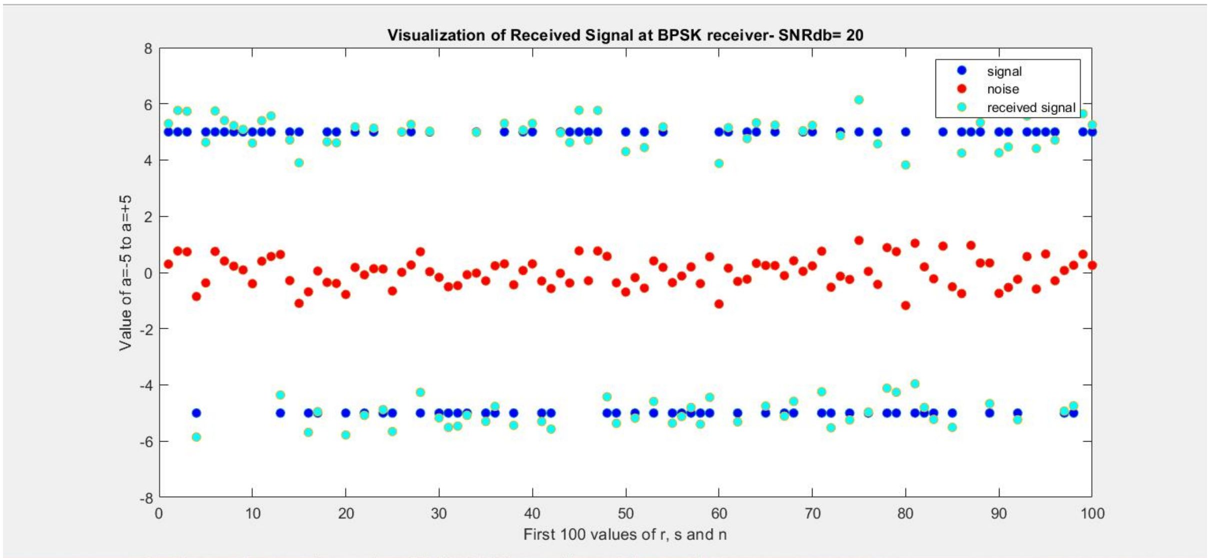
Exercise-1: Visualization of Received Signal at BPSK receiver.

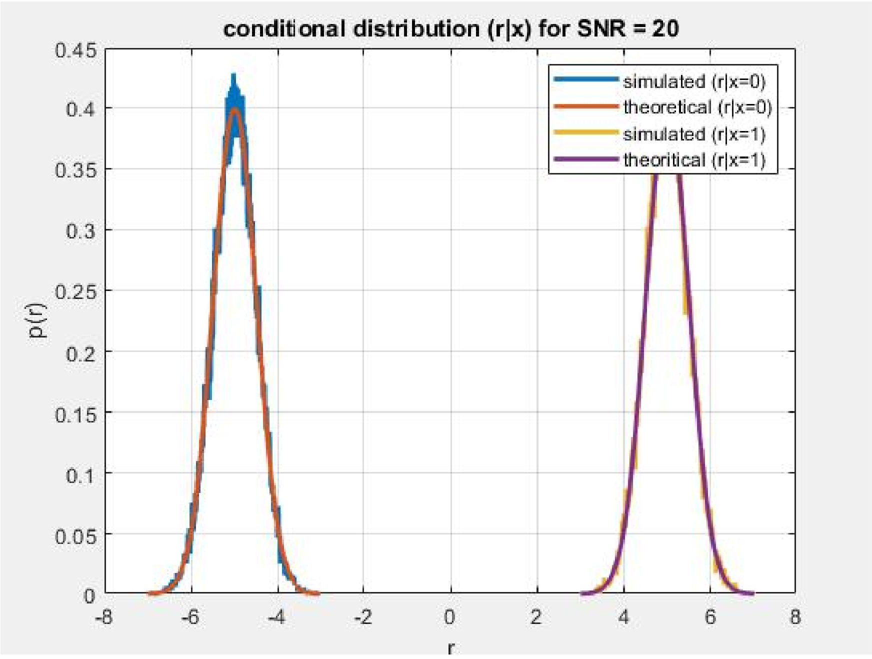
- **Code-**

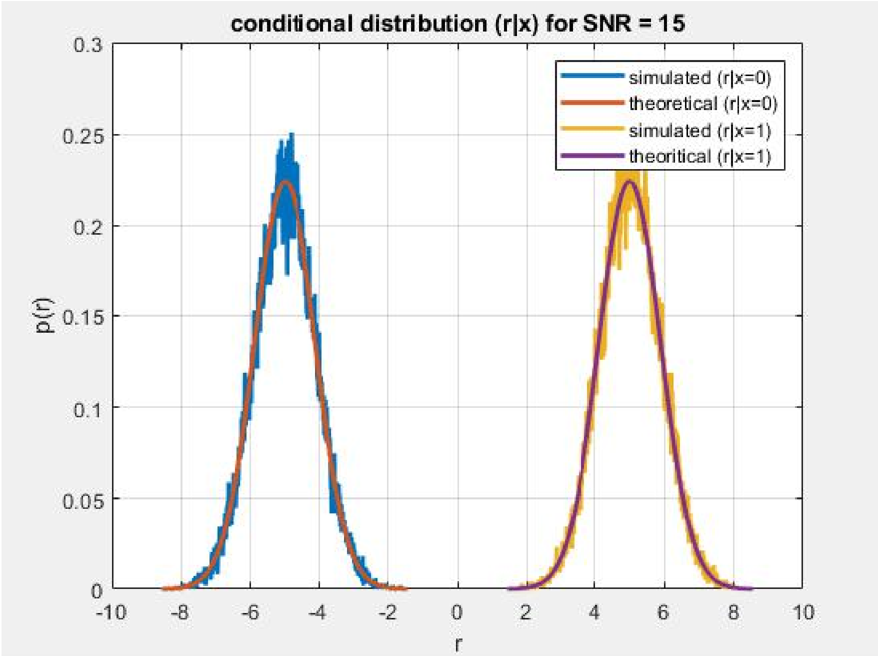
```
clear all;
close all;
q=0.5;
N=10000;
a=5;
SNRdb=20;
x=binornd(1,q,1,N);
s=a*(2*x-1);
SNR_lin=power(10,0.1*SNRdb);
sigma=sqrt(a^2/SNR_lin);
n=sigma*randn(1,N);
r=s+n;
xcap=double(r>0);
plot(1:N,s,'o','markerfacecolor','b');
hold on;
plot(1:N,n,'o','markerfacecolor','r');
hold on;
plot(1:N,r,'o','markerfacecolor','c');
axis([0 20 -8 8]);
legend('signal','noise','received signal');
ylabel('Value of a=-5 to a=+5');
xlabel('First 20 values of r, s and n');
title('Visualization of Received Signal at BPSK
receiver');
hold off;
```

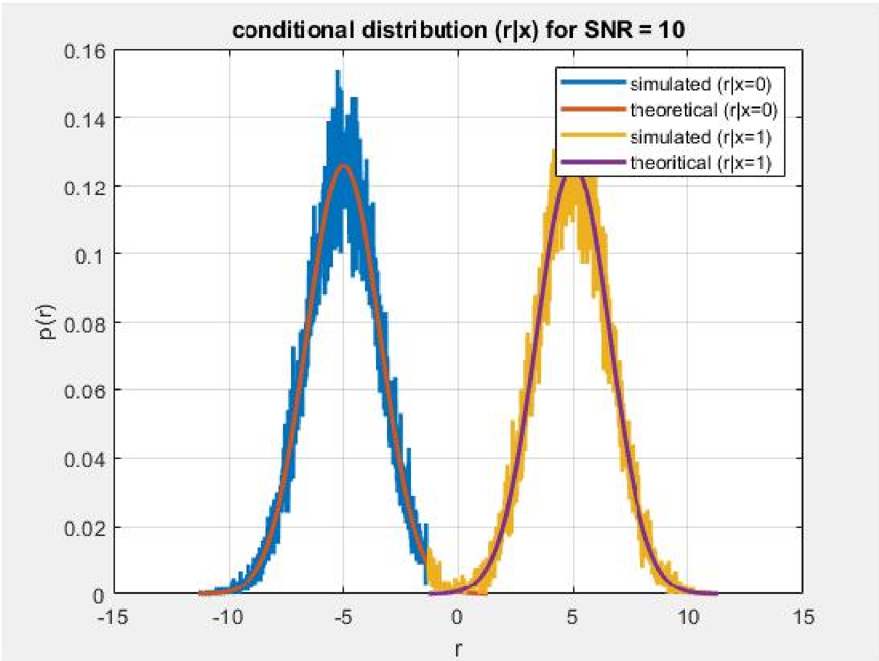
- **Output:**

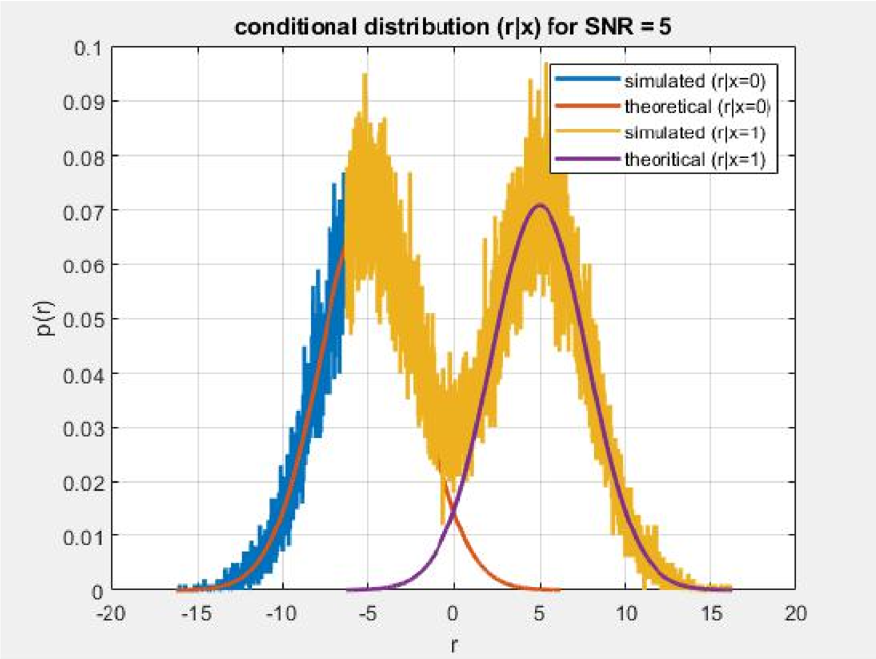
SNRdb- values - 20,20,30,40






conditional distribution (r|x) for SNR = 15
simulated (r|x=0)
theoretical (r|x=0)
simulated (r|x=1)
theoritical (r|x=1)
p(r)
r
0.3
0.25
0.2
0.15
0.1
0.05
0
-10
-8
-6
-4
-2
0
2
4
6
8
10


conditional distribution (r|x) for SNR = 10
simulated (r|x=0)
theoretical (r|x=0)
simulated (r|x=1)
theoritical (r|x=1)
p(r)
r
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-15
-10
-5
0
5
10
15



- **Inference:**

-> When the SNR value is increased the variation in noise is decreased as can be seen from plots.
-> At very small value of SNR, the noise is too much, so too much error.
-> The value of voltage signal a varies from -5 to +5, and the noise is nearly distributed between -2 to +2 for a good SNR value.
-> Error comes when sender sends bit 1 as +5V and received signal comes out to be below decision boundary i.e. 0V. and vice versa for 0 bit.

Exercise-2: Probability of Bit Error Simulator

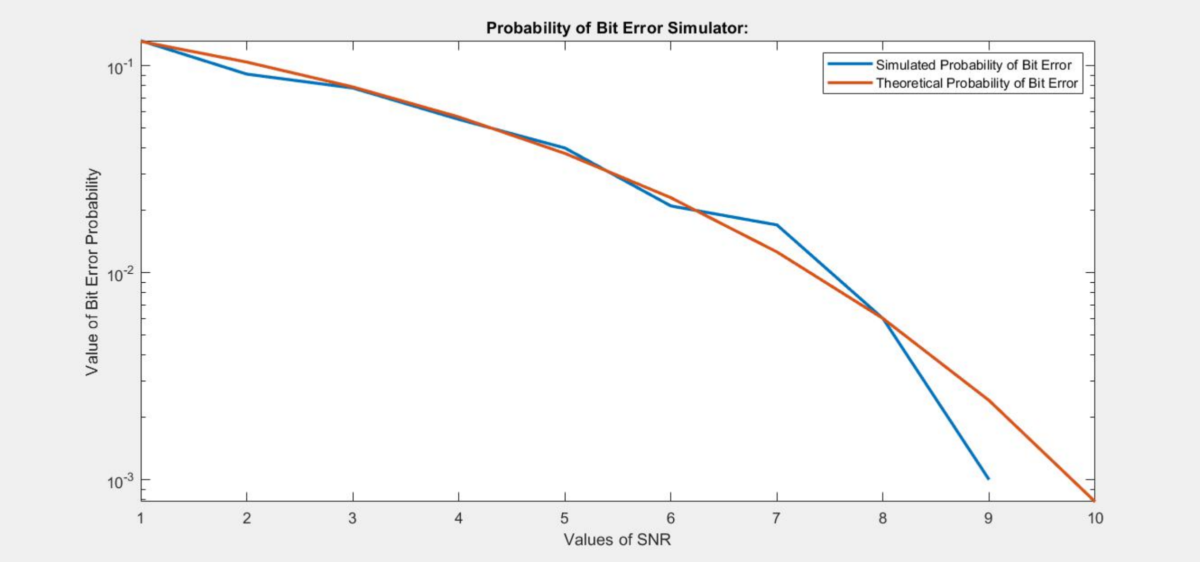
- **Code-**

```
clear vars;

close all;

q=0.5;

N=1000;
```

```
a=5;
SNR=1:10;
prob=1:10;
x=binornd(1,q,1,N);
s=a*(2*x-1);
SNR_lin=power(10,0.1.*SNR);
sigma=sqrt(a^2./SNR_lin);
for k=1:10
    n=sigma(k)*randn(1,N);
    r=s+n;
    xcap=double(r>0);
    prob(k)=mean(abs(xcap-x));
end
semilogy(SNR,prob,'markerface','b','linewidth',2);
hold on;
ptheoretical=qfunc(a./sigma);
plot(SNR,ptheoretical,'markerface','r','linewidth',2);
legend('Simulated Probability of Bit Error','Theoretical
Probability of Bit Error');
ylabel('Value of Bit Error Probability');
xlabel('Values of SNR');
title('Probability of Bit Error Simulator:');
hold on;
```

- **Output:**

SNR values from 1 to 10.



- **Inference:**

-> Here, initially we have determined probability of error in BPSK modelling for N=1000 samples for varying values of SNR from 0dB to 10dB.

->In first figure, we can clearly observe that simulated curve of probability of error differs from theoretical curve of probability of error.

-> For Nsim=1000 simulation ,we can clearly observe that after increasing number of simulations, simulated curve of probability of error becomes identical to theoretical curve of probability of error.

