Experiment 2

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Introduction:

This assignment deals with generating PRBS signal (or OOK) waveforms and their analysis when noise is added. Initially, we generate the PRBS9 sequence and plot their time, frequency domain representations by taking a defined value of samples/symbol. Additionally, for the noiseless PRBS sequence generated, we plot it's constellation diagram. Now, white gaussian noise is added and we see how the constellation diagram and the 'Eye diagram' turns out for SNR-5dB,10dB,15dB. The constellation diagrams are to tell the spread in the symbol values. The eye diagram tells us the distinction between the logic high and logic low.

Generating PRBS9 waveforms:

Symbols plot:

We have already seen in the last experiment how to generate PRBS9 sequences. We take 2^{12} symbols and make an OOK waveform with baud rate 10Gbaud implying each symbol period is 0.1ns. We plot a stem plot of symbols vs time for a 10ns duration (hence, taking only symbols till that time). This is done by generating a time vector having timestamps spaced at 'Tbaud' intervals and positioning the symbol at the middle of the period(so the first timestamp is at Tbaud/2). This has been explained in the code. The plot is as shown in fig.1.

Time and Frequency Domain plots:

Now we generate time domain equivalent waveforms which are actually sent. We use three cases of Nt (samples/ symbol)- 2, 4 and 8. For each Nt, we replicate the symbol in it's time slot of 'Tbaud', 'Nt' times done for all 2^{12} symbols. This is done by replicating the prbs sequences and concatenating values of each symbol window with the that of the rest of the symbols as explained in the earlier experiment. Now, for plotting purposes, the waveform is plotted only upto 10ns. For the PSD calculation, we account for the entire original length of the signal. The PSD calculation is carried out by finding the square of absolute values of the DFT normalizing with respect to 'N' (total no. of samples) and 'fs'. We also take twice to account for it being a real signal. This was also covered in the last experiment. The plots for time domain waveforms and the one-sided Power spectral density for the cases Nt = 2, 4 and 8 are given in fig. 2,3,4,5,6 and 7.

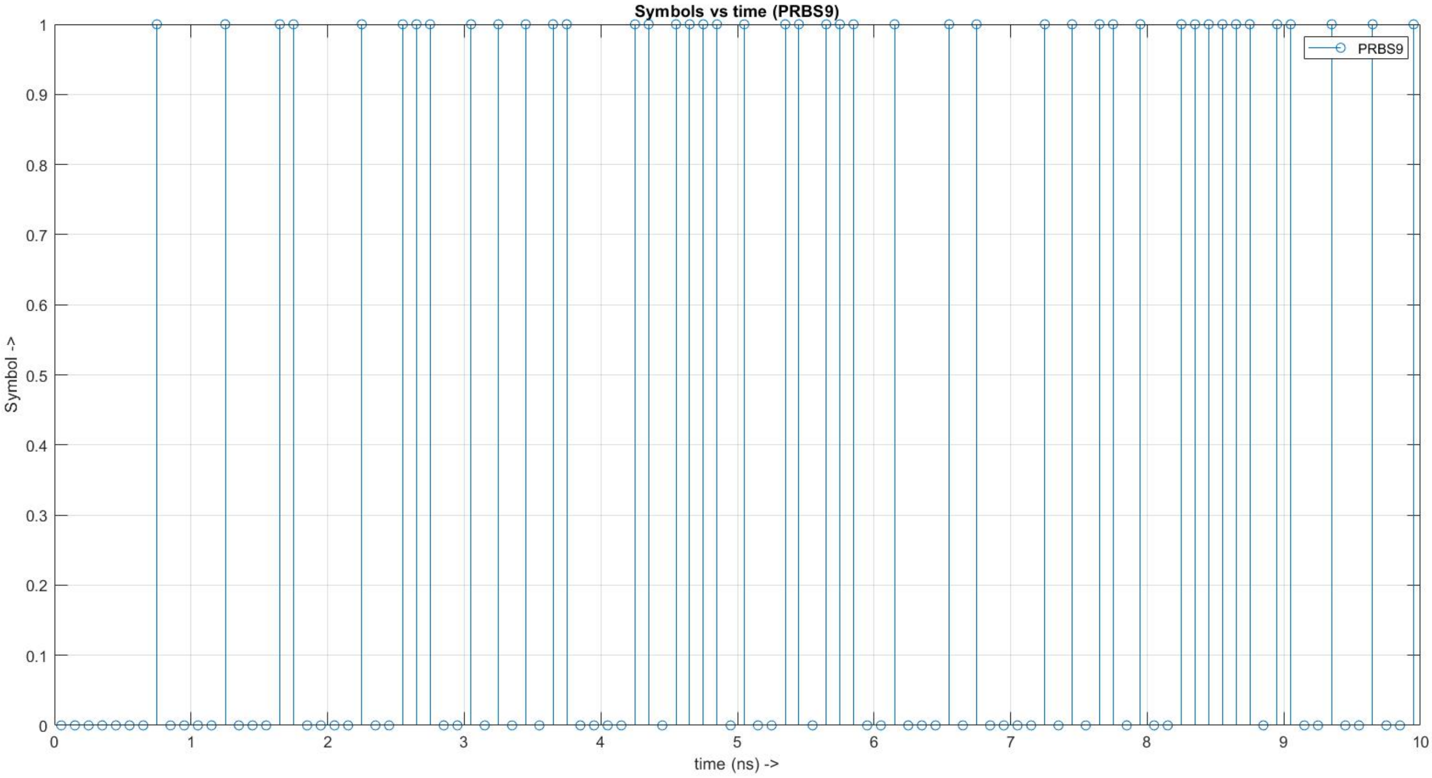

Figure 1: Symbols vs time for PRBS9 for a 10ns time window at a 10Gbaud rate.

The time window taken for plotting is the same: 10ns which is given.
Sampling frequency=fs = Nt*fbaud (samples/symb * symb/s gives samples/s)
Frequency window= fs/2 which is defined by DFT and it's a real signal, hence only 0 to fs/2 is required.
No. of DFT samples N = Nt*2^{12} (Nt samples/symbol * total number of symbols)

Frequency resolution= fs/N = fbaud/2^{12} (the Nt factor gets cancelled) which is same for all: 2.441 MHz.
<u>Nt = 2:</u>
Sampling frequency = 20GHz
Freq. window = 10GHz

Nt = 4:
Sampling frequency = 40GHz
Freq. window = 20GHz
Nt = 8:
Sampling frequency = 80GHz
Freq. window = 40Ghz

Clearly, we see that as the Nt increases the waveform is more accurate and hence the nulls at various frequencies become more apparent.

