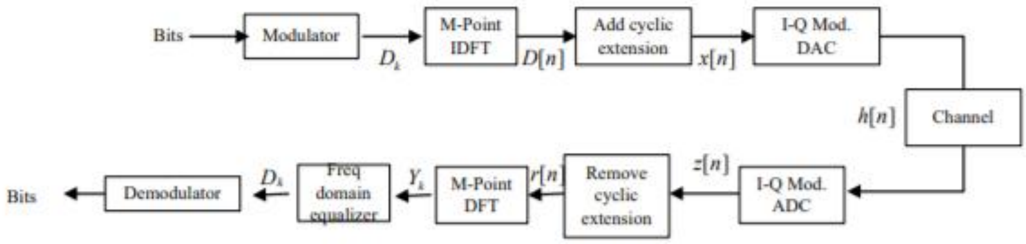
行動通訊

Project 2

Mobile Communication Course Project #2



In this project, we are going to implement an OFDM transceiver by using simulation. To simplify the simulation, DAC and ADC are omitted in the implementation. Discrete-time baseband signal model is used. Perfect timing and frequency synchronization are achieved. Time domain impulse response is known. Referring to the above figure, the information bits are modulated and fed into *M*-pont IDFT (or IFFT). After adding cyclic extension, the signal *x[n]* is send out.

Number of FFT points M = 64
Number of data sub-carriers = 52
Cyclic prefix = 16 samples
Modulation scheme = BPSK
Indexes of data subcarrier = [7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59]

$D_k \in \{-1,1\}$ is the modulated symbol by using BPSK.

The received signal can be expressed as:

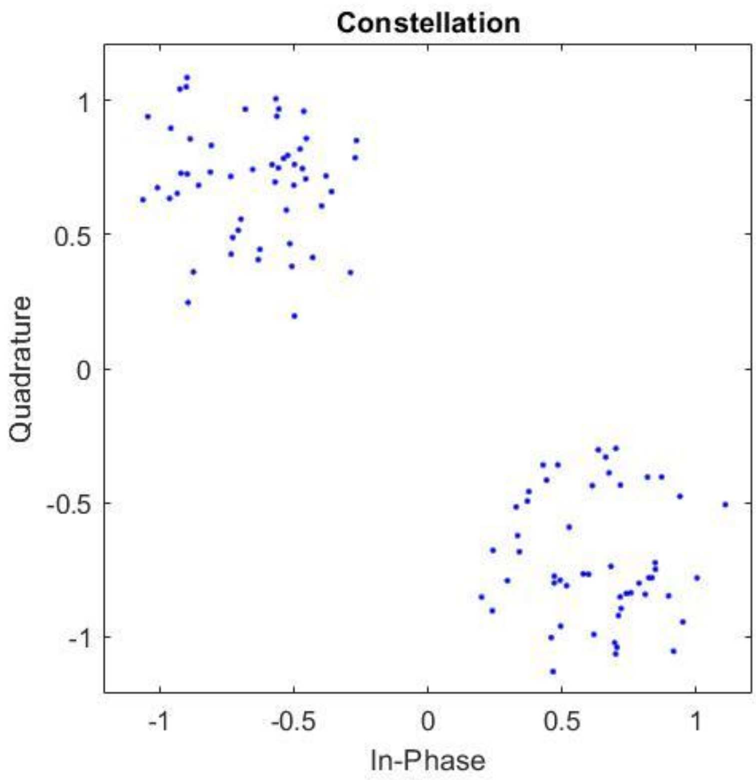
$$z[n] = x[n] * h[n] + n[n]$$

(I) $\tilde{h}[n]=[0.5-0.5j \quad 0 \quad 0.15+0.12j \quad 0 \quad 0 \quad -0.1+0.05j]$ and

$h[n]=\tilde{h}[n]/norm(\tilde{h}[n])$

By running two OFDM symbol periods, please draw the scatter (constellation) plot of Y_k (there are 2x52=104 points) at $\frac{Eb}{N_o}=20$ dB where $\frac{Eb}{N_o}$ is measured at the output of the M-point DFT (or FFT) operation. Similarly, please draw the scatter plot of $\widehat{D}_k$ at the output of the frequency domain equalizer, where the zero-forcing criterion is used. (You have to think about how the time domain impulse response is translated to the frequency response H_k)

