MODEL FOR INDOOR WIRELESS OPTICAL LINK

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Abstract: This paper deals with an indoor wireless optical link (IWOL). In the IWOL the laser beam carrying the information is propagated through the room and reflected on the walls and various objects. The multiple reflections and multipath distortion occurs by using this link. The power level diagram of the optical wireless link includes not only transmitted and received power but also reflection and placement losses. The directional properties of surface reflectivity are characterized by the so called relative directional reflectivity.

Keywords: Indoor wireless optical link, directional reflectance of surface, power level diagram

1. INTRODUCTION

An indoor wireless optical link (IWOL) works in the IR spectral region and, therefore, any interference with other links are not presented. It is possible to use two methods for the IWOL arrangement. The first method is called the diffuse method. The second method is called the quasi-diffuse method. In the diffuse method, the optical radiation is transmitted by a wide space angle. The optical radiation is scattered on the wall. The scattered radiation is then reflected to a receiver. In the quasi-diffuse method a narrow light beam is sent to a fixed surface. Then all receivers are deployed to fixed places.

For the IWOL design and communication quality assessment, the power balance equation and the power level diagram are used. In the power balance equation the influence of surface reflectivity on received power is shown. The influence of surface reflectivity on received power is simulated by a relative directional reflectivity of the surface (RDR- Relative Directional Reflectivity). The main properties of the reflecting surface and their influence on of the IWOL will be described bellow [1], [2].

2. THE POWER BALANCE EQUATION OF THE IWOL

The transmitter sends an optical signal into the atmosphere with some energy power. The transmitted power of laser diodes or LEDs is labeled P_v [W]. After the optical signal is reflected by the reflecting surface, the optical signal is then received by the receiver. The receiver power is labeled P_p [W].

In our case, we took measurements in a closed room so meteorological properties of the atmosphere were not taken into account.

In the receiver side the modulated optical signal is converted into the electrical signal. For this purpose a photodiode is used. Noise level measured at the unit frequency bandwidth is given by quantity NEP [W.Hz$^{-1/2}$]. The detected signal is demodulated and if it is necessary it can be decoded.

The receiver sensitivity P_o [W] is an important parameter of the receiving unit and it is given as the minimum optical power at the receiving aperture, which matches a fixed proportion of the SNR. In most applications, the quality of the receiver determines the quality of link transmission. The basic principle of information transmission in the IWOL is show in Figure 1.

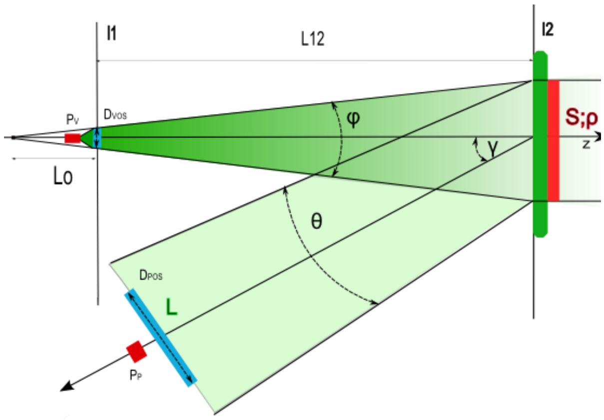

Figure 1: The basic principle of the IWOL function (P_V - transmitted power by the laser diode; P_p – the received power; L_O – auxiliary distance; L_{12} – is distance between the receiver and the transmitter; D_{VOS} – is diameter of transmitting optical system; D_{POS} – is diameter of receiving optical system; L – is radiance; φ – beam width; θ – width of the reflected beam; γ – is angle of reflection; S – laser spot; ρ – is surface reflectivity).

The received power P_P can be calculated by the equation (1):

$$P_P = L.\Omega.\rho.S.\cos(\gamma);\ [\text{mW}], \tag{1}$$

where L is radiance, Ω is space angle, ρ is surface reflectivity, S is laser spot size on reflecting surface and γ is angle of reflection. After equation (1) adjustment in the case of the Lambert surface it will be accepted the equation (2):

$$P_P = \frac{P_V.\rho.D_{POS}^2}{4.L_{12}^2}\cos(\gamma);\ [\text{mW}], \tag{2}$$

where P_V is transmitted power, L_{12} is distance between the receiver and the transmitter, resp. between reflecting wall and receiver, D_{POS} is diameter of receiving optical system and γ is angle of the reflection.

