Experiment 4

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Introduction

This assignment is about modelling a Mach Zender Modulator and using it to perform modulation for different formats like OOK, BPSK and QPSK along with plotting its transfer function. We also plot its Constellation diagrams or intensity or phase vs time plots and compare for different times, linewidths.

Plotting transfer function of the MZM:

First, we plot the transfer functions for the MZM. In order to do this, we send in individual bias voltage points to the MZM function to obtain the whole intensity plot. The linewidth, fsampling for the E-field of the laser don't matter here since here the inherent phase by the laser gets absorbed when we take the magnitude of Electric field and plot. Following are the parameters of the MZM transfer function plot.
a):
Vpi= 3 V
Voff (offset volt.) = 0 V
IL (Insertion loss) = 2 dB
ER (Extinction ratio) = 30 dB
Optical input power = -10 dBm
No. of points taken = 400
The transfer function is as plotted in fig.1.

b):
Vpi= 4 V
Voff= 0.8 V
IL = 3 dB
ER = 25 dB
Optical input power = -10 dBm
The transfer function is as plotted in fig.2.
No. of points taken = 400
The Extinction ratio and Insertion loss is verified from the peak and null points. We take 400 points here to plot 3 peaks and 2 nulls because it's enough to represent the waveform for the transfer function quite good. Also, it seems to be enough to get the peak and null points for intensity to reasonable accuracy such that the IL and ER can be verified.

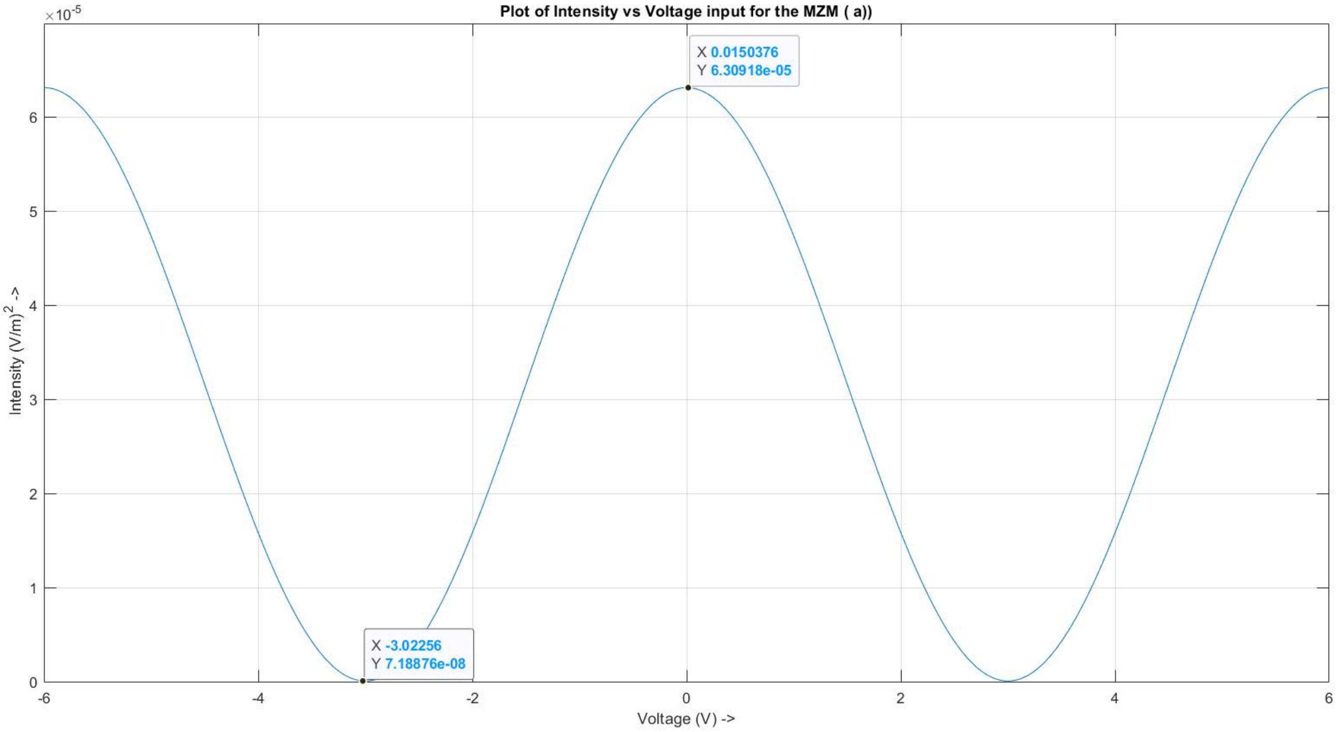

Figure 1: Transfer function plot (normalized intensity vs voltage) of MZM for part a). The peak and null points are marked.

