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**Τετραγωνική Διαμόρφωση Πλάτους Και Συχνότητας Για
Ιδιωτική Ασύρματη Επικοινωνία**

Διπλωματική Εργασία

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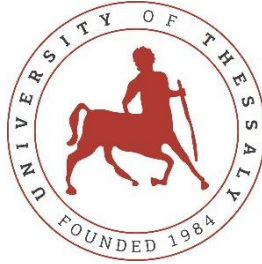
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Frequency QAM For Private Wireless Communication

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«Με πλήρη επίγνωση των συνεπειών του νόμου περί πνευματικών δικαιωμάτων, δηλώνω ρητά ότι η παρούσα διπλωματική εργασία, καθώς και τα ηλεκτρονικά αρχεία και πηγαίοι κώδικες που αναπτύχθηκαν ή τροποποιήθηκαν στα πλαίσια αυτής της εργασίας, αποτελεί αποκλειστικά προϊόν προσωπικής μου εργασίας, δεν προσβάλλει κάθε μορφής δικαιώματα διανοητικής ιδιοκτησίας, προσωπικότητας και προσωπικών δεδομένων τρίτων, δεν περιέχει έργα/εισφορές τρίτων για τα οποία απαιτείται άδεια των δημιουργών/δικαιούχων και δεν είναι προϊόν μερικής ή ολικής αντιγραφής, οι πηγές δε που χρησιμοποιήθηκαν περιορίζονται στις βιβλιογραφικές αναφορές και μόνον και πληρούν τους κανόνες της επιστημονικής παράθεσης. Τα σημεία όπου έχω χρησιμοποιήσει ιδέες, κείμενο, αρχεία ή/και πηγές άλλων συγγραφέων, αναφέρονται ευδιάκριτα στο κείμενο με την κατάλληλη παραπομπή και η σχετική αναφορά περιλαμβάνεται στο τμήμα των βιβλιογραφικών αναφορών με πλήρη περιγραφή. Αναλαμβάνω πλήρως, ατομικά και προσωπικά, όλες τις νομικές και διοικητικές συνέπειες που δύναται να προκύψουν στην περίπτωση κατά την οποία αποδειχθεί, διαχρονικά, ότι η εργασία αυτή ή τμήμα της δεν μου ανήκει διότι είναι προϊόν λογοκλοπής».

Ο Δηλών

Παπακωνσταντίνου Αθανάσιος
3/3/2021

ΠΕΡΙΛΗΨΗ

Σκοπός αυτής της διπλωματικής εργασίας είναι να συστήσει στον αναγνώστη την FQAM διαμόρφωση σήματος η οποία είναι συνδυασμός της QAM (Quadrature Amplitude Modulation) και της FSK (Frequency Shift Keying) διαμόρφωσης. Αρχικά, παρουσιάζεται μια γενική ανασκόπηση των QAM και FSK διαμορφώσεων, και στη συνέχεια αναλύεται πως γίνεται ο συνδυασμός αυτών των δύο για την παραγωγή της καινούριας διαμόρφωσης. Στην FQAM διαμόρφωση υπάρχουν εναλλαγές τόσο στην συχνότητα του φέροντος, όσο και στο πλάτος και τη φάση. Αφότου αναλυθεί στον αναγνώστη το FQAM σήμα στη βασική ζώνη, επεξηγείται η λειτουργία του FQAM transmitter και του FQAM receiver, έτσι ώστε να επιτυγχάνεται αξιόπιστη ασύρματη επικοινωνία. Τέλος, παρουσιάζεται μια προσομοίωση της FQAM διαμόρφωσης υπό την επήρεια προσθετικού θορύβου AWGN (Additive White Gaussian Noise) η οποία δημιουργήθηκε στο MATLAB και οι μετρήσεις BER (Bit Error Rate) που παρατίθενται εξήχθησαν μέσω προσομοιώσεων Monte Carlo.

ABSTRACT

Objective of this thesis is to introduce the reader to a hybrid modulation scheme FQAM, which combines QAM (Quadrature Amplitude Modulation) with FSK (Frequency Shift Keying). Initially, there is a general review of the QAM and FSK modulation schemes, while it continues with the combining procedure to end up with the new modulation scheme. The FQAM is a modulation scheme where there is variation in carrier signal frequency, amplitude and phase. After providing the reader with the equivalent complex FQAM baseband signal, there is a demonstration of how a FQAM transmitter and a FQAM receiver operate to achieve reliable wireless communication. Finally, we present a MATLAB based simulation in the presence of AWGN (Additive White Gaussian Noise) and the BER (Bit Error Rate) metrics are obtained through Monte Carlo simulation.

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CHAPTER 1

INTRODUCTION

The wireless communication systems use modulation schemes to deliver digital information. The various modulation schemes vary a carrier signal by frequency, amplitude or phase. In this thesis we present a modulation scheme FQAM, which varies a carrier signal waveform in each of the abovementioned properties. In the next chapters of this thesis, we analyze the general idea and how a FQAM transmitter and a FQAM receiver work, describe the baseband form of the FQAM signal, as well as we present simulation details and BER (Bit Error Rate) metrics of a FQAM modulation scheme in AWGN (Additive White Gaussian Noise).

1.1 Frequency Shift Keying - FSK

Frequency shift keying is a modulation scheme in which digital information is mapped to the frequency of a sinusoidal waveform. In M-FSK the digital transmission occurs through M discrete frequency changes of a carrier signal, to wit M different symbols containing $\log_2(M)$ bits. The frequency deviation of the M discrete symbols is constant

$$\Delta f = f_m - f_{(m-1)}, m = 1, 2, \dots, M \quad (1.1)$$

and can be expressed as

$$f_m = m\Delta f, m = 1, 2, \dots, M \quad (1.2)$$

The M signal waveform can be expressed as

$$s_m(t) = A \cdot \cos(2\pi f_m t + \theta_m), m = 1, 2, \dots, M, 0 \leq t \leq T \quad (1.3)$$

where A is the amplitude, T the duration of each symbol and θ_m the phase.

1.2 Quadrature Amplitude Modulation – QAM

Quadrature amplitude modulation or QAM, a modulation technique, varies both amplitude and phase to produce the discrete QAM symbols. QAM symbols are generated by the addition of two carrier waves of the same frequency which are modulated by

amplitude and are orthogonal between them. The M-QAM signal waveform can be expressed as

$$s_i(t) = A_i \cdot \cos(2\pi f_c t + \theta_i), i = 1, \dots, M, t \in [0, T] \quad (1.4)$$

where f_c is the carrier frequency, T the duration of the QAM symbol, A_i and θ_i the amplitude and phase of the i-th symbol. The two orthogonal carrier waves are commonly referred to as in-phase component $I(t)$ and quadrature component $Q(t)$ and the waveform can mathematically reconstruct as

$$s(t) = \cos(2\pi f_c t) \cdot I(t) + \cos(2\pi f_c t + \frac{\pi}{2}) \cdot Q(t) , \text{ or}$$

$$s(t) = \cos(2\pi f_c t) \cdot I(t) - \sin(2\pi f_c t) \cdot Q(t) \quad (1.5)$$

On the receiver side, a demodulator attempts to estimate $I(t)$ and $Q(t)$ by multiplying the received signal with a cosine and sine. The constellation diagram of 16-QAM is presented in figure 1.1.

