

Confidential **Flexible Circuitry Design Seminar**



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# Agenda



- Introduction
- Flexible Circuitry - Basic Constructions
- Flexible Circuitry - Material Overview
- Flexible Circuitry - Design Concepts
- Flexible Circuitry - High-Speed Design
- Summary
- Questions / Answers

# Design Seminar Objective



To increase awareness of information regarding flexible printed circuitry so that ... our industry continues it's strong growth rate and we can better serve our customers.

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# Introduction



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# Flex Circuits- a blessing or a curse?



- Designed properly, they can save time and money. If not, well.....
- Proper Design is a result of the vendor fully understanding the customer needs
- Communication is the key
- Involve the vendor as soon as possible in the design phase
- Flex Vendors are used to helping

# Good End-Use Applications

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- A need to save Space
- A need to save weight
- A High vibration or Mechanical shock Environment
- A solution to a Small interconnect challenge
- A high flexing environment or a “Flex to Service” application
- A need to eliminate solder connections for Reliability
- Heat Dissipaters For High Speed Components

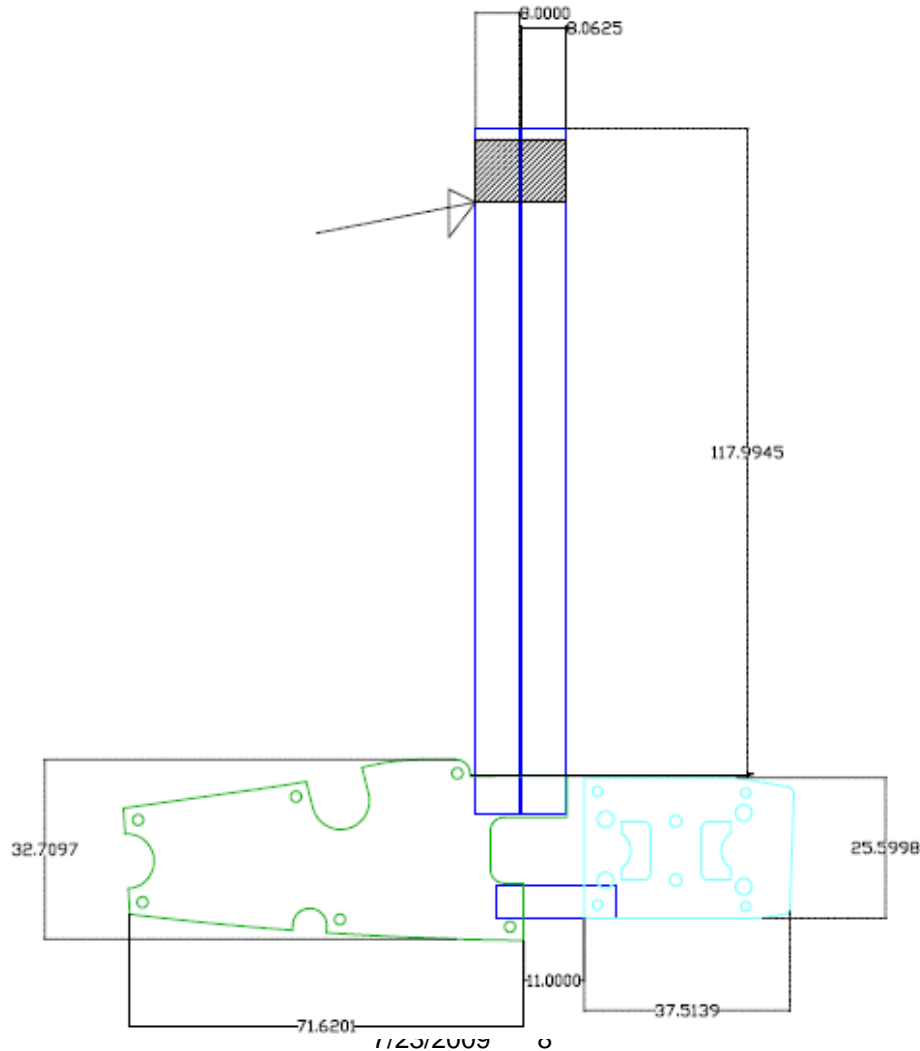
# Confidential **Bad End use Applications**



