ADDITIONAL GAIN CALCULATION FOR THE FREE-SPACE OPTICAL LINK TRANSCEIVER

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ABSTRACT

The variety of the optical intensity distributions at the transmitter and receiver planes is the reason to define so called additional gain, which increases the receiver gain. The total optical receiver gain is an additive value, so we can calculate the FSO link power budget as a sum of powers, some of gains and some of looses. This article deals with the additional gain calculation, which increases the total optical receiver's gain and which is reached by placing the receiver lens at the beam axis in the far distance.

1 INTRODUCTION

The back distance concept as a solution of spherical wave problems is applied in FSO-link model [1]. The back distance L_0 (see Fig. 1) is defined by

$$L_0 = \frac{D_{TXA}}{tg\varphi_{TX}} \tag{1}$$

where D_{TXA} is the transmitter optical lens diameter and φ_{TX} the full transmitting angle. Usual selected value of the full transmitting angle φ_{TX} = 6 mrad. For the transmitter the plan-convex doublet with the diameter D_{TXA} = 30 mm is commonly used.

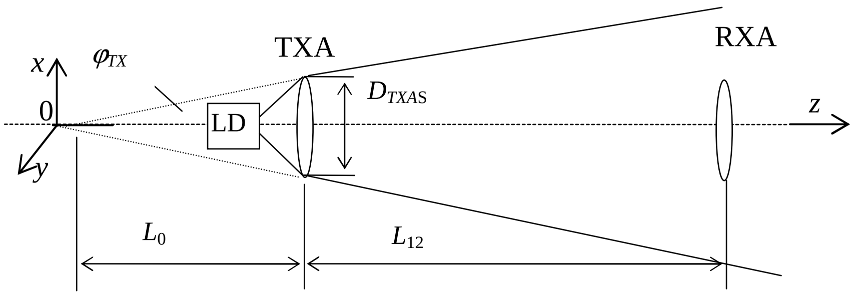

Fig. 1: *The back distance concept.*
(LD - laser diode; L_{12} – the transmitter to receiver distance; TXA and RXA - transmitter and receiver apertures; the 0xyz system of coordinates is used)

The assumed laser diode parameters are P_{LD} = 40 mW ≈ 16 dBm, λ = 850 nm, ψ_x = 10° and ψ_y = 30° (ψ_x – beam divergence at $x0z$ plane; ψ_y – beam divergence at $0yz$ plane). Diode emits the elliptical symmetry Gaussian beam defined by the major and minor half-width w_x and w_y respectively, corresponding to the diode divergences. Match the circular symmetry lens with the elliptical beam complicates the power budget calculation. This problem can be solved using the power equivalent Gaussian beam (PEGB) with the half-width w_{PEGB} given by equation (2) [3].

$$w_{PEGB} = \sqrt{w_x w_y} = w_x \sqrt{k_\psi} = w_y / \sqrt{k_\psi}\text{, where } k_\psi = \frac{\psi_y}{\psi_x}. \tag{2}$$

2 NORMALIZED OPTICAL INTENSITY DISTRIBUTIONS AT THE TXA AND THE RXA

The normalized beam intensity I_r as a function of the transverse coordinates x, y at the TXA is shown bellow (Fig. 2).

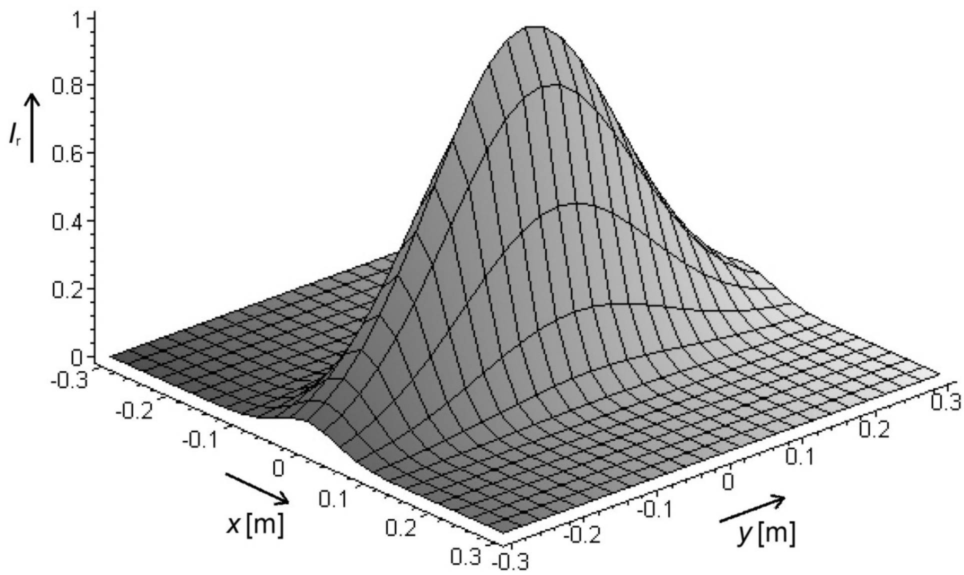

Fig. 2: *The normalized beam intensity I_r distribution in the elliptical symmetry beam spot at the TXA. (The simulation is presented for w_x = 0.3 m and w_y = 0.1 m.)*

The PEGB is used for the optical link power budget, but here comes another problem, how to choose the lens diameter with respect to the beam width. This problem will be discussed in the conclusion of this article.

