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Design of Fiber Optic-Based Trainer Module with Bus Topology Method Using Optical Distribution Point

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ABSTRACT

The fiber optic based trainer module designed for Politeknik Negeri Padang, especially in the Telecommunication Engineering Study Program for the Fiber Optic Communication System course, aims to improve students' understanding of optical fiber. This module provides an opportunity for students to practice optical fiber splicing and identify problems in the bus topology directly. The module design includes a block diagram showing the components and tools used, including an HLS (Heights Light Source) to provide the input signal and an OPM (Optical Power Meter) to measure the optical power at the Optical Distribution Point (ODP). Measurements are made to ensure attenuation in accordance with the predetermined link budget value: ODP1 with passive splitter 1:2 (8.0007 dB), ODP2 with passive splitter 1:4 (18.4517 dB), ODP3 with passive splitter 1:4 (28.9035 dB), and ODP4 with passive splitter 1:4 (38.555 dB). The measurement results show that correctly performed splicing results in attenuation below the link budget value. However, in ODP1, the disconnection of the pigtail caused the attenuation to exceed the link budget value by -50.00 dBm. The module proved to be effective in teaching but requires more attention to pigtail maintenance and the addition of a troubleshooting guide to improve its reliability.

INTRODUCTION

Optical fiber has become a popular transmission medium in the field of telecommunications, offering a solution to the limitations of other transmission media. It transmits data using light, providing high-speed transmission, larger bandwidth, compact size, easy capacity expansion, and excellent performance. These advantages have made fiber optic cables widely used in modern telecommunications.

The optical fiber has a disadvantage as it is more fragile and easily broken compared to other types of cables. This results in the loss of light energy in the fiber optic core, leading to disruption in the transmission process and causing significant attenuation. One type of loss that occurs in fiber optic cables is power loss, which is caused by devices used in fiber optic transmission. This results in higher power changes from the fiber optic transmitter to the receiver. Attenuation refers to the decrease in voltage level of the signal received on the fiber optic cable, which is caused by fiber loss, splicing, and poor quality connectors. Fusion splicing is the most commonly used method for joining fiber optic cables, as it produces less attenuation loss compared to mechanical methods.

Optical fiber has become an integral part of modern life (Stevan Danial et al, 2021). Network topology plays a crucial role in determining network performance, reliability, and scalability. One of the most commonly used network topologies, especially in small and medium-scale networks, is the bus topology. In this type of topology, all devices are connected to a single cable called a bus. This simplicity offers advantages such as ease of installation. However, it's important to understand that bus topology has some security drawbacks, as it has a single central point that can become a potential point of failure. If one part of the cable gets damaged, other devices cannot communicate.

LITERATURE REVIEW

Optical Fiber

Optical fiber consists of three main parts. The innermost part is called the core, which is made of glass or plastic and functions as a pathway for light to flow. Around the core, there is a cladding (protective layer) that reflects light back into the core, keeping the light on its path. Finally, the optical fiber is covered by a coating (outer layer) that protects the cable from physical damage and environmental factors such as moisture. With this structure, optical fiber can send data in the form of light very quickly and efficiently.

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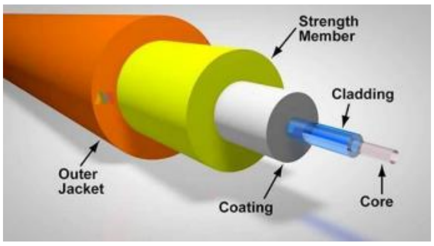

Figure 1. Fiber Optic Components

Bus topology

The bus topology is a network connected to one main cable (bus) that serves as a single communication line. If optical fiber is used in this topology, the optical fiber cable will act as the main bus, carrying data in the form of light along the network. The advantage of using optical fiber in a bus topology is its ability to transmit data at high speeds and over longer distances than copper cables.

The bus topology of the trainer module allows ease of understanding for students to learn the basics of networking more easily, as it only uses one main cable to connect all devices. This makes it ideal for teaching the basic concepts of how data flows in a network.

