# NEAR EAST UNIVERSITY

## Faculty of Engineering

## Department of Electrical and Electronics Engineering

# Fiber Optic Communication System

**Graduation Project**
**EE-400**

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## ABSTRACT

In fiber optic communication systems engineering covering basic aspects of modern fiber-optic communication systems that includes sources and receivers, optical fibers, optical amplifiers and current system architectures. The principles of operation and properties of optoelectronic components, as well as signal guiding characteristics of glass fibers are discussed. System design issues include underwater links, terrestrial point-to-point optical links and wavelength division multiplexing (WDM) fiber-optic networks. From this project you will obtain the knowledge needed to perform basic fiber-optic communication systems engineering calculations, and apply this knowledge to modern fiber optic systems. This will enable you to evaluate real systems, communicate effectively with colleagues, and understand the most recent literature in the field of fiber-optic communications.

Fiber-based networks form a key part of international communications systems. This project introduces the physical principles of optical fibers, and details their use in sensor technology and modern optical communication systems. The authors begin by setting out the basic propagation characteristics of single mode and multimode optical fibers. In later chapters they cover optical sources, optical detectors, and fiber-optic communication system design. They also treat a wide variety of related topics such as doped fiber amplifiers, dispersion compensation, fiber sensors, and measurement techniques for the characterization of optical fibers. Throughout the book, physical and engineering aspects of the subject are interwoven, and many worked examples and exercises are included. It will be an ideal textbook for undergraduate or graduate students taking projects in optical fiber communications, photonics, or optoelectronics.

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# INTRODUCTION

In this project optical fiber transmission system is studied with intensive care and an application of this unique system is shown. Optical Fiber transmission system is anew technologies, which have a large impact in telecommunication feature, telecommunication networks as well as videos transmission, reciever, transmitter and computer interconnections.

It provides several major advantages over conventional electronic transmission system. This includes immunity to electromagnetic interference, thinner and lighter cables, lower transmission losses and wider bandwidths. Optical fiber are vital in an information society, it is a threadlike structure capable of handling the transportation of a large volume of information traffic. We need it as the building block of our information highway system to help us in managing our energy resources, transportation and communications; delivering health care and community services; strengthening our military defense; developing business and providing materials for our entertainment and education. Here in this project I will discuss in four chapters the functions, the aims of the fiber optic and how we can use it in the network and communication

First Chapter about the Fiber Optic Data Communications Link, End-to-End.

Second Chapter represent the transmission medium of fiber optic witch contain the transmitter, receiver and connectors with the process of placing information onto an information carrier.

Third Chapter represents the Sharing the Transmission Medium, Time Division Multiplexing (TDM). Wavelength Division Multiplexing (WDM) With Fiber Optic Cable and Comparing Multiplexing Techniques for the Premises environment on the basis of link design flexibility.

Fourth Chapter about Brief History of Local Area Networks and Transmission Media Used To Implement An Ethernet LAN, Examining the Distance Constraint, also I will give some examples of LAN Extenders Shown In Typical Applications, Model 375 100Base-T to Fiber Transceiver for Fast Ethernet, Model 377 Series Single-Mode 100Base-T/F Media Converter. For conclusion I achieved my aims after finishing this project and the best thing for networks cables the fiber optic not just for has flexibility and many advantages but if we look to the security and the economy.

# CHAPTER ONE

# THE FIBER OPTIC DATA COMMUNICATIONS LINK FOR THE PREMISES ENVIRONMENT

## 1.1 Overview

In this chapter we consider the simple fiber optic data link for the premises environment. And also we will represent the fiber optic cable.

## 1.2 The Fiber Optic Data Communications Link, End-to-End

This is the basic building block for a fiber optic based network. A model of this simple link is shown in Figure 1-1.

The illustration indicates the Source-User pair, Transmitter and Receiver. It also clearly shows the fiber optic cable constituting the Transmission Medium as well as the connectors that provide the interface of the Transmitter to the Transmission Medium and the Transmission Medium to the Receiver.

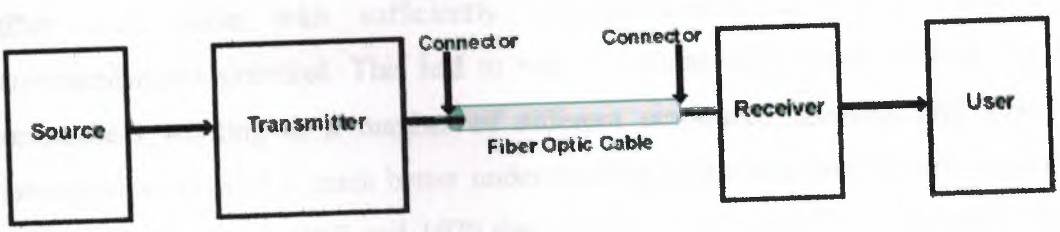



**Figure 1-1**: Model of "simple" fiber optic data link

All of these are components of the simple fiber optic data link. Each will be discussed. We will conclude by taking up the question of how to analyze the performance of the simple fiber optic data link.

## 1.3 Fiber Optic Cable

We begin by asking just what is a fiber optic cable? A fiber optic cable is a cylindrical pipe. It may be made out of glass or plastic or a combination of glass and plastic. It is fabricated in such a way that this pipe can guide light from one end of it to the other. The idea of having light guided through bent glass is not new or high tech. The author was once informed that Leonardo DaVinci actually mentioned such a means for guiding light in one of his notebooks. However, he has not been able to verify this assertion. What is known for certain is that total internal reflection of light in a beam of water - essentially guided light - was demonstrated by the physicist John Tyndall [1820-1893] in either 1854 or 1870 - depending upon which reference you consult.
Tyndall showed that light could be bent around a corner while it traveled through a jet of pouring water.Using light for communications came after this. Alexander Graham Bell [1847-1922] invented the photo-phone around 1880. Bell demonstrated that a membrane in response to sound could modulate an optical signal, light. But, this was a free space transmission system. The light was not guided. Guided optical communications had to wait for the 20th century. The first patent on guided optical communications over glass was obtained by AT &T in 1934. However, at that time there were really no materials to fabricate a glass (or other type of transparent material) fiber optic cable with sufficiently low attenuation to make guided optical communications practical. This had to wait for about thirty years. During the 1960's researchers working at a number of different academic, industrial and government laboratories obtained a much better understanding of the loss mechanisms in glass fiber optic cable. Between 1968 and 1970 the attenuation of glass fiber optic cable dropped from over 1000 dB/km to less than 20 dB/km. Corning patented its fabrication process for the cable.

The continued decrease in attenuation through the 1970's allowed practical guided light communications using glass fiber optic cable to take off. In the late 1980's and 1990's this momentum increased with the even lower cost plastic fiber optic cable and Plastic Clad Silica (PCS).Basically, a fiber optic cable is composed of two concentric layers termed the core and the cladding. These are shown on the right side of Figure 1-2. The core and cladding have different indices of refraction with the core having $n_1$ and the cladding $n_2$. Light is piped through the core.

A fiber optic cable has an additional coating around the cladding called the jacket. Core, cladding and jacket are all shown in the three dimensional view on the left side of Figure 1-2. The jacket usually consists of one or more layers of polymer. Its role is to protect the core and cladding from shocks that might affect their optical or physical properties. It acts as a shock absorber. The jacket also provides protection from abrasions, solvents and other contaminants. The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable. The illustration on the left side of Figure 1-2 is somewhat simplistic. In actuality, there may be a strength member added to the fiber optic cable so that it can be pulled during installation.

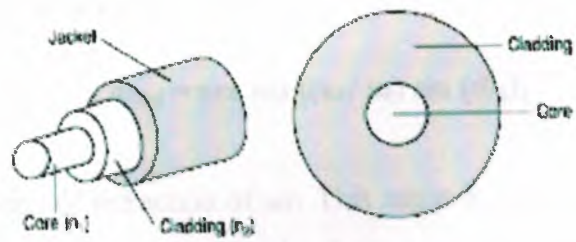



**Figure 1-2**: Fiber Optic Cable, 3 dimensional view and basic cross section

This would be added just inside the jacket. There may be a buffer between the strength member and the cladding. This protects the core and cladding from damage and allows the fiber optic cable to be bundled with other fiber optic cables.How is light guided down the fiber optic cable in the core? This occurs because the core and cladding have different indices of refraction with the index of the core, $n_1$, always being greater than the index of the cladding, $n_2$. Figure 1-3 shows how this is employed to effect the propagation of light down the fiber optic cable. As illustrated a light ray is injected into the fiber optic cable on the right. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than an entity called the critical angle then it is reflected back into the core. Since the angle of incidence is always equal to the angle of reflection the reflected light will again be reflected. Light can be guided down the fiber optic cable if it enters at less than the critical angle. This angle is fixed by the indices of refraction of the core and cladding and is given by the formula:

$$\Phi_c = \text{arc cosine } (n_2 / n_1).$$

The critical angle is measured from the cylindrical axis of the core. By way of example, if $n_1 = 1.446$ and $n_2 = 1.430$ then a quick computation will show that the critical angle is 8.53 degrees, a fairly small angle.

Of course, it must be noted that a light ray enters the core from the air outside, to the left of Figure 1-3. The refractive index of the air must be taken into account in order to assure that a light ray in the core will be at an angle less than the critical angle. This can be done fairly simply. The following basic rule then applies. Suppose a light ray enters the core from the air at an angle less than an entity called the external acceptance angle - $\Phi_{ext}$ it will be guided down the core. Here

$$\Phi_{ext} = \text{arc sin } [(n_1 / n_0) \sin (\Phi_c)]$$

With n0 being the index of refraction of air. This angle is, likewise, measured from the cylindrical axis of the core. In the example above a computation shows it to be 12.4 degrees - again a fairly small angle.

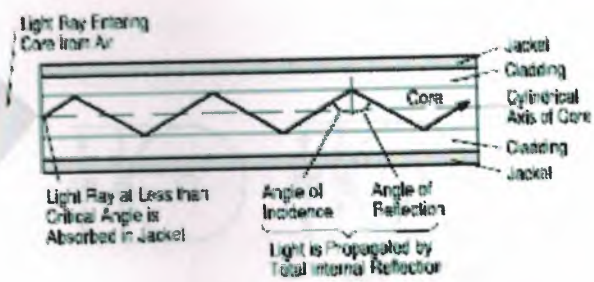



**Figure 1-3**: Propagation of a light ray down a fiber optic cable

## 1.3.1 Fiber optic data performance

Fiber optic data link performance is a subject that will be discussed in full at the end of this chapter. However, let's jump the gun just a little. In considering the performance of a fiber optic data link the network architect is interested in the effect that the fiber optic cable has on overall link performance. The more light that can be coupled into the core the more light will reach the Receiver and the lower the BER. The lower the attenuation in propagating down the core the more light reaches the Receiver and the lower the BER. The answers to these questions depend upon many factors. The major factors are the size of the fiber, the composition of the fiber and the mode of propagation. When it comes to size, fiber optic cables have exceedingly small diameters. Figure 1-4 illustrates the cross sections of the core and cladding diameters of four commonly used fiber optic cables. The diameter sizes shown are in microns, 10-6 m. To get some feeling for how small these sizes actually are, understand that a human hair has a diameter of 100 microns. Fiber optic cable sizes are usually expressed by first giving the core size followed by the cladding size. Consequently, 50/125 indicates a core diameter of 50 microns and a cladding diameter of 125 microns; 100/140 indicates a core diameter of 100 microns and a cladding diameter of 140 microns.

The larger the core the more light can be coupled into it from external acceptance angle cone. However, larger diameter cores may actually allow too much light in and too much light may cause Receiver saturation problems. The left most cable shown in Figure 1-4, the 125/8 cable, is often found when a fiber optic data link operates with single-mode propagation. The cable that is second from the right in Figure 1-4, the 62.5/125 cable, is often found in a fiber optic data link that operates with multi-mode propagation.

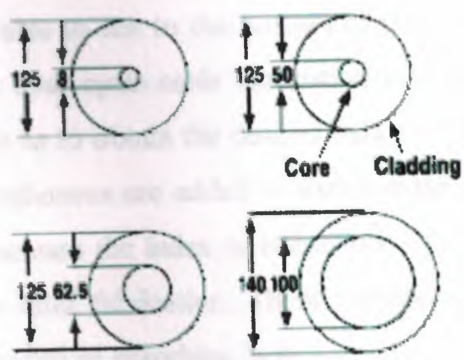



**Figure 1-4**: Typical core and cladding diameters -Sizes are in microns

## 1.4 Types of fiber optic cable

When it comes to composition or material makeup fiber optic cables are of three types: glass, plastic and Plastic Clad Silica (PCS). These three candidate types differ with respect to attenuation and cost. We will describe these in detail. Attenuation and cost will first be mentioned only qualitatively. Later, toward the end of this sub-chapter the candidates will be compared quantitatively. By the way, attenuation is principally caused by two physical effects, absorption and scattering. Absorption removes signal energy in the interaction between the propagating light (photons) and molecules in the core. Scattering redirects light out of the core to the cladding. When attenuation for a fiber optic cable is dealt with quantitatively it is referenced for operation at a particular optical wavelength, a window, where it is minimized.

### 1.4.1 Glass fiber optic cable

Glass fiber optic cable has the lowest attenuation and comes at the highest cost. A pure glass fiber optic cable has a glass core and a glass cladding. This candidate has, by far, the most wide spread use. It has been the most popular with link installers and it is the candidate with which installers have the most experience. The glass employed in a fiber optic cable is ultra pure, ultra transparent, silicon dioxide or fused quartz. One reference put this in perspective by noting that "if seawater were as clear as this type of fiber optic cable then you would be able to see to the bottom of the deepest trench in the Pacific Ocean." During the glass fiber optic cable fabrication process impurities are purposely added to the pure glass so as to obtain the desired indices of refraction needed to guide light. Germanium or phosphorous are added to increase the index of refraction. Boron or fluorine is added to decrease the index of refraction. Other impurities may somehow remain in the glass cable after fabrication. These residual impurities may increase the attenuation by either scattering or absorbing light.

