30 GHz Radio over FSO System using High Speed 2D-PDA and Its Optical Path Switching Performance

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Abstract We present a 30-GHz radio over FSO system using a high speed 2D-PDA, offering high optical alignment robustness and demonstrating 20-Gbps range high data rate wireless transmission. The BER performance under static and dynamic beam switching conditions will be discussed.

Introduction

Data traffic in optical fiber and wireless communications is increasing rapidly, and shows no signs of saturating. Data traffic in indoor communications has particular issues, and some scenarios for indoor communication applications have to be considered. Fig. 1 shows scenarios for advanced systems for indoor applications. Radio over fiber (RoF) based millimeter-wave communication is well known to be a good candidate for high-speed indoor communication [1]. It provides end-users with large radio coverage areas, owing to its characteristic of a wide field of view (FOV) and good flexibility for network construction and extension. A disadvantage of millimeter-wave communication is related to link budgets, and the signal to noise ratio (SNR) is strongly dependent on the wireless distance. A second scenario uses laser light based free space optic (FSO) communications [2]. This allows for high data rate communications of over 100 Gbps, which is comparable to data rates for fixed fiber communications. A disadvantage of FSO system is misalignment to the 10 μm single mode fiber based receiver over a distance of several meters, and a narrow FOV. The FSO beam must always search for and track the receiver's position. This leads to high cost designs due to the mechanical beam tracking function. Recently, we proposed radio over FSO [3] as shown inset in Fig. 1, which combines the technologies of RoF and FSO. High data rate optical signals are transmitted to access points (APs) through cascaded fiber and FSO links, and are located 1-2 m near end-users. Fixed position optical receivers at the APs can easily allow for good alignment from the relay nodes, while 1–2 m very short distance millimeter-wave radio communications involves a higher SNR. In this paper, we report on a 30 GHz radio over FSO system using a newly developed high-speed two-dimensional photodetector array (2D-PDA) device, and assess its static and dynamic optical beam switching performance related to bit error rate (BER) or link budget.

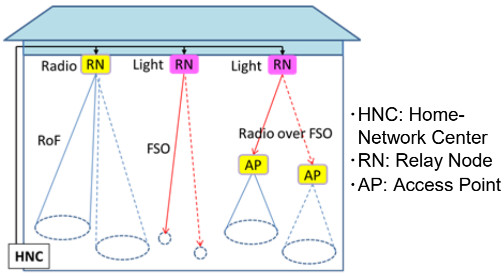


Fig. 1: Scenarios for indoor communications using (a) RoF, (b) FSO, and (c) Radio over FSO

2D-PDA device

2D-PDA with integrated multi-pixel photodetectors was designed with a square-shape 6 × 6 matrix structure (four corner pixels were eliminated, total pixel number = 32, in Fig. 2). It would be applicable for mode and space division multiplexing fiber communications [4], carrier (local lightwave) less, 90° hybrid circuit less, novel phase retrieval coherent detection [5], and high optical alignment robustness free space optics communications [6].

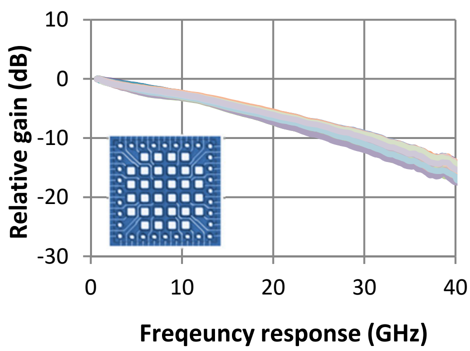


Fig. 2: Frequency response and top-view of 2D-PDA (inset)

The 2D-PDA device consists of an InGaAs

based III-V compound material, and PIN based 30 μm pixels were formed using a dry etching process. N-InP electrodes were common to each pixel. Lightwave was introduced from the back surface of the substrate. An f11 optical lens was installed in front of the 2D-PDA as an FSO receiver. The measured frequency response of all 32 pixels exhibited an average 3 dB bandwidth of 11.2 GHz. With a 30 GHz carrier signal, 9-12.5 dB insertion loss was measured compared to the reference value at a frequency of 0.1 GHz (see Fig. 2). The good flatness is attributed to compensating the frequency response by a digital pre-distortion technique (as discussed in later section) in our FSO narrow band radio system.

