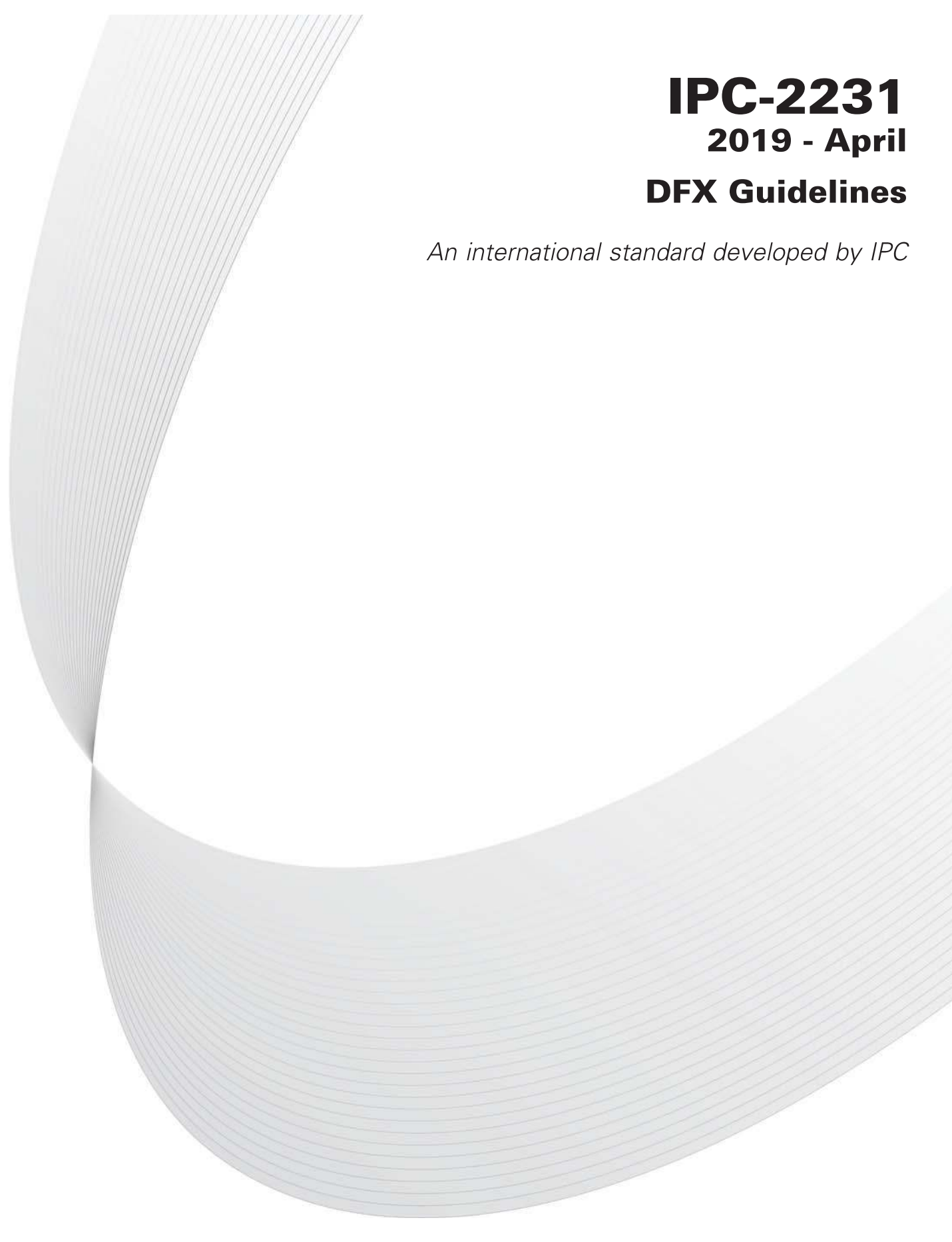




IPC-2231

2019 - April

DFX Guidelines

An international standard developed by IPC

Association Connecting Electronics Industries



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IPC-2231

DFX Guidelines

Developed by the DFX Standards Subcommittee (1-14) of the Printed Board Design Committee (1-10) of IPC

