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2022 - April

Acceptance Requirements for Optical Fiber, Optical Cable, and Hybrid Wiring Harness Assemblies

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May 2017

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IPC-A-640A

Acceptance Requirements for Optical Fiber, Optical Cable, and Hybrid Wiring Harness Assemblies

Developed by the Fiber Optic Cable Acceptability Task Group (7-31m) of the Product Assurance Committee (7-30) of IPC.

Supersedes:

IPC-A-640 - May 2017

Users of this publication are encouraged to participate in the development of future revisions.

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HIERARCHY OF IPC ACCEPTANCE SPECIFICATIONS (IPC-A-640A SERIES)

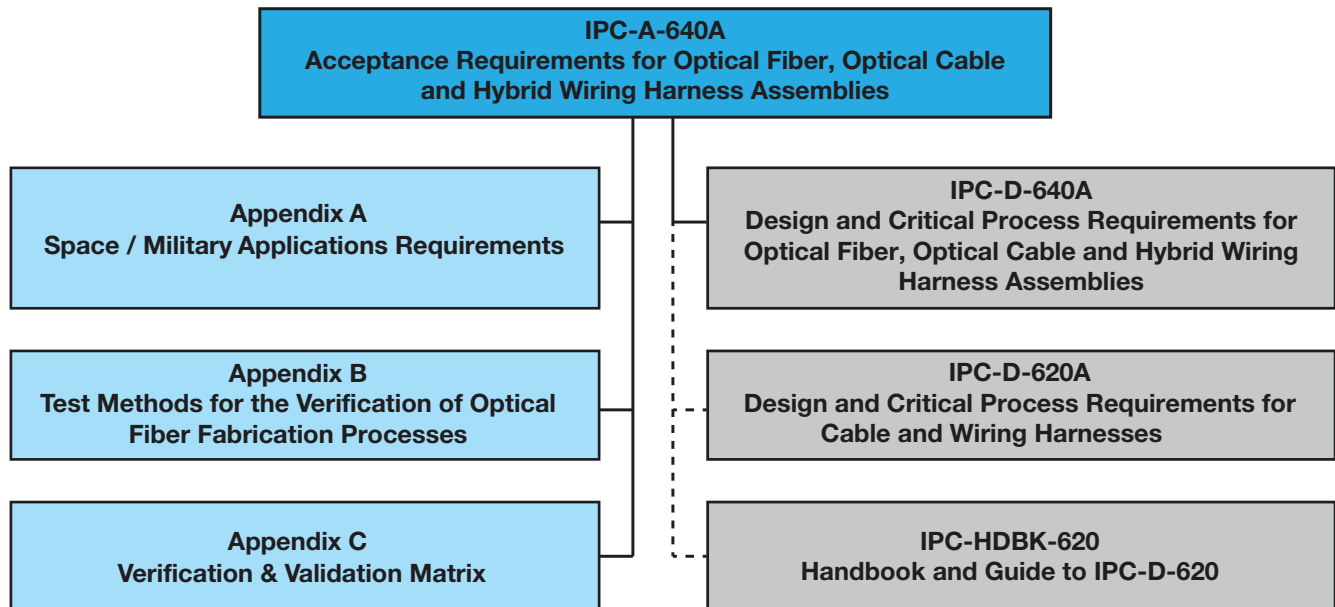


Figure 1 Hierarchy of IPC Design Specifications (IPC-A-640A Series)

FOREWARD

This standard provides information on the design and acceptance requirements for optical fiber, optical cable and hybrid wiring harness to the extent that they can be applied to the broad spectrum of optical cable and wiring harness design. It is therefore crucial that decisions concerning the choice of product classification, fiber technology, connectorization requirements, and performance and reliability requirements be made as early as possible.

As optical wiring and connector technology changes, specific requirements will be updated or new requirements added to the document set.

IPC invites input on the effectiveness of the documentation and encourages User response through completion of “Suggestions for Improvement” form located at the end of each document.

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources across many continents. Shown below are the principal members of the Fiber Optic Cable Acceptability Task Group (7-31m) of the Product Assurance Committee (7-30). It is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of the IPC extend their gratitude.

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Acceptance Requirements for Optical Fiber, Optical Cable, and Hybrid Wiring Harness Assemblies

1 GENERAL

1.1 Scope This standard provides acceptance requirements and technical insight that have been removed from acceptance standards for cable and wire harness assemblies incorporating optical fiber, optical cable and hybrid wiring technology. Reference materials listed in this text are among those considered as required reading. The User is encouraged to obtain all relevant reference materials, as this document cannot (nor can any single document) cover every material, process, environment, performance, or safety aspect that affect a given design.

1.2 Purpose This standard is intended to provide information on design and acceptance requirements for optical fiber, optical cable, hybrid wiring harness assemblies and fiber optic communications systems (FOCS) to the extent that they can be applied to the broad spectrum of optical cable and wiring harness design.

Neither this document nor its Appendices provide detailed procedures for the test, acceptance, commissioning and /or maintenance of FOCS.

This document is intended for use by the design engineer, manufacturing engineer, quality engineer or other individual(s) responsible for tailoring specific requirements of this document to the applicable performance class.

- a. This document defines acceptability criteria and limits for “New/Beginning of Life” hardware. It is not the intent of this document to establish or define “In Service” acceptance criteria to address performance or reliability issues caused by aging or use. However, the acceptability criteria and limits that are detailed in this document may be considered to be wide enough to be applicable to the more common hardware degradation conditions caused by aging/use. Use of these criteria for acceptance of “In Service” hardware conditions **shall [D1D2D3]** be as agreed between User and Supplier (AABUS).
- b. It is not the intent of this document to exclude any alternate documents or processes that meet or exceed the baseline requirements established by this document. Use of alternate documents or processes **shall [D1D2D3]** require review and prior approval of the User.
- c. For purposes of this document:
 - 1) The Designer is the design agent for the User.
 - 2) The User is the individual, organization, company, contractually designated authority, or agency responsible for the procurement or design of electrical/electronic/electromechanical (EEE) hardware, and having the authority to define the class of product and any variation or restrictions to the requirements of this document (e.g., the originator/custodian of the contract detailing these requirements). The User is considered the Design Authority.
 - 3) The Supplier is considered the individual, organization or company which provides the Manufacturer (assembler) components (e.g., electrical, electronic, electromechanical, mechanical, printed boards) and/or materials (e.g., solder, flux, cleaning agents).
 - 4) The Manufacturer is considered the entity that provides a service or product to the User.

Note: In some instances, the Manufacturer may also be considered the Supplier to the User.

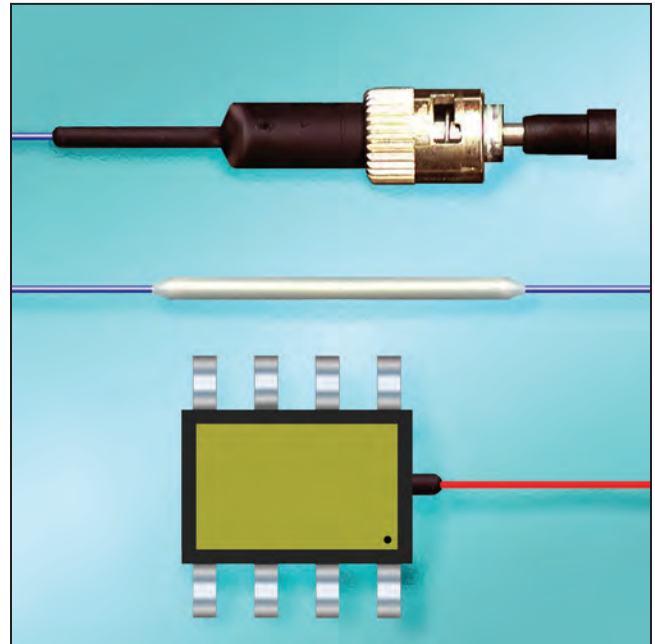


Figure 1-1 Optical Fiber Assemblies, Cables And Wiring Harnesses Connector, Splice and Transmitter
Image credit: NASA

1.3 Performance / Product Classification This document recognizes that optical wiring harnesses and cable assemblies are subject to classifications by intended end-item use. Three general end-product classes have been established to reflect differences in producibility, complexity, functional performance requirements and verification (inspection / test) frequency.

- a. It should be recognized that there may be requirement overlaps between performance / product classifications.
- b. The User is responsible for defining the performance / product classification.
- c. The contract **shall [D1D2D3]** specify the performance / product classification required, whether compliance to any of the Appendices is required and indicate any exceptions to specific parameters where appropriate.

1.3.1 Performance / Product Classification – Definitions

CLASS 1 – General Electronic Products

Includes products suitable for applications where the major requirement is function of the completed assembly.

CLASS 2 – Dedicated Service Electronic Products

Includes products where continued performance and extended life is required and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures.

CLASS 3 – High-Performance/Harsh-Environment Electronic Products

Includes products for which continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh and the equipment must function when required, such as life support or other critical systems.

Space / Military / Hazardous Applications

Includes products from Class 3, with additional considerations for unique materials requirements (e.g., flammability, outgassing), exposure to extreme operational conditions (e.g., vibration and thermal cycling, shock, gravitational-loading), and extreme or sensitive operational environments (e.g., oil and gas exploration, petrochemical, food, pharmaceutical). Space / Military / Hazardous Application deviations to IPC-A-640A requirements are defined and listed in Appendix A, “Space / Military / Hazardous Applications Requirements.”

1.4 Definition of Requirements The imperative form of action verbs are used throughout this document to identify acceptance requirements that may require compliance, depending upon the Performance Classification of the hardware.

- a. **SHALL / SHALL NOT** – The words **shall** or **shall not** are used whenever a requirement is intended to express a provision that is mandatory.
 - 1) To assist the users of this standard (e.g., User, Manufacturer, Designer), the action verbs **shall** and **shall not** are displayed in **bolded text**.
 - 2) Deviation from a **shall** or **shall not** requirement for a particular Performance Class may be considered if sufficient technical rationale/objective evidence (OE) is supplied to the User to justify the exception.
- b. **SHOULD / SHOULD NOT** – The words “should” or “should not” are used whenever a requirement is intended to express a provision that is non-mandatory, and which reflects general industry practice and/or procedure. The words “should” or “should not” are displayed in unbolded text.

1.4.1 Requirement Format (N/A/D)

To assist the User, each requirement is identified by its Performance Classification (x1x2x3) and applicability, where “x” represents:

N = No requirement has been established for this Class

A = Acceptable

D = Defect

Examples:

- [N1N2D3] is Requirement Not Established Class 1 or 2, Defect Class 3
- [N1D2D3] is Requirement Not Established Class 1, Defect Classes 2 and 3
- [N1A2D3] is Requirement Not Established Class 1, Acceptable Class 2, Defect Class 3
- [A1A2D3] is Acceptable Classes 1 and 2, Defect Class 3
- [D1D2D3] is Defect for all Classes.
- A defect for a Class 1 product means that the characteristic is also a defect for Class 2 product and Class 3 product.
- A defect for a Class 2 product means that the characteristic is also a defect for a Class 3 product but may not be a defect for a Class 1 product where less demanding criteria may apply.

1.4.2 Requirements Flowdown This document **shall not [D1D2D3]** be binding, unless separately and specifically included by the applicable contract, approved drawing(s) or purchase order.

- a. When invoked, the applicable requirements of this document **shall [D1D2D3]** be imposed on all applicable subcontracts, assembly drawing(s), documentation and purchase orders.

1.5 Note(s) / Italicized Text Information provided in notes or presented as *italicized* text is for informational purposes only.

1.6 Commercial Off-the-Shelf (COTS) The requirements of this document **shall not [D1D2D3]** apply to suppliers of Commercial-Off-The-Shelf (COTS) or catalog items (e.g., components, assemblies, subassemblies and/or hardware).

- a. The design and workmanship of COTS items **should** be evaluated and modified as required to ensure that the use of COTS in optical fiber, optical cable, hybrid wiring harness assemblies and fiber optic communications systems (FOCS) meets contract performance and reliability requirements.
- b. Modifications of COTS **shall [D1D2D3]** be documented.
- c. All modifications **shall [D1D2D3]** meet the applicable requirements of this document for the specified Product Class and be completed, inspected and tested in accordance with this document, unless otherwise specified by the User.

1.7 Existing or Previously Approved Designs The requirements of this document **shall not [D1D2D3]** constitute the sole cause for the redesign of previously approved designs.

- a. When drawings for existing or previously approved designs undergo revision, they **should** be reviewed and changes made that allow for compliance with the requirements of this document.

1.8 Line Drawings and Illustrations Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this standard. In the case of a discrepancy, **the description or written criteria (including applicable tables) always takes precedence over the illustrations (graphics or images).**

Note: Tables are considered a graphical representation of written criteria.

1.9 Measurement Units and Applications All dimensions and tolerances, as well as other forms of measurement in this standard, are expressed in SI (System International) units, with Imperial English equivalent dimensions provided in [brackets], except as noted.

