Designing Flex and Rigid Flex Products for High Reliability Applications

Adeodato Vigano
Circuits, LLC
• Benefits and applications
  • The Basics
• Design considerations
• Design for manufacturing
  • Materials properties
  • Documentation
• Industry standards and specifications
Flexible PCB Benefits

**PROS**
- Higher Reliability
- Smaller Size and Significant Weight Reduction
- Adapts to complex 3D shapes
- Reduced BOM and Assembly Costs by Eliminating Connectors
- No wiring time expended, no wiring errors and no debug and trouble-shooting time
- Superior resistance to heat, shock and vibration
- Corrosion and moisture resistance, suitable for aggressive environments
- Extended life expectancy for the unit

**CONS**
- Engineering development time and costs
- The raw circuit board is more expensive than the raw round wire required
- Flex “arms” are delicate, can tear easily
- Z axis expansion needs to be considered
Applications

**Defense and Aerospace**
- Replacing many wire harnesses for ruggedized applications, flexible circuit boards are able to survive hostile environments.
- Weight reduction paired with increased reliability.
- Dynamic flex applications.
- Field serviceability.

**Medical**
- Dramatic reduction of overall electronics package size.
- Weight reduction enables handheld and portable devices.
- Resistance to chemically aggressive environments for implantable devices.

**Industrial Controls**
- Un-matched performance for applications with repetitive motion.
- Durability and reliability in aggressive environments.

**Consumer Electronics**
- Weight reduction is key for hand-held devices, personal computing, GPS, cell phones.
- Stability of materials for high volume manufacturing.
The Basics: Board Types

**Installation Use:**
- **Use A**: Flex-To-Install
- **Use B**: Continuous / Dynamic Flex
- **Use C**: High Temperature Flex (above 105°C)
- **Use D**: UL Recognition

**Type 1**: Single-Sided Flex with No Plated Trough Holes

**Type 2**: Double-Sided Flex with Plated Trough Holes

**Type 3**: Multilayer Flex with Plated Trough Holes

**Type 4**: Multilayer Rigid-Flex with Plated Trough Holes

**Type 5**: Multilayer Flex with No Plated Trough Holes
The Basics: Materials

**Copper Foils**
- Rolled Annealed (RA) copper
- Electro-Deposited (ED) copper
- ¼ oz (ED) to 3 oz Cu weights

**Kapton®** - DuPont's trade name for pure polyimide film

**Pyralux®** - DuPont's trade name for flexible circuit materials (Cu clad laminates, coverlays and bonding adhesives)

**Coverlay** – Kapton coated with adhesive on one side (insulating material that is applied over a conductive pattern on the outer surface of the PCB)

**Bondply** – Kapton coated with adhesive on both sides

**Flex Materials**:
- Adhesiveless copper clad laminate:
  - AP excellent thermal, chemical, electrical and mechanical properties.
- Adhesive Based copper clad laminates:
  - LF (High Reliability) Military Grade.
  - FR (Fire Retardant) Commercial Grade.

**Rigid Materials for Stiffeners or Rigid-Flex Construction**:
- High Tg FR4
- Polyimide
- Reinforced PTFE
- Thermount
Laminates and Bonding Materials

Adhesive Based Commercial Grade: “FR” (1.0)
- Cu + Adh + Polyimide + Adh + Cu
- Easy processing, lowest cost, UL approved
- Significant amount of FR adhesive \(\rightarrow\) lowest reliability

Adhesive Based Defense-Aerospace Grade: “LF” (1.5)
- Cu + Adh + Polyimide + Adh + Cu
- Easy processing, better bond strength than FR
- Significant amount of LF acrylic \(\rightarrow\) lower reliability
- Typical of many “old school” military designs

Adhesiveless High Reliability Applications: “AP” (2.0)
- Cu + Polyimide + Cu
- Easy processing, stable and repeatable manufacturing.
- No adhesives \(\rightarrow\) high reliability devices

Adhesiveless High Speed Applications “TK” (4.0)
- Cu + Teflon + Polyimide + Teflon + Cu
- Pure Teflon processing, special equipment needed and significant know-how required
- Dimensional stability is the biggest challenge

Rogers LCP – Liquid Crystalline Polyimer (6.0)
- Cu + LCP + Cu
- Difficult processing, significant know-how required
- High reliability, high speed devices

