

4.1 Introduction

To utilize the properties of OFDM in VLC without requiring of DC-biasing, ACO-OFDM is used. For ACO-OFDM, the time-domain signal is made unipolar by simply clipping the negative part, which does not need a large DC bias. Only odd subcarriers are modulated by signals, while even subcarriers are vacant.

In this chapter Matlab software was used to simulate the performance of the BER of the ACO-OFDM system in the presence of double-sided signal clipping and AWGN.

4.2 System Assumption

The parameters and assumptions considered in the simulation are shown in Table 4.1. The system accuracy of the derived expression for the effective electrical SNR per bit in VLC-OFDM with double side clipping is verified by means of a Monte Carlo BER simulation. No clipping at the receiver is assumed. A ZF equalizer was used.

Table 4.1: Simulation Parameter

IFFT/FFT size	2048
Minimum optical power $P_{Tx,min}$	90mW
Maximum optical power $P_{Tx,max}$	400 mW
Average transmitted power $P_{Tx,mean}$	100 mW
path gain coefficient $g_{h(opt)}$	1
Biasing power $P_{Tx,bias}$ case one	95 mW
Biasing power $P_{Tx,bias}$ case two	50 mW
Spectral efficiency G_B	0.5
Modulation	QAM,16-QAM,64-QAM
Effective electrical SNR per bit $\Gamma_{b(elec)}$	0 : 50

4.3 System Flowchart

The System Flowchart is presented in Figure 4.1. The user enters the LED parameter ($P_{Tx,max}$, $P_{Tx,min}$) . For a specific IFFT/FFT, QAM modulation constellation, and $P_{Tx,bias}$,the clipping levels($\lambda_{bottom}, \lambda_{top}$) and the $P_{Tx,mean}$ are calculated. The system will check the value of the λ_{bottom} ,if it is greater than zero, then the following parameters will be calculated; the signal variance, noise variance, clipping noise, effective electrical SNR per bit ($\Gamma_{b(elec)}$), and the BER .

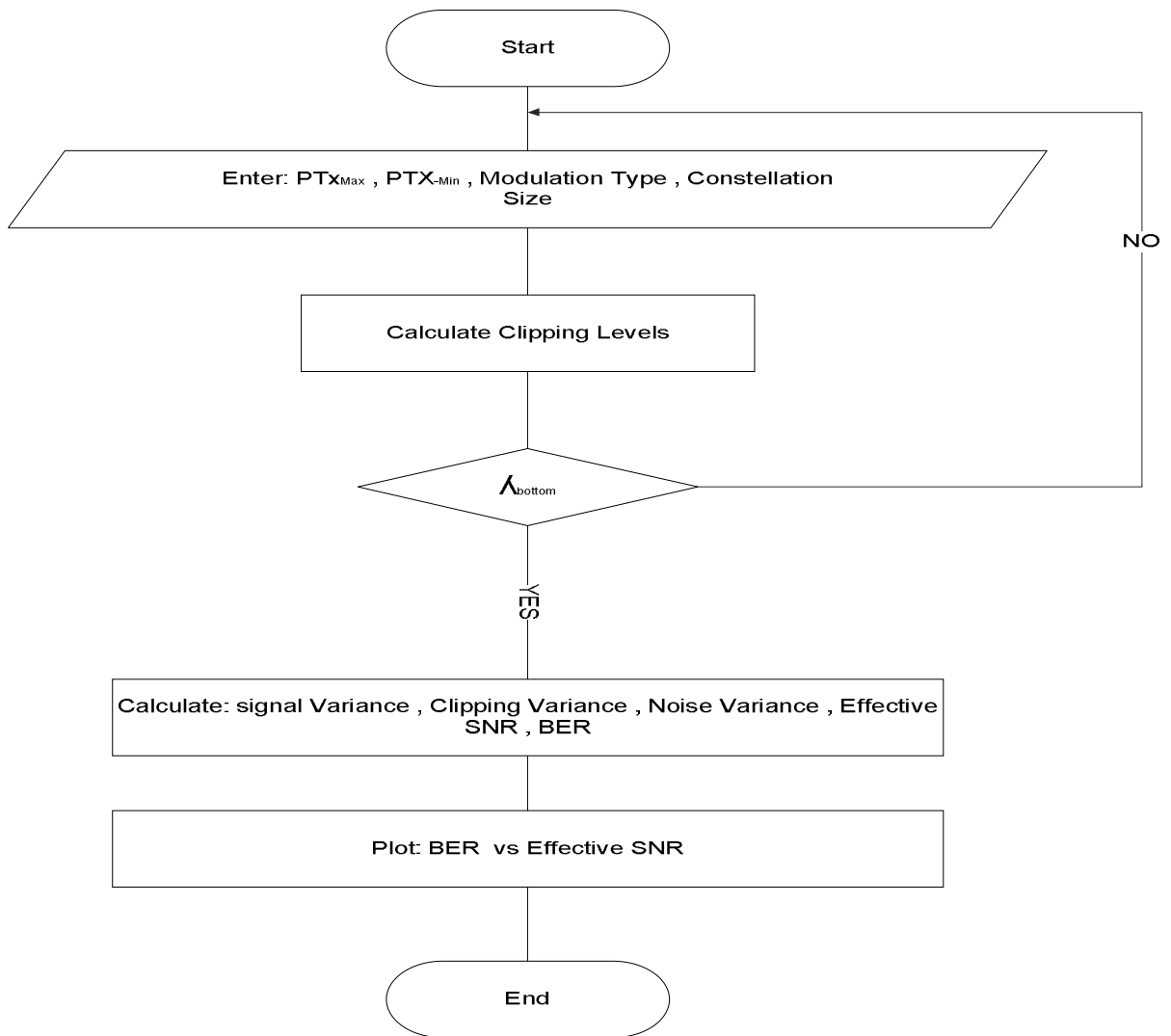


Figure 4.1: ACO-OFDM Flow Chart

4.4 Results and Discussion

The BER performance of the ACO-OFDM system in the presence of double-sided signal clipping and AWGN depends on the granularity of the constellation. An analytical expression for the BER performance of M -QAM ACO-OFDM can be expressed as

$$\text{BER} = \frac{4(\sqrt{M}-1)}{\sqrt{M} \log_2(M)} Q\left(\sqrt{\frac{3 \log_2(M)}{M-1}} \Gamma_{\text{b(elec)}}\right) + \frac{4(\sqrt{M}-2)}{\sqrt{M} \log_2(M)} Q\left(3\sqrt{\frac{3 \log_2(M)}{M-1}} \Gamma_{\text{b(elec)}}\right) \quad (4.1)$$

Where

$\Gamma_{\text{b(elec)}}$ is the effective electrical SNR per bit.

