COURSEWORK ASSIGNMENT

Module Title: Broadband Networks and Data Communications	**Module Code:** 7ENT050
Assignment Title: Matlab Simulation for Linear Transceiver Design in MIMO Communication Link	**Individual Assignment**
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Student ID Number **ONLY**:	Year Code:
17019396	

Marks Awarded %:	Marks Awarded after Lateness Penalty applied %:
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UNIVERSITY OF HERTFORDSHIRE
SCHOOL OF ENGINEERING AND TECHNOLOGY

Broadband Networks and Data Communication (7ENT1050)
Lab Experiment on Linear Transceiver Design for MIMO Radio Communication Link

Numerical Simulation Parameter Setting:

Speed of light: $3*10^8$ meters/second

Carrier frequency: 1.2 GHz

Transmission bandwidth: 20 MHz

The number of transmit antennas: N_t

The number of receive antennas: N_t /2

Tx-Rx distance: 50 meters (Group No 0), 100 meters (Group No 2), 150 meters (Group No 4), 200 meters (Group No 6), 250 meters (Group No 8), 300 meters (Group No 10)

Path loss model: free space path loss [3]

$$FSPL = (4*pi*distance/wavelength)^2 \qquad (7.13)$$

Maximum Transmit Power to Noise Ratio (MTPNR): 40 dB

Received noise power: 1 [Watt] (normalised)

Step2a. Start the Matlab software, and creat a new document (ctrl + N);

Step2b. Set the above system settings and N_t= 8 + 4**group no*; $N_r = N_t/2$;

For Group no=2, Nt=16, Nr=8 and distance=100;

Question 1: Calculate the free space path loss FSPL according to Eq. (7.13) and the maximum transmit power budget *Pmax [Watt]* according the value of MTPNR and the normalised received noise power (insert the answers below this question); (5%)

Code:

```
clear all
clc
Nt = 16;
Nr = Nt/2;
fc=1.2e9; %Carrier Frequency
d=100;% distance
v=3e8;
BW=20*10^6;
wavelength=v/fc;
noise=1;
MTPNR=40;
FSPL=(4*pi*d/wavelength)^2
Pmax=noise*10^(MTPNR/10)
```

Answer:

Command Window

New to MATLAB? See resources for Getting Started.

```
FSPL =

   2.5266e+07


Pmax =

       10000
```

Step 2c. Generate an N_r-by-N_t complex independent and identically distributed channel matrix $\mathbf{H_0}$, where each element of $\mathbf{H_0}$ satisfies zero mean and unit variance and generate the channel matrix $\mathbf{H} = (\text{FSPL})^{-1/2}\mathbf{H_0}$ that will be used for the following simulation. Make sure that you should use the same H for all the following questions.(Tip: you can save the H data and load the H data for each simulation run)

Code:

```
j=sqrt(-1);
if 1
  H0=(1/sqrt(2))*(randn(Nr,Nt)+j*randn(Nr,Nt));
save Channel H0
else
    load Channel H0
end;

H=H0*(FSPL)^(-1/2)
```

Answer:

