EE5141 : Wireless Communication

Computer Assignment 3

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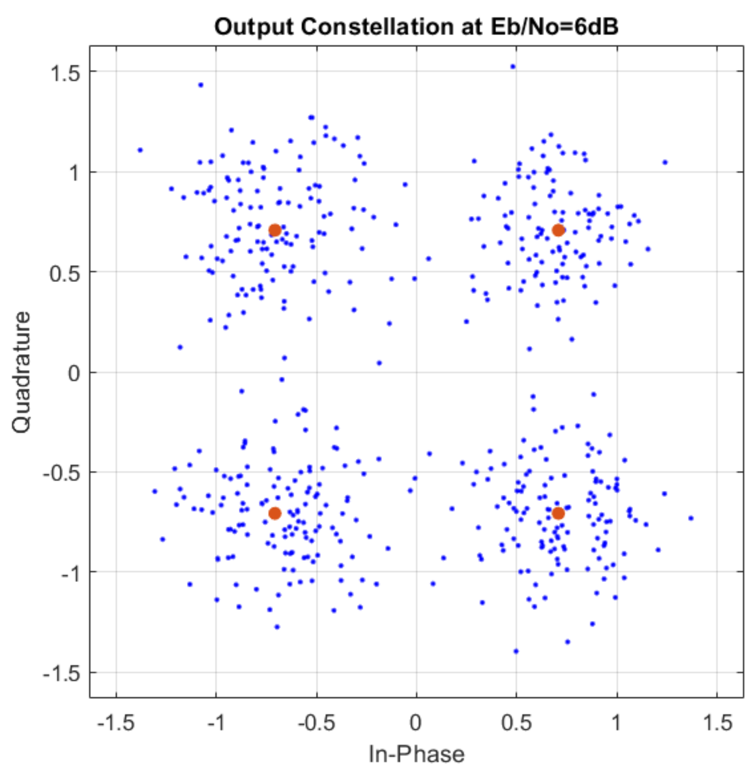
<u>Question 1</u> :

The task is to build a DQPSK modem and study the Bit Error Rate (BER) performance using Monte-Carlo simulations, as given in the Figure. Generate a random sequence of about 512 QPSK symbols (1024 bits) and apply pulse shaping with an SRRC pulse (roll off (alpha) = 0.35).

Bits	00	01	10	11
QPSK Symbol	$e^{j\frac{\pi}{4}}$	$e^{j\frac{3\pi}{4}}$	$e^{-j\frac{\pi}{4}}$	$e^{-j\frac{3\pi}{4}}$

A. Visualize received symbols for the case Eb/No = 6dB



For Eb/No = 6dB, we generate the noise, convolve it with a SRRC signal and add it to the RC pulse shaped signal. The received signal (desired signal + awgn) is passed through a matched receive filter (same SRRC filter as used in transmitter) and down-sampled to one sample per symbol (optimally sampling) . Then, the received symbols are plotted above.

The received signal is plotted in blue and the original location of the reference symbol is plotted in red. The symbols should ideally have been limited to 4 specific points mentioned in the table. But the presence awgn noise distorts and hence scatters the transmitted symbol.

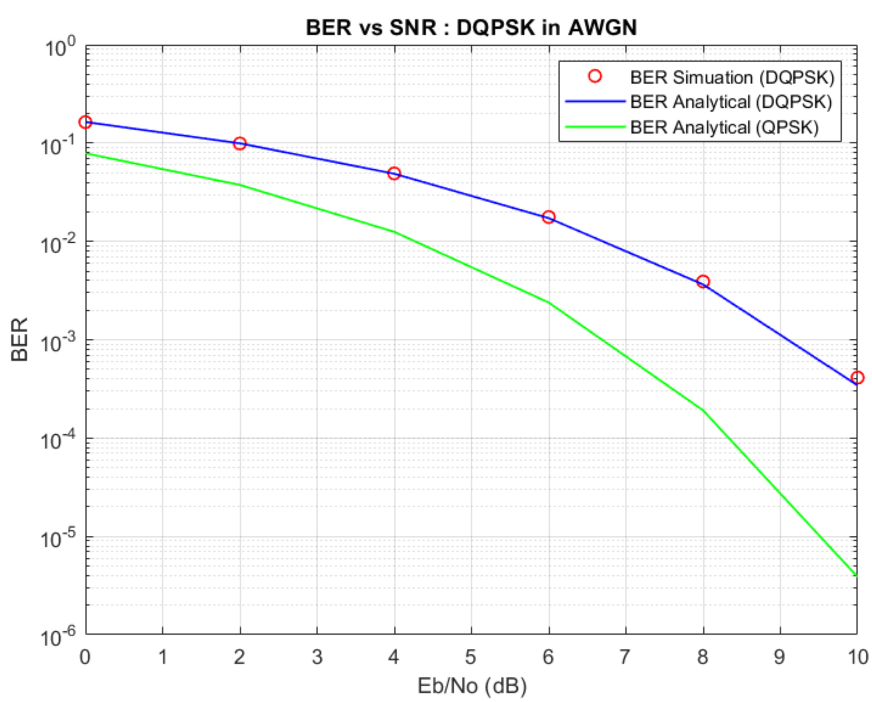
Differential Detection Rule :

