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ISPITIVANJE I KONTROLA KVALITETE SVJETLOVODNIH MREŽA

FIBRE OPTIC NETWORKS TESTING AND QUALITY CONTROL

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SAŽETAK

U radu je prikazano ispitivanje kontrola kvalitete svjetlovodnih mreža korištenjem analize mjerenja. Uz prikaz osnovnih elemenata svjetlovodnih mreža i opis metode mjerenja, objašnjene su obrada i analiza dobivenih rezultata. Provedena je studija slučaja na specifičnoj mreži gdje su analizirani rezultati i ponuđene preporuke za poboljšanje njene kvalitete. Korištenje mjerenja pomoću optičkog reflektometra u vremenskoj domeni omogućilo nam je identifikaciju i ispravak grešaka poput prekida, refleksije i gušenja u promatranoj dionici mreže. Navedena metoda pruža mogućnost u detaljan uvid u promjene gušenja duž cijele dužine vlakna, te time omogućava precizno lociranje problema kao što su mikro pukotine ili loši spojevi. Uz upotrebu korektivnih mjera, kao što su zamjena oštećenih segmenata i optimizacija spojeva, pokazano je da je moguće značajno smanjiti gubitke signala i poboljšali stabilnost mreže. Prikazana je analiza mreže koja se sastoji od više komponenti koje omogućuju pouzdanu i visokokvalitetnu prijenosnu infrastrukturu. Mreža koristi topologiju stabla koja omogućava efikasno raspoređivanje signala iz jednog centralnog izvora prema različitim krajnjim točkama, s mogućnošću dodatnog grananja prema potrebama.

Ključne riječi: *svjetlovodna mreža, kontrola kvalitete, analiza grešaka, optički reflektometar u vremenskoj domeni, korektivne mjere*

ABSTRACT

The article presents an examination of the quality control of fibre optic networks through measurement-based analysis. In addition to outlining the fundamental components of fibre optic networks, the article details the employed measurement methodology, data processing techniques, and the subsequent analysis of the obtained results. Based on a case study, a specific network was examined, the results were analysed and targeted recommendations for quality enhancement were proposed. Utilising Optical Time-Domain Reflectometry (OTDR), network anomalies such as signal interruptions, reflections, and attenuation, were identified and corrected. This method provides a detailed insight into attenuation variations along the entire fibre length, facilitating the precise localisation of issues such as microfractures or suboptimal connections. The findings demonstrate that corrective actions—such as replacing compromised fibre segments and optimising connector interfaces—can significantly reduce signal degradation and enhance overall network stability. Furthermore, the analysis encompasses a network architecture composed of multiple components designed to support a robust and high-quality transmission system. The network utilises a tree topology which allows efficient signal distribution from a single central source node to multiple endpoints, with the flexibility to incorporate additional branches as needed.

Keywords: *fibre optic network, quality control, error analysis, optical time domain reflectometer, corrective measure*

1. UVOD

1. INTRODUCTION

Today, fibre optic networks represent a critical component of modern communication systems [1]. They enable [2] long-distance data transmission with minimal signal loss. Given their essential role in both daily life and the economy, ensuring the high quality of these networks is of paramount importance. The performance of fibre optic networks highly depends on [3] the precision and reliability of measurements of key parameters such as attenuation, reflection and dispersion. Problems arise when irregularities within the network cause performance degradation, which may lead to interruptions in data transmission. Quality assurance in fibre optic networks represents a complex and crucial process that enables the achievement of high performance and long-term reliability in data transmission. Given their role in transmitting large volumes of data over long distances with minimal signal loss, it is essential to implement effective quality management across all segments of the network. The implementation of rigorous quality assurance processes involves a series of steps [4], including planning, testing, monitoring, and continuous improvement. Measurement plays a crucial role in the quality control of fibre optic networks, providing data that supports the maintenance of high performance and reliability. The effectiveness of these measurements ensures [5] that the network complies with technical standards and specifications, while also enabling the timely detection and resolution of potential issues.

The objective of this article was to identify, analyse and optimize measurement methods in optical fibre networks, with a particular focus on error analysis and the enhancement of quality control processes. The research focused on the collection and the data processing from real-world network environments, as well as the implementation of recommendations aimed at improving network infrastructure.