H

8x16 complex double

	1	2	3	4	5	6
1	-6.7616e-05 + 3.3198e-05i	-2.3388e-04 - 7.0012e-05i	1.9458e-05 + 1.8844e-04i	-1.0070e-04 - 8.8631e-05i	6.0334e-05 + 9.1737e-05i	5.5276e-05 - 4.1689e-05i
2	1.1772e-04 - 1.1749e-04i	2.7343e-04 - 1.5006e-05i	-2.6828e-04 - 1.3633e-04i	-3.9461e-05 - 6.5947e-06i	-4.2080e-05 - 3.9229e-05i	2.7368e-05 - 2.1058e-04i
3	3.5708e-04 - 1.7949e-04i	-1.5259e-04 - 9.6760e-05i	-5.1345e-05 + 2.9361e-05i	1.6409e-04 + 3.7743e-04i	-1.2659e-04 + 3.4492e-05i	3.9359e-05 - 1.2729e-04i
4	-1.8616e-04 + 8.6801e-05i	3.1908e-05 + 4.6687e-05i	-1.1931e-04 - 8.7020e-05i	1.7061e-04 - 1.6131e-04i	8.9292e-05 + 2.0714e-04i	7.2054e-06 - 5.6858e-05i
5	1.8054e-05 + 8.6191e-05i	1.5459e-04 + 3.3273e-04i	-1.0758e-04 + 7.2028e-05i	6.8303e-05 + 7.7793e-05i	9.4890e-06 - 3.2005e-04i	-1.0895e-04 - 1.0210e-04i
6	-2.0291e-04 + 4.0709e-05i	2.0706e-05 - 6.7838e-05i	-1.5864e-04 + 1.5972e-06i	1.4433e-04 - 1.5143e-04i	-2.6323e-05 - 2.2976e-04i	1.1068e-04 - 1.2189e-04i
7	1.8323e-04 + 5.5611e-05i	3.2294e-04 + 9.1079e-05i	1.0999e-05 - 6.1881e-06i	1.2249e-04 + 1.4498e-04i	4.1039e-05 + 5.8446e-05i	1.9820e-04 - 5.9343e-05i
8	1.9834e-04 - 1.2247e-04i	3.8721e-04 - 1.4552e-04i	2.9635e-04 + 4.1486e-04i	-5.3704e-05 + 4.6075e-05i	1.3894e-04 - 9.2109e-05i	-7.5134e-05 - 1.3261e-04i

H

8x16 complex double

	7	8	9	10	11	12
1	2.7119e-04 + 1.8877e-04i	7.4202e-05 + 2.2540e-05i	-1.4150e-04 + 1.0093e-04i	2.2959e-04 + 1.0965e-04i	-2.4510e-04 + 8.9071e-07i	1.1653e-04 + 7.6037e-05i
2	-2.4794e-05 - 1.3905e-04i	1.2016e-04 + 4.0430e-05i	1.1123e-04 + 3.2184e-04i	-2.1554e-04 + 5.4118e-05i	2.8881e-05 + 9.6570e-05i	3.0630e-05 - 2.0327e-04i
3	-3.4289e-05 + 2.5574e-04i	1.8876e-04 + 8.9034e-05i	-1.6399e-05 + 2.3454e-05i	-1.8806e-04 + 9.7961e-05i	1.6781e-04 - 1.2027e-04i	-2.6858e-04 - 1.3613e-04i
4	-1.2627e-04 - 5.2674e-05i	-3.5162e-04 - 2.0525e-04i	7.7806e-05 - 3.0336e-04i	-2.0733e-04 - 1.5856e-05i	-1.1294e-04 - 1.5126e-04i	-7.5517e-05 + 2.8423e-05i
5	-1.1146e-04 - 2.0422e-04i	-2.3571e-05 - 8.1832e-05i	-1.3514e-04 + 2.3766e-04i	-5.8609e-06 - 5.4615e-06i	-1.7804e-04 - 1.2797e-05i	-4.2488e-05 - 4.8938e-05i
6	-1.3406e-04 - 8.7033e-05i	4.9660e-05 - 2.5746e-04i	-2.2983e-04 + 1.8038e-04i	-8.6586e-05 + 1.2392e-05i	-2.1007e-05 - 3.5559e-05i	2.5512e-04 + 1.8148e-04i
7	4.9785e-05 + 1.3146e-04i	1.0090e-04 - 6.3177e-05i	1.0708e-04 - 8.1961e-05i	1.8487e-04 - 1.1108e-04i	-2.3021e-04 + 1.6808e-04i	1.2870e-04 + 1.8867e-04i
8	2.2466e-04 + 1.4854e-04i	-1.8356e-04 + 1.3354e-04i	1.6787e-04 + 3.1316e-05i	-2.0469e-04 + 2.0017e-04i	2.4399e-06 + 8.5258e-05i	-8.0298e-06 - 8.1703e-05i

