Overcoming the Complexity of Flex and Rigid Flex Design

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Abstract:
Flexible printed circuits are a growing technology both in terms of numbers and in technology advancement. Applied as cabling harness technology, IC packaging and as replacement for rigid board technologies, more designs are based on flexible substrates than ever and the numbers are rapidly growing. As density and layer count increases, so do the concerns about reliability and yield.

Proper care must be taken to ensure that the many risk factors in Flex manufacturing are kept under control. Layer stackup, adhesives, dielectrics, stiffeners, cover layers, bend and flex, width transitions, trace curves, embedded components are all well known factors in Flex design and manufacturing where each and every one requires special considerations.

Obviously, these factors have to be considered early in the design cycle as in all engineering: issues discovered late in the process become extremely costly.

In this paper, we will look at all of these areas and how new CAD technology can assist in keeping these effects under control.

Bend region stress, reliability and restrictions, adhesion concerns, layer stackup management together with design efficiency issues such as effective trace routing in complex curved regions will be covered in detail.

We will show that although Flex technology is becoming more and more advanced, given the proper precautions, yield, reliability and design efficiency can still be kept at a convincing high.

Introduction:
This is a presentation for PCB designers who want to learn more about flexible circuit design. In this presentation we will cover:

- What's driving use of flex and rigid-flex
- Basics of what is a flexible circuit
- How flex design differs from rigid design
- Several design tips for increasing yield
- A few cost saving measures

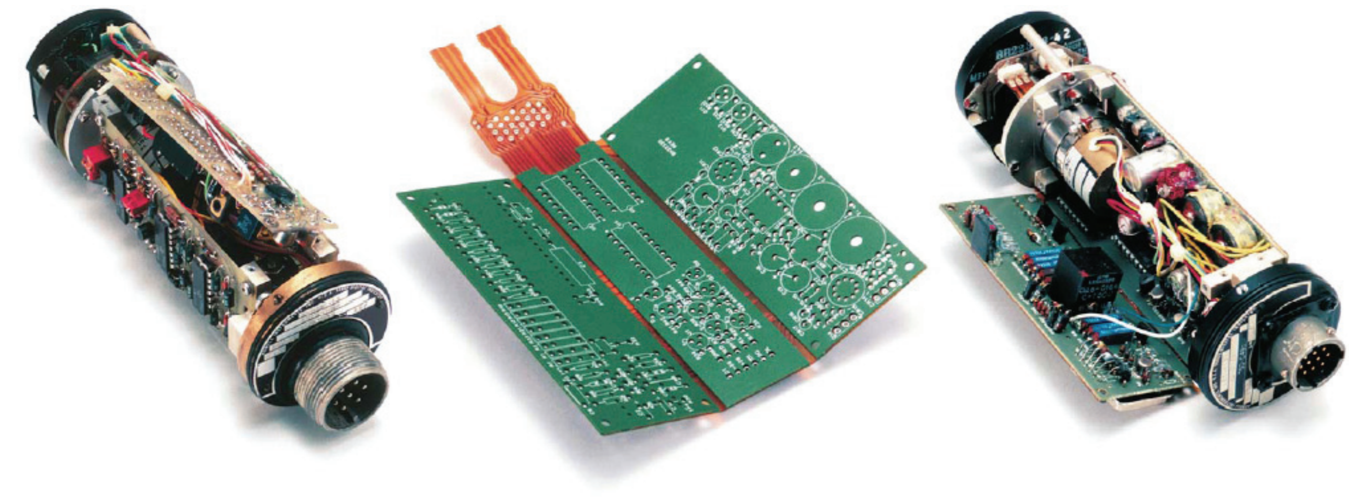
Why Flex? : The Drivers
The driving factors for flex can be summarized as:

- Demand for smaller, lighter, more reliable, more functional products
- Requires manufacturers to re-package

But along with these drivers come some specific benefits:

- Single flexible circuit can replace several rigid
- PCBs and their interconnecting cables
- Package size and weight reduction
- Improved interconnect reliability
- Enhanced electrical properties
- Reduced assembly cost

An example of a series of rigid flex designs is shown in Figure 1.



Before: A tangle of wires connects four circuit boards in this aircraft gauge.

The flex-circuit solution: A single circuit with three stiffeners provides all the necessary interconnects. Insert components into the flat circuit, solder, and fold.

After: The package is neat, lightweight, and less susceptible to connection failure.

Figure 1 – Rigid Flex Design Examples

What is a Flexible Circuit?

What then constitutes a flex circuit? In general the characteristics can be summarized as:

- An array of conductors bonded to a thin dielectric film
- A three-dimensional circuit
- Constructed from separate layers of adhesive, conductive and dielectric material laminated together

Figure 2 illustrates this in more detail.

