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Passive Optical Signal Tapping Device

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Abstract: A fully passive optical signal tapping device named Passive In-line Monitoring (PIM) device is developed to provide and increase the monitoring and maintenance capabilities of Fiber-To-The-Home (FTTH). This device will be permanently installed with the FTTH trunk lines to tap out a small ratio of triple-play signals for monitoring appliance without affecting the service transmission. The PIM device optically splits the full-duplex signals into two portions; 98% maintains in the transmission link, while the other 2% is simultaneously connects to a portable tester unit for identifying the signal presence and direction. Such features also allow the network operators to maintain and operate their network more cost-effectively and offer the end-users with an improved survivability and reliability network, which is continuously monitored 24 h a day and 7 days a week. A PIM device prototype had been successfully developed in this study and implemented in FTTH. The experimental results show the parameters of PIM device are operating wavelength 1310 /1480/1550 nm, operating bandwidth ± 15 nm, insertion loss ≤ 1.5 dB, return loss ≥ 35 dB and directionality ≥ 55 dB.

Key words: PIM device, FTTH, monitoring appliance, signal presence, survivability and reliability network

INTRODUCTION

Optical networks are high-capacity telecommunications networks based on optical technologies and components that provide routing, grooming and restoration at the wavelength level as well as wavelength-based services. As networks face increasing bandwidth demand and diminishing fiber availability, the network service providers are moving towards a crucial milestone in network evolution: the optical networks are based on the emergence of the optical layer in transport networks, provide higher capacity and reduced costs for new applications such as the Internet, video and multimedia interaction and advanced digital services (IEC, 2007).

FTTH is a network technology that deploys optical fiber cable directly to the home or business to deliver triple-play (data, voice and video) services with a high speed up to the customer premises via the Optical Distribution Network (ODN). The FTTH has played the major role in alleviating the last mile bottleneck for next generation broadband optical access network (Yeh and Chi, 2005). Today, FTTH has been recognized as the ultimate solution for providing various communications

and multimedia services, including carrier-class telephony, high-speed Internet access, digital cable television (CATV) and interactive two-way video-based services to the end users (Lee *et al.*, 2006). A rapidly growing number of households are connecting directly into fiber optic networks and thereby tapping into a new generation of high-bandwidth applications and services. The households receive Internet, telephone and video services via lightning-fast FTTH connections.

FTTH using Passive Optical Network (PON) with point-to-multipoint (P2MP) configuration/connectivity is the most promising way to provide high quality broadband access. The PON is a technology viewed by many as an attractive solution to the first mile problem; a PON minimizes the number of optical transceivers, Central Office (CO) terminations and fiber deployment. A PON is a P2MP optical network with no active elements in the signal path from source to destination. The only interior elements used in a PON are passive optical components, such as optical fiber, splices and splitters. A PON employs a passive device (i.e., optical splitter/branching device, etc., that not requiring any power) to split an optical signal signals from multiple fibers into one. The PON is capable of delivering triple-play (data, voice and

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voice) services at long reach up to 20 km between CO and customer premises. All transmission in a PON is performed between an Optical Line Terminal (OLT) and Optical Network Units (ONUs). The OLT resides at CO; while ONU is located at the end user location (Mukherjee, 2006).

Since, the FTTH can accommodate a large number of customer premises/subscribers, when any failure/fault (caused by natural disasters, wear out and overload, interruptions due to maintenance, etc.) occurs, the services will be interrupted/breakdown. Any service outage can suspend critical operations, which may cause tremendous financial loss in business for the network service providers and customers. According to the cases reported to the Federal Communication Commission (FCC) in US, more than one-third of service disruptions are due to fiber cable problems. This kind of problem usually take longer time to resolve compared to the transmission equipment failure (Bakar *et al.*, 2007).

