

# Performance Evaluation of Chromatic Dispersion Compensation Techniques in Single Mode Fibre for Radio over Fibre Applications

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## ABSTRACT

With the increasing growth and high demand for data, fiber optic transmission, especially radio over fibre (RoF), has become a viable option for data and wireless communication. In such systems however, dispersion is a huge limiting factor in achieving the high data transmission rates. This work reviews current dispersion systems and proposes a system of dispersion compensation with fibre grating. Simulations are conducted using Optisystem 7.0 at varied data rates of 10, 20 and 40Gbps over a 200km transmission distance. The output is analyzed on parameters such as bit error rate (BER), Q-factor and eye height. It is shown that data rate exceeding 10 GB/s is achievable over a 200km distance.

**Keywords:** Radio over Fibre, LTE, Wimax, single mode fiber, 3G

## Introduction

Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) have emerged as platforms of choice in future generation wireless platforms for broadband communications, where the focus is more on multimedia services than on voice services. The spectral region best placed to provide such broadband capability is a millimetre frequency band of up to 300GHz.

WiMAX as a digital wireless data communication system was designed to provide high speed broadband services to large geographical areas. Under line of sight conditions, it is capable of achieving transmission speeds of up to 1Gbps for fixed systems and can cover distances of up to 50 km. WiMAX is an access technology with standards defined for both fixed and mobile coverage. It supports different modulation techniques such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), 16-QAM and 64-QAM. The use of Orthogonal Frequency Division Multiplexing (OFDM) at the

physical layer provides immunity to signal multipath. A major disadvantage of WiMAX is that it cannot support both high bit rates and large distances simultaneously. The bit error rate increases substantially at the maximum operating distance. Additionally, to utilize the full functionality of WiMAX, specialized equipment with dedicated antennae are required. Performance is further compromised because of shared bandwidth among users.

Long term Evolution (LTE) is the next big step beyond High Speed Packet Access (HSPA) in the development of 3rd Generation Partnership Project (3GPP) technologies. Supporting and promoting the most important aspects of mobile telephony and broadband, namely unparalleled mobility and coverage, LTE has an increased focus on quality and operational efficiency in the explosive growth of data service usage (Opatic, 2009)

The transmission impairments of the wireless medium however do pose significant challenges. To provide efficient coverage at such high transmission frequencies

will require the use of small cell sizes, which leads to higher implementation costs.

Radio-over-Fibre (RoF) techniques have been a subject of intensive research over the last few decades and have found applications in optical signal processing, radar systems, millimetre-wave and photonic up- and down-converting links for applications such as broadband wireless access networks (Opatic, 2009). Radio over Fibre does offer a medium term solution and seeks to integrate LTE and WIMAX with existing fibre communications infrastructure. Radio over Fibre depends on the use of the best attributes of two technologies, both of which are well developed and offer great advantages. RoF utilises the great bandwidth, order of THz and low loss, less than 0.5 dB/km offered by optical fibre, to send radio signals to remote antennas. The strength of a radio signal is its ability to provide tetherless connection to users. In proposed RoF systems, the remote antennas only have to perform optical to electrical conversion and all the other signal processing is done in a central office (CO). This greatly simplifies the design of the remote antennas. A RoF system is therefore one which distributes radio signals from a CO to remote antennas using optical links. The important optical parameters that require modulation are the amplitude, frequency and phase of the optical field. The basic architecture of an RoF system is therefore made up of a central office (CO) and remote antennas, connected by optical links or a network. In Global System for Mobile Communication (GSM) systems, the mobile switching centre can serve as the CO and the base stations as the antennas. An important application area for RoF systems is for use in extending the range and capacity of radio signals to large indoor places such as shopping malls where there are high concentrations of people. RoF also provides an ideal solution for delivering broadband access to the last mile, in particular the network connection between the carrier's Central Office (CO) and the subscriber's location.

The use of optical fibre links to distribute telecommunication signals is the more successful application of RoF technology, usually known as hybrid fibre-radio (HFR)

networks (Opatic, 2009). RoF networks have been deployed in the last decade due to the increasing demand for high-bitrate communication services in today's access network. This demand is based on the steady market introduction of services requiring the transmission of massive data quantities, like high-definition movie distribution, on-line gaming and rich Internet experience. The RoF concept applied to the enhancements of community antenna television (CATV) networks reflected in the so-called hybrid-fibre coax (HFC) network, in which a combination of digital and analogue channels is distributed from a central location to many users distributed geographically (Shukla 2012, Darcie *et al.*, 1991). In HFC networks the last mile connection is provided through coaxial cable whilst in HFR networks the last mile connection is always a wireless link. This is not a minor difference, as the wireless environment is much more hostile than cable, imposing restrictive RoF link performance requirements. Figure 1 provides a schematic view of RoF and shows a typical RF signal (modulated by analogue or digital modulation techniques) being transported by an analogue fibre optic link. The RF signal may be baseband data, modulated IF, or the actual modulated RF signal to be distributed. The RF signal is used to modulate the optical source in a transmitter. The resulting optical signal is launched into an optical fibre. At the other end of the fibre, we need an optical receiver that converts the optical signal back to RF. The generated electrical signal must meet the specifications required by the wireless application, be it GSM, UMTS, wireless LAN, WiMax or other. By delivering the radio signals directly, the optical fibre link avoids the necessity to generate high frequency radio carriers at the antenna site. Since antenna sites are usually remote from easy access, there is a lot to gain from such an arrangement. Usually a single fibre can carry information in one direction only (simplex), which means that we usually require two fibres for bidirectional (duplex) communication. However, recent progress in wavelength division multiplexing makes it possible to use the same fibre for duplex communication using different wavelengths (Spirit *et al.*, 1994). Wavelength Division Multiplexing (WDM) can be used to combine several wavelengths together to send them through a fibre op-

tic network, greatly increasing the use of the available fibre bandwidth and maximizing total data throughput in order to meet future wireless bandwidth requirements (Bhowik 2012).

