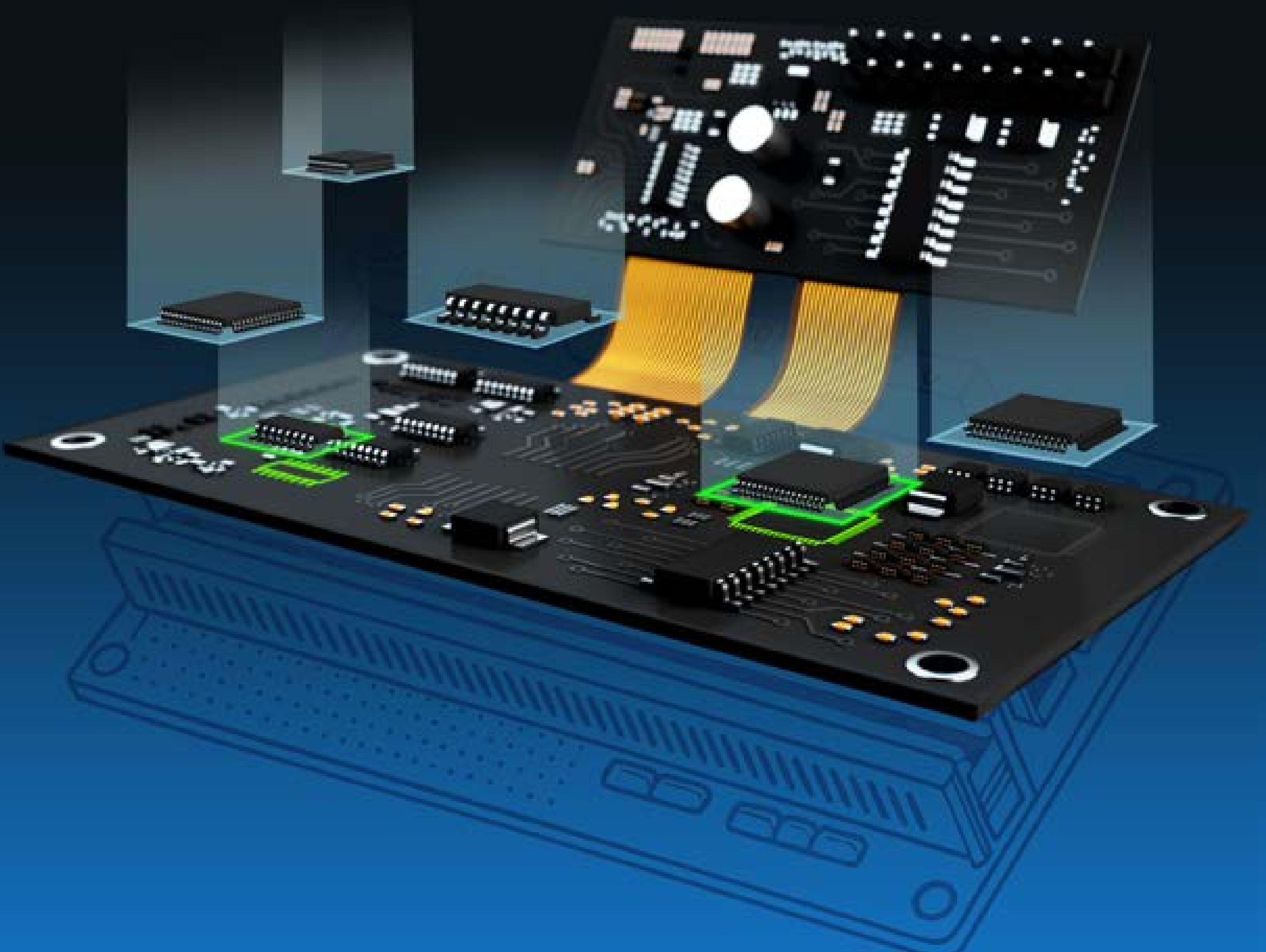
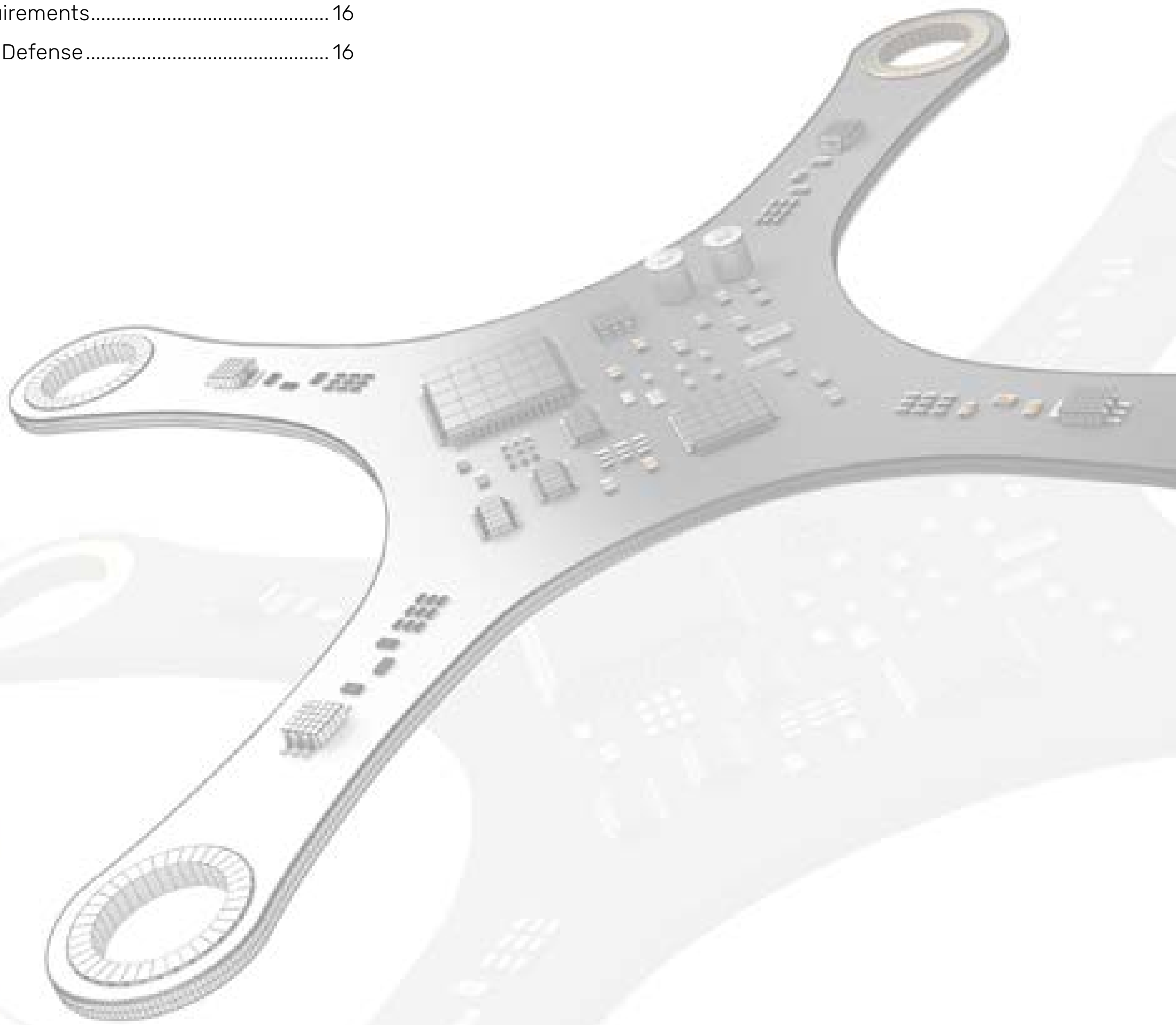
DESIGN **GUIDE**

Rigid-Flex PCB Design Review Checklist

A pre-fabrication design verification resource aligned with IPC-2223E, IPC-6013, IPC-2221, and IPC-TM-650



Contents



Overview

Rigid-flex PCB design sits at the intersection of mechanical engineering and electrical engineering in a way that standard rigid board design does not. In the flex zone, a trace routing decision impacts both impedance and long-term reliability simultaneously. A stackup choice made in the first week of a project determines whether the bend radius will be achievable, whether the PDN will perform, and whether the board will survive qualification testing, often before a single component has been placed. The consequences of getting these decisions wrong are difficult and expensive to reverse unlike rigid PCB designs where many issues can be corrected at the layout stage. Rigid-flex failures are frequently baked in at the stackup and floor planning stage, and only surface during fabrication, assembly, or environmental qualification.

This checklist provides a structured verification framework for rigid-flex PCB designs prior to fabrication release. It covers the ten design domains where rigid-flex errors most commonly originate: bend zone geometry and neutral axis design, stackup and material selection, flex zone trace routing, via and PTH placement, component placement relative to the bend zone, the rigid-to-flex transition zone, pre-layout mechanical simulation and physical bend testing, electrical analysis from impedance simulation through post-fabrication test, fabrication documentation, and design review sign-off. Each item is referenced to the governing IPC standard, primarily IPC-2223E, IPC-6013, IPC-2221, and IPC-TM-650, so designers and reviewers understand not just what to check but why it is required and what standard defines the acceptance criterion.

For designs destined for military, aerospace, medical, or automotive applications, the checklist extends into four industry-specific sections that cover requirements unique to those verticals: where MIL-PRF-50884 and MIL-PRF-31032 acceptance criteria differ from IPC-6013 Class 3, how outgassing limits and launch environment qualification change material selection and test requirements for space, how IEC 60601-1 creepage requirements and ISO 10993 biocompatibility constraints affect flex zone material choices for medical devices, and how AEC-Q200 thermal cycling profiles and ISO 26262 functional safety requirements impose specific design constraints on automotive rigid-flex assemblies. These sections cover only what changes because of the industry and does not duplicate the core checklist.

Checklist Sections

Section	Description
1. Bend Zone Design	Bend radius calculation per IPC-2223E for static and dynamic applications; bend zone construction rules including via keepouts, trace orientation, and trace stagger; neutral axis design and bookbinder construction requirements.
2. Stackup and Material Selection	Layer stackup architecture; adhesiveless polyimide and RA copper requirements for flex layers; no-flow prepreg at the rigid-to-flex boundary; polyimide coverlay specification and overlap; stiffener material, placement, and geometry.
3. Trace Routing	Flex zone routing rules for trace width, spacing, and curvature; crosshatch ground plane requirements; transition zone routing and strain relief fillets; controlled impedance simulation and test coupon requirements for flex zone stackups.
4. Via and PTH Design	Via placement prohibitions in dynamic flex zones; keepout enforcement from the transition line; annular ring and plating thickness requirements per IPC-6013 Class 2 and Class 3; teardrop pad requirements; plating void acceptance criteria.
5. Component Placement	Placement restrictions relative to bend zones and the transition boundary; solder joint stress management including underfill and staking; pre-bake protocol for polyimide moisture removal; assembly fixturing and 3D clearance verification.
6. Transition Zone	Mechanical taper and fillet requirements at the rigid-to-flex boundary; coverlay overlap and inspection range per IPC-2223E; stress relief features; staggered flex layer terminations and symmetrical stackup requirements.
7. Mechanical Analysis	Pre-layout FEA requirements for bend stress, solder joint strain, and trace corner radius optimization; vibration modal analysis and thermal cycling stress analysis; physical test requirements per IPC-TM-650 Methods 2.4.3, 2.4.8, and 2.6.7.2.
8. Electrical Analysis	Pre-layout signal integrity simulation using flex zone material properties; PDN current capacity and voltage drop analysis; post-fabrication test requirements including TDR, continuity, insulation resistance, HiPot, moisture resistance, and thermal stress coupons.

9. Fabrication Documentation	Required drawing callouts for bend zones, flex application type, stackup, impedance, stiffeners, and coverlay; design package completeness including layer map and test requirements; fabricator DFM review and capability confirmation.
10. Design Review Sign-Off	Multi-discipline approval record covering PCB design, signal integrity, mechanical engineering, manufacturing, and project lead review.
Industry-Specific Sections (complete only those applicable to your end-use application)	
A. Military and Defense	Requirements specific to rigid-flex construction under MIL-PRF-50884 and MIL-PRF-31032, including where acceptance criteria differ from IPC-6013 Class 3 at the transition zone, via construction, and coverlay; bend zone integrity verification under MIL-STD-810 environmental profiles; EMC ground plane continuity requirements under MIL-STD-461.
B. Aerospace and Space	Flex zone material changes required by outgassing limits (ASTM E595, NASA-STD-8739.4A); thermal vacuum and launch vibration qualification requirements specific to the rigid-to-flex transition zone; workmanship and conformal coating constraints for dynamic flex sections; IPC-6012ES acceptance criteria additions over IPC-6013 Class 3.
C. Medical Devices	ISO 10993 biocompatibility requirements for polyimide, coverlay adhesive, and stiffener materials in body-contact and implantable designs; IEC 60601-1 creepage and clearance impacts on flex zone trace spacing and coverlay CTI selection; IPC-6012EM acceptance criteria additions for life-critical rigid-flex PCBs; EMC ground plane continuity implications under IEC 60601-1-2.
D. Automotive and Functional Safety	RA copper and coverlay material requirements under AEC-Q200 and ISO 16750-4 thermal cycling profiles; flex conductor fatigue life under combined thermal and dynamic loading; ISO 26262 functional safety constraints on test point placement, single-point fault analysis at the transition zone, and Built-In Self Test (BIST) routing; conformal coating masking requirements for dynamic flex sections.

How to Use This Checklist

Review Sections 1 through 10 for every rigid-flex PCB design, regardless of end application. These sections are universal and apply to all industries and all IPC class levels. Items reference the governing IPC clause so the requirement can be verified against the source standard. Then complete the applicable industry-specific section or sections at the end of the document. Industry sections cover only what changes as a function of the end-use environment; they do not repeat core requirements.

Each checklist row contains the design requirement in the left column and the governing specification with the relevant standard citation in the center column. Mark each item Pass, Fail, or N/A in the right column. Yellow note rows flag items where specifications vary by application, require fabricator confirmation before finalizing, or where two applicable standards are in conflict. Green standard rows identify a specific IPC or industry standard clause that defines the governing acceptance criterion for the items in that category.