The power level equations (3) and (4) in dB measure are the basic tool for design of the optical links and the basic tool for evaluation of quality properties of the communication systems

$$P_P = P_V + 10\log(1/4) - \alpha_v - 20\log\left(\frac{L_{12}}{D_{POS}}\right) + 10\log(\rho.\cos(\gamma)) - \alpha_P;\ [\text{dBm}], \tag{3}$$

where α_V is attenuation of the transmitting optics and α_P is attenuation of the receiving optics. After (3) modification it holds

$$P_P = P_V - 6 - \alpha_V - \alpha_{12} + A_{PSO} - \alpha_P;\ [\text{dBm}], \tag{4}$$

$$\left[\alpha_{12} = 20\log\left(\frac{L_{12}}{D_{POS}}\right)\right];\ [\text{dB}], \tag{5}$$

where α_{12} is attenuation of propagation, and A_{PSO} represents properties of the reflection surface.

$$\left[A_{PSO} = 10\log(\rho.\cos(\gamma))\right];\ [\text{dB}], \tag{6}$$

For correct working of the IWOL system it is necessary the value of the received power is greater than the receiver sensitivity P_o. The value of the receiver sensitivity includes the noise level NEP and signal-to-noise ratio SNR. The amplification effect of the receiving lens is in the quantity α_{12} included.

The power balance equation (4) is represented in Figure 2 by the so called power level diagram [3], [4].

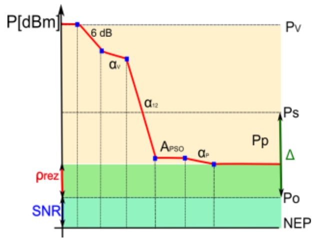

Figure 2: The power level diagram of the IWOL (α_v – attenuation of the transmitting optics; α_{12} – attenuation of propagation; α_P - attenuation of the receiving optics; A_{PSO} – measure of the power directional reflectivity of the surface; P_p – the received power; P_o - sensitivity of the receiver; P_s – saturated received power; P_V - transmitted power by the laser diode; SNR – signal to noise ratio; NEP – noise equivalent power; ρ_{rez} - link margin; Δ – dynamics of the receiver).

2.1. THE DIRECTIONAL REFLECTANCE OF SURFACE

The transmitted power passes through the atmosphere and is reflected on the wall (reflecting surface). The incident optical power on the walls or barriers is subordinate to the laws of interaction of radiation and matter. Reflection on the surface can be dispersion (diffusion) or specular (reflective). A special case is an absolute reflection. Variants of reflections are shown in Figure 3.

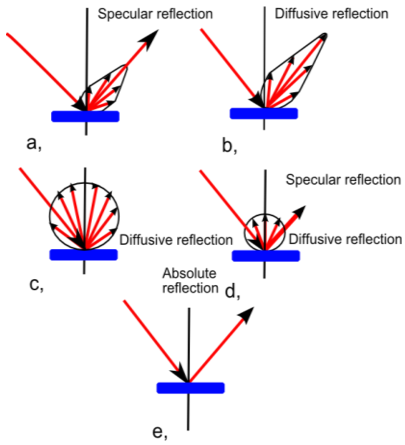

Figure 3: Variants of reflections on the surface [5].

For modeling diffusive and reflective surfaces were the chosen method of energy balance. It is supposed that the reflecting surface is planar with diffuse-reflective characteristics of the irradiated optical wave. The directional diffuse-reflective characteristics can be measured by directional reflectivity of the surfaces RDR [5], [6].

The RDR of a certain surface area is defined as a radiance of the real surface divided by the radiance of the ideal diffusion surface with the unitary reflectance, which is illuminated by the same intensity as the real surface. The RDR can by expressed as (7).

$$RDR = \frac{\pi . L_{(\gamma)}}{I_i}\text{; [-],} \tag{7}$$

where $L_{(\gamma)}$ is the radiance of a real surface in γ direction, while the radiation of the intensity I_i irradiates the surfaces perpendicularly. The circularly symmetric highly directional optical beam is falling on the reflecting surface perpendicularly. RDR can be simulated by the „cos“ function and expressed as (8)

$$RDR_{(A_n,n,\gamma)} = A_n \cdot \left[\frac{1+\cos(\gamma)}{2} \right]^n ; [-], \qquad (8)$$

where γ is angle of direction of observation, A_n and n are coefficients of directivity. The overview of the coefficients of directivity for non-lambert surfaces is given in Table 1. The coefficient A_n represents a measure of the disperse power on the surface and the coefficient n represents measure of the directional characteristics of the dispersed power. The coefficients are of the non-lambert directional reflectivity surface.

