

IPC-HDBK-620

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Handbook and Guide to IPC-D-620 and IPC/WHMA-A-620

An international standard developed by IPC

Association Connecting Electronics Industries



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Developed by the IPC-HDBK-620 Handbook Task Group (7-31h) and Wire Harness Design Task Group (7-31k) of the Product Assurance Committee (7-30) of IPC

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

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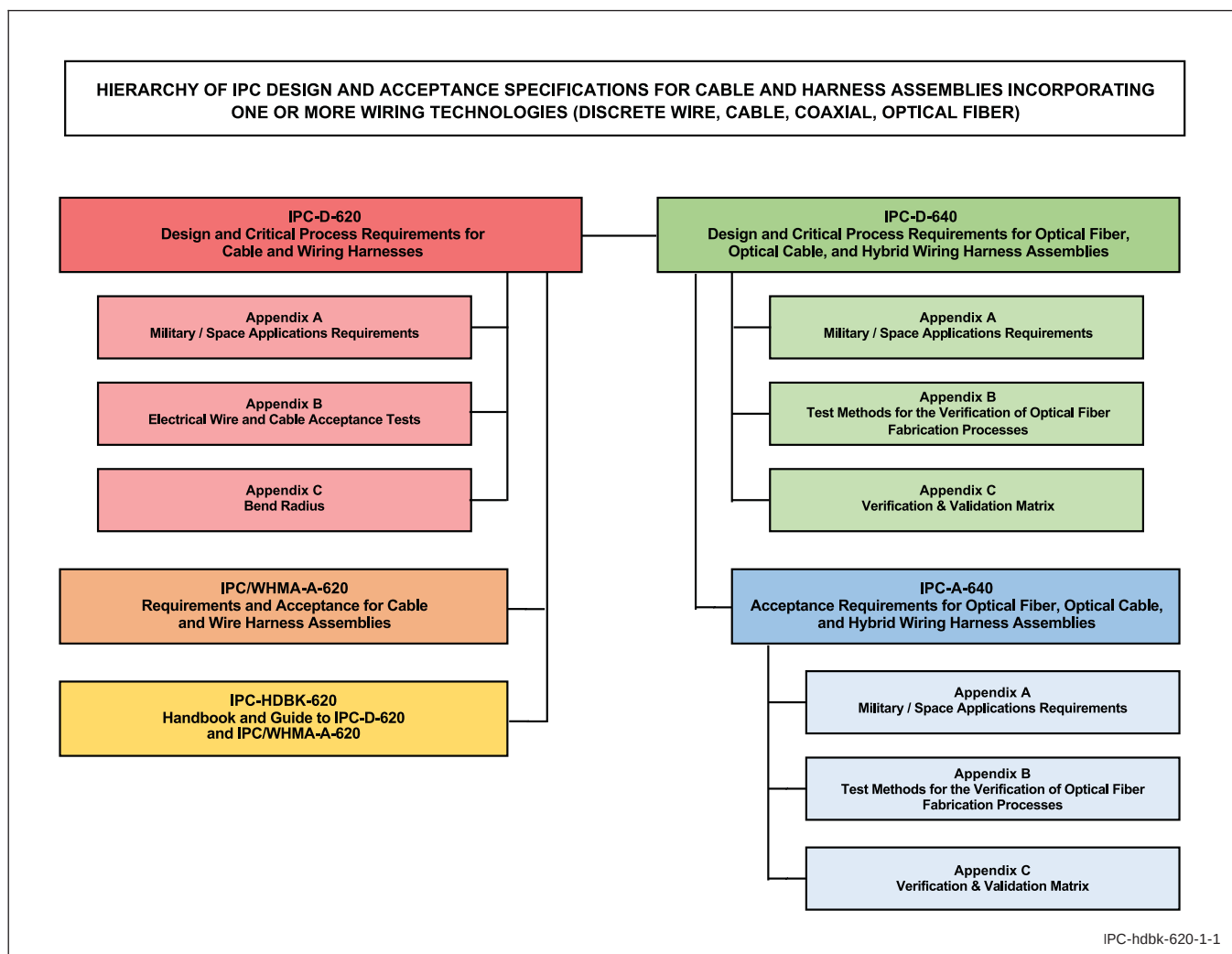


Figure 1-1 Hierarchy of IPC Design and Acceptance Specifications for Cable and Harness Assemblies Incorporating One or More Wiring Technologies (Discrete Wire, Cable, Coaxial, Optical Fiber)

This handbook is intended to provide information on the design requirements for cable and wiring harness design, to the extent that they can be applied to the broad spectrum of cable and wiring harness design.

It is therefore crucial that decisions concerning the choice of product classification, wiring technology, connectorization requirements, and performance and reliability requirements be made as early as possible.

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

The 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

Members of the IPC-HDBK-620 Handbook Task Group and Wire Harness Design Task Group worked together to develop this document. We thank them for their dedication and service to this effort. Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the IPC-HDBK-620 Handbook Task Group (7-31h) and Wire Harness Design Task Group (7-31k) of the Product Assurance Committee (7-30) 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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Handbook and Guide to IPC-D-620 and IPC/WHMA-A-620

1 GENERAL

Cables and wiring harnesses are equivalent to the human circulatory and nervous system. They deliver energy, transmit command and control instructions, and collect and distribute sensory data describing not only the environment external to the system, but the health and status of the system itself.

Often the most overlooked, ignored, and “taken for granted” component in a design, high quality cables and wiring harnesses are essential to the performance and reliability of any electrical/electronic system.

It is the Designer’s and Supplier’s responsibility to ensure that the technical issues associated with the design and manufacture of cable assemblies and wiring harnesses 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.

1.1 Scope This Handbook is a companion reference to IPC-D-620 “Design and Critical Process Requirements for Cable and Wiring Harnesses” and IPC/WHMA-A-620 “Requirements and Acceptance for Cable and Wire Harness Assemblies” and is intended to provide supporting information, guidance, and technical insight into the design and acceptance requirements for cable and wire harness assemblies.

The intent of this Handbook is to capture “how and why” information and provide additional technical rationale for the specification limits, acceptance criteria, as well as how those specifications and criteria interrelate. In addition, other supporting information is provided to give a broader understanding of the process considerations needed for the design and production of acceptable hardware.

The target user of this Handbook is a process or manufacturing engineer.

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 affect a given design.

This handbook addresses a wide range of technologies and processes used in cable and wiring harness assemblies, including optical fiber technology, adhesives and polymeric, torque, test, etc. Reference materials listed in this text are recommended for reading to obtain a complete understanding of the topics presented. 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 affect a given design.

It is not enough to understand the properties of the various components, materials and processes; the user **should** understand what is to be achieved by the set of selected components, materials, and processes within the end use environment and how to verify that the desired results have been realized.

This document is intended to be used as a reference only. It is the responsibility of the user to determine the suitability of the cable and/or wire harness assembly design as a functional system in the intended end use application.

1.2 Purpose IPC-HDBK-620 “Handbook and Guide to IPC-D-620 and IPC/WHMA-A-620” is the cable and wiring harness handbook companion to IPC-D-620 “Design and Critical Process Requirements for Cable and Wiring Harnesses” and IPC/WHMA-A-620 “Requirements and Acceptance for Cable and Wire Harness Assemblies.”

For purposes of this document:

- The Designer is the design agent for the User.
- 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 equipment 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.
- The Supplier is considered the individual, organization or company which provides the Manufacturer (assembler) components (e.g., electrical, electronic, electromechanical, mechanical, printed boards, etc.) and/or materials (e.g., solder, flux, cleaning agents, etc.).
- The Manufacturer is considered the entity that provides a service or product to the User.

1.3 Applicability This handbook is for guidance only. The design concepts, guidelines, and procedures presented in this document are not requirements, and this document is not binding, unless separately and specifically included by the applicable contract, approved drawing(s), or purchase order.

The use of words “**must**,” “**should**” and “**shall**” have no special meaning in this document and do not indicate a binding criterion.

1.4 Performance/Product Classification This document recognizes that electrical 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 overlaps in performance and reliability requirements between classes.

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 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

A sub-class within Class 3, often referred to as “Space/Military,” includes products from Performance Class 3 – High Performance/Harsh Environment Electronic Products, with additional considerations for unique materials requirements and more extreme operational environments, such as vibration, thermal cycling, and mechanical and thermal shock.

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.

- 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.
- Temperature values are expressed in degrees Celsius (°C) [Fahrenheit (°F)].
- Mass is expressed in grams (g) [ounces (oz)].
- 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, etc.).
- Time values are expressed in hours, minutes and seconds in the following coding format (hh:mm:ss).
- For the purposes of determining conformance to this specification, all specified limits in this standard are absolute limits as defined in ASTM E29.

1.5.1 Graphics Graphics (e.g., line drawings, charts, figures, images, etc.) are included to provide the User with a visual interpretation of the information, guidance, and technical insight detailed in this document.

- Graphics are not to scale, may depict individual features or surfaces in false colors to aid in identification, and **should** be treated as reference information only.
- Text contained in this document always takes precedence over graphics.

1.6 Terms and Definitions For purposes of this document, the acronyms, abbreviations, and terms used, but in addition to those listed in IPC-T-50, “Terms and Definitions for Interconnecting and Packaging Electronic Circuits” are listed in Section 21 “Definitions and Acronyms.”

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

1.7.1 Chemicals The chemicals (i.e., adhesives, cleaners, coatings, encapsulants, and solvents) used in assembly, rework, and/or repair 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 **must** be strictly followed in accordance with the supplier's instructions, applicable requirements, and government regulations.

1.7.1.1 Epoxies/Adhesives Epoxy resins and/or adhesives cause mild contact dermatitis (skin irritation) and/or allergic reactions. The manufacturer's instructions **shall** be followed at all times and suitable personal protective equipment (PPE) **should** be worn.

1.7.1.2 Toxic Products and Formulations The use of toxic products and formulations used throughout the manufacture, assembly, test, and rework/repair processes **shall** 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. The use of some materials referenced in this handbook and in the companion design and acceptance documents may be hazardous. To provide for personnel safety, follow the applicable local and federal Occupational, Safety, and Health Regulations.

1.7.2 Ergonomic Factors Ergonomic factors **should** be considered and implemented into the design to ensure the product can be manufactured, operated, and maintained without any undue risk of injury. The designer **should** make accommodation for all of the following:

- a. Product intended end use – how will the product be used in the field.
- b. Original manufacturing process – general lifting, moving, rework required.
- c. Maintenance/repair activity.

2 APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issue /revision in effect on the date of bids, or request for proposal, **shall** apply.

2.1 Aerospace

AS7928 Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification For

AS22759 Wire, Electric, Fluoropolymer-Insulated Copper or Copper Alloy

AS85049 Electrical General Specification for Connector Accessories

2.2 Commercial

AEC-Q100 Failure Mechanism Based Stress Test Qualification for Integrated Circuits

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

ARP 6167 Etching of Fluoropolymer Insulations

ASME Y14.100 Engineering Drawing Practices

ASME Y14.24 Types and Applications of Engineering Drawings

ASME Y14.34 Associated Lists, Engineering Drawing and Related Documentation Practices

ASME Y14.35 Revision of Engineering Drawings and Associated Lists

ASME Y14.44 Reference Designations for Electrical and Electronics Parts and Equipment

ASTM D495 Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulating Materials

ASTM D638 Standard Test Method for Tensile Properties of Plastics

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 Tim Whiskers in Aerospace and High Performance Electronic Systems, Control Level 2C

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

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

IPC-1072 Best Industry Practices for Intellectual Property Protection in Assembly Manufacturing

IPC-CC-830 Qualification and Performance of Electrical Insulating Compound for Printed Wiring Assemblies

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

ISO 9001 Quality Management Systems — Fundamentals and Vocabulary

J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

J-STD-001x S Space Applications Electronics Hardware Addendum to IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

SAE-ARP5316 Storage of Aerospace Elastomeric Seals and Seal Assemblies Which Include an Elastomer Element Prior to Hardware Assembly

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

Telcordia GR-20 Generic Requirements for Optical Fiber and Optical Fiber Cable

Telcordia GR-326 Generic Requirements for Single-Mode Optical Connectors and Jumper Assemblies

Telcordia GR-409 Generic Requirements for Indoor Fiber Optic Cable

UL 310 Standard for Safety, Quick-Connect Terminals

UL 486A-486B Standard for Safety, Wire Connectors

UL 486C Standard for Safety, Splicing Wire Connectors

2.3 Federal

None

2.4 Military Handbooks

NAVAIR 01-1A-505-1 Technical Manual, Installation and Repair Practices, Volume 1 - Aircraft Electric and Electronic Wiring

2.5 Military Specifications

MIL-A-46146 Adhesives-Sealants, Silicone, RTV, Noncorrosive (For Use with Sensitive Metals and Equipment)

MIL-I-46058 Insulating Compound, Electrical (for Coating Printed Circuit Assemblies) *Note: Inactive for New Design, effective 11-30-1998.*

MIL-PRF-8516 Sealing Compound, Synthetic Rubber, Electric Connectors and Electric Systems, Chemically Cured

MIL-STD-202 Test Method Standard - Electronic and Electrical Component Parts

MIL-STD-810 DoD Test Method Standard For Environmental Engineering Considerations And Laboratory Tests

MIL-STD-1472 Human Engineering

2.6 Other

Marchesi et al, 1991. Adhesion to Sodium Naphthalenide Treated Fluoropolymers. Part II. Effects of Treatment Conditions and Fluoropolymer Structure, The Journal of Adhesion, 36:1, 55-69, DOI: 10.1080/00218469108026523

CHENG et al, 2009. Hydrophilic treatment poly(tetrafluoroethylene) reinforced sulfonated poly(ether ether ketone) composite membrane for proton exchange membrane fuel cell application. Journal of Power Sources 194 (2009) 838-842

2.7 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. The following documents are referenced herein, but are not mandated for use unless specified in the contract.

