Modelling a Single Optic System in COMSOL

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Introduction

COMSOL is a finite element multiphysics simulation software with applications in modeling electromagnetic waves, mechanical structured, fluids, and heat transfer. COMSOL is especially well known for its ability to simulate multiple physics phenomena in a single model. This document explains how to set up a two dimensional COMSOL model for a single optic set-up, and its application in the upcoming laser damage experiments.

Focusing Lens Tutorial

The focusing lens tutorial is an extremely useful resource for setting up the model. The tutorial details the set-up of a plano-convex lens with a focal length of approximately 1 mm, and the parameters can be easily altered to fit the desired lens set-up. The tutorial analyzes the focusing lens model using both the Electromagnetic Waves, Frequency Domain interface and the Electromagnetic Waves, Beam Envelopes interface. Both interfaces are viable options for relatively small models. For larger optical systems, the Beam Envelope is the better option given that meshing density is reduced depending on envelope variability. Given the large scope of the LDF set-up, the Beam Envelope interface was implemented.

Parameters

Name	Description	Expression	Value
wl	Wavelength	1.064 [um]	1.064E-6 m
k	Wave number	2*pi/wl	6.2832E6 1/m
w	Beam half size	4.75 [mm]	0.00475 m
n_lens	Refractive index of lens	1.515	1.515
W_lens	Lens thickness	3 [mm]	0.003 m
H	Domain height	10 [mm]	0.01 m
R	f = 750 mm radius of curvature	386.25 [mm]	0.38625 m
W_air	Air domain size	1.25 [m]	1.25 m
f	Focus position	750 [mm]	0.75 m
E	Max amplitude of E field	sqrt(P_av*2*eta)	65,230 V/m
eta	Impedance of free space	377 [ohm]	377 Ω
P	Max Power	100 [W]	100 W
P_av	Average Power/Area	P/(pi*w^2)	5.6432E6 W/m²

Table 1. Parameters for simulating a f = 750 mm single optic system. The laser power and half size are estimations for the YLR-100-LP laser taken from LIGO-T070021.

Geometry and Meshing

The geometry closely matches that of the Focusing Lens Tutorial. The lens radius of curvature was calculated using the thin lens equation (Figure 1). For a plano convex lens with a focal length of 750 mm and 1000 mm, the corresponding radii of curvature are 386.25 mm and 515 mm respectively.The lens was formed by the intersection of a thin rectangle (making the back edge of the optic) and a circle with radius 386.25 mm. The center thickness of the lens was arbitrarily chosen to be 3 mm. Given the high mesh density at the lens, the lens thickness should not exceed 5 mm. Alternatively, a lens geometry can be imported from the ray optics library.

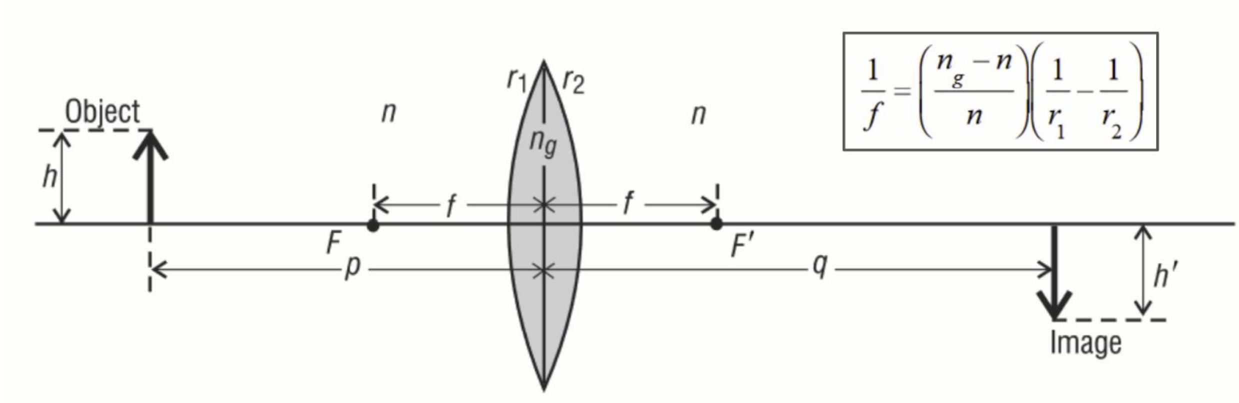


Figure 1. Defining quantities for image formation with a thin lens. Adapted from Pedrotti, Leno. "Fundamentals of Photonics." Basic Physical Optics, 2008. SPIE, doi:10.1117/3.784938.

