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How to model laser beam propagation in OpticStudio: Part 3 - Using Physical Optics Propagation to model Gaussian beams

Zemax OpticStudio

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This article is part of the [Tutorial Series] Modeling Laser Beam Propagation in OpticStudio free tutorial.

Three tools can be used in OpticStudio sequential mode to model Gaussian beam propagation. They are:

- the ray-based approach
- Paraxial Gaussian Beam analysis
- Physical Optics Propagation

In this series of three articles, we'll discuss how to set up a Gaussian laser source, how to analyze the beam as it propagates through the optical system, and how to optimize for the smallest spot size using these three methods. We'll also discuss when is appropriate to use which methods.

This article is part 3 of the series focusing on how to use the Physical Optics Propagation tool to model Gaussian beam, and when to use which tool.

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Introduction

Laser engineers often find it necessary to model laser beam propagation in an optical system. Different from the ray-based approach, Physical Optics Propagation (POP) models laser beams by propagating a coherent

Physical Optics Propagation

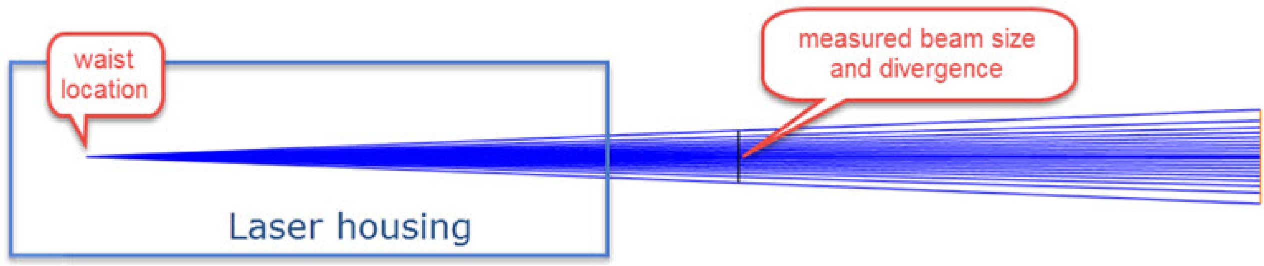
Physical Optics Propagation models optical systems by propagating wavefronts. The beam is represented by an array of discretely sampled points, analogous to the discrete sampling using rays for geometric optics analysis. The entire array is then propagated through the free space between optical surfaces. At each optical surface, a transfer function is computed which transfers the beam from one side of the optical surface to the other. Because the beam is described by its full complex-valued electric field in the array, Physical Optics Propagation allows very detailed study of arbitrary coherent optical beams, including Gaussian or higher order multi-mode laser beams of any form (beams are user definable), or diffraction effects far from focus, or effects of finite lens apertures, such as spatial filtering. This article will not get into the details of how to use Physical Optics Propagation tool. Users are recommended to read the series of three Knowledgebase articles that discuss the tool in detail at, Using Physical Optics Propagation (POP), Part 1: Inspecting the beams.

Example

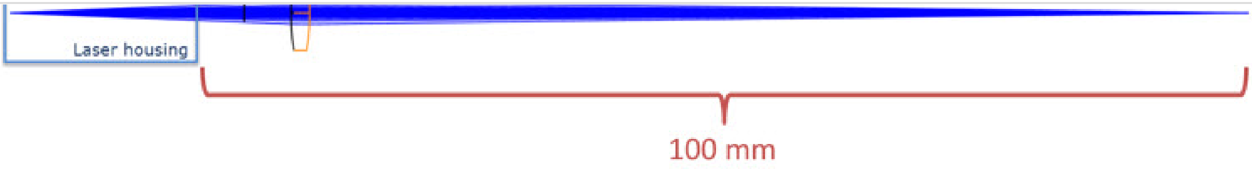
We'll tackle the same problem as described in part 1 and 2, design a laser beam focusing system using a singlet lens at 100 mm away from the laser output.

The specifications are the same:

- Nominal Wavelength = 355 nm
- Measured 5 mm from laser output:
  - Beam diameter = 2 mm
  - Measured divergence = 9 mrad



Knowing the wavelength and the far field divergence angle of a Gaussian beam, the beam waist is calculated to be 0.0125 mm, with a Rayleigh range of 1.383 mm.

