Experiment 5

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Introduction

This assignment deals with effects of dispersion in a single mode optical fiber of varying lengths and the effects of ASE (Amplified Spontaneous emission) noise from EDFAs on the Bit error rate of the signal or their distortion observed in the constellation diagram or the time domain waveform. We also see the effect of both fiber dispersion as well as ASE noise on the BER.

Single Mode Fiber Dispersion:

In this section we define the fiber in terms of a transfer function derived from the non-linear Schrodinger equation and find the output signal at the end of the fiber using CTFT -continuous time fourier transform (or FFT function in matlab) and taking the inverse fourier transform for the time domain waveform. We do this for 3 lengths- 10km, 80km, 1000km.

10Gbaud:

The signal is generated from a laser externally modulated using an MZM in the OOK format.
Bitrate used : 10GBps (Given)
Samples/symbol : 4 (Given)
No. of bits = 2^{12} (Given)
Fsampling : 40GHz (sps * Bitrate)
time duration : 409.6ns (no. of bits * 1/(bitrate))
We also use a PRBS9 sequence for sufficient randomness.

<u>Fiber transfer function parameters</u>:
lamda = 1550nm (operating lamda)
c = $3*10^8$
D = 17 ps/(nm-km) (Typical dispersion value for single mode glass fibers)
The output and input magnitude spectrum (magnitude of FFT of E-field (input / output)) is as shown in fig. 1 with the first null point at +fbaud . We see that for any length of fiber the magnitude spectrum is the same as that of the input. This is because as per the transfer function, all it does is to add a phase at different frequencies in the fourier domain. Intuitively as well the fiber doesn't add noise and we assume no attenuation here.
The time domain waveforms for input and output signal for lengths: 10km, 80km and 1000km are plotted in fig. 2,3 and 4 respectively. We plot for

times in between 100ns and 101ns so that this lies somewhere far from the start of the PRBS spectrum so that we can see a decent bit variation. In the plots we observe NRZ waveforms so some of the bits are continuous 1s or 0s. It's seen that with increasing length the pulse broadening becomes more due to increased dispersion and different frequency components travel at different speeds giving time delays. At L = 1000km we can see the effect of bits shifting from their original places compared to the input bitstream due to high time delays and more pulse broadening.
The constellation diagram is plotted for the three cases in figs. 5,6,7 and 8, by picking E-field values at the middle of the bitslot and using scatterplot. We observe that the phase spread in the constellation diagram keeps increasing with increasing length. This is because theres more time delays between different frequency components of E-field and this causes differences in phase which increases with increase in length.
Finally, the Bit error rate is calculated directly by estimating number of incorrect bits and taking its ratio with total bits transmitted- 2^{12}. Here, we don't have any receiver as such or any data about the shot/ thermal noise in receiver and hence we use this direct estimation method. In practical scenarios, the middle sample in the bitslot is taken for determining the bit value of 0 or 1 in that slot. The same is done here. We compare this middle sample with respect to the average value ((max value + min value) /2 and determine if its a 1 or 0. We do this for both the input and output Intensity vectors. Finally, the sum of absolute differences is taken to estimate number of incorrect bits.
The BER calculated is as shown below:

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BER for L=10km is: 0
BER for L=80km is: 0.13183
BER for L=1000km is: 0.4895
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We notice that BER is 0 for length 10km since the pulse broadening is minimal in this case. BER increases with length with increasing dispersion.
Hence, we can conclude that dispersion increases the bit error rate significantly by pulse broadening of the waveforms. We would need to use a length of fiber less than around lets say 40km to get a good BER value. This is in agreement with typical values for fiber lengths used with repeaters.

25Gbaud:

The procedure for this is exactly the same with the following bitstream parameters used:
Bitrate used : 25GBps (Given)

Samples/symbol : 4 (Given)
No. of bits = 2^{12} (Given)
Fsampling : 100GHz (sps * Bitrate)
time duration : 163.84ns (no. of bits * 1/(bitrate))
We also use a PRBS9 sequence for sufficient randomness.
The fiber parameters stay the same ofcourse. Now, we generate all the plots using the same procedure as shown in figs. 9- 16.The BER values are given as below:

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BER for 25Gbps L=10km is: 0.062741
BER for 25Gbps L=80km is: 0.45092
BER for 25Gbps L=1000km is: 0.46948
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We notice that the BER values have significantly risen for L = 10km and 80km with respect to the 10Gbaud case. We also see more phase spreads in constellation plots and more pulse broadening as well, compared to the 10Gbaud case. The reason for this is that when we use a higher baud rate signal theres more and more frequency components added and hence, more of such components are susceptible to dispersion causing greater time delay spreads between them. This gives rise to more pulse broadening and more phase spread for a given length(e.g, take L = 80km).

BER vs OSNR:

Back to back case:

In this section we see how the Bit error rate varies after adding noise from EDFA. In the first case, we assume its a back to back link with no fiber and the receiver has a preamplifier (EDFA) and we analyze the OSNR and BER after this preamplifier. The BER analysis is done purely based on the ASE (amplified spontaneous emission) noise added by the EDFA by estimating number of incorrect bits as specified in the earlier section as we have no information about receivers or the noise added by them.
First, we generate the transmitted electric field signal using laser and MZM as usual. The OSNR values chosen for this case are from 25- 65dB because it shows a gradual variation unlike the steep variation at low starting OSNR values. Additionally, we also see a gradual variation in BER in this range for the case with the fiber in the link as well.
The gain factor 'G' is chosen as 40dB which is close to the typical gain of the EDFA. We amplify the input signal power by gain G and confine its bandwidth to 20GHz(total optical bandwidth or 2*fbaud) which makes sense as

most of the signal power is confined in this band and hence average power calculated in this band would be close to the actual value. This agrees with the standard way of calculating OSNR as well. Now the average power (amplified) is calculated in this band by integrating the PSD. This can be verified to give close to P-peak/2 as well. Using OSNR and P-avg , we calculate P-ASE and hence calculate PSD-ASE (power spectral density) across a reference band 'B-opt' of 12.5GHz. We add this noise to the signal (confined to 20GHz).
Using the PSD of the output signal we scale and take a square root to obtain the magnitude of the Fourier transform of output field (at RX), since we know PSD is just the absolute square of the FFT spectrum obtained. We use the phase of FT of input E-field and generate the total Fourier transform of the output E-field. Here, we assume phase component of the fourier transform of signal is preserved.
Now, after generating the time domain waveform, we can find the BER by estimating incorrect bits as done in earlier sections. This is repeated for many OSNR values.
The BER vs OSNR plot is as shown in fig. 17. Another thing to note is that here we are approximating signal power using FFT and use different bandwidths for signal and noise for the OSNR and also do an approximate method (preserving phase in fourier domain) to generate the net output signal. So, values of BER may differ from conventional ones.
We observe theres a decrease in BER as OSNR increases which is intuitive since the spread due to noise is lower compared to peak signal powers as OSNR increases and hence BER is lower.

SM- Fiber in the link case:

We repeat the above procedure again exactly except that after the output of the MZM, the field is passed onto a single mode fiber of length 80km and then to the edfa (preamplifier) where noise is added before going to receiver. The BER vs OSNR plot is as shown in fig. 18. We obviously see higher BER for same OSNR compared to earlier since theres dispersion which being a major factor increases the BER considerably. However, we still see the decline in BER on increasing OSNR.

