

Comparative Analysis of Different Modulation Technique for Free-Space Optical Communication

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ABSTRACT: The system of transmission of data through a wireless medium is called as Free Space Optical (FSO) communication, which uses modulated carrier wave as a laser beam. Free-space optical communication is the latest technology that has a lot of popularity as an alternative to radio frequency (RF) communication over the last two decades. Optical communication has lots of advantage over baseband or RF transmission systems which has high aggregate bit rates and/ or very long transmission distances. This paper intends to give an overview of optical modulation techniques such as On-Off Keying (OOK), Binary Phase-Shift Keying (BPSK), Differential Phase-Shift Keying (DPSK) and Pulse Position Modulation (PPM) which compares their characteristics Bit Error Rate(BER), Signal-to-Noise Ratio (SNR) and the receiver sensitivity.

Keywords: Free Space Optics (FSO), On-Off Keying (OOK), Pulse Position Modulation (PPM), Binary Phase-Shift Keying (BPSK), Differential Phase-Shift Keying (DPSK)

I. INTRODUCTION

The key element of the optical communication system is the optical source, which can easily be modulated. In this narrow wavelength band, the energy is concentrated and is capable of being modulated at very high data rates. The semiconductor laser is one of the primary sources of light in modern an optical system which is used as a carrier [1]. At the receiver, they are converted to electronic signals by photodetectors. There are many types of photodetectors, but the photodiodes are used almost in optical communication applications because of their size, suitable material, high sensitivity, and fast response time [2]. The two most commonly used photodiodes are the pin photodiode and the Avalanche Photodiode (APD) because they have good quantum efficiency. It is necessary to understand the characteristics of these photodiodes and the noise associated with optical signal detection for the design of receiver system.

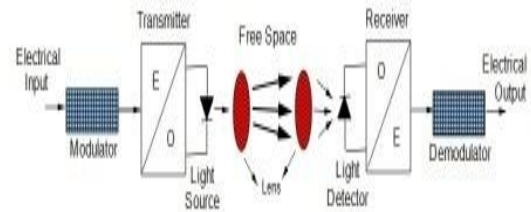


Figure 1 Block Diagram of FSO

1.1 PIN Photodiode

The pin photodiode consists of p region and n regions separated by a lightly n-doped intrinsic I region. When an incident photon has energy, the photon can give up its energy and excite an electron. This generates free electron-hole pairs called photocarriers. The pin photodetector is designed, where most of the incident light is absorbed [1]. The performance of a pin photodiode is often characterized by its responsivity which is given by :

$$R = I/P \quad (1)$$

Where I am the average photocurrent
P optical power incident on the photodiode.

1.2 Avalanche Photodiode

The primary signal photocurrent is multiplied internally by an avalanche photodiode. This increases the receiver sensitivity [1]. The pin photodetector and electronic amplifier have an advantage over APD because of its low cost [1]. For Free Space Optical (FSO) communication systems the required power under various modulation schemes can be derived from the Bit Error Rate (BER) expression for all modulation schemes and can be expressed as follows P

$$P = \frac{1}{R} \sqrt{\sigma^2 SNR} \quad (2)$$

Where R is the responsivity of the photodiode.
 σ Is the total noise power in the detector current.
SNR is the signal-to-noise ratio.

II. AN OVERVIEW OF OPTICAL WAVEFORMS

2.1 OOK Modulation

OOK modulation technique is the direct detection technique which is widely used in the optical communication [1]. It transmits bit 0's and 1's. when bit 0 is transmitted it remains in off state and when bit 1 is transmitted it remains in on a state. This modulation can be done by using RZ and NRZ waveforms. The probability of error from the optical photodiode can be found from the following equations.

$$BER - NRZOOK = \frac{1}{2} \operatorname{erfc}\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right) \quad (3)$$

$$BER - RZ OOK = 0.5 \operatorname{erfc}(0.5\sqrt{SNR}) \quad (4)$$

2.2 Differential Phase-Shift Keying (DPSK).

The DPSK modulation technique is the direct detection technique which is used for short distance communication [4]. The signal High 1 or Low 0 decided the phase of the previous bits transmitted. If the data bit is low ie 0 the bit does not reverse it continued there is no phase change when the data is high ie 1 the bit get reversed there is a phase change. The probability of error for the DPSK modulation from the optical photodiode can be given by the following equation,

$$BER = 0.5 \operatorname{erfc}\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right) \quad (5)$$

2.3 Pulse-Position Modulation (PPM)

PPM is especially suited for direct detection of an optical signal transmitted through free-space. A logical '0' and '1' could be represented by a pulse present in the 'first' slot and the 'second' slot, respectively [1]. 4PPM encodes two bits of information into each four-slot symbol whose duration is two-bit periods. M-ary PPM extends the number of bits represented by each of M distinct symbols to log2M which lowers the band-utilization efficiency.

