International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.650.1

Amendment 1
(10/2012)

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

Transmission media and optical systems characteristics – Optical fibre cables

---

Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable

Amendment 1

Recommendation ITU-T G.650.1 (2010) – Amendment 1

ITU-T

International Telecommunication Union

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA AND OPTICAL SYSTEMS CHARACTERISTICS	G.600–G.699
General	G.600–G.609
Symmetric cable pairs	G.610–G.619
Land coaxial cable pairs	G.620–G.629
Submarine cables	G.630–G.639
Free space optical systems	G.640–G.649
Optical fibre cables	**G.650–G.659**
Characteristics of optical components and subsystems	G.660–G.679
Characteristics of optical systems	G.680–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
MULTIMEDIA QUALITY OF SERVICE AND PERFORMANCE – GENERIC AND USER-RELATED ASPECTS	G.1000–G.1999
TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
PACKET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

Recommendation ITU-T G.650.1

Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable

Amendment 1

Summary

Amendment 1 to Recommendation ITU-T G.650.1 (2010) is aimed to provide measurement procedures for coherent multi-path interference (MPI) in short optical fibre cables (jumpers). An improvement in bending-loss in a single-mode fibre affects not only the fundamental mode but may also influence the higher order modes. This may change the cut-off wavelength mechanism. In this case, the single-mode operability of an optical fibre can be investigated by evaluating the MPI characteristics.

Appendix IV introduces three kinds of test methods:

– ECL/PM (External cavity laser/Power meter) method,

– LED/OSA (Light emitting diode/Optical spectrum analyser) method,

– FS (Fibre stretching) method.

A new note is added at the bottom of clause 3.6.1 which gives reference to MPI and the addition of Appendix IV.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.650	1993-03-12	XV
2.0	ITU-T G.650	1997-04-08	15
3.0	ITU-T G.650	2000-10-06	15
4.0	ITU-T G.650.1	2002-06-29	15
4.0	ITU-T G.650.2	2002-06-29	15
4.1	ITU-T G.650.1 (2002) Amd. 1	2003-03-16	15
4.1	ITU-T G.650.2 (2002) Amd. 1	2003-03-16	15
5.0	ITU-T G.650.1	2004-06-13	15
5.0	ITU-T G.650.2	2005-01-13	15
6.0	ITU-T G.650.2	2007-07-29	15
6.0	ITU-T G.650.1	2010-07-29	15
6.1	ITU-T G.650.1 (2010) Amd. 1	2012-10-29	15

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

Recommendation ITU-T G.650.1

Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable

Amendment 1

1) Abbreviations and acronyms

Add the following abbreviations to clause 4.

EELED Edge Emitting Light Emitting Diode

FS Fibre Stretching

FSR Free Spectral Range

MPI Multi-Path Interference

OSA Optical Spectrum Analyser

PM Power Meter

SSMF Standard Single Mode Fibre

2) Note to clause 3.6.1

Add the following at the end of clause 3.6.1.

NOTE – The single-mode operability of a short (typically less than 10 m) optical fibre can be additionally investigated by evaluating the MPI. General information on MPI is provided in clause 6.1 of [b-ITU-T G.Sup.47] and coherent MPI test methods are described in Appendix IV of this Recommendation.

3) Appendix IV

Add Appendix IV as shown below.

Appendix IV

Test methods for measuring coherent MPI in short optical fibre cables (jumpers)

(This appendix does not form an integral part of this Recommendation.)

The measurement of coherent MPI is performed to ensure low noise contribution from a short (typically < 10 m) cabled optical fibre. This test is particularly relevant to [ITU-T G.657] fibres, as they present a wide variety of high-order mode (HOM) transmission characteristics and tend to tightly bind these modes to the fibre core (mode stripping is difficult). MPI values are measured as a function of wavelength, with particular attention to the shortest wavelengths to be used over the cable. The result will be a function of both the length of the cable sample and the splice (connector) loss at the cable ends. Hence these parameters should be quantified and shared by the manufacturer. A further variable is the cable geometrical layout. A straight cable layout will generally give the highest MPI though "resonance wavelengths" may appear where the HOM is strongly damped, and the MPI is very low. More realistic geometries are preferred and are obtained by using controlled bending of the cable.