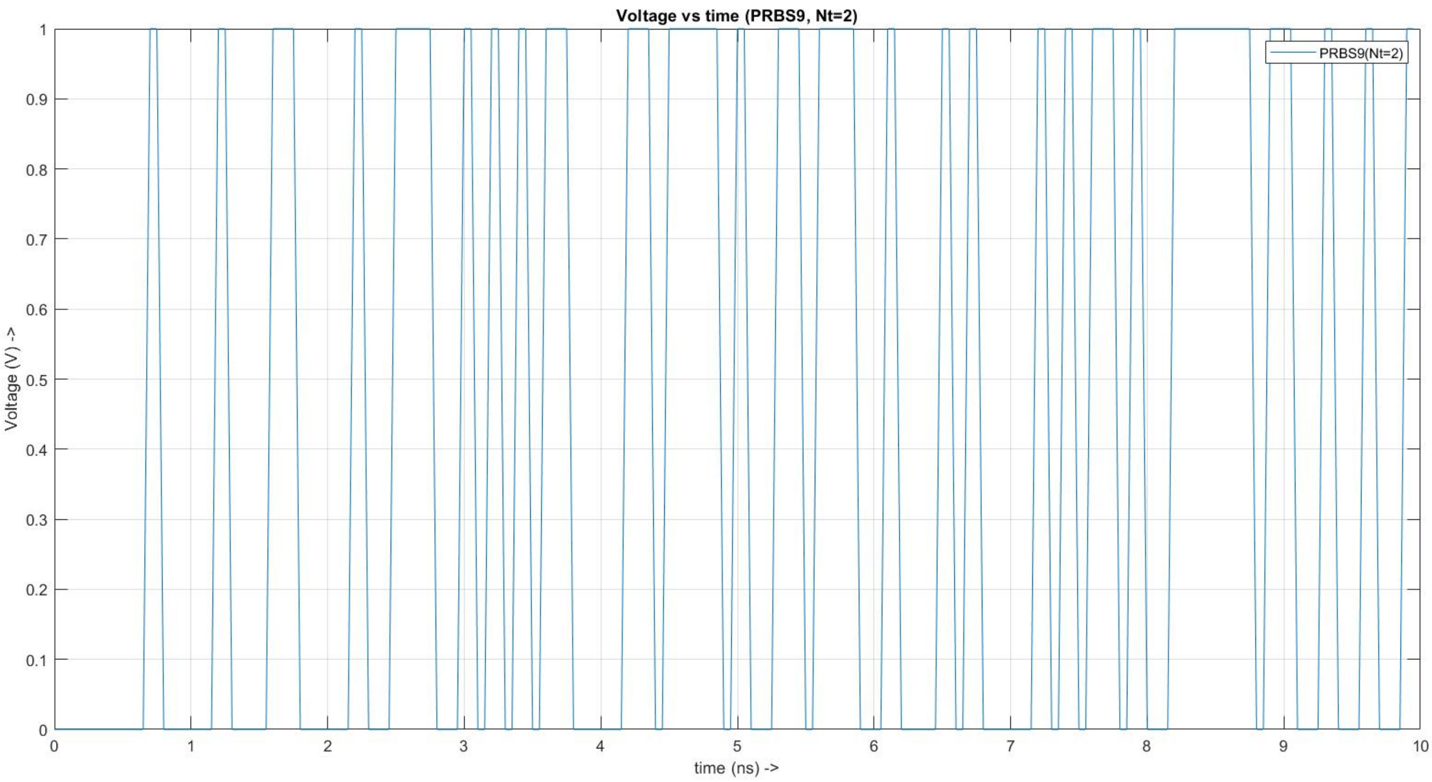

Figure 2: Voltage vs time for PRBS9 waveform with Nt = 2 samples/ symbol plotted only for 10ns.

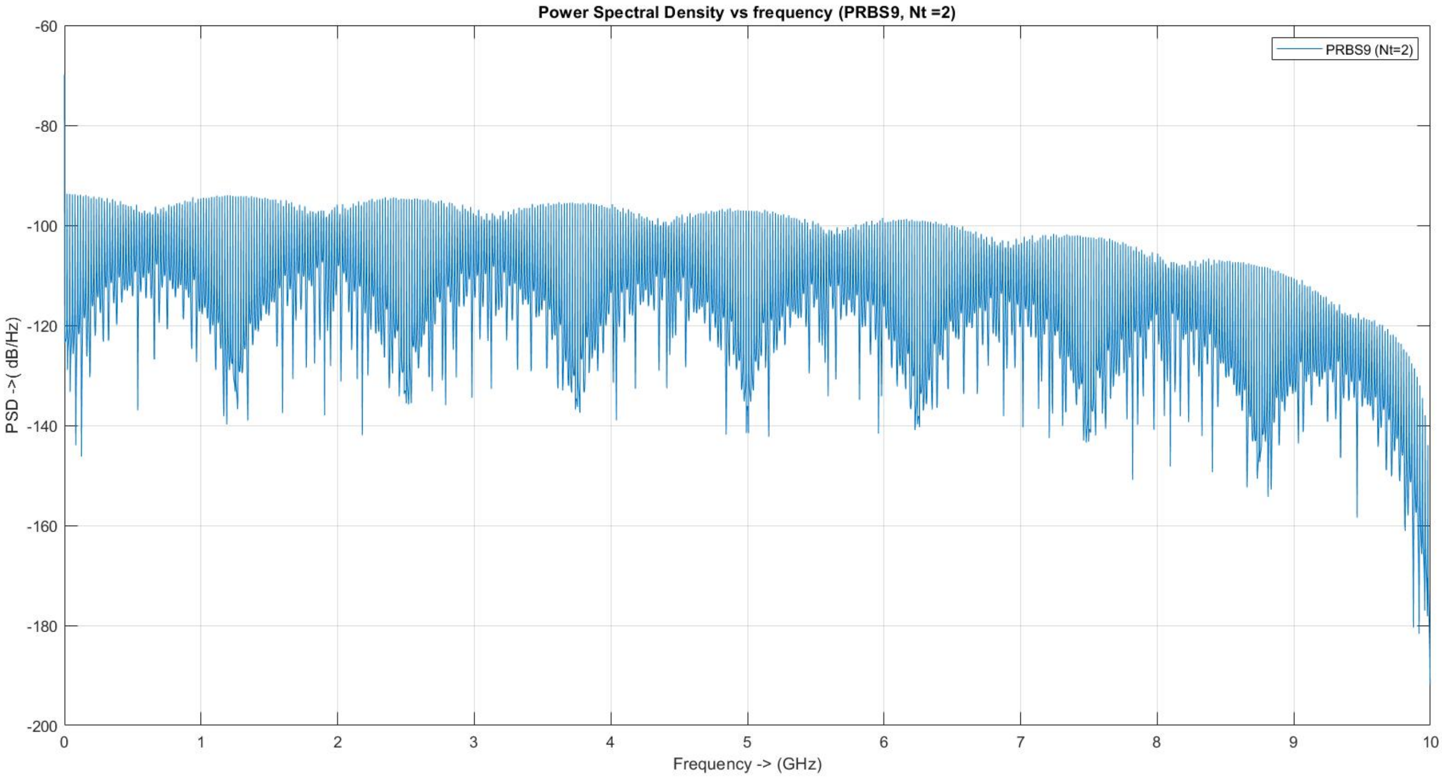

Figure 3: Power spectral density of the PRBS9 time domain waveform with Nt= 2 samples/symbol done by fourier transform.

