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

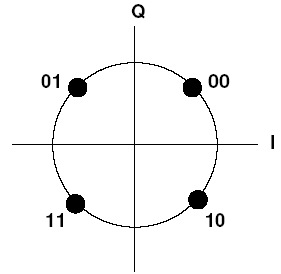
* Revise the Gray mapping concept in QPSK modulation and Rectangular pulse shape
* Go to (<https://matlab.mathworks.com/>) website and get familiar with MATLAB® using the tutorials.
* Run MATLAB® and try to understand the following functions:

# *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).

Mod\_symbols(1:6); real and imaginary

-0.7071 + 0.7071i 0.7071 - 0.7071i -0.7071 - 0.7071i -0.7071 - 0.7071i 0.7071 - 0.7071i -0.7071 - 0.7071i

magnitude

abs(mod\_symbols(1:6))

1 1 1 1 1 1

Phases

phase(mod\_symbols(1:6))

2.3562 -0.7854 -2.3562 -2.3562 -0.7854 -2.3562

phase(mod\_symbols(1:6))/pi

0.7500 -0.2500 -0.7500 -0.7500 -0.2500 -0.7500

The symbols are the positions in degrees as follows

135, -45, -135, -135, -45, -135

real(mod\_symbols(1:6))

-0.7071 0.7071 -0.7071 -0.7071 0.7071 -0.7071

imag(mod\_symbols(1:6))

0.7071 -0.7071 -0.7071 -0.7071 -0.7071 -0.7071

1. ***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.

Real and imaginary parts







1. ***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?

Noise power = 0.0982

Signal power = 1.0987

SNR = 1.0987/0.0982 = 11.1895

The variation is due to lack of enough samples to statistically depict AWGN

1. 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?



1. 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.

A graph of a graph

Description automatically generated

1. 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?

The 

The noise spectrum shows that noise samples are highly independent of each other and that is why they have high correlation only at one point and that is when they are on top of each other that is when each value is correlated with its own value, but when different noise samples are correlated they give low correlation.

1. Compute mean and variance of the noise by using *mean()* and *var()* commands and compare your results with part Q3 and Q4.

Answer

Mean = -8.4050e-04

Variance = -3.6706e-04

1. ***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?

the main lobes has the highest power which is at 0dB while the sidelobes appear at lower powers the highest being around -13dB

Sidelobes occur due to emissions that are not at the central transmitting frequency, they are a leakage from the central frequency to nearby frequencies, they can be reduced by choosing proper filtering techniques to contain the power in the central frequency, one famous technique for rectangular shaped filters is adjusting the alpha

A graph of a power spectrum

Description automatically generated

1. What is the null-to-null bandwidth of the signal? How is it related to symbol duration?

Null to Null bandwidth is 1000

Symbol duration = 1e-3

1. Which parameters can change the signal bandwidth? Which parameters can change how the bandwidth could be used more efficiently?

Parameters that change the signal bandwidth are Symbol rate and oversampling ratio

Using higher modulation although this can come at the cost of higher power or signal to noise ratio

Increasing signal to noise ratio as stated above but this is normally not desired

Increasing transmitting paths spatial diversity could improve bandwidth utilization also

Using robust pulse shaping techniques that will be resistant to channel effects

1. Plot real and imaginary parts of the first 6 symbols of the received signal and compare it with the results of Q2.

Plots for the Imaginary parts of the first 6 symbols of the signal

A graph of a function

Description automatically generated with medium confidence

Plots for the real part of the first 6 symbols of the signal

A graph of a graph of a graph

Description automatically generated with medium confidence

As observed in the plots, the amplitudes of the signal is affected by the noise, it goes both ways that some of the part of the signal are affected additively and some are subtractive and this is because of the nature of AWGN noise which has a mean zero and variance which varies around the mean both ways

1. Identify the part of the code where the constellation diagram of the received signal is plotted.
2. Briefly interpret the effect of the noise on the constellation diagram. Comment on noise power and modulation order relationship.

A diagram of blue dots

Description automatically generated

The noise causes symbol to have increased or decreased power depending on corresponding noise power levels, this causes the received symbols to be displaced from ideal power positions as follows,

1. Some are affected more on Imaginary part which can cause vertical displacement from the ideal position
2. Others are affected more on the real part which causes horizontal displacement from the ideal positions
3. Others have proportionally been affected in imaginary and real parts which can cause displacement both in vertical and horizontal positions
4. Some suffer less distortion and hence fall within ideal power levels.

The higher the noise power, the more displacement happens on the constellation diagrams and the more difficult it will be in associating the received symbols to their correct places, this may further lead to wrong detection and subsequently errors.

Higher modulation involves tight packing of constellation points which increases the possibility of symbols from different constellation points being close together hence making it more difficult to associate received symbols to their correct constellation points.

1. Identify the part of the code where the polar diagram is plotted. Observe how the transition between the symbols takes place.
2. Briefly comment on the polar diagram. What factors affect the transitions between symbols?

A graph of a diagram

Description automatically generated with medium confidence

Noise vectors introduce displacement from the original paths and positions such that the symbols do not take the same path at the receiver as they do at before being transmitted through the noisy channel.

This means the magnitude and phase of each symbol is affected which alters the incident and departure angles and thus the patterns are not aligned due to different phases and magnitude.

1. Identify the part where the eye diagram is plotted.
2. Briefly comment on the eye diagram.

A screenshot of a graph

Description automatically generated

The eye diagram shows that the amplitude of the received signal ıs affected this can be observed due to the height of the eye, when compared to tx signal the height of the rx eye ıs smaller, that ıs caused by the noise.

As for the wıdth ıs not as much effected, and this because we donot have anything to cause time jıtter or delay ın our channel

1. 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.
2. ***DETECTING THE SIGNAL***
3. Develop a detector algorithm for the received noisy signal and calculate BER.
4. Obtain BER vs. SNR curve for the following SNR values: [0, 3, 5, 10] dB. Also, briefly comment on the plots.
5. 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.
6. ***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)