Most problems in FTTH can be located using Optical Time Domain Reflectometer (OTDR) that provides a graphical trace that enables to locate and characterize every element in a link, including connectors, splices, splitters, couplers and fiber degradations or failures. OTDR was first reported by Barnoki and Jensen (1976) as a telecommunications application and became an established technique for attenuation monitoring and fault location in optical fiber network within the telecommunications industry (King *et al.*, 2004). According to Chomycz (1996), OTDR testing is the best method for determining the exact location of broken optical fiber in an installed optical fiber cable when the cable jacket is not visibly damaged. It determines the loss due to individual splice, connector or other single point anomalies installed in a system. It also provides the best representation of overall fiber integrity. Whenever a fault occurs, OTDR is plugged manually to the faulty fiber by the technician to detect where the failure is located. By means of OTDR, one can get the distance from the fault site to the measurement site along the optical fiber housed in the optical cable. However, one of the issues with testing using OTDR is this approach would produce inaccurate results if two trouble spots are very close together or if the pulse has a long travel length (White, 2008).

Besides, serious problems may occur when the technicians measure the optical signal strength at each node in the network for monitoring the signal quality and troubleshooting the connection problems. Typically, the technicians have to break the connection to shut down the node for measuring the relative optical strength at a node. If there are multiple wavelengths going through the same node, then the technicians need to use an Optical

Spectrum Analyzer (OSA) or wavemeter to examining the spectral composition of optical waveform. This creates a risk of contaminating the fiber ends when disconnecting or reconnecting the node to the FTTH. It leads to create some serious problems later on and possible costly repairs, therefore these measurements can be quite costly (Optics, 2006).

PIM DEVICE PROTOTYPE

The PIM device is a fully passive device, where all the optical components in the device do not require electronic control for their operation. It is developed to provide the monitoring and maintenance capabilities for the three main operating wavelengths in FTTH (1310, 1480/1490 and 1550 nm). Typically, the 1310 nm signal is used for data/voice upstream transmission and 1480/1490 nm for the downstream data/voice transmission. Meanwhile 1550 nm is used to transmit downstream video signal. The PIM device prototype consists four ports for tapping features, which are controlled by optical couplers to perform the optical power combining and splitting in the device (Fig. 1-4).

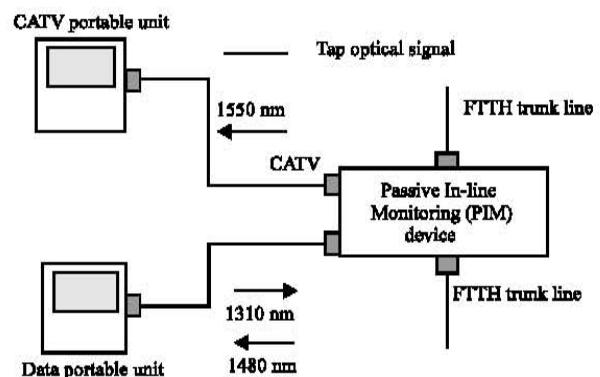


Fig. 1: Block diagram of PIM device prototype

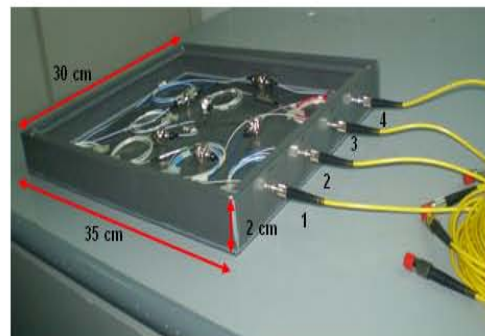


Fig. 2: Photographic view of PIM device prototype before packaging



Fig. 3: Photographic view of PIM device prototype before chasing



Fig. 4: Photographic view of developed PIM device prototype

Passive taper circuit: A taper circuit is designed to optically split the full-duplex (upstream and downstream) signals into two portions; 98% maintains in the transmission link, while the other 2% is simultaneously connects to a portable tester unit to provide a visual way for monitoring and identifying the receiving signals presence. The entire optical components that had been used in the taper circuit including connectors for connecting two optical fibers, splices for attaching one bare fiber to another, optical isolators that prevent unwanted light from flowing in a backward direction and optical couplers used to tap off a certain percentage of light for performance monitoring purposes.

