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A Novel Approach towards Performance Analysis of Optical Wireless Communications using Intensity Modulated OFDM

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Abstract:
Evaluation of two different types of Optical OFDM methods namely DCO and Flip has been done in paper. The paper compares two techniques in terms of Doppler Frequency and BER and similarly BER as a function of SNR for various multipaths fading channels (AWGN, Rician, Rayleigh Channels) .DCO OFDM scheme has been implemented in MATLAB SIMULINK software by applying a bias value of -6.25dBs, to minimize the error approximation. Similarly Flip OFDM with its negative and positive sample distribution were phase managed to reduce the error rate. Analysis shows that Flip OFDM with different modulation schemes like 8,16,32,64 QAM has outperformed in additive white Gaussian noise. Similarly in fading channels for Doppler shifts ranging between 1 – 5Hz analysis DCO OFDM outperformed Flip OFDM using differential modulation techniques (DBPSK , DQPSK).

Keywords: DCO-OFDM; OWC; RF; BER.

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) has been recently proposed for Optical Communication [1][2].Recent forecasts says that growing communication standards will fail to cope up with increasing demands for mobile data throughput because of limited RF (radio frequency) spectrum which has resulted in its depletion. So in order to handle this rising crisis for spectrum alternative regions of Electromagnetic Spectrum mainly optical and millimeter wave are currently under research.

However Optical Communication offers certain advantages in comparison to RF Communication:

a) No requirement for license

b) Huge unregulated bandwidth

c) No interference with operation of other electronic systems

d) Lower cost of implementation as existing lightning infrastructure can be utilized for communication

The LEDs and Photodiodes (PDs) constitute a Optical Wireless Communication (OWC) framework which can be employed for optical communication. This type of communication needs electric signal to be real and unipolar. To ensure that signal is real valued Hermitian Symmetry must be applied. The signal must also be unipolar because photons can never be negative so DC-bias is introduced which makes high power requirement for system. This technique is termed as DCO-OFDM. Alternative for this technique is ACO-OFDM which employs asymmetrical clipping to create unipolar signals. ACO-OFDM uses odd sub carriers to carry data and negative values are clipped at transmitter. When power efficiency is considered ACO is better but from bandwidth utilization aspect DCO is best because ACO uses half number of subcarriers [3]. So recently a new modulation technique has been proposed called Flip- OFDM. In the proposed technique original bipolar signal is decomposed in positive and negative parts. The polarity of negative parts before transmission is then inverted. Positive part is transmitted in first subframe whereas flipped part is sent on second subframe. Cyclic prefixes are added to OFDM subframes which are composed of n samples [4]. Hence, negative subframe will arrive late by (N +n) and follows positive subframe. However Flip–OFDM is less complex in comparison to ACO–OFDM [5]. The paper compares two Optical OFDM techniques namely DCO and modified Flip OFDM with respect to BER. The curves of BER are plotted against SNR with white Gaussian noise [6] after which tabulated results are explained for BER with SNR and BER with Doppler shifts. Rest portion of paper has been sorted as explained. Part (II) gives explanation about above discussed two OFDM schemes. Part (III) gives comparative analysis between OFDM techniques with respect to BER and SNR value. Finally in last section (IV) paper is concluded.

II. COMPARISON OF UNIPOLAR OFDM SCHEMES

In the section below detailed discussion about Optical OFDM techniques namely DCO and Flip has been done.

A. Direct Current Biased Optical-OFDM

DCO system implementation is shown in Fig1. Earlier known OFDM technique is DCO–OFDM. At first stage of modulation, input binary data is isolated into parallel lower rate information streams which can be transmitted over a number of subcarriers simultaneously. After passing through IFFT we get a real valued signal in this case which