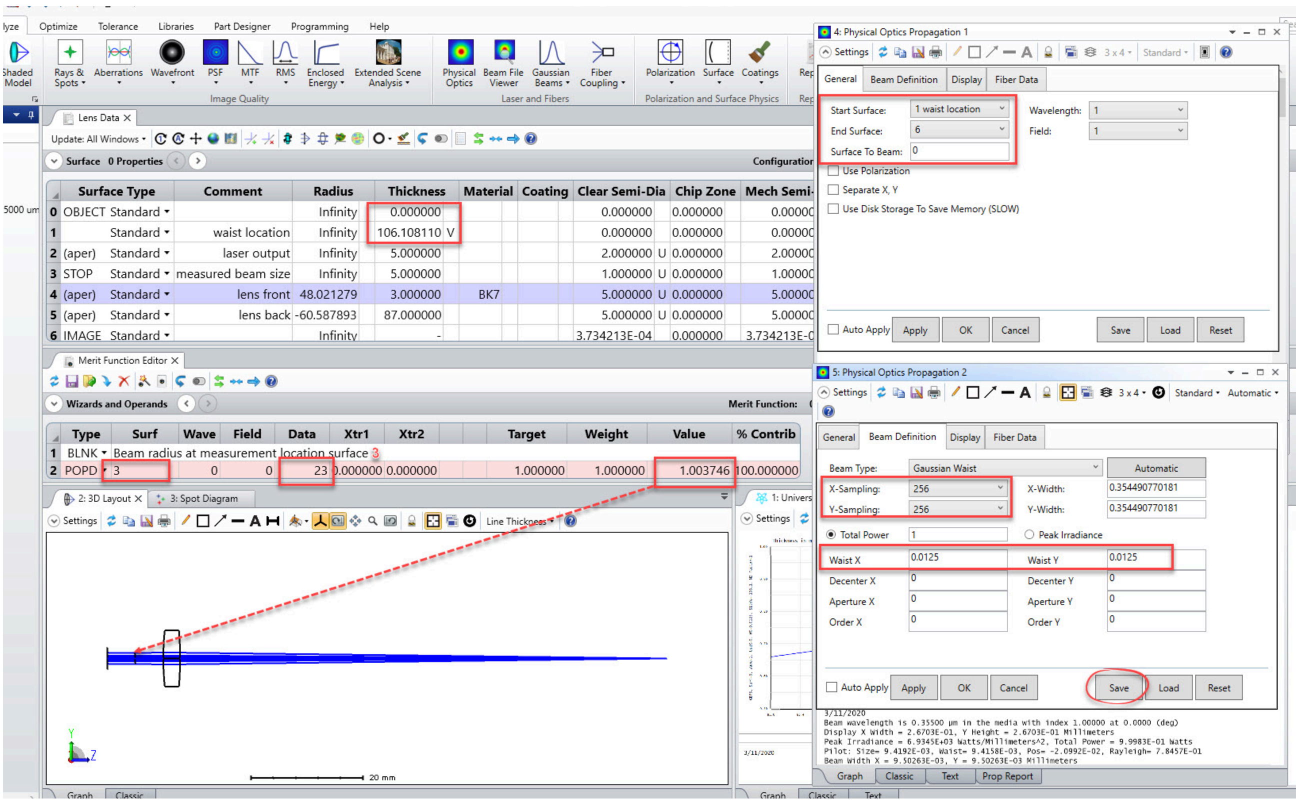


For this analysis, we will start with the same sample file we used previously in the ray-based approach, “1_rays optimized.zar”. We will insert a new surface after the object surface and change object surface thickness to zero and move its thickness 106.108 mm to surface 1 thickness.