1. $bit\ [b_{n,1}] = \begin{cases} 0\ if\ \ Re\ \{r_n\ \ r_{n-1}^*\} > 0 \\ 1\ if\ Re\ \{r_n\ \ r_{n-1}^*\} \leq 0 \end{cases}$

2. $bit\ [b_{n,0}] = \begin{cases} 0\ if\ \ Im\ \{r_n\ \ r_{n-1}^*\} > 0 \\ 1\ if\ Im\ \{r_n\ \ r_{n-1}^*\} \leq 0 \end{cases}$

BER is computed for Eb/No in the range [0, 10dB] in steps of 2 dB, using 500 bursts for averaging. The analytical BER and simulated values are plotted below.

B. BER Plot (Analytical vs Simulation) :



The analytical values of BER at different values of Eb/No are evaluated using the exact expression for DQPSK involving the Marcum Q function as given in Digital Communications, Proakis section 4.5.5.

We observe the analytical and simulation results match one another quite accurately as expected. The BER performance for QPSK coherent detection is better than DQPSK at the cost of a relatively complex receiver.

<u>Question 2, 3 & 4</u> :

This part of the assignment demonstrates a method to estimate the performance of QPSK in Rayleigh fading with single antenna and multiple antenna diversity.

<u>TASK 1 : AWGN vs Rayleigh Fading Channel Comparison</u>

Compare and plot the BER performance of QPSK modulation scheme in AWGN channel (analytical) and Rayleigh Fading channel (both simulation and analytical).

The Rayleigh channel gain (random variable :$\boldsymbol{\alpha}_n$) is generated as follows.

$\boldsymbol{\alpha}_n \triangleq \sqrt{X_n^{\,2} + Y_n^{\,2}}$, where X_n & Y_n are iid Gaussian random variables (*N(0,*σ^2*)*).

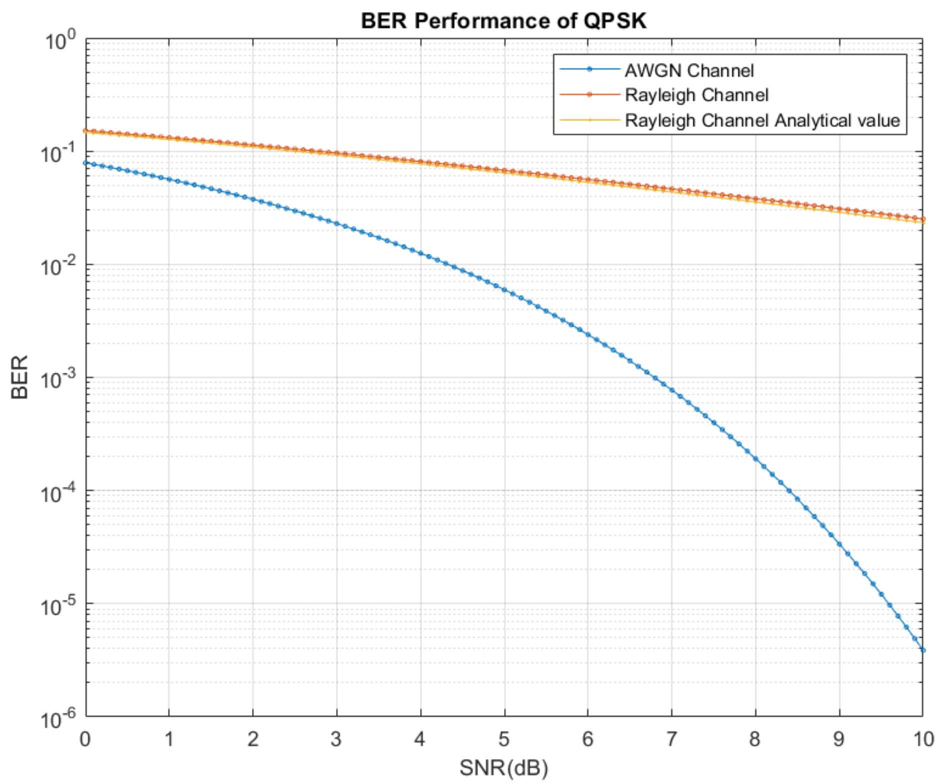
The instantaneous SNR (γ_n) is obtained as $\gamma_n = \boldsymbol{\alpha}_n^{\,2}(Eb/No)$ and hence the instantaneous $BER_n = Q\left(\sqrt{2\gamma_n}\right)$. In order to reasonably estimate the BER in Rayleigh fading, we generate N = 1000 such coefficients and take the average BER.

