THE ANALYSIS OF OPTICAL FIBER LINKS

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Abstract. Telecommunication industry is based on the optic fibre technology used as a transmitter, providing very high transmission speeds (40Gbps). For the maintenance of the optic fibre network there are various instruments for testing and measuring, having diversified capabilities. The paper aims to analyse some events that occurred in optic fibres.

Keywords: FOTS, FO, reflective event, non-reflective event, loss, dispersion, refraction index.

1. INTRODUCTION

An optic transmission system of the type point to point - FOTS - Fiber Optic Transmission System is formed of three components:
- the emitter equipped with an optical source (LED - Light Emitting Diode or LD - Laser Diode);
- the environment through which the light is propagated, in a guided manner, at a distance (FO - the optical fiber and the regenerators placed at equal distances along the fiber);
- the receiver that amplifies the current produced by a photodetector (PIN diode or APD diode) and processes the resulting electric signal [1], [2], [3].

The comparison between the performances of two optical systems can be done by appreciating the product between the debit transmitted and the maximum distance along which it can be transmitted (without regenerating the optical signal along the way) under the conditions of an equal probability of error (BER - Bit Error Rate, ordinarily ~ 10⁻³) [3], [4], [5].

The advantages of optical transmission by comparison to other ways of transmitting information at a distance are:
- B - the useful frequency band (or D - the debit of binary symbols) for an optical system is very great; optical carrier in the domain 10¹³-10¹⁶ Hz (usually near-infrared λ=1.55 μm) permits the realization of a product DL - Debit Length of the order of 10⁹-10¹² bit/s·Km by comparison to 10³-10⁶ bit/s·Km for a system transmitting via metallic environments under the conditions of a greater BER probability. The use of several optical carriers with different wavelengths and messages propagated along the same optic fiber, DWDM - Wavelength Division Multiplexing - confers a much greater transmission capacity to the system, at the same time permitting the use of codes detecting and correcting errors to reduce the error probability.
- reduced dimensions and weight of the optical fiber cables by comparison to the metallic environments;
- electric isolation between terminal equipment’s (emitter and receiver) and between them and the line (regenerating) equipment’s being no coupling problems between the diverse electric blocks;
- immunity to electromagnetic interferences and no diaphony;
- the propagation via FO is not affected by the external electromagnetic fields, which permits its installation in environments that are strongly polluted from an electromagnetic perspective; the lack of diaphony makes it possible to use several adjacent fibers in the same cable with no mutual influence among them;
- the security of the signal - the extraction of the information from an FO is impossible using non-invasive methods;
- reduced losses in optic power by propagation, especially if the system works in the third window, λ=1.55 μm as one can see in Figure 1; this permits important distances between regenerators, a major advantage by comparison to the metallic environments; moreover, from the perspective of the signal modulating the light in intensity, the fiber behaves as a low pass filter with a very high cutting frequency, having a constant transfer feature in the passband unlike the coaxial cable whose loss increases simultaneously to the frequency (in a non-linear manner ~ f¹/²) thus imposing the equalization in the receiver;
- reliability, simple maintenance, low cost (potentially), etc. [1], [2], [3], [4].

![Figure 1. Light loss through infrared fiber](image)

The loss limit is given by the Rayleigh diffusion law (Figure 2), which states that the optical power absorbed depends on λ⁻⁴ without depending on the intensity of the light. This appears in FO and is due to the fluctuations of density and to the composition [6].
2. ANALYSIS OF THE CONNECTIONS ALONG OPTICAL FIBER

The inverted pulse for single mode fibers is typically between (-48, -52) dB for wavelengths of 1310 nm and is between (-31, -38) dB for wavelengths of 1550 nm. The main features of the line along with this parameter:
- distance - localization of the features of the line, of the end of fiber or of the interruptions;
- losses - for example the loss at an individual junction or the total loss along the entire length of the connection;
- loss - of the fiber in the connection;
- reflexion - the size of the reflexion (or of the losses related to the return of an event).

To check some optical fiber connections, we made measurements in the optical fiber network that we are going to analyse and interpret them in the context of the modification of certain measurement parameters (Figure 3).

