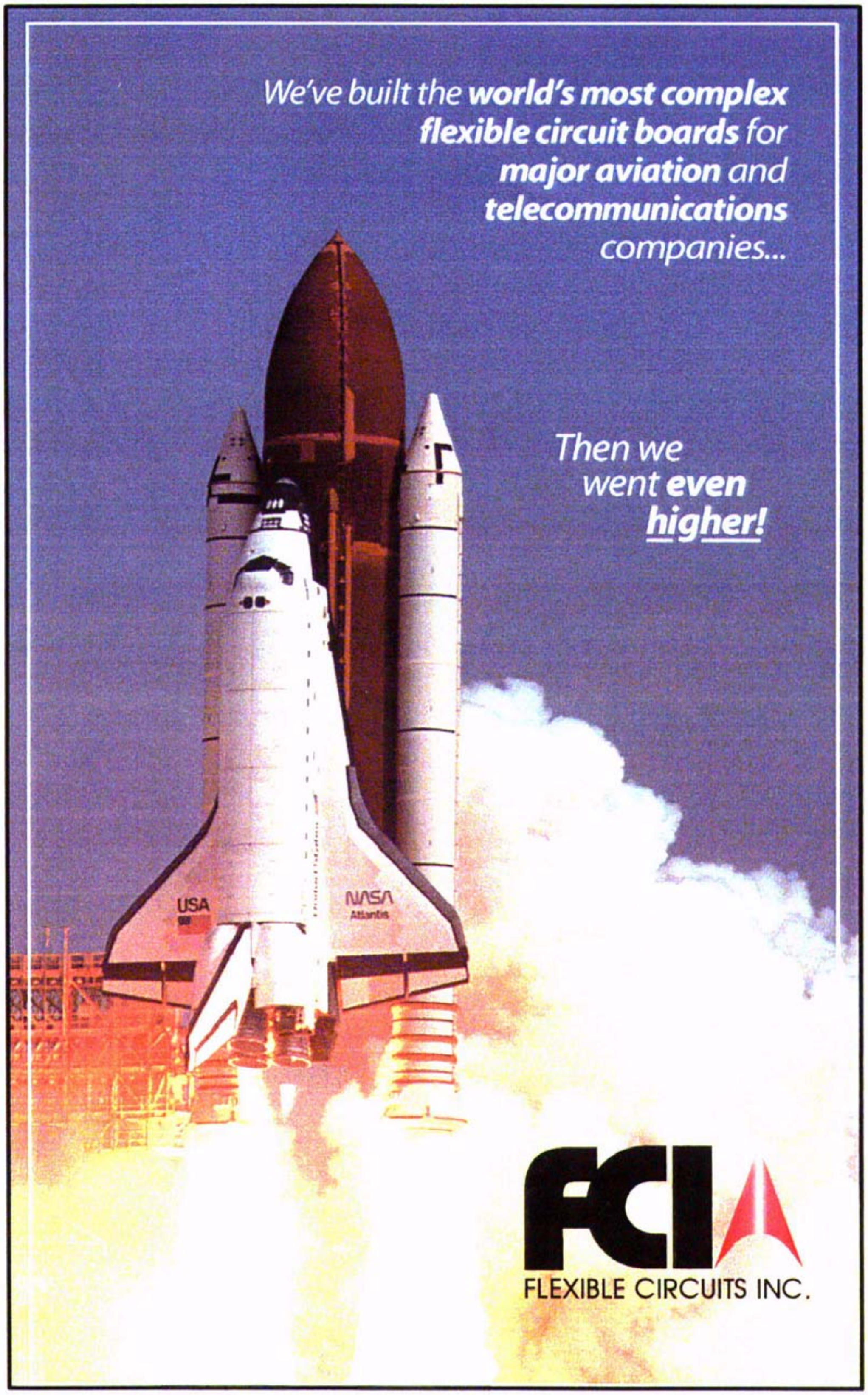
Flexible Circuits, Inc.

Design Guide

222 Valley Rd., Warrington, Pa. 18976-2580 TEL: (215) 343-2300 FAX: (215) 343-2075



Foreword

Flexible Circuits, Inc. produces high reliability flexible printed wiring interconnects. We are a MIL-P-50884 and IPC 6013 certified manufacturer. To provide this type of performance level, certain design techniques and proper material selection are crucial for the manufacture of and optimizing field performance. This guide along with direct contact with Flexible Circuits, Inc. will provide the necessary information required for achieving a successful interconnect package from concept through installation.

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Flexible Circuit or Rigid Board?

The most compelling difference between flexible circuits versus rigid circuits is flexibility. Flexible circuits are usually much thinner and are able to conform to the spacing limitations and environments into which they are installed.

Advantages of using flexible circuitry:

1) They can conform to three dimensional spacing limitations.
2) They have mobility (can be used where movement is required).
3) They are much thinner, thus more conductive layers can be added and will fit into tighter spaces.
4) They are much lighter in weight.

Disadvantages of using flexible circuitry:

1) They are generally much more expensive as a unit price.
2) They are more fragile. They can be subject to tearing if not properly handled.
3) Installation of terminals, connectors, etc. may require an additional stiffening material bonded to the flexible circuit.
4) "Z" axis expansion must be addressed during thermal exposure.

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Flexible Circuit or Round Wire?

Perhaps a short review of the advantages of flexible circuitry will help you make a decision.

1. Less weight and bulk when used as a direct round wire replacement.

2. It will virtually eliminate wiring errors and subsequently the need for trouble shooting wiring errors.

3. When all the costs of manufacturing, assembly, installation, and trouble shooting/repair are considered, a lower "end-use cost" is usually obtained with flexible circuitry.

4. Greater environmental resistance against corrosion, moisture and other atmosphere hazards because of the encapsulation of the copper conductors.

5. Improved durability because the materials used are highly resistant to flexing and tension.

6. Better adaptability. Able to fit into operational configurations where printed circuit boards simply cannot fit.

Why Settle for This? …

An actual unit, wired with old fashioned round wire.

When You Can Have This!!!

Same unit, using a 16 Layer flexible circuit.

SPECIFICATIONS

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The industry generally had accepted two specifications for the manufacture of flexible printed wiring boards, "MIL-P-50884" for military/aerospace field and "IPC" for industrial/commercial/medical fields. Today the industry is moving away from the military specifications and adopting the "IPC" specifications. IPC has created a complete array of specifications for manufacturing, assembling, and testing of flexible printed wiring boards for all performance levels. "IPC-6013" is the new fabrication and performance specification for flexible printed wiring boards that replaces MIL-P-50884.

Below is a list of the MIL-Specs and the IPC-Specs most commonly referenced:

MIL-SPECS

MIL-P-50884	Flex Manufacturing and Performance
MIL-STD-2118	Flex Design Standard
MIL-STD-105	Sampling Procedures and Inspection Tables
MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification for Marking
MIL-STD-202	Test Methods for Electronic Equipment
MIL-STD-2000	Soldering and Assembly
MIL-STD-45662	Calibration System Requirements
DOD-D-1000	Engineering Drawings
DOD-STD-100	Engineering Drawing Practices
ANSI-Y-145	Dimensioning and Tolerancing
MIL-S-13949	Plastic Sheet, Laminate, Metal Clad (for PWBs)
MIL-C-14550	Copper Plating (Electrodeposited)
MIL-I-43553	Ink Marking, Epoxy Base
MIL-G-45204	Gold Plating (Electrodeposited)
MIL-I-45208	Inspection System Requirements
MIL-Q-9858	Quality Program Requirements
MIL-P-81728	Plating Tin Lead (Electrodeposited)
MIL-P-55110	Printed Wiring Boards
QQ-N-290	Nickel Plating (Electrodeposited)

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IPC-SPECS

IPC-6013	Qualification and Performance Specification for Flexible Printed Boards
IPC-T-50	Terms and Definitions
IPC-MF-150	Metal Foil for Printed Wiring Applications
IPC-FC-231	Flexible Bare Dielectrics for Use in Flexible Printed Wiring
IPC-FC-232	Specification for Adhesive Coated Dielectric Films For Use as Cover Sheets for Flexible Printed Wiring
IPC-FC-241	Flexible Metal Clad Dielectrics for use in Fabrication of Flexible Printed Wiring
IPC-SM-840	Qualification and Performance of Permanent Solder Mask
IPC-2221	Generic Standard on Printed Board Design
IPC-2223	Sectional Design Standard for Flexible Printed Boards
IPC-4101	Laminate/Prepreg Materials Standard for Printed Boards
IPC-6011	Generic Performance Specification for Printed Boards
IPC-6012	Qualification and Performance Specification for Rigid Printed Boards
J-STD-001	Requirements for Soldered Electrical and Electronics Assemblies
J-STD-002	Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires
J-STD-003	Solderability Tests for Printed Boards
J-STD-004	Requirements for Soldering Fluxes
J-STD-005	General Requirements and Test Methods for Electronic Grade Solder Paste
J-STD-006	General Requirements and Test Methods for Soft Solder Alloys and Fluxed and Non-Fluxed Solid Solder for Electronic Soldering Applications.

Comparison of the new IPC-6013 to the old MIL-P-50884

(major highlighted differences)

1) Ease of use:

IPC contains an index and paragraphs are easy to follow. Specification tries to promote communication between manufacturer and user.

MIL is not user friendly and requires user to refer to many different paragraphs.

2) How current are specifications:

IPC contains all updated specifications.

MIL needs updating to current specifications.

3) Specification addresses different performance level requirements

IPC contains three performance levels (1,2,3).

Class 1- general use
Class 2 - industrial use
Class 3 – high reliability

MIL has one performance level only (basically high reliability). This can result in unnecessary testing and other costs when lower performance requirements may satisfy the application.

4) Rigid/Flex transition zone

IPC allows for visual imperfections in this zone that do not cause any functional degradation.

MIL does not address this area. Defaults to surface and sub-surface imperfections which do not adequately address anomalies that frequently occur in this zone. This results in unwarranted rejections or indecision.

5) Foreign Material (conductive and non-conductive)

IPC translucent foreign material is acceptable. All other foreign material is acceptable provided it is not closer than the minimum spacing on the drawing.

MIL must not be conductive, not be >.031", not reduce spacing >25%, and not propagate. This results in rejections that in most cases do not affect performance.

6) Measling and Crazing

IPC did an extensive study and found that these conditions do not cause any degradation in the performance of the printed wiring board and therefore concluded that "measling" and "crazing" are not rejectable items.

MIL measling and crazing must conform to sub-surface imperfections requirements. This results in unwarranted rejections that were proven not to have any performance degradation.

7) Solder Wicking

IPC specifically limits the amount of solder wicking by class.

MIL does not address this condition, therefore results in indecision.

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8) Minimum Annular Ring

IPC depends on Class. Class 3 is .002” external and .001” internal. Other classes are less stringent. This recognizes designs are becoming smaller and require tighter geometry’s.

MIL .005” min. for external and .002” min. for internal.

9) Solder Coating and Fused Tin-Lead

IPC solder finish must have coverage and be solderable

MIL solder coating must be .0003” min at the crest on the surface, .0001” min. at the crest in the hole and coverage at the “knee” of the hole. Tin Lead coating must be .0003” min. before fusing. HASL has never met MIL-P-50884, however it is method most widely used for soldering today.

10) Organic Solderability Preservative (OSP) coatings

IPC allows use of this technology.

MIL does not address this technology.

11) Copper Thickness after processing

IPC minimum copper foil thickness after processing is clearly defined

MIL not addressed. There is no minimum accepted value for how much copper can be removed during Processing.

12) Qualification

IPC to be agreed upon by user and supplier. Can be pre-production samples, production samples, test specimens (i.e. IPC-A-41, 42 or 43), or based on documentation from testing of specimens furnished on similar product. There is no QPL listing

MIL must submit test specimens using artwork pattern IPC-A-41,42 or 43 and pass a Qualification Certification testing every 3 years. A QPL list is generated.

13) Coupon Design

IPC Coupon design is per IPC-2221. Coupon design tries to represent circuit pattern.

MIL Coupon design per MIL-STD-2118. Coupon does not represent the circuit.

IPC-6013 Wiring Types

Type 1 Single-sided flexible printed wiring containing on conductive layer with or without stiffeners.

Type 2 Double-sided flexible printed wiring containing two conductive layers with plated-through holes, with or without stiffeners.

Type 3 Multilayer flexible printed wiring containing three or more conductive layers with plated –through holes, with or without stiffeners.

Type 4 Multilayer rigid and flexible material combinations containing three or more conductive layers with plated-through holes.

Type 5 Flexible or rigid-flex printed wiring containing two or more conductive layers without plated-through holes.

Installation Uses

Use A Capable of withstanding flex during installation

Use B Capable of withstanding continuous flexing for the number of cycles as specified on the procurement documentation.

Use C High temperature environment (over 105 degrees C)

Use D UL Recognition

Note: If Performance Class and Installation Usage are not specified, then the default selections will be:

Performance Class – Class 2
Installation Usage – Use A

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IPC-4101
Specification for Base Materials for Rigid and Multilayer Printed Boards

As the Printed Circuit Industry moves away from Military Specifications, this created a need to for an IPC specification for rigid materials. This specification covers the performance requirements for rigid laminates and prepregs used for the manufacture of rigid boards, rigid multilayer boards and flexible rigid/flex boards.

This specification is based on the canceled specification MIL-S-13949. It basically provides the industry with performance criteria that is equivalent to MIL-S-13949. However, it eliminates some of the redundant testing and costs associated with those tests.

What does this mean to the User?

Basically no impact except that drawings should now specify the above materials to be per IPC-4101 in lieu of canceled MIL-S-13949. Certification can only be made to IPC-4101. There is no longer any certification to MIL-S-13949.

Shown in the next pages are the major differences between the IPC-4101 and MIL-S-13949.

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Comparison of the IPC-4101 to the canceled MIL-S13949

(major highlighted differences)

General Information Differences

Prepregs and laminates are on the same slash sheet.
Slash sheets are recognized by "families" with open spaces for new materials that fit that family.
The entire specification is in metric with no English references.
The latest test methods are attached to the document.