The air domain consists of a large rectangle surrounded by perfectly matched layers (PMLs) of thickness 0.125 mm. The air domain makes up the majority of the model, and depending on its size, can take a long time to mesh.

The lens domain has the densest mesh, with a maximum element size of 0.01 mm. The PMLs and air domains have a maximum element size of 0.25 mm and approximately 0.225 mm respectively. Changing the mesh density in the air domain drastically changes the accuracy and resolution of the plots (Table 2, Figure 2).

Maximum Element Size	Minimum Element Size	# of Domain Elements	Beam Waist Position
0.2 mm	0.025 mm	947337	~750 mm
0.25 mm	0.025 mm	705993	~700 mm
0.5 mm	0.025 mm	645139	~500 mm

Table 2. Maximum element size, number of elements, and beam waist position. Decreasing the maximum element size below 0.25 mm increases the number of domain elements (and computation time), but also improves beam waist position accuracy. Increasing the maximum element size from 0.25 to 0.5 mm does not greatly reduce the number of elements, but significantly reduces simulation accuracy. This particular model has a beam waist of 2.375 mm (half of the actual beam waist) to reduce computation time.

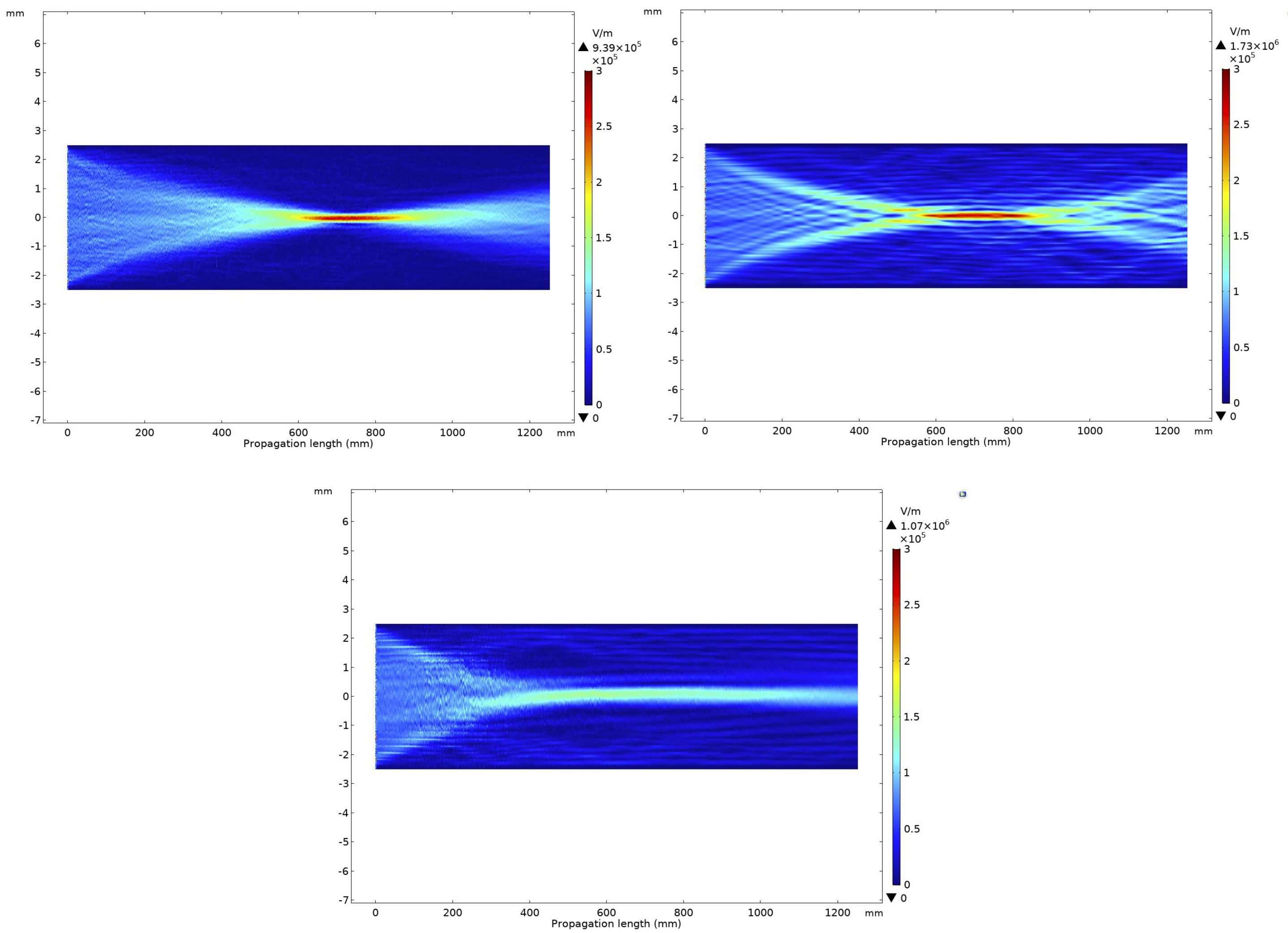


Figure 2. Comparison plots of the electric field norm over the entire domain for a maximum element size of 0.2, 0.25, and 0.5 mm. As resolution decreases, the beam waist shifts closer to the right and peak intensity decreases. Despite only having a 