Department of Electrical and Electronic Engineering

Brac University

EEE 342

Introduction to Communication Laboratory

Final Lab Project

Section: 3

Name of the project: EEE-342 Summer 2021 Project

Submitted by Group No.: 23

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Task-1

Objective:

Task-1's main objective is to design a communication link in Simulink using operational blocks.The communication link must fullfill a certain set of parameters such as:

Required signal to noise ratio (SNR) at the demodulated audio output of the receiver: 40 dB for a 1 kHz message signal at 50% modulation (m = 0.5).

▪ Carrier frequency: 1.35 MHz
▪ Maximum RF bandwidth available 9 kHz
▪ Channel noise power spectral density = -150dBm/Hz

Then whilst keeping these parameters satisfied in the communication link we were expected to answer a few questions.

Methodology:

The first step in this task was to decide which type of modulator is to be used.We went with DSB-AM-WC modulator as in one of the questions carrier power was asked to be determined. This determination of carrier power would have been impossible with DSB-AM-SC and SSB-AM-SC modulators as their modulated signal does not have any carrier component in the f-domain.

The designing of DSB-AM-WC modulator was done using the equation:

$$s(t)=Ac(1+u*m(t))\cos(2\pi fct)$$

Where

Ac= Carrier amplitude

f c= Carrier frequency

m(t)= Message signal (taken as $\cos(2\pi fmt)$

u= Modulation index ($\frac{Am}{Ac}$: as we are single tone message signal)

s(t)= Modulated Signal

Then for introducing the appropriate noise we used the Band-Limited White Noise Block. This is the only noise block we found for which the noise power could be set directly.

We used a synchronous demodulator in the demodulation stage. Care was taken to ensure that the synchronous signal and the carrier signal have the same parameters.

To calculate SNR we first needed to calculate the signal power and noise power. This was done using by feeding the signal and noise to a RMS block and then squaring it individually. This is because we know that power = $(\text{RMS})^2$
Later, the signal-to-noise ratio was found using a division block.
Lastly a dB converter(o/p=10log10(i/p)) block was used to calculate the SNR.

Basic Implementation in accordance with the given parameters:

Diagram of Circuit:

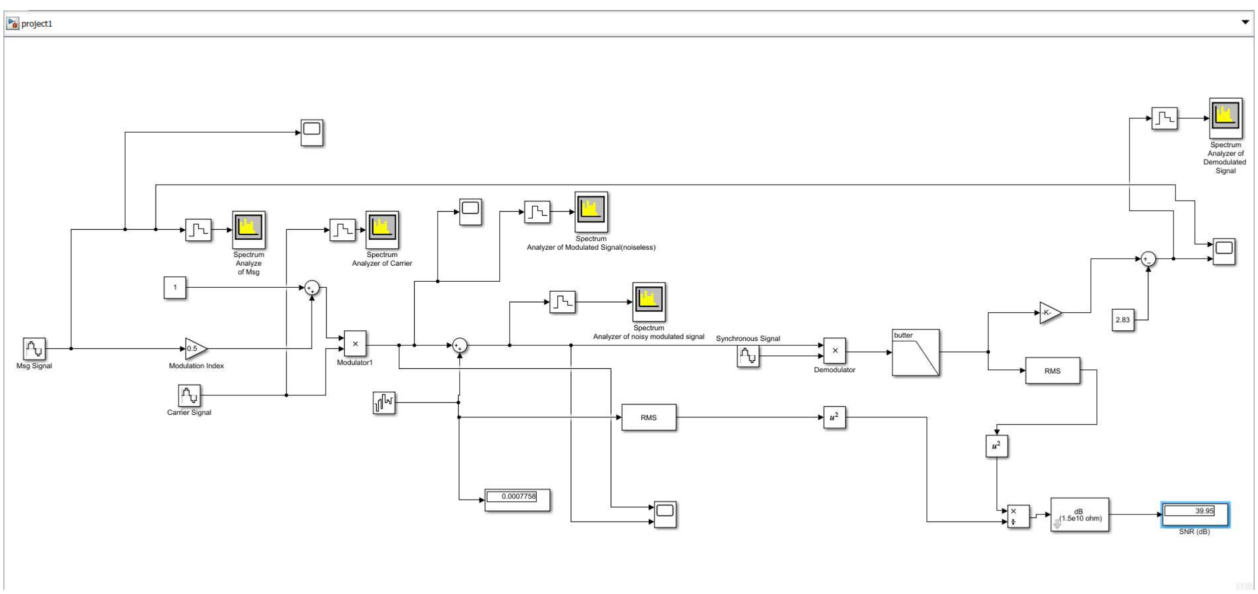


Fig.1

Comment: Notice that the SNR is 39.95dB.

Parameters:

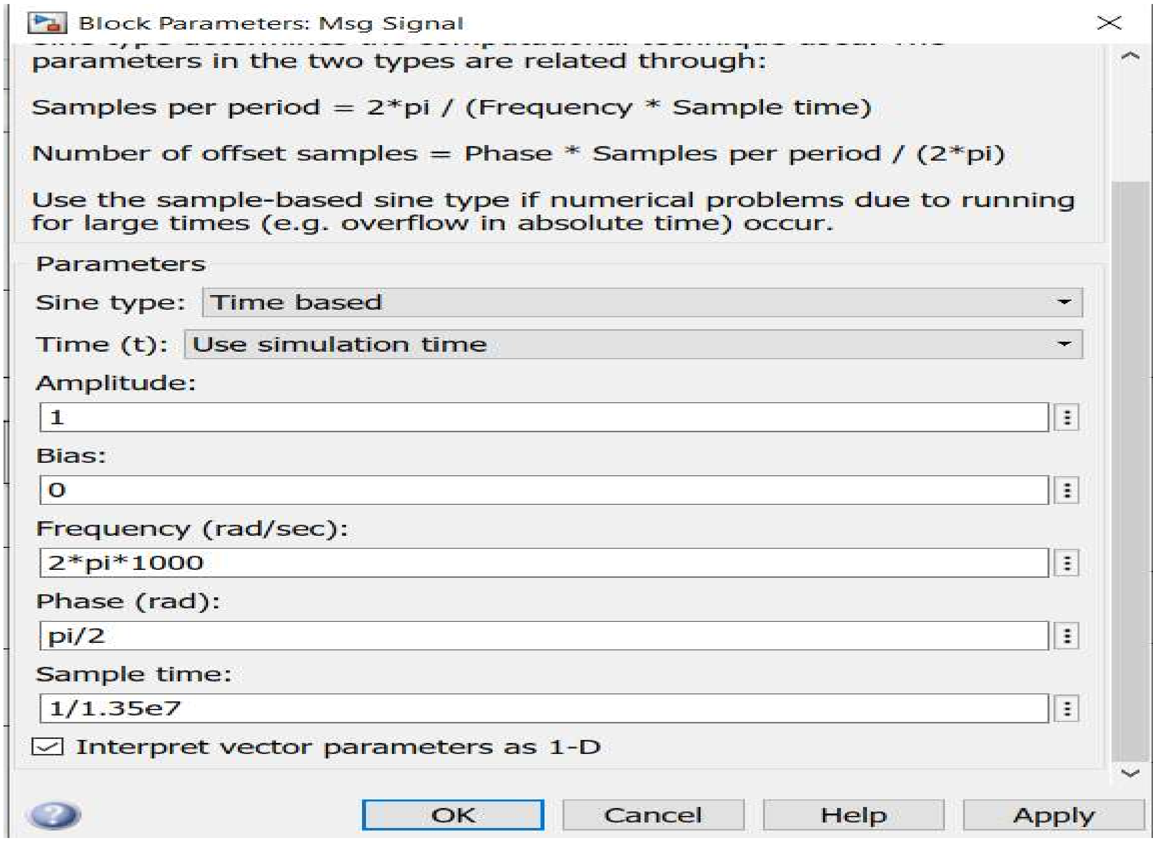


Fig.2

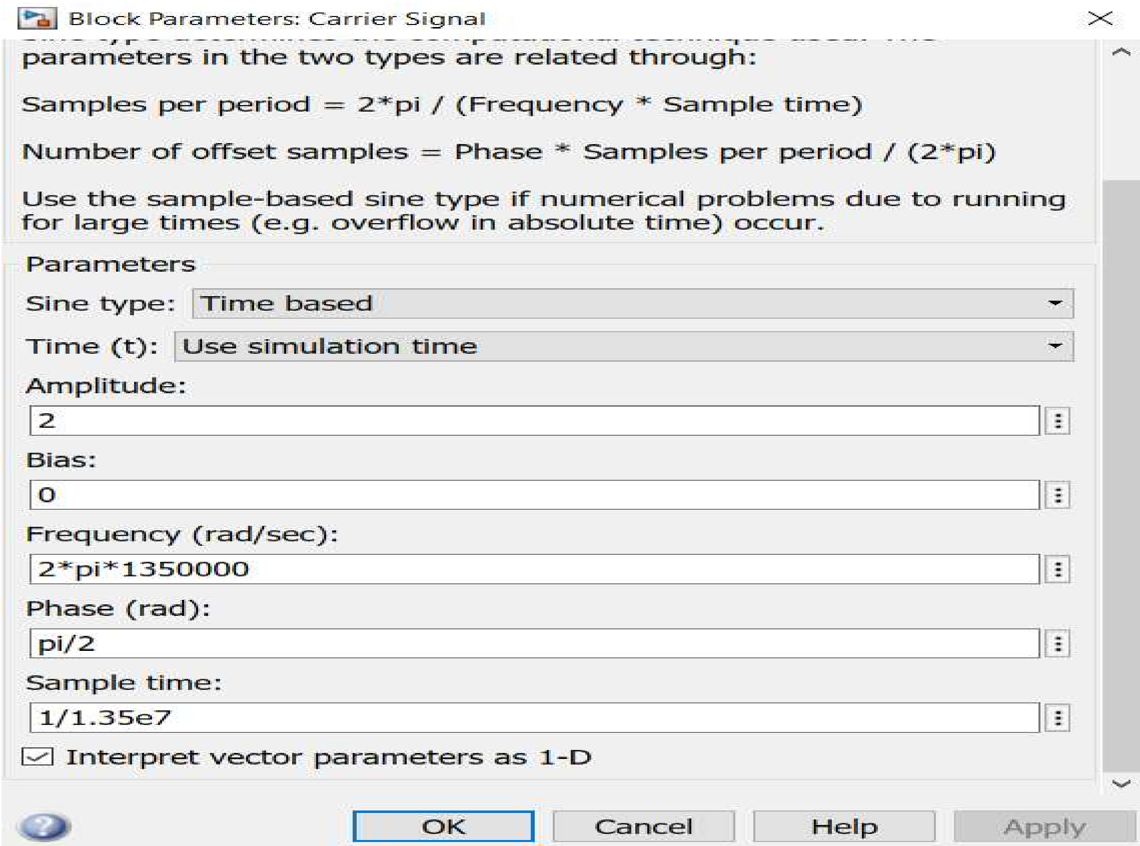

Block Parameters: Carrier Signal
parameters in the two types are related through:
Samples per period = 2*pi / (Frequency * Sample time)
Number of offset samples = Phase * Samples per period / (2*pi)
Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.
Parameters
Sine type: Time based
Time (t): Use simulation time
Amplitude:
2
Bias:
0
Frequency (rad/sec):
2*pi*1350000
Phase (rad):
pi/2
Sample time:
1/1.35e7
Interpret vector parameters as 1-D
OK
Cancel
Help
Apply

Fig.3

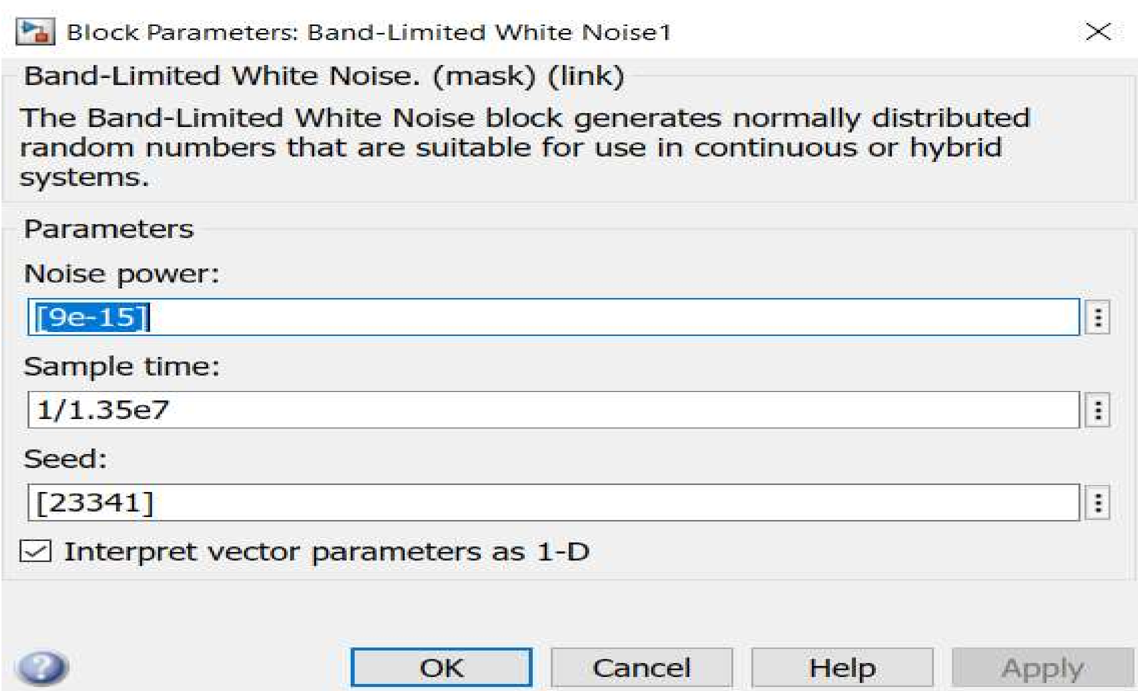

Block Parameters: Band-Limited White Noise1
Band-Limited White Noise. (mask) (link)
The Band-Limited White Noise block generates normally distributed random numbers that are suitable for use in continuous or hybrid systems.
Parameters
Noise power:
[9e-15]
Sample time:
1/1.35e7
Seed:
[23341]
Interpret vector parameters as 1-D
OK
Cancel
Help
Apply

Fig.4

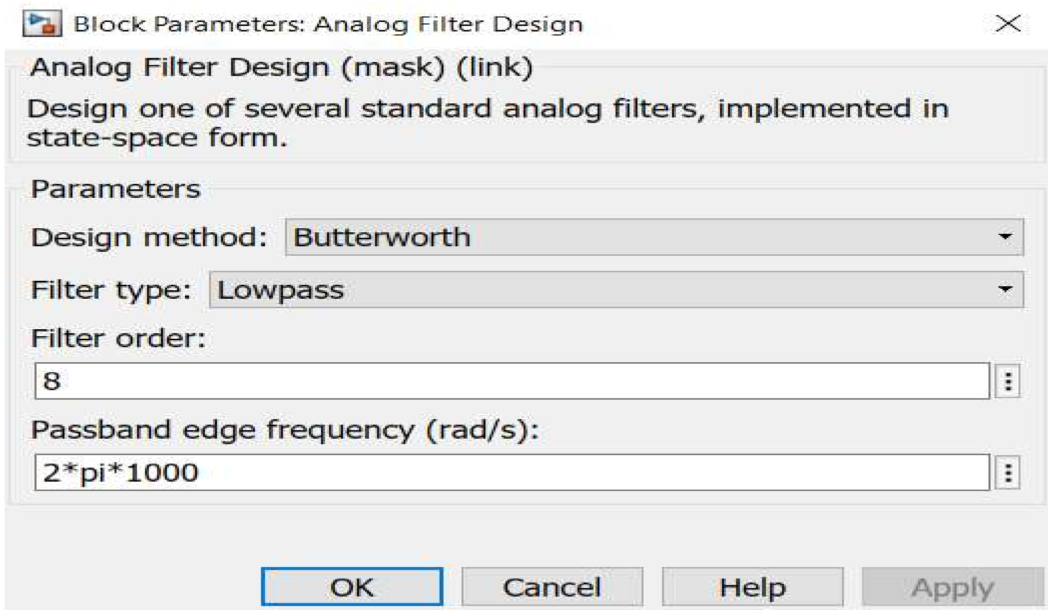


Fig.5

Calculation:

In this section we will state the logic behind the parameters of few of the blocks.

- **Message and Carrier Signal:**
  The fc=1.35Mhz and fm=1kHz has been specified by the question parameters.
  So the sampling time for both was taken as $1/1.35 \times 10^{7}$ s, This sampling period will ensure 10 samples for each carrier wave and 13500 samples for each message wave.
  Also this sampling period maintains Nyquist theorom,which states that the sampling frequency(fs=$1.35 \times 10^{7} Hz$) must be greater than the signal's frequency (fc=1.35Mhz and and fm=1kHz)
  Lastly we set the message's amplitude (Am) to 1 and carrier's amplitude (Ac) to 2 to get the modulation index(u) of 0.5
- **Band-Limited White Noise**
  dBm=dBm/Hz + 10log10(B.W)
  where BW=9kHz and dBm/Hz=-150
  dBm=-150+10log10(9000)
  dBm=-110.46
  Where dBm=10log10($\frac{P}{0.001}$)

$-110.46 = 10\log10(\frac{P}{0.001})$

$P = 9 \times 10^{-15} W$

This P is noise power

Sample Time is $1/1.35 \times 10^{7}$

- **Analog Filter**

  Has to be a lowpass filter with a cutoff frequency at 1000Hz.So that only message component can pass through.

Graphs:

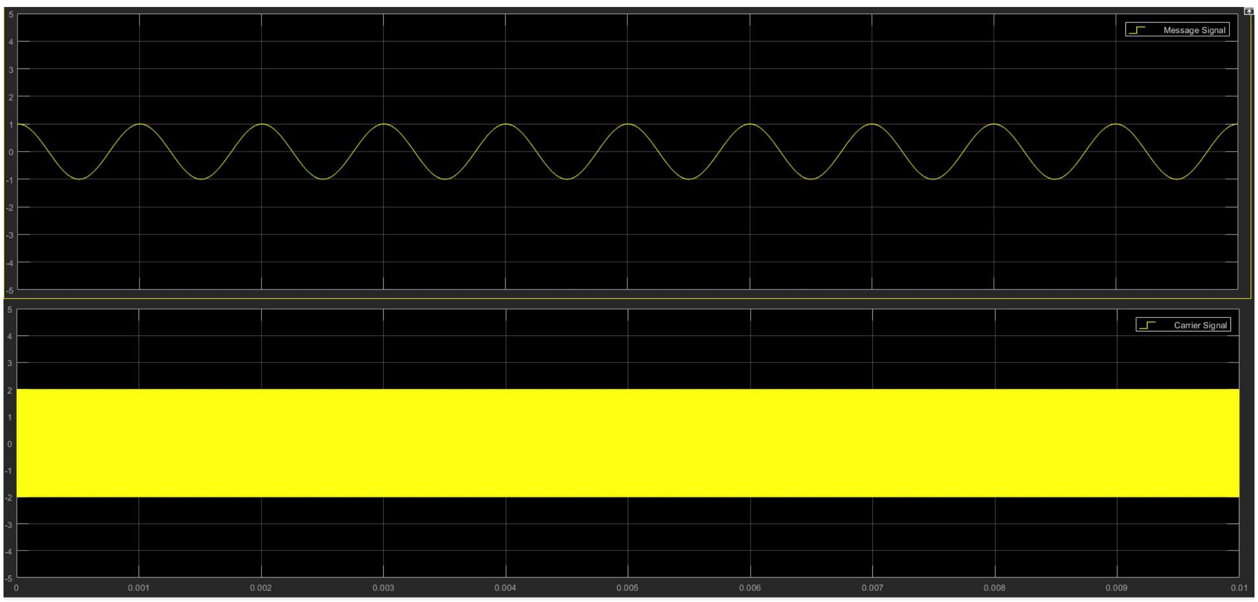


Fig.6

Message(Top Graph) and Carrier Signal(Bottom Graph) in Time Domain

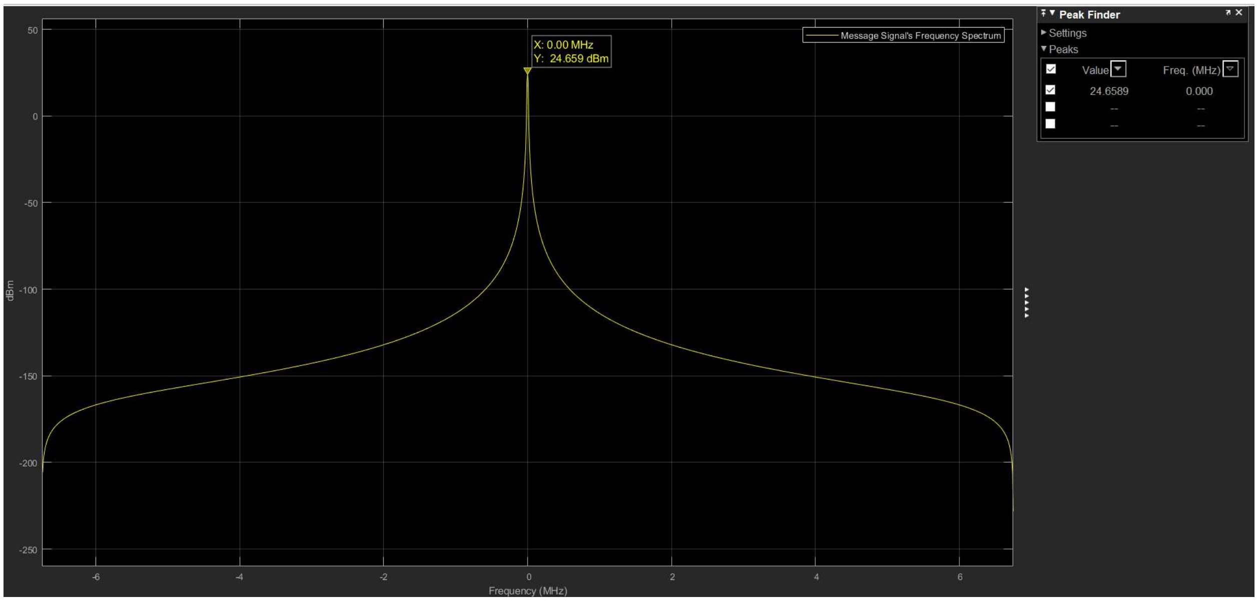


Fig.7

Message Signal In Frequency Domain

Comments: Peak is at 0.00Mhz and Power at peak is 24.659dBm

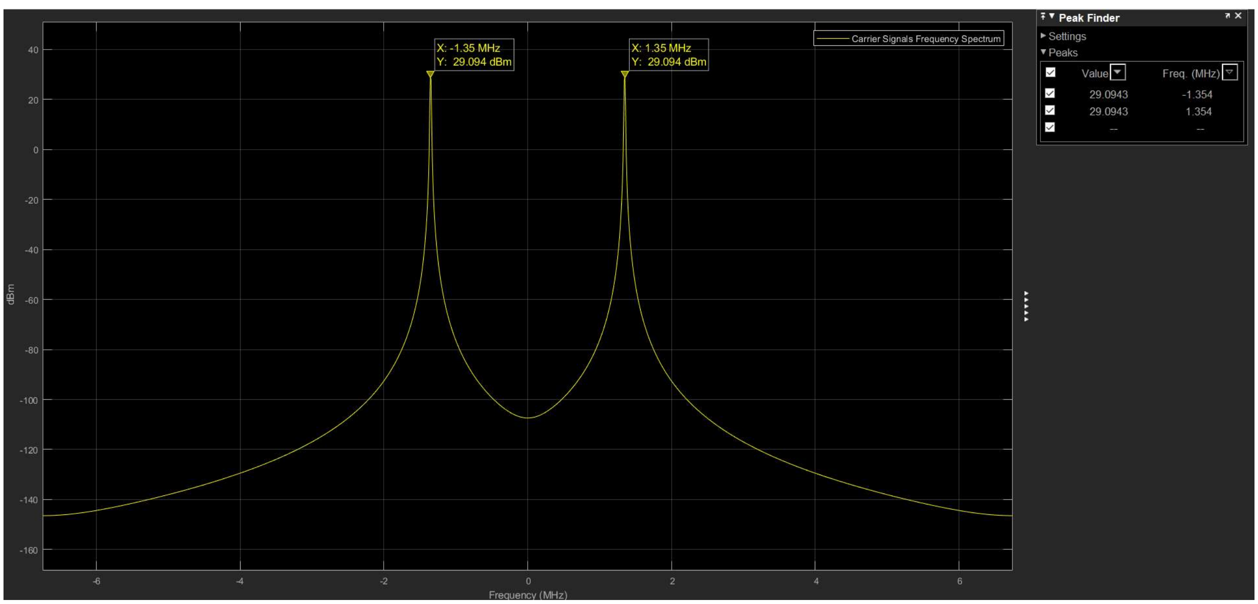


Fig.8

Carrier Signal in Frequency Domain

Comments:Peak is at 1.35Mhz and -1.35Mhz and Power at peak is 29.094dBm.This two peaks are expected because if you take the fourier transform of a cosine wave then there will be two peaks.

