

IPC-D-620A
2021 - December

**Design and Critical Process
Requirements for Cable and
Wiring Harnesses**

A standard developed by IPC



BUILD ELECTRONICS BETTER



Documents

Document Sharing Hub

The Principles of Standardization

In May 1995 the IPC's Technical Activities Executive Committee (TAEC) adopted Principles of Standardization as a guiding principle of IPC's standardization efforts.

Standards Should:

- Show relationship to Design for Manufacturability (DFM) and Design for the Environment (DFE)
- Minimize time to market
- Contain simple (simplified) language
- Just include spec information
- Focus on end product performance
- Include a feedback system on use and problems for future improvement

Standards Should Not:

- Inhibit innovation
- Increase time-to-market
- Keep people out
- Increase cycle time
- Tell you how to make something
- Contain anything that cannot be defended with data

Notice

IPC Standards and Publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for his particular need. Existence of such Standards and Publications shall not in any respect preclude any member or nonmember of IPC from manufacturing or selling products not conforming to such Standards and Publication, nor shall the existence of such Standards and Publications preclude their voluntary use by those other than IPC members, whether the standard is to be used either domestically or internationally.

Recommended Standards and Publications are adopted by IPC without regard to whether their adoption may involve patents on articles, materials, or processes. By such action, IPC does not assume any liability to any patent owner, nor do they assume any obligation whatever to parties adopting the Recommended Standard or Publication. Users are also wholly responsible for protecting themselves against all claims of liabilities for patent infringement.

IPC Position Statement on Specification Revision Change

It is the position of IPC's Technical Activities Executive Committee that the use and implementation of IPC publications is voluntary and is part of a relationship entered into by customer and supplier. When an IPC publication is updated and a new revision is published, it is the opinion of the TAEC that the use of the new revision as part of an existing relationship is not automatic unless required by the contract. The TAEC recommends the use of the latest revision. Adopted October 6, 1998

Thank you for your continued support.



IPC-D-620A

Design and Critical Process Requirements for Cable and Wiring Harnesses

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

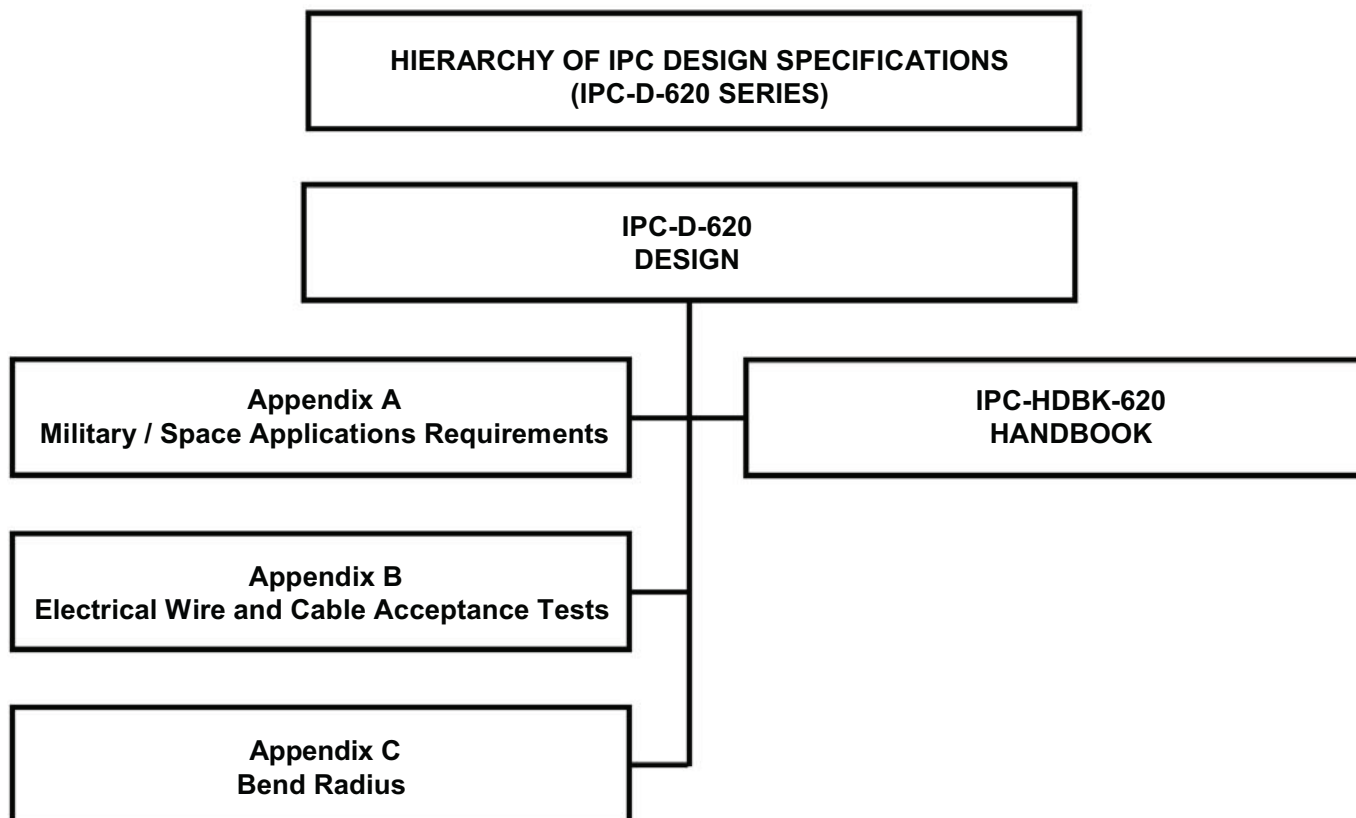
Supersedes:

IPC-D-620 -
December 2015

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

Contact:

IPC
3000 Lakeside Drive, Suite 309S
Bannockburn, Illinois
60015-1219
Tel 847 615.7100
Fax 847 615.7105



FORWARD

This standard 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.

