Optical Fiber Communication Design and Analysis for A Railway Line

2021 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET) | 978-1-6654-2816-3/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICRAMET53537.2021.9650501

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***Abstract*—This paper proposes an optical fiber communication design from Semarang to Surabaya to back up with an additional station and support a longer route than the previous study. This study considers the link budget and the rise time budget analysis to analyze the route's feasibility. The received power ranges from -22.67 dBm to -12.57 dBm. Meanwhile, the total rise time value ranges from 39.72 ps to 57.17 ps. The results indicate that the proposed design is potentially feasible to work appropriately.**

Keywords—optical fiber, communication, railway, power link, rise time.

I. Introduction

Transportation is one of the crucial aspects of mobilization for humans. There are a lot of transportation modes, including land modes transportation. Bus, car, and train are the kinds of land transportation, in which the train is the most efficient vehicle besides the others in fuel consumption. Because of that, the government makes trains for the backbone of national transportation modes and realizes it through Rencana Induk Perkeretaapian Nasional (RIPNAS) Program. The program objective is to instruct the National Railway Development Plan until the Year 2030. One of the observed aspects is technology modernization [1].

Modernization is essential for the railway because the train has become the most renowned transportation and increases every year. The first solution to this problem is to build the double-track railway in 2014. The second solution is to build high-speed train railways for the High-Speed Train (HST) to accommodate faster mobilization for passengers, which will start in 2030. The railway modernization and revitalization have to satisfy the requirements of safety, convenience, and security to operate the railway, comfortable and reliable communication and signaling. The necessary communications include SCADA (Supervisory Control and Data Acquisition), train control, an early warning system for a natural disaster, CCTV (Closed Circuit Television) [2], and passenger information services requiring certain media that satisfy high safety requirements, high reliability, high-temperature tolerance, and easy maintenance [3, 4]. The proper media to satisfy these requirements is the optical fiber [5].

An early study has analyzed the deployment feasibility of optical fiber from Bojonegoro station as the origin and Surabaya Pasar Turi station as the destination. The result showed that the proposed route is feasible for further implementation [6]. Therefore, based on this early study, this research has analyzed longer routes and different point-to-point methods for optical fiber deployment. The origin is Semarang Tawang Station, and the destination is Pasar Turi Station. Another point-to-point method is necessary to become the backup method. This research aims to conduct a feasibility study of more extended optical fiber deployment by analyzing the power link and rise time budgets.

The basis for path selection is the route used for HST in 2030 regarding RIPNAS supported by the early study. The other advantage of using the railway as optical fiber deployment in the selected route is easy maintenance where optical fiber is safe under the railway. Moreover, it makes the telecommunication provider use these media paths to overlay information.

II. Optical Network Design

A. Architectural Design

Fig. 1 illustrates a map of the location from Semarang Tawang Station to Surabaya Pasar Turi Station. This study considers the Google Maps application to determine the route from Semarang Tawang to Surabaya. The distance planning between stations consist of 21 points from Semarang Tawang station to Pasar Turi station in Surabaya.

Fig. 2 shows the research flow to the design route. The beginning step is a literature study and looking at policies from existing government programs. After determining the considered path and parameters, the next step is to analyze the proposed routes. The proposed design forms a single line planned at each station with 21 cores from Semarang Tawang station to Surabaya Pasar Turi station, as seen in Fig. 3.

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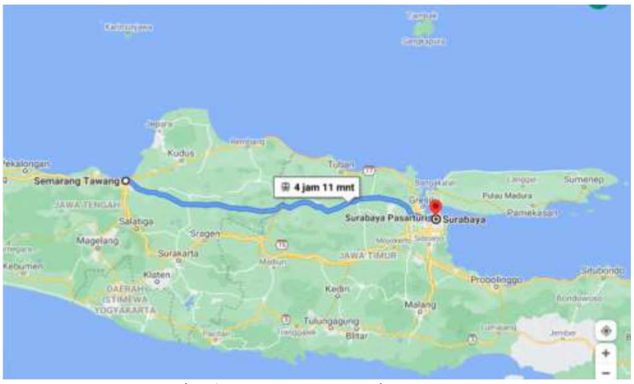

Fig. 1. Semarang – Surabaya rute.

