AirBorn
FLEXIBLE CIRCUITS, INC.

Flex Circuit
DESIGN MANUAL
AN OVERVIEW OF FLEX CIRCUIT DESIGN

DESCRIPTION OF FLEXIBLE CIRCUITS

Flexible printed wiring sometimes called flexible printed circuitry can be defined as a random arrangement of printed wiring, utilizing flexible base material with or without cover layers.

There are many different types of flexible circuits:

1. Single-sided — Single layer of copper with insulating material both sides. (Type I)
2. Double sided with plated through holes. (Type II)
3. Multi-layer with plated through holes. (Type III)
4. Rigid-Flex — a combination of flexible circuits with printed wiring boards. (Type IV)
5. Multi-layer wiring boards without plated through holes. (Type V)
6. Sculptured flex™

SF manufactures Single-sided, Double sided, Multi-layer, rigidflex and Sculptured flexible circuits, for the Military, Commercial, Medical and Aerospace markets.

Single sided flex circuits can be utilized wherever an instrument utilizes a wiring assembly.

Double sided and Multilayer Flex are used when density and connection configuration requires more than one layer. Layers are usually connected by plated through holes.

Sculptured flex have the required terminators (leads or pads) as integral extensions of the conductors. This is done by making the circuits as a three-dimensional entity.

Sculptured flex circuits are used as interboard or intraboard jumpers, component-to-component test leads and point to point wiring. The circuits can mate directly with solder terminations or plug into female sockets with a virtually unlimited choice of contact configurations and reformed fingers. In addition, variable thickness conductors provide high current carrying capacity and strain relief action.

Sculptured flex combined with standard multilayer printed circuit boards can be a significant way to reduce the high cost of rigid flex and increase reliability. This is called modular-flex™.

MANUFACTURING PROCESS

A flex circuit manufacturing plant is similar to a printed wiring board shop.

The Manufacturing sequence is as follows for a single-sided flex:

1. Prepare metal surface. (Cleanse off all dirt and oil)
2. Prepare insulation covercoats.
   (a) drill holes
   (b) route slots
   (c) die slots
   (d) laser machine slots or holes
3. Laminate metal to base material.
4. Coat metal with a U.V.-sensitive resist. (Dry film or liquid photoresist)
5. Expose phototool pattern to be etched.
7. Etch away unwanted metal leaving desired circuit pattern.
8. Laminate on covercoat.
9. Coat or plate on finish required. (tin, tin-lead, gold)
10. Cut part from manufacturing panel with dies or laser.
11. Test continuity.
12. Final inspect.
13. Package.

™ Sculptured Flex is a trademark.
™ Modular Flex is a trademark.
SEQUENTIAL DESIGN STEPS

Fully understanding a package's electrical and mechanical requirements and not "overdesigning" will result in a cost-effective flexible circuit.

1 Prepare a model of the package to be wired.

If the actual unit to use the circuit is unavailable, construct a full size model from cardboard, sheet metal or wood.

2 Determine optimum component layout.

Open the model to lay flat and place or sketch components in their required positions.

3 Develop preliminary circuit parameters.

Make a "paper doll" cut out of the circuit shape which will provide all necessary connections and conductor runs in a total size which will fit packaging constraints.
4 Develop initial circuit layout
Determine best conductor layout.

Prepare a single entry wire list showing each conductor in a continuous run to every termination point.

<table>
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<th>P2</th>
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<th>XA2</th>
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</table>

- Establish current carrying capacity requirements.
- Set resistivity requirements.
- Use Conductor Nomograph to determine copper conductor width and thickness required for current capacity and voltage drops.
- Condense wiring list as possible.
- Determine best layout of conductor runs to minimize the number of circuit layers and the mechanical area of the circuit.
- Separate analog and digital signals to minimize cross-talk by placing on opposite sides of circuit or on different layers. Shielding may be necessary.

5 Refine layout for conductor spacing, routing and address to components.
Spacing between conductors is determined by the voltage between conductors (DC or AC peak volts). Most polyimide/adhesive systems will withstand 2000 volts/mil.
- Routing of conductors should be as direct as possible with no unessential overlaps which create the need for additional layers.
- Prepare a detailed drawing with all dimensions specified and all components positioned.
- Specify terminal areas without assigning pin address when possible.
- Keep “edge” distance as large as possible. 020” is standard.
- 010” or smaller is possible with special tooling.

WITH THESE PRELIMINARY STEPS COMPLETED, BEGIN GENERATION OF SPECIFIC ARTWORK FOR CIRCUIT PRODUCTION.

6 Prepare a dimensionally accurate layout of the flexible circuit.
- Work oversize (i.e. 4 to 1) for clarity. With drafting accuracy of .010", the 1 to 1 should be .003" or less.
- Leave radii for bends or folds equal to 10 – 12x the total circuit thickness. For dynamic flex applications, this should be 100x. Flex circuits can be creased, but not often.
- Use 10 to 1 layouts of tight tolerance areas (i.e. conductor pin clusters) and reduce to layout scale.
- Make multiple copies of the master layout (1 to 1 scale) for subsequent fine-tuning of the layout.

7 Determine conductor sizes.
The metal most commonly used in flexible printed circuits is rolled and annealed copper with a purity of greater than 99%. Other materials used are: copper of varying hardness, beryllium copper, steel, nickel alloys, aluminum and m\(\mu\) metal.
- Allow for adequate heat dissipation. Flat copper conductors will dissipate heat more rapidly than round wire. The thin dielectric film of a flexible circuit results in less heat build-up than conventional wire coatings.
- Allow for etch loss contraction of flexible circuit layer of:
  - 1/2 mil/side for 1 oz. copper
  - 1 mil/side for 2 oz. copper

**TOP VIEW**

- Use .015” for conductor spacing unless the circuit requires tighter packaging or uses components with high density pin clusters. .005” spacing can be produced with good artwork.
- To avoid conductor stresses, don’t lay conductors over conductors at bend areas and don’t put conductors on the bias of bend areas.
- Bending cannot be done near vias, or plated through holes.
- Bending on Sculptured Flex cannot be done at the etched transition area or at the edge of the kapton/finger interface.
Determine metal type and weight.

Of importance in the design of any circuit is the resistance of the conductors and the current carrying capacity, the two being interrelated. Resistance of flat flexible conductors depends, as in the case of round wire, on the cross sectional area.

**Copper Weight vs. Thickness**

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<th>Weight per Foot</th>
<th>Thickness</th>
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<tr>
<td>½ oz/ft</td>
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<tr>
<td>1 oz/ft</td>
<td>.0014&quot;</td>
</tr>
<tr>
<td>2 oz/ft</td>
<td>.0028&quot;</td>
</tr>
<tr>
<td>3 oz/ft</td>
<td>.0042&quot;</td>
</tr>
<tr>
<td>4 oz/ft</td>
<td>.0056&quot;</td>
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</table>

5 oz/ft = .007"
6 oz/ft = .0084"
7 oz/ft = .0098"

Per IPC-150E copper thickness tolerances are ±10%.

