# Communication and Signal Processing Lab

**[EE5801]**

**Submitted by**
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EE21MTECH14002
(1st Semester)

**"Orthogonal Frequency Division Multiplexing (OFDM)"**

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**Telangana**

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# INTRODUCTION

## Orthogonal Frequency Division Multiplexing (OFDM):

Before going on to OFDM first try to understand what frequency division multiplexing (FDM) is? It is a multiplexing method which is used to divide a channel into many non-overlapping sub channels so that we can provide these multiple subchannel to multiple users.
-FDM allows multiple users to share one single link.

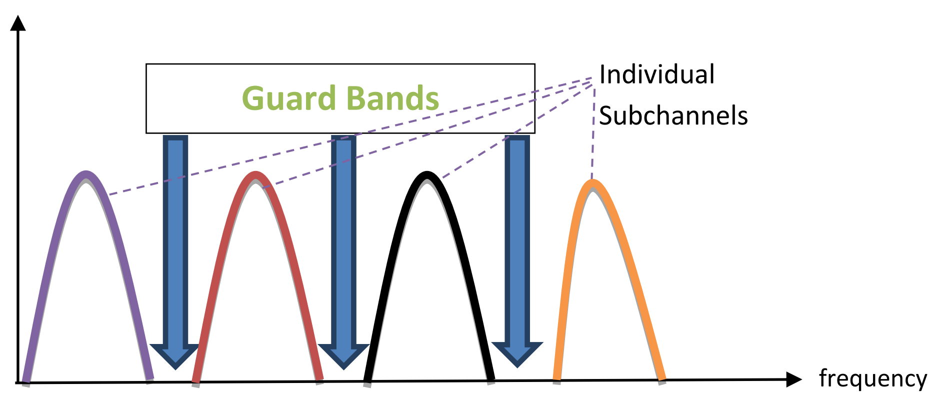
Now, Orthogonal frequency division multiplexing or OFDM is a variation of FDM. OFDM is a very popular multiplexing method used for many of the latest wireless and telecommunication standards such as Wi-Fi802.11, 4G and 5G cellular phone technologies WiMAX, satellite, and many others.

## Comparison between FDM and OFDM:

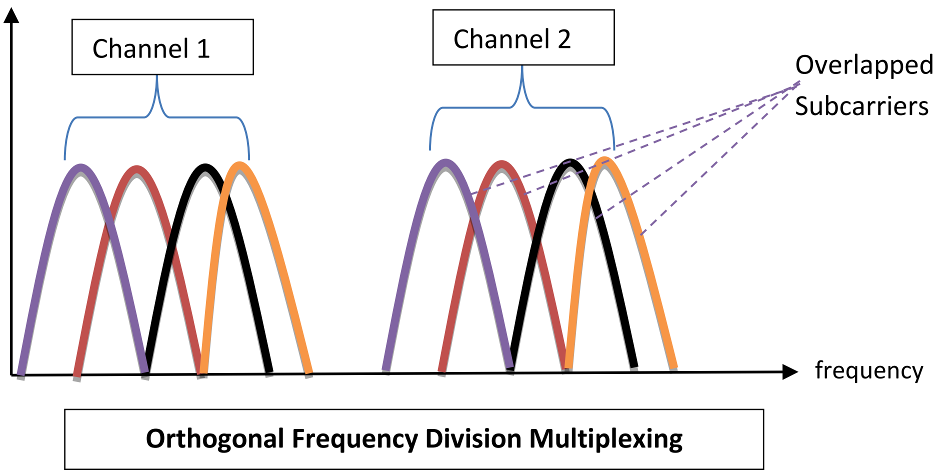
In general, FDM allows multiple users to share one link by dividing available bandwidth into different non-overlapping sub channels and guard bands are also provided that is a narrow frequency range is inserted between adjacent sub channels so that different signals travel separately and simultaneously without interfering with each other.

But, In OFDM on the other hand those sub channels are closely spaced not only there is no guard band between them, but they are overlapped.

