Fiber to The Home (FTTH) Network Design in Analyzing Macro Bending Problems in The Home Cable Installation Segment

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ABSTRACT

Fiber to The Home (FTTH) is one of the optical networks used for every home in accessing the internet in the form of voice, data, and video. In this study, the authors built an FTTH design from Handheld Light Source (HLS) as input, then connected to ODC. Furthermore, it is connected with ODP, OTP, and ROSET. After building the design, the design was tested using the link power budget calculation method, which is 22.803 dB. As a result, the design has a total attenuation value of 18.4 dB which means it meets the standards and can be used. Next, analyze the problems that have the potential to cause macro bending interference in the FTTH home cable installation segment cable. The methods used in this macro bending problem are the HLS calibration method, Optical Power Meter (OPM) measurement, and Visual Fault Locator (VFL) macro damage detection. From this analysis, the results of macro bending will be obtained on the parameters of curvature diameter, number of windings, and the search for critical angles of indoor cable macro bending. This macro bending in home wiring installations affects the total attenuation value on FTTH. In addition, the macro bending of 3-winded indoor cables with a diameter of 0.5 cm on each winding still meets the standards in the FTTH design. However, for macro bending 5 windings with a diameter of 0.5 cm each winding can cause the total attenuation value of FTTH to pass the Link power budget and ITU-T G984.

1. Introduction

Fiber optic is a transmission medium for telecommunications devices in the delivery of information through a light signal that passes through the medium of fiber optic cables / fiber optics. Fiber optic has a core as a place to propagate the light signal, then cladding as a light guide inside the core, and coating as a protector and colored for marking or coding [1]. Fiber optic is a transmission line or a kind of cable made of glass or plastic that is very smooth and smaller than a strand of hair, and can be used to transmit light signals from one place to another [2]. That is, fiber optics have a speed of conveying information signals equivalent to the speed of light. Thus, fiber optic cables are superior of course to ordinary copper cables in terms of the speed of conveying information signals to between telecommunications devices.

In 2022, many people need fast network access speeds. One of the technologies supporting very fast speeds in accessing data through the network is an optical network. The optical network has a transmission medium in the form of fiber optic cables as the transmission medium. One of the optical networks that is popular at the moment and widely used is the Fiber To The Home (FTTH) network. FTTH is a fiber optic technology architecture known as Passive Optical Network (PON)[3].

With the FTTH network, people today can access internet speeds of up to 100 Mbps, so people can access the internet at a very fast speed compared to previous technologies. This extremely fast speed is what causes people in the present to move from copper cable networks to fiber optic networks. The reason is that the needs of people today are greater in terms of data capacity in data transfer or access. In addition, capacity alone is not enough, because large capacity will certainly reduce the speed in data transfer. Therefore, fiber optic networks have emerged as a solution in large-capacity data access and accompanied by very fast data transfer rates. One solution in the use of fiber optic is the Fiber To The Home (FTTH) network.

Thus, after the author realized the importance of the FTTH optical network in the present as a need for super fast data access speeds, the author designed the FTTH network. In FTTH design, there are disturbances that often cause high attenuation values [4]. Interference with optical networks is certainly different from interference with other networks. This is because the transmission media used in each network is different so there will also be differences in terms of network design or network architecture, interference, handling cases, and maintenance.

In terms of disorders, FTTH has 2 types of disorders that often occur, namely loss and bending disorders. Losses are fiber optic cable breaks that can be seen physically and cause the disconnection of optical network access to the customer's home. This is because the fiber optic cable is squeezed by something or folded, so that the core inside the fiber optic cable becomes broken [5]. As a result, access from the FTTH optical network becomes cut off and does not reach the ONT (Optical Network Terminal) device or to the customer side. This will cause FTTH optical network access to be interrupted and cannot be accessed by customers.

In addition to losses, there is another disturbance that also affects the performance of the FTTH optical network, namely bending. Bending is one of the disturbances that often occurs when bending optical fibers at certain spokes, causing an increase in the attenuation value during the installation process [6]. According to research made by Sisca Arisya Harry Andhina from the State Polytechnic of Malang in 2019, entitled "Macro bending Loss Analysis on Single mode-Multi mode-Single mode-Single mode Fiber Optic Core" states that, bending is a weakening that occurs due to changes in the structure of optical fibers because they are bent so that there is a change in the refractive index and the angle of light coming rays that hit cladding. Bending consists of micro bending and macro bending [7]. Micro bending is a small bending that occurs in optical fibers due to non-uniformity in the formation of fibers or due to the presence of non-uniform pressure at the time of wiring. Meanwhile, macro bending is the bending of optical fibers with a long radius when compared to the radius of optical fibers [7].

Micro bending and macro bending reduce the performance of the FTTH optical network, but the difference between the two is the magnitude of the bending and the magnitude of the impact of the bending on the performance of the FTTH network. That is, bending on macro bending is greater than bending micro bending. Thus, bending has a great effect on FTTH optical network access. Bending can cause interference with optical cables which has an impact on the quality and attenuation value of fiber optic cables.

