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Optical Wireless Link for Railway Service

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Abstract: - Optical wireless links (OWL) have found many applications due to their specific properties. One of interesting applications is a 10Mb/s optical link connecting train wagons. The link design takes into account instability of mutual position and orientation of transmitter and receiver. The paper deals with analysis of extreme deviations, design, and modeling of transmitting and receiving optical systems for the link.

Key-Words: - Free Space Optics, Communications, Networking

1 Introduction

The optical link is intended for modernization of classical train carriages to provide new services both for the crew and passengers. The optical system designed is based on inexpensive LEDs and plastic Fresnel lens. As the electronics is based on circuitry for fiber applications, the optical system must provide optical power at photodiode between -30dBm to 0dBm under all circumstances (carriage movements, optics smear, etc.).

The extreme angular deviations of optical axes of transmitter and receiver can be determined from a simplified model in Fig. 1a that depicts situation in the horizontal plane. Axes of the wagons contain angle θ_A which depends on the track radius of curvature. However, the angle between optical axis o and abscissa $[0,0][x_0,y_0]$ (the join of receiver and transmitter) is only $\theta_A/2$. Movements of carriage caused by the rail irregularities could be expressed as side deviations Δx. Points A and B represent the extreme cases. Angular effect of eventual vertical deviations Δy is always smaller.

The angles α_A and α_B can be determined as

$$\alpha_A = arctg\left(\frac{L\sin(\theta_A/2) - \Delta x\cos(\theta_A)}{L\cos(\theta_A/2) + \Delta x\sin(\theta_A)}\right), \qquad (1a)$$

$$\alpha_B = arctg\left(\frac{L\sin(\theta_A/2) + \Delta x\cos(\theta_A)}{L\cos(\theta_A/2) - \Delta x\sin(\theta_A)}\right). \qquad (1b)$$

Actual values of L, θ_A, and Δx are given by railway standard specifications [1]. The values considered were: L from 0.3m to 1.5m, $\Delta x = 6$cm, $\theta_A = 10°$ (the sharpest track curve).

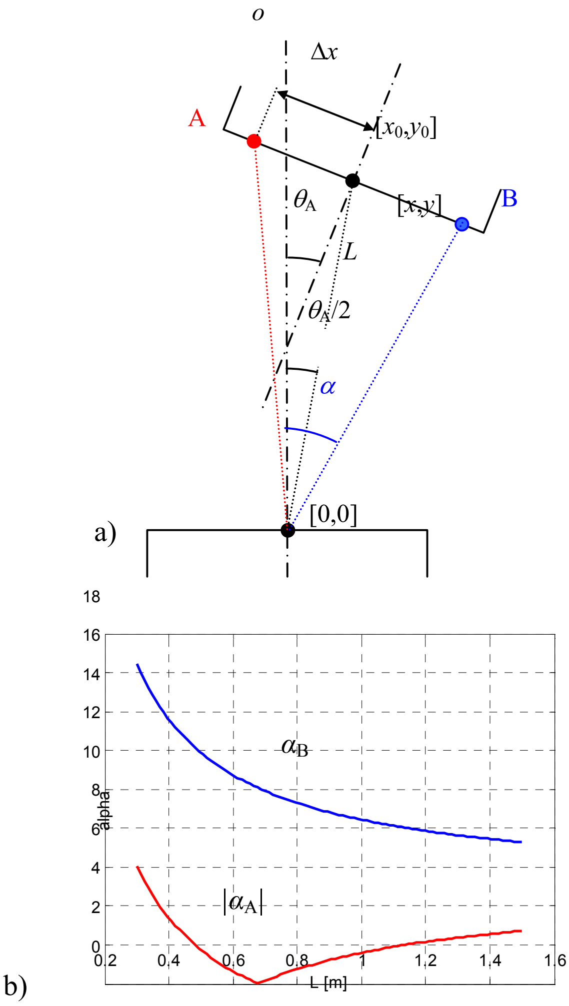


Fig. 1 Simplified geometrical model for determination of α_A and α_B (θ_A – angular divergence of wagon axes; α – angular position of opposite device with respect to the optical axis o; L – distance between [0,0] and $[x_0,y_0]$).

