Evaluate the Effect of Non linearity in Multi-mode Optical Fiber

Arnob Islam Khan, Md. Ehasanul Haque, Bobby Barua, Tasnim Mahmood Sajid

Abstract— Multi-mode optical fiber is a type of optical fiber mostly used for communication over short distances, such as within a building or on a campus. The equipment used for communications over multi-mode optical fiber is less expensive than that for single-mode optical fiber. Because of its high capacity and reliability, multi-mode optical fiber generally is used for backbone applications in buildings.This paper analyses the effect of fiber nonlinearity and Stimulated Raman Scattering (SRS) in multi mode optical fiber communication system with direct detection binary WSK receiver. The performance results are evaluated in terms of Signal to Noise Ratio (SNR) and Bit Error Rate (BER) by changing system parameters at a bit rate of 10 Gb/s and above. It is noticed that the system performance degrades with power penalty and the maximum amount of power penalty for 32 channels at 10^{-22} BER is -6.02 dB for channel spacing 80 GHz and the length of the fiber of 5 Km. This paper considers WDM system design that might be used with multimode fibers and gives a general description of the components which could be used to implement the system. The components described are sources, multiplexers, demultiplexers, and detectors. Emphasis is given to the demultiplexer technique which is the major developmental component in the WDM system.

Index Terms— Wavelength Shift Keying (WSK), Bit Error Rate (BER), Stimulated Raman Scattering (SRS), Fiber nonlinearities, Multi- mode Fiber (mmf).

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1 INTRODUCTION

Optical wavelength division multiplexing (WDM) involves the simultaneous transmittal of information via different wavelengths of light. The various wavelengths after generation by separate optical sources are mixed by a multiplexer and transmitted over an optical communication link. At the receiving end of the link_ the distinct wavelengths of light are separated by a demultiplexer and converted to electrical signals by a photo detector. By using WDM a single optical fiber will provide multiple transmission paths. WDM increases the information capacity of a single optical fiber and also provides a means for two-way simultaneous transmission (full duplex). For a given data transmission requirement a WDM system would require less optical fibers, repeaters, splices and/or connectors than a single wavelength system.

An additional attribute of WDM is that a faulty or failed transmitter will be confined to a single communication path and will not disturb the information transmitted on the same fiber at different wavelengths. In WDM systems the available bandwidth is divided into separate channels with each channel carrying one signal. The data rate of each channel can be limited, frequently to 10 Gb/s, but with many channels the total data rate is high. WDM has not always been a popular choice. The invention of erbium-doped fiber amplifiers (EDFA) is largely responsible for enabling this technique [1]. In order for WDM to be useful not only the fiber provides a large bandwidth, but also the optical amplifiers. At this time WDM is the technique of choice for many fiber optic communication systems [2, 3, and 4]. WDM has found convenient application in three areas, high-capacity point-to-point links, broadcast networks and multiple-access networks [2]. A typical example of a high capacity point-to-point link would be a trans-oceanic fiber link. That is, a system with a single user transmitting a large data rate over a long distance. Two of the primary limiting factors in long-haul WDM systems are dispersion and fiber nonlinearities. Prior to the 1990's dispersion was typically viewed as the larger obstacle, and nonlinear effects were frequently neglected. However, with improvements in dispersion shifted fibers, dispersion compensation filters and other dispersion management techniques, the problem of fiber dispersion has been somewhat mitigated. Simultaneously, as data rates have continued to increase, fiber nonlinearities have recently appeared as the most important limiting factor [5-7]. Of the numerous nonlinearities that fiber optic systems are subject to, four-wave mixing (FWM) and cross-phase modulation (XPM) have been found to be the most destructive.

The main difference between multi-mode and single-mode optical fiber is that the former has much larger core diameter, typically 50–100 micrometers; much larger than the wavelength of the light carried in it. Because of the large core and also the possibility of large numerical aperture, multimode fiber has higher "light-gathering" capacity than singlemode fiber. In practical terms, the larger core size simplifies connections and also allows the use of lower-cost electronics such as light-emitting diodes (LEDs) and vertical-cavity surface-emitting lasers (VCSELs) which operate at the 850 nm and 1300 nm wavelength (single-mode fibers used in telecommunications operate at 1310 or 1550 nm and require more expensive laser sources. Single mode fibers exist for

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nearly all visible wavelengths of light). [8] However, compared to single-mode fibers, the multi-mode fiber bandwidth–distance product limit is lower. Because multi-mode fiber has a larger core-size than single-mode fiber, it supports more than one propagation mode; hence it is limited by modal dispersion, while single mode is not.

The LED light sources sometimes used with multi-mode fiber produce a range of wavelengths and these each propagate at different speeds. This chromatic dispersion is another limit to the useful length for multi-mode fiber optic cable. In contrast, the lasers used to drive single-mode fibers produce coherent light of a single wavelength. Due to the modal dispersion, multi-mode fiber has higher pulse spreading rates than single mode fiber, limiting multi-mode fiber's infomation transmission capacity. Single-mode fibers are most often used in high-precision scientific research because the allowance of only one propagation mode of the light makes the light easier to focus properly.