The analytical expression for BER for QPSK in Rayleigh fading is given as follows

$$BER = 0.5(1 - \sqrt{\Gamma/(1 + \Gamma)})$$

where $\Gamma = E[\gamma^2](Eb/No)$ or $\Gamma = 2\boldsymbol{\sigma}^2(Eb/No)$ since $E[\gamma^2] = E[X^{\,2}] + E[Y^{\,2}]$

Observation : The BER is quite high for Rayleigh fading channel compared to AWGN channel for a given AWGN SNR. The signal attenuation due to rayleigh fading has significantly affected the BER performance, which can be ascertained from the fact that the SNR required for the same BER (say for ex, 0.01) is much higher than what is required in a simple AWGN channel.

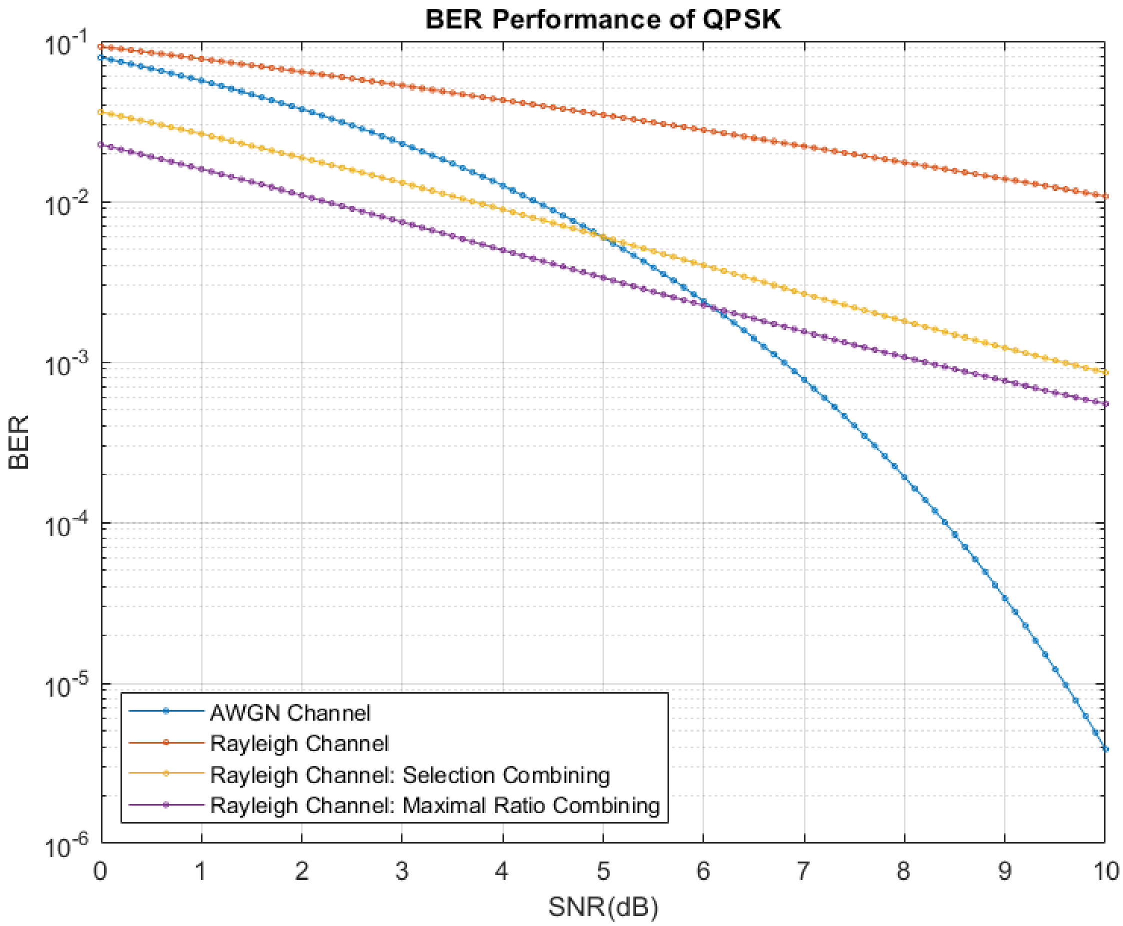


TASK 2 : Single Antenna & Multiple Antenna Diversity.

Under this task we compare the single antenna BER performance (done under task 1) with multiple antenna diversity (especially 2 specific combination logic: Antenna Selection Combining & Maximal Ratio Combining) for the same QPSK modulation. In the multiple antenna case we consider the simple 2 antenna combination only. For this, we generate two independent sets of rayleigh fading coefficients for each antenna. We have done MRC out of self-interest and to support our argument in Q4

- Antenna Selection Combining : SNR_rx (γ_sc) = max (γ_1 , γ_2)
- Maximal Ratio Combining : SNR_rx (γ_mcr) = $\gamma_1 + \gamma_2$

The BER is then calculated similar to task 1 by taking an average over large (N = 1000) number of iterations/experiments.



Observation : The BER performance under multiple antenna diversity is much better than performance of a single antenna. To be more specific, the MRC antenna combining logic is better than SC antenna combining logic. The inference is that it is better take advantage of the information from both the Rx antennas rather relying on only one (here, the antenna with maximum received SNR). Infact, with multiple antennas the BER performance is better than single antenna AWGN channel BER at low received SNR.

Importance of Antenna Diversity :

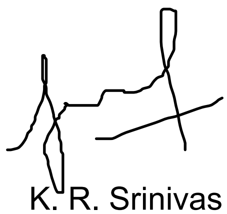
Antenna diversity is a technique that can be used to improve radio communication and maximize the chance of a packet getting through at a given time and in a given position between a receiver and transmitter in a non-static environment.

In Rayleigh channels, multipath radio waves can interfere with each other constructively or destructively due to **multipath propagation**, resulting in fast and random fluctuation of the received signal strength.

Diversity technique is used to reduce the effects of fading by **generating several copies of the signal**, which experience independent or estimated independent fading, to reduce the probability of simultaneous deep fades. Space diversity is one of the diversity techniques which use multiple antennas to improve the quality of the radio channels. We have discussed above 2 such kinds of diversity techniques, **Selection Combining** & **Maximal Ratio Combining.**

SELF DECLARATION

I certify that this assignment submission is my own work and not obtained from any other source.



