DESIGN AND IMPLEMENTATION OF AN OPTICAL LOOP TESTER

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CERTIFICATE

It is certified that the contents and form of the project report entitled **“Design and Implementation of an Optical Loop Tester”** submitted by 1) NC Sabahat Shaheen, 2) NC Madeeha Sattar, 3) NC Saira Riaz, 4) NC Mehreen Tahir have been found satisfactory for the requirement of degree.

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بسم الله الرحمن الرحيم

DEDICATION

All our efforts are dedicated to our beloved parents and teachers who have been a constant source of encouragement for us throughout our lives. May Allah almighty bless them with long lives and always provide us their loving and thorough guidance.

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All praises to Almighty Allah, who gave us the strength and knowledge to accomplish the objectives of this project. We are profoundly thankful to our project supervisor, Maj. Dr. Adnan Rashdi for his unparalleled help and motivation, Mr. Faisal Hayat for his help during the procurement phase of the project, Mr. Umar Hakeem for providing technical guidance, the college staff for their assistance, and our friends and family members for their support and patience throughout the project.

ABSTRACT

Optical Loop Tester (OLT) is an opto-electronic device which implements a specific functionality of Optical Time Domain Reflectometer (OTDR), that is, to

detect the location of a cut in the optical fiber using single ended measurement. A single OTDR can cost millions of dollars and is not manufactured in Pakistan. Thus, OLT is low-cost and incorporates its advantage of easy-handling and single-ended measurement. It is suitable for outdoor, long haul applications and can also be used for research purposes.

Light pulses are launched into the fiber under test and the reflected/backscattered light is collected from the same end. At any point in time, the light received by the device is the light scattered from the pulse passing through a region of the fiber. The speed of light in the fiber is known, so the time difference between the outgoing pulse and the incoming light signal is measured. OLT uses this information to calculate the pulse position in the fiber and correlate what it sees in backscattered/reflected light with an actual location in the fiber. Thus it can create a display of the amount of backscattered/reflected light at any point in the fiber. Such a display is commonly called a trace.

A trace is a plot of the amplitude of received signal against its distance along the fiber. This plot carriers a lot of information and is used to analyze the fiber characteristics at any point along the fiber. Whenever the pulse of light encounters an anomaly in the fiber characteristics (referred to as an event), there is a change in the amount of backscattered/reflected light. By examining the trace, the nature and location of the event can be predicted.

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CHAPTER-1

INTRODUCTION

1.1 OVERVIEW

The development of optical fiber has enabled a revolution in modern telecommunications. Since the optical fiber was first suggested i.e. about 35 years ago, the effective speed at which information can be transmitted has increased from kilohertz rates to multi-gigabit rates. State-of-the-art long distance transmission systems transmit digital pulses of light at OC-192 (10.0 gigabits per second (Gb/s)) and greater, at a single wavelength. With dense wavelength division multiplexing (DWDM), system bandwidth can easily approach several hundred gigabits per second, while best-in-class demonstrations have delivered 1.6 Tb/s over 10,000 kilometers; several manufacturers have demonstrated 5 Tb/s for use in metropolitan-area networks (MANs). It is not inconceivable that modern high-speed transmission systems may soon reach the effective bandwidth of single-mode optical fiber itself, about 25 THz. Along with these increased transmission speeds comes the requirement to test the optical medium through which the signals are passed. This document is devoted to describing one instrument used to perform tests on optical fibers, the *optical time-domain reflectometer* generally referred to as an OTDR.

The OTDR is an instrument used to test the light-transmission ability of an optical telecommunications fiber or cable, and it can also determine the location of a problem. The OTDR has become the most widely used and versatile instrument for testing optical fibers during installation, maintenance, and restoration. The OTDR can determine the length of a fiber and its end-to-end loss as well as the amount of reflected light and loss from various discrete components within the fiber. Modern OTDRs can locate and evaluate the losses of fusion splices and connectors and can even report whether each location and loss is within certain specification tolerances. Among all electronic test instruments, the OTDR is truly unique in its combination of extremely high dynamic range, rapid acquisition capabilities, and high resolution.

1.2 PROBLEM STATEMENT

When the optical fiber is laid underground as part of the optical network, the transmission may get disrupted in case a fiber breaks. The need for effective fiber testing and characterisation is growing with the rapid trend towards optical fiber based networks. In this regard, Optical Time-domain reflectometers are the most commonly used test equipment. OTDRs provide complete fiber characterisation and fault detection using single-ended measurement only. However, a single OTDR can cost a large sum of money and where mostly only fault detection feature is required in practice, OTDRs are not cost-effective. An optical loop tester provides the fault detection functionality of an OTDR. Moreover, it is low cost. Thus, it gives an optimum solution to the problem.

1.3 OBJECTIVE

The goal of this project is to develop an Optical Fault Locator (OLT). The primary purpose of the instrument is to detect the location of a cut in the optical fiber using single ended measurement. The instrument will interface to a personal computer.

1.4 INTRODUCTION TO THE DOCUMENT

This document describes the complete project, its theoretical and practical aspects. It begins with an introduction to the undertaken project, problem statement.

Chapter 2 gives the background study of the project. . It summarizes some of the instruments that are used for fiber characterization. It gives an idea of about the birth of the OTDRs, their history and the features, functions, and performance improvements since its inception.

Chapter 3 deals with the fundamentals of the optical fiber. It explains the basic phenomenon that governs the transmission of light in the fiber. It also lists and explains the losses that occur during the transmission.

Chapter 4 explains the basic principle on which the concept of Optical loop tester is based, that is optical time-domain reflectometry. It begins with a theoretical study of the technique of time-domain reflectometry. It explains the usage of OTDR in the telecommunication world. This chapter also covers the fundamentals of OTDR Operations and its design. An introduction is given to Raleigh scattering and Fresnel reflections; the two phenomenon upon which Optical time-domain reflectometry is based.

Chapter 5 focuses on the design of an Optical loop tester proposed in this project. The design strategy is discussed along with the hardware specifications of the system. The hardware implementation of the design is described in Chapter 6. The analysis and testing of the hardware developed is given in chapter 7 and the results are shown. It is the ending chapter of the document and ends with a discussion on possible future enhancements of this project.

CHAPTER-2

PROJECT BACKGROUND

2.1 INTRODUCTION

The development of optical fiber has enabled a revolution in modern telecommunications. In the 35 years since optical fiber was first suggested, the effective speed at which information can be transmitted has increased from kilohertz rates to multi-gigabit rates. Advantages of optical fiber cables over other media include improved performance in terms of speed, immunity to noise, available bandwidth, and distance the signal is able to cover without the need for regeneration. Though, it is important to have a thorough characterization of the media which is being used for transmission. For example, the information regarding the location of fiber breaks, cuts, splices or other connectors on the fiber cable is of prime utility.

2.2 INSTRUMENTS USED FOR FIBER CHARACTERIZATION

To verify that fibers are able to transmit light reliably, a variety of commercial instruments have been developed for certification, maintenance, and restoration of fiber systems. Instruments have been developed for certification, maintenance, and restoration of fiber systems. For example;

Loss Test Sets, consisting of a stabilized light source and power meter combination, are used for testing the end-to-end loss of an optical fiber.

Optical Return Loss (ORL) Test Sets measure the amount of light reflected back toward a transmitter.

Visible Fault Locators inject light from a visible laser or LED into a fiber. Where a break or sharp bend occurs, they allow the operator to "see" the location of the fault by virtue of light coupled out of the waveguide at the break.

Each of these instruments has its own benefits and attributes, and each can be used to test a limited subset of the complete fiber performance characteristics.

In the past, only the transmission loss of fiber cables was routinely measured. However, today's ever-increasing demand for higher speed has led to the requirement that fiber cable systems be tested and certified for operation at higher bit rates. Even though single-mode fibers have essentially unlimited transmission bandwidth, actual installed fiber cable systems can contain reflective connections and losses that may limit the speed at which light can be reliably transmitted. Test instruments have been developed that can assist in determining the speed limitations of installed fiber systems. For example;

Bit-error-rate Testers (BERT sets) introduce a pseudo-random code into one end of a fiber system and measure the fraction of bits that are incorrectly transmitted at the receiving end. In this way, the effective noise floor and, therefore, the dynamic range of the system can be determined.

Light sources, power meters, ORL testers, and the BERT sets can determine the loss of a fiber or noise-floor penalty of a transmission system, but they cannot determine the location of a problem within the fiber itself. The **OTDR** is an instrument used to test the light-transmission ability of an optical telecommunications fiber or cable, and it can also determine the location of a problem [2].

2.3 INTRODUCTION TO OTDRs

The OTDR has become the most widely used and versatile instrument for testing optical fibers during installation, maintenance, and restoration. The OTDR can determine the length of a fiber and its end-to-end loss as well as the amount of reflected light and loss from various discrete components within the fiber. Modern OTDRs can locate and evaluate the losses of fusion splices and connectors and can even report whether each location and loss is within certain specification tolerances. Among all electronic test instruments, the OTDR is truly unique in its combination of extremely high dynamic range, rapid acquisition capabilities, and high resolution. No other instrument used for any test application can boast over 200 dB of electrical dynamic range together with nearly 1 GHz of bandwidth and a 10-MHz sampling rate, all in the same package [5].

2.4 THE BIRTH OF OTDRs

The underlying principle of the OTDR is the detection and analysis of light scattered from tiny imperfections and impurities in the optical fiber. Rayleigh scattering in optical fibers has been understood for many years. The earliest publications reporting measurements of backscatter in optical fibers using a time-domain method appeared in early 1976. This technique, which is much the same as the principle used in modern OTDRs, involved introducing a short pulse of light into one end of an optical fiber (see figure 2.1). When the light travelled to the opposite end of the fiber, a small portion would reflect from the far end and travel back to the near end. Through the use of a beam splitter, in the form of a tapered fiber, the outgoing pulse could be introduced into the near end and the reflected pulse could be collected from the near end as well.

The reflected pulse was directed into a photomultiplier, where it was amplified and converted to a current pulse. The current pulses from both the incident pulse and the reflected pulse could then be viewed simultaneously on an oscilloscope. The length of the fiber was determined by multiplying a constant with the time difference of the incident and reflected pulses. The experimental setup could also be used to measure Rayleigh backscatter.

Time-domain backscatter methods for assurance testing of optical communications fibers appear to have been developed independently in the mid-1970s by two different research groups:

1) Barnoski and Jensen at Hughes Research Laboratories and Personick at Bell Telephone Laboratories.
2) The research group developed by Personick.

The early work of Personick is shown in Figure 2-1, since his work was applied directly to actual installed fiber-telecommunication links.

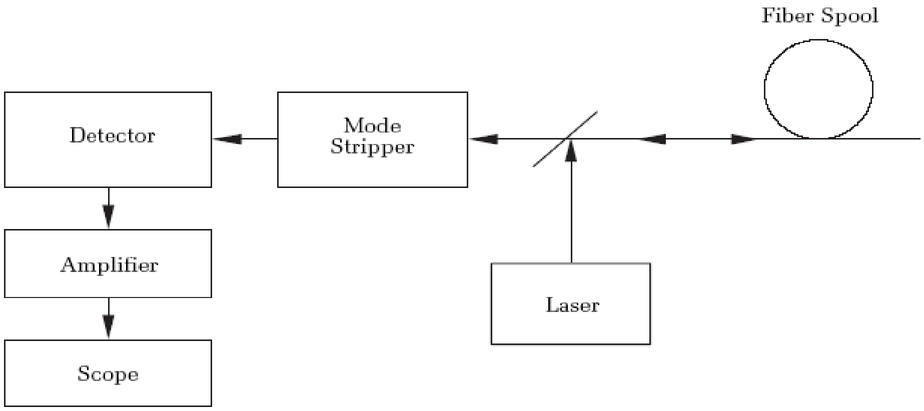


Figure 2-1 Original experimental arrangement used to detect Rayleigh scattering in multimode fibers.

In early 1976, Stewart Personick, then working at Bell Telephone Laboratories, was pursuing a means to test the lengths and losses of optical fibers using a time-of-flight method. Personick was experimenting with ways to reduce optical-detector overload in the laboratory. Using a back-reflection method similar to that illustrated in figure 2.1, Personick noticed an exponentially decaying signal immediately following the incident reflection on the oscilloscope.

Personick recognized that the exponential signal was, in fact, due to Rayleigh scattering from microscopic imperfections in the fiber itself. Reasoning that a logarithmic amplifier would “straighten out” the exponential signal, Personick employed such a log system. This improvement to the linear-amplifier method enabled the straightforward measurement of the fiber scattering (and thus fusion-splice losses and connector losses) based on the change in backscatter signals before and after the events.

Additional improvements to this primitive OTDR were quick to follow, including the use of an avalanche photodiode (APD) for improvements in sensitivity and the collection of various system components together into a self-contained instrument, similar to modern monolithic instruments. Following these important improvements, Personick and colleagues began using their OTDR successfully to measure the losses of splices and connectors in a research field trial of multimode fiber, then being installed under the streets in an area of Chicago [11].

2.5 HISTORY OF OTDRs

The birth and development of OTDRs can be described by dividing into a generations. All four generations of OTDRs show development in the field of optical fiber characterization methodology.

First generation OTDRs were multimode instruments that used photomultiplier tubes to amplify the very weak input signal. Equipped with the simplest data sampling systems and external oscilloscope displays, these systems were heavy and required skilled technicians to operate them.

In the early 1980s, the **Second-generation OTDRs** started to enter the market. They were still multimode instruments but offered simplified user control because of the use of 8-bit microprocessors. Most of these boxes were portable and could be used for maintenance and service applications. Digital data processing like storage and averaging was introduced. However, since only one sample per shot was acquired (only one sample was taken for each pulse launched), many repetitions of the pulse were needed to characterize a complete fiber trace. With this technique only modest noise reduction was achieved by averaging, even with long measurement times.

A big step forward in technical performance was achieved when **Third-generation OTDRs** were introduced. With a microprocessor and dedicated hardware for digital signal processing, measurement speed was greatly increased by providing one complete trace per shot. Thus noise reduction by averaging improved considerably. Real-time monitoring became a standard feature because of fast display refresh. Some instruments offered pure single-mode capability for characterizing long fiber links, and others could be equipped with plug-in modules that provided flexibility in measurement range, resolution, and different fiber types. Features such as automatic splice loss, a built-in printer, or masking with an acousto-optical switch illustrated the development of universal tools covering a broad range of applications and customer needs.

About 1990, the **Fourth generation of OTDRs** brought about a split into two different types of OTDRs: high-end and low-end OTDRs, which are mainly distinguished by performance and price.

In high-performance OTDRs, 32-bit microprocessors control the instrument and provide powerful data processing capabilities that increase measurement speed and implement new functions. It is now possible to provide all-haul OTDRs that cover both short-haul and long-haul measurement applications without having to change any module. Data storage on magnetic disk, interfacing to personal computers, user interfaces with screen windows, native language support for help screens, and scan trace algorithms are now available with these new instruments. The clear intention behind providing these features is to make the operation of an OTDR more user friendly and comfortable. However, performance improvement does cost. High-power lasers, low-noise avalanche diodes, powerful signal processors, and comprehensive equipment contribute strongly to a product's price.