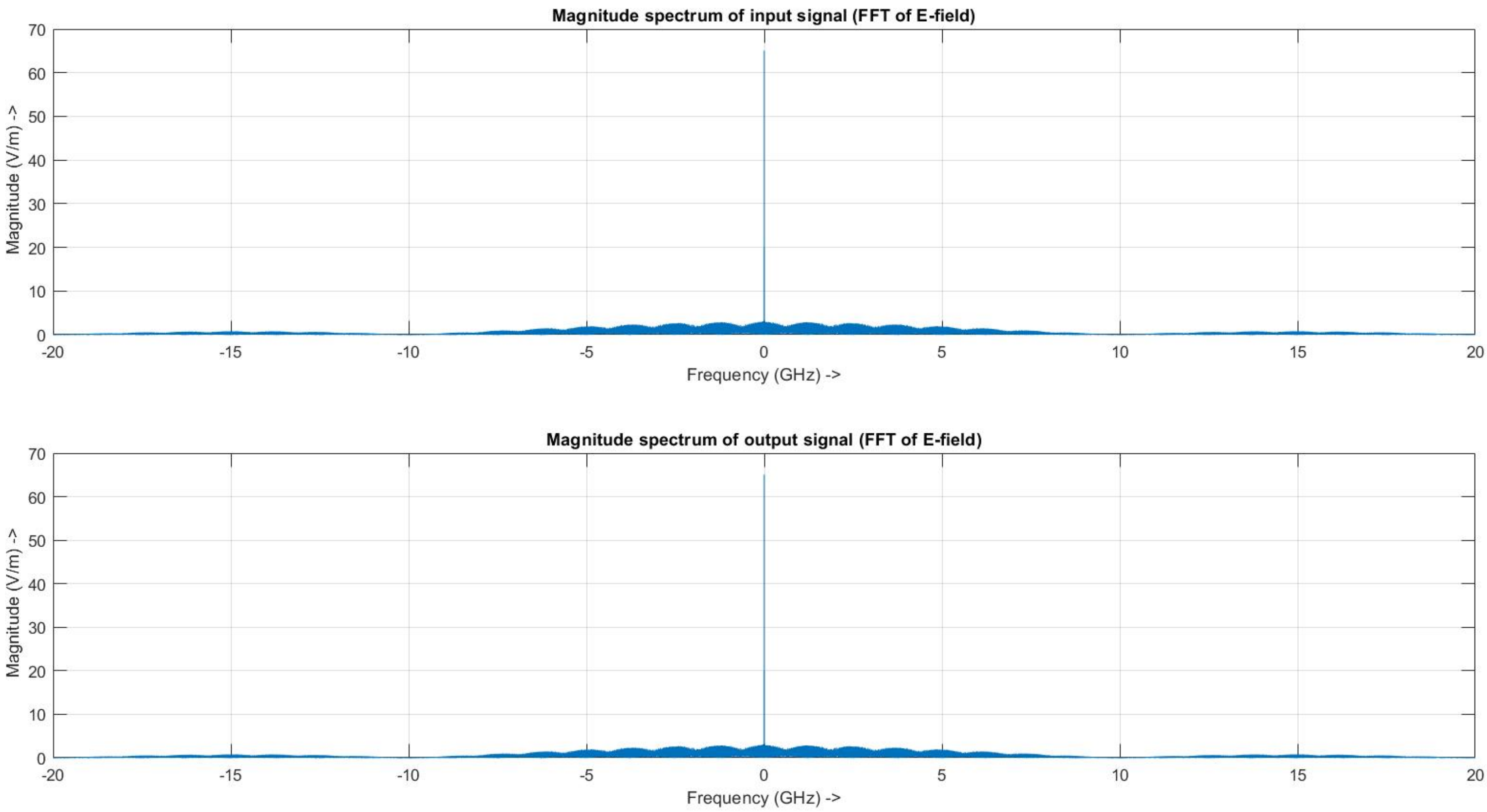


Figure 1: Plot of Magnitude spectrum of FFT of input and output E-field (10Gbaud) for fiber lengths L = 10km, 80km and 1000km.

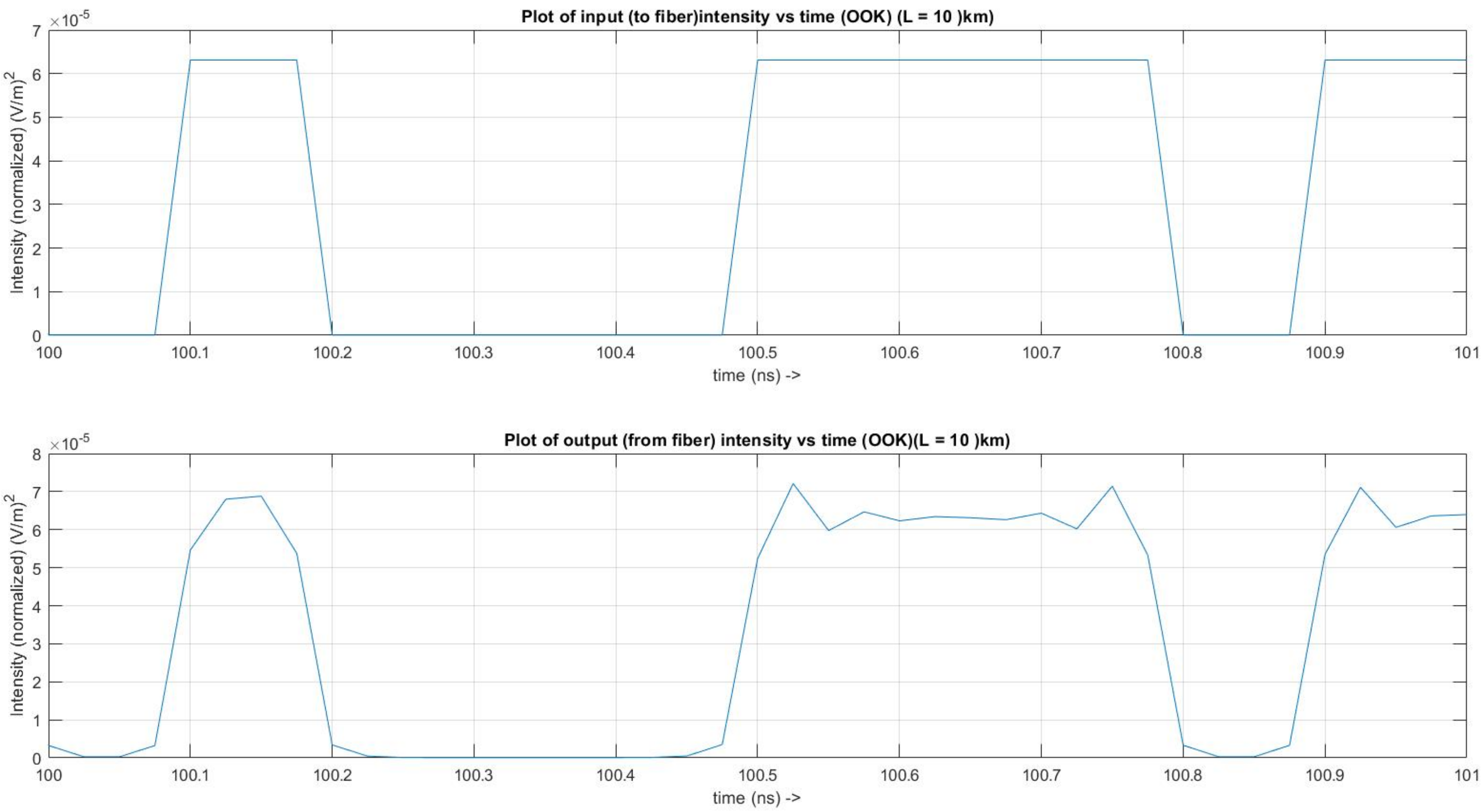


Figure 2: Time domain waveforms for input and output signal(10Gbaud) for 10 bits with a fiber length for 10km showing dispersion in output