A-A-52080 Tape, Lacing and Tying, Nylon

A-A-52081 Tape, Lacing and Tying, Polyester

A-A-52082 Tape, Lacing and Tying, TFE-Fluorocarbon

A-A-52083 Tape, Lacing and Tying, Glass

A-A-52084 Tape, Lacing and Tying, Aramid

A-A-59569 Commercial Item Description, Braid, Wire (Copper, Tin-Coated, Silver-Coated, or Nickel Coated, Tubular or Flat

SAE AIR1329 Electrical Connectors and Wiring, Compatibility of

SAE AIR4487 Investigation of Silver Plated Conductor Corrosion (Red Plague)

SAE AIR4789 Aerospace Information Report on Evaluating Corrosion Testing of Electrical Connectors and Accessories for the Purpose of Qualification

SAE AIR5468 Ultraviolet (UV) Lasers for Aerospace Wire Marking

SAE AIR5558 Ultraviolet (UV) Laser Marking Performance of Aerospace Wire Constructions

SAE AIR5575 Hot Stamp Wire Marking Concerns for Aerospace Vehicle Applications

SAE AIR5717 Mitigating Wire Insulation Damage During Processing and Handling

SAE AMS2491 Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding

ANSI/EIA-359-A Standard Colors for Color Identification and Coding

ANSI/NEMA MW 1000 Magnet Wire

ANSI/NEMA WC 27500 Aerospace and Industrial Electrical Cable

SAE AS21608 Ferrule, Shield Terminating, Crimp Style

SAE AS21919 Clamp, Loop Type, Cushioned Support

SAE AS22759 Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy

SAE AS23190 Wiring, Positioning and Support Accessories

SAE AS25274 Cap, Electrical (Wire End, Crimp Style, Type II, Class 1) for 105°C Total Conductor Temperature

SAE AS39029 General Specification for Contacts, Electrical Connector

- SAE AS4373** Test Methods for Insulated Electric Wire, Method 608, Fluoride Offgassing
- SAE AS4461** Assembly and Soldering Criteria for High Quality/High Reliability Soldered Wire and Cable Termination in Aerospace Vehicles
- SAE AS4536** Safety Cable Kit Procurement Specification and Requirement for Use
- SAE AS50881** Wiring, Aerospace Vehicle
- SAE AS5382** Aerospace Cable, Fiber Optic
- SAE AS5649** Wire and Cable Marking Process, UV Laser
- SAE AS81044** Wire, Electrical, Crosslinked Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy
- SAE AS83519** Shield Termination, Solder Style, Insulated, Heat-Shrinkable, Environment Resistant, General Specification for (Slash Sheet: /1, /2)
- ASME B107.14** Hand Torque Tools
- ASME Y14.100** Engineering Drawing Practices
- ASTM B 263** Standard Test Method for Determination of Cross-Sectional Area of Stranded Conductors
- ASTM B 298** Standard Specification for Silver-Coated Soft or Annealed Copper Wire
- ASTM B 624** Standard Specification for High-Strength, High-Conductivity Copper-Alloy Wire for Electronic Application
- ASTM B 961** Standard Specification for Silver Coated Copper and Copper Alloy Stranded Conductors for Electronic Space Application
- ASTM B172** Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors
- ASTM B173** Standard Specification for Rope-Lay-Stranded Copper Conductors Having Concentric-Stranded Members, for Electrical Conductors
- ASTM B174** Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors
- ASTM B263** Standard Test Method for Determination of Cross-Sectional Area of Stranded Conductors
- ASTM B738** Standard Specification for Fine-Wire Bunch-Stranded and Rope-Lay Bunch-Stranded Copper Conductors for Use as Electrical Conductors
- ASTM B8** Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft
- ASTM D4066** Standard Classification System for Nylon Injection and Extrusion Materials
- ASTM D5363** Standard Specification for Anaerobic Single-Component Adhesives
- ASTM D5948** Standard Specification for Molding Compounds, Thermosetting
- ASTM D635** Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position
- ASTM E3** Standard Guide for Preparation of Metallographic Specimens
- ASTM E595** Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment
- ECSS Q-70-20A** Determination of the Susceptibility of Silver-Plated Copper Wire and Cable to “Red-Plague” Corrosion
- EEE-INST-002** Instructions for EEE Parts Selection, Screening, Qualification and Derating.
- EV-067** (JSC) Foreign Object Debris (FOD) Control Plan for the Avionic Systems Division

FED-STD-228 Cable and Wire, Insulated; Methods of Testing

FED-STD-595 Federal Standard: Colors used in Government Procurement

SAE GEIA-HB-0005-1 Program Management/Systems Engineering Guidelines for Managing the Transition to Lead-Free Electronics

SAE GEIA-HB-0005-2 Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free Solder and Finishes

SAE GEIA-HB-0005-3 Rework/Repair Handbook to Address the Implications of Lead-Free Electronics and Mixed Assemblies in Aerospace and High Performance Electronic Systems

SAE GEIA-STD-0003 Long Term Storage of Electronic Devices

SAE GEIA-STD-0006 Requirements for Using Solder Dip to Replace the Finish on Electronic Piece Parts

IACS (UR) E11 E-11 Unified Requirements for Systems with Voltages Above 1 kV up to 15 kV, International Association of Classification Societies, Concerning Electrical Installations

IEC 60617 Graphical Symbols for Diagrams, Database Snapshot

IEC 61000 Electromagnetic Compatibility

IEEE Std 260.1 Standard Letter Symbols for Units of Measurement (SI Units, Customary Inch-Pound Units, and Certain Other Units)

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

IPC J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

IPC J-STD-001xS Space Applications Electronic Hardware Addendum to IPC J-STD-001x Requirements for Soldered Electrical and Electronic Assemblies

IPC/JEDEC J-STD-020 Moisture/Reflow Sensitivity Classification for Non-hermetic Solid State Surface Mount Devices

IPC/JEDEC J-STD-033 Handling, Packing, Shipping and Use of Moisture/Reflow Sensitive Surface Mount Devices

IPC/JEDEC J-STD-609 Marking and Labeling of Components, PCBs and PCBAs to Identify Lead (Pb), Pb-Free and Other Attributes

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

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

IPC-1601 Printed Board Handling and Storage Guidelines

IPC-2611 Generic Requirements for Electronic Product Documentation

IPC-A-610 Acceptability of Electronic Assemblies

IPC-OI-645 Standards for Visual Optical Inspection Aids

JPR 5335.05 JSC Foreign Object (FOD) Damage Prevention Program

J-STD-002 Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires

J-STD-004 Requirements for Soldering Fluxes

J-STD-006 Requirements for Electronic Grade Solder Alloys and Fluxed and Non-Fluxed Solid Solders for Electronic Soldering Applications

MIL-A-46106 Adhesive-Sealants, Silicone, RTV, One Component

MIL-C-39012 Connector, Coaxial, Radio-Frequency, General Specification For

MIL-C-85485 Cable, Electric, Filter Line, Radio Frequency Absorptive

- MIL-D-3464** Desiccants, Activated, Bagged, Packaging, Use and Static Dehumidification (Type II)
- MIL-DTL-17** Cables, Radio Frequency, Flexible and Semi-rigid, General Specification for
- MIL-DTL-5541** Chemical Conversion Coatings on Aluminum and Aluminum Alloys
- MIL-DTL-5846** Chromel and Alumel Thermocouple Electrical Wire, Detail Specification for
- MIL-DTL-16878** Wire, Electrical, Insulated, General Specification For
- MIL-DTL-24308** Connectors, Electrical, Rectangular, Non-environmental, Miniature, Polarized Shell, Rack and Panel, General Specification for
- MIL-DTL-64159** Coating Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant
- MIL-DTL-81381** Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy, General Specification for
- MIL-DTL-81706** Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys
- MIL-DTL-83528** General Specification for Gasketing Material, Conductive, Shielding Gasket, Electronic, Elastomer, EMI/RFI
- MIL-DTL-83723** Connectors, Electrical, (Circular, Environment Resisting), Receptacles and Plugs, General Specification for
- MIL-DTL-83733** Connectors, Electrical, Miniature, Rectangular Type Rack to Panel, Environment Resisting, 200°C Total Continuous Operating Temperature, General Specification for
- MIL-E-917** Electric Power Equipment Basic Requirements
- MIL-HDBK-216** RF Transmission Lines and Fittings
- MIL-HDBK-310** Global Climatic Data for Developing Military Products
- MIL-HDBK-338** Electronic Reliability Design Handbook
- MIL-HDBK-344** Environmental Stress Screening (ESS) of Electronic Equipment
- MIL-HDBK-454** General Guidelines for Electronic Equipment
- MIL-HDBK-863** Handbook for Wiring Data and System Schematic Diagrams Preparation of
- MIL-HDBK-1250** Handbook for Corrosion Prevention and Deterioration Control in Electronic Components and Assemblies
- MIL-HDBK-83575** General Handbook for Space Vehicle Wiring Harness Design and Testing
- MIL-I-631** Insulation, Electrical, Synthetic-Resin Composition, Non-Rigid
- MIL-I-3158** Insulation Tape, Electrical Glass-Fiber (Resin)
- MIL-I-3190** Insulation Sleeve, Electrical, Flexible, Coated, General Specification
- MIL-I-8835** Indicator, Humidity, Card, Chemically Impregnated (Irreversible/Reversible), 50-60-70-80-90% RH
- MIL-I-22129** Insulation Tubing, Electrical, Polytetrafluoroethylene (PTFE) Resin, Non Rigid
- SAE AMS-DTL-23053** Insulation Sleeve, Electrical, Heat Shrinkable, General Specification for
- MIL-I-24391** Insulation Tape, Electrical, Plastic Pressure-Sensitive
- MIL-PRF-23586** Sealing Compound (with Accelerator), Silicone Rubber, Electrical
- MIL-PRF-39012** Connectors, Coaxial, Radio Frequency, General Specification for
- MIL-PRF-81705** Barrier Materials, Flexible, Electrostatic-Free. Heat Sealable (Type 1)
- MIL-PRF-85045** General Specification for Cables, Fiber Optics
- MIL-S-901** Requirements for Shock Tests. H.I. (High-Impact) Shipboard Machinery, Equipment, and Systems

- SAE AS83519** Shield Termination, Solder Style, Insulated, Heat Shrinkable, Environment Resistant, General Specification for
- MIL-STD-167** Mechanical Vibrations of Shipboard Equipment
- MIL-STD-186** Manufacturing Process, Protective Finishing for Army Missile Weapon Systems
- MIL-STD-202** Test Method Standard, Electronic and Electrical Component Parts (Method 107, Test Condition B)
- MIL-STD-220** Test Method Standard - Method of Insertion Loss Measurement
- MIL-STD-403** Preparation For and Installation of Rivets and Screws, Rocket, Missile, and Airframe Structures
Note: Inactive for New Design, effective 10-24-2001.
- MIL-STD-461** Requirements for the control of Electromagnetic interference Characteristics of Subsystems and Equipment
- MIL-STD-464** Electromagnetic Environmental Effects, Requirements for Systems
- MIL-STD-681** Identification Coding and Application of Hookup and Lead Wire
- MIL-STD-704** Aircraft Electric Power Characteristics
- MIL-STD-740** Airborne and Structure-Borne Noise Measurements and Acceptance Criteria of Shipboard Equipment
- MIL-STD-810** Test Method Standard - Environmental Engineering Considerations and Laboratory Tests
- MIL-STD-889** Dissimilar Metals
- MIL-STD-1474** Design Criteria Standard, Noise Limits
- MIL-STD-2042** Fiber Optic Topology Installation Standard Methods for Naval Ships
- MIL-STD-2073-1** Standard Practice for Military Packaging (Method 50)
- MIL-STD-1399-Sect. 680** High Voltage Electric Power, Alternating Current
- MIL-STD-2223** Test Methods for Insulated Electric Wire
- MIL-DTL-713** Twine, Fibrous: Impregnated, Lacing and Tying
- SAE AS29606** Wire, Electrical, Stranded, Uninsulated Copper, Copper Alloy, or Aluminum, or Thermocouple Extension, General Specification for
- MIL-Y-1140** Yarn, Cord, Sleeving, Cloth, and Tape-Glass
- MS20003C** Indicator, Humidity Card, Three Spot, Impregnated Areas (Cobaltous Chloride), 30-40-50% RH
- MS33540** General Practices for Safety Wiring and Cotter Pinning
- MSFC-STD-3012** MSFC Technical Standard, Electrical, Electronic, and Electromechanical (EEE) Parts Management and Control Requirements for MSFC Space Flight Hardware
- MSFC-STD-3598** MSFC Technical Standard, Standard for Foreign Object Damage/Foreign Object Debris (FOD) Prevention
- NA-GSFC-2003-03** GSFC NASA Advisory, Fluoropolymer Degradation Resulting in Corrosion of Packaged Pre-wired Connector Assemblies
- NA-GSFC-2003-03** NASA Goddard Advisory, Fluoropolymer Degradation Resulting in Corrosion of Packaged Pre-wired Connector Assemblies
- AIA NAS 412** Foreign Object Damage/Foreign Object Debris (FOD) Prevention
- AIA NAS1747** Splice, Conductor and Shield Termination, Solder Style, Heat Shrinkable, Insulated, Specification for
- NASA 1228** Fastener Design Manual
- NASA PUBLICATION 1124** Outgassing Data for Selecting Spacecraft Materials
- NASA/TP-2003-212242** EEE-INST-002: Instructions for EEE Parts Selection, Screening, Qualification, and Corrosion

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

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

NASA-STD-8739.1 Workmanship Standard for Polymeric Application on Electronic Assemblies

NASM 33540 Safety Wiring, Safety Cabling, Cotter Pinning, General Practices for

NESC-RP-08-00481 Spacecraft Electrical Connector Selection and Application Process, Volume II: Appendices L through O

NFPA 70 National Electrical Codes

NIST 811 Guide for the Use of the International System of Units (SI)

A-A-59569 Braid Wire (Copper, Tin-Coated, Silver-Coated, or Nickel Coated, Tubular or Flat)

SAE AMS-DTL-23053/4 Insulation Sleeving, Electrical, Heat Shrinkable, Polyolefin, Dual-Wall, Outer Wall Cross-linked

SP-8063 Lubrication, Friction, and Wear, NASA Space Vehicle Design Criteria

TIA 568-B.3 Optical Fiber Cabling Components Standard

“Cause and Effects of Fluorocarbon Degradation In Electronics And Opto-Electronic Systems”; Roamer E. Predmore and John S. Canham, Ph.D.

“Corrosion of Silver-Plated Copper Conductors,” B.D. Dunn, A. de Rooij & D.S. Collins

Metallurgical Assessment of Spacecraft Parts, Material and Processes; “Red Plague Corrosion of Silver-Plated Copper”; Barrie D. Dunn; 6.8.3/pg. 446-447; Wiley-Praxis; 1997; ISBN 0-471-96428-X

2.8 Guidance on Use of “Inactive for New Design” Documents The term “Inactive for New Design” is used to identify an existing standardization document that is no longer approved for use in new designs because it is no longer maintained or updated by the document custodian. Inactive documents are often used for procurements and sustaining support of existing designs, equipment, or legacy programs. Use of “Inactive for New Design” documents for new design is not recommended, but may be allowed with prior User approval.