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

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Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the DFX Standards Subcommittee (1-14) of the Printed Board Design Committee (1-10) 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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DFX Guidelines

1 SCOPE

This document provides guidelines for establishing a best practice methodology for use in developing a formal DFX (Design for Manufacturing, Fabrication, Assembly, Testability, Cost, Reliability, Environment, Reuse) process for layout of printed board assemblies that utilize surface mount and through hole devices.

1.1 Purpose The document provides a DFX process framework to establish a discipline of design review necessary to perform a detailed analysis of manufacturability attributes commonly found in electronics hardware for fabrication and around which to model a printed board assembly.

1.2 Goals of This Document The goals of this document are to:

- Use a multi-discipline engineering assessment tactic on elements influencing DFX.
- Allow the user to establish standardized DFX checklist(s) for major design elements such as bare printed board fabrication, printed board assembly manufacturing, electrical testability, and elements influencing product reliability, reuse, and impact on environment.

1.3 Limitations of This Document Electronics hardware defined under this DFX review process is limited to features of influence on DFX for bare printed board and printed board assembly.

2 APPLICABLE DOCUMENTS

2.1 IPC¹

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

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

IPC-CH-65 Guidelines for Cleaning of Printed Boards and Assemblies

IPC-D-279 Design Guidelines for Reliable Surface Mount Technology Printed Board Assemblies

IPC-D-325 Documentation Requirements for Printed Boards, Assemblies and Support Drawings

IPC-A-610 Acceptability of Electronic Assemblies

IPC-A-630 Acceptability Standard for Manufacture, Inspection, and Testing of Electronic Enclosures

IPC-SM-785 Guidelines for Accelerated Reliability Test of Surface Mount Solder Attachments

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

IPC-2221 Generic Standard on Printed Board Design

IPC-2222 Sectional Design Standard for Rigid Organic Printed Boards

IPC-2223 Sectional Design Standard for Flexible Printed Boards

IPC-2224 Sectional Standard for Design of PWBs for PC Cards

IPC-2225 Sectional Design Standard for Organic Multichip Modules (MCM-L) and MCM-L Assemblies

IPC-2226 Sectional Design Standard for High Density Interconnect (HDI) Printed Boards

IPC-2581 Generic Requirements for Printed Board Assembly Products Manufacturing Description Data and Transfer Methodology

IPC-2615 Printed Board Dimensions and Tolerances

IPC-4761 Design Guide for Protection of Printed Board Via Structures

1. www.ipc.org

- IPC-6012** Qualification and Performance Specification for Rigid Printed Boards
- IPC-7351** Generic Requirements for Surface Mount Design and Land Pattern Standard
- IPC-7525** Guidelines for Stencil Design
- IPC-7711/7721** Rework, Modification and Repair of Electronic Assemblies
- IPC-7801** Reflow Oven Process Control Standard
- IPC-9701** Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments

2.2 SAE International²

- GEIA-STD-0005-1** Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder
- GEIA-STD-0005-2** Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems

