8-PSK MODULATION SIMULATION

Introduction

This project is a simulation of a digital communication system based on 8-PSK modulation. The program is capable of simulating random bit generation, pulse and signal generation, digital modulation at the transmitter, noise in channel, demodulation at the receiver, recovery of the bits, and provides visualizations of each process. The program also calculates and visualizes the power spectral density of the modulated signal and the bit error rate of the recovered data. The simulation provides an easy way to evaluate the performance of the system and verify whether the system with certain parameters meet a specific bandwidth requirement.

Procedure

The program first allowed the user to define the following parameters: number of symbols/bits (n/D), pulse duration 2*kt*tb, bit rate R, sample per bit bs, carrier frequency fc, and the roll-off factor r of the root RCRO pulses. The default values were set to meet the bandwidth specification required by the project.

Having taken all the inputs, the program started by producing a sequence of random binary bits as the data to be transmitted. The data was passed to a function, where three bits at a time were read [1], and converted to a corresponding symbol using the formula given in the 8-PSK simulation document [2] represented by two carriers, i.e. the multi-level signal I and Q. The I and Q vector were returned to the main script. The time vector of the signal was defined from -kt*tb to kt*tb+tb*D. Applying equation from homework set 3, part c [3] , the baseband signal of the I and Q carriers were obtained. Modulation was then performed on both I and Q signals, and according to the simulation document, the signal for transmission were constructed by

$$S(t) = I * \cos(\omega_c t) - Q * \sin(\omega_c t)$$

A noise was added to the signal to simulate the channel in real world, and the signals I and Q were recovered by

$$I(t) = S(t) * \cos(\omega_c t)$$

$$Q(t) = -S(t) * \sin(\omega_c t)$$

A matched filter, which was a low pass filters with impulse response of root raised cosine pulses, was applied on both the I and Q carrier signals to get the recovered signal. The modulation, demodulation process was suggested by the 8-PSK simulation document [2] and the receiver in this case is the optimal receiver for 8-psk signals, according to Cough [4].

The received signals were sampled at t = n * tb, and the data was recovered by comparing the I and Q values at each t = n * tb to the constellation. The specific decoding rule was given by the 8-PSK simulation document [2]

8-PSK Demodulation: Decoding the Bits

$$
\begin{aligned}
b_2 &= \begin{cases} 1 & R_Q > 0 \\ 0 & R_Q < 0 \end{cases} \\
b_1 &= \begin{cases} 1 & R_I > 0 \\ 0 & R_I < 0 \end{cases} \\
b_0 &= \begin{cases} 1 & |R_Q| > |R_I| \\ 0 & |R_Q| < |R_I|. \end{cases}
\end{aligned}
$$

The vector containing the detected bits were compared to the original data vector to find any bit errors as well as symbol errors.

At this point, a complete process of data transmission was complete and the program has a section that plots and visualizes each step in this process. The codes for plots were grouped in one section for manipulation convenience. This section visualizes the original data, the I and Q carrier, the modulated I and Q signal, the constructed 8-PSK signal, the transmission signal degraded by noise, the recovered I and Q carrier signal, the signal constellation of the recovered signal.

Then the above process was repeated for different noise levels to illustrate the effect of the noise in the channel on the recovery of the data.

Having demonstrated the data transmission process, the program proceeded to calculate the power spectral density of the modulated 8-PSK signal. The program ran for 100 iterations, generating random bits and calculating the PSD each time, and plotted the average PSD over the 100 iterations in both W/W scale and in Db scale. During this process, the average energy per bit of the signal was also evaluated and will be used in the next section.

In the final section, the bit error rate vs Eb/N0, which is an importance characteristic of a modulation technique, was evaluated. A set of Eb/N0 was define within the range of interest, and the variances of the noise needed to achieve such ratio were computed. The program ran the simulation for each value of variances and repeat multiple times at each noise level to obtain the averaged bit error rate, as well as the symbol error rate. The measured bit error rate and symbol error rate were shown on plots, and the theoretical curve of the upper bounds of these error rate was also shown on the plots for comparison.

Results

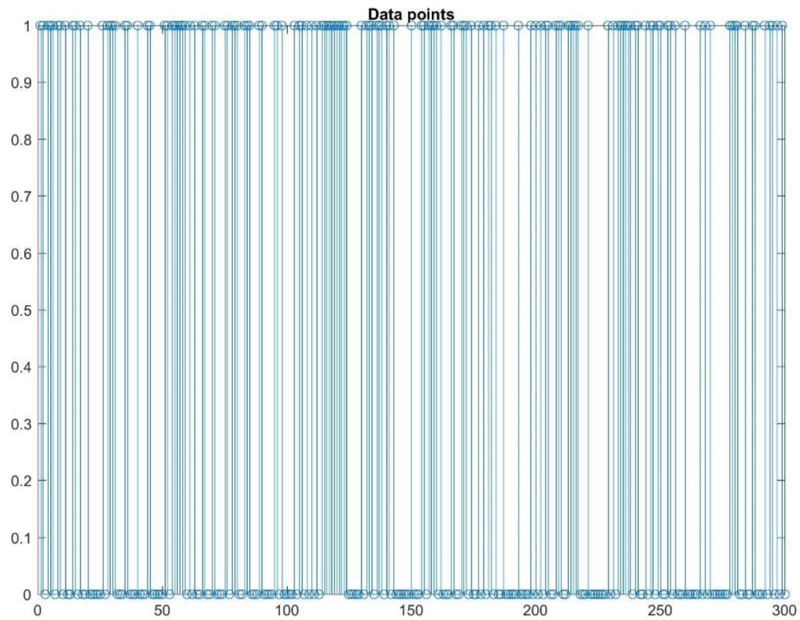

Figure 1 Random binary data

Figure 1 shows the generated data, with 1 corresponds to a 1 and 0 corresponds to a 0. A total of 300 bits and 100 symbols were shown.

