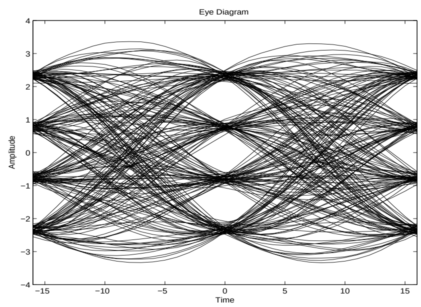
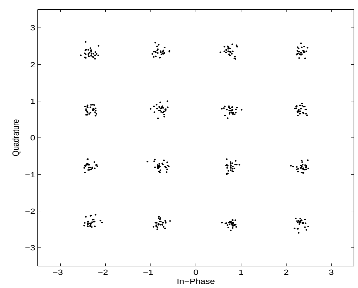
Experiment # 4

Quadrature Amplitude Modulation (QAM)





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1 Purpose

In this experiment you will implement 16-QAM and study eye the relevant eye pattern and constellation diagram ("scatter plot"). This experiment will be comprised of simulation steps only, due to its complexity. At the end of this experiment, you should have a better understanding of:

- Pulse Amplitude Modulation and Quadrature Amplitude Modulation and their demodulation;
- Constellation diagrams, and eye patterns for signals with multiple pulse amplitudes;
- Phase and noise features present in the received signal;

2 Background Reading and Preparation

Further reading about this topic can be found in [1]. This lab assumes that you are familiar with the concept of an eye pattern (or eye diagram), which was introduced in the prerequisite course ECE316. A simple search for ”eye pattern” will provide you with good explanations and examples.

3 Experiment

The approach taken this time will be “design and simulate” only. The design should follow closely lab preparation. The model to be worked on is supplied under `C:/ECE417_2018/Lab04_QAM`, to make your life easier.

3.1 Pulse Amplitude Modulation

Your first challenge is to figure out how many bits you will need per symbol if you are to design a basic 16-QAM system. After you convert your signal of interest to bits, you will group those bits in symbols and manipulate them appropriately to obtain a pulse amplitude modulated (PAM) signal, as Figure 1 indicates. This will be the PAM subsystem of your QAM transmitter.

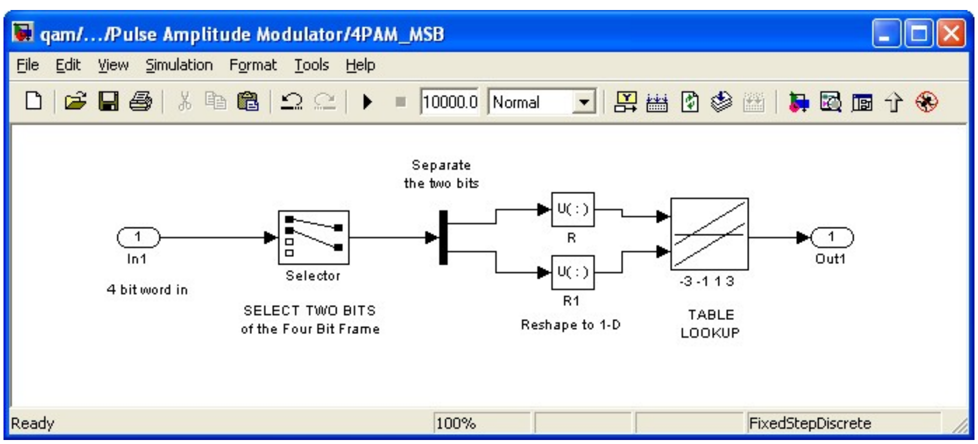

Figure 1: Pulse Amplitude Modulation Subsystem (for the two most significant bits)

The PAM signal is achieved by mapping the groups of bits to different levels with the use of a table. For instance, if the two input bits are ${}_b00$, the table will map to an output of -3, ${}_b01$ to -1, ${}_b10$ to +1 and ${}_b11$ to +3. The 16-QAM model provided to you has a PN sequence generator as a bit-source, which generates “frames” of 4 bits (zeros and ones), followed by two PAM sub-system, one for each half of the incoming 4 bit word.

3.2 In-Phase and Quadrature

The QAM system provided to you has a transmitter portion and a receiver portion, with a channel in between. The channel this time will **not** insert any bandwidth limitation, but it will insert noise and phase distortion. There are two signal paths on the transmitter: in-phase and quadrature, which will appear also on the receiver.

The basic block of the 16-QAM transmitter is comprised by two PAM subsystems generating bit streams in two separate paths, as Figure 2 displays.

