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Optical Fibre Line Failure Detecting

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ABSTRACT

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With the development of modern communications, in order to meet the needs of social development and technological progress the optical fibre communications has become the main communication medium for its high reliability and security. Fibre-optic cable is the channel for signal transmission. It is an important component in the entire fibre-optic network. Once the fibre-optic cable fault happened, the entire communication system would be impacted seriously. When fault occurs, it is important to find out, locate it accurately, and remove it quickly.

In this thesis, firstly we briefly describe the status of fibre optic communication technologies. Secondly is to introduce the definition and general characteristics of the fibre optic line communication. Then according to the causes and characteristics of fibre-optic cable fault, we use the Optical Time-Domain Reflect meter (OTDR) to test the line, determine the position and feature of the error point. Finally we get the solution to fix the problem.

KeyWords: Optical Fibre, Synchronous Digital Hierarchy, SDH Ring Protection, Optical Timer Domain Reflect meter, Fusion Splicing

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List of Abbreviations

ADM	Add-Drop Multiplexer
APS	Automatic Protection Switching
BDC	Backup Domain Controller
BER	Bite Error rate
B-ISDN	Broadband Integrated Service Digital Network
CD	Chromatic Dispersion
DCS	Cross-Connected System
DRI	Dual-Ring Interconnect
EMI	Electromagnetic Interference
EO	Electrical-to-Optical
GVD	Group Velocity Dispersion
LD	Laser Diode
LED	Light-Emitting Diode
LOF	Loss of Frame
LOS	Loss of Signal
MMF	Multi Mode Fibre
MS-SPRing	Multiplex Section-Shared Protection Ring
NE	Network Element
OSNR	Optical Signal-to-Noise Rate
OTDR	Optical Time Domain Reflect meter
PDH	Plesiochronous Digital Hierarchy
PMD	Polarization Mode Dispersion
PTE	Path-Terminating Equipment
RFI	Radio Frequency interference
SAN	Storage-Area Network
SDH	Synchronous Digital Hierarchy
SNCP	Sub Network Dependent Conversion Protocol
SONET	Synchronous Optical Networking
STM-N	Synchronous Transport Module Level N
TM	Terminal Multiplexer
VCSELs	Vertical Cavity Surface Emitting Lasers
WDM	Wavelength-Division Multiplexing
WTR	Wait to Restore

1. Introduction

1.1. Background description

Optical fibre is made of brittle glass. Usually its external diameter is 125μm. The core diameter of single mode fibre is only 7-8μm. For multimode fibre core diameter is 50μm. During the installation, connector may be broken, bilging and natural aging due to reason of the brutal work, strong external impact, all these elements will lead to the fault of optical fibre transmission system.

Cable communication failure not only gives a direct economic loss to the operators, but also causes great social influence as it brings inconvenience to the people's life. Therefore, it is important to ensure the wellness of optic fibre cable. Repair and maintenance of cable communication have a profound significance.

At present, majority of Chinese information capacity is transfer over the optic cable line. With the increase of optic fibre cable fault and optical fibre cable aging, the frequency of optic fibre line fault increases, and it is difficult to find error place in the traditional optical fibre management mode. It will take long time to eliminate failure factor, and affects the normal work of the network. Although nowadays ring network protection technology can guarantee the smooth and continue transmission in certain extent. But the shortcoming of traditional line maintenance still exists. So the implementation of the optic fibre cable line real-time detection and management, dynamic observations of the transmission properties of the optic fibre cable line degradation, the timely discovery and prevent hidden trouble, reduce the incidence of blocking become more and more important.

This project is done in Wuhan Post and Telecommunication Research Institute. The purpose of this project is finding the fault in the optical fibre line and use the fusion splicer to connect the fault point. In order to achieve this goal, Synchronous Digital Hierarchy (SDH) manage systems will inform the maintainers when fault happens, and then we use the OTDR (Optical Time Domain Reflect meter)and fusion splicer instruments to test and reconnect the fault point. By doing this work, a thorough understanding of optic fibre link fault detection and repairmen is obtained. Measured data is analyzed by fibre optic theories and the result shows that the ODTR detection method works well in real situations.

The purpose and process of the optic cable line detection is to collect equipment state information, then list the collected data and analysis, finally we make an effective evaluation.

1.2. Outlines of the thesis

Chapter 1 of this paper briefly describes the reasons for failure of the optical fibre communication systems ; Chapter 2 introduce the optical fibre link components and Synchronous Digital Hierarchy ring protection mechanism and describes the basic composition and characteristics of the optical fibre cable line systems; Chapter 3 describes the commonly used instrument of detecting the optical fibre cable line fault; Chapter 4 introduces the OTDR mechanism and how to use the OTDR testing different features of the optical fibre cable; Chapter 5 depends on the OTDR detecting method to find the accurate fault position of fibre optic line ; Chapter 6 makes a summary for what we have learned during the whole process.

2. Principles of Fibre Optic Transmission

2.1. The fibre optic link

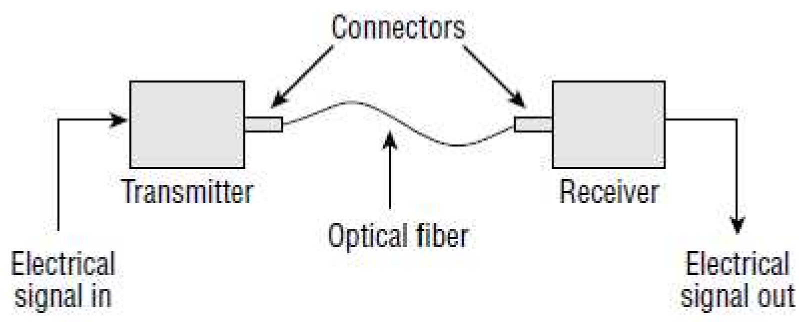

Figure 2.1. The fibre optic link /1/.

The only difference between the fibre optical links with other link is using optical fibre instead of wire. We can see following four basic components as Figure 2.1 shown:

- Transmitter which is used to convert a signal into the light and send the light
- Receiver which is used to capture the light and convert it back to a signal
- The optical fibre is the medium which is used to carried the light
- The connectors are used to link the cable between the transmitter and receiver

2.1.1. Optical transmitters

There are two functions of the transmitter. First, it is a light source launched into the optic fibre cable. Second, it modulates the light by the binary data it receives from the source. A transmitter's physical dimension must be compatible with the size of the fibre-optic cable being used. It means the light must being emitted in cone fibre with a cross-sectional diameter of 8 to 100 microns from the transmitter; otherwise, it cannot be coupled into the fibre-optic cable. The optical source must be able to generate enough optical power in order to meet the desired BER (Bite Error Rate). There should be efficiency in coupling the light generated by the optical source into the fibre-optic cable, and the optical source should have sufficient linearity to prevent the harmonics and distortion. It is extremely difficult to remove these interferences. The optical source must be easily modulated with an electrical signal and must be capable for high-speed modulation; otherwise, the bandwidth benefits of fibre-optic cable are lost. Small size, low weight, low cost and high reliability are also required. As Figure 2.2 illustrates the transmitter converts an electrical signal into light energy to be carried through the fibre optic link.

Figure2.2. Optical transmitter/1/.

2.1.2. Optical receivers

Figure 2.3 shows a schematic of an optical receiver. The receiver has two functions: it sense or detect the light coupled out of the fibre-optic cable and convert the light into electrical signal, and demodulate this light to determine the identity of the binary data that it represents. The receiver performs the Optical-to-Electrical (OE) transducer function.

A receiver is usually works with transmitter. Both are modules within the same package.

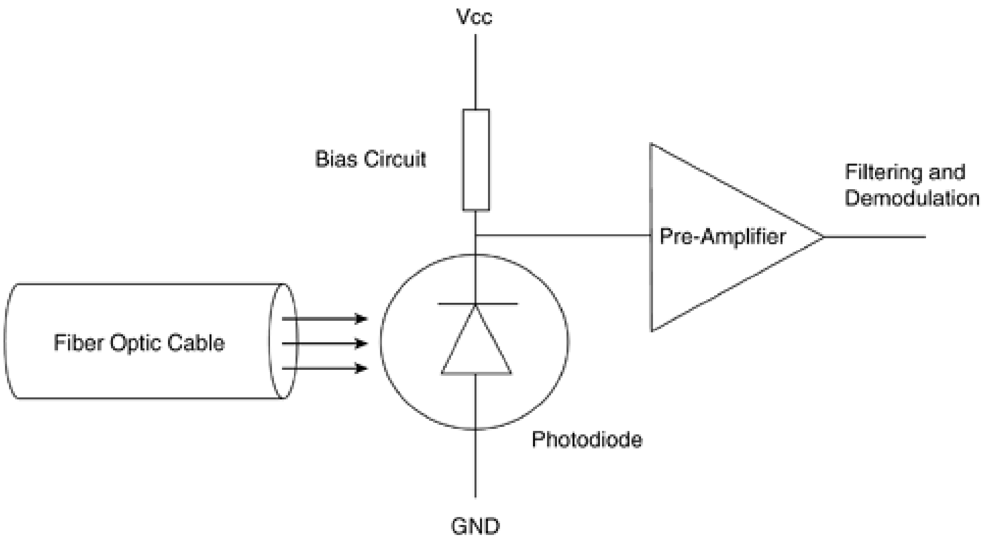

Figure 2.3. Schematic of an optical receiver/3/.

A receiver is usually works with transmitter. Both are modules within the same package. The light is detected by a photodiode and converts it to an electrical current. Due to the optical signal which transmitted from the fibre-optic cable and then demodulated to electrical current will have small amplitude. Consequently, the photodiode circuitry must quantities it by one or more amplification stages.

The receiver schematic in Figure 2.3 shows a photodiode, bias resistor circuit, and a low-noise pre-amp. The output of the pre-amp is an electrical waveform version of the original information from the source.

2.1.3. Optical fibre

We connect the transmitter and receiver by using the optical fibre to carry the signal. Different optical fibre is made of different material have different function depending on the requirements. The benefit we can get from the optical fibre is that it can transmit a large amount of light signal over a long distance and around corners.

“Optical fibres used in a fibre optic link have a core between 8 and 100 microns (millionths of a meter) in diameter. The cladding which surrounds the fibre may be as much as 140 microns in diameter. The optical fibre’s coating protects the cladding from abrasion. “Even with the thickness of the coating, however, optical fibre cable is much smaller and lighter than copper cabling, as shown in Figure 2.4, and can carry man times the information.” /1/

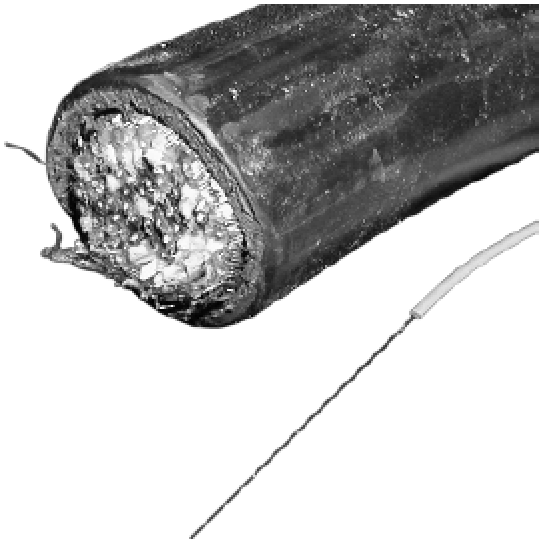

Figure 2.4: Comparison of fibre and copper cables/1/.

2.1.4. Connectors

Figure 2.5. Fibre optic connectors/1/.

The connector as Figure 2.5 shown is used to attach the optical fibre and provide the solid contact between mated transmitter and receiver. The connector must align the fibre end precisely with the light source or receiver to prevent signal loss.

2.2. Synchronous digital hierarchy

2.2.1. SDH concept

Synchronous Digital Hierarchy (SDH) is an international standard for wide band transmission hierarchy which defines the transmission rate, frame structure, multiplexing mode, and optical interface specifications of digital signal transmission. It is a synchronous system which intends to provide a more flexible, yet simple network infrastructure.

2.2.2. SDH generation background

With the development of information, modern society requires the ability of communication networks to provide various telecommunication services. The amount of information transmitted, switched, and processed by telecommunications network keeps increasing requiring modern communication networks to develop towards digitalization, integration and personalization.

Transmission system is an important part of communication networks. The quality of transmission system makes a direct effect on the development of communication network. Lots of countries construct the optical transmission network with larger capacity to develop the information highway. The optical transmission network based on SDH/WDM (Wavelength-Division Multiplexing) is the basic physical platform of the information highway. The transmission network should have universal unified interface specifications, so that every user in the world can communicate conveniently anytime and anywhere.

SDH has a lot of advantages /3/:

- First world standard in digital format.
- First optical interface.
- Transversal compatibility reduces networking cost. Multivendor environment drives price down.
- Flexible synchronous multiplexing structure.
- Easy and cost-efficient traffic add-and-drop and cross connect capability.
- Powerful management capability.
- New network architecture. Highly flexible and survivable self healing rings available.

- Backward and forward compatibility: Back compatibility to existing PDH (Plesiochronous Digital hierarchy) forward compatibility to future B-ISDN (Broadband Integrated Service Digital Network), etc.

When do we use SDH /3/:

- When network need to increase capacity, SDH simply acts as a mean of increasing transmission capacity.
- When network need to improve flexibility, to provide services quickly or to respond to new change more rapidly.
- When networks need to improve survivability for important user services.
- When networks need to reduce operation costs, which are becoming a heavy burden.

2.2.3. Basic SDH network topologies

Various topologies can be configured by using either SDH ADMs (Add-Drop Multiplexer) or DCSs (Cross-Connected System). The SONET (Synchronous Optical Networking) ring topologies are often used in North America, whereas Europe, Asia and Latin America mainly rely on SDH-based ring as well as meshed network topologies.

SDH point-to-point topology

Point-to-Point topologies are the method by using the dark fibre to connect two SDH PTEs (Path-Terminating Equipment) back to back. As describe in Figure 2.6, a point-to-point distribution include two PTE ADMS (Add-Drop Multiplexer) or TMs (Terminal Multiplexer) linked by fibre with or without an STE regenerator in the link. The TM can be used as an E1 concentrator and transport the E1 over an STM-N (Synchronous Transport Module Level N) link. Point-to-Point topologies are very popular to support Storage-Area Network (SAN) interconnectivity between data centres.