Attenuation is an important parameter, since attenuation affects the outcome of an output value on the receiver of a fiber optic communication system. Attenuation has a relationship with the design or installation of optical networks along fiber optic cables [8]. This is evidenced by a research that has been carried out by Indra Lesmana from the Department of Electrical Engineering, Faculty of Engineering, Tanjungpura University in 2018, entitled "Analysis of Measurement of Fiber Optic Cable Attenuation Between STO Lifters – Slashed STO Using OTDR EXFO FTB-200"[9].

From his research, he analyzed and stated that this very far difference in attenuation value (dB/Km) was influenced by bending factors [9]. In the measurement of fiber optic cable attenuation using the Optical Time Domain Reflectometer (OTDR) EXFO FTB-200 the measured bending value exceeds the PT standardization. Telkom resulted in the fiber optic cable transmission network at core 1, core 2, core 3, core 16, core 21, core 22, core 23, and core 24 experiencing problems caused by the attenuation value (dB / Km) which exceeded PT standardization. Telkom Indonesia and is not suitable as a fiber optic communication transmission medium on the STO Pemangkat – STO Tebas link[9].

That is, if attenuation is caused by bending, then bending is also a very important problem and must be addressed because it can cause the transmission media to be unfit in transmitting fiber optic communication. In addition, bending is also one of the potential causes of losses, because excessive bending can cause the breaking of optical fibers [10].

Losses can occur if the bending fault is not immediately repaired and left alone, so that over time the optical cable is bent because the bending case will cause potential cable faults to lead to the breaking of the optical cable or called losses. Thus, the author wants to choose the problem with the bending part in the FTTH optical network because according to the author, bending interference should not be ignored and must be corrected immediately in order to maintain the performance of the FTTH optical network.

In addition, according to research conducted by Dodi Setiabudi from the Department of Electrical Engineering, University of Jember in 2018, entitled "Analysis of Arch Attenuation and Critical Angle of Single Mode G-65x Optical Fiber Against Curve Radius on Fiber To The Home (FTTH) Network"[11]. States that in a circular or making an optical cable reel can trigger bending if the curvature of the fiber optic cable passes a certain limit and must not pass through the critical radius of its curvature [11]. Macro bending occurs because during the installation process the fiber optic cable is rolled or bent following the path that must be passed, but the bending that occurs has a longer radius when compared to the radius of the optical fiber, thus causing an increase in the attenuation value [12], [13]. Macro bending losses can be eliminated by means of fiber optic mounting not exceeding the permissible curvature critical radius [11].

Based on several journals about bending fiber optic cables that are the author's reference in making this study, the author is interested in analyzing macro bending problems because there is a high potential for losses. In addition, the author wants to prove the impact of macro bending. In order for macro bending to be seen more clearly on FTTH fiber optic cables, the author chose indoor cables which are a segment of home wiring installations in the FTTH network architecture. FTTH's home wiring installation segment is from Optical Termination Premises (OTP) to ROSET. ROSET is a passive device and final termination point used in FTTH [14]. From OTP to ROSET will be installed with indoor cable [15]. Thus, in this study, the authors wanted to look at the impact of macro bending passing through critical angles with varying curvatures on the indoor wiring segment of FTTH home wiring installation segments and see the impact on network performance.

From this, the author will be able to find out the boundaries of critical radius that must not be passed by the curvature of optical cables in home cable installations, namely indoor cables. Then, the author can prove that macro bending can cause light signals to come out of the core and its grooves

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according to the theory about the density of the medium affected by macro bending which causes light bias to part of it coming out of the core. Indoor cables are easily visible macro bending if they are fed by light or Visual Fault Locator (VFL), so that the light coming out of the cladding will be easily visible when macro bending occurs [16].

Therefore, the author raises this research with the title "Designing Fiber To The Home (FTTH) Networks in Analyzing Macro bending Problems in the Home Cable Installation Segment". FTTH design uses Hand held Light Source (HLS) as an optical signal transmission source [17]. Where, after the construction of the FTTH design, the author will analyze the feasibility of the design using the calculation of the power budget link. Link power budget calculation is used to calculate the power loss caused by the total attenuation between the output power on the transmitter and the sensitivity in the receiver [8],[18].

Link power budget is calculated for the requirement that the power of the design link is not less than or exceeds the required power threshold [19]. The calculation of the link power budget will be compared with the results of power measurements using an Optical Power Meter (OPM) on the receipt of the FTTH design [15]. OPM is used to measure the attenuation of fiber optic cables that are laid by optical signals [20]. After the design is completed, the author will later conduct an analysis of indoor cable macro bending and see its relationship and its effect on the FTTH design.

2. Literature Review

Optical fiber is made of a dialectical material consisting of a core material, namely glass and a protective layer, namely plastic. It is in this fiber that the light energy generated by the light source is channeled (transmitted) so that it can be received at the end of the receiving unit.

