Effects of specular surfaces of finite thickness on wireless optical communication channel response

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The finite thickness of glass surfaces, frequently used in office environments, must be taken into account in optical channel characterisation. A reflection coefficient that considers this effect is presented and then integrated into an optical channel simulation tool that processes both diffuse and specular contributions.

Introduction: The impulse response of the indoor optical channel is primarily determined by room dimensions, as well as by wall composition, colour and texture [1]. To estimate channel behaviour, specular dielectric panels should be addressed in a different manner than diffuse ones, due to the heavy dependence of the reflected power on the incidence angle $\theta_i$ and light wave polarisation in the former case. Classic electromagnetic analysis solves this problem by using a pair of complex coefficients that depend on the thickness to-wavelength ratio. Unfortunately, manufacturing tolerances of common glass are so wide that the thickness fluctuates across the sheet surface, with variations well above hundreds of nanometres. Therefore, those complex reflection coefficients become useless. An alternative approach is presented, which allows the expression of a general reflection coefficient $p_{\text{spec}}(\theta)$ to be obtained.

Discrete-reflections approach: It can be considered that each diffuse differential element radiates a spherical wave, which can be assumed to be a plane wave only in a small area around the incidence point of the specular sheet, for a given incidence angle $\theta_i$. This plane wave will hereinafter be called the incident ray. The incident ray will be reflected into the inner faces of the dielectric sheet. Owing to the high thickness value (typically 5-10mm), when compared with the light wavelength and the plane wave spot size, the paths of the different reflected rays are sufficiently far apart that interference is not to be expected. Moreover, each reflection and transmission of local plane waves at both faces is governed by Fresnel coefficients. Hence, the power of the reflected ray with angle $\theta_r = \theta_i$ reaching the photodetector area $dR$ (Fig. 1) is computed by calculating the discrete sum of the externally reflected beam power along with the $n$ individual power contributions from the diffuse sheet. Each of those contributions suffers 1, 3, 5, ..., $2n-3$ internal reflections before it leaves the glass at point $R$.

Results: Let $dP_L$ be the power of each incident ray with angle $\theta_i$ emitted by each single contributor in the diffuse area, which can be divided into two power terms, associated to the parallel-to-incidence-plane (L) electric field, respectively. The power of the component suffering only external reflection is given by:

$$dP_L(\theta_i) = \rho_3^2 dP_L + \rho_5^2 dP_L$$

where $\rho_3$ and $\rho_5$ are the Fresnel coefficients for the electric field. The power of those rays that experience $i$ internal reflections can be expressed as

$$dP_L(i) = \left(1 - \rho_3^2 \rho_5^2\right) dP_L + \left(1 - \rho_3^2 \rho_5^2\right)^2 dP_L$$

for $i = 1, 3, 5, ..., 2n-3$.

Performing the summation of the geometric series $dP_L(i)$, the total power $dP_L$ over the area element $dR$ is attained:

$$dP_L = dP_L(0) + \sum_{i=1}^{2n-3} dP_L(i)$$

$$= \frac{2\rho_3^2}{1 + \rho_3^2} + \frac{2\rho_5^2}{1 + \rho_5^2} dP_L$$

(1)

It should be noted that the number $n$ of individual diffuse radiators may be high but it is not infinite. Nevertheless, since Fresnel coefficients are below unity, the terms $dP_L(i)$ for $i > 5$ ($n > 4$) are negligible for most values of $\theta_i$, thus, considering $n = \infty$ will not generate appreciable error in eqn. 1.

![Fig. 2](image-url)

In a diffuse communications environment, the light that strikes the specular sheet comes from a diffuse area previously irradiated by a laser beam. Further, the laser itself is depolarised and blurred by a translucent element in the transmitter. Thus, the incident rays exhibit random polarisation. Averaging the power over the polarisation angle $\Psi$, which can be considered a random variable with constant pdf in the interval $[\pi, \pi]$, yields [3]

$$dP_L = dP_L = dP_L/2$$

(2)

References

After applying polarisation-averaging eqn. 2 to eqn. 1, the general coefficient \( p_G \) can easily be attained:

\[
p_G(\theta_1) = \frac{\partial P_i}{\partial P_i} = \frac{p_s^2(\theta_1)}{1 + p_s^2(\theta_1)} + \frac{p_s^2(\theta_1)}{1 + p_s^2(\theta_1)}
\]

(3)

Fig. 2 shows the squared (and polarisation-averaged) coefficient \( p_s^2 \) against \( \theta_1 \) expressed in log units, along with the polarisation-averaged coefficient for a single external reflection only, \( p_s^2 \). It can be seen that, where the refraction index is \( n = 1.5 \) (common glass), there is a difference of 3dB for incidence angles found between normal incidence (0°) and 40°.

Conclusions: The discrete-reflections approach makes it possible to obtain a general reflection coefficient that yields more realistic values of channel response. In addition, these values show that the contribution of specular surfaces to channel response is greater than could be expected if classic Fresnel coefficients were used. Therefore, a moderate improvement is observed in simulation models, when large glass sheets are present in the room or office in question, by the use of the general coefficient \( p_G \).

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References


Full-duplex 60GHz fibre optic transmission

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A full-duplex millimetre-wave fibre optic system based on a high-speed electroabsorption transceiver (EAT) is proposed. Full-duplex fibre optic transmission of broadband (155.2Mb/s) 60GHz-band millimetre-wave signals is experimentally demonstrated. Excellent transmission quality (BER < 10^-9) is achieved for uplink and downlink transmission, simultaneously.

Introduction: Future wireless communication systems are expected to offer broadband radio access and mobile multimedia services to a large number of subscribers. Consequently, the carrier frequency of such wireless systems will be within the millimetre-wave (mm-wave) band where a sufficient number of channels with wide bandwidth is available. Since the electrical transmission of such mm-wave signals over long distances is not feasible, fibre wireless systems have attracted great interest as they are considered to form the backbone of future broadband mm-wave wireless communication systems. Recently, different network architectures have been proposed, where the mm-wave signal is transmitted downlink from a central station (CS) to a remote base station (BS) by optical means [1 – 3]. Furthermore, full-duplex fibre optic microwave network architectures based on an electroabsorption transceiver (EAT) device were presented [4 – 6].

In this Letter, we report on a full-duplex mm-wave fibre optic transmission system employing a high-speed 60GHz EAT together with a dual-lightwave technique. For the first time, we demonstrate full-duplex broadband (155.52Mb/s) fibre optic transmission in the 60GHz band.

Electroabsorption transceiver: The packaged high-speed 60 GHz EAT employed in this Letter is an EA waveguide device with an absorption region consisting of tensile strained InGaAsP/InGaAsP multiquantum wells between two passive waveguide sections. The device has been specially designed to exhibit a minimum electrical return loss (-35dB) at 60GHz [1] improving the e/o frequency response around 60GHz. Generally, an EAT is capable of performing optical intensity modulation and photodetection simultaneously [4 – 6]. The 60GHz-band EAT employed in this work...