Exercise-3(a): Effect of changing the decision threshold:

- **Code-**

```
clear vars;
close all;
q=0.5;
N=100;
Nsim=1000;
```

```
a=5;
SNR=1:1:10;
pb=1:10;
prob=1:Nsim;
x=binornd(1,q,1,N);
s=a*(2*x-1);
SNR_lin=power(10,0.1.*SNR);
sigma=sqrt(a^2./SNR_lin);
for j=-5:5
for k=1:10
    for i=1:Nsim

        n=sigma(k)*randn(1,N);
        r=s+n;
        xcap=double(r>j);
        prob(i)=mean(abs(xcap-x));
    end
  pb(k)=mean(prob);
end
figure;
semilogy(SNR,pb,'o','markerface','b');
hold on;

ptheoretical=qfunc(a./sigma);
semilogy(SNR,ptheoretical,'linewidth',2);
str =['figure BPSK for value of q ',num2str(q),' and
decision boundary  ',num2str(j)];
title(str);
```

```
end
```

- **Output:**

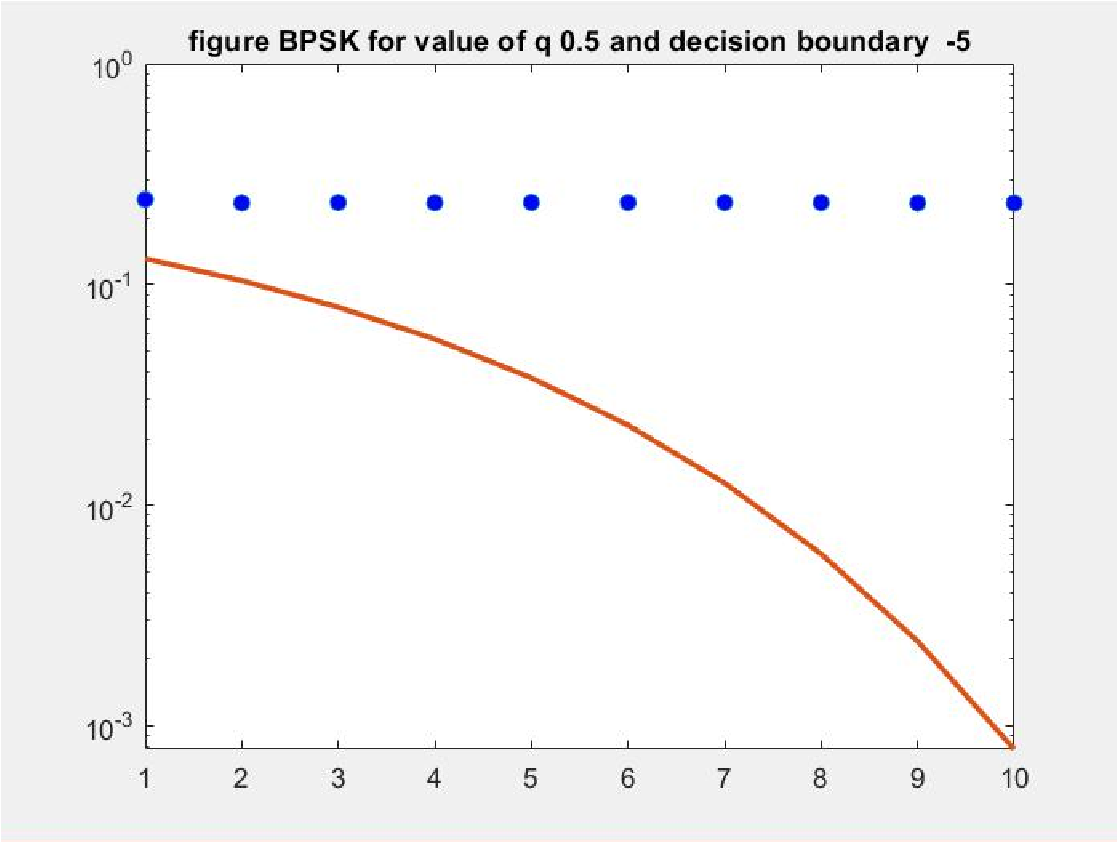


figure BPSK for value of q 0.5 and decision boundary -5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

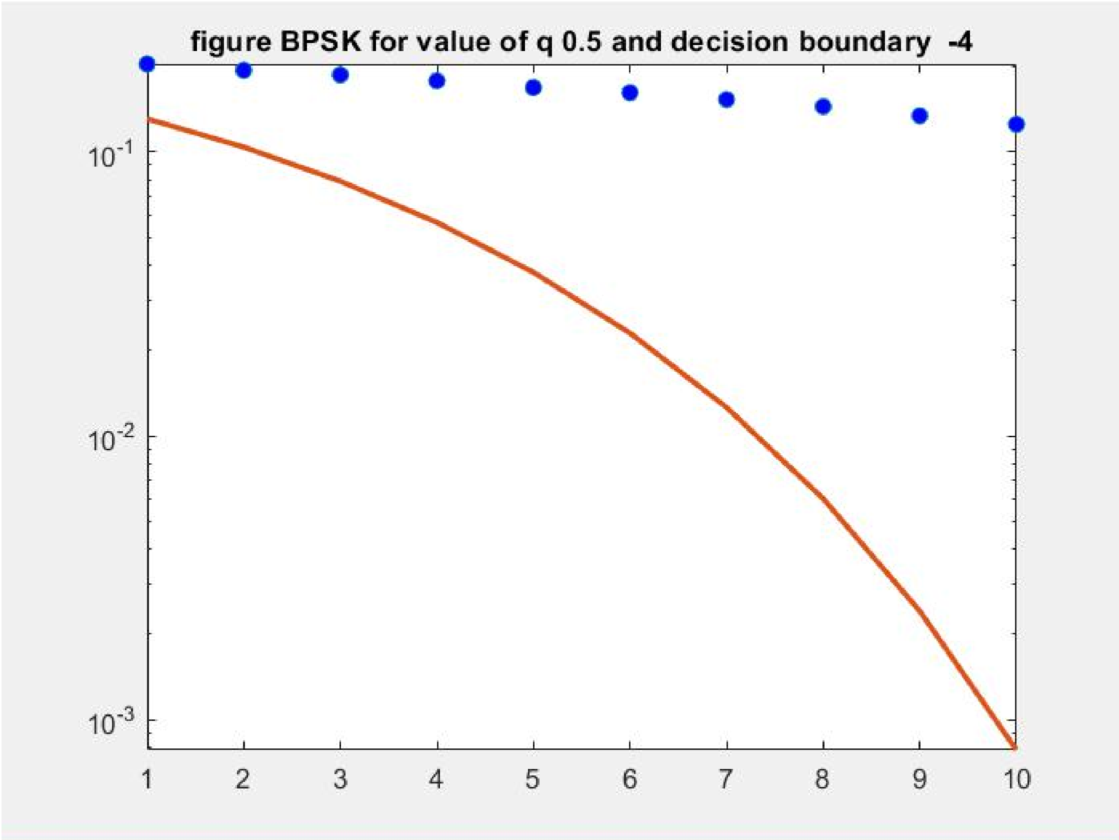


figure BPSK for value of q 0.5 and decision boundary -4
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

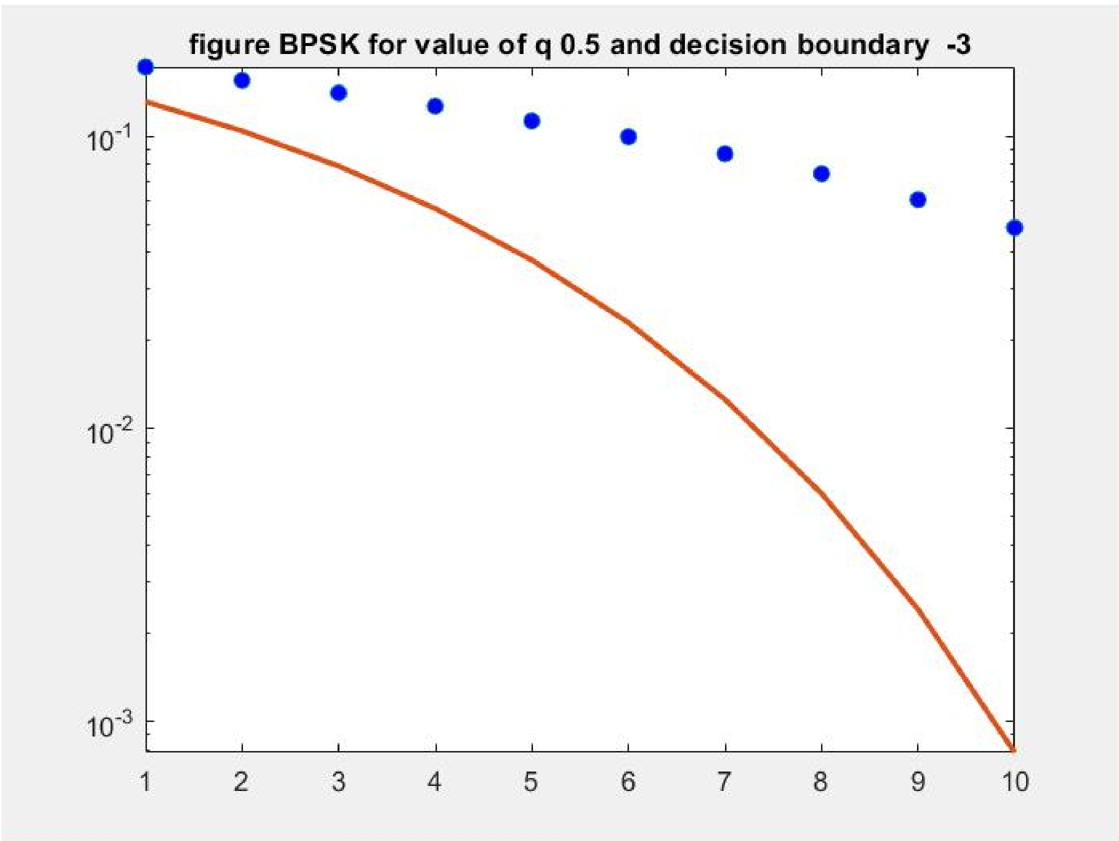


figure BPSK for value of q 0.5 and decision boundary -3
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

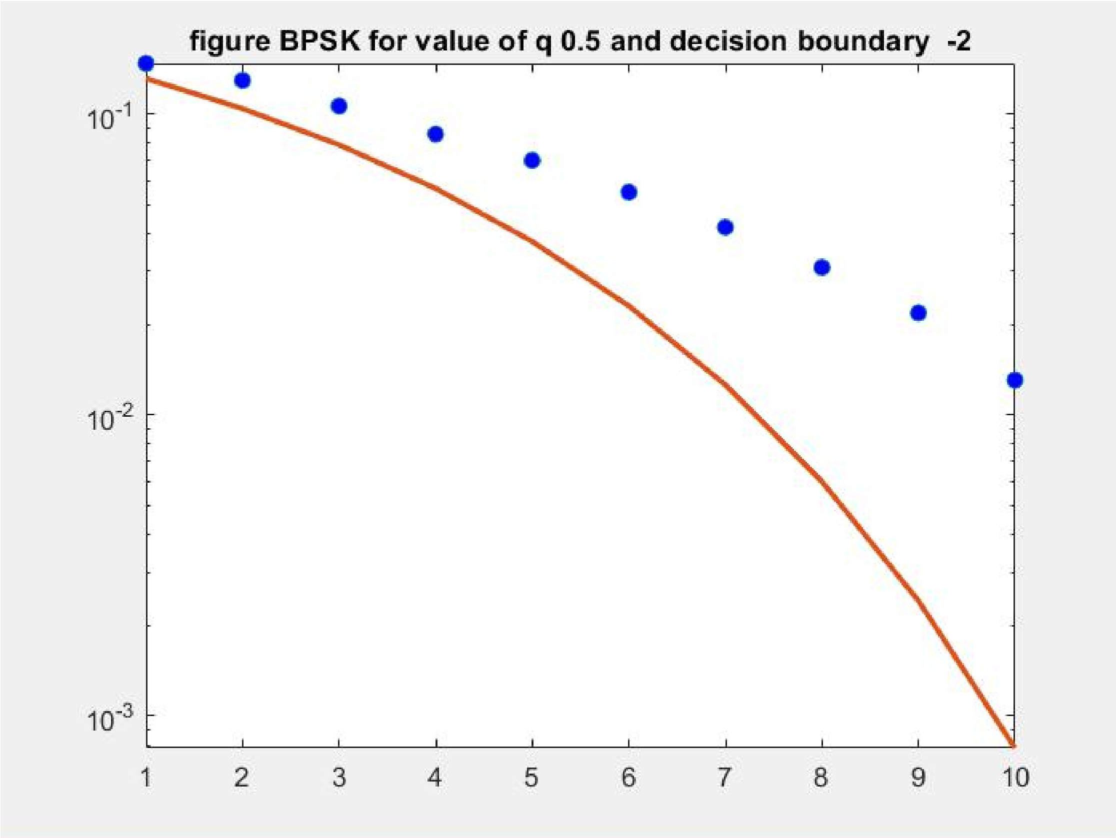


figure BPSK for value of q 0.5 and decision boundary -2
10^-1
10^-2
10^-3
1 2 3 4 5 6 7 8 9 10

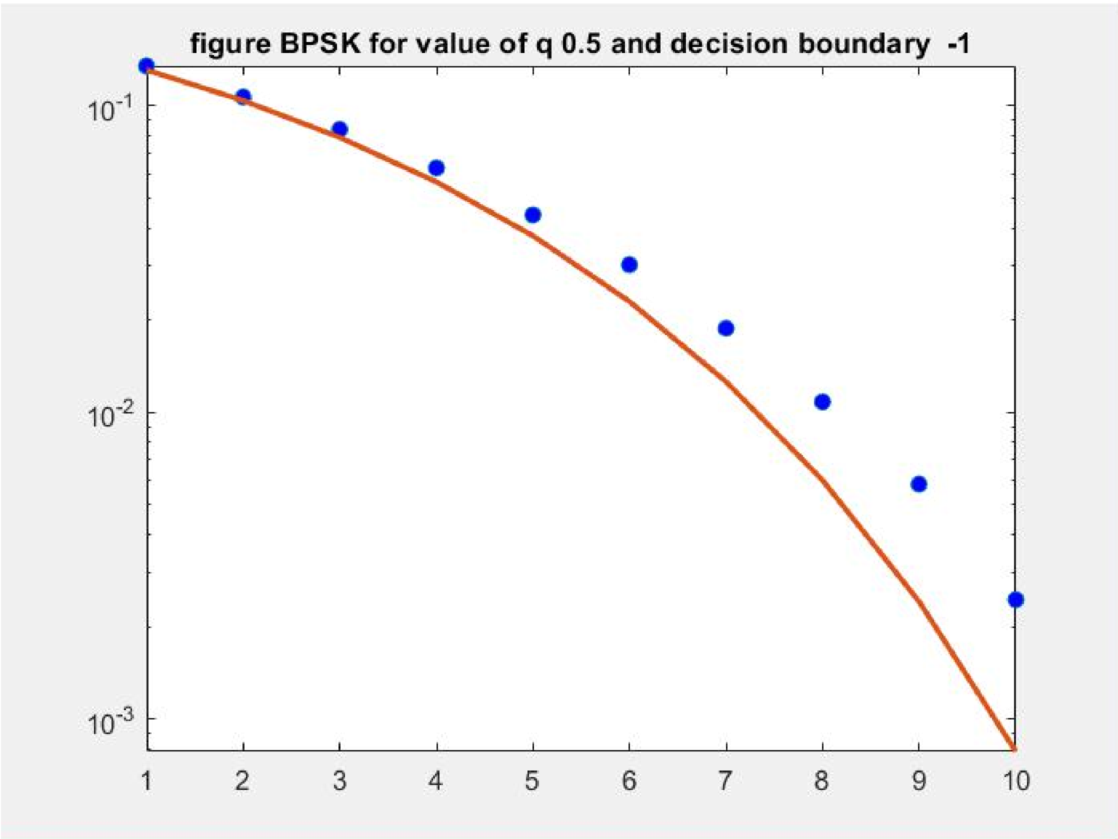


figure BPSK for value of q 0.5 and decision boundary -1
10^-1
10^-2
10^-3
1 2 3 4 5 6 7 8 9 10