Based on the structure of the fiber optic cable, the cable installation method is as follows:

2.1. Duct Cable Cable (Duct

Duct cable or cable duct is al ion is specifically designed to be installed below ground lev pipes under a resistant surface. Which installation uses a pr in the ground. Installation by means of an open trench (o duct cable is different. The difference occurs because it i

Figure 1. Duct Cable Form

2.2. Direct Burried Cable

Direct planting cable is a cable whose installation is buried in the ground by the open excavation method and the cable is directly planted in the ground without using a shield (duct).

Figure 2. Form of Direct Burried Cable

2.3. Aerial Cable

Aerial cable is a cable whose installation hangs in the air (aerial). This cable installation is hung between the support poles. The difference between aerial cables and other types of cables is that in aerial cables there is a reinforcing wire that serves to hold the data cable from hanging.

Figure 3. Basic Construction of Aerial Cable

Figure 4. Shape of Aerial Cable

3. Method

The methods used in this study are as follows:

1) Handheld Light Source (HLS): This method is used as the source of the built FTTH design. HLS serves as the sender of power or input power of this FTTH design. The value of the HLS input can be known by calibrating before taking measurements. Calibration is done by connecting HLS to OPM using patch cord cables.

2) Power Link Budget: This method is used to compare the results of design calculations with the measurement results on the design that has been built. The goal is to see the power of the design according to or not with the standards of the power link budget.

3) Optical Power Meter (OPM): This method is used to take measurements. Measurements are obtained using OPM measuring instruments. The OPM will measure the power value at receiver. Measurements are taken after calibrating the HLS. This aims to determine the input and output values in the FTTH design. Then it can find out the attenuation value in dB units later.

4) Visual Fault Locator (VFL): The method used to see the refraction of light on indoor cable macro bending. VFL can detect macro bending easily and quickly through the red light it emits.

3.1. Study of literature

In this stage, literature discussion activities are carried out from a research, namely Designing Transmission Attenuation Systems in Single Mode Aerial Fiber Optic Cables for Connection Loss in Passive Splitter Devices, where the authors collect data and learn relevant basic theories from various sources such as books, internet, resource persons and research that has been done related to the research that will be carried out by the author.

3.2. Design

3.2.1. Design

This design starts from making a design flow, designing an FTTH network and determining the tools and materials used for designing the FTTH network.

3.2.2. Workflow

The workflow contains a flowchart or flowchart which is a guideline in the form of stages from beginning to completion in the preparation of this final project. This workflow is as shown in Figure. 5. The author has this final project workflow as follows:

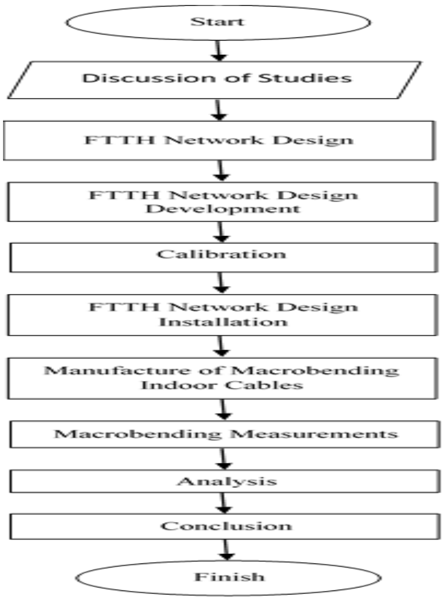

Figure 5. Workflow

3.2.3. FTTH Network Design

At this stage the author performs the design of the schematic or diagram block of the FTTH network design. For the general, the schematic or block diagram of the FTTH network design can be seen in Figure 6.

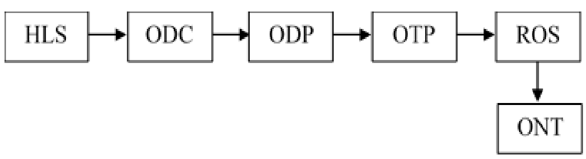

Figure 6. FTTH Design Diagram Block

3.3. Testing and Measurement

Measurements are made to obtain a value that will be compared with previously made calculations. Through measurement, the author can analyze and ascertain the value obtained from the measurement in accordance with the calculation or not. In making measurements, the author will obtain data that can be taken from measurements.

If the data obtained from the measurement results are in accordance with the calculation value, then the design that the author did went well. However, the value of the measurement is very different from the value obtained from the calculation, so there are additional losses caused by errors or poor in the installation of the device in the FTTH network design. The measuring instrument that the author uses is an Optical Power Meter (OPM).

Measurement and data collection were also carried out in the study of indoor cable macro bending. This measurement aims to obtain data from the macro bending. After that, the data obtained will be useful for analyzing the problem of indoor cable macro bending. Thus the author can see the influence of indoor cable macro bending through the data.

3.4. Analysis, Drawing Conclusions, and Making Reports

This is the final stage in the research process, that is, after all the test data has been collected, the writer will analyze the data, then draw conclusions as the material for the report.

