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# Experimental characterization of impulse response for optical indoor wireless channels

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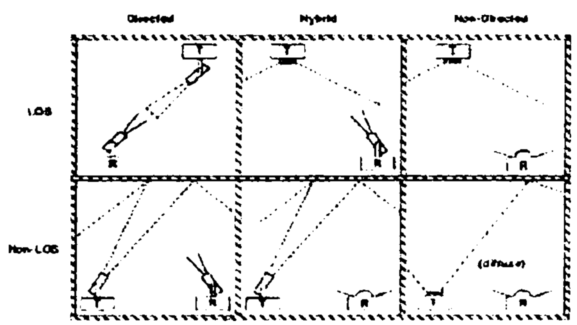
**Abstract – Indoor infrared wireless communications can offer in certain applications a valuable alternative to wireless radio. Its main advantages being: low cost, medical safety and unlicensed spectral band. The most suitable infrared band seems to be 1550nm because of the low noise and optical safety, even if sensible receptors at this wavelength are still hard to find at the ed_e of current technolo__. In this _a_er we show an experimen al se -up ha a'lows us es ima e he impulse response function at the 1550nm wavelength for indoor transmissions using a reduced-model of the actual indoor environment.**

**Keywords: diffuse infrared, indoor free space optics, wireless channel, impulse response**

## I. INTRODUCTION

Infrared (IR) is a medium extremely suitable for h - g d c mmu c uc ad-hoc wireless local area network [1]. More, high–quality wireless access to information networks and computing resources by users of portable computing and communication devices is achieved via infrared wireless links with low delay, high data rates, and reliable performance. All of these need an accurate characterization of the channel and understanding of the performance limits and design issues for wireless optical links. Indoor wireless IR channels are based in one of the following emitter-to-receiver configuration, fig.1: (i) line of sight. (LOS); (ii) quasi-diffuse (Non-LOS & Directed or Hybrid); and diffuse (Non-LOS & Non-Directed). The operation of LOS channel relies on a free path between emitter and receiver, which have to be pointed to each other. In quasi-diffuse channels, emitter and receiver have to be directed to the same surface, that reflects part of the optical beam toward the detector. In diffuse systems emitter and receiver have wide radiation and collecting patterns and the optical and optical signal may go into receiver after multiple reflections on surfaces that surround the communication cell. A standard algorithm, implemented to estimate the impulse response and frequency response of the infrared channels in empty indoor environments of different shapes and sizes, is described in [2]. Moreover computer estimation of impulse response becomes difficult when important features like the inclusion in the model of the effect of office furniture and people is needed [3].




## II. CHANNEL MODEL. METHODS TO GET CHANNEL IMPULSE RESPONSE.

Usually for optical wireless communications is used an intensity modulation with direct detection (IM/DD) system. In this case the propagation environment can be replaced by an equivalent filter. The transmitted waveform is the instantaneous optical power of the infrared emitter. The received waveform is the instantaneous current in the receiving photodetector, which is proportional to the integral over the photodetector surface of the total instantaneous optical power at each location. The channel can be modeled as a baseband linear system as indicated in Fig .2 and equation 1.

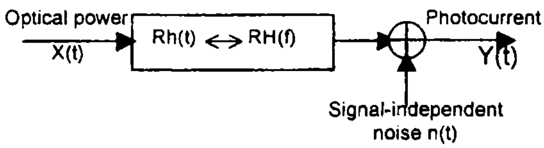



Fig. 2. Modeling link as a base-band linear, time-invariant system

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$$y(t) = x(t) \otimes Rh(t) + n(t) \quad (1)$$

Where $R$ is the detector responsivity, $n(t)$ is signal-independent additive noise and $h(t)$ is the channel impulse response, [4].

The channel can be described in terms of frequency response:

$$H(f) = \int_{-\infty}^{\infty} h(t) e^{-j2\pi f t} dt \quad (2)$$

which is the Fourier transform of h(t).

Channel response can be determined experimentally using three methods:

1. The direct method

A short impulse is emitted and the response is measured directly. Although this method is successfully employed in low frequency applications, for example in acoustics. It is hard to use in infrared.