In optical signal propagation, individual wavelength components of light pulse experience different propagation times due to the fact that the transport medium has different effective refractive indices for different wavelength, hence components or models receive the fibre terminals at different times. This phenomenon is known as dispersion. Dispersion increases along the fibre length and thus, limits the ultimate data rate supported by the fibre (Kalon *et al.*, 2014, Verma *et al.*, 2013). This causes intersymbol interference as pulse travels beyond its allocated bit slot to such an extent that it overlaps with the adjacent bits and it is no longer possible to determine whether or not a specific bit contains a 1 or 0. The focus of this paper therefore is on chromatic dispersion, which is dominant in Single Mode Fibre (SMF) and can be compensated using Dispersion Compensated Fibre (DCF) and Fibre Bragg Grating (FBG). Using the Optisystem, we demonstrate new ways of improving upon dispersion in fibre over long distances.

### Chromatic Dispersion (CD)

Chromatic dispersion (CD) is the broadening of the input signal as it travels down the length of the fibre (Kaur, 2015, Kumar *et al.*, 2013). Chromatic dispersion is the second derivative of optical phase with respect to optical frequency and may be represented as follows:

$$\text{Chromatic Dispersion} = \frac{\partial^2 \phi}{\partial \omega}$$

Where  $\phi$  = optical phase and  $\omega$  = optical frequency.

The dispersion-induced spectrum broadening would be very important even without nonlinearity.

Dispersion plays an important role in signal transmission over fibres (Udayakumar *et al.*, 2013). The interaction between dispersion and nonlinearity is an important issue in light wave system design. There exist some other fibres whose characteristics have been modified to give them a dispersion profile different from pure silica. They include Zero dispersion (DSF, Dispersion Shifted Fibre) or small dispersion (NZ-DSF, Non-Zero Dispersion Shifted Fibre) and Constant dispersion over a large window (DFE, Dispersion Flattened Fibre) around  $1.55\mu\text{m}$ . The main advantage of NZ-DSF is a reduction of the nonlinear effects that require phase matching, like Four Wave Mixing (FWM).

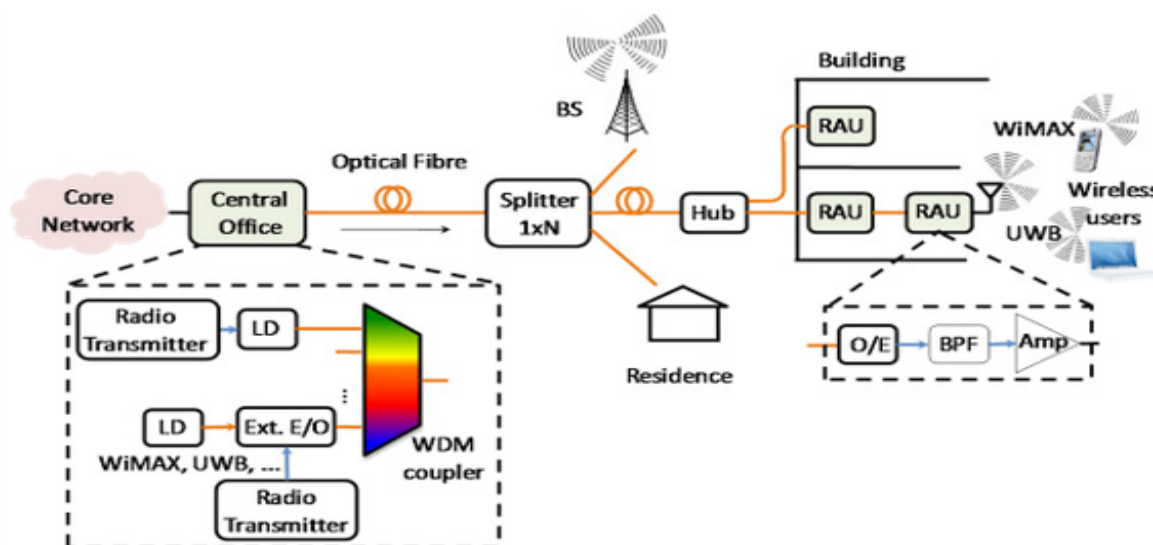


Fig. 1: Simplified schematic diagram of a RoF system

The use of dispersion compensation fibre is an efficient way to upgrade installed links made of standard single mode fibre (Bhowik 2012). According to relative positioning of Dispersion Compensated Fibre (DCF) and single mode fibre in Fig. 2, post-compensation, pre-compensation and symmetrical/mixed compensation can be made. A DCF Pre-compensation scheme achieves dispersion compensation by placing the DCF before a certain conventional single-mode fibre, or after the optical

transmitter. A post compensation scheme achieves dispersion compensation by placing the DCF after a certain conventional single-mode fibre, or after the optical transmitter. A symmetrical/mixed compensation scheme consists of post-compensation and pre-compensation. Different locations on the system will generate different nonlinear effects (Riant et al., 1999).

