Simulation and Best Design of an Optical Single Channel in Optical Communication Network

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Abstract: *The optical fiber is a very attractive communication medium since it offers a large bandwidth and low attenuation, and can therefore facilitate demanding services such as high-quality video transmission and others in computer networks. In this paper, a simulation and best design of an optical single channel in optical communication is presented. Also this paper show how the fiber dispersion, transmitter and receiver response times, type of signal coding, and spectral width of light source are affect to the performance of the optical fiber communication such as cable length, data rate, BER. Additional this paper show the power and rise time budget is used to obtain a rough estimate of the transmission distance and the bit rate. The work is achieved using optical system simulator packet (OPTSIM 3.6).*

Keywords: *Optical Networks, Fiber Optical Communication, Power Budget, Rise Time Budget, Fiber Dispersion*

Received April 7, 2009; Accepted July 7, 2010

1. Introduction

The role of a communication channel in optical fiber communications or optical fiber networks is to transport the optical signal from transmitter to receiver with as little loss in quality as possible. In practice, optical fiber broaden light pulses transmitted through them through modal or chromatic dispersion. Ideally, a communication channel should not degrade the quality of the optical signal launched into it. If optical pulses spread significantly outside their allocated bit slot, the transmitted signal is degraded so severely that it becomes impossible to recover the original signal with high accuracy.

The dispersion problem is most severe for multimode fibers. It is for this reason that most modern fiber optic systems employ single-mode fibers. Chromatic dispersion still leads to pulse broadening but its impact can be reduced by controlling the spectral width of the optical source or by employing a dispersion-management technique.

Today more than 80 percent of the world's long-distance traffic is carried over optical fiber cables [1]. Telecommunications applications of fiber-optic cable are widespread, ranging from global networks to desktop computers. These involve the transmission of voice, data, and video over distances of less than a meter to hundreds of kilometres, using one of a few standard fiber designs in one of several cable designs [2, 3]. Fiber optics have become the industry standard for the terrestrial transmission of telecommunication information. Fiber optics will continue to be a major player in the delivery of broadband services.

The aim of this paper is to simulation and optimization a digital fiber optic link. This link will be used as a single channel in digital optical communication system, and give details for characteristic transmitter, receiver, and fiber to design and build this single channel in optical communication, also this paper demonstrate how the rise time in transmitter and receiver, type of coding (NRZ & RZ), dispersion of the fiber optic channel are effected to the system and performance's, such as data rate transmitted, fiber length, and bit error rate (BER).

2. Optical Communication System

The typical optical communication system consists of a transmitter, optical source, transmission media, a detector and a receiver.

The fiber optic link system is similar in concept to any type of communication system [1, 4].

The data source provides a digital or electrical signal to a transmitter comprising an electrical stage which drives an optical source to give modulation of the light wave carrier. The optical source provides the electrical-optical conversion maybe either a semiconductor laser or light emitting diode (LED). The transmission medium consists one of an optical fiber cable type and the receiver consists of an optical detector which drives a further electrical stage and hence provides demodulation of the optical carrier [5].

There are many variables enter into system design, such as light source (transmitter power), coupling losses, response time of the light source and transmitter, signal coding, splice and connecter loss, type of fiber (single – or - multimode), fiber attenuation and dispersion, fiber core diameter, operating wavelength, optical amplifiers, direct versus indirect modulation of transmitter, receiver sensitivity, bit error rate or signal to noise ratio, receiver bandwidth, number of splices, couplers, type of couplers and connectors.

Many of these variables are interrelated. For example, fiber attenuation and dispersion depend on operating wavelength as well as the fiber type. Coupling losses depend on factors such as fiber NA and core diameter. Also there are additional variables involves in optical link design among the transmitter source, fiber optic link, and receiver (photo-detector). These variables are requirements to analyzing a link:

- The transmission distance or fiber optic link length.
- The channel capacity or bandwidth (data rate).
- The bit-error rate (BER).
- Power Budget.
- Rise time budget.

Figure 1 shows a generic optical communication system consisting of an optical transmitter, that consists of an optical source, a modulator, data source, NRZ driver, fiber optic as a communication channel, and an PIN as optical receiver. This system is building using optical simulation package (OPTSIM), also the results obtained from this simulator program.

