FOTP-XX

Fiber Optic Splice Loss Measurement Methods

Contents

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Foreword

(This Foreword is informative only and is not part of this Standard.)

This document comes from TIA Project No.XXXX and was formulated under the cognizance of TIA FO-6.3, Subcommittee on XXXXXXXXXXXXXXXXXXX.

This FOTP is part of the series of test procedures included within Recommended Standard EIA/TIA-455.

NOTE – This is the first and original issue of this FOTP.

There is one informative Annex.

Key words: insertion loss, single mode fiber, fusion splice, identical fiber, dissimilar fiber, measurement reproducibility

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1 Introduction

1.1 Intent

Two general needs are addressed by this standard. First, there is a need for generally accepted methods for accurate measurement of low loss splices, defined as those with insertion losses typically 0.05 dB or less. Second, it is desirable to have a generally accepted method to evaluate the performance of splicing equipment, systems, or methods designed or intended to make low loss splices.

This procedure defines methods by which the optical insertion loss of a low loss splice between two optical fibers can be measured. There are three procedures that may be used. In the first, sometimes referred to as “in-line”, optical power is first measured through a continuous length of fiber or cable. The fiber is then cut without removing the end from the power monitoring equipment, a low loss splice is made to rejoin it, and the power is re-measured. In the second procedure, known as “add-on”, optical power is initially measured through a first fiber. A second fiber is then spliced to the first and the power is re-measured emerging from the end of the second fiber. In the third method, power is first measured through a continuous length of fiber or cable, and it is cut without removing the end from the power monitoring equipment. A second piece of fiber is then inserted and spliced onto the cut ends (two splices), and the change in output power is measured as the loss of the two splices.

These procedures are similar to, and rely substantially on, FOTP-34, Interconnection Device Insertion Loss Test. The principal differences are that the present FOTP-XX procedures are intended for measurements on very low loss splices (typically made with identical fibers) as well as higher loss splices made with dissimilar fiber types, and these procedures are not intended for multimode fibers. In addition, this standard addresses the assessment of the measurement capability of the loss test equipment and measurement set-up.

The results of this test method are not directly comparable with those of FOTP-171 (a cable assembly test), which is sometimes used to evaluate connector loss. This standard tests a complete splice comprising normal parts, whereas FOTP-171 tests the interconnection loss of one normal part (half of a connection) mated with a reference quality part, which has been selected for near perfection of fiber and connector attributes.

1.2 Applicability

These procedures are intended for low loss splices between matched or mismatched single mode fibers only.

2 Normative references

Test or inspection requirements and definitions may include, but are not limited to, the following references:

TIA/EIA-440-B	*Fiber optic terminology*
FOTP-34A (TIA/EIA-455-34B)	*Interconnection device insertion loss test*
FOTP-57 (TIA/EIA-455-57B)	*Optical fiber end preparation and examination*
FOTP-77 (EIA/TIA-455-77)	*Procedures to qualify a higher-order mode filter for measurements on single mode fiber*
FOTP-171 (TIA/EIA-455-171B)	*Attenuation by substitution measurement -- for short-length multimode graded-index and single mode optical fiber cable assemblies*
TIA/EIA-455-B	*Standard Test Procedure for Standard Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and Other Components*

3 Apparatus

3.1 Light source

3.1.1 Unless otherwise specified in the Detail Specification, use a light source that meets all, or any of, the following requirements:

Fiber type	Center wavelength	Spectral width
Class IVa single mode	1310±30 nm	≤140 nm
Class IVb single mode	1550±30 nm	≤150 nm
Class IVb single mode	1625±30 nm	≤150 nm

3.1.2 Source stability

Unless otherwise permitted by the Detail Specification, the light source output intensity variability shall be ≤10% of the minimum expected attenuation to be measured.

