

IPC-2228

2022 - October

**Sectional Design Standard for
High Frequency (RF/Microwave)
Printed Boards**

An international standard developed by IPC



BUILD ELECTRONICS BETTER

IPC Mission

IPC is a global trade association dedicated to furthering the competitive excellence and financial success of its members, who are participants in the electronics industry.

In pursuit of these objectives, IPC will devote resources to management improvement and technology enhancement programs, the creation of relevant standards, protection of the environment, and pertinent government relations.

IPC encourages the active participation of all its members in these activities and commits to full cooperation with all related organizations.

About IPC Standards

IPC standards and publications are designed to serve the public interest through elimination of 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 their particular need. Existence of such IPC standards and publications shall not in any respect preclude any entity from manufacturing or selling products not conforming to such IPC standards and publication, nor shall the existence of such IPC standards and publications preclude their voluntary use.

IPC standards and publications are approved by IPC committees without regard to whether the IPC standards or publications may involve patents on articles, materials or processes. By such action, IPC does not assume any liability to any patent owner nor does IPC assume any obligation whatsoever to parties adopting an IPC standard or publication. Users are wholly responsible for protecting themselves against all claims of liabilities for patent infringement.

IPC Position Statement on Specification Revision Change

The use and implementation of IPC standards and publications are voluntary and part of a relationship entered into by customer and supplier. When an IPC standard or publication is revised or amended, the use of the latest revision or amendment as part of an existing relationship is not automatic unless required by the contract. IPC recommends the use of the latest revision or amendment.

Standards Improvement Recommendations

IPC welcomes comments for improvements to any standard in its library. All comments will be provided to the appropriate committee.

If a change to technical content is requested, data to support the request is recommended. Technical comments to include new technologies or make changes to published requirements should be accompanied by technical data to support the request. This information will be used by the committee to resolve the comment.

To submit your comments, visit the IPC Status of Standardization page at www.ipc.org/status.



IPC-2228

Sectional Design Standard for High Frequency (RF/Microwave) Printed Boards

Developed by the High Speed/High Frequency Design Subcommittee
(D-21) of the High Speed/High Frequency Committee (D-20) of IPC

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

Contact:

IPC
3000 Lakeside Drive, Suite 105 N
Bannockburn, Illinois
60015-1249
Tel 847 615.7100
Fax 847 615.7105

This Page Intentionally Left Blank

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the High Speed/High Frequency Design Subcommittee (D-21) of the High Speed/High Frequency Committee (D-20) 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.

| High Speed/High Frequency Committee | High Speed/High Frequency Design Subcommittee | Technical Liaisons of the IPC Board of Directors |
|---|---|---|
| Chair Lance Auer Conductor Analysis Technology, Inc. | Chair Scott Bowles Lockheed Martin | Bob Neves Microtek (Changzhou) Laboratories |
| Vice-Chair Don DeGroot Connected Community Networks, Inc. | Vice-Chair Giuliana Jessop TTM Technologies, Inc. | |
| High Speed/High Frequency Design Task Group | | |
| Jenna Averhoff Collins Aerospace | Timothy Glaze Hughes Circuits, Inc. | Glenn O'Neil Lockheed Martin Missile & Fire Control |
| Steven Bowles Lockheed Martin Corporation | Allen Holl TTM Technologies | Geny Partida Summit Interconnect – Anaheim |
| Lance Brack Raytheon Missile Defense | Joe Hughes Hughes Circuits, Inc. | Jose Rios Raytheon |
| Michael Coe Lockheed Martin Corporation | Kevin Kusiak Lockheed Martin Corporation | Thomas Romont IFTEC |
| Michael Collier Teledyne Advanced Electronic Solutions | Mike Lehmicke All Flex Solutions | Steven Roy Roy Design and Manufacturing Service |
| Michael Creeden Insulectro | Dan Loew L3Harris | Edward Sandor AGC Nelco America, Inc |
| Larry Driscoll AGC Nelco America, Inc. | Laura Martin Insulectro | Brian Stevens Collins Aerospace |
| Don Dupriest Lockheed Martin Missiles & Fire Control | Wale Milligan TTM Technologies | Bradley Toone L3 Harris Technologies Communication Systems – West |
| Gary Ferrari EPTAC Corporation | Kristopher Moyer California State University Sacramento | Todd Tosi Sanmina Corporation |
| Mahendra Gandhi Northrop Grumman Space Systems | Naji Norder National Instruments | Joe Wojniak Ball Aerospace & Technologies Corp. |

