DOD-STD-1678
NOTICE 1
26 December 1984

MILITARY STANDARD

FIBER OPTICS TEST METHODS AND INSTRUMENTATION

To all holders of DOD-STD-1678

1. The following pages of DOD-STD-1678 have been revised and supersede the pages listed:

New Page	Date	Superseded Page	Date
iii	30 November 1977	iii	Reprinted w/o change
iv	26 December 1984	iv	30 November 1977
v	26 December 1984	v	30 November 1977
vi	30 November 1977	vi	Blank Page
3	30 November 1977	3	Reprinted w/o change
4	26 December 1984	4	30 November 1977
1 thru 2 of 1040.1	26 Dec 1984	1040-1 thru 1040-2	30 November 1977
1 thru 8 of 6050.1	26 Dec 1984	6050-1 thru 6050-8	30 November 1977
1 thru 4 cf 6060.1	26 Dec 1984	6060-1 thru 6060-4	30 November 1977
1 thru 3 of 6070.1	26 Dec 1984	6070-1 thru 6070-4	30 November 1977
5 thru 7 of 6070.1	26 Dec 1984	New	

2. RETAIN THIS NOTICE AND INSERT BEFORE TABLE OF CONTENTS.

3. Holders of DOD-STD-1678 will verify that the page changes indicated herein have been entered. This notice will be retained as a check sheet. This issuance is a separate publication. Each notice is to be retained by stocking points until the Military Standard is completely revised or canceled.

Custodians:
Army - CR
Air Force - 85

Preparing Activity:
Navy - AS
(Project No. 60GP-0003)

Review Activities:
Navy - EC, SH
Air Force - 11, 13, 14, 17, 80, 90
Army - MI, AR

User Activities:
Army - AV
Navy - OS

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FIGURES

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3. DEFINITIONS

3.1 The following definitions listed in this military standard covers general terms. The general terms are defined in the following paragraphs.

3.1.1 Fiber. A fiber is a single discrete optical transmission element usually comprised by a fiber core and a fiber cladding.

3.1.2 Bundle. A bundle is a number of fibers grouped together.

3.1.3 Cable. A cable is a jacketed bundle or jacketed fiber in a form which can be terminated.

3.1.4 Multiple fiber cable. A multiple fiber cable is a construction in which a number of jacketed fibers are placed together in a common envelope.

3.1.5 Multiple bundle cable. A multiple fiber cable is a construction in which a number of jacketed fibers are placed together in a common envelope.

3.1.5 Multiple bundle cable. A multiple bundle cable is a construction in which a number of jacketed bundles are placed together in a common cylindrical envelope.

3.1.6 Harness. A harness is a construction in which a number of multiple fiber cables or jacketed bundles are placed together in an array which contains branches. A harness is usually installed within equipment or airframe and mechanically secured to that equipment or airframe.

3.1.7 Branched cable. A branched cable consist of a cable, multiple fiber cable, or multiple bundle cable which contains one or more breakouts.

3.1.8 Branch. A branch is that portion of a cable or arness which breaks out from and forms an arm with the main cable or harness run.

3.1.9 Breakout. The point where a branch meets and merges with the main cable or harness run or where it meets and merges with another branch is called a breakout.

3.1.10 Cable or harness run. The cable or harness run is that portion of a branched cable or harness where the cross-sectional area of the cable or harness is the largest.

3.1.11 Cable core. The portion of a cable contained within a common covering is the cable core.

3.1.12 Cable assembly. A cable assembly is a cable which is terminated and ready for installation.

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3.1.13 Multiple fiber cable assembly. A multiple fiber cable which is terminated and ready for installation is called a multiple fiber cable assembly.

3.1.14 Multiple bundle cable assembly. A multiple bundle cable assembly is a multiple bundle cable which is terminated and ready for installation.

3.1.15 Harness assembly. A harness assembly is a harness which is terminated and ready for installation.

3.1.16 Fiber optics. Fiber optics as applied to this standard is a general term used to describe the function where optical energy is guided to another location through fiber(s).

3.1.17 FO. FO is an abbrevation for fiber optics.

3.1.18 Acceptance pattern. The acceptance pattern of a fiber or fiber bundle is a curve of input radiation intensity plotted against the input (or launch) angle.

3.1.19 Launch angle. The launch angle is the angle between the input radiation vector and the axis of the fiber or fiber bundle.

3.1.20 Radiation pattern. The radiation pattern of a fiber or bundle is a curve of the ouput radiation intensity plotted against the output angle.

3.1.21 Numerical aperture, NA. The numerical aperture, NA, can be defined as follows.

3.1.21.1 Numerical aperture, NA (95% power). The numerical aperture of a fiber or bundle is defined by:

$$NA\ (95\%\ power) = \sin \theta$$

where θ is the angle between the axis of the output cone of light and the vector coincident with the surface of a cone which contains 95% of the total radiation power,

or where θ is the angle between the axis of the input cone of light and the vector coincident with the surface of a cone which contains 95% of the total input radiation power.

3.1.21.1 Numerical aperture, NA (5% intensity). The numerical aperture of a fiber or a bundle is defined by:

$$NA\ (5\%\ intensity) = \sin \theta'$$

where θ′ is the angle where the measured intensity of radiation is 5% of the maximum measured intensity when plotting either the acceptance or radiation pattern.

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METHOD 1040.1
NUMBER OF TRANSMITTING FIBERS

1. SCOPE.

1.1 This method determines the number of fibers in a bundle which are transmitting light.

2. SPECIMEN.

2.1 The specimen shall be taken from a representative sample of fiber optics cable.

3. APPARATUS.

3.1 Optical microscope. An optical microscope as described in Method 1010 of DOD-STD-1678 or equal shall be used. The magnification shall be sufficient to fill a photograph with the fiber bundle image.