Passive Splitter

Passive splitters are devices used in PON networks to split optical signals from one input into multiple outputs. There are different types of passive splitters, such as 1:2, 1:4, 1:8, and 1:16, each with different levels of attenuation, as shown in the table below.

Table 1. Damping passive divisor

Capacity	Limitations	Attenuation dB
1:2	Maximum	2.8 – 3.70 (dB)
1:4	Maximum	5.8 – 7.25 (dB)

Power *Link Budget*

The power link budget is an estimation of power requirements calculated to ensure that the received power level exceeds or is at least equivalent to the minimum power level. The purpose of calculating the link budget is to ensure that sufficient power reaches the receiver to maintain optimal quality during system usage.
The power link budget can be calculated using formula 1

$$a_{total} = L.\ a_{serat} + N_c.\ a_c + N_s\ .\ a_s + N_a\ .\ a_a + S_p \quad (1)$$

Keterangan:
a_{total} : Total Damping (dB)
a_{serat} : Fiber Optic Damping (dB/Km)
a_c : Connector Damping (dB/pieces)
a_s : Connection Damping (dB)
a_a : Damping Adapter (dB)
L : Fiber Optic Length (Km)
N_c : Connector Quantity
N_s : Number of Splices
N_a : Adapter Quantity
S_p : Passive Splitter

METHOD

This study utilizes a simulation method to design a fiber optic-based trainer module with a bus topology approach. It involves the use of an optical distribution point to examine bus topology networks on optical fiber. The network is divided into multiple users using passive splitters, following the research flow depicted in the figure.

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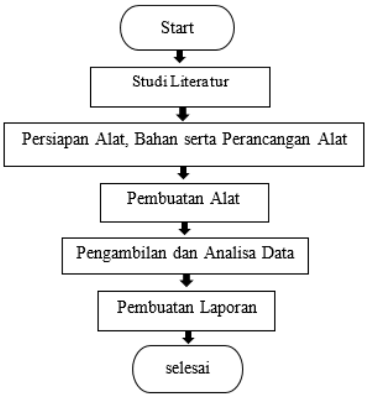

Figure 2. Design flow

The block diagram for the trainer module design consists of several main components, namely HLS (High Light Source), OTB (Optical Termination Box), ODP (Optical Distribution Point), and OPM (Optical Power Meter). HLS functions as a light source that sends signals through optical fibers. The signal is then forwarded to the OTB, which terminates the fiber optic cable and connects it with the ODP device. ODP plays a role in distributing the signal to several paths and allowing connection to multiple devices at once. The passive splitter in this system serves to divide the signal from one source into several outputs, thus increasing the use of optical fiber. OPM is used to measure the power or strength of the signal transmitted through the optical fiber.

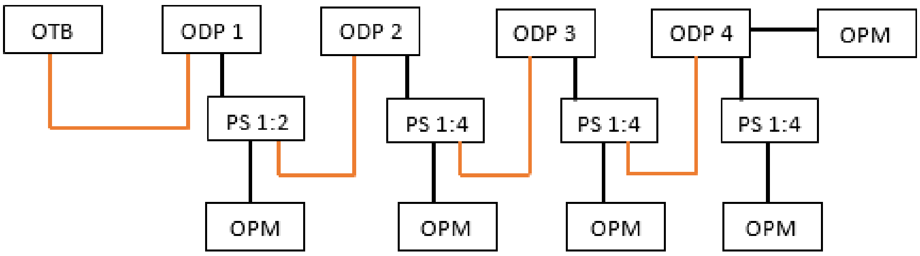

Figure 3. Block Diagram

Description:

: Fiber optic cable

: Core patch cord

RESULT

After completing the trainer module, you need to conduct a feasibility test to ensure that it aligns with the design and that the data obtained is appropriate. Before taking measurements, calibration must be performed to obtain the input value to be used in the measurement. This calibration process involves connecting the HLS and Optical Power Meter (OPM) using a patchcord cable to ensure the input value for the fiber optic communication system trainer module. The detailed results of the calibration process can be found in Table 2.

