OPTICAL WIRELESS LINK DISTANCE RESTRICTIONS

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ABSTRACT

The distance limits of the link can be calculated using the link power budget. The total gain at the optical receiver is an additive value, so we can calculate the power budget of the FSO link as a sum of powers, some of gains and some of looses. Most of these looses are distance dependant. This article deals with the definition of distance and related powers limitations, based on the practical point of view.

1. INTRODUCTION

The FSO link model [1] can be divided into three separated parts, the optical transmitter, the optical receiver and the transmission through the atmosphere. For the calculation of the link power budget the power equivalent Gaussian beam concept is used [2]. In the transmitter, the limitation is given by the laser diodes powers and their count. In the receiver system, the limits are given by the power detector and the construction possibilities. The transmission through the atmosphere is based on its descriptions shown in [5].

2. OPTICAL TRANSMITTER SYSTEM

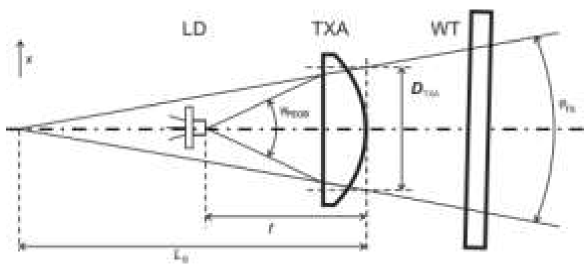

Figure 1: The back distance concept (LD – laser diode; D_{TXA} – transmitter diameter; f – transmitter lens focal length; L_0 – back distance; WT – receiver cover window; ψ_{PEGB} – laser diode beam divergence; φ_{TX} – output beam divergence).

The construction of the transmitter is shown on (Figure 1). The transmitter is described by the back distance L_0, diameter of transmitter lens D_{TXA} and the full transmitting angle φ_{TX}. Usual selected value of the full transmitting angle $\varphi_{\mathrm{TX}} = 3$ mrad. For the transmitter the plan-convex doublet with diameter $D_{\mathrm{TXA}} = 25.4$ mm with effective focal length f of 40 to 50 mm is commonly used. Assumed parameters of each laser diode are $P_{\mathrm{LD}} = 50$ mW ≈ 17 dBm, $\lambda = 1550$ nm or 830 nm. The diode emits the elliptical symmetry Gaussian beam. The match circular symmetry lens with elliptical beam complicates the power budget calculation. This problem can be solved using the power equivalent Gaussian beam (PEGB) with half-width w_{PEGB} described in [2]. The attenuation of the transmitter system α_{TS} is given by the sum of looses of its parts. The attenuation of the cover window α_{WT}, receiver lens α_{TXA} and attenuation due to the LD to TXA coupling are given by its practical measurement. The usual values are $\alpha_{\mathrm{WT}} = -1$ dB, $\alpha_{\mathrm{TXA}} = -0.6$ dB and $\alpha_{\mathrm{LD}} = -1$ dB. The attenuation of the transmitter system $\alpha_{\mathrm{TS}} = -2.6$ dB.

3. OPTICAL RECEIVER SYSTEM

The receiver system includes the receiver lens, the concentrator, interference filter and the detector. The attenuation of the receiver system α_{RS} is given by a sum of looses of its parts. The attenuation of cover window α_{WR}, receiver lens α_{RXA}, interference filter α_{IF}, collimator system α_{CS} and the attenuation due to the RXA to PD coupling α_{PD} are given by its practical measurement.

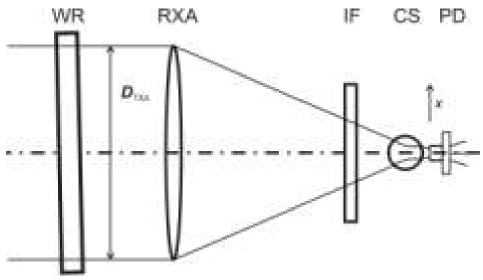

Figure 2: The receiver system (WR – receiver cover window; RXA – receiver lens; IF – interference filter; CS – collimator system; PD – photodiode).

There are two possible choices of the detector, the PIN photodiode or the APD photodiodes. For a long distance optical communications the APD photodiodes are commonly used due to its internal optical gain. Instead of using the collimator system the optical power to photodiode coupling is demanding on the construction accuracy. The practical measurement at the wavelength $\lambda = 1550$ nm gives us the values: $\alpha_{\mathrm{WR}} = -1$ dB, $\alpha_{\mathrm{RXA}} = -0.3$ dB, $\alpha_{\mathrm{IF}} = -0.5$ dB, $\alpha_{\mathrm{CS}} = -0.4$ dB and $\alpha_{\mathrm{PD}} = -3$ dB. For the wavelength $\lambda = 1550$ nm the value of overall receiver attenuation $\alpha_{\mathrm{RS}} = -5.2$ dB and for the $\lambda = 830$ nm wavelength the value $\alpha_{\mathrm{RS}} = -7.7$ dB (spectral transmittance required only at 830 nm, $\alpha_{\mathrm{IF}} = -3$ dB).