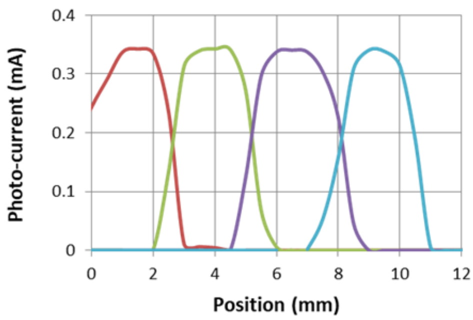
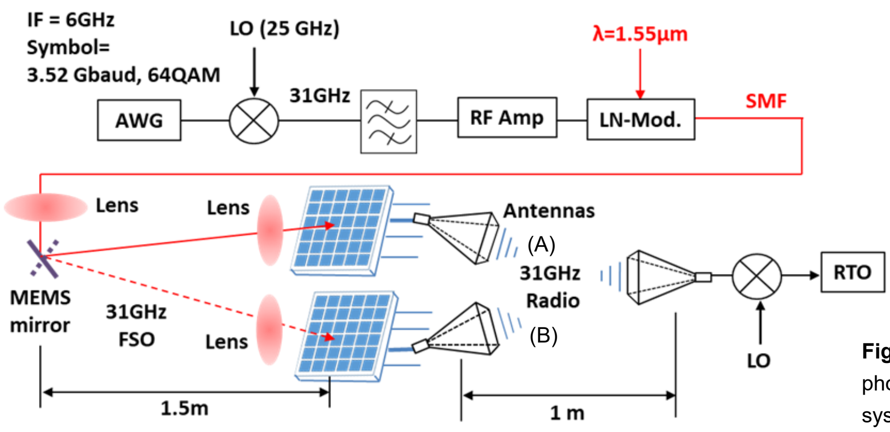


Fig. 3: Photo-current profile for each pixel versus the moving beam position

Fig. 3 shows the 2D-PDA photocurrent profiles versus the incident beam position on the optical lens. Four profiles could be measured from center four PD pixels. Thanks to the high optical alignment robustness of the FSO system design using the 2D-PDA, a large optical tolerance of 2 mm on the front lens could be obtained from each pixel. Additionally, approximately half of the photocurrent could be measured from the dead spaces between the PD pixels. This suggests that the dead space could be employed for signal detection, when using a larger beam size than the dead space. Therefore, the active area in the 2D-PDA can be recognized to be as large as 250 μm.

Radio over FSO system using 2D-PDA

Fig. 4 shows an experimental setup for the radio over FSO system using the 2D-PDA. In the transmission side, the signal was 3.52 Gbaud with QPSK, 16-QAM and 64-QAM modulation formats. The intermediate frequency (IF) was up-converted to 31 GHz using an RF mixer, where a local oscillator signal (LO) of 25 GHz was employed. The signal was converted to the optical domain by a lithium niobate intensity modulator. The 1.55 μm optical signal transmitted to the single mode fiber was reflected by a MEMS mirror in order to switch optical path-1 to path-2, where a FSO transmission distance of 1.5 m and an angle between the two optical paths of 30° was employed. From the experimental results shown in Fig. 3, high optical alignment robustness related to the switching is expected. An RF output from the PD-pixels was connected to a 20 dBi, 26.5 – 40 GHz horn antenna in this demonstration. Note: a 2-D patch antenna array located on the back surface of the 2D-PDA will be constructed instead of using the horn antenna in the next step. Through an optical path switched by the MEMS mirror, the 1 m point-to-point radio signal was received by another antenna, and the down-converted signal was analyzed using a real time oscilloscope. Additionally, a digital pre-distortion technology was used to compensate for distortions in the system. A compensated transfer function was pre-installed in an arbitrary waveform generator by measuring the transfer function of the entire radio over the FSO system.



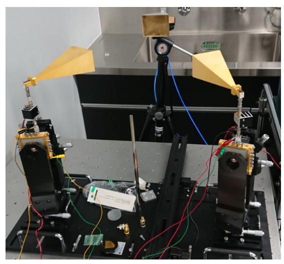


Fig. 4: Experimental setup and photograph for radio over FSO system using 2D-PDA receivers