For many customers these high-end instruments represent overkill for their applications. As a consequence, more and more manufacturers are offering simplified OTDRs such as fault 1ocators or mini-OTDRs. Some of the properties that describe these portable, low-end instruments include: lightweight, handheld, battery operated, limited dynamic range and resolution, and low display resolution [13].

2.6 FEATURES, FUNCTIONS AND PERFORMANCE IMPROVMENTS

In addition to the investigative work by the research community, several groups in the United States and Europe began designing commercial instruments to test optical-fiber length and loss. In those days, all fiber systems were of the multimode type, using Led's as transmission sources at 850 nm and 1300 nm. Due to the ready availability of silicon APDs and fast analog oscilloscopes, basic analog OTDRs were relatively straightforward to design. Therefore, the first commercial manufacturers of OTDRs were quick to provide instruments to the emerging optical fiber-test market. They were able to offer updates and improvements to existing instruments on a regular basis. Thus, competition and innovation among the two or three initial suppliers led to rapid advances in the technology of OTDRs. These early improvements included the development of sensitive preamplifiers based primarily on Personick's work in telecommunications receiver design. Other improvements included dedicated oscilloscope designs, more efficient data-acquisition systems, chart recorders to improve interpretation and documentation of test results, adoption of improved fiber-connector types, and the use of display measurement tools such as movable cursors. By 1985, there were at least five commercial suppliers of OTDRs whose instruments were designed for testing multimode fiber systems.

There have been essentially four phases in the history of OTDR development.

The first was the invention and early development of the OTDR.

The second phase consisted of the years in which OTDRs were brought from the laboratory into commercial development and gradually refined.

The third phase was the period in which the OTDR was transformed from basically a refined oscilloscope to a monolithic instrument designed specifically for testing optical fiber and capable not only of measuring the fiber waveform data but also of interpreting them.

The latest phase has been the reduction of the OTDR into a form factor that is small and portable, capable of running off batteries, and complete with software that produces automatic waveform analysis as well as test reporting.

Several manufacturers have further enhanced the utility of their test solutions by building the OTDR as one module designed to operate on a field-portable platform that accepts additional test modules, such as optical power meters and optical spectrum analyzers.

The 1980s saw the formative, refinement phase for OTDRs. Their development for multimode testing was a direct result of the introduction of multimode fiber into the telecommunications industry. In addition, the first half of the 1980s saw the emerging use of systems based on singlemode fiber. These systems offered the possibility of transmitting information over longer distances at greater speeds. With the introduction of single-mode systems, multimode fibers were gradually transitioned to local-area networks (LANs), where shorter distances tolerated the greater loss and larger dispersion of multimode fiber. Also, cost sensitivity was a driving force to use the lower-cost components available for transmission at 850 nm and 1300 nm, which are the operating wavelengths of standard multimode fiber. Due to this change in emphasis in the early 1980s, multimode OTDR development in the late 1980s was de-emphasized relative to the development of instruments used for testing single-mode fibers. It is fair to say that few significant performance improvements have been made to multimode OTDRs since 1991 (though operational, ergonomic, and analysis performance has improved dramatically). Meanwhile, single-mode OTDRs have realized regular and significant improvements in performance up to the present time.

The development of single-mode transmission systems led to improvements in the transmission quality of optical fibers, in the power of transmitters, and in the sensitivity of receivers. Because of these improvements, designers were able to increase the length of singlemode fiber cables. This led to requirements for OTDRs that were capable of testing fibers of ever-increasing length. To provide the instrument dynamic range that is required to test these fibers, several technologies were investigated. These technologies included techniques to improve the overall sensitivity of the instrument, such as photon counting, photomultiplier detectors, and coherent detection. In addition, reflective frequency-sweep techniques have been proposed, but these are only able to detect the positions of discrete reflective events in fiber and integrated optic systems.

Curiously, few of these exotic techniques led to practical performance improvements for the OTDR. In retrospect, it was primarily simple and incremental changes that gradually provided the performance improvements required for testing single-mode fibers. Silicon APDs are used in the multimode OTDR preamplifier. For single-mode testing, germanium and Inga as APDs were developed that provided improved sensitivity within the longer wavelength windows located at 1310 nm and 1550 nm. OTDR preamplifiers with improved noise, bandwidth, and sensitivity characteristics were developed. Noise reduction and resolution were improved by using high-speed acquisition systems. OTDR laser sources enjoyed regular increases in peak-power capabilities. One of the most significant enhancements to traditional OTDRs arrived with the introduction of digital acquisition systems that replaced the "real-time" analog displays. This led to improvements in speed, accuracy, sensitivity, and averaging capabilities as well as the ability to further improve noise characteristics using sophisticated digital signal processing of the OTDR waveform.

As a result of these changes, the dynamic range of single-mode OTDRs increased over the years, though as figure 2-2 shows, this trend has stabilized in recent years as device limits have come into play. **Two important improvements** to long-range OTDRs were enabled with the introduction of high-power Fabry–Perot lasers in 1992 and with the new generation of strained layer multi-quantum-well (SL-MQW) lasers in 1994. Essentially all instrument lasers are now of the SL-MQW type. It is also interesting to point out that laboratory developments have preceded commercial improvements by about three years.

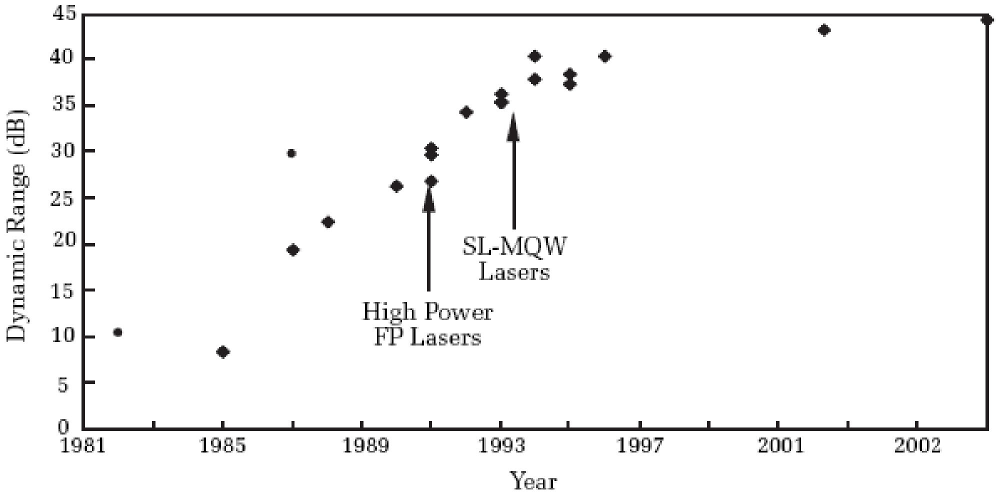


Figure 2-2 *The dynamic range (SNR = 1) of commercial, long-range 1550-nm OTDRs, by year of release [14].*

In the past, OTDRs were designed and used primarily as tools for measuring basic transmission characteristics of the fiber, such as length, loss, and back-reflection. With these traditional instruments, the OTDR operator had to set up the measurement parameters, wait for the data to be acquired, and then set about interpreting the waveform features to determine the loss characteristics of the fiber. In those times, the OTDR user was likely a technician or engineer who was highly trained in the use of the instrument and the interpretation of the data in terms of how various waveform features would affect the transmission system.

By the second half of the 1990s, OTDR development had entered an evolutionary phase that may be called the *expert system* phase. Several important driving factors have led to the new expert systems requirements. During the 1990s, OTDRs became increasingly used in a wider variety of test situations, including not only installation, but also maintenance and restoration. Along with this increase in the variety of test applications, OTDRs became used by a wider variety of people. Maintenance testing has shifted from the optical-transmission technician or engineer to technicians who may have responsibility for other testing functions, such as metallic cable and LAN maintenance.

Consequently, maintenance and restoration of the existing fiber system may occupy a small portion of their workday activities. As in installation, time is often of the essence in restoration testing. When these technicians need to use an OTDR, they prefer instruments that have the ability to perform "one button testing." These technicians require rapid information about the location of a fiber problem, rather than raw waveform information that they would have to analyze to get the same results. Figure 2-3 shows the growth in the number of suppliers with automatic event detection [14].

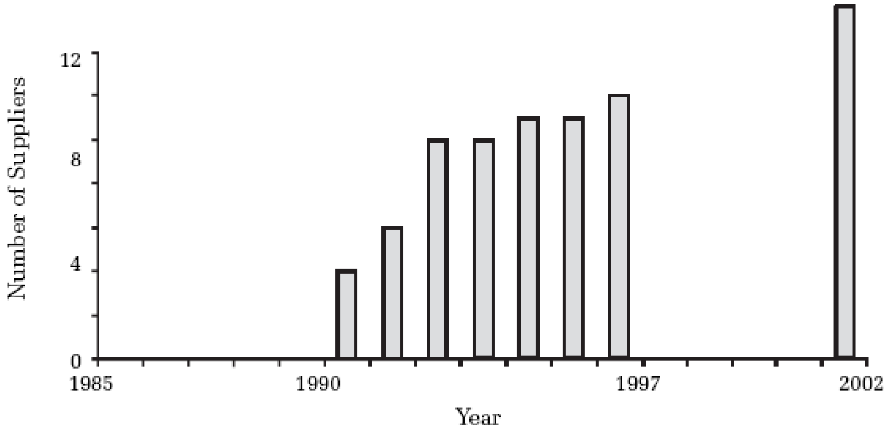


Figure 2-3 *Growth in the number of suppliers whose OTDRs have automatic event detection [14].*

CHAPTER-3

FIBER OPTICS FUNDAMENTALS

3.1 INTRODUCTION

The science of fiber optics deals with the transmission or guidance of light (rays or waveguide modes in the optical region of the spectrum) along transparent fibers of glass, plastic, or a similar medium [10]. Fiber-Optic light-guides are media whose transverse dimension (diameter, thickness) can be very small, typically 10mm to 1 mm. They are very flexible and can be produced in virtually any desired length. The material is usually glass, quartz or plastic. For special applications, other exotic materials such as liquid light guides, sapphire, fluoride or calcogenide may be used. There are some unavoidable requirements for good light transmission, such as pure glass materials for the core and cladding and high transparency for the spectrum of interest. Minimal optical dispersion is also desired. Process parameters such as glass transformation temperature, viscosity, inclusions and chemical affinity dictate the economics and quality of the fiber product. Light launched into a fiber will after a given length reach the core material boundary and pass to another medium (glass, air, etc.). Depending on the incident angle, some of the energy will be refracted outward (**leaky modes**) and some will reflect back into the core material [15]. The phenomenon responsible for the fiber or light-pipe performance is the law of total internal reflection.

3.2 TOTAL INTERNAL REFLECTION

A ray of light, incident upon the *interface* between two transparent optical materials having different indices of refraction will be totally internally reflected (rather than refracted) if

(1) the ray is incident upon the interface from the direction of the more dense material and

(2) the angle made by the ray with the normal to the interface is greater than some critical angle, the latter being dependent only on the indices of refraction of the media [9] (Fig. 3-1)

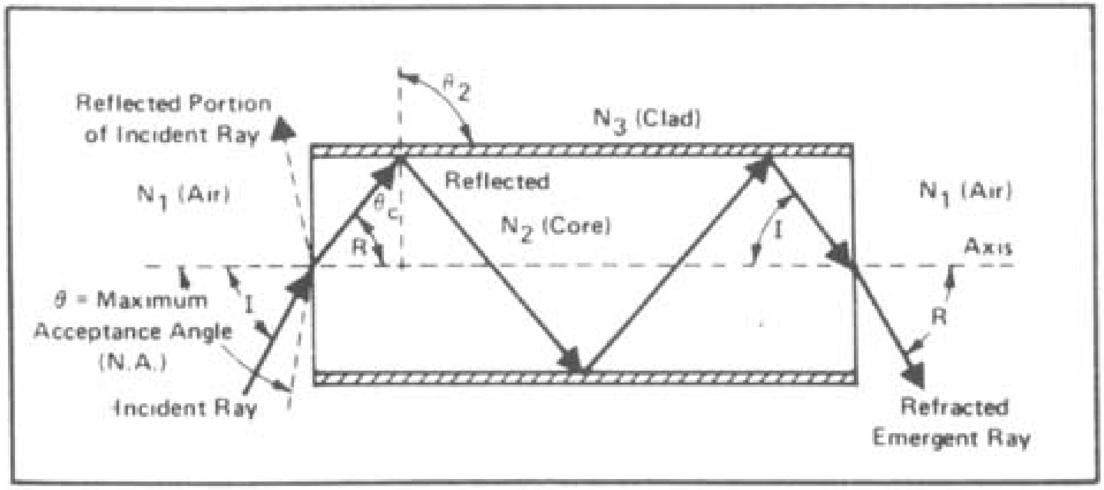


Figure 3-1 *Refraction, Reflection, and Numerical Aperture [9]*

Rays may be classified as meridional and skew. Meridional rays are those that pass through the axis of a fiber while being internally reflected. Skew rays are those that never intersect the fiber axis although their behaviour patterns resemble those of meridional rays in all other respects. An off-axis ray of light traversing a fiber 50 microns in diameter may be reflected 3000 times per foot of fiber length. This number increases in direct proportion to diameter decrease.

Total internal reflection between two transparent optical media results in a loss of less than 0.001 percent per reflection; thus a *useful* quantity of illumination can be transported. This spectral reflectance differs significantly from that of aluminium (shown graphically in Figure 3-2). An aluminium mirror cladding on a glass fiber core would sustain a loss of approximately 10 percent per reflection, a level that could not be tolerated in practical fiber optics. As indicated in Figure 3-1, the angle of reflection is equal to the angle of incidence. (By definition, the angle is that measured between the ray and the normal to the interface at the point of reflection.) Light is transmitted down the length of a fiber at a constant angle with the fiber axis. Scattering from the true geometric path can occur, however, as a result of

(1) imperfections in the bulk of the fiber;

(2) irregularities in the core/clad interface of the fiber; and

(3) surface scattering upon entry.

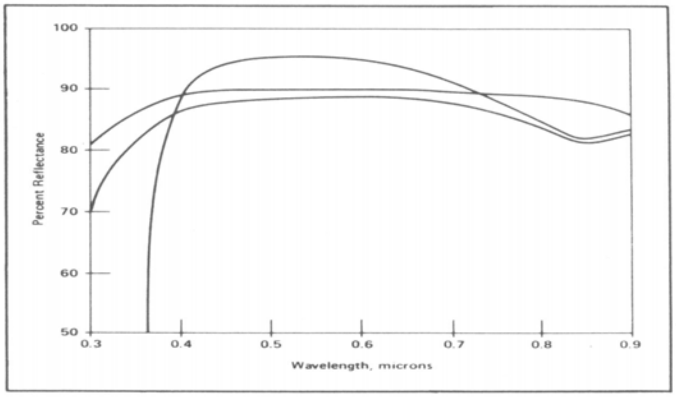


Figure 3-2 *Aluminum Mirror Reflectance [3]*

In the first two instances, light will be scattered in proportion to fiber length, depending upon the angle of incidence. To be functional, therefore, long fibers must have an optical quality superior to that of short fibers. Surface scattering occurs readily if optical polishing has not produced a surface that is perpendicular to the axis of the fiber; pits, scratches, and scuffs diffuse light very rapidly. The speed of light in matter is less than the speed of light in air, and the change in velocity that occurs when light passes from one medium to another results in refraction. It should be noted that a portion of the light incident on a boundary surface is not transmitted but is instead reflected back into the air. That portion that *is* transmitted is *totally reflected* from the sides, assuming that the angle is less than the critical angle (see Figure 3-1). The relationship between the angle of incidence I and the angle of refraction R is expressed by Snell's law as

$$\mathbf{N1 \sin \mathit{I} = N2 \sin \mathit{R}} \qquad \mathbf{[3.1]}$$

where N1 is the index of refraction of air and N2 the index of refraction of the core. Since N1 = 1 for all practical purposes, the refractive index of the core becomes [10]

$$\mathbf{N2 = \sin \mathit{I} / \sin R} \qquad \mathbf{[3.2]}$$

3.3 FIBER ATTENUATION- ABSORPTION, SCATTERING AND DISPERSION

Attenuation, a reduction in the transmitted power, has long been a problem for the fiber optics community. The increase in data loss over the length of a fiber has somewhat hindered widespread use of fiber as a means of communication. However, researchers have established three main sources of this loss: absorption, scattering and dispersion. [3], [4], [5].