IPC-D-620 is supplemented by Appendices A-C and a handbook (IPC-HDBK-620), which provide the engineering rationale and technical guidance on cable and wiring harness design. The User needs, as a minimum, the Design Requirements document (IPC-D-620), and the engineering description of the final product.

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

Acknowledgment

Members of the Wire Harness Design Task Group worked 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 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.

Product Assurance Committee

Chair
Robert W. Cooke
NASA Johnson Space Center

Vice-Chair
Debbie Wade
Advanced Rework Technology

Wire Harness Design Task Group

Chair
Robert W. Cooke
NASA Johnson Space Center

Vice-Chair
Sean Keating
Amphenol Ltd (UK)

Technical Liaison of the IPC Board of Directors

Bob Neves
Microtek (Changzhou) Laboratories

Members of Wire Harness Design Task Group

Dominik Alder Lockheed Martin Corporation	Thomas Cleere	Dave Harrell Viasat Inc.
Anisha Ankush ATRON Group LLC	Robert Cooke NASA Johnson Space Center	Eric Harenburg Boeing Company
Michael Baker	Stephen Cooke Electrical Components International	Rick Hawthorne Technical Training Center
Vincent Barone Panduit Corporation	Miguel Dominguez Continental Temic SA de CV	Gaston Hidalgo Toyota Motor North America
Geza Batiz Toro Co.	Bill Downton Cirris Systems Corporation	David Hillman Collins Aerospace
Cathy Becker JC Manufacturing	Caroline Ehlinger Collins Aerospace	Shelley Holt L3Harris Communications
James Blanche NASA Marshall Space Flight Center	Chris Fitzgerald NASA Goddard Space Flight Center	Ife Hsu Intel Corporation
Gerald Bogert Bechtel Plant Machinery, Inc.	Robert Fornefeld STI Electronics, Inc.	Paula Jackson Raytheon UK
Alvin Boutte NASA Goddard Space Flight Center	Daniel Foster Missile Defense Agency (MDA)	Kathy Johnston
Bud Bowen Winchester Interconnect	B.J. Franco Honeywell Aerospace	Lawrence Joy
Lance Brack Raytheon Missile Systems	Mahendra Gandhi Northrop Grumman Space Systems	Joseph Kane BAE Systems
Thomas Carle Ball Aerospace & Technologies Corp.	Matt Garrett Microsemi	Sean Keating Amphenol Ltd (UK)
Zhiman Chen Zhuzhou CRRC Times Electric Co., LTD.	Constantino Gonzalez ACME Training & Consulting	Jason Keeping Celestica International L.P.
	William Graver NTS - Baltimore	Russell Kido Practical Components Inc.

Rebekah Kovarik Lockheed Martin	Bob Potysman ATRON Group LLC	Stephen Tisdale Tisdale Environmental Consulting LLC
Vijay Kumar Lockheed Martin Missiles & Fire Control	Sue Powers-Hartman Killdeer Mountain Manufacturing, Inc.	Jonathon Vermillion Ball Aerospace & Technologies Corp.
Leo Lambert EPTAC Corporation	Ray Prasad Ray Prasad Consultancy Group	Daniel Versluis HYTEK
Theodore Laser L3Harris Communications	Erik Quam Uson LP	Debie Vorwald Collins Aerospace
Evan Levy	Edward Rios Motorola Solutions	Debbie Wade Advanced Rework Technology
John Mastorides Honeywell Aerospace	Richard Rumas Honeywell Canada	Schuyler Williams Lockheed Martin Missiles & Fire Control
Garry McGuire NASA Marshall Space Flight Center	Tammy Sargent Collins Aerospace	Alan Young Jet Propulsion Laboratory
Randy McNutt Northrop Grumman Aerospace Systems	Martin Scionti Raytheon Vision Systems	Style Yuan Winchester Electronics (Suzhou) Co., Ltd.
Roger Miedico Raytheon Company	Darrell Sensing BAE Systems	Jack Zhu Veoneer China CO., LTD
Brett Miller USA Harness, Inc.	Jose Servin Olivares Vitesco Technologies	Yaakov Zissman Elta Systems Ltd.
George Millman Raytheon Missile Systems	Gilbert Shelby Raytheon Systems Company	Paul Zutter U.S. Army Aviation & Missile Command
Fernando Moreno Cesar-Scott, Inc.	Kim Souva Kearfott Corporation	
Mark Northrup Raytheon Missile Systems	Toshiyasu Takei Japan Unix Co., Ltd.	
Agnieszka Ozarowski BAE Systems	Bob Teegarden Honeywell International - Torrance	