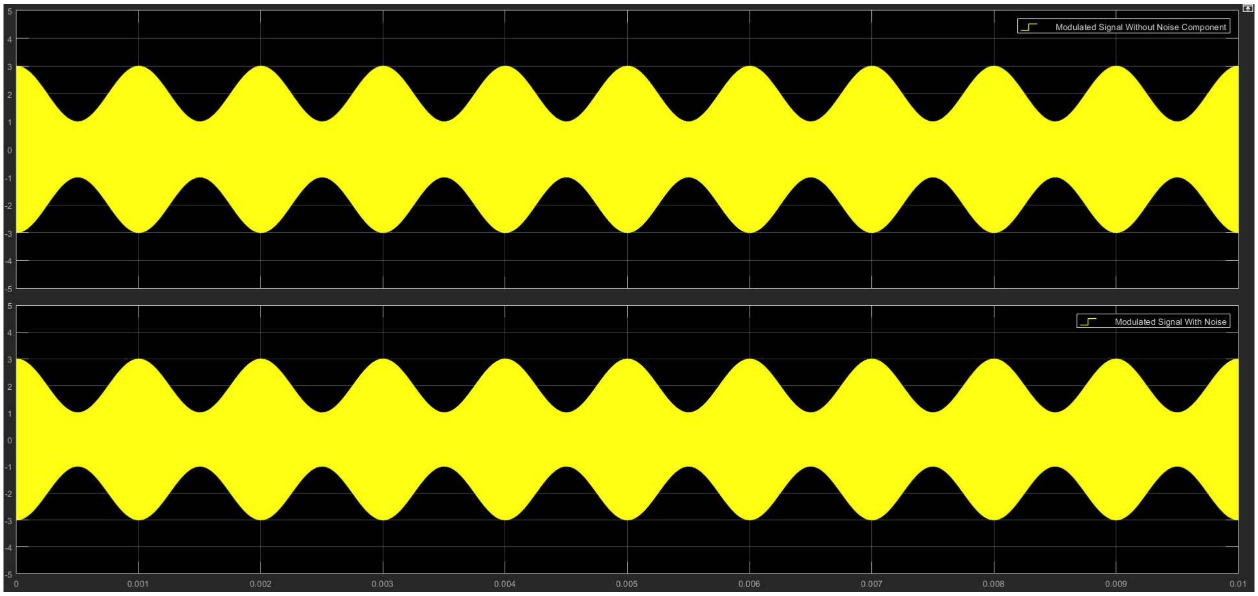


Fig.9

Modulated Signal without noise(top) and with noise(bottom)

Comments: The general shape of both the graphs show that indeed the modulation index $(u) = 0.5$ .There is very little effect of the noise on the modulated signal in the time-domain as the noise power(-110.46dBm/$9 \times 10^{-15} W$) is so small in terms of the power of the modulated signal (31.177dBm/1.31W). However, the effect of noise can be seen in the frequency domain.This is expected as the main advantage of the f-spectrum is that it shows all the components of a signal no matter how small they might be relative to one another.

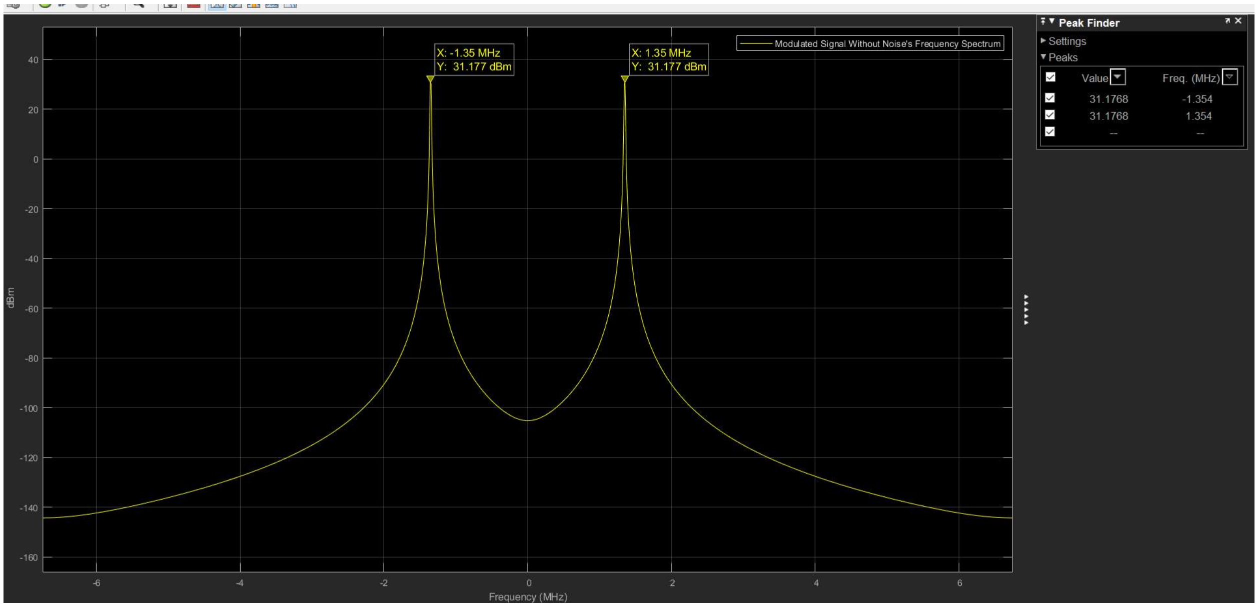


Fig.10

Modulated Signal without noise in the frequency spectrum

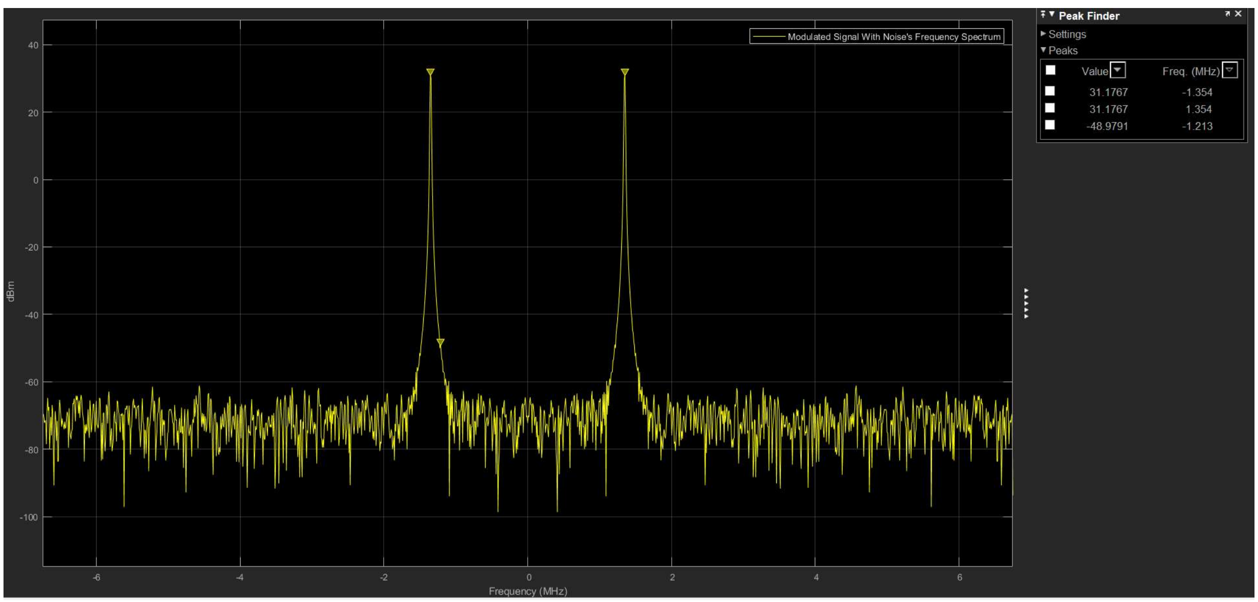


Fig.11

Modulated Signal with noise in the frequency spectrum

Comments: The effect of noise on the modulated signal can be seen on the f-spectrum very clearly even though it was indistinguishable on the time domain.

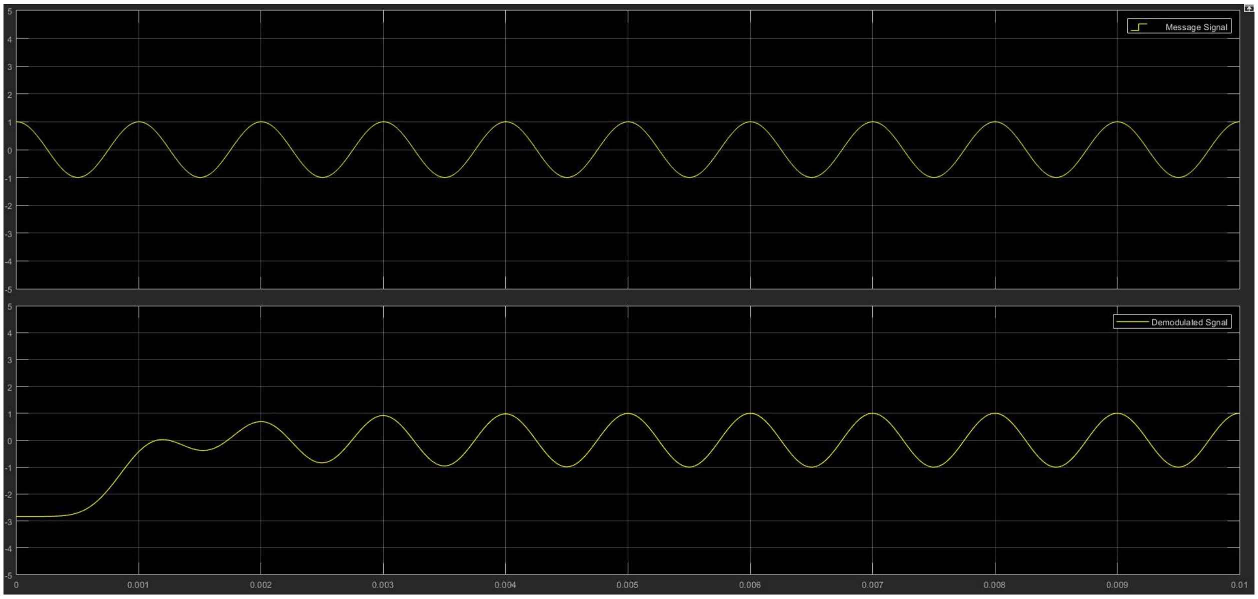


Fig.12

Message Signal and Demodulated Signal in time domain

Comments: The message signal and the demodulated signal become identical after approximately 0.003s.This slight delay can be associated with the fact that it takes some time for the message signal(eventual demodulated signal) to pass through the simulink components.

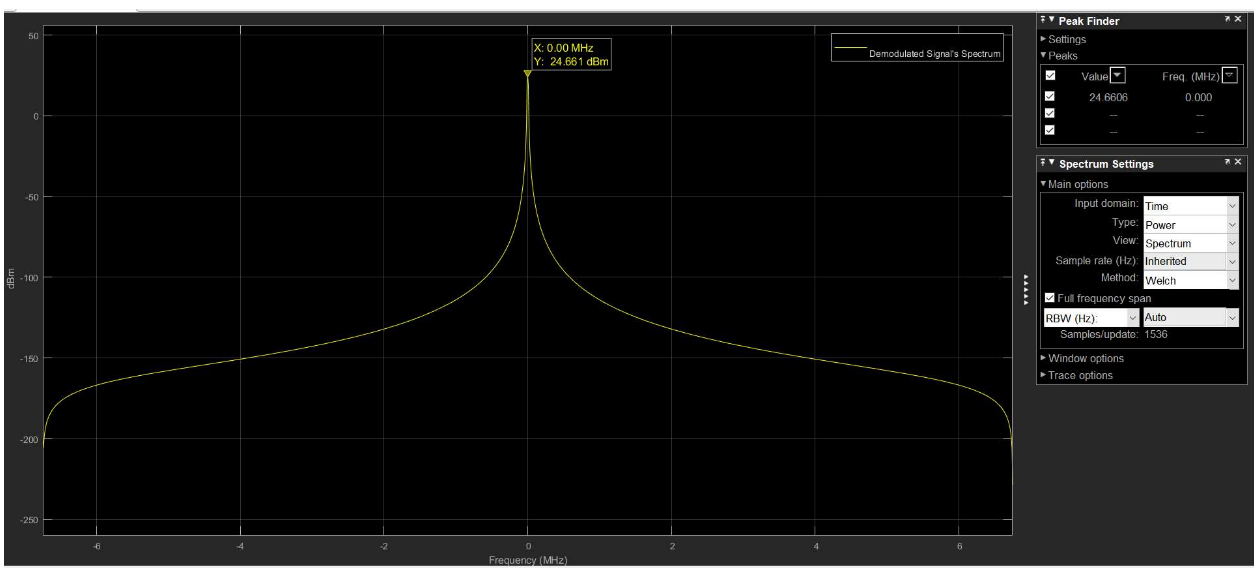


Fig.13

Demodulated Signal in Frequency Domain

Comments: As we can see the demodulated signal in the f-domain is centered at 0Hz and has a peak of 24.661dBm which is very similar to our message signal's f-spectrum (centered at 0hz and peak of 24.659dBm)

Questions and Answers:

Question-1:

Ans: The maximum RF Bandwidth (Channel) is 9kHz and we are using a DSB-AM modulator in our communication link. Thus the modulated signal in the f-domain will have a bandwidth of $2 \times$ message frequency(fm)

We know for proper transmission, the modulated signal's bandwidth(2fm) must be smaller or equal to the channel's bandwidth (9kHz).

So we can say that the maximum frequency of the message signal is 4.5kHz

2fm=9kHz

fm=4.5kHz, where fm is message frequency.

Question-2:

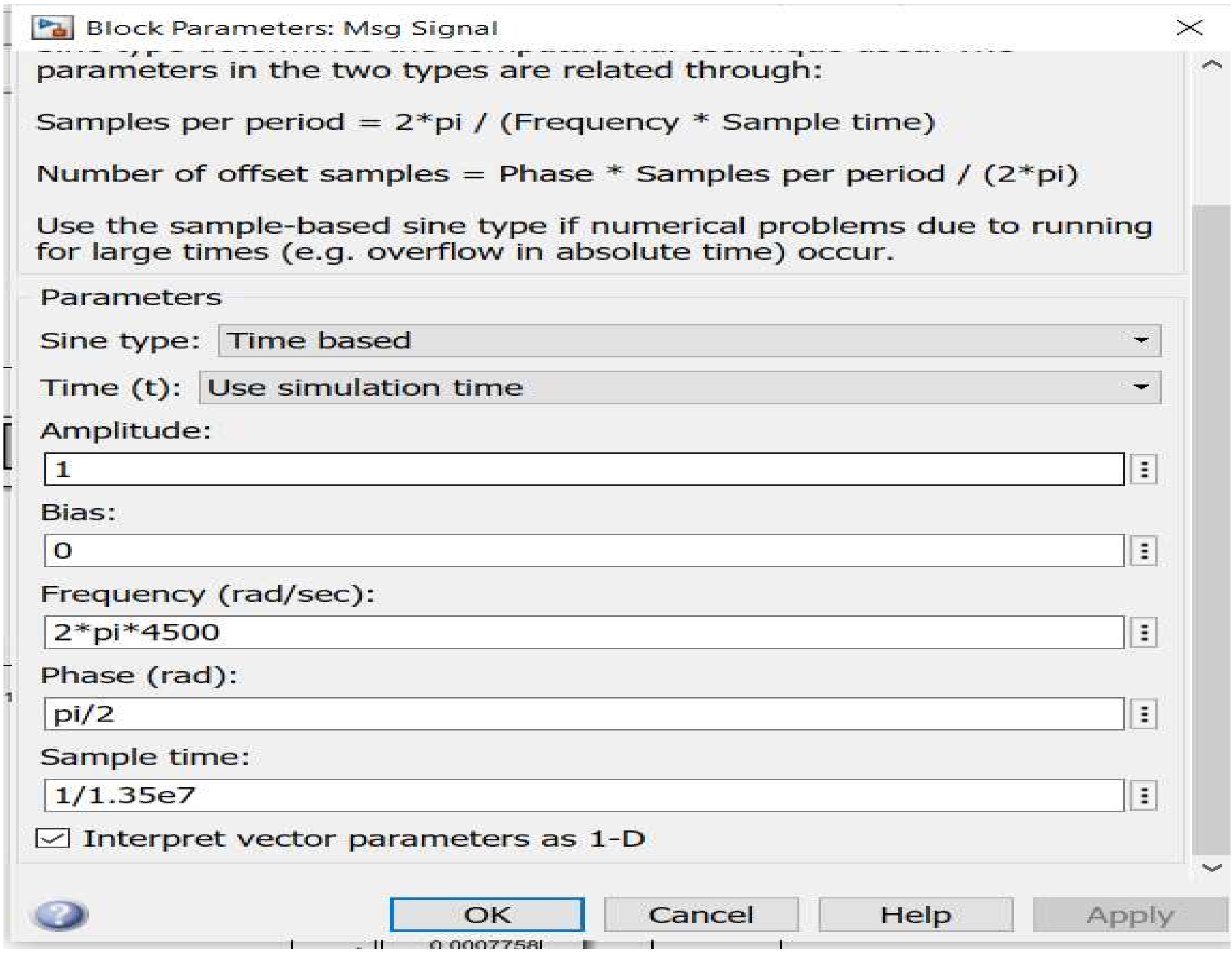


Fig.14

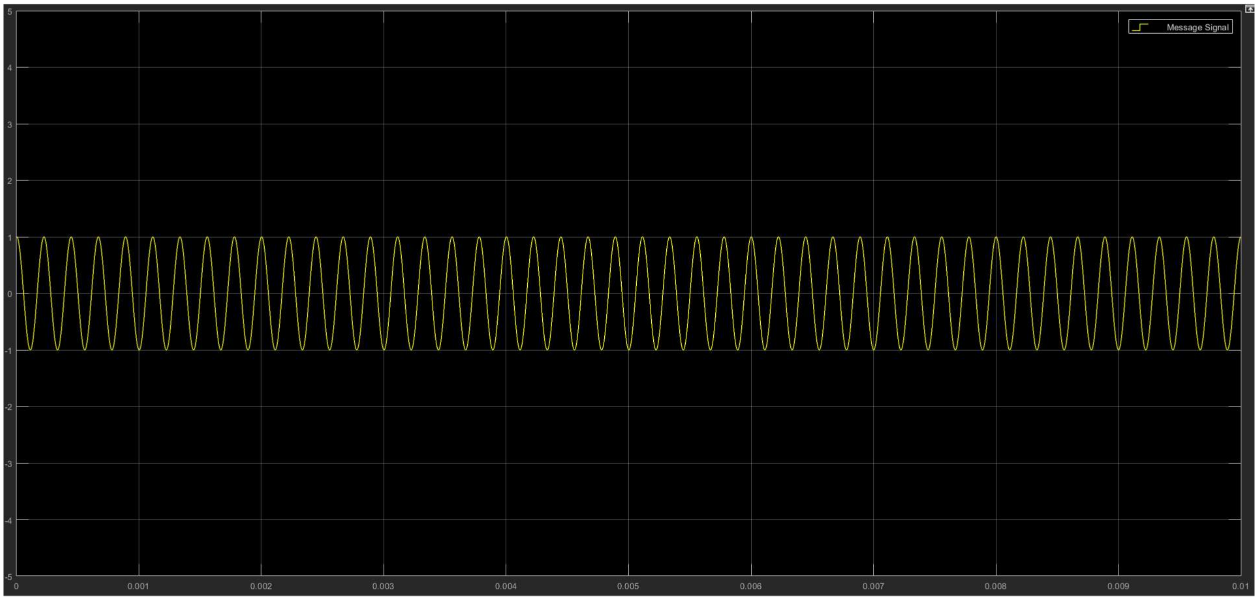


Fig.15

Message Signal at 4.5kHz in time domain

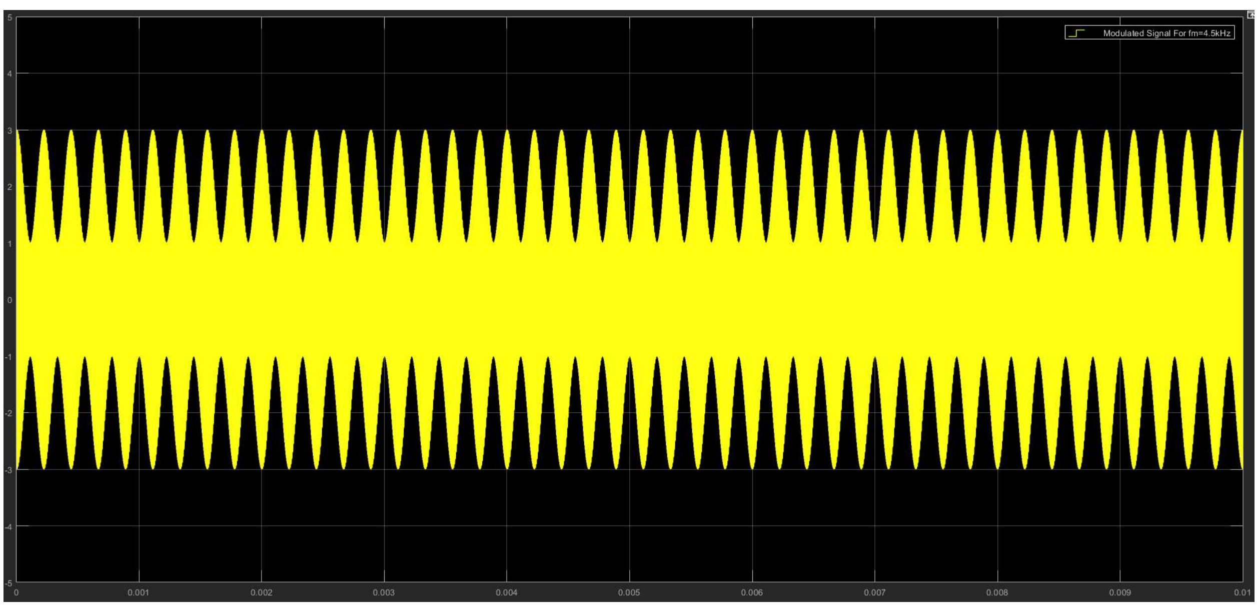


Fig.16

Modulated Signal when fm= 4.5kHz in time domain

Comment: It is worth noticing that the modulated signal still has a modulation index (u) of 0.5.

This is expected as the modulation index is amplitude-dependent and not frequency dependent.