The simulation setup for each compensation technique is shown below:

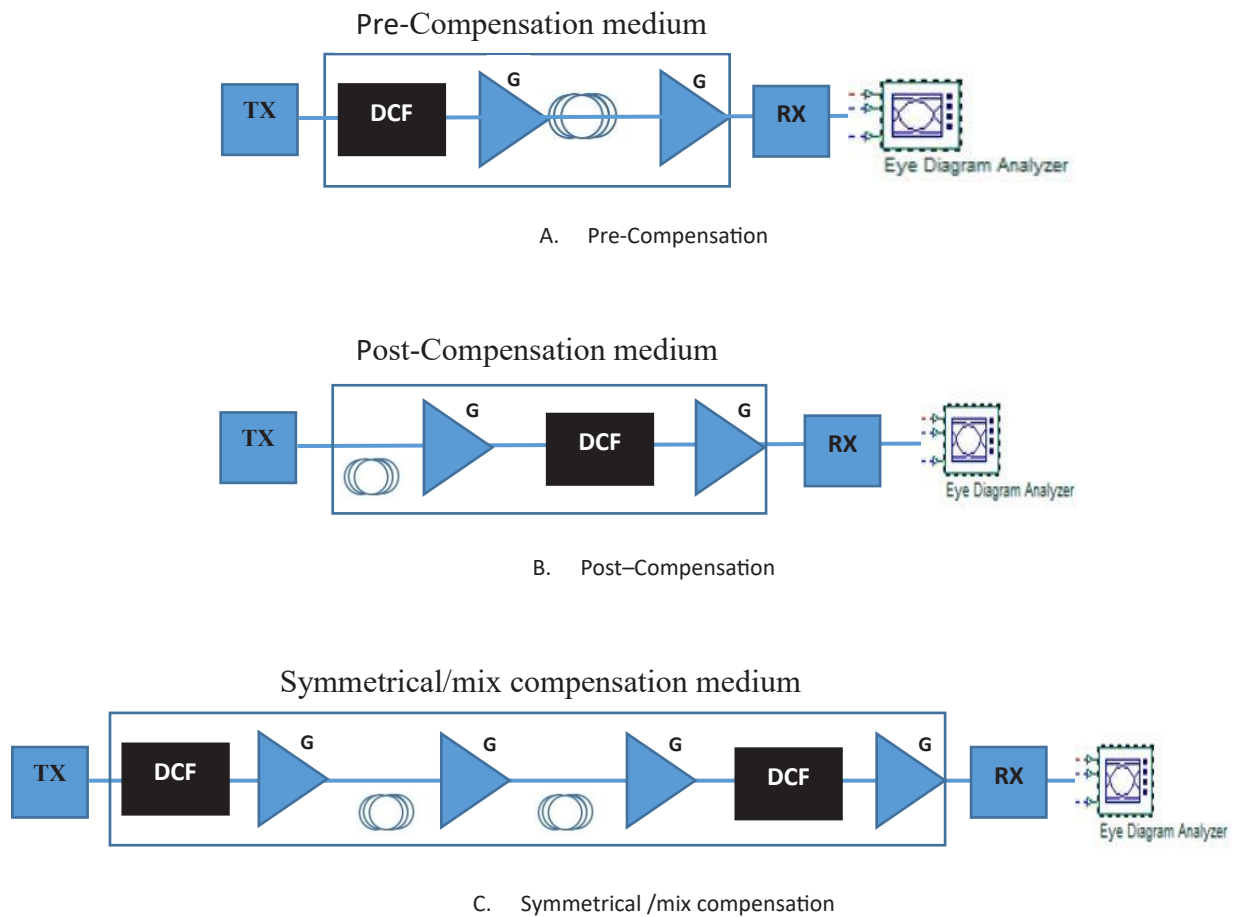


Fig. 2: Three Dispersion Compensation Schemes, A) pre-compensation B) post-compensation C) symmetrical /mixed compensation.