H

8x16 complex double

	12	13	14	15	16
1	1.1653e-04 + 7.6037e-05i	1.8419e-04 + 1.2311e-04i	1.0479e-04 - 5.8365e-05i	-1.2638e-04 + 7.9382e-05i	-1.8958e-05 + 3.8245e-05i
2	3.0630e-05 - 2.0327e-04i	-1.4697e-04 + 1.9630e-04i	-1.1650e-04 + 5.0426e-05i	2.1980e-05 + 2.2263e-04i	-2.5783e-06 + 2.0954e-04i
3	-2.6858e-04 - 1.3613e-04i	-4.8992e-05 + 4.5154e-05i	8.0820e-05 + 5.0956e-06i	2.2469e-04 + 3.8393e-04i	6.4821e-05 + 2.0217e-04i
4	-7.5517e-05 + 2.8423e-05i	1.9871e-04 + 2.2837e-04i	3.9648e-05 - 5.1294e-05i	1.5817e-05 + 4.2704e-05i	1.9164e-04 - 3.8772e-06i
5	-4.2488e-05 - 4.8938e-05i	2.1135e-04 + 1.4946e-04i	1.6027e-04 + 2.4914e-04i	-4.3416e-05 - 1.1117e-04i	6.3567e-05 + 1.2997e-04i
6	2.5512e-04 + 1.8148e-04i	1.0275e-04 + 3.0119e-05i	-5.9909e-05 + 3.1127e-05i	6.4240e-05 + 1.1302e-04i	2.3189e-04 - 4.5196e-05i
7	1.2870e-04 + 1.8867e-04i	6.9036e-05 + 1.2334e-04i	8.9489e-05 + 3.8409e-04i	-3.8700e-05 - 1.8568e-04i	-2.8534e-04 + 9.3003e-05i
8	-8.0298e-06 - 8.1703e-05i	-8.2453e-05 + 2.7348e-05i	1.1158e-04 - 4.1663e-05i	6.2339e-05 - 3.8523e-05i	-6.3199e-05 + 2.6943e-04i

Step2d. Find the eigenvalues and eigenvectors of **H’*H;**

Question 2. Plot the eigenvalues for **H’*H** in **decreasing order** and insert the figure below this question; (5%)

Code:

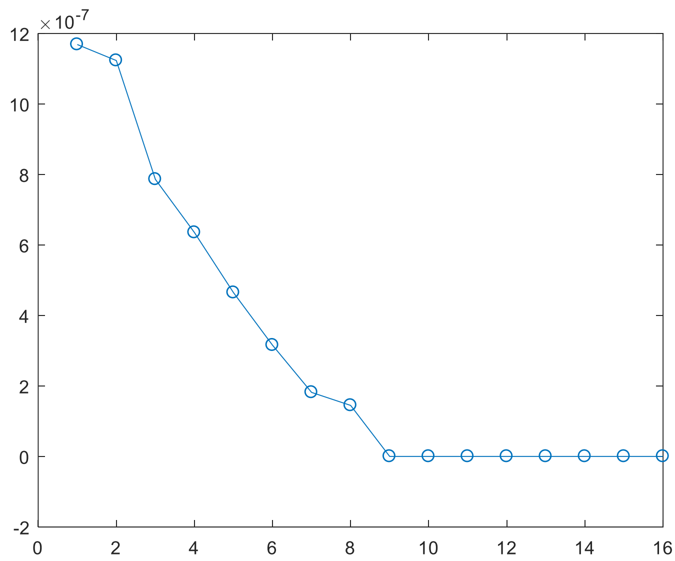
```
%Plot eigen values
 A=H'*H
 E=eig(A)

 K1=sort(real(E),'descend');
 figure, plot(K1,'o-')
 [U,D] = eig(A)
```