Paragraph 1.2.2

Laminates can be ordered as dielectric space (without copper foil) or as an overall thickness (including copper foil). Currently laminates can only be ordered as a dielectric space.

Table 1

The copper foil table now includes type "R" (reverse treated electrodeposited) for grade 1 and Type "S" (reverse treated electrodeposited) for grade 3.

Paragraph 1.2.5 and 3.8.3.1.2

Surface quality class now includes a "D" designation which provides the most stringent surface quality call out. No pits, dents or epoxy spots over 5 mils. MIL-S-13949 has "B" as the tightest class which allow 1 pit up to 15 mils.

Paragraph 1.2.7

Prepregs are ordered using 3 parameters (resin content, resin flow, and the "optional" parameter)
Prepregs can be tested by using new test methods such as rheology, % cure, or delta H.

Paragraph 3.1.2

Quality conformance testing is conducted as determined by the current Manufacturers Quality System. Changes in the testing frequencies can be made by following the guidelines in IPC-PC-90. In the absence of a "Manufacturing Quality System", conformance testing is conducted at the same frequency as MIL-S-13949.

Paragraph 3.1.5 and 3.3

Self declaration form IPC-LQP-1730 is a pre-requisite to certifying to IPC-4101. The document IPC-LQP-1730 will be published by the IPC at the same time as the IPC-4101 Specification

Paragraph 3.1.7 and 3.4

Qualification sample testing must be conducted by the supplier at any IPC-QL-653 approved laboratory. The qualification data must be summarized and readily available for review. The qualification testing regime is the same as prescribed by MIL-S-13949.

Paragraph 3.4.1

A “thin” laminate specimen 10 mils or less qualifies all thin laminates (30 mils or less).
A “thick” laminate specimen greater than 30 mils qualifies all thick laminates.

Paragraph 3.4.2

For a given slash sheet, the thinnest prepreg qualifies all the thicker prepregs.

Table 5

Table 5 now includes Delta Tg and average X/Y CTE as optional tests.
The test method for flammability has been changed from the “MIL” method to the standard “UL” method 94.

Table 6

Electrical tests and some environmental tests are performed on prepregs after pressing into a Thin laminate.
Prepreg testing for flammability is only conducted as a thin laminate specimen.

Paragraph 3.9.1.1

Peel strength is called out as a single value for 35 micron foil. Foil weight greater than 35 microns must meet the required value for 35 micron. Foils less than 35 micron may be plated up to 35 micron and tested as is the current specified procedure in MIL-S-13949.

Paragraph 3.9.1.2

Dimensional stability is now specified as a nominal value with a tolerance range. The supplier must provide the nominal value for dimensional stability for each construction. Currently the MIL-S-13949 specification uses zero as the nominal value. IPC-4101 will reward consistency of dimensional movement.

Paragraph 3.9.2.2.6

Gel time is an optional test. It can be replaced with other characterization tests if desired such As rheological flow, cure %, or Delta H.

Paragraph 3.9.2.2.8

Volatile content is an optional test.

Paragraph 3.10.2.3

Dicy Crystals is an optional test.

Paragraph 3.15

MSDS forms must be available for materials supplied under this specification.

Paragraph 5.2

The supplier is responsible for establishing written guidelines for their authorized distributors.

MATERIALS

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Selection of Materials

Materials are one of the most important ingredient in determining the circuit's performance and life expectancy. Materials should be selected based upon the following criteria:

What is the circuit's function?
What environment will the circuit be expected to operate in?
What is the interconnection method?
What is the life expectancy?
What is the cost to produce?

FCI has a vast knowledge and experience in matching the right material for the particular application. We use only the highest grades of materials. These next pages will describe these materials and their performance.

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Flexible Metal Clad Laminate

Flexible Metal Clad Laminates provide the base material (conductive and dielectric layers) for upon which flexible printed wiring boards can be produced.

Types:

Types are listed in IPC-FC-241. There are two(2) types of laminates that are typically used:

1) A composite of polyimide film, acrylic adhesive, and copper foil.
2) A composite of polyimide film and copper foil (no adhesive, this is commonly Referred to as “adhesive-less” laminate.

The first type is still the workhorse of the industry and is mostly used on Types 1, 2, 3, 5 and low layer count Type 4 (rigid/flex) application.

The second type is becoming more widely used especially on high layer count Type 4’s where excessive “z-axis” expansion of the materials during thermal exposure can cause plated-through hole failure. There are other areas where this material proves to be advantageous such as in high dynamic flexing applications.

Material Availability

Maximum sheet size (in.)	24 x 36 (FCI typically uses 18 x24 sheets)
Polyimide film thickness (mils)	1, 2, 3, or 5
Copper foil weight (oz.)	½, 1, or 2
Adhesive thickness (mils)	1

*Other materials are available as special orders
*Adhesive is available with a flame retardant called “FR” type

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Adhesive Coated Kapton (Covercoat)

Adhesive coated Kapton is the material used for providing a dielectric layer over the flexible printed wiring conductive surfaces.

Types:

Types are listed in IPC-FC-232. Typical only one type is used; Kapton coated with Acrylic adhesive. This material is used for all applications (Types 1, 2, 3, 4, and 5).

Material Availability

Standard Roll size	24" wide
Polyimide film thickness (mils)	½, 1, 2, 3, or 5
Adhesive thickness (mils)	½, 1, 2, or 3

*Other materials are available as special orders
*Adhesive is available with a flame retardant called "FR" type

Flexible Adhesives

Flexible Adhesives are used to laminate various flexible materials together. This could be to laminate multiple flexible layers, attachment of stiffeners, heatsinks ,etc.

Types:

Types are listed in IPC-FC-232. Typically only one type is; Acrylic adhesive. This material is used for all applications (Types 1, 2, 3, 4, and 5). Other types are available, however FCI's use is very minimal.

Material Availability

Standard Roll size	24" wide (FCI typically uses 18 x24 sheets)
Adhesive thickness (mils)	1, 2, or 3

*Adhesive is available with a flame retardant called "FR" type

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Rigid Laminates

Rigid Laminate is a glass cloth coated with a resin system subsequently laminated to copper foil. This material is used by the flexible printed wiring industry for rigid/flex applications providing the base material (conductive and dielectric layers) for upon which rigid printed wiring conductive layers can be produced. It also used as "stiffener" material for the flexible circuit.

Types:

Types are listed in IPC-4101. There are many types of Rigid Laminates available to the industry. The most commonly used are Types GF and GI. Type GF is an "epoxy" resin system that is typically used for low layer count rigid/flex and stiffener applications. Type GI is used in high layer count rigid/flex applications where greater thermal resistance is required.

Material Availability

Standard sheet size (in.)	36 x 48 (FCI typically uses 18 x24)
Core thickness (mils)	5, 8, 10, 14, 20, 31, 47, 62, 93
Copper foil thickness (oz.)	½, 1, 2,

*Other materials are available as special orders

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Prepreg

Prepreg is a glass cloth coated with a resin system not fully cured (B-staged) to allow for subsequent lamination. This material is used by the flexible printed wiring industry for rigid/flex applications as an adhesive and dielectric to laminate conductive layers together.

Types:

Types are listed in IPC-4101. There are many types of Prepregs available to the industry. The most commonly used are Types GF and GI. Type GF is an "epoxy" resin system that is typically used for low layer count rigid/flex and stiffener applications. Type GI is used in high layer count rigid/flex applications where greater thermal resistance is required. Most of the Prepreg used for this application is a "No Flow" type.

Material Availability

Standard Roll size (in.)	36" wide (FCI typically uses 18 x24 sheets)
Glass Styles	106, 1080, 2112, 2116, 7628

*Other materials are available as special orders

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Copper Foil

Copper foil is most widely used as the conductive metal material. There are many types of copper foils available.

Types:

Types are listed in IPC-MF-150

Class	Description
1	Standard Electroplated (STD-Type E)
2	High Ductility electrodeposited (HD-Type E)
3	High temperature elongation electrodeposited (HTE-Type E)
4	Annealed electrodeposited (ANN-Type E)
5	As rolled wrought (AR-Type W)
6	Light cold rolled-wrought (LCR-Type W)
7	Annealed-wrought (ANN-Type W)
8	As rolled-wrought low temperature annealable (LTA-Type W)

*FCI uses **ONLY** Type "HTE" (High Temperature Elongation) for Rigid Laminates and Type "W7" (Annealed Wrought) for Flexible Laminates. These foils are best suited for high stress environments and are strongly recommended for optimum field longevity.

Material Availability

Standard roll size (in.)	24
Foil thickness (oz.)	½, 1, 2, 3
Treatment (bond enhancement)	single or double

*Other materials are available as special orders

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Z-Axis Expansion

Materials move in a lateral direction ("X" and "Y" axis). However there is also another direction "Z-axis" that must be considered when selecting materials. This is an expansion of the materials that relates to the thickness of the flexible circuit. When designs are one, two, or three layers, the thickness is generally thin and the expansion rate is small enough to be of no concern. However, as layer count and thickness increase, the expansion rate for the materials become a major concern. If the expansion rate of the materials is greater than the copper plating in the through hole can "stretch", then the plating will "crack" causing an open failed circuit. The result of this phenomenon is shown in the sketch on the next page.

Increasing the copper plating thickness can help resist the "Z-axis" forces from the material, however this does not guarantee that these forces won't still cause the plating to crack. The solution to the problem is to eliminate or reduce these forces. These forces are the material's Thermal Coefficient of Expansion (TCE). The expansion rates for the materials are shown below.

Expansion Rates of Materials Used to Produce Flexible Circuits

Material Type	Thermal Coefficient of Expansion (TCE)
Copper	9 x 10 (-6) inch/inch/F
Acrylic Adhesive	400 x 10 (-6) inch/inch/F
Kapton	11 x 10 (-6) inch/inch/F
GI Rigid (Average)	50 x 10 (-6) inch/inch/F
GF Rigid (Average)	175 x 10 (-6) inch/inch/F

Notice that the expansion rate of the "Acrylic Adhesive" material is almost 40 times greater than the rate of "Kapton" and "GF Rigid" material is 3.5 times greater than the rate of "GI Rigid".

The conclusions drawn from these expansion rates are that "Acrylic Adhesive" should be eliminated from the plated-through hole crossectional area and that "GI" in lieu of "GF" should be used for the rigid laminates and prepregs in rigid/flex applications. These materials would provide the least amount of "Z-Axis" expansion and **dramatically** reduce the possibility for "cracked hole barrels".

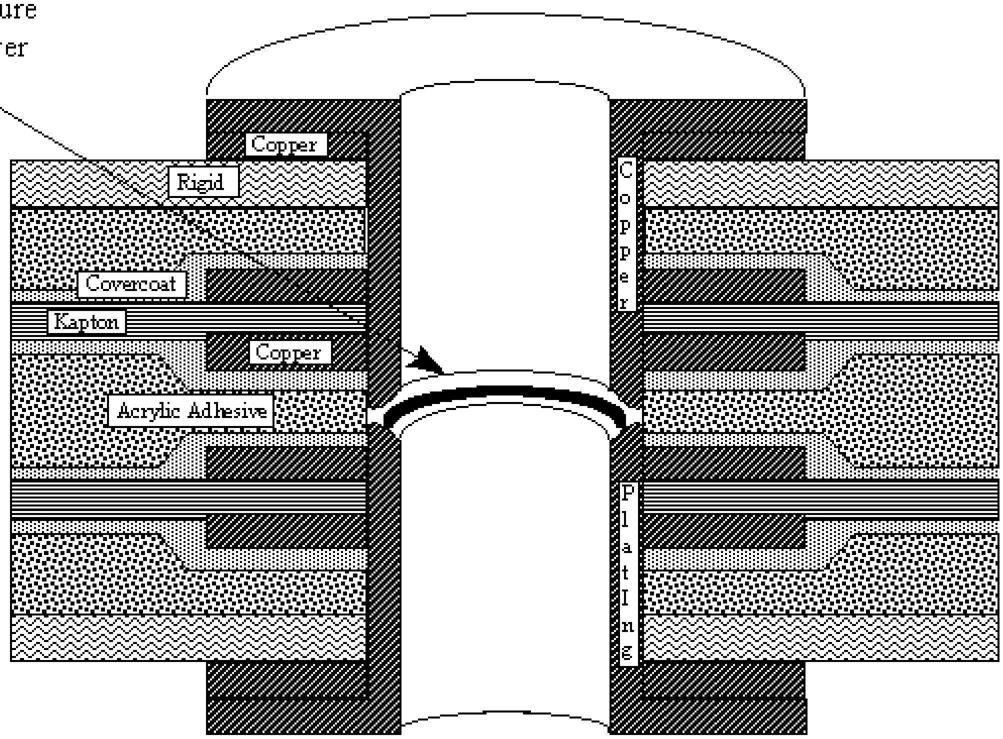
This can be achieved by utilizing "Adhesive-less" Flexible Metal Clad Laminates in conjunction with Covercoats eliminated from the plated through-hole crossectional area.