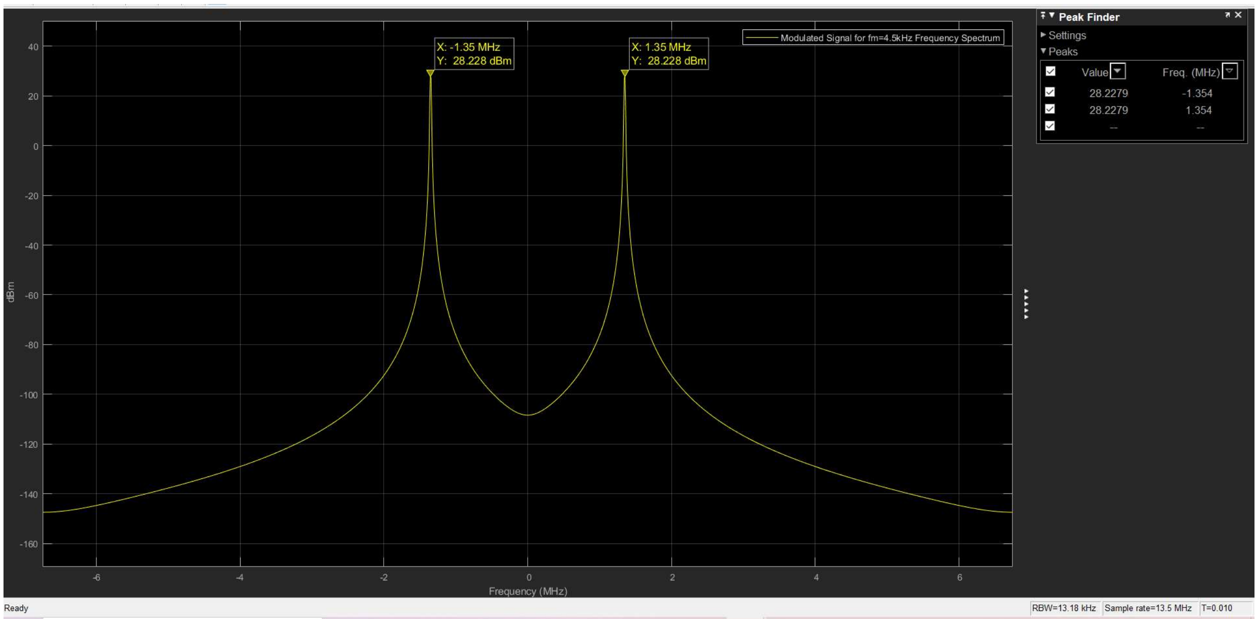


Fig.17

Modulated Signal when fm= 4.5kHz in frequency domain

Comments: Peaks at 1.35MHz and -1.35MHz and value of 28.228dBm

<u>Question-3:</u>

To answer this question we will show both the theoretical value and the experimental value.

First, let us see the carrier power.

Theoretical Value:

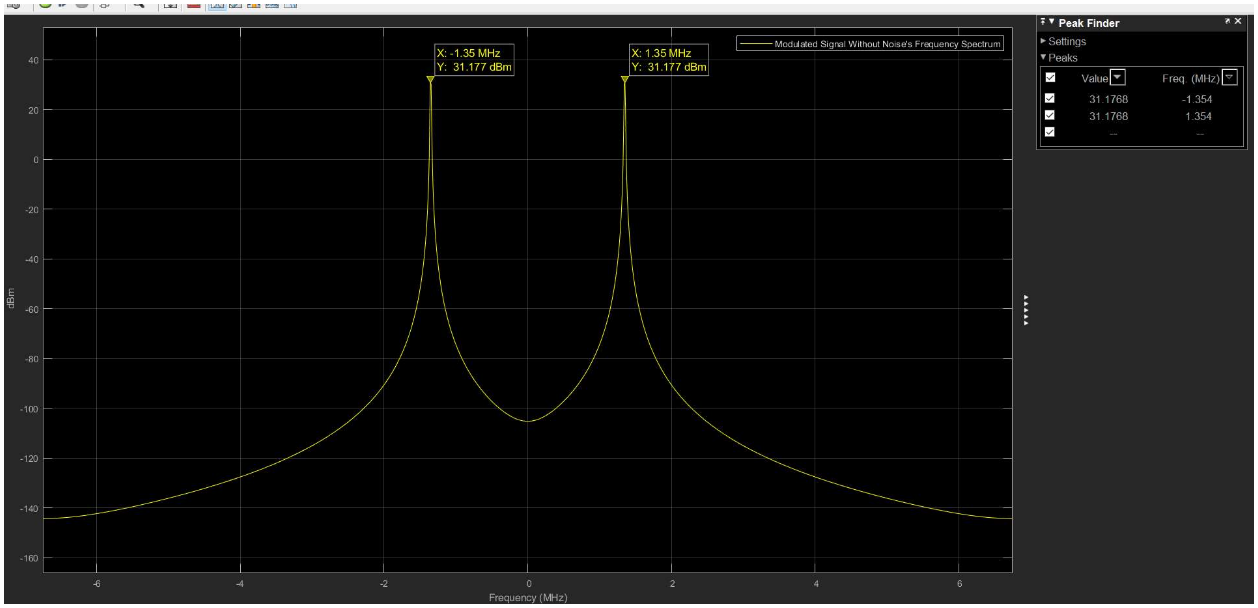
We know that the carrier power (Pc) is given by the following equation:

Pc= $\frac{Ac^2}{2}$, where Ac is carrier amplitude.

So Pc= $\frac{2^2}{2}$ =2W

Pc=33dBm (Theoretical Value)

Experimental Value:



Pc=31.1768dBm **(experimental value)** as read from the graph. We can clearly see that the carrier component of the modulated signal in the f-domain has a peak of value 31.1768dBm at 1.35MHz and -1.35Mhz

Owing to the inaccuracies of the blocks involved, especially the spectrum analyzer, there is a slight difference between the theoretical and experimental values.

Now let us see the sideband power.

Theoretical:

We know that the individual sideband power (Pusb/Plsb) is given by the following equation:

Pusb/lsb= $\frac{uAc^2}{8}$, where Ac is carrier amplitude and u is the modulation index.

So Pusb/lsb= $\frac{0.5*2^2}{8}$ = 0.25W

Pusb/lsb=23.98dBm **(Theoretical Value)**

Experimental:

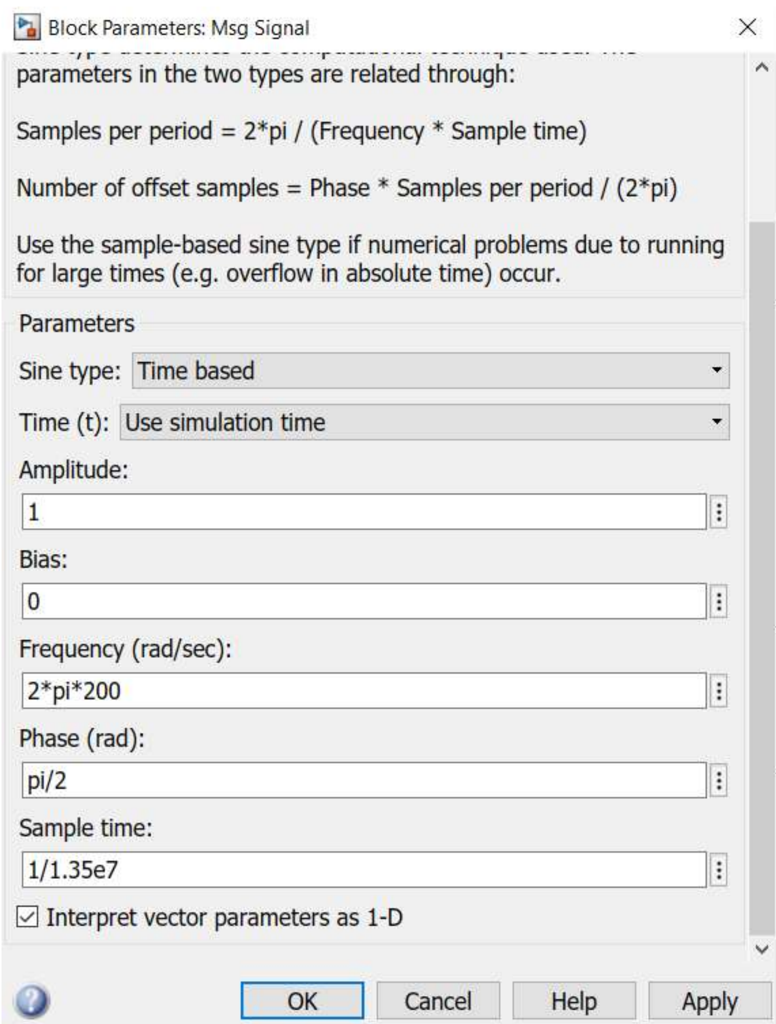
Now here lies which was created due to the problem statement itself. Since our fc=1.35Mhz is so much larger than our fm=1kHz,

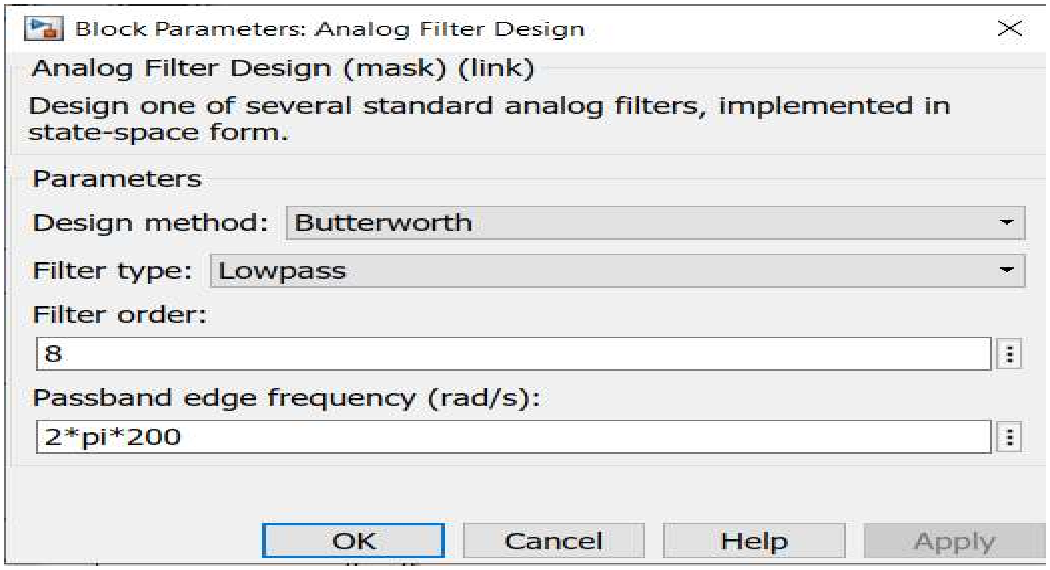
the USB and LSB of the f-spectrum at fc+fm and fc-fm cannot be distinguished in the naked eye. This is because of the x-axis scale in the f-spectrum.

Thus we could not read the peak values from the f-spectrum of the modulated signal. The only peak which was very visible was the carrier component (at fc) whereas the USB and LSB were not distinguishable.
But based on the theoretical value we can say this much that the USB will be present at around 1.351Mhz and will have a peak value of around 23.98dBm whilst LSB will be present around 1.349Mhz and will have a peak value of around 23,98dBm.
[When we took a larger value of fm=0.5MHz the usb and lsb were distinguishable and at the correct places.]

Question-4:

Message Frequency=200Hz:





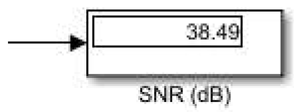
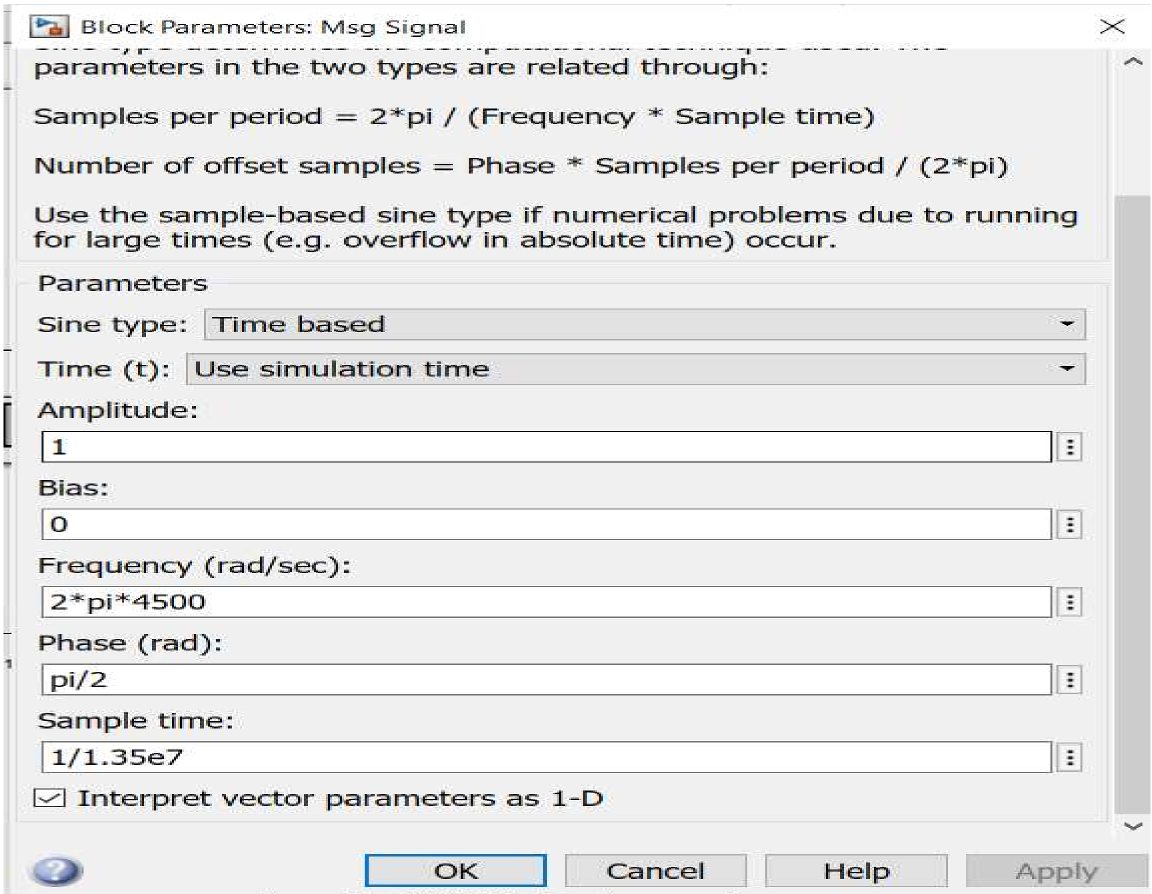
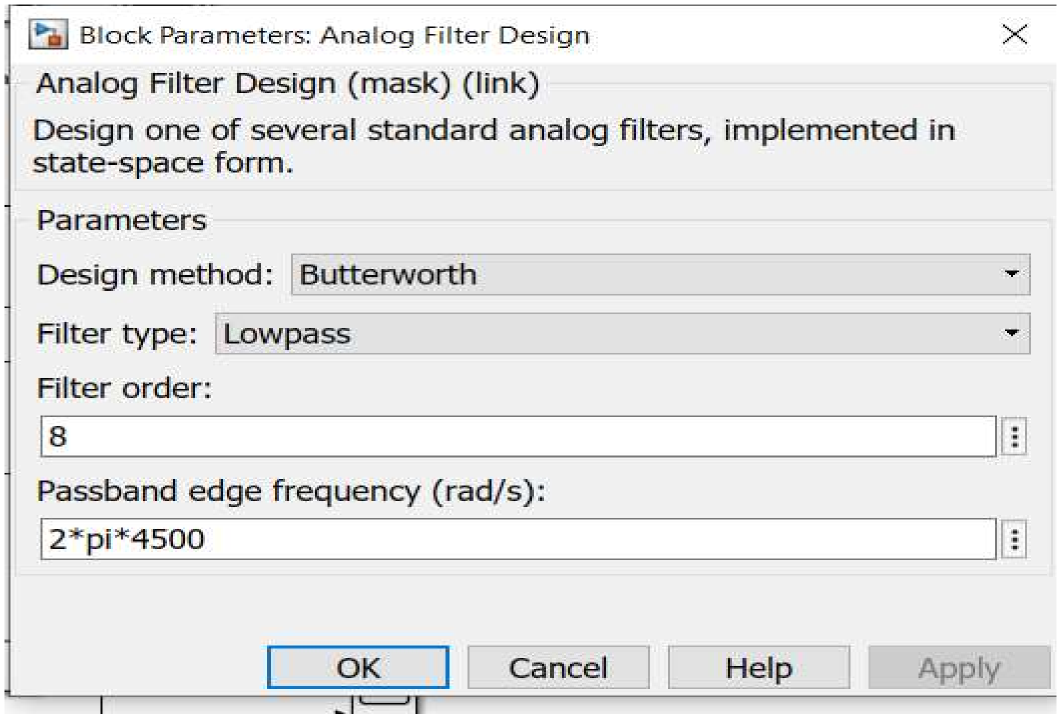


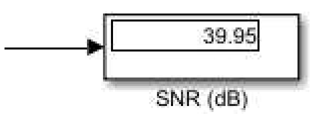
Fig 18 19 20

Comments: Set the message signal at 200Hz and the Low pass filter at 200Hz. The SNR is 38.49dB

Message Frequency=4.5kHz:







<u>Fig.21 22 23</u>

Comments: Set the message signal at 4500Hz and the Low pass filter at 4500Hz. The SNR is 38.95dB

Modulation index (u) **=1:**

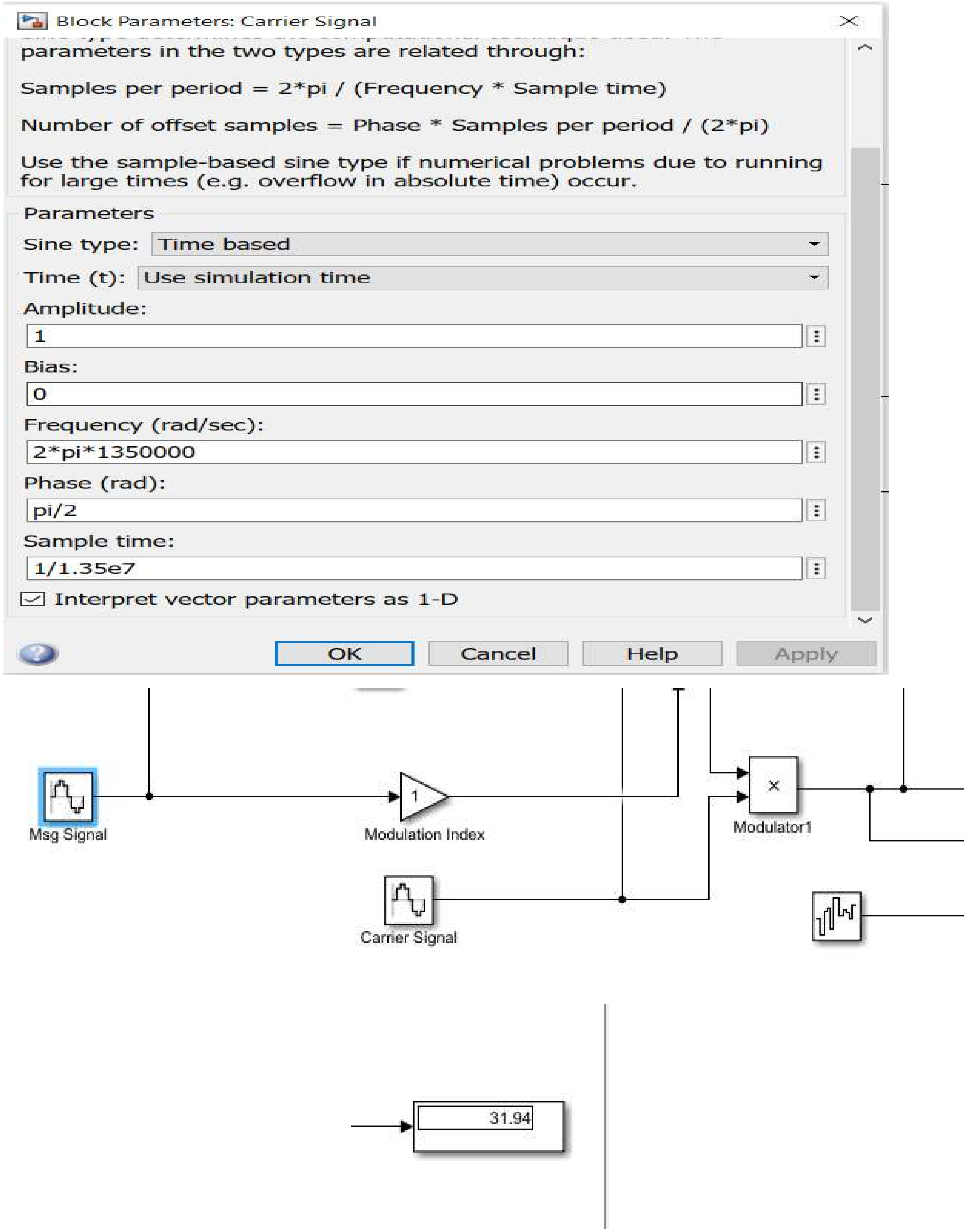
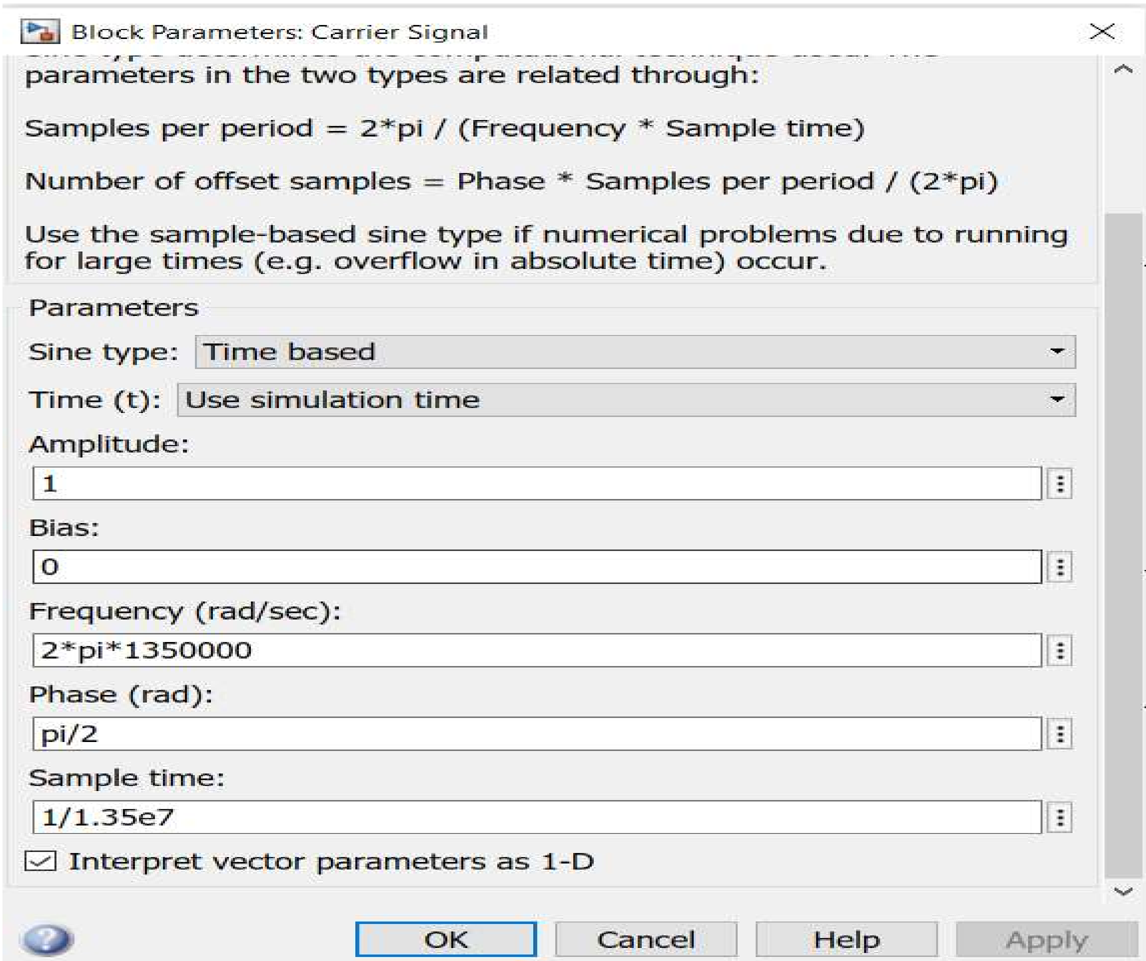
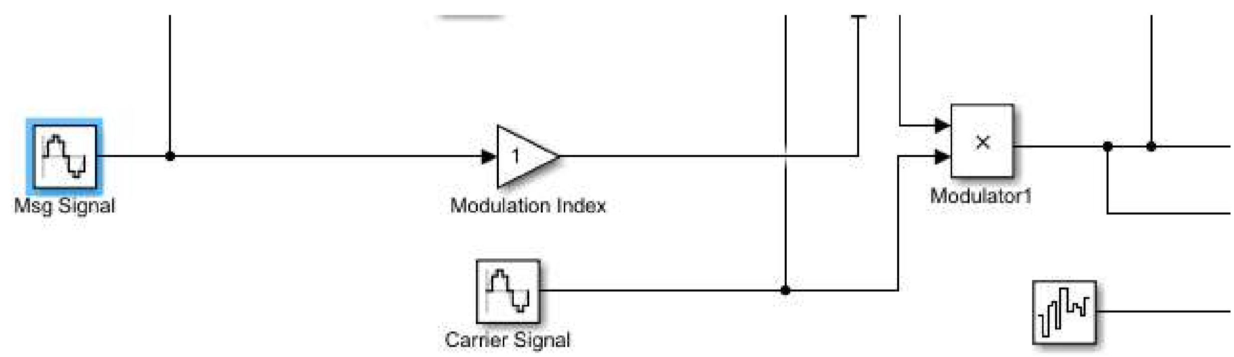


