CIE 428 Project 3 Report

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Binary Frequency Shift Keying

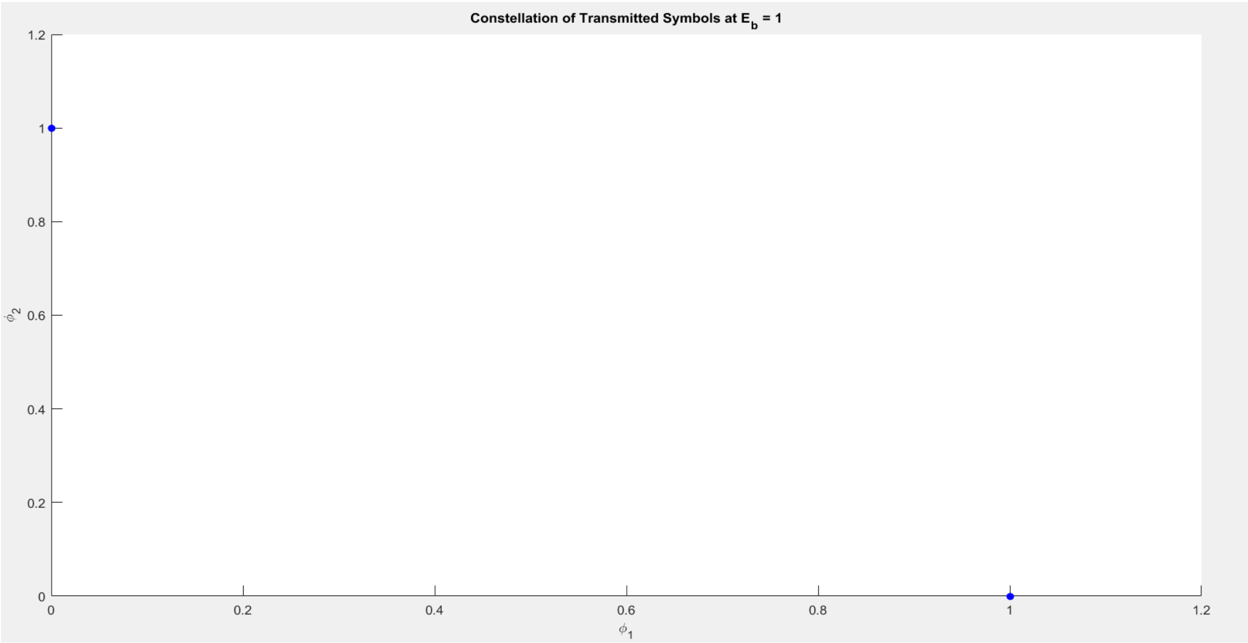

Fig (1) Constellation of the transmitted $BFSK$ symbols at $E_b = 1$

As you can see, all the transmitted symbols reside at $\sqrt{E_b}\,\widehat{\varphi_1} + \sqrt{E_b}\,\widehat{\varphi_2}$.

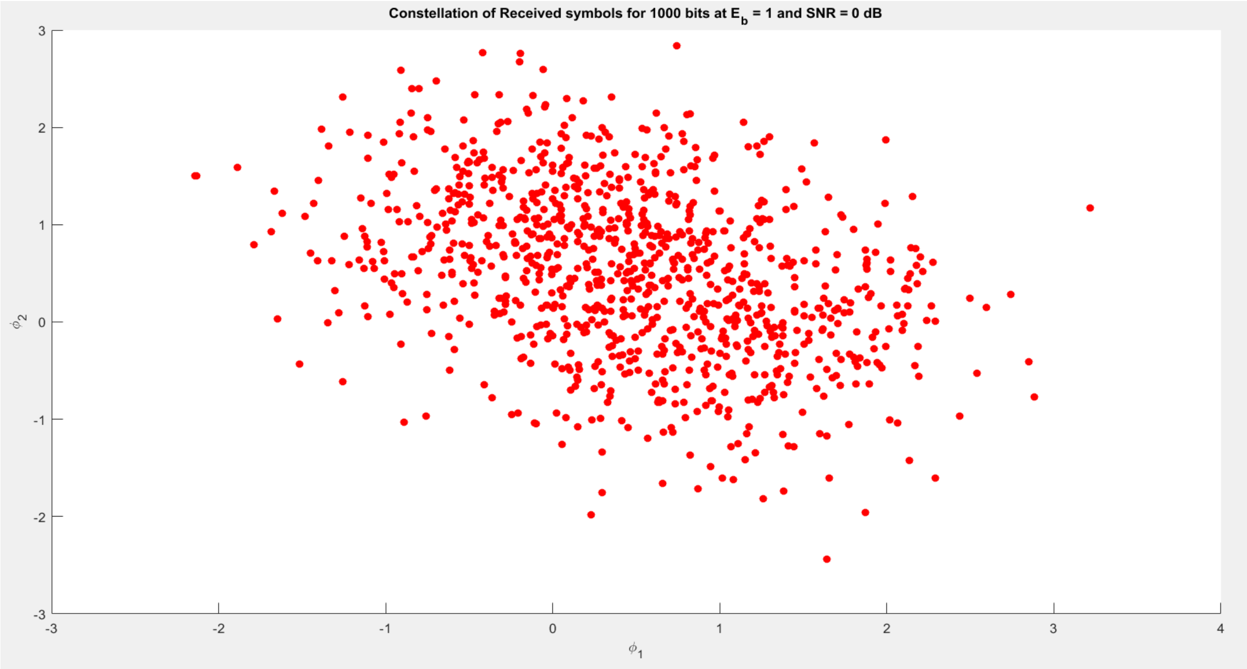

Fig (2) Constellation of Received $BFSK$ symbols at $E_b = 1$ and $SNR = 0\ dB$

The received symbols are nearly normally distributed around the transmitted symbols due to the addition of gaussian distributed random noise which can be readily seen in the next figure.