2.9 Documentation References Documentation references cited in this handbook are provided as additional sources of supporting information, guidance, and technical insight into the design and acceptance requirements for cable and wire harness assemblies. Documentation references are not requirements, and are not binding unless separately and specifically included by the applicable contract, approved drawing(s), or purchase order.

3 ENGINEERING DESIGN

3.1 General The engineering design process is the execution of a plan to enable engineering teams to create functional systems or products. Typically, this is accomplished by balancing cost - performance trade-offs, while also considering many elements such as design objectives and requirements, product function, synthesis, analysis, product performance, testing, and evaluation. In addition to functional requirements, cable and wiring harness design often necessitates the consideration of aesthetic, safety, economic, and environmental aspects of the product’s intended end use. Further, the design process **should** address reliability, heat dissipation, testability, the ease of manufacture, and the ability to service or repair the unit.

The output of the engineering design process is the definition or specification of an object satisfying a set of defined requirements. The design output is typically manifested as “engineering outputs documents” such as drawings, purchase specifications, or computer aided design (CAD) database models.

This section outlines the basis for considering different methods & materials which are used in the design, assembly, installation, testing, and repair of cable and wiring harness assemblies (including optical fiber, optical cable, and hybrids). The information herein provides guidance on why engineering design would choose specific materials and provides reasoning behind use of those materials. Advantages and disadvantages are outlined so consideration is provided for various aspects of the material.

3.2 Design Philosophy Before the product design effort can begin, the designer needs to know the customer’s expectations, as well as the performance and reliability requirements for the product (e.g., What does the customer want?). This information is then assessed against design capabilities (e.g., Can we design it using currently available technology?).

manufacturing capabilities (e.g., Can we build it using current processes and staff?), cost/schedule issues (e.g., How much will parts and tooling cost, When will production start and finish, Will we make a profit?), and possible alternatives (e.g., Can the customer's expectations be met using a different design solution?). These considerations and requirements **should** then be defined and ranked by a concurrent engineering or cross-functional team through a process such as Quality Function Deployment (QFD), and used to capture the voice of the customer.

3.3 Establishing the Design Team Creating an interdisciplinary team with the right mix of skills is vital to the smooth and successful execution of any project. The design team can include, but is not limited to, members who participate in the translation of the customer's request into baseline performance and reliability requirements, contracts, procurement, design, assembly, documentation, quality, and test.

The design team can consider the general design guidelines and issues presented in the body of this document as a methodology for achieving its reliability goals. Figure 3-1 illustrates the general design steps, process flow, and the interactive nature of the Design for Reliability (DfR) process using concurrent engineering.

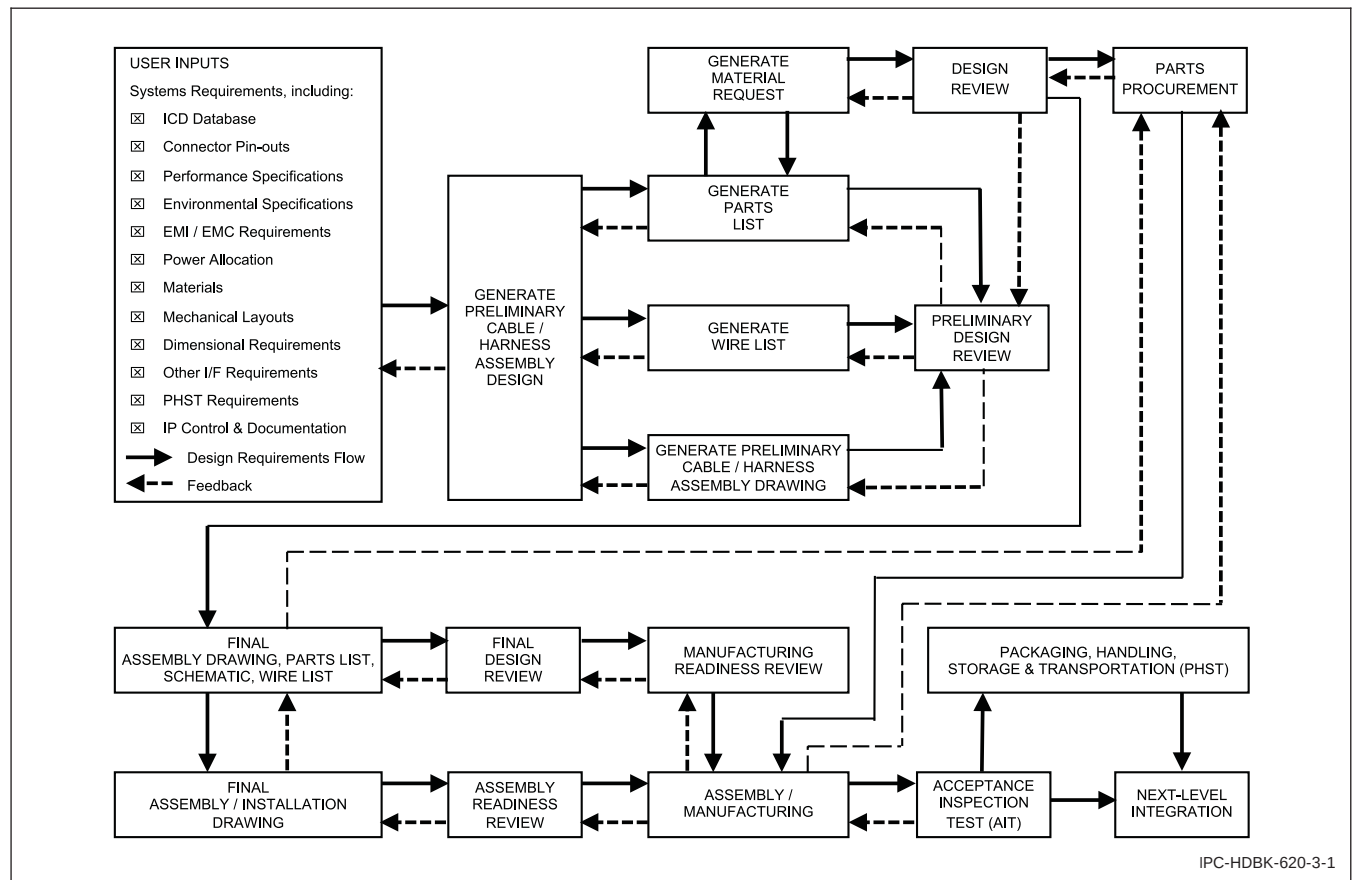


Figure 3-1 Cable and Harness Design Process

3.4 Defining Reliability Requirements

The basic reliability requirements to be defined include:

- Expected service life (e.g., single-use/disposable, days/months/years).
- Expected service environment (normal and worst case).
- Acceptable failure rate(s)/probability(ies) as a function of time.
- Acceptable failure rate(s)/probability(ies) as a function of criticality.
- Technical support and obsolescence strategies (repair, replacement, upgrade, service, maintenance, warranty).
- Life cycle environment(s).
- Definition of acceptable performance.
- Criticality of function(s).
- Available test equipment.

3.5 Understanding the Life Cycle The life cycle of any cable or wire harness assembly begins at the component level (including the wire) and continues through the assembly level; the life cycle includes exposure to the following environments:

- Assembly/Process
 - Test
 - Storage
 - Transportation
 - Installation
 - Operation
- a. Test, storage and transportation **should** be considered at both component and assembly levels as well as before, during, and after the assembly process.

3.5.1 Defining the Life Cycle Environment For each environment in the life cycle, it is critical to identify, characterize and quantify the parameters listed below:

- *Temperature Range*: Minimum/normal/maximum, cryogenic, high temperature, etc.
 - *Temperature Cycles*: Type, magnitude, duration, number, rate of change
 - *Duty Cycles and Duration*: (On/Off/Count)
 - *Humidity (RH)*: Minimum/normal/maximum, condensing, immersion, desiccated
 - *Pressure Conditions*: Vacuum, reduced, atmospheric, elevated, combination, etc.
 - *Vibration*: Type, magnitude, duration, etc.
 - *Shock*: Type, magnitude, duration, etc.
 - *Electrical/Electromagnetic*: ESD, EMC, EMI, EMP, high frequency, high voltage, surge, etc.
 - *Chemical Exposure*: Corrosives, oxidizers, solvents, etc.
 - *Radiation*: Ionizing/non-ionizing, visible light, thermal (convective/conductive), ultra-violet (UV), etc.
 - *Contamination*: Particulate/non-particulate, biologic, organic/inorganic, nuclear, etc.
- a. When the life environments have been identified and defined, the engineering team is prepared to develop the Systems Requirements Specification (SyRS).

3.6 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 **must** function together to produce the capabilities required to fulfill a mission need, including hardware, equipment, software, or any combination thereof.

- a. The SyRS contains the technical information needed by the Supplier to ensure the cable or wire harness design meets specification and delivers the required performance and reliability.
- b. Once the SyRS is placed on contract, the Supplier further develops the specification and develops their own, more detailed requirements document baselined against their internal processes.
- c. System Requirements Specifications (SyRS) typically contain the following information:
- (1) Interface Control Document (ICD)
 - (2) Performance and Reliability Specifications
 - (3) Environmental Specifications
 - (4) Material Specifications
 - (5) Packaging, Handling, Shipping, and Transportation (PHS&T) Requirements
 - (6) Intellectual Property (IP) Control & Documentation Requirements

3.6.1 Interface Control Document (ICD) The Interface Control Document (ICD) describes the interface or interfaces between sub-systems or to a system or sub-system, and contain the following information (as required) to ensure the cable or wire harness design meets specification and delivers the required performance and reliability:

- a. Circuit Types (e.g., power, signal, optical, etc.)
- b. Schematic Diagrams
- c. Mechanical Layouts and Dimensional Requirements
- d. Connectors (e.g., type, location, contact style, etc.)
- e. Connector Pin-Outs
- f. Power Allocation, Derating, Temperature Rating
- g. EMI/EMC Requirements
- h. Marking/Labeling Requirements
- i. Other Interface (I/F) Requirements

3.6.2 Engineering Drawings Unless otherwise specified by or approved by the user, engineering drawings **should** conform to ASME Y14.100, “Engineering Drawing Practices,” and the referenced documents cited therein. The types of drawings to be provided **should** be as agreed to between the User and the Supplier (AABUS). The User **should** specify if any of the drawings require specific User approval.

The type of engineering drawings may include some, but not necessarily all, of the drawing types described below:

- a. *Layout Drawing*. This type of drawing depicts design development requirements. It is similar to a detail, assembly, or installation drawing, except that it presents pictorial, notational, or dimensional data to the extent necessary to convey the design solution used in preparing other engineering drawings.
- b. *Detail Drawing*. A detail drawing provides the complete end-product definition of the part or parts depicted on the drawing. A detail drawing establishes item identification for each part described thereon.
- c. *Assembly Drawing*. An assembly drawing defines the configuration and contents of the assembly or assemblies depicted thereon. If the assembly drawing contains detailed requirements for one or more parts used in the assembly, it is a detail assembly drawing.
- d. *Installation Drawing*. An installation drawing provides information for properly positioning and installing items relative to their supporting structure and adjacent items, as applicable.
- e. *Altered Item Drawing*. An altered item drawing delineates the physical alteration of an existing item under the control of another design activity or defined by a nationally recognized standard.
- f. *Control Drawing*. A control drawing is a drawing disclosing engineering form, fit, function, and performance requirements for the acquisition of interchangeable purchased items of existing designs, or items specially developed by vendors to the control drawing requirements. This category of drawing can be further sub-divided into:
 - (1) Procurement control drawing
 - (2) Vendor item control drawing
 - (3) Source control drawing
 - (4) Envelope drawing
- g. *Interface Drawing*. An interface drawing depicts physical and functional interfaces of related or co-functioning items. It does not establish item identification.
- h. *Identification Cross Reference Drawing*. An identification cross reference drawing is an administrative type drawing which assigns unique identifiers to provide a cross reference to the original incompatible identifier. The drawing does not establish item identification.
- i. *Electrical/Electronic Diagrams*. An electrical/electronic diagram depicts the elements or functions of electrical or electronic items using standard symbols in accordance with ANSI/IEEE 91 and IEEE 315 and connecting lines or data in tabular form.
- j. *Schematic Diagram or Circuit Diagram*. This is one form of an electrical/electronic diagram. A schematic diagram depicts the electrical connections and functions of a specific circuit arrangement without regard to the physical shape, or location of the elements.
- k. *Connection Diagram or Wiring Diagram*. This is one form of an electrical/electronic diagram. A connection diagram or wiring diagram depicts the general physical arrangements of electrical connections and wires between circuit elements in an installation or assembly. It contains the details necessary to make or trace connections involved.

- l. *Wiring List*. A wiring list consists of tabular data and instructions necessary to establish wiring connections. Wiring lists serve the same basis purpose as a connection diagram or wiring diagram; their tabular format allows their use in manufacturing requirements planning (MRP) database driven software systems (e.g., SAP, etc.).
- m. *Special Application Drawings*. A special application drawing includes the following types of drawings used for the manufacture of cable and wire harness assemblies:
 - (1) *Wiring Harness Drawing* – A wiring harness drawing specifies the engineering requirements and establishes item identification for a wiring harness.
 - (2) *Cable Assembly Drawing* – A cable assembly drawing depicts an electrical cable assembly of defined length, specifies the engineering requirements, and establishes item identification for that assembly.

3.6.2.1 Content of Assembly Drawings Assembly drawings **should** include the following information, as a minimum, in addition to any information specified in ASME Y14.100 and the documents referenced therein. If the information is readily available from an industry-recognized current standard, or from a current military specification, it need not be duplicated on the engineering drawings. The exceptions would be where it is determined that placing the information directly into the drawing reduces assembly errors/omissions and/or rework, where contract cost savings can be realized by not requiring the purchase of a separate document, where requirements are document revision specific, or where otherwise specified by the User.

Additional detailed information may be required for the specific design application and this information **should** be provided on the engineering drawings:

- a. Marking information.
- b. Safety related items.
- c. Parts Lists (PLs) or Bill of Materials (BOMs).
- d. Hardware stack-up.
- e. Torque values for threaded items that require a torque.
- f. Isometric assembly views.
- g. Reference to the product design requirements that apply.
- h. Any governmental or security restrictions (e.g., International Traffic in Arms Regulations [ITAR], Intellectual Property, etc.) and/or classification markings.
- i. Interface dimensions (with tolerance) shown as INT in a rectangular box.
- j. Applicable environmental criteria (e.g., shock, vibration, temperature, etc.).
- k. Inspection and test criteria.
- l. Foreign Object Debris (FOD) controls.
- m. Application issues.
- n. Special handling, storage, and processing requirements.
- o. Manufacturing processes.
- p. Drawings **should** be formatted in a generic fashion such that the drawings can be used by any manufacturer who can manufacture the product. Drawings **should not** flow down supplier/manufacturer internal or proprietary procedures; drawings **should** flow down User requirements, using generally accepted industry standards whenever possible.