3.2 Photomicrographic camera. A photomicrographic camera as described in Method 1010 of DOD-STD-1678 or equivalent shall be used.

3.3 Illumination source. A white incandescent light source with adjustable intensity shall be used for illuminating the specimen on the front and back. A diffusion plate shall be used between the illumination source and specimen back.

4. PROCEDURE.

Step 1	Both ends of the specimen shall be prepared in accordance with Method 8040 of DOD-STD-1678 and finished so that the endfaces are perpendicular to the axis of the specimen.
Step 2	One end of the specimen shall be illuminated by the back illuminating source. The opposite end of the specimen shall be placed in the field of view of the optical microscope and illuminated at an oblique angle to the specimen face.
Step 3	The intensity of the front and back illumination, the front illumination angle, the shutter speed and "F" stop shall be adjusted to obtain a clear photograph and to obtain maximum contrast between transmitting and non-transmitting fibers.

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Step 4 — Several photographs of the specimen shall be taken using different intensity settings of the back illuminating source. The front illumination, shutter speed and "F" stop shall not be readjusted.

Step 5 — Using Procedure I, Method 1030 of DOD-STD-1678, the number of transmitting fibers shall be determined on each photograph.

NOTE: If the number of transmitting fibers is large compared to the number of non-transmitting fibers, the number of non-transmitting fibers shall be counted. This presupposes that the total number of fibers is known.

Step 6 — If the number of transmitting fibers on the photographs obtained using the two lowest intensities are different, the intensity of the back illuminating source shall be lowered and an additional photograph taken. When the number of transmitting fibers in the two photographs are the same, this number is reported.

5. RESULTS.

5.1 Reporting. The following information shall be reported with each test:

a. Operator and date.

b. Specimen identification.

c. Specimen length.

d. The number of transmitting fibers obtained on the two lowest intensities.

5.2 Documentation. The following information shall be recorded and shall be made available upon request:

a. The type of microscope, type of objective lens, and magnification.

b. Date of last equipment calibration and when calibration is next due.

METHOD 6050.1

OPTICAL FIBER BANDWIDTH BY TIME DOMAIN TECNIQUES

1. SCOPE.

1.1 This method describes a procedure for determining the bandwidth of a multimode optical fiber at a specified wavelength with specified launching conditions, using time domain techniques. The results are expressed as the "magnitude of the transfer function" and the "-3 dB bandwidth (optical)." Only those limitations to bandwidth due to intermodal effects are determined.

2. SPECIMEN.

2.1 Test specimen. The test specimen shall be a known length of multimode optical fiber. The core diameter shall be determined by Method 1010 of DOD -STD-1678. The numerical aperture shall be determined by Method 6040 of DOD-STD-1678.

2.2 Reference specimen. The reference specimen shall be either a short length from the same sample as the test specimen or a short length of fiber which is representative of the fiber under test, as required by the applicable specification. The length of the reference specimen shall not be greater than 1 percent of the length of the test specimen.

2.3 End preparation. A flat end face, perpendicular to the fiber axis shall be prepared at both ends of the test and reference speimens in accordance with Method 8040 of DOD-STD-1678.

2.4 Specimen handling. The test specimen shall be suspended in a manner which relieves tension and minimizes microbending. Care should be taken to minimize external microbending.

3. APPARATUS (See Figure 6050-1).

3.1 Light source. A suitable source (such as an injection laser diode), which produces short duration, narrow spectral width pulses shall be used.

3.1.1 Waveform. The source shall be modulated electrically or optically to produce short pulse waveforms. The pulse duration and shape shall be such that the magnitude of the Fourier transform of the waveform (as measured with the detector specified in 3.3 and following the procedure of 4.1) shall not vary by more than 15 dB over the range of frequencies of interest.

3.1.2 Wavelength. The center of the spectral linewidth shall be know to an accuracy of +5 nm and shall be within ± 10 nm of the specified wavelength. For injection laser diodes, the center of the stimulated emission shall be considered to be the center of the linewidth; the stimulated emission must exceed the spontaneous emission by no less than 15 dB.

3.1.3 Spectral linewidth. The spectral linewidth of the source will, in part, establish the upper frequency limit for valid measurements of the bandwidth limitations due to intermodal effects. The spectral linewidth shall be such that the measured -3 dB bandwidth (optical) will not differ from that which would be measured with a zero spectral width source by more than 10 percent. The required spectral linewidth will depend on wavelength, fiber length, and fiber composition. This condition,

$$\Delta\lambda \text{ (nm)} \leq \frac{\text{IDF (GHz km nm)}}{\text{L (km) IDL (GHz)}}$$

where $\Delta\lambda$ is the spectral width full width, half maximum (FWHM) of the source, L is the length of the test specimen, IDL (Intermodal Distortion Limit) is the highest frequency of interest for this measurement, and IDF (Intermodal Distortion Factor) is a parameter inversely proportional to the magnitude of the material dispersion (IDF = $0.2/|M|$ (ns/km nm)), may be used to estimate the maximum source linewidth for a valid measurement. For the germanium-phosphorus doped silica system, IDF can be estimated from the following table 6050-I.

TABLE 6050-I.