Specify final width and thickness of the copper conductors by the desired current capacity and voltage drop per conductor. See the following Copper Conductor Characteristics Table. Conductor resistance Nomograph and Temperature Rise charts for detailed considerations.
## Copper Conductor Characteristics

<table>
<thead>
<tr>
<th>Copper Weight</th>
<th>Flat Conductor Dimensions</th>
<th>Cross Section</th>
<th>A.W.G. Wire Size based on cross section</th>
<th>Resistance milliOhms per ft.</th>
<th>Current Amp 30°C Rise</th>
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<td>Thick (in.)</td>
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</table>
Based on single flat conductors with .010" insulation assuming 10°C allowable temperature rise at 20°C ambient temperature. To find the conductor width of a circuit line using 2 oz. copper that will carry 2 amperes of current, follow the 2 oz. copper line to the 2 amps intersection point and trace a horizontal line to the conductor width scale. Conductor width is .030". Equivalent wire gage and conductor resistance can be read from the appropriate scales.
Find the AWG round wire size with equivalent resistance rating of a 2-oz x 0.030" conductor.

Project horizontally from 0.030" on the width scale to the 2-oz curve; then project up vertically to the AWG baseline. Read 30 as the closest AWG size.

Find the AWG wire size that can carry a current equal to a 2-oz x 0.030" conductor.

Project horizontally from 0.030" on the width scale to the 2-oz curve. The intersection occurs at the 2 amps constant current curve. Follow that curve down until it intersects the Wire Current Rating Line. Project that intersection vertically to the AWG baseline. Read 28 as the closest AWG wire size.

Find the width of a 2-oz flat conductor that can safely carry 10 amps without exceeding a 10°C temperature rise.

Locate the intersection of the 2-oz curve with the 10 amps constant current curve. Project that intersection horizontally to the width scale. Read 0.31".

Find other combinations of width and thickness for conductors capable of carrying 10 amps without rising more than 10°C.

Note the intersection on the 10 amps constant current curve with 3-, 4-, 5- and 6-oz. Project each of these horizontally to the width scale. Read 0.25”, 0.21”, 0.185” and 0.165” respectively.

Find the flat conductor size for handling 4 amps at a maximum drop of 0.125 V/ft.

Calculate the required resistance per foot from 
\[ R = \frac{E}{I} = \frac{0.125}{4} = 0.031 \text{ Ohm/ft} = 31 \text{ mOhm/ft} \]
Locate this resistance on the baseline and project it vertically to intersect the 2-, 3- and 4-oz. curves. Project these intersections horizontally to the width scale. Read 0.098", 0.065", and 0.049" respectively. If you were selecting the conductor on the basis of the lowest temperature rise, you would naturally choose the 2-oz x 0.098" size, for it has about 100% more surface area than 4-oz conductor and about 33% more surface area than the 3-oz conductor.
This design chart has been prepared as an aid in estimating temperature rises (above ambient) vs. current for various cross-sectional areas of etched copper conductors. Include a 20% derating for unknown variations. Additional current derating of 15% is suggested for conductor thickness of .0042" inch (.11 mm) (3 oz./ft²) or more.

Permissible temperature rise is defined as the difference between the maximum safe operating temperature of the laminate and maximum ambient temperature in location where the panel will be used.

For single conductor applications the chart may be used directly for determining conductor widths, conductor thickness, cross-sectional area, and current-carrying capacity for various temperature rises.

For groups of similar parallel conductors, if closely spaced, the temperature rise may be found by using an equivalent cross-section and an equivalent current. The equivalent cross-section is equal to the sum of the cross-sections of the parallel conductors, and the equivalent current is the sum of the currents in the conductors.

The effect of heating due to attachment of power dissipating parts is not included.

The conductor thicknesses in the design chart do not include conductor overplating with metals other than copper.
Insulating Materials

The choice of insulating materials must take into consideration the operating environment, the manufacturing environment, electrical characteristics, mechanical requirements and the cost. Temperature range, moisture absorption characteristics, chemical inertness, flexing strength, tensile strength, dielectric strength, dielectric constant, aging effects, and cost are all important factors influencing the selection of a suitable base material. Some materials may have unusual qualities which may make them more suitable to meet certain environmental conditions, but they may not be universally useful. The following tables show the most common insulating materials and their properties.

KAPTON
- Most widely used insulation.
- Dimensionally stable "X, Y, Z" directions.
- Compatible with all printed circuit processes.
- Does not support combustion.
- Very high tensile strength.
- Approximately same expansion coefficient as copper.
- Flexible and adherable.
- Absorbs moisture significantly.

MYLAR
- Dimensionally stable.
- Sensitive to chemicals in printed circuit processing.
- Extremely high tensile strength.
- Flexible and adherable.
- Inexpensive.
- Sensitive to soldering temperatures.

TEFLON FEP
- Excellent dielectric.
- Low in tensile strength.
- Flexible and adherable.
- Not dimensionally stable.
- Expensive.
- Does not absorb water.

NOMEX
- Dimensionally stable.
- High tensile strength.
- Flexible and adherable.
- Sensitive to chemicals in printed circuit processing.
- Absorbs water significantly.
- Inexpensive.
- Resists solder temperature.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit of Measure</th>
<th>Kapton* Polymide Film</th>
<th>Teflon* Fep</th>
<th>Nomex*</th>
<th>Mylar*</th>
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<tbody>
<tr>
<td>Dielectric Strength</td>
<td>VDC/Mil-1 Mil</td>
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<td>5,000</td>
<td>1,200 (10 Mil)</td>
<td>7,000</td>
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<td>31</td>
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<td>Dissipation Factor</td>
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<td>.0003</td>
<td>.007</td>
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<td>Tensile Strength</td>
<td>PSI</td>
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<td>4,000</td>
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<td>Elongation</td>
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<td>Weather Resistance</td>
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<td>Poor</td>
<td>Excellent</td>
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*Kapton, Teflon, Nomex, Mylar are registered trademarks of DuPont*
There are many other materials available in the market that can be used for more specialized applications. These include Upilex, Apical, Kapton E Film, Black Kapton, and UL Material.