There are three methods for measuring MPI. The first, the "Narrowband ECL/PM method", uses an external cavity laser (ECL) and a power meter (PM) and is quite accurate but may be time consuming and limited in wavelength range. The second, the "Wideband LED/OSA method", uses a wideband source (such as an edge emitting light emitting diode, EELED) and an optical spectrum analyser (OSA). This method typically has a higher noise floor but enables MPI measurements over the entire transmission band of the fibre. The third method uses a fixed wavelength light source, such as in an actual transmitter, and involves varying the length of the jumper by stretching. It is termed the "Fibre stretching" or "FS" method. This method has the advantages of:

1) low cost light sources;

2) ability to find MPI using actual transceivers in a system test arrangement; and

3) avoidance of extraneous wavelength dependencies in the test set-up.

Disadvantages include a more complicated set-up and the inability to measure fibres in configurations other than straight, under tension.

IV.1 First test method: The narrowband ECL/PM technique

IV.1.1 General

The narrowband ECL/PM technique monitors transmitted optical power through the jumper as a function of wavelength. The interference phenomenon between the fundamental, LP_{01}, and HOM is measured by capturing the maximum and minimum transmitted power over a range of wavelengths. Polarization variation of the input is used to ensure true power extremes are found.

IV.1.2 Test apparatus

A schematic of the apparatus required for the first test method is shown in Figure IV.1.

IV.1.2.1 Optical source

A tuneable external cavity laser (ECL) is used with recommended characteristics: linewidth < 200 kHz, power > –4 dBm at the shortest wavelengths of interest (usually 1260 nm) and wide tuning range (~100 nm). The stability of the power should be < 0.01 dB over the testing time and should vary < 0.05 dB over the wavelength range required to sample the free spectral range (FSR) of the jumper interference pattern (this is typically ~2 nm). The laser RIN should be less than –145 dBm/Hz over the 10 MHz-500 MHz range. It is useful to measure the MPI of the ECL in isolation and values typically are < –55 dB. Output should be taken through a standard single mode fibre (ITU-T G.652 type, henceforth termed, "SSMF") with an angled connector.

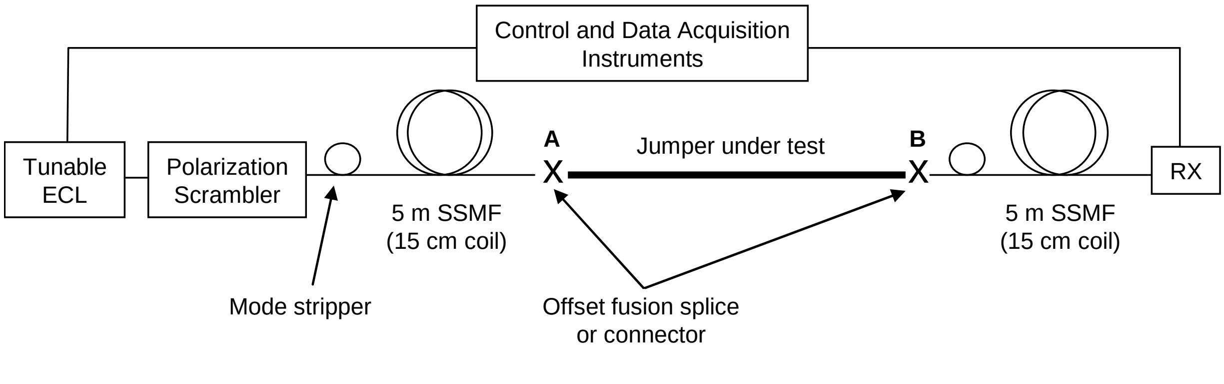

Figure IV.1 – Schematic of set-up for narrowband ECL/PM method. Here the "RX" receiver consists of a power meter or a photodetector/oscilloscope pair SSMF is the standard single mode ITU-T G.652 fibre