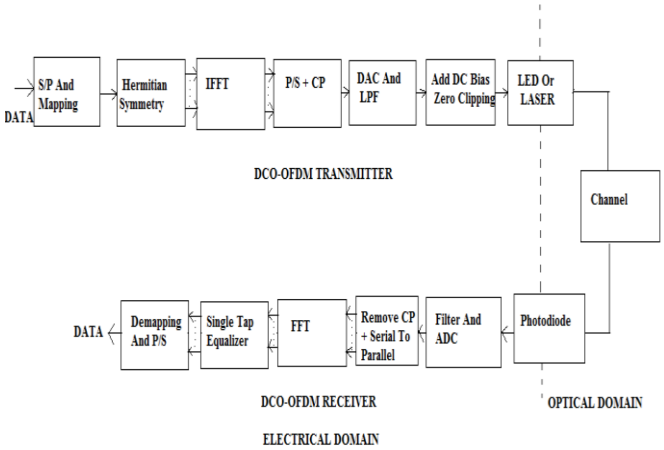

Figure.1. DCO-OFDM System Block

Otherwise would have been complex signal. This has happened because of Hermitian Symmetry. For $X_n = C_n + jD_n$, where n = 0,1,2...,N-1 indicates subcarrier indexing, Hermitian Symmtery has been applied as

$$X_{N-n} = X_n^* \qquad (1)$$

Where n=0,1,2...,N/2 and $X_0 = X_n = 0$.

After N- point Inverse Fast Fourier Transform (IFFT) of K^{th} sample the output is denoted

$$x_K = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \exp\left(\frac{j2\pi nK}{N}\right) \qquad (2)$$

Thus a bipolar data sequence with N point real value is generated followed by addition of CP (Cyclic Prefix) to each OFDM symbol resulting in length ($N+N_{CP}$) where N_{CP} is the length of cyclic prefix. This is sent to parallel to serial converter so as to transmit data serially. Bipolar signal is made unipolar by addition of DC bias .We therefore need to decide the value of applied bias. If value is large then E_b/N_o (Energy per bit To Noise power density) becomes quite large, making this technique inefficient in terms of power. Thus , optimum bias value is required .V_{dc} denotes the applied DC bias level which is set according to standard deviation of x(n) [7] .

$$V_{DC} = \mu \sqrt{\left(E\left(X(n)\right)^2\right)} \qquad (3)$$

But it is not possible practically to introduce biasing which makes all time – domain OFDM samples non – negative. Thus clipping is required to clip signal at zero level to make sure that non – negative data transmission does not take place.

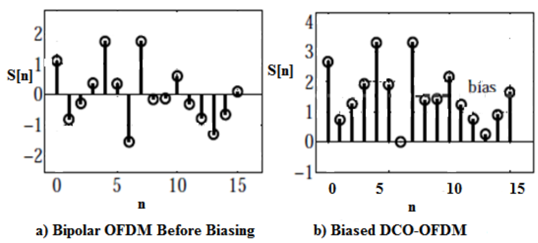

Figure.2. Bipolar to unipolar conversion in DCO – OFDM

This unipolar to bipolar conversion is as depicted above in Fig 2. Finally after all transmitter end operations signal propagates through channel (AWGN, Rayleigh, Rician) and undergoes some attenuation. At receiver end, received DCO – OFDM frames are converted into parallel data streams by serial to parallel converter. The received DCO – OFDM symbols must be same as that of transmitted symbols. Extraction of cyclic prefix is done after symbol is received followed by Fast Fourier Transform (FFT). The output of FFT Block is:

$$X_n = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} x_K \exp\left(\frac{-j2\pi nK}{N}\right) \qquad (4)$$

Demodulation is then performed to recover transmitted data and BER analysis is done by comparing it to originally transmitted bits.

B. Flip OFDM

The Flip–OFDM system is as shown in Figure 3. Real OFDM signal generation is same as discussed in DCO –OFDM but here no DC Bias is added instead positive and negative part extraction is done from bipolar OFDM signal as:

$$x(K) = x^+(K) + x^-(K) \qquad (5)$$

The two components are then being sent separately on two consecutive symbols of OFDM. Positive component $x^+(K)$ is sent in first and then flipped component $-x^-$ (K) in second subframe . Cyclic prefixes which are composed of p samples are appended to each OFDM subframe. Hence, clearly negative subframes get delayed by (N+p) and follows positive subframe. The detection process at receiver takes place at Flip-OFDM Reciever Side as depicted in Fig 3.