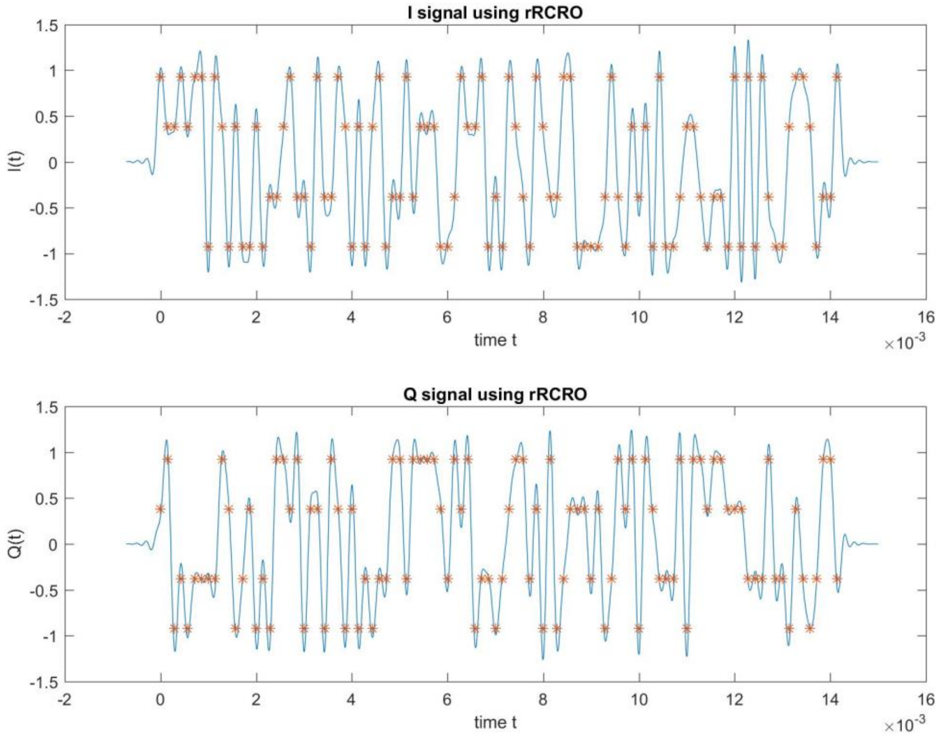

Figure 2 I and Q carrier

Figure 2 shows the constructed I and Q carrier, where the stars represents the data points. The root RCRO pulse did not produce a signal with zero ISI, since the stars does not always lie on the curve.

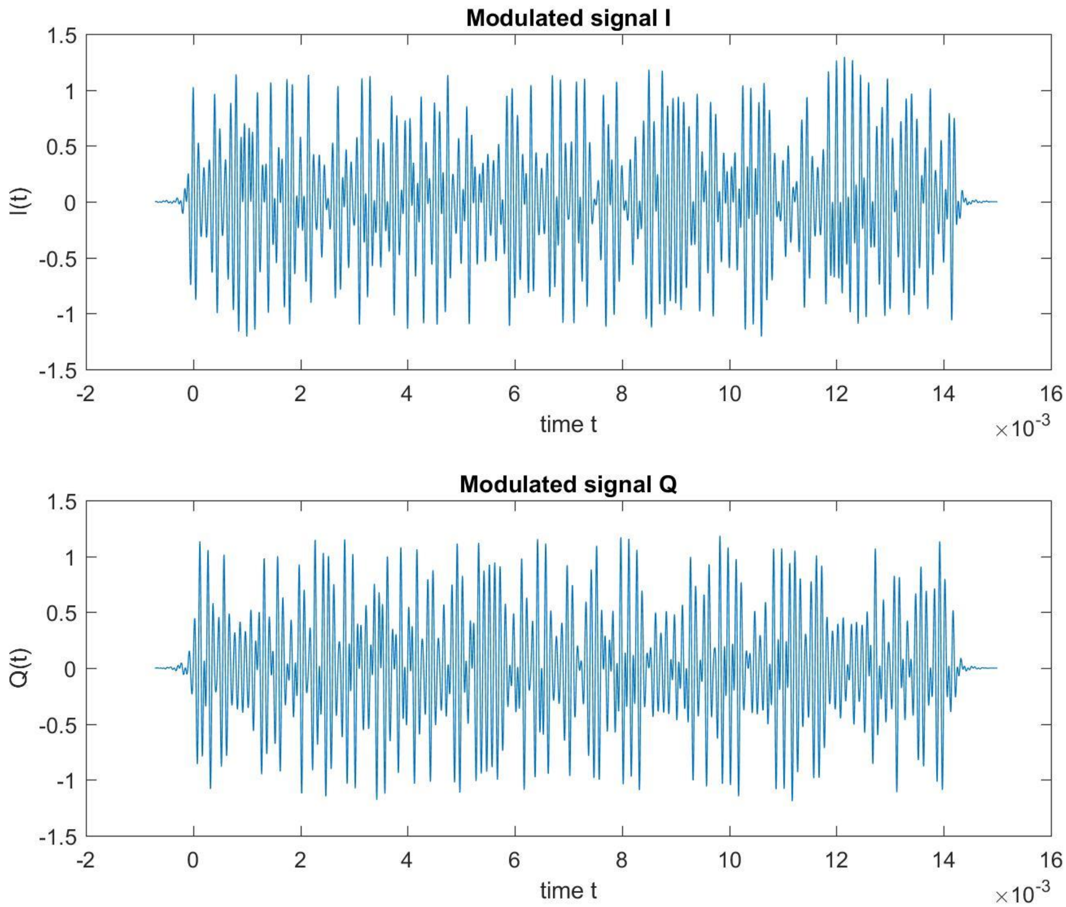

Figure 3 Modulated carrier

Figure 3 shows the modulated I and Q signal with a carrier frequency of 10kHz. Since the bit rate was set to 7000 bit/s, the modulation didn't look like have increased the frequency by a lot.

