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Abstract

The communication system is a system which describes the information exchange between two points. The process of transmission and reception of information is called communication. The major elements of communication are the Transmitter of information, Channel or medium of communication and the Receiver of information.

In our project we show the MATLAB simulation of transmitter and receiver for Quadrature Phase Shift Keying (QPSK) & Quadrature Amplitude Modulation (QAM) modulation and apply these modulation techniques with Orthogonal frequency division multiplexing (OFDM) to compare which is the better method by analyzing the Bit error rate (BER) vs Signal to noise ratio (SNR) graphs for each of the techniques.

After visual analysis of the BER vs SNR graph, we conclude that QPSK is the better technique as it has a lower bit error rate compared to QAM for a given SNR value

Literature Survey

I. Sadeque, Md. Golam. (2015). Bit Error Rate (BER) Comparison of AWGN Channels for Different Type's Digital Modulation Using MATLAB Simulink. American Scientific Research Journal for Engineering, Technology, and Sciences.

In this paper, three basic types of digital modulation techniques are discussed then the bit error rate performance characteristics of receiver are evaluated by using MATLAB Simulink model for FSK, PSK and QAM modulation techniques. The AWGN channel is used between transmitter and receiver. This paper focuses on the characterization and the design of analog signal waveforms that carry digital information and compares their performance on an AWGN channel. The main comparison is done using Bit Error Rate as a performance metric for each of the modulation techniques. The equivalent distance between two points in BFSK is lower than that of QPSK. By MATLAB code it is seen that BER of BFSK is greater than QPSK. By MATLAB SIMULINK the Simulink model to generate BFSK & QPSK signal is designed, and the output shows their signal propagation respectively

From this paper, we inferred that Bit Error Rate is a valid metric to measure between different modulation techniques. It is observed that if the distance is higher, probability of error will be less. We try to observe similar patterns from our project.

II. Brijesh Kumar, Sumit Jindal, Prakash Dua. A REVIEW PAPER ON ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM). International Journal of Scientific & Engineering Research, Volume 6, Issue 2, February-2015. ISSN 2229-5518

In this paper, we see that OFDM is a new and attractive modulation program with strongly efficient throughout bandwidth usage, immune to be able to multipath fading environment, superior spectral and power proficiency. OFDM is really a multicarrier transmission technique, which usually divides the bandwidth straight into many carriers; each one is modulated by a decreased rate data stream.

OFDM has higher capacity transmission and adjustable carrier modulation technique only recently that this advances in integrated world technology have made the particular implementation of OFDM turn out to be feasible and economical.

From this paper we use understand the implementation of OFDM technique and apply QAM-16 and QPSK Modulation technique to this to observe the better technique by comparing visually the Bit error Rate vs Signal to noise ratio graph for each of the techniques.

Introduction

Transmitter

A transmitter is an electrical device used in telecommunications to generate radio waves so that data can be transmitted or sent using an antenna. The transmitter can produce a radio frequency alternating current, which is then applied to the antenna, which radiates it as radio waves. Transmitters come in a variety of shapes and sizes, depending on the standard and the type of device; for example, many current gadgets with communication capabilities include transmitters such as Wi-Fi, Bluetooth, NFC, and cellular.

Fig 1: Transmitter tower

Receiver

A receiver is a device that selects a signal from among all the signals received from a communication channel, recovers the base band signal and delivers it to the user.

The receiver is the destination of the message. The receiver's task is to interpret the sender's message, both verbal and nonverbal, with as little distortion as possible. The process of interpreting the message is known as decoding. Because words and nonverbal signals have different meanings to different people, countless problems can occur at this point in the communication process:

- The sender inadequately encodes the original message with words not present in the receiver's vocabulary; ambiguous, nonspecific ideas; or nonverbal signals that distract the receiver or contradict the verbal message.
- The receiver is intimidated by the position or authority of the sender, resulting in tension that prevents effective concentration on the message and failure to ask for needed clarification.

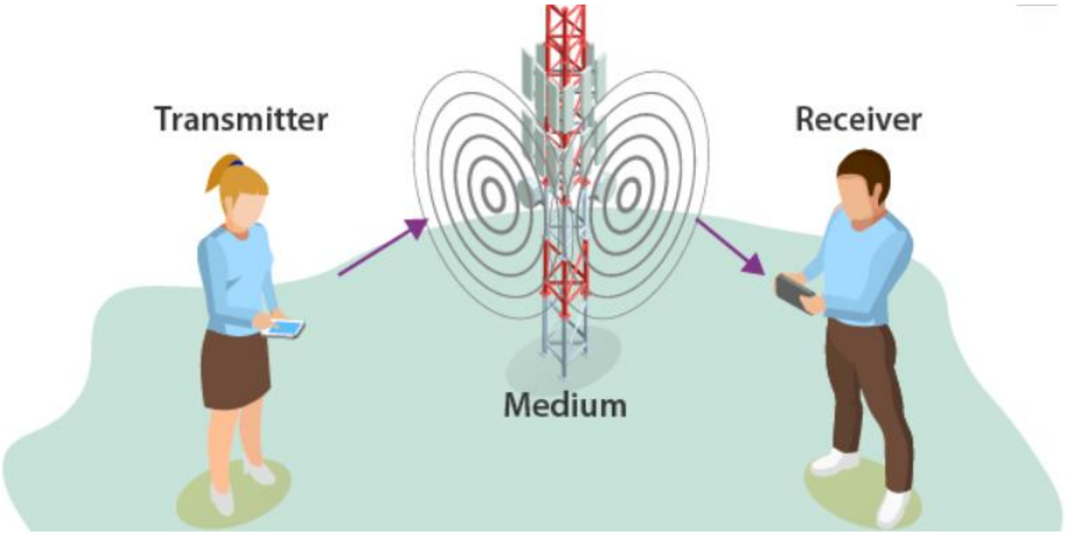

Fig 2: Transmitter and receiver

Modulation

Modulation is the process of superimposing a message signal (also called as modulation signal) with a carrier signal.
The frequency band that is occupied by the modulation signal is called the baseband and therefore modulation signal is also known as baseband signal.

Depending on the signal there are 2 types of modulation:

- Analog Modulation
- Digital Modulation

Demodulation

The process of separating the original information or signal from the modulated carrier. In the case of amplitude or frequency modulation it involves a device, called a demodulator or detector, which produces a signal corresponding to the instantaneous changes in amplitude or frequency, respectively.