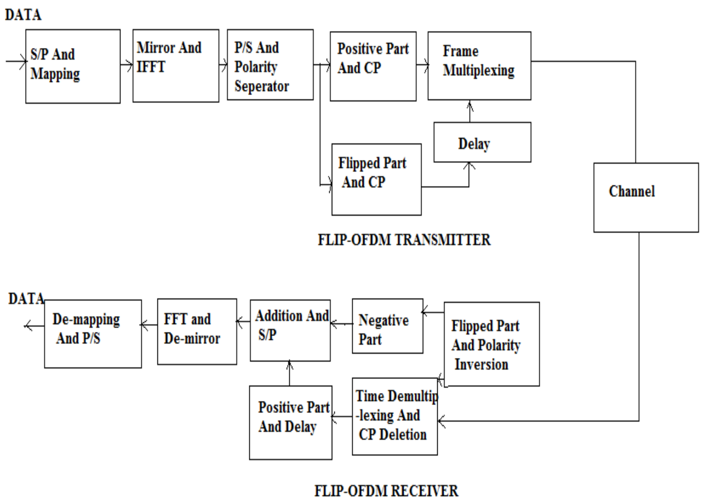

Figure.3. Flip-OFDM System Block

The frames resulting after positive and negative part extraction are given as:

$$x^+(K) = \begin{cases} x(K) & if \quad x(K) \geq 0 \\ 0 & otherwise \end{cases}$$

$$(6)$$

$$x^-(K) = \begin{cases} x(K) & if \quad x(K) \leq 0 \\ 0 & otherwise \end{cases}$$

Here K=1,2,3......,N

The cyclic prefixes from each subframe are removed at receiver side and reconstructed bipolar signal is given as

$$y(K) = y^+(K) - y^-(K) \qquad (7)$$

And $y^+(K)$, $y^-(K)$ represents positive and flipped frames .

III. Performance Estimation Of Two Optical OFDM Schemes (DCO, Flip)

Channel Description

This section describes Additive Gaussian Channel, and multipath (Rayleigh, Rician) Channels used in performance comparison between DCO and Flip.

In AWGN Channel Gaussian noise gets added with signal passing from it. Fading does not occur in this case but transmitted signal is distorted only by AWGN process.
The mathematical expression for received signal is defined as:

$$Y(t) = T(t) + N(t) \qquad (8)$$

Where Y (t) means the received signal, T(t) signifies transmitted signal and N(t) represents White Gaussian Noise (AWGN) [8]. Another important point about AWGN is that for all frequencies the amplitude frequency response of channel is flat and phase frequency response is linear. Thus modulated signal goes without any phase distortion and amplitude loss. In Rayleigh Channel Model multipath propagation leads to constructive and destructive interference as well as causes phase shifting of signal. Another main point is that between transmitter and receiver there is no direct path means there exists no line of sight. The received signal is given

$$r(n) = \sum h(n, \tau) S(n - m) + w(n) \qquad (9)$$

r(n) , h(n) signifies received signal and channel impulse response, w(n) means Gaussian noise with zero mean , unit variance. Rayleigh Distribution [9] is given by addition of non-dependent orthogonal variables whose pdf is:

$$n(z) = \frac{z}{\sigma^2} e^{\frac{-z^2}{2\sigma^2}} \qquad z \geq 0 \qquad (10)$$

here σ^2 denotes the mean power of received signal in time domain. Signal given by eq. (10) is basically Rayleigh random signal. Rician Channel has strong LOS between transmitter and receiver. Rician Distribution is denoted by k so called Rice factor,

$$k = \frac{n}{2\sigma^2} \qquad (11)$$

When K=0 the model becomes Rayleigh Model and K=∞ model reduces to AWGN Channel.

