

Low cost undergraduate experiments with lasers and personal computer

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Few interesting high school level experiments using laser and personal computer are demonstrated with a budget of US \$ 100.00, for each experiment (excluding the price of computer). The experiments demonstrated are single-slit diffraction, characterization of a Gaussian beam and characterization of an optical fiber. Suggestions for using the same setup to demonstrate few other experiments using laser are also given.

I. INTRODUCTION

Theoretical courses on lasers and fiber optics are being introduced at undergraduate level science and engineering programs. However, to realize few experiments on these areas of modern science require huge amount of money to procure the basic equipment like lasers, optics, precise mechanical mounts, etc. Hence, many good academic institutions could offer conventional optics experiments only. Without compromising on the quality of experiment, we present an alternative solution by using locally available components. The experiments demonstrated in this paper were adopted to the students of first year Bachelor of Engineering course (all branches)¹. We find that the students enjoy the experiments and more importantly understand the physics and applications of advances in science more easily. These experiments also can be adopted for senior school students as well as to fresh students of degree program.

II. DETAILS OF EXPERIMENT

This report discuss demonstration of three experiments viz., (i) Single-slit and double-slit diffraction, (ii) Measurement of numerical aperture of optical fiber and (iii) Measurement of beam divergence of a Gaussian beam on a budget of nearly \$ 100.00 for each experiment. For these experiments the light source and detector are common. The light source used is a semiconductor laser source which is available for \$ 1.00 from platform vendor or in supermarket. The aluminum jacket (usually coated with yellow color paint) of the laser is carefully removed and connected to a home made IC regulated DC power supply (see Figure 1 for details). The laser source needs 4.0 - 5.0 V DC power supply for proper operation. We are using such lasers for last one year (12 hours per week) and they are still working. The detector is a charge coupled device (CCD) or a Complementary metal oxide semiconductor (CMOS) device. These are widely used in closed circuit television camera (CCTV) for surveillance purposes. The detector is removed from

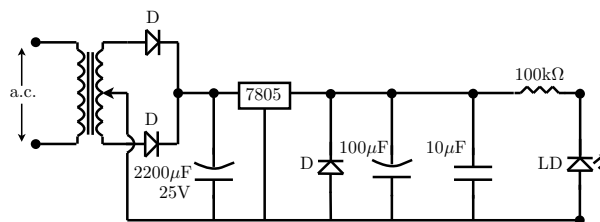


FIG. 1: Regulated DC power supply for semiconductor laser diode using 7805 IC regulator. D represents diode IN4001. The transformer output is 12-0-12 V, 500mA. The 100k Ω resistor may be replaced with a variable resistor to optimize the optical power output of the laser diode (LD).

the housing and mounted externally for flexible operation. A TV tuner card is inserted into a free PCI slot of the computer. Output of the detector is connected to the AV input of the TV tuner.

A. Equipment

Equipment required for each experiment is given in Table 1. The authors believe that few computers (PC-486 / Pentium or higher) as well as research optical benches with carriers are available for use in any undergraduate physics laboratory. In case of non-availability of these, the experiment may be performed with mini-television set and an optical bench. While using a mini TV, tracing paper or a graph sheet may be used to record the diffraction pattern. Setting up the experiment does not consume much time. However, care must be taken to align the light source properly on the optical bench. Spirit levels may be used for perfect alignment of the light source. Before proceeding further into the experiment, one should ensure that the light is propagating parallel to the optical bench and it is on a single plane only. In the proceeding sections, we assume that the light is propagating along the Z-direction.

B. Tricks and suggestions

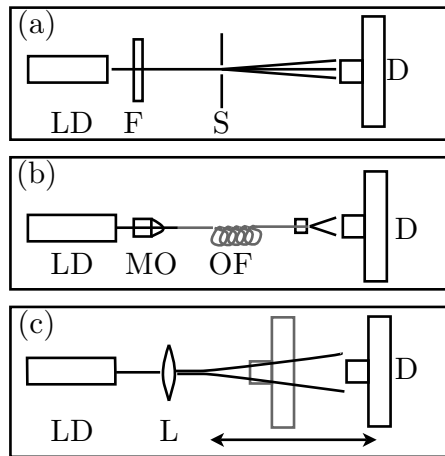


FIG. 2: Schematic of the experimental setup; (a) Single slit diffraction (b) Numerical aperture of optical fiber and (c) Gaussian beam characteristics. LD - laser diode, F - intensity filter, S - single/double slit, D - CCD or CMOS detector, MO - microscope objective, OF - optical fiber, L - lens (needed if He-Ne laser is used).

Schematics of the experimental setup are given in Figure 2. To perform the experiments the following suggestions may be employed:

- (a) For the experiment on single slit diffraction, align the laser carefully and pass the light through the slit and to the detector. If the detector shows a white screen, it means the laser power is too high, hence the detector has reached saturation limit. Color glass plates (preferably blue / violet) may be used to reduce the intensity of the laser. Once the laser power is optimized, measure the fringe pattern using a slit of known width to calibrate the detector pixels. The width of the standard slit may be measured using any conventional method. Once the detector pixels are calibrated, one can measure the width of unknown slit (b) from the following equation²

$$b = \frac{n\lambda D}{ky_n}. \quad (1)$$

Here, λ is wavelength of light source used, D - distance between detector and slit, y_n is the distance of n th minima from the center and k is the calibration constant of the detector. A plot of n versus y_n gives a straight line. By calculating the slope of the curve and using experimental constants in the above equation width of the slit may be estimated.

