COMMUNICATIONS

MODULATION SCHEMES

1 BER of Each modulation method

1.1 BPSK

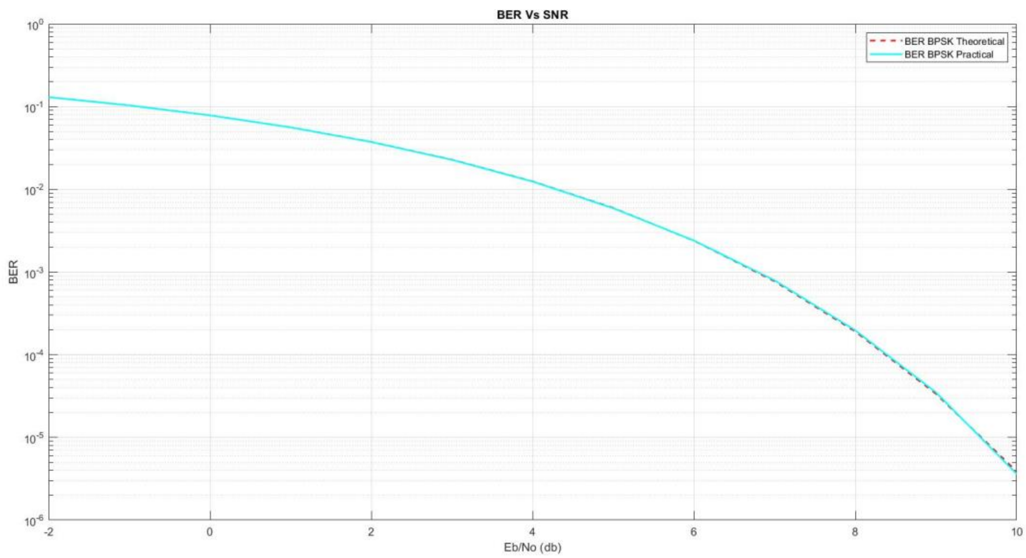


Figure 1: BER of BPSK vs Theoretical BER of BPSK

Comment:

The practical BER from MATLAB has been estimated by comparing the mapped values after addition of noise by the decision boundary zero because it is at the middle between the 2 mapped symbols.

As we can notice from **figure 1**, theoretical BER and practical BER estimated from MATLAB are exactly the same for both low SNR and High SNR as the theoretical BER is equal to:

$$BER_{BPSK} = 0.5\ erfc(\sqrt{\frac{E_b}{N_o}})$$

It is estimated for bits as number of bits tends to infinity and here we use a very large number of bits (3,600,000 bit) and because of that both graphs appear to be the same.

1.2 QPSK

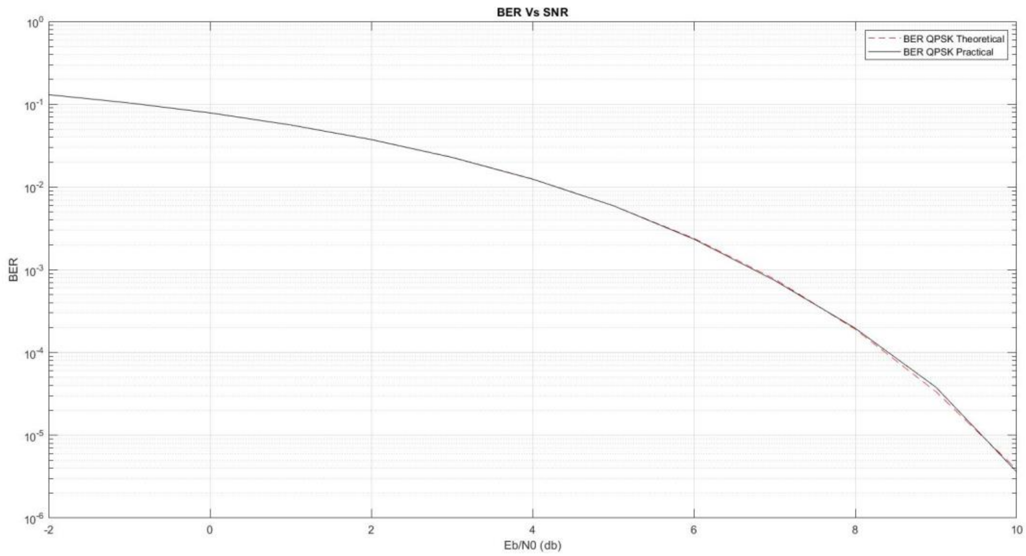


Figure 2: BER of QPSK vs Theoretical BER of QPSK

Comment:

The practical BER from MATLAB has been estimated by comparing the mapped values after addition of noise by the decision regions represented by the four quadrants because each of the 4 symbols lies exactly in one of the 4 quadrants.