$Q(.)$ is the complementary cumulative distribution function (CCDF).

M is modulation constellation size.

To investigate the effect of the clipping noise on the BER performance three different scenarios were carried out when the clipping noise was ignored and when it is exist. In Scenario One, two cases with different QAM modulation constellation size $M = [4, 16, 64]$ and have been compared. In the first case $P_{\text{Tx,bias}} \geq P_{\text{Tx,min}}$ and in the second case where $P_{\text{Tx,bias}} < P_{\text{Tx,min}}$. The average optical power constrain is chosen to be $P_{\text{Tx, mean}} = 100$ mW. According to the result of the comparison in scenario one, the best case was chosen. In scenario two, the BER performance is presented for best case with different biasing power. The average optical power constrain was $P_{\text{Tx, mean}} = 100$ mW. In scenario three, the BER performance is presented for best case. In this scenario the constellation size was $M=4$ and the biasing to zero biasing, while, the power transmitted was varied.

Scenario One:

In the absence of clipping noise

1. Case A:

In this case, the BER performance of the studied ACO-OFDM system was presented for two cases (sufficient forward biasing and insufficient forward biasing) with different QAM modulation constellation size $M = [4, 16, 64]$ and have been compared. In the first case (sufficient forward biasing) $P_{Tx,bias} \geq P_{Tx,min}$ and in the second case (insufficient forward biasing) $P_{Tx,bias} < P_{Tx,min}$. The average optical power constrain is chosen to be $P_{Tx, mean1} = 100$ mW.

A) QAM

Figure 4.2 shows the BER performance ACO-OFDM with QAM

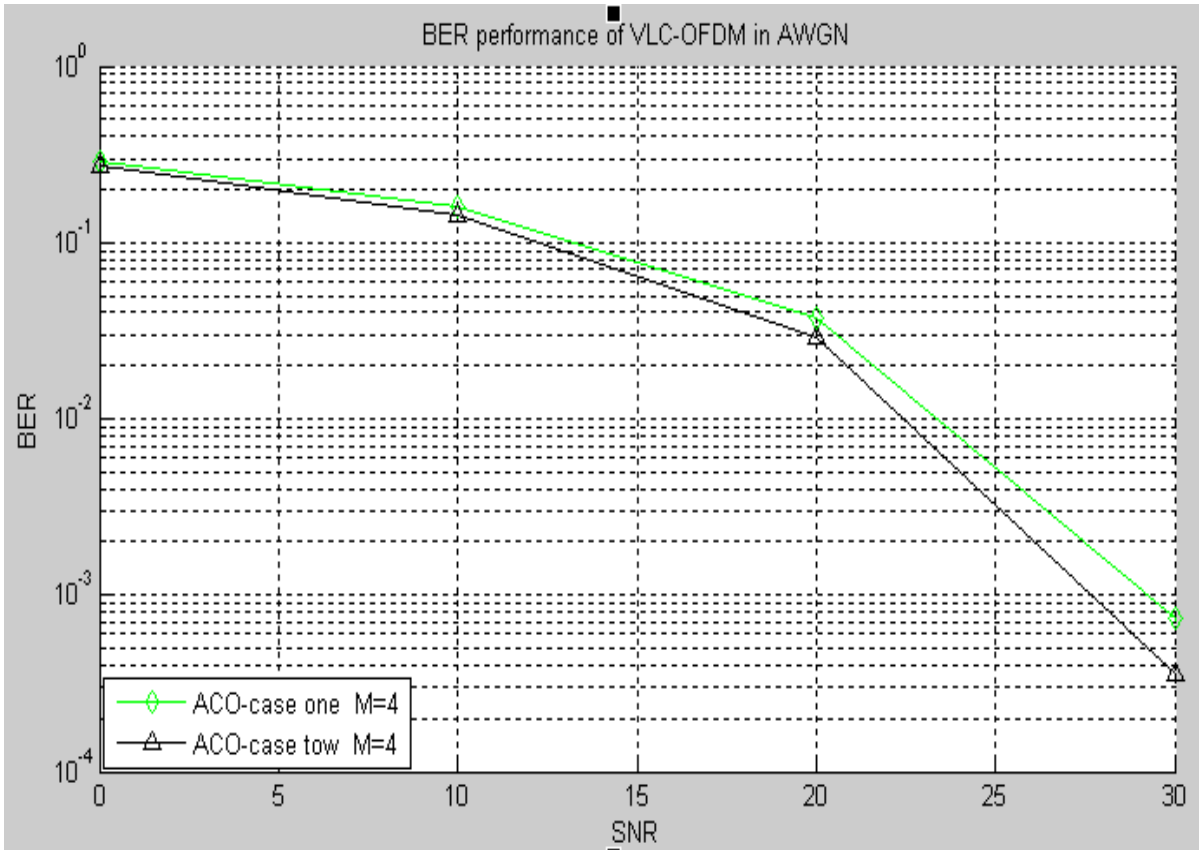


Figure 4.2: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with QAM modulation.

Figure 4.2, compares the two cases of ACO-OFDM. It is obvious from the figures that the BER in case two (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$) is better than in case one ($P_{Tx,bias} \geq P_{Tx,min}$).