2.3 IEEE³

- IEEE Std 1500(TM)/IEC 62528** Standard Testability Method for Embedded Core-based Integrated Circuits
- IEEE 1149.1** IEEE Standard for Test Access Port and Boundary-Scan Architecture
- IEEE 1149.4** IEEE Standard for a Mixed-Signal Test Bus
- IEEE 1149.5** IEEE Standard for Module Test and Maintenance Bus (MTM-Bus) Protocol
- IEEE 1149.6** IEEE Standard for Boundary-Scan Testing of Advanced Digital Networks
- IEEE 1149.7** IEEE Standard for Reduced-Pin and Enhanced-Functionality Test Access Port and Boundary-Scan Architecture
- IEEE 1149.8.1** IEEE Standard for Boundary-Scan-Based Stimulus of Interconnections to Passive and/or Active Components
- IEEE 1232** IEEE Standard for Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE)
- IEEE 62525** (IEEE Std 1450) International Standard Test Interface Language (STIL) for Digital Test Vector Data
- IEEE 1500** IEEE Standard Testability Method for Embedded Core-based Integrated Circuits
- IEEE 1522** IEEE Standard for Testability and Diagnosability Characteristics and Metrics
- IEEE 1532** IEEE Standard for In-System Configuration of Programmable Devices
- IEEE 1581** IEEE Standard for Static Component Interconnection Test Protocol and Architecture
- IEEE 1687** IEEE Standard for Access and Control of Instrumentation Embedded within a Semiconductor Device

2.4 JEDEC⁴

- JESD-B106-D** Test Method B106C Resistance to Soldering Temperature For Through-Hole Mounted Devices
- JESD22-A111** Evaluation Procedure for Determining Capability to Bottom Side Board Attach by Full Body Solder Immersion of Small Surface Mount Solid State Devices

2.5 Government

- MIL-A-28870** General Specification for Assemblies, Electrical Backplane, Printed Wiring
- MIL-P-50884** General Specification for Printed Wiring, Flexible and Rigid Flex
- MIL-DTL-31000** Technical Data Packages
- MIL-HDBK-454** General Guidelines for Electronic Equipment
- MIL-STD-2119** Design Requirements for Printed-Wiring Electrical Backplane Assemblies

2. www.sae.org

3. www.ieee.org

4. www.jedec.org

3 TERMS AND DEFINITIONS

Terms and definitions used herein are in accordance with IPC-T-50 except as otherwise specified.

Note: Any definition denoted with an asterisk (*) is a reprint of the term defined in IPC-T-50.

***Assembly** A number of parts, subassemblies or combinations thereof joined together. (Note: This term can be used in conjunction with other terms listed herein, e.g., “Printed Board Assembly.”)

***Automatic Test Equipment** Equipment that automatically analyzes functional or static parameters in order to evaluate performance.

Contract Data Requirements List (CDRL) A list in the RFP (Request for Proposal) specifying the amount and kind of deliverable data to be submitted to the Customer. This list covers a variety of data, such as schedules, test reports, drawings and associated lists, contract work breakdown structure (WBS), and various Program plans (e.g., PA, configuration management, safety, and reliability). The Customer may require that some data be submitted with the proposal; the rest of the data is delivered at specified times during the execution of the Program.

***In-Circuit Testing** The application of test signals directly to a device’s input terminals and sensing the results directly from the device’s output terminals.

Integrated Product Team (IPT) Multidisciplinary group of people who are collectively responsible for delivering a defined product or process.

Management The function that coordinates the efforts of people to accomplish goals and objectives using available resources efficiently and effectively. It includes planning, organizing, staffing, leading or directing, and controlling an organization or initiative to accomplish a goal.

Nodal A point in a network or diagram at which lines or pathways intersect or branch. (from Google Search - Dictionary)

***Nominal** The design target dimension for a physical characteristic of a product or a feature to which a tolerance may be applied that establishes the limits of variation from the target that are acceptable.

***Plated-Through-Hole (PTH)/Plated Hole** A hole with plating on its walls that makes an electrical connection between conductive patterns on internal layers, external layer, or both, of a printed board. (See Figure P-6).

***Printed Board** Interconnections for electronic circuits. It may include embedded components. (This includes single-sided, double-sided, multilayer, rigid, rigid-flex, and flex constructions.)