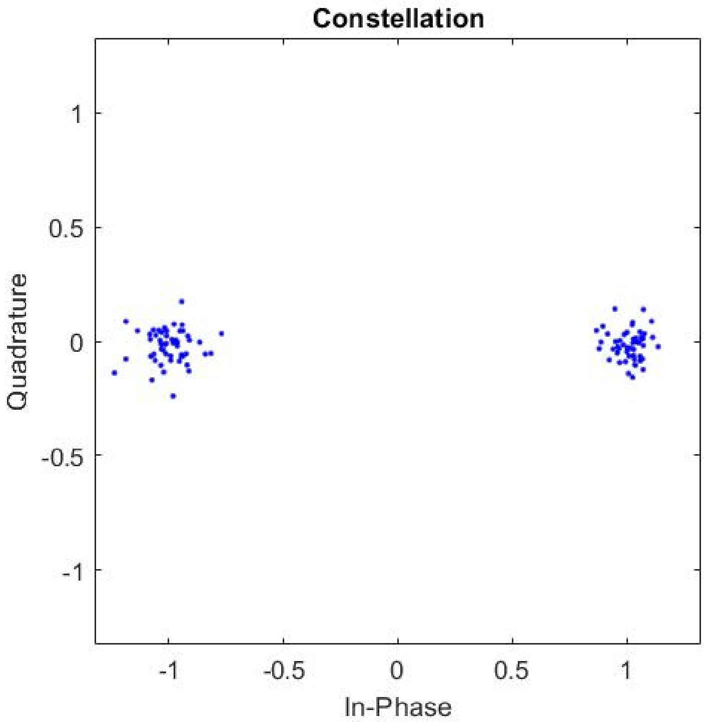
1.未使用 frequency domain equalizer 的 Constellation



說明:

在此時仍未經過 frequency domain equalizer 的使用，會受到通道的相位與頻率誤差影響，因此星座圖上會發現仍有所偏移，會集中於左上與右下兩邊集中。