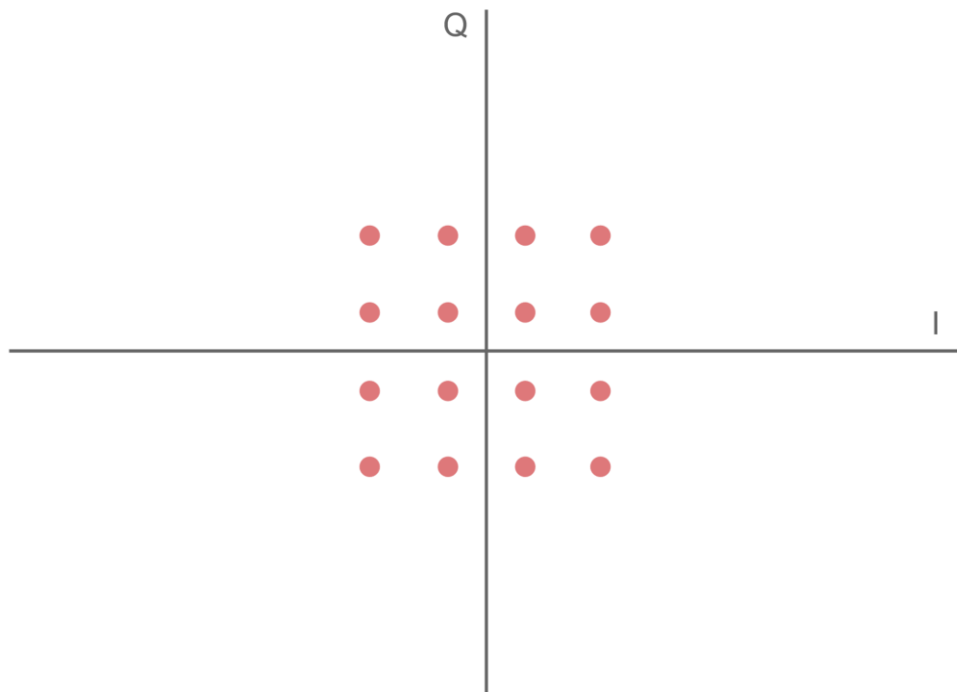


Figure 1.1: Constellation of 16-QAM, adopted by [1].

1.3 Additive White Gaussian Noise – AWGN

Additive white Gaussian noise or AWGN is a model to capture the undesired random disturbance of an information signal. The main source of the noise is the thermal noise generated by the random motion of electrons, which behave independently and so the thermal noise can be considered as the addition of many random variables. According to the central limit theorem, the distribution of this sum will be Gaussian, with average value of zero, and described as white because it has uniform power across the frequency band of the system.

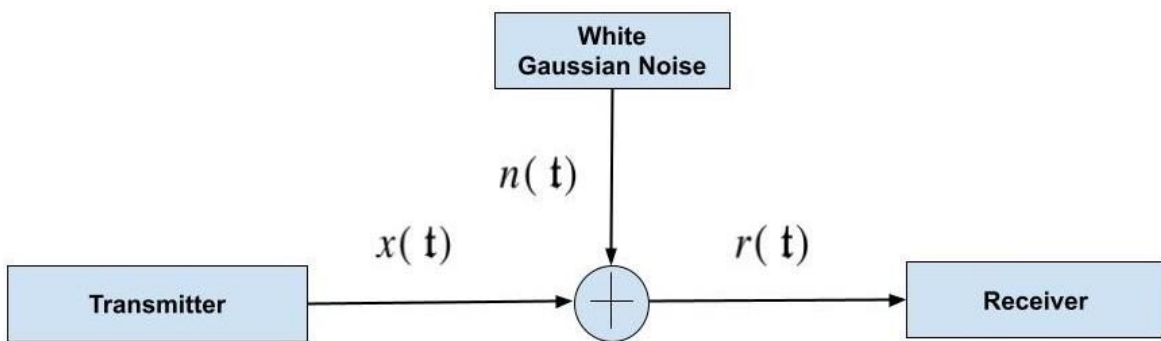


Figure 1.2: Additive White Gaussian Noise.

CHAPTER 2

FQAM SYSTEM MODEL

In this chapter we will analyze the Frequency and Quadrature amplitude Modulation (FQAM) scheme, which is a hybrid modulation of Frequency Shift Keying (FSK) and Quadrature Amplitude Modulation (QAM), considered as in [2]. The M-FQAM or (MF, MQ)-FQAM combines MF-FSK modulation and MQ-QAM, hence the modulation order is

$$M = M_F M_Q \quad (2.1)$$

2.1 FQAM Transmitter

In the transmitter side the information bits that are to be delivered to the receiver are organized in symbols depending on the modulation order. Each M-FQAM symbol carries $\log_2(M_F) + \log_2(M_Q) = \log_2(M)$ information bits, with the first $\log_2(M_F)$ bits indicating the active frequency tone among the M_F candidates and modulating the selected tone with an ordinary MQ-QAM. The M_F frequency tones that are allotted to the M-FQAM symbols in order to guarantee the orthogonality condition in frequency detection are chosen to be multiple of $\frac{1}{T}$ where T is the M-FQAM symbol duration

$$f_m = \frac{m}{T}, m = 1, \dots, M_F \quad (2.2)$$

The M_Q symbols of the MQ-QAM are given by

$$X_k = A_k e^{j\varphi_k}, k = 1, \dots, M_Q \quad (2.3)$$

where A_k and φ_k are the amplitude and phase. Therefore, at the transmitter, the equivalent complex baseband FQAM signal of duration T can be written as follows:

$$X_{m,k}(t) = A_k \cdot e^{j(2\pi f_m t + \varphi_k)}, m = 1, \dots, M_F, k = 1, \dots, M_Q, T \in [0, T] \quad (2.4)$$

The FQAM transmitter is shown in figure 2.1.

Let's see an example of the FQAM modulation. In figure 2.2 is given the constellation of 16-FQAM or (4,4)-FQAM, which is a combination of 4-FSK and 4-QAM. In

the FQAM modulator a sequence of $n = \log_2(M_F \cdot M_Q)$ bits correspond in one of the M different FQAM symbols. The first $n_1 = \log_2(M_F)$ bits of the sequence are converted in in decimal number Z and based in that number the carrier frequency is calculated as $f_m = f_z + 1$. The carrier frequency is modulated by the MQ-QAM symbol of the constellation, which corresponds to $n_2 = \log_2(M_Q)$ bits of the sequence, based on Gray mapping. In figure 2.2 we present the constellation of (4,4) FQAM.