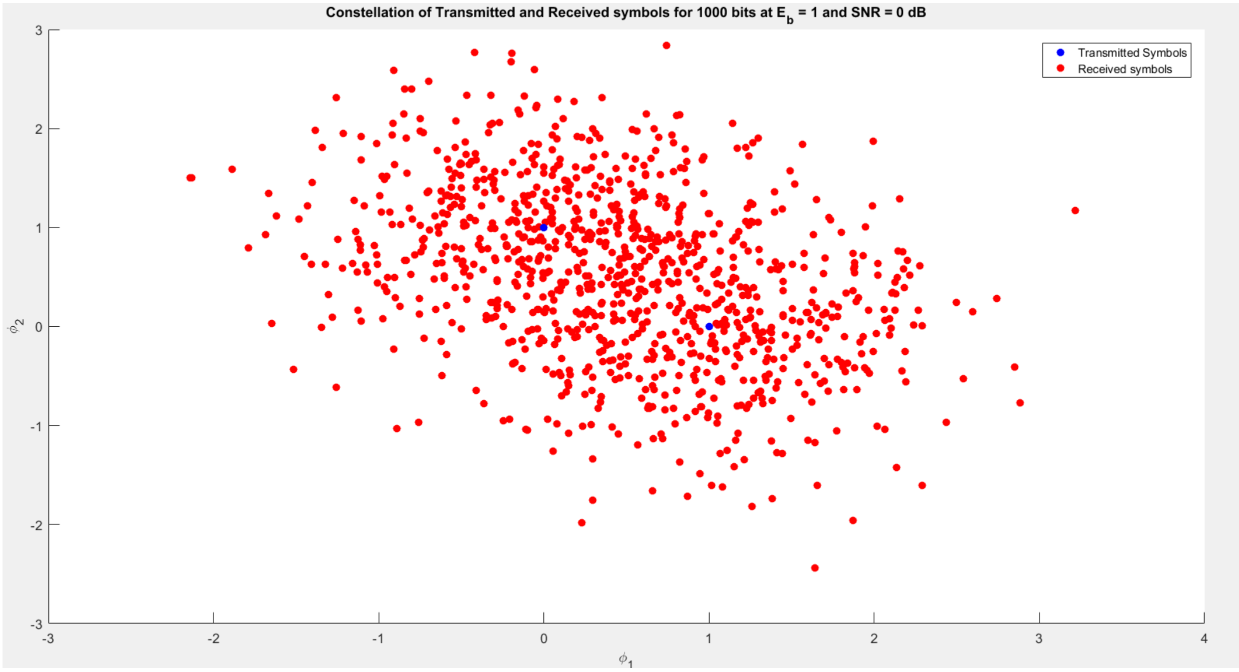

Fig (3) Constellation of Transmitted and Received $BFSK$ symbols at $E_b = 1$ and $SNR = 0\ dB$