Answer:

E

16x1 double

	1
1	-1.0135e-22
2	-8.0714e-23
3	-6.3120e-23
4	-2.3938e-23
5	1.4862e-23
6	5.2018e-23
7	6.4755e-23
8	1.0601e-22
9	4.3415e-08
10	2.5841e-07
11	3.0517e-07
12	4.3916e-07
13	4.9752e-07
14	7.9717e-07
15	9.2757e-07
16	1.1738e-06

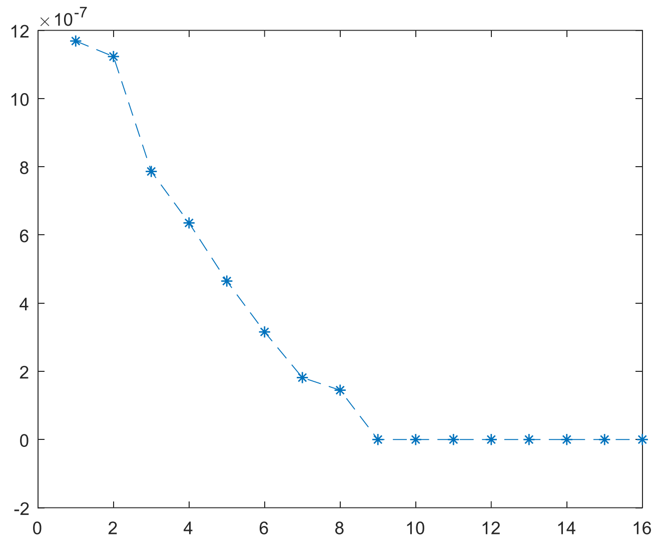


Step2e. Let **U** and **D** denote the eigenvector matrix and eigenvalue matrix of **H’*H,** reconstruct a matrix **A**=$\sum_{n=1}^{Nt} \boldsymbol{D}(n,n) * \boldsymbol{U}(:,n) * \boldsymbol{U}(:,n)'$ where $\boldsymbol{D}(n,n)$ and $\boldsymbol{U}(:,n)$ denote the n-th diagonal element of matrix **D** and the n-th column of matrix **U**.

Code:

```
%nth diagonal elemetnt of matrix D and nth coulmn of matrix U
 %reconstructing matrix A

 B=zeros(Nt,Nt);
 for n=1:Nt;
     B=B+D(n,n)*U(:,n)*U(:,n)';
 end;
 K=eig(B);
 K2=sort(real(K),'descend');
 figure,plot(K2,'*--');
```

Answer:



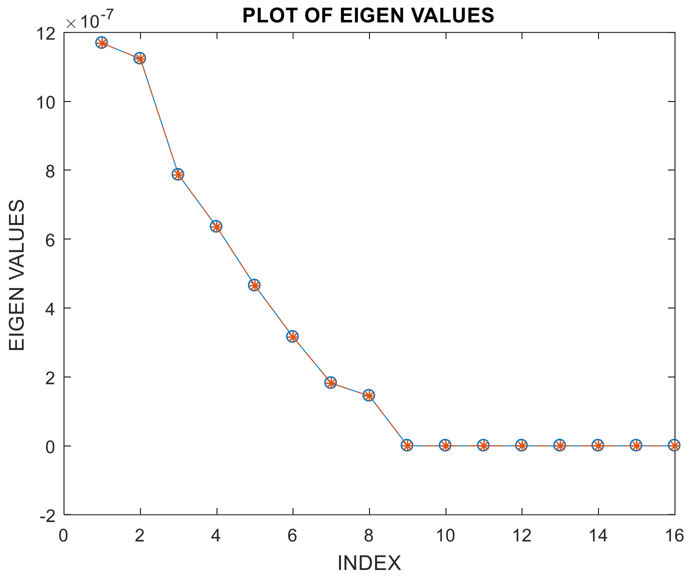
Question 3. Compare the eigenvalues of **A** with the diagonal elements of **D**, and explain the reason.(5%)