OOK Modulation:

Here, we plot the OOK modulated intensity and phase plots with the constellation diagram. This is done by biasing the MZM at 0.5Vpi with a chosen swing of Vpi (peak to peak) so that the modulation depth is high and we can see the waveforms clearly. However, practically, ofcourse it might be chosen to be a lower value for linearity. Here, we have 0 rise time, so it isn't an issue and we use a full swing of Vpi for illustration. The data rate is 10Gbps using PRBS9 and samples per sec. is 8. So, by definition, fsampling for the laser as well has to be in sync with the fsampling for the input OOK voltage waveform. Therefore, fsampling for E-field is 80GHz. The time duration chosen is 10ns with total of 100 symbols enough to plot and show clearly the OOK intensity waveform. Additionally,we want to represent a good OOK output showing the amplitudes present and with low phase noise. Hence,

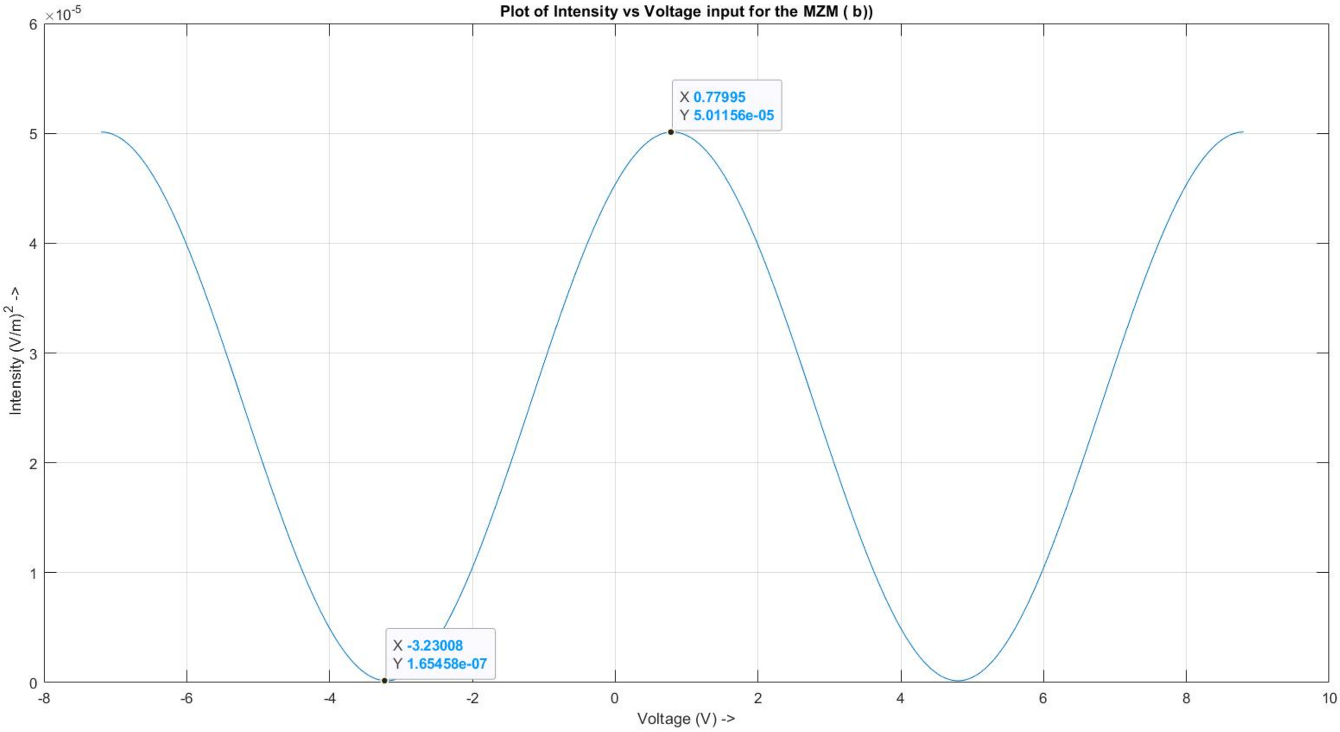

Figure 2: Transfer function plot (normalized intensity vs voltage) of MZM for part b). The peak and null points are marked.

choosing only 10ns of time duration.
The output intensity vs time and phase vs time plots are in fig. 3. We see that the OOK modulated intensity is right, but the phase is also oscillating between 0 and -90 deg. This is because of the finite extinction ratio of the modulator and the way we apply the phase to both arms of the MZM. As seen in the code for the MZM function, instead of introducing a phase of +theta to E2 electric field and 0 deg. to E1, we introduce a phase of -theta/2 to E1 and +theta/2 to E2. This, with non unity 'eta' causes the jumps to -90 deg. in phase when destructive interference occurs. This doesn't matter, we are only interested in the intensity for OOK.
The constellation spread is shown in fig. 4. We see the Electric fields being near origin or at (1,0) with minimal phase spread as intended.