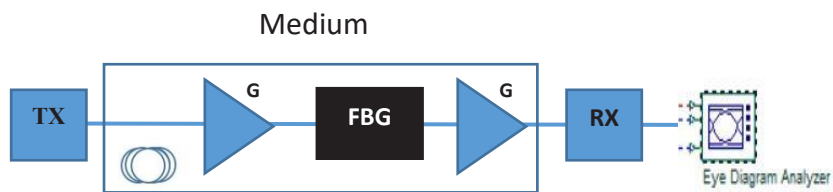


Fig. 3: Simulation Setup for FBG: Main System Simulation

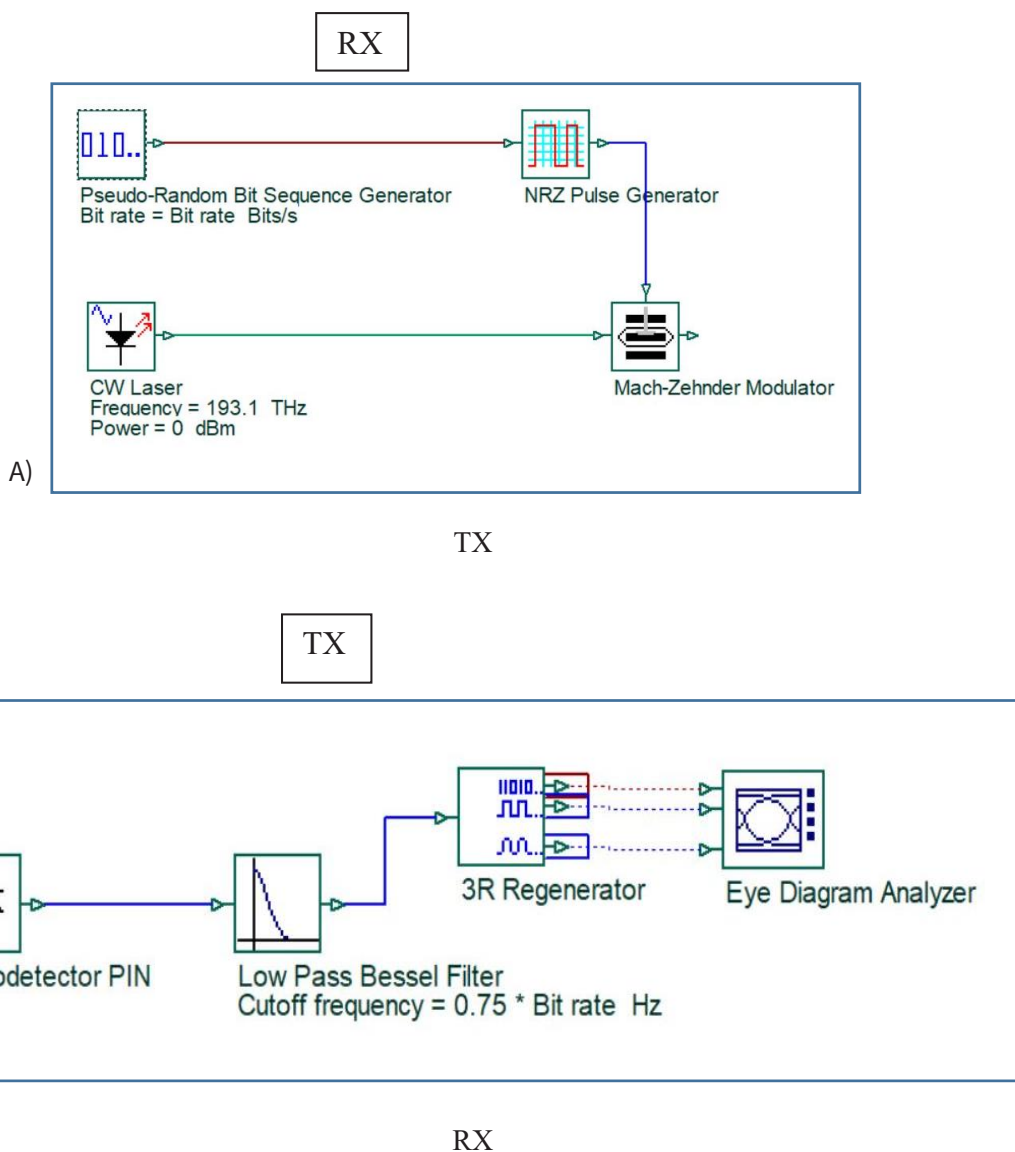


Fig. 4: Detailed implementation of RX and TX in simulations: A) RX B) TX

### PRE - COMPENSATION MEDIUM

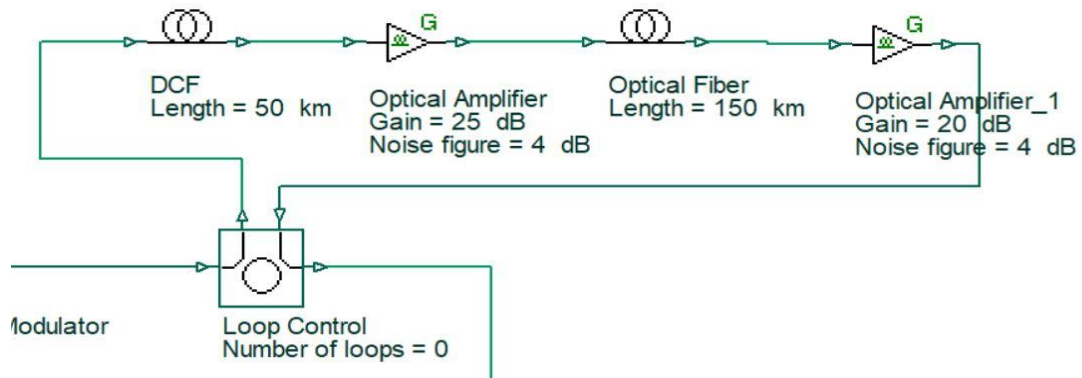


Fig. 5: A) The implementation for Pre-Compensation medium

### POST - COMPENSATION MEDIUM

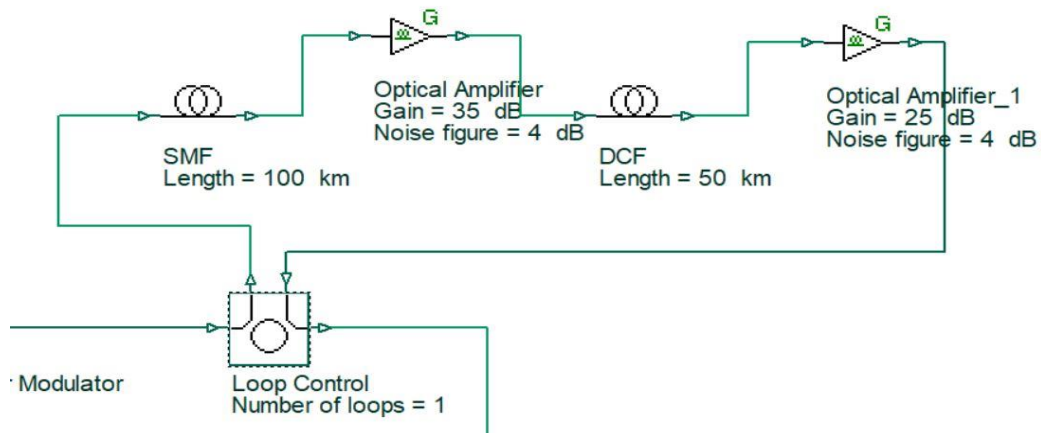


Fig. 5: B) The implementation for Post-Compensation medium

### SYMMETRICAL MEDIUM

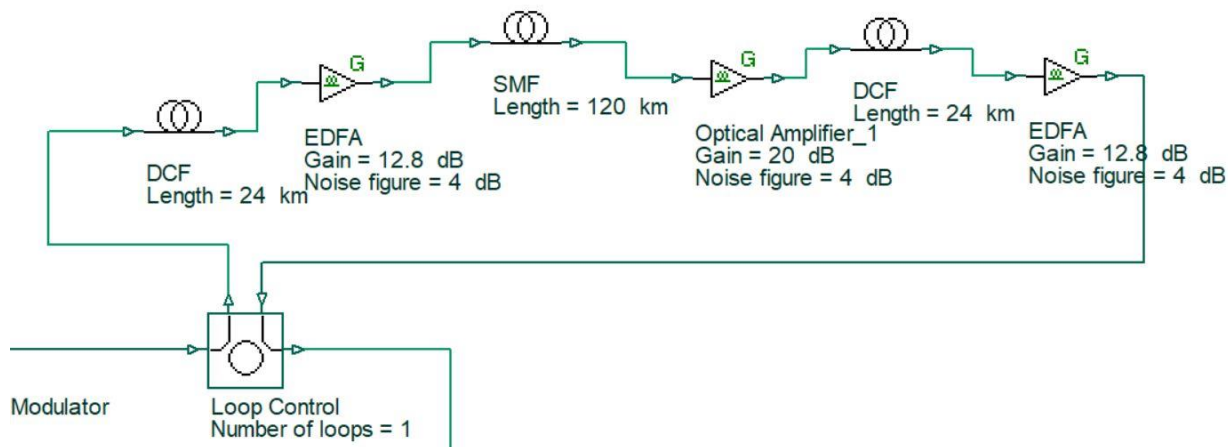


Fig. 5: C) The implementation for Symmetrical medium

### FBG MEDIUM

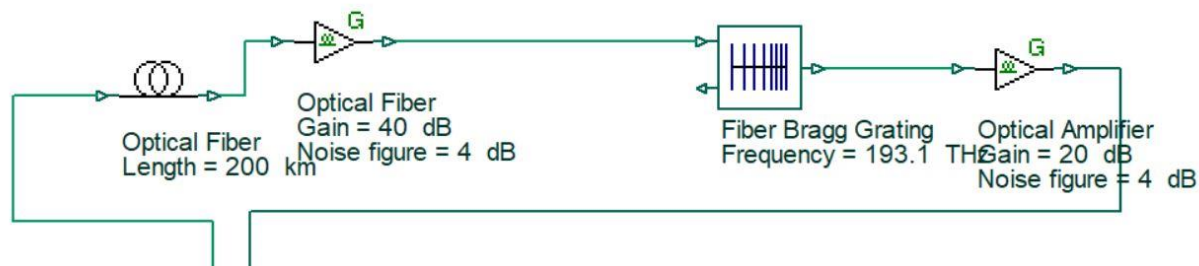


Fig. 5: D) The implementation for FBG medium

#### Structure of Refractive Index change in FBG

FBG structure varies with respect to the refractive index, or the grating period. The grating period can be uniform or graded, and either localized or distributed in a superstructure.

**Chirped Fibre Bragg Grating:** Here, the refractive index profile of the grating may be modified to add other features, such as a linear variation in the grating period, called a chirp. The reflected wavelength changes with

the grating period, broadening the reflected spectrum. A grating possessing a chirp has the property of adding dispersion— which means that different wavelengths reflected from the grating will be subject to different delays (Gnanagurunathan *et al.*, 2010; Islam *et al.*, 2012).

A **Tiled Fibre Bragg Grating** refractive index is at an angle to the optical axis, which is quite different from the Chirped Fibre Bragg Grating. The angle of tilt in a

Tiled Fibre Bragg Grating has an effect on the reflected wavelength, and on bandwidth.

