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A NOVEL APPROACH OF DISPERSION COMPENSATION BASED ON FIBER BRAGG GRATING

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Abstract- Among the promising advancements towards cost-effective long-haul transmission is the use of Fiber Bragg Gratings (FBGs) as the dispersion compensating module (DCM). In this paper we discuss the feasibility of long-haul Wavelength Division Multiplexing (WDM) optical transmission using FBGs for the dispersion compensation & the performance is analysed by comparing the results of the receivers. A 10 Gb/s Non Return To Zero (NRZ) signal is launched onto a 100 km long standard single mode fiber. Comparison of eye diagrams & Bit Error Rate (BER) show a marked improvement in the link performance due to compensation of dispersion.

Keywords- Fiber Bragg gratings, optical fiber dispersion, optical filter, dispersion compensation, photodiode.

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Introduction & Previous work

Dispersion compensating fiber (DCF) is currently used as the standard solution for dispersion compensation in long-haul transmission links, since it yields colourless, slope matched dispersion cancellation with negligible cascading impairments. However, DCF is also limited in optical input power to avoid nonlinear impairments, has a relatively high insertion loss and is bulky. Chirped FBGs could possibly replace DCF as the standard solution for in-line dispersion compensation. Chirped FBGs have a negligible nonlinearity, low insertion loss and small size [1-2]. Wavelength Division Multiplexing (WDM) systems where multiple light signals at different frequencies are simultaneously launched in an optical fiber, the highly-selective filtering capabilities of Bragg gratings combined with its all-fiber configuration and flexibility make this technology an ideal candidate. For telecommunication applications, FBG-components have already been used for purposes such as pump laser stabilizers to improve the performances of pump lasers in optical amplifiers [4], gain flattening filters to equalize the gain of optical amplifiers [5], highly selective filters for channel selection in dense WDM systems [6] and chromatic dispersion compensators for temporal pulse shaping in long-haul and/or high bit rate systems [7]. This potentially allows simpler erbium-doped fiber amplifier (EDFA) design by cascading the FBG and transmission fiber without a mid-stage amplifier, resulting in a significant cost reduction.

The formation of permanent gratings in an optical fiber was first demonstrated by Hill *et al.* in 1978 at the Canadian Communications Research Centre (CRC), Ottawa, Ont., Canada, [1]. They launched intense Argon-ion laser radiation into a germania-doped fiber and observed that after several minutes an increase in the reflected light intensity occurred which grew until almost all the light was reflected from the fiber. Spectral measurements, done indirectly by strain and temperature tuning of the fiber grating, confirmed that a very narrowband Bragg grating filter had been formed over the entire 1-m length of fiber. This achievement, subsequently called "*Hill gratings*," was an outgrowth of research on the nonlinear properties of germania-doped silica fiber. It established an unknown photosensitivity of Germania fiber, which prompted other inquires, several years later, into the cause of the fiber photoinduced refractivity and its dependence on the wavelength of the light which was used to the form the gratings. Detailed studies [11] show that the grating strength increased as the square of the light intensity, suggesting a two-photon process as the mechanism.

In the original experiments, laser radiation at 488 nm was reflected from the fiber end producing a standing wave pattern that formed the grating. A single photon at one-half this wavelength, namely at 244 nm in the ultraviolet, proved to be far more effective. Meltz *et al.* [5] showed that this radiation could be used to form gratings that would reflect any wavelength by illuminating the fiber through the side of the cladding with two intersecting beams of UV light; now, the period of the interference maxima and the index change was set by the angle between the beams and the UV wavelength rather than by the visible radiation which was launched into the fiber core. Moreover, the grating formation was found to be orders-of-magnitude more efficient. At first, the observation of photo-induced refractivity in fibers was only a scientific curiosity, but over time it has become the basis for a technology that now has a broad and important role in optical communications and sensor systems. Research into the underlying mechanisms of fiber photosensitivity and its uses is on-going in many universities and industrial laboratories in Europe, North and South America, Asia, and Australia. Several hundred photosensitivity and fiber grating related articles have appeared in the scientific literature and in the proceedings of topical conferences, workshops, and symposia. FBG's are now commercially available and they have found key applications in routing, filtering, control, and amplification of optical signals in the next generation of high-capacity WDM telecommunication networks.

In this paper, the performance of high speed optical fiber based network is analysed by using dispersion compensating module (DCM) based on FBGs. The optimal operating condition of the DCM was obtained by considering dispersion management using a 10 Gb/s Non Return To Zero (NRZ) signal by launching it into a 100 km long standard single mode fiber. Section II discusses the proposed work regarding the dispersion compensation using a FBG configuration. Results for the simulation are validated and the impact of the FBG on the receivers is compared in section III, followed by the concluding remarks in the Section IV.

