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# Bi-directional Multi Dimension CAP Transmission for Smart Grid Communication Services

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**Abstract:** We experimentally demonstrate bi-directional multi dimension carrierless amplitude and phase (CAP) transmission for smart grid communication services based on optical fiber networks. The proposed system is able to support multi-Gb/s transmission with high spectral efficiency.

**OCIS codes:** (000.2700) General science; (060.2330) Fiber optics communication.

## 1. Introduction

Recently, smart grid power infrastructure has emerged as the promising solution of future electric power distribution [1]. Main characteristics of smart grid include self-healing, flexible consumer participation, physical and cyber attack-resistance, and ability of providing more stable power with lower frequency and voltage fluctuations [2, 3]. The present power grid only allows one-way communication from the control systems to the downlink access points of distribution [4]. In such insufficient system, point of consumption could not play a role as the generator. However, the core fiber optical transmission networks for smart grid communication services have to fulfill several technical requirements which consist of high bit rate transmission, high spectral efficiency, multi-user supporting, and bi-directional communication.

In this paper, we have proposed the novel bi-directional multi dimension carrierless amplitude and phase (CAP) transmission systems for smart grid communication services. CAP is a multi dimensional and multi level signal modulation format employing orthogonal waveforms. These waveforms are generated by using FIR filters with orthogonal impulse responses in time domain, i.e. statistical expectation of correlation between different waveforms is zero [5, 6]. In principle, CAP modulation is similar to orthogonal frequency division multiplexing (OFDM) modulation, in the sense that both of CAP and OFDM support multiple levels modulation with more than one dimension or sub-carrier. Contrary to OFDM, generation of orthogonal sub-carriers in frequency domain is not required for CAP. Additionally, CAP supports modulation in more than two dimensions, provided that orthogonal pulse shapes can be identified [7]. To the best of author's knowledge, this is the first demonstration of the smart grid communication systems based on bi-directional fiber optical link using multi dimensional CAP and employing directly modulated (DM) vertical cavity surface emitting lasers (VCSELs) operating around 1550 nm wavelength (193.4145 THz) as transmitters. Moreover, in this paper, 3 dimension (3D) CAP with 2 level/dimension (2 L/D) and 4 level/dimension (4L/D) transmissions achieved bit rate of 4.5 Gb/s and 7.2 Gb/s separately.

## 2. Experiment Setup

Figure. 1 shows the setup implemented in the experiment. The arbitrary waveform generator (AWG) with 12 GSa/s is used to generate the 3D CAP with 2-L/D and 4-L/D signals. For example, 3D CAP constellations are shown in Fig. 2 (a) and Fig. 2 (b). As it can be noticed, denotation of 2-L/D can be considered as QPSK in two dimensions, as well the denotation of 4-L/D can be considered as 16 QAM in two dimensions.

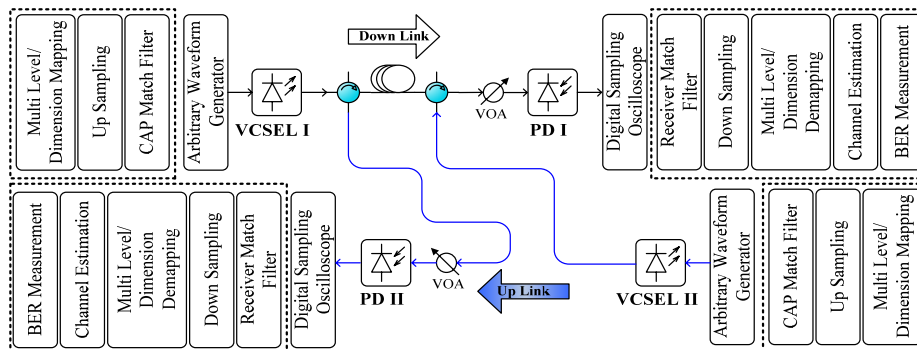


Fig. 1. Experiment Setup of Bi-directional CAP Transmission.