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<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Upilex</td>
<td>- more dimensionally stable than Kapton</td>
<td>- sometimes difficult to obtain with a proper adhesive system</td>
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<tr>
<td></td>
<td>- better water absorption properties than Kapton – good for impedance control</td>
<td></td>
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<tr>
<td>Apical</td>
<td>- basically a Kapton replacement</td>
<td>- sometimes difficult to obtain with a proper adhesive system</td>
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<tr>
<td>Kapton E Film</td>
<td>- one of many adhesiveless systems available in the market today.</td>
<td></td>
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<tr>
<td>Black Kapton</td>
<td>- may be used in certain instances as a replacement for a shield layer</td>
<td>- not readily available</td>
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<tr>
<td>UL Rated Systems</td>
<td>- allows UL rating of circuit</td>
<td>- supply is limited</td>
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<tr>
<td></td>
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<td>- cost is high</td>
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<th>FEP Plastic</th>
<th>FEP Glass Cloth</th>
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<td>Appearance</td>
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<td>Clear</td>
<td>Blush</td>
<td>Amber</td>
<td>White</td>
<td>Opaque</td>
</tr>
<tr>
<td>Bondability with Adhesives</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Bondability to Inert</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Water Absorption (g/L)</td>
<td>&lt;0.01</td>
<td>10</td>
<td>&lt;0.01</td>
<td>0.18</td>
<td>3/24 hr</td>
<td>0</td>
</tr>
<tr>
<td>Volume Resistivity (ohm·cm)</td>
<td>10¹⁰</td>
<td>10</td>
<td>&gt;2 x 10³</td>
<td>10</td>
<td>10²</td>
<td>3.1 x 10⁹</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>2.2</td>
<td>2.5</td>
<td>2.1</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td>10¹–10¹⁰ Hz</td>
<td>10²</td>
<td>2 x 10⁻⁶</td>
<td>2 x 10⁻⁶</td>
<td>10⁻⁶</td>
<td>3 x 10⁻⁴</td>
</tr>
<tr>
<td>Service Temp.</td>
<td>250</td>
<td>250</td>
<td>200</td>
<td>200</td>
<td>300</td>
<td>125</td>
</tr>
<tr>
<td>Elasticity</td>
<td>650 1600</td>
<td>650 1600</td>
<td>650 1600</td>
<td>650 1600</td>
<td>7000</td>
<td>1100</td>
</tr>
<tr>
<td>Sample Size</td>
<td>15</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>19.2</td>
</tr>
</tbody>
</table>
# Insulation Characteristics

## DESCRIPTION AND TEST METHOD

<table>
<thead>
<tr>
<th>PHYSICAL PROPERTIES</th>
<th>KAPTON® POLYIMIDE</th>
<th>NOMEX® ARAMID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Specimen Thickness</td>
<td>0.001&quot;</td>
<td>0.002&quot;</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D882, MD, psi</td>
<td>25°C</td>
<td>17,000</td>
</tr>
<tr>
<td>200°C</td>
<td>23,000</td>
<td>13,000</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D882, MD</td>
<td>25°C</td>
<td>70%</td>
</tr>
<tr>
<td>200°C</td>
<td>90%</td>
<td>4%</td>
</tr>
<tr>
<td>Folding Endurance (MIT)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D643, MD, Cycles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,000</td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>Burst Strength (Mullen)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D774, psi</td>
<td>23°C</td>
<td>75</td>
</tr>
<tr>
<td>Tear Strength – Propagating (Elmendorf)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D1922, gm/mil</td>
<td>23°C</td>
<td>8</td>
</tr>
<tr>
<td>Tear Strength – Initial (Graves)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D1004, gm/mil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>510</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Area Factor, ft²/lb/mil</td>
<td>135</td>
<td>200</td>
</tr>
<tr>
<td>Density – ASTM D1505 gm/cc</td>
<td>1.42</td>
<td>1.8</td>
</tr>
<tr>
<td>Compressive Creep (Cold Flow)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 hours (W R &amp; D Test)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9%</td>
<td>(2.3 miles)</td>
<td></td>
</tr>
</tbody>
</table>

**Bend Test at Cryogenic Temperature**

-268.9°C, 0.5” dia. mandrel

**ELECTRICAL PROPERTIES**

<table>
<thead>
<tr>
<th></th>
<th>KAPTON® POLYIMIDE</th>
<th>NOMEX® ARAMID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Specimen Thickness</td>
<td>0.001&quot;</td>
<td>0.002&quot;</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D149, volts</td>
<td>23°C</td>
<td>7,000</td>
</tr>
<tr>
<td></td>
<td>150°C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>200°C</td>
<td>5,600</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D150</td>
<td>60 Hz, 23°C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10³ Hz, 23°C</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>10⁶ Hz, 23°C</td>
<td>-</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 Hz</td>
<td>3.8</td>
<td>2.3</td>
</tr>
<tr>
<td>10³ Hz</td>
<td>3.5</td>
<td>2.0</td>
</tr>
<tr>
<td>10⁴ Hz</td>
<td>3.4</td>
<td>-</td>
</tr>
<tr>
<td>10⁹ Hz</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D257, 50% RH, ohms, 23°C</td>
<td>10¹⁶</td>
<td>10¹⁶</td>
</tr>
<tr>
<td>Volume Resistivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM D257, ohm-cm</td>
<td>23°C</td>
<td>10¹³</td>
</tr>
<tr>
<td></td>
<td>120°C</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>200°C</td>
<td>10¹⁴</td>
</tr>
</tbody>
</table>
DESCRIPTION AND TEST METHOD (Cont’d)

**CHEMICAL PROPERTIES**

<table>
<thead>
<tr>
<th>Property</th>
<th>KAPTON® POLYIMIDE</th>
<th>NOMEX® ARAMID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Specimen Thickness</td>
<td>.001”</td>
<td>.002”</td>
</tr>
<tr>
<td>Sodium hydroxide 10% solution 5 days immersion at 23°C</td>
<td>Derades</td>
<td>Absorbed</td>
</tr>
<tr>
<td>Fungus Resistance (Soil Burial)</td>
<td>Inert</td>
<td>Inert</td>
</tr>
<tr>
<td>Effect of Acids, ASTM D543</td>
<td>None</td>
<td>Small</td>
</tr>
<tr>
<td>Transformer Oil, 180 days at 150°C</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

**THERMAL PROPERTIES**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flammability (UL 94)</td>
<td>94V-0</td>
</tr>
<tr>
<td>Melting Point (Fisher-Johns MP Apparatus)</td>
<td>None</td>
</tr>
<tr>
<td>Zero Strength Temperature</td>
<td>815°C</td>
</tr>
<tr>
<td>Service Temperature, Continuous</td>
<td>-268°C to 250°C</td>
</tr>
<tr>
<td>Shrinkage, ASTM D1204, MD 30 minutes at 150°C</td>
<td>0.15%</td>
</tr>
<tr>
<td>Shrinkage, ASTM D1204, MD 30 minutes at 250°C</td>
<td>0.3%</td>
</tr>
<tr>
<td>Outgassing Begins at</td>
<td>350°F</td>
</tr>
</tbody>
</table>