Commercial Applications: “FR” (1)
- Adh + Polyimide + Adh
- Easy processing, lowest cost, UL approved

Defense-Aerospace Applications: “LF” (1.5)
- Adh + Polyimide + Adh
- Easy processing, better bond strength than FR
- Typical of many “old school” military designs

High Speed “TK” (4.0)
- Pure Teflon processing, special equipment needed and significant know-how required

LCP Prepreg (6.0)
- Difficult processing, significant know-how required

Adhesiveless Polyimide Blend: “JT” (???)
- Modified Polyimide-Epoxy Blend, no acrylic
- “Easy” processing, behaves like LF
- Higher MOT, high reliability devices
- Limited shelf life, developing market

Adhesiveless High Temp. Applications “HT” (???)
- Modified Polyimide Blend, no acrylic
- High temperature processing, behaves like AP
- Highest MOT, high reliability devices
- Just released to the market, process parameters are still under development
The Basics: Surface Finish

<table>
<thead>
<tr>
<th></th>
<th>HASL</th>
<th>Pb Free HASL</th>
<th>ENIG</th>
<th>IAg</th>
<th>OSP (Entek)</th>
<th>ISn</th>
<th>Hard Au</th>
<th>Soft Au</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solderability</strong></td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
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<tr>
<td><strong>Joint Integrity</strong></td>
<td>Excellent</td>
<td>Very Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
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<tr>
<td><strong>Planarity</strong></td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Shelf Life</strong></td>
<td>Very Good</td>
<td>Good</td>
<td>Very Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Very Good</td>
<td>Very Good</td>
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<tr>
<td><strong>Fab cost</strong></td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Medium</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td><strong>RoHS</strong></td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Bare Board Rework</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Minimum Bend Radius

- For single and double sided flex the minimum bend radius should be 6 times the overall thickness.
- For multilayer and rigid flex, the minimum bend radius should be 12 times the overall thickness.
- Critical area is the inside of the bend where delamination, dielectric and conductor fractures can occur.
- Failures in the compression area (inside of the bend) may go undetected until after the board is in service.
- This is the most common mechanical failure mechanism for a flex board and it can happen with just one excessive fold of the board.
- Elevated PCB temperature during bending is not recommended.

**Designer Tips:**

- Even distribution of copper features in the bend area.
- Power & ground planes on the outside of the bend and cross-hatched.
- For border-line conditions there is no substitute for a mechanical mockup that can be destructively tested after bend.
Tear Prevention

**Flex Tear Prevention**

- Second most common mechanical failure mode for flex and rigid-flex.
- Can be caused by mis-handling as well as fatigue from repetitive motion.
- Tear Stops: unterminated (or grounded) conductors placed at or near corners to stop tear propagation, may run the entire length of the board.
- Rounded Corners are a must: where possible inside radii should be .030” or greater. Eliminate sharp edges wherever possible.

**Designer Tips:**

- Avoid 90 degree corners, applies to inside and outside corners.
- Avoid mechanical stress build-up caused by uneven circuitry. Route traces with rounded or 45 degree corners in critical areas.
- Allow space for tear stops in the vicinity of inside corners.
Balanced Circuitry

- Allows mechanical stress to distribute evenly when circuit is flexed repeatedly perpendicular to the conductors.
- A “must” for dynamic flex applications (single sided, double sided and multi-layer), highly recommended for all constructions.
- Prevents higher stress conditions to develop around isolated traces or other copper features.
- Use additional copper fill to balance geometries when necessary.

Designer Tips:
- Balanced geometry of copper features.
- Eliminate void areas as much as possible.
- Add un-terminated (or grounded) copper pour to even distribution if necessary.
- Adjust width of flex area to avoid large void areas if possible.
Strain Relief Fillets

- Two-part epoxy fillet applied to rigid-flex interfaces or stiffener-flex interfaces.
- The most commonly used material is *Eccobond® 45* made by Emerson and Cumings.
- Rigid, semi-rigid and flexible (most popular) formulations are available based on the amount of hardener used.
- *Eccobond®* is available in black and clear (black more widely used).
- Prevents conductor strain when bent near the rigid to flex transition area.
- Fully encapsulates prepreg flow or “squeeze-out” for rigid flex boards. This prevents those sharp edges to pierce the softer flex material.

