EXPERIMENTAL DEMONSTRATION OF CAP TRANSMITTER USING VERY HIGH SPEED IC HARDWARE DESCRIPTION LANGUAGE (VHDL)

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Specially dedicated to *Abang*, *Mak*and *Abah*

Thanks for all of your support.

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*In the name of ALLAH S.W.T, The Most Merciful and The Most Gracious*

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# ABSTRACT

Carrierless Amplitude Phase (CAP) Modulation is a multidimensional and multilevel of modulation scheme which it is strongly inspired by QAM modulation scheme. CAP does not depend on a carrier and it is much simpler. Lots of CAP modulation experiments have been proposed and demonstrate but none of them were introduced in real time system. Therefore Very High Speed IC Hardware Description Language (VHDL) has been chosen as a method to investigate the modulation of CAP transmitter in real time. This project focused on 2D CAP transmitter implementation in VHDL. The aim of this project is to investigate the CAP transmitter modulation by using Fast Fourier Transform (FFT) and implement the core signal processing blocks using VHDL. Therefore 4 selected blocks of CAP transmitter: random generator, constellation mapper, modulation and Inverse Fast Fourier Transform (IFFT) were designed and analyzed. Then they were compared to the theory of CAP modulation and Quadrature Amplitude Modulation (QAM).The transition table was created based on modulation theory for proofing purposed. Quartus II has been used for simulation in implementing 4 RAMs, 1 radix butterfly and designing an IFFT. 3 stages were connected with each other using CORDIC algorithm and 23 multiplexers. We believe that this project is a good start for implementing 2D-CAP in the real time. Real time is good because it is timeliness, fast, low loss rate, low end to end delay and very cost effectively.

# ABSTRAK

Modulasi *Carrierless Amplitude Phase* (CAP) tergolong dalam pelbagai dimensi dan pelbagai aras skim modulasi yang mana ianya banyak dipengaruhi oleh skim *Quadrature Amplitude Modulation* (QAM). CAP tidak bergantung kepada pembawa malah ianya sangat ringkas. Pelbagai kaji selidik terhadap modulasi CAP telah dijalankan dan didemonstrasikan namun tiada satu daripadanya mengkaji dalam masa yang sebenar. Oleh itu *Very High Speed IC Hardware Description Language* (VHDL) telah dipilih sebagai kaedah untuk mengkaji modulasi penghantar CAP dalam masa yang sebenar. Fokus projek ini adalah menjurus kepada penghantar 2D CAP yang dilaksanakan menggunakan VHDL. Tujuan projek ini dilaksanakan adalah untuk mengkaji modulasi penghantar CAP dengan menggunakan *Inverst Fast Fourier Transform* (IFFT) dan menghasilkan blok asas bagi proses isyarat dengan bantuan VHDL. Justeru itu, 4 blok penghantar CAP: penjana rawak, buruj mapper, proses modulasi dan juga IFFT telah direka dan dianalisa. Keempat-empat blok telah dibandingkan dengan teori modulasi CAP dan juga modulasi QAM. Jadual peralihan telah dibangunkan berdasarkan teori untuk tujuan pembuktian. Quartus II telah digunakan sebagai simulasi bagi melaksanakan sistem 4 RAM, 1 *radix butterfly* dan merekacipta IFFT. 3 peringkat telah disambung antara satu sama lain menggunakan algoritma CORDIC dan juga dengan bantuan 23 pemultipleks. Kami percaya projek ini merupakan satu permulaan projek yang bagus untuk melaksanakan 2D-CAP di dalam masa yang sebenar. Masa yang sebenar amat bagus keranaianya mempunyai ketepatan masa. Kadar kehilangan yang rendah, lajakan yang rendah dan kos yang sangat effektif.