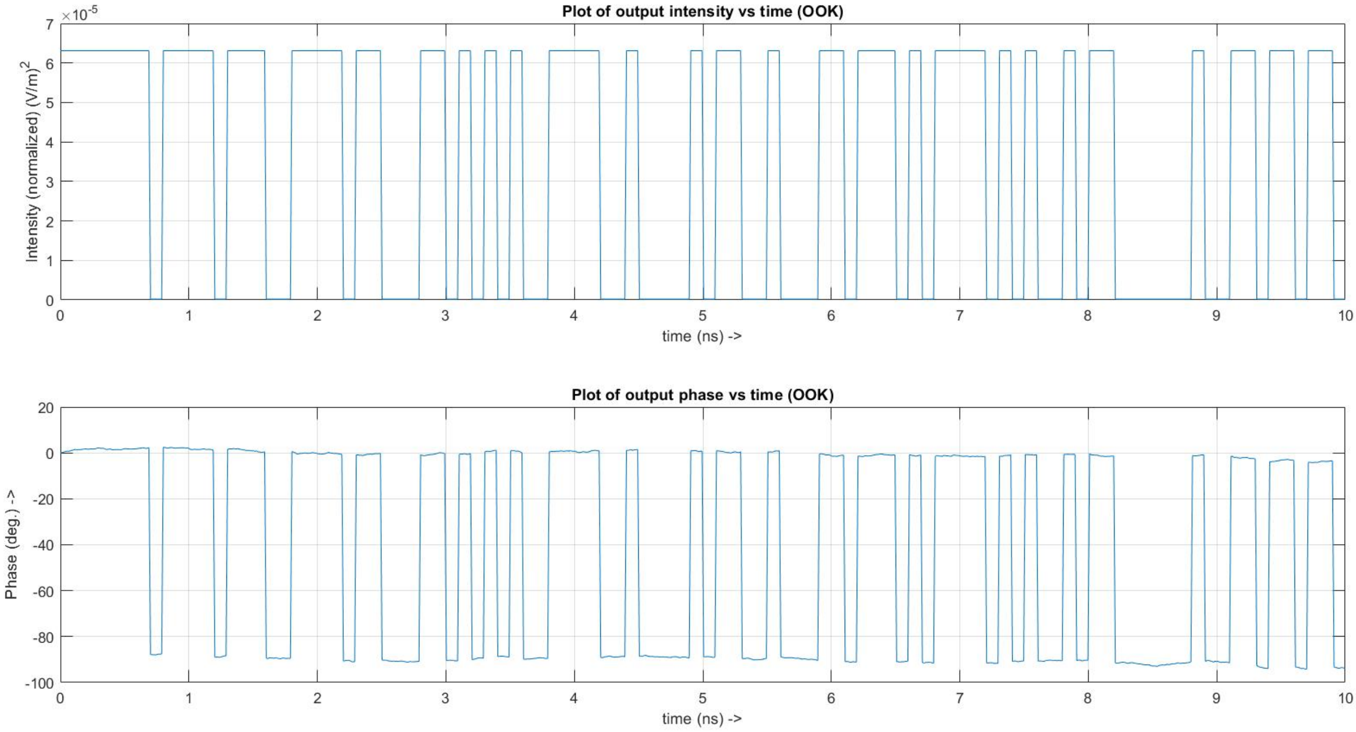

Figure 3: Plots for intensity, phase as a function of time for OOK.

BPSK Modulation:

Here, we perform the BPSK modulation using the same 10Gbps data rate of PRBS9 biasing the MZM at Vpi with a full swing of 2Vpi (peak to peak). The samples per symbol is 8 and hence the fsampling for both input OOK voltage waveform and the E-field for laser is the same at 80GHz. The time duration chosen is also the same, at 10ns with a total of 100 bits (or symbols- since it's BPSK it doesn't matter) because it's sufficient enough to represent the phase modulation time domain waveform clearly and also clearly showing the constellation points at (1,0) and (-1,0) with low phase noise. Sampling frequency is already in the GHz range. Hence, for a low phase noise and clear representation of the BPSK constellation, we take only a time of 10ns. Additionally, as seen in the code, we add a phase of +2pi for all the angles below -90 deg. to conveniently view the phase modulation waveform.
The intensity and phase plots are as shown in fig. 5. We observe that the

