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**DIGITAL COMMUNICATIONS LABORATORY**

**Lab report #1: An introduction to basic digital baseband communication through MATLAB® simulations**

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**İNTRODUCTİON**

This report explains principal tasks that were achieved during the first lab on digital communication systems. The main goal of the lab was to enable students compile MATLAB codes of basic communication concepts and comprehensively examine fundamental behaviors of communication systems in the presence of noise, it also incorporates the design of a simple receiver. This workshop constitutes gradual preparation of students for the upcoming complex link level simulations. Some MATLAB script are presented in this report.

**A-)MODULATİON**

We used QPSK in First Lab, and QPSK, or Quadrature Phase Shift Keying, is a digital modulation scheme used in communication systems to transmit data over radio waves or other wired and wireless communication channels. It is a type of phase modulation that represents data by modulating the phase of the carrier signal.

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**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).**

**-**Phase unit is radian but we can change it to degree by multiplying with 180/pi we can find degree unit for first phase= 2.3562\*180/pi=135

A screenshot of a computer program

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First 6 real, imag, phase, angle parts of symbols

**B-)PULSE-SHAPİNG**

Pulse shaping refers to the process of modifying a digital signal's shape before transmission to improve its characteristics, especially in the context of communication systems. The goal of pulse shaping is to optimize the signal for efficient and reliable transmission through a communication channel. This is important because the characteristics of the channel can affect the quality of the transmitted signal.

**Q2-)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.**

We used rectangular filter in time domain. But we copy the data and repeat it with number of 16. As you can see from the figure below. So this rectangular filter contains 16 repeated data. Also there are a lot of filter, raise cosine, root-raise cosine, sinc, gaussian etc.

A graph of a graph

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**First 6 symbols**

**C-NOISE GENERATİON**

Noise in wireless communication refers to any unwanted and random interference or disturbances that can degrade the quality of the transmitted signals. Various factors contribute to the presence of noise in wireless channels, and managing or minimizing this noise is crucial for maintaining reliable and efficient communication.

**Q3-)** 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?

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**Signal Power is 1**

**Noise Power is 0.0975**

**SNR=10\*log(1/0.1009)=10.1119**

**Q4-)** **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?**

-The Probability Density Function (PDF) is a concept in probability theory and statistics that describes the likelihood of a continuous random variable taking on a specific value within a given range. Generally PDF has a bell curve shape and its has gaussian distribution(normal distribution).

-As we can see from figure mean is zero, y axis shows probability of each value of the random variable.

A graph of a graph

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Description automatically generated with medium confidence

**Histogram Real Part of Noise**  **Histogram İmag Part of 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.**

A graph of a pyramid

Description automatically generated

**İn 3D figure , we can see the real and imag part of the shape has gaussian distribution and their mean is 0.**

**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?**

A graph with a line

Description automatically generated

**Correlation of Noise**

-This figure shows us about cross-correlation of noise and, from figure we can understand there is no correlation between noise elements and we can understand they are independent from each other.

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

The result in Q3 and Q4 are closely the same with result obtained in Q7, also it is observed that the average power of the noise is equal to the variance.

A screenshot of a computer

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**D-) ANALYSIS OF THE RECEIVED SIGNAL**

**Q8-)** **Identify main and side lobes and comment on them. What is the reason for observing sidelobes?**

Sidelobes are lobes outside the main lobe,and these shape because of the rectangular pulse shape that we used, we have side lobes. As we know, rectangular in time domain, sinc in frequency domain. These sidelobes comes from sinc shape.

A graph of a graph

Description automatically generated

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

The "Null-to-Null Bandwidth" of an AM signal refers to the frequency range between the points where the amplitude of the signal drops to zero. It helps for determining to the frequency range.