Table of Contents

1 GENERAL	1	3.2.7 Intellectual Property (IP) Control Requirements	11
1.1 Scope	1	4 SELECTION OF PARTS, MATERIALS AND PROCESSES	11
1.2 Purpose	1	4.1 Commonality	11
1.3 Performance / Product Classification	1	4.2 Flammability	12
1.4 Definition of Requirements	2	4.3 Outgassing	12
1.4.1 Design Requirement Format (A/N)	2	4.4 Flammability, Odor, And Offgassing	12
1.4.2 Requirements Flowdown	2	4.5 Toxic Products and Formulations	12
1.4.3 Commercial Off-The-Shelf (COTS)	2	4.6 Foreign Object Debris (FOD) Control Plan	12
1.4.4 Existing or Previously Approved Designs	2	4.7 Prohibited / Restricted Usage Parts, Materials, Processes (PMP)	12
1.5 Measurement Units and Applications	3	4.7.1 Acetic Acid Cure RTV Silicone Sealants, Adhesives, and Coatings	12
1.5.1 Use of Measurement	3	4.7.2 Beeswax Wax (ALL TYPES) Lacing Tape	12
1.5.2 Verification of Dimensions	3	4.7.3 Beryllium (Be)	12
1.5.3 Line Drawings and Illustrations	3	4.7.4 Cadmium (Cd)	13
1.6 Definition of Terms	3	4.7.5 Crimping Of Solder-Tinned and Solid Conductors	13
1.7 Engineering Documentation	3	4.7.6 Cuprous Oxide Corrosion (Red Plague)	14
1.8 Order of Precedence	3	4.7.7 Fluorine Attach (White Plague)	14
1.9 Conflict	3	4.7.8 FN / HN Grade Polyimide (Kapton®) Insulated Wiring	14
1.10 Clause References	4	4.7.9 Glass / Glass-Like Materials	14
1.11 Appendices A-C	4	4.7.10 Use of Lead-Free Tin (Sn) Materials and/or Processes	15
1.12 Approval of Departures from Standards and Requirements	4	4.7.11 Lock Washers	15
1.13 Supply Chain Traceability	4	4.7.12 Magnesium (Mg)	16
1.14 Trusted Source	4	4.7.13 Mercury (Hg)	16
1.15 Materials and Substances Declaration	4	4.7.14 Micro-D Connectors	16
2 APPLICABLE DOCUMENTS	5	4.7.15 Natural Rubber Materials	16
2.1 Aerospace	4	4.7.16 Polyvinyl Chloride (PVC)	16
2.2 Commercial	4	4.7.17 Silver (Ag)	16
2.3 Federal	5	4.7.18 Splices	17
2.4 Military Specifications	5	4.8 Wire & Cable	17
2.5 Reference	5	4.8.1 Conductor Sizing	18
3 DESIGN PHILOSOPHY	7	4.8.2 Conductor Material and Coating	18
3.1 General Design Requirements	8	4.8.3 Multi-Conductor Cables	19
3.1.1 Effect of Combined Conditions / Characteristics	8	4.8.4 Coaxial Cables	19
3.2 System Requirements Specification (SyRS)	9	4.8.5 Optical Fiber, Optical Fiber Cable, and Optical Fiber Assemblies	19
3.2.1 Interface Control Document (ICD)	9	4.9 Connectors	20
3.2.2 Performance and Reliability	9	4.9.1 Mating Provisions	21
3.2.2.1 Interchangeability	9	4.9.2 Moisture Protection	21
3.2.2.2 Design for Maintainability (DFM)	10	4.9.3 Pin Assignment	21
3.2.2.3 Ergonomic Design	10	4.9.4 Protection of Connectors	22
3.2.2.4 Service Life	10	4.9.5 Protection of Severed Electrical Circuits	22
3.2.3 Workmanship	10	5 ELECTRICAL REQUIREMENTS	22
3.2.4 Environmental Requirements	10	5.1 Derating	2
3.2.5 Packaging, Handling, Shipping, and Transportation (PHS&T)	10		
3.2.6 Documentation Requirements	10		



5.2	Coronal Discharge (Suppression)	23	6.9	Identification and Marking	30
5.3	Electrical Bonding	23	6.9.1	Cable and Harness Assemblies	31
5.4	Shield Design and Grounding	23	6.9.2	Optical Cable	31
5.4.1	Electromagnetic Pulse (EMP) Environment	24	6.9.3	Connectors	31
5.4.2	Category IV Circuits	24	6.9.4	Clamp Locating Marks	31
5.4.3	Category I, II, III, and V Circuits (No EMP)	25	7	QUALITY ASSURANCE (QA) REQUIREMENTS	31
5.4.4	Ungrounded / Floating Shield Terminations (No EMP)	25	7.1	Responsibility for Inspections and Tests	31
5.4.5	Magnetic Shields	25	7.2	Classification of Inspections and Tests	32
5.5	Circuit Isolation	26	7.3	Workmanship, Acceptance, and Testing	32
5.5.1	Group-Grounding of Individual Shield Terminations	26	7.4	Qualification	32
5.5.2	Separation of Redundant Systems	26	7.5	Time-Critical or Limited-Life	32
6	ASSEMBLY/FABRICATION REQUIREMENTS	27	8	DOCUMENTATION	33
6.1	Wire Terminations	27	8.1	Data	33
6.1.1	Splices (Use Of)	27	8.2	Connector Orientation (Clocking)	34
6.1.2	Types of Splices	27	8.3	Connector Pin-Out	34
6.1.3	Dead-Ending	28	8.4	Dimensioning and Tolerance	34
6.1.4	Insulation Compatibility with Sealing and Servicing	28	9	DEFINITIONS AND ACRONYMS	34
6.2	Form Layout Fixture	28	APPENDIX A	Military/Space Applications Requirements	48
6.3	Forming Wires into Cables and Harnesses	28	APPENDIX B	Electrical Wire and Cable Acceptance Tests	52
6.4	Wire Lay	28	APPENDIX C	Bend Radius	54
6.5	Bend Radius	28			
6.6	Cable / Harness Management (Installation / Routing)	29			
6.7	Protection and Support	29			
6.8	Etching Fluoropolymer-Insulated Electrical Wire	30			

