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# Optical Moderator Improves Flexibility Feature of Fiber-to-the Home Network

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**Abstract:** The purpose of this study was to develop a virtual lab to allow the design of new optical devices to be embedded into the network before it is sent for fabrication. A new 2×3 Optical splitter is designed and tested for the effectiveness of the lab. The device is designed using the OptiBPM software before being exported to Optical System to embed into the network. The Optical Splitter 2×3 has two different inputs and divides 50% of the input power to the first and third arm. While on the second arm, 50% of both input signals are combined. Before the design can be exported, they need to be sliced into a few parts for them to function as desired. Both of the designs will be embedded into Fiber-to-The-Home (FTTH) network test pad to be tested. Analysis of the design is done based on the performance before and after they are embedded into the network and based on the losses of output power to the input and maximum Q factor. The result shows that total insertion loss 2×3 Optical Splitter before being exported is 0.1899dB and changed to 0.3464dB after embedded into the network. The distance that the 2×3 splitter can achieve is up to 28 km at arm 1 and 3. While for arm 2, it can only achieve up to 15 km. The result obtained shows that the performance of the designs is better when embedded into the network and the virtual lab is suitable for testing new devices in the network before fabrication.

**Key words:** Optical splitter, insertion loss, refractive index, characterization, Q factor

## INTRODUCTION

Nowadays, fiber network become an important issue in optical network field in order to provide an efficient and continues service to the end user without interruption (Ab-Rahman *et al*., 2011). This project introduces a low cost and efficient type of FTTH that have a simplest method and faster performance more than the others FTTH (Ab-Rahman *et al*., 2010; Ng *et al*., 2010b). The FTTH can protect environment also in order, play roles as a wider global struggle to ensure presence and future used is in high technology (Ab-Rahman *et al*., 2009). In this FTTH, a virtual lab platform introduces as an easy way to embedded project design with combined all OptiWave project design into virtual lab platform. Virtual Laboratory provides a method of how equipments that is usually prepared at laboratory are compensated with virtual equipments (http://pkukmweb.ukm.my/~kbj/makmalmaya/Makmal_Maya.htm). Virtual laboratory developed in this paper is a design laboratory that used in the photonics technology. New devices will be designed and embedded into the communication network virtually before they are sent for fabrication process. All the parameter must achieve an optimum before go through fabrication process (OptiBPM, 2007). Through virtual lab, the loss of a reflective of component at specific location can also determine (Ng *et al*., 2010a).

In order to test the stability and reliability of the laboratory, a new device known as the 2×3 Optical Splitter is designed. The device combines two signals from two different terminals. The design consists of optical splitter and optical combiner. This device is designed to deal with the reliability issue of optical network where survivability and reliability issue is critical.

Beam Propagation Method (BPM) is a step by step method of stimulating the passage of light through any wave guiding medium. An optical field can be tracked at any point as it propagates along guiding structure in fiber optics (OptiBPM, 2007). The analysis of Beam propagation method that is based on the low-order finite

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difference algorithm is much easier to use (Yu *et al*., 1994). This method is used broadly for the application of optical waveguide because of its stability. The stability is an advantage because it allows the design of a device without the need of consideration on the danger of diversion (Kenji and Tsutomu, 2001).

In this study, the device that is designed using the Beam Propagation Method is Multi Ratio Optical Splitter (MROS). It is designed using the SU-8 commercial material that has a refractive index of 1.599. It is based on the planar waveguide that have a high flexibility in terms of design and can be developed for a variety of usage.

## MATERIALS AND METHODS

Optical Splitter 2×3 is designed based on the symmetrical Y splitter where the input power is distributed equally. Two 1×2 Y splitter that have signal with different wavelengths, $\lambda_1$ and $\lambda_2$ is combined to produce three output power that have the same percentage at arm 1 and 3 whilst for arm 2, the output power is the combination of the input power from both terminal. The desired output power is 50% of $\lambda_1$ at arm 1, 50% of $\lambda_2$ at arm 3 and 50% $\lambda_1$ and 50% $\lambda_2$ at arm 2. The width of the waveguide is set to be the same to avoid losses during the propagation of the signal.

Parameter that's been used in this design is shown in Table 1 and the layout of the design is shown in Fig. 1. Figure 2 shows the 3-D graph of effective index ratio of waveguide against propagation distance.

**Simulation characterization (OptiBPM):** The design is first simulated using the OptiBPM software to get the optimized performance of the device. From Fig. 3, it shown that when the width is 0 um between 100 and -100 um, the E field goes higher. Figure 4 depicts that, output power of each arm (Arm 1, 2, 3 and 4) whereas arm at path 3 is different graph compared to the others. Arm at path 3 have some increase when the distance near the 3000 μm.