Null to Null BW=f1-f2=1000-(-1000)=2000Hz

Symbol duration=1/2\*T=1/2\*2000=2.5 x 10^4

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

Modulation, symbol duration and signal frequency, the bandwidth can be used efficiently by error correction codes, which reduces the amount of retransmission required, thus saving bandwidth. Or by use of higher order modulation techniques to increase the amount of data that can be transmitted over a given bandwidth.

Number of samples per symbol significantly affect the bandwidth as can be seen in the two following figures. The bandwidth can be used more efficiently selecting the optimal sampling ratio.

A graph of a waveform

Description automatically generatedA graph of a power spectrum

Description automatically generated

As you can see by changing over sampling ratio Bw is changed left 1.5\*10^4k right one is just 2000k but null to null bw is same.

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

Comparison with Q2 real and imaginart parts of 6 symbols transmitted and received signal from figure. From this comparison, we can see the random fluctuations on the received real and imaginer part of the signal because of the noise. Because of these fluctuations we can see the errors when we are performing demodulation. İt means you are lose data but we can peform some error correction methods.

A graph of data on a white background

Description automatically generated with medium confidence

**Q12-)** **Briefly interpret the effect of the noise on the constellation diagram. Comment on noise power and modulation order relationship.**

Constellation diagram is a graphical representation used in digital communication systems to visualize and analyze the modulation of a signal. Analyzing a constellation diagram provides insights into how well a signal is performing in the presence of noise and other impairments. Ideally, the points should be well-separated and distinguishable, minimizing the likelihood of errors during demodulation. The number of points or symbols on the constellation diagram is determined by the modulation order. Higher modulation orders (e.g., 16-QAM or 64-QAM) have more points, allowing for the transmission of more bits per symbol but requiring a higher signal-to-noise ratio for reliable communication.

A diagram of blue dots

Description automatically generated

The more SNR means better constellation diagram, higher order modulation means you need to more SNR to differentiate between of the symbols. In this example SNR is 10dB.

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

The polar diagram forms a vector between constellation points of two consecutive symbols in the data stream. The direction of the vector is random because symbols are randomly generated, the magnitude of the vector is discrete for the original signal but random for the receive signal, this because the initial or original transmitted unit vector has been randomly modified by the noise.

A graph of a diagram

Description automatically generated

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

A diagram of a diagram

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Description automatically generated with medium confidence

From the figure above, it can be inferred that receiver does not collect the expected the signal amplitude this is based on the aspect that the two horizontal lines spread as compared to the one in eye diagram of original signal. We can see the noise effect from Rx eye diagram, it can be seen from amplitude fluctuations. The receiver should be designed to what we see from eye diagram also from others.

**Q15-)** **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.**

-These Power Spectrum, Real and İmag part of transmitted(blue one) and received(orange one) signal, Constellation, Polar diagram, Eye diagrams for Tx and Rx these tables for 0dB.

As can be understood with different db values, the effect of the SNR value can be clearly seen in the constellation and polar diagram. at low SNR values, it is not possible to distinguish which received signal belongs to where, while as the SNR increases, it becomes clear. also, while the eye diagram is difficult to distinguish at low SNRs, it becomes easier as the SNR increases. Impact of the noise is harmful for the communication. Low SNR means that the signal strength and noise power are getting closer and closer.

From the table according to SNR noise power is changing and with this Current true SNR is changing

Following simulation results is given at the next pages

|  |  |  |  |
| --- | --- | --- | --- |
| SNR | Signal Power | Noise Power | Current True SNR |
| 0 | 1 | 1.0038 | -0.0163 |
| 3 | 1 | 0.4985 | 3.0230 |
| 5 | 1 | 0.3185 | 4.9691 |
| 10 | 1 | 0.0992 | 10.0354 |