Code:

```
%Plot eigen values
 A=H'*H
 E=eig(A)

 K1=sort(real(E),'descend');
 figure, plot(K1,'o-')
 title('PLOT OF EIGEN VALUES');
 xlabel('INDEX');
 ylabel('EIGEN VALUES');
  [U,D] = eig(A)
 %nth diagonal elemetnt of matrix D and nth coulmn of matrix U
 %reconstructing matrix A

 B=zeros(Nt,Nt);
 for n=1:Nt;
```

```
    B=B+D(n,n)*U(:,n)*U(:,n)';
end;
K=eig(B);
K2=sort(real(K),'descend');
hold on,plot(K2,'*--'); %comparing eigen values of B with A
```

Answer: *They are equal.*



Step2f. Do the singular value decomposition for the matrix **H** as **H = Us*Ds*Vs'** where **Us, Vs** and **Ds** denote the left singular vector matrix, the right singular vector matrix and the singular value matrix, respectively.

[Us,Ds,Vs]=svd(H);

Question 4. 1) Observe if the product **Us'*H*Vs** is a diagonal matrix or not and explain the reason. 2) Compare the singular values, i.e., the diagonal elements of **Ds** with the eigenvalues of **H'*H**, i.e., the diagonal elements of **D** and explain the reason for this.(5%)

Code:

```
%Singular value decomposision for matrix H

 [Us,Ds,Vs]=svd(H); %Singular Value Decomposition
product=real(Us'*H*Vs)%real part of complex number
SingularVal=sort(diag(real(Ds)),'ascend')
```

Answer: The product is a diagonal matrix and that's because H is being multiplied by unitary matrices Us and Vs. The product is a diagonal matrix and that's because H is being multiplied by unitary matrices Us and Vs.

product

8x16 double

	1	2	3	4	5	6	7	8
1	0.0012	2.4395e-19	-1.3553e-19	2.9138e-19	-1.4908e-19	1.1308e-19	-1.6263e-19	2.7105e-20
2	1.0842e-19	0.0011	1.2197e-19	-1.0842e-19	9.4868e-20	2.0329e-20	-8.1315e-20	5.4210e-20
3	1.6941e-19	1.6263e-19	9.5658e-04	-1.8974e-19	8.1315e-20	1.8296e-19	-1.9990e-19	-1.0884e-19
4	3.5575e-20	2.4395e-19	-3.8625e-19	8.0202e-04	-1.0503e-19	9.3174e-20	-2.7105e-20	1.2197e-19
5	-2.3039e-19	5.4210e-20	5.4210e-20	-8.8091e-20	6.5773e-04	-1.0842e-19	-1.3553e-19	1.4908e-19
6	8.5339e-20	2.0498e-19	9.8256e-20	-1.0164e-20	-1.0164e-19	5.8652e-04	9.4868e-19	-5.4210e-20
7	-7.1151e-20	5.4210e-20	-1.7534e-19	-1.9312e-19	-2.1684e-19	5.4210e-20	4.8152e-04	1.0164e-20
8	5.4210e-20	6.7763e-21	1.4294e-20	8.4703e-20	-1.1858e-20	3.3881e-20	5.5057e-20	2.3439e-04

