Quad photodiode array for optical wireless communication

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Abstract

Optical spectrum offers bandwidths far beyond the radio-frequency (RF) technologies. Optical Wireless Communication (OWC) is meant to serve many users in small areas with high-capacity connection. Due to its ultrahigh capacity, OWC can help unload the traffic from the RF channels so that the RF spectrum can be freed for other services. Receivers used in indoor OWC scenario must have a wide field-of-view (FoV) and high sensitivity to be able to capture light from different directions at eye safety levels. VTEC Lasers & Sensors B.V. developed a quad photodiode array with 100 µm diameter. Each photodiode has a shape of 90° sector of a circle and has a separate Trans-Impedance Amplifier (TIA). Such choice allows the system to retain the bandwidth of a single photodiode while increasing the aperture. At -8 dBm incident power, where TIA saturates, the device achieved an error free (BER < 10^{-9}) transmission at 16 Gbps, and 20 Gbps below the error-free FEC floor (BER < 10^{-3}). Incidence angle of the beam was varied between 0° and 16° and no penalty was observed in this range. Hence it can be concluded that the device has a full angle FoV greater than 32°. The results prove that the presented quad photodiode can be used in the indoor OWC communication scenario.

Introduction

The demand for wireless communication has been growing for the past decades. There are more and more devices connected to the wireless networks. Most of the traffic is generated indoors. OWC is a promising solution for high-density high-throughput user scenarios and it can also be used to unload the traffic from existing radio frequency technologies [1]. Optical spectrum is unlicensed, so it is free to use with the only limitation being eye safety limits. There is huge amount of bandwidth available and by keeping whole communication system in the optical domain the latency of the communication link can be decreased. In an optical beam steered system proposed by Koonen et al [2] the light beam is only directed where and when needed thus conserving the energy. Optical beam steering also makes wireless communication secure and private, due to the fact that light does not propagate through walls and that information is only transmitted on the line of sight so eavesdropping is extremely difficult.

In the indoor optical communication system the light is transmitted at wide range of angles and at eye-safe power levels. For that reason the optical receiver in such system must accept beam incoming from wide FoV and must have a high sensitivity due the eye-safe power transmission and high coupling loss to a receiver.

VTEC Lasers & Sensors has developed a quad photodiode array with 100 µm diameter. Each of the four PDs has a separate TIA. The benefit of separate TIAs is the possibility to measure the direction of the incident light beam. Such PD array could be used simultaneously for data transfer and localization.

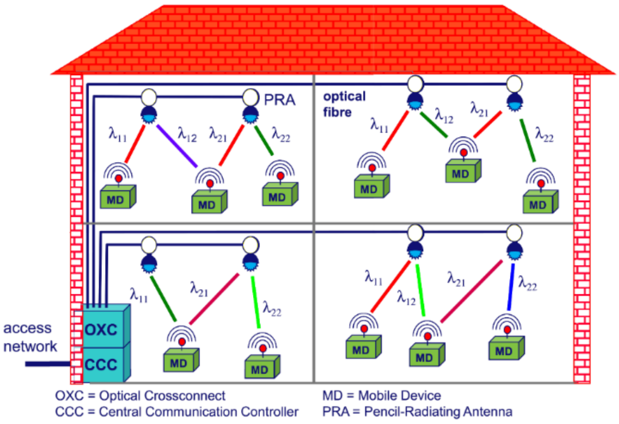


Figure 1 Indoor optical wireless beam steered communication scenario.

Experimental setup

The quad photodiode array was characterized by injecting light from a fibre mounted on a platform with 6 degrees of freedom, so that the angle and position of the fibre could be controlled. The diagram of the experimental setup is shown in Figure 2. Tunable laser source which emitted light at 1530 nm with 12 dBm output power was connected to a Polarization Controller to optimize the transmission power for the modulator inside Bit Error Rate Tester (BERT). Modulated light from the BERT was then amplified with Erbium Doped Fibre Amplifier (EDFA) to compensate for the losses of the components in the link. Then Variable Optical Attenuator (VOA) was placed to control the incident power level on the photodiode array. Fibre was then aligned to the photodiode with a mount with which the position and the angle of the fibre could be precisely controlled as shown in the Figure 3. The RF output of the photodiode array was then connected back to the BERT through a DC block to keep threshold voltage around 0 V.

