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Three-Dimension Carrierless Amplitude Phase Modulation (3-D CAP) Performance Analysis using MATLAB Simulink

Sharifah Saon[1,2]*, Fatimah Athirah Razale[1], Abd Kadir Mahamad[1,2] and Maisara Othman[1]

[1]Faculty of Electrical and Electronic Engineering,
[2]Internet of Things Focus Group, Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor Malaysia.

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Abstract: To cope with a drastically global mobile data traffic grow, the advanced modulation format is required to boost the high-capacity services. As an alternative, multi-dimensional carrierless amplitude phase (CAP) modulation is chosen as one of the modulation technique compared to the multi-carrier systems. This modulation technique is able to handle the data transmission of multiple signals over single channel simultaneously. Therefore, this article discussed a development of three-dimensional carrierless amplitude phase (3D-CAP) modulation scheme. In order to ensure the successfulness of CAP modulation simulation, the digital filters are designed by a minimum algorithm with the additional linear constraint to avoid the intersymbol interference. CAP is known as a multilevel modulation scheme which it can reach high spectral efficiency and can be generated at low cost. An interesting feature of CAP is that its signal basis can be extended to three or more dimensions. In this article, MATLAB Simulink is used as a development platform to simulate and study the performance of 1-D, 2-D, and 3-D CAP, that has been tested with data and sound input. Herewith the performance of 3D-CAP are presented; for data input, the results of EWM is − 0.048 dB, MER is 0.048 dB, and power received is − 0.057 dB, meanwhile for sound input the results of EWM is − 0.052 dB, MER is 0.052 dB, and the power received is − 0.050 dB.

Keywords: 3D-CAP; EVM; MER; Power received; Data communication

1. Introduction

Good infrastructure is the foundation of social inclusion and economic growth. Digital access of internet will be increased through broadband infrastructure expansion and other initiatives to ensure their affordability.

Multimedia broadband service provisioning, which is the emerging services that end users are demanding, such as high-definition video streaming, video-calls and access to cloud computing have put severe pressure on the telecommunication network infrastructure to provide high capacity communication systems. Reported that 2016 global data traffic reached 7.2 Exabyte (EB) per month [1], while estimated of 30.6 EB data traffic to be transferred via mobile networks every month by 2020 [2], and increase to 49 EB by 2021 [1].

Different transmission and modulation format would be beneficial, in order to overcome this problem and offer the required bandwidth and increase flexibility, multiplexing and transparency. Multipoint transparent architectures that can eventually use the wavelength domain to achieve multiplexing, is one of the optical technologies solutions. Therefore multidimensional (high-dimensional) carrier-less amplitude-phase (CAP) modulation have been proposed for digital subscriber line (DSL) during early and mid-1990s by the Bell Labs. Moreover, CAP has the potential in reducing the system cost due to the simplicity of the transceiver design and the absence of the local oscillator. Eventually the capacity has not been increased, however the CAP has potential for providing more flexibility in increasing the number of dimensions with low implementation cost to support multiple services for next generation access and indoor networks.

Despite their many advantage, high-dimensional CAP requires excess bandwidth due to the higher up-sampling factor, which contribute in a decreased of spectral efficiency [3].

Furthermore, an examination of the bit error rate (BER), error vector magnitude (EVM),

*Corresponding author: sharifa@uthm.edu.my

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modulation error ratio (MER) and received optical power will be carried out.

2. A Review of CAP Modulation

Higher order modulation formats so-called CAP has been proposed for copper wires as early as 1975. CAP is a multi-dimensional and multi-level signal format employing orthogonal waveforms for each dimension. These waveforms are obtained from finite impulse response (FIR) filters with orthogonal filter responses. In its principle, it is similar to quadrature amplitude modulation (QAM), both CAP and QAM supports multiple levels. Compare to QAM, however, CAP does not require the generation of sinusoidal carriers at the transceiver [4,5]. While, due to the potentially high spectral efficiency and the possibility of generating the required orthogonal pulses by means of transversal filters, CAP modulation has received attention in the research area of data and optical communications. In [6] 2D-CAP 8-L/D over 50 m polymer optical fiber (POF) has been demonstrated with resonant cavity light emitting diodes (RC-LEDs). In [3], first experimental investigations has been reported on the 3D-CAP and 4D-CAP for optical fiber transmission at bit rates up to 937.5 Mb/s.