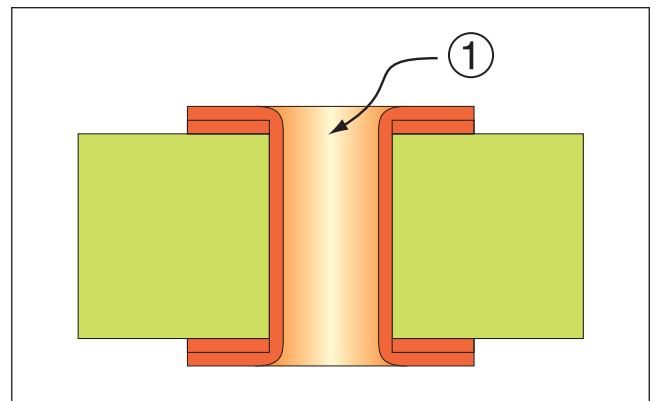


Figure P-6 Plated-Through-Hole (PTH)
1. Plated-Through-Hole

***Printed Board Assembly (PBA)** An assembly that uses a printed board for component mounting and interconnecting purposes.

***Registration** The degree of conformity of the position of a pattern (or portion thereof), a hole, or other feature to its intended position on a product.

Reliability Physics/Physics of Failure (RP/PoF) A technique under the practice of Design for Reliability that leverages the knowledge and understanding of the processes and mechanisms that induce failure to predict reliability and improve product performance.

Statement of Work (SOW) A formal document that captures and defines the work activities, deliverables, and timeline a vendor must execute in performance of specified work for a client.

4 OVERVIEW OF DESIGN FOR EXCELLENCE (DFX) PRACTICES

Design for Excellence (DFX) includes many disciplines. Modifications to accommodate DFX needs are less costly when addressed early in the design phase.

This document expands on the existing definition of performing DFX.

DFX is more than just checking for errors. It is a series of decisions about potential downstream problems made during the design phase with full knowledge of impact, cost, quality needs, and schedule requirements. The earlier in the design cycle problems or trade-offs are found, the least costly modifications are to implement.

4.1 Design for Manufacturing (DFM) The DFM scope covers the Design for Fabrication (DFF) and Design for Assembly (DFA). Many DFM guides use the word manufacturing interchangeably with their specific function (fabrication, assembly).

Design for manufacturing is a process of optimizing a design to ensure that it can be built with highest quality at the best cost. Decisions made during every stage of design effect the manufacturability of a product. Manufacturing checks should be done on the CAM data files, such as BOM, approved manufacturer list (AML), approved vendor list (AVL), netlist, IPC-2581, ODB++, or Gerber / Drill and Rout / Pick and Place, in the Documentation Package and not on the CAD data.

For more information, refer to IPC-D-325 and IPC-261x series.

In addition to checking the data files, all drawings in the Documentation Package should be reviewed for accuracy and completeness. A best practice is to generate notes for each board via a program or copied from a repository of approved notes.

Checks performed by the ECAD design tool are not necessarily the same as the checks used to check the manufacturability. DFM tools check post processed data for errors specific to the manufacturing process.

Make sure all documents supporting the product are reviewed by the manufacturer performing the DFM prior to release of the design for manufacturing. Notify the manufacturer performing the DFM to use the supplied documentation package and notes and to modify the DFM output based on any issues already resolved by the supplied documents. The manufacturer performing the DFM should provide the results in an easy to read and understand format as agreed between user and supplier. Defects should be prioritized from Critical to Preferred.

4.2 Printed Board Design for Fabrication (DFF) Due to the existence of published design for fabrication guides, only an overview section is provided in this document. Please refer to IPC-222x series of standards for detailed design guides. IPC-2221 Generic Standard on Printed Board Design covers all fabrications. Specific types of fabrications are covered in IPC-2222 (rigid), IPC-2223 (flex), IPC-2224 (PCMCIA), IPC-2225 (MCM-L), IPC-2226 (HDI). For inorganic substrates, and board types not covered in the detailed design guides above, consult the fabricator's design guide and expertise.