Based on the data collected in the Table 2 above, the total output power is the sum of the output power on each arm.

$$\text{Total Output Power (Simulated Output Power)} = 0.23970 + 0.45266 + 0.23970 = 0.93204 \approx 93.2\%$$

From the value of the loss at each arm, the total loss for 2×3 Optical Splitter with an input of 0.48685 at each terminal is as follows:

Table 1: Data for each parameter

| Parameter | Input data |
|---|---|
| Substrate length | 30200 μm |
| Substrate width | 900 μm |
| Refractive index of substrate wafer (n1) | 1.522 |
| Refractive index of waveguide substrate wafer (n2) | 1.599 |
| Waveguide width | 6 μm |
| Wavelength | 1.55 μm |
| Medium | Gaussian |
| Polarization | TE, TM |
| Boundary condition | Simple TBC Method |
| BPM solver | Paraxial |

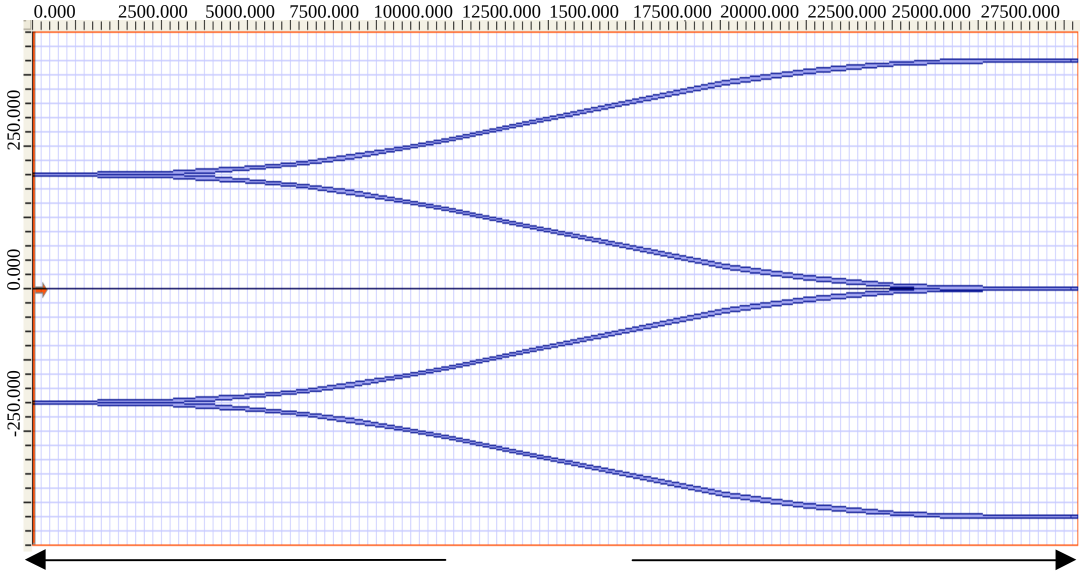

Fig. 1: Layout design of Multi Ratio Optical Splitter (MROS)

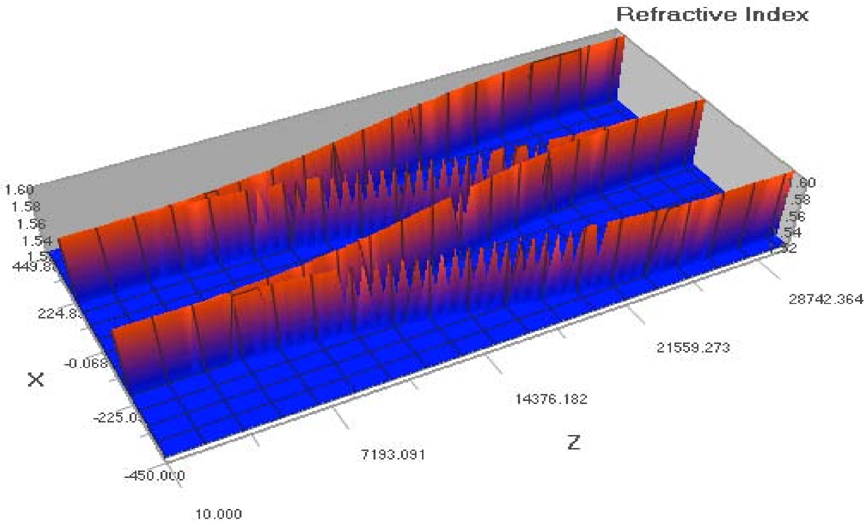

Fig. 2: 3-D graph of effective index ratio of waveguide against propagation distance