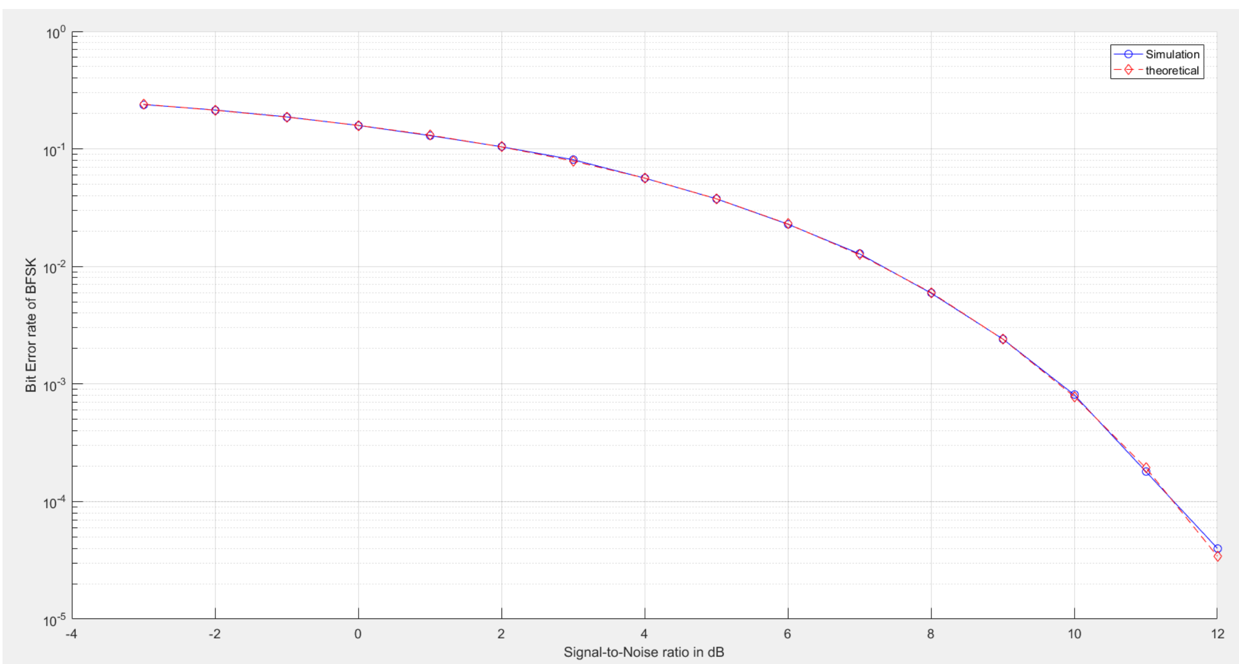

Fig (4) Bit-error rate of $BFSK$ signal plotted against the Signal-to-noise ratio

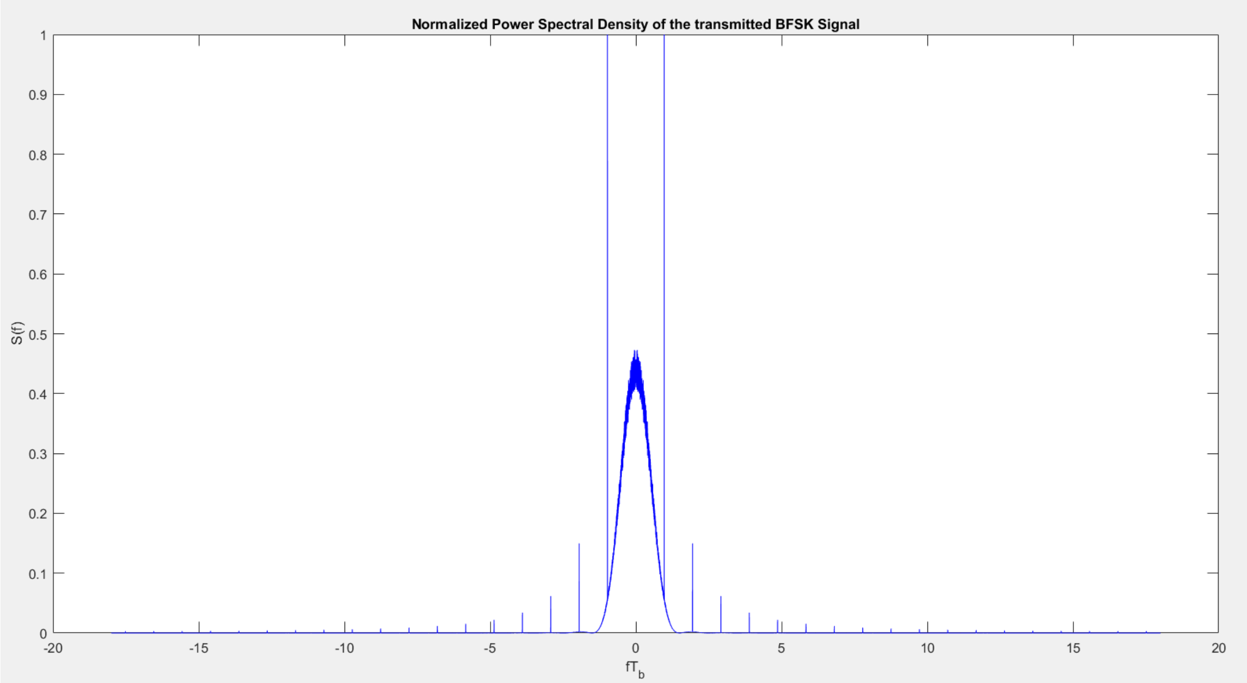

Fig (5) Normalized Power Spectral Density of baseband $BFSK$ Signal

Note:

The spectral shaping function of $BFSK$ is as follows:

$$g(t) = \sqrt{\frac{2E_b}{T_b}} \cos\frac{\pi t}{T_b} \pm \sqrt{\frac{2E_b}{T_b}} \sin\frac{\pi t}{T_b}$$

The power spectral density of $BFSK$ is the sum of the power spectral densities of the in-phase and the quadrature components

$$S_B(f) = \frac{E_b}{2T_b}\left(\delta\left(f - \frac{1}{2T_b}\right) + \delta\left(f + \frac{1}{2T_b}\right)\right) + \frac{8E_b cos^2(\pi T_b f)}{\pi^2(4{T_b}^2 f^2 - 1)}$$

On simulating, due to the high power of the deltas, I separated the in-phase and the quadrature parts and computed the PSD of each component on its own, then normalized each of them differently in order to make their magnitudes comparable. Lastly, I added the two normalized $PSDs$ which results in Fig (5). The graph illustrates the properties of the $BFSK$ spectrum. However, it is not an accurate reference for magnitudes