**Designer Tip:**
Strain relief fillets are usually specified by a note in the Fab drawing, for example:

“Apply Eccobond 45, color black at interface marked, top and bottom sides. Eccobond fillet must not extend more than .100” from rigid-flex interface”
Staggered Conductors

The “I-Beam” Effect

• This condition takes place when traces from 2 or more adjacent layers are running overlapping each other.
• Increases non-uniform stress buildup when the board is flexed perpendicular to the traces.
• Applies to both innerlayers and outerlayers equally.
• Creates “high” and “low” areas during coverlay or multilayer lamination that can lead to inadequate fill of adhesive at the foot of the trace (micro-voids).
• “Staggered” conductor routing is necessary for dynamic flex applications and recommended for all constructions.

Designer Tips:
✓ Stagger traces for adjacent conductors where possible
✓ Use power / ground plane to break up the “I-Beam” effect when overlap routing cannot be avoided.
Ground Plane Design:

- Solid copper plane
  - Easy to make
  - More stable mechanically
  - More consistent electrically
- Cross-hatched design.
  - Less weight
  - Improved flexibility (needs evaluated on a case-by-case basis)
- Silver Inks.
  - Further improvement in weight loss and flexibility
  - Lower cost
  - Cannot carry much current, less than 25% of copper
  - Used for shielding only
- Shielding Coverlays
  - Extremely lightweight and flexible
  - Designed for dynamic flex
  - Lowest cost
  - Virtually no current carrying capacity
  - Not available for defense applications

Designer Tips:

- Evaluate electrical requirements first, a solid copper plane is unmatched for controlled signals.
- Use cross-hatched design when possible to reduce weight and flexibility.
- Ground vias are not allowed in the bend area of the flex.
Hole to Interface

Distance from Rigid-Flex Interface

- Recommended *minimum* distance is 50 mils from the edge of the hole to the rigid-flex interface.
- Prepreg is pre-routed .020” inside the interface edge to allow for flow as it changes from B to C Stages.
- Coverlay and flex bondply are also routed .020” inside the interface line.
- Allow for the barrel of the hole to be drilled through the area of the board where prepreg flow can be controlled and the laminate is stress free.
- Larger holes affect the material more than smaller diameter holes and need to be kept even further from interface.

Designer Tip:
Keep all holes a minimum of 50 mils from the rigid-flex interface
Controlling Adhesive Squeeze-Out

- Coverlay materials require 1 mil of adhesive for every ounce of copper weight on the surface layers.
- Adhesive flow under normal conditions is 3-4 mils per mil of thickness, can be up to 6 mils per mil.
- Use copper pad as a “dam” to limit coverlay flow onto the pad.
- Where a trace enters a pad there will be additional coverlay flow, this should be taken into account for fine pitch BGAs, tight SMT devices or wire-bond pads.

**Designer Tips:**
- Avoid coverlay-defined pads
- Coverlay annular ring = pad size + .005”
- Allow for additional flow where a trace enters a pad.
The “Bikini” Method

- Improve Plated Through Hole (PTH) reliability by removing acrylic adhesive from the areas that will be drilled and plated.
- Large difference in plasma desmear attack of acrylic vs. polyimide or FR4
- Huge difference in CTE(z):
  - Copper: 9 ppm / °F
  - Kapton: 11 ppm / °F
  - Rigid GI: 50 ppm / °F
  - Rigid GF: 120 ppm / °F
  - Acrylic Adhesive: 400 ppm / °F

**Designer Tips:**
- The board house will determine where Bondply and Prepreg are used, no need to have a CAD layer for them.
- Bikini construction specified in the fab drawing: “No acrylic adhesive allowed in PTH areas”
Type 4 Rigid-Flex Options:
Bonded – Loose Leaf – Bookbinder – Formed Flex

**Bonded Flex Layers:**
- Multiple flex cores are bonded together creating a solid unit.
  - Basic construction, easy to build and reliable.

**Loose Leaf Flex Layers:**
- Each flex core is independent of the next one. Coverlay is required on both sides of the core.
  - More difficult to build because of the multiple coverlays and “air gaps”.
  - Significant improvement of bend radius (12X versus 6X)

**Bookbinder Layers:**
- Not only loose leaf but each flex core has a different length to suit the shape that the flex will have after it is bent.
  - Most difficult construction: requires building a board that is not flat.
  - Limited number of boards per panel due to extra tooling required.
  - Significantly lower manufacturing yield, higher unit cost.