Static performance on Radio over FSO

A MEMS mirror for switching optical paths or RF links was utilized assuming point-to-point indoor FSO relay communication. As there are very few requirements for MHz-GHz range switching speeds for routing, a 10 ms switchable MEMS mirror was adopted in our demonstration. Fig. 5(a),(b) shows the measurement results on constellation diagrams and bit error rate (BER) curves from the two receivers (A), (B) respectively. A constant symbol rate of 3.52 Gbaud and different modulation formats (QPSK, 16-QAM and 64-QAM) using a single carrier were transmitted over the system. The optical path was statically switched by the MEMS mirror from path-1 to path-2. For QPSK and 16-QAM signals, a very good BER curve with a minimum value less of than $1x10^{-4}$ could be confirmed. It suggests that the data rate would be 7.04 Gbps and 14.08 Gbps under error free condition when assuming 7 % error forward error correction. For 64-QAM modulation format, the minimum BER was confirmed to be as low as 3-4 x 10^{-3} (the same level as 7% FEC limit). For 64-QAM BER improvement, a higher SNR in the receiver would be needed, and then the approximately 10 dB insertion loss at 30 GHz related to the 2D-PDA device should be improved.

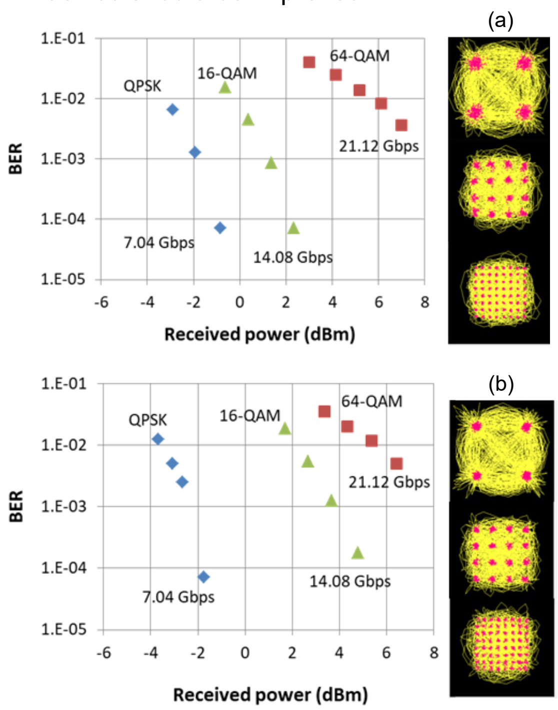


Fig. 5: Measured BER and constellation diagrams for each receiver (A), (B)

Dynamic switching performance

The performance of dynamic optical path switching on the radio over FSO was demonstrated using the MEMS mirror, which was controlled by a voltage swing. Fig. 6 shows the dynamic switching performance on the 30 GHz radio output from each 2D-PDA through antennas, with a symbol rate of 3.52 Gbaud (16-QAM). By periodically switching the MEMS mirror at 30 second intervals, it was seen that the pulse shape waveform of the 16-QAM radio signal was successfully launched by two receivers alternately. When inputting the FSO beam to each receiver (ON-state), the short period signal related to the 16-QAM ON-state was confirmed. Fig. 7 shows the EVMs using 16-QAM measured every 5 second during the radio ON state (30 second) for one channel, to confirm the stability and reproducibility of EVM (BER) in the radio over FSO system. This should depend on the optical alignment tolerance during the dynamic optical path switching process. We found very stable EVMs in the 9% range during the 10 times switching cycle.

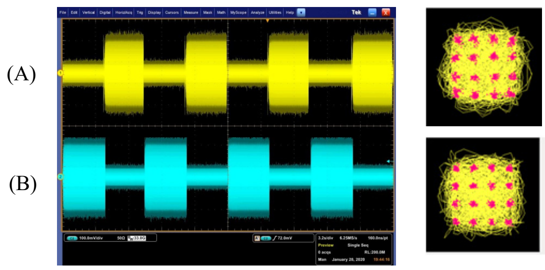


Fig. 6: Dynamic switching performance of receiver (A), (B) in the radio over FSO system

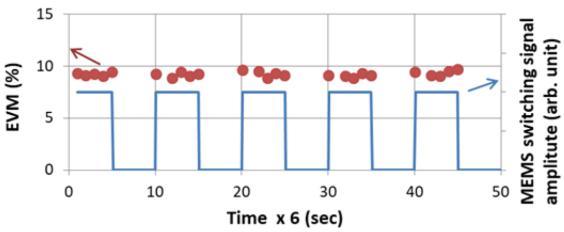


Fig. 7: Estimated EVM stability while switching path (10-cycle test result) to receiver (A)

Conclusions

We designed and fabricated a 30 GHz Radio over the FSO system using a high speed 2D-PDA and demonstrated high data rate wireless transmission above 20 Gbps range under static beam conditions. A very stable EVM using 16-QAM under dynamic optical path switching conditions was confirmed.

Acknowledgements

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