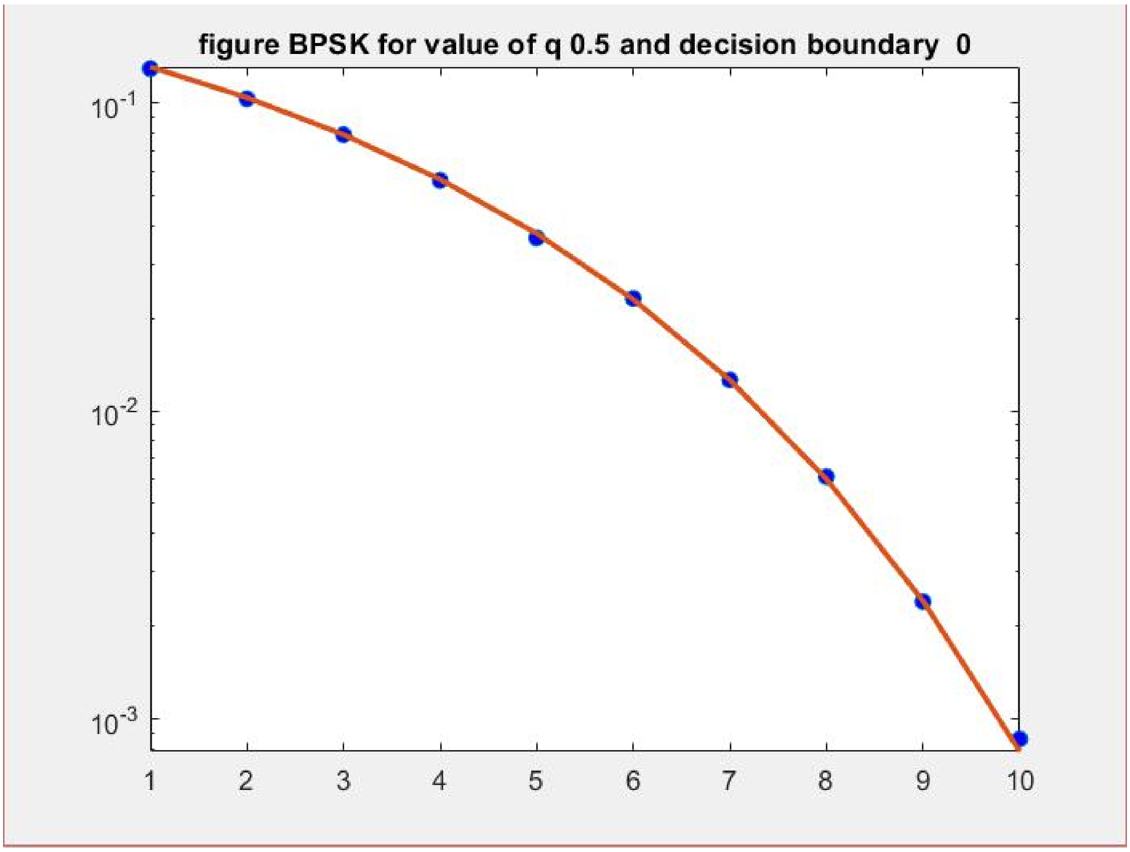


figure BPSK for value of q 0.5 and decision boundary 0
10-1
10-2
10-3
1
2
3
4
5
6
7
8
9
10

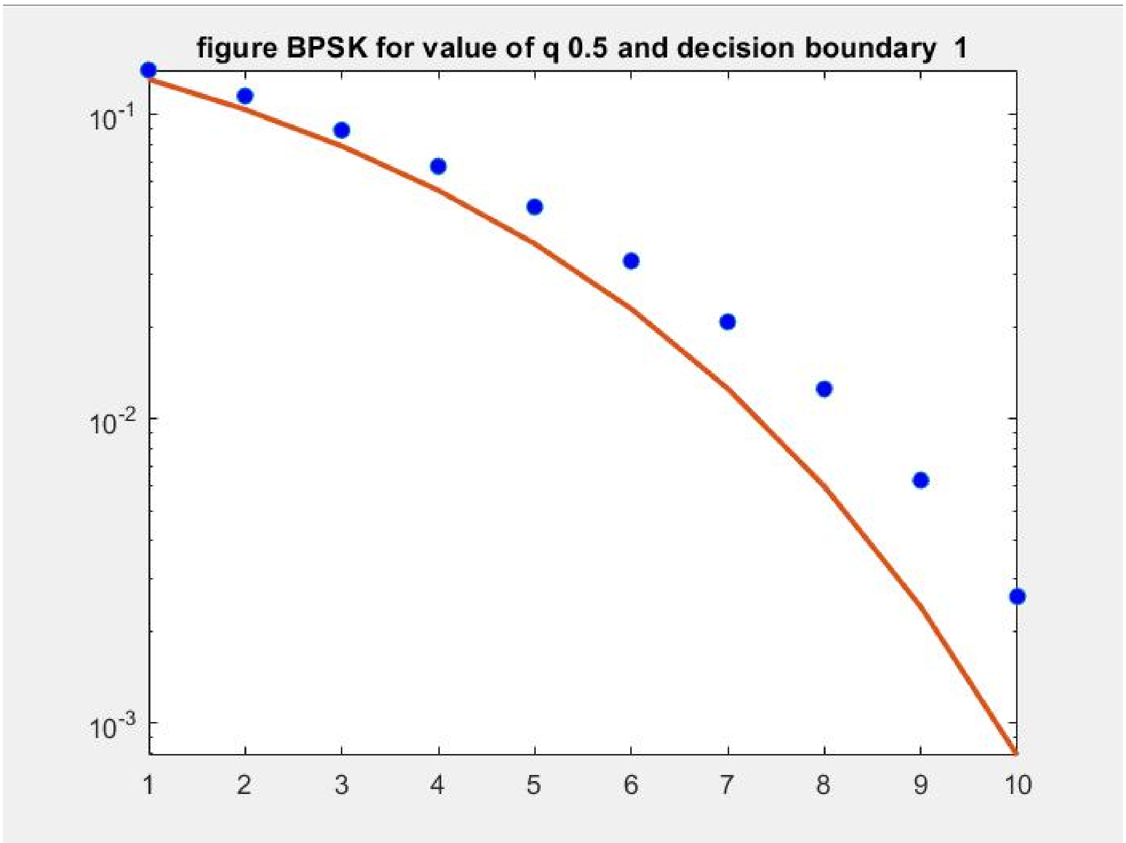


figure BPSK for value of q 0.5 and decision boundary 1
10-1
10-2
10-3
1
2
3
4
5
6
7
8
9
10

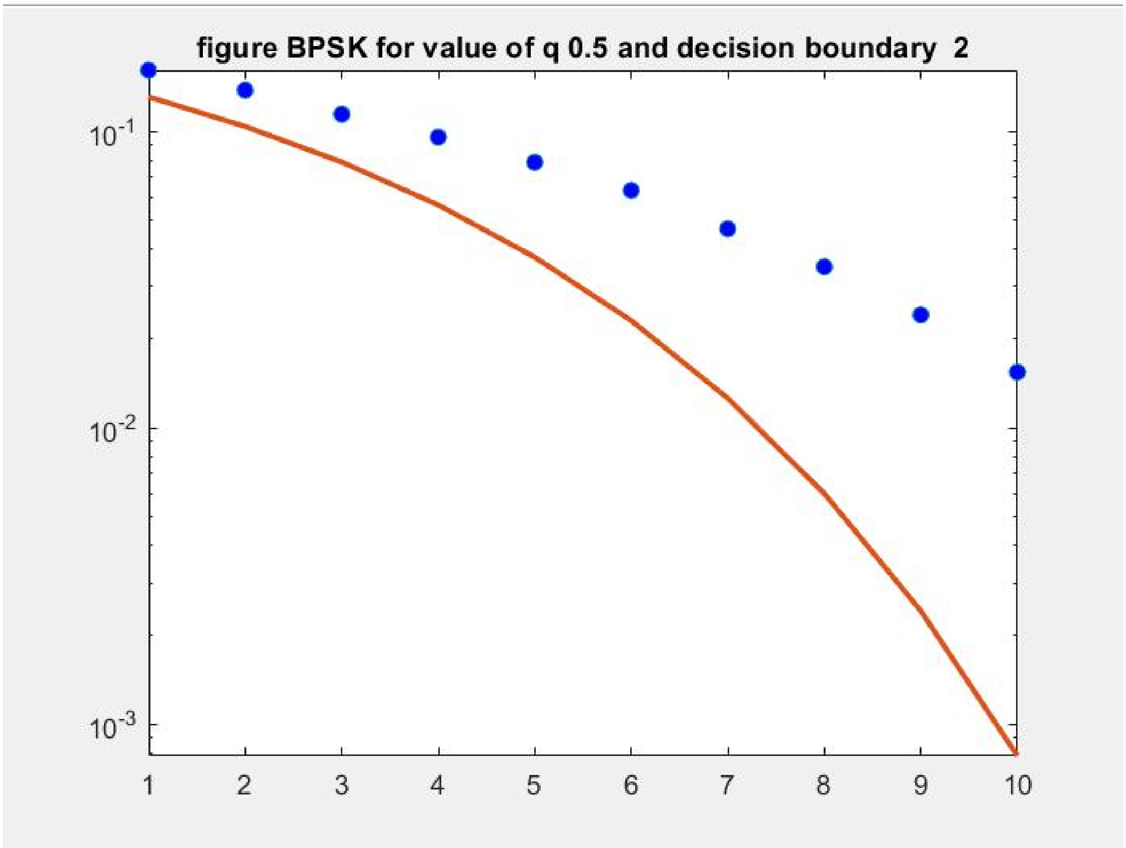


figure BPSK for value of q 0.5 and decision boundary 2
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

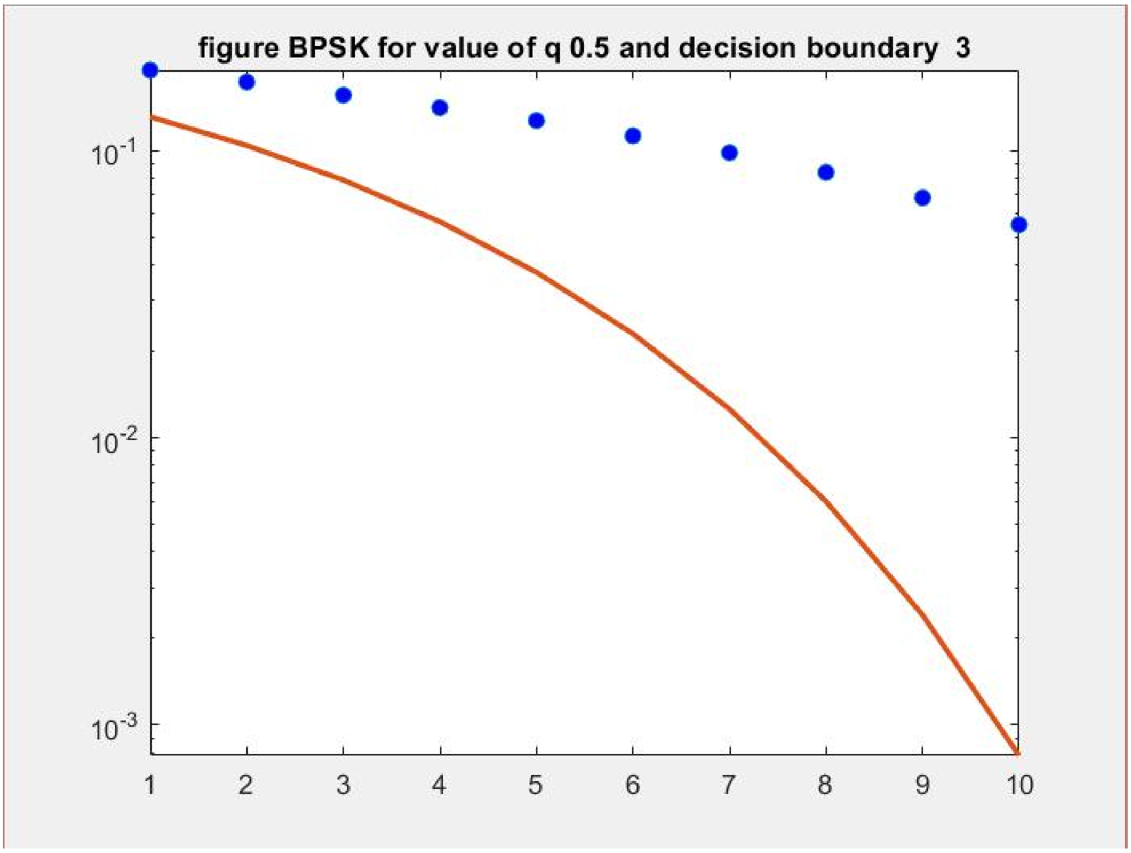


figure BPSK for value of q 0.5 and decision boundary 3
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

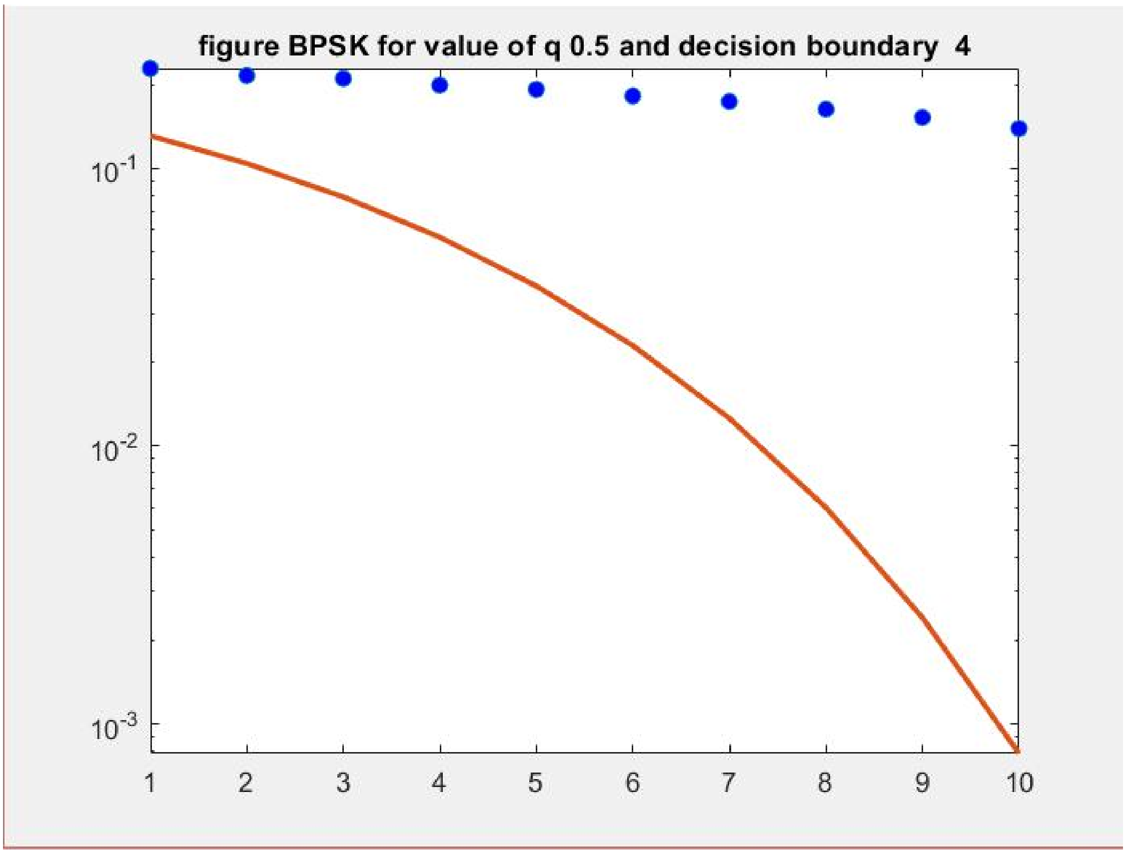


figure BPSK for value of q 0.5 and decision boundary 4
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