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1 Question 1

```
%% EE5141 Wireless Communication : Computer Assignment 3
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clear all
close all

%% Wireless Communication  : Computer Assignment 3 Question 1

alpha = 0.35 ;
sym_rate = 25e3 ;
T = 1/sym_rate ;
t = -5*T:T/oversampling:5*T ;
N = 512;
oversampling = 8;

ebno_awgn_db = 0:2:10;
snr_awgn_db = ebno_awgn_db +3;
ebno_awgn = 10.^( ebno_awgn_db /10) ;
snr_awgn = 10.^( snr_awgn_db /10) ;

% analytical BER performance for QPSK in AWGN channel
qpsk_awgn_ber = qfunc(sqrt(2.*ebno_awgn)) ;

ber = zeros (1 , length ( ebno_awgn_db ) ) ;



for i=1:length(t)

    if (t(i)==0)

        h(i)=1-alpha+4*(alpha)/pi;

    else if t(i)==T/(4*alpha) || t(i)==-T/(4*alpha)

            h(i)=(alpha/sqrt(2))*(((1+2/pi)*sin(pi/(4*alpha)))...
            +((1-2/pi)*cos(pi/(4*alpha))));
        else

            h(i)=(sin(pi*(1-alpha)*t(i)/T)+(4*alpha*t(i)/T).*cos(pi*(1+alpha)...
            *t(i)/T))./(pi*(t(i)/T).*(1-(4*alpha*t(i)/T).^2));
        end
```

```
    end
end

h = h/sqrt(sum(h.^2)) ;
P_n = zeros(1,length( ebno_awgn_db)) ;
P_s = zeros(1,length( ebno_awgn_db)) ;
a = zeros(1,length( ebno_awgn_db)) ;

N_itr = 1000;

for itr =1: N_itr

  for j =1: length(snr_awgn_db)

     bit_tx=rand(1,2*N)>0.5 ;
     sym = zeros (1,N);
     sym(1) = exp(1j*pi/4) ;

     for i =2:N

         bits = [bit_tx(2*i-1),bit_tx(2*i)];

         switch(bi2de(bits,'left-msb'))
             case 0
                 del_theta = pi/4;
             case 1
                 del_theta = (3*pi)/4;
             case 2
                 del_theta = -pi/4;
             case 3
                 del_theta = -(3*pi)/4;
         end

         sym(i)=sym(i-1)*exp((1j*del_theta)) ;
     end

    tx_seq = upsample(sym,8);
    tx_sig = conv(tx_seq,h,'same')/8;
    tx_rc = conv(tx_sig,h,'same');

    Ps1 = var(tx_rc(1:8:end)) ;
    P_s(j) =P_s(j)+Ps1 ;

    awgn = randn(1,length(sym))+1j*randn(1,length(sym));
    awgn1 = upsample(awgn ,8) ;
    n_sqrc = conv(awgn1,h,'same');
```

```
    Pn1 = var(n_sqrc(1:8: end));
    P_n(j) = P_n(j)+Pn1 ;

    a1 = sqrt(Ps1/(Pn1*snr_awgn(j)));
    a(j) = a(j) + a1 ;
    rx_sig = a1*n_sqrc + tx_rc(1:4096);
