6.25 Gb/s POF Link Using GaN µLED Arrays and Optically Generated Pulse Amplitude Modulation

X. Li[a], N. Bamiedakis[a], J.L. Wei[a], J. J. D. McKendry[b], E. Xie[b], R. Ferreira[b], E. Gu[b], M. D. Dawson[b], R. V. Penty[a], I. H. White[a]

[a]Electrical Engineering Division, Engineering Department, University of Cambridge, Cambridge CB3 0FA, UK;
[b]Institute of Photonics, Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NW, UK
E-mail address: xl336@cam.ac.uk

Abstract: Optically-generated PAM schemes using µLED arrays are implemented for high-speed POF links for the first time. 6.25Gb/s PAM-16 transmission is demonstrated using 4 µLEDs, exhibiting 3.8dB greater power-margin than a link with a single µLED.
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1. Introduction

Recently, data transmission using visible light-emitting-diodes (LEDs) over plastic optical fiber (POF) has drawn attention for ultra low-cost high-speed short-reach communication links, such as in-home networks and automotive information systems [1]. Unidirectional 5 Gb/s data transmission over POF has been demonstrated using a single RCLED and an electrically-generated 32-level pulse amplitude modulation (PAM-32) modulation scheme [2]. However, the non-linear optical-power-versus-current characteristic of common LEDs introduces distortion and limits the optical system performance for advanced modulation formats [3]. Optical domain digital-to-analogue conversion (DAC) techniques have already been proposed for use in free-space LED-based links in order to mitigate the LED non-linearity [4, 5]. PAM, orthogonal frequency division multiplexing and multilevel pulse position modulation have been investigated using this method [5-7]. Moreover, optically-generated multilevel modulation has been implemented over multimode fibre links using 2-D vertical-cavity surface-emitting lasers [8].

In this paper therefore, we investigate the potential to achieve higher data transmission capacity in ultra low-cost POF links using optically-generated multilevel modulation schemes. This modelling and experimental study focuses on a POF link using micro-pixelated LED (µLED) arrays to optically generate a PAM modulation scheme. µLEDs, with diameters ≤100 µm, are of great interest for use in low-cost optical links as they exhibit higher modulation bandwidths than conventional large-size LEDs [9]. Moreover, µLEDs can be easily formed into arrays which achieve high coupling efficiency with POF owing to their small dimensions. Simulation results show that a greater system margin is available for optically-generated PAM links compared with electrically-generated PAM links. An optical link is set up over POF implementing an optically generated PAM-16 scheme using 4 µLEDs. Record 6.25 Gb/s transmission with a bit-error-rate (BER) $<10^{-3}$ is achieved over 10 m of POF.

2. Optically-generated PAM and simulation results

For optically-generated PAM schemes, N µLEDs are required in order to implement a 2^N-PAM scheme. Each µLED is driven using on-off keying and the output power of the µLEDs are adjusted to follow a 2^N relationship. For each symbol, different combinations of µLEDs are turned on to generate the corresponding signal levels. 4 µLEDs with an output power ratio of 1:2:4:8 are required to generate a PAM-16 signal [Fig. 1(a)]. The driving signal for each µLED can be generated by converting the input serial data sequence to 4 parallel data streams [Fig. 1(b)].

Basic modelling studies are carried out for this scheme using the link model presented in [2] and parameter components that match the actual devices using in the link demonstration. The obtained power budget for a POF link implemented with a single µLED (electrically-generated PAM) and multiple µLEDs (optically-generated PAM) are shown in Fig. 1(c). Multiple µLEDs are able to generate more optical power and therefore, provide extra power budget compared with a single µLED link. Moreover, the non-linear behaviour of the µLEDs is mitigated resulting in a smaller nonlinearity penalty in the link. However, a larger extinction penalty is expected in the multiple µLED

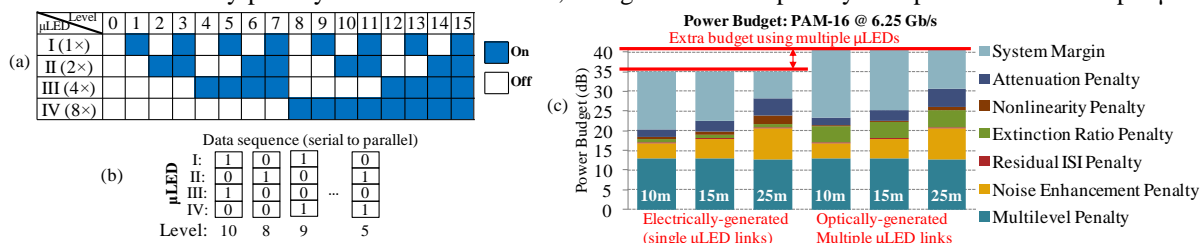

Fig. 1 Schematic of (a) PAM-16 generation using 4 µLEDs, (b) modulating data sequence for each µLED and (c) power budget analysis results.

links due to the required DC bias to all of the μLEDs. The simulation results show that the multiple μLED scheme offers a 3.8 dB greater link power margin for a PAM-16 modulation and 6.25 Gb/s data rate for all POF lengths.