IV.1.2.2 Polarization scrambler

Since the coupling at the connection points will be polarization dependent, power measurements must be made at many random polarizations of the incoming light. The polarization may be changed by use of a polarization controller (manual or electronic) or a scrambler. In the case of a controller, at least 100 randomized polarization states should be used for each wavelength measured (therefore the manual controller is not recommended). The use of the scrambler requires knowledge of the scrambling speed (degree/s change on the Poincaré sphere, or highest frequency component in the scrambling instrument). The power measurement must be made on a time scale that is short compared to the time for the polarization to change substantially. Power meters usually require ~0.1 – 20 ms to obtain a reading. Thus scrambling frequencies should be below the range 1 - 0.005 kHz, depending on the averaging time chosen for the power meter. If the photodetector/OSA receiver is used (see clause IV.1.2.4 below) then the scrambling speed is virtually unlimited. The polarization scrambler should have angled connections. It is useful to test the combined ECL – scrambler combination for MPI. Typical results are < –50 dB. Verify that randomly distributed polarization states on the Poincaré sphere are obtained.

IV.1.2.3 Mode stripping loop

The single mode fibre in the launch line should be looped to the appropriate dimension to eliminate all but the fundamental LP_{01} mode propagation. An alternative is to use a long (several hundred metres) piece of SSMF to sufficiently attenuate the HOM.

IV.1.2.4 Optical receiver

The light should be received by a power meter or a photodetector/oscilloscope combination. The power meter averaging time should be adjusted so that power measurements are made rapidly compared to the time over which the polarization scrambler changes the polarization significantly. Linearity of the power meter at the power levels used in the test should be ensured. The power meter response should be corrected for the different wavelengths used in the test. Built-in software may allow the power meter to run in MIN-MAX mode or LOGGING mode to get power statistics. Data is collected at each wavelength until > 100 measured power values have been captured.

The photodetector/oscilloscope combination allows very high scrambling rates to be used (thereby shortening the testing time). Operate at high optical power to minimize receiver noise (but verify linearity of the detector at these power levels). Use a vertical offset on the oscilloscope trace and expand the vertical scale to maximize signal capture. Do not average. Set the acquisition sample rate according to a polarization scrambling speed and maximize the number of samples (record length). Set the time base to either capture all data in a single trigger and identify maximum and minimum voltages or run multiple triggers with a fast time base and collect voltage extrema over a sequence of triggers. The oscilloscope data acquisition should be triggered in synchronism with the ECL wavelength steps.

IV.1.3 Measurements procedure

IV.1.3.1 Preparation of the fibre under test

If the short cable (fibre) to be tested has connectors, make sure proper cleaning procedures are followed. Choose a cable length to be tested and connectorize the ends or prepare the ends for fusion splice.

IV.1.3.2 Baseline measurement

This step identifies the lowest MPI the test set-up is capable of measuring. In addition, the average transmitted power obtained here is useful in removing the light source power variation with wavelength as prescribed in clause IV.1.3.5.

Before including the test cable in the measurement set-up, measure a baseline response by connecting the polarization scrambler and RX in Figure IV.1 with either a 10 m long SSMF or two connectorized 5 m SSMF fibres. Angled connectors should be used for both ends of the SSMF. Sweep the wavelength (over a range of roughly ±3 nm) in steps small enough to resolve the interference fringes expected in the test cable (iteration might be required, or use a small step such as 0.02 nm). At each wavelength capture the minimum, maximum and average power for >100 randomized polarization values. Use a wide enough wavelength scan to capture the free spectral range (FSR) of the jumper interference pattern. Since the FSR is not known before the jumper is measured, the baseline measurement might need to be repeated after a jumper measurement has been performed.