8.61% decrease in the number of elements, the 0.5 mm plot has almost no discernible beam waist and significantly worse resolution than the 0.25 m plot. These plots have a beam waist of 2.375 mm (half of the actual beam waist) to reduce computation time.

Results

The COMSOL simulation was run for both the f = 750 and f = 1000 mm optics (Figure 3). To find the simulated beam waist, the electric field on the optical axis was plotted with respect to propagation. For the f = 750 mm and f = 1000 mm plot, the beam waists lie at 700 mm and 950 mm respectively. Comparing the resulting plots with the A la Mode plots of the same set-up, we see the COMSOL plots appear to be slightly shifted to the left (Figure 4). This leftward shift may be a result of a lower mesh density, but unfortunately COMSOL had difficulty plotting when there were a large number of elements. This limit occurred when the maximum element size fell below 0.2225 mm for the f = 750 mm plot and 0.225 mm for the f = 1000 mm plot.

The optical axis plot is relatively flat, and the beam waist is not easily visible. It was estimated that the beam waist fell at the center of the plot's main peak, however in the f = 1000 mm case, the center of the peak coincides with a slight dip in the electric field. Based on these plots, it seems that the laser will have an area of high intensity over the length of approximately 100 mm. Since the laser is not sharply focused, positioning the sample at a point of high intensity should be a little easier.