**SPEC. NUMBERS AND/OR DESCRIPTIONS**

<table>
<thead>
<tr>
<th>Conductors:</th>
<th>COMMERCIAL</th>
<th>MILITARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>QQ-C-576b/IPC-150</td>
<td>MIL-F-55561/IPC-150</td>
</tr>
<tr>
<td>Brass</td>
<td>QQ-B-613b</td>
<td>QQ-B-613b</td>
</tr>
<tr>
<td>Insulation: Polymide</td>
<td>IPC-FC-232</td>
<td>MIL-P-46112A/IPC-FC-232</td>
</tr>
<tr>
<td>Insulation/Adhesive:</td>
<td>IPC-FC-232</td>
<td>MIL-P-46112A/IPC-FC-232</td>
</tr>
<tr>
<td>Adhesive: Acrylic</td>
<td>IPC-FC-233</td>
<td>IPC-FC-233</td>
</tr>
<tr>
<td>Plating: Tin</td>
<td>IPC-FC-241</td>
<td>MIL-T-10727</td>
</tr>
<tr>
<td>Plating: Tin-Lead</td>
<td>QQ-S-571</td>
<td>MIL-P-81728</td>
</tr>
<tr>
<td>Clad Insulation: Polymide/Copper</td>
<td>IPC-FC-241</td>
<td>IPC-FC-241</td>
</tr>
<tr>
<td>Solder: Tin/Lead</td>
<td>IPC-240</td>
<td>MIL-P-50884-C</td>
</tr>
<tr>
<td>Circuit: Finished</td>
<td>1IPC-FC-250</td>
<td>MIL-STD-2118</td>
</tr>
<tr>
<td>Design Standard Circuit</td>
<td>1IPC-ML-990</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1IPC-FC-240C</td>
<td></td>
</tr>
</tbody>
</table>
Methods of Connector Attachment

Set component address methods for double row solder joints

The following illustrations show the best methods of addressing components:

- Right-angle address to multirow rectangular connectors with single layer requiring conductors to pass between pins.
- Right-angle bilateral address to multirow rectangular connectors.
- In-line address to rectangular multirow connectors.
- Everted bilateral address to multirow rectangular connectors.
- Everted address to rectangular multirow connectors.
10 Set component address methods for circular connector solder joints

in-line address to circular connectors with straight rows.

right-angle address to circular connectors with straight rows.

everted address to circular connectors with straight rows.

right-angle address to circular connectors with radial rows. Conductors must pass between pins.

circular connectors with straight and radial pin geometries.

right-angle bilateral address to circular connectors with radial rows. Conductors must pass between pins.

right-angle multilayer approach to a circular connector with radial rows.
Establish terminal construction

- Make pads as large as possible, at least 2 x the size of the hole for the component lead, to avoid manufacturing yield problems. If circuit densities force smaller pads, consider internal via's for sequential layers.

- Allow .008" - .010" clearance between the maximum pin diameter and the minimum finished hole size. (per MIL-STD-2000).

- Design all pads with fillets and tie-down ears to protect against pad lifting during soldering of components. (Avoid potential shorts.) The increase in pad area will reduce the chances of hole breakout, prevent stress build-up from drilling and possible conductor-to-pad interface cracks.

- Apply minimum spacing requirements to adjacent conductors and pads.

- Try to maintain a minimum of .030" from the edge of a circuit to a conductor or pad and allow ± .010" for required outline tolerances, material misregistration and process tolerance build-ups. Example: Pin of .020". Minimum annular ring of .005". Hole size .028". Pad Size .058".

- Terminal pads associated with large conductor areas (ground planes, voltage planes, heat sinks, etc.) should be relieved locally to facilitate soldering.

- Specify hole sizes with Standard Drill Tolerance and tolerances of ± .003".

- Do not specify hole-to-pad concentricity, specify annular ring.

- Minimum annular ring on single-sided circuits (unsupported pad) should be .015", but .005" is common.

- on PTH .005" annular is standard.

In connector areas where small center to center spacing between pads is utilized, it may be necessary to slab or truncate pads in order to run conductors through the pattern. Elongated pads may be used to increase solerable pad area in at least two directions and give the ability to capture the pad with the coverlayer.

Inlet holes must be put in artwork.
Maximize Copper Area
The practice of favoring copper in design so that the majority of the area of the flex circuit is copper counteracts the shrinkage that normally occurs as the material relaxes when copper is removed.

Refine conductor sizes and spacing.
While conductor size is determined by current requirements, an efficient layout will consider the following.

- Keep conductors parallel and consistent in size.
- Avoid sharp corners which may trap etching acid.
- Provide fillets to all interfaces.
- Keep spacing to maximum possible and do not consider etch loss to get proper spacing.
- Avoid open areas or congested conductor runs.

<table>
<thead>
<tr>
<th>RECOMMENDED</th>
<th>NOT RECOMMENDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid acute internal angles.</td>
<td><img src="image" alt="Good" /> <img src="image" alt="Good" /> <img src="image" alt="OK" /> ![ ]</td>
</tr>
<tr>
<td>Avoid sharp external angles which can cause foil delamination.</td>
<td>![ ] ![ ]</td>
</tr>
<tr>
<td>Always use the shortest practical circuit routing.</td>
<td>![ ] ![ ]</td>
</tr>
<tr>
<td>Maintain equal spacing where conductors pass between lands.</td>
<td>![ ] ![ ]</td>
</tr>
</tbody>
</table>
13 Accommodate required bends and folds

- The radius of a bend in a one-layer flexible circuit should not be less than ten times the circuit thickness.
- For dynamic flexing arrangements, this should be 100 x. Flex can be creased however.
- Conductors should run perpendicular to fold lines.

- Keep folds neat and uniform
- Add extra copper (space permitting) to help hold the fold shape.

14 Provide Tear Stops

- Kapton tensile strength is typically 25,000 pounds for 1 mil material but tear strength is low.
- Copper reinforced areas (tear stops) should be used for corners of 120° or less to restrict possible damage during assembly.
15 Adjust covercoat to pad, if necessary

- When pads can not have tabs or fillets, the covercoat should lap onto the pad at least .005" for 270°.

- Use slots or irregular shapes as last resort only.

- Adhesives will extrude .003" – .010" around the covercoat opening. A very tight hole-to-pad ratio may cause problems meeting specifications.

- Terminal pad baring can be done by combination, strip or for individual pads. When individual access holes are used, their diameter should be larger than the pad diameter.

SAME SIDE OPENING

REVERSE BARING

- For circuits to be plated with a special finish only on the pads, all plated areas must be run to a common buss outside of the circuit. (This connection is severed in finishing operations.)

- Plating is most commonly 63/37 or 60/40 tin-lead. Normal thickness is 300 to 800 micro inches. Plating can be done to MIL-P-81728 or QQ-S-571. Other common platings are bright tin to MIL-T-10727 and gold over nickel to MIL-G-45204. Gold can be soft 95 knoop or hard.
Check conductor run dimensional tolerances

Final refinement of conductor runs should result in tolerances and dimensions within the parameters illustrated in the following example to result in the most economical and functional flexible circuit.

Determine need for stiffeners or backers.

To facilitate component insertion, to assure mechanical strength, or to obtain selective stiffness required in some applications, reinforcement in key areas is often desirable.

- Any standardly available board material may be used. (FR4, G10, Polyimide Glass).

A) Minimum edge distance .015" (Design for .030" if space available).

B) Pad diameter should be at least 2 x through hole diameter.

C) Through holes should be .008" - .010" larger than component lead diameter.

D) Minimum spacing .005" conventional. <.005" premium cost.