Constellation diagrams:

Noiseless:

The constellation diagram for a given sequence of symbols is directly plotted using the 'scatterplot' function since we already have the vector of modulated OOK symbols. Here, it is done for all 2^{12} symbols. The plot is as shown in fig. 8. There's no noise, so the points are exactly at (0,0) and (1,0).

With noise:

Noise is added to the symbols vector by the 'awgn' function. We measure the power of the input symbols vector and add approriate amount of noise to

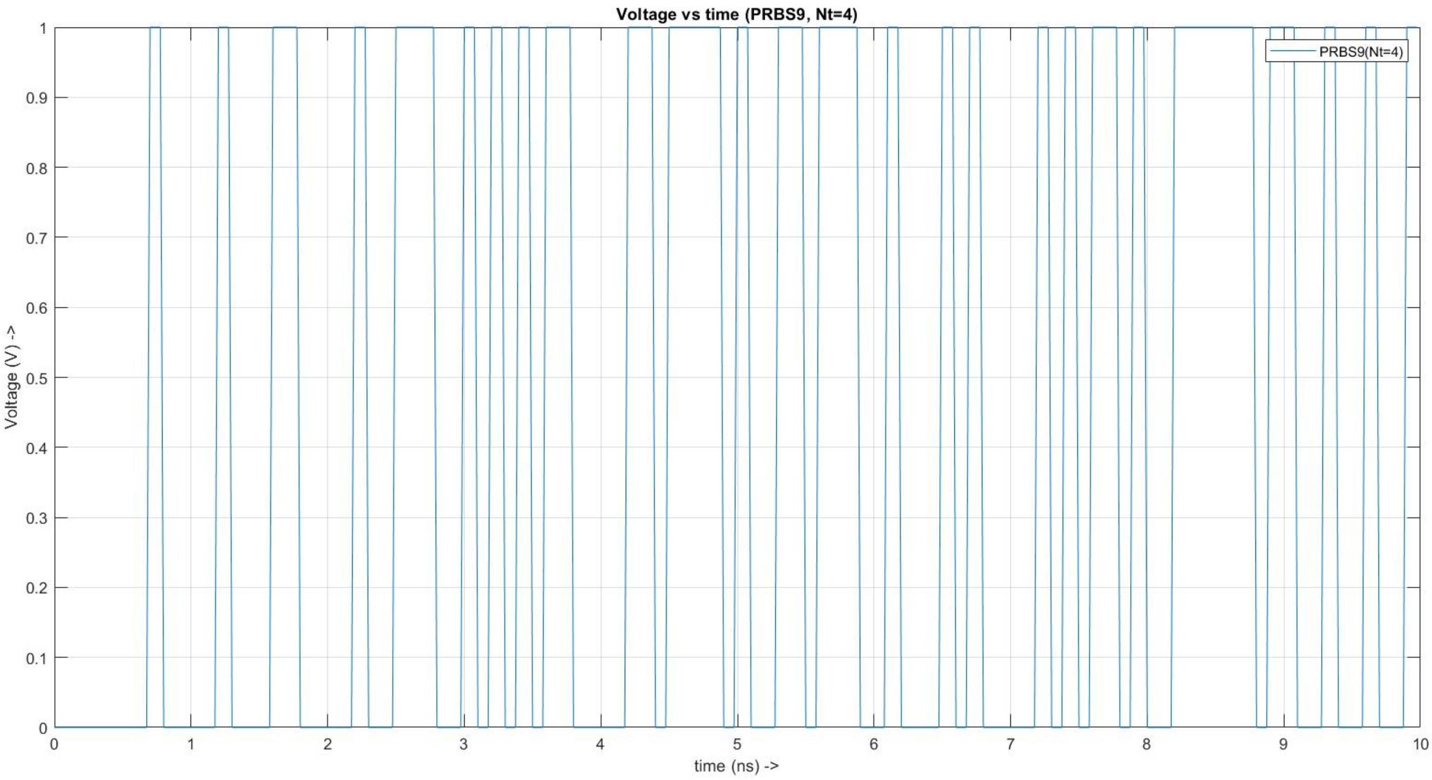

Figure 4: Voltage vs time for PRBS9 waveform with Nt = 4 samples/ symbol plotted only for 10ns.

give a desired SNR, which is taken as 5dB, 10dB and 15dB here. The output symbols vector is plotted via 'scatterplot' as shown in fig. 9 10 and 11 for SNR= 5dB, 10dB and 15dB respectively. Here, the noise is added directly to the discrete symbols. Even if we were to have a waveform to which we add noise and we take one sample for each symbol and plot the constellation diagram we will get the same effect. This is because since its white gaussian noise, the probability density of noise added at each sample would be independent and identical and hence, the dispersion caused in amplitude for the same SNR and same total number of symbols plotted on the constellation diagram, for both cases on an average is the same. Clearly, we see that the signal is more distinguishable as 0 or 1 when the SNR increases. The variation is also along only the I-axis, since real white gaussian noise is added. In OOK, we are concerned only about the intensity/ amplitude noise, hence