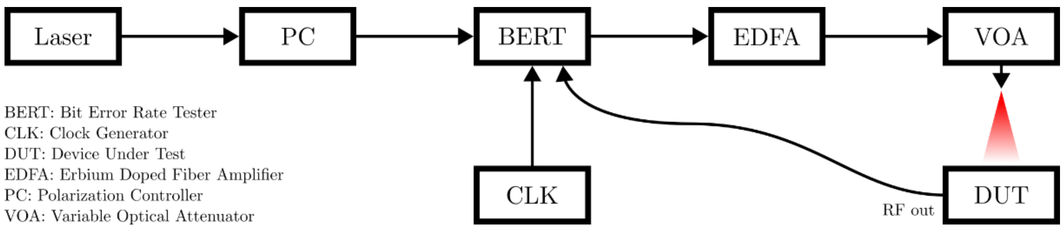


Figure 2 Diagram of the experimental setup used to characterize the photodiode.

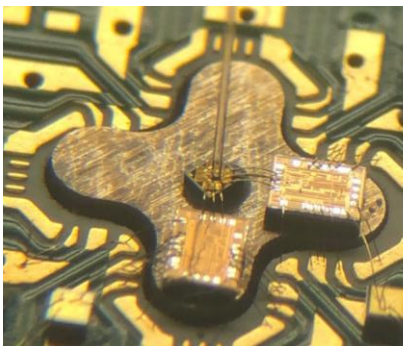


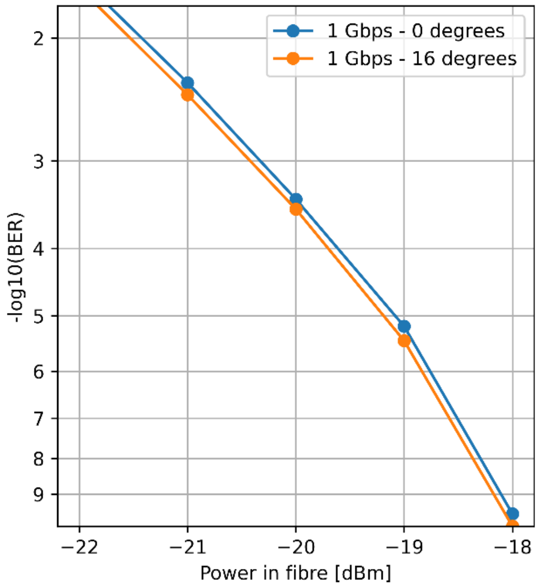
Figure 3 Picture of the fibre aligned to the photodiode array.

The first objective of the experiment was to verify the FoV of the device. FoV was verified by changing the angle of the fibre on the mount with respect to the photodiode. The maximum angle which is supported by the mounting is 16 degrees relative to the normal incidence (half angle). Figure 3 shows the fibre aligned to the photodiode at 0 degrees incidence angle. The data rate in the FoV measurement was 1 Gbps. The only modulation format which was considered is OOK NRZ.

The second objective was to verify the bit error rate dependency on the incident light power for various bit rates. The light power output by the BERT was swept by the VOA, and the bit rate was controlled by the BERT. The signal was transmitted in OOK NRZ format. In this measurement the photodiode array was illuminated at normal incidence angle.

Results

Setup described in the previous section was used to measure the FoV of the Quad Photodiode and the BER relation with the incident power level. In the Figure 4 BER curves vs received power are shown. At 1 Gbps the BER curves for incidence angles of 0 degrees and 16 degrees overlap. Hence, in this range of angles there is no penalty for receiving signal in the range of angles which are supported by the fibre mount. Figure 5 shows eye diagrams for selected bit rates of the RF output of the photodiode array. The input light power in all the cases is -8 dBm, at this power the TIA reached saturation. Hence, increasing the power would not increase the eye opening. At 10 Gbps and 16 Gbps eye opening is sufficient to achieve error free data transmission. Data rates of 20 Gbps and 23 Gbps are further beyond the bandwidth of the photodiode so the eye opening is smaller and error-free data transmission was not achieved.