Optimization algorithm (OA) can be applied in the simulation work to extend the conventional 2D-CAP scheme to higher dimensionality and to promise the perfect reconstruction of the filters. The advantage of this modulation technique is that the frequency magnitude response of the transceiver filter possible to be identical. Additionally, it is a point-to-point method to enhance the design to higher dimensionality CAP systems.

Fig. 1 shows basic block diagram of CAP modulation. The transmitted signal of CAP can be formulated as in equation 1:

$$s(t)=\sum_{n=-\infty}\left[a_n g_i(t-nT)+b_n g_q(t-nT)\right] \qquad (1)$$

Where a_n and b_n are the real and imaginary parts, T is the period, $g_i(t)=g(t)\cos(2\pi f_c t)$ and $g_q(t)=g(t)\sin(2\pi f_c t)$ are the in-phase and quadrate phase filter responses, respectively.

$$y(t)=G\Re[s(t)*h(t)+n(t)] \qquad (2)$$

Received signal, as in equation 2 is captured and sampled, where; G is gain and $\Re$ is the photodetector responsivity [7].

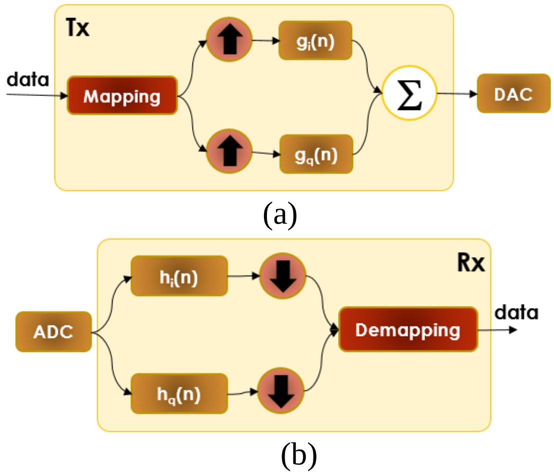


Fig. 1 Block diagram of (a) transmitter and (b) receiver of the 2D-CAP modulation.

In order to model the 3D-CAP, three encoded streams data that can be transmitted simultaneously are requested. For CAP system to work, the complete reconstruction criteria must be satisfied.

To optimize the achievements of the system against additive Gaussian noise, one of the filters would be matched filter, which us their impulse response will be time-reversed version. The filter's design at the receiver must fulfill the following specification:

- $g_n(t) * h_n(t)$ is unity for zero times delay.
- $g_n(t) * h_n(t)$ is zero for time delay which are the non-zero integer multiples of T.
- $g_n(t) * h_{1-n}(t)$ is zero for all time delays which are all integer multiples of T, include the zero.

2.1. Performance Evaluation

The two inputs are used for simulating the 3D-CAP, which are sound and data. Where, the sound input signal are fixed to the following specifications; 16 bits with 44100 Hz of fundamental frequency, in column vector, and .wav file format are required. While, the data signal, must agree the M-ary number of 16 with the initial seed fixed to 37. Both inputs are used to investigate the characteristics of CAP and their performance on the BER, EVM, MER and power received.

BER is the number of bits received from the data stream in the communication channel that corrected to its noise errors. BER curve can be used to explain the performance of a digital communication system. The $\frac{E_b}{N_O}$ ratio is proportionally related to the signal to noise ratio (SNR), with takes into account the bits rates of different constellations.