B) 16-QAM

Figure 4.3 shows the BER performance ACO-OFDM with 16-QAM

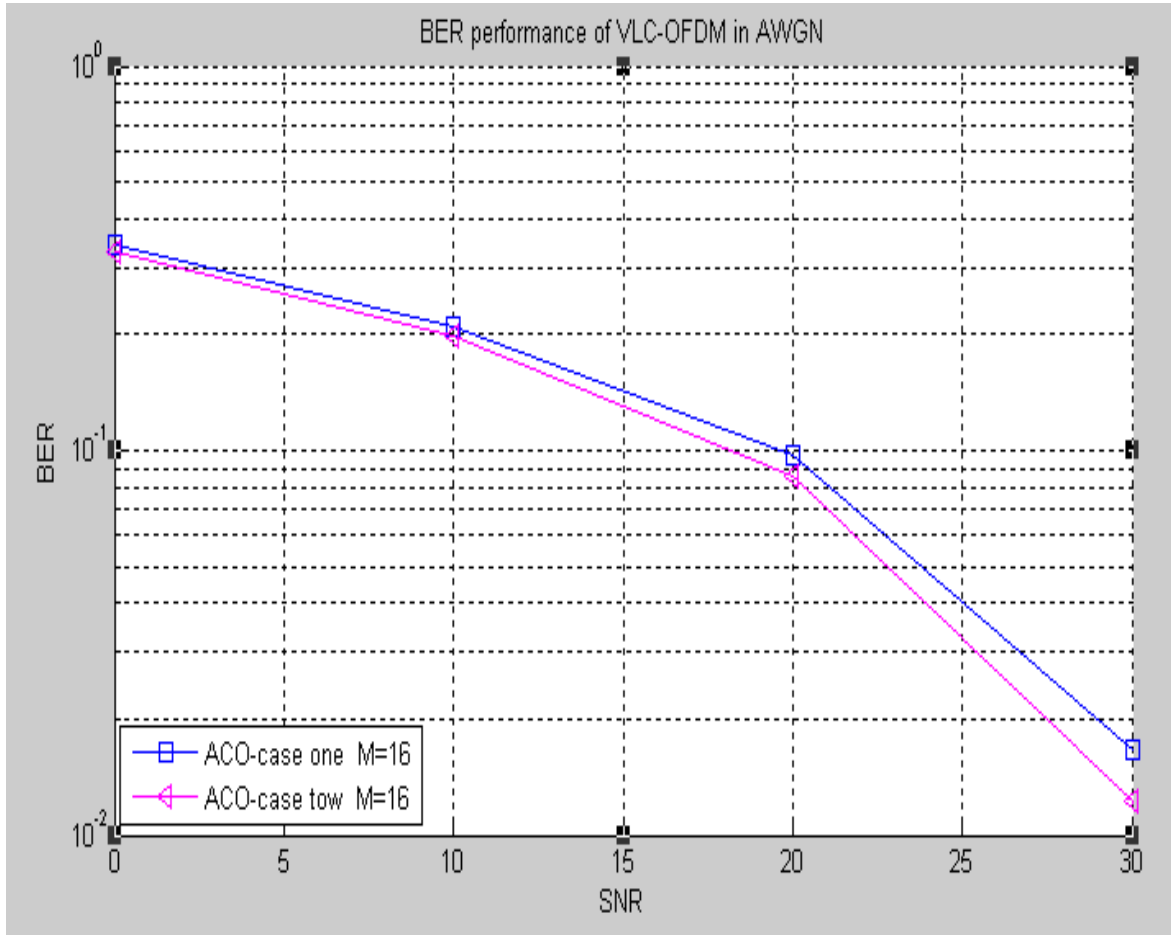


Figure 4.3: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with 16-QAM modulation.

Figure 4.3 is also a comparison between the two cases of ACO-OFDM but with different QAM constellation size [$M=16$]. It shows that using 16-QAM increases the BER of the system (in sufficient forward biasing 9% and in the insufficient forward biasing 5%) compared to Figure 4.2 when $M=4$ was used.