Table 1: Bits Correspondence in Symbol for (4,4)-FQAM

| Input Bits | Frequency Tone | QAM Symbol | FQAM Symbol |
|------------|----------------|------------|-------------|
| 0000 | f 0 | S1 | X0,1 |
| 0100 | f 0 | s2 | X0,2 |
| 1100 | f 0 | s3 | X0,3 |
| 1000 | f 0 | s4 | X0,4 |
| 0001 | f 1 | s1 | X1,1 |
| 0101 | f 1 | s2 | X1,2 |
| 1101 | f 1 | s3 | X1,3 |
| 1001 | f 1 | s4 | X1,4 |
| 0011 | f 2 | s1 | X2,1 |
| 0111 | f 2 | s2 | X2,2 |
| 1111 | f 2 | s3 | X2,3 |
| 1011 | f 2 | s4 | X2,4 |
| 0010 | f 3 | s1 | X3,1 |
| 0110 | f 3 | s2 | X3,2 |
| 1110 | f 3 | s3 | X3,3 |
| 1010 | f 3 | s4 | X3,4 |

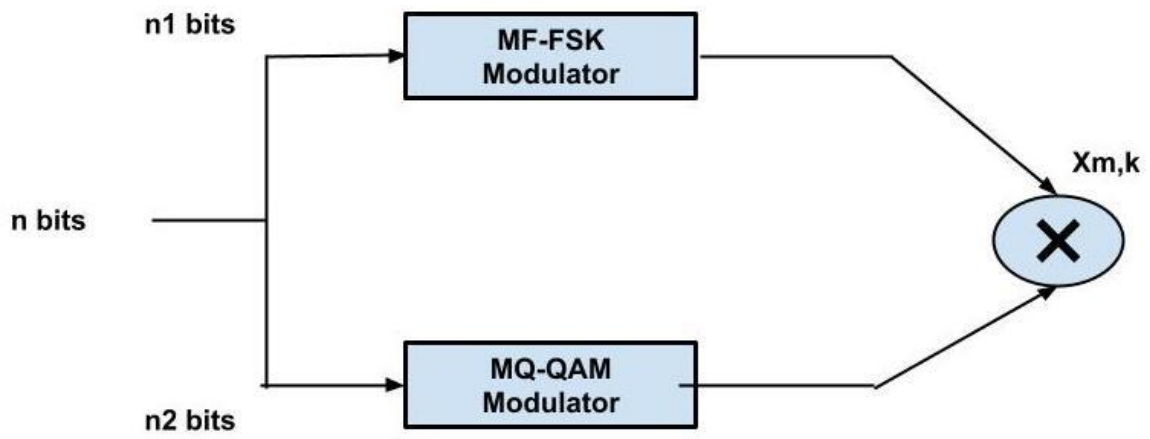


Figure 2.1: FQAM Transmitter.

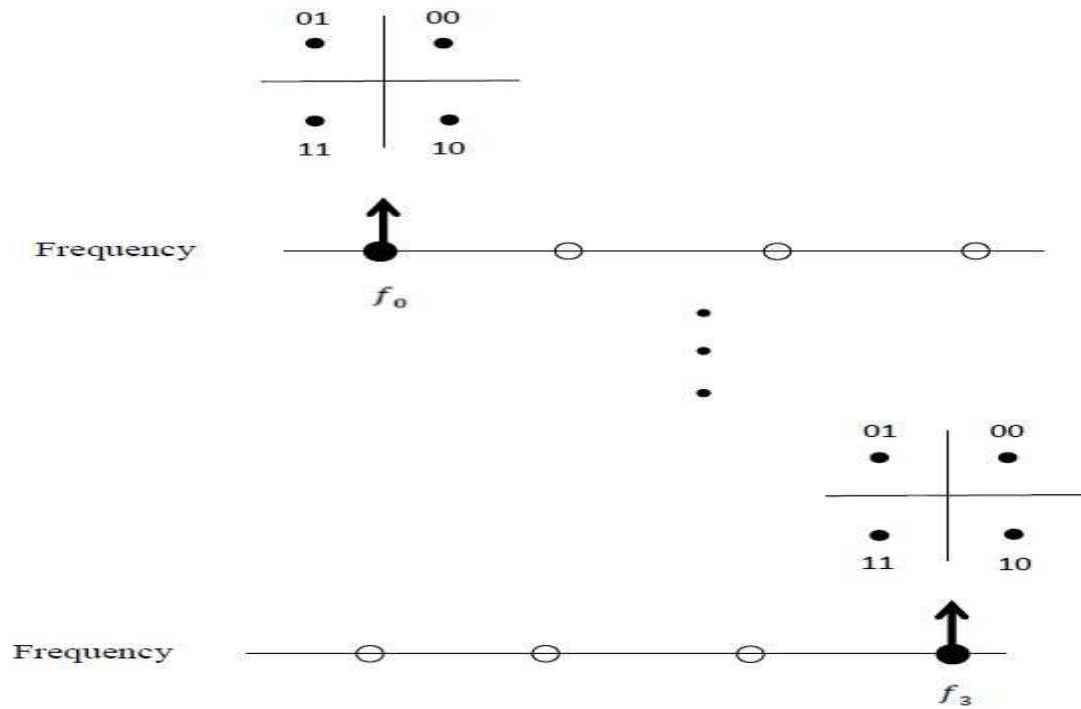


Figure 2.2: (4,4)-FQAM Constellation, adopted by [3]

2.2 FQAM Receiver

On the receiver side, a two-stage demodulation process is used to extract the information bits from each FQAM symbol. In the first stage the objective is to identify the active frequency tone of the symbol and reproduce the corresponding $\log_2(M_F)$ bits. As described in [4] “a non-coherent detection of FSK frequencies can be done by using a Band Pass Filter (BPF) implementation, followed by an envelope detector (ED) that consists of a Half-wave Rectifier (HWR) and a Low Pass Filter (LPF)”. In the second stage, after retrieving the active frequency tone, we detect coherently the remaining bits by using an ordinary M-QAM demodulator. In figure 2.3 there is a block diagram of the scheme.

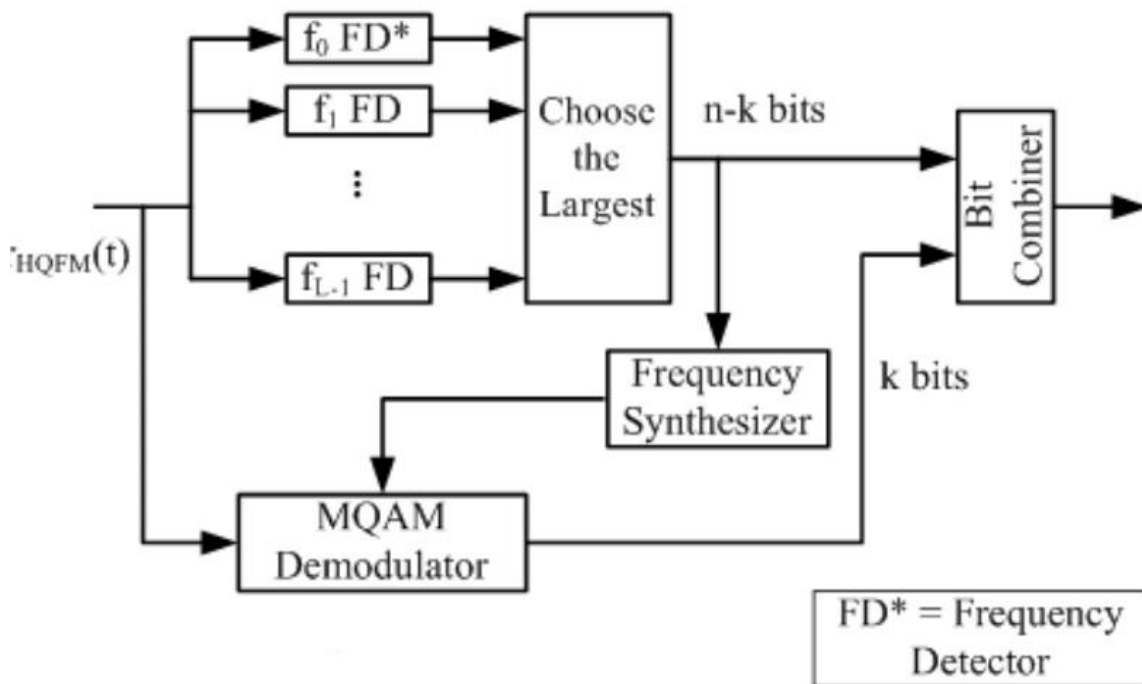


Figure 2.3: FQAM Receiver, adopted by [5].