2 SYSTEM MODEL

An N channel WDM system block diagram of the increased capacity type is shown in figure I. Each input channel has an optical source transmitting light at a given wavelength. The outputs of these sources are combined onto a single transmission fiber using a passive multiplexer.

The multiplexed optical signals travel through the transmission fiber to a passive demultiplexer that separates the multiplexed signals into their optical wavelength components. A nonwavelength selective detector is used to convert each optical signal out of the demultiplexer into an electrical signal. For a WDM system, various signals such as analog and digital data, video signals, and audio signal can be transmitted simultaneously on the single transmission fiber.

Each optical transmitter at the subsystem will transmit at the given wavelengths (λ1, λ2, λ3, λ4). These transmitted signals are mixed in the multiplexer and produce four identical outputs. These outputs are distributed to the four subsystems via the fiber optic links. At each subsystem the output of the multiplexer is separated into its four optical components (λ1, λ2, λ3, λ4) by a demultiplexer. Each of the four optical outputs of the demultiplexer is converted from an optical signal to an electrical signal by the detector. If one of the transmitters fails in a mode of transmitting erroneous data on the bus or transmitting continuous noise, it will not affect the other data transmissions because of the separation of optical wavelengths. Such a fault will be confined to its own transmission path.

The model of WSK-DWDM system is shown in figure 1. The transmitted signal is given by –

$$S_m(t) = ACos\ (W_{mt} + f_m)\text{ ,Where } \mu = 1, 2, \ldots, M \qquad (1)$$

In the transmitter, the data of 10 Gbps is used to directly modulate a laser to generate the WSK signal which is transmitted through a single-mode fiber. In the WSK direct detection receiver with MZI, the MZI act as an optical filter and differentially detect the 'mark' and 'space' of received WSK signal which are then directly fed to a pair of photo detectors.

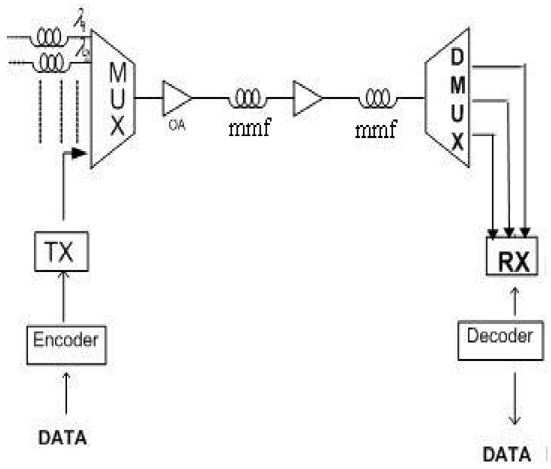

Fig. 1 System model of an N channel WDM system

The difference of the two photo currents are applied to the amplifier which is followed by an equalizer. The equalizer is required to equalize the pulse shape distortion caused by the photo detector capacitance and due to the input resistance and capacitance of the amplifier. After passing through the baseband filter, the signal is detected at the decision circuit by comparing it with a threshold of zero value.

3 THEORETICAL ANALYSIS

Assume N equally spaced channels with channel separation Δv (Hz).The degradation caused by SRS will be most severe for the shortest wavelength channel (called this the zeroth channel).Assuming scrambled polarization and the Raman gain to be in the linear regime, the power lost, D by the zeroth channel is,

$$D = \sum_{i=1}^{N-1} \frac{\lambda_i}{\lambda_0} P_i \gamma_i L_e \,/\, 2A \qquad (2)$$

Where,

P_i =the injected power (Watts) in the ith channel,

λ_i = the wavelength of the ith channel,

A = the effective core area given by the appropriate overlap integrals,

And L_e = the effective length of the fiber.

For SMF in a nonzero dispersion region $d_{12} \approx D_1 . \Delta\lambda_{12}$ where $\Delta\lambda_{12} = \lambda_1 - \lambda_2$ is the wavelength separation between channel 1 and 2. So, for MMF the dispersions will be-

$$D_1 = d_{21} / D\lambda_{12} + D\lambda_{13} \qquad (3)$$

$$D_2 = d_{12} / D\lambda_{21} + D\lambda_{23} \qquad (4)$$

$$D_3 = d_{13} / D\lambda_{31} + D\lambda_{32} \qquad (5)$$

The probability of error or BER is given by-

$$BER(Pe) = 0.5erfc\left[D \;/\; SNR\right] \qquad (6)$$

Where,

$$D = D_1 + D_2 + D_3 \qquad (7)$$

D = Dispersion
λ = Wave length of the fiber (Here, we consider the fiber distance equal)
d_{12} **=** Walk-off length
Signal-to-noise ratio,

$$SNR(r) = \frac{I_s}{\sigma\sqrt{2}}$$

Where,

$$I_s = R_d P_s(r)$$

And, $\sigma = P_{th} + P_{shot} + P_{XPM} + D$

Where,

$$P_{th} = Thermal\ noise = \frac{4kTB}{R_L}$$ And,

$$P_{shot} = shot\ Noise = 2eI_s B$$

4 RESULTS AND DISCUSSION

Following the analytical approach presented in section 3, we evaluated the BER performance of WSK-DWDM system considering the effect of changing system parameters such as no. of channels, area of the fiber and the channel separation.