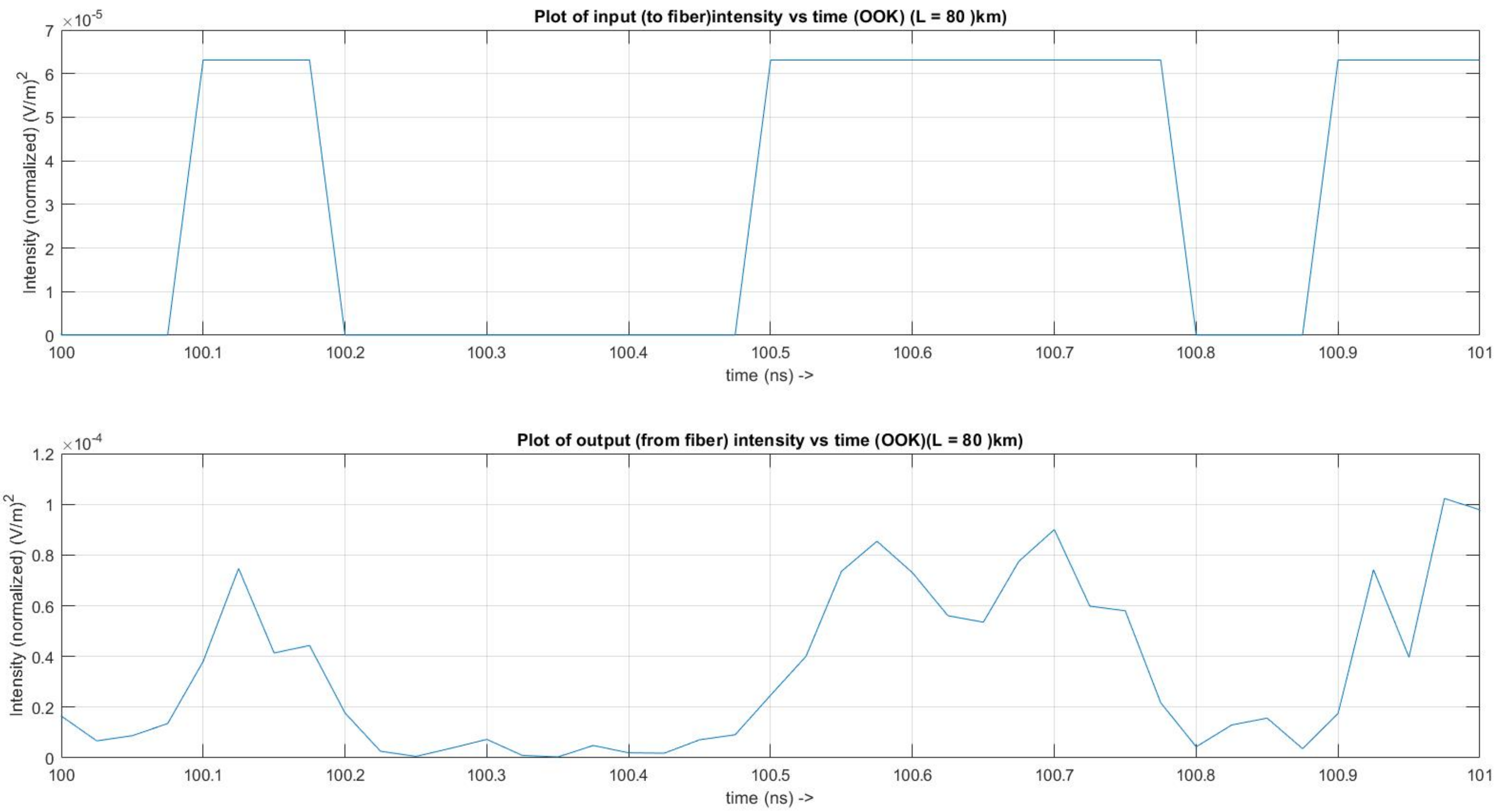


Figure 3: Time domain waveforms for input and output signal (10Gbaud) for 10 bits with a fiber length for 80km showing dispersion in output

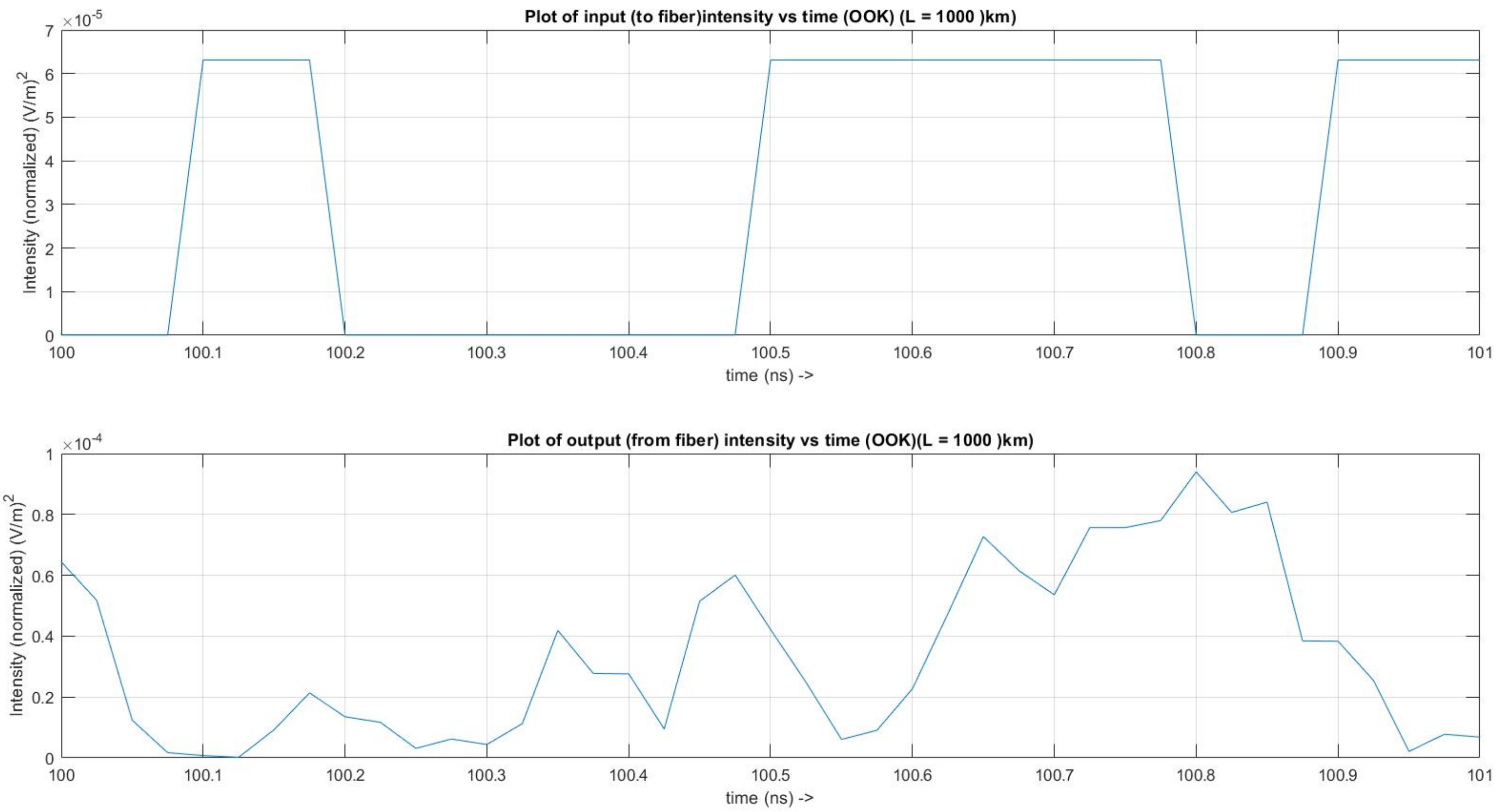


Figure 4: Time domain waveforms for input and output signal(10Gbaud) for 10 bits with a fiber length for 1000km showing dispersion in output