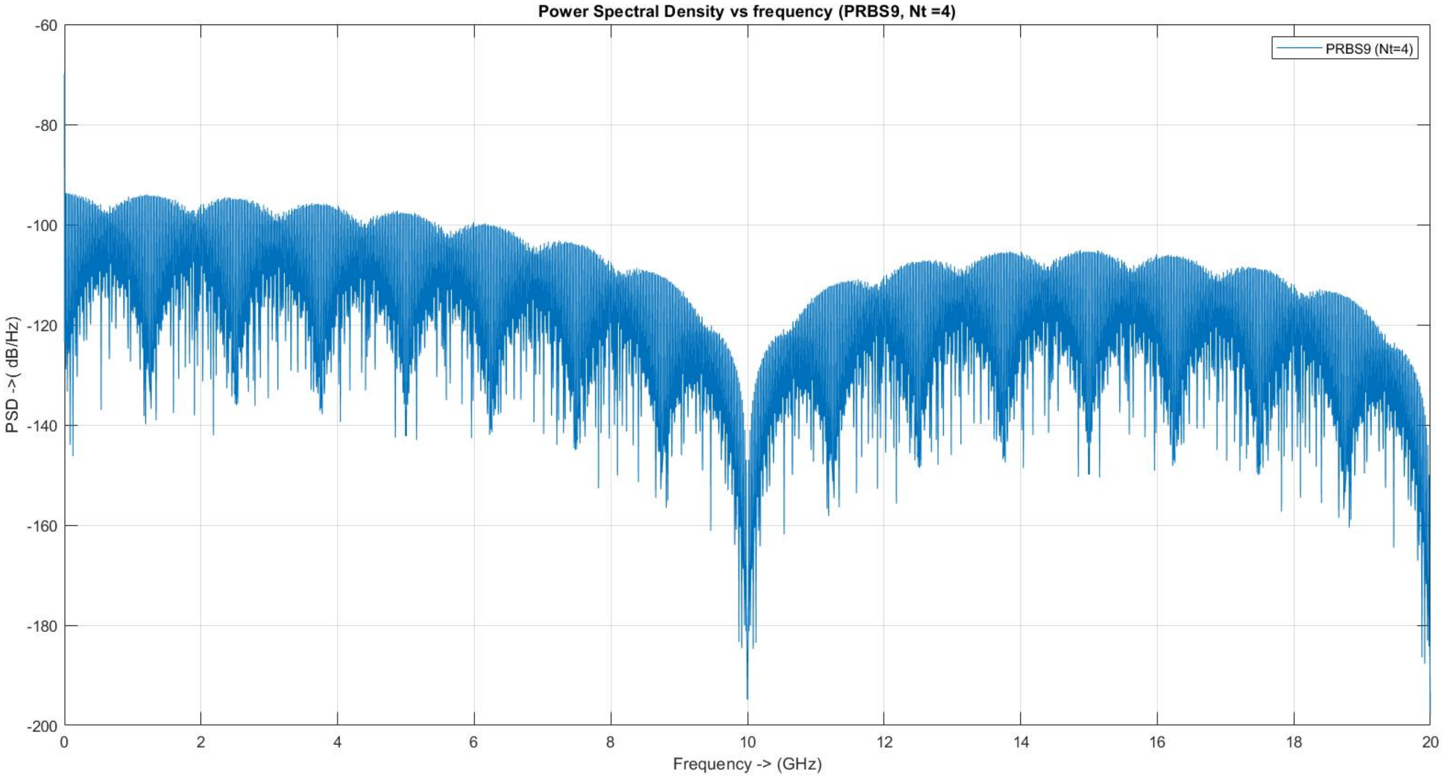

Figure 5: Power spectral density of the PRBS9 time domain waveform with Nt= 4 samples/symbol done by fourier transform.

phase noise is irrelevant.

Eye diagram:

We need the time domain waveform for plotting the eye diagram. Hence, we use the most accurate waveform we have- the one with Nt = 8 samples/symb representing all 2^{12} symbols. White gaussian noise is then added to this waveform after measuring it's power to obtain a signal at a given SNR- 5dB, 10dB and 15dB in this case using the 'awgn' function. Now, we just pass the signal to the 'eyediagram' function. The arguments of the eye diagram function are chosen as:
x- input signal in time domain, this is the signal after noise addition.

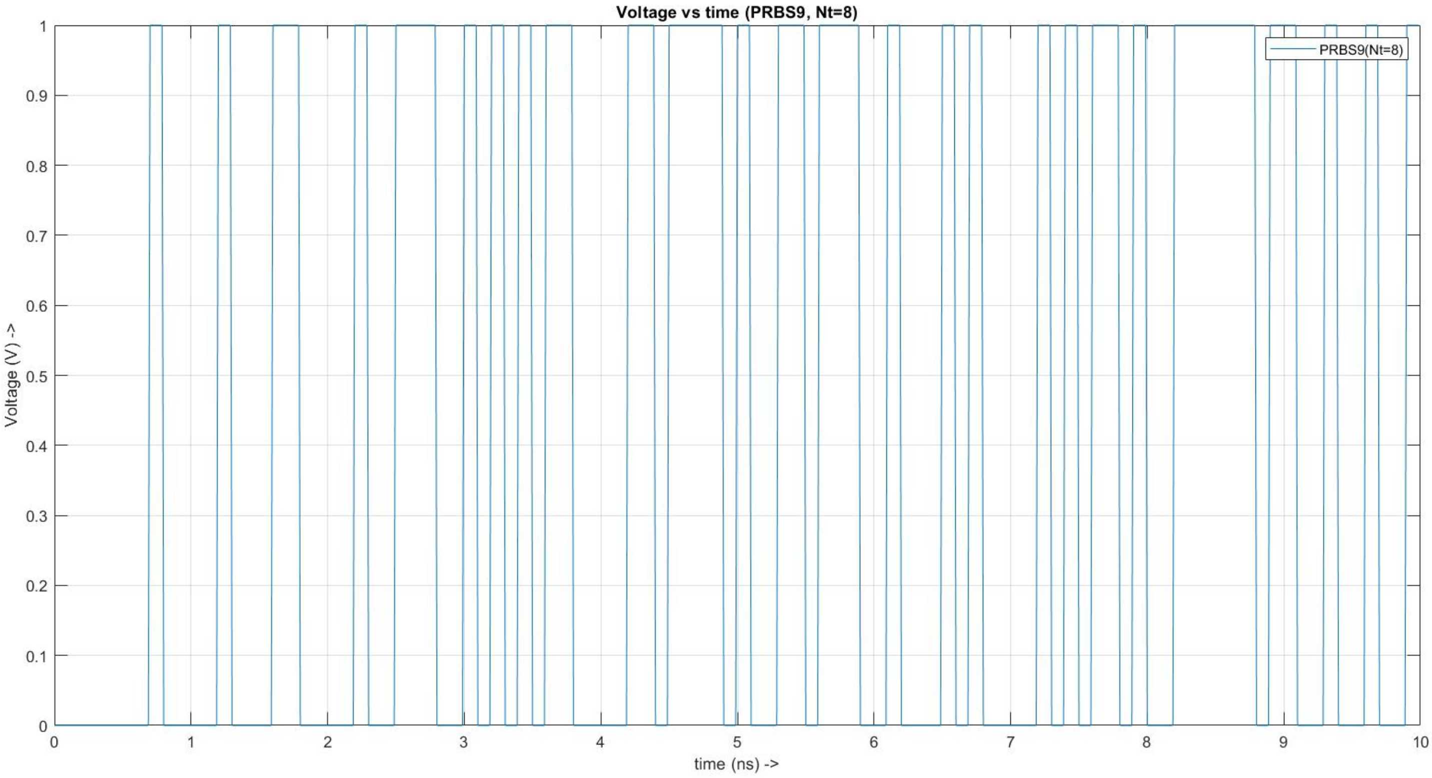

Figure 6: Voltage vs time for PRBS9 waveform with Nt = 8 samples/ symbol plotted only for 10ns.

n- no. of points plotted/ assumed periodicity in the signal chosen as 16. Although Nt =8 implying assumed periodicity should also be 8, we can't align the eye in the middle for a proper observation with n=8. Hence, we choose n= 16 and it plots over two symbols.
period- this ensures it plots over -period/2 to period/2. So, here, since we are plotting 2 symbols, the argument is given as 0.1ns*2. (Tbaud= 0.1ns)
offset- This offsets the plot by k samples where 0 <= k<= n-1. k is chosen as 3 here for placing the eye in the middle.
The plots are shown in fig. 12, 13 and 14 for SNR 5dB, 10dB and 15dB respectively. Another thing to note is that, the signal plotted is periodic in itself, so the starting and ending timestamps don't matter as long as the entire interval corresponds to 2*Tbaud for 2 symbols.

