實驗8:
BPSK 在AWGN通道錯誤率效能分析

第二組
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實驗目的

1. 探討接收端利用Matched Filter，以適當取樣時間解調AWGN通道之BPSK信號，並探討其錯誤率效能

2. 與OOK相比，探討其錯誤能效能差距

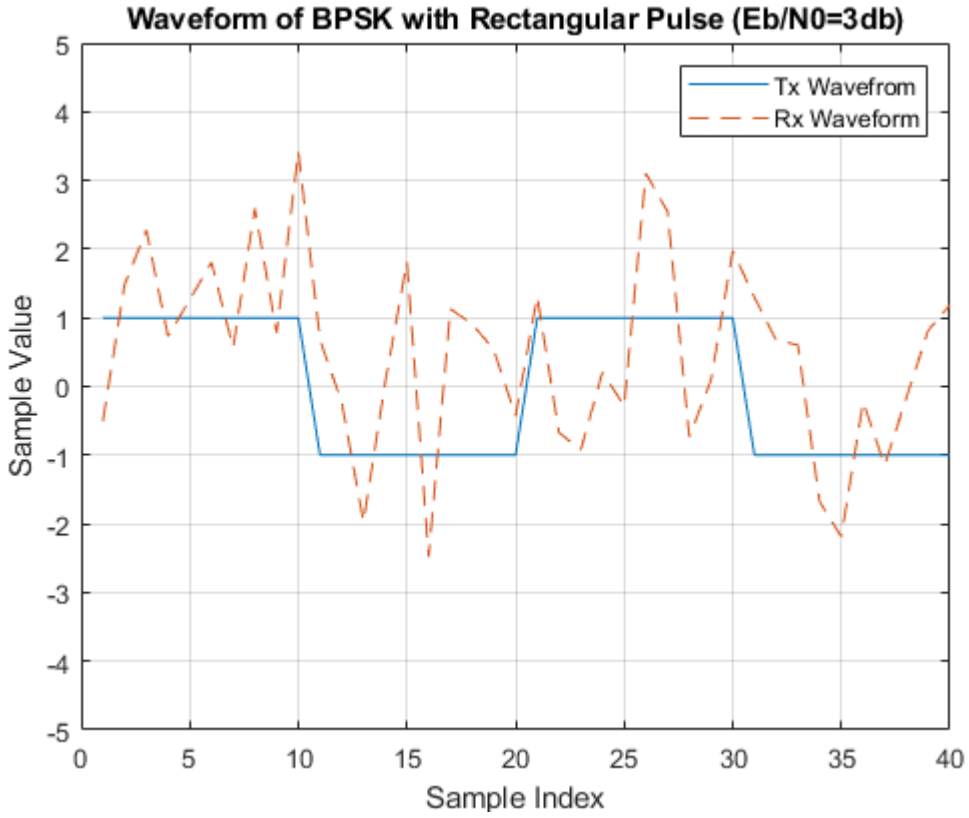
問題1: 傳送波形vs接收波形(程式碼)