CHAPTER 3

SIMULATIONS AND RESULTS

In this chapter we deal with an experiment, simulating FQAM modulation using MATLAB. The chapter is divided into two subsections. The first section is about the simulation clarification and every system configuration that is used to build the FQAM scheme and the second section concerns the numerical results of the error rate performance in AWGN. Apart from the FQAM modulation, we present the performance of the FBPSK modulation, which is a combination of BPSK (Binary Phase-Shift Keying) and BFSK (Binary Frequency-Shift Keying), and which is a modulation scheme that is simulated following similar methodology with the FQAM simulation.

3.1 FQAM System Build

In this section we will analyze the process to simulate the FQAM modulation scheme which will provide us the numerical results of the error rate performance. The experiment starts with a sequence of k information bits which are divided into symbols of length $\log_2(M)$, where M is the modulation order. As explained in chapter 2, in each symbol the first $\log_2(M_F)$ bits indicate the frequency tone that is to be used. For the purpose of this experiment, the bit rate is 1 MHz and the starting frequency f_c to compute each distinct frequency tone is multiple to the relevant symbol rate depending on the modulation order. The remaining bits are used for mapping the In-phase and Quadrature components, using a conventional M-QAM modulator, and are multiplied by $\cos(2\pi f_i t)$ and $\sin(2\pi f_i t)$ respectively. The f_i is the selected frequency tone and t is the time, but actually, is an expression that indicates how many samples are sent to the receiver for each symbol and will be referring to as oversampling factor. The output of the multipliers are summed to generate the FQAM signal. Figure 3.1 displays a random sequence of 100 bits modulated by (4,16)-FQAM, where MF=4 and MQ=16 and figure 3.2 shows the same sequence plus noise. From those figures we can see the distinction

between the symbols that differs from one another in frequency because of the FSK and in amplitude and phase because of the QAM.

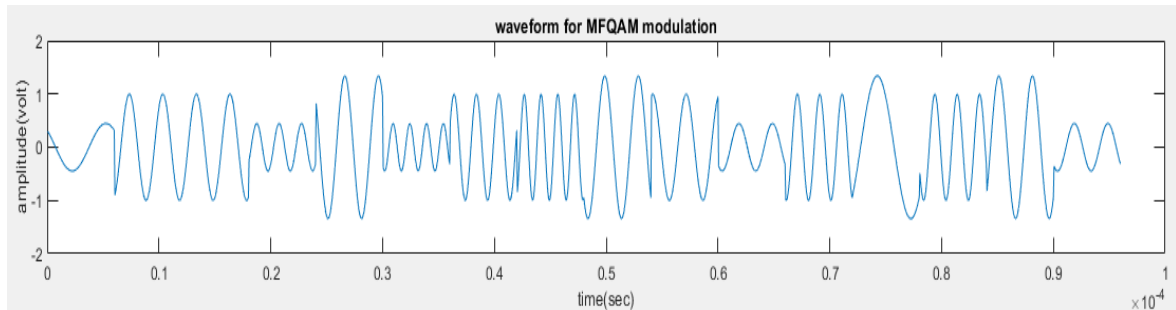


Figure 3.1: FQAM Signal

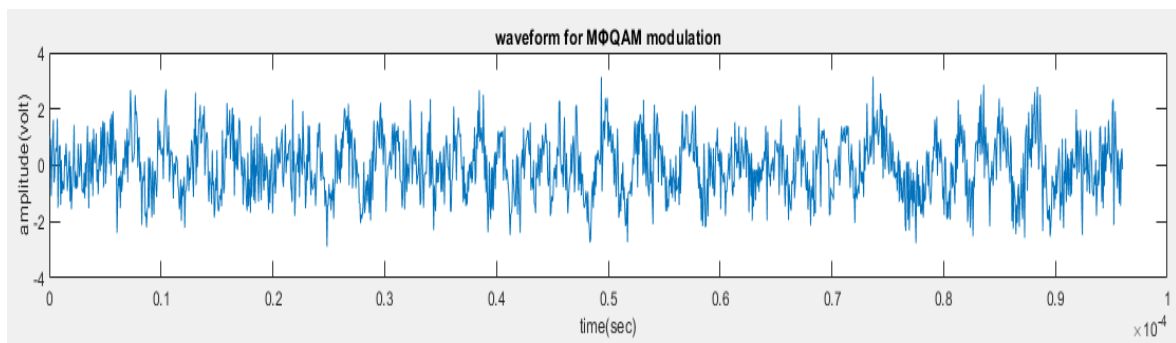


Figure 3.2: FQAM Signal Noise Added

On the receiver side, if we assume perfect synchronization, the noise added symbols are subjected to a two-stage demodulation. In the first stage the active frequency tone has to be recognized. For the purpose of this experiment an FFT (Fast Fourier Transform) based central frequency detector is used, of which the general idea is described in [6]. In the second stage, after the carrier frequency estimation, a regular QAM demodulator is used. The outputs of the two-stage demodulator in the FQAM receiver are combined to reconstruct the transmitted symbol. Figure 3.3 displays the FQAM modulator and demodulator scheme.

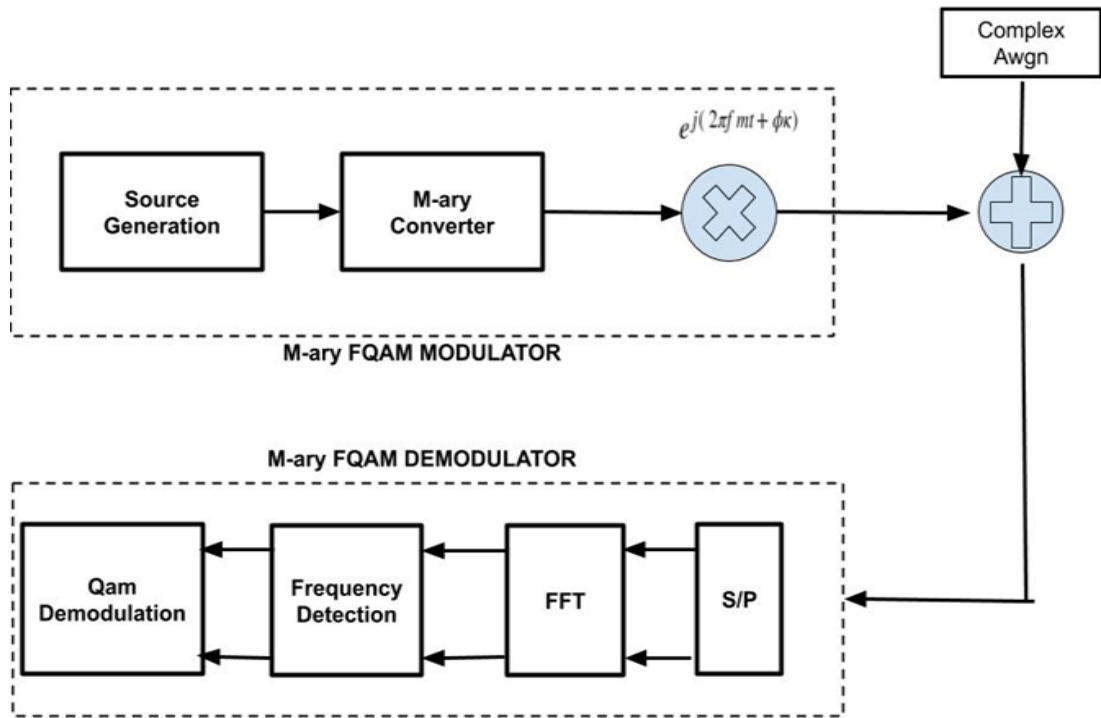


Figure 3.3: FQAM Modulator/Demodulator.