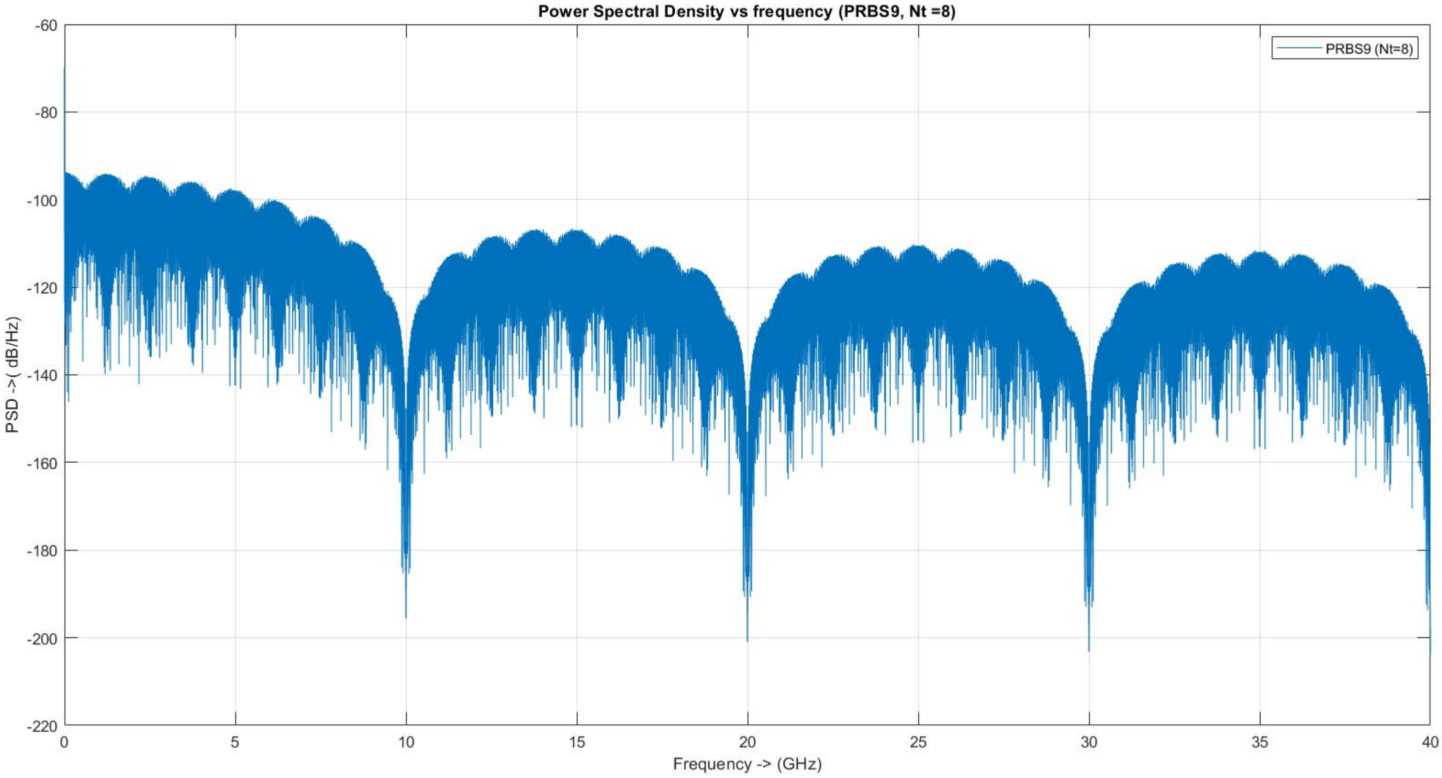

Figure 7: Power spectral density of the PRBS9 time domain waveform with Nt= 8 samples/symbol done by fourier transform.

<u>Inferences:</u>

1. The eye opening increases as SNR increases. It's almost impossible to make out 0 or 1 when SNR is 5dB. The amount of distortion can be quantified by the width of the upper/lower lobe (or logic high/low). As SNR increases, this width decreases.
2. The repeated crests and troughs correspond to the sampled points of the original waveform (there are around 8 of these in each symbol period as Nt=8). Hence, if we want to distinguish between 0 and 1 the best, we should look at the values in between the original samples as they give a wide eye opening. The timestamps corresponding to these openings are same in SNR 15 and 10dB. We can't make them out in 5dB.
3.Measure of jitter / time variation of zero crossing increases as SNR drops which is evident from the zero crossings in the diagrams. This is because the

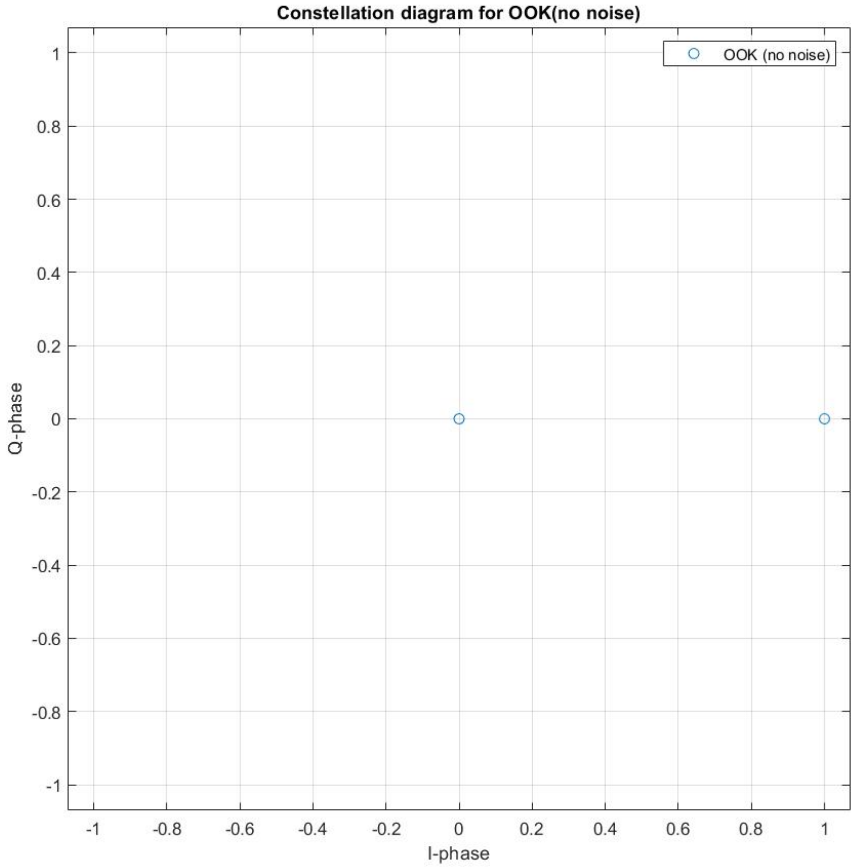

Figure 8: Constellation diagram for OOK with no noise.

amplitude variation in a signal with a finite rise time can influence the zero corssings and hence cause a spread or what we call as jitter.

