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MEASUREMENT OF MULTIMODE OPTICAL FIBER ATTENUATION: AN NBS SPECIAL TEST SERVICE

National Bureau of Standards
U.S. Department of Commerce
Boulder, Colorado 80303

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This document is one of a series that describes optical fiber measurement procedures and capabilities at the National Bureau of Standards (NBS). We concentrate here on the measurement of attenuation of multimode, telecommunication-grade fibers for the wavelength range of 850 nm to 1300 nm. The document gives details on the measurement procedure, which is based on the Electronics Industries Association Recommended Standard as published in RS 455. The procedure is based on two restricted launch conditions, either of which may be used to control the modal power distribution at launch. The intent is to approximate the conditions that exist in a long link, to the end that the reported attenuation coefficient is indicative of what can be expected in long, concatenated links.

Key words: attenuation; fiber attenuation; fiber characterization; measurement; measurement techniques; optical fibers; optical waveguides.

1. Introduction

This report provides a guide to a Special Test Service being offered by the National Bureau of Standards for the measurement of multimode (telecommunication-grade) optical fiber attenuation. The intent is to offer the service as a Special Test on an interim basis. After quality assurance provisions have been tested and data have been collected to demonstrate the stability and predictability of the results, the service will be offered as a Measurement Assurance Program (MAP). A revised version of this report will be issued at that time.

We specifically exclude two major classes of fibers from consideration: (1) fibers that have a near-step index profile, such as those sometimes found in short-haul data bus applications; and (2) monomode fibers. Standard measurement procedures for such fibers are not yet fully developed. The short-haul fibers present an especially challenging problem because parameters should be measured in the proper environment which, for the data bus applications, is quite complex.

This document should be used as a supplement to existing archival literature, which is referenced. The following four sections address four key elements of the measurement service: description of the service; design philosophy; system description; operating procedure. Following that, discussion turns to errors, quality assurance, and interaction with participants.

This report describes the configuration and techniques used by NBS. Alternatives to the arrangement shown in figure 4-1 are acceptable and alternate procedures are allowed. The test procedures and launch conditions are those recommended by the Electronic Industries Association. Alternatives are allowed within the framework of those recommendations.

*Electromagnetic Technology Division, National Engineering Laboratory.

2. Description of the Service

The Optical Electronic Metrology Group of the Electromagnetic Technology Division of NBS offers a Special Test for attenuation of multimode optical fibers at 850 nm and 1300 nm wavelengths. Attention is, for now, restricted to telecommunication-grade (graded-index) fibers. The service is provided using NBS-characterized transfer standards, as described below. Participation in this program is offered for an annual fee of $2,500. The basic philosophy and some details of the MAP concept (which will evolve from this program) are given in references 1 and 2.

The direct costs for the services provided by this program are to be borne by the participants. The minimum services provided to each participant are as follows:

- An NBS-characterized transfer standard, evaluated at specified wavelengths, is forwarded to the participants twice each year. The participants measure the attenuation of this standard in accordance with their normal procedures or according to the procedures provided by NBS. The data are sent to NBS for analysis. A report will be prepared by NBS and sent to the participant. The report will give information on the precision of the intercomparison and relate the participant's data to the data collected to date by other participants and by NBS. Data from this program, along with appropriate NBS reports, will form the basis for documenting the precision of the attenuation measurements.

- A limited amount of consultation is available from the NBS staff to assist in resolving problems associated with the measurements. If necessary, an NBS staff member will visit the participant's laboratory to assist with measurement problems. In that event, the participant is expected to pay travel and lodging costs. In addition, NBS will have the option of interpreting the visit as one of the two interactions described above. Participants will be encouraged to attend group training seminars which are conducted periodically by NBS.

- NBS will maintain more than one transfer standard. All of them will be typical telecommunication-grade fibers having graded refractive index profiles. The fibers will be at least 1 km long but not longer than 3 km. Participants can have a voice in which transfer standard they receive.

- NBS will maintain intimate contact with the participant before, during, and after each interaction. Acknowledgment of order, payment, and requests will be prompt. Complete packing and shipping instructions will be given. Receipt of the transfer standard will be acknowledged. The participant and NBS will each prepay shipping charges. A suitable shipping carton will be provided by NBS.

The program is intended to allow participants to monitor progress in their measurement laboratories using this NBS-maintained transfer standard. The measurement procedure that will be used is fully described below; see also reference 3. The program is administered by

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3. System Design Philosophy

The measurement system used by NBS is designed to yield results which approximate the attenuation expected in a system consisting of several concatenated fibers. To this end, special attention is given to the proper light launch conditions. The launch establishes an equilibrium modal power distribution, so that the attenuation is uniform along the fiber; i.e., the attenuation coefficient for the first hundred meters or so of fiber is the same as that near the end of the fiber.

Either a "cut-back" technique (cf. section 5.4.1) or the insertion loss method (section 5.4.2) is used to determine attenuation or attenuation coefficient for the test fiber. The cut-back method has the advantage of more properly accounting for the input coupling loss since that loss is included for both the reference fiber and the test fiber. The insertion loss method is amenable to repeated measurements, however. For small values of attenuation, the cut-back technique is preferred.

The measurement procedures are those recommended by the Electronic Industries Association (EIA) in standard procedure RS-455.* It is almost universally accepted by the U.S. fiber community as the procedure that yields good precision and acceptable interlaboratory variations. The question of accuracy, as opposed to precision, is not addressed.

Reference 3 gives considerable attention to the light launch conditions that yield acceptable precision. References 4 and 5 give perspective to the evolution of these launch conditions and the associated reduction of variation in interlaboratory test results. The system design allows for use of either the limited-phase-space launch (LPS launch) or the mode filter launch. Details on the technology of each are contained in reference 3. The EIA specifications of the recommended light launch conditions and test procedures are in appendices A through D of this document.

If the length of the test fiber is known, the loss can be given as the integrated or average attenuation coefficient, in decibels/kilometer. If the length is not known, the total attenuation only (in decibels) is given. The philosophy of this test will be to maintain a record of test fiber length so attenuation coefficient can be used. To this end, NBS will monitor the amount of fiber used by each participant and adjust the reported length accordingly.

The NBS-characterized transfer standard, as described here, is expected to be stable. Experience indicates that with reasonable care and with a proper shipping container, the fiber does not suffer measurable damage from handling and shipping. The shipping container is, in fact, an important part of the system design philosophy. The experience gained through previous interlaboratory tests will be fully utilized in this Special Test [4,5]. Further transfer standard stability is expected by virtue of a suitable mix in the fibers selected for the standard. Only telecommunication-grade fibers will be used; the lengths will vary. Long fibers tend to be more forgiving, and for this reason the menu of available transfer standards will include long (~3 km) test fibers. In the interest of completeness, the menu will also include 1 km lengths.

*The EIA test procedures are available, for a fee, from EIA, 2001 Eye St. N.W., Washington, DC 20006.

