Characteristics and Measurements of Optical Fibers

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Abstract **— Wide utilization of optical fibers in the telecommunication networks is based on their superior characteristics. This paper describes characteristics of single mode optical fibers in accordance with ITU-T Recommendations. Measurements are made on ITU–T G.652 fibers. The results are even better than those defined in the Recommendations.**

Keywords **— ITU-T Recommendations, Single mode fibers optical fibers, OTDR, Coefficient of attenuation.**

I. Introduction

THE optical fibers today are ultimately used on long distances in case of intercontinental and national backbone segments of the telecommunication networks. Additionally, they are implemented in the metro segment for connection of business customers. In the last decade implementation of the optical fibers is more and more evident in the access segment of the network, known as Fiber to the Home (FTTH).

Wide utilization of the optical fibers is based on their superior characteristics as a transmission medium compared with the other media, mainly in terms of very high bandwidth that could be supported which allows transmission of huge amount of information and very low attenuation which allows transmission on long distances without additional amplifiers. Due to this, the main focus of this paper is to consider characteristics of optical fibers, both specified and measured, from the operator point of view.

At the beginning in the Section 2 some general considerations from ITU-T Recommendations related to the single mode optical fibers are given. In Section 3 most frequently used fibers in accordance with ITU-T G.652 are described, while Sections 4 and 5 are related to some measurements methods, measured results and comparison between actual parameters and the ones defined in the Recommendations. Finally, some concluding remarks are given.

II. ITU-T Recommendations related to optical fibers - General description

There are several ITU-T Recommendations (G.652 – G.657) [1-7] that are related with the characteristics of single mode optical fibers and cables They define geometrical, optical, transmission and mechanical parameters of the optical fibers and cables which are described in three categories of attributes:

- Attributes of optical fibers
- Attributes of the cables
- Link attributes

In terms of optical fiber attributes, it should be noted that only those parameters that are related with the basic design of the fibers are recommended. Among other attributes for the fibers, the following ones could be mentioned: mode field diameter, cladding diameter, and cutoff wavelength, bend radius, number of turns, macro bending loss.

Since, geometrical and optical characteristics of the fiber are not affected in the process of cabling, in terms of cable attributes, only parameters that are related to the transmission characteristics of cabled factory lengths such as Attenuation coefficient and Polarization Mode Dispersion (PMD) coefficient are given in the Recommendations.

Link attributes are affected by different factors, which are not related only to the optical fibers, like: splices, connectors, installation etc. These factors are not specified in the recommendations. For the purpose of link attributes estimation, some typical values for the optical link are given. Methods for estimation of parameters necessary for link design are based on measurements, modeling or other considerations.

In the telecommunication networks, G.652 fibers are most frequently used. Those fibers are known as Standard Single Mode Optical Fibers. They have wavelength with zero dispersion around 1310 nm and are optimized for operation in 1310 nm wavelength region. These cables can be also used in 1550 nm region where they are not optimized. Standard optical fibers show higher dispersion level in the windows from C and L band (1530-1565 nm; 1570 – 1610 nm respectively).

Continuous traffic increase, in late 1990 - ties, lead to special design of fiber - non zero dispersion shifted fiber (NZDSF) - mainly dedicated to Dense Wavelength Division Multiplex (DWDM) transport. The main characteristic of this fiber described in ITU - T G.655 is optimal level of chromatic dispersion in C and L bands that is enough to overcome the problems from nonlinear effects like four - wave mixing.

Specific use of optical fibers in the access network, especially increased number of manipulations in this network segment, higher density of distribution and drop cable network and limited space, lead to specifications of G.657 fibers that are less sensitive on macro bending loss and could be used also for in-building installation. In the

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recommendation, two categories of cables (A and B) are described. Fibers in the category A are convenient for utilization in the range 1260 to 1625 nm. The requirements for this category of fibers are subset of the characteristics described in G.652 D and have the same transmission characteristics. The main difference is in the improved bending loss and smaller size specifications.

