

Experiment 5

Name: Balasubramaniam M C

Roll: EE18B155

April 8 2021

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.

Fiber transfer function parameters:

$\lambda = 1550\text{nm}$ (operating λ)

$c = 3 \times 10^8$

$D = 17 \text{ ps}/(\text{nm}\cdot\text{km})$ (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 $\pm f_{\text{baud}}$.

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 $L = 1000\text{km}$ 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 bit slot and using scatterplot. We observe that the phase spread in the constellation diagram keeps increasing with increasing length. This is because there's 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 bit slot 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 it's 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:

```
BER for L=10km is: 0
BER for L=80km is: 0.13306
BER for L=1000km is: 0.4895
```

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. For the case of 80km, the BER is still 0.13 because when we calculate BER, we make the decision using the power vs time plots, so even if there's some separation in the constellation diagram for bit 0 and 1 on an absolute scale, the E-fields may be very close to each other.

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 let's 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:

BER for 25Gbps L=10km is: 0.062744

BER for 25Gbps L=80km is: 0.45068

BER for 25Gbps L=1000km is: 0.46899

We notice that the BER values have significantly risen for $L = 10\text{km}$ 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 there's 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 $L = 80\text{km}$).

BER vs OSNR:

In this section we see how the Bit error rate varies after adding noise from EDFA. We take the case of having no fiber in the link, ie, just TX-EDFA-RX and a case of having fiber in the link before EDFA which adds noise (TX-Fiber-EDFA-RX).

The range of OSNR values taken is 0-70dB for a clear comparison of both cases. The BER analysis is done purely based on the ASE (amplified spontaneous emission) noise added by the EDFA (and ofcourse considering fiber dispersion for the 2nd case) 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 gain factor 'G' is chosen as 30dB which is close to the typical gain of the EDFA. We amplify the input signal power by gain G due to EDFA. The average power (amplified) is calculated in the $[-f_{\text{baud}}, f_{\text{baud}}]$ band which is close to $(P_{\text{max}} + P_{\text{min}})/2$. 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 across the whole band using the same PSD of ASE noise with awgn noise of given PSD in time domain. The time domain noise is added to the output amplified power (in time domain) from the EDFA.

Now, after generating the time domain waveform of EDFA output power, we can find the BER by estimating incorrect bits as done in earlier sections. This is repeated for many OSNR values and iterated over each OSNR.

The BER vs OSNR plot is as shown in fig. 17.

We observe there's 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. We see that for the back to back case BER drops to orders of 10^{-3} at OSNR approximately $> 27\text{dB}$ as shown in fig. 18. The BER for the fiber in the middle case saturates to around 0.15, 0.14 after a particular OSNR in agreement with BER calculated due to dispersion in fiber of length 80km (10Gbaud) earlier. We also used the same input power as earlier considering a close to ideal laser of LW 0.01kHz; an MZM of insertion loss of 0dB and Extinction ratio of 100dB. Obviously, fiber adds dispersion and increases BER and we see that the BER plot with fiber in the middle is higher than the back to back case.

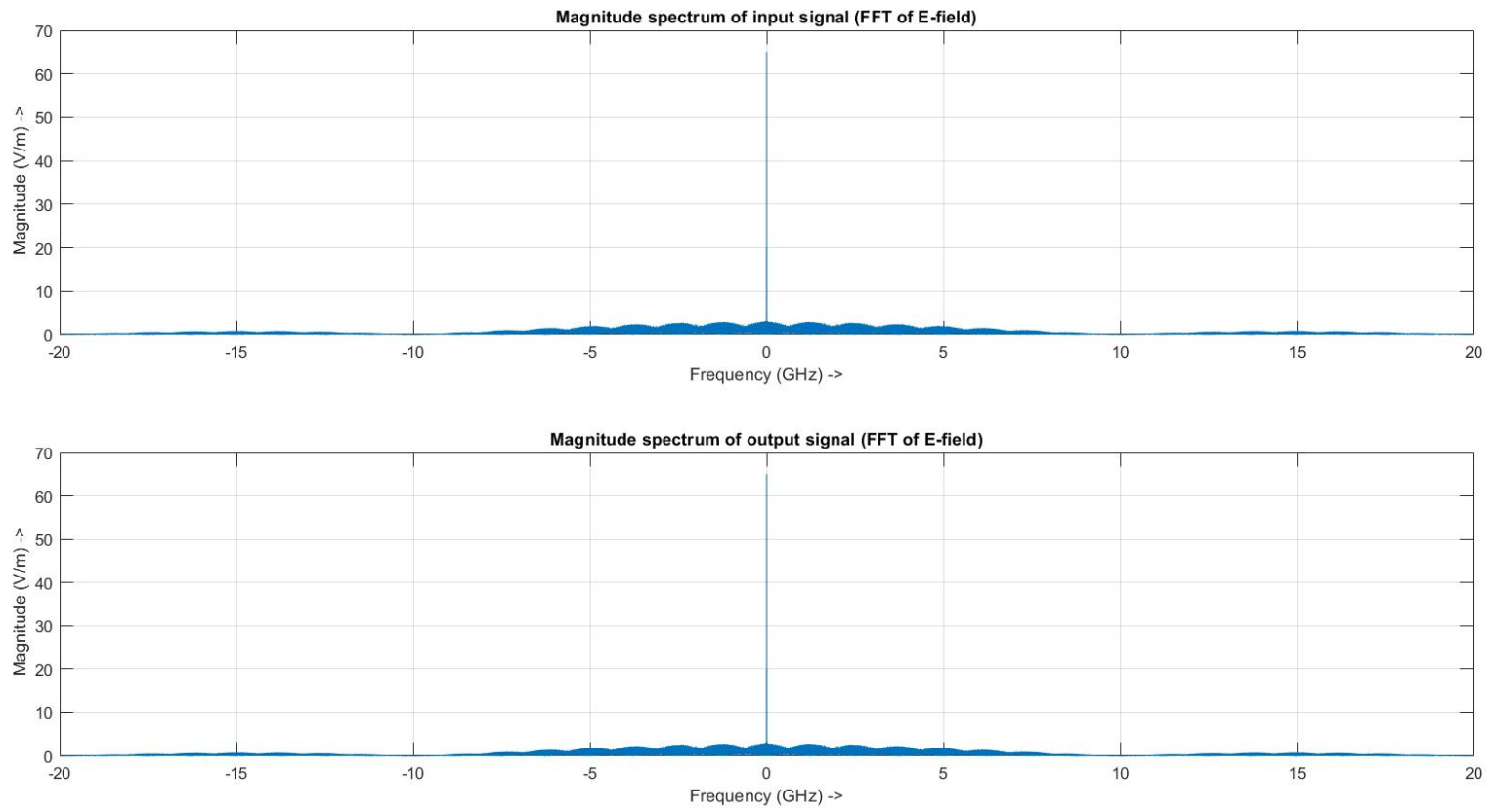


Figure 1: Plot of Magnitude spectrum of FFT of input and output E-field (10Gbaud) for fiber lengths $L = 10\text{km}$, 80km and 1000km .