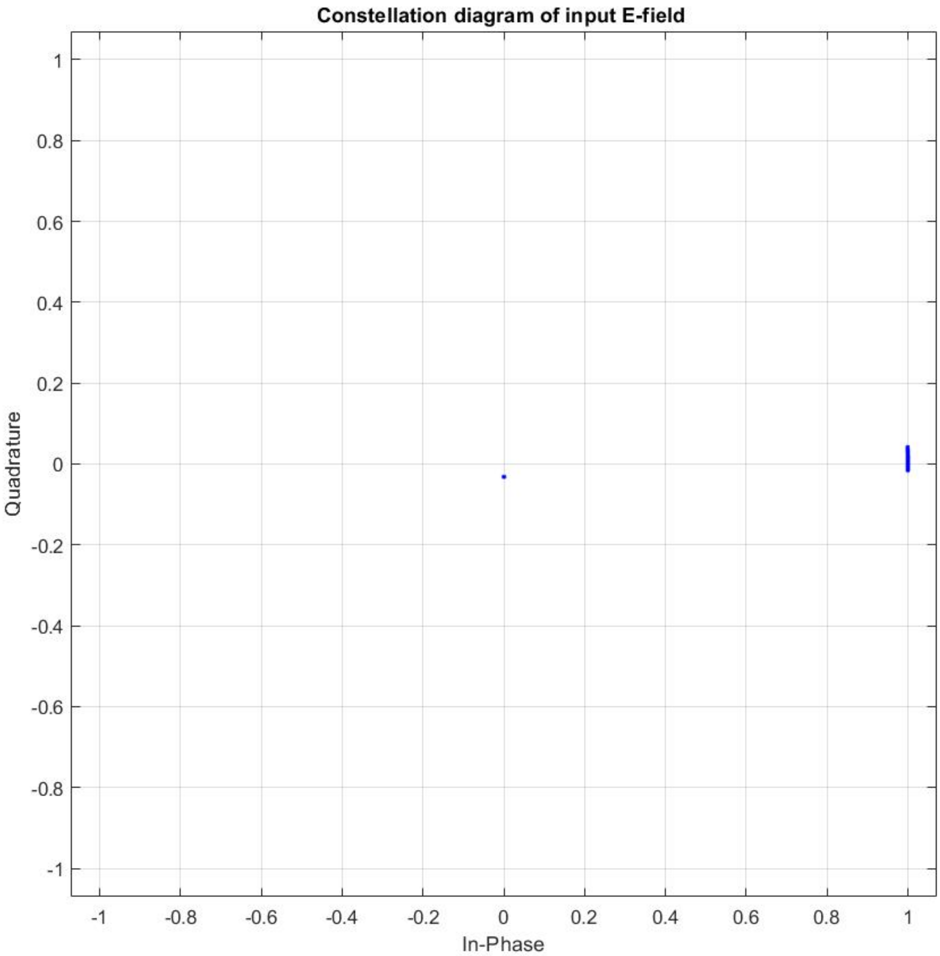


Figure 5: Constellation diagram for input signal at 10Gbaud

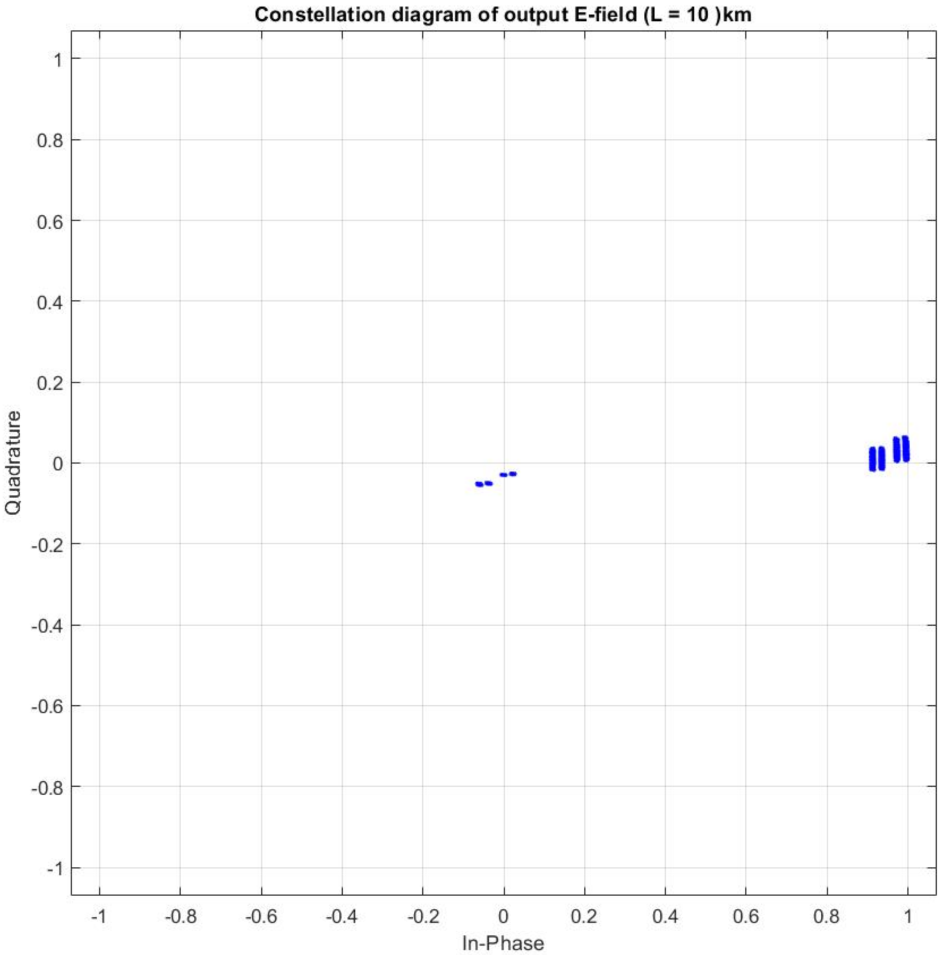


Figure 6: Constellation diagram for output signal (10Gbaud) for fiber length of 10km

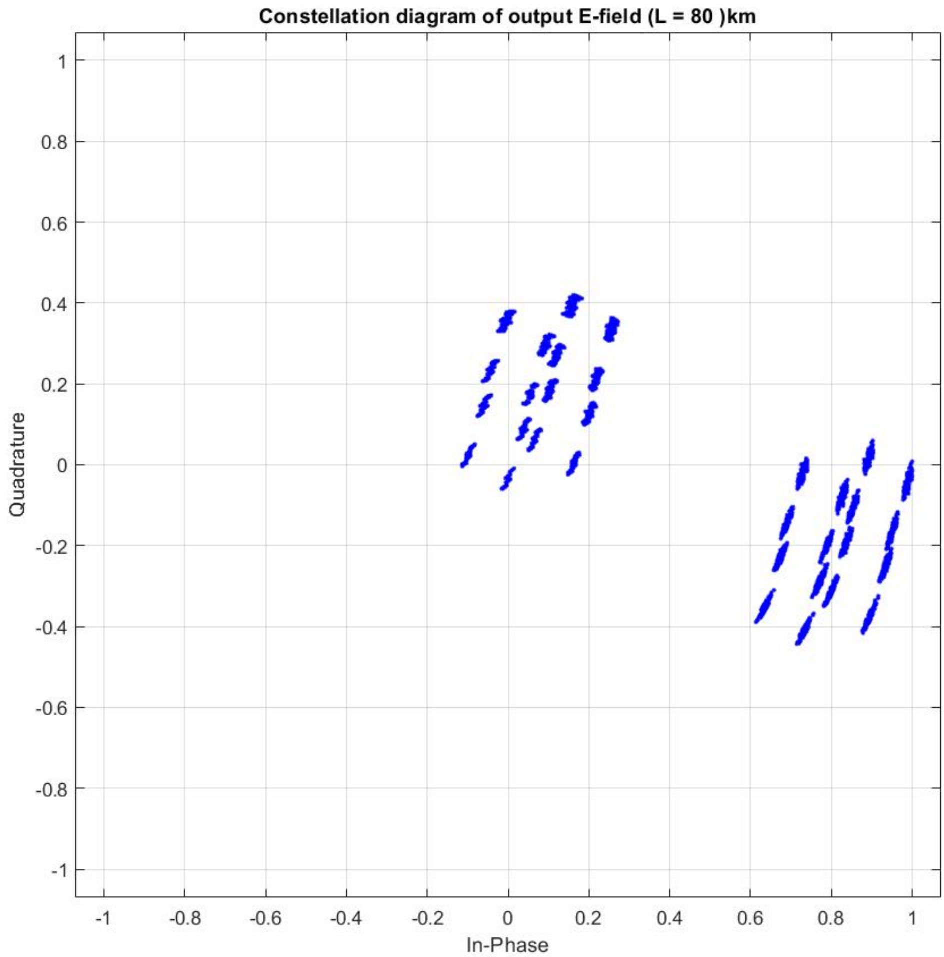


Figure 7: Constellation diagram for output signal (10Gbaud) for fiber length of 80km

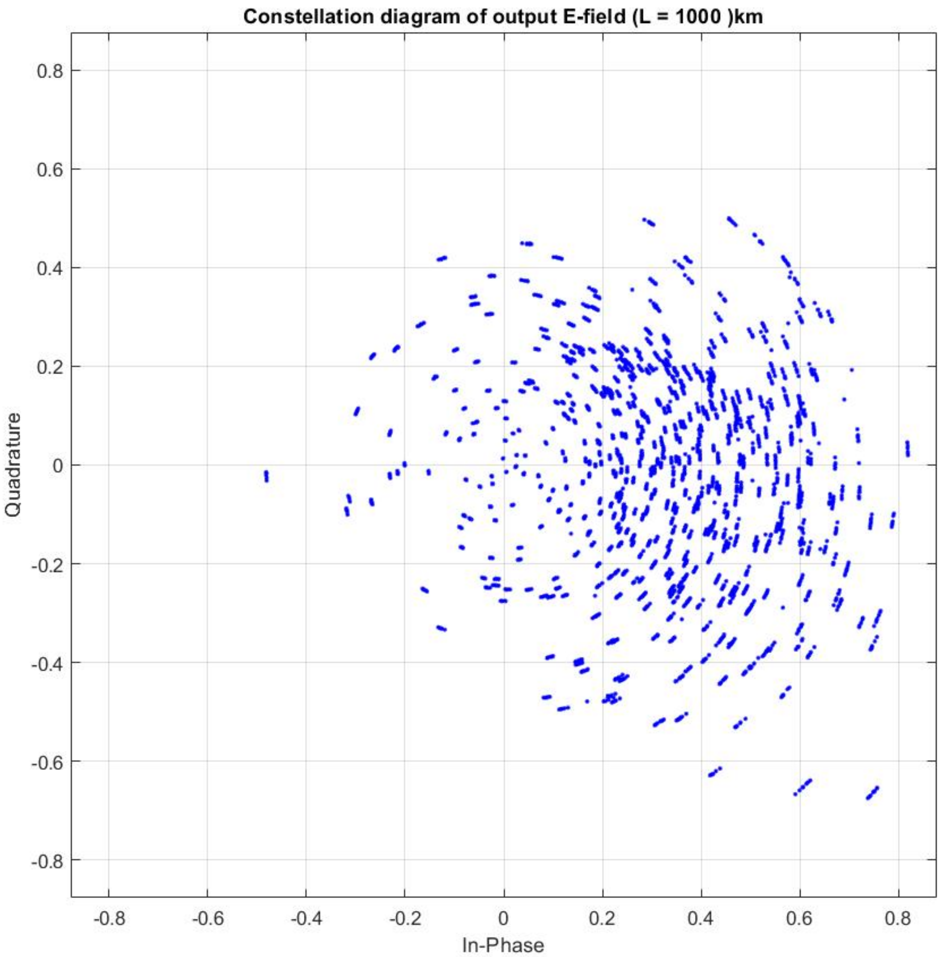


Figure 8: Constellation diagram for output signal (10Gbaud) for fiber length of 1000km