BER equation for 2-PPM can be expressed as

$$BER 2 - PPM = \frac{1}{2} \operatorname{erfc}\left(\frac{\sqrt{SNR}}{2}\right) \quad (6)$$

BER equation for 4-PPM can be expressed as

$$BER 4 - PPM = \frac{1}{2} \operatorname{erfc}\left(\frac{\sqrt{SNR}}{\sqrt{2}}\right) \quad (7)$$

BER equation for 8-PPM can be expressed as

$$BER 8 - PPM = \frac{1}{2} \operatorname{erfc}\left(\frac{\sqrt{3\sqrt{SNR}}}{\sqrt{2}}\right) \quad (8)$$

BER equation for 16-PPM can be expressed as

$$BER 16 - PPM = \frac{1}{2} \operatorname{erfc}(2\sqrt{SNR}) \quad (9)$$

2.4 Binary Phase Shift Keying (BPSK)

The BPSK modulation technique is the coherent detection technique. In optical communication, the carrier is always taken as the laser [7]. The demodulation can be done by two methods homodyne and heterodyne detection. The phase shift occurs in BPSK modulation is 0 degree and 180 degrees. The BER of this technique is given by the equation

$$BER = 1/2 \operatorname{erfc}(\sqrt{SNR}) \quad (10)$$

TABLE I COMPARISON OF DIFFERENT MODULATION TECHNIQUE

Modulation Techniques	Features
OOK-NRZ	Direct detection, Moderate SNR, Low Cost, requires the adaptive threshold
OOK-RZ	Direct-detection, High sensitivity
PPM	Direct-detection, Superior power efficiency than any other baseband modulation
DPSK	Direct detection used for short distance communication
BPSK	Coherent detection, long-haul communication, power efficiency

III. RECEIVER SENSITIVITY

3.1 Analysis

The lowest power level at which the receiver can detect the optical signal and demodulate it data is known as optical receiver sensitivity [2].

$$P_{rec}(R_1) = \frac{1}{(Q\sigma_T + Q^2 q B_e / R(1 - r_1^2 Q^2))} \quad (11)$$

Where,

$$Q = (I_1 - I_0 / \sigma_1 - \sigma_0)$$

The receiver sensitivity for the OOK modulation technique is given by,

$$P_b = 1/2 \operatorname{erfc}\left(\frac{\sqrt{n_p}}{2}\right) \quad (12)$$

Where,

n_p = No of photons per bit

The receiver sensitivity for the BPSK modulation technique is given by,

$$P_b = \frac{1}{2} \operatorname{erfc}(\sqrt{n_p}) \quad (13)$$

n_p = No of photons per bit

The receiver sensitivity for the DPSK modulation technique is given by,

$$P_b = \frac{1}{2} \operatorname{erfc}\left(\frac{\sqrt{n_p}}{\sqrt{2}}\right) \quad (14)$$

n_p = No of photons per bit

The receiver sensitivity for the PPM modulation technique is given by,

$$P_b = \frac{1}{2} \operatorname{erfc}(\sqrt{n_p}/2) \quad (15)$$

TABLE II COMPARISON OF DIFFERENT MODULATION TECHNIQUE RECEIVER SENSITIVITY

BER	Modulation	Receiver Sensitivity
10 ⁻⁹	OOK	70 PPB
10 ⁻⁹	BPSK	9 PPB for Homodyne 18 PPB for Heterodyne
10 ⁻⁹	DPSK	18.4 PPB for NRZ and 18.1 PPB for RZ
10 ⁻⁹	M-PPM	5 PPB