We can see that with the same available bandwidth hence OFDM would allow more data transmissions than FDM and OFDM is bandwidth efficient in comparison to FDM, because in FDM our bandwidth is occupied by the guard band and the subchannels also separated in frequency but in OFDM all these guard bands are removed and all subcarriers are overlapped on each other which saves lot of our bandwidth that we can further use to create more links and by that providing channels to more users .




Frequency Division Multiplexing




## How does OFDM prevent interference between subchannels?

The key is that in OFDM we will combine them closely together in a way they are orthogonal to each other.

## Meaning of orthogonal

Orthogonal means the two or multiple objects act independently. Orthogonal signal means in this case any neighbor signal have no dependence are or interference with one another which also means that receiver can detect these signals separately.

Orthogonality is a property that allows multiple signals to transmit over a common channel with successful detection.

OFDM would better utilize available bandwidth thus offering high data transmission rate than FDM.

## Mathematically: Orthogonality Condition

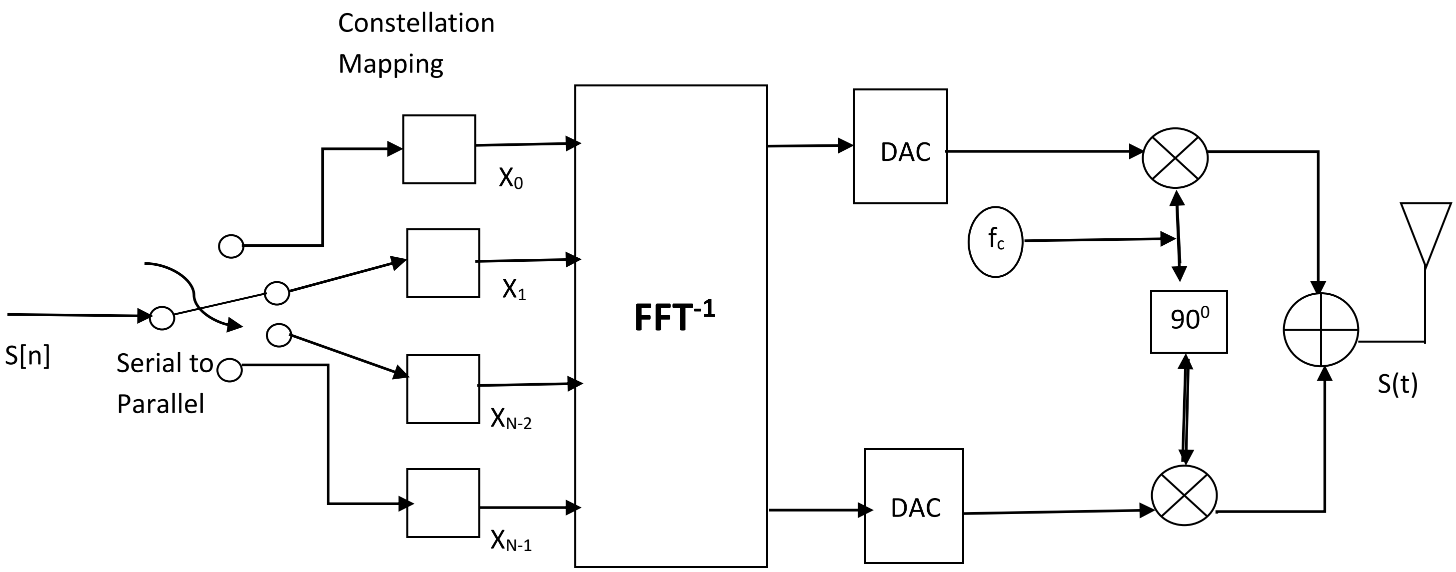
Two signals $x_1(t)$ and $x_2(t)$ over an interval $t_1$ to $t_2$ are orthogonal if and only if