Figures

Figure 3-1	Wire, Cables, and Harnesses	8
Figure 3-2	Cable and Harness Design Process	11
Figure 4-1	Waxed Lacing Tape	12
Figure 4-2	Red Plague (Cuprous Oxide Corrosion) on Braid, with Microsection (Inset)	14
Figure 4-3	White Plague (Fluorine Attack).	14
Figure 4-4	FN / HN Grade Polyimide (Kapton®)	14
Figure 4-5	Glass / Glass-Like Materials (e.g., Fuses).	14
Figure 4-6	Tin Whiskers on Cardguide.	15
Figure 4-7	Lock Washer	15
Figure 4-8	Serrated-face / Wedge-lock Washer (paired set).	15
Figure 4-9	Micro-D Connector (Fiber / Copper Combination).	16
Figure 4-10	In-Line Lash Solder Splice	17
Figure 4-11	Fiber Optic Cable	19
Figure 4-12	Exploded View of an Assembled Connector	19
Figure 5-1	Solder Ferrule Termination	23
Figure 5-2	Two-Piece Shield Crimp with Ground Wire	24
Figure 5-3	Soldered Shield (Wrapped) Termination.	24
Figure 5-4	Group Grounding of Individual Shield Terminations.	25
Figure 6-1	Example of a Pre-Formed Heat-Shrinkable Branch Boot.	27
Figure 8-1	Connection Orientation (Clocking).	33

Tables

Table 1	Derating (Class 3, Military Space)	42
Table 2	Summary of Circuit Categories and Shielding Requirements.	43
Table 3	Bond Classification	44
Table 4	Types of Splices.	46
Table 5	Electrical Creepage and Clearance Distance.	47
Table A1	Military/Space Applications Requirements.	49

This Page Intentionally Left Blank

Design and Critical Process Requirements for Cable and Wiring Harnesses

1 GENERAL

1.1 Scope This document provides design and critical process requirements and technical insight that have been removed from the acceptance standards for cable and wire harness assemblies. 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.

1.2 Purpose This document is the cable and wiring harness and systems-level design requirements companion to IPC/WHMA-A-620 and its associated space addendum.

The intent of this document is to set forth the general design requirements for electrical wiring harnesses and cable assemblies. This document is intended for use by the design engineer, manufacturing engineer, quality engineer, or other individual responsible for the tailoring of specific requirements of this document to the applicable performance class.

- a. In-Service Criteria. This document defines design requirements criteria to meet the expected performance and reliability for the expected product service life. It is not the intent of this document to establish or define “In Service” design requirements or acceptance criteria to address performance or reliability issues caused by aging or use. However, the criteria and limits that are currently detailed in this document may be considered to be wide enough to be applicable to the more common hardware degradation conditions caused by aging / use. Use of these criteria for “In Service” hardware conditions should be AABUS.
- b. Alternate / Contractor-Proprietary Documents or Processes. It is not the intent of this document to exclude any alternate or contractor-proprietary documents or processes that meet or exceed the baseline of requirements established by this document. Use of alternate or contractor-proprietary documents or processes **shall** [A1A2A3] require review and prior approval of the User.
- c. 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 (i.e., 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) and/or materials (e.g., solder, flux, cleaning agents).
 - The Manufacturer is considered the entity that provides a service or product to the User.

1.3 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 requirement overlaps between classes,

The User is responsible for defining the performance class required, whether compliance to any of the A through C Appendices is required, and to indicate any exceptions to specific parameters where appropriate.

Class 1 – General Electronic Products

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

Class 2 – Dedicated Service Electronic Products

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

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

Includes products from Performance Class 3 – High Performance/Harsh Environment Electronic, with additional considerations for unique materials requirements and more extreme operational environments, such as vibration and thermal cycling. Space classification deviations to IPC-D-620 requirements are defined and listed in Appendix A, “Military / Space Applications Requirements”.

1.4 Definition of Requirements The imperative form of action verbs are used throughout this document to identify design requirements that may require compliance, depending upon the Performance Classification of the hardware. To assist the User, these action verbs are in bold text.

- SHALL / SHALL NOT.** The words **shall** or **shall not** are used whenever a requirement is intended to express a provision that is mandatory. Deviation from a **shall** or **shall not** requirement for a particular Performance Class may be considered if sufficient technical rationale / objective evidence (OE) is supplied to the User to justify the exception.
- SHOULD.** The word **should** is used whenever a requirement is intended to express a provision that is non-mandatory, and which reflects general industry practice and / or procedure.
- MAY.** The word **MAY** is intended to express an action or provision that is permissible.

1.4.1 Design Requirement Format (A/N)

This is a design document, and the requirements are formatted to allow verification and validation (V&V). As such, there are no quality acceptance conditions specified (see IPC/WHMA-A-620). To assist the User, each requirement is identified by its Performance Classification [x1x2x3] and applicability, where “x” represents:

N = Not Applicable

A = Applicable

Examples:

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

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

[A1A2A3] = Applicable for all Classes

1.4.2 Requirements Flowdown This document **shall not** [A1A2A3] be binding, unless separately and specifically included by the applicable contract, approved drawing(s), or purchase order.

- When invoked, the applicable requirements of this document **shall** [A1A2A3] be imposed on all applicable subcontracts, assembly drawing(s), documentation and purchase orders.

1.4.2.1 Notes / Italicized Text Information provided in notes or presented as italicized text is for informational purposes only.

- When invoked, the applicable requirements of this document **shall** [A1A2A3] be imposed on all applicable subcontracts, assembly drawing(s), documentation and purchase orders.

1.4.3 Commercial Off-The-Shelf (COTS) The requirements of this document **shall not** [A1A2A3] apply to suppliers of Commercial-Off-The-Shelf (COTS) or catalog items (e.g. components, assemblies, sub-assemblies, and/or hardware, etc.).

- The design and workmanship of COTS items should be evaluated and modified as required to ensure that the use of COTS in wiring harnesses and cable assemblies meets contract performance and reliability requirements.
- Modifications of COTS **shall** [A1A2A3] be documented.
- All modifications **shall** [A1A2A3] meet the applicable requirements of this document for the specified Product Class, and be completed, inspected, and tested in accordance with IPC/WHMA-A-620 and/or IPC/WHMA-A-620X-S, unless otherwise specified by the User.