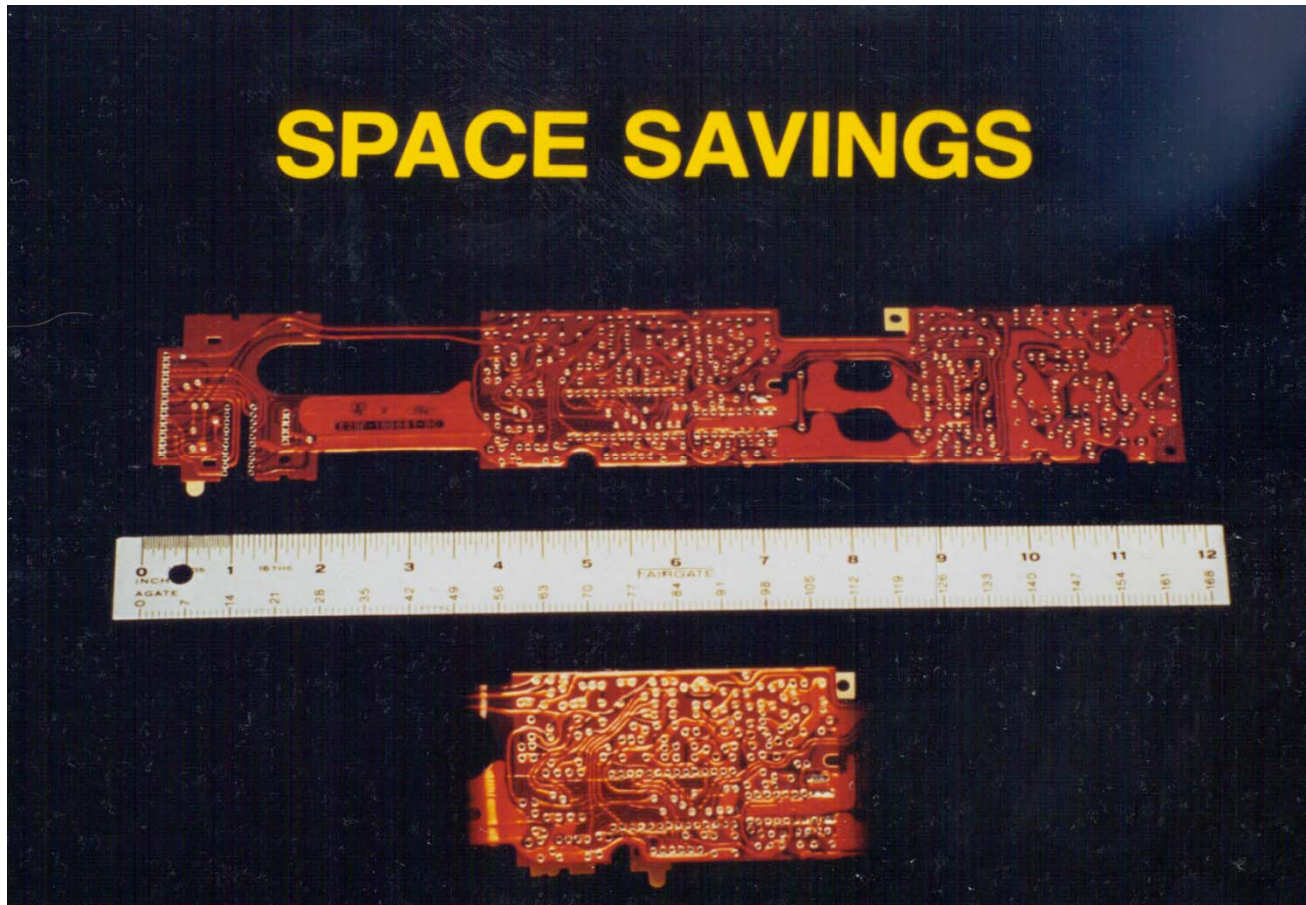
- **Very Large Size (Cost)**
- **Just because you like them**
- **A replacement for Large PCB's and Interconnect**
- **An application where a simple, inexpensive wiring harness will do**

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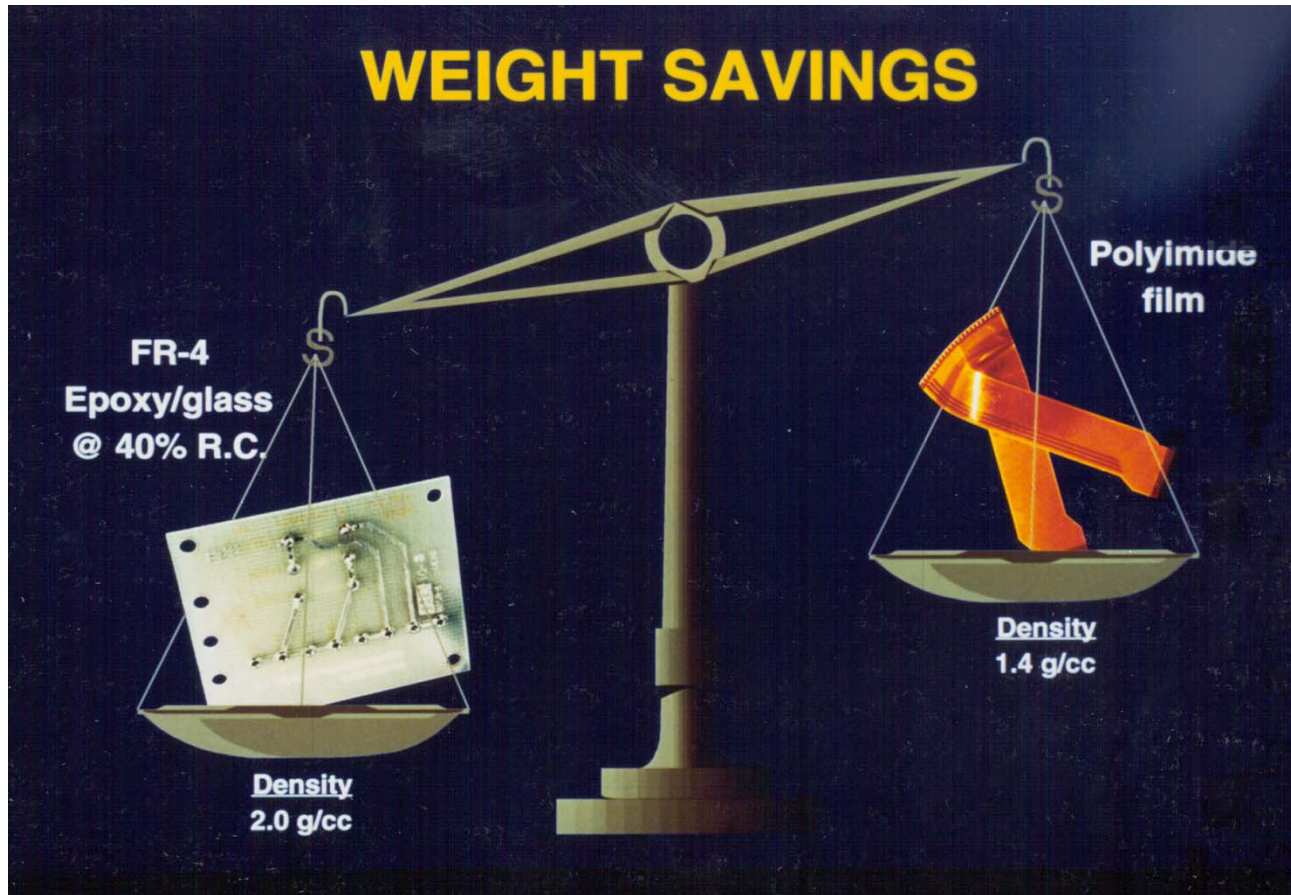
# 90% chance this is not a Good Rigid-Flex Design- possibly a good rigidized flex design