This checklist is a verification tool, not a substitute for the referenced standards. Designers are expected to have access to IPC-2223E as the primary design authority for rigid-flex PCBs. All items referencing IPC-6013 Class 3 assume that classification has been declared on the fabrication drawing before the checklist is completed; Class cannot be retroactively upgraded after fabrication.

1. Bend Zone Design

Governing standards: IPC-2223E (primary) and IPC-6013. The bend zone is the highest-risk region in any rigid-flex design and the leading cause of field failures. All bend parameters must be established before routing begins.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
1.1 Bend Radius Calculation		
Static bend radius (fold-once during assembly) calculated and documented	Minimum 6x total flex thickness for single-layer and double-layer; 12x for three or more flex layers. (IPC-2223E Section 4)	Select...
Dynamic bend radius (repeated flexing in operation) calculated and documented	Minimum 100x thickness single-layer; 150x double-layer; 200x multilayer. (IPC-2223E)	Select...
Bend ratio formula applied: r/h where r = minimum bend radius, h = total flex thickness	IPC-2223E governing formula. Confirm total flex thickness with fabricator before calculating. (IPC-2223E)	Select...
Note: Bend radius multipliers increase with layer count. IPC-2223E tables are authoritative. Always confirm with your fabricator as material choices affect the required radius.		
1.2 Bend Zone Construction Rules		
No plated through-holes or vias placed in the bend zone	Prohibited - vias crack under mechanical stress. (IPC-2223E)	Select...
Via keepout enforced from flex-to-rigid transition line	Minimum 0.050" to 0.100" (1.27–2.54 mm) from transition line. (IPC-2223E)	Select...
No components placed in active bend zones	Components create rigid stress concentration and damage solder joints. (IPC-2223E)	Select...
Traces routed perpendicular to the bend line	Minimizes tensile and compressive stress on conductors. (IPC-2223E Section 4)	Select...
No 90-degree or sharp-angle trace turns in flex zone	Sharp angles create stress concentration points. Use curved transitions. (IPC-2223E)	Select...
Traces staggered across layers in bend zone (not stacked)	Stacked traces create an I-beam effect, drastically reducing flexibility and increasing crack risk. (IPC-2223E)	Select...
Bend line and minimum bend radius dimensioned on fabrication drawing	Required callout; fabricator cannot verify compliance without this. (IPC-2223E)	Select...
1.3 Neutral Axis Design		
Flex layers positioned at the center of the stackup	Locates conductors at the neutral axis, minimizing bending stress. (IPC-2223E Section 4)	Select...
Conductors smaller than 10 mils positioned inside the neutral bend axis	Thin conductors withstand compression better than stretching. (IPC-2223E)	Select...
Copper balance maintained symmetrically in flex zone	Asymmetric copper causes board to curl toward the heavy side. (IPC-2223E)	Select...
Bookbinder (unbonded) construction specified for multilayer flex requiring tight bend radii	Required for tight radii with 3+ flex layers. (IPC-2223E)	Select...

2. Stackup and Material Selection

Governing standards: IPC-2223E (material guidance), IPC-4203/1 (coverlay), and IPC-6013 (qualification). Material decisions cannot be reversed after fabrication begins. Confirm the stackup with the fabricator before routing starts.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
2.1 Layer Stackup Architecture		
Stackup reviewed for balance: flex layers centered in the overall construction; rigid build-up above and below the flex zone approximately matched in thickness and copper weight	This is a manufacturing requirement, not purely a design preference. Flex layers should be located at or near the center of the total stackup. Unequal rigid build-up above and below the flex region creates differential CTE-driven stress during reflow and causes warping, a finding consistent across multiple fabricator design guides. A 6-layer rigid section above the flex and a 1-layer rigid section below is a candidate for warping and should be reviewed with the fabricator before committing to the stackup. Within the flex zone itself, conductors should be centered on the neutral axis to minimize bending strain. These are related but distinct requirements: neutral axis positioning governs bend performance; overall stackup balance governs reflow warping. Both must be addressed. Asymmetric layer counts are not automatically invalid but require explicit fabricator review and warping risk assessment. (IPC-2223E; fabricator DFM review)	Select...
All rigid sections share the same layer count and stackup	Mixed layer counts create differential thermal expansion and lamination problems. (IPC-2223E)	Select...
Power and ground plane pairs placed on adjacent layers	Maximizes distributed capacitance and minimizes PDN inductance. (IPC-2221)	Select...
Stackup diagram provided differentiating rigid and flex zones with all layer boundaries and material callouts	Required fabrication documentation. (IPC-2223E)	Select...
Air-gap (unbonded) construction specified for high-flexibility multilayer flex sections	Required for tight radii with multiple flex layers. (IPC-2223E)	Select...
2.2 Flex Layer Materials		
Adhesiveless polyimide core specified for flex layers	Adhesive-based cores have high CTE mismatch causing cracked vias. Adhesiveless cores are mandatory for dynamic applications. (IPC-2223E)	Select...
Standard: IPC-2223E: Adhesiveless flex cores are mandatory for dynamic flex applications. Acrylic adhesive thickness through the rigid portion must not exceed 10% of total construction thickness. (IPC-2223E)		
Rolled Annealed (RA) copper specified for all dynamic flex layers	RA copper has superior ductility and fatigue resistance vs. electrodeposited (ED) copper. Non-negotiable for dynamic flex. (IPC-2223E)	Select...
ED copper acceptable for rigid sections only (not in dynamic flex zones)	ED copper is more brittle; acceptable only where not subject to repeated bending. (IPC-2223E)	Select...
Copper weight that's appropriate for current and flexibility requirements	Min. 0.25 oz for flex zones. Conductor sizing per IPC-2221 current capacity tables. (IPC-2221; IPC-2223E)	Select...

2.3 Rigid Section Materials		
FR-4 specified for rigid sections (standard applications)	High-Tg FR-4 (Tg > 170 °C) required for IPC-6013 Class 3 / high-reliability. (IPC-6013; IPC-4101)	Select...
No-flow or low-flow prepreg specified at rigid-to-flex boundary	Prevents resin flow into flex zones during lamination. (IPC-2223E)	Select...
Acrylic adhesive thickness in rigid section does not exceed 10% of total construction	Explicit IPC-2223E requirement. Excess adhesive causes thermal expansion mismatch and via cracking. (IPC-2223E)	Select...
2.4 Coverlay		
Polyimide coverlay specified for flex zones (not standard LPI solder mask)	LPI solder mask cracks under repeated bending. Polyimide coverlay required. (IPC-4203/1; IPC-6013)	Select...
Coverlay engages rigid area by approximately 0.025" (0.64 mm) overlap	Explicit IPC-2223E requirement. Ensures sealed transition and prevents edge lifting. (IPC-2223E)	Select...
Coverlay thickness specified (typically 12.5 µm or 25 µm polyimide + adhesive)	Select based on dynamic vs. static use. (IPC-4203/1)	Select...
Laser-cut coverlay specified for fine-pitch component areas	Mechanical punching is too inaccurate for fine pitch. Laser cutting achieves approx. 0.2 mm minimum clearance. (IPC-2223E)	Select...
Standard: IPC-6013 acceptance criteria for coverlay: no adhesive voids that propagate under flexing, no lifted edges, no adhesive wicking beyond acceptable limits. (IPC-6013)		
2.5 Stiffeners		
Stiffeners specified under all connector mounting areas	Prevents mechanical stress on solder joints during connector mating/unmating. (IPC-2223E)	Select...
Stiffener material specified: FR-4 for components; polyimide for ZIF connectors or thin sections	(IPC-2223E)	Select...
Stiffeners do not extend into the active bend zone	Must not rigidize any area intended to flex. (IPC-2223E)	Select...
Stiffener overlap with coverlay defined (min. 30 mil / 0.76 mm)	Stiffener must lap onto coverlay for secure mechanical attachment. (IPC-2223E)	Select...
Rounded corners specified on all stiffener outlines	Sharp corners concentrate stress and can initiate cracking. (IPC-2223E)	Select...

3. Trace Routing

Governing standards: IPC-2223E (routing rules in flex zones) and IPC-2221 (conductor sizing). Routing decisions must account simultaneously for electrical performance and bending stress.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
3.1 Flex Zone Routing Rules		
Minimum trace width in flex zone meets fabricator minimum (typically 0.005" / 0.127 mm)	Wider traces improve durability and current capacity. (IPC-2223E)	Select...
Minimum trace spacing meets fabri-cator minimum (typically 0.006" / 0.152 mm)	Wider spacing reduces mechanical stress concentration. (IPC-2221; IPC-2223E)	Select...

Curved transitions used at all trace direction changes in flex zone	Reduces stress concentration at direction changes. (IPC-2223E Section 4)	Select...
Teardrop pad connections at all via-to-trace junctions in or near flex zones	Reduces stress at via-pad interface; mandatory for Class 3. (IPC-2223E; IPC-6013 Class 3)	Select...
Traces do not run parallel to the bend axis in the bend zone	Parallel traces are more susceptible to delamination and cracking. (IPC-2223E)	Select...
No large solid copper pours in flex or bend areas	Solid pours rigidize the flex zone. Use crosshatch pattern. (IPC-2223E)	Select...
3.2 Ground and Power Planes in Flex Zones		
Crosshatch copper pattern used for ground/power planes in flex zones	Maintains electrical continuity while preserving flexibility. (IPC-2223E)	Select...
Crosshatch geometry defined on fabrication drawing: hatch width (HW), hatch pitch (HP), and orientation angle explicitly specified	IPC-2223E requires crosshatch in flex zones but does not mandate specific geometry - parameters must be defined by the designer and confirmed against fabricator capability. Key constraints: (1) Hatch conductor width (HW): minimum 0.010" (0.25 mm) for standard fabricators; narrower than this risks etching non-uniformity. (2) Hatch pitch (HP): the longest dimension of any opening should not exceed 0.050" (1.27 mm) - larger openings reduce shielding effectiveness and create localized stiffness discontinuities. (3) Orientation: hatching at 45° to the bend axis is standard practice; hatching parallel or perpendicular to the bend axis concentrates stress at conductor junctions. (4) Copper fill percentage: flexibility improvement is proportional to copper removal - removing 30% of the copper on a single plane provides minimal flexibility gain; 60–70% removal produces meaningful improvement. HW/HP ratio determines fill percentage. (5) These parameters affect both mechanical flexibility and impedance - any change to hatch geometry on an impedance-controlled design requires re-simulation. Confirm final geometry with fabricator before routing. (IPC-2223E)	Select...
For impedance-controlled signals in flex zones: narrow solid reference strip specified beneath each signal trace in place of crosshatch plane	A full crosshatch plane cannot maintain a consistent reference for impedance-controlled signals. A narrow solid copper strip approximately 2x the signal trace width provides a defined reference impedance without fully rigidizing the flex area. This approach must be explicitly designed and called out, it cannot be assumed from a crosshatch fill. Verify impedance with simulation using the strip geometry. Remainder of the plane area uses crosshatch. (IPC-2223E)	Select...
3.3 Transition Zone Routing		
Trace width changes are gradual at the rigid-to-flex boundary (no abrupt neckdowns)	Abrupt changes create mechanical stress concentration and impedance discontinuities. (IPC-2223E)	Select...
Features on outer surfaces kept at least 0.025" (0.64 mm) from flex-to-rigid transition	Rolled edge at rigid-flex boundary can damage features placed too close. (IPC-2223E)	Select...
Strain relief fillets applied to traces at the rigid-to-flex boundary	Explicitly required per IPC-2223E design figures. (IPC-2223E)	Select...

3.4 Controlled Impedance in Flex Zones		
Controlled impedance target defined (typically 50 Ω single-ended, 90–100 Ω differential)	Polyimide Dk ~3.4; differs from FR-4 (Dk ~4.2–4.5). Calculations must use flex-zone material properties. (IPC-2223E)	Select...
Impedance test coupons specified on panel representing the flex zone stackup	Coupons must reflect the composite flex structure including coverlay. (IPC-TM-650 Method 2.5.5.7)	Select...
Impedance tolerance agreed with fabricator before routing	±10% is baseline achievable. ±5% is extremely difficult in flex zones due to material movement. (IPC-TM-650 Method 2.5.5.7)	Select...
Standard: IPC-TM-650 Method 2.5.5.7 defines TDR impedance testing. Method 2.5.5.12A covers signal loss. Both should be specified on the fabrication drawing for high-speed designs. (IPC-TM-650)		

4. Via and PTH Design

Governing standards: IPC-2223E (via placement) and IPC-6013 (plating and annular ring acceptance). Via placement relative to the flex zone and transition line is one of the most common sources of rigid-flex failures.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
4.1 Via Placement Rules		
No vias placed in dynamic flex zones	Strictly prohibited - vias crack under repeated bending. (IPC-2223E)	Select...
Vias in static flex zones reinforced with teardrop pads if used	Blind/buried vias preferred over PTH in flex areas. (IPC-2223E)	Select...
PTH/via keepout enforced from flex-to-rigid transition line (min. 0.050" / 1.27 mm)	IPC-2223E minimum. 0.100" (2.54 mm) recommended for additional margin. (IPC-2223E)	Select...
Blind and buried vias used in flex regions where interconnects are required	Less mechanically disruptive than PTH in flex areas. (IPC-2223E; IPC-6013)	Select...
4.2 Annular Ring and Plating Requirements		
Annular ring sized to meet IPC-6013 Class requirements	Class 2: controlled breakout permitted. Class 3: no fractured or lifted rings, no breakout. (IPC-6013; IPC-6012)	Select...
PTH copper plating thickness meets minimum per IPC-6013	Per IPC-6013 Class 3: minimum average hole wall thickness 0.001" (25.4 μm); minimum at any point no less than 0.0007" (17.8 μm). Class 2 minimum average: 0.0008" (20.3 μm). Confirm against IPC-6013 tables - these differ from IPC-6012 rigid board values. (IPC-6013)	Select...
Plating void criteria applied per IPC-6013 class	Class 3: zero voids in hole wall; no voids at the knee (pad-to-hole-wall transition) for any class. Class 2: up to 3 voids permitted in the sidewall provided total voided area does not exceed 5% of the hole wall surface. Class 1: up to 3 voids not exceeding 10% of sidewall area. (IPC-6013)	Select...
Teardrop pads at all via-to-trace junctions in or near flex zones	Mandatory for Class 3. (IPC-6013; IPC-2223E)	Select...
Pad size uses IPC-2221 formula: finished hole dia. + 2× min. annular ring + fabrication allowance	(IPC-2221; IPC-6012)	Select...

