Quad-channel WDM and PDM 40 Gbps Radio over fiber system using a Dispersion Compensation Fiber

[1]Himanshu Rawat, [1]Chakresh Kumar* and [2]Ghanendra Kumar
[1]University School of Information, Communication & Technology,
[2]University School of Automation and Robotics,
Guru Gobind Singh Indraprastha University, New Delhi-110 078, India
*Corresponding E-mail-ckumarggsipu@gmail.com

Abstract: Chromatic dispersion is one of the main limiting factors that limits the effectiveness of an optical fiber system. To fully utilize the merits of an optical fiber system dispersion needs to be reduced or eliminated completely if performance metrics of the system such as bit error rate (BER) of the system is to be improved upon. Here, a 40 Gbps radio over fiber (RoF) optical fiber system is designed and a dispersion compensation fiber (DCF) is used to reduce the effects of chromatic dispersion. A DCF can be employed along with the regular optical fiber. The following work is conducted using Opti System software, which is engineered explicitly for designing optical communication systems.

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

1. Introduction

Optical fiber involves transmitting optical signal over an optical fiber cable. This trend can be extended to transmission of radio signals as radio signals can also be transmitted like optical signal in Radio over Fiber (RoF) technology [1]. This help utilize merits of optical communication such as large bandwidth and low interference in radio frequency signal transmission [1].

Optical communication system has enormous potential benefits over traditional co-axial cables which can be further improved upon by using multiplexing techniques such as wavelength division multiplexing (WDM) and Polarization Division Multiplexing (PDM). These techniques help increase the available bandwidth and overall data rate possible. WDM technique involves transmitting multiple signals over the optical fiber, but the different signals are transmitted at different wavelength [2]. PDM is a multiplexing technique which involves transmitting two optical signals with two different states of polarization which are orthogonal to each other [3].

Optical fiber with its better performance characteristics compared to different electrical cable transmission is still affected by a phenomenon of dispersion which adversely affects its performance. Among different dispersion phenomenon, chromatic dispersion has a huge detrimental effect over operation of optical fiber system. Dispersion causes light pulse to spread as it traverses through the optical fiber [4]. In chromatic dispersion, the light pulse spreads as the optical source emits light of more than one frequency. By integrating the single mode fiber with a dispersion compensation fiber, dispersion can be effectively managed [5][6][7].

DCF is a negative dispersion co-efficient optical fiber [6]. The length of DCF is chosen such that it compensates for dispersion in standard single mode fiber. The negative dispersion coefficient in DCF is much higher in DCF so that its length is much smaller than a standard single mode fiber [2][8]. Dispersion must be compensated before signal detection; otherwise, each transmitted symbol will broaden excessively and overlap with neighbouring symbols, and cause distortion in the electrical signals detected at the receiver section [9].

The required length of DCF can be determined using Eq. 1 [4][10], where D_{SMF} represents the positive dispersion of the optical fiber transmission, L_{SMF} is the transmission length, D_{DCF} denotes the negative dispersion of the DCF, and L_{DCF} is the length of the DCF compensator.

$$D_{SMF}L_{SMF}+D_{DCF}L_{DCF}=0 \qquad (1)$$

There are three approaches by which DCF can be arranged in an optical channel which are pre-compensation, post compensation and symmetrical compensation [4]. In pre-compensation the DCF is places before the optical fiber. In post compensation the DCF is placed after the optical fiber. In symmetrical compensation, two DCFs are employed, one before the fiber and other after the fiber. In symmetrical compensation the dispersion compensation is spread in two DCFs.

2. System description

A four-channel radio over fiber (RoF) channel is made using wavelength division multiplexing (WDM) and polarization division multiplexing (PDM). Furthermore, a dispersion compensation fiber (DCF) is used to counter the effects of chromatic dispersion. The designed system consists of transmitter section, channel and receiver section.