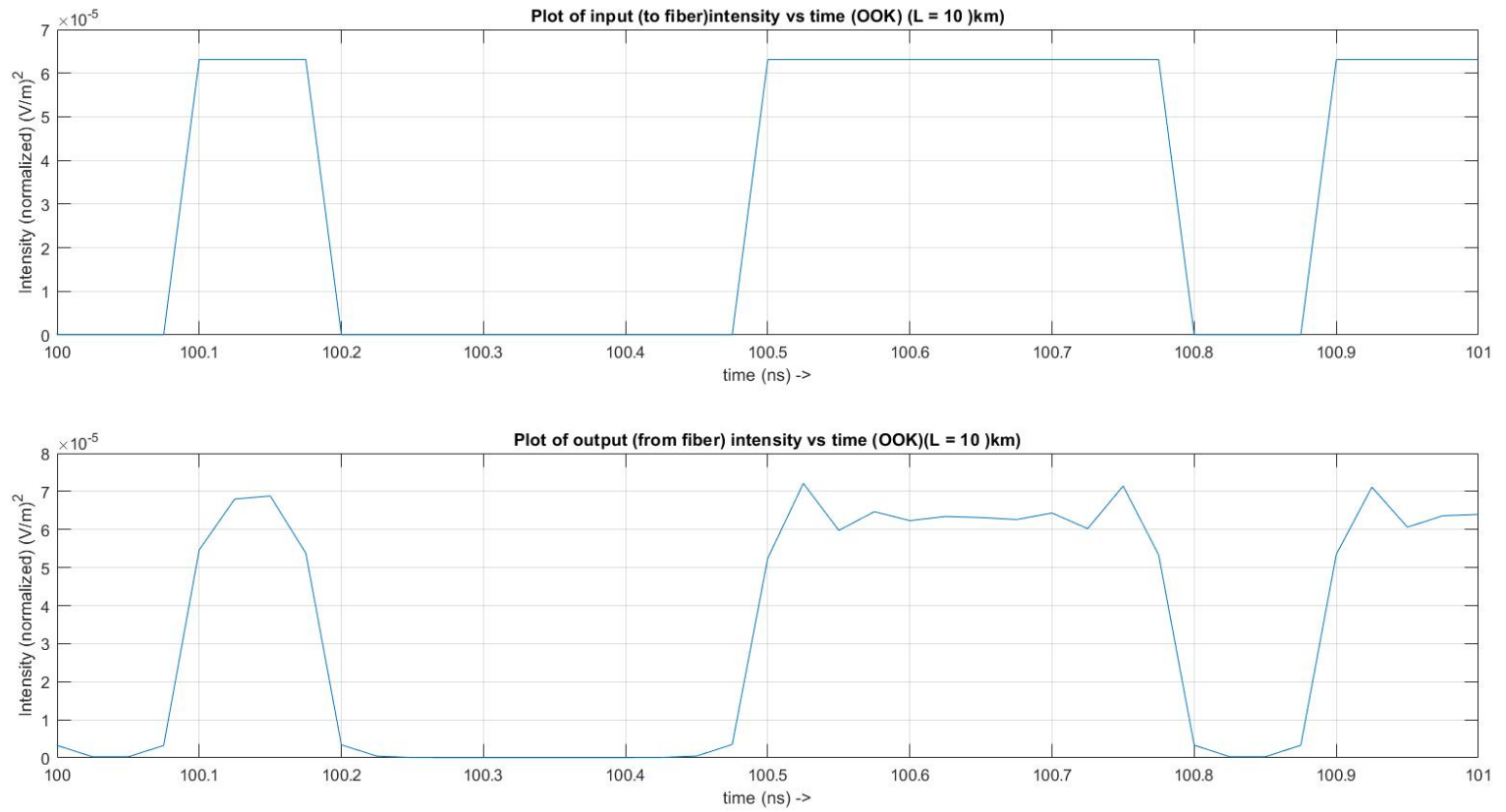


Figure 2: Time domain waveforms for input and output signal(10Gbaud) for 10 bits with a fiber length for 10km showing dispersion in output

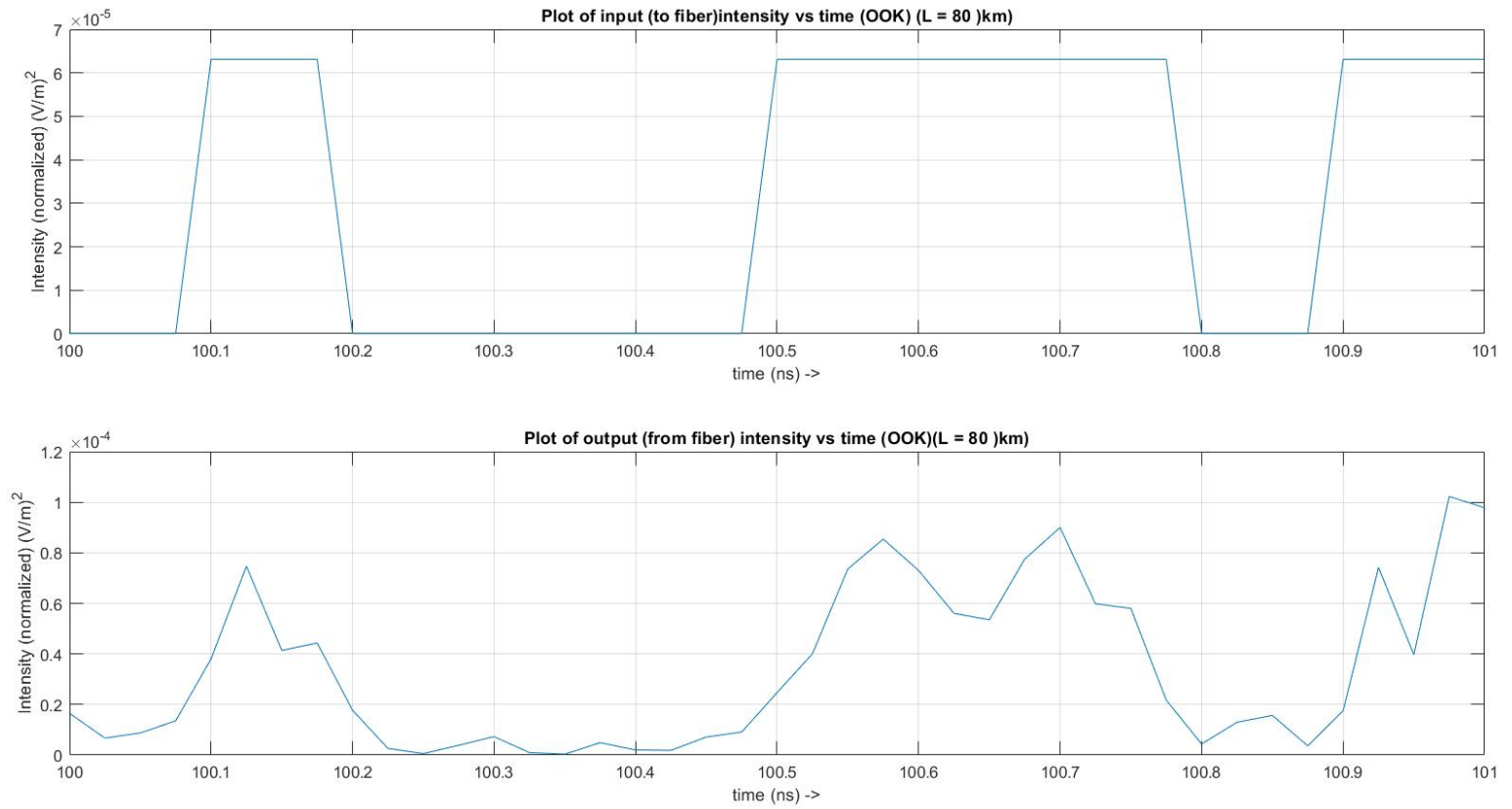


Figure 3: Time domain waveforms for input and output signal (10Gbaud) for 10 bits with a fiber length for 80km showing dispersion in output

