Organic Visible Light Communications: Methods to Achieve 10 Mb/s

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***Abstract*—In this review, we summarise methods towards achieving 10 Mb/s connectivity for visible light communications links utilising organic polymer based light-emitting diodes as the transmitter. We present two different methods; on-off keying supported by least mean squares equalisation and orthogonal frequency division multiplexing without equalisation.**

I. Introduction

NEXT generation 5G access networks will be based on multiple technologies. Wireless access based on radio frequencies are expected to maintain their position as the main method for internet access. However, with limited spectral availability [1], alternative technologies are beginning to become attractive for research. One of the most important is visible light communications (VLC), which utilises common light-emitting diodes (LEDs) for illumination, data communication, and indoor localization has been the focus of ever increasing attention due to its huge unlicensed spectrum, around 10,000x that of radio frequencies, low power consumption and low costs. The key challenge to date in the literature has involved driving up data rates as far as possible, with remarkable results. Currently, transmission speeds in the Gb/s region (over a very short span) are possible and have been demonstrated abundantly [2].

One of the major unanswered questions within the field of VLC is the uplink. Since lights are predominantly installed in the ceiling of homes and offices, it is not a natural tendency to consider VLC as an uplink technology. Two options remain; (*i*) the use of VLC as a broadcast technology for low-latency download; and (*ii*) using alternative frequency bands (i.e. infrared or wireless (WiFi)), which has been suggested in numerous reports in the literature [3]. The infrared option is a far more mature technology than VLC with higher bandwidths, which can be exploited for downlink when VLC is switched off (i.e., total dimming in an indoor environment or daytime for outdoor application). However, eye safety requirements must be met, and LED based lighting must be modified to include one or two infrared LEDs. This was the motivation for the report in [4], where we proposed to use of organic polymer diodes as VLC transmitters for the first time. Using organic polymer LEDs (PLEDS) is an attractive prospect because high end electronic devices are beginning to be produced using PLEDs and hence the light emitted by a display can be utilised for the VLC uplink. Several improvements were reported in the literature [5], [6] eventually realising several methods to achieve >10 Mb/s connectivity [7]. In this paper, we review these two methods and provide a summary of the results. The first report to achieve 10 Mb/s utilised on-off keying modulation and a simple least mean squares (LMS) equaliser on a field programmable gate array (FPGA) [4]. The second method utilised orthogonal frequency division multiplexing without bit loading algorithms [5].

II. The PLED under test

A schematic of the PLEDs used in this work is illustrated in Fig. 1. The preparation of the PLEDs used has been well documented in the literature [4]–[7] so are not documented here to conserve space. Two different PLEDs with similar characteristics (~300 kHz bandwidth) were used and the specific differences can be referred to the literature for the two reports.

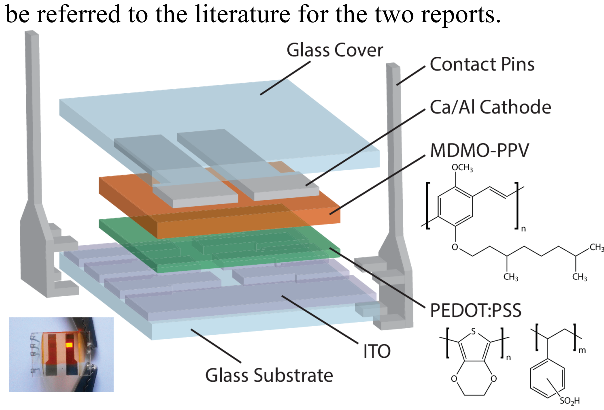

Fig. 1 Schematic diagram of the PLED under test

The PLEDs are orange emitters as can be seen from the photograph inset in Fig. 1. The diodes exhibit high linearity in their drive current-optical power responses which allow clipping free use of correctly designed modulation formats.

III. 10 Mb/s OVLC

The physical test setup for both cases was identical and can be seen in Fig. 2. For further details of signal processing algorithms, refer to [4], [5].

A. OOK + LMS equaliser

The raw BER performance of the PLED under test for OOK+LMS is shown in Fig. 3. Clearly, a data rate of 3 Mb/s can be supported with error free performance (BER <10^{-6}) before the device fails to support higher data rates without significant errors. As a result, an LMS equalizer with *N*-taps was implemented on the Xilinx ML605 FPGA board with bit error rate (BER) measurements repeated for a range of data rates, which can be seen in Fig. 4.