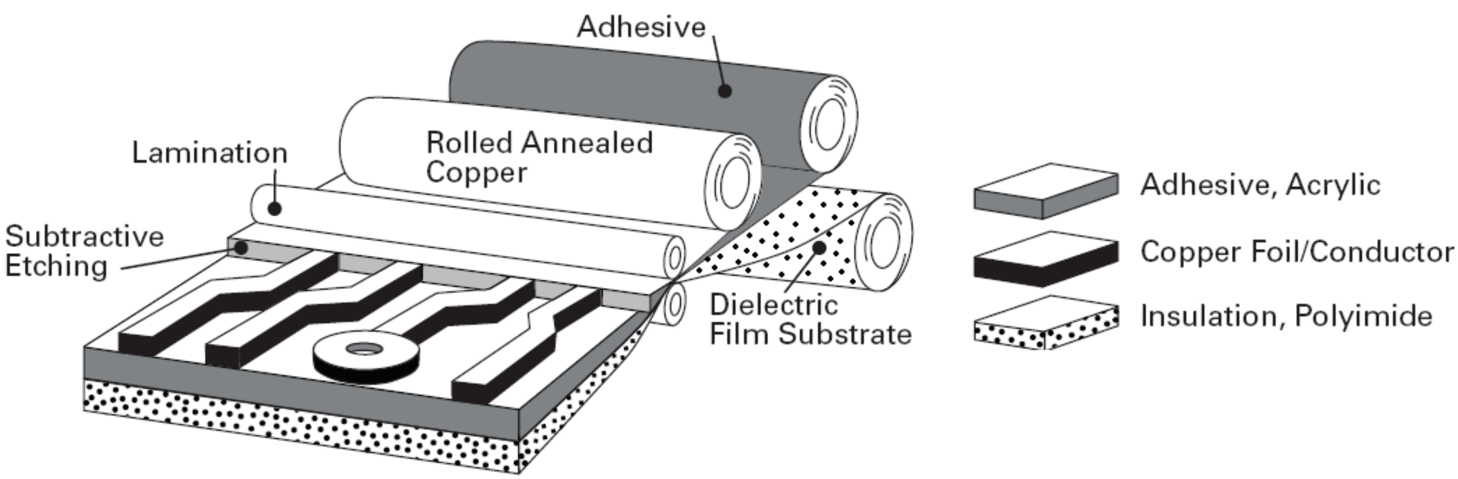


Figure 2 – Flex Circuit Fundamentals

Flex Circuit Design

Why would flex be used in a design? The answers to that question depend on the application of the design. There are two main applications: flex to install and dynamic flex. The attributes of these technologies are listed below.

Flex to install:

- Capable of withstanding flex during install
- Flexed minimally – during install only

Dynamic flex:

- Capable of withstanding continuous flex
- Flexed repeatedly during its life cycle

The actual construction of the flex circuit will thus depend a great deal on the application. Figure 3 illustrates the structure of a single sided flex circuit. The characteristics of that circuit can be summarized as:

- Single layer of conductive material laminated to a flexible dielectric film
- Single Access Uncovered
    - No cover layer
- Single Access Covered
    - Top cover layer with apertures (openings)
- Double Access or Back Bared
    - Top and bottom cover layer with apertures on both sides

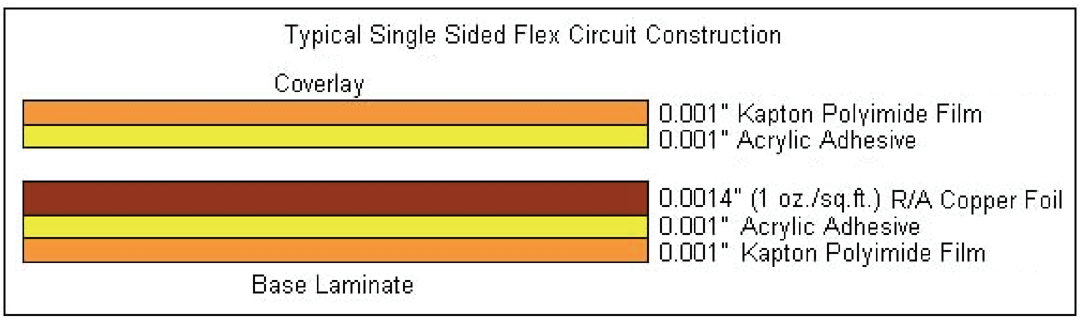


Figure 3 – Typical Single Sided Flex Construction

Double sided flex circuit characteristics can be summarized as:

- Two layers of conductive material laminated to a flexible dielectric film core
- With or without through holes
- With one, both or neither cover layers
- Cost about 2X single sided

Figure 4 shows an example.

