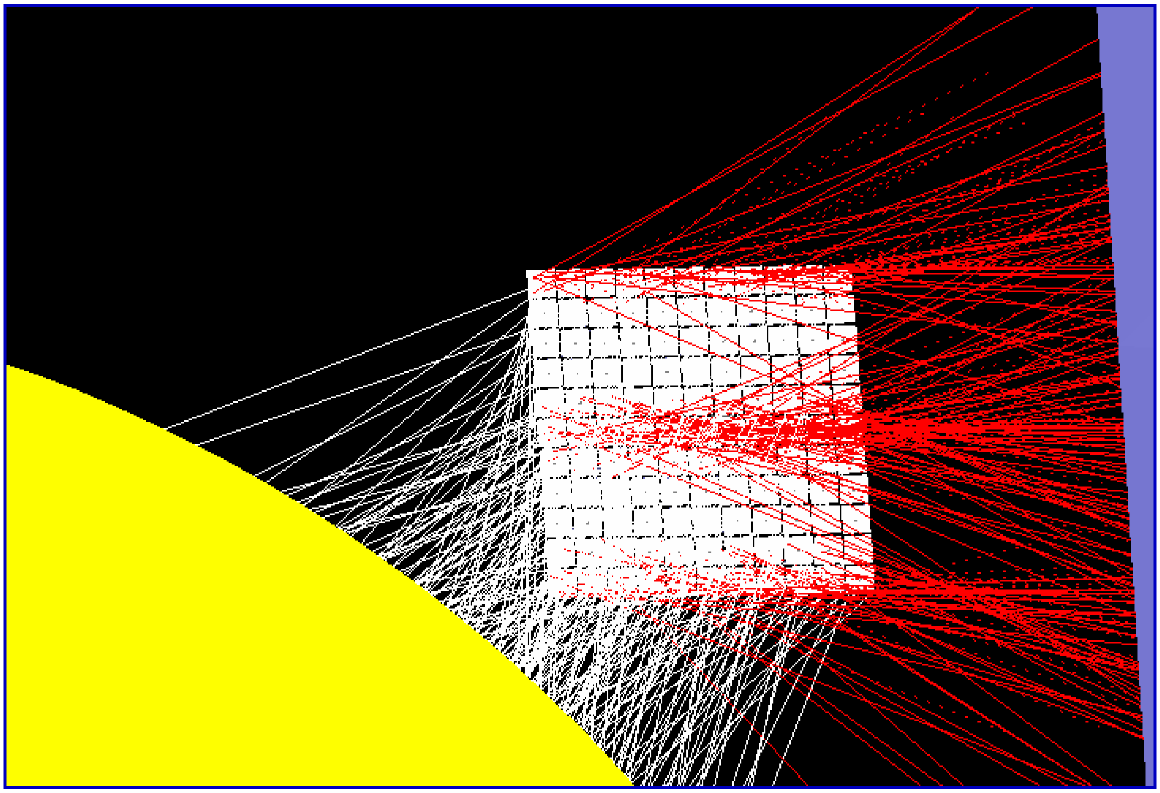

Figure 13. Incoming White Illumination Rays and Outgoing Reflected Red Rays

FRED™ also has the capability to visualize and enhance the graphical display of the opto-mechanical system to improve the clarity of your presentations to customers and managers. If you need to perform other important illumination design, optical design, scattered or stray light analysis FRED™ has a scripting language to extend the capability of the program even further. If you need to design or analyze a digital projector light engine or other illumination system give FRED™ a try.