### 1.4.2 Plastic fiber optic cable

Plastic fiber optic cable has the highest attenuation, but comes at the lowest cost. Plastic fiber optic cable has a plastic core and plastic cladding. This fiber optic cable is quite thick. Typical dimensions are 480/500, 735/750 and 980/1000. The core generally consists of PMMA (polymethylmethacrylate) coated with a fluropolymer. Plastic fiber optic cable was pioneered in Japan principally for use in the automotive industry. It is just beginning to gain attention in the premises data communications market in the United States. The increased interest is due to two reasons. First, the higher attenuation relative to glass may not be a serious obstacle with the short cable runs often required in premise networks. Secondly, the cost advantage sparks interest when network architects are faced with budget decisions. Plastic fiber optic cable does have a problem with flammability. Because of this, it may not be appropriate for certain environments and care has to be given when it is run through a plenum. Otherwise, plastic fiber is considered extremely rugged with a tight bend radius and the ability to withstand abuse.

### 1.4.3 Plastic Clad Silica (PCS) fiber optic cable

Plastic Clad Silica (PCS) fiber optic cable has an attenuation that lies between glass and plastic and a cost that lies between their costs as well. Plastic Clad Silica (PCS) fiber optic cable has a glass core which is often vitreous silica while the cladding is plastic - usually a silicone elastomer with a lower refractive index. In 1984 the IEC standardized PCS fiber optic cable to have the following dimensions: core 200 microns, silicone elastomer cladding 380 microns, jacket 600 microns. PCS fabricated with a silicone elastomer cladding suffers from three major defects. It has considerable plasticity. This makes connector application difficult. Adhesive bonding is not possible and it is practically insoluble in organic solvents. All of this makes this type of fiber optic cable not particularly popular with link installers. However, there have been some improvements in it in recent years.

## 1.5 The single-mode fiber optic cable

A propagation fiber optic cable can be one of two types, multi-mode or single-mode. These provide different performance with respect to both attenuation and time dispersion. The single-mode fiber optic cable provides the better performance at, of course, a higher cost. In order to understand the difference in these types an explanation must be given of what is meant by mode of propagation. Light has a dual nature and can be viewed as either a wave phenomenon or a particle phenomenon (photons).

For the present purposes consider it as a wave. When this wave is guided down a fiber optic cable. It exhibits certain modes. These are variations in the intensity of the light, both over the cable cross-section and down the cable length. These modes are actually numbered from lowest to highest. In a very simple sense each of these modes can be thought of as a ray of light. Although, it should be noted that the term ray of light is a hold over from classical physics and does not really describe the true nature of light. In any case, view the modes as rays of light. For a given fiber optic cables the number of modes that exist depend upon the dimensions of the cable and the variation of the indices of refraction of both core and cladding across the cross section. There are three principal possibilities. These are illustrated in Figure 1-5. Consider the top illustration in Figure 1-5. This diagram corresponds to multi-mode propagation with a refractive index profile that is called step index. As can be seen the diameter of the core is fairly large relative to the cladding. There is also a sharp discontinuity in the index of refraction as you go from core to cladding. As a result, when light enters the fiber optic cable on the right it propagates down toward the left in multiple rays or multiple modes.

This yields the designation multi-mode. As indicated the lowest order mode travels straight down the center. It travels along the cylindrical axis of the core. The higher modes represented by rays, bounce back and forth, going down the cable to the left. The higher the mode the more bounces per unit distance down to the left. Over to the left of this top illustration are shown a candidate input pulse and the resulting output pulse. Note that the output pulse is significantly attenuated relative to the input pulse. It also suffers significant time dispersion. The reasons for this are as follows. The higher order modes, the bouncing rays, tend to leak into the cladding as they propagate down the fiber optic cable. They lose some of their energy into heat. This results in an attenuated output signal. The input pulse is split among the different rays that travel down the fiber optic cable. The bouncing rays and the lowest order mode, traveling down the center axis, are all traversing paths of different lengths from input to output. Consequently, they do not all reach the right end of the fiber optic cable at the same time. When the output pulse is constructed from these separate ray components the result is time dispersion.

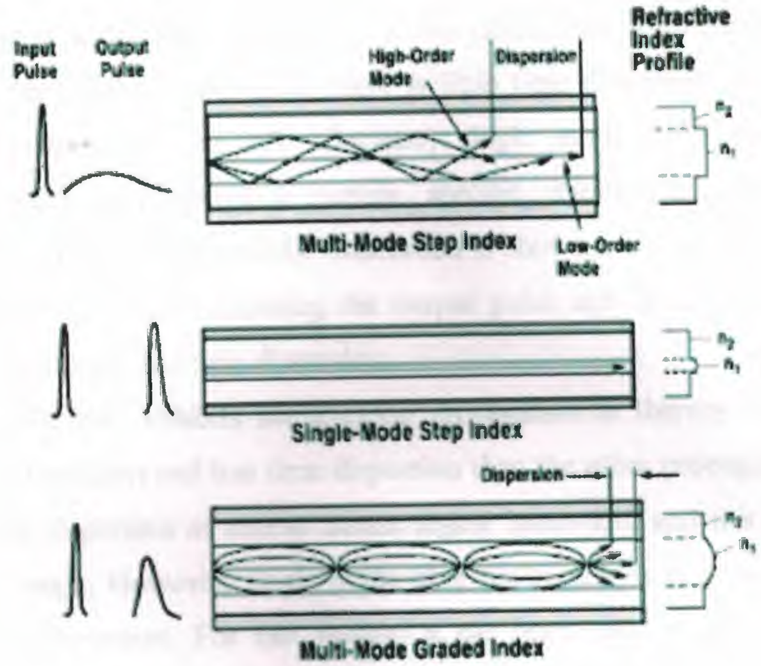



**Figure 1-5**: Types of mode propagation in fiber optic cable (Courtesy of AMP

## 1.6 Multi-mode Propagation

Fiber optic cable that exhibits multi-mode propagation with a step index profile is thereby characterized as having higher attenuation and more time dispersion than the other propagation candidates have. However, it is also the least costly and in the premises environment the most widely used. It is especially attractive for link lengths up to 5 km. Usually; it has a core diameter that ranges from 100 microns to 970 microns. It can be fabricated either from glass, plastic or PCS. Consider the middle illustration in Figure 1-5. This diagram corresponds to single-mode propagation with a refractive index profile that is called step index. As can be seen the diameter of the core is fairly small relative to the cladding. Typically, the cladding is ten times thicker than the core. Because of this when light enters the fiber optic cable on the right it propagates down toward the left in just a single ray, a single-mode, and the lowest order mode. In extremely simple terms this lowest order mode is confined to a thin cylinder around the axis of the core. (In actuality it is a little more complex).

The higher order modes are absent. Consequently, there is no energy lost to heat by having these modes leak into the cladding. They simply are not present. All energy is confined to this single, lowest order, mode. Since the higher order mode energy is not lost, attenuation is not significant. Also, since the input signal is confined to a single ray path, that of the lowest order mode, there is little time dispersion, only that due to propagation through the non-zero diameter, single mode cylinder. Single mode propagation exists only above a certain specific wavelength called the cutoff wavelength. To the left of this middle illustration is shown a candidate input pulse and the resulting output pulse. Comparing the output pulse and the input pulse note that there is little attenuation and time dispersion.

Fiber optic cable that exhibits single-mode propagation is thereby characterized as having lower attenuation and less time dispersion than the other propagation candidates have. Less time dispersion of course means higher bandwidth and this is in the 50 to 100 GHz/ km range. However, single mode fiber optic cable is also the most costly in the premises environment. For this reason, it has been used more with Wide Area Networks than with premises data communications. It is attractive more for link lengths go all the way up to 100 km. Nonetheless; single-mode fiber optic cable has been getting increased attention as Local Area Networks have been extended to greater distances over corporate campuses. The core diameter for this type of fiber optic cable is exceedingly small ranging from 5 microns to 10 microns. The standard cladding diameter is 125 microns.

Single-mode fiber optic cable is fabricated from glass. Because of the thickness of the core, plastic cannot be used to fabricate single-mode fiber optic cable. The author is unaware of PCS being used to fabricate it. It should be noted that not all single-mode fibers use a step index profile.

Some use more complex profiles to optimize performance at a particular wavelength. Consider the bottom illustration in Figure 1-5. This corresponds to multi-mode propagation with a refractive index profile that is called graded index. Here the variation of the index of refraction is gradual as it extends out from the axis of the core through the core to the cladding. There is no sharp discontinuity in the indices of refraction between core and cladding. The core here is much larger than in the single-mode step index case discussed above.

Multi-mode propagation exists with a graded index. However, as illustrated the paths of the higher order modes are somewhat confined. They appear to follow a series of ellipses. Because the higher mode paths are confined the attenuation through them due to leakage is more limited than with a step index. The time dispersion is more limited than with a step index, therefore, attenuation and time dispersion are present, just limited.

To the left of this bottom illustration is shown a candidate input pulse and the resulting output pulse. When comparing the output pulse and the input pulse, note that there is some attenuation and time dispersion, but not nearly as great as with multi-mode step index fiber optic cable.

Fiber optic cable that exhibits multi-mode propagation with a graded index profile is thereby characterized as having attenuation and time dispersion properties somewhere between the other two candidates. Likewise its cost is somewhere between the other two candidates. Popular graded index fiber optic cables have core diameters of 50, 62.5 and 85 microns. They have a cladding diameter of 125 microns - the same as single-mode fiber optic cables. This type of fiber optic cable is extremely popular in premise data communications applications. In particular, the 62.5/125 fiber optic cable is the most popular and most widely used in these applications.

Glass is generally used to fabricate multi-mode graded index fiber optic cable. However, there has been some work at fabricating it with plastic. The illustration Figure 1-6 provides a three dimensional view of multi-mode and single-mode propagation down a fiber optic cable. Table 1-1 provides the attenuation and bandwidth characteristics of the different fiber optic cable candidates. This table is far from being all inclusive; however, the common types are represented.

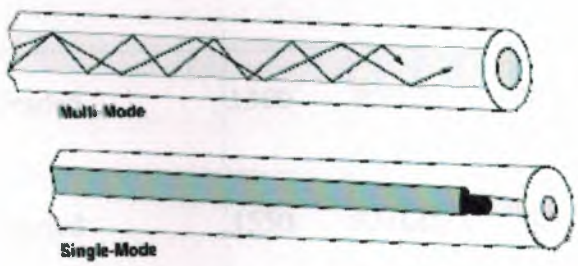



**Figure 1-6:** Three dimensional view, optical power in multi-mode and single-mode fibers

**Table 1-1**: Attenuation and Bandwidth characteristics of different fiber optic cable candidates

| **Mode** | **Material** | **Index of Refraction Profile** | **microns** | **Size (microns)** | **Atten. dB/km** | **Bandwidth MHz/km** |
|---|---|---|---|---|---|---|
| Multi-mode | Glass | Step | 800 | 62.5/125 | 5.0 | 6 |
| Multi-mode | Glass | Step | 850 | 62.5/125 | 4.0 | 6 |
| Multi-mode | Glass | Graded | 850 | 62.5/125 | 3.3 | 200 |
| Multi-mode | Glass | Graded | 850 | 50/125 | 2.7 | 600 |
| Multi-mode | Glass | Graded | 1300 | 62.5/125 | 0.9 | 800 |
| Multi-mode | Glass | Graded | 1300 | 50/125 | 0.7 | 1500 |
| Multi-mode | Glass | Graded | 850 | 85/125 | 2.8 | 200 |
| Multi-mode | Glass | Graded | 1300 | 85/125 | 0.7 | 400 |
| Multi-mode | Glass | Graded | 1550 | 85/125 | 0.4 | 500 |
| Multi-mode | Glass | Graded | 850 | 100/140 | 3.5 | 300 |
| Multi-mode | Glass | Graded | 1300 | 100/140 | 1.5 | 500 |
| Multi-mode | Glass | Graded | 1550 | 100/140 | 0.9 | 500 |
| Multi- | Plastic | Step | 650 | 485/500 | 240 | 5 @ 680 |

| | | | | | | |
|---|---|---|---|---|---|---|
| mode | | | | | | |
| Multi-mode | Plastic | Step | 650 | 735/750 | 230 | 5 @ 680 |
| Multi-mode | Plastic | Step | 650 | 980/1000 | 220 | 5 @ 680 |
| Multi-mode | PCS | Step | 790 | 200/350 | 10 | 20 |
| Single-mode | Glass | Step | 650 | 3.7/80 or 125 | 10 | 600 |
| Single-mode | Glass | Step | 850 | 5/80 or 125 | 2.3 | 1000 |
| Single-mode | Glass | Step | 1300 | 9.3/125 | 0.5 | * |
| Single-mode | Glass | Step | 1550 | 8.1/125 | 0.2 | * |

* Too high to measure accurately. Effectively infinite.

Figure 1-7 illustrates the variation of attenuation with wavelength taken over an ensemble of fiber optic cable material types. The three principal windows of operation, propagation through a cable, are indicated. These correspond to wavelength regions where attenuation is low and matched to the ability of a Transmitter to generate light efficiently and a Receiver to carry out detection. The 'OH' symbols indicate that at these particular wavelengths the presence of Hydroxyl radicals in the cable material cause a bump up in attenuation. These radicals result from the presence of water. They enter the fiber optic cable material through either a chemical reaction in the manufacturing process or as humidity in the environment. The illustration Figure 1-8 shows the variation of attenuation with wavelength for, standard, single-mode fiber optic cable.

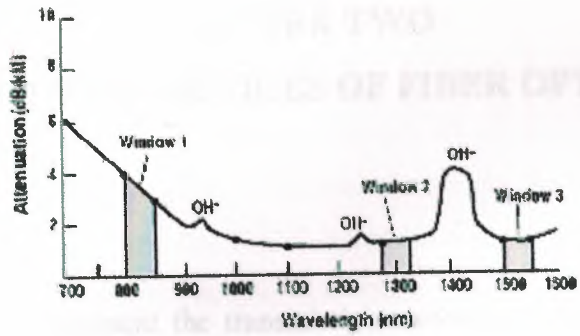


**Figure 1-7:** Attenuation vs. Wavelength

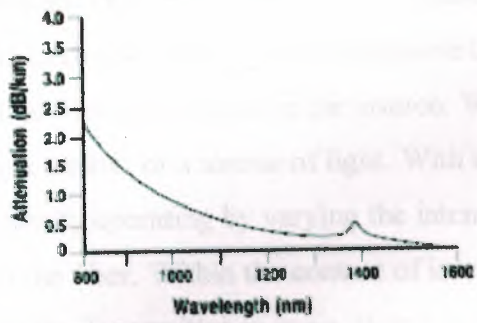


**Figure 1-8**: Attenuation spectrum of standard single-mode fiber

# CHAPTER TWO

# THE TRANSMITION DEVICES OF FIBER OPTIC CABLES

## 2.1 Overview

In this chapter we will represent the transmission medium of fiber optic witch contain the transmitter, receiver and connectors with the process of placing information onto an information carrier.