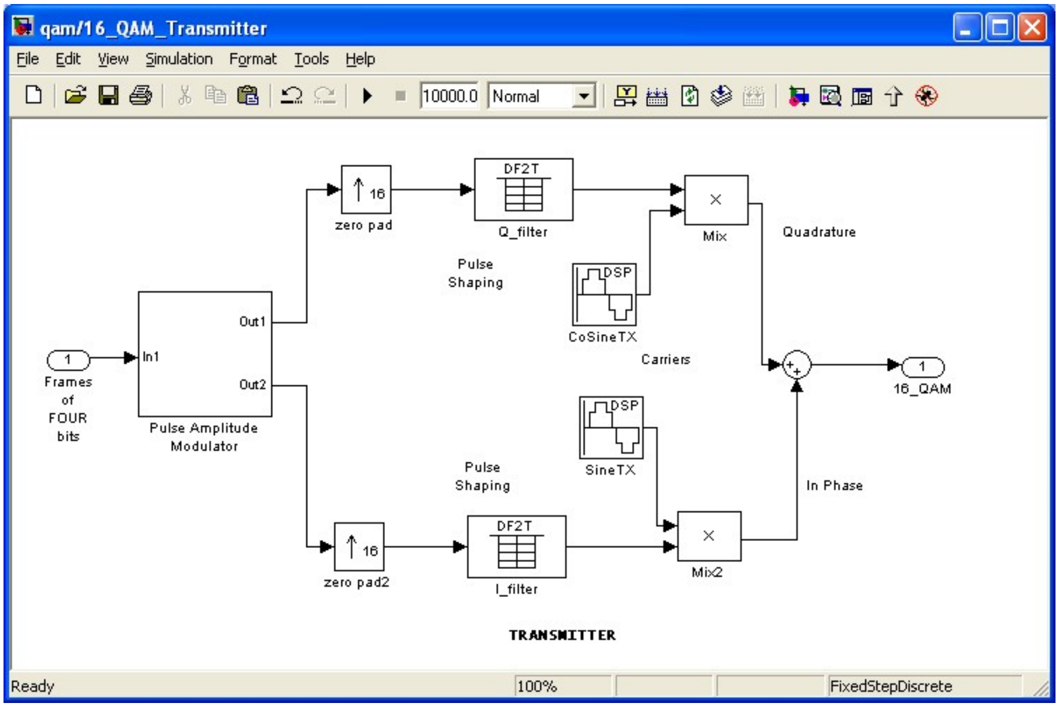

Figure 2: QAM Transmitter

The incoming bit stream to the PAM subsystems is divided in frames of 4 bits. The two MSBs are passed through one of them, resulting in a sequence of 4 different values after the table lookup. The two LSBs are passed through the other PAM subsystem. The output of each PAM subsystem will eventually form the in-phase and quadrature signals on the transmitter. The sequences are then interpolated (padded) with zeros and passed through the pulse-shaping filter, in order to mitigate any bandwidth limitations imposed by the channel (i.e., the rate is slowed down to fit into less channel bandwidth). Finally, each of these signals is mixed with its respective carrier. The carriers are 90 degrees apart, ensuring the orthogonality of both signals as they go into the channel after they are added.

A brief inspection of the complete model provided to you will show you that the whole system is comprised of a transmitter (as shown on Figure 2), a channel and a receiver. The channel provided simply adds noise and/or phase delay, according to the switches you select. The receiver feeds the incoming signal first to two mixers with sine and cosine carriers. The path then leads to matched filters, a slicer and decision-making block. The resulting eye pattern and constellations are formed from the output of this block.

Both transmitter and receiver will need their respective pulse-shaping and matched filters, which you are to design using the filter design tool (`FDA Tool`). Your best option is to type **`fdatool`** at the **`Matlab`** prompt. When you are done with the filter specifications, go under file/export (top-left corner on the tool) and give a name to your filter. This name is used in the **`Matlab`** workspace as a variable and must be used on the filter blocks on the QAM system to call your filter. If you export it as variable **`a`**, make sure all the filter blocks on the QAM system will be calling variable **`a`**. This will be done from the **`Direct Form II Transposed`** block (double-click on it and you will see). By defining your filters as a variable in the workspace, it will save you a lot of time.

Your task now is to design two Square-root raised-cosine filters which will be suitable to the system. You will experiment with 90% and 50% excess bandwidth. You have to choose the appropriate order and to figure out your Nyquist bandwidth for these filters. Remember, you have a sampling rate of 48KHz for this model, and there are zeros being interpolated to slow the rate down. On Figure 2, for instance, the interpolation is done by a factor of 16.

- *What is the advantage of using QAM instead of PAM?*

Prepare your QAM system to use the 90 percent excess bandwidth filters. Set the channel block to zero noise and zero phase distortion. This will be your "paradigm" of QAM systems. Run it and you should see the eye pattern as presented in Figure 3.