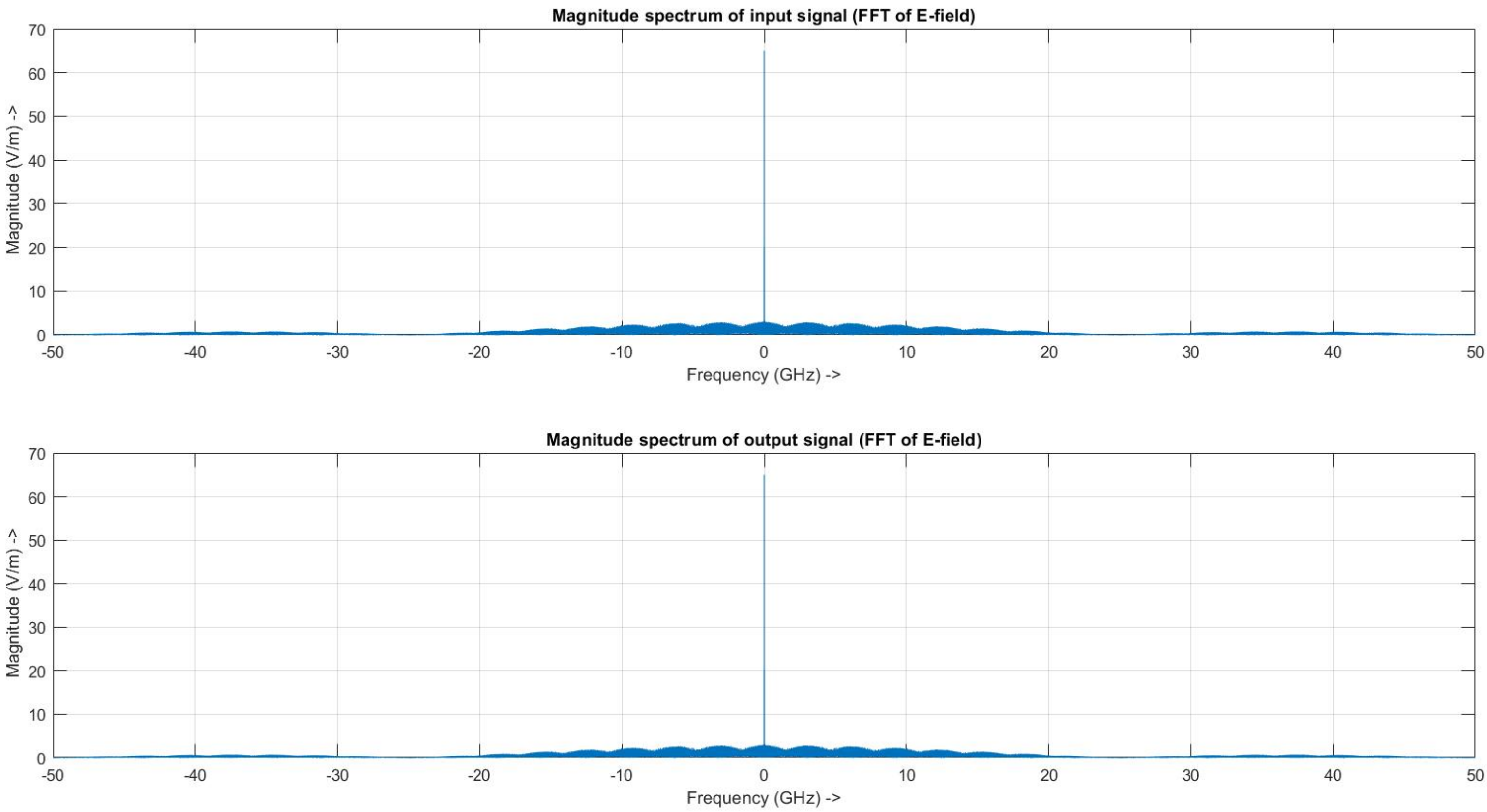


Figure 9: Plot of Magnitude spectrum of FFT of input and output E-field (25Gbaud) for fiber lengths L = 10km, 80km and 1000km.

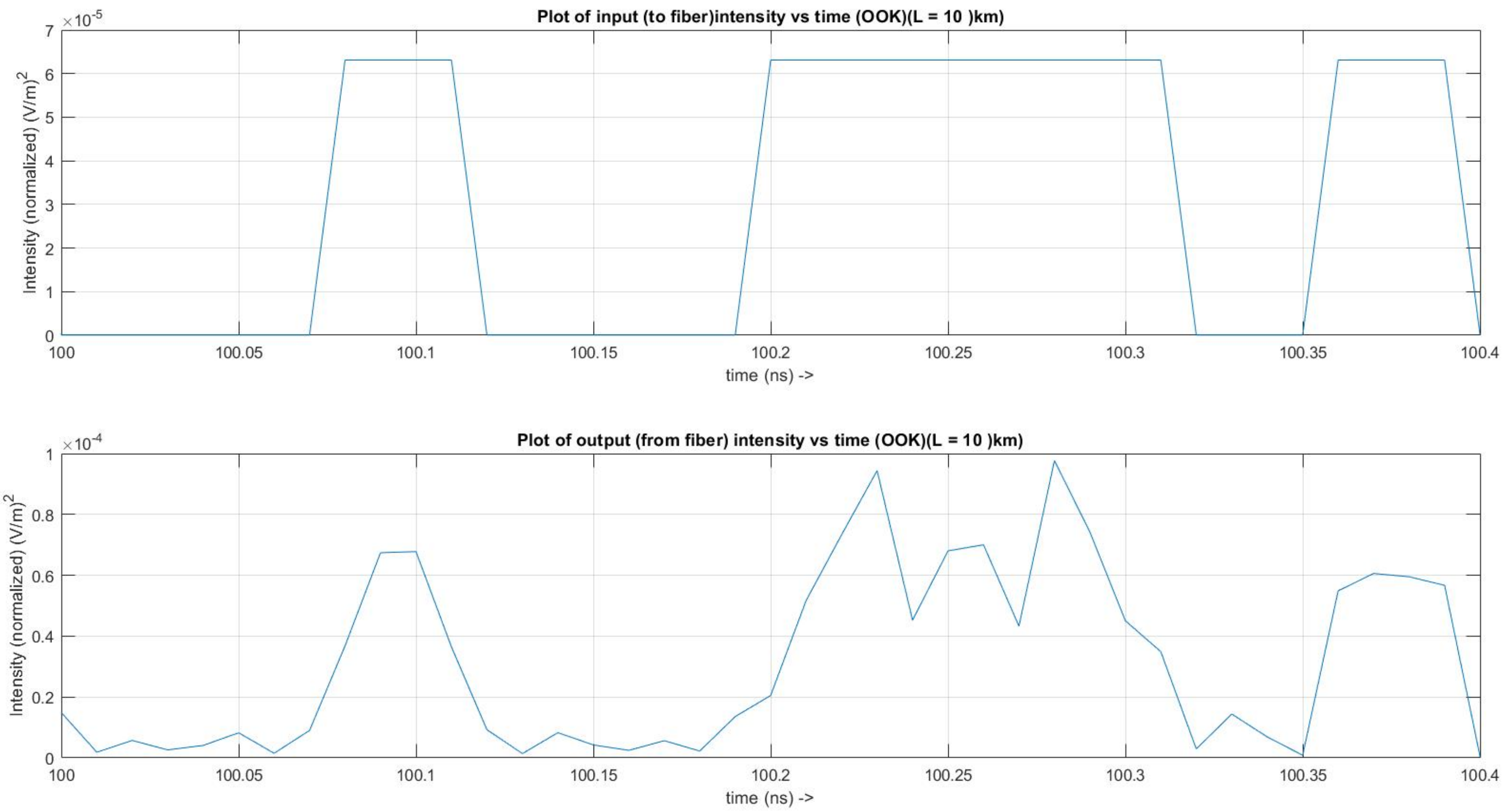


Figure 10: Time domain waveforms for input and output signal(25Gbaud) for 10 bits with a fiber length for 10km showing dispersion in output