****See "Construction" Section of this "Guide" for crossectional view of how this is accomplished**

Z-Axis Expansion cont'd

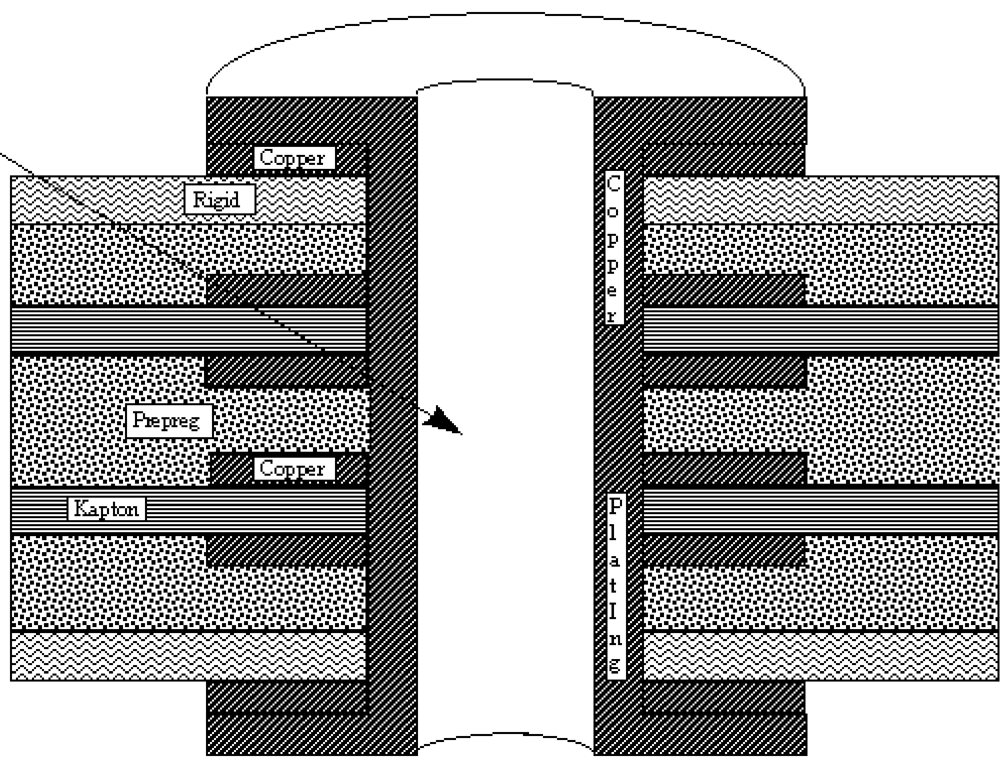
Copper Plating Barrel Fracture at the Acrylic Adhesive Layer

Crossectional View of Plated Thru Holes in a Rigid/Flex construction with Acrylic Adhesive (after Solder Float at 550°F 10 seconds)



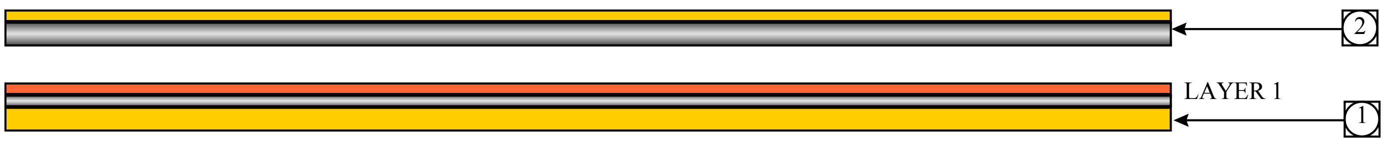
NO Barrel Fracture

Crossectional View of Plated Thru Holes in a Rigid/Flex construction without Acrylic Adhesive (after Solder Float at 550°F 10 seconds)



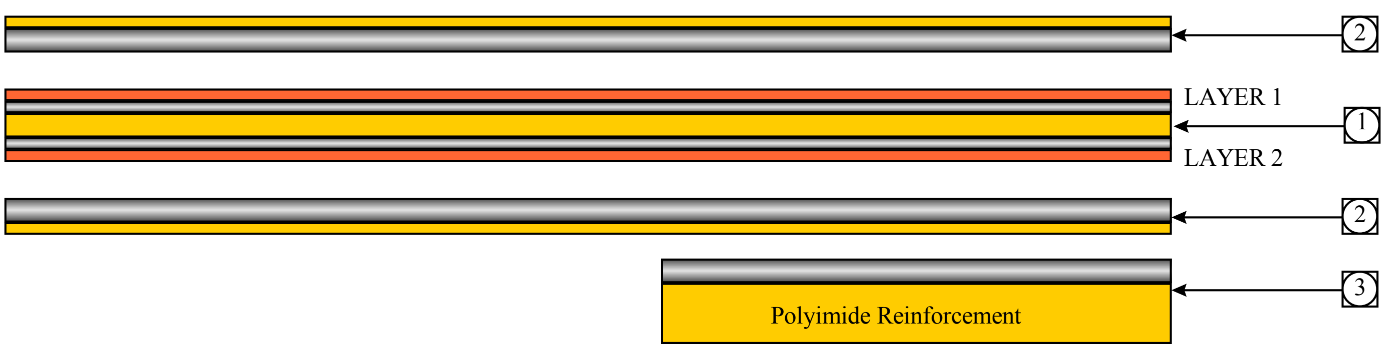
CONSTRUCTIONS

Figure 1: IPC-6013 Type 1 (Single-Sided Flex)



Materials:
1. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/0 CF W7 1X/0 3
2. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2 3

Figure 2: IPC-6013 Type 2 (Double-Sided Flex With Polyimide Reinforcement)



Materials:
1. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/1 CF W7 1X/1X 3
2. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E5M2 3

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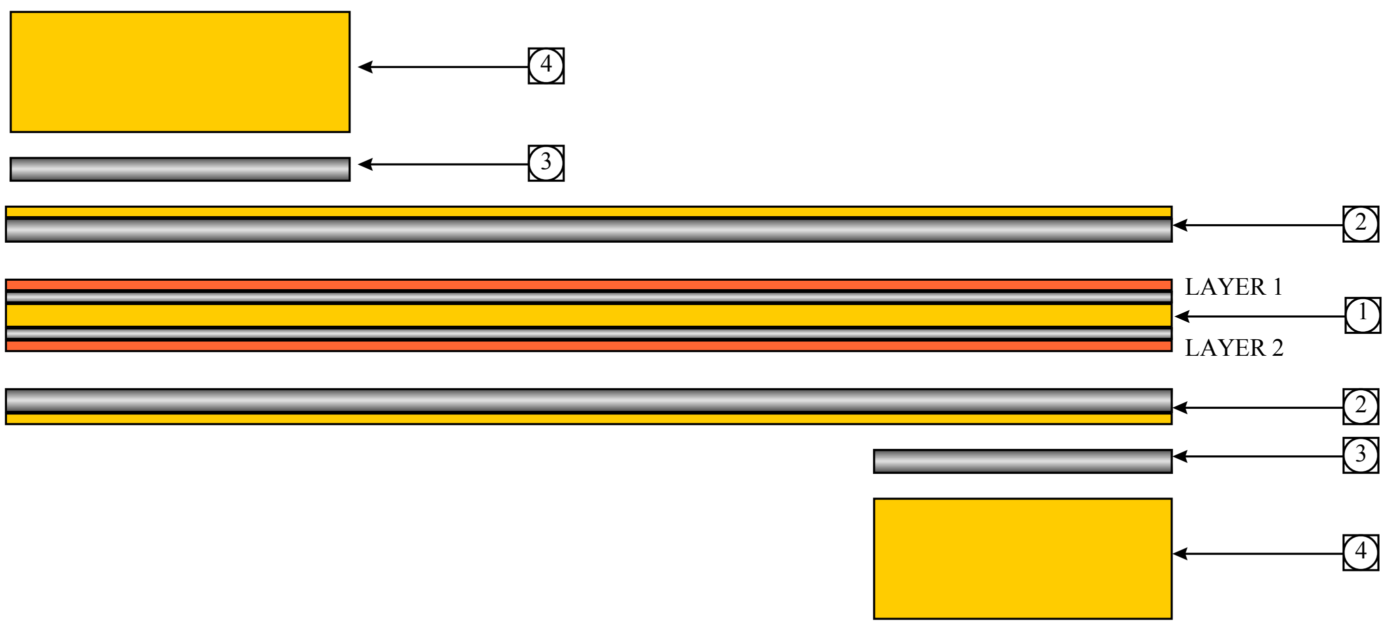
Figure 3: IPC-6013 Type 2 (Double-Sided Flex With Stiffeners)



Materials:

1. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/1 CF W7 1X/1X 3
2. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/18-0000M2 3
4. Rigid Laminate IAW IPC-4101/21 GFN XXXX 0/0

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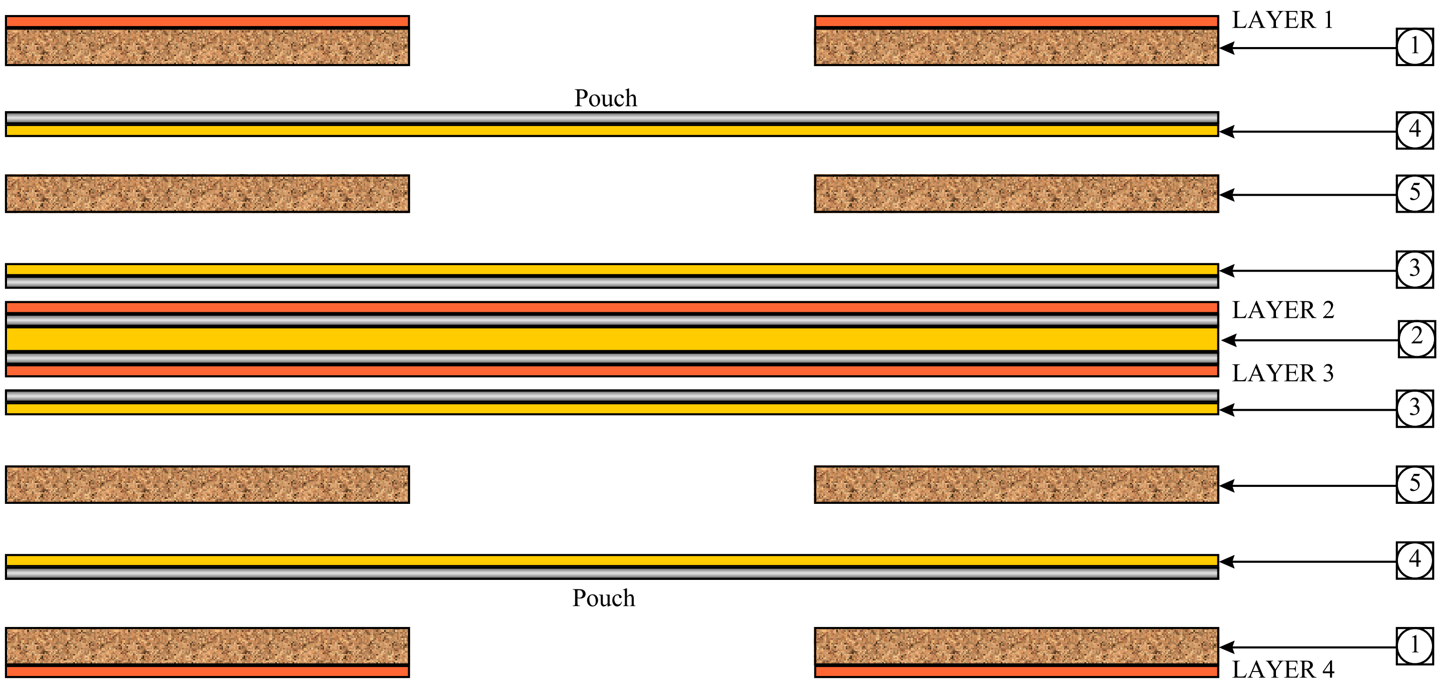
Figure 4: IPC-6013 Type 3 (Multi-Layer Flex)

Materials:
1. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/0 CF W7 1X/0 3
2. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/1 CF W7 1X/1X 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2/2 3
4. Adhesive Coated Dielectric Film IAW IPC-FC-232C/18-0000M2/0 3
5. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2 3

Figure 5: IPC-6013 Type 4
(Multi-Layer Rigid-Flex, Using Acrylic Adhesive)



Materials:
1. Rigid Laminate IAW IPC-4101/41 GIL XXXX H1/H1
2. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/1 CF W7 1X/1X 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2/03
4. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M1/03
5. Pre-Preg IAW IPC-4101/42 E1080

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Figure 6: **IPC-6013 Type 4**
(Multi-Layer Rigid-Flex with Silver Shields, Using Acrylic Adhesive)

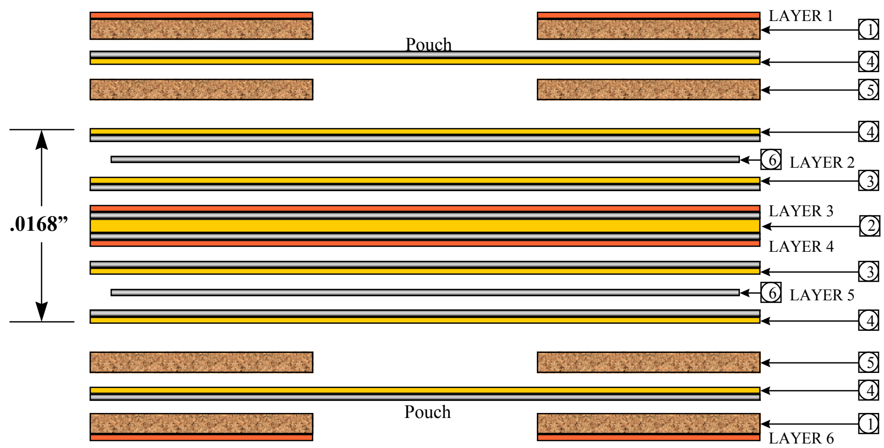
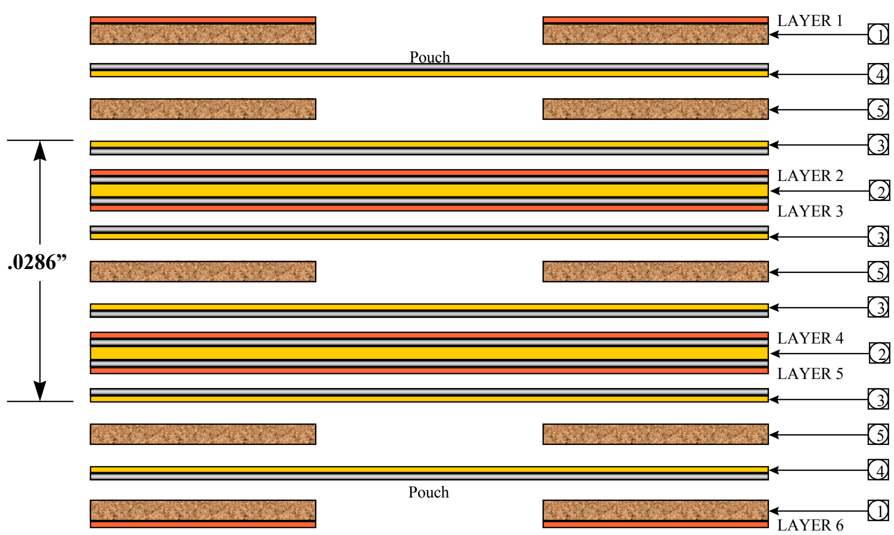