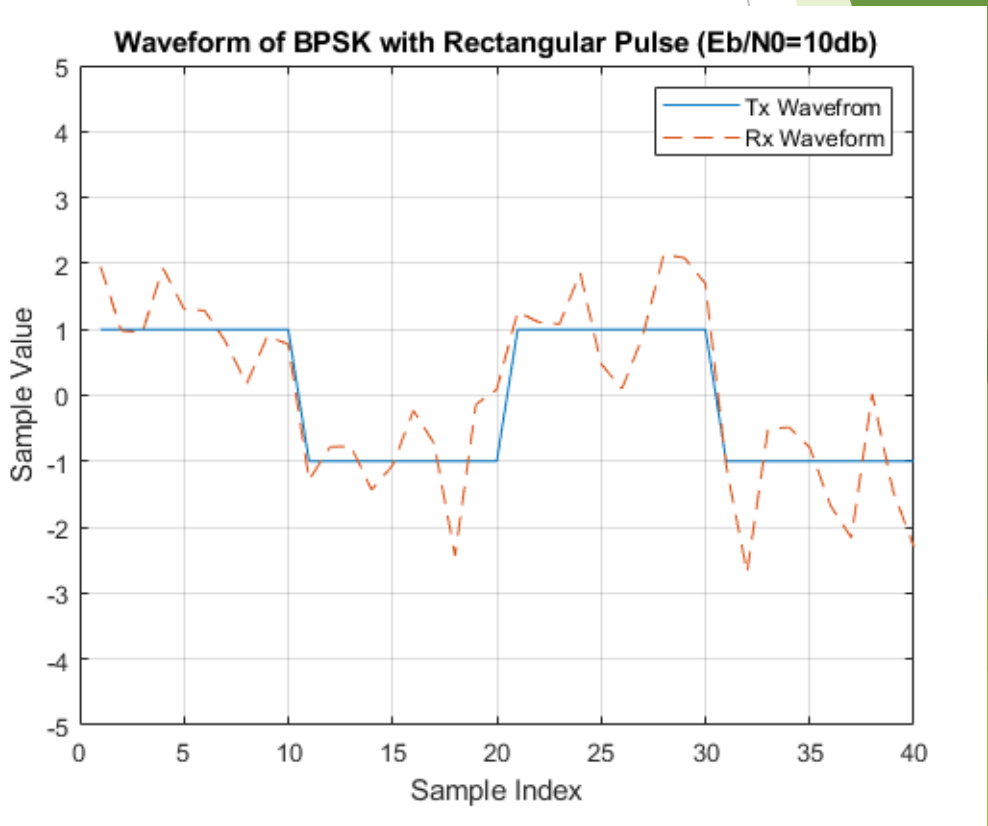
```
clear all;
close all;
clc;
%%parameter
data_number = 10^5; % # of bits
EbN0dB_vec = [0 2 4 6 8 10 11.5] ;% Eb/N0 in dB
Fs=10; % sampling frequency (used to generate received samples
%% transmitter
Data_bit=(rand(1,data_number) > 0.5 ); % random bits
a=0;
b=0;
for k=1:data_number
    if Data_bit(k)==1
        a=a+1;
        Data_bit_map(k) = 1; %bit 1 mapping 到 1
    else
        b=b+1;
        Data_bit_map(k) = -1; %bit 0 mapping 到 -1
    end
end
%disp('bit1的機率'),a/data_number
%disp('bit0的機率'),b/data_number

p1=ones(1,Fs);% discrete-time rectangular pulse that represents on
Data_pulse_array=(p1.')*Data_bit_map;
Data_pulse=reshape(Data_pulse_array,1,length(p1)*data_number);

```

```
for kk=1:length(EbN0dB_vec)
%% AWGN channel
[a b] = size(Data_pulse);
EbN0dB = EbN0dB_vec(kk);
EbN0 = 10^(EbN0dB/10); % EbN0 is now in linear scale
sgma = sqrt( 0.5/EbN0/2*10*2 );
noise = normrnd(0, sgma, a, b ) ;
Data_receive=Data_pulse+noise;% received samples
%Data_receive=Data_pulse;
%% receiver
D_filtered=conv(Data_receive,p1);% MF output
index=1:length(Data_receive);
%plot(index(1:40),Data_pulse(1:40))
%ylim([-5 5])
%plot(index(1:40),Data_receive(1:40))

D_demapping=D_filtered(10:10:end)/10;% sampling at symbol rate
% decsion based on D_demapping
D_demap_N = (D_demapping > 0);
% BER computation
Error_num=sum(xor(D_demap_N,Data_bit));
BER(kk) = Error_num/data_number;
%fprintf('EbN0 in dB is %g\n',EbN0dB);
%fprintf('Bit error rate is %g\n',BER);
x=index(1:40);
tx=Data_pulse(1:40);
rx=Data_receive(1:40);
figure(kk)
plot(x,tx)
hold on
plot(x,rx,'--')
legend('Tx Wavefrom','Rx Waveform')
grid on

ylim([-5 5])
if kk==1
    title('Waveform of BPSK with Rectangular Pulse (Eb/N0=3db)')
end
if kk==2
    title('Waveform of BPSK with Rectangular Pulse (Eb/N0=10db)')
end
ylabel('Sample Value')
xlabel('Sample Index')
end
```

問題1: 傳送波形vs接收波形 (圖形)

左圖：
3dB BPSK訊號受雜訊影響較大，由Rx Waveform較難推得原先的訊號(Tx Waveform)。
右圖：
10dB BPSK訊號受雜訊影響相對較小，從Rx Waveform較容易推得原先的傳送訊號(Rx Waveform)





問題2(f)
錯誤率比較(理論vs模擬)
(程式碼)

```
clear all;
close all;
clc;
%%parameter
data_number = 10^5; % # of bits
EbN0dB_vec = [0 2 4 6 8 10 11.5] ;% Eb/N0 in dB
Fs=10; % sampling frequency (used to generate received samples
%% transmitter
Data_bit=(rand(1,data_number) > 0.5 ); % random bits
a=0;
b=0;
for k=1:data_number
    if Data_bit(k)==1
        a=a+1;
        Data_bit_map(k) = 1; %bit 1 mapping 到 1
    else
        b=b+1;
        Data_bit_map(k) = -1; %bit 0 mapping 到 -1
    end
end
%disp('bit1的機率'),a/data_number
%disp('bit0的機率'),b/data_number

p1=ones(1,Fs);% discrete-time rectangular pulse that represents on
Data_pulse_array=(p1.')*Data_bit_map;
Data_pulse=reshape(Data_pulse_array,1,length(p1)*data_number);