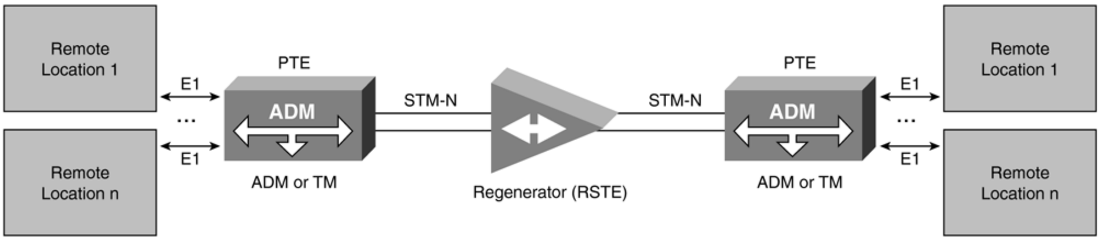

Figure 2.6. SDH point-to-point topology/3/.

Point-to-Point topologies use 1: N protection mechanisms for using one standby link to protect N active links. The best protection is obtained by using 1:1 ratio. Working path is used when the system is working in normal conditions. When the system fails, the protection path will be activated with a switchover time less than 50ms. Ideally, the protect path of fibre must use diverse physical routing to achieve maximum redundancy.

SDH point-to-multipoint topology

A point-to-multipoint architecture accomplish the adding and dropping of the circuits along the path. The SDH ADM in the middle is a unique NE specifically designed for this task. As illustrated in Figure 2.7, the ADM is usually works in an SDH link to facilitate adding and dropping of tributary or STM-N channels at intermediate points in the network. Compare with Point-to-Point topologies, this topologies also use 1: N protection mechanisms for one standby link is used to protect N active links. And also, maximum protection is obtained by using a 1: 1ratio or 1+1 topology.

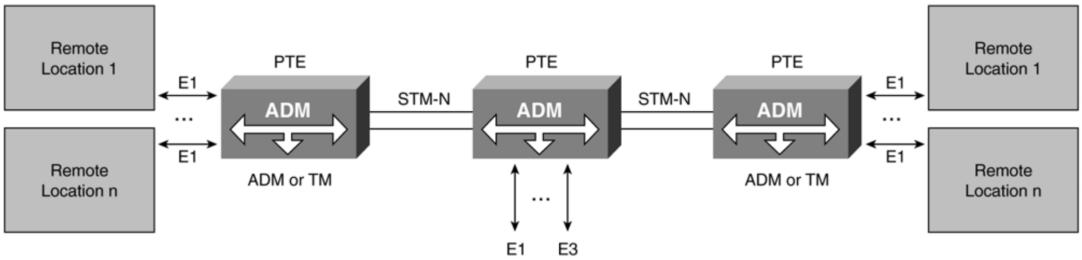

Figure 2.7. SDH point-to-multipoint topology/3/.

SDH hub topology

The hub network topology is a scalable architecture that uses PTE devices in a hub-and-spoke configuration. As illustrated in Figure 2.8, the hub is implemented as BDCs (Backup Domain Controller) that concentrates traffic are central site and allows cross-connecting services. During the BDCs implementation, we use two of more ADMs and a BDCS switch to allow the cross-connecting at both the SDH STS and the tributary level. Hub topologies have the same protection mechanism by using the 1: N protection method in which one standby link is used to protect N active links, with maximum protection obtained by using 1:1 or 1+1 protection.

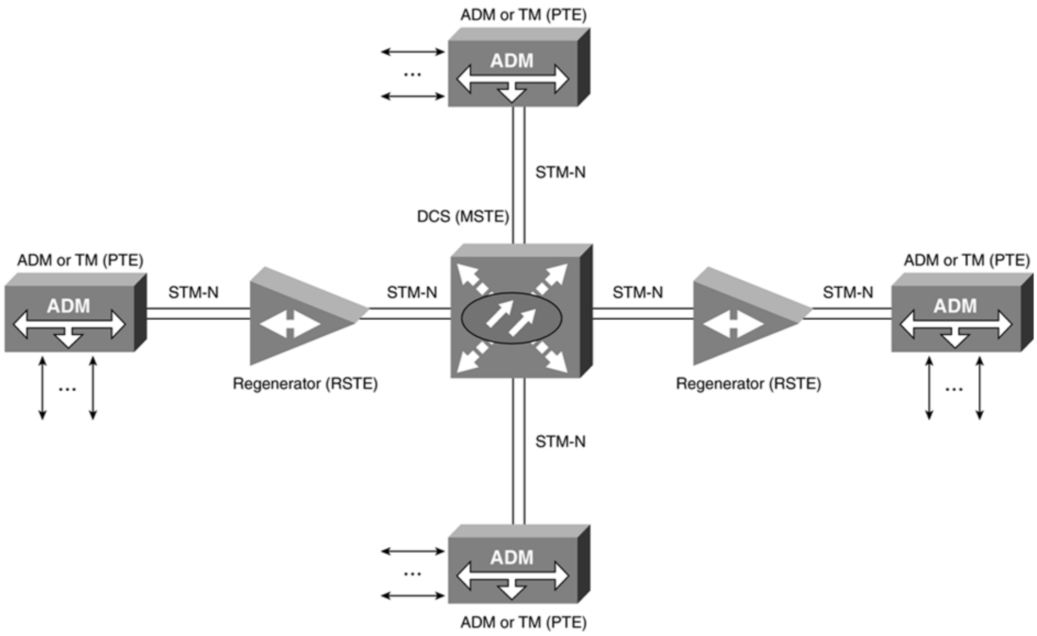

Figure 2.8. SDH hub topology/3/.

Ring topology

SDH rings provide low restoration times for the potent protection mechanisms. As Figure 2.9 show we use the ADM as the ring architecture in SDH building block. Multiple ADMS can be constructed as a chain for configuring the data flow for either bidirectional or unidirectional. The main advantage of the ring topology is the high survivability and low restoration. If the fibre cable is broken, the ADMs will automatic reroute the affected services by altering to the alternate path through the ring without interruption. The ability of survivable services, diverse routing of fibre facilities and flexibility of rearrange to alternate serving node, all these benefits has made rings become the most popular metro access and core SDH architecture. “Rings use advanced protection mechanisms and protocols, such as APS, Sub network Dependent Conversion Protocol (SNCP) two-fibre, MS-SPRing two-fibre, and MS-SPRing (Multiplex Section-shared Protection Ring) four-fibre.” /3/

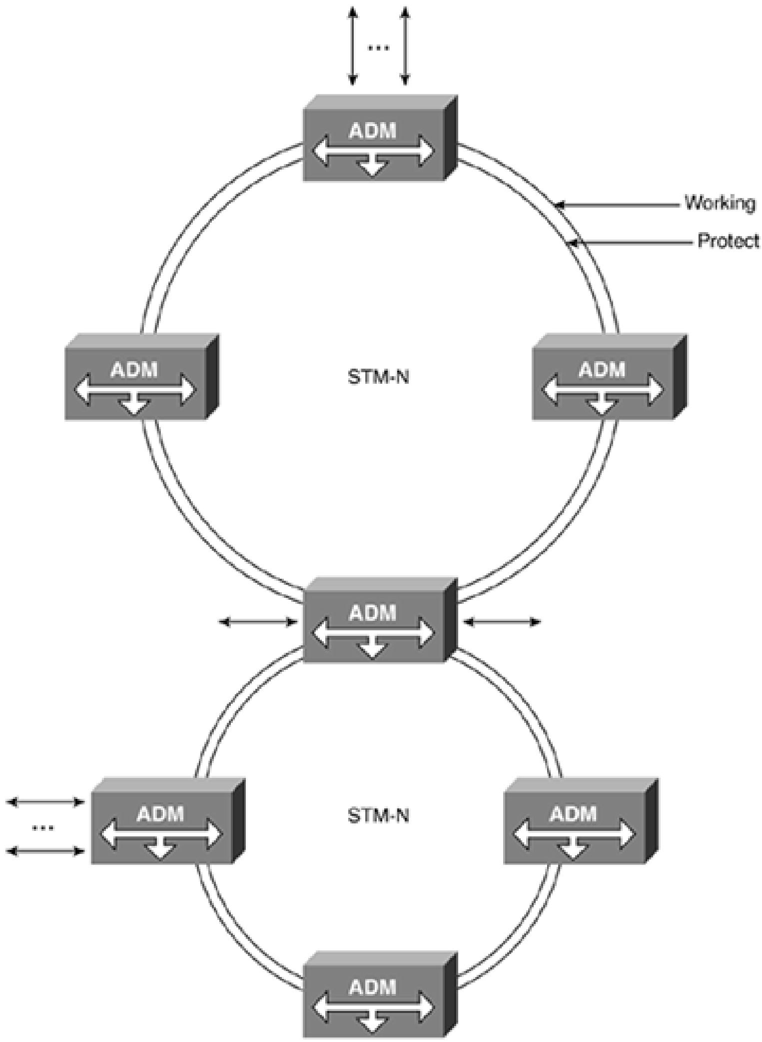

Figure 2.9. SDH ring topology/3/.

2.2.4. SDH protection architectures

In this section we will discuss different SDH protection architectures and mechanisms include APS (Automatic Protection Switching), linear and ring protection architectures. SDH defines a maximum switch of 50 ms for an MS-SPRing ring less than 1200km of fibre. According to the specification, it takes 10ms for discovery of the problem and 50ms to perform the switch, but commonly it usually completes the whole process in 50ms. Furthermore, most SDH networks work faster than this example. SDH protection will be active if there is an LOS (Loss of Signal), LOF (Loss of Frame), or even signal degradation, such as the BER(Bite Error Rate) exceeding a preconfigured limit. “Protection implies that a backup resource has been established for recovery if the primary resource fails, and restoration implies re-establishing the end-to-end path based on resource available after the failure.” /3/ SDH protection includes nonrevertive and revertive protection mechanisms. For the nonrevertice protection, the system will not choose reverted line as the working path by using the original protection line instead. With the revertive protection, the system reverts to the original line after restoration.

Automatic protection switching

APS (Automatic Protection Switching) is a solution to provide link recovery in case of failure. Link recovery is designed by having SDH devices with two sets of fibre. One set (transmit and receive) is used for working traffic, and the other set (transmit and receive pair) is used for protection. “APS protection can be configured for linear or ring topologies. Each type of topology has specific choice of 1:1, 1: N, or 1+1 protection. These can further be configured with unidirectional or bidirectional switching mechanism.”/3/

2.2.5. Common network elements in SDH network

SDH transmission network is composed by different types of Network Elements (NE) which are connected by optical cable. The following contents describe the characteristics and basic functions of common Network Elements (NE) in an SDH network.

Regenerator

The regenerator is a device that regenerates attenuated signals. After long distance transmitting between multiplexers, the signal level will attenuate too low to drive the receiver. The regenerator is sometimes called a repeater.

Terminal multiplexer

"The Terminal Multiplexer (TM) is a Path-Terminating Element (PTE) that can concentrate or aggregates DS1s, DS3s, E1s, E3s, and STM-Ns." /3/ Figure 2.10 shows a schematic of a TM. As we can see from this graph, DS1, E1 and E3 levels' signals is matched to their associated SDH electrical payloads in the TM. After the STM-N signals were launched into the fibre, Electrical-to-Optical (EO) conversion will be taken by the TM. "The TM is analogous to the channel bank in the TDM world and allows lower-speed user access to the SDH network." /3/

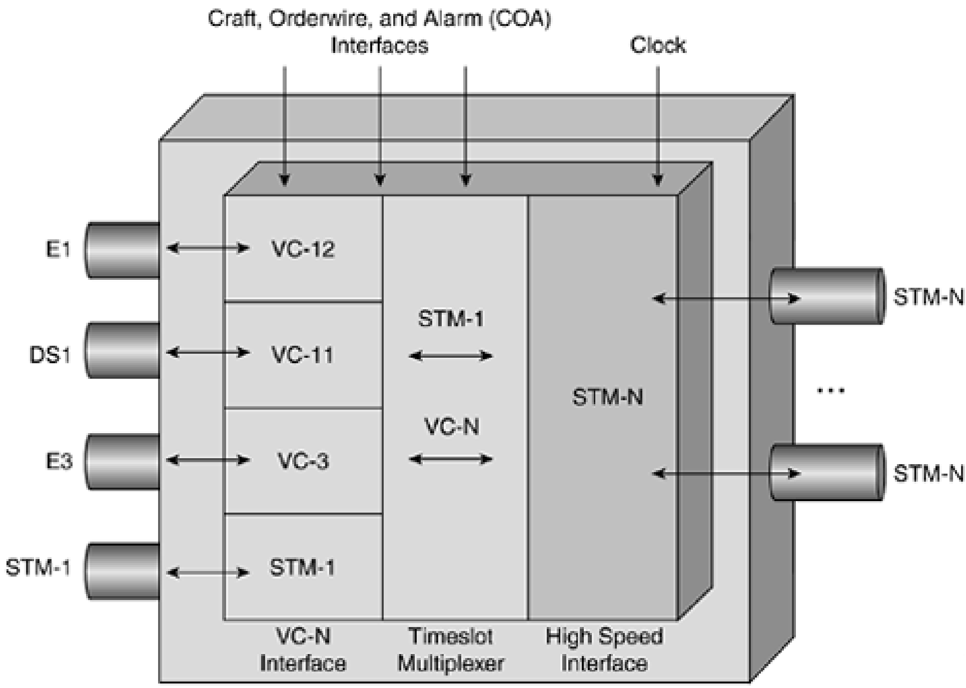

Figure 2.10. SDH terminals multiplexer/3/.

Add/Drop multiplexer

"An ADM is PTE that can multiplex or demultiplex signals to or from an STM-N signal."/3/Only signals that need to be accessed will be dropped or inserted, and then the rest signals will pass through the NE with other signal processing.

Different PDH signals are match with associated SDH VC-Ns in the TM. "The multiplexed payloads are then mapped into STM-N signals based on the line rate of the STM-N transmission."/3/ After an EO conversion, the STM-N signals will be transmitted into the fibre again. "SDH enables add, drop, and pass-through capability where a signal that terminates at one node is duplicated and is then sent to the next and subsequent nodes."/3/ In a case the ADM used as the matching nodes when interconnecting SDH rings. In rings survivability application, drop and pass-through capability provides alternate routing for traffic pass through interconnecting rings in a matched node configuration. If the connection is broken at one node, the signal will choose an alternate route and be transmitted again to the target node.

2.2.6. SDH ring protection mechanisms

The SDH gives the ability to create topologies with protection for the data transferred.

This section introduces the SDH unidirectional and bidirectional ring architectures and figure out the difference between two-fibre and four-fibre SDH rings. We also make a comparison between multiplex section (ring) switching versus path (span) switching.

SDH have three attributes with choices for each as illustrated in Table2.1.

Table 2.1. SDH ring types/3/.