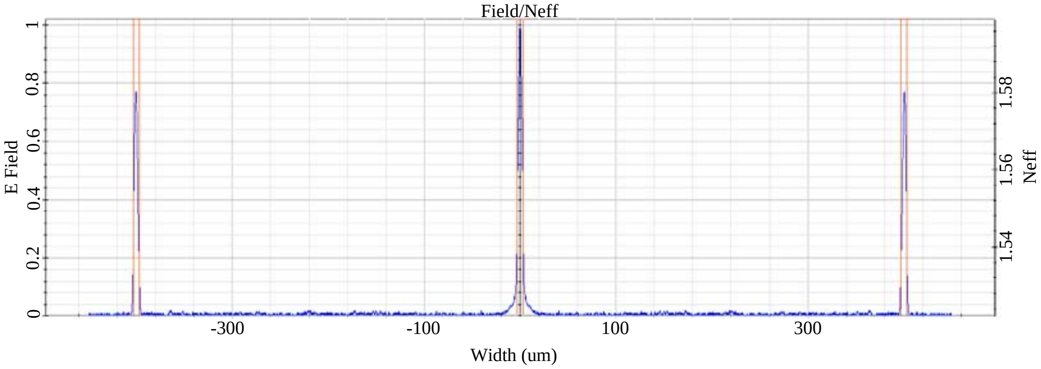

Fig. 3: MROS Optical field at the end of propagation

$$\text{Total loss} = \frac{|\text{Pcut} - \text{Pin}|}{\text{Pin}}$$
$$= 0.04279 \approx 4.28\%$$

$$\text{Total insertion loss} = 10\log_{10} {}^{P_o}\!/_{P_{in}}$$
$$L = 0.1899\text{dB}$$

Insertion losses of each arm:

$$\text{Insertion loss}, L_1 = 10\log P_{o1} / P_{in}$$
$$= -6.09\text{dB}$$

$$\text{Insertion loss, } L_2 = 10 \log P_{o2}/P_{in} = -3.33 \text{ dB}$$

$$\text{Insertion loss, } L_3 = 10 \log P_{o3}/P_{in} = -6.09 \text{ dB}$$

Table 2: Output power of each arm (OptiBPM)

| Arm | Simulated output power | Percentage of output power (%) | Actual output power | Total loss |
|---|---|---|---|---|
| 1 | 0.23970 | 50% $\lambda_1$ | 0.25 | 0.0103 |
| 2 | 0.45264 | 50% $\lambda_1$+50% $\lambda_2$ | 0.50 | 0.4736 |
| 3 | 0.23970 | 50% $\lambda_2$ | 0.25 | 0.0103 |

The total loss is relatively small and acceptable. The total insertion loss is still in the range of normal insertion loss of optical devices.

**Exporting design into OptiSystem:** Before exporting the design into OptiSystem, 2x3 Optical Splitter need to be sliced into 5 parts as shown in Fig. 5. Each part is simulated using OptiBPM and the result is shown in Table 3.