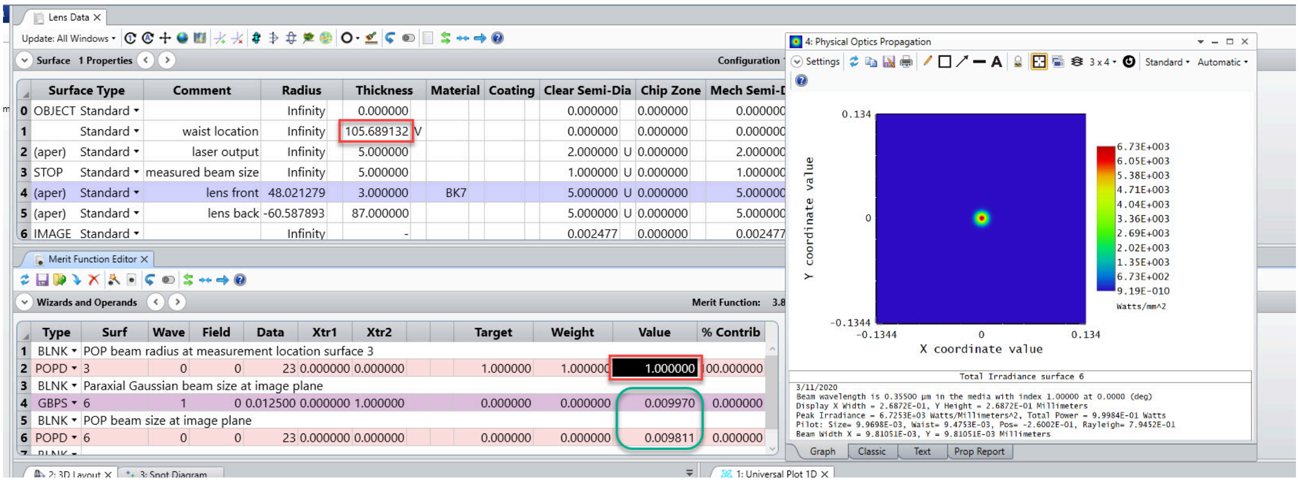
- In the **Physical Optics Propagation...Settings...General** tab, enter Start Surface as surface 1 and End Surface as surface 6.
- In the **Physical Optics Propagation...Settings...Beam Definition** tab, set the Beam Type as Gaussian Waist, enter X/Y Sampling of 256x256, Waist X/Y as 0.0125 mm, and press the Automatic button to let OpticStudio compute the appropriate array size to sample the beam.

When done with the Settings, press the Save button at the bottom. OpticStudio will save all current settings into a configuration file, and these same settings will be used for computing the POPD operand placed in the Merit Function Editor.

In the Merit Function Editor, remove all existing operands and start fresh. Enter operand POPD with Data value 23 for surface 3, which will return the beam X half width or beam radius at surface 3 which is where the beam size is measured to be 1 mm. Update the Merit Function Editor and the POPD operand returns beam radius at the surface 3 to be 1.0037 mm, not exactly 1 mm as the measured beam size.