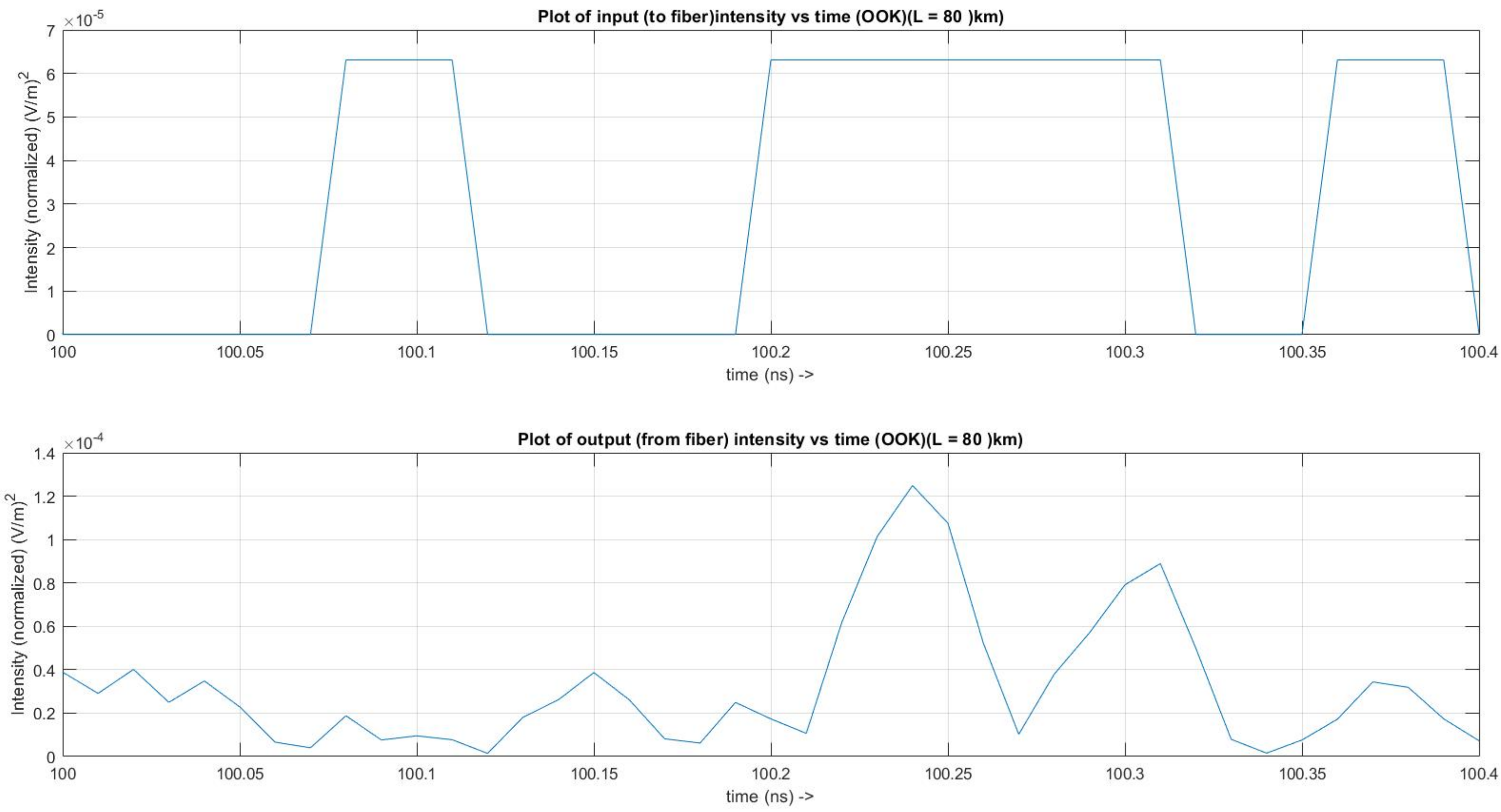
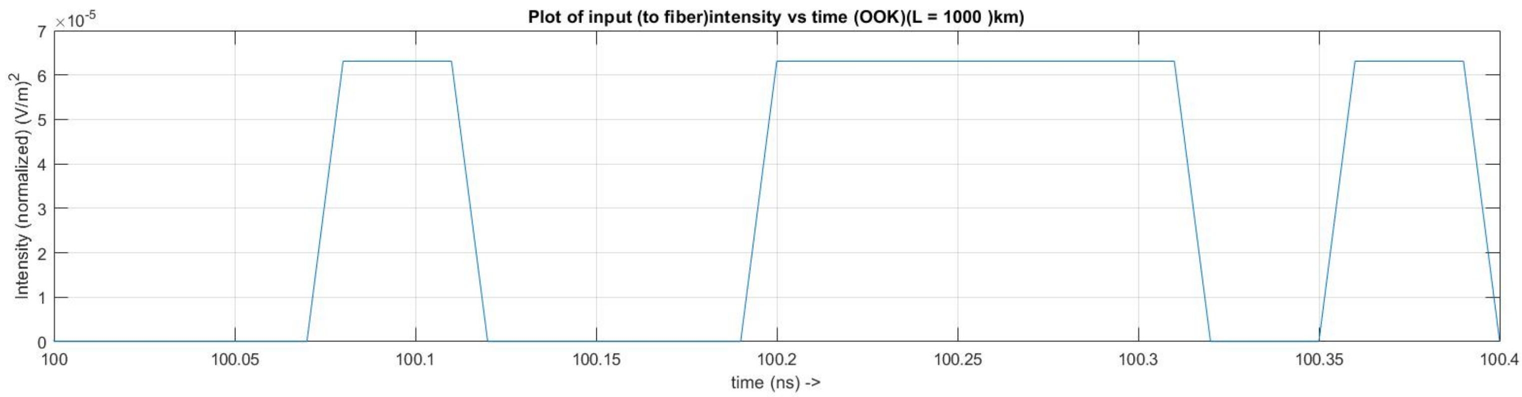


Figure 11: Time domain waveforms for input and output signal (25Gbaud) for 10 bits with a fiber length for 80km showing dispersion in output



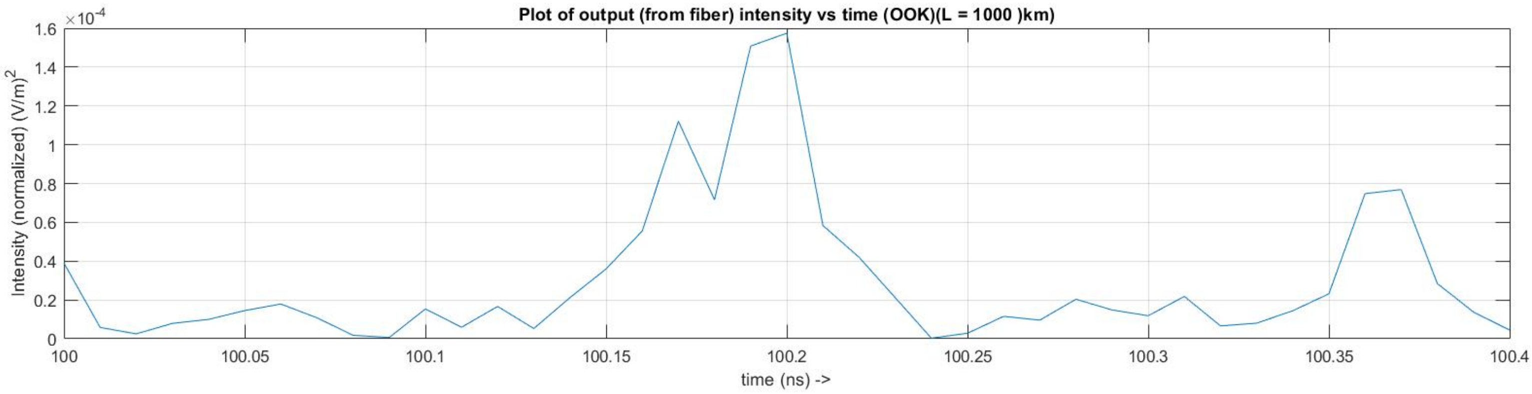


Figure 12: Time domain waveforms for input and output signal(25Gbaud) for 10 bits with a fiber length for 1000km showing dispersion in output