Figure 7: **IPC-6013 Type 4**
(Multi-Layer Rigid-Flex with Copper Shields, Using Acrylic Adhesive)



**** The silver shield version is thinner by .0118" for every four layers ****

Materials:
1. Rigid Laminate IAW IPC-4101/41 GIL XXXX H1/H1
2. Flexible Metal Clad Dielectric IAW IPC-FC-241C/1-E1E1 M1/1 CF W7 1X/1X 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2/03
4. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M1/03
5. Pre-Preg IAW IPC-4101/42 E1080
6. Silver Shield (Epoxy or Polyester Types)

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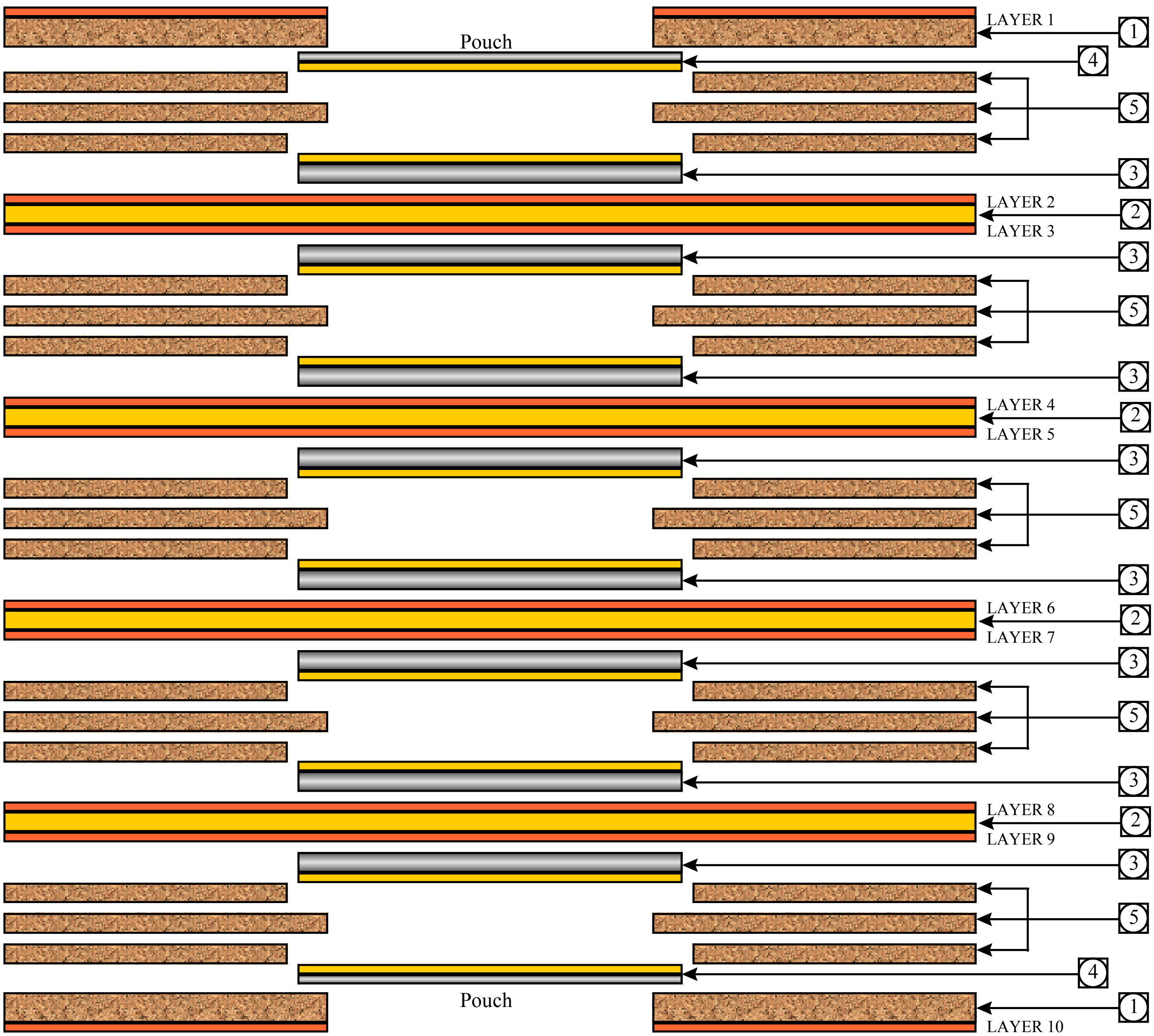
Figure 8: IPC-6013 Type 4 (Multi-Layer Rigid-Flex, Using Adhesiveless Laminate)



Materials:

1. Rigid Laminate IAW IPC-4101/41 GIL XXXX H1/H1
2. Flexible Metal Clad Dielectric IAW IPC-FC-241C/11-E1E2 0/0 CF W7 1X/1X 3
3. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M2/03
4. Adhesive Coated Dielectric Film IAW IPC-FC-232C/1-E1E1M1/03
5. Pre-Preg IAW IPC-4101/42 E1080

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ARTWORK

Artwork Guidelines for Flexible Printed Wiring Boards

Artwork design is another key ingredient in determining the circuit's performance and life expectancy. Most design software systems do not automatically design artwork for optimum flexible circuitry applications. These systems were designed for generating artwork for "rigid boards" and not for flexible circuitry. FCI highly recommends a system that can either automatically or manually add features such as "fillets", "anchoring spurs", "radius corners", etc. These enhancements are MOST crucial for optimizing the performance and life expectancy of the flexible circuit. FCI has a software system that can easily add these features to most artwork software files. The format most commonly used is Gerber.

These next pages will the show the recommended artwork features.

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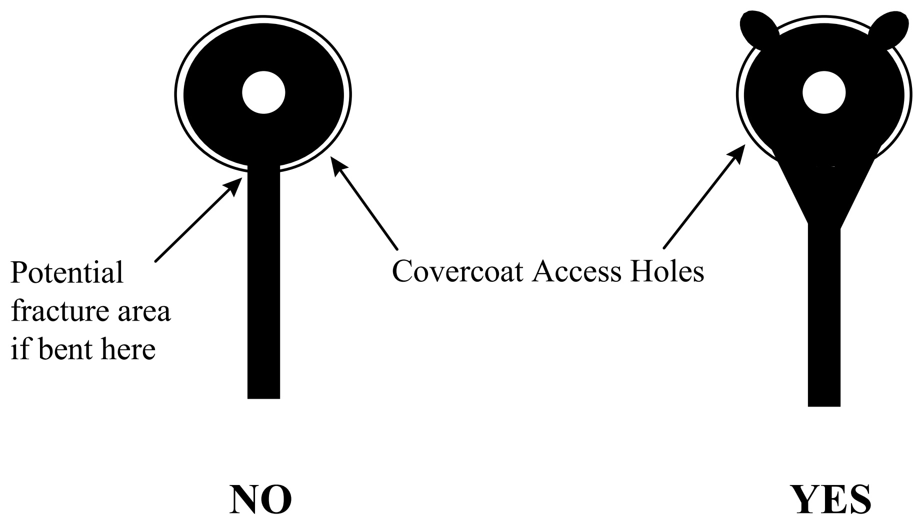
Artwork Guidelines cont'd

Anchoring Spurs and Fillets



1) Use of "Anchoring Spurs" help hold down the pad during soldering/component application when the covercoat cannot lap the pad. Notice how much more copper surface area is captured by the covercoat.

2) The "Fillet" increases the copper surface area adding mechanical strength to the pad for solder/ component application.

3) If the flex circuit is allowed to be flexed at the conductor/covercoat interface shown in the "NO" example, the conductor can fracture due to lack of mechanical strength. The "YES" example has much more copper at this interface and thus has more mechanical strength.

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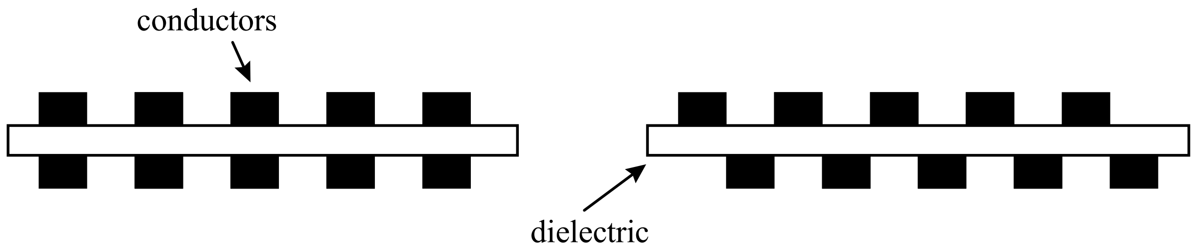
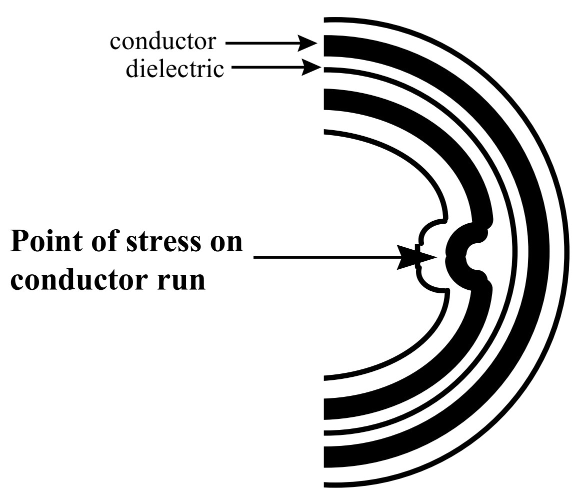
Artwork Guidelines cont'd

I-Beaming



NO **YES**

1) In an "I-Beam" condition, during flexing the conductors on the inside radius will be stressed (see sketch below) and will prematurely fail. By staggering the conductors as shown in the "YES" column, the stress will be evenly displaced during the bend optimizing flexure life.



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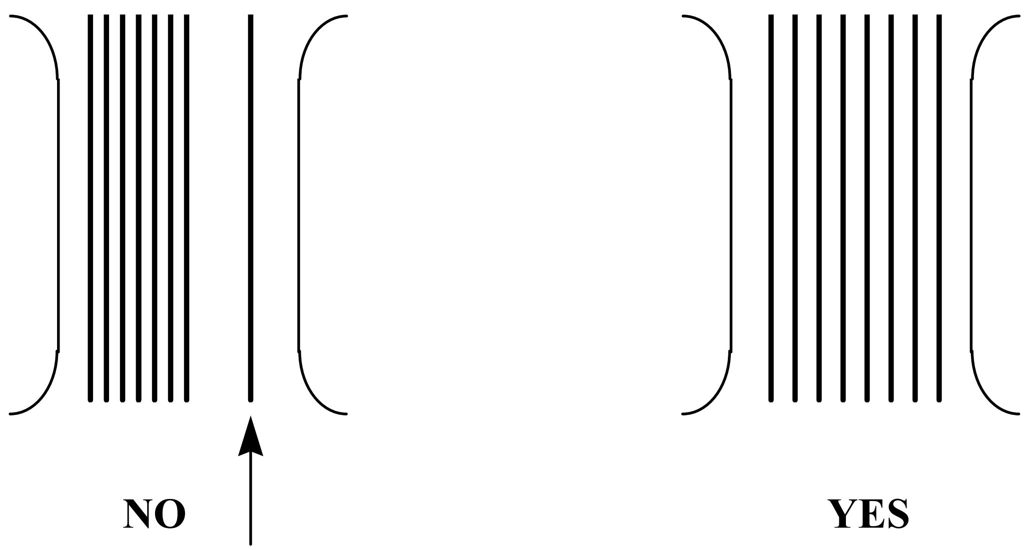
Artwork Guidelines cont'd

Conductor Isolation



1) The conductor shown by itself in the "NO" column will be subject to premature breaking during flexure. The evenly spaced conductors shown in the "YES" column will provide maximum flex life.

2) Also notice that the conductors are evenly distributed across the available area in the "YES" column. This will not cause any induced stresses during flexure. This is **extremely important** in dynamic flexing applications.

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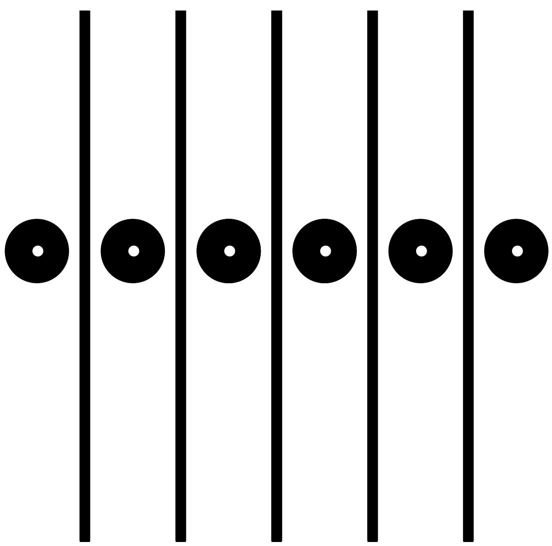
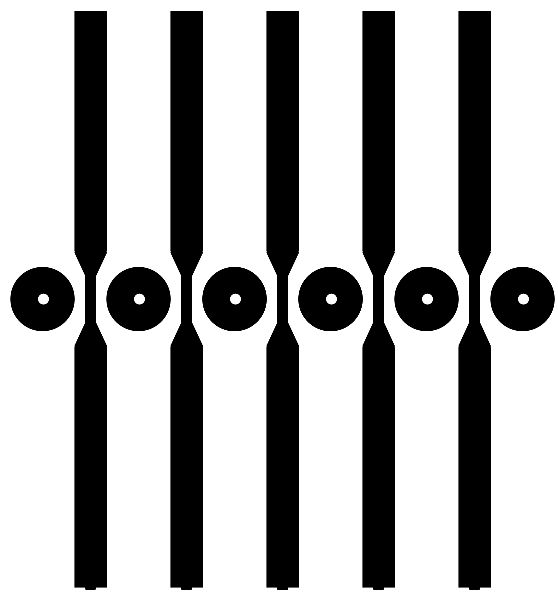
Artwork Guidelines cont'd

Maximizing Line Widths



NO



YES

1) Increasing the conductor widths where space permits will increase manufacturing yields. Notice that the narrow width is only required between pads.