IV.1.3.3 Insert short-cabled fibre

Either disconnect the two 5 m SSMF fibres or cut the SSMF at its centre and insert the test cable into the set-up (between points A and B in Figure IV.1), and characterize splice/connector losses at each end. Intentional offset fusion splices are a convenient way to obtain a desired connection loss. An alternative is to use offset connectors. When the MFD values of SSMF and test fibre are 9.0±0.5 μm at 1310 nm, an offset of 1-2 μm corresponds to a connection loss of 0.5-1 dB (this loss should be directly measured). The coupling ratio of LP_{01} power in the 5 m SSMF lead to LP_{01} power in the test cable is desired for both connection points. It may be necessary to use mode filters and trial and error to eliminate the higher order modes (see the following note for more details). The geometrical layout of the test cable may be substantially straight, as this is the configuration which will generally give worst case MPI results. Other, more preferable, configurations can be tested as well, which involve multiple small radius cable bends.

NOTE – The meaning of the MPI value obtained from this measurement is unclear without accurate knowledge of the LP_{01} loss through each of the connection points. Stripping of the high order mode is required to determine this loss. Some additional comments are made here on mode stripping in ITU-T G.657 fibres. Some ITU-T G.657.A fibres may be mode stripped by using a suitably small fibre loop (the loop should not be so small that it attenuates the LP_{01} mode). If this is the case for the fibre under test, the first connection is made while monitoring the power through the jumper with a mode stripping loop present. When the first connection is satisfactory, the second connection is made, again with mode stripping loops present and power through the 5 m SSMF jumper is monitored until the total loss (through both splices) is satisfactory.

Some ITU-T G.657.A fibres and all ITU-T G.657.B fibres cannot be mode stripped with fibre loops. However, these fibres generally do have a substantial HOM loss with fibre length (even when straight). Lengths required to strip out the HOM may be several hundred metres for some fibre types. In this case the first offset connection is made between the 5 m SSMF and a spool of the desired jumper fibre. Accounting for the LP_{01} loss through the spool (this may be measured separately using an aligned splice to the SSMF launch fibre) the offset connection is adjusted until the desired LP_{01} loss is obtained. The spooled test fibre is now cut back to the desired jumper length and connectorized or fusion spliced to the output 5 m SSMF. Loss through this second connection point is found by monitoring power at the RX and comparing with LP_{01} input power minus the first connection LP_{01} loss.

In either case, LP_{01} loss data should be taken over the FSR (~ ±–3 nm) of the jumper interference pattern. The average over this wavelength range is the connection loss. For consistency, it is important to equalize the splice loss at each end of the test cable. This is because, for a fixed total loss in the splices, maximum MPI is found when the individual splice losses are equal.

IV.1.3.4 Short-cabled fibre measurement

The measurement procedure of clause IV.1.3.2 is followed. With the jumper under test included, ensure that the wavelength scan range is sufficient to encompass several cycles of the roughly sinusoidal variation in transmitted power (FSR). In addition, ensure that the wavelength step is sufficiently small to resolve the spectral intensity pattern.

IV.1.3.5 Calculations

Though not mandatory, it is informative to first subtract the baseline average power from the maximum and minimum power measured through the test cable. This corrects for the power variation with wavelength of the light source. To compute the MPI, the data (corrected maximum and minimum transmitted power versus wavelength) is processed through a moving window of width ≥ FSR. For each position of the window (denoted by its central wavelength), the maximum and minimum power are found and used in equation (IV-1) to find the MPI.

$$MPI(dB) = 20\log\left[\frac{10^{PR/20} - 1}{10^{PR/20} + 1}\right] \quad \text{(IV-1)}$$

where PR is the difference between the maximum and minimum power levels detected (in dB). Note that if the photodetector/oscilloscope method is used, the output data is an electrical voltage, not an optical power. Due to the linearity of the photodetector, equation (IV-1) can still be used with a voltage difference when voltages have been converted to dB (10 log V). Dark current corrections should be made prior to this conversion. Verify that the MPI, computed directly from the baseline data, is suitably low.

IV.1.3.6 Presentation of the results

a) Test set-up arrangement.

b) Optical source characteristics.

c) Polarization scrambling rate.

d) Fibre identification (cabled or uncabled), length, insertion loss and splice loss.

e) Methodology for measuring insertion/splice loss.

f) Geometrical layout of test cable.

g) Receiver characteristics (including signal acquisition time).

h) Table of MPI versus wavelength.

i) After data is taken for a number of fibres of a given design, a mapping between the cut-off wavelength and MPI noise may be compiled.