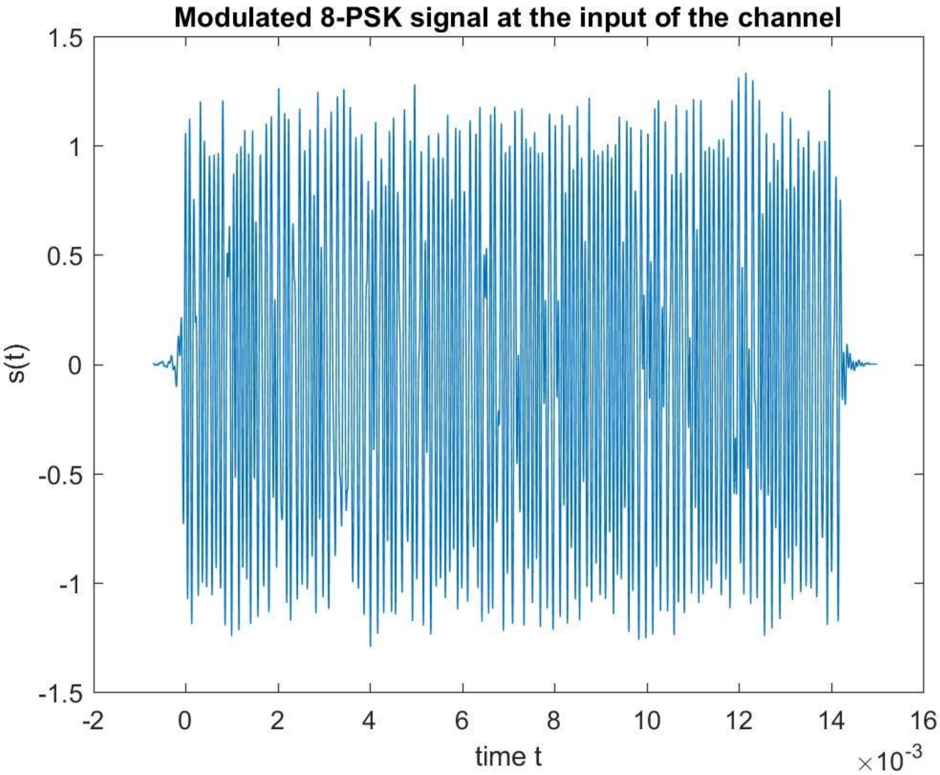

Figure 4 8-PSK bandpass signal

Figure 4 shows the 8-PSK modulated signal, produced by subtracting Q from I, whose carrier phase were off by 90 degrees.

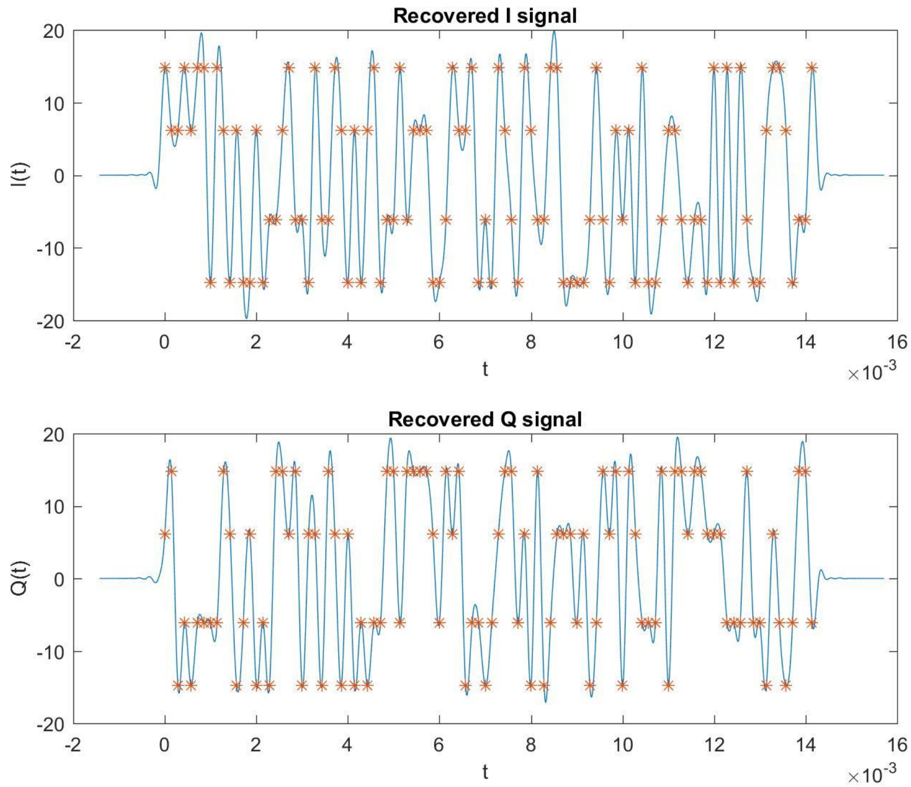

Figure 5 Recovered I and Q signal

Figure 5 shows the recovered signal. In this case, no noise was added, so the data was perfectly recovered. It can be seen that by passing the signal through the matched filter, zero-ISI was achieved.