```

```
for kk=1:length(EbN0dB_vec)
%% AWGN channel
[a b] = size(Data_pulse);
EbN0dB = EbN0dB_vec(kk);
EbN0 = 10^(EbN0dB/10); % EbN0 is now in linear scale
sgma = sqrt( 0.5/EbN0/2*10*2 );
noise = normrnd(0, sgma, a, b ) ;
Data_receive=Data_pulse+noise;% received samples
%Data_receive=Data_pulse;
%% receiver
D_filtered=conv(Data_receive,p1);% MF output
index=1:length(Data_receive);
%plot(index(1:40),Data_pulse(1:40))
%ylim([-5 5])
%plot(index(1:40),Data_receive(1:40))

D_demapping=D_filtered(10:10:end)/10;% sampling at symbol rate
% decsion based on D_demapping
D_demap_N = (D_demapping > 0);
% BER computation
Error_num=sum(xor(D_demap_N,Data_bit));
BER(kk) = Error_num/data_number;

end

%% generate plots
figure;
semilogy(EbN0dB_vec, BER,'o-');
hold
xlabel('Eb/N0 (dB), where Eb: average energy per bit');
ylabel('Bit Error Rate')
axis([0 12 1e-4 1e0])
title('BPSK with Rectangular Pulse (Simulation)')


ebnodB = [0 2 4 6 8 10 11.5];
ebno = 10.^(ebnodB/10);
Pb = qfunc(sqrt(2*ebno));
semilogy(ebnodB,Pb,'*-')
legend('BPSK (Simulation)','BPSK(Theory)')
grid on
```

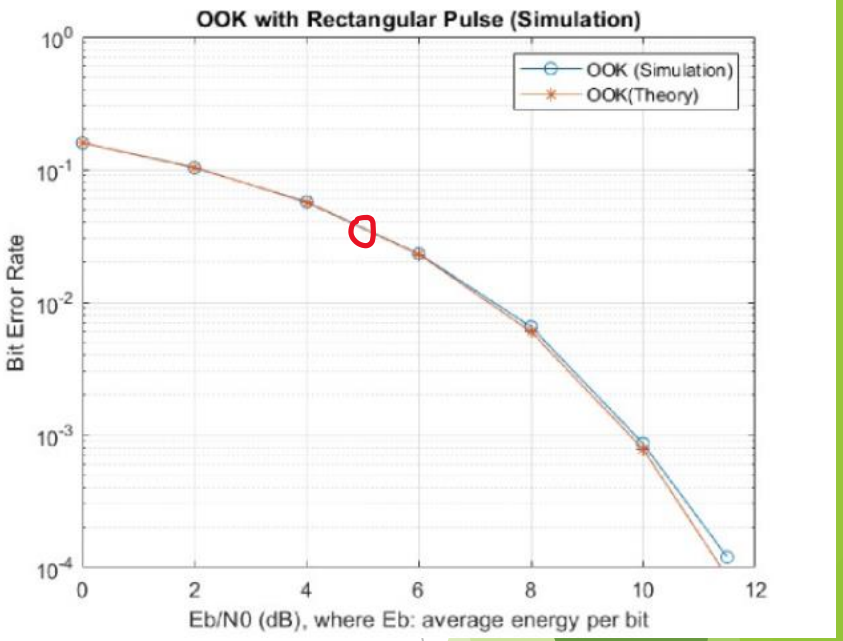
問題2(f)
傳送波形vs接收波形 (圖形)

