Link Range of Free Space Laser Communication System

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Abstract – **In this paper a model analytical description of a Free Space Laser Communication System the type ground-to-space is constructed. It is used for quantitative determination of the maximum range between transmitter and receiver depending on the bit error rate (BER). The laser radiation extinction in the atmosphere is accounted for by means of the visibility.**

Keywords – **Laser Communication, Wireless Communication, Free Space Optics, Ground-to-Space Optical Communication, Atmospheric Attenuation.**

I. Introduction

Contemporary development of laser physics and technology offers new possibilities for the use of free space laser communication systems (FSLCS) [1]. The development of FSLCS of the type ground-to-space (or ground-to-space LCS) is of special interest [2-5]. This is due to two reasons: (I) these systems, in contrast to FSLCS of the type ground-to-ground (point-to-point), have no alternative in fiber optic communication systems (FOCS); (II) ground-to-space LCS are directly with present and future free space reclamation.

In this paper we attempt to construct an analytical model of ground-to-space LCS, and to connect parameters of structural links and characteristics of free space with the quantitative indices of the system as a whole.

II. Analytical Model of Surface-to-Space LCS

We assume that the transmitter part of the system is constructed on the basis of single mode Nd^{3+}:YAG laser excited by semiconductor lasers. This gives us reason to adopt Gaussian-amplitude and synphase distribution of the optical field in the aperture of the transmitter's aerial. Of course, we must take into account the unavoidable and very often considerable diversions of the real distribution from the shown theoretical idealization which leads to a substantial increase of the laser beam divergence. For this purpose, we correct the current radius of the Gaussian laser beam with the experimentally determined radius of the beam at distance Z from the transmitter's aperture, introducing their ratio $K(Z) > 1$.

On the basis of diffraction spatial structure of the Gaussian laser beam and accounting for the energy losses in the transmitter's and receiver's aerials, losses from the extinction in the earth's atmosphere and losses due to the use of pulse code modulation (PCM) we obtain the expression for the mean signal optical flux in the aperture of the photo-detector, namely:

$$\Phi_S = \frac{\tau_t \tau_r \tau_m}{2\sqrt{2}\left(1-e^{-2}\right)}\left[1-\exp\left(-\frac{k^2\rho_0^2 R_r^2}{2K^2(Z)Z^2}\right)\right]\Phi_L\,, \quad (1)$$

where:

Φ_L – optical flux in the laser output aperture (before PCM),

$k = 2\pi/\lambda$,

R_r – radius of the receiver aerial aperture,

ρ_0 – distance from the center of transmitter aerial aperture on which the optical field decreases e times (or initial radius of Gaussian laser beam),

τ_t, τ_r, τ_m – transparencies of transmitter aerial, of receiver aerial, and of free space, respectively.

For $\lambda = 0{,}53$ μm (second harmonic of Nd^{3+}:YAG laser) it is possible to neglect the absorption of laser radiation in the atmospheric aerosols and atmospheric gases ($\tau_{aer}^{(a)} = \tau_{mol}^{(a)} = 1$) and to assume that the extinction is only due to corresponding scatterings, i.e.:

$$\tau_m = \tau_{aer}^{(s)}\tau_{mol}^{(s)}\,. \quad (2)$$

The determination of $\tau_{mol}^{(s)}$ is accomplished on the basis of Relay theory of scattering. For standard atmosphere and for $\lambda = 0{,}53$ μm we have $\tau_{mol}^{(s)} = 0{,}9$.

To find $\tau_{aer}^{(s)}$ we use the Elterman's model, according to which for laser beam propagation through the entire atmosphere we have

$$\tau_{aer}^{(s)}(S_m) = \exp\left[-\frac{1}{b(S_M)}\alpha_{aer}(0,S_m)\right]. \quad (3)$$

The quantity

$$\alpha_{aer}(0,S_m)[\mathrm{km}^{-1}] = \frac{3{,}92}{S_m[\mathrm{km}]}\left(\frac{\lambda[\mu\mathrm{m}]}{0{,}55}\right)^{-0{,}585 S_m[\mathrm{km}]^{1/3}} \quad (4)$$

in Eq. (3) is the volume coefficient of aerosol scattering at ground level,

S_m is the visibility at ground level,

b is a coefficient determined by the curve in of Fig. 1.