Fig.24 25 25 27

Comments: The message signal's amplitude (Am) is 1 and so the carrier's amplitude(Ac) must be set to 1 too to ensure a modulation index of 1. Moreover, the modulation index block should also be set to 1. The SNR is 31.94dB

Question-5:





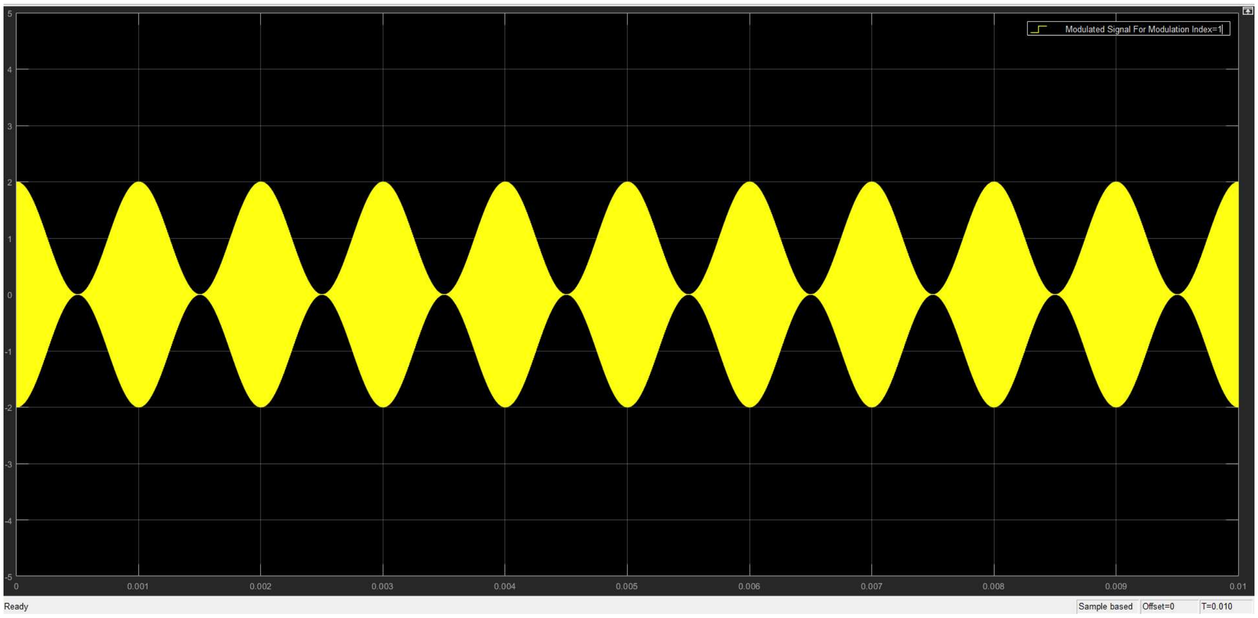


Fig.30

Modulated Signal in the time domain when modulation index (u) set to 1.

Comments: From the waveshape of the modulated signal it can be clearly seen that modulation index (u)=1

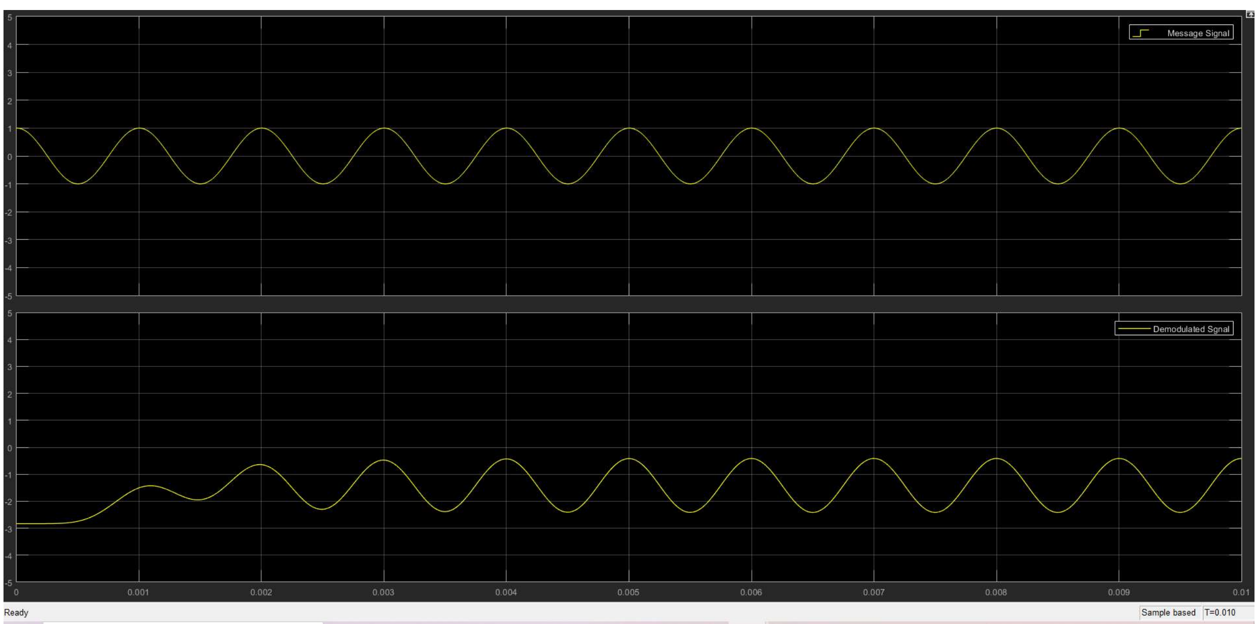


Fig.31

Message Signal(top) and Demodulated Signal(bottom) when (u)=1

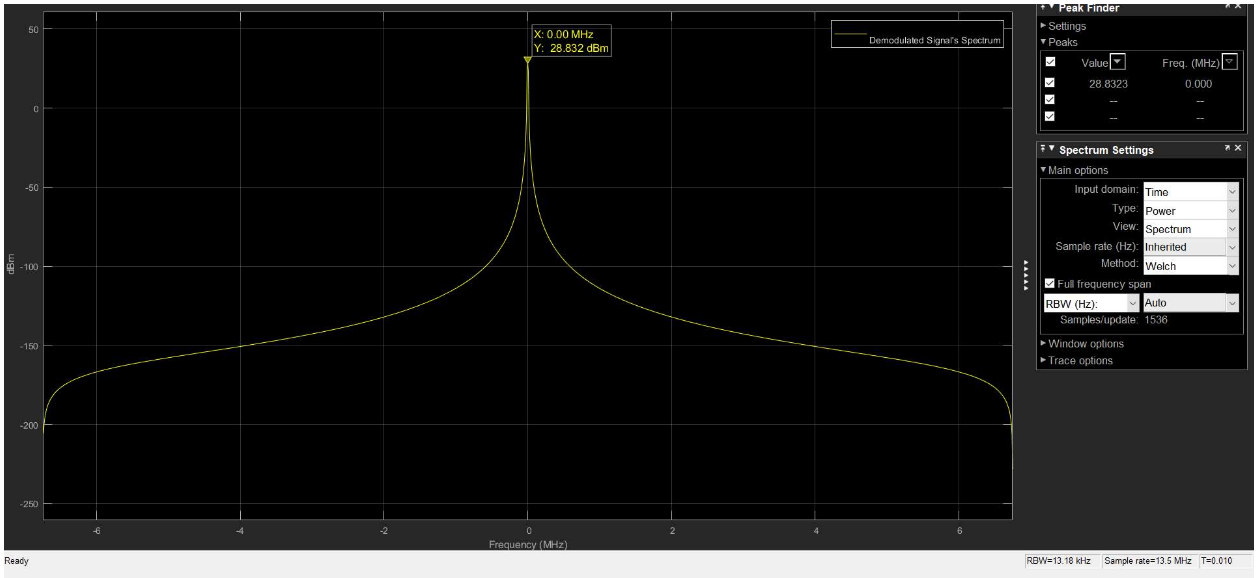
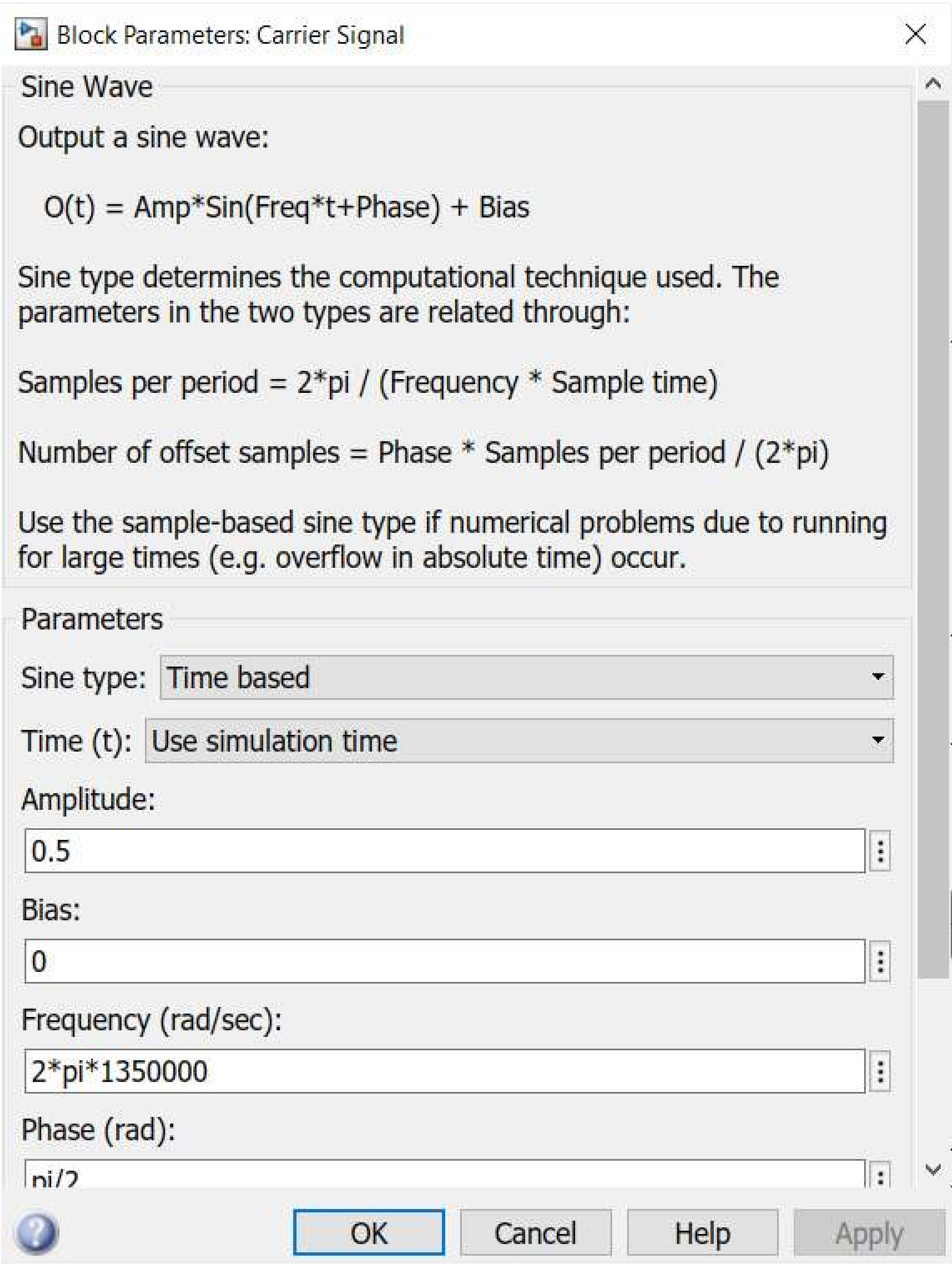
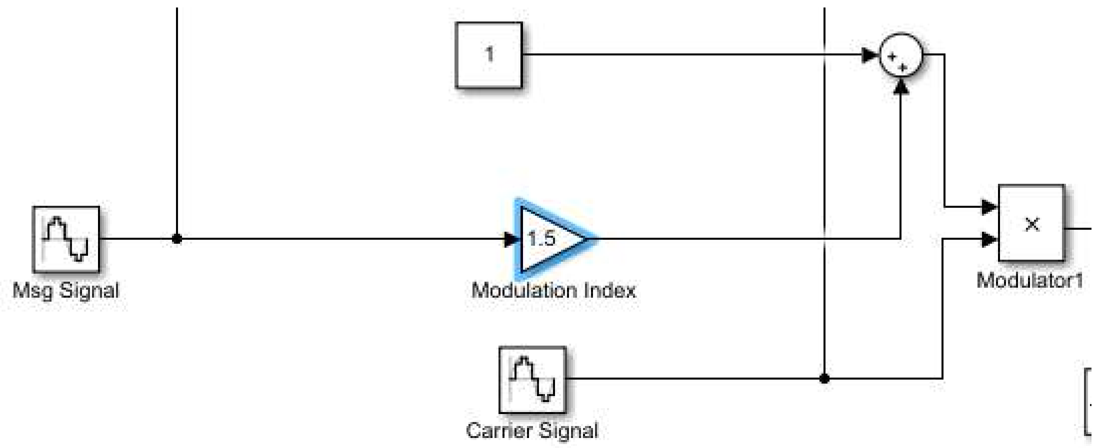


Fig.32

Demodulated Signal in f-domain when $(u)=1$


Block Parameters: Carrier Signal
Sine Wave
Output a sine wave:
O(t) = Amp*Sin(Freq*t+Phase) + Bias
Sine type determines the computational technique used. The parameters in the two types are related through:
Samples per period = 2*pi / (Frequency * Sample time)
Number of offset samples = Phase * Samples per period / (2*pi)
Use the sample-based sine type if numerical problems due to running for large times (e.g. overflow in absolute time) occur.
Parameters
Sine type: Time based
Time (t): Use simulation time
Amplitude:
0.5
Bias:
0
Frequency (rad/sec):
2*pi*1350000
Phase (rad):
pi/2
OK
Cancel
Help
Apply



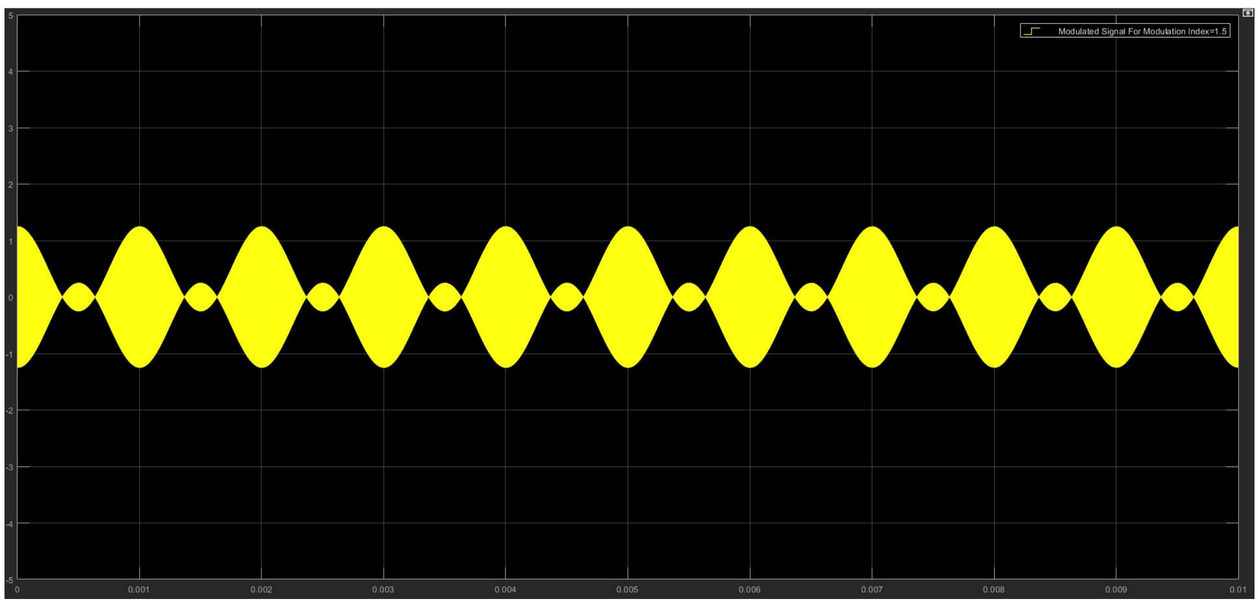


Fig.35

Modulated Signal in the time domain when modulation index (u) set to 1.5.

Comments: From the waveshape of the modulated signal it can be clearly seen that modulation index (u)=1.5

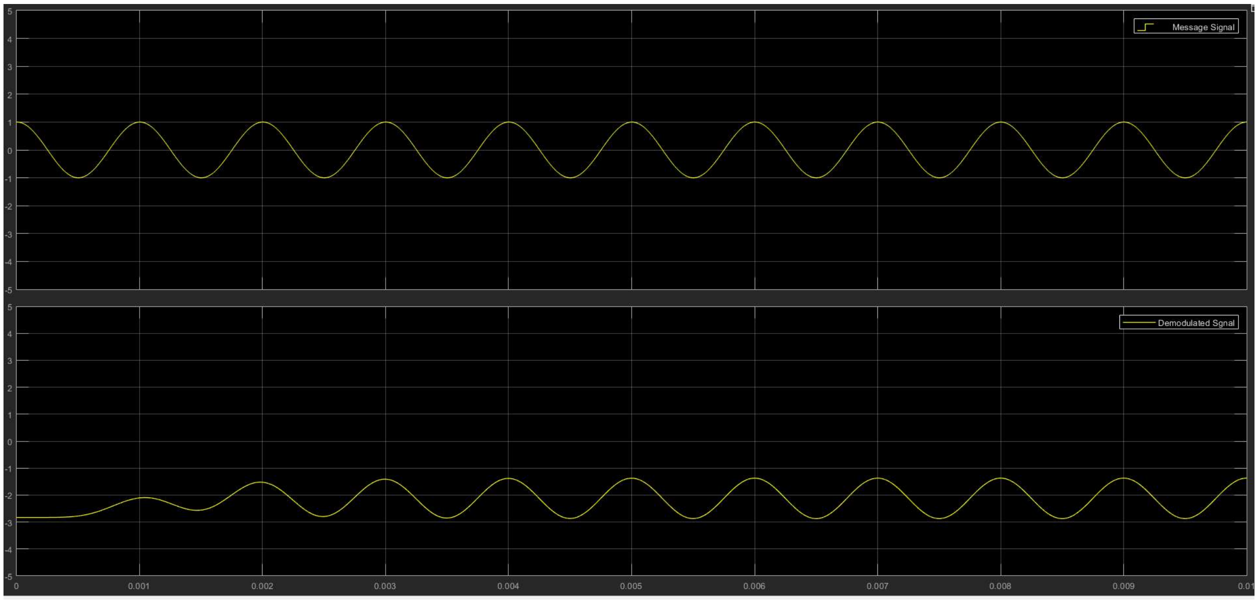


Fig.36

Message Signal(top) and Demodulated Signal(bottom) when (u)=1.5

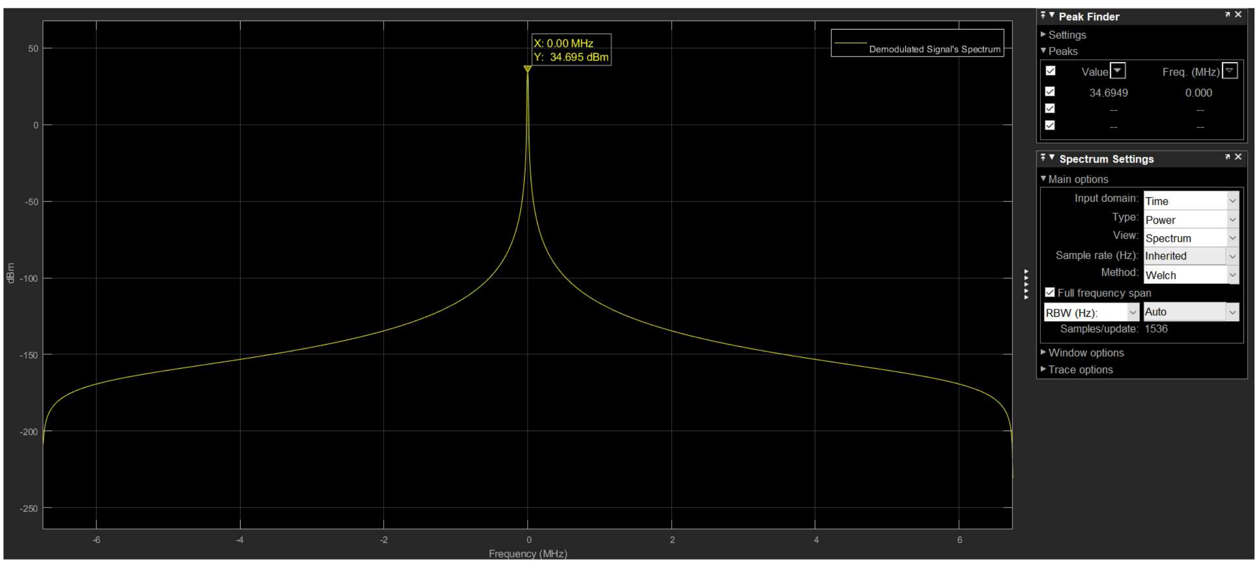


Fig.37

Demodulated Signal in f-domain when (u)=1.5

Answer:

From fig.30 we can clearly see that when the modulation index (u)=1 the upper envelope and the lower envelope of the modulated signal do not coincide. So,we can retrieve our message signal from the modulated signal.However, from fig,35 we see that when the modulation index (u)=1.5 the upper envelope and lower

envelope of the modulated signal coincide. At this point, the modulated signal is distorted and it is very difficult to retrieve our original message signal from it. We can further prove that this is indeed the case.
For instance, if we compare fig.31 and fig.36, we can see that the demodulated signal when
(u)=1 is the same as our message signal in the time domain.However, for fig,36 we see that the demodulated signal when (u)=1.5 is slightly different from our message signal. This difference between the demodulated signal and the message signal will increase as we increase the modulation index (u).
Similar comparisons can be made for the f-domain too.
Please refer to fig.7(message signal in f-domain), fig.32(demodulated signal in f-domain when (u)=1), and fig.37 (demodulated signal in f-domain when (u)=1.5).
That is fig.7 and fig.32 are more similar than fig.7 and fig.37
Thus a modulation index of greater than one should be avoided.