In the RoF optical communication system devised, the transmitter section is made up of four channels with light sources operating from 1550 nm to 1551.5 nm with a spacing of 0.5 nm as shown in figure 1. The optical system's comprises of two 2x1 WDM multiplexer which makes up the 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 (NRZ) format. After this with the help of an MZ modulator a CW laser is used to modulate the NRZ signal obtained. The output of the two 2x1 WDM multiplexers is fed to 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. The output of the two polarization controllers is finally fed to a 2x1 WDM multiplexer before transmission.

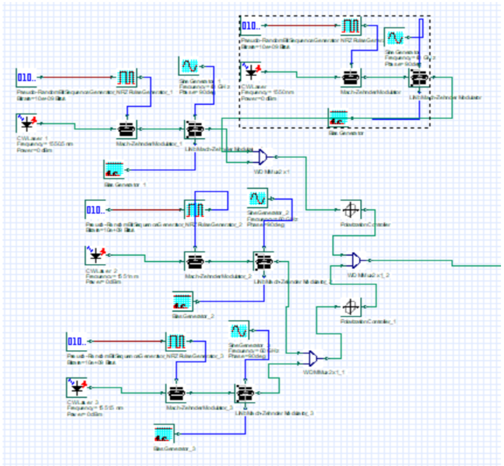

Figure 1: Transmitter section.

The output of 2x1 WDM multiplexer is transmitted through the channel. Figure 2 shows the channel. The channel consists of a pre and post amplifiers of 20dB gain and 2 dB noise figure each. A Dispersion compensation fiber is incorporated in the channel in post compensation scheme after the optical fiber to combat the effect of chromatic dispersion. The value of dispersion coefficient is taken as negative for the DCF so as to negate the effect of positive dispersion coefficient of the optical channel on the transmitted optical signal. The dispersion co-efficient of the DCF is varied as the length of optical fiber is changed.

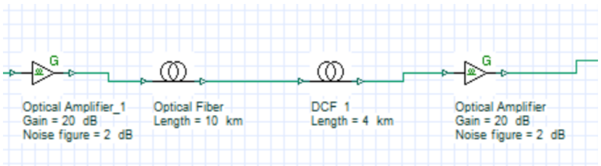

Figure 2: Channel

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 four multiplexed received optical signal into individual output optical signals. 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. After this a PIN photodiode is used to detect the optical signal and convert the optical signal into an electrical signal. Finally, Further, a BER analyser is used to analyse the received signal.

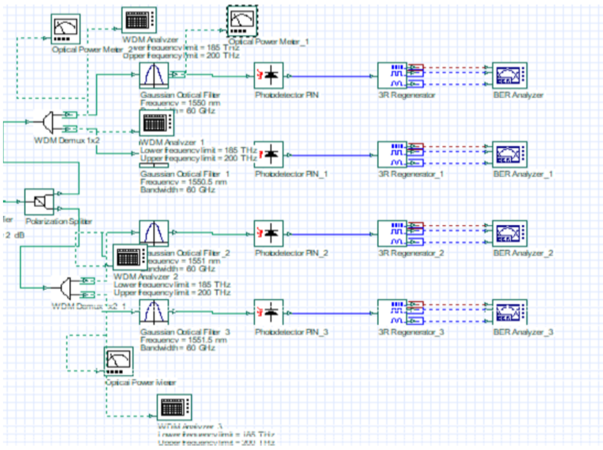

Figure 3: Receiver Section

3. Results and discussions

The performance of the optical system was measured in terms of parameters such as signal power, optical SNR, BER, eye diagram and Q factor. The variation of these parameters with distance is shown in Table 1 for the WDM-PDM 40 Gbps optical system with DCF. It can be observed from table 1 as distance increases signal power, OSNR, BER and Q-factor decreases for all the four multiplexed channels.

The variations in received power, SNR and bit error rate(BER) when the system does not employ a DCF for dispersion compensation are shown in Table 2.