product

8x16 double

	9	10	11	12	13	14	15	16
1	-6.4375e-20	6.7763e-21	4.0658e-20	3.1552e-20	3.0917e-20	-3.1340e-20	-4.0658e-20	3.5575e-20
2	6.7763e-20	5.4210e-20	1.0842e-19	-2.7105e-20	9.4868e-20	4.7434e-20	0	-3.3881e-21
3	-5.4210e-20	-4.9551e-20	1.8635e-20	1.3553e-20	4.0658e-20	-1.6941e-20	-3.7269e-20	6.7763e-21
4	3.3881e-20	8.1315e-20	7.1151e-20	0	-1.3553e-20	4.7434e-20	-1.3553e-20	2.7105e-20
5	6.7763e-21	-6.0986e-20	-3.2187e-20	-4.0658e-20	-4.7434e-20	3.3881e-21	-2.3717e-20	-3.3881e-21
6	3.0493e-20	-6.7763e-21	2.7105e-20	-3.0493e-20	-4.0658e-20	0	6.7763e-20	-6.7763e-21
7	2.0329e-20	-1.0164e-20	2.3717e-20	-4.7434e-20	1.3553e-20	7.4539e-20	-2.7105e-20	6.7763e-20
8	-2.7105e-20	-2.2870e-20	5.5904e-20	2.7105e-20	-2.7105e-20	1.5247e-20	-2.7105e-20	5.0822e-20

Command Window

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```
product =

  Columns 1 through 12

    0.0012    0.0000   -0.0000    0.0000   -0.0000    0.0000   -0.0000    0.0000   -0.0000    0.0000    0.0000    0.0000
    0.0000    0.0011    0.0000   -0.0000    0.0000    0.0000   -0.0000    0.0000    0.0000    0.0000    0.0000   -0.0000
    0.0000    0.0000    0.0010   -0.0000    0.0000    0.0000   -0.0000   -0.0000   -0.0000   -0.0000    0.0000    0.0000
    0.0000    0.0000   -0.0000    0.0008   -0.0000    0.0000   -0.0000    0.0000    0.0000    0.0000    0.0000         0
   -0.0000    0.0000    0.0000   -0.0000    0.0007   -0.0000   -0.0000    0.0000    0.0000   -0.0000   -0.0000   -0.0000
    0.0000    0.0000    0.0000   -0.0000   -0.0000    0.0006    0.0000   -0.0000    0.0000   -0.0000    0.0000   -0.0000
   -0.0000    0.0000   -0.0000   -0.0000   -0.0000    0.0000    0.0005    0.0000    0.0000   -0.0000    0.0000   -0.0000
    0.0000    0.0000    0.0000    0.0000   -0.0000    0.0000    0.0000    0.0002   -0.0000   -0.0000    0.0000    0.0000

  Columns 13 through 16

    0.0000   -0.0000   -0.0000    0.0000
    0.0000    0.0000         0   -0.0000
    0.0000   -0.0000   -0.0000    0.0000
   -0.0000    0.0000   -0.0000    0.0000
   -0.0000    0.0000   -0.0000   -0.0000
   -0.0000         0    0.0000   -0.0000
    0.0000    0.0000   -0.0000    0.0000
   -0.0000    0.0000   -0.0000    0.0000
```

SingularVal

8x1 double

	1
1	2.3439e-04
2	4.8152e-04
3	5.8652e-04
4	6.5773e-04
5	8.0202e-04
6	9.5658e-04
7	0.0011
8	0.0012

Question 5.1) Count the total number of subchannels, i.e., the number of non-zero (greater than 1e-6) singular values of the matrix **H**, and denote this number as N_{all}.(5%) 2) Let us assume that the maximum transmit power *Pmax* obtained in Question 1 is **equal**ly allocated to *N* subchannels, where $N=1,\ldots,N_{all}$. Give the corresponding transmit beamforming matrix **F**and the receive beamforming matrix **G**that can diagonalise the matrix **H**.(5%) 3) Plot the data rate

*Rate = bandwidth*C, [symbols/second]*(7.14)

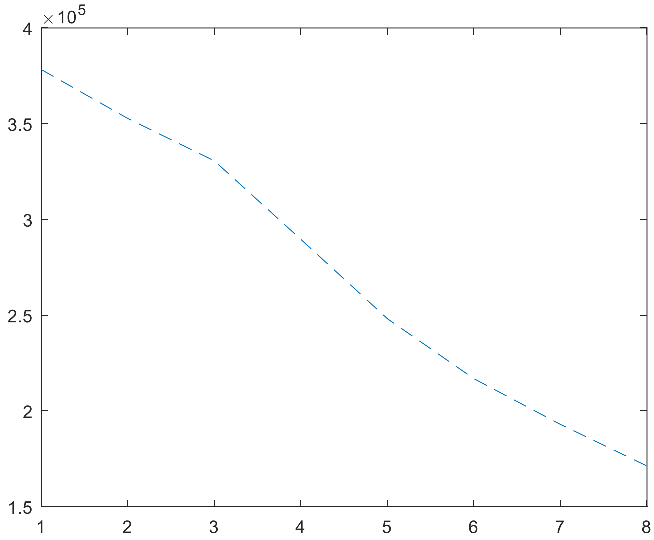
vs $N=1,\ldots,N_{all}$ and insert the figure below the question(5%).

Code:

```
%data rate

 Nall=find(Ds>1e-6);

 P1=Pmax/1;
 C1=log2(1+P1*Ds(1,1)^2);

 P2=Pmax/2;
 C2=log2(1+P2*Ds(1,1)^2)+log2(1+P2*Ds(2,2)^2);

 P3=Pmax/3;
 C3=log2(1+P3*Ds(1,1)^2)+log2(1+P3*Ds(2,2)^2)+log2(1+P3*Ds(3,3)^2);

 P4=Pmax/4;

C4=log2(1+P4*Ds(1,1)^2)+log2(1+P4*Ds(2,2)^2)+log2(1+P4*Ds(3,3)^2)+log2(1+P4
*Ds(4,4)^2);

 P5=Pmax/5;

C5=log2(1+P5*Ds(1,1)^2)+log2(1+P5*Ds(2,2)^2)+log2(1+P5*Ds(3,3)^2)+log2(1+P5
*Ds(4,4)^2)+log2(1+P5*Ds(5,5)^2);
```

```
P6=Pmax/6;

C6=log2(1+P6*Ds(1,1)^2)+log2(1+P6*Ds(2,2)^2)+log2(1+P6*Ds(3,3)^2)+log2(1+P6
*Ds(4,4)^2)+log2(1+P6*Ds(5,5)^2)+log2(1+P6*Ds(6,6)^2);

P7=Pmax/7;

C7=log2(1+P7*Ds(1,1)^2)+log2(1+P7*Ds(2,2)^2)+log2(1+P7*Ds(3,3)^2)+log2(1+P7
*Ds(4,4)^2)+log2(1+P7*Ds(5,5)^2)+log2(1+P7*Ds(6,6)^2)+log2(1+P7*Ds(7,7)^2);

P8=Pmax/8;

C8=log2(1+P8*Ds(1,1)^2)+log2(1+P8*Ds(2,2)^2)+log2(1+P8*Ds(3,3)^2)+log2(1+P8
*Ds(4,4)^2)+log2(1+P8*Ds(5,5)^2)+log2(1+P8*Ds(6,6)^2)+log2(1+P8*Ds(7,7)^2)+
log2(1+P8*Ds(8,8)^2);

C=[C1 C2 C3 C4 C5 C6 C7 C8 ];
DataRate=BW*C
x=1:8;
figure, plot(x,DataRate,'--');
```

Answer: As the number of sub channels grows, the data rate decreases.



Command Window

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```
DataRate =

   1.0e+05 *

    3.9032    3.7168    3.2956    2.8720    2.5764    2.3184    2.0681    1.8497
```