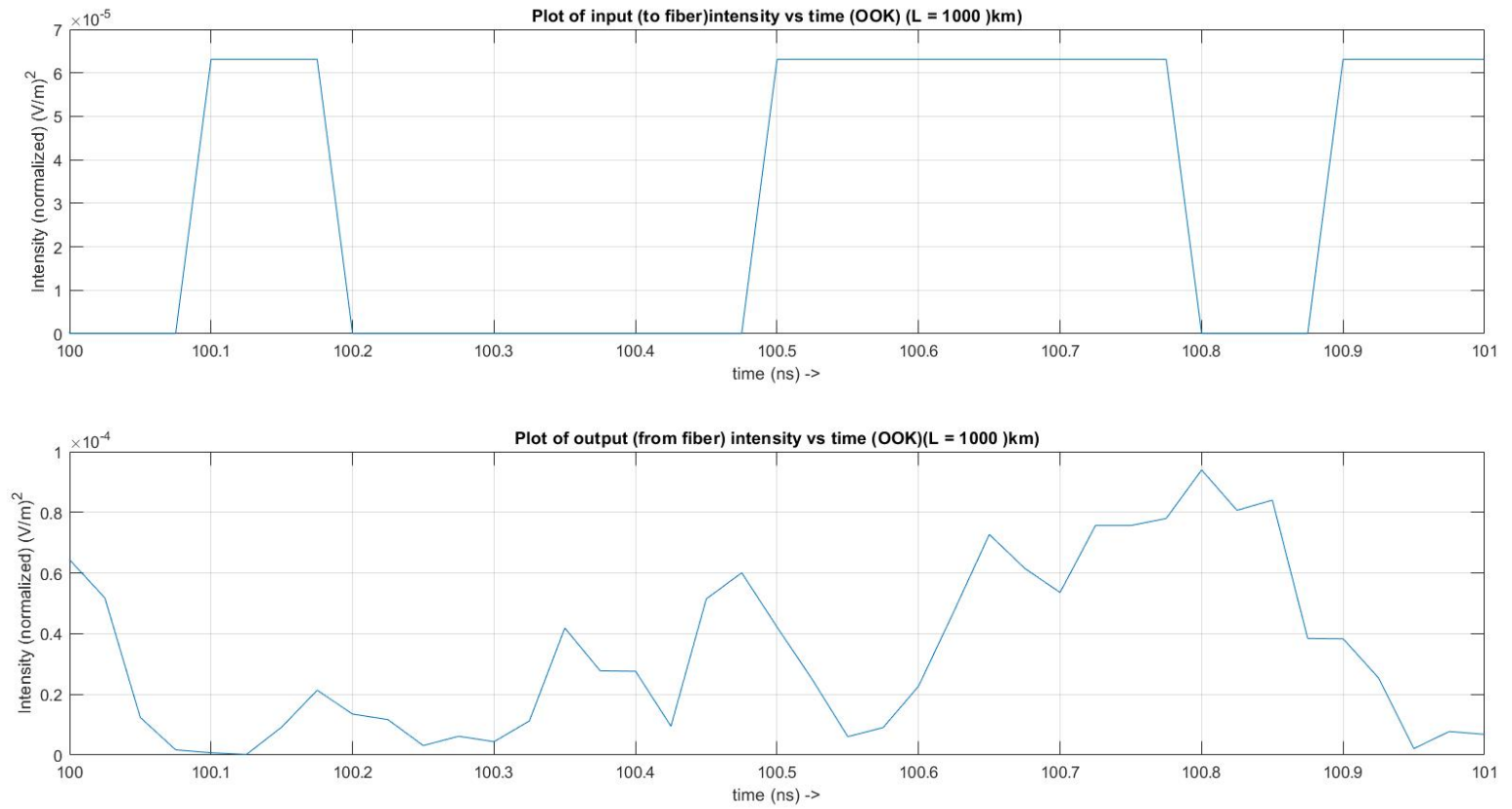


Figure 4: Time domain waveforms for input and output signal(10Gbaud) for 10 bits with a fiber length for 1000km showing dispersion in output

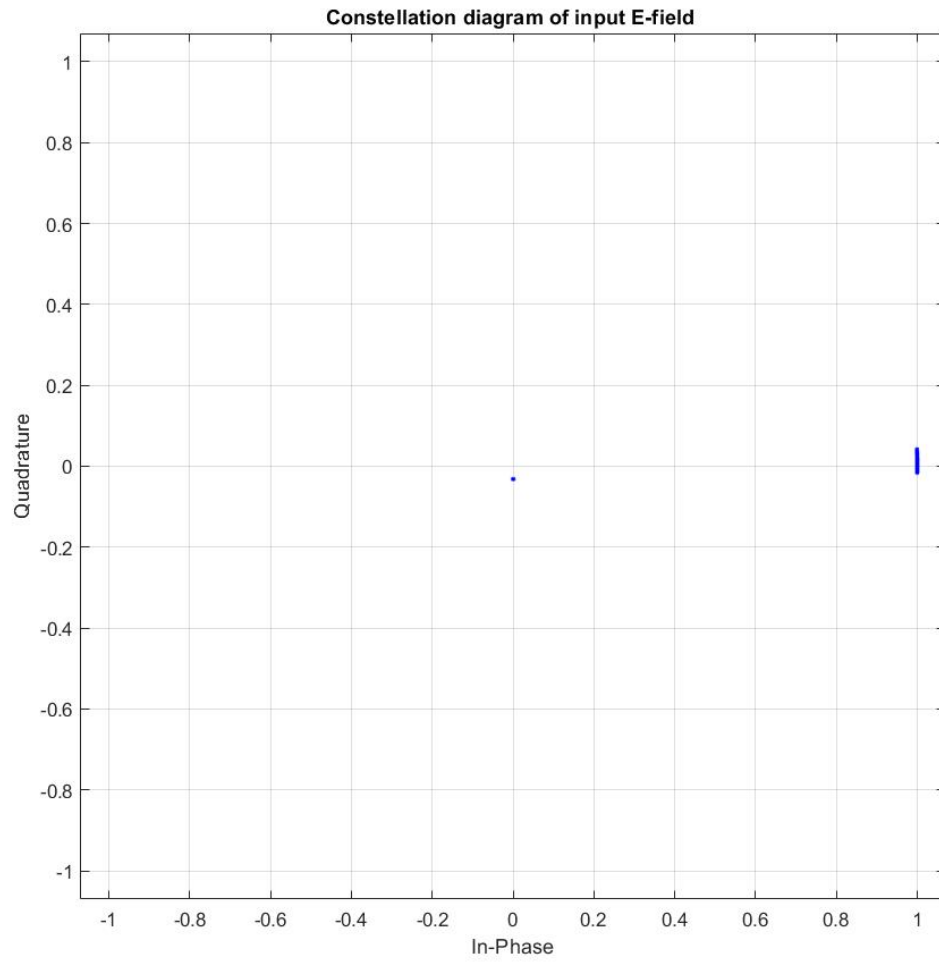


Figure 5: Constellation diagram for input signal at 10Gbaud

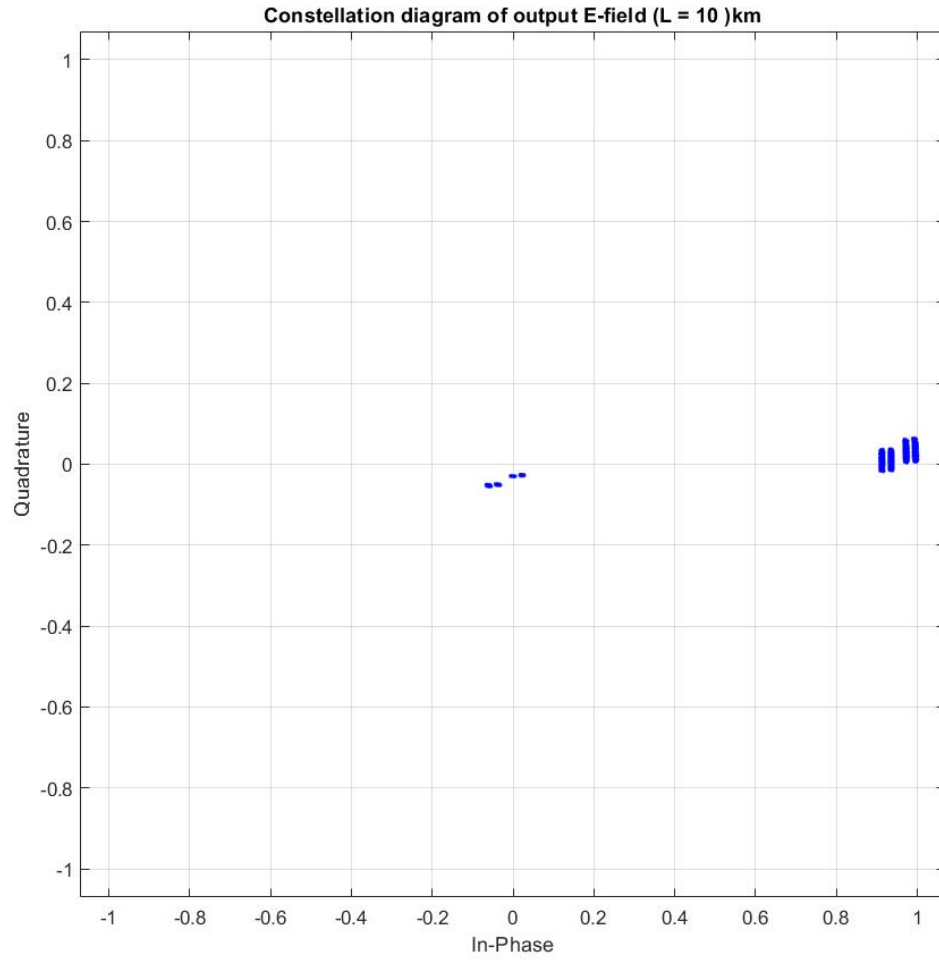


Figure 6: Constellation diagram for output signal (10Gbaud) for fiber length of 10km

