CS-330 Assignment 3
Modulation, Channel Impairments

Deadline: 4/12/2024 23:59 via turnin

20 November 2024

General Information

The goal of this assignment is to become familiar with different modulation schemes, the impact of noise and frequency offset, as well as pulse shaping.

Exercise 1

In this exercise you will investigate Amplitude Modulation. Because this exercise is quite CPU intensive, free as many system resources as necessary before doing your final testing and don't forget to throttle your flowgraphs.

1. Create a new flowgraph (**lab3_1_transmitter.grc**) that has sampling rate of 384 KSPS (384000 samples/sec). Note: If your computer doesn't support this high a sampling rate, select a supported sampling rate and use that.

2. Use a **Wav File Source block** to read a WAV file sampled at 48 kHz. This will be your source stream. For convenience you can use the provided audio file.

3. Use the **Repeat** block to increase the duration of every sample from the source block, so that the sampling rate is 384 kHz. Explain how you chose this value.

4. Plot the resulting signal at a **Time Sink** with the target sampling rate equal to 384 KSPS.

   Now you are going to modulate and transmit this signal using Amplitude Modulation. The mathematical formula for the AM is:

$$y(t) = A\left[1 + \mu x(t)\right]cos(2\pi f_c t)$$

   where $y(t)$ is the modulated signal, A the amplitude, μ the modulation index, $x(t)$ the input data signal with the proper symbol duration and f_c the carrier frequency.

5. Modulate the signal that you have constructed with AM using the following parameters:

   - $A = 1$
   - $\mu = 0.8$
   - $f_c = 150kHz$

   Use a **Time Sink** to plot both the modulating and the modulated signal on the same graph. 📷

6. Research the bibliography and report what the modulation index is. Try different values and report what do you observe.

7. Add a **ZMQ PUB Sink** block. This block creates a socket where other flowgraphs can connect to receive the stream supplied. Set the address to "tcp://127.0.0.1:50001".

We will now build the receiver.

8. Create a second flowgraph (**lab3_1_receiver.grc**) and add a **ZMQ SUB Source** block. This block connects to the socket that the **ZMQ PUB Sink** created earlier. Set the address to "tcp://127.0.0.1:50001". Also, set "samp_rate" to 384 kHz. From now on, we will work on this new flowgraph.

9. In the transmission process you have introduced extra samples in the stream. Now you have to remove them. What is the decimation factor you have to use? Let that be DECIMATION.

10. Add a **Frequency Xlating FIR Filter**. This block performs three functions: frequency translation, filtering, and decimation. Set the following parameters:

    - Type: Float->Complex (Real Taps)
    - Decimation: DECIMATION
    - Taps: firdes.low_pass(1,samp_rate,samp_rate/(2*DECIMATION), 2000)
    - Center Frequency: 150 kHz
    - Sample Rate: samp_rate

    Explain in short why each function of the block is necessary.

11. The output of the previous block is complex numbers. Their magnitude is proportional to the input. Based on that, add a block to convert the complex output to a float. Pass this through a filter to only keep frequencies between 1 and the maximum frequency in the modulating signal. This produces the original modulation signal. What is the cutoff frequency?

12. Use a **Audio Sink** to listen to the signal you have received. Also, use a **Frequency Sink** to show the spectrum of the signal. Be careful when selecting the sample rate of the Sinks. If you have done everything correctly, you should hear the music correctly. 📷

13. Congratulations, you now have a functioning AM transceiver!

Exercise 2

This exercise will help you to get familiar with the modulation and constellation, as well as the impairment of noise. For this assignment you will use the **lab3_2.grc** flowgraph.

1. The *lab3_2.grc* flowgraph uses a BPSK modulation that maps data into constellation points. There are two sliders. The first controls the amplitude of noise, whereas the second inserts a Carrier Frequency Offset (CFO) at the system. Ignore the CFO slider for now. Play with the noise slider by adjusting its value and **report** what you observe. How does are the constellation points affected?

2. Modify properly the flowgraph in order to support other modulations schemes too. More precisely the flowgraph should support:

   - BPSK
   - QPSK
   - 16-QAM
   - 64-QAM

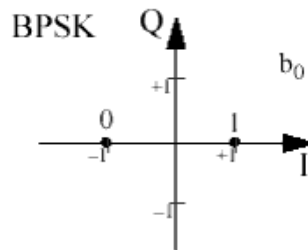   The constellation point mappings are depicted at Figures 1-4.
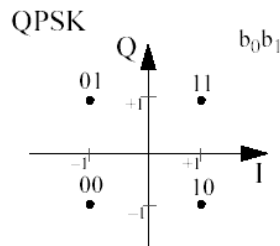

Figure 1: BPSK constellation points

Figure 2: QPSK constellation points

3. You may observe that the maximum IQ amplitude of each modulation scheme is different. This means that the mean energy of each modulation scheme is different. In general this is not desirable. For this reason, perform normalization at the constellation points of each modulation scheme. The normalization factors can be retrieved from the table below. Report a screenshot for each one of the modulations.

