Measurement of End Face Geometry on Fiber Optic Termini

Importance of end face geometry
The geometry of the end face or tip of fiber optic termini is a key factor for controlling the performance of the connector. This geometry will determine which areas come into contact when two connectors or termini are mated. Measuring end face parameters such as the radius of curvature, the apex offset, and the fiber height during the polishing process provides both quality control and quality assurance.

Controlling the end face geometry of a fiber optic termini provides the following benefits:

1. Helps guarantee optical performance
2. Minimizes Loss
3. Minimizes Back Reflection
4. Confirms Consistency for Quality Control of Polishing Process
5. Provides Assurance for Long Term Stability of the termini when exposed to the following:
    - •Time
    - •Temperature
    - •Pressure
    - •Vibration

Fiber Optic Connector End Face Geometry Measurement Techniques
There are a number of instruments that can provide information on the end face geometry . Three common measuring devices are:

1. Stylus Profilometer
2. Atomic Force Microscope (AFM)
3. Interferometric microscope.

Both the stylus profilometer and the atomic force microscope use a probe or tip to drag over the surface and measure the differential height from one point to the next. The stylus profilometer contacts the surface whereas the probe of the AFM is not in contact with the surface. Both provide a two dimension profile of the surface. AFM often uses multiple side by side profiles to map the surface in 3 dimensions. Accuracy is extremely good in providing a 2D profile but measuring a surface can be time consuming.

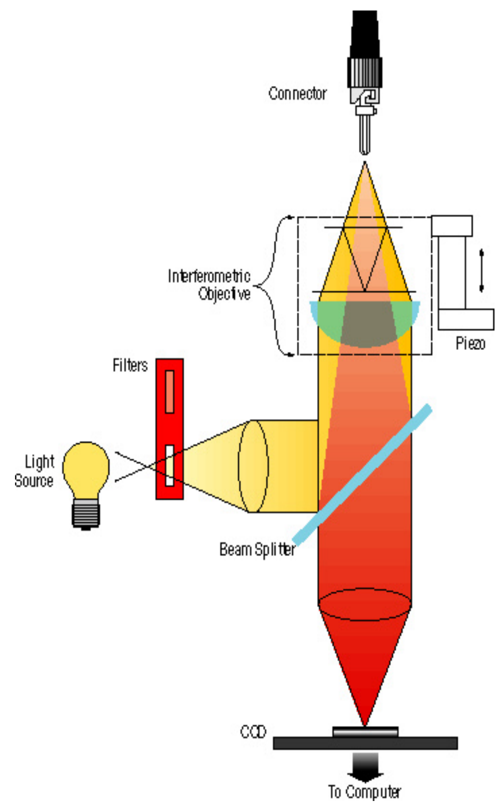


Fig. 1 Optical Path for Interferometer

Interferometry uses light waves to measure the surface in 3 dimensions. This makes it the preferred method for analyzing fiber optic end faces because it provide immediate information on the entire surface. With this method, an interferometric image, with constructive and destructive interference patterns (light and dark fringes respectively) is generated by combining the light from the image with the light reflected off a reference mirror. These interference patterns (fringes) form a contour map on the surface with the dark fringes spaced at ½ of a wavelength steps down the surface. A computer can analyze the fringe spacing and separate these steps into 255 shades of gray, identifying the height of each pixel relative to the adjacent pixel very accurately. This process only takes a few seconds to provide a complete 3 dimensional profile of the surface.

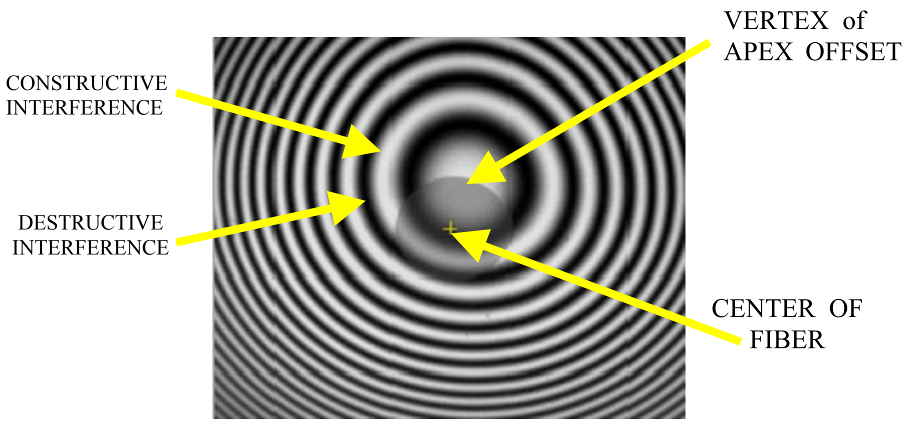


Fig. 2 Typical Interferometric Image of end face of fiber optic termini.

Interferometric Microscope Types

Two types of light are used for interferometric analysis of fiber optic termini. Each type uses a different method to analyze the surface and provides different amounts of information. The two types are:

1. Monochromatic or Narrow band light interferometry
2. White or Broadband light interferometry

Monochromatic Interferometry is pictured above in Fig 2. This image shows continuous fringes across the center of the termini end face surface. Each fringe is ½ of a wavelength above or below the adjacent fringe. Using a technique called Phase Shift Analysis, a piezo moves the reference mirror in a known direction. A computer observes the change in the fringes pattern, and is able to assign a differential height value to every adjacent pixel in its view.