λ(nm)	IDF(GHz km nm)	λ(nm)	IDF(GHz km nm)
800	1.6	1200	18.
820	1.7	1250	42.
840	1.9	1300	220.
860	2.1	1340	40.
880	2.3	1510	11.
900	2.5		

Note: Gaussian impulse response shapes and Gaussian pulse shapes were assumed to generate these data. They will therefore apply most accurately to well compensated graded index fibers.

3.1.4 Spectrum stability. The spectral characteristics of the source shall be stable throughout the duration of a single pulse and over the time during which the measurement is made.

3.2 Launch system.

3.2.1 Mode scrambler. The light source shall be optically coupled to a mode scrambler, the output of which is independent of the spatial characteristics of the light source. The mode scrambler shall conform to one of the following types as specified in the applicable procurement specification. The prefered mode scrambler shall be a 3 meter length of fiber, constructed as follows: a one meter, step index fiber fusion spliced to a one meter graded index fiber which is fusion spliced to another one meter, step index fiber. See figure 6050-2. In lieu of the preferred type mode scrambler, the following shall be used: a single, 2 meter length of step index fiber. If necessary, large winding bends or a microbending device can be placed in the mode scrambler to alleviate its sensitivity to laser diode alignment. See figure 6050-3.

3.2.2 Coupling to specimen. The output of the mode scrambler shall be coupled to the input end of the specimen in such a way that both the size of the spot on the end of the specimen and the launch numerical aperture can be adjusted to specification. The fiber position shall be stable over the duration of the experiment. A viewing system may be used to aid fiber alignment.

3.3 Detection system.

3.3.1 Bandwidth . A detector with sufficient speed that the conditions of 3.1.1 can be met shall be used.

3.3.2 Uniformity. A detector that has been shown to have a uniform response (± 10%) over its active area shall be used.

3.3.3 Linearity. A detector that is linear in response over the range of power and energy required shall be used. A variable neutral density filter or other suitable device may be used to limit the range of power and energy over which the detector is used.

3.3.4 Stability. A detector that has been shown to be sufficiently stable, that is, a detector for which the ratio of output signal to applied optical power is sufficiently constant with time, shall be used.

3.3.5 Coupling. The output of the fiber shall be coupled to the detector in such a manner that all modes of the fiber are coupled equally.

3.4 Electronic instrumentation.

3.4.1 Display instrument. The detected optical pulse shall be displayed on a suitable instrument such as a high speed sampling oscilloscope. The instrument shall have a calibrated time base and shall be linear in amplitude response over the range of encountered signals.

3.4.2 Data recording. The display instrument shall be suitably connected to some external means of recording the detected pulse waveform for subsequent computer processing.

3.5 Computation.

3.5.1 Equipment. Suitable computational equipment capable of providing Fourier transforms of detected waveforms and computing ratios of linear arrays shall be provided.

3.5.2 Sampling. An appropriate transform technique along with suitable sampling parameters including the number of samples, the time between samples, the Nyquist frequency, and the frequency resolution, where applicable, shall be chosen. The same sampling parameters shall be used for Procedures I and II. The frequency resolution shall be at least a factor of ten smaller than the smallest -3 dB frequency measured.

4. PROCEDURE.

4.1 System calibration. This section describes the procedure necessary to calibrate the system using the reference specimen.

Step 1 Alignment. The reference specimen shall be placed into the test system in such a manner that the specified launching conditions are obtained. The reference fiber core shall be centered in the output light signal from the mode scrambler. The intensity distribution across the input end of the refeerence fiber core shall vary by less than 25%. The launch numerical aperture, NA shall exeed the NA of the reference fiber. The output of the reference fiber shall be properly coupled to the detector.

Step 2 Signal level and time base adjustment. Display unit gain, neutral density filters and/or other devices shall be adjusted to obtain a single stable pulse waveform on the display instrument. The sweep rate used in this step must be the same as that used in Step 2 of paragraph 4.2 and must be such that an entire waveform is observed. Electrical phenomena (ringing, reflections, etc.) must be taken into account while performing measurements.

Step 3 Measurement. The system shall be caused to record a waveform and, using the known sampling parameters, to compute and properly scale the Fourier transform of that waveform. The magnitude of the transform shall be normalized to its value at the lowest frequency computed (not, in general, zero frequency). This normalized transform is called the system calibration function, $|G(f)|$ and shall be stored and/or otherwise recorded for use in Procedure III and for reporting in Section 5.

4.2 Measurement of test specimen. This section describes the procedure for measurement of a test specimen using the system as previously calibrated.

Step 1 Alignment. The test specimen shall be placed into the test system in such a manner that the specified launching conditions are obtained. The test fiber core shall be centered in the output light signal from the mode scrambler. The intensity distribution across the input end of the test fiber core shall vary by less than 25%. The launch numerical aperture, NA, shall exceed the NA of the test fiber. The output of the test fiber shall be properly coupled to the detector.

Step 2 Signal level and time base adjustment. With the test specimen properly aligned, neutral density filters, as available, shall be adjusted to achieve a signal level on the detector that is approximately equal to the signal level obtained in Step 2 of the system calibration (4.1) (to within the demonstrated linearity range of the detector and electronics). Also, the same electronic gain (including detector gain, if any) and time base shall be used. The entire waveform must be displayed. Again, electrical phenomena (ringing, reflections, etc.) must be accounted for as in step 2 of the system calibration (4.1).

4.2.3 Measurement. The system can be caused to record a waveform and, using the known sampling parameters, to compute and properly scale the Fourier transform of that waveform. The magnitude of the transform shall be normalized to its value at the lowest frequency computed (not, in general, zero frequency). This normalized transform is called $|F(f)|$ and shall be stored and/or otherwise recorded for use in Computations (4.3) and for reporting in Section 5.