# Confidential Flexible Interconnect Design Advantages



# Flexible Interconnect Design Advantages



# Flexible Interconnect Design Advantages



- **Multi-planar routing and orientation of conductors**
- **Thermal characteristics**
- **Reproducible electrical characteristics**
- **Simplification = improved reliability**
- **Lower installed cost**

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# Flexible Circuitry - Basic Constructions

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# Single-sided Flexible Circuit







-  Rolled Annealed Copper
-  Polyimide Film
-  Adhesive

- **One conductive layer**
- **Excellent for dynamic flex life**
- **Very high reliability**
- **Lowest-cost interconnect solution**

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# Double-sided Flexible Circuit

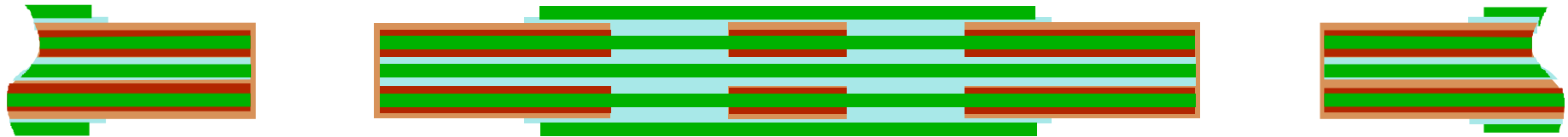






-  Rolled Annealed Copper
-  Electro deposited Copper
-  Polyimide Film
-  Adhesive

- **Two conductive layers**
- **Greater conductor routing per unit area**
- **Typically limited to flex for packaging**

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# Multi-layer Flexible Circuit

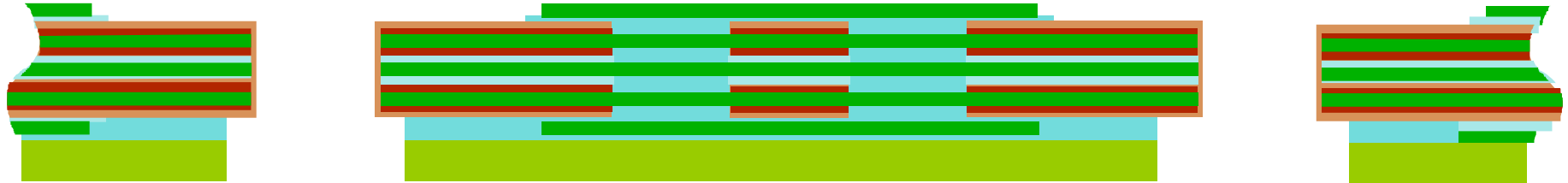







-  Rolled Annealed Copper
-  Electro deposited Copper
-  Polyimide Film
-  Adhesive

- **Three or more conductive layers**
- **Maximum conductor routing per unit area**
- **Limited flexibility for installation**

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# Rigidized Multi-layer Flexible Circuit

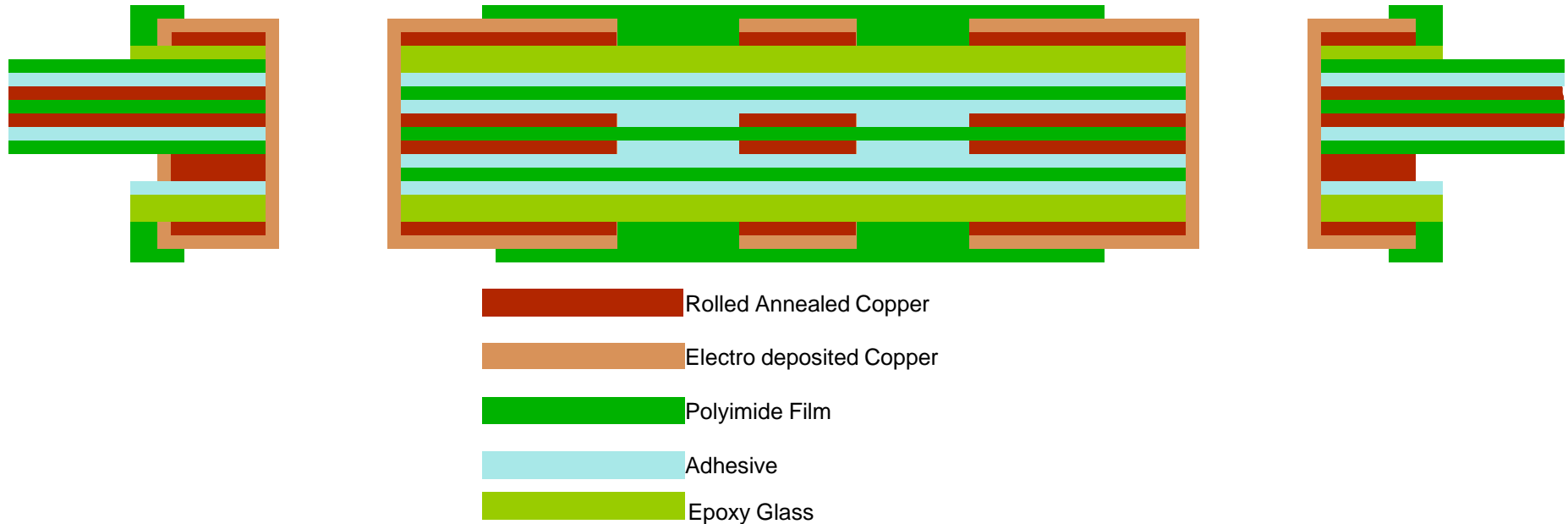


-  Rolled Annealed Copper
-  Electro deposited Copper
-  Polyimide Film
-  Adhesive
-  Epoxy Glass