Work with your fabricator(s) and manufacturer(s) to match DFF guidelines to supplier capability and project requirements. Be sure to consider material availability and process differences when establishing design rules for printed boards that may be manufactured in different regions (Europe, Asia, America, other regions). Some of the bigger items to consider are:

- Board type
- Laminate material
- Symmetry of stackup
- Copper density balance
- Trace width and spacing
- Complexity of via connections
- Incorporation of embedded components
- Incorporation of printed components
- Mixed Dielectrics
- Signal Integrity
- Thermal Management
- Panel Utilization
- Regional material and process differences
- Make sure fab meets other DFX requirements

4.3 Design for Assembly (DFA) When DFM guides discuss placement clearances, they are defining DFA criteria. It is important to establish the requirements of assembly as part of the board requirements. Often component spacing rules are reduced to fit more packages on the printed board. These rules define the space needed by automated component insertion machine. Violation of the rules may force a costlier manual assembly of the board. The decision on placement rules needs to be made before the printed board is released for fabrication. Work with your assembler to establish good DFA guidelines.

- Elimination of hand soldering or wave soldering when possible
- Component spacing
- What are the size of components and complexity of packaging limitations, if any
- Orientation of components to wave solder
- Shadowing during wave solder
- Solder Pallet Clearance
- Appropriate dimensions and spacing for PTHs and bond pads
- Attachment methods
- Moisture sensitivity level (MSL)
- Cleanliness
- Inspection
- Component thermal mass and placement on assembly
- Spacing under component to allow cleaning if required

Make sure all documents supporting the product are submitted to the manufacturer performing the DFA. Notify the manufacturer to review the drawings and notes on the Assembly drawing, Fabrication Drawing, and/or Fabrication text file. Notify the manufacturer performing the DFA to use the supplied drawing and notes and modify the DFA output based on any issues already resolved by the supplied documents. Not having this performed leads to duplication of effort and reporting of errors that do not actually exist. Pictures of the potential defect should be listed with an x/y coordinate of the defect based on the zero coordinate of the supplied data file. Any defects should be prioritized from Critical to Preferred. A header must include at a minimum the part number of the board, date performed, Company name and contact information, and company that requested the data.

4.4 Design for Test/Testability (DFT) DFT is the name given to design techniques that added testability features to an electronic hardware product design. The premise of the added features is that they make it easier to develop and apply manufacturing tests for the designed hardware. The purpose of manufacturing tests is to validate that the product hardware contains no defects that could adversely affect the product's correct functioning.

Make sure all documents supporting the product are submitted to the manufacturer performing the DFT. Notify the manufacturer to review the drawings and notes on the Assembly drawing, Fabrication Drawing, and/or Fabrication text file. If required, Boundary scan data should be provided prior to having the DFT performed. Notify the manufacturer performing the DFT to use the supplied drawing and notes and modify the DFT output based on any issues already resolved by the supplied documents. Not having this performed leads to duplication of effort and reporting of errors that do not actually exist. Pictures of a potential defect should be listed with an x/y coordinate of the defect based on the zero coordinate of the supplied data file. At a minimum, a header must include the part number of the board, date performed, Company name and contact information, and company that requested the data.

Raw data should never be submitted as results because it is un-readable by the majority of the design team.

4.5 Design for Cost (DFC) Cost of a product is determined by either marketplace demands or bids for specific design tasks. Cost goals can be realized by treating cost as an independent design requirement that must be met during all phases of product development. Many military/aerospace companies refer to this practice as CAIV (Cost As an Independent Variable) and include cost analysis at all design reviews.

4.6 Design for Reliability (DFR) Design for Reliability (DFR) is the process for weaving the reliability engineering into the total development cycle. DFR takes the entire life cycle of the product into consideration when making decisions during the design phase. Some of the questions that DFR answers are:

- Where is the product to be used?
- How long must the product work without a failure?

- What are the consequences of failure?
- How is the product to be used?
- What environment is the product intended to withstand?