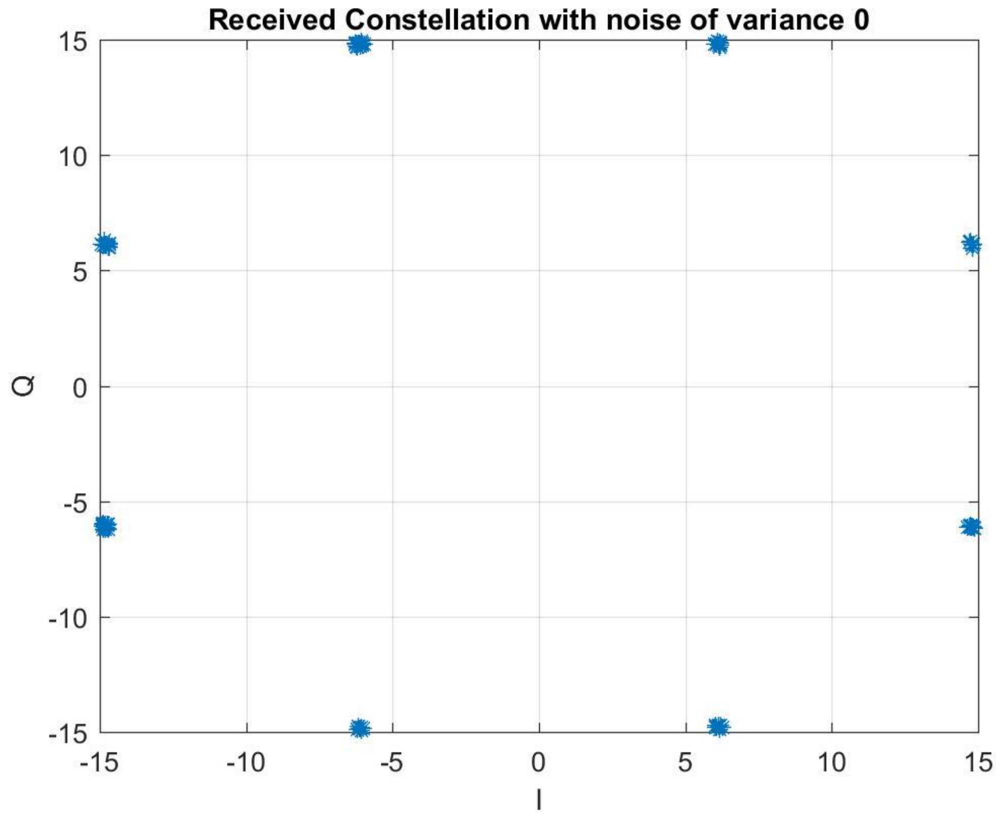

Figure 6 received 8-PSK signal constellation

Figure 6 shows the received signal constellation when no noise was present in the channel. The eight constellation points lies correctly on the expected location and forming a ring pattern.

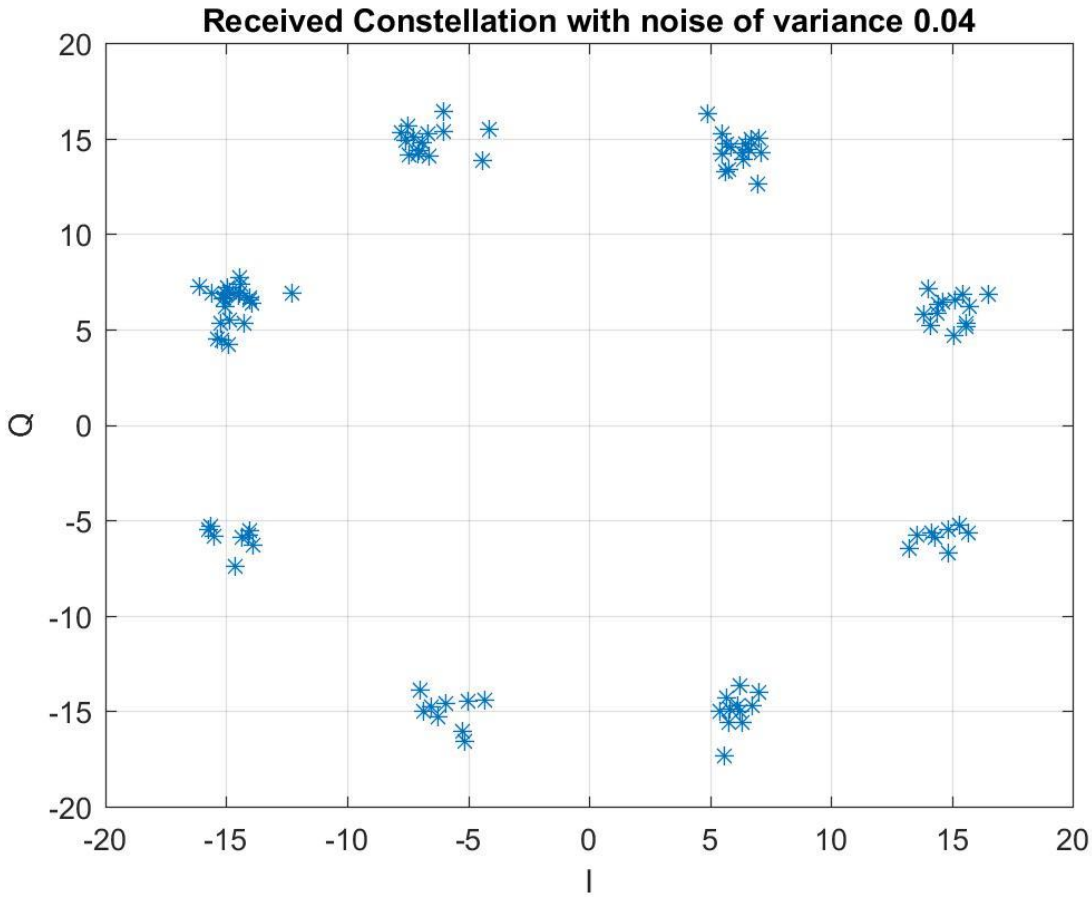

Figure 7 Received 8-PSK signal constellation with noise of variance 0.04

Figure 7 shows the received signal constellation with noise of variance 0.04. Noise have moved the constellation points apart from the correct position but is still too small to cause a symbol error.