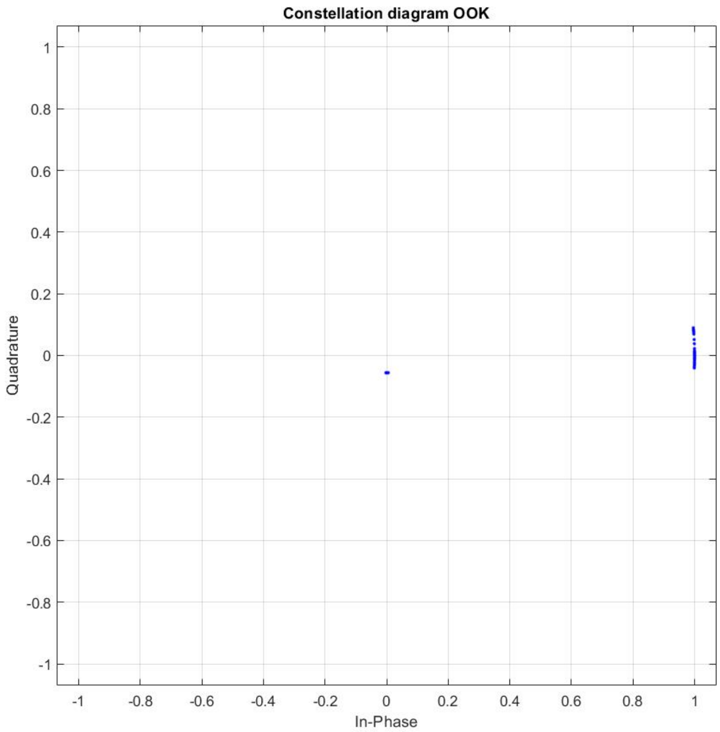

Figure 4: Constellation diagram for OOK modulation.

intensity is also almost unchanged with minor fluctuations (due to finite ER).
The constellation points are as shown in fig. 6.

Making an IQ Modulator:

Here, we generate QPSK modulation using an IQ modulator from two instances of the MZM function. We assume that the data sequence of 10Gbps PRBS9 (with sps= 8, hence sampling rate = 80GHz) is given to each MZM to perform BPSK modulation and then add a phase of pi/2 to one of them and add to give QPSK modulation. So, the net IQ modulator would give a 20Gbps output datarate. Since the 2 input voltage waveforms to the 2 MZMs are at a sampling rate of 80GHz, in order to maintain sync, we have to have fsampling for the input electric field to be 80GHz again as well. We use a time duration of 10ns with total 100 symbols again so that the out-