- **Three or more conductive layers with selective rigidizing**
- **Maximum conductor routing per unit area**
- **Limited flexibility for installation**

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# Rigid-flex Flexible Circuit



- Three or more conductive layers, dual-sided SMT assembly
- Maximum conductor routing per unit area
- Limited flexibility for installation

**Most costly interconnect solution-but maybe the best**

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# Flexible Circuitry - Material Overview

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# Flexible Circuit Base Laminates



- Adhesive Based
  - Metal Foil Conductor
  - Adhesive
  - Dielectric Film (Insulator)
  
- Adhesiveless
  - Dielectric - Polyimide
  - Metal Conductor - Copper
    - Vacuum Deposition Plus Plating
    - Electroless / Electrolytic Plating
    - Polyimide Polymer Coated onto Copper Foil
    - Fusion Lamination of Polyimide to Copper

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# Adhesive Base Laminate



## Composition of Flexible Electrical Laminates

The diagram illustrates the composition of flexible electrical laminates as a stack of three layers. The top layer is a dark green rectangle labeled "Copper Foil (treated)". The middle layer is an orange rectangle with a wavy top edge, labeled "Adhesive". The bottom layer is a red rectangle labeled "Dielectric Film". The entire diagram is set against a dark blue background with a faint globe graphic in the lower right corner.

- Copper Foil (treated)
- Adhesive
- Dielectric Film

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# Flexible Circuitry Dielectric Substrates



Dielectric Material	Continuous Service Temp (°C)	Tear Resistance (psi)	Tensile Strength (percent)	Ultimate Elongation (percent)	Moisture Absorption (10 <sup>3</sup> Hz)	Dielectric Constant (volts/mil)	Dielectric Strength (10 <sup>3</sup> Hz)	Dissipation Factor
Polyimide	200-230	Fair	25,000	70	2.9	3.3	7,000	0.0025
Polyester	105	Fair	25,000	60-165	<0.8	3.2	7,000	0.005
PEN	155	Fair	30,000	60-75	<0.08	2.9	7,500	0.005

# Flexible Circuitry Adhesive Comparison

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<b>Type</b>	<b><u>Temperature Resistance</u></b>	<b><u>Chemical Resistance</u></b>	<b><u>Adhesion</u></b>	<b><u>Flexibility</u></b>
■ Polyester	Fair	Good	Excellent	Excellent
■ Modified Acrylic	Very Good	Good	Excellent	Good
■ Epoxy	Good	Fair	Excellent	Fair
■ Polyimide	Excellent	Very Good	Very Good*	Fair
■ Butyral Phenolic	Good	Good	Good	Excellent

# Adhesiveless vs. Conventional



<u>Property</u>	<u>Adhesiveless</u>	<u>Conventional</u>
Maximum Operating Temp	200°C	105 - 125°C
Flammability	VTM-O	Formulated
Chemical Resistance	Excellent	Variable
Peel Strength (lb./inch)	5-8	8-15
Copper Thickness (microns)	5-35	18, 35, 70
Adhesive Smear	None	Variable

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# Flexible Circuitry Dielectric Coatings



<u>Coating Method</u>	<u>Dynamic Flexing</u>	<u>Electrical Properties</u>	<u>Encapsulation</u>	<u>Cost</u>
Coverlayer Films	Excellent	Excellent	Good	Medium
Liquid Covercoats	Fair	Fair	Excellent	Low
Flexible Soldermask	Fair	Excellent	Good	High

# Flexible Circuitry Finishes



- **OSP - Organic Solder Preservative**
- **HASL - Hot-air Solder Leveled**
- **Tin/Lead Plate - Electrolytic**
- **Immersion Tin**
- **Immersion Silver**
- **Nickel/Gold Plate - Electrolytic (Hard or soft)**
- **Electroless Nickel / Immersion Gold**

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# Material Overview - Mechanical Properties

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# Flexibility Considerations?