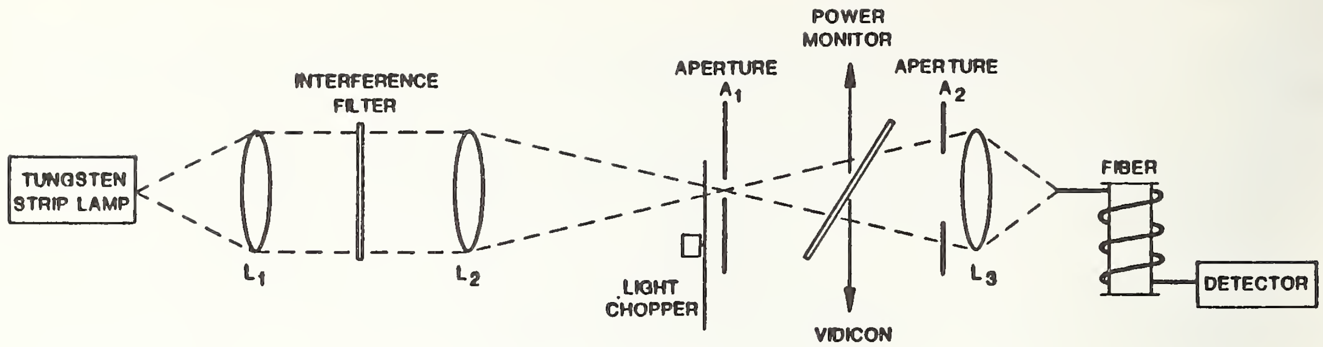

Figure 4-1. Block diagram of measurement configuration used at NBS.

4. System Description

The NBS measurement system consists of the following:

1. Light source.
2. Launch optics.
3. Optical and electronic components for energy conversion and signal processing.
4. Desk-top computer for control and data manipulation, including calculation of averages and standard deviations.

A block diagram of the configuration is given in figure 4-1. The details in the following apply specifically to this system. Other components may serve as well.

4.1 Light Source

A tungsten strip filament lamp is driven by a regulated power supply to provide a stable source of white light which is filtered to provide a nominal 10 nm line width at the wavelength of interest. The interference filters used to select the wavelength provide average blocking of 10^4 from the ultraviolet to the infrared outside the passband of the filter.

The effective light source is the aperture A_1. The size of A_1 determines the size of the launch spot on the fiber. A_1 is in the focal plane of L_2. Figure 4-1 shows a typical configuration, but alternatives are possible.

The interference filters are designed for use at normal incidence, so the light is collimated by L_1 before it encounters the filter. When the filter is used with other than normal rays, the apparent thickness of the vacuum deposited layers is changed, causing a shift of the peak transmitted wavelength. The shift is always toward the shorter wavelengths.

One side of the interference filters normally has a highly reflective metallic appearance. The reverse side appears colored or opaque. If filter heating is a potential problem, the reflective surface should face the source. Such orientation minimizes the heating effect caused by IR absorption in the colored glass that may be used.

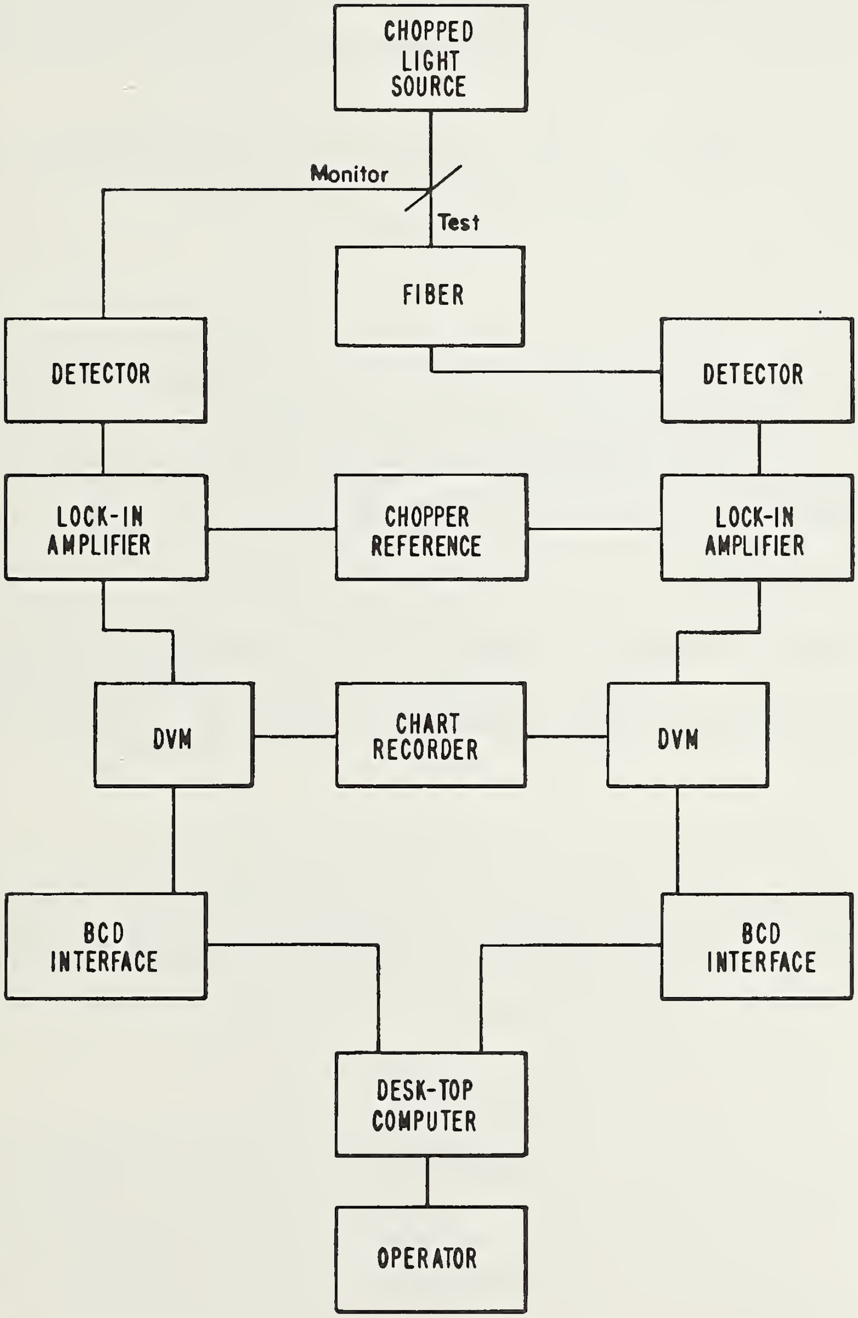

Figure 4-2. Block diagram of control experiment control and interdependence of system components.

4.2 Launch Optics

Three lenses, two apertures, and a beamsplitter comprise the launch optics of the system. Lenses L_1 and L_2 establish the proper collimation of light and subsequent focusing of the strip lamp onto A_1. L_1 is a 75 mm lens; L_2 has a focal length of 250 mm. L_3 is a 12.5 mm camera lens with iris diaphragm and maximum aperture f/1.4. The lens will accept a cover plate onto which may be attached an aperture that may alternatively be used to control the effective lens aperture. The aperture of L_3, whether internal or external to the lens, is designated A_2 in figure 4-1. Aperture A_2 controls the launch numerical aperture (LNA) of the system.

The beamsplitter is placed in the system to provide a way of examining the launch conditions via the vidicon and monitor. It also allows the launch power to be monitored. If drift is encountered, the final calculation of attenuation can account for the drift.

4.3 Optical and Electronic Components

The light chopper is placed in front of aperture A_1. The detector at the end of the fiber is matched to the detector placed in the power monitor arm. Those detectors are wide area silicon photodiodes for operation at 850 nm and germanium photodiodes for operation at long wavelength (1300 nm). Figure 4-2 shows how the operator controls the signal processing.

4.4 Control and Data Handling

The desk-top computer drives the entire data-gathering function and calculates average attenuation and standard deviation. The computer program, which is described later, contains prompts and audible tones to assist in the data-collecting function. Results are printed by the computer.