SDH Attribute	Value
Fibers per link	2-fiber 4-fiber
Signal direction	Unidirectional Bidirectional
Protection switching	Multiplex section switching Path switching

The common use topologies always several attributes at one time as following:

- Two-fiber subnetwork connection protection ring(two-fiber SNCP)
- Two-fiber multiplex section-shared protection ring(two-fiber MS-SPRing)
- Four-fiber multiplex section-shared protection ring(four-fiber MS-SPRing)

Unidirectional versus bidirectional rings

"In a unidirectional ring, the working traffic is routed over the clockwise spans around the ring, and the counter clockwise spans are protection spans used to carry traffic when the working span fails."/3/ As we can see the data flow in Figure 2.11.Traffic from NE1 to NE2 traverses span 1in a clockwise flow, and the traffic from NE2 to NE1 traverses span 2, span 3, and span 4in clockwise flow as well.

Spans 5,6,7,8 are used as protection spans and will be active to carry the traffic when one of the working clockwise spans fail.

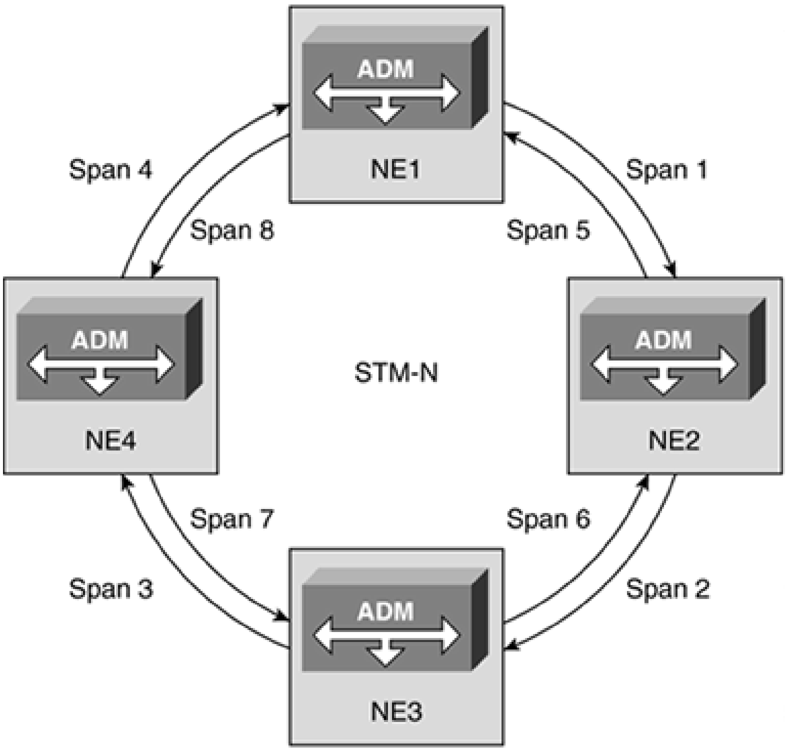

Figure 2.11. Unidirectional versus bidirectional rings/3/.

Bidirectional traffic flows also works as the schematic of Figure 2.11 show. The traffic flows as the same as the unidirectional traffic. It the links between NE1 and NE2 were failed, the system will choose the spans between NE2-NE3, NE3-NE4, and NE4-NE1 instead.

Two-Fibre versus four-fibre rings

"Unidirectional and bidirectional systems both implement two-fibre and four fibre systems. Most commercial unidirectional systems, such as SNCP are two-fibre systems, whereas bidirectional systems, such as MS-SPRing, implement both two-fibre and four-fibre infrastructures. "/3/The two-fibre STM-N unidirectional system with two nodes is illustrated in Figure 2.12. Fibre span 1 carriers N working channels eastbound, fibre span 5 carriers N protection channel westbound.

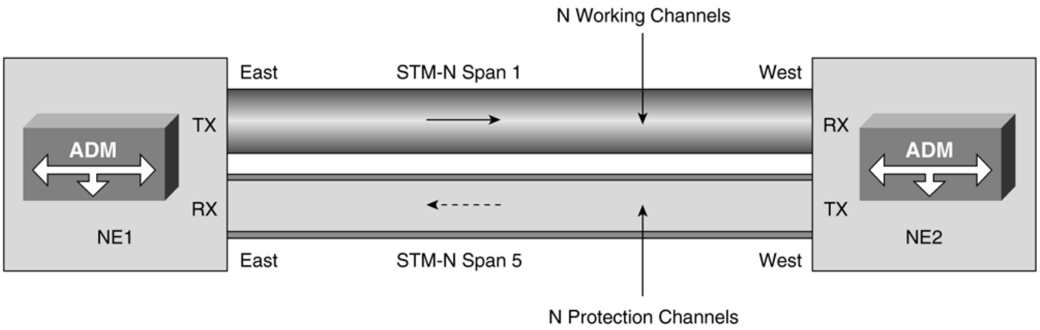

Figure 2.12. Two-fibre unidirectional ring/3/.

A two-fibre STM-N bidirectional system with two nodes is illustrated in Figure 2.12. For each fibre , a maximum of half number of channels are used as working channels, and the other half are defined as protection channels. Let’s take an STM-16 system as example, it would carry eight working VC-4s and eight protection VC-4s eastbound from NE1 to NE2, while carrying working VC-4s and eight protection VC-4s westbound from NE2 to NE1.

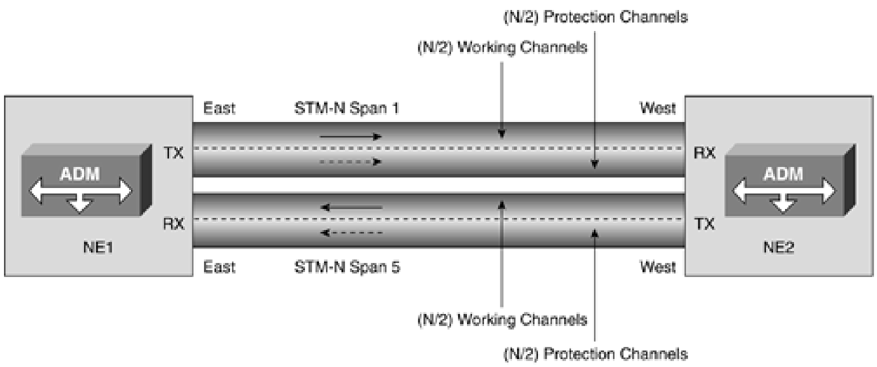

Figure 2.13.Two-fibre bidirectional ring/3/.

There are some other ring protections modes, such as 4-fibre path bi-directional protection ring. The further detail of ring protection can be found in the chapter called “SDH Ring Architectures” of reference /3/

2.3. Optical fiber

"An optical fibre is a long thin strand of impurity –free glass which used as the transport medium for data. A typical point-to-point fibre optic communication network consists of a transmitter, a transport medium and a receiver as in Figure 2.14." /2/

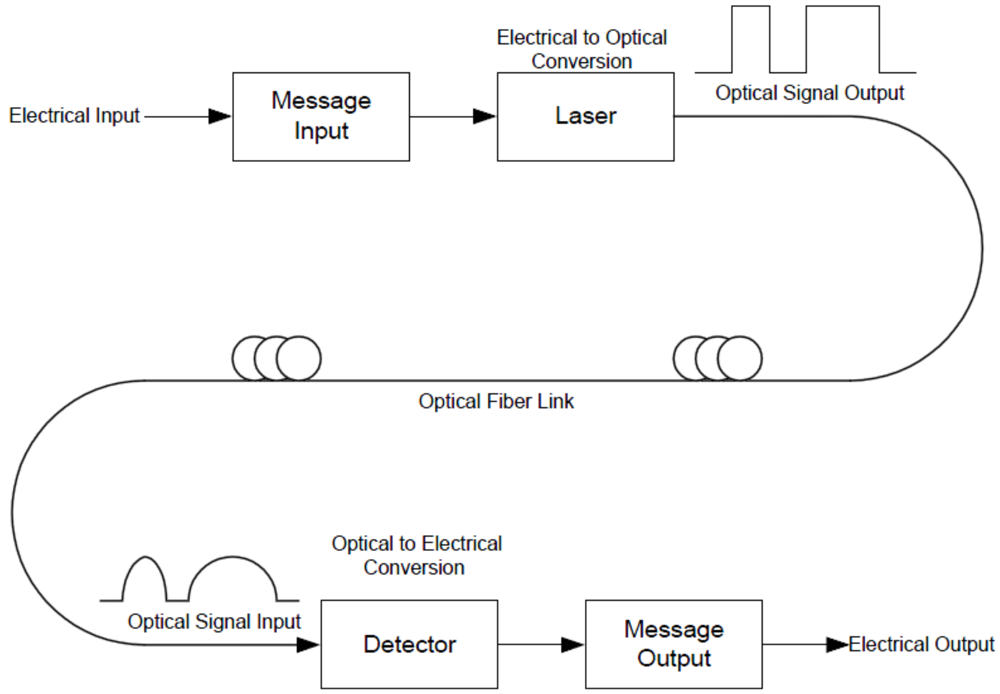

Figure 2.14. Typical components found in a point-to-point optical communication System/2/.

2.3.1. Structure of optical fibre

A fibre optic cable is comprised by two concentric layers, called the core and the cladding, as Figure 2.15 showing. The core has a refractive index of n1, the have a refractive index of n2, and n1 is different of n2. The index of refraction is a way of measuring the light in a material.

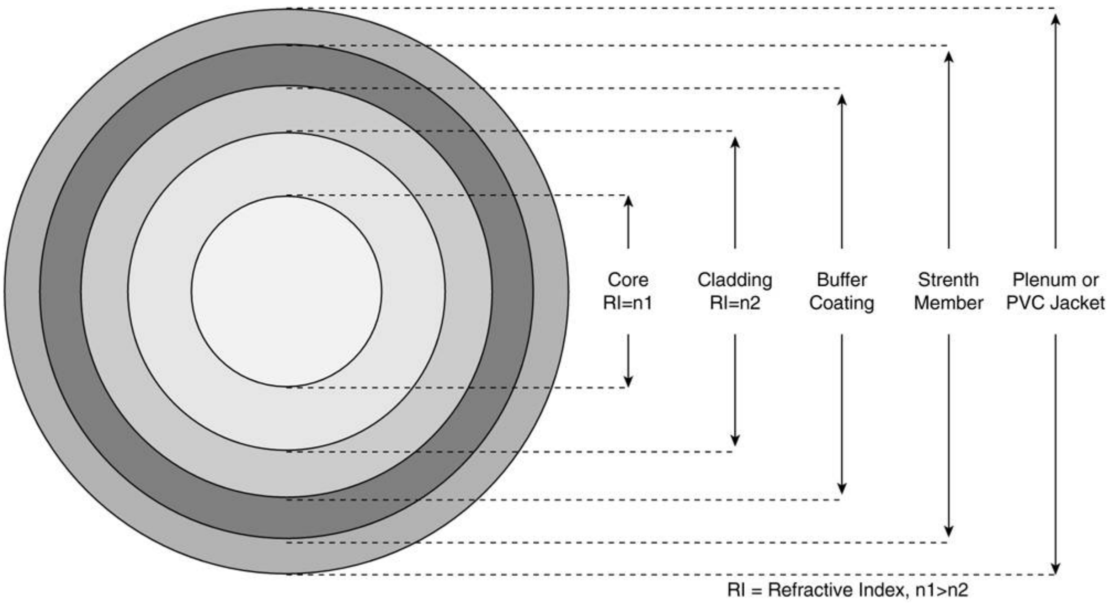

Figure 2.15. Cross section of a fibre-optic cable/3/

The index of refraction is calculated by dividing the speed of light in vacuum by the speed of light in another medium, as shown in the following formula:

Refractive index of the medium = $\frac{\text{Speed of light in a vacuum}}{\text{Speed of light in the medium}}$/3/

2.3.2. Total internal reflection

Figure 2.16 shows the propagation of light down the fibre-optic cable using the principle of the total internal reflection. As illustrated, a light ray is injected into the fibre optic cable on the left. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than the critical angle with respect to the normal axis, it is reflected back into the core. Because the angle of incidence is always equal to the angle of reflection, the reflected light continues to be reflected.

The light ray then continues bouncing down the length of the fibre-optic cable. If the angle of incidence at the core-to-cladding interface is less than the critical angle, both reflection and refraction take place. Because of refraction at each incidence on the interface, the light beam attenuates and dies off over a certain distance.

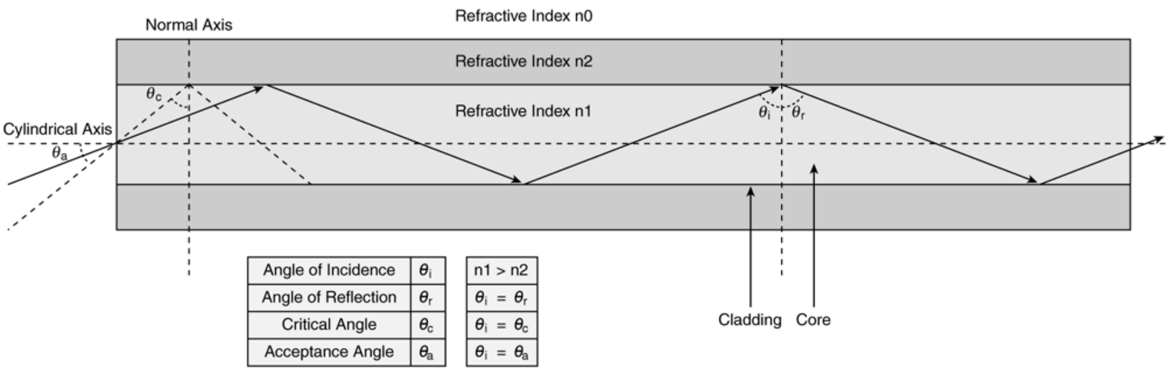

Figure 2.16. Total internal reflection/3/.

The critical angle is only depends on the indices of refraction of the core and cladding and it is calculated by following formula:

$\theta c = \cos^{-1}(\frac{n_2}{n_1})$ /3/

Figure 2.22 shows a light ray entering the core from the outside air to the left of the cable. “Light must enter the core from the air at angle less than an entity known as the acceptance angle (θa)” /3/:

$\theta a = \sin^{-1} [\frac{n_1}{n_0} \times \sin (\Theta_c)]$ /3/

We suppose the n1=1.557 and n2 =1.343 so the critical angle can be calculated as 30.39degrees. The refractive index of air is represented by n_0 and equals to one, so we can calculate the acceptance angle which enters the cylindrical axis of the core is 51.96 degrees.

The optical fibre also has a numerical aperture (NA). The NA is given by the following formula:

NA = Sin $\Theta_{\alpha}= \sqrt{(n_1{}^2 - n_2{}^2)}$ /3/

For a three-dimensional perspective, in order to keep the signals reflected and transmitted correctly through the core, the light must enter the core through an acceptance cone traceable by rotating the acceptance angle to the cylindrical fibre axis.