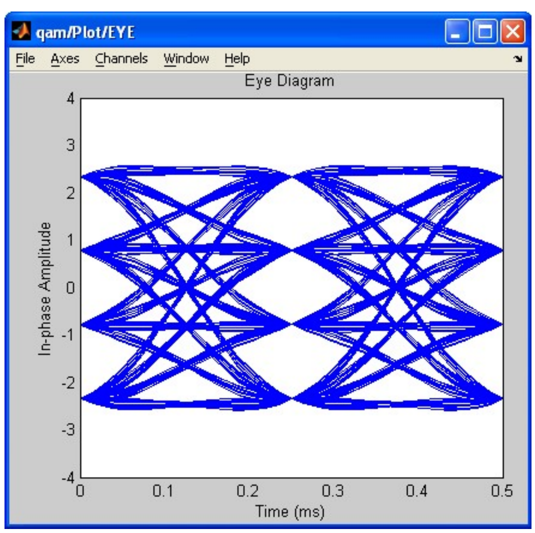

Figure 3: Eye Pattern, 90% Excess Bandwidth filters

- *Explain how the multiple eyes are formed. Draw, if you will. Is this pattern similar to one produced by a 4 PAM system?*

You should also see a constellation diagram, similar to Figure 4.

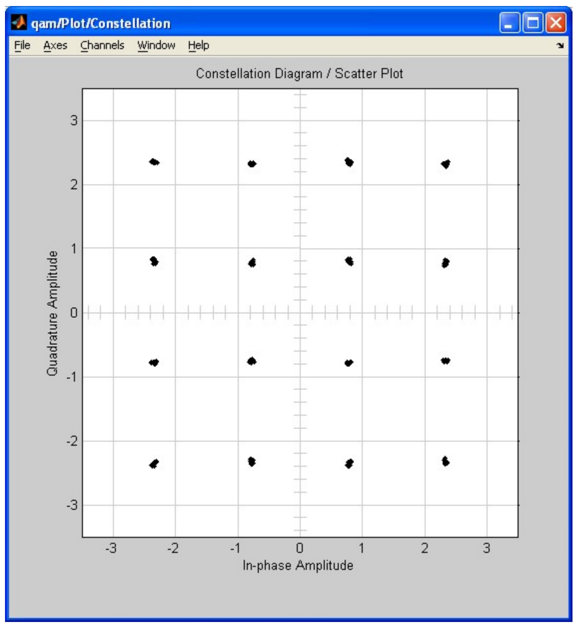

Figure 4: Constellation Diagram for 16 QAM

- *Create a table indicating what bit values correspond to what point in the diagram (look at the model). Be sure to indicate how I and Q form each point. Is this constellation Grey coded?*

Stop your model. Add noise to the signal path and run it again. Your constellation should look like Figure 5 below.

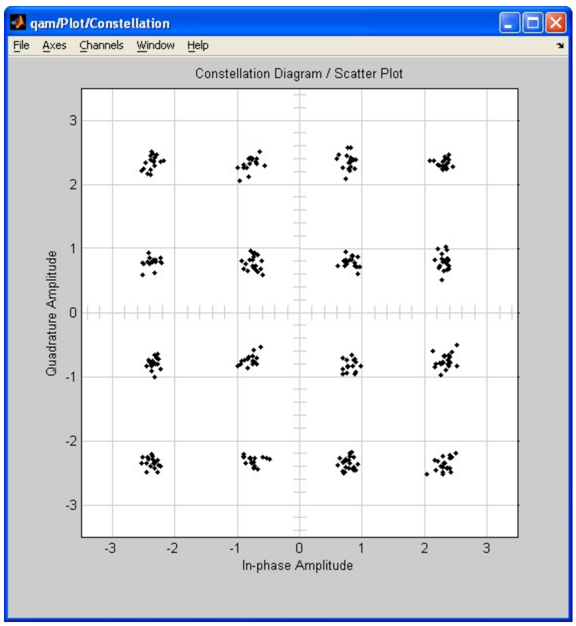

Figure 5: Noisy Constellation

- *Increase the noise gain until you observe the eye pattern closing, and look at the constellation diagram. How would the noise create trouble for the decision-making?*

- *Assume you have two systems with the same transmitted power and subject to the same amount of noise. One is 16 QAM and the other 256 QAM (no need to draw the constellation for this one). On which of them you expect to have more difficulty making your decision? Why?*

- *Stop your system and switch the noise off. Now change your Tx and Rx filters so that you have some ISI happening in your system. How would the eye pattern and the constellation diagram indicate the presence of ISI?*

Stop your model. Remove noise and add fixed phase distortion (in the channel block, the switch will enable a constant number to add distortion). Your constellation is now going weird, as shown in Figure 6.