Optical couplers with low insertion loss, low excess loss and high stability and reliability performance capable are the main component used in the circuit design to divide the 1310, 1480 and 1550 nm three communication windows. Since, it is one of the passive optical components, it do not require external source of energy to perform an operation or transformation on an optical signal. The concept of a coupler encompasses a variety of

functions, including splitting light signal into two streams, combining two light streams, tapping off a or transferring a selective range of optical power from small portion of optical power for monitoring purposes, one fiber to another (Keiser, 2000). Optical coupler consists of two fibers fused together. Signal power received on any input port is split between both output ports. The splitting ratio of a splitter can be controlled by the length of the fused region and therefore is constant parameters. Often, coupler is manufactured to have only one input or one output. A coupler with only one input is referred as a splitter and coupler with only one output is referred as a combiner. A tap coupler is used to branch off a small portion of the signal power for monitoring purpose. Coupler is characterized by the following parameters:

- **Splitting loss:** Power level at the coupler's output vs. power level at its input (in dB). The splitting loss of an ideal 2×2 coupler is 3 dB
- **Insertion loss:** Power loss which results from imperfections of the coupler's manufacturing process. Typically, this value ranges from 0.1 to 1 dB
- **Directivity:** Some amount of input power leaked from one input port to another input port. Coupler is highly directional devices with the directivity parameter reaching 40-50 dB (Mukherjee, 2006)

Another important component in the prototype is optical isolator that allow light to pass through them in only one direction. This is important in a number of instances to prevent scattered or reflected light from travelling in the reverse direction (Keiser, 2000).

Characteristics of PIM device: Two methods are being used to study the specifications of PIM device prototype: device testing and network testing. The parameters of each port in the PIM device prototype such as insertion loss, reflection loss and crosstalk are measured through a device testing, which used a Tunable Light Source (TLS), circulator and OSA, as depicted in Fig 5 and 6. Tunable light source is used for light emitting with different emission wavelengths and OSA is used for examining the spectral composition of optical waveform. Meanwhile the network testing utilizes the OTDR to study the specifications of PIM device.

In specifying the performance of PIM device prototype, we indicated the percentage division of optical power between the output ports of the couplers by means of the splitting ratio or coupling ratio by adjusting the parameters. However, in any practical coupler there is always some light that is lost when a signal goes through

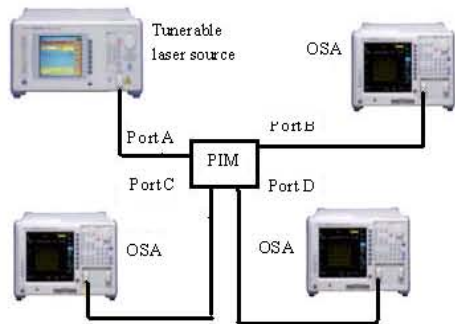


Fig. 5: The experimental setup for measuring the insertion loss of each port in the PIM device

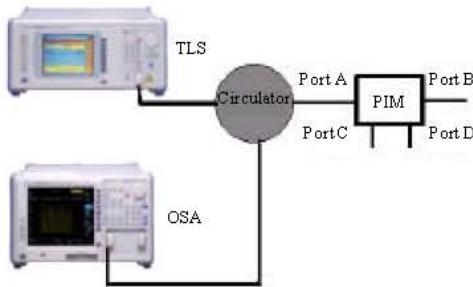


Fig. 6: The experimental setup for measuring the crosstalk of each port in the PIM device

it. The two basic losses are excess loss and insertion loss. The excess loss is defined as the to-port path. Another performance parameter is crosstalk, which measures the degree of isolation between the input at one port and the optical power scattered or reflected back in to the other input port (Keiser, 2000). The specifications and performances of PIM device are listed in Table 1 and 2.

