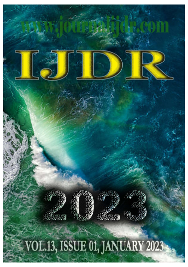
Availableonlineathttp://www.journalijdr.com

ISSN:2230-9926

IJDR

International Journal of Development Research
Vol. 13, Issue, 01, pp. 61333-61337, January, 2023
https://doi.org/10.37118/ijdr.26031.01.2023



RESEARCH ARTICLE **OPENACCESS**

ANALYSIS OF INSERTION AND RETURN LOSS MEASUREMENTS IN MECHANICAL FIBER OPTIC CONNECTORS

Allann Breno de Sales Pereira*[1], Benedito Isaias Lima Fuly[1], José Carlos Grilo Rodrigues[1] and Roberto Shigueru Nobuyasu Junior[2]

[1]Institute of Electrical and Energy Systems, Federal University of Itajubá
[2]Institute of Physics and Chemistry, Federal University of Itajubá

ARTICLEINFO

Article History:
Received 17th November, 2022
Received in revised form
21st November, 2022
Accepted 09th December, 2022
Published online 27th January, 2023

KeyWords:

Optical fibers;
Mechanical Connectorization;
Optical Losses.

****Corresponding author:***
Allann Breno de Sales Pereira,

ABSTRACT

This article analyzes fiber optic connectorizations used in data transmission. In this analysis, optical loss measurementsismade in mechanical connectors such as Insertion Loss (IL) and Return Loss (RL) based on the certification requirements for the commercialisation of telecommunications products by the National Telecommunications Agency (ANATEL) and international standards. In addition to the fundamental theoretical argument, we performed an evaluation of field-mounted connectors from ten different manufacturers sold in Brazil. These measurements were made based on two groups of tests: climatic and mechanical tests, in which the optical loss values are measured both initially and during the tests, thus depending on the requirements of the standards.

Citation:*Allann Breno de Sales Pereira, Benedito Isaias Lima Fuly, José Carlos Grilo Rodrigues and Roberto ShigueruNobuyasu Junior. 2023.* "Analysis of insertion and return loss measurements in mechanical fiber optic connectors*", International Journal of Development Research*, 13, (01), 61333-61332.

INTRODUCTION

This article analyzes the existing international standards adopted by ANATEL regarding the technical requirements for the certification of optical products sold in Brazil. As well as data transmission over metallic cables, fiber optic transmission also requires connection points at certain moments. These points can be understood as transitions between active elements of a data system or between passive elements. According to(Frenzel 2016), the term passive implies equipment that does not convert electrical-optical or optical-electrical signals, for example, amplifiers, repeaters or any other equipment based on the consumption of electrical energy. The diversity of components that make up this data transmission network is very large, and the distance of the links without signal regeneration can be in the order of centimeters, between elements of a datacenter, or even in the order of tens of kilometers, as for example 70 kilometers on submarine fiber optic cables(Carter, et al. 2009) .Through specific adapters, which ensure alignment and proximity of the branches to be joined, there is an interest in this mechanical connectorization related to energy efficiency optical power. In this article, we perform a careful analysis of the most relevant factors involved in optical signal losses in data transmission, especially at the interface between devices.

We used the equipment and physical structure of the Telecommunications Equipment Testing Laboratories (LTET) of the Federal University of Itajubá (UNIFEI). In the article, we presented the results of several tests - described in the methodology section - regarding mechanical connectors under the essential optical parameters in optical communication, Insertion Loss and Return Loss.

Fundamentals of Propagation in Optical Fibers:Currently, very small power losses are achieved in an optical fiber, reaching up to around 0.20 dB/km for wavelengths near 1.55 µm. The reduction obtained in the current versions, compared to the first experimental results, was mainly due to improvements in materials, new manufacturing technologies, choice of better wavelengths, among other factors(Ribeiro 2013).As the transmission medium is a dielectric material, there is no possibility of inducing current from external sources. As a result, the transmission is not susceptible to electromagnetic interference. In the same way, as the optical fiber does not radiate the wave that is guided inside, there is no possibility of interference in nearby systems. In Figure 1there is a typical schematic of the construction of an optical cable for high-capacity systems. There are some layers of protection inFigure 1, external to the core. At the core is where the light beam is guided, following a resulting direction parallel to the longitudinal axis.