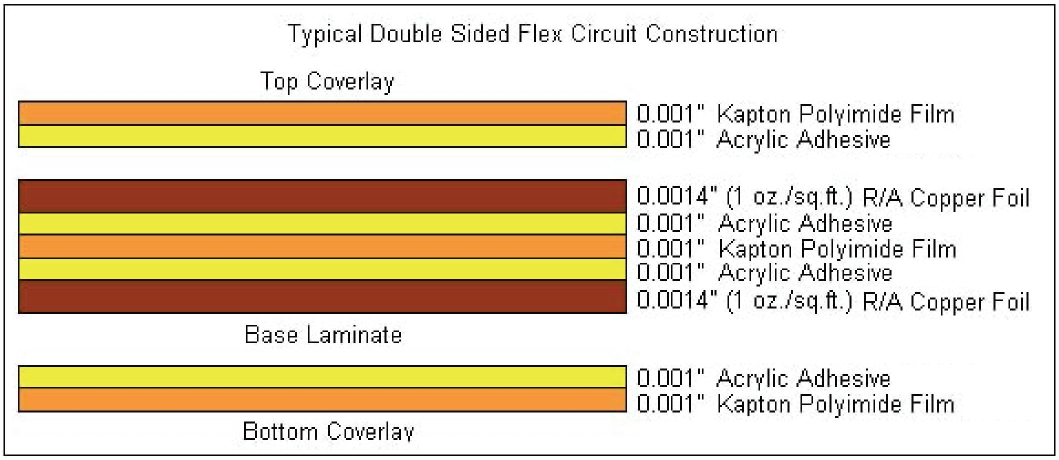


Figure 4 – Typical Double Sided Flex Construction

Multi-layer flex has additional complications in the design. Typical characteristics are:

- More than two layers of conductive material laminated to flexible dielectric film
- May or may not be continuously laminated together throughout the construction
- Uses vias for interconnect
- Cost about 5x double sided

An example is shown in Figure 5.

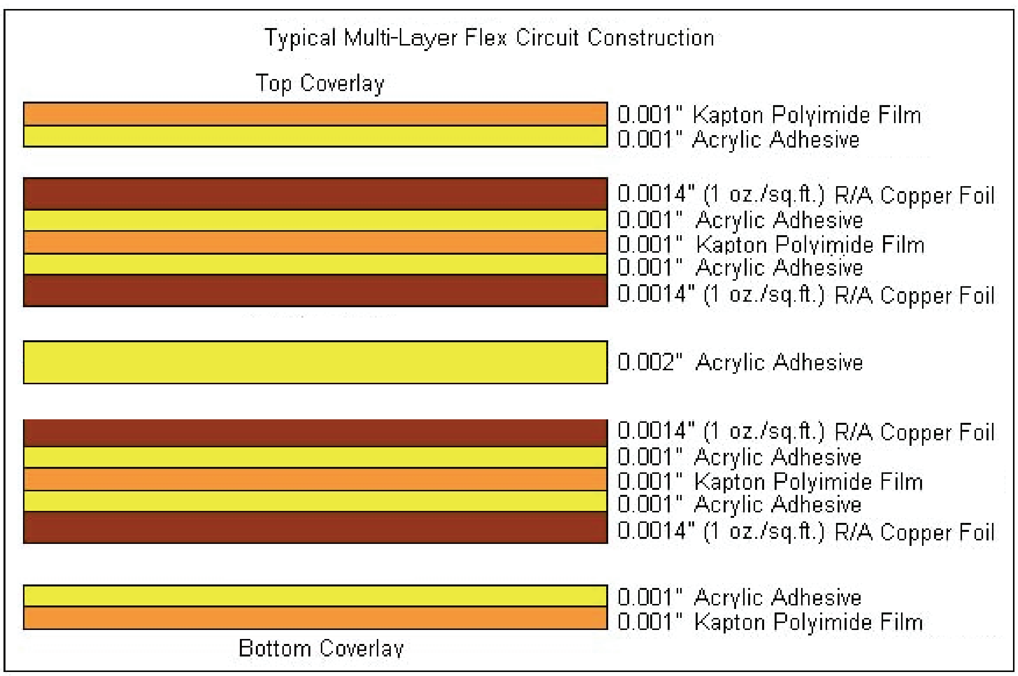


Figure 5 – Typical Multi-layer Flex Construction

Rigid flex represents a hybrid between the world of flex and rigid board design. Characteristics are:

- Hybrid construction of rigid and flexible substrates laminated together into a single package
- Combined drilling and plating operations provide the necessary interlayer connections
- Uses vias for interconnect

- High layer counts may require varying length of flex layers to facilitate bending (about 2% of rigid-flex designs)
- Cost about 7x same layer count rigid
- Best for double sided component mounting

An example is shown in Figure 6.