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	14.06	40.26	2.53×10^{-48}	14.53
	1550.5 nm	15.19	41.43	1.97×10^{-50}	14.85
	1551 nm	14.14	40.40	8.55×10^{-48}	14.44
	1551.5 nm	15.22	41.55	3.88×10^{-50}	14.81
45 Km DCF length = 8 Km Dispersion in DCF = -90 ps/nm/km	1550 nm	10.25	39.99	8.18×10^{-48}	14.44
	1550.5 nm	11.40	41.16	5.92×10^{-52}	15.09
	1551 nm	10.35	40.13	4.12×10^{-44}	13.84
	1551.5 nm	11.42	41.25	1.46×10^{-47}	14.40
60 Km DCF length = 8 Km Dispersion in DCF = -120 ps/nm/km	1550 nm	7.25	39.57	7.17×10^{-42}	13.47
	1550.5 nm	8.40	40.74	1.62×10^{-45}	14.07
	1551 nm	7.35	39.71	8.73×10^{-47}	14.28
	1551.5 nm	8.42	40.82	1.68×10^{-42}	13.58
80 Km DCF length = 8 Km Dispersion in DCF = -160 ps/nm/km	1550 nm	3.25	38.49	6.78×10^{-45}	13.97
	1550.5 nm	4.40	39.66	3.41×10^{-44}	13.86
	1551 nm	3.35	38.63	1.29×10^{-41}	13.43
	1551.5 nm	4.42	39.74	4.11×10^{-45}	14.01

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.

It can be clearly seen that the system having DCF offers much better BER than the system without DCF.

The eye diagram for the optical system is shown for optical link length of 30 Km and 80 Km is shown in figures 4 and 5 respectively.

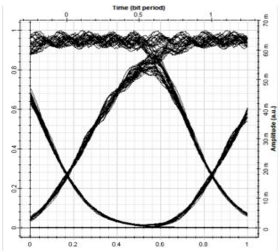
Figure 4(a): Eye diagram for channel-1 at 30 Km

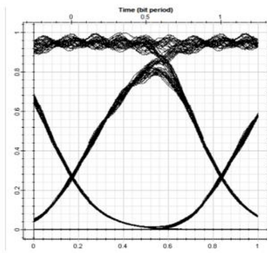
Figure 4(b): Eye diagram for channel-2 at

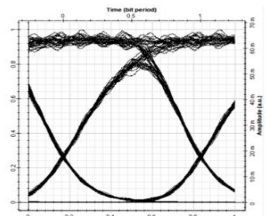
Figure 4(c): Eye diagram for channel-3 at 30 Km

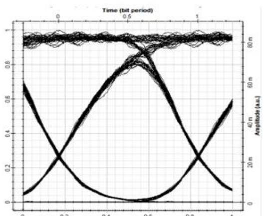
Figure 4(d): Eye diagram for channel-4 at

Figure 4: Eye diagram of the four channels at optical fiber length of 30 Km.

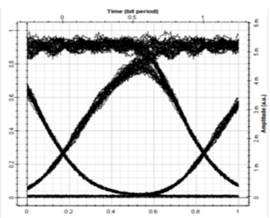
Figure 5(a): Eye diagram for channel-1 at 80 Km

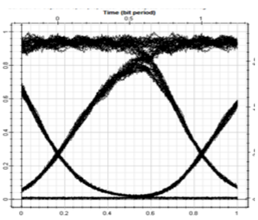
Figure 5(b): Eye diagram for channel-2 at 80 K

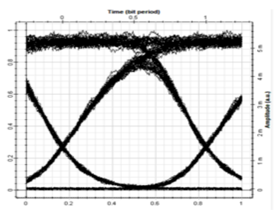
Figure 5(c): Eye diagram for channel-3 at 80 Km

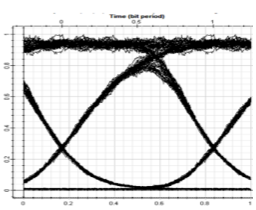
Figure 5(d): Eye diagram for channel-3 at 80 K

Figure 5: Eye diagram of the four channels at optical fiber length of 80 Km

4. Conclusions

In this work, a 40Gbps radio over fiber system is designed (RoF) using WDM and PDM multiplexing techniques and chromatic dispersion is adjusted in the optical fiber by adding a dispersion compensation fiber(DCF) in the channel. The performance of the system is reported in terms of received optical power, optical SNR, Q-factor, eye diagram and bit error rate (BER). The system performance with DCF shows much better BER with increasing distance when compared to the system when DCF is not used.

