2-D Pulsed Laser Beam Modeling Using PROP

Gurshawn Singh

2-D Pulsed-Laser Beam Modeling Using PROP

Gurshawn Singh
Rush-Henrietta Senior High School
Advisor: Dr. John A. Marozas

Laboratory for Laser Energetics
University of Rochester
250 East River Rd.
Rochester, NY 14623-1299

1. Abstract

Many complexities of laser propagation can be eased by the use of PROP to model a laser. PROP is a computational tool that was created at the Lawrence Livermore National Laboratories [1]. This code can be specified to create different types of lasers with different beam fluences and different pulse shapes. As it is implemented at the University of Rochester LLE, it will allow scientists to propagate any laser, any distance, with the use of hardware such as lenses, rod amplifiers, slab amplifiers, spatial filters, and active mirrors. Since PROP can model 2-D effects on lasers, many effects such as diffraction, aberrations, small-scale self-focusing, 2-D gain and saturation can be accounted for. PROP is also flexible as it takes user input data and analyzes it, creating a profile from that data. Using the features of PROP, a rod amplifier spatial filter chain was modeled to demonstrate many of its functions and capabilities. PROP will replace the current 1-D code at LLE creating new possibilities of diagnosing laser-induced damage and accurately modeling the 60-beam laser chain at OMEGA.

2. Introduction

The laser propagation program, PROP, was introduced to the Laboratory for Laser Energetics at the University of Rochester for its capabilities to model laser propagation itself including two dimensional effects. The current laser modeling program, Rainbow does not have the capabilities to model two-dimensional effects. Using PROP will allow the scientists at the Laboratory for Laser Energetics to take into account the two-dimensional effects such as diffraction, small-scale self-focusing, two-dimensional gain, and saturation. The modeling of these effects will lead to further investigation and inquiry upon the harm that they can cause to the high-powered laser system. PROP also has the capability to model the one-dimensional effects and the components such as rod amplifiers, slab amplifiers, spatial filters, aberrations and deformable mirrors. Along with these individual components, a Rod Amplifier Spatial Filter chain typical of that in OMEGA was created using PROP to demonstrate its abilities.

The knowledge of each component is vital while using PROP. Each component has several parameters specific to the modeling of that component. By understanding these parameters, and the significance of each, the programming of PROP is quite simple. In the following paragraphs are brief descriptions of some of the main components and effects for understanding the small scale model of OMEGA that was modeled in PROP. Among these are spatial filters, amplifiers, and aberrations.

An aberration is an effect that comes from the propagation of a laser through space. It is basically an unavoidable and unwanted consequence of propagation, affecting the two main components of a beam: the phase and the intensity. When the beam is propagated, the aberration causes the phase front to distort. The phase front is focused locally into regions of high intensity and low intensity. With this modulated intensity, the beam must be focused so the high intensity peaks don't cause any laser damage.

The spatial filter's purpose is to remove any high spatial frequency components, such as those caused by an aberration. The beam first goes through a lens, where all high and low frequency waves are focused into a pinhole. When the laser goes through the pinhole, the higher frequencies on the edges of the profile are blocked, allowing the center portion of the beam to maintain its path as it is magnified in the second lens. The end result of the beam is a much smoother profile.

There are two main types of amplifiers, rod amplifiers and slab amplifiers. Slab amplification is a simple linear process. As the beam goes through the slab, ions in the slab stimulate the beam, creating a higher intensity end result. Rod amplifiers amplify the beam without a uniform gain profile. The rod has flash lamps on either side of it that keep the ions inside the rod stimulated. Therefore, the ions closer to the lamps are more energized than those in the middle of the rod. So when the beam goes through the rod, the edges of the rod have a higher intensity. This creates the inconsistency on the gain profile.

3. Using PROP

Using special syntax, one is able to direct PROP to model whatever is needed within the program. This input into PROP is done so using a *.txt file, usually made with Microsoft Notepad. In this notepad document, the parameters of the components and features needed to be set can be specified. The basic format of this text-based document is similar to any other basic programming structure. At the top, the heading consists of the title, sizes of the plots, and other global factors. From there, the beam injection and temporal calculations are described. The strength, intensity, fluence, and shape are all detailed in this area. The next part describes the physical components of the laser that is being modeled, for example the amplifiers and filters. Different features of the program for user preference can be activated in these sections. These are all detailed in the user manual.