- End Use
- Installation / Packaging
- Processing

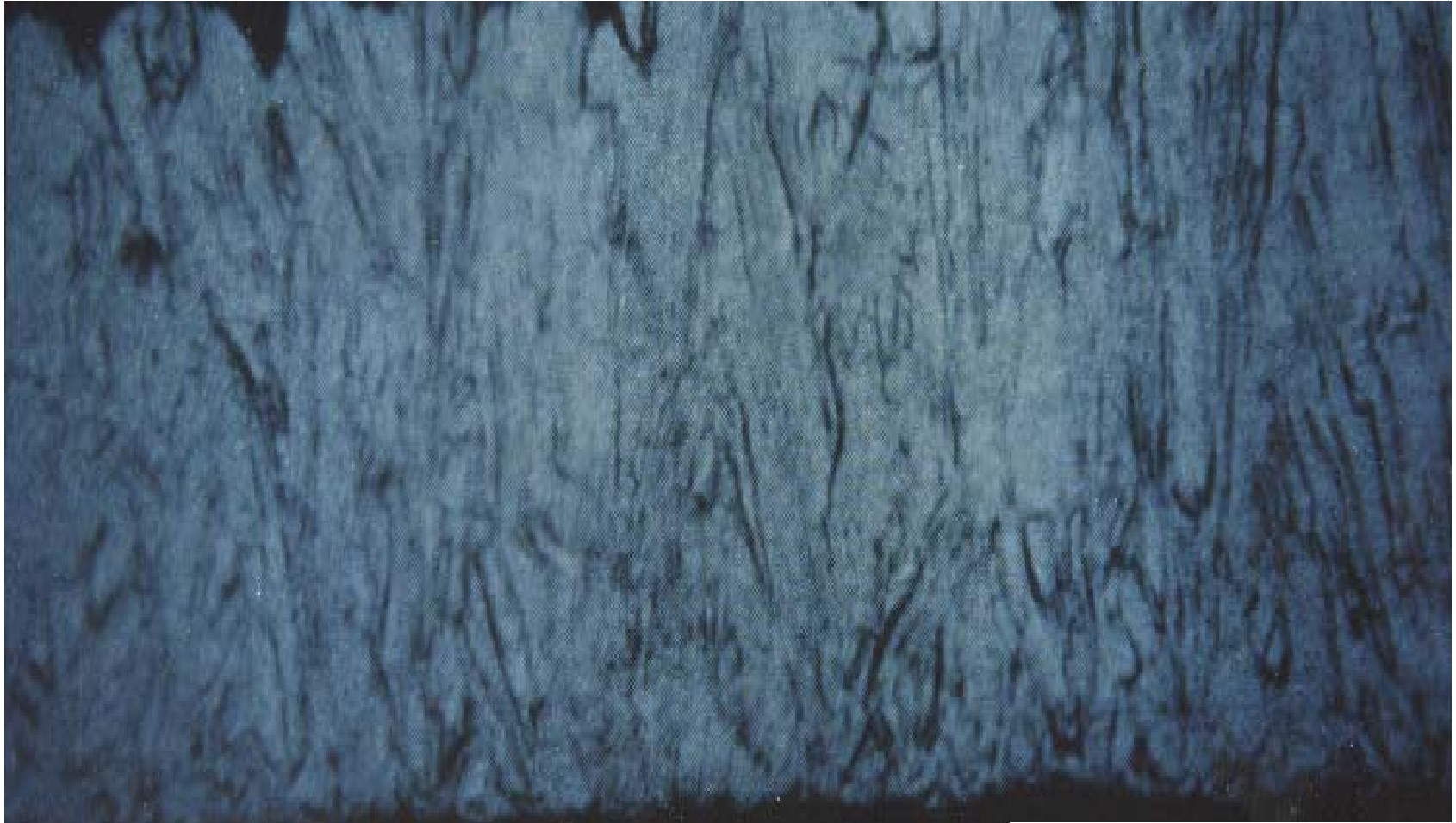
# Base Laminate Copper Foils



- **Electro-deposited**
- **Electro-deposited High Ductility**
- **HTE (High Temperature Elongation)**
- **Rolled Annealed**

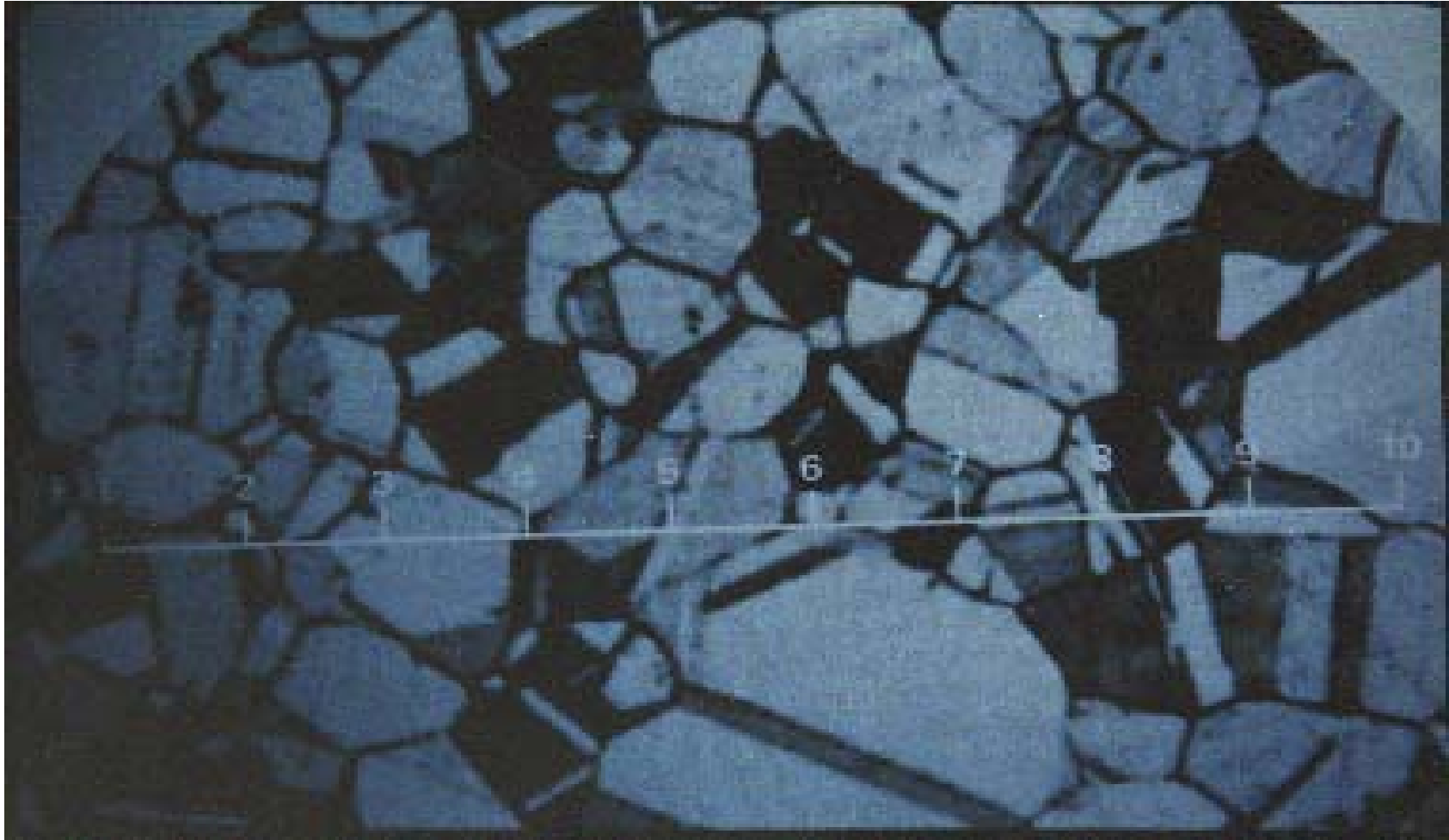
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# High Ductility Electro-deposited Copper (X-section view)