3.2 Results

In this section we present the performance of FQAM modulation in AWGN and the BER (Bit Error Rate) is measured through Monte Carlo simulation. In each simulation we assume perfect synchronization between transmitter and receiver and the SNR (Signal-to-Noise Ratio) is defined as $\frac{Eb}{N_0}$, where $Eb = 1$ and is the energy power per bit and N_0 is the Noise power. The following figures depict the BER performance in AWGN. The figures 3.4 and 3.5 are for the (4,4)-FQAM scheme with oversampling factor equal to 100 and 200 respectively and the figures 3.6 and 3.7 are for the (4,16)-FQAM scheme with oversampling factor also equal to 100 and 200 respectively. The performance of each (MF, MQ)-FQAM scheme is compared to 4,16 and 64 QAM.

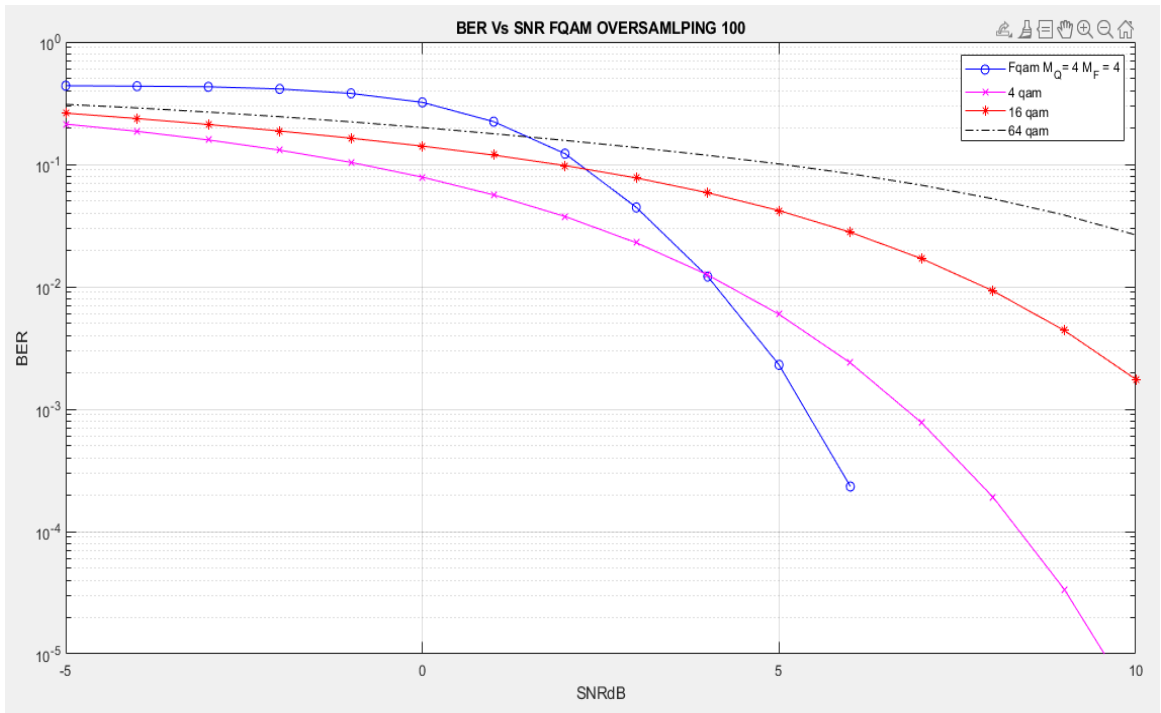


Figure 3.4: (4,4)-FQAM BER curve with oversampling factor 100

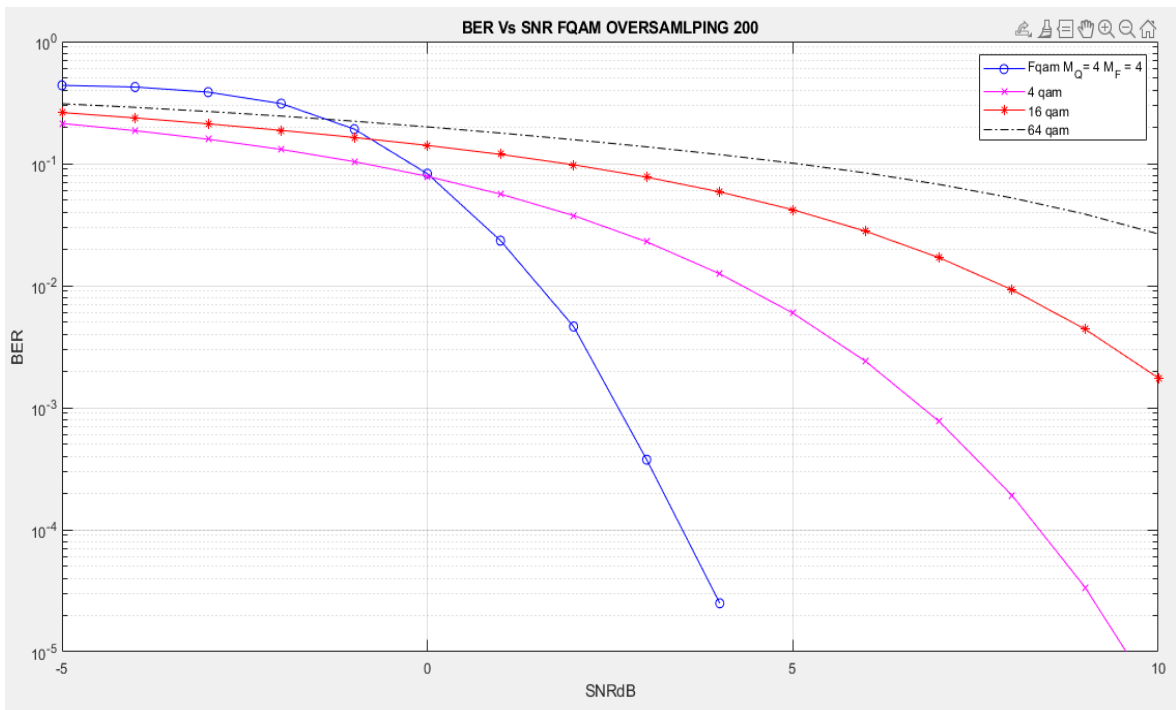


Figure 3.5: (4,4)-FQAM BER curve with oversampling factor 200

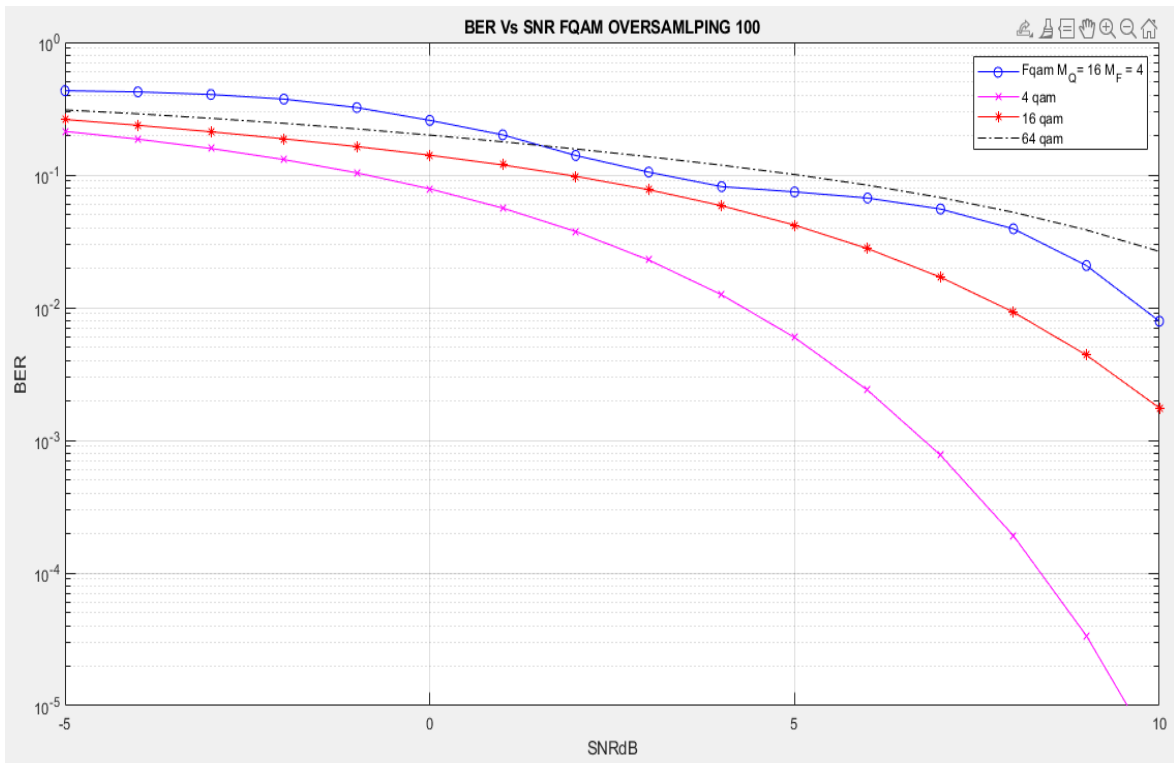


Figure 3.6: (4,16)-FQAM BER curve with oversampling factor 100

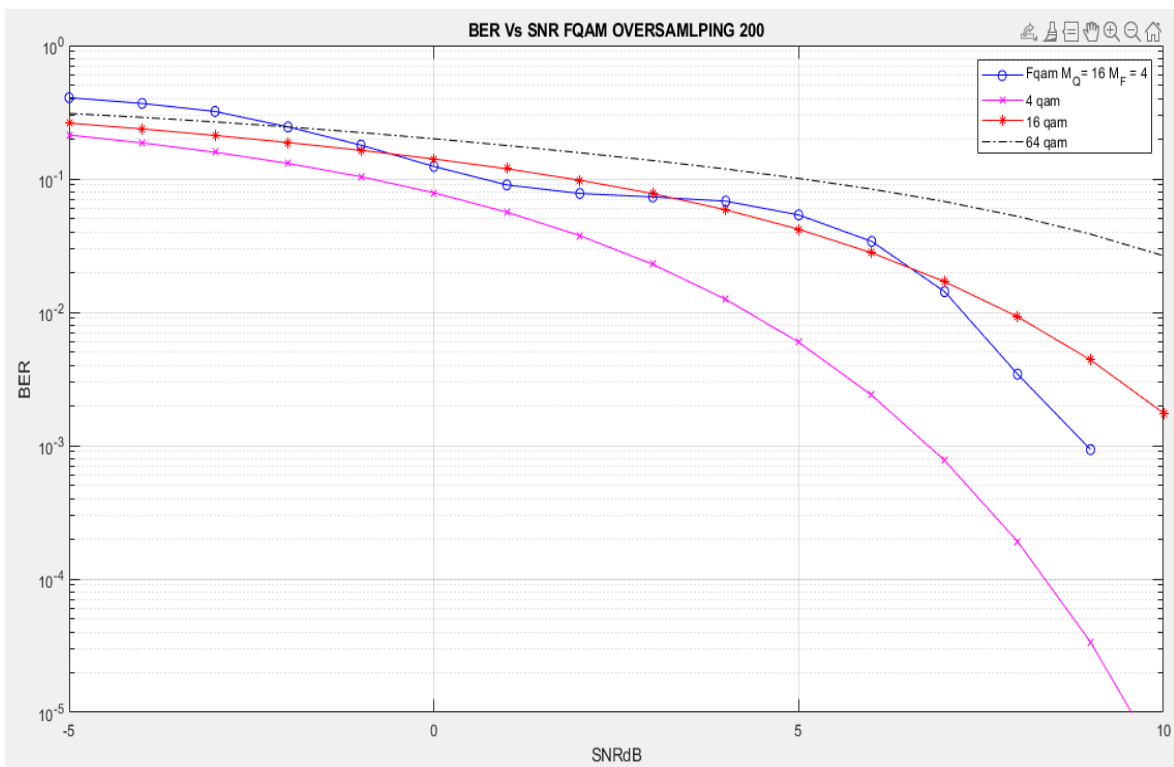


Figure 3.7: (4,16)-FQAM BER curve with oversampling factor 200

As we can clearly observe from figures 3.4,3.5 for (4,4)-FQAM and figures 3.6,3.7 for (4,16)-FQAM respectively, when the oversampling factor is configured to 200, the schemes perform better, which is rational if we consider the fact that each symbol consists of 200 samples and the