EE304L Communication Systems

Course Project Report
Design of QAM system over the AWGN channel

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Problem Statement

QAM is a digital modulation technique involving both amplitude and phase shift keying. Write a MATLAB code to simulate QAM modulation. Plot the QAM modulated signal as well as the constellation diagram.

Introduction

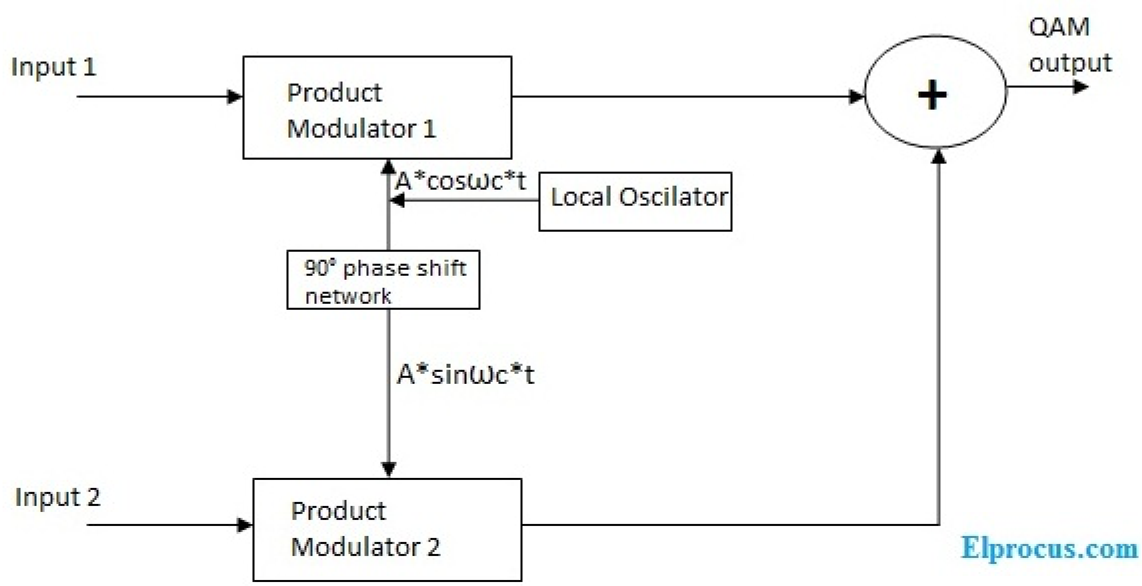
Quadrature amplitude modulation (QAM) is a modulation technique that involves using two orthogonal carrier signals to transmit two signals simultaneously in the same bandwidth. Generally, these carrier signals are out of phase by 90 degrees, thus making them orthogonal to each other, hence the name quadrature. In digital QAM, each symbol (A symbol is a set of bits) is mapped to a signal.

Each of these symbols is uniquely encoded to a signal, and each signal may have a different amplitude and phase. When modulation involves only a change of amplitude, it is called amplitude phase shift keying (APSK). The constellation diagram is circular in the case of APSK. Quadrature amplitude modulation involves both a phase and amplitude shift, so it involves both amplitude and phase shift keying. The constellation diagram of QAM is a group of squares where the number of squares depends on the number of bits per symbol. We have taken 4 bits per symbol.

Additive White Gaussian Noise (AWGN) is a generally accepted noise model which involves random processes. As the name implies, it is additive in nature. The noise has uniform power spectral density, which means the power of the noise is constant across all frequencies. The noise distribution at any instant is a Gaussian distribution with zero mean and variance η/2, where η is the power of the noise.

Key Steps in the Solution

The QAM block diagram for modulation at the transmitter is as follows:



Here, the carrier signal, a sinusoidal signal A*Cos(2*pi*frequency of carrier*t), experiences a 90-degree phase shift to give us another signal A*Cos (2*pi*frequency of carrier*t-90), which is nothing but A*sin(2*pi*frequency of carrier*t).

As the carrier signals are at a phase of 90 degrees to each other (quadrature phase), this modulation method is called quadrature amplitude modulation.