As we can notice from **figure 2**, theoretical BER and practical BER estimated from MATLAB are exactly the same for both low SNR and High SNR as the theoretical BER is equal to:

$$BER_{QPSK} = 0.5\, erfc(\sqrt{\frac{E_b}{N_o}})$$

It is estimated for bits as number of bits tends to infinity and here we use a very large number of bits (3,600,000 bit) and because of that both graphs appear to be the same.

1.3 8-PSK

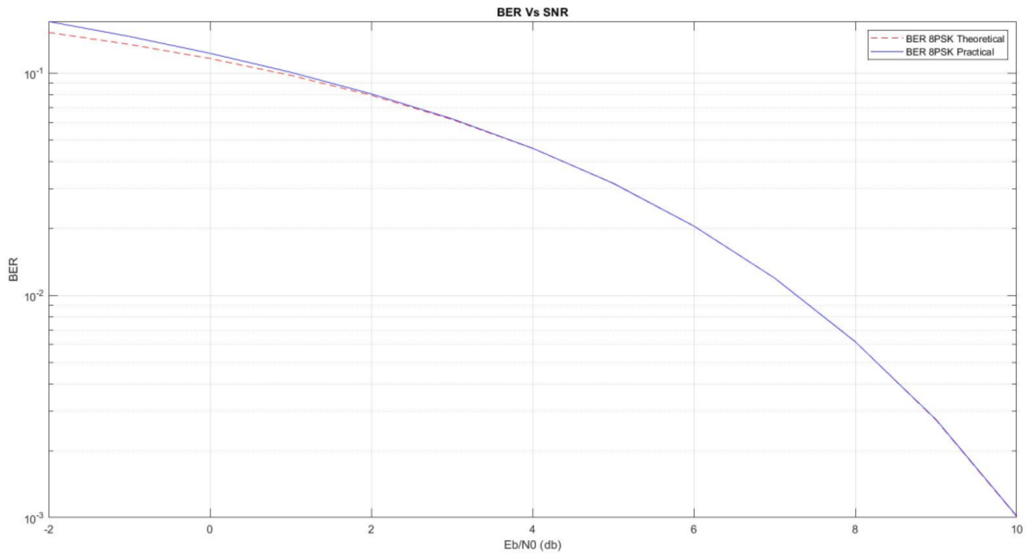


Figure 3: BER of 8-PSK vs Theoretical BER of 8-PSK

Comment:

The practical BER from MATLAB has been estimated by comparing the mapped values after addition of noise by the decision regions represented by dividing the circular space into 8 partitions because each of the 8 symbols lies exactly at the center of one partition from them.

As we can notice from **figure 3**, theoretical BER and practical BER estimated from MATLAB are different at low SNR while they are exactly the same at High SNR as the theoretical BER is equal to:

$$BER_{8-PSK} = \frac{SER_{8-PSK}}{3} = \frac{erfc\left(\sqrt{\frac{E_{symbol}}{N_O}}\,\sin\left(\frac{\pi}{8}\right)\right)}{3}$$

It appears that BER is estimated from SER, this SER is tight upper bound and by dividing it over three (number of bits per symbol), we made an approximation that we are using **gray encoding** at **high SNR** which means that the symbol errors occurs in only one bit in the symbol but in fact at low SNR values the noise is too high so it may flip more than one bit making the assumption we stated above not applicable at this case so at low SNR there is a difference between both graphs making the actual BER higher than the theoretical as more than 1 bit has been changed and when the SNR increases noise becomes smaller and flips only one bit in the symbol which agrees with the assumption making both graphs to be the same at higher SNR.