EVM is used to measure the performance of a digital signal of the transmitter and receiver and it also to measure how far the points are from the ideal locations. The received signal will have all constellation points which exactly point at the ideal locations. While, MER is the basis for measure the performance of a digital radio of transmitter or receiver by using the digital modulation liked QAM, and the power received used to measure the loss measurements as well as the power from a source or presented at a receiver. Actually, the QAM is akin to CAP, because both of it supports multiple levels and modulation in more than one dimension. The CAP does not require the generation of sinusoidal at both parts which is at the transmitter and at the receiver, in contrast with the QAM. Moreover, CAP can support modulation in more than two dimensions, with the conditions that orthogonal pulse shapes that can be identified.

Mathematical equation of BER, EVM, MER and power received, represented as in equation (3), (4), (5) and (6).

$$\text{BER} = \frac{1}{2}\ \text{erfc}\left(\frac{E_b}{N_0}\right) \tag{3}$$

$$\text{EVM (dB)} = 10 \log \left(\frac{P_{error}}{P_{ref}}\right) \tag{4}$$

$$\text{MER (dB)} = 10 \log \left(\frac{P_{signal}}{P_{error}}\right) \tag{5}$$

$$\text{Power (dB)} = 10 \log \left(\frac{P_{signal}}{P_{ref}}\right) \tag{6}$$

Where, the E_b, N_0, P_{signal}, P_{error} and P_{ref}, are the energy per bit, noise power spectral density, signal power, error power and reference power, respectively.

3. Methodology

In order to extend the conventional CAP scheme to higher dimensionality and to promise the perfect reconstruction of the filters, the optimization algorithm were applied to the simulation work. In addition, point-to-point method was used to enhance the conformist design to higher dimensionality CAP systems. Conventional CAP scheme generated using MATLAB Simulink is shown as in Fig. 2.

This CAP was designed using the rectangular quadrature amplitude modulation of sixteen (QAM-16) module, available in MATLAB Simulink. Thus, produce CAP-16. Actually, the QAM is similar to CAP, because both of it supports multiple levels and modulation in more than one dimension. However, CAP does not use the sinusoidal carrier to generate two orthogonal components. The samples/symbol ratio is linearly proportional to the number of dimensions. It shows how the CAP is worked to produce the orthogonal waveform.

The transmitter and the receiver are implemented in a digital fashion. At the transmitter part, the process is called encoding process. The transmitter will separate the data stream that wants to enter the binary data blocks. Every block data is encoded into a single pair. After encoding, the two orthogonal signals are produced, which it is summed before transmission. For that implementation, the input sequences are up-sampled to match the implementation sampling rate and in turn of this process. Meanwhile, at the receiver part, the process is called decoding process, which its function to decode the data symbol , for recovering the block binary digits. The output of the receiver is down-sampled to the original symbol rate. The two-orthogonal summed modulated signals allow being separated.