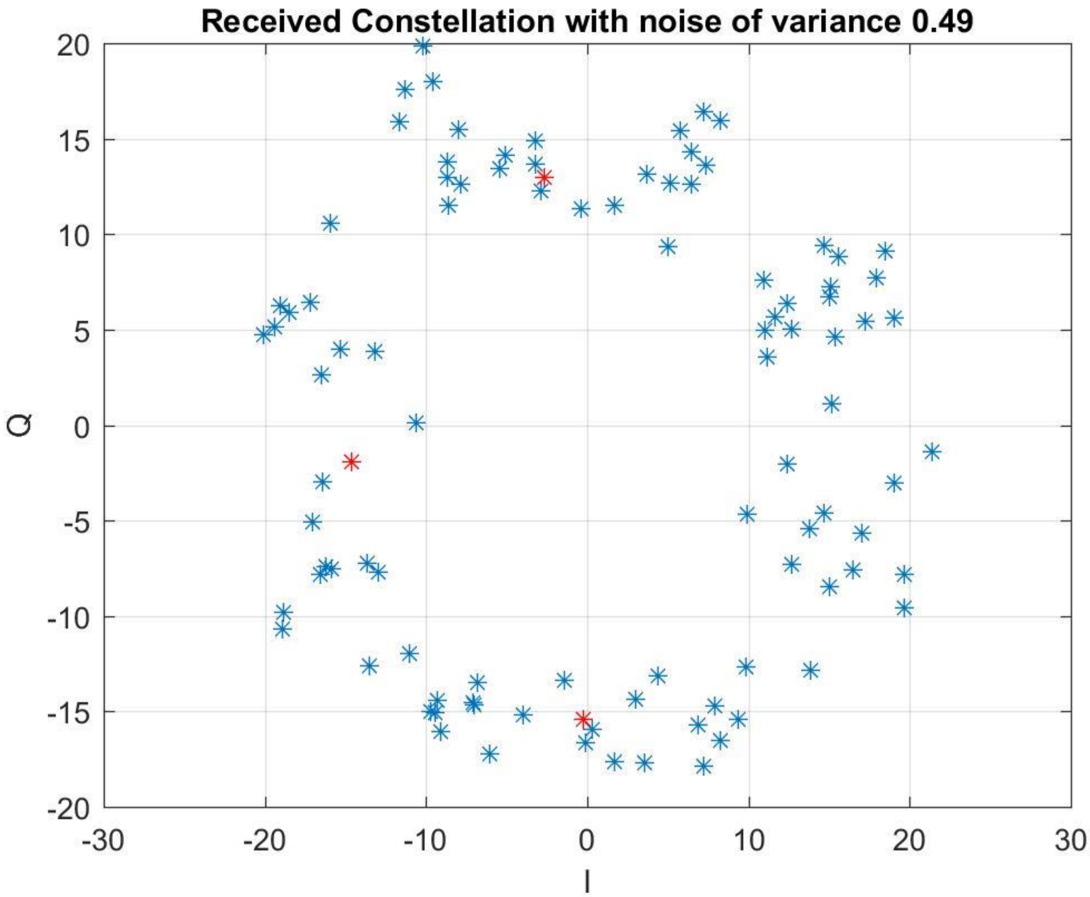

Figure 8 Received 8-PSK signal constellation with noise of variance 0.49

Figure 8 shows the result of a stronger noise of variance 0.49. Some bit errors start to appear but didn't have a large impact.

Figure

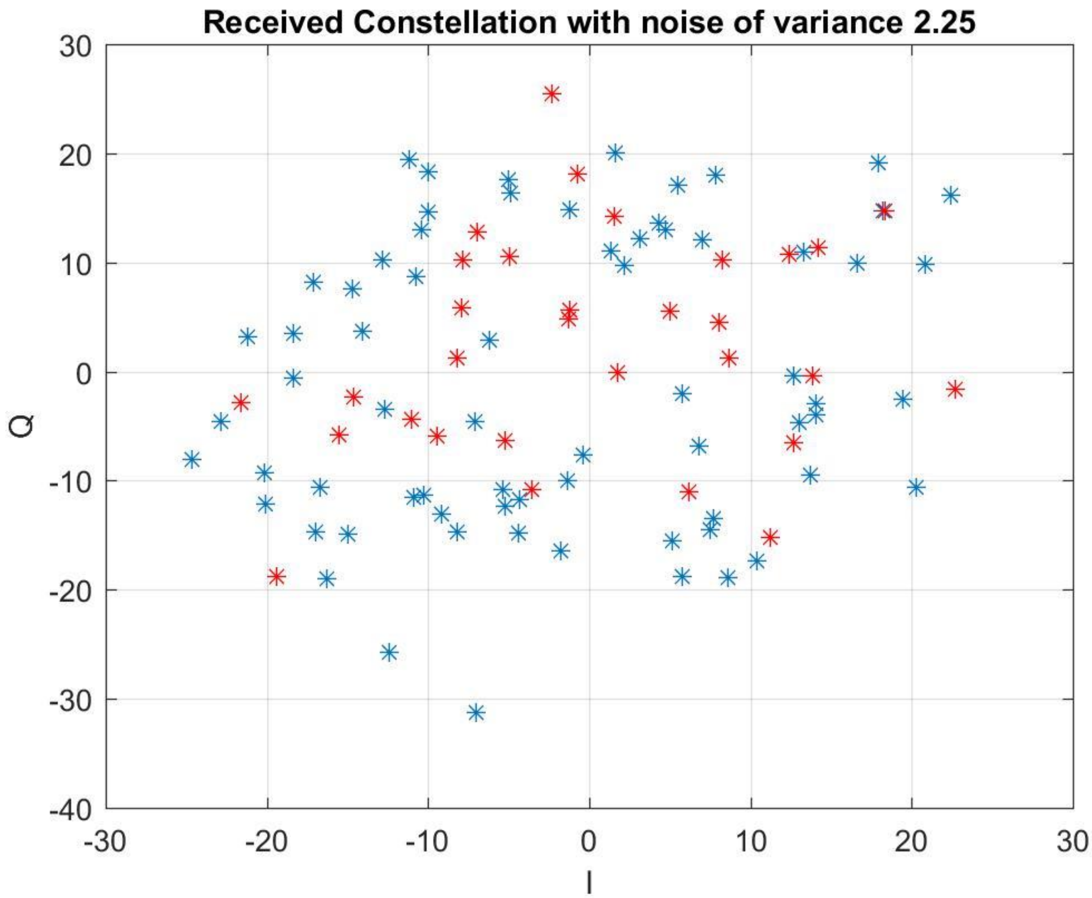

Figure 9 Received 8-PSK signal constellation with noise of variance 2.25

Figure 9 shows the constellation when variance is 2.25. The eight constellation points cannot be seen on the plot anymore and considerable amount of symbol errors were made.