1.4.4 Existing or Previously Approved Designs The requirements of this document **shall not** [A1A2A3] constitute the sole cause for the redesign of previously approved designs.

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

1.5 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 ($^{\circ}\text{C}$) [Fahrenheit ($^{\circ}\text{F}$)].
- 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 (hh:mm:ss).

1.5.1 Use of Measurement Units All specified measurement units in this standard are defined as “nominal”.

1.5.2 Verification of Dimensions Actual measurement of specific dimensions and determination of percentages are not required, except for referee purposes or when specified by contract. For determining conformance to the measurement units specified in this standard, round all observed or calculated values “to the nearest unit” in the last right-hand digit used in expressing the specification limit (e.g., the retained digit), in accordance with ASTM Practice E29 [6.4 – Rounding Procedure].

***Note:** This standard uses other SI prefixes (ASTM SI 10, Section 3.2), as applicable, to eliminate leading zeroes (for example, 0.0012 mm becomes 1.2 μm) or as alternative to powers-of-ten (3.6 x 10³ mm becomes 3.6 m).*

1.5.3 Line Drawings and Illustrations Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this standard. **The written requirement always takes precedence over the drawings and illustrations.** Figures and images in the document are not to scale, may not reflect the quoted measurements and should be treated as reference only. Text takes precedence over the figures.

1.6 Definition of Terms

For purposes of this document, the acronyms, abbreviations, and terms listed in Section 9 “Definitions and Acronyms” are in addition to those listed in IPC-T-50. Other than those acronyms, abbreviations, and terms listed in Section 9, the acronyms, abbreviations, and terms used in this standard are in accordance with IPC-T-50.

1.7 Engineering Documentation The design engineer is responsible for ensuring that all applicable design details are clearly and completely depicted on the engineering documentation (drawings), including manufacturing, assembly, and test methods and standards.

- Drawings **shall [A1A2A3]** impose the appropriate Product Class, and specify that cable and harness assemblies are to be fabricated, inspected, and tested in accordance with IPC/WHMA-A-620 and/or IPC/WHMA-A-620X-S, unless otherwise specified by the User.
- See 8.0 Documentation - Documentation for additional requirements.

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

1.9 Conflict

- In the event of conflict between the requirements of this document and the approved assembly drawing(s) / documentation, the User approved assembly drawing(s) / documentation **shall [A1A2A3]** govern.
- In the event of a conflict between the text of this document and the applicable documents cited herein, the text of this document **shall [A1A2A3]** take precedence.
- In the event of conflict between the requirements of this document and an assembly drawing(s)/ documentation that has not been User approved, this document **shall [A1A2A3]** govern.
- If no criteria is specified, required, or cited, criteria **shall [A1A2A3]** be established and agreed upon between the Manufacturer and User.

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

1.11 Appendices A-C For the purpose of this document, Appendices A-C are considered separate and optional documents to IPC-D-620, which provide additional engineering rationale and technical guidance on cable and wiring harness design.

- Appendices A-C **shall not [A1A2A3]** be binding, unless separately and specifically invoked by the applicable contract, approved drawing(s), or purchase order.
- When invoked, the applicable requirements of the appendices **shall [A1A2A3]** be imposed on all applicable subcontracts, assembly drawing(s), documentation and purchase orders.
- When not invoked, the applicability of the Appendices, individual requirements of the Appendices, and/or flowdown of said appendices and/or individual requirements **shall [A1A2A3]** be AABUS.

1.12 Approval of Departures from Standards and Requirements This document is intended for use in specifications or contracts to incorporate requirements which are common to most cable and wiring harness designs, and establishes the minimum design requirements for most applications.

- Special requirements may exist which are not covered by, do not comply with, or which are in conflict with program-specific documents, and / or program-specified design requirements.
- The requirements herein may be tailored by the Designer, however, such tailoring **shall [A1A2A3]** require technical evaluation and approval by the User prior to use.
- Use of alternate control plans, documents, or processes **shall [A1A2A3]** require technical evaluation and approval of the User prior to use.
- Requests for relief from requirements in this document **shall [A1A2A3]** require technical evaluation and approval of the User prior to use.
- Engineering documentation **shall [A1A2A3]** contain the details for such instances, and take precedence over appropriate sections of this document and the applicable requirements document(s).

1.13 Supply Chain Traceability When a supply chain traceability program is specified by contract, IPC-1782 or equivalent may be used. Duration of maintenance of records **shall [N1N2D3]** be AABUS. See Appendix A for Military / Space requirement(s).

1.14 Trusted Source When design, manufacturing, or supply activities (as applicable) are required by contract to be certified as a "Trusted Source" for markets requiring high levels of confidence in the integrity of delivered products, IPC-1791 (or equivalent) **may** be used. See Appendix A for Military / Space requirement(s).

1.15 Materials and Substances Declaration When a Materials and Substances Declaration Plan is specified by contract, IPC-1751 (or equivalent) **may** be used. See Appendix A for Military / Space requirement(s).

2 APPLICABLE DOCUMENTS

The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issue / revision identified herein, or the issue / revision in effect on the date of invitation for bid, or request for proposal, **shall [A1A2A3]** apply.