Another structure type is the *Long-Period Grating*, which is designed to achieve a broader response than the standard FBG. They typically have grating periods on the range of 100 micrometres to a millimetre, and are therefore much easier to manufacture. For standard grating, a Bragg wavelength reflects at 1550 nm, with a grating period of 500 nm using an effective refractive index of 1.5.

## Methodology

Using Optisystem 7.0 simulator software, the simulation for each dispersion compensation techniques is considered. The first simulation setup is for DCF as dispersion compensator, followed by FBG. The simulation consists of a transmitter, which is made up of a data source, a modulator driver (NRZ driver), a laser source and a Mach-Zehnder modulator. The data source produces a pseudorandom sequence of bits at a rate of 10Gbit/s. The output of the data source is given to the modulator driver which produces an NRZ format pulse. CW Laser source output power is 10dBm at an ideal frequency of 193.1 THz. MZM has an excitation ratio of 30db. The loop control system has one and two loops for DCF and one FBG respectively. The total transmission distance for the SMF is 200 km. EDFA is deployed to restrict the effect of optical loss. The receiver side consists of a PIN photodetector which has a responsivity of 1A/W and a dark current of 10 nA. The electrical signal obtained is filtered by a low pass Bessel filter and a 3R regenerator. Their results are analyzed against parameters such as BER, Q-factor, and eye diagram.

## Results and Analysis

### Simulation for DCF as Dispersion Compensator

As already noted, DCF as a compensator can be implemented in three flavors (Pre-compensation, post-compensation and symmetrical compensation). Table 1

provides detailed information on the parameters used in simulating the three DCF placements in the setup.