IV.2 Second test method: The wideband LED/OSA technique

IV.2.1 General

The wideband LED/OSA technique monitors transmitted optical power through the jumper under test as a function of wavelength. The interference phenomenon between the fundamental, LP_{01}, and HOM is measured by capturing the maximum and minimum transmitted power over a range of wavelengths. Polarization variation of the input is used to ensure true power extremes are found.

IV.2.2 Test apparatus

A schematic of the apparatus required for the second test method is shown in Figure IV.2.

IV.2.2.1 Optical source

A wideband light source (typically LED-based) with peak power density > –40 dBm/nm and stability < ±0.03 dB/15 minutes with output in the wavelength range of interest (usually 1260-1625 nm). Note that the stability of this source will not be as good as the ECL used in the first test method. This limits the lowest MPI which can be measured. It is useful to measure the MPI of the wideband source in isolation and values typically are < –40 dB across the full spectral band. Output should be taken through SSMF. Angled connectors should be used when available.

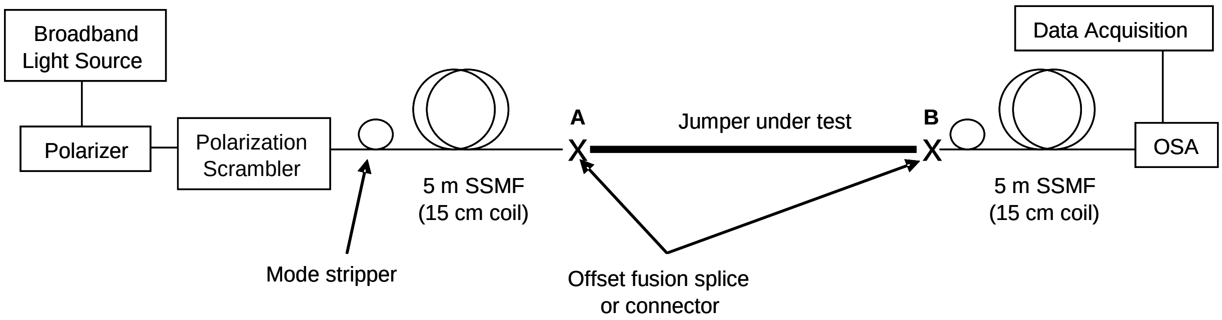

Figure IV.2 – Schematic of set-up for the wideband LED/OSA method. The polarizer is not necessary if the broadband light source has an internal polarizer

IV.2.2.2 Polarization scrambler

Since the coupling at the connection points will be polarization dependent, OSA power density measurements must be made at many random polarizations of the incoming light. The polarization may be changed by use of a polarization controller (manual or electronic) or a scrambler. In the case of a controller, at least 100 randomized polarization states should be used for each wavelength measured (therefore a manual controller is not recommended). The use of the scrambler requires knowledge of the scrambling speed (degree/sec change on the Poincaré sphere, or highest frequency component in the scrambling instrument). The OSA power density measurement at each wavelength must be made on a time scale which is short compared to the time for the polarization to change substantially. Adjustment of the number of wavelengths tested, the sweep speed and the sensitivity allows the user to vary the acquisition time of the OSA to match the speed of the polarization scrambler. Note that only slow scrambling speeds are possible. The polarization scrambler should have angled connections. It is useful to test the LED – scrambler combination for MPI. Verify that randomly distributed polarization states on the Poincaré sphere are obtained.

IV.2.2.3 Mode stripping loop

See clause IV.1.2.3.

IV.2.2.4 Optical receiver

The OSA should be configured with the correct number of wavelength points and the sweep time so that the residence time at each wavelength is much shorter (~10 times) than the inverse of the polarization scrambling speed. This prevents polarization averaging during OSA measurement at each wavelength. Choose the vertical scale to maximize the signal. Measurements are taken using the MAXIMUM and MINIMUM power density functions on the OSA (if available). Resolution bandwidth should be 0.1 nm or less and the number of wavelength points should be sufficient to resolve the interference fringes over the FSR.