**Formed (Shaped) Flex:**
- Any of the above constructions, mechanically formed after assembly with the intent of holding the required shape.
  - *Never heat up flex before forming or bending.*
  - High initial setup cost, requires individual forms for each flex board.
  - No impact on bare board cost.
  - Does not stay “formed” forever!

**Designer Tip:**
- There is no “bad” construction but this choice will heavily influence the cost of the board.
Dynamic Applications

- Any lack of symmetry in the design will increase the chances of stress build-up in the flex area.
- 1 ounce copper performs better than ½ ounce copper.
- Thin dielectric performs better than thick dielectric.
- Any imperfection will cause premature failure, flex area should be “pristine”.

**Designer Tips:**
- Run conductors perpendicular to bend direction.
- Straight conductors in the dynamic flex area, if this can’t be avoided use rounded corners.
- Balanced conductors.
- Symmetrical stackup.
- Thin, adhesiveless dielectric materials.
- 1 ounce rolled annealed copper.
- Absolutely no plated through holes in the flex area.
- Avoid surface plating in the flex area.
- Loose leaf construction.
Design for Manufacturing

- **Standard panel sizes:**
  - 18” x 24” (16” x 22” usable area)
  - 18” x 12” (16” x 10” usable area)
- **Conductor width and spacing:**
  Etch factor is ½ mil for every ½ ounce
- **Drilled vs. Finished Size:** + .004”
- **Coverlay:**
  - Allow for acrylic flow, no coverlay-defined pads
  - Prevent “Soda Strawing” – 1 mil acrylic per ounce of copper
- **Copper fill and copper distribution for innerlayers, SS and DS designs**
- **Rolled-Annealed copper grain direction**
- **Assembly considerations:** Panelization for pick and place
Copper grain direction

- The mechanical rolling process starts orienting the copper molecules parallel to each other.
- The thermal annealing process completes the orientation.
- Improved mechanical properties of the copper foil: tensile strength and elongation.
- Small impact on flex-to-install boards, bigger impact on dynamic flex applications.
- Selecting the correct grain direction is **not a substitute** for an unbalanced stackup, poor construction and flex design.
Impedance Control

• Impedance is the single most important transmission line property used to determine the performance of a high-speed circuit

• Impedance can be controlled with several different configurations and by using Characteristic, Differential, and Coplanar models.

• Transmission lines are signal carrying circuits composed of conductors and dielectric material configured to control high frequency or narrow pulse type signals

• Two types of transmission lines configurations used to control impedance:
  – Micro-strip - conductor is above a ground plane.
  – Stripline – conductor is running between two ground planes

• Impedance is controlled through:
  – Conductor width
  – dielectric thickness

• Flex Materials have advantages over rigid laminates based on:
  – Non-hybrid dielectric → more uniform local Dk.
  – Better controlled dielectric thickness.
CAM Process

- Full Design Rule Check (DRC) and artwork modifications (after customer approval)
- Panelization
- Netlist extraction before/after modifications

- Adjust for manufacturing process: hole sizes, trace widths, mask openings, compensation.
- Build destructive test coupons
- Output all artwork (silver halide films) and programs for drill, route, laser, test.
Kapton® Physical Properties

-Produced by polymerizing an aromatic dianhydride and an aromatic diamine.
-No known organic solvents will attack Kapton, it will not melt or burn.
-All-polyimide Kapton film has been successfully used in applications with temperature ranging from -269°C (-452°F) to +400°C (+725°F).
-Excellent resistance to radiation (gamma and neutron exposure) and UV exposure. NOTE – the combined effect of radiation and chemical exposure should be evaluated on a case by case basis.
-Chemical resistance to:
  - Strong Acids: Excellent
  - Strong Alkali: Fair
  - Solvents: Excellent
-Like any materials created by a condensation reaction, polyimide is quite hygroscopic. Continued exposure to high humidity environments will affect mechanical and electrical properties.