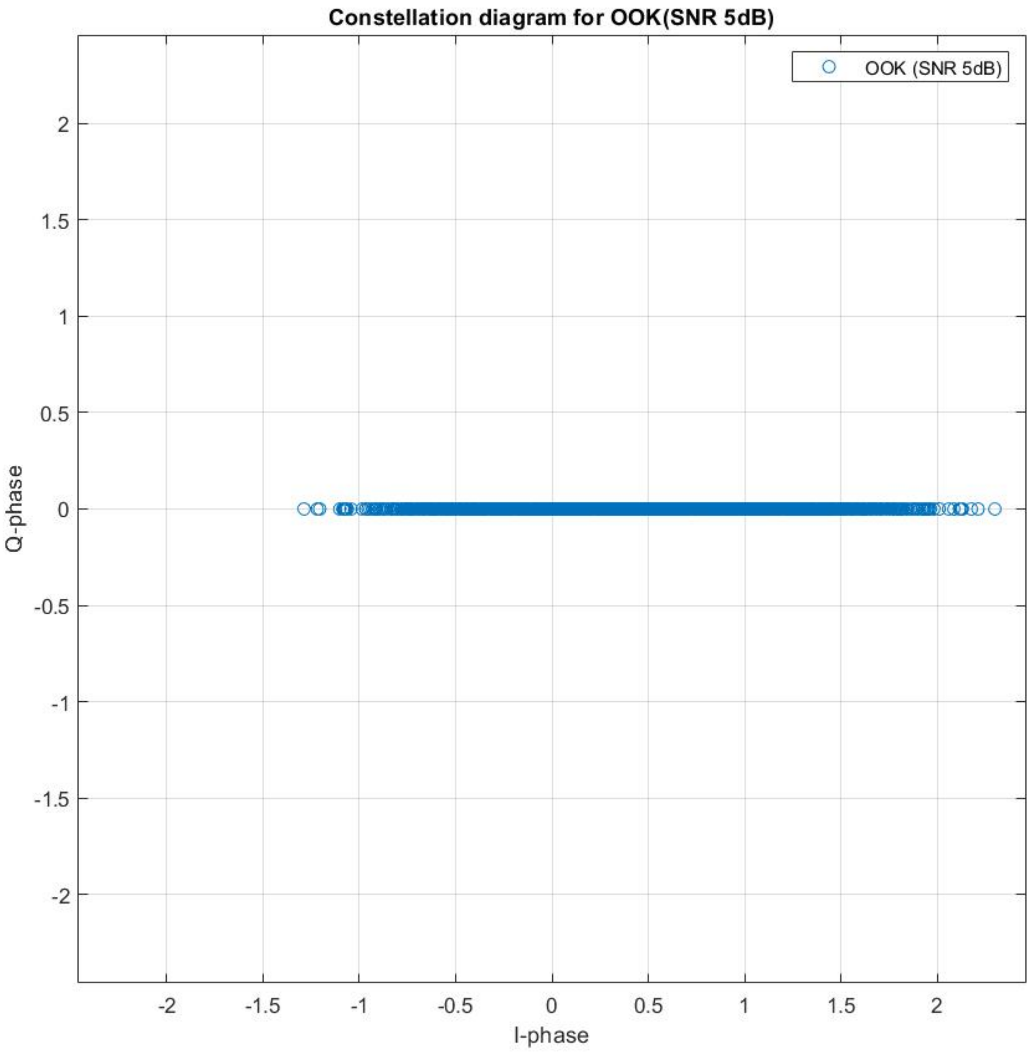

Figure 9: Constellation diagram for OOK with SNR 5dB

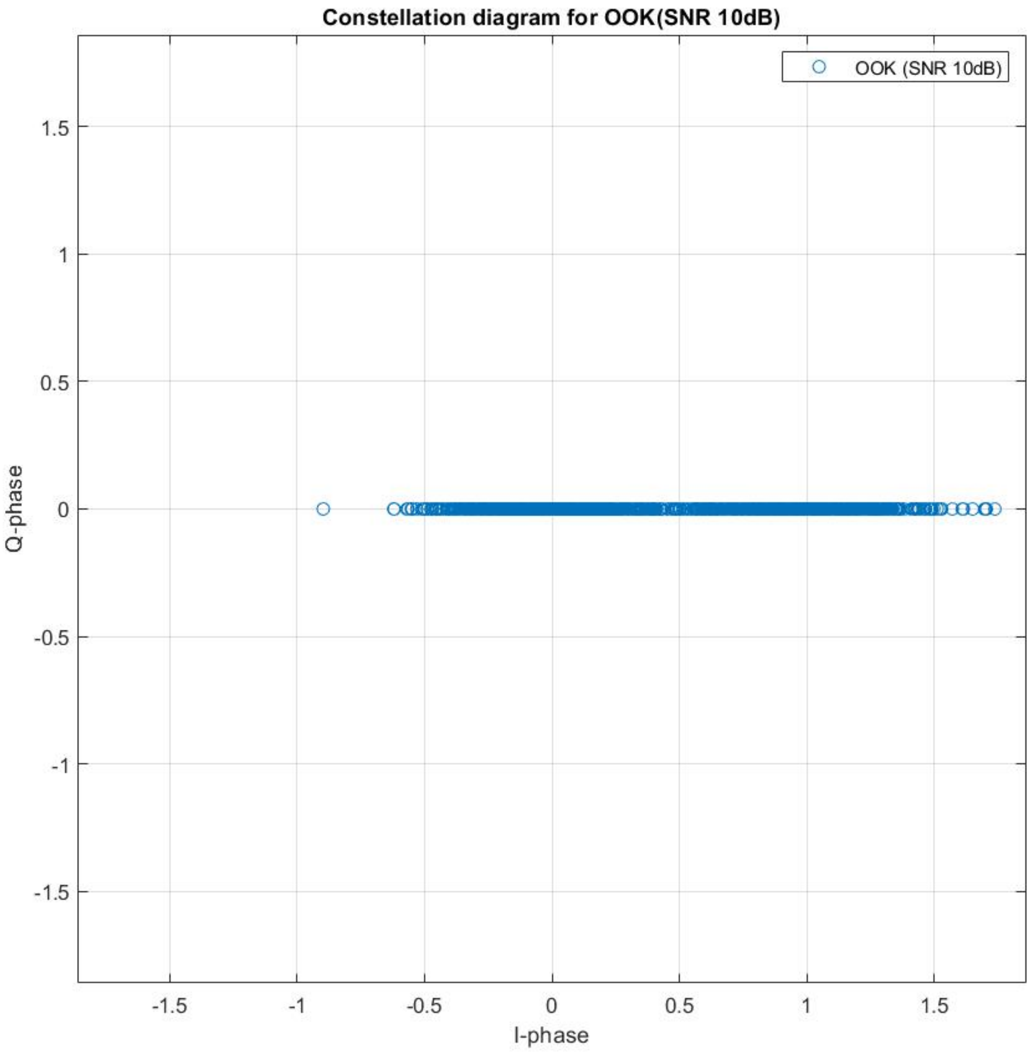

Figure 10: Constellation diagram for OOK with SNR 10dB