3.6.2.2 Parts Lists (PLs)/Bill of Materials (BOMs) A manufacturing release Parts List (PL) or Bill of Material (BOM) may consist of several sections, each containing information necessary for the implementation of required manufacturing action as authorized by a covering job order. The Designer **should** understand that Bill of Material requirements may change due to design and/or option changes requested by the User, or by changes to the Engineering Bill of Material caused by material shortages or substitutions.

- a. Bill of Materials (BOM)/Parts Lists (PL) typically include (but are not limited to) the following information:
 - (1) Job order.
 - (2) Numeric Parts List.
 - (3) Indented Parts List.
 - (4) Priority Make List.

- (5) Priority Buy List.
 - (6) Floor Stock Requirements.
 - (7) Inventory Requirement Cards.
 - (8) Production Purchase Requisition.
 - (9) Shop Order Control Cards.
 - (10) Automated Manufacturing Planning System Files.
 - (11) Part numbers.
 - (12) Part description.
 - (13) Reference designations (when applicable).
 - (14) Find/item number.
 - (15) Quantity (e.g., quantity, A/R-as required).
 - (16) Next higher assembly P/N.
 - (17) Reference Notes applicable to individual part numbers (e.g., “Torque per Note 1,” etc.).
 - (18) Applicable specification (e.g., MIL-PRF-38535/111).
 - (19) Identification of MSL for moisture sensitive parts.
 - (20) Identification of ESD sensitive parts.
 - (21) Parts requiring removal of gold plating.
 - (22) Identification if parts are customer furnished or Government furnished material.
 - (23) Special storage or kitting requirements.
 - (24) Special handling or processing requirements.
- b. The BOM/PL used by the supplier, in addition to containing the above information may also include the following information:
- (1) Job Order.
 - (2) Make or Buy decision.
 - (3) Inventory.

3.7 Performance and Reliability The final design **must** ensure that the overall performance and reliability requirements are met under the most severe extremes of acceptance testing, storage, transportation, and operational environments specified in the detail specification and/or contract.

3.8 Interchangeability Any two (2) or more wiring harnesses or cable assemblies bearing the same part number **should** possess such functional and physical characteristics as to be equivalent in performance, durability, and connectivity; and, **should** be capable of being changed, one for another, without alteration of the items themselves or of adjoining items.

3.9 Design for Maintainability (DFM) Cable and wiring harness assemblies **should** be designed with features that contribute to the ease and rapidity of maintenance without removal of other equipment, interconnections, wire bundles, and/or fluid lines.

- a. All wiring **should** be accessible, repairable, and replaceable at the maintenance level specified by the User.
- b. Cable and wiring harness length **should** provide enough additional wire length for reworking the entire connection at least one (1) time, at both ends of the wire.
- c. Conductors connecting contacts within the same connector (e.g., jumpers, confidence loops, etc.) **should** be captivated or restrained (e.g., cable clamp, wire tie, lacing, sealing gland, etc.).
- d. *Access.* When cable and wiring harness assemblies are required to be disconnected and/or reconnected, the design **should** incorporate sufficient flexibility, length, and protection to permit disconnection and reconnection without damage to wiring or connectors.
- e. *Ease of Connect/Disconnect.* Electrical connections **should** require no more than one (1) operation to disconnect and reconnect without damage to wiring or connectors.

3.10 Ergonomic Design Cables and wiring harnesses designed for use, or deployment, by humans **should** be designed to work with the human body (human-machine design) in the intended environment and application. A systems engineering process that adequately considers human performance variability and limitations is of critical importance to the health, safety, and performance of the User, as well as to the protection of hardware and systems.

As with any other system component, there are limits to human capabilities in any human-machine design. It is therefore important that the design of equipment accommodates the physical characteristics of the entire intended User population, and be based on the expected worst-case use environment. Ergonomic issues such as range of motion, repetitive motion injury issues, reduced access during mate/demate actions, and/or reduced operation/manipulation capabilities while wearing personal protective equipment such as gloves, **must** be taken into account.

Consult 7.9.1 “Circular Connector Installation” and MIL-STD-1472 for additional technical guidance. Additional guidance on incorporating ergonomic (human factors) considerations in cable and wiring harness designs can be found in 7.9.1 “Circular Connector Installation” and MIL-STD-1472.

Rationale: *The human is often the critical factor in the success of a human-machine design. A design that ignores the capabilities, characteristics, and limitations of all intended users could lead to performance or reliability issues, equipment damage, and/or safety/injury consequences to the users.*

3.11 Design Compliance Monitoring The design team **should** actively and continuously monitor the design for compliance with the design requirements during the design life cycle (including design, development, test, operations, and maintenance).

Rationale: *Successful design involves a series of tradeoffs. Ignoring or dismissing a seemingly innocuous shield grounding error in a wiring harness assembly due to use of an alternate part number connector could result in reduced performance or reliability once the wiring harness is integrated into the system and begins interacting with other components/sub-systems. As a design containing errors progresses, it becomes more difficult to isolate the fault and more costly to revise or correct. There is also a danger of problems going undetected before the hardware is delivered to the User. It is therefore essential that design requirements are continually monitored throughout the life cycle.*

3.12 Service Life Cables and wiring harnesses **should** meet the design service life requirements specified in the detail specification and/or contract.

3.13 Workmanship Workmanship processes or criteria not covered by IPC/WHMA-A-620 and/or IPC-A-640 (where applicable) **should** be documented in engineering documentation.

3.14 Environmental Requirements Cables and wiring harnesses **should** be capable of meeting the environmental design requirements specified in the detail specification and/or contract.

3.15 Packaging, Handling, Shipping, and Transportation (PHS&T) Cables and wiring harnesses **should** be packaged, handled, shipped, and transported in accordance with the PHS&T requirements specified in the detail specification and/or contract.

3.16 Documentation Requirements The documentation package **should** be in accordance with ASME Y14.100 (incl.: sub-set Y14.24, Y14.34, Y14.35, and Y14.44); the User-specified format; or, an equivalent format agreed upon by the Designer and User. See 17, “Content of Engineering Drawings For Cable and/or Wire Harnesses.”

3.17 Intellectual Property (IP) Control Requirements The use, control, and disposition of tangible and intangible information related to the design and manufacture of the product, including data, drawings, engineering documentation, trade secrets, etc., **should** be in accordance with IPC-1072; the User-specified control plan; or, an equivalent control plan agreed upon by the Designer and User.

3.18 Quality Management System (QMS) Requirements A quality management system (QMS) is a collection of integrated processes, procedures, and resources focused on producing and continually improving safe, reliable products that meet or exceed User and applicable governmental and regulatory requirements. The fundamental premise is that the proper implementation and maintenance of a QMS **should** result in improved product quality, schedule and cost performance while meeting/exceeding User requirements and enhancing User satisfaction.

When invoked by contract, the engineering documentation package **should** specify the quality system requirements identified in the paragraphs below (where applicable). Determination of applicability includes identification of the required quality system document and may include, where considered appropriate, tailoring of the quality system document requirements to identify the specific quality requirements within the document that apply to the solicitation, contract, or work tasking document. Where tailoring is chosen, the tailoring process **should** be documented, providing objective evidence of rationale for excluding specific requirements identified within the quality system documentation.

- a. *Critical and Complex.* Work that is both critical and complex **should** be performed in accordance with the quality system requirements of SAE AS9100. SAE AS9120 or ISO 9001 may be used when specified by User.
 - (1) Critical work is defined as any task that, if performed incorrectly or in violation of prescribed requirements, could result in loss of performance or reliability of the hardware that could result in serious injury to the User, damage to interconnected hardware/systems (including loss of data), or create an inability to detect a problem in the hardware/system. Examples of critical work includes, but is not limited to design and manufacture of Performance/Product Classification 3 or Space/Military hardware, safety-critical hardware and systems, fracture-critical components, mission critical hardware, etc.
 - (2) Complex work involves either:
 - (a) the design, manufacture, fabrication, assembly, testing, integration, maintenance, or repair of machinery, equipment, subsystems, systems, or platforms
 - (b) the manufacture/fabrication of parts or assemblies which have quality characteristics not wholly visible in the end item and for which conformance can only be established progressively through precise measurements, tests, and controls applied.
- b. *Critical.* Critical, but not complex, work (e.g., noncomplex work) **should** be performed in accordance with the quality system requirements of SAE AS9100, SAE AS9120, ISO 9001, or the inspection and test quality system requirements of SAE AS9003. Noncomplex work includes manufacture of “build to print” piece parts or performance of a discrete manufacturing/test operation such as non-destructive testing, or laboratory testing for chemical composition or mechanical properties.
- c. Complex, but not critical, work **should** be performed in accordance with the quality system requirements of SAE AS9100 or ISO 9001.
- d. Work that is neither critical nor complex **should** be performed in accordance with the quality system requirements of SAE AS9100, ISO 9001, or SAE AS9003, or in accordance with test and inspection requirements that are specified or approved by the User and that are supported by records evidencing their performance and outcome.

4 GENERAL DESIGN CONSIDERATIONS

The following section lists many of the elements that **must** be considered during the design of cable and wiring harness assemblies. These elements are for reference purposes only. Applicable governmental safety standards, environmental requirements, regulatory compliance requirements and industry standards **must** be identified and implemented within all systems and product designs.

4.1 General Manufacturing and Assembly All cable and wiring harness design **must** take into consideration the actual assembly operations required to consistently and efficiently manufacture the hardware. Ergonomic accessibility, tool clearances, visual clearances, **must** be addressed during all phases of the design process.

The design team **must** strive for optimal ease of assembly and repair. Design teams **should** employ manufacturing alignment guides and features, include keying features to prevent any component from being installed in the wrong location or orientation. In addition, ‘blind’ connector mating operations **should** be minimized.

When designing a cable and/or wiring harness assembly, the logical order of assembly, testing, installation, and post-installation testing (if required) **must** be taken into account. Assembly order consideration can reduce or eliminate difficult assembly operations, reduce installation damage and repair, and reduce unnecessary steps to correct in-process assembly defects.

4.2 Thermal Management The foremost recommendation for successful thermal design is to minimize the amount of heat that needs to be removed, based on the known worst-case operational requirements and expected use. This can be accomplished by conservative design practices, such as power derating of conductors and terminations to minimize voltage drop and power-induced thermal loading. Thermal consideration at all sub-system levels **should** be predicted with sufficient accuracy during the early design phase so that operating, reliability, and safety constraints will be met in the final design.

The design team **should** always develop a cable and/or wiring harness assembly with consideration of end use thermal performance and operational requirements, based on the intended end-use thermal environment. Cable and/or wiring harness assembly designs intended for use in an indoor, thermally controlled environment with good air flow (such as an office environment), can shed thermal loads more efficiently than a cable and/or wiring harness assembly installed in a sealed and an unventilated cabinet installed outside in direct sunlight. Prototype models **should** be developed to validate cooling approaches and determine design limitations. Numerical models can help establish the level of passive (conductive) and active (convective/fan assisted) cooling possible and help in identification of unrealistic goals before the design proceeds.

For example, given an enclosure volume of 6,554 cm³ [400 in³], and a maximum allowable internal temperature rise of +20 °C [+36 °F], it would be imprudent to assume that 50 W could be continuously dissipated by free convection methods alone, especially if the hardware is expected to be exposed to ambient temperatures of +52 °C [+125 °F].

Thermal considerations **should** include wires routed individually, wires routed within a bundle, and/or temperature rise due to the maximum current carried by the conductors.

4.2.1 Touch Temperature The design team **must** design wire harnesses, cable assemblies, and associated hardware to preclude incidental and/or continuous tactile (contact) exposure (referred to as “Touch Temperature”) to surface temperatures that can cause discomfort and/or injury. Touch temperature design limits **must** conform to all applicable local, state, and federal (national) safety regulations.

For Military/Space applications, the maximum temperature limits for normally exposed surfaces that would not cause injury for the stated condition are typically:

- (1) Maximum of 45 °C [113 °F] for continuous contact (more than 30 seconds)
- (2) Maximum of 49 °C [120 °F] for incidental contact (less than 30 seconds)

4.2.2 Conduction All cable and/or wiring harness assemblies, even if primarily convectively cooled, will experience some thermal conduction through the connectors (when mated) and at mechanical restraint points, such as cable clamps.

4.3 Design for Safety When designing cable or wiring harness assemblies, care **must** be given to ensure the assembly meets all regulatory statutes and industry standards. The following are just a few of the elements that **must** be considered:

- a. Mass
- b. Sharp edges
- c. High Voltage/Amperage protections
- d. Touch temperature
- e. Operator protections

4.4 Shipping and Physical Shock Early in the design phase, the physical robustness of the cable or wiring harness assembly **must** be considered. In addition to physical damage, the shipping package design teams **must** consider environmental concerns.

- a. Packaging requirements **should** be documented and validated to ensure the product is adequately protected.
- b. Packaging **should** be designed to prevent contamination and/or damage to the final product during shipment.
- c. Accommodation **must** be made to protect cable and/or wiring harness assemblies from moisture, corrosives, and other contaminants.
- d. Common practices used to validate packaging include, but are not limited to, drop, shock, and vibration testing.

4.5 Selection of Parts, Materials, and Tools Normally, the parts and materials needed to manufacture assemblies, or otherwise needed to install the assemblies into their ultimate next-higher level assembly, will have been specified by the user activity, or otherwise, will have been defined on the applicable documentation (e.g., assembly drawings, wire lists, parts lists, etc.), which may or may not require User approval.

- a. This handbook will provide some general guidance that may be useful when parts and materials have otherwise not been previously selected or otherwise mandated.
- b. Tools needed are normally selected by the manufacturer. However, some tooling may have been selected or otherwise mandated by the user.

- c. In some cases, the tool requirement may be specified in the specification for the part; example, a specific MS crimp tool for an SAE AS7928 style terminal lug.

4.5.1 Standard Parts and Materials Whenever possible, standard parts and materials (e.g., items purchased to recognized commercial, industrial or military/NASA specifications) **should** be purchased directly from the Original Component Manufacturer (OCM), their authorized distributors, or trusted/qualified sources to reduce the risk of the parts and materials being counterfeit or below performance specification. Such items **should** be suitable for their intended end-use/purpose.