2. POPIS I OPIS KORIŠTENIH NORMI

2. LIST AND DESCRIPTION OF USED STANDARDS

2.1. MEĐUNARODNE NORME

2.1. INTERNATIONAL STANDARDS

One of the most important international bodies responsible for defining standards in fibre optic networks is the International Telecommunication Union (ITU). The ITU-T G.652 [6] standard defines the characteristics of standard single-mode fibres (SMF), which are most commonly used in telecommunication networks. This standard specifies parameters such as attenuation, dispersion and fibre bendability, all of which are crucial for optimising network performance.

The ITU-T G.655 standard [7] refers to non-zero dispersion-shifted fibres, which are used in high-speed, long-haul networks, while the ITU-T G.657 standard [8] defines bend-insensitive fibres, which are essential for modern networks where fibres are often installed in confined spaces and exposed to sharp bends. There are also standards established by the International Organisation for Standardisation (ISO) and the International Electrotechnical Commission (IEC). The ISO/IEC 11801-1 [9] standard specifies cabling for local area networks (LANs) and industrial environments. It also defines various cable categories and classes based on their performance and intended application. The ISO/IEC 27001 standard [10] provides guidelines for implementing security measures that protect networks from unauthorised access, data loss and other security threats. Implementing security controls by this standard is essential for safeguarding confidential information and ensuring business continuity.

2.2. EUROPSKE I NACIONALNE NORME

2.2. EUROPEAN AND NATIONAL STANDARDS

The national standards are mostly international and European standards accepted at the national level. The European Committee for Electrotechnical Standardization (CENELEC) plays a key role in establishing standards for optical fibre networks. The EN 60793 standard [11] specifies the general characteristics of optical fibres, including mechanical, optical and environmental requirements. It is crucial for ensuring the quality and durability of fibres used in various applications, ranging from telecommunications to industrial automation. The standard EN 50173 [12] is applied for cabling and maintenance in commercial, residential and industrial buildings, including the use of optical fibres.

3. OTDR METODA MJERENJA
3. OTDR MEASUREMENT METHOD

An Optical Time-Domain Reflectometer (OTDR) (Figure 1) [13] provides a detailed insight into attenuation variations along the entire length of the fibre, enabling the precise location of problems such as micro-cracks or poor splices. Reflection measurements are typically performed using this device, which allows for accurate identification of points in the network where signal reflection occurs. The device operates by emitting light pulses through the fibre and measuring the amount of reflected signal along its length. This enables precise identification of critical reflection points and the implementation of necessary corrective measures to reduce their severity. In addition, the OTDR is commonly used to measure fibre length, as it emits a light pulse through the fibre and measures the time required for the reflected signal to return. Based on this data, it can accurately calculate the fibre length and detect potential irregularities such as fibre breaks or poor splices. A Yokogawa AQ7270 device was used for the measurements (Figure 1). OTDR traces display losses and reflections along the optical fibre, allowing for precise localization of network problems such as poor splices or defects. By analysing the OTDR trace, engineers can visualise points of signal loss and quickly identify and resolve faults. Attenuation measurement is a fundamental measurement and is often sufficient for relatively short optical fibre networks (up to several kilometres). However, on long routes (several tens of kilometres) and on routes where Dense Wavelength Division Multiplexing (DWDM) systems are used, it is often necessary to perform dispersion measurements (chromatic, non-chromatic, and polarisation).

Slika 1 *Prikaz OTDR mjernog uređaja*

Figure 1 *Front panel of the OTDR measurement device*

4. OPIS MREŽE I PREGLED MREŽNE INFRASTRUKTURE
4. NETWORK DESCRIPTION AND NETWORK INFRASTRUCTURE OVERVIEW

The analysed optical fibre network (Figure 2) consists of several components that enable a reliable and high-quality transmission infrastructure. Special attention was paid to the routing and placement of the individual cables to avoid additional costs. The network was designed with the primary goal of ensuring optimal connectivity between the distribution node, business offices and the end user, using modern fibre optic technologies and the ©GIS software tool.