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| | | |
|---|---|---|
| ASK | - | Amplitude Shift Keying |
| FSK | - | Frequency Shift Keying |
| PSK | - | Phase Shift Keying |
| PAM | - | Pulse Amplitude Modulation |
| QAM | - | Quadrature Amplitude Modualtion |
| CAP | - | Carrierless Amplitude Phase |
| GbE | - | Gb Ethernet |
| FPGA | - | Field programmable gate arrays |
| VHDL | - | Very High Speed IC Hardware Description Language |
| IFFT | - | Inverse Fast Fourier Transform |
| OOK | - | On Off Keying |
| BPSK | - | Binary Phase Shift Keying |
| QPSK | - | Quadrature Phase Shift Keying |
| DAC | - | Digital to Analog Converter |
| LPF | - | Low Pass Filter |
| IJSETR | - | International Journal of Science, Engineering and Technology Research |
| SIPO | - | Serial input parallel output |
| DSO | - | Digital Signal Oscilloscope |
| EML | - | External Modulator laser |
| PD | - | Photodiode |
| 2D | - | 2 Dimensional |
| LFSR | - | Linear Feedback Shift Register |
| FSM | - | Finite State Machine |
| DFT | - | Discrete Fourier Transform |
| RAM | - | Random Access Memory |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

The fiber optic communication actually started since 1790s when French engineer, Claude Chappe, who invented the “Optical telegraph” introduced a series of semaphores which mounted on towers. Then, communication technology become popular when optical telephone system was introduced by Alexander Graham Bell in 1880. Apart of it, new technology slowly took place to solve the optical transmission problem. In 1930s, Heinrich Lamm the first person demonstrated image transmission through a bundle of optical fiber [1]. This is the starting step where fiber optic starts its revolution. The new technology was introduced year by year in order to make sure the network is stable, give the highest speed of transmission and at the same time it is efficient.

Not only the technology has changes but the modulation technique also has their revolution. They were upgraded to new phase which using digital technique instead of analog technique. Digital modulation has two main categories which are amplitude/phase modulation and frequency modulation. Basically frequency modulation is known as nonlinear modulation or constant envelope modulation while amplitude/phase modulation is called linear modulation.

Linear modulation generally has better spectral properties than nonlinear modulation, since nonlinear processing leads to spectral broadening [2]. The constellation size must be chosen once modulation technique is determined. The larger constellation size, the higher data rates it is.

The simplest digital modulation technique is amplitude shift keying (ASK). ASK refers to a type of amplitude modulation where binary information directly modulates the amplitude of analog carrier. Mathematically amplitude shift keying is shown in equation 1.1 [3].

$$v_{(ask)}(t) = [\,1 + \,v_m(t)][\tfrac{A}{2}\cos(w_c t)] \quad (1.1)$$

where $v_{(ask)}(t)$ is amplitude shift keying wave

$v_m(t)$ = digital information (modulating) signal (volts)

A/2 = un-modulated carrier amplitude (volts)

$\omega_c$ = analog carrier radian frequency (radians per second, $2\pi f_c t$)

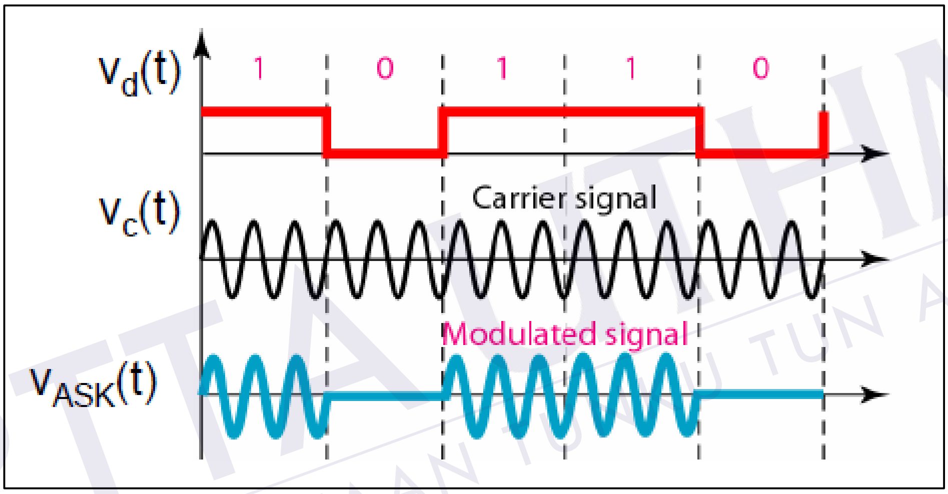


Figure 1.1: Modulation of digital signal of amplitude shift keying (ASK)