This type of interferometry is extremely quick and shows extremely high details of the surface. The limitation of this method is that it assumes that each fringe is adjacent to the next, so for rough surfaces or if there is a sudden change in height more than ¼ of a wavelength, monochromatic interferometry has difficulties interpreting the fringe patterns and may not get accurate measurements.

White light interferometry is used to measure rough surfaces or surfaces with step height. As pictured in Fig 3, white light interferometry shows just a few fringes visible on the surface that gradually fade away. With this technique, the piezo moves the mirror so that the fringes scan across the surface from the top down to the bottom. The computer is able to assign a height to every pixel as the fringes move down the surface. White light interferometry will measure both rough and smooth surfaces without difficulty. The disadvantage is that it requires more time to process the many images needed and it does not show as much detail as the monochromatic method.

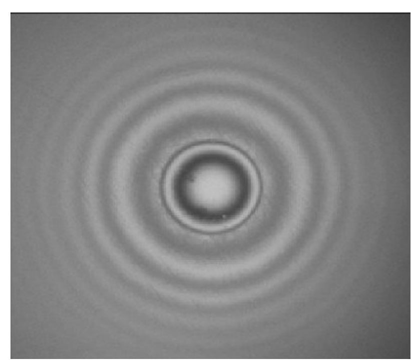


FIG. 3 White Light Interferometry

Measurement Techniques and Methodologies

Measurement areas

The end face of a fiber optic termini is not a perfect surface. Present manufacturing techniques do not provide the ideal flat or spherical end faces that we want to measure. In order for different facilities to be in agreement when measuring the surfaces, we define certain measurement areas and use them to find the best fit sphere or plane.

The following are the three measurement areas which are used:

Fitting Area: Centered on the ferrule surface and defined by a circular area having a diameter D with a smaller Extracting Area (E) subtracted from its center.
Fitting Area = D – E

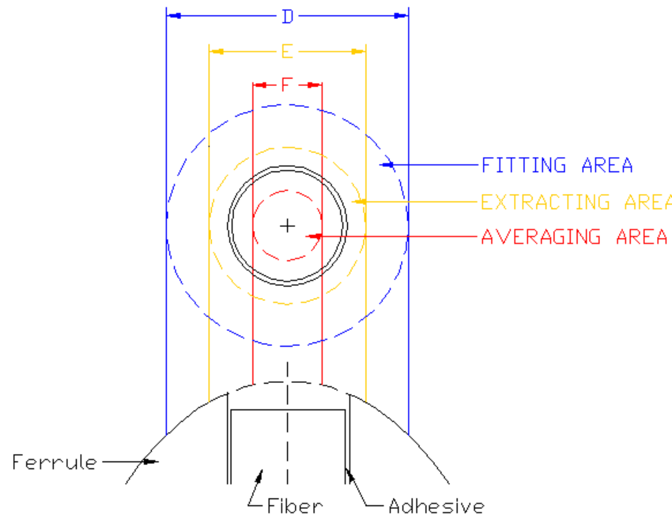


Fig. 4 Measurement Areas

Extracting Area: Includes the fiber endface region and the adhesive region and is defined by a circular area having a diameter E.

Averaging Area: This is set on the fiber surface and defined by a circle having a diameter F for measuring the height of the fiber.

Key Measurement Parameters

Radius of Curvature:

The radius of curvature is defined as the radius of the best fitting sphere over the defined Fitting Area. This can be calculated using a least squares method to find the best radius. Because the Fitting Area is symmetrical around the fiber, the position of the ferrule has no effect on the calculation.

Apex Offset:

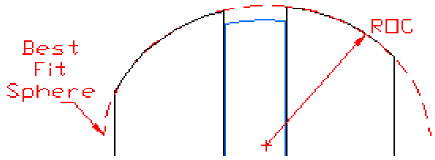
Measuring the apex offset (offset of the polish from the fiber) requires defining the "high point" or vertex of the polish. Since the fiber itself could be recessed or protruded, the sphericity of the ferrule surface (as defined by the Fitting Area) is used to calculate the vertex. The apex offset is defined as the distance from the vertex of the ferrule sphere to the center of the fiber. In order to calculate the vertex accurately, the system must be calibrated to determine how perpendicular the ferrule is being held to the reference mirror.

Fiber Height:

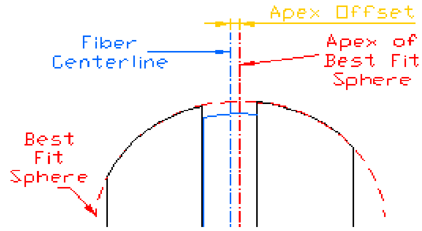
There are two possible ways to define fiber height, Spherical Height and Planar Height.

1. ***Spherical Height*** is useful when the ideal connector endface (ferrule and fiber) is considered to be a continuous sphere. It is defined as the difference in height between the center of the fiber and the theoretical height in the center based on the ferrule radius. The Averaging Area is used for both height calculations.