The fundamental elements of this fibre optic network are:

- Distribution node: It can be a large cabinet or a small box mounted on a pole. The node serves as a central point for connecting various segments of the network and is powered by an incoming cable from a distribution point, typically located in a post office or municipal building. Distribution nodes are essential for managing data traffic and ensuring optimal network functionality. They are strategically placed to reduce material costs and to maximize network coverage and efficiency.
- Optical cables: The network uses single-mode fibre optic cables, such as Prysmian's 12 and 48 core cables, which are primarily used for underground installations. The Nexans 24-fibre cable is used for aerial installations. Due to their high bandwidth capacity and low dispersion, they are used for connections over long distances.
- Splice box: A passive component in an optical fibre network, its function is to enable the physical connection or splicing of optical fibres within the network, thereby ensuring continuity in data transmission. Splice boxes provide mechanical protection for the splices, preventing physical damage to the fibres and signal loss. They also facilitate proper routing of fibres within the network, ensuring stable and reliable data transmission between various

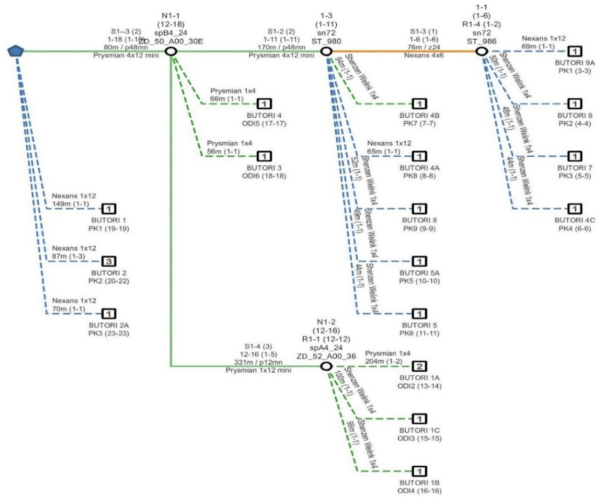
network points. This component is essential for maintaining the long-term integrity and performance of optical fibre systems.

The network uses a tree topology (Figure 3) that enables efficient signal distribution from a single central source to various endpoints, with the possibility of further branching as needed. This structure is particularly suitable for networks with a broad bandwidth and a large number of users, as it allows flexible management of network resources and facilitates the straightforward addition of new endpoints or subordinate nodes.

Slika 2 *Prikaz projektirane svjetlovodne mreže u računalnom programu ©GIS*

Figure 2 *Visualization of designed fibre optic network in the ©GIS software tool*

The network components are arranged according to the specific needs of users, with the main distribution node located nearby. These components connect various endpoints, including users, office buildings and industrial facilities, using a combination of underground and aerial fibre optic cable installations. For the purposes of this network, optical cables are laid in newly excavated ducts, while in certain areas aerial installations are used due to specific terrain requirements and to reduce installation costs. Aerial installations are particularly employed in parts of the network that connect remote facilities where underground deployment is either not feasible or not economically viable. The distribution node represents a key point in the optical fibre network, where the distribution and interconnection of optical fibres from different parts of the network take place. These nodes are designed to provide flexibility, reliability, and long-term durability, whether used in outdoor or indoor environments.



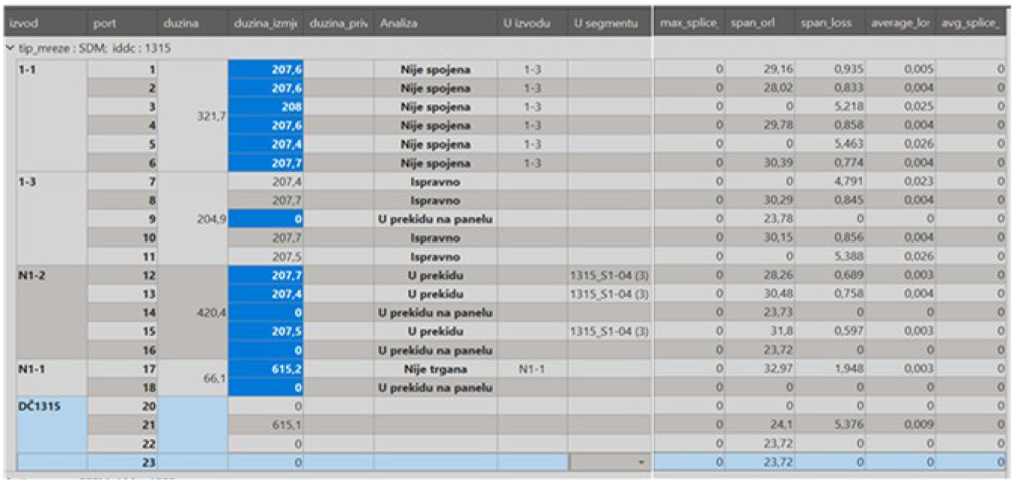
Slika 3 *Shema spajanja svjetlovodne mreže*

