Optical fibre loss metrology

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In this paper we report some experimental results concerning the measurement of the propagation losses, optical insertion and return losses of optical fibers using nondestructive methods.
The attenuation of the optical power corresponding to an optical signal launched into the fiber was measured at λ=0.63 μm with a bandwidth $\Delta\lambda$=0.03 μm using the Optical Transmission Method. Also, using the Two Point Method and an Optical Time Domain Reflectometer we measured the attenuation of a single optical fibre having 28964 m for a 1 μs laser pulse having λ=1.55 μm. Based on an original set-up the optical insertion and return losses of optical fibers were measured for λ=1.55 μm. In the case of the propagation losses for λ=1.55 μm we performed an error calculation.
The obtained results can be used in optical telecommunications, for the design of optical fiber sensors and other optoelectronic integrated circuits.

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1. Introduction

Over the last years many theoretical and experimental papers concerning the characterization of the optical fibers using nondestructive methods were reported due to their use in optical telecommunications, for the fabrication of optical sensors and other optoelectronic integrated circuits [1]-[5]. The propagation, insertion and return losses are very important parameters which characterize the optical fibers.

The optical transmission method used for the of the optical attenuation measurement is one of the most utilised to determine the losses of the optical fibers. Based on the theoretical model presented in ref. [4] we evaluated the attenuation of the optical power fiber at λ=0.63 μm with a bandwidth $\Delta\lambda$=0.03 μm. Using the Two Point Method and an Optical Time Domain Reflectometer we measured the attenuation of a single optical fibre having 28964 m for a 1 μs laser pulse having λ=1.55 μm. Also, using an original set-up we determined the optical insertion and return losses of optical fibers for λ=1.55 μm which is wide used in optical telecommunications.

The paper is organized as follows: in Sec. 2 we present some experimental results concerning the determination of the optical attenuation, optical insertion and return losses of optical fibers while in Section 3 in the case of the propagation losses for λ =1.55 μ m we performed an error calculation. In Sect. 4 we outlined the conclusions of this paper.

2. Experimental results

The propagation losses of an optical guide are described by the attenuation α, defined by the relation [1,5]:

$$\alpha = \frac{10\log\left(\frac{P_0}{P_1}\right)}{z_1 - z_0} \text{ (dB/cm)} \tag{1}$$

where P_0 and P_1 represent the optical powers corresponding to the coordinates z_0 and z_1, respectively of the guide.

The attenuation of the optical signal power, α_p transmitted through an optical fiber is given by:

$$\alpha_p = -10\log\frac{P_0}{P_i} \tag{2}$$

where P_i and P_0 and are the incident and respectively emergent optical powers.

The experimental set-up used for the measurement of the attenuation of the optical power correspopnding to an optical signal launched into the fiber was measured using the optical transmission method is presented in Fig. 1 [5].

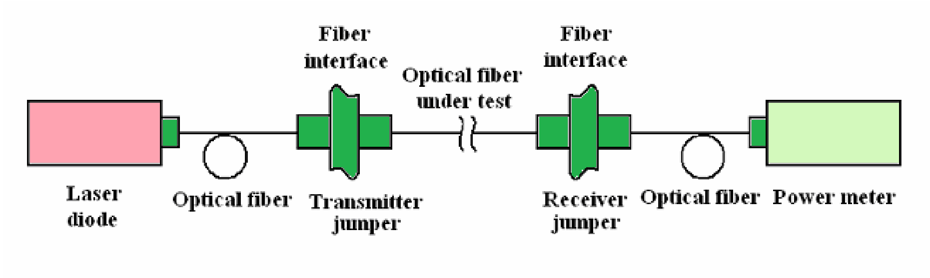

Fig. 1. The experimental set-up used for the measurement of the attenuation of the optical power.

The optical signal emitted by a laser diode having the wavelength λ=0.650 μm inside a bandwidth $\Delta\lambda$=30 nm and the power in the range $10 \div 100$ mW is launched into the optical fiber under test and after that measured by an optical power meter as receiver. The experimental set-up presented above permits the inversion of the optical source and the receiver then the measurement of the attenuation of the optical power in both senses of the optical power.

Using the experimental set-up described in Fig. 1 we measured the attenuation of the optical fibre for several emergent optical powers The results presented in Table 1 are are in good agreement with others obtained by several authors [1]. Also, performing the measurement of the attenuation of the optical power for several wavelengths it is possible to determine the spectral attenuation.

Table 1.