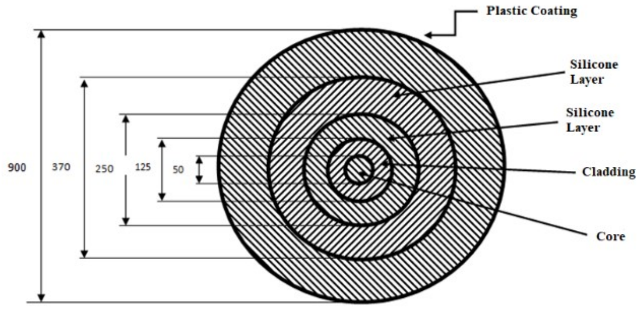
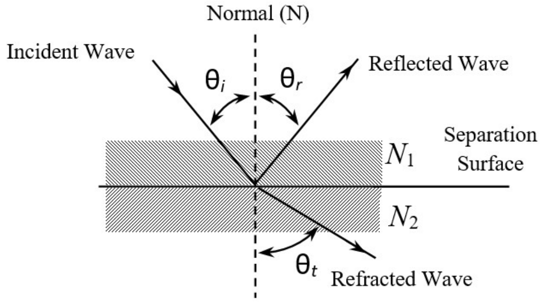


Figure 1. Cross-sectional view of a typical optical fiber. Source: The authors

Theory of fiber optic transmission

Reflection and refraction of the electromagnetic wave: The electromagnetic wave, which results from the mutual inductions between the electric and magnetic fields, was proposed by Maxwell in the mid-18th century. These fields travel through space, carrying electromagnetic energy. There are different ways to originate the electromagnetic wave. For the usual sources used in optical transmission systems, it is obtained from the transition of electrons in the energy layers of atoms. When electromagnetic waves fall on the boundary of two media, part of their energy returns to the first medium and forms the reflected wave and part of its energy is transferred to the second medium, constituting the refracted wave. This behavior is fundamental in the description of optical fiber and is schematized in Figure 2. The phenomena associated with the transfer of electromagnetic energy in the separation between two media obey the known laws of physics. One of them, which summarizes the so-called law of reflection, establishes that the propagation directions of the reflected wave and the incident wave are belong to the same plane and the reflection angle $\theta_r$is equal to the incidence θ_i,taking as a reference the normal to the interface of the two means, as in Figure 2 .



Source: The authors

Figure 2. Interface of an electromagnetic wave at the interface of two media.

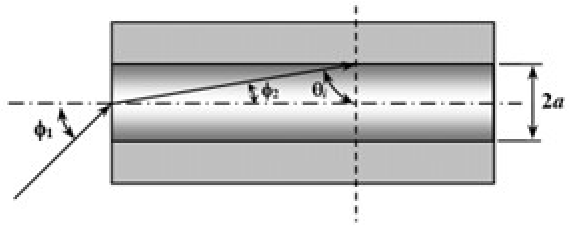
Furthermore, it was verified that there is a total reflection of the wave at the separation limit between two dielectric media for values of the angle of incidence greater than a certain critical angle. The law of refraction or Snell's law, presented in equation (1)

$$\frac{Sen\theta_i}{Sen\theta_t}=\frac{N_1}{N_2} \tag{1}$$

Equation(1) indicates the relationship between the angle of refraction and the angle of incidence. When the refractive index of medium 1 is greater than that of medium 2, there is an angle of incidence for which the refraction is at 90° to the normal. From this value, there is no more energy transfer to the second medium. Therefore, the incident wave is fully reflected. This particular value of the angle of incidence is called the critical angle θ_c. For incidence greater than the critical angle, the field in the second medium becomes evanescent, with an amplitude that exponentially decreases in the direction normal to the interface and it moves parallel to it. As the fiber structure indicates a core with a higher refractive index than the shell, the beam reflected at the interface of the two regions is successively reflected along its entire length, forming the optical beam guided in the core.