3.5. Research Materials and Tools

In this research, several components are needed to be able to support the tool's work system, namely Single Mode optical cable type Aerial 100 m, 95% Alcohol, Majun Fabric, Protection Sleeve, Tissues, adapter, OTB, Fusion splicer, Passive Splitter, OPM, OTDR, screwdriver, cutting pliers, tube cutter.

4. Result

4.1. Calibration Results for Device Measurements In FTTH Design

The measurement results of 3 calibration sessions will be displayed in Table 1. Measurement Results of 3 Calibration Sessions as follows:

Table 1. HLS Calibration Measurement Results

EXPERIMENT TO-	ACCEPTANCE POWER VALUE (dBm)
1	-7.24 dBm
2	-7,25 dBm
3	-7,25 dBm

4.2. Power Measurement Results Using Optical Power Meter (OPM) at the Output of Each FTTH Design Device

The measurement results of each FTTH device output will be displayed in Table 2 as follows:

Table 2. FTTH design device output measurement results

Device	λ (nm)	PTx (dBm)	PRx (dBm)
ODC			-13,66
ODP			-25,27
OTP	1310	-7,25	-25,61
ROSET			-25,65

4.3. Measurement Results and Data Retrieval in Indoor Cable Macro bending Research

4.3.1. Measurement Results of Curvature Diameter Parameters: The measurement results of the indoor cable macro bending study on the curvature diameter parameter will be displayed in accordance with Table 3 are as follows:

Table 3. The results of the Measurement of the Attenuation Value of the Curvature Diameter Parameter

Cable To -	Curvature diameter (cm)	Attenuation value = (PTx or calibration – PRx OPM) dB
1	-	(-7,56 dBm) – (-7,66 dBm) = 0,1 dB
2	1 cm	(-7,56 dBm) – (-7,91 dBm) = 0,35 dB
3	0.75 cm	(-7,56 dBm) – (-8,47 dBm) = 0,91 dB
4	0.5 cm	(-7,56 dBm) – (-9,71 dBm) = 2,15 dB

4.3.2. Measurement Results of Macro bending Winding Count Parameters: The measurement results of the indoor cable macro bending study on the winding count parameter will be displayed in accordance with Table 4 as follows:

Table 4. The Results of Measuring the Attenuation Value of the Variable Number of Windings

Cable To-	Number of Twists	Attenuation value = (PTx or calibration - PRx OPM) dB
5	3	(-7,56 dBm) – (-10,59 dBm) = 3,03 dB
6	5	(-7,56 dBm) – (-15,56 dBm) = 8 dB

4.3.3. Indoor Cable VFL Light Refraction Display Data Results: The results of the VFL light refraction display in the indoor cable macro bending study will be displayed in Table 5 as follows:

Table 5. VLS Light Refraction Display Data Results

Cable To-	Cable Condition	Photo display of light refraction on the cable
1	Normal / No Treatment	Figure.7
2	Curvature diameter 1 cm	Figure.8
3	Curvature diameter 0,75 cm	Figure.9
4	Curvature diameter 0,5 cm	Figure.10
5	Curvature diameters of 0.5 and 3 windings	Figure.11
6	Curvature diameters of 0.5 and 5 windings	Figure.12

Here are the images produced from the photos at the refraction of light in Table 6, i.e. Figure.7, Figure.8, Figure.9, Figure.10, Figure.11, and Figure.12 as follows:

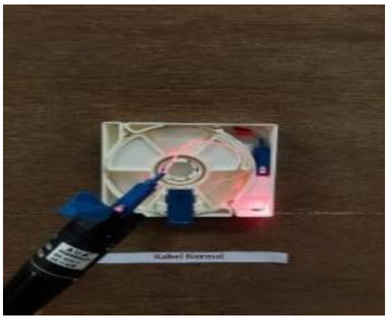

Figure 7. VFL on Normal / No Treatment

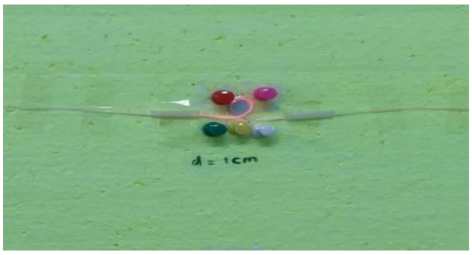

Figure 8. VFL **on** Curvature diameter 1 cm

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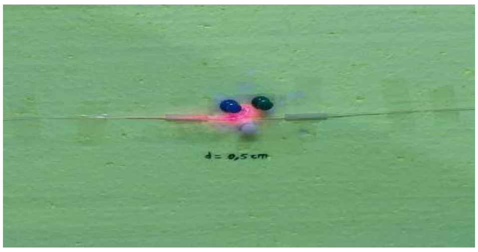