Power budget: Attenuation is the reduction of signal strength during transmission. Greater signal loss equals higher attenuation. A signal can lose intensity, or experience increased attenuation, with each surface or medium it traverses. Optical signal strength is measured in decibels (dB) and is based on a logarithmic scale. If a signal attenuates too much, the destination device cannot identify it, or worse, it may not even reach the destination. This is why some optical links depend on repeaters, which amplify the signal. Many factors contribute to the attenuation rate of signals including components/devices and transmission through optical fiber cables. Optical fiber cables also contribute to signal attenuation. As light travels through an optical cable, some of its energy gets dispersed and absorbed by the cable. The attenuation rate varies depending on the cable type used (Network Instruments, 2005).

Table 1: The specifications and performances of PIM device

Specifications	Parameters
Operating wavelength	1310/1480/1550 nm
Operating bandwidth	± 15 nm
Insertion loss	≤ 1.5 dB
Return loss	≥ 35 dB
Directionality	≥ 55 dB
Storage temperature range	-40 to 85°C
Operating temperature range	-20 to 70°C

Since, the attenuation (reduction) of the signal strength is important when considering the factors such as the effects of tapping off a small part of an optical signal for monitoring purposes, for examining the power loss through some optical element, or when calculating the signal attenuation in a specific length of optical fiber. We are doing a power budget to calculate the maximum number of PIM device that can be installed in the network. The power budget for network configuration is based on the power drop for each type of splitter, which has different value of insertion loss. All the losses for basic components including OLT and ONUs in FTTH are estimated in the power budget. This is purposely to calculate the maximum number of PIM devices can be installed in the FTTH without affecting the upstream and downstream transmission. The more number of devices installed with the main line, the more easily to specify the failure part before verifying the exact location with an OTDR.

Table 3 shows the calculation of total system losses for multiple wavelengths with the sensitivity level -30 dBm and safe margin 5 dB, the maximum losses in the network are allow are less than -25 dB. Only maximum up to 4 unit of PIM devices are achieve the acceptability signal level, to consider it as safe (no interruption). With the maximum distance between the OLT and ONU can up to 20 km, this indicates that each PIM device can be installed at every 1 to 2.5 km within distribution region of FTTH. However, if the maximum number of PIM devices is more than 4 units, the subscribers still can receive the triple-play signal with several noise and disruption.

FTTH SURVIVABILITY SCHEME WITH COMBINED OTDR AND PIM DEVICE

This study presents a network survivability scheme for FTTH using P2MP configuration, with the excellent combination of OTDR and PIM device. The proposed survivability scheme can be grouped into two parts: (1) network testing monitoring in feeder region with OTDR and (2) transmission surveillance in distribution region with PIM device.

Table 2: The values of insertion loss from theoretically, device testing, and network testing

	Theoretically		Device testing		Network testing	
	1480	1550	1480	1550	1310	1550
Insertion loss	(nm)					
Port A-B	-	-	-	-	1.227 dB	-
Port B-A	0.88 dB	0.84 dB	1.19 dB	1.08 dB	Uninterested	1.283 dB
Port A-C	Uninterested	9.71 dB	Uninterested	10.12 dB	-	-
Port A-D	28.79 dB	Uninterested	25.64 dB	Uninterested	-	-

Table 3: The calculation values of total system losses for triple-play signals

	Total system losses for multiple wavelengths		
	1310	1480	1550
No. of PIM device	(nm)		
1	-22.41 dB	-20.23 dB	-19.79 dB
2	-23.07 dB	-21.11 dB	-20.63 dB
3	-23.73 dB	-21.99 dB	-21.47 dB
4	-24.79 dB	-22.87 dB	-22.31 dB
5	-25.05 dB	-23.75 dB	-23.15 dB
6	-25.71 dB	-24.63 dB	-23.99 dB
7	-26.37 dB	-25.51 dB	-24.83 dB
8	-27.03 dB	-26.39 dB	-25.67 dB
9	-27.69 dB	-27.27 dB	-26.51 dB

Total system losses: 20 km Fiber attenuation+Insertion loss of PIM device+Device/component losses (e.g., patch cords, optical splitter, splices, connectors and adapters, etc.)