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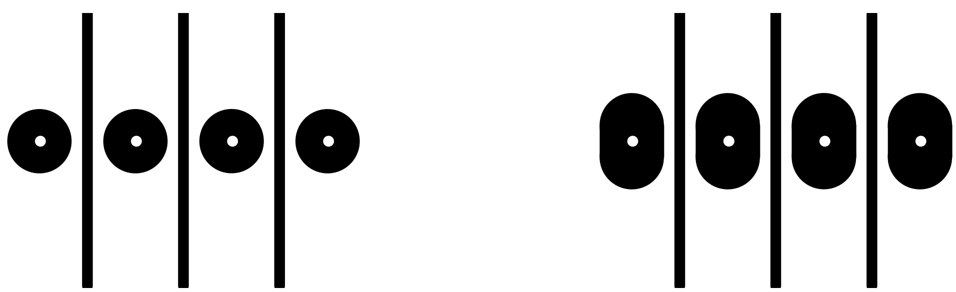
Artwork Guidelines cont'd

Elongated Pads



TYPICAL **ENHANCED**

1) Elongated Pads can increase the annular ring in tight geometry and also increase terminal area bond strength.

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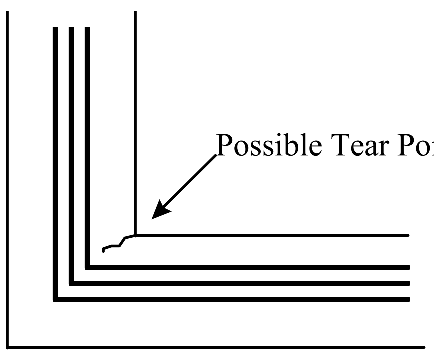
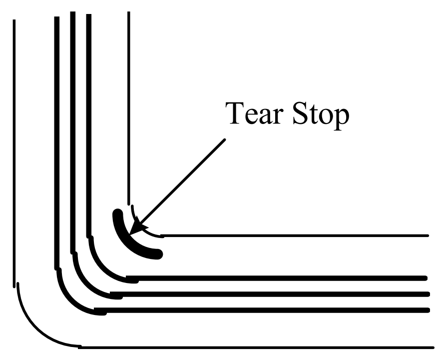
Artwork Guidelines cont'd

Tear Stops



NO



YES

1) All inside corners should have a radius to prevent tearing. A "tear stop" which is an extra piece of copper will further will help stop a tear from entering the conductive path area.

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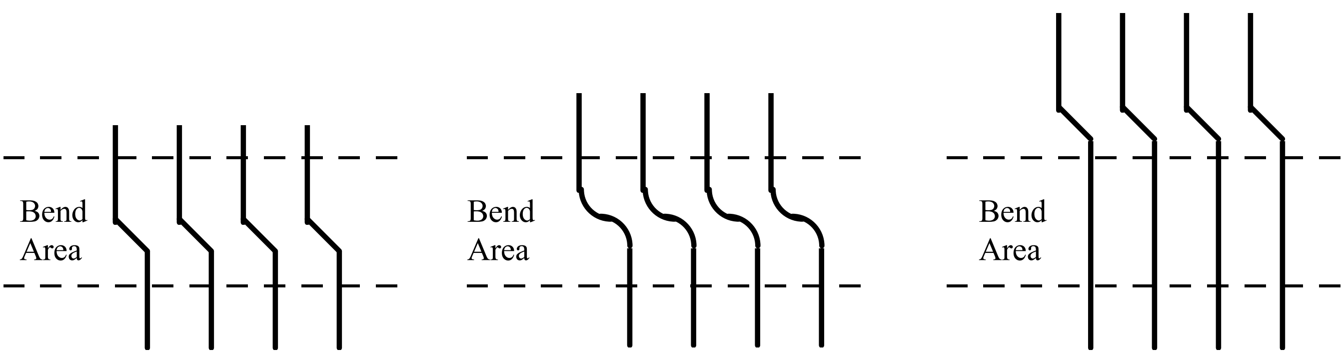
Artwork Guidelines cont'd

Traversing conductors in the bend area



NO **OK** **PREFERRED**

1) The conductors shown in the "NO" column will have stress risers at the their angles. Premature failures (conductor fractures) can occur at these points. The conductors shown in the "OK" column have their angled corners "radiused" to reduce the stress points. However it is still preferred to not have any traversing conductors in the bend area as shown in the "PREFERRED" column especially in dynamic flexing applications.

2) There shall be NO "vias" in the bend areas.

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Pad Size vs. Hole Size Calculation

The area where Artwork designs fail most to allow enough processing tolerance to meet the minimum annular ring is "pad size" calculation. FCI uses the formula from MIL-STD-2118 to calculate the minimum pad size for the required hole size. The formula is as follows:

Minimum Pad Size = A + 2B +2C(when required) + D

A = Maximum diameter of the drilled hole for internal lands and finished hole for external Lands.
B = Minimum annular ring required
C = Maximum allowance for etchback (when required)
D = Standard Fabrication Allowance. This was determined by statistical survey, which considers tooling and process variations required to fabricate boards.

**** FCI will accept all Artwork down to reduced producibility ****

STANDARD FABRICATION ALLOWANCES

GREATEST BOARD DIMENSION	ALLOWANCES (INCHES)		
	PREFERRED	**STANDARD**	**REDUCED PRODUCIBILITY**
UP TO 12 INCHES	**.028**	**.020**	**.012**
12 TO 18 INCHES	**.034**	**.024**	**.016**
GREATER THAN 18 INCHES	DRAWING TOLERANCES MUST REFLECT BEND AND FOLD ALLOWANCES BETWEEN COMPONENT MOUNTING RIGID AREAS		

Example A: Double Sided Circuit with .035 +/-.003 hole size

Minimum Pad Size = .040 (drill size) + .010 (2 x .005 annular ring) + 0 (no etchback) + .012 (reduced producibilty factor) or **= .062"**

Example B: Multilayer Circuit with .035 +/- .003 hole size

Minimum Pad Size = .041 (drill size) + .004 (2 x .002 annular ring) + .006 (2 x .003 max. etchback) +
(Internal Layer) .012 (reduced producibility factor) or **= .063"**

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MISCELLANEOUS

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Stiffeners/Reinforcements

Stiffeners/Reinforcements are added to flexible circuitry to provide strain relief when attaching connectors and/or other terminating devices.

There are two(2) types of stiffening methods used:

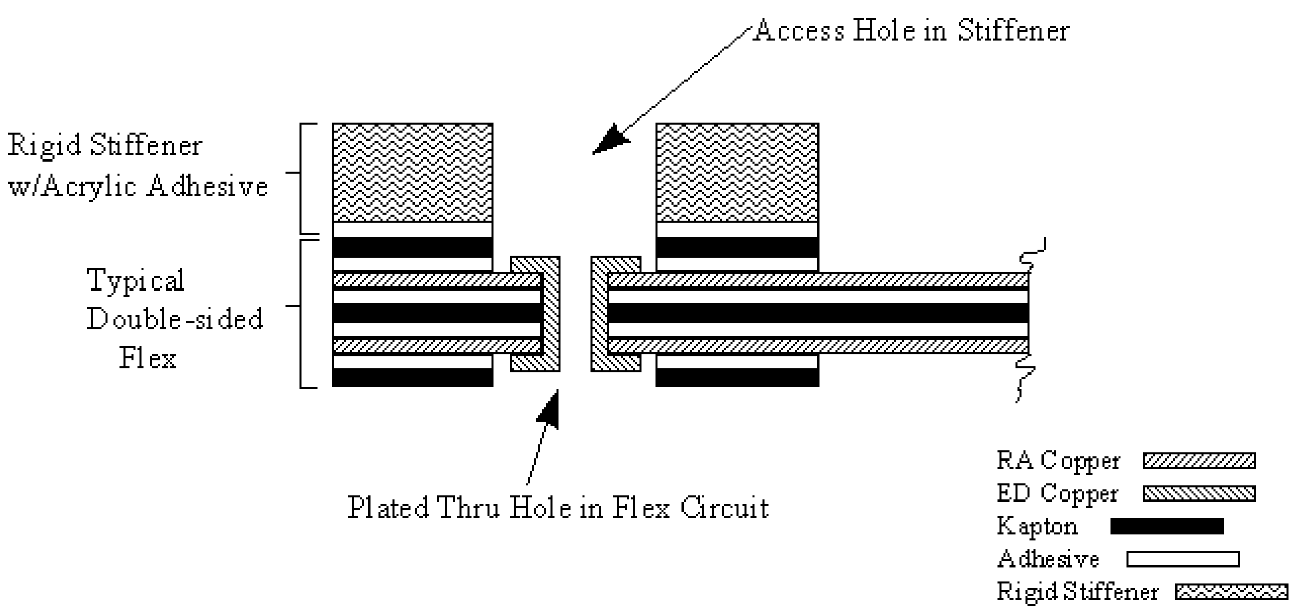
1) Use of Rigid material with "pre-casted" adhesive (usually acrylic adhesive).
2) Use of Adhesive Coated Kapton material.

Type "1" is the most common method. It provides a highly rigidized surface for component attachment. Since the flexible circuit can no longer bend in the solder joint area, the stress on the solder joints is thus eliminated. Typically the holes in the stiffener should be larger than the circuit pad to prevent damage to the pads during lamination and/or adhesive squeeze into the holes.

This material is available in various thicknesses from .005" to .125" with .031" being the most common thickness used. Type GF material is typical used; with GI used in high temperature applications.

Hard Tooling such as Lamination Fixtures, Rout Fixtures, NC Drill and Rout Programs are required to bond Stiffeners. Therefore, common tooling holes should be incorporated into the Flexible Circuit and Stiffener for this purpose only.

Example of flexible circuit with "rigidized" stiffener



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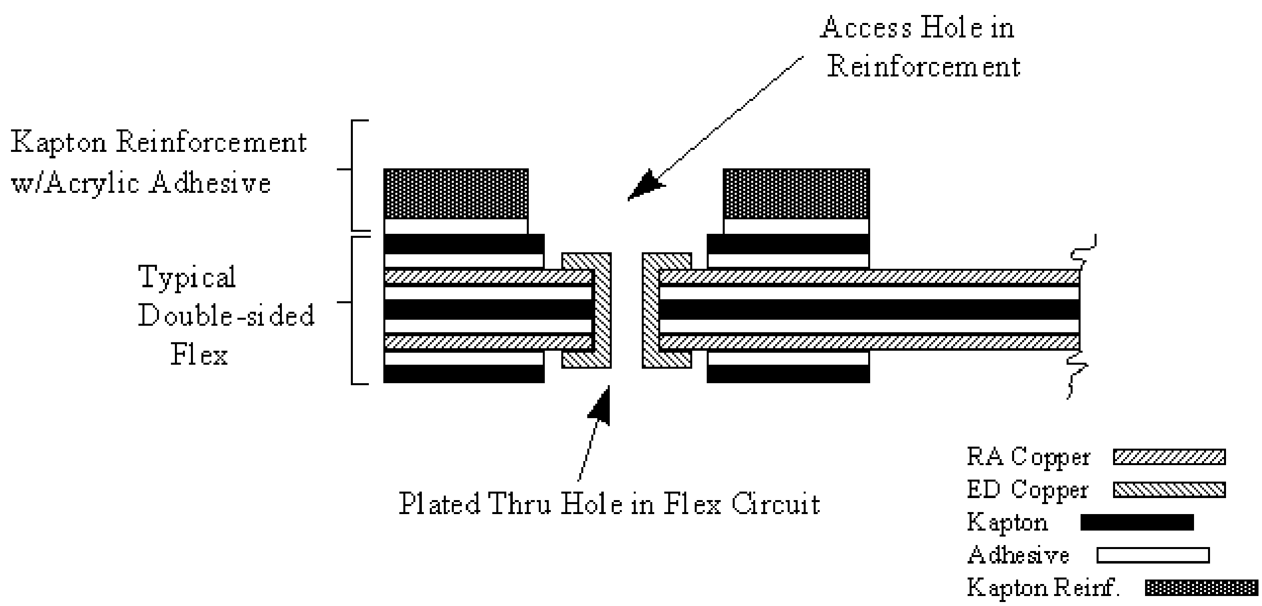
Stiffeners/Reinforcements cont'd

Type "2" is used when only a slight additional stiffness is needed. This material is typically 5 mil Kapton coated with Acrylic Adhesive. They can be applied to both sides of the flexible circuit. This method although not nearly as effective as rigidized stiffeners are generally less costly to apply than using rigidized stiffeners since they are attached when the covercoat is applied and do not require the tooling expense.

Example of flexible circuit with "Adhesive Coated Kapton" reinforcement



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Desmear/Etchback

Desmear is the removal of "adhesive smear" inside the hole barrel caused by the drilling operation. Etchback is the horizontal removal of the "adhesive" material. Both of these processes are typically performed using "plasma" technology.

History

Prior to the development of adhesive less flex materials, etchback was necessary in multilayer rigid/flex type constructions (especially in high layer counts). These constructions employed use of acrylic adhesive in the flex materials. This resulted in excessive "z axis" expansion of the composite during thermal stressing which can cause a separation at the interface of the inner layer copper foil and the through hole plating.
Etchback helped reduce this from occurring. Any similar constructions built today (generally more than 6 layers) would still require etchback.