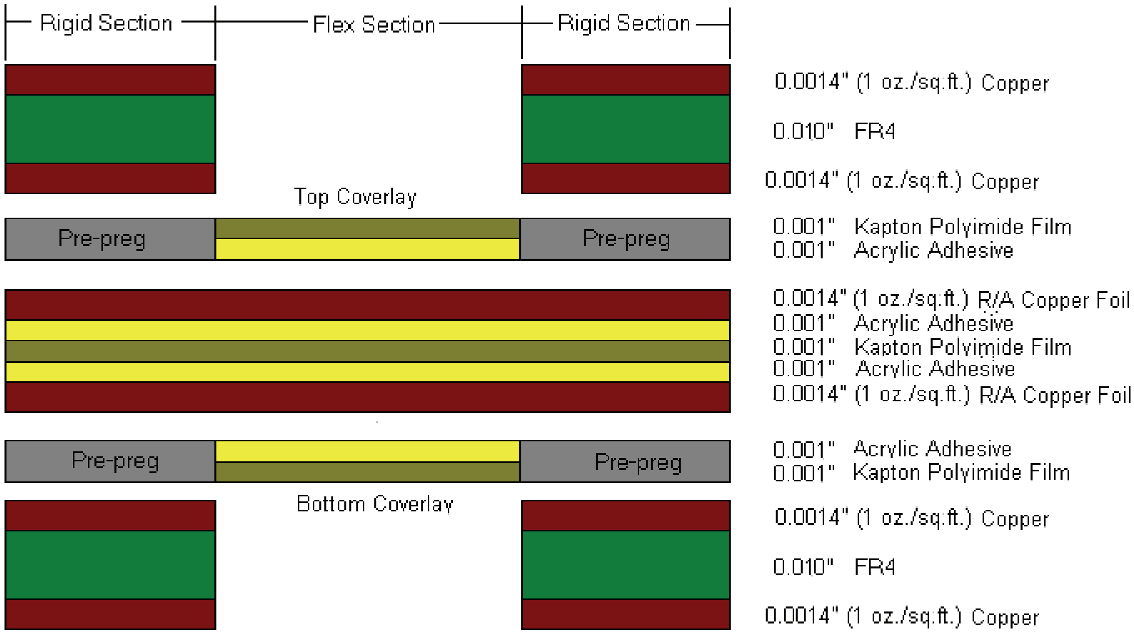


Figure 6 – Rigid Flex Construction

Flex Fabrication:
Figure 7 shows a typical flex fabrication process.

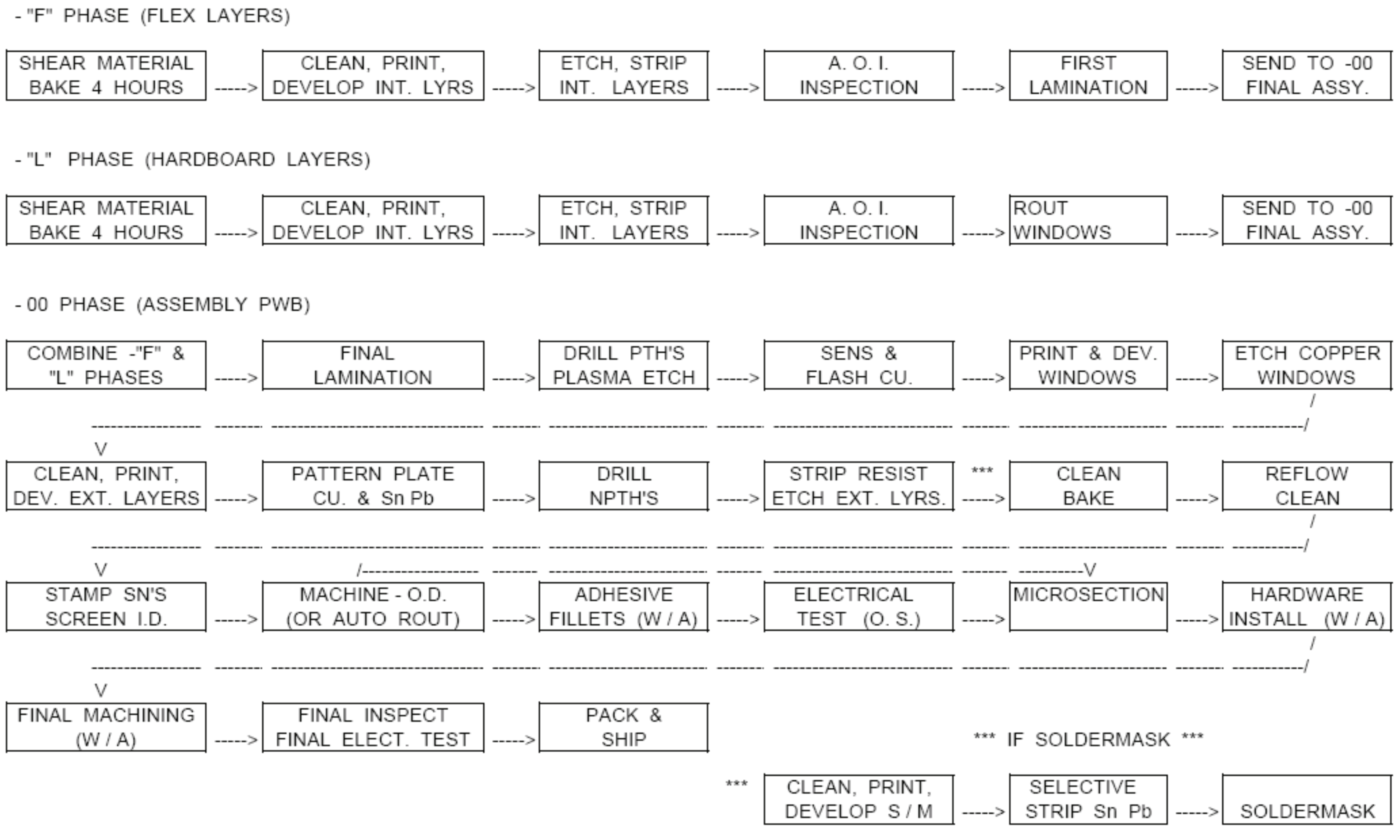


Figure 7 – Flex Fabrication Process

Flex Design is NOT Rigid Design:
It is important to always keep in mind that flex and rigid design have significant differences. A listing of the differences is shown below.

