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Design and Critical Process Requirements for Optical Fiber, Optical Cable and Hybrid Wiring Harness Assemblies

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June 2016

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- Just include spec information
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IPC-D-640A

Design and Critical Process Requirements for Optical Fiber, Optical Cable and Hybrid Wiring Harness Assemblies

Developed by the Fiber Optic Cable Acceptability Task Group (7-31m)
of the Acceptability Subcommittee (7-31) of IPC

Supersedes:

IPC-D-640 - June 2016

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

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

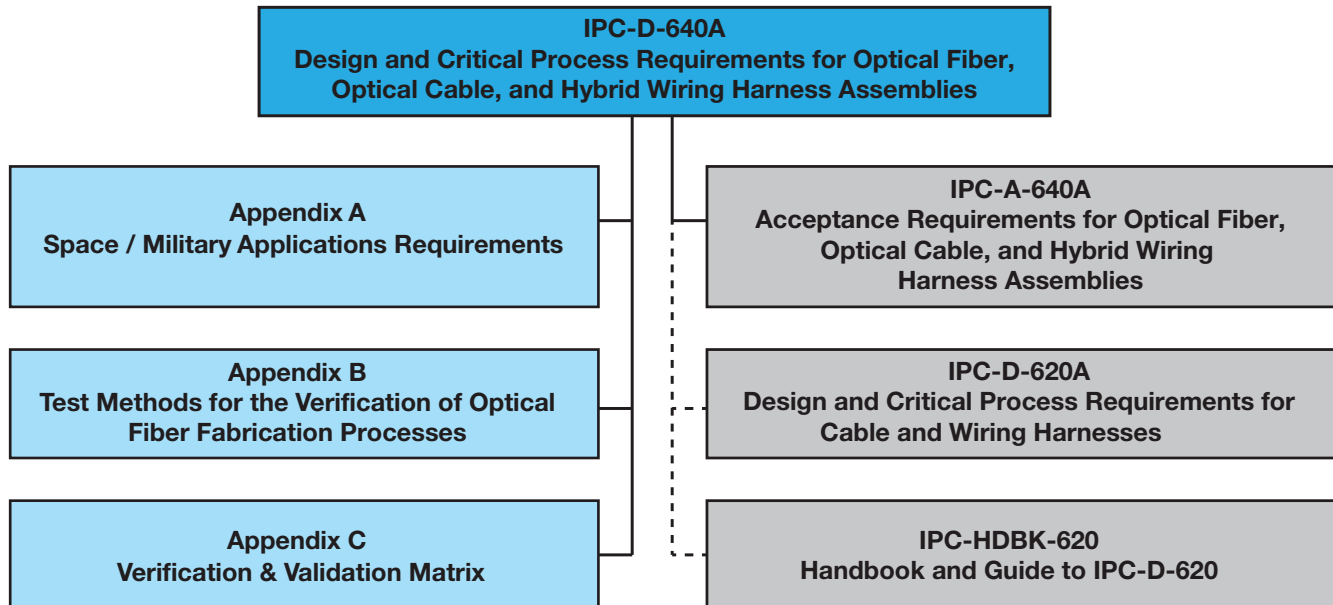


Figure 1 Hierarchy of IPC Design Specifications (IPC-D-640A Series)

FOREWARD

This standard provides information on the design and critical process requirements for optical fiber, optical cable, and hybrid wiring harness assemblies 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” forms 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. While the principal members of the Fiber Optic Cable Acceptability Task Group (7-31m) of the Acceptability Subcommittee (7-31) are shown below, 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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Design and Critical Process Requirements for Optical Fiber, Optical Cable and Hybrid Wiring Harness Assemblies

1 GENERAL

1.1 Scope This document provides design and critical process requirements and technical insight 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 referenced materials, as this document cannot (nor can any single document) cover every material, process, environment, performance, or safety aspect, that impact a given design.

1.2 Purpose This standard is intended to provide information on the general design 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.

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

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** [A1A2A3] require review and prior approval of the User.

For purposes of this document:

- a. The Designer is the design agent for the User.
- b. 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 (i.e., the originator / custodian of the contract detailing these requirements). The User is considered the Design Authority.
- c. The Supplier is considered the individual, organization or company which provides the Manufacturer (assembler) components (electrical, electronic, electromechanical, mechanical, printed boards) and/or materials (solder, flux, cleaning agents).
- d. The Manufacturer is considered the entity that provides a service or product to the User.

1.3 Performance / Product Classification This document recognizes that optical wiring harnesses and cable assemblies are subject to performance / product 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. It should be recognized that there may be requirement overlaps between classes.

The User is responsible for defining the product class. The contract **shall** [A1A2A3] specify the performance class required, whether compliance to any of the Appendices is required, and indicate any exceptions to specific parameters where appropriate.

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.