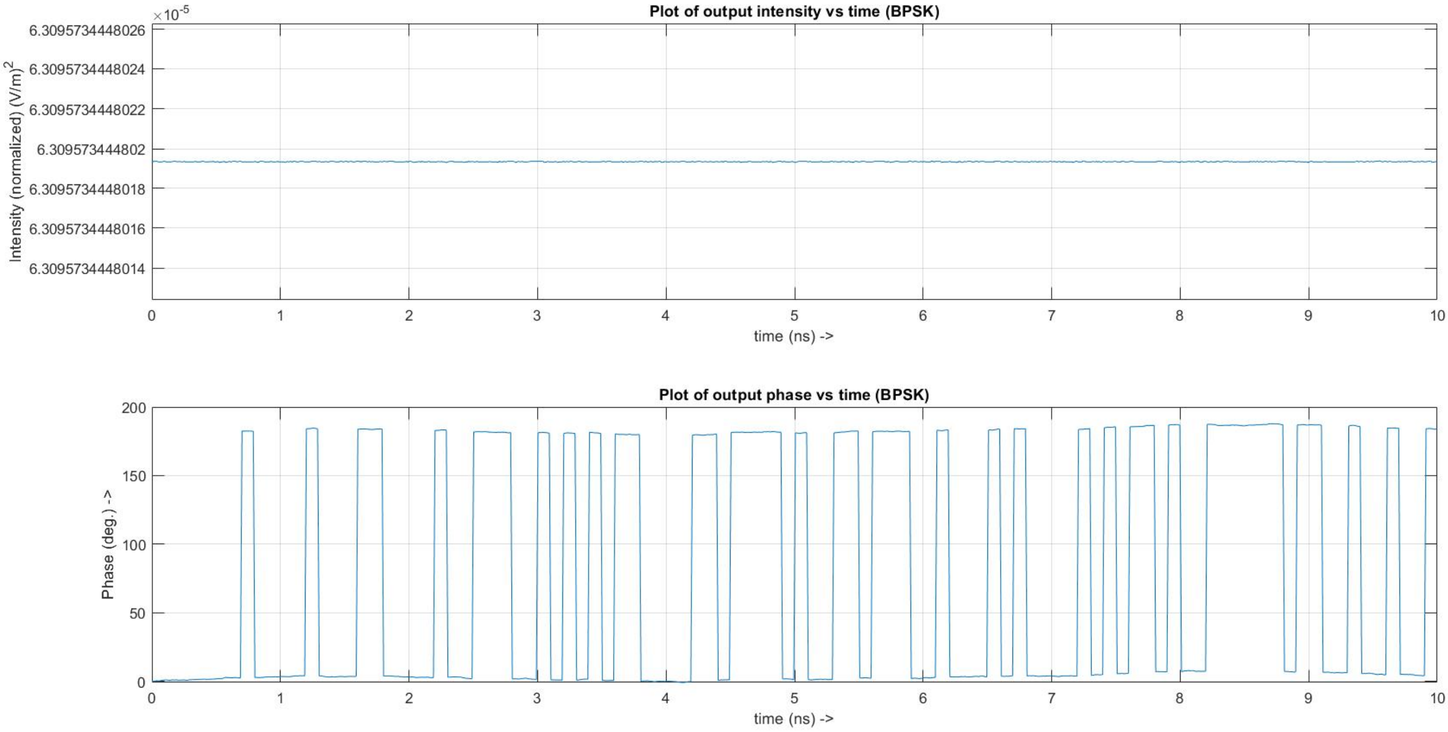

Figure 5: Plots for intensity, phase as a function of time for BPSK.

put phase modulation and constellation is clearly represented with low phase noise for the constellation diagram as well. Also, the PRBS9 sequences for the two MZMs are shifted slightly by some bits so that we dont have exactly identical sequences fed to them. Finally, a phase of 90 deg. is added to one of the Electric fields (which are BPSK modulated) to generate the QPSK modulation.
The intensity and phase with time plots are shown in fig. 7. We see the intensity is almost constant with the phase having values of 45, 135, 225 and 315 deg.
The constellation diagram is shown in fig. 8 with low phase noise as well.

QPSK Modulation for PRBS13:

In this section, we plot constellation diagrams of QPSK modulation outputs for different linewidths of 1MHz and 10MHz and time durations of 50ns and

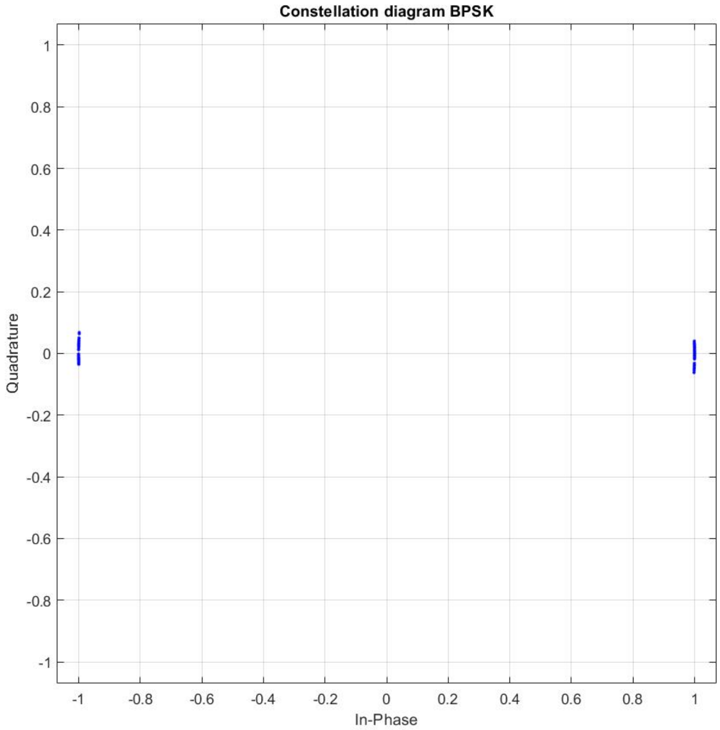

Figure 6: Constellation diagram for BPSK modulation.

600ns. The baud rate specified is 1 Gbaud. So, we feed in 1 Gbps input OOK voltage waveforms to the two MZMs. Since the linewidth is in MHz, we need to choose sufficiently low enough time durations (of order of ns) in order to represent phase spreads within a quadrant of the plot. Hence, parameters chosen for both linewidths are:

<u>LW = 1MHz and 10MHz:</u>
For a time duration of 50ns chosen,
sps = 4
fsampling = 4GHz (since bitrate for each MZM = baud rate = 1Gbaud implying fsampling = sps*bitrate)

For a time duration of 600ns chosen,
sps = 8
fsampling = 8GHz (since bitrate for each MZM = baud rate = 1Gbaud im-