3. Optical Power Budget and Rise Time Budget

There are two important parameters in fiber optic communication design, the power budget and the rise time budget. The average optical power launched into the communication channel, should be as large as possible to enhance the bit error rate (BER) at the receiver end. If the signal is too weak when it reaches the far end of the system the data will be difficult to separate from the background noise this will cause the number of errors in the received data bits to increase. The received power must be high enough to keep the BER to a low value, on the other hand the received power must below enough to avoid damage to the receiver. The minimum power require received can calculated by find the power budget system this useful for estimate the fiber length, attenuation, loss in connecters and splices.
The power budget can be defined as: [7]

$$powerbudget = \frac{Ptx}{P\min} \qquad (1)$$

$$powerbudget(dB) = Ptx[dB] - P\min[dB] \qquad (2)$$

From equation (1) the power budget equals the ratio of the transmitted power to minimum power received needed to perform the required operation under the bit rate transmitted, and BER. From the power budget, the attenuation and total loss permitted in the transmission link will be known, and this total attenuation represents the attenuation in the fiber optic expressed in (dB/km), in addition to the coupling loss resulted from the connection of the node to the link. As shown in equation (3)

$$\alpha_{fiber} L + \alpha_{coupling} N \leq powerbudget[dB] \qquad (3)$$

Equation (3) shows that the power budget depends on the length of fiber optic used (segment length L), and number of nodes in the network (N). The link budget makes it possible to calculate the link length that will carry signals without a repeater in attenuation limited systems or how many connectors and splices can be used at a given distance in dispersion-limited links.

The second parameters are the rise time budget. It is important to ensure system is able to perform the intended bit and can transport the information in high bit rate. In other words the power and rise time budget are used to obtain a rough estimate of the transmission distance and the bit rate in communication system.

One can calculate transmission capacity or bandwidth channel from the time response or the rise time of the signal in the transmitter, receiver, and dispersion in a fiber. The overall time response can be defined as:

$$\Delta t_{overall} = \sqrt{\Delta t^2{}_{transmitter} + \Delta t^2_{receiver} + \Delta t^2{}_{fiber}} \qquad (4)$$

The overall response time is the square root of the sum of the squares of transmitter rise time, receiver rise time, and the pulse spreading caused by fiber dispersion. Transmitter and receiver rise time and full times are listed on data sheets, fiber response times must be calculated from the fiber length, the characteristic dispersion per unit length, and the source spectral width.

There are three types of dispersion, modal, chromatic (is the sum of material and waveguide dispersion), and polarization-mode dispersion. In single mode fibers, modal dispersion is zero, but chromatic dispersion and polarization-mode dispersion are significant.

You can calculate the total pulse spreading caused by dispersion with a sum of squares of all dispersion types in fiber optic.

$$\Delta t^2 \, fiber = \sqrt{\Delta t^2_{\mathrm{mod}\,al} + \Delta t^2_{chromatic} + \Delta t^2_{PMD}} \qquad (5)$$

For multimode fibers, polarization mode dispersion is insignificant, so only model and chromatic dispersion are considered. Single mode fibers do not suffer modal dispersion, so only chromatic and polarization mode dispersion are considered.

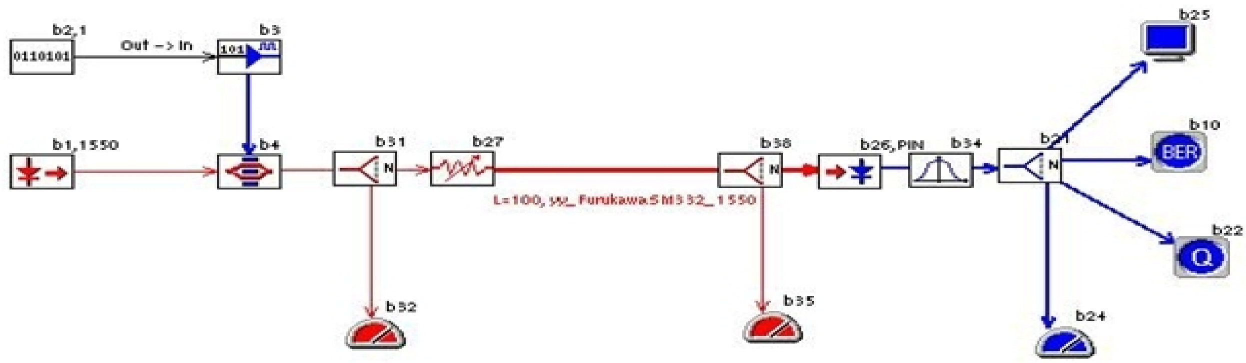

Figure 1. Single channel optical communication

The transmission capacity of an optical fiber communications system is the total analog bandwidth or digital data rate it can carry [3, 7].

With wavelength division multiplexing, total capacity of a fiber is the sum of the capacity of all optical channels the fiber carries. Single channel capacity depends on how fast all the parts of the system respond to changes in signal intensity. In practice, transmission speed is mainly affected by properties of the transmitter, fiber, and receiver.