4.3 Computations. This section specifies the procedure by which the magnitude of the fiber transfer function and the fiber bandwidth are computed.

Step 1 Transfer function. The magnitude of the transfer function of the test specimen shall be determined by

$$|H(f)| = \left|\frac{F(f)}{G(f)}\right|$$

where $|H(f)|$ is the magnitude of the transfer function, $|F(f)|$ is the magnitude of the transform obtained in 4.2.3, $|G(f)|$ is the system response function obtained in 4.1.3 and f is frequency. $|H(f)|$ shall be expressed in decibels (optical) using $|H(f)|_{dB} = 10 \log_{10} |H(f)|$. $|H(f)|_{dB}$ shall be retained for reporting in Section 5.

Step 2 -3 dB Bandwidth (optical). The -3_{dB} bandwidth (optical) shall be determined as the lowest frequency at which $|H(f)|_{dB} = -3$ dB and shall be designated f_{-3dB}. The quantity $f_{-3\,dB}$ shall be retained for reporting in Section 5.

5. RESULTS.

5.1 Reporting. The following information shall be reported with each test:

a. Operator and date.

b. Specimen identification.

c. Specimen length.

d. Reference length.

e. Source wavelength.

f. Launching conditions.

g. Magnitude of transfer function, ($|H(f)|_{dB}$ vs. f).

h. -3 dB Bandwidth (optical), ($f_{-3\,dB}$).

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5.2 Documentation. The following information shall be recorded and shall be made available upon request:

a. Source manufacturer, type, actual wavelength, and spectral characteristics.

b. Detector manufacturer, type, spatial response uniformity, gain at operating voltage, if applicable, and range of linearity.

c. Detection electronics/display system details.

d. Data recording method.

e. Lowest frequency at which $|G(f)| = -15$ dB.

f. Computation details, including sampling parameters.

g. dates of last equipment calibration and when calibration is next due.

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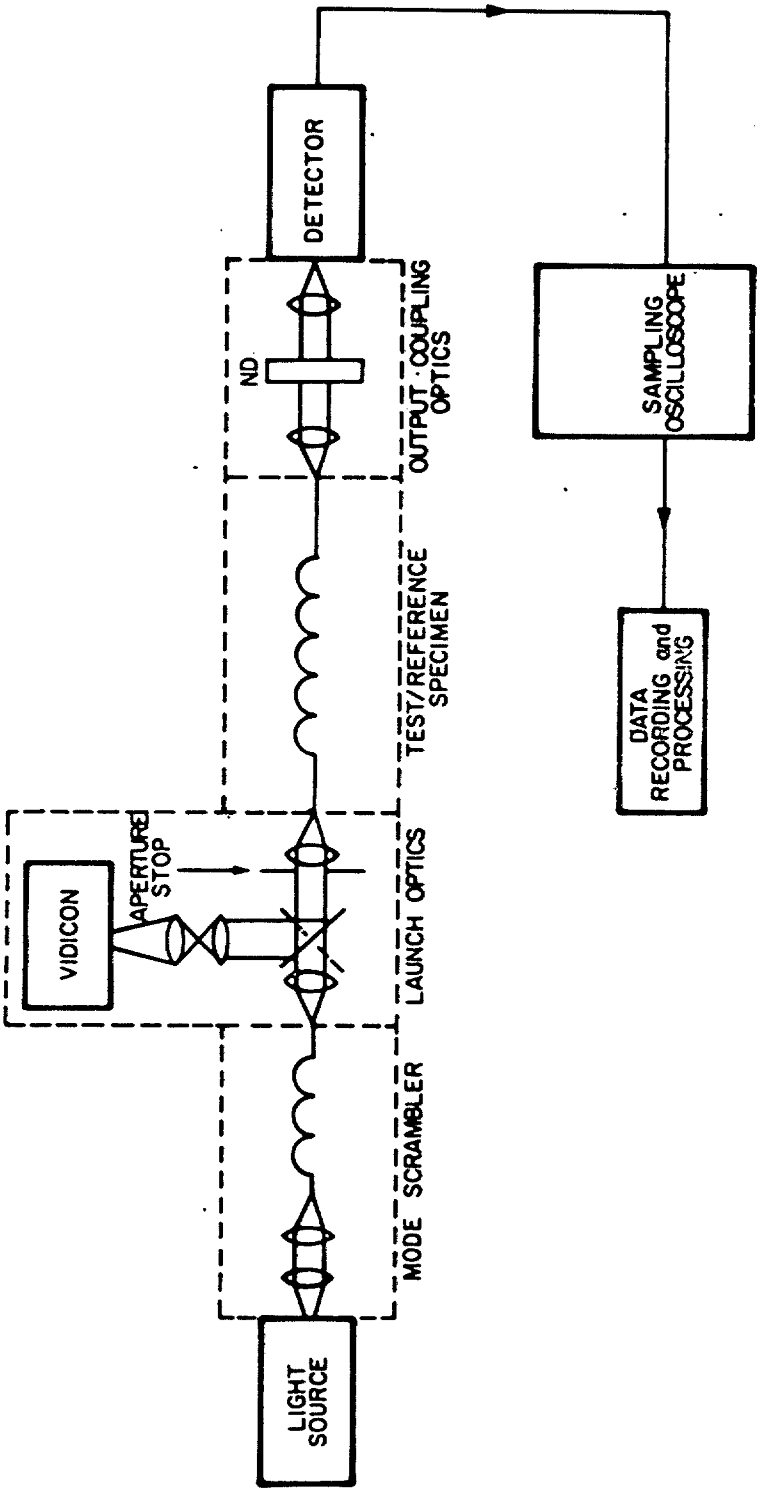

FIGURE 6050.1-1. Example system for fiber bandwidth measurement by time domain techniques.