$$\int_{t_1}^{t_2} x_1(t)x_2^*(t)dt = 0$$

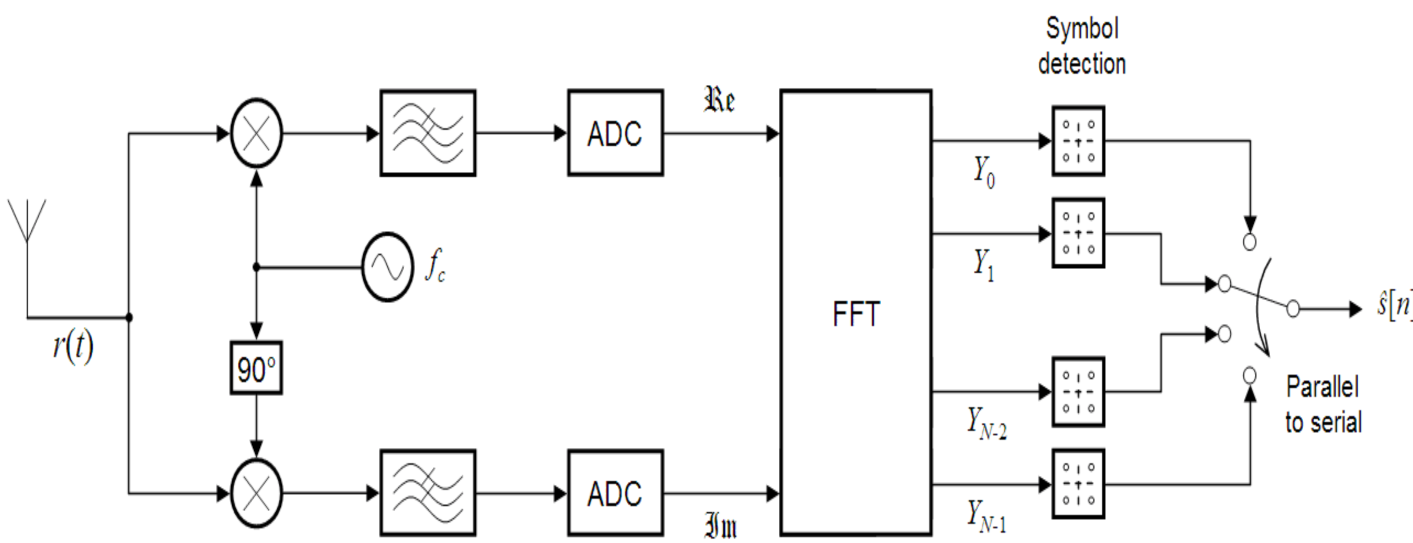
**OR**

$$\int_{t_1}^{t_2} x_1^*(t)x_2(t)dt = 0$$

## OFDM System Model: Transmitter




## OFDM System Model: Receiver



## Advantages and disadvantages of OFDM

Advantages of OFDM are listed as follows:

- OFDM is immune to frequency selective fading because of dividing a channel into narrowband sub channels.
- OFDM reduces Inter-Symbol Interference through use of a cyclic prefix and fading caused by multipath propagation.
- Using sufficient channel coding we can easily recover lost symbols.
- Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems.
- To implement modulation and demodulation functions OFDM is computationally capable by using Fast Fourier Transform or FFT.
- It is immune against narrow-band co-channel interference.

Disadvantages of OFDM are as follows:

- It requires linear transmitter circuitry, which suffers from poor power efficiency.
- The OFDM signal has a noise like amplitude with a very large dynamic range; hence it requires RF power amplifiers with a high peak to average power ratio.
- It suffers loss of efficiency caused by cyclic prefix.
- It is sensitive to Doppler shift.
- Single carrier systems are less sensitive to carrier offset and drift but OFDM on the other hand is more sensitive to carrier offset and drift.