Proposed Work

A fiber Bragg grating consists of a periodic modulation of the index of refraction along the core of an optical fiber thus creating a wavelength-selective mirror as presented in Figure 1. FBGs are created by the exposition of a photosensitive fiber to an intensity pattern of UV light. In its basic form, the resulting grating reflects selectively the light guided by the optical fiber at the Bragg wavelength given by:

$$\lambda B = 2n\Lambda \qquad (1)$$

where *n* and Λ are the effective index of refraction of the fiber and the pitch of the grating in the fiber. A uniform grating can be represented by a sinusoidal modulation of the refractive index of the fiber core given by:

$$n(z)=n_{core} + \delta(n)\left[1+\cos\left(\frac{2\pi z}{\Lambda}+\varphi(z)\right)\right] \qquad (2)$$

where n_{core} is the unexposed core refractive index and δn is the amplitude of the photoinduced index change. Using coupled mode theory, one can deduced themaximum reflectivity of a uniform grating at the Bragg wavelength

$$R_{MAX}^2 = \tanh^2\left[\frac{\pi\delta L n\eta}{\lambda}\right] \qquad (3)$$

where *L* is the grating length and η is the fraction of the fiber mode power contained by the fiber core. One can see that depending on the refractive index change profile and intensity in the fiber combined with the pitch of the grating profile, numerous types of functions can be devised [2].

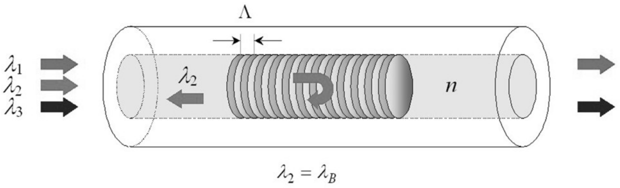

Fig. 1-Principle of operation of a fiber Bragg grating.

Wavelength Division Multiplexing (WDM) systems where multiple light signals at different frequencies are simultaneously launched in an optical fiber, the highly-selective filtering capabilities of Bragg gratings combined with its all-fiber configuration and flexibility make this technology an ideal candidate. FBG technology has gained favour in wide range of applications because of its all fiber configuration, great flexibility, and highly efficient filtering functions. Fiber Bragg gratings are most commonly used for filtering and chromatic dispersion compensation, because their efficiency reduces the cost of optical networking.

Impact of the receivers: Photodetector is the fundamental element of optical receiver, followed by amplifiers and signal conditioning circuitry. The internal gain of the Avalanche Photo Diode (APD) is obtained by having a high electric field that energizes photo-generated electrons and holes. APD has high gain due to self multiplying mechanism, used in high end systems[12]. The tradeoff is the 'excess noise' due to random nature of the self multiplying process. Fig.2 shows Signal to Noise Ratio (SNR) vs. received power for PIN & APD receiver

Quantum Efficiency (h) = number of e-h pairs generated / number of incident photons

$$\eta = \frac{I_p / q}{P_0 / h\nu} \Longrightarrow \Re = \frac{I_p}{P_0} = \frac{\eta q}{h\nu}$$

$$\boxed{\Re_{APD} = \Re_{PIN} M} \qquad \boxed{M = \frac{I_M}{I_p}}$$

Avalanche PD's have an internal gain *M.* Responsivity (mA/mW) =Â. I_M = average value of the total multiplied current M = 1 for PIN diodes

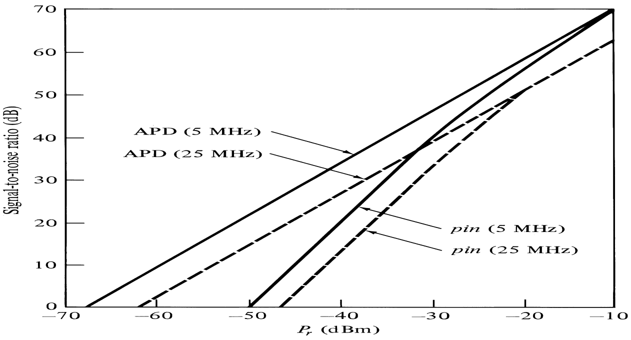

Fig. 2-SNR vs. received power for PIN & APD receiver[11]

The design approach explores dispersion compensating module (DCM) discussing the Fiber Bragg Gratings (FBGs) for the dispersion compensation. A 10 Gb/s Non Return To Zero (NRZ) signal is launched onto a 100 km long standard single mode fiber as shown in theFig.3

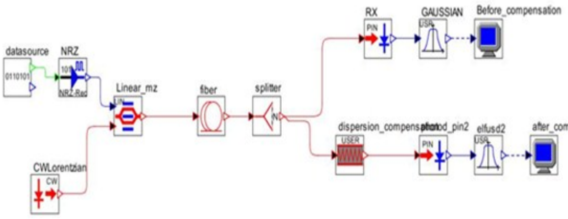

Fig. 3-Simulated model for the Fiber Bragg Grating as a Dispersion Compensator

The model illustrates how to compensate fiber dispersion using the realistic fiber grating component. The dispersion compensation is performed using advanced optical communication system simulation package OptSim 5.2.