The source should be allowed to stabilize for a period sufficient to meet the above criterion, prior to assessing the source stability or performing loss measurements. Assessment of the source stability should be conducted over a time period not less than that anticipated for measuring the loss of a sample, including the reference and any repeat measurements (see subclause 3.7 for the methodology of the stability assessment). The source stability should be re-assessed periodically and at a minimum before and after loss measurements have been completed. Significant change in power level may require further time to stabilize. If adequate source stability cannot be assured, the source output shall be monitored by a detector to allow the power measurements to be corrected. The corrected power, using the source monitor, shall also comply with the above stability criteria.

Connection of test sample to light source

The first or input or reference fiber sample should remain connected to the light source for the duration of the test.

3.2 Source monitoring equipment

If adequate stability of the optical source cannot be assured, use apparatus capable of monitoring the source output continuously with 0.001 dB resolution. If branching devices are used for the purpose of monitoring power from a single input fiber, take care to ensure that polarization effects between the branches are not significant. Test equipment that ratiometrically corrects test sample power readings for source power fluctuations, producing a single stabilized reading, reduces the number of required readings and simplifies the calculations.

3.3 Cladding mode stripper

Remove light from cladding modes in the test sample. Often the fiber coating is sufficient to perform this function. Otherwise, it will be necessary to use cladding mode strippers near the optical source and detector. If distinct cladding mode strippers are used, apply them directly to the fiber cladding and avoid microbending at these sites.

3.4 High order mode filter

If higher order modes are capable of propagating to the detector, as may sometimes be the case with some coatings and very short lengths of fiber, locate high order mode filters both before and after the splice. Often a single 30 mm diameter loop of fiber will suffice. See FOTP-77. At a minimum, it is recommended that 30 mm loops are made in the fiber exiting the source.

3.5 Detection equipment

3.5.1 Use of integrating sphere

The detection equipment, such as a lock-in amplifier or optical power meter, shall be capable of measuring all guided-mode optical power emitted from the test sample. If there is any doubt, but particularly with fibers of NA higher than 0.12, the detector shall be equipped with an integrating sphere.

3.5.2 Detector linearity

The detector shall be linear in optical power response consistent with the accuracy required for the measurement. Detector linearity is difficult to verify over the range of very low losses (0 to 0.1 dB) because calibrated low loss attenuators are not readily available. A recommended approach is to measure linearity over a larger range (e.g. 0 to 3 dB). Any significant (>10%) departure from linearity is a strong indicator of a problem with the source-detector equipment. Power meters with distinct ranges shall be set to a fixed range, suitable to measure all relevant power levels.

3.5.3 Detector stability

Detector stability is generally measured together with the source, and practically it may be difficult or unnecessary to separate them. Furthermore, some types of fiber may exhibit instability under some conditions of wavelength and optical power, and it is recommended the stability is assessed with the fiber under test. Hence, the stability requirement defined here refers to the relevant source-detector or source-fiber-detector combination. Fixed elements that remain throughout the measurements, such as the optical isolator and integrating sphere, should also be included in the stability set-up.

Stability shall be equivalent to the stability of the source at the lowest and highest power readings encountered in the test set-up, i.e. an optical output variation ≤10% of the minimum expected attenuation to be measured

Stability may be improved by optional use of an optical isolator located at the source and/or a depolarizer located at the detector. A source with a built-in isolator is recommended to obviate any possible change in back reflection arising from use of an external isolator located in the fiber. The system should be checked to ensure introducing these additional elements does not severely attenuate the signal and the signal-to-noise ratio (e.g. source on/off) is at least 20:1.

3.5.4 Detector accuracy

Detector accuracy is generally based on calibration performed by the equipment vendor using a secondary standard source. Since loss is measured relative to the unattenuated signal and the magnitude of the loss is relatively small, departure from the stated accuracy should not be a significant issue. The vendor specified accuracy of ±0.5 dB, or better, over the power range of the detector is acceptable.

3.5.5 Detector resolution

The optical power meter display resolution or recorded resolution of an analog measurement device shall be 0.001 dB or better.