# Rolled, Annealed Copper (Surface view)

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# Copper Foil Properties (for 1 oz. Copper)



Property	Electro-deposited Copper	
	Rolled, Annealed Copper	(High Ductility)
Purity	99.8%	99.9%
Resistivity (at 200C) Ωg/m <sup>2</sup>	0.16Ωg/m <sup>2</sup>	0.152
Break Elongation	10%	25%
Fatigue Ductility	10.25%	150%
Surface Quality RMS max.	20 μm in RMS max.	20 μm in
Standard Weights oz/sq ft	1/8 -20 oz/sq. ft	1/2 - 5
Maximum width	80 in.	25.5 in.

# Flexibility - Bend Radius Calculation

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**Copper Elongation**  
Values for 1 oz Copper

	ED	RA
Dynamic Flex	< .3%	< 1.0%
Flex to Install	< 10%	< 20%
1 Time Bend	< 16%	< 25%

$$E\% = T / (T + 2 \times (B + R))$$

Other considerations for conductor failure are Operating environment, Laminate type, Conductor lay out and Handling.

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# Flexible Circuitry - Design Concepts



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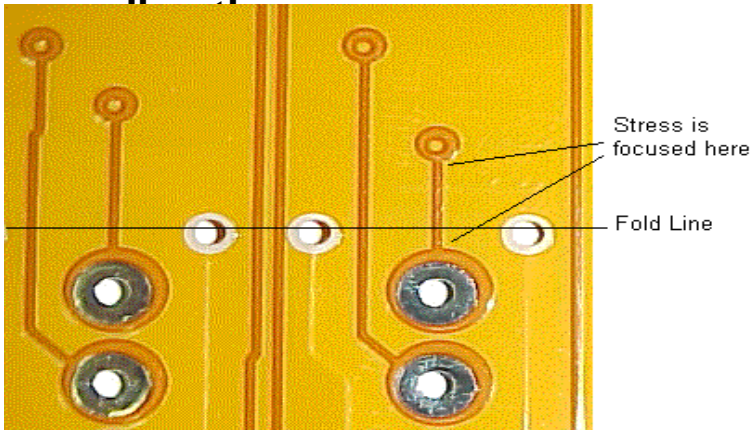
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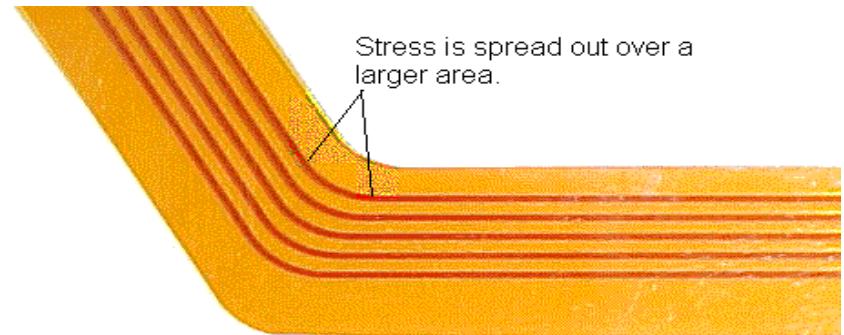
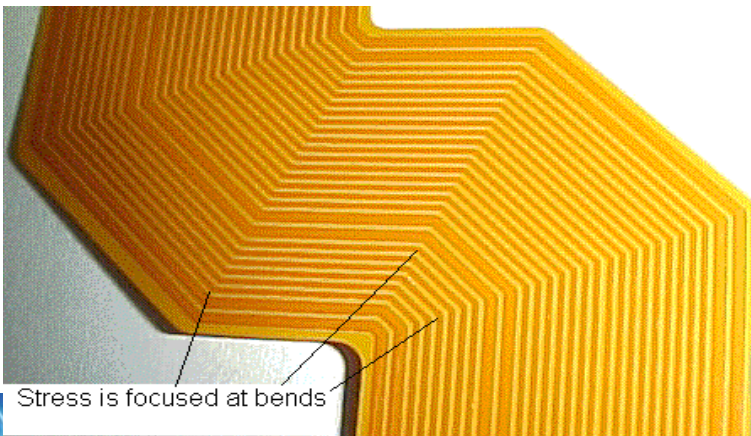
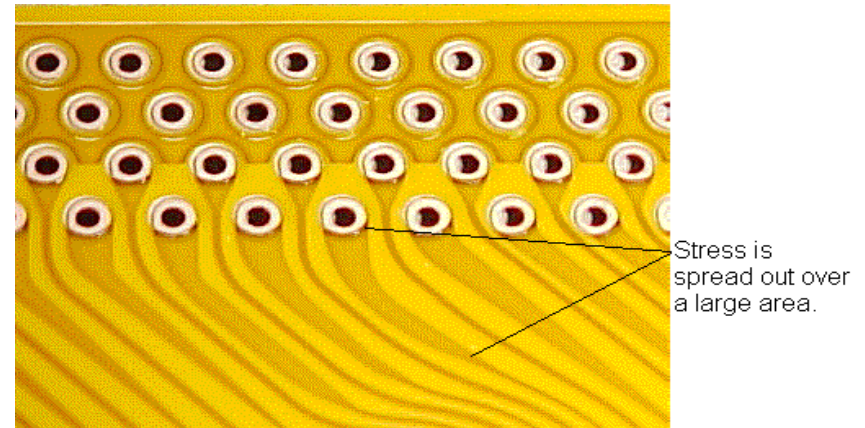
# Avoid Abrupt Conductor Changes