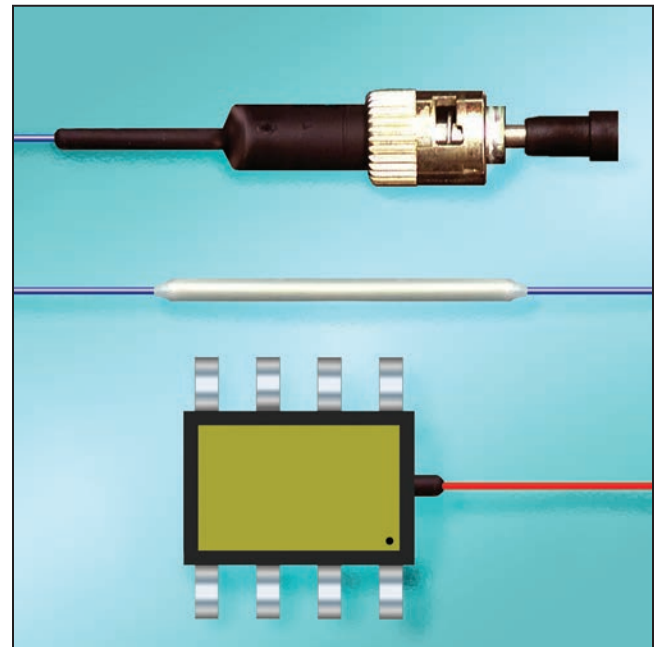


Figure 1-1 Optical Fiber Assemblies, Cables And Wiring Harnesses Connector, Splice and Transmitter
Image credit: NASA

CLASS 3 – High-Performance Electronic Products

Includes products where 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 classification deviations to IPC-D-640A requirements are defined and listed in Appendix A.

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 nonmandatory, and which reflects general industry practice and/or procedure. The words “should” or “should not” are displayed in unbolded text.

1.4.1 Design Requirement Format (A/N) This is a design document, and the requirements are formatted to allow verification and validation (V&V). As such, there are no quality acceptance conditions specified in the document. To assist the User, each requirement in the design section of the document is identified by its Performance Classification (x1x2x3) and applicability, where “x” represents:

N = Not Applicable
A = Applicable

Examples:

[N1N2A3] = Not Applicable for Class 1 or Class 2; Applicable for Class 3

[N1A2A3] = Not Applicable for Class 1; Applicable for Class 2 and Class 3

[A1A2A3] = Applicable for all Classes

1.4.2 Requirements Flowdown This document **shall not [A1A2A3]** 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 [A1A2A3]** be imposed on all applicable subcontracts, assembly drawing(s), documentation, and purchase orders.

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

1.4.4 Commercial Off-the-Shelf (COTS) The requirements of this document **shall not [A1A2A3]** apply to Commercial-Off-the-Shelf (COTS) or catalog items (e.g., components, assemblies, sub-assemblies 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 wiring harnesses and cable assemblies meets contract performance and reliability requirements.
- b. Modifications of COTS **shall [A1A2A3]** be documented.
- c. All modifications **shall [A1A2A3]** 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.

1.4.5 Existing or Previously Approved Designs The requirements of this document **shall not [A1A2A3]** 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.

1.4.6 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.

1.5 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 nondimensional 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”

1.6 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 10.

1.6.1 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).

1.6.2 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.

1.7 Engineering Documentation The design engineer is responsible for ensuring that all applicable design details are clearly and completely depicted on the engineering documentation (drawings). Drawings **shall** [A1A2A3] 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.

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

1.8.1 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** [A1A2A3] 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** [A1A2A3] 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** [A1A2A3] govern.
- d. If no criteria is specified, required, or cited, criteria **shall** [A1A2A3] be established and agreed upon between the Manufacturer and User.

1.8.2 Clause References When a clause in this document is referenced, its subordinate clauses **shall [A1A2A3]** also apply.

1.9 Appendices A and B For the purpose of this document, Appendices A and B are considered separate and optional documents to IPC-D-640A, which provide additional engineering rationale and technical guidance on the design of optical fiber, optical cable, and hybrid wiring harness assemblies.

- a. Appendices **shall not [A1A2A3]** 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 [A1A2A3]** 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 [A1A2A3]** be AABUS.

1.10 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 it establishes the minimum design requirements for most applications.

- a. 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. The requirements herein may be tailored by the Designer; however, such tailoring **shall [A1A2A3]** require technical evaluation and approval by the User prior to use. See Section 9 for additional information.
- c. Use of alternate control plans, documents, or processes **shall [A1A2A3]** require technical evaluation and approval of the User prior to use.
- d. Requests for relief from requirements in this document **shall [A1A2A3]** require technical evaluation and approval of the User prior to use.
- e. Engineering documentation **shall [A1A2A3]** contain the details for such instances, and take precedence over appropriate sections of this document and the applicable requirements document(s).

1.11 Foreign Object Debris (FOD) Control Plan When a Foreign Object Debris (FOD) Prevention Program (a.k.a.: FOD Control Plan) is required, it **shall [A1A2A3]** 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-116.

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

1.12.1 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 if used incorrectly. All safety precautions **shall [A1A2A3]** be strictly followed in accordance with the supplier's instructions, applicable requirements, and government regulations.

1.12.1.1 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 [A1A2A3]** be followed at all times.
- b. Suitable personal protective equipment (PPE) **should** be worn.

1.12.1.2 Toxic Products and Formulations The use of toxic products and formulations used throughout the manufacture, assembly, test, and rework/repair processes **shall [A1A2A3]** 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.

1.12.1.3 Protection From Bare Fibers Exposure to bare fiber and fiber waste is a personnel safety concern and **shall [A1A2A3]** be handled as such.