Vias on or near stiffener edges maintain 50 mil (1.27 mm) clearance from stiffener edge	Vias near stiffener boundaries are at elevated cracking risk due to differential stiffness. (IPC-2223E)	Select...
Standard: IPC-6013 Class 3: Copper plating measuring less than 80% of required thickness is a void. Max one void per panel. No voids at the interface of hole wall and internal conductive layer. (IPC-6013)		
Note: Button plating (pad plating) vs. panel plating - fabrication method affects how IPC-6013 thickness minimums are applied and measured: Unlike rigid boards where the entire panel surface receives copper during electroplating (panel plating), flex and rigid-flex circuits commonly use button plating (also called pad plating), in which copper is deposited only at the through-hole barrels and their surrounding pads and not across the full board surface. This preserves the ductility of the base copper in the flex conductors, which would be degraded by additional electrodeposited copper over the full surface. The consequence for inspection is that IPC-6013 plating thickness minimums apply to the hole wall and pad surfaces only. Inspectors and fabricators from a rigid-board background may incorrectly expect panel plating uniformity across the flex zone and misapply acceptance criteria. Confirm with the fabricator during DFM review (Section 9.3) whether button plating or panel plating is used, how they measure and certify compliance with IPC-6013 hole wall thickness minimums for each method, and whether their process qualifications were conducted under the same plating method specified for this design. (IPC-6013; IPC-2223E)		

5. Component Placement

Governing standards: IPC-2223E (placement restrictions) and IPC-7711/7721 (rework). Placement must account for mechanical stress at solder joints, assembly access, and board behavior during and after bending.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
5.1 Placement Restrictions		
No components placed in active bend zones	Fundamental IPC-2223E requirement - solder joints will fail during flexing. (IPC-2223E)	Select...
Components requiring flex-zone placement mounted on stiffeners	Stiffener must extend beyond the component footprint. (IPC-2223E)	Select...
Components placed at a minimum of 0.025" from flex-to-rigid transition on outer edge	Rollover at rigid edge can damage components placed too close. (IPC-2223E)	Select...
Heavy or tall components placed in rigid sections only	Mass and height create lever-arm stress on solder joints during flex and handling. (IPC-2223E)	Select...
5.2 Solder Joint Stress Management		
Epoxy underfill or staking applied to large SMT components near flex zones	Prevents solder joint failure from mechanical stress. (IPC-2223E)	Select...
FPC/ZIF connector insertion force direction verified against flex zone orientation	Insertion force must not stress the adjacent flex zone or solder joints. (IPC-2223E)	Select...
Test points placed in rigid sections only	Test points in flex zones create rigid stress concentrations. (IPC-2223E)	Select...
Fiducial markers placed in rigid sections	Flex-zone fiducials shift position when the board deflects during optical inspection. (IPC-2223E)	Select...
5.3 Assembly Process Requirements		
Pre-bake protocol defined for polyimide moisture removal before reflow	Polyimide absorbs up to 3% moisture by weight; moisture causes delamination in reflow. (IPC-6013)	Select...

Baking parameters specified: 100–120 °C for several hours immediately before reflow	Confirm exact protocol with fabricator and assembler. (IPC-6013)	Select...
Panelization waste tabs connect rigid sections only (not flex sections)	Flex section tabs compromise bend geometry during assembly handling. (IPC-2223E)	Select...
Assembly fixture or support specified for SMT placement on flex-adjacent rigid sections	Standard SMT conveyors cannot handle unrestrained flex sections; fixturing required. (IPC-7711)	Select...
3D clearance verified in all intended folded or bent configurations	Rigid sections must not contact each other or adjacent components in the assembled orientation. (IPC-2223E)	Select...

6. Rigid-to-Flex Transition Zone

Governing standards: IPC-2223E and IPC-6013E (added specific transition zone acceptance criteria in the E revision). The transition zone is the highest-stress location in a rigid-flex PCB and the most common failure point.

Design Requirement	**Specification / Standard Reference**	**Pass / Fail / N/A**
6.1 Mechanical Transition Design		
Gradual taper or fillet specified at rigid-to-flex boundary (no abrupt thickness changes)	Abrupt transitions concentrate stress. Taper required. (IPC-2223E)	Select...
Coverlay extends past the rigid-to-flex boundary by specified overlap (typically 0.5–1 mm)	Must engage the rigid section for mechanical anchoring. (IPC-2223E)	Select...
Transition zone inspection range noted on drawing: 3.0 mm from transition centerline	Manufacturing inspection scope per IPC-2223E. (IPC-2223E)	Select...
Rigid-to-flex boundary explicitly dimensioned on all fabrication drawings	Required. Fabricator cannot assume transition locations. (IPC-2223E)	Select...
Stress relief slots or diamond cutouts used where transition stress is elevated	Distributes bending stress over a larger area. (IPC-2223E)	Select...
Soda strawing acceptance criteria confirmed with fabricator and inspector before first article	Soda strawing, a lifting or tenting of the coverlay film around a conductor trace, creating a tube-like appearance, is an accepted condition unique to IPC-6013 and does not appear in IPC-6012. It results from the coverlay adhesive not fully wetting the conductor sidewalls during lamination and is considered a workmanship characteristic rather than a defect, provided the conductor is not exposed and the coverlay remains adhered at the pad openings. Inspectors and quality engineers from a rigid-board background will not find this condition in IPC-6012 and may incorrectly raise it as a non-conformance. Confirm before first article inspection that: (a) the applicable acceptance standard is IPC-6013, not IPC-6012; (b) the inspector has reviewed the IPC-6013 soda strawing acceptance criteria for the declared class; and (c) any fabrication drawing quality notes reference IPC-6013 and IPC-A-600 for visual acceptance, not IPC-6012. (IPC-6013; IPC-A-600)	Select...

Flex layer terminations staggered (not all ending at the same location)	Distributes stress across multiple planes. IPC-2223E includes staggered layer bands as a design figure. (IPC-2223E)	Select...
Symmetrical layer stackup maintained in flex zones	Prevents warping and maintains consistent bend behavior. (IPC-2223E)	Select...
No unbalanced copper distribution in rigid sections adjacent to flex transition	Unbalanced copper causes bowing or twisting during reflow, affecting transition geometry. (IPC-2223E)	Select...
6.2 Layer Transition Architecture		
Flex layer terminations staggered (not all ending at the same location)	Distributes stress across multiple planes. IPC-2223E includes staggered layer bands as a design figure. (IPC-2223E)	Select...
Symmetrical layer stackup maintained in flex zones	Prevents warping and maintains consistent bend behavior. (IPC-2223E)	Select...
No unbalanced copper distribution in rigid sections adjacent to flex transition	Unbalanced copper causes bowing or twisting during reflow, affecting transition geometry. (IPC-2223E)	Select...
Standard: IPC-6013E added specific acceptance criteria for the rigid-to-flex transition zone, recognizing it as the most failure-prone area. Imperfections in this zone that do not cause functional degradation are permitted within defined limits. (IPC-6013E)		

7. Mechanical Analysis

Governing standards: IPC-TM-650 Method 2.4.3 (flexural endurance), IPC-TM-650 Method 2.4.8 (peel strength), and IPC-TM-650 Method 2.6.7.2 (thermal shock). Dynamic applications with more than 1,000 bend cycles require formal simulation and test validation.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
7.1 Pre-Layout Mechanical Simulation		
FEA performed to simulate bending stress distribution across the flex zone	Target strain less than 0.3% across the flex region for dynamic applications. This is an industry best practice design target, not a limit defined in IPC-TM-650 2.4.3 - that method defines how to test flex endurance, not a design strain limit. The 0.3% figure represents the threshold below which conductor fatigue life is generally acceptable for copper in dynamic flex applications; designs exceeding this should be reassessed. (IPC-2223E; IPC-TM-650 2.4.3)	Select...
FEA model includes correct material properties: polyimide tensile strength (~231 MPa), RA copper, adhesive layers	If simulation approaches polyimide tensile limit, increase bend radius or change material. (IPC-2223E)	Select...
Stress analysis performed for both concave and convex bending orientations	Both tensile and compressive loads must be analyzed. (IPC-TM-650 2.4.3)	Select...
Solder joint strain verified below fatigue threshold for components adjacent to flex zones	Target solder joint strain <500 μ for QFP-class components with FR-4 stiffener. (IPC-9704)	Select...
Trace corner radius verified: rounded corners (min. 0.1 mm radius) reduce peak stress by ~40%	Rounding trace corners in the flex zone significantly extends fatigue life. (IPC-2223E)	Select...

Note: FEA is not universally required by IPC for all rigid-flex designs. For static fold-once designs, manual bend radius calculation per IPC-2223E is typically sufficient. For dynamic applications exceeding 1,000 cycles, FEA should be treated as mandatory before routing begins.		
7.2 Vibration and Thermal Analysis		
Modal analysis performed for designs subject to vibration environments	Rigid-flex boards exhibit different modal behavior than solid rigid boards due to hinge regions. (IPC-TM-650 2.4.3)	Select...
Dynamic bending environment fully defined: cycles, bend angle, frequency, operating temperature range	All four parameters are required for bend life prediction. (IPC-TM-650 2.4.3)	Select...
Thermal cycling stress analysis performed for designs operating over wide temperature ranges	CTE mismatch between polyimide, FR-4, and copper generates cyclic stress at the transition zone. (IPC-TM-650 2.6.7.2)	Select...
7.3 Physical Bend and Environmental Testing		
Flexural endurance test specified per IPC-TM-650 Method 2.4.3 for dynamic applications	Failure criterion: 10% increase in trace resistance. Required for IPC-6013 Class 3 dynamic products. (IPC-TM-650 2.4.3; IPC-6013)	Select...
Bend cycle test parameters match intended application: radius, angle, frequency, temperature	Test conditions must represent worst-case in-service conditions. (IPC-TM-650 2.4.3)	Select...
Peel strength test per IPC-TM-650 Method 2.4.8 specified for coverlay adhesion verification	Confirms coverlay adhesive bonding meets minimum requirements. (IPC-TM-650 2.4.8)	Select...
Thermal shock test per IPC-TM-650 Method 2.6.7.2 specified for temperature-cycling applications	-65 °C / +150 °C for 100 cycles. No delamination or solder joint failure permitted. (IPC-TM-650 2.6.7.2)	Select...
Standard: Key IPC-TM-650 mechanical test methods for rigid-flex: 2.4.3 (flex endurance), 2.4.8 (peel strength), 2.6.7.2 (thermal shock), 2.6.27 (thermal stress / reflow simulation). (IPC-TM-650)		

8. Electrical Analysis

Governing standards: IPC-TM-650 Methods 2.5.5.7 (TDR impedance), 2.5.7.2 (HiPot), 2.5.1 (insulation resistance), 2.6.3 (moisture/insulation resistance), and IPC-9257 (electrical flex circuit testing). High-frequency and high-reliability designs require both pre-layout simulation and post-fabrication electrical test verification.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
8.1 Signal Integrity Analysis - Pre-Layout		
Impedance simulation performed using flex-zone material properties (polyimide Dk ~3.4, not FR-4)	Flex and rigid zones must be simulated separately; using FR-4 Dk for flex zones produces incorrect impedance values. (IPC-2223E)	Select...
Insertion loss and return loss modelled for all high-speed differential pairs crossing the flex zone	Flex zone transitions create discontinuities not captured by standard rigid SI simulation. (IPC-TM-650 2.5.5.12A)	Select...
Crosstalk analysis performed for high-speed signals routed in parallel through the flex zone	Reduced ground plane coverage in flex zones increases coupling. Crosstalk analysis is simulation-based; no dedicated IPC-TM-650 test method exists for crosstalk. Verify against system signal integrity budget.	Select...

Differential pair routing length matched within tolerance across the rigid-to-flex boundary	IPC-2223E includes conductor pitch and differential pair design as explicit design figures. Length matching must account for Dk difference across the transition. (IPC-2223E)	Select...
8.2 Power Delivery Network (PDN) Analysis		
Current capacity of all power and ground conductors in flex zones verified per IPC-2221	Flex zone conductors must maintain adequate current capacity while permitting required bending. (IPC-2221)	Select...
Voltage drop analysis performed for power traces routed through flex zones	Thin flex conductors have higher resistance per unit length than rigid section traces. (IPC-2221)	Select...
PDN impedance target defined and verified for high-speed devices	Pre-layout simulation establishes target impedance profiles; post-layout analysis confirms physical implementation meets targets. (IPC-2221)	Select...
8.3 Post-Fabrication Electrical Testing		
TDR impedance test specified per IPC-TM-650 Method 2.5.5.7	Required for all impedance-controlled designs. Confirms impedance continuity across the rigid-to-flex transition. (IPC-TM-650 2.5.5.7)	Select...
Continuity test specified for all nets (flying probe or fixture)	Detects open circuits, trace breaks, and plating problems. (IPC-TM-650; IPC-6013)	Select...
Insulation resistance test specified per IPC-TM-650 Method 2.5.1	Min. 10 MΩ between adjacent isolated nets. (IPC-TM-650 2.5.1)	Select...
Dielectric withstand voltage (HiPot) test specified per IPC-TM-650 Method 2.5.7.2	Confirms insulation strength of thin dielectric layers in flex sections. (IPC-TM-650 2.5.7.2)	Select...
Moisture and insulation resistance test per IPC-TM-650 Method 2.6.3 for high-humidity environments	Required for outdoor and industrial applications. (IPC-TM-650 2.6.3)	Select...
Thermal stress coupon test per IPC-TM-650 Method 2.6.27 specified (reflow simulation)	Min. 6 reflow cycles at 260 °C peak; detects latent microvia and via barrel failures. Failure criterion: less than 5% change in resistance. Note: the 10% criterion applies to flex endurance Method 2.4.3, not this method. (IPC-TM-650 2.6.27)	Select...
Post-bend-cycle electrical continuity verified (resistance increase <10% defines failure per IPC-TM-650 2.4.3)	Verify all nets before and after specified bend cycle count. Failure criterion of 10% resistance increase applies to this flex endurance test only, not to thermal stress coupons. (IPC-TM-650 2.4.3)	Select...
Standard: Full IPC-TM-650 test method reference for rigid-flex electrical verification: 2.4.3 (flex endurance; failure = 10% resistance increase), 2.4.8 (peel strength), 2.5.1 (insulation resistance), 2.5.5.7 (TDR), 2.5.5.12A (signal loss), 2.5.7.2 (HiPot), 2.6.3 (moisture resistance), 2.6.7.2 (thermal shock), 2.6.27 (thermal stress / reflow simulation; failure = 5% resistance change). (IPC-TM-650)		