C) 64-QAM

Figure 4.4 shows the BER performance ACO-OFDM with 64-QAM

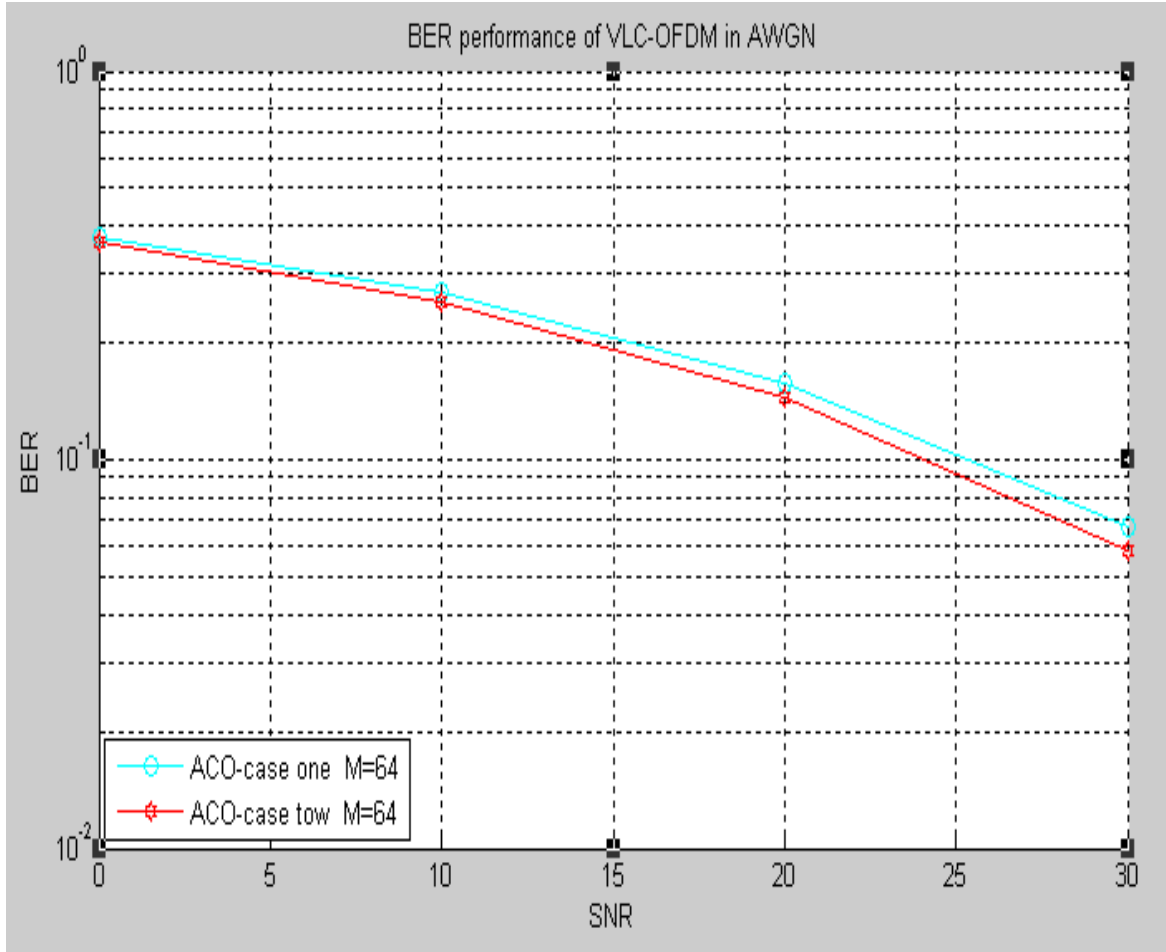


Figure 4.4: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with 64-QAM modulation.

Figure 4.2, 4.3, and 4.4 compares the two cases of ACO-OFDM. It is obvious from the figures that the BER in in case two (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$) is better than in case one ($P_{Tx,bias} \geq P_{Tx,min}$). Also it was noticed that using a higher-order modulation exhibit higher error-rates.

2. Case B:

The previous scenario, show that the BER performance of the insufficient forward biasing case (case two) is better than the sufficient forward biasing case (case one). In this scenario, the BER performance is presented for case two with different biasing power. The average optical power constrain was $P_{Tx, \text{mean}} = 100 \text{ mW}$