The height H is connected with the distance Z with the relation

$$H = Z\cos\psi\,, \quad (5)$$

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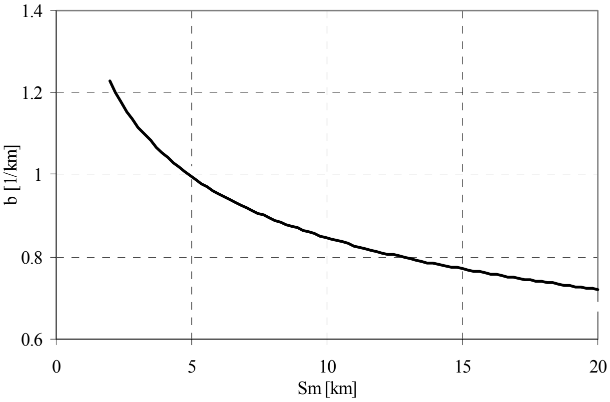

Fig. 1. Dependence of coefficient *b* on visibility

where ψ is the zenith angle of free space channel.

We further sopouse that a photo-multiplyer (PMP) is used as an optical radiation detector.

Analyzing the operation of a photo detector we obtain an expression for signal-to-noise ratio (*SNR*), namely:

$$SNR = \frac{S_C^2 \Phi_S^2}{2eN\Delta f\left(\sqrt{2}S_C\Phi_S + i_B + i_D\right)}, \quad (6)$$

where $S_C = e\eta\lambda/hc$ is cathode sensitivity of PMP (η is its quantum efficiency; *e*, electron charge; *h*, Plank's constant, *N*, noise coefficient from amplifying; Δ*f*, signal frequency-spectrum bandwidth; i_B and i_D, mean values of background and dark currents in the cathode circuit of PMP, respectively. The values of the currents are calculated with the well known relations

$$i_B = \frac{\pi^2 e\eta\lambda\tau_r}{hc} L_{\lambda,B} \frac{R_{PMP}^2 R_r^2}{f^2} (\Delta\lambda)_F \quad (7)$$

and

$$i_D = \frac{i_{Da}}{G}, \quad (8)$$

where $L_{\lambda,B}$ is the spectral density of background brightness; R_{PMP}, radius of input aperture of PMP; *f*, equivalent focal distance of receiver aerial; $(\Delta\lambda)_F$, interference filter optical bandwidth; i_{Da}, anode dark current of PMP; *G*, current gain coefficient of PMP.

The connection between *BER* and *SNR* is given by the equation

$$BER = \frac{1}{\sqrt{\pi SNR}} \exp\left(-\frac{1}{4} SNR\right). \quad (9)$$

The calculation of the dependence $Z_{max} = Z_{max}(BER)$ is performed by substituting (1) in (6) and (6) in (9) with the subsequent solution of the resulting relation with respect to *Z*. Fixing the value of *BER* transforms *Z* to Z_{max}.

III. CALCULATIONS

As example the dependence of Z_{max} on *BER* with parameter S_M is carried out with the following values: $\Phi_L = 1$ W; $\rho_0 = 2$ cm; $K(Z) \approx K = 10$; $\tau_t = 0{,}8$; $R_r = 20$ cm; $\tau_r = 0{,}4$; $f = 2$ m; $(\Delta\lambda)_F = 10$ Å; $\Delta f = 100$ MHz (information capacity 200 Mbit/s); $\psi = 0$; $R_{PMP} = 3$ mm; $\eta = 0{,}1$; $N = 1{,}5$; $G = 10^7$; $i_{Da} = 10$ nA; $L_{\lambda,B} = 10^{-3}$ [W/m^2.sr.Å]. The results are shown in Fig. 2 for $S_M = 2$ km, 5 km, 10 km, 20 km.

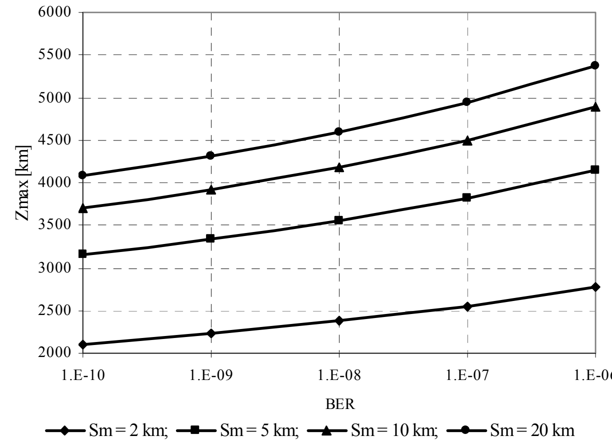

Fig. 2. Dependence of range limit value on the bit error rate

IV. CONCLUSION

As one can see on Fig. 2, in the most important from a practical viewpoint interval of *BER* (from 10^{-10} to 10^{-6}) the decrease in information losses (decrease of *BER*) leads to an acceptable decrease of the system link range. The values of the realizable link range demonstrate the great potential of ground-to-space LCS. One can also see the strong influence of the atmospheric transparency on Z_{max} for a given *BER* value. For a relatively clean atmosphere, $S_m > 10$ km, the S_m value is not of substantial importance. However, for low visibility ($S_m < 5$ km), Z_{max} drops rather quickly with S_m.

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