16-ary Quadrature Amplitude Modulation

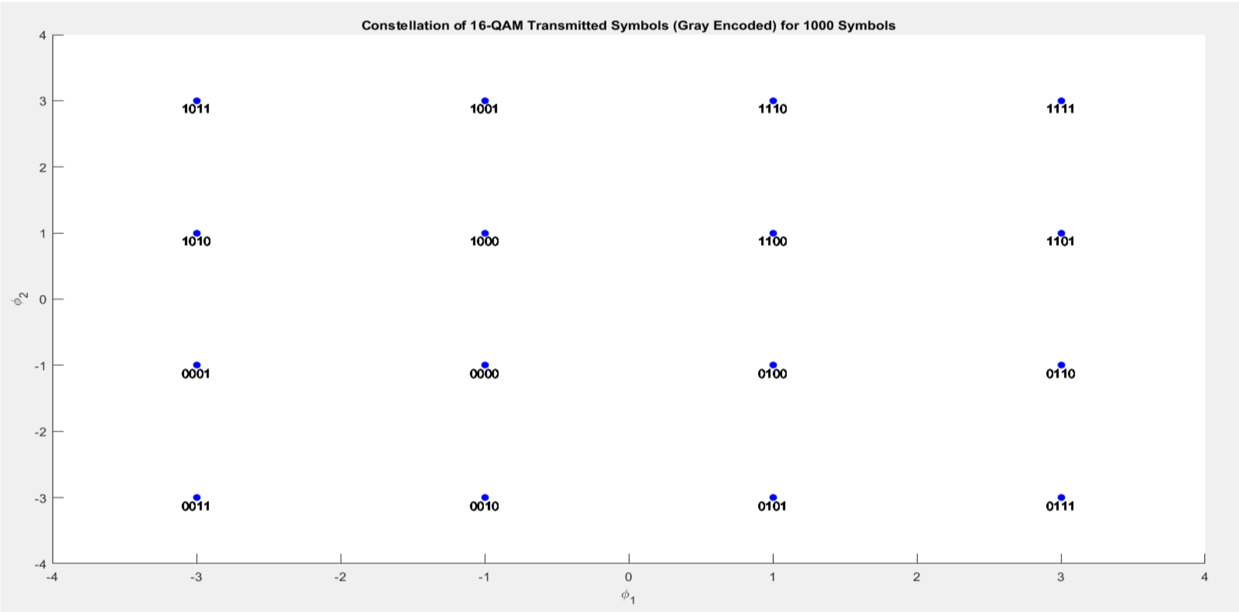

Fig (6) Constellation of the transmitted $BFSK$ symbols at $E_o = 1$

As you can see, all the transmitted symbols reside at $\sqrt{E_o}\, a_k \widehat{\varphi_1} + \sqrt{E_o} b_k\, \widehat{\varphi_2}$ where $a_k = -3, -1, 1, 3$ and $b_k = -3, -1, 1, 3$

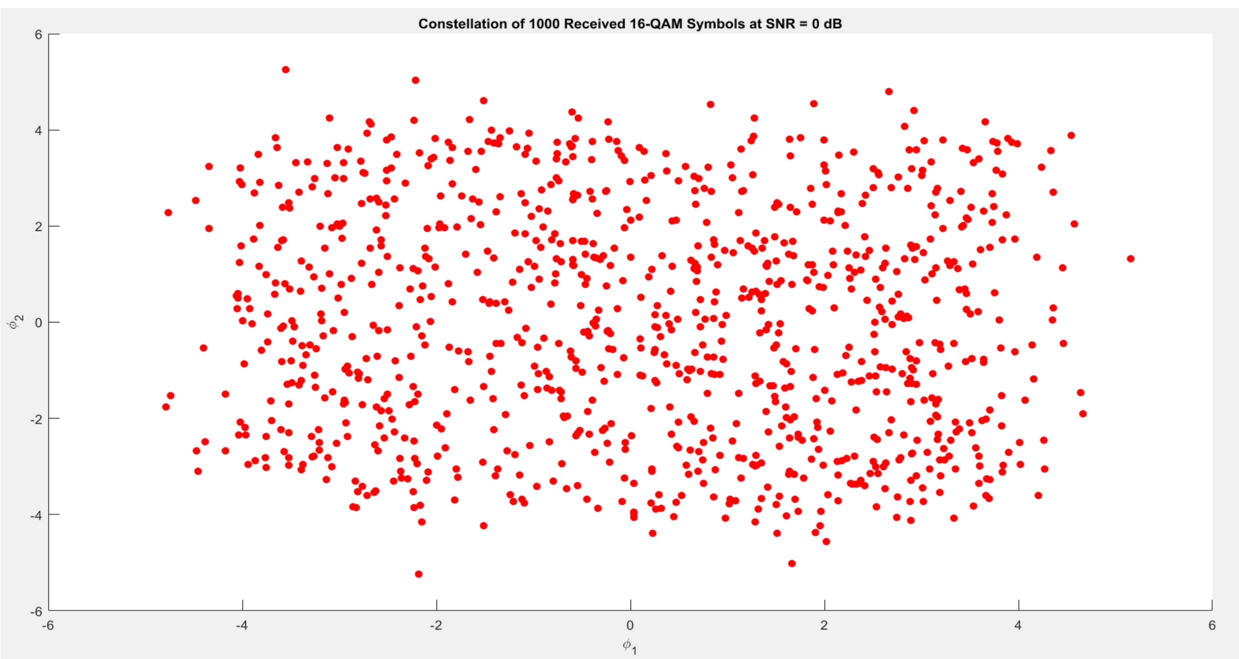

Fig (7) Constellation of Received $16 - QAM$ symbols at $E_o = 1$ and $SNR = 0\ dB$

The received symbols are nearly normally distributed around the transmitted symbols due to the addition of gaussian distributed random noise which can be readily seen in the next figure.