As illustrated in Figure 2.17, the size of the acceptance cone is depends on the refractive difference between the core and the cladding. There is a maximum angle at the fibre axis which light can enter the fibre so that it will propagate or transmit through the core of the fibre. The sine value of this maximum angle is the Numerical Aperture. "Fibre with a large NA requires less precision to splice and work."/3/

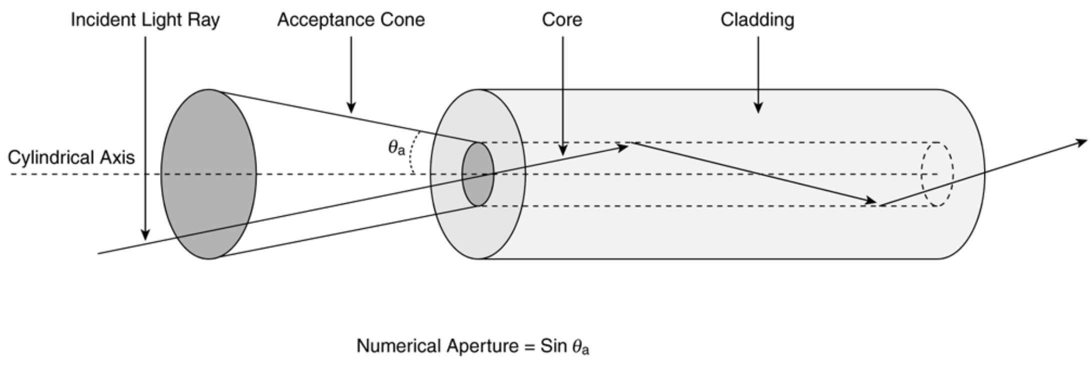

Figure 2.17. Acceptance cone/3/.

2.3.3. Performance consideration

The amount of light that can be transmitted into the core through the external acceptance angle is directly proportional of the fibre-optic cable. The greater the amount of light can be coupled into the core, the lower the Bit Error Rate (BER), due to the more variable light reaches the receiver. The attenuation of the light is inversely proportional to the efficiency of the optical cable. It means the lower the attenuation in propagation the lower the BER. “The low attenuation will lead more light reaches to the receiver, less dispersion, faster the signalling rate and higher the end-to-end data rate from source to destination.”/3/

Optical-Power Measurement

We introduce a unit concept to express power in optical communications with a logarithmic scale called Decibel (dB). The decibel does not directly show a magnitude value; actually it is a ratio of the output power to the input power.

Loss or gain = $10\log_{10}(\frac{P_{Output}}{P_{Input}})$ /3/

The decibel mille (dBm) is the power level related to 1 mill watt (mW). Sometime the transmitter or receiver power is very small, and then we need dBm unit to record. A 1mW signal has a level of 0 dBm. We calculate the signal in following formula:

dBm = $10\log_{10}[\frac{P(mW)}{1(mW)}]$ /3/

We can get the conclusion according to the above formula if the signal power is weaker than 1 mW, the value of signal in dBm unit will be negative. Otherwise, the dBm value will be positive.

2.3.4. Laser back reflection

Back reflection is sometimes called optical return loss is a peculiar phenomenon where by a fraction of the transmitted optical power will reflect back toward the source upon encountering variations in refractive index. Splices, patches and defects in the fibre all can cause back reflections. Fibre with more than 20dB of back reflection is considered quite high and optical isolators should be used on laser sources. For example the back reflection of an air-glass interface, as one would see in a broken fibre is -15 dB. If a laser with –5dBm output power was launched into this broken fibre, and then the laser would have –20dBm optical power reflecting back into the laser cavity disrupting the standing optical wave generating noise in the output optical signal.

2.4. Fibre-optic characteristics

Back reflection is also called optical return loss when the light hit atoms in the fibre, it will reflect to any direction random. Some of light will reflect back toward the source. Splices, patches and defects in the fibre all can cause back reflection. For example the back reflection of an air-glass interface, as one would see in a broken fibre is -15dB. If a laser with -5dBm output power was launched into this broken fibre, and then the laser would have -20 dBm optical powers reflecting back into the laser cavity disrupting the standing optical wave generating noise in the output optical signal.

Optical fibre systems have many advantages by comparing with metallic-based communication systems, like interference, attenuation and bandwidth characteristics. Fibre can be classified as linear and nonlinear.

2.4.1. Interference

Light signals transmit through fibre optic cable are immune from Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI). So the fibre network is suitable for the environment which has strong EMI and RFI interference. The character makes the fibre optic cable become the important medium in industry and biomedical network.

2.4.2. Linear characteristics

Linear characteristics include attenuation, Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD), and Optical Signal-to-Noise Ratio (OSNR).

Attenuation

Attenuation is caused by internal and external factors. Intrinsic attenuation is caused by substances inherently present in the fibre, whereas extrinsic attenuation is caused by external forces such as bending. “The attenuation coefficient α is expressed in decibels per kilometre and represents the loss in decibels per kilometre of fibre.” /3/

Intrinsic attenuation

Intrinsic attenuation is caused by the material immanent facts likes the impurities during the fibre optic manufacturing process. It is impossible to clean up all impurities. When a light signal hits an impurity in the fibre, it may scatters to any direction random or it may absorbed by this impurity point. So intrinsic loss attenuation can be divided into two phenomenons:

- Material absorption
- Rayleigh scattering

Material absorption

Material absorption is leaded by the impurities in the fibre. “The most common impurity is the hydroxyl (OH-) molecule, which remains as residue despite stringent manufacturing techniques.”/3/ Figure 2.18 shows the variation of attenuation with different wavelength. We can observe there are three windows of 850nm, 1310nm, 1550nm wavelength bands. During these three regions, the attenuation is relatively lower than the loss in nearby duration and the light transmitting efficiency is also higher.

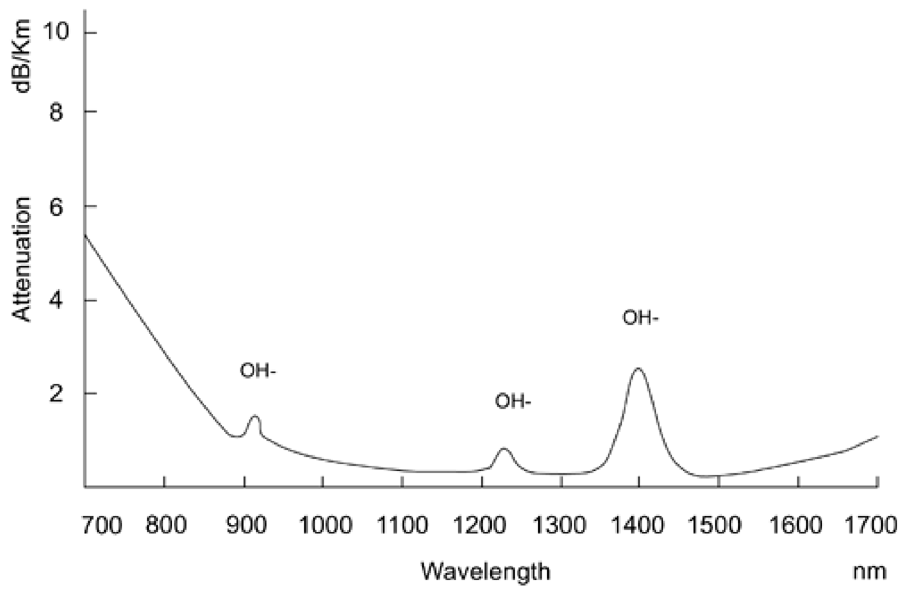

Figure 2.18. Attenuation versus wavelength/3/.

Rayleigh scattering

The light interacts with the silica molecules during transmitting in the core fibre. Rayleigh scattering is the result of these elastic collisions between the light and the silica molecules in the fibre. If the scattered light keeps forwarding then there is no attenuation occurs. Otherwise, the light scattered to any direction not supposed to go then the attenuation occurs. Due to the different incident angle, some portion of the light propagates forward and the other parts deviates out of the propagation path and escapes from the fibre core. Some scattered light is reflected back toward the light source. We use an Optical Time Domain Reflect meter (OTDR) to capture this signal. The same principle applies to analyzing splice loss. “Short wavelengths are scattered more than longer wavelengths.” /3/

Extrinsic attenuation

Extrinsic attenuation is caused by two external mechanisms: macro bending or micro bending. The strain is happened on the fibre which region is bent. It affects the refractive index and the critical angle of the light ray in that specific area.

A macro bend is a significant bend which is observe by eyes, and the loss is generally reversible after bends vanished. We should no twist the fibre smaller than the specific minimum bend radius in order to get rid of the macro bends.

Micro bending is caused by imperfections in the cylindrical geometry of fibre during the manufacturing process. “Micro bending might be related to temperature, tensile stress, or crushing force.” /3/Both bends will cause a reduction of optical power. The behind one is inspected by the OTDR.

Chromatic dispersion

“Chromatic dispersion is the spreading of a light pulse as it travels down a fibre.”/3/ Light can be considered as an electromagnetic wave from quantum perspective. During the light propagating process, all of its spectral components propagate constantly. “These spectral components travel at different group velocities that lead to dispersion called Group Velocity Dispersion (GVD).”/3/It also termed as chromatic dispersion. As the result of chromatic dispersion, the pulses spread leads that it cannot be distinguished by the receiver. Light pulses were transmitted at high data rates will leads high dispersion which brings errors and loss information.

Optical signal-to-noise rate

The Optical Signal-to-Noise Ratio (OSNR) indicates the ratio of the nets signal power to the net noise power and it shows the quality of the signal. With the increase of transmitting time and distance, the receiver cannot distinguish the useful signal from the noise. “Regeneration helps mitigate these undesirable effects before they can render the system unusable and ensures that the signal can be detected by the receiver.”/3/ Following devices like optical amplifiers, laser, taps and fibre will add noise. Finally the optical amplifier noise is considered the major source for OSNR penalty and degradation.

2.5. Fibre span analysis

"Span analysis is the calculation and verification of fibre-optic system's operating characteristics."/3/It include following elements such as fibre routing, electronics, wavelengths, fibre type, and circuit length. "Both the passive and active components of the circuit have to be included in the loss-budget calculation. Passive loss is made up of fibre loss, connector loss, splice loss, and losses involved with coupler or splitters in the link. Active components are system gain, wavelength, transmitter power, receiver sensitivity, and dynamic range.

The total span loss is also called link budget can be measured by an optical meter, which consider the loss associate with span components such as connectors, splices, patch panels, jumpers, and the optical safety margin. The safety margin usually sets to 3dB. Then add all these factors together by comparing with the maximum attenuation to decide whether this system will operate satisfactory or not.

Transmitter launch power

"Span analysis is the calculation and verification of fibre-optic system's operating characteristics."/3/It include following elements such as fibre routing, electronics, wavelengths, fibre type, and circuit length. "Both the passive and active components of the circuit have to be included in the loss-budget calculation. Passive loss is made up of fibre loss, connector loss, splice loss, and losses involved with coupler or splitters in the link. Active components are system gain, wavelength, transmitter power, receiver sensitivity, and dynamic range.

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“Power measured in dBm at a particular wavelength generated by the transmitter LED or LD used to launch the signal is known as the transmitter launch power.”/3/ The higher the transmitters launch power, the better. “If the signal strength is not within the receiver’s dynamic range, the receiver cannot decipher the signal and perform an OE conversion.”/3/

Receiver sensitivity and dynamic range

“Receiver sensitivity and dynamic range are the minimum acceptable value of received power needed to achieve an acceptable BER or performance.”/3/ We suppose the worst-case values of extinction ratio, jitter, pulse rise times and fall times, optical return loss, receiver connector degradations, and measurement tolerances in the receiver sensitivity situation.

Power budget and margin calculations

To guarantee the fibre system works in correct way, we need to calculate the span’s power budget. Worst case is happened when minimum transmitter power and minimum receiver sensitivity happens.

Power budget (P_B)= Minimum transmitter power (P_{TMIM}) –Minimum receiver sensitivity (P_{RMIN}) /3/

Span loss (P_s)= (Fiber attenuation×km) + (Splice attenuation×Number of splices) + (Connector attenuation×Number of splices) + (Connector attenuation×Number of connectors) + (In-line device losses) + (Nonlinear losses) + (Safety margin) /3/

The next calculation involves the power margin (P_M), which represents the amount of power available after subtracting linear and nonlinear span losses (P_S) from the power budget (P_B). A P_M greater than zero indicates that power budget is sufficient to operate the receiver. The formula for power margin (P_M) is as follows:

Power margin (P_M)=Power budget (P_B)- Span loss (P_S) /3/

To prevent receiver saturation, the input power received by the receiver, after the signal has undergone span loss, must not exceed the maximum receiver sensitivity specification (P_{TMAX}). This signal level is denoted as (P_{IN}). The maximum transmitter power (P_{TMAX}) must be considered as the launch power for this calculation. The span loss (P_s) remains constant.

Input power (P_{IN}) =Maximum transmitter power (P_{TMAX})- Span loss (P_S) /3/

The design equation
Input power (P_{IN}) $<=$Maximum receiver sensitivity (P_{RMAX}) /3/

Must be satisfied to prevent receiver saturation and ensure system viability. If the input power (P_{IN}) is greater than the maximum receiver sensitivity (P_{RMAX}), passive attenuation must be considered to reduce signal level and bring it within the dynamic range of the receiver.

3. OTDR

3.1. OTDR techniques

The Optical Time Domain Reflectmeter(OTDR) is used for measuring the characteristics of fibre optic cable. It has following function as verify splice loss, measure the cable length and locate the faults.

The OTDR used the collected data to draw a picture called a “trace” which includes valuable information and also can be stored as a record. Usually the OTDR shows us the location of terminated point and analysis the number and loss of connections and splices. OTDR traces are also used for troubleshooting due to it can show the location of fault points by comparing with the initial installation documentation.
“Light reflecting back in an optical fibre is the result of reflection or backscatter. Reflections happen when the light travelling through the optical fibre encounters changes in the refractive index. These reflections are called Fresnel reflections, Backscatter, or Rayleigh scattering, result from evenly distributed compositional and density variations in the optical fibre.”/4/ Figure 3.1 shows the photons that travel back toward the OTDR are considered backscatter.

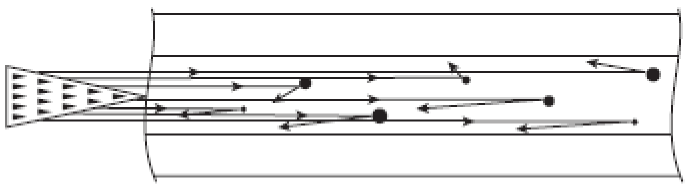

Figure 3.1. Backscattered photons/4/.