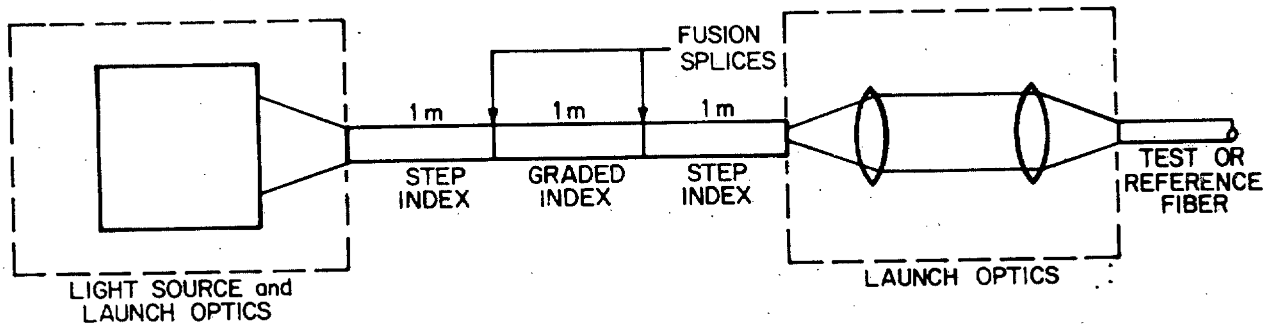

FIGURE 6050.1-2. Example of preferred type mode scrambler.

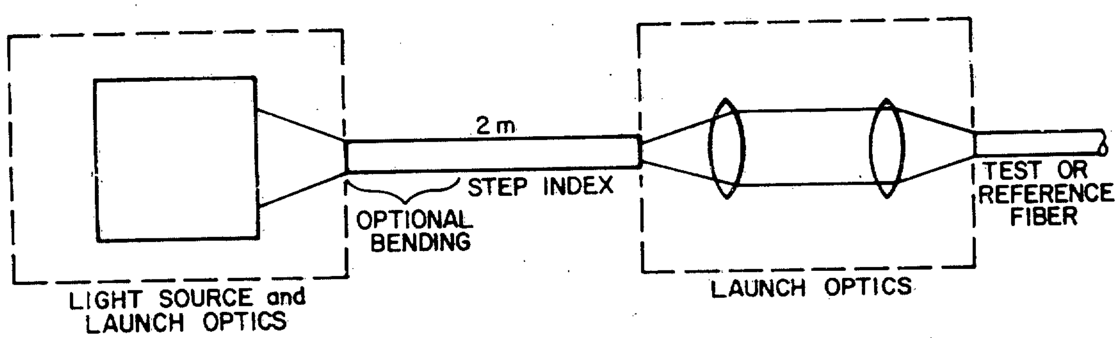

FIGURE 6050.1-3. Example of substitute type mode scrambler.

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METHOD 6060.1

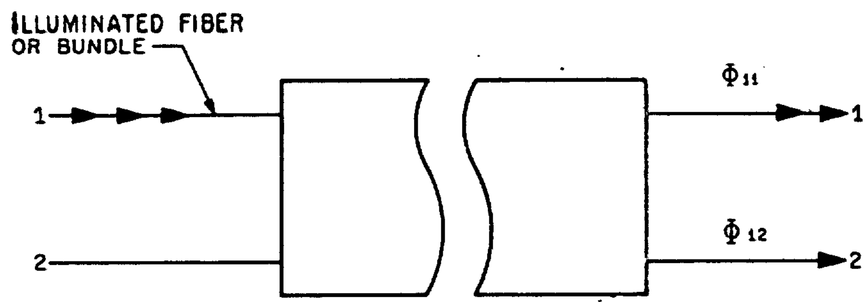
FAR-END CROSSTALK

1. SCOPE.

1.1 This method describes a procedure for measuring far-end corsstalk between two fibers (or two bundles) where each fiber (or bundle) acts as a transmission element. It employs radiant power measurements and is defined by:

$$FEXT\ (1,\ 2) = 10\ \log_{10}\ (\Phi_{11}/\Phi_{12})$$

where the first subscript represents the fiber being illuminated and the second subscript represents the fiber being monitored.



NOTE: FEXT (1, 2) is the positive unit referred to as "dB down."

2. SPECIMEN.

2.1 The test specimen shall be taken from a representative sample of FO cable.

3. APPARATUS.

3.1 The apparatus shall be as specified herein and in Method 6010, Procedure II or III, of DOD-STD-1678.

3.2 Radiation detectors. Two detectors shall be used to detect the output radiation emanating from the illuminated and neighboring fiber (bundle). The spectral responsivity and response time of the detector(s) shall be compatible with the radiation source and light modulator.

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4. PROCEDURE.

Step 1 The output of the source shall be adjusted, where necessary, to obtain the specified center wavelength, and its intensity shall be adjusted to obtain sufficient detectable radiation.

Step 2 Both ends of the illuminated fiber (bundle) and neighboring fiber (bundle) shall be prepared in accordance with Method 8040 of DOD-STD-1678 and finished so that the endfaces are perpendicular to the axis of the specimen, or index matching fluid shall be used to couple the optical power between fiber (bundle) and detector. The length (L_1) of the test specimen shall be measured.

