

Traceability of Measurements on Optical Fibres and Calibration of Optical Reflectometers in Time Domain

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Abstract – In this paper we present the procedure to calibrate the Optical Time Domain Reflectometer, one of the most used instruments in the measurement of optical fibers. At the same time, since the procedure of calibration imposes the study and the development of a sample/artefact called recirculating delay line, we have studied and described its realization and calibration.

I. Introduction

The optical fiber settlement has in Italy a quite tormented story. In 1995 *Telecom* (National Telecommunications Group) had announced with large emphasis the birth of *Socrates* project, consisting in introducing the optical technology in the houses and in life of the italians. Investments perhaps exaggerated for the real needs of that moment (some figures talk about 13.000 billion of the old lira) were followed by a “dark” period for the optic fibers, accomplice also the development of wide band systems on the same telephone cable (xDSL, *X Digital Subscriber Loop*). The increasing request of wide band, and internet generally, contributed to the raising of these optic devices and to the birth of new technologies, revaluing also the thousands of kilometers of fiber already settled; during this period *Telecom* realized the DWDM net (Dense Wavelength Division Multiplexing) on DSF (Dispersion-shifted Fiber) or FTTH (Fiber To The Home) techniques (with the birth of the standard Gigabit Ethernet on optic fiber). The development of these new technologies also have contributed to develop new instruments devoted to the analysis of these devices, i.e. optical spectrum analyzers (DARES) for the analysis of the sources and amplifiers in optical fiber technology, optical power meters for the evaluation of the system losses, optical time domain reflectometer (OTDR) for the survey of losses located along the fiber or the detection of possible breaks. Many of them are “field-instruments” and therefore subject to a quick degradation of their performances in term of accuracy, so periodic calibration of these instruments should be done by European accreditation laboratories or, in Italy, by a SIT center (Service of Calibration in Italy, law n° 273, August,11,1991) as imposed from the European standards on Quality (ISO 9000:2000).

II. OTDR Calibration

The second edition of IEC standard 61746:2001, regarding the calibration of OTDR, is, at present, in phase of approval. Its application is limited only to some leading national institutes (NPL in Great Britain and METAS in Switzerland) and some European laboratories (OTC and Anritsu in Great Britain). From the analysis of the proposed methods, we have preferred to apply only passive methods, that do not need the use of sources or other special instruments and also because they are nearer to the real operating conditions. In particular we realize the recirculating delay line - RDL - a passive device which doesn't need frequent calibrations and check controls to verify its

correct behaviour. Evaluating the uncertainty involved in RDL calibration procedure is, generally, a difficult task since we have to study the limited modulation capacity of the source, together with the presence of troubles to the connectors especially those linked to the output of the RDL loop. In Figure 1 are shown all the instruments involved in our tests.