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| --- | --- |
| **0dB** | |
| A graph of a power spectrum  Description automatically generated | A graph of a graph of a graph  Description automatically generated with medium confidence |
| A diagram of a blue circle with red dots  Description automatically generated | A diagram of a diagram with a blue square and a blue square  Description automatically generated with medium confidence |
| A diagram of a sound wave  Description automatically generated with medium confidence | A graph of a diagram  Description automatically generated with medium confidence |
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| **3dB** | |
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| A diagram of a diagram  Description automatically generated with medium confidence | A diagram of a square and a square with blue lines  Description automatically generated |
| A graph of a diagram  Description automatically generated with medium confidence | A diagram of a diagram  Description automatically generated with medium confidence |
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| **5dB** | |
| A graph of a power spectrum  Description automatically generated | A graph of a diagram  Description automatically generated with medium confidence |
| A diagram of blue dots  Description automatically generated | A diagram of a diagram with a blue square and a white square  Description automatically generated with medium confidence |
| A diagram of a diagram  Description automatically generated with medium confidence | A diagram of a diagram  Description automatically generated with medium confidence |
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| **10dB** | |
| A graph of a power spectrum  Description automatically generated | A graph of a diagram  Description automatically generated with medium confidence |
| A diagram of blue dots  Description automatically generated | A diagram of a diagram  Description automatically generated with medium confidence |
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**Q16-) Develop a detector algorithm for the received noisy signal and calculate BER.**

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**Q17-)Obtain BER vs. SNR curve for the following SNR values: [0, 3, 5, 10] dB. Also, briefly comment on the plots**

When we increase the snr, that is, when we increase the signal strength, we can easily observe that the BER decreases, which was something we expected.

**A graph with numbers and a line

Description automatically generated**

**Q18-)** **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.**

With the increase in SNR, we see the same effect of BER decrease in SER. In short, increasing the signal strength allows you to transmit the signal better in the wireless environment.

**A graph with numbers and symbols

Description automatically generated**

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

-From the below diagrams, its noticed that he frequency offset generates circular change on the constellation diagram, it generates many eyes in the eye diagram and bounds polar diagram in a circular manner. Also frequency offset causes shift in the spectrum as we can see from the figures below differences between 0Hz and 25Hz. Also infer that the impact of the noise and impact of the frequency off set are appeantly different this is in comparison with result in question result in Q15.

-Also we can say frequency ofsett means you are multiplying your signal with a sinusoid, its like FM modulation

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| **Frequency Offset=25Hz** | **Frequency Offset=0Hz** |
| A graph of a circle with a red dot  Description automatically generated | A graph with red dots  Description automatically generated |
| A graph with a cross in the center  Description automatically generated | A diagram of a square with a cross in the center  Description automatically generated |
| A graph of a graph showing a number of different colored lines  Description automatically generated with medium confidence | A graph of a number of lines  Description automatically generated with medium confidence |
| A graph of a sound wave  Description automatically generated | A graph with numbers and lines  Description automatically generated |
| **A graph of a power spectrum  Description automatically generated** | **A graph of a power spectrum  Description automatically generated** |

**Q20-) Change the carrier frequency to -115 Hz. Observe the plots again. Comment on the constellation, polar and eye diagram as well as spectrum.**

-When we look the different frequency offsets we can see the circular shifts from different the constellation diagrams and polar diagrams ,and also and what it's causing. From spectrum we can see the shift value and differences between 0Hz, 25Hz, -115Hz. Also, eye diagram there are a lot of fluctuation, It's so complicated that we can't choose properly the shapes.

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| **Frequency Offset= -115Hz** | |
| A graph of a circle  Description automatically generated | A diagram of a circle with lines and points  Description automatically generated |
| A graph of an amplification  Description automatically generated | **A graph of an audio spectrum  Description automatically generated with medium confidence** |
| **A screen shot of a graph  Description automatically generated** | |

**Conclusion**

In this lab, we have seen the use of simple matlab, what the frequency offset causes, what the SNR causes and what it changes, we have also designed receivers and calculated BER, SER and compared them with SNR. We modelled them by generating random bits. then we saw the effects of noise by filtering them and adding noise to them. Afterwards, we saw the effects from eye diagram, constellation, polar diagram, power spectrum.