- a. Linear dimensions and tolerances use centimeters (cm) [inches (in)] as the main form of dimensional expression; millimeters (mm) [inches (in)] or micrometers (μm) [microinches (μin)] are used when the required precision makes the use of centimeters (cm) too cumbersome.
- b. Temperature values are expressed in degrees Celsius ($^{\circ}\text{C}$) [Fahrenheit ($^{\circ}\text{F}$)].
- c. Mass is expressed in grams (g) [ounces (oz)].
- d. Wire, wire harness, and cable diameters are expressed in the non-dimensional unit (d), where a numerical dimension, such as 2d, is solely dependent on a physical attribute of the hardware (e.g., wire gauge, harness diameter).
- e. Time values are expressed in hours, minutes and seconds (hh:mm:ss).
- f. Verification of Dimensions. Unless specified otherwise, actual measurement of specific part mounting and fiber dimensions, and determination of percentages, are not required except for referee purposes. For determining conformance to the specifications in this Standard, round all observed or calculated values “to the nearest unit” in the last right-hand digit used in expressing the specification limit, in accordance with ASTM Practice E29 [6 - Rounding Method].
- g. For purposes of this document, the following mathematical operators/symbols are used throughout this document as defined:
 - = “equal/equals”
 - < “less than”
 - $\leq$ “less than or equal to”
 - > “greater than”
 - $\geq$ “greater than or equal to”
 - % “percent”
 - $^{\circ}$ “degree / degrees”
 - $\pm$ “plus or minus”

1.10 Acronyms, Abbreviations, and Terms For purposes of this document, the acronyms, abbreviations and terms used, but in addition to those listed in IPC-T-50 are listed in Section 9.

1.10.1 Use of Lead For readability and translation, this document uses the noun “lead” only to describe the leads / terminations of a component. When the metallic element “lead” is referenced as a metal or as an alloy in solder, it is written as lead (Pb) or in its alloy form (e.g., SnPb).

1.10.2 Periodic Table Elements Periodic table elements are abbreviated in the standard. See Section 9 for full spellings of abbreviations (including elements) and acronyms used in this standard.

1.11 Engineering Documentation The design engineer is responsible for ensuring all applicable design details are clearly and completely depicted on the engineering documentation (drawings). Drawings **shall [D1D2D3]** impose the appropriate Product Class, and specify that fiber optic cable and harness assemblies are to be fabricated, inspected and tested in accordance with requirements of this document, unless otherwise specified by the User.

1.12 Order of Precedence The contract always takes precedence over this document, referenced standards and drawings.

1.12.1 Conflict

- a. In the event of conflict between the requirements of this document and the approved assembly drawing(s)/documentation, the User-approved assembly drawing(s)/documentation **shall [D1D2D3]** govern.
- b. In the event of a conflict between the text of this document and the applicable documents cited herein, the text of this document **shall [D1D2D3]** take precedence.
- c. In the event of conflict between the requirements of this document and an assembly drawing(s)/ documentation that has not been User approved, this document **shall [D1D2D3]** govern.
- d. If no criteria are specified, required or cited, criteria **shall [D1D2D3]** be established and agreed upon between the Manufacturer and User.

1.12.2 Clause References When a clause in this document is referenced, its subordinate clauses **shall [D1D2D3]** also apply.

1.13 Appendices A – C For the purpose of this document, Appendices A - C are considered separate and optional documents to IPC-A-640A, which provide additional engineering rationale and technical guidance on the quality acceptance of optical fiber, optical cable, and hybrid wiring harness assemblies.

- a. Appendices A - C **shall not [D1D2D3]** be binding, unless separately and specifically included by the applicable contract, approved drawing(s) or purchase order.
- b. When invoked, the applicable requirements of the appendices **shall [D1D2D3]** be imposed on all applicable subcontracts, assembly drawing(s), documentation and purchase orders.
- c. When not invoked, the applicability of the Appendices, individual requirements of the Appendices, and/or flowdown of said appendices and/or individual requirements **shall [D1D2D3]** be AABUS.

1.14 Approval of Departures from Standards and Requirements This document is intended for use in specifications or contracts to incorporate requirements that are common to most optical fiber, optical cable and hybrid wiring harness assemblies, and establishes the minimum design and acceptance requirements for most applications.

- a. Special Requirements. Special requirements may exist which are not covered by, do not comply with or which are in conflict with program-specific documents, and/or program-specified design requirements.
- b. Tailoring of Requirements. The requirements herein may be tailored by the Designer; however, such tailoring **shall [D1D2D3]** require technical evaluation and approval by the User prior to use. See Section 7 for additional information.
- c. Use of Alternate Plans / Documents. Use of alternate control plans, documents or processes **shall [D1D2D3]** require technical evaluation and approval of the User prior to use.
- d. Requests for Relief. Requests for relief from requirements in this document **shall [D1D2D3]** require technical evaluation and approval of the User prior to use.
- e. Requests for Relief – Technical Details. Engineering documentation **shall [D1D2D3]** contain the details for such instances and take precedence over appropriate sections of this document and the applicable requirements document(s).

1.15 Personnel Proficiency All instructors, operators and inspection personnel **shall [D1D2D3]** be proficient in the tasks to be performed.

- a. Objective evidence of that proficiency **shall [D1D2D3]** be maintained and available for review.
- b. Objective evidence **shall [D1D2D3]** include records of training to the applicable job functions being performed, work experience, testing to the requirements of this standard and/or results of periodic reviews of proficiency.
- c. Supervised on-the-job training **shall [D1D2D3]** be acceptable until proficiency is demonstrated.

1.16 Facilities Work areas/facilities used for the assembly, processing and testing of optical fiber, optical cable and hybrid wiring harness assemblies **shall [D1D2D3]** be classified as a Controlled Work Area (CWA), and maintained at environmental conditions and cleanliness levels that prevent the introduction of foreign object debris (FOD), and/or contamination that would interfere with the assembly process or damage/degrade the hardware.

- a. For the purpose of this document, a CWA is defined as an enclosed assembly/processing area maintained to a high degree of shop cleanliness, environmental control and FOD control, either by process or procedure, to limit the level and type of contaminants that would interfere with the assembly process or damage/degrade the hardware.
- b. See Appendix A – Space / Military / Hazardous Applications Requirements for additional technical guidance and/or alternate requirements.

1.16.1 Temperature For operator comfort, the temperature **shall [D1D2D3]** be maintained between 18 °C and 30 °C [64.4 °F and 86 °F].

1.16.2 Humidity The range (lower and upper limits) of humidity in the assembly area **shall [D1D2D3]** allow optical fiber components and assembly materials to function correctly in the process, based on vendor recommendations or documented evidence of process performance.

- a. Humidity **shall [D1D2D3]** be controlled to the extent necessary to prevent condensation or corrosion on sensitive surfaces, latent damage to moisture-sensitive devices/assemblies or to preclude buildup of electrical static charges.
- b. For operator comfort and protection of sensitive surfaces, relative humidity (RH) **should not** exceed 70 %.
- c. When RH decreases to a level ≤ 30 %, the Manufacturer **shall [D1D2D3]** verify that electrostatic discharge (ESD) control is adequate (see 1.17).

1.16.3 Process Control & Test For process control and testing, more restrictive temperature and humidity limits may be required.

1.16.4 Positive Pressure When specified by contract, the minimum positive pressure differential between the CWA and any adjacent area subject to lesser environmental control requirements **shall [D1D2D3]** be 1.27 mm [0.05 in] of water above the local ambient atmospheric pressure, with all entryways closed.

Note: When the entryways are open, there should be adequate blower capacity to maintain an outward flow of air from the CWA to minimize the migration of airborne contaminants into the facility.

1.16.5 Personnel Behavior Personnel **should** conduct themselves in a manner that will minimize the possibility of contaminating the product, or that will degrade process controls, product quality, performance or yield.

- a. Eating, drinking or use of tobacco/nontobacco products (including vapor delivery, smokeless) **shall [D1D2D3]** be prohibited in the CWA.

1.16.6 Field Assembly Operations In field assembly operations in which the controlled environmental conditions required by this standard cannot be effectively achieved, precautions **shall [D1D2D3]** be taken to minimize the effects of the uncontrolled environment (e.g., humidity, temperature) on the operation being performed on the hardware.

1.16.7 Foreign Object Debris (FOD) Control Plan When a FOD Prevention Program (FOD Control Plan) is required, it **shall [D1D2D3]** be established for the design, development, manufacturing, assembly, repair, processing, testing, maintenance, operation and check-out of optical fiber, optical cable and hybrid wiring harness assemblies to prevent immediate and latent damage and to ensure compliance to the specified cleanliness level.

See IPC-WP-116A for technical guidance and requirements.

1.17 Safety Personnel involved with the design, assembly, installation and testing of optical fiber, optical cable, hybrid wiring harness assemblies and FOCS may be exposed to multiple safety concerns in: (1) the work place; (2) the environment in which the FOCS is situated; and/or (3) equipment selection, arrangement, system construction, and maintenance procedures.

1.17.1 Chemicals The chemicals (e.g., adhesives, cleaners, coatings, encapsulants and solvents) used in the assembly, rework and/or repair of optical fiber, optical cable and hybrid wiring harness assemblies can be **HAZARDOUS, VOLATILE, REACTIVE, FLAMMABLE and/or FATAL** if inhaled, ingested, allowed to contact the skin or eyes or used incorrectly. All safety precautions **shall [D1D2D3]** be strictly followed in accordance with the supplier's instructions, applicable requirements and government regulations.

1.17.2 Epoxies/Adhesives Epoxy resins and/or adhesives used in the assembly, rework and/or repair of optical fiber and optical terminations may cause mild dermatitis (skin irritation) and/or allergic reactions.

- a. The manufacturer's instructions **shall [D1D2D3]** be followed at all times.
- b. Suitable personal protective equipment (PPE) **should** be worn.

1.17.3 Toxic Products and Formulations The use of toxic products and formulations throughout manufacture, assembly, test and rework/repair processes **shall [D1D2D3]** conform to all local, state and federal (national) safety and environmental regulations. For United States facilities, all Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) regulations apply.

1.17.4 Protection from Bare Fibers

Exposure to bare fiber and fiber waste is a personnel safety concern and **shall [D1D2D3]** be handled as such.

- a. All necessary precautions **shall [D1D2D3]** be taken to protect personnel from skin puncture (especially around the eyes), ingestion, or inhalation while fabricating, inspecting or testing.
- b. As a minimum, personnel who may come in contact with bare fibers during cleaving and termination processes **shall [D1D2D3]** wear wraparound safety goggles to prevent accidental ingress of glass shards into the eyes, and to reduce the chance of eye damage.
- c. Slivers of bare fiber **shall [D1D2D3]** be placed in a specially marked container for later disposal.
- d. Fiber waste **shall not [D1D2D3]** be disposed of in general / office trash.
- e. Recommendations:
 - 1) Keep all food and beverages out of the work area. If fiber particles are ingested, they may cause internal hemorrhaging (bleeding).
 - 2) It is strongly recommended that contact wearers not handle their lenses until they have thoroughly washed their hands. Fiber particles entering the eye can result in serious injury or loss of sight.
 - 3) It is strongly recommended that personnel working with fiber optic systems not rub or touch their eyes until they have thoroughly washed their hands. Fiber particles entering the eye can result in serious injury or loss of sight.
 - 4) Wear disposable aprons to minimize fiber particles on clothing. Fiber particles on clothing can later get into food or drinks and/or be ingested by other means.
 - 5) Thoroughly clean the work area following completion of work with fiber.

1.17.5 Eye Safety – Energized Source Concern Light sources used in the test and operation of optical fiber and cable operate in the visible and/or nonvisible light spectrum and may be classified as high power. Exposure, even incidental, may cause injury or permanent eye damage. **Never assume that a fiber is not energized simply because visible light is not evident.**

- a. All optical fiber **shall [D1D2D3]** be treated as “energized” during inspection and test until it is verified that the fiber is “dark.”

Technical guidance: Use a fiber optic power meter to make certain the fiber is dark. When using an optical tracer or continuity checker, look at the fiber from an angle at least 15.24 cm [6 in] away from the eye to determine if the visible light is present.

- b. The direct viewing of the end of an energized optical fiber, terminated optical fiber or connectorized fiber cable, especially with a microscope, **shall [D1D2D3]** be PROHIBITED.

Technical guidance: Use of a Visual Fault Locator (VFL) is standard industry practice and considered a safe method for continuity testing, fiber tracing, and fault location / testing of energized optical fibers.