2. The spread spectrum method

A pseudo-random binary sequence is transmitted and the received signal is cross-correlated with the input sequence to yield the impulse response.

3. The frequency sweep method

Signals are transmitted by sweeping through a finite range of frequencies and the complex channel response captured for the entire frequency range. The broader the range of frequencies considered, the closer is the a roximation of the measurements to the channel transfer function.

This is the method we chose to implement.

## III. MESUREMENT OF THE IMPULSE RESPONSE FOR A REDUCED SIZE MODEL

Here we show that the impulse response function of an actual room can be estimated once we measured the impulse response function of a reduced model channel (RMC). This is our most important theoretical result. It offers a high degree of flexibility to our experiment allowing us to test real environment conditions in a laboratory. It allows us to anticipate technological advances in infrared 1550nm receivers by performing experiments with existent low-cost photodiodes.

In order to estimate the response of a room we must build our model keeping certain proportions. For this we used a link simulator of impulse response for diffuse indoor optical wireless channels, [2].

Let $x_1$, $y_1$, $z_1$ be the dimmensions of the room, $x_1(R)$, $y_1(R)$, $z_1(R)$, and $x_1(S)$, $y_1(S)$, $z_1(S)$ the coordonates of the reciever and of the source respectivlly. We will have $x_2$, $y_2$, $z_2$, $x_2(R)$, $y_2(R)$, $z_2(R)$, $x_2(S)$, $y_2(S)$, $z_2(S)$ for the model. $\Delta A_1$ is the size of the reciever used in the real room and $\Delta A_2$ is the size of the reciever used in the model.

We have empirically shown that if the relations (3) and (4) exist between the model and the real room than the impulse response given by the direct optical path care of identical amplitude and differ only by a time offset, as shown in Fig. 3.

$$R = \frac{x_2}{x_1} = \frac{y_2}{y_1} = \frac{z_2}{z_1} = \frac{x_2(R)}{x_1(R)} = \frac{y_2(R)}{y_1(R)} = \frac{z_2(R)}{z_1(R)} = \frac{x_2(S)}{x_1(S)} = \frac{y_2(S)}{y_1(S)} = \frac{z_2(S)}{z_1(S)} \quad (3)$$

$$R^2 = \frac{\Delta A_2}{\Delta A_1} \quad (4)$$

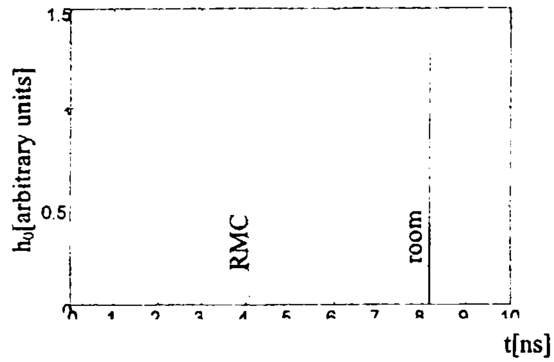


Fig.3. The impulse response for the direct link

For the multi path components a correction is needed: R scales the time axes and the function amplitude is scaled by $\sqrt{R}$. In Fig.4 we show the high orders impulse response for $R=2$.

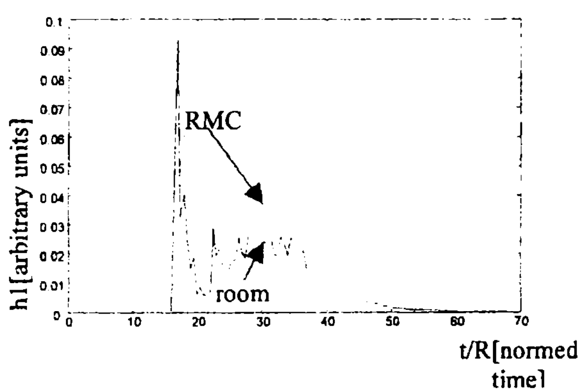


Fig.4. The impulse response for the reflected links

*The measurement resolution*

If we reduce the room dimensions we reduce both spread distance and time, so we need a wider band for the measurement system.

$$f_{max} = \frac{c}{\Delta d} \quad (5)$$

$$\Delta x = \frac{\Delta d}{\sqrt{3}} = \frac{c}{\sqrt{3} \cdot f_{max}} \quad (6)$$

We find the relationship between the spread distance ($\Delta d$) and the band with of the measurement system ($f_{max}$) in equation (5), where c is the speed of light. Consequently the spatial resolution ($\Delta x$) of the model is given by equation (6).