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength</td>
<td>231 MPa – 33,500 psi</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>77%</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>2.5 GPa – 370,000 psi</td>
</tr>
<tr>
<td>Folding Endurance</td>
<td>285,000 cycles</td>
</tr>
<tr>
<td>Density</td>
<td>1.42 g/cc</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.34</td>
</tr>
<tr>
<td>Linear Coefficient of Thermal Expansion</td>
<td>20 ppm / °C – 11 ppm / °F</td>
</tr>
<tr>
<td>Coefficient of Thermal Conductivity</td>
<td>0.12 W / m K</td>
</tr>
<tr>
<td>Shrinkage after 2 Hrs @ 150 °C</td>
<td>0.17%</td>
</tr>
<tr>
<td>Shrinkage after 4 Hrs @ 400 °C</td>
<td>1.25%</td>
</tr>
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</table>
## Electrical Properties: All Polyimide Films

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Value</th>
<th>Property</th>
<th>Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Strength – 1 mil film</td>
<td>7,700 V/mil</td>
<td>Dissipation Factor (1 kHz) – 1 mil film</td>
<td>.0018</td>
</tr>
<tr>
<td>Dielectric Strength – 2 mil film</td>
<td>6,100 V/mil</td>
<td>Dissipation Factor (1 kHz) – 2 mil film</td>
<td>.0020</td>
</tr>
<tr>
<td>Dielectric Strength – 3 mil film</td>
<td>5,200 V/mil</td>
<td>Dissipation Factor (1 kHz) – 3 mil film</td>
<td>.0020</td>
</tr>
<tr>
<td>Dielectric Strength – 5 mil film</td>
<td>3,900 V/mil</td>
<td>Dissipation Factor (1 kHz) – 5 mil film</td>
<td>.0026</td>
</tr>
<tr>
<td>Dielectric Constant (1 kHz) – 1 mil film</td>
<td>3.4</td>
<td>Volume Resistivity – 1 mil film</td>
<td>$1.5 \times 10^{17}$ Ω cm</td>
</tr>
<tr>
<td>Dielectric Constant (1 kHz) – 2 mil film</td>
<td>3.4</td>
<td>Volume Resistivity – 2 mil film</td>
<td>$1.5 \times 10^{17}$ Ω cm</td>
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<tr>
<td>Dielectric Constant (1 kHz) – 3 mil film</td>
<td>3.5</td>
<td>Volume Resistivity – 3 mil film</td>
<td>$1.4 \times 10^{17}$ Ω cm</td>
</tr>
<tr>
<td>Dielectric Constant (1 kHz) – 5 mil film</td>
<td>3.5</td>
<td>Volume Resistivity – 5 mil film</td>
<td>$1.0 \times 10^{17}$ Ω cm</td>
</tr>
</tbody>
</table>

**Graphs:**

- **Dielectric Constant vs. Frequency:**
  - Frequency range: $10^2$ to $10^5$ Hz
  - Temperature range: 0°C (32°F) to 300°C (572°F)

- **Dissipation Factor vs. Frequency:**
  - Frequency range: $10^2$ to $10^5$ Hz
  - Temperature range: 0°C (32°F) to 250°C (482°F)
## Pyralux® Properties: Composite Films

<table>
<thead>
<tr>
<th>Property</th>
<th>Composite Typical Value</th>
<th>LF Adhesive Typical Value</th>
<th>FR Adhesive Typical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant @ 1 GHz</td>
<td>3.6 – 3.8</td>
<td>3.2</td>
<td>3.3</td>
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<tr>
<td>Dissipation Factor</td>
<td>0.02 – 0.03</td>
<td>.028</td>
<td>.026</td>
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<tr>
<td>Dielectric Strength</td>
<td>2000-3000 V/mil</td>
<td>5000 V/mil</td>
<td>4000 V/mil</td>
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<tr>
<td>Volume Resistivity @ 20 °C</td>
<td>$10^8$ MΩ cm</td>
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<tr>
<td>Volume Resistivity @ 150 °C</td>
<td>$10^5$ MΩ cm</td>
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<tr>
<td>Flow – mils / mils of adhesive thickness</td>
<td>2-4</td>
<td>2 - 4</td>
<td>2 - 4</td>
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<tr>
<td>Density</td>
<td>1.3 – 1.4 g/cm³</td>
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<td>1.1 g/cm³</td>
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<tr>
<td>Glass Transition Temperature (Tg)</td>
<td>N/A</td>
<td>40 °C</td>
<td>40 °C</td>
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<tr>
<td>Rated Service Temperature</td>
<td>-60 °C to +125 °C</td>
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<td></td>
</tr>
<tr>
<td>CTE Z-Axis below Tg</td>
<td>100 ppm/°C</td>
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</tr>
<tr>
<td>CTE Z-Axis above Tg</td>
<td>400 ppm/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solder resistance, 10 min @ 500 °F (260 °C)</td>
<td>No blistering or delam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outgassing NASA SP-R-0022 (LF Only)</td>
<td>≤1.0%TML, ≤0.10% CVCM</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
Drawing Requirements