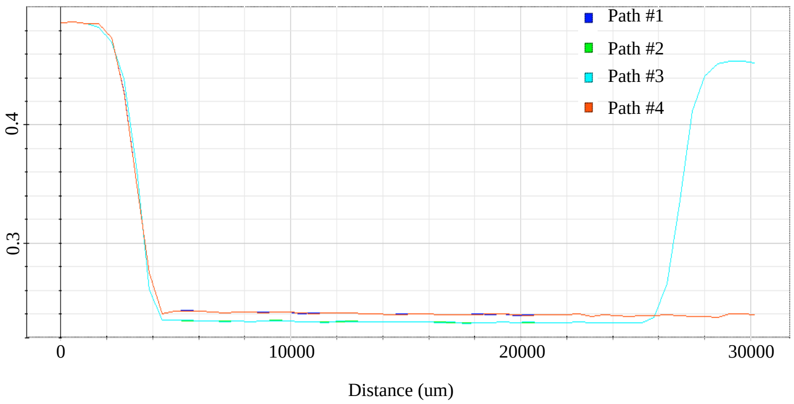

Fig. 4: Output power of each arm

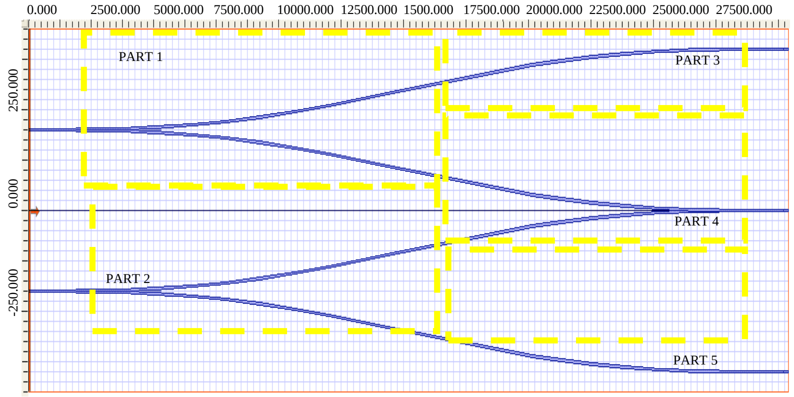

Fig. 5: Apportionment of 2×3 Optical Splitter in OptiBPM

Table 3: Output power of each arm of 2×3 Optical Splitter (OptiSystem)

| Arm | Simulated output power | Percentage of output power (%) | Actual output power | Total loss |
|---|---|---|---|---|
| 1 | 0.48007 | 50 | 0.5 | 0.01993 |
| 2 | 0.48007 | 50 | 0.5 | 0.01993 |
| 3 | 0.95385 | 100 | 1.0 | 0.04615 |
| 4 | 0.93648 | 100 | 1.0 | 0.06352 |
| 5 | 0.95385 | 100 | 1.0 | 0.04615 |

Referring to the Table 3 above, the total output power at each part is the sum of output power of each arm in that part.

- Total Output Power of Part 1 = 0.96014 ≈ 96.0%
- Total Output Power of Part 2 = 0.96014 ≈ 96.0%
- Total Output Power of Part 3 =0.97627 ≈ 97.6%
- Total Output Power of Part 4 = 0.93648 ≈ 93.6%
- Total Output Power of Part 5 = 0.97627 ≈ 97.6%

Based on the total losses obtained, the total loss of each part with an input power from terminal 1 and 2 of 0.48685 is as follows:

$$\text{Total loss of Part 1 and 2} = \frac{|P_{out} - P_{in}|}{P_{in}}$$
$$= 0.01393 \approx 1.39\%$$

- Total losses of Part 3 and 5 = 0.01230 ≈ 1.23%
- Total losses of Part 4 = 0.03823 ≈ 3.82%
- Total loss = 0.09069 ≈ 9.07%
- Total insertion loss of part 1 and 2, $L_{1,2} = 10 \log_{10} P_o/P_{in}$
- Total insertion loss of part 1 and 2, $L_{1,2}$ = -0.0609 dB
- Total insertion loss of part 3 dan 5, $L_{3,5}$ = -0.0895 dB
- Total insertion loss of part 4, $L_4$ = -0.1693 dB
- Total insertion loss, L = -0.4701

The percentage of losses is relatively low and still acceptable. Each part has a low insertion loss and still in the range of typical insertion loss of optical devices.

**Simulation characterization (OptiSystem):** Each part that had been simulated in OptiBPM is then exported into OptiSystem and simulated separately to see the performance of the design before embedded into the network. Table 4 shows the output power of 2×3 Optical Splitter after simulated using OptiSystem.

By referring to Table 4, the total output power of 2×3 Optical Splitter is the sum of output power on each arm.

$$\text{Total output power} = 1002.678\ \mu\text{W}$$

Based on the total loss on each arm, the total loss of 2x3 Optical Splitter with an input power of 542.969 µW from both terminals is as follows:

$$\text{Total loss} = \frac{0.023 + 41.143 + 0.023}{1085.938}$$
$$= 0.03793 \approx 3.79\%$$

$$\text{Total Insertion loss} = 10\log_{10}\frac{\text{Po}}{\text{Pin}}$$
$$= 0.3464\,\text{dB}$$

The percentage of loss is low and still in the range of acceptable loss. As for the insertion loss, it is lower than insertion loss of optical devices that is less than 0.5 dB.

From the comparison made in Table 5, the insertion loss is lower before the design is exported into OptiSystem. The highest loss occurs when the design is simulated separately. This is due to the loss that occurs at the optical combiner in Part 4. The combiner combines two input signals that have a different phase and the angular divergence is the critical factor that governs the combination of the signal is perfect with minimal loss. After parts are combined in the OptiSystem, the total loss decreased. This is due to the fraction of power at each part of the design where it reduces the loss of power at the angular divergence. Instead, the signal in the first phase is distributed equally before entering the second phase without having to go through the angular divergence that has a high possibility of causing losses.