1.4 16-QAM

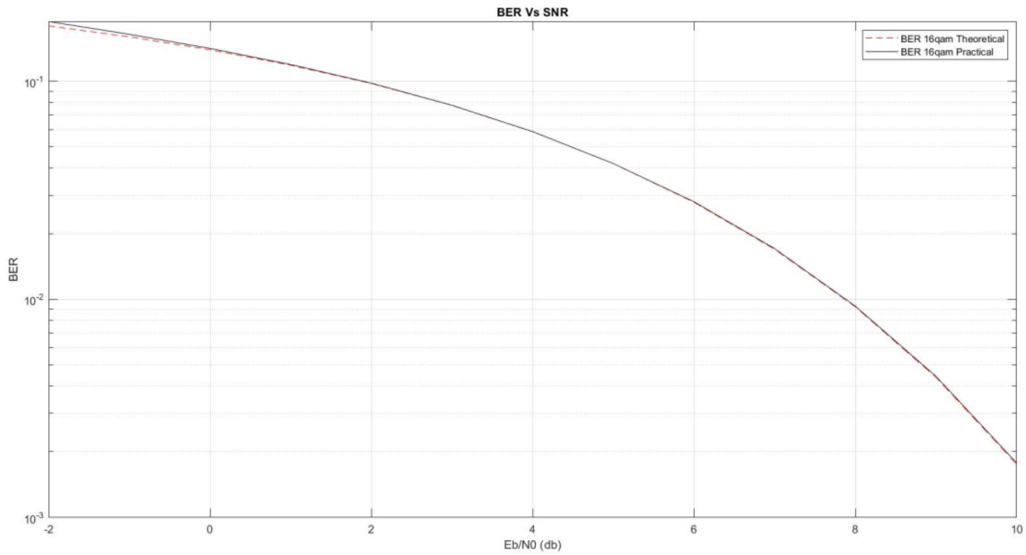


Figure 4: BER of 16-QAM vs Theoretical BER of 16-QAM

Comment:

As we can notice from **figure 4**, theoretical BER and practical BER estimated from MATLAB are different at low SNR while they are exactly the same at High SNR as the theoretical BER is equal to:

$$BER_{16-QAM} = \frac{SER_{16-QAM}}{4} = \frac{1.5\, erfc\left(\sqrt{\frac{E_b}{2.5\, N_O}}\right)}{4}$$

It appears that BER is estimated from SER by dividing it over four (number of bits per symbol), we made an approximation that we are using **gray encoding** at **high SNR** which means that the symbol errors occurs in only one bit in the symbol but in fact at low SNR values the noise is too high so it may flip more than one bit making the assumption we stated above not applicable at this case so at low SNR there is a difference between both graphs making the actual BER higher than the theoretical as more than 1 bit has been changed and when the SNR increases noise becomes smaller and flips only one bit in the symbol which agrees with the assumption making both graphs to be the same at higher SNR.

1.5 BER of All Modulation Methods

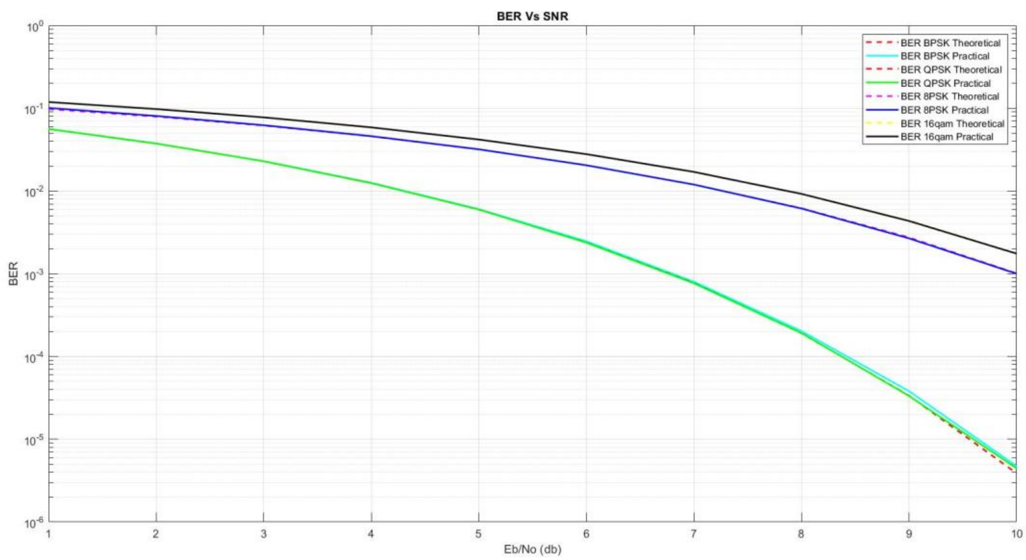


Figure 5: BER of all modulation methods vs their theoretical BER

Comment:

From **figure 5**, it appears that the highest BER is 16 QAM, then 8-PSK then both BPSK & QPSK (BPSK & QPSK Have the same BER) which is expected because the increase in constellation points makes them closer to each other, this makes the received signals to appear in wrong decision regions because decision regions increase so, they became with smaller area at higher modulation order.

To make 16 QAM and 8 PSK achieve the same BER of BPSK & QPSK we can increase symbols' energy but this is a higher power consumption so there is a tradeoff between power consumption and BER.

So, in high noise environments with power constraints for the system we can't use 8-PSK nor 16-QAM, so it is preferred to use QPSK modulation as it has the same performance as BPSK with smaller Bandwidth for the same bit rate.