3.2. OTDR working mechanism

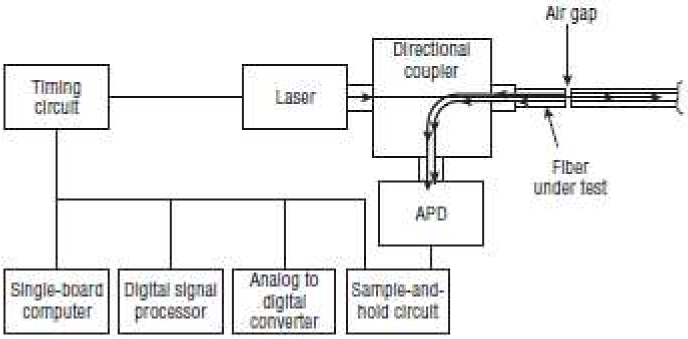

Figure 3.2. OTDR block diagram/4/.

A typical OTDR includes eight basic components: the directional coupler, laser generator, time circuit, signal-board computer, Digital Signal Processor (DSP), and analogy to digital converter, sample-and-hold circuit, and avalanche photodiode. "Figure 3.2 is a block diagram of the OTDR showing how light is launched from the laser through the directional coupler into the optical fibre. The directional coupler channels light returned by the optical fibre to the avalanche photodiode."/4/ "The avalanche photodiode converts the light energy into electrical energy. The electrical energy is sampled at a very high rate by the sample-and-hold circuit. The sample-and-hold circuit maintains the instantaneous voltage level of each sample long enough for the analogy to digital converter to convert the electrical value to a numerical value. The numerical value from the analogy to digital converter s processed by the DSP and the result is sent to the single-board computer to be stored in memory and displayed on the screen. The entire process is typically repeated many times during a single test of an optical fibre and coordinated by the timing circuit."/4/

The OTDR will send the light constantly during certain period. The OTDR capture each sample in round–trip time means the actually transmitting time is half of what the OTDR counts. Let's assume the OTDR is taking 500 million samples per second or one sample every two nanoseconds. If the refractive index for the optical fibre under test were equal to 1.5, every five samples would represent the distance of 1 meter, as shown in Figure4.3.The following formula is used to find distance based on time and refractive index. In this formula, the speed of light is rounded up to 3×10^{8} m/s:

$$\text{Distance}=\frac{\left(\frac{\text{Time in ns}}{2}\right)\times(\text{Speed of light in free space})}{\text{Refrative Index}}$$

For the above example:

$$\text{Distance}=\frac{\left(\frac{10\text{ ns}}{2}\right)\times(3\times10^{8}\text{m/s})}{1.5}$$

Distance = 1 m

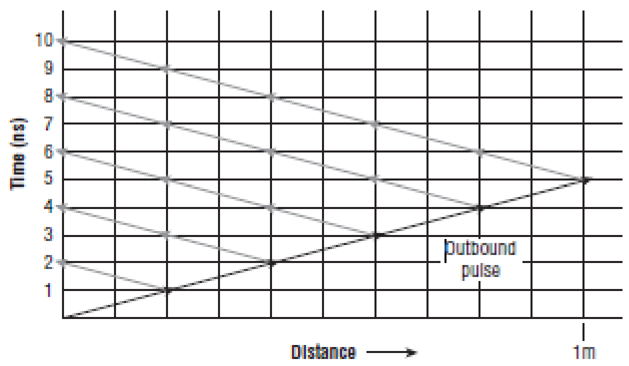

Figure 3.3. OTDR sampling at 2 ns rate/4/.

OTDR Display

The OTDR shows the time or distance on the horizontal axis and amplitude on the vertical axis. The horizontal axis's unit is shown in meters or kilometres, and dB (decimal) in vertical axis.

The trace generated by the OTDR shows in Figure 3.4 shows event loss, event reflectance, and optical fibre attenuation rate.

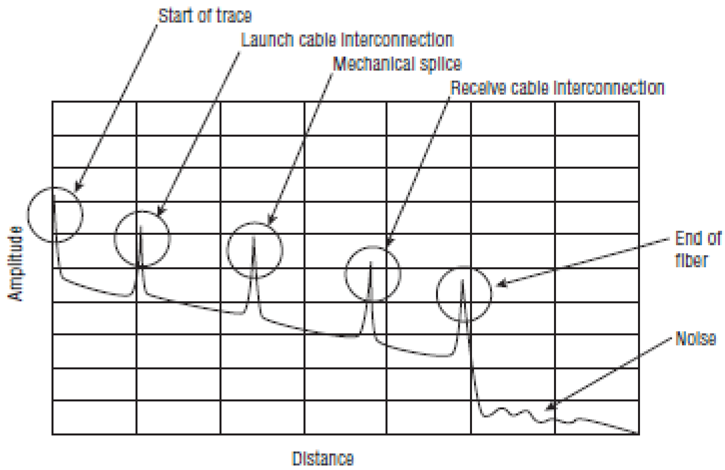

Figure 3.4. Event-Filled OTDR traces/4/.

3.3. OTDR setup

Appropriate setting leads more accurate results. When we set up the OTDR, we need to select the correct fibre type, wavelength or wavelengths, range and resolution, pulse width, average, refractive index, thresholds, and backscatter coefficient.

3.3.1. Fibre type

The OTDR has several optical fibre types testing modes. A multimode module cannot be used to test a signal-mode optical fibre.

3.3.2. Wavelength

The wavelength for OTDR testing is depends on the light source module of OTDR.

3.3.3. Range and resolution

"The distance range of an unzoomed trace displayed on the OTDR and the distance between data points is determined by range and resolution." /4/ As common, the OTDR range should be set to 1.5 times the length of the fibre optic link. If the range is set too short, the entire link may not be displayed. If the range is set too long, the trace will show only a small part of the display.

3.3.4. Pulse width

The pulse width determines the size of the dead zone and maximum length optical fibre that can be tested. If the pulse width is set properly, the trace will stay smooth until the end of the fibre optic link.

3.4. Testing and trace analysis

Baseline trace

At beginning, we need to generate the baseline trace. Before we use the OTDR to test the optical fibre cable we need to check following items:
"All connector have been cleaned and inspected are undamaged."/4/
"Launch and receiver cable have optical fibre similar to the optical fibre under test."/4/

“Launch and receiver cables are the correct length.”/4/

“Launch and receiver cables are properly connected to each end of the fibre optic link under test.”/4/

“The correct fibre type, wavelength, range and resolution, pulse width, average, refractive index, and backscatter coefficient have been entered into the OTDR.”/4/

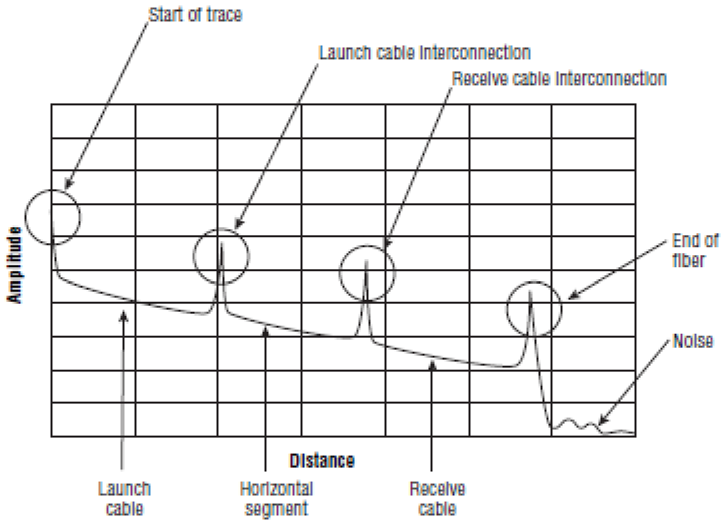

Figure 3.5. Baseline trace of horizontal segment/4/.

The OTDR shows an example baseline trace in Figure 3.5 which includes the 100m length of the launch and receiver cable and 85m length of horizontal segment. Looking at the trace from left to right there is a large back reflection at the input to the launch cable. Because a 20 ns pulse width was selected, the trace is smooth within 10 m. The smooth trace slopes gradually to the back reflection caused by the connector pair where the launch cable and horizontal segment are connected together.

The trace becomes smooth again 10 m after the interconnection back reflection. The trace remains smooth up to the back reflection caused by the connector pair where receive cable and horizontal segment interconnect. The trace again becomes smooth 10 m after the interconnection back reflection until a large back reflection is generated by the end of the receive cable. The receive cable back reflection is followed by a large reduction in amplitude, and then the trace disappears into the noise floor.”/4/

3.5. Making measurements with the OTDR

3.5.1. Measuring the attenuation of a partial length of optical fibre

After taking the baseline trace, we put the two cursors on a smooth section of the optical fibre. The longer the section, less noise impact will be and then more accurate result we will get. The trace in Figure 3.6 shows the segment between A and B cursor is 50m in horizontal axis. The loss of this 50m segment at a wavelength of 850 nm is approximately 0.14dB.

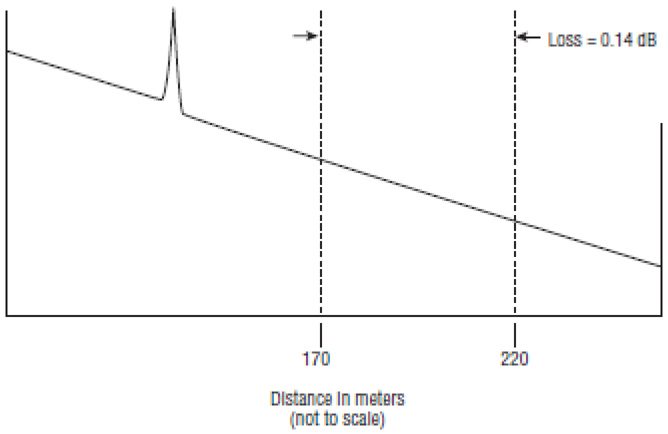

Figure 3.6. Measuring the attenuation of a cable segment using the 2-points Method/4/.

3.5.2. Measuring the distance to the end of the optical fibre

A break point in an optical fibre looks like the end of the optical fibre in OTDR display. It makes us are capable to measure the distance to the break point or end point.

When light escapes from the optical fibre, a strong back reflection called Fresnel reflection will be generated from the end point. Figure 3.7 figures out the trace with and without the Fresnel refection.

To measure the distance to the end of the optical fibre after zooming in on the back reflection, we place the A cursor on a smooth section of the trace just in front of the back reflection or the drop in the trace. Move the B cursor toward the A cursor until it is in the leading edge of the back reflection. Keeping moving the B cursor toward the A cursor until the A-B loss is ±0.5 dB. It should be 0.5 dB of loss for the no reflective trace and 0.5 dB of gain for the reflective trace. The length for the entire span is the distance for the B cursor.

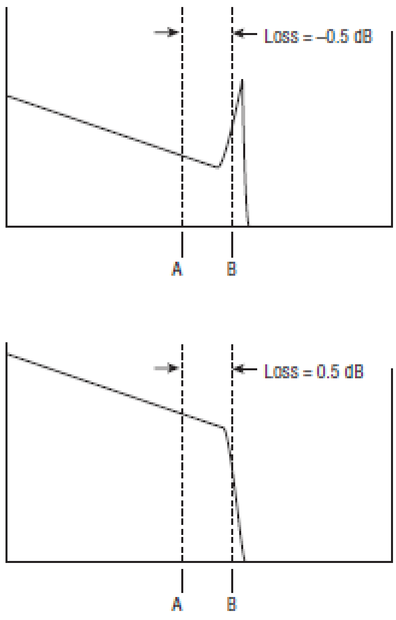

Figure 3.7. Measuring the distance to the end of an optical fibre using the 2-points Method/4/.

3.5.3. Measuring the length of a cable segment

The first step in measuring the length of a cable segment is to horizontally zoom in on the interconnection. We put the cursors in the leading edge of the reflective events for that segment. The cursors should intersect the leading edge of the reflective event at the same vertical height above the smooth part of the trace as shown in Figure 3.8. The distance between two cursors is the length of the cable segment.

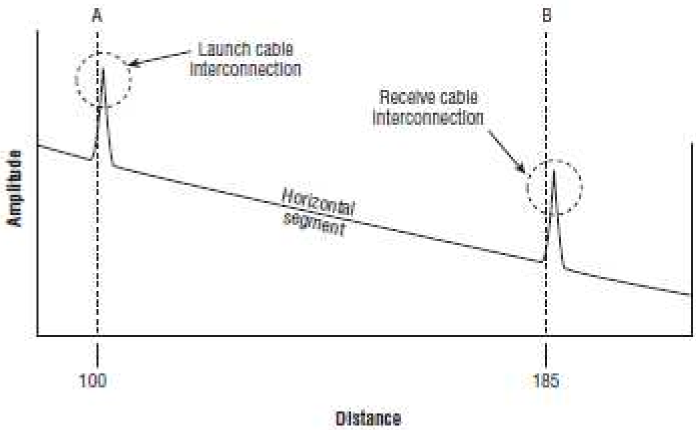

Figure 3.8. Measuring the length of a cable segment/4/.

3.5.4. Measuring interconnection loss

We begin to measuring the interconnection loss by horizontally zoom in OTDR display. We put the A cursor in front of the back reflection, then position the B cursor on a smooth area on the trace after interconnection back reflection. Figure 3.9 shows loss for the interconnection and the optical fibre between the cursors is 0.4dB on the OTDR display and the distance between the A and B cursors is 50m.

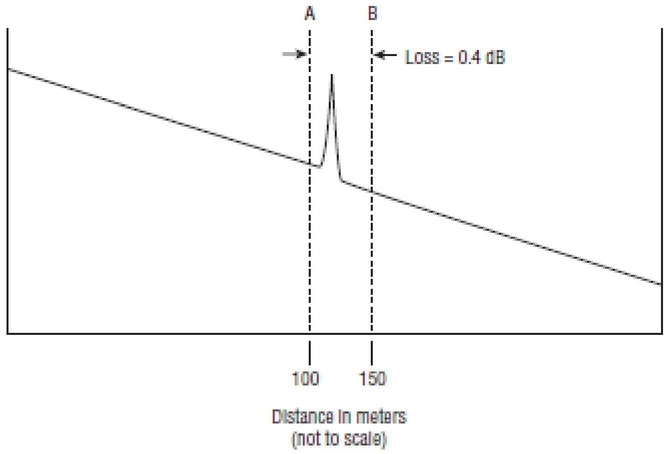

Figure 3.9. Measuring interconnection loss with the OTDR/4/.

In order to find the loss for only the interconnection, the loss for the optical fibre between cursors A and B needs to be subtracted from the A-B loss displayed by the OTDR. This loss was previously at 0.14 dB for 50m. So the loss for only the interconnection equals 0.4dB-0.14dB, which is 0.26dB.