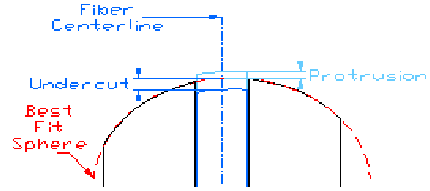
2. ***Planar Height*** is useful when the ideal connector endface is considered to be a flat fiber in the middle of a spherical ferrule. It is defined as the difference in height between the center of the fiber and the height in the center of the theoretical plane formed by connecting the points on the ferrule at diameter E, the Extracting Area.



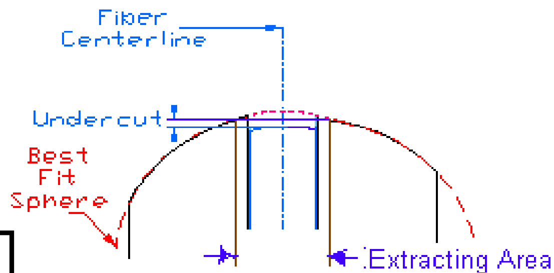
Radius of Curvature



Apex Offset



Spherical Fiber Height



Planar Fiber Height

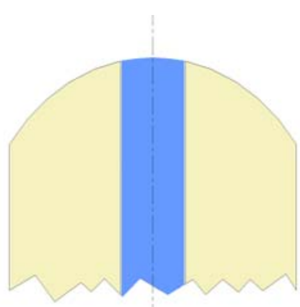
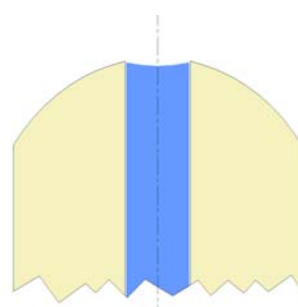
Fig. 5 Key Measurement Parameters

Termini End Face Configurations

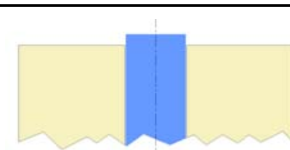
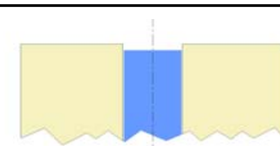
Over the years fiber optic termini have been manufactured a number of different ways. In general, from all the processes, there are 4 possible configurations for the end face of the termini. The general shape of the surface can be either a domed surface or a flat surface. For each of these general shapes, the end face can be polished to provide physical contact (PC polish) of the fibers on mating of the termini or not provide contact (NC polish) of the fibers on mating.

The tables below demonstrate these configurations.

DOMED

PC	NC
Standard for telecommunications to minimize loss and back reflection.	Used in high vibration environments to minimize damage to fiber. Standard process slightly modified.
	

FLAT

PC	NC
Not normally used for single fiber termini, but is used on multi fiber connectors such as MT and MT-RJ.	Used in high vibration environments to minimize damage to fiber.
	

Interferometric Type for Configurations

The type of interferometry used is dependent on the configuration of the end face. As mentioned previously, monochromatic interferometry is best for smooth surfaces, whereas white light interferometry is best when step heights are involved. White light could be used for all but monochromatic light is faster.

Below is a table listing the measurement type for the different configurations:

Ferrule End Face	Polish Type	Measurement Type
Domed	PC	Monochrome/Narrow Band
	NC	White Light/Broadband
Flat	PC	White Light/Broadband
	NC	White Light/Broadband

October 19, 2004
Eric A. Norland

COMPARISON CHART FOR NORLAND INTERFEROMETERS

Feature	CC-6000	AC-3000	AC-3005	Advantage
Measures Single Fiber PC/APC Connectors	▪	▪		▪
Measures Single Fiber Flat Polished Connectors		▪		▪
Measures Cleaved Fibers		▪		▪
Measures Raw Ferrules	▪	▪		▪
Measures Multifiber connectors			▪	▪
Measures up to 6 rows of 12 fibers			▪	
Measures up to 4 rows of 12 fibers				▪
Low-Cost	▪			
USB Compatible - Plug and Play	▪			
Measurements display as 3-D Graphics		▪	▪	▪
Automatic Pass/Fail Testing	▪	▪	▪	▪
Customizable Reports with Graphics		▪	▪	▪
Export data to Excel	▪	▪	▪	▪
Mireau Interferometer		▪		▪
Michelson Interferometer	▪		▪	
Tilting Stage for APC		▪	▪	▪
Separate Mounts for APC	▪			
Red Light Interferometry for smooth surfaces	▪	▪	▪	▪
White Light Interferometry for rough surfaces		▪	▪	▪
Non-Contact Interferometry	▪	▪	▪	▪
Auto-Level Angle Calibrating	▪	▪	▪	▪
Fixed Mirrors	▪	▪	▪	▪
Compact Size - Transportable with Laptop	▪			

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NAVAL SURFACE WARFARE CENTER
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IN REPLY REFER TO
9504
Ser 96315/067
31 October 2003

