Design and Characterize of 4 Channel FTTH Demultiplexer Using Cascaded Wavelength Selective Coupler -With Application Proposal Highlights

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Abstracts: The purpose of this paper is to design and characterize the Mux/Demultiplexer (Mux/Demux) which used the concept of coupled mode theory. The design is based on cascading the wavelength selective coupler (WSC) device utilizing commercial specification. The device is designed on silica substrate with compliance of fiber-to-the-home (FTTH) wavelengths such as wavelength 1310 nm (upstream data/voice), 1480 nm (downstream data/voice), 1550 nm (video) and 1625 nm (testing). The designed WSC coupler is used as a router for specific wavelength in order to detect any optical line failure in FTTH access network application in which the optical time domain reflectometer (OTDR) launched wavelength (1625 nm) is used as troubleshooting signal. The performance of the devices was modeled using the beam propagation method (BPM-Cad) product from the Optiwave Inc. This paper also highlights the parameter studies and the effect to the design specification and performance. We analyze the following parameters such as: wavelength, separation between waveguides (a), waveguide width (d), number of mesh, TE and TM polarization, and refractive indices for substrate (n₁) and waveguide (n₂). Finally, we proposed two applications of WSC and wavelength Demux in real FTTH access network to increase the system efficiency, survivability and monitoring.

Key words: Demultiplexer, wavelength selective coupler, cascaded, waveguide based device, FTTH access network

INTRODUCTION

As telecommunication traffic increases due to the rapid growth in use of phones, faxes, computer networks, and Internet, fiber capacity will have to keep pace. The wavelength division multiplexing (WDM) technique arises as a promising technology solution to realize very high capacity long distance transmission systems by exploiting the wide bandwidth available in optical fiber. Because of the dramatic increase in capacity of optical communication using WDM, there has been an increasing interest in the development of particular devices to mange a number of wavelengths. Various types of optical WDM have been proposed and demonstrated, include gratings, thin film filters, fused-fiber coupler, waveguide-type, Bragg reflector in fiber devices, etc. These approaches can only used for wavelength filtering or separation. WDM couplers are the most common components used in multiplexing and demultiplexing the wavelengths (Ching, F.L., 2004).

The planar lightwave components (PLCs) have several advantages compare to optical fiber devices. The PLC is affected in size and weight aspect. Besides, it can be produced in a large quantity in one time, which is called a mass-production. For this coupler design, we used SU8 polymer refractive indices as a waveguide core and silica glass as substrate. SU8 polymers is high functionality, sensitive to near Ultraviolet (UV) radiation, excellent thermal stability, high optical 360 nm and its thickness in between 1 μm to 200 μs. The cured SU-8 is highly resistant to chemicals (Rahman, M.S.A. and S. Shaari, 2005).

FTTH is a network technology whereby triple-play can be delivered to residential and business customers using optical fiber cables from the point of origination to the home. The point of origination is called as central office (CO) in telephone industry and head end or hub in cable television (CATV) industry. The head end is the master point where all signals are collected for the subscriber interface in both directions (Rahman, M.S.A., A.A. Ehsan, 2006). The hub is a secondary location that interfaces with the head end and then radiates connections out to subscribers.
FTTH is the major role in alleviating the last mile bottleneck for next generation broadband optical access network (Rahman, M.S.A., A.A. Ehsan, 2006). 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, and interactive two-way video-based services to the end users. There are two fundamental FTTH architectures deployed in today’s access network, point-to-point (P2P), which is commonly referred to active optical network (AON) and point-to-multipoint (P2MP), which is commonly referred to passive optical network (PON) (Rahman, M.S.A., A.A. Ehsan, 2006).

Survivability in FTTH has become today critical issue and takes an attention many of researchers and network designers to upgrade the existing network with the restoration schemes. Survivability in FTTH involves of failure detection, status monitoring and instantly restoration (Rahman, M.S.A., A.A. Ehsan, 2006). OTDR is ideal for occasional or experienced users looking for modularity, ruggedness, ease of use, automation and top of the line optical performance. An OTDR is fundamentally optical radar. In the same way radar locates distant objects, an OTDR can locate defects and problems in an optical fiber. OTDR has provided 1625 nm wavelength to be used as monitoring signal when injected to FTTH network. In this paper, we proposed the designed WSC is suited to couple the 1625 nm to the data communication wavelength. Furthermore, by cascading the coupler devices, the propagate wavelengths can be separated to the single output port.