- Manufacturing Specification including PCB Class, Type and Use
- Raw Materials Specifications (optional but recommended)
- Metal Finish definition and (if applicable) specifications
- Drilling information that includes number of drilled holes per each diameter and finished hole size requirements (data to define hole locations should be digital)
- Dimensional Information: Identify all critical dimensions to a datum point. Define the rigid to flex interfaces. Typical outline tolerances are +/- .005” for rigid edges, +/- .003” for flex laser routed edges.
- Stiffener location, side, thickness and bonding requirements
- Board Markings: location, format and (if applicable) specifications
- If an assembly pallet or break-away array are defined, a dimensional drawing is required
- Stackup or a board construction and layer order chart, this should show which layers are rigid and which layers are flex, include copper weights and dielectric thicknesses
- ITAR Requirements or other IP Control restrictions
Class 1 – General Electronic Products
– Includes consumer products, some computer and computer peripherals suitable for applications where cosmetic imperfections are not important and the major requirement is function of the completed printed board.

Class 2 – Dedicated Service Electronic Products
– Includes communications equipment, sophisticated business machines, instruments where high performance and extended life is required and for which uninterrupted service is desired but not critical. Certain cosmetic imperfections are allowed.

Class 3 – High Reliability Electronic Parts
– Includes the equipment and products where continued performance on demand is critical. Equipment downtime cannot be tolerated and must function when required such as in life support items or flight control systems. Printed boards in this class are suitable for applications where high levels of assurance are required and service is essential.

Type 1 – Single Sided Flex, no plating, with or without stiffeners
Type 2 – Double Sided Flex, plated through, with or without stiffeners
Type 3 – Multilayer Flex, 3 or more Layers, plated through, with or without stiffeners
Type 4 – Multilayer Rigid-Flex, 3 or more layers, plated through
Type 5 – Flex or Rigid-Flex, with 2 or more layers with no plating

Use A – Flex only at installation
Use B – Continuous flexing for the number of cycles specified in the procurement documents
Use C – High temperature operating environment (over 105 °C or 221 °F)
Use D – Requiring UL recognition
Specs and References

IPC specifications [www.ipc.org](http://www.ipc.org)
- IPC-6013, Qualification and Performance Specification for Flexible Printed Wiring.
- IPC-2221A, Generic Standard on Printed Board Design
- IPC-2223, Sectional Design Standard for Flexible Printed Boards
- IPC-4202, Flexible Base Dielectrics for Use in Flexible Printed Circuitry
- IPC-4203, Adhesive Coated Dielectric Films for Use as Cover Sheets for Flexible Printed Circuitry and Flexible Adhesive Bonding Films
- IPC-4204 Flexible Metal-Clad Dielectrics for Use in Fabrication of Flexible Printed Circuitry
- IPC-MF-150, Copper Foil for Printed Wiring Applications
- IPC Position Paper: Transitioning from MIL-P-50884C and MIL-PRF-31032 to IPC-6013 and Amendment 1

- IPC recommends that companies using MIL-PRF-31032 specifications for printed circuits alternatively specify that flexible circuits be supplied under IPC-6013 Class 3 performance requirements. Government agencies have generally accepted that this is a COTS (Commercial, Off-The-Shelf) equivalent to MIL-PRF-31032.
- MIL-PRF-31032/3A, Printed Wiring Board, Flexible, Single and Double Layer, With or Without Plated Holes, With or Without Stiffeners, for Soldered Part Mounting.
- MIL-PRF-31032/4A, Printed Wiring Board, Rigid-Flex or Flexible, Multilayer, with Plated Holes, with or Without Stiffeners, for Soldered Part Mounting.