The gain of the receiver lens is given by the receiver to transmitter lens ratio and the variety of the intensity distribution

$$\gamma_{\mathrm{RXA}} = 20 \log \frac{D_{\mathrm{RXA}}}{D_{\mathrm{TXA}}} + 3.67 . \tag{1}$$

For the photodiode selection the beam spot measurements has been also made.

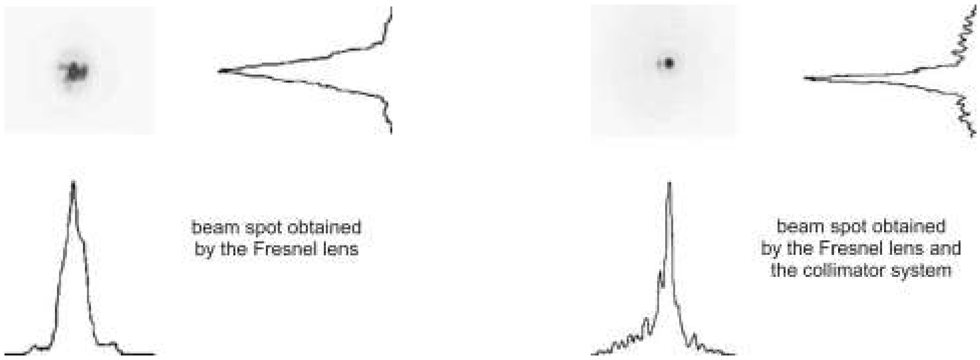

Figure 3: The beam spot of the Fresnel lens (left) and the combination of the Fresnel lens in combination with the collimator system (right).

On the picture (Figure 3) is the beam spot measured by the beam profiler. For the intensity decrease to I_0/e^{-2} the PEGB spot diameter is 0.35 mm. For reduction of the power coupling attenuation α_{PD}, the photodiode with larger active area must be used. Using the another lens allows us to decrease the beam spot radius down to 0.13 mm and to use the photodiodes with 0.2 mm active area diameter. For the PIN to the APD confrontation the following photodiodes has been chosen:

Hamamatsu InGaAs PIN photodiode C8376-05 at $\lambda = 1550$ nm, active area diameter $D_{FD} = 0.5$ mm, photo sensitivity $S = 0.95$ A/W and $NEP_1 = 8.10^{-15}$ W/Hz$^{1/2}$ (for 1550 nm, 10 Mbps data bit rate and OOK modulation the $NEP = -76$ dBm).

Perkin-Elmer Si-APD C30921S at $\lambda = 830$ nm, active area diameter $D_{FD} = 0.5$ mm, photo sensitivity $S = 128$ A/W and $NEP_1 = 0.86.10^{-15}$ W/Hz$^{1/2}$ (for 830 nm, 10 Mbps data bit rate and OOK modulation the $NEP = -86$ dBm). The APD with similar parameters at $\lambda = 1550$ nm are inaccessible and will not be discussed.

4. GAIN OF RECEIVER CALCULATION

For the FSO-link the transmission through the atmosphere could be described with attenuation due to the particles influence, the turbulence attenuation and propagation attenuation. The turbulence distortion may be seen as hot flux eddies, which come from small temperature variations related to the sun heating of the earth and the turbulent motion of the air due to winds and convection. The propagation attenuation α_{12} is given by the link distance L_{12} and the full transmitted angle represented by the back distance L_0. These looses can be decreased only by decreasing the beam angle, which leads to higher probability to link miss-pointing, due to the console thermal or wind deformations. The attenuation due to the particles influence α_{part} is for the clear atmosphere and the wavelength of $\lambda = 1550$ nm given by $\alpha_{1part} = 0.48$ dB/km [5]. The turbulence attenuation description is a little more complicated, because we have to consider the irradiance flux variance described in [5]. The overall attenuation of the atmosphere is given by a sum (2) Figure 4.

$$\alpha_{atmc} = \alpha_{1part} L_{12} + 20\log\frac{L_0}{\left(L_0 + L_{12}\right)} + \alpha_{turb}(L_{12})\,. \tag{2}$$