9. Fabrication Documentation and DFM

Governing standards: IPC-2223E (documentation requirements), IPC-6013 (qualification criteria), and IPC-A-600 (visual acceptance). Every critical rigid-flex parameter must be stated explicitly as ambiguity causes scrapped panels and non-conforming deliveries.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
9.1 Required Drawing Callouts		
Bend zone location and bend radius explicitly dimensioned on fabrication drawing	Minimum required callout per IPC-2223E; without this, fabricator cannot verify compliance. (IPC-2223E)	Select...
Flex section labelled with application type: static or dynamic	Drives material, copper type, and bend radius requirements. (IPC-2223E)	Select...
Separate fab notes provided for rigid sections and flex sections	IPC-2223E requires separate notes. Combined notes create ambiguity. (IPC-2223E)	Select...
Stackup diagram showing all layers with material callouts and layer boundaries	Must identify flex (PI), rigid (FR-4), adhesive, and prepreg layers. (IPC-2223E)	Select...
Impedance trace details specified: layer, trace width, target impedance, tolerance	Must reference the specific layer and dielectric stack in the flex zone. (IPC-2223E; IPC-TM-650 2.5.5.7)	Select...
Stiffener locations, materials, and thicknesses called out on drawing	All stiffener parameters must be explicit; cannot be inferred. (IPC-2223E)	Select...
Coverlay type, thickness, and overlap distance specified	Must distinguish between polyimide coverlay and flexible LPI solder mask. (IPC-2223E; IPC-4203/1)	Select...
IPC class specified on drawing: IPC-6013 Class 2 or Class 3	Class 3 for high-reliability applications. Cannot be retroactively upgraded after fabrication. (IPC-6013)	Select...
IPC-6013 Type declared on drawing alongside Class	IPC-6013 classifies flex and rigid-flex circuits into five Types that must be declared on the fabrication drawing: Type 1 (single-sided flex, no PTH), Type 2 (double-sided flex with PTH), Type 3 (multilayer flex without rigid sections), Type 4 (multilayer rigid-flex with PTH), Type 5 (multilayer rigid-flex, specific construction). The Type determines which fabrication and acceptance requirements apply - plating requirements, coverlay requirements, and inspection criteria all vary by Type. Declaring Class without Type is an incomplete callout. Most rigid-flex designs are Type 4. Confirm Type with the fabricator during DFM review and verify it is consistent with the stackup and construction specified. (IPC-6013)	Select...
Layer map provided identifying rigid vs. flex layers by Gerber layer number	Required beyond standard Gerbers for rigid-flex fabrication. (IPC-2223E)	Select...
Outline drawing marks bend zones, transition zones, and stiffener locations	Primary mechanical reference for fabrication and inspection. (IPC-2223E)	Select...
Test requirements documented: impedance coupons, bend cycle test, IST if required	IST required for Class 3 qualification. (IPC-TM-650)	Select...
Visual inspection criteria specified: IPC-A-600 class and IPC-6013 revision	IPC-A-600 is used jointly with IPC-6013 to determine visual acceptance. (IPC-A-600; IPC-6013)	Select...

9.2 Design Package Completeness		
Layer map provided identifying rigid vs. flex layers by Gerber layer number	Required beyond standard Gerbers for rigid-flex fabrication. (IPC-2223E)	Select...
Outline drawing marks bend zones, transition zones, and stiffener locations	Primary mechanical reference for fabrication and inspection. (IPC-2223E)	Select...
Test requirements documented: impedance coupons, bend cycle test, IST if required	IST required for Class 3 qualification. (IPC-TM-650)	Select...
Visual inspection criteria specified: IPC-A-600 class and IPC-6013 revision	IPC-A-600 is used jointly with IPC-6013 to determine visual acceptance. (IPC-A-600; IPC-6013)	Select...
9.3 Fabricator Engagement		
Preliminary stackup reviewed and confirmed with fabricator before routing begins	Stackup changes after routing is complete are expensive or impossible. (IPC-2223E)	Select...
Fabricator DFM review completed before final file release	DFM review identifies manufacturability issues not caught by DRC. (IPC-2223E)	Select...
Fabricator capabilities confirmed: impedance Cpk, microvia capability, registration accuracy	Verify specific capabilities before committing. (IPC-2223E)	Select...

10. Design Review Sign-Off

Role	Name	Signature	Date
PCB Designer			
Signal Integrity / PDN Engineer			
Mechanical Engineer			
Manufacturing / DFM Review			
Project Lead / Approver			

Industry-Specific Requirements

The following sections cover rigid-flex design requirements that change specifically because of the end-use industry, this includes different material choices, acceptance criteria, test requirements, or design rules imposed by the governing standard for that vertical. Complete only the section(s) applicable to your application. These sections do not repeat the core requirements in Sections 1–10; they add what those sections do not cover.

Section A: Military and Defense

MILITARY / DEFENSE	**Governing standards:** MIL-PRF-50884 (flex/rigid-flex specific); MIL-PRF-31032 (all PCBs, required for new programs); MIL-STD-810 (environmental); MIL-STD-461 (EMC); MIL-HDBK-454 (general electronic equipment guidelines).

The following items are specific to rigid-flex design for military applications. They address requirements that differ from or add to IPC-2223E and IPC-6013 Class 3 because of how MIL-PRF-50884 and MIL-PRF-31032 define acceptance, test, and construction criteria differently, particularly at the transition zone, via construction, and bend zone qualification under environmental stress.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
A.1 Material and Construction - Differences from IPC-2223E		
MIL-PRF-50884 specified as governing fabrication standard where required by program master drawing	MIL-PRF-50884 is the legacy flex and rigid-flex specific MIL spec. Many programs originally qualified to it cannot be converted to MIL-PRF-31032 without program office approval. Confirm which spec the master drawing references. (MIL-PRF-50884; MIL-PRF-31032)	Select...
Minimum annular ring confirmed against MIL-PRF-31032 requirements, which exceed IPC-6013 Class 3 in some configurations	MIL-PRF-31032 demands a larger minimum annular ring than IPC-6013 Class 3 in certain via size and layer configurations. Verify specific requirement against the governing MIL drawing. (MIL-PRF-31032)	Select...
Surface imperfection criteria applied per MIL-PRF-31032 - stricter than IPC-A-600 for measling, crazing, and foreign material	MIL-PRF-31032 mandates rejection of minor surface imperfections such as measling and crazing that IPC-A-600 Class 3 permits within defined limits. Affects coverlay and laminate acceptance at the transition zone. (MIL-PRF-31032)	Select...
Solder coating thickness confirmed against MIL-PRF-31032 requirements where they exceed IPC-6013 Class 3	MIL-PRF-31032 specifies stricter solder coating thickness minimums than IPC-6013 Class 3 for certain surface finishes. Confirm with the DLA-qualified fabricator. (MIL-PRF-31032)	Select...
Copper plating void criteria applied: void defined as plating measuring <80% of required thickness; max one void per panel; no voids at hole wall to internal layer interface	MIL-PRF-31032 defines void thresholds more explicitly than IPC-6013. These criteria apply to all PTH in rigid sections and are especially critical near the rigid-to-flex transition. (MIL-PRF-31032)	Select...
Standard: MIL-PRF-50884 is the original flex-specific military specification and still governs many active programs. MIL-PRF-31032 supersedes it for new program starts but imposes additional facility qualification requirements. IPC-6013 Class 3 is a prerequisite for both; it does not replace either. (MIL-PRF-50884; MIL-PRF-31032; IPC-6013)		
A.2 Transition Zone and Coverlay Acceptance		
Transition zone inspected and accepted per MIL-PRF-31032 visual criteria, not IPC-6013E alone	IPC-6013E added transition zone acceptance criteria that are not mirrored in MIL-PRF-31032. Applying IPC-6013E criteria to a MIL-PRF-31032 program can cause unwarranted rejections. Confirm which acceptance standard governs with the program quality engineer. (MIL-PRF-31032; IPC-6013E)	Select...
Coverlay adhesion and edge quality verified against MIL-PRF-50884 acceptance criteria	MIL-PRF-50884 defines specific acceptance limits for coverlay edge lifting, adhesive wicking, and void size in the flex zone that differ from IPC-4203/1. (MIL-PRF-50884; IPC-4203/1)	Select...
A.3 Environmental Qualification - Rigid-Flex Specific Test Requirements		
Bend zone integrity verified after MIL-STD-810 Method 514 vibration testing (random and sinusoidal)	Rigid-flex boards must demonstrate that the flex section and transition zone survive the vibration profile without trace cracking, coverlay delamination, or via failure. Test coupons must include the transition zone. (MIL-STD-810 Method 514)	Select...
Bend zone and transition zone integrity verified after MIL-STD-810 Method 516 mechanical shock testing	Pyrotechnic or transportation shock must not cause trace cracking or delamination in the flex zone or at the transition boundary. (MIL-STD-810 Method 516)	Select...
Thermal cycling per MIL-STD-810 Method 503 applied across full military temperature range (-55 °C to +125 °C) with electrical continuity monitoring	CTE mismatch at the rigid-to-flex transition is exacerbated by the wider military temperature range. Continuity monitoring during thermal cycling is required to detect intermittent failures. (MIL-STD-810 Method 503; IPC-TM-650 2.6.7.2)	Select...

High-Tg FR-4 (Tg > 170 °C) or polyimide rigid material specified where operating temperatures exceed standard FR-4 capability	Military temperature range of -55 °C to +125 °C can approach or exceed Tg of standard FR-4. High-Tg or polyimide rigid required for qualification. (MIL-PRF-31032; IPC-6013)	Select...
Humidity exposure per MIL-STD-810 Method 507 verified at the rigid-to-flex transition and coverlay	Humidity exposure can cause adhesive degradation and delamination at the transition zone, particularly for adhesive-based coverlay systems. (MIL-STD-810 Method 507; IPC-TM-650 2.6.3)	Select...
A.4 EMC Design Requirements Specific to Rigid-Flex Construction		
Ground plane continuity verified across the rigid-to-flex transition for MIL-STD-461 compliance	Gaps or interruptions in the ground plane at the transition zone create EMC vulnerabilities. Crosshatch planes in the flex zone must be designed to maintain adequate shielding effectiveness. (MIL-STD-461; IPC-2223E)	Select...
Shield layer or conductive coverlay specified in flex section for designs with radiated emission or susceptibility requirements	Where MIL-STD-461 radiated limits cannot be met with standard crosshatch construction, a dedicated shield layer in the flex section may be required. Material selection must preserve flex zone bend capability. (MIL-STD-461; IPC-2223E)	Select...
Critical: Applying IPC-6013E transition zone acceptance criteria to a MIL-PRF-31032 program without confirming with the program quality engineer can result in either unwarranted rejections (where IPC-6013E is more permissive) or non-conforming acceptance (where MIL-PRF-31032 is stricter). The governing document hierarchy must be resolved before inspection begins. (MIL-PRF-31032; IPC-6013E)		

Section B: Aerospace and Space

AEROSPACE / SPACE	**Governing standards:** MIL-PRF-50884 (flex/rigid-flex specific); MIL-PRF-31032 (all PCBs, required for new programs); MIL-STD-810 (environmental); MIL-STD-461 (EMC); MIL-HDBK-454 (general electronic equipment guidelines).

The following items are specific to rigid-flex design for aerospace and space applications. They address how the material choices for the flex zone, outgassing requirements, environmental test profiles, and workmanship standards impose constraints that go beyond IPC-2223E and IPC-6013 Class 3. The distinction between commercial aviation and space is significant and noted where requirements differ.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
B.1 Flex Zone Material Changes Required by Aerospace and Space Standards		
Polyimide substrate confirmed for all flex sections in space applications (FR-4 prohibited for space)	Standard FR-4 is prohibited in space applications. It lacks the thermal stability (-200 °C to +300 °C) and radiation tolerance required for orbital environments. The rigid sections may still use FR-4 or high-Tg variants for LEO/commercial launches; confirm with mission thermal analysis. (NASA-STD-8739.4A; IPC-2223E)	Select...
All adhesive materials in the flex zone confirmed against NASA GSFC outgassing database or ASTM E595 limits	In vacuum, outgassing from adhesives used in coverlay, stiffeners, and flex cores can contaminate optical sensors or solar panels. Limits: Total Mass Loss (TML) < 1.0%, Collected Volatile Condensable Material (CVCM) < 0.1% per ASTM E595. Polyimide base material typically passes; adhesive selection requires explicit verification. (ASTM E595; NASA-STD-8739.4A)	Select...
Acrylic-based coverlay adhesive reviewed for outgassing compliance in space applications	Acrylic adhesives used in standard polyimide coverlay systems may not meet ASTM E595 CVCM limits. Confirm material lot approval with NASA GSFC outgassing database before specifying. (ASTM E595; NASA-STD-8739.4A)	Select...

