



INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series G
Supplement 59
(02/2018)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Guidance on optical fibre and cable reliability

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Supplement 59 to ITU-T G-series Recommendations

Guidance on optical fibre and cable reliability

Summary

Supplement 59 to ITU-T G-series Recommendations provides guidance regarding the long term reliability of cabled optical fibres. This Supplement uses currently accepted models combined with current experience to describe items that can impact the performance of an optical fibre over time. The document describes "optical reliability" for fibres, "mechanical reliability" for fibres and describes how optical cables impact these properties.

Keywords

Optical fibre and cable reliability, optical reliability, mechanical reliability.

Introduction

Supplement 59 to the ITU-T G-series Recommendations provides information on long-term reliability of optical fibre and cable. ITU-T establishes optical fibre and cable Recommendations such as [ITU-T G.651.1], [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655], [ITU-T G.656], and [ITU-T G.657]. Also, ITU-T standardized optical cables as described in some of the L series Recommendations. This Supplement also provides more detail on optical fibres reliability described in [ITU-T G-Sup.40].

Supplement 59 to ITU-T G-series Recommendations

Guidance on optical fibre and cable reliability

1 Scope

The scope of this Supplement is to give the end user guidance on the long-term performance of optical fibre and cables. Though it is difficult to address all situations and to guarantee long-term performances, this Supplement helps understand general long-term behaviour of optical fibres and cables and provides guidelines to help the end users minimize the number of mechanical and optical failures during the expected lifetime of the fibre and cable.

2 References

- [ITU-T G.650.1] Recommendation ITU-T G.650.1 (2018), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable*.
- [ITU-T G.651.1] Recommendation ITU-T G.651.1 (2007), *Characteristics of a 50/125 μm multimode graded index optical fibre cable for the optical access network*.
- [ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.
- [ITU-T G.653] Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted, single-mode optical fibre and cable*.
- [ITU-T G.654] Recommendation ITU-T G.654 (2016), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.
- [ITU-T G.655] Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- [ITU-T G.656] Recommendation ITU-T G.656 (2010), *Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport*.
- [ITU-T G.657] Recommendation ITU-T G.657 (2016), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable*.
- [ITU-T G-Sup.40] ITU-T G-series Recommendation – Supplement 40(2010), *Optical fibre and cable Recommendations and standards guideline*.
- [ITU-T L.126/L.27] Recommendation ITU-T L.126/L.27 (1996), *Method for estimating the concentration of hydrogen in optical fibre cables*.

3 Definitions

None.

4 Abbreviations and acronyms

CAPEX	CAPital EXpenditure
FTTx	Fibre To The x
MDU	Multi-Dwelling Unit

MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
RIA	Radiation Induced Attenuation

5 Conventions

None.

6 General comments on reliability

Optical cables were first deployed commercially in 1977. Thus, our knowledge of their performance in the field is 40 years and much information provided in this Supplement is speculative, although today significant spontaneous fibre breakage in these old fibres is not known. Detailed analysis of attenuation characteristics and mechanical attributes for cabled fibre that have been installed for 25 years [b-Hopland 1] [b-Hopland 2] indicate that the optical properties are very stable over time. With this background we can use our accumulated field knowledge combined with accelerated aging to estimate the reliability of optical cables.

Reliability falls into two major categories:

- Mechanical reliability (will the fibre break over the cable lifetime)
- Optical reliability (will optical transmission deteriorate over the cable lifetime)

It is hard to separate optical fibre reliability from optical cable reliability as the two are intimately related, but in this Supplement we will focus primarily on the fibre attributes and how they relate to cabled optical fibre.

General trends in optical transmission must be considered in our evaluation of optical reliability. The general trend is towards more information traveling down optical fibres. Optical cables are trending toward higher fibre counts in smaller optical cables resulting in the potential for more residual strain on the individual optical fibres. There is a trend towards the use of more of the optical spectrum and thus a desire to preserve the attenuation across the full spectrum from 1260 to 1625 nm to allow the most opportunities for bandwidth upgrades.

In general, the reliability of an optical cable during the course of its deployment is strongly impacted by the attention paid to the reliability during the phases of work carried out before the cable is put into service.