From: Commander, Carderock Division, Naval Surface Warfare Center,
Naval Ship Systems Engineering Station, Philadelphia, PA
To: Commander, Naval Sea Systems Command
Headquarters (Code 05Z5)
Commander, Naval Air Systems Command
Headquarters Patuxent River (Code 4.5)
Commander, Space and Naval Warfare Systems Command
Headquarters San Diego (Code PMW-165)

GUIDANCE DOCUMENT: METHOD TO MEASURE FERRULE END FACES, FIBER OPTIC CONNECTORS AND TERMINI

(1) Guidance Document, Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements, Ferrules with Domed End Faces of 31 October 2003
(2) Guidance Document, Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements, Ferrules with Flat End Faces of 31 October 2003
(3) Guidance Document, Terminology used for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements of 31 October 2003

1. Purpose

This letter addresses guidelines to be used for specifying and measuring the ferrule end face geometry on fiber optic connectors and termini. Measurement method addressed is one using an interferometer. It is recognized that no one standardized ferrule end face geometry is in current use by all Platforms (such as ship, aircraft or ground-based). Acceptance criteria for ferrule end face geometry is addressed for domed end face ferrules (configured with either a physical contact, PC, or a non-contact, NC, polish) and for flat end face ferrules (with a NC polish only).

2. Measurement parameters

Guidance for limits on measurement parameter, measurement instrumentation considerations and measurement parameter interpretations are provided. This guidance for ferrules with a domed, end face geometry is provided in enclosure (1). Similar guidance for ferrules with a flat, end face geometry is provided in enclosure (2). Terminology used for ferrule end face geometry, that is not defined as part of enclosures (1) and (2), is provided in enclosure (3).

3. Distribution statement

Distribution Statement A: Approved For Public Release, Distribution Is Unlimited.

Subj: GUIDANCE DOCUMENT: METHOD TO MEASURE FERRULE END FACES, FIBER OPTIC CONNECTORS AND TERMINI

4. Points of contact

Please direct questions or comments to the Naval Surface Warfare Center Carderock Division, Ship Systems Engineering Station (NSWCCD-SSES) point of contact for fiber optic component testing and principle contact for NAVAIR/SPAWAR applications on this subject is E. Bluebond. He can be contacted by FAX: (215) 897-8509 or E-mail: bluebondej@nswccd.navy.mil. The Naval Surface Warfare Center, Dahlgren Division (NSWC DD) point of contact for specification requirements and principle contact for NAVSEA applications on this subject is R. Throm (Alternate: G. Brown). He can be contacted by FAX: (540) 653-8673 or E-mail: thromra@nswc.navy.mil (browngd@nswc.navy.mil).

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Appendix: Navy Guidance Document 31- October - 2003

Guidance Document
Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements,
Ferrules with Domed End Faces

1. Summary of configurations for end face geometry and measurement conditions.

   a. End face geometry configurations. There are two types of end faces for the ferrule (either domed or flat) and two types of polishes (either physical contact, PC, or non-contact, NC) addressed. This enclosure addresses the ferrules with a domed end face. The domed end face may contain either a PC polish or a non-contact polish. Both polishes for a ferrule with a domed end face are addressed in this enclosure. In general, possible configurations, for the ferrule and polish, end face geometry, are summarized in table form.

Possible Configurations for End Face Geometry

Ferrule End Face	Polish	Comments
Domed	PC	1/, 2/
Domed	NC	1/
Flat	PC	
Flat	NC	

1/ Configuration covered in this enclosure.
2/ Recommended.

   b. Measurement parameters. The three parameters measured for end face geometry are fiber height, radius of curvature and offset. There are different ways to determine the offset. For a ferrule with a domed end face, the apex offset is the recommended offset to use. Recommended measurement conditions used will differ depending on the end face geometry.
   c. Measurement conditions. Measurement parameters can be determined using either a broad band or a narrow band measurement and the fiber height calculated based on the spherical surface or the planar surface. For the ferrule with an end face geometry addressed in this enclosure, the following measurement conditions are recommended:

Measurement conditions for end face geometry addressed.

Configurations for End Face Geometry		Measurement Conditions	
Ferrule End Face	Polish	Measurement Type	Calculated Fiber Height
Domed	PC	Narrow band	From spherical surface
Domed	NC	Broad band	From spherical surface

2. Connector end face geometry parameters for domed ferrules.

   a. Radius of curvature: 7 mm to 25 mm.
   b. Apex offset: ≤ 50 microns.
   c. Fiber height for a PC (Physical Contact) polish.
      (1) Protrusion: ≤ 0.05 microns (50 nanometers (nm)).

Enclosure (1)

(2) Undercut. The maximum value (limit) for the spherical undercut is dependent upon the radius of curvature measured for the connector under test. Current commercial equation is as follows: $U = -0.02R^3 + 1.3R^2 - 31R + 325$, where U is the maximum acceptable undercut in nanometers and R is the radius of curvature in mm. This equation is used for a radius of curvature between 10 to 25 mm. A constant value for the maximum acceptable undercut of 125 nm is used with a radius of curvature between 7 to 10 nm. The table below lists the maximum acceptable undercut for every mm of the radius of curvature (ROC).