IV.2.3 Measurements procedure

IV.2.3.1 Preparation of the fibre under test

See clause IV.1.3.1.

IV.2.3.2 Baseline measurement

Before including the test cable in the measurement set-up, measure a baseline response by connecting the polarization scrambler and OSA in Figure IV.2 with a 10 m long SSMF. With the OSA configured with the correct number of wavelengths, sweep speed, resolution bandwidth and vertical scale, apply averaging and measure the baseline response. Maxima and minima can also be measured if baseline MPI data is desired. Save the averaged trace for use later in removing the spectral dependency of the power output from the LED source.

IV.2.3.3 Insert short-cabled fibre

See clause IV.1.3.3.

IV.2.3.4 Short-cabled fibre measurement

Procedure if OSA has MAX power and MIN power trace capabilities – Put the OSA into MAX trace mode. Allow > 100 sweeps to get the highest signal at each wavelength with respect to input polarization. Save this trace and perform the same test with the MIN trace mode (some OSA models can perform these acquisitions simultaneously). Subtract the baseline trace found in clause IV.2.3.2 from the MAX trace result and from the MIN trace result. Output the resulting two traces.

Procedure if the OSA does not perform MAX power and MIN power data manipulation internally – Take > 100 sweeps and output the data from each one to a control computer. Use the computer to sort out the maximum and minimum for each wavelength. The baseline can either be subtracted on the OSA or during data sorting on the computer.

IV.2.3.5 Calculations

See clause IV.1.3.5.

IV.2.3.6 Presentation of the results

See clause IV.1.3.6.

IV.3 Third test method: The fibre stretching technique

IV.3.1 General

The fibre stretching technique utilizes the fact that the transmitted power, with interference between the LP_{01} mode and an HOM in the jumper, changes periodically with the optical phase difference through the jumper. This optical phase difference is dependent on wavelength (which was exploited in the other two techniques) but is also proportional to the jumper length. The length is most easily varied by stretching the fibre. In this case the maximum and minimum transmitted power is measured as fibre length is varied. Polarization variation of the input is used to ensure true power extremes are found. For typical fibres with a 2nm FSR, the required length variation is of the order of 2-4 mm; for a fibre span of 2 metres this corresponds to a strain of $\sim 10^{-3}$, substantially below proof-test levels. Higher strains may be required for fibres with a larger FSR. This method may be less easily applied in cases where the jumper is buffered and/or jacketed.

IV.3.2 Test apparatus

A schematic of the apparatus required for the third test method is shown in Figure IV.3. The source can be either a tuneable laser or a transceiver. Polarization changes are made by the polarization scrambler. Angled connectors are used throughout to minimize reflections. The upstream fusion splice is attached to a fixed stage, while the other fusion splice is attached to a movable translation stage.

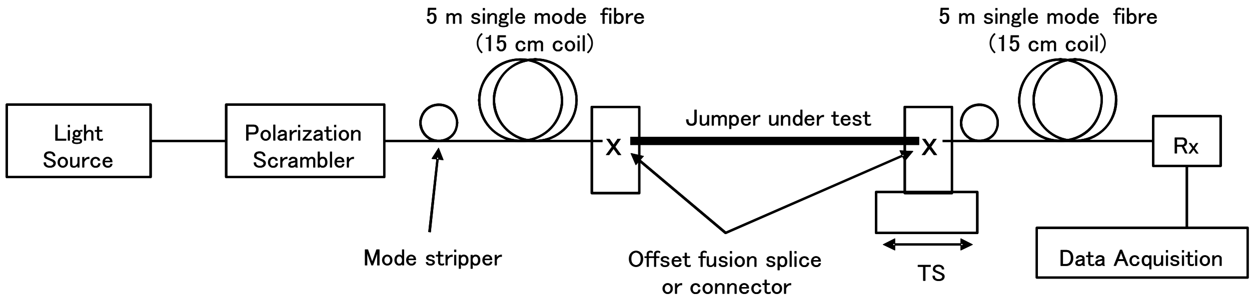

Figure IV.3 – Schematic of set-up for the fibre stretching method. "TS" is a translation stage. Here the "RX" receiver consists of a power meter or a photodetector/oscilloscope pair

