Design of Quad-channel Wavelength Division Multiplexed 40 Gbps Radio over Fiber system with DCF and FBG

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Abstract: Dispersion restricts the performance of optical fiber communication systems, resulting in a decrease in both the maximum bitrate and the maximum distance over which the fiber can transmit information without errors. Multiple techniques can be used to improve upon this effect of dispersion. In this study, the performance of a four-channel WDM-PDM Radio over Fiber system is analysed. The system employs dispersion compensation techniques using Dispersion Compensation Fiber (DCF) and Fiber Bragg Grating (FBG). The effects of various performance metrics, including bit error rate (BER), optical signal-to-noise ratio (SNR), and received power, are evaluated by adjusting the length of optical fiber cable used between the transmitter and receiver. The results and observations are generated using Opti System software.

Keywords: Bit error rate (BER), Dispersion compensation fiber(DCF), Eye Diagram, Fiber Bragg Grating(FBG), Polarization division multiplexing (PDM), Q-factor,Radio over fiber (RoF) systems, Signal to noise ratio (SNR), Wavelength Division Multiplexing (WDM),

1. Introduction

Optical fiber communication has pioneered the high-speed data transmission revolution in present time. The major advantages of optical fiber communication include high bandwidth and low interference which can be extended for transmission of Radio Frequency signals by using a Radio over Fiber system. In Radio over Fiber systems a radio signal is modulated using an optical signal and transmitted over an optical fiber cable. In the milli meter band i.e. 3 to 300 GHz of which 60GHz is most popularly used for wireless communications [1].

An optical system can also be designed using different phenomena such as polarization division multiplexing (PDM) where multiple signals can be multiplexed using wavelength division multiplexing and are then sent at two different states of polarization which are orthogonal to each other [2].

As the optical signal traverses through the optical fiber it suffers through numerous impediments which causes the signal strength to deteriorate with increasing distance. The two major reasons for decrease in strength of an optical signal through an optical fiber are attenuation and dispersion. Attenuation causes signal strength to drop as it traverses through fiber whereas dispersion in an optical fiber cable is the phenomena of spreading of light pulse when the wave travels through an optical fiber cable from one end to another [3]. An optical fiber may suffer from dispersion of two types which are chromatic dispersion and intermodal dispersion. Chromatic dispersion occurs when the source emits more than one frequency and each frequency travels at different speed than other. Intermodal dispersion is caused by the difference in propagation delay between different modes within a multimode fiber [4].

There are various methods to mitigate the impacts of dispersion in optical fibers. The two most important methods for compensating for chromatic dispersion are by using a DCF or by using an FBG [5]. One such method involves using a dispersion compensation fiber (DCF) to counteract chromatic dispersion and enhance overall performance. A DCF features a fiber with a negative dispersion coefficient, which works in conjunction with standard optical fiber to offset dispersion effects. To maximize

effectiveness, the length of the DCF is kept to a minimum [6][7].
A different method to diminish the impact of chromatic dispersion and enhance the performance of optical fibers is through the application of fiber Bragg gratings (FBGs). An FBG is embedded within the optical fiber, where it selectively reflects certain light frequencies while permitting others to pass [9][10]. This device operates as a distributed Bragg reflector, designed within a short segment of optical fiber to reflect specific wavelengths and allow the transmission of all other frequencies [7][8]. An FBG can either reflect the desired signal and transmit it towards the receiver or it can reflect the undesired signal to reduce the chromatic dispersion [8].

To mitigate chromatic dispersion (CD), fiber Bragg gratings (FBGs) can be arranged in three different configurations [11]. First, the FBG is located before the link fiber called pre-compensation. Second, the FBG is situated after the link fiber called post compensation. Third, FBGs are positioned both before and after the link fiber called as symmetrical compensation technique [12].

The above techniques for compensating for dispersion combined with multiple multiplexing techniques can greatly increase the bandwidth of the system and enhance its cost effectiveness and performance.