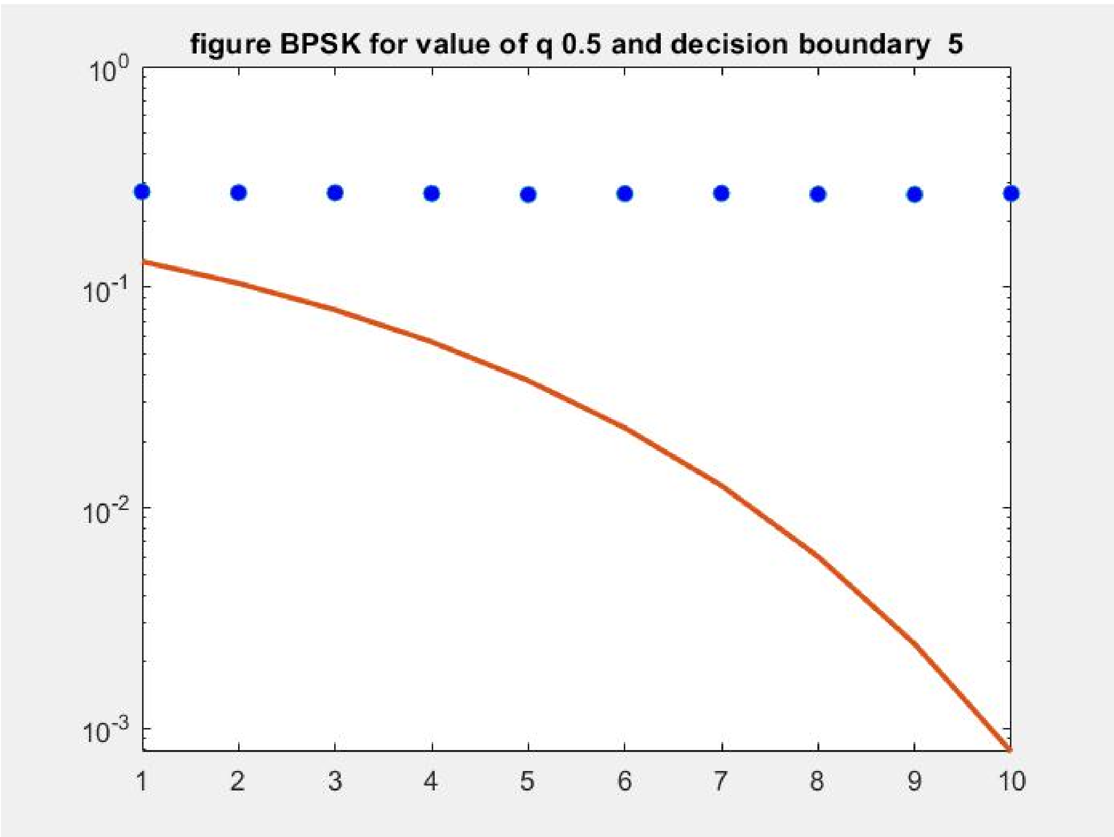


figure BPSK for value of q 0.5 and decision boundary 5
10^{0}
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

Inference:

Here, above given figures show changing probability of error as we change decision threshold for BPSK modulation scheme with q=0.5. Initially, decision threshold is at -5. As we increase value of decision threshold, probability of error decreases. When decision threshold is at 0, probability of bit error is minimum. Now, as we continue to increase decision threshold further, probability of error increases.

Question:

For what value of decision threshold does the simulated bit error probability attain the smallest value?

Simulated bit error probability for BPSK given q=0.5 attains smallest value when decision threshold is at 0.

Exercise-3(b): Effect of changing the decision threshold:

- **Code-**

```
clear vars;
close all;
q=0.3;
N=100;
Nsim=1000;
a=5;
SNR=1:1:10;
pb=1:10;
prob=1:Nsim;
x=binornd(1,q,1,N);
```

```
s=a*(2*x-1);
SNR_lin=power(10,0.1.*SNR);
sigma=sqrt(a^2./SNR_lin);
for j=-5:5
for k=1:10
    for i=1:Nsim

        n=sigma(k)*randn(1,N);
        r=s+n;
        xcap=double(r>j);
        prob(i)=mean(abs(xcap-x));
    end
  pb(k)=mean(prob);
end
figure;
semilogy(SNR,pb,'o','markerface','b');
hold on;

ptheoretical=qfunc(a./sigma);
semilogy(SNR,ptheoretical,'linewidth',2);
str =['figure for BPSK for value of q ',num2str(q),' and 
decision boundary  ',num2str(j)];
title(str);

End
```

- ***Output:***

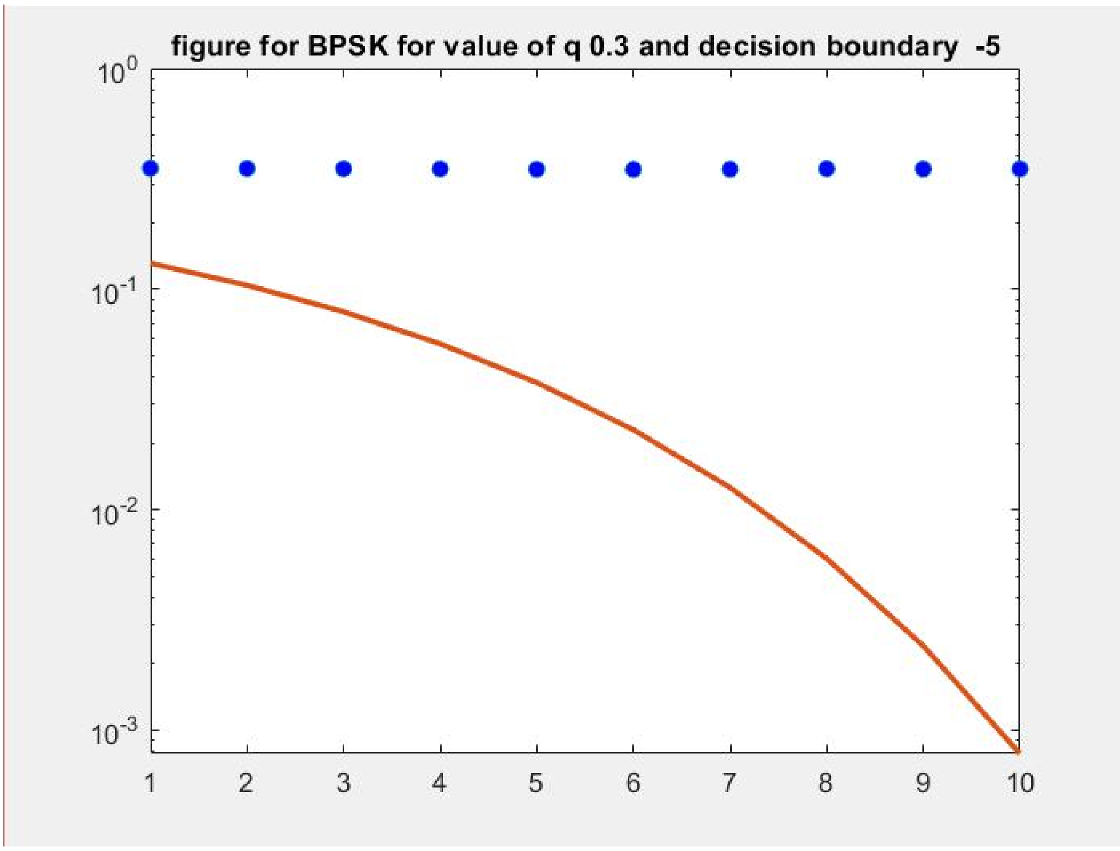


figure for BPSK for value of q 0.3 and decision boundary -5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

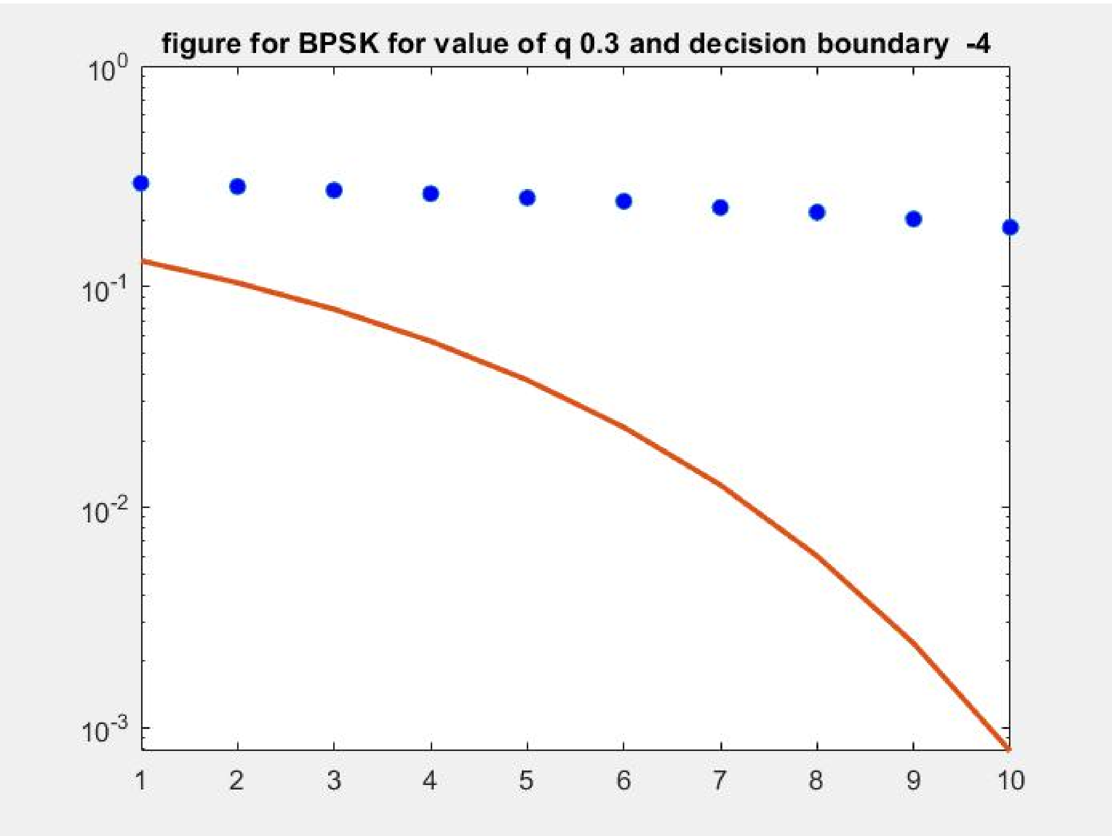


figure for BPSK for value of q 0.3 and decision boundary -4
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

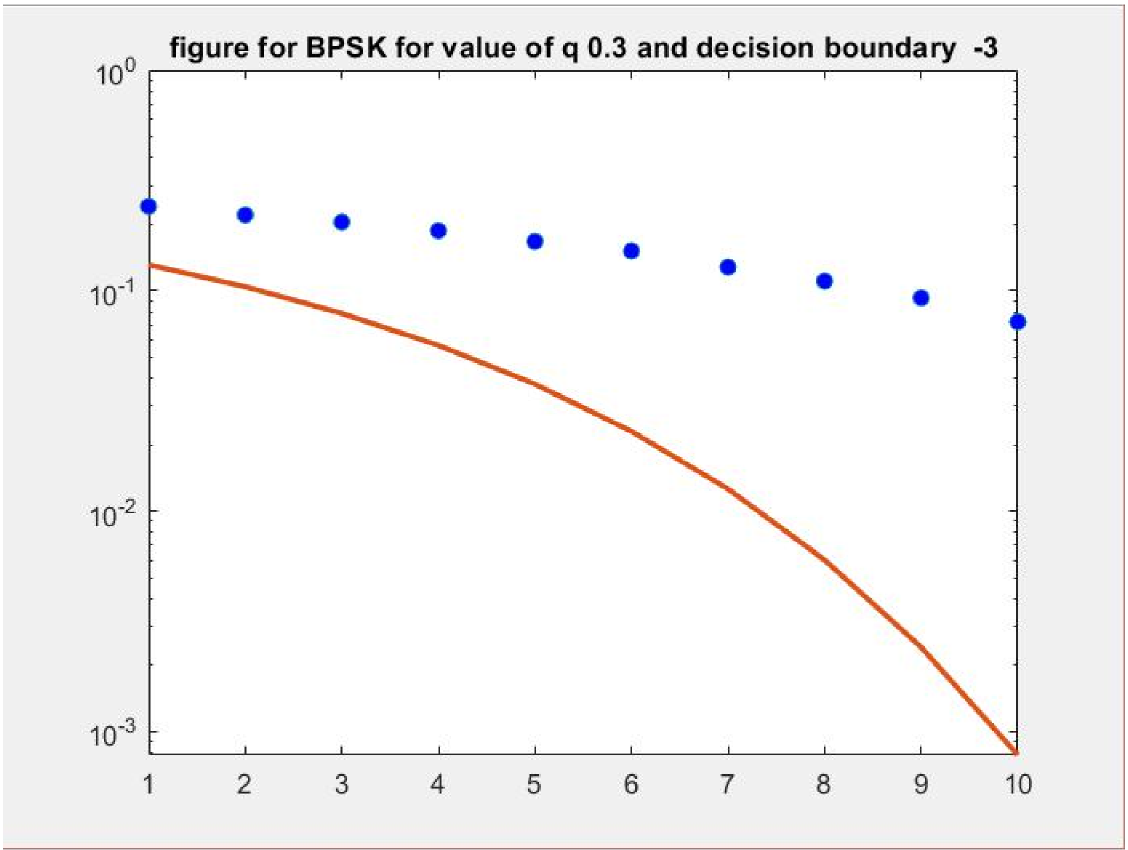


figure for BPSK for value of q 0.3 and decision boundary -3
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

