Frequency Response of a Fluorescent Fibre Detector Intended for Visible Light Communications

Ivan L. C. Pinheiro, Bettina F. C. B. Maia, Maristela C. R. Alves, Cláudia B. Marcondes, Vinicius N. H. Silva and Ricardo M. Ribeiro

***Abstract*— White LEDs can be simultaneously used for communication and illumination. This paper describes the frequency response of an omnidirectional light collector (OLC) made from fluorescent plastic optical fibres able to filter the slow luminescence from the phosphor coating of the LED. This OLC is useful for omnidirectional detection of modulated optical carrier in the visible spectrum. The OLC is intending to relax the mobility constraints of an optical wireless receiver.**

Keywords*— *Fluorescence, Omnidirectional Light Collector, Plastic Optical Fibre, Visible Light Communications.

I. Introduction

Many devices have been networked in what is known as the Internet of Things (IoT) [1]. Each IoT device may require the use of VLC (Visible Light Communications) or LiFi (Light-Fidelity) technology [1], since even with frequency and spatial reuse the RF spectrum is becoming heavily congested. Additionally, using LED-based as optical source, instead of LDs (laser didodes), ensure the eye safety requirements. LiFi links is prone to be faded by the mobility, thus it becomes crucial to increase the field-of-view (FoV) of the receiver [2].

When the directivity is high the FoV should be low because the trade-off (*étendue*) between them. However, if a wide FoV with high optical gain are simultaneously required, a fluorescent concentrator is an attractive alternative to efficiently collect light and steer it toward a fast photodetector [2,3].

This paper proposes an omnidirectional light collector (OLC) which consists of a few centimeters of plastic optical fibre (POF) made of dye-doped polyestirene (FPOF) coupled to an amplified photodiode presenting typically $\phi = 1$mm diameter. Experimental results on the frequency response of OLC up to few dozen MHz are described.

II. The Omnidirectional Light Collector (OLC)

The OLC was made from the 1-mm diameter FPOF IF-810087 red fluorescent doped-polyestirene POF emitting 635 nm from Industrial Fiber Optics (USA). It is surrounded by a glass capillary tube with an internal diameter of 1.10 mm. It can be excited with blue light (from the W-LEDs) and presents luminescence in the red, relatively well spectrally separated, thus reducing the strength of reabsorption. The FPOFs have step-index (SI) profile with 1.60 core refractive index, 827 μm average core-diameter, 1000 μm fibre-diameter and NA = 0.58 numerical aperture. A fraction of the blue light (460 nm) will be absorbed and re-emitted as a fluorescence at longer wavelength (635 nm). The fluorescence light will be partly captured by the NA of the fibre and by total internal reflection is guided toward the photodiode.

The splice was made with SuperBonder gel between the OLC itself and a small strand of bare PMMA-POF providing an insertion loss of ~0.4 dB. The physical length of the OLC was set at L = 3.0 cm. The reason for splicing the OLC with the PMMA-POF was to expose the entire length L to the external light field, thus minimizing the reabsorption of the fluorescence.

III. Frequency Response and Discussions

The most common W-LED have an InGaN-based semiconductor chip that emits blue (~ 460 nm) light which optically pumps a yellow phosphor ($Y_3Al_5O_{12}$) layer coating the surface of the LED. In this way, it can simultaneously illuminate and transmit data [4]. Figure 1 schematically shows the experimental setup and Figure 2 shows comparatively the plots of the frequency responses. The used silicon photodetector was a PDA10 model from Thorlabs (USA) with 150 MHz bandwidth and 10 kΩ transimpedance gain.

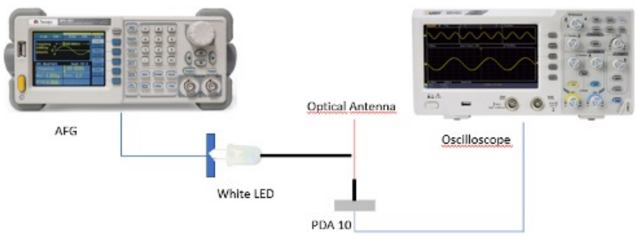

Fig. 1. Schematic drawn of the experimental setup to measure the frequency response of the W-LED + OLC short-link system.

At first, the frequency response of a single W-LED was measured (see Fig. 2, circles). It was obtained fc = 3 MHz@-3dB cut-off frequency because the yellow phosphor has a very slow luminescent response [4]. At second, the measurements were repeated with the insertion of a blue-filter just before the photodetector (see Fig. 2 triangles). Now, it was obtained fc = 16 MHz cut-off frequency, compatible with the "fast" blue-spectrum component of the W-LED [4]. At third, the experimental setup of Fig. 1 was used to measure the frequency response a single W-LED + FPOF- OLC (without the blue-filter) system. Sinusoidal modulated white light was coupled to a small piece of POF and the exiting beam was directed at 90º of the FPOF-OLC axis.