E) Minimum conductor width .005" conventional. <.005" premium cost.

G) Hole diameter treated same as C.

H) Offset conductors from one side to the other to avoid I-beam effect in fold areas.

J) Fold line.

- Added thickness of dielectric film will provide some stiffening plus wear resistance

- Hole diameters in reinforcement materials should be at least .020" larger than through holes.

- Adhesives for bonding reinforcements can be the same as used in the main circuit or transfer tape can be used.

A strain relief material is sometimes used to form a radius between the flexible circuit and stiffener material in any selections subject to flexing.
Determine best method of external connection

Flexible circuits can be adapted to any connector design. Provide exact dimensional data for all connector types.

**Pads**
- Components can be soldered directly to a bared pad in the flexible circuit.

**Pins**
- Can be soldered into flex for direct board plug in or for wire wrap around.

- Exact dimensional data is required including pin diameter, pin length, and pin spacing (relative to the center of the conductor).

**Sculptured**
- Terminal pins for circuit and connections can be eliminated with fingers available in Sculptured circuits.

**Crimp-ons**
- Insulation displacement terminals penetrate th insulation and are rolled over to mechanically gri the conductor.

- External shells plug into crimp-on pins to serve a connectors.

**Hard Wire**
- Wire through circuit pad
- Wire lap-soldered to finger
- Brazing can also be done.

**Pressure Contacts**
- Gold pressure contacts or sculptured posts.
19 Allow for strain relieving in key areas
Terminal areas do not normally require reinforcement since the laminated construction divided stress among all terminations. If additional strain relief is required, additional rigid areas or mounting holes for mechanical fasteners can be provided.
- FR4 and G10 stiffeners can be bonded to the circuit.
- Terminal areas can be potted for strain relief and environmental protection.

- Solder posts can be potted
- Solder posts simplify assembly

20 Determine mounting requirements
- If necessary, secure circuit within package to prevent flopping and to provide vibration resistance. Mounting holes can be built into the circuit for internal or external mounting. Mounting holes should have a copper ring.

- Mounting can be by strain bar, screws or clips.

21 For Flexing and Dynamic Applications
- 1 oz. or ½ oz. copper is the best metal thickness.
- Use uniform dielectric layers, top and bottom.
- Provide largest possible flex radius, at least .25” for extended life.
- Flex life in excess of 1,000,000 cycles is attainable. It is recommended that phenol butyral be the adhesive in such applications.

22 Establish shielding and EMI requirements
Since flexible circuit conductors are location-fixed, designing sensitive conductors away from radiating lines can avoid shielding needs. Grounded guard conductors can also isolate sensitive circuits and eliminate cross-talk.

Thin copper foil or copper mesh foil are the most commonly used materials for shielding. Silver epoxy can also be used.

- Limit shields use to minimize cost and to maintain flexibility.

- Copper shields are recommended for reliability. A cross hatch pattern in art work will increase flexibility.
Designate any areas requiring flexing of double or single sided circuits. Adding inner layer shields to multilayer circuits will increase the bend radius and reduce flexibility.

In cases of high RF energy, video signals and digital pulses a full 360° shield may be required. This can be achieved by incorporating guard conductors on the edges of a circuit. The guard conductors are exposed in the coverlayer and base dielectric at specified increments. The same result can be achieved with copper shields using plated-through holes to make connections to guard conductors.

---

**Plating Considerations**

**PLATING** – Copper pad coverage costs can be reduced by adding plating buses to circuits which have only pad terminals and would not normally extend to the circuit edge.

**EXAMPLE:**
Connectors

Finger Disconnects:

Amp Canada Product Communications Dept. Tel: (905) 470-4463
Amp Canada AMPFAX (800) 245-4356
Amp Inc (U.S. Customers) (800) 522-6752

Pad Connections:
All connectors with either solder type contacts or contacts suitable to adapt for flex interface
Example:
1. MIL-C24308 Connectors ("D" Subminiatures)
2. MIL-C-55302
3. "MDM" Microminiature Connectors
   (AND MANY MORE)

Insert arrangements such as:
1. MIL-C-26482
2. MIL-C-38999
3. MIL-C-27599
   (AND MANY MORE)

Other termination techniques.
1. "High Density" pressure contacts
2. Lap solder fingers (with or without self aligning groove)
3. Insulation displacement contacts (for most I.D.C. connectors)

NOTE: Custom artwork is required for the above
(Consult with the Factory).
Tooling

For Outline Stamping of Flex Circuits
Tolerances are for outline dimensions

* Routed Steel Rule Die
  Hold ± .015” tolerance – least expensive
  – 2 x routed

* Laser machined Steel Rule Die
  Hold ± .010” tolerance – most expensive
  – >50,000 parts average life

* Matched metal dies
  Hold ± .005” tolerance – to cut complex outlines

* Laser capability available
  Hold ± .005” tolerance

* Routing capability
  Hold ± .010” tolerance – primarily used for more
  than single-layer prototypes

Laser Machining of Dielectric Materials

Industry practices for flexible printed circuit production methods, use steel rule dies for cutting large holes, slots and outlines which offers tolerances in the order of ±.010”. Similarly, hole patterns are N.C. drilled.

As packaging demands tighter dimensional tolerances, registration problems are intensifying.

SF addressed these problem areas with an intensive R & D program and successfully developed laser machining of insulation materials.

SF has a laser process for machining polyimide, epoxy adhesive film or film or acrylic thermostet film adhesive to tolerances of .010”. This process can machine holes, slots and outlines at one time.

Since the same basic art is used for laser machining masks to what is used for etching the conductor patterns in the copper, complete uniformity is maintained from a registration standpoint.

Tooling costs and manufacturing costs are lower than traditional machining, for small lots only.

ARTWORK GENERATION
All artwork and manufacturing information is CAD/CAM generated. SF will take basic Gerber compatible discs or tapes from customers for processing. Data can also go via modem.
Soldering

Hand Soldering:

1. Preparation:
   A. 37½ watt temp. controlled iron with a 1/4 dia. tip.
   B. Solder: approx. .015" dia., composition SN 63 or SN 60 per FEO. SPEC. QQ-S-571 Type RA
   C. Clean terminals (pre-tinned or equivalent)

2. Method:
   A. Clean terminals with Isopropyl Alcohol (99% pure by volume) Ethyl (FED. Spec. O-E-760,
      Grade 1, Class A or B
   B. Dry with filtered air.
   C. Pre-bake at 250°F (120°C) for approx. 30 min.
   D. Solder
      1. Max Tip Temp 500°F (260°C)
      2. Dwell time 1–5 seconds
   E. Remove Flux with a degreaser or by brush and approved solvent (per "A" above)
   F. Dry with filtered air.