Figure 3 *Fibre optic network connection diagram*

5. MJERENJE NITI NA MREŽI I ANALIZA PROBLEMA

5. MEASUREMENT OF NETWORK THREADS AND PROBLEM ANALYSIS

After the installation of all network components, measurements are conducted on all fibres to verify network integrity and identify potential faults. For this purpose, an OTDR device is used. The process begins with device calibration, followed by connecting the optical fibre to the OTDR using an appropriate connector and selecting the correct wavelength. Upon completion of the measurement, the data can be stored for later transfer to a computer for analysis. The analysis provides a visual representation of all fibres and the locations of their splices. A measurement analysis with detected faults (errors) is shown in Figure 4 in tabular form. It should be noted that the software used for data analysis was set to the Croatian language. Following the analysis, several problematic measurements were identified. As shown in Figure 8, most fibres exhibited faults such as attenuation, panel breaks, fibre discontinuities, or unconnected splices. The OTDR device enables precise localization of these problems and provides information on the exact length of each segment. Two common faults are



izvod	port	duzina	duzina_izmj	duzina_priv	Analiza	U izvodu	U segmentu	max_splice_	span_orl	span_loss	average_lo	avg_splice_
tip_mreze : SDM; iddc : 1315												
1-1	1	321,7	207,6		Nije spojena	1-3		0	29,16	0,935	0,005	0
	2		207,6		Nije spojena	1-3		0	28,02	0,833	0,004	0
	3		208		Nije spojena	1-3		0	0	5,218	0,025	0
	4		207,6		Nije spojena	1-3		0	29,78	0,858	0,004	0
	5		207,4		Nije spojena	1-3		0	0	5,463	0,026	0
	6		207,7		Nije spojena	1-3		0	30,39	0,774	0,004	0
1-3	7	204,9	207,4		Ispravno			0	0	4,791	0,023	0
	8		207,7		Ispravno			0	30,29	0,845	0,004	0
	9		0		U prekidu na panelu			0	23,78	0	0	0
	10		207,7		Ispravno			0	30,15	0,856	0,004	0
	11		207,5		Ispravno			0	0	5,388	0,026	0
N1-2	12	420,4	207,7		U prekidu		1315_S1-04 (3)	0	28,26	0,689	0,003	0
	13		207,4		U prekidu		1315_S1-04 (3)	0	30,48	0,758	0,004	0
	14		0		U prekidu na panelu			0	23,73	0	0	0
	15		207,5		U prekidu		1315_S1-04 (3)	0	31,8	0,597	0,003	0
	16		0		U prekidu na panelu			0	23,72	0	0	0
N1-1	17	66,1	615,2		Nije trgana	N1-1		0	32,97	1,948	0,003	0
	18		0		U prekidu na panelu			0	0	0	0	0
DČ1315	20		0					0	0	0	0	0
	21		615,1					0	24,1	5,376	0,009	0
	22		0					0	23,72	0	0	0
	23		0					0	23,72	0	0	0

***Slika 4** Prikaz analize mjerenja s greškama u tabličnom prikazu*

***Figure 4** Measurement analysis results with associated errors*

shown and explained below (subsections 5.1. and 5.2.): a broken fibre and a broken plate.

Optical fibre networks are subject to dynamic changes that can affect their performance. Variations in network load, the installation of new devices or changes in network topology [14] may lead to fluctuations in performance. Timely measurements ensure the detection of the effects of such changes and allow for the adjustment of network resources to maintain a high quality of service.

