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Optimization of Dispersion in Optical Fiber Communication

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***Abstract*— Fiber-optic communication is a method of transmitting information by sending light pulses through fiber optics The light forms an electromagnetic carrier wave that is modulated to carry information. The main objective of this paper is to observe the dispersion losses that often limit the performance of modern lightwave systems. Perhaps, Optical amplifiers are used to solve the fiber loss problem but at the same time degrade the system performance by induced dispersion problem, as a result of electronic regenerators, with this optical amplifiers are not in a position to restore the amplified signal which was transmitted at its original level or state. With the effect of this induced dispersion, degradation of the transmitted signal accumulates over multiple amplifiers. To overcome dispersion problem, this paper helps in providing several dispersion management schemes with emphasis on the physics and improvement realized in practice. Finally We consider why dispersion management is needed and also discuss the methods used at the transmitter (precompensation schemes) or receiver (postcompensation schemes) for managing and eliminating the dispersion in order to obtain the desired research objectives.**

Index terms - Fiber-optics, lightwave systems, dispersion, precompensation schemes, postcompensation schemes.

I. INTRODUCTION

In today's metropolitan area networks, as internet usage continues to grow there had been a tremendous growth in the modern communication systems in order to achieve high signaling rates, optical communication plays an tremendous role and results in the development of high speed telecommunication systems, internet, and also in local area networks(LAN). Telecommunications service providers have to face continuously growing bandwidth demands in all networks areas, from long-haul to access [1], [2]. Because installing new communication links would require huge investments, telecommunications carriers prefer to increase the capacity of their existing fiber links by using dense wavelength-division multiplexing (DWDM) systems and/or higher bit rates systems. However, most of the installed optical fibers are old and exhibit physical characteristics that may limit their ability to transmit high-speed signals. Optical communication systems use high carrier frequencies (100 THz) in the visible or near-infrared region of the electromagnetic spectrum. Optical communication system consists of a transmitter, a communication channel, and a receiver, as these three elements are common to all communication systems. Optical communication systems can be mainly categorized into two broad forms: *guided mode* and *unguided mode* An *optical mode* refers to a specific solution of the wave equation that satisfies the appropriate boundary conditions and has the property that its spatial distribution does not change with propagation. In the case of guided lightwave systems, the optical beam emitted by the transmitter remains spatially confined. Since all guided optical communication systems currently use optical fibers, the commonly used term for them is fiber-optic communication systems. In the case of unguided optical communication systems, the optical beam emitted by the transmitter spreads in space, similar to the spreading of microwaves. However, unguided optical systems are less suitable for broadcasting applications than microwave systems because optical beams spread mainly in the forward direction (as a result of their short wavelength) [1]. Fiber medium used in such systems can be any transparent medium such as plastic or glass as they are more flexible and efficient.

II. DISPERSION IN OPTICAL FIBER

In any transmission medium the signal is attenuated, or suffers loss, and is subject to degradations due to contamination by random signals and noise, as well as possible distortions imposed by mechanisms within the medium itself. Therefore, in any communication system there is a maximum permitted distance between the transmitter and the receiver beyond which the system effectively ceases to give intelligible communication. For longhaul applications these factors necessitate the installation of repeaters or line amplifier at intervals, both to remove signal distortion and to increase signal level before transmission is continued down the link. For modern glass optical fiber, the maximum transmission distance is limited not by attenuation but by dispersion, or spreading of optical pulses as they travel along fiber [4]. Thus dispersion is the broadening or spreading out of a light pulse in time as it propagates down the fiber. Dispersion is a critical factor limiting the quality of signal transmission over optical links. Dispersion is a consequence of the physical properties of the transmission medium. Single-mode fibers, used in high-speed optical networks, are subject to Chromatic Dispersion (CD) that causes pulse broadening depending on wavelength, and to Polarization Mode Dispersion (PMD) that causes pulse broadening depending on polarization. Excessive spreading will cause bits to "overflow" their intended time slots and overlap adjacent bits. The receiver may then have difficulty discerning and properly interpreting adjacent bits, increasing the Bit Error Rate. To preserve the transmission quality, the maximum amount of time dispersion must be limited to a small proportion of the signal bit rate, typically 10% of the bit time. Dispersion in optical fiber includes model dispersion, material dispersion and waveguide dispersion which are shown below in fig.1