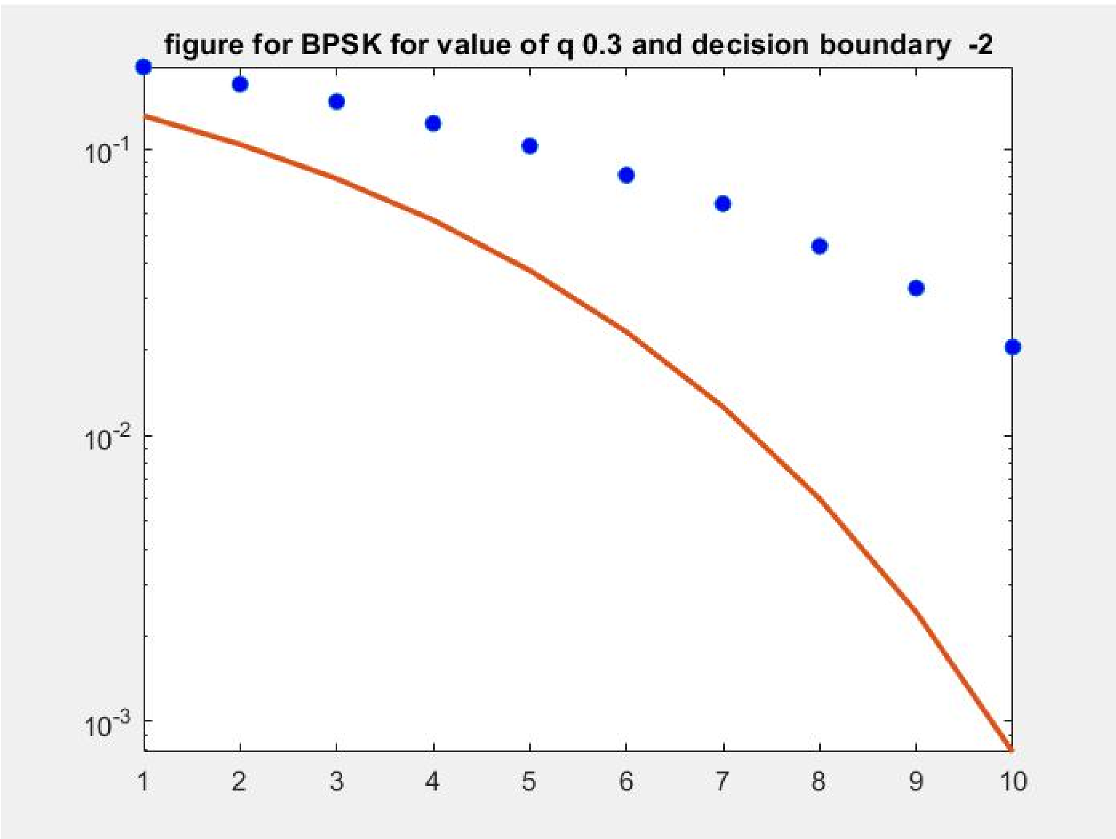


figure for BPSK for value of q 0.3 and decision boundary -2
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

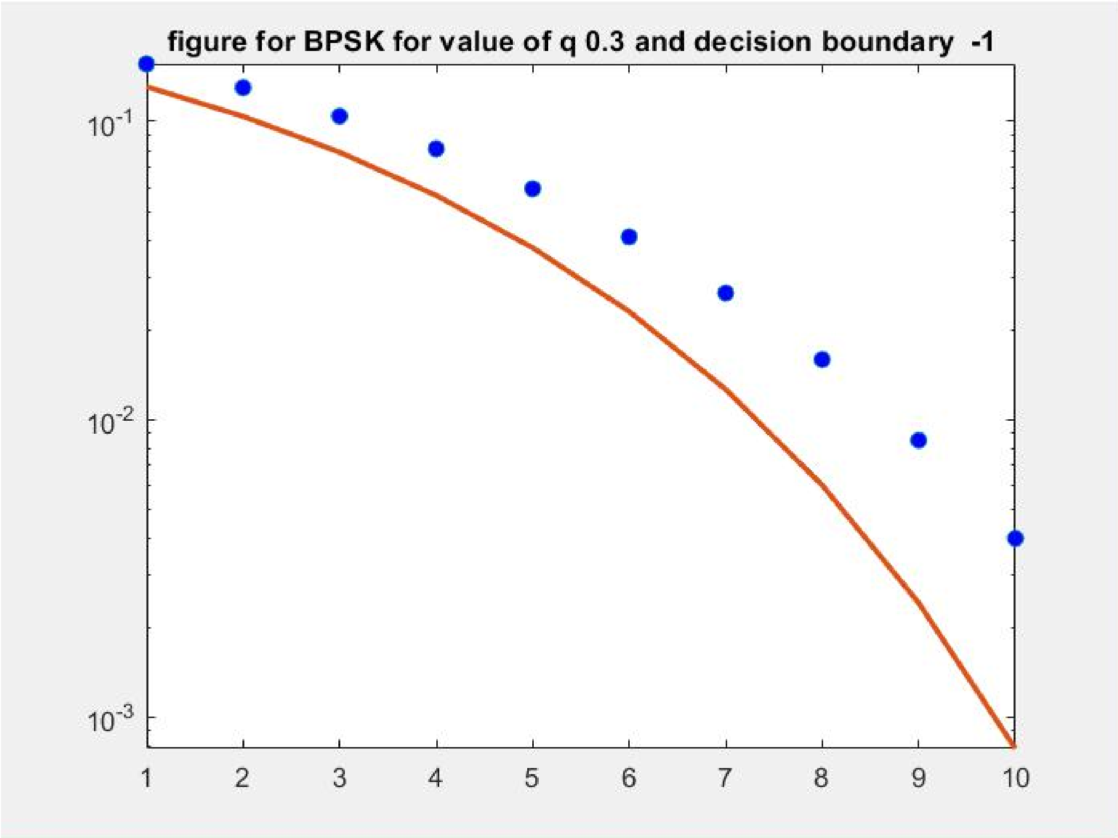


figure for BPSK for value of q 0.3 and decision boundary -1
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

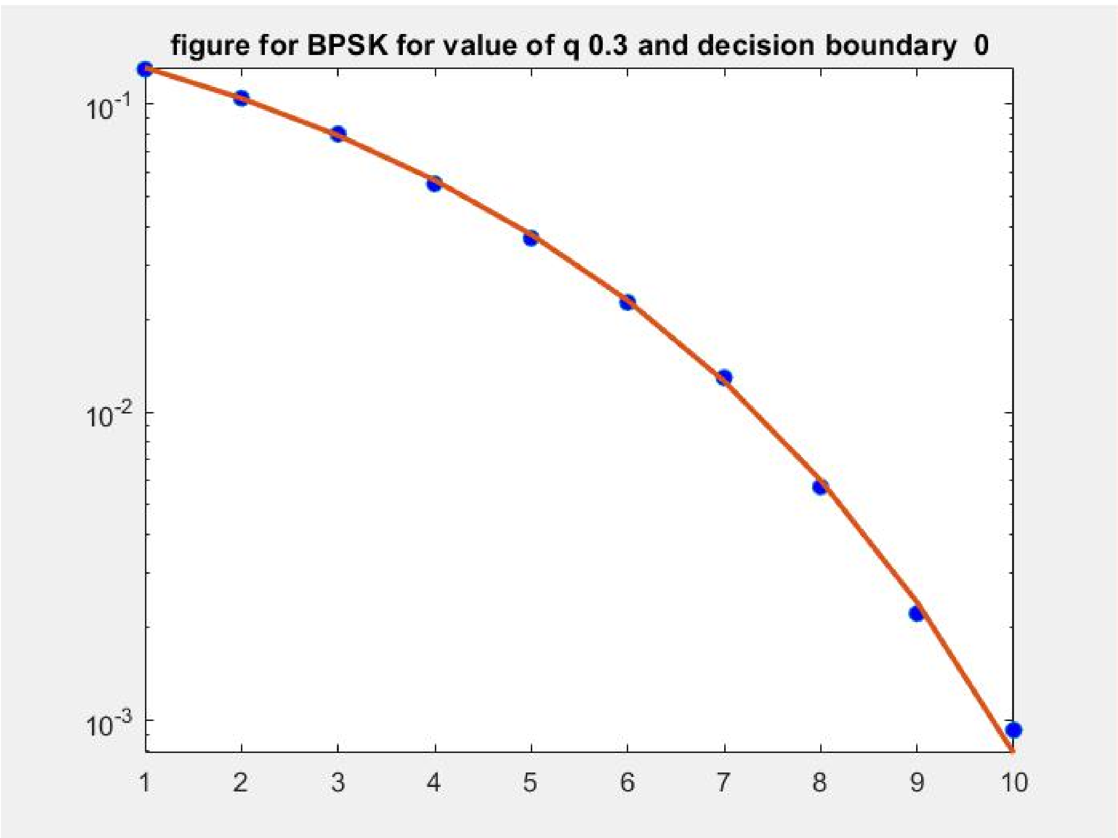


figure for BPSK for value of q 0.3 and decision boundary 0
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

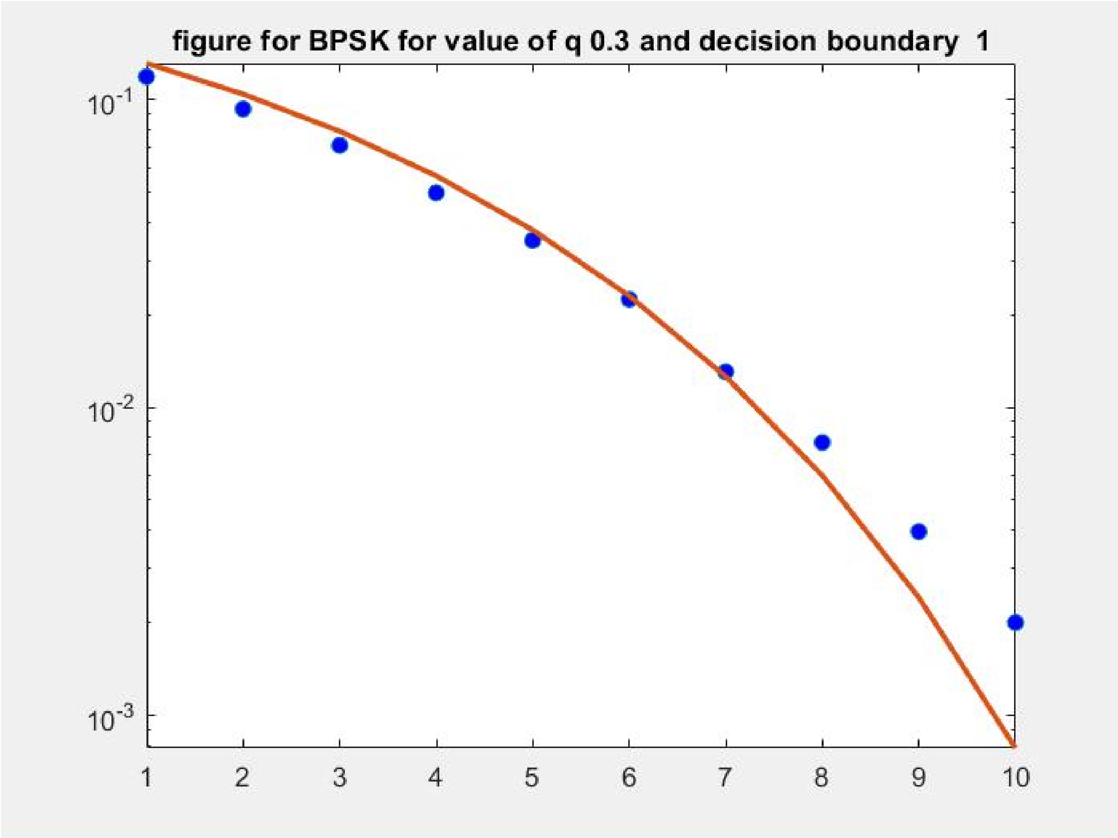


figure for BPSK for value of q 0.3 and decision boundary 1
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

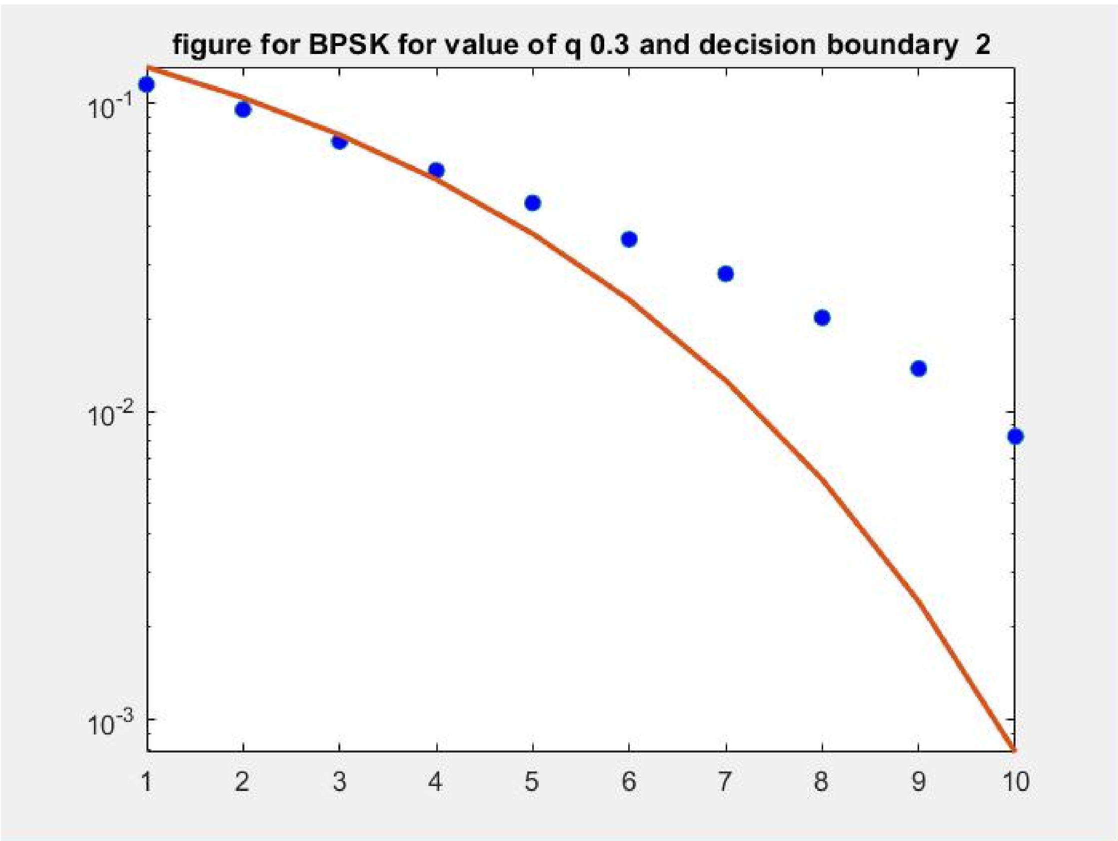


figure for BPSK for value of q 0.3 and decision boundary 2
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