**MATLAB Code:**

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%
% Assignment:     07
% Name:           DEESHANT SHARMA
% Roll No:        EE21MTECH14002
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%


%%%%%%%%%%%%% |ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING | %%%%%%%%%%%%%%%

clc;
clear all;


[BER,SER,BER_theory,SER_theory]=deal(zeros(1,11));

%Initialization
Bandwidth= 100;          % In Khz
Base_Freq= 5;            % Base Frequency in KHz
Sym_Time = 1/Base_Freq;  % Symbol Time
N_subcarr= 20;           % Total Number of Subcarriers
N=1e3;                   % Iteration
Tx_samples=zeros((N/N_subcarr),1);


for Eb_No_dB=0:10

    n=1;    %Es=nEb where n=1 for BPSK
    Es_No_dB=Eb_No_dB+10*log10(n);
    Es_No=10^( Es_No_dB/10);

    BPSK_symbols=[1,-1];    %BPSK constellation set (Already Normalised)
    E_s=1/2*sum(BPSK_symbols.^2);
    sd_BPSK=sqrt(E_s/(2*Es_No));


    symbols_in_error=0;
    bits_in_error=0;

     for i=1:N/N_subcarr

       %Generating a random bit
       Rand_bit_BPSK=randi([0 1],N_subcarr,1);

       %Mapping the bits to BPSK symbol set
       BPSK_sym_array=zeros(N_subcarr,1);
       for i=1:N_subcarr
```

```
      BPSK_sym_array(i,1)=comm_func.BPSK_mod(Rand_bit_BPSK(i,1));
      end

      %IFFT
      Tx_samples=sqrt(N_subcarr)*ifft(BPSK_sym_array);

      %Adding AWGN noise
      Noise = sd_BPSK*(randn(20,1)+1i*randn(20,1));

      %Received Signal
      BPSK_rec = Tx_samples + Noise;

      %fft of a received signal
      BPSK_rec_fft=fft(BPSK_rec);

      % Estimated Symbol
      Est_symbol_BPSK=zeros(N_subcarr,1);

        for w=1:20
 Est_symbol_BPSK(w,1)=comm_func.ML_decode(BPSK_rec_fft(w,1),2,BPSK_symbols);
        end

        %Number of corrupted Symbol for BPSK
        for w=1:20
        if Est_symbol_BPSK(w,1)~=BPSK_sym_array(w,1)
        symbols_in_error=symbols_in_error+1;
        end
        end

        %Estimated Bit BPSK
        Est_Bit_BPSK=zeros(N_subcarr,1);

        for w=1:20
        if Est_symbol_BPSK(w,1)==-1
        Est_Bit_BPSK(w,1)=0;
        else
        Est_Bit_BPSK(w,1)=1;
        end
        end

        %Number of corrupted Bit for BPSK
        for w=1:20
        if Est_Bit_BPSK(w,1)~=Rand_bit_BPSK(w,1)
        bits_in_error=bits_in_error+1;
        end
        end
    end
    BER(Eb_No_dB+1)=bits_in_error/1e3;
    SER(Eb_No_dB+1)=symbols_in_error/1e3;
    Eb_No=10^(Eb_No_dB/10);
    BER_theory(Eb_No_dB+1)=qfunc(sqrt(2*Eb_No));
    SER_theory(Eb_No_dB+1)=qfunc(sqrt(2*Eb_No));
end
    %NOTE: SER and BER for BPSK is same. Also, the Bit energy is same as
```

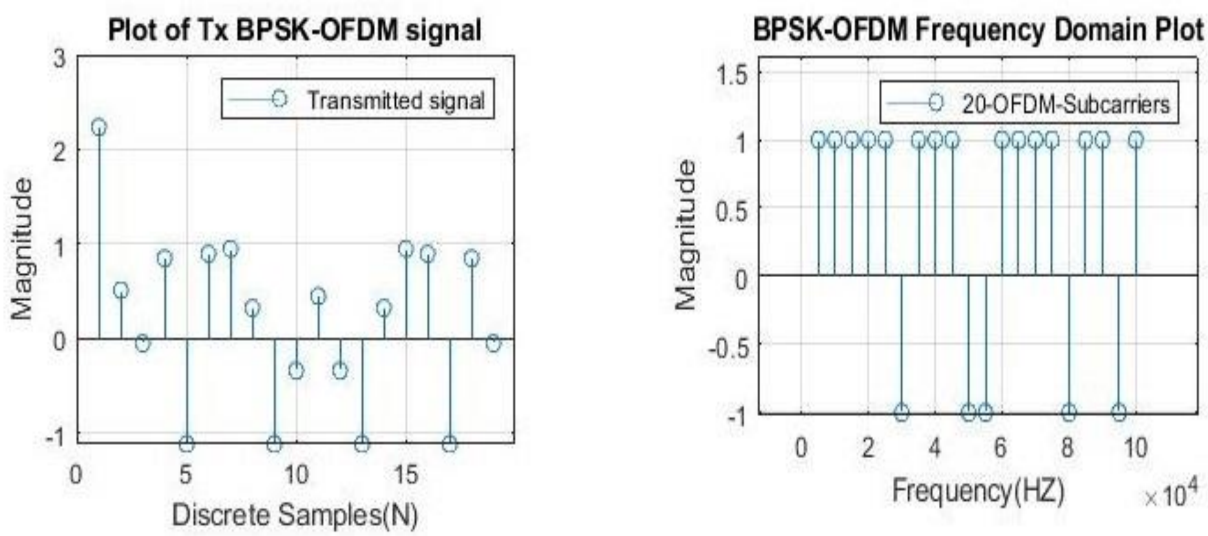
```
    %symbol energy Eb=Es.