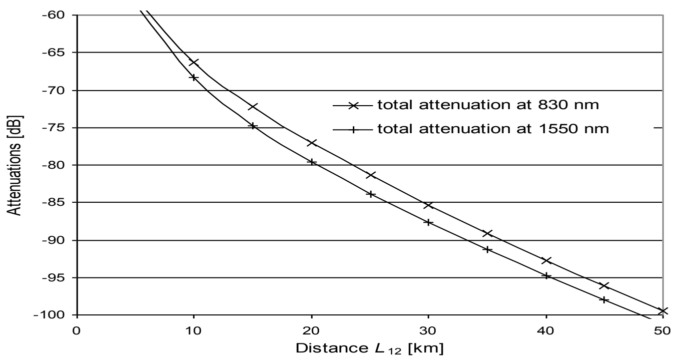

Figure 4: Transmission through the atmosphere overall attenuation graph.

5. LINK POWER BUDGET

For distance limit calculations it is necessary to calculate the minimal value of the receiver systems input power P_{RXA} and the output power of the transmitter system P_{TXA}. The difference between these powers increased by the gain of the receiver lens γ_{RXA} is proportional to the maximal distance taken from the graph on Figure 4.

The FSO-link power budget diagram (Figure 5) shows transparently the powers and attenuations at characteristic points of the whole transmission system. The P_{LD} is the sum of powers of all used laser diodes in the transmitter system. The output power of the transmitter system P_{TXA} is the P_{LD} decreased by the attenuation of the transmitter system α_{TS}. The minimum power P_{MIN} to guarantee requested bit error rate $BER = 10^{-6}$ is equal to the photodiode's noise equivalent power NEP increased by the signal to noise ration $SNR = 13.5$ dB. The required minimum power at the photodiode P_{PD} is then P_{MIN} increased by the link power margin (15 dB reserve used). The minimal value of the receiver systems input power P_{RXA} is then P_{MIN} increased by the attenuation of the receiver system α_{RS}.

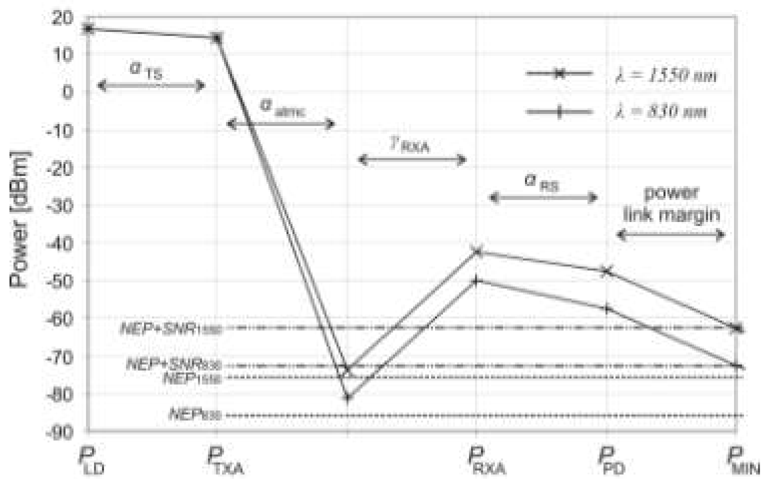

Figure 5: Link power budget diagram of the FSO-links at 1550 and 830 nm.
(P_{TXA} – output power of the transmitter system, P_{RXA} – input power of the receiver system, P_{PD} – power at the photodiode, P_{MIN} – minimum power to guarantee requested BER = 10^{-6}).

FD part name	InGaAs PIN - C8376-05	Si-APD - C30921S
wavelength λ	1550 nm	830 nm
***NEP* @ 10 Mbps/OOK**	-76 dBm	-86 dBm
possible attenuations	-88.2 dB	-95.7 dB
distance limit	32 km	45 km

Chart 1: Distance limits for the FSO-Links with the APD and PIN photodiodes.

CONCLUSIONS

This work shows the design of two FSO-links with similar system parameters at different wavelengths. Both of them obtain good results. The most significant difference comes with the photodiode selection. The Si-APD photodiode at 830 nm have better sensitivity and lower *NEP* then InGaAs-PIN working at the wavelength of 1550nm.

The advantages using the PIN at the wavelength of 1550 nm are that safety limits allows 50x more power then for the wavelength of 830 nm, PD is less influenced by background power. The main disadvantage is the higher price of LD and PD.

The advantages using the APD at the wavelength of 830 nm are more variety of cheaper LD and PD, APD with better sensitivity and internal gain. The disadvantages are that the APD is very influenced by background power, needs higher voltage and requires temperature stability.

For the transmission speed of 10 Mbps with OOK modulation, $BER = 10^{-6}$ and 15 dB link power margin the link at 830 nm gives the 45 km link range and the link at 1550 nm gives 32 km link range.

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