IV.3.2.1 Optical source

If a tuneable laser is used, the laser performance should conform to the specifications given in clause IV.1.2.1. Alternatively, an optical transceiver may be used. In either case, ensure that wavelength and power output are stable over the several minutes required for performing the test. If an optical transceiver can be chosen which is comparable to that used in the actual deployed system, the MPI results are particularly relevant.

If a transceiver (e.g., a DFB one) with optical properties equivalent to those of the tuneable laser described in clause IV.1.2.1 is employed, the results will be substantially source-independent; otherwise (e.g., if a Fabry-Perot transceiver is used) the results may depend on the transceiver properties.

IV.3.2.2 Measurement settings

IV.3.2.2.1 Polarization scrambler

To ensure that worst-case conditions are achieved, transmitted power measurements must be made at many random polarizations of the incoming light. The polarization may be changed by using a polarization controller (manual or electronic) or a scrambler, preferably with angled connections. The use of the scrambler requires knowledge of the scrambling speed (degree/s change on the Poincaré sphere, or highest frequency component in the scrambling instrument). The scrambling speed should be slow enough to guarantee that each power meter measurement is completed before there is significant polarization change. In other terms, the time employed by the scrambler to produce an appreciable polarization change must be longer than the power meter integration time, to avoid that the power variations induced by polarization scrambling are averaged-out by the power meter integration time. So, with a power meter integration time of 100 ms, a scrambling frequency of 5 Hz must be used, meaning that a substantial variation of the polarization takes place in 200 ms.

IV.3.2.2.2 Translation stage

The translation length must be set after the mode beating period has been determined, which should be done with the polarization scrambling turned off. The translation length should be chosen between a lower limit dictated by the periodicity of the mode beating (two periods is recommended) and an upper limit corresponding to an appropriate fibre strain. In the case of a two-metre cable sample, the lower limit of the translation length would be ~2 mm and the upper limit would be ~20 mm. The velocity of the translation stage must be slow enough to guarantee that the time employed for a complete peak/trough cycle is much longer than the power meter integration time, to avoid that the power oscillations induced by fibre length variation are averaged-out by the power meter integration time. As an example, a translation velocity of 0.2 mm/s would complete a peak/trough cycle of 1 mm in 5 s, much longer than the power meter integration time of 100 ms.

IV.3.2.2.3 Sampling frequency

Once the power meter integration time, the speed of the scrambling, the translation stage velocity and its excursion have been set in accordance with the criteria exposed in the previous two points, the frequency of the power meter acquisitions must be decided. The sampling frequency should be high enough to guarantee a clear identification of the peak/trough cycle determined by the fibre stretching, with no less than 25 points collected for each oscillation period. However, the time distance between two consecutive acquisitions must be greater than the power meter integration time, to ensure that they correspond to truly different interference and polarization states. Namely, an acquisition every 200 ms would be compatible with the parameter values exemplified in the previous (a)-(b) points.

IV.3.2.2.4 Number of measurements

A reliable MPI evaluation can be obtained only if a large enough number of power meter readings, corresponding to a different polarization state of the injected light and phase differences between the co-propagating mode, are collected. With the suggested parameter values, a translation length of 4 mm, corresponding to 4 beating periods, would provide 100 power meter readings and would take 20 seconds. To assess the reliability of the resulting MPI value, this measurement should be repeated at least 20 times, so that in 400 seconds 20 different MPI values can be calculated, having collected a total of 2000 power meter readings corresponding to a different state of the injected light polarization and of the mode phase different. The average and the standard deviation of the collected MPI values provide a complete statistical description of the expected penalty.