2.1 Visualisation of a feature to observe several types of events.

For analysis we measured fiber no. 9 on section 1 (Figure 4) [7], [8]. Following its feature (TO_09.SOR) one can observe 4 reflective events given by mechanical connections realized by connectors of the type FC/PC - Fiber Connector/Physical Contact.

The type of straight connectors with physical contact if adequately cleaned and non-deteriorated has internal losses of 0.1-0.3dB and returns losses >30dB (theoretically >45dB).

The values measured show that at the event 13, the respective connection has amplitude of the reflexion of -31.496dB, and the internal loss of the connection is of 0.337 dB, being very close to the admitted values.

To attain the proposed objective, we made measurements along several optical fiber sectors with particularities regarding the cable ancientness, length, and the different types of discontinuities appearing along these sectors.

The measurements were made on free fibers and on fibers presenting certain types of events, to highlight them.

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Figure 4. Measurement sheet no.1

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Figure 3. The general scheme used for measurements

The cables on which we made measurements are Siemens type, aerial, having the following technical features:
- 20 single mode fibers;
- operation wavelength: 1310 nm and 1550 nm;
- cladding diameter: 125 μm +/- 2 μm;
- core diameter: 9 μm;
- approximate cable diameter: 10.8 mm;
- approximate weight: 90 kg/km;
- array of working temperatures: -30° C...+70° C;
- minimal ray of the bends: 170 mm;
- refraction index: step;
- effective group index of refraction (at 1310 nm): 1.4675;
- effective group index of refraction (at 1550 nm): 1.4681;
- numerical aperture: 0.13;
- loss in the domain 1285-1330 nm: <0.38dB/km;
- loss at 1550 nm: < 0.25 dB/km;
- dispersion at 1550 nm: < 18 ps/nm×km.

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The other reflexive connection represented by event 20, although it has a smaller value of the amplitude, also has an internal loss of 0.215 dB which fits the values of this type of connections.

The events also noticed along this feature are non-reflective events and represent the losses introduced by the points in which the optical fiber has been welded.

As one can observe, there can also appear negative values of the loss, which means a gain. Measured from the other end, this welding is a loss, and the correct value will be the average of the two measurements.

At the installation of the optical fiber cable, welding losses have been imposed < 0.1dB. As one can observe in the Event Table, some welding’s have values > 0.1 dB, yet if we want to calculate the loss/km of this section, we make the following equation:

\[ \alpha = \frac{16,436 \text{ dB}}{64,076 \text{ km}} = 0,256 \text{ dB/km} \]  \hspace{1cm} (1)

where: \( \alpha \) – cumulative loss, \( L \) – optical fiber section length. This value permits to realize communications both in the wavelength of 1310 nm and in that of 1550 nm.

In order to obtain attenuation, found between the interval 0.2-0.357 dB/km [1], [3], [11], it is needed that:
- \( L \leq [2.8; 5] \) km for \( \alpha = 1 \) dB;
- \( L \leq [27; 50] \) km for \( \alpha = 10 \) dB;
- \( L \leq [56; 100] \) km for \( \alpha = 20 \) dB (Figure 5).

2.2 Optical fiber analysis using different Pulse Width values.

We used 3 pulse values, namely (Figure 6):
- average pulse of 1μs \( \rightarrow \) measurement sheet TO_09A.SOR;
- long pulse of 10μs \( \rightarrow \) measurement sheet TO_09B.SOR;
- short pulse of 30 ns \( \rightarrow \) measurement sheet TO_09C.SOR.

We observe out of the measurement sheet (Figure 6) that, for the three values, the features are different for the same physical length of the fiber:
- Short pulses have a smaller dynamic that cannot go through the whole fiber with a good resolution; towards the end of the feature, the noise emerged hinders the analysis of the events in the fiber, the result being a number of 19 events. On a short distance, it has a very good resolution, being indicated to use these pulses for the measurements of shorter fibers.
- For the long pulses, one can note only 14 events, which leads us to the conclusion that although it went through the whole fiber length very well, the analysis on the discontinuities present along the fiber is slightly erroneous, not managing to analyse the smaller losses. At the same time, the distance to the measurement point at
which the events are exhibited is imprecise, being greater
than the correct place of the event. Hence, the conclusion
is that a pulse of greater width is indicated to measure the
fibers of greater lengths.
• The average pulse whose width is 1 μs used to measure
this fiber is the most correct, this actually brings to light
the highest number of events: 23.