Fibers in the category B are convenient for transmission in 1310, 1550 and 1625 nm for limited distances inside the building. Parameters for mode-field diameter and Chromatic Dispersion Coefficient could be out of the range of G.652 Recommendation.

Since in the telecommunication networks today, fibers with characteristics in accordance with the recommendation G.652 are most frequently used, in the text bellow, some of the main considerations for this type of fibers will be given.

III. ITU T G.652 OPTICAL FIBERS

Fibers that have specifications in accordance with ITU T G.652 are divided into several categories (A, B, C, D).

In terms of attributes of optical fiber, all categories have the same values of parameters. The only difference is in the value of macro bending loss, which maximum (1 dB) for the fibers from G.652 A appears on 1550 nm, while for other categories maximum is on 1625 nm.

Other differences are related with the cable attributes for attenuation and PMD coefficient.

In case of conventional fibers in accordance with G.652 B, transmission in the range from 1360 to 1480 nm is not possible since water peak occurs at 1383 nm ± 3 nm and the attenuation is much higher than in the 1310 or 1550 nm region.

On the other hand, attenuation in water peak region in case of G.652D fibers is decreased to lower or equal than attenuation at 1310 nm. It means that the whole region from 1310 -1625 nm can be used.

G.652 D fibers, as G.652 B has PMD coefficients less or equal to 0,2 ps/sqrt.km which is different from fibers in A and C Category that have PMD coefficients less or equal to 0,5 ps/sqrt.km. It means that these fibers can be used for higher transmission speeds.

Other characteristics of G. 652 D fibers like chromatic dispersion at 1550 nm, wavelength with zero dispersion, cut off wavelength, are the same as for conventional G.652 B fibers.

G.652 D cables are mainly used for big distances in the backbone or metro networks. Lately, they are used in local metro and access networks too. Local metro and access networks have different design and architecture. They support different applications including 10 Gigabit Ethernet, IP, ATM, SDH using one channel or DWDM and Coarse Wavelength Division Multiplexing (CWDM) transmission. These fibers are also fully compatible with traditional 1310 nm equipment since attenuation and dispersion characteristics are the same as G.652 B fiber.

Based on the above described elements, in general, today position of G.652 B cables is replaced with G.652.D and they become more and more dominant on the market.

IV. MEASUREMENTS OF OPTICAL FIBERS

Usually in the practice, the most frequent measurements for optical fibers and cables are related to the attenuation and dispersion. Different measurement techniques can be used for attenuation loss. Among them are the following:

- Insertion Loss Method
- Cutback Method
- OTDR (Optical Time Domain Reflectometry)

In the text below, first short general description of these measurement techniques will be given and then some practical results from the measurements will be shown.

A. Insertion Loss Method

In this method, output power for two fibers with different lengths is measured. The difference in the power loss between two fibers is considered as a result of bigger length of one of the fibers. Under assumption that additional loss is equally distributed, dividing difference in the power loss with additional length of the longer fiber, loss/km can be calculated in dB/km. Spectral distribution of attenuation loss can be presented using for example tunable source.

B. Cutback Method

With this method two measurements are done on the same fiber. First, output power is measured on the longer fiber, than cable is cut and measurements are repeated on the shorter fiber. This method is accurate, but it cannot be used for determination of attenuation loss for fibers that are in operations.

C. OTDR (Optical Time Domain Reflectometry)

This technique has an advantage since it does not require cutting of the fiber while it is functional. It works not with the transmitted signal, but with the reflected one. It requires access at only one fiber end.

Block diagram of OTDR setup is presented in the Fig. 1. Pulse signal that is inserted via coupler is transmitted through the fiber. For ideal fiber, Rayleigh scattering will be uniform through the fiber, but for fibers with uniform losses, reflected power is decreasing with constant slope when measured power is presented on logarithm or dB axis.