Results and Discussions

The dispersion management scheme is taken into account by employing a Fiber Bragg Grating technology. The in line dispersion is compensated using a real grating component for a 100 km fiber. The results are validated by comparing the Q factor of the FBG simulated model for before compensation and after compensation as shown in the fig.2. The simulation results are shown in Table.1.

Table-1-Simulation Results for the FBG dispersion compensation for PIN receiver

FBG for PIN Receiver	Before Compensation	After Compensation
QFactor (dB)	9.697680	27.359391
BER	.0011152	1e-040

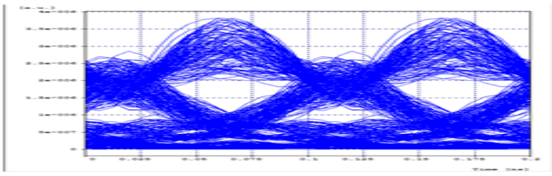

Fig.4-a

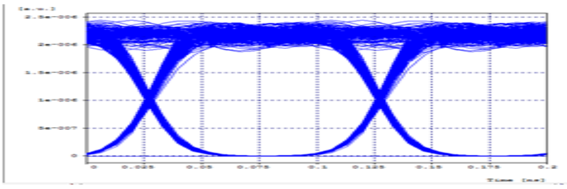

Fig. 4-b

Fig.(4)Fiber length =100 km, PIN receiver Fig.4(a)" Q Factor (dB) =9.68768, BER= .00111522 & Fig.4(b) QFactor (dB) =27.359391,BER =1e-040

Table-2-Simulation Results for the FBG dispersion compensation for ApD receiver

FBG for ApD Receiver	Before Compensation	After Compenstion
QFactor (dB)	9.906662	40
BER	0.0009372	1.00E-40

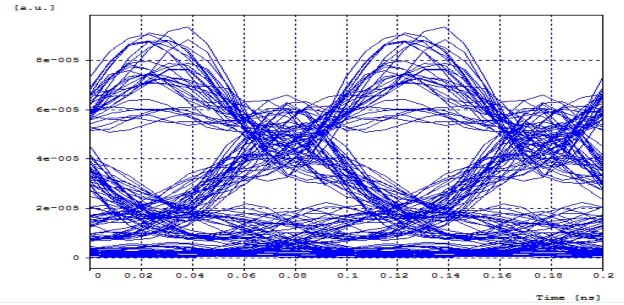

Fig. 5-a

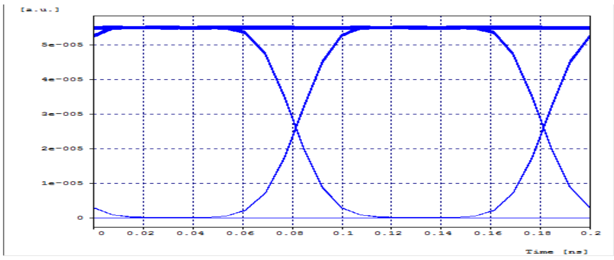

Fig. 5-b

"Fig.(5)" Fiber length =100 km, APD receiver : "Fig(5.a)" Q Factor (dB)=9.906662, BER= .0009372 & "Fig(5.b)" Q Factor (dB) =40.00, BER =1e-040

Exact analysis based on the impact of the FBG on the receivers are developed to compute the bit-error rate (BER) for the positive intrinsic negative (PIN) & ultrafast avalanche-photodiode (APD) based for a 10 Gb/s system.

The results for the positive intrinsic negative (PIN) & APD receivers are shown in table 1 and table 2 respecively, from the results it can be observed that APD receiver shows a significant improvement for the simulated model of the fiber bragg grating in terms of dispersion compensation.

However, if the PIN receiver is used for the same model the dispersion comoensation is comparatively in lesser amount as compared to the model in which APD receiver is employed.

Conclusions and Extending the modeled scheme

It is shown in this paper that the recent advances in fiber Bragg grating technology now allow the realization of a high-performance, high speed optical fibers with good in line dispersion compensation. The system performance is evaluated for a 10 Gb/s system using a real grating component for the in line dispersion compensation. Also, the impact of the FBG on the PIN & APD receivers is observed.The results demonstrate the Q Factor has improved by a factor of nearly 10 times when a APD receiver is used as in comparison to the PIN receiver. However, this technology could be extended to other types of applications with the discovery of large photosensitivity in different material systems.

To extend this technology, effect of fiber nonlinearities can be studied in this modelled scheme and the comparison of the results can be made exemparily.

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