NOTE: If etchback is required, it must be specified on the procurement drawing

Today

With the availability of adhesive-less clad flex materials, GI type core, prepreg, and with an engineered technique of keeping the covercoat material out of the plated through holes, the "z axis" expansion is <u>dramatically</u> reduced. The harmful stress at the interface of the inner layer copper foil is eliminated hence, etchback is no longer needed.

See Next Page for Pictorial

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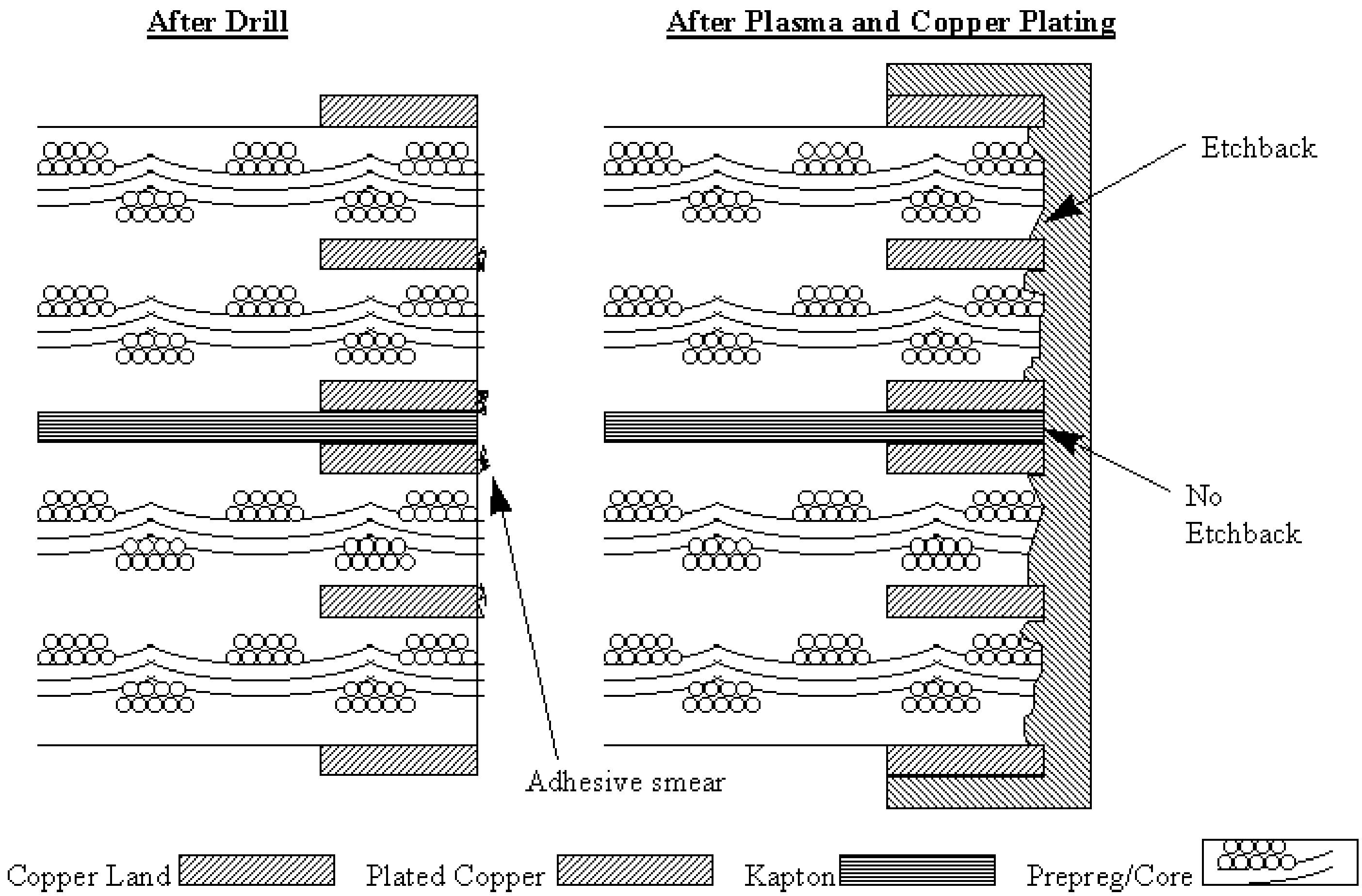
Desmear/Etchback cont'd



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Dynamic Flexing Applications

Materials Selection and Design are the two(2) major components to maximize flexure life. This Section will cover materials only. A later section will discuss design.

There are two(2) types of dynamic flex applications:
1) Continuous back and forth bend (a rolling type action)
2) A bend over a radius where the flexing action is at the same focal point.

In the first application, FCI has found that the "Adhesive-less" Flexible Metal Clad Laminate has the longest life.
In the second type application, FCI has found that the Flexible Metal Clad Laminate with "Acrylic Adhesive" has the longest life.

There are common practices that should be employed on both applications:

1) Material construction should be balanced (copper weights, adhesive thickness, Kapton Thickness should be same from the center origin of the material.
2) 1 oz Copper performs the best. Durable enough but does not impose thickness.
3) The thickness of the materials at the bend area should be minimized.
4) Electrodeposited Copper should be avoided in bend areas.
5) Rolled Annealed Copper Foil (Type W7) should be used.

The following items should be identified on the procurement document:

1) Direction of bend
2) Degree of bend
3) Number of fold cycles
4) Diameter of mandrel
5) Points of application

Guidelines for determining minimum bend radius capability of the material

1) Single and double-sided
   a) Minimum bend radius to be 6 times the thickness of the materials.
2) Mulitlayer Flex
   a) Minimum bend radius to be 12 times the thickness of the materials.

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Silver Epoxy Shielding

Silver Epoxy is a single component epoxy based medium containing very minute silver particles suspended throughout the medium. This material allows for electrically conductive paths to be placed on non-conductive surfaces.

This provides an alternative method to copper for shielding conductive paths from electromagnetic interference. See Next Page for effectiveness of Silver Epoxy Shielding.

For Specific Material Characteristics see the "Data Sheets" contained in this guide.

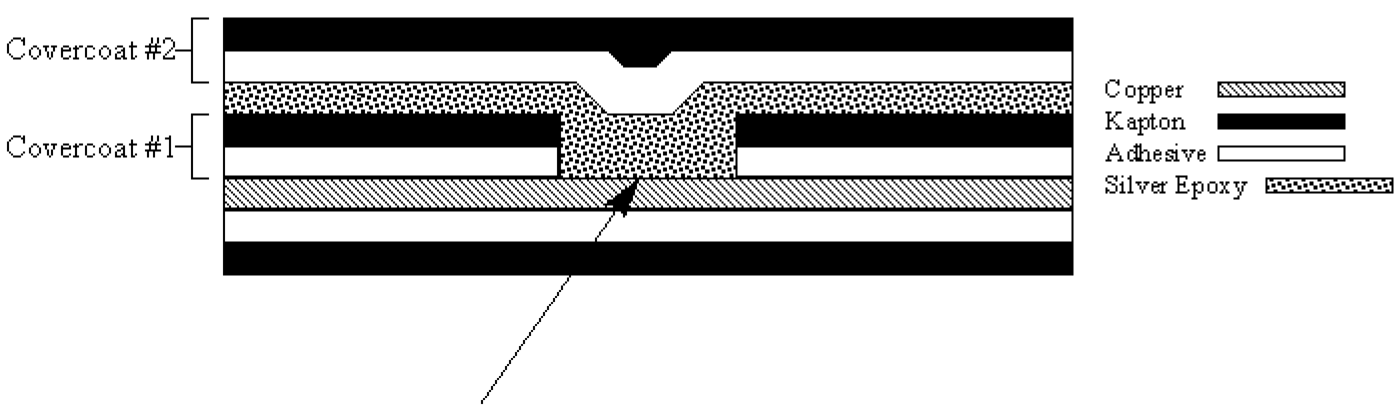
Advantages of Silver Epoxy

1) Enables a reduction in layer count and thus reduces thickness. This increases flexibility when compared to using copper as the shield material.
2) Typically reduces cost due to less material needs to be processed.
3) The thickness of Silver Epoxy is thin; approx..0005" thick.

Disadvantages of Silver Epoxy

1) Since Silver Epoxy is "screened" applied, the accuracy of locating the image is not as precise as methods used to produce printed copper shields. Generally +/.015" is required for feature tolerance.
2) Silver Epoxy cannot be used as an electrical connection inside a plated through hole. Connection must be made external to the plated through hole. (See sketch below).

A silver epoxy shield connection to ground is made to the land feature through an access hole in the dielectric layer (covercoat#1). Another dielectric covercoat(#2) is applied to insulate the silver epoxy.



A silver epoxy ground connection is made to the land feature through an access hole in the dielectric layer (covercoat#1). Another dielectric covercoat (#2) is applied to insulate the silver epoxy.

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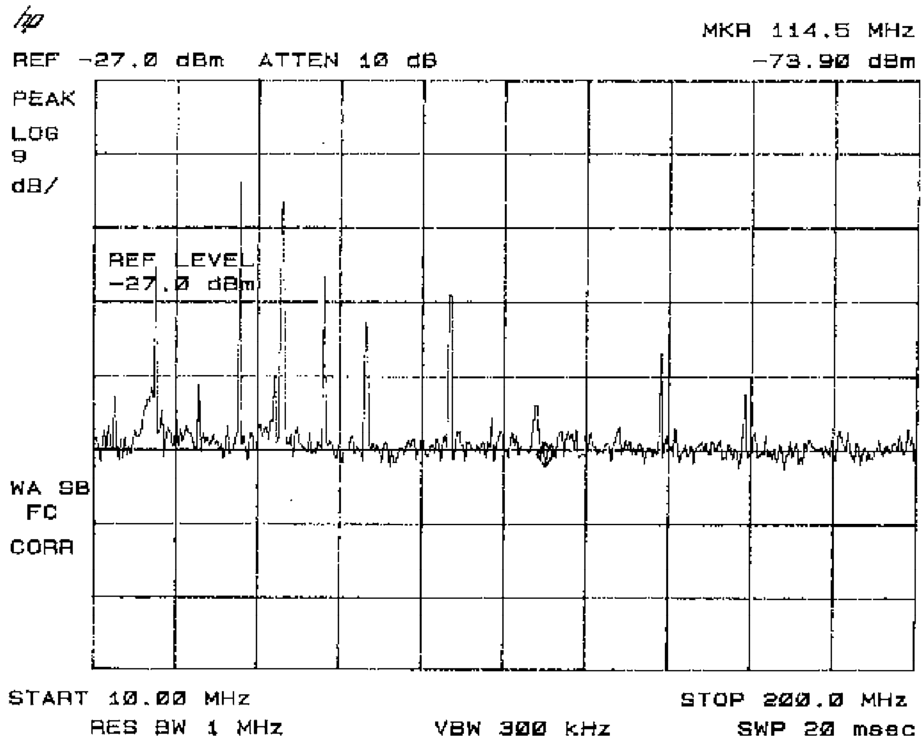
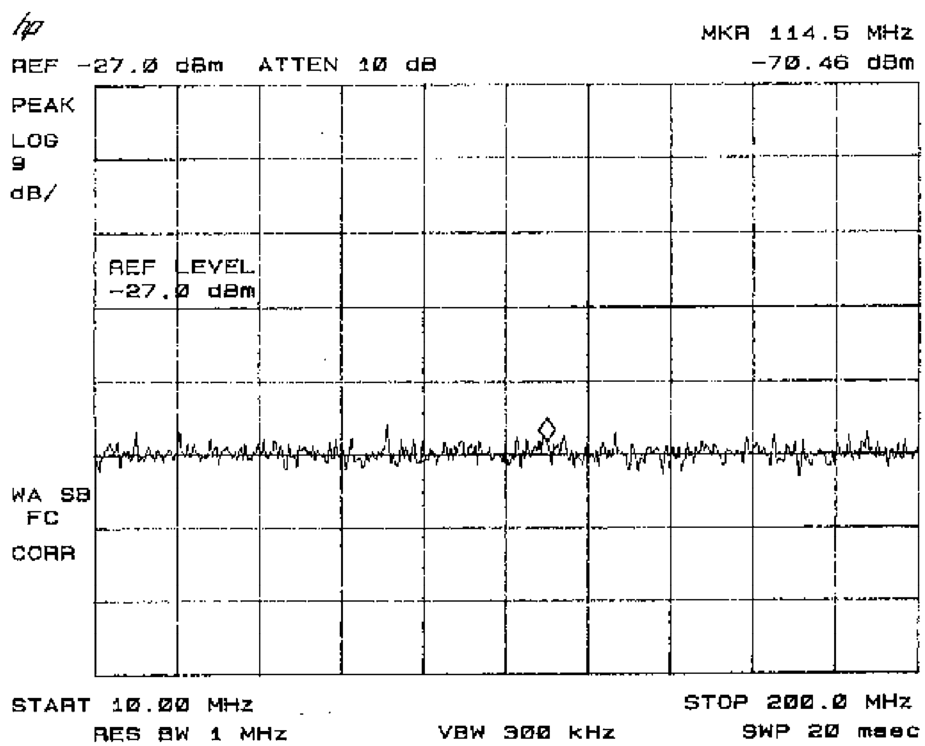
Noise Level with no Shielding



Noise Level with Silver Epoxy Shielding



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Surface Mount Applications:

Material construction can play a vital role a role in two(2) key areas:

1) Does a restraining material need to be added?
2) How to maintain "co-planarity" of the flexible printed wiring board for device attachment?

Item #1

Glass reinforced Epoxy or Polyimide can be used in most surface mount applications. Typically these materials have "X" and "Y" movement of approx. 15 ppm/°C. However, lower ppm's can be achieved by increasing the "glass" content of the rigid material. Utilizing heavier glass cloth styles such as type "7628" will lower the "X" and "Y" movement down to as low as 8 ppm's. This should be considered as a possible alternative to using highly expensive restraining materials such as Molybdenum, or using very expensive rigid materials such as Copper-Invar-Copper or Kevlar.