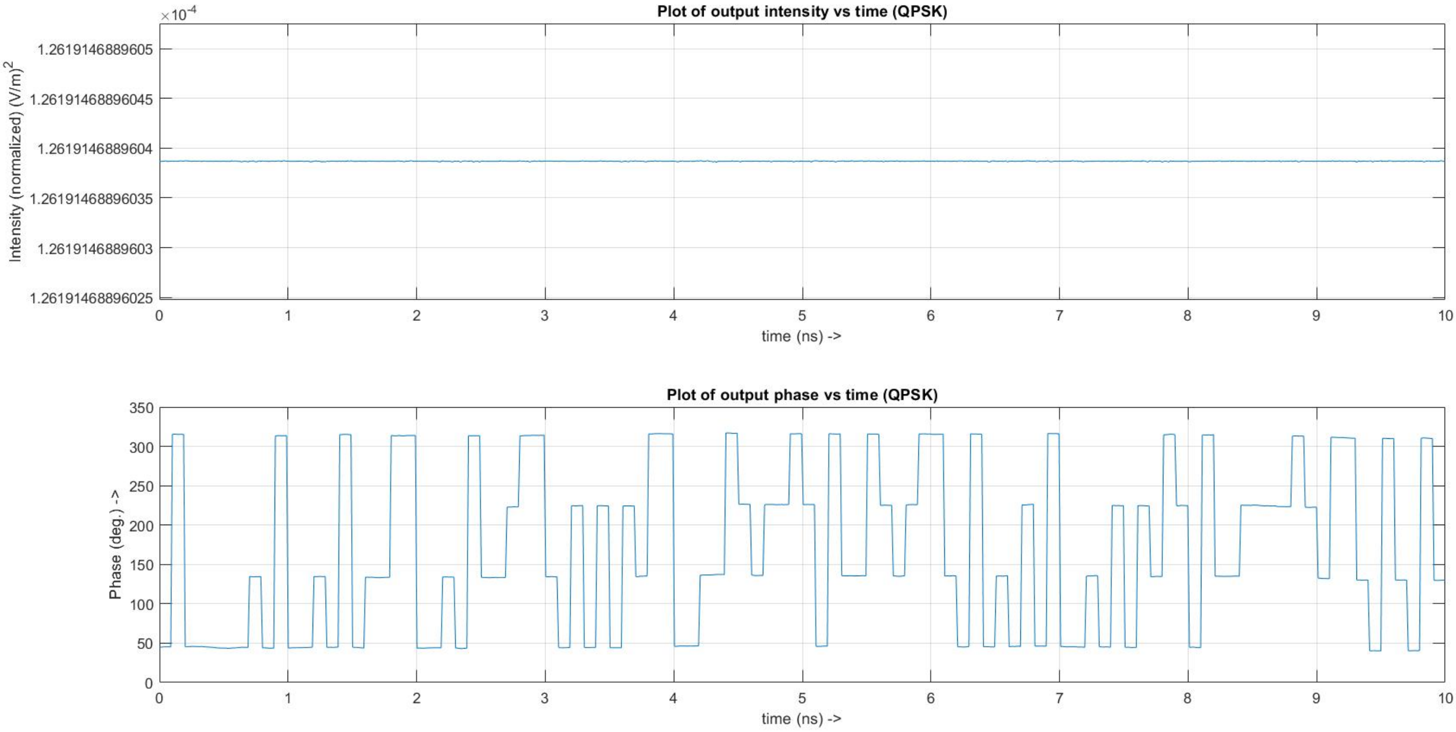

Figure 7: Plots for intensity, phase as a function of time for QPSK.

plying fsampling = sps*bitrate)

Firstly, for both linewidths we have the same parameters because practically looking at it we want to test out for two linewidths for a given time duration with the same sampling frequency to avoid any bias given. For the case of having the constellation diagram confined to a quadrant (as in not crossing the quadrant), we choose a small enough time duration of 50ns, since the linewidths are of the order of MHz. We can't go lower since the plots become too sparse. It's already at 50 symbols for this time durations. The 'sps' or samples per symbol is also low to give low phase noise using a low sampling frequency to make the constellation fit within the quadrants for both linewidths.
Now, we want the constellations to span the whole circle, so we choose a high time duration of 600ns and not go lower for this reason. We don't go higher as well because then the distinction between 1MHz and 10MHz linewidths