Flow Soldering:

1. Preparation:
   A. Pre-bake at 250°F (120°C) for approx. 30 min.
   B. Solder
      1. Max. Temp 475°F (245°C)
   C. Cleaning (same as above)
Sculptured™ Flexible Circuits

- No connections: Each rigid contact is an integral part of the conductor.
- Flexible body: Minimizes stress in contact area.
- Custom contacts: Simple solution to difficult terminating problems.
- Pin arrangement: Preformed as required.
- Strong contacts: Insure ease of insertion and assist automated assembly.
- Power lines: Individual conductor widths may be increased to carry additional current.
- Choice of contact finish: Solder, bright tin, gold, etc.

Flex Modular Assembly

- SCULPTURED FLEX
- MATRIX PCB
- GND
- PCB
Sculptured Jumpers

ORDERING CODE
S-J 100-12-3 K A T

Sculptured Jumper
Conductor Pitch
Number of Conductors
Cable Length
Insulation Material

K = .001" kapton

DESIGN TIPS
1. Always form fingers prior to solder assembly.
2. For ease of assembly, keep cable width within 3 inches.
3. Take advantage of sculptured jumpers' unique strain-relieving characteristics by using a 10% service loop as shown.
4. Jumper fingers are designed to plug into most sockets.

10% service loop.
Vertical Jumpers

Thin, flexible, vertical jumpers reduce P.C. board and assembly costs by bridging signals on the board. Vertical jumpers eliminate multilayers, isolate sensitive lines, and save space.

ORDERING CODE

V-J 100-12-3 K A T

Surface Finish
S - Solder
T - Bright Tin

Finger Arrangement
A - Straight
B - Right Angle
C - Right Angle Staggered
D - Straight Stagger

Vertical Sculptured Jumper
Conductor Pitch
Number of Conductors
Cable Length
Insulation Material

K = .001" kapton
36° Rotary Switch

Fits:
ALCO, GRAYHILL & RCL
1/2" Diameter, 36°
Single Pole, P.C. Mountable Rotary Switch.

Insulation:
.001" Kapton
Pushbutton–Toggle Switch

Before

After

Fits:
ALCO, C & K, GRAYHILL
& CHICAGO Switch
Standard Double Pole,
P.C. Mountable Pushbutton or Toggle Switch

Insulation:
.001” Kapton
Power Circuits

Now you can get high current capacity in a self-terminating flexible circuit. Sculptured power circuits are often designed to carry 100 amperes or more.

Sculptured circuits are designed with integral contacts that mate with any component lead configuration. Often, the only non-recurring charge is artwork.

POWER CABLES ARE CUSTOM DESIGNED TO YOUR NEEDS. THICKNESS MAY BE VARIED FOR FLEXIBILITY FROM .004 TO .020 (STD); OR THICKER AS REQUIRED. YOUR NEEDS WILL DICTATE.
Custom Circuits

NO HARD TOOLING, NO LIMIT ON CUSTOM FEATURES.

Sculptured circuits can interconnect your entire front panel and motherboard. No additional hardware is needed. The pins shown are not added to this circuit, but are an integral part of the circuit itself.

Sculptured circuits save time, money and precious board space because connectors are built in, not added on. Higher pin densities are attainable than with any conventional connector.

Look closely. This is no ordinary FLEXIBLE interconnect. SYSTEM

"Our limitations are the imagination itself."
Artwork and Tooling Information

1. Side 1 & 2 Artwork Definition

1. E. SFC Circuits require two pieces of artwork. SIDE 1 defines the areas to be sculptured, and SIDE 2 defines the conductor pattern.

A - SIDE 1

B - SIDE 2

NOTE: The registration between the side 1 and 2 artwork is critical. Misregistration should not be greater than .001".

Raised Pad Illustration

hold down tabs

SIDE 1 O.D.
SIDE 1 I.D.

SIDE 2 O.D.
A - A

truncated

Forming Illustrations

1 - Straight Stagger

2 - Right Angle Stagger
Other Terminating Methods

I.E. Types of terminals which may be provided on the sculptured flexible circuits (SFC)

Example:

(AND MANY OTHERS)

Marking (Artwork Specs)

I.E. Etched information (P/N's, etc.) should meet the following requirements.

A. POSITIVE lettering at 1:1
   1 – .015” min wide x .075” min high

B. NEGATIVE lettering at 1:1
   2 – .010” min wide x .075” min high

Fold Areas

A. PERMANENCE
   1 – Most dielectrics such as Kapton have an exceptional memory. In order to maintain most folds it is necessary to have the right proportions of dielectric versus copper. Therefore, it is sometimes necessary to add extra copper to enhance this permanence.

B. THINGS TO AVOID
   1 – The artwork should not have conductor transitions (change in thickness) closer than .060” from a fold area if possible.
   2 – Parallel conductors should avoid being closer than .030” from a lateral fold.
   3 – Folded cable should be creased and shipped flat to avoid expensive shipping containers.

C. FOLD INDICATORS
Complex Packaging

The solution to a complex packaging problem is often the separating of it into individual parts which become a number of simple flex parts. Flex modularized allows you to break down these complex packages into simple flex circuits combined with standard printed circuit boards, doubled or multilayer.

This situation has in the past been packaged with harnesses or rigid flex, both solutions are complex and expensive.

Flex modularized consists of conventional sculptured flex with extended terminated fingers which are assembled into circuit boards usually in matrix holes along the edge. The sculptured fingers eliminates the need for interface hardware between the board and the flex circuits. Connectors or jumpers are not required.

This replacement for rigid flex can be used by manufacturers of high reliability, commercial and military electronics.

In the past, the weakness of using conventional flex with multilayer boards was the attachment hardware, connectors or pins. This was often the failure point.

The manufacturing of a flex-hardboard combination which is one single laminated assembly becomes a great problem. Controlling the different shrinkage and expansion rates of adjoining materials proved to be an extremely complex challenge.

The problems in procurement and using rigid flex such as long lead time, late deliveries, difficult to assemble, impossible to repair, and expensive. Any damage to the flex circuits sections of rigid flex often means scrapping the whole assembly. Make flex modularized an attractive alternative.

With the design flexibility offered by sculpture flex, the connections are an integral part of the flex. The contacts are supported by the dielectric structure of the circuit. With an improvement in reliability of flex modularized and the cost savings of as much as 50% compared to standard rigid flex.

As time passes, repair and redesign may be required. Flex modularized allows repair and simplifies redesign.

Why Flex?

High Reliability
Flexible circuits are precise replicas of artwork. Under exacting controls, the artwork produces circuits with excellent repeatability and reliability.

Etched circuits replace solder connections and hand wiring, eliminating wiring errors completely. After installation, the elimination of connections means fewer failures.

In use, flexible circuits have proven reliable through hundreds of millions of dynamic cycles. Only this type of circuit meets the need to have moving parts joined by current-carrying circuits with virtually no space restrictions.

The toughness of polyimide ensures reliability even with rough handling. Exceptional heat resistance allows polyimide to survive soldering of devices, as well as high heat in use.

With greater automation of the manufacturing process, it is easier to prevent circuit failures that were previously due to human error. Electrical properties are more predictable and consistent.