The PEGB half-width at the receiver's plane equals

$$w_{RXA} = w_{TXA} \frac{L_0 + L_{12}}{L_0}, \tag{3}$$

where w_{TXA} - PEGB half-width at the TXA and w_{RXA} - PEGB half-width at the RXA. In Fig. 3 (see detail) the range ρ where I_{r} can be assumed as a constant is shown. We stipulate ourselves the 99% I_{r} decrease criterion, where we assumed the constant intensity. The maximum value of the radial distance ρ for this requirement is given by

$$\rho_{\max} = 0,07 w_{TXA} \frac{L_0 + L_{12}}{L_0}, \tag{4}$$

where $\rho_{\max}$ is the maximum radial distance. The graphs in Fig. 3 hold for parameters D_{TXA} = 30 mm, L_0 = 5 m and L_{12} = 1 km.

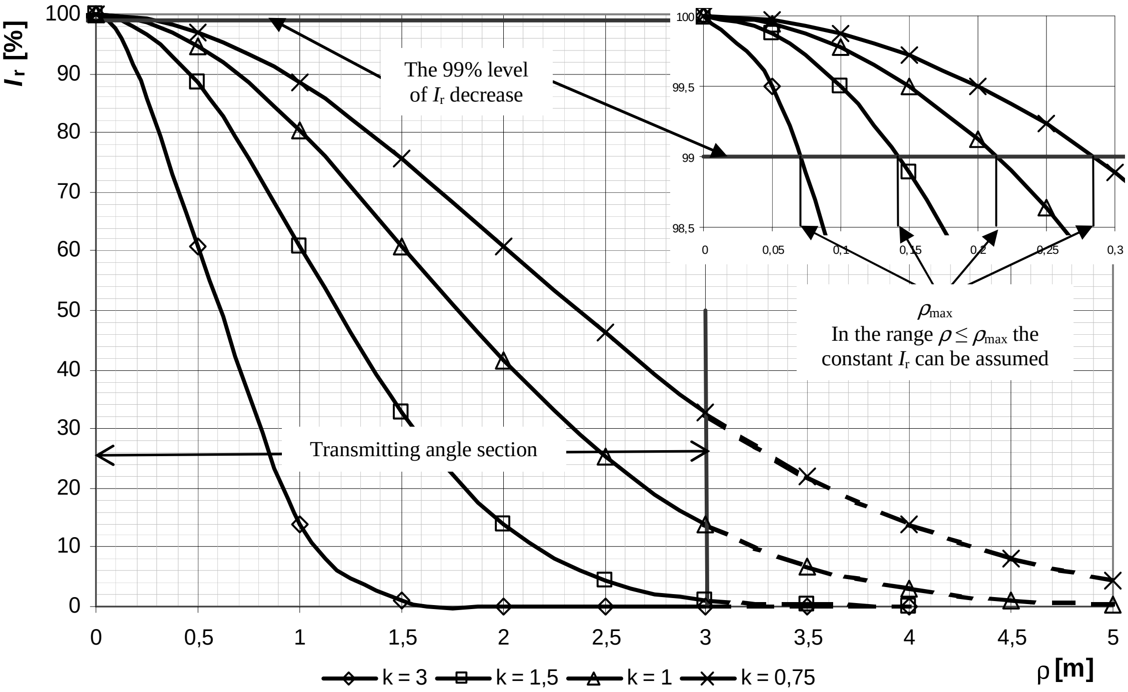

Fig. 3: *Distribution of relative intensity at the receiver's plane RXA for the different values of filling coefficient k = D_{TXA} to $2w_{TXA}$.*
(I_r – relative intensity, ρ – radial distance)

We come to the conclusion that in the frame of $\rho \le \rho_{\max}$ we can calculate with constant value of the optical intensity at RXA. In this conclusion existence of so called additional gain of the FSO link receiver is implicit (see bellow).

3 RECEIVER GAIN CALCULATION

For the additional receiver gain calculation by reduced power balance equation, it is now necessary to specify the maximum receiver lens diameter $D_{RXA,\max}$ for the certain range L_{12}. If $D_{RXA} \le \rho_{\max,}$ the relative optical intensity I_{r} is approximately constant. So the maximum receiver lens diameter $D_{RXA,\max} = 2\rho_{\max}$ is defined by (4). Dependence $D_{RXA,\max}$ on L_{12} is illustrated in Fig. 4 (for the same parameters as in Fig. 3).