5. Operating Procedures

Prior to making measurements, the operator must establish parameters for the launch optics. In particular, the magnification (m) of the source aperture (A_1) and the effect of aperture A_2 on launch numerical aperture (LNA) must be known (see fig. 4-1). The launch spot size (A_L) is given by

$$A_L \cong A_1(f_3/\ell) = A_1 m \qquad (5\text{-}1)$$

where f_3 is the focal length of L_3 and ℓ is the distance from A_1 to L_3. As the system is configured at this writing, m = 1/21.6.

Lens L_3 has focal length 12.5 mm. The diameter of A_2 determines the launch numerical aperture (LNA) through the relationships

$$\text{LNA} \cong \frac{1}{2f\#} \qquad (5\text{-}2)$$

and

$$f\# = f_3/d \qquad (5\text{-}3)$$

where d is the diameter of aperture A_2. The f# markings on the lens are accurate enough to establish launch numerical aperture via eq (5-2); confirmation of this fact is discussed in the next section.

5.1 Measuring Demagnification and LNA

Whether using the LPS launch or the mode filter launch, knowledge of the launch spot size (A_L) and the launch numerical aperture is required. Launch spot size is deduced from the known size of aperture A_1, and the measured demagnification

$$A_1 = A_L/m.$$

5.1.1 Demagnification

Demagnification is measured as follows:

1. Place an aperture that is small with respect to expected size A_L in front of the detector.
2. Place the detector on the translation stage in the image plane of L_3.
3. Measure the launch spot size A_L by noting the translation stage readings at the 5 percent intensity points of the spot. Improved precision is had by moving the detector (using the translation stage) in both the horizontal and the vertical planes. The average of the two deduced sizes is used to determine m, using A_1 and the measured value of A_L. A_1 is measured using a microscope and a vernier translation stage. The aperture is placed on the movable bed and the translation stage movement, as read on the vernier, is noted as the diameter of the aperture is scanned.
4. Determine m at several wavelengths to confirm that m is insensitive to wavelength.

5.1.2 LNA

Launch numerical aperture can be measured to confirm that eq (5-2) is adequate. The measurement that is described in the following will also verify that an external aperture in front of L_3 serves as well as using the f-stops on lens L_3. L_3 has focal length of 12.5 mm. If the f-stop is set at 4, the aperture of the lens is

$$d = f_3/4 = \frac{12.5 \text{ mm}}{4} = 3.125 \text{ mm}.$$

The measured LNA is the same for the two following conditions:

1. f-stop set at 4, no external aperture, or
2. f-stop at the extreme (1.4) and an external aperture of diameter 3.125 mm in the front of the lens.

Evidently, the total power of the lens elements that precede the iris diaphragm is small, so the external stop has the same diameter as the iris diaphragm. In general, the external stop and the iris diaphragm need not be the same size.

To measure LNA, place the detector on the translation stage in the far field of the image of A_1. The detector must have an aperture larger than the one used to measure launch spot size because signal level is now considerably lower. The aperture must be small with respect to the expected width of the far-field pattern. The distance from the image plane of L_3 to the plane of measurement is denoted D and is read from the vernier scale. LNA is then found from the value of D and the value of W, the width of the pattern at the 5 percent intensity points in the far field:

$$LNA = \sin(\tan^{-1}\frac{W}{2D}).$$

5.2 Meter Settings

The chopper is set at about 43 Hz; harmonics of 60 Hz should thereby be avoided. The time constant of the lock-in amplifier (LIA) is set at 0.4 s for most measurements. The chopper has a two-aperture blade.

The sensitivity scale of the LIA is set with due consideration of the anticipated attenuation of the fiber. One should avoid making a scale change when going from the test fiber to the reference fiber if possible. A change of scale usually represents a 5 dB change; the scale markings sometimes imply that the change is 10/3 or 3/10, depending on direction. Measurements in our case indicate the change is $\sqrt{10}$, or 5 dB (optical).

With the long test fiber in place, the sensitivity scale is set to allow for the expected increase in level when the short reference fiber is in place. Adjustment of input power may be called for. In this regard, the decibel (electrical) scale on the LIA can be used for guidance. A 5 dB increase in optical power corresponds to 10 dB electrical power.

The sample rate adjustment of the digital voltmeter must be turned off to facilitate computer operation. Sampling will then be done in response to a command from the computer.

The phase of the LIA is adjusted after the optical path is established. Readjustment is normally not required unless the electrical phase is changed. If measurements are made at 850 nm and 1300 nm, for example, the detector may be changed. In that event, the LIA phase must be readjusted before measurements are made at the second wavelength. Failing to adjust the phase properly will lead to abnormally high standard deviation.

5.3 Computer Operation

The NBS program that takes data and calculates attenuation is stored under the file name "ATTEN." Several prompts appear on the screen during the course of the measurements. The program will not continue until the operator responds to a prompt. In many cases, the screen asks for a yes or no response. The operator should respond with Y or N.

The operator has the option of monitoring the light source or not, as he chooses. The program will ask for that decision. No extra effort is required of the operator if he chooses to monitor the light source. The program adjusts for drift if that choice is made.

The operator will be asked to specify the number of readings and the time (in milliseconds) between readings. The program is liberally laced with audible "beeps" to help track the process. Several time constants of the LIA should elapse between readings, to insure that the readings are independent. Thirty to sixty readings are taken each time, yielding a reasonable average and standard deviation.

The program allows for printout of only the attenuation, including standard deviation, or printout of the intermediate data as well. If the intermediate reading is not printed, it is displayed on the screen, allowing the operator to view the data; unusual or obviously erroneous data can be spotted at that time.

5.4 Measurement Using the LPS Launch

For low-loss fibers, a true cut-back approach is recommended. This technique ensures proper allowance for input coupling loss. The alternative is an insertion loss approach, described below. The procedure described here is that usually used at the NBS/Boulder Laboratories.

5.4.1 The Cut-Back LPS Method

The procedure is as follows:

1. Prepare the two ends of the test fiber. Remove the fiber jacket and lacquer, if any, from about 10 cm of each fiber end. Place these 10 cm sections on the mode-stripping felt pads at the input and output ends of the fiber. Carefully cleave or polish the ends and examine them for acceptability. The fiber end should be smooth and free of hackles and dust. The cladding will invariably be damaged, by virtue of the cleaving process. The core, however, must be undamaged. Place the fiber ends on the supporting beds at the input and output ends. Be sure the detector is placed to ensure that all the light out of the fiber is collected. The grooves in the bed help with the alignment. The fiber should extend beyond the bed by only a small amount (a few millimeters).
2. Use the vidicon to assist in the alignment. The maximum output--power criterion is used to complement the visual inspection. At long wavelengths, the silicon vidicon tube is not effective; transverse alignment is therefore done at a short wavelength (e.g., 850 nm). The filter wheel is then set at the desired long wavelength and the focus is adjusted by using the maximum response criterion. Apertures A_1 and A_2 are set according to the needs of the LPS launch: launch spot size and LNA are to be 0.70 ± 0.05 of the fiber core size and fiber NA.
3. Adjust the phase of the LIA (lock-in amplifier) for maximum response. With the fiber properly aligned and the digital volt meter (DVM) reading the detector response, note the meter deflection of the LIA. Determine whether or not the meters will saturate when the long test fiber is replaced by the short reference fiber. If the expected fiber optical loss is 2 dB, for example, the meter should be at least 4 dB below maximum. If it is not, decrease the input source drive voltage so a 4 dB increase in signal level will be accommodated without changing scale of the LIA. If a change of scale cannot be conveniently avoided, proceed with the measurement but adjust the final calculated attenuation by subtracting 5 dB. The LIA phase must be readjusted if the phase path of the signal is changed. Normally, such readjustment is not required once the system is set for the wavelength of interest.
4. Turn the sample rate knob completely counterclockwise to allow for remotely controlled sampling rate. Begin (RUN) the computer program. A computer prompt instructs the operator to block the light, allowing detector dark current to be accounted for.