Cost Savings
Less manual labor and reduced need to correct production errors can lower the installed cost of flexible circuits by as much as 30% compared to hardboard circuits. Installing or replacing complete interconnection systems rather than individual hardboards eliminates wiring errors, greatly reducing rework and cutting assembly costs.

The use of flexible circuits eliminates the high labor cost of routing, wrapping and soldering wires, resulting in substantial savings.

In low volume applications, flexible circuits are most cost-effective when the circuit design is very complex. Most high volume applications afford outstanding economy regardless of the complexity of the circuit layout.

The development of simpler, more direct methods of integrating circuits and devices is leading to lower costs.

Interconnected screened-through holes with conductive ink has cut the costs of double-sided circuits. The trend to surface mounted devices promises even greater savings.
Turning the Potential of Flexible Circuitry to your Advantage . . . Basic Design Considerations

Before beginning a project involving flexible circuitry, the designer should be familiar with several basic design guidelines that are specific to flexible circuitry. A knowledge of certain requirements, design relationships and trade-offs is essential for bringing a design from concept to production by the simplest, most cost-effective route.

Each of the following steps is critically important:

1. Before beginning a design, analyze the final product requirements thoroughly – know the electrical requirements, dimensional restrictions and assembly limitations.

2. Refer to flexible circuit design guide books throughout the design process. Learn the trade-offs that will allow design improvements.

3. Don't delay designing the flexible circuit. This should proceed simultaneously with the design of the product into which it will go. The designer must consider a great number of factors at the same time, including conductor spacing, component address, optimum designing for bend areas, covercoat configuration and shielding.

4. Contact flexible manufacturer early in the design process. Specialists can provide design assistance, as well as check designs for manufacturability and possible cost savings.

5. Build a prototype of the circuit as soon as possible in order to allow time for modification and improvement of the circuit.

6. Visit the facilities of flexible circuit manufacturer to evaluate their experience and production capabilities.

7. Allow circuit manufacturer adequate time to develop schedules and quotations for artwork, tooling and production.

Cost Factors

Since flex circuits normally replace conventional wiring methods this presentation will focus on the benefits of using a flex circuit.

Flex circuits have the following advantages:
1. Reduction in package size and weight.
2. Reduction of assembly time and errors.
3. Subassembly costs.
4. Repeatable/Reproducible electrical characteristics.
5. Custom shielding and impedance control.
6. Improved reliability.
7. Connects moving parts.
8. Engineered appearance.
9. Dense connections.
11. Capable of combining component with wire.

Break-Even Quantity — Flex vs Conventional Wiring Harness

\[
N = \frac{(NRF - NRc)}{(Rc - Rf)}
\]

where:
- \(N\) = Break Even Quantity
- \(NRF\) = Non-Recurring Flex Costs
- \(NRc\) = Non-Recurring Conventional Costs
- \(Rc\) = Recurring Conventional Costs
- \(Rf\) = Recurring Flex Costs

Further Reference

It is highly recommended that the designer have copies of the following specs:
1PC-D-249 Design Standard for Flexible Circuits
MIL-STD-2118 Design Requirements
# Comparison of Recurring Elements

**Conventional Wiring Harness**
- Wire
- Identification sleeves
- Braiding (shielding)
- Terminals, pins, lugs
- Cut-strip wires
- Identify wires
- Crimps, solder, -term./pins/lugs
- Insert pins in connectors
- Lay wires on harness boards
- Lace
- Shield preparation
- Wire twisting
- Install braiding
- Inspect harness
- Bench test harness
- Route to component terminal
- Final cut – strip, tin solder
- Secure harness w/clamps ties
- Test completed assembly
- Correct wiring errors
- Rework
- Reinspect
- Retest

**Flexible Circuit**
- Unit price/circuit
- Lot inspection
- Test
- Installation
- Inspection
- Test

# Comparison of Non-Recurring Elements

**Conventional Wiring Harness**
- Schematic diagrams
- Wiring diagrams
- Wire lists
- Harness assembly drawings
- Parts lists
- Harness boards
- Manufacturing engineering (production planning)
- Industrial engineering (line set up and assembly)
- Potting molds
- Bread board model
- Testing equipment and support

**Flexible Circuit**
- Preliminary Circuit layout
- Developed circuit layout
- Prepare artwork
- Mock-up artwork
- Make corrections
- Prepare master artwork
- Prepare master marking drawing
- Flexible circuit assembly drawings
- Flexible circuit installation drawing
- Tooling (dies, punches, drill tapes, laser masks, composites)
- Potting molds

Total installed costs in production quantities are typically 50 to 70% of conventional wiring.

MIL-P-81728 plating is used when there is contact from the flex circuit to a buss bar. QQS-571 plating is done when there is no contact to a buss bar.

Gold can be specified in various purities and hardnesses. For wire bondable gold purity of 99.9999% is recommended with a knoop hardness of 90 – 95%.

Other coatings sometimes used are immersion tin or various commercial anti-tarnish coatings.
Impedance Controlled Flex Circuits

Physical dimensions and material characteristics affect electrical properties like attenuation, propagation delay and impedance. Flex circuit designers and manufacturers must understand which physical tolerances require tight control and which ones are not as critical. Design changes which increase manufacturing yield, and simplify the design requires a complete understanding of the results.

Manufacturers must build controlled impedance flex circuits in most signal transmission applications. At low frequencies impedance control is not important because the tracks act as a resistor. The tracks, vias and pads, are largely invisible to the circuit.

High speed logic now cause the flex foil to function more like a wave guide. The speed of wave propagation becomes important, and variations or changes in the impedance could cause scattered or finger signals. Since controlling impedance is so important with high speed logic, the flex circuit manufacturer must understand the effects of his manufacturing tolerances on impedance.

Impedance of a metal track on a board can be expressed as a function of flex dimensions.

For surface micro strip:

\[ Z_0 = \frac{87}{\sqrt{\Sigma_r + 1.41}} \ln \left[ \frac{5.98 \times h}{0.8 \times w + t} \right] \Omega \]

(Good for \(0.1 < w/h < 3.0\) and \(1 < \Sigma_r < 15\))

For strip line:

\[ Z_0 = \frac{60}{\sqrt{\Sigma_r}} \ln \left[ \frac{4h}{0.67 \times \pi \times w (0.8 + t/w)} \right] \Omega \]

(Good for \(w/(h-t) < 0.35\) and \(t/h < 0.25\))

In these equations, \(w\) is line width
\(t\) is line thickness
\(h\) is thickness of dielectric
(Fig. 1 and 2)

Propagation delay, another quantity of importance can be expressed as follows for surface micro strip:

For surface micro strip:

\[ t_{pd} = 1.107 \sqrt{0.475 \Sigma_r + 0.67} \text{ ns/ft} \]

For strip line:

\[ t_{pd} = 1.017 \sqrt{\Sigma_r} \text{ ns/ft} \]

You can calculate how sensitive impedance and propagation delay are to physical parameter changes.

Fig. 1 Shows how the variation in the dielectric thickness affects the impedance of micro strip.

Fig. 2 Shows how the variation in the dielectric constant affects the propagation delay of centered strip line.