2. System description

A four-channel radio over fiber(RoF) channel is designed using wavelength division multiplexing(WDM) and polarization division multiplexing(PDM). The system consists of transmitter section, channel and receiver section.

The transmitter section is shown in Figure 1. In the RoF optical communication system shown, the transmitter section consists of two 2x1 WDM multiplexer making four channels. Each channel consists of a 10Gbps Pseudo Random bit generator to generate the input bit sequence. The output of pseudo random bit generator is fed to the NRZ pulse generator which encodes the input bit sequence in non-return to zero format. After this with the help of an MZ modulator a CW laser is used to modulate the NRZ signal obtained. The various light sources are operating from 1550 nm to 1551.5 nm with a spacing of 0.5 nm The output of the two 2x1 WDM multiplexers is fed to a polarization controller to change the azimuth parameter of the polarization controller to obtain two orthogonal signal which will be transmitted over the optical fiber cable. Finally, the output of the two polarization controllers is multiplexed using a 2x1 WDM multiplexer before transmission through an optical fiber cable.

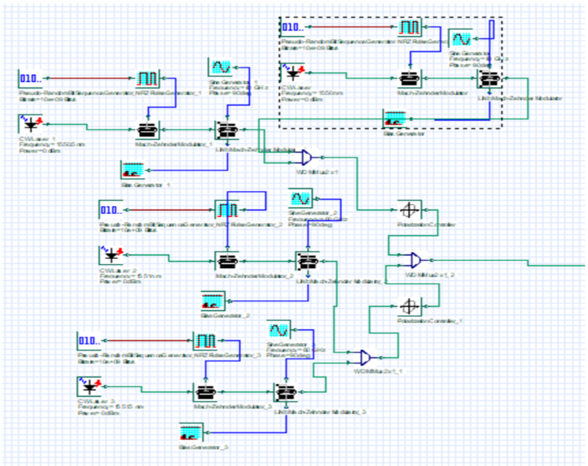

Figure 1: Transmitter section.

The output of 2x1 WDM multiplexer is transmitted through an optical fiber cable as channel. The channel also consists of a pre and post amplifiers of 20dB gain and 2 dB noise figure each. Figure 2 shows the channel. A Dispersion compensation fiber is used after the optical fiber to combat the effect of chromatic dispersion on the signal as it is transmitted through the optical fiber. The value of dispersion is taken as negative for the DCF to negate the effect of dispersion on the optical signal.

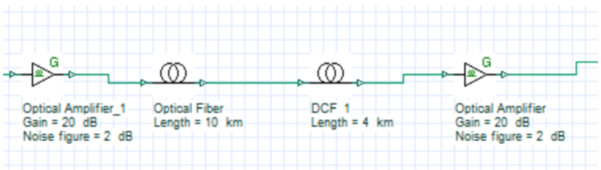

Figure 2: Channel

At the receiver, a polarization splitter separates the received signal according to its state of polarization. After this two 1x2 WDM demultiplexers are used to demultiplex the multiplexed received optical signal into individual output signals. After the demultiplexer, the original input signal is recovered after passing it through a gaussian optical filter. The output of the gaussian filter is passed through a fiber bragg grating with frequency being adjusted according to the channel. The reflected signal of the FBG is fed to the PIN photodetector. The output of the photodetector is an electrical signal. The original input signal is recovered after passing it through a gaussian optical filter. A WDM analyser is used to view the value of received signal power and optical signal to noise ratio(OSNR) at the receiver. Further, a BER analyser is used to analyse the received signal.

