Bend-to-Install Design Guide for Flexible Circuits

PhaseBlue Series Circuit Materials

5 South Spencer Road
Spencer, MA 01562 USA

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1. Purpose and Scope

A flex circuit bent once to fit its enclosure survives when three things are right: the bend radius, the stackup in the bend zone, and the way it is formed. This guide gives design engineers the rules for each, for static bend-to-install use (IPC-2223 “use A” / flex-to-install).
It covers single-sided, double-sided and multilayer flex, rigid-flex transitions, and RF lines that must keep impedance and phase through a bend. It does not cover dynamic flexing (hinges, sliding cables, repeated cycling); those designs need tighter radii rules and fatigue qualification.
Sections 2 to 7 are general flex practice. Section 8 covers what changes when the construction uses a PhaseBlue aerogel-core dielectric. Section 9 is a checklist to run before release. Values are common industry practice unless a standard is cited. Current revisions are IPC-2223F (May 2026) and IPC-6013F (2026); section numbers quoted here come from earlier revisions, so confirm them against F.

2. Bend Mechanics Fundamentals

Copper fails in a bend because of strain, and strain grows with distance from the neutral axis. The neutral axis is the plane in the stackup that neither stretches nor compresses. Material outside the bend stretches; material inside compresses.
For a layer at distance y from the neutral axis, bent to inside radius R and the neutral axis a depth c below the inside, surface strain is approximately:

$$\varepsilon \approx y / (R + c)$$

Three consequences drive every rule in this guide:

- **Thinner is better.** Halving the flex thickness roughly halves copper strain at the same radius.
- **Symmetry matters.** Copper placed on the neutral axis sees almost no strain. A balanced stackup puts the neutral axis at the copper; an unbalanced one pushes the copper outward.
- **Static bends tolerate plastic strain.** A bend-to-install part can take copper past its yield point once, because it is never cycled. Rolled-annealed (RA) copper tolerates roughly 10 to 32% elongation and electrodeposited (ED) copper roughly 3 to 10%, depending on grade and thickness.

The practical limit for a static bend is not yield, but cracking, delamination, coverlay lifting, and springback that loads solder joints after installation.

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3. Minimum Bend Radius

Start with the thickness-ratio rule below, check it with the IPC-2223 (5.2.3) strain formula for the actual stackup, and use the larger radius. Ratios are inside bend radius divided by total flex thickness in the bend zone including copper, dielectric, adhesive, and coverlay.

Construction (Bend Zone)	Minimum Ratio; Static Bend-to-Install	Example: 0.2 mm Thick Flex
Single-sided	6x	1.2 mm radius
Double-sided	10x	2.0 mm radius
Multilayer (3+ copper layers)	20x	4.0 mm radius
Dynamic, for comparison	100x or more	20 mm radius

These are rules of thumb, not guarantees. Go larger when:

- The copper is electrodeposited rather than rolled-annealed.
- Copper is thicker than 1 oz (35 µm).
- Plated copper (from through-hole plating) is present in the bend zone.
- The flex uses adhesive-based layers, which add thickness and can crack.
- Controlled-impedance lines cross the bend.

A multilayer bend zone rarely needs every layer bonded together. Unbonded, “air-gap” or bookbinder constructions let each layer bend about its own neutral axis, so the ratio applies to each layer’s thickness rather than the whole stack.

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4. Stack-Up and Material Choices

The bend zone should be the thinnest, most symmetric, most ductile part of the circuit. Choose its materials first.

Choice	Preferred In Bend Zone	Why
Base laminate	Adhesiveless polyimide	Thinner, more stable, no brittle adhesive layer
Copper type	Rolled-annealed (RA) (IPC-4562 Grade 7 or 8)	Higher elongation and crack resistance than ED
Copper grain direction	Along the length of the traces, across the bend	RA copper is strongest in its rolling direction
Copper weight	½ oz (18 µm) or less where current allows	Less strain, less springback
Cover layer	Polyimide coverlay	More flexible than flexible solder mask or LPI
Plating	Button (pads-only) plating; no panel plating in the bend	Plated copper is brittle and adds thickness
Stiffeners	End at least 0.75 mm (0.030") before the bend starts	Stiffener edges are stress concentrators

Balance copper on both sides of the dielectric in double-sided bend zones so the neutral axis sits at the dielectric center. In a single-sided bend zone, make the coverlay about as thick as the base film so the copper sits near the neutral axis.