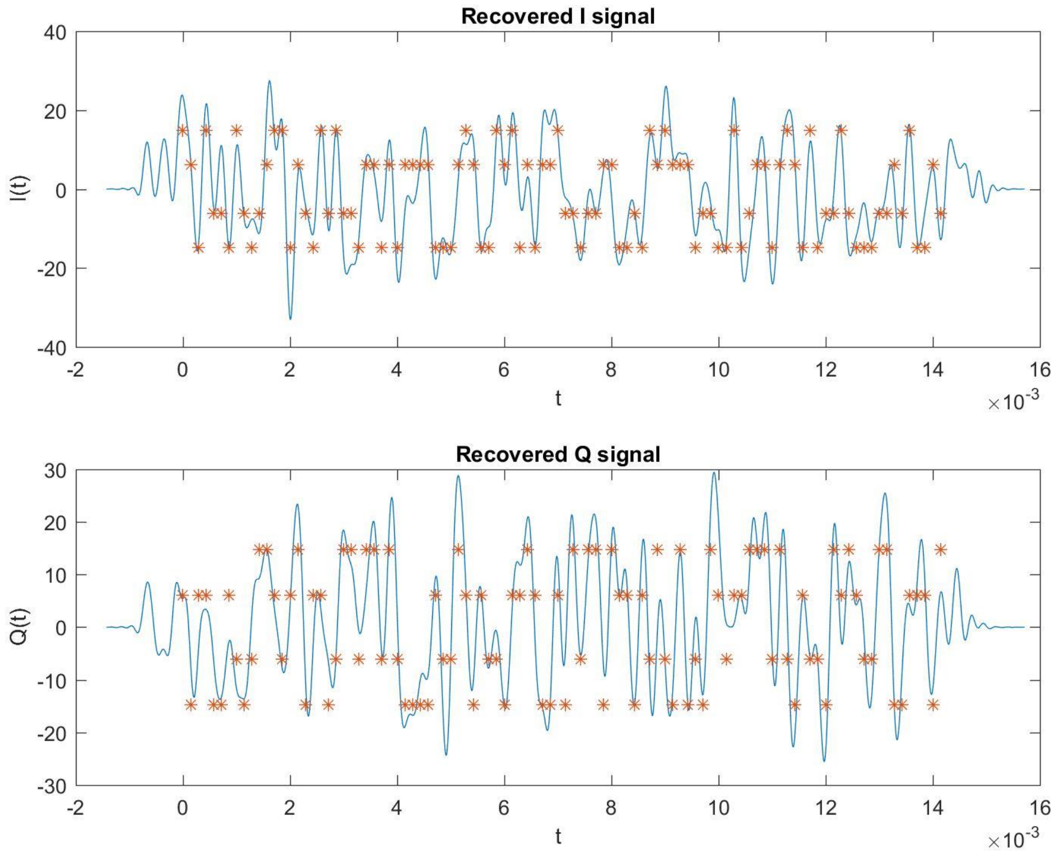

Figure 10 Recovered I and Q signal with presence of noise with variance 2.25

This can also be seen in figure 10, where the signal at some point obviously deviate from the correct value marked by the stars.

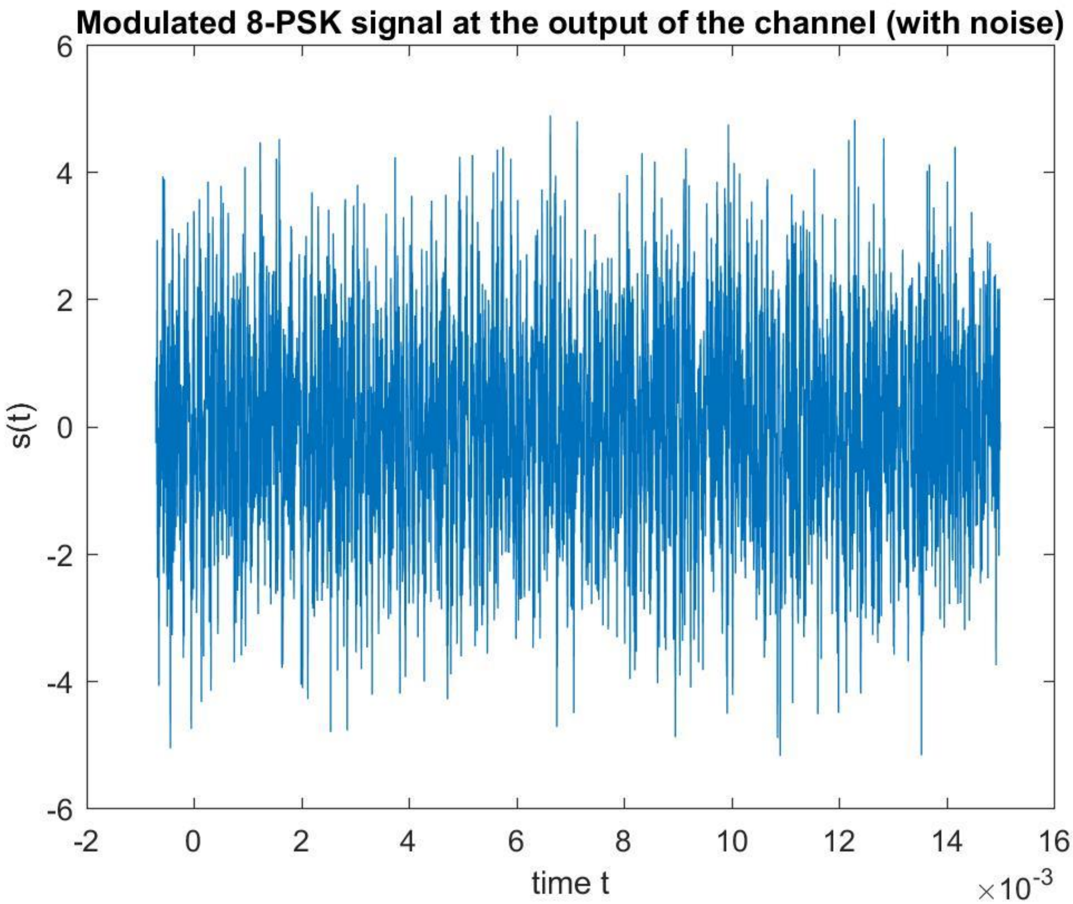

Figure 11 8-PSK signal added by a noise with variance 2.25 out of a noisy channel

Figure 11 shows the modulated 8-PSK signal with noise of variance 2.25. The effect of noise was significant.