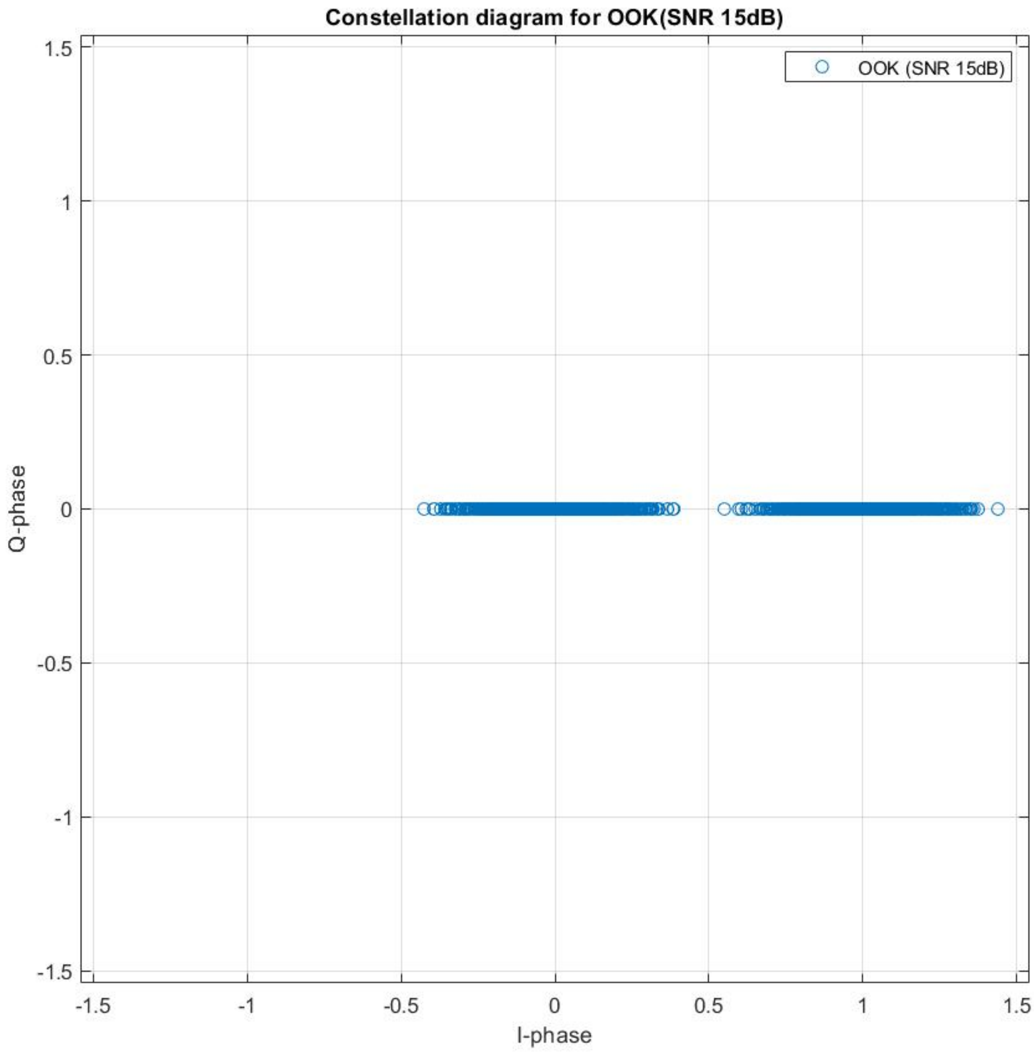

Figure 11: Constellation diagram for OOK with SNR 15dB

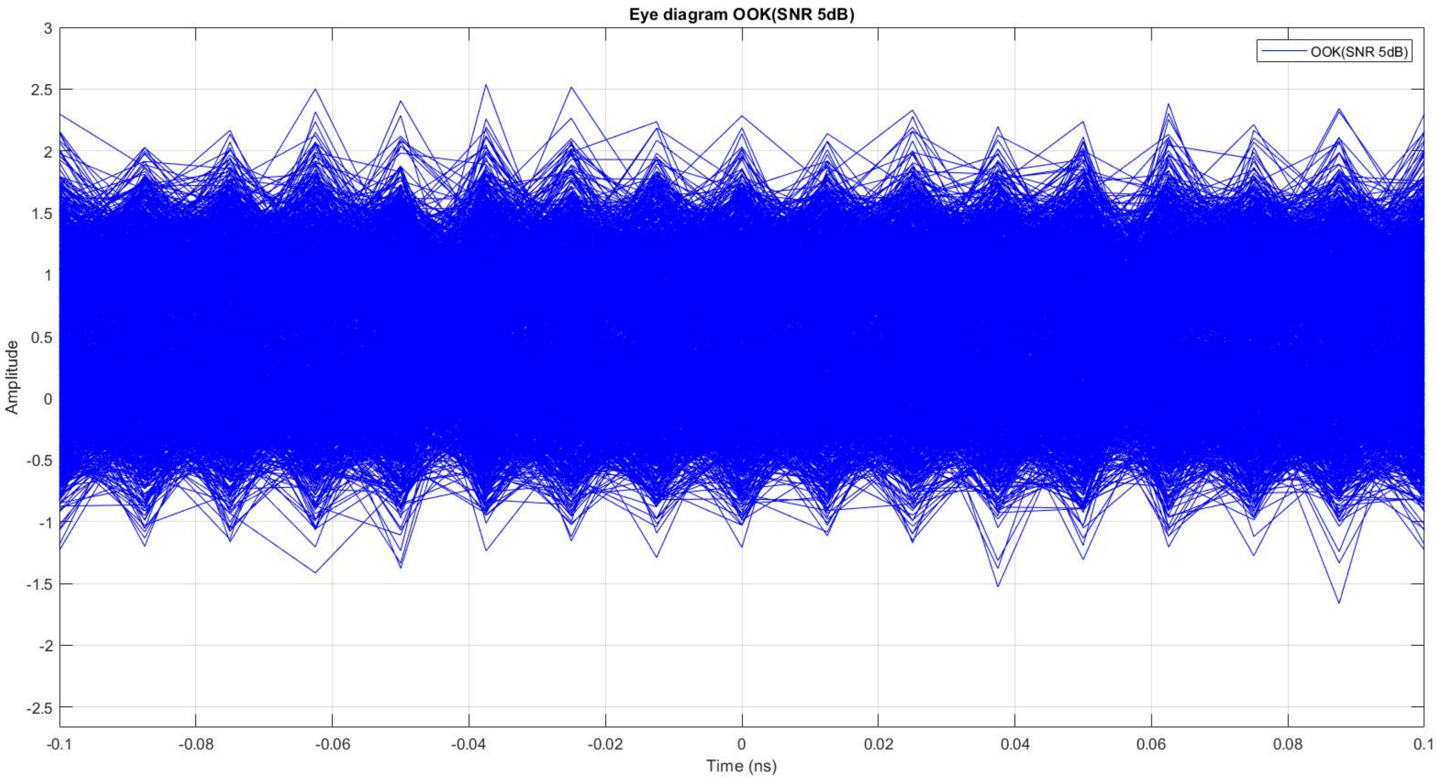

Figure 12: Eye diagram for OOK signal SNR 5dB