Table 2. 1310 nm and 1550 nm HLS Calibration Measurement Results

Experiment	Reception Power Value (dBm)	
	λ 1310 nm	**λ 1550 nm**
1	-7.69	-7.43
2	-7.72	-7.37
3	-7.73	-7.38

Damping Measurement Results of ODP 1 with Passive Splitter 1:2

To measure the attenuation of user 1 on the passive splitter, we used a 1:2 splitter with a 2-meter passive fiber optic cable. We inputted HLS and connected it to one of the ports on the OTB using a patch cord. The output was measured using an OPM connected to a passive splitter with 1 user. The power values received at passive splitter 1:2

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are listed in table 3.

Table 3. Measurement results of ODP 1 with Passive Splitter 1:2

Passive Splitter 1:2	Distance (Km)	P_{Tx} (dBm)		P_{Rx} (dBm)	
		λ 1310 nm	λ 1550 nm	λ 1310 nm	λ 1550 nm
User 1	0,002 Km	-7,71	-7,39	-10,73	-10,46

Damping Measurement Results of ODP 2 with Passive Splitter 1:4

Please take note of the following information: Measurements were conducted on ODP 2 using a 1:4 passive splitter, which serves 3 users. The aim of these measurements was to assess the quality of the optical signal received. This involved using a 5-meter cable and recording the output power received at each user for wavelengths λ 1310 nm and 1550 nm. The attenuation received is detailed in Table 4.

Table 4. Measurement of ODP 2 with Passive Splitter 1:4

Passive Splitter 1:4	Distance (Km)	P_{Tx} (dBm)		P_{Rx} (dBm)	
		λ 1310 nm	λ 1550 nm	λ 1310 nm	λ 1550 nm
User 2	0,005 Km	-7,71	-7,39	-17,88	-17,81
User 3				-17,83	-17,54
User 4				-17,56	-17,52

Damping Measurement Results of ODP 3 with Passive Splitter 1:4

Measurements were conducted on ODP 3 using a 1:4 passive splitter, similar to ODP 2, which has 3 users. The goal was to assess the quality of the optical signal received. For this measurement, a 10-meter cable was utilized, and the results of the output power received by each user at wavelengths of 1310 nm and 1550 nm are detailed in Table 5.

Table 5. ODP 3 Measurement with Passive Splitter 1:4

Passive Splitter 1:4	Distance (Km)	P_{Tx} (dBm)		P_{Rx} (dBm)	
		λ 1310 nm	λ 1550 nm	λ 1310 nm	λ 1550 nm
User 5	0,010 Km	-7,71	-7,39	-25,13	-25.08
User 6				-25,44	-25,37
User 7				-25.75	-25,66

Damping Measurement Results of ODP 4 with Passive Splitter 1:4

Measurements on ODP 4 with passive splitter 1: 4 fiber optic length 2.10km. The following output power values received at the passive splitter in each user can be seen in table 5.

Table 6. Measurement of ODP 4 with Passive Splitter 1:4

Passive Splitter 1:4	Distance (Km)	P_{Tx} (dBm)		P_{Rx} (dBm)	
		λ 1310 nm	λ 1550 nm	λ 1310 nm	λ 1550 nm
User 8	2,10 Km	-7,71	-7,39	-32,38	-31,94
User 9				-32,81	-32,58
User 10				-32,89	-32,49
User 11				-32,93	-32,71

Damping Measurement Results on ODP without Passive Splitter

To measure the attenuation in each Optical Distribution Point (ODP) without a passive splitter, we use the Headend Launching System (HLS) as the input and connect it to one of the ports on the Optical Termination Box (OTB) using a patch cord. The output is then measured using an Optical Power Meter (OPM) connected to one of the ports on the ODP. This measurement is aimed at determining the attenuation of the ODP without a passive splitter. The power values received at each ODP can be found in Table 7.