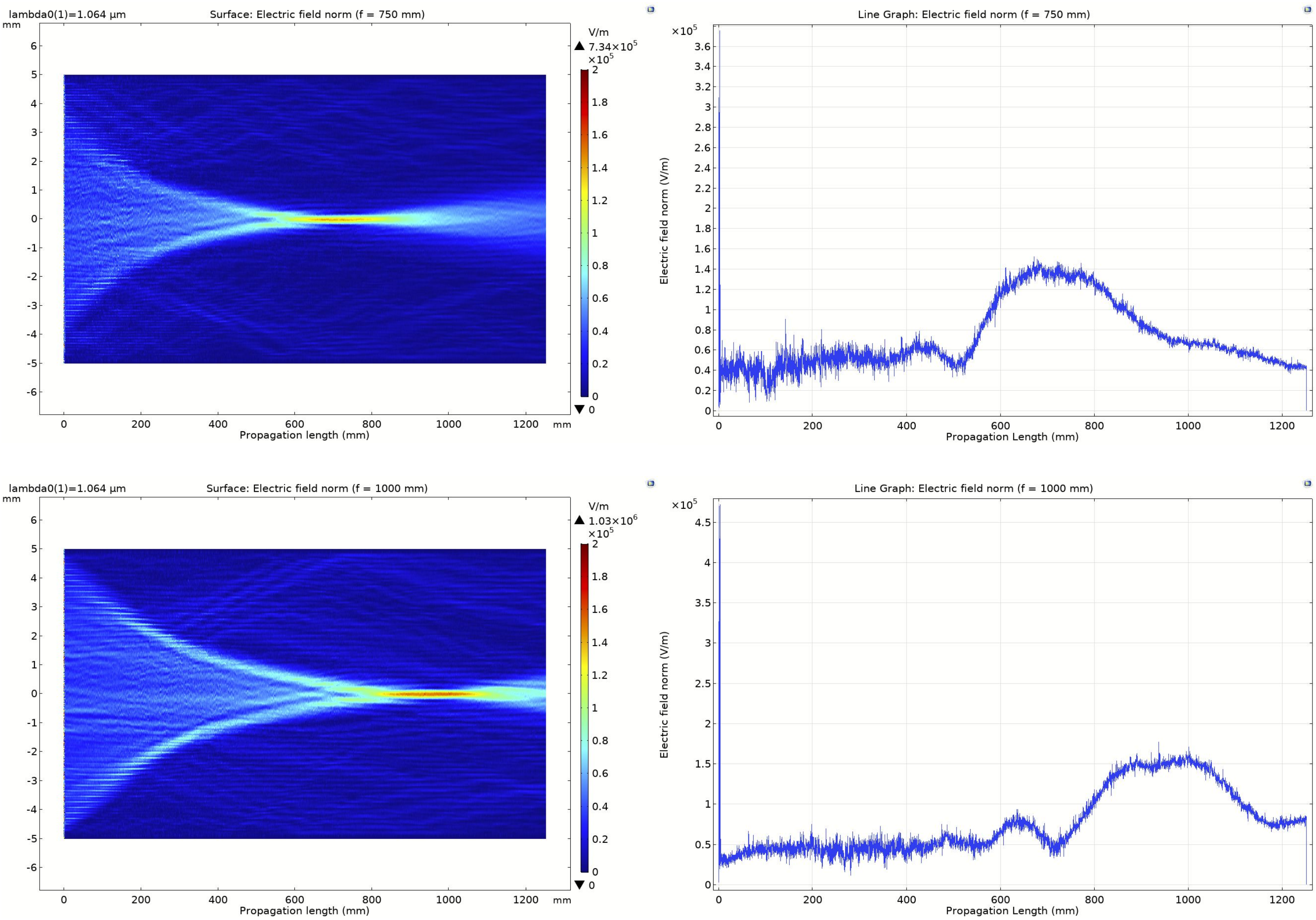
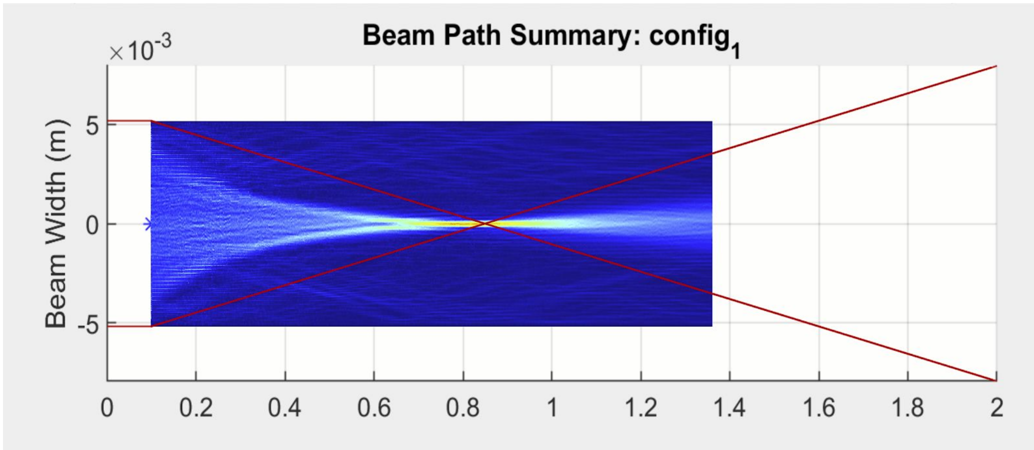


Figure 3.Electric field norm over the entire domain and at the optical axis (y = 0). The optical axis plots more clearly show areas of high intensity. Based on these optical axis plots, it appears the beam waist occurs somewhere around 700 mm and 950 mm for the f = 750 mm and f = 1000 mm plots respectively. It is unclear whether this deviation is due to mesh density.