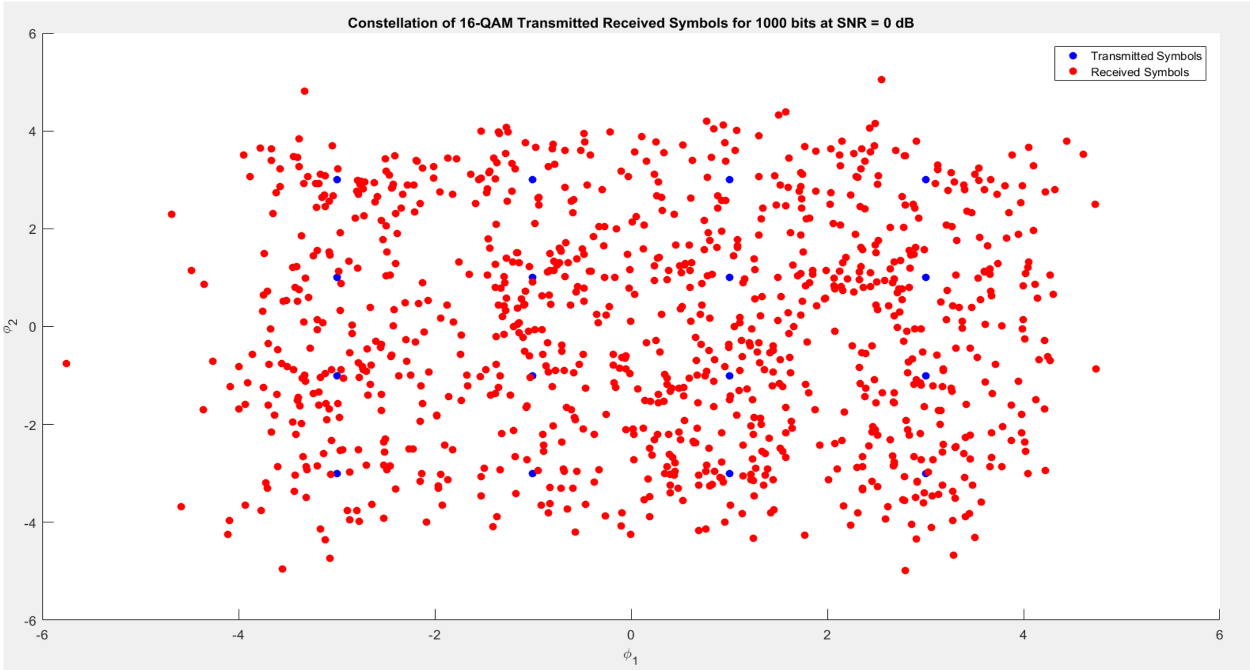

Fig (8) Constellation of Transmitted and Received $16 - QAM$ symbols at $E_o = 1$ and $SNR = 0\ dB$

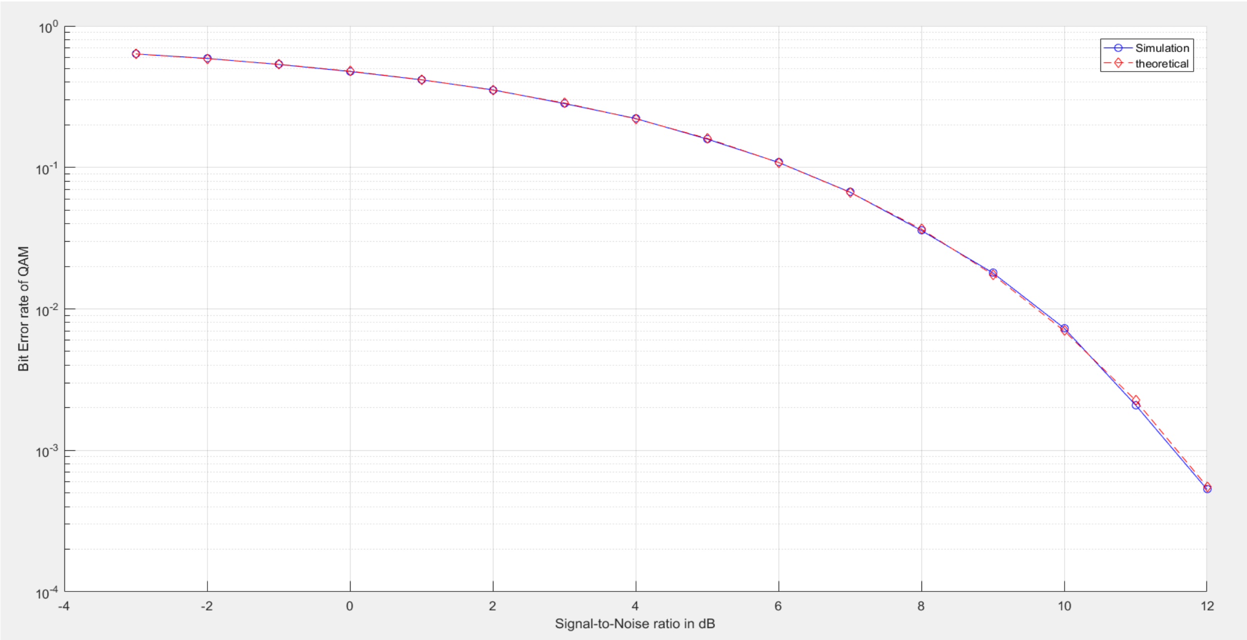

Fig (9) Bit-error rate of $16 - QAM$ signal plotted against the Signal-to-noise ratio