IV. SIMULATION RESULTS AND DISCUSSION

Simulation parameters chosen for DCO – OFDM and Flip-OFDM are:

Table .1. Simulation Parameters

Channel	Modulation	Parameter
AWGN	8 QAM , 16 QAM , 32 QAM , 64 QAM	SNR
Rician	DBPSK , BPSK , DQPSK , QPSK	Doppler Shift
Rayleigh	DBPSK , BPSK , DQPSK , QPSK	Doppler Shift

A. FOR AWGN CHANNEL

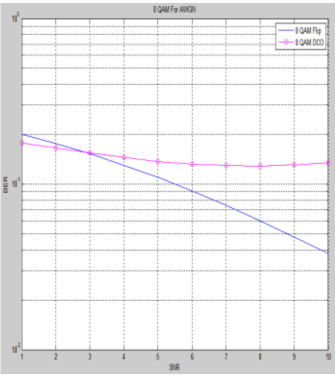

Figure.4. 8 QAM

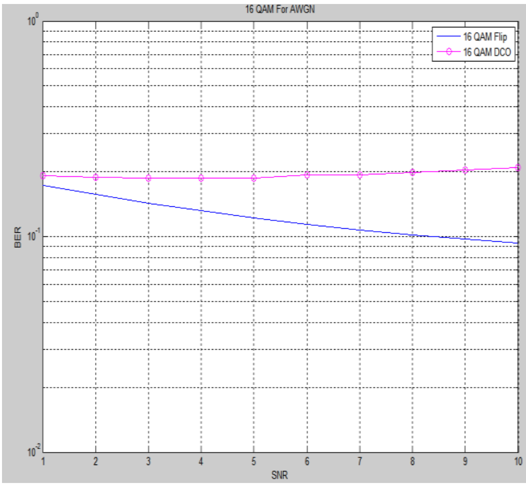

Figure.5. 16 QAM

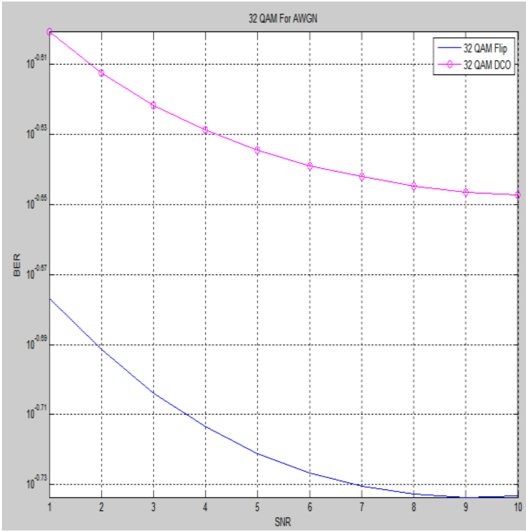

Figure.6. 32 QAM

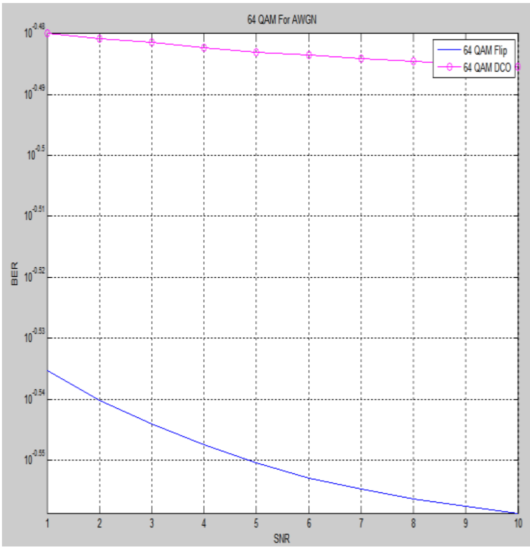

Figure.7. 64 QAM

The above figures are showing comparison of BER with respect to increasing SNR values. Different modulation schemes of QAM with order M = 8, 16, 32, 64 are taken for analysis. The results describe the fine approach taken for the analysis of Flip and DCO OFDM. This paper shows that with increasing SNR in the complete transmitter cum receiver system, BER reduces drastically for Flip OFDM as compared to DCO OFDM. So Flip is better in AWGN Channel. Another analysis in the results proves that with increasing order of M QAM performance degrades.