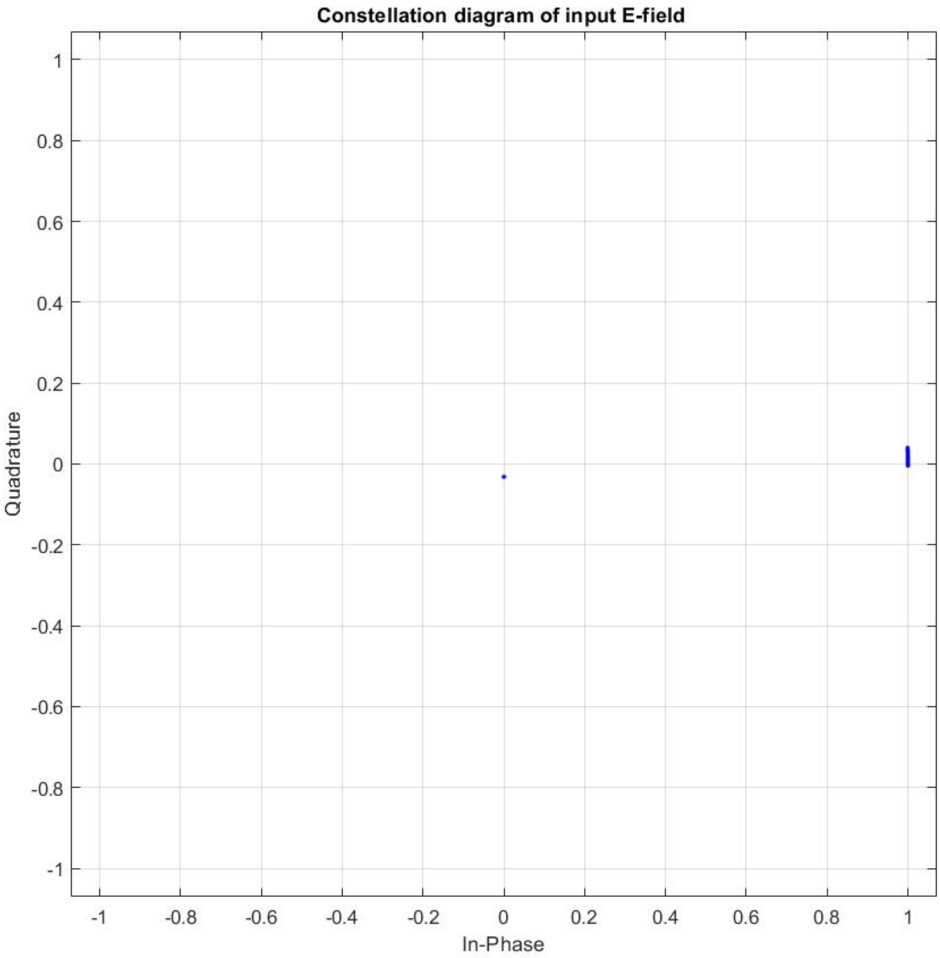


Figure 13: Constellation diagram for input signal at 25Gbaud

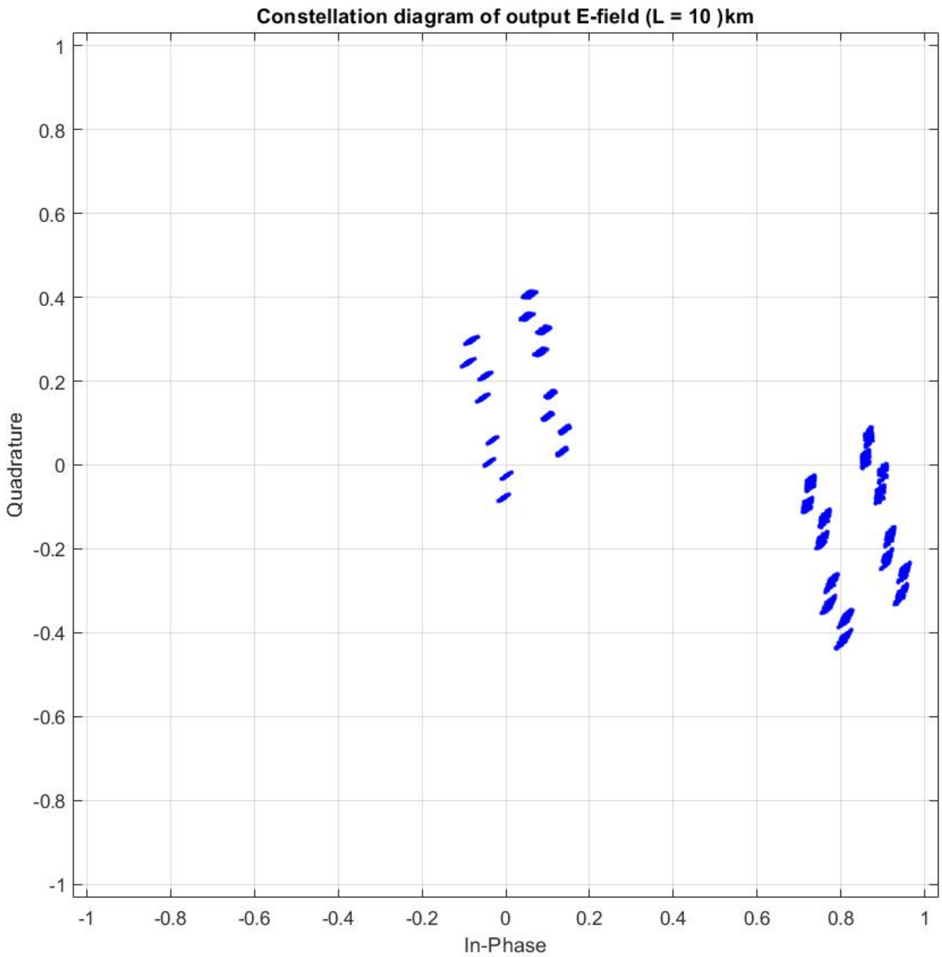


Figure 14: Constellation diagram for output signal (25Gbaud) for fiber length of 10km

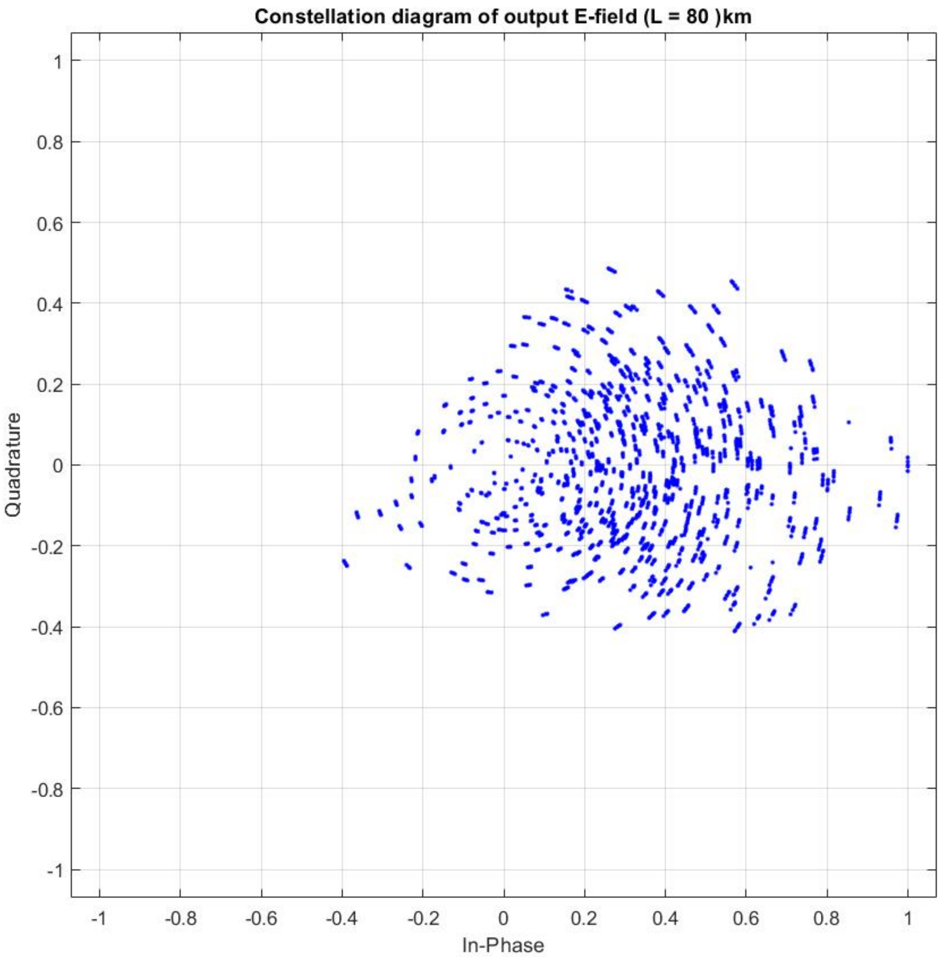


Figure 15: Constellation diagram for output signal (25Gbaud) for fiber length of 80km

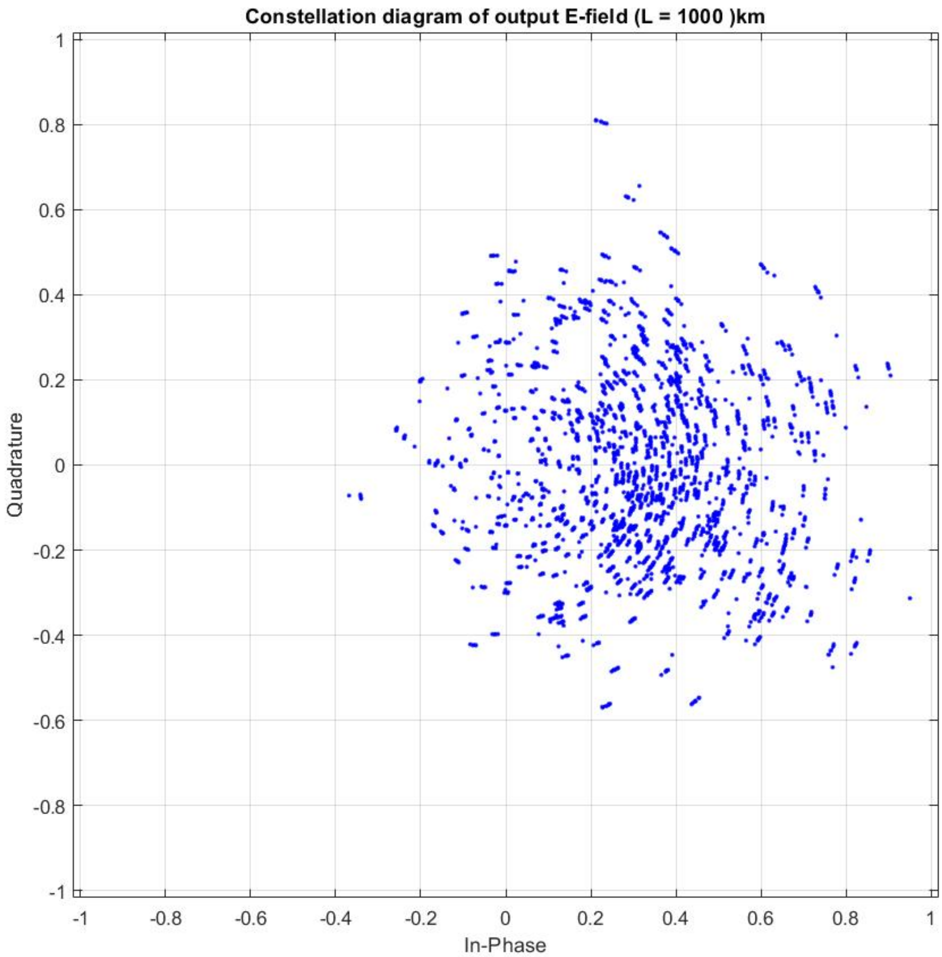


Figure 16: Constellation diagram for output signal (25Gbaud) for fiber length of 1000km