Figure 1.1 illustrates a binary ASK signal [4]. The entire time the binary input is high, the output is a constant-amplitude, constant-frequency signal, and for the entire time the binary input is low, the modulated signal is off.

ASK normally is used to transmit digital data over optical fiber but it has its disadvantages. ASK is very susceptible to noise interference noise usually affects the amplitude, therefore ASK is the modulation technique most affected by noise.

Frequency shift keying (FSK) refers to a type of frequency modulation. It modulates the signal by switching the two frequencies. The frequency is designated as the 'mark' which corresponds to binary one while the other frequency is known as 'space' frequency or zero respectively. The general expression for FSK is given in equation 1.2 [3].

$$v_{(fsk)}(t) = V_c \cos\{ 2\pi \, [f_c + v_m(t) \Delta f] t\} \qquad (1.2)$$

where $v_{(fsk)}(t)$ is binary FSK waveform

$V_c$= peak analog carrier center frequency (volts)

$\Delta f$ = peak change (shift) in the analog carrier frequency

$f_c$= analog carrier center frequency (hertz)

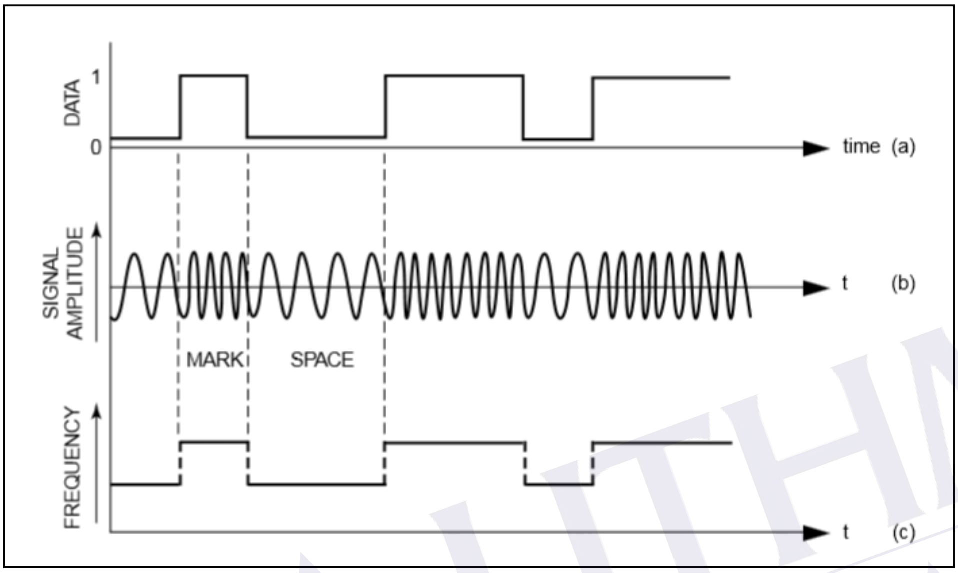


Figure 1.2: FSK modulation. Binary data (a) frequency modulates the carrier to produce the FSK signal (b)which has the frequency characteristic (c).

Figure 1.2 shows the FSK modulation [5]. From Figure 1.2, notes that the frequency modulates the carrier to produce the FSK signal. When binary data is ‘0’, the number of vibrations per unit time is low. This is called lower frequency. However when binary data is ‘1’, number of vibrations per unit time is increased and this is called high frequency.