5. When readings on the long test fiber are completed, the computer will prompt the operator to prepare the reference fiber. To do so, cut the fiber about 2 m from the input end. Without disturbing the light launch conditions, prepare the newly-cut end with a smooth cleave. Couple the 2 m section to the detector using the same care used with the test fiber. With the reference fiber in place, ensure that the meters have not saturated under the new conditions of increased signal level.
6. Continue the measurement process by pressing "continue" on the computer.
7. Conclude the measurement by responding to all the prompts of the computer.

5.4.2 The Insertion Loss LPS Method

This method is like that described in the foregoing, with the following exception. The initial step is to remove about 2 m of fiber from the test fiber. The four ends are prepared as described in paragraph 5.4.1-1. The short 2 m section is the reference fiber. The reference fiber and the test fiber input ends are placed in the two grooves of the input bed. Likewise, the two output ends are aligned on the bed at the detector end. Measurement proceeds as before but now end preparation is not required after the measurement begins. The translation stage allows for movement of the reference and the test fibers, at will. A new adjustment of alignment and focus of input light coupling is required each time, but the method allows for remeasurement without preparing fiber ends each time. The technique assumes that the quality of the input ends are equivalent and that the alignment produces equivalent input power levels in moving from one fiber to another. This two-fiber method is not recommended for low-loss fibers, in which case input coupling loss may be a significant part of fiber insertion loss.

The EIA document which describes the insertion loss method is FOTP#53, which is published in the RS 455 series.

5.5 Measurement Using the Mode Filter Launch

The mode filter launch requires the filter to be qualified for the fiber to be tested. Since fiber NA is relatively insensitive to wavelength for the range of wavelengths of interest, a mode filter needs to be qualified only at 850 nm. The same filter can be used to measure attenuation of the same fiber at longer wavelengths. However, a filter qualified for one fiber may not be adequate for another fiber. Similar fibers from the same manufacturer often have similar characteristics, however, and the same filter will serve in that case.

A mode filter is qualified through the far-field radiation pattern. The pattern for the long test fiber is measured first. The technique is as follows.

1. Use a spectral filter of 80 to 100 nm width to improve signal-to-noise ratio in the far field of the fiber. The spectral filters in the filter wheel are nominally 10 nm wide.
2. The fiber is overfilled at launch with this method. The launch spot size is at least the fiber core size and launch NA is at least as large as fiber NA.
3. Prepare the two ends of the long test fiber and place one end on the mode stripper and bed at the input end of the system. The output end is likewise placed in the groove of the far-field measurement apparatus. Each fiber end should have its jacket, buffer, and lacquer, if any, removed for about 10 cm, as previously described. This facilitates the mode stripper, if one is used.

4. Adjust the phase of the LIA. Adjust the scan rate by adjusting the stepper motor speed to less than about 40 steps/second if the LIA time constant is 0.4 s.
5. Using the strip chart recorder, record the far-field pattern of the test fiber with no mode filter in place.
6. Remove about 2 m of fiber and prepare both ends. Repeat the far-field pattern measurement for the short fiber with the mode filter in place.
7. Adjust the mode filter until the far-field beamwidth at the 5 percent intensity points is the same for the short fiber with the mode filter as it is with the long fiber without the mode filter. The tolerance on the match is ±3 percent. Denoting θ_L as the beamwidth for the long fiber and θ_S that for the short fiber with filter, the EIA requirement is

$$\frac{\theta_S - \theta_L}{\theta_L} = -0.03 \pm 0.03.$$

8. After the mode filter is qualified, remove the short fiber from the circuit. Use the filter with the long test fiber and the reference fiber to measure the attenuation using the technique described in section 5.4.1 (The Cut-Back LPS Method). The filter must be in place on the test fiber and the reference fiber, to ensure that the insertion loss of the mode filter is accounted for.
9. The insertion loss LPS method may be used with a mode filter launch, the procedure being analogous to that described in section 5.4.2. The initial step is to prepare the four ends of two fibers. One fiber is the long test fiber, the other is a short reference piece removed from the test fiber. The mode filter is qualified as described above. The reference and test fiber input ends are then placed in the two grooves of the translation stage bed at the input end of the system. The translation stage allows the operator to alternately move the reference and the test fibers into alignment and focus so light can be launched into the chosen fiber. Power is launched alternately into the reference fiber and the test fiber with the filter in place in each case. The two output ends are aligned on the bed at the output end so coupling between the fiber and the detector is the same for each of the two fibers. The ratio of powers out of the two fibers yields the loss of the test fiber, assuming the input and output coupling losses are the same for the two fibers and that the loss of the short reference fiber is neglibly small.

   The insertion loss method of fiber attenuation measurement is designated FOTP #53 by the EIA.

5.6 Procedures Summary

The techniques described here are based on EIA procedures (RS 455). The output reading is in decibels. Conversion to decibels/kilometer requires knowledge of test fiber length, as determined independently.

The EIA recommended light launch conditions (FOTP #50) and the recommended measurement procedures (FOTP #46) are given in the appendices; FOTP #50 is reproduced in appendices A through C while FOTP #46 is reproduced in appendix D.

6. Measurement Errors

Systematic error is the difference between the average of a large number of measurements and the true value. Systematic error can often be estimated even though the true value of the parameter being measured is unknown. The measurement of fiber attenuation is unusual because there exists no true (unique) value of the attenuation coefficient. Because measured loss depends on light launch conditions. Fiber loss is therefore not a function of the fiber only. This is discussed in detail in references 3 through 5.

Systematic measurement error therefore remains unknown and possibly undefinable. The procedure used by NBS follows the recommendations of the Electronics Industries Association in RS 455. The procedure defines the light launch condition to be used. If the recommended launch conditions are followed, the measurement is expected to yield consistent results.

Random errors are attributable to two causes: those from the electrical and optical components and those introduced by the operator. Random operator errors are those introduced in cleaving the fiber ends and those introduced in aligning the paraphernalia for proper launch. The total measurement random error is found by preparing new fiber ends and completely realigning the system each time a measurement is made. This yields a measure of precision but not of accuracy.

7. Quality Control

A desk-top computer is used for control and operation of the test equipment. It has permanent file storage and an interactive terminal to allow data management and archival storage of measurement history. As this Special Test evolves into a Measurement Assurance Program, all reports to participants will be generated by a computer. The computer file will be arranged so participant, transfer standard identification, loss data, wavelength, and historical perspectives can be accessed at will. The computer will also help track shipping history and associated problems.

Previous experience in handling transfer standards will be exploited. Guidelines include the following:

1. Format. computer files will be arranged so data for each transfer standard are clearly identifiable for each wavelength. Each data set will thus be treated statistically as an independent entity for each wavelength and each fiber. Code numbers will identify separate sets of data. The computer will detect trends, shifts and excessive scatter in the data. The reports will then include analysis of anomalies.
2. Reports to Participant. The reports will contain pertinent shipping information, including dates, condition of carton, result of visual inspection, amount of fiber used and condition of fiber. Participant's data will be compared with accumulated data from other participants and NBS.
3. Calibration Equipment calibration data will be stored on computer and updated at regular six-month intervals.

The transfer standards will be in one of three categories at a given time:

1. Preliminary status. During the first few months, the transfer standard will not yet have been characterized by many laboratories outside of NBS. During this period, the data collected by NBS

will form the basis of comparison and guidance. During this time, the quality control functions will also be modified as required in accordance with accumulating data. The transfer standard will be in service while in the preliminary status but it will be monitored closely, watching for instabilities that may appear as a result of handling and shipping.