demodulator's estimations become more accurate. The behavior of (4,4)-FQAM modulation is comparable to 4-QAM but outperforms it in high SNRs. Alike to (4,4)-FQAM the (4,16)-FQAM behavior is comparable to 16 and 64-QAM and outperforms them in high SNRs.

In the following tables we record the involvement of the mistakenly carrier frequency identification and the incorrectly QAM demodulation in the total symbol errors, as well as the case in which there was false estimation in both of them. The metrics is about (0-4) SNR in dB. Table 2 refers to (4,16)-FQAM and table 3 to (4,4)-FQAM and the oversampling factor is equal to 100. An interesting observation for (4,4)-FQAM is that in every QAM demodulation error the carrier frequency was false estimated too.

Table 2: (4,16)-FQAM Error Analysis

| | 0 dB | 1 dB | 2 dB | 3 dB | 4 dB |
|------|------|------|------|------|------|
| FSK | 858 | 635 | 488 | 378 | 310 |
| QAM | 890 | 673 | 505 | 349 | 263 |
| Both | 784 | 565 | 421 | 308 | 242 |

Table 3: (4,4)-FQAM Error Analysis

| | 0 dB | 1 dB | 2 dB | 3 dB | 4 dB |
|------|------|------|------|------|------|
| FSK | 1460 | 1057 | 614 | 216 | 54 |
| QAM | 1091 | 783 | 447 | 172 | 42 |
| Both | 1091 | 783 | 447 | 172 | 42 |

In figure 3.8 and 3.9 we present the BER curves of FBPSK modulation which, as mentioned, is a combination of BPSK and BFSK modulations in AWGN for 100 and 200 oversampling factor respectively, compared to BFSK with non-coherent demodulator.

