Faculty of Engineering – Cairo University

Electronics and Electrical Communications Engineering Department

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Assignment #2

Optical OFDM

Submitted to

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BER Graph

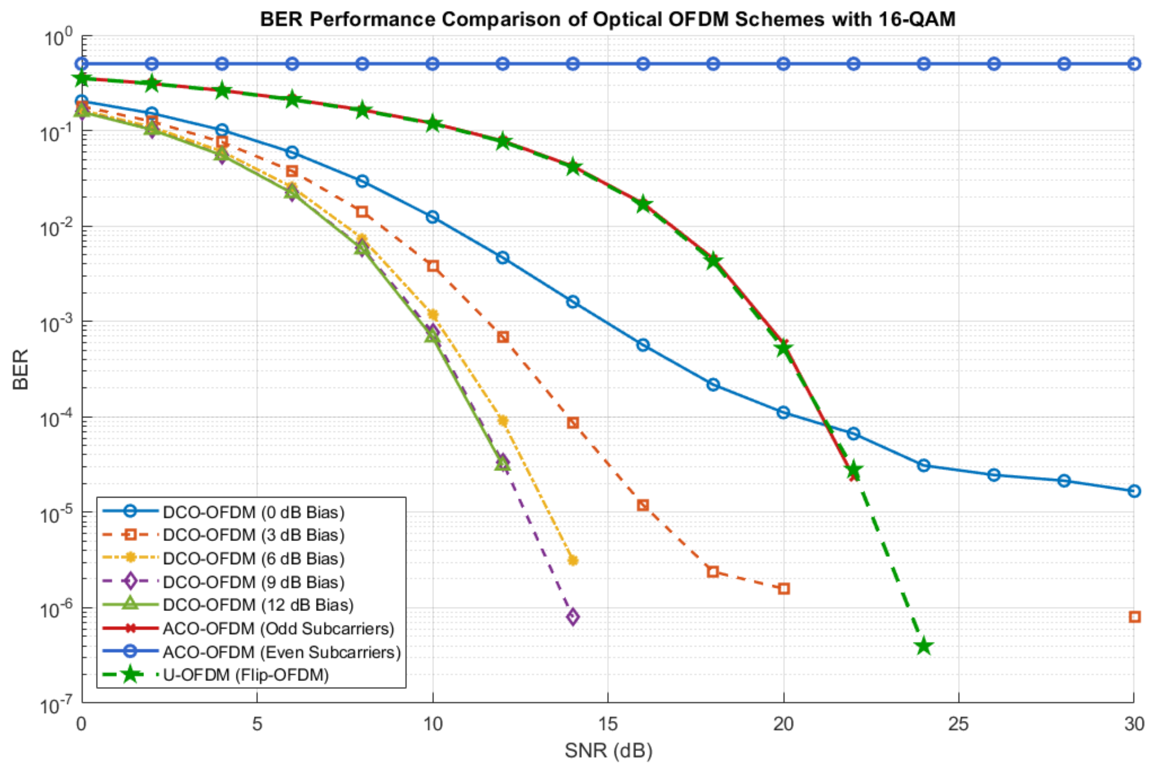

Figure 1 - BER vs SNR curves of the DCO-OFDM, the ACO-OFDM, and the U-OFDM.

- <u>**Comments**</u>

→ The BER curves for the ACO-OFDM and the U-OFDM are similar to each other, due to their equivalent SNR, as they have the same power efficiency.

→ And their BER performance is higher than the BER performance of the DCO-OFDM, because DCO-OFDM modulates all subcarriers, giving full spectral efficiency, while ACO-OFDM only modulates odd subcarriers, which makes the time-domain signal anti-symmetric, hence, the signal's energy is concentrated in half the subcarriers, reducing effective SNR per bit.

- **How the DC-bias value affect the BER of the DCO-OFDM and why?**

→ At higher levels of DC-bias, the BER performance of the DCO-OFDM decreases, because then clipping noise is neglected, as most of the negative components avoid the clipping, hence clipping noise is less.

→ Also, at higher levels of DC-bias, the SNR of DCO-OFDM for a certain BER is approximately equal to the SNR of bipolar OFDM plus the bias level in dB.