Phase shift keying (PSK) refers to a type of phase modulation. PSK modulates the signal by alternate signal between +1 and -1 and it creates 180 degree of phase reversals. Equation 1.3 shows the basic expression for PSK [3].

$$v_{(psk)}(t) = b(t)\sqrt{2\text{p}} \cos 2\pi f_c t \qquad (1.3)$$

where 0< t< T

b(t) = +1 or -1

$f_c$ = Frequency carrier (Hertz)

The signal has power $P = \frac{A^2}{2}$ so that A =$\sqrt{2\text{p}}$, where A represent the peak value of sinusoidal carrier.

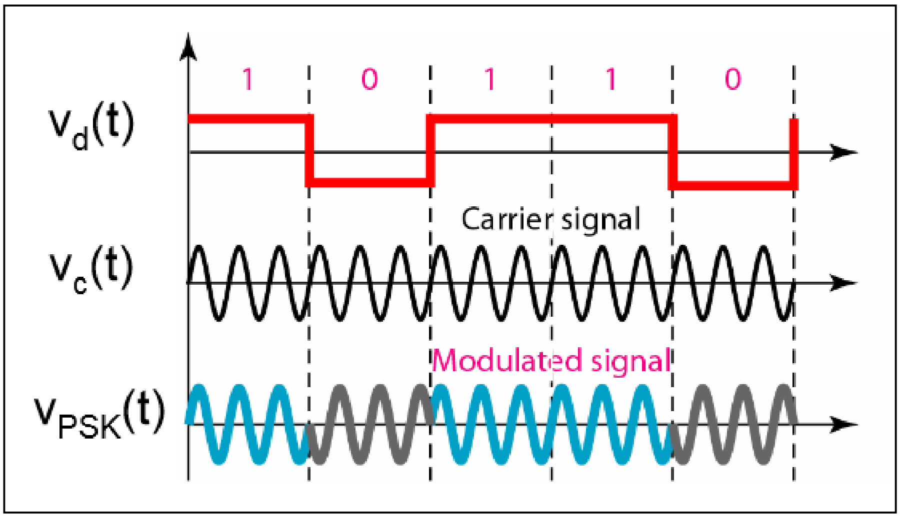


Figure 1.3: Modulation of digital signal of phase shift keying (PSK)

Figure 1.3 shows the modulation of digital signal of phase shift keying [6]. It is called phase shift keying when modulated signal has difference phase. Look at the transition between data '0' and '1'. There is a phase shift at 180 degrees and the waveforms are mirror images with each other.

The general principles of signal space analysis will then be applied to the analysis of amplitude and phase modulation techniques, including Pulse Amplitude modulation (PAM), Phase-shift keying (PSK) and Quadrature amplitude modulation (QAM) [7]. QAM function does not appear the same within each symbol period due to presence of the sinusoidal functions and potential arbitrary choice of a carrier frequency. Usually QAM basic function have non periodic symbol rate, even they keep repeating transmit the same message. It has two dimensional signaling as shown in Figure 1.4 [4]. However QAM have same spectrum efficiency and need a splitter.