The simulation setup for each compensation technique is shown in the diagrams in Fig. 3. The detailed implementation of RX and TX is shown in diagrams in Fig. 4. Figure 5 shows detailed implementation diagrams for the various medium used in each of the compensation schemes and our proposed scheme.

**Table 1: Simulation Parameters for DCF**

SMF Parameters	Values
Reference wavelength	1550 nm
Length	150 km
Attenuation	0.2 db/km
Dispersion	17.25 ps/nm/km
Dispersion slope	0.08 ps/nm <sup>2</sup> /km
PMD coefficient	3 ps/km
Differential group delay	0.2 ps/km

DCF Parameters	Value
Reference wavelength	1550
Length	50 km
Attenuation	0.2 db/km
Dispersion	-80ps/nm/km
Dispersion slope	0.085ps/nm <sup>2</sup> /km
PMD coefficient	3ps/km
Differential group delay	0.2ps/km

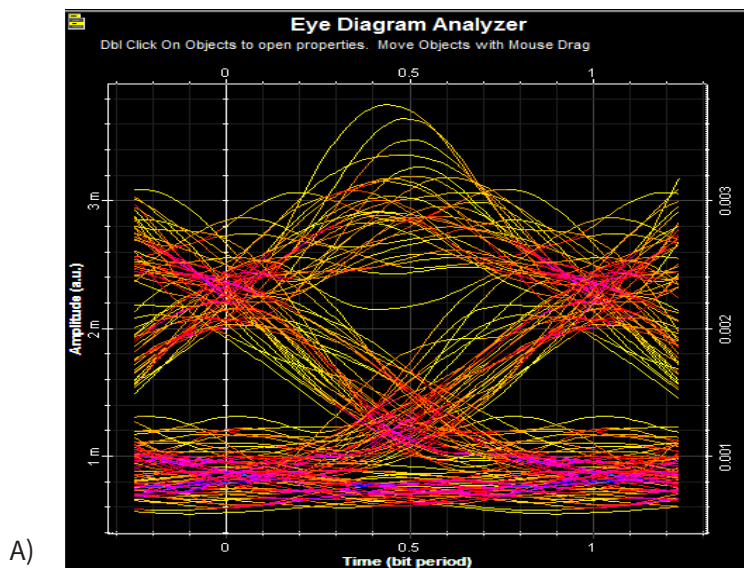
### Simulation for FBG as Dispersion Compensation

FBG is post-compensated in this simulation. The simulation parameters used are shown in Table 2. The eye diagrams shown in Fig. 6 are for each type of DCF compensator at 10 gb/s over 200 km. As can be observed from the results obtained, the eye diagram for symmetrical compensation is wider and well organized, indicating that the signal received is of higher quality

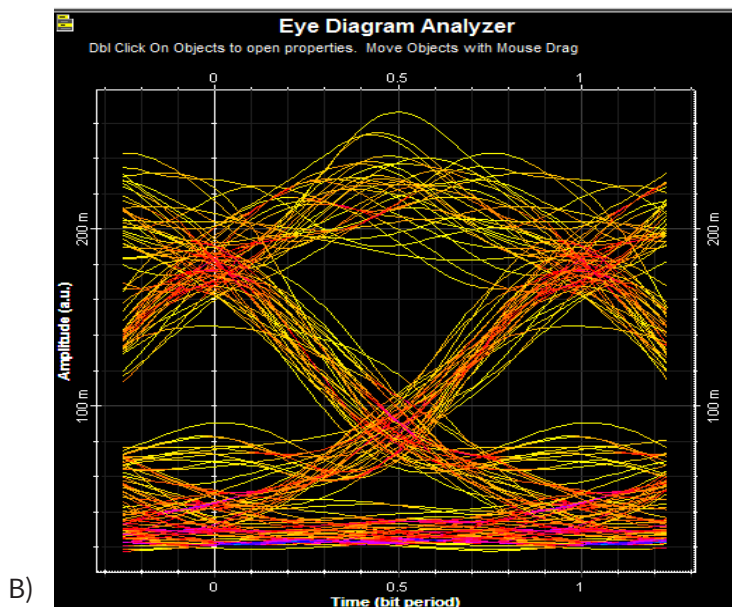


with little attenuation. Post-compensation performed better than pre-compensation. The Q-factor values obtained and shown in Table 3 confirm these results. The table compares the Q-factor, Min BER and Eye height for the three different compensation schemes that were used. From the table, it can be seen that symmetrical

compensation has a huge Q-factor with considerable Min BER. Even though post-compensation has very little BER, its Q-factor has very little influence on the signal quality. Pre-compensation performed the worst, with the least eye height and Q-factor.