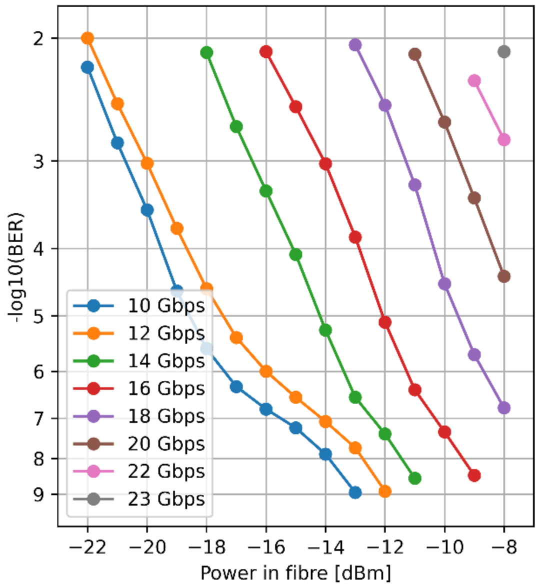


Figure 4 Left: BER vs received power measurement at 1 Gbps at normal incidence and angled at 16 degrees. Right: BER vs received power measurement for bit rates ranging from 10 Gbps to 23 Gbps. 'Power in fibre' is measured after the BERT.

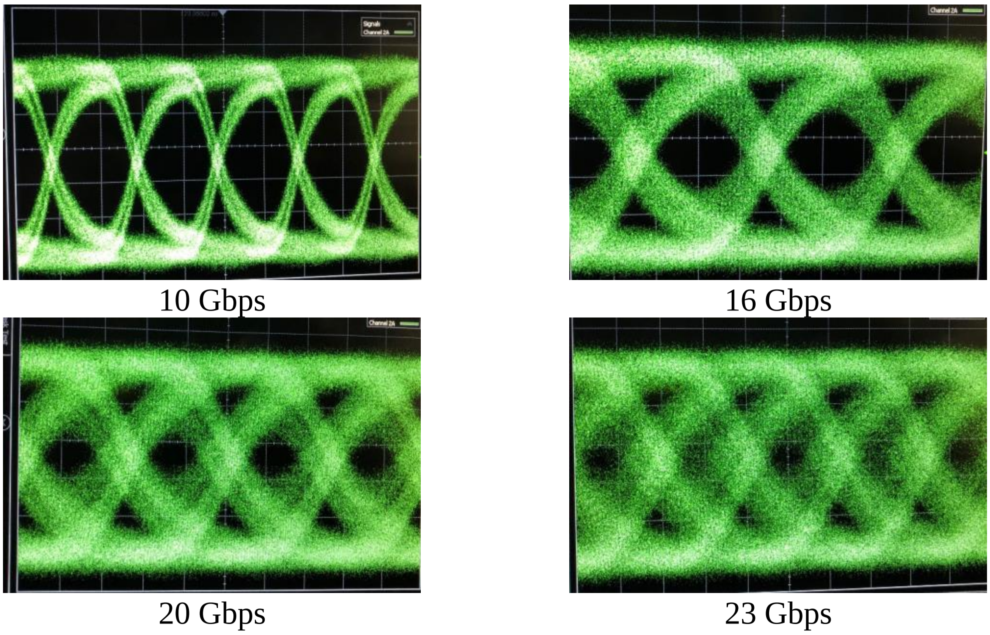


Figure 5 Eye diagrams for selected bit rates measured on the RF output of the photodiode at 0 deg launching.

Discussion and Conclusions

The results obtained in this experiment show an improvement compared to the previous experiments done in the indoor optical wireless communication scenario. The previous experiment of Koonen et al. [2] achieved a maximum bit rate of 1.25 Gbps (Gigabit Ethernet speed) with error free data transmission. The Quad Photodiode array used in this work allowed to receive the data rates up to 16 Gbps with error free transmission. By using hard decision Forward Error Correction (FEC) data rates could be increased up to 20 Gbps, and by using soft decision FEC up to 23 Gbps. All the data transmission was performed at eye safe power levels. Also, the FoV of the DUT is wider than of the photodiode array presented in [2]. Therefore, the Quad photodiode array shown in this paper can potentially replace it as a receiver in an indoor OWC system.

In the future work, higher order modulation formats will be used to increase the spectral efficiency and to increase the bit rates. It is possible to receive coherent symbols with direct detection by using Kramers-Kronig relations [3]. Hence, it will be possible to use the Quad Photodiode, which used in this work, in a coherent data transmission system for indoor OWC.

References

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