figure(1);
f=5*(10^3):5*(10^3):100*(10^3);
subplot(2,1,1);
stem(f,BPSK_sym_array,'DisplayName','20-OFDM-Subcarriers');
title('BPSK-OFDM Frequency Domain Plot');
ylabel('Magnitude');
xlabel('Frequency(HZ)');
grid on;
legend();

subplot(2,1,2);
stem(Tx_samples,'DisplayName','Transmitted signal');
title('Plot of Tx BPSK-OFDM signal');
ylabel('Magnitude');
xlabel('Discrete Samples(N)');
grid on;
legend;

Eb_No_dB=0:10;
figure(2);
subplot(1,2,1);
semilogy(Eb_No_dB,BER,'r*-',Eb_No_dB,BER_theory,'ko-');
title('BER of BPSK');
ylabel('BER--->');
xlabel('Eb/No(dB)--->');
grid on;
legend('Practical BER','Theoratical BER');

subplot(1,2,2);
semilogy(Eb_No_dB,SER,'r*-',Eb_No_dB,SER_theory,'ko-');
title('SER of BPSK');
ylabel('SER--->');
xlabel('Eb/No(dB)--->');
grid on;
legend('Practical SER','Theoratical SER');



%======================== QPSK =========================%

for Eb_No_dB=0:10
    n=2;    %Es=nEb where n=2 for QPSK
    Es_No_dB=Eb_No_dB+10*log10(n);
    Es_No=10^( Es_No_dB/10);

    QPSK_symbols=(1/sqrt(2))*[1+1i,1-1i,-1+1i,-1-1i];
    E_s=1/4*sum(abs(QPSK_symbols).^2); %Normalising QPSK constellation set for unit energy
    sigma = sqrt(E_s/(2*Es_No));

    symbols_in_error=0;
    bits_in_error=0;

    for i=1:N/N_subcarr %Note : Submitted plot was generated using 1e4 iterations for accuracy.
```

```
        for j=1:N_subcarr
        %Generating a random bit
        Rand_bit=randi([0 1],1,2);

        %Mapping the bits to QPSK symbol set
        QPSK=comm_func.QPSK_mod(Rand_bit);
        QPSK_sym_array(j)=QPSK;

        %ifft to get transmitted OFDM sample
        Tx_sample=ifft(QPSK);
        Tx_samples(j)=Tx_sample;
        %Adding AWGN noise
        Noise = sigma*complex(randn(1),randn(1));

        %Received QPSK
        QPSK_rec = Tx_sample + Noise;

        %fft of received bit
        QPSK_rec_fft=fft(QPSK_rec);

        %Implementing Maximum likelihood (minimum distance) decoding on the sampled values
        Decoded_QPSK=comm_func.ML_decode(QPSK_rec_fft,4,QPSK_symbols);
        Decoded_Rand_bit=comm_func.QPSK_demod(Decoded_QPSK);