- a. All necessary precautions **shall [A1A2A3]** 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 [A1A2A3]** wear wrap-around safety goggles to prevent accidental ingress of glass shards into the eyes and reduce the chance of eye damage.
- c. Slivers of bare fiber **shall [A1A2A3]** be placed in a specially marked container for later disposal.
- d. Fiber waste **shall not [A1A2A3]** 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.
 - 2) It is strongly recommended that contact wearers not handle their lenses until they have thoroughly washed their hands.
 - 3) Do not rub or touch your eyes while working with fiber optic systems until your hands have been thoroughly cleaned.
 - 4) Wear disposable aprons to minimize fiber particles on your clothing. Fiber particles on clothing can later get into food and, drinks, and/or be ingested by other means.
 - 5) Thoroughly clean the work area following completion of work with fiber.

1.12.2 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 unenergized simply because visible light is not evident.

- a. All optical fiber **shall [A1A2A3]** 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 your 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 [A1A2A3]** 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.
- c. At a minimum, personnel **shall [A1A2A3]** wear wrap-around safety goggles for eye protection.
- d. Protection from eye exposure to Class 2 or higher laser light emissions **shall [A1A2A3]** be in accordance with ANSI Z136.2 and IEC 60825-2, or other applicable federal (national) laser safety regulations.
 - 1) Skin and eye protection **shall [A1A2A3]** be provided and used when working with Class 3b and 4 sources.
 - 2) Personnel entering or working in an area where Class 2 or higher lasers are in use **shall [A1A2A3]** have completed basic laser safety training.
- e. Test Equipment. The equipment manufacturer’s operation and safety instructions **shall [A1A2A3]** be followed.
 - 1) Microscopes used to examine the endface of an optical fiber or terminus **shall not [A1A2A3]** be used while the fiber is energized.
 - 2) Use of visual fault location equipment **shall [A1A2A3]** 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.

1.13 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 61340-5-1, or 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.

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-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

IPC-1791 Trusted Electronic Designer, Fabricator and Assembler Requirements

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

2.2 Joint Industry Standards

TIA EIA-455 Standard Test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and Other Fiber Optic Components

2.3 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

2.4 ASTM International³

ASTM E29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

ASTM E595 Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

2.5 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)

2.6 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

2.7 International Electrotechnical Commission (IEC)⁶

IEC 60825-2 Safety of Laser Products – Part 2: Safety of Optical Fibre Communication Systems (OFCS)

IEC 61340-5-1 Electrostatics – Part 5-1: Protection Of Electronic Devices From Electrostatic Phenomena – General Requirements

2.8 International Organization for Standardization (ISO)⁷

ISO 9001 Quality Management Systems – Requirements

2.9 Laser Institute of America (LIA)⁸

ANSI Z136.1 Safe Use of Lasers

ANSI Z136.2 Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources

2.10 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

¹ www.ipc.org

² <https://www.asme.org/>

³ <https://www.astm.org/>

⁴ <https://www.esda.org/>

⁵ <https://www.ieee.org/>

⁶ <https://www.iec.ch/>

⁷ www.iso.org

⁸ <https://www.lia.org/>

⁹ www.nfpa.org

2.11 SAE International¹⁰**GEIA-STD-0005-1** Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder**GEIA-STD-0005-2** Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems**2.12 Telecommunications Industry Association¹¹****TIA-598** Optical Fiber Cable Color Coding**2.13 UL¹²****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 United States Department of Defense (DoD)¹³****MIL-HDBK-415** Design Handbook for Fiber Optic Communications Systems**MIL-STD-188-111** Interoperability and Performance Standards for Fiber Optic Communications Systems**MIL-STD-2052** Fiber Optic Systems Design

2.15 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**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**DOD-STD-1678** Fiber Optics Test Methods and Instrumentation**IEEE Std. 315** Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters)**IPC/WHMA-A-620** Requirements and Acceptance for Cable and Wire Harness Assemblies**IPC/WHMA-A-620(SPACE)** 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**IPC-A-610DC** Telecom Addendum**IPC-OI-645** Standard for Visual Optical Inspection Aids¹⁰ <https://www.sae.org/>¹¹ <https://tiaonline.org/>¹² www.ul.com¹³ <https://www.dla.mil/HQ/InformationOperations/DLMS/elibrary/manuals/milstds/>

IPC-TM-650 IPC Test Methods Manual**IPC-1791** Trusted Electronic Designer, Fabricator and Assembler Requirements**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, Nonhermetic, 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, Multi-Mode, 50/125/450 μm , Graded Index, Hermetic Coated, Tight Buffer**SAE AS5382/6** Cable, Fiber Optic, Multi-Mode, 200/230/500 μm , Step Index, Tight Buffer**3 DESIGN PHILOSOPHY**

An optical fiber can best be described as a filament-shaped optical waveguide, constructed of transparent dielectric material (e.g., glass, fused silica, plastic) for the transmission of data and/or communications using radiant spectrum energy (e.g., visible/invisible light) (see Figure 3-1). The smaller physical size and reduced weight of optical fiber and optical fiber cable make the technology attractive for designs requiring high-speed, secure and interference-immune communications while reducing the transmission speed limitations, bulk and weight of conventional metallic wire and cable.

It is the Manufacturer's responsibility to ensure that the technical issues associated with the design and manufacture of optical fiber, optical fiber cable, optical fiber assemblies and wiring harnesses incorporating optical fiber/cable (e.g., hybrids) are conveyed to the User and that a dialogue is established, so that appropriate and timely decisions are made commensurate with realistic expectations and reality.