**Embedding design into the FTTH (EPON) network:** The design that has already been simulated using the OptiSystem is then embedded into the communication network to test the performance of the device. In this study, FTTH (EPON) network platform that has a sensitivity of -25 dBm is chose as the test pad for the design.

Table 4: Output power of 2x3 optical splitter after simulated using OptiSystem

| Arm | Simulated output power (µW) | Percentage of output power (%) | Actual output power (µW) | Total loss (µW) |
|---|---|---|---|---|
| 1 | 260.944 | 10 | 260.967 | 0.023 |
| 2 | 480.791 | 40 | 521.934 | 41.143 |
| 3 | 260.943 | 20 | 260.967 | 0.023 |

Table 5: Comparison of total insertion loss of 2x3 Optical Splitter

| | Overall design (OptiBPM) | Part by part of the design (OptiBPM) | Overall design (OptiSystem) |
|---|---|---|---|
| Total insertion loss (dB) | -0.1899 | -0.4701 | -0.3464 |

Table 6: Comparison of achieved distance for both wavelengths at area A

| Wavelength (nm) | Achieved distance based on output power (±km) | Achieved distance based on maximum Q factor (±km) |
|---|---|---|
| 1480 | 22.1 | 22.1-28.2 |
| 1550 | 22.0 | 25 |

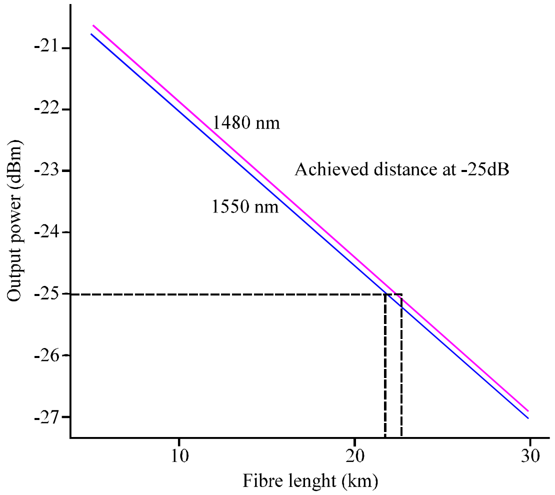

Fig. 6a: Graph of output power against distance at arm 1 (Area A)

The platform uses two Optical Line Terminals where each of them has two different wavelengths. Terminal 1 has signal with wavelength of 1550 and 1480 nm while on the second arm the wavelengths are 1440 and 1530 nm. The wavelengths that exit from the first arm of 2×3 Optical Splitter represent area A. Arm 2 that has all four wavelengths from both terminals represent area B and arm C represents area C.

All three arms are then connected to a 1×4 Optical Splitter where output of each arm is the combination of wavelengths. Each arm of the 1×4 Optical Splitter is then connected to a demultiplexer to separate the wavelengths for distribution. The distance that can be achieved is measures from the demultiplexer.

The simulated result of 2×3 Optical Splitter is analysed based on the distance that can be achieved by each arm. The distance is compared between arms

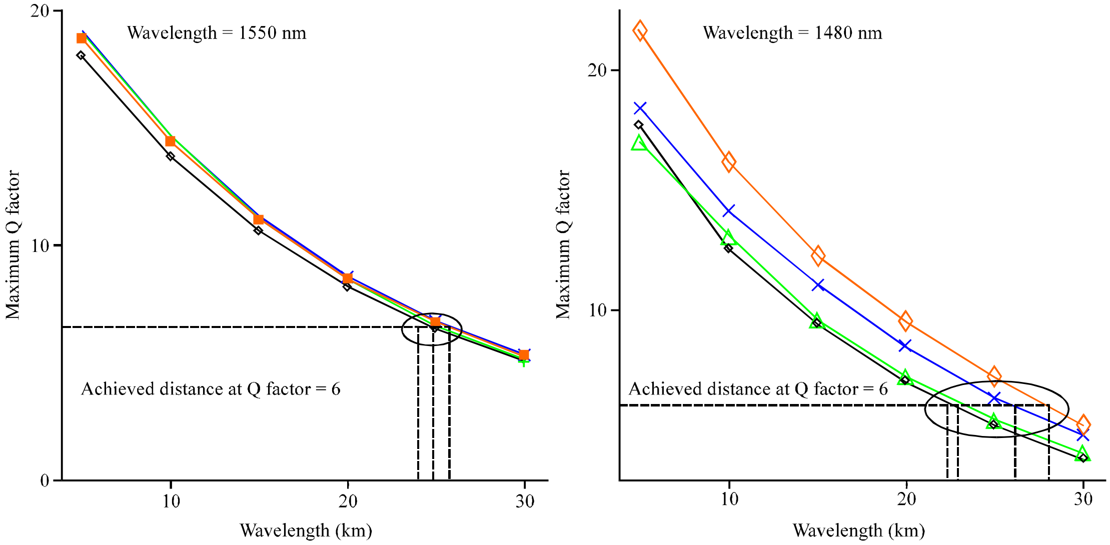

Fig. 6b: Graph of maximum Q factor against distance at arm 1 (Area A)