The first step in our solution is to generate a random set of symbols to be the input signal. Then we have done a module to implement the modulation. To achieve this task, we must encode the message signal into symbols. This was done using a custom function.

```
M = 4 % Number of Bits per Symbol

BAUD_RATE = 1 % Symbols transmitted per second

L = 50 % Number of Symbols to be transmitted
```

```
SAMPLING_RATE = 20 % Samples per second in Khz
Fc = 1 % Carrier Frequency in Khz
Ac = 1 % Carrier Amplitude
T = L / BAUD_RATE; % tx signal length in seconds
N = SAMPLING_RATE * T * 1000; % Number of samples
required
samples_per_symbol = N/L;
n = 0:N-1;


% Carrier Signals
in_phase = Ac*cos(2*pi*Fc*n/N*T);
quadrature = Ac*sin(2*pi*Fc*n/N*T);


% Generating a random input message signal
message_signal = randi([0 2^M-1],L,1);
```

Using a simple loop, the symbols are then used to generate the modulated signal (the signal to be transmitted).

```
encoded_message_signal = zeros(L,1);
tx_signal = zeros(N,1);
for i = 1:L
```

```
    encoded_message_signal(i) =
symbols(message_signal(i)+1);
    for j = 1:samples_per_symbol
        k = (i-1)*samples_per_symbol + j; % Index of the
tx sample
        tx_signal(k) = real(encoded_message_signal(i)) *
in_phase(k) + imag(encoded_message_signal(i)) *
quadrature(k);
    end
end
```

Another function here was used to generate white Gaussian noise. The generation of the AWGN was implemented using the inbuilt random function. The signal received at the receiver output is just a sum of the message signal and the added noise.

```
% Custom Implementation of AWGN Channel
% Specific to Digital modulation and Complex Symbols
% Assuming input signal has unit average power and is
single channel

function y = AWGN_Custom(x,SNR)
    % Converting Db to linear
    signal_power = 10^(1/10);
    SNR = 10^(SNR/10);
```

```
    noise_power = signal_power/SNR;

    noise = sqrt(noise_power/2)* complex(randn(size(x)),
randn(size(x)));

    y = x + noise;

end
```

Then we plotted the constellation diagrams of the 16-QAM (4-bit) without noise and after the addition of AWGN.

```
figure

subplot(2,1,1)

plot(in_phase)

title("In-Phase Carrier")

subplot(2,1,2)

plot(quadrature)

title("Quadrature Carrier")

sgtitle("Carrier")


figure

scatterplot(symbols)

title("Constellation Diagram")


figure
```

```
plot(tx_signal)
title("Transmitted Modulated Signal")


% Passing through AWGN Channel
SNR = 25 % Db
encoded_message_signal_with_noise =
AWGN_Custom(encoded_message_signal,SNR);
figure
scatterplot(encoded_message_signal_with_noise)
title("Message Symbols with Noise")
```

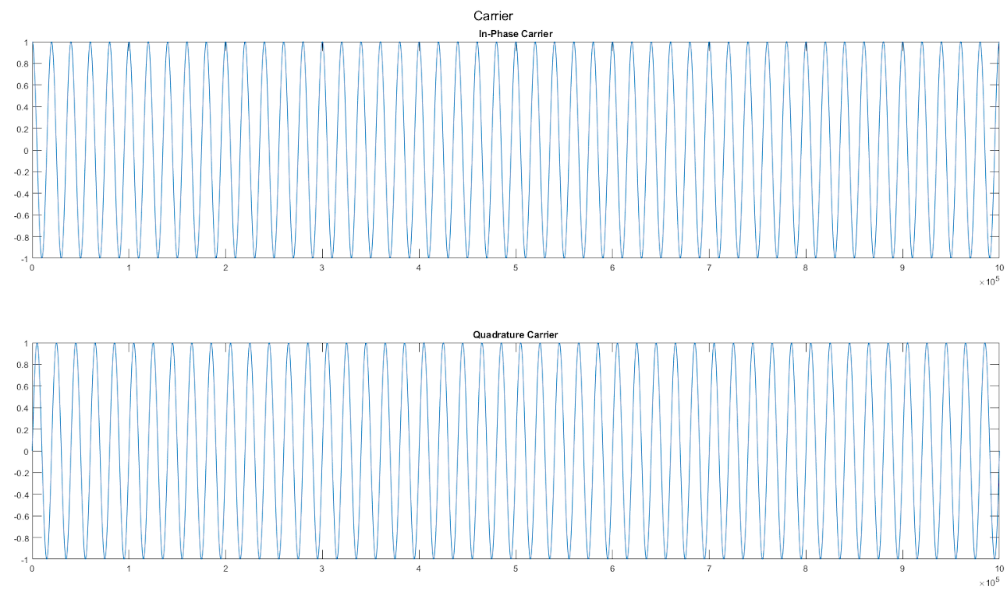
The entire code repository is hosted on this page.