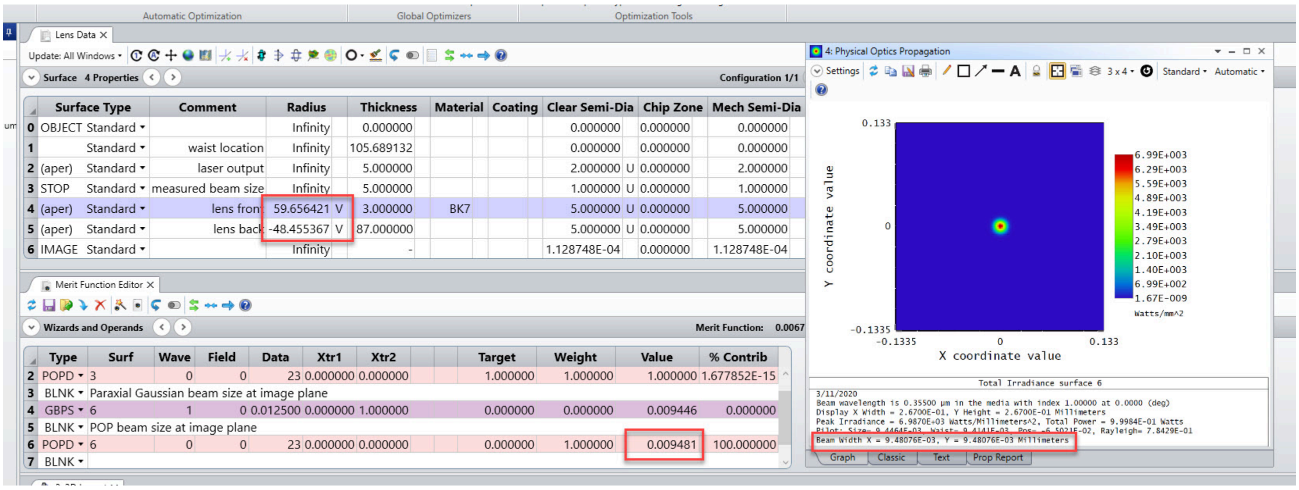


can assign a Weight of 1 and Target of 1 mm to the POPD operand on line 2, and set the thickness on surface 1 as variable to optimize (Local optimizer in Optimize> Automatic optimization> Optimize!). After optimization, the new thickness on surface 1 is 105.689 mm and the POP beam size on surface 3 is now exactly 1 mm. I then added two more operands GBPS and POPD on line 4 and 6 in the Merit function editor to return the Paraxial Gaussian beam size and the POP beam size at the image plane. The Paraxial Gaussian Beam returns beams size of 9.97 um and the POP returns beam size of 9.811 um. This is the file named "3_POP new waist location.ZAR".



We can further run an optimization to see if this is in fact the smallest beam size we can achieve using a singlet lens at 100 mm away from laser output. In the Lens Data Editor, remove the thickness variable solve on surface 1. Add variable solve to the front and back radii of the singlet lens. In the Merit Function Editor, assign a Target of 0 and Weight of 1 on the POPD operand on line 6. This is to optimize for the smallest POP beam size on the image plane. Run local optimization with 5 cycles in 'Cycles'.

After optimization, POPD returns a slightly smaller beam radius of 9.48 um. Note the POP computed spot size 9.48 um agrees quite well with the Paraxial Gaussian Beam computed spot size 9.45 um. This file, “3_POP optimized.zar” can be found in the article Download section.



When to use which tool

Ray-based approach and wavefront-based approach by Physical Optics Propagation are two different representations of the beam as it propagates through free space.

- Rays propagate along straight lines without interfering with one another;
- wavefronts propagate while coherently interfering with themselves.

The ray method is fast, flexible, but rays are not well suited to model certain effects, primarily diffraction.

OpticStudio provides some ray-based diffraction computations, such as the diffraction MTF or PSF. These diffraction computations make a simplifying approximation: that all the important diffraction effects occur going from the exit pupil to the image. This is sometimes called the "single step" approximation. Rays are used to propagate the beam from the object, through all the optics and intervening spaces, all the way to the exit pupil in image space. The ray distribution in the exit pupil, with transmitted amplitude and accumulated OPD for computing the phase, is used to form a complex amplitude wavefront. Then, in a single step, a diffraction computation is used to propagate this complex amplitude wavefront to the region near focus. Geometrical optics and the single step approximation work quite well for the majority of traditional optical designs, where the beam is not near focus anywhere except the final image. However, the model breaks down for several important cases:

- When the beam comes to an intermediate focus, especially near optics that truncate the beam (rays by themselves do not predict the correct distribution near focus).
- When the diffraction effects far from focus are of interest (rays remain uniform in amplitude and phase, wavefronts develop amplitude and phase structure).
- When the propagation length is long and the beam is nearly collimated (collimated rays will remain collimated over any distance, real beams diffract and spread).

Physical Optics Propagation models optical system by propagating wavefronts, where the beam is represented by an array of discretely sampled points describing the full complex amplitude and phase of the electric field as beam propagates through the optical system. This allows very detailed study of arbitrary coherent optical beams.

In general, the physical optics model is more accurate at predicting the detailed amplitude and phase structure of the beam away from focus than conventional ray tracing. The table below summarizes several special scenarios where ray approach may not be applicable, and POP should be used instead.

Three scenarios where ray method is not recommended:

	Rays?	**Paraxial Gaussian?**	**Physical Optics?**
When the beam comes to an intermediate focus, especially near optics that truncate the beam	NO	NO	YES
When the diffraction effects far from focus are of interest	NO	NO	YES

collimated

This article is the last article of the [Tutorial Series] Modeling Laser Beam Propagation in OpticStudio free tutorial.

Previous article: **How to model laser beam propagation in OpticStudio: Part 2 - Using Paraxial Gaussian Beam analysis to model Gaussian beam**

Associated files

Article attachments

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