Table 7. ODP Measurement Results without Passive Splitter

Device	Distance (Km)	P_{Tx} (dBm)		P_{Rx} (dBm)	
		λ 1310 nm	λ 1550 nm	λ 1310 nm	λ 1550 nm
ODP 1	0,002 Km	-7,71	-7,39	-7,93	-7,68
ODP 2	0,005 Km			-8,25	-8,16
ODP 3	0,010 Km			-8,40	-8,19
ODP 4	2,10 Km			-12,32	-11,28

Power Measurement Results After the pigtail on ODP 1 is disconnected

The attenuation value of each ODP will be measured after disconnecting ODP 1, resulting in a loss value. The received output power values at ODP are listed in table 8.

Table 8 Measurement results after ODP 1 is disconnected

Device	P_{Tx} (dBm)		P_{Rx} (dBm)	
	λ 1310 nm	**λ 1550 nm**	**λ 1310 nm**	**λ 1550 nm**
ODP 1	-7,71	-7,39	-50,00	-50,00
ODP 2			-50,00	-50,00
ODP 3			-50,00	-50,00
ODP 4			-50,00	-50,00

After disconnecting ODP 1, the power measurement results showed a significant decrease in the quality of the received signal. We used an Optical Power Meter (OPM) to measure the power in the fiber optic systems. The results indicated a drastic decrease in the power received at the receiver side, suggesting a high loss of power.

The disconnection of the pitail at ODP 1 cut off the transmission path, causing the signal to not be forwarded properly. Additionally, the measurements revealed an increase in attenuation in the cables and connectors along the transmission path, contributing to the signal loss. The disconnection of the pigtail on ODP 1 not only affected the direct connection but also caused an increase in attenuation in other parts of the network.

DISCUSSION

After the next data collection, please analyze the data we collected. The data analysis should cover the attenuation obtained from ODP 1 with a passive splitter 1:2, ODP 2 with a passive splitter 1:4, ODP 3 with a passive splitter 1:4, ODP 4 with a passive splitter 1:4, as well as ODP 1, 2, 3, and 4 without a passive splitter. Additionally, please address the issues with attenuation after disconnecting ODP 1 and explain how these issues affect the attenuation at all outputs.

Discussion of Calibration Measurement Results

After completing the trainer module, it is important to conduct a feasibility test to ensure that the module aligns with the design and that the data obtained is accurate. Prior to taking measurements, calibration must be performed to determine the input values for the measurements.

The measurement process involves using a Handle Light Source (HLS) as the input and an Optical Power Meter (OPM) to measure the output power received. Two patchcord cables are used to connect the HLS and OPM, and connectors are utilized to link the two patchcords. Calibration is carried out three times to obtain consistent results and to determine the input damping value. The calibration values, displayed in table 4.1, are divided by the average to derive the input attenuation. At a wavelength of 1310 nm, the input attenuation is -7.71 dBm, and at a wavelength of 1550 nm, it is -7.39 dBm.

Discussion of Damping Measurement Results of ODP 1

The measurement results for ODP 1 involved using a 1:2 passive splitter to assess the system's ability to transmit optical signals to users. For this measurement, only a 2-meter length of optical fiber was used. The light source (HLS) was connected to one of the ports on the OTB. The system's output was then measured using an OPM connected to a passive splitter.

The power link budget calculation aims to estimate the total attenuation required in building the trainer module. In fiber optic systems, various factors such as connector losses, cable length, and splicing process can contribute to signal attenuation. Before performing the power link budget calculation, it is important to identify all the factors that can cause attenuation and assess the amount of attenuation produced by each. By understanding and calculating the attenuation values, we can create an accurate power link budget for the trailer module.

a_{total} = L. a_{serat} + N_c. a_c + N_s . a_s + N_a . a_a+ $Sp_{1:2}$

a_{total} = (0.002 Km , 0.35 dB) + (8 , 0.25 dB) + (3 , 0.1 dB) + (4 , 0.5dB) + 3.70 dB

a_{total} = 0.0007 dB + 2 dB + 0.3 dB + 2 dB + 3.70

a_{total} = 8,0007 dB

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Discussion of ODP 2 Damping Measurement Results