2.使用了 frequency domain equalizer 的 Constellation

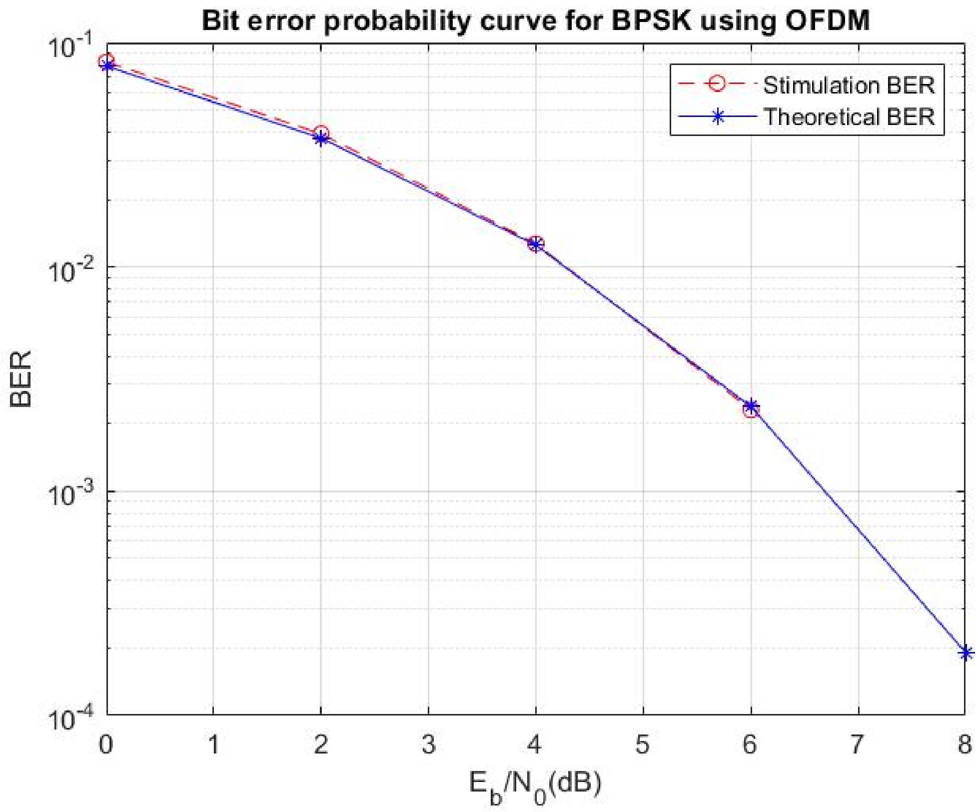


說明:

frequency domain equalizer 已廣泛應用於多載波系統中，通過減少保護間隔形式的傳輸冗餘來提高傳輸速率。所提出的均衡算法能夠通過適當地利用標準化多載波系統中固有的空子載波來消除由於減少或缺乏這種冗餘而引起的符號間和載波間干擾。

在此處經過等化器後，能得到接近理想的模擬圖。經過等化後(Dk)，通道失真會受到等化，Constellation 就會較接近理想。
而在做 IDFT transfer 時，有 52 個 data sub-carriers，用 M=64 執行，所以通道的雜訊要$\times\sqrt{64/52}$來放大，否則會使造成星座圖擴散的太大。

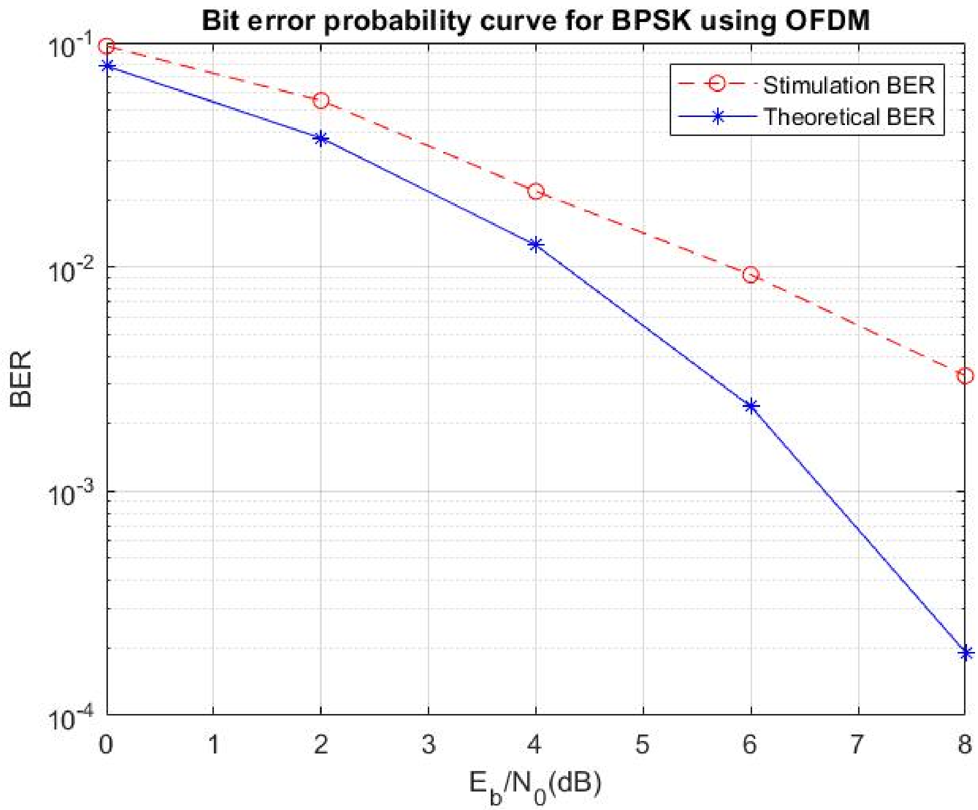
(II) Please draw the bit error rate curves by obtaining the error rate statistics at $\frac{Eb}{N_o} = 0,2,4,6,8$. The channel impulse response : $h[n] = [1]$.