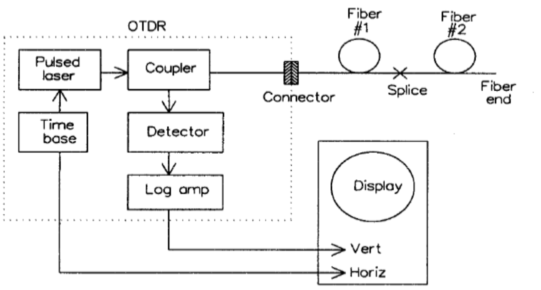

Fig.1. Block Diagram of Optical Time Domain Reflectometar [8]

D. Practical measurements

Measurements of the attenuation in practice are done by telecom operators in several cases:

- During the acceptance tests of new installed cable prior to put it into commercial operation
- During the operation of the cable - when new transmission equipment is installed, for the purpose of preventive maintenance or for detection and localization of faults.

Some examples of the performed measurements are given below. First, measurement set-up is described, than the results of measurements are presented and finally comparison of the results with the recommended parameters in G.652 B is done.

E. Measurement set up

Measurement of the attenuation for optical fibers is done using OTDR measurement technique. Agilent Instrument 3M MINI-OTDR 2000 is used that is placed on the end of the link near Optical Distribution Frame (ODF) where optical fibers terminate. Fibers from the measured cable are connected to the inputs of the instrument. Measurement set- up is presented in the Fig. 2.

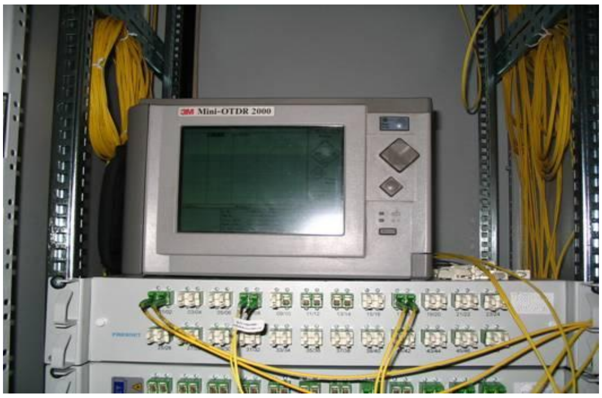

Fig. 2. Measurement set-up

F. Measurement examples

First example is related to the measurement of the attenuation in case of optical cable with 24 SM fibers which length is 41.224m. Optical and geometric parameters of the fiber in accordance with the product specification data are given in Table 1.

TABLE 1: PARAMETERS OF THE FIBER IN ACCORDANCE WITH PRODUCT SPECIFICATIONS

	Specifications from the vendor	G.652B Specifications
MFD (1310 nm)	9,3± 0,7 μm	8,6-9,5 ± 0,6 μm
MFD (1550 nm)	10,5± 1 μm	
Cladding diameter	125± 1,5 μm	125± 1 μm
Core concentricity error	< 1 μm	< 0,6 μm
Cladding noncircularity	< 2%	< 1%
cut-off wavelength	< 1250 nm	< 1260 nm
Attenuation coefficient at 1310 nm	< 0,36 dB/km	< 0,4 dB/km
Attenuation coefficient at 1550 nm	< 0,20 dB/km	< 0, dB/km

It could be concluded that with small discrepancies, optical and geometrical characteristics of the fiber, in general are in accordance with the defined values in ITU-T Rec. G.652, while in terms of coefficient of attenuation, in accordance with product specifications, the analyzed fiber has better performances than recommended ones.

Results from the measurements of the attenuation on 1310 nm and 1550 nm for total cable length as well as calculations for the coefficient of attenuation (total attenuation/total length) for each fiber are given in Table 2. It should be noted that coefficient of attenuation is calculated under assumption that all fibers has 41.224 m length, even though there are small differences in the length of the fibers. Exception is made for fibers number 19 -24 where the total length is 9200 m, since they are part of the branch from the main cable. Measurements are done with pulse width of 300 ns.

Results show that coefficient of attenuation on both wavelengths are in accordance with the recommendation, except for the fibers number 19, 22 and 24 where coefficients of attenuation on 1310 nm are higher than recommended values. In such cases operators usually makes additional measurements on separate parts of the link in order to identify the main reason for the increased attenuation. In order to improve the results for example: some splices could be repaired, part of optical cable could be replaced, connectors could be cleaned up or replaced.