3. Experimental setup and results

The experimental setup used in the demonstration of the optically generated PAM POF link is illustrated in Fig. 2(a). Two μLED-array boards, each operating with two 450 nm μLEDs, are used. The output beams of the 4 μLEDs are combined using a beam splitter and coupled into POF using aspherical lenses [Fig. 2(b)]. At the receiver end, an avalanche photodiode (APD) is employed to detect the transmitted signal and the resultant waveform is captured using a digital communication analyzer for offline processing. 4 independent data streams from a pulse pattern generator (PPG) are employed to drive the 4 μLEDs, while the operation (bias, RF amplitude) of each μLED is adjusted so that the optical power received at the APD from each μLED follows the 1:2:4:8 ratio. Finally, the electrical delays of the 4 input data streams are appropriately adjusted to synchronize all 4 μLEDs.
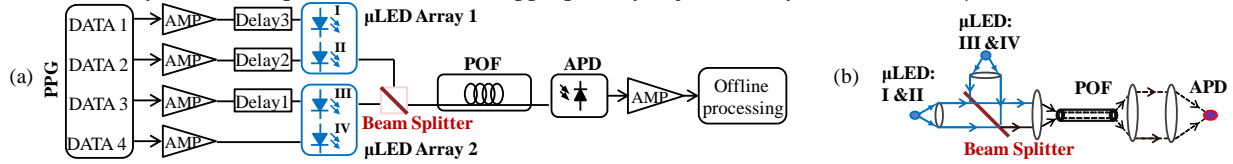

Fig. 2 (a) Experimental setup for optically implemented PAM link and (b) schematic for optical coupling

The received PAM-16 waveform at 6.25 Gb/s is shown in Fig. 3(a) with the equivalent ideal PAM-16 signal noted. The waveform is severely distorted due to the link bandwidth limitation while the corresponding eye diagram is completely closed [Fig. 3(b)]. Offline processing consisting of a feed-forward equalizer (FFE) and a decision-feedback equalizer (DFE) is used to retrieve the transmitted data sequence. The equalized eye-diagram has clearly distinguishable 16 levels [Fig. 3(c)]. The respective BER can be calculated using the equalized waveform and the measured APD noise performance. The BER performance of the link is evaluated at various symbol rates for the optical back-to-back case (B2B, short POF patchcord) and 10 m of POF [Fig. 3(d)]. The highest data rate achieved using the proposed scheme is 6.25 Gb/s. A BER$<10^{-3}$ is achieved after transmission over 10 m of POF. The penalty for the optical B2B link and 10 m POF link is measured to be ~1 dB.
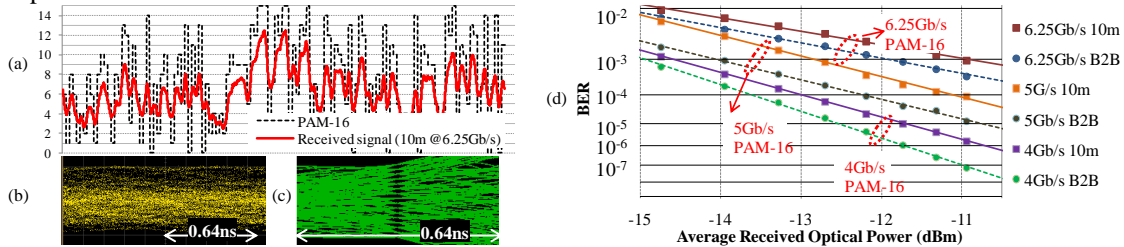

Fig. 3 (a) Experimentally captured waveform, (b) eye-diagram and (c) equalized eye-diagram for 6.25 Gb/s PAM-16 link over 10 m of POF; (d) BER performance for optically implemented PAM-16 link at 4, 5 and 6.25 Gb/s over b2b and 10 m of POF

4. Conclusion

In this work, we propose the use of an optically-generated PAM scheme using multiple μLEDs in order to achieve a high data rate transmission over low-cost POF links. Simulation shows a 3.8 dB greater link power margin using the proposed technique and 6.25 Gb/s data transmission over 10 m of POF using 4 μLEDs and a PAM-16 modulation is experimentally demonstrated with a BER$<10^{-3}$.

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