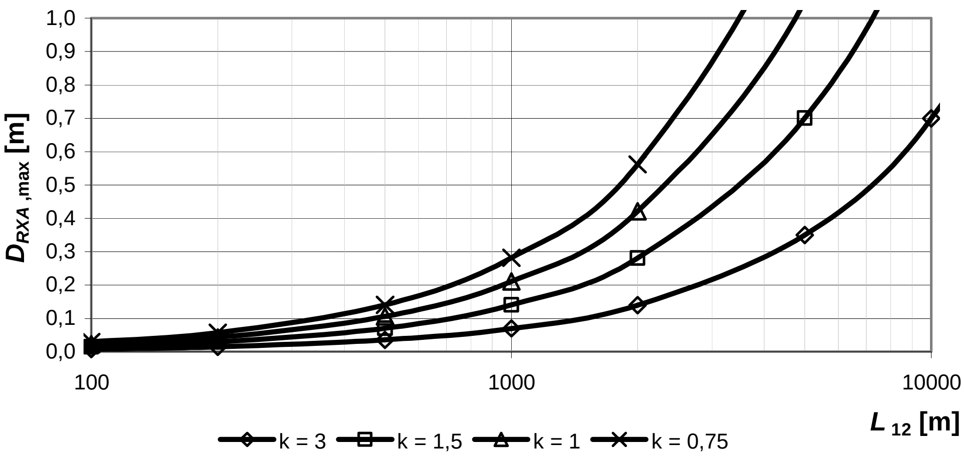

Fig. 4: *The maximum receiver lens diameter versus L_{12} at the different filling coefficient $k = D_{RXA} / 2w_{TXA}$.*

The reduced power balance equation, for the $D_{RXA} \leq D_{RXA,\max}$ is given by [3]

$$\frac{P_{RXA}}{P_{TXA}} = \frac{I_{0,RXA}}{I_{0,TXA}} \frac{D_{RXA}^2}{D_{TXA}^2} \frac{D_{TXA}^2}{2w_{TXA}^2 \left(1 - e^{-\frac{D_{TXA}^2}{2w_{TXA}^2}}\right)}, \tag{5}$$

where P_{RXA} and P_{TXA} are the optical powers at the RXA and the TXA respectively, $I_{0,RXA}$ and $I_{0,TXA}$ are the on-axis laser beam intensities at the RXA and the RXA respectively.

The third part on the right side of (5) defines so called additional gain γ_{add} (see 6), which is presented in the Fig. 5.

$$\gamma_{add} = 10 \log \frac{2k^2}{1 - e^{-2k^2}} \text{ where } k = \frac{D_{TXA}}{2w_{TXA}}. \tag{6}$$

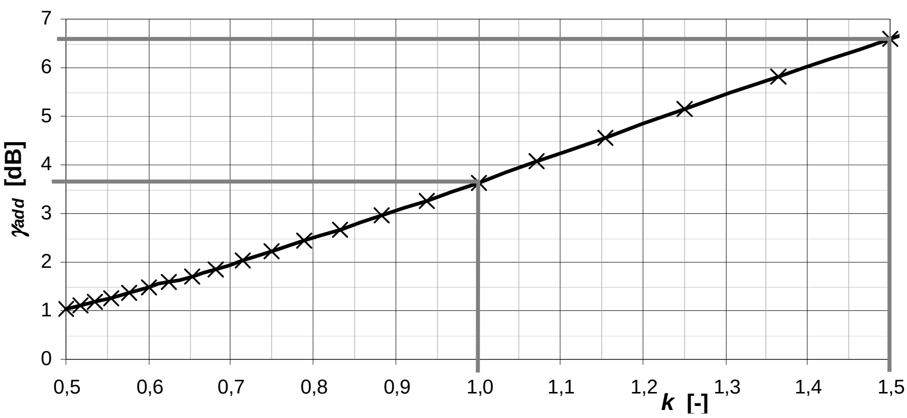

Fig. 5: *The additional receiver gain versus $k = D_{TXA} / 2w_{TXA}$.*

CONCLUSIONS

The variety of the optical intensity distributions at the TXA and the RXA planes is the reason to define so called additional gain γ_{add}, which increases the receiver gain (see Fig. 5). In Fig. 5 dependency of the additional gain γ_{add} on the filling coefficient k is presented. The filling coefficient implies ratio between the transmitting lens diameter and beam width at the TXA plane. The practical aspects of the FSO links lead us to use the k values in interval from 1.0 to 1.5, in which the γ_{add} achieves values from 3.64 dB to 6.58 dB. Too small k means high transmitting losses and too high k leads to the narrow beam that is not resistant to the misspointing and the other atmospheric effects.

ACKNOWLEDGEMENTS

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