5.1. GREŠKA – NIT U PREKIDU

5.1. ERROR – BROKEN THREAD

Based on the provided OTDR report for thread nr. 12 of the underground splice points, the measurement indicates a break-related problem at a wavelength of 1550 nm. The total fibre length is 207.7 m, with an average signal loss (attenuation) of 0.003 dB/m and a total loss of 0.689 dB across the entire fibre length. According to the OTDR diagram report (Figure 5), a break is present in the thread.

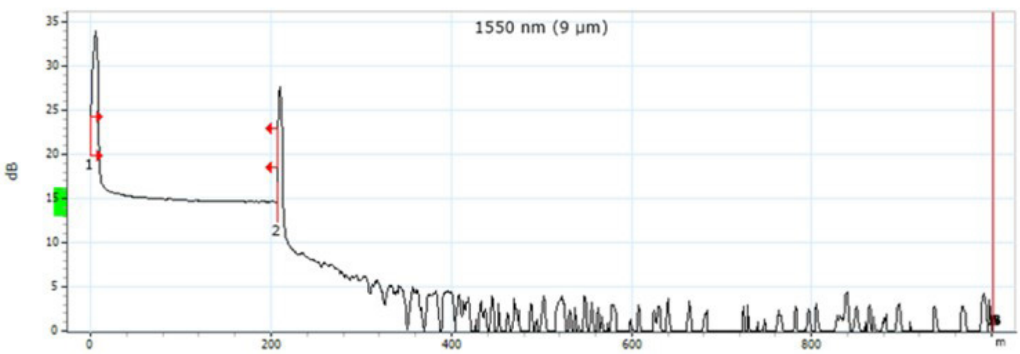
This break was detected at a distance of 207.7 metres, suggesting a significant problem at that location caused by a damaged fibre or a faulty splice. According to the diagram in Figure 5, the first reflection (point 1) occurs at the OTDR connector (beginning of the fibre) and has a level of about 33 dB. The second reflection (point 2) is a splice or connector at 207.7 m. After point 2, a drop from 15 dB to about 5 dB (discontinuity) is visible. The value of -41.2 dB is not shown on the diagram, as it is a back-reflected signal (reflectance).

Possible causes of the fault:

- Damaged fibre: indicating possible physical damage to the fibre, such as a tear or bend that prevents normal signal transmission.
- Mechanical stress: optical fibre may have been subjected to mechanical strain, such as excessive tension, which may cause a break or macro bending.

Remedial action:

- Visual inspection: A visual inspection should be carried out at the location of the break to



***Slika 5** Dijagram sa prikazom prekida na niti 12*

***Figure 5** OTDR diagram indicate a fibre break on thread number 12* identify any physical irregularities or damage to the fibre.

- Replacement of the damaged segment: If the fibre is physically damaged, the affected section of the cable must be replaced with a new one.
- Retesting: After the repair has been completed, an OTDR measurement should be repeated to verify the quality of the splice connection and ensure that no additional losses or reflections occur.

Following the implementation of corrective measures, the new report is expected to show a reduction in the total loss along the fibre. Reflection will be significantly reduced, the overall splice loss will be minimised, allowing the signal to propagate through the fibre without interference. The expected loss should fall within the normal operating range for a fibre of this length.

After the corrective measures were implemented, the new OTDR diagram for thread nr. 12 is shown (Figure 6):

- Elimination of reflections: No reflections are observed at previously problematic locations, indicating that the splices have been properly executed and no longer cause back-reflections that could interfere with the signal.
- Uniform signal trace: The signal line is now smooth and continuous, without abrupt drops, indicating stable data transmission throughout the entire fibre length.

Measurement results after corrections:

- Fibre length: 420.6 m,
- Average loss attenuation: 0 dB/m,
- Total signal loss: 0.203 dB.

Following the replacement of the affected segment, the line is stable and free of reflections, indicating a clean and consistent signal path that ensures high transmission reliability and speed. The resolved issues reduce the need for further interventions, thereby lowering maintenance costs and extending the infrastructure's operational lifespan. Regular monitoring is recommended to ensure that the quality remains consistent over time. Fibre 12 is now fully operational and ready for use.