## 2.2 Transmitter

The Transmitter component serves two functions. First, it must be a source of the light coupled into the fiber optic cable. Secondly, it must modulate this light so as to represent the binary data that it is receiving from the Source. With the first of these functions it is merely a light emitter or a source of light. With the second of these functions it is a valve, generally operating by varying the intensity of the light that it is emitting and coupling into the fiber. Within the context of interest in this book the Source provides the data to the Transmitter as some digital electrical signal. The Transmitter can then be thought of as Electro-Optical (EO) transducer. First some history. At the dawn of fiber optic data communications twenty-five years ago, there was no such thing as a commercially available Transmitter. The network architect putting together a fiber optic data link had to design the Transmitter himself. Everything was customized.

The Transmitter was typically designed using discrete electrical and Electro-optical devices. This very quickly gave way to designs based upon hybrid modules containing integrated circuits, discrete components (resistors and capacitors) and optical source diodes (light emitting diodes-LED's or laser diodes). The modulation function was generally performed using separate integrated circuits and everything was placed on the same printed circuit board. By the 1980's higher and higher data transmission speeds were becoming of interest to the data link architect. The design of the Transmitter while still generally customized became more complex to accommodate these higher speeds. A greater part of the Transmitter was implemented using VLSI circuits and attention was given to minimizing the number of board interconnects. Intense research efforts were undertaken to integrate the optical source diode and the transistor level circuits needed for modulation on a common integrated circuit substrate, without compromising performance. At present, the Transmitter continues to be primarily designed as a hybrid unit, containing both discrete components and integrated circuits in a single package. By the late 1980's commercially available Transmitter's became available. As a result, the link design could be kept separate from the Transmitter design.

The link architect was relieved from the need to do high-speed circuit design or to design proper bias circuits for optical diodes.

The Transmitter could generally be looked at as a black box selected to satisfy certain requirements relative to power, wavelength, data rate, bandwidth, etc. This is where the situation remains today. To do a proper selection of a commercially available Transmitter you have to be able to know what you need in order to match your other link requirements. You have to be able to understand the differences between Transmitter candidates. There are many. We cannot begin to approach this in total. However, we can look at this in a limited way. Transmitter candidates can be compared on the basis of two characteristics. Transmitter candidates can be compared on the basis of the optical source component employed and the method of modulation.Let us deal with the optical source component of the Transmitter first. This has to meet a number of requirements. These are delineated below:

First, its physical dimensions must be compatible with the size of the fiber optic cable being used. This means it must emit light in a cone with cross sectional diameter 8-100 microns, or it cannot be coupled into the fiber optic cable.

Secondly, the optical source must be able to generate enough optical power so that the desired BER can be met.

Thirdly, there should be high efficiency in coupling the light generated by the optical source into the fiber optic cable.

Fourthly, the optical source should have sufficient linearity to prevent the generation of harmonics and intermediations distortion. If such interference is generated it is extremely difficult to remove. This would cancel the interference resistance benefits of the fiber optic cable.

Fifthly, the optical source must be easily modulated with an electrical signal and must be capable of high-speed modulation-or else the bandwidth benefits of the fiber optic cable are lost.

Finally, there are the usual requirements of small size, low weight, low cost and high reliability. The light emitting junction diode stands out as matching these requirements.

It can be modulated at the needed speeds. The proper selection of semiconductor materials and processing techniques results in high optical power and efficient coupling of it to the fiber optic cable. These optical sources are easily manufactured using standard integrated circuit processing. This leads to low cost and high reliability. There are two types of light emitting junction diodes that can be used as the optical source of the Transmitter. These are the light emitting diode (LED) and the laser diode (LD). This is not the place to discuss the physics of their operation. LED's are simpler and generate incoherent, lower power, light. LD's are more complex and generate coherent, higher power light. Figure 2-1 illustrates the optical power output, P, from each of these devices as a function of the electrical current input, I, from the modulation circuitry. As the figure indicates the LED has a relatively linear P-I characteristic while the LD has a strong non-linearity or threshold effect. The LD may also be prone to kinks where the power actually decreases with increasing bandwidth. With minor exceptions, LDs have advantages over LED's in the following ways:

- They can be modulated at very high speeds.
- They produce greater optical power.
- They have higher coupling efficiency to the fiber optic cable.

LED's have advantages over LD's because they have

- Higher reliability
- Better linearity
- Lower cost

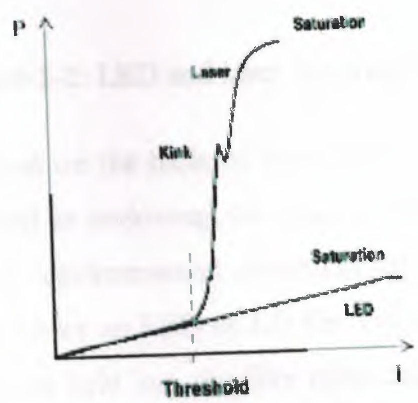



**Figure 2-1**: LED and laser diodes: P-I characteristics

Both the LED and LD generate an optical beam with such dimensions that it can be coupled into a fiber optic cable. However, the LD produces an output beam with much less spatial width than an LED. This gives it greater coupling efficiency. Each can be modulated with a digital electrical signal. For very high-speed data rates the link architect is generally driven to a Transmitter having a LD. When cost is a major issue the link architect is generally driven to a Transmitter having an LED. A key difference in the optical output of an LED and a LD is the wavelength spread over which the optical power is distributed. The spectral width is 3 dB optical power width (measured in nm or microns). The spectral width impacts the effective transmitted signal bandwidth. A larger spectral width takes up a larger portion of the fiber optic cable link bandwidth. Figure 2-2 illustrates the spectral width of the two devices. The optical power generated by each device is the area under the curve. The spectral width is the half-power spread. A LD will always have a smaller spectral width than a LED. The specific value of the spectral width depends on the details of the diode structure and the semiconductor material. However, typical values for a LED are around 40 nm for operation at 850 nm and 80 nm at 1310 nm. Typical values for a LD are 1 nm for operation at 850 nm and 3 nm at 1310 nm.

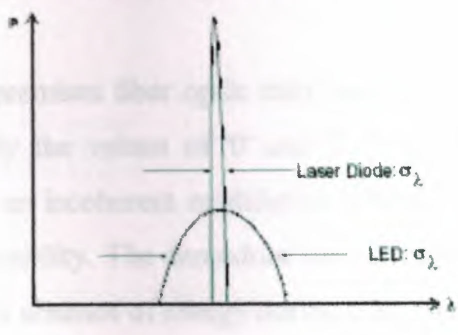



**Figure 2-2**: LED and laser spectral widths

Once a Transmitter is selected on the basis of being either an LED or a LD additional concern should be considered in reviewing the specifications of the candidates. These concerns include packaging, environmental sensitivity of device characteristics, heat sinking and reliability. With either an LED or LD the Transmitter package must have a transparent window to transmit light into the fiber optic cable. It may be packaged with either a fiber optic cable pigtail or with a transparent plastic or glass window. Some vendors supply the Transmitter with a package having a small hemispherical lens to help focus the light into the fiber optic cable. Packaging must also address the thermal coupling for the LED or LD. A complete Transmitter module may consume over 1 W-significant power consumption in a small package. Attention has to be paid to the heat sinking capabilities. Plastic packages can be used for lower speed and lower reliability applications. However, for high speed and high reliability look for the Transmitter to be in a metal package with built-in fins for heat sinking.

### 2.2.1 The Modulator Component of the Transmitter

Let us now deal with the modulator component of the Transmitter. There are several different schemes for carrying out the modulation function. These are respectively: Intensity Modulation, Frequency Shift Keying, Phase Shift Keying and Polarization Modulation. Within the context of a premise fiber optic data link the only one really employed is Intensity Modulation. This is the only one that will be described.

Intensity Modulation also is referred to as Amplitude Shift Keying (ASK) and On-Off Keying (OOK). This is the simplest method for modulating the carrier generated by the optical source. The resulting modulated optical carrier is given by:

$$E_s(t) = E_o\ m(t) \cos ( 2\Phi f_s t )$$

Within the context of a premises fiber optic data link the modulating signal m (t), the Information, assumes only the values of '0' and '1.' The parameter '$f_s$' is the optical carrier frequency. This is an incoherent modulation scheme. This means that the carrier does not have to exhibit stability. The demodulation function in the Receiver will just be looking for the presence or absence of energy during a bit time interval.

### 2.2.2 Intensity Modulation

Intensity Modulation is employed universally for premises fiber optic data links because it is well matched to the operation of both LED's and LD's. The carrier that each of these sources produce is easy to modulate with this technique. Passing current through them operates both of these devices. The amount of power that they radiate (sometimes referred to as the radiance) is proportional to this current. In this way the optical power takes the shape of the input current. If the input current is the waveform m (t) representing the binary information stream then the resulting optical signal will look like bursts of optical signal when m (t) represents a '1' and the absence of optical signal when m(t) represents a '0.' The situation is illustrated in Figure 2-11 and Figure 2-12. The first of these figures shows the essential Transmitter circuitry for modulating either an LED or LD with Intensity Modulation. The second of these figures illustrates the input current representing the Information and the resulting optical signal generated and provided to the fiber optic cable.

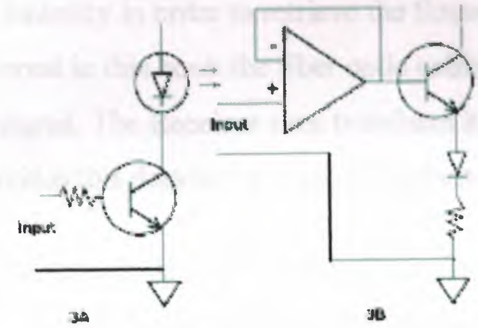


**Figure 2-3**: Two methods for modulating LEDs or LDs

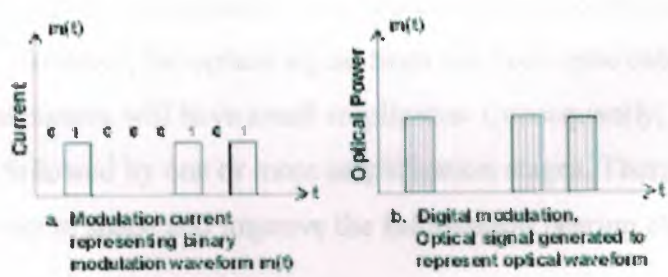



**Figure 2-4**: a. Input current representing modulation waveform, m(t); b. Output optical signal representing m(t). Vertical cross hatches indicate optical carrier

It must be noted that one reason for the popularity of Intensity Modulation is its suitability for operation with LED's. An LED can only produce incoherent optical power. Since Intensity Modulation does not require coherence it can be used with an LED.

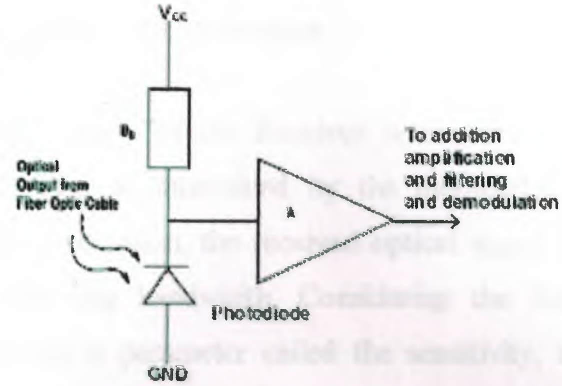



**Figure 2-5:** Example of Receiver block diagram - first stage

The complete Receiver may incorporate a number of other functions. If the data link is supporting synchronous communications this will include clock recovery. Other functions may include decoding (e.g. 4B/5B encoded information), error detection and recovery.

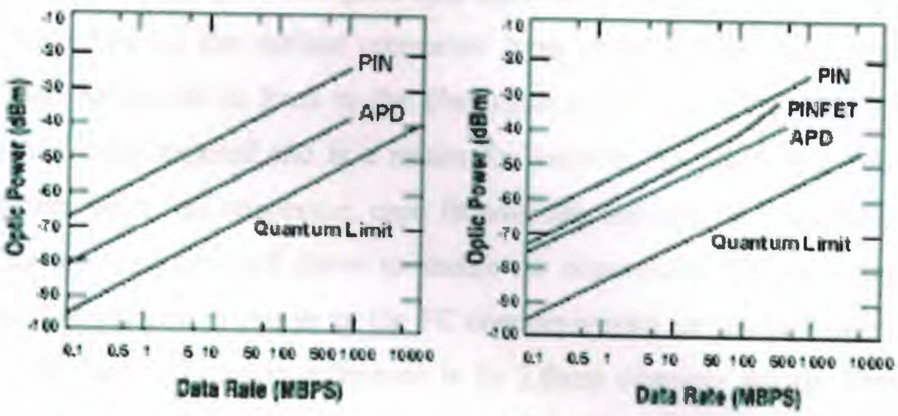
The complete Receiver must have high detectability, high bandwidth and low noise. It must have high detectability so that it can detect low-level optical signals coming out of the fiber optic cable. The higher the sensitivity, the more attenuated signals it can detect. It must have high bandwidth or fast rise time so that it can respond fast enough and demodulate, high speed, digital data. It must have low noise so that it does not significantly impact the BER of the link and counter the interference resistance of the fiber optic cable Transmission Medium.

## 2.3.1 The Photodiode Structures

There are two types of photodiode structures; Positive Intrinsic Negative (PIN) and the Avalanche Photo Diode (APD). In most premises applications the PIN is the preferred element in the Receiver. This is mainly due to fact that it can be operated from a standard power supply; typically between 5 and 15 V. APD devices have much better sensitivity. In fact it has 5 to 10 dB more sensitivity. They also have twice the bandwidth. However, they cannot be used on a 5V printed circuit board. They also require a stable power supply. This makes cost higher. APD devices are usually found in long haul communications links.

## 2.3.2 The Demodulation Performance

The demodulation performance of the Receiver is characterized by the BER that it delivers to the User. This is determined by the modulation scheme - in premise applications - Intensity modulation, the received optical signal power, the noise in the Receiver and the processing bandwidth. Considering the Receiver performance is generally characterized by a parameter called the sensitivity, this is usually a curve indicating the minimum optical power that the Receiver can detect versus the data rate, in order to achieve a particular BER. The sensitivity curve varies from Receiver to Receiver. It subsumes within it the signal-to-noise ratio parameter that generally drives all communications link performance. The sensitivity depends upon the type of photodiode employed and the wavelength of operation. Typical examples of sensitivity curves are illustrated in Figure 2-6. In examining the specification of any Receiver you need to look at the sensitivity parameter. The curve designated Quantum Limit in Figure 2-6 is a reference. In a sense it represents optimum performance on the part of the photodiode in the Receiver. That is, performance where there is 100% efficiency in converting light from the fiber optic cable into an electric current for demodulation.