Table 7: Comparison of achieved distance for all wavelengths at area B

| Wavelength (nm) | Achieved distance based on output power (±km) | Achieved distance based on maximum Q factor (±km) |
|---|---|---|
| 1480 | 11.5 | 13.8 |
| 1550 | 11.8 | 13.8 |
| 1530 | 11.0 | 13.4 |
| 1440 | 11.0 | 13.8 |

Table 8: Comparison of achieved distance for both wavelengths at area C

| Wavelength (nm) | Achieved distance based on output power (±km) | Achieved distance based on maximum Q factor (±km) |
|---|---|---|
| 1440 | 22.3 | 24-26.2 |
| 1530 | 22.0 | 22.0 |

because of the optical power that is distributed to each arm are different. The comparison is based on the output power and maximum Q factor on each arm.

**Maximum distance at arm 1 (Area A):** From Table 6, the maximum distance that can be achieved by 1480 nm wavelength is up to ±22.1 km based on the output power while for 1550 nm, the maximum distance that can be achieved is up to ±22 km. The distance is measured at output power is -25 dBm because the platform used has the sensitivity of -25 dBm. As for the distance that can be achieved based on maximum Q factor, the distance is measured when the value of Q factor is ideal, 6. The distance that can be achieved by wavelength of 1480 nm is in the range of 22.1 to 28.2 km. At 1550 nm, the distance that can be achieved is up to ±25 km. By referring to Fig. 6a and b, the different coloured curve represents the arms of 1×4 Optical Splitter after being demultiplexed. It can be seen that the distance that can be achieved by all arms are almost equal when the same wavelength is used.

**Maximum distance at arm 2 (Area B):** By referring to Table 7, the maximum distance that can be achieved by each arm is almost equal when the same wavelength is used. Analysis is made using the output power and maximum Q factor and the distance that can be achieved is in the range of 11.0 to 11.8 km and 13.4 to 13.8 km, respectively. The distance is measured when output power (Fig. 7) is at -25 dB and maximum Q factor is at 6 (Fig. 8).

**Maximum length at arm 3 (Area C):** Based on Table 8, the maximum distance that can be achieved by 1440 nm wavelength based on the output power is up to ±22.3 km while 1530 nm wavelength can achieve up to ±22 km. The distance shown in Fig. 9, is measured at output power is -25 dB because the platform has a sensitivity of -25 dBm. As for distance that can be achieved based on the maximum Q factor, 1440 nm wavelength can achieve in the range of ±24 to 26.2 km. The 1550 nm wavelength can achieve up to ±22 km. By referring to Fig. 10, the different coloured curve represents the arms of 1x4 Optical Splitter after being demultiplexed. It can be seen that the distance that can be achieved by all arms are almost equal when the same wavelength is used.

**Analysis of device performance in the network:** Before the signal received by area A is being demultiplexed, each arm has two different wavelengths. The achieved distance is measured after both wavelengths are separated. Since all arms have the same percentage of output power, the distance achieved is also similar. By referring to the graph, the distance that can be achieved by 1550 and 1480 nm shows not much difference. The range of distance that can be achieved is between 22 to 28 km. Since, area A receives signal form only one terminal, therefore only signals from two wavelengths is received. In general, the accepted radius for area A is 28 km from the demultiplexer. The graph of distance against wavelength Area A is shown in Fig. 11.

Area B receives signal from four combined wavelengths from terminal 1 and 2 (1480, 1550, 1440 and 1530 nm). All four arms have four combined wavelength before being separated by the demultiplexer. The percentage of output power at each arm is similar therefore the distance that can be achieved by each arm is also similar. By referring to the graph, the difference

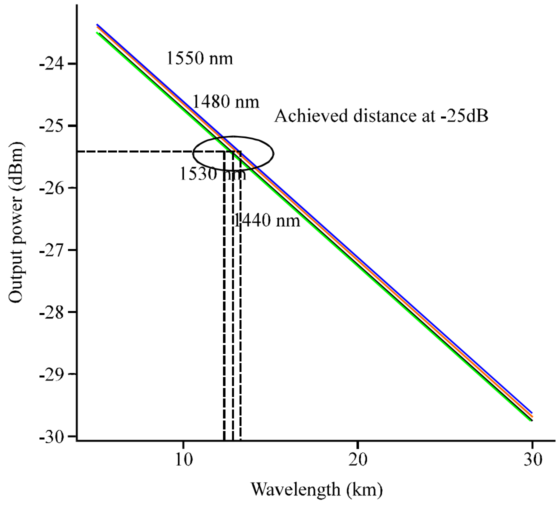

Fig. 7: Graph of output power against distance at arm 2 (Area B)