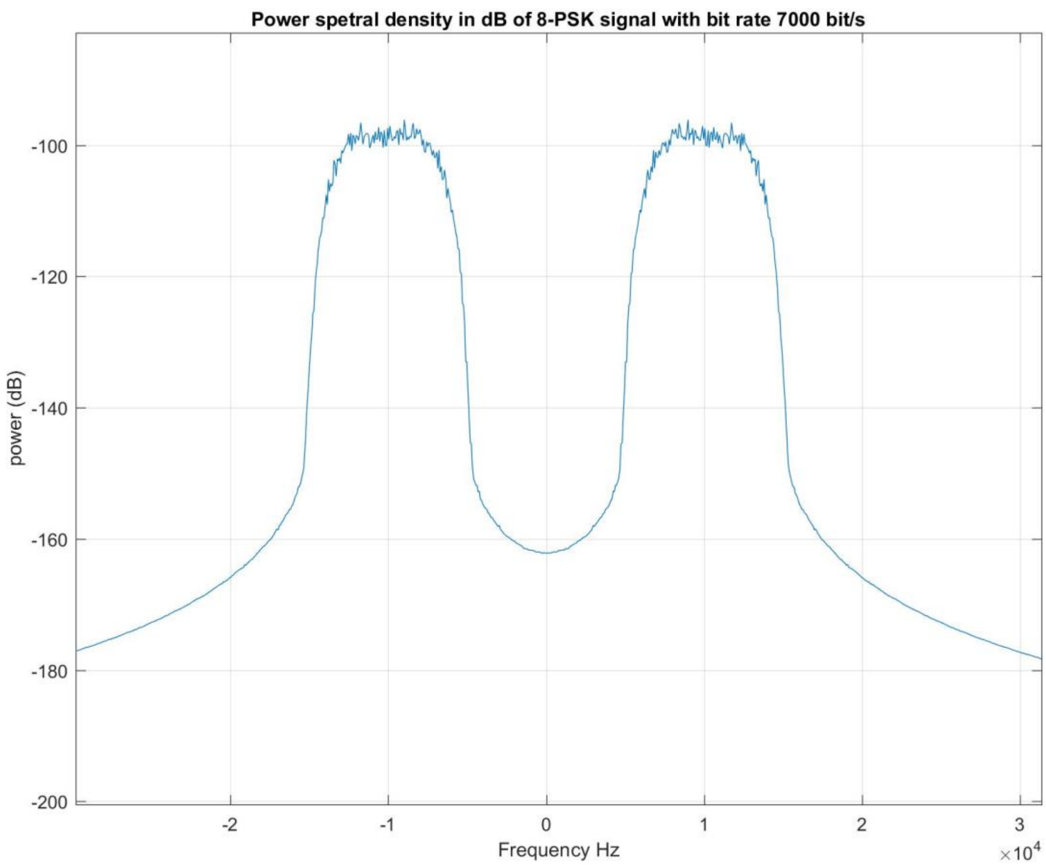

Figure 12 Power spectral density of modulated 8-PSK signal

Figure 12 shows the PSD of the signal. The spectra was centered at 10kHz, which was the carrier frequency as required, and the power at 5kHz higher or lower the center frequency is 50dB below the in-band signal power.

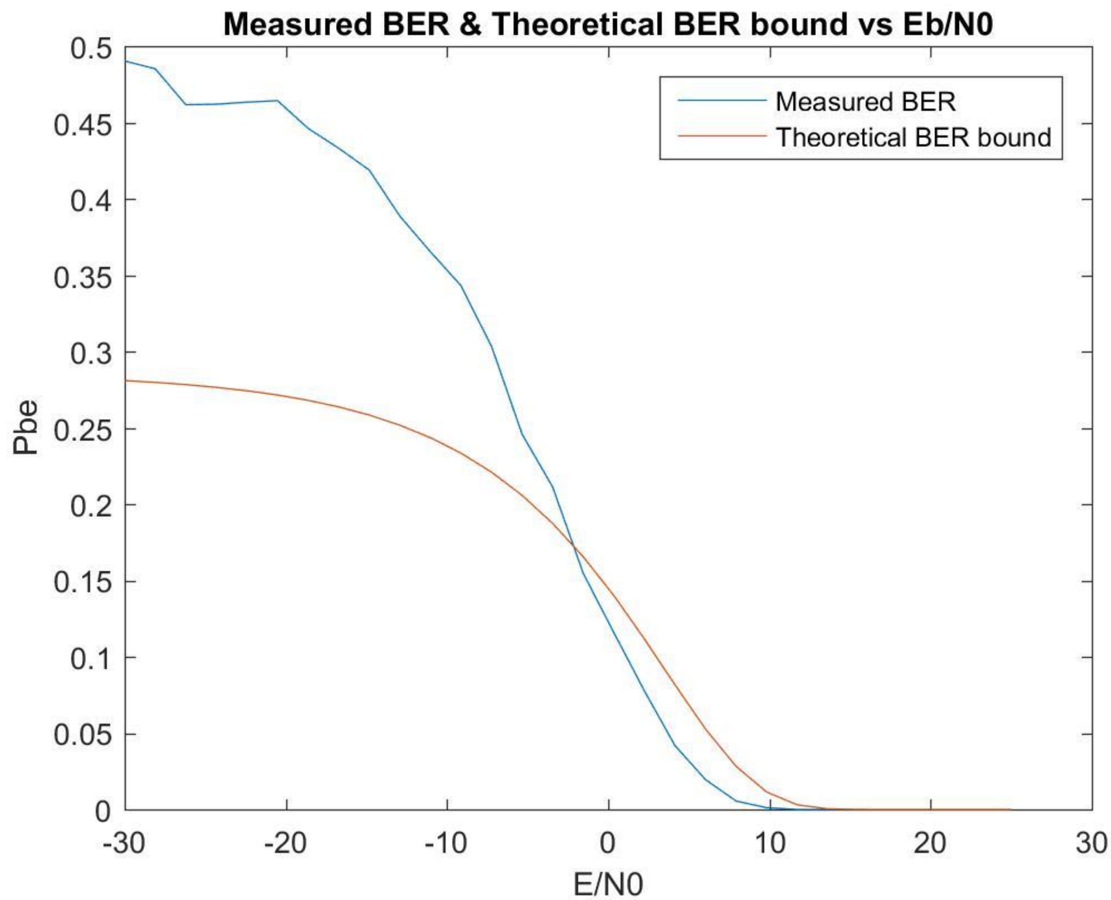

Figure 13 Measured and theoretical BER

Figure 13 shows the measure bit error rate and the theoretical BER bound for the 8-PSK modulation. The theoretic bound failed to work for low Eb/N0 value, but for Eb/N0 > 0 dB, it did set the bound of the

BER.