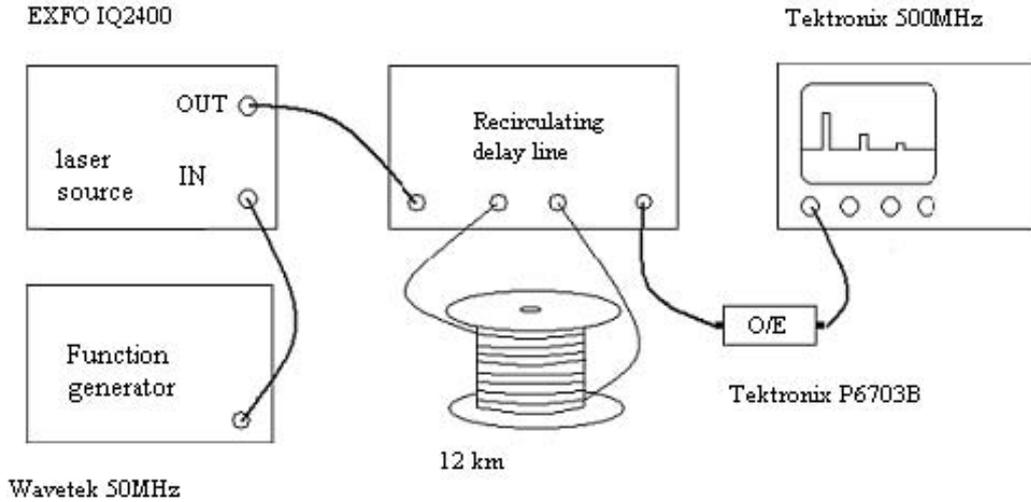


Figure 1. Measurement apparatus

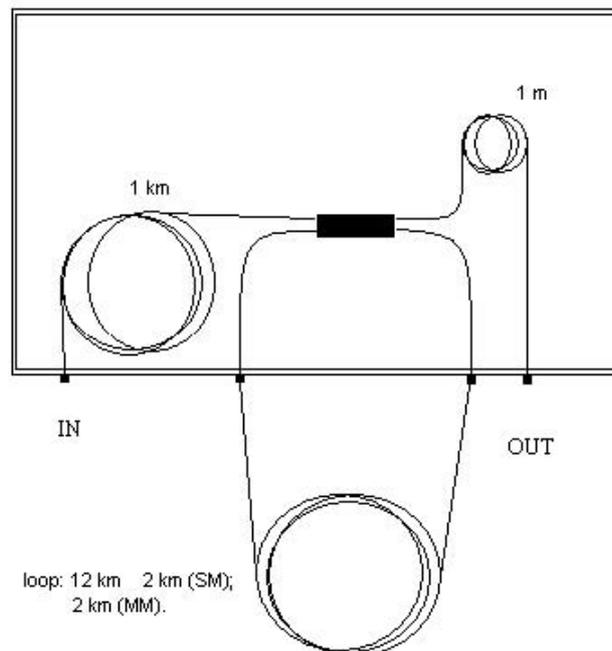


Figure 2. Recirculating delay line

The RDL that we have used for the calibration of the OTDR is a modified version with respect to the standard. In fact it constitutes of about 1 km of fiber before the coupler and a reflective ending to the RDL output. In this case we will have a 1 km shifted track with reflection peaks superimposed to the only backscattering contribution. The diagram of the RDL is composed by the following devices:

- 1 km of input fiber;
- *Lightech*© directional coupler with coupling factor of 50% (3 dB), with losses < 0.1dB, PDL of ± 0.1 dB;
- 1 meter of fiber left to allow, in a second moment, the integration of the external loop fiber in a metallic box;
- a metallic box with 4 FC/PC connectors.

We realized two versions, in which the fibers will be respectively single mode (SM) or multi mode (MM). (See Figure 2). The loop fiber is connected externally, to choose different lengths of fiber for the test. This means to be able to choose the distance ranges in which the OTDR will be calibrated. All the connectors are FC/PC connectors. During the OTDR calibration the output of the recirculating delay line will be closed with a reflective ending or connected to an O/E converter during the measurement that characterize the time of flight. The loop fiber is arranged with two fibers, calibrated from the METAS swiss laboratory. In Table I we report the time of flight of the optical pulses travelling the fiber under test. The specific length, L , is found assuming a group index equal to 1.46 and evaluating the uncertainty associated to this measurement. It is important to underline that we will use all the 12 km fiber because this allows to cover all the OTDR ranges of measure.

SM FIBER (≈ 12 km)	$\lambda = 1310$ nm	u	$\lambda = 1551$ nm	u
Time of flight	62786.6 ns	1.6 ns	62758.5 ns	1.5 ns
Length L	12892.43 m	0.32 m	12886.65 m	0.31 m