**Coupling Mode Theory:**

In WDM systems, sources operating at various wavelengths within 1550 nm windows are combined for transmission and are separated for reception, as conceptually shown in Figure 1. A Mux is required to combine the wavelengths before they are sent through a single fiber. At the end of the transmission, they are split by a Demux. The Demux is basically a device consists either fiber Bragg filter, Arrayed Waveguide Grating (AWG) components or other active method.

![Fig. 1: Power coupling between two waveguide](image1)

The light power of the guiding mode is mostly confined within the core. When two waveguide is placed side to side, the power of light in one waveguide will couple to the guiding mode in another waveguide. The power coupling ratio depends on the distance, coupling coefficients and the difference of propagation constants of the guiding modes in both waveguides (Cherin, A.H., 1983; Ching, F.L., 2004). Figure 1 and 2 showed the power variation with the propagation distance for this coupling. \( L_c \) represents the coupling length for the waveguide. The cut off break to determine the coupling length is determined from the internship power coupling between the wavelengths with respect to the coupling length as shown in Figure 2.

![Fig. 2: Power coupling between two identical waveguide (phase matched)](image2)
According to the coupling mode theory, if two waveguides are sufficiently close such that their evanescent fields overlap, the propagating light can be coupled from one into the other (Ching, F.L., 2004; Shaari, S., K.S. Leong, O.S. Siah, 2000). Two parallel planar waveguides that are assumed to be single mode, made of two slabs of widths \(d\), separation \(2a\), and refractive indices \(n_1\) and \(n_2\), embedded in a medium of refractive index \(n\) slightly smaller than \(n_1\) and \(n_2\). The separation between the waveguides is such the optical field outside the slab of one waveguide (in the absence of the other) overlaps slightly with the slab of the other waveguide (Tamir, T., 1990).

Say \(u_{1}(y)e^{j\beta_1 z}\) and \(u_{2}(y)e^{j\beta_2 z}\) are the transverse field associated to each waveguide. The coupling modifies the amplitudes of these modes without affecting their transverse spatial distributions or their propagation constants. The amplitudes of the modes of waveguides 1 and 2 are therefore functions of \(z\), \(a_1(z)\) and \(a_2(z)\). It can be shown that the slowly varying amplitude \(a_1(z)\) and \(a_2(z)\) are governed by (Shaari, S., K.S. Leong, O.S. Siah, 2000)

\[
\frac{da_1}{dz} = -j \alpha_{12} \exp(j \Delta \beta z) a_2(z) \tag{1}
\]

\[
\frac{da_2}{dz} = -j \alpha_{12} \exp(-j \Delta \beta z) a_1(z) \tag{2}
\]

where, \(\Delta \beta = \beta_1 - \beta_2\)

is the phase mismatch per unit length, and

\[
\alpha_{12} = \frac{1}{2} (n_2^2 - n^2) \frac{\kappa^2}{\beta_2} \int_{a}^{a+2a} u_{1}(y)u_{2}(y) dy \tag{3}
\]

\[
\alpha_{21} = \frac{1}{2} (n_1^2 - n^2) \frac{\kappa^2}{\beta_1} \int_{-a}^{a} u_{2}(y)u_{1}(y) dy \tag{4}
\]

are coupling coefficients for waveguide 1 and waveguide 2 respectively.

The optical power \(P_{1}(z)\) and \(P_{2}(z)\) are proportional to the square of their amplitudes and when the guides are identical, where \(n_1 = n_2\), \(\beta_1 = \beta_2\), and \(\beta = 0\), therefore (Shaari, S., K.S. Leong, O.S. Siah, 2000)

\[
P_{1}(z) = P_{1}(0) \cos^2 \alpha z \tag{5}
\]

\[
P_{2}(z) = P_{2}(0) \sin^2 \alpha z \tag{6}
\]

Where \(\alpha = \sqrt{\alpha_{12} \alpha_{21}}\), the coupling coefficient.