Item #2

To achieve optimum co-planarity, the material construction should be balanced. The materials and their thicknesses should be the same from the center origin of the composite. This will help reduce possible warp and twist.

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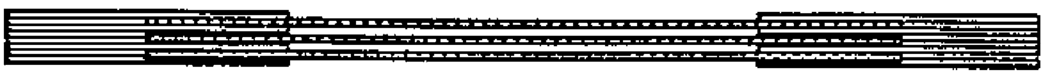
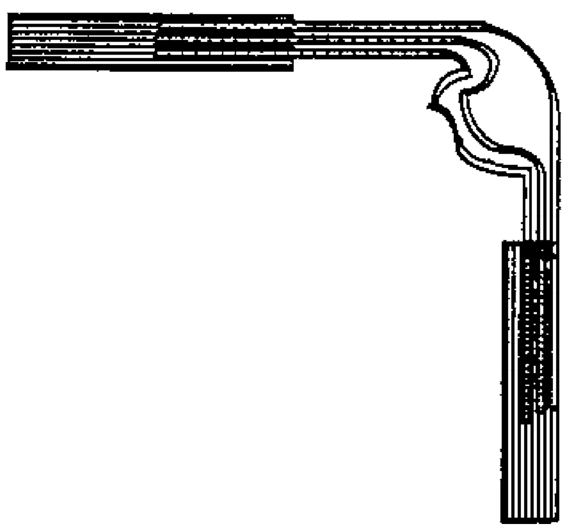
Bookbind

When multilayer flexible circuits were first developed, it was soon discovered that they did not bend easily. Therefore, a method to increase flexibility was crucial. This was overcome by eliminating the adhesive material between the flex layers.



This “unbonded” area dramatically improved the ability of the circuit to “bend”. In most cases, this is sufficient enough for proper installation. However, there are applications where there is not enough space between the laminated sections for the flex circuit to bend into installation. There could be severe “buckling” of the flexible material on the inside radius of the bend, while the outer material must “stretch” to bend. This could lead to damage to the conductive paths.



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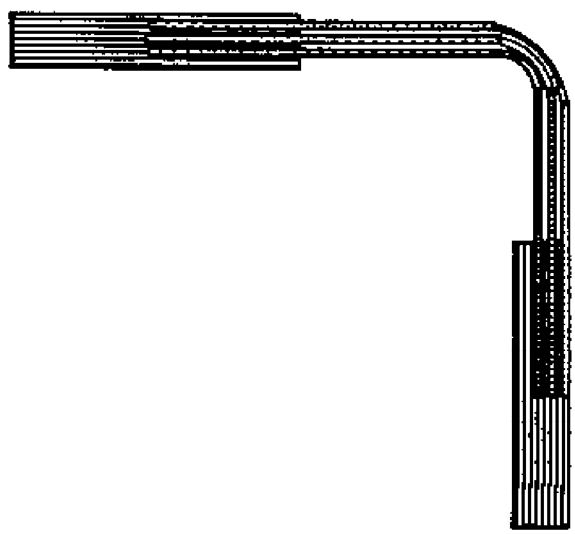
Bookbind cont'd

A solution to the problem is to lengthen each flex layer to compensate for the required bend radius. This allows the bend to be accomplished without placing any stress on the conductive paths.



The concept is simple however the calculation is somewhat involved. The artwork for each flex layer must be modified in length based upon the required bend radius. The layer that becomes the inside radius requires no size compensation (basically is a nominal length). Each subsequent flex layer shall be compensated/lengthened based upon the following criteria:

1) What is the Bend Radius?
2) What is the Bend Angle?
3) What is the Flex Thickness?
4) What is the Air Gap (usually the thickness of the adhesive removed)?

Using the above information, the compensation length can be determined using the calculation shown on the next page:

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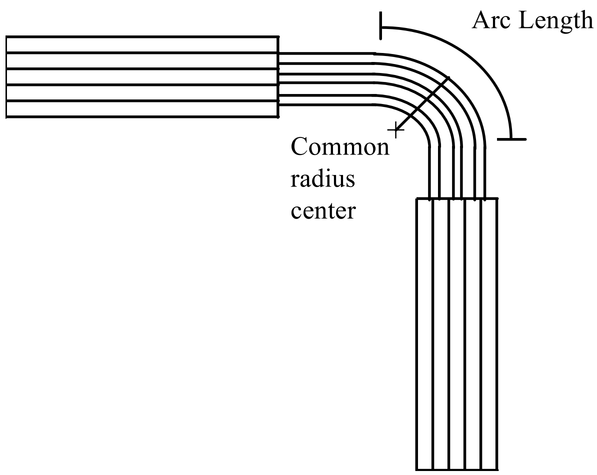
Bookbind cont'd

Calculation Example:

The length of the flex through the bend = (2¶ R) x (Bend Angle Value)

Bend Angle is 90° therefore the Bend Angle Value is ¼ of 360° or .25

Inner radius = .200"
Flex thickness = .012"
Air Gap = .002" between each flex layer



Shortest flex radius is .206" (inner radius + ½ of the flex thickness)
Middle flex radius is .220" (shortest radius + flex thickness of .012" + .002" for Air Gap)
Longest flex radius is .234" (middle radius + flex thickness of .012" + .002" for Air Gap)

Using the Calculation above, the Artwork lengths must be as follows:

Shortest Flex Layer length = **.324"** (usually this becomes the nominal length)
Middle Flex Layer length = **.346"**
Longest Flex Layer length = **.368"**

Bookbind cont'd

Important items to consider:

1) Bookbind manufacture is expensive. There are special tooling and processing techniques required to produce a bookbind flexible printed wiring board due to the "hump" protruding above the panel's surface. Some of the areas affected are tooling design, reduction in the number of circuits fitting on a panel, drilling, lamination, imaging, etc.

2) Frequently other design methods can be utilized to avoid using bookbind processing such as lengthening the flexible bend area or reducing the thickness of the flex layers to increase flexibility. These techniques can sometimes satisfy the installation issue.

3) Typically bookbind yields are lower than non-bookbind designs.

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Heat Sinks

Heat Sinks are used to remove heat caused by the activity of components from the circuit board. Generally they are manufactured from Aluminum or Copper and are anodized for protection and to promote a bondable surface. Thicknesses range from .020-.125”.

The Materials used for attaching Heat Sinks to the Circuit Board are:

1) Acrylic Adhesive
2) No-Flow Prepreg
3) High Strength Liquid Epoxy Adhesive

Types 1 and 2 are most frequently used due to they have a controlled rate of adhesive flow, are easily fabricated to match the Heat Sink’s pattern, and are the same materials that are used in the manufacture of the circuit board.

Hard Tooling such as Lamination Fixtures, Steel Rule Dies, NC Drill Programs, etc. may be required to bond the Heat Sink to the circuit board. This means that common tooling holes should be incorporated into the Heat Sink and Circuit Board design.

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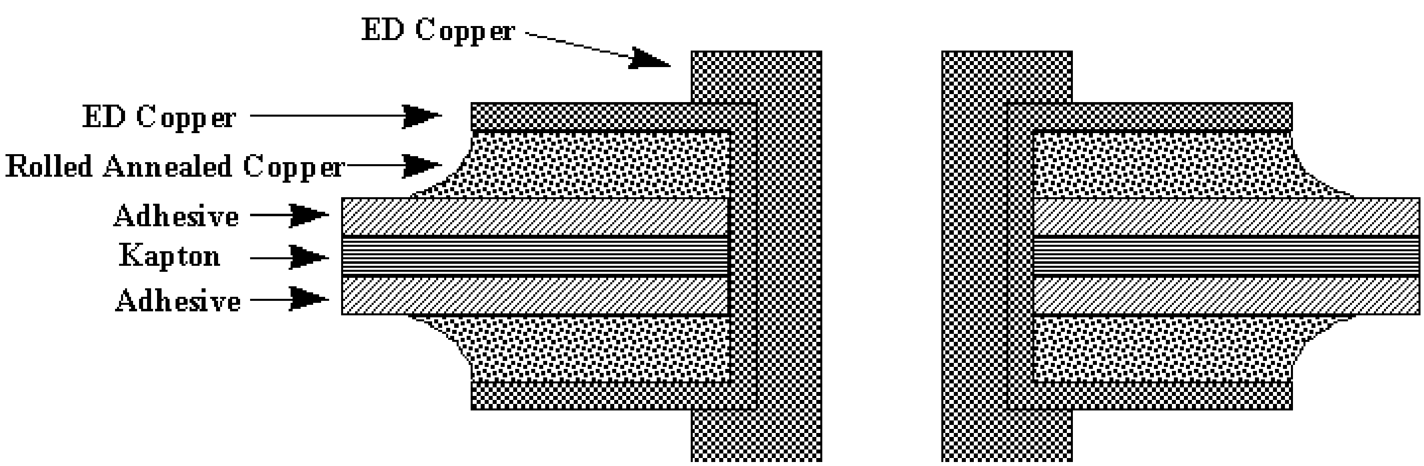
Pad Only Plating

Electrodeposited Copper is used to provide a conductive path through a hole. Generally the thickness of the copper plating is .001” min. However, the ED copper does not have the high ductility performance of Rolled Annealed Copper that is used on the laminate. Therefore when flexibility is a concern, it is desirable to limit the amount of ED copper on the conductive surfaces while still maintaining the required .001” min. plating inside the hole. Certain process techniques are employed to achieve this.

1) The circuit panels are “electroless” copper plated per standard procedure.
2) The circuit panels are ED copper plated but only to a thickness of .0002-.0004”.
3) A plating resist image is printed on the circuit panels that exposes only the holes and a slight amount on the surface around the perimeter of the hole.
4) These exposed holes are subsequently ED copper plated up to .001” min.
5) The plating resist is stripped from the panels and re-coated with an “etch” resist to print and etch the circuit image per standard procedure.

The end result of this process is shown below:



Solder Mask

Solder Mask is sometimes applied to "rigid/flex" circuits to insulate the external conductors. Most solder mask is applied over "bare copper. There are many types of solder masks available. The most common types are:

1) A "screenable wet film"
2) LPI (liquid photo imageable)
3) Dry Film
4) PIC (photo imageable coverlay)

Screenable Wet Film

FCI uses type SR1010. Historically this method type has been the workhorse of the industry. It is an inexpensive type solder mask that meets IPC-SM-840 Class 3. It satisfies most applications but is not recommended for tight tolerance.

LPI

FCI uses type Taiyo PSR4000. This mask meets IPC-SM-840 Class 3. When tight tolerances are required, this mask is preferred over the screenable type. Since the image is applied photographically, very precise features and registration can be produced. This mask is also more durable the screenable type.

Dry Film

FCI uses type DuPont Vacrel 8000 series available in 2, 3, and 4 mil thick. This mask meets IPC-SM-840 Class 3. The demand for this product has waned in favor of the LPI's due to the cost. However, this mask is the most durable and has the same advantages of the LPI for tight tolerance application.

PIC

FCI uses type DuPont 1000 and 2000. This solder mask is a photo imageable covercoat that is generally applied to single and double sided circuits. It has the ability to "flex" along with the flexible circuit and not crack or peel. It is an inexpensive alternative to a Kapton covercoat. However, it is not a permanent dielectric and therefore is not recommended for high reliability applications.

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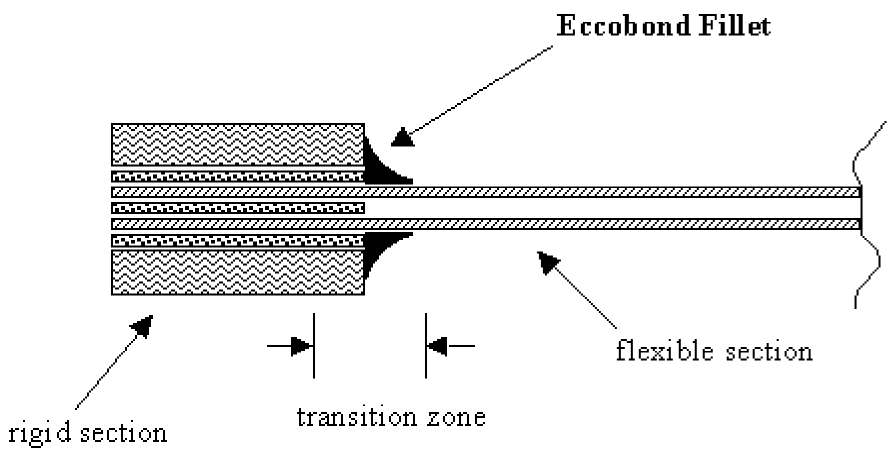
Eccobond Fillet (Rigid/Flex Transition Zone)

In “rigid/flex” type circuits and circuits which require a rigidized stiffener, the area where the flexible section intersects the rigid section is called the transition zone. This zone generally contains material edges that are not smooth. These rough edges can cause damage to the conductor paths if the flex circuit is bent sharply against them. To prevent this from occurring, it is highly recommended placing a bead of an epoxy material at this transition area. The material most commonly used is “Eccobond 45”.

Eccobond 45 is available in clear or black color and in many different formulations. However, only “flexible formulation” should be used for this application. Flexible formulation has an elastic properly that will stretch with the flexible circuit as it is bent and will not crack or separate from the flexible circuit.