    rx_sym = rx_sig(1:8:end);

    bit_rx = zeros(1,N*2) ;
    bit_rx(1:2) = bit_tx(1:2) ;

    for i =2: N

        if(real(rx_sym(i)*conj(rx_sym(i-1)))>0)
        bit_rx(2*i) = 0 ;
        else
        bit_rx(2*i) = 1 ;
        end

        if(imag(rx_sym(i)*conj(rx_sym(i-1)))>0)
        bit_rx(2*i-1) = 0 ;
        else
        bit_rx(2*i-1) = 1 ;
        end
    end

    err =0;
    for i =1: N
        if(bit_rx(i)~= bit_tx(i))
            err = err +1;
        end
    end

  ber(j) = ber(j) +(err/N) ;
  end
end

ber = ber/N_itr ;

P_s = P_s/N_itr ;
P_n = P_n/N_itr ;
a = a/N_itr ;
SNR_meas = 10*log10(P_s./((a.^2).*P_n )) ;
a =(2-2^(0.5))*ebno_awgn ;
b = (2+2^(0.5))*ebno_awgn ;
ber_theo = 0.5*(1 - marcumq ( sqrt (b),sqrt (a) ,1)+ marcumq ( sqrt (a),sqrt (b) ,1));
```

```
figure;

semilogy(ebno_awgn_db,ber,'ro','linewidth',1);
hold on;
semilogy(ebno_awgn_db,ber_theo,'b-','linewidth',1);
semilogy(ebno_awgn_db,qpsk_awgn_ber,'g-','linewidth',1);
legend("BER Simuation (DQPSK)","BER Analytical (DQPSK)","BER Analytical (QPSK)");
title("BER vs SNR : DQPSK in AWGN") ;
xlabel('Eb/No (dB)') ;
ylabel('BER') ;
grid on ;
```

2 Question 2

```
clear all ;
close all ;

%% Wireless Communication  : Computer Assignment 3 Question 2

snr_awgn_db = (0:0.1:10) ;
snr_awgn = 10.^(snr_awgn_db/10) ;

qpsk_awgn_ber = qfunc(sqrt(2.*snr_awgn)) ;

mu = 0 ;
var = 0.5 ;
N = 1000 ;
normal_x = normrnd(mu,sqrt(var),N,1) ; normal_y = normrnd(mu,sqrt(var),N,1) ;
alpha = abs(normal_x+normal_y*i) ;

%(sqrt(2))*
ber_rayleigh = zeros(N,1) ;
qpsk_rayleigh_ber = zeros(length(snr_awgn_db),1) ;

for i=1:length(snr_awgn_db)

    for j=1:N
        snr_inst = (alpha(j)^2)*snr_awgn(i);
        ber_inst = qfunc(sqrt(2.*snr_inst)) ;
        ber_rayleigh(j) = ber_inst;
    end
    qpsk_rayleigh_ber(i) = mean(ber_rayleigh) ;

end
```

```
qpsk_rayl_ber = 0.5*(1 - sqrt(snr_awgn./(1+snr_awgn))) ;

semilogy(snr_awgn_db,qpsk_awgn_ber,'-o','MarkerSize',2);
hold on

semilogy(snr_awgn_db,qpsk_rayleigh_ber,'-o','MarkerSize',2);
hold on

semilogy(snr_awgn_db,qpsk_rayl_ber,'-*','MarkerSize',1);
hold on
legend('AWGN Channel','Rayleigh Channel','Rayleigh Channel Analytical value');


grid on; ylabel("BER"); xlabel("SNR(dB)"); title('BER Performance of QPSK');
```