2. Active status. Once sufficient data have accumulated for a transfer standard, it will be in active status. After a standard has been measured by 10 participants, it will be placed in the active status.

3. Inactive status. It may happen that a fiber transfer standard becomes unstable after being handled a few times. If it appears that the characteristics of a fiber are not stable, that standard will be placed in inactive status until the source of the problem can be determined and resolved. This category may also include fibers that have not been measured for a year.

The expert editorial assistance of Edie DeWeese is gratefully acknowledged.

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Appendix A. Light Launch Conditions for Long-Length, Graded-Index, Optical Fiber Spectral Attenuation Measurements (FOTP #50)

A.1 Intent

This procedure is the accepted EIA Standard Proposal and is published in the EIA RS 455 series as FOTP #50. It establishes the light launch conditions for measurements of fiber spectral attenuation. It applies only to Class I graded-index multimode fibers (see table A-1).

Either of two procedures is allowed. Procedure A uses overfilled launch conditions and a mode filter (cf. appendix B). Procedure B uses restricted launch conditions created by beam optics (cf. appendix C). Both procedures have yielded attenuation values that add approximately linearly in concatenated links.

A.2 Test Equipment

1. Light Source

The source shall be that used in the measurement of fiber attenuation (FOTP #46; see appendix D).

2. Beam Optics

The beam optics shall be capable of creating a substantially uniform radiance beam with an image spot of variable size and variable angular convergence, movable upon the input endface of a fiber.

Table A.1. Classes of fibers

General type	Class	Index	Profile parameter, g*	Core material†	Cladding material†	Jacket material
	Ia	graded	$3 > g > 1$	glass	glass	--
	Ib	quasi-	$10 \geq g \geq 3$	glass	glass	--
	Ic	step	$g > 10$	glass	glass	--
Multi-mode	IIa	step	$g > 10$	glass	plastic††	--
	IIb	step	$g > 10$	glass	plastic‡	plastic
	III	step	$g > 10$	plastic	plastic	--
Single mode	IV	to be deter-mined	to be deter-mined	glass	glass	--
Special	V					

* The symbol "α" has been used in the past to refer to the profile parameter, but in the interest of international standardization "g" is now being used, while "α" is being used for attenuation rate.

† The term "glass" refers to an amorphous material consisting of metalic oxides.

††The cladding of Class IIa fibers is normally retained for purposes of connectorization.

‡ The cladding of Class IIb fibers is normally removed for purposes of connectorization.

3. Fiber Support, Output Optics, Detector System

These shall be according to one of the methods of FOTP #46 and FOTP #47, capable of recording the light output intensity from the fiber versus angular position relative to the fiber axis.

4. Mode Filter (Procedure A)

A mode filter, such as a mandrel wrap, an s-shaped macrobend, or a dummy fiber, shall be provided. Appendix B gives examples of such filters.

5. Cladding-Mode Stripper (Procedure B)

Such strippers shall be used at the source and detector ends of the fiber.

A.3 Test Sample

1. The test sample shall be a length of multimode fiber prepared in the method common to FOTP #46 and FOTP #47.

2. The minimum fiber test length shall be 1 km.

A.4 Test Procedures

1. Procedure A

   a. On the full length of test fiber, the beam optics are adjusted to produce a nominal launch spot of diameter greater than the nominal core diameter and a nominal launch numerical aperture greater than the nominal fiber NA. (If the nominal fiber core diameter and/or nominal fiber NA are not known, they must be determined by FOTP #43 and/or FOTP #47, respectively.) The fiber is positioned in the input beam to obtain an imaged spot centered on the core or to obtain maximum power at the fiber output.

   b. For this fiber the far-field radiation pattern is obtained as per FOTP #47. The 5 percent intensity radiation angle θ_5 is measured.

   c. The mode filter (appendix B) is applied to a 1 to 2 m length of test fiber such that its 5 percent intensity radiation angle θ_5 is -3 ± 3 percent of the width measured in A.4(1b). This tolerance should be met under repeated applications of the mode filter.

   d. Transmission measurements on the test fiber shall be performed with this mode filter applied to the full length and to a cut-back reference length of 1 to 2 m.

2. Procedure B

   a. The beam optics (appendix C) are adjusted to produce an imaged launch spot having a diameter at the 5 percent intensity points equal to 70 ± 5 percent of the nominal core diameter and a launch numerical aperture (sine of half-width at the 5 percent intensity points) equal to 70 ± 5 percent of the fiber nominal NA. (If the nominal values of core diameter and/or NA are not known, they must be determined by FOTP #43 and/or FOTP #47, respectively.)

   b. The launch beam shall be imaged and centered on the fiber core to within a tolerance of 5 μm.

c. Transmission measurements on the test fiber shall be performed with this launch beam and a cut-back reference length of 1 to 2 m.

A.5 Documentation

The following information shall be reported:

1. Which procedure, A or B, was used.
2. Details of procedure A, if used:
   a. The long-length far-field pattern width.
   b. The type of mode filter used.
   c. The short-length far-field pattern width attained with the mode filter.
3. If procedure B was used, the launch spot diameter and launch NA width.
4. The nominal fiber core diameter and NA.
5. The type of cladding-mode stripper used.
6. The cutback reference length.

A.6 Summary

The following details shall be specified in the detail specification.

A. Type of fiber or cable to be tested.

B. Procedure number and type.

Appendix B. Examples of Mode Filters (FOTP #50)

B.1 Dummy Fiber Mode Filter

The fiber usually is a type similar to that of the test fiber. The filtered incoherent light source of FOTP #46 is used. The dummy fiber is spliced to a 1 to 2 m length of test fiber (fig. B-1) and the launch conditions and dummy fiber length are adjusted such that the criterion given in A.4(1c) is satisfied. The dummy fiber length is usually between 0.5 and 1 km [6]. The splice is then broken and the dummy fiber mode filter used as in A.4(1d).

B.2 Mandrel Wrap Mode Filter

The input end of the test fiber is overfilled in both launch numerical aperture and spot size with light from the incoherent filtered source of FOTP #46. The input fiber end is subjected to a helical wrap within a 15 mm region of a smooth mandrel (fig. B-2), with no overlapping turns and no tension beyond that required to maintain contact between the fiber and mandrel. (Sticky tape may be used to support the wrap.) About 1 m of fiber should follow the wrap, but if the coating has an index lower than that of the cladding, a cladding-mode stripper may have to follow the filter.

The far-field pattern is affected by the number of wraps and the mandrel diameter [7]. Both are selected so that the criterion of A.4(1c) is satisfied, and these values will be sensitive to fiber core and outside diameters, to fiber numerical aperture, and to fiber length. For a particular fiber, figure B-3 (after ref. 8) shows the percentage change in θ_5 in going from the unfiltered full length to the filtered short length. For this fiber, 5 turns around a 2.5 cm diameter mandrel meets the criterion very well; otherwise fewer turns around a smaller mandrel could be used.

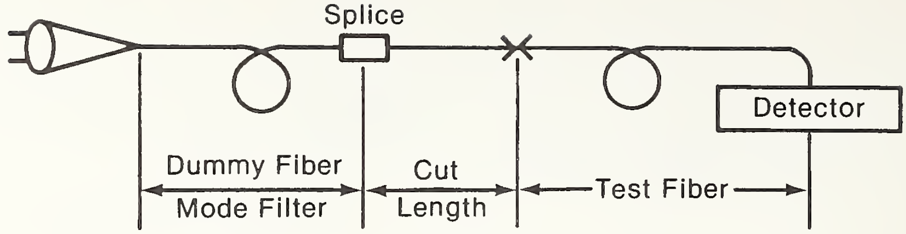

Figure B-1. Dummy fiber mode filter.