Figure 9. VFL on Curvature diameter 0,75 cm

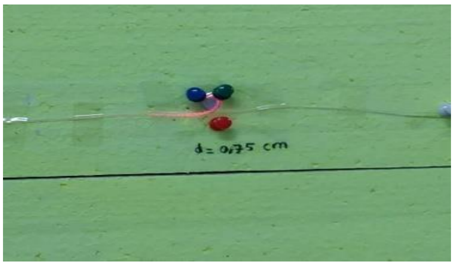

Figure 10. VFL on Curvature diameter 0,5 cm

Figure 11. VFL on Curvature diameters of 0.5 and 3 windings

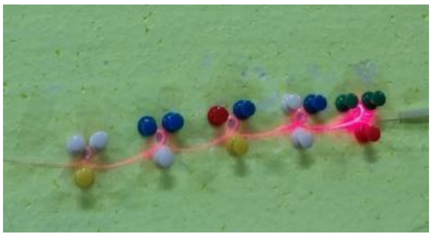

Figure 12. VFL on Curvature diameters of 0.5 and 5 windings

4.3.4. Measurement Results in ROSET On Each Macro bending Indoor Cable In The Parameter Of The Number Of Windings which is Connected To FTTH Network Design: The results of this measurement will be displayed in Table VI as follows:

Table 6. Results of Attenuation Values in Roset for Parameters of Number of Indoor Cable Macro bending Windings

Cable To-	Cable Condition	PTX IN ODC (dBm)	PRX IN ROSET (dBm)
1	Curvature diameters of 0.5 and 3 windings	-6,99	-29,28
2	Curvature diameters of 0.5 and 5 windings	-6,99	-35,07

4.3.5. *Measurement Results and Critical Radius Search Data*: The measurement results and critical radius value search data will be displayed according to Table VII as follows:

Table 7. Measurement Results of The Attenuation Value and The Display of Critical Radius Light

Cable To-	Cable Condition	Rated Receiving Power (dBm)	Light Refraction Display When given VFL (Visual Fault Locator)
7	The Curvature Diameter of Each Winding is 0.5 cm, 0.4 cm, and 0.3 cm	-50	The refraction of light at a diameter of 0.5 cm is visible bright on the winding, then at a diameter of 0.4 cm it looks brighter and it looks like a beam of light will break, while at 0.3 cm it is visible only the light spot on the winding and the light is not passed on afterwards. It looks like Figure. 9

Here is Figure.13 referred to by Table 7 above:

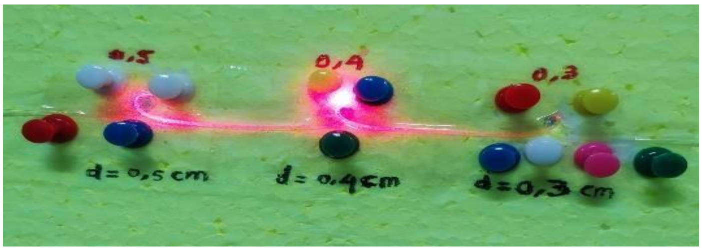

Figure 13. VFL on Critical Radius

4.4. Discussion

After the FTTH design was successfully built, the author tested the feasibility of this design by taking measurements using OPM. In this design, the author uses a source or design input derived from a Handled Light Source (HLS). The input value provided by HLS can be known by calibrating. In calibrating, it is carried out in 3 sessions and chooses the values that often appear. The result of the 3-session calibration corresponds to Table I, where the calibration value that often appears is -7.25 dBm. After the calibration value is obtained -7.25 dBm, measurements can be taken at each FTTH device output. The output of each device is measured starting from ODC to ROSET.

The results of the measurement of the output of such FTTH devices are displayed according to table II. In this table, the PTx value is the sender or input value of the FTTH design, while PRx is the power received at each device output using a measuring instrument called an Optical Power Meter (OPM). The closer the device approaches the final termination point, the smaller its PRx value. This is due to attenuation or reduced power due to connectors, passive splitters, adapters, connections, cable lengths, and it could be due to FTTH interference. Measurement of the output of each FTTH device aims to determine the acceptance value of each device and to make it easier to find the problem points of the device when testing the feasibility of the FTTH design.

Therefore, the author must calculate a special budget link that is in accordance with the FTTH design that the author built using the total attenuation formula (1). The following is the calculation of the budget link in the FTTH design which is the standard for the feasibility of this design:

α[illegible] = [illegible] [illegible]fiber + . α[illegible] + N[illegible]. α[illegible] + Na . [illegible]a + [illegible] (1)

Description :

L : Distance(Km)

α[illegible] : Total Attenuation (dB)

[illegible]fiber : Fiber Optic Attenuation (dB/Km)

α[illegible] : Fiber Optic Splice Attenuation (dB/pcs)

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αc	: Connector Attenuation (dB/pairs)
�a	: Adapter Attenuation (dB/pcs)
�a	: Number of Adapters
�c	: Number of Connectors
�s	: Number of Splices
��	: Splitter's Attenuation (dB)

Is Known	:
L	= 0,018 (Km)
�fiber	= 0,35 (dB/Km)
α�	= 0,1 (dB/pcs)
αc	= 0,25 (dB/pcs)
�a	= 0,5 (dB/pcs)
�a	= 5
�c	= 12
�s	= 4
��:4	= 6.41 (dB)
��:8	= 10.49 (dB)

Asked : total attenuation or α_{total} =?