3.6 Test set up and stability

The stability of the complete test set-up should be assessed by monitoring the source output power P_0 over a time period comparable to, or greater than, the time required to make a measurement of interest. Values should be recorded at intervals sufficient to generate >30 data points. If the averaging time of the power meter is a variable parameter, it should be set to the same value as for the loss measurement.

The measurement stability ($\pm D$) is estimated as 2x the standard deviation ($\pm 2\sigma$) of the data points. With a sample size of >30 the stability may be sufficiently well estimated without the need for a statistical correction factor. Systems exhibiting drift should be allowed to stabilize before taking measurements.

3.7 Assessment of test repeatability and reproducibility

The measurement capability, or the ability of the measurement system to discriminate parts within the loss range of interest, should be validated using an accepted statistical method. A recommended method is gage reproducibility and repeatability (R&R) (Refs. 1, 2). An example application of the gage R&R method for assessment of loss measurement equipment is described in Annex 3.

4 Sampling and specimens

4.1 Test sample

The test sample shall be a splice and two single mode optical fibers or optical fiber cables of the length specified for each test method.

4.2 Splice preparation

Follow the manufacturer's instructions regarding assembly methods, materials and tools to make the splice. If manufacturer's instructions are not available or adequate, at a minimum the fiber samples must be prepared and spliced in accordance with the following guidance:

4.2.1 Wherever a fiber is to be spliced, the coating(s) shall be stripped cleanly from the fiber for a distance of at least 3 cm from the end, using a tool which does not scratch or damage the fiber in any way.

4.2.2 The bare fiber shall be cleaned following accepted practice, using a lint-free wipe dampened with solvent or an ultrasonic cleaner containing solvent.

4.2.3 The fiber shall be cleaved with a precision fiber cleaver, clean and in good condition, capable of routinely achieving an average end angle of 1.0 degree or smaller on standard single mode fiber. The distance of the cleave from the cut end of the coating(s) shall be as directed by the splicing equipment or system manufacturer unless otherwise specified otherwise. If no guidance is available the cleave length shall be 12 mm.

4.3 Test sample specifications

In the case of fibers which attenuate more than 1.0 dB/km at the test wavelength the attenuation and fiber lengths should be recorded. To the extent that measurable attenuation effects may be attributed to changes in the length of the sample this effect will need to be calculated and the data corrected appropriately. Because the results of low loss splicing depend on the intrinsic properties of the fibers being spliced, even when they are identical, the following properties of the samples may also be noted: core concentricity or eccentricity, mode field diameter, numerical aperture, cladding diameter and/or tolerance.

4.4 Test sample length

Unless otherwise specified in the Detail Specification, use any length greater than 2 m (6 ft.) for splices tested with single mode fiber. If 2 m are not available or attenuation at the test wavelength would render the output power difficult to measure, a shorter length may be tested, but the length must be noted.

4.5 Test sample deployment

Unless otherwise specified in the Detail Specification, do not allow bends of diameter < 7.5 cm (≅3 in.) in the attached optical fiber cable.

4.6 Test conditions

Unless otherwise specified, the tests will be carried out indoors under standard atmospheric conditions of 22 ±5 °C, 760 ±100 mbar pressure, and relative humidity <85%. The work place shall be well-lighted and clean. Care shall be taken to avoid proximity to heavy equipment, roads bearing heavy vehicles, or any other source of floor vibration or electromagnetic interference such as generators, heavy motors, or power transformers.

5 Loss Test Procedures

5.1 Procedure A: in-line method

5.1.1 Method attributes: suitable for identical fiber splices (i.e. made from same length of fiber), fiber ends at the source and detector remain fixed.

5.1.2 Configure the test equipment and sample fiber as shown in Figure 1 for test method A. Follow all requirements for the test equipment as defined in Clause 3 of this document.