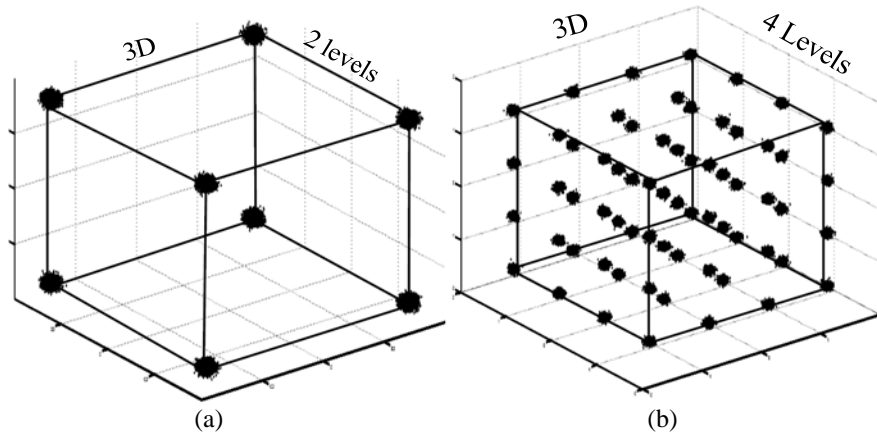


Fig. 2. CAP Constellations of (a) 3D 2-L/D (b) 3D 4-L/D.

As it is shown in the experiment setup configuration, for down link, data in the transmitter side is firstly mapped according to the given modulation level, such as 2-L/D and 4-L/D. Those symbols are up sampled and later shaped (or filtered), according to the optimization algorithm. The transmitter signature filters are implemented as fixed FIR filters. The 3D CAP signals at bit rate of 4.5 Gb/s (2-L/D) with an up sampling factor of 8 and 7.2 Gb/s (4-L/D) with an up sampling factor of 10 are generated by the arbitrary waveform generator (AWG). Afterward, optical CAP signals are directly modulated with 1548.24 nm (193.63 THz) VCSEL with 4.5 GHz bandwidth operating at 4 mA bias level. Furthermore, table 1 shows the main parameters of CAP transmission experiment including bit rate with 7-% overhead forward error correction (FEC), spectral efficiency (SE), up sample factor, bandwidth and symbol rate. In the down link receiver side, a photodiode with 10 GHz bandwidth is used for direct detection. A 40 GSa/s digital sampling oscilloscope (DSO) is employed to sample the received analog signals. Several off-line digital signal processing (DSP) algorithms are implemented including receiver match filter, down sampling, signal demapping and DSP algorithms for transmission channel estimation. Finally the systems' bit error rate (BER) performance in terms of received optical power is obtained to measure the CAP system performance. Furthermore, the similar transmitter-receiver structure is used for the up link transmission. However the carrier frequency is assigned to be different from down link carrier. The optical CAP signals of down link are directly modulated with 1548.96 nm (193.54 THz) VCSEL. As it can be noticed, approximate 100 GHz channel spacing between up and down link is employed to mitigate cross talk interference. Moreover, off-line DSP algorithms of blind CMA channel estimation equalizer are implemented to compensate for inter symbol interference induced by 20 km single mode fiber (SMF) transmission impairments. Time domains cross correlation responses of match filters are shown in Fig. 3 (a). Moreover Fig. 3 (b) shows the optimized match filter impulse and frequency responses for 3D CAP.

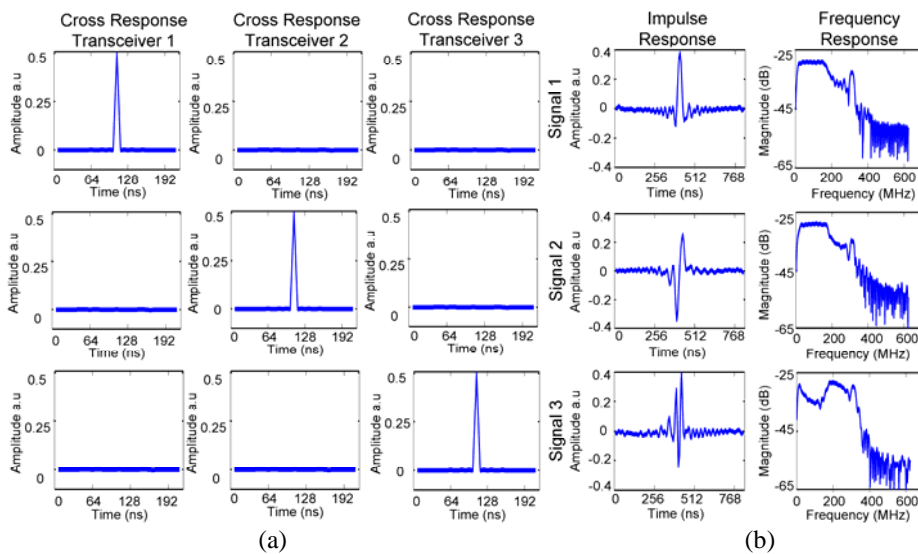


Fig. 3. (a) 3D CAP cross-correlation of transmitter-receiver match filters; (b) 3D CAP optimal match filter impulse and frequency responses.