Description of the optical fiber: The optical fiber has the shape of a cylindrical structure, whose cross section is shown in Figure 1and with a longitudinal representation shown in Figure 3. In this representation, the incidence of the optical beam with an angle $\phi_1$in relation to the normal to the surface separating the entrance face and the air is shown. To ensure transmission through the core, it is necessary to have an angle of incidence at its interface with the shell as equal to or greater than the critical angle. For this, on the surface of separation between the face of the core and the air, the angle of incidence must be equal to or smaller than a certain specific value that depends on the characteristics of the fiber. The sine of this angle must be at most equal to the parameter designated as numerical fiber aperture (AN), determined by equation (2)

$$AN=\sqrt{N_1^2-N_2^2} \tag{2}$$



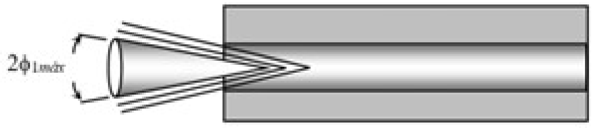
Source: The authors.

Figure 3. Longitudinal representation of the optical fiber with the parameters that define its numerical aperture

This maximum angle ($\varphi_{1m\acute{a}x}$) must be considered in all planes passing through the longitudinal axis. Therefore, it determines a pickup cone on the fiber face with opening $2\varphi_{1m\acute{a}x}$, according to equation (3)

$$2\varphi_{1m\acute{a}x}=2arcsen(AN) \tag{3}$$

and is represented inFigure 4. If the incidence at the entrance face exceeds this limit, the interface between the core and the shell the angle of incidence becomes smaller than the critical value and part of the energy is transferred to the house at each reflection. After a certain distance, there is practically no transmission of this beam by the nucleus. Therefore, the incidence directions on the inlet face that have this behavior have their energies leaked to the hull and, consequently, affect the overall fiber efficiency.



Source: The authors.

Figure 4. Capture angle at the fiber face, determined by its numerical aperture

Insertion Losses (IL): Insertion loss, also known as attenuation, is the measure of the reduction of the light signal when compared with the output power ($\boldsymbol{P_{out}}$)by the input power ($\boldsymbol{P_{in}}$), where the measurements are made in decibels (dB), according to equation(4) .

$$IL=-10Log_{10}\left(\frac{P_{out}}{P_{in}}\right) \tag{4}$$

For parallel optical surfaces, that is, at the ends of fiber optic cables, reflection losses known as Fresnel loss occur. In order to reduce these losses, a gel with a corresponding index and anti-reflective coating can be used. This gel is used in temporary joining equipment known as a bare fiber aligner, where the use of connectors is not required.

Return loss (RL): On the flat end face of the fiber, a reflected wave is produced, and this wave can influence the output power and frequency of the laser source (Neumann 2013).Several methods for preparing the final phase of the fiber are used, and, for some applications, methodologies are applied to reduce the reflection factor. However, the simplest and most efficient is to create an angle of inclination in relation to the normal axis of the fiber and sanding and polishing the fiber at this angle. This causes the reflected beam of light to be angled apart from the incident beam and minimizes power fluctuations due to interference effects in the air space between the faces, although it does not reduce the Fresnel loss. The RL (equation (5))is also given in dB and the focus of study of this work occurs at the terminals of fiber optic cables, that is, in the mechanical coupling through the use of connectors and adapters.

$$RL = -10Log_{10}\left(\frac{P_r}{P_i}\right) \tag{5}$$

The ratio between the amplitude of a reflected pulse $P_r$and that of an incident pulse $P_i$can be characterized by a reflection coefficient due to the reflection of pulses at the termination of a confining medium(Ibbotson 1999). The proportion of pulse energy reflected back to any point is the return loss. If the fiber ends are cut and polished with an angle not equal to the connector end face, additional losses can occur, producing failures and increased noise levels in the transmitted signal (Al-Azzawi 2006).