- *By looking at the constellation diagram, how can you tell that there is phase distortion? How can you improve the receiver in order to fix the problem?*

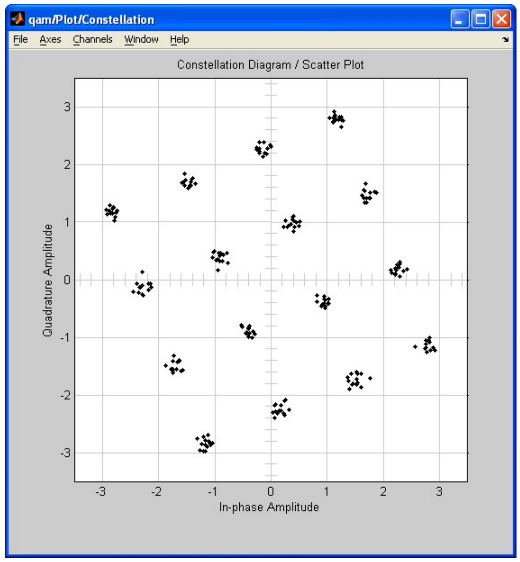

Figure 6: Rotated Constellation = Phase Distortion

Stop your model. Now substitute the 90 percent excess bandwidth filters with 50% ones. Run the model as a reference. Now let us assume that you have two systems, and their outputs present the two eye patterns as shown in Figure 7.

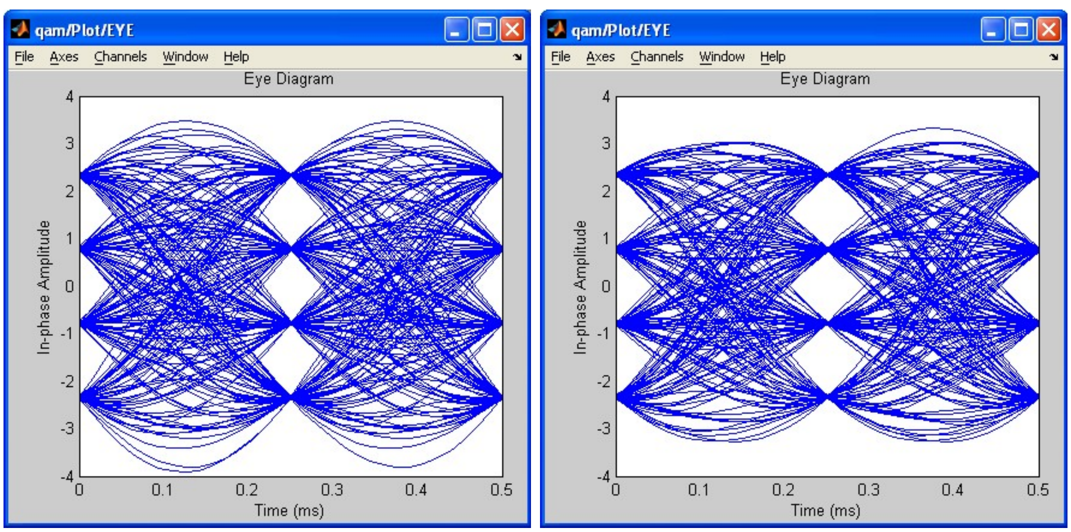

Figure 7: Eye Patterns Representing the Outputs of Two Systems

- *Which of the two would you say utilizes less bandwidth? What indicates the difference in bandwidth? Would you be able to tell it from the constellation diagram?*

Now add noise and the slow-varying phase distortion (that is the one which comes from the sinusoid). Let it run for about one minute. Observe the effect of a time varying channel. If you feel like drawing it, great. Show your artwork to the T.A. (extra marks unlikely, though).

4 Accomplishments

During this simulation-only experiment, you became familiar (so we hope) with a 16-QAM system. You are now capable of utilizing a constellation diagram as a tool to interpret some features found on a complex signal, and to assist in making decisions to recover information from the received signal.

Preparation - Quadrature Amplitude Modulation

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1. Draw a block diagram for the 16- QAM **transmitter**, from an A/D converter to the quadrature amplitude modulated signal to be input to a channel. Give details on how to operate on the baseband signal prior to mixing with the carriers. This will include a PAM stage and a pulse-shaping filter, for instance. How many bits are there per symbol?

2. Explain the purpose of splitting the signal into an in-phase component and a quadrature component.

3. Draw a block diagram of a QAM receiver. Assume that the signal has not been corrupted in any fashion by the channel, and that everything is synchronized perfectly. Sketch the signal constellation and the eye pattern.

4. Suppose now that the signal was passed through a noisy channel. Draw the resulting received signal constellation. Also, how would you identify the delay added by the channel from looking at the constellation?

5. If the phase delay introduced by the channel increases with time, what would happen to the constellation?

6. Give some examples of systems that utilize QAM (Google it!).

References

[1] S. Haykin and M. Moher, *Introduction to Analog and Digital Communications, 2nd. Ed."*, Wiley, 2007.