Step 3 One end of the illuminated fiber (bundle) shall be placed in the specified radiation beam so that its entire end is illuminated and that uniform illumination is present across the fiber launch cone specified in the specification sheet.

Step 4 The input end of the non-illuminated fiber (Fiber 2) shall be optically blocked to prevent ambient light from entering the fiber and affecting the FEXT measurement.

Step 5 Both ends of the illuminated and neighboring fiber (bundle) shall be placed so that the axis of the output cone of radiation is perpendicularly incident on their respective detectors and all of the radiation impinges on the detectors.

NOTE: One detector may be used and Φ_{11} and Φ_{12} measured serially (see Step 6).

Step 6 The relative radiant power, Φ_{11}, of the illuminated fiber (bundle) and Φ_{12} of the neighboring fiber (bundle) shall be measured at the specified wavelength(s).

NOTE: If the measured value of Φ_{12} is small (less than 10 times the background noise of the dark detector) then either a shorter length of the specimen or a greater source intensity should be used. It may be necessary to use a calibrated attenuator in the illuminating fiber detector circuit (Φ_{11}).

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5. RESULTS.

5.1 Reporting. The following details shall be reported with each test:

a. Operator and date.

b. Specimen identification.

c. The measured power (in watts) Φ_{11} and Φ_{12}.

d. The radiation source, center wavelength(s), bandpass at the wavelength(s) and numerical aperture of the launched radiation cone.

e. The length (L_1) of the specimen.

f. The identity and refractive index at the wavelength(s) of interest of any index matching fluids, if used.

g. The far-end cross talk, FEXT (1, 2).

5.2 Documentation. The following information shall be recorded and shall be made available upon request:

a. Source manufacturer, type, actual wavelength, and spectral characteristics.

b. Detector manufacturer, type, spatial response uniformity, gain at operating voltage, if applicable, and range of linearity.

c. Computation details, including sampling parameters.

d. Dates of last equipment calibration and when calibration is next due.

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METHOD 6070.1

OPTICAL FIBER BANDWIDTH BY FREQUENCY DOMAIN TECHNIQUES

1. SCOPE.

1.1 This method describes a procedure for determining the bandwidth of a multimode optical fiber at a specified wavelength with specified launching conditions, using frequency domain techniques. The results are expressed as the "magnitude of the transfer function" and the "-3 dB bandwidth (optical)." Only those limitations to bandwidth due to intermodal effects are determined.

2. SPECIMEN.

2.1 Test specimen. The test specimen shall be a known length of multimode optical fiber. The core diameter shall be determined by Method 1010 of DOD-STD-1678. The Numerical Aperture shall be determined by Method 6040 of DOD-STD-1678.

2.2 Reference specimen. The reference specimen shall be either a short length from the same sample as the test specimen or a short length of fiber which is representative of the fiber under test, as required by the applicable specification. The length of the reference specimen shall not be greater than 1 percent of the length of the test specimen.

2.3 End preparation. A flat end face, perpendicular to the fiber axis, shall be prepared at both ends of the test and reference specimens in accordance with Method 8040 of DOD-STD-1678.

2.4 Specimen handling. The test specimen shall be suspended in a manner which relieves tension and minimizes microbending. No external microbending shall be intentionally introduced.

3. APPARATUS (see Figure 6070-1).

3.1 Light source. A suitable source (such as a continuous wave (cw) injection laser diode), capable of being stably amplitude modulated over a broad frequency range and having a narrow spectral width shall be used.

3.1.1 Modulation. The source shall be modulated electrically or optically to produce a sinusoidally time varying output power. The frequency of modulation shall be variable over a sufficiently wide range and the variation of modulation amplitude over the frequency range of interest shall be no greater than 15 dB (optical), (as measured with the detector specified in 3.3, the electronics specified in 3.4, and using the procedure of 4.1).

3.1.2 Wavelenth. The center of the spectral linewidth shall be known to an accuracy of ± 5 nm and shall be within ± 10 nm of the specified wavelength. For injection laser diodes, the center of the stimulated emission shall be considered to be the center of the linewidth; the stimulated emission must exceed the spontaneous emission by no less than 15 dB.

3.1.3 Spectral linewidth. The spectral linewidth of the source will, in part, establish the upper frequency limit for valid measurements by this procedure of the bandwidth limitations due to intermodal effects. The spectral linewidth shall be such that the measured -3 dB bandwidth (optical) will not differ from that which would be measured with a zero spectral width source by more than 10 percent. The required spectral linewidth will depend on wavelength, fiber length, and fiber composition. This condition,

$$\Delta\lambda(\text{nm}) \leq \frac{\text{IDF (GHz km nm)}}{\text{L (km) IDL(GHz)}}$$

where $\Delta\lambda$ is the spectral width of the source full width, half maximum (FWHM), L is the length of the test specimen, IDL (Intermodal Distortion Limit) is the highest frequency of interest for this measurement, and IDF (Intermodal Distortion Factor) is a parameter inversely proportional to the magnitude of the material dispersion (IDF = 0.2/ M (ns/km·nm)), may be used to estimate the maximum source linewidth for a valid measurement. For the germanium-phosphorus doped silica system, IDF can be estimated from the following table 6070-I:

TABLE 6070-I

λ(nm)	IDF(GHz km nm)	λ(nm)	IDF(GHz km nm)
800	1.6	1200	18.
820	1.7	1250	42.
840	1.9	1300	220.
860	2.1	1340	40.
880	2.3	1510	11.
900	2.5		

Note: Gaussian impulse response shapes and Gaussian pulse shapes were assumed to generate these data. They will therefore apply most accurately to well compensated graded index fibers.