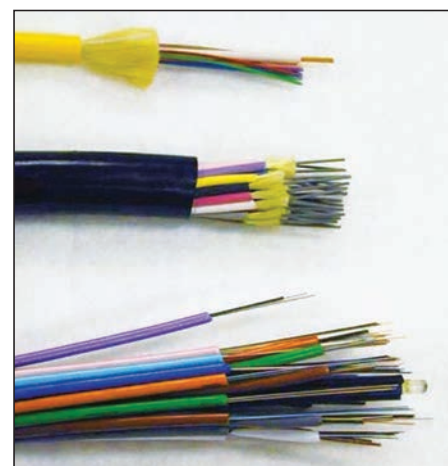


Figure 3-1 Basic Types of Optical Cables

Tight Buffered – Distribution (top)

Tight Buffered – Breakout (center)

Loose Buffered (bottom)

Photo credit: The Light Brigade

3.1 General Design Requirements The design of optical fiber, optical fiber cable and optical fiber assemblies **shall [A1A2A3]** be based on the known worst-case operational requirements and expected use. These include but are not limited to:

- Assembly processes
- Shipping and storage
- Installation
- Test exposure
- Service environment (operational temperature limits, mechanical, thermal and vibration stress; contamination; corrosives; EMC/EMI/RFI, ionizing/nonionizing radiation, moisture or other fluid media exposure)
- Post-use test and data recovery
- Life expectancy

See Figure 3-2.

- a. Any known conditions that contribute to degradation of performance and/or reliability of hardware in service **shall [A1A2A3]** require special consideration.
- b. The basic design requirements to ensure reliable interconnecting optical fiber, optical fiber cable and optical fiber assemblies include but are not limited to:
 - 1) The physical and optical properties of the fiber, including:
 - Core size
 - Core type
 - Coatings
 - Weight
 - Tensile strength
 - Signal propagation rates
 - 2) The physical and optical properties of cable assembly, including:
 - Active and spare fiber count
 - Connectors
 - EMI/RFI/magnetic shielding
 - Ionizing/Nonionizing radiation
 - Construction (jacketed, armored, loose tube, hybrid)
 - Signal propagation rates
 - Identification/markings
 - 3) Environmental sealing features that control the entry of humidity and/or contamination.
 - 4) Stress-relief and connector/cable attachment features that provide protection from both tensile and compressive forces.
 - 5) Material properties, including:
 - Arc tracking resistance
 - Chemical/Material compatibility
 - Flammability
 - Odor
 - Outgassing
 - Low-pressure / vacuum stability
 - Ultraviolet stability
 - Resistance/Reactance to corrosives, solvents, oxidizers, chemicals, etc.
 - Resistance to heat/cold
 - Resistance to abrasion damage and cold flow

- 6) Unique application / use issues, including:
 - Acoustic, mechanical, thermal shock
 - Acceleration (g-load)
 - Environment (condensing/corrosive/explosive atmosphere)
 - Electric field density (high voltage / lightning)
- 7) Splices – The use of splices should be minimized as much as possible and only considered where the use of a connector is impractical or would reduce reliability; where the use of a splice would optimize complicated wiring when the harness supports branch circuits or parallel-connected devices; or, where use of a splice facilitates/simplifies installation (i.e., joining harness sections/branches).
- 8) Nonmetallic components – Insulation jackets, potting materials, lacing tapes, braid sleeving, plastic straps, wrap sleeving, and plastic tubing.
- 9) Special handling, storage and processing requirements that may contribute to degradation of performance and/or reliability of hardware in service (e.g., Red Plague / White Plague control).
- 10) Vulnerability to Foreign Object Debris (FOD) damage (see 1.11).
- 11) Unique system-level testing requirements.
- 12) Proprietary and export control compliance requirements.
- 13) Environmental/Regulated materials (e.g., RoHS, REACH).
- 14) Safety, maintainability, reliability, cost, etc.

3.2 System Requirements Specification (SyRS) The System Requirements Specification (SyRS), often referred to as the System Requirement Document (SRD), is a Design Authority-developed and structured collection of information that describes and defines the requirements, and verification of those requirements, for a combination of elements that are required to function together to produce the capabilities required to fulfill a mission need, including hardware, equipment, software or any combination thereof.

The SyRS **shall [A1A2A3]** contain the technical information needed by the Supplier to ensure the optical fiber, optical fiber cable and optical fiber assembly design meet specification and deliver the required performance and reliability. Once the SyRS is placed on contract, the Manufacturer should further develop the specification and develop their own, more detailed requirements document baselined against their internal processes.