        %Comparing the decoded bit/symbol with the transmitted bit/symbol
        %to increment the errors
        symbols_in_error=symbols_in_error+nnz(Decoded_QPSK-QPSK);
        bits_in_error=bits_in_error+nnz(Decoded_Rand_bit-Rand_bit);
        end
        i=i+20;
    end
    BER(Eb_No_dB+1)=bits_in_error/1e3;
    SER(Eb_No_dB+1)=symbols_in_error/1e3;
    Eb_No=10^(Eb_No_dB/10);
    BER_theory(Eb_No_dB+1)=qfunc(sqrt(2*Eb_No));
    SER_theory(Eb_No_dB+1)=2*qfunc(sqrt(2*Eb_No));
end

%All Plots of QPSK

figure(3);
f=5*(10^3):5*(10^3):100*(10^3);
subplot(2,1,1);
stem(f,QPSK_sym_array,'DisplayName','20-OFDM-Subcarriers');
title('QPSK-OFDM Frequency Domain Plot');
ylabel('Magnitude');
xlabel('Frequency(HZ)');
grid on;
legend();

subplot(2,1,2);
stem(Tx_samples,'DisplayName','Transmitted signal');
title('Plot of Tx QPSK-OFDM signal');
```

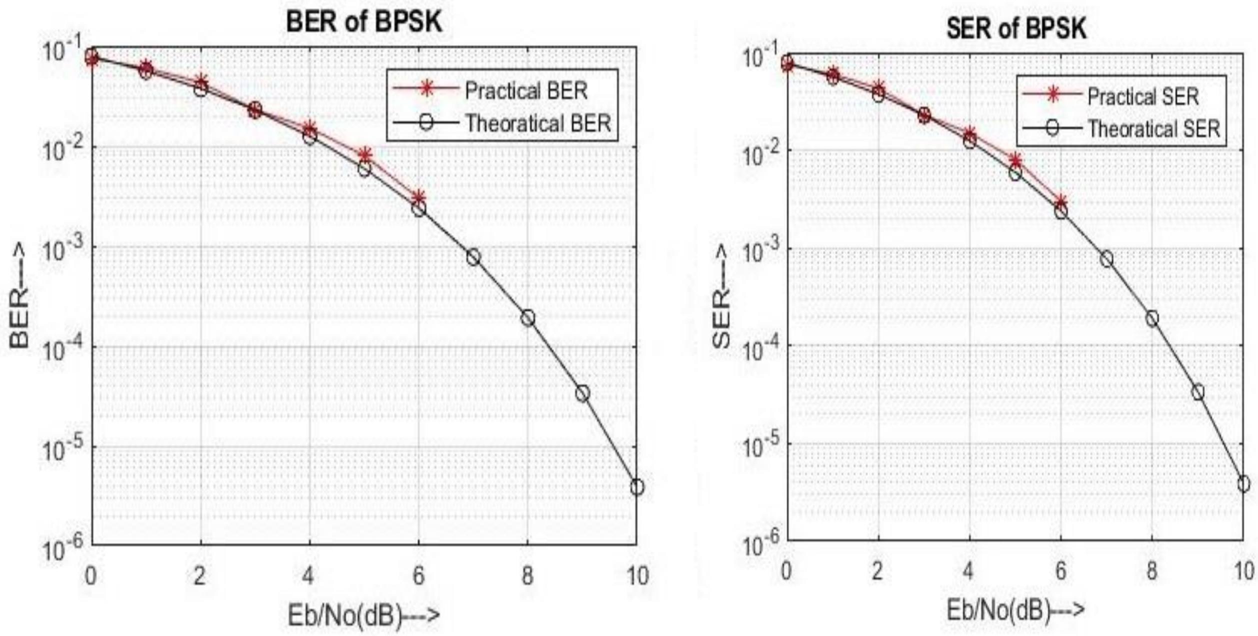
```
ylabel('Magnitude');
xlabel('Discrete Samples(N)');
grid on;
legend;