Note: On using the approximate error probability expression at which we ignored the $erfc^2$ term due its minimal contribution, the theoretical error probability curve had higher values especially at low SNR values. Consequently, I used the exact error probability expression which is $\frac{3}{2} erfc\left(\sqrt{\frac{E_{av}}{10N_o}}\right) - \frac{9}{16} erfc^2\left(\sqrt{\frac{E_{av}}{10N_o}}\right)$ for $16 - QAM$ and the two curves coincide.

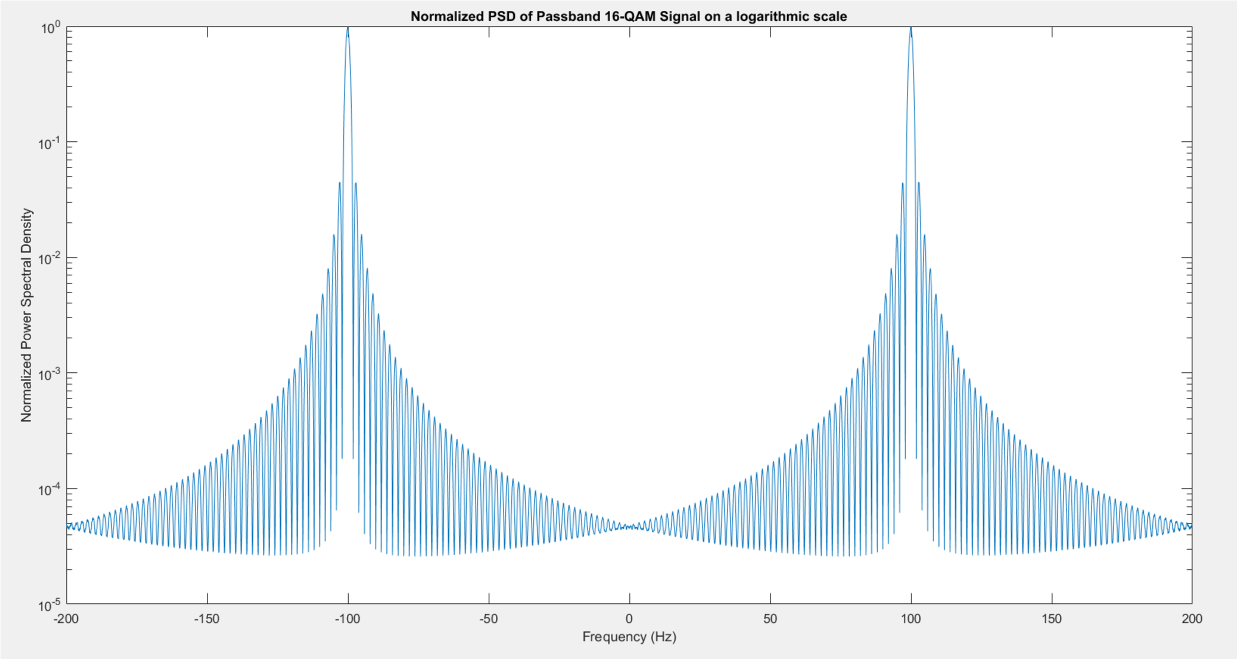

Fig (10) Normalized Power Spectral Density of $16 - QAM$ Passband Signal on a logarithmic scale