Reduced Dimensional Stability Relative to Rigid (Figure 8):

- Dimensional stability is 3 times worse for polyimide laminate @ 0.10% (1000ppm) as opposed to 0.035% (350ppm) for FR4
- Increase your annular ring minimum if you are designing long or multilayer flex to minimize cracking
- Minimum conductor width 5x thickness is recommended

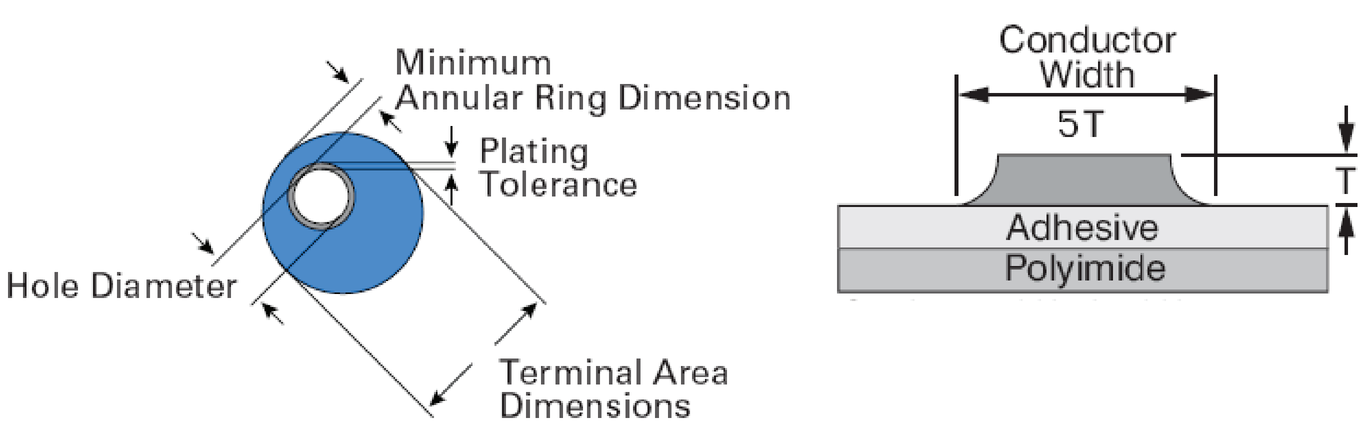


Figure 8 – Designing for Reduced Dimensional Stability

Reduced Bond Strength (Figure 9):

- Bond strength of copper to polyimide base weaker than FR4
- Unsupported pads (not-plated through) should be encapsulated under cover layer to minimize de-lamination
    - Add anchor spurs or elongate the pad shape
    - Alternative – make cover layer opening smaller than pad
    - Not required in rigid areas of rigid-flex

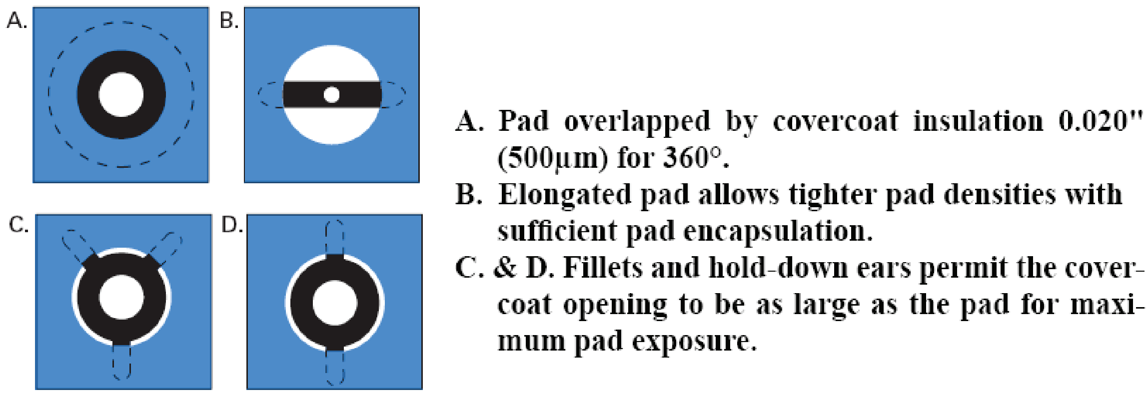


Figure 9 – Reduced Bond Strength

Flex Can Tear (Figure 10):

- Polyimide has high initial tear strength, but once a tear starts it propagates easily
    - Radius all inside corners (.063" minimum)
    - Use copper tear stops on all corners, slits
    - Consider polyimide or Teflon patch to strengthen tear stops