The OLCs based on FPOFs perform detection in two steps: pump-to-fluorescence wavelength conversion and detection by the PDA10. Therefore, the frequency response of the

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fluorescence mechanism will impact on a W-LED+FPOF link bandwidth.

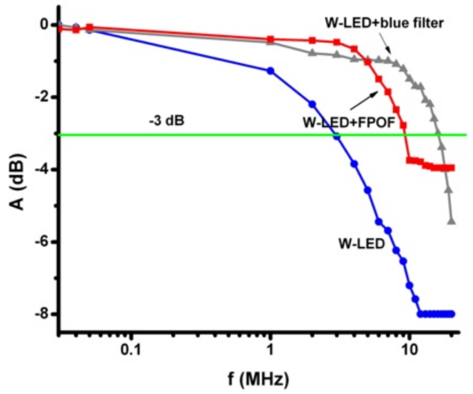

Fig. 2. Frequency response of a single W-LED (circles), W-LED+blue-filter (triangles) and W-LED+red-FPOF (squares).

From the frequency response plot (Fig. 2 squares), it was possible to extract fc ~ 9.3 MHz, which is lower than the cut-off frequency of the W-LED with blue-filter [2]. This is because of the delay imposed by the reabsorption phenomena in the fluorescent fibre [5]. However, the FPOF itself acts as a filter that removes the slow yellow-red phosphor luminescence portion of the W-LED spectrum [2]. In the fluorescence process, there is a fast conversion from λ = 460 nm to λ = 635 nm and we now have a "fast red" spectrum that impinges the photodiode.

Figure 3 shows in the time domain, by using an oscilloscope, a qualitative demonstration through an experimental setup similar to that shown in Fig. 1 of a 500 kbits/s NRZ-OOK digital signal transmitted over the VLC link for a distance of few centimeters.

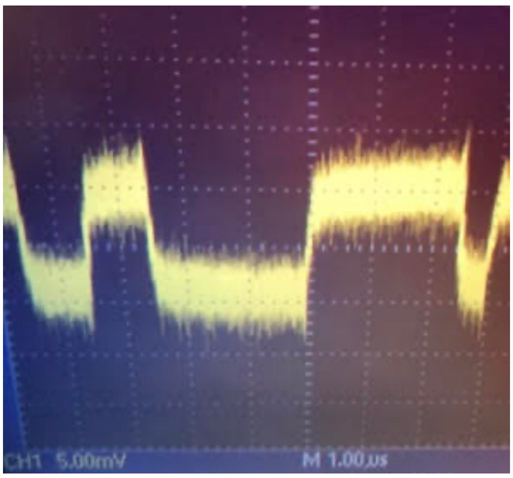

Fig. 3. Oscilloscope trace of an NRZ-OOK digital signal output of a VLC link like of that is shown by Fig. 1.

The lifetime of the FPOF was not here measured, but previously it was achieved 6.7 ns for a yellow-FPOF [6] in good agreement with [2].

By assuming an OLC with L = 3 cm and n = 1.60 we will have a maximum delay time of $\Delta\tau = L_2n/c \sim 0.16$ ns, which corresponds to a bandwidth limitation at $0.35/\Delta\tau = 0.35/(0.16\text{x}10^{-9}) \sim 2.2$ GHz. Therefore, even the severe limitation of 2.2 GHz corresponding to L = 3 cm is due to a relative delay between lower order modes in the POF, which is well above the typical 10-20 MHz bandwidth of common W-LEDs. Nevertheless, FPOFs impose a more severe limit on the OLC bandwidth where fluorescent materials exhibit a typical response of a few ns and re-absorption mechanism [5].

A comparison of our simple and compact OLC may be outlined with an already reported but relatively bulky 13-cm long green-FPOF with a parallel plastic Fresnel linear lens to concentrates the light along the fibre [2]. A 70 MHz bandwidth Si-APD with 3 mm^2 area was the photodiode coupled at the end of the FPOF [2]. A W-LED+FPOF link operating in OOK modulation with ~10 MHz frequency cut-off and BER < 10^{-3} was demonstrated [2].

IV. Conclusions

A simple and compact receiving "red-FPOF-OLC" was here described able to detect blue light and simultaneously filter out the slow phosphor luminescence from the W-LED. The bandwidth was limited at ~ 10 MHz by the fibre fluorescence. It was able to detect the incidence of a sinusoidal tone and 500 kbits/s NRZ-OOK digital modulating the transmitter with good fidelity. Therefore, the FPOF may be a good candidate as an omnidirectional detector in the VLC. Further researches may be carried out on a faster free-optical link using for instance a laser diode transmitter and new dye-doped fibre OLC formulation coupled to an avalanche photodiode as receiver.

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