2.1 Aerospace

AIR1329 Electrical Connectors and Wiring, Compatibility of

AS4373 Test Methods for Insulated Electric Wire

AIR4487 Investigation of Silver Plated Conductor Corrosion (Red Plague)

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

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

2.2 Commercial

ANSI/NEMA WC 27500 Standard for Aerospace and Industrial Electrical Cable

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

ARP6167 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 E29 Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

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

IPC-1071 Best Industry Practices for Intellectual Property Protection in Printed Board Manufacturing

IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronics Circuits

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)

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

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

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

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

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

2.3 Federal

NASA-STD-8739.4 Workmanship Standard for Crimping, Interconnecting Cables, Harnesses, and Wiring

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

2.4 Military Specifications

MIL-DTL-17 Cables, Radio Frequency, Flexible and Semi-rigid, General Specification for

MIL-STD-704 Aircraft Electric Power Characteristics

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

A-A-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

ASTM B174 Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors

ASTM B8 Standard Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft

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 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

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

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

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

IPC-2611 Generic Requirements for Electronic Product Documentation

IPC-OI-645 Standards for Visual Optical Inspection Aids

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

MIL-C-27500 Cable, Electrical Shielded and Unshielded, Aerospace

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

MIL-DTL-5846 Chromel and Alumel Thermocouple Electrical Wire, Detail Specification for

MIL-DTL-24308 Connectors, Electrical, Rectangular, Non-environmental, Miniature, Polarized Shell, Rack and Panel, General Specification for

MIL-DTL-38999 Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect, (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for

MIL-DTL-81381 Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy, General Specification for

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-HDBK-216 R. F. Transmission Lines and Fittings; cancelled 8 Sept 2001; no replacement

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

MIL-I-631 Insulation, Electrical, Synthetic-Resin Composition, Non-Rigid

MIL-I-22129 Insulation Tubing, Electrical, Polytetrafluoroethylene (PTFE) Resin, Non-Rigid

MIL-I-23053 Insulation Sleeving, Electrical, Heat Shrinkable, General Specification for

MIL-PRF-39012 Connectors, Coaxial, Radio Frequency, General Specification for

MIL-S-83519 Shield Termination, Solder Style, Insulated, Heat Shrinkable, Environment Resistant, General Specification for

MIL-STD-202 Test Method Standard, Electronic and Electrical Component Parts (Method 107, Test Condition B)

MIL-STD-1399-Sect. 680 High Voltage Electric Power, Alternating Current

MIL-STD-1472 Human Engineering

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

MIL-W-22759 Wire, Electric, Fluoropolymer-Insulated Copper or Copper Alloy

MIL-W-83575 Military Specification Wiring Harness, Space Vehicle, Design and Testing, General Specifications

NA-GSFC-2003-03 NASA Goddard Advisory, Fluoropolymer Degradation Resulting in Corrosion of Packaged Pre-wired Connector Assemblies

NASA PUBLICATION 1124 Outgassing Data for Selecting Spacecraft Materials

NAS1747 Splice, Conductor and Shield Termination, Solder Style, Heat Shrinkable, Insulated, Specification for

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

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

NFPA 70 National Electrical Codes

QQ-B-575 Braid, Wire Copper, Tin-Coated Tubular

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 AMS 2491 Surface Treatment of Polytetrafluoroethylene, Preparation for Bonding

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 AS5382 Aerospace Cable, Fiber Optic

SAE AS5649 Wire and Cable Marking Process, UV Laser

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

SAE AS21608 Ferrule, Shield Terminating, Crimp Style

SAE AS23190 Wiring, Positioning and Support Accessories

SAE AS81044 Wire, Electric, 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)

3 DESIGN PHILOSOPHY

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. See Figure 3-1.

It is the 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.

3.1 General Design Requirements The design of electrical wiring harnesses and cable assemblies **shall [A1A2A3]** be based on the known worst-case operational requirements and expected use. These include, but are not limited to: assembly processes; shipping and storage; installation; test exposure; service environment (operational temperature limits, mechanical, thermal, and vibration stress; contamination; corrosives; EMC/EMI/RFI, ionizing / non-ionizing radiation, moisture or other fluid media exposure); post-use test and data recovery; and life expectancy.

The basic design considerations to assure reliable interconnecting cable and wire assemblies include, but are not limited to:

- a. The physical and electrical properties of the wire and cable, including gauge/size, base metal, coatings, strand count and construction (e.g., rope-lay strand, bunch-lay strand, concentric-lay-stranded, Litz / woven, etc.), weight, tensile strength, current and voltage derating, conductivity and signal propagation rates, etc.
- b. The physical and electrical properties of the cable and harness assembly, including active and spare wire count, connectors, EMI / RFI / magnetic shielding, ionizing / non-ionizing radiation, construction (coaxial, discrete wire, hybrid, multi-conductor, optical fiber), redundancy, voltage drop, identification / marking, etc.
- c. Material properties, including arc tracking resistance, chemical / material compatibility, flammability, odor, outgassing, lowpressure / vacuum stability, ultra-violet stability, resistance / reactance to corrosives, solvents, oxidizers, chemicals, etc., resistance to heat / cold, resistance to abrasion damage and cold flow, resistance to weathering, resistance to mold and/or fungal growth, etc.
- d. Application issues, including acoustic, mechanical, thermal shock, acceleration (g-load), environment (condensing / corrosive / explosive atmosphere), electric field density (high voltage / lightning).
- e. Non-metallic components - insulation jackets, potting materials, lacing tapes, braid sleeving, plastic straps, wrap sleeving, and plastic tubing.
- f. Special handling, storage, and processing requirements that may contribute to degradation of performance and/or reliability of hardware in service (e.g., Red Plague / White Plague control).
- g. Vulnerability to Foreign Object Debris (FOD) damage.
- h. Unique system-level testing requirements.
- i. Proprietary and export control compliance requirements.
- j. Environmental / Regulated materials (e.g., RoHS, REACH, etc.).
- k. Safety, maintainability, reliability, cost, etc.