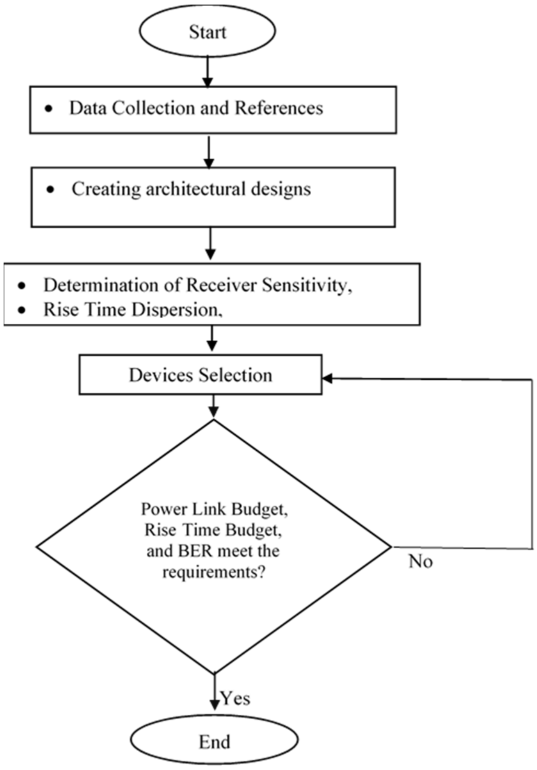

Fig. 2. Research flow.

Table I shows the necessary cable length between stations. The required cable length is the distance between the optical links added by the cable reserve of 7% of the distance. This additional cable allocation facilitates the connection process when an interrupted cable enters the operation, anticipating changes in the optical transceiver layout due to station development and potential additional requirements. The total bandwidth for 21 stations in this study uses 1xSTM-1 (Level 1 Synchronous Transport Module) with a capacity value of 155.52 Mbps or the equivalent of 63 E1, where 1 x E1 is 2.048 Mbps [7].

Then the used bandwidth is 4 x E1, and there is a reserved bandwidth of 3 x E1. Thus, the allocated bandwidth for the signaling equipment at each station is 2 x E1. In contrast, the bandwidth files for telecommunications are lean phones, console phones, and voice recorders, where the allocation of each station is 2 x E1.

TABLE I. OPTICAL CABLE CONNECTION LINES

Route	Origin Station	Destination Station	Distance (km)	Total Cable Length (km)
1.	Smg Tawang	Alastua	5.75	6.1525
2.	Alastua	Brumbung	6.9	7.383
3.	Brumbung	Gubug	16.71	17.8797
4.	Gubug	KarangJati	12.97	13.8779
5.	KarangJati	Sedadi	8.82	9.4374
6.	Sedadi	Ngrombo	5.74	6.1418
7.	Ngrombo	Djambon	12.15	13.0005
8.	Jambon	Keradenan	15.02	16.0714
9.	Keradenan	Doplang	15.86	16.9702
10.	Doplang	Randublatung	12.12	12.9684
11.	Randublatung	Wadu	11.21	11.9947
12.	Wadu	Bojonegoro	42.82	45.8174
13.	Bojonegoro	Kapas	6.38	6.8266
14.	Kapas	Babat	27.93	29.8851
15.	Babat	Pucuk	11.17	11.9519
16.	Pucuk	Lamongan	16.7	17.869
17.	Lamongan	Duduk	11.95	12.7865
18.	Duduk	Cerme	9.49	10.1543
19.	Cerme	Kandangan	10.15	10.8605
20.	Kandangan	Tandes	3.26	3.4882
21.	Tandes	Pasar Turi	5.01	5.3607
Total links and Their distances				286.8777

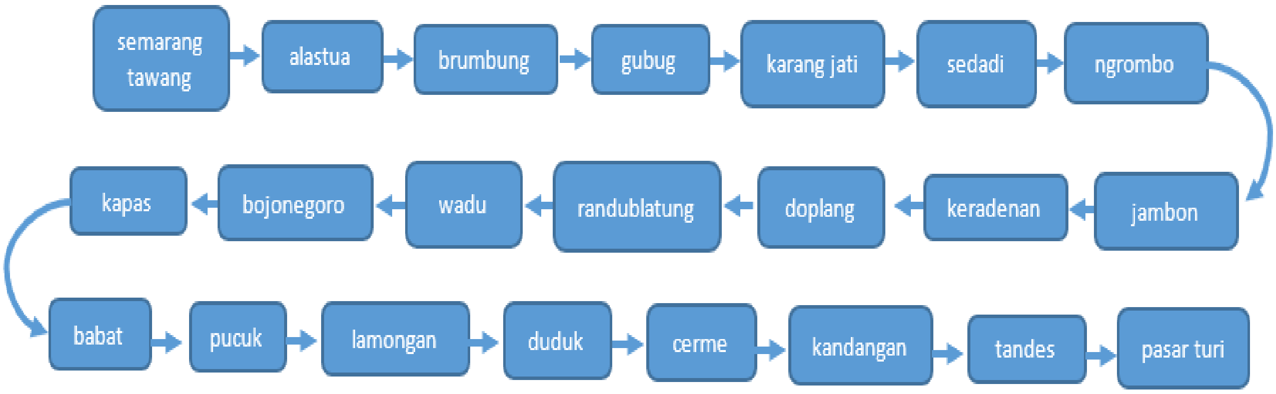

Figure 3. Proposed routes from Semarang to Surabaya.