4.7 Design for Environment (DFE) Design for Environment was developed in a concerted effort to deal with legislation concerning the hazardous materials used in producing electronic products and the disposal of the product at end of its life-cycle.

Some of the legislation that Design for Environment deals with:

- European Union: The Restriction of Hazardous Substances Directive (ROHS)
- European Union: Waste Electrical and Electronic Equipment Directive (WEEE)
- United States: Conflict Minerals Law

In addition, the United States Environmental Protection Agency (EPA) created the Design for the Environment Program (DFE) to prevent pollution and its risks to humans and the environment. The effects of material and processes must be considered in all phases of a circuit card assembly's life cycle.

4.8 Design for Reuse Reuse can take two forms: within an organization and by third parties. Reuse has the benefits of getting more people to use and improve the design for cost and quality. Design elements that can be reused include specifications, block diagrams, interfaces, test plans, test setups, firmware, software, and routing.

5 PRINTED BOARD ASSEMBLY DESIGN PROCESS

5.1 Overview The Printed Board Assembly process is intended to guide the engineering development of Printed Board Assemblies by identifying inputs, tasks, and outputs required to perform design. It represents the collection of design best practices. It applies to development, prototype and production programs and is applicable to all electronic assemblies from consumer level to industrial to medical to avionics/military to space applications.

The documentation of this process may be tailored as appropriate for each individual project or company with engineering management concurrence. The level of tailoring and associated risks should be defined at the start of the program.

Critical to the success of the design process is an emphasis on generating an accurate specification, implementing best practices, design for excellence (DFX), and conducting thorough design reviews at the conclusion of each design phase.

The process is divided into six major phases:

- Concept Design and Analysis
- Detailed Design
- Design Release
- First Build Support
- Product Validation
- Support

5.2 Concept Design and Analysis

5.2.1 Overview The Concept Development Phase evaluates the proposed concept against the requirements to determine the feasibility based on the established design for excellence (DFX) principals.

The Concept Development Phase confirms appropriate resources, looks at ways to compress the schedule, and establishes the requirements that will drive the design effort. This phase should be completed prior to commencing the time consuming design phases to assure that all of the major requirements are analyzed, documented, and reviewed; and that bottlenecks are reduced or eliminated. The key outputs of the Concept Development Phase is completing preliminary documentation of program-unique requirements of the printed board assembly level in the requirements specification, the schedule, and appropriate resource requirements. Detail must be sufficient to convey all of the requirements at the level of understanding by the design engineer. Successful completion of the requirements document in adequate detail defining the requirements analysis and functional allocation to accomplish the design must be assured by a disciplined and timely concept design review.

5.2.2 Inputs

- Product size
- Product function
- Product environment
- Product regulatory requirements
- Product max cost per unit at a quantity
- Product lifecycle
- Product Budget
- Product Schedule

5.2.3 Tasks

- Review requirements and all applicable regulations and standards.
- Review all hardware systems requirements.
- Determine component requirements including use of COTS or custom devices.
- Assess the expected life cycle of the product and determine what steps in design and component choice are needed to assure the product meets life cycle requirements.
- Assess additional resource requirements and ways to compress the schedule.
- Discuss and establish preliminary design verification plan, qualification test plan, manufacturing test plan.
- Start to draft an engineering specification that notes special technologies, hardware requirements for software, and system constraints.

5.2.4 Outputs

- Block diagram with critical components
- Consensus on critical materials, components, and packages
- Placement strategy and preliminary manufacturing strategy
- Allowable board outline area, mechanical dimensions, and interconnects
- Draft verification plan
- Draft qualification test plan
- Draft manufacturing plan (fabrication, assembly, test, etc.)
- Identification of resources needed and when to produce, verify, and qualify board
- Dependency identification
- Risk Info/Mitigation Plans
- Support Area Agreements

5.3 Detailed Design

5.3.1 Overview The Detailed Design Phase completes the detailed test plans and procedures, completes part selection and schematic design, establishes the printed board requirements, and accomplishes the place and route efforts for printed board assembly. Tools, artwork, and data files are developed for printed board assembly. A Pre-Release Design Review should be conducted and the documentation package prepared for use by design, manufacturing and test.

