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Enhancing the Performance of Optical Communication System

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Abstract **- Optical fiber is a remarkable communication medium as it provides low loss transmission over an enormous frequency range of at least 25 THz. The low loss property allows signals to be transmitted over long distances at high speeds before they need to be amplified or regenerated.**

As transmission systems evolved to longer distances and higher data rates, dispersion and nonlinearities became an important limiting factor of such systems thereby degrading the performance. The main motivation of this work was to study theoretical and simulation of broadband optical communication systems due to dispersion and fiber nonlinearities. The group velocity dispersion (GVD) effect is the major factor that leads to overlap of pulses representing adjacent bits to degrade the performance of high bit-rate, long distance optical communications systems. Fiber nonlinearities have become one of most significant limiting factors of system performance since the advent of erbium-doped fiber amplifiers (EDFAs) because input power is increasing and the effects of fiber nonlinearities are accumulating with the use of EDFAs. In wavelength-division-multiplexing (WDM) systems, inter-channel interference due to fiber nonlinearities may limit the system performance significantly. The effect of nonlinearities at different data rates and effective length of fiber have been studied. The data rates, transmission lengths and the channel spacing have to be optimized in order to have an efficient transmission without any nonlinear effect. The nonlinear effects tends to manifest themselves when optical power is very high, they become important in WDM systems. Four wave mixing (FWM) is one of the dominating degradation effects in WDM systems with dense channel spacing. The effect of FWM at various channel spacing in WDM systems have been analyzed in this thesis.
To enhance the overall performance of the optical communication systems, various types of dispersion compensation techniques are used. By using these techniques, the effect of the dispersion can be reduced to great extent. The compensation techniques are fiber based and devices based. In this thesis, the performance of different dispersion compensation techniques with different modulation formats at high bit rates are reported. The compensation techniques proposed are dispersion compensation fiber (DCF), negative dispersion fiber (NDF) and fiber bragg grating (FBG). The comparison of different dispersion compensation techniques at different bit rate has been done. The comparison of different techniques has been analyzed from the eye closure, bit error rate (BER) and Q-factor characteristics.

Keywords - Optical Communication, Duo-Binary, Dispersion Compensation, Q Factor, Eye Diagrams.

INTRODUCTION

Since its invention in the early 1970s, the use of and demand for optical fiber have grown tremendously. The uses of optical fiber today are quite numerous. With the explosion of information traffic due to the Internet, electronic commerce, computer networks, multimedia, voice, data, and video, the need for a transmission medium with the bandwidth capabilities for handling such vast amounts of information is paramount. Fiber optics, with its comparatively infinite bandwidth, has proven to be the solution.

In the information age, we are seeing a relentless demand for networks of higher capacities at lower costs. Optical communication technology has developed rapidly to achieve larger transmission capacity and longer transmission distance. The speed offered by optical fibers is much higher as compared to other conventional methods. Another benefit of fiber is that even when run alongside each other for long distances, fiber cables experience effectively negligible crosstalk, in contrast to some types of electrical transmission lines. Fibers offer high speed, large capacity and high reliability by the use of its huge bandwidth. Focus on development of broadband optical communication systems is incredible since it offers combination of wide bandwidth and low losses unmatched by any other transmission medium. Fiber optic communication is a method of transmitting information from one place to another by sending light signal through an optical fiber therefore it's obvious to achieve higher data rates compared to any other media of transferring information. Now a day's optical fiber is the only transmission medium which carries such large bandwidth (approx. 32 THz) because of higher carrier frequency in terahertz range *i.e.* 10^{14} Hz with low losses. The loss of optical fiber measured up to 20 dB/km during 1970's has been reduced significantly to 0.22 dB/km.

Dispersion Compensation Techniques

The ideal dispersion compensator must have a quite stringent list of characteristics. Regarding the chromatic dispersion, it has to be well matched to the transport fiber, have a smooth dispersion profile (i.e. no dispersion ripples or group delay ripples), be tunable potentially provide a high channel-to-channel variation in the dispersion. Furthermore, it has to be free of polarization effects [polarization dependent loss (PDL) and polarization mode dispersion (PMD)]. Regarding the wavelength, it has to be broadband, being usable over the whole wavelength range (high spectral

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efficiency) and should accommodate high signal bandwidths. The ideal compensator must also provide low insertion loss and being capable of handling high optical power. Finally it must be compact, consume no or low power and must be low-cost.

In order to improve overall system performance and to reduce the transmission performance influenced by the dispersion as much as possible, several dispersion compensation technologies were proposed. Amongst the various techniques proposed in the literature, the ones that appear to hold immediate promise for dispersion compensation and management could be broadly classified as: dispersion compensating fibers (DCF), chirped fiber Bragg gratings (FBG), and high-order mode (HOM) fiber. Furthermore, not truly dispersion compensation devices, electronic dispersion compensation and advanced modulation formats are attractive due to the high dispersion tolerance they provide.