- Stress is focused on abrupt changes in conductor size and



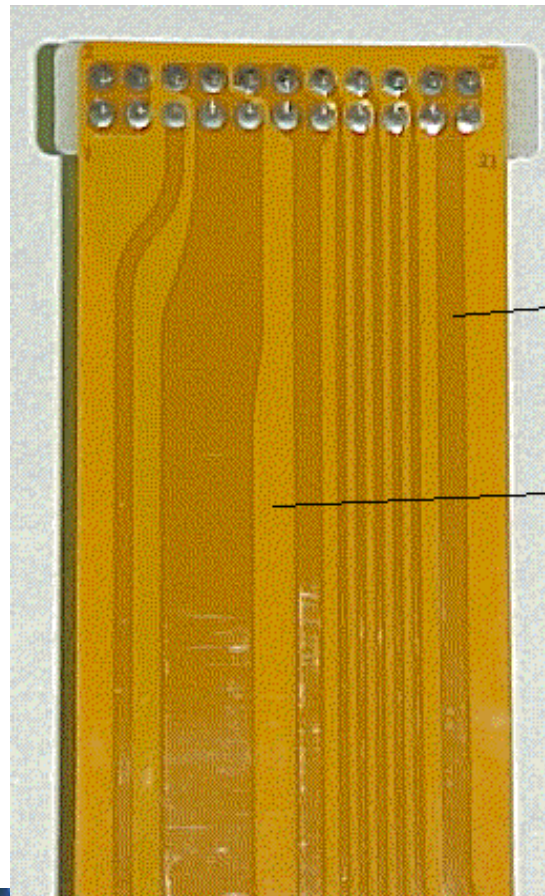
- Radiused Conductors and filleted pads Spread stress out and reduce breakage.



# Uniformly Route Conductors



## ■ A Non Uniform Layout Reduces Flex Life.

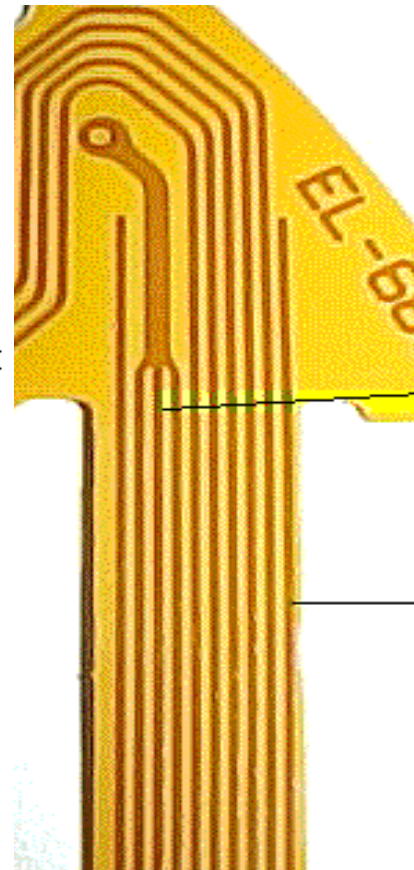


Nonuniform conductor layout focuses stress unevenly across the bend areas and promote conductor breakage.

Larger conductors tend to offset stress onto the smaller conductors next to them.

Gaps in the conductor layout focus stress on the conductors next to the gaps.

## ■ A Uniform Layout Is Important In Improving Flex Life.



A uniform conductor layout Spreads stress out evenly over a flex area.

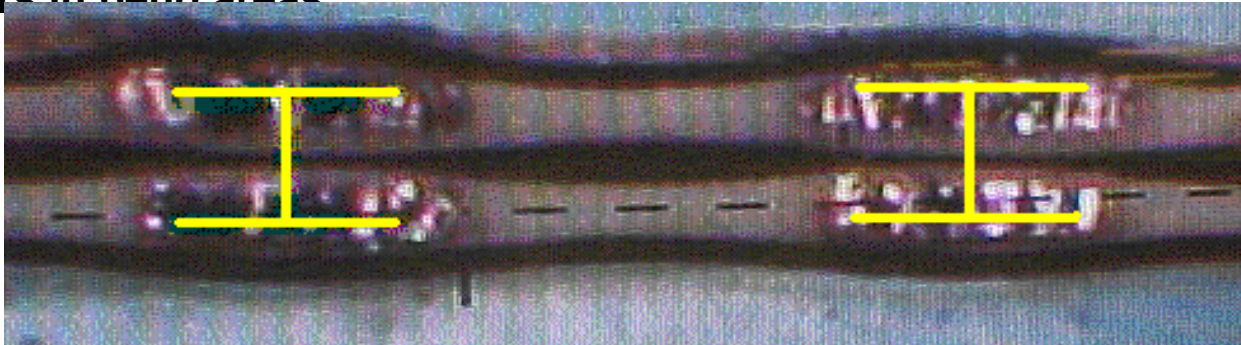
Large conductors may be split for uniform layout.