n	1	10	50	100	500	1000	5000	10000	100000
A_n	0,50ρ	1,293ρ	2,863ρ	3,999ρ	8,925ρ	12,62ρ	28,21ρ	39,89ρ	126,1ρ

In the following Figure 4 the simulating function (8) for the chosen coefficients of directivity is shown. The first figure corresponds to the full diffuse reflective surface. The second and the third picture show the characteristics of highly reflective surfaces. On condition that the surface is irradiated perpendicularly the maximum of reflected radiation appears in the *z* direction (see Figure 1). For some special surfaces the same direction of the scattered radiation in which the surface is irradiated is preferred. In case of full diffusive surface (white matt paper, Lambert surface) the coefficient of directivity n is smaller than is case of partially specular surface which is presented in Figure 4.

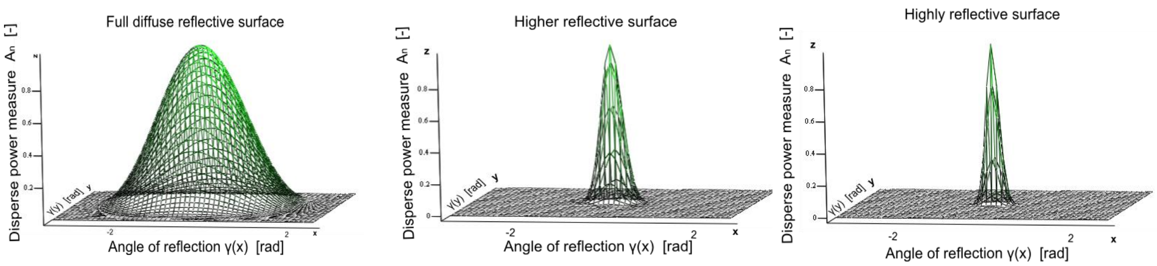

Figure 4: The directional characteristics of the dispersed power on the reflecting surface. (A_n = 1, n = 2; A_n = 1, n = 10; A_n = 1, n = 100)

2.2. THE RDR INVOLVEMENT INTO POWER BALANCE OF THE IWOL

Influence of the relative directional reflectivity of the reflecting surface on power budget of the IWOL is represented in Figure 5. In this figure a scheme of the experimental measuring chain arranged in the room model is shown in Figure 5.

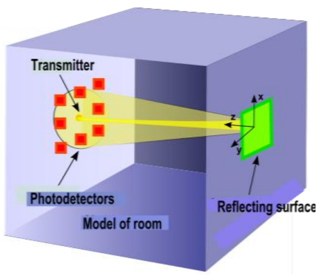

Figure 5: The basic principle of the RDR measurement.

The relative directional reflectivity of the reflecting surface will affect the reflected wave and then consequently the total energy balance of the IWOL. If character of the reflecting surface is similar to the ideal Lambert surface with the unit reflectance, the RDR such a surface equals 1. The power level diagram of the IWOL including reflective properties of the reflecting surface through A_{PSO} is represented in Figure 6.

When using the RDR, it is possible to include the reflective properties of the reflecting surface into power budget of the IWOL and to make it as computer – aided calculation. The power level diagram of the IWOL where the RDR is included is represented in Figure 6.

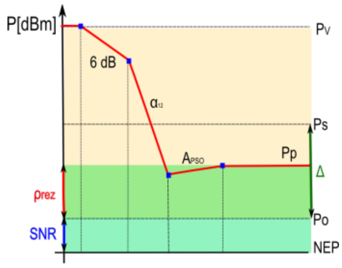

Figure 6: The power level diagram of the IWOL including the special RDR function (A_{PSO}- parameters of the reflective properties of the reflecting surface).

The directional dependence of the RDR is an important characteristic of the reflecting surfaces and must be taken into account when considering power budget of the IWOL.

3. CONCLUSION

In the first part of this paper, the possible ways of the optical wireless links placement for an indoor optical network are presented. The positional structure and transmission of information method was described. In the next section of the paper, the power level equation was analyzed and the power level diagram was clarified. The important limits have been written for the design and reliable working of the optical link. It was described the influence of directional reflectance of the reflecting surface on the optical properties of the indoor optical link. The choice of the special function for modeling the reflective properties of the reflecting surface was made. This special function allows us to specify properties of the reflecting surface and has been experimentally verified in the room model.

An interesting application of the indoor wireless optical links is for communication between PC and printer, communication between sensors within the electronic security alarm systems, electronic fire systems or in automation technology, etc. at the same room.

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