SyRS typically contain the following information:

- a. Interface Control Document (ICD)
- b. Performance and Reliability Specifications
- c. Environmental Specifications
- d. Material Specifications
- e. Packaging, Handling, Shipping, and Transportation (PHS&T) Requirements
- f. Intellectual Property (IP) Control & Documentation Requirements

3.2.1 Interface Control Document (ICD) The Interface Control Document (ICD) **shall [A1A2A3]** describe the interface or interfaces between subsystems or to a system or subsystem and contain the following information (as required):

- a. System Architecture and network topology
- b. Optical Fiber (fiber type, fiber count)
- c. Schematic Diagrams
- d. Mechanical Layouts and Dimensional Requirements
- e. Connectors (type, location, contact style, keying, special tooling, etc.)
- f. Connector Pin-Outs
- g. Power Allocation, Derating, Temperature Rating
- h. EMI/EMC Requirements (if applicable)
- i. Marking/Labeling Requirements.
- j. Other I/F Requirements
- k. Torque Requirements (if applicable)

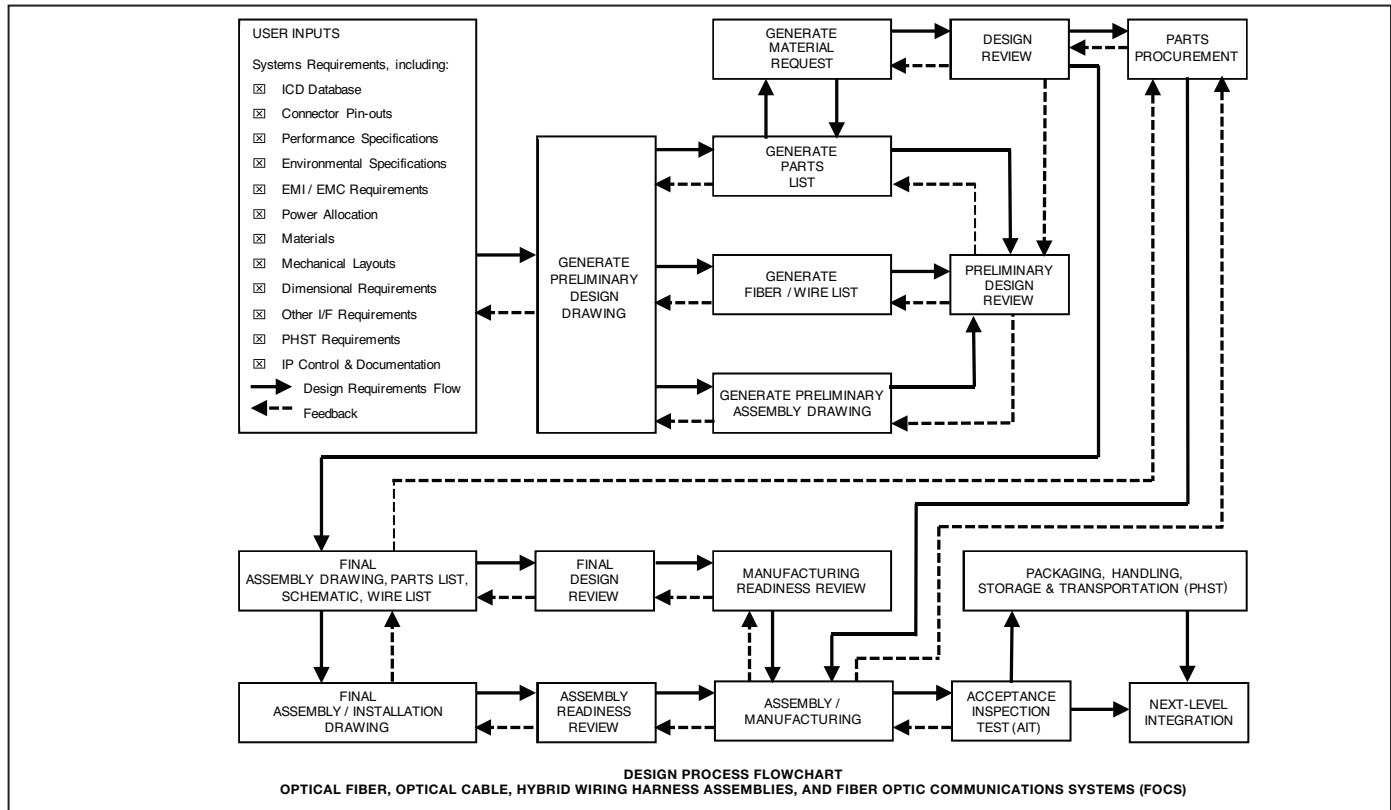


Figure 3-2 Design Process Flowchart

3.2.1.1 Link Design The design of fiber optic links **should** follow a logical sequence; however, it should be noted that link design is often an iterative process if problems (e.g., routing restrictions, power budget issues) are encountered. The design process as defined below is relatively simple with the exception of determining power penalties, calculating rise time and verifying that the link is neither power nor dispersion limited.

- Designate node locations.
- Determine link routing (note that the final route may not be the shortest, most direct).
- Measure the total length of the fiber path.
- Determine optical line rate from system design information.
- Select operating wavelength and spectral width.
- Select fiber, transmitter and receiver.
- Make power budget calculations.
- Make rise time and dispersion calculations.
- Repeat steps a-h, seeking the best/optimal design.

3.2.1.2 Fiber Selection Generally, the most critical factors when selecting the fiber used in link design are fiber attenuation and dispersion coefficient. However, other attributes that influence overall system reliability, such as ability to withstand extreme temperature ranges, vibration, shock and/or alignment error, are also important considerations in link design.

Since single-mode (SM) fiber is superior to multimode (MM) in both these criteria, it has become the de facto “fiber of choice” for all high-bit-rate, long-distance links, and it is also used in local-distribution (fiber-in-the-loop) designs.