3.3.1 ABSORPTION

Absorption occurs when the light beam is partially absorbed by lingering materials, namely water and metal ions, within the core of the fiber as well as in the cladding (see Figure 3-3). Though absorption in standard glass fibers tends to increase between the critical lengths of 700 and 1550 nanometers (nm) almost any type of fiber at any length will have light absorbed by some of the traces of impurities that inevitably appear in all fibers. As the light signal travels through the fiber, each impurity absorbs some of the light, weakening the signal; therefore, longer fibers are more prone to attenuation due to absorption than shorter ones [6], [7], [8].

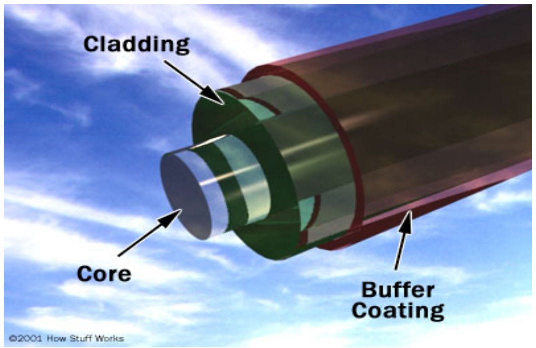


Figure 3-3 Lingering materials within the core and the cladding [6]

3.3.2 SCATTERING

Scattering, another significant aspect of attenuation, occurs when atoms or other particles within the fiber spread the light. This process differs with absorption in that, for the most part, foreign particles on the fiber are not absorbing the light, but the light signal bounces off the particle rather than the fiber's wall and spreads the signal in another direction [3].

For glass fibers, the foremost type of scattering is Rayleigh scattering, which somewhat contrasts with the accepted definition of scattering. With this process, atoms or other particles within the fiber fleetingly absorb the light signal and instantly re-emit the light in another direction. In this way, Rayleigh scattering appears very much like absorption, but it absorbs and re-directs the light so quickly that it is considered scattering [6], [7].

Both scattering and absorption are cumulative, in that they keep building up. Light is absorbed and scattered continuously, so the signal at the end of the fiber is almost never exactly the same signal as it was at the beginning. However, for the most part, the signal loss is minimal and does not greatly hinder the communication.

3.3.3 THREE TYPES OF DISPERSION

Dispersion can be classified into the following three types.

3.3.3.1 MATERIAL DISPERSION

Dispersion in optical fibers can be categorized into three main types. The first is material dispersion, also known as chromatic dispersion. This type of intramodal dispersion results from the fact that the refractive index of the fiber medium varies as a function of wavelength (Keiser, 1983). Since neither the light source nor the fiber optic cable is 100 percent pure, the pulse being transmitted becomes less and less precise as the light's wavelengths are separated over long distances. The exact same effect occurs when a glass prism disperses light into a spectrum [3].

3.3.3.2 WAVE-GUIDE DISPERSION

Wave-guide dispersion, another type, is very similar to material dispersion in that they both cause signals of different wavelengths and frequencies to separate from the light pulse. However, wave-guide dispersion depends on the shape, design, and chemical composition of the fiber core. Only 80 percent of the power from a light source is confined to the core in a standard single-mode fiber, while the other 20 percent actually propagates through the inner layer of the cladding. This 20 percent travels at a faster velocity because the refractive index of the cladding is lower than that of the core. Consequently, signals of differing frequencies and wavelengths are dispersed and the pulse becomes indistinguishable. An increase in the wave-guide dispersion in an optical fiber can be used in order to counterbalance material dispersion and shift the wavelength of zero chromatic dispersion to 1550 nanometers. Engineers used this concept to develop zero-dispersion-shifted fibers designed to have larger wave-guide dispersion (see Figure 3-4).

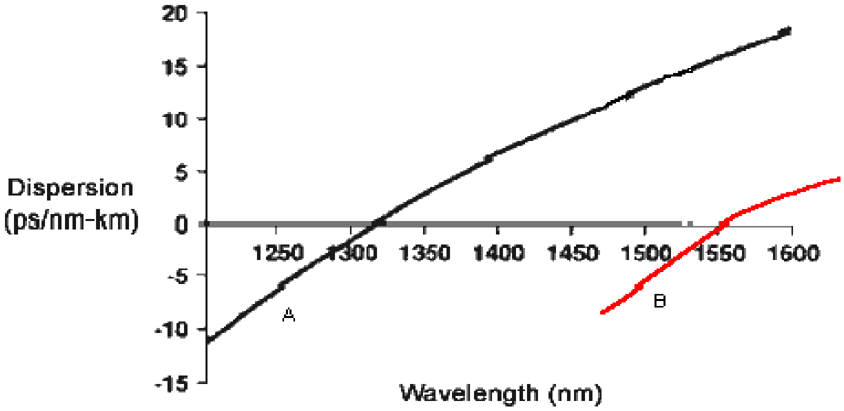


Figure 3-4 Typical Dispersion vs. Wavelength Curves- Fiber dispersion varies as a function of wavelength [4].

Developers doped the core with erbium in order to increase the difference between the refractive indices of the cladding and the core, thus enlarging waveguide dispersion [3], [4].

3.3.3.3 MODAL DISPERSION

The third and final significant type of dispersion is related to the fact that a pulse of light transmitted through a fiber optic cable is composed of several modes, or rays, of light instead of only one single beam; therefore, it is called modal dispersion. Since the rays of the light pulse are not perfectly focused together into one beam, each mode of light travels a different path, some short and some long. As a result, the modes will not be received at the same time, and the signal will be distorted or even lost over long distances [3].

3.4 FIBER OPTIC SPLICE, CONNECTOR AND COUPLER

Fiber optic connections permit the transfer of optical power from one component to another. Fiber optic connections also permit fiber optic systems to be more than just point-to-point data communication links. In fact, fiber optic data links are often of a more complex design than point-to-point data links [11].

A system connection may require a fiber optic splice, connector, or coupler. One type of system connection is a permanent connection made by splicing optical fibers together. A fiber optic **splice** makes a permanent joint between two fibers or two groups of fibers. There are two types of fiber optic splices--mechanical splices and fusion splices. Even though removal of some mechanical splices is possible, they are intended to be permanent. Another type of connection that allows for system reconfiguration is a fiber optic **connector**. Fiber optic connectors permit easy coupling and uncoupling of optical fibers. Fiber optic connectors sometimes resemble familiar electrical plugs and sockets. Systems may also divide or combine optical signals between fibers. Fiber optic **couplers** distribute or combine optical signals between fibers. Couplers can distribute an optical signal from a single fiber into several fibers. Couplers may also combine optical signals from several fibers into one fiber [14].

Fiber optic connection losses may affect system performance. **Poor fiber end preparation** and **poor fiber alignment** are the main causes of coupling loss. Another source of coupling loss is differences in optical properties between the connected fibers. If the connected fibers have different optical properties, such as different numerical apertures, core and cladding diameters, and refractive index profiles, then coupling losses may increase [12], [13].

3.5 BENDING LOSSES

At a bend the propagation conditions alter and light rays which would propagate in a straight fiber are lost in the cladding. Two types of bending losses occur in the optical fibers which are as follows:

3.5.1 MACROBENDING

Macrobending is due to tight bends. Macrobending is commonly caused by poor installation or handling Fiber bending with a constant bend radius is referred to as macrobending. This produces at least 2 loss mechanisms:

3.5.1.1 REDUCTION IN PROPAGATION MODES

In multimode fibers, the number of propagating modes is reduced as a function of bend radius. The equation governing the number of propagating modes is as follows:

$$M(R) \cong M_0 \left(1 - D_F n_2^2/(R\ NA^2)\right)$$

[3.3]

M_0 … number of propagating modes without bending

$M(R)$ … number of propagating modes with bending;

n_2 … clad refractive index

R … bend radius;

D_F … fiber diameter;

NA … numerical aperture

The percent of light decoupled (mode leakage) is:

$$\Delta M/M \cong D_F n_2^2/(R\ NA^2) \times 100\ (\%)$$

[3.4]

From the above equation, it can be seen that to minimize mode losses, fibers with small diameters and high numerical apertures are best suited [15].

3.5.1.2 ELECTROMAGNETIC RADIATION LOSS BY DIFFERENCES IN PROPAGATION (WAVE FRONT) VELOCITY

The main portion of electromagnetic energy is concentrated in the fiber core, while other portions are transmitted in the cladding and a slight amount outside the cladding.

In bending the fiber with bending radius R, the light will move with the mediums propagation velocity. In the fiber cross section, the area radially further from the radius center will need to move with a greater velocity than that of the fiber core to maintain the signal transport speed. Figure 3-5 is showing this phenomenon. At reaching a critical value, z_{kr}, a barrier is reached. The speed of light in a medium cannot exceed its natural value $c = c_0/n_M$ (with $c_0 = 2.9979\ 108$ m/s and n_M .. index of refraction for Medium M). The transport velocity lies beyond this point. Seeing as the signal velocity no longer exists, light can no longer be transmitted in this configuration and relevant portion of the energy radiates into the surroundings.

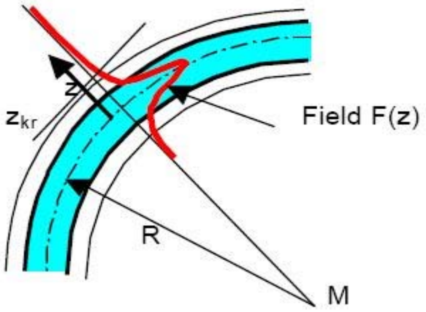


Figure 3-5 Bent fiber with bend radius R. The field on the far side of the center bend radius reaches the speed of light at distance z_{kr}. As a result, light is radiated.

In this way, losses exist resulting in higher attenuation. For multimode fibers, this effect is relatively small when compared to the effect described in above. However, this type of attenuation does more seriously affect single mode fibers as bending is applied. For single mode fibers the reduction coefficient is calculated by:

$$\alpha_B = (c_1/\sqrt{R}) \exp(-c_2 R) \qquad \textbf{[3.5]}$$

Where c_1, $c_2, \ldots$ constants depending on fiber manufacture and wavelength.

The stronger the electromagnetic field of transmitted modes out of the core, the more pronounced this effect. Modes of longer wavelength lead to larger field expansion, which should be taken into account in given cable configurations [15].

3.5.2 MICROBENDING

Microbending occurs due to microscopic fiber deformation, commonly caused by poor cable design. Along the length of the fiber, periodic or statistically distributed locations of curvatures occur, whose magnitude continuously varies. The associated loss mechanism is mainly exhibited by a permanent transformation of the transmitted mode.

Microbending in fibers is more critical than macrobending because it is due to processing rather than mishandling. Figure 3-6 shows this phenomenon. Loss can occur due to distortion of the core cladding interface, induced by manufacture or poor cable design.

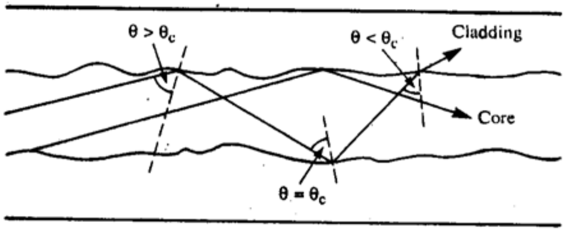


Figure 3-6 *Microbending in fibers [15]*

Minimum bend radius for a cable is typically 10 to 20 times the outer diameter of the cable. Figure 2-7 shows the bend test results for a cable with single turn and a diameter of 12.5 mm.

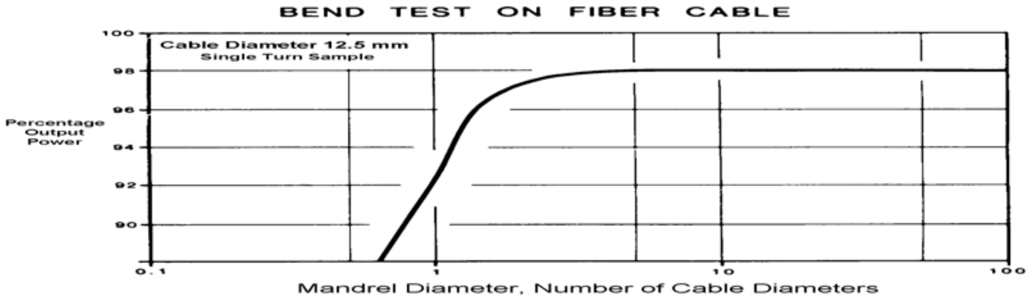


Figure 3-7 *Bend loss tests for cables [15]*

Common value used in Cabling Standards is 15 times the cable diameter[15].

CHAPTER-4

TIME DOMAIN REFLECTROMETRY

4.1 INTRODUCTION

In this chapter, a very important measurement technique is explained that is used to determine the characteristics of electrical lines by observing reflected waveforms, called Time Domain Reflectrometry. The complete method is explained, along with the numerous uses. The instrument used to characterize and locate faults in metallic cables is called a TDR (Time Domain Reflectrometer). The equivalent device for optical fiber is an OTDR (Optical Time-Domain Reflectrometer). The functionality of OTDR is explained, along with its design and explanation of its output trace. Two phenomenon fundamental to the OTDR operation are Fresnel Reflections and Rayleigh Back-scattering. These are also explained in detail.

4.2 TIME DOMAIN REFLECTROMETRY

TDR (Time-domain reflectrometry**)** is a measurement technique used to determine the characteristics of electrical lines by observing reflected waveforms. Time-domain transmissometry (TDT) is an analogous technique that measures the transmitted (rather than reflected) impulse. Together, they provide a powerful means of analyzing electrical or optical transmission media such as coaxial cables and optical fibers. The term Coherent optical time domain reflectrometry (COTDR) is also used in this regard.

The amplitude of the reflected signal can be determined from the impedance of the discontinuity. The distance to the reflecting impedance can also be determined from the time that a pulse takes to return. The limitation of this method is the minimum system rise time. The total rise time consists of the combined rise time of the driving pulse and that of the oscilloscope that monitors the reflections [3].