Figure 1: Impedance versus dielectric thickness for surface microstrip where \(w = 4\) mil, \(t = 1\) mil, and \(\Sigma_r = 4.5\).

Figure 2: Propagation delay versus dielectric constant for centered stripline. \(\Sigma_r\) is relative dielectric constant.
Instead of doing straight worst case analysis of tolerances, efforts are made to consider a number of variations and controlling specific processes to hit the desired result.

To look at other structural features which influence electrical properties, other advanced techniques are used. They calculate the affects of magnetic fields around conductors.

One of the conditions which are monitored very closely by flex circuit manufacturers is conductor undercut. It is a fact of life, and fortunately does not have to be eliminated. If its effect can be understood, it can be included as a design parameter.

Generally, undercut becomes more important as geometries shrink. Fig. 3 illustrates how undercut alters the impedance of a centered strip line configuration.

On very wide lines undercut has relatively little effect on the electrical properties. At narrow line widths the effect on impedance becomes appreciable – about 5 ohms.

If a flex designer knows the magnitude of this effect in advance it is possible to adjust the nominal line width to ensure a final desired impedance.

Most micro strip formulas in literature apply only to surface micro strip, yet designs often cover conductors with a dielectric layer.

In Fig. 4, the impedance of a buried micro strip line is compared to a surface micro strip line of the same width and ground plane separation.

Impedance decreases 5 to 15% depending on line width and burial depth. Surprising, a very thin coverage of dielectric still has an effect on impedance.

To obtain the performance one desires, careful consideration to the variables must be done.
Detailed Conductor Design

Figure 1 is used to determine the resistance of conductors for various thicknesses and widths.

The advantage that flat conductors have over round wires in current load is due to their larger surface area.

Multi-Layer Cables

Fully loaded flat conductor runs can carry up to 155% higher current loads than round wire of the same size as shown below.

<table>
<thead>
<tr>
<th>No. of Conductors</th>
<th>In Air (%)</th>
<th>In Vacuum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27 (1 layer)</td>
<td>+150</td>
<td>+155</td>
</tr>
<tr>
<td>15 (3 Layers)</td>
<td>+135</td>
<td>+150</td>
</tr>
<tr>
<td>250 (10 Layers)</td>
<td>+105</td>
<td>+105</td>
</tr>
</tbody>
</table>

This increase results in a lower voltage drop. This is due to a greater heat transfer surface and to the thinner insulation used.

Breakdown Voltage

Typical breakdown characteristics of one sided flexible circuits in the conductors exposed to air for various conductor spacing (See Figure 2) due to the etched edge irregularity the conductor spacing should be increased from the graphs ideal value.
Heat Dissipation

To find the current handling capabilities of flat conductors at 20°C ambient temperature if other temperature rises are allowable, refer to Figure 1 and 2.

![Figure 1: Current carrying capability of a single 1-ounce copper conductor for various allowable temperature rises at 20°C ambient.](image1)

![Figure 2: Current carrying capability of a single 2-ounce copper conductor for various allowable temperature rises at 20°C ambient.](image2)

Since resistance of copper changes with temperature, operation at ambience other than 20°C requires a correction to the value found from the nomograph.

To find conductor resistance at any ambient temperature other than 20°C, use the relation:

\[ R_2 = R_1 \left[ 1 + \alpha_1 (T_2 - T_1) \right] \]  \(1\)

- \(R_1\) = resistance at 20°C in ohms per foot (from nomograph)
- \(R_2\) = resistance at new ambient temperature in ohms per foot
- \(T_1\) = 20°C
- \(T_2\) = new temperature in °C (ambient plus allowable rise)
- \(\alpha_1\) = resistance temperature coefficient of copper at temperature \(T_1\) (= 0.393 at 20°C)

Figure 3 can be used to find the resistance temperature coefficient of copper, \(\alpha_1\), for any temperature \((T_1)\) from 0°C to 120°C.

![Figure 3: Resistance temperature coefficient of copper.](image3)
Detailed Conductor Design Continued

To find the current handling capability at some ambient temperature other than 20°C for a given allowable temperature rise, use the following relationship:

\[ I_2 = I_1 \sqrt{\frac{R_1}{R_2}} \]  \hspace{1cm} (2)

NOTE: This formula relates current and resistance for a given power (heat) dissipation. It does not take into account variables such as radiation, convection or conduction.

where:

- \( I_1 \) = current producing a given temperature rise at 20°C in amperes.
- \( I_2 \) = current in amperes which will produce the same temperature rise at the new ambient.
- \( R_1 \) = conductor resistance at 20°C in ohms per foot.
- \( R_2 \) = conductor resistance at the new ambient in ohms per foot.

All preceding design charts and calculations hold for only single conductor cases. The values thus derived must be derated if more than one conductor in a cable will be carrying significant current and contributing to the heat load.

A general rule of thumb indicates that single conductor current capabilities should be derated by 20% if two conductors will be carrying equal current and by 50% if 15 conductors carry equal current.

Figures 4 through 8 further define the current capabilities of flexible cables when such factors as number of conductors conductor spacing, heat sinking, etc. are considered.

Data for the design charts of Figures 1, 2 and 4 through 8 were obtained from measurements on a standard cable with the following parameters, only one of which was varied for each series of tests:

- Conductor material ............ rolled copper
- Conductor width .............. 0.060"
- Conductor thickness .......... 0.0028" (2 oz.)
- Conductor spacing .......... 0.006"
- Number of conductors .......... 10
- Insulation thickness ............. 0.005" base and 0.005" covercoat
All measurements were made with a thermocouple bridge using 0.010" thermocouple wire to reduce heat transfer down the thermocouple wire leads to a minimum. Equilibrium was maintained before measurement. Location of the thermocouple, unless otherwise specified, was at the assumed hot spot (middle of cable span and on surface of insulation directly over current carrying conductors). All measurements were made at approximately 25°C room ambient temperatures unless otherwise specified without previous conditioning of the samples other than standard processing procedures.

Figure 7: Temperature rise in a multilayer circuit compared with rise in a single layer at 20°C ambient. Only one conductor per cable carrying current.

Figure 8: Temperature rise in a single conductor, heat sunked cable compared with rise in air at 20°C ambient, only one conductor carrying current.
FLEX TYPES COMMONLY MANUFACTURED BY StrataFLEX

1) One-layer of copper with polymide covercoats one or both sides. Solder pads can be on top side, bottom side or both.

2) Four layers of copper with plated through holes. Parts can be panel plated for the plated thru holes, pattern plated for high density interconnect systems or selective plated for higher flexibility.

3) Single, double or three-layer flex with exposed windows for fingers.

4) Sculptured flex — 1, 2 or 3 layers with plated thru holes.

5) Shielded flex utilizing copper or silver epoxy as the shield.

6) Flex modular to replace rigid-flex.

7) Continuous flex up to 200 feet plus in length.

8) Fine-line routinely to .004 lines and spaces.

9) Rigid-flex with specialized material and construction.