Answer :

α_{total} = � �fiber + . α� + N�. α� + Na . �a + (��:4 + ��:8)

α_{total} = 0.018 km . 0,35 dB/km + 12 . 0.25 dB + 4 . 0.1 dB + 5 . 0.5 dB + (6.41 dB + 10.49 dB)

α_{total} = 0.0063 dB + 3 dB + 0.4 dB + 2.5 dB + 16.9 dB

α_{total} = 22.803 dB

So, the total attenuation value of the budget link calculation above has a value that is in accordance with the ITU-T G984 standard, which is below 28 dB.

From the calculation of the budget link above, the standard total attenuation value of the FTTH design that the author built must be smaller than the value of 22.803 dB and must not exceed this value. If the total attenuation value on the draft is greater than the value of 22.803 dB, then in this design there is a disturbance or is not feasible and does not comply with the proper standards of the calculation of the link budget. However, if the total attenuation value in this FTTH design is smaller than the total attenuation value in the budget link calculation table, then this FTTH network design has good transmission feasibility and quality or meets the standards. To find out this, the author takes measurements and data results in table II to compare the total attenuation in the design with the total attenuation in the calculation of the budget link.

In Table 2, the author obtained data in the form of PTx (Input Power or sender) and PRx (Output or receiving Power) values. PTx is populated with the calibration value in table I. Where the sender or PTx value is -7.25 dBm. The PRx value is obtained from measurements using OPM and is filled in according to table II. From the PRx value in ROSET, the author can find out the total attenuation value in this FTTH design by doing the following calculations:

Total attenuation (α_{total}) = PTx – PRx (2)

αtotal = -7.25 dBm – (-25.65 dBm)

αtotal = 18.4 dB

From the calculation of total attenuation in the FTTH design above, it will be compared with the total attenuation value in the calculation of the power budget link, which is a total attenuation value of 22.803 dB. The total attenuation comparison value is 18.4 dB < 22.803 dB, so the total attenuation in the FTTH design is less than the total attenuation value of the link budget calculation. Thus, the total attenuation value of the FTTH design is smaller than the total attenuation value in the budget link calculation, while meeting the ITU-T G984 standard which is smaller than 28 dB. This means that this FTTH design is suitable for use and has a very good transmission quality for optical signals. This FTTH design is worth using.

4.4.1 Discussion of Macro bending Research indoor cables Curvature Diameter Parameters
The results of the study of macro bending of indoor wires on the parameters of curvature diameters correspond to table III. From the table obtained the attenuation value on indoor cables under normal conditions and on each macro bending of indoor wires with curvature diameters of 1 cm, 0.75 cm, and 0.5 cm. From the table, it can be seen that, the value of the curvature diameter affects the attenuation value. The greater the attenuation value, the worse the quality, and vice versa, the smaller the attenuation value, the better the quality.

In indoor cables of normal condition or without macro bending obtained a attenuation value of 0.1 dB. A attenuation of 0.1 dB is obtained by subtracting the PTx value by the PRx value, where the PTx value is obtained from the calibration of HLS and OPM connected with the patch cord cable. This calibration is carried out before taking measurements on each indoor cable. Meanwhile, the PRx value is obtained from measurements using OPM which are carried out on the receiving side of the macro bending of the indoor cable whose sender side has been given HLS and patch cord. Likewise with the acquisition of attenuation values in other indoor cable macro bending.

The value of 0.1 dB is a very small value and means that the quality of this indoor cable is good. Then in indoor cables that undergo macro bending with a curvature diameter of 1 cm has a attenuation value of 0.35 dB. The curvature diameter of 0.75 cm has a attenuation value of 0.91 dB, and the curvature diameter of 0.5 cm has a attenuation value of 2.15 dB. From the attenuation value of each cable, the author analyzes that the curvature diameter has an influence on the attenuation value. Where, the curvature diameter of 1 cm on the indoor cable already has an influence on the attenuation value. The greatest attenuation value was at the smallest curvature diameter of this study, namely at a diameter of 0.5 cm.

From this data, the smaller the curvature diameter value, the greater the attenuation value. The greater the attenuation value, the worse the quality of the transmission in transmitting optical signals. Thus, macro bending of indoor cables with smaller curvature diameters can have a greater influence on FTTH designs because they degrade their quality on the final reception or ROSET.

4.4.2 Discussion of Macro bending Research indoor cables Parameters number of windings
The results of the study of macro bending of indoor wires on the parameters of the number of windings correspond to table 4.4. From the table obtained the attenuation value on 2 indoor wires with the same curvature diameter of 0.5 cm, but a different number of windings, namely 3 windings and 5 windings. The result of the attenuation value on the table is obtained with the PTx value subtracted by the PRx value according to table 4. The PTx value obtained from calibration before subtracting is -7.56 dBm. While the PRx value is obtained by doing png size using OPM.