4.3 PRINCIPLE OF OPERATION

The TDR works on the same principle as radar. A pulse of energy is transmitted down a cable. When that pulse reaches the end of the cable, or a fault along the cable, part or all of the pulse energy is reflected back to the instrument. The TDR measures the time it takes for the signal to travel down the cable, see the problem, and reflect back. The TDR then converts this time to distance and displays the information as a waveform and/or distance reading.

A TDR transmits a short rise time pulse along the conductor. If the conductor is of uniform impedance and properly terminated, the entire transmitted pulse will be absorbed in the far-end termination and no signal will be reflected toward the TDR. Any impedance discontinuities will cause some of the incident signal to be sent back towards the source. This is similar in principle to radar.

Increases in the impedance create a reflection that reinforces the original pulse whilst decreases in the impedance create a reflection that opposes the original pulse.

The resulting reflected pulse that is measured at the output/input to the TDR is displayed or plotted as a function of time and, because the speed of signal propagation is relatively constant for a given transmission medium, can be read as a function of cable length.

Because of this sensitivity to impedance variations, a TDR may be used to verify cable impedance characteristics, splice and connector locations and associated losses, and estimate cable lengths.

4.4 TYPES OF TDRs

There are two ways a TDR can display the information it receives. The first and more traditional method is to display the actual waveform or "signature" of the cable. The display, which is either a CRT or an LCD, will display the outgoing (transmitted) pulse generated by the TDR and any reflections which are caused by impedance discontinuities along the length of the cable.

The second type of display is simply a numeric readout which supplies the distance indication in feet or meters to the first major reflection caused by an impedance change or discontinuity. Some instruments also display if the fault is an “Open” or “Short” indicating a “High Impedance” change or a “Low Impedance” change respectively.

Traditional Waveform TDRs supply more information than do the digital numeric versions. However, the simplified digital models are less expensive and easier to operate. Costing only a fraction of a traditional TDR, many simplified digital TDRs are just as accurate and can locate most major cable faults.

4.5 METHODS

The TDR analysis begins with the propagation of a step or impulse of energy into a system and the subsequent observation of the energy reflected by the system. By analyzing the magnitude, duration and shape of the reflected waveform, the nature of the impedance variation in the transmission system can be determined [11].

4.5.1 RESISTIVE LOAD

If a pure resistive load is placed on the output of the reflectometer and a step signal is applied, a step signal is observed on the CRT (Cathode Ray Tube), and its height is a function of the resistance. The magnitude of the step caused by the resistive load may be expressed as a fraction of the input signal as given by:

$$\rho = \frac{R_L - Z_0}{R_L + Z_0} \qquad \textbf{[4.1]}$$

where Z_0 is the characteristic impedance of the transmission line.

4.5.2 REACTIVE LOAD

For reactive loads, the observed waveform depends upon the time constant formed by the load and the characteristic impedance of the line.

4.6 EXPLANATION

Consider the case where the far end of the cable is shorted (that is, it is terminated into zero ohms impedance). When the rising edge of the pulse is launched down the cable, the voltage at the launching point "steps up" to a given value instantly and the pulse begins propagating down the cable towards the short. When the pulse hits the short, no energy is absorbed at the far end. Instead, an opposing pulse reflects back from the short towards the launching end. It is only when this opposing reflection finally reaches the launch point that the voltage at this launching point abruptly drops back to zero, signaling the fact that there is a short at the end of the cable. That is, the TDR had no indication that there is a short at the end of the cable until its emitted pulse can travel down the cable at roughly the speed of light and the echo can return back up the cable at the same speed. It is only after this round-trip delay that the short can be perceived by the TDR. Assuming that one knows the signal propagation speed in the particular cable-under-test. In this way, the distance to the short can be measured.

A similar effect occurs if the far end of the cable is an open circuit (terminated into infinite impedance). In this case, though, the reflection from the far end is polarized identically with the original pulse and adds to it rather than cancelling it out. So after a round-trip delay, the voltage at the TDR abruptly jumps to twice the originally-applied voltage.

Note that a theoretical perfect termination at the far end of the cable would entirely absorb the applied pulse without causing any reflection. In this case, it would be impossible to determine the actual length of the cable. Luckily, perfect terminations are very rare and some small reflection is nearly always caused.

The magnitude of the reflection is referred to as the reflection coefficient or ρ. The coefficient ranges from 1 (open circuit) to -1 (short circuit). The value of zero means that there is no reflection. The reflection coefficient is calculated as in equation 4.1:

$$\rho = \frac{R_L - Z_0}{R_L + Z_0}$$

Where Zo is defined as the characteristic impedance of the transmission medium and Zt is the impedance of the termination at the far end of the transmission line.

Any discontinuity can be viewed as termination impedance and substituted as Zt. This includes abrupt changes in the characteristic impedance. As an example, a trace width on a printed circuit board doubled at its midsection would constitute a discontinuity. Some of the energy will be reflected back to the driving source; the remaining energy will be transmitted. This is also known as a scattering junction.

4.7 USAGE

Time domain reflectometers are commonly used for in-place testing of very long cable runs, where it is impractical to dig up or remove what may be a kilometers-long cable. They are indispensable for preventive maintenance of telecommunication lines, as they can reveal growing resistance levels on joints and connectors as they corrode, and increasing insulation leakage as it degrades and absorbs moisture long before either leads to catastrophic failures. Using a TDR, it is possible to pinpoint a fault to within centimeters.

TDRs are also very useful tools for Technical Surveillance Counter-Measures, where they help determine the existence and location of wire taps. The slight change in line impedance caused by the introduction of a tap or splice will show up on the screen of a TDR when connected to a phone line.

TDR equipment is also an essential tool in the failure analysis of today's high-speed printed circuit boards. The signal traces on these boards are carefully crafted to emulate a transmission line. By observing reflections, any unsoldered pins of a ball grid array device can be detected. Additionally, short circuited pins can also be detected in a similar fashion.

The TDR principle is used in industrial settings, in situations as diverse as the testing of integrated circuit packages to measuring liquid levels. In the former, the time domain reflectometer is used to isolate failing sites in the same. The latter is primarily limited to the process industry [10].

4.7.1 IMPEDANCE

Any time two metallic conductors are placed close together, they form cable impedance. A TDR looks for a change in impedance which can be caused by a variety of circumstances, including cable damage, water ingress, change in cable type, improper installation, and even manufacturing flaws.

The insulating material that keeps the conductors separated is called the cable dielectric. The impedance of the cable is determined by the spacing of the conductors from each other and the type of dielectric used. Figure 4-1 shows the spacing between the conductors and its impact on the impedance of the cable.

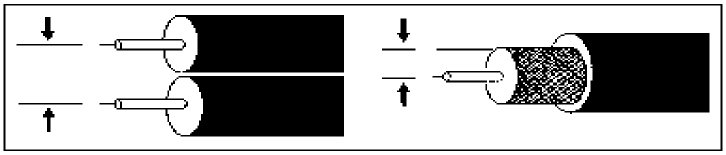


Figure 4-1 *Spacing between the conductors [10]*

If the conductors are manufactured with exact spacing and the dielectric is exactly constant, then the cable will be constant. If the conductors are randomly spaced or the dielectric changes along the cable, then the impedance will also vary along the cable.

A TDR sends electrical pulses down the cable and samples the reflected energy. Any impedance change will cause some energy to reflect back toward the TDR and will be displayed. Figure 4-2 shows that how much the impedance changes, it determines the amplitude of the reflection.

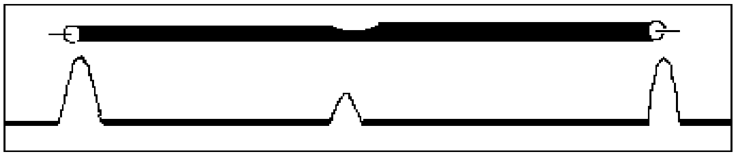


Figure 4-2 *Amplitudes of the reflections due to impedance change [10]*

4.7.2 PULSE WIDTHS

Many TDRs have selectable pulse width settings. The larger the pulse width, the more energy is transmitted and therefore the further the signal will travel down the cable. Pulse widths may include 2 nsec, 10 nsec, 100 nsec, 1000 nsec, 2000 nsec, and 4000 nsec. A TDR may contain only one or all of the pulse width settings.

Even when testing very long lengths of cable, always start the fault finding procedure in the shortest pulse width available, as the fault may be only a short distance away. If the fault is not located, switch to the next larger pulse width and retest. Keep switching to the next larger pulse until the fault is located.

Sometimes larger pulse widths are helpful even for locating faults that are relatively dose. If the fault is very small, the signal strength of a small pulse may not be enough to travel down the cable, "see" the fault, and travel back. The attenuation of the cable combined with the small reflection of the partial fault can make it difficult to detect. A larger pulse width would transmit more energy down the cable, making it easier to see the small fault.

4.7.3 BLIND SPOTS

The pulse generated by the TDR takes a certain amount of time and thus distance to launch. This distance is known as the blind spot. The length of the blind spot varies with the pulse width. The larger the pulse width, the larger the blind spot.

It is more difficult to locate a fault contained within the blind spot. If a fault is suspected within the first few feet of cable, it is advisable to add a length of cable between the TDR and the cable being tested. Any faults that may have been hidden in the blind spot can now easily be located. When adding a length of cable to eliminate the blind spot, remember the TDR is also reading the length of this jumper cable. The length of the jumper must be subtracted from the cable when measuring from the point of connection.

It is best if the jumper cable is the same impedance as the cable under test. The quality of the connection is an important factor regardless of the type of connection or jumper being used.

4.7.4 VELOCITY OF PROPAGATION (VOP)

The TDR is an extremely accurate instrument. However, variables in the cable itself sometimes cause errors in distance measurements. One way to minimize error is to use the correct Velocity of Propagation (VOP) of the cable under test. The VOP is a specification of the cable indicating the speed at which a signal travels down the cable. Different cables have different VOPs. In order to assure the most accurate distance measurements, the cable VOP must be determined.

The speed of light in a vacuum is 186,400 miles per second. This speed is represented by the number 1 (100%). All other signals are slower. A cable with a VOP of .85 would transmit a signal at 85% of the speed of light. A twisted pair cable, which typically has a lower VOP (such as .65), can transmit a signal at 65% of the speed of light.

The VOP number of a cable is determined by the dielectric material that separates the two conductors. In a coaxial cable, the foam separating the center conductor and the outer sheath is the material determining the VOP. In twisted pair, the VOP number is determined by the spacing between the plastic.

Knowing the VOP of a cable is the most important factor when using a TDR for fault finding. By entering the correct VOP, the instrument is calibrated to the particular cable. Typically, the VOP of the cable under test will be listed in the cable manufacturer's catalog or specification sheet. If not, simply measure a length of good cable (no faults) and change the TDR's VOP setting until the display shows the same distance reading as the measured length. The VOP of a cable can change with temperature and age. It can also vary from one manufacturing run to another. Even new cable can vary as much as +/- 3%.

One might think the variations in VOP would make it almost impossible to locate a fault accurately. Fortunately, there are ways to minimize the error in the VOP when testing a faulted cable, resulting in very accurate distance measurements. These techniques do not work when testing or measuring good (no fault) cable.

The most common technique used to reduce VOP error is to test the faulty cable from both ends. The procedure is as follows:

Determine the path of the cable. With a Measuring wheel or tape, measure the exact length of the cable being tested. Set the VOP according to the manufacturer’s specifications, test the cable from one end, and record the distance reading. Next, using the same VOP setting, test from the opposite end of the cable and record. If the sum of the readings is the exact length of the cable that was measured, the VOP is correct and the fault has been located.

If the sum of the two readings is more than the measured distance, reduce the VOP setting and re-test. If the sum of the two readings is less than the measured distance, increase the VOP setting. In this case, the operator must also consider the possibility of two faults.

The same result can be obtained mathematically. Take the actual cable length and divide by the sum of the two TDR readings obtained by the tests from each end. This gives the adjustment factor. Then multiply each of the TDR readings by the adjustment factor. This result will be the corrected length readings.

4.7.5 LOCATION OF MULTIPLE FAULTS

Sometimes a cable contains more than one fault. Multiple faults in a cable can be caused by many factors, including rodent damage, improper or faulty installation, construction, ground shift, or even structural flaws from the manufacturing process. If a fault is a complete open or a dead short, the TDR will read only to that point and not beyond.

If the fault is not an open or short, the TDR may indicate the first fault and other faults further down the cable. In the case of a waveform TDR, the waveform signature of the cable will show most of the discontinuities, both large and small, along the length of the cable.

In the cast of a digital numeric TDR, only the distance to the first major fault will be indicated, and not the smaller faults beyond the larger fault. The cable must be tested from the opposite end for signs of other possible faults.

4.7.6 TESTING OF TERMINATED CABLES

When testing cables it is best if the cable is not terminated. A termination can absorb the pulse and no signal will return to the instrument. The TDRs transmitted pulse must be reflected back to the instrument by a fault or the end of the cable in order to indicate a distance. It is best if all equipment and components are disconnected from the cable under test.

Sometimes it is not always practical to disconnect the far end of the cable. However, it is still possible to test a cable that is terminated. If the cable is damaged, the signal will reflect back at the damaged point prior to being absorbed by a termination.

If a reflection is created at the point of termination, it is possible the TDR has found a faulty terminator.

4.8 FUNDAMENTALS OF OTDR OPERATION

In recent years it has become apparent that fiber-optics are steadily replacing other media as an appropriate means of communication signal transmission. Examples include Telephony, Cable television companies, local area networks (LAN) and power companies. Advantages of optical fiber cables over other media include improved performance in terms of speed, immunity to noise, available bandwidth, and distance the signal is able to cover without the need for regeneration.

It is important to have a thorough characterization of the media which is being used for transmission. For example the information regarding the location of fiber breaks, cuts, splices or other connectors on the fiber cable is of prime utility. The instrument used for this kind of characterization is called an Optical

Time Domain Reflectometer. The following article gives a comprehensive overview of an OTDR, its working methodology, major components, features, usage and limitations of the instrument.

An optical time domain reflectometer (OTDR) is a fiber optic tester for the characterization of fiber and optical networks. The purpose of an OTDR is to detect, locate, and measure events (discontinuities such as cuts, splices or connectors etc) at any location on the fiber link. The instrument is also capable of measuring other parameters of interest like Optical return loss. One of the main benefits of an OTDR is that it allows complete characterization of the fiber from only one end of the fiber.

At any point in time, the light the OTDR sees is the light scattered from the pulse passing through a region of the fiber. Only a small amount of light is scattered back toward the OTDR, but with sensitive receivers and signal averaging, it is possible to make measurements over relatively long distances. Since it is possible to calibrate the speed of the pulse as it passes down the fiber, the OTDR can measure time, calculate the pulse position in the fiber and correlate what it sees in backscattered light with an actual location in the fiber. Thus, it can create a display of the amount of backscattered light at any point in the fiber. Since the pulse is attenuated in the fiber as it passes along the fiber and suffers loss in connectors and splices, the amount of power in the test pulse decreases as it passes along the fiber in the cable plant under test. Thus the portion of the light being backscattered will be reduced accordingly, producing a picture of the actual loss occurring in the fiber. Some calculations are necessary to convert this information into a display, since the process occurs twice, once going out from the OTDR and once on the return path from the scattering at the test pulse [11].