Task 2 and 3:

Objective:

The purpose of this experiment is to build a system of modulation and demodulation using different Phase-Shift Keying (PSK) techniques such as Binary Phase-Shift Keying (BPSK) and Quadrature Phase-Shift Keying (QPSK). We designed it in such a manner so that we can observe the performance curve by varying the Eb:No ratio, show waveforms at different points at different SNR values, and we will show the constellation figure of the modulator. Furthermore, we will also be constructing a BPSK modulator with operation function blocks based on time domain to evaluate and simulate the BPSK modulator.

Methodology:

BPSK and QPSK are different modulation techniques. BPSK encodes one bit at a time while QPSK on the other hand encodes two bits at meaning. This means that BPSK will be using the sequence of either 0 or 1 which means it has only two possible inputs. QPSK will be using a combination of 0 and 1 at the same time meaning it has four possible inputs: 00, 01, 10, 11. For this experiment, we started with the random integer generator which will provide a random sequence using an appropriate initial seed number. There is an option of “Set Size”. We will set it to 2 for BPSK and 4 for QPSK in relevance to their possible sequence. Next, we connected a built in modulator block with a demodulator block for each technique with a AWGN channel between these two blocks. We vary the Eb:No ratio to see how the output would change with a change in noise level. The modulator block gives out an output which is complex in digital mode and since it is easier for everyone to read only real values from the graphs, we used a “Complex to Real Image” block so that we convert the complex output values to real values. The real part is multiplied with a sine block and the complex part is multiplied with a cosine block and these two multiplied outputs are later on added together and connected to a scope to find out the only real output of the modulator. To the same scope, we connected a constellation diagram block to view the signal as a two dimensional scatter diagram in the complex plane. Next, we connected a “Error Rate Calculation” block to a display to view the potential error rate in this experiment. Using the “bertool” operation in MATLAB, we see the performance curve of this experiment.

MATLAB Simulink Blocks used for BPSK and QPSK:

- Random Integer Generator
- BPSK modulator and demodulator
- QPSK modulator and demodulator
- AWGN channel
- Complex to Real Image
- Sine Wave, Cosine Wave, Product, Add
- Constellation Diagram
- Error Rate Calculation
- To workspace
- Scope, Display

Block Diagram for BPSK:

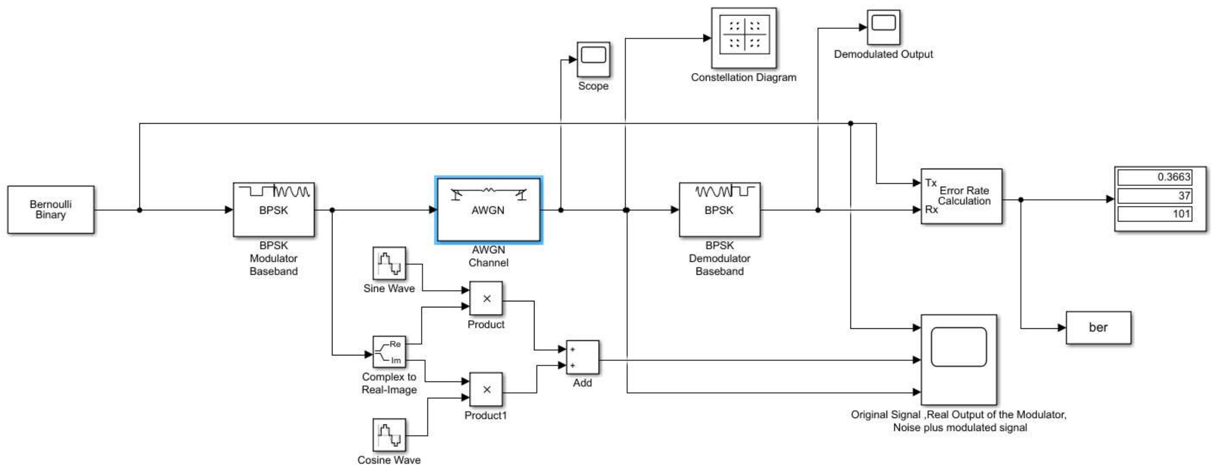
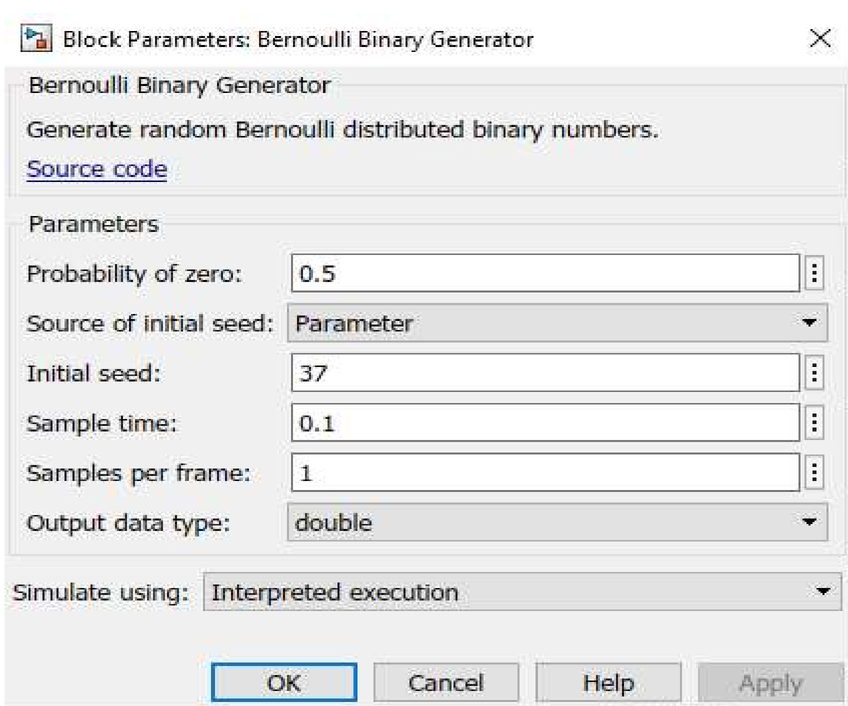


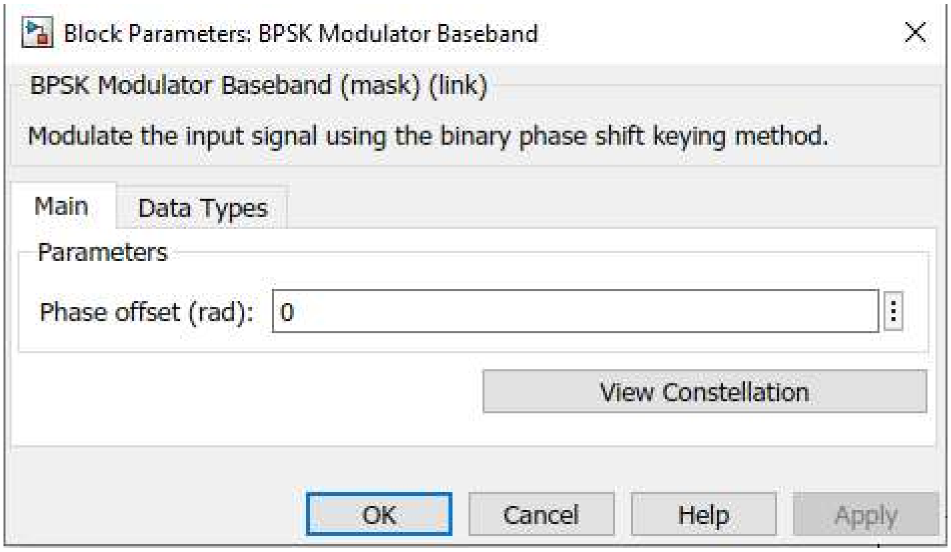
Fig.38

Parameters used for BPSK:

Bernoulli Binary:



BPSK Modulator Baseband:



AWGN Channel:

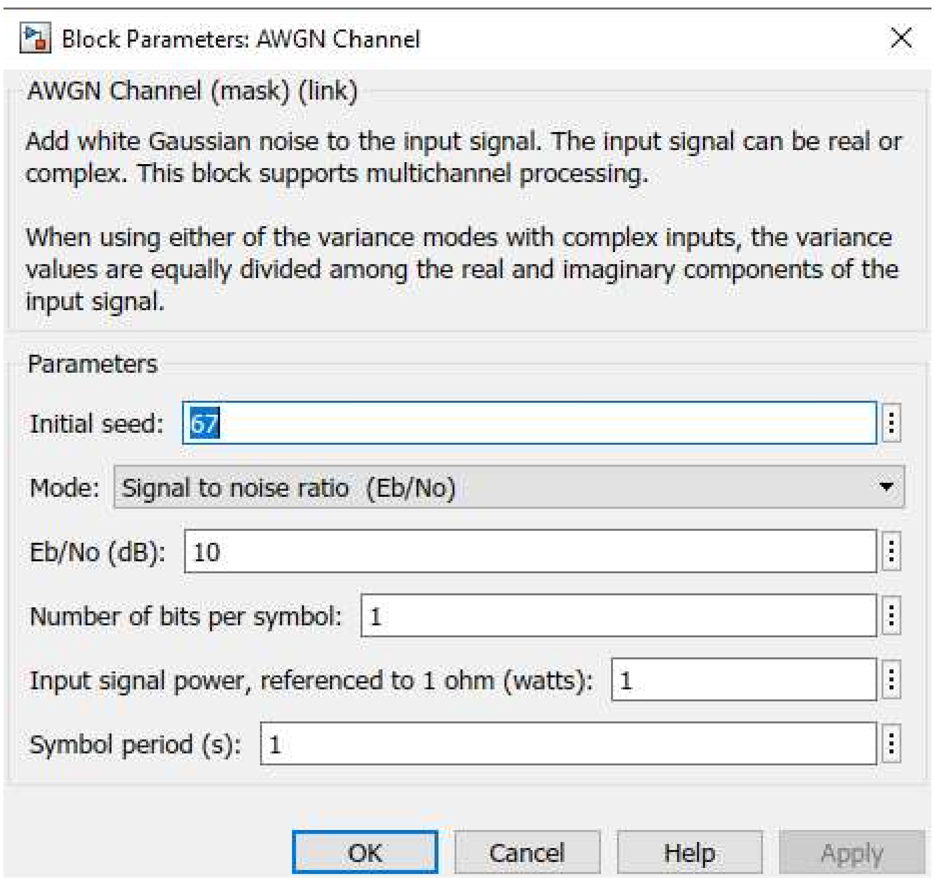


Fig.39 40 41

Comment: The ratio of Eb:No will vary according to the requirement of the experiment.

Complex to Real Image:

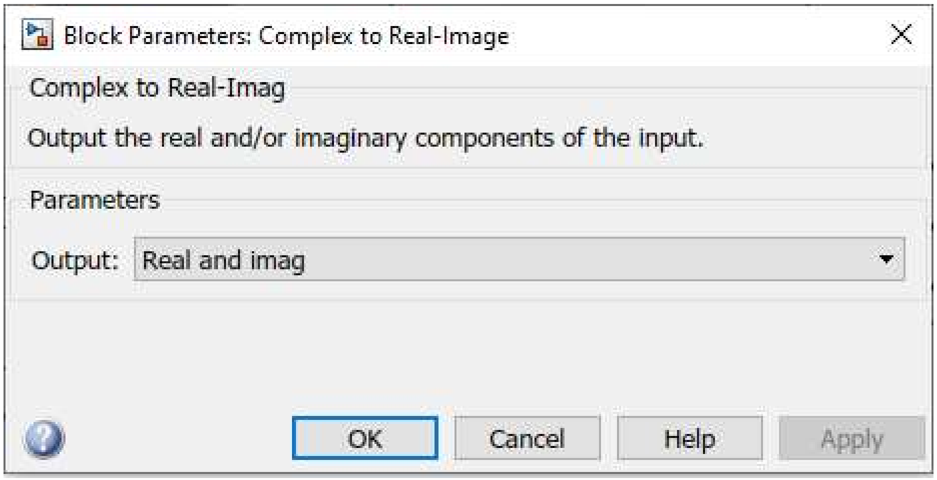


Fig.42

BPSK Demodulator Baseband:

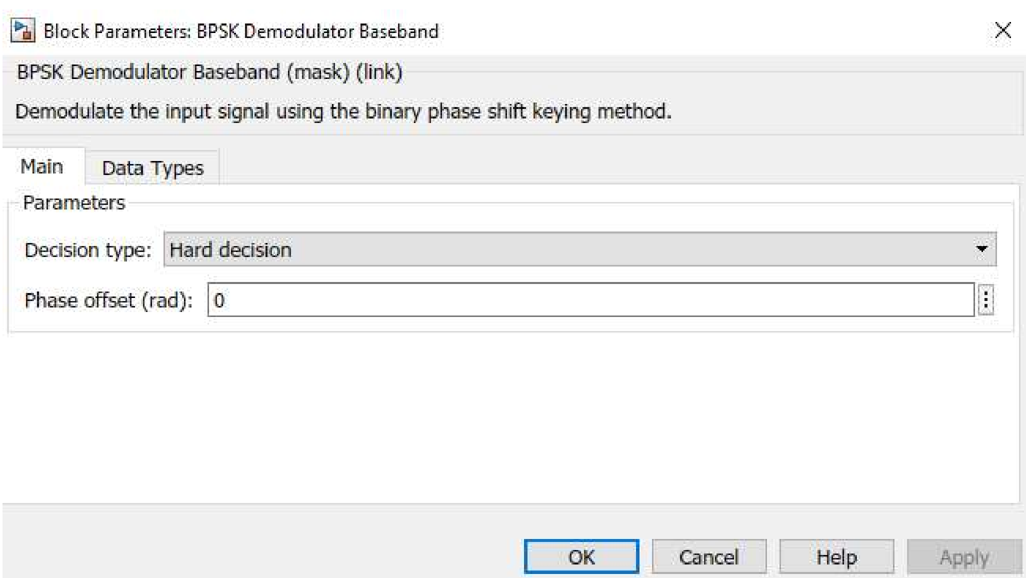


Fig.43

To Workspace:

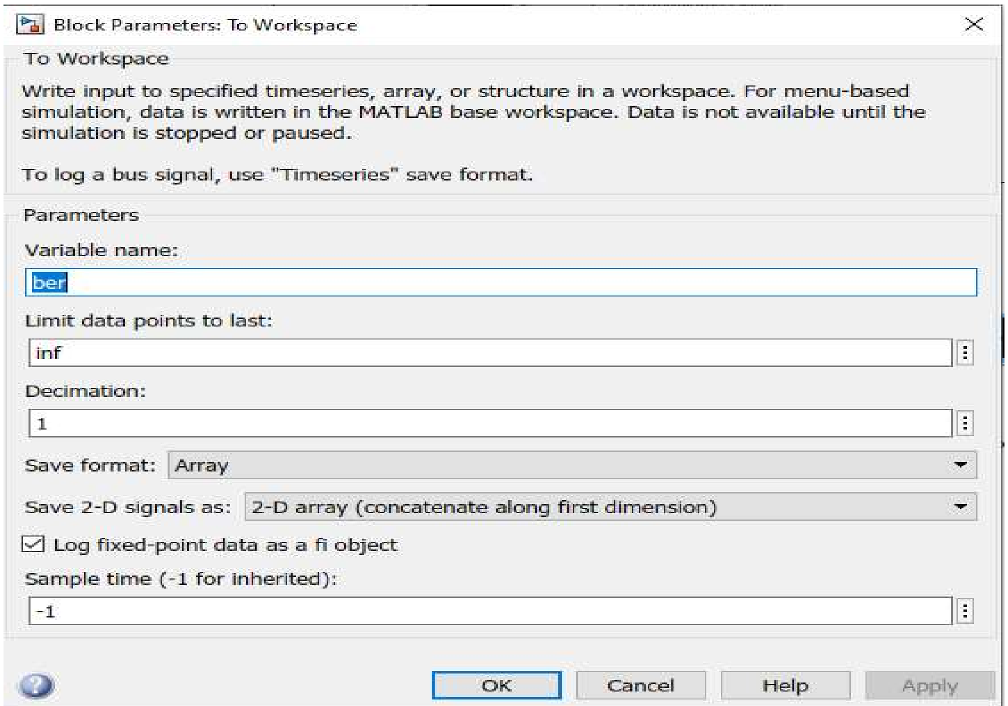


Fig.44

Sine Wave:

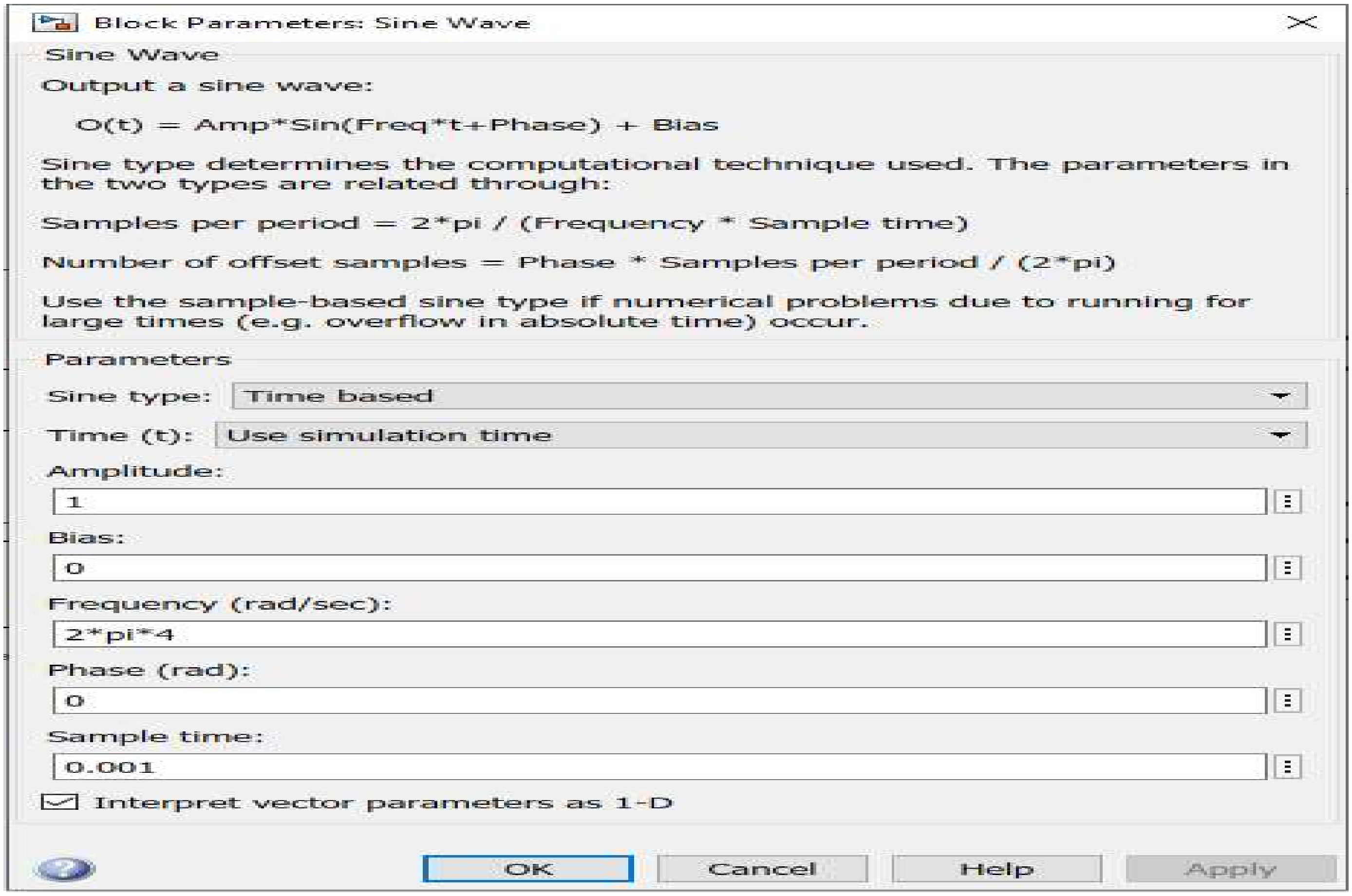


Fig.45

Cosine Wave:

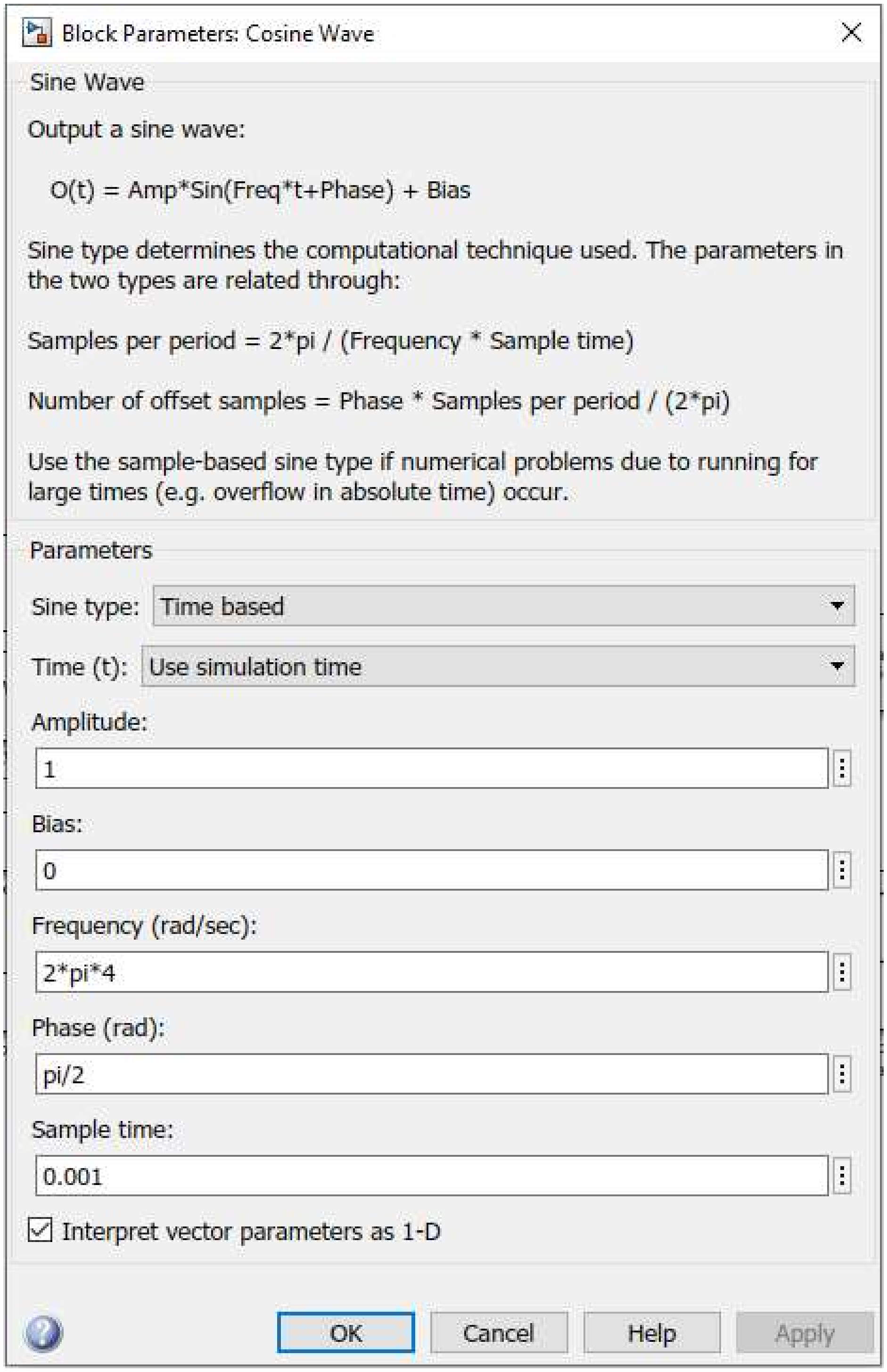


Fig.46

Error Rate Calculation:

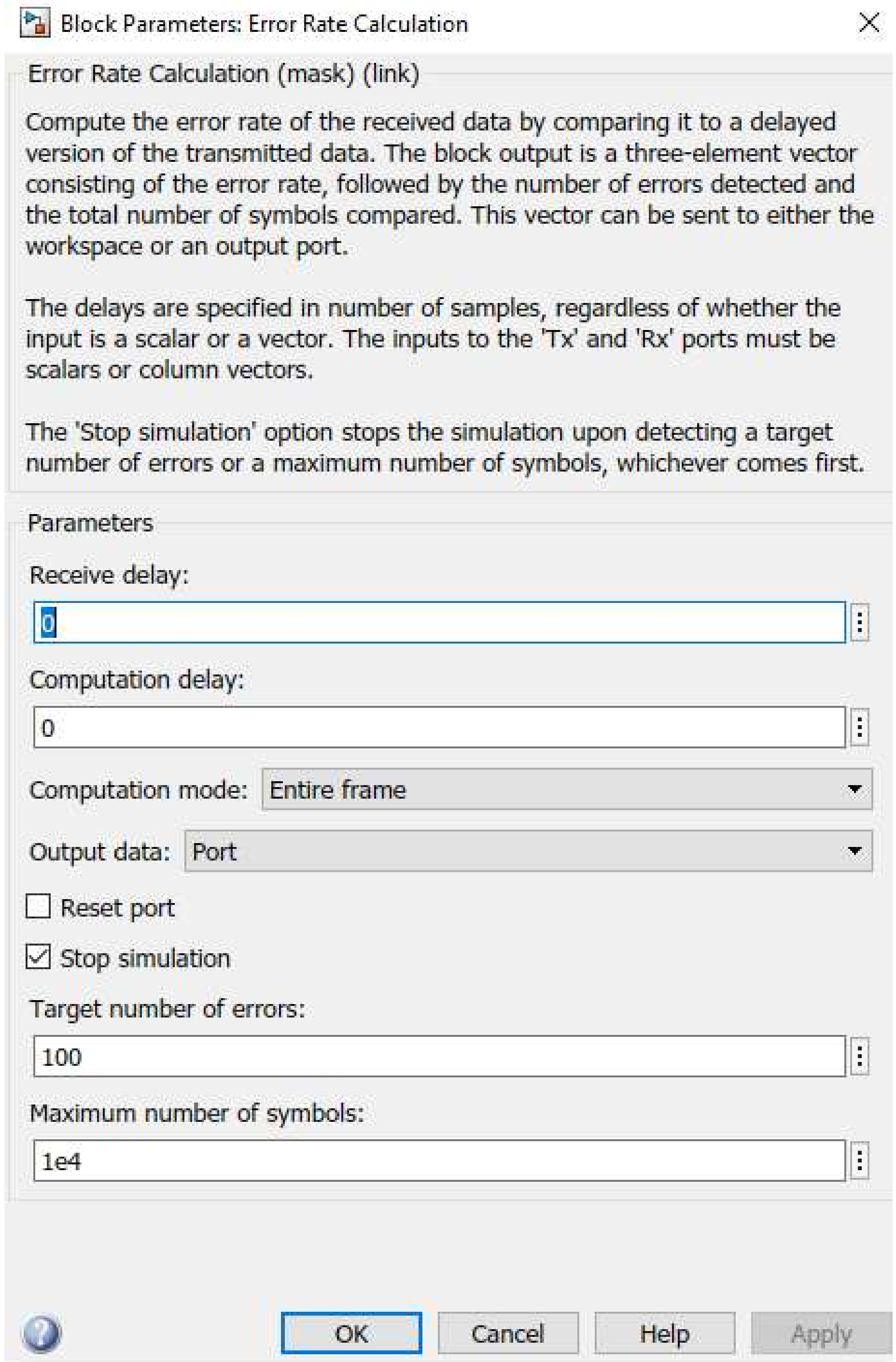
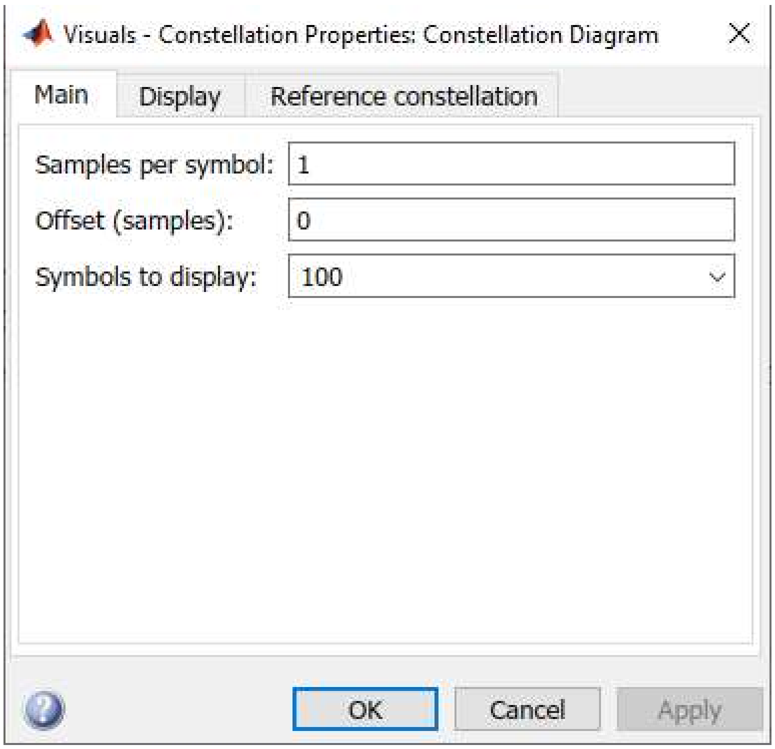


Fig.47

Comment: The output data has been changed to ‘port’ so that we can connect it to a display.

Constellation Diagram:



Reference constellation set to BPSK.

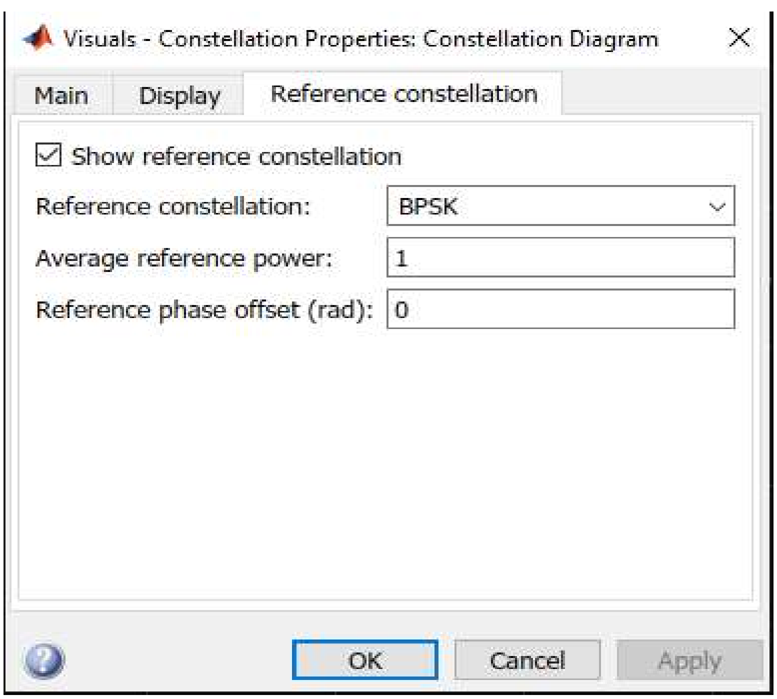


Fig.48 49

Output Results:

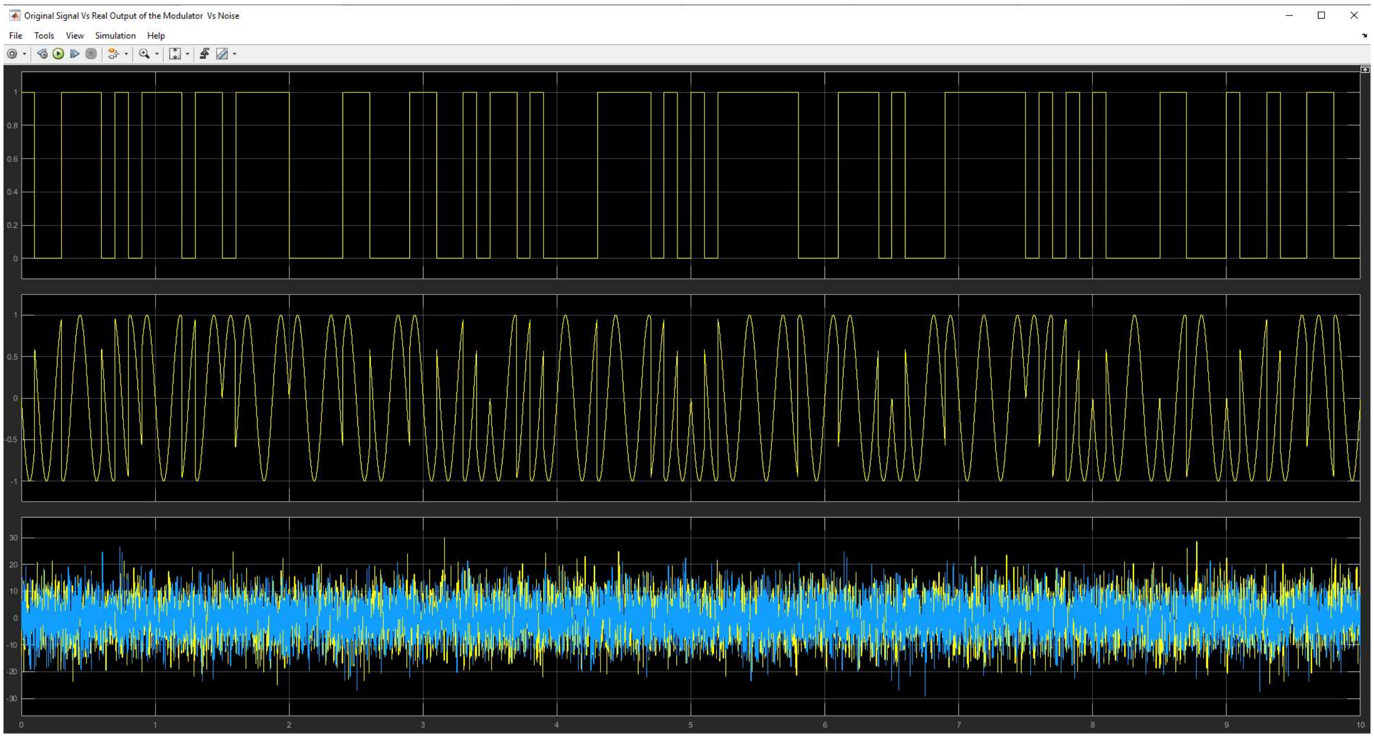


Fig.50

Original Input, Real part output of the modulator and the modulated signal with noise plus modulated signal

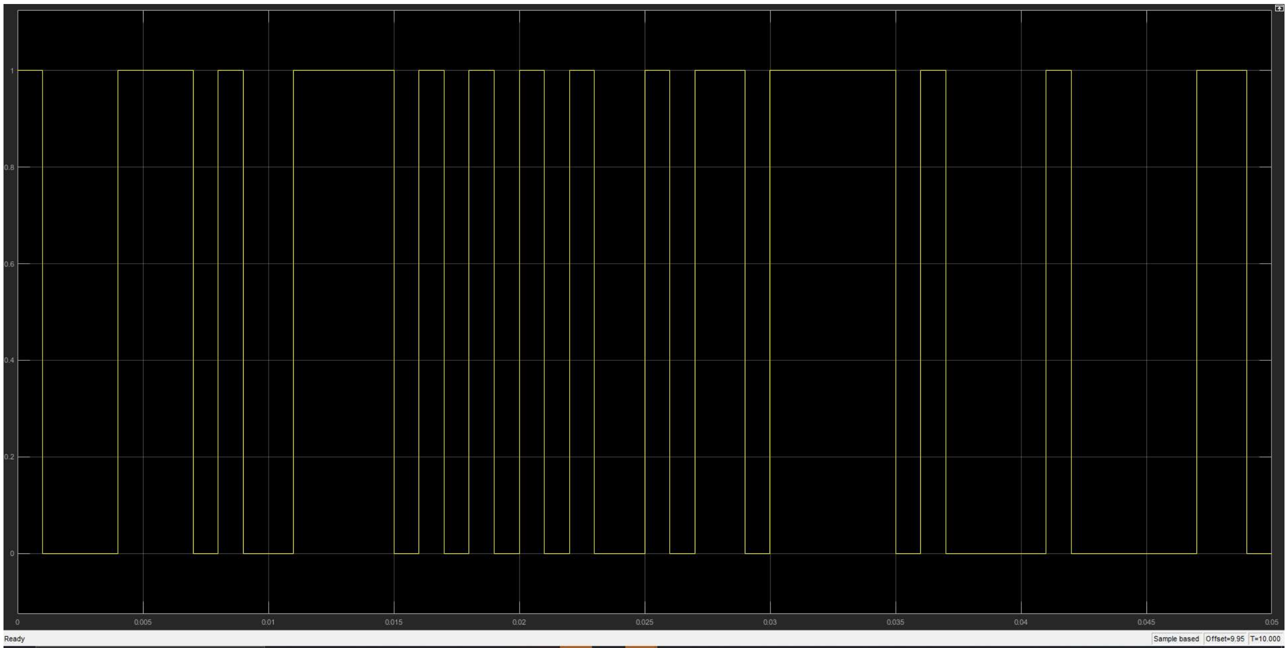


Fig.51

Demodulation output with a time span of 0.05

Constellation Diagram:

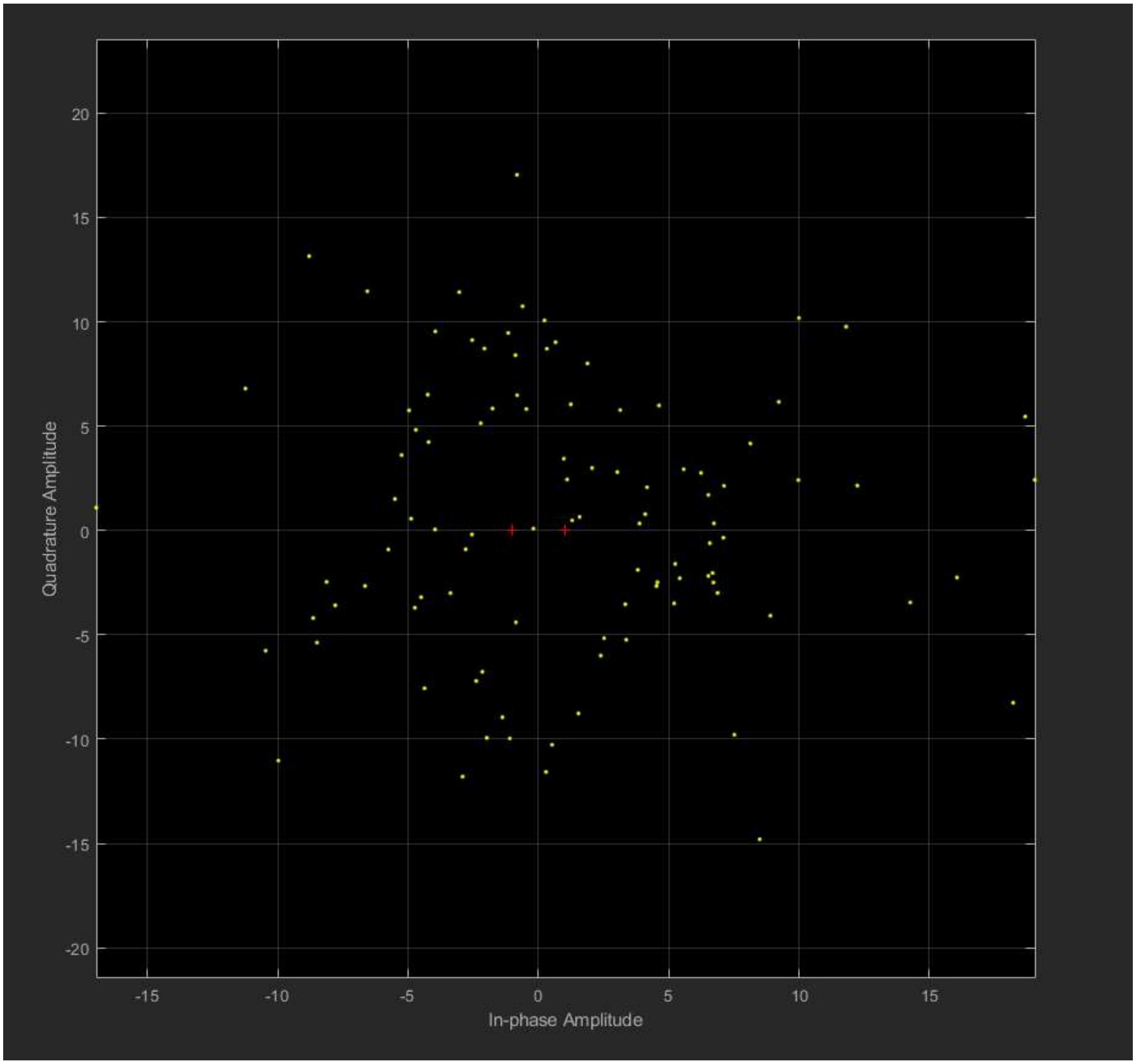
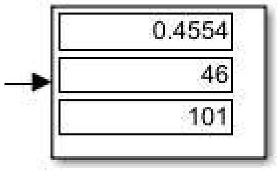


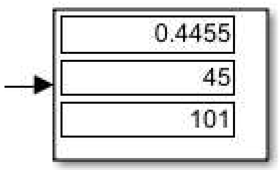
Fig52

Error Rate Results:

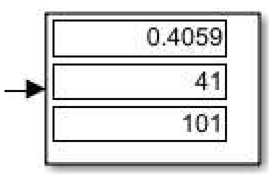
When Eb/No rate is 2dB,



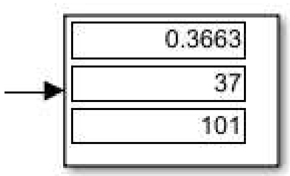
When Eb/No rate is 5dB,



When Eb/No rate is 8dB,



When Eb/No rate is 10dB,



When Eb/No rate is 15dB,

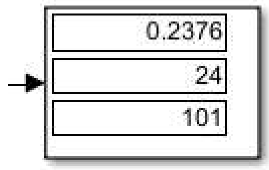


Fig 53-57

Comment: The general trend is that as the Eb/No ratio increases, the error rate decreases.

Block Diagram for QPSK:

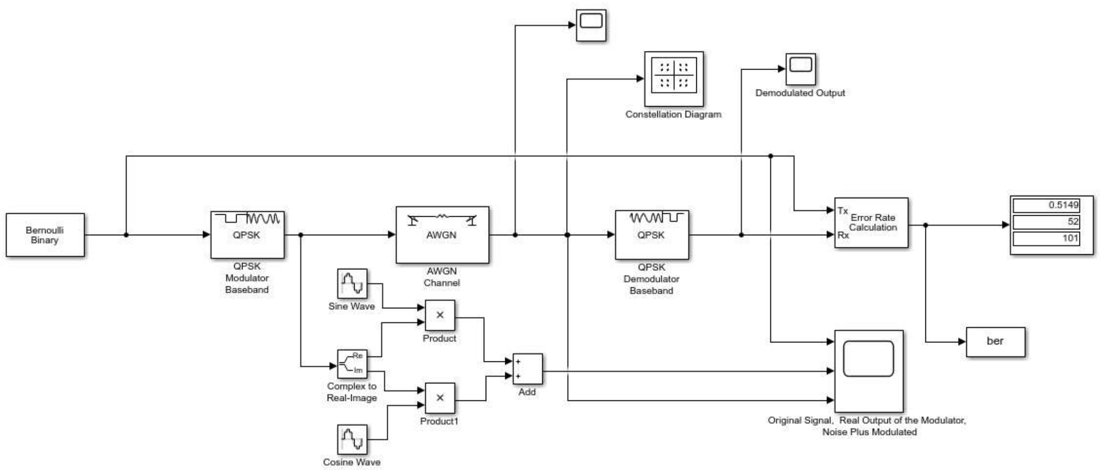


Fig.58

Parameters used for QPSK:

Most of the parameters compared to BPSK are kept the same such as the Bernoulli Generator, sine wave, cosine wave, complex to real image, error rate calculation. Only changes are provided below via screenshots.