- (b) For the measurement on numerical aperture it is better to use plastic optical fibers. Glass fibers need

great care while using in a undergraduate laboratory. Also, the end preparation of plastic fiber is much easier than that of glass fibers. We use microscope objective of magnification 20X. A small holder is used to hold the output end of the optical fiber to couple the light to detector. The detector is moved from the end of the fiber at regular distances along Z-axis. At every position (z_i) the output light is traced. The Gaussian width (ω_o) is plotted against different spatial positions. The slope gives the solid angle and hence the numerical aperture of the optical fiber. The difference in refractive index of core and cladding of the fiber may be estimated from the following³

$$\text{N.A.} = \tan^{-1} \left(\frac{z_i}{\omega_o} \right). \quad (2)$$

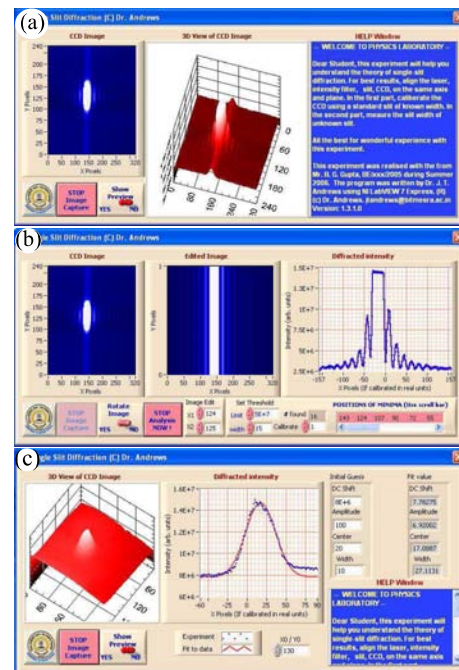


FIG. 3: Front panel of software code. (a) The laser diffraction pattern from the detector is displayed as 2D and 3D images. (b) Selected area of diffraction pattern is analyzed. The positions of minima are shown in the lower right corner. (c) For use with laser beam characterization and numerical aperture measurement. Selected line of the data is displayed as a 2D curve. From the initial values, best values for Gaussian fit are iterated and displayed. The Gaussian width is $\approx 1/e^2$ of the maximum irradiance.

- (c) To measure the angle of divergence of a laser beam, the experimental setup shown in Figure 2c, is used. Semiconductor lasers usually emit elliptical Gaussian beam. Since the light source used in the experiment is a semiconductor laser, the divergence along X & Y directions are different. Hence, care must be

taken to measure the divergence along XY planes. The laser or detector may be rotated to match the axis of laser beam and the XY axis of the detector. A plot of ω_o and spatial position (z_i) yields the divergence of the laser beams in *radian*. The student may be asked to find the divergence along X and Y directions. If a He-Ne laser is used a lens having short focal length of (≈ 5 -10mm) may be used to magnify the spot size of the beam. Correct value of angle of divergence (θ) may be estimated from the following⁴

$$\theta = \frac{\theta'}{M}, \quad (3)$$

where the M is the magnification factor of the lens and θ' is the angle of divergence measured using lens.

TABLE I: Price details of equipment.

S. No.	Equipment needed	Cost (US \$)	Remarks	Brand used
Common equipment for all experiments				
1	Semiconductor laser with power supply	2.00	Fig. 1	Home made
2	CCD	50.00	Optional	Dynalog
3	Mini TV	10.00	...	VT-765
4	TV tuner	25.00	Optional	Philips
5	PC	...	Optional	Compaq
6	Optical bench with carrier and mounts	OSAW
	TOTAL*	62.00	—	—
Additional equipment for laser diffraction				
7	Adjustable single slit	10.00	...	OSAW
	TOTAL*	72.00	—	—
Additional equipment for NA of optical fiber				
8	Tungsten halogen lamp with PS	5.00	Optional	Phillips
9	Fiber coupler with MO	30.00	...	Holmarc
	TOTAL*	97.00		
Additional equipment for Gaussian beam parameters				
10	Lens with mount	30.00	...	Holmarc
	TOTAL*	92.00	—	—

*Excluding the price of Optical bench, Desktop PC and TV tuner card.

The experiments demonstrated above do not require dark room. However, semi dark atmosphere is advised for avoiding background noise. In the absence of dark room, the detector may be covered with a box to improve the quality of results.

C. Software

A software code has been written using LabVIEWTM Express 7 (National Instruments, Texas, USA)) for accessing the detector through TV tuner card. The software acquires the images from detector and analyze the fringes. Slightly different codes are used as per the requirement of the experiment. A sample front panel of the software are shown in Figure 3. On request, executable copy of software is available from the author free of cost.

For the experiment on single slit diffraction the image is analyzed for valleys (minima) of the fringes and are displayed on the screen. The student record these values and calculate slit width from equation 1. For the experiment on Optical fiber and Laser beam parameters, the software displays the intensity curve along X or Y direction from one row only. Using few initial parameters like DC shift, approximate center, probable width, the program calculates the best values for Gaussian fit and display it for each measurement.

III. CONCLUSIONS

To conclude, three laser based experiments using commercial CCD/CMOS detector are demonstrated. The total cost excluding personal computer is less than US \$ 100.00 for each experiment. These experiments are being used physics laboratory of undergraduate students of engineering.

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¹ Please, see <http://www.bitmesra.ac.in>.

² F. A. Jenkins and H. E. White, *Fundamentals of Optics*, (McGraw-Hill, New York 1957); M. Born and E. Wolf, *Principles of Optics*, (Pergamon, Oxford 1986).

³ G. Keiser, *Optical Fiber Communications*, (McGraw-Hill, New York 1983).

⁴ B. E. A. Saleh, M. C. Teich, *Fundamentals of Photonics*, (John Wiley, New Yor 1991) pp 45-60.