https://github.com/benstindavis/EE304L-Course-Project

Results and Plots

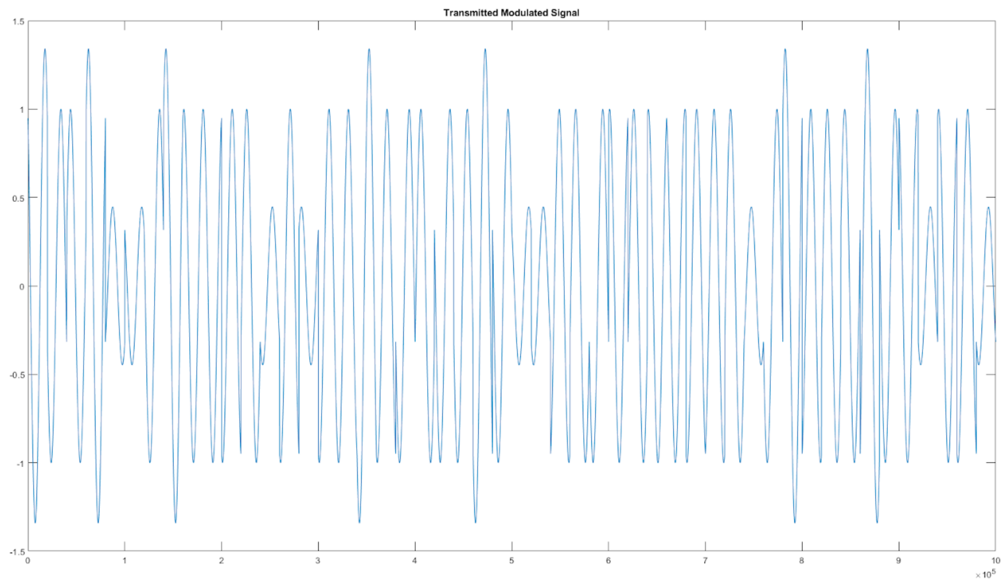
The parameters like Baud Rate, Carrier frequency and Amplitude were chosen such that we can see the signals in the plots clearly, choosing industry standard values will make the plots convoluted and difficult to understand.