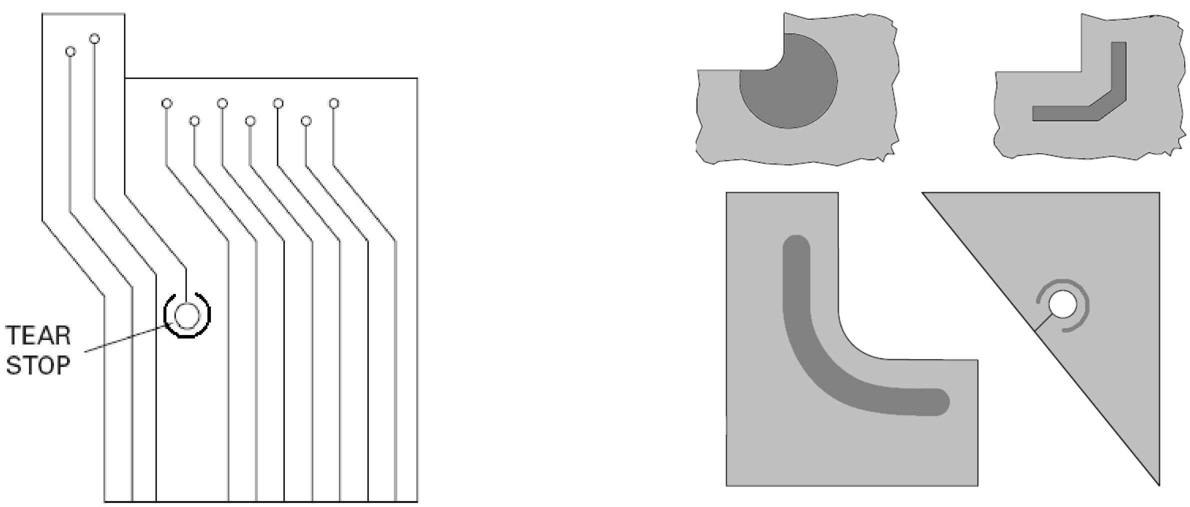


Figure 10 – Tear Stop Patches for Flex

Conductors May Fracture (Figure 11):

- Proper conductor patterns in bend areas reduce fracture potential
    - Traces perpendicular to bend axis
    - Cross hatch solid copper fills
        - Easier to bend hatched copper
    - Minimize trace corners and width changes
    - No vias

- Locate trace corners away from bend area boundary
- Limit tandem parallel traces (I-beam)
- True arcs (not segmented)

Conductors May Fracture (Figure 12):

- Traces with sharp transitions may fracture
  - Use arcs anywhere and everywhere possible
  - Add elongated tapers
  - Teardrop everything
  - Avoid acute angles

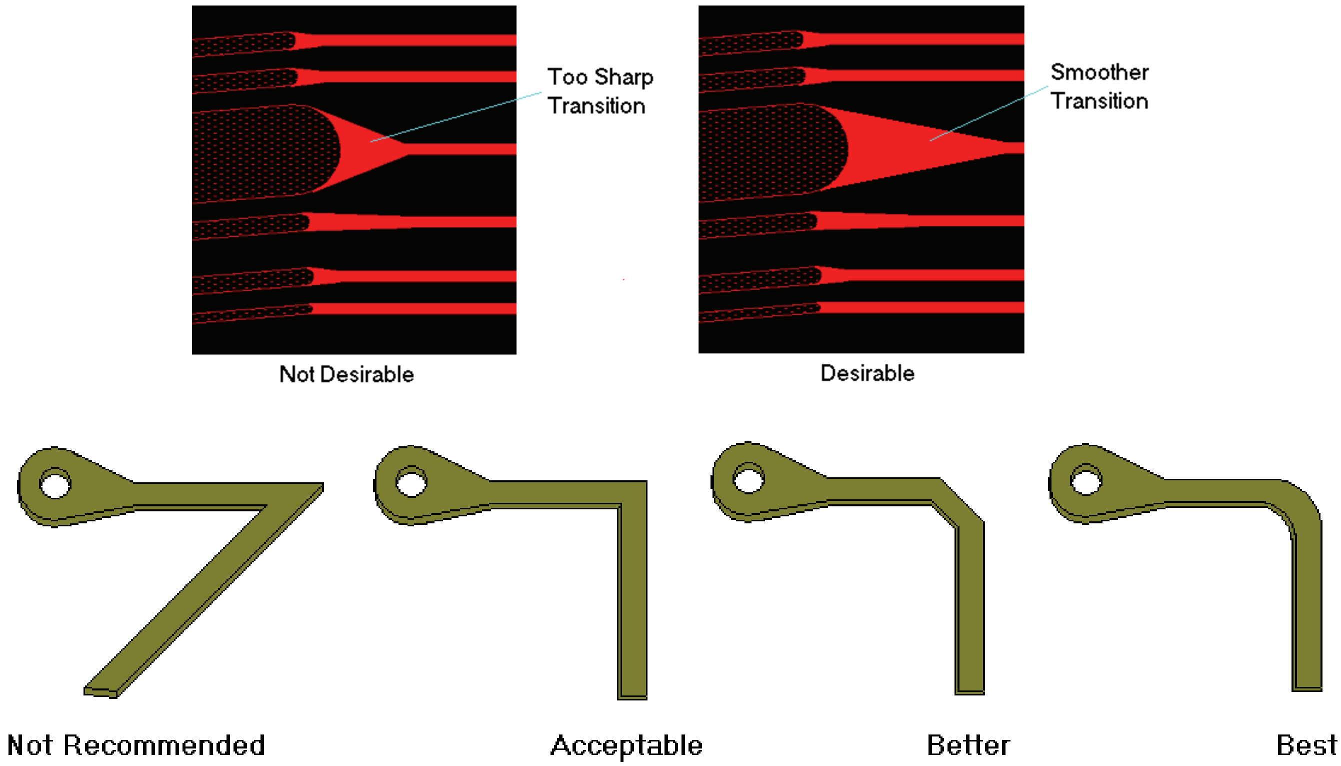


Figure 12 – Flex Conductor Fracture

Design Tips for Flex
There are some tips that a design can use in successfully designing with flex. Two, illustrated in Figure 12, are shown below.