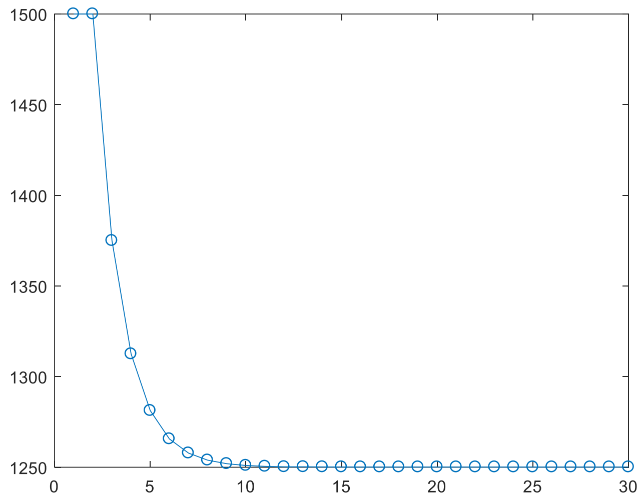
Question 6. Based on the water-filling power allocation expression in Eq. (7.11) and Figure 3, find the water-filling power allocation result and the data rate based on Eq. (7.14).Give the results below the question.(Tip: using bisection search method [4] to find the water level μ in Eq. (7.13))(25%)

Code:

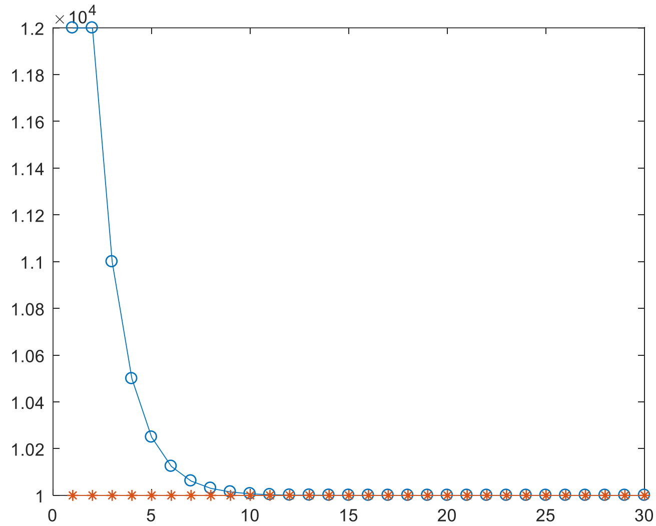
```
SingularValues=find(Ds>1e-6);
 mu=1000;
 epsilon=1e-5;


step = mu/2;

m = 0;
flag = 0;
while flag == 0
    m = m +1;

 Pi=subplus(mu-(1./(SingularValues.^2)));
 if sum(Pi)>Pmax
      step = step/2;
     mu=mu-step;
     Pi=subplus(mu-(1./(SingularValues.^2)));
 end

 if sum(Pi)<Pmax-epsilon
          step = step;
         mu=mu+step;
         Pi=subplus(mu-(1./(SingularValues.^2)));
 end

muall(m) = mu;
Powerall(m) = sum(Pi);

if sum(Pi)<=Pmax && Pmax-sum(Pi)<= epsilon
    flag = 1;
end

end

Pi

 c=(log2(1+Pi.*(SingularValues.^2))) %%% sum of log
 r=BW*c;

figure,plot(muall,'o-')
figure,plot(Powerall,'o-')
hold on,plot(Pmax.*ones(size(Powerall)),'*-')
```

Answer:

Graph for `figure,plot(muall,'o-')`



Graph for `figure,plot(Powerall,'o-')`
`hold on,plot(Pmax.*ones(size(Powerall)),'*-')`



Pi

8x1 double

	1
1	1.2491e+03
2	1.2501e+03
3	1.2501e+03
4	1.2501e+03
5	1.2501e+03
6	1.2501e+03
7	1.2501e+03
8	1.2501e+03

c

8x1 double

	1
1	10.2879
2	16.9317
3	18.7837
4	19.9026
5	20.7068
6	21.3350
7	21.8506
8	22.2879

Useful Bibliography

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4. Weisstein, Eric W. "Bisection". MathWorld.https://en.wikipedia.org/wiki/Bisection_method

THE END