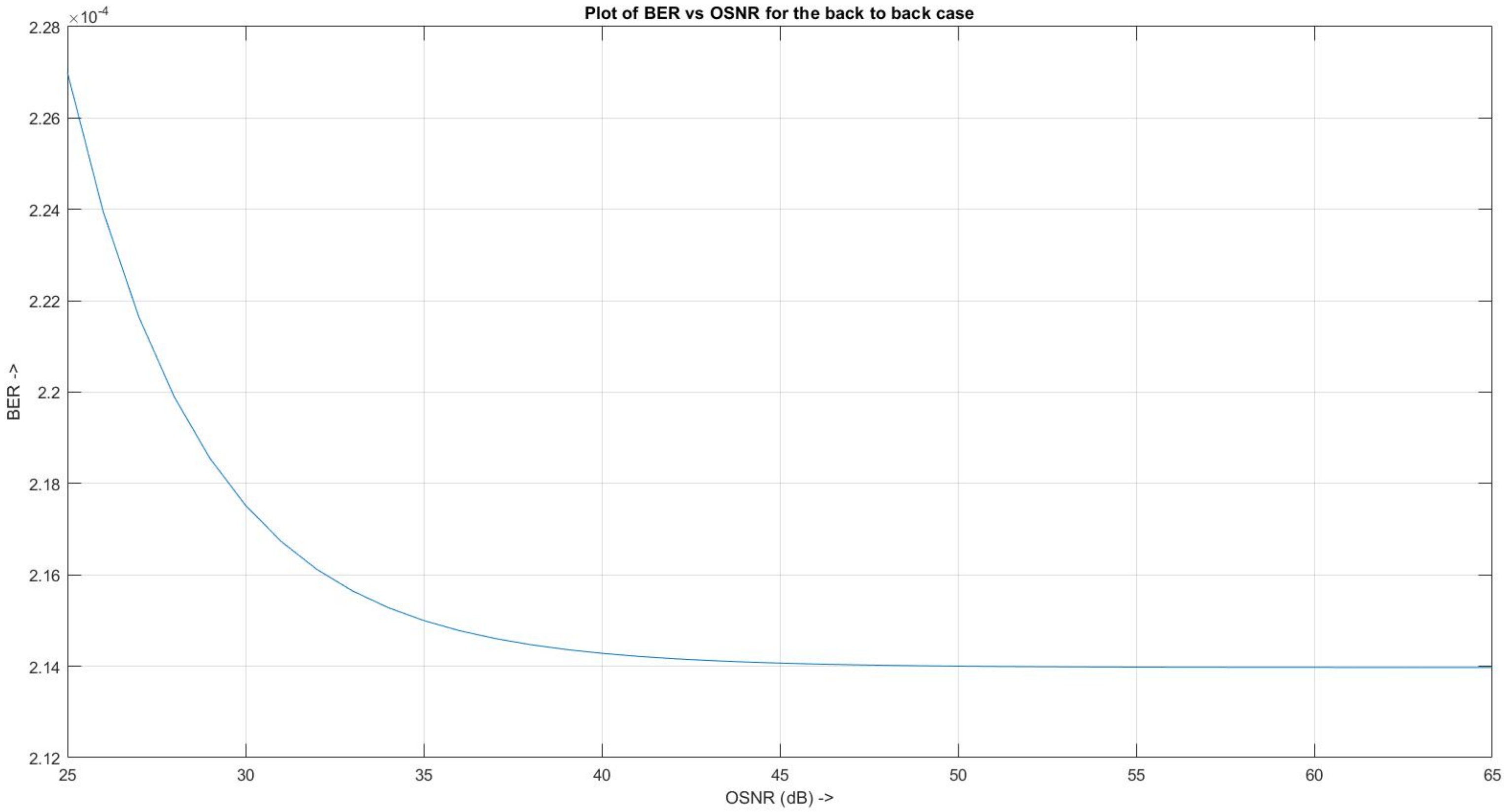


Figure 17: BER vs OSNR for the TX and RX back to back case.

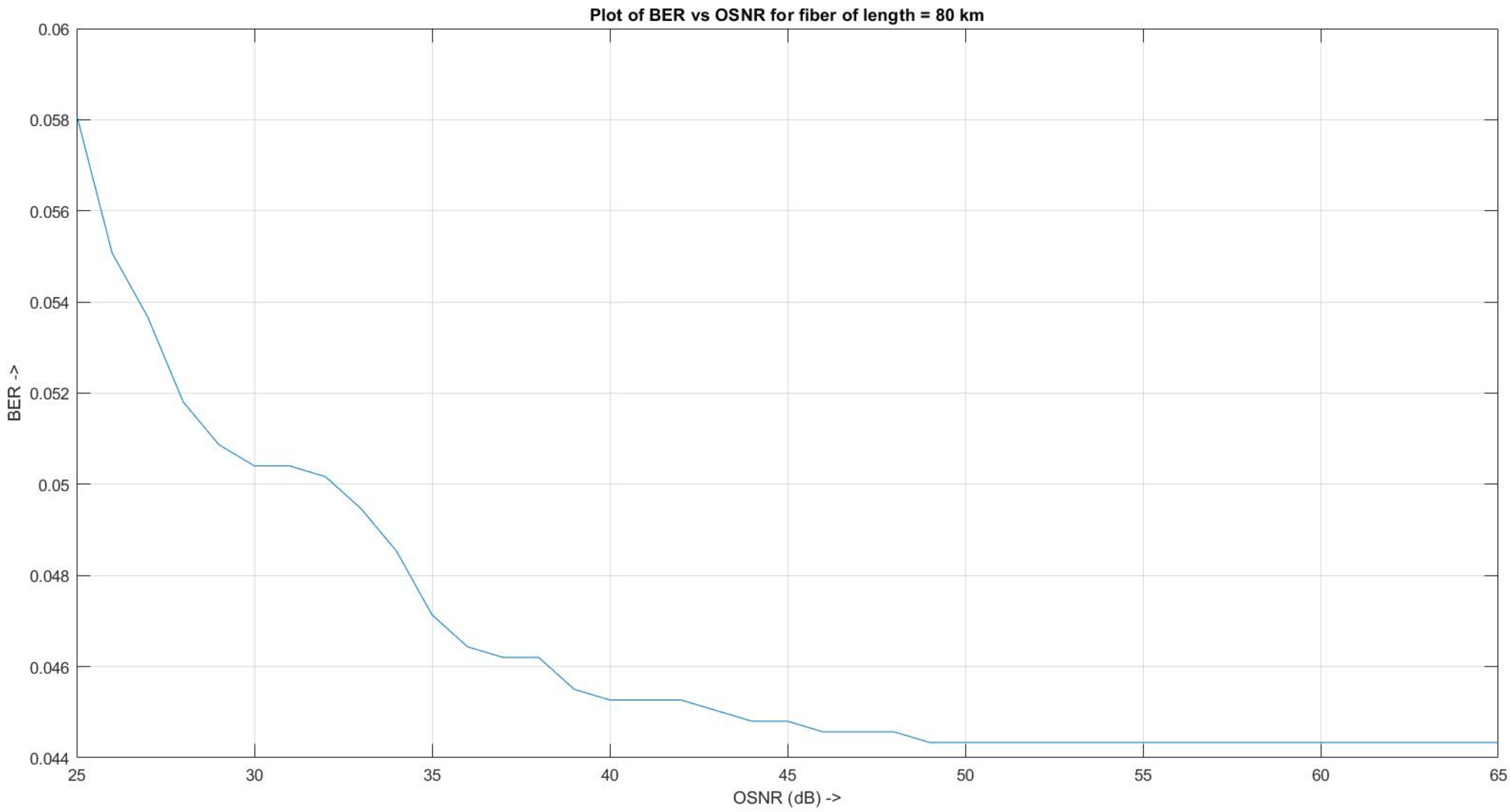


Figure 18: BER vs OSNR with an 80km fiber in the link.