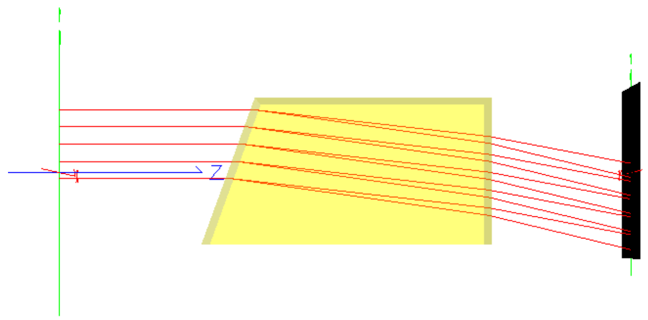
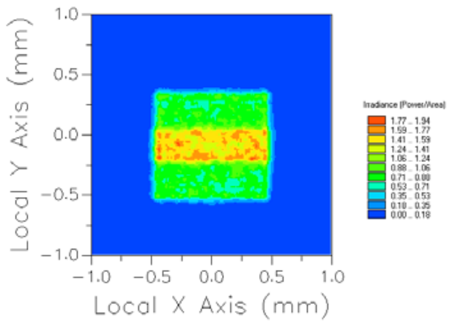
FRED Polarization Application Note





Introduction

FRED has the capability to simulate polarization of rays through an optical system. Light sources can be randomly, circularly, or linearly polarized. Optical components that filter or manipulate polarization, such as birefringent wave plates and polarizers, can be accurately modeled. In this application note, some simple examples of polarization modeling in FRED will be explored, including absorptive dichroic and wiregrid polarizers, a calcite half-wave plate, and the Maltese cross phenomenon. Each of these features can be applied to more complex optical systems such as Liquid Crystal Displays (LCDs), interferometers, and polarization microscopes.

Example 1: Polarizers

Consider a simple polarizer system, consisting of randomly-polarized rays followed by a dummy surface, an x-polarizer, and a detector surface. Create a coherent detailed optical source with an elliptical grid plane of 10 x 10 rays traveling in the z-direction. Under the polarization tab, select “Polarized” and choose “Randomize” for Ellipticity, Handedness, and Angle of Polarization Ellipse. The dummy and detector surface are elliptical planes with “Absorb” coating and “Halt All” raytrace control. Analysis surfaces are assigned to each plane.

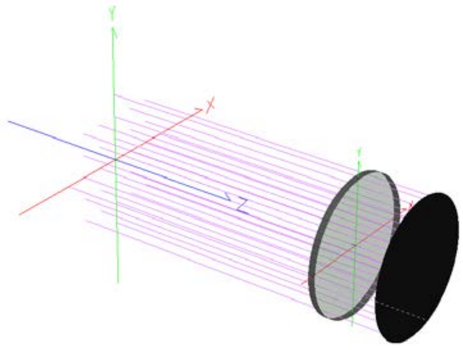


Figure 1. Randomly polarized light is filtered through an x-polarizer and collected by a detector.

There are two methods to model a polarizer. The simplest technique is to add a polarizer coating to a surface. In the Coatings category of the FRED document, right-click and select *Create a New Coating…*. Under the drop-down menu, select "Polarizer/Waveplate Coating (Jones Matrix)". Choose the "X Linear Polarizer" coating type and assign it to the polarizer surface.

A more accurate technique is to model absorption-based polarization in a custom material. In the Material category of the FRED document, right-click and select *Create a New Material…*. Under the drop-down menu, select "Sampled Birefringent and/or Optically Active Material". The material must have differing real refractive index components, and may also have differing imaginary refractive index components. Orient the crystal axis in the local +X direction (1,0,0). An absorptive dichroic x-polarizer could be modeled with n_o=1.61, n_e=1.65, k_o=100, k_e=0. A wiregrid x-polarizer can be modeled with n_o=1, n_e=1.001, k_o=100, k_e=0. The imaginary refractive index indicates absorption. In this case, ordinary components of polarization (perpendicular to the crystal axis) are absorbed, leaving only polarization components along the +X crystal axis.