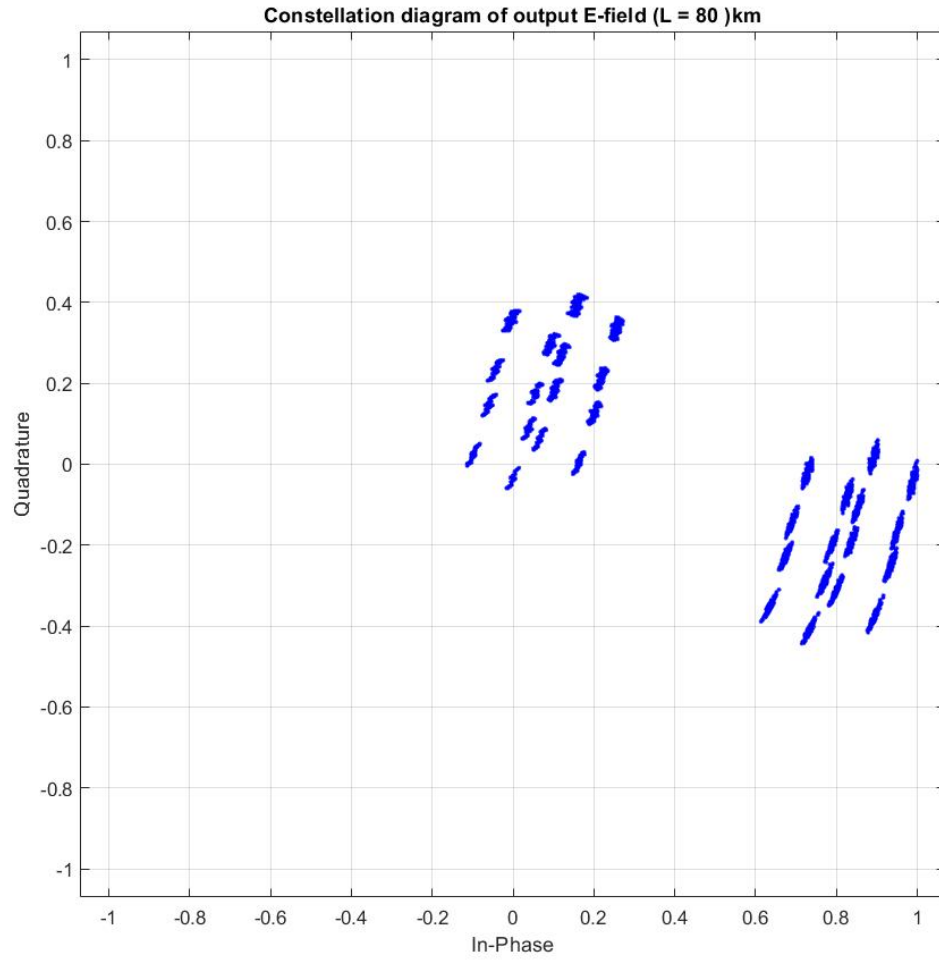


Figure 7: Constellation diagram for output signal (10Gbaud) for fiber length of 80km

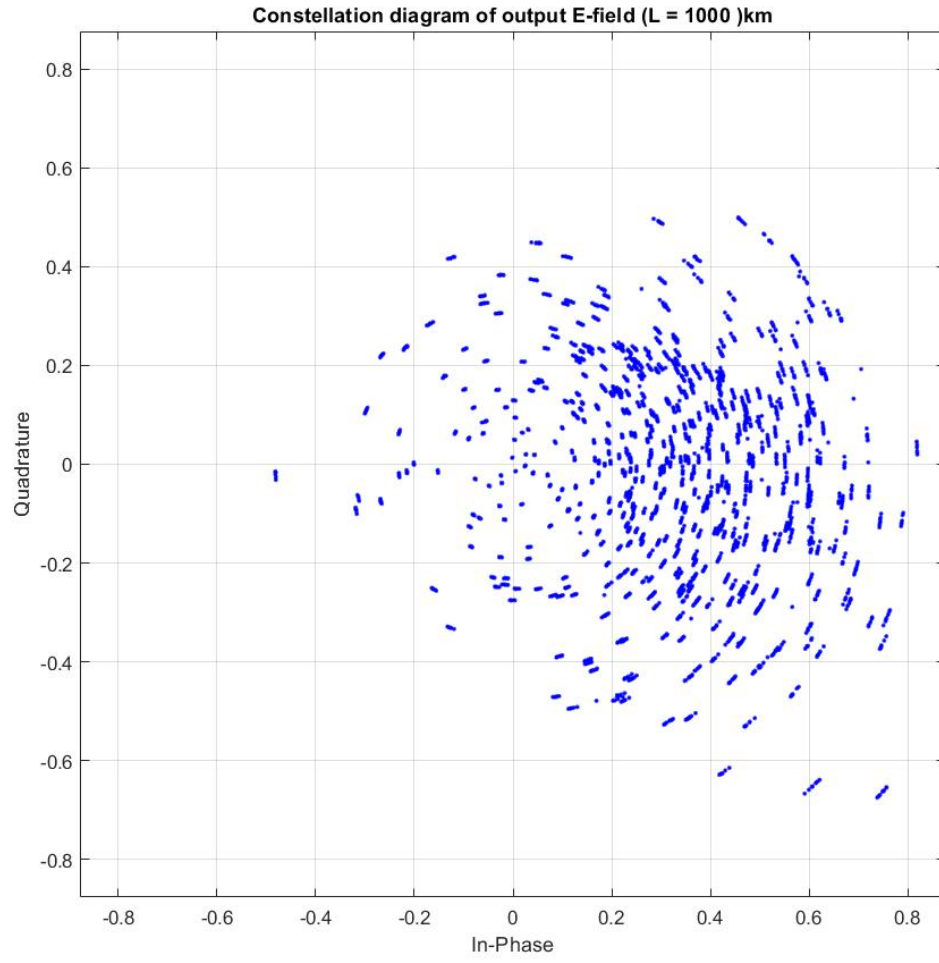


Figure 8: Constellation diagram for output signal (10Gbaud) for fiber length of 1000km