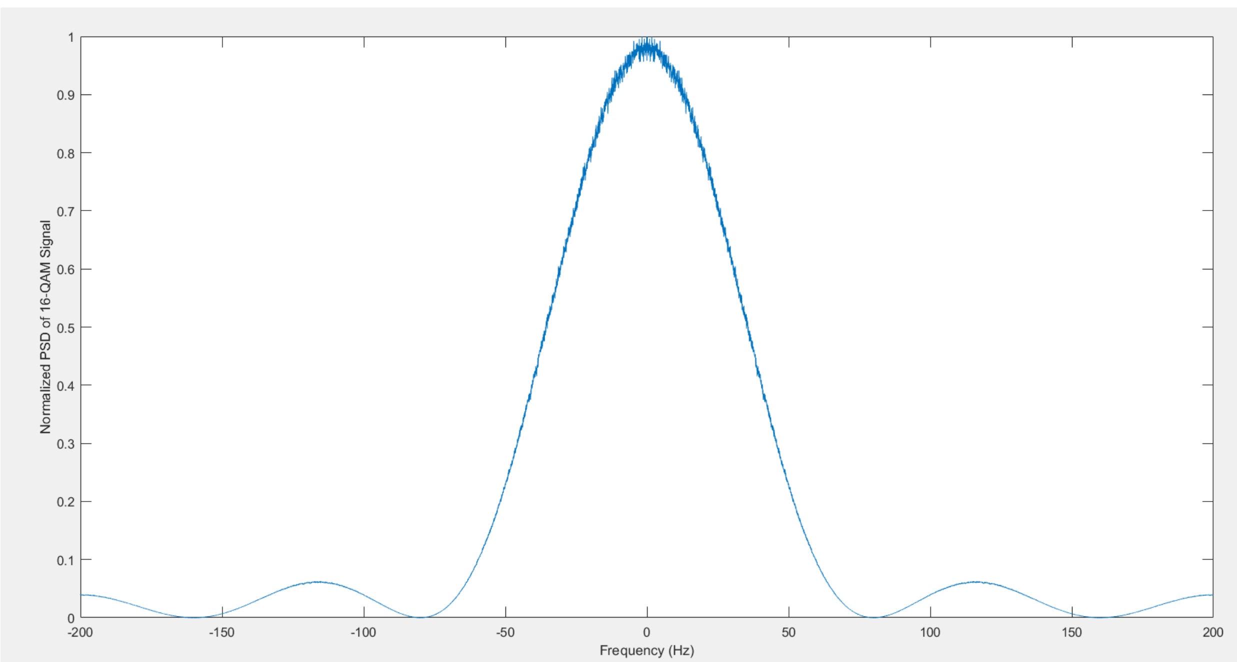

Fig (11) Normalized Power Spectral Density of $16 - QAM$ Baseband Signal

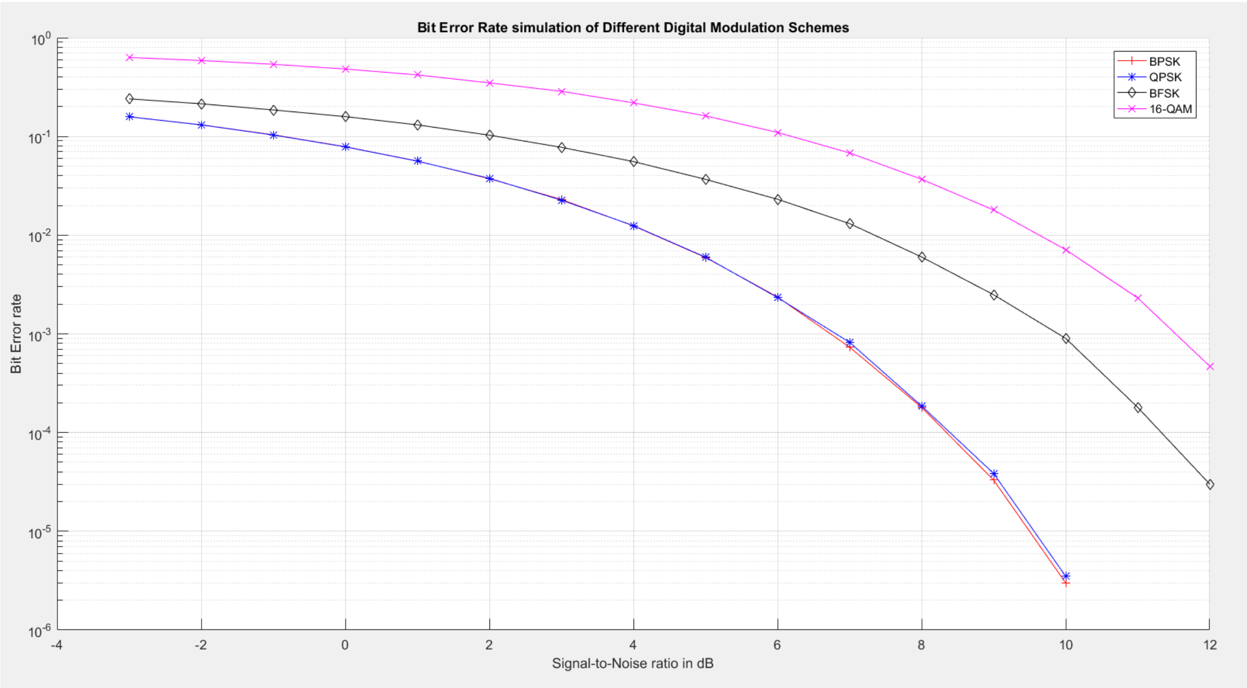

Fig (12) Bit-error rate of different digital modulation schemes

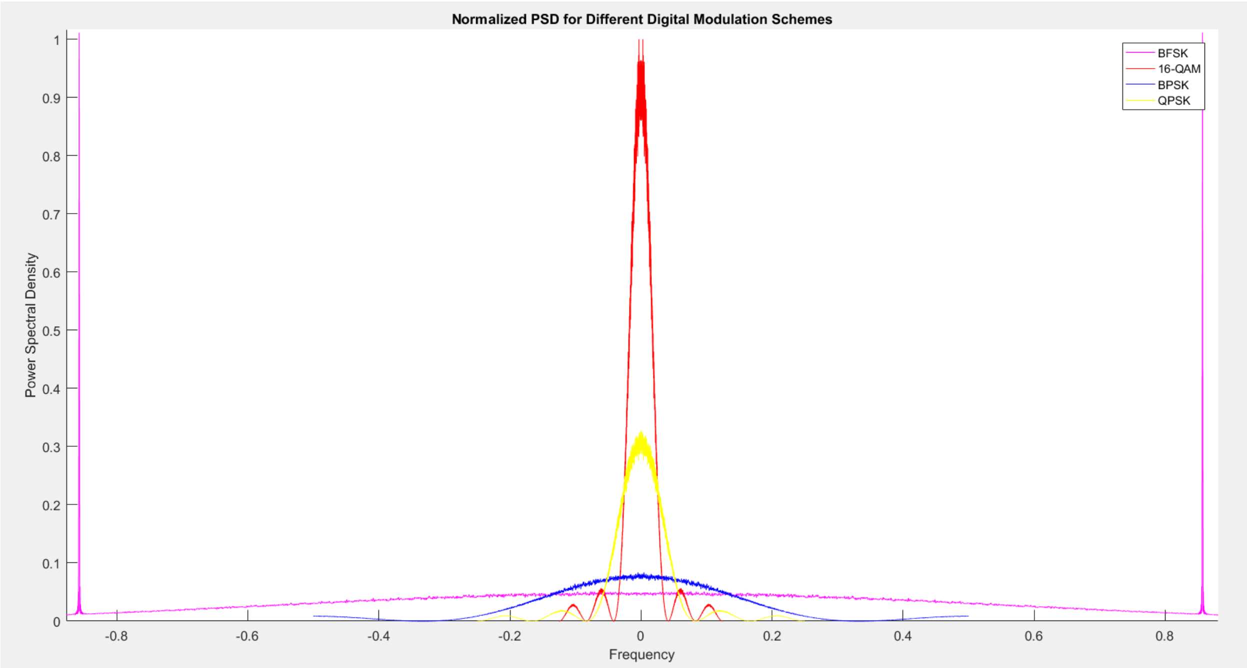

Fig (13) Normalized Power Spectral Density of different digital modulation schemes

Inferences from Fig (12) and Fig (13)

1. By comparing $QPSK$ and $BPSK$, we see that both of them have them have the same bit-error rate; however, $QPSK$ has a higher spectral efficiency that's why $QPSK$ is a bandwidth conserving modulation scheme.