This Page Intentionally Left Blank

Currently in preview, click buy full version

Table of Contents

| | | | | | |
|----------|--|---|-----------|---|---|
| 1 | SCOPE | 1 | 3.2.4.1 | Electromagnetic Effects | 3 |
| 1.1 | Purpose | 1 | 3.2.4.1.1 | Stackup | 4 |
| 1.2 | Document Hierarchy | 1 | 3.2.4.1.2 | Geometries and Routing | 4 |
| 1.3 | Presentation | 1 | 3.2.4.1.3 | Decoupling | 4 |
| 1.4 | Interpretation | 1 | 3.2.5 | Mechanical Design | 4 |
| 1.5 | Definition of Terms | 1 | 3.2.6 | Preliminary Design Review | 4 |
| 1.5.1 | Anisotropy | 1 | 3.2.7 | Breadboard | 4 |
| 1.5.2 | Directional Coupler | 1 | 3.2.8 | Prototype | 4 |
| 1.5.3 | Directivity | 1 | 3.2.9 | Documentation | 4 |
| 1.5.4 | Distributed Component | 1 | 3.2.10 | Final Design Review | 4 |
| 1.5.5 | Ground-to-Ground-Spacing | 1 | 3.3 | Performance Requirements | 4 |
| 1.5.6 | Ground-to-Signal-Spacing | 1 | 4 | MATERIALS | 4 |
| 1.5.7 | Impedance | 1 | 4.1 | Dielectric Base Materials (Including Cores and Bonding layers) | 4 |
| 1.5.8 | Lumped | 1 | 4.2 | Microwave Printed Circuit Board Materials | 5 |
| 1.5.9 | Open Circuit | 1 | 4.2.1 | Substrate Selection | 5 |
| 1.5.10 | Static Relative Permittivity | 1 | 4.2.1.1 | Relative Permittivity | 5 |
| 1.5.11 | S-Parameters | 2 | 4.2.1.2 | Loss Tangent | 5 |
| 1.5.12 | Semi-Rigid Cable | 2 | 4.2.1.3 | Thickness | 6 |
| 1.5.13 | Short Circuit | 2 | 4.2.1.4 | Environment | 6 |
| 1.5.14 | Smith Chart | 2 | 4.2.1.5 | Cost Drivers | 7 |
| 1.5.15 | Soft Substrate | 2 | 4.3 | Bonding Materials | 7 |
| 1.5.16 | TEM Mode (Transverse Electromagnetic Mode) | 2 | 4.3.1 | Thermoplastic Bonding Films | 7 |
| 1.5.17 | VSWR (Voltage Standing Wave Ratio) | 2 | 4.3.2 | Thermoset Bonding Layers | 7 |
| 1.5.18 | Wavelength | 2 | 4.3.3 | PTFE Bonding Considerations | 8 |
| 1.5.19 | As Agreed Between User and Supplier (AABUS) | 2 | 4.4 | Laminate Materials | 8 |
| 1.6 | Classification of Products | 2 | 4.4.1 | Laminate Material Code Designation | 8 |
| 1.6.1 | Printed Board Type | 2 | 4.5 | Copper Foil and Other Metals | 8 |
| 1.7 | Applicability | 2 | 4.5.1 | Thin Cladding Considerations | 8 |
| 2 | APPLICABLE DOCUMENTS | 2 | 4.5.2 | Thick Cladding Considerations | 8 |
| 2.1 | IPC | 2 | 4.5.3 | Copper Profile | 9 |
| 3 | GENERAL REQUIREMENTS | 3 | 4.6 | Conductive Materials (Platings and Coatings) | 9 |
| 3.1 | Information Hierarchy | 3 | 4.7 | Electronic Component Materials | 9 |
| 3.1.1 | Order of Precedence | 3 | 4.8 | Organic Protective Coatings (Solder Mask, Conformal Coating and OSP) | 9 |
| 3.2 | Design Considerations | 3 | 4.9 | Markings and Legends | 9 |
| 3.2.1 | Initial Input | 3 | 5 | MECHANICAL/PHYSICAL PROPERTIES | 9 |
| 3.2.2 | Design Options | 3 | 5.1 | Fabrication Requirements | 9 |
| 3.2.3 | Transmission Line Type, Materials, and Components | 3 | 5.2 | Product/Printed Board Configuration | 9 |
| 3.2.4 | Electrical Design | 3 | 5.2.1 | Printed Board Geometries | 9 |
| | | | 5.2.1.1 | Borders and Spacing | 9 |