- **Analysis of how to get the RMS of the OFDM symbol**

- **Plot of the BER vs the power-efficiency of the DCO-OFDM for each DC bias value**

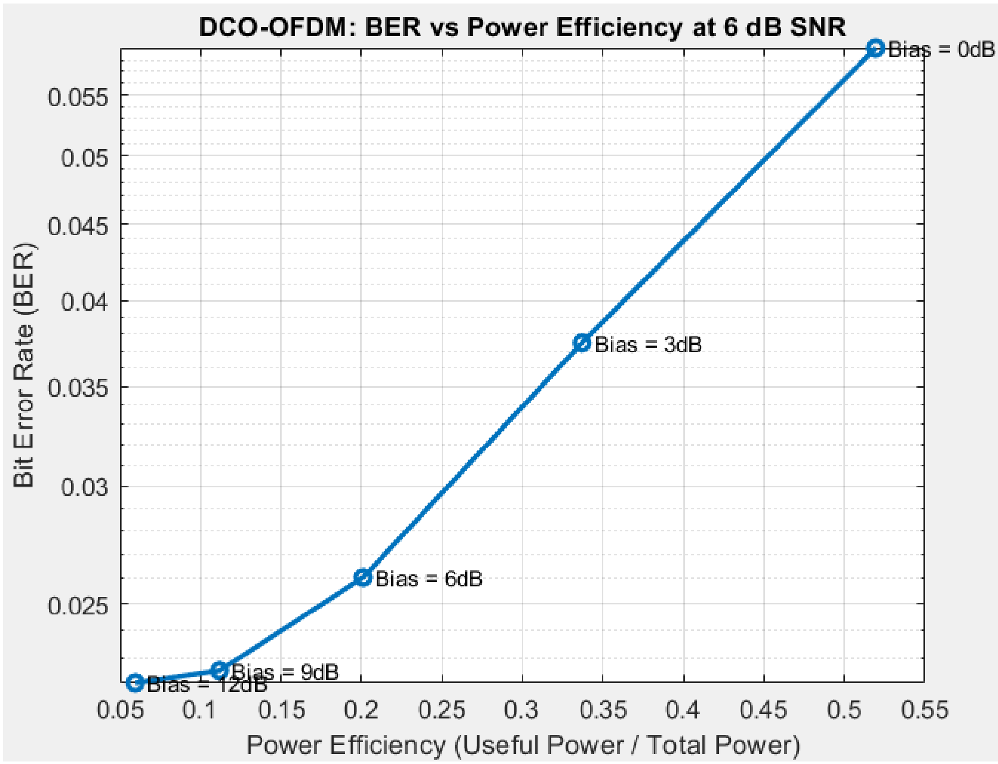

Figure 2 - BER of DCO-OFDM vs power-efficiency for bias values when SNR=6dB.

