1-1-2014

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10.1364/CLEO_SI.2014.SM4J.7

This is an Author's Accepted Manuscript of: Wang K., Nirmalathas A., Lim C., Skafidas E., Alameh K. (2014). Free-space 120 Gb/s reconfigurable card-to-card optical wireless interconnects with 16-CAP modulation. Optics InfoBase Conference Papers. Paper: SM4J.7. San Jose, CA.

Free-Space 120 Gb/s Reconfigurable Card-to-Card Optical Wireless Interconnects with 16-CAP Modulation

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Abstract: In this paper, we propose and experimentally demonstrate reconfigurable card-to-card optical wireless interconnects architecture with 16-Carrierless-Amplitude/Phase modulation. Results show that 3×40 Gb/s interconnection is achieved with 2 mW transmission power.

OCIS codes: (200.4650) Optical interconnects; (200.2605) Free-space optical communication

1. Introduction

As applications in data centers and high performance computing demand denser system integration and widespread adoption of multi-core and multi-process architectures, requirement for interconnects at very high data rates has become a necessity [1]. While polymer-waveguides based interconnect technologies and fixed fiber based interconnects have been proven to be effective alternatives to copper-based card-to-card interconnects [2, 3], providing high-speed reconfigurable optical interconnects that meet the emerging requirements of flexible connectivity has become a major challenge. In previous studies, reconfigurable optical interconnects architecture based on free-space optical technology has been demonstrated [4-6]. However, the simplest on-off-keying (OOK) modulation format was used in all previous demonstrations and the highest bit rate was only 3×10 Gb/s. While such schemes demonstrates the ability to realize reconfigurable optical interconnects, its aggregate data rate is still inadequate for many applications. In this paper, we propose a reconfigurable card-to-card optical interconnect architecture with VCSELs being modulated using the 16-Carrierless Amplitude/Phase (16-CAP) format. We experimentally demonstrate, for the first time, the highest speed optical interconnects over a wireless link. Up to 120 (3×40) Gb/s interconnects are achieved using compact integrated optical interconnect modules.

2. Proposed reconfigurable card-to-card optical wireless interconnect architecture with CAP modulation

The architecture of the proposed high-speed free-space reconfigurable card-to-card optical wireless interconnects architecture is shown in Fig. 1 [6]. A dedicated optical interconnect module is integrated onto each electronic card (typically a PCB) and inside the module a VCSEL array is used in conjunction with a collimation lens array to generate digitally-modulated collimated Gaussian optical beams. A MEMS-based transmitter mirror array is employed to adaptively steer the optical beams to various destinations, thus providing reconfigurablity and flexibility. After propagating in free-space, at the receiver side the modulated optical signals are appropriately steered with another receiver MEMS mirror array and focused onto the corresponding PD elements. In addition, each VCSEL transmitter array is modulated with the CAP modulation format, which is more spectral-efficient compared with the simplest OOK format, as illustrated in the inset of Fig. 1 [7]. Compared with other advanced modulation formats such as QAM and OFDM, CAP has the advantages of simpler implementation by selecting appropriate electrical filters and the capability of direct modulation.

3. Experiments and discussions

The proposed high-speed reconfigurable card-to-card optical interconnect architecture was experimentally demonstrated using the setup shown in Fig. 2. An optical interconnect module was designed, fabricated and integrated onto a PCB, as displayed in the inset of Fig. 2 [6]. Specifically, a 1×4 VCSEL array (850 nm, ~17^o divergent angle and 250 μm pitch), the corresponding VCSEL driver circuits, a 1×4 PD array (60 μm active diameter, 250 μm pitch and ~0.6 A/W responsivity) and 4 trans-impedance amplifier chips were integrated onto a single small-size PCB. A micro-lens array (250 μm pitch) was then aligned and mounted on top of the VCSEL array and the PD array to collimate the VCSEL beams and focus received optical beams onto the active windows of the PD elements. Separate MEMS steering mirror chips were used to switch the optical beams to various ports or cards.

In the experiments, 40 Gb/s 16-CAP signals were generated using an arbitrary waveform generator (AWG) and after signal detection at the receiver side, the signals were sampled and stored in a digital storage scope for offline demodulation. The VCSELs and PDs used had a 3-dB modulation bandwidth of ~10 GHz and the transmission power from each VCSEL was 2 mW. In addition, since separate MEMS mirror chips were employed instead of an array as proposed before and the size of MEMS chips was larger than the transmitter pitch, as shown in the inset of Fig. 2, only three channels (1, 2 and 4) were used for data transmission.