B. Device Selection

After obtaining location and design data, the next step is determining the needed types and specifications of the equipment. The considered optical cable is the ITU-T G.654.B standard, which has a low loss characteristic and can reach distances of 100 km without utilizing repeaters [8]. The transceiver device has a transmit power of 4 dBm. It also has a low sensitivity level of -24 dBm. Details of the optical cable parameters and the transceiver device parameters are in Table II.

C. Calculation of Power Link Budget

This study considers the power link budget analysis to ensure that the receiver device can receive the transmit power carrying information from the transmitter after passing through the optical fiber medium at a certain distance [9]. Equation (1) describes the calculation of total optical power losses (P_T). The variables include cable attenuation per distance (α_f) in dB/km, cable length (L) in km, splicing number (m), splicing loss (Ls) in dB/splice, connectors number (n), connector loss (Lc) in dB/connector, and the system margin (M_S).

$$P_T = \alpha_f . L + m . L_s + n . L_C + M_s \quad (1)$$

$$P_R = P_S + P_T \quad (2)$$

Equation (2) explains the calculation of received power P_R (dBm). This equation uses two parameters: the total optical power loss P_T (dB) and source power P_S (dBm).

D. Calculation of the Rise Time Budget

The rise time budget is a method to determine the optical system's total time required from the initial steady-state conditions [10]. Equation (3) is a formula to determine the Rise Time Group Velocity Dispersion (t_{GVD}), where D is Chromatic Dispersion (ps/nm.km) and L is the cable length (Km). $\alpha\lambda$ is the Spectral Width (nm). Besides, (4) is a formula to calculate the Total Rise Time (t_{sys}), where the calculation component consists of the rise time transmitter (t_{tx}), rise time receiver (t_{rx}), and Rise Time Group Velocity Dispersion (t_{GVD}). The aim of the formula in (5) is to calculate the maximum rise time dispersion (t_{Max_sys}).

$$t_{GVD} = D . L . \alpha\lambda \quad (3)$$

$$t_{sys} = \sqrt{t_{tx}^2 + t_{GVD}^2 + t_{rx}^2} \quad (4)$$

$$t_{Max\_sys} = \frac{70\% \, (NRZ)}{Data\, rate(bps)} \quad (5)$$

TABLE II. OPTICAL COMMUNICATION SYSTEM PARAMETERS

Parameter	Value	Unit
Data Rate	155.52	Mbps
BER	10^{-12}	-
Encoding Signal	NRZ	-
Wavelength	1550	nm
Margin System	8	dB
Connector Attenuation	2	dB/connector
Joint attenuation	0.2	dB/splice
Transceiver Device		
Transmit power	4	dBm
Receiver sensitivity	-24	dBm
Transceiver rise time	28	Ps
Spectral Width (σ_λ)	0.3	nm
Optic Fiber Cable (ITU-T G.654.B)		
Attenuation (af)	0.175	dB/km
Chromatic Dispersion (D)	3	ps/nm.km

III. RESULT AND DISCUSSION

A. Power Link Budget Results

Power link or link loss budget is the first analysis considered in optical fiber communication deployment analysis. The first step in this analysis is collecting all the parameters and put into the equation. Total power losses can be calculated by summing all the losses such as cable loss, splicing loss, and connector loss [11]. It is also considers system margin.

Table III highlights the calculation results of total power losses for each of the 21 routes. Route 9 shows the smallest total power loss value of 16.57 dB. It happens due to it has the shortest distance. Besides, the most significant value of 26.82 dB is owned by route 12, with the longest route of 45.82 km. Another work with the farthest route is 147 km, where the most significant power loss value is 35.57 dB [12].

Table IV describes the feasibility of the deployment by comparing the received power value and the sensitivity of the transceiver. The received power value is obtained by subtracting the value of source power from the total

TABLE III. CALCULATION RESULTS OF TOTAL POWER LOSSES

Route	Cable loss (dB)	Splicing loss	Connector loss	System Margin	Total Power Losses (dB)
1	1.08	0.6	8	8	17.68
2	1.29	0.6	8	8	17.89
3	3.13	1.0	8	8	20.13
4	2.43	0.8	8	8	19.23
5	1.65	0.6	8	8	18.25
6	1.07	0.6	8	8	17.67
7	2.28	0.8	8	8	19.08
8	2.81	1.0	8	8	19.81
9	0.37	0.2	8	8	16.57
10	2.27	0.8	8	8	19.07
11	2.10	0.8	8	8	18.90
12	8.02	2.8	8	8	26.82
13	1.19	0.6	8	8	17.79
14	5.23	1.8	8	8	23.03
15	2.09	0.8	8	8	18.89
16	3.13	1.0	8	8	20.13
17	2.24	0.8	8	8	19.04
18	1.78	0.6	8	8	18.38
19	1.90	0.6	8	8	18.50
20	0.61	0.2	8	8	16.81
21	0.94	0.4	8	8	17.34