At transfer distance \(z = L = \pi/2\alpha\), the power is transferred completely from waveguide 1 to waveguide 2. A waveguide coupler of fixed length changes its power-transfer ratio if a small phase mismatch \(\beta\) is introduced. The power transfer ratio \(\alpha = P_{1}(L)/P_{1}(0)\) can be written as a function of \(\beta\) (Shaari, S., K.S. Leong, O.S. Siah, 2000),

\[
\alpha = \left(\frac{\pi}{2}\right)^2 \sin \gamma \left\{ \frac{1}{2} \left[ 1 + \left( \frac{\Delta \beta_{12}}{\pi} \right)^2 \right]^{1/2} \right\} \tag{7}
\]
Where $\sin c(x) = \sin(\pi x)/(\pi x)$

Waveguides as well as optical fibers show increased losses due to bending effects. At longer wavelengths, they become more susceptible to microbending losses. At a bend, the geometry of the core-bending interface changes and some of the guided light is transmitted from the core into the cladding. The radius of curvature of fiber bend is critical to the amount of power lost.

The loss coefficient associated with a fiber end is given by (Saleh, B.E.A. and M.C. Teich, 2007)

$$\frac{P_{out}}{P_{in}} = e^{-\alpha_{bends}d}$$  \hspace{1cm} (8)

And the attenuation coefficient

$$\alpha_{bends} = c_1 e^{-c_2r}$$  \hspace{1cm} (9)

Where $r$ is the radius of curvature of the fiber bend and $c_1$ and $c_2$ are constants. The losses are negligible until the radius reaches a critical size given by (Saleh, B.E.A. and M.C. Teich, 2007).

$$r_{critical} = \frac{3n_{eff}^2\lambda}{4\pi (NA)^2}$$  \hspace{1cm} (10)

In these fibers, the bend losses show a dramatic increase above a critical wavelength when the fiber is bent perturbed. In particular, it has been observed that the bend losses can be appreciably high at 1550 nm in fibers designed for operation at 1300 nm. Bending loss can be reduced by making the bend radius larger or by increasing the confinement of the mode field. However, these changes result in either an increase in overall device length or increased insertion loss (Saleh, B.E.A. and M.C. Teich, 2007).

**Design Methodology:**

Waveguide design consists of several steps in order to get a proper design which follows the specification needed. The design process can be simplified in the flow chart (see Figure 3) and the specification for the WSC is shown in Figure 4. The 1310 nm, 1480 nm and 1550 nm wavelengths (triple-play signals) enter the waveguide in port 1 and 1625 nm wavelength enters the waveguide at port 3. The 1625 nm wavelength generated by the OTDR will be used to scan the status of FTTH network. All the wavelengths must flow out through port 2. In reverse mode, the device is applicable to split the 1625 nm wavelength from the triple-play signals. The wavelength configuration for each arm of WSC is determined by the length of coupling area. The cut-off value can be defined from the analysis of graph power coupling versus coupling length as shown in Figure 2. The S-band is adding up to the design architecture to make it able to be connected to the pigtail. Additional structure will require the optimization of the new design to achieve the specification that has to be determined at the first. The analysis of coupler design will involve the study of parameter and its effect to the final performance. It can be done by adjusting the parameter at different input values. For instance, determine the coupling length and plot the graph in order to understand the effect to the waveguide and to the output power ratio.

**Design Parameter:**

Study the shape of propagation for each couplers and cut off the waveguide until the output ratio for all wavelength is optimize. In order to follow the specification, the design consists of three couplers that joint together (see Figure 5). The coupler will split the optical power through the desired output port. The parameter coupler is listed in Table 1. The length of linear waveguide for each coupler after cut-off is listed in Table 2. After the length of each couplers is determined, BPM_CAD is used to simulate the waveguide. The software provided the analysis of optical field, refractive index and the cut view of the waveguide through the simulation. Each wavelength will be injected to the waveguide input port (Figure 5) and the ratio output power is analyzed at each arm of the waveguide. Figure 6 to 13 display the optical field and the output power ratio with respect to the different wavelengths injected. We notice that a small amount of power remains in WSC 2, and resulting in undesirable crosstalk. Table 3 display the power output ratio for each wavelength. The wavelengths of 1480 nm, 1550 nm and 1625 nm have a ratio above 0.9. The calculation of the true loss and insertion loss is listed in Table 4.
Fig. 3: Flow chart of design step