A modulator performs modulation whereas a demodulator performs demodulation (the inverse of modulation).

Quadrature Amplitude Modulation (QAM)

It Combines Amplitude and phase shifts and Digital Signals are created using IQ modulation. I in IQ is called InPhase component AND Q is called Quadrature component. Quadrature refers to shifting by 90 degree.

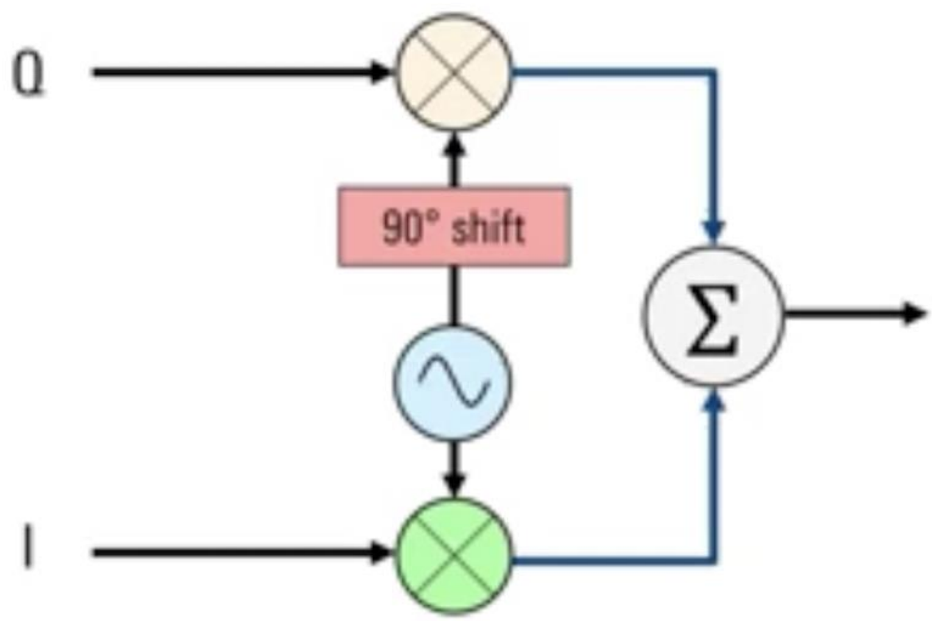

Fig 3. Transmitter Block

The result of this IQ modulation is a constellation diagram in which points are arranged in a square shape. Each point also referred to as symbol has a unique combination of amplitude and phase. In 16-QAM, each symbol is represented by 4 bits
Higher order QAMs are 64QAM, 256QAM , 1024QAM, 4096QAM
By increasing modulation order:

- Increases bit rate
- Reduces resistance to errors

Higher order QAMs are often used in controlled environments and less susceptible to noise and interference. In over-the-air, Technologies such as cellular, Wi-Fi, the system is made in such a way that they dynamically adapt modulation order based on channel conditions. In QAM, we can modulate two individual signals and transmitted to the receiver level by using the two input signals, the channel bandwidth also increases. Therefore QAM can transmit two message signals over the same channel.

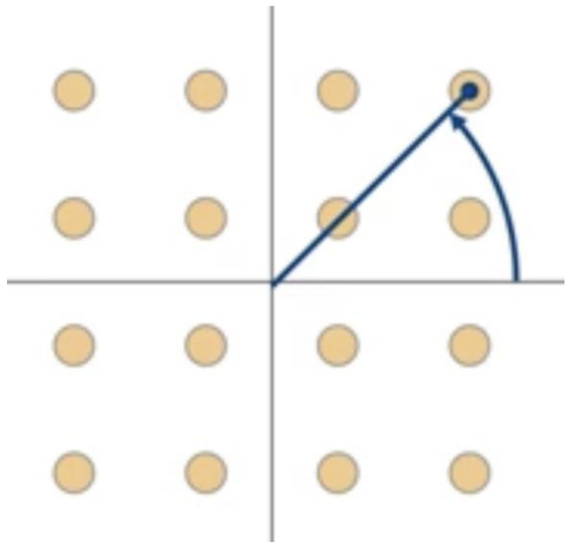

Fig 4: IQ Modulation constellation diagram

Transmitter

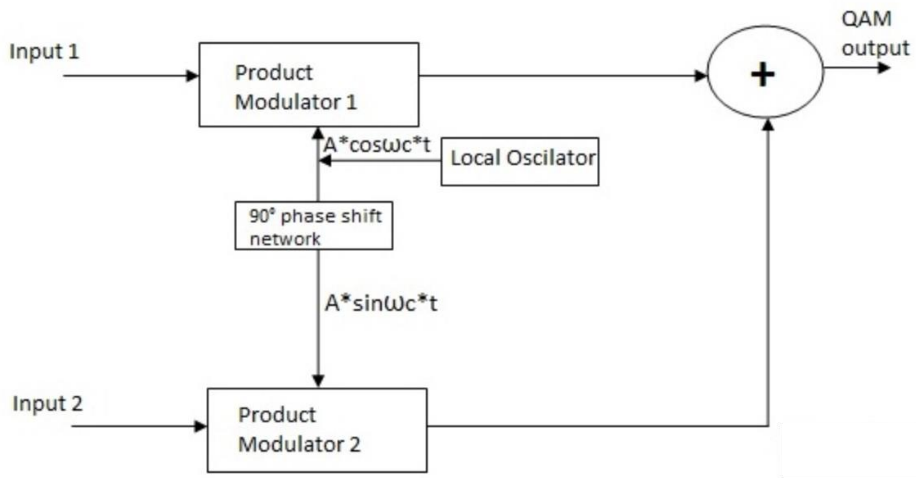

Fig 5: Transmitter block diagram for QAM

Product modulator1 and local oscillator are called the in-phase channel and product modulator2 and local oscillator are called a quadrature channel. Both output signals of the in-phase channel and quadrature channel are added up so the resultant output will be QAM.