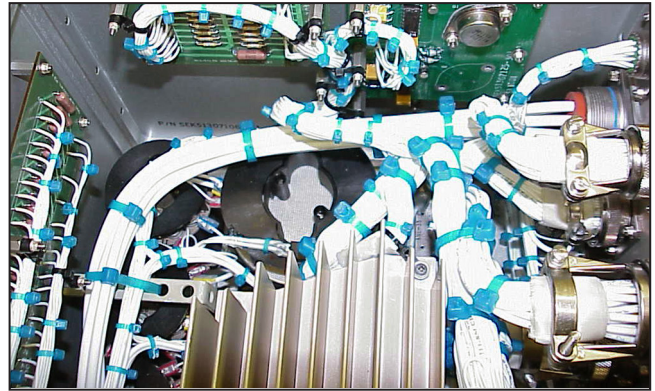


Figure 3-1 Wire, Cables, and Harnesses
(Photo Courtesy of NASA)

3.1.1 Effect of Combined Conditions / Characteristics The effect of cumulative conditions / characteristics on overall performance / reliability should be considered in addition to the effects of individual conditions / characteristics, even though they may not individually have any measurable impact on overall performance or reliability. These situations need to become drawing notes to supersede the standard.

Rationale: Design conditions provided in this specification are individually defined and created with separate consideration for their impact upon performance and/or reliable operation for the defined product classification in the expected worst-case operational requirements and expected use. Where related conditions can be combined, the cumulative performance impact for the product may be significant. For example, allowable strand damage per IPC/WHMA-A-620 [Table 3-1] may not be acceptable, to meet required current carrying capacity, even though supported by derating analysis.

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

- a. The SyRS **shall** [A1A2A3] contain 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 should further develop the specification and develop 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

3.2.1 Interface Control Document (ICD) The Interface Control Document (ICD) **shall** [A1A2A3] describe 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 (power, signal, optical, etc.)
- b. Schematic Diagrams
- c. Mechanical Layouts and Dimensional Requirements
- d. Connectors (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 I/F Requirements

3.2.2 Performance and Reliability The design **shall** [A1A2A3] assure 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.

3.2.2.1 Interchangeability Any two or more wiring harnesses or cable assemblies bearing the same part number **shall** [A1A2A3] possess such functional and physical characteristics as to be equivalent in performance, durability, and connectivity; and, **shall** [A1A2A3] be capable of being changed, one for another, without alteration of the items themselves or of adjoining items.

3.2.2.2 Design for Maintainability (DFM) Cable and wiring harness assemblies **shall [A1A2A3]** 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 **shall [A1A2A3]** 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 time, at both ends of the wire.
- c. Conductors connecting contacts within the same connector (i.e., jumpers) **shall [N1A2A3]** be captivated or restrained (e.g., cable clamp, wire tie, lacing, sealing gland).
- d. Access – When cable and wiring harness assemblies are required to be disconnected and/or reconnected, the design **shall [N1N2A3]** 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 operation to disconnect and reconnect without damage to wiring or connectors. See Appendix A for Military / Space requirement.

3.2.2.3 Ergonomic Design Cables and wiring harnesses designed for use, or deployment, by humans **shall [A1A2A3]** be designed to work with the human body in the intended environment and application.

3.2.2.4 Service Life Cables and wiring harnesses **shall [A1A2A3]** meet the design service life requirements specified in the detail specification and/or contract.

3.2.3 Workmanship Workmanship processes or criteria not covered by IPC/WHMA-A-620 **shall [A1A2A3]** be documented in engineering documentation.

3.2.4 Environmental Requirements Cables and wiring harnesses **shall [A1A2A3]** be capable of meeting the environmental design requirements specified in the detail specification and/or contract. See Appendix A for Military / Space requirement.

3.2.5 Packaging, Handling, Shipping, and Transportation (PHS&T) Cables and wiring harnesses **shall [A1A2A3]** be packaged, handled, shipped, and transported in accordance with the PHS&T requirements specified in the detail specification and/or contract.

3.2.6 Documentation Requirements

The documentation package **shall [A1A2A3]** 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 8.0 Documentation.