4.5.2 Counterfeit EEE Parts Avoidance The design team **should** take appropriate steps to mitigate entry of suspect counterfeit EEE parts into the supply chain while maximizing the availability of authentic, originally designed and qualified parts throughout the product's life cycle.

- a. The design team **should** document the required actions to mitigate and control the introduction and /or use of suspect counterfeit EEE parts through a Counterfeit Control Plan (CCP).
- b. The CCP **should** specify controls in the selection, procurement, acquisition, and inspection of EEE parts.
- c. The controls **should** cover all reliability grades of parts, including commercial grade, to prevent entry of suspect counterfeit parts.
- d. See SAE AS5553 for additional technical guidance.

4.5.3 Non-Standard Parts and Materials Any parts and materials not selected in accordance with paragraph 4.5.1 are considered non-standard and as such User approval may be required for their use.

5 MATERIALS AND PROCESSES

5.1 Materials and Processes – Non-Metals Nonmetallic materials **should** be selected and qualified with each application by consideration of the following, as a minimum:

- a. Design engineering properties.
- b. Application operational requirements.
- c. Compatibility with other materials used.
- d. Material hazards and restrictions specified in Section 4.
- e. Environmental and health restrictions mandated by applicable local, state, and federal (national) safety and environmental regulations.

5.1.1 Composition and Processing Specifications for composition and processing **should** be used to ensure a product that is reproducible and meets all physical, chemical, and mechanical requirements.

5.1.2 Compatibility Nonmetallic materials **should** be evaluated and tested, or documented on the basis of detailed history for compatibility with temperature, pressure, radiation, and fluid or gas environments. Tests for compatibility with hazardous fluids and gases such as oxygen or hydrogen **should** consider energy sources available in the proposed application that could initiate adverse reactions.

5.1.3 Special Considerations

5.1.3.1 Chlorinated Fluorocarbons (CFCs) All materials **should** be free of CFCs as mandated by federal or state regulations.

5.1.3.2 Shelf-Life Limitations Many nonmetallic materials **should** have a shelf life specified by the manufacturer. All materials so specified may be controlled by a shelf life control program and **should not** be used beyond expiration dates unless based on test information supplied by the manufacturer (or test information obtained by the user for the production lot(s) of concern).

5.1.4 Polymer Materials The selection of polymers **should** be made such that the system can operate in the specified environments with limited or no maintenance over the specified lifetime with an acceptable level of deterioration and degradation. Therefore, the selection of suitable materials, appropriate processing methods, and appropriate protective treatments **should** be made such that design margins are adequate for the system's anticipated worst case environment.

5.1.4.1 Elastomers Elastomeric components **should** be hydrolytically stable, **should not** subject to reversion, and possess adequate resistance to aging, low temperature, ozone, heat aging, working fluids, lubricants, and propellants for the intended application and environment. Elastomeric materials in contact with hydrazine **should** be limited.

5.1.4.1.1 Cured Elastomers Cured elastomers that are age sensitive **should** be controlled by SAE ARP5316, or other approved document.

- All cured elastomeric materials **should** be marked with a cure date, either on the item itself or on the packaging.
- A first in/first out (FIFO) system **should** be implemented to control inventory.
- Cured elastomeric materials **should** be protected from sunlight, fuel, oil, water, dust, and ozone.
- A maximum storage temperature of 37.8 °C [100 °F] is recommended.
- The maximum storage temperature **should not** exceed 51.7 °C [125 °F].

5.1.4.1.2 Non-Cured Elastomers Materials that are procured in a non-cured state such as sealants and potting compounds **should** be held in controlled temperature storage not to exceed 26.7 °C [80 °F].

- Some specific materials require storage at reduced temperatures and **should** be stored as recommended by the manufacturer.
- A first in/first out (FIFO), system is recommended as the most effective method for tracking and maintaining adequate storage times.
- Overage materials may be used if testing can insure that the material is adequate for the intended uses.

5.1.4.1.3 Silicone Elastomers Some one-part silicone products, including commercial adhesives/sealants, as well as those meeting the requirements of MIL-A-46106, give off acetic acid during cure. These materials can cause corrosion to copper, aluminum, and steel.

Alcohol liberating sealants **should** be used instead of acetic acid liberating sealants.

5.1.4.1.4 Foamed Plastics Foamed plastics **should** be applied in a manner as to preclude damaging fragile components or exerting undue stress on adjacent surfaces. They **should** be hydrolytically stable and **should not** be subject to reversion.

5.1.4.1.5 Outgassing and Flammability Only a few foamed plastics meet outgassing and flammability requirements. Often such materials require baking at elevated temperatures to reduce outgassing to acceptable levels.

5.1.4.1.6 Special Considerations Foamed plastics **should not** be used for metal skin reinforcement in structural components, nor as a core material in sandwich structural components other than all plastic sandwich parts, low density filler putties, or syntactic foam.

5.1.4.2 Plastics Plastics which serve as electrical insulation **should** be selected in accordance with 5.1.4.2.1. Plastics which do not serve as electrical insulation (structural parts, and so forth) **should** meet all physical and mechanical properties required for plastic insulating materials, including non-flammability and non-toxicity; outgassing/offgassing; mold/fungus resistance; UV stability; however, these plastics may not need to meet the arcing and tracking resistance requirements.

5.1.4.2.1 Electrical Insulation Materials Various types of materials are suitable for use in the manufacture of assemblies, and when installing these assemblies into their next-higher assembly. The following guidance is recommended regarding insulation materials:

5.1.4.2.2 Arc and Tracking Resistance Structural insulators, such as laminates, molding compounds, encapsulating materials, bus bar coverings, and similar materials subject to arcing conditions **should** have an arc resistance of not less than 130 seconds and a track resistance of not less than 70 minutes for low voltage (< 2,000 V) equipment. For equipment rated at 2000 V and higher, a minimum track resistance of 300 minutes is recommended. Arc resistance may be determined via ASTM D495, and tracking resistance may be determined by ASTM D638.

5.1.4.2.3 Offgassing/Outgassing Collected Volatile Condensable Material (CVCM) offgassing/outgassing of nonmetallic materials **should not** exceed the Total Mass Loss (TML) as specified by contract.

5.1.4.2.4 Classes and Definitions of Insulating Materials Temperature classes of insulating materials have traditionally been established by definition based on a chemical composition of the materials. Methods of temperature classification are

on the results of thermal evaluation tests are coming into use. Since the temperature classification of a material that has been accepted for a long time will have been established by field experience, its life temperature characteristics determined by test provides a basis for comparison with the thermal life of a new material.

The purpose of assigning each material to a definite temperature class, therefore, is to facilitate comparisons between materials and to provide a single number to designate each class for purposes of standardization. The life expectancy under the test conditions may be shorter than, and has no direct relation to, the life expectancy of the material in actual service.

The classes and definitions of insulating materials are grouped according to the classifications noted below. New classifications may be created, and new materials may be developed for existing classifications. Therefore, the listing in the subsequent paragraphs may not be all inclusive.

- a. Class 90 – Materials or combinations of materials such as cotton, silk, and paper without impregnation. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 90 °C [194 °F].
- b. Class 105 – Materials or combinations of materials such as cotton, silk, and paper when suitably impregnated or coated or when immersed in a dielectric liquid such as oil. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 105 °C [221 °F].
- c. Class 130 – Materials or combinations of materials such as mica, glass fiber, and so forth, with suitable bonding substances. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 130 °C [266 °F].
- d. Class 155 – Materials or combinations of materials such as mica, glass fiber, and so forth, with suitable bonding substances. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 155 °C [311 °F].
- e. Class 180 – Materials or combinations of materials such as silicone elastomer, mica, glass fiber, and so forth, with suitable bonding substances such as appropriate silicone resins. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 180 °C [356 °F].
- f. Class 200 – Materials or combinations of materials such as mica, glass fiber, asbestos, and so forth, with suitable bonding substances. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to have comparable thermal life at 200 °C [392 °F].
- g. Class 220 – Materials or combinations of materials which by experience or accepted tests can be shown to have the required thermal life at 220 °C [428 °F].
- h. Class 240 – Materials or combinations of materials which by experience or accepted tests can be shown to have the required thermal life at 240 °C [464 °F].
- i. Class over 240 – Materials consisting entirely of mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations, of materials may be included in this class if by experience, or accepted tests they can be shown to have the required thermal life at temperatures over 240 °C [464 °F].

5.1.4.3 Lubricants Selection of a lubricant **should** consider life cycles (including installation, test, and utilization), design margins, material compatibility, stability in the expected operational environmental, potential for contamination of adjacent/sensitive hardware, and User safety.

Designs **should** avoid the use of lubricants that **must** be periodically re-applied or replaced by the User during normal operation.

5.1.4.3.1 Application NASA SP-8063 can be used as a guide in the design and application of lubricants.

5.1.4.3.2 Application Documents Application documents for dry film lubricants **should** define surface finish requirements for surfaces to be coated. The use of film lubricants are recommended for applications requiring minimum levels of friction, maximum life, and maximum load-bearing capability.

5.1.4.3.3 Silicone Grease Silicone greases are not recommended as a thermal couplant, except in hermetically-sealed assemblies. Silicone contamination of surfaces can result in the loss of adhesion and/or surface solderability. Caution **should** be exercised to minimize or eliminate any potential for silicone contamination. If concerns exist, select non-silicone based materials, if possible.

5.1.4.4 Other Materials

5.1.4.4.1 Adhesives Adhesives for general use **should** be qualified to MIL-A-46146. Adhesives for structural applications **should** be qualified for the specific materials to be bonded.

5.1.4.4.2 Structural Bonding Structural bonding **should** meet the requirements of MIL-S-83377. All bonding processes and materials selected for structural components **should** be validated and verified to meet the desired properties for the entire life of the component. This is accomplished through the test of tag-end test specimens under the simulated service conditions, except for high temperature nozzle bonds, or through hardware qualifications and acceptance tests plus lap shear witness coupons processed concurrently using the same material cleaning method and cure cycles.

5.1.4.4.3 Electrical/Electronic Component Bonding, Coating, and Encapsulation The selection and application of polymeric adhesive materials for the bonding, conformal coating, and/or encapsulation/potting of electrical/electronic components and modules in cable and wire harness assemblies **should** meet the applicable requirements of IPC-D-620, IPC/WHMA-A-620, and J-STD-001. Several types of polymers are used in the fabrication of electronic products and provide a singular or combination of electrical, environmental protection, mechanical, or thermal characteristics depending on the formulation, application, and cure. Formulations are available with specific curing methods including thermally-activated, ultraviolet (UV) light, two-component (resin and activator), and ambient moisture (RH) cure.

Selection of an appropriate polymer **should** enable the finished assembly to meet all mechanical, thermal, electrical, and/or optical requirements associated with test and intended use, with consideration given to the following characteristics: dielectric constant, permittivity, dielectric withstanding voltage, tensile modulus over temperature range, coefficient of thermal expansion (CTE), glass transition temperature (T_g), viscosity and transmissivity, and User-specific requirements.

Specific requirements **should** be identified on the approved engineering drawing.

- a. *Conformal Coating.* Though normally associated with printed wiring assembly, the selective use of conformal coatings in cable and harness assemblies to provide additional environmental protection is increasing as the complexity and functionality of wiring technology increases.

It **should** be emphasized that conformal coating is specifically used to protect the EEE assembly from potential degradation of circuit performance and reliability due to incidental contact with conductive FOD, liquid splash, and/or condensing moisture. With the exception of epoxy resin (ER) and poly-paraxylylene (XY) coating chemistries, conformal coatings are not hermetic.

Additionally, conformal coating materials are not to be used for encapsulation or potting, even though the process of conformally coating a component results in encapsulating the component within a uniform thickness coating.

- b. *Encapsulation.* Encapsulation, or potting compound, is a thick material that is used to completely fill small sub-assemblies (e.g., connector backshells, in-line amplifier modules, power supplies, etc.). Popular encapsulating materials include foam, rubber, and similar materials, most of which are doped with dye or naturally opaque to provide a solid color through which the encapsulated assembly/components cannot be seen. Since the interior of the encapsulated assembly is usually not visible, it is essential that the encapsulation process (e.g., measuring, mixing, filling, and curing) be closely controlled to ensure that the finished product meets the customer's needs. For instance, the presence of bubbles in the encapsulation/potting material in the connector backshell that bridge high voltage/high current contacts may result in reduced electrical isolation, arcing or failure.

- (1) *Contact Float.* Additional process steps may be required to ensure that the potting/encapsulation of the connector backshell does not negate the "contact float" feature or flow through the contact insert body and contaminate the interconnect surfaces. This may require the detailed application of a resilient polymer staking material (e.g., RTV) around each wire at the point where the wire enters the contact insert body, followed by the application of a thin layer (approximately 10 - 20 % of the backshell length) of resilient material to allow the wires to flex slightly in response to the movement of the contact(s) (float) during mating/demating operations. Once these materials have achieved full section cure, the backshell can be filled with encapsulant/potting material as specified on the engineering drawing.

- (2) *Stress Relief.* If the addition of stress relief is desired, the designer may wish to consider using a rigid polymer such as epoxy resin (ER) to encapsulate the final 20-25% of the backshell height to create a "cap" that bonds the cable jacket to the backshell structure. The addition of an epoxy cap also tends to improve environmental resistance.

- (3) *Electrical Testing.* The encapsulated/potted assembly is often considered "non-repairable." All specified electrical tests **should** be performed prior to encapsulation to validate correct assembly. This provides an opportunity for corrective rework/repair. The specified electrical testing **should** also be performed following full section cure.

encapsulation to verify that the finished assembly meets all specified mechanical, thermal, electrical, and/or optical requirements.

5.1.4.4.4 Torque Striping Torque stripping is one of the methods used to provide visual verification that a fastener has been properly tightened and torqued. Once mating threaded fasteners (e.g., nuts, bolts/screws) have been tightened to the specified tightness requirement (including a torque range if applicable), a stripe is added to both mating fasteners to provide a visual indication that the fasteners are tight. If subsequent inspection notes that the mating stripes no longer align, this is an indication that the fasteners have loosened.

Other methods are available to assure the tightness of fasteners. These methods can include independent witnessing of the tightening operation or by including verification of tightness of fasteners as a periodic audit function.

5.1.4.4.5 Conformal Coatings Conformal coating is typically used as an environmental barrier against condensing moisture and incidental splash contact, a dielectric barrier against contact with electrically conductive foreign object debris (FOD), and as a mitigation against metallic whisker development.