Fig. 4: Structure of WSC which operate the wavelength used in FTTH application

Fig. 5: The structure of Design 1
Table 1: Design 1 Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive indices of core</td>
<td>1.599</td>
</tr>
<tr>
<td>Refractive indices of substrate</td>
<td>1.522</td>
</tr>
<tr>
<td>Width waveguide, d</td>
<td>6 mm</td>
</tr>
<tr>
<td>Separation between waveguides, a</td>
<td>1 mm</td>
</tr>
<tr>
<td>Wavelength (nm)</td>
<td>1310, 1480, 1550, 1625</td>
</tr>
<tr>
<td>Number of mesh</td>
<td>15000</td>
</tr>
<tr>
<td>Field</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Polarization</td>
<td>TE</td>
</tr>
<tr>
<td>Simulation configuration</td>
<td>Run with graphic interface</td>
</tr>
<tr>
<td>BPM solver</td>
<td>Paraxial</td>
</tr>
<tr>
<td>Boundary condition</td>
<td>TBC simple</td>
</tr>
</tbody>
</table>

Table 2: The length of couplers

<table>
<thead>
<tr>
<th>Length, L</th>
<th>L₁</th>
<th>L₂</th>
<th>L₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear waveguide length (μm)</td>
<td>14 500</td>
<td>8800</td>
<td>14 400</td>
</tr>
<tr>
<td>Wavelength (nm)</td>
<td>1310</td>
<td>1310</td>
<td>1550</td>
</tr>
<tr>
<td>1480</td>
<td>1480</td>
<td>1625</td>
<td></td>
</tr>
<tr>
<td>1550</td>
<td>1625</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: The loss for each wavelength

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Power Output Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1310 nm (I₁)</td>
<td>0.898982</td>
</tr>
<tr>
<td>1480 nm (I₁)</td>
<td>0.924180</td>
</tr>
<tr>
<td>1550 nm (I₁)</td>
<td>0.959949</td>
</tr>
<tr>
<td>1625 nm (I₁)</td>
<td>0.951815</td>
</tr>
</tbody>
</table>

Table 4: The output ratio for each wavelength

<table>
<thead>
<tr>
<th>Loss (dB)</th>
<th>I₁</th>
<th>I₂</th>
<th>I₃</th>
<th>I₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>True loss</td>
<td>0.331</td>
<td>0.233</td>
<td>0.077</td>
<td>0.073</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>0.021</td>
<td>0.010</td>
<td>0.010</td>
<td>0.039</td>
</tr>
</tbody>
</table>

Crosstalk Analysis:

The most significant parameter when designing the wavelength selective based device is the crosstalk. Crosstalk refers to the interruption of leakage of uninterested wavelengths to the interested wavelength before interpreting by the receiver. Normally, the acceptable value is bigger than 20 dB. From the Figure 7, 9, 11 and 13, the crosstalk value for the designed mux/demultiplexer is 20 dB after we do the comparison between the signal and the maximum leakage other signal to each arm of the device. This means that the signal is far affected by the leakage signals from neighbors’ line.

Fig. 6: Optical field for 1310 nm wavelength
Fig. 7: The power output ratio for 1310 nm

Fig. 8: Optical field for 1480 nm wavelength

Fig. 9: The power output ratio for 1480 nm
Fig. 10: Optical field for 1550 nm wavelength

Fig. 11: The power output ratio for 1550 nm

Fig. 12: Optical field for 1625 nm wavelength
Fig. 13: The power output ratio for 1625 nm

Parameter Analysis:

The coupling parameter for parameter studies is listed in Table 5. The waveguide length is 34 900 μm and the design is based on Figure 4. The coupling length is analyzed by analyzing the propagation graph. The couplers parameter studied is done by observe the effect of waveguide size, waveguide spacing, the operation wavelength, refractive index core, refractive index substrate, number of mesh and the effect of TM polarization. This coupling length results are displayed in Figure 14 to 21. Refractive indices difference studies are in the range of 0.039, 0.077, 0.09 and 0.11. The refractive indices values are 1.522/1.561 (0.039), 1.522/1.599 (0.077), 1.522/1.612 (0.09) and 1.522/1.632 (0.11). The coupling length for refractive indices difference is shown in Figure 17. Figure 19 displays a graph for difference value of refractive indices with a same range between core and substrate which is 0.077. Table 6 indicates the equation that is produced from the waveguide width and spacing between waveguide.