5.1.3 Insert the original length of optical fiber or cable between the light source and detector, adding mode filters and/or cladding mode strippers as specified by the test method. Allow the system to stabilize until the power readings remain stable to the level consistent with the requirements in 3.1.2 and 3.5.3. Read the initial power, P_0. If optical source monitoring is required, also read the initial source monitor power, P_{M0}.

5.1.4 Cut the test sample fiber/cable within 25% of its length of the center prepare the free fiber ends, and splice them together as specified in Clause 4 of this document.

5.1.5 Re-measure the optical power, P_1, and the source monitor power, P_{M1} (if required).

5.2 Procedure B: add-on method

5.2.1 Method attributes: suitable for dissimilar fiber splices, directional loss measurements can be performed (see 5.2.7 and 5.2.8).

5.2.2 Configure the test equipment and first length of fiber as shown in Figure 2 for test method B. Follow all requirements for the test equipment as defined in clause 3 of this document. Use of a bare fiber adapter (BFA) and integrating sphere (IS) are recommended.

5.2.3 Allow the system to stabilize until the power readings remain stable to the level consistent with the requirements in 3.1.2 and 3.5.3. Read the initial power, P_0. If optical source monitoring is required, also read the initial source monitor power, P_{M0}.

5.2.4 Remove the first (reference) fiber from the bare fiber adapter. Splice on the second (test) fiber as specified in clause 4 of this document. Add mode filters and/or cladding mode strippers as specified by the test method.

5.2.5 Prepare the end of the second fiber as directed in subclause 4.2 and insert it in the detector, bare fiber adapter, or integrating sphere exactly as the end of the first fiber had been installed.

5.2.6 Re-measure the optical power, P_1, and the source monitor power, P_{M1} (if required).

5.2.7 The splice loss in the reverse direction (test-to-reference fiber) may be determined by starting in the condition with the added-on test fiber (attained in step

5.2.5) and measuring the transmitted power P_0 (and optionally P_{M0}). A second length of the first (or reference) fiber is added-on, following steps 5.2.3 to 5.2.6, and the transmitted power and P_1 (and P_{M1}) is measured.

If the first fiber is non-attenuating and the second (test) fiber is attenuating, this second splice procedure of method B has the advantage of not requiring an absorption correction and can be used as the preferred loss measurement method for dissimilar fibers.

5.2.8 As an alternative method to 5.2.7, the initial splice (attained in 5.2.6) may be cut-out, reversed, spliced back and re-measured, enabling the loss in both directions to be determined for the same splice.

A significant directional splice loss, corresponding to an absolute difference in the insertion loss between the two directions of greater than the lower loss, indicates a problem with the measurement set-up and/or departure from single mode transmission. Use of an integrating sphere and/or change of source wavelength will generally rectify directional issues.

5.3 Procedure C: inserted section

5.3.1 Method attributes: suitable for dissimilar fiber splices, the fiber ends remain fixed between measurements, two splices in each direction are measured in aggregate, the method is independent of direction and gives a “correct” value in the presence of apparent directional loss.

5.3.2 Configure the test equipment and sample fiber as shown in Figure 3 for test method C. Follow all requirements for the test equipment as defined in clause 3 of this document.

5.3.3 Insert the original length of optical fiber or cable between the light source and detector, adding mode filters and/or cladding mode strippers as specified by the test method. Allow the system to stabilize until the power readings remain stable to the level consistent with the requirements in 3.1.2 and 3.5.3. Read the initial power, P_0. If optical source monitoring is required, also read the initial source monitor power, P_{M0}.

5.3.4 Cut the test sample fiber/cable within 25% of its length of the center prepare the free fiber ends, splice on a second (test) length of fiber as specified in clause 4 of this document. Then splice the other free end of the second fiber to the first (reference) fiber.

5.3.5 Re-measure the optical power, P_1, and the source monitor power, P_{M1} (if required).

NOTE: The insertion loss calculated for the inserted section method is the combined loss of the two splices.