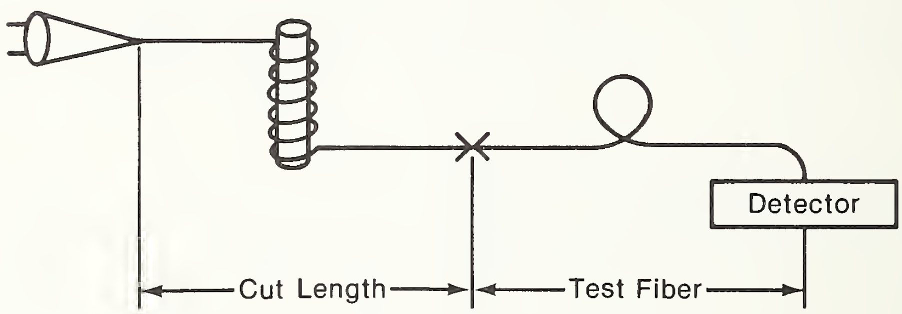

Figure B-2. Mandrel wrap mode filter.

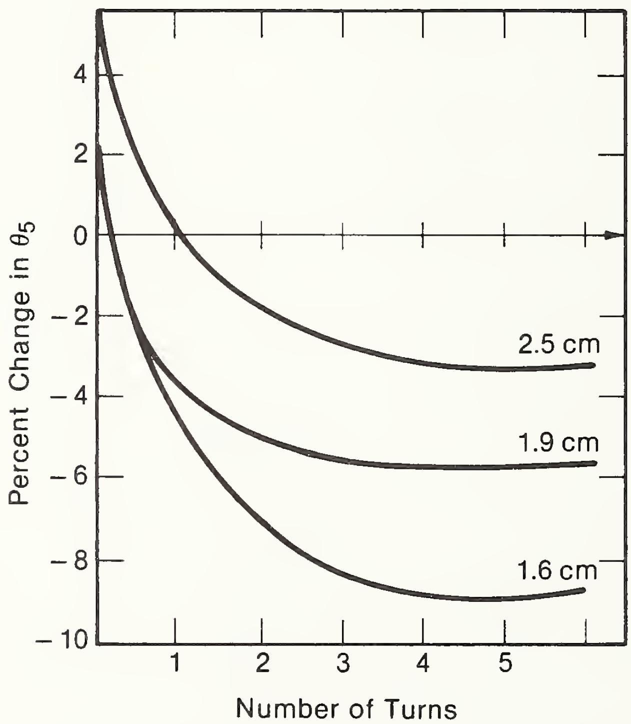

Figure B-3. Change in the far-field 5 percent intensity angle in going from full fiber length to a short length with a mandrel wrap for various numbers of turns and mandrel diameters. Fiber length 2.14 km, core diameter 50 μm, fiber diameter 125 μm (after ref. 8).

Appendix C. Example of Beam Optics Launch System (FOTP #50)

Figure C-1 shows a typical beam optics system. All components are commercially available. Light from a tungsten filament source (a flat filament for best uniformity) is imaged onto aperture A1 by the condenser lens L1, after passing through an optical filter F for wavelength selection. Light passing through A1 is collimated by L2 when the optical distance between these elements is exactly equal to f2, the focal length of L2. The light proceeds through the uncoated pellicle beamsplitter B to the launch NA (LNA) control aperture A2. This round aperture restricts the beam diameter entering L3, thereby limiting the maximum angle of light which L3 focuses at its front focal plane. (Both A1 and A2 are knife edged.) An image of A1, whose size is A1 x F3/F2, is located exactly in this focal plane, as is the test fiber end, mounted (in a vacuum chuck, for example) on a suitable micropositioner. Light reflected from the fiber endface is recollimated by L3 and directed by B to the viewing telescope V. F3 is typically 8 mm, and with a 20X eyepiece in V overall magnification of the fiber end is about 400. By providing a concentric circle reticle in the eyepiece and aligning V such that the optical spot produced on the end of the fiber is centered in the reticle, it is quite easy to center the fiber position within 5 μm.

Usually A1 and A2 are movable plates with two or more aperture sizes: one to create a large diameter and LNA spot to locate and align the fiber, and the others to create the appropriate 70 percent spot diameter and LNA for tests. A rotatable detent mechanism is precise enough for A2; greater precision is required if A1 is to be moved and this is usually accomplished with a precision stepper-motor-driven translator. Filters F are also mounted on a detented rotating wheel for wavelength selection and white light fiber viewing. It is best to place a large, stationary aperture in front of filter(s) F to prevent light leakage through the filter edges.

A system is designed as follows:

- Choose L3 for a short focal length (6 to 10 mm) and NA greater than 0.35.
- Size the aperture(s) A2 = 2 • NA3 • F3 and locate A2 immediately adjacent to L3.
- Separate L2 and L3 by typically 15 to 25 cm (not critical).
- Choose A1 and L2 to create the proper launch spot sizes. Trade off a short optical system (small F2) for a larger aperture A1 and less position sensitivity in A1. Typical demagnification of A1 is 1/15.
- Choose L1 to magnify light source filament by factor of 1 to 5, depending on filament size. Magnification is not critical as long as the image is greater than the largest aperture in A1.
- Use standard 1 in diameter interference filters close to A1.

A single lens can be used in place of L2 and L3, but the two-lens system offers the following advantages:

- Diffraction-limited launch near- and far-field patterns.
- Free choice of distance between L2 and L3.
- Ability to introduce any other collimated light source into optical path between L2 and L3, with free choice of image size of the additional source.
- Spot size/NA accuracy limited only by tolerances of F2 and F3, and accuracy of A1.

With sufficient attention to detail in implementation and alignment, long-term measurement reproducibility significantly better than 0.1 dB/km has been achieved.