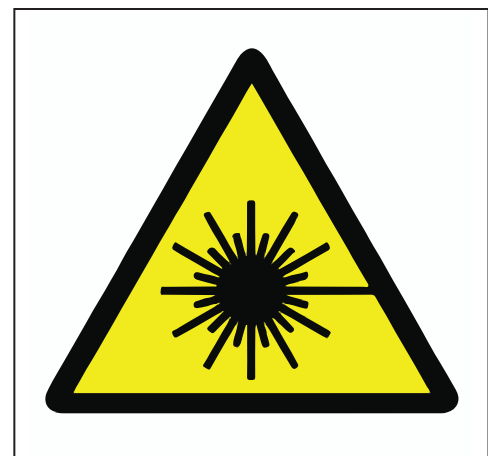


Figure 1-2 International Laser Warning Label
Image Credit: NASA

- c. At a minimum, personnel **shall [D1D2D3]** wear wraparound safety goggles for eye protection.
- d. Protection from eye exposure to Class 2 or higher laser light emissions **shall [D1D2D3]** be in accordance with ANSI Z136.1 and ANSI Z136.2, or other applicable federal (national) laser safety regulations.
 - 1) Skin and eye protection **shall [D1D2D3]** be provided and used when working with Class 3b and 4 sources.
- e. Test Equipment. The equipment manufacturer's operation and safety instructions **shall [D1D2D3]** be followed.
 - 1) Microscopes used to examine the end face of an optical fiber or terminus **shall not [D1D2D3]** be used while the fiber is energized.
 - 2) Use of Visual Fault Locator (VFL) equipment **shall [D1D2D3]** be strictly controlled to prevent direct exposure to the beam when connected or disconnected from the fiber under test. Exposure, even incidental or reflected, may cause injury or permanent eye damage.



Figure 1-3 Example of a Laser Warning Label
Designed for Use in a Fiber Optic Communications
Systems (FOCS) Image Credit: NASA

1.18 Tools and Equipment

1.18.1 Control

Each Manufacturer **shall [D1D2D3]**:

- a. Select tools appropriate to the intended function.
- b. Clean and properly maintain all tools and equipment.
- c. Examine all elements of tools for physical damage.
- d. Prohibit unauthorized, defective or uncalibrated tools in the work area.
- e. Document detailed operating procedures and maintenance schedules for tools and equipment requiring calibration or setups.
- f. Maintain records of tool and equipment calibration and functional testing.
- g. Ensure test fixtures, test adapters and test equipment are maintained to assure the integrity of the test.
- h. Ensure process tooling and process equipment are maintained to assure acceptability of the product.
- i. Ensure that tools, equipment, and systems provide protection from electrical overstress or ESD when ESD sensitive parts or assemblies are involved.

1.18.2 Calibration Tools, measuring equipment, specialized inspection equipment for fiber optics, and mechanical and electrical test equipment **shall [D1D2D3]** be calibrated or validated using a documented process that ensures:

- a. The documented calibration system is in accordance with ANSI/NCSL Z540.3 or other national or international standard.
- b. Measurement standards used for calibrating tools are traceable to National Institute of Standards and Technology (NIST) or other national or international standard.
- c. Calibration of tools, measuring equipment and mechanical and electrical test equipment is performed in an environment compatible with the environmental requirements of the process or hardware to be tested.
- d. Calibration intervals are based on the type of tool and records of the tool's calibration. Intervals may be lengthened or shortened on the basis of stability demonstrated over previous calibration periods.
- e. Procedures are generated and utilized for the calibration of all tooling stated herein. Procedures include, as a minimum, the standards to be used, parameters to be measured, accuracy, tolerances, environmental factors and steps in the calibration process. The procedures may be the Supplier's specifications if judged adequate and need not be rewritten but are documented.
- f. Records are maintained that document calibration.
- g. Tools are labeled to indicate, as a minimum:
 - 1) Date of calibration.
 - 2) Calibration due date.
 - 3) Any limitation of use.
 - 4) Tool identification.

1.19 Electrostatic Discharge (ESD) Protection Optical fiber, cable, harness assemblies, optoelectronic assemblies (e.g., amplifiers, attenuators, detectors, transmitters, receivers) that contain components or parts sensitive to ESD **shall [D1D2D3]** be protected by a documented ESD Control Program in accordance with either ANSI/ESD S20.20, IEC-61340-5, or equivalent as otherwise specified, when the Relative Humidity (RH) in the assembly / test area decreases to 30 % or lower. This includes selection and use of protective devices such as connector covers, etc.

a. Documentation necessary for an effective program **shall [D1D2D3]** be available for review.

1.20 Contamination Assemblies produced in accordance with this standard **shall [D1D2D3]** be free of all extraneous matter (including but not limited to strength member clippings, insulation slugs or any other item not required to be present).

a. Handling of cleaned assemblies **shall [D1D2D3]** prevent recontamination.

1.21 Rework / Repair In the event a rework or repair action takes place, any tests/inspections that were previously performed **shall [D1D2D3]** be repeated in their entirety for the portion of the product that was affected by the rework or repair. See 9.4.3.

a. Rework. Rework **shall [D1D2D3]** meet all applicable requirements of this standard.

b. Repair. Repairs **shall [D1D2D3]** be conducted in accordance with a documented procedure.

1) The repair method **shall [D1D2D3]** be determined by agreement between the Manufacturer and the User.

1.22 Statistical Process Control (SPC) When a statistical process control (SPC) system is used, it **shall [D1D2D3]** include the following elements as a minimum:

- a. Training is provided to personnel with assigned responsibilities in the development, implementation and utilization of process control and statistical methods that are commensurate with their responsibilities.
- b. Quantitative methodologies and evidence are maintained to demonstrate the process is capable and in control.
- c. Improvement strategies define initial process control limits and methodologies, leading to a reduction in the occurrence of process indicators to achieve continuous process improvement.
- d. Criteria for switching to sample-based inspection are defined. When processes exceed control limits or demonstrate an adverse trend or run, the criteria for reversion to higher levels of inspection (up to 100 %) are also defined.
- e. When defect(s) are identified in the lot sample, and the number exceeds the limit allowed by the sampling plan, the entire lot is 100 % inspected for the occurrence(s) to the defect(s).
- f. A system is in place to initiate corrective action for the occurrence of process indicators, out-of-control process(es) and/or discrepant assemblies.
- g. A documented audit plan is defined to monitor process characteristics and/or output at a prescribed frequency.
- h. Objective evidence of process control may be in the form of control charts or other tools and techniques of SPC derived from application of process parameter and/or product parameter data.

1.23 Supply Chain Traceability

- a. When specified by contract, a supply chain traceability program in accordance with IPC-1782, or equivalent, **shall [D1D2D3]** be developed and maintained.
- b. Duration of maintenance of records **shall [D1D2D3]** be AABUS.

2 APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issue/revision identified herein, or the issue/revision in effect on the date of invitation for bid or request for proposal applies.

2.1 IPC¹

IPC-WP-116 Guidance for the Development and Implementation of a Foreign Object Debris (FOD) Control Plan

IPC-A-610DC Telecom Addendum

IPC-OI-645 Standard for Visual Optical Inspection Aids

IPC-1782 Standard for Manufacturing and Supply Chain Traceability of Electronic Products

IPC-8497-1 Cleaning Methods and Contamination Assessment for Optical Assembly

¹ www.ipc.org

2.2 American Society of Mechanical Engineers (ASME)²**ASME Y14.100** Engineering Drawing Practices**ASME Y14.24** Types and Applications of Engineering Drawings**ASME Y14.34** Associated Lists**ASME Y14.35** Revision of Engineering Drawings and Associated Documents**ASME Y14.44** Reference Designations for Electrical and Electronics Parts and Equipment**2.3 ASTM International³** ASTM E595 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment**2.4 EOS/ESD Association⁴****ANSI/ESD S20.2 ESD** Association Standard for the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)**2.5 Institute of Electrical and Electronics Engineers (IEEE)⁵****IEEE C2** National Electrical Safety Code (NESC)**IEEE 1202 IEEE** Standard for Flame-Propagation Testing of Wire & Cable**2.6 International Electrotechnical Commission (IEC)⁶****IEC 61300-3-35** Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-35: Examinations and measurements - Visual inspection of fibre optic connectors and fibre-stub transceivers**IEC 61754-13** Fibre optic connector interfaces - Part 13: Type FC-PC connector**2.7 Laser Institute of America (LIA)⁷****ANSI Z136.1** Safe Use of Lasers**ANSI Z136.2** Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources**2.8 National Aeronautics and Space Administration (NASA)⁸****NASA-STD-6001** Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion**2.9 National Fire Protection Association (NFPA)⁹****NFPA 262** Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces**2.10 NCSL International¹⁰****ANSI/NCSL Z540.3** American National Standards for Calibration - Requirements for the Calibration of Measuring and Test Equipment**2.11 Telecommunications Industry Association¹¹****TIA-598** Optical Fiber Cable Color Coding**TIA-604-5 FOCIS 5** Fiber Optic Connector Intermateability Standard - Type MPO**2.12 United States Department of Defense (DoD)¹²****MIL-HDBK-415** Design Handbook for Fiber Optic Communications Systems**MIL-STD-188-111** Interoperability and Performance Standards for Fiber Optic Communications Systems

² www.asme.org³ www.astm.org⁴ www.esda.org⁵ www.ieee.org⁶ www.iec.ch⁷ www.lia.org⁸ standards.nasa.gov⁹ www.nfpa.org¹⁰ www.ncsli.org¹¹ www.tiaonline.org¹² <https://www.dla.mil/HQ/InformationOperations/DLMS/elibrary/manuals/milstds/>

MIL-STD-961 Military Standard: Defense and Program-Unique Specifications Format and Content

MIL-STD-962 Department of Defense Standard Practice: Defense Standards Format and Content

MIL-STD-967 Department of Defense Standard Practice: Defense Handbooks Format and Content

MIL-STD-1686 Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)

MIL-STD-2052 Fiber Optic Systems Design

2.13 UL¹³

UL 1666 Standard for Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts

UL 1685 Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables

2.14 Reference Unless otherwise specified, these documents fall in order of precedence behind the contract, approved drawings and any standards imposed on the program. The requirements and recommendations in these documents are not binding and are not to be construed as implied requirements to be imposed on the program. Nor are they to be used if they conflict with any contractual or program-specific requirements.

A-A-52083 Commercial Item Description, Tape, Lacing and Tying, Glass

AIR1351 Manufacturers' Identification of Aerospace Electrical and Electronic Wiring Devices and Accessories

AIR5575 Hot Stamp Wire Marking Concerns for Aerospace Vehicle Applications

AIR5717 Mitigating Wire Insulation Damage during Processing and Handling

AMS2491 Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding

ANSI Z535 Safety Color Chart for Use with the ANSI Z535 Standards

ANSI/EIA-364-38 Cable Pull-Out Test Procedure for Electrical Connectors

ANSI/TIA-440 Fiber Optic Terminology

ANSI/TIA-455 General Requirements for Standard Test Procedures for Optical Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and other Fiber Optic Components

ANSI/TIA-598 Optical Fiber Cable Color Coding

ARINC 801-1 Fiber Optic Connectors

ARINC 802-2 Fiber Optic Cables

ARINC 803-3 Fiber Optic System Design Guidelines

ARINC 804-1 Fiber Optic Active Device Specification

ARINC 805-3 Fiber Optic Test Procedures

ARINC 806-4 Fiber Optic Installation and Maintenance

ARINC 807-3 Fiber Optic Training Requirements

AS5649 Wire and Cable Marking Process, UV Laser

AS9100 Quality Management Systems - Requirements for Aviation, Space and Defense Organizations

ASME Y14.24 Types and Applications of Engineering Drawings

ASME Y14.34 Associated Lists

ASME Y14.35 Revision of Engineering (Chapter Drawings and Associated Lists)

DOD-STD-1678 Fiber Optics Test Methods and Instrumentation

IEEE Std. 315 Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters)

IEEE C2 National Electrical Safety Code (NESC)

IPC/WHMA-A-620 Requirements and Acceptance for Cable and Wire Harness Assemblies

IPC/WHMA-A-620-S Space Applications Electronic Hardware Addendum to IPC/WHMA-A-620

IPC-2611 Generic Requirements for Electronic Product Documentation

IPC-8497-1 Cleaning Methods and Contamination Assessment for Optical Assembly

¹³ www.ul.com

IPC-A-610GC Telecom Addendum

IPC-TM-650 IPC Test Methods Manual

IPC-WP-113 Guidance for the Development and Implementation of a Red Plague Control Plan (RPCP)

IPC-WP-114 Guidance for the Development and Implementation of a White Plague Control Plan (WPCP)

IPC-WP-116 Guidance for the Development and Implementation of a Foreign Object Debris (FOD) Control Plan

MIL-DTL-83522 Connectors, Fiber Optic, Single Ferrule, General Specification for

MIL-DTL-83526 Connectors, Fiber Optic, Circular, Environmental Resistant, Hermaphroditic, General Specification for

MIL-HDBK-83575 General Handbook for Space Vehicle Wiring Harness Design and Testing

MIL-HDBK-863 Handbook for Wiring Data and System Schematic Diagrams, Preparation of

MIL-PRF-28876 Connectors, Fiber Optic, Circular, Plug and Receptacle Style, Multiple Removable Termini, General Specification for

MIL-PRF-29504 Termini, Fiber Optic Connector, Removable, General Specification for