Dispersion Compensating Fibers

Dispersion compensating fibers are used to compensate the accumulated chromatic dispersion by employing a negative dispersion slope on a lengthy link. The core radius of such a fiber is considerably smaller than that of standard single mode fiber but has a higher refractive index, which leads to a large negative chromatic dispersion.

Dispersion compensation is broadly classified into three types depending on the adjustment of the DCF in an optical link. These are pre, post and symmetrical compensation whose layout has been shown in figure (a), (b) and (c) respectively.

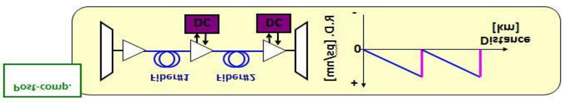

Figure (a): Post compensation technique

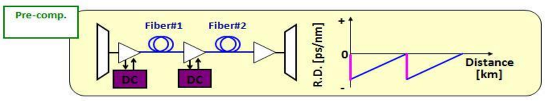

Figure (b): Pre compensation technique

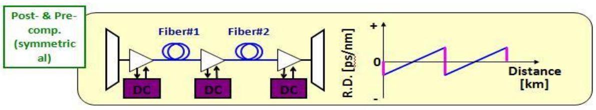

Figure (c): Symmetrical compensation technique

Figure (a),(b),(c): Different compensation techniques

Dispersion compensating fiber (DCF) is the predominant technology for dispersion compensation. It consists of an optical fiber that has a special design such as providing a large negative dispersion coefficient while the dispersion of the transport fiber is positive. A proper length of DCF allows the compensation of the chromatic dispersion accumulated over a given length of the transport fiber, although standard modules with predetermined dispersion values (with a typical granularity corresponding to the dispersion of 20 km of SSMF) are commercially available. The main advantage of this technology is the fact that it provides a broadband operation with a smooth dispersion property and good optical characteristics. In the first generation of DCF, only about 60% of the SSMF dispersion slope was allowed to be compensated. Now, 100% slope matching for both SSMF and E-LEAF is commercially available. DCF also presents slope-mismatch problem and a quite large insertion loss although improvements have been reported recently.

Fiber Bragg Grating

The first in-fiber Bragg grating was demonstrated by Hill in 1978, As shown in figure below, fiber Bragg grating (FBG) is a type of distributed Bragg reflector is constructed in a short segment of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by adding a periodic variation to the refractive index of the fiber core, which generates a wavelength specific dielectric mirror. A fiber Bragg grating can therefore be used as an inline optical fiber to block certain wavelengths, or as a wavelength-specific reflector.

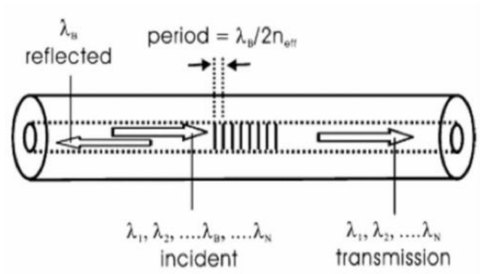

Figure : Fiber Bragg grating

SOLITONS

Figure 1: Pre compensation

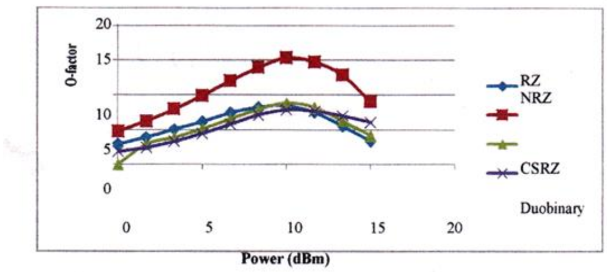

Figure 2 : Post Compensation

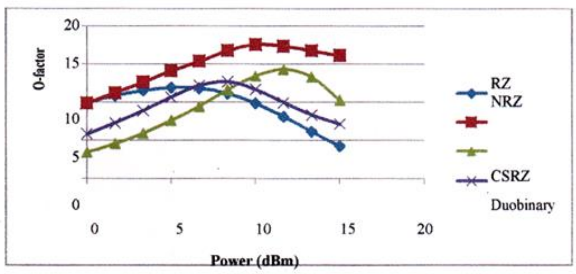

Figure 3 : Symmetrical compensation

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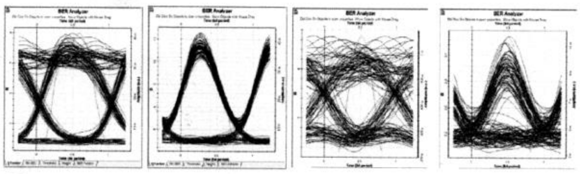
Solitons are narrow pulses with high peak powers and special shapes. The most commonly used soliton pulses are called fundamental solitons. As we know, most of the pulses undergo broadening (spreading in time) due to group velocity dispersion when propagating through optical fiber. However the soliton pulses take advantage of nonlinear effects in silica, specifically self-phase modulation to overcome the pulse broadening effects of group velocity dispersion. Thus these pulses can propagate for longer distances with no change in shape.