Mechanical connectorization: The performance of an optical system is greatly influenced by optical connection devices, including connectors. They are devices used to connect a fiber optic cable to another fiber optic device such as detectors, optical amplifiers, optical light power meters, or even with other fiber cable in an easily and reliably way (Al-Azzawi 2006). Although there are several types of mechanical splices, currently the most used is the fusion splice. They have lower losses, proper dimensions, mechanical stability and immunity to environmental effects when compared to connectors. However, the variety of applications made the telecommunications industry to develop several techniques in order to improve its performance for different applications. Most connectors are constructed from a ferrule, which is responsible for securing the final portion of the fiber, providing alignment; an Epoxy material used to secure the fiber cable terminal to the connector body; a connector body, and a strain relief device made of plastic or rubber for joining the connector body and the fiber cable.According to(Lizuka 2002), the biggest challenge of fiber optic connector design is to design connectors that can be mass produced despite strict machining tolerances. Regarding(Neumann 2013), designers and connector manufacturers seek the best precision in the alignment of the cores, so that two identical fibers, when joined without geometric misalignment, do not present power loss. However, in reality, there are two types of losses, intrinsic and extrinsic, as the fibers are slightly different. The first is due to amplitude distribution mismatch, and the second is due to a misalignment caused by the small size of the core. Therefore, extrinsic losses can be analyzed through three misalignment criteria: the transverse displacement (of the axes of the core) (6), the longitudinal displacement (length gap)(7) and the inclination of the polishes (8), based on equations (6),(7) e (8).

$$\eta = \exp\left[-\left(\frac{S}{wG}\right)^2\right] \tag{6}$$

where S is equal to the transverse displacement of the fiber axes, and WG is equal to Spot Size (radius of the fundamental mode field), and

$$\eta = \frac{1}{1 + \left(\frac{0,5Z_w}{z_R}\right)^2} \tag{7}$$

where $Z_w$is the length of the gap between the fiber end faces, and $Z_R$is a variable dependent on the refractive index of air, spot size and light wavelength,

$$\eta = \exp\left[-\left(\frac{\theta}{\theta_d}\right)^2\right] \tag{8}$$

where $\theta$is the inclination angle between the input and the output fiber axes, and $\theta_d$is the divergence angle, which is also dependent on the same variables as Z_R.On the other hand, according to(Al-Azzawi 2006) the signal attenuation is caused by several factors in addition to those described above, such as overlapping of the fiber cables core, numerical aperture, polishing of the connector end and reflections at the interface/junction of the fiber cable. Analogously to (Neumann 2013), it also describes the losses in the unions, through the equations below, given in dB. Equation(9)describes the loss given by the diameter mismatchP_{dia},where$dia_t$and dia_rcorrespond to the transmission and reception cable diameters, respectively.

$$P_{dia} = 10Log_{10}\left(\frac{dia_t^2 - dia_r^2}{dia_t^2}\right) \tag{9}$$

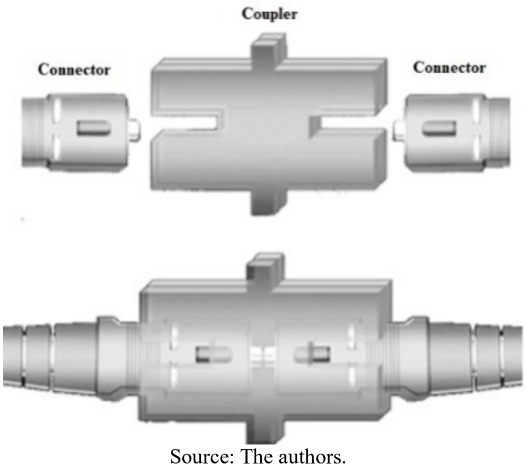
Equation(10) describes the loss due to numerical aperture mismatchP_{NA}, where$NA_r$is the numerical aperture of the transmission cable andNA_t corresponds to the numerical aperture of the reception cable.