B. FOR RAYLEIGH CHANNEL

Table.2. BPSK using Rayleigh in DCO – OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.4952	0.4952	0.4952	0.4952	0.4952
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table .3. DBPSK using Rayleigh in DCO – OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.007663	0.007666	0.00766	0.007656	0.00766
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.4. QPSK using Rayleigh in DCO – OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.5178	0.5178	0.5178	0.5178	0.5178
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.5. DQPSK using Rayleigh in DCO-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.09093	0.09094	0.09094	0.09094	0.09093
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.6. BPSK using Rayleigh in Flip -OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.5077	0.5077	0.5077	0.5077	0.5077
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table .7. DBPSK using Rayleigh in Flip -OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.0966	0.0966	0.0966	0.0966	0.0966
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table .8. QPSK using Rayleigh in Flip –OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.4999	0.4999	0.4999	0.4999	0.4999
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.9. DQPSK using Rayleigh in Flip – OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.3099	0.3099	0.3099	0.3099	0.3099
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

C. FOR RICIAN CHANNEL

Table .10. BPSK using Rician channel for DCO- OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.4952	0.4952	0.4952	0.4952	0.4952
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table. 11. DBPSK using Rician for DCO-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.007663	0.007666	0.007666	0.007663	0.007663
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table .12. QPSK using Rician for DCO-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.5178	0.5178	0.5178	0.5178	0.5178
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.13. DQPSK using Rician for DCO-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.09092	0.09092	0.09092	0.09092	0.09092
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table .14. BPSK using Rician in Flip-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.5077	0.5077	0.5077	0.5077	0.5077
Trans mitted Bits	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$	$2.978*10^5$

Table.15. DBPSK using Rician in Flip-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.0966	0.0966	0.0966	0.0966	0.0966
Trans mitted Bits	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5

Table.16. QPSK using Rician in Flip-OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.4999	0.4999	0.4999	0.4999	0.4999
Trans mitted Bits	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5

Table .17. DQPSK using Rician for Flip –OFDM

	D.F.=1	D.F.=2	D.F.=3	D.F.=4	D.F.=5
Error Bits	0.3099	0.3099	0.3099	0.3099	0.3099
Trans mitted Bits	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5	2.978* 10^5

Phase Modulation is robust to Channel Fading hence in case of Fading Channels it is preferred. The above table describes the performance of OWC System under Rayleigh, Rician Channel with varying Doppler Frequency.