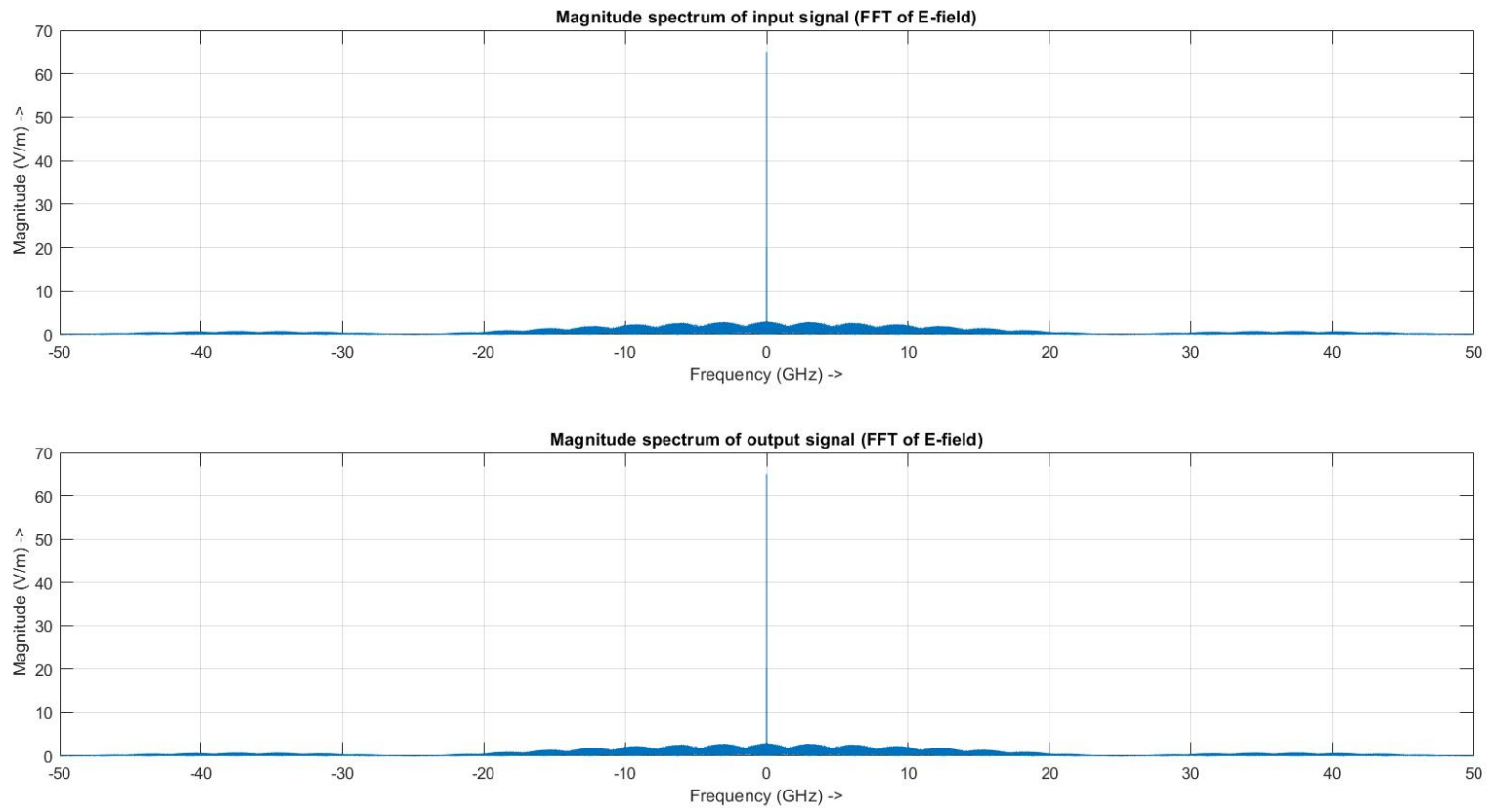


Figure 9: Plot of Magnitude spectrum of FFT of input and output E-field (25Gbaud) for fiber lengths $L = 10\text{km}$, 80km and 1000km .

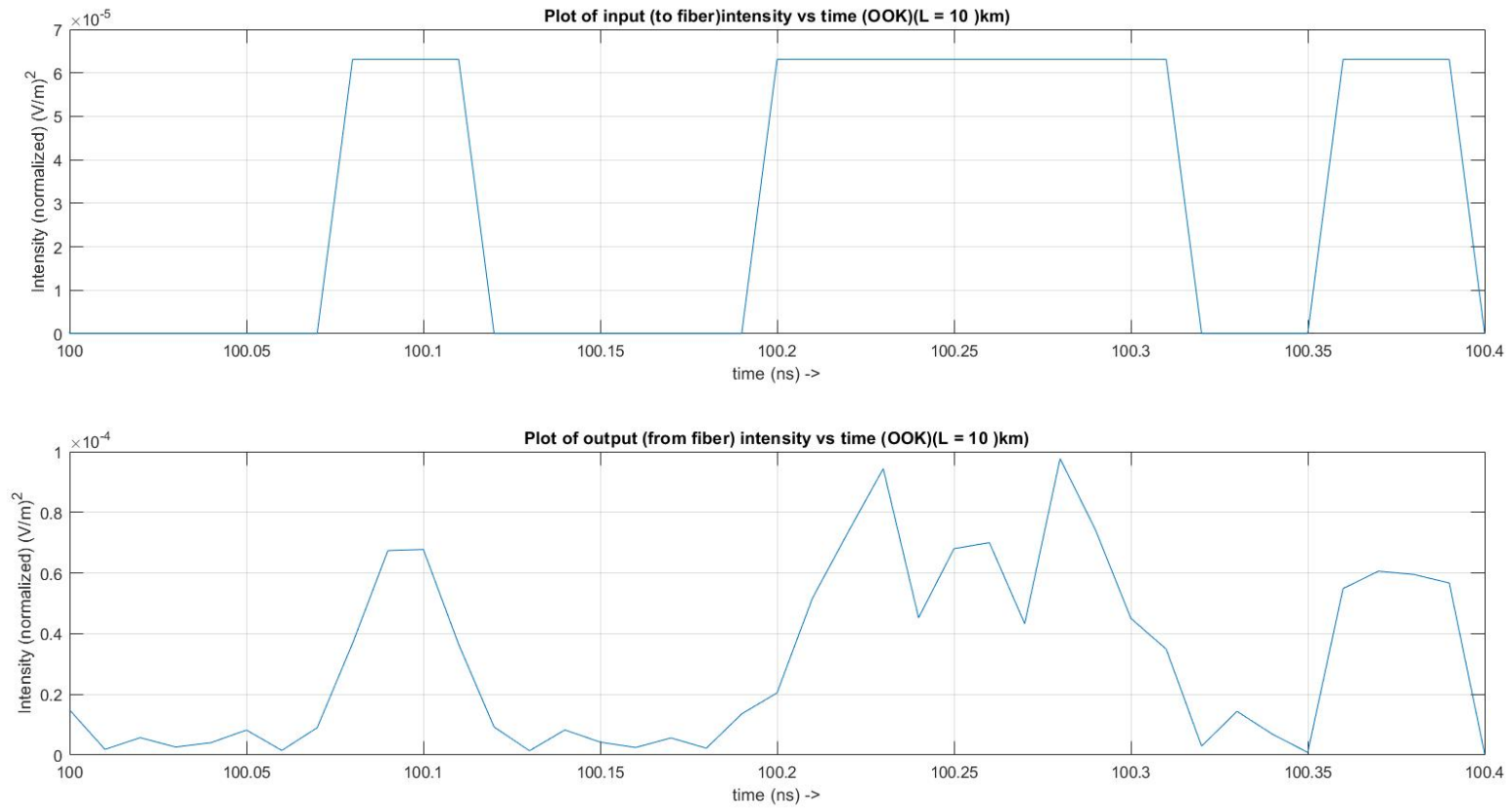


Figure 10: Time domain waveforms for input and output signal(25Gbaud) for 10 bits with a fiber length for 10km showing dispersion in output

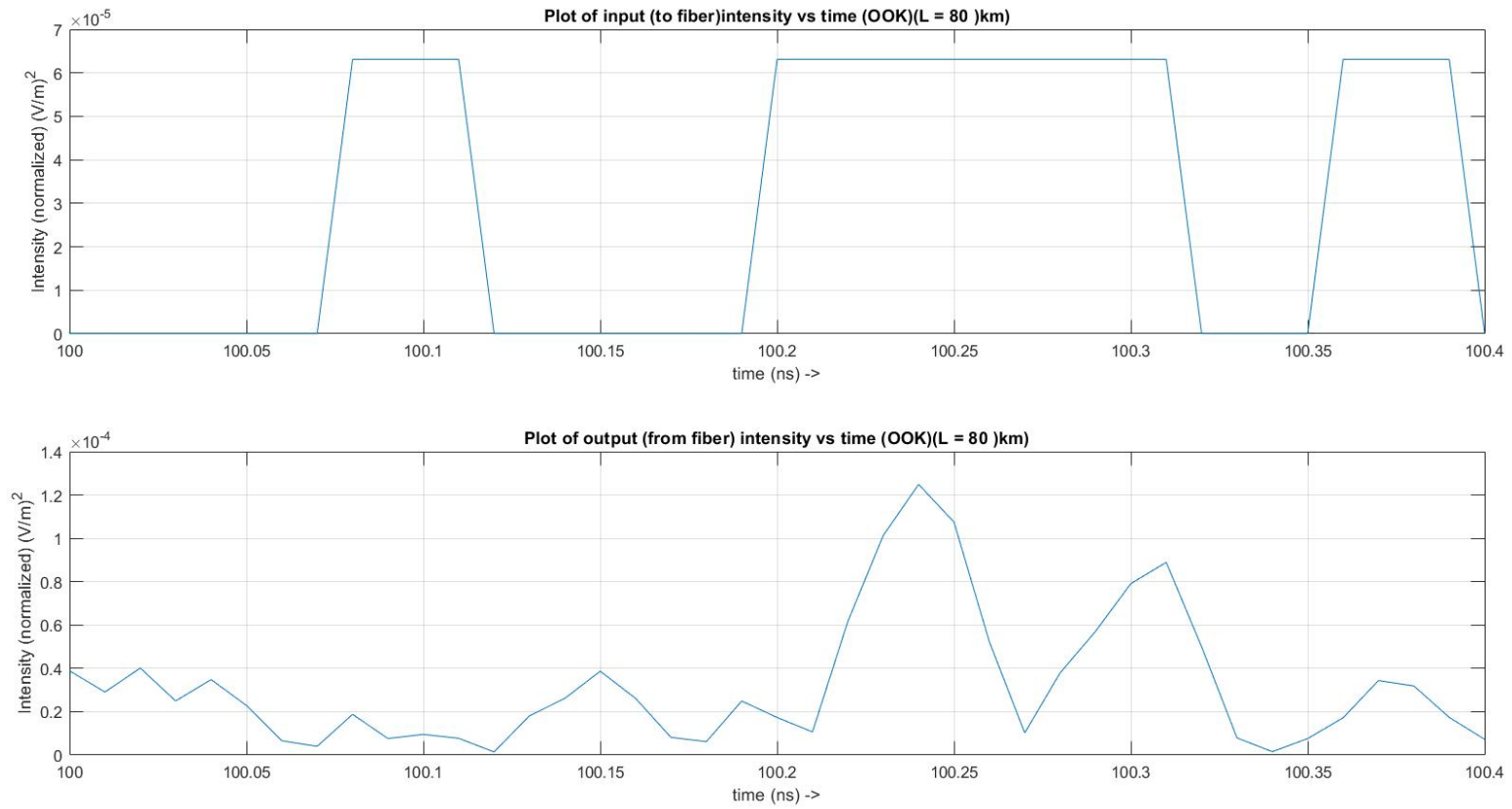


Figure 11: Time domain waveforms for input and output signal (25Gbaud) for 10 bits with a fiber length for 80km showing dispersion in output