Stiffener adhesive in space designs confirmed against ASTM E595 outgassing limits	Stiffener bonding adhesives are a common outgassing source. All adhesives in contact with the board assembly must be evaluated. (ASTM E595; NASA-STD-8739.4A)	Select...
Radiation dose and shielding requirements for the flex section defined for the orbital environment	Polyimide is more radiation-tolerant than FR-4, but the adhesive layers and copper traces in the flex zone can degrade under total ionising dose (TID). Confirm requirements with mission radiation analysis. (NASA-STD-8739.4A; IPC-2223E)	Select...
B.2 Thermal and Environmental Qualification - Rigid-Flex Specific		
Thermal vacuum (TVAC) cycling defined with electrical continuity monitoring across the rigid-to-flex transition	TVAC cycling subjects the transition zone to simultaneous vacuum outgassing stress and thermal expansion cycling. Continuity monitoring during TVAC is required to detect intermittent failures at the transition zone. (GSFC-STD-7000; IPC-TM-650 2.6.7.2)	Select...
Thermal cycle profile for space covers -40 °C to +80 °C minimum for LEO; -55 °C to +125 °C for some GEO or launch applications	CTE mismatch at the rigid-to-flex transition is the primary failure driver under thermal cycling in space. The temperature range must be confirmed from the mission thermal model, not assumed. (GSFC-STD-7000; MIL-STD-1540E)	Select...
Bend zone and transition zone integrity verified after random vibration per GEVS (GSFC-STD-7000) or equivalent launch vehicle user manual	Rigid-flex transition zones are susceptible to delamination under launch vibration loads. Test must be conducted with the board in the deployed (bent) configuration if applicable. (GSFC-STD-7000; IPC-TM-650 2.4.3)	Select...
Pyrotechnic shock survivability of the flex zone and transition verified where separation events are in the mission profile	Pyrotechnic shock from stage separation or fairing jettison generates high-frequency, high-amplitude transients that can crack vias and delaminate the transition zone. (GSFC-STD-7000; MIL-STD-810 Method 516)	Select...
Flexural endurance test per IPC-TM-650 Method 2.4.3 performed on coupons that include the transition zone, not flex-only coupons	Aerospace qualification tests must include the transition zone in the test coupon. Flex-only coupon tests do not capture the highest-stress region of the assembly. (IPC-TM-650 2.4.3; IPC-6013)	Select...
B.3 Workmanship and Assembly - Rigid-Flex Specific Differences		
Soldering workmanship in the rigid sections adjacent to the flex zone performed per J-STD-001FS (space addendum)	J-STD-001FS imposes higher solder joint quality requirements than J-STD-001F for non-space applications. Specifically, solder bridges and cold joints near the transition zone are zero-defect for space hardware. (J-STD-001FS)	Select...
Conformal coating application verified to not bridge across the rigid-to-flex transition in a way that restricts intended bending	Conformal coating applied to the full assembly must not cross the transition zone in a manner that creates a rigid joint preventing the designed flex motion. Coating must be selectively masked at the flex section if a dynamic application. (NASA-STD-8739.1B; IPC-CC-830)	Select...
Moisture bake-out of the rigid-flex assembly performed immediately before integration into flight hardware	Polyimide in the flex zone absorbs moisture that causes outgassing in vacuum. Bake-out at 70–125 °C in vacuum or dry nitrogen is required immediately before integration. (NASA-STD-8739.4A; IPC-6013)	Select...
B.4 IPC-6012ES Aerospace Amendment - Additional Acceptance Criteria		
IPC-6012ES applied on top of IPC-6013 Class 3 for aerospace PCBs	IPC-6012ES is an addendum to IPC-6012 specifically for aerospace applications. It adds acceptance criteria beyond IPC-6013 Class 3 for conductor defects, registration, and via quality. (IPC-6012ES; IPC-6013)	Select...

Annular ring requirements per IPC-6012ES verified — more stringent than IPC-6013 Class 3 for certain configurations	IPC-6012ES tightens annular ring acceptance, particularly for external layers. Verify specific requirements against IPC-6012ES Table 3-4. (IPC-6012ES)	Select...
Conductor imperfection limits per IPC-6012ES verified for the flex zone conductor surfaces	IPC-6012ES reduces acceptable conductor scratches, nicks, and pinholes below IPC-6013 Class 3 limits for aerospace. (IPC-6012ES)	Select...
Standard: IPC-6012ES is the aerospace amendment to IPC-6012 and adds requirements specifically for PCBs used in avionics and space flight hardware, including stricter conductor and via quality limits than IPC-6013 Class 3. It must be specified in addition to, not instead of, IPC-6013 Class 3. (IPC-6012ES; IPC-6013)		

Section C: Medical Devices

MEDICAL	**Governing standards:** IPC-6012EM (medical electronics amendment); IEC 60601-1 (electrical safety, creepage and clearance); IEC 60601-1-2 (EMC collateral); ISO 10993 (biocompatibility, body-contact and implantable devices); ISO 14971 (risk management).

The following items are specific to rigid-flex design for medical device applications. They address how IEC 60601-1 creepage and clearance requirements interact with coverlay material selection, how ISO 10993 biocompatibility requirements constrain flex zone material choices, how sterilization compatibility affects coverlay and surface finish selection, and how IPC-6012EM adds acceptance criteria beyond IPC-6013 Class 3 for life-critical rigid-flex PCBs.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
C.1 Flex Zone Material Changes Required by Medical Standards		
Biocompatible polyimide confirmed per ISO 10993-5 (cytotoxicity) for body-contact or implantable designs	Polyimide is generally biocompatible but must be explicitly confirmed per ISO 10993-5 for any device where the flex section may contact tissue or body fluids. Standard polyimide used in industrial rigid-flex designs is not automatically ISO 10993 approved. (ISO 10993-5; ISO 10993-6)	Select...
Coverlay adhesive confirmed for biocompatibility per ISO 10993-10 (sensitization) for body-contact applications	Acrylic coverlay adhesives are not automatically biocompatible. ISO 10993-10 sensitization testing is required for any adhesive in a body-contact device. (ISO 10993-10)	Select...
Surface finish selected for compatibility with the intended sterilization method (EtO gas, gamma radiation, or autoclave)	ENIG and ENEPIG are generally sterilization compatible. OSP surface finish can degrade under gamma radiation and EtO exposure. The sterilization method must be confirmed before finalizing the surface finish specification. (IPC-6012EM; ISO 11135; ISO 11137)	Select...
Parylene C conformal coating specified for implantable or surgically adjacent flex section surfaces	Parylene C provides a biocompatible, sterilization-resistant, pinhole-free coating and is the standard for implantable and surgically adjacent PCBAs. Standard acrylic or urethane conformal coatings are not acceptable for implantable applications. (IPC-CC-830; ISO 10993-5)	Select...
Stiffener adhesive confirmed for biocompatibility where the stiffener is in or adjacent to a body-contact region	Stiffener adhesives are often overlooked in biocompatibility assessments. All materials in a body-contact device must be evaluated. (ISO 10993; IPC-2223E)	Select...

C.2 IEC 60601-1 Creepage and Clearance - Impact on Flex Zone and Coverlay Design		
IEC 60601-1 creepage and clearance distances implemented in PCB DRC rules before layout of the flex zone	IEC 60601-1 defines creepage and clearance distances based on working voltage, pollution degree, and rated impulse voltage. These distances are typically larger than IPC-2221 minimums and must be added as DRC constraints in the CAD tool before flex zone routing begins. (IEC 60601-1)	Select...
CTI (Comparative Tracking Index) of the polyimide substrate and coverlay confirmed against IEC 60601-1 creepage requirements	IEC 60601-1 requires increased creepage distance for materials with lower CTI. The CTI group of the selected polyimide and coverlay must be confirmed against the required creepage, as using a lower-CTI material without adjusting trace spacing will constitute a design violation. (IEC 60601-1)	Select...
Leakage current path analysis performed for the flex section, particularly at the rigid-to-flex transition	The rigid-to-flex transition introduces a change in dielectric thickness and material. IEC 60601-1 leakage current analysis must account for the composite structure at the transition zone, not just the rigid sections. (IEC 60601-1)	Select...
Functional Earth (FE) and Protective Earth (PE) ground architecture confirmed to not create leakage current paths through the flex zone	Using chassis ground indiscriminately through the flex zone can increase leakage current risk. FE and PE must be routed separately through the rigid sections where possible, or the flex zone routing reviewed against IEC 60601-1 leakage current limits. (IEC 60601-1)	Select...
C.3 IPC-6012EM - Additional Acceptance Criteria for Medical Rigid-Flex PCBs		
IPC-6012EM applied on top of IPC-6013 Class 3 for life-critical medical rigid-flex PCBs	IPC-6012EM is specifically for PCBs in medical electrical equipment where failure can directly endanger life. It adds acceptance criteria beyond IPC-6013 Class 3. Applies to Class III medical devices and implantable devices. (IPC-6012EM; IPC-6013)	Select...
Conductor quality limits per IPC-6012EM verified for flex zone conductors	IPC-6012EM tightens the acceptance criteria for conductor nicks, scratches, and pinholes below IPC-6013 Class 3 limits for life-critical applications. (IPC-6012EM)	Select...
Via quality and plating thickness confirmed against IPC-6012EM requirements	IPC-6012EM adds requirements for via plating uniformity and void acceptance that exceed IPC-6013 Class 3 for medical applications. (IPC-6012EM; IPC-6013)	Select...
C.4 EMC Design - IEC 60601-1-2 Implications for Rigid-Flex Construction		
Crosshatch ground plane in flex zone evaluated for shielding effectiveness against IEC 60601-1-2 immunity requirements	The crosshatch ground plane required in the flex zone for flexibility reduces shielding effectiveness compared to a solid plane. IEC 60601-1-2 immunity requirements must be verified with the reduced ground coverage that crosshatch provides. (IEC 60601-1-2; IPC-2223E)	Select...
Ground plane continuity across the rigid-to-flex transition verified for IEC 60601-1-2 conducted immunity compliance	Gaps or impedance discontinuities in the ground plane at the transition zone can create RF immunity vulnerabilities. (IEC 60601-1-2; IPC-2223E)	Select...
Shield layer evaluated for flex sections carrying signals relevant to IEC 60601-1-2 radiated emission limits	Where a flex section carries high-frequency signals, a dedicated thin shield layer within the flex section may be needed to meet IEC 60601-1-2 radiated emission limits. Material and thickness must be compatible with the required bend radius. (IEC 60601-1-2; IPC-2223E)	Select...

Critical: IPC-6012EM applies only to rigid-flex PCBs in medical electrical equipment where PCB failure can directly endanger patient life. It does not replace IPC-6013 Class 3, both must be specified. If the device classification (Class I, II, or III) has not been confirmed, the applicable acceptance standard cannot be determined. Confirm FDA or EU MDR device classification before specifying the fabrication standard. (IPC-6012EM; IPC-6013; FDA 21 CFR Part 860)

Section D: Automotive and Functional Safety

AUTOMOTIVE	**Governing standards:** AEC-Q200 (passive component qualification); ISO 26262:2018 (functional safety, ASIL A–D); ISO 16750-3/4 (environmental and mechanical loads); IPC-6013 Class 2 or 3 per application; JEDEC JESD22 (environmental stress testing).

The following items are specific to rigid-flex design for automotive applications. They address how AEC-Q200 thermal cycling requirements, the wide automotive temperature range (-40 °C to +125 °C or +150 °C), ISO 26262 functional safety constraints, and ISO 16750 environmental loads impose specific design and test requirements on the flex zone, transition zone, and component placement that do not apply to commercial rigid-flex designs.

Design Requirement	Specification / Standard Reference	Pass / Fail / N/A
D.1 Flex Zone Material and Construction - Automotive Temperature Range		
RA copper confirmed for all flex sections subject to the full automotive thermal cycling range (-40 °C to +125 °C)	The AEC-Q200 and ISO 16750-4 thermal cycling profile (-40 °C to +125 °C, Grade 2) imposes fatigue cycling on flex conductors beyond what commercial dynamic flex applications require. RA copper is mandatory for any flex section that will experience this temperature range in operation. (AEC-Q200; IPC-2223E)	Select...
High-Tg FR-4 (Tg > 170 °C) or polyimide rigid material specified for under-hood applications (continuous +150 °C operation)	Standard FR-4 (Tg ~130–140 °C) approaches or exceeds its glass transition temperature in under-hood environments. AEC-Q200 Grade 0 requires +150 °C capability. The rigid sections must use High-Tg FR-4 or polyimide. (AEC-Q200; ISO 16750-4; IPC-4101)	Select...
Adhesiveless polyimide core confirmed specifically for flex sections in engine compartment or powertrain applications	Adhesive-based flex cores have lower thermal stability than adhesiveless constructions. For Grade 0 (-40 °C to +150 °C) applications, adhesiveless cores are required not only for dynamic reasons (IPC-2223E) but also for thermal stability. (IPC-2223E; AEC-Q200)	Select...
Coverlay material confirmed for continuous temperature rating matching the operating environment	Standard acrylic-adhesive polyimide coverlay is rated to approximately +105 °C to +130 °C continuous. Under-hood applications may require coverlay with a higher-temperature adhesive system. Confirm material rating against ISO 16750-4 temperature profile. (ISO 16750-4; IPC-4203/1)	Select...
D.2 Bend Zone and Flex Section Design Under ISO 16750 Environmental Loads		
Bend zone integrity verified after ISO 16750-3 vibration profile: vehicle body (20–2000 Hz random) or powertrain (10–2000 Hz)	ISO 16750-3 defines separate vibration profiles for body, chassis, and powertrain mounting locations. The flex zone and transition zone must survive the applicable profile without trace cracking or delamination. Test coupons must include the transition zone. (ISO 16750-3; IPC-TM-650 2.4.3)	Select...
Mechanical shock survivability of the flex zone verified per ISO 16750-3 shock test	ISO 16750-3 defines shock pulses (e.g., half-sine, 50 g, 11 ms) representative of road events and assembly handling. Rigid-flex transition zones must survive without via cracking or coverlay delamination. (ISO 16750-3; IPC-TM-650 2.4.3)	Select...
Thermal cycling per ISO 16750-4 performed across the full automotive temperature range with electrical continuity monitoring at the flex zone	Automotive thermal cycling (-40 °C to +125 °C or +150 °C) combined with the flex section's CTE mismatch at the transition zone requires continuity monitoring during test to detect intermittent failures. (ISO 16750-4; IPC-TM-650 2.6.7.2)	Select...
Humidity and condensation testing per ISO 16750-4 verified at the rigid-to-flex transition and coverlay	Automotive PCBs in non-sealed enclosures are exposed to condensation cycling. The transition zone and coverlay overlap are potential ingress points. (ISO 16750-4; IPC-TM-650 2.6.3)	Select...

