# Wireless Communication Systems Laboratory
# Lab#1: An introduction to basic digital baseband communication through MATLAB® simulations

## Objective

The objective of the first lab is to introduce a basic digital communication system through MATLAB® simulations. The students will be familiar with the following items:

- Waveform generation.
- Signal detection.
- Evaluating various plots to quantify the performance of basic digital communication systems: Bit-error-rate versus signal-to-noise-ratio, power spectrum, power versus time, constellation plot, polar plot, and eye diagram.
- Performance evaluation of the communication systems in the presence of noise.
  - A system in AWGN channel with a simple QPSK modulation and rectangular pulse shaping filter.
  - Polar, constellation, eye diagram before sampling.
  - BER vs. SNR.
  - Mean, variance, histogram, PDF, and CDF analysis through MATLAB®.
  - The concepts of independence and correlation.
  - Basic Fourier transform and power spectrum of a signal.
- Carrier shifting the signal to intermediate frequency (also introducing carrier frequency offset).
- Introducing phase offset and observing the effect on the communication systems.

EEL 6936 - Wireless Communication Systems Lab.

## **Pre-lab**

- Go to Mathworks website and get familiar with MATLAB® using the tutorials.
- Run MATLAB® and try to understand the following functions (MATLAB help menu or online help could be useful).
  - *randn*
  - *repmat*
  - *reshape*
  - *length*
  - *size*
  - *sqrt*
  - *plot*
  - *semilogy*
  - *abs*
  - *sum*
  - *mean*
  - *subplot*
  - *pwelch*
  - *fftshift*
  - *scatterplot*
  - *eyediagram*
  - *real*
  - *imag*
  - *hist*
  - *hist3*
- Explain additive white Gaussian noise (AWGN).
- Consider a random signal with the mean of 1 and the variance of 2. What is the power of this signal? How do you calculate signal power in MATLAB®?
- How do you use *fftshift()* with *pwelch()* in MATLAB®? Give an example.

# Procedure

*Use the code: Lab1_Basic_digital_comm_setup.m*

### A. 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.
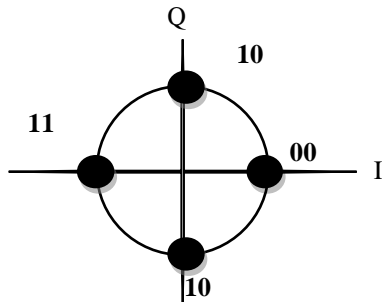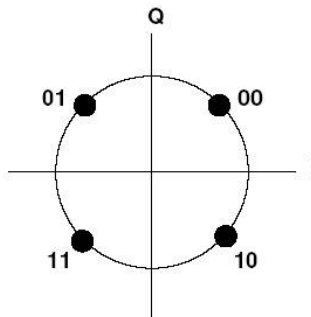


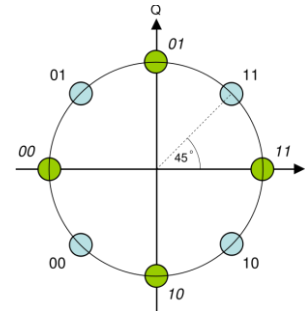**Figure 1**



**Figure 2**



**Figure 3**

Some techniques were proposed in order to minimize the bit error probability. For example: in Figure 3, the dibit '11' is represented by phase of 0° or 45°, the dibit '01' is represented by phase of 90° or 135°, the dibit '00' is represented by phase of 180° or 225°, and the dibit '10' is represented by phase of 270° or 315°.

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.

**Q1.** For the first 6 symbols, compute the real and imaginary parts as well as magnitude and phase (please, explain the unit of the phase).

### B. PULSE-SHAPING (BASEBAND FILTERING)

In digital communications, pulse shaping filter is 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, rectangular, and sinc are some of the filter types commonly used in

digital communications for pulse shaping. These terms will become explained further in the proceeding experiments.

3. Identify part of the code where the filtering is performed.

4. Understand how pulse shaping is realized using MATLAB® functions.

**Q2.** Plot the real and imaginary parts of the first 6 symbols and the corresponding transmitted signals (i.e., output of the filter). Comment on the filter type that is used in transmission.

### C. 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 Gaussian distributed random process.

5. Identify the part of the code where noise is generated and added to the original signal.

**Q3.** Compute the power of the noise and the original transmission signal. Find signal to noise ratio (SNR), compare it with the desired value and check if they are the same or not. What is the reason of this behavior?

**Q4.** Use *hist()* 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?

**Q5.** 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.

**Q6.** 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?

**Q7.** Compute mean and variance of the noise by using *mean()* and *var()* commands and compare your results with part Q3 and Q4.

### D. 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 modulations analysis.

6.  Identify the part where the frequency spectrum of the signal is plotted.

**Q8.** Identify main and side lobes and comment on them. What is the reason of observing side lobes?

**Q9.** What is the null-to-null bandwidth of the signal? How is it related to symbol duration?

**Q10.** Which parameters can change the signal bandwidth and how the bandwidth could be used more efficiently?

**Q11.** Plot real and imaginary parts of the first 6 symbols of the received signal and compare it with the results of Q2.

7.  Identify the part of the code where the constellation diagram of the received signal is plotted.

**Q12.** Briefly interpret the effect of the noise on the constellation diagram. Make a comment on noise power and modulation order relationship.

8.  Identify the part of the code where the polar diagram is plotted. Observe how the transition between the symbols takes place.

**Q13.** Briefly comment on the polar diagram. What factors affect the transitions between symbols?

9.  Identify the part where the eye diagram is plotted.

**Q14.** Briefly comment on the eye diagram.

**Q15.** For the SNR values of [-5 0 5 10 100], 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.

### E. DETECTING THE SIGNAL

**Q16.** Develop a detector algorithm for the received noisy signal and calculate BER. Please, comment on the filter you used in receiver.

**Q17.** Obtain BER versus SNR curve for the following SNR values of [ -5 0 5 10 100 ] dB. Briefly comment on the plot.

**Q18.** Write a simple routine to calculate symbol error rate and obtain SER versus SNR, then compare it with BER versus SNR. Briefly comment on your findings.

### Use the code: Lab1_IF_Freq_offset.m

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

10. For an SNR value of 100 dB, run the script and observe the plots for a carrier frequency of 51.2 Hz.

**Q19.** Compare it with 0 Hz carrier frequency. Comment on the constellation, polar and eye diagram as well as spectrum.

**Q20.** Change the carrier frequency to 42.7 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