Surveillance in feeder region with OTDR: The surveillance in feeder region is very simple; it only required a commercially available OTDR. The OTDR will be located at CO for in-service monitoring and failure analyzing against fiber degradations or failures/cuts over the feeder region. In order to locate a fault without affecting the triple-play services, it is essential to use a wavelength different from the triple-play signals for failure detection (Sankawa *et al.*, 1990). As shown in Fig. 7 and 8, the triple-play signals are combined (multiplexed) with 1625 nm OTDR testing signal. When four kinds of signals are distributed, the triple-play signal will be split up by the Wavelength Selective Couplers (WSCs), which are installed after the OLT and before the passive optical splitter. The WSC coupler is actually a demultiplexer but with limited to two output ports. It is an optical device that functions to split out the signal according to their frequencies but each output arms are not limited only to one wavelength as applied in demultiplexer. The WSC coupler is designed on silica substrate with compliance of FTTH wavelengths. The designed WSC coupler is used as a router for specific wavelength in order to detect any optical line failure in FTTH application. The triple-play signals enter the waveguide in port 1 and OTDR testing signal enters the waveguide at port 3. All the wavelengths must flow out through port 2. In reverse mode, the device is applicable to split the 1625 nm testing signal from triple-play signals (Rahman *et al.*, 2008). The WSCs only allow the triple-play signals to pass through the optical splitter

and filter the 1625 nm testing signal that contaminates the services.

The status of the network system in feeder region can be monitored by using OTDR easily because there is just a single sharing fiber (feeder fiber) with a point-to-point (P2P) connection from OLT to the optical splitter. However, we filtered the 1625 nm OTDR testing signal in this architecture because the optical splitter will make the identification of a fiber fault beyond the splitter very difficult. The OTDR testing signal from all the splitter ports is added into one trace in downstream direction (from CO towards the customer premises). Therefore, it can become very complicated to localize the failure in the correct split branch of FTTH (Caviglia and Biase, 1998; NIC, 2007).

Surveillance in distribution region with PIM device: The PIM device will be installed on every node with the main lines permanently in the distribution region. The upstream and downstream (full-duplex) signals from the FTTH trunk line will be entering into the taper circuit in PIM device. It taps out 2% signals to provide a visual way for monitoring and identifying the receiving signals presence and direction when simultaneously connect the port C and D to a portable tester unit, such as small television (TV) screen for viewing the broadcast channel of CATV video or Personal Digital Assistant (PDA) for data communication.

The technicians only need to bring a portable tester unit to test the transmission signals from CO or remote point. As shown in Fig. 7 and 8, the output signals from port C and D are connected to a portable tester located at CO. The portable tester can be shared by different PIM device by the use of space-division devices or other suitable devices (e.g., optical switch, optical selector, etc.) (Caviglia and Biase, 1998). It allows the technicians to identify fiber degradations or failures/faults and failure locations without making a site visit. One there is any interruptions or terminations reported by the end-users, it enables the technicians to firstly determine the problem occurs in which respective section and the exact failure location will be verified by using OTDR.