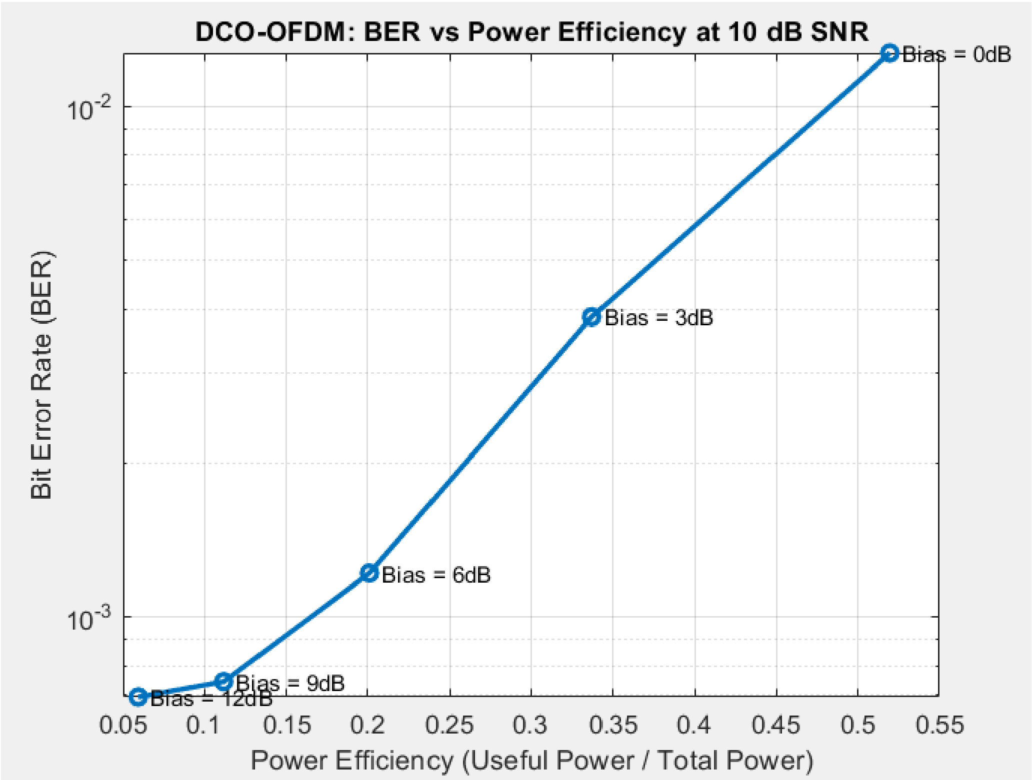

Figure 3 - BER of DCO-OFDM vs power-efficiency for bias values when SNR=10 dB.

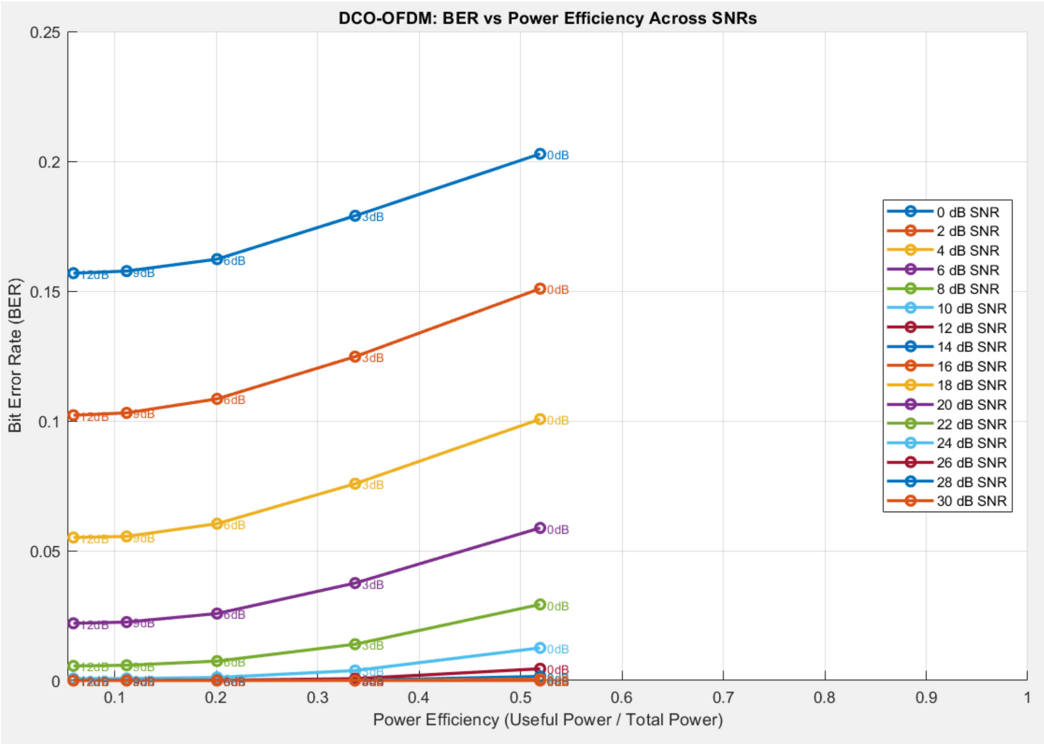

Figure 4 - BER of DCO-OFDM vs power-efficiency for bias values for SNR values.

- **What DC bias value would you use and why?**

→ I would choose bias= 6dB. Obviously from the graphs increasing the bias will decrease the power efficiency but achieve good BER (reliable communication).

→ As shown in Figure.4 the DC bias of 6 dB achieves good BER for different SNR values, also the power efficiency is suitable comparing to other bias values' performance.

→ As noticed in Figures 2, 3, and 4: low DC bias (0 dB) achieves high power efficiency≈52% due to sending the symbols with the least DC power added but it causes high BER, while high bias achieves low BER but costs much more power consequently unacceptable low power efficiency≈5% in case bias=12dB.

→ Compromise done between reasonable power efficiency and low BER leads to choosing DC bias 6 dB to achieve good performance for SNR values as shown in Figure.4.

→ If choosing the lowest BER is prioritized over the power efficiency, we can choose DC bias of 9 dB as it offers approximately as good BER as DC bias=12 dB but the power efficiency is much better.