MIL-PRF-49291 Fiber, Optical, (Metric), General Specification for

MIL-PRF-64266 Connectors, Fiber Optic, Circular, Plug and Receptacle Style, Multiple Removable Genderless Termini, Environment Resisting, General Specification for

MIL-PRF-85045 Cables, Fiber Optics, (Metric), General Specification for

MIL-STD-2042(SH) Fiber Optic Cable Topology Installation, Standard Methods for Naval Ships

MIL-T-43435 Tape, Impregnated, Lacing, and Tying

NASA PUBLICATION 1124 Outgassing Data for Selecting Spacecraft Materials (<http://outgassing.nasa.gov>)

NASA SSQ 21654 Cable, Single Fiber, Multimode, Space Quality, General Specification For

NASA-STD-6001 Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

NASA-STD-6016 Standard Materials and Processes Requirements for Spacecraft

NASA-STD-8739.5 Fiber Optic Terminations, Cable Assemblies, and Installation

SAE AS16781 Fiber Optics Test Methods and Instrumentation

SAE AS5382 Aerospace Cable, Fiber Optic

SAE AS5382/1 Cable, Fiber Optic, Multimode, 100/140/172 μm Graded Index, Hermetic Coated, Tight Buffer

SAE AS5382/2 Cable, Fiber Optic, Multimode, 100/140/172 μm Graded Index, Non-Hermetic, Loose Tube

SAE AS5382/3 Cable, Fiber Optic, Single-Mode, 6/125/250 μm , Hermetic Coated, Tight Buffer

SAE AS5382/4 Cable, Fiber Optic, Single-Mode, 4.6/125/450 μm , Hermetic Coated, Tight Buffer

SAE AS5382/5 Cable, Fiber Optic, Multimode, 50/125/450 μm , Graded Index, Hermetic Coated, Tight Buffer

SAE AS5382/6 Cable, Fiber Optic, Multimode, 200/230/500 μm , Step Index, Tight Buffer

SAE GEIA-STD-0005-1 Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder

SAE GEIA-STD-0005-2 Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems

TIA-526 Standard Test Procedures for Fiber Optic Systems

3 ASSEMBLY

The engineering documentation **shall [D1D2D3]** define the parts, tooling, equipment and assembly procedures required to ensure the production of optical fiber, optical cable and/or hybrid wiring harness assemblies that meet the specified performance and reliability requirements.

- a. All parts, materials, tooling and equipment **shall [D1D2D3]** be verified for compliance to the engineering documentation prior to the start of fabrication activities.
- b. When major elements of the proven processes are changed (e.g., adhesives, cleaning media or system, tooling, marking), validation of the acceptability of the change(s) **shall [D1D2D3]** be performed and documented.

- c. Fiber/Cable Storage – Bulk optical fiber and/or optical fiber cable (spool and loose) **shall [D1D2D3]** be stored and controlled in accordance with material Supplier recommendations or in accordance with the Manufacturer's documented procedures for controlling moisture, contamination, or damage / degradation. See Appendix A for additional technical guidance and/or alternate requirements.
- d. Limited Shelf-Life – Limited shelf-life items **shall [D1D2D3]** be stored and controlled in accordance with material Supplier recommendations or in accordance with the Manufacturer's documented procedures for controlling shelf life and shelf-life extensions.

***Note:** Parts and materials drawn from inventory having lot date codes older than five years should require technical evaluation to determine the need for rescreen/retest prior to use. Parts stored in conditions where environmental conditions (moisture/temperature) and/or ESD are not controlled should not be used.*

3.1 Handling – Optical Fiber / Optical Cable, General Requirements Optical fiber is made of a dielectric material (e.g., glass, fused silica, plastic) that can be easily damaged (e.g., break, crack, shatter) or degraded (e.g., microbend, macrobend) if improperly handled. The following are a list of general requirements when handling optical fiber, optical cable, hybrid wiring harness fiber and fiber optic modules.

- a. Handling procedures for optical fiber, optical cable, hybrid wiring harness fiber **shall [D1D2D3]** be documented and available for review.
- b. Personnel handling optical fiber, optical cable and hybrid wiring harness fiber **shall [D1D2D3]** be trained or be certified.
- c. When handling optical fiber, optical cable or hybrid wiring harness, individual optical fiber(s) **shall not [D1D2D3]** be pulled in excess of maximum tensile limits.
- d. Optical fiber, optical cable and hybrid wiring harness fiber **shall not [D1D2D3]** be caught (snag) on surrounding items (tools, board, etc.) during handling.
- e. Excessive force **shall not [D1D2D3]** be applied when handling optical fiber, optical cable and hybrid wiring harness fiber.
- f. Optical fiber, optical cable **shall not [D1D2D3]** be pinched.

Notes:

- 1) Be careful not to pinch 250 μm and 400 μm fiber with your fingernails.
- 2) Acrylate coating can easily be abraded or damaged.

- g. Knots **shall not [D1D2D3]** be tied on optical fiber and/or optical cables.
- h. Optical fiber and/or optical cables **shall not [D1D2D3]** be pulled during detangling.

Technical guidance: Rotate the fiber or cable by hand and gently ease out the tangle.

- i. Optical fiber that has been untangled **shall [D1D2D3]** be verified with VFL.
- j. Optical fiber and/or optical cables **shall not [D1D2D3]** be bent sharply.
- k. Optical fiber and/or optical cables **shall not [D1D2D3]** be twisted beyond the natural curl of the fiber/cable. For bend radius, refer to Table 11-1.
- l. Optical component or module **shall not [D1D2D3]** be lifted by the fiber, component body or connector. Always support the optical fiber or optical cable.
- m. Nothing **shall [D1D2D3]** be placed on top of the fiber (not even paper).
- n. Optical fiber and/or optical cables **shall not [D1D2D3]** lie or drag on the floor.
- o. Optical fiber and/or optical cables **shall not [D1D2D3]** hang off the edge of the work bench.

3.1.1 Handling – Optical Fiber / Optical Cable – Work-In-Progress In particular cases, it may be necessary to temporarily secure or hold fiber in place during the assembly process.

3.1.1.1 Temporary Securing – Adhesive (Tapes) When tape is used in process optical fiber, cables and harness assemblies:

- a. ESD tape and tab ends **shall [D1D2D3]** be used.
- b. Tape **shall [D1D2D3]** be placed over connectors or components instead of fiber when possible.
- c. Tape removal **shall [D1D2D3]** be performed by placing the finger lightly down on the fiber and pulling the tape in the opposite direction (away from the finger).
- d. Operator **shall not [D1D2D3]** pinch fiber with fingernail when removing tape.

3.1.1.2 Temporary Securing – Adhesive (Glues/Polymeric)

- Adhesive **shall** [D1D2D3] meet engineering documentation requirements in terms of application.
- Adhesive **shall** [D1D2D3] meet documented shelf-life requirements.
- Adhesive **shall not** [D1D2D3] be applied directly to 250 μm or 400 μm fiber.

Note: It is acceptable to apply adhesives over 900 μm fiber.

- Adhesive **shall** [D1D2D3] be cured in accordance with the material data sheet or AABUS.

3.2 Optical Fiber End Preparation The supplier engineering documentation **shall** [D1D2D3] define the parts, tooling, equipment and procedures used in preparing the fiber optic cable for termination.

3.2.1 Procedures – Optical Fiber Processing

3.2.1.1 Preconditioning When specified by contract, optical fiber and cables **shall** [D1D2D3] be thermally preconditioned prior to preparation for termination.

- Engineering documentation **shall** [D1D2D3] define parameters for preconditioning.

3.2.1.2 Cables Cables (see Figure 3-1 for a typical fiber optic cable) **shall** [D1D2D3] be prepared for termination in a fashion that will allow for the fiber to be exposed in a manner that induces minimal damage and cleans the fiber effectively. See 8.4.4.1 for additional requirements.

3.2.1.3 Cleaved/Bare Fiber The angle of the cleaved fiber end **shall** [D1D2D3] be within engineering specification.

3.2.1.4 Removal of Outer Jacket(s) All outer protective materials **shall** [D1D2D3] be removed, in the proper dimensions and in accordance with the Supplier's engineering documentation.

3.2.1.4.1 Chemical Strippers The use of chemical strippers (e.g., acetone) for removal of certain buffer materials is acceptable.

- Chemically stripped fiber ends **shall** [D1D2D3] be thoroughly cleaned immediately after stripping to remove any residual chemical stripping compounds and buffer material residue.
- This process **shall** [D1D2D3] be documented by the supplier.
- All necessary safety precautions **shall** [D1D2D3] be observed.

3.2.1.4.2 Mechanical Strippers Mechanical strippers **shall** [D1D2D3] remove jacket and coating materials without damaging or degrading the fiber.

- Mechanical strippers **shall** [D1D2D3] be visually inspected for unacceptable damage or wear prior to use (see 1.18.1).
- Mechanical strippers **shall** [D1D2D3] be calibrated (see 1.18.2).
- Stripped fiber ends **shall** [D1D2D3] be thoroughly cleaned immediately after stripping to remove any residual jacket and/or coating material residue(s).
- The process **shall** [D1D2D3] be documented.
- See Appendix A for additional technical guidance and/or alternate requirements.

3.2.1.4.3 Thermal Strippers

- Thermal strippers **shall** [D1D2D3] remove and trim the individual components of the optical cable or fiber (e.g., jacket, strength member, buffers) without damaging or degrading underlying cable components or fiber.
- Thermal strippers **shall** [D1D2D3] be visually inspected for unacceptable damage or wear and tested prior to use.
- See Appendix A for additional technical guidance and/or alternate requirements.

3.2.1.5 Adhesives All parts that come in contact with the adhesives, including all dispenser parts and mixing pans as well as the fiber and connector to be bonded, **shall** [D1D2D3] be thoroughly cleaned with appropriate solvents before bonding.

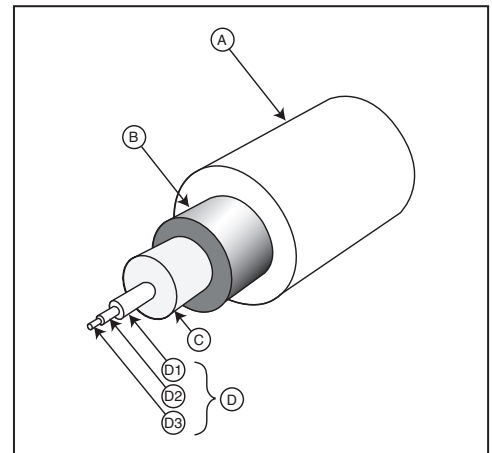


Figure 3-1 Typical Fiber Optic Cable

A – Outer jacket
 B – Strength member
 C – Buffer
 D – Optical fiber
 D1 – Coating
 D2 – Cladding
 D3 – Core

3.2.1.6 Waste Disposal Procedures for collecting, controlling and disposing of fiber optic waste **shall [D1D2D3]** be documented.

3.2.1.7 Inspection When inspecting for cracks on or through the fiber end face, optical fiber **shall [D1D2D3]** be back-lit using an incoherent, low-intensity light source from the opposite end of the cable without touching the fiber.

- a. When the opposite end of the cable is not accessible, inspection techniques which produce core illumination **shall [D1D2D3]** be used.
- b. Equipment **shall [D1D2D3]** be capable of a minimum 200X magnification.

3.2.1.8 End Face Finishing The connector end face may be finished by either polishing or cleaving, provided the process is compatible with the finished product's quality requirements as established by the Supplier's engineering documentation.

3.2.1.9 Additional Preparation The optical fiber **shall [D1D2D3]** be further prepared if warranted by the specific application, fiber construction or process requirement.

- a. The Supplier's engineering documentation **shall [D1D2D3]** document any additional requirements.

3.3 Splicing

- a. Fiber optic cables **shall [D1D2D3]** be prepared for splicing in accordance with the procedures established in 3.1 (e.g., strip, clean, cleave).
- b. Prior to splicing, the fiber and splicing device **shall [D1D2D3]** be examined in all axes to ensure there is no visible contamination or other nonconformances (e.g., damage, missing parts) to specific requirements of the engineering documentation.
 - 1) Fiber – If contamination is detected, the fiber **shall [D1D2D3]** be prepared again (e.g., strip, clean, cleave).
 - 2) Splicing Device – The splicing device **shall [D1D2D3]** be examined to ensure there is no blockage of the fiber channel or other contamination/damage that would prevent proper operation of the device.
- c. Splices **shall [D1D2D3]** be performed using the appropriate method shown below or as specified in the engineering documentation.
- d. A fusion splice exposed to re-arcing (i.e., the exposure of the fused section to multiple fusion cycles) **shall [D1D2D3]** be reterminated in accordance with documented procedures.

3.3.1 Fusion Splicing Fusion splicing of fiber optics **shall [D1D2D3]** be performed in accordance with engineering documentation.