CAP Signals	Bit Rate (Gb/s)	SE (bits/s/Hz)	Up Sample Factor	Bandwidth (GHz)	Symbol Rate (Gbaud)
3D 2L/D	4.5	2.25	8	2	1.5
3D 4L/D	7.2	3.6	10	2	1.2

Table 1. 3D CAP up & down link: bit rate, spectral efficiency, up sampling factor, bandwidth and symbol rate with 2-L/D and 4-L/D.

#### 4. Results

Results of BER performance in terms of received optical power are presented as below. Fig. 3 (a) and Fig. 3 (b) show the comparison between with and without offline channel estimation DSP algorithms for 3D 2-L/D CAP and 3D 4-L/D CAP in both of down and up transmission links. In short, BER performances are improved approximate 0.5 dB by using offline channel estimation DSP algorithms after 20 km SMF transmission for smart grid communication services.

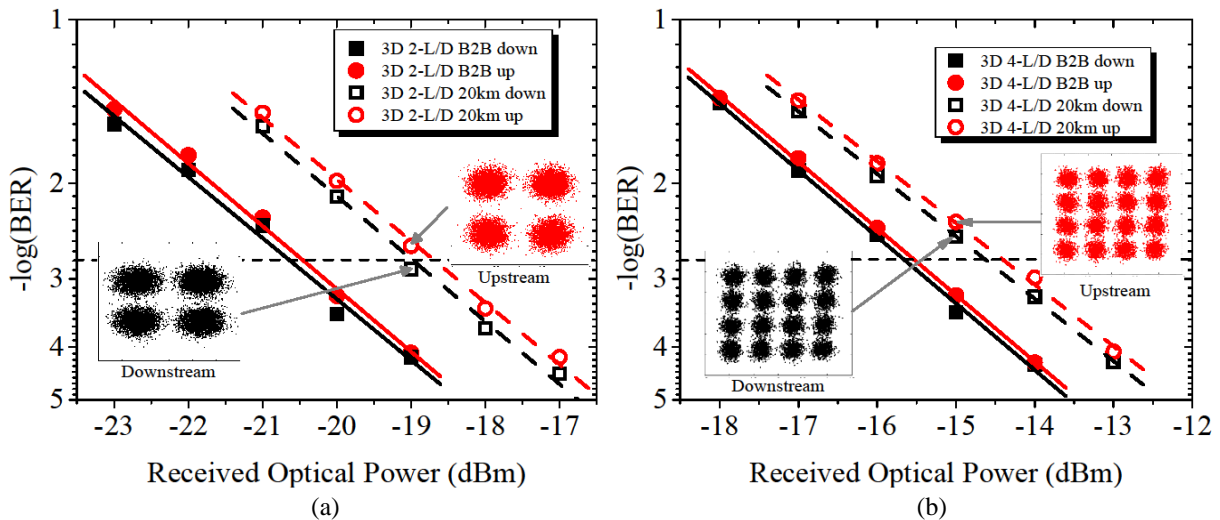


Fig. 4 BER vs. Received Optical Power of (a) 3D CAP 2-L/D bidirectional transmission; (b) 3D CAP 4-L/D bidirectional transmission

#### 5. Conclusion

A bi-directional optical transmission using 3D/4D CAP with 2-L/D and 4-L/D modulation is demonstrated. In order to achieve smart grid communication service of metro-access reach, blind coordinate transformed CMA equalizer to estimate transmission channel is implemented. This experiment demonstrated system provides potentially a cost effective solution for next generation smart grid power infrastructure access networks. The spectral efficiency achievements of 2.25 bits/s/Hz and 3.6 bits/s/Hz for 3D-CAP 2-level/dimension and 3D-CAP 4-level/dimension are presented in this paper. To the best of author's knowledge this is the first demonstration of a bi-directional optical link for smart grid networks using multi dimensional CAP and employing direct modulated VCSELs.

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