**Receiver sensitivites.**
**BER = $10^{-9}$, $\lambda$ = 0.82μm.**
**The photodiodes are silicon devices**

**Receiver sensitivites.**
**BER = $10^{-9}$, $\lambda$ = 1.55μm.**
**The photodiodes are InFaAs devices.**
**The PINFET receiver includes a high-impedance (or Transimpedance) preamplifier.**

**Figure 2-6**: Receiver sensitivities for BER = $10^{-9}$, with different devices.

## 2.4 Connectors

The Connector is a mechanical device mounted on the end of a fiber optic cable, light source, Receiver or housing. It allows it to be mated to a similar device. The Transmitter provides the Information bearing light to the fiber optic cable through a connector. The Receiver gets the Information bearing light from the fiber optic cable through a connector. The connector must direct light and collect light. It must also be easily attached and detached from equipment. This is a key point. The connector is disconnect able. With this feature it is different than a splice which will be discussed in the next sub-chapter.

A connector marks a place in the premises fiber optic data link where signal power can be lost and the BER can be affected. It marks a place in the premises fiber optic data link where reliability can be affected by a mechanical connection. There are many different connector types. The ones for glass fiber optic cable are briefly described below and put in perspective. This is followed by discussion of connectors for plastic fiber optic cable. However, it must be noted that the ST connector is the most widely used connector for premise data communications.

Connectors to be used with glass fiber optic cable are listed below in alphabetical order. Bionic - One of the earliest connector types used in fiber optic data links. It has a tapered sleeve that is fixed to the fiber optic cable. When this plug is inserted into its receptacle the tapered end is a means for locating the fiber optic cable in the proper position. With this connector, caps fit over the ferrules, rest against guided rings and screw onto the threaded sleeve to secure the connection. This connector is in little use today.D4 - It is very similar to the FC connector with its threaded coupling, keying and PC end finish. The main difference is its 2.0mm diameter ferrule. Designed originally by the Nippon Electric Corp. FC/PC - Used for single-mode fiber optic cable. It offers extremely precise positioning of the single-mode fiber optic cable with respect to the Transmitter's optical source emitter and the Receiver's optical detector. It features a position locatable notch and a threaded receptacle. Once installed the position is maintained with absolute accuracy.SC - Used primarily with single-mode fiber optic cables. It offers low cost, simplicity and durability. It provides for accurate alignment via its ceramic ferrule. It is a push on-pull off connector with a locking tab. SMA - The predecessor of the ST connector. It features a threaded cap and housing. The use of this connector has decreased markedly in recent years being replaced by ST and SC connectors. ST - A keyed bayonet type similar to a BNC connector. It is used for both multi-mode and single-mode fiber optic cables. Its use is wide spread. It has the ability both to be inserted into and removed from a fiber optic cable both quickly and easily. Method of location is also easy. There are two versions ST and ST-II. These are keyed and spring loaded. They are push-in and twist types. Photographs of several of these connectors are provided in Figure 2-7.


**Figure 2-7**: Common connectors for glass fiber optic cable (Courtesy of AMP Incorporated)

Plastic Fiber Optic Cable Connectors - Connectors that are exclusively used for plastic fiber optic cable stress very low cost and easy application. Often used in applications with no polishing or epoxy. Figure 2-8 illustrates such a connector. Connectors for plastic fiber optic cable include both proprietary designs and standard designs. Connectors used for glass fiber optic cable, such as ST or SMA are also available for use with plastic fiber optic cable. As plastic fiber optic cable gains in popularity in the data communications world there will be undoubtedly greater standardization.

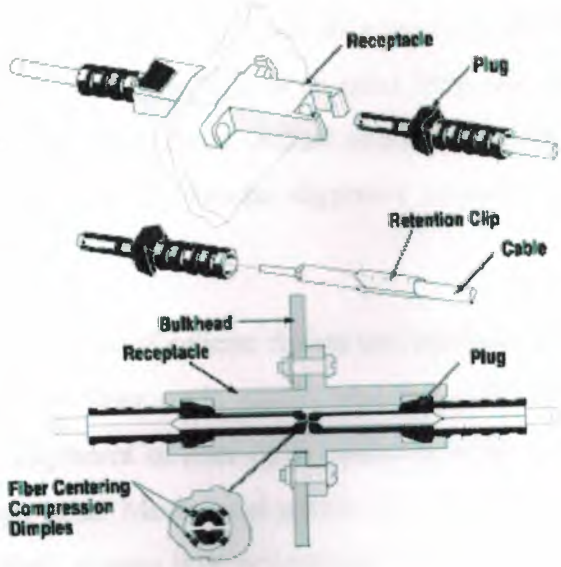



**Figure 2-8**: Plastic fiber optic cable connector (Illustration courtesy of AMP Incorporated)

## 2.5 Splicing

A splice is a device to connect one fiber optic cable to another permanently. It is the attribute of permanence that distinguishes a splice from connectors. Nonetheless, some vendors offer splices that can be disconnected that are not permanent so that they can be disconnected for repairs or rearrangements. The terminology can get confusing. Fiber optic cables may have to be spliced together for any of a number of reasons. One reason is to realize a link of a particular length. The network installer may have in his inventory several fiber optic cables but none long enough to satisfy the required link length. This may easily arise since cable manufacturers offer cables in limited lengths - usually 1 to 6 km. If a link of 10 km has to be installed this can be done by splicing several together. The installer may then satisfy the distance requirement and not have to buy a new fiber optic cable. Splices may be required at building entrances, wiring closets, couplers and literally any intermediary point between Transmitter and Receiver. At first glance you may think that splicing two fiber optic cables together is like connecting two wires. To the contrary, the requirements for a fiber-optic connection and a wire connection are very different. Two copper connectors can be joined by solder or by connectors that have been crimped or soldered to the wires. The purpose is to create an intimate contact between the mated halves in order to have a low resistance path across a junction. On the other hand, connecting two fiber optic cables requires precise alignment of the mated fiber cores or spots in a single-mode fiber optic cable. This is demanded so that nearly all of the light is coupled from one fiber optic cable across a junction to the other fiber optic cable. Actual contact between the fiber optic cables is not even mandatory. The need for precise alignment creates a challenge to a designer of a splice.

There are two principal types of splices: fusion and mechanical. Fusion splices - uses an electric arc to weld two fiber optic cables together. The splices offer sophisticated, computer controlled alignment of fiber optic cables to achieve losses as low as 0.05 dB. This comes at a high cost. Mechanical-splices all share common elements. They are easily applied in the field, require little or no tooling and offer losses of about 0.2 dB.

## 2.6 Analyzing Performance of a Link

You have a tentative design for a fiber optic data link of the type that is being dealt with in this chapter. You want to know whether this tentative design will satisfy your performance requirements. You characterize your performance requirements by BER. This generally depends upon the specific Source-User application. This could be as high as $10^{-3}$ for applications like digitized voice or as low as $10^{-10}$ for scientific data. The tendency though has been to require lower and lower BERs. The question then is will the tentative fiber optic link design provide the required BER? The answer to this question hinges on the sensitivity of the Receiver that you have chosen for your fiber optic data link design. This indicates how much received optical power must appear at the Receiver in order to deliver the required BER.

To determine whether your tentative fiber optic link design can meet the sensitivity you must analyze it. You must determine how much power does reach the Receiver. This is done with a fiber optic data link power budget. A power budget for a particular example is presented in Table 2-1 below and is then discussed. This example corresponds to the design of a fiber optic data link with the following attributes:

1. Data Rate of 50 MBPS.
2. BER of 10-9.
3. Link length of 5 km (premises distances).

4. Multi-mode, step index, glass fiber optic cable having dimensions 62.5/125. Transmitter uses LED at 850 nm.
5. Receiver uses PIN and has sensitivity of -40 dBm at 50 MBPS.
6. Fiber optic cable has 1 splice.

**Table 2-1**: Example Power Budget for a fiber optic data link

| LINK ELEMENT | VALUE | COMMENTS |
|---|---|---|
| Transmitter LED output power | 3 dBm | Specified value by vendor |
| Source coupling loss | -5 dB | Accounts for reflections, area mismatch etc. |
| Transmitter to fiber optic cable connector loss | -1 dB | Transmitter to fiber optic cable with ST connector. Loss accounts for misalignment |
| Splice loss | -0.25 dB | Mechanical splice |
| Fiber Optic Cable Attenuation | -20 dB | Line 2 of Table 2-1 applied to 5 km |
| Fiber optic cable to receiver connector loss | -1 dB | Fiber optic cable to Receiver with ST connector. Loss Accounts for misalignment |
| Optical Power Delivered at Receiver | -24.25 dB | |
| Receiver Sensitivity | -40 dBm | Specified in link design. Consistent with Figure 2-14 |
| LOSS MARGIN | 15.75 dB | |

The entries in Table 2-1 are more or less self-explanatory. Clearly, the optical power at the Receiver is greater than that required by the sensitivity of the PIN to give the required BER. What is important to note is the entry termed Loss Margin? This specifies the amount by which the received optical power exceeds the required sensitivity.

In this example it is 15.75 dB. Good design practice requires it to be at least 10 dB. Why? Because no matter how careful the power budget is put together, entries are always forgotten, are too optimistic or vendor specifications are not accurate.

# CHAPTER THREE

# EXPLOITING THE BANDWIDTH OF FIBER OPTIC CABLE-EMPLOYMENT BY MULTIPLE USERS

## 3.1 Overview

In this chapter, I will represent the Sharing the Transmission Medium, Time Division Multiplexing (TDM). Wavelength Division Multiplexing (WDM) With Fiber Optic Cable and Comparing Multiplexing Techniques for the Premises environment on the basis of link design flexibility.

## 3.2 Sharing the Transmission Medium

You are the network manager of a company. You have a Source-User link requirement given to you. In response you install a premises fiber optic data link. The situation is just like that illustrated in Figure 2-1. However, the bandwidth required by the particular Source-User pair, the bandwidth to accommodate the Source-User speed requirement, is much, much, less than is available from the fiber optic data linking. The tremendous bandwidth of the installed fiber optic cable is being wasted. On the face of it, this is not an economically efficient installation.

You would like to justify the installation of the link to the Controller of your company, the person who reviews your budget. The Controller doesn't understand the attenuation benefits of fiber optic cable. The Controller doesn't understand the interference benefits of fiber optic cable. The Controller hates waste. He just wants to see most of the bandwidth of the fiber optic cable used not wasted. There is a solution to this problem. Don't just dedicate the tremendous bandwidth of the fiber optic cable to a single, particular, Source-User communication requirement. Instead, allow it to be shared by a multiplicity of Source-User requirements. It allows it to carve a multiplicity of fiber optic data links out of the same fiber optic cable. The technique used to bring about this sharing of the fiber optic cable among a multiplicity of Source-User transmission requirements is called multiplexing. It is not particular to fiber optic cable. It occurs with any transmission medium e.g. wire, microwave, etc., where the available bandwidth far surpasses any individual Source-User requirement. However, multiplexing is particularly attractive when the transmission medium is fiber optic cable. Why? Because the tremendous bandwidth presented by fiber optic cable presents the greatest opportunity for sharing between different Source-User pairs. Conceptually, multiplexing is illustrated in Figure 3-1. The figure shows 'N' Source-User pairs indexed as 1, 2. There is a multiplexer provided at each end of the fiber optic cable. The multiplexer on the left takes the data provided by each of the Sources. It combines these data streams together and sends the resultant stream out on the fiber optic cable. In this way the individual Source generated data streams share the fiber optic cable. The multiplexer on the left performs what is called a multiplexing or combining function. The multiplexer on the right takes the combined stream put out by the fiber optic cable. It separates the combined stream into the individual Source streams composing it. It directs each of these component streams to the corresponding User. The multiplexer on the right performs what is called a demultiplexing function. A few things should be noted about this illustration shown in Figure 3-1.

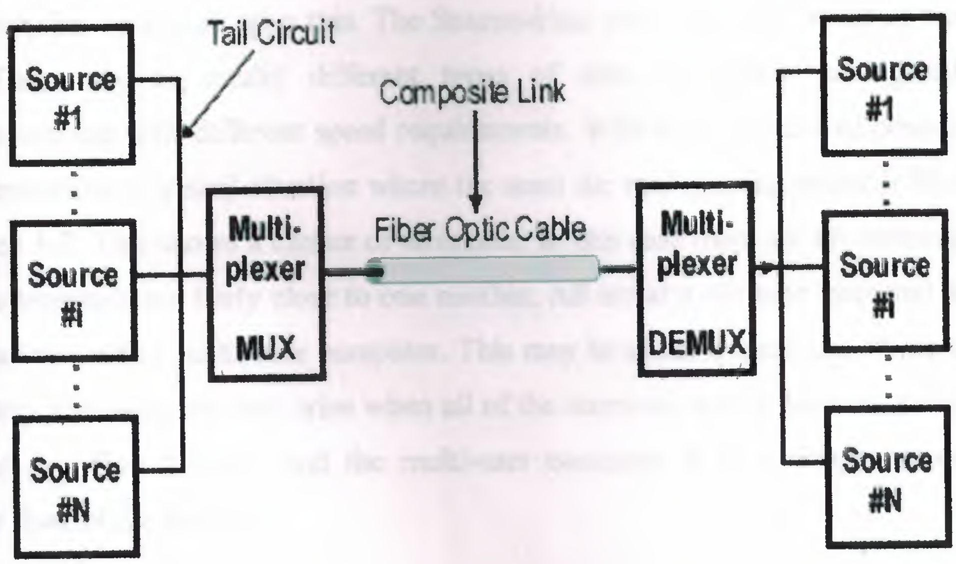



**Figure 3-1**: Conceptual view of Multiplexing. A single fiber optic cable is "carved" into a multiplicity of fiber optic data links.

First, the Transmitter and Receiver are still present even though they are not shown. The Transmitter is considered part of the multiplexer on the left and the Receiver is considered part of the multiplexer on the right.