At a rigid-flex transition, keep the first bend at least 1.5 mm (0.060”) from the rigid edge. Specify an epoxy or silicone bead along that edge when the flex leaves the rigid section at a sharp angle.

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5. Conductor Routing in Bend Zones

Route conductors straight across the bend, perpendicular to the bend line, and keep everything else out of it.

- **Perpendicular crossing.** Traces run at 90° to the bend axis. Angled traces see twisting strain as well as bending strain.
- **No features in the bend.** Keep vias, pads, plated holes, component leads and test points outside the bend zone, with at least 0.75 mm (0.030”) of clearance to where the bend starts.
- **Stagger layers.** On double-sided or multilayer flex, offset traces on adjacent layers instead of stacking them directly over each other (the “I-beam” effect stiffens the flex and concentrates strain).
- **Uniform width.** Keep trace width constant through the bend. Make width changes, necking and jogs outside the bend zone.
- **Curved corners.** Use radiused corners, not 90° or 45° corners, anywhere near the bend.
- **Teardrops and anchors.** Teardrop at every trace-to-pad junction on the flex; add anchoring spurs (“rabbit ears”) on pads near the bend.
- **Hatched planes.** Crosshatch copper planes in the bend zone where the electrical design allows it. For RF, see the next section before hatching.
- **Distribute copper.** Spread traces evenly across the flex width. Add dummy copper at the edges so outer traces are not carrying all the strain.
- **Tear stops.** Put a radiused relief or a copper tear-stop at every inside corner and slot in the flex outline.

6. RF and Controlled-Impedance Lines Through a Bend

A bend stretches the dielectric outside the neutral axis and compresses it inside, so thickness and local Dk shift and impedance moves with them. A formed section cannot be retuned after installation, so Dk drift with temperature shows up directly as phase error.

- **Radius.** Use at least 1.5x to 2x the mechanical minimum from the radius table for controlled-impedance lines. Measure or simulate the bent geometry if phase matching between channels matters.
- **Geometry.** Stripline and grounded coplanar waveguide hold impedance through a bend better than microstrip, because their fields are more contained.
- **Ground planes.** A crosshatched reference raises impedance and adds loss and radiation above a few GHz. For RF, keep the reference plane solid under the line and make the bend zone thinner or unbonded instead of hatching it.

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- **Stitching.** Put ground stitching vias on both sides of the bend zone, outside it, to keep the return path continuous.
- **Symmetry across channels.** Bend phase-matched lines with the same radius, the same angle and the same position relative to the bend so their phase shifts track.
- **Characterize bent, not flat.** Specify impedance and phase test coupons or measurements on formed parts, not only on flat panels.

Dk stability across temperature matters more in a formed part than a flat one. The bent section cannot be retuned after installation, so any drift in the dielectric shows up directly as phase error.

7. Forming and Installation

Form the bend once, over a mandrel, in a controlled sequence, and never unbend it. Most field failures of static flex come from rework, re-forming or hand-bending over sharp edges.

1. **Bake before forming.** Polyimide absorbs moisture. Bake per the fabricator's recommendation (typically 1–2 hours at 120°C) if parts have been stored unsealed, especially before soldering.
2. **Assemble flat.** Complete soldering and inspection with the flex flat. Forming after soldering is standard; soldering after forming is not.
3. **Use a mandrel or fixture.** Form over a radiused mandrel sized to the design radius. Never crease the flex or bend it over a sheet-metal edge.
4. **One bend at a time.** On multi-bend parts, form bends in the order specified on the drawing, usually from the center outward.
5. **Bend at room temperature, or heat-form.** For tight radii or to reduce springback, heat-form in a fixture (typically 150 °C for polyimide, confirmed against the coverlay and adhesive ratings), then cool before release.
6. **Retain the shape.** Hold the formed shape with the enclosure, clips, adhesive tape or potting so the solder joints do not carry the springback force.
7. **No re-forming.** Treat a mis-formed part as scrap unless the design was qualified for re-forming.

On the drawing, call out the bend location, inside radius, bend angle, bend direction (which side is inside), sequence, and any forming temperature. A fabricator cannot infer these from the Gerbers.

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8. Bending PhaseBlue Constructions

PhaseBlue's nanoporous polyimide aerogel core bends like polyimide but compresses like a foam, so the inside of a bend is the zone to design around. The general rules in this guide apply; the points below are what changes.