4.9 OTDR DESIGN

The principle optical components in a simple standard OTDR include a laser, a receiver, a coupler and a front-panel connector.

A laser is pigtailed to a connector on the OTDR through a 3dB optical coupler. This coupler is typically a fused bidirectional device but may also be made of discrete optical components.

The laser fires short, intense bursts of light that are directed through the coupler and then out through the front-panel connector and into the fiber under test.

As the pulse travels along the fiber, some of the light is lost via absorption and Rayleigh scattering. The pulse is also attenuated at discrete locations, such as splices, connectors, and bends, where local abrupt changes in the waveguide geometry couples light out of the core and into the cladding. When the pulse encounters discontinuities in the index of refraction (such as those found in connectors or the cleaved end of a fiber), part of the pulse's optical energy is reflected back toward the OTDR as shown in the figure 4-3.

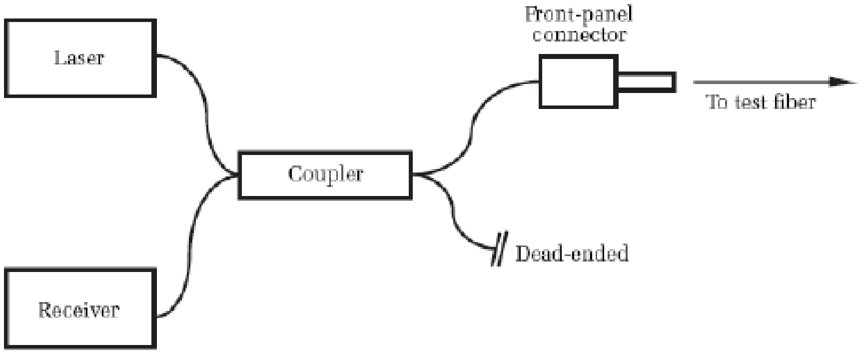


Figure 4-3 Principle optical components in a standard OTDR

4.10 SPECIFICATIONS OF AN OTDR

Some specifications of an OTDR are dynamic range, dead zone, resolution, pulse width, wavelength and averaging [10].

4.10.1 DYNAMIC RANGE

The dynamic range is one of the most important characteristics of an OTDR since it determines the maximum observable length of a fiber. The higher the dynamic range, the higher the signal-to-noise ratio and the better the trace and event detection.

4.10.2 DEAD ZONE

The photodiode, the component receiving the signal is designed to receive a given level range. Incase of a strong reflection (of the pulse), the photodiode gets saturated. Once a photodiode is saturated it requires a few nanoseconds (or longer) to recover. During this recovery time it is virtually blind. The length of the fiber that is not fully characterized during this period (pulse width + recovery time) is termed the dead zone. Dead zone is determined mostly by pulse width and to a lesser extent by the 'saturability' of the photodiode.

4.10.3 RESOLUTION

Resolution is the minimum distance between two acquisition points. This data point resolution can be within centimeters depending upon pulse width and range. The ability of the OTDR to locate an event is affected by the sampling resolution. If the OTDR samples every 4 cm, it can only locate a fiber end within 4 cm.

4.10.4 PULSE-WIDTH

Pulse width is the term used to describe exactly how long the laser stays on. For example, if the pulse width is set to 100 ns (nanoseconds) the laser emits light for 100 billionths of a second then switches off. The duration of pulse width controls the amount of light that is injected into a fiber. Long pulse widths are used to see long distances down a fiber cable. However this increases the dead zone.

4.10.5 WAVELENGTH

The behavior of an optical system is directly related to its wavelength of transmission. Optical fiber exhibits different loss characteristics at different wavelengths. In addition, splice loss values also vary accordingly. In general, the fiber should be tested using the same wavelength that is used for transmission. The current wavelengths used are 850 nm and 1300 nm for multimode fiber and 1310 nm, 1550 nm, and 1625 nm for single mode fiber.

4.10.6 AVERAGING

Averaging is the process by which each acquisition point is sampled repeatedly, and the results are averaged in order to improve the signal-to-noise ratio.

4.11 USAGE OF OTDR

The use of an OTDR can broadly be classified as a two step process.

4.11.1 ACQUISITION

The OTDR acquires the data and displays the results either graphically or numerically. This involves the configuration of parameters like injection level, pulse width, wavelength, range and averaging information. The newest OTDR instruments integrate software programs that automatically detect and configure the optimum test parameters and show results in simple formats.

4.11.2 MEASUREMENT

The technician analyzes the data and based on the results makes decision regarding event interpretation. Two types of events are reflective and non-reflective events. Reflective events occur in case of a discontinuity in the fiber. Non-reflective events are generally produced by fusion splices or bending losses.

For each event, the OTDR makes measurements of distance location, loss and reflectance.

4.12 OTDR OUTPUT TRACE

There is a lot of information in an OTDR display. The slope of the fiber trace shows the attenuation coefficient of the fiber and is calibrated in dB/km by the OTDR. In order to measure fiber attenuation, you need a fairly long length of fiber with no distortions on either end from the OTDR resolution or overloading due to large reflections.

If the fiber looks nonlinear at either end, especially near a reflective event like a connector, avoid that section when measuring loss. Connectors and splices are called "events" in OTDR jargon. Both should show a loss, but connectors and mechanical splices will also show a reflective peak so you can distinguish them from fusion splices. Also, the height of that peak will indicate the amount of reflection at the event, unless it is so large that it saturates the OTDR receiver. Then peak will have a flat top and tail on the far end, indicating the receiver was overloaded. The width of the peak shows the distance resolution of the OTDR, or how close it can detect events.

Reflective pulses show the resolution of the OTDR. Two events closer than the pulse width cannot be seen. Generally longer pulse widths are used to be able to see farther along the cable plant and narrower pulses are used when high resolution is needed, although it limits the distance the OTDR can see as shown in the figure 4-4 and a typical OTDR trace as shown in figure 4-5.

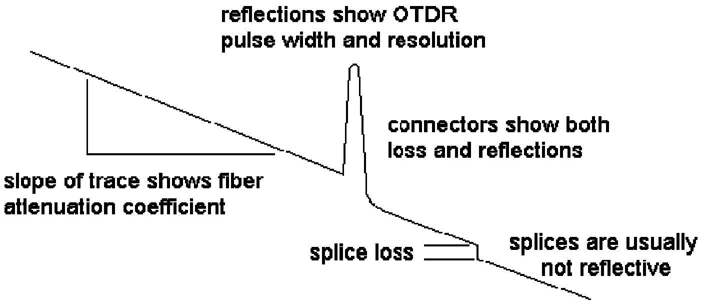


Figure 4-4 Slope of the OTDR trace showing fiber attenuation, connector and splice loss

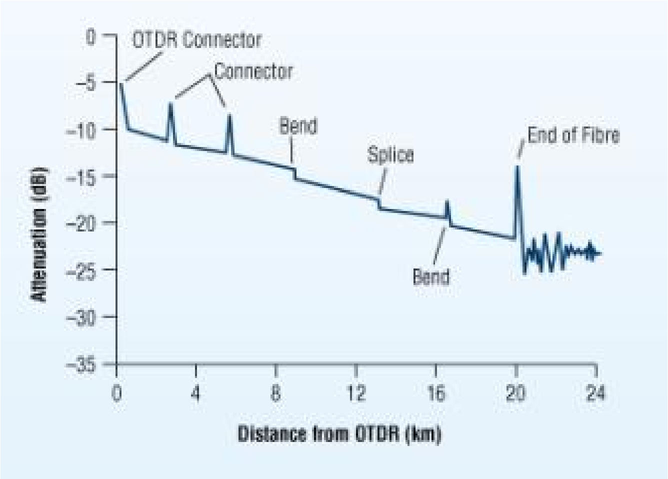


Figure 4-5 A Typical OTDR Trace

The spikes near the beginning of the waveform are from the reflective connectors at the instrument's front panel and from a jumper used to connect the instrument to the OTDR. The two bends in the waveform result from non-reflective fusion splices. The large reflection at the end of the waveform is caused by the un-terminated end of the fiber. The “grass” after the end of the fiber results from the OTDR’s system noise.

The losses of splices and connectors should be known in decibels, and the distances to events, in meters or feet. Accordingly, the vertical scale of the OTDR’s waveform is marked in decibels, and that the horizontal scale is marked in distance units. To provide measurements in decibels and meters, the OTDR must make internal conversions because its receiver measures the linear optical power (not decibels) as a function of time (not distance). To display the events as functions of distance, the OTDR divides the time base by 2 (since the light must travel out and back, thus going twice the distance) and multiplies this time by the group velocity of light in the fiber.

Ordinarily, when we calculate power attenuation in decibels we use the equation 10log $(P0/P1)$. The OTDR needs to display the attenuation that we would see if we were (for example) measuring the loss with an optical power meter. To do this, however, the OTDR uses the equation 5 log $(P0/P1)$, where $P0$ is the strength of the Rayleigh scattering just before the event and $P1$ is the strength of the Rayleigh scattering just after the event. The OTDR uses 5log instead of 10 log because light that returns to the OTDR has travelled down the fiber and back, thus been attenuated twice by the fiber and its components.

4.13 RAYLEIGH BACK-SCATTERING

Rayleigh backscattering is fundamental to OTDR operation and is the method by which OTDRs measure the end-to-end loss of a fiber-optic line as well as the discrete losses of splices and connectors. Rayleigh scattering occurs when light is scattered by the microscopic index fluctuations in the fiber and that it is the primary contributor to fiber attenuation in modern telecommunications-grade fiber. Standard OTDRs launch repetitive laser pulses (these are typically rectangular) into the test fiber.

Suppose that at time $t = 0$, an OTDR launches an infinitesimally narrow pulse into a fiber with duration $dz = dt \cdot vg$ (where vg is the group velocity of the laser pulse) and peak power$P0$. Ignoring multiple backscattering, the total backscatter power near the

OTDR's front-panel connector is 1, 2

$$dPbs = 0.5 \cdot P0 \cdot \alpha S \cdot S \cdot dz \qquad \textbf{[4.2]}$$

where S is the backscatter factor, αS is the attenuation (1/km) due to Rayleigh scattering, $P0$ is the pulse power, and dz is the physical length of a differential pulse section. The total backscatter near the OTDR's front panel from a wide pulse is thus

$$Pbs = 0.5 \cdot P0 \cdot \alpha S \cdot S \int \exp(-z \cdot \alpha) dz \qquad \textbf{[4.3]}$$

where α is the total attenuation constant (1/km) for the fiber and D is the physical pulse width (twice the displayed pulse width). In modern telecommunications fiber, α and αS are nearly the same. Solving the equation [4.2], we have

$$Pbs = 0.5 \cdot P0 \cdot \alpha S \cdot S \qquad \textbf{[4.4]}$$

Expanding the exponent term in equation [4.3] and keeping only the first- and second-order terms, we have

$$Pbs = P0 \cdot \alpha S \cdot S \cdot W(1 - W \cdot \alpha)\, dz \qquad \textbf{[4.5]}$$

where W is the displayed pulse width (km) and is half the physical length of the pulse on the fiber, D. If the length of the laser pulse is small compared with the fiber's attenuation

constant, then the quantity $(1 - W\alpha)$ is approximately 1, and we have

$$Pbs = P0 \cdot \alpha S \cdot S \cdot W \qquad \textbf{[4.6]}$$

The backscatter coefficient, S, depends on the type of fiber being tested, and is proportional to the square of the ratio of the fiber's numerical aperture to its core index

$$S = (\mathrm{NA}/n)^{2} \qquad \textbf{[4.7]}$$

It can be seen that the backscatter level is proportional to the square of the numerical aperture. This is the reason the backscatter level (when testing single-mode fibers) rises at some splice points. Suppose, for example, that the fiber on one side of a splice is standard single mode, with a numerical aperture of 0.13, and the fiber on the other side of the splice is dispersion-shifted single mode, with a numerical aperture of 0.17. The difference in backscatter level for these two fibers is about 1.2 dB. Consequently, as long as the fusion splice has less than about 0.6 dB of loss, the backscatter level increases across the splice. This gives the mistaken impression that the splice is a point of power amplification and is sometimes referred to as a *gain splice.*

4.14 FRESNEL REFLECTIONS

When light travelling through a dielectric medium encounters a discontinuity in the index of refraction, a portion of the light transmits through the discontinuity and a portion is reflected. Discontinuities in fiber-optic systems typically occur at connectors, mechanical splices, and cut, or cleaved, fiber ends. For connectors and mechanical splices the manufacturer's specifications will commonly use the term optical return loss (ORL) when stating their values.

For a perpendicularly cleaved fiber, the reflection from the end is

$$R = \left(\frac{n_t - n_i}{n_t + n_i} \right)^2 \qquad \textbf{[4.8]}$$

where *nt* is the index of the medium into which the light transmits and *ni* is the index of the fiber. For air, the index is approximately 1.000; for single-mode optical fibers the index is about 1.468. The reflection from a square fiber cleave is about 3.6%, or -14.4 dB.

4.15 LIMITATIONS OF OTDR

The limited distance resolution of the OTDR makes it very hard to use in a Local Area Network (LAN) or building environment where cables are usually only a few hundred meters long. The OTDR has a great deal of difficulty resolving features in the short cables of a LAN and is likely to show "ghosts" from reflections at connectors.

Critics charge that it can produce inaccurate results if two trouble spots are very close together or if the pulse has a long travel length. Experts also urge training in order to interpret the data correctly. Another factor is the relatively high price for a device that might be used only sparingly. Proponents, however, counter that being able to pinpoint and address light loss points is well worth the price, both for the OTDR device and for the training needed to operate and properly understand the data that OTDR records.

CHAPTER-5

DESIGN STRATEGY AND HARDWARE SPECIFICATIONS

5.1 INTRODUCTION

Optical loop tester is a device which implements a specific functionality of OTDR, that is, to detect the location of a cut in the optical fiber using single ended measurement. A fiber cut means, a refractive index discontinuity (such as a glass to air interface), resulting in reflections (Fresnel reflection) which are processed for the localization of the fault. By knowing the speed of light in the fiber and the time lapsed between the launched pulse and the received pulse, the distance at which fiber cut has occurred is determined.

5.2 OVERVIEW OF OPERATION

The measurement starts by launching a narrow pulse of light into the optical fiber by a Laser diode through a coupler. As the pulse of light propagates through the fiber, part of it is back scattered into the launching end through various mechanisms with Raleigh scattering being the dominant one. At points where there is a refractive index discontinuity (such as a cut in the fiber or a splice), some of the light is reflected back (Fresnel Reflection). For a break in the fiber (fiber-air interface), the reflections are typically around 4% of the incident power level (14dB below the incident pulse). The measurement of the distance at which the fiber is cut, involves the detection of this reflected pulse. Knowing the refractive index of the fiber (and hence the propagation velocity through the fiber), and measuring the time interval between transmitted and reflected pulses, the location of the fiber cut can be calculated. The measurement of loss curve and other characteristics involve capturing, storing and processing the entire trace of scattered and reflected light.

A photo-detector, also connected to the fiber through the coupler collects the back scattered/reflected light. The received signal is amplified and sampled using a high speed Analog to Digital Converter (ADC). A sophisticated data acquisition system stores the trace for the intended length of time. A Digital Signal Processor performs the computations with the trace to recover parameters of interest. One common practice to improve measurement SNR is to do multiple trace measurements and average them. Finally, the data is transferred to the host PC from where it can be directed to an output device (screen/printer). The proposed design of Optical Loop Tester is shown in the figure 5-1.