IV.3.2.2.5 Using a manual polarization scrambler

If a manual scrambler is to be used, as a preliminary step it is necessary to test the light source – scrambler combination to verify that randomly distributed polarization states on the entire Poincaré sphere are obtained. In this case, instead of continuously scrambling the polarization while the fibre stretching takes place, it could be easier to change the polarization after every translation run. Assuming that 100 power meter acquisitions are made during each run, and that 20 runs are performed with 20 different polarization states, the MPI can be calculated on a total of 2000 power meter readings.

IV.3.2.3 Mode stripping loop

See clause IV.1.2.3.

IV.3.2.4 Optical receiver

See clause IV.1.2.4.

IV.3.3 Measurements procedure

IV.3.3.1 Preparation of the fibre under test

This test method employs an uncabled fibre jumper with offset fusion splices at the ends. The fibre is nominally 2 m in length and the splice losses must be individually characterized (see clause IV.1.3.3).

IV.3.3.2 Baseline measurement

Before including the test fibre in the measurement set-up, measure a baseline response by connecting the polarization scrambler and RX in Figure IV.3 with a 10 m long SSMF and stretching 2 m of it without affecting the splice/connection loss.

IV.3.3.3 Insert short fibre test sample

The test fibre may be attached using paper tape to the translation stages. It is recommended that the fibre be straight, with the tape covering ~ 10 cm of fibre at either side of the fusion splice (covering the splice for protection). The fibre between the stages is usually ~2m in length and under slight tension (straight).

IV.3.3.4 Short-cabled fibre measurement

With the light source and polarization scrambler active, the translation stage is moved in small increments. With each movement, the transmitted power is recorded along with the position of the stage. The stage movement must be sufficient to eventually allow exploration of two FSR of the test fibre (the transmitted power vs. fibre length goes through two maxima and minima). At this point the stage reverses direction and more data is taken. This process continues until enough polarization states have been sampled (~100) at each fibre length. If desired, the light source wavelength can be slowly varied as well.

IV.3.3.5 Calculations

Find the MPI by determining the maximum and minimum power transmitted through the sample over all fibre stretch lengths and polarization states; then use the formula:

$$MPI(dB) = 20\log\left[\frac{10^{PR/20}-1}{10^{PR/20}+1}\right] \qquad \text{(IV-1)}$$

where PR is the difference between the maximum and minimum power levels detected (in dB). Note that if the photodetector/oscilloscope method is used, the output data is an electrical voltage, not an optical power. Due to the linearity of the photodetector, equation (IV-1) can still be used with a voltage difference when voltages have been converted to dB (10 log V). Dark current corrections should be made prior to this conversion. Verify that the MPI, computed directly from the baseline data, is suitably low.

IV.3.3.6 Presentation of the results

See clause IV.1.3.6.

4) Bibliography

Add the following entry to the bibliography:

[b-ITU-T G.Sup.47] ITU-T G-series Recommendations – Supplement 47 (2012), *General aspects of optical fibre and cable*.

SERIES OF ITU-T RECOMMENDATIONS

Series A	Organization of the work of ITU-T
Series D	General tariff principles
Series E	Overall network operation, telephone service, service operation and human factors
Series F	Non-telephone telecommunication services
Series G	**Transmission systems and media, digital systems and networks**
Series H	Audiovisual and multimedia systems
Series I	Integrated services digital network
Series J	Cable networks and transmission of television, sound programme and other multimedia signals
Series K	Protection against interference
Series L	Construction, installation and protection of cables and other elements of outside plant
Series M	Telecommunication management, including TMN and network maintenance
Series N	Maintenance: international sound programme and television transmission circuits
Series O	Specifications of measuring equipment
Series P	Terminals and subjective and objective assessment methods
Series Q	Switching and signalling
Series R	Telegraph transmission
Series S	Telegraph services terminal equipment
Series T	Terminals for telematic services
Series U	Telegraph switching
Series V	Data communication over the telephone network
Series X	Data networks, open system communications and security
Series Y	Global information infrastructure, Internet protocol aspects and next-generation networks
Series Z	Languages and general software aspects for telecommunication systems

Printed in Switzerland
Geneva, 2013