2. $16 - QAM$ has the highest spectral efficiency. Consequently, it can provide the highest bit-rate if used; however, this is compromised by being the worst of them when it comes to bit-error rate.
3. $BFSK$ has a higher error probability than $BPSK$ and $QPSK$ and it also has the lowest spectral efficiency which justifies the fact that it is rarely used.

Note: The $BFSK$ spectrum seems to deviate when it comes to the position of the delta functions on the frequency axis. I cannot find out the reason.

By removing $BFSK$ from Fig (13):

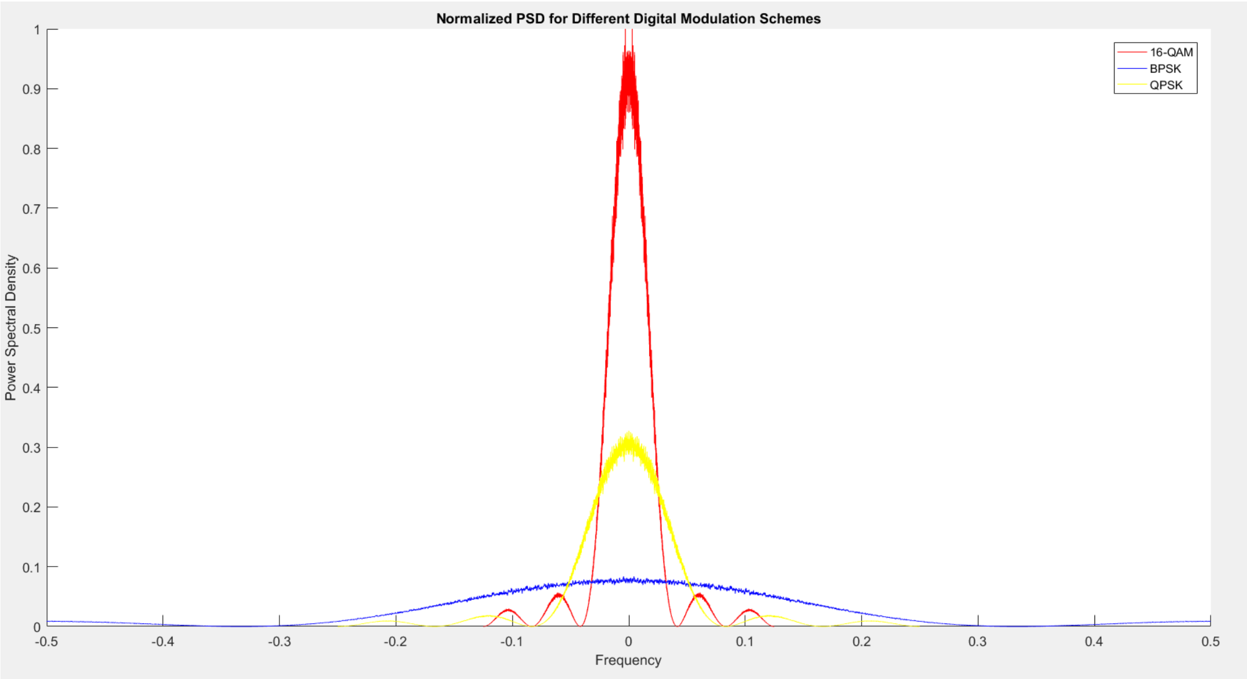

Fig (14) Normalized Power Spectral Density of different digital modulation schemes