Polarization Spot Diagram

To monitor polarization of light through a system, an analysis surface can be used to produce a polarization spot diagram. After a raytrace is performed, navigate to *Analysis → Polarization Spot Diagram…* The polarization of each ray with respect to the analysis surface will be symbolized as an ellipse with an arrow to designate handedness. If the z-axis of the analysis surface is aligned with the direction of ray propagation, handedness is determined by aligning your thumb in the direction that the ray is coming from and applying the right hand rule. For example, if a ray is propagating along the global +Z-axis and the analysis surface +Z axis is pointed in the same direction, align your thumb along the global -Z axis and apply the right hand rule to determine handedness of the ray.

As expected, rays coming from the light source have random polarization (Figure 2). After tracing rays through the x-polarizer to the detector, generate a new Polarization Spot Diagram to confirm that only x-polarized ray components propagate through the polarizer.

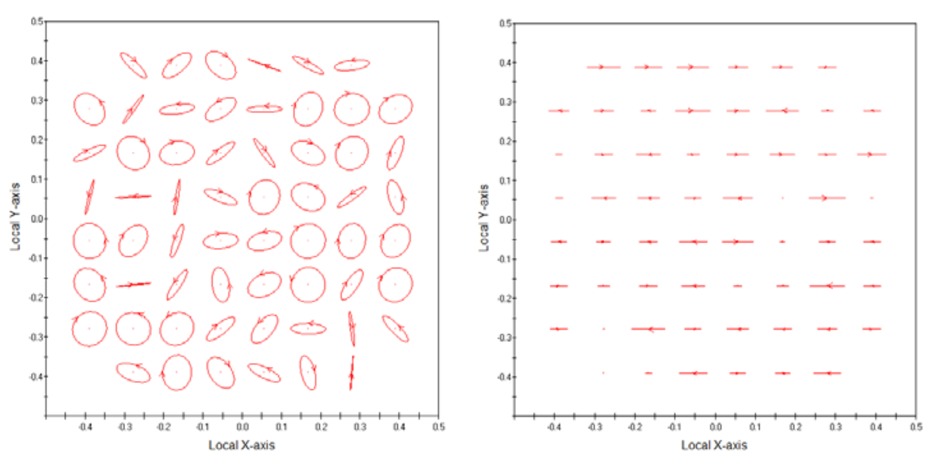


Figure 2. Polarization Spot Diagram. Left side: randomly-polarized light before entering the x-polarizer. Right side: x-polarized components of the rays pass through the polarizer and y-polarized components are absorbed by the polarizer. In the case of random incident polarization, ~50% of the incident power will be collected by the detector.

Example 2: Wave Plates

Wave plates are made from materials that have different real refractive index values for ordinary and extraordinary rays. Oriented properly, the wave plate can shift one polarization component of light with respect to another, transforming its polarization state. Quarter-wave plates change linear to circular polarization and visa-versa. Half-wave plates change x-polarized light into y-polarized light or RHC into LHC polarized light.

Start with the FRED system in Example 1, and create a wave plate element after the x-polarizer (Figure 3). There are two methods to model a wave plate. The simplest method is to assign a ½ wave plate coating a surface. Under the Coatings category of the FRED document, right-click and select *Create a New Coating…*. Under the drop-down menu, select “Polarizer/Waveplate Coating (Jones matrix)”. Choose “1/2 wave +45 Fast Axis” for the coating type. This ensures that the wave plate crystal axis is rotated at 45 degrees with respect to x-polarized incident light.