Table 5: Parameter studies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refractive indices of core</td>
<td>1.599</td>
</tr>
<tr>
<td>Refractive indices of substrate</td>
<td>1.522</td>
</tr>
<tr>
<td>Width waveguide, d (mm)</td>
<td>3, 4, 5, 6, 7, 8</td>
</tr>
<tr>
<td>Separation between waveguides, a (mm)</td>
<td>0.5, 1.5, 2</td>
</tr>
<tr>
<td>Wavelength (nm)</td>
<td>1310, 1480, 1550, 1625</td>
</tr>
<tr>
<td>Number of mesh</td>
<td>500, 1000, 1500, 2000</td>
</tr>
<tr>
<td>Field</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Polarization</td>
<td>TE, TM</td>
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</tr>
</tbody>
</table>

Table 6: Equation from waveguide width graph and spacing between waveguides graph

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Waveguide Width</th>
<th>Waveguide spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1310 nm</td>
<td>$y = 1238.4e^{3.754x}$</td>
<td>$y = 777.19e^{0.59x}$</td>
</tr>
<tr>
<td>1480 nm</td>
<td>$y = 1107.9e^{3.324x}$</td>
<td>$y = 896.64e^{0.778x}$</td>
</tr>
<tr>
<td>1550 nm</td>
<td>$y = 1033.3e^{3.592x}$</td>
<td>$y = 763.64e^{0.751x}$</td>
</tr>
<tr>
<td>1625 nm</td>
<td>$y = 1040.8e^{3.747x}$</td>
<td>$y = 811.48e^{0.473x}$</td>
</tr>
</tbody>
</table>

Application 1: WSC in FTTH Monitoring System:

We are developing a Smart Customer Access Network (SCAN), which involves in the failure detection, automatic recovery and increases the survivability and maintainability of the FTTH access network. SCAN is the new upgraded values of recent FTTH technology toward the implementation of smart network. SCAN consists of 4 main subsystems that support the operations, they including Centralized Failure Detection System (CFDS),
Fig. 14: The coupling length for different length

Fig. 15: The coupling length for different waveguide width

Fig. 16: The coupling length for different spacing between waveguide
Fig. 17: The coupling length for refractive indices difference

Fig. 18: The power output ratio for different number of mesh.

Fig. 19: The coupling length for difference refractive index value
Access Control System (ACS), Optical Cross Add and Drop Multiplexer (OXADM) and Optical In-line Taper (OIT) (Rahman, M.S.A., A.A. Ehsan, 2006; Rahman, M.S.A., A.A. Ehsan, 2006).

CFDS is one of the subsystems for the SCAN, which able to monitor the status for each line and detect the failure in multi-line drop region of FTTH access network downwardly from CO towards customer premises. CFDS is a centralized monitoring and access control program that provides the network service provider of the FTTH access network with a means of viewing optical signals flow and detecting breakdowns and other circumstances which may require some action with the graphical user interface (GUI) capabilities of MATLAB. CFDS has the same features of the OTDR and computer-based emulation software for performing data post-processing which given more OTDR processing functions but with more flexibility and reliability of FTTH access network used for optical communication. To locate a failure without affecting the transmission services to other customers, it is essential to use a wavelength different from the triple-play signals for failure detection. SCAN is using the operating wavelength 1625 nm for failure detection control and in-service troubleshooting. When four kinds of signals (1310 nm, 1490 nm, 1550 nm and 1625 nm) are distributed from the CO to eight customer premises, the WSC that used in this proposed design only allow the OTDR signal at 1625 nm to enter into the taper circuit and reject all unwanted signals (1310 nm, 1490 nm and 1550 nm) that contaminate the OTDR measurement (Girard, A., 2006).

CFDS is interfaced with the OTDR to accumulate every testing result to be displayed on a single computer screen for further analysis. The analysis result will be sent to field engineers or service providers for promptly action. Anywhere, the traffic from the failure line will be diverted to stand by (protection) line to ensure the traffic flow continuously. CFDS is focusing on providing survivability through event identification against losses and failures. CFDS used event identification method to differentiate the mechanism of the optical signal at working (good or ideal) and non-working (breakdown or failure) condition. The CFDS will be designed to operate by itself with a minimum need for operator action. It will be automatically inform the operator regarding the failure location and the information will be sent to field engineer through the wireless technology through the mobile phone or WiFi / Internet computer. It is ideal for users who are inexperienced or non-specialized in optical fiber testing. With CFDS no more cost and time misspending due to the troubleshooting mechanism is done downwardly.