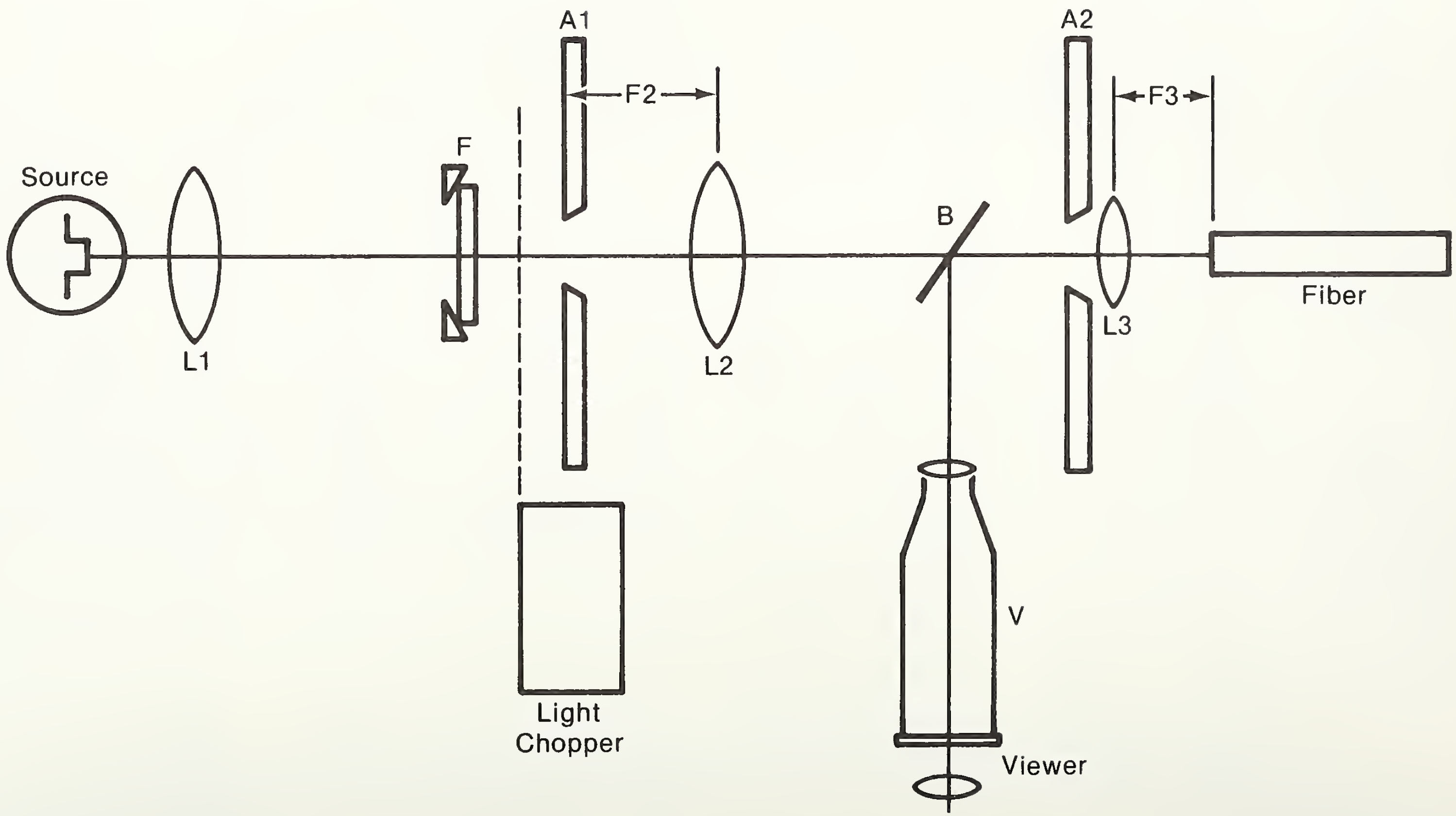

Figure C-1. Schematic of a limited-beam optics launch system.

Alignment of the system is accomplished as follows. The optical system axis is established with a low-power helium-neon laser. Optical elements and apertures are inserted one at a time, maintaining correct beam alignment. The laser is removed and the tungsten light source is imaged onto A1. The location of A1 relative to L2 must be adjusted precisely to distance F2 by looking back toward the filtered light source through L2 with an infrared viewer or camera focused for infinity at the test wavelenth (not shown in fig. C-1). This is done by temporarily inserting an additional beamsplitter between L2 and L3, with the IR viewer perpendicular to the optical axis. Location of A1 is correct when its image is in focus in the IR viewer. Correct fiber location is now obtained by rotating temporary beamsplitter so that light reflected from fiber input end is in focus on IR viewer at test wavelength. Without moving the test fiber, V is adjusted so the fiber end is in focus when viewed with white light.

Appendix D. Spectral Attenuation Measurement for Long-Length, Graded-Index Optical Fibers (FOTP #46)

D.1 Intent

1. Restrictions

   This test method describes a procedure for measuring the spectral attenuation of long-length (≥1 km), graded-index, multimode optical fibers. The method is published as FOTP #46 in the RS 455 series of the EIA.

2. Definition of Spectral Attenuation

   The fiber attenuation $A(\lambda)$, in decibels, at wavelength λ between two cross sections 1 and 2 separated by distance L is defined as:

$$A(\lambda) = 10 \log \frac{P_1}{P_2}$$

   where P_1 is the optical power traversing the cross section 1 and P_2 is power traversing cross section 2.

   For a uniform fiber under equilibrium conditions, it is possible to define an attenuation per unit length, or an attenuation rate $\alpha(\lambda) = A(\lambda)/L$ which is independent of the length of the fiber.

D.2 Test Equipment

(See fig. D-1).

1. Light Source

   A suitable spectrally rich incoherent light source such as a tungsten-halogen or xenon arc lamp shall be used. It shall be stable in intensity over a time period sufficient to perform the measurement.

2. Optical Filters/Monochromator

   A specified set of test wavelengths shall be obtained by filtering the spectrally rich light source with a set of optical filters or a monochromator. The 3 dB optical bandwidth of the filters shall be less than or equal to 25 nm.

3. Input Optics

   The necessary input optics depends on which procedure of FOTP-50 is used for the launch.

   a. Procedure A, Mode Filter

      Suitable optics shall be used to produce a beam of uniform intensity over the fiber core with a launch numerical aperture greater than the fiber numerical aperture.

   b. Procedure B, Beam Optics

      Suitable optics shall be used to independently control launch spot size and numerical aperture and to center the launch spot on fiber core.

4. Mode Filter

   If procedure A is used, a mode filter which removes cladding modes, leaky modes, and selected propagating modes shall be provided. The method used for selecting a mode filter is described in FOTP-50. A mandrel wrap or long length of dummy fiber is recommended for use.

5. Fiber Support and Positioning Apparatus

   A means of stably supporting the input end of the fiber, such as a vacuum chuck, shall be arranged. This support shall be mounted on a positioning device so that the fiber end can be repeatedly positioned in the input beam.

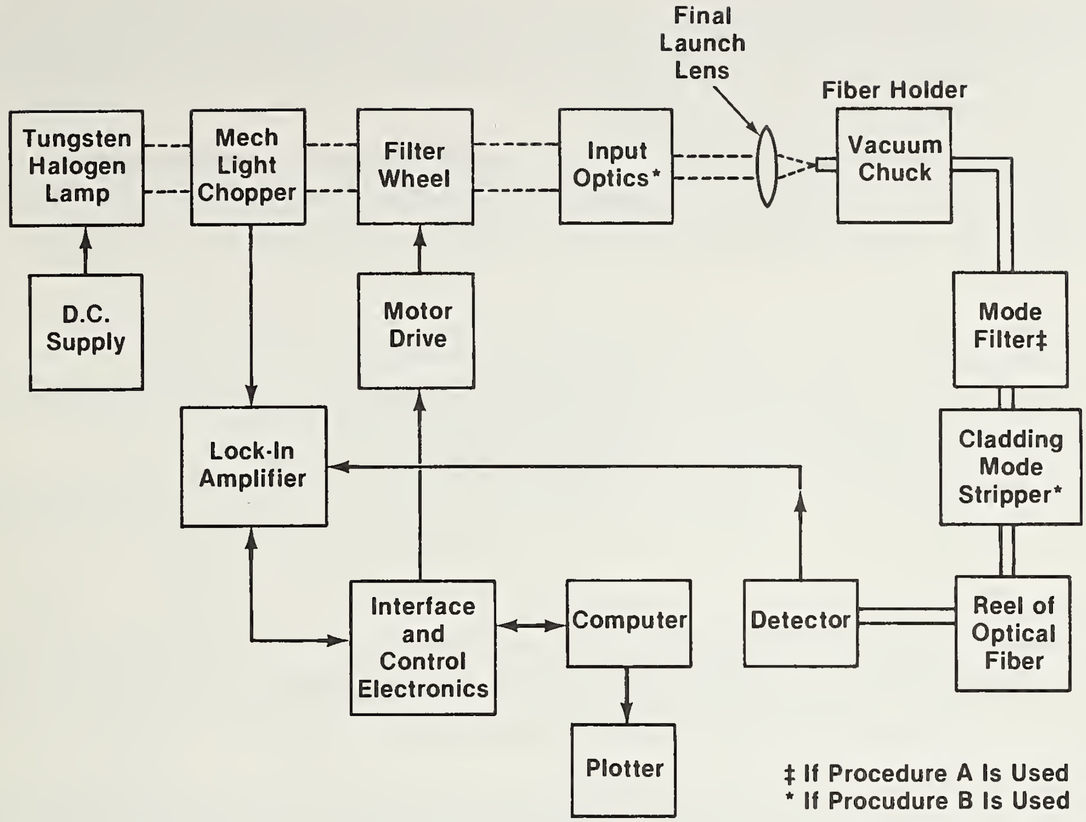

Figure D-1. Configuration for spectral loss measurement set.