3.1.4 Spectrum stability. The spectral characteristics of the source shall be stable throughout the duration of the measurement.

3.2 Launch system.

3.2.1 Mode scrambler. The light source shall be optically coupled to a mode scrambler, the output of which is independent of the spatial characteristics of the light source. The mode scrambler shall conform to one of the following types as specified in the applicable procurement specification. The prefered mode scrambler shall be a 3 meter length of fiber, constructed as follows: a one meter, step index fiber fusion spliced to a one meter graded index fiber which is fusion spliced to another one meter, step index fiber. See figure 6070-2. In lieu of the preferred type mode scambler, the following shall be used: a single, 2 meter length of step index fiber. If necessary, large winding bends or a microbending device can be placed in the mode scrambler to alleviate its sensitivity to laser diode alignment. See figure 6070-3.

Supersedes page 6070-2 of 30 November 1977

3.2.2 Coupling to specimen. The output of the mode scrambler shall be coupled to the input end of the specimen in such a way that both the size of the spot on the end of the specimen and the launch numerical aperture can be adjusted to specification. The fiber position shall be stable over the duration of the experiment. A viewing system may be used to aid fiber alignment.

3.3 Detection system.

3.3.1 Bandwidth. A detector with sufficient speed that the conditions of 3.1.1 can be met shall be used.

3.3.2 Uniformity. A detector that has been shown to have a uniform response (± 10%) over its active area shall be used.

3.3.3 Linearity. A detector that is linear in response over the range of power required shall be used. A variable neutral density filter or other suitable device may be used to limit the range of power over which the detector is used.

3.3.4 Stability. A detector that has been shown to be sufficiently stable, that is, a detector for which the ratio of output signal to applied optical power is sufficiently constant with time, shall be used.

3.3.5 Coupling. The output of the fiber shall be coupled to the detector in such a manner that all modes of the fiber are coupled equally.

3.4 Electronic instrumentation.

3.4.1 Detection instrument. The output of the detector may be amplified with a suitable wideband low noise amplifier. It shall thereafter be detected with a suitable narrowband instrument, such as a spectrum analyzer, capable of providing a calibrated display of optical detector output versus frequency. The display shall provide output signals equivalent to the display information. The bandwidth of the instrument shall be sufficiently narrow that any harmonics of the modulation frequency are not detected.

3.4.2 Source electronics. The optical source shall be modulated with a variable radio frequency (rf) source, compatible with the detection electronics, such as a tracking generator.

3.4.3 Data recording. The detection electronics shall be connected to a suitable means of recording data for subsequent computation and reporting.

3.5 Computation.

3.5.1 Equipment. Suitable computational equipment capable of computing ratios of linear arrays shall be provided.

3.5.2 Software. Appropriate software, compatible with the procedures of 4. shall be used.

4. PROCEDURE.

4.1 System calibration. This section describes the procedure necessary to calibrate the system using the reference specimen.

Step 1 Alignment. The reference specimen shall be placed into the test system in such a manner that the specified launching conditions are obtained. The reference fiber core shall be centered in the output light signal from the mode scrambler. The intensity distribution across the input end of the reference fiber core shall vary by les than 25%. The launch numerical aperture, NA, shall exceed the NA of the reference fiber. The output of the reference fiber shall be properly coupled to the detector.

Step 2 Signal level and frequency range adjustment. With the source electronics adjusted to sinusoidally modulate the source at frequencies covering the range of interest, the modulation level, neutral density filters (if used), and display electronics shall be adjusted to display the output of the detector as a function of frequency. The source modulation level and adjustments of the display electronics chosen for this step must be suitable for use in Step 2 of Procedure II.

Step 3 Measurement. The system shall be caused to record the magnitude of the detected modulation (detector output) as a function of frequency as the modulation frequency is varied either continuously or discretely over the range of interest. This function is called the system calibration function, $|G(f)|$. It shall be suitably normalized and shall be recorded and stored for use in Procedure III and for reporting as in Section 5.

4.2 Measurement of test specimen. This section describes the procedure for measurement of a test specimen using the system as previously calibrated.

Step 1 Alignment. The test specimen shall be placed into the test system in such a way that the specified launching conditions are obtained. The test fibercore shall be centered in the output light signal from the mode scrambler. The intensity distribution across the input end of the test fiber core shall vary by less than 25%. The launch numerical aperture, NA, shall exceed the NA of the test fiber. The output of the test fibershall be properly coupled to the detector.

Step 2 Signal level and frequency range adjustment. With the test specimen properly aligned, neutral density filters, as available, shall be adjusted to achieve a signal level on the detector that is approximately equal to the signal level obtained in Step 2 of Procedure I (to within the demonstrated linearity range of the detector and electronics). The same electronic gain (including detector gain, if any) and display electronics adjustments shall be as used in Step 2 of Procedure I.

Step 3 Measurement. The system can be caused to record the magnitude of the detected modulation (detector output) as a function of frequency as the modulation frequency is varied either continuously or discretely over the range of interest. This curve is called $|F(f)|$. It shall be normalized in the same manner as $|G(f)|$ and shall be recorded and stored for use in Procedure III and for reporting as Section 5.

4.3 Computations. This section specifies the procedure by which the magnitude of the fiber transfer function and the fiber bandwidth are computed.