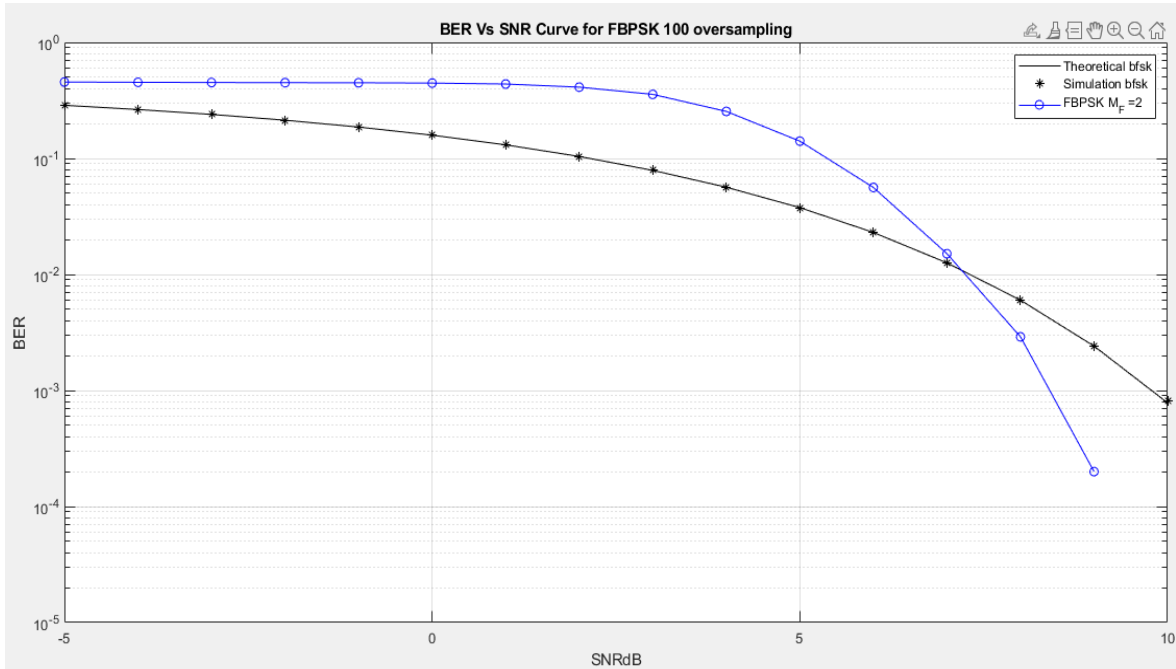


Figure 3.8: FBPSK BER curve with oversampling factor 100

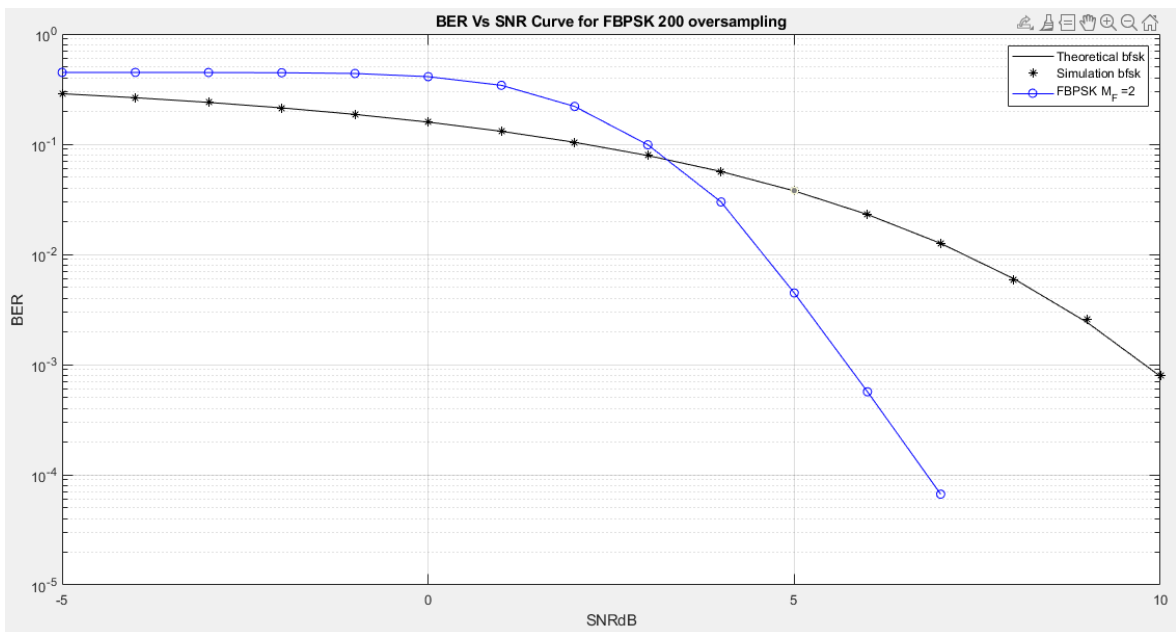


Figure 3.9: FBPSK BER curve with oversampling factor 200

From figures 3.8,3.9 we are observing the behavior of FBPSK in comparison to BFSK. It is clear that FBPSK in low SNRs underperforms BFSK, but presents sharper BER reduction in high SNRs and outperforms BFSK.

Chapter 4

CONCLUSIONS

In this thesis we analyzed a modulation scheme for private wireless communication. We demonstrated a FQAM simulation and the performance under AWGN channel. The simulation results, comparing FQAM modulation with QAM modulation scheme, prove that FQAM is a reliable communication scheme. We could continue our research and extend the simulation, to investigate the FQAM modulation performance in different channels, apart from AWGN, such as a fading channel. A limitation that we faced in the FQAM simulation, is that the FFT based central frequency detector that is used in the receiver side, could not operate properly in case the oversampling factor expression equals to less than 100. Finally, the fact that FQAM is a modulation scheme that varies frequency, amplitude and phase makes it a significant tool for modern future communication systems.