Flex conductor fatigue life calculated for the combined effect of thermal cycling and dynamic flex motion where both occur simultaneously	Automotive applications where the rigid-flex board both flexes in operation and experiences thermal cycling (e.g., articulating camera mounts, door assemblies) must verify conductor fatigue life under the combined loading, not each load independently. (IPC-TM-650 2.4.3; AEC-Q200)	Select...
D.3 ISO 26262 Functional Safety - Rigid-Flex Specific Design Constraints		
ASIL level confirmed for the rigid-flex assembly before design begins; ASIL determines acceptable single-point fault tolerance	ISO 26262 Part 3 HARA assigns ASIL A, B, C, or D to each safety-related function. The ASIL level determines the hardware architectural metrics (SPFM, LFM) and PMHF target that the PCB design must support. (ISO 26262:2018 Part 3)	Select...
Test point placement for ASIL-rated diagnostic circuits confirmed to rigid sections only	ISO 26262 requires diagnostic coverage for ASIL-rated functions. Test points enabling in-circuit diagnostic access must be placed in rigid sections as placing them in flex zones creates stress concentrations and may be inaccessible in the assembled configuration. (ISO 26262 Part 5; IPC-2223E)	Select...
Signal routing for safety-critical differential pairs through the flex zone evaluated for impedance continuity and crosstalk relative to ASIL diagnostic coverage targets	For ASIL C and D functions, signal faults caused by impedance discontinuities or crosstalk at the rigid-to-flex transition must be either tolerable (per HARA) or detectable by a diagnostic mechanism. The flex zone transition is a potential single-point fault source. (ISO 26262 Part 5; IPC-TM-650 2.5.5.7)	Select...
Built-In Self Test (BIST) or equivalent diagnostic for ASIL C and D circuits routed to accessible test points in rigid sections only	BIST signal routing must terminate at test points in rigid sections. Any BIST signal trace crossing a flex zone transition must be evaluated for impedance continuity failure modes that could mask a safety fault. (ISO 26262 Part 5; IPC-2223E)	Select...
Flex zone single-point fault analysis performed: a flex conductor open or short at the transition zone identified as a potential ASIL-relevant failure mode	The rigid-to-flex transition is the most likely location for a flex PCB conductor failure. For ASIL-rated designs, this failure mode must appear in the FMEDA and either be mitigated by redundant routing or declared tolerable within the ASIL budget. (ISO 26262 Part 9; IPC-TM-650 2.4.3)	Select...
D.4 Conformal Coating and Environmental Protection for Automotive Flex Sections		
Conformal coating specified to not bridge across the rigid-to-flex transition in a way that restricts intended dynamic bending	Automotive conformal coating (typically acrylic or urethane per IPC-CC-830) applied to the full assembly must be selectively masked at any flex section intended to move in operation. A coating bridge across a dynamic flex section will fail by cracking, creating a potential contamination path. (IPC-CC-830; ISO 16750-4)	Select...
Conformal coating thickness and coverage confirmed at the rigid-to-flex transition to prevent moisture ingress at this high-stress boundary	The transition zone is the most mechanically active boundary on the board. Conformal coating must fully cover the transition zone edge without creating a bridge that restricts bending. (IPC-CC-830; ISO 16750-4; IPC-2223E)	Select...
Standard: AEC-Q200 revision D is the current automotive passive component qualification standard. For rigid-flex designs subject to the full automotive temperature range, AEC-Q200 Grade 2 (-40 °C to +125 °C) is the baseline; Grade 0 (-40 °C to +150 °C) applies to under-hood and powertrain applications. Passive component qualification must account for the thermal cycling stress the flex section imposes on component leads and solder joints adjacent to the flex zone. (AEC-Q200; ISO 16750-4)		

Standards Referenced in This Checklist

CORE SECTIONS 1–10: IPC-2223E (primary rigid-flex design standard) | IPC-6013 / IPC-6013E (fabrication quality and acceptance) | IPC-2221 (conductor sizing, annular ring formula) | IPC-4203/1 (coverlay materials) | IPC-A-600 (visual acceptance) | IPC-4101 (base material specification) | IPC-7711/7721 (rework) | IPC-9257 (electrical flex circuit testing) | IPC-TM-650 Methods 2.4.3, 2.4.8, 2.5.1, 2.5.5.7, 2.5.5.12A, 2.5.7.2, 2.6.3, 2.6.7.2, 2.6.27 | IPC-9704 (solder joint fatigue)

SECTION A - MILITARY: MIL-PRF-50884 (flex/rigid-flex) | MIL-PRF-31032 (all PCBs) | MIL-HDBK-454 (general EEE guidelines) | MIL-STD-810 Methods 503, 514, 516 | MIL-STD-461

SECTION B - AEROSPACE/SPACE: IPC-6012ES (aerospace amendment) | J-STD-001FS (space addendum) | NASA-STD-8739.1B (polymeric applications) | NASA-STD-8739.4A (flight polymer materials) | GSFC-STD-7000 GEVS (environmental verification) | MIL-STD-1540E (space product verification) | ASTM E595 (outgassing) | IPC-CC-830 (conformal coating) | ECSS-Q-ST-70-11 (European space soldering)

SECTION C - MEDICAL: IPC-6012EM (medical electronics amendment) | IEC 60601-1 (electrical safety) | IEC 60601-1-2 (EMC collateral standard) | ISO 10993-5 (cytotoxicity) | ISO 10993-6 (implantation) | ISO 10993-10 (sensitization) | ISO 14971 (risk management) | ISO 11135 (EtO sterilization) | ISO 11137 (radiation sterilization) | IPC-CC-830 (conformal coating)

SECTION D - AUTOMOTIVE: AEC-Q200 (passive component qualification) | ISO 26262:2018 Parts 3, 5, 9 (functional safety) | ISO 16750-3 (mechanical loads) | ISO 16750-4 (climatic loads) | IPC-CC-830 (conformal coating) | JEDEC JESD22 (environmental stress testing)

Rigid-Flex PCB Design Glossary

Terminology and definitions for rigid-flex PCB design, fabrication, and qualification

Referenced standards: IPC-2223E, IPC-6013, IPC-6012EM, IPC-6012ES, IPC-4203/1, IPC-2221, IPC-4101, IPC-TM-650, MIL-PRF-31032, MIL-PRF-50884, MIL-STD-810, ISO 26262, AEC-Q200

This glossary defines the technical terms used in the Rigid-Flex PCB Design Review Checklist and in the referenced IPC and industry standards. Definitions are written to reflect the specific meaning of each term in the context of rigid-flex PCB design. Where a term is formally defined in a published standard, the governing standard is cited. Terms that are used informally in the industry but are not formally defined in IPC standards are identified as such.

Terms are listed alphabetically. The standard citation at the end of each definition identifies the primary governing document for that term, not an exhaustive list of every document that references it.

Term	Definition
A	
Acrylic Adhesive	A pressure-sensitive adhesive used to bond polyimide coverlay to the flex conductor layer and to bond flex layers to rigid sections. In rigid-flex construction, the total acrylic adhesive thickness through the rigid portion must not exceed 10% of the total board construction thickness. Acrylic adhesive systems have inferior thermal stability compared to adhesiveless constructions and are prohibited in dynamic flex cores. — **IPC-2223E**
Adhesiveless Flex Core	A flex laminate in which the copper is bonded directly to the polyimide base film without an intermediate adhesive layer, typically by sputtering or electrodeposition. Adhesiveless cores have significantly lower coefficient of thermal expansion mismatch than adhesive-based systems, making them mandatory for dynamic flex applications to prevent via cracking and delamination under thermal and mechanical cycling. — **IPC-2223E**
AEC-Q200	Stress Test Qualification for Passive Components. An automotive electronics council qualification standard that defines the stress test requirements for passive components (resistors, capacitors, inductors, and similar) intended for use in automotive applications. AEC-Q200 certified components exhibit approximately 10 times lower failure rates than industrial-grade equivalents under automotive environmental conditions. Applies to all passive components on rigid-flex PCBs designed for automotive use. AEC-Q200 Grade 2 covers -40 °C to +125 °C; Grade 0 covers -40 °C to +150 °C for under-hood applications. — **AEC-Q200**

ASIL (Automotive Safety Integrity Level)	A risk classification defined by ISO 26262 for road vehicle functional safety. ASIL levels range from A (lowest) to D (highest) and are determined through a Hazard Analysis and Risk Assessment (HARA). The ASIL level assigned to a function drives hardware architectural requirements including single-point fault metrics, latent fault metrics, and probabilistic metric for hardware failures (PMHF). PCB design decisions including test point placement, diagnostic routing, and signal integrity must be consistent with the ASIL target for safety-related circuits. — I**SO 26262:2018 Part 3**
ASTM E595	Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment. Defines the test procedure used to qualify materials for use in space applications. Acceptance limits are Total Mass Loss (TML) less than 1.0% and Collected Volatile Condensable Material (CVCM) less than 0.1% of the initial specimen mass. All polymer materials used in the flex zone of a space-grade rigid-flex PCB (including polyimide base film, coverlay adhesive, stiffener adhesive, and conformal coating) must meet these limits. — **ASTM E595**
B	
Bend Radius	The radius of curvature at the innermost surface of the flex zone when bent. IPC-2223E specifies minimum bend radius as a multiple of total flex thickness: for static (fold-once) applications, 6x for single-layer and double-layer constructions, 12x for three or more flex layers. For dynamic (repeated bending) applications: 100x for single-layer, 150x for double-layer, 200x for multilayer. Bend radius is the most fundamental design parameter in any rigid-flex or flex circuit design and must be calculated before routing begins. — **IPC-2223E Section 4**
Bend Ratio	The ratio r/h, where r is the minimum bend radius and h is the total flex thickness. The bend ratio quantitatively describes the severity of bending imposed on the flex section and is used in IPC-2223E tables to determine material and construction requirements. — **IPC-2223E**
Bend Zone	The region of a rigid-flex or flex circuit that is designed to flex during installation or operation. The bend zone is governed by explicit design rules covering via prohibition, trace orientation, copper pour prohibition, component exclusion, and neutral axis management. It is the highest-stress region of any rigid-flex PCB and the primary location of field failures. The bend zone must be explicitly dimensioned on the fabrication drawing. — **IPC-2223E**
BIST (Built-In Self Test)	A design technique in which diagnostic circuitry is integrated within the PCB or electronic assembly to test its own functionality during operation or power-up. Required for ASIL C and ASIL D rated functions under ISO 26262 to detect latent faults. For rigid-flex PCBs, BIST signal routing must terminate at test points located exclusively in the rigid sections. Any BIST signal trace crossing a flex zone transition must be evaluated as a potential single-point fault source in the FMEDA. — **ISO 26262:2018 Part 5**
Bookbinder Construction	A multilayer flex construction in which the individual flex layers are not bonded together through the bend zone, allowing them to slide relative to one another during bending. This construction is required for multilayer flex sections with three or more layers requiring tight bend radii, because bonded multilayer flex forces all layers to share the same bend radius, dramatically increasing strain on the outermost layers. — **IPC-2223E**
C	
CoC (Certificate of Conformance)	A document provided by a manufacturer certifying that a delivered product meets the requirements of the applicable specification, drawing, or contract. For military PCB programs under MIL-PRF-31032 and MIL-PRF-50884, a CoC is required for each production lot and must reference the specific standard revision, class, and qualification test data. A CoC does not replace lot sampling or inspection but supplements the traceability record. — **MIL-PRF-31032; MIL-PRF-50884**

Crazing	A laminate condition in which interconnected microcracks appear within the glass fiber reinforcement below the surface of the base material, typically caused by mechanical stress, thermal shock, or excessive drilling parameters. Crazing is visible as a white, web-like pattern beneath the board surface. MIL-PRF-31032 defines rejection criteria for crazing that are stricter than IPC-A-600 Class 3. In rigid-flex PCBs, crazing is a particular risk at the rigid-to-flex transition zone where differential thermal expansion generates high inter-laminar stress. — **IPC-A-600; MIL-PRF-31032**
Creepage	The shortest distance along the surface of a solid insulating material between two conductive parts. IEC 60601-1 defines minimum creepage distances for medical electrical equipment based on working voltage, pollution degree, and the Comparative Tracking Index (CTI) of the insulating material. For rigid-flex PCBs in medical applications, creepage requirements must be incorporated into DRC rules before flex zone routing begins. Creepage is a surface measurement and must not be confused with clearance, which is the shortest distance through air. — **IEC 60601-1; IEC 60112**
CTI (Comparative Tracking Index)	A measure of the resistance of a solid electrical insulating material to tracking (the formation of a conductive carbon path across its surface) under the influence of electric voltage and a contaminating electrolyte. IEC 60601-1 uses CTI groupings to determine required creepage distances for medical electrical equipment. A lower CTI material requires a greater creepage distance for the same working voltage. The CTI of the polyimide substrate and coverlay must be confirmed against IEC 60601-1 creepage requirements for medical device designs. — **IEC 60601-1; IEC 60112**
CTE (Coefficient of Thermal Expansion)	The rate at which a material expands or contracts per degree of temperature change, expressed in parts per million per degree Celsius (ppm/°C). CTE mismatch between dissimilar materials bonded together - for example, polyimide flex core and FR-4 rigid section at the transition zone - generates mechanical stress during thermal cycling. Managing CTE mismatch at the rigid-to-flex boundary is a primary concern in rigid-flex stackup design. — **IPC-2223E; IPC-6013**
CVCM (Collected Volatile Condensable Material)	The fraction of a material's initial mass that outgasses in vacuum and condenses on a collector surface maintained at a specified temperature. CVCM is one of the two acceptance metrics under ASTM E595 for space-grade materials. The limit is less than 0.1% of initial specimen mass. CVCM is more critical than TML for space applications because condensed volatile material can deposit on optical surfaces, thermal radiators, and solar cells, causing permanent performance degradation. — **ASTM E595; NASA-STD-8739.4A**
Coverlay	A flexible protective layer applied to the outer surfaces of the flex zone in place of solder mask. Coverlay is constructed from a polyimide film with an adhesive layer and is laminated over the conductor pattern to protect it and define the solder pad openings. Polyimide coverlay is mandatory for flex zones; standard liquid photoimageable (LPI) solder mask cracks under repeated bending and is not acceptable. Coverlay must overlap the rigid section by approximately 0.025 inch (0.64 mm) to ensure a sealed transition. — **IPC-4203/1; IPC-2223E; IPC-6013**
Cross-Hatch Copper	A conductor pattern used for ground and power planes in the flex zone in which the copper is patterned as a grid or mesh rather than a solid fill. Crosshatch planes maintain electrical continuity while preserving the mechanical flexibility of the flex section. Solid copper pours are prohibited in the flex and bend zones because they act as structural elements that increase bending stiffness and shift the neutral axis. — **IPC-2223E**