| | | | | | |
|----------|---|----|---|---|----|
| 5.2.1.2 | Dimensional Aspect Ratio | 9 | 10 GENERAL CIRCUIT FEATURE REQUIREMENTS | 14 | |
| 5.2.1.3 | Bow and Twist | 9 | 10.1 | Conductor Characteristics | 14 |
| 5.2.2 | Mechanical Support | 9 | 10.1.1 | Printed Board Edge Spacing | 15 |
| 5.3 | Design Requirements for Printed Board Assembly | 9 | 10.1.2 | Balanced Conductors | 15 |
| 5.3.1 | Assembly Array (or Pallet) | 10 | 10.1.3 | Flush Conductors for Rotating or Sliding Contacts | 15 |
| 5.4 | Dimensioning Systems | 10 | 10.2 | Land Characteristics | 15 |
| 5.4.1 | Profiles, Cutouts and Notches | 10 | 10.2.1 | Offset Lands | 15 |
| 5.4.1.1 | Hole Location Tolerances | 10 | 10.3 | Large Conductive Areas | 15 |
| 6 | ELECTRICAL PROPERTIES AND CHARACTERISTICS | 10 | 11 DOCUMENTATION | 15 | |
| 6.1 | Via Spacing Considerations | 10 | 11.1 | Design Features Listing | 15 |
| 6.2 | Ground Stitching Vias | 10 | 11.2 | Master Drawing | 15 |
| 6.3 | Annular Ring Considerations | 10 | 11.3 | Master Pattern | 15 |
| 6.4 | Plated Edge Designs | 10 | 11.4 | Protected Via Structures | 15 |
| 7 | THERMAL MANAGEMENT | 12 | 11.4.1 | Protected Through Via Structures | 15 |
| 8 | COMPONENT AND ASSEMBLY ISSUES | 12 | 11.4.2 | Protected Blind and Buried Structures | 15 |
| 8.1 | General Attachment Requirements | 12 | 12 QUALITY ASSURANCE | 15 | |
| 8.1.1 | Attachment of Wires/Leads to Terminals | 12 | 12.1 | Quality Conformance Evaluations | 16 |
| 8.2 | Connector Attachment | 12 | 12.2 | Reliability | 16 |
| 9 | HOLE/INTERCONNECTIONS | 13 | Appendix A HISTORICAL RF ENGINEERING EQUATIONS | 17 | |
| 9.1 | General Requirements for Lands with Holes | 13 | A.1 | Stripline | 17 |
| 9.1.1 | Land Requirements | 13 | A.1.1 | Characteristic Impedance of Stripline | 18 |
| 9.1.2 | Thermal Relief in Conductor Planes | 13 | A.1.1.1 | Narrow Signal Lines | 18 |
| 9.1.3 | Clearance Area in Planes | 13 | A.1.1.2 | Wide Signal Lines | 19 |
| 9.1.3.1 | Small Pitch Clearance Area in Planes | 13 | A.1.2 | Attenuation in Stripline | 19 |
| 9.1.4 | Nonfunctional Lands | 13 | A.1.2.1 | Narrow Signal Lines | 19 |
| 9.1.5 | Conductive Pattern Feature Location Tolerance | 13 | A.1.2.2 | Wide Signal Lines | 20 |
| 9.2 | Holes | 13 | A.2 | Asymmetric | 20 |
| 9.2.1 | Unsupported Holes (Non-plated Holes) | 13 | A.3 | Microstrip | 20 |
| 9.2.2 | Plated-Through Holes (PTHs) | 13 | A.3.1 | Characteristic Impedance and Effective Permittivity of Microstrip | 21 |
| 9.2.2.1 | Aspect Ratio | 13 | A.3.2 | Attenuation in Microstrip | 23 |
| 9.2.2.2 | Specifying Finned Hole Sizes for Soldered Component Leads | 13 | Appendix B DESIGN TUTORIAL | 24 | |
| 9.2.2.3 | Specifying Hole Sizes for Vias | 13 | B.1 | Plated-Through Holes | 24 |
| 9.2.3 | Enhancement | 13 | B.2 | Etching | 24 |
| | | | B.3 | Surface Roughness of Copper Foil | 38 |