While in low noise environments we may prefer 8-PSK or 16-QAM as they will not be affected too much by the noise and don't need to increase the power as the environment has low noise and on the other hand, they will give us smaller bandwidth than both QPSK & BPSK for the same bit rate.

2 QPSK With Gray Encoding vs Without Gray Encoding

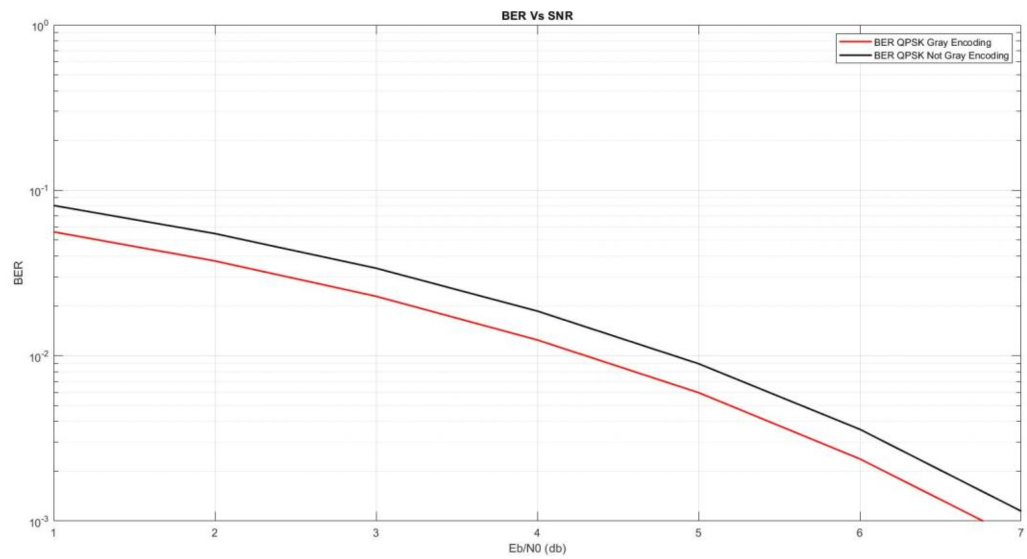
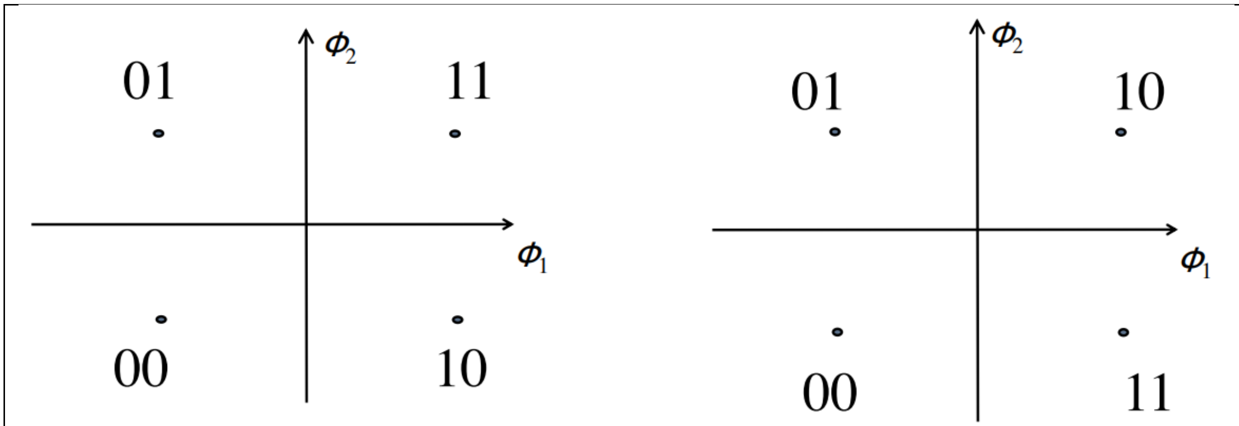


Figure 6: BER with Gray Encoding vs BER with no Gray Encoding

Comment:

From **figure 6**, although the SER is the same as the symbol changed in general in the 2 cases, it appears that BER without using gray encoding is higher than BER using gray encoding because gray encoding assures that adjacent decision regions are different only in one bit so it guarantees that if the transmitted symbol deviates due to noise from the correct region to its adjacent region only one bit will be flipped while if we used random encoding if a symbol deviated from the correct region to the adjacent region it could happen that more than one bit will be flipped so gray encoding minimize the BER for the same SER.



Gray Encoding vs Non-Gray Encoding