Another measurement example is related to the measurement of attenuation not for the whole length of the fiber, but only on some link that could be of interest for the operator. In this case measurements are done with set up of two vertical markers at the beginning and at the end of the link which is under consideration. Measurement of the attenuation between two splices in the range of 1550 nm is presented in the Fig.3. Measurement is done with 100 ns pulse. If the width of the pulse is smaller, the measurements are more precise.

TABLE 2: MEASURED RESULTS

No of Fiber	**Attenuation (dB)**		**Attenuation coefficient (dB/km)**	
	1310 nm	**1550 nm**	**1310 nm**	**1550 nm**
1	14.743	9131	0,358	0,221
2	14.628	9075	0,355	0,220
3	14.495	8952	0,352	0,217
13	14.100	8767	0,342	0,213
14	14.221	8904	0,345	0,216
15	14.608	9083	0,354	0,220
16	14.185	8847	0,344	0,215
15	15.355	9846	0,372	0,239
18	14.559	9121	0,353	0,221
19	3.876	2470	0,421	0,268
20	3.436	2245	0,373	0,244
21	3.190	1895	0,347	0,206
22	3.753	2473	0,408	0,269
23	3.675	2362	0,399	0,257
24	4.005	2566	0,435	0,279

As it could be noticed from the figure, the instrument shows the length of the link and the attenuation.

Additionally, the difference between the level of optical power immediately prior and after the splice could be determined. It actually gives the level of the losses that are inserted by the splice.

Fig. 3. Measurement of the attenuation between two splices

Such measurement is presented in the Fig. 4. In this case, vertical markers are positioned right before and after the position on the curve where splice is detected.

It should be emphasized that in case when splices on fibers are well done and introduce very low attenuation, they could not be noticed on the attenuation diagram observed on the total fiber length. In that case, other application can be used, that as an input uses results from measurements by OTDR and as output gives comparative view of measurements for all fibers of one cable. In this case, position of splices could be better located.

Fig. 4. Measurement of the attenuation between and after the splice

Results from this application are presented in Fig.5.This method is useful in fault localization process.

In order to have information for the status of the optical cables in the network on one centralize position, operators can use centralized system that could collect data from distributed OTDRs. In that way operational and management process could be more efficient.

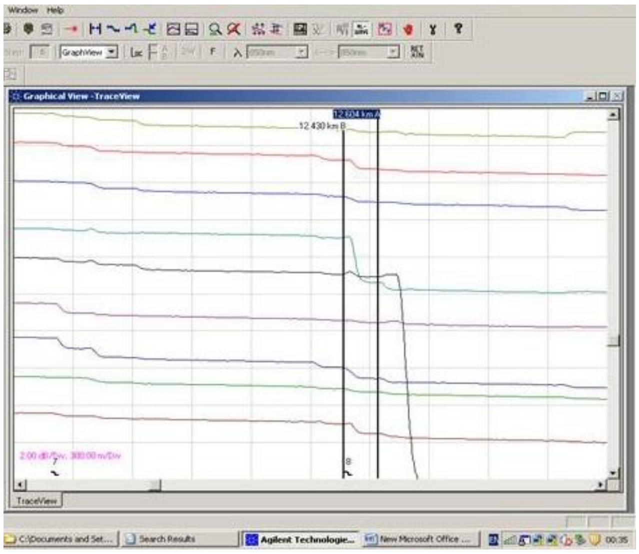

Fig. 5. Comparative view of the attenuation for several fibers

V. Conclusion

There are several ITU-T Recommendations (G.652 – G.657) that are related with the characteristics of single mode optical fibers and cables. In general, in the telecommunication networks most frequently, fibers in accordance with G.652 B were used. Today, mainly due to the lower attenuation in water peak region, G.652D fibers overtake their position on the market.

In practice, measurement of the attenuation is made using OTDR measurement technique. The results presented in this paper show that coefficient of the attenuation of the measured G.652 B fibers are even better than values described in the Recommendation.

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