The ORL - Optical Return Loss can be calculated by using
the relationship below:

\[
\text{ORL (dB)} = B - 10 \cdot \log_{10} \left[ \left( \frac{A}{w} \right)^3 - 1 \right] \cdot w
\]

Where: B – Rayleigh backscatter coefficient (dB), A – reflection amplitude (dB), w – pulse width (s) [9].

The analyse of the ORL using Matlab it is shown in the
Figures 7 and 8.

\[
\begin{align*}
\text{Figure 7. ORL (dB) depending on B (dB) for the wave} \\
\text{length of 1310 nm}
\end{align*}
\]

\[
\begin{align*}
\text{Figure 8. ORL (dB) depending on B (dB) for the wave} \\
\text{length of 1550 nm}
\end{align*}
\]

From Figure 7 and 8 we can notice how the lower goes
the w (30 ns), the higher gets the ORL reaching the
maximum value of 27.2288 dB, for a wavelength of 1310
nm as well as 44.2288 dB for a wavelength of 1550 nm.

From the determinations in the Matlab it can be observed
the fact that in order to obtain a theoretical ORL higher
than 45 dB it is of the utmost importance that w>30 ns.

2.3 Measuring the optical fiber to observe a rupture.

We measured, on a 68.3 km section, the fiber no. 10 via
two methods:
• the normal mode of measurement of an optical fiber
(Figure 9, measurement sheet no. 3, feature TO_10A.SOR). One can observe that this feature has a
sudden fall at 20,990 km where the end of fiber is also
indicated as well.

The value of the End Threshold represents the first event
with a loss above or equal to the value set and is declared
as End, and all the subsequent events shall be ignored.

\[
\begin{align*}
\text{Figure 9. Measurement sheet no.3}
\end{align*}
\]

- Way of detecting the rupture of a fiber. As one can
observe in the measurement sheet no. 4 (Figure 10), the
feature TO_10FL.SOR, the end threshold, is given at the
same distance as at the first modality of measurement.
This way of working requires the modification of the
following parameters: refraction index, wavelength and
end threshold value.
Comparing the two ways of working, one can see that in the first are highlighted all the events up to the end threshold, in the second way there appear only the reflexion of the beginning of the feature and that in its end.

2.4 Measurement of the optical fiber in two wavelengths 1550nm and 1310nm.

We made the measurements on fiber no. 9, measurement sheets no. 5, 6, TO_09.SOR features for 1550 nm (Figure 11), TO_09D.SOR for 1310 nm (Figure 12), fiber no. 9 measurement sheets no. 7, TO_09.SOR and TO_09D.SOR (Figure 13).

Out of the analysis of the two features we can note first of all that the fiber end does not coincide, and similarly does the position of the events along the fiber, they appear to be shifting in the same physical point of welding. For a wavelength of 1550 nm, the number of events highlighted is smaller. The loss per km in the case of the wavelength
of 1550 nm is smaller than for that of 1310 nm, the result being a smaller total loss at the first wavelength.

3. CONCLUSIONS

In point of the width of the pulse used, we can say that to measure the optical fibers of smaller wavelengths it takes a pulse of smaller width to have a better resolution, whereas for longer the optical fibers one needs a pulse of bigger width.

Most long-haul systems operate on 1550 nm for reasons of smaller losses at greater wavelengths, using a low number of regenerators. To determine the losses due to the bending of the optical fiber cable, we represented and compared simultaneously, on the same window, the waveforms for two wavelengths (Figure 13, measurement sheet no. 7). If the level of dB is about the same in the case of both measurements, what is actually signalled is a non-alignment of the cores or of the cores’ geometry – cladding, different for the two optical fibers combined in that point. Visualizing the two features in our measurement, we can note that the fiber is very good from this perspective.

4. REFERENCES

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