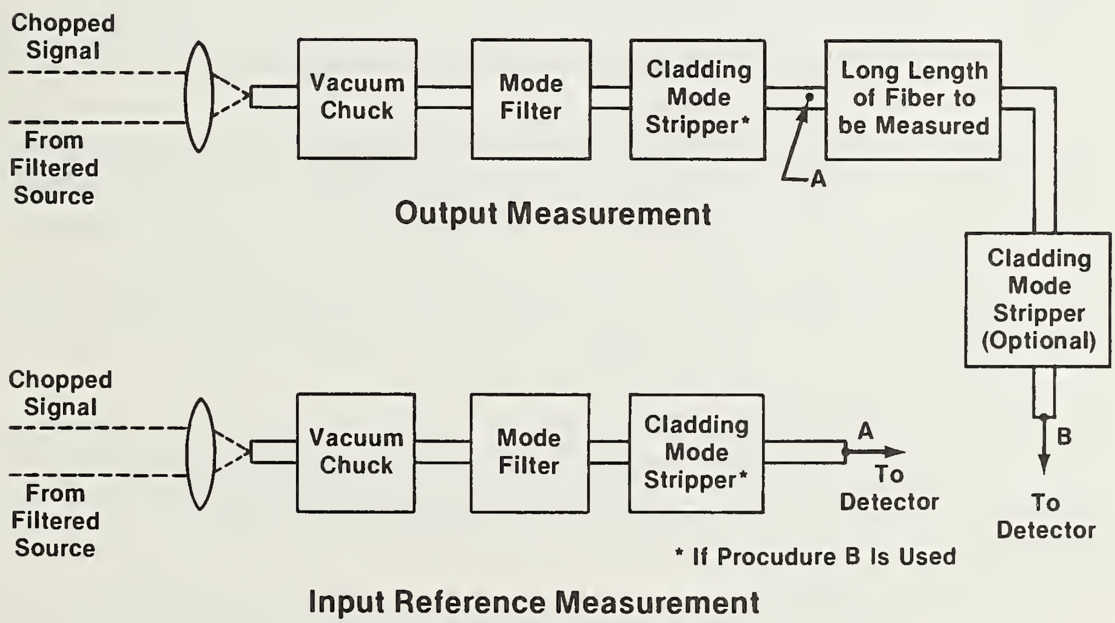

Figure D-2. Two-point spectral attenuation measurement.

6. Cladding Mode Stripper

A device which extracts cladding modes shall be employed at the input end of the test fiber. If procedure B is used, a cladding mode stripper may be needed to extract the cladding modes.

7. Detector--Signal Detection Electronics

A detector which is linear over the range of intensities that are encountered shall be used. A typical system might include a photovoltaic mode photodiode amplified by a current-input preamplifier, with synchronous detection by a lock-in amplifier.

D.3 Test Sample

1. The test sample shall be a known length (⩾1 km) of multimode optical fiber.
2. A flat end face shall be prepared at the input and output ends of the test sample by a fracturing or grinding and polishing procedure as described in FOTP #57.
3. The test sample shall be supported (usually on a reel) in a manner which minimizes microbending losses.

D.4 Test Procedure

1. The length of fiber whose attenuation is to be measured shall be prepared so that its end faces are smooth and perpendicular to the fiber axis per FOTP #57. Any coating on the fiber shall be removed from a length of fiber in the vicinity of the fiber supports (and mode filter if used).
2. Using the mode filter or beam optics procedure described in FOTP #50, create a launching condition that will establish an approximate steady-state condition throughout the length of the fiber under test.
3. The input end of the fiber shall be placed in the positioning device and aligned as described in FOTP #50. The output radiation from the long fiber under test shall be collected by the detector.
4. The test fiber shall be positioned in the input beam in accordance with the procedures of FOTP #50, for the first test wavelength. The output signal level shall be recorded in the test data.
5. Attenuation at other wavelengths can be measured by using the appropriate filters in the source beam. The output signal (point B, fig. D-2) for each wavelength of interest shall be recorded in the test data. This process shall be accomplished without changing the launching conditions described in D.4(4).
6. The test fiber shall then be cut at the input end (see point A, fig. D-2). A flat end face shall be prepared on this newly created output end. Radiation from this fiber end shall then be collected by the detector.
7. Following the procedure described in D.4(5), the signal for each wavelength shall be recorded in the test data for the input reference fiber. Once again, this process shall be accomplished without changing the launching conditions described in D.4(4).
8. Calculations:
   a. Spectral Attenuation

   Spectral attenuation $A(\lambda)$ shall be calculated for each wavelength λ using the following formula:

$$A(\lambda) = -10 \log_{10} \frac{P_B(\lambda)}{P_A(\lambda)}$$

where $P_B(\lambda)$ is the output power of the test fiber at wavelength λ (point B), and $P_A(\lambda)$ is the input power to the test fiber at wavelength λ (output of input reference fiber at point A).

b. Spectral Attenuation Coefficient

The spectral attenuation coefficient shall be calculated for each wavelength λ using the following formula:

$$\alpha(\lambda) = \frac{A(\lambda)}{L}$$

where L is the test sample length in kilometers.

D.5 Documentation

1. The following data shall be reported:
   a. Date.
   b. Name of operator.
   c. Title of test.
   d. Identification of fiber measured.
   e. Test length.
   f. Temperature.
   g. Spectral attenuation versus center wavelength.
   h. Spectral attenuation coefficient versus center wavelength.

2. The following test equipment information shall be available:
   a. Type of radiation source.
   b. Description of optical filters or monochromator used (report FWHM of filter if >10 nm), including location.
   c. Description of cladding mode stripper and index-matching fluid used.
   d. Description of input optics used--mode filter or beam optics.
   e. Description of input beam optics, including launch conditions.
   f. Detection and recording techniques.
   g. Details of computation techniques.
   h. Description of fiber support mechanism.
   i. Date of latest calibration of test equipment.

D.6 Summary

The following details shall be specified in the detail specification:

a. Type of fiber to be tested.
b. Procedure number.
c. Failure or acceptance criteria.
d. Number of samples.
e. Type of input optics to be used.
f. Wavelengths.
g. Other test conditions.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This document is one of a series that describes optical fiber measurement procedures and capabilities at the National Bureau of Standards (NBS). We concentrate here on the measurement of attenuation of multimode, telecommunication-grade fibers for the wavelength range of 850 nm to 1300 nm. The document gives details on the measurement procedure, which is based on the Electronics Industries Association Recommended Standard as published in RS 455. The procedure is based on two restricted launch conditions, either of which may be used to control the modal power distribution at launch. The intent is to approximate the conditions that exist in a long link, to the end that the reported attenuation coefficient is indicative of what can be expected in long, concatenated links.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

attenuation; fiber attenuation; fiber characterization; measurement; measurement techniques; optical fibers; optical waveguides.

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