Carrier wave



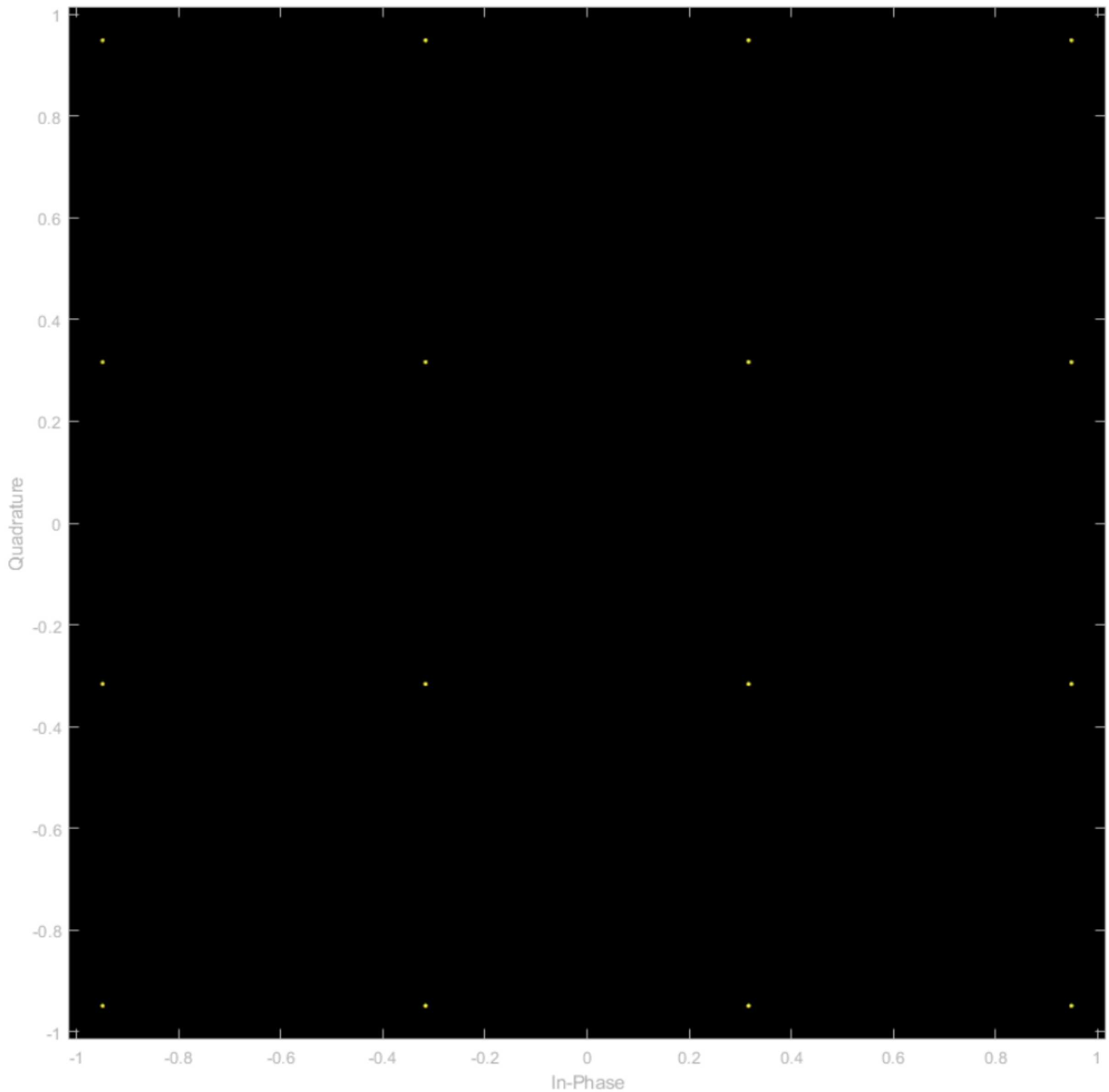
- The first picture in this plot shows the in-phase carrier - A cos (2*pi*frequency*t)
- The second plot shows the carrier, which is shifted by 90 degrees - the quadrature signal - A sin (2*pi*frequency*t)

Transmitted signal



- This is the plot of the modulated signal which is modulated using the QAM scheme.
- We can see that for every bit in the symbol(4 bits), there is a different signal which is encoded with it (with a different amplitude and phase).
- We have both amplitude and phase change (amplitude and phase shift keying).