說明：

我們從這張圖中能觀察到，除了在 Eb/No=0~4dB 之間有稍微的誤差之外，在 4~8 的曲線中，基本上理論值與模擬值是互相符合的，這是因為此題所設計的的無雜訊通道後 (h[n]=1 ： 理想通道響應)，訊號幾乎不受到任何的通道衰減或干擾，因此不會有其他的通道失真，故照理來講模擬圖和理論值會很類似。

(III) Please draw the bit error rate curves by obtaining the error rate statistics at $\frac{Eb}{N_o}=0,2,4,6,8$. The channel impulse response : $h\,[n]=\tilde{h}[n]/norm(\tilde{h}[n])$.



說明：

經過 channel impulse response h[n]=~h[n]/norm(~h[n]),很明顯看到模擬圖與理論值有很大的差異，因為在此處及非理想通道響應，因此訊號所受到通道衰減或干擾比較大，故模擬圖與理論值在 BER 的表現上有所明顯的落差。

Matlab Code

```matlab
%----------------------先宣告題目所需的條件-----------------------------%
clear all;close all;clc ;
M = 64;                  % Number of FFT points
sc = 52;                 % Number of data sub-carriers
ofdmbit = 52;            % Number of bits per OFDM symbol
                         % 由於是使用BPSK來調變，因此BPSK的sub-carrier也是52
Nsymbol = 100;           % Number of symbols
%--------------------使用BPSK symbol進行調變---------------------------%
Data=randi([0,1],ofdmbit*Nsymbol,1)'; %目前已經使用randi取代randint的用法了
dk=2*Data-1;                          % modulating data
dk_sym=reshape(dk,sc,Nsymbol);        % serial to parallel conversion
%把 subcarrier 放入題目所給的 data subcarrier
%注意在data subcarrier上32與34之間沒有第33號sub carrier
Dk = zeros(M, Nsymbol);
Dk((7:32), :) = dk_sym((1:26), :);
Dk((34:59), :) = dk_sym((27:52), :);
%---------------- M-point IDFT (傅立葉轉換成時域data )------------------%
IDFT = [];
for i = 1:Nsymbol
 IDFT = [IDFT ifft(Dk(:, i), M)];
end
%-----------------adding 16 samples (Cyclic prefix)--------------------%
D_cp = zeros(M+16, Nsymbol);
D_cp((1:16), :) = IDFT((49:64), :);
D_cp((17:80), :) = IDFT((1:64), :);
```

```
%-------------receiving signal z[n] = x[n] * h[n] + n[n]----------------%
h = [0.5-0.5j 0 0.15+0.12j 0 0 -0.1+0.05j];
%----------------- parallel to serial coversion------------------------%
x_n = reshape(D_cp, 1, (M+16)*Nsymbol);
h_n = h./norm(h);
xh = conv(x_n, h_n);
%------------------awgn addition,題目所述Eb/No =20----------------------%
Eb_N0 = 20;
Eb=mean(abs(x_n).^2);
Np=Eb*10^(-(Eb_N0/10));
znn = xh(1:end-5);
z_n = awgn(znn, 20, 'measured');
%----------------------cyclic prefix removal-------------------------%
receiver = reshape(z_n, 80, Nsymbol);
rn = receiver(17:end, :);
%--------------------------M-point DFT-------------------------------%
DFT = [];
for i = 1:Nsymbol
 DFT = [DFT fft(rn(:, i), M)];
end
%-------------------------delete zeros-------------------------------%
Yk64 = [DFT((7:32),:) ; DFT((34:59),:)];
Yk52 = [Yk64(:,1).' Yk64(:,2).'] ;
scatterplot(Yk52);
title('Constellation');
%----------------------pass through equalizer------------------------%
Hn = fft(h_n, M);
Dk = [];
for i = 1:Nsymbol
 Dk = [Dk DFT(:,i)./Hn.'];
end
Dkreceiver = [Dk((7:32),:) ; Dk((34:59),:)];
%-----------------serial to parallel coversion-----------------------%
Dkr = reshape(Dkreceiver, 1, 52*Nsymbol);
scatterplot(Dkr(1, 1:104));
title('Constellation');
```