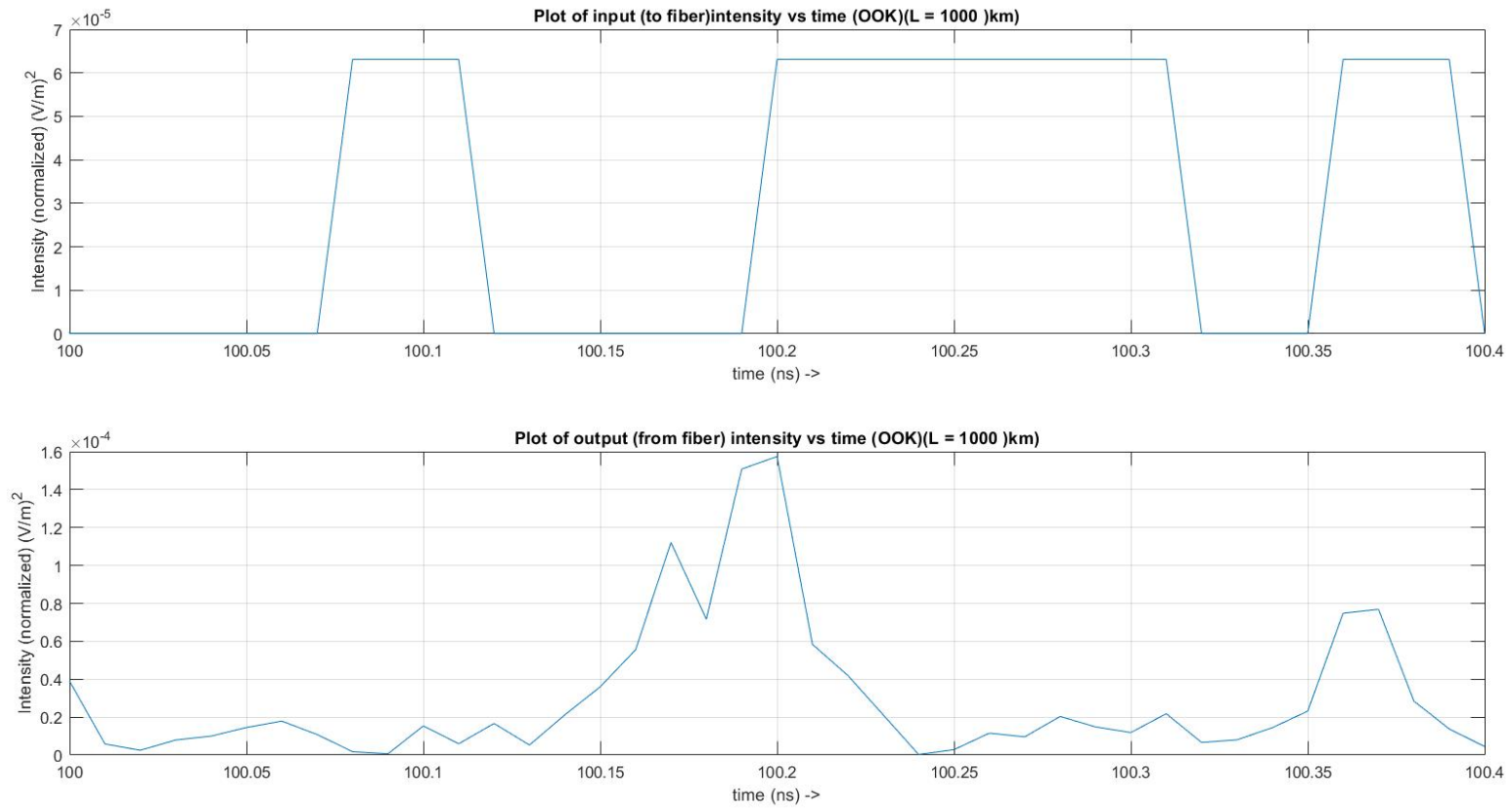


Figure 12: Time domain waveforms for input and output signal(25Gbaud) for 10 bits with a fiber length for 1000km showing dispersion in output