On cost and safety grounds it is good to keep the transmitter power to the minimum acceptable value, and select a transmitter light source with enough power to enable the system to operate under the worse case conditions with the maximum losses considered above. Also the design should leave some extra margin above the receiver's minimum requirements to allow for system aging, fluctuations, and repairs, such as splicing a broken cable. However, it should not deliver so much power that it overloads the receiver.

4. Simulation and Results Analysis

The results obtained from using simulation program (OPTSIM 3.6) in this work, are indicated and presented graphically in figures. Figure 2 show the four sub-figures for the rise time versus data rate at different fiber optic length (10, 20, 50, 100) km over fiber backbone. These figures clearly shows the increase of length link due to increase the rise time so this due to decrease in data rate or bandwidth channel capacity. Therefore we must decrease the overall rise time to transmit signal at high data rate reach to 40Gbps and longer channel length see table 1.

Also one can decrease the spectral width of light source in transmitter to get enhancement in performance of the system or to transmit higher data rate, as shown in figure 3. Or we can chose the NRZ coding instead of RZ coding for transmitter, as shown in figure 4 , the figure show the NRZ coding best than RZ for the digital transmitter, one can transmit at higher data rate on the same rise time value when using the NRZ code instead of RZ coding.

Table 1: Time response for NRZ and RZ code at different data rate

Data Rate	100 M bps	1Gbps	10Gbps	40Gbps
Time Response for NRZ code	7 ns	0.7 ns	0.07 ns	17.5 p
Time Response for RZ code	3.5 ns	0.35 ns	0.035 ns	8.75 ps

The magnitude of the dispersion problem increases with the length of the cable and so the transmission data rate, decreases with fiber length, as show in figure 5 the figure show when the fiber length increase we need more transmitted power to get the same BER in the system. And we must calculate the loss budget in system to be sure that enough power reaches the receiver to give adequate performance.

On the other hand when the data rate increases, the BER increases if the power is held constant, as show in figure 6 then the over all rise time must decrease on the higher data rate to get the lower BER and good performance in communication system. We can see how transmitter and receiver properties affect data rate. Finally, from the previous results in figures, it is become clear, we can get the best and optimization in fiber optic channel design when chosen the transmitter and receiver that have a rise time value between (0.1-0.5 ns) at fiber length less than 100 km, to transmit at data rate equal 1Gbps, for example we can use the OPT3395-5 optical transmitter module which converts electrical data signals to light waves in the 1550 nm band, 1nm spectral source width and 0.3 ns optical rise time. on the other hand use the OPT1375-5 fiber optic receiver module which converts light waves in the 1550 nm band to electrical data signals at a data rate of 20 Mbps to 1.25 Gbps, output rise time 250ps, photodiode responsivity 0.9 A/W, fiber optic dispersion is 0.1 ps/nm/km @ 1550 nm ,fiber attenuation is (0.01 dB/km).

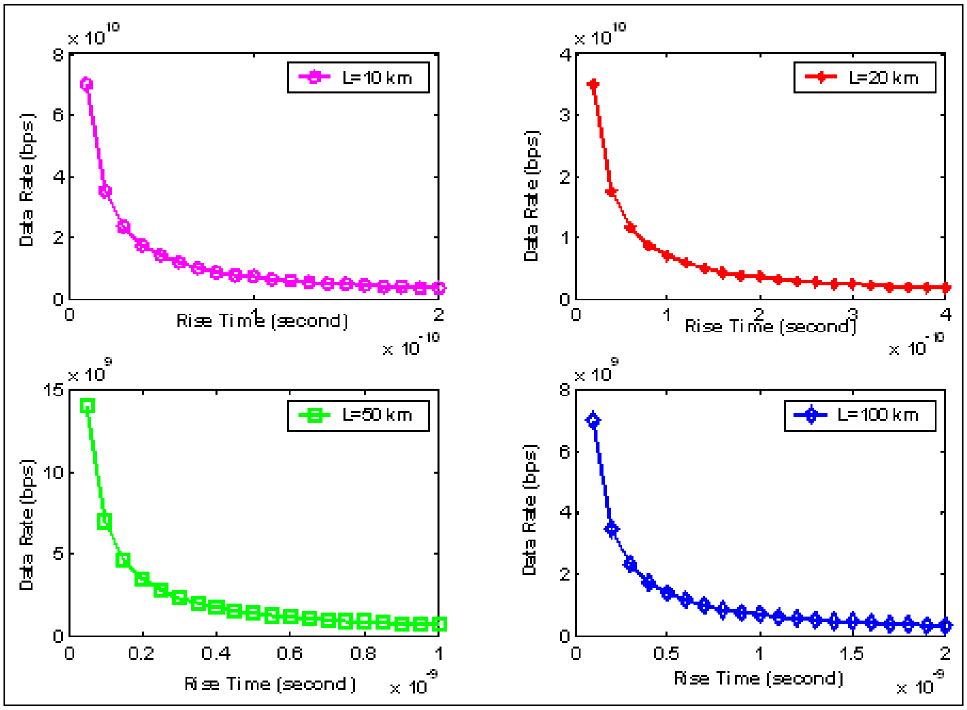

Figure 2. Rise time versus Data rate at different fiber length.