- a. Pull Test – Documented Value – Completed fusion splices **shall [D1D2D3]** be able to withstand a tensile (pull) test according to the engineering documentation.
- b. Pull Test – Minimum Value – If the engineering documentation does not specify any value, Class 3 products **shall [D1D2D3]** be able to withstand a minimum of 4.45N [1 lb].
- c. Safety – Fusion splicing should not be performed in environments in which combustible gases may exist, unless it has been determined that the fusion process will not cause electromagnetic interference (EMI) to nearby equipment and that combustible atmospheres are not present.

Safety note: Fusion splicing involves the use of an electric arc to provide a point-source of intense heat to melt and fuse the optical fiber.

3.3.2 Mechanical Splicing

- a. Mechanical splicing of optical fibers **shall [D1D2D3]** be performed in accordance with engineering documentation.
- b. See Appendix A for additional technical guidance and/or alternate requirements.

3.3.3 Chemical Splicing

- a. Unless otherwise specified in the contract, chemical splicing **shall [D1D2D3]** be used only for the temporary joining of optical fiber for diagnostics (e.g., continuity verification, testing).
- b. See Appendix A for additional technical guidance and/or alternate requirements.

3.3.4 Environmental Seals Environmental seals **shall [D1D2D3]** provide isolation from humidity and/or contamination for splice interior parts.

3.3.5 Location

- a. Unless otherwise specified by engineering documentation, splices **shall not [D1D2D3]** be located in areas of the optical fiber, optical cable and/or hybrid wiring harness assembly expected to be subjected to flexure, motion or tensile/compression loading.
- b. See Appendix A for additional technical guidance and/or alternate requirements.

3.3.6 Protection Splices **shall [D1D2D3]** be protected from environmental conditions (e.g., direct sunlight, rain, wind), mechanical force (e.g., crushing, pinching, acute bending, repetitive flexure, Severe Wind and Moisture Problem (SWAMP) areas, tensile loading, shock, stress) and thermal extremes that would adversely affect the performance and reliability of the optical path.

- a. Strength Member – Strength members **shall [D1D2D3]** be secured to splice enclosures or other means of protection to prevent mechanical stress on the optical fiber.
- b. Other Means of Protection – If a splice enclosure cannot be used for a specific application, engineering documentation **shall [D1D2D3]** provide for other means of protection.

3.3.7 Testing Completed splices **shall [D1D2D3]** be tested to ensure loss characteristics are consistent with the loss allowances specified by design and operation engineering documentation.

- a. Tests – Unless otherwise specified by engineering documentation, the maximum allowable losses **shall [D1D2D3]** be as specified in 9.1.
- b. Test Records – Records of testing **shall [D1D2D3]** be maintained with the assembly/subassembly documentation.

3.4 Optical Fiber Cable Assemblies

- a. Optical fiber cables **shall [D1D2D3]** be prepared for connector assembly in accordance with the procedures established in this standard, or as stated in the engineering documentation.
- b. Fiber Optic Connector Termination – The optical fiber **shall [D1D2D3]** be prepared in accordance with 3.1, or as stated in the engineering documentation.
- c. Identification – Optical fiber cables **shall [D1D2D3]** be identified in such a way (e.g., color-coded jacket) to visibly distinguish these cables from wire or coaxial cables.

***Note:** Identification is not always possible with 900 μm or smaller diameter fibers, and the method of identification should be AABUS.*

- d. Cable connectors **shall [D1D2D3]** be permanently marked with a mating connector designation retained within 15 cm [6 in] of the connector body, or as stated in the engineering documentation.
- e. In-process Verification – As a minimum, prior to assembly, prepared fiber optic cables **shall [D1D2D3]** be subject to documented in-process verification.
- f. Connector Parts – Prior to assembly, prepared fiber optic connector parts **shall [D1D2D3]** be visually inspected for the following:
 - 1) Blockage in the internal fiber channel
 - 2) Cleanliness
 - 3) Cracks or deformities on the connector ferrule
 - 4) Verification that all connectors are in accordance with engineering documentation and are intermateable
 - 5) Verification that heat-shrinkable sleeving dimensions, crimp sleeve requirements, etc., are in accordance with engineering documentation

3.5 Optical Fiber Assemblies

- a. Optical fiber cables **shall [D1D2D3]** be prepared for connector assembly in accordance with the procedures established in this standard or as stated in the engineering documentation.
- b. The optical fiber **shall [D1D2D3]** be prepared in accordance with 3.1 or as stated in the engineering documentation.
- c. In-Process Verification – As a minimum, prior to assembly, prepared fiber optic cables **shall [D1D2D3]** be subject to documented in-process verification.
- d. Connector Parts – Prior to assembly, fiber optic connector parts **shall [D1D2D3]** be visually examined for the following:
 - 1) Absence of blockage in the internal fiber channel
 - 2) Cleanliness
 - 3) Cracks or deformities on the connector ferrule

- 4) Verification that all connector parts are from the same manufacturer and connector series to prevent connector intermateability problems
- 5) Verification that heat-shrinkable sleeving dimensions, crimp sleeve requirements, etc., are in accordance with engineering documentation

3.6 Cleanliness The cleanliness of completed optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be in accordance with Section 5 and/or engineering documentation.

3.7 Inspection Completed optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be inspected in accordance with Section 8.

3.8 Post-assembly Test Completed optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be tested per Section 9 to ensure measured optical performance (e.g., insertion loss or return loss) meets or exceeds the performance requirements in the engineering documentation.

3.9 Post-test Inspection Upon completion of the test(s), optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be inspected per 8.4.5 for the following:

- a. Absence of cracks in fiber end face, found using normal and back lighting
- b. Unacceptable pistoning of the fiber in connector
- c. Absence of cracks in epoxy bond line at the end face
- d. Unacceptable shrinkage of the outer jacket and other cable components

3.10 Documentation Records of testing and inspection **shall [D1D2D3]** be maintained with the assembly or subassembly documentation or as specified by engineering documentation.

3.10.1 Traceability See Appendix A for additional technical guidance and/or alternate requirements.

3.10.2 Test Data See Appendix A for additional technical guidance and/or alternate requirements.

4 INSTALLATION

Optical fiber, optical fiber cable, optical fiber assemblies and interconnecting harness assemblies containing optical fiber / optical cable (e.g., hybrids) **shall [D1D2D3]** be designed to prevent damage or degradation during installation.

4.1 General Installation Requirements Optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** only be installed by trained or certified personnel.

4.1.1 Bundling (Fiber in the Wiring Harness)

- a. If the design specifies bundling, the optical fiber/fiber cable **shall [D1D2D3]** be uniquely color-coded to facilitate rapid identification and marked with a printed legend to identify the quantities and types of fibers within the cable (see 8.4.4.5).
- b. See Appendix A for additional technical guidance and/or alternate requirements.

***Note:** Unless otherwise specified, fiber optic cable should not be combined in the same wiring bundle as wire or coaxial cable assemblies. If integrated into the wiring bundle / harness assembly, it is recommended that the optical fiber/fiber cable be located in the approximate center of the harness cross-section to minimize bending effects.*

4.1.2 Conduits Conduits should be used to route optical fibers/cables where access is limited or restricted.

4.1.3 Bend Radii The minimum short-term (Installation) and long-term (Optimum) bend radius **shall [D1D2D3]** comply with Table 11-1, unless specified otherwise on the engineering documentation.

***Note:** Compliance to this requirement often requires preplanning the routing, use of conduit, cable trays, and careful use of clamps, cable ties and/or lacing.*

4.1.4 Axial Alignment Axial alignment of the fiber/cable to the connector/terminator axis **shall [D1D2D3]** be maintained for a minimum of 10 D or 5 cm [2 in], whichever is greater, between the constraint point (entry/exit of connector/terminator) to the start of the bend.

4.1.5 Tensile Load The maximum installation tensile load, the maximum use tensile load and the maximum unsecured vertical rise for cable and harness assemblies installed in raceways, trays, ducts/innerducts, conduits and multi-fiber cables **shall [D1D2D3]** be specified on the engineering documentation.

- a. Optical fiber, optical fiber cable and hybrid cable assemblies **shall not [D1D2D3]** be subjected to tensile loading exceeding the maximum use/installation tensile load specifications.

- b. Optical fiber, optical fiber cable and hybrid cable assemblies **shall [D1D2D3]** be installed by pulling.

***Rationale:** Pushing can compress and kink the fiber and violate bend radius requirements.*

- c. Only approved lubricant(s) **shall [D1D2D3]** be used when installing fiber in conduit.

- 1) See Appendix A for additional technical guidance and/or alternate requirements.

***Rationale:** Lubrication helps prevent exceeding the maximum installation tensile load.*

4.1.6 Mating Fiber optic cable connector or termination end faces **shall [D1D2D3]** be visually examined before each mate for damage and/or contamination and cleaned if necessary (see Section 5).

- a. Both sides (“male” and “female”) of an optical interconnect **shall [D1D2D3]** be inspected and verified as clean and free of contamination/damage prior to mating.

***Rationale:** The cleanliness and mechanical integrity of the optical interface is critical to the performance and reliability of the system.*

4.1.7 Torquing Mated fiber optic connectors **shall [D1D2D3]** be torqued or staked per engineering documentation.

4.1.8 Coefficient of Thermal Expansion (CTE) Issues The design **shall [D1D2D3]** allow for thermal expansion/contraction expected during normal operations.

***Rationale:** While this requirement is more applicable to outdoor and unprotected (e.g., non-conduit, open) installations, failure to allow for thermal expansion can result in attenuation during thermal events and breakage in extreme incidents.*

4.2 Routing The following **shall [D1D2D3]** be considered in the design of routing of optical fiber, cables and harness assemblies:

- a. **Shall [D1D2D3]** be installed/routed along flat surfaces (either vertical or horizontal) whenever possible
- b. **Shall [D1D2D3]** be properly supported and secured by cable clamps
- c. **Shall not [D1D2D3]** be routed near, attached to or come in contact with thermal or vibration sources that could degrade performance or reliability
- d. **Shall [D1D2D3]** be protected against damage caused by flexing, pulling, abrasion and other handling stress
- e. **Shall not [D1D2D3]** be routed through areas where relative movement occurs (e.g., at hinges, rotating pieces, vibration-isolated hardware) or potential for damage or kinking of the cable may exist
- f. **Shall not [D1D2D3]** be routed over sharp or rough edges, unless protected against damage (e.g., abrasion, chaffing, coldflow)
- g. Ribbon fibers **shall [D1D2D3]** be kept separate during routing unless otherwise specified in the engineering documentation.
- h. Fibers **shall [D1D2D3]** only be moved and positioned during routing with plastic or rubber-tipped tweezers in order to avoid potential pinching.
- i. See Appendix A for additional technical guidance and/or alternate requirements.

4.3 Protection and Support Optical fiber, optical cable and cable assemblies **shall [D1D2D3]** be protected from environmental conditions (e.g., direct sunlight, rain, wind), mechanical force (e.g., crushing, pinching, acute bending, repetitive flexure, SWAMP areas) and thermal extremes.

- a. Optical fiber, optical cable and cable assemblies **shall not [D1D2D3]** be installed in locations where exposure to thermal sources (e.g., direct sunlight, power supplies, blowers) can exceed the maximum thermal limit.
- b. Installed optical fiber, optical cable and cable assemblies **shall [D1D2D3]** be protected and supported in accordance with the engineering documentation.

- 1) Support devices (e.g., cable clamps) **shall [D1D2D3]** hold the wiring harnesses and cable assemblies in place without deforming or damaging the fiber/cable outer jacket, without increasing attenuation in excess of the link power budget or without causing undue mechanical strain on the connections.

- 2) Support devices (e.g., cable clamps, ties) **shall [D1D2D3]** be spaced approximately every 20 cm [8 in] or per the engineering documentation.

- 3) Portions of the support device that contact the fiber/cable jacket **shall [D1D2D3]** be compatible with the cable material (e.g., no chemical reaction between the materials).
- 4) Conduits should be used to route and protect optical fiber and cable where access is limited or restricted.
- c. Protection caps **shall [D1D2D3]** be installed on all connectors when not in use.
- d. Protection cap material **shall not [D1D2D3]** degrade the optical, mechanical and/or environmental performance of the finished optical termination.
- e. See Appendix A for additional technical guidance and/or alternate requirements.

5 CLEANING

Cleanliness is critical to performance and reliability when using fiber optics in critical applications, Class 3 and/or Military/Space products. Fiber optic connectors and components often contain many microscopic particles, which need to be removed prior to use. Metallic-shelled fiber optic connectors may also have a contaminant coating of oil or film residue from machining processes.

- a. Both sides (“male” and “female”) of an optical interconnect **shall [D1D2D3]** be inspected and verified as clean and free of contamination.

5.1 General Requirements Optical fiber terminations, components and assemblies **shall [D1D2D3]** be cleaned and handled in a manner that will not reduce the optical characteristics of the termination or adversely affect performance or reliability.