AWGN Channel:

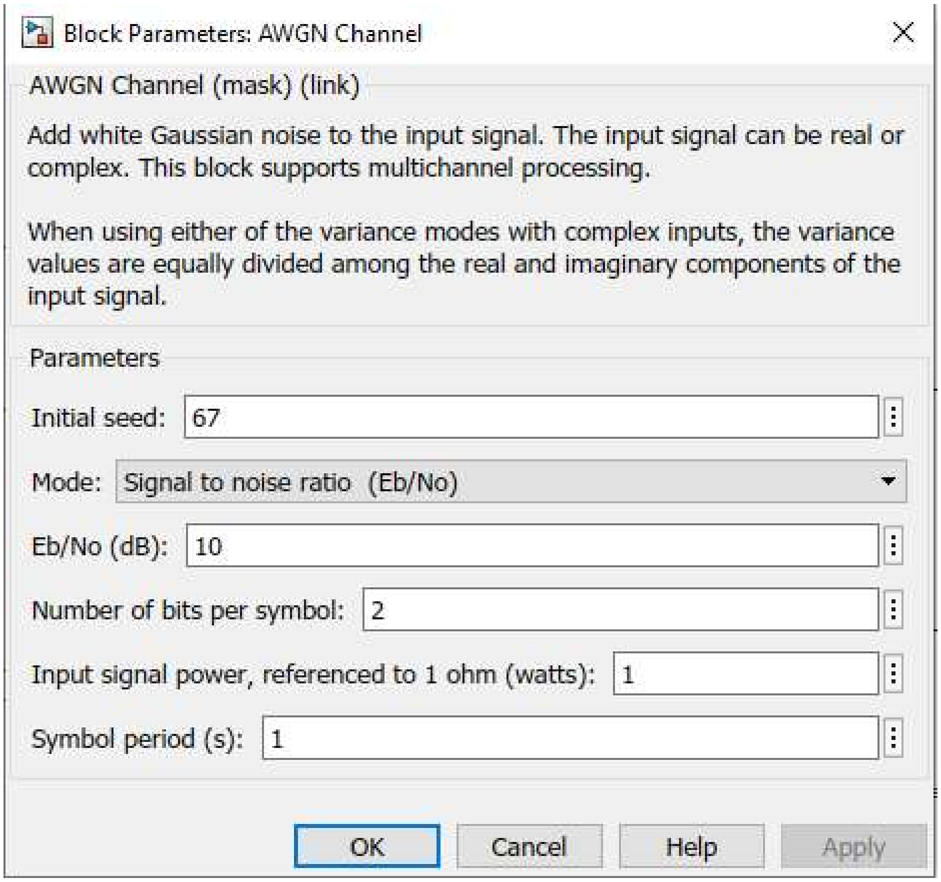


Fig.59

Comments: Number of bits per symbol is now set to 2 since we are taking two bits simultaneously such as 00, 01, 10, 11

QPSK Modulator Baseband:

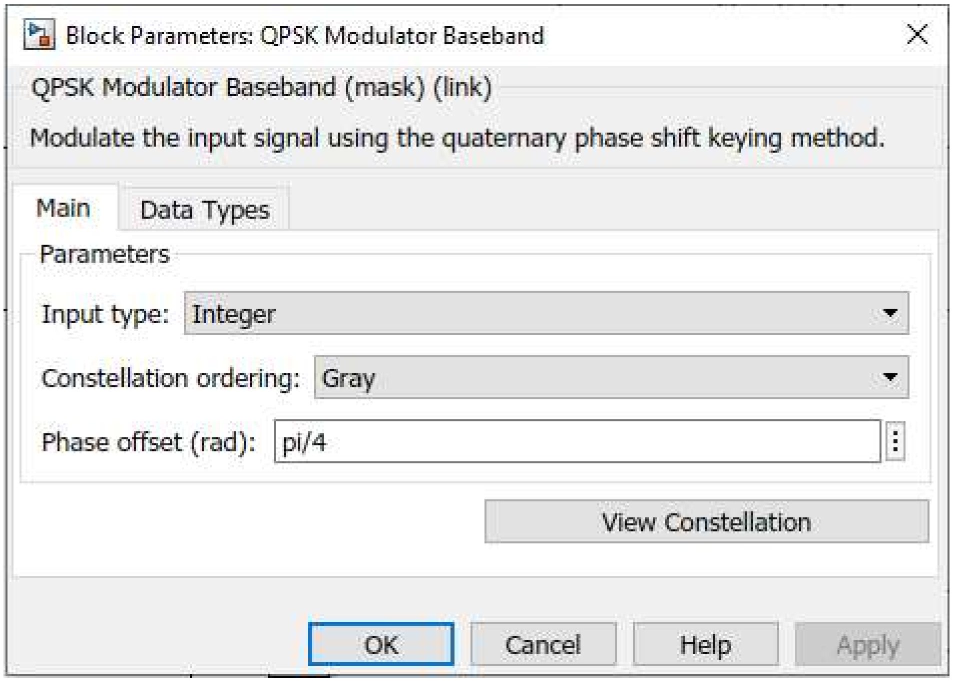
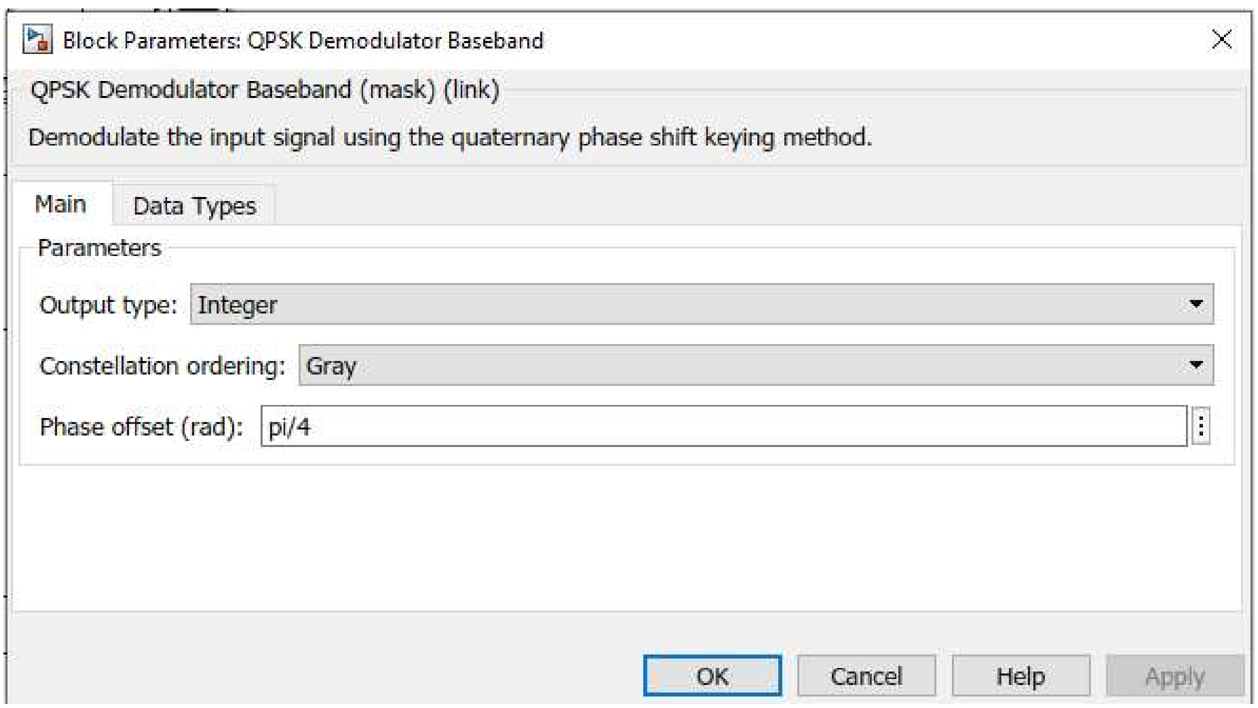


Fig.60

QPSK Demodulator Baseband:



Reference Constellation: Setting of the Constellation Diagram Block

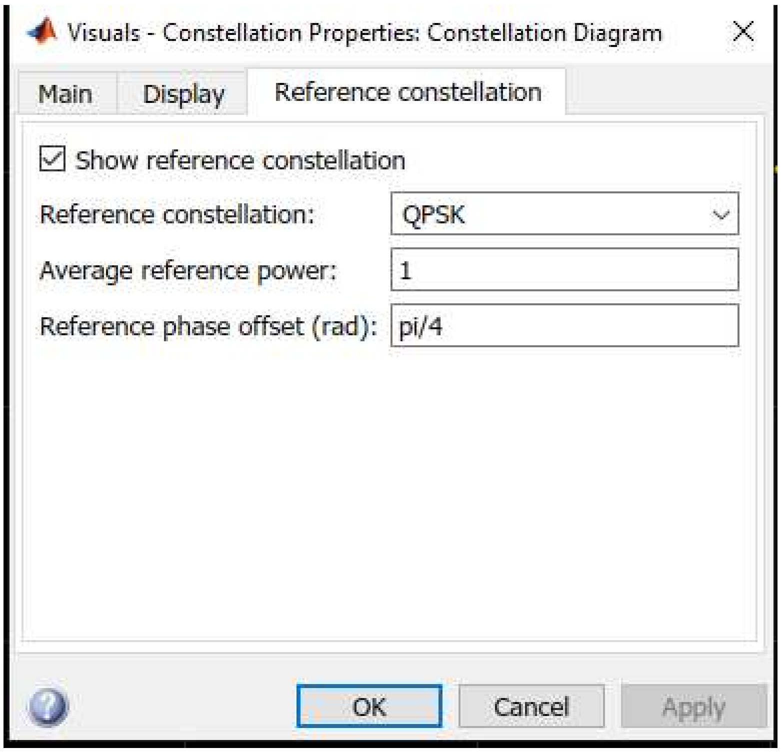


Fig 61-2

Output Results:

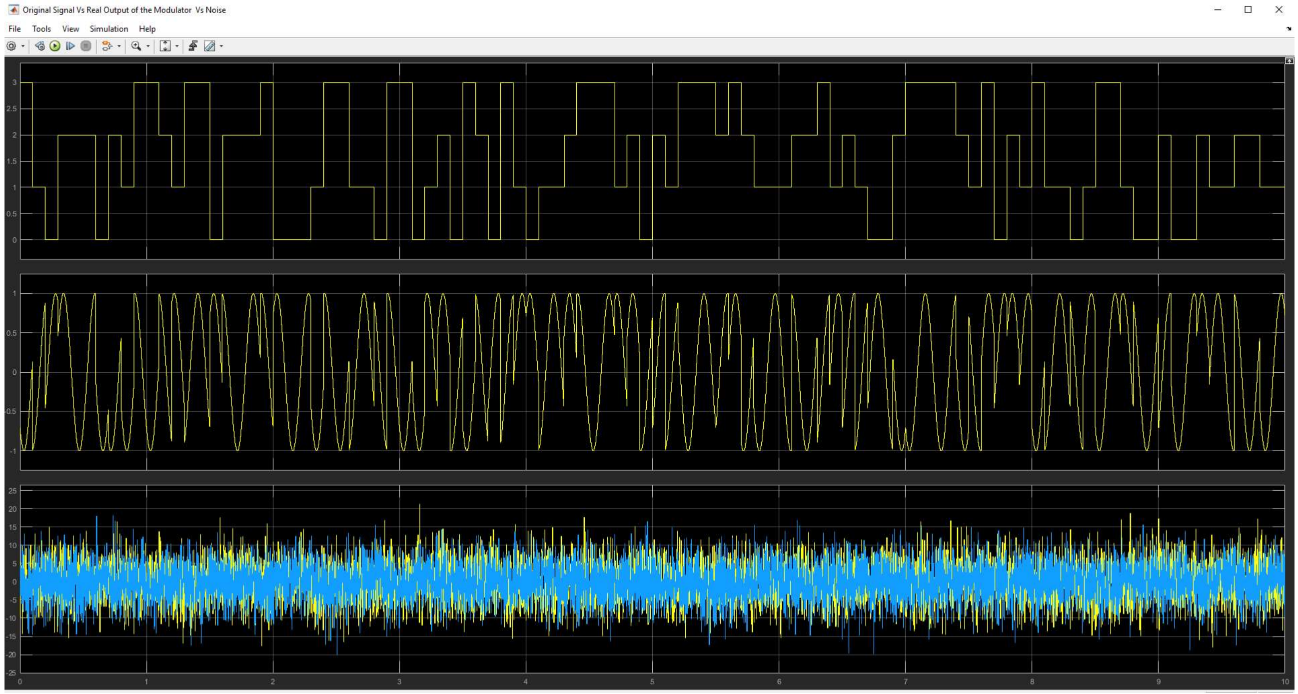
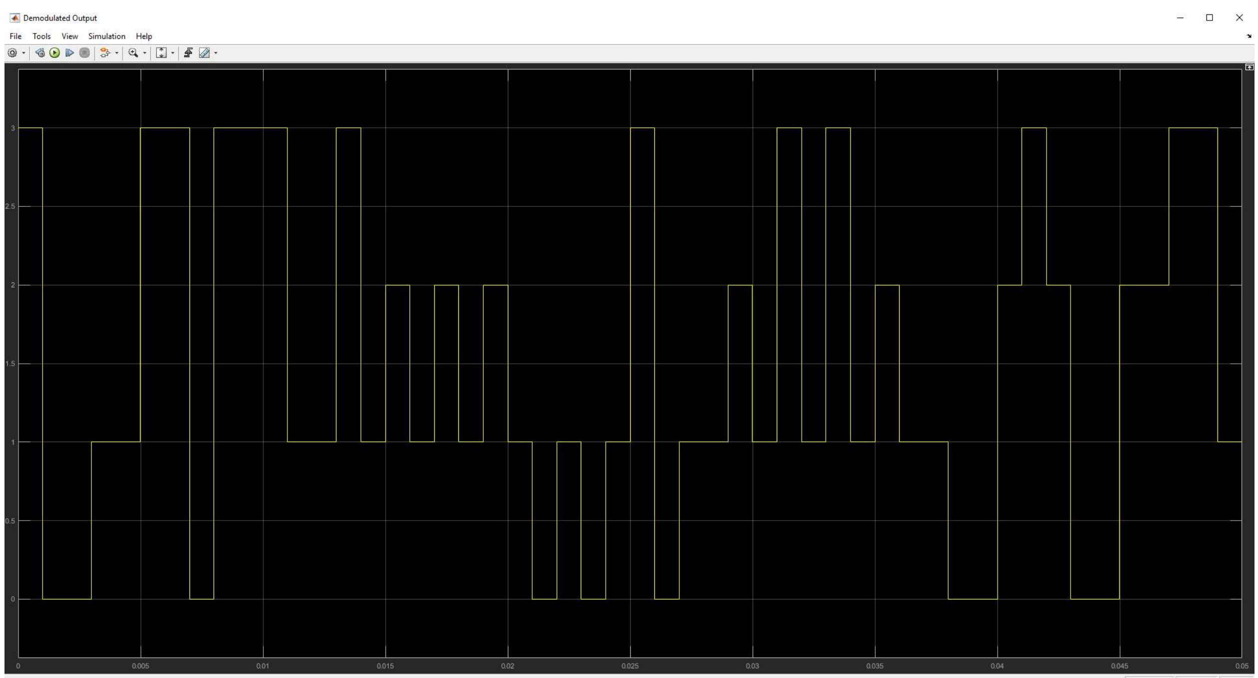


Fig.63

Original Signal Vs Real Output of the Modulator Vs Noise Plus Modulated Signal



Demodulation output with a time span of 0.05

Constellation Diagram:

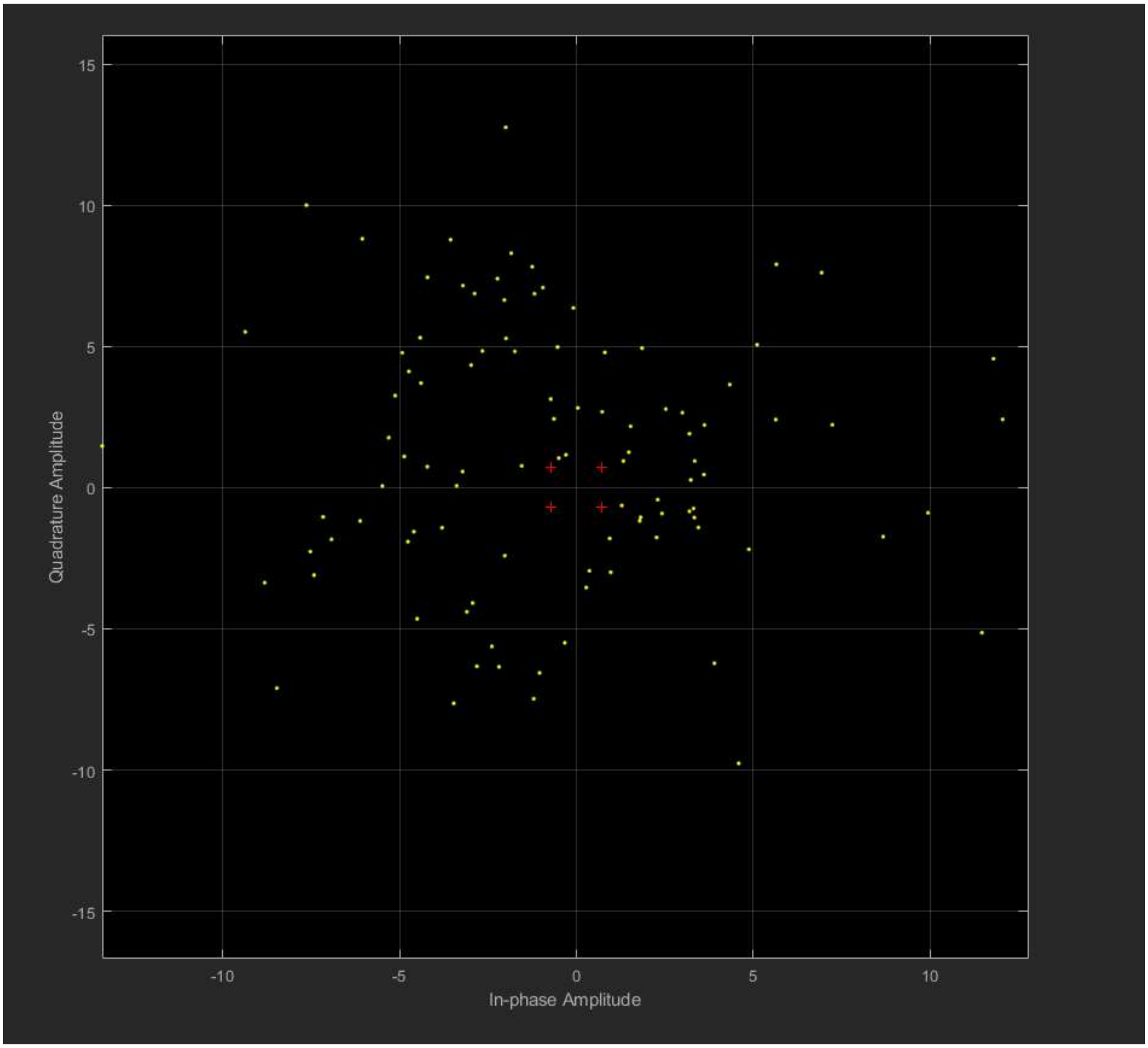
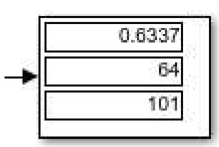


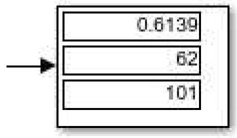
Fig.65

Error Rate Results:

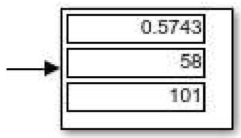
When Eb/No rate is 2dB,



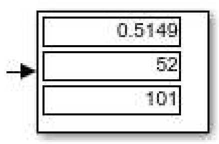
When Eb/No rate is 5dB,



When Eb/No rate is 8dB,



When Eb/No rate is 10dB,



When Eb/No rate is 15dB,

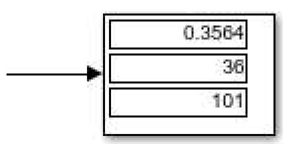


Fig 66-70

Comment: Like BPSK, we can see the error rate decrease as the ratio of Eb/No increases.

Performance Curve:

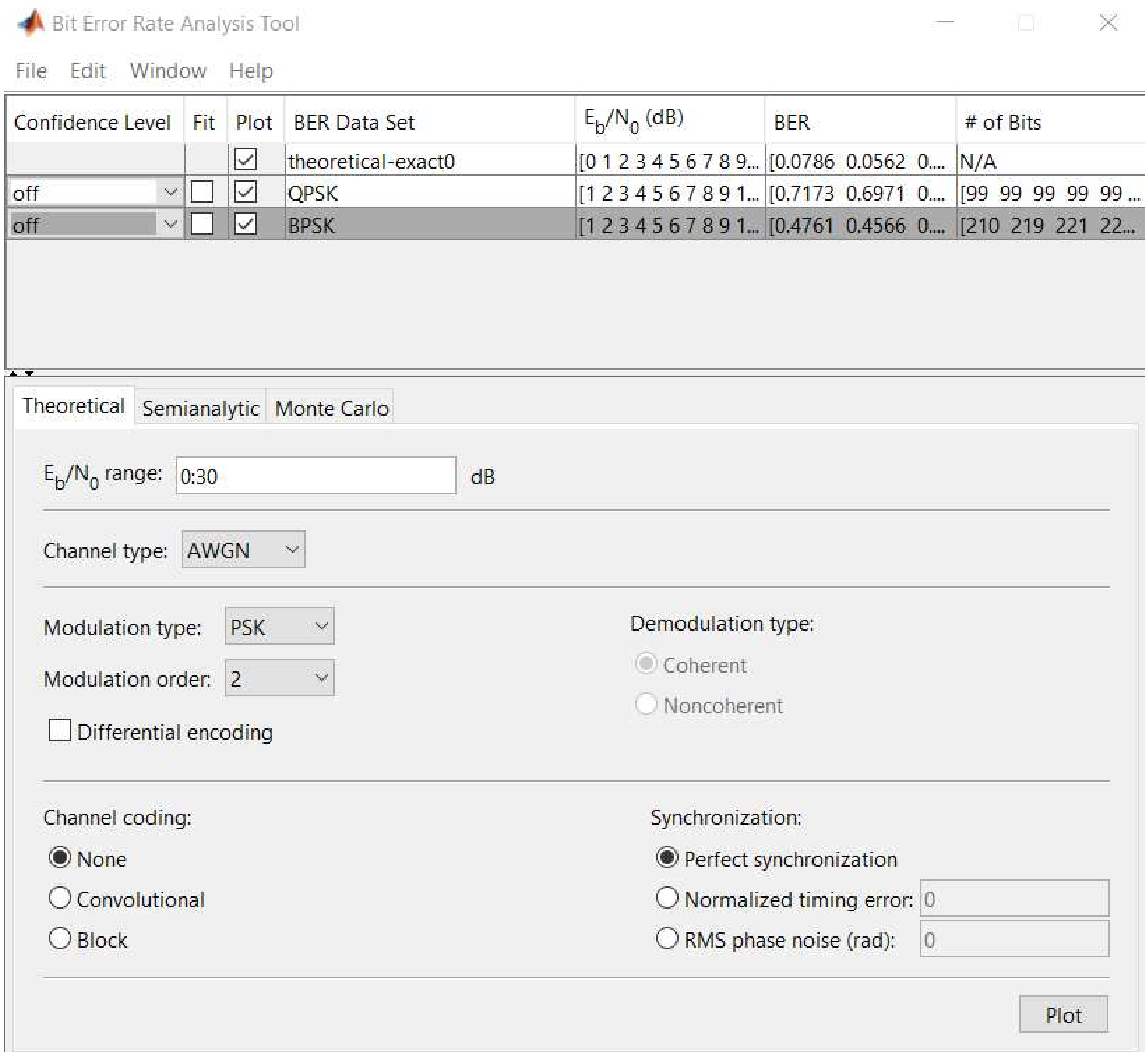


Fig.71

Comment:Using the 'bertool' function, we can view the performance curve of BPSK as well as QPSK.