- **How much does this value cover of the Gaussian distribution of the samples?**

→ $x \sim \mathcal{N}(0, \sigma^2)$, add a DC bias of $k\sigma$ becomes: $x' = x + k\sigma$

→ The objective is to know how many samples still negative after DC bias $Q(k)$ (clipped samples), to know the cover of Gaussian distribution of the samples $\Phi(z)$.

→ For DC bias=6dB→ $\mathrm{k} = 10^{\frac{6}{20}} \approx 2$

→ $P(\frac{x}{\sigma} < -k) = Q(k) \quad , Q(k) = \frac{1}{\sqrt{2\pi}} \int_{k}^{\infty} e^{-\frac{t^2}{2}} dt$

→ $P(x < -k\sigma) = \Phi(-k) = Q(k) \quad , \Phi(z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{z} e^{-\frac{t^2}{2}} dt$

→ $Q(k) = 1 - \Phi(k)$= $Q(2) \approx 0.0228 \rightarrow \ \Phi(z) \approx 1 - 0.0228 \approx 0.9772$

→ **Non-clipped** % $= \mathbf{100} \times \left(\mathbf{1} - \boldsymbol{Q(k)}\right) = \mathbf{97.72}$%

→ Same done for:

→ DC bias=0 dB→ $\mathrm{k} = 10^{\frac{0}{20}}$=1 → Non-clipped % $= 100 \times \left(1 - Q(k)\right) = 84.13\%$

→ DC bias=3 dB→ $\mathrm{k} = 10^{\frac{3}{20}} \approx 1.41$ → Non-clipped % $= 100 \times \left(1 - Q(k)\right) = 92.07\%$

→ DC bias=12 dB→ $\mathrm{k} = 10^{\frac{12}{20}} \approx 4$ → Non-clipped % $= 100 \times \left(1 - Q(k)\right) = 99.9\%$

→ So, the most reasonable bias is 6dB considering both BER and power efficiency.

- **Explanation of the chosen modulation order of the QAM**

→ In DCO-OFDM, all subcarriers are used to carry data, while in ACO-OFDM, only odd subcarriers are modulated, so because ACO-OFDM transmits data on only half of the subcarriers, then we must double its modulation order to have the same average bit rate as

DCO-OFDM, which means if DCO-OFDM uses QPSK (sending 2 bits per symbol), then ACO-OFDM should use 16-QAM (sending 4 bits per symbol), to compensate for lost subcarriers.

→ This should be done to achieve fair comparison between the DCO-OFDM and ACO-OFDM, and make them both have the same bit rate or throughput.

→ DCO-OFDM → 2 bits per symbol → one channel use → 2 bits per channel use.

→ ACO-OFDM, U-OFDM→ 4 bits per symbol → 2 channel uses→ 2 bits per channel use.

→ So we have a trade-off between the power and BW, ACO-OFDM is more power-efficient (no DC bias) but less spectrally efficient, and vice versa for the DCO-OFDM.

- **Comparison of the BER of the two cases of the ACO-OFDM**

- **Comparison of U-OFDM and ACO-OFDM**
  - **Power Efficiency**

→ They both have the same power efficiency, as both do not use DC bias.

→ Power efficiency of both is high.

→ ACO-OFDM generates a bipolar signal with only odd subcarriers modulated. And due to anti-symmetry, clipping negative parts at zero does not distort the data, and no DC bias is needed. This results in high power efficiency.

→ U-OFDM splits the positive and negative components of the bipolar signal and transmits them in two frames, avoiding clipping or DC bias.

  - **Spectral efficiency**

→ The first half in each one is due to the Hermitian symmetry, since we use it in each one to ensure signal is real, because this is an intensity modulation for optical systems, so it should be real.

→ ACO-OFDM only modulates odd subcarriers, hence another half of the signal is not modulated, which explains reducing the spectral efficiency with the other half.

→ U-OFDM uses and modulates all the subcarriers, but transmits them in two consecutive OFDM symbols, hence signal in time becomes longer, so time-domain efficiency is halved, not the spectral efficiency.

→ Hence, U-OFDM has higher spectral efficiency than ACO-OFDM.

ACO-OFDM	U-OFDM
$SE_{ACO} = \frac{1}{2} * \frac{1}{2} * \#bit/symbol$	$SE_{U} = \frac{1}{2} * \#bit/symbol$

MATLAB Code