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TABLE IV. CALCULATION RESULTS OF POWER LINK BUDGET

Total Power Losses (dB)	Source Power (dBm)	Received power (dBm)	Sensitivity	Feasibility
17.68	4	-13.68	-24	YES
17.89	4	-13.89	-24	YES
20.13	4	-16.13	-24	YES
19.23	4	-15.23	-24	YES
18.25	4	-14.25	-24	YES
17.67	4	-13.67	-24	YES
19.08	4	-15.08	-24	YES
19.81	4	-15.81	-24	YES
16.57	4	-12.57	-24	YES
19.07	4	-15.07	-24	YES
18.90	4	-14.90	-24	YES
26.82	4	-22.82	-24	YES
17.79	4	-13.79	-24	YES
23.03	4	-19.03	-24	YES
18.89	4	-14.89	-24	YES
20.13	4	-16.13	-24	YES
19.04	4	-15.04	-24	YES
18.38	4	-14.38	-24	YES
18.50	4	-14.50	-24	YES
16.81	4	-12.81	-24	YES
17.34	4	-13.34	-24	YES

power losses. This calculation is supported by the research conducted in the Trilochan Patra. et al. [13]. Route 12 contributes the highest received power value of -22.67 dBm. However, there is the smallest received power value at -12.57 dBm owned by route 9.

This table shows that all the received power values are higher than the sensitivity values. Therefore, we can indicate that each route can work for the optical communication lines.

B. *Rise Time Budget Results*

Rise time budget analysis is the second step of the deployment analysis obtained by square rooting the rise time transmitter, receiver, and group velocity dispersion. Table V shows the total rise time for each route. Based on the calculation, route 20 has the smallest total rise time value of 39.72 ps. On the other hand, the most considerable total rise time value is 57.17 ps, obtained by route 12.

In this analysis, we can compare the total rise time with the maximum permissible rise time. Thus, even though this research's total rise time value is larger than the rise time value obtained from another 45.32 ps, it is still smaller than the maximum permissible rise time [6]. Due to all total rise time values being lower than the maximum permissible rise time, these results indicate that all-optical fiber links can work appropriately.

TABLE V. CALCULATION RESULTS OF TOTAL RISE TIME

Route	*Tgvd*	*ttx*	*trx*	*tsys*	*tmax_sys (ps)*	Feasi-bility
	(ps)	(ps)	(ps)	(ps)	NRZ 155.52 Mbps	
1	5.54	28	28	39.98	4501.03	YES
2	6.64	28	28	40.15	4501.03	YES
3	16.09	28	28	42.74	4501.03	YES
4	12.49	28	28	41.52	4501.03	YES
5	8.49	28	28	40.50	4501.03	YES
6	5.53	28	28	39.98	4501.03	YES
7	11.70	28	28	41.29	4501.03	YES
8	14.46	28	28	42.16	4501.03	YES
9	15.27	28	28	42.44	4501.03	YES
10	11.67	28	28	41.28	4501.03	YES
11	10.80	28	28	41.04	4501.03	YES
12	41.24	28	28	57.17	4501.03	YES
13	6.14	28	28	40.07	4501.03	YES
14	26.90	28	28	47.87	4501.03	YES
15	10.76	28	28	41.03	4501.03	YES
16	16.08	28	28	42.74	4501.03	YES
17	11.51	28	28	41.24	4501.03	YES
18	9.14	28	28	40.64	4501.03	YES
19	9.77	28	28	40.79	4501.03	YES
20	3.14	28	28	39.72	4501.03	YES
21	4.82	28	28	39.89	4501.03	YES

IV. CONCLUSION

The proposed design of optical fiber communication from Semarang to Surabaya has 21 routes between Semarang and Surabaya. Regarding power link budget analysis, the received power ranges from -22.67 dBm to -12.57 dBm. Besides, based on the rise time budget analysis, the total rise time value ranges from 39.72 ps to 57.17 ps. These results indicate that the proposed optical fiber communication lines are feasible for deployment and can work appropriately.

ACKNOWLEDGMENT

Ministry of Research and Technology / National Agency for Research and Innovation, Republic of Indonesia supports this research through Penelitian Dasar Grant, contract number: NKB-028/UN2.RST/HKP.05.00/2021, the year 2021.

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