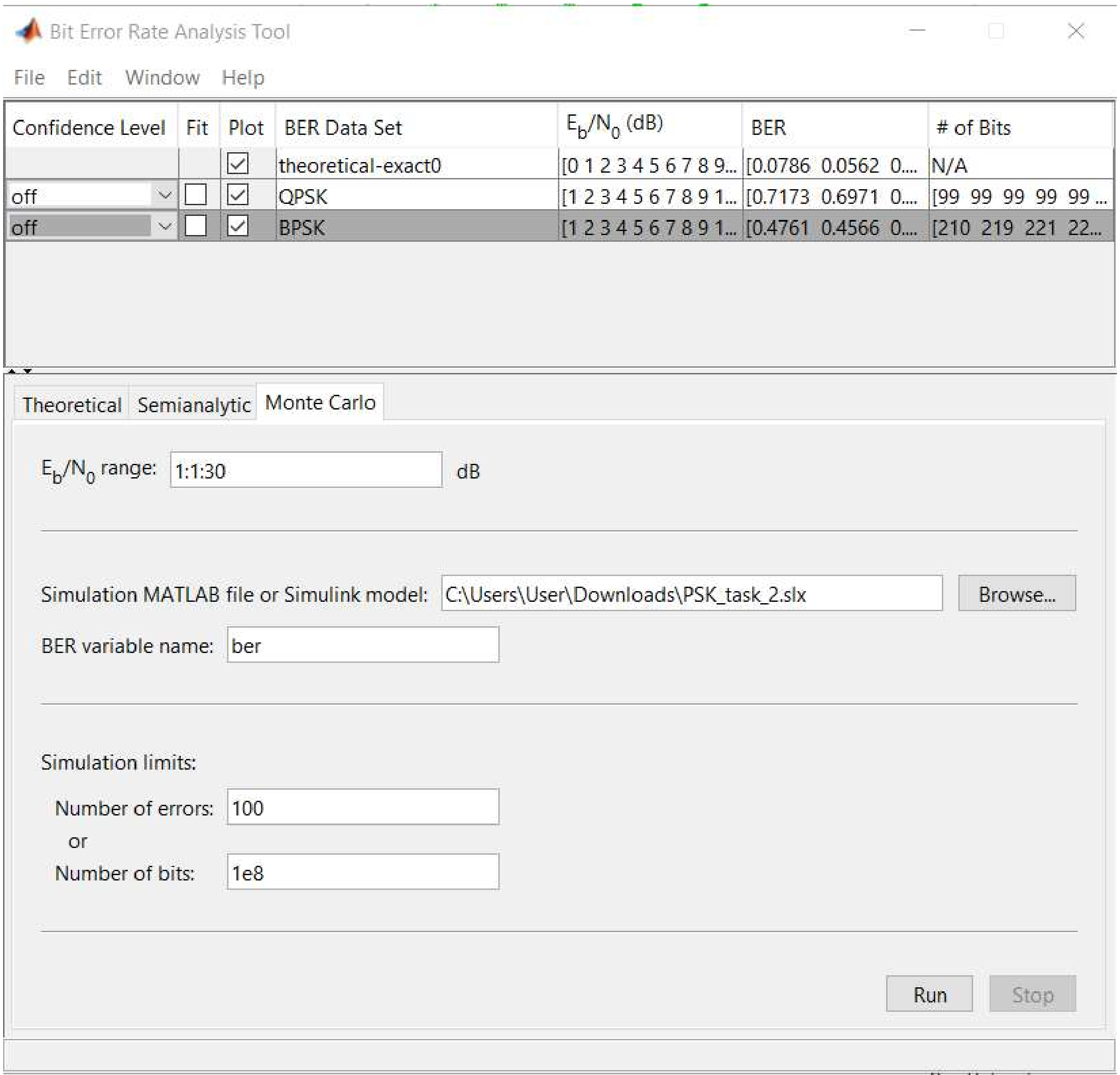

Bit Error Rate Analysis Tool
File Edit Window Help
Confidence Level
Fit
Plot
BER Data Set
Eb/N0 (dB)
BER
# of Bits
theoretical-exact0
[0 1 2 3 4 5 6 7 8 9...
[0.0786 0.0562 0....
N/A
off
QPSK
[1 2 3 4 5 6 7 8 9 1...
[0.7173 0.6971 0....
[99 99 99 99 99 ...
off
BPSK
[1 2 3 4 5 6 7 8 9 1...
[0.4761 0.4566 0....
[210 219 221 22...
Theoretical
Semianalytic
Monte Carlo
Eb/N0 range:
1:1:30
dB
Simulation MATLAB file or Simulink model:
C:\Users\User\Downloads\PSK_task_2.slx
Browse...
BER variable name:
ber
Simulation limits:
Number of errors:
100
or
Number of bits:
1e8
Run
Stop

Fig.72

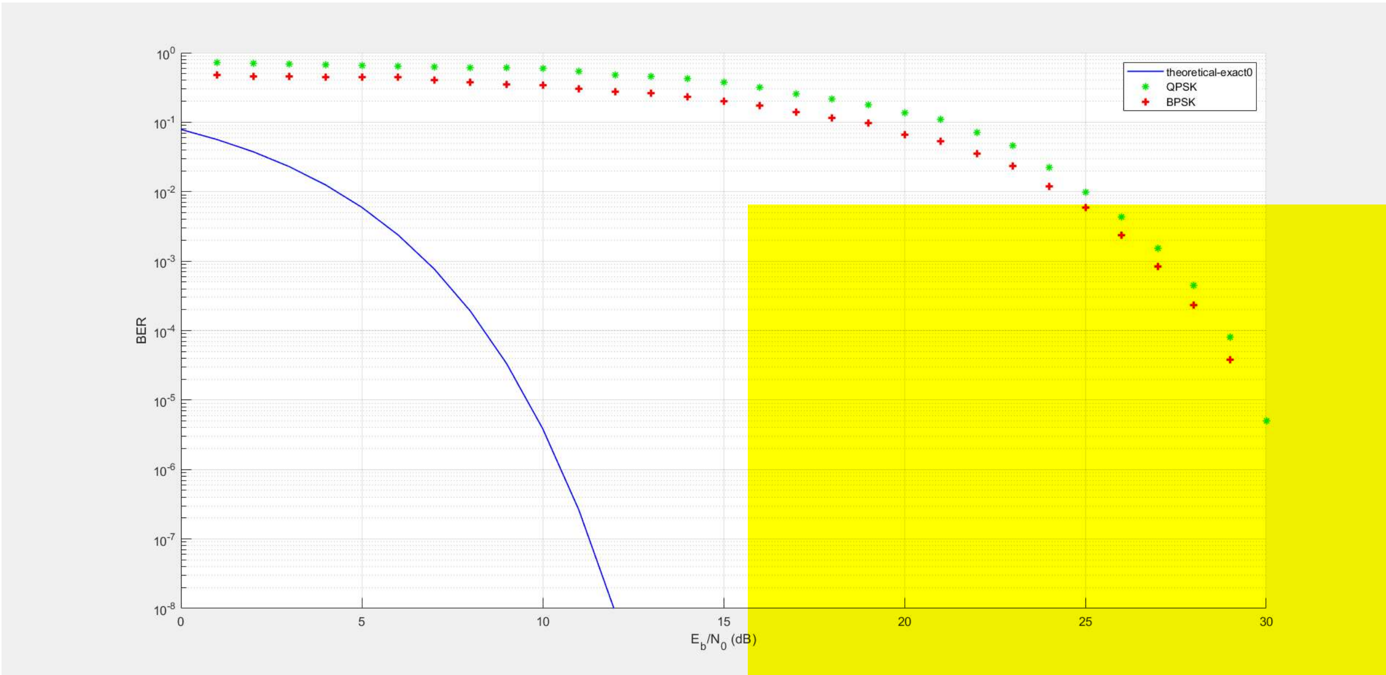


Fig.73

Performance curve of BER Vs Eb/No (dB)

Since, QPSK uses two bits simultaneously instead of one bit like BPSK uses, QPSK requires a slightly higher power than BPSK. Therefore, the power signal ratio of BPSK: QPSK should be low.

From the performance curve, if we extrapolate both the curves, we can get an estimation of Eb/No value at BER value of 10^-5.

For BPSK, Eb/No= 29dB

For QPSK, Eb/No= 30db

Power signal ratio of BPSK:QPSK= 29:30

So, $Eb_{BPSK} = 0.97*Eb_{QPSK}$

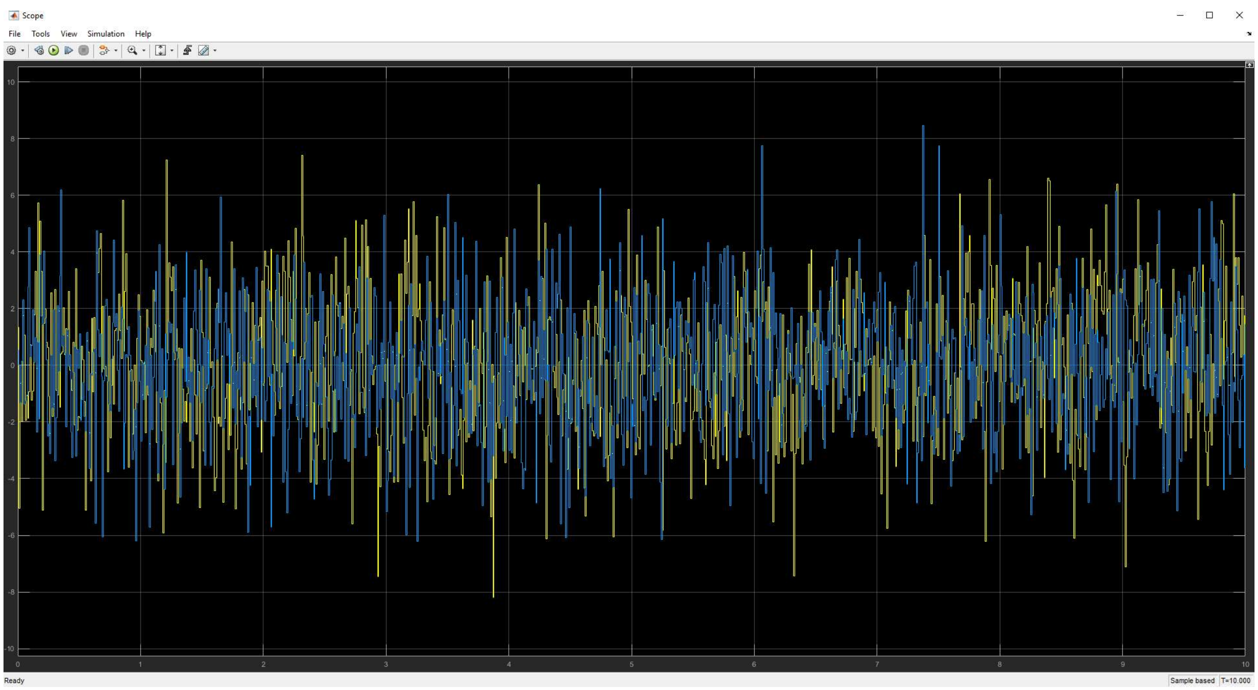
Hence, it is evident from the curve that BPSK requires lower power to operate as it only uses one bit rather than two bits simultaneously.

Comments: BPSK gives out one bit per symbol whereas QPSK gives out two bits per symbol. This means that BPSK gives out one bit per Hz whereas QPSK gives out two. From the performance curve, we found out the following relation BPSK is 97% of QPSK in terms of power signal in order to achieve a BER value of 10^-5 which is almost the same. In this way, we can conclude that QPSK is bandwidth efficient since it emits two bits instead of one with almost the same power requirement. We can conclude although QPSK requires slightly more power than BPSK, it is bandwidth efficient as it emits twice the number of bits with the same bandwidth.

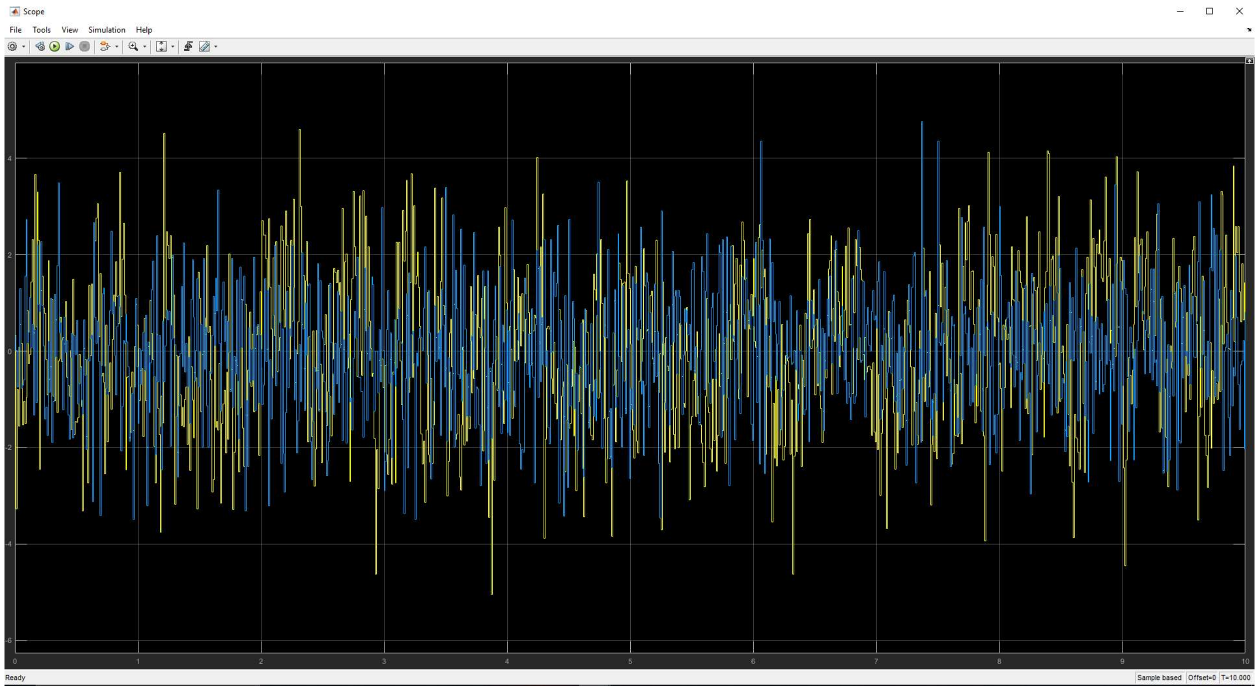
<u>Different waveforms at different SNR:</u>

Waveforms for BPSK:

At Eb/No=10dB,



At Eb/No=15dB,



At Eb/No=25dB,

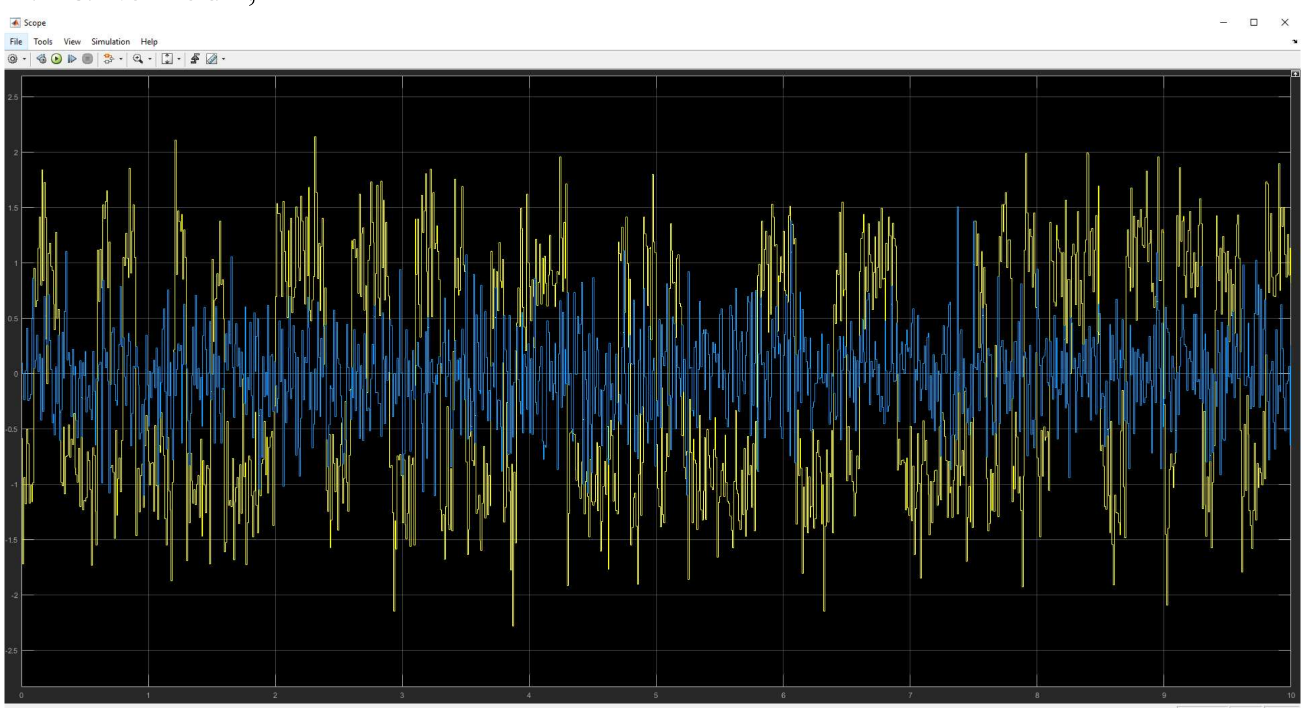
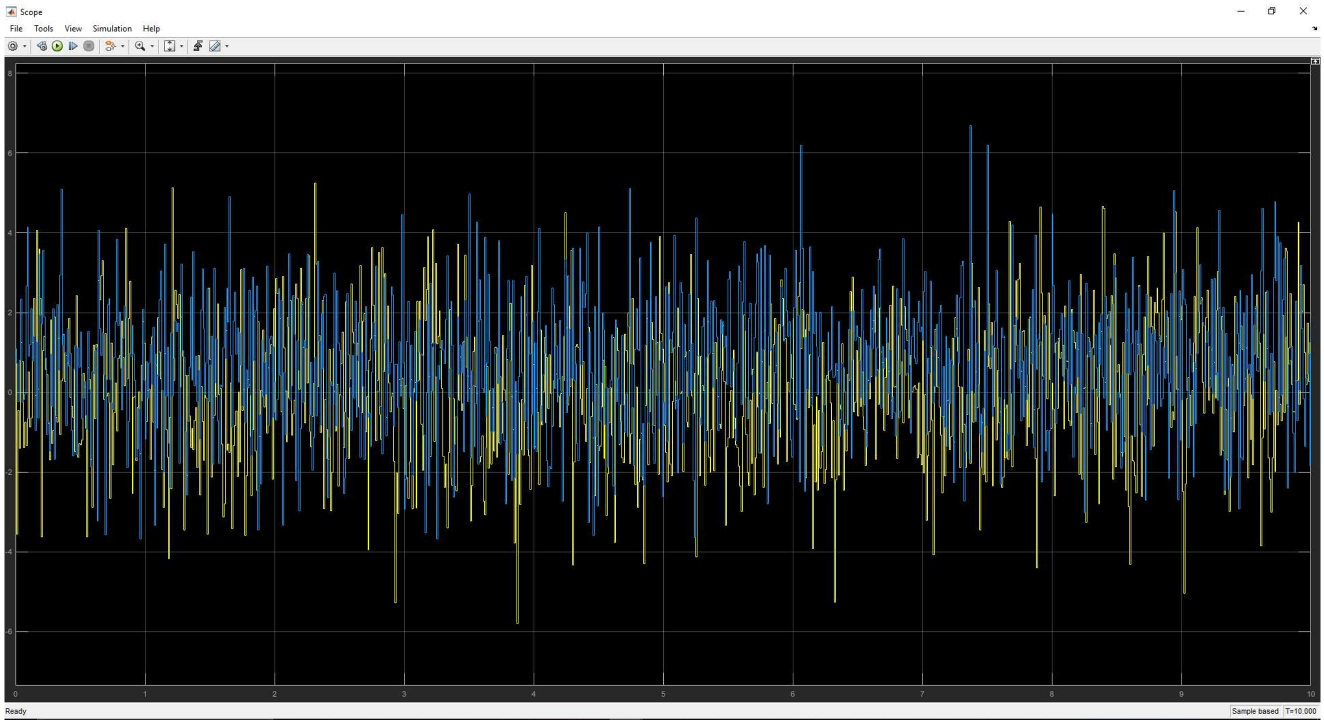


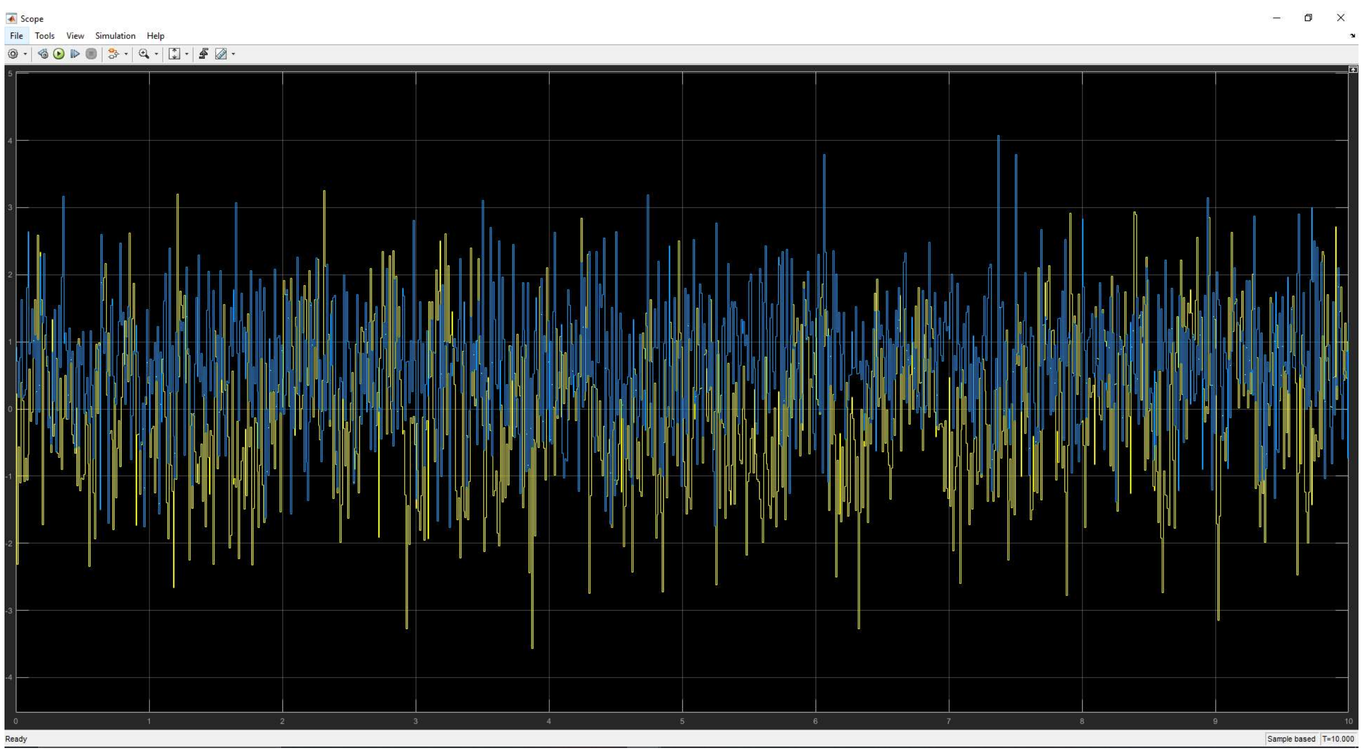
Fig.74-6

Waveforms for QPSK:

At Eb/No=10dB,



At Eb/No=15dB,



At Eb/No=25dB,

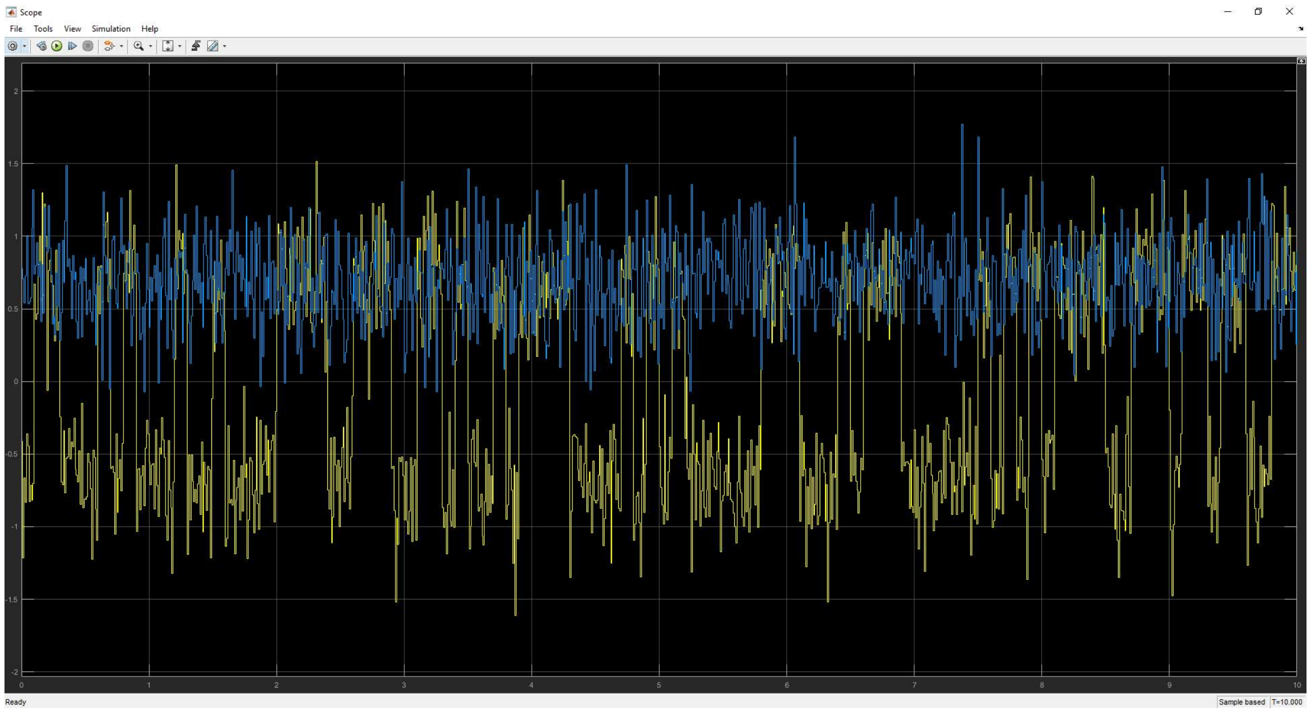


Fig.77-79

Access the simulation files from the link below:
https://drive.google.com/drive/folders/1_ZkXSAUU-JreafleTay0gwYNayklMW47?usp=sharing