Table I 12km fiber calibrated by METAS

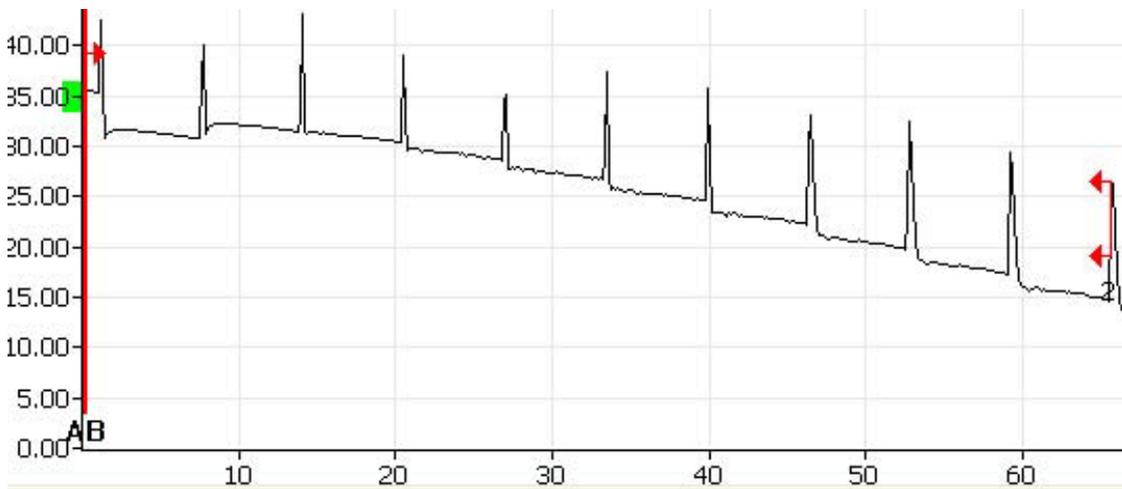


Figure 3. RDL trace with 12 km optical fiber

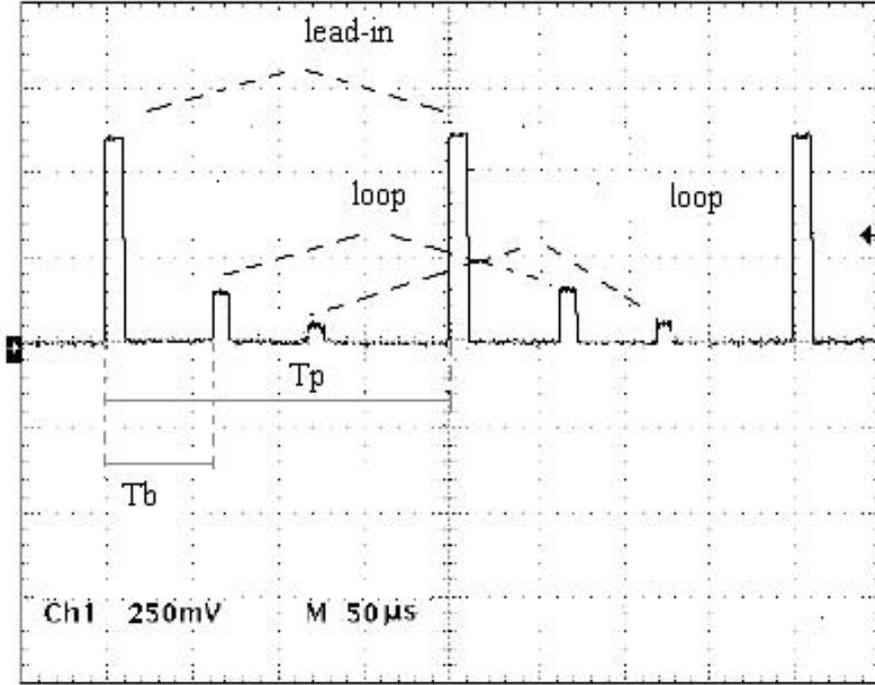


Figure 4. Exemple of recirculating delay line output

In Figure 3 it is possible to observe the step track related to the backscattered signal with superimposed the peaks related to the reflective ending of the RDL. If we recall [19] the expression of the position model visualized from an OTDR, neglecting the sampling error we have:

$$L_{OTDR} = S_L L_{ref} + \Delta L_0$$

where:

- L_{ref} is the (true) reference position of the sample (i.e. a known event)
- S_L is the scale factor (ideally equal to 1) and
- ΔL_0 is the position offset (ideally equal to 1)

We have to calibrate the lead-in fiber (we only know the approximative length of 1 km of the input fiber) and the loop fiber (that includes, besides the external one, the coupler length and the exceeding fiber). With the first one we will compute the position offset while with the second one we will compute the OTDR scale factor. To have an idea of the times that we will go to measure, we can compute them using, for the time of lead-in, the length of the input fiber (about 1 km) and for the loop time the length of the output fiber (about 12.8 km); in this case we obtain:

$$t_{lead-in} \approx \frac{L_{input} \cdot n}{c} = \frac{1000 \cdot 1.46}{3 \cdot 10^8} \approx 4.9 \mu s$$

$$t_{loop} \approx \frac{L_{external} \cdot n}{c} = \frac{12800 \cdot 1.46}{3 \cdot 10^8} \approx 62.3 \mu s$$

We should drive the laser with a pulse duration that permit to distinguish the pulses generated from the recirculating delay line. We have planned a TTL shape wave (0-5 V). This TTL signal is

modulated (with rise time of about 20 ns) with a frequency of 5 kHz and a duty cycle of 5%. We obtain at the output a first pulse with amplitude of about 800 mV (and about 150 ns of rise time), a second pulse of about 170 mV and a third one of 40 mV; all the other were covered from the noise (See Figure 4). The rise time of the signal present to the output of the Optical/Electrical (O/E) converter is strongly determined from the features of the source (the datasheet of the O/E converter gives a rise time of 350 ps). In any case, for these frequencies, the fiber has not any problem of bandwidth limitation.

III. CONCLUSIONS

In this paper we follow the purpose to produce a procedure to calibrate the OTDR, one of the most used instruments in the measurement of optical fibers (there are four or five laboratories in Europe that can perform such a calibration). At the same time, since the procedure of calibration imposes the study and the development of a sample/artefact - the so called recirculating delay line - we have studied and described its realization and calibration.

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