Table of Maximum Acceptable Undercut Values versus the Radius of curvature.
For Ferrules with a Domed End Face and with a PC Polish

ROC (mm)	7	8	9	10	11	12	13	14	15	16
Undercut (nm)	125	125	125	125	115	106	98	91	85	80

ROC (mm)	17	18	19	20	21	22	23	24	25
Undercut (nm)	75	72	68	65	62	59	56	53	50

Note: For military applications, further study is required before the performance criteria can be specified. For present, the commercial telecommunications industry criteria are listed.

Note: If a one value limit must be employed, the following values are offered as guidance:
(1) Termini/test probe: $\leq$ 0.125 microns (125 nm).
(2) ST connector: $\leq$ 75 nm.

d. Fiber height for a NC (Non-Contact) polish.
(1) Protrusion: N/A (not applicable).
(2) Undercut. The minimum value (limit) for the spherical undercut is dependent upon the radius of curvature measured and on the ferrule hole diameter for the connector under test. The table below lists the minimum acceptable undercut for every mm of the radius of curvature (ROC).

Table of Minimum Acceptable Undercut Values versus the Radius of curvature.
For Ferrules with a Domed End Face and with a NC Polish
Ferrule hole diameter: 125 microns

ROC (mm)	7	8	9	10	11	12	13	14	15	16
Undercut (nm)	329	294	267	245	228	213	200	190	180	172

ROC (mm)	17	18	19	20	21	22	23	24	25
Undercut (nm)	165	159	153	148	143	139	135	131	128

Table of Minimum Acceptable Undercut Values versus the Radius of curvature.
For Ferrules with a Domed End Face and with a NC Polish
Ferrule hole diameter: 140 microns

ROC (mm)	7	8	9	10	11	12	13	14	15	16
Undercut (nm)	400	356	322	295	273	254	238	225	213	203

ROC (mm)	17	18	19	20	21	22	23	24	25
Undercut (nm)	194	186	179	173	167	161	157	152	148

Enclosure (1): Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements, Ferrules with Domed End Faces

Table of Minimum Acceptable Undercut Values versus the Radius of curvature.
For Ferrules with a Domed End Face and with a NC Polish
Ferrule hole diameter: 172 microns

ROC (mm)	7	8	9	10	11	12	13	14	15	16
Undercut (nm)	578	512	461	420	386	358	334	314	297	281

ROC (mm)	17	18	19	20	21	22	23	24	25
Undercut (nm)	268	255	245	235	226	218	211	204	198

Note: These tables for minimum acceptable undercut values versus the radius of curvature are based on a fiber height of 50 nm below the surface of the ferrule. Calculations for the tables are based on a geometric approach utilizing the Pythagorean theorem.

Note: For military applications, further study is required before the performance criteria are finalized.

Note: If a one value limit must be employed, the following values are offered as guidance:

(1) Termini/test probe: $\geq$ 0.4 microns (400 nm).

(2) ST connector: $\geq$ 0.3 microns (300 nm).

These values are minimum limits, not maximums as is the case for a domed end face with a PC polish.

e. Relationship of fiber height to spherical surface of ferrule. Protrusion (i.e., spherical protrusion) is the positive distance above the spherical surface. Undercut (i.e., spherical undercut) is positive distance below the spherical surface.

Note: Only a partial region of the spherical surface is used for the fiber height measurement. This region is limited to the portion of the surface directly over the fiber.

f. Interferometer measurement. Interferometers traditionally provided the extended/protracted fiber measurement in terms of fiber height. With respect to the distance above the spherical surface, a particular interferometer may provide the fiber height as either a positive or negative value. Refer to the operating manual for the particular interferometer. Some recent interferometers provide the extended/protracted fiber measurement either in terms of protrusion or in terms of undercut.

(1) If the interferometer provides either a measurement of fiber height with a positive distance below the spherical surface or of undercut, use the applicable undercut value in the table as the upper/positive limit. Use the value for protrusion as the lower/negative limit (for example, a 0.05 micron protrusion, as the lower limit, would be specified as -0.05 microns).

(2) If the interferometer provides either a measurement of fiber height with a positive distance above the spherical surface or of protrusion, use the applicable undercut value in the table as the lower/negative limit. Use the value for protrusion as the upper/positive limit (for example, a 0.05 micron protrusion, as the upper limit, would be specified as +0.05 microns).

3. Curve fitting areas for interferometer measurement calculations (see figure 1 at end this of enclosure).

   a. Diameter F. The outside diameter of the Averaging Area, an area of a circle that is centered on the fiber surface. The center of the fiber is considered to be concentric with the center of the ferrule.
   b. Diameter E. The outside diameter of the Extracting Area, an area of a circle that includes the fiber end face and the adhesive region around the ferrule hole diameter.
   c. Diameter D. The outer diameter of the Fitting Area, an area centered on the ferrule surface and defined by a donut shaped area with outer diameter D and inside diameter E. The outer diameter of the Fitting Area is also referred to as the Region of Interest Width.

Table of Standardized Diameters to be used for the Curve fitting areas.