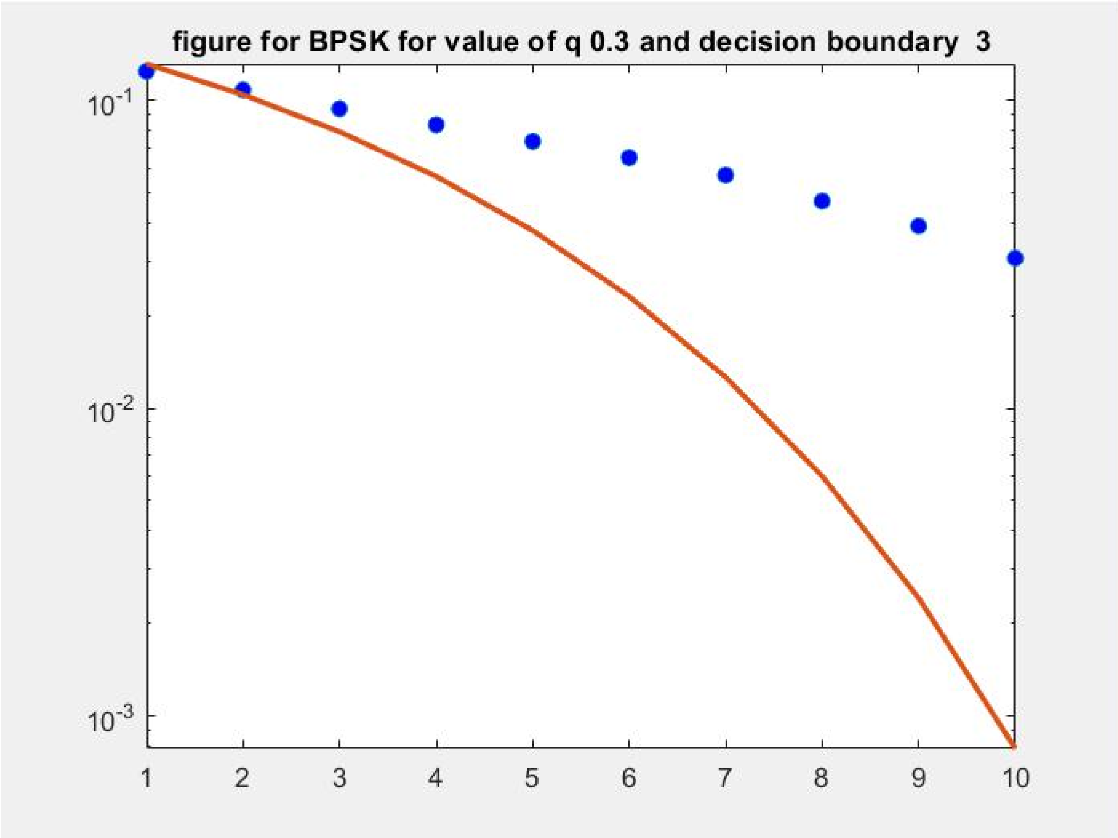


figure for BPSK for value of q 0.3 and decision boundary 3
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

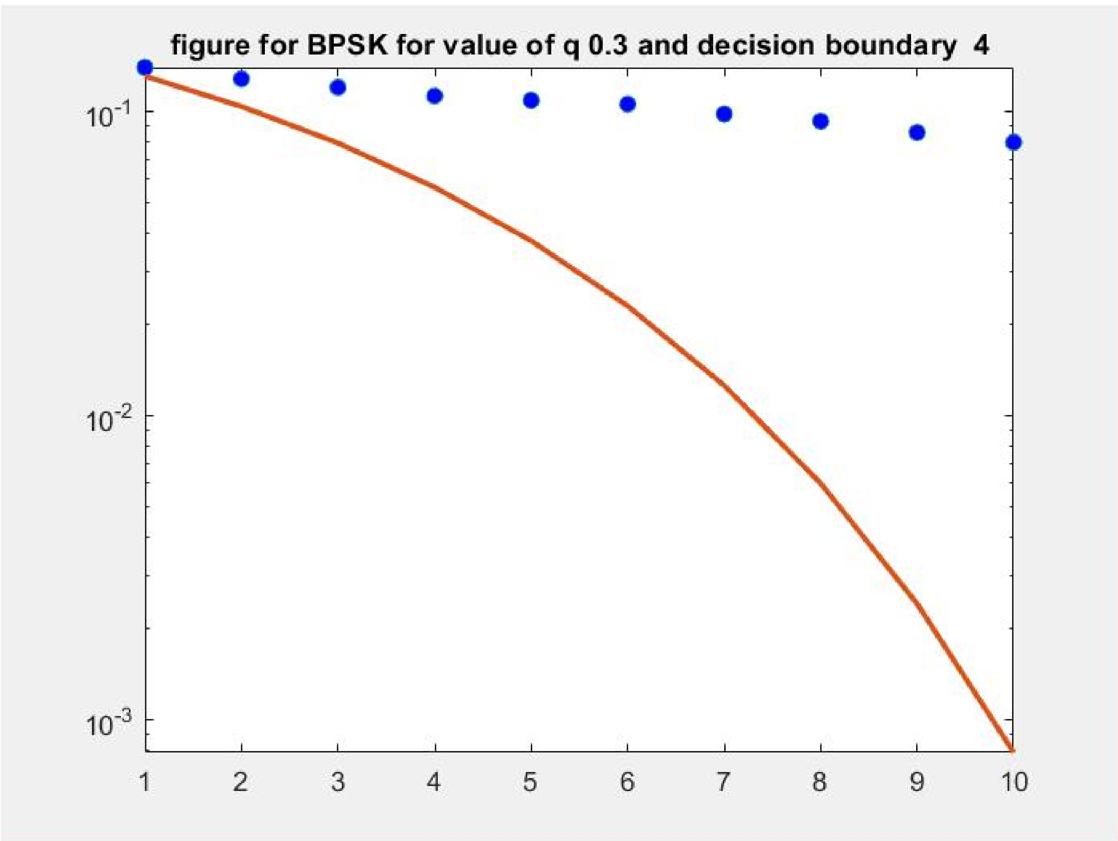
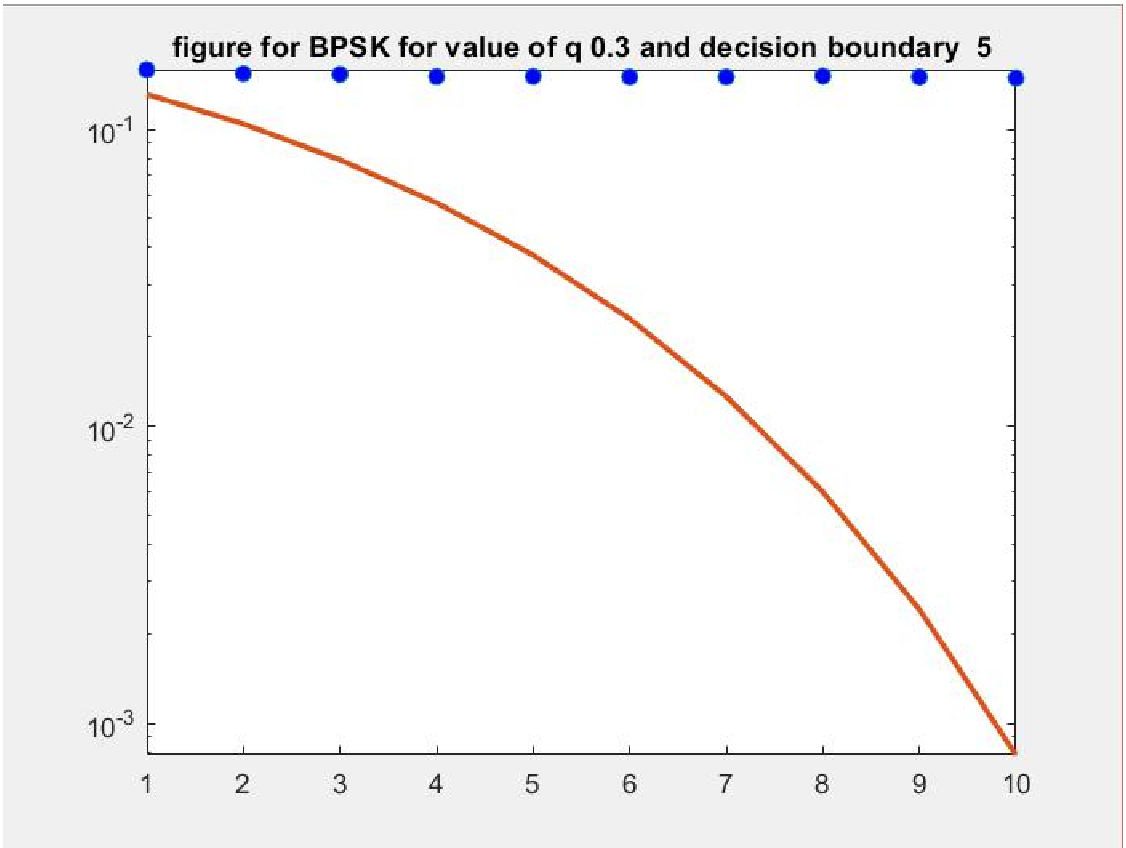


figure for BPSK for value of q 0.3 and decision boundary 4
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10



➢ **Inference:**

Here, above given figures show changing probability of error as we change decision threshold for BPSK modulation scheme with q=0.3. Initially, decision threshold is at -5. As we increase value of decision threshold, probability of error decreases. When decision threshold is at 0, probability of bit error is minimum. Now, as we continue to increase decision threshold further, probability of error increases.

Question:

For what value of decision threshold does the simulated bit error probability attain the smallest value?

Simulated bit error probability for BPSK given q=0.3 attains smallest value when decision threshold is at 0.

Exercise-3(c): Effect of changing the decision threshold:

- **Code-**

```
%% vary decision boundary from 0 volts to +5 volts for
OOK given q=0.5
clear vars;
close all;
q=0.5;
N=1000;
Nsim=100;
a=5;
SNR=1:1:10;
pb=1:10;
prob=1:Nsim;
x=binornd(1,q,1,N);
s=(a*(2*x-1)).*x;
SNR_lin=power(10,0.1.*SNR);
sigma=sqrt(a^2./SNR_lin);
for j=0:0.5:5
for k=1:10
    for i=1:Nsim

        n=sigma(k)*randn(1,N);
        r=s+n;
        xcap=double(r>j);
        prob(i)=mean(abs(xcap-x));
```

```
    end
  pb(k)=mean(prob);
end
figure;
semilogy(SNR,pb,'o','markerface','b');
hold on;

ptheoretical=qfunc(a./sigma);
semilogy(SNR,ptheoretical,'linewidth',2);
str =['figure for OOK for value of q ',num2str(q),' and decision boundary  ',num2str(j)];
title(str);

End
```

- **Output:**

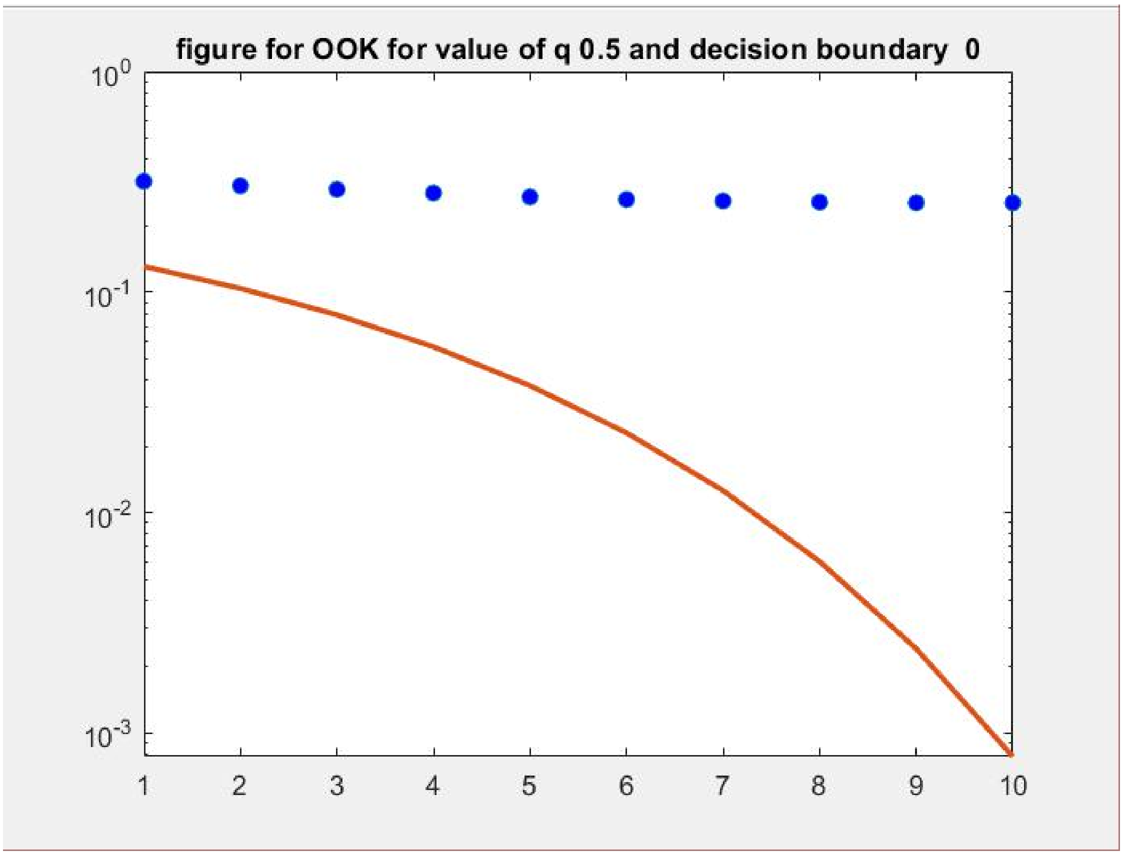


figure for OOK for value of q 0.5 and decision boundary 0
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

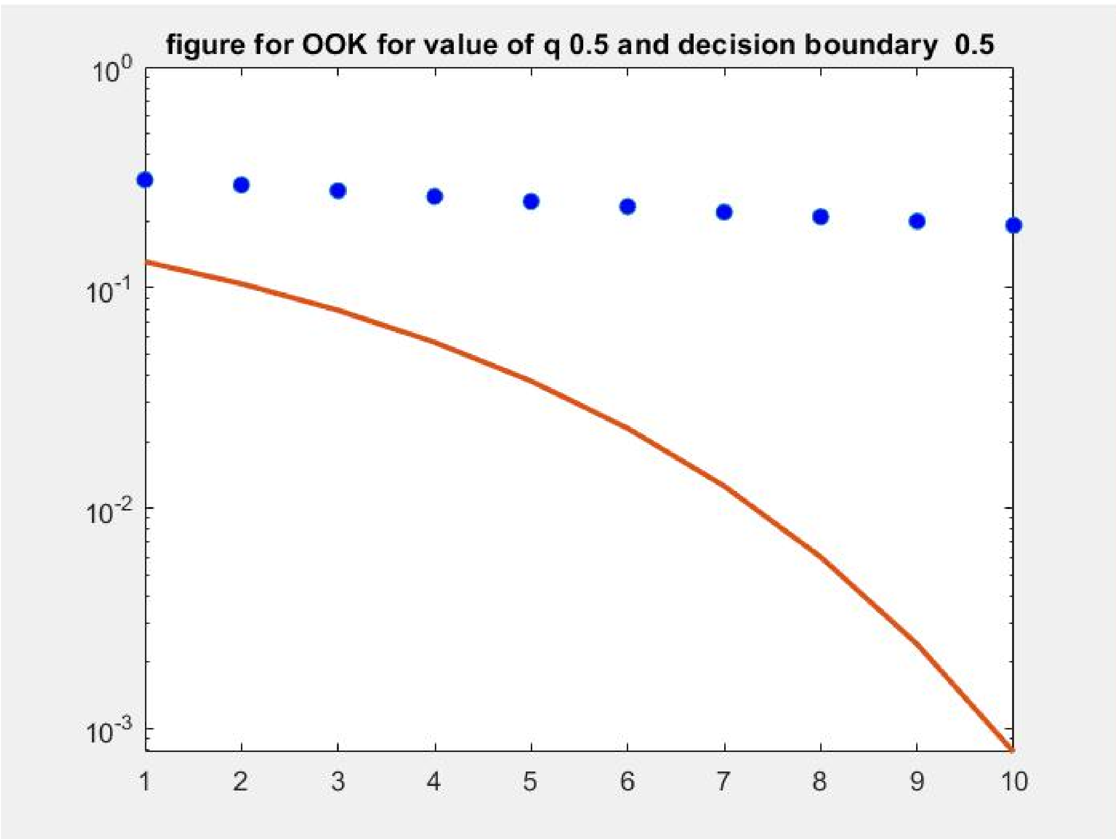


figure for OOK for value of q 0.5 and decision boundary 0.5
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
9
10