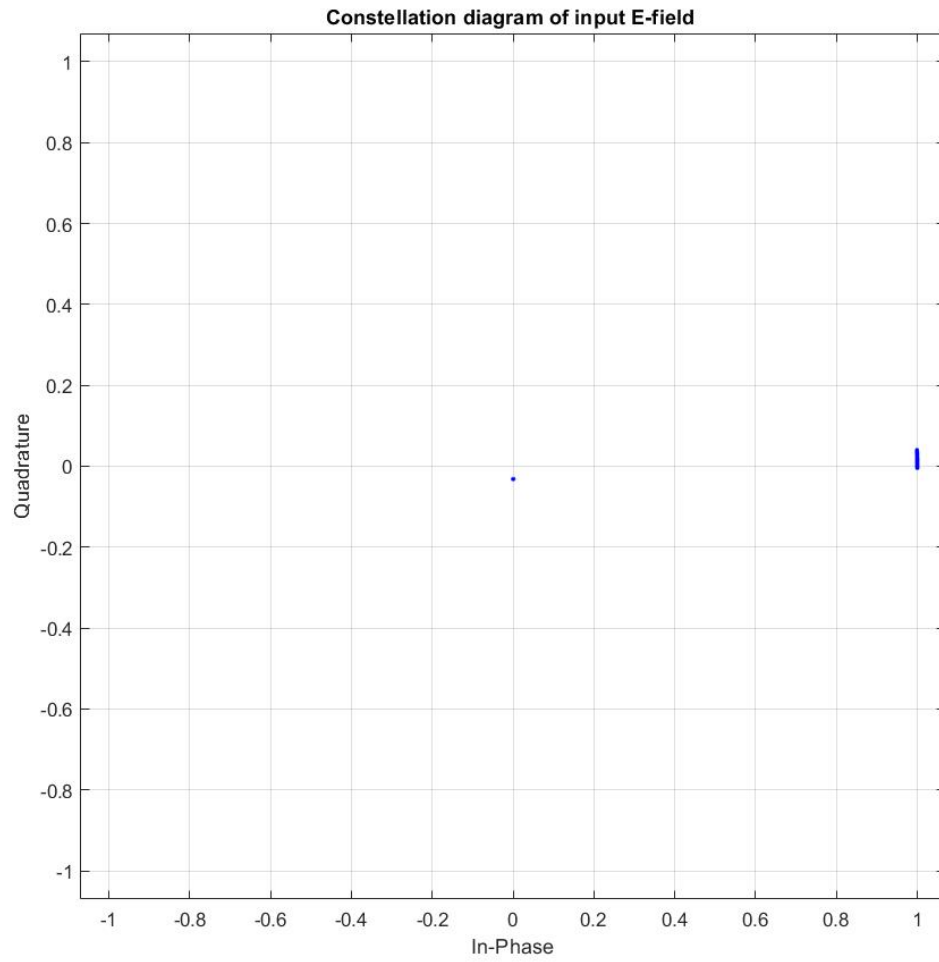


Figure 13: Constellation diagram for input signal at 25Gbaud

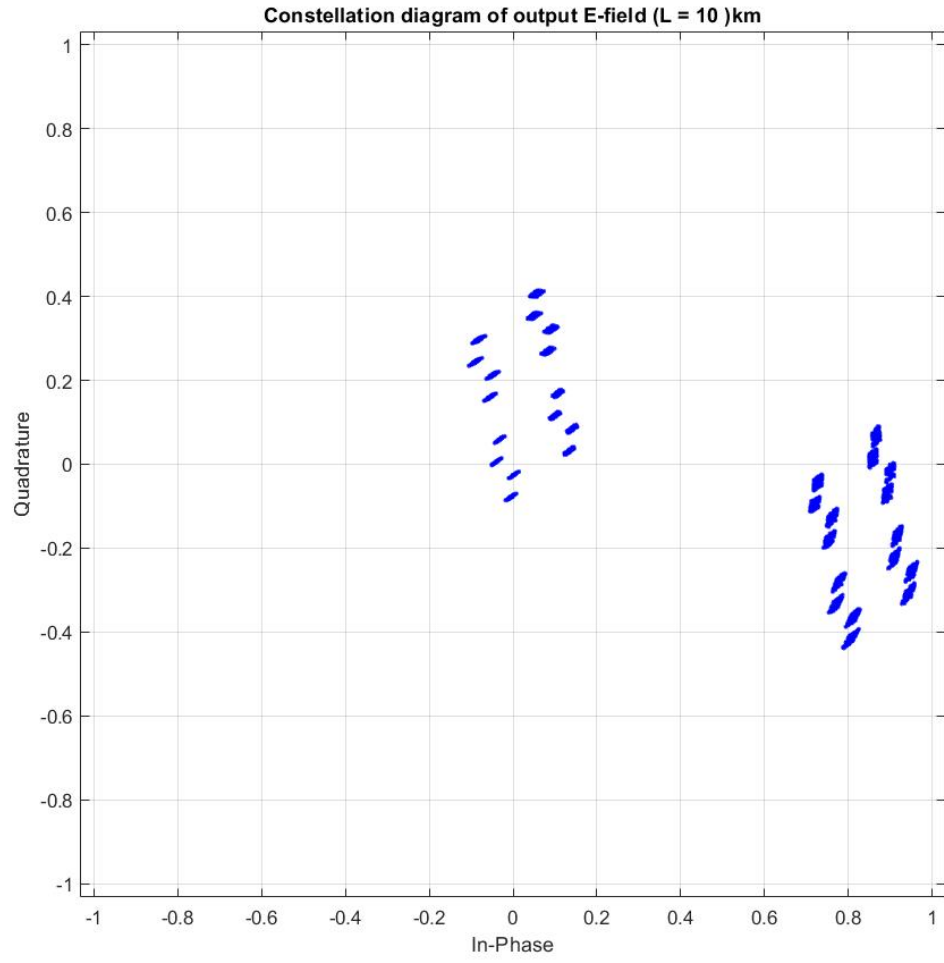


Figure 14: Constellation diagram for output signal (25Gbaud) for fiber length of 10km

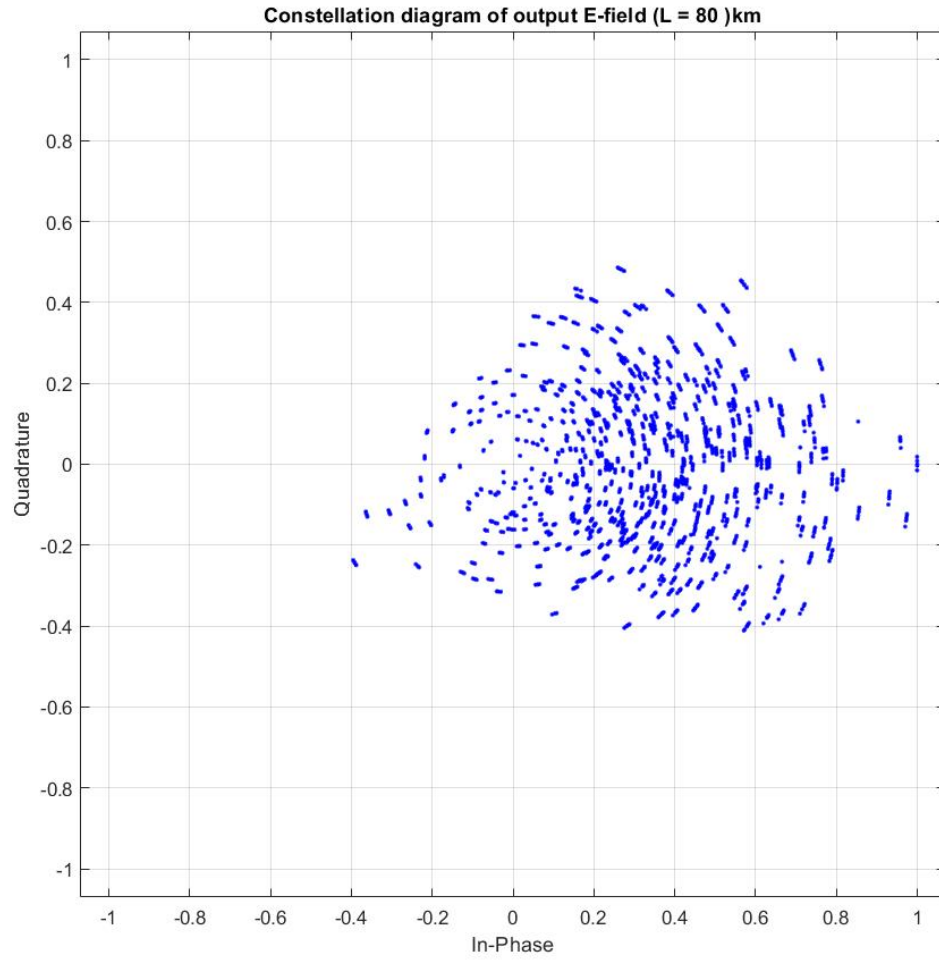


Figure 15: Constellation diagram for output signal (25Gbaud) for fiber length of 80km

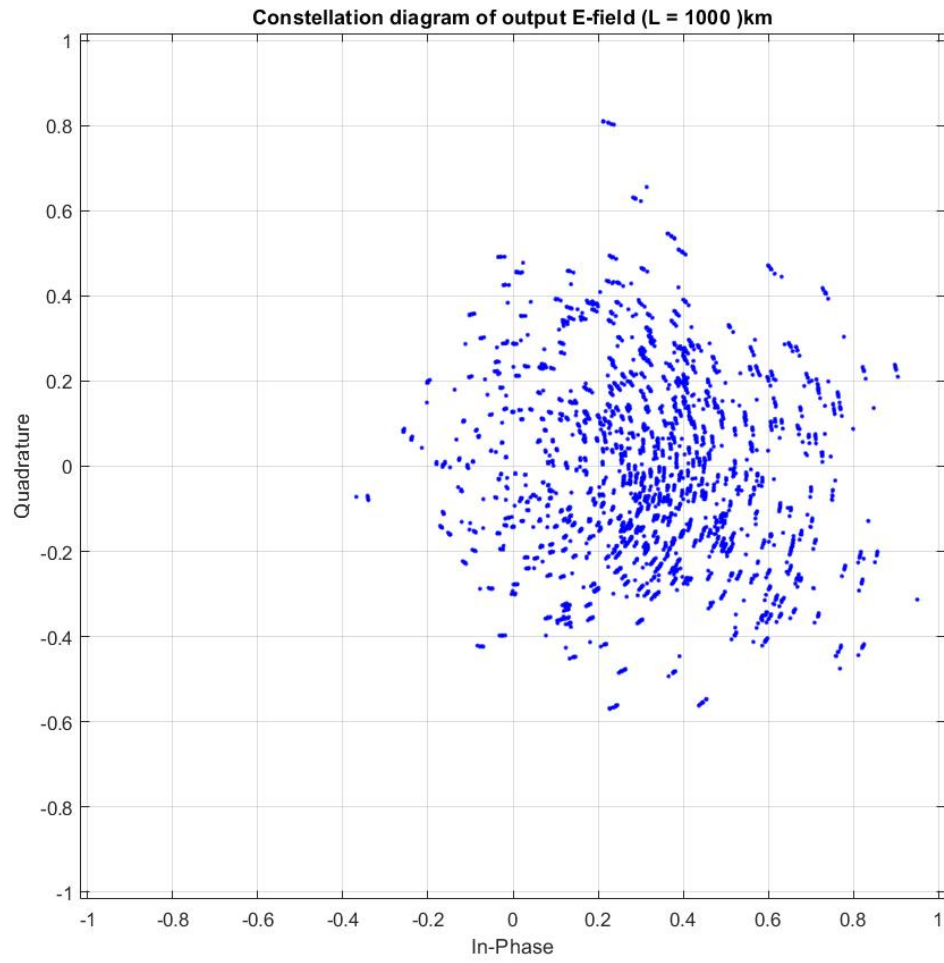


Figure 16: Constellation diagram for output signal (25Gbaud) for fiber length of 1000km