3.5.5. Measuring the loss of a fusion splice or macro bend

When different backscatter coefficients optical fibres are fusion-spliced together, the splice point will leads a loss or gain in OTDR test from one direction. In order to find accurate fusion splice loss, the splice must be tested in both direction and the result average together. The losses of loss and gain should be added together and the sum divided by 2.

To find the loss of a fusion splice or macro bend, horizontally zoom in on the event. The loss from a fusion splice or macro bend is typically very small and will require vertical zoom in addition to horizontal zoom. Place the A cursor on the smooth part of the trace before the dip in the trace. Place the B cursor on the smooth part of the trace after the dip, as shown in Figure 3.10. The loss for this event is 0.25 dB. The loss for the event includes the loss for the fusion splice or macro bend plus the 50 m of optical fibre between the cursors. Subtract the loss for the 50 m of optical fibre that was previously measured at 0.14 dB from the event loss. The loss for this fusion splice or macro bend is 0.11 dB.

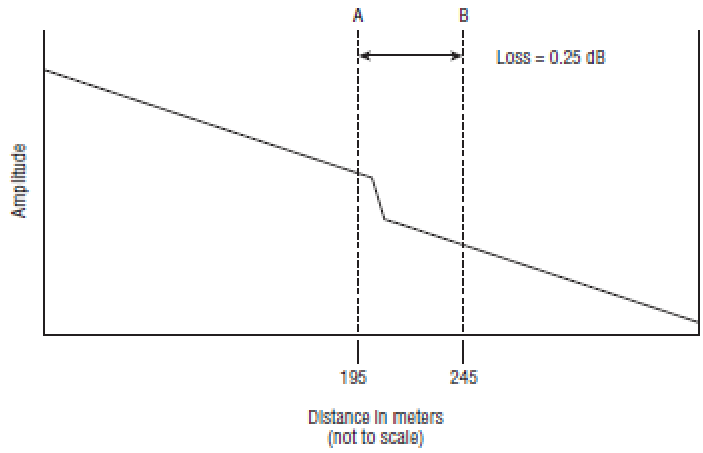

Figure 3.10. Measuring the loss of a fusion splice or macro bend/4/.

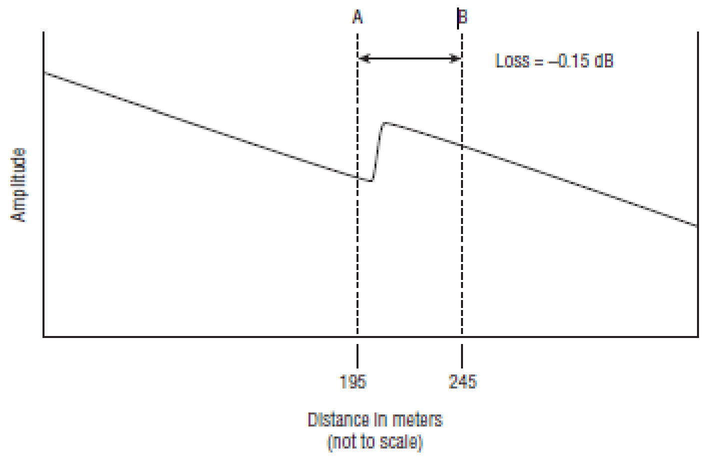

Figure 3.11. Measuring the gain of a fusion splice/4/.

In order to find the exact value of gain, we need to zoom in the trace vertically and horizontally. Then put the A cursor on the smooth part of the trace before the bump in the trace and place the B cursors on the smooth part of the tracer after the bump, as shown in Figure 3.11. We can read the gain of this event is 0.15dB. The gain for the event includes the gain for the fusion splice plus the 50 m of optical fibre between the cursors. Add the value for the loss for the 50m of optical fibre that was previously measured at 0.14dB to the event gain. The gain for this fusion splice is 0.29 dB.

3.5.6. Measuring the loss of a cable segment and interconnections

To find the loss for a cable segment includes the interconnections, we need to know the exact length of this segment. We can read the length of cable segment in Figure 3.12 as example for 85m.

Firstly we zoom in horizontally on the cable segment. And then put the A cursor on a smooth section of the trace in front of leftmost cable segment interconnection back interconnection back reflection, distribute the B cursor on the smooth part of the trace after the rightmost cable segment interconnection back reflection. At last fix the A cursor and place the B cursor the position until the distance between these two cursors equals the length of the cable segment pulse 50m.

We can read the loss of A-B segment is 1.5dB. If we want to get the loss value for the cable segment includes the interconnections, we should subtract the loss for the 50m of optical fibre from the 1.5dB for the cable segment and interconnections. So the loss of the cable segment and the interconnections (1.36dB) equal the loss of A-B segment (1.5dB) subtract the loss for 50m of optical fibre (0.14dB for 850nm signal).

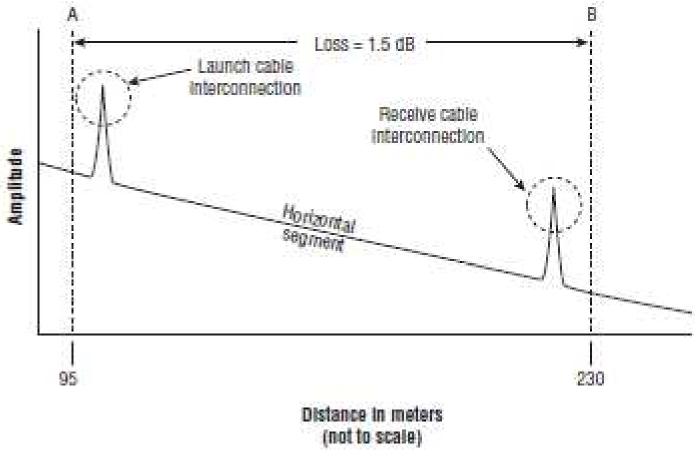

Figure 3.12. Measuring the loss of a cable segment and interconnections/4/.

4. The Optical Fibre Line Measurement

4.1. Introduction of real optical fibre measurement

Firstly we build the optical fibre loop between two shelves which located at same classroom in Wu Han Institute of Post and Telecommunication as following Figure 4.1.

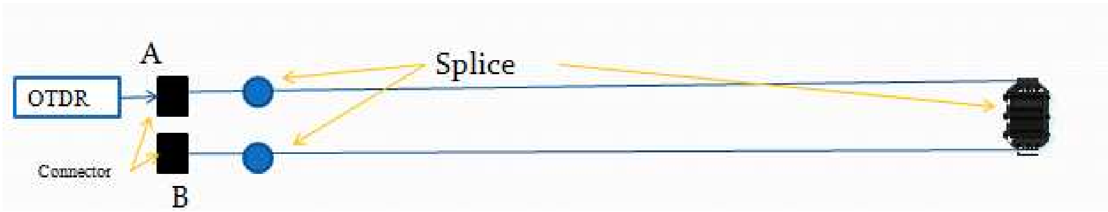

Figure 4.1. Optical fibre cable distribution in real test.

We distribute the start point A and end point B in the same classroom. The connector box locates at the other room. A point and B point represent the patch cord shelves. We choose the 12 core optical fibres as the connecting line. In order to get the average attenuation value of each core fibre, we need to use do the OTDR test from both ways.

In order to evaluate value we tested whether is fulfil the requirement, we need to calculate the cable loss budget at the benignly. We accumulated all the facts which may increase the attenuation. Firstly the total fibre loss can be calculated by the unit fibre attenuation times the total length of the fibre. Secondly the total connector can be calculated by the unit connector attenuation times the number of connector. And the total splice loss can be calculated same the previous parameter. Finally the total link loss is the addition of these three facts. As the Table4.1shows the tested attenuation value should between 0.574dBm and 1.064dBm as we used the signal mode optical fibre and 1550nm signal generated by OTDR.

Table 4.1. Optical fibre loss budget table.

Cable Plant Passive Component Loss

Step 1.Fiber loss at the operating wavelength

Cable Length	0.412 Km
Fiber Type	Single Mode
Wavelength	1550nm
Fiber Atten. dB/km	0.36-0.4

Total Fiber Loss=Cable Length*Fiber Attenutaion Per km

Total Fiber Loss dB	0.148-0.164

Step 2.Connector Loss

Per Connector Loss	0.3 dB (typical adhesive/polish conn)	0.75 dB(Worst Case)
Connectors Number	1	1

Total Connector Loss=Per Connector Loss*Connectors Number

Total Connector Loss	0.3 dB	0.75 dB

Step 3. Splice Loss

Typical Splice loss	0.05 dB
Splice Number	3

Total Splice Loss=Typical Per Splice Loss*Splice Number

Total Splice Loss	0.15 dB

	Typical	Worst
Total Fiber Loss(dB)	0.124	0.164
Total Connector Loss(dB)	0.3	0.75
Total Splice Loss(dB)	0.15	0.15
Other(dB)	0	0

Total Link Loss=Total Fiber Loss+Total Connector Loss+Total Splice Loss+Other

Total Link Loss(dB)	0.574	1.064

4.2. Optical fibre splicing

Due to the limit of one duration optical fibre cable is about 400m. If we want to build long distance optical fibre communication, we need to splice several duration of optical fibre cable together. If there is fault point in the fibre, we can also use the fusion splice method to connect the optical fibre.

We finished the whole welding process as following steps:

1) Start dealing with the fiber end face. Firstly we remove PVC jacket, and wipe out the ointment on the buffer coating lay of the fiber. Then use the miller pincer to remove the cladding. In order to keep the core fiber clean, we wipe it

with alcohol cotton until we can hear a “quack” friction sound as Figure4.2 illustrated.

Figure 4.2. Fibre optic interface processing diagram.

2) Distributing the suitable position and orientation of each fibre connect point, fixed it with the cover of fusion splicer, and then push the blade to cut the core fibre as Figure 4.3 distributed.

Figure 4.3. The fibre end face cutting diagram.

3) Penetrated heat shrinkable tubing for both core fibres, and put two ends of fibre well caught on the left and right fibre folder, leave the end point with discharge needle of 0.5-1.5nm, as show in Figure 4.4.

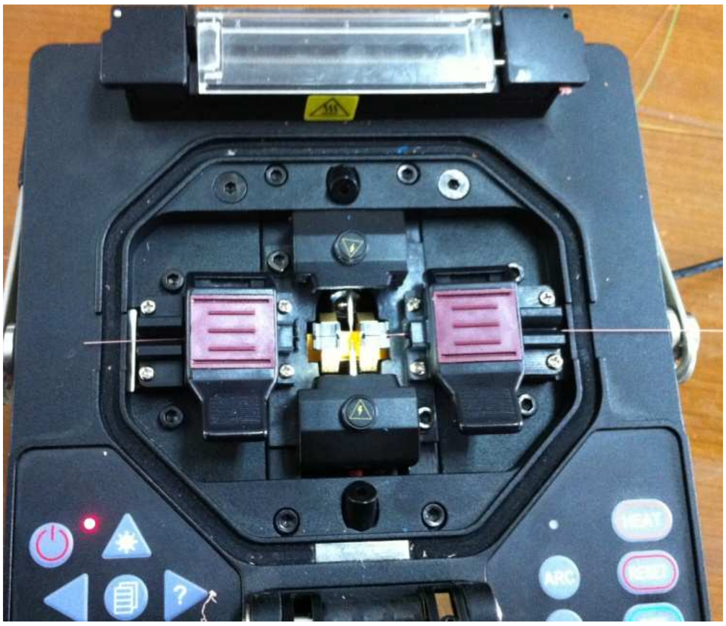

Figure 4.4. Fibre splice installation

4) We close the cover and press the SET button. After setting the welding machine will start welding automatically, after finished welding the loss estimate will be shown on the welding machine interface in Figure 4.5. We treated the welding is failure when splice loss is greater than 0.04dB.

5) We open the cover; gently remove the connected fibre from the welding territory to the heating part. Then move the shrinkable tube to the welding part of the connected fibre, press the heat button.

Figure 4.5. Splice loss assessment.

From above diagram, it shows our splice loss assessment is only 0.01dB, this value full fill the requirement.

6) After heating a few seconds, move the fibre out from the cover. The shrinkable will be reinforcing after cool down.

4.3. OTDR setting

Set the OTDR parameters

Firstly we need to set OTDR parameters, like refractive index N, pulse width W and wavelength λ. We make sure the setting values are approached to the measured core fibre parameters in order to minimize the test error. We set the refractive index N with 1.4667, pulse width with 50ns and wavelength with 1550nm as we can see from following Figure 4.6.

Figure 4.6. OTDR parameter setting.

Select the appropriate range of test files

OTDR has different testing resolution in different test range. In our test the length we actually measured show be smaller than the test range we set. The total range we measured is approximately 400m, so we set the distance range as 0.5km.

Amplification of the application of the instrument

The zoom function of OTDR can be used to get more accurate value when move the cursor to the corresponding point, such as turning point, the start and end of the fibre reflect point.

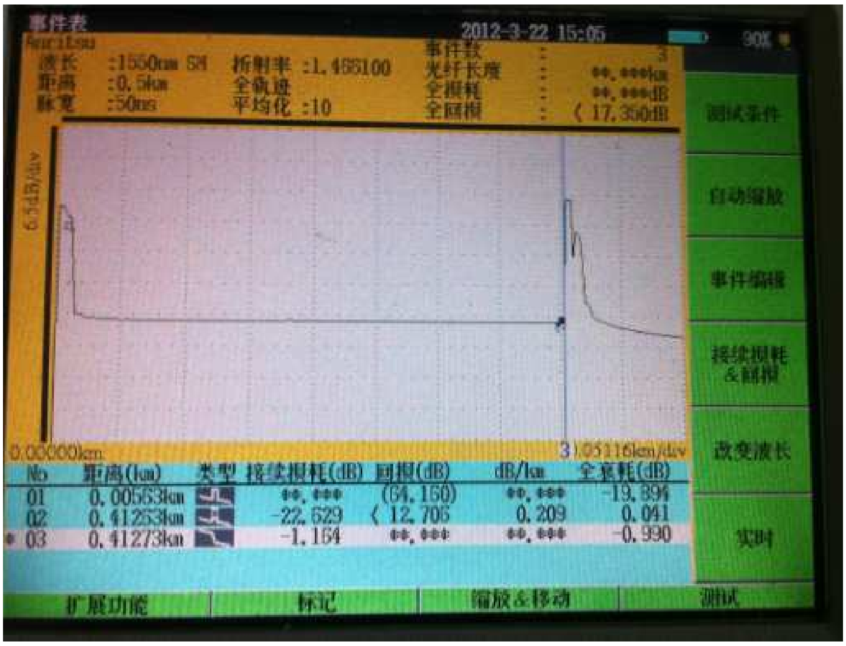

Figure 4.7. OTDR test results.

From above Figure 4.7 we know that the total length of the optical fibre line is 412.63m.