$$P_{NA} = 10Log_{10}\left(\frac{NA_r}{NA_t}\right)^2 \tag{10}$$

Finally, equation(11) describes the separation lossP_{sep} which described the loss due to longitudinal spacing (air gap between the optical fiber interfaces).

$$P_{sep} = 10Log_{10}\left(\frac{\frac{d}{2}}{\frac{d}{2} + S\tan(\arcsin)\frac{NA}{n_o}}\right) \tag{11}$$

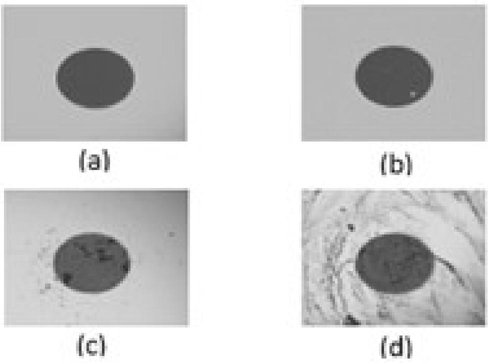
Therefore, another relevant and critical issue in the analysis of connector performance are the mechanical characteristics such as durability, resistance to environmental weathering and compatibility. These issues can influence the appearance of dirt, tension of the fiber optic cable, core misalignment due to thermal expansion, and incompatibilities by the type of connector, thus causing additional optical losses. In Figure , two SC-type connectors without an angle can be seen in the final interface and an adapter, necessary for the alignment of the optical fiber, before and after being coupled.



Source: The authors.

Figure 5. Mechanical connection of two fiber optic connectors using an adapter.

Another relevant issue in fiber handling and fiber terminal connectorization for good connectorization efficiency is cleaning, followed by microscopic inspection. Figure shows examples of fiber optic end face conditions where a 400x magnification microscope was used where only in (a) the connector is in proper working condition. For surface visualization, a proper software is required, which, in addition to showing the image in real time, analyzes the quality of the connector's final surface, based on the IEC 61300-3-35 standard, and thus determines if the connector is in operating conditions. In (a) we present a surface without the presence of debris and suitable for use; (b) is apparently the same as (a), but there is a small gap in the coating, and therefore it is not suitable; in (c) there is the presence of typical small debris and optical loss enhancers. Finally, in (d) there is debris typically caused by mistaken cleaning with excessive use of some solvent, such as isopropyl alcohol.



Source: LTET-Unifei Laboratory Archive

Figure 6. Examples of different conditions of the connector end face

According to (N. e H. 1978), there will always be a residual transverse displacement of the central axis in relation to the bolt axis. Therefore, the insertion loss of a connector changes periodically, when successive connectorizations occur in the devices. Furthermore, the radial displacement must be less than 0.15 times the radial field extension of the fundamental fiber mode field, known as Spot Size, to obtain insertion losses less than 0.1 dB.

METHODOLOGY

Low insertion and return optical losses are expected for optical connectors. However, some other characteristics are desirable in connectors such as, for example, easy installation and use, repeatability when reconnected multiple times, compatibility with the environment when necessary to be waterproof and resistant to temperature variations, in addition to mechanical strength and durability, so that it has a life span compatible with different applications. Therefore, this article presents a synthesis of the results obtained in the process of certification of optical connectors in Brazil under ANATEL's technical requirements. This agency makes available on its official website some lists of requirements (ANATEL 2021), which periodically updated and divided into categories for the various telecommunications products sold in the country. The tests carried out in this article were carried out according to the update of 08/20/2021, and Table 1below shows the list of tests performed.