PROP can be run by the user specifying each parameter in the script, or PROP can be run by input files. The previous paragraph explained the specifying of parameters in a script. The use of input files has its benefits, as it's more user friendly. There are input files that were made specifying the beam injection, pulse shape, and 2-D profiles. Each component has a separate input file, either in the binary format (more efficient and consumes less storage) or the ASCII format (text based and much simpler than binary). Although the input files are quite complex, the user has more freedom to change parameters according to their need rather than relying on PROP's intrinsic functions and settings.

4. MATLAB and Input files

Input files were created using MATLAB, a mathematical programming environment. For each component/effect in PROP (amplifiers, aberrations, beam profiles), a program using MATLAB was created. Each program is directed to generate an input file. These input files take user input data, and using the functions programmed in the script, they generate the entire input file. The user only has to specify in PROP that the input file exists, so the desired effects can be modeled through the input file.

The MATLAB program, PropPulseGen, was created in order to create the pulse specified by the user. MATLAB was programmed to read the functional form of the pulse:

$$pulse = e^{-\ln(2)*(2*(t-t_0)/tfwhm)^{SG}} \qquad \text{EQ. 4.1}$$

The user specifies the reference in time (t_0), the full-width-half-max (twfhm), and the supergaussian index (SG) of the pulse needed. With this data, MATLAB calculates the pulse, shows a graph of the pulse, and creates an input file. The input file is then moved to the PROP directory and the script is changed in PROP, so PROP is aware that there is an input file it must read. Once that is done, PROP will create a beam with the pulse that was specified in the MATLAB program.

The PropGainProfile generates an input file of small signal gain profiles of OMEGA amplifiers for PROP. There are different stages of rod amplifiers in OMEGA with different aperture radii. The A and B amplifiers have a 64 mm diameter aperture, the C stage amplifiers have 90 mm diameter aperture, the stage-D amplifiers also have 90 mm diameter aperture, and the E and F stages use disk amplifiers (disk amplifiers have a constant value of the stored energy per unit volume Estored). The small signal gain (SSG) of an amplifier is defined by the expression [2]:

$$SSG = e^{\{\alpha*L*Estored\}} \qquad \text{EQ. 4.2}$$

The user specifies the alpha (α), which is a constant that depends on the laser material. The OMEGA system uses doped phosphate laser glass, so the alpha constant is 0.2120 cm^2/J. The L stands for pumped length of laser glass, and equals 30.5 cm for all OMEGA amplifiers. For each amplifier stage, the Estored value is different, and is given by a specific functional form. Once the small signal gain value is calculated, the MATLAB script plots the data on a graph, and then creates an input file. The user can make sure the data is correct with the graph provided, and from there decide whether to go on and use the input file in PROP.

PropBeamGen generates the beam energy input file. This script uses the functional forms of a square beam (eq. 4.3) and a round beam (eq. 4.4), depending on the

$$Beam = e^{-\ln(2)(2X/xfwhm)^{SG}} e^{-\ln(2)(2Y/yfwhm)^{SG}} \quad \text{EQ.4.3}$$

$$Beam = e^{-\ln(2)(2R/dfwhm)^{SG}} \quad \text{EQ. 4.4}$$

user's preferences, and creates a beam intensity profile. Each beam profile is specific to the full width half max of the x (xfwhm) and y (yfwhm) values of the square beam and the diametrical (dfwhm) value of the round beam.

Through input files, PROP can model a pulse profile, two-dimensional gain profiles, two-dimensional aberration profiles, and two-dimensional apodization files. Once the MATLAB program for these programs runs, an input file is generated. These input files are compliant with PROP, in that they follow the format that PROP can read the file in, ultimately producing the expected effects. These files are made in either the binary (*.bin) or ASCII (*.dat) formats. They should then be transferred to the correct directory where the PROP script resides. The PROP script must be altered so that PROP will expect these input files.

5. Rod Amplifier Spatial Filter Chain

Using PROP, a chain of components, similar to those in OMEGA, was created. As in OMEGA, the beam in PROP was aberrated, and then propagated through a spatial filter, rod amplifier, and spatial filter again. This chain was modeled through the input files created by a MATLAB script. The script was used to create a pulse, a beam, and a