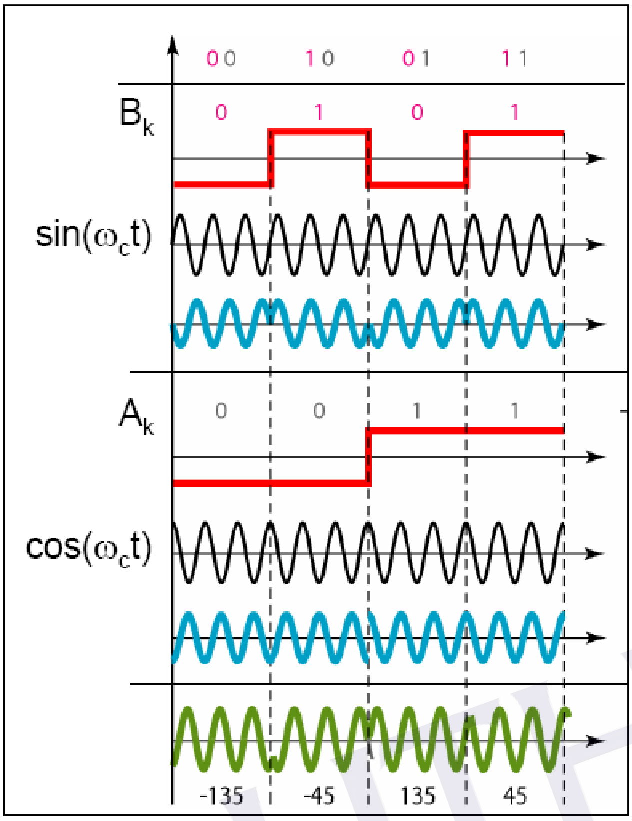


Figure 1.4: Quadrature amplitude modulation (QAM).

The carrier modulation in QAM is superfluous due to 2 dimensional basic modulations. Although periodicity is not a big issue, but the usage of it can allow minor simplification in implementation in few cases like Carrierless Amplitude Phase (CAP) modulation.

CAP is a multi-dimensional and multi-level signal format employing orthogonal waveforms [8]. The CAP modulations are the vibrational scheme of QAM for single carrier systems [9]. As the technology changes, the inventor start to implement digital technique because digital are more real time compared to analog. Real time in communication means user can exchange information instantly.

We believe that in future the investigation of 10-Gb Ethernet (GbE) in real time systems using field-programmable gate arrays (FPGAs) can be potentially attractive candidate for optical fiber system using multi-dimensional CAP [10]. This project is focus on CAP modulation using FPGA with VHDL.

## 1.2 PROBLEM STATEMENT

CAP modulation experiments have been done by using various types of input but not in real time system. Real time is preferable because there is no transmission delay in sending or receiving information. FPGA is one of the methods that can be used to modulate CAP in a real time system.

J.B. Jesper, I.O. Miguel and T.M. Idelfonso reviewed the modulation formats for beyond – 100 Gbps optical lines [10]. They also believed that capabilities of FPGA indicated a real time is the best solution and it could be realistic within a few years ahead. This project focused on experimentally demonstrates of CAP transmitter in real time

## 1.3 OBJECTIVES

The objectives of the project are:

1.3.1 To design the CAP transmitter modulation using IFFT.

1.3.2 To simulate the core signal processing blocks of CAP transmitter using VHDL language.

## 1.4 SCOPE

The objectives of this project can be achieved with several outlined scopes. This project is focused on 2D CAP transmitter. It consists of a few blocks such as random generator, constellation mapper, modulation and IFFT. Results were compared with theoretical result. These blocks are designed using Quartus Altera II.

## 1.5 REPORT OUTLINE

This report is organized in five chapters. Chapter one gives an overview and the introduction of the project.

Chapter two discussed about literature review about modulation. A few types of modulation that had been used are discussed. This chapter also explained a little bit about CAP modulation and also FPGA.

Chapter three explains the design methodology of the project. The design overview and block diagram are also discussed.

Chapter four discussed the result of CAP transmitter modulation using VHDL language while Chapter five is summarizing overall of this project.

## 1.6 SUMMARY OF WORK

The project flow is outlined as illustrated in Figure 1.5. The project begins with literature review. Literature review will covered some of advanced modulation format, CAP and also FPGA. The generation for each topic together with their advantages and disadvantages were also stated. Then it is followed by designing the block diagram of CAP modulation. Block diagram consists of two parts which are transmitter and also receiver.

Each block will be converted to VHDL code. At this phase, input sources need to be declared together with parameters. The programs for each block will be tested by running the VHDL code. If there is an error, VHDL code and structure of the program will be modified in order to fix it. The last step of the project is writing thesis.