An attenuation measurement was conducted at Optical Distribution Point (ODP) 2 using a 1:4 passive splitter to assess the optical signal quality received by three users. The measurement involved the use of a 5-meter cable, and the output power received by each user was measured at wavelengths of λ 1310 nm and λ 1550 nm. The results indicate that the receiving power (PRx) received by each user is lower. Specifically, user 2 received -17.88 dBm at λ 1310 nm and -17.81 dBm at λ 1550 nm, user 3 received -17.83 dBm at λ 1310 nm and -17.54 dBm at λ 1550 nm, and user 4 received -17.56 dBm at λ 1310 nm and -17.52 dBm at λ 1550 nm.

The use of a 1:4 passive splitter causes greater attenuation compared to ODP 1, which uses a 1:2 passive splitter. This difference shows that the more channels that are shared, the greater the attenuation that occurs, resulting in lower signal quality for users. The greater attenuation in ODP 2 could be due to the longer cable length, the addition of passive splitters, or other factors such as the addition of connectors.

I need to perform a special power link budget calculation based on the trainer module design created by the author. This calculation is to determine the maximum allowable attenuation for building the trainer module. In optical fiber systems, attenuation can be caused by factors such as cable length, passive splitters, splicing, connectors, and adapters. The following is the link budget calculation for the trainer module.

a_{total} = L. a_{serat} + N_c. a_c + N_s . a_s + N_a . a_a + $S_{P\,1:2}$ + $S_{P\,1:4}$
a_{total} = (0.005 Km . 0,35 dB) + (14 . 0,25 dB) + (5 . 0,1 dB) + (7 . 0.5dB) + (3.70dB) + (7.25dB)
a_{total} = 0.00175 dB + 3,5 dB + 0,5 dB + 3,5 dB + 3.70 dB + 7.25 dB
a_{total} = 18,4517 dB

Discussion of ODP 3 Damping Measurement Results

This measurement involves using a 10-meter cable with wavelengths of λ 1310 nm and λ 1550 nm. At a wavelength of λ 1310 nm, the output power received by users 5, 6, and 7 is -25.13 dBm, -25.44 dBm, and -25.75 dBm, respectively. The discrepancy in output power values is attributed to the varying attenuation that occurs in each branch of the passive splitter. Despite the 1:4 passive splitter being designed to distribute power equally, there is always some variation in attenuation at each user output in practice. This variation can be caused by differences in component quality or other factors that impact the attenuation on each branch..

At a wavelength of 1550 nm, the output power received by users 5, 6, and 7 is -25.08 dBm, -25.37 dBm, and -25.66 dBm, respectively. The output power at 1550 nm is higher than that at 1310 nm due to the lower attenuation characteristics of the optical fiber at 1550 nm compared to 1310 nm. Below is the link budget calculation for the trainer module.

a_{total} = L. a_{serat} + N_c. a_c + N_s . a_s + N_a . a_a + $S_{P\,1:2}$ + $S_{P\,1:4}$ + $S_{P\,1:4}$
a_{total} = (0.010 Km , 0.35 dB) + (20 , 0.25 dB) + (7 , 0.1 dB) + (10 , 0.5dB) + (3.70 dB) + (7.25 dB) + (7.25 dB)
a_{total} = 0.0035 dB + 5 dB + 0.7 dB + 5 dB + 3.70 dB + 7.25 dB + 7.25 dB
a_{total} = 28,9035 dB

Discussion of ODP 4 Damping Measurement Results

Measurements were taken at a distance of 2.10 km with wavelengths of 1310 nm and 1550 nm. The output power received by users 8, 9, 10, and 11 at a wavelength of 1310 nm is -32.38 dBm, -32.81 dBm, -32.89 dBm, and -32.93 dBm, respectively. Meanwhile, at a wavelength of 1550 nm, the output power received by each user is -31.94 dBm, -32.58 dBm, -32.49 dBm, and -32.71 dBm. The following is the calculation of the link budget on the trainer module built.