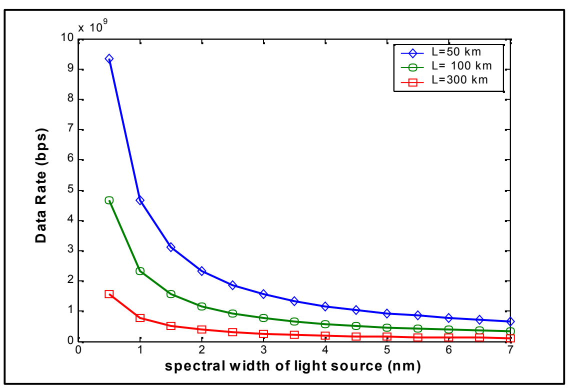

Figure 3. Spectral width of light source versus Data rate at different fiber length.

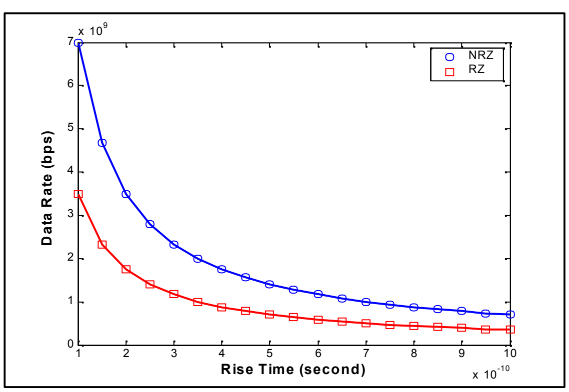

Figure 4. Rise time versus data rate at NRZ and RZ coding.

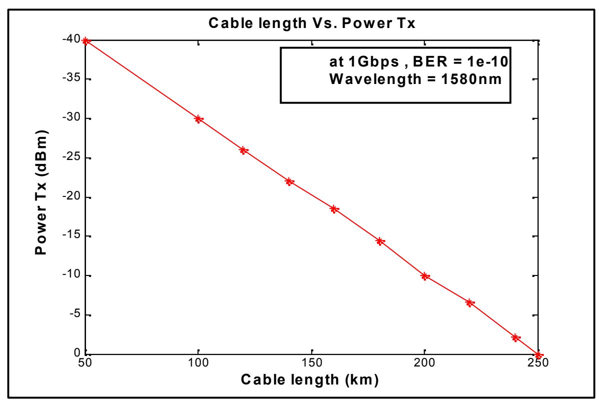

Figure 5. Cable length versus power transmitted at 1Gbps to get BER (10e-10).

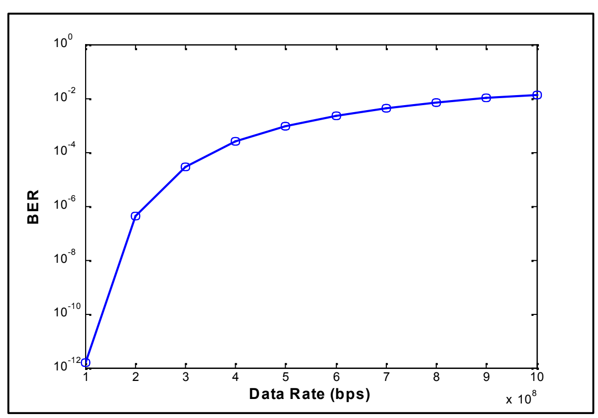

Figure 6. Data rate versus BER.

Figure 2. Rise time versus Data rate at different fiber length.

5. Conclusion

The results obtained in this work indicate the fiber dispersion, transmitter, receiver response times, and Spectral width of light source are playing critical and important roles in system bandwidth budgets. Pulse dispersion in fiber must be calculated to be sure the system can transmit signals at the proper speed, because dispersion limits the maximum bit rate that may be used with fibers.

Loss budgets and transmission capacity are very important and crucial in single and multi-channel system. The power and rise time budget are used to obtain a rough estimate of the transmission distance and the bit rate. We need enough power or light to cover all optical transmission losses and to deliver enough light to the receiver to achieve the desired bit error rate. Also single channel design techniques can be applied to each channel in a multi-wavelength system.

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