

Experiment 04: QPSK & QAM

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Abstract

In this lab you will explore two digital modulation schemes, namely Quaternary Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM). This will be done by running `Simulink` models.

Keywords

In-Phase — Quadrature — Constellation Diagram — Eye Pattern

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Introduction

QPSK and QAM are two widely used digital modulation schemes. They find application in optical communications, high-speed modems, cellular telephony, satellite communications and other means of communication where bandwidth efficiency is needed. The main objective of such modulation schemes is to maximize the number and speed of transmitted bits within a given bandwidth, while keeping the rate of error as low as possible.

QPSK does this by shifting the angle of the carrier in four discrete angle values, while keeping the amplitude constant. Typical values are $\pm 45^\circ$ and $\pm 135^\circ$, representing two bits each. These two bits (called *dibit*) are Gray Coded. This coding results in only one bit of difference between adjacent values, aiming at a reduced bit error rate. In contrast, QAM maintains the frequency of the carrier, while changing the amplitudes of the in-phase and quadrature components. We will concentrate on 16-QAM in this lab, meaning that there will be four amplitude levels (two bits represented per level) for the in-phase component and four amplitude levels for the quadrature component. The bits representing adjacent levels are also Gray Coded.

Throughout the experiment, keep in mind that the golden objective of any communication system is to transport a message from one point to another without errors (or changes at all). For the particular case of the modulation methods to be seen here, the objective is to take a message, code it in bits, arrange them, transmit them, then receive them somehow to recombine them into the original message. This all happens in the presence of noise, relative movement between transmitter and receiver, and other complicating factors that affect the decoding of the message that is being transmitted. You have likely seen the first picture sent by the probe *Philae* as it landed on *Comet 67P/Churyumov–Gerasimenko*. Now consider that the probe was launched almost 10 years ago, using the technology of the time, and that it takes 25 minutes for the signal transmitted to arrive at the receiver on earth [?]. These were (and are!) the challenges that the Engineers had to overcome.

Before starting the lab, complete the **lab preparation** and hand it to the T.A.. From this point on, you will use all simulation models found in the folder `Documents/MATLAB/ECE464`. The simulation models presented here are modified versions of those found in [?]. Please refer to the book if you want to explore these digital modulation schemes further.

1. Quaternary Phase Shift Keying (QPSK)

You will start by probing with the simplest version of Phase Shift Keying, which is a Binary Phase Shift Keying (BPSK). In particular, you should observe that you will achieve a better utilization of the bandwidth by coding four levels (two bits) instead of two levels (one bit). You will then explore with the ratio between the energy per bit and noise, as well as with the simulation time and see how they affect the bit error rate.

1.1 Binary Phase Shift Keying (BPSK)

Open the model named `bpsk.mdl`. You will notice that the message source is a standard `Random Integer Generator` from `Simulink`, which is passed through a `Phase Modulator`. The output of the modulator is monitored via a time domain scope, and is passed through an additive white Gaussian noise channel (AWGN). The received signal (after the channel) is multiplied by a synchronized version of the carrier (which simulates a local oscillator), and passed through an *integrate-and-dump* subsystem, prior to being decoded. The integrate-and-dump subsystem, as the name implies, performs a cumulative sum of the incoming samples at defined intervals. At the end of the interval, the integration restarts, and the result of the previous integration is dumped. In this receiver, a version of the carrier is used for the demodulation (i.e., this is coherent demodulation). In addition, the transmitted bit rate is known and the sampling of the incoming signal is at a fixed rate. The output of the integrate-and-dump is passed through two other blocks that will effectively extract the bits into a 0 and 1 stream. This stream is compared to the original transmitted stream so that the error rate can be calculated.

Your tasks are:

- Observe the phase shifts on the time domain scope. This is binary shift, so you should see only two changes in phase;
- Modify the gain on the transmitted signal and observe the consequence on the signal after the AWGN channel;
- Observe the spectrum scope and change the parameters of the scope to provide a meaningful display. The display is slow to respond, due to the number of points it is set up to calculate. Feel free to reduce the number and make it faster, as long as you can still see a meaningful plot.

When you are done with these tasks, close the model.

1.2 Quaternary Phase Shift Keying (QPSK)

Now you will explore with four shifts in phase, as described before. The QPSK modulated signal can be seen as two BPSK signals in quadrature, that is, two BPSK signals modulated separately by a sine and cosine of the same frequency.