D. THE GRAPHS FOR COMPARISON

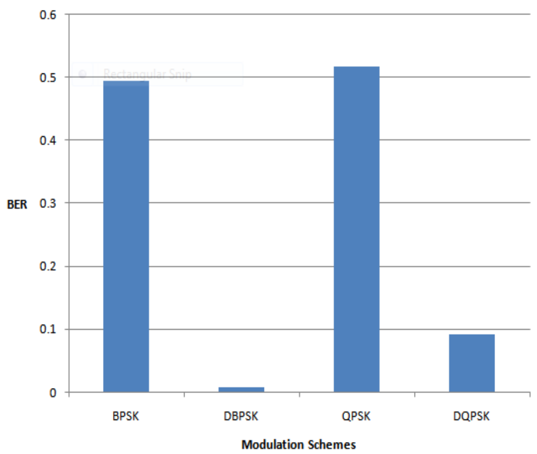

Figure.8. DCO with Rayleigh Channel

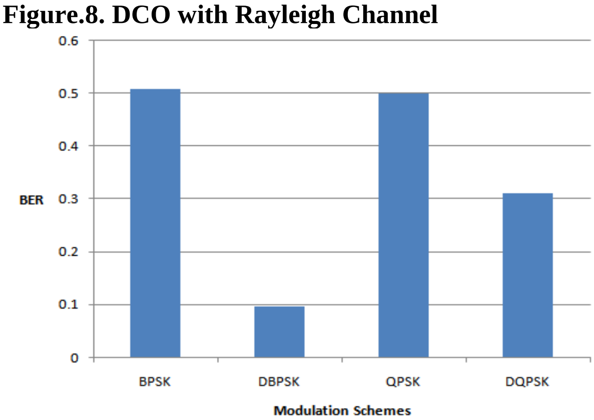

Figure.9. Flip with Rayleigh Channel

The other analysis from Fig 8, 9 shows that Fading introduced by Rayleigh Channel reduces drastically due to the use of Differential Schemes. BER increases as order of Modulation Schemes increases this is the reason that in DBPSK BER is less in both cases as compared to DQPSK.

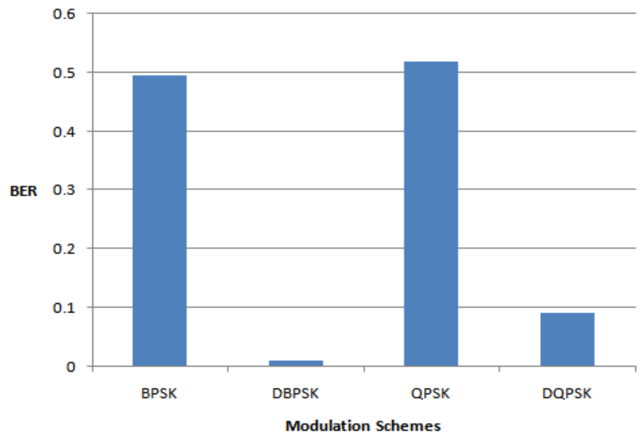

Figure.10. DCO with Rician Channel

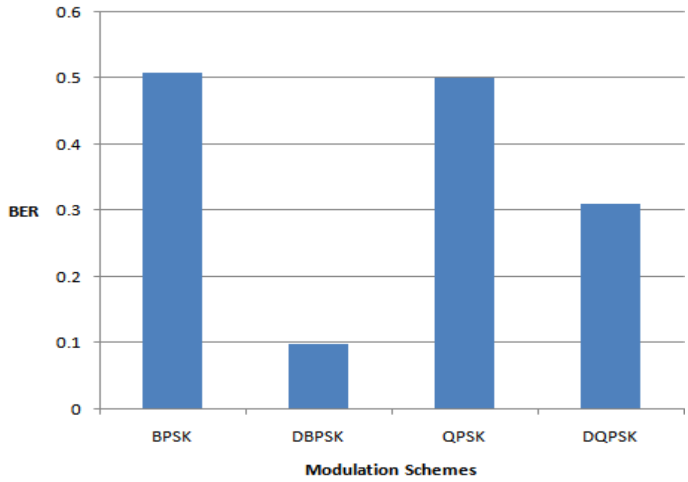

Figure.11. Flip with Rician Channel

Fig 10, 11 shows that Rician Channel in Optical-OFDM shows a similar trend as that of Rayleigh Channel. Differential Modulation Schemes as compared with their normal Schemes shows drastic decrease in BER and BER is increasing as the order of Differential Modulation Scheme is raised.

V. CONCLUSION

This paper has shown all possible combinations of channels that are available for all types of simulation scenario that could be developed using MATLAB/ SIMULINK 2013a version. The possibility of expanding this research work based on visible light communications is to expand the feasibility of this work in a real time scenario. After a lot of simulations conducted under a lot of challenges, the paper demonstrates that such techniques of Optical Wireless Communication Systems are best suited at low power and out of two different types of Optical OFDM, i.e., DCO OFDM and Flip OFDM, in AWGN Channel with all possible modulation techniques the results are show casing a significant amount of improvement in BER results in Flip OFDM. Similarly if the Fading Channels are taken results evaluated in tables above has shown that both Flip OFDM and DCO OFDM both performs better using Differential PSK schemes, thus the utilization of both schemes has shown a lot of scope towards its applications in low cost and high complexity environment.

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