- Conformal coatings **should** be qualified to conform to MIL-I-46058 or IPC-CC-830.
- Conformal coatings **should not** be considered as an absolute environmental barrier, used for adhesive bonding (e.g., staking) of electrical/electronic components, or used as encapsulation.

5.1.4.4.6 Encapsulants Materials and processes used to encase components and assemblies in plastic or elastomeric resins for electrical insulation, protection from environmental conditions, and protection from mechanical damage **should** be qualified by component or assembly-level testing or past experience under equivalent or more limited thermo-mechanical and radiation stresses.

5.1.4.4.7 Sealing Materials Some assemblies may need to function in a humid environment or otherwise in applications where water or other liquid can exist. In such cases, it may be necessary to provide a means of sealing off components such as connectors, etc.

- Materials used for sealing **should** be elastomeric and reversion resistant.
- Materials **should** be of a non-corrosive cure formulation and chemically compatible.
- Materials **should** also be fully cured at the time of delivery of the assembly. If not fully cured, the material may out-gas unacceptable chemicals, or otherwise may not have developed the necessary mechanical and sealing properties needed for the application.

Various sealing materials are available. Examples include cured synthetic rubber, with an operating range of -51 °C to 93 °C [-60 °F to + 200 °F] which acts as a deterrent to fatigue, corrosion, and contamination, as well as an aid in reducing arc-over between electrical connector pins (see MIL-STD-8516).

Another example is a silicone rubber sealing compound with accelerator, with an operating range of -6 °C to 204 °C [-80 °F to +400 °F], for use in applications where tear resistance is not critical.

5.1.4.4.8 Special Considerations Proper curing is essential and in some cases, vacuum de-airing may be needed to eliminate air bubbles. Volatile by-products formed during cure **should** be removed. Factors affecting the rate and degree of cure are numerous, such as; catalyst concentration, humidity, diluents (if used to lower the viscosity), thickness of section area exposed for the release of volatiles and post-cure employed.

Because of the high volume expansion of RTV silicones they are not recommended for use for the total filling of confined items. Pressures developed during heating are of a high order. Literature pertaining to the manufacturer's product **should** be thoroughly understood prior to consideration of RTV silicones, and all applications for use of this material **should** be thoroughly evaluated prior to use (see MIL-PRF-23586).

5.1.4.4.9 Cleaning Prior to Application All processes involving polymers require careful surface preparation to ensure adequate adhesion. Each qualified material **should** be associated with one or more documents describing its application and usage. Each application document **should** detail the specific cleaning procedure for all surfaces to be coated (or bonded) and a maximum time period between surface preparation and coating (or bonding), after which, surfaces **should** be reprocessed. Materials covered by this section **should** be qualified with the specific surface preparation procedure described.

5.1.4.4.10 Creep/Shrinkage Material expansion/contraction in response to temperature **must** be assessed.

- a. Polymer systems such as epoxies (ER), are widely known to expand and contract in response to temperature changes, and this movement can exert destructive force on fragile components such as glass-bodied components and even glass seals in connectors. This movement is the basis for the restriction on its use for the adhesive bonding (staking) of glass-bodied components such as diodes in IPC J-STD-001.
- b. At elevated temperatures, polymers may soften and lose their mechanical strength.
- c. At cryogenic temperatures, polymers may become brittle and susceptible to fracture. Materials such as silicone (SR) and polyurethane (UR) may become non-resilient (rigid) and exhibit creep and shrinkage behavior similar to epoxies (ER).

5.1.4.4.11 Processing Requirements – Embedment/Encapsulant Materials Processing requirements for encapsulation **should** consider as a minimum the following: surface preparation or cleaning, resin or elastomers preparation, processing temperatures (including exothermic heat of reaction), shrinkage during cure, and rework or repair requirements.

Processing requirements for encapsulation **should** consider as a minimum the following: surface preparation (including but not limited to surface abrading, etching and priming) or cleaning, resin or elastomers preparation, processing temperatures (including exothermic heat of reaction), shrinkage during cure, and rework or repair requirements.

Note(s): For additional information, consult the following references:

- Marchesi et al, 1991. Adhesion to Sodium Naphthalenide Treated Fluoropolymers. Part II. Effects of Treatment Conditions and Fluoropolymer Structure, *The Journal of Adhesion*, 36:1, 55-69, DOI: 10.1080/00218469108026523
- CHENG et al, 2009. Hydrophilic treatment poly(tetrafluoroethylene) reinforced sulfonated poly(ether ether ketone) composite membrane for proton exchange membrane fuel cell application. *Journal of Power Sources* 194 (2009) 838-842 <4C-Add-on>

5.1.5 Prohibited/Restricted Usage Parts, Materials, Processes (PMP) Various materials and processes exist that are not recommended for use because of potential personnel hazards, restrictions by Government regulations, or for other reasons. Some of these materials may have been specifically prohibited from use by the User. The following are examples of prohibited/restricted-use materials and processes:

5.1.5.1 Acetic Acid Cure RTV Silicone Sealants, Adhesives, and Coatings Acetic acid cure RTV silicone sealants, adhesives, and coatings **shall not** be used in the assembly or manufacture of electrical wiring harnesses and cable assemblies or as environmental sealants for electrical enclosures (e.g., conduit, fittings, and boxes).

Rationale: Release of acetic acid during cure of Room Temperature Vulcanizing (RTV) silicones creates potential corrosion and contamination issues.

5.1.5.2 Asbestos Materials containing asbestos **should not** be used since asbestos is a known human health hazard.

5.1.5.3 Beeswax/Wax Lacing Tape (ALL TYPES) Beeswax impregnated lacing tape **shall not** be used in critical application, Class 3, and/or Space products, without prior User approval.

- a. Wax impregnated lacing tape **shall not** be exposed to cleaning solvents.

Rationale:

- (1) Organic materials, such as beeswax, may provide a nutrient source for fungal growth that may adversely affect unit performance or service life or constitute a health hazard to higher order life; or, serve as a fuel source (in the event of a fire).
- (2) No cleaning solvent/process may be used that can damage or degrade materials or reduce the performance or reliability of the hardware.

5.1.5.4 Beryllium (Be) Unalloyed beryllium (Be), and beryllium alloys containing greater than 4% (percent) beryllium by weight as an alloying constituent, **shall not** be used in critical application, Class 3, and/or Space products, unless suitably protected to prevent erosion, or formation of salts or oxides.



Figure 5-1 Waxed Lacing Tape
Photo Courtesy of NASA

Alloys containing 4% (percent) or less of beryllium by weight are specifically exempted from this requirement.

- a. Environmental tests, under expected conditions, **shall** be conducted to verify that the coating used provides satisfactory protection for the beryllium surface.
- b. Beryllium and alloys or oxides of beryllium **shall not** be ground, filed, drilled, sawed, or in any other way machined at any stage of manufacturing, assembly, testing, modification, or operation, without approved environmental compliance and Foreign Object Debris (FOD) programs and personal protective equipment (PPE) specifically designed for control of beryllium contamination/exposure.

Rationale: *Beryllium is an extremely toxic material whose threshold limit is 0.002 mg/m³. Mists, dusts, or fumes containing beryllium or its compounds can cause a delayed type of pneumonitis that may manifest itself after an extended period of time.*

5.1.5.5 Cadmium (Cd) Cadmium and its compounds are extremely toxic even in low concentrations, and will bioaccumulate in organisms and ecosystems. When working with cadmium, it is important to do so under a fume hood to protect against dangerous fumes. For example, silver solder used for brazing, which contains cadmium, **should** be handled with care. Serious toxicity problems have resulted from long-term exposure to cadmium plating baths.

- a. Manufacturers **should** evaluate the components, fasteners, and other items they intend on using to verify that they do not contain cadmium.
- b. Cadmium and cadmium plating on electrical connectors, cables, wiring harness assemblies, and mechanical hardware **shall not** be used where exposure to temperatures in excess of 75 °C [167 °F] and reduced atmospheric pressures could cause sublimation (vaporization) and deposition of cadmium on optical or electrically energized surfaces; in applications where the transfer migration of cadmium contamination is prohibited; or, in applications sensitive to the adverse effects of metallic whisker growth and contamination.

Rationale:

- (1) *Cadmium has the ability to sublime (vaporize), if exposed to temperatures in excess of 75 °C [167 °F], and reduced atmospheric pressure or vacuum. The resulting toxic, heavy-metal vapor can be inhaled by the User, or condense onto surfaces as a thin, electrically conductive layer, impacting the performance of electrical circuits and optical systems.*
- (2) *Cadmium plating on the surfaces of hardware and fasteners can be transferred to tool surfaces (screwdrivers, wrenches, etc.) and then transferred to the surfaces of other hardware and fasteners.*
- (3) *Cadmium is subject to the spontaneous growth of Cadmium whiskers. The propensity of Cadmium to grow whiskers appears to be lower than that of zinc (Zn) but higher than tin (Sn). Cadmium whiskers (like tin whiskers) grow spontaneously and are capable of causing electrical failures ranging from parametric deviations to sustained plasma arcing that can result in catastrophic short circuits.*
- (4) *One common source of cadmium is commercially available fasteners (nuts/bolts) that have been cadmium plated.*

5.1.5.6 Crimping of Solder-Tinned and Solid Conductors Designs requiring any of the following **shall** detail the process and acceptance criteria on the engineering documentation and have prior approval from the User:

- a. Crimping of solder-tinned stranded wire.
- b. Crimping of solid wire
- c. Soldering of completed crimp terminations.

See Appendix A for Military/Space requirement.

Rationale:

- (1) *Solder (a malleable alloy) acts as a variable thickness lubricant. The mechanical integrity of the crimp termination degrades as the solder coating deforms and flows under mechanical pressure and recrystallizes under temperature cycling.*
- (2) *Crimping of solid conductors is not allowed because the compression set process requires that the conductor have some “compressibility.” A solid wire is not compressible. Unless the crimp contact is perfectly sized for the conductor, the conductor cross-section is significantly reduced during compression set and micro-fractures develop, resulting in loss of current carrying capacity and reduced life.*
- (3) *Though often proposed as a means to ensure that a crimped termination is “bullet proof,” soldering a crimped termination produces a termination that is in violation of requirements for both a soldered termination and a crimped termination.*

termination. Application of soldering temperatures to a completed crimp termination anneals the crimp, relaxing the compression set developed to produce the gas-tight cold-weld during the crimping process. Additionally, a crimp termination that has been soldered also violates the requirements for complete wetting, because the solder cannot flow into the compression zone and wet all the surfaces of the contact-conductor interface.

5.1.5.7 Cuprous Oxide Corrosion (Red Plague) When the use of silver-coated copper conductors (e.g., wiring, shielding, terminations, etc.) is determined to be a performance and reliability concern, a Red Plague Control Plan (RPCP)” **shall** be invoked by contract.

See IPC-WP-113, “Guidance for the Development and Implementation of a Red Plague Control Plan (RPCP)” for technical guidance and requirements.

Rationale: Red Plague (cuprous oxide corrosion) can develop in silver-coated soft or annealed copper conductors (component leads, single and multi-stranded wires and PCB conductors) when a galvanic cell forms between the copper base metal and the silver coating in the presence of moisture (H_2O) and oxygen (O_2) at an exposed copper-silver interface (i.e., conductor end, pin-hole, scratch, nick, etc.).

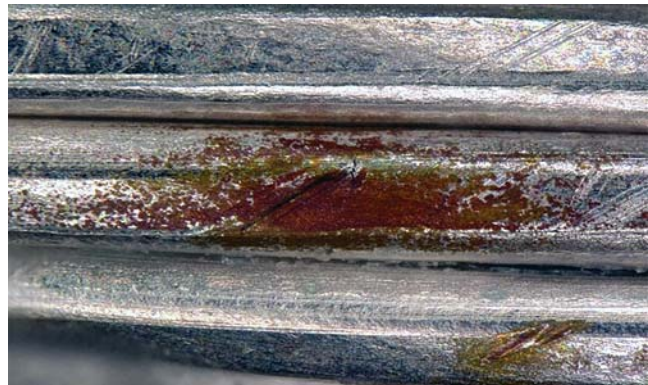


Figure 5-2 Red Plague (Cuprous Oxide Corrosion on Wire Strands)

Photo Courtesy of NASA

5.1.5.8 Flammable Materials Flammable materials include any material in a form which will ignite or explode from an electric spark, flame, or from heating, and which, if so ignited, will independently support combustion in the presence of air. Material flammability can be determined by various test methods. Some example test methods include; DTIC AD 297457, ASTM D5948, Standard Specification for Molding Compounds – Thermosetting, and ASTM D635, Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position.

5.1.5.9 Fluorine Attack (White Plague) To reduce the risk of Fluorine Attack (White Plague), when fluoropolymer-insulated, silver-coated copper wiring is either stored in sealed packaging (e.g., vapor-proof bagging, moisture barrier bag – MBB) or used in enclosed environments/compartments is determined to be a performance and reliability concern, a “White Plague Control Plan (WPCP)” **shall** be invoked.

See IPC-WP-114, “Guidance for the Development and Implementation of a White Plague Control Plan (WPCP)” for technical guidance and requirements.

Rationale:

- (1) During the manufacturing of fluoropolymer-insulated electrical wires and cables made with tin-coated, silver-coated, or nickel-coated conductors of copper or copper alloy, the extrusion of fluorocarbon resin occurs at a temperature high enough that oxidative degradation of the polymer may occur, resulting in the evolution or outgassing of a number of materials, including carbonyl-difluoride (COF_2), an extremely reactive compound. This outgassing from the insulation jacket is both internal (to the wire strand/cable bundle), and external (to the surrounding environment).
- (2) In the presence of trace atmospheric moisture (e.g., humidity), the carbonyl-difluoride hydrolyzes to generate carbon dioxide (CO_2) and hydrogen fluoride (HF). The hydrogen fluoride (HF) will then hydrate to form concentrated hydrofluoric acid ($2HF$), which is a corrosive agent that reacts with metal and metal oxides.
- (3) While fluorine outgassing is a concern for all fluoropolymer insulations, ethylene tetrafluoroethylene (ETFE) and cross-linked ethylene tetrafluoroethylene (XL-ETFE) have been reported to have a higher evolution rate, possibly due to the blending and extrusion processes typically used for this polymer.