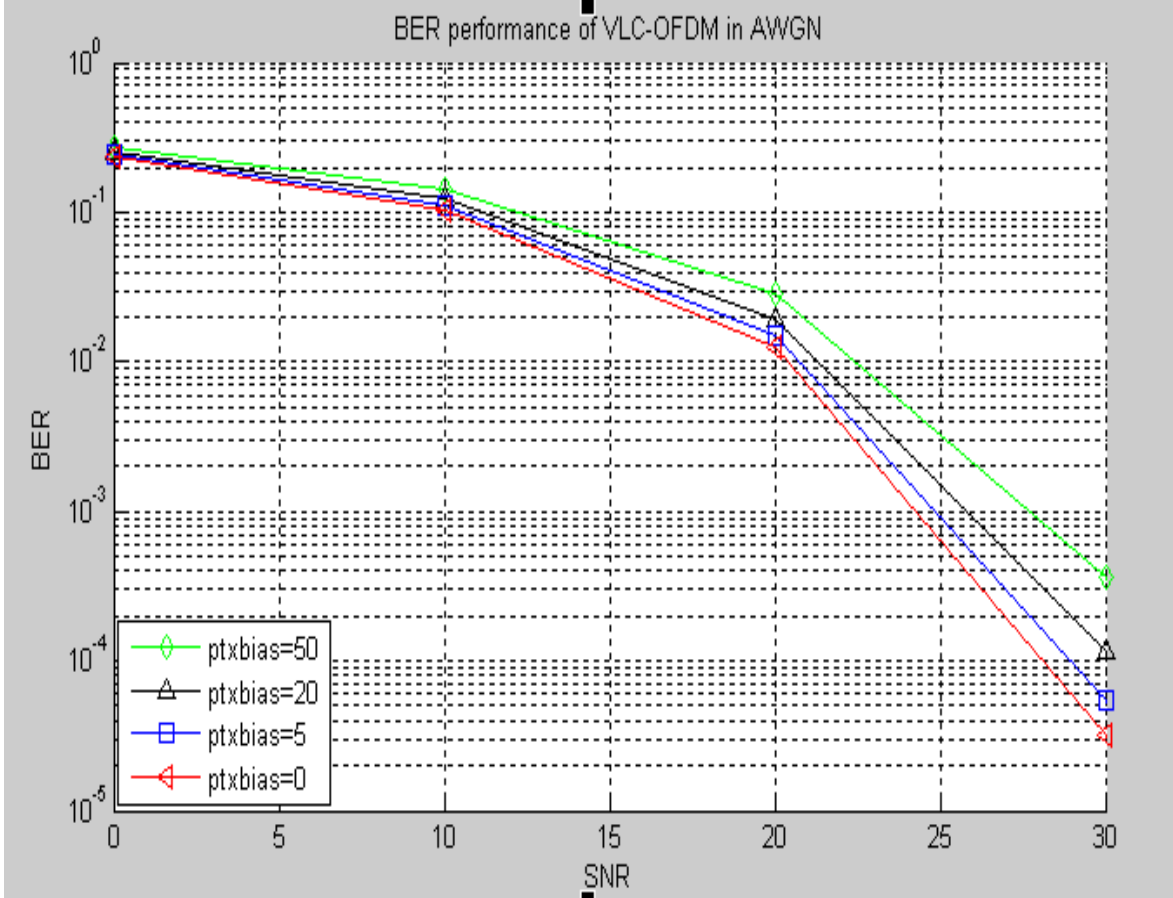


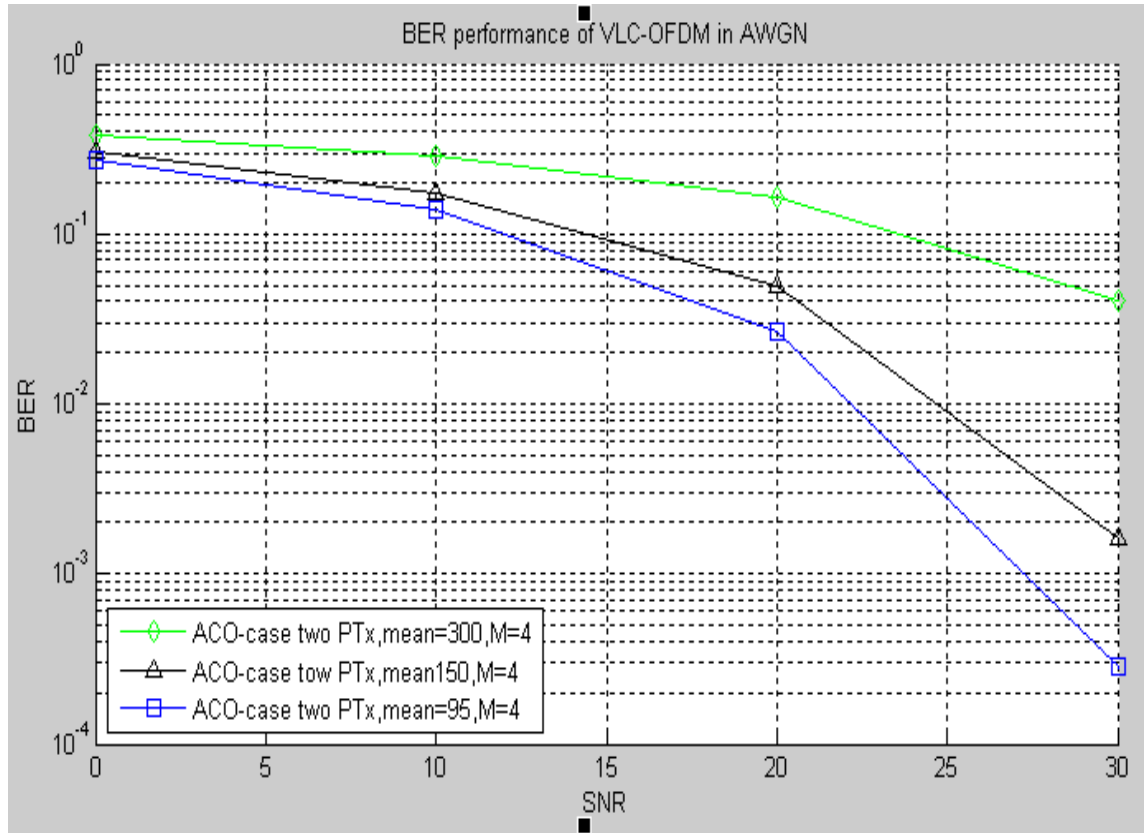
Figure 4.5: BER versus SNR ($\Gamma_{b(\text{elec})}$), for ACO-OFDM with different biasing power

Figure 4.5 compares the different ptx_bias (50, 20, 5, and 0) mW of case two (insufficient forward biasing where $P_{Tx, \text{bias}} < P_{Tx, \text{min}}$) in terms of BER and QAM modulation technique. The results showed that the biasing power affect in the BER performance and lower biasing case gives lower error rate and the zero biasing achieves the best BER.

3. Case C:

In this scenario, the BER performance of the studied ACO-OFDM system is presented for the second case (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$). In this scenario the constellation size was 4 and the biasing to zero biasing, while, the power transmitted was varied.

Figure 4.6 BER versus SNR ($\Gamma_{b(elec)}$), for ACO-O



ACO-OFDM with different power transmitted and zero biasing

Figure 4.6 compares the QAM ACO-OFDM with different power transmitted and zeros biasing. The results showed that the for a dynamic range of LED between $p_{tx,max}$ and $p_{tx,min}$ since the average transmitted power increased the error rate increased.

Scenario Two:

When the clipping noise exist.