Step 1 Transfer function. The magnitude of the transfer function of the test specimen shall be determined by

$$|H(f)| = \left| \frac{F(f)}{G(f)} \right|$$

where $|H(f)|$ is the magnitude of the transfer function, $|F(f)|$ is the magnitude of the transform obtained in Step 3 of Procedure II, $|G(f)|$ is the system response function obtained in Step 3 of Procedure I and f is frequency. $|H(f)|$ shall be expressed in decibels (optical) using $H(f)_{dB}=10 \log_{10} |H(f)|$. $|H(f)|_{dB}$ shall be retained for reporting in Section 5.

Step 2 -3 dB Bandwidth (optical). The -3 dB bandwidth (optical) shall be determined as the lowest frequency at which $|H(f)|_{dB} = -3$ dB and shall be designated $f_{-3\ dB}$. Because the transforms have been normalized to their value at the lowest frequency computed the bandwidth computed as above shall be considered valid only if it exceeds the lowest frequency at which H(f) is computed by more than a factor of 10. The quantity $f_{-3\ dB}$ shall be retained for reporting in Section 5.

5. RESULTS.

5.1 Reporting. The following information shall be reported with each test:

a. Operator and date.

b. Specimen identification.

c. Specimen length.

d. Reference length.

e. Source wavelength.

f. Launching conditions.

g. Magnitude of transfer function, ($|H(f)|_{dB}$ vs. f).

h. -3 dB Bandwidth (optical), ($f_{-3\ dB}$).

5.2 Documentation. The following information shall be recorded and shall be made available upon request:

a. Source manufacturer, type, actual wavelength, and spectral characterisitics.

b. Detector manufacturer, type, spatial response uniformity, gain at operating voltage, if applicable, and range of linearity.

c. Detection electronics/display system details.

d. Data recording method.

e. Computation details.

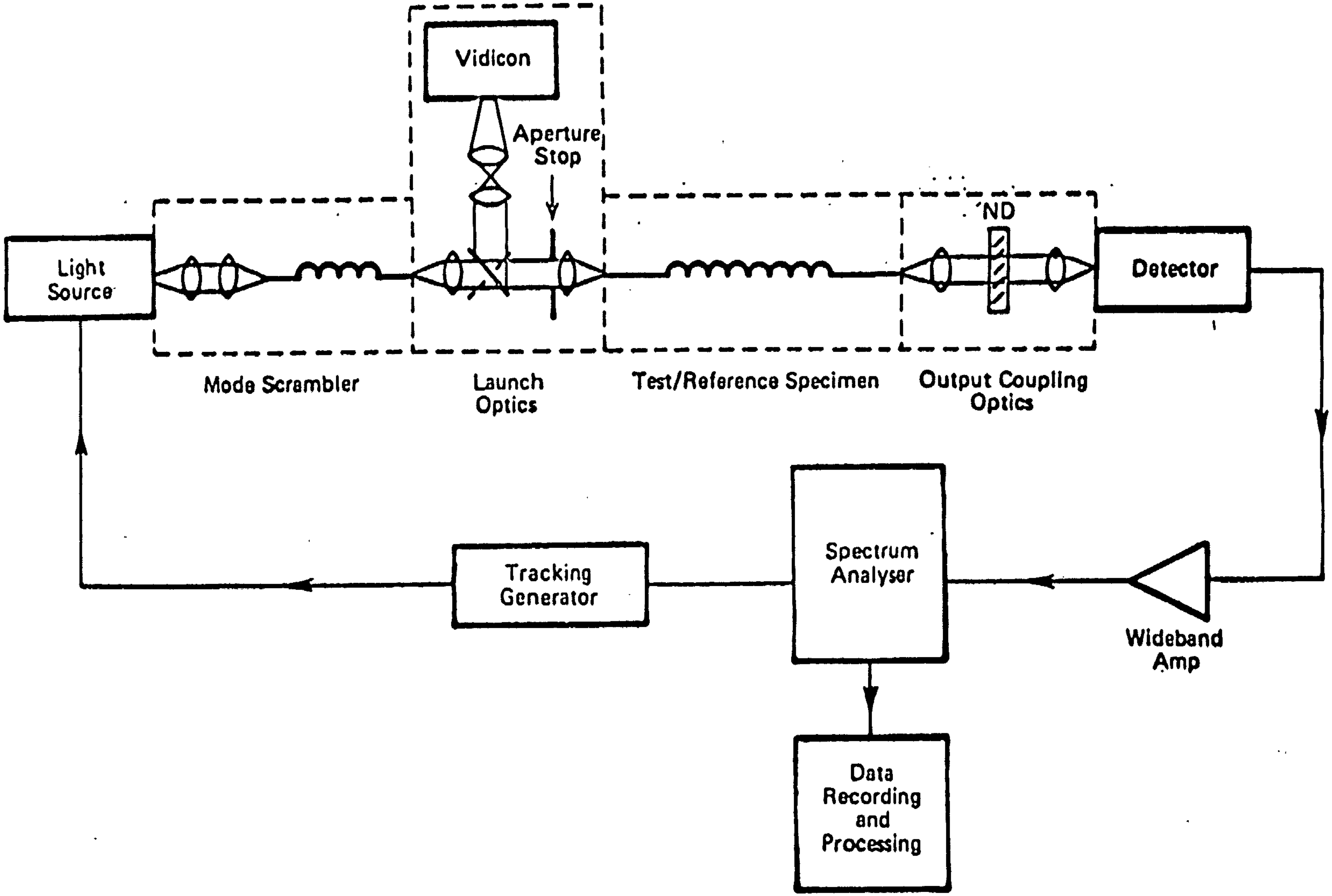

FIGURE 6070.1-1. Example system for fiber bandwidth measurements by frequency domain techniques.