Table 1. List of tests

	Climatic	Mechanical
R	Dry heat Moisture Thermal cycle	Bending, Twisting, Axial and Angular Retention, Axial Pull, Stability, Impact, Durability and Vibration
S	Dry heat Moisture Thermal cycle	Stability, Torsion, Impact, Durability, Vibration
W	Thermal aging Moisture Thermal cycle	Bending, Twisting, Immersion in Water, Axial Pull, Stability, Impact, Durability, Vibration

The first column of Table 1 was divided into R, S and W, respectively, Fiber Optic Connector, Field Mounted Fiber Optic Connector for compact cables and Fiber Optic Reinforced Connector. These are the three types of connectors sold in Brazil. Figure 5below is an example of each existing connector type.We tested a total of ten connectors from different manufacturers in order to analyze the results and they were divided into three Groups I, II, and III. Group I is composed of all twenty samples from each manufacturer, Group II is composed of samples from 1 to 10, and Group III is composed of samples from 11 to 20 of Group I.

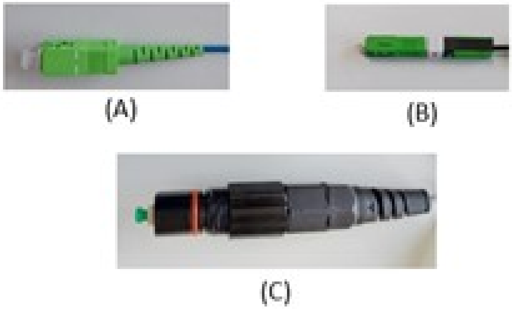


Figure 5. The three types of connectors tested. Source: LTET-Unifei archive

RESULTS

Previously, before the application of the tests, we carried out the initial measurement of IL and RL. Measurements were performed for Group I of each type S connector (see Table 1) from all manufacturers, arranged in alphabetical order from A to J, as can be seen in the graph in Figure 6, therefore, we obtained an average initial IL value of 0.20 dB, a Maximum IL value of 0.32 dB and an average minimum RL of 54.6 dB.

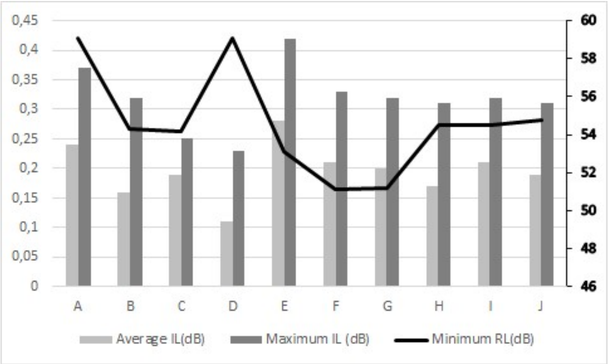


Figure 6. Initial IL and RL Measurements

After the initial measurements, Groups II and III were used for climatic tests and mechanical tests, respectively. The graph in Figure shows the results of the tests of Group II, obtaining a maximum variation of IL average of 0.15 dB, and a minimum RL average of 55.3 dB.

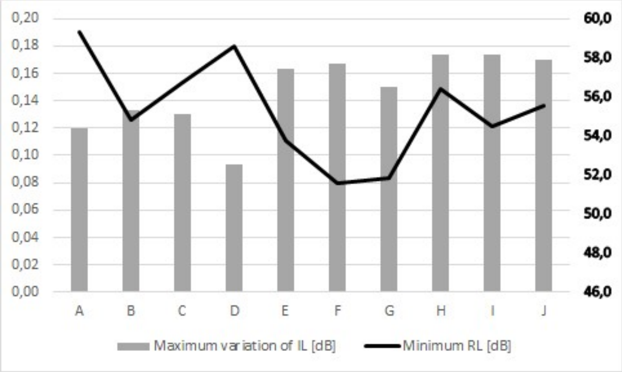


Figure 9. Result of Group II tests

The graph presented in
Figure 7 shows the results of the tests of Group III, obtaining a maximum variation of IL average of 0.14 dB, and minimum RL average of 55.2 dB.