5. References

1) Sharma, A., Chaudhary, S., Thakur, D. & Dhasratan, V. (2020). A Cost-Effective High-Speed Radio over Fibre System for Millimeter Wave Applications. Journal of Optical Communications, 41(2), 177-180. https://doi.org/10.1515/joc-2017-0166

2) M. Sliti, "16 Channels WDM Radio Over Fiber System with DCF and FBG compensators," *2022 27th Asia Pacific Conference on Communications (APCC)*, Jeju Island, Korea, Republic of, 2022, pp. 54-59, doi: 10.1109/APCC55198.2022.9943747.

3) Upadhyay, K., Srivastava, S., Shukla, N. & Chaudhary, S. (2019). High-Speed 120 Gbps AMI-WDM-PDM Free Space Optical Transmission System. Journal of Optical Communications, 40(4), 429-433. https://doi.org/10.1515/joc-2017-0086

4) N. S. Effendi, Y. Natali and C. Apriono, "Study of Dispersion Compensation with Dispersion Compensating Fiber in 10 Gbps Single-Mode Fiber," *2021 International Conference on Green Energy, Computing and Sustainable Technology (GECOST)*, Miri, Malaysia, 2021, pp. 1-6, doi: 10.1109/GECOST52368.2021.9538764.

5) H. Singh and A. Mahajan, "15 Gb/s transmission over 25 km using negative dispersion fiber on lightwave systems without

dispersion compensation," *2016* International Conference on Computational Techniques in Information and Communication Technologies (ICCTICT), New Delhi, India, 2016, pp. 262-266, doi: 10.1109/ICCTICT.2016.7514589.
6) Salgals, T., Supe, A., Bobrovs, V., Porins, J., & Spolitis, S. (2020). Comparison of Dispersion Compensation Techniques for Real-Time up to 160 Gbit/s DWDM C-Band Transmission. *Elektronika Ir Elektrotechnika*, *26*(2), 85-93. https://doi.org/10.5755/j01.eie.26.2.25892
7) J. -M. Hsu, C. -W. Yao and J. -Z. Chen, "Wavelength-Tunable Dispersion Compensating Photonic Crystal Fibers Suitable for Conventional/Coarse Wavelength Division Multiplexing Systems," in Journal of Lightwave Technology, vol. 33, no. 11, pp. 2240-2245, 1 June1, 2015, doi: 10.1109/JLT.2014.2380439.
8) K. Miziya, S. K. Sudheer and A. C. Kuriakose, "Characterization of an optical communication system utilizing dispersion compensating fiber and nonlinear optical effects," *2013 Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT)*, Tiruchengode, India, 2013, pp. 1-6, doi: 10.1109/ICCCNT.2013.6726479.
9) R. Mishra, N. K. Shukla, M. Atif and C. K. Dwivedi, "Performance Analysis of 8 Channel DWDM Systems via Dispersion Compensation Fiber Using NRZ, RZ, CSRZ Modulation Schemes," 2018 International Conference on Computer Communication and Informatics (ICCCI), Coimbatore, India, 2018, pp. 1-6, doi: 10.1109/ICCCI.2018.8441500.
10) A. P. Fatikah, Y. Natali and C. Apriono, "Bidirectional Radio Over Fiber with Millimeter Wave to Support 5G Fronthaul Network," *2023 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, Malang, Indonesia, 2023, pp. 386-390, doi: 10.1109/COMNETSAT59769.2023.10420665.