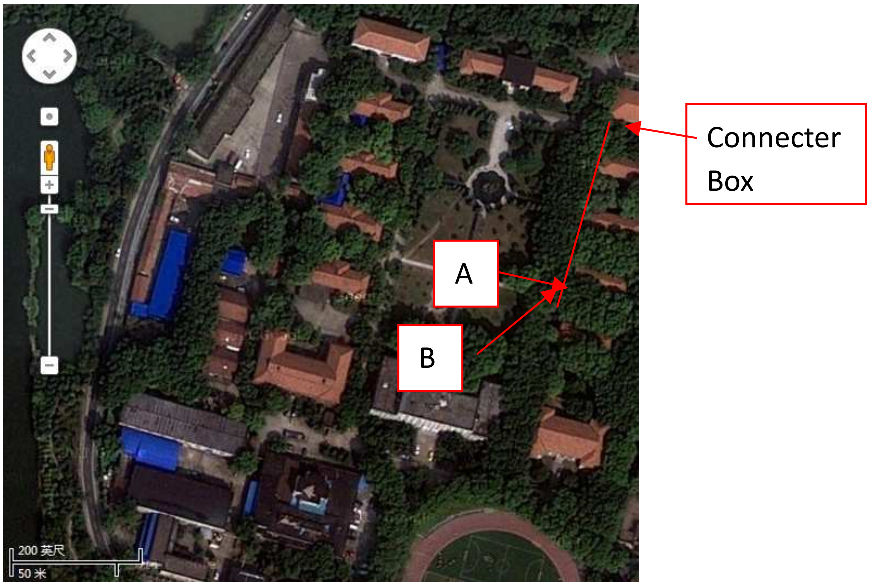

Figure 4.8. Optical fibre geographic location.

Table 4.2. Total geographic cable length calculation.

Real Distance between two buildings= $\frac{\text{Distance on the photo}}{\text{plotting scale}} = \frac{4.6cm}{2.3cm}$ *50m=100m

Totoal Length of Opitcal Fiber Cable=2*Real Distance between two buildings=2*100=200m

Figure 4.9. OTDR end point connecting diagram.

According to our estimate, the geographic distance (shown as the Figure 4.8) from A point across the connector box, then back to the B point is about 200 as Table 4.2 shows. We still leave 100m twisted fibre cable on A and B points. So the total length of the cable in real situation without launch cable and pigtail cable is about 400m. This value is almost same with the result which we test from OTDR.

As Table 4.3 show, we use OTDR test fibre loss of 12 core fibre optic from both direction and listed in the following table. Finally we calculate the average value in order to get value closer to the real loss of each core fibre.

Table 4.3. Repeater Section Fibre Optic Loss Test Record Form.

Repeater Section Fibre Optic Loss Test Record			
Test Instrument: OTDR		Cable Length：413m	Test pulse width：50ns
		Wavelength：1550nm	
Fibre-optic serial Number		Loss value	Average loss
01	B----A	0.216	0.189
	A----B	0.162	
02	B----A	0.086	0.129
	A----B	0.171	
03	B----A	0.221	0.684
	A----B	1.146	
04	B----A	0.918	0.615
	A----B	0.312	
05	B----A	0.103	0.442
	A----B	0.780	
06	B----A	0.843	1.058
	A----B	1.273	
07	B----A	0.001	0.038
	A----B	0.074	
08	B----A	0.094	0.265
	A----B	0.436	
09	B----A	0.077	0.049
	A----B	0.021	
10	B----A		0.071

	A----B	0.071	
11	B----A	0.092	0.048
	A----B	0.004	
12	B----A	0.012	0.042
	A----B	0.071	

During this test, we firstly welding at the middle position of 12 core optical fibre then spliced these 12 cores optical fibre cables with the 12 tail cables and distribute them into the box on the patch cord shelf.

According to the comparison, we can see the attenuation of 3th line and 6th line measured from A point to B point is beyond the loss budget value. It may caused by the quality of splices or connectors.

The attenuation values measured from both directions sometimes are different, this mainly due to the core fibre diameter and relative refractive index of two core fibre. It will not only cause an increase in splice loss but also affect the measured values of OTDR from both directions change great. If the mode field diameter of two welding fibre are not the same as Figure4.10; because the small mode field diameter optical fibre has stronger transmission capacity of the Rayleigh scattering than big mode field diameter. When the light signal which generated by the OTDR transmitted from big mode field diameter to the same mode field diameter, if some part of light not passing through the same diameter core, it will reflect to any direction. OTDR will receive less signals reflect back. On the contrary, the OTDR will capture more signals reflect back than the previous situation, so the splice loss may be negative.

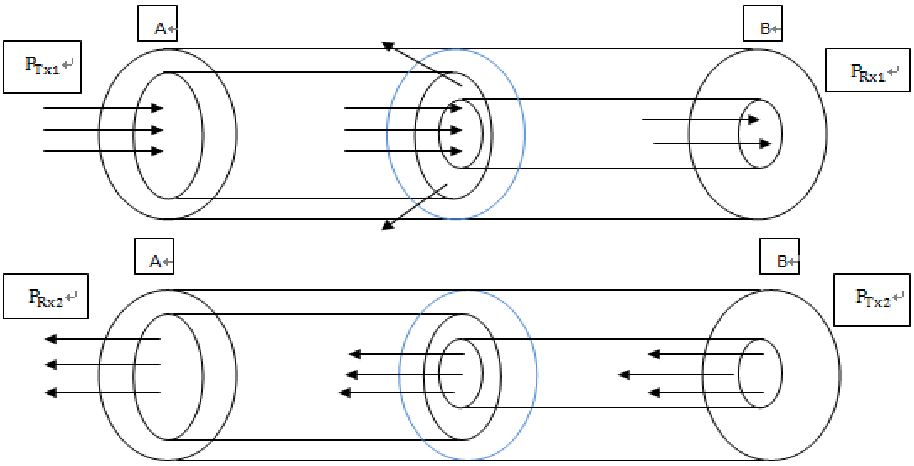

Figure 4.10. OTDR testing in different fibre mode field diameter.

We did not get the attenuation value of 10th optical fibre cable from end B to A. We can get the conclusion that the patch panel at B point is broken. Because when we measured from A to B, the B point is at end of measured cable. If this point is broken, the OTDR still can receive the Fresnel reflection signal from the endpoint. But if we started measure from B point, when light was transmitted from OTDR and reach to the broken point at B. It can be treated as sent to the air at beginning, as the result the OTDR cannot show any reflect signal in such short distance.

5. Judgment and finding fault of fibre optic cable line

Search and positioning of optical fibre cable line fault is very important for keeping the equipment work in good condition. It is necessary to know how to use the relevant instruments to repair the specific location and the specific reasons of failure.

5.1. Common fault occurrence and cause

According to the experience of practice, the cable faults are often caused at the cable connector. No matter what kind of continuation method, but the original coating has been removed. So the optical fibres' own strength and reliability has dropped down. If several fibre channels failed at the same time, then we decide this failure is often cause human mistake or bit by the animals. Optical fibre cable lines' common failure phenomena and causes are shown in Table 5.1. /5/

Table 5.1. Common Failure Phenomena and Causes of Optical Fibre Cable Line./5/

Failure' phenomenon	Possible causes of the Failures
One or more fibre splice loss increases	Installation problem of the fibre splice protect pipe or water damage of connect box
One or more fibre attenuation curve step	Fibre optic cable damage by mechanical force sprains, part of the fibre injured but not yet completely disconnected
A fibre attenuation steps or broken fibre, other fibre intact	Fibre optic cable damage by mechanical force due to itself quality reasons

The original optical fibre splice point steps of the level of elongated	Fibre optic cable broken at the splicing point
Optical communications business is totally breakdown	Fibre optic cable pulled off by external influences or vandalism

5.2. OTDR measurement curve fault finding

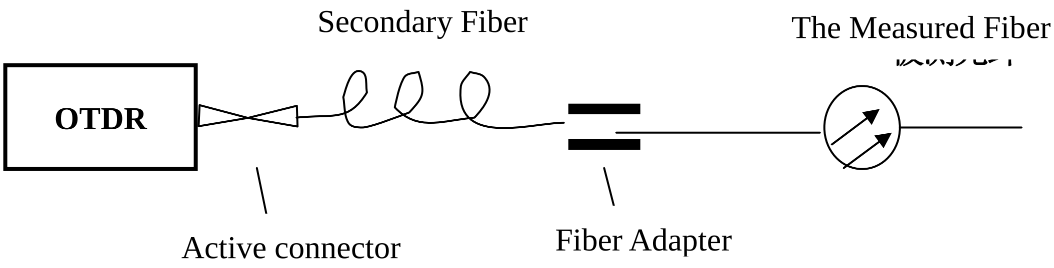

Figure 5.1. OTDR test diagram.

After confirming the fibre optical line failure, we used Optical Time Domain Reflect meter (OTDR) to test the fibre optical line failure point (connecting like Figure 5.1) by determine the character and location of the line fault. Firstly we pulled the fault line out from the Light Ware Terminal Equipment, and then inserted one point of cable into the light output port of the OTDR. Next is to observe optical fibre backscatter signal curve. “According the point of Fresnel Reflection Peak on the OTDR display we read the distance to the point of failure from the test side.”/6/Finally we can determine the approximate distance to the point of failure. Comparing with the original OTDR backscatter curve (Figure5.2), we decide the fault point is in which two monuments, and then narrow the range. After conversion and precisely measure we can get the accurate location of the fault point. If the condition is approved, two-way test will be more accurately to determine the position of fault point.

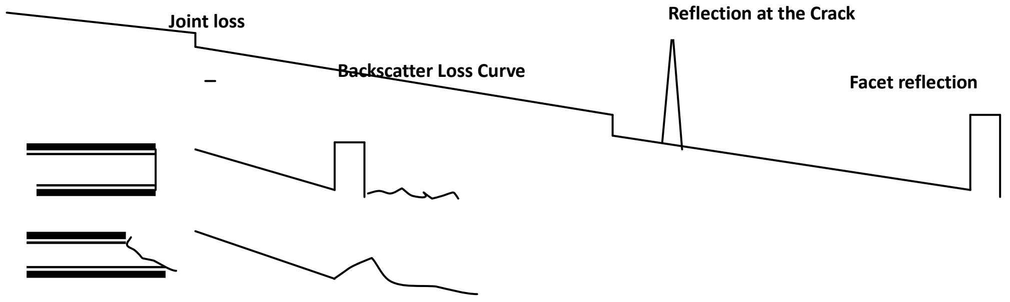

Figure 5.2. Typical OTDR measurement curve.

5.3. Optical fibre cable line testing

In the laboratory, we use the SDH equipment “FonSWeaver 780B” which provided by a Chinese company called “FiberHome”. Two SDH equipments are located in two building which has 2.4km distance between each other and connected with optic fibre cable. Next two figures (Figure5.3 and Figure5.4) illustrated two SDH equipments in different shelves.

Figure 5.3. Near End SDH Equipment Panel.

Figure 5.4. Remote End SDH equipment.

We use the most 7th left side deck on the near end equipment and same with the remote end equipment. Every single deck has receiver and transmitter port. If two SDH equipments are well connected and work in good condition. Red alarm light on both devices is off.

Network management interface uses the most left side green line to show these two SDH equipment is well connected (Figure 5.5).

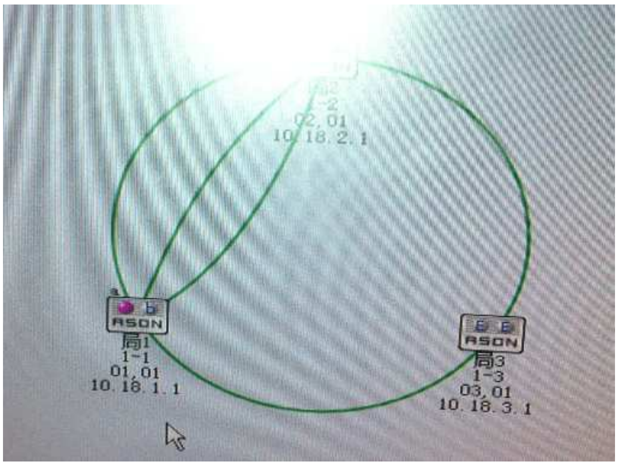

Figure 5.5. Network Management Interface Connecting Diagram.

Figure 5.6. Single Deck Connection on Network Management Interface.

From Figure5.6, we can observe from the network management interface: the light of the 7th slot is green; it means that the connection of deck is working good condition.

When transmission system is working fine, we can measure the attenuation at the optic receiver side directly on the SDH management interface. According to our measurement, we get the attenuation of the power at receiver side is 8.00dBm. It shows as Figure 5.7.

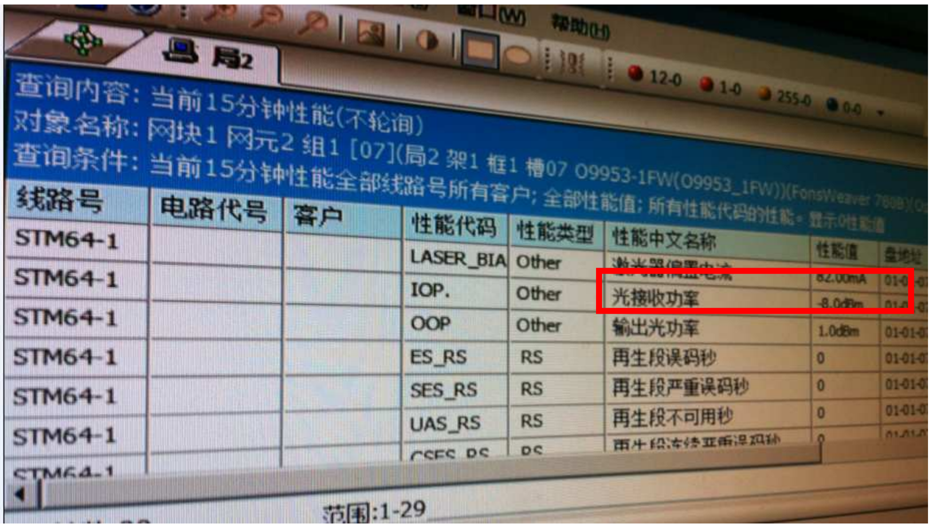

Figure 5.7. Feature diagram.

After that we used the optical power meter to measure the attenuation again, and got attenuation value equal 7.79dBm (Figure 5.8). This value is almost same with the result we go from the optic fibre manage system.

Figure 5.8. The Optical Power Meter Value.

We simulated one fault is occurred at the end of the optical cable connection by disconnect the fibre optic insert at the remote end SDH equipment. When it happened, the most left side band's alarm light will turn red as Figure 5.9 shows:

Figure 5.9. Instrument panel diagram after disconnect fibre.

As Figure 5.10 shows below, the most left side connecting line is red; it means the connection between two SDH equipment were broken in somewhere.

