EFFECT OF OPTICAL ELEMENTS ON TRANSMITTED LASER BEAM

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Abstract: The paper deals with scalar diffraction theory and introduces an important solution of wave equation – Gaussian beam. In practical part, approach based on Fast Fourier Transform algorithm is discussed. Simple program for user-friendly simulation of this approach in MATLAB was created and the results of it will be demonstrated.

Keywords: Diffraction, Gaussian beam, Fourier transform, GUI

1. INTRODUCTION

In modern life there is increasing demand on optical communications. Reasons are both practical (use of non-license band, directivity of the transmitter and receiver) and high data rate. When the laser beam is being shaped, wave behaviour of the transmitted beam is critical. By these effects stands diffraction as the most critical. Therefore diffraction will be described theoretically and its influence on transmitted beam will also be simulated. A program in MATLAB environment will be created to allow user to change input parameters of the simulation.

2. THEORY OF DIFFRACTION

Diffraction occurs when electromagnetic radiation is bended in a way other than refraction or reflection. This phenomenon is described in wave theory of electromagnetism. Its consequences are derived from Huygens-Fresnel principle. For the description of diffraction phenomenon and its effects, double integral is used. That means, double integral is needed to be calculated through the whole diffraction object and for every point in observation plane. That would be too excessive and computationally intensive. Therefore, analytical approximations are often used to simplify and speed up the calculation for the price of accuracy. In standard situations and technical use this accuracy is more than sufficient.

Fresnel approximation leads to simplified integral

$$\psi(x,y,z) = C\iint_{S_0} \psi_0\left(x_M, y_M\right) \cdot e^{\frac{\mathrm{jk}}{2z}\left(x_M^2 + y_M^2\right)} e^{-\frac{\mathrm{jk}}{z}\left(x \cdot x_M + y \cdot y_M\right)} \mathrm{d}x_M \mathrm{d}y_M \,. \tag{1}$$

Wave function describing Fresnel diffraction in the point (x,y,z) is calculated as Fourier transform of product of wave function $\psi_0(x_\mathrm{M}, y_\mathrm{M})$ in the plane of diffraction aperture and a phasor $e^{\frac{\mathrm{jk}}{2z}\left(x_M^2 + y_M^2\right)}$.

For the need of technical practice, there is more convenient to introduce model describing distribution of intensity $I(x,y,z)$ in the plane of observation rather than a wave function. These relates as follows

$$I\left(x,y,z\right) = \left|\psi\left(x,y,z\right)\right|^2 . \tag{2}$$

Final expression describing distribution of diffraction of planar wave ψ_0 on circular aperture in the distance z is as follows

$$I\left(x,y,z\right)\propto\left|FT\left\{\psi_0\left(x_M,y_M\right)e^{\frac{\mathrm{jk}}{2z}\left(x_M^2+y_M^2\right)}\right\}\right|^2 . \tag{3}$$

From this equation is obvious, how nature itself can perform Fourier transform of a signal.

3. SIMULATION

Simulation of diffraction uses a model described with expression (3) and was built in MATLAB program. It provides flexibility during the development of the simulation as well as built-in functions for 2D signals processing.

To ensure that even less skilled MATLAB users may use the program for the simulation, it was built in the form of GUI (graphical user interface).

Script simulates diffraction of planar Gaussian wave with beam width w and wavelength λ on a circular plane with radius r in the distance z. Simulation consists of several parts. In the first part, input parameters are defined:

- Wavelength λ
- Distance of observation plane from the diffraction aperture z
- Radius of diffraction aperture r
- Beam width of Gaussian beam w
- Number of points of discretisation N