Secondly, the Sources and Users are shown close to the multiplexer. For multiplexing to make sense this is usually the case. The connection from Source-to-multiplexer and multiplexer-to-User is called a tail circuit. If the tail circuit is too long a separate data link may be needed just to bring data from the Source to the multiplexer or from the multiplexer to the User. The cost of this separate data link may counter any savings effected by multiplexing.

Thirdly, the link between the multiplexer, the link in this case realized by the fiber optic cable, is termed the composite link. This is the link where traffic is composed of all the separate Source streams.

Finally, separate Users are shown in Figure 3-1. However, it may be that there is just one User with separate ports and all Sources are communicating with this common user. There may be variations upon this. The Source-User pairs need not be all of the same type. They may be totally different types of data equipment serving different applications and with different speed requirements. Within the context of premise data communications a typical situation where the need for multiplexing arises is illustrated in Figure 3-2. This shows a cluster of terminals. In this case there are six terminals. All of these terminals are fairly close to one another. All are at a distance from and want to communicate with a multi-user computer. This may be either a multi-use PC or a mini-computer. This situation may arise when all of the terminals are co-located on the same floor of an office building and the multi-user computer is in a computer room on another floor of the building.

The communication connection of each of these terminals could be effected by the approach illustrated in Figure 3-3. Here each of the terminals is connected to a dedicated port at the computer by a separate cable. The cable could be a twisted pair cable.

**Figure 3-2:** Terminal cluster isolated from multi-user computer

**Figure 3-3**: Terminals in cluster. Each connected by dedicated cables to multi-user computer

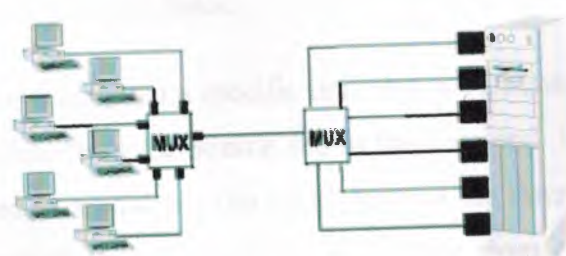



**Figure 3-4**: Terminals sharing a single cable to multi-user computer by multiplexing

A more economically efficient way of realizing the communication connection is shown in Figure 3-4. Here each of the six terminals is connected to a multiplexer. The data streams from these terminals are collected by the multiplexer. The streams are combined and then sent on a single cable to another multiplexer located near the multi-user computer. This second multiplexer separates out the individual terminal data streams and provides each to its dedicated port.The connection going from the computer to the terminals is similarly handled. The six cables shown in Figure 3-3 has been replaced by the single composite link cable shown in Figure 3-4. Cable cost has been significantly reduced. Of course, this comes at the cost of two multiplexers. Yet, if the terminals are in a cluster the tradeoff is in the direction of a net decrease in cost. There are two techniques for carrying out multiplexing on fiber optic cable in the premise environment. These two techniques are Time Division Multiplexing (TDM) and Wavelength Division Multiplexing (WDM). These techniques are described in the sequel. Examples are introduced of specific products for realizing these techniques. These products are readily available from Telebyte. TDM and WDM are then compared.

## 3.3 Time Division Multiplexing (TDM) with Fiber Optic Cable

With TDM a multiplicity of communication links, each for a given Source-User pair, share the same fiber optic cable on the basis of time. The multiplexer(s) set up a continuous sequence of time slots using clocks. The duration of the time slots depends upon a number of different engineering design factors; most notably the needed transmission speeds for the different links.

Each communication link is assigned a specific time slot, a TDM channel, during which it is allowed to send its data from the Source end to the User end. During this time slot no other link is permitted to send data. The multiplexer at the Source end takes in data from the Sources connected to it. It then loads the data from each Source into its corresponding TDM channel. The multiplexer at the User end unloads the data from each channel and sends it to the corresponding User.

The Telebyte Model 570 Quick Mux is an excellent example of a TDM based multiplexer that can exploit the bandwidth of fiber optic cables for premises data communications. The Telebyte Model 570 Quick Mux can actually carry out multiplexing in the premise environment when Unshielded Twisted Pair (UTP) cable is being employed. However, this unit can be adapted for transmission over a fiber optic cable. This is accomplished simply by using the Telebyte Model 270 High Speed Fiber Optic Line Driver. This attaches to the output port for the composite link of the Telebyte Model 570 Quick Mux and is then used for transmitting and receiving over a fiber optic cable. Both the Telebyte Model 570 Quick Mux and the Model 270 are pictured in Figure 3-5

**Figure 3-5**: Model 570 TDM Multiplexer with Model 270 Fiber Optic Line Driver

The Telebyte Model 570 Quick Mux has eight (8) input ports. This unit can accommodate Source-to-User communications that is asynchronous and full duplex at any data speed up to 19.2 KBPS. Each input port can also take in the bi-directional control signals DTR and DCD. The fiber optic data link between the Source and User multiplexers can be as long as 2 km. The unit has a status display. The unit can easily accommodate different port speeds, Source-User transmission speeds. The true advantage of the Telebyte Model 570 Quick Mux is its versatility that is its ability to be used with both fiber optic cable and UTP transmission media. The illustration Figure 3-6 shows an application of the Telebyte Model 570 Quick Mux with the Telebyte Model 270. On the right side of the figure are eight (8) different data devices. There are all different types, i.e., PCs, a plotter and 2 printers. All of these data devices need to communicate with the UNIX Server shown on the left side. Each data device is assigned a dedicated port at the UNIX Server. The two (2) Model 570's and two (2) Model 270's effect the communication from/to all these devices by using just one (1) fiber optic cable. When the transmission medium is fiber optic cable the data devices can be as far as 2 km from the UNIX Server. The Telebyte Model 273 Four Channel Fiber Optic Multiplexer is another excellent example of a TDM based multiplexer that can exploit the bandwidth of a fiber optic cable for premises data communications. A photograph of this unit is shown in Figure 3-7. Unlike the Model 570 Quick Mux, the Telebyte Model 273 Four Channel Fiber Optic Multiplexer only operates with a fiber optic cable.

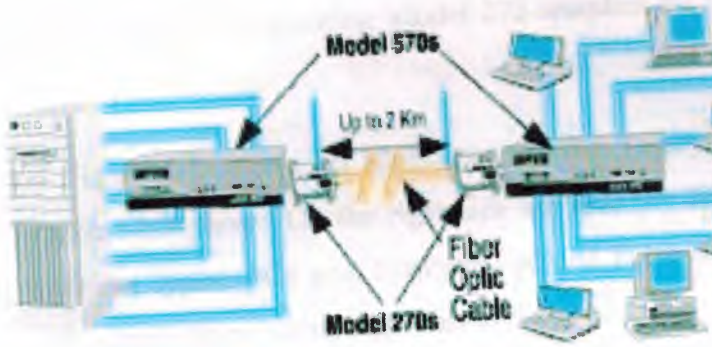



**Figure 3-6**: Model 570 TDM Multiplexer with Model 270 realizing time division multiplexed data communications all to a UNIX server.

**Figure 3-7**: Model 273 Four channel fiber optic TDM Multiplexer

The Telebyte Model 273 Four Channel Fiber Optic Multiplexer has four (4) input ports and can accommodate Source-to-User communication that is asynchronous and full duplex at any data speed up to 64 KBPS. This is much higher than the Model 570 Quick Mux. On each input port it can also take in a bi-directional control signal e.g. DTR/DCD. Control signals can be transmitted at a speed up to 16 KBPS. A jumper option allows upgrading TDM channel 1 of the Telebyte Model 273 Four Channel Fiber Optic Multiplexer to 128 KBPS while reducing the number of total channels from 4 to 3. The fiber optic data link between the Source and User multiplexers can be as long as 2 km. The Telebyte Model 273 Four Channel Fiber Optic Multiplexer has a status display. Transmit and Receive data are indicated for each TDM channel. As a further aid to installation and verification of fiber optic data link performance the Telebyte Model 273 Four Channel Fiber Optic Multiplexer is equipped with a front panel TEST switch. The switch on one Multiplexer, say the one near the Sources sends a test pattern to the remote Model 273. This causes the remote Model 273 to go into loop-back while the originating Model 273 searches for the reception of the test pattern.

The illustration Figure 3-8 shows an application of the Telebyte Model 273 Four Channel Fiber Optic Multiplexer. On the right side are four (4) different data devices. These are of different types, PCs and terminals. All of these data devices need to communicate with a main frame computer. This is not shown but what is shown on the left is the Front End Processor (FEP) of this main frame computer. All communication to/from the main frame computer is through ports of the FEP. Each data device is assigned a *dedicated port at the FEP. The two* Model 273's effect the communication from/to all these devices by using just one fiber optic cable that can be as long as 2 km.

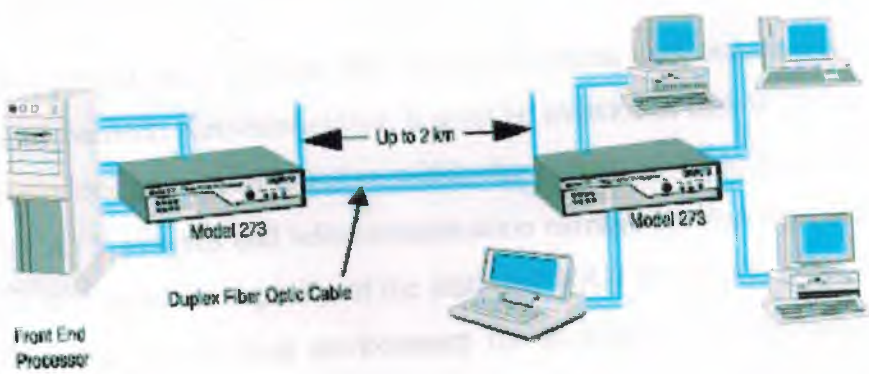



**Figure 3-8**: Model 273 realizing time division multiplexed data communications to a mainframe computer through its FEP.

## 3.4 Wavelength Division Multiplexing (WDM) With Fiber Optic Cable

With WDM a multiplicity of communication links, each for a given Source-User pair, share the same fiber optic cable on the basis of wavelength. The data stream from each Source is assigned an optical wavelength. The multiplexer has within it the modulation and transmission processing circuitry. The multiplexer modulates each data stream from each Source. After the modulation process the resulting optical signal generated for each Source data stream is placed on its assigned wavelength. The multiplexer then couples the totality of optical signals generated for all Source data streams into the fiber optic cable. These different wavelength optical signals propagate simultaneously. This is in contrast to TDM.The fiber optic cable is thereby carved into a multiplicity of data links - each data link corresponding to a different one of these optical wavelengths assigned to the Sources. At the User end the multiplexer receives these simultaneous optical signals. It separates these signals out according to their different wavelengths by using prisms. This constitutes the demultiplexing operation. The separated signals correspond to the different Source-User data streams. These are further demodulated. The resulting separated data streams are then provided to the respective Users. At this point a slight digression is necessary.

The focus of this project is on premise data communications, data communications in the local area environment. Notwithstanding, it must be mentioned that WDM has been receiving a tremendous amount of attention within the context of Wide Area Networks (WANs). Both CATV systems and telecommunication carriers are making greater and greater use of it to expand the capacity of the installed WAN fiber optic cabling plant. Within the Wide Area Networking environment the multiplicity of channels carved from a single fiber has increased tremendously using WDM. The increase has led to the term Dense Wavelength Division Multiplexing (DWDM) to describe the newer WDMs employed. Now, back to our main topic. The Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer is an excellent example of a WDM based multiplexer that can exploit the bandwidth of a fiber optic cable for premises data communications. A photograph of this unit is shown in Figure 3-9.

**Figure 3-9**: Model 381 2 Channel WDM

The Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer is totally passive. It employs wavelength division multiplexing with a single-mode output. This essentially doubles the data carrying capacity of a fiber optic cable. It carves out two channels out of the fiber optic cable. The Telebyte Model 381 2 Channel WDM-Wavelength Division Multiplexer allows the combining and separating of individual wavelengths allowing the two individual channels to be transmitted simultaneously over the same fiber optic cable. The Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer requires the attached data devices, the Sources, to provide the necessary wavelengths for operation. The wavelengths being multiplexed are 1310 nm and 1550 nm. Consequently, each Source must have a Transmitter that provides the necessary optical signal to this unit. Similarly, each User must have a Receiver to take the corresponding optical signal from this unit. The Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer is completely protocol and speed independent. Both analog and digital applications can be transmitted simultaneously on the same fiber. Within the premise environment the unit can multiplex and thereby merge the optical transmissions of data, voice, video and other types of information on a single fiber optic cable.

Furthermore, the unit can be employed for inter-office service channel monitoring and perform out of band network management.Because the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer is passive it has high reliability. Also, with respect to the type of data traffic it can multiplex, it has much greater flexibility than the TDM based products described above. The TDM based products essentially handle only digital traffic. The Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer is a stand-alone unit. However, there is a rack-mounted version of it, the Model 2381. This is hosted in Telebyte's Model 2200 Card cage. Both units utilize a fused biconic taper concept to effect the multiplexing of the individual channels. This allows for high isolation, low insertion loss and back reflectance over a wide range of temperature and mechanical stresses. High isolation means that there will be little interference between the two channels being multiplexed, effectively low cross talk. Low insertion loss and back reflectance mean greater optical signal levels delivered to the User end of the cable.

This all works to a lower BER. The illustration showed in Figure 3-10 shows an application of the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer. This is an application in the office building facility of a company. On the left side of the figure are two different data devices, the Ethernet Server and a digital leased T1 line. The Ethernet Server is at the hub of the company's LAN. The leased T1 line brings in voice traffic from some of the company's remote locations. For purposes of this example these are the Sources. Within the office building facility the Ethernet Server needs to communicate to the Ethernet Switch shown on the right side of the figure. The leased T1 line needs to be connected to the company's digital PBX so that these voice conversations can be routed in the building to the appropriate personnel. The Ethernet Switch and the PBX are the Users in this example.

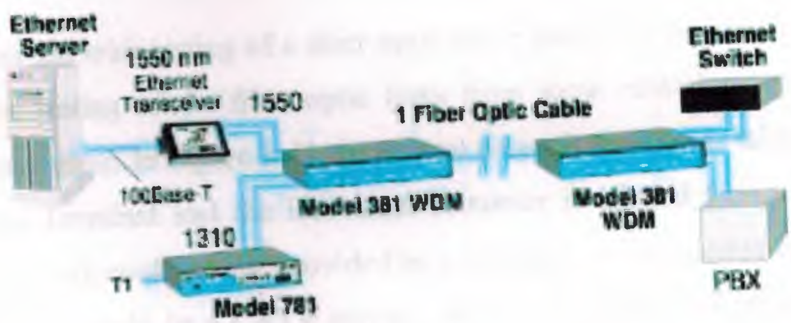



**Figure 3-10**: Model 381 realizing wavelength division multiplexed data communications. Application also employs Model 376 and Model 781.