3 Question 3

```
clear all ;
close all ;

%% Wireless Communication: Computer Assignment 3 Question 3

snr_awgn_db = (0:0.1:10) ;
snr_awgn = 10.^(snr_awgn_db/10) ;

% analytical BER performance for QPSK in AWGN channel
qpsk_awgn_ber = qfunc(sqrt(2.*snr_awgn)) ;

% rayleigh RV Generation from two IID gaussian RV.
mu = 0 ;      % mean of gaussian rv
var = 0.5 ;   % variance of gaussian rv
N = 1000 ;    % # iteration

normal_x = normrnd(mu,sqrt(var),N,1) ; normal_y = normrnd(mu,sqrt(var),N,1) ;
alpha = abs(normal_x+normal_y*i) ;

% generate rayleigh coefficients for MRC and SC antenna selection
normal_xi = normrnd(mu,sqrt(var),N,1) ; normal_yi = normrnd(mu,sqrt(var),N,1) ;
alpha_i = abs(normal_xi+normal_yi*i) ;

normal_xj = normrnd(mu,sqrt(var),N,1) ; normal_yj = normrnd(mu,sqrt(var),N,1) ;
alpha_j = abs(normal_xj+normal_yj*i) ;

ber_rayleigh = zeros(N,1) ;
```

```
qpsk_rayleigh_ber = zeros(length(snr_awgn_db),1) ;

ber_rayleigh_sc = zeros(N,1) ;
qpsk_rayleigh_ber_sc = zeros(length(snr_awgn_db),1) ;

ber_rayleigh_mrc = zeros(N,1) ;
qpsk_rayleigh_ber_mrc = zeros(length(snr_awgn_db),1) ;

% Averaging over several iteration to get reasonable BER estimates
for i=1:length(snr_awgn_db)

    for j=1:N

        snr_inst = 2*(alpha(j)^2)*snr_awgn(i);
        snr_inst_i = 2*(alpha_i(j)^2)*snr_awgn(i);
        snr_inst_j = 2*(alpha_j(j)^2)*snr_awgn(i);

        % single antenna logic
        ber_inst = qfunc(sqrt(2.*snr_inst)) ;
        ber_rayleigh(j) = ber_inst;

        % selection combining logic
        snr_sc = max(snr_inst_i,snr_inst_j) ;
        ber_inst_sc = qfunc(sqrt(2.*snr_sc)) ;
        ber_rayleigh_sc(j) = ber_inst_sc ;

        % maximal ratio combining
        snr_mrc = snr_inst_i+snr_inst_j ;
        ber_inst_mrc = qfunc(sqrt(2.*snr_mrc)) ;
        ber_rayleigh_mrc(j) = ber_inst_mrc ;

    end
    qpsk_rayleigh_ber(i) = mean(ber_rayleigh) ;
    qpsk_rayleigh_ber_sc(i) = mean(ber_rayleigh_sc) ;
    qpsk_rayleigh_ber_mrc(i) = mean(ber_rayleigh_mrc) ;

end

semilogy(snr_awgn_db,qpsk_awgn_ber,'-o','MarkerSize',2);
hold on

semilogy(snr_awgn_db,qpsk_rayleigh_ber,'-o','MarkerSize',2);
hold on

semilogy(snr_awgn_db,qpsk_rayleigh_ber_sc,'-o','MarkerSize',2);
hold on
```

```
semilogy(snr_awgn_db,qpsk_rayleigh_ber_mrc,'-o','MarkerSize',2);

legend({'AWGN Channel','Rayleigh Channel','Rayleigh Channel: Selection Combining',...
'Rayleigh Channel: Maximal Ratio Combining'},'Location','southwest');
grid on; ylabel("BER"); xlabel("SNR(dB)"); title('BER Performance of QPSK');
```