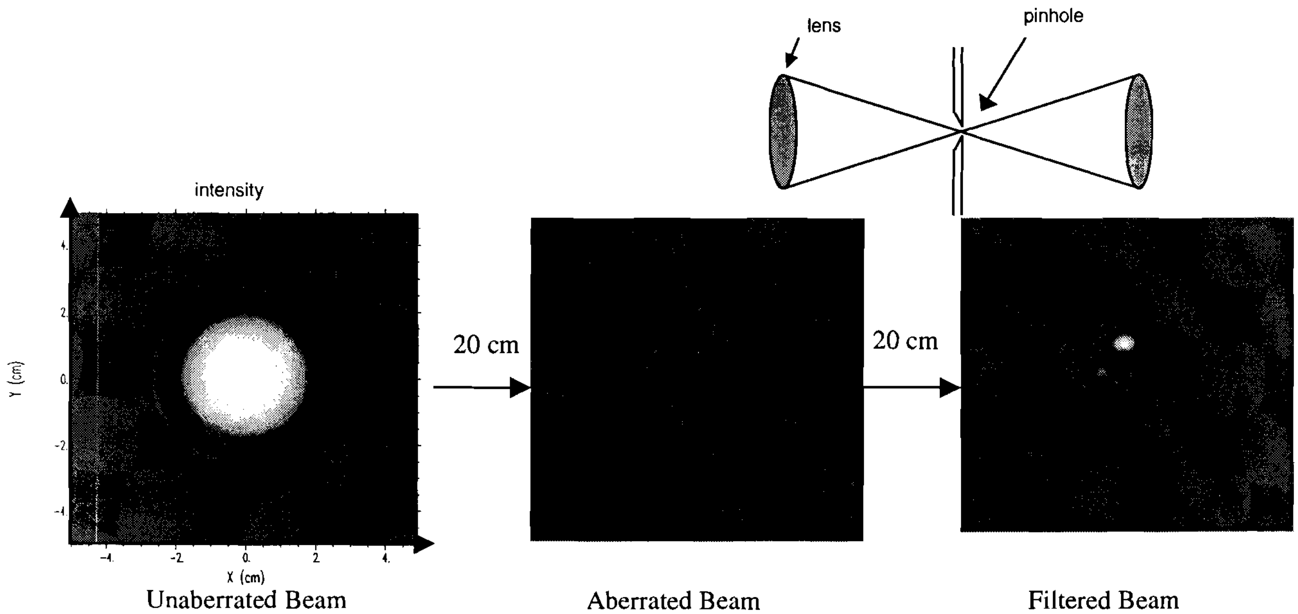

FIGURE 5.1

gain profile. The aberration, amplifiers, and filters were all created using PROP's intrinsic functions. The distances between these components were taken into consideration, so this model is quite accurate.

The output files in PROP display graphics and graphs, with information about the beam. The first graphic of fig. 5.1 is the original beam, before any propagation or altering. The beam is then propagated 20 centimeters, and aberration through the air occurs. Higher intensity and lower intensity areas can be seen on the beam. By focusing the beam through a lens and cutting off this high frequency

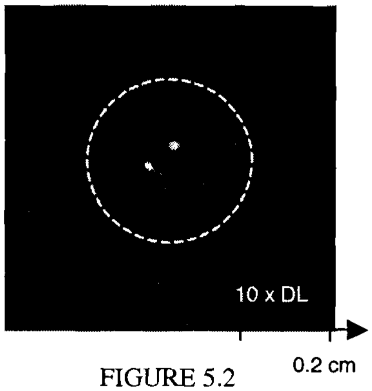

FIGURE 5.2

FIGURE 5.3

through the pinhole, we get a much cleaner and smoother beam. The beam at the pinhole would resemble figure 5.2. Since the beam is extremely small it is then enlarged with another lens and the product is the filtered beam as in the last graphic in figure 5.1.

Then, the filtered beam is propagated through a rod amplifier, creating distortion on the beam, so then we put it through another spatial filter. The spatial filter is the last component, so the outcoming beam is the end result (fig. 5.3).

6. Conclusion

PROP has become a useful tool for scientists at LLE. Many 2-D effects on OMEGA can be accounted for with PROP such as diffraction, aberrations, small scale self-focusing, 2-D gain and saturation effects. Also, hardware such as amplifiers and spatial filters were accurately modeled. These features allow scientists to diagnose laser induced damage. Currently, PROP is heavily relied on to model intensity modulations on the new LLE EP program.

7. Acknowledgements

I would like to thank my advisor, Dr. John A. Marozas, who made himself readily available when I needed any type of help. He took numerous hours out of his day just to help me and make sure I was on track. Also, Dr. Jack Kelly took time out of his busy schedule to answer any question I had. Lastly, I would like to thank Dr. R.S. Craxton for putting together the program and everyone at LLE including all the students for making the program an awesome experience.

8. References

1. Sacks et al. "The PROP92 Fourier Beam Propagation Code," LLNL Annual Report
2. Siegman, Anthony E. Lasers. 1996.