3.2.1.3 Fiber Counts and Cable Design Fiber count **shall** [A1A2A3] accommodate all types of point-to-point interconnections and operational modes within each optical link. Since the fiber count per link can vary considerably, based on bandwidth, data rates and whether the communication is simplex or duplex, each optical link in a system may have a different fiber count:

- Simplex, unprotected/nonredundant communication requires only a one (1) fiber link, while duplex unprotected/nonredundant communication requires a two (2) fiber link.
- Protected/Redundant fiber systems require duplication of all fiber (and components) in the link. A simplex system would require a two (2)-fiber link, while a duplex design requires a four (4)-fiber link.

3.2.1.3.1 Damage/Maintenance Planning Cable designs should include additional fibers to the final fiber count to accommodate the possibility of damaged fibers, capacity increases and/or maintenance issues. Recommended practice is to add four (4) additional fibers for every four (4) active fiber links.

Rationale: *Installation of fiber can require significant planning and expense. However, the actual number of individual fibers in a cable often has negligible impact on cross-sectional diameter, weight or cost (within reason). The practice of adding additional fibers to the original design permits the designer to accommodate damage and/or maintenance issues with a single cable, without requiring the installation of additional cable.*

3.2.1.3.2 Incremental Sizing of Cable (Fiber Count) The fiber cable shall [A1A2A3] be specified in multiple fiber-count unit increments (1, 2, 4, 6, 8, etc.) that meet/exceed the final fiber count.

Rationale: *This practice permits the designer to implement each link to the fiber count required by the design, with spare fiber(s) to accommodate damage and/or maintenance issues with a single cable, without requiring the installation of additional cable.*

3.2.1.3.3 Connectorization When specified, all active and dark (unused) fibers shall [A1A2A3] be connectorized and terminated to fiber distribution panels at each node.

Rationale: *This practice allows the unused (dark) fiber to be used for periodic maintenance and system performance testing, while providing a low cost, additional capability to respond to system growth, and/or damage restoration issues.*

3.2.1.3.3.1 Physical Contact (PC) Connectors Physical contact (PC) connectors are characterized by the physical and mechanical alignment, mating and contact between optical fibers utilizing precision cylindrical ferrules (see Figure 3-3). The light enters and exits the interconnect interface in a precise manner as determined by each fiber and ferrule. When properly aligned, polished and cleaned, PC connections provide minimal signal loss and optical reflectance.

- Cleaning and polishing the terminated optical fiber and ferrule are critical to performance and reliability.
- During mating, clean unobstructed PC connections displace moisture that may impact and/or reduce performance.
- PC connections are more susceptible to misalignment, scratches and contamination. Keeping the interface clean prior to mating and remating is critical.
- PC connections are better suited for clean controlled environments with infrequent mates and remates.

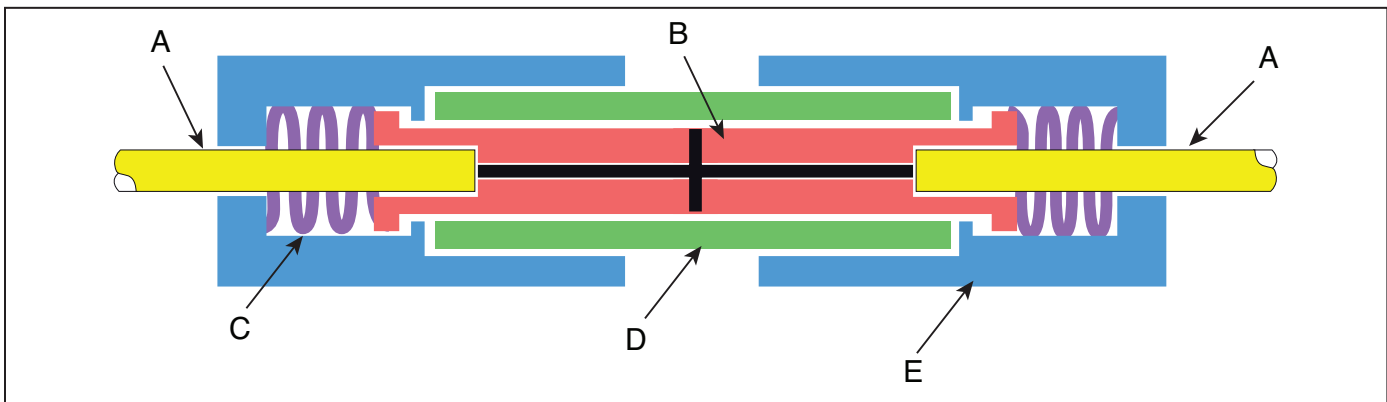


Figure 3-3 Physical Contact (PC) Connector (X-Section)

Original Image: Amphenol Aerospace Graphic Enhancement: NASA

- A – Optical fiber
- B – Ferrule
- C – Axial spring
- D – Alignment sleeve
- E – Connector assembly

3.2.1.3.3.1.1 Physical Contact (PC) Connector Types Fiber optic interconnect technology has advanced significantly since connectors were first used commercially in the 1970s. Biconic connectors, SMAs with stainless steel ferrules and even plastic lenses were early technologies incorporating fiber optic connectors. Eventually, alternative technologies displaced these initial solutions. Advances in ceramic manufacturing enabled high-precision, physical contact fiber optic connectors. Today, there are hundreds of single and multi-channel fiber optic connector types serving numerous industries including datacom, telecom, military, oil and gas, mining, etc.