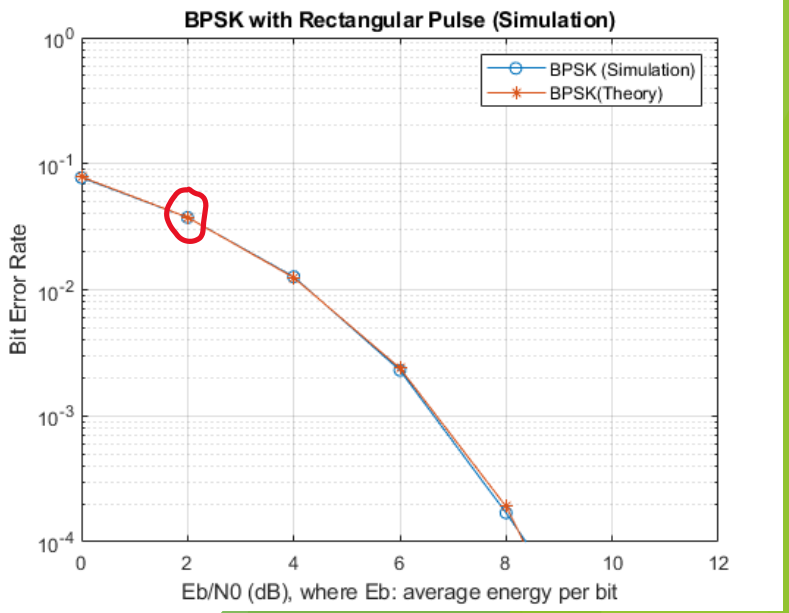
1. 觀察 BPSK錯誤率，理論與模擬之錯誤率十分相近。

因為BER看得是平均來說每個位元的錯誤率，差距的來源可能為產生的位元數量。當位元數大，每次平均結果會越接近理論之，反之則每次差異較大。(※因為位元為隨機產生，每次模擬結果不盡相同)

2. BPSK 與 OOK錯誤率比較

由理論得知，若想達成相同的錯誤率，BPSK與OOK的SNR大約相差3dB(BPSK較佳)。從圖中我們可以發現與推論相符。
在紅筆圈起處，錯誤率約0.05，OOK與BPSK的SNR分別約為5dB以及2dB。花較少能量達到相同錯誤率，故BPSK較佳。





問題2(g): Conditional pdf (程式碼)

```
close all; clc;
%%parameter
data_number = 10^5; % # of bits
EbN0dB_vec = [3 10] ;% Eb/N0 in dB
Fs=10; % sampling frequency (used to generate received samples
%% transmitter
Data_bit=(rand(1,data_number) > 0.5 ); % random bits
for k=1:data_number
    if Data_bit(k)==1
        Data_bit_map(k) = 1; %bit 1 mapping 到 1
    else
        Data_bit_map(k) = -1; %bit 0 mapping 到 -1
    end
end
p1=ones(1,Fs);% discrete-time rectangular pulse that represents on
Data_pulse_array=(p1.')*Data_bit_map;
Data_pulse=reshape(Data_pulse_array,1,length(p1)*data_number);
%計算bit 0 、 bit 1 的數量
num1=0;
num0=0;
for eig=1:1000000
    if (Data_pulse(eig)==1)
        num1=num1+1;
    else
        num0=num0+1;
    end
end

for kk=1:length(EbN0dB_vec)
    %AWGN channel
    [a b] = size(Data_pulse);
    EbN0dB = EbN0dB_vec(kk);
    EbN0 = 10^(EbN0dB/10*2); % EbN0 is now in linear scale
    sgma = sqrt( 0.5/EbN0/2*10 );
    bit1=ones(1,num1)+normrnd(0, sgma, a, num1 ) ;
    bit0=(zeros(1,num0)-1)+normrnd(0, sgma, a, num0 ); %bit 0 為 -1
    b1_filtered=conv(bit1,p1);% MF output
    b1_demapping=b1_filtered(10:10:end)/10;
    b0_filtered=conv(bit0,p1);% MF output
    b0_demapping=b0_filtered(10:10:end)/10;
    subplot(length(EbN0dB_vec),1,kk)
    b1_h=histogram(b1_demapping,'Normalization','pdf');
    hold on
    b0_h=histogram(b0_demapping,'Normalization','pdf');
    xlim([-2.5 2.5])
    hold on
    x = -2.5:.01:2.5;
    ave0 = normpdf(x,-1,sgma/sqrt(10));
    ave1 = normpdf(x,1,sgma/sqrt(10));
    plot(x,ave0,'r','LineWidth',2)
    hold on
    plot(x,ave1,'b','LineWidth',2)
    legend('Bit 0(sim)','Bit 1(sim)','Bit 0 (theory)','Bit 1(theory)','Location','northwest')
    grid on

    xlabel('v(T)')
    ylabel('Probability Density')
    if (kk ==1)
        title('BPSK Conditinal PDF (3db)')
    end
    if(kk ==2)
        title('BPSK Conditinal PDF (10db)')
    end
    kk;
end
```

問題2(g): Conditional pdf (圖形)

1. 離散模擬連續情形，需調整sigma參數以近似連續結果。

$$\sigma_0^2 = 10\,\sigma_{sample}^2$$

2. 當SNR增加，雜訊對於訊號的影響相對降低，bit0、bit1的訊號分布更為集中。

因此在判斷傳送位元時，更容易正確辨別，因此錯誤率變小。