II

```
%-----------------------先宣告題目所需的條件-----------------------------%
clear all;close all;clc ;
M = 64;                    % Number of FFT points
sc = 52;                   % Number of data sub-carriers
ofdmbit = 52;              % Number of bits per OFDM symbol
                           % 由於是使用BPSK來調變，因此BPSK的sub-carrier也是52
Nsymbol = 100;             % Number of symbols
%--------------------使用BPSK symbol進行調變-----------------------------%
Data=randi([0,1],ofdmbit*Nsymbol,1)'; %目前已經使用randi取代randint的用法了
dk=2*Data-1;                          % modulating data
dk_sym=reshape(dk,sc,Nsymbol);        % serial to parallel conversion
%把 subcarrier 放入題目所給的 data subcarrier
%注意在data subcarrier上32與34之間沒有第33號sub carrier
Dk = zeros(M, Nsymbol);
Dk((7:32), :) = dk_sym((1:26), :);
Dk((34:59), :) = dk_sym((27:52), :);
%----------------- M-point IDFT (傅立葉轉換成時域data )------------------%
IDFT = [];
for i = 1:Nsymbol
 IDFT = [IDFT ifft(Dk(:, i), M)];
end
%------------------adding 16 samples (Cyclic prefix)--------------------%
D_cp = zeros(M+16, Nsymbol);
D_cp((1:16), :) = IDFT((49:64), :);
D_cp((17:80), :) = IDFT((1:64), :);
```

```
%--------receiving signal z[n] = x[n] * h[n] + n[n](此次h=1)-------------%
h=1;
%----------------- parallel to serial coversion------------------------%
x_n=reshape(D_cp,1,(M+16)*Nsymbol);
xh=conv(x_n,h);
%-------------awgn addition,題目所述Eb/No在0.2.4.6.8下的情況-------------%
Eb=mean(abs(x_n).^2);
for Eb_N0=0:2:8;
 %theoretical BER
 BPSK_Pb(Eb_N0/2+1)=0.5*erfc(sqrt(10^(Eb_N0/10)));

 Np=Eb*10^(-(Eb_N0/10));

nn=sqrt(64/52)*sqrt(Np/2)*(randn(1,length(D_cp(:,1))*Nsymbol)+1i*randn(1,length(D_cp(:,1))*Nsymbol));
 z_n=xh(1,1:end)+nn;

 %------------------------cyclic prefix removal-----------------------%
 receiver=reshape(z_n,80,Nsymbol);
 r_n=receiver(17:end,:);

 %--------------------------M-point DFT------------------------------%
 DFT=[];
 for i=1:Nsymbol
 DFT=[DFT fft(r_n(:,i),M)];
 end
```

```
    %------------------------pass through equalizer-------------------------%
    Yk64=[DFT((7:32),:) ; DFT((34:59),:)];
    Yk52=[Yk64(:,1).' Yk64(:,2).'] ;

    %--------------------------scatterplot(Yk52)--------------------------%
    H_n=fft(h,M);
    Dk=[ ];
    for i=1:Nsymbol
    Dk=[Dk DFT(:,i)./H_n.'];
    end
    Dkreceiver=[Dk((7:32),:) ; Dk((34:59),:)];

    %--------------------serial to parallel coversion----------------------%
    Dkr=reshape(Dkreceiver,1,ofdmbit*Nsymbol);
    Dkre=sign(real(Dkr));
    ber(Eb_N0/2+1)=length(find(Dkre ~=dk))/(52*Nsymbol);
end
semilogy((0:2:8),ber,'r--o');
hold on
semilogy((0:2:8),BPSK_Pb,'b-*');
hold on
grid on;
title('Bit error probability curve for BPSK using OFDM');
xlabel('E_b/N_0(dB)');ylabel('BER');
%----------------scatterplot(Dkr(1,1:104))----------------------------%
legend('Stimulation BER','Theoretical BER');
```