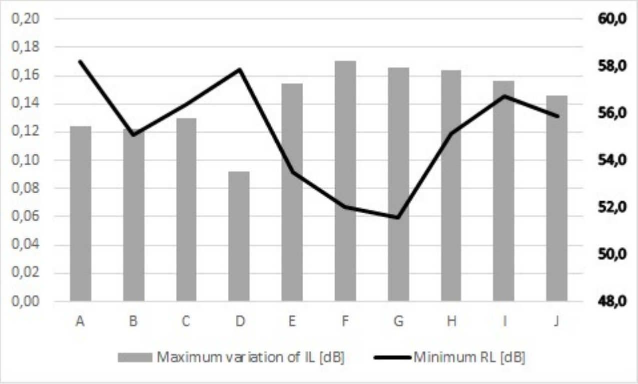


Figure 7. Result of Group III tests

A greater variation of IL was observed in the trials of Group II (climatic) than in those of group III (mechanical). However, a lower mean minimum RL was observed in the Group III trials when compared to Group II.

CONCLUSIONS AND FUTURE WORK

In this analysis, it was possible to observe some characteristics in the tests of IL and RL in mechanical connectorizations in comparison to a sample of two hundred connectors from ten different manufacturers. The first observable aspect was the maintenance of efficiency after the tests, which can be seen by the graphs in Figure and in

Figure 7when compared with the graph in Figure 6. Hence, for connectors with better IL and RL measurements, they tend to present less IL variation and to maintain a higher minimum RL on average compared to the initial measurements of the various samples.In addition, it was observed that after the various tests performed, the performance of the connectors, in terms of RL, was not impaired when compared to the initial measurement of RL, because the average of the minimum RL was high, that is, it approached the ideal values. Furthermore, the division into two groups for the tests, climatic and mechanical, does not converge to the decrease in the efficiency of the connectors for testing in a specific group, because just as they present smaller changes in the variation of IL for a group, they also present less minimum RL average.

Finally, for further research, variations in test parameters could be analyzed, such as temperature, humidity, cycle duration and total for climatic tests, and loads, repetitions and vibration test cycles for mechanical tests, for example. This can lead to a better requirement of the criteria adopted by the competent national body to inspect the products marketed in Brazil.

ACKNOWLEDGMENT

The authors would like to thank the Coordination for the Improvement of Higher Education Personnel (CAPES), The Brazilian National Council for Scientific and Technological Development (CNPq) and Minas Gerais State Agency for Research and Development (FAPEMIG) for their support and support in carrying out this research.

REFERENCES

Al-Azzawi, Abdul. Photonics Principles and Practices. Boca Raton: CRC Press, 2006.

ANATEL. RequisitosTécnicos para Certificação. 12 de 04 de 2021. https://www.gov.br/anatel/pt-br/assuntos/noticias/anatel-atualiza-o-plano-estrutural-de-redes-de-telecomunicacoes (acessoem 07 de 05 de 2019).

Carter, Lionel, et al. Submarine Cables and the Oceans – Connecting the World. Cambridge: The Lavenham Press, 2009.

Frenzel, Louis E. Jr. PRINCIPLES OF ELECTRONIC COMMUNICATION SYSTEMS. New York: McGraw-Hill Education, 2016.

Ibbotson, Lem. The Fundamentals of Signal Transmission In Line, Waveguide, fibre and free space. London: Elsevier, 1999.

Lizuka, Keigo. Elements of Photonics. New York: Wiley-Interscience, 2002.

N., Shimizu, e Tsuchiya H. “Single-mode Fiber Connectors.” Electron, 1978: 611-613.

Neumann, Ernst-Georg. Single-mode Fibers Fundamentals. New York: Springer, 2013.

Ribeiro, José Antônio Justino. Comunicaçõesópticas. São Paulo: EditoraÉtica, 2013.

****