Beam Fluctuations and Laser Beam Expansion Models

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ABSTRACT: *The minimum divergence of the laser beam which fulfil the power design of the laser communication system is described. The Bit-Error rate and laser beam fluctuations are explained. The proposed model is based on the current laser beam expansion models. The solution to the power design is arrived based on laser beam divergence. The experimentation is supported by the numerical simulation results.*

Keywords: Free Space Optics, Power Design, Mechanical Vibrations, Atmospheric Turbulence

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1. Introduction

Free space optics (FSO) systems have been becoming subject of great interest in the last years [1-6], because they are an alternative of fiber optics and their technical and economical parameters most fully correspond to the requirements resulting from the growing significance of the communication networks. But operation of FSO systems is associated with a number of difficulties [1-4] – influence of atmospheric transparency, atmospheric turbulence and mechanical vibrations of the antennas. The last two caused fluctuations of laser beam propagation direction and this leads to random changes of the optical flux falling on the receiving aperture and increasing the Bit-Error-Rate (BER) of communication system. In previous works the effect of these random factors on FSO power design was studied [6-9] and an algorithm for power design of FSO was suggested [10]. The presence of domain of power design problem [10] demands analysis of the parameters of FSO system that affect it. One of these parameters is laser beam divergence.

The aim of this paper is on the base of the domain of the power design problem described in [10] to obtain an expression of minimum laser beam divergence angle.

Numerical analysis of its impact on power design of FSO is also performed.

2. Theoretical Analysis

Obtaining the relations for the minimum divergence of the laser beam is based on the algorithm for power design of FSO presented in [10] where a simplified model of mechanical vibrations and atmospheric turbulence is used.

FSO system (Figure 1) is considered, which consists of a laser source generating a Gaussian laser beam with initial radius r_0, pulse-code modulator (PCM), optical transmission antenna (TA) with transparency τ_1, optical reception antenna (RA) with radius R_2 and transparency τ_2 and photodetector (PhD).

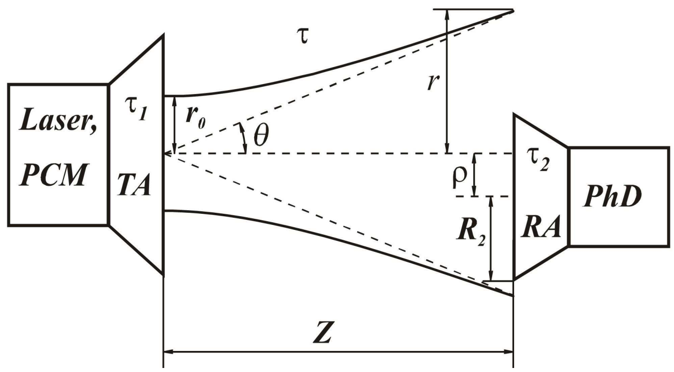

Figure 1. FSO system

Let Z is the length of the atmospheric communication channel, τ– its transparency, and r is the radius of the laser beam in the receiver's aperture plane.

The domain of power design problem is described by expression [10]

$$1-8\frac{\sigma_\psi^2}{\langle\psi\rangle^2}\left[\mathrm{erfcinv}(2\,BER)\right]^2>0\,, \tag{1}$$

where $X= erfcinv(Y)$ is the inverse function of $Y= erfc(X)$ and function ψ describes the surface density of a Gaussian laser beam in a plane perpendicular to the direction of propagation–

$$\psi=\exp\left(-2\frac{\rho^2}{r^2}\right) \tag{2}$$

ρ is the linear misalignment between the centre of receiving antenna and the laser beam axis, caused by atmospheric turbulence and mechanical vibrations of antennas (Fig. 1).

The average value and the variances of this function are given with the relations [6-7]

$$\langle\psi\rangle=\frac{1}{\sqrt{1+\frac{4.\sigma_\rho^2}{r^2}}}\,, \tag{3}$$

$$\sigma_\psi^2=\frac{1}{\sqrt{1+\frac{8.\sigma_\rho^2}{r^2}}}-\langle\psi\rangle^2\,. \tag{4}$$

In Eqs. (3) and (4) σ_ρ^2 are the variances of the linear displacement ρ. When these variances σ_ρ^2 are big the radius of laser beam r has to be big enough to satisfy Eq. (1). If r_{min} is the minimal value of the laser beam radius that satisfy Eq. (1) it can be expressed with the minimum divergence angle by relation

$$r_{\min} = \theta_{\min}.Z \tag{5}$$

Having used Eqs. (1), (3), (4) and (5) can be achieved following biquadrate equation

$$\theta_{\min}^4 + 8\frac{\sigma_\rho^2}{Z^2}.\theta_{\min}^2 - \frac{1024.\sigma_\rho^4.[erfcinv(2BER)]^4}{Z^4.\left(1+16[erfcinv(2BER)]^2\right)} = 0 \tag{6}$$

Only one solution of this equation is positive and from it is obtained the final expression for minimum divergence angle

$$\theta_{\min} = \frac{2\sigma_\rho}{Z}\sqrt{\frac{8[erfcinv(2BER)]^2+1}{\sqrt{16[erfcinv(2BER)]^2+1}} - 1} \tag{7}$$

This equation can be used to calculate minimal angle of laser beam divergence that satisfy domain of power design problem, when the statistic of laser beam direction fluctuation is known and some value of BER has to be achieved.

3. Numerical Results and Discusion

The obtained expression for $\theta_{\min}$ is used for an example calculation. The results are given on Figure 2 for Z=3000 m and σ_ρ = 0, 3 m – weak mechanical vibrations and weak turbulence, σ_ρ = 0,61 m – middle vibrations and turbulence, and σ_ρ = 1, 25 m

– very strong mechanical vibrations and turbulence.

The nature of the graphs in Figure 2 is quite expected. When the turbulence and mechanical vibration caused big variances of the laser shape in the receiver's plane the FSO system needs laser beam with bigger divergence to satisfy domain of the power design problem. In this case for Bit-Error Rates from 10^{-12} to 10^{-6}, that are interesting for the practice, the minimum divergence angle varies with approximately 20% between 2,5 and 2 mrad. When the linear deviation of laser shape is smaller – σ_ρ =0,3 m and σ_ρ = 0,61 m – the variation of $\theta_{\min}$ is smaller too.

4. Conclusions

An expression of minimum laser beam divergence angle that satisfy the domain of the FSO power design problem is obtained in this paper. It can be used when the power parameter of the system are calculated for the proper choice of the laser source.

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