a_{total} = L. a_{serat} + N_c. a_c + N_s . a_s + N_a . a_a + $S_{P\,1:2}$ + $S_{P\,1:4}$ + $S_{P\,1:4}$ + $S_{P\,1:4}$
a_{total} = (2.10 Km , 0.35 dB) + (23 , 0.25 dB) + (8 , 0.1 dB) + (12 , 0.5dB) + + (3.70 dB) + (7.25 dB) + (7.25 dB) + (7.25 dB)
a_{total} = 0.735 dB + 5,75 dB + 0.8 dB + 6 dB + 3.70 dB + 7.25 dB + 7.25 dB + 7.25 dB
a_{total} = 38,555 dB

Discussion of Damping Measurement Results on ODP without Passive Splitter

The results of the attenuation measurements on ODP 1, ODP 2, ODP 3, and ODP 4 provide a clear picture of how distance and the use of passive splitters affect the quality of the received optical signal. In ODP 1, which is 2 meters away, the output power at a wavelength of 1310 nm is -7.93 dBm, and at 1550 nm is -7.68 dBm. This value indicates that the received signal is still quite good due to the very short distance.

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In ODP 2, when the distance was 5 meters, the output power decreased slightly to -8.25 dBm at a wavelength of 1310 nm and -8.16 dBm at a wavelength of 1550 nm. This decrease is still within the standard, but it indicates that attenuation begins to occur as the distance increases. Additionally, in ODP 3, with a 10-meter cable, the output power at a wavelength of 1310 nm was recorded at -8.40 dBm, while at 1550 nm it was -8.19 dBm.

The significant decrease in ODP 3 suggests that more signal loss happens over longer distances. ODP 4, which has a distance of 2.10 km, exhibits a lower output power of -12.32 dBm at a wavelength of 1310 nm and -11.28 dBm at 1550 nm. This confirms that as the transmission distance increases, the signal experiences greater attenuation, resulting in lower received signal quality. This demonstrates that transmission distance significantly impacts optical signal quality. Essentially, the longer the distance, the more signal loss occurs, ultimately affecting the power received by the user.

Discussion of Measurement Results After the pigtail on ODP 1 is disconnected

The power measurement results after disconnecting the pigtail on ODP 1 showed that the output power values at ODP 2, ODP 3, and ODP 4 are all -50.00 dBm. This indicates a significant decrease in the output power value after the pigtail on ODP 1 was disconnected. The output power loss value suggests that there is significant damage or attenuation in ODP 1, which can impact the overall performance of the fiber optic system. It is important to make repairs to ensure the optimal performance of the system and to avoid disruption to data transmission. Immediate repair is necessary to prevent further damage.

CONCLUSION

In this final project, the design of a fiber optic-based trainer module with a bus topology method using an optical distribution point (ODP) has been completed. As a result, it can be concluded that:

1. The design utilizes Optical Distribution Point (ODP) devices to connect fiber optic components, and the bus topology enables all devices to connect directly to the data processing center..
2. Signal attenuation refers to the decrease in signal strength as it travels through an optical fiber. The higher the attenuation, the weaker the signal that reaches the destination. In a bus topology, high attenuation can cause the signal to be too weak to be received properly. This can lead to degraded network performance and make the connection unstable or unreliable.
3. In order to determine the attenuation value and link budget, we need to utilize Optical Power Meter (OPM) and Light Source measuring instruments. First, we measure the signal strength coming out of the Optical Termination Box (OTB) and compare it with the signal strength going into the Optical Distribution Point (ODP). The variance between these two measurements indicates the attenuation value. The link budget is a calculation that demonstrates how much attenuation is permissible for the signal to be received properly. By comparing the measurement results with the link budget value, we can assess whether the network is functioning correctly or requires adjustments.

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