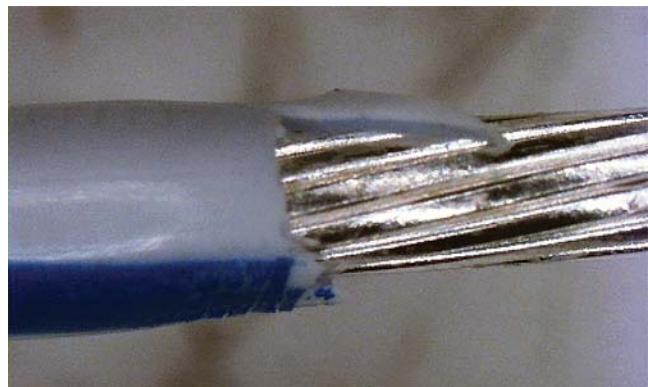


Figure 5-3 White Plague (Fluorine Attack)

Note frosted texture on silver coating

Photo Courtesy of NASA

5.1.5.10 FN/HN Grade Polyimide (Kapton®) Insulated Wiring FN/HN grade polyimide-insulated wire (MIL-W-81381/07-/22) **shall not** be used in critical, Class 3, and/or Space applications or products, without prior User approval.

Rationale:

- (1) This insulation material is susceptible to degradation of mechanical and electrical integrity due to lack of abrasion and cut-through resistance, and exhibits increased susceptibility to wet-arc and dry-arc tracking.
- (2) Insulation failures that result in a hard short to ground, or between conductors, at potentials of +28 V dc or higher, can result in an explosive burning and carbonization of the insulation materials that sustains the arc event until power is removed, and allows the arc event to resume once the circuit is re-energized (i.e., carbonization is not self-quenching like it is with fluoropolymer-insulated electrical wires and cables).

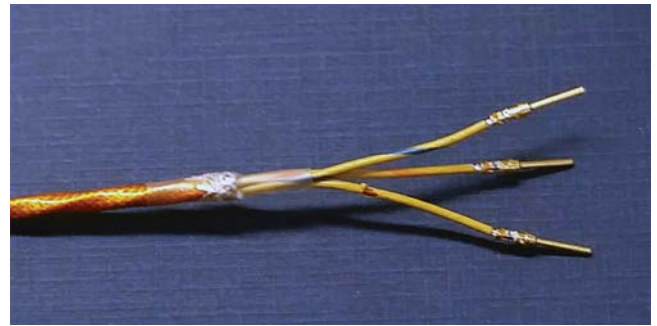


Figure 5-4 FN/HN Grade Polyimide (Kapton®) Insulated Wiring

Photo Courtesy of NASA

5.1.5.11 Fragile or Brittle Materials Fragile materials include any material which is easily broken, damaged, or destroyed as a result of a lack of material strength or sturdy construction. In general, brittle materials fall within the category of fragile materials because the material's inelasticity increases the likelihood of fracture or structural failure when the material is subjected to the application of pressure or force beyond the material's strength. However, certain brittle materials may be used in small quantities, within a part, when the materials is so mounted, constrained or otherwise disposed within the part that it will not be strained under any processing, environmental, and handling conditions to which the part reasonably may be subjected. (For example, glass and ceramic terminal seals and bushings have been employed successfully in packaging certain semiconductor devices and as dielectric seals in hermetic connectors).

- a. Any material in a frail form which is not positively protected against mechanical damage as used in a part or subassembly **should** be considered fragile.
- b. Cast iron, semi-steel, porcelain, and similar brittle materials **should not** be used as structural frames, brackets, mounting panels, spacers, or enclosures.

5.1.5.12 Glass/Glass-Like Materials Windows and other glass structures (e.g., optics, instrument covers, etc.) that include any piece of glass and other glass-like materials (e.g., germanium, sapphire, etc.) **shall not** be used in critical application, Class 3, and/or Space products unless it is suitably contained or protected.

Exception: EEE components (e.g., connectors, RF feed-through, diodes, components with glass-body seals, optical fiber) that use glass as the component body, dielectric, wave guide, or hermetic seal are specifically exempted from this requirement.

Rationale: The breakage/shattering of glass represent an acute eye injury and laceration risk and Foreign Object Debris (FOD) hazard.

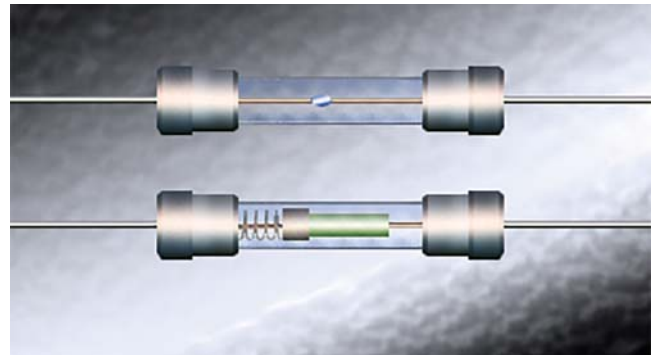


Figure 5-5 Glass/Glass-Like Materials (e.g., Fuses)

Photo Courtesy of NASA

5.1.5.13 Use of Lead-Free Tin (Sn) Materials and/or Processes When the use of lead-free Tin (Sn) materials and/or processes is determined to be a performance and reliability concern, a Lead-Free Control Plan (LFCP) in conformance with the requirements of SAE GEIA-STD-0005-1 and SAE GEIA-STD-0005-2 **shall** be invoked.

- a. The User **shall** be responsible for specifying the LFCP Control Level (e.g., 1, 2A, 2B, 2C, 3).

For the purpose of this document:

- Lead-free Tin (Sn) is defined as metallic Tin (Sn) containing less than 3 percent lead (< 3% Pb) by weight as an alloying constituent.

- Lead-free Tin (Sn) technology is defined as electrical/electronic components and associated mechanical hardware and materials composed of, or coated/plated (internal/external surfaces) with metallic Tin (Sn) containing less than 3 percent lead (< 3% Pb) by weight as an alloying constituent.

Notes:

- <1> This definition differs from the more traditional definition of “Pb-free/lead free” as a metallic alloy containing less than 0.1 percent lead (< 0.1% Pb) by weight as an alloying constituent.
- <2> The word “components” includes EEE parts and assemblies, mechanical hardware, wire, cable, connectors/interconnects/terminators, clamps, braid/over-braid shield, printed circuits, etc.

Rationale: Lead-Free Tin (< 3% Pb) technology is susceptible to the spontaneous growth of electrically conductive, single crystal structures known as tin whiskers. Over time these whiskers may grow to be several millimeters (mm) long. Tin whiskers are capable of causing electrical failures ranging from parametric deviations (soft short) to sustained arcing (hard short) resulting in severe electrical and thermal damage.

5.1.5.14 Lock Washers (Tooth Type) Lock washers with a locking feature (e.g., tooth) designed to cut and gouge into the surface to mechanically lock the fastener **shall not** be used in critical application, Class 3, and/or Space applications or products without an interposer (flat) washer between the lock washer and the mounting surface.

- Unless otherwise specified, the sharp edges of the lock washer **shall** be against the flat washer.
- Serrated-face/wedge-lock type washers are acceptable for use in critical and high vibration applications with prior User approval.

Rationale:

- (1) Lock washers with a “tooth” locking feature may generate particles and/or shavings that represent an acute eye injury and laceration risk and Foreign Object Debris (FOD) hazard.
- (2) Use without a flat interposer washer may allow the locking feature to cut through the protective coatings or platings on the mounting surface, reducing long-term electrical and mechanical performance and reliability.
- (3) Serrated-face/wedge-lock type washers are classified as tension-locking, rather than friction-locking, devices, and **must** be assembled correctly.

5.1.5.15 Magnesium (Mg) Magnesium (Mg) and magnesium-base alloys **shall not** be used in applications subject to mechanical wear, physical abuse, foreign object damage, electrical current flow (including ground return paths), exposure to corrosive environments, or at any location where fluid or moisture entrapment is possible.

Rationale:

- (1) Magnesium metal and magnesium-base alloys are explosive hazards; they are highly flammable in their pure form when molten or in powder or ribbon form.
- (2) Burning or molten magnesium metal reacts violently with water, producing hydrogen gas.

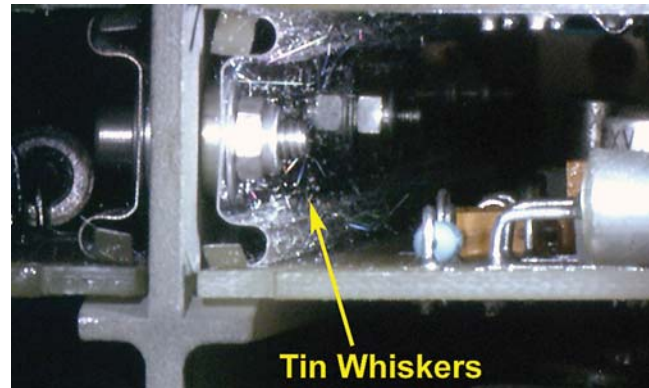


Figure 5-6 Tin Whiskers

Photo Courtesy of NASA Electronics Parts & Packaging (NEPP) Program



Figure 5-7 Lock Washer (Internal/Split/External Tooth)

Photo Courtesy of NASA



Figure 5-8 Serrated-Face/Wedge-Lock Washer (paired set)

Photo Courtesy of NASA

5.1.5.16 Mercury (Hg) Mercury is highly toxic to humans and is corrosive to metals. Equipment, components and assemblies **should** be free of mercury, and mercury **should not** be used in the manufacture or testing of assemblies.

- Manufacturers **should** evaluate materials to confirm that they do not contain intentionally added mercury. For example, some potting compounds may use a catalyst that contains mercury as a method of minimizing the presence of air bubbles during the potting process. Trace amounts of mercury that are not intentionally used as an additive, and that are in quantities that do not exceed the RoHS limit for mercury, may be acceptable in some specific instances, unless specified otherwise by the User.
- Equipment containing mercury (Hg) **shall not** be used in critical application, Class 3, and/or Space products; or, in applications where mercury liquid or vapor could come in contact with electrical/electronic equipment or personnel, or be released into the environment.

Rationale: Mercury (Hg) is a particularly hazardous material because of its toxicity to bio-organisms, corrosive effects on metals, and ability to conduct electricity in a liquid or vapor phase.

5.1.5.17 Micro-D Connectors Micro-D size connectors **shall not** be used in Category IV (EED), life-critical, and/or extreme operational environment (high vibration, thermal cycling, mechanical shock) designs or products, unless provided with (a) hood “clamping” mechanisms surrounding the female contact engagement time(s) or a reverse gender “bulged wire twist” pin design, (b) positive locking/retention devices, and (c) prior approval by the User.

Rationale: Connector contact systems having two (2) points of contact engagement, or less; that do not utilize a military style hood “clamping” mechanism to support female contact engagement times; and, that do not incorporate a positive locking/retention device may not be suitable for use in high vibration and/or thermal cycling environments where signal integrity and EMI immunity are critical to performance and reliability of critical circuits.



Figure 5-9 Micro-D Connector (Fiber/Copper Combination)

Original Image: Amphenol Aerospace

Graphic Enhancement: NASA

5.1.5.18 Natural Rubber Materials Natural rubber materials **shall not** be used in critical, Class 3, and/or Space applications or products.

Rationale: Natural rubber materials outgas sulfur when subjected to heat, low pressure, or vacuum conditions; have limited resistance to extreme temperatures, sunlight, or ozone; are fungus nutrients; and, exhibit significant compositional variation from batch to batch.

5.1.5.19 Polychlorinated Biphenyls (PCB) PCBs are a type of organic compound that **should not** be used because they are an environmental pollutant. Historically, their main use was within components such as certain types of capacitors, and transformers.

5.1.5.20 Polyvinyl Chloride (PVC) PVC, commonly referred to as vinyl, is hazardous to human health and the environment throughout its entire life cycle. PVC is useless without the addition of a plethora of toxic additives, which can make the PVC product itself harmful to consumers. These chemicals can leach out of PVC, posing risks to children and consumers. New car smell? New shower curtain smell? That’s the smell of poisonous chemicals out-gassing from the PVC. One of the most toxic additives is di-2-ethylhexyl phthalate (DEHP), a phthalate that is a suspected carcinogen and reproductive toxicant readily found in numerous PVC products.

- When heated in a fire, PVC releases toxic hydrogen chloride gas, forming deadly hydrochloric acid when inhaled.
- PVC cannot be effectively recycled due to the many different toxic additives used to soften or stabilize PVC, which can contaminate the recycling batch.
- Polyvinylchloride (PVC) insulated wire or cable **shall not** be used in critical application, Class 3, and/or Space products; in applications where temperatures exceed 49 °C [120 °F] and/or atmospheric pressure falls below 20684 Pa [< 3 psi] under normal or emergency conditions; or, in plenum, floor, or ceiling installations requiring fire/smoke retardant materials.
- Non-lead stabilized PVC (classified as RoHS compatible) **shall not** be used without User approval.

Rationale: Outgassed product(s) generated during exposure to high heat or fire are hazardous, corrosive, and toxic. Products include, but may not be limited to, hydrogen chloride (HCl), hydrofluorocarbon (HFC), carbonyl dichloride/phosgene (COCl_2), carbon monoxide (CO), carbon dioxide (CO_2), chlorine monoxide (ClO), and acidic carbonaceous coke.

5.1.5.21 Silver (Ag) Silver-plated hardware and finishes **shall not** be used in applications where condensing moisture, salt fog, sulfur compounds, or atomic oxygen (AO) are present.

Rationale:

- (1) The primary concern with silver is electro-migration of the silver ion across the insulation gap (and to some extent within the glass weave structure) between printed traces on the PWB in the presence of moisture and electrical potential to form current leakage paths. This phenomenon is not an issue in silver-coated copper stranded wiring.
- (2) Silver reacts rapidly with atomic oxygen (AO) and/or sulfur compounds to generate a loose, friable, black oxide that can cause contamination and affect the operation of mechanisms.
- (3) Bare or defectively insulated silver or silver-coated copper components such as wire, pins, sockets, or connectors impressed with a direct current (dc) potential can spontaneously ignite and burn when exposed to ethylene glycol solutions that do not contain a silver chelating agent.