The fillet material is applied using a pneumatic applicator and can be applied within a typical bead width of approx. .020-.080”. An example is shown below:



(Crossectional View at Rigid/flex interface)

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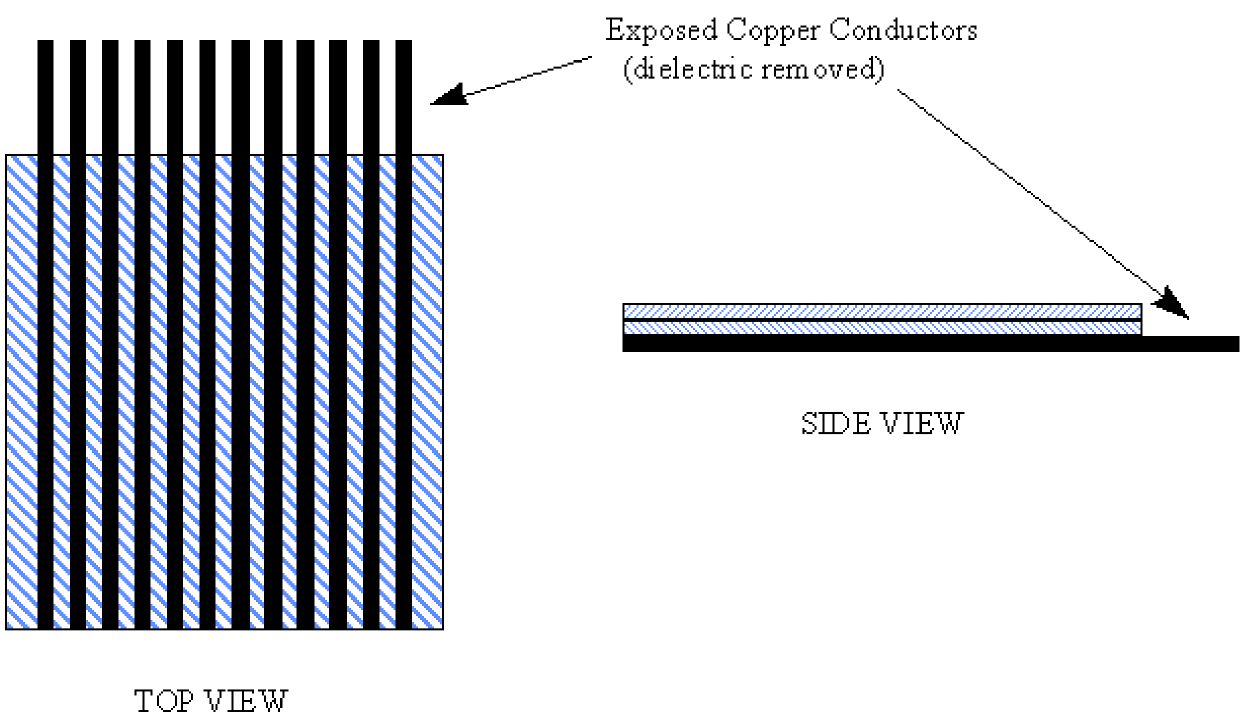
Laser Skiving

Laser Skiving is an enabling technology that utilizes laser numerically controlled equipment to remove unwanted dielectric materials such as Kapton and Adhesives. It can benefit the flexible circuit industry in the following areas:

1) To create "free floating" copper conductors. These copper conductors act as non-insulated wires that can be "lapped" soldered to circuit boards or installed into plated thru holes and soldered. See sketch below.

2) Laser cut circuit profile. Typically used where "steel rule dies" cannot meet tight tolerances (<+/-.005"). Critical edge distance from the first conductor to the circuit edge for installation into "Zif" connectors or similar applications.

3) To create covercoat access holes. Again this is used where an NC drill cannot meet tight tolerances such as reduced annular ring applications (eliminates adhesive flow issue) or tight surface mount access geometry's are necessary.



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DATA SHEETS

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Pyralux LF (w/Acrylic Adhesive) Copper-Clad Properties

Property	Typical Value	Test Method
Peel Strength lb/in (kg/cm)		IPC-TM-650, No. 2.4.9
After lamination (min.)	8 (1.4)	Method B
After soldering (min.)	7 (1.3)	Method D
Solder Float Resistance		IPC-TM-650, No. 2.4.13
10 sec. At 288°C (550°F)	Pass	Method B
Thickness Tolerance	+/- 10%	IPC-TM-650, No. 4.6.2
Dimensional Stability		IPC-TM-650, No. 2.2.4
Max. percent	0.15	
Dielectric Constant (at 1 MHz)	4.0	IPC-TM-650, No. 2.5.5.3
Dissipation Factor, max. (at 1 MHz)	0.03	IPC-TM-650, No. 2.5.5.3
Dielectric Strength	137 kV/mm (3500 V/mil)	ASTM D-149
Insulation Resistance (at ambient)	10^7 megohms	IPC-TM-650, No. 2.6.3.2
Volume Resistivity, min. (at ambient)	10^7 megohms-cm	ASTM D-257
Surface Resistance, min. (at ambient)	10^8 megohms-cm	ASTM D-257

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Pyralux AP (Adhesive-less) Copper-Clad Properties

Property	Typical Value	Test Method
Peel Strength		IPC-TM-650, No. 2.4.9
As fabricated, N/mm (lb/in)	>1.4 (>8)	
After soldering, N/mm (lb/in)	>1.3 (>7)	
Solder Float Resistance		IPC-TM-650, No. 2.4.13
sec. At 315°C (600°F)	>120	
Dimensional Stability		IPC-TM-650, No. 2.2.4
Method B, %	-0.04	
Method C, %	-0.05	
Dielectric Thickness	+/- 10%	IPC-TM-650, No. 4.6.2
Flammability	V-0	UL94
Dielectric Constant (at 1 MHz)	3.2	IPC-TM-650, No. 2.5.5.3
Dissipation Factor (at 1 MHz)	0.02	IPC-TM-650, No. 2.5.5.3
Dielectric Strength, kV/mil	6	IPC-TM-650, No. 2.5.6.1
Volume Resistivity, ohm-cm	10^{17}	IPC-TM-650, No. 2.5.17.1
Surface Resistivity, ohms	$>10^{18}$	IPC-TM-650, No. 2.5.17.1
Moisture & Insulation Resistance, ohms	$>10^{10}$	IPC-TM-650, No. 2.6.3.2
ARC Resistance, sec.	150	IPC-TM-650, No. 2.5.1
Moisture Absorption, %	0.8	IPC-TM-650, No. 2.6.2
Tensile Strength, Mpa (kpsi)	>345 (>50)	IPC-TM-650, No. 2.4.19
Elongation, %	>50	IPC-TM-650, No. 2.4.19
Propagation Tear Strength, g	23	IPC-TM-650, No. 2.4.17.1

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Pyralux FR (Flame Retardant) Copper-Clad Properties

Property	Typical Value	Test Method
Flammability	VTM-0	UL94
Meets UL796 Direct Support Requirements	Yes	UL796
Peel Strength		IPC-TM-650, No. 2.4.9
After lamination	2.1 kg/cm^2 (12 lb/in)	Method B
After soldering	1.9 kg/cm^2 (11 lb/in)	Method D
Solder Float Resistance		IPC-TM-650, No. 2.4.13
10 sec. At 288°C (550°F)	Pass	Method B
Thickness Tolerance	+/- 10%	IPC-TM-650, No. 4.6.2
Dimensional Stability		IPC-TM-650, No. 2.2.4
	-0.10%	Method B
	-0.10%	Method C
Dielectric Constant (at 1 MHz)	3.5	IPC-TM-650, No. 2.5.5.3
Dissipation Factor (at 1 MHz)	0.02	IPC-TM-650, No. 2.5.5.3
Dielectric Strength	137 kV/mm (3500 V/mil)	IPC-TM-650, No. 2.5.6.1
Insulation Resistance (at ambient)	10^6 megohms	IPC-TM-650, No. 2.6.3.2
Volume Resistivity (at ambient)	10^9 megohms-cm	ASTM D-257
Surface Resistance (at ambient)	10^7 megohms	ASTM D-257

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Silver Epoxy Data Sheet

PHYSICAL PROPERTIES

Sheets Resistivity (ohms/sq/mil thickness)	.012
Bulk Resistivity (ohm-cm)	3×10^{-5}
Adhesion Strength (psi)	
Tensile	1500
Lap Shear	2000
Thermal Conductivity (cal/cm/sec/°C)	.01
Specific Heat (cal/g/°C)	.07
Coefficient of Thermal Expansion (/°C)	3×10^{-5}
Modulus (tensile, psi)	6×10^{6}
Poisson's Ratio	.35

Composition	TYPES 5504	5815	6838	8072	8294	8762
Precious Metal Content (%)	70 (Silver)	55 (Silver)	75 (Silver)	60 (Silver)	89 (Gold)	70 (Alumina)
Sheet Resistivity (ohms/sq/mil)	<0.10	<0.10	<0.05	<0.10	<0.10	-
Viscosity, cp:	68-92M	800-950	37-50M	2-2.8M	240-340M	100-160M
Brookfield	HBF	LVT	HBF	RVT	HBF	HBF
Spindle	4	2	4	3	6	5
RPM	10	30	10	20	10	10
Coverage: (in^2/oz/ 2mils wet film thickness)	350	480	300	430	147	452
(cm^2/gm/50 microns wet film thickness)	72	100	62	89	29	93
Application:	Screen Print	Dip/ Spray	Brush/ Bond	Dip/ Spray	Stylus	Stylus
Recommended Thinner:	ALL TYPES: Butyl Cellosolve Acetate					

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Allied Signal Laminate Type GF (IPC-4101/21)
Typical Properties

Property	Unit	Test value	Test method
Tg min. (DSC)	°C	135	
CTE X-Axis	ppm/°C	14	Ambient to Tg
Y-Axis	ppm/°C	13	Ambient to Tg
Z-Axis	ppm/°C	175	Ambient to 288°C
Solder Float, 288°C	seconds	>120	Condition A
Permittivity (DK), max. @			
1 MHz	---	4.7	C-24/23/50
500 MHz	---	4.35	C-24/23/50
1 GHz (HP4291)	---	4.34	C-24/23/50
Loss Tangent (DF), max. @			
1 MHz	---	0.020	C-24/23/50
500 MHz	---	0.017	C-24/23/50
1 GHz (2 Fluid Cell)	---	0.016	C-24/23/50
Surface Resistivity	megohms	$2x10^5$	Condition F
		$1x10^8$	E-24/125
Volume Resistivity	min.	$8x10^7$	Condition F
	megohms	$2x10^7$	E-24/125
Dielectric Breakdown, min.	kV	55	D-48/50
Arc Resistance	seconds	100	---
Peel Strength, 1 oz.	lb/in (Kg/M)	9.0 (161)	Condition A
		9.0 (161)	After Thermal Stress
		9.0 (161)	E-1/125
Flexure Strength			
LW	psi	80,000	Condition A
CW		60,000	
Flammability	---	V-0	UL94
Moisture Absorption	%	<0.25	D-24/23
Tensil Strength			
LW	psi	50,000	Condition A
CW		40,000	Condition A
Modulus of Elasticity			
LW	psi	$3.5x10^6$	Condition A
CW		$3.0x10^6$	Condition A

Allied Signal Laminate Type GIL (IPC-4101/41)
Typical Properties

Property	Test value	Unit	Test method
Tg (Glass Transition Temperature)	250	°C	IPC-TM-650 2.4.24
(Final Cure at 235°C)	265	°C	IPC-TM-650 2.4.25
Coeffiecient of Thermal Expansion			
Z-Axis, Ambient to 260°C	50	ppm/°C	IPC-TM-650 2.4.24
X, Y Axis: -60°C to 150°C	14, 16	°C	IPC-TM-650 2.4.41
Thermal Decomposition Temperature	330	°C	(5% wt, loss by TGA)
Peel Strength	1oz Cu 2oz Cu		
After Thermal Stress	6.0 6.5	lbs/in	IPC-TM-650 2.4.8
At Elev. Temp (170°C)	5.5 5.5	lbs/in	IPC-TM-650 2.4.8.3
Termal Stress to Failure (288°C) >3600	Seconds	IPC-TM-650 2.6.8.1	
Moisture Absorption	.005” .062”		
	1.95 .35	%	IPC-TM-650 2.6.2.1
Thermal Conductivity	0.0031	watts/cm°C	ASTM C518
UL 94 Flammability	HB	---	UL Standard 94
Modulus of Elasticity in Flexure	215°C 235°C		
At ambient	19.5 25.0	E’ (Gpa)	(DMA)
at 150°C	18.0 24.0		
at 200°C	17.0 23.5		
at 250°F	15.5 22.0		
Dimensional Stability			
X Direction (Crosswise)	-0.0002	in/in	IPC-TM-650 2.4.39
Y Direction (Lengthwise)	-0.0004		
Electric Strength	1450	volts/mil	IPC-TM-650 2.5.6.2
Arc Resistance	125	Seconds	IPC-TM-650 2.5.1
Dielectric Constant	.006” .062”		
Permittivity	4.25 4.35	---	IPC-TM-650 2.5.5.3
Dissipation Factor (Loss Tangent)	0.017 0.0068	---	
Resin Content, Retained	50.5 40.5	%	(burn-off)

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Arlon GFK NO FLOW Prepreg (IPC-4101/21)
Typical Properties

Glass Transition Temperature		130°C
Continuous Operating Temperature		140°C
Flammability (UL File E48692)		94 V0
Coeffeicient of Thermal Expansion (ppm/°C)		X = 11 Y = 10 Z = 56
Peel Strength (lb/in) as Received		9.0
Flexure Strength (psi)		84,000
Water Absorption (%)		0.1
Dielectric Constant	0.062” Rigid (1 MHz)	4.8
(Permittivity)	0.008” Laminate (1 MHz)	4.3
Dissipation Factor		0.022
Volume Resistivity (Megohm-cm)	ambient	5.1×10^7
	Cond. D24/23	7.4×10^6
Surface Resistivity (Megohms)	ambient	8.8×10^6
	Cond. D24/23	1.5×10^6

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Hitachi GIJ NO FLOW Prepreg Type(IPC-4101/42)

		Nominal Thickness (cloth style)			
ITEM	**UNIT**	**1.2mils(106)**	**2mils(1080)**	**4mils(2116)**	**METHOD**
Scaled Flow	mils	1.57-2.36	2.36-2.76	4.33-4.72	IPC 2.3.38
Resin Content	%	68 +/- 3	60 +/- 4	50 +/- 4	IPC 2.3.16
Resin Flow	%	4.0 +/- 3.0	3.5 +/- 1.5	3.5 +/- 1.5	IPC 2.3.17
Volatile Content	%	under 2.0	under 2.0	under 2.0	MIL-S-13949H/13