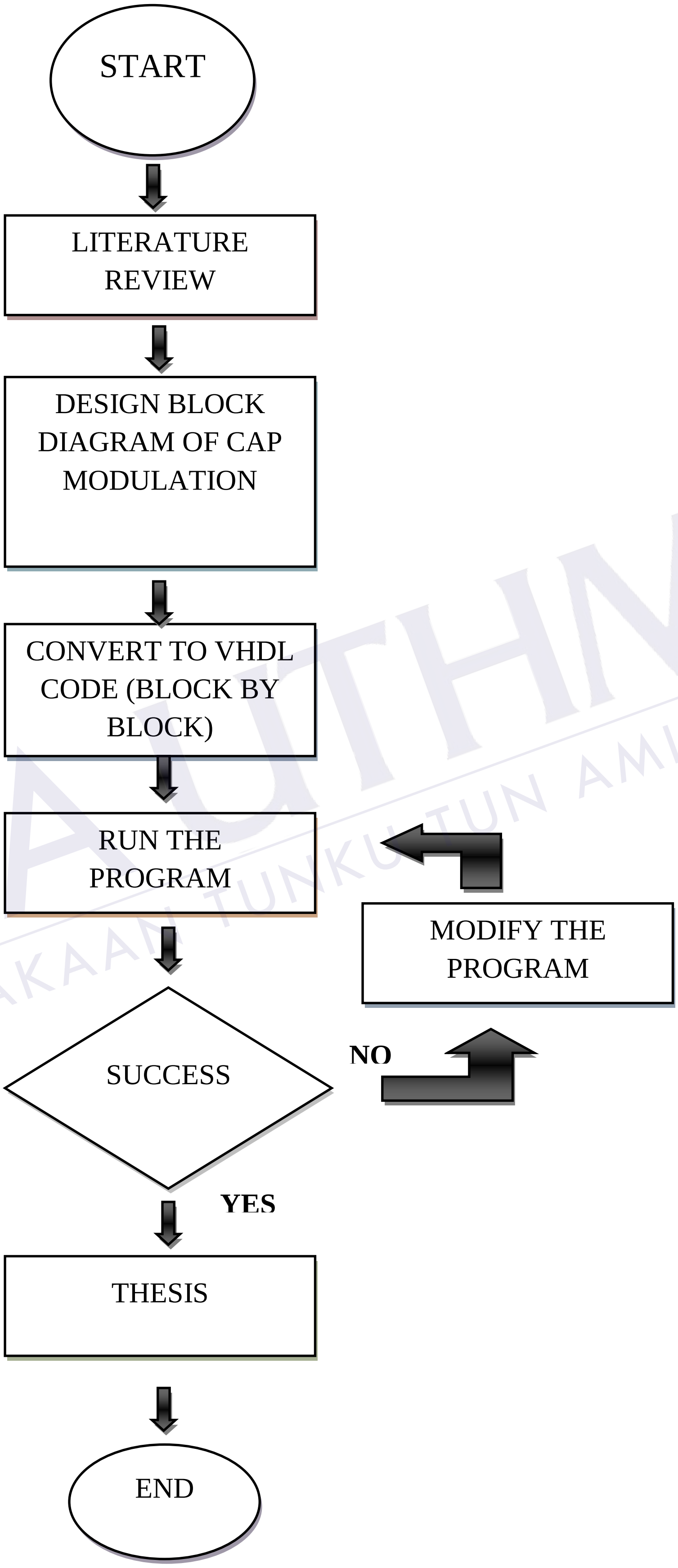


Figure 1.5: Project work flow

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

In this chapter, the definition of high dimensionality is explained. The advantages of high dimensionality modulation and also the techniques that have been used will be discussed.

## 2.2 CHARACTERISTIC OF SEVERAL MODULATION FORMATS

There are generations of modulation formats that involve in communication system. The explanation consists of their structure, advantages and also disadvantages.

### 2.2.1 ON OFF KEYING (OOK)

On Off Keying [11] or known as OOK is commonly used few years back. OOK is the simplest modulation format where it used logical ‘1’ and ‘0’ to represent the on and off data as shown in Figure 2.1. The optical power is modulated according to the binary input signal.