From the table obtained the attenuation value for macro bending of indoor wires of 3 windings and 5 windings. In macro bending indoor cables that have 3 numbers of windings obtained a attenuation value of 3.03 dB. As for the indoor cable macro bending which has 5 windings, a attenuation value of 8 dB is obtained. From this, the number of windings affects the attenuation value. The greater the number of windings, the greater the attenuation value and the worse the quality.

Thus, when installing FTTH, if the indoor cable undergoes macro bending and has many windings on the macro bending, it will cause a large total attenuation value at the final reception point in roset later.

This will cause the quality of the optical signal obtained at ROSET to be very poor and not meet the ITU-T G984 standard.

To find out the number of windings that can still be tolerated in indoor cable macro bending with a curvature diameter of 0.5 cm, the author connects this cable into the FTTH design that the author built. The author replaced the normal condition indoor cables in the FTTH design with 3 windings and 5 windings indoor cables one by one and measurements were taken at ROSET. The results of these measurements are obtained and filled in in table VI. In the table, the PTx value is filled with the calibration value before the measurement and a calibration value of -6.99 dBm is obtained. This value of -6.99 dBm will be the input value of odc or FTTH design at the time of making the measurement.

Based on table VI obtained PRx in ROSET through measurements using OPM and filled in according to this table. For 3 windings it has a value of PRx = -29.28 dBm and 5 windings have a value of PRx = -35.07 dBm. To find out the total attenuation value, a calculation is carried out by subtracting the PTx value with the PRx value as follows:

$$\alpha_{total} = PTx - PRx \quad (3)$$

Total attenuation for macro bending diameter 0.5 cm and 3 number of windings:

$$\alpha_{total} = -6.99 \text{ dBm} - (-29.28 \text{ dBm})$$

$$\alpha_{total}\, l = 22.29 \text{ dB}$$

Total attenuation for macro bending diameter 0.5 cm and 5 number of windings:

$$\alpha_{total} = -6.99 \text{ dBm} - (-35.07 \text{ dBm})$$

$$\alpha_{total}\, l = 28.08 \text{ dB}$$

From the calculations above, the author can analyze that for the total attenuation of macro bending diameters of 0.5 cm and 3 the number of windings still meets the standards of the link budget calculations of the FTTH and ITU- T G984 designs. This is because the total attenuation value for this 3-winded macro bending is still below the value of 22.803 dB and the value of 28 dB. Where 22.803 dB (total attenuation of 3 windings) < 22.803 dB (FTTH design link budget calculation) < 28 dB (ITU-T G984). This means that the total attenuation of 3 windings < the calculation of the link budget designed by FTTH < ITU-T G984, then it still meets the standards and is still feasible.

However, in the calculation results of the total attenuation value of the macro bending of the indoor cable diameter of 0.5 cm and 5 the number of windings is 28.08 dB. This total attenuation value passes or exceeds the total attenuation standard value of the FTTH draft budget link calculation and passes the total attenuation of itu-T G984. Where, 28.08 dB (total attenuation of 5 windings) > 28 dB (ITU-T G984) > 22,803 dB (calculation of the ftth design link budget). This means that the attenuation of a total of 5 coils > ITU-T G984 > the calculation of the FTTH draft budget link, it does not meet the eligibility standards.

Thus, the macro bending of indoor cables curvature diameter of 0.5 cm with 3 numbers of windings still meets the standards and is still feasible. As for the macro bending indoor cable, the curvature diameter is 0.5 cm with 5 numbers of windings passing the tolerance value, so it does not meet the standards both from the calculation of the link budget designed by ftth author and the standard from ITU-T G984. From this, the macro bending indoor cable curvature diameter of 0.5 cm should not have a number of windings that are more than 3 windings in the FTTH installation. This is because, 3 windings for a diameter of 0.5 cm have a total attenuation value that almost passes the tolerance value or standard calculation link budget design FTTH.

4.4.3 Discussion of Light Refraction Research on Indoor Cable Macro bending Using Visual Fault Locator (VFL)

The results of the light refraction research on indoor cable macro bending obtained data in the form of images according to table V. From the table, a photo can be seen which is a display of light refraction in each state of indoor cables using VFL devices. Based on table V, the normal indoor cable in ROSET has a refraction of light that is still bright and evenly distributed until it has a light output that still remains bright. In this normal indoor cable, there is a dominant light in certain grooves, but the light is still continued with good intensity because it has been proven by measurements using OPM according to table III which shows a very small attenuation value of 0.1 dB.

However, for indoor cables that are subjected to macro bending, it has a different form of light refraction display. This difference lies in the macro bending of the cable, the light looks like it has a point or refracts out of the cable. The smaller the curvature diameter of the indoor cable macro bending, the brighter the light spot on its macro bending winding. In addition, after macro bending winding the intensity of light becomes reduced. This is due to the light coming out of the indoor cable core.