α_p (dB)	0	0,2	0,4	0,6	1	3	6	20
P_0 / P	1	0.955	0.912	0.891	0.794	0.5	0.251	0.01

Using the Two Point Method and an Optical Time Domain Reflectometer (Agilent) we measured the attenuation of a single optical fibre having 28964 m for a 1 μs laser pulse having λ=1.55 μm obtaining 0.2 dB/km and a loss of 0.52. The attenuation is defined as the slope of the straight line and the abscissa (distance) (Fig. 2).

In Fig. 3 we present the original experimental set-up used for the measurement of optical insertion and return losses of optical fibers for λ=1.55 μm. We used an erbium fiber laser as high power source (5 W), a power meter for return loss (RL) measurement, a power meter for source monitoring ΔP_0, a power meter (Anritsu) $\Delta IL_1 + \Delta IL_2$ for insertion loss measurement, several splices and couplers. The high power level P_{in} launched into the DUT (Device under Test)-input-connector was measured using a modified integrated sphere (UDT 2500) and an appropriate power meter (UDT 111). The low power measurements were performed with a fibre optic test set photodyne 2286XQ.

The optical connectors were cleaned prior to each mating. The high powers can only be attained with absolutely clean connectors. Any contamination of the fibre core end face might lead to the destruction of the connector. The insertion loss of the test assamblies turned out to be very stable. At any rate, the return loss exceeded 65 dB, which was the range limit of the measurement set-up.

The insertion loss, IL is defined as the ratio of the power out of a device, P_{out} to the power into the device P_{in} for one wavelength, input state of polarization, and typically for the fundamental mode of the fibre [6], [7]:

$$IL = -10\log(P_{out} / P_{in}) \tag{3}$$

A basic insertion loss measurement involves a source, a DUT and a detector Two measurements are required, one without the DUT for P_{in} and one with the DUT for P_{out}. The former measurement is referred to as the reference measurement. In the reference measurement, there may be some loss at the point of coupling between the source and detector (or input and output fiber). For the DUT measurement, there are two sources of excess loss: the coupling between the source (or input fiber) and DUT and between the DUT and detector (or output fiber). Variations in each of these excess losses contribute to the overall uncertainty in the insertion loss measurement for the DUT. The repeatability of coupling losses to the DUT can dominate the uncertainty associated with insertion loss measurements. Slow power fluctuations of the source are tolerated by using an optical tap (i. e. a directional coupler with a small coupling ratio and an additional detector so that P_{in} and P_{out} are measured relative to the source power, at the time of the measurement. When the insertion loss is large, causing the received power to be low detector noise contributes to measurement uncertainty.

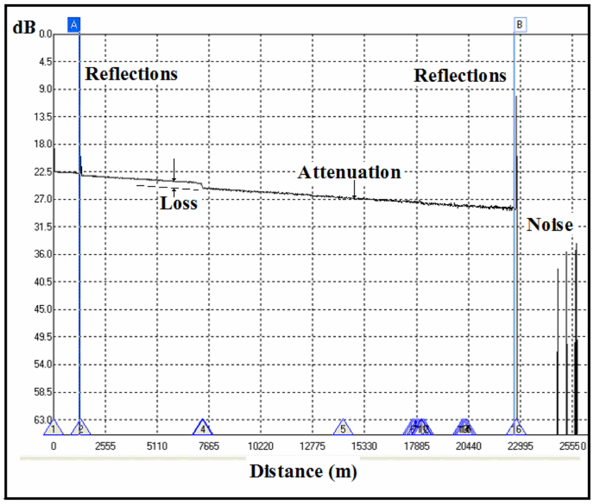

Fig. 2. The attenuation vs the length of the optical fibre.

Concerning the return reflection) loss a remedy is to minimize reflections by using fusion splices where possible, angled connectors, and isolators between reflections that cannot be eliminated or substantially reduced. Fusion splices can be optimized to have losses <0.1 dB. To reduce the impact of reflections, one can also broaden the source linewidth.

When the insertion loss is large, causing the received power to be low, detector noise contributes to measurement uncertainty. For a partially polarized source, any variation of the state of polarization over time into an element with power dependent losses (PDL) introduces power fluctuations. To minimize these effects, taps and other components with minimum PDL are used. Finally, highly coherent sources combined with discrete reflections, for example from connectors, contribute interference noise. A remedy is to minimize reflections by using fusion splices where possible, angled connectors, and isolators between reflections that cannot be eliminated or substantially reduced. Fusion splices can be optimized to have losses <0.1 dB and unmeasurably small PDL. To reduce the impact of reflections, one can also broaden the source linewidth.

Table 2.