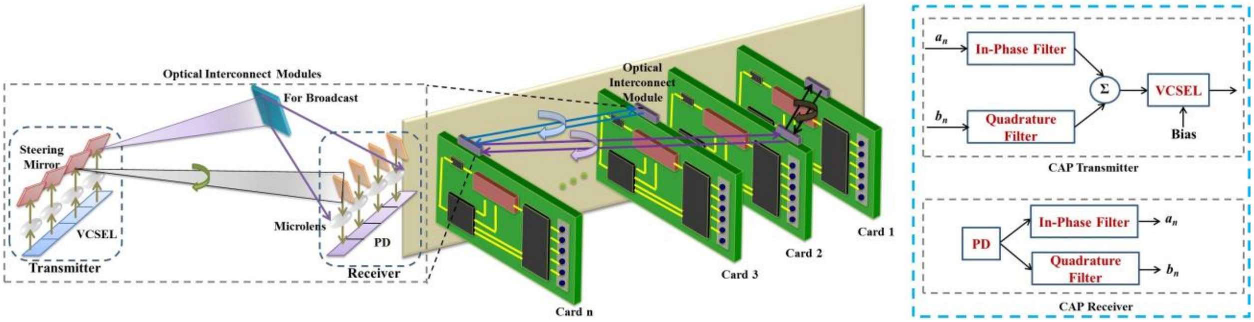

Fig. 1Reconfigurable card-to-card optical interconnects architecture with CAP modulation.

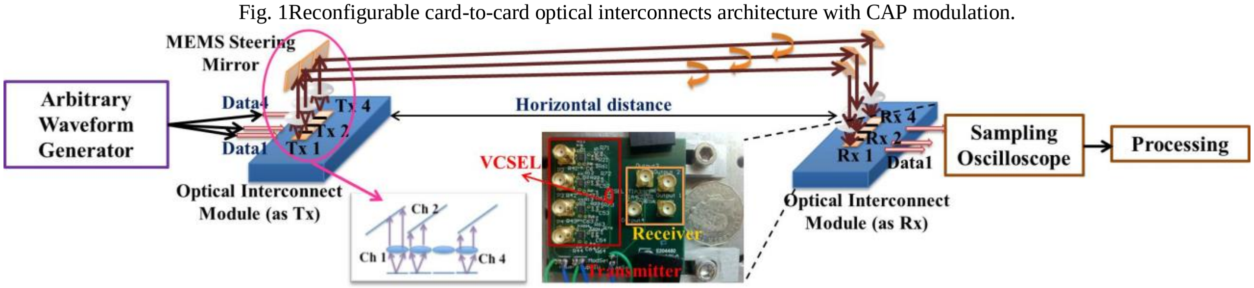

Fig.2 Experimental setup to demonstrate proposed reconfigurable optical interconnects architecture with CAP modulation.

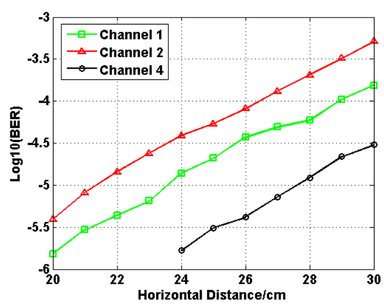

Fig. 3 BER vs distance for configuration 1.

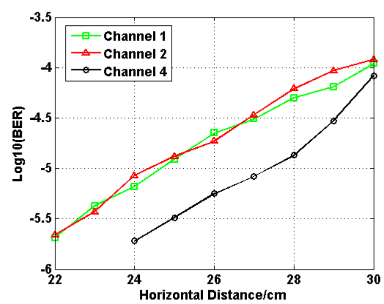

Fig. 4 BER vs distance for configuration 2.

To demonstrate the concept of the high-speed reconfigurable optical interconnect architecture, VCSEL element n (n = 1, 2, or 4) inside the array sent data to PD element n. The measured bit-error-rate (BER) with respect to the horizontal distance between transmitter and receiver modules is shown in Fig. 3. It is clear that for all channels the BER increases with the horizontal distance, mainly due to Gaussian beam divergence. Furthermore, it can be seen from the Fig. 3 that channel 4 has the best performance while channel 2 has the worst. This is because channel 4 detected the signal with PD element 4, which was further away from other channels and was less vulnerable to inter-channel crosstalk. It should also be noted that for interconnect applications, the BER requirement is quite high and forward-error-correction (FEC) code can be employed for a much better BER performance (10^{-9} or even better) [8].

The reconfigurability and flexibility of proposed optical interconnect architecture was demonstrated by the second configuration, where three different interconnects were established, namely, interconnect 1 between VCSEL element 1 and PD element 2, interconnect 2 between VCSEL element 2 and PD element 4, and interconnect 3 between VCSEL element 4 and PD element 1. The measured BER is shown in Fig. 4, where all interconnect channels have comparable BER with the previous channel configuration.

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