Pre-Compensation eye diagram



Post-Compensation eye diagram

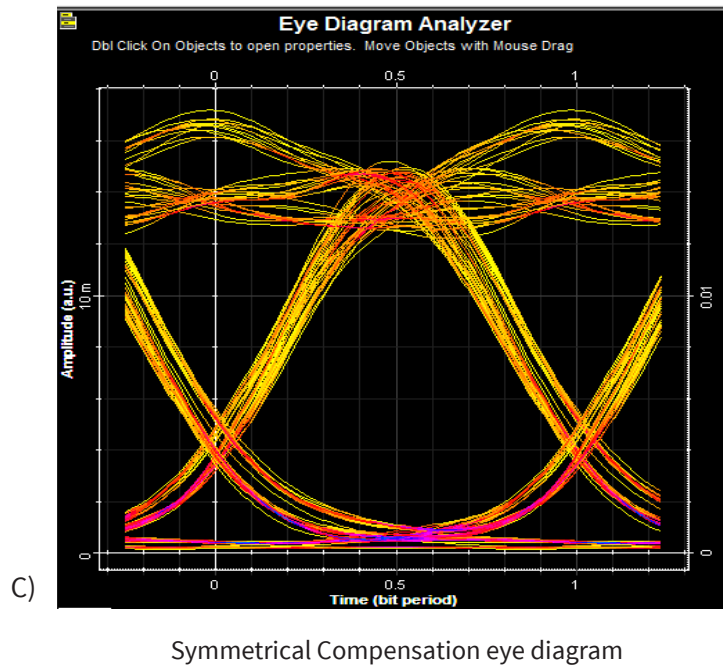


Fig. 6: Eye diagrams for DCF compensator at 10gb/s over 200km

Table 2: FBG Simulation Parameters used in the experiments

FBG Parameters	Values
Dispersion	17.25 ps/nm/km
Attenuation	0.2
Dispersion Slope	0.08 ps/nm <sup>2</sup> /km
Fiber length	200 km
Frequency	193.1 (THz)
Effective Refractive Index	1.45
Length of Grating	80 mm
Apodization function	Than
Chirp function	Linear

Table 3: Q-factor, BER and Height for DCF compensators

	Pre Compensation	Post Compensation	Mix Compensation
Q-factor	2.75398	3.23806	15.2922
Min BER	0.00250132	0.000574932	4.03595e – 053
Eye Height	-0.00160187	0.0114179	0.0105176

A Fibre Bragg Grating (FBG) is used as a compensator in our next simulation. The eye diagram for each FBG compensator is shown in Figure 7. The FBG compensator performs well to reduce dispersion in fibre optic communication. It can be observed that the eye diagram is wider, with a considerable eye height. With this clarity, it can be said that received signal will be readable.

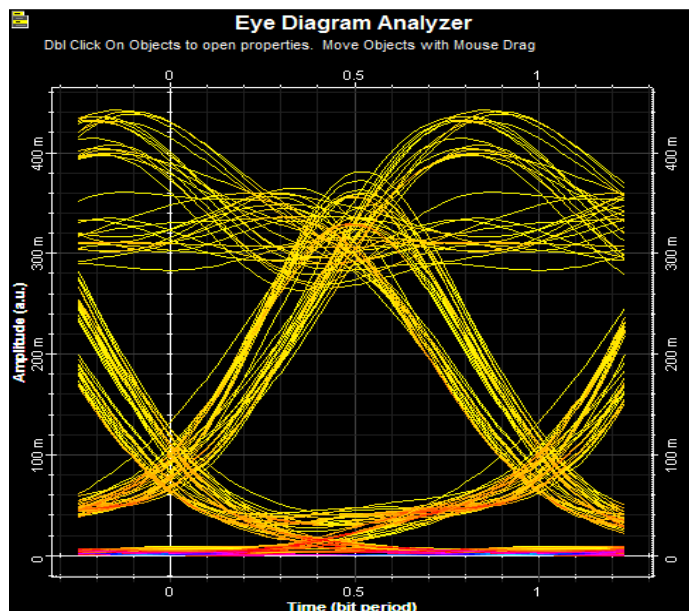


Fig. 7: Eye diagram for FBG compensator

Table 4: shows the values for Q-factor, Min BER and Eye height for the FBG as a compensator.

Q-factor	7.83208
Min BER	2.26553e-015
Eye Height	0.184665

Table 4 Q-factor, Min BER and Eye Height values for FBG

Comparing the above simulation results and findings, it can be clearly stated that from the eye diagram and Q-factor, DCF symmetrical compensation performs

better than all the studied dispersion compensators. Increasing the data rate from 10 GB/s to 20 GB/s, and holding the same parameters, the following results were achieved.

Fig. 8 shows the eye diagram for the DCF symmetrical compensation scheme when the data rate is increased from 10 GB/s to 20 GB/s over a 200 km distance.