Nr.	Assembly FLASH chain	IL (dB) before	IL (dB) after
1.	27 s+32 s	0.12	0.11
2.	31 s+21 s	0.20	0.18
3.	22 s+27 L	0.04	0.04
4.	26 L+25 L	0.04	0.06
5.	24 L+25 s	0.15	0.13
6.	26 s+10 s	0.02	0.03
7.	3 s+56 s	0.10	0.07
8.	55 s+19 L	0.03	0.06
sum		0.70	0.68

We tested several DUT: jumpers: 24 × LSH HRL lenght 4 m (L), 26 × LSH HRL short 1 m (s), 14 × Lx.5 HRL lenght 4 m (L), 16 × Lx.5 HRL short 1 m (s), 12 × Fibergate HRL (FGAT) lenght 4 m (L), 56 × Fibergate HRL (FGAT) short 1 m (L) and adapters, respectively: 30 × FLSH, 30 × Lx.5 and 20 × Fibergate for both high and low laser powers.

For P_{in} =2.2 W several experimental results in the case of FLASH and Lx.5 chains, respectively measured before and after the test are presented in tables 2 and 3.

The IL diagram shows a small modulation of max. $\pm$0.05 dB that is correlated to the cycle of day (bright) and night (dark) and thus definitely not caused by the DUTs. Hence, the comparison of the IL measured before and after the test also showed no degradation. Concerning the IL stability both channels revealed a small correlated modulation that might cause a measurement error of max $\pm$ 0.03 dB.

Table 3.

Nr.	Assembly Lx.5 chain	IL (dB) before	IL (dB) after
1.	13 L+31 s	0.10	0.10
2.	20 s+8 s	0.05	0.05
3.	13 s+19 s	0.10	0.09
4.	4 s+26 L	0.08	0.08
5.	6 L+16 L	0.02	0.03
6.	12 L+30 L	0.05	0.05
7.	28 s+12 s	0.10	0.11
8.	9 s+22 L	0.08	0.08
sum		0.58	0.59

In the case of a 2.2 W optical power of the laser radiation the IL and RL long term reliability of the FLASH and Lx.5 chains, respectively are presented in Figs 4 and 5.

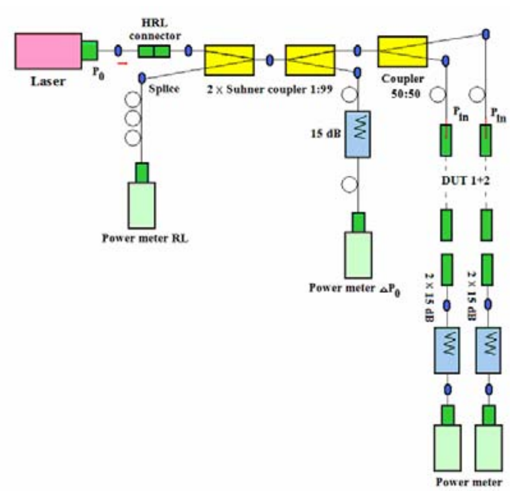

Fig. 3. The experimental set-up used for the measurement of optical insertion and return losses of optical fibers for λ =1.55 μm.

The RL exceeded both the measurement confidence level of 50 dB during test and the measurement limit of 65 dB before and after the test. In the case of RL stability the RL noise was both small and stable enough to allow RL measurements up to 50 dB with errors of max. ± 2 dB.

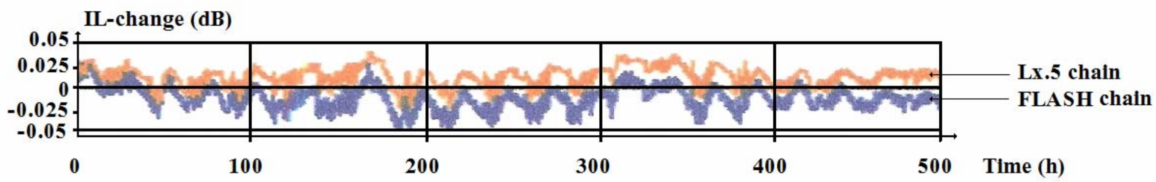

Fig. 4. IL changes vs time for FLASH and Lx.5 chains, respectively.

All connector types passed the long term reliability test without any performance degradation and damage.