III

```
%-----------------------先宣告題目所需的條件------------------------------%
clear all;close all;clc ;
M = 64;                  % Number of FFT points
sc = 52;                 % Number of data sub-carriers
ofdmbit = 52;            % Number of bits per OFDM symbol
                         % 由於是使用BPSK來調變，因此BPSK的sub-carrier也是52
Nsymbol = 100;           % Number of symbols
%--------------------使用BPSK symbol進行調變-----------------------------%
Data=randi([0,1],ofdmbit*Nsymbol,1)'; %目前已經使用randi取代randint的用法了
dk=2*Data-1;                          % modulating data
dk_sym=reshape(dk,sc,Nsymbol);        % serial to parallel conversion
%把 subcarrier 放入題目所給的 data subcarrier
%注意在data subcarrier上32與34之間沒有第33號sub carrie
Dk=zeros(M,Nsymbol);
Dk([7:32],:)=dk_sym([1:26],:);
Dk([34:59],:)=dk_sym([27:52],:);
%---------------- M-point IDFT (傅立葉轉換成時域data )------------------%
IDFT = [];
for i = 1:Nsymbol
  IDFT = [IDFT ifft(Dk(:, i), M)];
end
%------------------adding 16 samples (Cyclic prefix)--------------------%
D_cp = zeros(M+16, Nsymbol);
D_cp((1:16), :) = IDFT((49:64), :);
D_cp((17:80), :) = IDFT((1:64), :);
%-------------receiving signal z[n] = x[n] * h[n] + n[n]----------------%
h = [0.5-0.5j 0 0.15+0.12j 0 0 -0.1+0.05j];
%----------------- parallel to serial coversion------------------------%
x_n = reshape(D_cp, 1, (M+16)*Nsymbol);
h_n = h./norm(h);
xh = conv(x_n, h_n);
%--------------------------awgn addition ------------------------------%
Eb=mean(abs(x_n).^2);
%---------------------------SNR =20----------------------------------%
Eb=mean(abs(x_n).^2);
for Eb_N0=0:2:8;
 %theoretical BER
 BPSK_Pb(Eb_N0/2+1)=0.5*erfc(sqrt(10^(Eb_N0/10)));

 Np=Eb*10^(-(Eb_N0/10));

nn=sqrt(64/52)*sqrt(Np/2)*(randn(1,length(D_cp(:,1))*Nsymbol)+1i*randn(1,length(D_cp(:,1))*Nsymbol));
 z_n=xh(1,1:end-5)+nn;

 %-----------------------cyclic prefix removal-------------------------%
 receiver=reshape(z_n,80,Nsymbol);
 r_n=receiver(17:end,:);
```

```
%-----------------------------M-point DFT--------------------------------%
DFT=[];
for i=1:Nsymbol
DFT=[DFT fft(r_n(:,i),M)];
end

%----------------------pass through equalizer---------------------------%
Yk64=[DFT((7:32),:) ; DFT((34:59),:)];
Yk52=[Yk64(:,1).' Yk64(:,2).'] ;

%-------------------------scatterplot(Yk52)-----------------------------%
Hn=fft(h,M);
Dk=[];
for i=1:Nsymbol
Dk=[Dk DFT(:,i)./Hn.'];
end
Dkreceiver=[Dk((7:32),:) ; Dk((34:59),:)];
```

```
 %-------------------serial to parallel coversion------------------------%
 Dkr=reshape(Dkreceiver,1,ofdmbit*Nsymbol);
 Dkre=sign(real(Dkr));
 ber(Eb_N0/2+1)=length(find(Dkre ~=dk))/(52*Nsymbol);
end
semilogy([0:2:8],ber,'r--o');
hold on
semilogy([0:2:8],BPSK_Pb,'b-*');
hold on
grid on
title('Bit error probability curve for BPSK using OFDM');
xlabel('E_b/N_0(dB)');ylabel('BER');
%-------------------scatterplot(Dkr(1,1:104))--------------------------%
legend('Stimulation BER','Theoretical BER')
```