This application requires two Sources to be connected to two Users by a single fiber optic cable. The fiber optic cable has to be shared-multiplexed. As shown in Figure 3-10 the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer aided by two other Telebyte products realizes the needed connection on the single fiber optic cable. The Ethernet Server on the left is generating 10Base-T LAN data traffic. It supplies this traffic to the Telebyte Model 376 10Base-T to single mode transceiver. This essentially acts as the Transmitter for the Ethernet Server Source. It puts the 10Base-T data traffic on a single-mode optical signal at a 1550 nm wavelength. The leased T1 line on the left supplies its digital voice traffic to the Telebyte Model 781 Fiber Optic Modem. This acts as a Transmitter for the T1 traffic. It puts the T1 traffic on a single-mode optical signal at a 1310 nm wavelength. Both of these wavelengths are compatible with Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer. Both of these optical signals are taken by the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer and coupled into the single fiber optic cable and transmitted simultaneously.

On the right side you will see that the Telebyte Model 381 2 Channel WDM - Wavelength Division takes the combined signal out of the single fiber optic cable. It separates it according to wavelengths. The unit then provides the respective Source traffic to the respective Users. The illustration Figure 3-11 shows another application of the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer and its companion products the Model 2381 and Model 2200.

This application is concerned with testing of a fiber optic cable based communications network. It concerns the testing of the fiber optic links from some central network location to individual customers. In Figure 3-11 the central network location is labeled Service Provider Optical Terminal and the individual customer is labeled Customer Optical Terminal. The network could be one provided by a common carrier dealing with digital communications or it could be a CATV service. Within the context of premise data communications the network could be almost anything ranging from a building security network to a LAN. In this application the data traffic is carried by the fiber optic cable based network at a wavelength of 1310 nm. This is clearly shown at the Service Provider Optical Terminal and at the Customer Optical terminal. The network manager would like to test the continuity of the fiber optic cable connections out to individual customers by doing loop back tests. The network manager would like to do this by sending a test signal out from the Service Provider Optical Terminal to each Customer Optical Terminal and then detecting the signal's return to the Service Provider Optical Terminal. The network manager would like to do this without disturbing the traffic being carried at 1310 nm. In other words the network manager wants to perform out of band loop back testing.

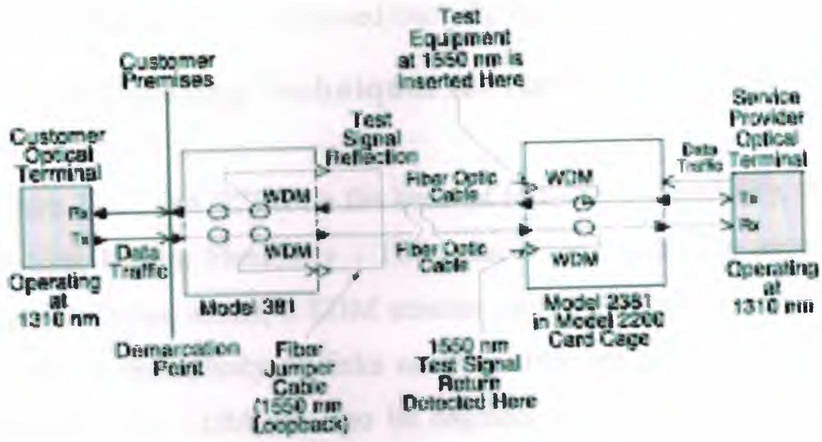



**Figure 3-11**: Typical application of out-of-band loop access and testing using WDM's

Figure 3-11 shows how this can be done with WDM. First of all, as the illustration shows at the Service Provider Optical Terminal there is a Model 2200 Card Cage populated with Model 2381 rack mounted cards. This is a convenient way to package the needed WDMs so that loop back testing can be performed simultaneously on a multiplicity of Service Provider Optical Terminal-to-Customer Optical Terminal fiber optic links. Only one such link is shown but imagine that the testing is going on with multiple links. Each rack-mounted card will correspond to each one of these links. Consider a specific one of these links.

At the Service Provider Optical Terminal end the traffic (data or other) at 1310 nm intended for this link is provided to a Model 2381 WDM. It is multiplexed with an optical test signal generated at a wavelength of 1550 nm. The combined optical signal is then sent over a fiber optic cable to the Customer Optical Terminal end. The stand alone Model 381 at the Customer Optical Terminal end separates the traffic (data or other) from the injected test signal on the basis of wavelength. It forwards the traffic at the 1310 nm wavelength to the Customer Optical Terminal. However, it takes the 1550 nm wavelength test signal and combines it with traffic coming from the Customer Optical Terminal and intended for the Service Provider Optical Terminal. The test signal and this traffic are multiplexed and sent back along another fiber optic cable to the Service

Provider Optical Cable. When this combined traffic stream reaches the Model 2200 Card Cage it is separated by a Model 2381 again on the basis of wavelength. The traffic (data or other) on the 1310 nm wavelength is forwarded to the Service Provider Optical Terminal. The test signal on the 1550 nm wavelength is detected for completion of the loop back test. If the test signal is not received back the loop back test fails.

## 3.5 Comparing Multiplexing Techniques for the Premises environment

It is best to compare TDM and WDM on the basis of link design flexibility, speed and impact on BER. Link Design Flexibility - TDM can be engineered to accommodate different link types. In other words, a TDM scheme can be designed to carve a given fiber optic cable into a multiplicity of links carrying different types of traffic and at different transmission rates. TDM can also be engineered to have different time slot assignment strategies. Slots may be permanently assigned. Slots may be assigned upon demand (Demand Assignment Multiple Access - DAMA). Slots may vary depending upon the type of link being configured. Slots may even be dispensed with altogether with data instead being encapsulated in a packet with Source and User addresses (statistical multiplexing). However, within the context of premises environment there is strong anecdotal evidence that TDM works best when it is used to configure a multiplicity of links all of the same traffic type, with time slots all of the same duration and permanently assigned. This simplest version of TDM is easiest to design and manage in premise data communications.

The more complex versions are really meant for the WAN environment. On the other hand, in the premises environment WDM, generally, has much greater flexibility. WDM is essentially an analog technique. As a result, with WDM it is much easier to carve a fiber optic cable into a multiplicity of links of quite different types. The character of the traffic and the data rates can be quite different and not pose any real difficulties for WDM. You can mix 10Base-T Ethernet LAN traffic with 100Base-T Ethernet LAN traffic with digital video and with out of band testing signals and so on. With WDM it is much easier to accommodate analog traffic. It is much easier to add new links on to an existing architecture. With TDM the addition of new links with different traffic requirements may require revisiting the design of all the time slots, a major effort. With respect to flexibility the one drawback that WDM has relative to TDM in the premises environment is in the number of simultaneous links it can handle. This is usually much smaller with WDM than with TDM. Nonetheless, advances in DWDM for the WAN environment may filter down to the premise environment and reverse this drawback.

Speed - Design of TDM implicitly depends upon digital components. Digital circuitry is required to take data in from the various Sources. Digital components are needed to store the data. Digital components are needed to load the data into corresponding time slots, unload it and deliver it to the respective Users. How fast must these digital components operate? Roughly, they must operate at the speed of the composite link of the multiplexer. With a fiber optic cable transmission medium, depending upon cable length, a composite link of multiple GBPS could be accommodated. However, commercially available, electrically based, digital logic speeds today are of the order of 1 billion operations per second.

This can and probably will change in the future as device technology continues to progress. But, let us talk in terms of today. TDM is really speed limited when it comes to fiber optic cable. It can not provide a composite link speed to take full advantage of the tremendous bandwidth presented by fiber optic cable. This is not just particular to the premises environment it also applies to the WAN environment. On the other hand, WDM does not have this speed constraint. It is an analog technique. Its operation does not depend upon the speed of digital circuitry. It can provide composite link speeds that are in line with the enormous bandwidth presented by fiber optic cable. Impact on BER - Both TDM and WDM, carve a multiplicity of links from a given fiber optic cable. However, there may be cross talk between the links created. This cross talk is interference that can impact the BER and affect the performance of the application underlying the need for communication. With TDM cross-talk arises when some of the data assigned to one time slot slides into an adjacent time slot. How does this happen? TDM depends upon accurate clocking. The multiplexer at the Source end depends upon time slot boundaries being where they are supposed to be so that the correct Source data is loaded into the correct time slot. The multiplexer at the User end depends upon time slot boundaries being where they are supposed to be so that the correct User gets data from the correct time slot. Accurate clocks are supposed to indicate to the multiplexer where the time slot boundaries are. However, clocks drift, chiefly in response to variations in environmental conditions like temperature. What is more, the entire transmitted data streams, the composite link, may shift small amounts back and forth in time, an effect called jitter. This may make it difficult for the multiplexer at the User end to place time slot boundaries accurately.

Protection against TDM cross-talk is achieved by putting guard times in the slots. Data is not packed end-to-end in a time slot. Rather, there is either a dead space, or dummy bits or some other mechanism built into the TDM protocol so that if data slides from one slot to another its impact on BER is minimal. With WDM cross talk arises because the optical signal spectrum for a given link placed upon one particular (center) wavelength is not bounded in wavelength (equivalently frequency). This is a consequence of it being a physical signal that can actually be generated. The optical signal spectrum will spill over onto the optical signal spectrum for another link placed at another (center) wavelength.

The amount of spillage depends upon how close the wavelengths are and how much optical filtering is built into the WDM to buffer it. The protection against cross-talk here is measured by a parameter called isolation. This is the attenuation (dB) of the optical signal placed at one (center) wavelength as measured at another (center) wavelength. The greater the attenuation the less effective spillage and the less impact on BER. At the present time, clock stability for digital circuitry is such that TDM cross-talk presents no real impact on BER in the context of premises data communications and at the composite link speeds that can be accommodated.

The TDM cross-talk situation may be different when considering WANs. However, this is the case in the premise environment. The situation is not as good for WDM. Here, depending upon the specific WDM design, the amount of isolation may vary from a low value of 16 dB all the way to 50 dB. A low value of isolation means that the impact upon BER could be significant. In such situations WDM is limited to communications applications that can tolerate a high BER. Digital voice and video would be in this group. However, LAN traffic would not be in this group. From the perspective of BER generated by cross-talk TDM is more favorable than WDM.

# CHAPTER FOUR

# EXPLOITING THE DELAY PROPERTIES OF FIBER OPTIC CABLE FOR LOCAL AREA NETWORK (LAN) EXTENSION

## 4.1 Overview

Our chapter it will speak about Brief History of Local Area Networks and Transmission Media Used to Implement an Ethernet LAN, Examining the Distance Constraint, also I will give some examples of LAN Extenders Shown In Typical Applications, Model 375 100Base-T to Fiber Transceiver for Fast Ethernet, Model 377 Series Single-Mode 100Base-T/F Media Converter. Fiber optic cable provides a way for extending reach of Local Area Networks (LANs). If you are well versed on the subject of LANs you are welcome to jump right into this subject and skip the next two subchapters. However, if you have not been initiated into LAN technology then you will find the subjects covered in these next two subchapters worthwhile reading.

## 4.2 Brief History of Local Area Networks

Two full generations ago, in the early days of the data revolution, each computer served only a single user. In the computer room (or at that time 'the building') of an installation there was 1 CPU, 1 keyboard, 1 card reader, (maybe) 1 magnetic tape reader, 1 printer, 1 keypunch machine etc. From a usage point of view this was highly inefficient. Most data processing managers were concerned that this highly expensive equipment spent most of the time waiting for users to employ it. Most data processing managers knew this looked bad to the Controllers of their organizations. This led to the pioneering development of time-sharing operating systems by MIT with Project MAC.

Time-sharing opened up computational equipment to more than one user. Whole departments, companies, schools etc. began making use of the expensive computational equipment. A key element in time-sharing systems concerned the keyboard. A computer terminal replaced it. The multiple terminals were connected to the CPU by data communications links. There was a marriage of computation and data communications.

In particular, the data communications was mostly (though not exclusively) premises data communications.

Throughout the years time-sharing led to distribute computation. The idea of distributed computation being that applications programs would reside on one central computer called the Server. Applications users would reside at PCs. When an applications user wanted to run a program a copy of it would be downloaded to him/her. In this way multiple users could work with the same program simultaneously. This was much more efficient than the original time sharing. Distributed computation required a data communications network to tie the Server to the PCs and peripherals. This network was called a Local Area Network (LAN). This network had to have high bandwidth. In fact, it had to accommodate speeds that were orders of magnitude greater than the original time-sharing networks. Entire applications programs had to be downloaded to multiple users. Files, the results of running applications programs, had to be uploaded to be stored in central memory.

LANs first came on the scene in a noticeable sense in the late 1970's. From that time until the present many flavors of LANs have been offered in the marketplace. There are still a number of different flavors each with its group of advocates and cult following. However, some time around the late 1980's the market place began to recognize Ethernet as the flavor of choice. All of the discussion in the sequel will concern only Ethernet.

The Ethernet LAN architecture had its origins in work done at Xerox Palo Alto Research Center (PARC) by Robert Metcalf in the early 1970's. Metcalf later went on to become the founder of 3COM. Xerox was later joined by DEC and Intel in promoting Ethernet as the coming LAN standard. In the development of the Ethernet LAN architecture Metcalf built upon previous research funded by the Advanced Research Projects Agency (ARPA) at the University of Hawaii. This ARPA program was concerned with an asynchronous multiple access data communications technique called ALOHA.

The basic operation of an Ethernet LAN can be briefly explained with the aid of Figure 4-1. This illustration indicates various data equipment that all need to communicate with each other. The data equipment constitute the users of the LAN. Each is a Source and User within the context of the discussion of Chapter 1. The location on the LAN of each data equipment unit is termed the station.


**Figure 4-1**: Ethernet Bus architecture

The communication between the data equipment is accomplished by having all the data equipment tap onto a Transmission Medium. Each station taps onto the Transmission Medium. The Transmission Medium is typically some type of cable. As shown in Figure 4-1 it is labeled Broadcast Channel - The Ethernet Bus. The Bus Interface Units (BIUs) provide the essential interfacing at a station between the data equipment and the Broadcast Channel. That is, they provide the transmit/receive capability and all needed intelligence.