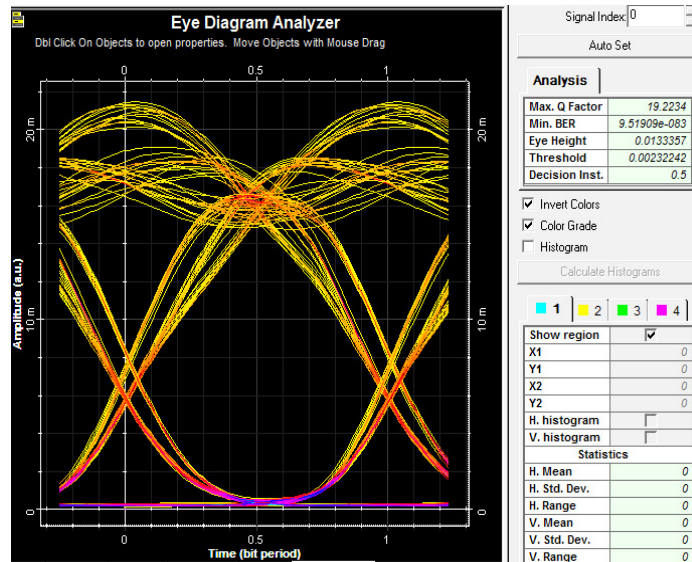


Fig. 8: DCF Symmetrical compensation at 20 GB/s at 200 km

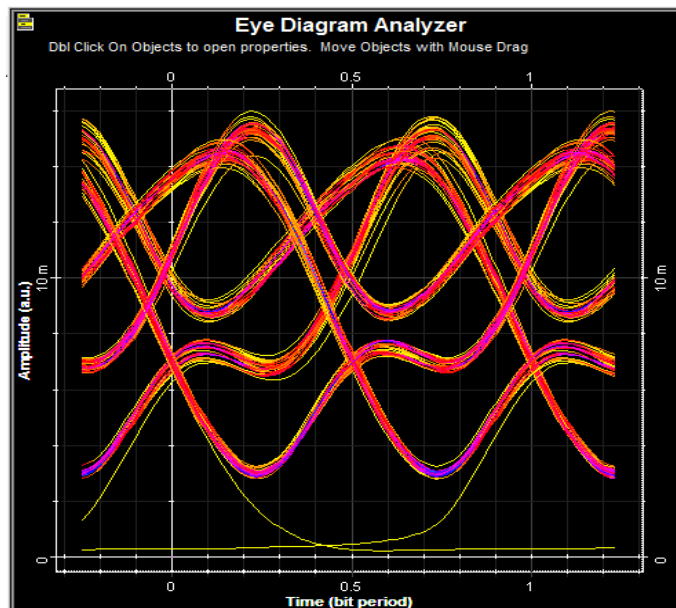


Fig. 9: DCF Symmetrical Compensation at 40 GB/s over 200 km

From the eye diagrams obtained for all the compensators, together with their parameter values, it was observed that DCF symmetrical compensation performed better, despite its BER value. The worst of them at 20 Gb/s over 200 km is FBG whose values were not even available due to huge signal dispersions. Figure 9 shows the eye

diagram for the DCF symmetrical compensation scheme when the data rate is increased to 40 GB/s over a 200 km distance. It can be seen that at 40 GB/s dispersion increased considerably, indicating that higher bandwidth leads to greater dispersion. The results obtained confirm that as data rate increases, dispersion also increases.

## Conclusions

Chromatic dispersion is a disturbing phenomenon in optical communication. In this paper, the various kinds of dispersion compensation were studied, with particular focus on DCF and FBG. Their performance in reducing dispersion in a long haul transmission system was analyzed. From the simulations performed using Optisystem 7.0 simulator, it has been shown that such dispersion can be compensated for by use of a symmetrical DCF as a compensator in the optical transmission fibre and this performs better than FBG and other DCF (pre- and post-compensation).

## References

- Bhowik, K., Ahmed, M. and Momim, A. (2012). Reduction of dispersion in optical communication by fiber bragg grating and optical phase conjugation techniques. *International Journal of Mobile Network Communications & Telematics (IJMNCT)* 2 (3), 49-58.
- Darcie, T.E., Bodeep, G.E. and Saleh, A.A.M. (1991). Fiber-reflection induced impairment in Lightwave AM-VSB CATV system. *IEEE J. Lightwave Technology*, 9 (8), 991-995.
- Galle, M.A., (2007). Single-arm-3-wave interferometer for measuring dispersion in short length of fiber. *Optics Express*, 15(25), 16896-16906.
- Gnanagurunathan, G., and Rahman, F.A. (2006). Comparing FBG and DCF as dispersion compensators in the long haul narrowband WDM systems. *International Conference on Wireless and Optical Communications Network 2006*, Bangalore, India, p4.
- Islam, J., Islam, S. and Rahman, M. (2012). Dispersion Compensation in Optical Fiber Communication Using Fiber Bragg Grating. *Global Journal of researches in Engineering Electrical and Electronics Engineering*, 12(2), 25-29.
- Jamaludin, Z., Abas, A.F., Noor, A.S.M. and Abdullah, M.K. (2005). Issues on Polarization Mode Dispersion (PMD) for high speed fiber optics transmission, *Suranaree Journal Science Technology* 12(2), 98-106.
- Kalon, N.K and Kaur, G. (2014). Various Dispersion compensation techniques for optical system: A survey. *Open journal of communications and software*, 1(1), 1-5.
- Kaur, M., Sarangal, H. and Bagga, P. (2015). Dispersion Compensation with Dispersion Compensation Fiber (DCF). *International Journal of Advanced Research in Computer and Communication Engineering*, 4(2), 354-356.
- Kumar, S., Jaiswal, A.K., Kumar, M., and Saxena, R. (2013). Performance Analysis of Dispersion Compensation in Long Haul Optical Fiber with DCF. *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, 6(6), 19-23.
- Riant, I., Gurib, S., Gourhant, J., Sansonetti, P., Bungarzeanu, C. and Kashyap, R. (1999). Chirped Fiber Bragg Gratings for WDM Chromatic Dispersion Compensation in Multispan 10-Gb/s Transmission, *IEEE Journal Of Selected Topics In Quantum Electronics*, 5(5), 1312-1324.
- Shukla A. (2012). *Elements Of Optical Communication and Opto Electronics*. New Delhi: University of Science Press.
- Spirit, D.M., Ellis, A.D. and Barnsley, P.E. (1994) Optical Time Division Multiplexing: Systems and Networks, *IEEE Communications Magazine*, 32(12), 56-62.
- Udayakumar, R., Khanaa, V. and Saravanan, T. (2013). Chromatic Dispersion Compensation in Optical Fiber Communication System and its Simulation. *Indian Journal of Science and Technology*, 6(6s), 4763-4766.
- Verma, A.S, Jaiswal, A.K. and Kumar, M. (2013). An Improved Methodology for Dispersion Compensation and Synchronization in Optical Fiber Communication Networks. *International Journal of Emerging Technology and Advanced Engineering*, 3(5), 769-775.