Receiver

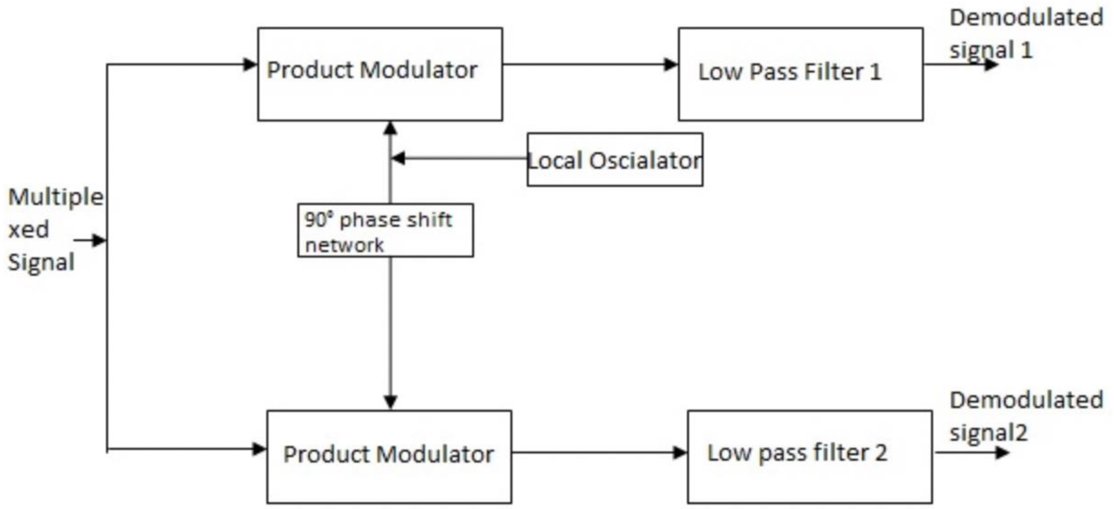

Fig 6: Receiver block diagram for QAM

The QAM signal is forwarded from the upper channel of receiver and lower channel, and the resultant signals of product modulators are forwarded from LPF1 and LPF2. These low pass filters are fixed to the cut off frequencies of input 1 and input 2 signals. Then the filtered outputs are the recovered original signals.

Advantages:

- It supports a high data rate. So, a huge number of bits can be carried by the carrier signal. Thereby increasing throughput
- QAM's noise immunity is very high. Due to this noise interference is very less.
- It has a low probability of error value.
- QAM expertly uses channel bandwidth.

Applications:

- QAM technique is widely used in the radio communications field because of the increase of the bit data rate.
- QAM is used in applications ranging from short-range wireless communications to long-distance telephone systems.

- QAM is used in microwave and telecommunication systems to transmit the information.
- The 64 QAM and 256 QAM are used in digital cable television and cable modem.

MATLAB Code:

```
clear;
clc;
clf;

N = 2*10^5;
M = 16;
data = [0:M-1];
W=qammod(data,M);
alpha16qam = [-3 -1 1 3]; %16-QAM
EsNodB = [0:20];
out = zeros(1,N);
t = linspace (0, 1, N);
ip = randsrc(1,N, alpha16qam) +
j*randsrc(1,N,alpha16qam);
for i=1:length(EsNodB)
    s = (1/sqrt(10))*ip; %Normalization %transmitted
signal
    w0 = 1/sqrt(2)*[randn(1,N) + j*randn(1,N)]; %white
guassian noise of 0 dB
    w = 10^(-EsNodB(i)/20)*w0; %extra white gaussian
noise
    r = s + w; %transmitted signal with noise =
received signal

    r_re = real(r);
    r_im = imag(r);
    %dem = r_re + r_im
    out_re(find(r_re < -2/sqrt(10)))              = -3;
    out_re(find(r_re >  2/sqrt(10)))              =  3;
    out_re(find(r_re > -2/sqrt(10) & r_re <= 0)) = -1;
    out_re(find(r_re > 0 & r_re <=  2/sqrt(10))) =  1;
    out_im(find(r_im < -2/sqrt(10)))              = -3;
    out_im(find(r_im >  2/sqrt(10)))              =  3;
```

```
    out_im(find(r_im > -2/sqrt(10) & r_im <= 0)) = -1;
    out_im(find(r_im > 0 & r_im <=  2/sqrt(10))) =  1;
    out = out_re + j*out_im;
    ber(i) = size(find([ip - out]),2); %counting the
number of errors
end
ber
simBer = ber/N;
theoryBer = 3/2*erfc(sqrt(0.1*(10.^(EsNodB/10))));
figure
plot(t, s,'b-.'); axis([-0.1 1.2 -2 2]);
title('Transmitted Signal')

figure
plot(t,out,'r--'); axis([-0.1 1.2 -4 4]);
title('Recieved Signal')

figure
semilogy(EsNodB, theoryBer, 'b.-','LineWidth',2) %Plot
the BER
hold on;
semilogy(EsNodB, simBer, 'mx-','LineWidth',2) %Plot the
BER
axis([0 20 10^-5 1])
grid on
legend('theory', 'simulation');
xlabel('Es/No, dB');
ylabel('Symbol Error Rate')
title('Symbol error probability curve for 16-QAM
modulation')

scatterplot(W,1,0,'b*');
```

OUTPUT:

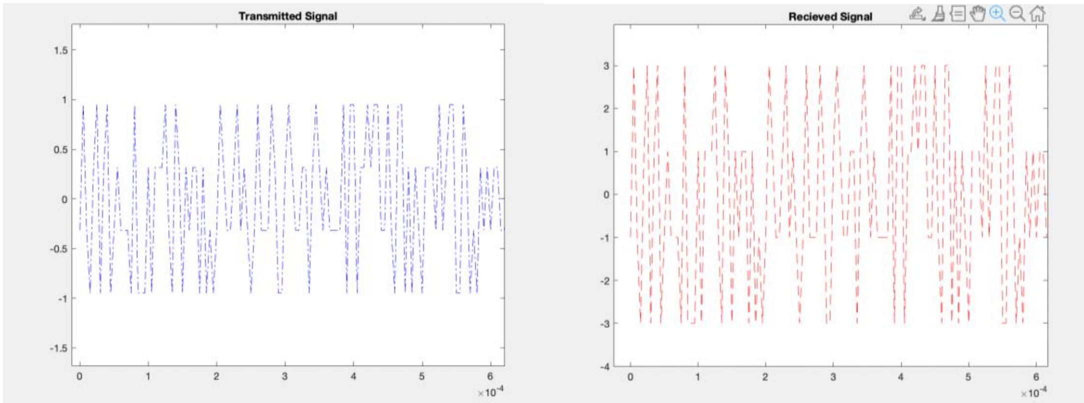

Fig 7: Transmitter and Receiver output for QAM

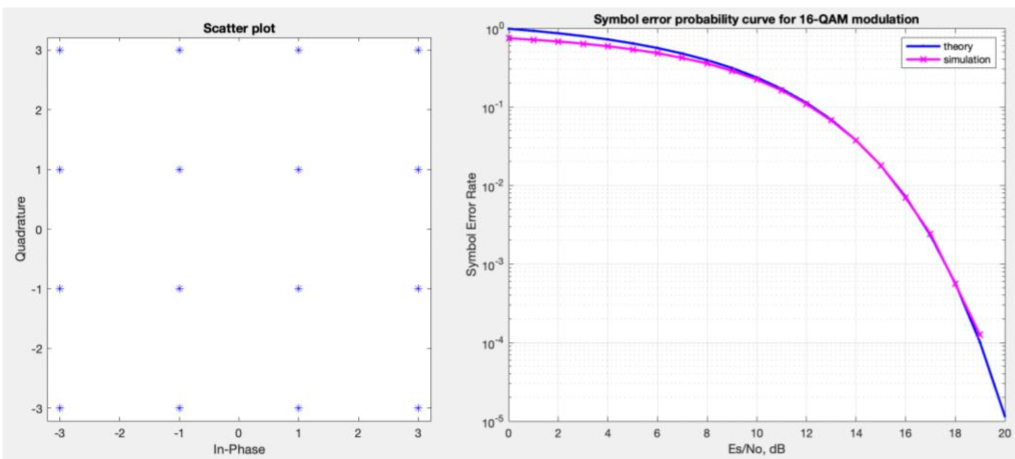

Fig 8: Scatter plot and Symbol error probability curve for 16 - QAM

Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying QPSK is a variation of BPSK, and it is also a Double Side Band Suppressed Carrier DSBSC modulation scheme, which sends two bits of digital information at a time, called as bigits.

Instead of the conversion of digital bits into a series of digital stream, it converts them into bit pairs. This decreases the data bit rate to half, which allows space for the other users.

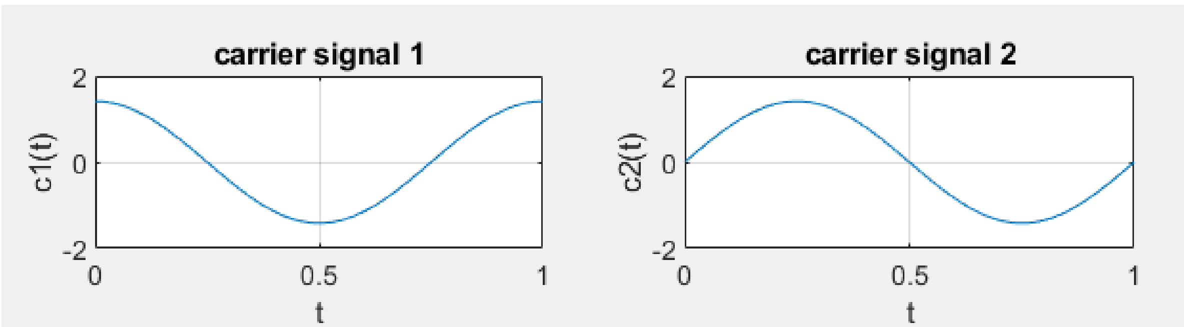

Fig 9: Carrier signals

Transmitter - QPSK modulator components:

- Bit splitter
- Two multipliers with local oscillator
- 2-bit Serial to Parallel converter
- Summer Circuit (adds multiple voltage signals)

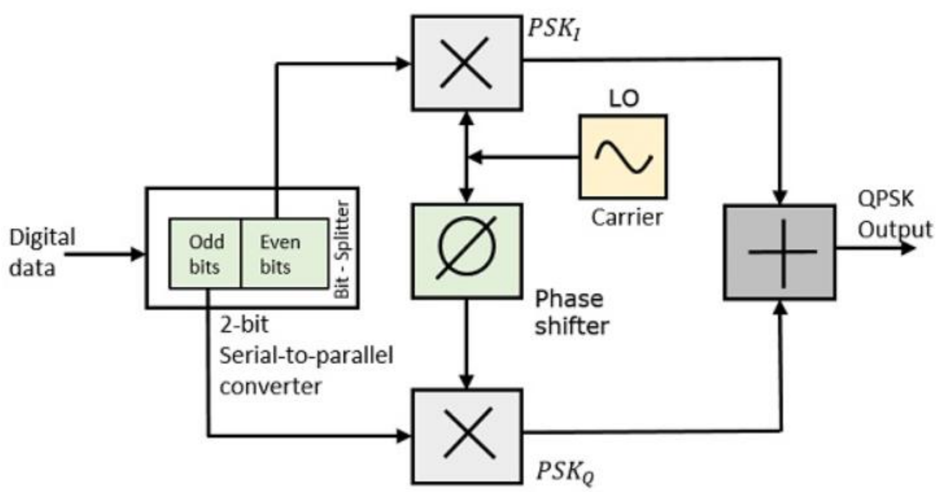

Fig 10: Transmitter block diagram for QPSK

Message signal is taken, and the even bits and odd bits are separated by the bit-splitter. It is then multiplied with carrier to generate PSKI (In-Phase modulation signal) and PSKQ (Quadrature modulation signal). PSKQ needs to be phase shifted by 90 degree (usually done by carrier)

Modulating values

00 – 0^o ; 01 - 90^o ; 10 - 180^o ; 11 - 270^o

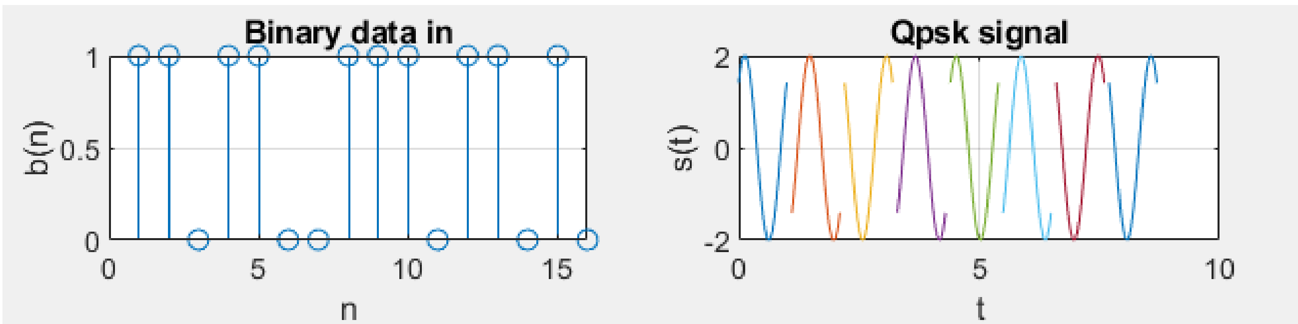

Fig 11: Modulated QPSK Signal

Receiver - QPSK demodulator components

- Two product demodulator circuits
- Two band pass filters
- Two integrator / summer circuits
- 2-bit parallel to serial converter