	Cladding		Polyimide Coating
Diameter (microns)	125 1/	140	100/140/172
Diameter F – averaging area OD 4/	50	50	50
Diameter E – extracting area OD 2/	140	155	185
Diameter D – fitting area OD 3/	250	270	300

1/ Page 16 of IEC standard IEC 1300-3-23 lists the "suggested" diameters for D, E & F for the 125 micron, nominal fiber diameter and an ROC of 8 to 25 mm. Other size fiber diameters D, E & F are proportional based on these values as indicated in the following notes.
2/Use an outer diameter that is 15 microns greater than the cladding diameter or coating diameter, as applicable.
3/ Use an outer diameter that is about 110 microns above the extraction diameter.
4/ Diameter F is not increased for larger fiber sizes since fiber height is calculated at the center of the fiber and is not the average height of the total fiber. A 50 micron diameter provides a more robust measurement for the center of the fiber (more pixels).

4. Other measurement variables.

   a. Interferometer measurement method.
      (1) Narrow band (monochromatic light). In general, use for connectors with a PC polish. Use where there will be less dispersion from the end face, such as with a "sharper" radius of curvature (smaller value). Monochromatic light (such as red light) provides a measurement with better resolution.
      (2) Broad band (white light). In general, use for connectors with a non-contact polish. Use to eliminate ambiguity for a configuration with a step height. White light provides a coarser measurement.
   b. Surface reflectivity. Adjust lighting level (such as camera gain, image and contrast) to prevent light saturation of the detector/camera.
      (1) Ceramic surface. Adjust for a lower reflectivity.
      (2) Metal ferrule with ceramic (jeweled) insert. Adjust for a lower reflectivity (similar reflectance level as for ceramic ferrule since region being detected is within the ceramic insert).
      (3) Metal ferrule. Adjust for a higher reflectivity.

Enclosure (1): Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements, Ferrules with Domed End Faces

5. NAVAIR fiber optic, cable harnesses/connectors approach for end face geometry.

    a. Connector end face geometry parameters, along with optical performance (cable harness assembly loss and for single mode also return loss), are to be used as part of cable harness acceptance criteria unless otherwise specified by the particular Platform or specific cable harness application.
    b. Commonality will standardize on the end face geometry guidance listed in this enclosure.

6. Navy Shipboard, fiber optic connectors approach for end face geometry.

    a. Connector end face geometry parameters are provided as guidance to augment steps for termination and inspection currently specified in MIL-STD-2042.
    b. Polishing procedures, listed in MIL-STD-2042, produce PC polishes within the range specified.

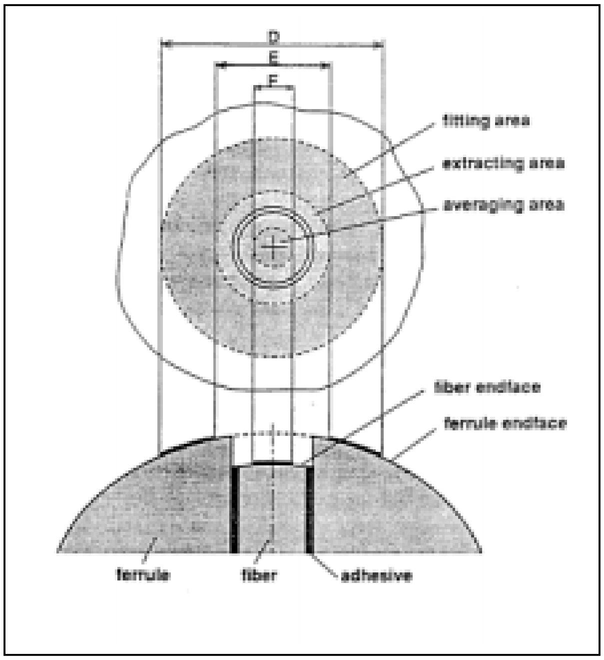

Figure 1. Curve fitting diameters and areas.

DOC: EndFaceltr0310doc

31 October 2003

Guidance Document
Guidance for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements,
Ferrules with Flat End Faces

1. Summary of configurations for end face geometry and measurement conditions.

   a. End face geometry configurations. There are two types of end faces for the ferrule (either domed or flat) and two types of polishes (either physical contact, PC, or non-contact, NC) addressed. This enclosure addresses the ferrules with a flat end face. The flat end face may contain either a PC polish or a non-contact polish. Only the NC polish for a ferrule with a flat end face is addressed in this enclosure. End face geometry measurements are less meaningful for the configuration of a ferrule with a flat end face containing a PC polish. No meaningful parameter limits can be established to ensure that fiber-to-fiber contact will always be obtained. In general, possible configurations, for the ferrule and polish, end face geometry, are summarized in table form.

Possible Configurations for End Face Geometry

Ferrule End Face	Polish	Comments
Domed	PC	
Domed	NC	
Flat	PC	
Flat	NC	1/

1/ Configuration covered in this enclosure.

   b. Measurement parameters. The three parameters measured for end face geometry are fiber height, radius of curvature and offset. There are different ways to determine the offset. For a ferrule with a flat end face, the angular offset is the recommended offset to use. Recommended measurement conditions used will differ depending on the end face geometry.
   c. Measurement conditions. Measurement parameters can be determined using either a broad band or a narrow band measurement and the fiber height calculated based on the spherical surface or the planar surface. For the ferrule with an end face geometry addressed in this enclosure, the following measurement conditions are recommended:

Measurement conditions for end face geometry addressed.