- Employing a paper or Mylar mock-up can be useful in determining adequacy of flex lengths, minimum bend radius, and service loops
- Lending physicality to the three-dimensional design, the mock-up can identify problem areas early in the design process

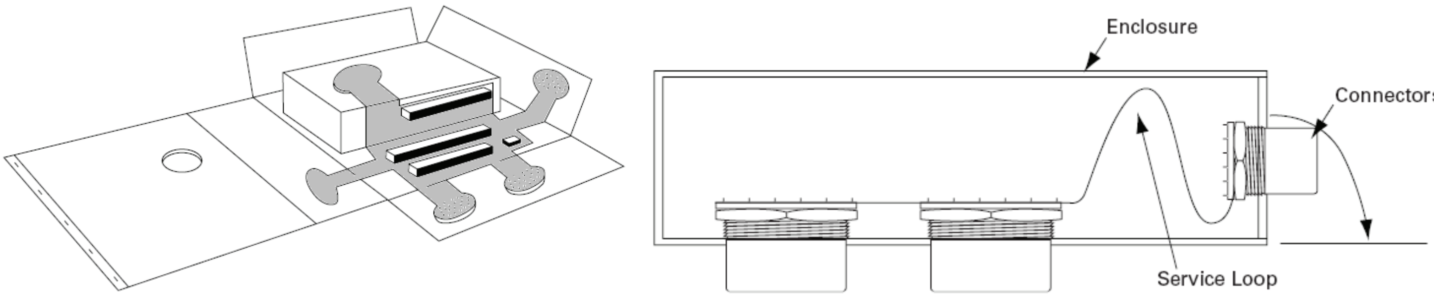


Figure 12 – Use of 3-D Mock-Ups for Flex Design

In addition designers should be aware that:

•Rigid-flex layers can have independent shapes
•Openings can be pre-routed to minimize final routing impact on flexible materials

For example see Figure 13.

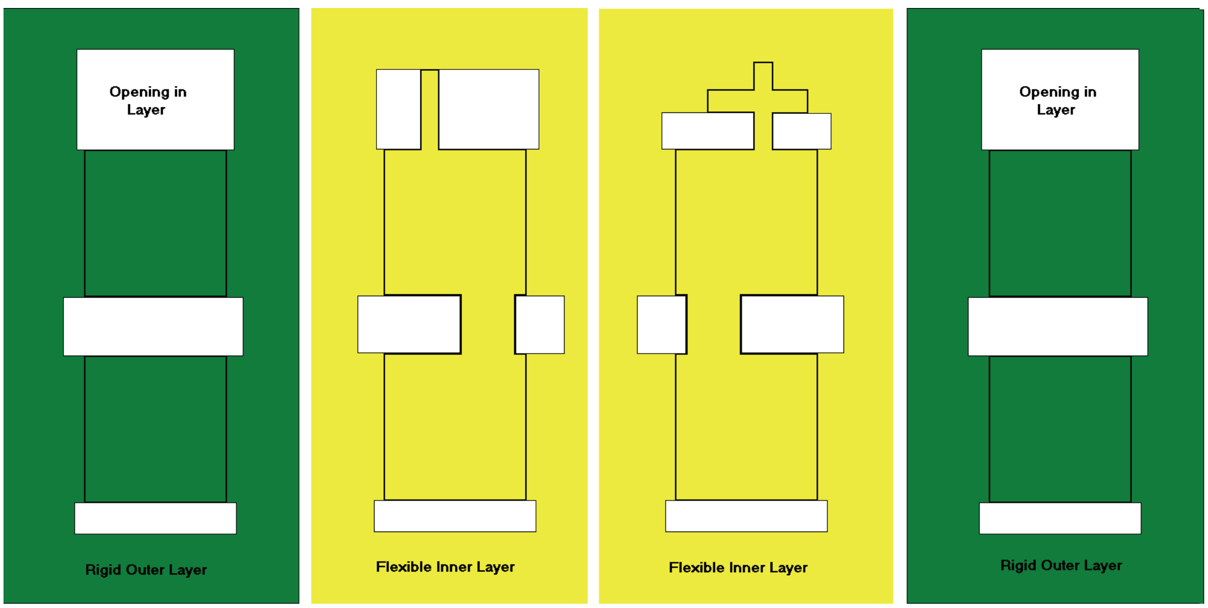


Figure 13 – Separate Shapes for Flex Layers

Cost Saving Techniques
The design techniques described above will be of little use unless they are cost effective. In this section we will provide some cost saving techniques.