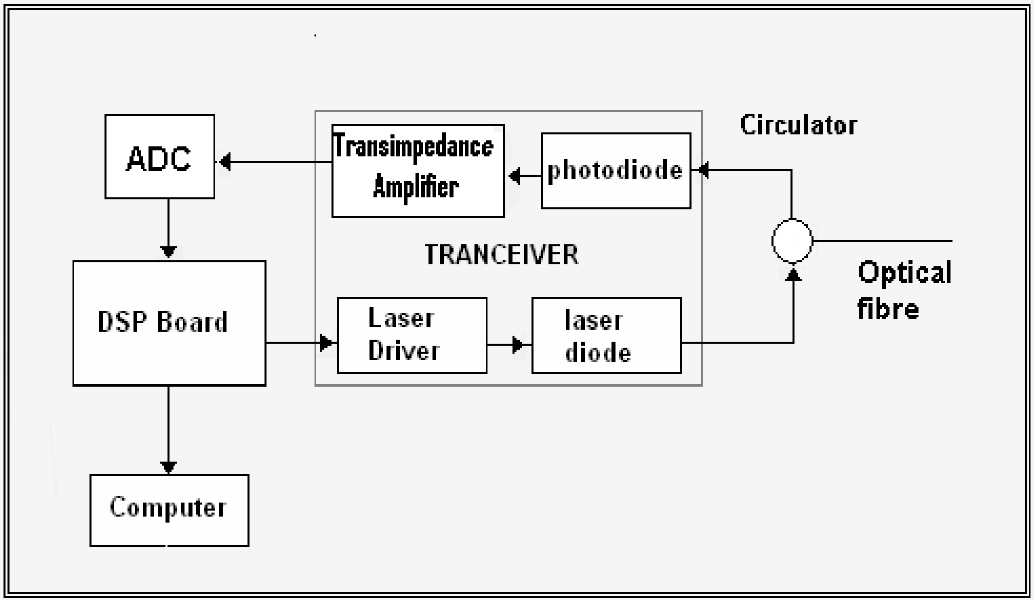


Figure 5-1 Proposed Design of Optical Loop Tester

5.3 HARDWARE SPECIFICATIONS OF THE SYSTEM

The complete system consists of two modules:

1) Daughter Card comprising Optical Transceiver and Analog Front-end

2) Digital Signal Processing Board (Motherboard)

5.3.1 DAUGHTER CARD

- Optical Transceiver
- Analog-to-digital Converter

5.3.1.1 OPTICAL TRANSCEIVER

The Optical Transceiver comprises of:

- Laser Driver
- Laser Diode
- Circulator
- Photodiode
- Trans-impedance amplifier

The Optical interface consists of the Laser diode and a photo detector which connect to the under-test optical fiber through an optical circulator. The Laser diode is controlled by a Laser switch which is a separate IC component. It controls the Laser pulse width based on the width of a control pulse received from the signal processing board through the DSP/AFE connector and also the magnitude of current which is to be supplied to the Laser Diode.

The external interfaces on this board are:

- **Optical Circulator:** Allows coupling of Laser diode and photo detector and connects them to the optical fiber under test.

- **Analog-to-digital Converter (ADC):** Allows the optical board to be connected to the AFE board. Thus laser diode injects the laser pulse into 3-port circulator whose second end is connected to the optical fiber cable and the received reflected pulse is then transferred to the third port which connects with the photodiode and converts the light signal into electrical signal. A trans-impedance amplifier converts the photo detector's current (which is a linear function of received optical power) into a differential voltage signal which is fed to the Analog-to-digital convertor.

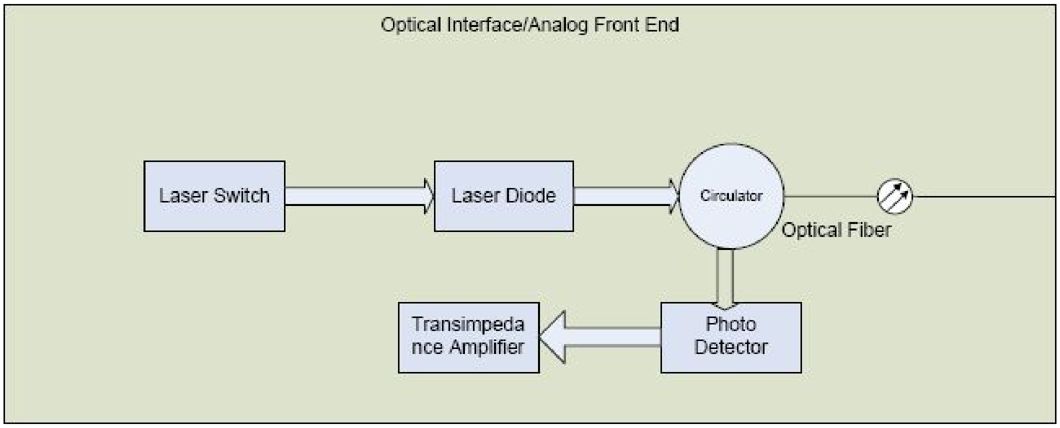


Figure 5-2 *Optical interface of the PCB Design module of OLT*

5.3.1.1.1 LINK BUDGET ANALYSIS

For selecting the appropriate power levels for our Laser diode (transmitter) and the sensitivity of the APD (receiver) required for the OLT application, link budget analysis is carried out, considering all the losses which occur while using a 10 Kms long fiber cable, as the laser pulse leaves the Laser Diode and the reflected pulse reaches the receiver.

Input power at the transmitter = 110 mW

= 20.41 dBm

Losses = connector loss + insertion loss of circulator + fiber length loss + termination or cut loss + other losses

Losses = (0.8 db x 4) + (0.8 X 2) + (0.35 X 10 km) + (14.4) + (10)

= 32.7dB

Received power at the photodiode = 20.41dBm - 32.7dB

= -12.29dBm

= 0.0590 mW

5.3.1.1.2 LASER DRIVER

For operating the laser diode in the pulse operation, a switch is requires that can turn on and off the laser diode for specific period of time and provide laser diode the current for producing the required power of the optical pulse. For this, laser driver was the best option for laser diode operation. The main parameters for selecting the laser driver are its switching frequency and the pulsed output current it can provide for producing the required optical power.

Thus after seeing the specifications of the laser diode, it requires 400mA current for producing an 80mW optical pulse. So we selected the laser diode which can switch in 700mA current into the laser diode. For the switching frequency we decided to select the maximum switching frequency to be 155 MHz, however at the moment we are switching the laser diode at 14 MHz, but we provided this provision for future upgrades.

The interface circuitry for the laser driver and laser diode is shown in figure 5-3:

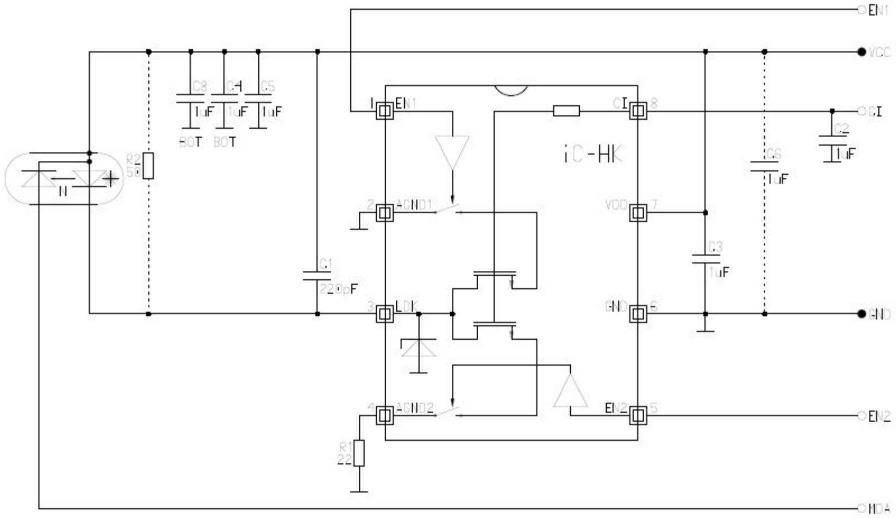


Figure 5-3 Circuit of Laser driver for pulsed current operation of Laser Diode.

The duration for which the laser diode is switched on is controlled by the enable pin. The time for which the high signal is applied to the enable pin the current flows through the laser diode and light pulse is generated. Signal Patterns for pulse current of 100mA is shown in the figure 5-4:

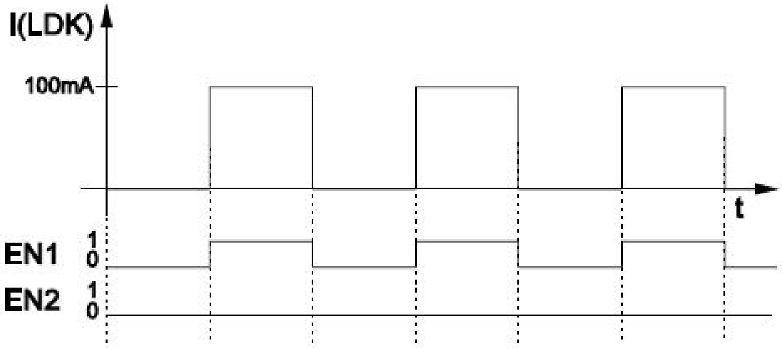


Figure 5-4 *Signal Patterns for pulse current of 100mA*

The amount of current is controlled by the voltage at the V(CI) pin. Thus greater the voltage greater will be the amount of the current flowing into the laser diode.

The V(CI) voltage and the corresponding current curves for different resistances are given below in figure 5-5:

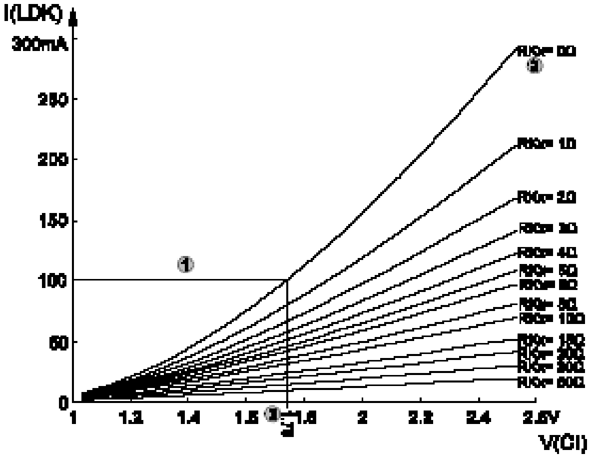


Figure 5-5 Determining V(CI) for pulse current of 100mA

5.3.1.1.3 LASER DIODE

A laser diode is a laser where the active medium is a semiconductor similar to that found in a light-emitting diode. The most common and practical type of laser diode is formed from a p-n junction and powered by injected electric current.

The laser diode being used, is a 1310 nm newly developed Strained Multiple Quantum Well (strained-MQW) structure pulsed laser diode coaxial module with single mode fiber. It is designed for a light source of optical measurement equipment (OTDR).

It provides high output power of 110 mW at a current of 400 mA which is provided by the laser driver to drive the laser diode. It supports a pulse width of upto 10 us and has rise and fall times of 1ns each.

A typical performance curve of the laser diode used is shown in the figure 5-6:

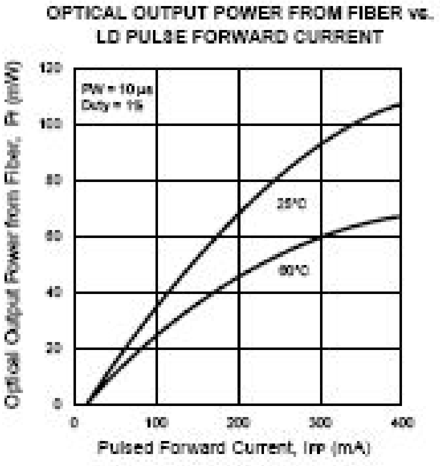


Figure 5-6 A Typical Performance Curve of the Laser Diode

5.3.1.1.4 OPTICAL CIRCULATOR

Optical circulator is a special fiber optic device that is capable of separating optical power travelling in opposite directions in one optical fiber. It can be used to achieve bi-directional transmission over a single fiber. Because of its high isolation between the input and reflected optical power and its low insertion loss, optical circulator is widely used in advanced communication systems and fiber-optical sensor systems. Circulator that has been used is a special wavelength circulator covering standard 1310nm wavelength window. It is a 3-port circulator. A high-power light pulse is input to it at port 1. This pulse is coupled to fiber under test through port 2. Light which is reflected back is separated from the outgoing signal by the circulator and routed to port 3. Port 3 is connected to the photodiode at the receiving end. Thus, the circulator acts as a splitter.

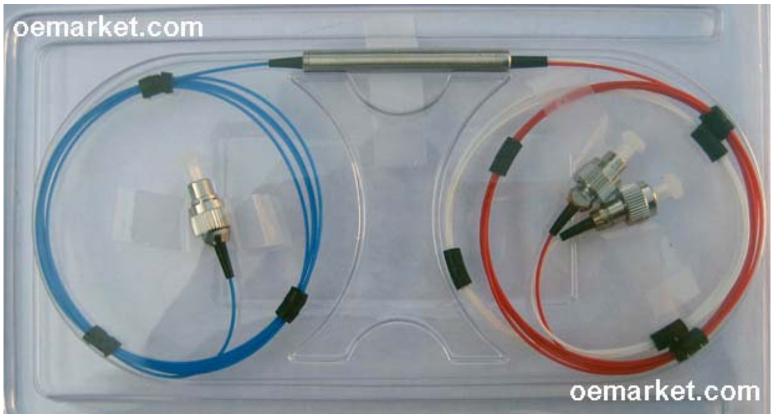


Figure 5-7 3-port circulator

5.3.1.1.5 PHOTO-DIODE

A photodiode is a type of photo-detector capable of converting light into either current or voltage, depending upon the mode of operation. Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fiber connection to allow light to reach the sensitive part of the device.

PIN photodiodes are designed for optical network monitoring applications. The photodiode die is fabricated with a proprietary InGaAs in a wafer fabrication and assembled into a hermetically-sealed package with antireflective-coated lens. A stainless steel bushing is used to actively couple the fiber to the package. The fiber is reinforced with the rubber boot, which relieves fiber bending stresses.

5.3.1.1.6 TRANSIMPEDANCE AMPLIFIER

Trans-impedance amplifier is a type of amplifier which converts current into voltage and amplifies it by multiplying the input current by the gain resistor. A typical circuit of a Trans-impedance Amplifier is shown in the figure 5-8:

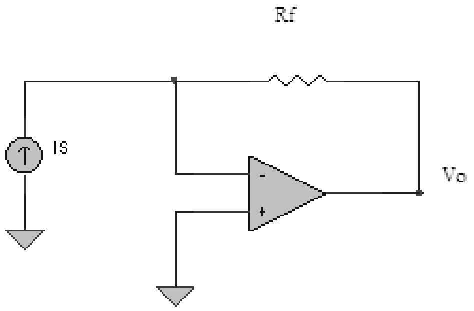


Figure 5-8 Trans-impedance Amplifier (Current to Voltage conversion)

The op amp current-to-voltage converter (trans-impedance amplifier) is a fairly simple circuit. Two key principles clarify operation of a current-to-voltage converter:

1. Because no current flows into the op amp itself, the current IS has nowhere to go but through the resistor RF.
2. One leg of RF is held at ground potential (0V). The main job of the op-amp is to adjust the output such that the inverting input equals the non-inverting input. And, because the non-inverting input is at ground (0V), the inverting input along with RF will be held at 0V.