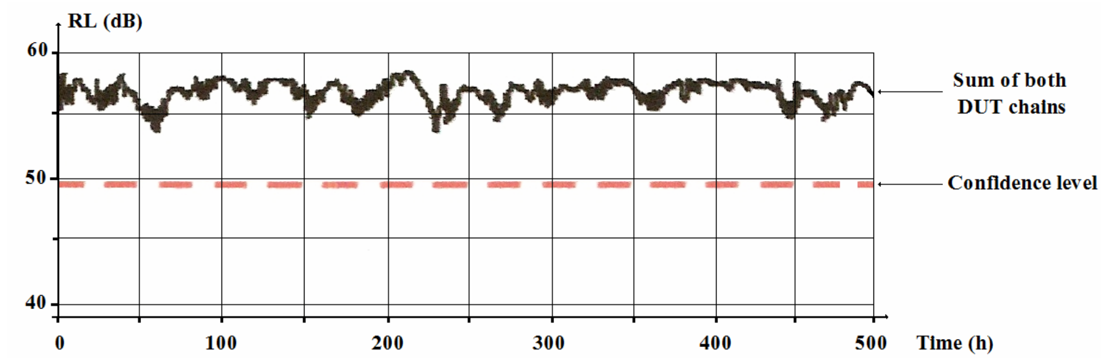

Fig. 5. RL vs time for FLASH and Lx.5 chains, respectively.

3. Error calculation

Taking into account Eq. (1) by differentiating one obtained:

$$d\alpha = 4{,}34\,\frac{1}{P_0(z_1 - z_0)^3}\,dP_0 + 4{,}34\,\frac{1}{P_1(z_1 - z_0)^3}\,dP_1 + 4{,}34\,\frac{\ln\frac{P_0}{P_1}}{(z_1 - z_0)^2}\,dz_1 . \qquad (4)$$

In Eq. (4) the coefficients of the differentials, $C_i = \frac{\partial\alpha}{\partial x_i}$ represent the influence (sensivity) coefficients. By approximating the differentials as standard deviations one obtained the compound square in the form [9]:

$$u_c = \sqrt{\left[\frac{4.34}{P_0(z_1 - z_0)^3}\right]^2 \cdot u_c^2(P_0) + \left[\frac{4.34}{P_1(z_1 - z_0)^3}\right]^2 \cdot u_c^2(P_1) + \left[\frac{4.34}{(z_1 - z_0)^2}\right]^2 \cdot u_c^2(z_1) + \left(\frac{4.34}{z_1 - z_0}\right)^2 \cdot u_c^2(z_1)}$$

In the case of two optical fibres having 4 m and 8 m length, respectively and a laser radiation having λ =*1.55* μm, taking into account a normal (Gaussian) distribution the experimental satndard deviation for 5 determinations (n=5)

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(P_i - \overline{P_0}\right)^2}{n-1}} \qquad (5)$$

we evaluated the uncertainty budget (Table 4). The error for the measurement of the fiber length was 1,0 % . The compound standard uncertainty for the measured powers uncertainty P_0 and P_1 is about 0,048 W. Then, for the attenuation coefficient one obtained the value: $\alpha = (\ 0{,}200\ \pm 0{,}014\ )$ dB/m

Table 4.

Parameter	Estimated value	Distribution	Standard uncertainty u(x_i)	Influence coefficients $C_i = \frac{\partial\alpha}{\partial x_i}$	Contribution to standard uncertainty $u_c^2(x_i)\cdot\left(\frac{\partial\alpha}{\partial x_i}\right)^2$
Power P_0 [w]	2.4 w	Normal	0.048 w	0.0283	184.5×10^{-8}
Power P_1 [w]	2.0 w	Normal	0.048 w	0.0339	264.7×10^{-8}
Length z_1 [m]	4.00 m	Rectangular	0.023 m	0.2713	3893.6×10^{-8}
Length z_1 [m]	8.00 m	Rectangular	0.046 m	0.2713	15574.5×10^{-8}
$u_c(\alpha)$					0,014 dB/m

4. Conclusions

Based on the Optical Transmission Method in this paper we report some experimental results concerning the measurement of the attenuation of the optical power corresponding to an optical signal emitted by a laser diode having the wavelength λ =0.63 μ m with a bandwidth $\Delta\lambda$ =0.03 μm launched into an optical fiber. Using the Two Point Method and an Optical Time Domain Reflectometer we measured the attenuation of a single optical fibre having 28964 m for a 1 μs laser pulse having λ =1.55 μ m. Also, using an original set-up we determined the optical insertion and return losses of optical fibers for λ =1.55 μ m which is wide used in optical telecommunications. In the case of the propagation losses for λ =1.55 μm we performed an error calculation.

The obtained results are in good agreement with other published in the literature (i. e. [2], [8]) and can be used in optical telecommunications, for the design of optical fiber sensors and other complex optoelectronic integrated circuits.

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