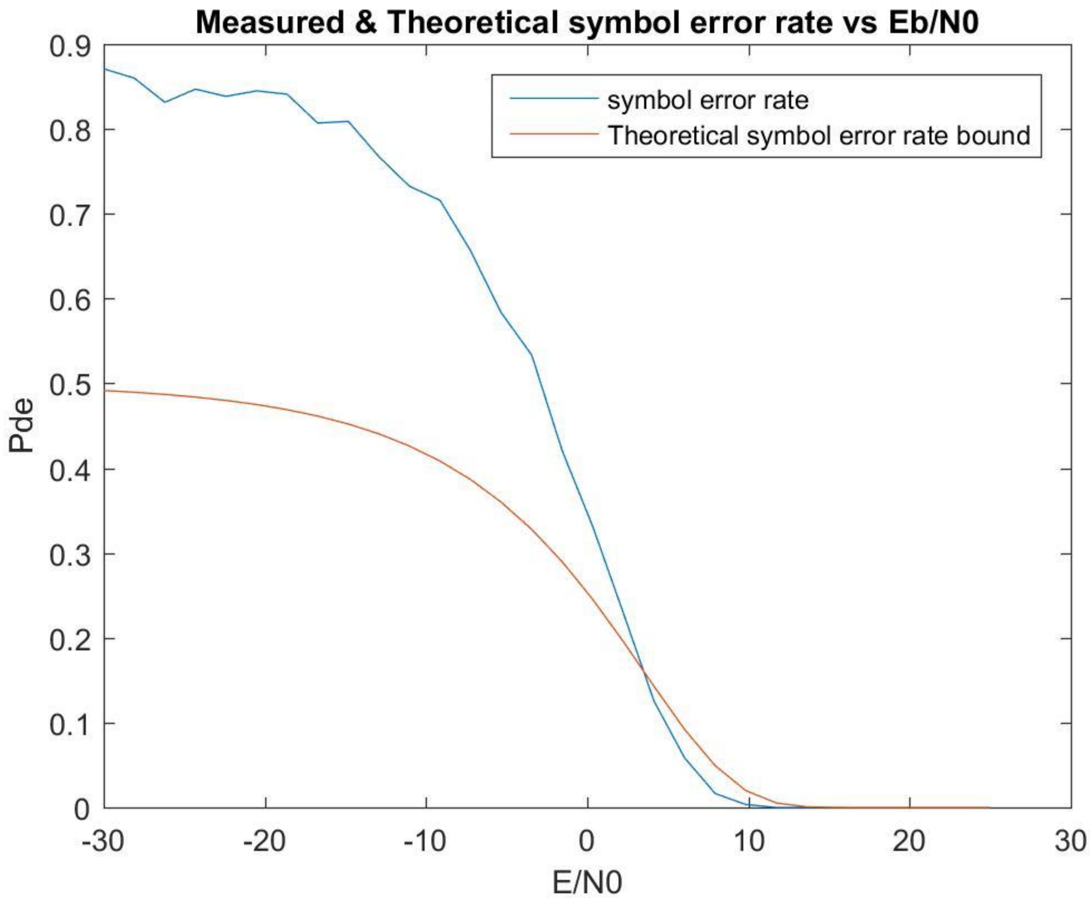

Figure 14 Measured and theoretical symbol error rate

Figure 14 shows the measured symbol error rate and the theoretical symbol error rate bound for the 8-PSK modulation. Unlike the bit error rate which has a maximum of 0.5, the highest value of symbol error rate is 0.875 since there are 8 different symbols for 8-PSK signal. The theoretic bound failed to work for low Eb/N0 value, but for Eb/N0 > 5 dB, it did set the bound of the symbol error rate.

Discussion

In this simulation, instead of using a phase modulator, two carriers were used to represent the component of the complex envelop. [4] The bandpass signal was formed by subtracting the two out-of-phase signal and they were recovered from the bandpass signal at the receiver using the orthogonality of sine and cosine. This approach is equivalent to the method that uses phase changes, but simplified the code to some extent.

Because the RCRO pulses have an absolute bandwidth, the PSD curve has a sharp cutoff frequency and most energy was concentrated inside the band. The bit rate R can be adjusted to adapt to bandwidth specifications of the channel.

The symbol errors, shown in red on the constellation plot in the simulation, started to increase quickly when Eb/N0 is smaller than 10dB. However, since one symbol consists of three bits, the bit error rate performance of the 8-PSK modulation technique still outperformed BPSK. Comparing the measured bit error rate to the theoretical bound, we can verify that the receiver was optimized and the matched filter is indeed the optimal receiver.

In bit error rate measurement, it is hard to measure the error rate for high Eb/N0 because it takes a lot of bits for an error to appear. Using too many bits will make the program unable finished running in a reasonable time.

Conclusion

The main purpose of this simulation is to visualized the process of 8-PSK modulation, and illustrate the signal constellation as well as the effect of noise, which was inevitable in practice. The processes and the outputs matches the theory described in the text book written by Couch and help to understand the intuition behind the digital communication system.

References

[1] D. Barragán, "ASK, OOK, FSK, BPSK, QPSK, 8PSK modulations.," 24 March 2007. [Online]. Available: http://www.mathworks.com/matlabcentral/fileexchange/14410-ask--ook--fsk--bpsk--qpsk--8 psk-modulations. [Accessed 2016].

[2] S. Jacobs, "8-PSK Simulation," [Online]. Available: https://courseweb. pitt.edu/bbcswebdav/pid-20270142-dt-content-rid-16531862_2/courses/2164_UPITT _ECE_1473_SEC1030/2134_UPITT_ECE_1473_SEC1030_Imported Content_20130103100340/Course%20Documents%20QPSK%20and%208-PSK%20Simulations/eight_psk_sim_1.pdf. [Accessed 2016].

[3] S. Jacobs, "EE 1473 - Digital Communication Systems CourseWeb," [Online]. Available: https://courseweb.pitt.edu/bbcswebdav/pid-20270121-dt-content-rid-16728413_2/courses/2164_UPITT_ECE_1473_SEC1030/ee1473_hw3%281%29.pdf. [Accessed 2016].

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