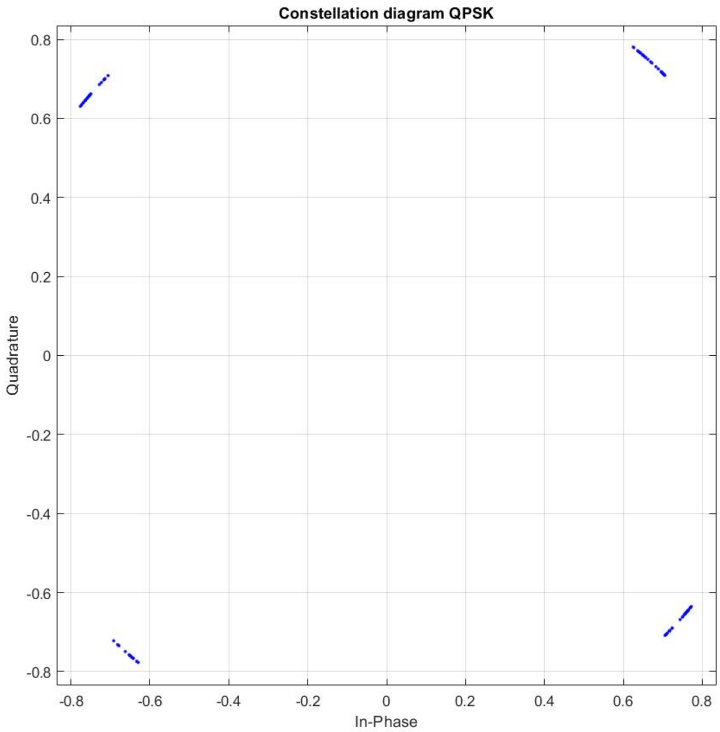

Figure 8: Constellation diagram for QPSK modulation (PRBS9).

becomes lower. We also choose an sps of 8 to increase the sampling frequency and hence, the phase spread sufficiently.
The plots for a time duration of 50ns are shown in fig. 9 and 10 for linewidths 1MHz and 10MHz respectively. We see that the phase spread is confined in each quadrant for each linewidth and that the plots are not as dense as in the later plots showing lower time durations used. The spread is more in the 10MHz case obviously.
The plots for a time duration of 600ns are shown in fig. 11 and 12 for linewidths of 1MHz and 10MHz respectively. We see that both spreads cover full circle and that the 10MHz case is slightly more dense and spread around compared to the 1MHz case which appears patchy in some places.

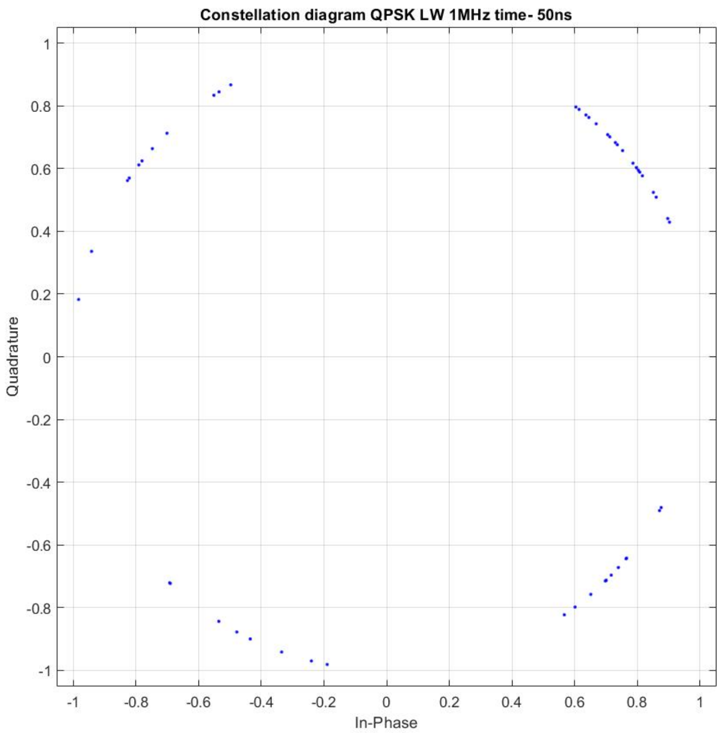

Figure 9: Constellation diagram for QPSK modulation for t-duration= 50ns, Linewidth 1MHz.