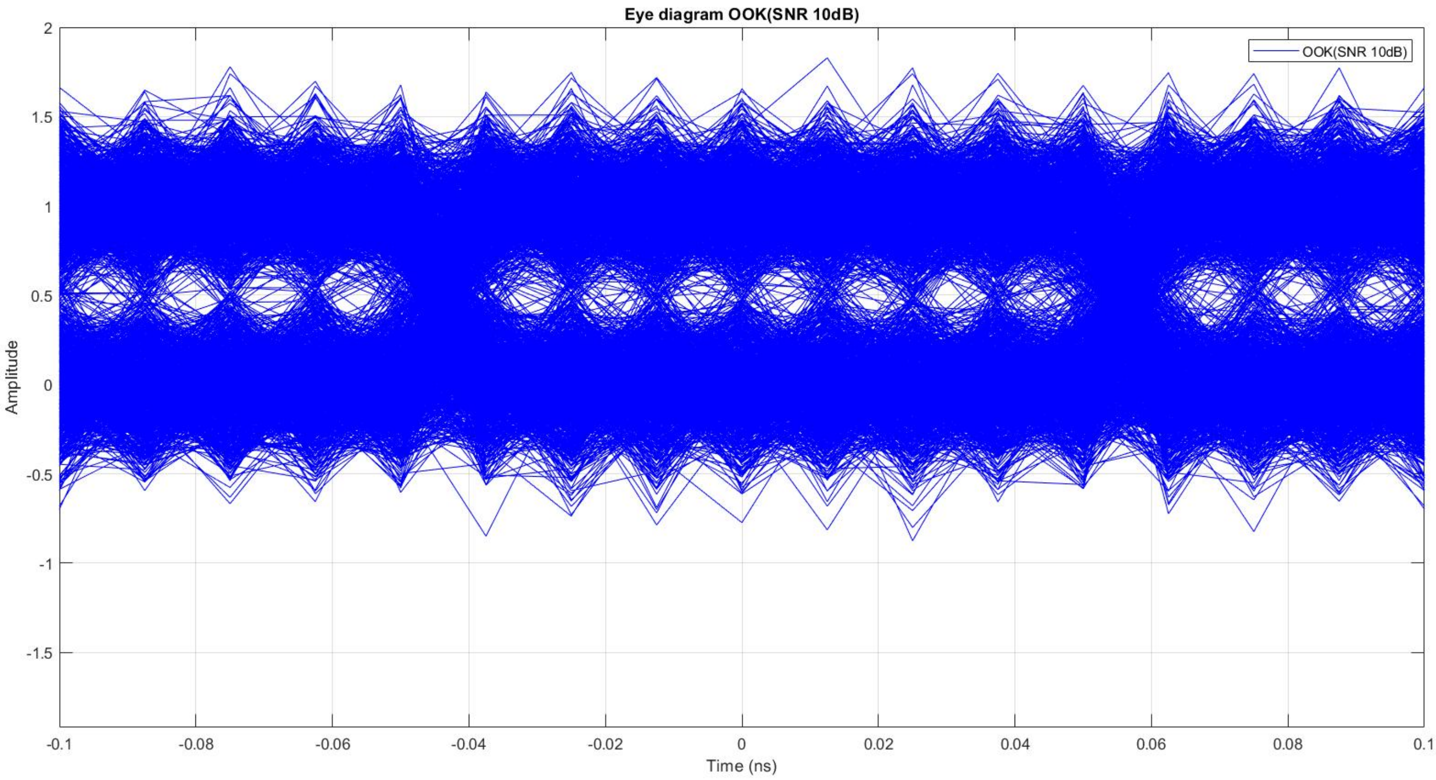

Figure 13: Eye diagram for OOK signal SNR 10dB

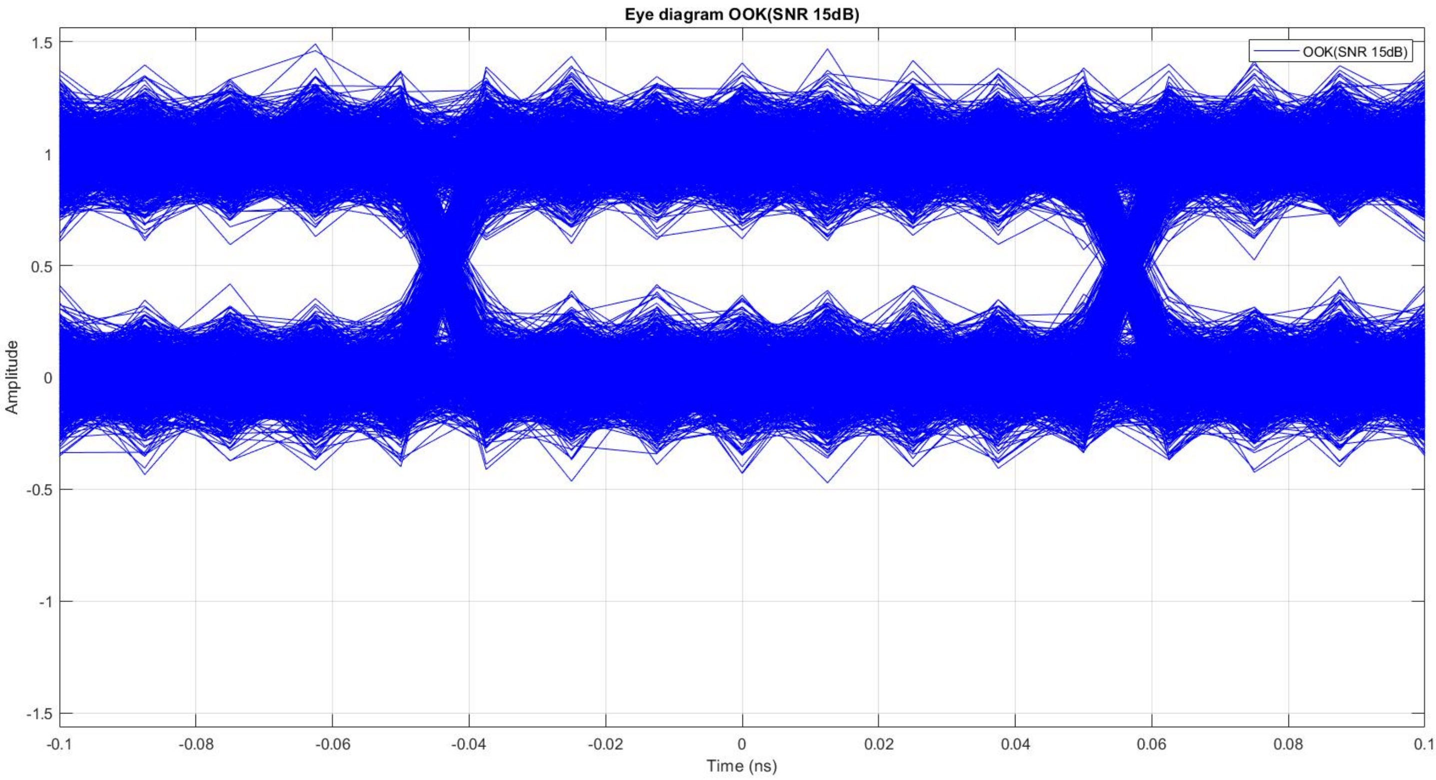

Figure 14: Eye diagram for OOK signal SNR 15dB