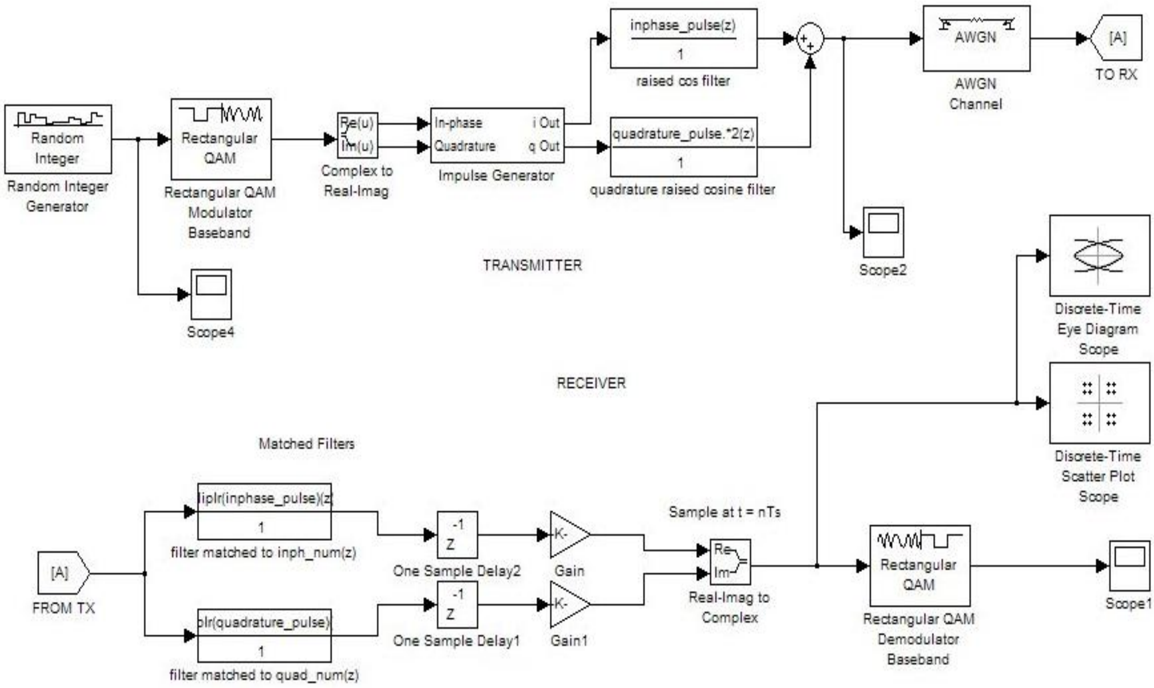


Fig. 2 Conventional CAP modulation

4. Simulation of 3D-CAP

The simulation performance of carrierless amplitude Phase (CAP) modulation using MATLAB Simulink is discussed. The schematics have been designed from one-dimensional until three-dimensional of CAP. Multidimensional CAP modulation is possible to be an attractive modulation format for next-generation multiple services access networks.

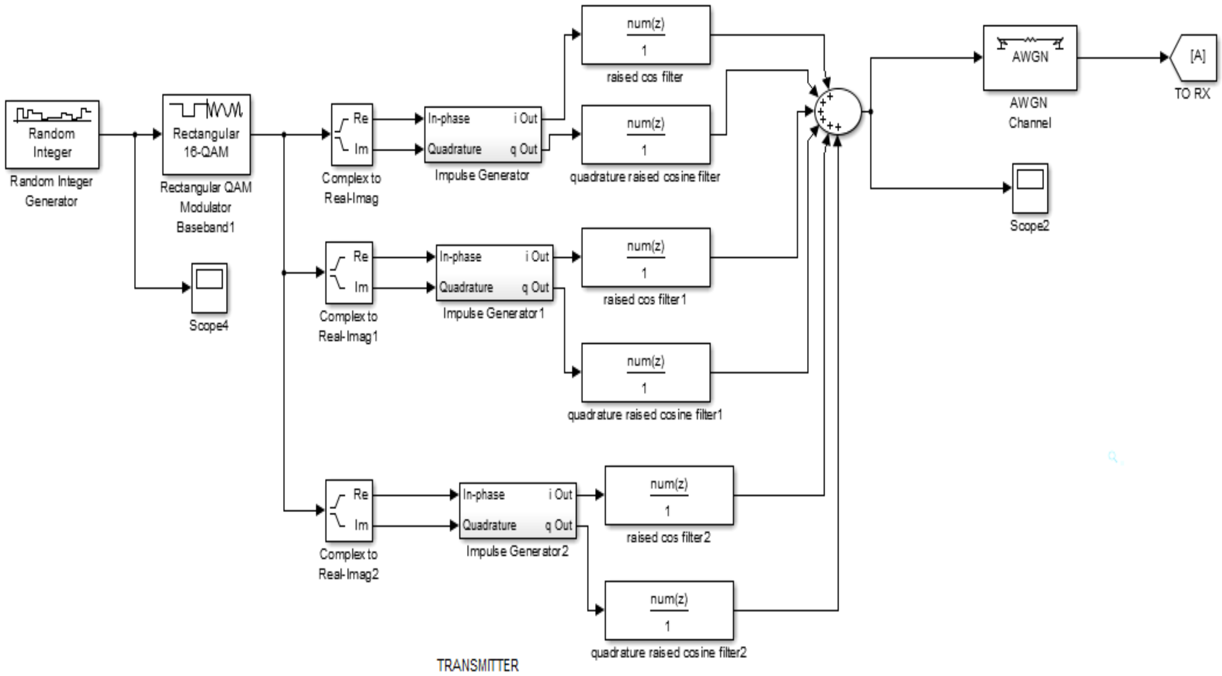
In this section, the simulation results have been discussed in order to determine the three-dimensional of the CAP (3D-CAP) for data and sound input signal, it is designed 3D-CAP modulation system, which three-orthogonal transmitter are shaping filters sharing a same band is required, as shown in Fig. 3. The three of optimal sequences are selected by minmax algorithm to meet the requirement. For the 3D-CAP signal, it is the receiver matched filter that cannot be directly calculated by linear constraint. The receiver needs to calculate the different band with respect to transmitter shaping filter. Thus, from this process, it needs to decode the signal for each band.