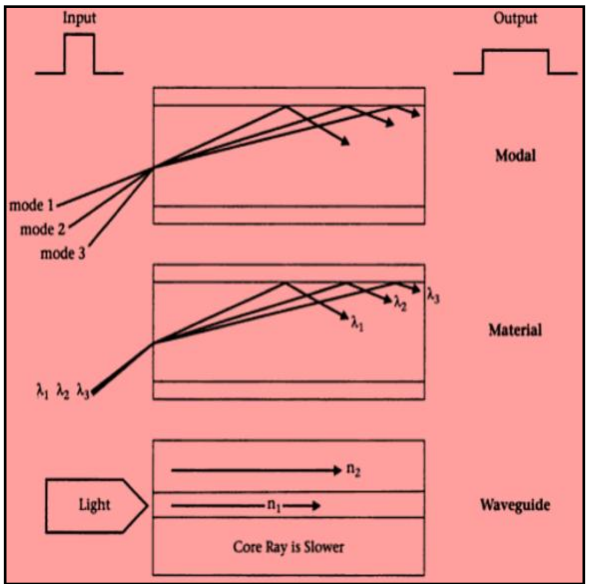

Fig.1 Types of Dispersion

III. LIMITATIONS OF DISPERSION-INDUCED

Dispersion induced limits the transmission distance and carrier frequency that can be used in the links. Group velocity dispersion (GVD) is the main limiting factor in high-bit-rate transmission systems operating over standard single-mode fibers. Moreover, "chirp," occurring in directly modulated lasers decreases drastically the length of the transmission link. Dispersion of transmitted optical signal causes distortion for both digital and analog transmission along optical fiber. When considering the major implementation of optical fiber transmission which involves some form of digital modulation, the dispersion mechanism within the fiber cause broadening of transmitted light pulses as they travel along the channel. It may be observed from the figure that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver input [2]. The effect is known as inter symbol interference (ISI) Thus, an increasing number of errors may be encountered on the digital optical channel as the ISI becomes more pronounced

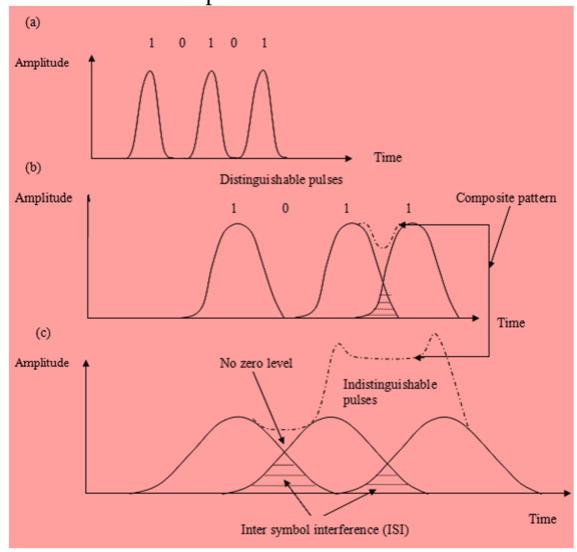

Fig.2 An illustration using the digital bit pattern 1011 of the broadening of light pulses as they are transmitted along a fiber: (a) Fiber input; (b) Fiber output at a distance L1; (c) Fiber output at a distances L2>L1

IV DISPERSION MANAGEMENT

Dispersion management refers to the approaches to transmission degradations caused by fiber dispersion using different types of single mode optical fiber and other nonlinear passive optical devices. Hence multiple sections of constant dispersion single-mode fiber and dispersion-compensating elements whose lengths and group velocity dispersion are chosen to optimize the overall transmission performance of an optical fiber communication system are usually employed. It should be noted that single-mode fiber dispersion tends to create limits for the generation, propagation and application of ultrashort pulses. In addition, optical amplifiers which are used in long-haul optical fiber systems also cause dispersion and thus restrict overall transmission distances. It is therefore necessary to control and manage the dispersion on a single-mode fiber link to constrain its effect on the optical fiber system. A common method for managing dispersion is to combine two or more types of single mode fiber to produce the desired dispersion over the entire link span. Optical amplifiers solve the loss problem but, at the same time, worsen the dispersion problem since, in contrast with electronic regenerators; an optical amplifier does not restore the amplified signal to its original state. As a result, dispersion-induced degradation of the transmitted signal accumulates over multiple amplifiers. For this reason, several dispersion-management schemes were developed during the 1990s to address the dispersion problem.

There are several types of dispersion management techniques which are evaluated below in our discussion.