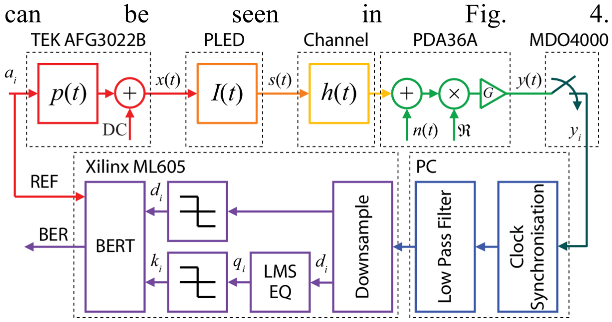

Fig. 2 Block diagram of general OVLC test setup

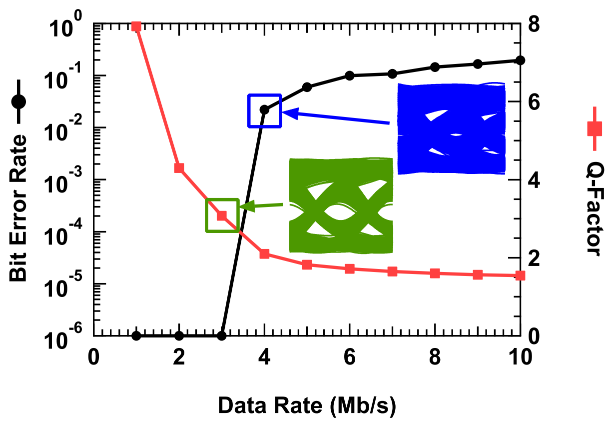

Fig. 3 Raw BER performance of PLED used for OOK test

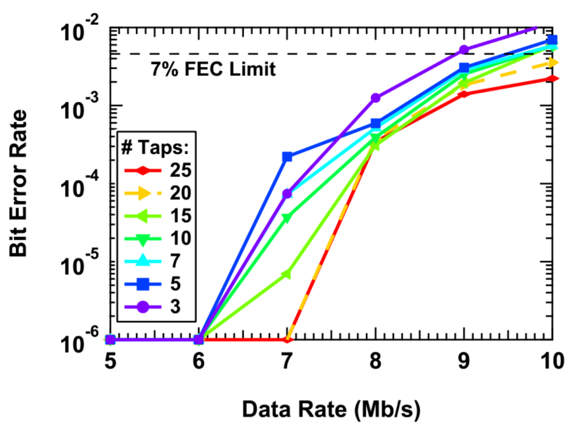

Fig. 4 BER performance when using LMS equaliser

Error free performance can be achieved up to a data rate of 7 Mb/s, after which errors start to occur. Using a higher order LMS filter enables support of transmission speeds underneath the 7% forward error correction (FEC) limit.

B. *Orthogonal frequency division multiplexing*

The BER performance of the OFDM system under test is shown in Fig. 5, alongside the raw BER performance of the same PLED, along with the received 16-QAM constellations (OFDM) and eye diagrams (OOK). When power pre-emphasis is applied, a transmission speed up to 10 Mb/s can be achieved. We show that judicious selection of either a LMS equalisation or OFDM modulation can enable a PLED with ~300 kHz bandwidth to operate at 10 Mb/s.

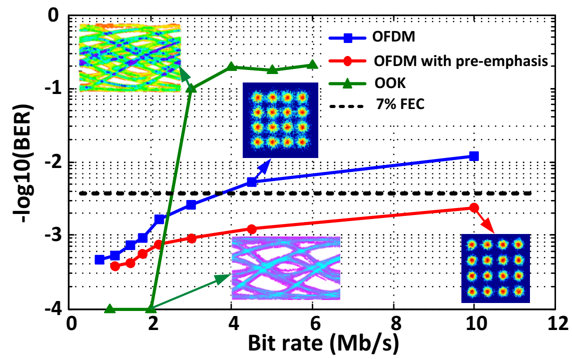

Fig. 5 BER performance of OFDM

IV. Conclusion

We have reviewed two methods to achieve 10 Mb/s achieved in [4], [5] by using PLEDs as transmitters in VLC systems. We anticipate future transmission speeds will increase towards the Gb/s mark as bandwidths increase in PLEDs. This will lead to a significant research domain for the uplink in VLC systems.

Acknowledgement

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