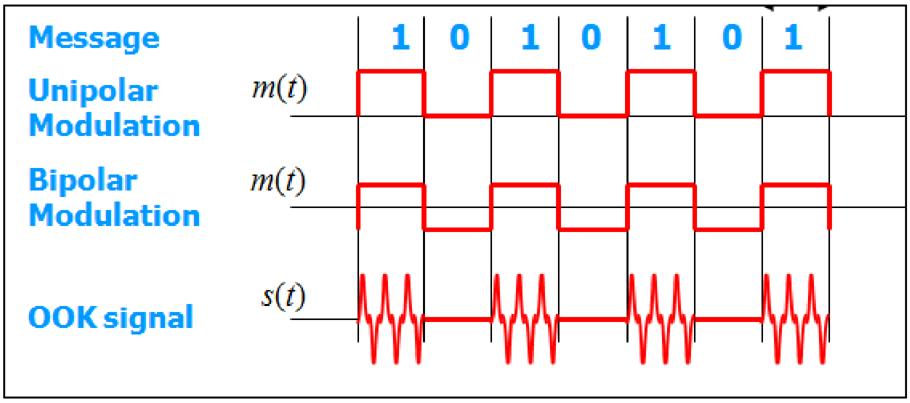


Figure 2.1: On Off Keying (OOK) modulation.

There are a few disadvantages for OOK modulation scheme. OOK has no error detection capability so it cannot monitor the performance well. It also has a long sequence of '1' or '0' due to no pulse transition is applied. Due to result for bandwidth is not so efficient then the generation of modulation move to BPSK.

### 2.2.2 BINARY PHASE SHIFT KEYING (BPSK)

Just like OOK, Binary Phase Shift Keying (BPSK) also using symbol '1' and '0' to modulate the phase of the carrier. Logical '1' is represented as *sin ωt* while '0' represented as – *sin ωt*. The constellation for BPSK is assigned by different carrier phases at 180º each as shown in Figure 2.2 [12]. In the constellation diagram, *I* axis is refer to the in-phase carrier wave while the *Q* stands for Quadrature carrier. BPSK has very complex circuit at receiver due to phase shift detection.

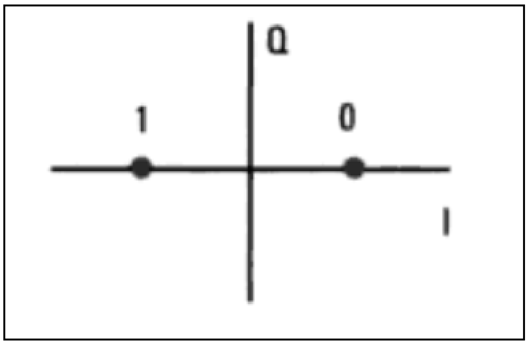


Figure 2.2: One dimension constellation diagram.

Figure 2.3 shows a simplified block diagram of a BPSK [13]. A phase reversing process was done at balanced modulator. The output is depends on the logic condition of digital input either it is in phase or 180º out of phase with the

# REFERENCES


1. Maurice Gagnaire, “Broadband Local Loops for High Speed Internet Access”, Artech House, 2003.
2. Andrea Goldsmith, “Wireless Communication”, Cambridge University Press, Aug 8, 2005.
3. A.K. Nigam, “Unit 3: Digital Modulation”, ITM University, Gurgaon, 2013.
4. S. Vijayachitra, “Communication Engineering”, Tata McGraw Hill Education, 2013.
5. N. Vlajic, “Analog Transmission of Digital Data: ASK, FSK, PSK, QAM”, CSE 3213, 2010.
6. Kwandwo Boateng and Charles Badu, “EE452 Senior Capstone Project: Integration of Matlab Tools for DSP Code Generation”, Bradley University, 2006.
7. David Brandon and Jeff Keip, “Efficient FSK/PSK Modulator Uses Multichannel DDS to Switch at Zero Crossings”, vol. 46, Jan 2012.
8. S.K Ibrahim, “High Speed Optical Communication Systems: Study of Multilevel Modulation Formats”, VDM Verlag Publisher, 3rd July 2008.
9. Fang Ming Wu, Chun Ting Lin, Chia Chien Wei, Cheng Wei Chen, Hou Tzu Huang and Chun Hung Ho, “1.1-Gb/s White LED Based Visible Light Communication Employing Carrier-Less Amplitude and Phase Modulation”, IEEE Photonics Technology Letters, Vol. 24, No. 19, Oct 1, 2012.