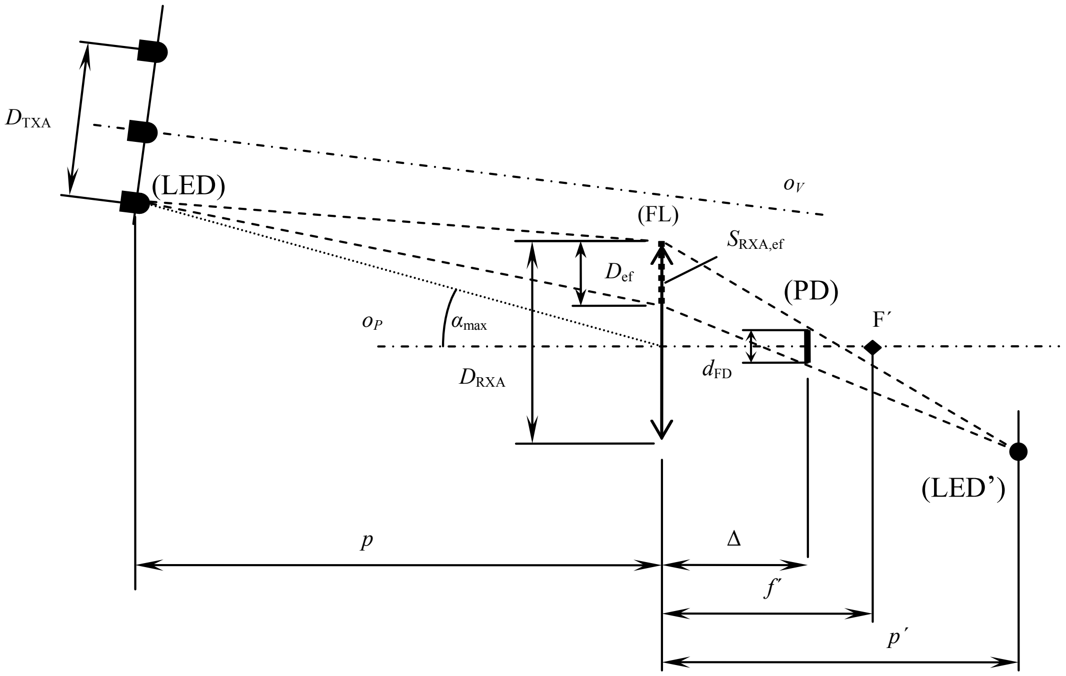


Fig. 2 Design model of receiving optical system under extreme deviation (photodiode aperture is irradiated only by the outer LED); D_{TXA} – diameter of transmitting aperture; D_{RXA} – diameter of Fresnel lens; PD – photodiode; LED’ – image of the outer LED; F’ – second focal point

Analysis of angular position of A and B (α_A, α_B) exhibits the maximum of $|\alpha|_{max} = 16°$ for $L = 0.3$m, Fig. 1. This value determines required field of view of the receiver and required beam divergence of the transmitter.

2 Model of the Optical System

Fig. 2 shows a design model of the receiver optical system. The transmitting aperture is composed from several properly directed LEDs without any optics.

Using some basic principles of ray optics an analytical formula for the maximum distance Δ between photodiode and lens can be obtained as

$$\Delta = \frac{pf'\left(D_{RXA} - d_{PD}\right)}{2pf'\,\mathrm{tg}\left(\alpha_{max} - \mathrm{arctg}\frac{D_{TXA}}{2p}\right) + D_{RXA}\left(p - f'\right)} \cdot \quad (2)$$

Because Δ is smaller than p’, only a fraction of the receiving aperture participate on the power reception. It is denoted as effective aperture $S_{RXA,ef}$ (Fig. 2). Gain G of the optical system is defined as ratio of the actually received power to that received without any optics, i.e.

$$G = 20\log\left(\frac{D_{ef}}{d_{PD}}\right) = 20\log\left(\frac{pf'}{pf' - \Delta(p - f')}\right) \text{ [dB]}, \quad (3)$$

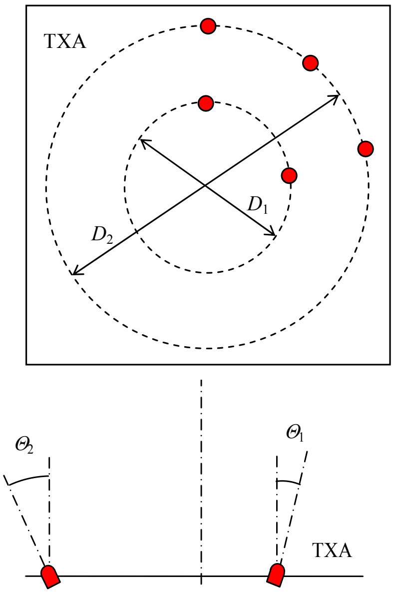
where D_{ef} is diameter of the effective aperture and d_{PD} is diameter of active area of the photodiode. In the case of irradiation by several LEDs the received power is given as a sum of individual contributions