The output Vo can be described simply as the voltage across the resistor VRF.

$$Vo = VRF = -IS \times RF \qquad \textbf{[5.1]}$$

Thus we have to select the appropriate value of gain resistor Rf so that the output voltages remain in the Analog Front End input voltage range.

The part number selected for the OLT application gives an output voltage signal of 1 V p-p. The ADC which converts this voltage signal to digital should accept differential input of the same voltage swing.

5.3.1.1.7 ANALOG TO DIGITAL CONVERTER

The analog front end (AFE) comes as an analog to digital interface between the optical transceiver and the Digital Signal Processing Board. It comprises of a 10-bit Analog to Digital Converter.

The ADC converts the analog signal into the digital form by sampling and quantization. The resolution of the ADC selected is 10 bit, i.e. it can represent 1024 levels. The sampling frequency of the ADC is selected according to the Nyquist Criterion; i.e sampling frequency should be at least double the signal frequency to protect the signal from being distorted when recovered.

The part selected for ADC is a monolithic, 10-bit, with analog-to-digital converter fabricated in a CMOS process. It has a sampling rate of 20 MSPS and is designed for high speed applications where wide bandwidth and low power consumption are essential. It accepts a differential input with a voltage swing of 1 Vp-p. Its high sample clock rate is made possible by a fully differential pipelined architecture with both an internal sample and hold and internal band-gap voltage reference. Thus we selected the ADC having sampling frequency to be 20MHz that is the maximum signal frequency that can be applied is 10MHz. The Output of the ADC is CMOS and TTL compatible, and can be interfaced to TMS320C6713.

5.3.2 DIGITAL SIGNAL PROCESSING BOARD

The DSP Board is used as a control unit for the system. It is responsible for giving control signals to the ADC and Optical transceiver attached to it. Its main function is Data Acquisition from the ADC, Pulse generation for the Optical transmitter and generating clock for the ADC. It also performs synchronisation of the Data Acquisition.

The TMS320C6713 Digital Signal Processesor Starter Kit is incorporated in the design of OLT. The TMS320C67x™ DSPs (including the TMS320C6713 device) compose the floating-point DSP generation in the TMS320C6000™ DSP platform. The C6713 device is based on the high-performance, advanced very-long-instruction-word (VLIW) architecture developed by Texas Instruments (TI), making this DSP an excellent choice for multichannel and multifunction applications.

CHAPTER-6

IMPLEMENTATION ON THE DIGITAL SIGNAL PROCESSING BOARD (TMS320C6713)

6.1 INTRODUCTION

The design and implementation of the Optical Loop tester system is accomplished using TMS30C6713 Digital Starter Kit (DSK) from Spectrum Digital. The DSP Board is used as a control unit for the system. This chapter provides a hardware and software solution for interfacing the designed hardware with the DSK. It describes various peripherals of the DSK that are used in this application, their functionalities and configuration. The architecture used for data acquisition, control signals and interfaces.

6.2 OVERVIEW OF OPERATION

The Optical Transceiver plugs in as a daughter-card on the DSK, which is programmed to give control signals to the daughter-card and to acquire trace data from the Analog Front-end. It then performs signal processing on this data and displays it on screen for analysis. The DSK interfaces to a computer.

The tasks performed by the DSK can be summarized as:

- Pulse Generation
- Data Acquisition
- Synchronization of Data Acquisition
- Clock generation for the ADC

6.3 PULSE GENERATION

The driver circuit for Laser diode needs a control pulse for operation of the Laser Diode.

The DSK should be able to provide accurate control pulses from 10ns to 10 us long. To meet this objective the General-purpose input-output (GPIO) peripheral on the DSK is used. The general-purpose input/output (GPIO) peripheral provides dedicated general-purpose pins that can be configured as either inputs or outputs. When configured as an output, the user can write to an internal register to control the state driven on the output pin. GPIO pin 4 is configured as an output pin to generate a pulse. It is given as an input to the laser driver circuit. The required pulse-widths can be modified in the software. The GPIO peripheral is configured through a number of registers including GPIO Enable Register (GPEN), GPIO Direction Register (GPDIR), GPIO Value Register (GPVAL). The GPIO pins are muxed with Host-port interface data pins on the DSK. An external pull-up resistor is used to bring out the GPIO signals [18].

6.4 DATA ACQUISITION

The DSK has to read data samples from the ADC at a rate equal to the frequency at which the ADC is operating. To meet this objective, External Memory Interface is used. EMIF is a daughter card interface on the DSK. EMIF support a glueless interface to a variety of external devices, including:

- Pipelined synchronous-burst SRAM (SBSRAM).
- Synchronous DRAM (SDRAM).
- Asynchronous devices, including SRAM, ROM, and FIFOs.

- An external shared-memory device [22].

The ADC output is interfaced to the DSK via the EMIF. ADC acts as an asynchronous device [23]. EMIF allows a high degree of programmability for shaping asynchronous accesses. The programmable parameters that allow this are:

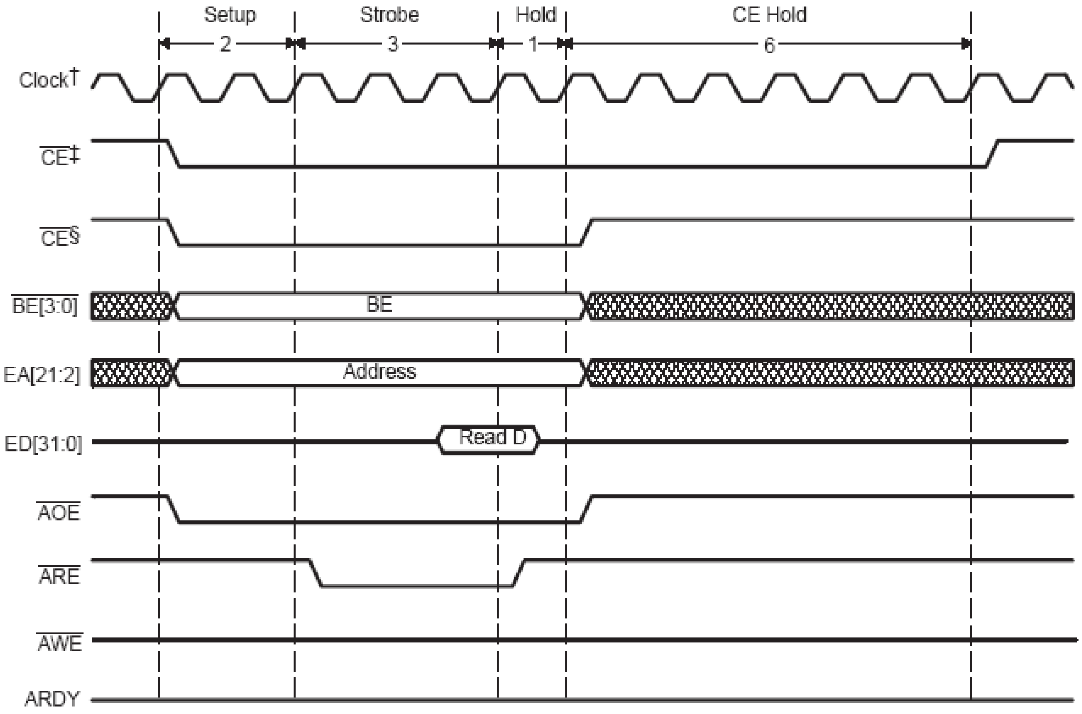
- **Setup**: The time between the beginning of a memory cycle (CE low, address valid) and the activation of the read or write strobe.
- **Strobe**: The time between the activation and deactivation of the read (ARE) or write strobe (AWE).
- **Hold**: The time between the deactivation of the read or write strobe and the end of the cycle (which can be either an address change or the deactivation of the CE signal) [25].

In the system, the reflected pulse from the cut is received by the Photo diode and it converts the light signal into current value and this current is converted into voltage with the help of Trans-impedance amplifier. The voltage from the Trans-impedance amplifier is converted into digital form by ADC which is actually a 10 bit ADC. The ten least significant places of the EMIF are connected to the ADC output. In the software these bits are extracted from the 32 bit interface by performing bitwise AND operation.

6.5 SYNCHRONISATION OF DATA ACQUISITION

The C6713 EMIF requires that a clock source be provided for the EMIF clock output signal (ECLKOUT). This clock is used for the synchronisation of the data acquisition. It is achieved by modifying the values for the setup, strobe and hold periods. Synchronisation ensures that the data is being read at the exact instant when the ADC output has stabilised. Thus, the EMIF clock is used to give offset to the EMIF read. The figure shows how the setup, read and hold value is used for synchronisation [25].

As the clock source the output of the SYSCLK3 is used. It is a clock output provided on the DSP board and controlled via Phase-locked Loop (PLL) controller [24]. An external source can also be utilized for this purpose. The ECLKOUT is produced internally (based on the source clock). All of the memories interfacing with the C6713 should operate off of ECLKOUT (EMIF clock cycle) [25]. Figure 6.1 shows how the setup, strobe and hold are inserted.



† Clock = CLKOUT1 for C620x/C670x
= ECLKOUT for C621x/C671x
= ECLKOUT1 for C64x
‡ $\overline{\text{CE}}$ waveform for C620x/C670x
§ $\overline{\text{CE}}$ waveform for C621x/C671x/C64x

Figure 6-1 *Synchronisation of Data Acquisition Example[25]*

The PLL controller is set to generate a clock at its maximum frequency that is around 100 MHz. We get period of 11 ns for this clock. The ADC clock's time period is 72 ns. Therefore, we give an offset of 5 EMIF clock cycles before reading the data. According to the ADC datasheet the output of ADC has stabilised till this time. The output of ADC was observed on a logic analyzer in conjunction with clock output for precise synchronisation of data acquisition.

6.5.1 PHASE-LOCKED LOOP CONTROLLER (PLL)

The PLL controller features software-configurable PLL multiplier controller, dividers, and reset controller. The PLL controller offers flexibility and convenience by way of software-configurable multiplier and dividers to modify the input signal internally. The resulting clock outputs are passed to the DSP core, peripherals and other modules inside the C6000™ DSP [24].

6.5.1.1 PLL CONTROL REGISTERS

The PLL controller registers configure the operation of the PLL controller. The PLL controller registers are listed [24].

- Controller Peripheral Identification Register (PLLPID PLL)
- Control/Status Register (PLLCSR PLL)
- Multiplier Control Register (PLLM PLL)
- Controller Divider Registers (PLLDIV0-PLLDIV3 PLL)
- Oscillator Divider 1 Register (OSCDIV1)

6.5.1.2 FUNCTIONAL DESCRIPTION OF MULTIPLIERS AND DIVIDERS

The PLL controller is capable of programming the PLL through the PLL multiplier control register (PLLM) from a ´1 to ´32 multiplier rate. The clock dividers (OSCDIV1, D0, D1, D2, and D3) are programmable from ÷1 to ÷32 divider ratio and may be disabled. When in PLL mode (PLLEN = 1), the input reference clock is supplied to divider D0. If D0 is enabled, D0EN = 1, the input reference clock is divided down by the value in the PLL divider ratio bits (RATIO) in PLLDIV0. The output from divider D0 is input to the PLL. The PLL multiplies the clock by the value in the PLL multiplier bits (PLLM) in the PLL multiplier control register (PLLM). The output from the PLL (PLLOUT) is input to dividers D1, D2, and D3.

When in PLL mode (PLLEN = 1), the input reference clock is supplied to divider D0. If D0 is enabled, D0EN = 1, the input reference clock is divided down by the value in the PLL divider ratio bits (RATIO) in PLLDIV0. The output from divider D0 is input to the PLL. The PLL multiplies the clock by the value in the PLL multiplier bits (PLLM) in the PLL multiplier control register (PLLM). The output from the PLL (PLLOUT) is input to dividers D1, D2, and D3. When enabled (DnEN = 1), the dividers D1, D2, and D3 divide down by the value in RATIO in PLLDIVn the output clock of the PLL. The output clocks of dividers D1, D2, and D3 have 50% duty cycle and are SYSCLK1, SYSCLK2, and SYSCLK3, respectively. The SYSCLK3 acts as the clock source for the EMIF clock [24]. The divider D3 is assigned a value so that EMIF clock operates at its maximum rate of around 100 MHz. The output was verified on a Logic Analyzer.

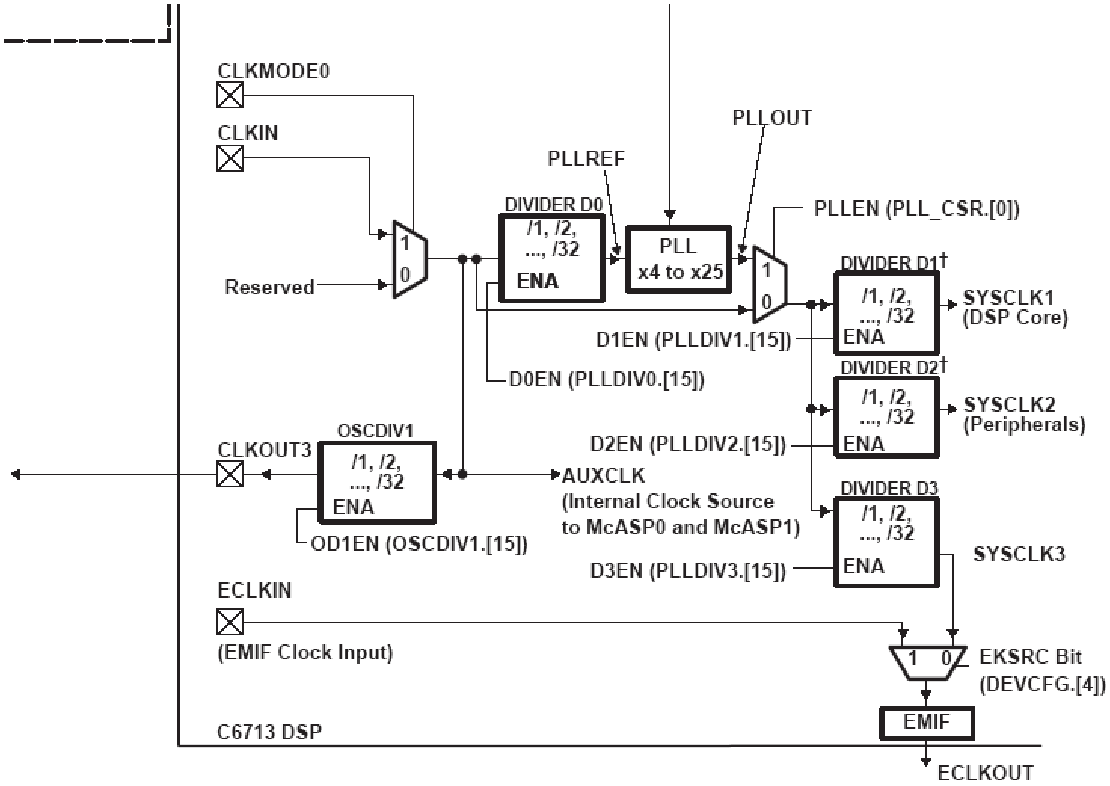


Figure 6.2 Diagrammatic Description of Multipliers and Dividers in PLL Controller [24]

6.6 CLOCK GENERATION FOR THE ADC

An ADC requires a clock for its operation. The data conversion is performed according to this clock. According to the datasheet of the ADC used for the OLT, at each rising edge of the clock the data conversion starts. The DSK is responsible for providing the ADC clock. This objective is achieved by using a 32-bit General-purpose Timer on the DSK. The 32-bit general-purpose timers that can be used to generate periodic hardware interrupts.