5.1.5.22 Splices The use of splices in critical, Class 3, and/or Space applications **shall** be determined by the following considerations (in the following order):

- a. The routing of a dedicated, continuous, and unbroken conductor from point to point is not practical due to assembly and manufacturing sequence (e.g., the hardware is assembled in modules and/or sections).
- b. The use of a connector is prohibited by contact under-utilization, weight, and/or size restrictions (e.g., a separate connector is needed to support only this circuit).
- c. The use of a splice can optimize complicated wiring (e.g., when the harness supports common branch circuits or parallel-connected devices).
- d. The use of a splice facilitates and simplifies installation (e.g., joining harness sections/branches).
- e. Solderless (crimp) splices are preferred.
- f. *Category IV Circuits.* The use of splices in Category IV circuits, such as electro-explosive device (EED) or initiator circuits (e.g., air bag, emergency, etc.). See Appendix A of IPC-D-620 for Military/Space requirement.
- g. *Heat Shrinkable Soldering Devices.* The use of solder splices utilizing “contained solder rings, flux, and/or meltable seals” (e.g., heat shrinkable soldering devices) for space electronics or other hardware exposed to reduced pressures or vacuum environments.
- h. *Solder Splices.* The use of solder splices **shall** be kept to a minimum.
- i. *Thermocouple Circuits.* The use of splices in thermocouple circuits **shall** be prohibited.

Exception: The above is not applicable to shield terminations.

Rationale: Historically, the cable and harness designer’s goal has been to minimize the use of splices in the design and manufacture of wiring harnesses. The justification for this design philosophy was relatively straightforward: “The simplest and most reliable wiring design was considered to be one that resulted in the routing of a dedicated, continuous and unbroken conductor from point to point.” However, this design goal often becomes difficult to achieve, without multiplying the number of dedicated conductors, when the harness **must** support branch circuits or parallel-connected devices; and impossible to achieve when the wiring system is progressively assembled as hardware sub-systems are integrated over a period of time (such as in the assembly of a vehicle). The designer **must** either accept a bulky, complex and heavy wiring harness that is easily damaged during installation, a harness design using expensive, bulky, and heavy connectors, or design optimization through the careful specification and use of splices.



Figure 5-10 In-Line Lash Solder Splice
Image Courtesy of NASA

5.1.5.23 Toxic Pyrolytic Materials Toxic pyrolytic materials include those materials which emit toxic gases or other harmful products when exposed to high temperatures, including fire. Toxicity of materials can be determined by performing a pyrolysis test. One such test method is DTIC AD 297457, Procedure for Determining Toxicity of Synthetic Compounds.

5.1.5.24 Zinc (Zn) Zinc plating **shall not** be used on EEE parts and connector hardware in critical application, Class 3, and/or Space products.

Rationale: *Electrically-deposited zinc (Zn) coatings have been shown to exhibit spontaneous metallic whisker growth that appears to be more aggressive than that observed with electrically-deposited bright tin (Sn), and are capable of causing electrical failures ranging from parametric deviations to sustained plasma arcing that can result in catastrophic short circuits. Zinc is known to sublime in a vacuum or elevated temperature environment, representing a serious health concern (heavy metal poisoning) if inhaled.*

5.1.5.25 Other Non-Recommended Materials The following other types of materials **should not** be used:

- a. Linen.
- b. Cellulose acetate.
- c. Cellulose nitrate.
- d. Regenerate cellulose.
- e. Wood.
- f. Jute/hemp.
- g. Leather.
- h. Cork.
- i. Paper and cardboard.
- j. Organic fiberboard.
- k. Hair or wool felts.
- l. Plastic materials using cotton, linen or wood flour as a filler.
- m. Radioactive materials.
- n. Graphite loaded lubricants and gaskets.
- o. Sulfur containing packaging materials (cardboard, brown paper, etc.).

6 CABLE AND WIRE HARNESS ASSEMBLIES

6.1 Connector Selection This section gives an overview of the technical considerations which **should** be made when selecting electrical connectors. There are literally hundreds of thousands of variations of connector types. This section is only intended to give an overview of the basic requirements to consider. Discussion with the connector manufacture is recommended before final selection.

6.1.1 Common Connector Definitions

- a. *Shell* – Houses the contact insert and contacts.
- b. *Contact Insert* – The dielectric or insulating inner core, holds contacts.
- c. *Coupling Nut* – Outer threaded or grooved ring which holds mated pair together.
- d. *Jam Nut* – Nut that holds receptacle to a panel.
- e. *Bayonet Coupling* – A non-threaded, ramp type of coupling.
- f. *Contacts* – Pin or socket used to achieve electrical engagement.
- g. *Solder Contact* – A contact to which wire is joined by soldering.
- h. *Crimp Contact* – A contact to which wire is joined mechanically.
- i. *Plug* – The cable/coupling half of a mating pair.
- j. *Receptacle* – The panel/receiving half of a mating pair.
- k. *Mating Pair* – Two connectors that couple together. Shell size insert arrangement and rotation **should** be complete.

- l. *Plating* – The metal finish applied to contacts and or shell components (protective) to resist corrosion and wear.
- m. *Grommet* – Resilient part at back of insert (attached or separate); gives wire moisture seal.
- n. *Gland* – Resilient ring in rear accessory, provides seal on jacketed cable.
- o. *Sealing Plug* – Plastic type slug, placed in unused grommet holes to seal.
- p. *Grounding Fingers* – A metal strap around plug shell for positive shell-to-shell conductivity/shielding.
- q. *Male and Female* – The male half always goes into female.
- r. *Hermetic* – A connector with fused glass insert for air tightness.
- s. *Mating/Unmating Forces* – Torque required to couple/uncouple a mating pair of connectors or contacts.
- t. *Rear Termination* – An accessory which threads to back of shell.
- u. *Strain Relief* – A type of accessory which clamps wires for support.
- v. *Potting Boot* – A type of accessory which forms a mold for potting compound.
- w. *EMI or RFI Back Shell* – A type of accessory to terminate wire shielding.
- x. *Interface Seal* – A resilient part on the face of pin inserts which provides moisture seal.

6.1.2 Top Level Considerations Connectors **should** be selected so that contacts on the “live” or “hot” side of the connection are socket type rather than pin type to minimize personnel hazard and to prevent accidental shorting of live circuits if the connector is unmated with power still applied.

When selecting a connector the following general top level considerations **should** be made by the design engineer/authority:

6.1.2.1 Electrical Considerations

- a. Connector service rating.
- b. Dielectric withstanding Voltage (DWV).
- c. Insulation resistance.
- d. Number, type and arrangement of contacts (e.g., filtered, coax, twinax, triax, quadrax, removable, PWB pin tail, wire wrap, solder cup, crimp, thermocouple, compliant, optical fiber, etc.).
- e. Maximum (derated) current capacity.
- f. Minimum electrical clearance/creepage distance.

6.1.2.2 Contacts Connectors using removable crimp contacts are preferred to solder contact types. One acceptable contact is AS39029, or otherwise as specified by the base connector specification.

- a. Wire size **should** be within the crimp barrel size range as identified in the contact specification.
- b. Crimp tools used by the manufacturer **should** be such as to meet specified performance in accordance with the applicable connector specification, and the crimp connections **should** be replaceable in the field using standard crimp tools available in the field.

6.1.2.2.1 Spare Contacts In some applications, the user may require a certain number or percentage (e.g., 10%) of spare contacts to be provided within a connector for future growth. These spare contacts may require sealing grommets be installed if the connector is environmentally sealed. In some cases, unused contacts may need to be terminated with a dead-ended pigtail lead that can be connected to in the future without damaging the connector. In other applications, the connector insert may be provided with unused holes such that the contacts can be added later if needed. However, if the connector manufacturer recommends that all un-used insert holes be filled for improved performance and reliability in shock, vibration, thermal cycling, or harsh environmental considerations, then this is preferred over leaving the holes un-filled.

6.1.2.3 Environmental Considerations Connectors **should** be selected for the expected worst-case service environment. In cases where the connector is expected to be used in wet, condensing moisture, or SWAMP conditions, the connector **should** be sealed against the ingress of water and/or water vapor under all service conditions, including changes in altitude, atmospheric pressure, relative humidity, and temperature. The connectors **should** have an interfacial seal as well as sealing at wire ends. Environment resisting connectors having a sealing grommet at the exit of the backshell is preferred; however, fully potting the backshell with a polymeric material may also provide the required environmental resistance in applications where a grommet seal connector would not be suitable.

Additional considerations:

- a. Dust proof.
- b. Moisture resistance.
- c. Altitude.
- d. Water submersion, depth and altitude.
- e. Temperature range.
- f. Fluids.
- g. Gas environments.
- h. Ultra-Violet (UV) resistance.
- i. Radiation.
- j. Corrosion resistance (Environmental vs Material).
- k. Weight and size restrictions.
- l. EMI/RFI shielding requirements.
- m. Vibration and shock requirements.
- n. Firewall capability.
- o. Shell grounding.

6.1.2.4 Special Features

- a. Fail-safe lanyard release.
- b. Scope-proof.
- c. Pre-mated earth.
- d. Coupling mechanism.
- e. Blind mate requirement.
- f. Identification of whether unused/spare contacts **should** be provided with contacts installed or otherwise plugged.

6.1.2.5 Safety The establishment of electrical safety factors is the responsibility of the designer since the designer **should** be aware of factors that can affect safety such as peak voltages, switching surges, transients, etc. that can be expected in a particular circuit.

6.1.3 Connector Overview Connectors will generally come as a plug and receptacle known as a mated pair (unless it is a hermaphroditic style). In their most basic form connectors can be circular, rectangular or proprietary shapes.

Figure 6-1 shows an overview at top level of what most connectors, regardless of type, will be made up. The coupling mechanism is also an important part of the connector selection consideration; this is explained in more detail in section 7.6.

Figure 6-2 shows a cut-away of an assembled connector.

6.2 Connector Types There are many connector types available. Some of the more historically used connector types are circular, rectangular, and proprietary shaped.

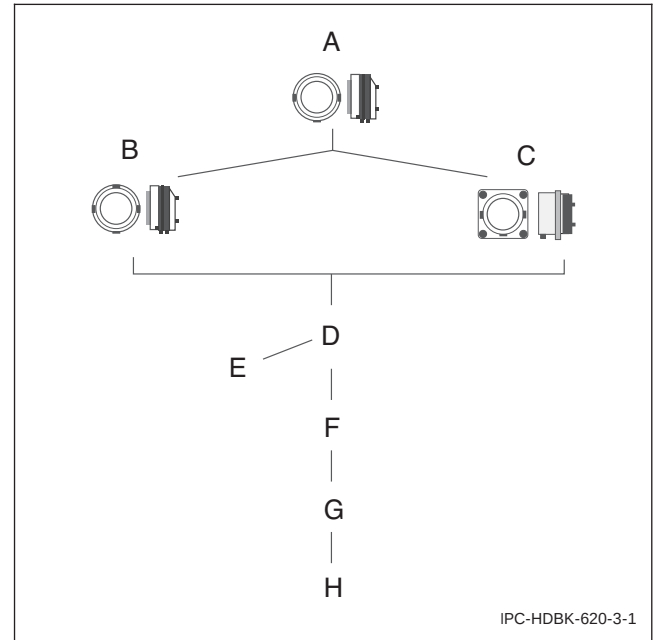


Figure 6-1 Common Connection Make Up

A. Dustcap	D. Shell	G. Contacts
B. Plug	E. Coupling Mechanism	H. Rear Accessories
C. Receptable	F. Insert	

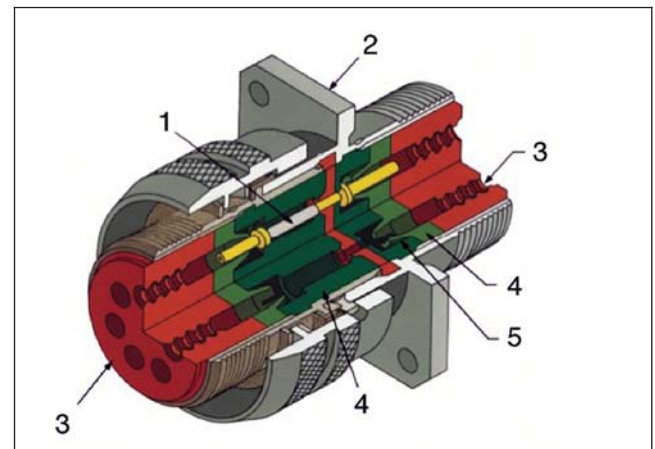


Figure 6-2 Assembled Connector Cut Away

Image Credit: Amphenol Ltd. (UK)

6.2.1 Circular Connectors There are many types of circular connectors in the world market place today. When selecting which one to use it is important to ensure that both halves meet all the technical, environmental and space considerations. Circular connectors are traditionally easier to manufacture and easier to seal due to their shape. These are often used for their superior EMI performance, as they provide a reliable 360 degree termination of a cable harness shield to the connector (see Figure 6-3).

6.2.2 Rectangular Connectors Rectangular connectors are capable of a higher density of contacts in the connector area. Though initially used in rack and panel designs, rectangular connectors are now widely used in avionic and instrumentation boxes where space is a premium (see Figure 6-4).

6.2.2.1 D-Shell/D-Sub/Micro-D Connectors The D-Shell/D-SUB (D-sub miniature) is a type of electrical connector named for their characteristic D-shaped metal shield that provides mechanical support, ensures correct orientation, and assists in screening against electromagnetic interference. A D-sub connector typically contains two or more parallel rows of pins or sockets and various contact counts, types, and pin-pin spacing densities are available. Typically crimp and insert and solder cup contacts are used for cable mounted applications. There are also numerous PCB and panel mount configurations available, as well as mixed signal/function variants.

Originally introduced in 1952 by Cannon, an alpha-numeric numbering system was introduced to rapidly identify the connector shell size, contact count, and connector gender. The D-SUB connector series was identified by the prefix “D,” followed by the shell size (A, B, C, D, E), the number of contacts, and the gender (P = plug/pin contacts, S = connector/socket contacts). When originally introduced, the shell size also denoted the row count and total number of contact positions in the shell (e.g., A = 2 rows/15 contacts, B = 2 rows/25 contacts, C = 2 rows/37 contacts, D = 3 rows/50 contacts, E = 3 rows/9 contacts).

Over time, multiple variations of shell size, contact count, and contact type have been introduced to increase circuit capability and design flexibility while retaining an industry-accepted shell design. An example of this enhanced circuit capability would be the “DB-13W3” connector, which provides ten (10) regular pin or socket contacts, and three (3) coaxial contacts for R/G/B video signals.

A micro version of the connector (referred to as a “Micro-D”) was introduced to provide the same pin count in a connector shell approximately half the size of the original D-SUB.

Specifications: IEC 60807-3, DIN 41652, MIL-DTL-24308, MIL-DTL-83513.



Figure 6-3 Circular Connectors

Photo Credit: Amphenol Ltd. (UK)



Figure 6-4 Rectangular Connectors

Photo Credit: Amphenol Ltd. (UK)



Figure 6-5 D-Shell Connector

Photo Courtesy of NASA