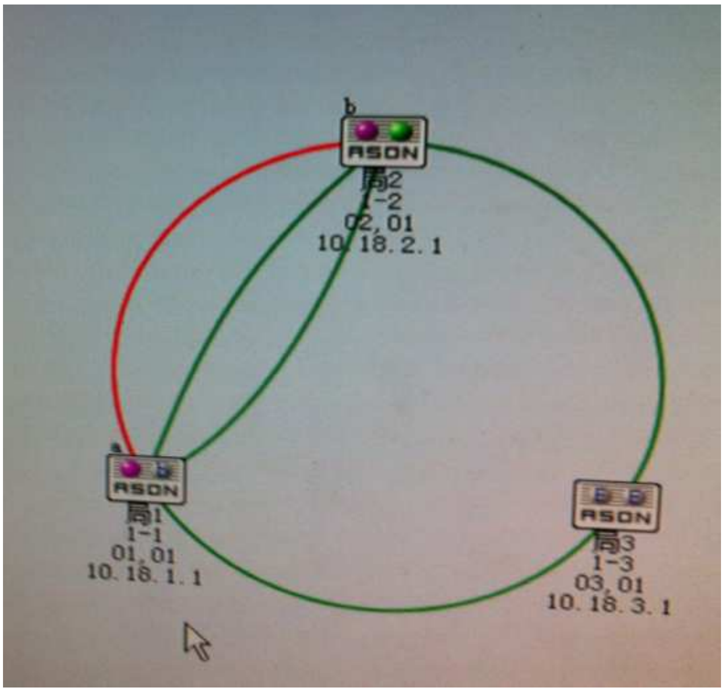

Figure 5.10. SDH connection diagram.

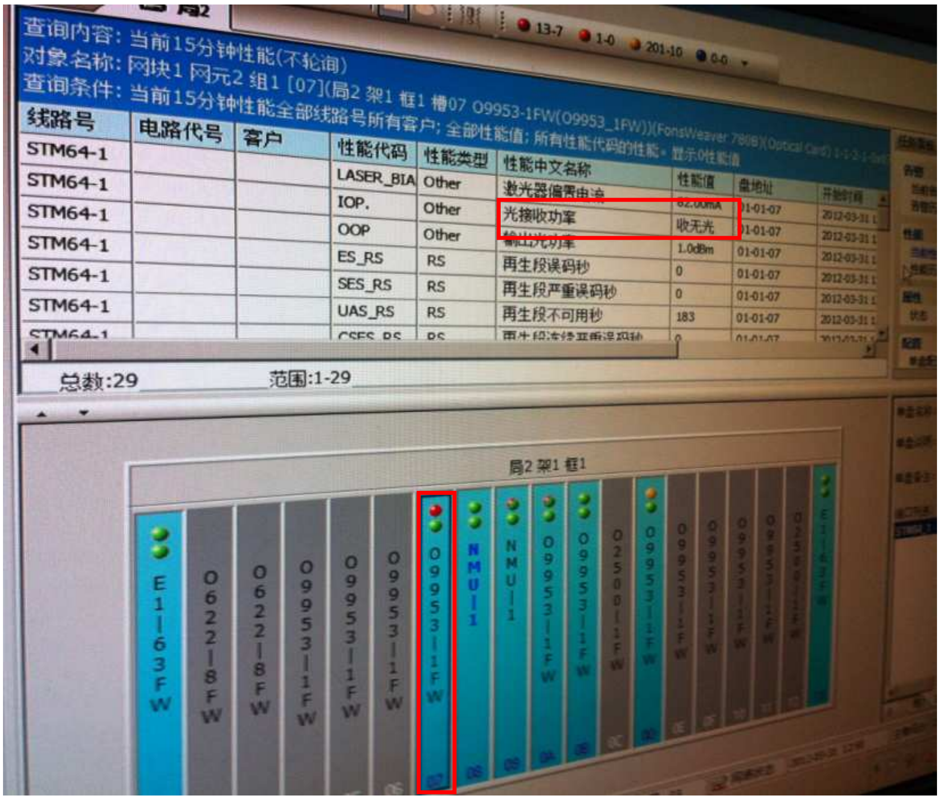

Figure 5.11. Network Alarm Diagram.

As the Figure 5.11 shows above, the 7th deck connection is red; it means the connections between two SDH equipments were broken in some place.

We can determine the character of the fault is “Loss of Signal (LOS) from Figure 5.12

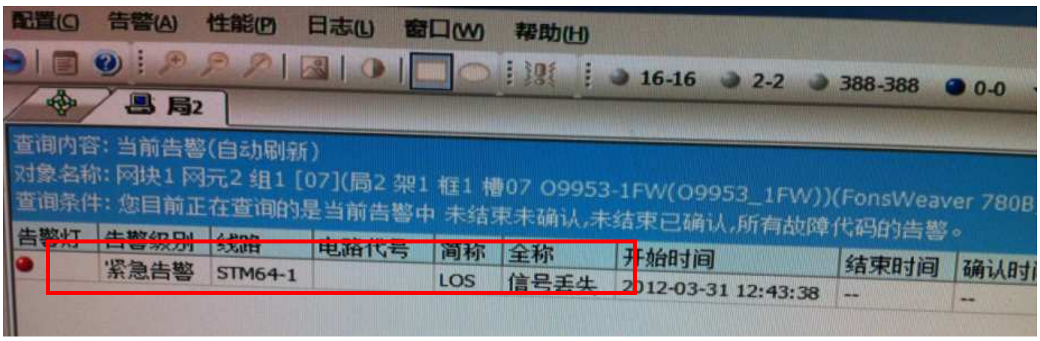

Figure 5.12. Alarm Indication after Disconnecting Fibre.

We used the optical power meter instead but no signal received also. As we can observe from the Figure 5.13:

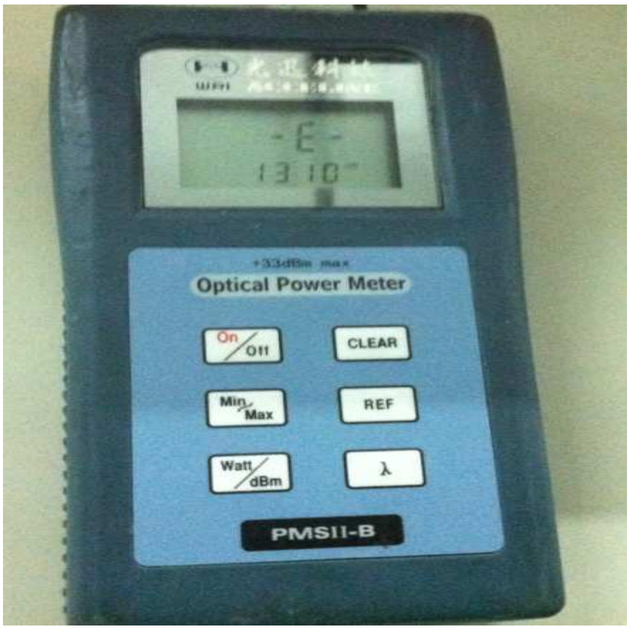

Figure 5.13. Optical Power Meter.

Then we can use the OTDR to measure the distance between the fault point and the transmitter point of the SDH. The OTDR should be set as follow steps:

As Figure 5.14 expressed, we chose the Fault Location Function on OTDR

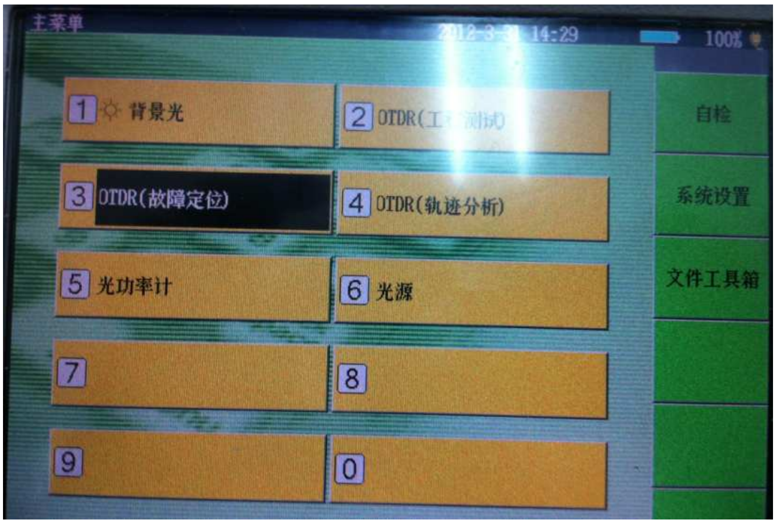

Figure 5.14. OTDR function setting diagram.

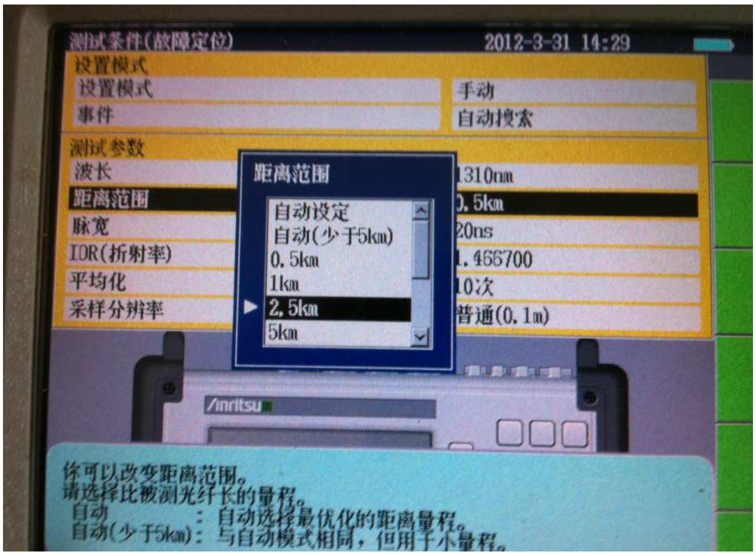

Figure 5.15. OTDR setting distance range with 2.5km.

Figure 5.16. OTDR setting pulse widths with 50ns.

Because the distance between two SDH equipment is about 2km. the failure must located in this range, so we set the range 2.5km and pulse width with 50ns(Figure 5.15 and Figure 5.16).

After we finished setting part, then press the button F4. The OTDR will start automatic measuring. Then we use the zoom in function to remove the cursor to the peak of the Fresnel reflection. The OTDR will automatic show the distance to this point. For our case the range is about 2.085kma as the Figure 5.17 show.

Figure 5.17. Measurement result of OTDR.

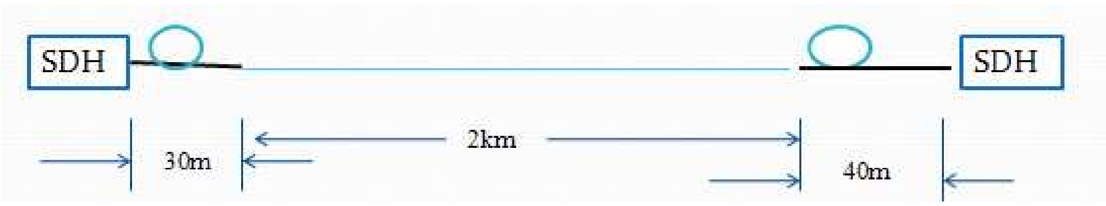

Figure 5.18. SDH Equipment with Optical Fibre Line Connection Diagram.

In geographic perspective, the optical fibre line is distributed as Figure 5.18. The total length of the optical fibre is about 2km. The total length of the patch cord is about 70m, and the length of pig tail cable is about 10m. So the total length of the cable is about 2.08km. By comparing with the OTDR result it shows the position which we measured is almost the end of the fibre optic connection line. This is same conclusion what we supposed to get.

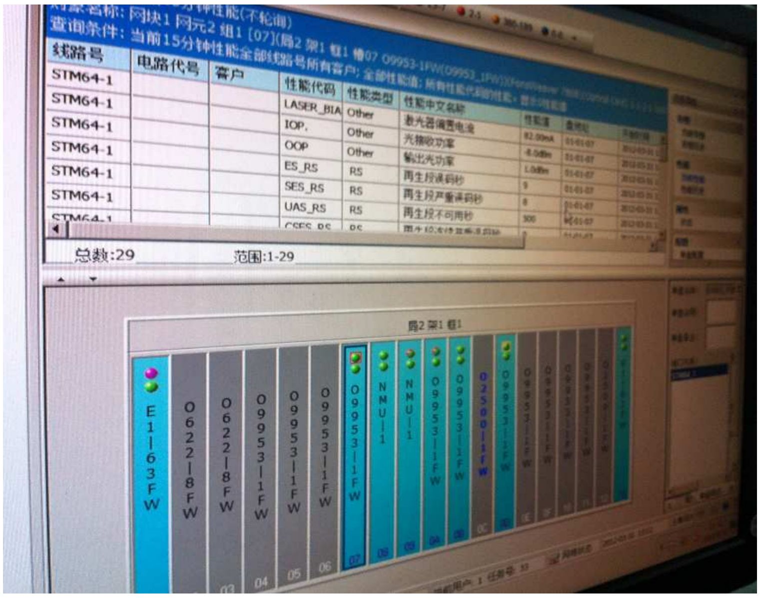

Figure 5.19. Optical fibre management interface after reconnect the cable.

In this lab we did not cut the cable at one point in order to get the fault point. Instead we just pull the cable out from transmitter or receiver port to simulate the failure situation. So after we connected the cable with SDH equipment again, the signal deck works well again as Figure 5.19. But when we meet the failure point in the real life, after the fusion splicing the attention at receiver side which shows on SDH management interface will increase a little bit.

6. Summary and Outlook

We analysis the causes and characteristics of optical fibre fault in this thesis. The actual demand for the fast recovery of communication requires us to ensure wellness of communication. We need to processing failure of optical fibre cable line promptly and accurately and this project gives a good solution to find, locate and repair the cable line fault in actual situation.

The completed work of this thesis:

1) Get clear reasons with cable line failure and explore the basic methods to determine the fault of optical fibre cable line
2) Base on the optical fibre cable line test, locate and then deal with the fault point.
3) Base on analysis failure of the optical fibre cable line, we are able to quickly find the fault point and deal with failure in the future.

Actually we pull the fibre optical line off to simulate we meet a real fault in SDH communication. However we are still able to locate the position of failure point, and fix it by fusions splicing. To my own perspective, I did really achieve a great deal of information and experiences from this project.

Acknowledge

There were plenty of people who support and help me during this long period of time. First, I really appreciate my guiding teacher Dr Gao Chao who gave me a lot of supports on background knowledge and the teachers from WuHan Institute of Post and Telecommunication guided me during the operational program. Special thanks to my parents and friends, they also gave me considerable support and help.

Vaasa, Finland; 23th January 2013

Xie Feng

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