Lab # 1: Introduction to the Basic Digital Baseband Communication Systems through Numerical Implementation

# Objective

The objective of the lab is to introduce the basic digital baseband communication systems through computer simulations. The students will be familiar with the following items:

* Transceiver design:
  + Modulation and demodulation.
  + Pulse shaping and waveform generation.
  + Match filtering.
  + Signal detection and estimation.
* Performance evaluation of the communication systems in the presence of noise through various measurement techniques and tools:
  + Bit-error-rate versus signal-to-noise-ratio.
  + Spectrotemporal analysis.
  + I-Q constellation and I-Q polar plots.
  + Eye diagram.
  + Statistical signal analysis.
* An introduction to impairments:
  + AWGN
  + Phase offset
  + Frequency offset

# Pre-lab

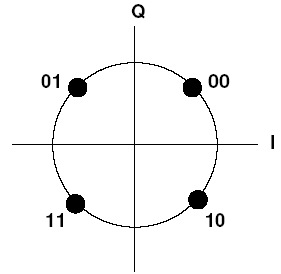
* Revise the Gray mapping concept in QPSK modulation and Rectangular pulse shape
* Go to (<https://matlab.mathworks.com/>) website and get familiar with MATLAB® using the tutorials.
* Run MATLAB® and try to understand the following functions:

# *randn, repmat, reshape, kron, upfirdn, conv, length, size, sqrt, plot, semilogy, abs, angle, sum, mean, subplot, pwelch, fft, fftshift, scatterplot, eyediagram, real, imag, hist, and hist3.*Procedure

***Use the code:*** ***Lab1\_Basic\_digital\_comm\_setup.m***

1. ***MODULATION***

QPSK is a type of phase modulation where every two bits are represented by one symbol. Two of the most common QPSK constellations are shown below.



**Figure 2**

**Figure 1**

Q

I

**00**

**10**

**11**

**10**

These are not the only possible constellations for QPSK, but the most common ones which are deployed in practice.

1. Identify the modulation part of the code. Understand how the modulation/mapping is performed.
2. Observe the constellation diagram.
3. For the first 6 symbols, compute the real and imaginary parts as well as magnitude and phase (please, explain the unit of the phase).
4. ***PULSE-SHAPING (BASEBAND FILTERING)***

In digital communications, pulse shaping filters are used to generate the waveform of the transmitted signal. By pulse shaping, the transmission bandwidth and the inter-symbol interference is kept under control. Root-raised cosine, Gaussian, and rectangular are some of the filter types commonly used in digital communications for pulse shaping. These terms will be explained further in the subsequent experiments.

1. Identify the part of the code where the filtering is performed.
2. Understand how pulse shaping is realized using MATLAB® functions.
3. Plot the real and imaginary parts of the first 6 symbols and the corresponding transmitted signals (i.e., the output of the filter). Comment on the filter type that is used in transmission.
4. ***NOISE GENERATION***

Noise is an unwanted effect in any kind of communication system which distorts the original signal. Noise in communication systems is usually modeled by the Gaussian distributed random process.

1. Identify the part of the code where noise is generated and added to the original signal.
2. Compute the power of the noise and the received signal. Find the signal to noise ratio (SNR), compare it with the desired value and check if they are the same or not. What is the reason for this behavior?
3. Use *histogram()* command to plot an estimate of the probability density function (pdf) of the real and imaginary parts of the noise. Briefly comment on the probability density function (PDF). What does a value on the y-axis tell you about the noise?
4. Use *hist3()* command to plot the joint PDF of the complex noise vector (i.e. both real and imaginary parts of the noise). Please, interpret the plot.
5. Use *xcorr()* command to plot the correlation of noise. Briefly comment on the correlation of noise samples. What does the correlation tell you about the noise spectrum?
6. Compute mean and variance of the noise by using *mean()* and *var()* commands and compare your results with part Q3 and Q4.
7. ***ANALYSIS OF THE RECEIVED SIGNAL***

Signal analysis can be performed in time, frequency, modulation and code domains. For example, frequency analysis can be done through Fourier transform for deterministic signals and through some other spectrum estimation methods like Welch for random signals. Moreover, plotting constellation, polar, and eye diagrams provide modulation analysis.

1. Identify the part where the frequency spectrum of the signal is plotted.
2. Identify main and side lobes and comment on them. What is the reason for observing sidelobes?
3. What is the null-to-null bandwidth of the signal? How is it related to symbol duration?

1. Which parameters can change the signal bandwidth? Which parameters can change how the bandwidth could be used more efficiently?
2. Plot real and imaginary parts of the first 6 symbols of the received signal and compare it with the results of Q2.
3. Identify the part of the code where the constellation diagram of the received signal is plotted.
4. Briefly interpret the effect of the noise on the constellation diagram. Comment on noise power and modulation order relationship.
5. Identify the part of the code where the polar diagram is plotted. Observe how the transition between the symbols takes place.
6. Briefly comment on the polar diagram. What factors affect the transitions between symbols?
7. Identify the part where the eye diagram is plotted.
8. Briefly comment on the eye diagram.
9. For the SNR values of [0, 3, 5, 10], obtain constellation, eye, and polar diagrams, power spectrum, and time (real and imaginary part) domain signal plots. Make a brief comment on the plots considering the change in SNR.
10. ***DETECTING THE SIGNAL***
11. Develop a detector algorithm for the received noisy signal and calculate BER.
12. Obtain BER vs. SNR curve for the following SNR values: [0, 3, 5, 10] dB. Also, briefly comment on the plots.
13. Write a simple routine to calculate the symbol error rate and obtain SER versus SNR, then compare it with BER versus SNR. Briefly comment on your findings.
14. ***FREQUENCY OFFSET***

This section introduces the frequency offset on the received signal. Any frequency misalignment between transmitter and receiver affects signal spectrum, constellation, and polar diagrams.

***Use the code: Lab1\_FrequencyOffset.m***

For an SNR value of 100 dB, run the script and observe the plots for a carrier frequency of 25 Hz.

1. Compare it with 0 Hz carrier frequency. Comment on the constellation, polar and eye diagram as well as spectrum.
2. Change the carrier frequency to -115 Hz. Observe the plots again. Comment on the constellation, polar and eye diagram as well as spectrum.

# References

* Lecture notes
* Contemporary Communication Systems Using Matlab, J. G. Proakis, M. Salehi, and G. Bauch, Publisher: Thomson, ISBN:0-534-40617-3
* 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on channel model for frequencies from 0.5 to 100 GHz (Release 16)