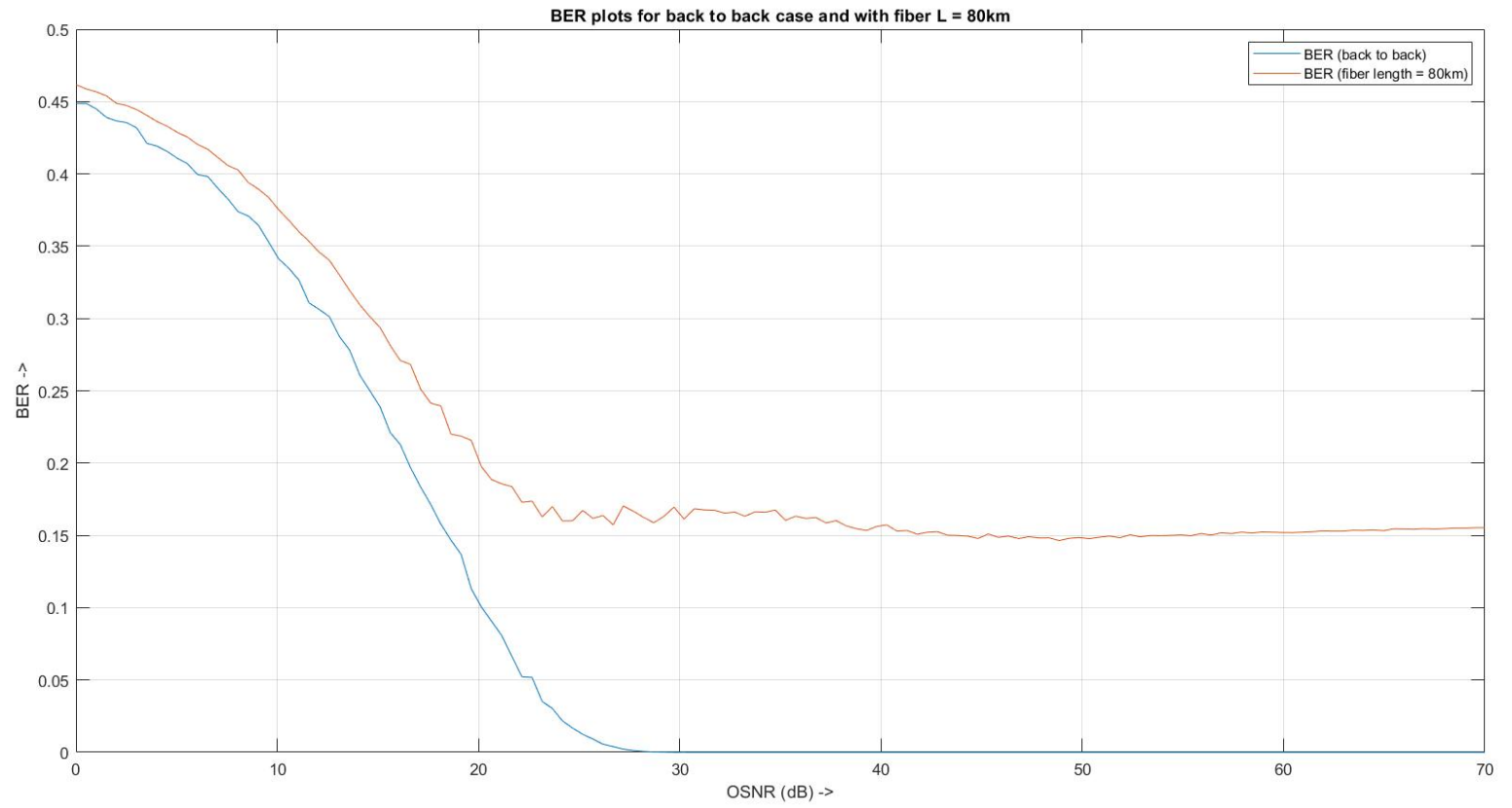


Figure 17: BER vs OSNR for the TX and RX back to back case and fiber of length 80km case .

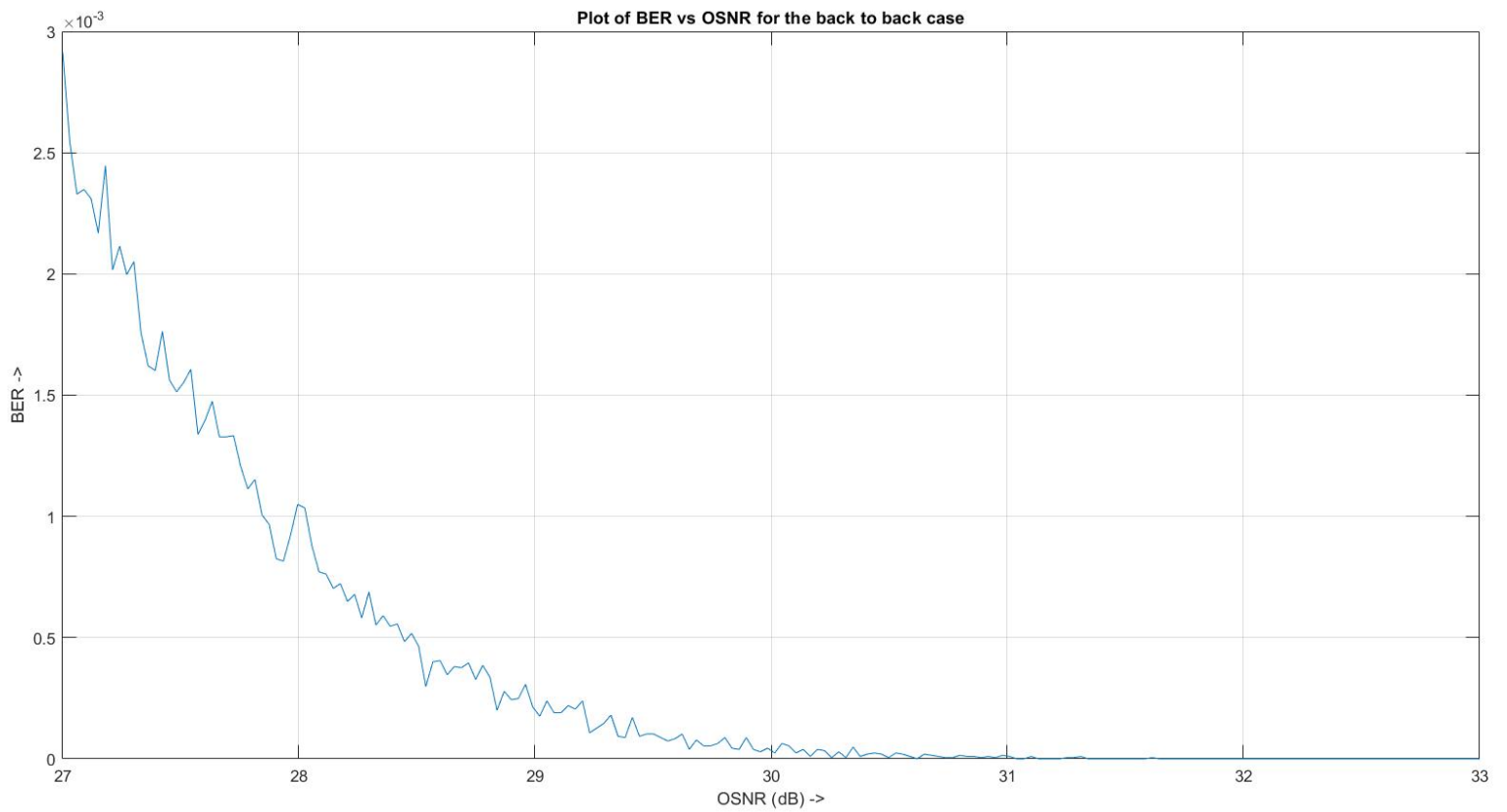


Figure 18: BER vs OSNR for the TX and RX back to back case showing low BER at OSNR > 27dB.