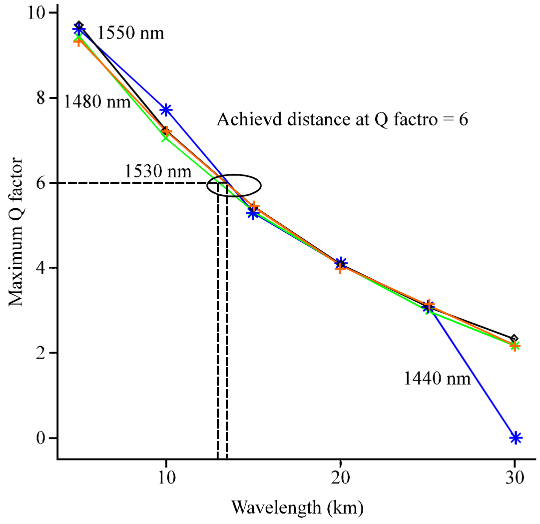

Fig. 8: Graph of maximum Q factor against distance at arm 2 (Area B)

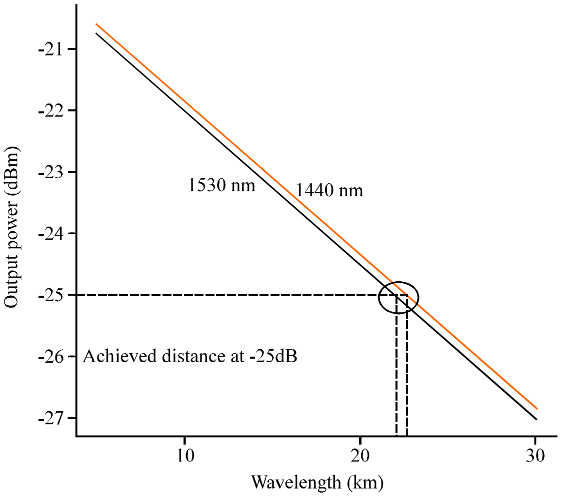

Fig. 9: Graph of output power against distance at arm 3 (Area C)

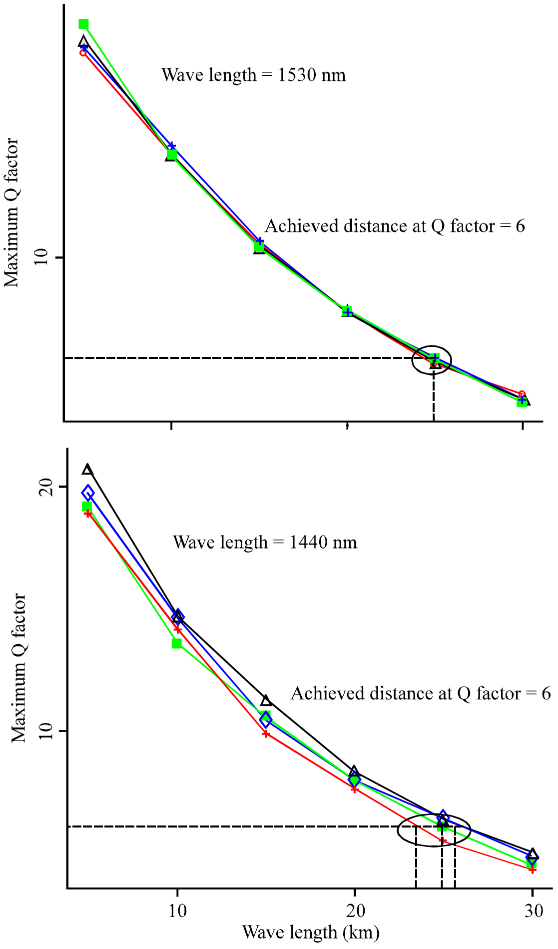

Fig. 10: Graph of maximum Q factor against distance at arm 3 (Area C)