Eb_No_dB=0:10;

figure(4);
subplot(1,2,1);
semilogy(Eb_No_dB,BER,'r*-',Eb_No_dB,BER_theory,'ko-');
title('BER of QPSK');
ylabel('BER--->');
xlabel('Eb/No(dB)--->');
legend('Practical BER','Theoratical BER');
grid on;

subplot(1,2,2);
semilogy(Eb_No_dB,SER,'r*-',Eb_No_dB,SER_theory,'ko-');
title('SER of QPSK');
ylabel('SER--->');
xlabel('Eb/No(dB)--->');
legend('Practical SER','Theoratical SER');
grid on;




classdef comm_func
   methods(Static)

      %function for BPSK Modulation
      function bpsk=BPSK_mod(x)
         bpsk=2*x-1;
      end

      %function for BPSK Demodulation
      function bdemod=BPSK_demod(x)
         bdemod=(x+1)*0.5;
      end

      %function for QPSK Modulation
      function qpsk=QPSK_mod(x)
         qpsk=(1/sqrt(2))*(2*((x(1)-0.5)+i*(x(2)-0.5)));
      end

      %function for QPSK Demodulation
      function qdemod=QPSK_demod(x)
         temp(1)=(real(x)>0);
         temp(2)=(imag(x)>0);
         qdemod=temp;
      end