These phases can be described as follows:

i) Manufacturing of the optical fibres (fibre drawing and primary protection, storage)

The manufacturing phase of the fibres is critical from the point of view of reliability of the optical cable during the commercial operation. In this phase it is recommended that tests be carried out to ensure that optical and mechanical degradations will not adversely impact system performance during the lifetime of the cable deployment and storage.

ii) Design of the optical cable structure

The structural characteristics of the optical cables (fibre protection, strength member, filling materials, protections sheaths, armour, etc.) should be chosen so they will comply with the limits stated in *i)* for stress and for minimum bending radius, during all the next phases.

Important inputs for the definition of these characteristics are the foreseen installation method and mechanical stress (cable directly put underground, laid in ducts, laid on external poles, etc.) and, possibly, also an indication of the path that the cable will follow.

Finally, the choice of the characteristics of the cable should also be compliant, without degradation of the characteristics of the fibres, with the maximum temperature or humidity excursions that the cable has to face during the lifetime.

iii) Insertion of the fibres in the optical cable (cabling)

The cabling of the optical fibres should comply with all conditions set out in points *i)* and *ii)*

iv) Design of the infrastructure for the cable laying

The infrastructure for the cable laying installation should be designed and implemented in order to preserve as much as possible the cable, from external damages different from those indicated in point *i)*.

v) Laying operations

Even in this phase, attention should be placed on maximum stress and minimum bending radius of the fibres in order to respect the limits mentioned in point *i)*.

vi) Life of the deployed optical cable

The cable faults during the lifetime of the deployed optical cables can be divided into two categories: internal faults and external faults.

The internal faults (fibre breakage, increase of attenuation, etc.) are those related to the quality of the optical fibres. With the adoption of the reliability objectives pointed out in *i)* and *ii)* these internal faults should be kept to a minimum or not present at all.

External faults are those caused by external elements (excavations for other services, floods, landslides, etc.). The number of this type of faults mainly depends on the quality of the protections used in the laying of the cable (depth of the excavation, dimensioning of the infrastructure of overhead lines, etc.). External faults are outside the scope of this Supplement.

The main purpose of this Supplement is limited to the study of the reliability objectives quoted in point i), i.e., the following:

- illustrate the processes by which the quality of the fibres degrades from the point of view of mechanical strength and from that of the increase in attenuation;
- list the test methods to check these degradations;
- give the quality objectives currently adopted during the manufacturing process of the fibres.

It should be clearly pointed out that in this framework the reliability objectives during the commercial life of optical cables, and the input for defining those to be considered during the production of the fibres (point *i)* are not specified in ITU-T. Examples of the main factors that have an impact on the choice of the reliability objectives to be considered during the commercial life of the optical cables are outlined in Appendix II.

However, the 40 years of satisfactory operating experience on optical cables and their wide deployment in all parts of the telecommunications networks (from the access network to intercontinental deployment) is a guarantee that the reliability objectives currently adopted in ITU-T for the production of optical fibres described in clauses 7 and 8 are suitable to ensure a very high reliability with respect to internal faults in all operating conditions.

7 Optical reliability

In the 40 years of commercial optical cable deployment, several mechanisms have been identified that deteriorate the optical performance of glass fibres. These mechanisms can be considered as starting points in identifying processes that need to be accounted for to assure the optical

performances of manufactured and cabled fibres prescribed in ITU-T G.65x series

Recommendations. This clause focuses on three known mechanisms that have an impact on optical reliability:

- Bending loss (microbending and macrobending)
- Chemical attacks (hydrogen being the most common contributor)
- Radiation sensitivity

Many of the tests performed on optical fibre and cable found in IEC and ITU-T documents were developed to help assure long term reliability of optical cables. All the tests focused on optical reliability and monitored the fibre or cabled attenuation during the course of the test to see if any change occurs. If the change is under the recommended threshold the optical cable is expected to operate in the field for a reasonable period of time (typically 20-30 years) without significant degradation in the transmission properties.

7.1 Bending loss

Bending loss falls into two types, macrobend loss and microbend loss. In the simplest terms macrobends are visible bends on the scale of several millimetres in radius and microbends are very small, in the order of a few microns in radius. Bends occur on many length scales in optical fibres and separating macrobends from microbends can often be difficult especially in the transition region between the two phenomena. For single-mode fibres both effects cause increasing loss with increasing wavelengths, in particular threatening the higher wavelengths (C- and L-bands up to 1625 nm).

Optical fibre with improved macrobend performance is the subject of [ITU-T G.657]. One key attribute discussed in this Supplement is the loss as a function of bend radius for several fibre types. From an installation and deployment perspective the concept is that as long as an installer deploys an optical cable with macrobends that are greater than or equal to the minimum design radius, the impact of macrobend loss on the deployed link can be quantified. With known macrobend properties deployment guidelines for optical cable as well as storage guidelines for optical fibres in splice boxes can be developed.