5.2. GREŠKA – PREKID NA PANELU

5.2. ERROR – BROKEN PANEL

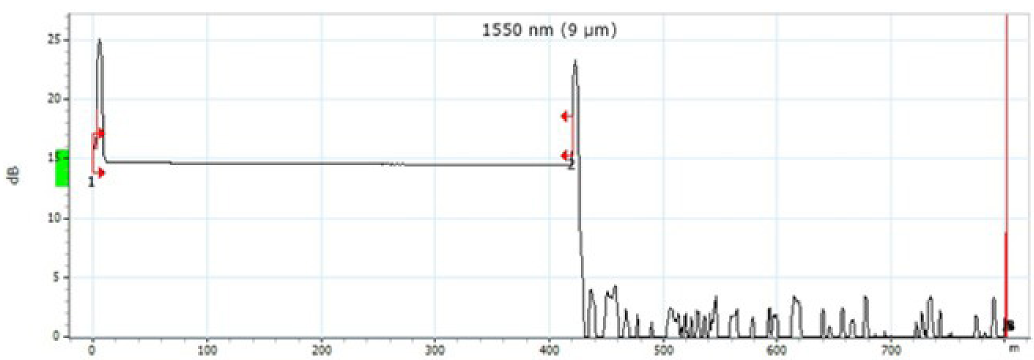
Based on the OTDR report for thread nr. 9 in the network, the measurement indicates significant signal disruption occurring at the beginning of the fibre. The diagram shows a sharp signal drop (Figure 7), which indicates a physical break in the fibre or an improperly executed connection at the panel. According to the obtained results, it is evident that the fibre is non-operational, which may result in a complete loss of communication for all devices connected through this link.

Measurement results:

- Fibre length: 1000.4 m (due to a damaged panel),
- Splice loss: 0.00 dB,
- Reflection: > -25 dB,
- Average loss: unknown.

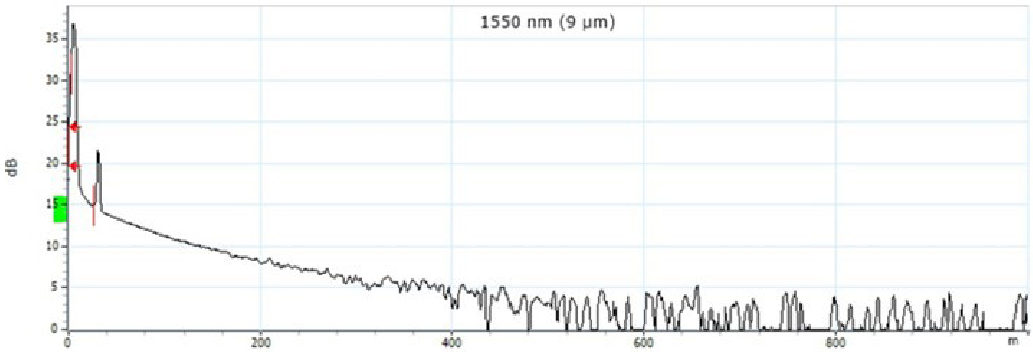
The problem with this strand originates from a break at the panel, which can be caused by various factors, including:

- Physical damage to the fibre: During installation or maintenance, the fibre may have



Slika 6 *Dijagram za nit 12 nakon korekcija*

Figure 6 *OTDR diagram for thread nr. 12 after corrections*



Slika 7 *Dijagram za nit 9 s prekidom u panelu*

Figure 7 *OTDR diagram for thread nr. 9 indicating a break at the panel*

been broken or mishandled, resulting in a signal loss transmission.

- Improperly connected or damaged connectors: leading to signal loss at that specific point.
- Contamination in the connector, such as the presence of dust, dirt, or other particles inside the connector, may lead to an interruption in signal transmission.

The fault most likely occurred due to an improper connection at the control panel or damage sustained during installation or maintenance. If the connector is not properly connected or if the fibre is broken inside the connector, the signal cannot pass smoothly through the fibre, resulting in a break.