1. Case A:**A) QAM**

Figure 4.8 shows the BER performance ACO-OFDM with QAM

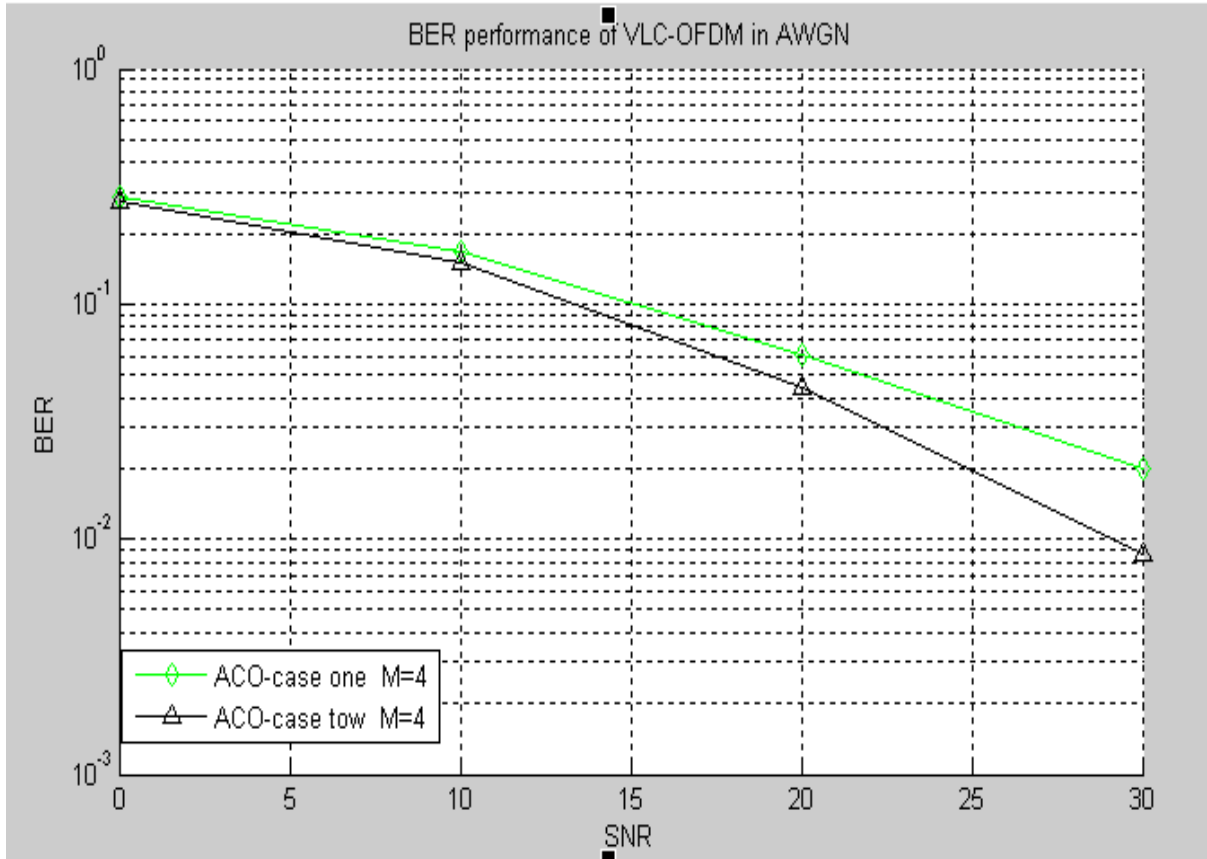


Figure 4.8: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with QAM modulation and with clipping noise .

The BER performance ACO-OFDM with QAM and no clipping noise Shown in figure 4.8. As in case one scenario one it is obvious from the figure that the BER in case two (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$) is better than case one ($P_{Tx,bias} > P_{Tx,min}$). But if it is

compared to figure 4.2 it is obvious that the BER in the case of absence of clipping noise is better than the one with clipping noise.

B) 16-QAM

Figure 4.9 shows the BER performance ACO-OFDM with 16-QAM and no clipping noise

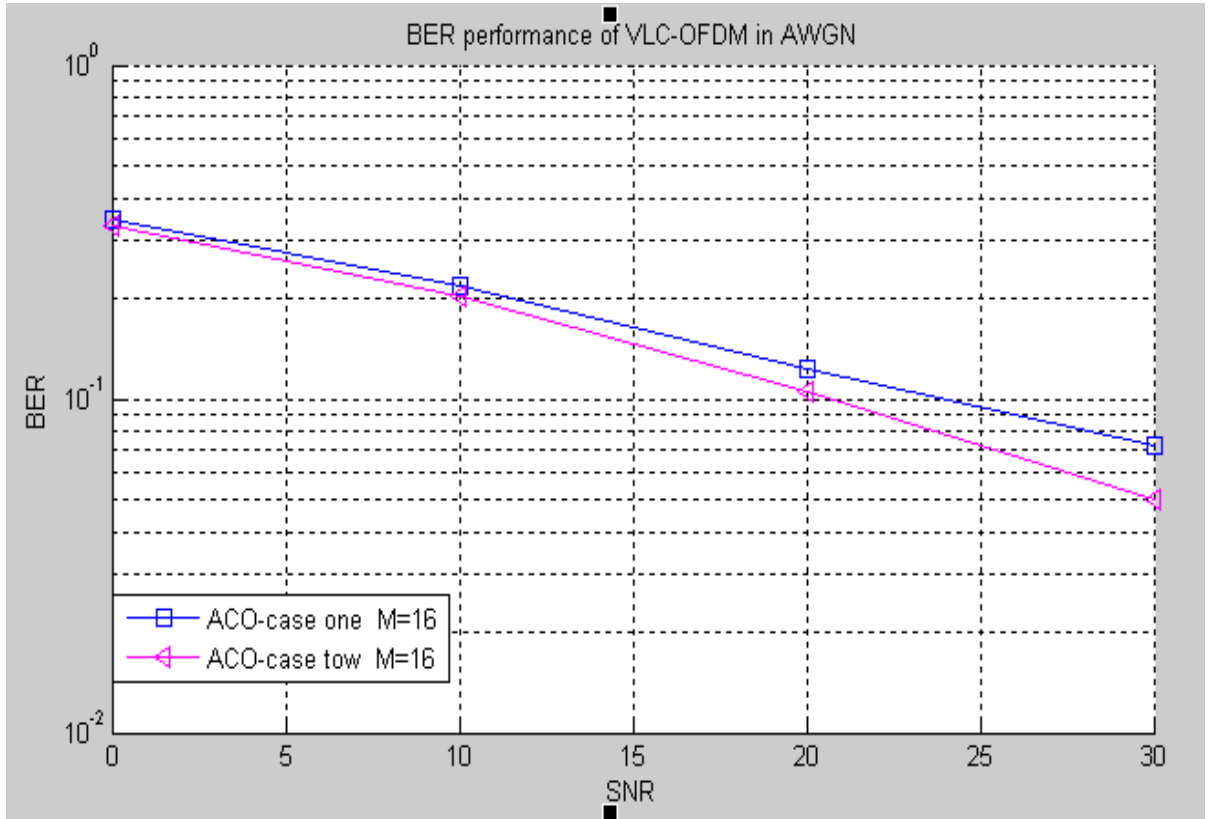


Figure 4.9: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with 16-QAM modulation and zero clipping noise .

Figure 4.9, shows the same result as figure 4.3 and that the BER in case two is better than case one and when using higher order modulation the error rate well increased but if the two figures had compared it found that the BER when the clipping noise had ignored is better than when it is exist.