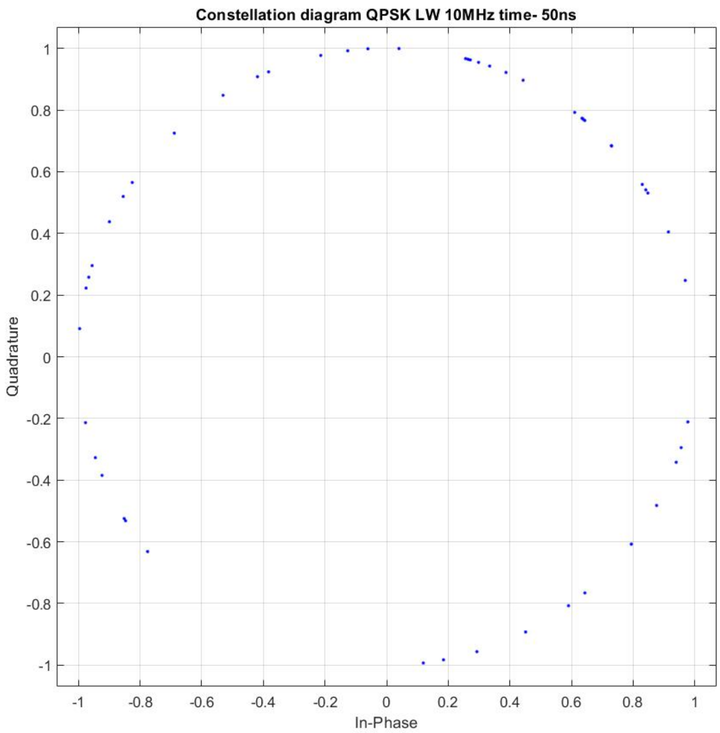

Figure 10: Constellation diagram for QPSK modulation for t-duration= 50ns, Linewidth 10MHz.

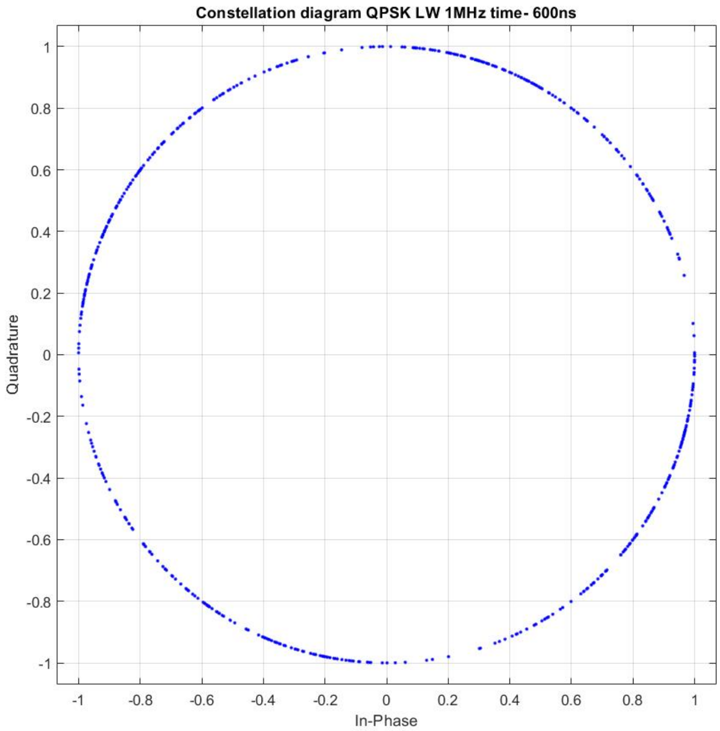

Figure 11: Constellation diagram for QPSK modulation for t-duration= 600ns, Linewidth 1MHz.

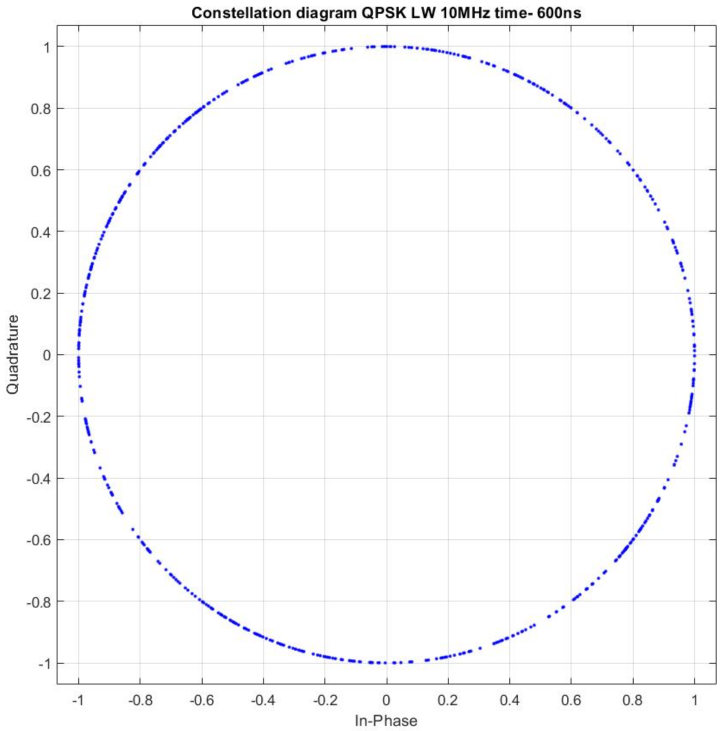

Figure 12: Constellation diagram for QPSK modulation for t-duration= 600ns, Linewidth 10MHz.