5.4 Number of required readings

One reading of P_0 and P_1 per sample splice is sufficient. If further verification is desired, or to characterize the repeatability and reproducibility of the set up and procedure, additional readings may be desirable (see Annex A3).

6 Calculations or interpretation of results

6.1 Calculate insertion loss for each of the measurements. If source monitor power readings are available, use equation 1a (power measured in Watts) or equation 1b (power measured in dB or dBm):

$$\text{Insertion Loss} = -10 \log_{10} [(P_1/P_0) / (P_{M1}/P_{M0})] \text{ (dB)} \qquad (1a)$$

$$\text{Insertion Loss} = (P'_0 - P'_1) - (P'_{M0} - P'_{M1}) \text{ (dB)} \qquad (1b)$$

If source monitoring was not used, or was electronically referenced to the test sample readings (see 3.2), use equation 2a (power in Watts) or equation 2b (power in dB):

$$\text{Insertion Loss} = -10 \log_{10} (P_1/P_0) \text{ (dB)} \qquad (2a)$$

$$\text{Insertion Loss} = P'_0 - P'_1 \text{ (dB)} \qquad (2b)$$

NOTE: The above equations express insertion loss as a positive quantity.

7 Documentation

7.1 Report the following information for each test:

7.1.1 Test procedure number (FOTP-xx), detail procedure (A, B, or C) and method used.

7.1.2 Test date.

7.1.3 Test samples identification and detailed properties in accordance with subclause 4.3.

7.1.4 Insertion losses, of the samples and mean and standard deviation of the data set.

7.1.5 Source wavelength(s).

7.1.6 Test sample preparation procedure and tools used.

7.1.7 All applicable settings and specifications of the splicing equipment, system, tools, and/or method.

7.1.8 Documented stability and reproducibility and repeatability of the test set up, or other documentation that it meets the criteria of clause 3.

7.1.9 Test equipment type, model and serial numbers.

7.2 United States military applications require that the following information also be reported for each test. For other (nonmilitary) applications, this information need not be reported, but shall be available for review upon request:

7.2.1 Mandrel diameter used, if any.

7.3 The following information shall also be reported for U.S. military applications only:

7.3.1 Title of test.

7.3.2 Test personnel.

7.3.3 Test equipment and date of latest calibration.

8. Specification information

The following information shall be specified in the Detail Specification:

8.1 Number and type of samples to be tested.

8.2 Number of insertion loss readings to be taken, if other than in accordance with 5.4.

8.3 Test procedure number (FOTP-xx), and method to be used. See 1.2.

8.4 Test wavelength(s).

Figures

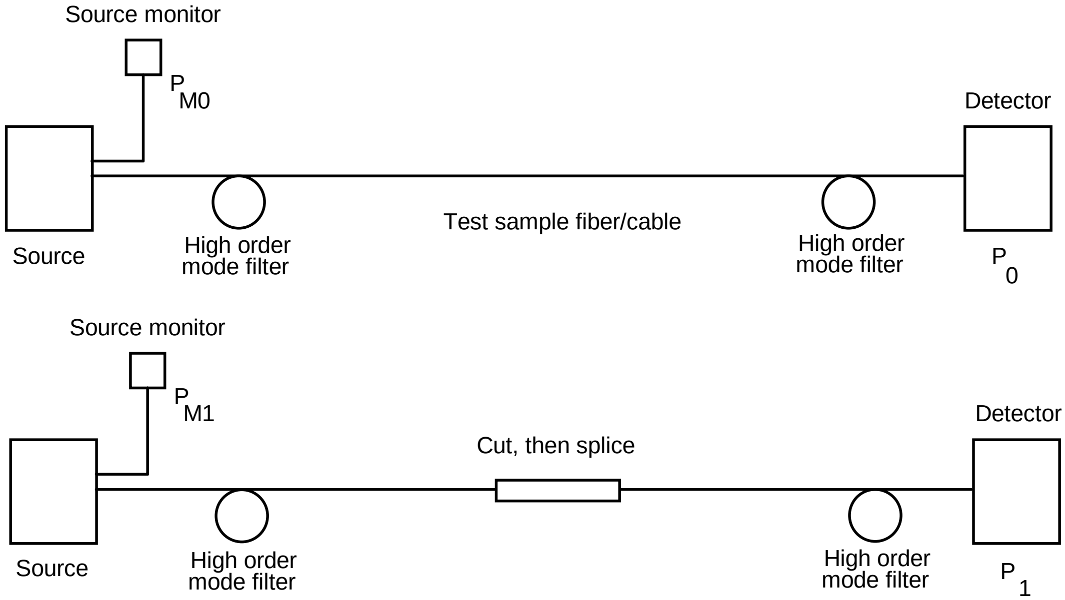

Figure 1 – Method A: in-line

Refer to 3.4 for discussion of "High order mode filter"

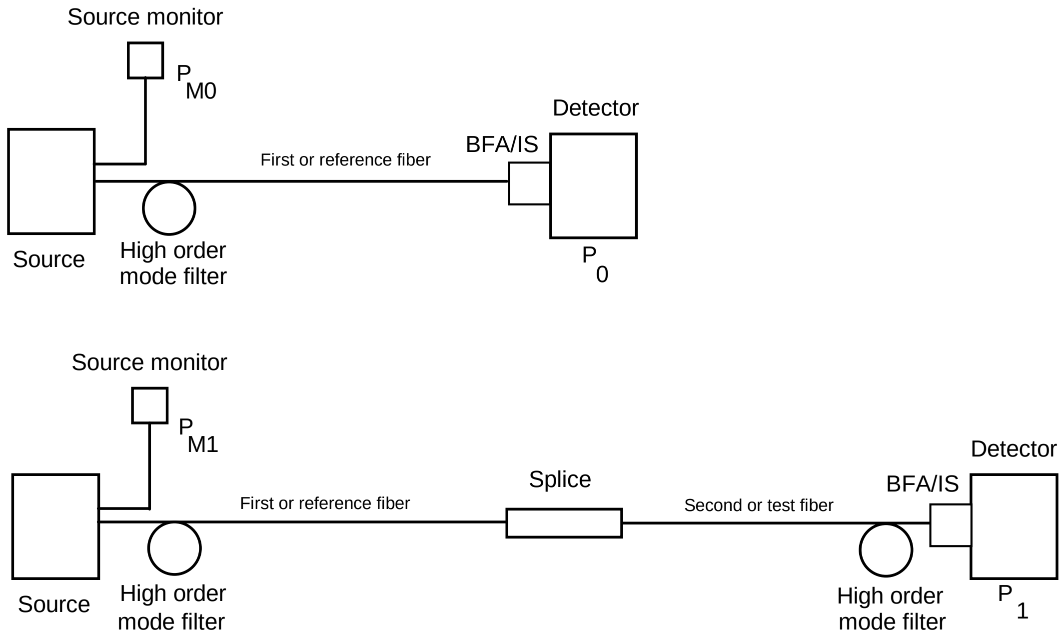

Figure 2 – Method B: add-on

Refer to 5.2 for discussion of method

BFA = bare fiber adapter, IS = integrating sphere

Figures (cont.)