C) 46-QAM

Figure 4.8 shows the BER performance ACO-OFDM with 46-QAM and no clipping noise

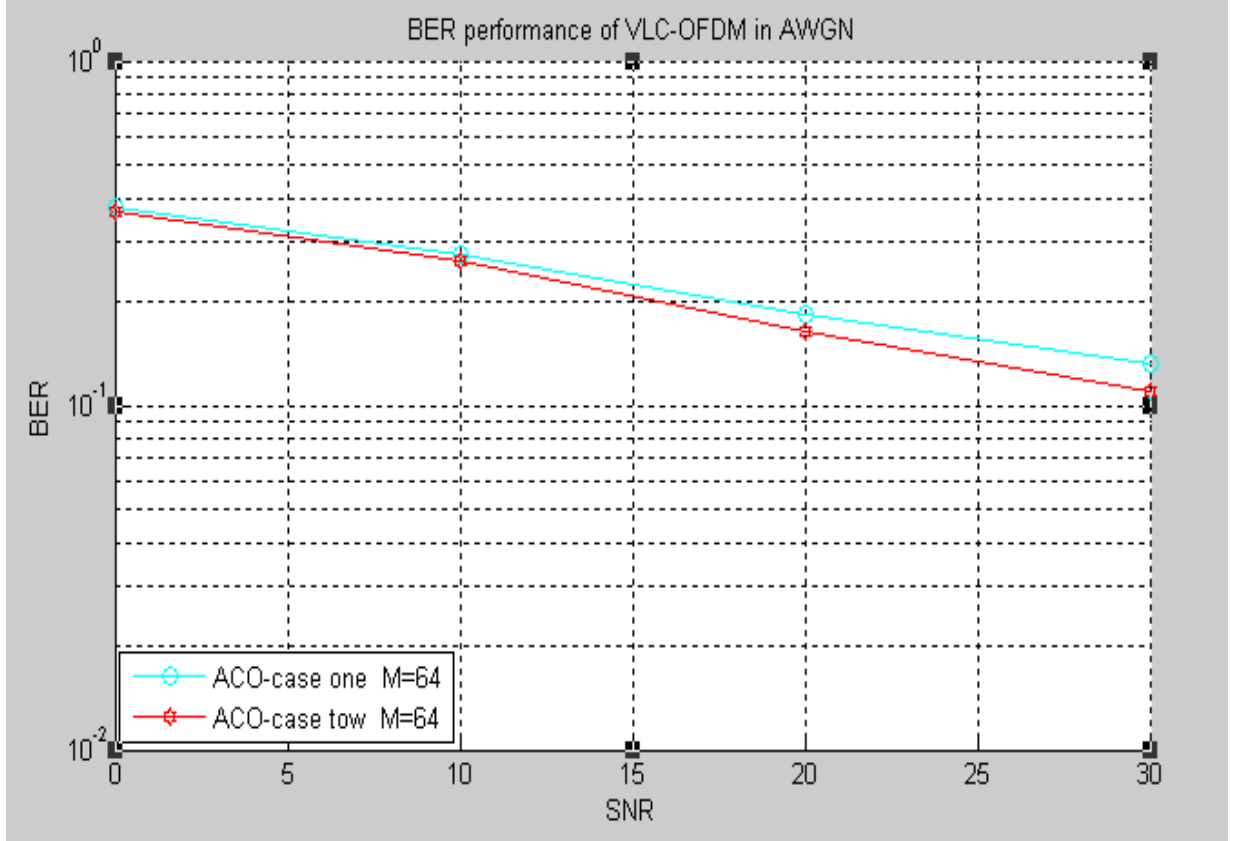


Figure 4.10: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with 64QAM modulation and with clipping noise.

Figure 4.8, 4.9, and 4.10 compares the two cases of ACO-OFDM where clipping noise was ignored. It is obvious from the figures that the BER in case two (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$) is better than case one ($P_{Tx,bias} > P_{Tx,min}$) and also it was noticed that using a higher-order modulation exhibit higher error-rates .and it is obvious that the error rate in figure 4.3, 4.2 and 4.1 when the clipping noise was ignored is better than the figures where the clipping noise exist.

4.4.2.2 Case B:

Figure 4.8 shows the BER performance ACO-OFDM with different biasing power and with clipping noise