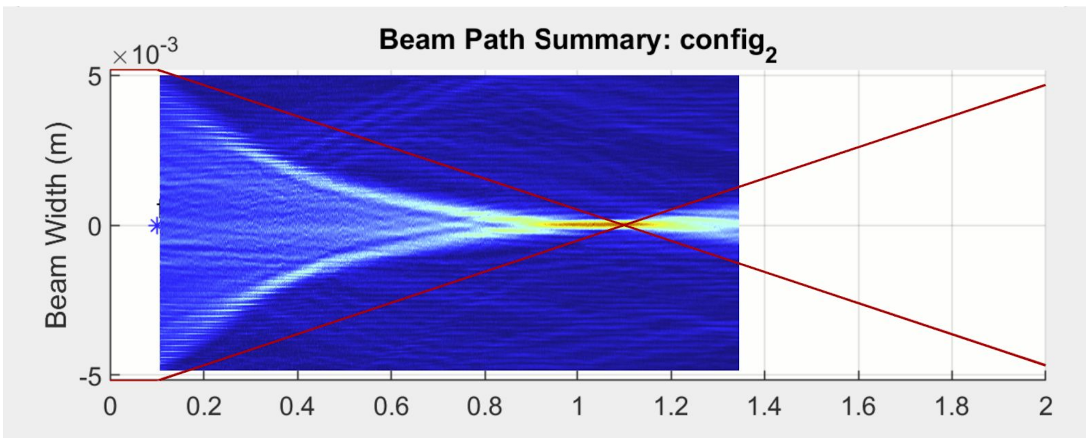


Figure 4. A la Mode Beam Path plots superimposed over the COMSOL electric field norm plots. The A la Mode plots can be found on Table 5 of T2000449-v3. The COMSOL plots are much more sloped than their A la Mode counterparts. Additionally, the COMSOL plot beam waists are less focused and lie slightly to the left of the A la Mode beam waists.

Finally, the electric field was plotted on the estimated focal plane (Figure 5). These plots were made at x = 750 mm and x = 1000 mm to coincide with the estimated beam waist of the f = 750 mm and f = 1000 mm set-ups. Based on figure 3, the beam waist actually falls 50 mm to the left, so the maximum values in the plots may not represent the overall maximum electric field norm of the beam. Both of the plots in Figure 5 have very accentuated peaks. Thus, when positioning the test sample, the sample must be within 0.25 mm of the optical axis.

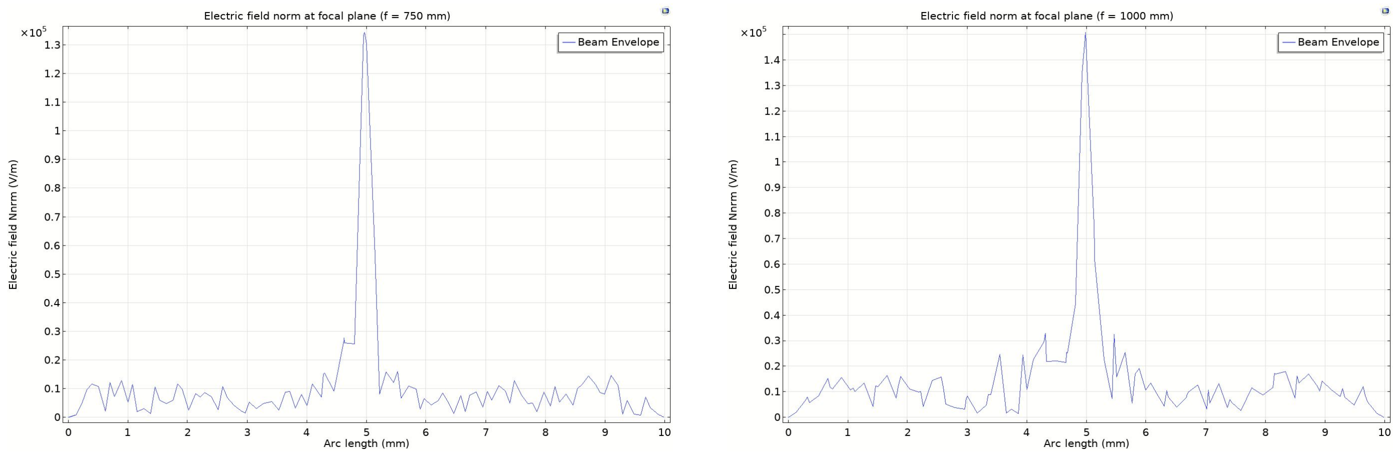


Figure 5. Electric field norm at x = 750 mm and x = 1000 mm for the two optical set-ups. The plots have a maximum electric field of approximately 1.35×10^5 and 1.5×10^5 V/m, respectively. The peaks for these plots are very tall and narrow, indicating a highly focused beam in the y direction.