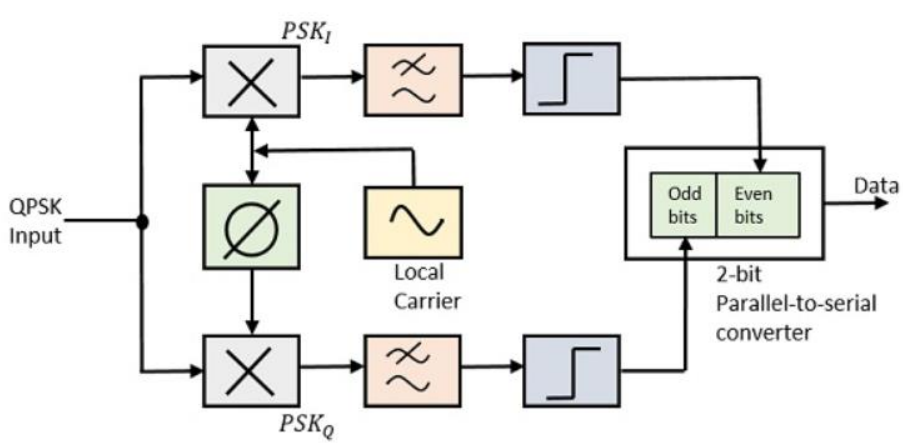

Fig 12: Receiver block diagram for QPSK

Two product detectors and summer circuits (x1 and x2) simultaneously demodulate the two BPSK signals to give demodulated PSKI and PSKQ. These signals are passed to decision maker (Low pass filter + square wave generator) for processing and then to parallel to serial converter to combine the bits accordingly and form the output data

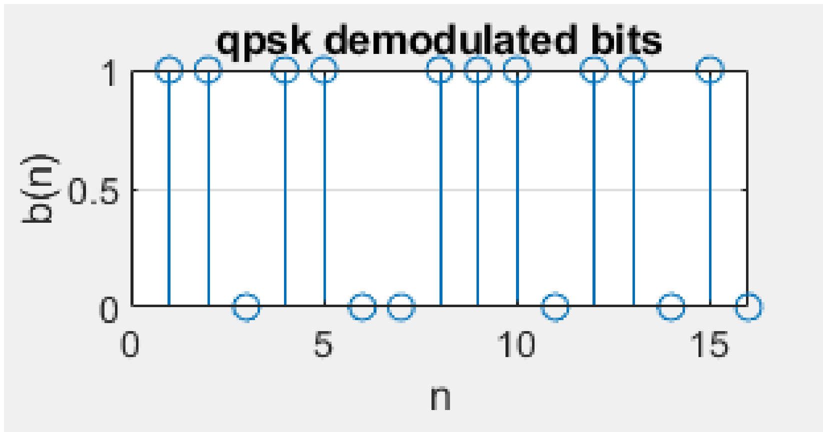

Fig 13: Demodulated QPSK Signal

Advantages:

- Allows the signal to carry twice as much information as ordinary PSK using the same Bandwidth
- Provides good noise immunity
- Low error probability
- Carrier power remains almost constant because amplitude of QPSK is not much

Applications:

- Satellite transmission of MPEG2
- Cable modem
- Cellular phone systems

MATLAB Code:

```
clc;
clear all;
```

```
close all;

% generating quadrature carrier signal
Tb = 1;
t = 0:(Tb/100):Tb;
fc = 1;
c1 = sqrt(2/Tb) * cos(2 * pi * fc * t);
c2 = sqrt(2/Tb) * sin(2 * pi * fc * t);

% plotting carriers c1 and c2
subplot(3,2,1);
plot(t, c1);
title ('carrier signal 1');
xlabel('t');
ylabel('c1(t)');
grid on;
subplot(3,2,2);
plot(t, c2);
title('carrier signal 2');
xlabel('t');
ylabel('c2(t)');
grid on;

% Let us generate the message signal
N = 16;
m = rand(1,N);
t1 = 0;
t2 = Tb;
for i = 1:2:(N-1)
    t = t1:(Tb/100):t2;
    if m(i) > 0.5
        m(i) = 1;
        m_s = ones(1, length(t));
    else
        m(i) = 0;
        m_s = -1 * ones(1, length(t));
    end
    odd_sig(i, :) = c1.*m_s;

    if m(i+1) > 0.5
```

```
        m(i+1) = 1;
        m_s = ones(1, length(t));
    else
        m(i+1) = 0;
        m_s = -1 * ones(1, length(t));
    end
    even_sig(i, :) = c2.*m_s;

    qpsk = odd_sig + even_sig;

    % Let us plot the QPSK signal
    subplot(3, 2, 4);
    plot(t, qpsk(i,:));
    title('Qpsk signal');
    xlabel('t');
    ylabel('s(t)');
    grid on;
    hold on;
    t1 = t1 + (Tb + 0.1);
    t2 = t2 + (Tb + 0.1);
end

hold off;

% Plotting message signal
subplot(3,2,3);
stem(m);
title ('Binary data in');
xlabel('n');
ylabel('b(n)');
grid on;

% demodulation
t1 = 0;
t2 = Tb;
for i = 1:N-1
    t = t1:(Tb/100):t2;
    x1 =  sum(c1.*qpsk(i,:));
    x2 =  sum(c2.*qpsk(i,:));
    if (x1 > 0 && x2 > 0)
```

```
            demod(i) = 1;
            demod(i+1) = 1;

        elseif (x1 > 0 && x2 < 0)
            demod(i) = 1;
            demod(i+1) = 0;

        elseif (x1 < 0 && x2 < 0)
            demod(i) = 0;
            demod(i+1) = 0;

         elseif (x1 < 0 && x2 > 0)
            demod(i) = 0;
            demod(i+1) = 1;
        end

        t1 = t1 + (Tb + 0.01);
        t2 = t2 + (Tb + 0.01);
    end

    subplot(3,2,5);
    stem(demod);
    title('qpsk demodulated bits');
    xlabel('n');
    ylabel('b(n)');
    grid on;
```

OUTPUT:

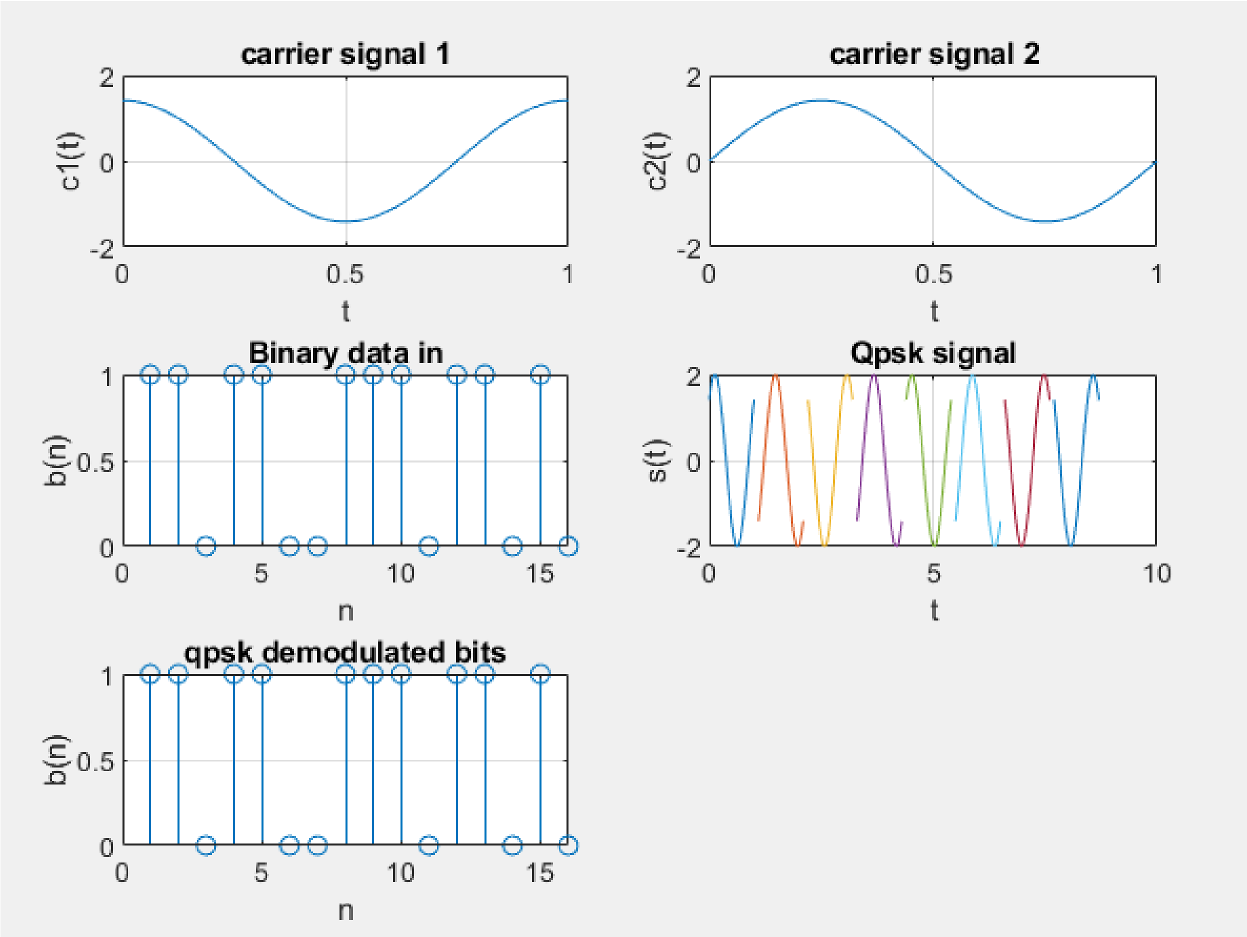

Fig 14: QPSK Signal output

Orthogonal Frequency Division Multiplexing (OFDM)

Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within equivalent bandwidths.

OFDM is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels.

The OFDM scheme differs from traditional FDM in the following interrelated ways:

1. Multiple carriers (called subcarriers) carry the information stream, parallelly
2. The subcarriers are orthogonal to each other, and
3. A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference.
4. Increases data rate

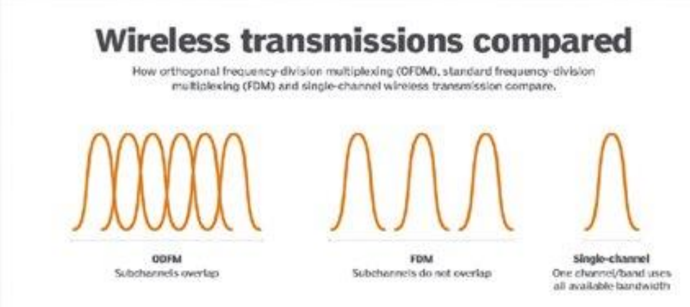

Fig 15: Introduction to OFDM

Transmitter and Receiver:

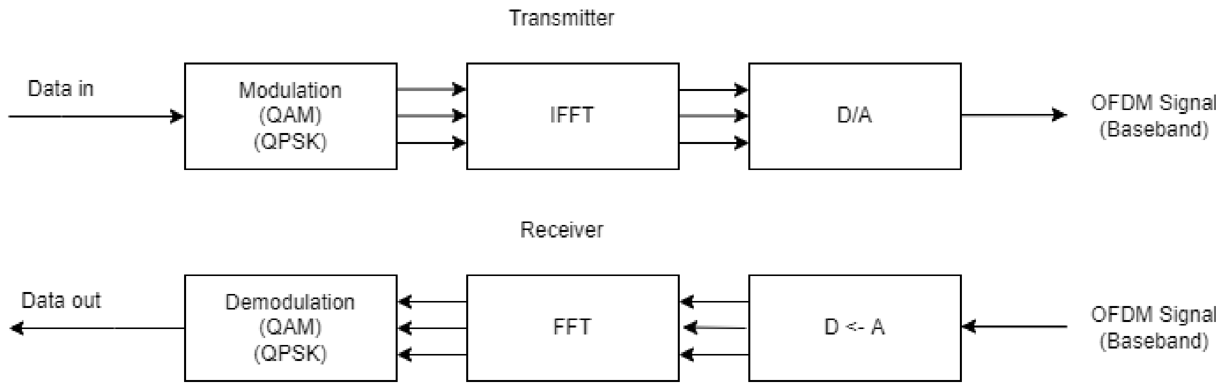

Fig 16: Transmitter & Receiver blocks for OFDM

Advantages:

- OFDM is more resilient to electromagnetic interference, and it enables more efficient use of total available bandwidth because the subchannels are closely spaced.
- Advanced error correction can be used to spread out the overall data and compensate for small errors. So, narrowband interference on a single subchannel will not affect the other channels, enabling the overall system to still operate.