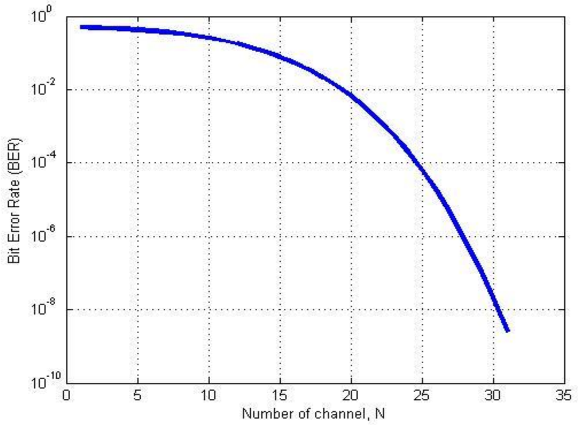

Fig. 2. BER Vs. No. of channel varying channel spacing (For SMF)

Number of channel for channel spacing V=80GHz, number ofchannel 32, area of fiber 100 mm2, input power =0.01W and length of the multi-mode fiber is 5 km, Raman gain coefficient=0.00005 m-1.

We get the following figure for Multi-Mode Fiber-

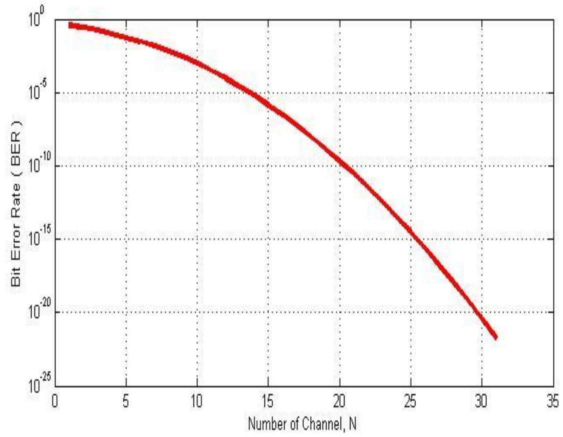

Fig. 3 BER Vs. No. of channel varying channel spacing (For MMF)

We get the following figure in comparison with Single Mode Fiber and Multi-Mode Fiber. We use dotted line for Single Mode Fiber and use solid line for Multi-Mode Fiber.

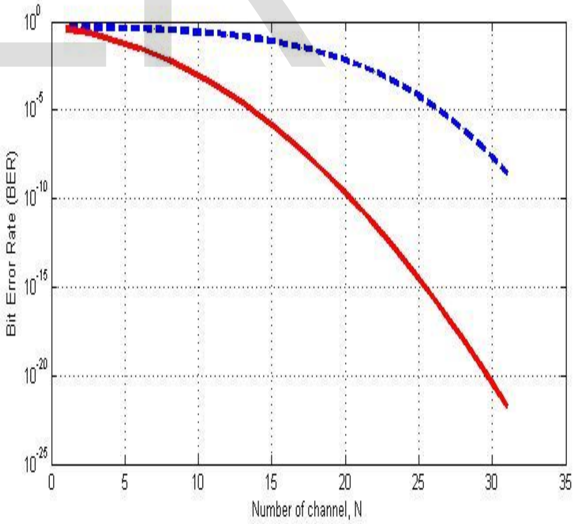

Fig. 4. BER Vs. No. of channel varying channel spacing (For SMF & MMF)

Plots of fig. 4 show the variation of Bit Error Rate (BER) vs. Number of channel for Single Mode Fibre and Multi-mode Fiber. It has been observed that the BER of Multi-mode Fiber is -6.02 dB in comparison with Single Mode Fiber. To improve the BER we used equal distance Multi-mode Fiber. It has been observed that as the channel spacing increases the Bit Error Rate decreases. But At 800 GHz channel spacing after 16 channels Bit Error Rate becomes constant. Similarly for channel spacing larger than 800GHz Bit Error Rate (BER) becomes constant at a specific number of channels.

5 CONCLUSION

The Bit Error Rate has been evaluated in the presence of SRS, XPM and receiver noise. The calculation of SRS has been done considering walk off effect. Results are evaluated in terms of BER and Power penalty at a BER of 10-22 for multimode fiber. The results of the analysis are in compliance with the mathematical equations reported in the literature and hence validate this method. The following conclusions are made from the analysis:

- It can be seen that 80 GHz channel spacing is the optimal channel spacing for BER and power penalty.
- It can be seen from the power penalty curves that the repeater can be used at an interval of 120 km.
- By comparing the figures 32 channels can be used for a Bit Error Rate (BER) of 10^{-22}.
- For better performance equal distance optical fibers can be used.

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