Configurations for End Face Geometry		Measurement Conditions	
Ferrule End Face	Polish	Measurement Type	Calculated Fiber Height
Flat	NC	Broad band	From planar surface

2. Connector end face geometry parameters for flat ferrules.

   a. Radius of curvature.
      (1) Intent. Inspect to ensure consistency of a flat surface contour rather then specifying stringent pass/fail criteria. The criteria provided are to ensure there is not an overly concave or overly convex surface contour (i.e., not have a sharp/steep radius of curvature (ROC)).
      (2) Acceptable ROC: $\leq$ -80 mm and $\geq$ + 80 mm.

Enclosure (2)

(3) Relationships of radius of curvature.

(a) Positive radius of curvature is convex to a flat ferrule end face. A flat/gradual convex radius of curvature is considered to be from +80 to positive infinity.

(b) Negative radius of curvature is concave to a flat ferrule end face. A flat/gradual concave radius of curvature is considered to be from – 80 to negative infinity.

Note: As the radius of curvature goes from a gradual convex contour to a gradual concave contour, the values go from + 80 mm up to positive infinity, inverts from positive infinity to negative infinity, then goes down from negative infinity to – 80 mm.

Note: The radius of curvature of a close to flat surface may change readily from one measurement to the next from a large positive value (such as + 20,000 mm) to a large negative value (such as –20,000 mm). A large

b. Angular offset: (a measure of the polish angle).

(1) Intent. Inspect to ensure consistency of a near perpendicular surface rather then specifying stringent pass/fail criteria. The criteria provided are to ensure there is not an overly steep angle on the surface contour.

(2) Acceptable Angular offset. $\leq 0.5^{o}$.

c. Fiber height for NC (Non-Contact) polish.

Note: Fiber height for a ferrule with a flat end face is to be measured from a planar surface as opposed to the apex of a spherical surface.

(1) Protrusion: none.

(2) Undercut. 65 nm minimum, 400 nm maximum.

Note: For military applications, further study is required before the performance criteria can be specified. For present, the currently used criteria are listed.

Note: If a one value limit must be employed, the following values are offered as guidance:

(1) Termini/test probe: $\leq$ 0.075 microns (75 nm).

(2) ST connector: $\leq$ 0.100 microns (100 nm).

d. Relationship of fiber height to planar surface of ferrule. Protrusion (i.e., spherical protrusion) is the positive distance above the planar surface. Undercut (i.e., spherical undercut) is positive distance below the planar surface.

e. Interferometer measurement. Interferometers traditionally provided the extended/protracted fiber measurement in terms of fiber height. With respect to the distance above the planar surface, a particular interferometer may provide the fiber height as either a positive or negative value. Refer to the operating manual for the particular interferometer. Some recent interferometers provide the extended/protracted fiber measurement either in terms of protrusion or in terms of undercut.

(1) If the interferometer provides either a measurement of fiber height with a positive distance below the planar surface or of undercut, use the applicable undercut value in the table as the upper/positive limit. Use the value for protrusion as the lower/negative limit (for example, a 0.05 micron protrusion, as the lower limit, would be specified as -0.05 microns).

(2) If the interferometer provides either a measurement of fiber height with a positive distance above the planar surface or of protrusion, use the applicable undercut value in the table as the lower/negative limit. Use the value for protrusion as the upper/positive limit (for example, a 0.05 micron protrusion, as the upper limit, would be specified as +0.05 microns).

f. Interferometer determination of the planar surface. The planar surface is to be determined from an ideal sphere after mapping the ferrule end face. From this best fit/ideal sphere, a plane shall be mapped using the points on the ideal sphere at diameter E, the outer diameter of the extraction area (see curve fitting areas for interferometer measurement calculations below).

3. Curve fitting areas for interferometer measurement calculations (see figure 1 at end of this enclosure).

a. Diameter F. The outside diameter of the Averaging Area, an area of a circle that is centered on the fiber surface. The center of the fiber is considered to be concentric with the center of the ferrule.

b. Diameter E. The outside diameter of the Extracting Area, an area of a circle that includes the fiber end face and the adhesive region around the ferrule hole diameter.

c. Diameter D. The outer diameter of the Fitting Area, an area centered on the ferrule surface and defined by a donut shaped area with outer diameter D and inside diameter E. The outer diameter of the Fitting Area is also referred to as the Region of Interest Width.

Table of Standardized Diameters to be used for the Curve fitting areas.

	Cladding		Polyimide Coating
Diameter (microns)	125 1/	140	100/140/172
Diameter F – averaging area OD 4/	50	50	50
Diameter E – extracting area OD 2/	140	155	185
Diameter D – fitting area OD 3/	250	270	300

1/ Page 16 of IEC standard IEC 1300-3-23 lists the “suggested” diameters for D, E & F for the 125 micron, nominal fiber diameter and an ROC of 8 to 25 mm. Other size fiber diameters D, E & F are proportional based on these values as indicated in the following notes.