It is an essential feature of the Ethernet LAN architecture that any data equipment can transmit to any other data equipment and any data equipment can listen to all transmissions on the Broadcast Channel, whether intended for it or for some other data equipment user. Implicitly, the Ethernet architecture assumes that there is no coordination in the transmissions of the different data equipment. This is quite a bit different from the sharing of a Transmission Medium by TDM where coordination is essential. Transmitted data only goes in its assigned slot.Now how does an Ethernet LAN operate? It operates by making use of three essential items. First, it employs a Carrier Sense Multiple Access/Collision Detection (CSMA/CD) protocol. Secondly, data to be communicated is enveloped in packets that have the addresses of the data equipment units communicating. The packet has the address of the equipment sending data (the origin) and the data equipment that is the intended recipient (the destination). Thirdly, the Ethernet Bus - the Transmission Medium - is taken as passive and supports broadcast type transmissions. The way in which the Ethernet LAN architecture uses these items is explained briefly. Consider a specific data equipment unit at its station. This will be our data equipment unit, station and BIU of interest. For the sake of an example, suppose it is a PC wanting to communicate with the Computer with File Server at its station. Before attempting to transmit a data packet onto the Ethernet Bus our terminal's BIU first listens to determine if the Bus is idle. That is, it listens to determine if there are any other packets from other data equipment already on the Bus. It attempts to sense the presence of a communication signal representing a packet, a carrier, on the Bus. Our BIU and any BIU have circuitry to perform this Carrier Sensing. An active BIU transmits its packet on the Bus only if the Bus has been sensed as idle. In other words, it only transmits its packet if it has determined that no other packet is already on the Bus - carrier is absent. If the Bus is sensed, as busy- carrier is present- then the BIU defers its transmission until the Bus is sensed as idle again. This procedure allows the various data equipment to operate asynchronously yet avoid interfering with one another's communications. However, it may be that a carrier has not sensed an existing packet is already on the Bus. Transmission of a packet by the BIU of interest begins but there are still problems. There are propagation delays and carrier detection processing delays. Because of these, it may be that the packet from our PC's BIU still interferes with, or collides with, a packet transmitted by another equipment's BIU. This interfering packet is one that has not yet reached our BIU by the end of the interval in which it had performed the carrier sensing. A BIU monitors the transmission of the packet it is sending out to determine if it does collide with another packet. To do this it makes use of the broadcast nature of the transmission medium. A BIU can monitor what it has put on the Ethernet Bus and also any other traffic on the Ethernet Bus. Our BIU and any BIU has circuitry to perform Collision Detection. The BIU that transmitted the interfering packet also has circuitry to perform Collision Detection.

When both BIUs sense a collision they cease transmitting. Each BIU then waits a random amount of time before re-transmitting - that is sensing for carrier and transmitting the packet onto the bus. If another collision occurs then this random time wait is repeated but increased. In fact, it is increased at an exponential rate until the collision event disappears. This approach to getting out of collisions is called exponential back off.

## 4.3 Transmission Media Used To Implement An Ethernet LAN

Early implementations of Ethernet LANs employed thick coaxial cable. Actually, it was thick yellow coaxial cable - the original recipe Ethernet cable. The cable was defined by the 10Base-5 standard. This implementation was called Thick net. It could deliver a BER of $10^{-8}$. It supported a data rate of 10 MBPS. The maximum LAN cable segment length was 500 meters. Unfortunately, the thick coaxial cable was difficult to work with. As a result, second wave implementations of Ethernet LANs employed thin coaxial cable.

The cable was RG58 A/U coaxial cable - sometimes called cheaper net. This cable was defined by the 10Base-2 standard. The implementation was called Thinned. It supported a data rate of 10 MBPS. But, it had a BER somewhat degraded relative to Thicket .Thinnet ultimately gave way to the replacement of coaxial cable with Unshielded Twisted Pair cable (UTP). This came about through an interesting merging of the Ethernet LAN architecture with another LAN flavor StarLAN was based upon what a Telco, a phone company, normally does for businesses that is, provide voice communications.

The Transmission Medium a Telco uses within a facility for voice communications is Unshielded Twisted Pair cable (UTP). It provides voice communications within a facility and to the outside world by connecting all of the phones, the handsets, through a telephone closet or wiring closet. The distance from handset to telephone closet is relatively limited, maybe 250 meters. The StarLAN idea was to take this basic approach for voice and use it for a LAN. The LAN stations would be connected through a closet. The existing UTP cable present in a facility for voice would be used for the LAN data traffic. However, in 1990 aspects of StarLAN were taken and merged with the Ethernet LAN architecture. This resulted in a new Ethernet LAN based upon UTP and defined by the 10Base-T standard. It was with this UTP approach that Ethernet really took off in the market place. Ethernet under the 10Base-T standard has a hub and spoke architecture. This is illustrated in Figure 4-2.

The various data equipment units, the stations, are all connected to a central point called a Multipoint Repeater or Hub. The connections are by UTP cable. This architecture does support the Broadcast Channel-Ethernet Bus. This occurs because all data equipment units can broadcast to all other data equipment units through the Hub. Likewise, all data equipment units can listen to the transmissions from all other data equipment units as they are received via the UTP cable connection to the Hub. The Hub takes the place of the telephone closet. The Hub may be strictly passive or it may perform signal restoration functions.

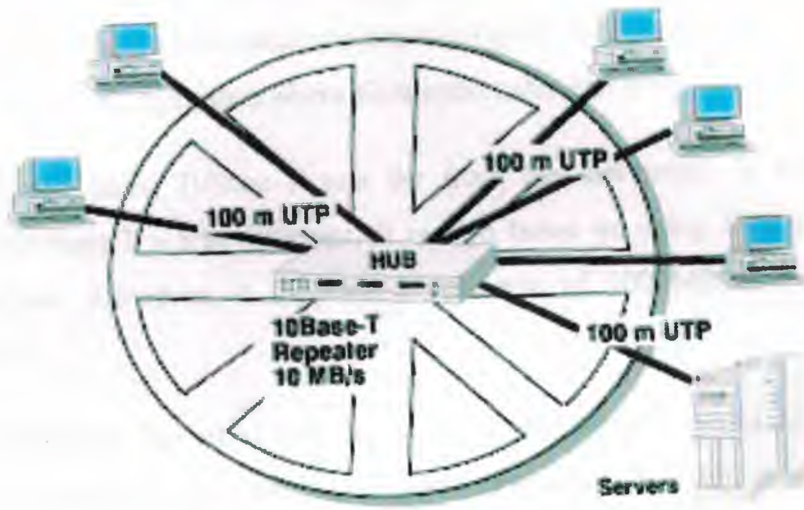



**Figure 4-2**: 10Base-T hub-and-spoke architecture

The illustration Figure 4-3 indicates how the 10Base-T topology may actually look in an office set-up at some facility. Here the data equipment units are all PCs. One serves as the file server. The illustration shows what is usually referred to as a 10Base-T Work Group. It may serve one specific department in a company. By connecting together these work groups Ethernet LANs may be extended. This is accomplished by connecting hubs using LAN network elements called bridges, routers and switches. A description of their operation is beyond the focus of the present discussion.

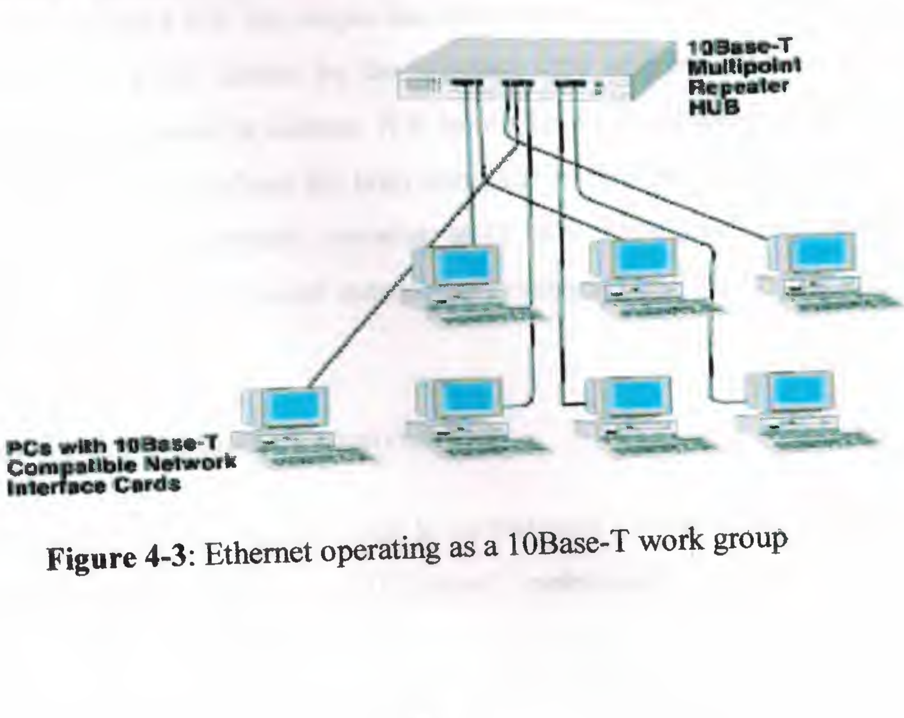



**Figure 4-3**: Ethernet operating as a 10Base-T work group

But, let us get back to 10Base-T. It supports a data rate of 10 MBPS. It has a BER comparable to Thinned. However, the LAN segment length is reduced even further. With 10Base-T the LAN segment length is only 100 m - a short distance but a distance that is tolerable for many data equipment stations in a typical business. However, it may be too short for others. This is a place where fiber optic cable can come to the rescue.

For the LAN market place 10Base-T was far from the last word. It led to the development of 100Base-T - Fast Ethernet. It is also based on using UTP cable for transmission medium. However, it supports a data rate of 100 MBPS over cable segments of 100 m.

Fast Ethernet, itself, is not the end of the road. Vendors are starting to promote Giga Bit Ethernet which is capable of supporting 1 GBPS. However, we will stop at Fast Ethernet and the problem that both it and 10Base-T have - the short cable segment of 100 m.

Before continuing it will be worthwhile to define two terms that come up in discussing Ethernet characteristics. These are 1) Network Diameter and 2) Slot Time.

The Network Diameter is simply the maximum end-to-end distance between data equipment users, stations, in an Ethernet network. It is really what has been referred to

above as the cable segment. The Network Diameter is the same for both 10Base-T and 100Base-T, 100 m.After a BIU has begun the transmission of a packet the Slot Time is the time interval that a BIU listens for the presence of a collision with an interfering packet. The Slot Time cannot be infinite. It is set for both the 10Base-T and 100Base-T Ethernet architectures. It is defined for both standards as the time duration of 512 bits. With a 10Base-T Ethernet network operating at 10 MBPS the Slot Time translates to 51.2sec. With a 100Base-T Ethernet network operating at 100 MBPS the Slot Time translates to 5.12sec.

## 4.4 Examining the Distance Constraint

The distance constraint of an Ethernet LAN is the Network Diameter. As noted above this is 100 m for both the 10Base-T and 100Base-T implementations. This may not be enough for all potential users of an Ethernet LAN. Now how do you support LAN users that are separated by more than this 100-m constraint? To deal with this question it is important to understand where this constraint comes from and what is driving it.

Many people believe that the Network Diameter is set strictly by the attenuation properties of the UTP copper cable connecting data equipment to the Hub. This is erroneous. Attenuation does affect the Network Diameter, but it is not the dominant influence. However, if it were, you would be able to see the immediate possibilities of improving it by using fiber optic cable rather than UTP copper cable. The significantly less attenuation of fiber optic cable would boost the Network Diameter. No, it is not attenuation but instead the Slot Time that really sets the Network Diameter. The Slot Time is related to the amount of time delay between a transmitting BIU and the furthermost receiving BIU. The diagram showed in Figure 4-3 illustrates the Slot Time issues to be discussed now. Here we show two data equipment users of an Ethernet LAN - either 10Base-T or 100Base-T - it doesn't matter. These are labeled as Data Terminal Equipment Unit A and Data Terminal Equipment Unit B. For brevity they will be referred to as Unit A and Unit B. The BIU's are taken as subsumed in the ovals.

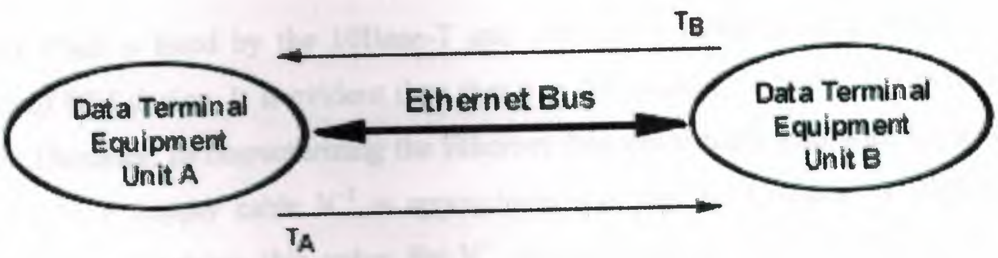



**Figure 4-4:** 2 Stations communicating on an Ethernet Bus. Delays shown.

Suppose Unit A transmits a data packet over the Ethernet Bus to Unit B. The transmitted data packet travels along the Ethernet Bus. It takes a time interval of $T_A$ seconds to reach Unit B. In the meantime, Unit B has performed carrier sensing and has determined, from its perspective, that the Ethernet Bus is not busy and so it also begins to transmit a data packet. From a collision detection point of view the worst case occurs when Unit B begins to transmit its data packet just before the data packet from Unit A arrives in front of it. Why is this worst case? When the Unit A data packet arrives at

Unit B, Unit B immediately knows that a collision has occurred and can begin recovery operations. However, Unit A will not know that there has been any collision problem until the data packet from Unit B arrives in front of it. This packet from Unit B takes a time interval of $T_B$ seconds to arrive at Unit A. Putting this together Unit A has to wait at least $T_A + T_B$ seconds before it can detect the presence/absence of a collision. There is some additional time needed to sense the presence/absence of a collision at both Unit A and Unit B. The collision detection processing time is denoted as $T_C$. For 100Base-T networks a typical value for this is 1.12 □sec. The Slot Time is the sum $T_A + T_B + T_C$.$T_A$ and $T_B$ usually can be taken as equal and denoted as t. Putting these together brings:

$$\Phi = (\text{Slot Time} - T_C) / 2$$

The one-way delay Φ is equal to the distance between Unit A and Unit B divided by the velocity of transmission between Units A and B. The maximum distance is of course the Network Diameter. The velocity of transmission will be denoted by 'V.' this is the speed of an electromagnetic wave on the Ethernet Bus. Applying these brings:

$$\text{Network Diameter} = (V/2)(\text{Slot Time} - T_C)$$

The Slot Time is fixed by the 10Base-T and 100Base-T Ethernet standards. $T_C$ is a function of BIU design. It is evident then that it is the value of V that really drives the Network Diameter. In characterizing the Ethernet Bus you usually deal with the inverse of V. For UTP copper cable $V^{-1}$ is approximately 8 nsec/m. Consider a 100Base-T Ethernet LAN. Applying this value for $V^{-1}$ above brings a value of 250 m for the Network Diameter.