Remedial measures to resolve the fault:

- Visual inspection: It is necessary to perform a visual inspection of the connector at the panel to determine whether there is any physical damage or improper connection.
- Connector cleaning: If contamination is detected, the connector should be cleaned using special connector cleaning tools.
- Reconnection: In a case of improper mating, the connector should be connected correctly, ensuring proper alignment of the optical fibres.
- Damaged component replacement: If the fibre or connector is found to be damaged, replace the affected component to restore proper signal transmission.

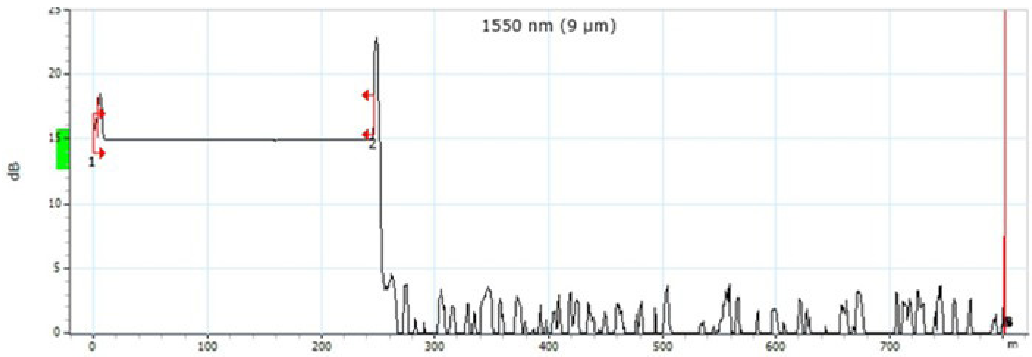
Following the implementation of corrective measures, the OTDR diagram trace is expected to show a stable signal transmission through the fibre strand without interruption or significant signal loss. The signal loss at the location of the previous fault should now be minimal and the entire system is expected to operate properly.

After replacing the damaged connector, a new measurement was performed (Figure 8) to evaluate the effectiveness of the repair work.

Measurement results after the corrections:

After the corrective measures were completed, thread nr. 9 demonstrates stable and high-quality signal transmission with minimal losses. The signal loss has been reduced to an acceptable level of 0.021 dB, and reflections are also within the standard limits. The results confirm that the fibre is in proper working condition and complies with all relevant technical standards.

- Segment length: 246.2 m,



Slika 8 *Dijagram za nit 9 nakon korekcija*

Figure 8 *Diagram for thread nr. 9 after corrections*

- Signal loss: 0.021 dB,
- Reflection: -51.2 dB.

The value of -51.2 dB is not shown on the diagram (Figure 8), as it is a back-reflected signal (reflectance).

These results indicate that the corrective measures were successfully implemented, with minimal losses and reflections within acceptable limits, ensuring high network quality.

6. ZAKLJUČAK I MOGUĆI SMJEROVI BUDUĆIH ISTRAŽIVANJA

6. CONCLUSION AND POSSIBLE WAYS OF FUTURE RESEARCH

Fibre optic networks represent the core communication infrastructure of the modern era. They ensure the transmission of large amounts of data over long distances with minimal signal loss. Advanced measurement technologies, such as the OTDR method, allow precise monitoring of the network status, identification and analysis of faults, thus ensuring high quality and reliability of services. The adoption of new technologies, such as single-mode fibres and passive optical networks (PONs), has further enhanced the capacity and stability of fibre optic systems.

In this article, problems in a fibre optic network are analysed using the OTDR method, which enables to detect and rectify major faults such as interruptions, reflections and attenuations in the network. Corrective measures, such as replacing damaged segments and optimising connections, significantly reduced signal losses and improved the stability of the network. As a result, high data transmission quality has been secured over the long term, the need for further interventions has been minimised and the overall reliability of the network has increased.

For future research, it is recommended to focus on the development of more advanced diagnostic and monitoring techniques to prevent faults in fibre optic networks. The use of new materials could further reduce signal losses and increase network capacity. Additionally, improving technician training during network installation is essential, as human factor has a significant impact on both the duration and cost of project, as well as the long-term performance of the network.

7. ZAHVALA

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