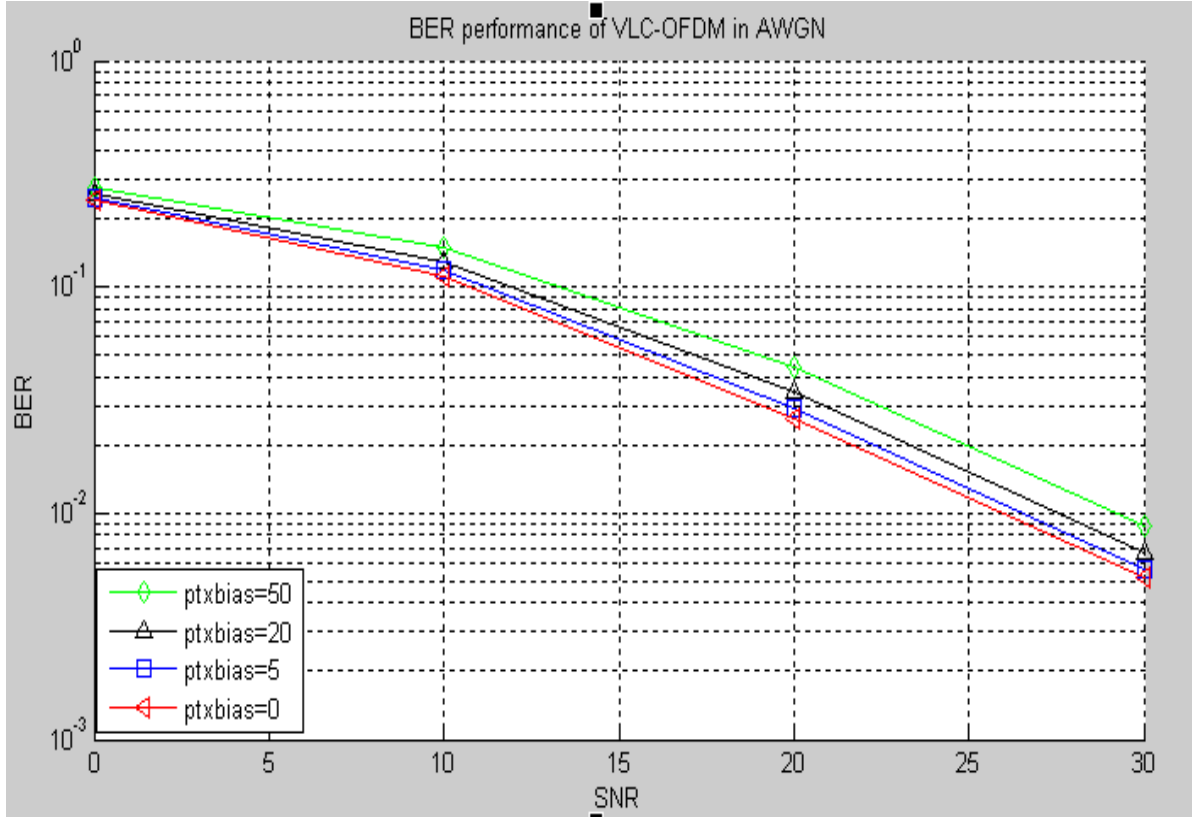


Figure 4.11: BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with different biasing power and with clipping noise

Figure 4.11 compares the different ptx_bias (50, 20, 5, and 0) mW of case two (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$) in terms of BER, QAM modulation technique and with clipping noise. The results showed that the biasing power affects the BER performance and lower biasing case gives lower error rate and the zero biasing achieves the best BER. But if we compare it with figure 4.4 where clipping noise was ignored it is obvious that the error rate increased by clipping noise.

4.4.2.3 Case C:

Figure 4.12 show the BER performance of the studied ACO-OFDM system for the second case (insufficient forward biasing where $P_{Tx,bias} < P_{Tx,min}$), QAM modulation, the biasing to zero biasing and with clipping noise , while the power transmitted was varied.

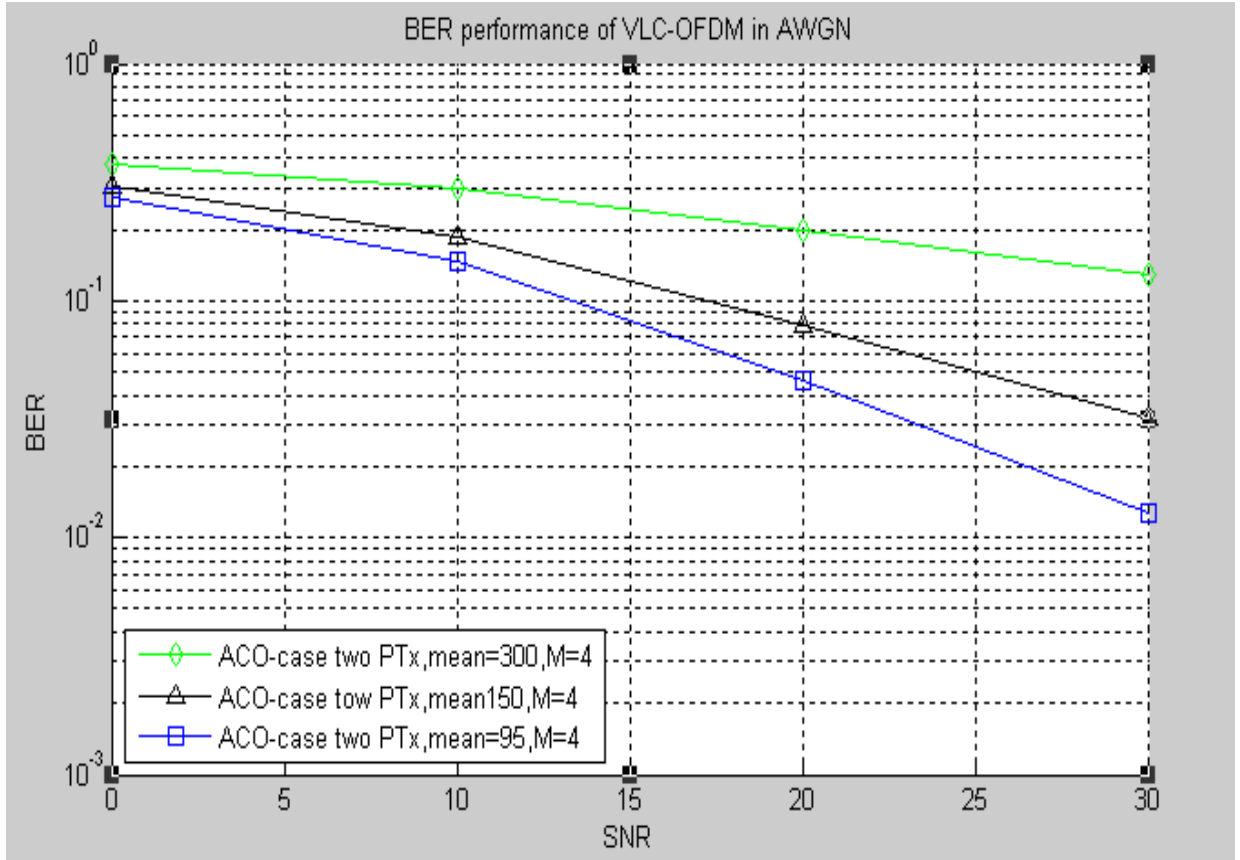


Figure 4.12 BER versus SNR ($\Gamma_{b(elec)}$), for ACO-OFDM with different power transmitted ,zero biasing and with clipping noise

Figure 4.12 shows the BER performance ACO-OFDM with different transmitted power and with clipping noise. The figure show that for a dynamic range of LED between $p_{tx,max}$ and $p_{tx,min}$, a lower average optical power with respect to the given dynamic range is more suitable and give lower error rate. And if it compared to figure 4.5 it is cleared that the BER when the clipping noise was ignored is better than when it exist.

The BER performance of the ACO-OFDM had been studied in tow cases and different scenarios. In the first case, the BER performance in the present of clipping noise was discussed. In the second case, the clipping noise had been ignored. It is found that, that the BER performance of ACO-OFDM is more severely degraded with the increase of the modulation order for a particular double-sided signal clipping scenario, the clipping noise affects in the BER performance and ACO-OFDM is more suitable for applications with lower radiated average optical power.