Modulation	Normalization factor
BPSK	1
QPSK	$1/\sqrt{2}$
16-QAM	$1/\sqrt{10}$
64-QAM	$1/\sqrt{42}$

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16-QAM

Q $b_0b_1b_2\,b_3$

00 10	01 10	11 10	10 10
00 11	01 11	11 11	10 11
00 01	01 01	11 01	10 01
00 00	01 00	11 00	10 00
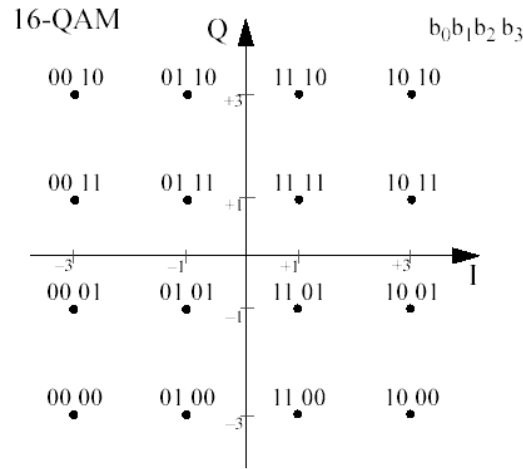
Figure 3: **16-QAM constellation points**

64-QAM

Q $b_0b_1b_2b_3\,b_4b_5$

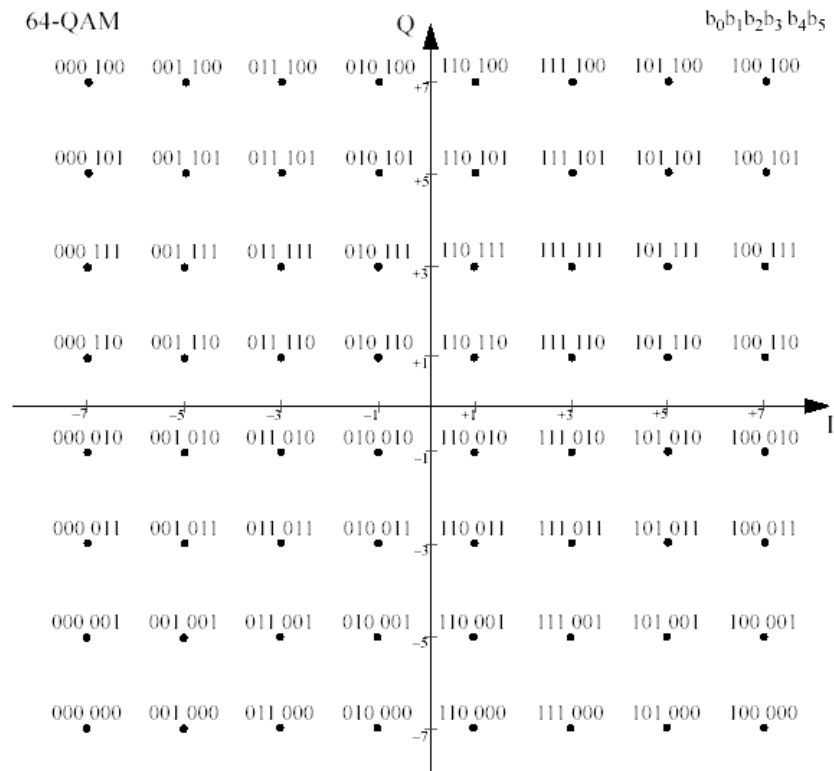|							
000 100	001 100	011 100	010 100	110 100	111 100	101 100	100 100
000 101	001 101	011 101	010 101	110 101	111 101	101 101	100 101
000 111	001 111	011 111	010 111	110 111	111 111	101 111	100 111
000 110	001 110	011 110	010 110	110 110	111 110	101 110	100 110
000 010	001 010	011 010	010 010	110 010	111 010	101 010	100 010
000 011	001 011	011 011	010 011	110 011	111 011	101 011	100 011
000 001	001 001	011 001	010 001	110 001	111 001	101 001	100 001
000 000	001 000	011 000	010 000	110 000	111 000	101 000	100 000

Figure 4: **64-QAM constellation points**

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4. For each one of the modulations report the maximum possible noise amplitude that can be achieved without errors. Without a demodulator this value can not be precise so you can just provide an empirical estimation. Compare your findings and provide a brief explanation.

5. Alter the flowgraph of the previous task, in order to support 16-PSK modulation too. Assuming that one of the constellation points is the $(1+0j)$ find the others. How did you compute the coordinates of the rest of the constellation points? Provide a screenshot of the constellation.

6. Compare the spectrum of 16-PSK and 16-QAM. What do you observe?

Exercise 3

Now we will repeat the last exercise with the Carrier Frequency Offset (CFO) impairment. CFO is a common hardware impairment between the TX and RX device and telecommunication standards should always deal with it.

1. How does CFO affect the constellation points?

2. How is each of the modulations affected? Is there any similarity with the previous exercise or not? Discuss.

3. Compare the 16-PSK with the QPSK, regarding the immunity in noise and CFO.

About Submission

The submission of the Assignments will be done through the **turnin** process. If needed, more info will be sent to the list prior to the deadline. You can turnin this assignment until **Wednesday 4/12 23:59**. Use the command below:

turnin assignment3@hy330 <dir>

You should provide a report as a **single pdf file**, containing your comments, screenshots or anything that you believe will be helpful for your grading. Also include any .grc files that you have created or changed.

About Oral Examination

All the students who have submitted their exercises are requested to attend the oral exam session, in order to present their solutions. A short quiz will also take place during that time. You will need to choose a timeslot for the oral exam using Doodle. More details will be sent to you via email.

Attention

- Each student will only be examined during the timeslot chosen.

- During this session both the Assignments 3 and 4 will be examined.

- Both the timely submission and the oral exam session will contribute to the grading of the assignment.