Always Consider Your Layer and Foil Type Choices (Figure 14):

- RA foil offers more improved performance for flexing multi-layer
- ED foil is less expensive

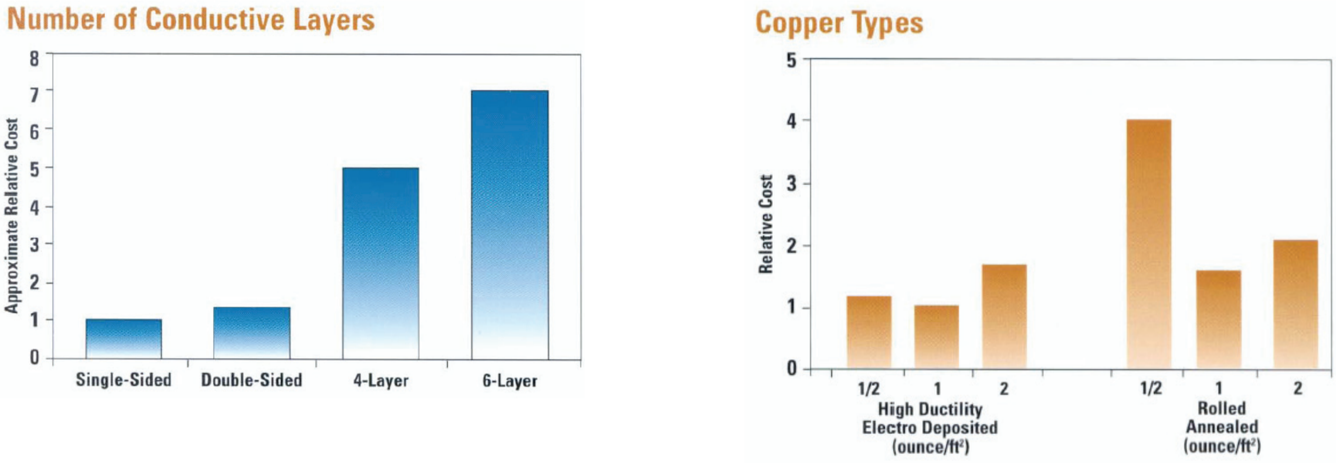


Figure 14 – Foil and Layer Choices

In addition:

- Choose your vendor before you start and involve them in the design process
- Flex circuits with stiffeners can be much less expensive than flex-rigid circuits
- Consider using zero Ω resistors to bridge tracks and keep a circuit as single sided
- Design rigid-flex with an even number of layers to avoid bow and twist
- Maximize your material utilization
- Creative bending and flexing can save space and layers
- Consider how flex circuits will be "nested" on a panel (Figure 15)

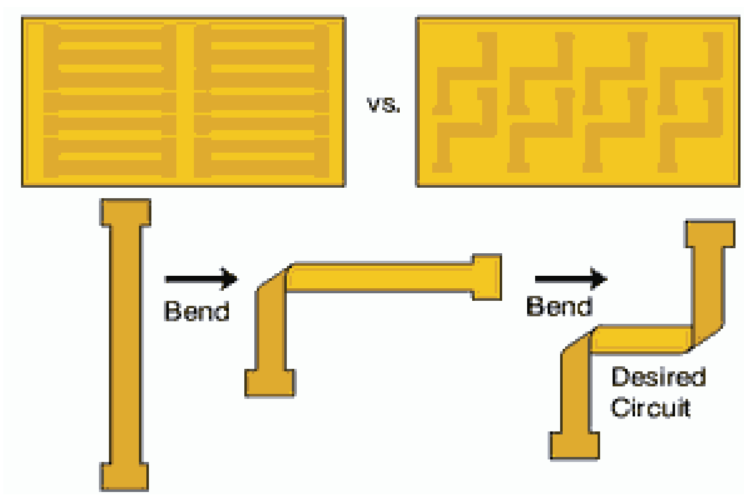


Figure 15 – Nested Flex Designs on a Panel

Additional reading can also benefit the designer. We suggest:

- IPC Standards
    - IPC-2223A "Sectional Design Standard for Flexible Printed Circuit Design"
    - IPC-4202 "Flexible bare dielectrics for use in flexible printed wiring"
    - IPC-4203 "Specifications for adhesive coated dielectric films for use as cover sheets for flexible printed wiring"
    - IPC-4204 "Metal-clad dielectrics for use in fabrication of flexible printed circuits"
- Mil Specs
    - MIL-P-50884 "Specification for flexible and rigid-flex printed wiring"
    - MIL-STD-2118 "Design requirements for flexible and rigid-flex printed wiring"
- Books

    - Joseph Fjelstad "An engineer's guide to flexible circuit technology"
- Design Guides
    - Available for download at most flex fabricator's web sites

Conclusions:

- The use of flexible circuits is increasing
    - May be the next packaging frontier
    - Many benefits for miniaturization
    - For some designs – it's the only solution
- Flex design is not rigid design with different materials
    - Complex fabrication process
    - Mechanical stress of three-dimensional circuit
- Fabricator and Designer collaboration is the key to lower cost, higher yield flexibles
    - Designers know the desired application of the flexible circuit
    - Fabricators can suggest lower cost alternative