- a. Specific procedures **shall [D1D2D3]** be developed, documented and maintained for cleaning, drying and visual inspection.
- b. Cleaning processes **shall [D1D2D3]** ensure removal of dirt, oil, grease and particulate matter.
- c. Cleaning and visual inspection **shall [D1D2D3]** be performed prior to mating assemblies at all stages of the test and integration process.
- d. If not terminated immediately, cleaned fiber and cable components **shall [D1D2D3]** be protected from contamination, degradation and/or damage.
- e. Materials or devices (e.g., protection caps) **shall not [D1D2D3]** reduce the optical characteristics of the termination or adversely affect performance or reliability.
- f. Immersion cleaning is not recommended, and specific processes **shall [D1D2D3]** be developed to prevent damage, degradation or introduction of latent defect.

Notes:

- 1) Lack of or improper cleaning of both (mating) surfaces may result in cross-contamination that may cause damage to the optical end faces or power loss.
- 2) See IPC-8497-1 for technical guidance and recommendations on various cleaning processes used in the industry and the advantages and disadvantages for each process.

5.1.1 Solvents Cleaning solvents **shall [D1D2D3]** be of the type specified in the engineering documentation.

- a. Solvents or cleaners used to remove grease, oil, dirt, flux and FOD **shall [D1D2D3]** be selected for their ability to remove both ionic and nonionic contamination.
- b. Solvents **shall [D1D2D3]** be nonconductive, noncorrosive and dry-residue free.
- c. Solvents **shall not [D1D2D3]** damage or degrade the quality of parts or materials.
- d. Prior to use, the appropriate engineering activity **shall [D1D2D3]** verify compatibility between solvents used for cleaning the assembly and all materials, including epoxies.

Note: Cleaning of the optical end faces of terminated connector assemblies is typically performed with 99% reagent-grade isopropyl alcohol.



Figure 5-1 Contamination (Oil and Debris)
Figure source: Fiber Optic Precision Cleaning

5.1.2 Canned Air Canned air (e.g., compressed gas media) used to remove gross contamination (e.g., fibers/hair, dust) from the connector, ferrule or end face prior to more detailed cleaning and/or blow-off drying **shall [D1D2D3]** be propellant-free, residue-free, inert and specifically listed for use with optical fiber and optical hardware.

Notes:

- 1) *Incorrect use of canned air can result in propellant residue deposits on the ferrule and/or end face, even when the product is identified as propellant-free. To reduce this type of contamination, it is recommended that the nozzle be cleared by pre-spraying two short bursts of the can, pointed away from the hardware and User, prior to spraying the connector, ferrule or end face.*
- 2) *The use of an inline filter is recommended. See Appendix A for additional technical guidance.*

5.1.3 Compressed Air / Dry Nitrogen / Other Gas Media Compressed gas media (e.g., compressed air, high-pressure dry nitrogen, dry carbon dioxide) used to remove gross contamination (e.g., fibers/hair, dust) from optical fiber terminations (including end faces), components and assemblies prior to more detailed cleaning and/or blow-off drying **shall [D1D2D3]** meet dryness and cleanliness (particulate and nonvolatile residue (NVR)) requirements specified by engineering documentation.

Example:

Pressurized, fine-filtered, dry air: Particulate size < 0.2 μm ; hydrocarbon vapors < 0.003 mg/kg [$< 0.003 \text{ ppmw}$]; dew point < - 40 $^{\circ}\text{C}$ [$< - 40 \text{ }^{\circ}\text{F}$]

- a. Gas media **shall [D1D2D3]** be noncorrosive and nonflammable.
- b. Gas media delivery device (e.g., nozzle) **shall [D1D2D3]** have a variable-pressure / variable-flow capability and be rated as ESD-safe.
- c. Application of the gas media during blow-off and drying **shall not [D1D2D3]** impart thermal shock to the hardware or cool surfaces below local dew point (i.e., induce condensation formation).
- d. Unfiltered, unconditioned “shop air” **shall not [D1D2D3]** be used.
- e. A detailed procedure of use for canned air/ gas media **shall [D1D2D3]** be used.
- f. Canned air / gas media **shall not [D1D2D3]** be used as the single method for cleaning FO connectors, unless objective evidence of the cleaning efficiency is available.
- g. Canned air / gas media **shall [D1D2D3]** be used for cleaning connectors for specialized equipment.

Notes:

- 1) *Unfiltered, unconditioned “shop air” often contains contaminants (e.g., hydrocarbon liquid/vapor, particulate matter, water/water vapor), which can seriously contaminate or damage sensitive optical surfaces and mechanisms.*
- 2) *The use of an inline filter is recommended. See Appendix A for additional technical guidance.*

5.1.4 Wipes/Swabs Manual cleaning and/or drying of fiber optic terminations **shall [D1D2D3]** be performed using an approved nonabrasive, low-NVR, lint-free wipe or swab.

Notes:

- 1) *Always wipe in one direction, using a fresh, clean section/surface of the wipe/ swab on each successive wipe operation.*
- 2) *Wipe in a straight line and overlap the previous stroke. Never use a circular or back and forth (scrubbing) motion, as this may drive contaminants into and scratch sensitive surfaces.*
- 3) *When using a wipe/swab moistened with an approved solvent, always squeeze out excess solvent prior to contact with the hardware surface. Only wet the wipe/swab, not the surface to be cleaned.*

5.2 Drying Optical fiber terminations (including end faces), components and assemblies **shall [D1D2D3]** be promptly and thoroughly dried following cleaning, using a documented process and approved materials, to prevent recontamination and/or degradation of the cleaned surfaces.



Figure 5-2 Contamination (Before Cleaning)
Image Credit: Fiber Optic Precision Cleaning



Figure 5-3 Contamination (After Cleaning)
Image Credit: Fiber Optic Precision Cleaning

6 DOCUMENTATION

Effective communication between the design and manufacturing functions is the most important element in managing the development and maintenance of any electronic product, whether it is designed and built by a company that is vertically integrated (all functions under the same organization) or if the product is being outsourced to one or multiple suppliers, each of which provides a particular function or service in the development, manufacture or maintenance of the product. The degree of detail and clarity will determine the success or failure of all the factors that make up the life cycle of the end product.

The documentation package may consist of multiple pieces of information (data) that fully describe the characteristics and functional performance requirements of the hardware to which the documentation pertains. This package may include functional and schematic diagrams, assembly descriptions, fabrication data (master drawing), wire lists, test requirements, specification performance control documents and material identification descriptions/parts lists (PLs).

Since the stages of manufacture vary, and different industry contributors need different information, the completeness of any data set should be predicated on need and updated accordingly. The revision methodology of any data set should follow proven concepts of Configuration Management and Control, thereby ensuring there is no ambiguity as to the meaning or effectivity of information or requirements at any point during the development, design and assembly cycles.

6.1 General The documentation package **shall [D1D2D3]** be developed in accordance with the design and development processes required by the organizations quality management system (e.g., ISO 9001).

6.2 Data The documentation data package **shall [D1D2D3]** be in accordance with ASME Y14.100 (incl.: subset Y14.24, Y14.34, Y14.35 and Y14.44), the User-specified format or an equivalent format agreed upon by the Designer and User.

- a. Straight-Line Format – When practical, each wire harness or cable assembly should be presented on a separate sheet and in a straight line (elementary) format.
- b. Connection Lists – Connection lists **shall [D1D2D3]** list all modules/assemblies to which the cable/harness assembly is connected and identify each connection and attached wiring.
- c. Critical Circuit Wiring – Circuit functions that may be affected by length, routing, bundling, bend radii, etc., **shall [D1D2D3]** be identified as critical.
- d. Marking and Identification – To facilitate installation and servicing, each wiring harness or cable assembly and each connector **shall [D1D2D3]** be identified and physically marked with:
 - 1) Its reference designation,
 - 2) The reference designation of its mating connector,
 - 3) The drawing part number, and
 - 4) A unique serial number at the time of fabrication, when specified by the User.
- e. Legibility – The method and location of the physical identification **shall [D1D2D3]** ensure legibility when installed.
- f. Method – The method of identification **shall not [D1D2D3]** impair the functional characteristics of the wire harness or cable assembly.
- g. Symbols – Symbols that define items on a drawing **shall [D1D2D3]** be consistently used. Recommended symbols include:
 - 1) Circle – Item number
 - 2) Square – Note reference
 - 3) Vertical triangle – Operation
 - 4) The initials “INT” surrounded by a rectangle – Interface dimension

6.3 Connector Orientation (Clocking) Unless otherwise specified, the connector **shall [D1D2D3]** be depicted with the connector mating key or keyway at position 12 (“A”), with a clocking tolerance of $\pm 15^\circ$.

- a. Angle type cable clamps **shall [D1D2D3]** be depicted at clock position 9 (“F”), or to the left as shown in Figure 6-1.

6.4 Connector Pin-Out Unless otherwise specified on the approved drawing, the connector pin-out **shall [D1D2D3]** be depicted as the mating face view (shown in inset, Figure 6-1a and Figures 6-1b, 6-1c and 6-1d) or as applicable to the specific connector type used.

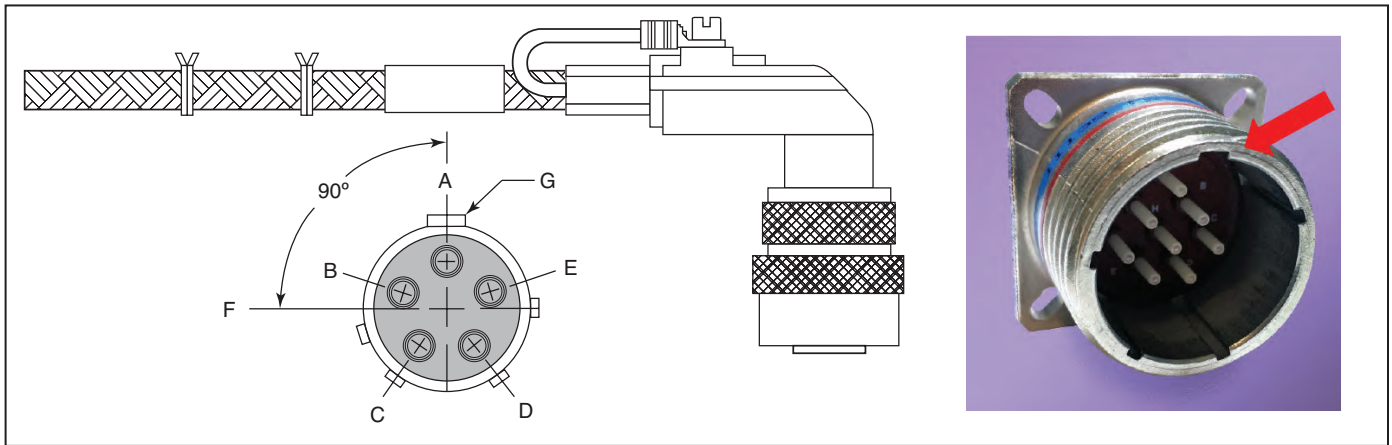


Figure 6-1a Connector Orientation (Clocking) and Mating Face View (Inset) with D38999 Bulkhead Example (Arrow identifies key)

A, B, C, D, E – Contact positions

F – Optical cable/harness

G – Polarizing key

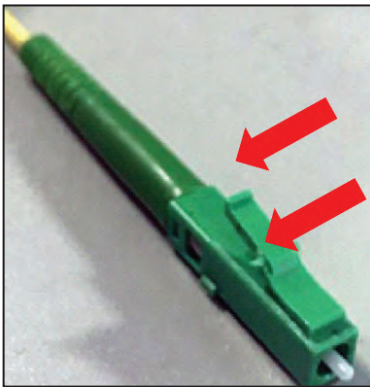


FIGURE 6-1b Connector Orientation (Clocking), Example - APC Connector without Dust Cap

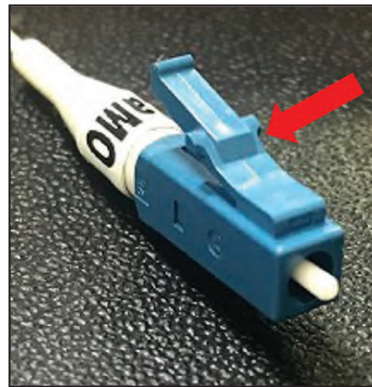


FIGURE 6-1c Connector Orientation (Clocking), Example - LC Connector without Dust Cap

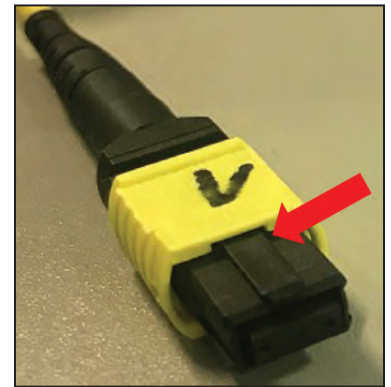


FIGURE 6-1d Connector Orientation (Clocking), Example - MPO Connector without Dust Cap

6.5 Dimensioning and Tolerance Unless otherwise specified on the approved drawing, the following **shall [D1D2D3]** apply:

- Datum – Dimensions, including location of breakout points, bends, etc., **shall [D1D2D3]** be measured from the connector or terminator face at one end of the wire harness (DATUM).
- Length – Length **shall [D1D2D3]** be measured from the DATUM to the final termination (e.g., connector face, terminals, splice).
- Breakout Length – Breakout lengths **shall [D1D2D3]** be referenced from the approximate center-line of the harness assembly at the breakout point to its final termination (e.g., connector face, terminals, splice).
- Tolerance – Measurement tolerances **shall [D1D2D3]** be as specified in Table 11-2 unless otherwise specified on the drawing/documentation.
- Tolerances – Noncumulative – If the engineering drawing has multiple dimensions called out between a connector and termination, breakout or overall length, the tolerances **shall [D1D2D3]** be considered noncumulative and will be applied to the sum of the dimensions (entire length to the termination point), not to each individual dimension.