Data and sound were inserted in the block diagram to investigate the characteristics of CAP and their performance in terms of EVM, MER and power received. The reading value of 3D-CAP with data as an input signal are EWM = $-$ 0.048 dB, MER = 0.048 dB, and power received = $-$ 0.057 dB.

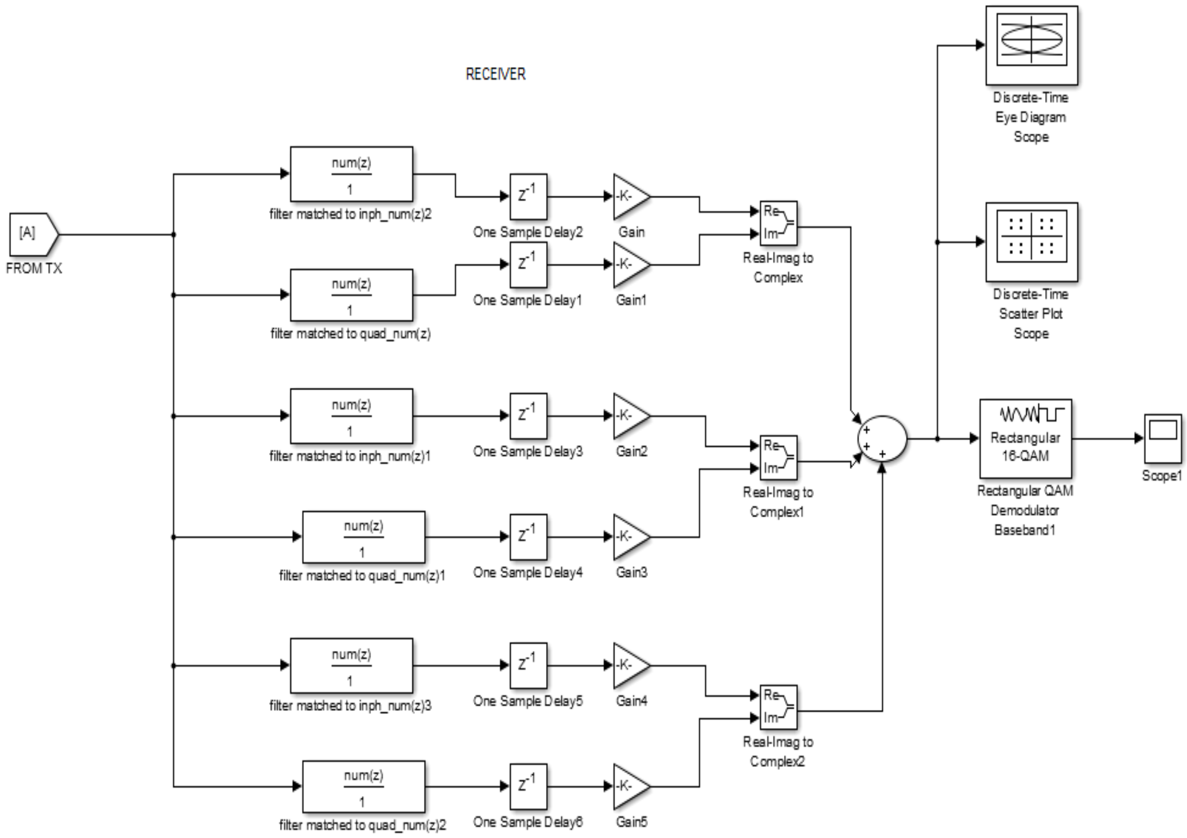
Meanwhile, the results of 3D-CAP with sound as an input signal are EWM = $-$ 0.052 dB, the MER = 0.052 dB and power received = $-$ 0.050 dB. In overall, the results of 3D for data and sound input show improvement compared to results of 1D-CAP and 2D-CAP.