      %function for ML decoding
```

```
      function decoded=ML_decode(x,no_of_symbols,symbol_array)
         for j=1:no_of_symbols
            D(j)=abs(x-symbol_array(j))^2;
         end
         [M,I] = min(D);
         decoded=symbol_array(I);
      end
   end
end
```

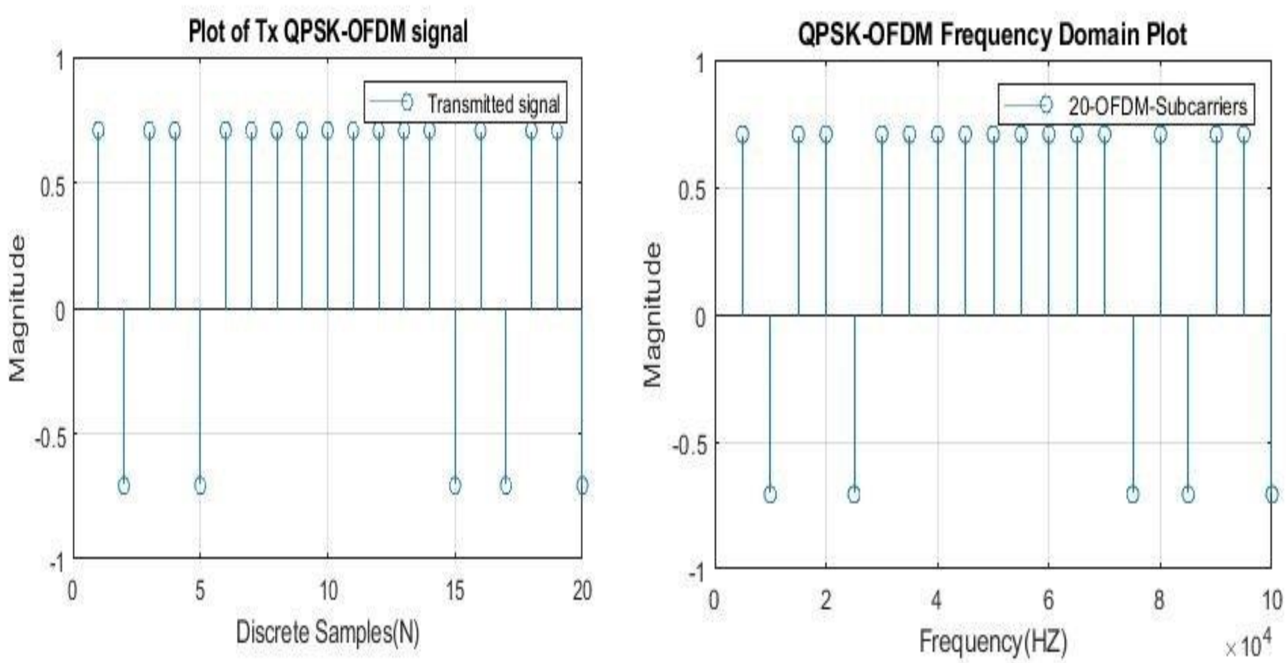
## MATLAB PLOTS:



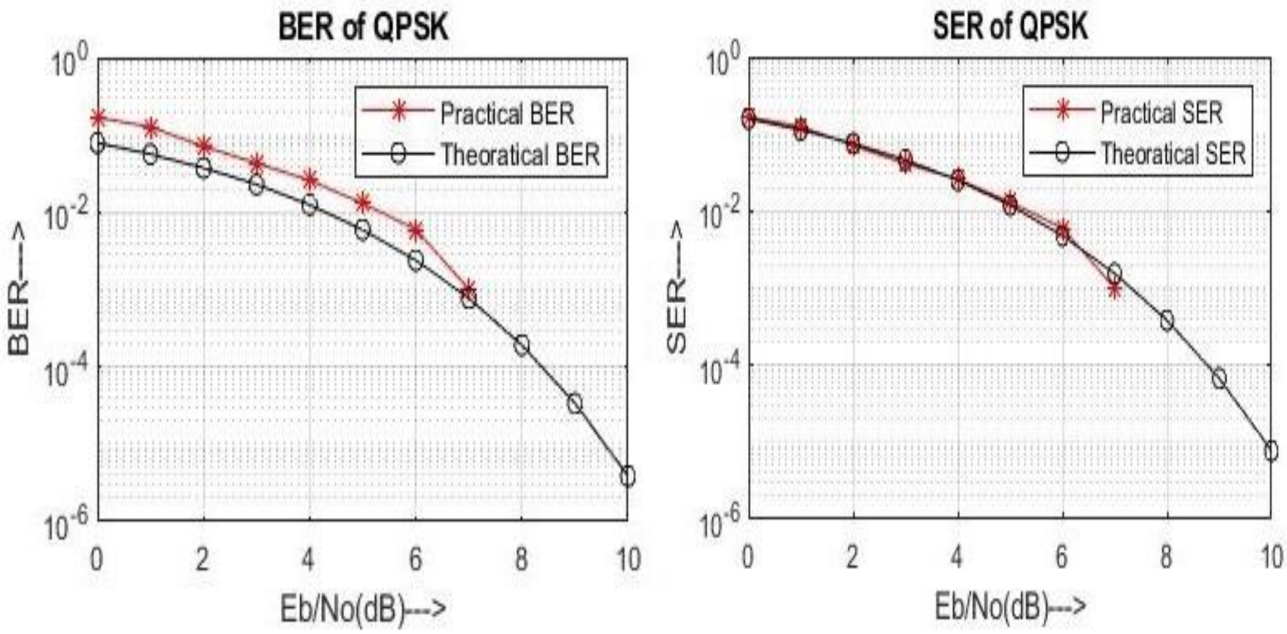

**1. BPSK- OFDM Time Domain and Frequency Domain**




**2. BPSK- OFDM: BER and SER Plot**




**3. QPSK- OFDM Time Domain and Frequency Domain Plot**




**4. QPSK-OFDM: BER and SER Plot**

## Limitations of OFDM

There are some obstacles in using OFDM which are as given:

- OFDM signal exhibits very high Peak to Average Power Ratio (PAPR).
- Very sensitive to frequency errors (Tx. & Rx. offset).
- Intercarrier Interference (ICI) between the subcarriers.

## Applications of OFDM

OFDM technique is the most remarkable technique of this era. Some of its applications is given below:

- Highly flexible communication system because with OFDM the spectrum utilization is high, and the system stability is good.
- OFDM-based communication technology, enabling the transmission process to achieve low latency, high-speed data transmission.

- At present, OFDM has been widely used in Europe and Australia, digital broadband audio systems and digital broadband video systems.
- Wireless LAN Networks
- 5.3.1 HIPERLAN/2.
- IEEE 802.11g.
- IEEE 802.16 Broadband Wireless Access System.
- Wireless ATM transmission system.
- IEEE 802.11a.