6.6 Documentation for Maintenance/Emergency Restoration A documentation package detailing the final “as-built” configuration of the optical fiber system, consisting of data logs and optical frequency domain reflectometer (OFDR)/optical time domain reflectometry (OTDR) maps should be developed and either maintained or delivered as part of the contract deliverable. These data are critical to the maintenance and technical support of the fiber installation, often allowing rapid location and resolution of performance/connectivity issues.

- At a minimum, the following data should be included in the package:
 - Optical fiber/cable/component data (manufacturer data, including part numbers)
 - Routing plan(s)
 - Identification of priority circuits
 - OFDR/OTDR map
 - Attenuation/optical loss test report

7 TAILORING

This specification is intended for use in equipment specifications or contracts to incorporate those acceptance requirements which are common to most optical fiber, optical fiber cable and optical harness assemblies. The requirements stated in this specification are a composite of those that have been found to be cost effective for high-reliability applications. This document establishes the minimum requirements for most applications.

Where possible, the requirements are stated in ways that are self-tailored to each application.

- a. For example, electromagnetic pulse (EMP) requirements are not imposed by this specification unless an EMP environment is indicated by some other compliance document, or contract. Nevertheless, all requirements of this specification **shall [D1D2D3]** be evaluated for each application and those that are not appropriate, or clearly increase program life-cycle costs, should be excluded or changed.
- b. Manufacturers are encouraged to identify to the User any requirements imposed by this document that are believed to be excessive or not applicable to the design and intended use. Any tailoring of the requirements of this standard **shall [D1D2D3]** be subject to User approval.

8 QUALITY ASSURANCE REQUIREMENTS – GENERAL AND VISUAL

This section covers the general and visual acceptance criteria for inspection of individual fiber optic cables and for the overall fiber optic system (e.g., individual fiber optic cables, splices, connectors, termination boxes, cable ways) covered in this standard. The requirements herein are intended to verify the integrity of the optical transmission path.

8.1 Product Class Conditions Target, acceptable and defect conditions are listed for each product class.

- a. The inspector **shall not [D1D2D3]** select the product class for the assembly under inspection.
- b. Documentation that specifies the applicable class for the assembly under inspection **shall [D1D2D3]** be provided to the inspector.
- c. For purposes of this document, the descriptions of these conditions follow:
 - 1) Target – A condition that is close to perfect (sometimes labeled as “preferred”). It is a desirable condition which is not always achievable and may not be necessary to ensure reliability of the assembly in its service environment.
 - 2) Acceptable – This characteristic indicates a condition that, while not necessarily perfect, will maintain the integrity and reliability of the assembly in its service environment.
 - 3) Defect – A defect is a condition that fails to meet the acceptance criteria of this document or negatively affects the form, fit or function of the assembly in its end-use environment. The Manufacturer **shall [D1D2D3]** document and disposition each defect. It is the responsibility of the Manufacturer to identify defects that are unique to the assembly process. It is the responsibility of the User to define unique defect categories applicable to the product.
 - 4) Disposition – Disposition is the determination of how defects **should** be treated. Dispositions include but are not limited to rework, use as is (UAI), scrap or repair. User concurrence **shall [N1D2D3]** be required for UAI and for repair dispositions.
 - 5) Conditions Not Specified – Conditions that are not specified as defective are considered acceptable, unless it can be established that the condition affects end-User-defined form, fit, function or reliability.

8.2 Inspection Inspection for acceptability **shall [D1D2D3]** be performed on all fiber optic terminations and cable assemblies to the requirements specified by this standard, User-specified product verification requirements and the approved engineering documentation.

- a. If any elements of the fiber optic components are required to be moved to aid inspection, they **shall not [D1D2D3]** be disturbed in a fashion that will cause damage.
- b. Unless otherwise specified in the contract, all inspection **shall [D1D2D3]** be 100% visual.
- c. Sampling – Manufacturers may define a sampling inspection program as part of a documented process control plan. If there is no documented process control plan, the Manufacturer **shall [D1D2D3]** perform 100% inspection.
- d. Lighting – Illumination at the surface of workstations should be at least 1000 lux [~ 93 foot candles].
 - 1) Supplemental lighting may be necessary to assist in visual inspection.
 - 2) Light sources should be selected to prevent shadows on the item being inspected, except shadows caused by the item being inspected.

***Note:** In selecting a light source, color temperature and polarization are important considerations when inspecting surfaces with a high reflectivity index. Light temperature ranges from 3,000 K to 5,000 K enable the identification of various metal*



and plating features and contaminants with increased clarity. Polarized light reduces “ghost imaging” caused by the reflection of light off of multiple adjacent surfaces.

- e. Magnification Aids – Unless specified on the engineering documentation, the magnification power for inspection **shall [D1D2D3]** be as specified in Table 11-3. Other magnification powers within the inspection range may be used. If the presence of a defect cannot be determined at the inspection power, the item is considered acceptable.
- f. Eye Safety – Light sources used in the test and inspection of optical fiber and cable operate in the visible and/or nonvisible light spectrum and may be classified as high-power. Exposure, even incidental, may cause injury or permanent eye damage. Never assume that a fiber is unenergized simply because visible light is not evident. See 1.15.2 for additional information and requirements.

8.3 Responsibility for Inspections and Tests Unless otherwise specified in the contract, the Supplier **shall [D1D2D3]** be responsible for the performance of all inspections and test requirements as specified in the contract and this standard.

- a. The Supplier may use their own facility or any other facilities for the performance of the inspection and test requirements specified herein, unless disapproved by the User or as otherwise specified in the contract.
- b. The User reserves the right to perform/witness any of the inspections and/or tests set forth in the specification where such inspections or tests are deemed necessary to ensure that supplies and services conform to prescribed requirements.

8.4 Classification of Inspections and Tests The tests and inspections specified herein are classified as follows:

- a. Parts, materials and process controls
- b. Process verification audit
- c. Acceptance tests
- d. Qualification tests
- e. Workmanship

8.4.1 Parts, Materials and Process Controls All parts, tools, materials and processes **shall [D1D2D3]** be verified as controlled and inspected prior to and during assembly.

- a. Each optical fiber, optical cable and optical harness assembly **shall [D1D2D3]** have inspection records and test records maintained by serial number or other method to provide traceability.
- b. Complete records **shall [D1D2D3]** be maintained in accordance with the record retention requirements specified in the contract.
- c. The records **shall [D1D2D3]** document all relevant test data, all rework or modifications and all installations or removals, for whatever reason.
- d. Adhesives **shall [D1D2D3]** be selected, controlled, mixed, and applied per engineering documentation.
 - 1) See Appendix A for additional technical guidance and/or alternate requirements.

8.4.2 Process Verification Audit The following functions **shall [D1D2D3]** be performed:

- a. Product Verification – Witness or verify all tests, examinations, peer verifications, inspections and measurements specified by this Standard and the specific engineering documentation have been performed.
- b. Personnel Training / Certification – Verify that all personnel who assemble, inspect, or install hardware in accordance with this Standard have been trained (at a minimum) or certified (See 1.15).
- c. Processes and Procedures – Verify, through in-process surveillance of all assembly operations, all processes and procedures implementing the requirements of this Standard are current, approved, adequate and are being accurately used.
- d. Part Cleanliness – Verify all parts were cleaned and undamaged prior to being assembled.
- e. Facility Control – Verify facility cleanliness, environmental conditions and lighting requirements are met.

8.4.3 Acceptance and Qualification Testing Acceptance and qualification testing **shall [D1D2D3]** be specified to conform to the Product Classification specified in this standard.

- a. Any deviation from or additions to the default requirements contained within this standard **shall [D1D2D3]** be noted on the drawing and approved by the User.

8.4.3.1 Acceptance Test The acceptance criteria for optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be the satisfactory completion of all contractually imposed acceptance tests and inspections.

- a. If a test discrepancy occurs during an acceptance test, the test **shall [D1D2D3]** be interrupted and the discrepancy noted.

- b. The disposition of the discrepancy should be completed before acceptance testing resumes.
- c. If the discrepancy is dispositioned as due only to the test setup, test cables or a failure in the test equipment, the test being conducted at the time of the failure may be continued after the discrepancy is corrected, provided it can be verified the discrepancy did not result in an overstress test condition or latent damage.
- d. If an overstress test condition occurred or if the discrepancy is dispositioned as a failure in the cable/wiring harness under test, the preliminary failure analysis and appropriate corrective action **shall [D1D2D3]** be completed in accordance with the established procedures for handling nonconforming supplies.
- e. The acceptance test in which the failure occurred, and any previous test whose results could possibly have induced the failure, or whose validity was comprised by the corrective action, **shall [D1D2D3]** then be entirely repeated.

8.4.3.2 Qualification When required by contract, qualification may be partially or totally satisfied by the testing of higher levels of assembly.

- a. Qualification tests **shall [D1D2D3]** be conducted to approved test plans that indicate which tests and test procedures will be conducted at which levels of assembly.
- b. Applications having constraints on allowable outgassing **shall [D1D2D3]** qualify to that requirement either by test or by an analysis using applicable materials test data to determine the estimated total mass loss and the estimated loss of volatile condensable materials for each wiring harness during its service life.
- c. Applications of optical fiber and/or harnesses routed across moving or rotating structure or interfaces (e.g., articulated (flex) joints, expansion joints / panels, hinged doors, moving panels) **shall [D1D2D3]** include applicable harness stiffness measurements and fatigue testing.
- d. Tests and measurements **shall [D1D2D3]** be conducted under the worst-case dimensional conditions, with maximum motion at ambient and worst-case design environmental conditions.
- e. See Appendix B.

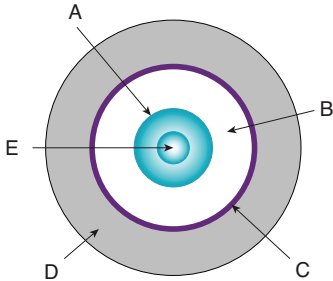
8.4.4 Workmanship Optical fiber, optical fiber cable and optical fiber assemblies **shall [D1D2D3]** be inspected and verified to be free of the following end face conditions:

- a. Surface cracks located in Zone A (core zone) of single-mode (SM) fiber **shall [D1D2D3]** be cause for rejection, regardless of size or quantity.
- b. Surface cracks located in Zone B (cladding zone) of SM or multimode (MM) fiber, that when extended would intersect Zone A, **shall [D1D2D3]** be cause for rejection, regardless of size or quantity.
- c. Subsurface cracks **shall [D1D2D3]** be cause for rejection, regardless of size, quantity, location within the fiber or fiber type.
- d. Edge chip(s) extending into Zone A **shall [D1D2D3]** be cause for rejection, regardless of size, quantity or fiber type.
- e. End face conditions that result in an attenuation (loss) in excess of the link loss budget limit for that termination **shall [D1D2D3]** be cause for rejection, regardless of size, type or quantity.
- f. See Table 8-1, Table 8-2 and Table 8-3 for specific condition types and limits (as applicable to the specific fiber type and end face profile).

8.4.4.1 Bare/Cleaved Fiber Cleaved/Bare fiber **shall [D1D2D3]** be inspected for the following:

- a. All outer protective materials are removed, in the proper dimensions and in accordance with the engineering documentation.
- b. Chemical Stripping – No evidence of wicking or damage to the coating.
- c. Coating – No visual evidence of cracks, nicks, cuts or other physical damage to the coating.
- d. Fiber – Angle of cleaved fiber end is within engineering specification.
- e. Damage – Prepared fiber end is free of cracks (surface/subsurface), scratches, edge chips, hackle, pits and other damages/defects defined by engineering documentation, and the core is clearly discernible.
- f. Contamination – Prepared fiber ends are clean and free of residual chemical stripping compounds, unbonded buffer materials and other contaminants (e.g., particulates, films, oils, greases).
- g. See 8.4.5 for visual examples.