D	
DFMEA (Design Failure Mode and Effects Analysis)	A structured analytical method for identifying potential failure modes in a design, their effects on system function, and their causes. Required for automotive designs per AIAG-VDA FMEA methodology and for medical devices per ISO 14971. For rigid-flex PCBs, the DFMEA must include flex zone conductor failure modes, particularly open circuits at the transition zone, as these represent single-point fault candidates in safety-critical designs. Any design change requires the DFMEA to be updated before re-release. — **ISO 14971; ISO 26262:2018 Part 9; AIAG-VDA FMEA**
DHF (Design History File)	A compilation of documents that describe the design history of a finished medical device, required by FDA 21 CFR Part 820.30. The DHF must contain or reference all design and development planning records, design inputs, design outputs, design review results, design verification and validation records, and design change records. PCB-level design decisions that affect device safety must be documented in the DHF and traceable to the corresponding risk management file entries. — **FDA 21 CFR Part 820.30; ISO 13485**
DLA (Defense Logistics Agency)	The U.S. Department of Defense agency responsible for managing the Qualified Products List (QPL) and Qualified Manufacturers List (QML) for military-grade electronic components and PCBs. All PCBs produced for U.S. DoD programs under MIL-PRF-31032 must be fabricated at a DLA-qualified facility. IPC-6013 Class 3 from a non-DLA-qualified shop does not satisfy MIL-PRF-31032 requirements regardless of technical equivalence. — **MIL-PRF-31032**
DMR (Device Master Record)	A compilation of records containing the procedures and specifications for a finished medical device, required by FDA 21 CFR Part 820.181. The DMR includes PCB drawings, fabrication specifications, assembly procedures, quality standards, and labelling requirements. The DMR serves as the definitive technical reference for manufacturing and inspection of the device throughout its production life. — **FDA 21 CFR Part 820.181; ISO 13485**
Dynamic Flex	A flex circuit application in which the flex zone undergoes repeated bending during normal operation - for example, a printer head cable or a hinge connection in a wearable device. Dynamic flex applications impose the most demanding design requirements, including adhesiveless polyimide cores, rolled annealed copper, higher bend radius multipliers (100x–200x), and bookbinder construction for multilayer designs. Flexural endurance testing per IPC-TM-650 Method 2.4.3 is required for dynamic flex qualification. — **IPC-2223E; IPC-TM-650 2.4.3**
Dk (Dielectric Constant)	A material property describing the ability of the dielectric to store electrical energy relative to a vacuum. Dk directly affects transmission line impedance and signal propagation velocity. Polyimide (Dk approximately 3.4 at 1 GHz) has a lower Dk than standard FR-4 (Dk approximately 4.2–4.5), which means traces in the flex zone must be wider than equivalent impedance traces in the rigid section. Using FR-4 Dk values to calculate flex zone impedance will produce designs that are out of tolerance after fabrication. — **IPC-2223E**
E	
ED Copper (Electrodeposited Copper)	Copper foil produced by electroplating copper onto a rotating drum from a copper sulphate solution. ED copper has a columnar grain structure that makes it more brittle and less ductile than rolled annealed copper. ED copper is acceptable for rigid sections of a rigid-flex PCB but must not be specified for dynamic flex layers, where its lower fatigue resistance leads to premature conductor cracking. — **IPC-2223E**
ENEPIG (Electroless Nickel Electroless Palladium Immersion Gold)	A multi-layer surface finish consisting of electroless nickel, electroless palladium, and immersion gold layers. ENEPIG provides improved wire bondability and solderability compared to ENIG, and eliminates the black pad failure mode associated with ENIG. It is preferred for high-reliability and military applications and is compatible with standard sterilization methods. — **IPC-4556**

ENIG (Electroless Nickel Immersion Gold)	A surface finish consisting of a thin layer of immersion gold over electroless nickel plating. ENIG provides a flat, solderable surface compatible with most assembly processes and is generally compatible with standard sterilization methods used in medical device manufacturing. It is one of the preferred surface finishes for rigid-flex PCBs due to its flatness and shelf life. — **IPC-4552**
EtO (Ethylene Oxide)	A gas used as a low-temperature sterilization method for medical devices and assemblies that cannot withstand the heat of steam autoclave sterilization. EtO sterilization is widely used for single-use medical devices incorporating rigid-flex PCBs. All materials in an EtO-sterilized assembly (including the polyimide flex core, coverlay, stiffener adhesive, and conformal coating) must be confirmed compatible with EtO exposure and subsequent aeration. ENIG and ENEPIG surface finishes are generally EtO-compatible; OSP may degrade. — **ISO 11135; IPC-6012EM**
ESD (Electrostatic Discharge)	The rapid transfer of electrostatic charge between two objects at different electrostatic potentials. ESD events can permanently damage or degrade semiconductor devices and are a significant risk during PCB handling, assembly, and test. ESD control programs per ANSI/ESD S20.20 are required for aerospace and space hardware and are best practice for all high-reliability electronics manufacturing. Rigid-flex PCBs require particular care during handling because the flex section can generate triboelectric charge. — **ANSI/ESD S20.20**
F	
FAI (First Article Inspection)	A formal verification process that confirms the first production unit of a new or modified design fully meets all drawing and specification requirements before series production is approved. Required under AS9102 for aerospace programs and under MIL-PRF-31032 for military programs. A new FAI is required after any design change or production lapse exceeding two years. — **AS9102; MIL-PRF-31032**
FEA (Finite Element Analysis)	A computational method that divides a structure into a mesh of small elements and solves the equations of structural mechanics to determine stress, strain, and deformation under applied loads. For rigid-flex PCBs, FEA is used to simulate bending stress distribution across the flex zone, verify that conductor strain remains below the fatigue threshold, and optimize trace corner radii and transition zone geometry. FEA is not universally required by IPC-2223E for static flex designs but is recommended for dynamic applications exceeding 1,000 bend cycles and for all aerospace, medical, and automotive designs. — **IPC-2223E; IPC-TM-650 2.4.3**
FPC (Flexible Printed Circuit)	A printed circuit constructed entirely on a flexible dielectric substrate (typically polyimide) without rigid sections. An FPC differs from a rigid-flex PCB in that it contains no bonded rigid laminate sections. FPCs are terminated using ZIF or anisotropic conductive film (ACF) connectors. Design rules for the flex sections of rigid-flex PCBs are derived from FPC design standards and are governed by IPC-2223E. The term FPC connector (or FPC/ZIF connector) is commonly used to describe the mating connector for a flex circuit tail in a rigid-flex assembly. — **IPC-2223E**
Flex Zone	The region of a rigid-flex PCB that is constructed entirely from flexible materials (polyimide core, RA copper, and polyimide coverlay) and is designed to bend. The flex zone is bounded by the rigid-to-flex transition lines on either side. Design rules for the flex zone differ significantly from those for the rigid sections and are governed primarily by IPC-2223E. — **IPC-2223E**
Flex Zone Stiffening	Any design feature, material, or manufacturing condition that adds unintended mechanical stiffness to the flex zone, reducing its ability to bend at the designed radius and increasing strain in the conductors. Common sources include solid copper pours, stacked traces across flex layers, conformal coating bridging the transition, stiffeners extending into the bend zone, components placed in the bend zone, and adhesive resin flowing into the flex zone during lamination. Flex zone stiffening shifts strain concentration toward the transition boundary and invalidates the IPC-2223E bend radius calculation. — **IPC-2223E**

Flexural Endurance	The ability of a flex circuit conductor to withstand repeated bending without failure, quantified as the number of bend cycles to a defined failure criterion. IPC-TM-650 Method 2.4.3 defines the standard flex endurance test. The failure criterion is a 10% increase in measured conductor resistance relative to the initial value. Test parameters (bend radius, bend angle, frequency, and temperature) must match the intended in-service conditions. — **IPC-TM-650 2.4.3**
FR-4	A flame-retardant woven glass fibre reinforced epoxy laminate material used for the rigid sections of rigid-flex PCBs. Standard FR-4 has a glass transition temperature (Tg) of approximately 130–140 °C. High-Tg FR-4 (Tg greater than 170 °C) is required for IPC-6013 Class 3 and high-reliability applications. FR-4 is prohibited in the flex zones of rigid-flex PCBs and is not suitable for space applications due to its limited thermal stability and radiation tolerance. — **IPC-4101; IPC-6013**
G	
GEVS (General Environmental Verification Standard)	GSFC-STD-7000. A NASA Goddard Space Flight Center standard that defines the environmental test requirements for space flight hardware, including vibration, acoustic, thermal vacuum, and shock test levels. The GEVS protoflight test approach combines qualification and acceptance testing on the same unit. Rigid-flex PCBs on space flight hardware must survive the applicable GEVS test levels with no delamination, via cracking, or conductor failure at the rigid-to-flex transition zone. — **GSFC-STD-7000**
Glass Transition Temperature (Tg)	The temperature at which an amorphous polymer transitions from a hard, glassy state to a soft, rubbery state. Above Tg, the material loses mechanical strength and dimensional stability. For FR-4 rigid sections in high-reliability applications, a Tg greater than 170 °C is required. Automotive under-hood and space applications may require polyimide rigid sections, which have significantly higher Tg values than FR-4. — **IPC-4101; IPC-6013**
H	
HiPot (Dielectric Withstand Voltage)	A high-voltage electrical test that applies a voltage significantly above the normal operating voltage between isolated conductors to verify that the dielectric insulation will not break down under overvoltage conditions. For rigid-flex PCBs, HiPot testing per IPC-TM-650 Method 2.5.7.2 is particularly important because the thin polyimide dielectric in the flex section has different breakdown characteristics than FR-4. — **IPC-TM-650 2.5.7.2**
High-Tg FR-4	A variant of FR-4 laminate engineered with a glass transition temperature greater than 170 °C, achieved through modified epoxy resin chemistry. Required for rigid sections in IPC-6013 Class 3 applications and for designs operating across wide temperature ranges. High-Tg FR-4 provides improved thermal reliability and reduced z-axis expansion during reflow compared to standard FR-4. — **IPC-4101; IPC-6013**
I	
IPC-2221	Generic Standard on Printed Board Design. Provides foundational design rules for all printed circuit board types, including conductor sizing for current capacity, annular ring calculation formulas, minimum spacing rules, and hole-to-conductor clearances. Referenced in rigid-flex design for current capacity verification of flex zone conductors and annular ring pad size calculations. — **IPC-2221**
IPC-2223E	Sectional Design Standard for Flexible Printed Boards. The primary governing standard for the design of flexible circuits and rigid-flex PCBs. Covers bend radius requirements, stackup and material selection, coverlay requirements, trace routing rules for flex zones, via prohibitions, transition zone design, and documentation requirements. The E revision is the current edition. All rigid-flex designs must be verified against IPC-2223E before release to fabrication. — **IPC-2223E**
IPC-4203/1	Cover and Bonding Material for Flexible Printed Circuitry. Defines material requirements for coverlay films and adhesives used to protect conductor patterns on flexible circuits. Establishes the material qualification requirements that distinguish polyimide coverlay from LPI solder mask and specifies adhesive performance requirements. — **IPC-4203/1**

IPC-6013	Qualification and Performance Specification for Flexible Printed Boards. Defines acceptance criteria for manufactured flexible and rigid-flex PCBs across three classes: Class 1 (general electronic products), Class 2 (dedicated service electronic products), and Class 3 (high-reliability electronic products). Covers hole wall plating thickness, annular ring quality, coverlay adhesion, surface finish requirements, and transition zone acceptance. IPC-6013E is the current revision. The class must be declared on the fabrication drawing before manufacture - it cannot be retroactively upgraded. — **IPC-6013**
IPC-6012EM	Qualification and Performance Specification for Rigid Printed Boards for Medical Electronic Equipment and Instruments. An amendment applied on top of IPC-6013 Class 3 for printed circuit boards used in life-critical medical electrical equipment. Adds stricter conductor quality, via plating, and workmanship acceptance criteria. Applies to Class III medical devices and implantable devices where PCB failure can directly endanger patient life. — **IPC-6012EM; IPC-6013**
IPC-6012ES	Qualification and Performance Specification for Rigid Printed Boards for Aerospace and Defense Applications. An amendment applied on top of IPC-6013 Class 3 for PCBs used in aerospace and defense applications. Adds stricter acceptance criteria for conductor imperfections, annular ring, and via quality beyond the IPC-6013 Class 3 baseline. — **IPC-6012ES; IPC-6013**
IPC-TM-650	Test Methods Manual. A collection of standardized test methods published by IPC for evaluating the properties of printed circuit boards and related materials. Key methods referenced in rigid-flex design include: 2.4.3 (flex endurance; failure = 10% resistance increase), 2.4.8 (peel strength), 2.5.1 (insulation resistance), 2.5.5.7 (TDR impedance), 2.5.5.12A (signal loss / insertion loss), 2.5.7.2 (dielectric withstand voltage / HiPot), 2.6.3 (moisture and insulation resistance), 2.6.7.2 (thermal shock), 2.6.27 (thermal stress / reflow simulation; failure = 5% resistance change). — **IPC-TM-650**
K	
Knee (Via)	The junction between the plated hole wall and the pad surface - the transition point where the plating changes direction from vertical (hole wall) to horizontal (pad). The knee is the most mechanically stressed location in a plated through-hole under thermal cycling and is a zero-void zone under IPC-6013 for all classes. Via failures in rigid-flex PCBs frequently initiate at the knee, particularly where the via is located near the rigid-to-flex transition. — **IPC-6013**
L	
LPI Solder Mask (Liquid Photoimageable)	A photocurable polymer coating applied to the outer surfaces of printed circuit boards to protect conductors and define solder pad openings. LPI solder mask is the standard protective coating for rigid PCBs but is not acceptable in the flex zones of rigid-flex PCBs because it lacks the elongation at break required to survive repeated bending without cracking. Polyimide coverlay must be used in flex zones. — **IPC-4203/1; IPC-6013**
M	
Measling	A laminate condition characterized by discrete white spots or crosses below the surface of the base material, caused by separation of the glass fiber bundles from the resin at weave intersections. Measling is typically caused by thermal stress, moisture absorption followed by rapid heating, or mechanical impact. Unlike crazing (which involves interconnected cracks), measling spots are discrete and localized. IPC-A-600 defines acceptance criteria for measling by class. MIL-PRF-31032 applies stricter rejection criteria than IPC-A-600 Class 3, which can cause rejection disputes when MIL acceptance standards are applied to designs otherwise meeting IPC Class 3. — **IPC-A-600; MIL-PRF-31032**