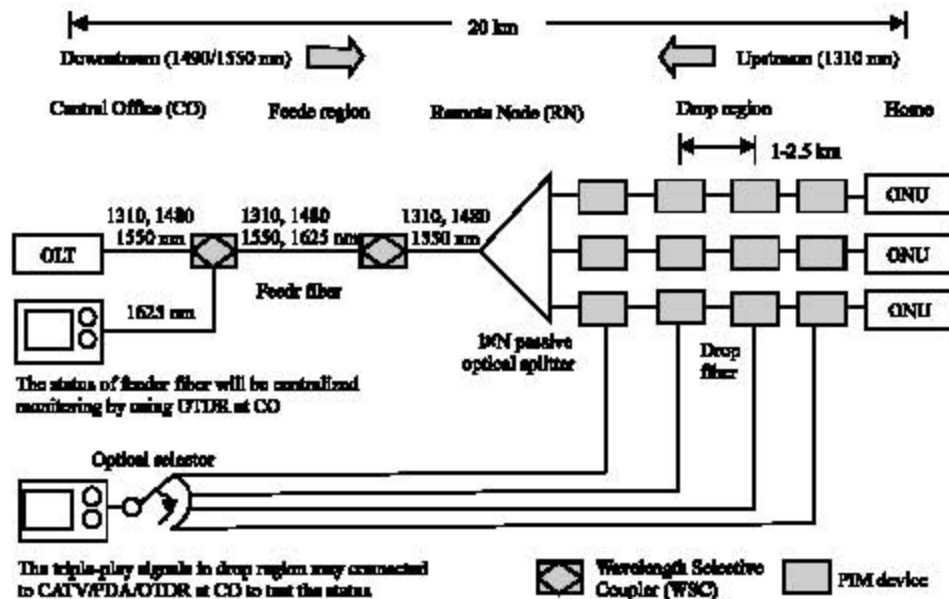


Fig. 7: The proposed network survivability scheme for FTTH with the excellent combination of OTDR and PIM device

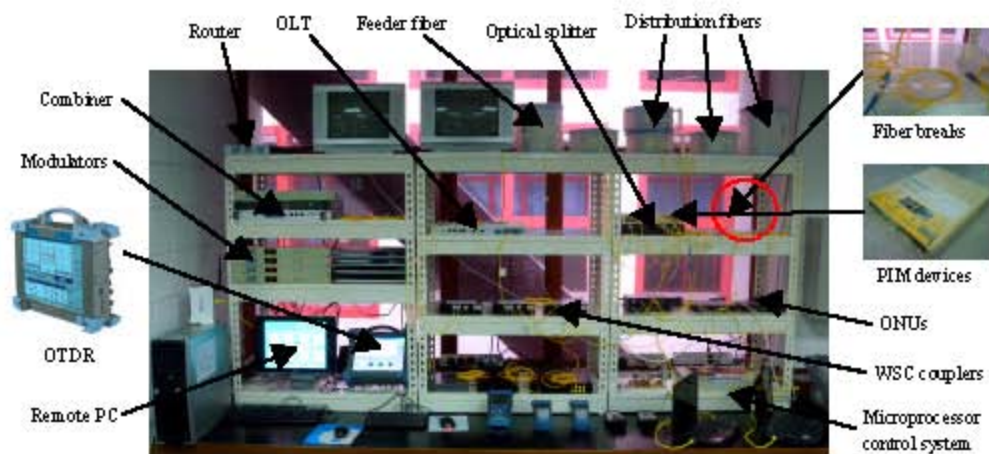


Fig. 8: Photographic view of FTTH network testbed in Networking System Laboratory at Universiti Kebangsaan Malaysia (UKM)

The CATV screen captures for 1550 nm video signals receive from OLT, ONUs and PIM device are compared in Fig. 9. Figure 9a shows the original Radio Frequency (RF) signals before modulate by modulator head end system at CO. Figure 9b and c are screen captures for the video signals optically split with 90 and 10% at port B and C. Here, we can clearly observe the brightness of video signals is decreasing from Fig. 9a-c. The RF signals are very clear rather

than other signals due to there are no losses produce when the signals pass through the medium. Figure 9 also shows the video signal deployments in between 90 to 10%. The 90% tapped signals are much clearer and brighter 10% tapped signals. However, the brightness and clearness of video signals are not important in this monitoring purpose because we are focused on whether the end-users can receive the video or not.



Fig. 9: Comparison of brightness for 1550 nm video signals; (a) original signal (before modulate) (b) 90% tapped signals (receive from ONU) and (c) 10% tapped signals (receive from PIM device)

CONCLUSION

We successfully develop a fully passive optical signal tapping device prototype in this study. A network survivability scheme is proposed for FTTH with the combined OTDR and PIM device to provide the monitoring and maintenance capabilities. The PIM device taps out a small ratio of triple-play signals for monitoring appliance without affecting the service transmission in 24 h a day and 7 days a week. As a result, network downtime and maintenance time are dramatically reduced, which enables the network operators to improve network reliability and efficiency, while maintaining cost-effective service agreements.

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