Additionally, the measurements of the system performance employing the different schemes were carried out for differentiate the bit error rate (BER). The analysis of the given results allows proving the behavior of the different modulation schemes under the limitations which is caused by the active components.

By referring to Fig. 4, the result of BER versus the $\frac{E_b}{N_O}$ (dB) is presented. The results are the most interesting from the practical point of view. Here, 3D-CAP offers the higher order modulations formats. The value of BER decreases gradually with the increment of the $\frac{E_b}{N_O}$ (dB) values.



(a) 3D-CAP Transmitter



(b) 3D-CAP Receiver

Fig. 3 3D-CAP Modulation using MATLAB Simulink

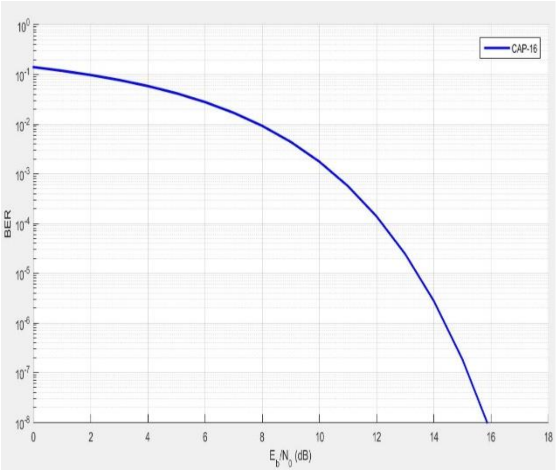


Fig. 4 BER of 3D-CAP

The compression reading of EVM, MER and power of multidimensional CAP is shown in table 1. The consumption in CAP scheme is the employment of high performance of analog to digital converter (ADC) and digital to analog converter (DAC), the signal quality dependency on the resolution of ADC and DAC. Data on the table 1 shows that the reading value of EVM, MER, and power received of 3D-CAP is the best reading value compared to the other CAPs. The results proven that by adding the number of dimensions, it shows an improvement on the EVM, MER and power received performance of the CAP modulation for both input signals.

Table 1 Comparison of CAP scheme

Input signal	CAP	EVM (dB)	MER (dB)	Power received (dB)
Data	1D	– 7.186	7.186	– 7.055
	2D	– 1.319	1.319	– 0.720
	3D	– 0.048	0.048	– 0.057
Sound	1D	– 2.352	2.352	– 1.72
	2D	– 0.149	0.149	– 0.068
	3D	– 0.052	0.052	– 0.050

5. Conclusion

The 3D-CAP using MATLAB Simulink was successfully developed. Conventional CAP and 2-CAP are the fundamental step before modeling the 3D-CAP. For modeling of three dimensions CAP, the data and sound are used as an input signal, and several number of filters and others part are added to the conventional CAP model.

The measurement results showed that CAP has same spectral efficiency as a corresponding QAM modulation formats. Hence, this conceptual framework of multi-level multi-dimensional CAP expected to extend the reach and coverage area. Multi-dimensional modulation CAP has potential for providing more flexibility in increasing the number of dimensions with low implementation cost needed to support multiple services for next generation access network.

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