The timers are clocked by an internal on-chip oscillator source. The timers have an input pin and an output pin. The input and output pins, (TINP and TOUT) can function as timer clock input and clock output. The output pin of Timer 1, that is, TOUT1 is used for clocking the ADC. With an internal clock the timer signals the ADC converter to start a conversion. The internal timer input clock source frequency is CPU rate/4 [16].

6.6.1 TIMER REGISTERS

There are three registers that configure timer operation:

- **Timer Control (CTL)**: It determines the operating mode of the timer, monitors the timer status, and controls the function of the TOUT pin.
- **Timer Period (PRD)**: It contains the number of timer input clock cycles to count.
- **Timer Counter (CNT)**: It gives the current value of the incrementing counter.

Once the timer reaches a value equal to the value in the timer period register (PRD), the timer is reset to 0 on the next CPU clock. The figure shows a clock cycle of the timer.

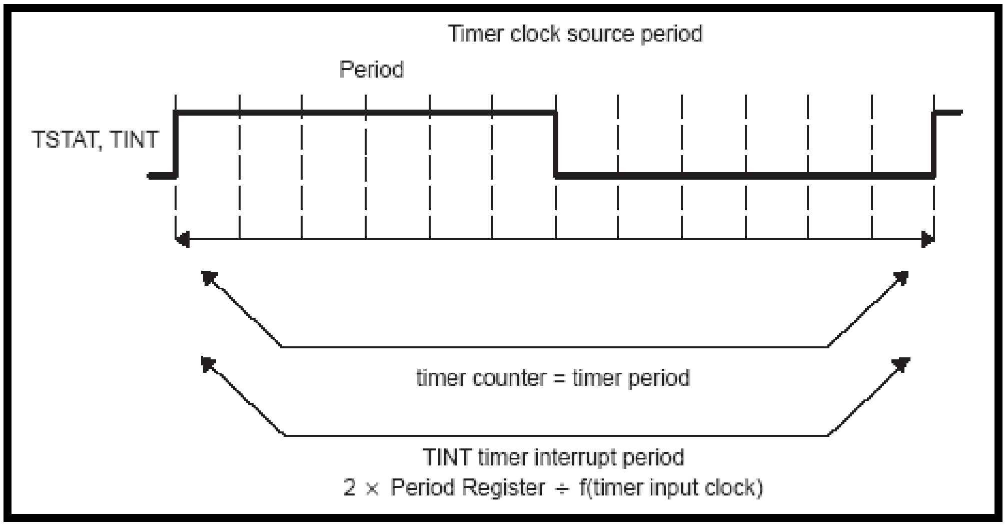


Figure 6-3 Timer Operation in Clock Mode [17]

The frequency of the timer is set by writing to the timer period register according to the following formula:

$$\text{Frequency} = f\ (\text{clock source}) / 2 * \text{timer period register} \qquad \textbf{[6.1]}$$

The operating frequency for the ADC is 20 MHz. However, the timer register can be configured to generate 14 MHz or 28 MHz as closest to 20 MHz. A frequency of 14 MHz is set on the timer as ADCs can operate at any frequency less than or equal to their operating frequency.

6.7 HARDWARE CONNECTIONS

The DSK is used as a control unit for the complete system. It interfaces to the Optical transceiver as a mother board. It gives control signals e-g hardware interrupts and clocks to the daughter-card. The function of data acquisition from the Analog Front-End is also performed by the DSK. The synchronisation for data acquisition is performed so that there is no data loss.

The hardware connections described in this report are shown in the figure 6.4. The DSK Timer1 output is connected to clock input of the ADC. The GPIO pin 4 is connected to the laser driver circuit. GPIO performs the function of generating a pulse for the laser diode. 10-bit output of ADC is given as input to the EMIF data pins. The daughter card is given 5V power supply from the DSK.

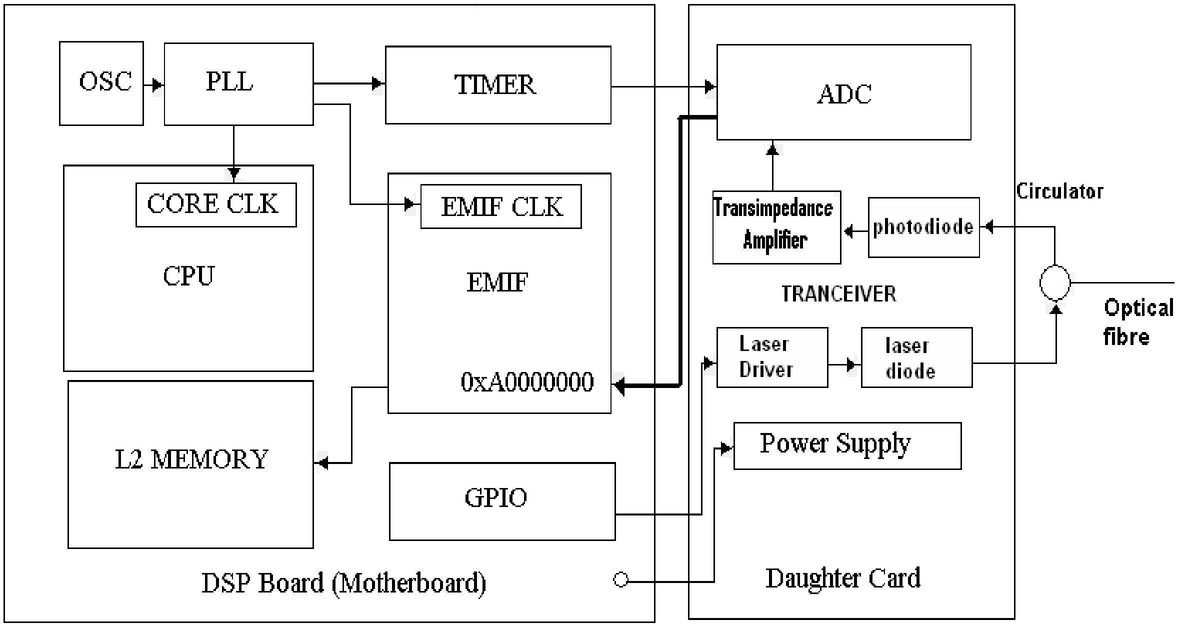


Figure 6.4 Hardware Connections of the DSK to the PCB Design

6.8 SOFTWARE INTERFACE

The software interface objective is to read data samples from the EMIF at the rate at which ADC is operating. The Timer1 output is used as the operating clock for ADC. The frequency of timer1 can be modified by writing to the timer register. The software algorithm developed uses an interrupt routine triggered by timer interrupts to read samples from the ADC at the required frequency. A sample is read each time the Timer1 output ticks [23]. The objective of pulse generation is achieved through GPIO. A single pin of GPIO is configured as an output pin for this purpose. The pulse-width has to be defined in software. It is to be noted that the software is capable of generating a pulse of width between 100 ns and 10us. It is critical to have a pulse of precise pulse-width for accurate readings. Finally, the synchronisation for data acquisition needs to be performed so that no sample value is lost or over-written. The EMIF provides a clock for this purpose. It is a high frequency clock used to give offset to the EMIF data read.

The data is read at the instant when the ADC values are settled. For more information on changing the values of registers of the Timer, GPIO or EMIF peripherals, see references [19], [20], [21].

6.9 MEMORY ARCHITECTURE OF THE DSK

The C6713 uses a two-level cache-based architecture. The Level 1 program cache (L1P) is a 4K-Byte direct-mapped cache and the Level 1 data cache (L1D) is a 4K-Byte 2-way set-associative cache. The Level 2 memory/cache (L2) consists of a 256K-Byte memory space that is shared between program and data space. 64K Bytes of the 256K Bytes in L2 memory can be configured as mapped memory, cache, or combinations of the two. The remaining 192K Bytes in L2 serves as mapped SRAM [22]. The L2 is configured as mapped memory and is used for storing the captured data for analysis.

CHAPTER-7

ANALYSIS AND TESTING

7.1 INTRODUCTION

This chapter describes the setup for testing the complete optical Loop tester system implemented in hardware. The results are discussed and possible future enhancements for the project are described.

7.2 TESTING

For testing the hardware and software assembly we setup the optical transceiver assembly and connected it with the optical circulator, whose port 1 was connected to the laser diode, port 2 was open (fiber end) and port 3 had a photodiode. Since the port 2 is open this means that we have setup a system for a fault at approximately 0m as it has an open end in the beginning.

As the program is run, the data acquisition starts first, followed by the launching of the pulse at a pre-defined sample number. The GPIO generates an enable pulse for the optical loop tester for making a measurement.

The key data processing activities are real-time trace measurement, and trace processing. These activities are individually described in the following.

7.2.1 REAL-TIME MEASUREMENT

Real time measurement of optical power trace involves firing a controlled width pulse of Laser into the optical fiber and capturing the received power trace for a specified period of time. The process might be repeated multiple times if averaging is to be performed.

7.2.2 DATA PROCESSING

Trace processing involves extraction of various parameters of interest from the data captured during measurement. The currently envisaged parameter is the length of the fiber or the location where the fiber is broken. Future enhancement might involve measurement of return loss, locations of splices etc.

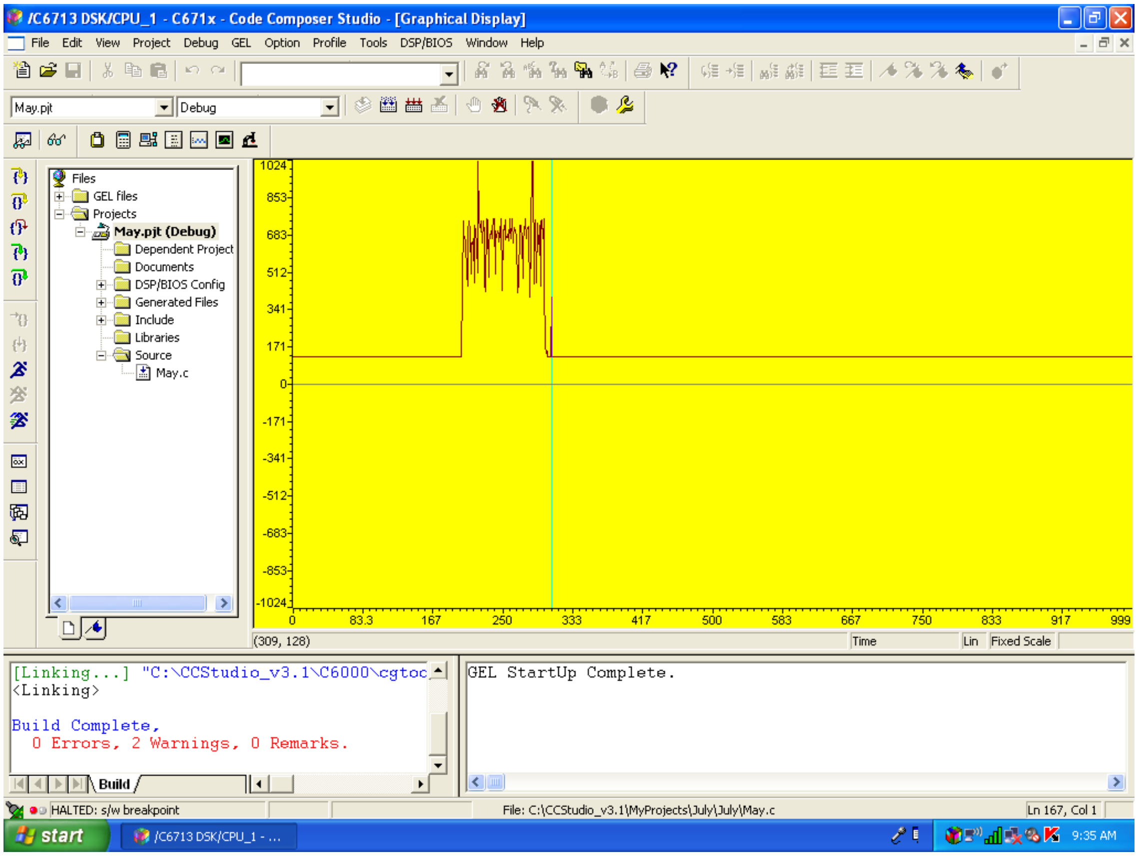
7.2.2.1 PEAK DETECTION

For the calculation of the distance of the fault the peak is to be detected in the received data. As the peak is received from the place where the cut is situated, the main task of the program is to detect the peak and then to perform calculations on basis of the speed of the light in the optical fiber to get the distance.

A function was written for the detection of the peak in the data which will specify the region of the peaks in the data on basis of the distance of the peak from the testing point.

7.3 RESULTS

When the system starts the GPIO generates a pulse of 7.2 micro-second at sample number 200 which triggers the laser diode for this period. Thus the light pulse travels through the circulator and after being reflected from 0m, it is detected by the photodiode which converts light back into electrical signal, which is then sampled at 14MHz and the data received is captured. The trace that was captured on the Code composer Studio is shown in figure 7.1.



```
[Linking...] "C:\CCStudio_v3.1\C6000\cgtoc
<Linking>

Build Complete,
  0 Errors, 2 Warnings, 0 Remarks.
```

```
GEL StartUp Complete.
```

```
HALTED: s/w breakpoint
File: C:\CCStudio_v3.1\MyProjects\July\July\May.c
Ln 167, Col 1
```

Figure 7.1 *Trace of the reflected pulse at 0m distance*

It meets the requirement as the pulse is received at sample number 200 which is the sample number at which it was launched. This shows that the pulse is reflected from 0m distance. The fiber to be tested is then connected with the system. The pulse is now received at an offset of 20 samples. This corresponds to a length of 200 meters for the fiber. The result matches with the actual length of the fiber that is 200 meters.

7.4 CONCLUSION AND FUTURE ENHANCEMENTS

From all the above discussion we conclude that Optical Loop Tester is a device which can locate the fiber cut in any fiber optics network scheme. It implements a specific functionality of an OTDR. The Fault-finding functionality is the most useful one of an OTDR. It is common for network operators to be only interested in locating cuts in an Optical fiber network. An OLT provides a low-cost solution for such a scenario. However for future advancements to make it an OTDR, further algorithms and routines can be defined so that the device can perform other functionalities of the OTDR like attenuation, splice loss and connector loss in the future upgrades of this device. Moreover in future it can be upgraded to having a PCI interface so that it just becomes one whole system on board and could be placed remotely anywhere to take the trace and transfer it to the control centre remotely.

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