- Single-Channel PC** – PC connectors are characterized by the direct contact of mated, polished fibers using tight tolerance ferrules and alignment sleeves and/or mating pins. This alignment technology exhibits reliable optical performance, with several designs becoming industry standards. Typically, these connectors are offered as single-fiber solutions with metal or plastic shells.

Figure 3-4 shows some of the popular single-channel connectors. LC and SC connectors are commonly used in the datacom and telecom industries. FC and ST connectors are becoming less popular but are still used in instrumentation.

- b. **Multi-Channel PC** – Many applications require multiple fiber optic channels in a single connector to reduce space and facilitate connectivity. Multi-channel connectors house multiple fiber optic termini (Figure 3-5) in a precision insert. The termini can be configured as a pin/socket combination or genderless. As with the single-channel physical contact connector, the main components of the termini are the ceramic ferrule, spring and pin body. The insert is then mounted in a metal or composite shell to provide environmental protection (see Figure 3-6) and group connectivity. Further advances in technology as well as the need for higher density have ushered in a completely new family of commercial interconnect technology. MPO connectors, such as the MTP, can terminate with up to 24 fibers in a very small form factor. All of these commercial interconnect solutions use a physical contact form of mating.

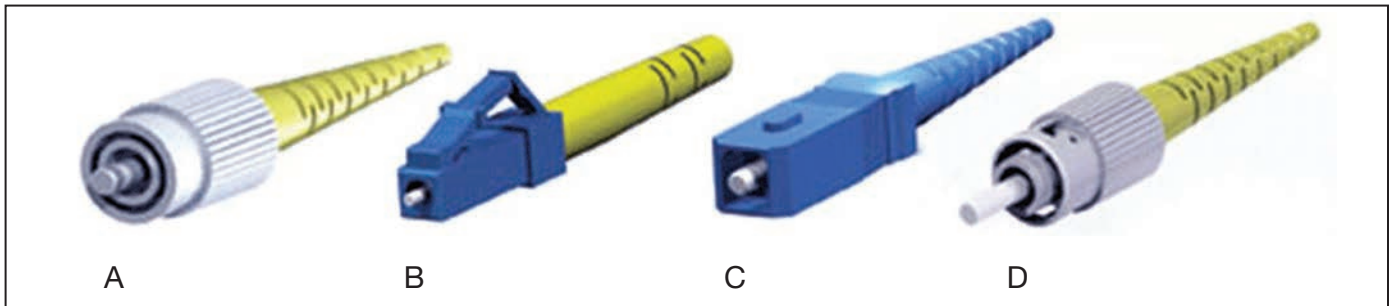


Figure 3-4 Common Commercial Single-Channel PC Connectors

Original Image: Amphenol Aerospace Graphic Enhancement: NASA

- A – Ferrule connector (FC)
 B – Lucent connector (LC)
 C – Subscriber connector (SC)
 D – Straight tip connector (ST)

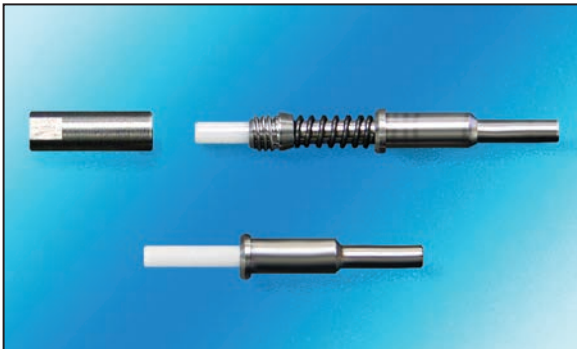


Figure 3-5 Optical Fiber Contact (M29504/4 & M29504/5)

Original Image: Amphenol Aerospace Graphic Enhancement: NASA



Figure 3-6 Multi-channel Optical Connector (ARINC 801)

Original Image: Amphenol Aerospace Graphic Enhancement: NASA

3.2.1.3.3.2 Expanded Beam (EB) Similar to PC optical connections, expanded beam (EB) connections also use precision alignment, cylindrical ferrules and polishing procedures (see Figure 3-7). However, EB connectors are specifically designed to not require direct physical contact between optical termini to transfer the optical signal. These connections use internal lenses (typically, spherical lenses) to expand the light from the emitting fiber, transmit the light to the adjacent termini and then collimate and refocus the light into the receiving fiber.

- EB technology is ideal for use in highly contaminated environments and demanding applications requiring ease of use and minimal maintenance. The impact of debris, such as dirt and dust particles, is less (when compared with PC connections).
- Due to the lack of an alignment sleeve, EB connections are more susceptible to misalignment error (axial, offset, lateral and angular) between termini faces but are easier to clean and dry. In addition, because of the air gap, there is no physical contact between the fiber endfaces, which reduces mechanical damage (scratching, crashing, etc.) experienced by PC connectors.
- EB technology is more reliable (than PC connectors) when used in harsh military and commercial applications where frequent mate cycles will expose the optical connection to contamination.
- EB technology will typically have higher optical insertion and return losses when compared to PC connections with possible wavelength restrictions on very specialized systems. This is due to the inherent air gap, additional lenses and possible anti-reflective coatings used by the design. Therefore, design engineers should consider the expanded beam performance as part of the system design. In many cases, this difference in performance is acceptable. In others, a system specification may dictate the utilization of PC connectors.