5.3.2 Inputs

- Block diagram with critical components
- Consensus on critical materials, components and packages
- Placement strategy and preliminary manufacturing strategy
- Allowable board outline area, mechanical dimensions, and interconnects
- Draft verification plan
- Draft qualification test plan

- Draft manufacturing plan (fabrication, assembly, test, etc.)
- Identification of resources needed and when to produce, verify, and qualify board
- Dependency identification
- Risk Info/Mitigation Plans
- Support Area Agreements

5.3.3 Tasks

- Complete component selection and schematic design with any needed test elements.
- Perform calculations, tolerance analysis, software investigations, and simulations on schematic and layout.
- Hold in process reviews as needed, including a schematic review.
- Finalize board profile, requirements, materials, placement, engineering bill of materials, layout.
- Generate manufacturing data including any special process instructions.
- Run automated checks.

5.3.4 Outputs

- Schematics
- Bill of Materials (BOM)
- Mechanical drawings with critical dimensions and 3D CAD
- Printed board and printed board assembly manufacturing data
- Documentation package
- Verification plan
- Qualification test plan
- Manufacturing plan (fabrication, assembly, test, etc.)
- Lifecycle plan, as required

5.4 Design Release

5.4.1 Overview The design release process ensures that all the design steps were taken to reduce revisions, plans are in place for when the printed board assemblies arrive, and manufacturing documentation is clear and complete.

5.4.2 Inputs

- Schematics
- Bill of Materials (BOM)
- Mechanical drawings with critical dimensions and 3D CAD
- Printed board and printed board assembly manufacturing data
- Documentation package
- Verification plan
- Qualification test plan
- Manufacturing plan (fabrication, assembly, test, etc.)
- Lifecycle plan, as required

5.4.3 Tasks

- Perform a review of documentation package and iterate design based on input of reviews.
- Perform reviews of the design with respect to test plans.
- Review disposition of results from automated and manual checks.
- Release the data in a version control system.
- Send documentation, any consigned materials, and purchase order to suppliers.

5.4.4 Outputs

- Release documentation package and plans for manufacturing, verification, qualification, and production test
- Consigned materials and purchase order sent to suppliers

5.5 First Build Support

5.5.1 Overview The first build will uncover issues not caught prior to release and to get the boards on schedule. The goal of the support is to document and address each issue, improve the design and manufacturing processes, and provide feedback to the designers.

5.5.2 Inputs

- Release documentation package and plans for manufacturing, verification, qualification, and production test
- Consigned materials and purchase order sent to suppliers
- Supplier contacts

5.5.3 Tasks

- Track design through the manufacturing process. Record and address any issues that arise.
- Implement corrective actions as required.
- Perform a first article inspection on the printed board assemblies when they arrive to ensure they match production documentation.

5.5.4 Outputs

- Engineering and manufacturing change orders
- Corrective actions for design and manufacturing
- First Article Inspection Report (FAIR)

5.6 Product Validation

5.6.1 Overview This procedure defines the steps necessary to validate the design. This involves execution of the validation plan and qualification test plan. Implement corrective actions for each issue uncovered.

5.6.2 Inputs

- First Article Hardware
- Test Equipment and Software
- Verification plan
- Qualification test plan

5.6.3 Tasks

- Execute the verification plan.
- Execute the qualification test plan.
- Record findings and propose corrective actions.
- Execute corrective actions, including revisions if necessary.

5.6.4 Outputs

- Engineering and manufacturing changes
- Tested Hardware (Chip, Card, Unit)
- Test Reports
- Lessons Learned