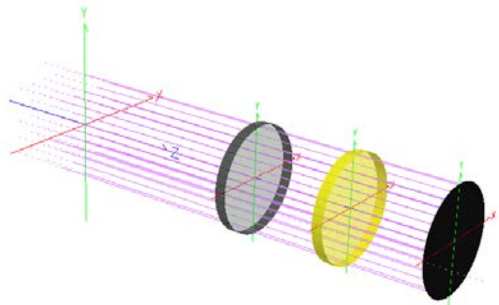


Figure 3. Randomly polarized light is filtered through an x-polarizer. The remaining light passes through a +45° ½ wave plate (yellow), which transforms x-polarized light into y-polarized light.

A more accurate approach to model a wave plate is assign a custom birefringent material to a rod element. Under the Material category of the FRED document, right-click and select *Create a New Material…*. Under the drop-down menu, select “Sampled Birefringent and/or Optically Active Material”. Orient the crystal axis to +45° (0.707,0.707,0). Assign the following properties to the material (based on a calcite crystal): Wavelength=0.59 µm, n_o=1.658, n_e=1.486, k_o=0, k_e=0.

To function as a ½ wave plate, the length of the rod must be chosen such that the ordinary and extraordinary polarization components are displaced by a net value of ½λ:

$$L = \frac{\lambda(K + \frac{1}{2})}{n_o - n_e}$$

Where L=rod length, λ is light wavelength in *system* units, K=an integer, and n_o and n_e are ordinary and extraordinary components of the birefringent index of refraction. A coherent raytrace through this volume birefringent material will split each ray into ordinary and extraordinary components. As a result, the Polarization Spot Diagram will display each separate component (Figure 4).

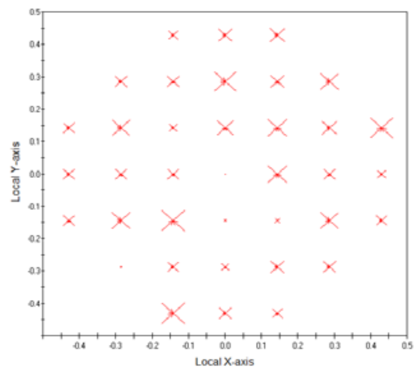


Figure 4. Polarization Spot Diagram after x-polarized light passes through a calcite ½ wave plate. Ordinary and extraordinary components of the polarization are plotted as separate rays.

To ensure that light is indeed y-polarized, view the Coherent Vector Wave Field at the detector surface. Right-click the graph and click “Show X Component of Field”. Then, right-click “Show Statistics” and observe the integral of energy in the x-polarization component. Do the same for the y-polarization component. Nearly all incident energy should be in the y-polarization component. Additionally, you can check polarization at the detector by combining split rays (right-click graph and select *Coherent Field Operations→Synthesize Field…*) and re-evaluating the Polarization Spot Diagram.

The thickness of the wave plate determines the fraction of x- and y-polarized light that reaches the detector. To illustrate this, the rod wave plate is replaced with a 3° wedge of calcite. X- and y-components of the coherent field are shown in Figure 5.