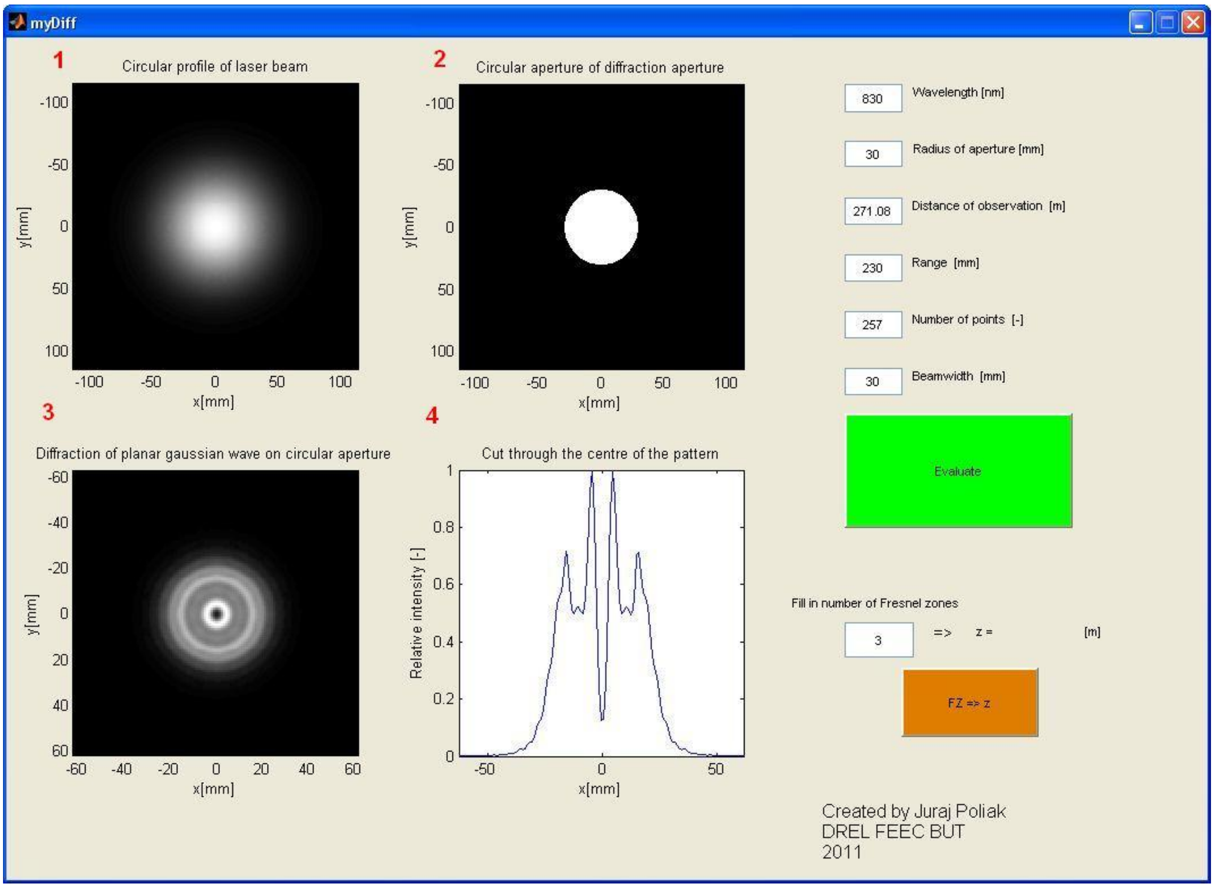
These parameters are read and used for the calculation. In the final part of the simulation, results are displayed.

Input parameters can be changed in the right side of main window of GUI (Figure 1). To run the calculation, the “Evaluate” button has to be pressed. Results are shown in the form of 4 images. Image 1 to 4 show the Gaussian profile of laser beam in the plane of diffraction aperture, circular aperture, diffraction pattern in the distance z and cut through the centre of the diffraction pattern respectively.

Simulation assumes that diffracting beam is planar, i.e. distribution of the phase in the cut upright to the direction of the propagation is constant. This assumption is never fulfilled as the beams are always slightly divergent. However, its consequences are never visible on the shape of the diffraction pattern, only on its radial size.

When diffraction for given number of Fresnel zones is needed to be simulated, orange button named “FZ => z” may be used. After entering desired number of Fresnel zones, pressing the button will calculate the distance when exactly this number of Fresnel zones is observed. Then this number as input parameter of calculation must be filled.

Besides educational purposes, this program may also be used for analysis of what minimum radius of the output lens is needed. This is always a compromise between level of diffraction effect and perfection of the shape of bigger lens. As it can be seen from the fourth image on Figure 1, in the desired centre of receiver may be lower intensity, so the receiver will “lock” to the next peak. This will cause a problem as this peak is too narrow and in turbulent atmosphere will cause higher BER. Additionally, in mobile links this effect is even more critical as these peaks are changing with the distance.



830 Wavelength [nm]
30 Radius of aperture [mm]
271.08 Distance of observation [m]
230 Range [mm]
257 Number of points [-]
30 Beamwidth [mm]

Fill in number of Fresnel zones
3 => z = [m]

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Figure 1: Simulation results in created MATLAB GUI.

4. CONCLUSION

In the article useful tool for simulation of diffraction was introduced. The simulation is limited with approximations, e.g. circular Gaussian beam, planar distribution of laser beam, but also need of MATLAB to be installed on the PC. Author is currently working on extending the program to include also elliptical Gaussian beam and divergent laser beam. Simulation was consulted with prof. Jiří Komrska as well as confronted with real experiment.

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