The cause of light coming out of the indoor cable core that is subject to macro bending is because when macro bending occurs, the medium density of cladding decreases on the outer side when it is circular. According to the formula of the equation snellius (3) as follows:

$$n1 \sin \theta 1 = n2 \sin \theta 2 \quad (4)$$

description:

n1 = core/core refractive index

ϴ1 = Angle of light coming

n2 = sheath refractive index/cladding

ϴ2 = angle of refrain of light

From this equation, it produces the sound of the snell equation, that is, if the light comes from a tight medium and then enters a tighter medium, the light will be refracted close to the normal line. Meanwhile, if the light from the tight medium enters a more tenuous medium, then the light will be refracted away from the normal line. That is, the density of the medium or the value of the refractive index affects the refractive index of light close to or away from the normal line.

In this indoor cable macro bending event, the cladding part will change its medium density which of course also changes the value of the refractive index. Where, when macro bending occurs, the inner side of the macro bending circle will become tighter the cladding medium, while the outer side of the macro bending circle will experience estrangement in the cladding medium. This causes the light from the core of the indoor cable that undergoes macro bending to refract out past the outer side of its cladding circle.

The smaller the diameter of the macro bending curvature, the more light will come out of the indoor cable core. This is evidenced by the increasingly broken and more light coming out of the cladding as the diameter of its macro bending curvature gets smaller according to table V. In addition, evidence of light intensity from the cores reduced or out of the cores and indoor cable cladding can be seen on the light display which has a number of windings of 5. Where in macro bending indoor cables the curvature diameter is 0.5 cm and 5 the number of windings, the more towards the light receiver the more it fades when compared to the sender.

In the picture in the table, the sender comes from the right in the form of a VFL. So for 5 windings, the refraction of light from the right winding is brighter and the more to the left, the refraction of the light fades in each winding. Thus macro bending is proven to be able to change the value of the refractive index by changing the density of the cladding medium first, then light will come out of its core and the intensity of light is reduced in reception. This causes the quality of the optical signal in the reception to be very poor and the signal received at the reception later is not intact and many are lost.

4.4.4 Research Discussion on Finding Critical Radius in Indoor Cable Macro bending

The search for critical radius aims to find out the boundary of the critical point of occurrence of indoor cable macro bending or the maximum occurrence of macro bending on indoor cables. The results of the study of searching for critical radius in indoor cable macro bending are shown in table VII. From the table, 3 macro bending windings of indoor wires are shown with each having a curvature diameter of 0.5 cm, 0.4 cm, and 0.3 cm. This arrangement if you pay attention to the image from left to right. The more to the right, the smaller the size of the curvature diameter. In table VII there is an image that shows a photo of the form of refraction of light on the cable when given a VLF on the sender's side or from the left in the figure.

By the time the VFL light passes through a curvature diameter of 0.5 cm the light appears bright enough on its macro bending winding. After that the light passes through a curvature diameter of 0.4 cm and the refraction of the light is very bright and begins to look broken or like there is a broken point which causes the light to refract out a lot of indoor cable cladding. However, light still appears to be passed on to a curvature diameter of 0.3 cm. On the winding of the curvature diameter of 0.3 cm, the light appears to fade and there is a point on the macro bending winding.

The point on the macro bending winding with a curvature diameter of 0.3 cm is visible as the end point of light, since after that point no more light is passed to the right or to the receiving side. Thus the point is the breaking point of the core of the indoor cable, so the light is cut off. From this, the author analyzes that the critical radius value of macro bending indoor cables is at a curvature diameter of 0.3 cm. Because at a diameter of 0.3 cm, macro bending turns into losses or break of the cores of the indoor cable.

In addition, to prove that the cable has suffered losses or breaks, it can also be proven by measuring using OPM on the receiving side and HLS on the sender side. The results of this measurement are also found in table VII. In the table, the measurement results using OPM on the receiver side are -50 dBm. If PRx is -50 dBm in OPM, then it indicates a loss because the value of -50 dBm is the smallest value of PRx that can be measured in OPM in dBm units.

5. Conclusion

In this final project, the construction of the Fiber To The Home (FTTH) design and the analysis of the problem of macro bending indoor cables, which is a segment of home wiring installations on FTTH, have been carried out. From this, it can be concluded that macro bending indoor cables in FTTH home wiring installations has an influence on the total attenuation value of FTTH.

1. The curvature diameter in indoor cable macro bending affects the attenuation value. The smaller the curvature diameter of the indoor cable macro bending, the greater the attenuation value. Conversely, if the larger the curvature diameter of the indoor cable macro bending, the smaller the attenuation value will be. The number of macro bending windings of indoor wires affects the attenuation value.
2. The greater the number of windings of the indoor cable macro bending, the greater the damping value. Conversely, the less the winding amount of the indoor cable macro bending, the smaller the damping value will be.

The critical radius on indoor cable macro bending is when the diameter value of the indoor cable macro bending curvature = 0.3 cm.

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