Applications:

- Orthogonal frequency-division multiplexing is used in many technologies, including the following:
- Digital radio, Digital Radio Mondiale, and digital audio broadcasting and satellite radio.
- Wired data transmission, Asymmetric Digital Subscriber Line (ADSL), Institute of Electrical and Electronics Engineers (IEEE) 1901 powerline networking, cable internet providers.
- Wireless LAN (WLAN) data transmission. All Wi-Fi systems use OFDM, including IEEE 802.11a/b/g/n/ac/ax..

- Cellular data. Long-Term Evolution (LTE) and 4G cellphone networks use OFDM. It is also an integral part of 5G NR cellular deployments.

OFDM – QAM

MATLAB Code:

```
close all;
clear all;
clc;
```

Generating and coding data

```
t_data = randi([0,1],9600,1)';
x = 1;
si = 1; % for BER rows

for d = 1:100;
data = t_data(x:x+95);
x = x+96;
k = 3;
n = 6;
s1 = size(data,2); % Size of input matrix
j = s1/k;
```

Convolutionally encoding data

```
constlen = 7;
codegen = [171 133]; % Polynomial
trellis = poly2trellis(constlen, codegen);
codedata = convenc(data, trellis);

%Interleaving coded data
s2 = size(codedata,2);
j = s2/4;
matrix = reshape(codedata,j,4);
intlvddata = matintrlv(matrix',2,2)'; % Interleave
intlvddata = intlvddata';
```

Binary to decimal conversion

```
dec = bi2de(intlvddata','left-msb');

%16-QAM Modulation
M = 16;
y = qammod(dec,M);
% scatterplot(y);
```

Pilot insertion

```
lendata=length(y);
pilt=3+3j;
nofpits=4;
k=1;
for i=(1:13:52)
```

```
    pilt_data1(i)=pilt;


    for j=(i+1:i+12);
        pilt_data1(j)=y(k);
        k=k+1;
    end
end


pilt_data1=pilt_data1';   % size of pilt_data =52
pilt_data(1:52)=pilt_data1(1:52);    % upsizing to 64
pilt_data(13:64)=pilt_data1(1:52);   % upsizing to 64


for i=1:52

    pilt_data(i+6)=pilt_data1(i);

end
```

IFFT

```
ifft_sig=ifft(pilt_data',64);
```

Adding Cyclic Extension

```
cext_data=zeros(80,1);
cext_data(1:16)=ifft_sig(49:64);
for i=1:64
    cext_data(i+16)=ifft_sig(i);
end
```

Channel

```
% SNR
o=1;
for snr=0:2:50
ofdm_sig=awgn(cext_data,snr,'measured'); % Adding white Gaussian Noise
```

RECEIVER

```
%Removing Cyclic Extension
for i=1:64
    rxed_sig(i)=ofdm_sig(i+16);
end
```

FFT

```
ff_sig=fft(rxed_sig,64);
```

Pilot

```
for i=1:52
```

```
    synched_sig1(i)=ff_sig(i+6);
end


k=1;


for i=(1:13:52)
    for j=(i+1:i+12);
        synched_sig(k)=synched_sig1(j);
        k=k+1;
    end
end
```

Demodulation

```
dem_data= qamdemod(synched_sig,16);
```

Decimal to binary conversion

```
bin=de2bi(dem_data','left-msb');
bin=bin';
```

De-Interleaving

```
deintlvddata = matdeintrlv(bin,2,2); % De-Interleave
deintlvddata=deintlvddata';
deintlvddata=deintlvddata(:)';

% Decoding data
n=6;
k=3;
decodedata =vitdec(deintlvddata,trellis,5,'trunc','hard');  % decoding datausing
veterbi decoder
rxed_data=decodedata;
```

Calculating BER

```
rxed_data=rxed_data(:)';
errors=0;
c=xor(data,rxed_data);
errors=nnz(c);
BER(si,o)=errors/length(data);
o=o+1;
 end % SNR loop ends here
 si=si+1;
end % main data loop
```

Time averaging for optimum results

```
for col=1:25;
    ber(1,col)=0;
for row=1:100;
        ber(1,col)=ber(1,col)+BER(row,col);
```

```
    end
end
ber = ber./100;

figure
i=0:2:48;
semilogy(i,ber, 'r*');
title('BER vs SNR');
ylabel('BER');
xlabel('SNR (dB)');
grid on
hold on
EsNodB = [0:16];
theoryBer = 3/2*erfc(sqrt(0.1*(10.^(EsNodB/10))));
semilogy(EsNodB, theoryBer, 'b.-','LineWidth',2) %Plot the BER
legend('Simulation','Theory','Location','Best')
```

OUTPUT:

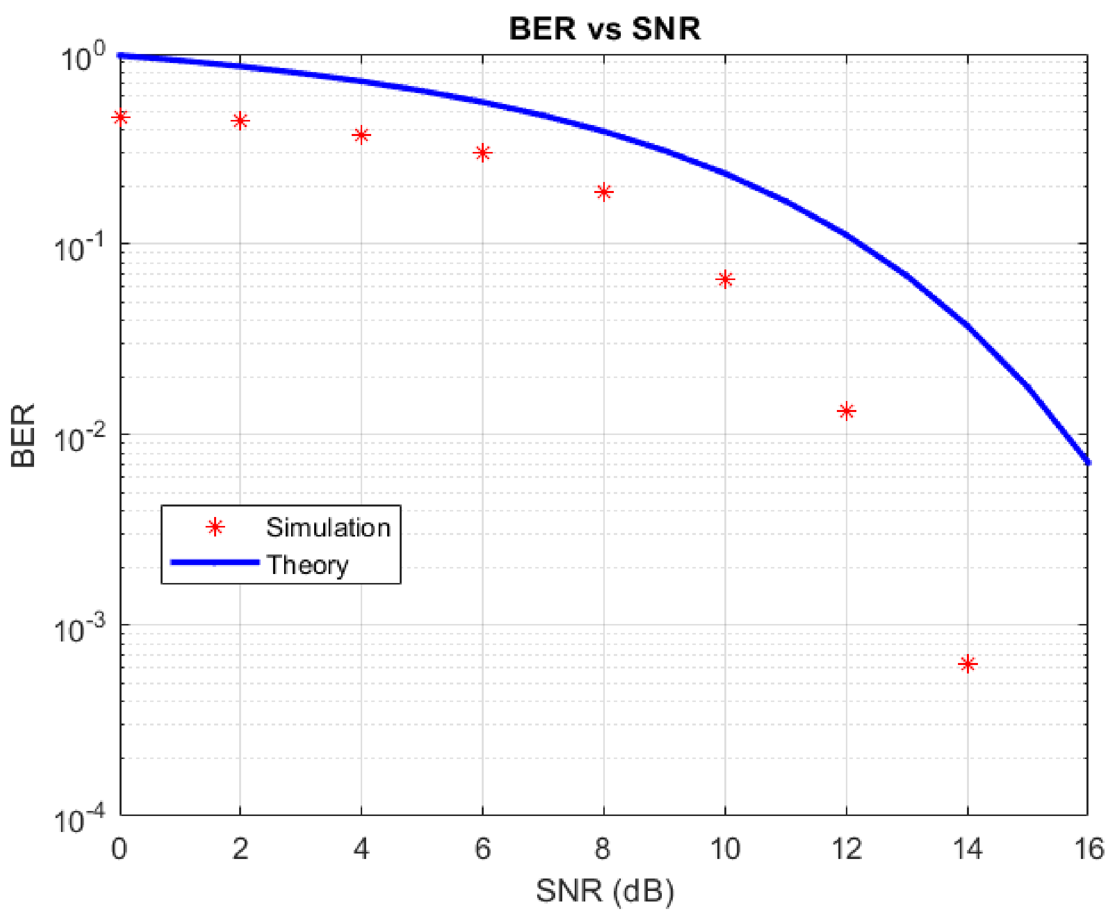

Fig 17: Bit error rate vs Signal to noise ration for OFDM - QAM

OFDM - QPSK

MATLAB Code:

```
clear; clc;

M = 4;
k = log2(M);
numSC = 128;
cpLen = 32;
maxBitErrors = 100;
maxNumBits = 1e7;
xTrial = (0:M-1)';

qpskMod = comm.QPSKModulator('BitInput',true);
qpskDemod = comm.QPSKDemodulator('BitOutput',true);


ofdmMod = comm.OFDMModulator('FFTLength',numSC,'CyclicPrefixLength',cpLen);
ofdmDemod = comm.OFDMDemodulator('FFTLength',numSC,'CyclicPrefixLength',cpLen);


channel = comm.AWGNChannel('NoiseMethod','Variance', 'VarianceSource','Input
port');


errorRate = comm.ErrorRate('ResetInputPort',true);


ofdmDims = info(ofdmMod)
```

```
ofdmDims = struct with fields:
    DataInputSize: [117 1]
       OutputSize: [160 1]
```

```
numDC = ofdmDims.DataInputSize(1)
```

```
numDC = 117
```

```
frameSize = [k*numDC 1];


EbNoVec = (0:10)';
snrVec = EbNoVec + 10*log10(k) + 10*log10(numDC/numSC);


berVec = zeros(length(EbNoVec),3);
errorStats = zeros(1,3);

for m = 1:length(EbNoVec)
    snr = snrVec(m);
    while errorStats(2) <= maxBitErrors && errorStats(3) <= maxNumBits
        dataIn = randi([0,1],frameSize);
        qpskTx = qpskMod(dataIn);
```

```
        txSig = ofdmMod(qpskTx);
        powerDB = 10*log10(var(txSig));
        noiseVar = 10.^(0.1*(powerDB-snr));
        rxSig = channel(txSig,noiseVar);
        qpskRx = ofdmDemod(rxSig);
        dataOut = qpskDemod(qpskRx);
        errorStats = errorRate(dataIn,dataOut,0);
    end

    berVec(m,:) = errorStats;
    errorStats = errorRate(dataIn,dataOut,1);
end

berTheory = berawgn(EbNoVec,'psk',M,'nondiff');
figure
semilogy(EbNoVec,berVec(:,1),'*')
hold on
semilogy(EbNoVec,berTheory)
title('BER vs SNR');
legend('Simulation','Theory','Location','Best')
xlabel('SNR (dB)')
ylabel('Bit Error Rate')
grid on
hold off
```

OUTPUT:

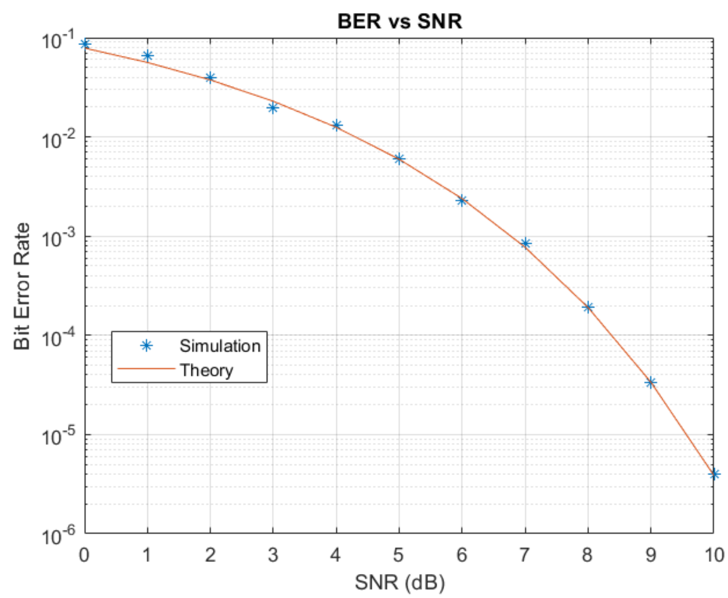

Fig 18: Bit error rate vs Signal to noise ration for OFDM - QPSK

CONCLUSION

It is observed that for Signal to Noise Ratio, the BER for QAM is higher than QPSK

For example, when SNR = ‘4’

For QAM, in 100 bits, 5 bits have a probability of error

For QPSK, in 100 bits, 1 bit has a probability of error

Observing the graph, we deduce that OFDM using QPSK's theoretical and simulated points are closer than that of QAM

Hence, the performance of QPSK is better than 16 QAM because the BER values with respect to the Average received SNR (in dB) in case of QPSK are lower than the values obtained in the case of 16 QAM.

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