RESULTS AND DISCUSSION

In optical communication systems only optical signal to noise ratio (OSNR) could not accurately measure the system performance. Quality factor is one of the important indicators to measure the optical performance by which to characterize the BER. In the previous chapter, various component and parameters used in simulation setup are discussed. Using some of these components, the values of bit error rate (BER), Q- factor, timing jitters, average eye opening are measured. Eye diagrams and optical spectrum at the receiver end is measured. The measurement component used is bit error rate analyzer to measure Q-factor, bit error rate and eye diagrams. The graphs are taken by varying the values of global parameters at different stages of simulation.

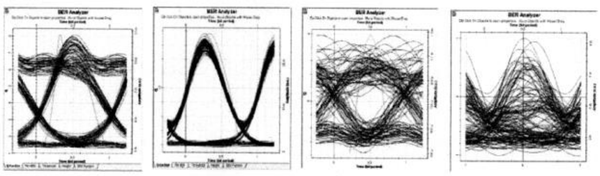
Figures below shows the effect on Q- factor with the variation in optical power in three different compensation formats with NRZ, RZ, CSRZ and duobinary modulation formats.

Eye diagrams of different compensation techniques are shown below.



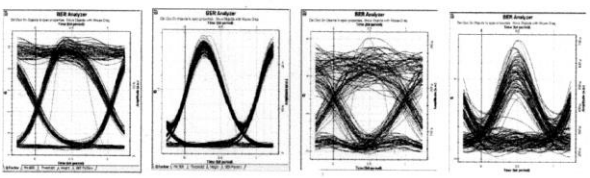
a) NRZ b) RZ c) Duobinary d) CSRZ

Figure (a): Q- factor post compensation



a) NRZ b) RZ c) Duobinary d) CSRZ

Figure (b): Q- factor pre compensation



a) NRZ b) RZ c) duobinary d) CSRZ

Figure (c): Q- factor symmetrical compensation

CONCLUSIONS

The main objective of this dissertation is to design models for higher data rates (40, 50 Gbps) for optical communication which are free from the effect of dispersion and nonlinearities to make them efficient fiber optical communication systems. We have discussed the performance of single channel system at a data rate of 60 Gbps for different dispersion compensation techniques. The symmetrical compensation is found to be best followed by post and pre compensation. The results are analyzed with the help of eye diagrams in terms of bit error rate (BER), maximum q-factor and percentage eye opening.

With the selection of best compensation technique, the system has been tested for different modulation formats *i.e*. NRZ, RZ, CSRZ and duobinary to select the best format. The results confirm NRZ to be best in terms of Q-factor and BER. The power optimization has been done in order to minimize the power penalty and effect of nonlinearities. 2 channel WDM system has been designed to visualize the effect of four wave mixing. This nonlinearity due to four wave mixing has been compensated by the use of non-zero dispersion shifted fiber.

The parameters obtained from these analyses are applied to WDM systems with 8, 16 and 32 channels respectively. The data rate for 8 channel WDM system is 50 Gbps whereas 16 and 32 channel WDM system are operating at 40 Gbps. The analysis of these systems is done in terms of Q-factor and minimum BER. The use of gain flattening filter helps in increasing the transmission distance and stabilization of Q-factor by employing almost same power content to every channel. The distance of transmission in these channels is approximately 120 km.

To check whether these systems would be feasible to install in a network, we have designed two different topology networks (ring and tree) to analyze the results. The ring topology network is designed with four nodes with each node supporting 8 channels. The results at each node are analyzed in terms of Q-factor, minimum BER and the power penalty is also being considered by measuring the input power at each node. The results shows a huge power loss at various nodes in a ring topology network which could be compensated with the help of optical amplifiers. The tree topology network is designed for 6 nodes. The results show that power penalties in case of a tree network are greatly reduced as it almost provides same power at each node. The drawback of this network is that whole system will fail if the link between centre office and remote control breaks.

Future scope

1. There are a lot more techniques for the compensation of dispersion and nonlinearities which could be applied to these systems to enhance their efficiency.

2. The data rate of channels could be increased upto 100 Gbps or more for ultra-high speed communication links.

3. The number of channels has to be increased following increasing number of users in day to day life. The need for increased channel capacity with higher data rates must be on the top priority for the designers.

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