Open the model named `qpsk.mdl`. You will notice that this model is very similar to the previous one except for the four groups of bits (di-bits) that will be used to modulate the phase of the carrier. The dibits representing the levels are rearranged to Gray code and sent to the modulator. The AWGN channel adds white Gaussian noise. At the demodulator, the bits are detected and recombined taking into account the fact that they have been Gray coded. For this model, you have two time domain displays, one frequency domain (spectrum) display and a constellation display. The constellation display takes in coordinates from the in-phase and quadrature paths, which are combined into a complex number prior to being sent to the diagram.

Your tasks are:

- Observe the phase shifts on the time domain scopes. Try before and after the channel. There are now four different phase changes;
- Modify the gain on the transmitted signal and observe the consequence on the signal (time domain) after the AWGN channel;
- Open the constellation diagram and the spectrum scope, and vary the gain to observe the effect. The spectrum scope may be slow, so make changes to it as you see fit to make it run as you wish;
- Run the system with the slider gain – prior to the AWGN channel – reduced to 1. Double-click on the slider gain and on the constellation diagram, so that they are open while the system runs. Observe the effect on the constellation as the gain is increased up to 5. For this part you should close the spectrum scope (it takes too long to run);
- Run the system for different values of E_b/N_o (the default value is 10). Keep the slider gain at 5. Remember that when you increase the value of E_b/N_o , you have more energy per bit while keeping the noise at the same level. Observe the effect on the constellation diagram;

- Observe the BER (Bit Error Rate) calculator while the system runs, and modify the slider gain and the E_b/N_o value. When you decrease the value of E_b/N_o (or the gain), you should see more errors occurring as a result. Verify that this is the case.
- Run both the QPSK and the BPSK models, keeping only the spectrum scope open. This may be slow, so find the best compromise. Visually compare the bandwidth utilized (around the carrier) with that of the BPSK. Keep in mind that you are now transmitting twice the number of bits as you did with BPSK. Which modulation strategy works more efficiently in terms of the spectrum used?

You will use this model to compare with the one you will run below, so keep it open but not running.

2. Quadrature Amplitude Modulation (QAM)

In this section you will explore QAM, and in particular 16-QAM. With this modulation scheme, you will have two orthogonal paths, one being modulated by a sine and one by a cosine carrier of the same frequency. The amplitude of these carriers is modulated in a predetermined number of levels, so these can be seen as two PAM systems in quadrature. In this case, 4 levels (each representing 2 bits). As they are orthogonal, each time the received signal is sampled (and the bits extracted), you will have one level of each carrier sampled, representing two bits each, to a total of 4 bits being received. Then they are decoded and recombined.

Open the model named `qam.mdl`. This model too takes the input from a random generator. This time, however, the bits are organized in symbols (groups of bits) and are sent in two paths labeled in-phase and quadrature. No pulse-shaping is done in this model, as it typically would be done in practice. As in the previous case, a sine and a cosine of the same frequency are used as carriers for the two paths. The same carriers are used at the demodulator. Also at the demodulator the bits are recombined to reverse the process done prior to the multiplication by the carrier.

Your tasks are:

- Run the model, and observe the time domain scopes. Compare what you see with the time domain signal of the QPSK model. This one changes amplitude (PAM) whereas the other changes phase (PSK);
- With the model running, compare the bandwidth visually between QPSK and QAM. Keep in mind that you are now receiving 4 bits every time we sample and decode the received signal;
- Change the E_b/N_o value for the AWGN. The default value is 20. Run the model and lower this value gradually down to 5. Observe the changes in the constellation;
- Repeat the procedure above for the QPSK model, and observe which of the two needs the lowest E_b/N_o to achieve no errors after running a 20 second simulation. Again, keep in mind that you are transmitting twice as many bits.

The objective here is to compare the spectrum efficiency and the performance in terms of bit errors between QPSK and QAM.

3. Accomplishments

In this experiment, you have probed three digital modulation schemes. You made changes to the signal gain and noise level, and observed the consequences in the spectrum and the constellation diagram. The latter shows clusters of bits as they are detected from the received signal prior to their recombination. You have also explored the differences in bandwidth efficiency, by comparing the bandwidths of BPSK, QPSK and 16-QAM.

Acknowledgments

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References