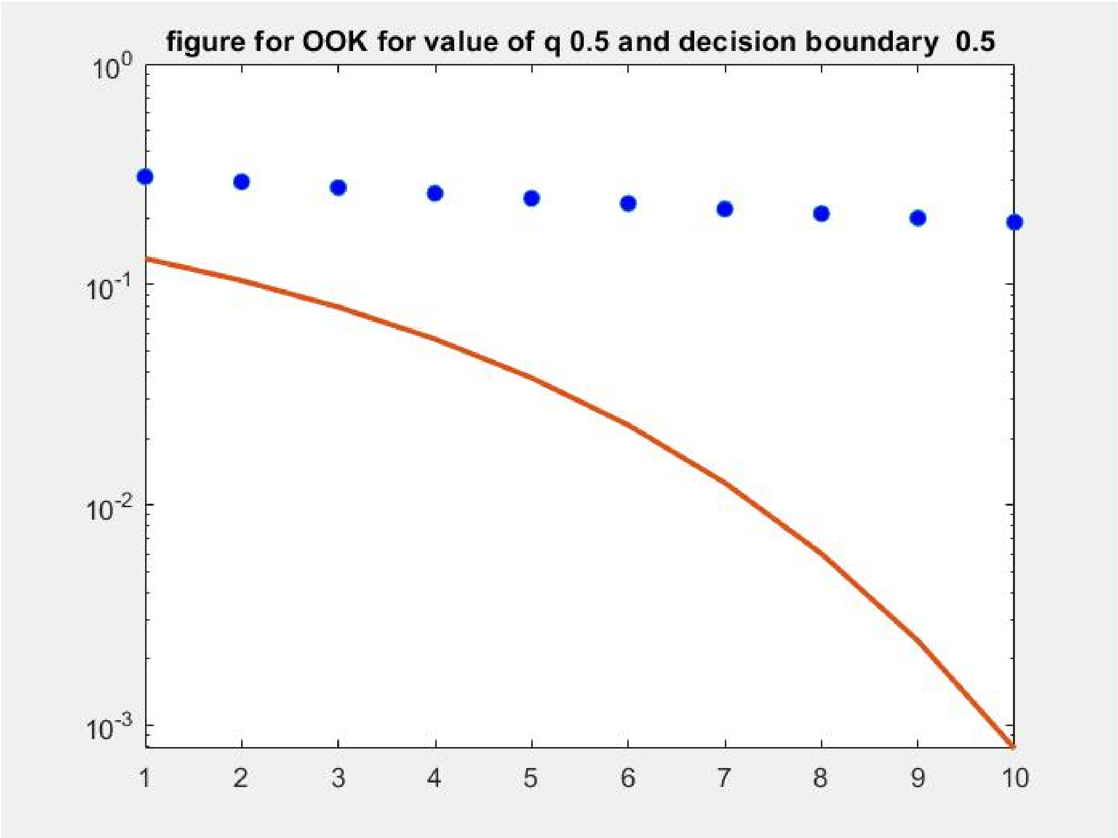


figure for OOK for value of q 0.5 and decision boundary 0.5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

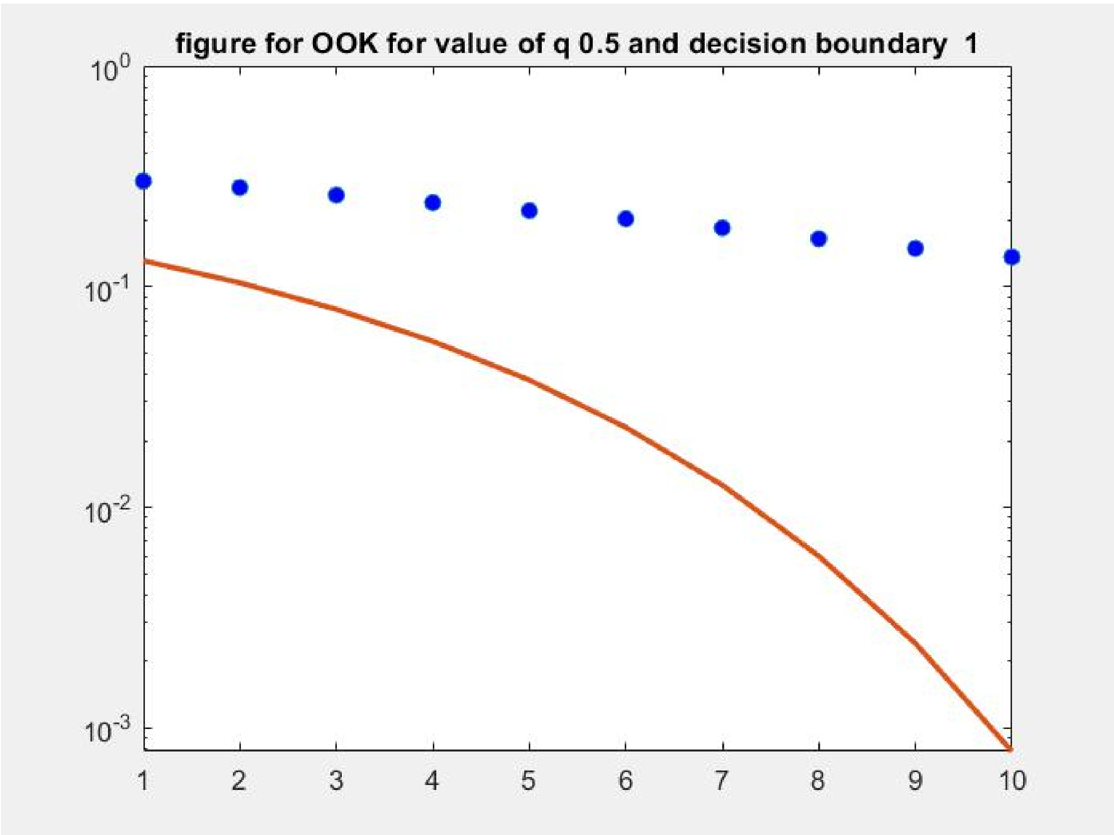


figure for OOK for value of q 0.5 and decision boundary 1
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

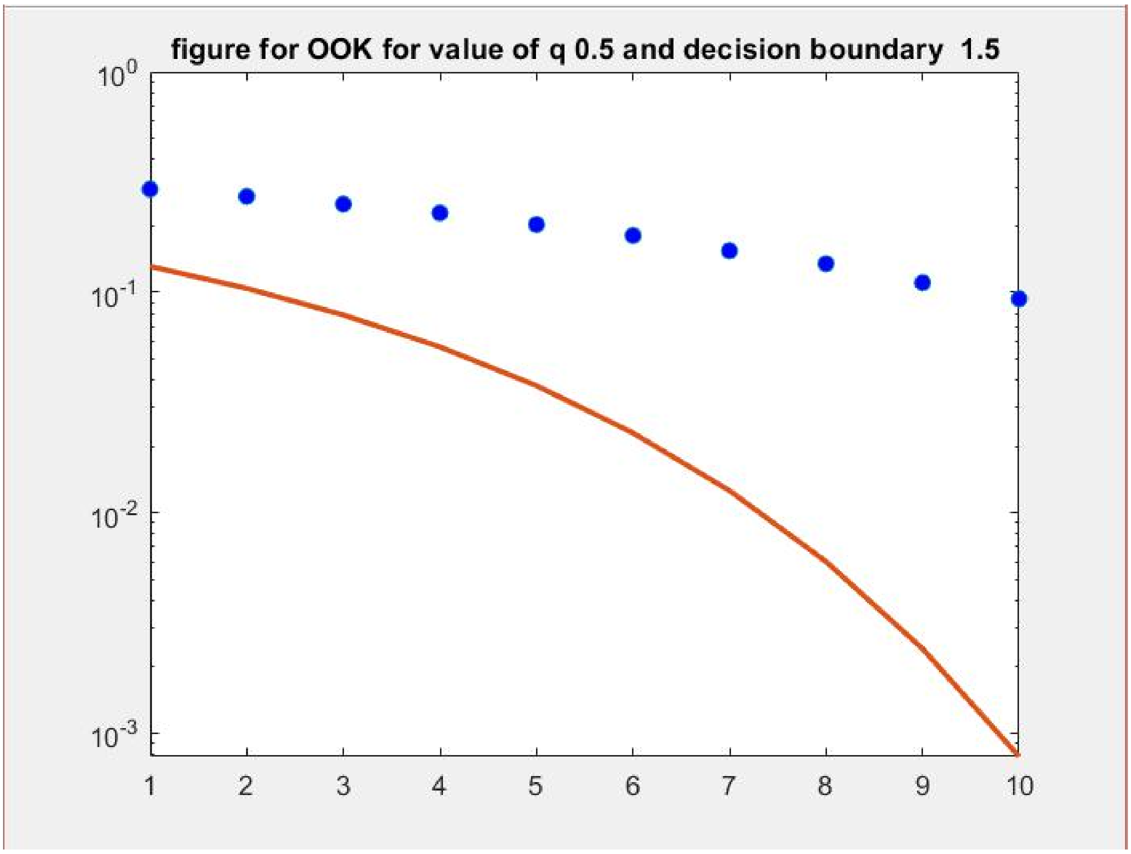


figure for OOK for value of q 0.5 and decision boundary 1.5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

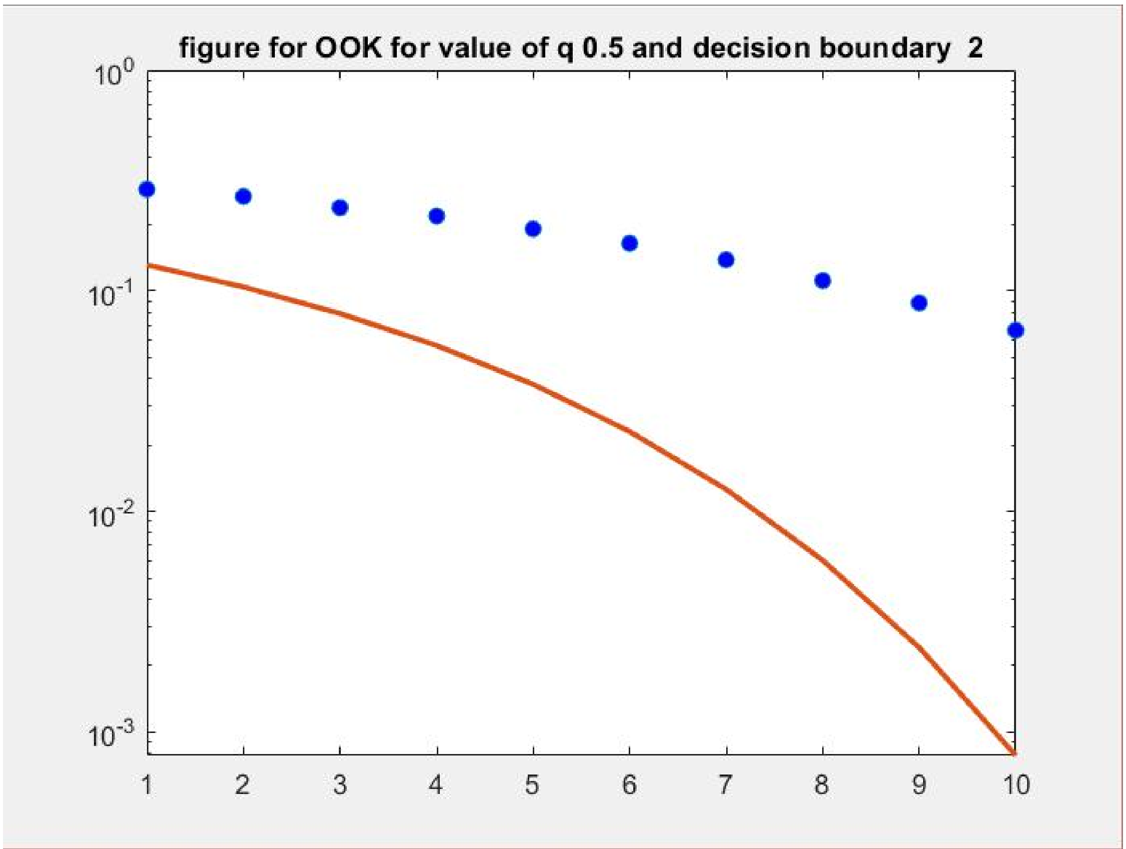


figure for OOK for value of q 0.5 and decision boundary 2
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

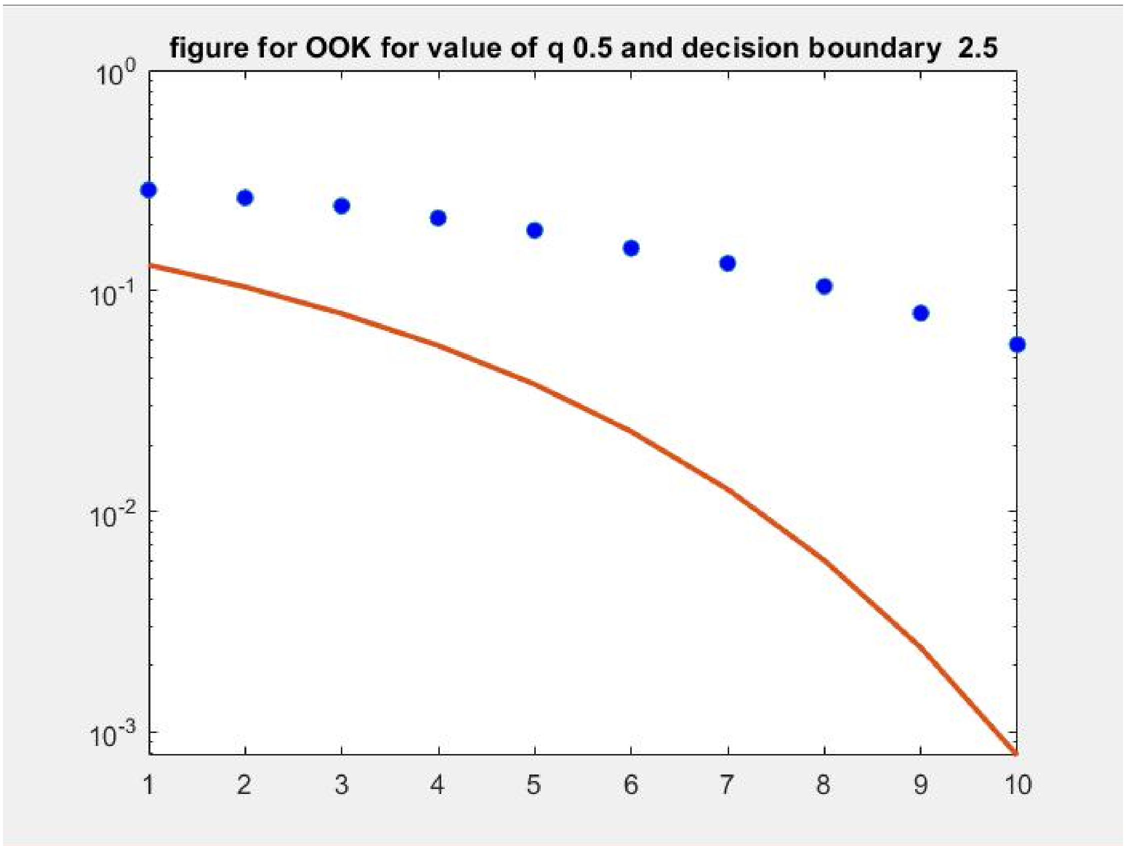


figure for OOK for value of q 0.5 and decision boundary 2.5
10^0
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