On the face of it this is quite a bit better than the 100-m allotted for the Network Diameter by the standard. The difference is accounted for by a number of delay items that were excluded from the example. These were excluded in order to bring out the principle point - the dependence of Network Diameter on $V^{-1}$. This difference is taken up by margin allotted for other processing functions. These functions include the delay through the Hub. They include processing delays in software at the interface between the data equipment and its BIU. The margin is also allotted for deleterious properties of cable, However, the essential point remains. The achievable Network Diameter is determined by the delay through the transmission medium. The speed of $V^{-1}$ through UTP copper cable results in a Network Diameter of 100 m.Consider a fiber optic cable. Typically, the value of $V^{-1}$ is 5 nsec/m for multi-mode fiber optic cable. This is almost 50% lower than for UTP copper cable. Applying this value in the above example would bring a Network Diameter of 400 m, quite a bit more than 250 m.By using a fiber optic cable you can connect data equipment stations to the LAN that are much further apart than the 100 m distance allowed for by the assumed UTP copper cable in 10Base-T or 100Base-T LANs. You can do this because the velocity of light through a fiber optic cable is much faster than the group velocity of electromagnetic waves in copper cable- the speed of current in copper cable. You can do this because the transmission delay, $V^{-1}$, of a packet traversing a fiber optic cable is about 50% lower than it is for UTP copper cable.

How would you do it? How would you exploit a fiber optic cable to bring distant users into a UTP copper cable based Ethernet LAN? How would you accommodate really distant stations to a 10Base-T or 100Base-T Ethernet LAN, stations much further than the Network Diameter?In order to do this you need to connect them to the Hub using a fiber optic cable. This may be either a multi-mode or single-mode fiber optic cable. However, neither the Ethernet Hub nor the BIU at the distant data equipment user knows anything about signaling on a fiber optic cable Transmission Medium. So, at the Hub you need some type of equipment that will take the 10Base-T or 100Base-T packets, in their electrical format, and convert it to light to propagate down a fiber optic cable. You need the same equipment at the distant data equipment's BIU for transmission toward the Hub. Similarly, you need this device to be able to take the light wave representations of a packet coming out of the fiber optic cable and convert it to an electrical format recognizable by the Hub or the BIU. This is called a LAN Extender. By using a LAN Extender you get a distance benefit. In addition, on the particular LAN link you get the other benefits available with fiber optic cable. These include protection from ground loops, power surges and lightning.

## 4.5 Examples of LAN Extenders Shown In Typical Applications

Telebyte offers a variety of LAN Extenders. These are now described. Model 10Base-T to Multi-Mode Fiber Optic Converter This unit is pictured in Figure 4-5. It extends the distance of a 10Base-T Ethernet LAN to over 2 km. The Model 373 10Base-T to Multi-

Mode Fiber Optic Converter takes 10Base-T Ethernet signals and converts them to/from optical signals that are transmitted/received from multi-mode fiber optic cable.


**Figure 4-5:** Model 373 10Base-T to Multi-Mode Fiber Optic Converter

The Model 373 has a group of 5 LED's. These indicate the presence of the fiber optic link, traffic going back and forth in both directions, the presence of a collision and power. The unit even includes a Link Test switch. This assures compatibility between older and newer Ethernet adapters. It allows the enabling/disabling of the Link Test heart beat option. The Model 373 uses ST connectors for the fiber optic cable. It is designed for transmission/reception over 62.5/125 multi-mode fiber optic cables. On the 10Base-T port side the Model 373 is in full compliance with the IEEE 802.3 specification. The Model 373 is also in full compliance with the Ethernet 10Base-FL standard. This is the standard for using multi-mode fiber optic cable to extend the Network Diameter of a 10Base-T Ethernet LAN. The Model 373 is illustrated in a typical application in Figure 4-6. This shows the stations of a 10Base-T Ethernet LAN in a typical business environment. Most of the stations of the LAN are located near one another in the same building. This is Building A. All of the stations in Building A are within 100 m of one another. For purposes of this example, these people at these stations may all be in the company's Accounting Department. They can all be connected to the LAN through the Hub located in Building using the UTP copper cable - the ordinary building block of a 10Base-T LAN. They are all within the 100-m Network Diameter for a UTP copper cable based 10Base-T network. However, there is one remote station of this LAN that is not in Building A. This may be the station of the manufacturing manager. His office is in Building B- the production facility. Building B is located some distance away from the front office of Building A. In fact, Building B is about 1 km away from Building A. The manufacturing manager needs to be tied into the

Accounting Department LAN so that he can update the Controller with inventory and purchasing information. As Figure 4-6 indicates the manufacturing manager in Building B can easily be tied into the LAN. This is accomplished by placing a Model 373 at the Hub in Building A. A multi-mode fiber optic cable to another Model 373 in Building B then connects the Model 373. The second Model 373 is connected to the manufacturing manager's work station. The pair of Model 373's and the fiber optic cable will be completely transparent to all stations of the LAN, both the Accounting Department stations in Building A and the remote station of the manufacturing manager in Building B.

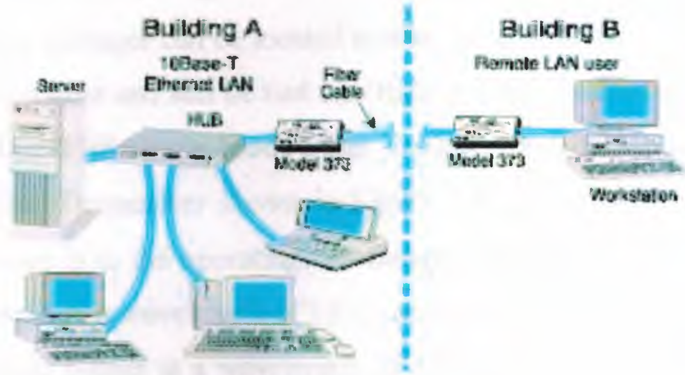



**Figure 4-6**: Model 373 shown in a typical application

Model 374 10Base-T to Single-Mode Fiber Optic Converter. This unit is pictured in Figure 4-7. It is the almost the same as the Model 373 except that its fiber optic components are adapted for single-mode transmission. Because single mode fiber optic cable has much lower attenuation this allows a significant extension of distance. In fact, the Model 374 10Base-T to Single-Mode Fiber Optic Converter extends the distance of a 10Base-T Ethernet LAN to over 14 km. The ability to achieve the extended distance is due to full duplex transmission. Full-Duplex has one important advantage. Since there are separate transmit and receive paths, DTE's can transmit and receive at the same time. Collisions are therefore eliminated. Full Duplex Ethernet is a collision free environment. For single-mode fiber optic cable transmission there is no standard comparable to 10Base-FL.

**Figure 4-7**: Model 374 LAN Spreader - 10Base-T to Single-Mode Fiber Optic Converter

The application illustrated in Figure 4-6 also applies to the Model 374. However, now our manufacturing manager can be located in a building as far as 14 km away from the Accounting Department and still be tied into their 10Base-T Ethernet LAN.

Model 376 10Base-T to Single-Mode Fiber Transceiver. The Model 376 10Base-T to Single Mode Fiber Transceiver shown in Figure 4-8 is almost the same as the Model 374. The difference is in the operating wavelength. The Model 374 generates a single-mode optical output at a wavelength of 1310 nm. In contrast, the Model 376 generates a single-mode optical output at a wavelength of 1550 nm. Single-mode fiber optic cable has significantly less attenuation at the higher wavelength. This allows the Model 376 to extend a 10Base-T Ethernet LAN to a distance of 38 km, quite a bit more than the 14 km of the Model 374. It achieves this distance by using a laser diode in its transmitter.The application illustrated in Figure 4-6 also applies to the Model 376. However, now our manufacturing manager can be located in a building as far as 38 km away from the Accounting Department and still be tied into their 10Base-T Ethernet LAN. The Model 374 puts out 10Base-T data packets on an optical signal at a wavelength of 1310 nm. The Model 376 puts out 10Base-T data packets on an optical signal at a wavelength of 1550 nm. This allows the optical outputs of both units to be multiplexed on the same single-mode fiber optic cable. This can be accomplished by employing the Telebyte Model 381 2 Channel WDM - Wavelength Division Multiplexer. The Model 381 was discussed in Chapter 3.

**Figure 4-8**: Model 376 10Base-T to Single-Mode Fibber Transceiver

The application illustrated in Figure 4-9 shows this. This is an extension of the application provided in Figure 4-6. Two 10Base-T Ethernet LANs located in Building A are shown on the left of this illustration. The top one, LAN #1 is the one that belongs to the Accounting Department. It needs to tie in User #1, the manufacturing manager, who is located remotely in Building B. The bottom one, LAN #2 is the one that belongs to the Engineering Department. It needs to tie in User #2, the manufacturing test technician, who is located with his boss in Building B. The traffic from each LAN can be placed on an appropriate optical wavelength for the Model 381 WDM. This is accomplished by using the Model 374 as a LAN Extender for LAN #1 and using the Model 376 as a LAN Extender for LAN #2. At the remote, Building B side, the traffic can be demultiplexed and provided to the appropriate Users.

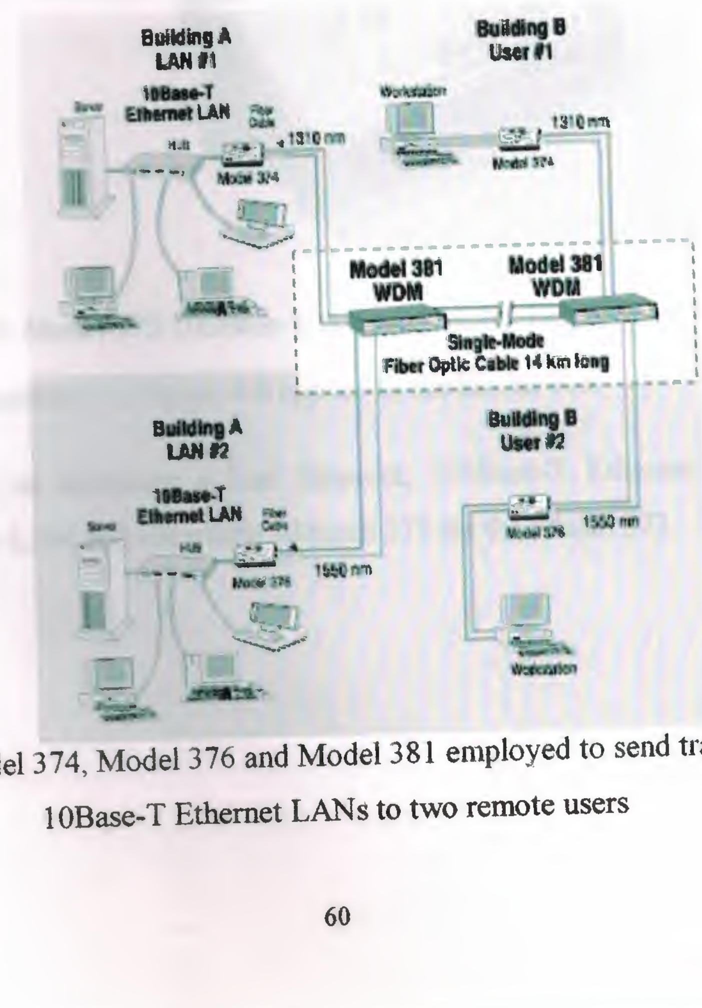



**Figure 4-9**: Model 374, Model 376 and Model 381 employed to send traffic from two 10Base-T Ethernet LANs to two remote users

## 4.6 Model 375 100Base-T to Fiber Transceiver for Fast Ethernet

This unit is pictured in Figure 4-10. It extends the distance of a 100Base-T Ethernet LAN to over 2 km. In other words, it is a Fast Ethernet LAN Extender. The Model 375 takes 100Base-T Ethernet signals and converts them to/from optical signals that are transmitted/received from multi-mode fiber optic cable.

The Model 375 100Base-T to Fiber Transceiver for Fast Ethernet has a group of 3 LED's. These report if the 100Base-T port and fiber optic port are active and powered. This unit allows any two 100Base-T compliant ports to be connected by multi-mode, 62.5.125 fiber optic cable. A modified version can be obtained for single-mode operation.

The Model 375 assures that collision information is preserved and translated from one segment to the other. The Model 375 is compatible with the Fast Ethernet standard for fiber optic transmission, 100Base-FX. Far end fault detection is possible with the Model 375.


**Figure 4-10**: Model 375 100Base-T to Fiber Transceiver for Fast Ethernet

The application illustrated in Figure 4-6 applies to the Model 375.

You merely have to substitute a Fast Ethernet, 100Base-T Ethernet LAN, for the 10Base-T Ethernet LAN and substitute a Model 375 for the Model 373.

## 4.7 Model 377 Series Single-Mode 100Base-T/F Media Converter

This is a series of units. One version is pictured in Figure 4-11. The Model 377 series of media converters are designed to convert 100Base-T, Fast Ethernet, signals meant for UTP copper cable transmission to light pulses.

The resulting optical signal is appropriate for single-mode transmission.

The Model 377 series support full duplex operation. Detailed discussion of this is really beyond our scope. However, full duplex operation allows greater LAN throughput. Explained very simply, this is accomplished by being able to transmit while carrying out collision sensing.

The Model 377 series presents this as a major innovation. It greatly improves the response time over a LAN as compared to half duplex operation.

The Model 377SC and the Model 377ST employ a Fabry-Perot Laser Diode- LD-transmitter.

These units can achieve 100Base-T Ethernet LAN extension to 33 km. The Model 377ST-1 uses an even more powerful LD transmitter. This unit can achieve 100Base-T Ethernet LAN extension to an amazing 90 km.


**Figure 4-11**: Model 377 100Base-T/F Media Converter

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