What is different:

- **Compression on the inside radius.** A solid film compresses elastically at the inside of a bend. A porous core can densify locally, which raises Dk and lowers thickness in that zone. Radius choice sets how much of the core is compressed.
- **Bond layers carry more of the strain.** The thin bonding films or adhesives that join the core to copper and cover layers are the stiffest, most strain-sensitive layers in the stack. Their elongation, not the core's, often limits the radius.
- **Stable, low Dk is the reason to use the material**. A bend that densifies the core erodes the Dk stability advantage locally. For phase-critical lines, the radius should keep the core in its elastic range.
- **Low mass and thickness help.** A thinner, lighter stackup at the same electrical performance reduces copper strain and springback force on joints.

Recommended Practice:

- Start at the multilayer ratio (20x) for any aerogel-core bend zone, even single-sided, until bend testing supports a smaller one.
- Put the bend where the stackup is thinnest and symmetric about the core, so the core sits on the neutral axis.
- Form over a mandrel at room temperature unless Blueshift has qualified a heat-forming window for the construction.
- Avoid clamping or fixturing pressure on the core in the bend zone during forming and installation.
- For RF lines through the bend, measure impedance and phase on formed samples, not flat coupons.

Data to Confirm with Blueshift Applications Engineering

- Qualified minimum bend radius for each standard PhaseBlue flex construction
- Dk and thickness change in the bend zone versus radius
- Approved bonding films and cover layers for flex-to-install use, and their elongation
- Heat-forming temperature and time window, if any
- Recommended bake and storage conditions before assembly and forming

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9. Design Checklist and Verification

Run this checklist before releasing a bend-to-install design, then verify on formed parts.

Design Reviews:

- Inside bend radius meets or exceeds the ratio for the bend-zone construction
- Bend zone uses RA copper, adhesiveless base, and coverlay
- No vias, pads, plated holes or stiffener edges within 0.75 mm of the bend
- Traces cross the bend at 90°, constant width, staggered between layers
- Stackup in the bend zone is balanced about the neutral axis
- RF lines use a radius margin and a solid reference plane
- Tear stops at every inside corner and slot
- Drawing calls out bend location, radius, angle, direction, sequence and forming method

Verification on Formed Samples:

Test	What It Shows	Typical Method
Continuity and resistance after forming	Cracked or thinned conductors	4-wire resistance before and after forming
Thermal cycling in the formed state	Cracks that grow with CTE mismatch	Cycle per the product's environmental spec
Cross-section of the bend	Copper cracking, delamination, core compression	Microsection at the bend apex
Visual inspection	Coverlay lifting, wrinkling, crazing	10× magnification at inside and outside radius
Impedance and phase, formed	RF shift caused by the bend	TDR and VNA on formed parts vs flat

Qualify with parts formed by the production fixture and process, not hand-formed prototypes.

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10. References and Glossary

Standards:

- IPC-2223F (2026), Sectional Design Standard for Flexible/Rigid-Flexible Printed Boards: bend radius method (5.2.3), transition keep-outs (5.2.2.3), pre-bake (5.3.5). Revision F adds guidance on panel vs. button plating.
- IPC-6013F (2026), Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards: Use A and Use B, acceptance and qualification.
- IPC-4202 (flexible base dielectrics), IPC-4203 (cover and bonding materials), IPC-4204 (flexible metal-clad dielectrics), IPC-4562 (metal foil: copper grades and minimum elongation).
- IPC-FA-251, Assembly Guidelines for Single and Double Sided Flexible Printed Circuits: pre-bake.

Ratios, clearances, and temperatures in this guide are common industry values unless attributed to a standard. Confirm them against the current revision, the fabricator's design rules, and the material datasheets.

Glossary:

Term	Meaning
Bend zone	The length of flex that is curved when installed, plus clearance on each side
Neutral axis	The plane in the stackup that neither stretches nor compresses in a bend
Bend-to-install	A static bend formed once during assembly and not flexed again
RA copper	Rolled-annealed copper; ductile, with grain along the rolling direction
ED copper	Electrodeposited copper; less ductile, columnar grain
Coverlay	A polyimide film with adhesive, laminated over the outer copper
Unbonded (air-gap) construction	Multilayer flex whose layers are not bonded together in the bend zone
Springback	The flex's tendency to return toward flat after forming

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