All the results from database are load into MATLAB Current Directory when pressed the 'Open' button in Line's Status window. CFDS accumulated all the results in a single screen for centralized monitoring. Every eight graphs that represented the characteristics of optical lines displayed in Linestatus window, where the distance (km) represented on the x-axis and optical signal level (dB) represented on the y-axis as depicted in Figure 23. CFDS checked each optical line's status by finding every loss in a line when pressing the 'Status' button. Two failure messages "Line 5 FAILURE at 15.1918 km from CO!" and "Line 8 FAILURE at 30.4601 km from CO!" displayed to show the failure locations in the optical network (see Figure 24).

![Fig. 20: The coupling length of TE and TM polarization for difference waveguide width](image)
Application II: Wavelength Splitting Element in ONU Architecture:

The incoming signal from the optical splitter is split according to their application. Towards that, the optical network unit (ONU) architecture consists of wavelength splitting element by means of Demux. In this paper, the cascaded WSC Demux is function the wavelength carrying data (1310 nm, 1490nm, 1550 nm) and monitoring wavelength (1625 nm) to exit in different output ports. Then the signals will pass through the converter (in this case of transceiver) to convert the optical domain signal to electronic domain signal and split according to their facilities; voice, data and video. Figure 25 shows the ONU architecture consists of wavelength Demux and optical converter. The 1625 nm injection port (either to working or protection line) is according to the design solution on monitoring system, and we proposed as simple design in (Rahman, M.S.A., A.A. Ehsan, 2006; Rahman, M.S.A., A.A. Ehsan, 2006).

Fig. 21: The coupling length of TE and TM polarization for difference waveguide width

Fig. 22: The propose architecture of CFDS. The WSC is used to split the OTDR wavelength to bypass the optical splitter and re-injected before reach the ONU.
Fig. 23: Every eight graphs display in Line's status window. Two failure messages display to show the failure for centralized monitoring locations in the optical network.

Fig. 24: The optical power level in line 1 are decreasing 0.292 dB at 15.1969 km and 1.582 dB at 30.4602 km (in Line's Detail window)
Fig. 25: The architecture of ONU consists of wavelength Demux to split the information signal according to their facilities.

Discussion:
The results showed that the higher the wavelength, the lower the coupling length. From Figure 16, for the waveguide width, the larger the size, the harder the optic coupling process occurred and the larger size of waveguide is needed for the coupled occurred. From Figure 17, the coupled process became slower when the waveguide spacing increases. The evanescent value of the first waveguide become nearer to the other waveguide as the spacing between waveguide decreases. As for refractive index studied, the larger the refractive index difference between core and substrate, the slower the coupled process. Meanwhile, for mesh studies, the simulation results could be very sensitive to the number of mesh points. The usage of more mesh points results in better precisions. For Figure 20, the length of waveguide is 34 900 μm. At mesh 1000, the output is optimized for all wavelengths. For TE and TM polarization, there are differences in coupled length when TM and TE polarization is applied. From Figure 21, the TM polarization coupled slower that TE polarization when the waveguide size increases. Beside that, the higher the waveguide size, the larger the differences of coupled between TE and TM.

Conclusion:
We have demonstrated a Mux/Demux device design where function is to combine and split four wavelengths in FTTH application. The device consists of short and long coupling length wavelength selective couplers, cascaded together to perform the function. Neglecting the error due to a very long distance or propagation, a beam propagation method study have proven that such WDM device can be made from the coupling concept. While the objective has been achieved, the design process is still under process in order to improve the coupler design and produce a high power output ratio at the end of the coupler. For the future action, the improved design will be fabricated in order to produce new and reliable device. This device may bring a benefit to a FTTH network with 2 proposals on reported. While the objective has been achieved, the design process is still under process in order to improve the coupler design and produce a high power output ratio at the end of the coupler. For the future action, the improved design will be fabricated in order to produce new device. This device may bring a benefit to a FTTH network.

The ideal of PLC Demux/WSC will be realized through the Optiwave simulators (OptiSystem and BPM_Cad) and after that the designed layout is being used to produce the photomask for actual fabrication for waveguide-based devices (Rahman, M.S.A. and S. Shaari, 2004). The device fabricated bases on waveguide are expected to have less losses, efficient and integratable as compare to fiber-based devices.

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