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APPENDIX

FQAM MATLAB SIMULATION CODE

Parts of the code are adopted by [7] and [8].

```
clc;
clear all;
close all;

M_Q=input(' enter the M_Q value : ');
M_F=input(' enter the M_F value : ');
Oversampling_Factor=input(' enter oversampling factor : ');

fprintf('\n\n\n');

Eb=1; %Energy Per Bit
SNRdB=-5:1:10; %SNR in dB
SNR=10.^(SNRdB/10);
ber=[];

M= M_F*M_Q; %Modulation Order
Ld=log2(M);
ds=ceil(Ld);
dif=ds-Ld;
bp=.000001; %bit period
k=1;
if(dif~=0)
    error('the value of M is only acceptable if log2(M) is an integer');
end
%XXXXXXXXXXXXXXXXXXXXXXXXX binary Information Generation
XXXXXXXXXXXXXXXXXXXXXXXXX
nbit=input("Enter number of bit nbit:");
nbit=nbit-(mod(nbit,log2(M))); %nbit proper for matrix ,(nbit/log2(M)
x log2(M))

msg=round(rand(nbit,1)); % information generation as binary form
disp(' binary information at transmitter ');
disp(msg);
fprintf('\n\n');

% binary information convert into symbolic form for M-array FQAM
modulation

M=M; % order of FQAM modulation
msg_reshape=reshape(msg,log2(M),nbit/log2(M) '); %Reshape to Symbols
disp(' information are reshaped for convert symbolic form');
disp(msg_reshape);
fprintf('\n\n');
size(msg_reshape);
```

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for (j=1:1:nbit/log2(M))
    for (i=1:1:log2(M_F))
        a(j,i)=num2str(msg_reshape(j,i)); %Frequency Bits
    end

    for (i=(log2(M_F)+1):1:log2(M))
        b(j,k)=num2str(msg_reshape(j,i)); %QAM bits
        k=k+1;
    end
    k=1;
end

Qas=bin2dec(b); %QAM Bits Binary to Decimal
Qass=Qas';
Fas=bin2dec(a); %Frequency Bits Binary to Decimal
Fass=Fas';

p=qammod(Qass,M_Q); %constalation design for M-array QAM acording to
symbol
sym=0:1:M_Q-1; % considerable symbol of M-array QAM, just for
scatterplot
pp=qammod(sym,M_Q); %constalation diagram for M-array
QAM
scatterplot(pp),grid on;
title('consttelation diagram for M-array QAM');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% FQAM modulation %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%% Transmitter %%%%%%%%%%%

RR=real(p); %QAM Real Part
II=imag(p); %QAM Imaginary Part
sp=bp*log2(M); %Symbol Period
sr=1/sp; % symbol rate
f_start=sr; %Starting Frequency

t=sp/Oversampling_Factor:sp/Oversampling_Factor:sp; %n=T/OSF
ss=length(t);
m=[];

%Normalizing factor
if M_Q == 4
    a= 1/sqrt(2);
else if M_Q == 16
    a = sqrt(1/10);
end

end

%Transmission
for (i=1:1:length(Fass))

    f=f_start*(Fass(i)+1); %Frequency Selection

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yr=a*RR(i)*cos(2*pi*f*t);           % real component
yim=a*II(i)*sin(2*pi*f*t);         % Quadrature component
y=yr+yim;

m=[m y];
end

                                %Plot FQAM Signal
tt=sp/Oversampling_Factor:sp/Oversampling_Factor:sp*length(Fass);
figure(1);
subplot(3,1,3);
plot(tt,m);
title('waveform for MFQAM modulation' );
xlabel('time(sec)');
ylabel('amplitude(volt)');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% AWGN %%%%%%%%%
%%%%%%%% Frequency Trap %%%%%%%%%
%In trap table there is the central frequency id for every
%M_F Frequencies
trap=[];
for(i=1:1:M_F)
f=f_start*i

kr=cos(2*pi*f*t);
kim=sin(2*pi*f*t);
k=kr+kim;
h = abs(fft(k));
h(1) = [];
tmax = max(h);
h(ceil(end/2):end) = [];
abovecutoff = h > tmax / 2; %3 dB is factor of 2
lowbin = find(abovecutoff, 1, 'first');
highbin = sum(abovecutoff);
centbin = sqrt(lowbin * highbin);
trap=[trap centbin];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Receiver %%%%%%%%%
for count=1:1:length(SNR)
snumber=0;
fnumber=0;
qnumber=0;
bother=0;
tro=[];

No=Eb/SNR(count);
Noise=sqrt(No/2)*(randn(1,(ss*length(Fass)))+1i*randn(1,(ss*length(Fass))));
m_new= m + Noise; %Noise added Signal

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m_reshape=reshape(m_new,Oversampling_Factor,(length(m_new)/Oversampling_Fac
tor)); %%Symbol Reshape In Receiver
l=(length(m_new)/Oversampling_Factor);
V=[];
clear j;

for(i=1:l:l)
    %% Frequency Carrier Detection
    h = abs(fft(m_reshape(i,:))); %For Each Symbol
    h(1) = [];
    tmax = max(h);
    h(ceil(end/2):end) = [];
    abovecutoff = h > tmax /3;
    lowbin = find(abovecutoff, 1, 'first');
    highbin = sum(abovecutoff);
    centbin = sqrt(lowbin * highbin);

    A(1:M_F)=-centbin;

    B=trapz+A;

    minimum=min(min(abs(B)));
    [x]=find(abs(B)==minimum); %% x=active carrier

    q=x-1; %% M-F ary bits
    tro=[tro q];
    p=de2bi(q,log2(M_F),'left-msb');

    %%% Signal Reconstruction
    f=f_start*x;

    y1=cos(2*pi*f*t);
    y2=sin(2*pi*f*t);
    mm1=y1.*(m_reshape(i,:)./a);
    mm2=y2.*(m_reshape(i,:)./a);
    z1=trapz(t,mm1); % integration
    z2=trapz(t,mm2); % integration
    zz1=round(2*z1/sp);
    zz2=round(2*z2/sp);

    %QAM Demodulation
    gt=zz1+j*zz2;
    ax=qamdemod(gt,M_Q);
    bi_in=de2bi(ax,log2(M_Q),'left-msb'); %% M_Q ary bits
    V=[V p bi_in]; %%% Bits
Reconstruction
end

tf = isequal(msg',V); %Vector Comparison with initial
[number, ratio] = biterr(msg',V);

ber(count)=ratio; %BER Metrics
diffelements=sum(Fass~=tro);
result=diffelements/numel(Fass);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%SER

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        %QAM,FSK,BOTH Errors
V_reshape=reshape(V,log2(M),nbit/log2(M)');
for i=1:1:l
    sf=isequal(msg_reshape(i,:),V_reshape(i,:));

    if sf==0
        snumber= snumber + 1;

ff=isequal(msg_reshape(i,(1:log2(M_F))),V_reshape(i,(1:log2(M_F))));

qf=isequal(msg_reshape(i,(log2(M_F)+1):log2(M)),V_reshape(i,(log2(M_F)+1):log2(M)));

        if ff==0
            fnumber=fnumber+1;
        end
        if qf==0
            qnumber=qnumber+1;
        end
        if ff==0 && qf==0
            bother = bother +1;
        end
    end
end

ser(count)=snumber/l;           %Symbol Error Rate
fer(count)=fnumber/snumber;    %Frequency Error Rate
qer(count)=qnumber/snumber;    %QAM Error Rate
aller(count)=bother/snumber;   %Both Error Rate

end

berQ4 = berawgn(SNRdB,'qam',4); %4-QAM Ber
berQ16 = berawgn(SNRdB,'qam',16); %16-QAM Ber
berQ64 = berawgn(SNRdB,'qam',64); %64-QAM Ber

figure(3);

semilogy(SNRdB,ber,'-bo',SNRdB,berQ4,'-mx',SNRdB,berQ16,'-
*r',SNRdB,berQ64,'-.k')
hold on;
grid on;
legend('Fqam M_Q= 4 M_F = 4','4 qam','16 qam','64 qam');
axis([min(SNRdB) max(SNRdB) 10^(-5) 1]);
title('BER Vs SNR FQAM OVERSAMPLING 100');
xlabel('SNRdB'); ylabel('BER');
hold off

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