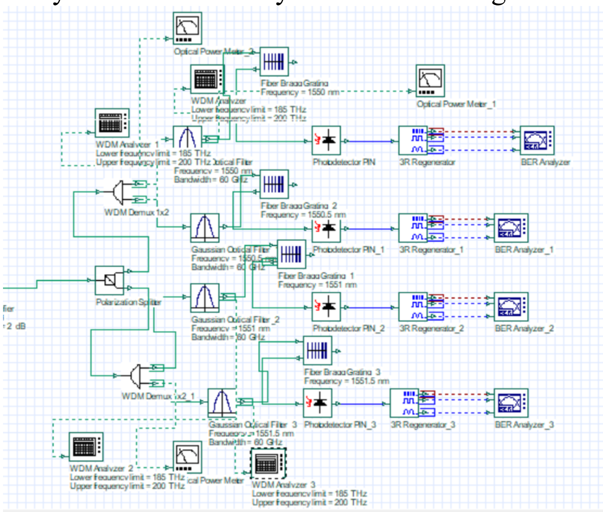

Figure 3: Receiver Section

3. Results and discussions

Table 1 shows the variation of various system performance parameters such as signal power, optical SNR, BER and Q factor as the distance between the transmitter and receiver increases while the dispersion is compensated for using an dispersion compensation fiber by varying the dispersion value for each fiber and changing the dispersion compensation fiber length. Dispersion in the single mode optical fiber is taken to be 16 nm/ps/km. Whereas, Table 2 shows the results of the system when the DCF is not used for compensating for chromatic dispersion. Figure 4 and 5 shows the eye diagram for the Radio over fiber system using PDM, DCF and Fiber Bragg grating.

Fiber length	Channel	Received Power(dBm)	Optical Signal to noise ratio(dbm)	BER	Q-factor
30 Km DCF length = 4 Km Dispersion in DCF = -120 ps/nm/km	1550 nm	14.05	40.33	1.50×10^{-39}	13.07
	1550.5 nm	15.19	41.43	1.56×10^{-40}	13.24
	1551 nm	14.14	40.47	9.27×10^{-42}	13.79
	1551.5 nm	15.21	41.59	9.51×10^{-42}	13.45
45 Km DCF length = 8 Km Dispersion in DCF = -90 ps/nm/km	1550 nm	10.25	40.06	1.07×10^{-40}	13.27
	1550.5 nm	11.40	41.16	7.10×10^{-38}	12.77
	1551 nm	10.35	40.13	3.48×10^{-42}	13.52
	1551.5 nm	11.42	41.25	1.20×10^{-38}	12.91
60 Km DCF length = 8 Km Dispersion in DCF = -120 ps/nm/km	1550 nm	7.25	39.63	8.91×10^{-38}	12.76
	1550.5 nm	8.40	40.74	7.57×10^{-35}	12.22
	1551 nm	7.34	39.78	1.71×10^{-37}	12.71
	1551.5 nm	8.41	40.90	2.39×10^{-38}	12.86
80 Km DCF length = 8 Km Dispersion in DCF = -160 ps/nm/km	1550 nm	3.25	38.49	8.83×10^{-27}	10.63
	1550.5 nm	4.40	39.66	1.59×10^{-28}	10.99
	1551 nm	3.34	38.71	6.58×10^{-27}	10.65
	1551.5 nm	4.41	39.82	7.53×10^{-29}	11.05

Table1: Variation for Received power, SNR, BER and Q- factor with distance with DCF.

Fiber Length	Channel	Received power (dBm)	Signal to Noise ratio(SNR) (in dBm)	Bit error rate (BER)
30Km	1550.0 nm	14.85	40.29	5.70×10^{-29}
	1550.5 nm	16.00	41.46	2.56×10^{-27}
	1551.0 nm	14.95	40.44	3.33×10^{-32}
	1551.5 nm	16.02	41.55	1.14×10^{-28}
45Km	1550.0 nm	11.85	40.13	1.48×10^{-23}
	1550.5 nm	13.00	41.30	2.72×10^{-20}
	1551.0 nm	11.95	40.27	3.64×10^{-24}
	1551.5 nm	13.02	41.39	2.57×10^{-22}
60Km	1550.0 nm	8.85	39.82	1.84×10^{-14}
	1550.5 nm	10.00	40.99	5.44×10^{-13}
	1551.0 nm	8.95	39.97	1.23×10^{-15}
	1551.5 nm	10.02	41.08	1.73×10^{-14}
80Km	1550.0 nm	4.85	39.01	1.90×10^{-06}
	1550.5 nm	6.00	40.18	3.44×10^{-06}
	1551.0 nm	4.95	39.15	1.55×10^{-06}
	1551.5 nm	6.02	40.26	3.41×10^{-06}