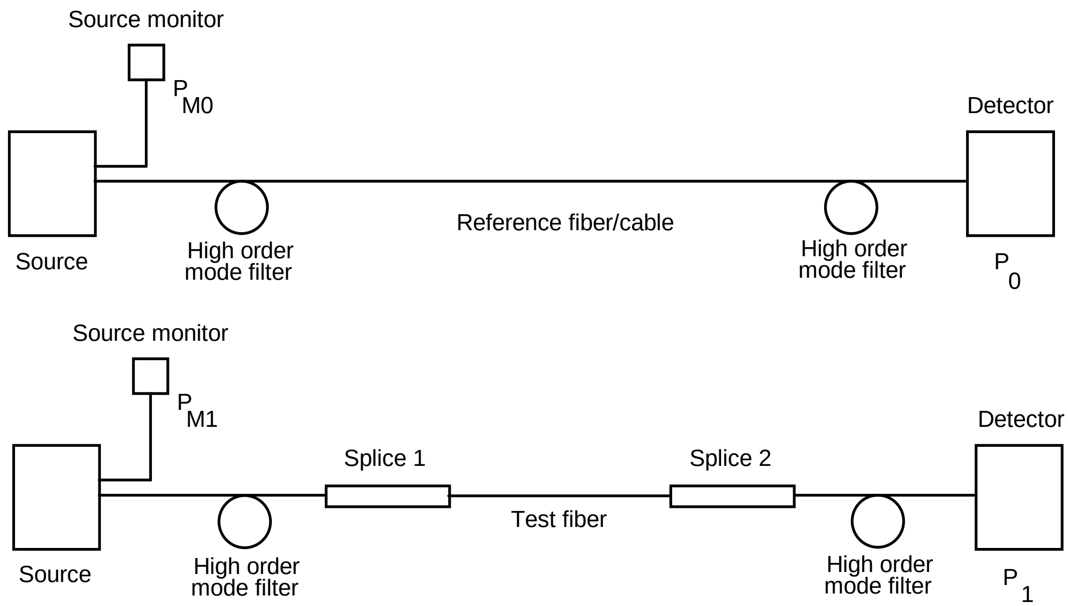

Figure 3 – Method C: inserted section
Refer to 3.4 for discussion of "High order mode filter"

Literature References

1) MSA-3: Measurement Systems Analysis, Automotive Industry Action Group, 3rd edition, May 2003.
2) Minitab

Annex A (informative)

Comparison between this FOTP and IEC or ITU-T requirements

TIA's Fiber-Optic FO-6 Committee and its various subcommittees have a deliberate policy of making every reasonable effort to "harmonize" its test methods with those of IEC (International Electrotechnical Committee) and ITU-T (International

Telecommunications Union-Telecommunication Standardization Sector -- formerly CCITT).

A1. IEC

IEC Publication 874-1, Third Edition, 4.4.7, Test Method 5, is comparable to the methods of FOTP-xx. However, the methods still differ in several respects. The IEC test proposes using fiber with idealized characteristics (presumably to be selected for nominal geometric properties). It defines the measurement condition only in terms of the mode power distribution at the joint under test, and, for multimode measurements, uses an incomplete definition of the steady-state condition that does not replicate the effect of mode mixing or mode filtering that normally follow the component under test. And attention has not been given to the accuracy and repeatability requirements for measuring very low splice losses.

There are no known IEC documents in progress at this time that relate to this FOTP.

A2. ITU-T

There are no references to any test equivalent to this FOTP known to exist in ITU-T documents.

A3. Gage R&R Method

The Gage R&R method is recommended for evaluating the capability of the measurement system relative to the loss range corresponding to the parts under test. This involves using 1 to 3 appraisers to each make repeat measurements on 10 to 30 different parts. For a complete description of the Gage R&R method see Reference 1. Using Method B (Figure 2) as an example, the reference power (P_0) is recorded, the splice is made and at least two repeat measurements are made of the final power (P_1). The repeats can be assessed by repeated preparation and insertion of the free end of the output fiber in the bare fiber adapter.

The measurement system is assessed as the percentage Gage R&R. This can be calculated as the fraction of measurement variation with respect to the total variation, or as a fraction of the measurement variation with respect to a suitable constant such as the nominal loss value expected. As described in Ref. 1, Gage R&R values <10% are acceptable, 10% to 30% marginal, and >30% indicate the measurement method is not capable.

It is recommended that the specific test method and equipment set to be used is assessed using the Gage R&R or equivalent method before performing measurements on the actual parts of interest. Gage R&R diagnostics enables the identification and correction of sources of measurement error and periodic re-assessment serves as a useful check of the test system.