MIL-PRF-31032	Performance Specification for Printed Circuit Board/Printed Wiring Board. The primary U.S. military performance specification for all printed circuit board types. Requires fabrication at a DLA-qualified facility listed on the Qualified Products List (QPL) or Qualified Manufacturers List (QML). IPC-6013 Class 3 is a prerequisite but does not satisfy MIL-PRF-31032 alone. MIL-PRF-31032 adds additional acceptance criteria, mandatory ongoing qualification testing, Technical Review Board requirements, and traceability obligations. — **MIL-PRF-31032**
MIL-PRF-50884	Performance Specification for Printed Wiring Boards, Flexible or Rigid-Flex. The legacy U.S. military specification specifically covering flexible and rigid-flex printed circuit boards. Many active programs were originally qualified under MIL-PRF-50884 and continue to reference it. It cannot be interchanged with MIL-PRF-31032 on existing programs without program office approval. Defines acceptance criteria for coverlay adhesion, transition zone quality, and flex conductor integrity that are specific to flexible constructions. — **MIL-PRF-50884**
MIL-STD-461	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment. Defines the EMC test requirements (conducted and radiated emissions and susceptibility) for military electronic equipment. For rigid-flex PCBs in military applications, the crosshatch ground plane in the flex zone and ground plane continuity across the transition zone must be evaluated against MIL-STD-461 radiated emission and immunity limits. — **MIL-STD-461**
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests. Defines environmental test methods representing the mechanical and climatic stresses equipment may encounter during its service life. Key methods for rigid-flex PCB qualification include Method 503 (temperature cycling), Method 514 (vibration), and Method 516 (shock). For rigid-flex designs, test coupons and assemblies must include the transition zone, which is the most failure-prone region under these conditions. — **MIL-STD-810**
N	
Neutral Axis	The plane within the cross-section of a bent beam or laminate at which there is no tensile or compressive strain. Material on the outer radius of the bend is in tension; material on the inner radius is in compression. For rigid-flex design, positioning the copper conductors as close to the neutral axis as possible minimizes the strain imposed on them during bending. IPC-2223E requires flex layers to be centered in the stackup to locate conductors at the neutral axis, and specifies that conductors smaller than 10 mils should be positioned inside the neutral axis to benefit from the compressive rather than tensile loading. — **IPC-2223E Section 4**
No-Flow Prepreg	A glass fibre reinforced resin bonding sheet that has been partially cured to limit resin flow during lamination. Used at the rigid-to-flex boundary in rigid-flex PCBs to prevent resin from flowing into the flex zone during the lamination press cycle. Standard prepreg allows unrestricted resin flow which would bond and stiffen the flex zone adjacent to the transition. No-flow or low-flow prepreg is mandatory at all rigid-to-flex boundaries. — **IPC-2223E**
O	
OSP (Organic Solderability Preservative)	A surface finish consisting of a thin organic compound applied to bare copper pads to prevent oxidation prior to soldering. OSP provides a flat, coplanar surface at low cost but has limited shelf life and may degrade under certain sterilization methods including gamma radiation and ethylene oxide exposure. OSP is generally not recommended for high-reliability rigid-flex applications or for medical devices subject to radiation sterilization. — **IPC-4555**
P	
Panelization	The process of arranging multiple PCB designs on a larger fabrication panel to improve manufacturing efficiency and reduce per-unit cost. For rigid-flex PCBs, panelization requires that all waste tabs and breakaway connections be located in the rigid sections only. Tabs attached to flex sections compromise the bend geometry during handling and assembly conveying and can cause delamination or distortion of the flex zone. Panel routing, V-scoring, or breakaway tabs must not cross flex section boundaries. Fiducial markers for optical alignment must also be located within rigid sections. — **IPC-2223E**

Peel Strength	A measure of the force per unit width required to separate a bonded layer from its substrate at a defined peel angle. For rigid-flex PCBs, peel strength testing per IPC-TM-650 Method 2.4.8 is used to verify the adhesion of coverlay to the flex conductor layer. Peel strength is a critical qualification parameter for dynamic flex applications where coverlay adhesion is the primary factor determining resistance to delamination under repeated bending. — **IPC-TM-650 2.4.8**
PMHF (Probabilistic Metric for Hardware Failures)	A quantitative safety metric defined by ISO 26262 Part 5 that expresses the rate of residual risk from random hardware failures in safety-related functions, expressed in failures per hour (FIT). ASIL D requires PMHF below 1 FIT. PCB design decisions (including conductor routing redundancy, via placement near the flex transition, and diagnostic coverage) directly affect the PMHF calculation for ASIL-rated circuits. — **ISO 26262:2018 Part 5**
PPAP (Production Part Approval Process)	A standardized automotive industry process that verifies a supplier's design and manufacturing process is capable of producing parts that consistently meet customer requirements. Required before production launch by most automotive OEMs. For rigid-flex PCBs, PPAP documentation must include dimensional results, material certifications, and process capability data (Cpk) for critical characteristics including bend radius, impedance, and plating thickness. Any design or process change requires PPAP re-approval. — **AIAG PPAP; IATF 16949**
Polyimide	A high-performance polymer film used as the base dielectric material in flexible circuits and rigid-flex PCBs. Key properties relevant to rigid-flex design include: dielectric constant of approximately 3.4 at 1 GHz, tensile strength of approximately 231 MPa, low coefficient of thermal expansion, and moisture absorption of up to 3% by weight (requiring pre-bake before reflow). Polyimide is mandatory for flex sections in space applications due to its thermal stability and radiation tolerance. — **IPC-2223E; IPC-4203/1**
Prepreg	A B-staged (partially cured) glass fiber reinforced resin sheet used as a bonding and dielectric layer in multilayer PCB stackups. Standard prepreg allows significant resin flow during lamination and must not be used at the rigid-to-flex boundary. No-flow or low-flow prepreg variants are required at that location to prevent resin infiltration into the flex zone. — **IPC-2223E; IPC-4101**
R	
Rigidizing (Flex Zone)	The addition of unintended mechanical stiffness to the flex zone of a rigid-flex PCB, reducing its ability to bend at the designed radius and increasing conductor strain. The term is used informally in PCB design practice and is not formally defined in IPC-2223E, which addresses the same concept through specific prohibited conditions. Common sources of unintended rigidizing include: solid copper pours or planes in the flex zone (which act as structural members); stacked traces across multiple flex layers (which create a composite beam effect); conformal coating bridging the rigid-to-flex transition without masking; stiffeners extending into the active bend zone; components placed in the bend zone; and adhesive resin flowing into the flex zone during lamination. Any of these conditions invalidates the IPC-2223E bend radius calculation and increases fatigue failure risk. See also: Flex Zone Stiffening. — **IPC-2223E**
RA Copper (Rolled Annealed Copper)	Copper foil produced by mechanically rolling copper to the required thickness and then annealing it to relieve work hardening. The rolling process produces a fine-grained, directional microstructure that gives RA copper superior ductility and fatigue resistance compared to electrodeposited copper. RA copper is mandatory for dynamic flex layers. Its higher elongation at break allows it to survive the repeated tensile and compressive cycling that would cause ED copper to crack. — **IPC-2223E**
Rigid-to-Flex Transition Zone	The boundary region where the rigid section structure terminates and the flex section begins. The transition zone is the highest-stress location in a rigid-flex PCB under both mechanical and thermal loading, due to the abrupt change in bending stiffness and the CTE mismatch between FR-4 and polyimide. IPC-6013E added explicit acceptance criteria for the transition zone. Design requirements include gradual tapers, coverlay overlap of 0.5–1 mm into the rigid section, staggered flex layer terminations, and a 3.0 mm inspection zone on either side of the boundary. — **IPC-2223E; IPC-6013E**

S	
Static Flex	A flex circuit application in which the flex zone is bent once or a very limited number of times during assembly or installation and then remains in a fixed position during operation. Static flex applications have less demanding design requirements than dynamic flex, with lower bend radius multipliers (6x for single and double layer, 12x for three or more layers). The flex application type (static or dynamic) must be explicitly declared on the fabrication drawing. — **IPC-2223E**
Stiffener	A rigid material bonded to the surface of the flex zone to provide mechanical support for components, connectors, or other features that require a rigid mounting surface. Stiffeners are typically FR-4 for through-hole and SMT component areas, or polyimide for thin sections and ZIF connector areas. Stiffeners must not extend into the active bend zone, must overlap the coverlay by a minimum of 30 mils (0.76 mm), must have rounded corners to prevent stress concentration, and must be sized to extend beyond the component footprint. — **IPC-2223E**
Strain Relief	A design feature that distributes mechanical stress over a larger area to reduce peak strain at a specific location. In rigid-flex design, strain relief fillets are required at all trace-to-pad junctions at the rigid-to-flex boundary. Teardrop pads at via-to-trace junctions provide strain relief at the mechanically vulnerable pad-to-trace transition. Rounded trace corners in the flex zone reduce peak stress by approximately 40% compared to sharp corners. — **IPC-2223E; IPC-6013**
T	
TDR (Time Domain Reflectometry)	An electrical measurement technique that launches a fast electrical pulse down a transmission line and analyses reflections to determine impedance as a function of position. TDR testing per IPC-TM-650 Method 2.5.5.7 is the standard method for verifying controlled impedance in rigid-flex PCBs. TDR is particularly important for rigid-flex because it reveals impedance discontinuities at the rigid-to-flex transition that are not visible with a single-point measurement. — **IPC-TM-650 2.5.5.7**
Teardrop Pad	A pad geometry in which the conductor trace blends smoothly into the pad using a tapered fillet rather than meeting at a right angle. Teardrop pads reduce stress concentration at the via-to-trace junction under mechanical and thermal loading. In rigid-flex designs, teardrop pads are mandatory at all via-to-trace junctions in or near flex zones and are required for all Class 3 designs per IPC-6013. — **IPC-6013; IPC-2223E**
Tg — see Glass Transition Temperature	See Glass Transition Temperature.
TML (Total Mass Loss)	The total fraction of a material's initial mass lost through outgassing when tested per ASTM E595 in a vacuum environment. The acceptance limit is less than 1.0% of initial specimen mass. TML represents all volatile material released, including water vapor. Materials with high TML may cause contamination of adjacent surfaces in a spacecraft and must not be used in space-grade rigid-flex assemblies without explicit approval. — **ASTM E595; NASA-STD-8739.4A**
TRB (Technical Review Board)	An internal review body required at DLA-qualified PCB fabrication facilities under MIL-PRF-31032. The TRB evaluates proposed changes to materials, processes, and equipment that could affect the qualification status of manufactured PCBs. Changes exceeding defined thresholds require TRB review before implementation and may trigger partial or full re-qualification testing. — **MIL-PRF-31032**
TVAC (Thermal Vacuum)	A test environment that subjects hardware simultaneously to vacuum conditions and thermal cycling, simulating the space environment and orbital temperature extremes. Required for space flight hardware per GSFC-STD-7000 GEVS. For rigid-flex PCBs, TVAC subjects the transition zone to simultaneous outgassing stress and thermal expansion cycling. Electrical continuity must be monitored during TVAC to detect intermittent failures at the transition zone. — **GSFC-STD-7000; NASA-STD-8739.4A**

Thermal Shock	A test condition in which a specimen is subjected to rapid transfers between temperature extremes to accelerate fatigue failures caused by CTE mismatch. IPC-TM-650 Method 2.6.7.2 defines the standard thermal shock test: -65 °C to +150 °C for a minimum of 100 cycles with rapid transfer. For rigid-flex PCBs, the transition zone is the primary failure location under thermal shock due to CTE mismatch between the polyimide flex section and FR-4 rigid section. — **IPC-TM-650 2.6.7.2**
Thermal Stress Coupon Test	A test in which a PCB coupon is subjected to multiple simulated reflow cycles at peak temperature (minimum 6 cycles at 260 °C) to verify the integrity of plated through-holes and microvias under assembly thermal stress. Governed by IPC-TM-650 Method 2.6.27. The failure criterion is a 5% change in measured resistance. This test detects latent microvia and via barrel failures that are not visible at room temperature. The 5% failure criterion for this method differs from the 10% criterion used for flex endurance testing per Method 2.4.3. — **IPC-TM-650 2.6.27**
Transition Line	The boundary line on a rigid-flex PCB drawing that defines where the rigid section ends and the flex section begins. The transition line must be explicitly dimensioned on the fabrication drawing. It defines the via keepout zone boundary (minimum 0.050 inch from the transition line), the coverlay overlap extent, and the region subject to the 3.0 mm inspection zone requirement per IPC-2223E. — **IPC-2223E**
V	
Via Keepout Zone	A defined area around the rigid-to-flex transition line within which plated through-holes and vias are prohibited. IPC-2223E requires a minimum keepout of 0.050 inch (1.27 mm) from the transition line, with 0.100 inch (2.54 mm) recommended for additional margin. Vias within the keepout zone are subject toelevated cracking risk due to the mechanical stress concentration at the transition boundary. — **IPC-2223E**
Void (Plating)	An area in the hole wall copper plating of a PTH where the plating is absent or measures less than 80% of the required minimum thickness, as defined by IPC-6013. IPC-6013 Class 3 requires zero voids in the hole wall. The knee (pad-to-hole-wall junction) is a zero-void zone for all classes. Class 2 permits up to three voids in the sidewall provided total voided area does not exceed 5% of the hole wall surface. Class 1 permits up to three voids not exceeding 10% of sidewall area. — **IPC-6013**
Z	
ZIF Connector (Zero Insertion Force)	A connector designed to accept a flex circuit tail without requiring insertion force, using a locking mechanism that clamps the tail after insertion. ZIF connectors require polyimide stiffeners (not FR-4) because FR-4 stiffeners are too thick for the ZIF connector throat clearance. The stiffener must be dimensioned precisely to match the connector manufacturer's specified tail thickness. ZIF connectors are a common termination method for rigid-flex and flex circuit designs. — **IPC-2223E**

Note on informal terminology

Some terms used commonly in rigid-flex PCB design practice (including 'flex zone stiffening', 'bookbinder construction', and 'transition zone') are not formally defined in the current revision of IPC-2223E but are widely used in fabricator application notes and design training materials. Where a term is used in this glossary but lacks a formal IPC definition, the closest governing standard clause is cited. Designers should not rely on informal terms in fabrication drawings or quality documentation where a formally defined IPC term or parameter exists.

cādence®

Cadence is a pivotal leader in electronic design and computational expertise, using their Intelligent System Design Strategy to turn design concepts into reality. Cadence customers are the world's most creative and innovative companies, delivering extraordinary electronic products from chips to boards to systems in the most dynamic market applications. **www.cadence.com**