Microbending loss occurs in single-mode fibre when small transverse perturbations in the fibre axis result in the coupling of energy out of the fundamental mode and into lossy higher-order and radiation modes. Significant microbending loss can occur even when the magnitude of the perturbations have nanometre scale size if they occur at the appropriate frequency along the fibre axis so that strong (sometimes resonant) mode coupling occurs. The spectral dependence of microbending loss varies with the axial distribution of the perturbations. Microbends can be a result of temperature changes causing the cables to expand and contract or swelling of the fibre coating or cabling materials as they react with the external environment. Fibres and cables are exposed to many stress tests including temperature changes, humidity, liquid water and other solvents to estimate how the optical cable will perform over the deployed lifetime. Typical stress test standardized in IEC can be found in Appendix VI.4 of [ITU-T G-Sup.40].

7.2 Hydrogen

Hydrogen is a small molecule that can easily diffuse into the glass structure. Hydrogen can react with glass to create irreversible absorption peaks (Type 1) that add to the optical loss or interstitial molecular hydrogen that can be present in the glass adding to the attenuation (Type 2) [b-Lemaire]. Both mechanisms are of concern in deployed optical cables as they can add to the overall attenuation of the optical cable.

Interstitial hydrogen (Type 2) is only a problem where optical cable is subject to high partial pressures of hydrogen. One application where this type of hydrogen is of concern is underwater cables. Optical cables used in deep water, over 100 meters below the surface of the water, are put in hermetic packages, most commonly stainless steel tubes, to prevent Type 2 absorption from occurring. Type 2 absorption in optical cables deployed in shallow water (less than 100 m in depth) increases due to hydrogen, and the impact increases with depth. The impact of Type 2 hydrogen is reversible. Once the cable is removed from the water, the hydrogen diffuses out of the cable and attenuation returns to normal.

Hydrogen can react with defects in the glass matrix. These Type 1 defects are most apparent in ITU-T G.652.B fibres. These defects form as hydrogen reacts with the glass resulting in OH groups which – if created in sufficient quantity in the light guiding portion of the optical fibre – add to the attenuation of the optical fibre across the full useable spectrum. In sufficient quantity these defects can cause the optical fibres to become unusable.

In 2001 ITU-T introduced full spectrum ITU-T G.652 fibre. These ITU-T G.652 fibres differed from their predecessors in that the glass that is transmitting the light is stabilized so that under typical deployment conditions Type 1 hydrogen defects do not form in sufficient quantity to adversely impact the transmission properties of the optical fibre. Today most optical fibres meet this specification providing more reliable long-term optical performance. If ITU-T G.652 fibres are exposed to hydrogen concentrations significantly higher than what occurs in ambient conditions these defects may form and degrade the optical performance of the fibre. More information on hydrogen in optical cables is provided in [ITU-T L.126/L.27].

7.3 Impact of nuclear radiation

The exposure of germanium-doped optical fibres to doses of ionizing radiation can cause defects to form in the atomic structure of the glass resulting in an increase in absorption losses (radiation induced attenuation: RIA). Radiation testing is currently performed at high doses rates over short time intervals. The results of these accelerated tests are then used to estimate the increase in the fibre attenuation over the estimated useful lifetime when the radiation exposure is at the typical background levels. We have experience with optical cables deployed since 1977 and background radiation does not appear to impact the attenuation performance of deployed cables under normal conditions. [b-IEC TR 62283] provides guidance for nuclear radiation tests, but it still need refinement before accurate predictions can be made.

7.4 Attenuation stability

The expected lifetime of optical fibres is typically more than 20-30 years. The purpose of aging tests is to help an end user predict optical properties during the life of the optical cable. These tests look at cyclical conditions as may be encountered with changing conditions over the course of the year, localized events such as bends, as well as degradation in performance over the cable lifetime. A number of tests that have been developed in both IEC SC86A as well as ITU-T SG15 are listed in Appendix VI.4 of [ITU-T G-Sup.40].

Many of the tests performed are for cyclical type events and time based, for example:

- Temperature cycling of optical fibre and cable
- Humidity aging of optical fibre and cable
- Macrobend tests of optical fibre and cable
- Crush and impact tests of optical cable
- And other tests