$$P_{FD} = \frac{\pi}{4} d_{PD}^2 T_{RXA} \sum_k \frac{I_{i,k}(l,m)}{L_k^2} 10^{0,1G_k} \cos\alpha_k \ , \quad (4)$$

where T_{RXA} is transmission of lens, $I_{i,k}$ (l,m) is the individual LED irradiance, l,m are direction cosines, L_k is distance between k-th LED and center of effective aperture, G_k is receiver gain (in dB) for k-th LED and α_k is the incidence angle of radiation of k-th LED on effective aperture.

3 Computer Simulation

Fig. 3 shows configuration of transmitting LEDs. The diodes (Vishay TSFF5200) are uniformly distributed around two circles (N_1 diodes on the inner circle and N_2 diodes on the outer one) and are deflected radially such way, that their axes make angles Θ_1, Θ_2 respectively with the normal line of TXA. Fig. 4 shows power (in dBm) received by a test aperture $D_{test} = 15$mm in dependence on angular deviations α_x, and α_y and a section for $\alpha_y = 0$; both at $L = 0.3$m. The test aperture is always oriented perpendicularly to the beam going from the transmitter center. Its size is chosen similarly to the size of effective aperture of the actual receiver to get a realistic image of field distribution.



N_1	D_1 [mm]	Θ_1 [°]	N_2	D_2 [mm]	Θ_2 [°]
4	38	7	8	75	20

Fig. 3 Configuration of transmitting LEDs.

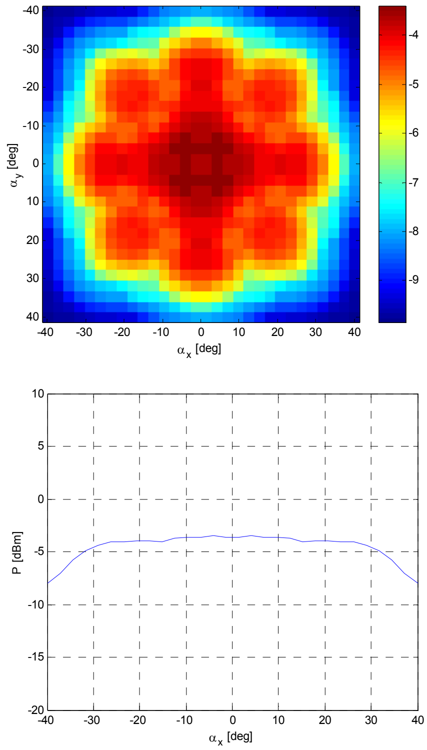


Fig. 4 Distribution of transmitter filed received by 15mm test aperture.

The receiver optics consists of Fresnel lens D_{RXA} = 50mm (E.F.L. 33 mm) and a photodiode with diameter of active area d_{FD} = 4mm. Fig. 5 shows results of numerical analysis of received power for θ_A = 10° and $\Delta = 25$mm as a function of side deviations Δ_x and Δ_y for $L = 1.5$m.

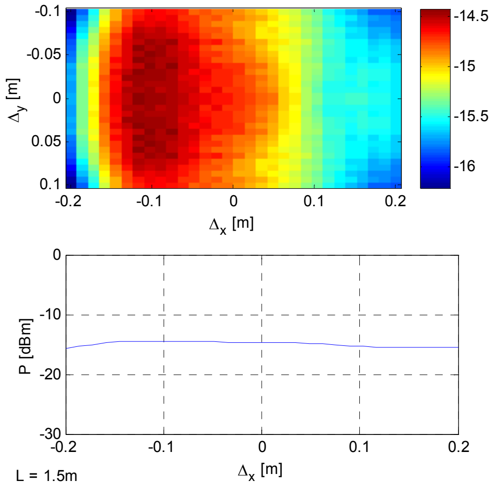


Fig. 5 Received power as function of Δx and Δy (see Fig.1)

5 Conclusions

The optical system designed is based on inexpensive LEDs and plastic Fresnel lens and provides optical power at photodiode between -30dBm to 0dBm under all circumstances. The optical link is intended for modernization of classical train wagons to increase safety and provide new services both for the crew and passengers.

6 Acknowledgements

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