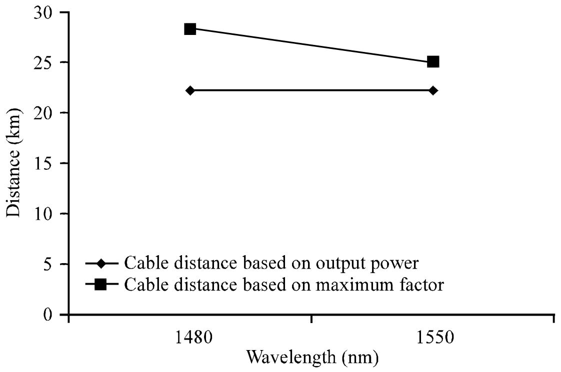

Fig. 11: Graph of distance against wavelength for arm 1 (Area A)

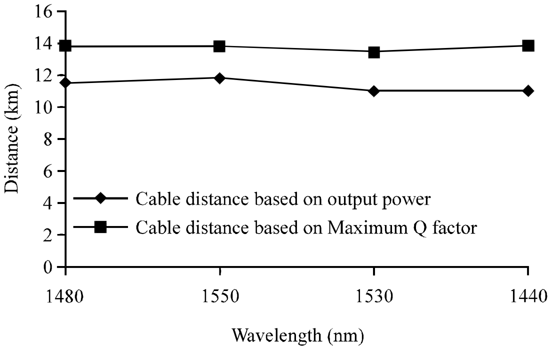

Fig. 12: Graph of distance against wavelength for arm 2 (Area B)

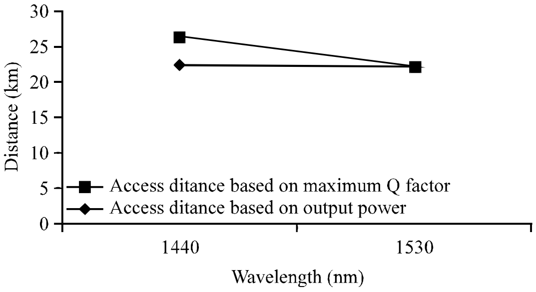

Fig. 13: Graph of distance against wavelength for arm 3 (Area C)

between distances that can be achieved by each wavelength is not obvious that is in the range of 11 to 14 km. Refer to the Fig. 12, the accepted radius of area B is smaller than the other two areas because of the lower percentage of output power at each wavelength. The maximum radius of area B from the demultiplexer is 14 km.

From the Fig. 13, two signals that have two different wavelengths of 1440 and 1530 nm are transmitted from terminal 2 into arm 3 of 2×3 Optical Splitter that represents area C. Before the signal is separated, each arm has two combined wavelength. The achieved distance is measured after both wavelengths on each arm are separated. By referring to the graph, it can be seen that the distance that can be achieved by both wavelength has not much difference. The accepted radius of area C is in the range of 22 to 26.2 km. In general, the maximum radius of area C from the demultiplexer is 26 km.

From the analysis that is made based on all three graphs, the accepted radius of arm 2 is smaller than the other two arms even though it combines four wavelengths from both terminals. This is due to the fraction of input power is smaller at the end of arm 2 where each of the wavelength only carry 25% of the overall input power. For arm 1 and 3, the output power that can be carried by all wavelengths is 50% of the input power. However, in terms of the reliability of the network, if one of the terminal experiences breakdown, only one of the area will be affected. In this case, area B is a privileged area because it receives signal from both terminals. If such breakdown happens, the users in area B can still receive signals from the other terminal.

## CONCLUSION

From the simulation and analysis that has been made, this virtual lab can be used to test the performance of the device before and after it is embedded into the network. Other institutions, they used virtual laboratory platform based on the hardware and software resources. But they developed it by using a software platform like ASP. NET and C# programming language. Compared to this project, author's project used OptiWave software such as OptiSystem, OptiBPM, OptiGrating and OptiSpice. All project design which used OptiWave software will embedded into virtual lab platform. So, it easy to see the experiment simulation process, previous experiment and so on.

Simulation characterization between OptiBPM and OptiSystem is made and the difference of the characterization is not obviously different. The total loss in OptiBPM and OptiSystem is relatively low and the device shows a better performance after being exported into OptiSystem. Multi Ratio Optical Splitter is designed using the SU-8 polymer material known as commercial material that has a refractive index of 1.599. It is based on the planar waveguide that have a high flexibility in terms of design and can be developed for a variety of usage. Author's project shown an improvement of nowadays fiber technologies, whereas the fabrication to made MROS is low cost compared with conventional technology.

Conventional technology used fused coupler for optical splitter fabrication.

So, the optimization result from OptiSystem is strongly based on the initial design using the OptiBPM. If the design shows a poor performance in OptiBPM, it will also affect the performance in OptiSystem.

## ACKNOWLEDGMENT

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