IV. SIMULATION AND RESULTS

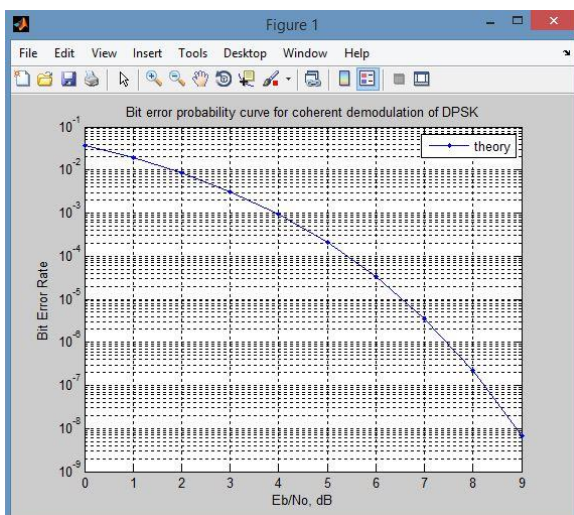


Figure 2 Simulation of BPSK

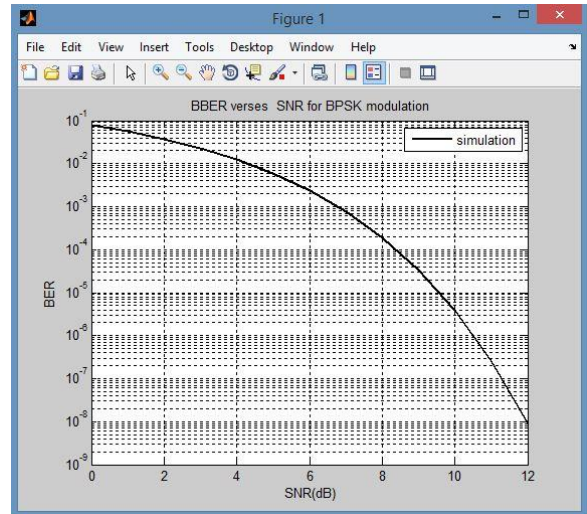


Figure 4 Simulation of DPSK

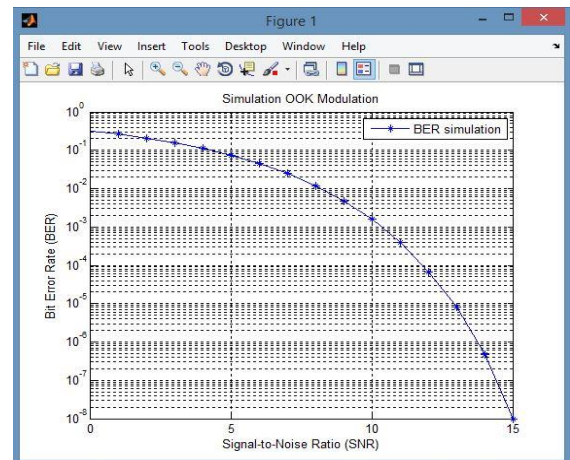


Figure 3 Simulation of OOK

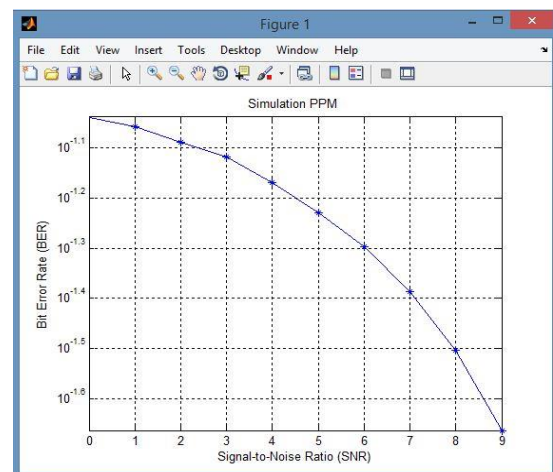


Figure 5 Simulation of PPM

V. CONCLUSION

As it is shown in this paper, the most power-efficient modulation scheme used for FSO communication systems is Pulse Position Modulation Technique. And we simulated the BER performance for different modulation schemes. Thus the simulation results show an excellent agreement with the analytical results. In our simulations, BER for 10⁻⁹ is evaluated and the receiver sensitivity theoretical analysis is also done.

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