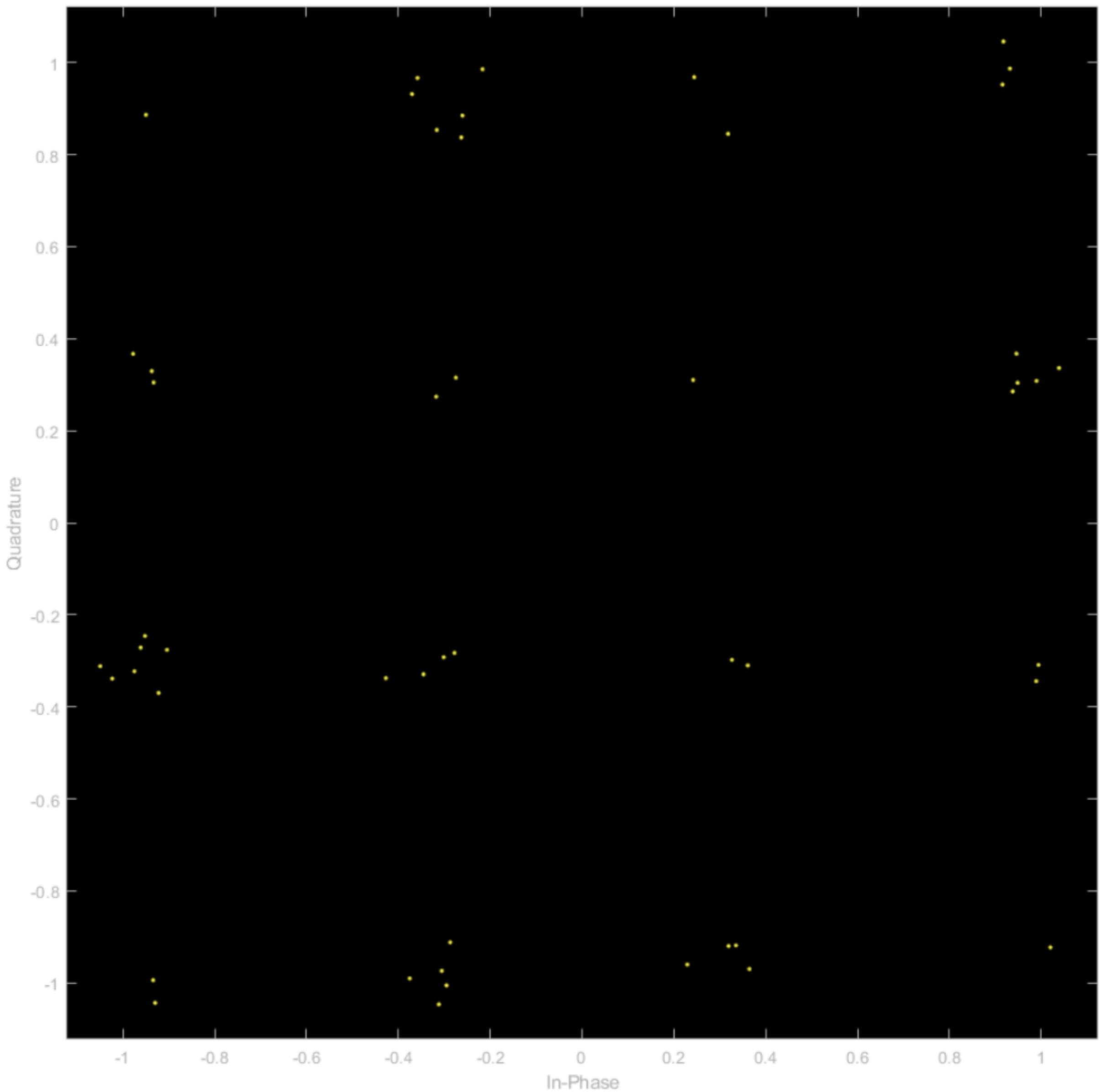
Constellation Diagram



- This figure shows us the constellation of the modulated signal before the addition of noise.
- We have 4 bits per symbol, giving us symbols from 0 to 15.

- We can see that the constellation diagram is a group of squares with yellow dots at different amplitudes. Each dot represents a symbol from which the decision boundary is found.
- Only QAM has such a constellation diagram.

Constellation Diagram of Received Signal



- This figure shows us the constellation diagram of the modulated signal along with the AWGN signal.
- Here the number of symbols is not uniformly distributed as we have added random noise to the signal, but we can approximately see a group of squares from the above plot, which suggests that the signal was modulated using QAM.

Summary

We wrote code to generate random symbols, which are used as input and are then modulated using QAM. QAM involves symbols, each of which is uniquely mapped to a signal, and each signal may have a different amplitude and phase. As QAM involves both Amplitude and Phase Shift Keying, the constellation diagram

The main difficulty we faced was generating the symbols from the given input. Finally, we decided to implement the encoding using a look-up table logic which uses the inbuilt “qammod” function to generate the table and uses the table to encode the message signal. The AWGN channel was designed explicitly for the Unit Average Power signal, which means the input message signal must have an average power of one. The same behaviour can be achieved using the inbuilt “awgn” function but we have written our own custom function.

This project was a great learning experience as we got to apply the theoretical knowledge of QAM and digital communication to perform simulations and extend our knowledge to any general case where QAM is used.