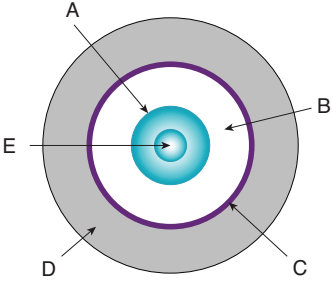
Table 8-1 Allowable Conditions for Fiber Connectors

Allowable Conditions for Fiber Connectors ^{9, 10, 11} (Includes: S-M PC Connectors (RL ≥ 26 dB); S-M PC Connectors (RL ≥ 45 dB); S-M APC Connectors; MM PC Connectors)					
Zone/ Description (Figure 8-1)	Diameter (μm)/ Optical Mode	Type	Maximum Allowable Conditions ^{3,4} Quantity/Size (μm)		
			Non-Linear ^{1,4}	Linear ²	
 Figure 8-1 End Face Note: End Face Zones A-E are highlighted for illustration purposes only and may not be discernible using normal viewing techniques. A - Core Zone B - Cladding Zone⁶ C - Adhesive Zone D - Contact Zone^{4,7} E - Core⁸	A Core Zone	0 to 25 / Single-Mode (S-M)	PC connector (RL ≥ 26 dB)	None	None
			PC connector (RL ≥ 45 dB)	None	None
		APC connector	None	4 / ≤ 3 None / > 3	
	0 to 65 / Multimode (MM)	PC connector	4 / ≤ 5 None / > 5	Unlimited / ≤ 3 None / > 3	
B Cladding Zone ⁶	25 to 115 / Single-Mode (S-M)	PC connector (RL ≥ 26 dB)	Unlimited / < 5 5 / 5 to 10 None / > 10	Unlimited / ≤ 3 None / > 3	
		PC connector (RL ≥ 45 dB)	Unlimited / < 2 5 / 2 to 5 None / > 5	Unlimited / ≤ 3 None / > 3 ³	
		APC connector	Unlimited / < 2 5 / 2 to 5 None / > 5	Unlimited	
	65 to 115 / Multimode (MM)	PC connector	Unlimited / < 5 5 / 5 to 10 None / > 10	Unlimited / ≤ 5 None / > 5 ³	
C Adhesive Zone	115 to 135	All connector types	Unlimited	Unlimited	
D Contact Zone ^{4, 7}	135 to 250 / Single-Mode (S-M)	PC connector (RL ≥ 26 dB)	Unlimited / < 20 5 / 20 to 30 None / > 30	Unlimited	
		PC connector (RL ≥ 45 dB)	None / > 10	Unlimited	
		APC connector	None / > 10	Unlimited	
	135 to 250 / Multimode (MM)	PC connector	Unlimited / < 20 5 / 20 to 30 None / > 30	Unlimited	
E Core ⁸	—	Fiber	None	None	

Notes:

- Conditions defined as "permanent nonlinear features that interfere with optical transmissivity" include contamination, cracks, edge chips, hackles, pits, voids in adhesive zone, non-concentricity, etc.
- Conditions defined as "permanent linear features that interfere with optical transmissivity" include scratches.
- When inspecting after polishing or while performing quality assurance of a new connector, a maximum of five fine scratches < 3 μm [< 0.12 mil] width may be set in Zone B to establish that a reliable process is being used by the manufacturer.
- Any linear or nonlinear features that extend across multiple zones are subject to the most stringent criteria.
- The size of a condition or feature is equal to the smallest circle that can completely encompass the feature.
- MT ferrules (e.g., ribbon) have allowable edge chipping from 115 μm to 125 μm.
- Zone D criteria do not apply to MT-ferrule or metallic-ferrule connectors.
- Zone E is contained within the central region of Zone A and is dimensionless.
- No requirements are established for the area beyond the perimeter of Zone D (Contact Zone). However, the removal of contaminants from this area is recommended as "Good Workmanship Practice" to prevent the migration of contaminants during use and to ensure proper mating of the optical surface(s).
- Defect criteria and limits listed are applicable to "New" hardware. Use of these criteria for acceptance of "In Service" hardware should be AABUS.
- Data extracted from IPC-A-610DC and IEC 61300-3-35.

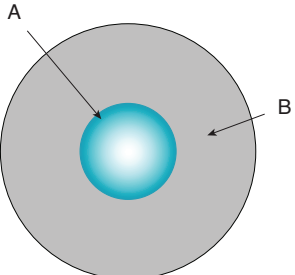
Table 8-2 Allowable Conditions for Single-Mode Transceivers (With Internal Fiber Stubs)^{9, 10, 11}

	Zone/ Description (Figure 8-2)	Description	Diameter (μm)	Maximum Allowable Conditions ^{3, 4} Quantity/Size (μm)	
				Non-Linear ^{1, 4}	Linear ²
	A	Core Zone	0 to 15	None	2 / ≤ 3 None / > 3
	B ⁶	Cladding Zone	15 to 115	Unlimited / < 5 5 / 5 to 10 None / > 10	Unlimited / ≤ 3 None / > 3 ³
	C	Adhesive Zone	115 to 135	Unlimited	Unlimited
	D ^{4, 7}	Contact Zone	135 to 250	Unlimited / < 20 5 / 20 to 30 None / > 30	Unlimited
	E ⁸	Core	–	None	2 / ≤ 3 None / > 3

Notes:

- Conditions defined as “permanent nonlinear features that interfere with optical transmissivity” include contamination, cracks, edge chips, hackles, pits, voids in adhesive zone, non-concentricity, etc.
- Conditions defined as “permanent linear features that interfere with optical transmissivity” include scratches.
- When inspecting after polishing or while performing quality assurance of a new connector, a maximum of five fine scratches < 3 μm [0.12 mil] width may be set in Zone B to establish that a reliable process is being used by the manufacturer.
- Any linear or nonlinear features that extend across multiple zones are subject to the most stringent criteria.
- The size of a defect is equal to the smallest circle that can completely encompass the defect.
- MT ferrules (e.g., ribbon) have allowable edge chipping from 115 μm to 125 μm.
- Zone D criteria do not apply to MT-ferrule or metallic-ferrule connectors.
- Zone E is contained within the central region of Zone A and is dimensionless.
- No requirements are established for the area beyond the perimeter of Zone D (Contact Zone). However, the removal of contaminants from this area is recommended as “Good Workmanship Practice” to prevent the migration of contaminants during use and to ensure proper mating of the optical surface(s).
- Acceptability criteria and limits are designated as applicable to “New” hardware. Use of these criteria and limits for acceptance of “In Service” hardware should be AABUS.
- Data extracted from IPC-A-610DC and IEC 61300-3-35.

Table 8-3 Lensed Device Acceptance Criteria^{3, 4}

	Zone (Figure 8-3)	Description	Diameter (μm)	Allowable Defects Quantity / Size (μm)		
				Particles	Bubbles in Glass	Cracks
	A ¹	Viewing area	500	3 / ≤ 75	2 / ≤ 3 None / > 3	None
	C ²	Lens	1.5 mm	No Limit	No limit / < 125	None

Notes:

- Zone A (Viewing Area) is the main area of concern for this type of device. Inspection at 200 X magnification is recommended.
- The outer diameter of Zone C (Lens) will not be visible at 200 X. Inspection should be performed at a lower magnification (e.g., 100 X or lower).
- Acceptability criteria and limits are designated as applicable to “New” hardware. Use of these criteria and limits for acceptance of “In Service” hardware should be AABUS.
- Data extracted from IPC-A-610DC.

8.4.4.2 Fiber Optic Termination

- a. Terminated optical fibers **shall [D1D2D3]** be inspected for the following:
 - 1) Installation and assembly of the terminator is per engineering documentation.
 - 2) Terminator is free of damage, and end face geometries are compliant with 8.4.5, Table 8-1, Table 8-2, and Table 8-3 (as applicable) and/or engineering documentation.
 - 3) Proper positioning of the strain relief per the engineering documentation.
- b. Terminations exhibiting surface or subsurface cracks in the core **shall [D1D2D3]** be reterminated or scrapped.
- c. Retermination of the optical fiber/optical cable is to be considered rework and **shall [D1D2D3]** be AABUS.
- d. Repolishing **shall not [D1D2D3]** be used to repair/remove cracks.

Note(s):

- 1) *Cracks are non-repairable.*
- 2) *To facilitate inspection of the core, the optical fiber should be back-lit using a noncoherent, low-intensity light source from the opposite end of the fiber, without touching the fiber, as part of the examination, when appropriate. When the opposite end of the fiber is not accessible, inspection techniques which produce core illumination should be used.*
- 3) *The dimensions of scratches listed in Table 8-1, Table 8-2 and Table 8-3 should not be measured, if their length is estimated to be $< 3 \mu\text{m}$ [$< 0.12 \text{ mil}$].*

8.4.4.3 Connector Connectorized optical fibers **shall [D1D2D3]** be inspected for the following:

- a. Installation and assembly of the connector is per engineering documentation.
- b. Connector is free of damage, and end face geometries are compliant with 8.4.5, Table 8-1, Table 8-2 and Table 8-3 (as applicable) and/or engineering documentation.
- c. Proper positioning of the strain relief per engineering documentation.

8.4.4.4 Fiber Assembly/Cable Assembly Fiber and/or cable assemblies **shall [D1D2D3]** be inspected for the following:

- a. Dimensions are per engineering documentation.
- b. Axial alignment of the fiber/cable to the connector/terminator axis is maintained for a minimum of 10 D or 5 cm [2 in], whichever is greater, between the constraint point (entry/exit of connector/terminator) to the start of the bend or per the engineering documentation (see 8.4.5.1).
- c. The strength member, when visible, is uniformly distributed and securely attached to the connector or terminus.
- d. Heat-shrinkable sleeving and/or crimp sleeve is positioned per engineering documentation.
- e. Positioning and attachment of the strain-relief device is per engineering documentation.
- f. All visibly inspectable surfaces are free of visually detectable contamination (e.g., gross dirt, fibers, particles, oils, greases).
- g. Freedom from damage (e.g., cuts, cracks, nicks, gouges, tears) exposing underlying elements or violating environmental protection.
- h. Freedom from kinks, knots or twists.

8.4.4.5 Identification The identification of optical fibers, cables, connectors and hybrid harness assemblies to be visibly distinguishable from wire or coaxial cables **shall [D1D2D3]** be in compliance with the following or as specified by engineering requirements:

- a. Optical Fibers – Individual optical fiber(s) are identified by numerical position, fiber unit and fiber group by color code, legend, block code or other unique marking method, per ANSI/TIA-598 or as specified by engineering requirements.
- b. Optical Cable – The outer jacket of optical cable is uniquely color-coded and marked with a printed legend to facilitate identification and identify the quantities and types of fibers within the cable, per ANSI/TIA-598 or as specified by engineering requirements.
- c. Optical Connectors – Fiber and cable connectors are permanently marked with mating connector designation within 15 cm [6 in] of the connector body, or as stated in the engineering documentation.
- d. Interconnecting Harness Assemblies Containing Fiber (Hybrids) – Interconnecting harness assemblies containing optical fiber/optical cable (e.g., hybrids) are permanently marked with one or more uniquely colored bands (e.g., sleeves, tape) that are equally spaced throughout the length of the harness assembly, at intervals not exceeding 15.24 cm [6 in] as measured from centerline to centerline of each marker band.

8.4.4.6 Damage There shall [D1D2D3] be no visible damage in excess of that specified in 8.4.5, Table 8-1, Table 8-2, Table 8-3, and as follows (when as applicable):

- a. Core/Cladding (optical fiber back-lit using an incoherent, low-intensity light source)
 - 1) Cracks (surface/subsurface)
 - 2) Scratches
 - 3) Edge chips (no chip extending into core)
 - 4) Hackle
 - 5) Pits
 - 6) Other damage/defects defined by engineering documentation
 - 7) Core is clearly discernible
- b. Strength Member
 - 1) Improper strain relief (bunching, birdcaging, induced bend, etc.)
 - 2) Severed strands
 - 3) Protruding strands
 - 4) Missing
 - 5) Unterminated
- c. Jacket/Buffer
 - 1) Evidence of chemical stripper wicking, corrosion or damage
 - 2) Thermal (burns, charring, melting)
 - 3) Discoloration (minor discoloration due to use of thermal stripper acceptable)
 - 4) Cracks, nicks, cuts or other physical damage beyond specification
- d. Connector/Terminator
 - 1) General (cracks, nicks, cuts, gouges, flaking plating or other physical damage)
 - 2) Ferrule (cracks, nicks, cuts, scrapes or other physical damage)
 - 3) End face damage/contamination
- e. Contamination/FOD

8.4.4.7 Inspection After Test Upon completion of the test(s), optical fiber, optical fiber cable and optical fiber assemblies shall [D1D2D3] be inspected for the following:

- a. Absence of cracks in fiber end face, using normal and back lighting
- b. Connector free of damage; end face geometries compliant with 8.4.5, Table 8-1, Table 8-2, and Table 8-3 (as applicable) and/or engineering documentation
- c. Proper positioning of strain relief per engineering documentation
- d. Pistoning of the fiber in the connector or termination is within specification.
- e. No cracks, voids or missing/excessive epoxy in the bond line.
- f. Shrinkage of buffer, outer jacket and/or other cable components within specification

***Note:** An unacceptable amount of shrinkage after temperature cycling is defined as an amount sufficient to result in an optical loss (e.g., attenuation) in excess of that specified in the engineering documentation (see 9.1).*