For example in a 1mx1mx0.60m model for 1ns temporal resolution one needs 30cm of spread distance, which corresponds to a spatial resolution of

17.3 cm and needs 1 GHz of the band with of the measurement system. Other values are shown in Table 1.It's obviously that a smaller temporal of resolution is demanded than a greater measurement frequency is needed.

Table 1

| Measurement frequency [GHz] | Temporal resolution [ns] | Spatial resolution [cm] |
|---|---|---|
| 1 | ' | '7.3 |
| 2 | 0.5 | 8.66 |
| 2.5 | 0.75 | 13 |
| 10 | 0.1 | 1.73 |

## IV. EXPERIMENTAL SET-UP

A sketch of the experimental set-up is shown in Fig.5. The system can measure by means of the spectral method the impulse response of all types of channels presented in figure 1, in all kind of rooms or environments of different size and shapes, empty or filled with office furniture and people. The key of the experiment relies on a reduced model channel (RMC) of the real environmental channel to be tested. Here we demonstrate that between the two channels there is a scale factor relationship. The RF output a HP 8753A vector analyzer is swiped from 300kHz to 3GHz and than applied to an external optical modulator of a 1550nm laser diode optical signal in order to provide after splitting and detection, the reference R(f) and the output of the RMC A(f) signals. The impulse response is obtained by inverse Fourier transform of the frequency characteristics of the reduced model channel: H(f)=A(f)/R(f). Compared to [4] the advantage of RMC is obviously: a measuring dynamic of 60-70 dB available using optical amplification and common 1550 nm emitters and receptors is sufficient to estimate superior impulse response bounds (k=2.3), which is not the case for real environments.

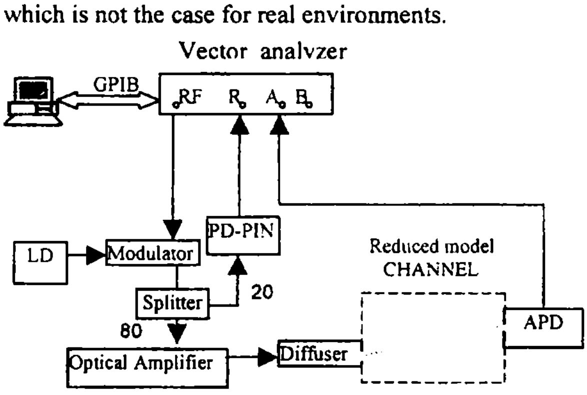


Fig. 5. Experimental set-up

## V. RESULTATS

Here we present the measured impulse response for a direct link in a 1mx1mx0.60m reduced model room. The distance between the emitter and the receiver is 62 cm. The measurement frequency is 2 GHz which assures a temporal resolution of 0.5 ns and a spatial resolution of 8.66 cm (see table 1).

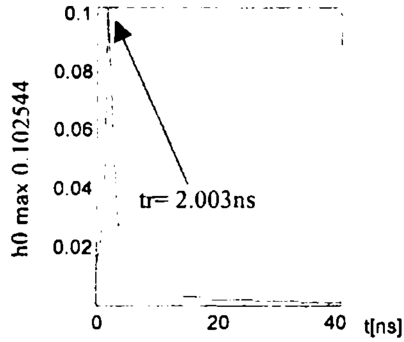


Fig. 6. The measured impulse response for the direct link

The measurement result is illustrated in Fig.6. A Dirac form impulse response is obtained at tr=2.003ns which is in good agreement with the calculated freeway propagation time between the emitter and the receiver.

## VI. CONCLUSIONS

We have presented a method and an experimental set-up for measuring the impulse response for indoor infrared channels. All kind of real indoor environments can be measure on a reduced model channel. We have shown that between the real channel and the model exists a mathematical relationship.

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