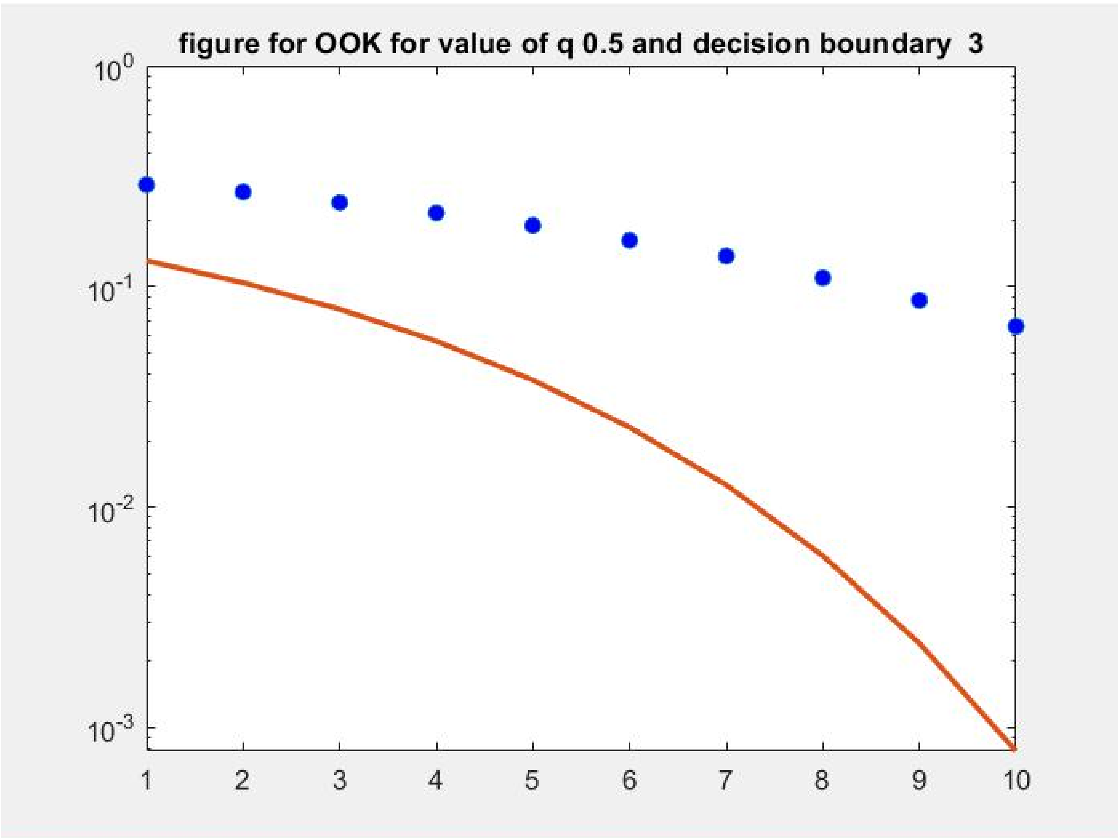


figure for OOK for value of q 0.5 and decision boundary 3
10^0
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

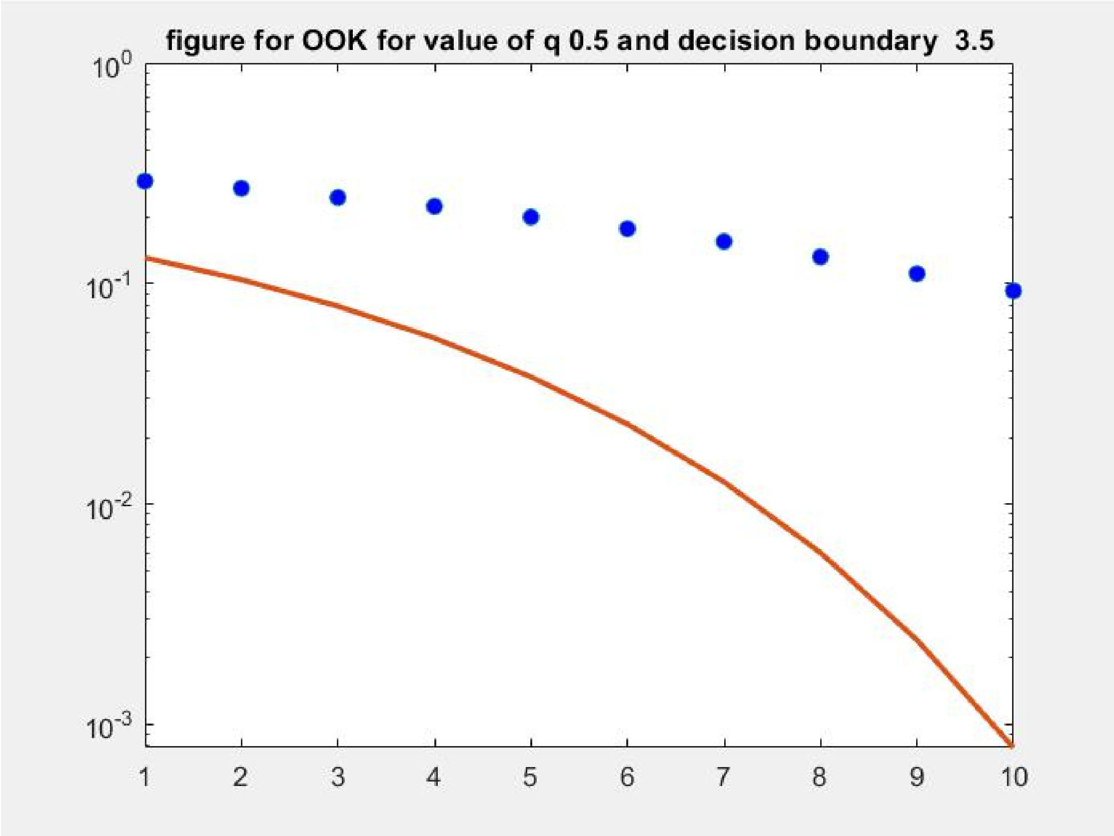


figure for OOK for value of q 0.5 and decision boundary 3.5
10^0
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

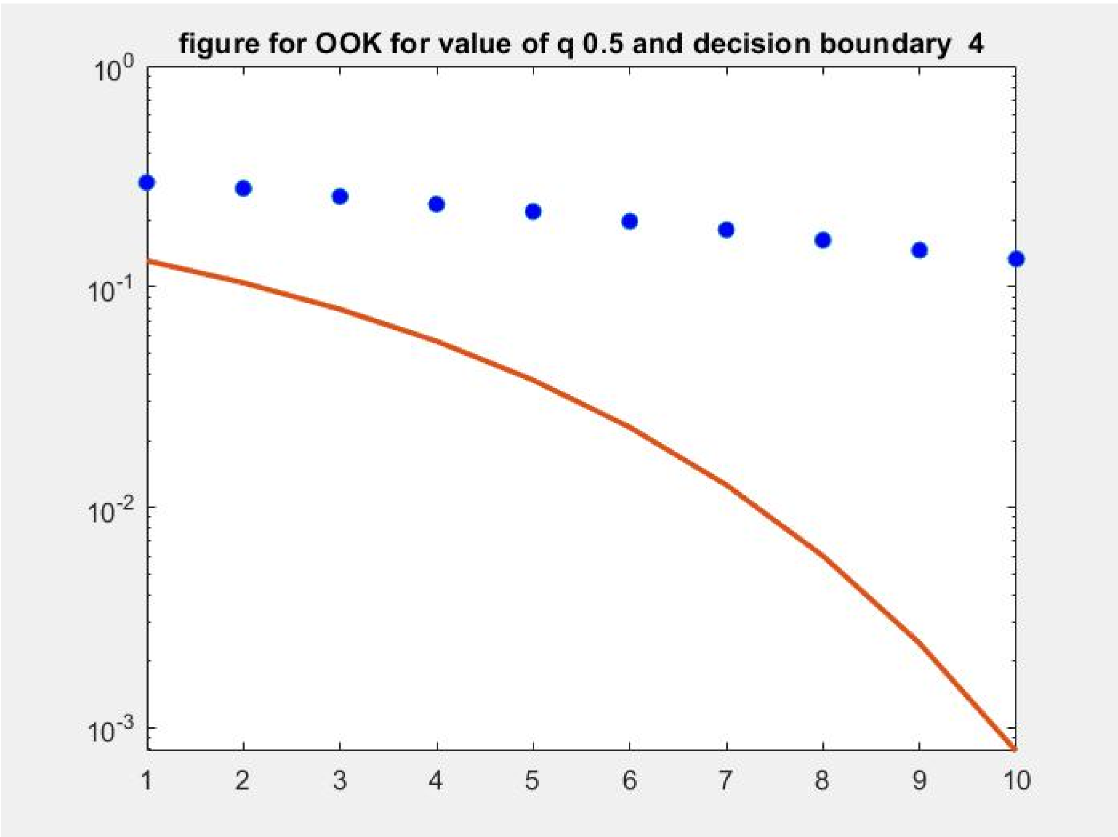


figure for OOK for value of q 0.5 and decision boundary 4
10^0
10^{-1}
10^{-2}
10^{-3}
1 2 3 4 5 6 7 8 9 10

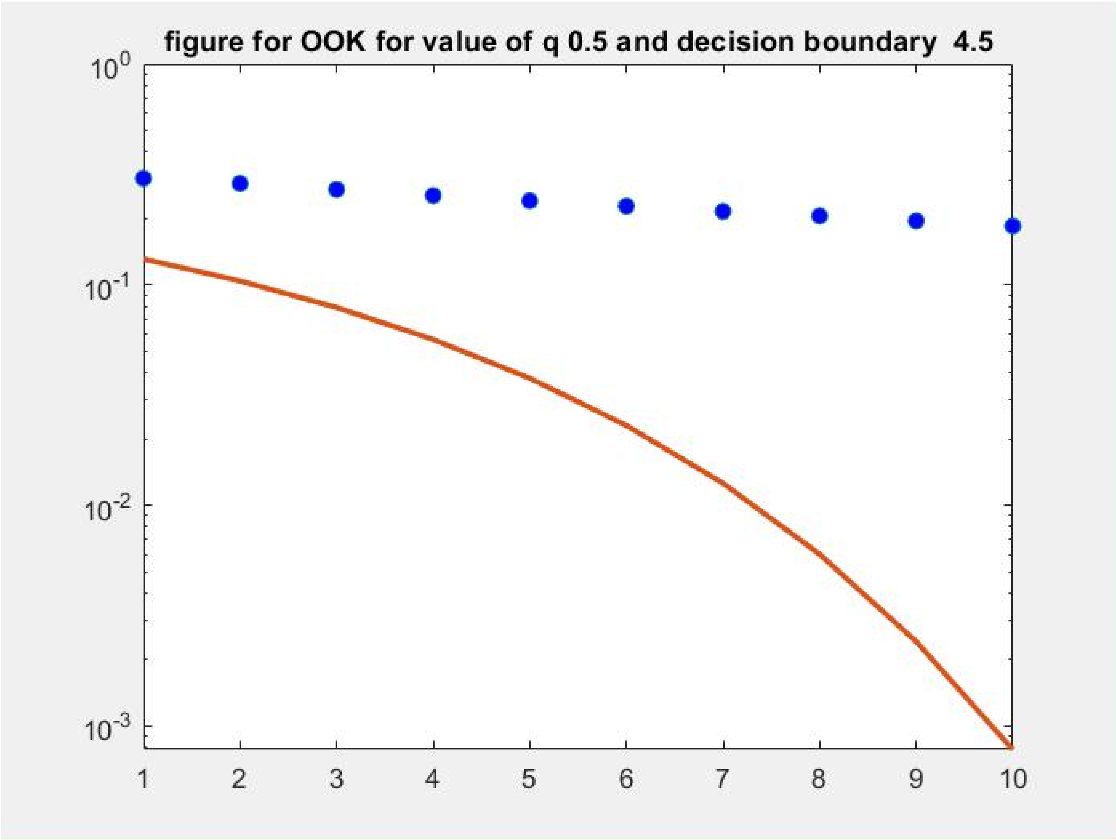


figure for OOK for value of q 0.5 and decision boundary 4.5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

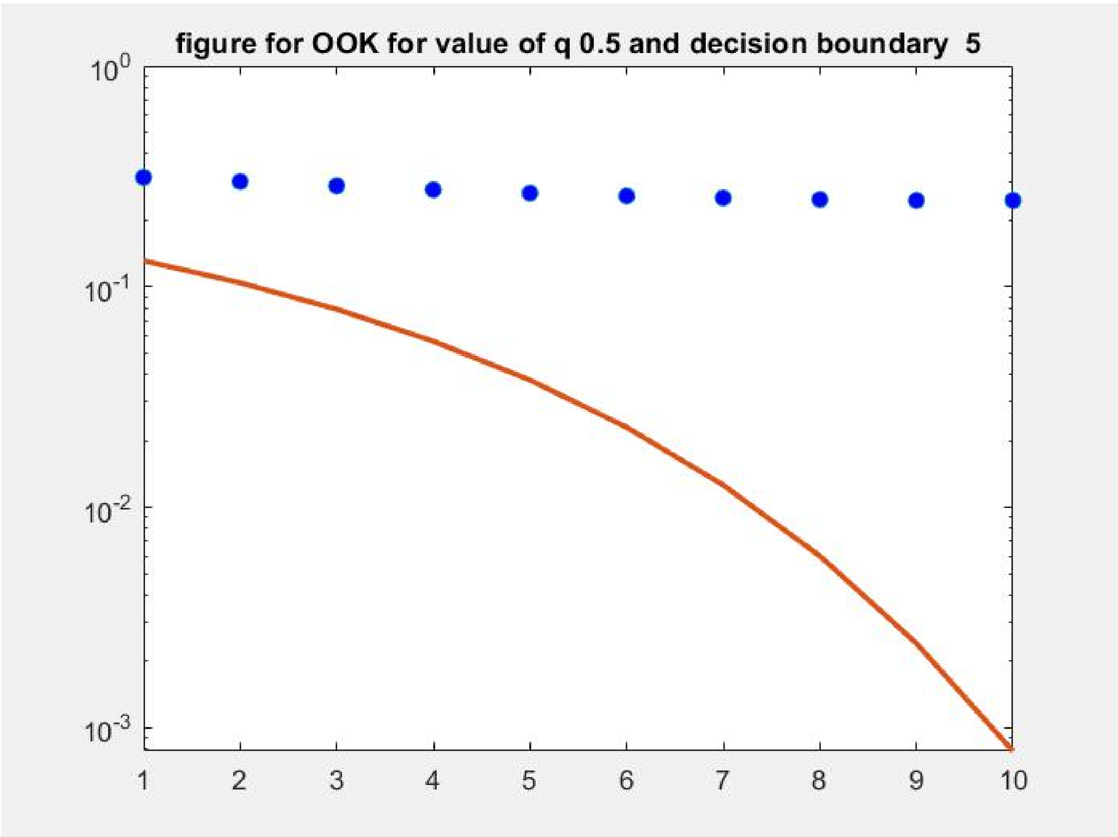


figure for OOK for value of q 0.5 and decision boundary 5
10^0
10^-1
10^-2
10^-3
1
2
3
4
5
6
7
8
9
10

➢ **Inference:**

Here, above given figures show changing probability of error as we change decision threshold for OOK modulation scheme. Initially, decision threshold is at 0. As we increase value of decision threshold, probability of error decreases. When decision threshold is at 2.5, probability of error is minimum. Now, as we continue to increase decision threshold further, probability of error increases.

Question:

For what value of decision threshold does the simulated bit error probability attain the smallest value?

Simulated bit error probability for OOK with q=0.5 attains smallest value when decision threshold is at 2.5.