(i) Precompensation technique:

It is an approach of dispersion management in which the characteristics of input pulses are modified at the transmitter prior to their launch into the fiber link. The whole concept constitute the changing of spectral amplitude of input pulse in a way that degradation induced due to dispersion is either eliminated or reduced to considerable amount. However, it is not easy to implement in practice. In a simple approach, the input pulse is chirped suitably to minimize the dispersion induce pulse broadening. Since the frequency chirp is applied at the transmitter before propagation of the pulse, this scheme is called prechirp technique [1]. The expression of prechirp technique is given as

$$L = \frac{C+\sqrt{(1+2C^2)}}{1+C^2} L_D \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,
C= Represents the chirp function (Change in frequency with respect to time)
L = Fiber length (in Km)
L_D is the dispersion length of the fiber

(ii) Dispersion compensating fiber

A special kind of fiber, known as dispersion-compensating fiber (DCF), has been developed for dispersion compensation. The use of DCF provides an all-optical technique that is capable of compensating the fiber dispersion completely if the average optical power is kept low enough that the nonlinear effects inside the optical fibers are negligible. It takes the advantages of linear nature. The condition for perfect dispersion compensation is

$$D_1L_1+D_2L_2=0\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Moreover, the length should be chosen to satisfy
$$L_2=-(D_1/D_2)*L_2\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

For practical reasons, L_2 should be as small as possible. This is possible only if the DCF has a large negative value of D_2.

(iii) Postcompensation technique:

Electronic techniques can be used for compensation of group velocity dispersion (GVD) within the receiver. The philosophy behind this approach is that even though the optical signal has been degraded by GVD, one may be able to equalize the effects of dispersion electronically if the fiber acts as a linear system. It is relatively easy to compensate for dispersion if a heterodyne receiver is used for signal detection . A heterodyne receiver first converts the optical signal into a microwave signal at the intermediate frequency ωIF while preserving both the amplitude and phase information. A microwave bandpass filter whose impulse response is governed by the transfer function

$$H(\omega) = \exp[-i(\omega-\omega_{IF})^2\beta_2 L/2]\ldots\ldots\ldots\ldots..(4)$$

Where L is the fiber length, should restore to its original form the signal received. This conclusion follows from the standard theory of linear systems with z=L. This technique is most practical for dispersion compensation in coherent lightwave systems [1].

V. ADVANTAGES OF DISPERSION COMPENSATION

Optical fiber communication system for operation at a system wavelength, including a transmitter, a receiver, and a transmission line comprising successive amplified fiber spans of alternating sign of dispersion; in which the transmission line includes an initial fiber span following the transmitter, a terminal span before the receiver, and at least one intermediate span; in which length and dispersion magnitude of the terminal span is such as to compensate dispersion for a signal introduced into the receiver.

1. Dispersion-shifted fiber (DSF), in properly balancing effects of material dispersion and waveguide dispersion, have hulled chromatic dispersion and minimized bit rate-limiting effects due to that cause for operation at the system wavelength of 1550nm. This permitted operation within the preferred low-loss region of the prevalent silica –based fiber.

2. Proper dispersion management takes non-linear effects, as well as chromatic dispersion, into account and increases per-channel bit-rates for single channel as well as for WDM (wavelength division multiplexing) operation. Dispersion averaging is used, in which dispersion is permitted to cross zero-ideally, to make equal excursions into both positive and negative regimes. Averaging over the transmission line is accomplished by use of an initial length of fiber, nominally of dispersion of half that of a succeeding amplified fiber span. As with traditional compensation systems, the final length of the fiber returns the signal dispersion to zero for detection.

3. Thus critical placement and lengths of dispersion-compensation fiber maximize capacity in upgraded in ground optical communication systems. Higher per-channel bit rates are permitted in single-channel systems and in WDM. As in WDM, it is expected to permit simultaneous operation of multiple channels, each operating at the same per-

channel bit rates. Prospects for WDM become realistic with the advent of the erbium-doped fiber amplifier (EDFA) with its ability to simultaneously amplify all channels of the WDM set.

VI. CONCLUSION

Dispersion in optical fibers limits the quality of signal transmission. Both CD and PMD must be measured to assess the potential of upgrading networks to higher transmission speeds, or to evaluate the need for compensations. Also various precompensation and postcompensation dispersion techniques are evaluated for enhancement of performance of optical fiber communication system. As deployment of optical communication systems is costly and reconfiguration is in some cases impossible or not economical. Finally we can say that experiments and simulation of systems are necessary to predict and optimize system performance. Thus dispersion compensation offers an obvious way to increase transmission capacity.

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Under his guidance many students have done their Research work and more than 20 scholars are still doing their Research Work