Table 2: Variation for Received power, SNR, BER and Q- factor with distance without DCF.

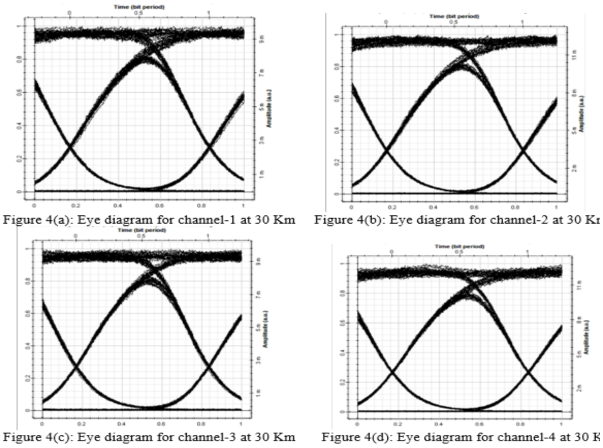

Figure 4(a): Eye diagram for channel-1 at 30 Km
Figure 4(b): Eye diagram for channel-2 at 30 Kr
Figure 4(c): Eye diagram for channel-3 at 30 Km
Figure 4(d): Eye diagram for channel-4 at 30 K

Figure 4: Eye diagram at optical fiber length of 30 Km with DCF and FBG.

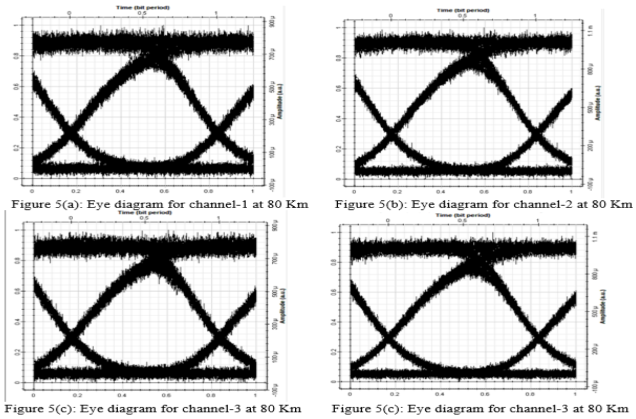

Figure 5(a): Eye diagram for channel-1 at 80 Km
Figure 5(b): Eye diagram for channel-2 at 80 Km
Figure 5(c): Eye diagram for channel-3 at 80 Km
Figure 5(c): Eye diagram for channel-3 at 80 Km

Figure 5: Eye diagram at optical fiber length of 80 Km with DCF and FBG.

4. Conclusions

Here, a Radio over fiber system has been developed by applying WDM and PDM techniques. Furthermore, the negative effect of chromatic dispersion is reduced by utilizing techniques such as dispersion compensation fiber and Fiber Bragg grating. When the system to reduce dispersion is not employed the bit error rate for channel 1 is found as 5.70×10^{-29} for 30 Km and 1.90×10^{-06} for 80 Km. Similar results are obtained for remaining three channels in absence of dispersion compensation techniques. But when dispersion compensation methods are implemented the bit error rate for channel 1 is found as 1.50×10^{-39} for 30 Km and 8.83×10^{-27} for 80 Km optical fiber communication distance. Thus, bit error rate and thus bandwidth can be significantly improved upon by using DCF and an FBG for compensating chromatic dispersion.

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