| Figures | | Tables | |
|----------------|---|---------------|---|
| Figure 5-1 | Numerous Internal Routing | 9 | |
| Figure 6-1 | Common Nets Anchored to Printed Board Edge (Preferred) | 11 | Table 4-1 Typical Characteristics of Thermoplastic Bonding Films |
| Figure 6-2 | Common Nets Not Anchored to Printed Board Edge (Not Preferred) | 11 | 7 |
| Figure 6-3 | Non-functional Lands Added to Some Layers with Even Distribution | 12 | Table 4-2 Characteristics of Typical Thermoset Bonding Layers. |
| Figure 6-4 | Non-functional Lands Added to Layers Where Internal Layers are Not Common to Edge Plating | 12 | 7 |
| Figure 8-1 | RF Connector Example. | 12 | Table 4-3 Thick Metal Claddings |
| Figure 10-1 | Conductor Etch Factor | 14 | 8 |
| Figure 10-2 | Overhang Resulting from Surface Finish Metal Being Used as Etch Resist | 14 | Table 9-1 Minimum Standard Fabrication Allowance for Interconnection Lands. |
| Figure A-1 | Stripline. | 18 | 13 |
| Figure A-2 | Cutaway View of Stripline | 18 | |
| Figure A-3 | Cross Sectional View of Microstrip Line without Metal Cover. | 20 | |
| Figure A-4 | Cross-Sectional View of Microstrip Line with Metal Cover | 21 | |

This Page Intentionally Left Blank

Currently in preview, click buy full version

Sectional Design Standard for High Frequency (RF/Microwave) Printed Boards

1 SCOPE

This standard establishes the specific requirements for the design of rigid, flexible and rigid-flexible printed boards utilizing radio frequency (RF) and/or Microwave circuitry and/or high frequency laminates where RF transmission lines and related passive metal layers are considered as distributed circuits, instead of conventional lumped circuit elements. This standard is used to support product typically requiring materials meeting the requirements of IPC-4103 and fabricated to the requirements of IPC-6018.

1.1 Purpose The requirements contained herein are intended to establish specific design details that **shall** be used in conjunction with IPC-2221 to produce designs intended to mount and attach components. The components may be through-hole, surface mount, fine pitch, ultra-fine pitch, array mounting or unpackaged bare die.

The base organic materials used may be homogeneous, reinforced, or used in combination with inorganic materials; the interconnections may be on single layers, double layers, or multilayered conductors. They may be any combination able to perform the desired physical, thermal, environmental, and electronic functions.

It is incumbent upon the printed board design engineer to work with material suppliers and to initiate a dialogue with a fabricator who has experience with specialty materials and fabrication processes required for manufacturing RF/Microwave designs. The designer should solicit feedback regarding producibility of design attributes to ensure design intent is achievable.

1.2 Document Hierarchy Document hierarchy **shall** be in accordance with the generic standard IPC-2221.

1.3 Presentation Presentation **shall** be in accordance with the generic standard IPC-2221.

1.4 Interpretation Interpretation **shall** be in accordance with the generic standard IPC-2221.

1.5 Definition of Terms The definition of all terms used herein **shall** be in accordance with IPC-T-50 and as defined herein.

1.5.1 Anisotropy The condition for a substance having differing values for properties, such as permittivity, depending on the direction within the material. Isotropy describes the case where a property is the same in all directions. Isotropy may exist in non-crystalline homogeneous (single phase) substances. In a microwave laminate based on a polymer composite, anisotropy of the dielectric layer exists.

1.5.2 Directional Coupler A device or structure which causes some of the energy propagating along one transmission line to be transferred to a second transmission line so that most of the transferred energy propagates in a specific direction along the second line. The other direction is considered isolated. At lower frequencies this function can be accomplished in a design with lumped capacitive and inductive elements while at microwave frequencies two stripline or microstrip traces that run parallel to each other for a certain distance can serve the purpose. One use for such devices is to sample amplitude or phase of a signal traveling in a specific direction.

1.5.3 Directivity The difference between the isolation and the coupling values of a directional coupler.

1.5.4 Distributed Component An electrical component with dimensions greater than or on the order of the wavelength of the propagating signal. The reactive and resistive electrical characteristics of such a component are said to be distributed.

1.5.5 Ground-to-Ground-Spacing Distance between ground planes in a stripline circuit.

1.5.6 Ground-to-Signal-Spacing Distance between ground and signal planes or conductors in a transmission line.

1.5.7 Impedance A measure of the opposition to the flow of alternating current in a circuit, equal to the ratio of the RMS electromotive force in the circuit to the RMS current produced by it. Impedance is usually represented in complex notation as $Z = R + jX$, where R is the ohmic resistance, X is the reactive, either inductive or capacitive, and j is $\sqrt{-1}$.

1.5.8 Lumped Circuit elements that are not distributed.

1.5.9 Open Circuit A high impedance condition that ideally exhibits 0 dB return loss and a reflection coefficient of 1.0.

1.5.10 Static Relative Permittivity The ratio of the capacitance (C_x) of a given configuration of electrodes with a specified dielectric, filling all the region of electro potential field, to the capacitance (C_v) of the same electrode configuration with a vacuum (or air) as the dielectric.