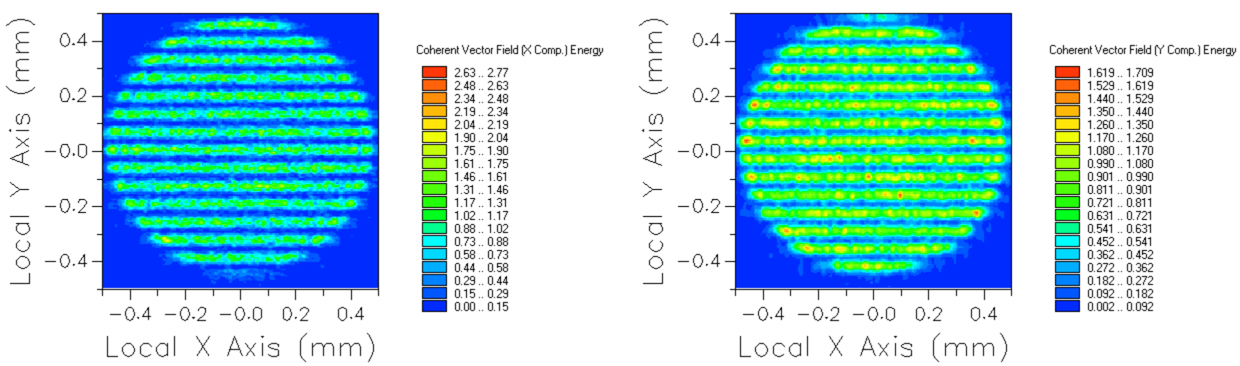


Figure 5. X- and y-components of the coherent vector field upon detector after x-polarized light passes through a wedge calcite crystal with +45° optical axis. The waveplate thickness varies along the y-dimension, and thus acts as a ½ waveplate at periodic locations along the wedge.

Example 3: Maltese Cross Phenomenon

The Maltese Cross is an interference figure formed by birefringent materials place between crossed linear polarizers. This phenomenon allows easy identification of birefringent specimens found in nature such as plankton, starch grains, and fatty molecules. A Maltese cross can also form when an expanding beam of locally y-polarized light passes through two orthogonally-oriented linear polarizers. Figure 5 shows a system set up in FRED to simulate irradiance just beyond the crossed polarizers.

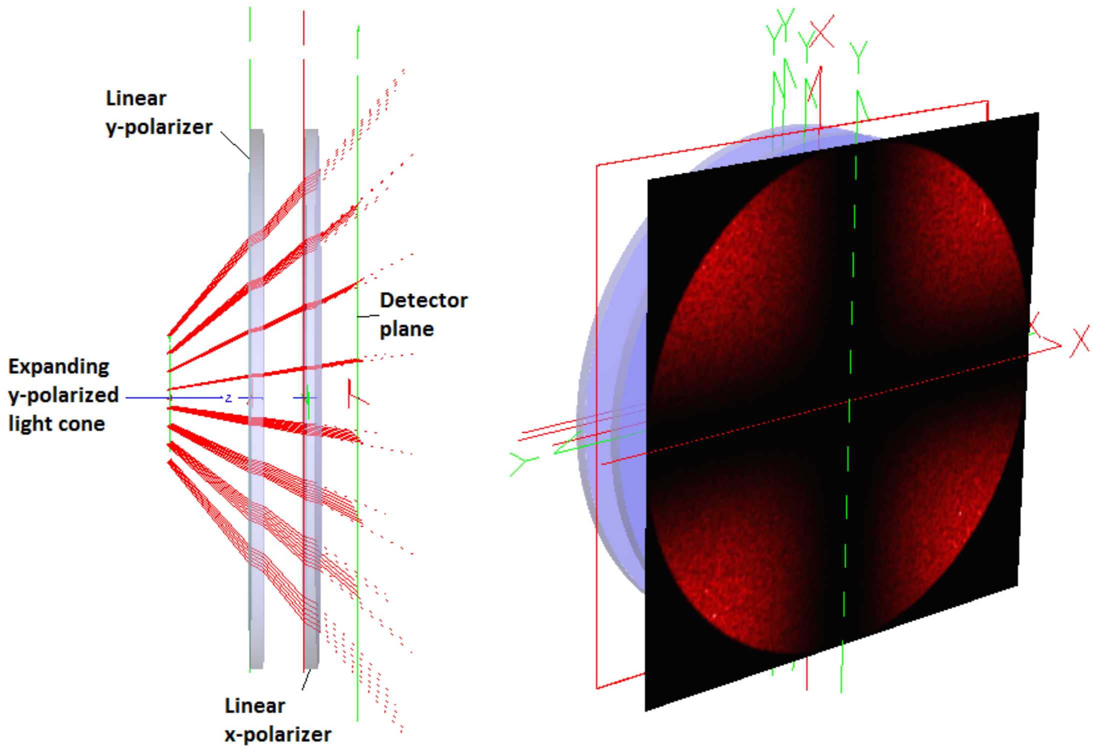


Figure 6. Maltese cross. Left side: cross-section of system. Right side: irradiance pattern on detector.

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