10. M. B. Othman, X. Zhang, L. Deng, J. Bevensee Jensen and I. Tafur Monroy, "Experimental Demonstration of 3D / 4D-CAP Modulation Employing CTCMA Channel Estimation", Journal of Lightwave Technology, 2012.

11. J. R Smith, "Programming the PIC Microcontroller with MBasic", Newnes, 2005.

12. A. Tarmo, "Introduction to Telecommunications Network Engineering", Artech House, 1 Jan 2003.

13. Mandeep, " Chapter 2: Digital Modulation", USM.

14. E. Ata, "Network Communications Technology", Cengage Learning, 2011.

15. D. D. Falconer, "Carrierless AM/PM," 1975.

16. G. Maurice, "Broadband Local Loops for High-speed Internet Access", Artech House, 31 May 2002.

17. K. P. Keshab, N. Takao, "Digital Signal Processing for Multimedia Systems", CRC Press, 11 March 1999.

18. Henrik Bostrom, "An FPGA Implementation of a digital FM modulator", Linkopings Universitet, Sweeden, 9th June 2011.

19. Aseem Pandey, Shyam Ratan Agrawalla & Shrikant Manivannan, "VLSI Implementation of OFDM", Wipro Technologies, September 2002.

20. Nasreen Mev and Brig. R.M Khaire, "Implementation of OFDM Transmitter and Receiver Using FPGA", International Journal of Soft Computing and Engineering (IJSCE), Volume -3, Issue-3, July 2013.

21. David Pellerin, "An Introduction to VHDL for synthesis and simulation", Accolade Design Automation.Inc, 1995.

22. S.N.H. Chaw, "Design and Simulation of FPGA Based 16-QAM Mapper and Demapper Using VHDL", published in International Journal of Science, Engineering and Technology (IJSETR), vol. 1, issue 1, July 2012.

23. D.T Prashant and A.M. Shah, “Low Power QPSK Modulator on FPGA”, in International Journal of Advanced Research in Computer Science and Software Engineering, vol. 4, issue 1, January 2014..

24. M. I. Olmedo, T. Zuo, J. bevensee Jensen, Q. Zhong, X. Xu, S. Popov and I.Tafur Monroy, “Multiband Carrierless Amplitude Phase Modulation for High Capacity Optical Data Links”, published in Journal of Lightware Technology, vol. 32, 2014.

25. R.H. Sharma and K.R. Bhatt, “A review on Implementation of QAM on FPGA”, published in International Journal of Innovative Research in Computer and Communication Engineering, vol. 3, issue 3, March 2015.

26. Maisara Othman, “High Dimensional Modulation MIMO Techniques for Access Networks”, DTU Fotonik, Technical University of Denmark, 2012.

27. R. Ramaswami, K. Nsivarajan & G.H Sasaki, “Optical networks: A practical perspective”, Morgan Kaufmann Publisher, 3rd Edition, 2009.

28. M. B. Othman, J. Bevensee Jensen, Xu Zhang, and I. Tafur Monroy, “Performance Evaluation of Spectral Amplitude Codes for OCDMA PON," in (15th International Conference on Optical Net-work Design and Modeling (ONDM), 2011.

29. Kris Gaj, “Sine/Cosine Using CORDIC Algorithm”, Gaurav Doshi.

30. J.B. Jesper, I.O. Miguel and T.M. Idelfonso, “Modulation Formats for Beyond – 100Gbps Ethernet Optical Links – A Review of Research”, in Asia Communications and Photonics Conference (ACP) 2013.

31. F. M. Gutierrez, “Implementation of a Tx/Rx OFDM System in a FPGA”, Universitat Politecnica De Catalunya, 2009.