2/Use an outer diameter that is 15 microns greater than the cladding diameter or coating diameter, as applicable.

3/ Use an outer diameter that is about 110 microns above the extraction diameter.

4/ Diameter F is not increased for larger fiber sizes since fiber height is calculated at the center of the fiber and is not the average height of the total fiber. A 50 micron diameter provides a more robust measurement for the center of the fiber (more pixels).

4. Other measurement variables.

a. Interferometer measurement method.

(1) Broad band (white light). In general, use for connectors with a non-contact polish. Use to eliminate ambiguity for a configuration with a step height. White light provides a coarser measurement.

b. Surface reflectivity. Adjust lighting level (such as camera gain, image and contrast) to prevent light saturation of the detector/camera.

(1) Ceramic surface. Adjust for a lower reflectivity.

(2) Metal ferrule with ceramic (jeweled) insert. Adjust for a lower reflectivity (similar reflectance level as for ceramic ferrule since region being detected is within the ceramic insert).
(3) Metal ferrule. Adjust for a higher reflectivity.

5. NAVAIR fiber optic, cable harnesses/connectors approach for end face geometry.

a. Connector ferrules with domed end faces are recommend for Commonality standardization, unless otherwise specified by the particular Platform.
b. Connector end face geometry parameters, along with optical performance (cable harness assembly loss and for single mode also return loss), are to be used as part of cable harness acceptance criteria unless otherwise specified by the particular Platform or specific cable harness application.

Commonality will standardize on the end face geometry guidance listed in this enclosure.

6. Navy Shipboard, fiber optic connectors approach for end face geometry.

a. Connector end face geometry parameters are not applicable.

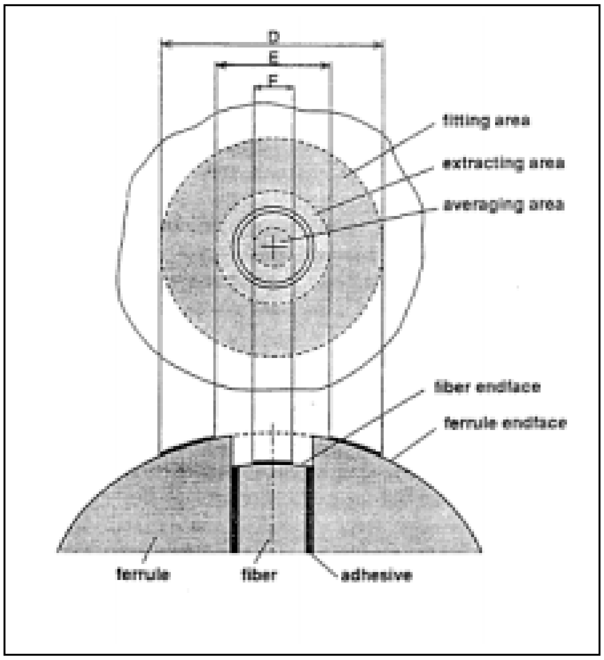

Figure 1. Curve fitting diameters and areas.

31 October 2003

Guidance Document

Terminology used for Interferometer Inspection of Fiber Optic Ferrule, Fiber End Face Measurements

1. Domed end face. A ferrule in which the mating connection surface has a radius (or domed) shape.

2. Domed ferrule. See domed end face.

3. End face geometry. Measurement of the ferrule end face for radius of curvature, measurement of the fiber from a defined surface for fiber height, and measurement of the highest point on the surface contour from the center of the fiber for offset.

4. Ferrule end face. Surface of the ferrule that makes contact with the mating ferrule and/or the mating fiber and the surface that is perpendicular to the longitudinal axis of the optical fiber.

5. Fiber height, domed end face. The height of the fiber is compared to the region of the sphere over the fiber that is formed by an ideally polished connector end face. The difference is the fiber height. The fiber height is measured as the degree of fiber protrusion or undercut from this region of the sphere.

6. Fiber height, flat end face. The height of the fiber is compared to the planar surface determined from predetermined distances on the connector end face. The difference is the fiber height. The fiber height is measured as the degree of fiber protrusion or undercut from the planar surface.

7. Flat end face. A ferrule in which the mating connection surface has essentially a planar (or flat) shape with a very limited degree of tilt.

8. Flat ferrule. See flat end face.

9. NC polish. Ferrule end face is polished in a manner so that the ferrules are the first to make contact when connection surfaces are mated together without the fibers coming into contact.

10. Non-contact polish. See NC polish.

11. Offset. The polish offset is the distance between the highest point on the connector end face (where the center of the bull's eye pattern is observed) and the center of the fiber. This offset is also referred to as the linear offset, eccentricity or apex offset.

12. Offset, angular. The angle between a radial line from the center of the spherical surface to the high point of the polish and a line through the longitudinal axis in the center of the fiber.

14. PC polish. Ferrule end face is polished in a manner so that the fibers first make contact when connection surfaces are mated together.

15. Physical contact polish. See PC polish.

16 Radius of curvature, domed end face. An ideally polished connector end face should have the fiber and the connector form a uniform, spherical surface with the fiber at the highest point (apex). The radius of this sphere formed by the polished connector is called the radius of curvature.

Enclosure (3)