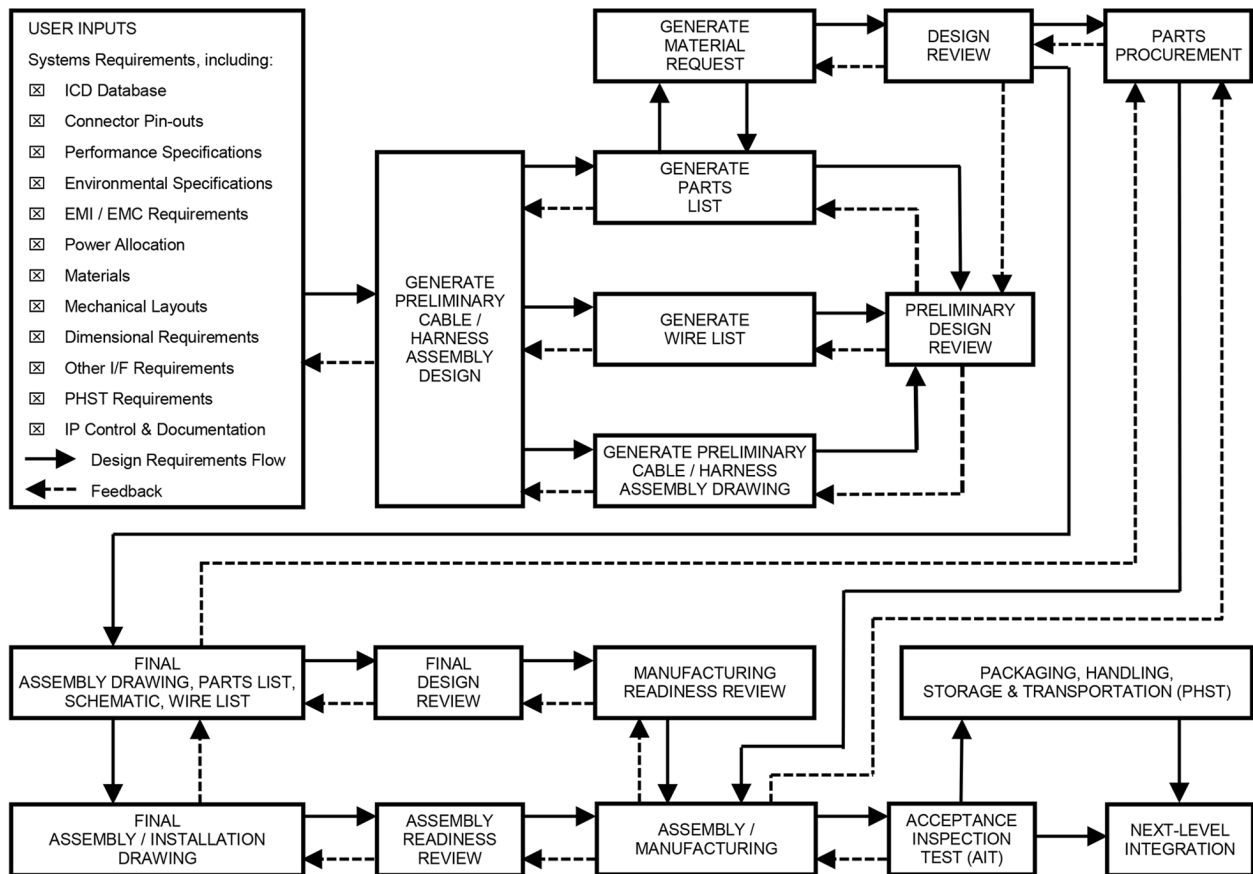


Figure 3-2 - Cable and Harness Design Process

3.2.7 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., **shall [A1A2A3]** be in accordance with IPC-1071; the User-specified control plan; or, an equivalent control plan agreed upon by the Designer and User.

4 SELECTION OF PARTS, MATERIALS AND PROCESSES

Unless otherwise specified in the contract, the parts, materials, and processes **shall** [A1A2A3] be selected and controlled in accordance with the approved Materials and Processes Plan / Requirements, and specified on the drawing.

4.1 Commonality The objective in the selection of parts, materials, and processes should be to maximize commonality and thereby minimize the variety of parts, related tools, and test equipment required in the fabrication, installation, and maintenance of cables and wiring harness assemblies.

- a. Whenever a selected specification provides more than one characteristic or tolerance for an item, the Supplier **shall** [A1A2A3] use items of broadest characteristics in the equipment and of the greatest allowable tolerances that will fulfill the performance and reliability requirements of the design.
- b. A readily available item of equivalent form, fit, and function that, (a) meets the specified minimum quality requirements, and that (b) does not increase life cycle cost, may be used.

4.2 Flammability

- Insulation materials **shall** [A1A2A3] be non-combustible or self-extinguishing.
- Selection and use **shall** [A1A2A3] be traceable to acceptable flammability test reports. See Appendix A for Military / Space requirement.

4.3 Outgassing See Appendix A for Military / Space requirement.

4.4 Flammability, Odor, And Offgassing See Appendix A for Military / Space requirement.

4.5 Toxic Products and Formulations The use of toxic products and formulations used throughout manufacture, assembly, test, and checkout **shall** [A1A2A3] conform to all local, state, and Federal (national) safety and environmental regulations. For United States facilities, all Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) regulations apply.

WARNING: The chemicals (i.e., adhesives, cleaners, coatings, encapsulants, fluxes, Solder alloys and solvents) used in electronic manufacturing, rework and repair processes can be hazardous, volatile, reactive, flammable and/or fatal if used incorrectly.

4.6 Foreign Object Debris (FOD) Control Plan When a Foreign Object Debris (FOD) Prevention Program (also known as a FOD Control Plan) is required, it **shall** [A1A2A3] be established for the design, development, manufacturing, assembly, repair, processing, testing, maintenance, operation, and check out of cable and wiring harness assemblies to prevent immediate and latent damage, and to ensure compliance to the User specified cleanliness level.

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

4.7 Prohibited / Restricted Usage Parts, Materials, Processes (PMP) Unless otherwise specified in the contract, the use of the following Parts, Materials, and Processes (PMP) **shall** [A1A2A3] be prohibited or restricted.



Figure 4-1 Waxed Lacing Tape

Image Credit: NASA

4.7.1 Acetic Acid Cure RTV Silicone Sealants, Adhesives, and Coatings Acetic acid cure RTV silicone sealants, adhesives, and coatings **shall not** [A1A2A3] 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 ($C_2H_4O_2$) during the curing phase of Room Temperature Vulcanizing (RTV) silicones creates potential corrosion, contamination, and health issues. While classified as a weak acid, acetic acid can attack electrical/electronic components and metals such as copper and aluminum. Exposure to acetic acid vapor can cause eye, skin, mucous membrane, and upper respiratory tract irritation. Odor: vinegar

4.7.2 Beeswax Wax (ALL TYPES) Lacing Tape

- Beeswax impregnated lacing tape **shall not** [N1N2A3] be used in critical application, Class 3, and/or Space products, without prior User approval. See Figure 4-1.
- Wax impregnated lacing tape **shall not** [A1A2A3] 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.

4.7.3 Beryllium (Be) Unalloyed beryllium (Be), and beryllium alloys containing greater than 4% (percent) beryllium by weight as an alloying constituent, **shall not** [A1A2A3] be used in critical application, Class 3, and/or Space products, unless suitably protected to prevent erosion, or formation of salts or oxides.

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

Environmental tests, under expected conditions, **shall** [A1A2A3] be conducted to verify that the coating used provides satisfactory protection for the beryllium surface.