- e. EB connections are generally sealed because they react differently to moisture than PC connections. Moisture on the inner lenses can degrade performance by scattering the light as it tries to pass through the moisture contaminant.

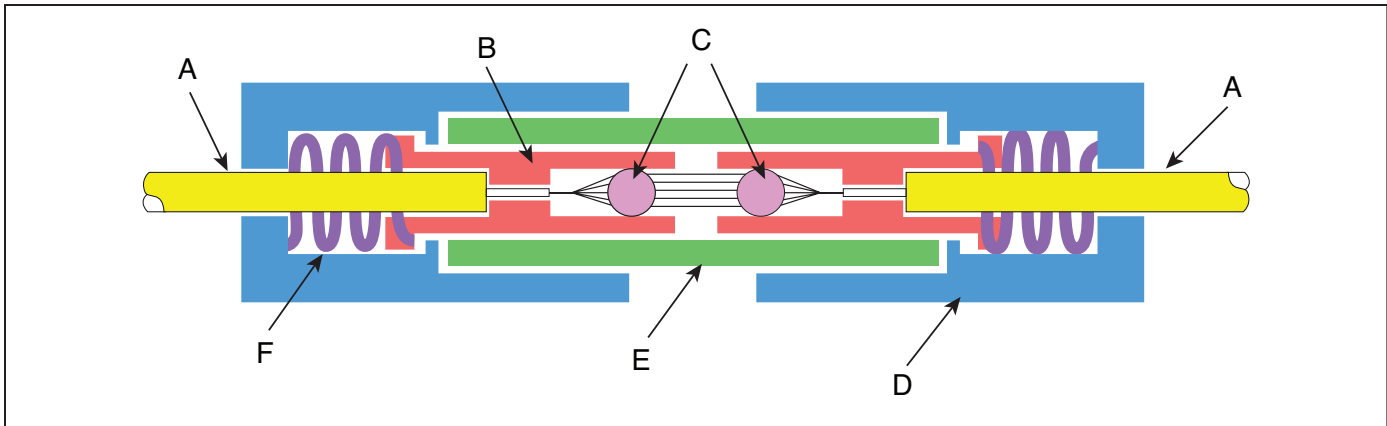


Figure 3-7 Expanded Beam (EB) Connector (X-Section)

Original Image: Amphenol Aerospace

Graphic Enhancement: NASA

- A – Optical fiber
- B – Ferrule
- C – Lenses
- D – Axial spring
- E – Alignment sleeve
- F – Connector assembly

3.2.1.3.3.2.1 Expanded Beam (EB) Connector Types While the selection of EB connector products may not be as diverse as PC connectors, there are multiple types of EB connectors. Figure 3-8 portrays an EB contact used in single-channel connector shells. Figure 3-9 depicts a multi-channel EB connector using a monolithic insert.

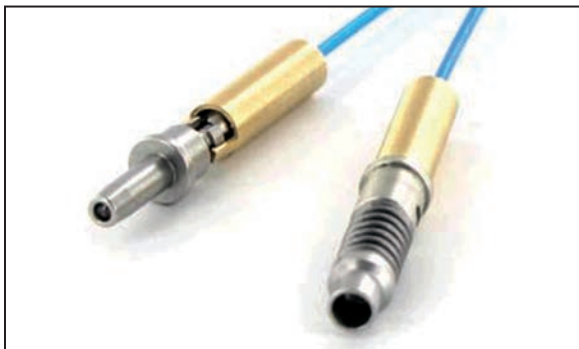


Figure 3-8 EB Single-Channel Contact

Original Image: Amphenol Aerospace Graphic Enhancement: NASA



Figure 3-9 EB Multi-channel Connector

Original Image: Amphenol Aerospace Graphic Enhancement: NASA

3.2.1.3.3.2.2 Comparison of PC and EB Technology

- a. Optical Performance (IL and RL) – PC technology has a typical insertion loss (IL) of 0.3 dB and a return loss (RL) of -65 dB, while EB connectors exhibit a typical insertion loss (IL) of 1.5 dB and a return loss (RL) of -30 dB.
 - PC connectors exhibit better performance in designs with a limited or tight link budget (power) and/or those designs requiring reduced back reflection (e.g., analog systems).
- b. Environmental Performance – Performance and reliability issues caused by mechanical shock, vibration and temperature extremes can be mitigated and controlled through connector designs that minimize the impact of these external environmental factors.
 - PC and EB technologies show very little variance between how each performs optically when subjected to these elements.
- c. Wavelength Independence – The anti-reflective (AR) coatings employed to reduce return loss in expanded beam connectors also serve to limit the wavelengths supported by the connection.
 - Physical contact technology is the preferred choice for designs incorporating wavelength dynamic or broad spectrum (e.g., wavelength division multiplexing) sources.
- d. Debris and Moisture Susceptibility – Susceptibility to contamination affects optical performance of PC and EB in different ways, depending on the contaminant. Because EB connectors expand the light beam across the interconnect point, the impact of contamination such as dirt and dust particles is minimized in comparison to PC connections. Moisture also affects PC