Gaurd conductors may be added to protect signal lines on the edge of the circuit.

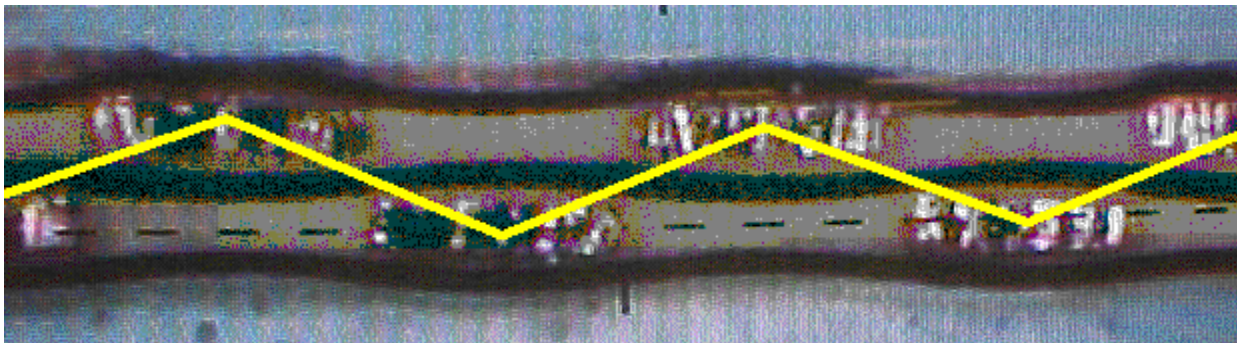
# Design to Ensure the Copper in Neutral Axis



- **Conductor Stacking (I beaming), resist Z axis bending and create stress on conductors in bend areas**



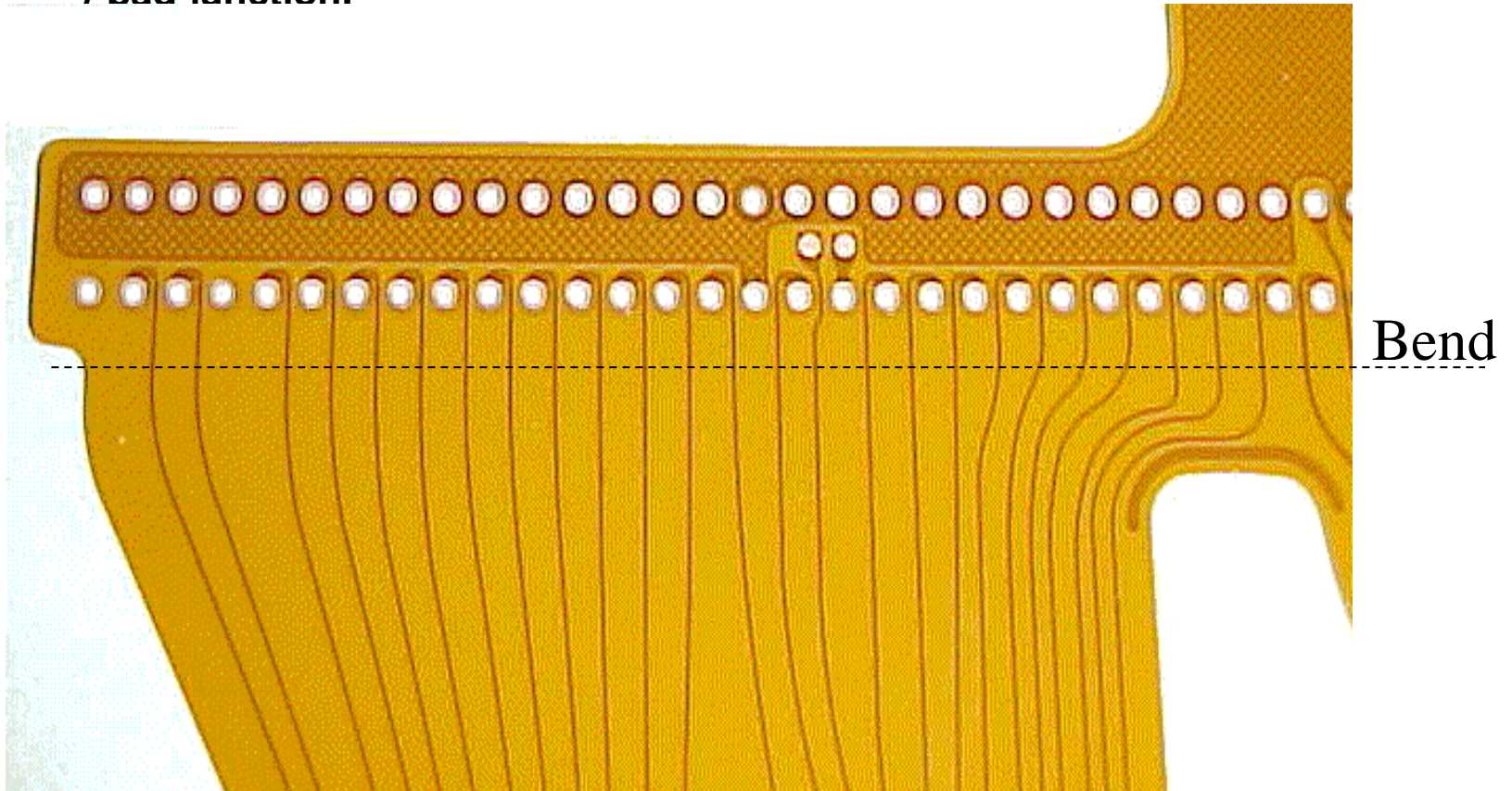
- **Alternating conductor layout allows conductors freer movement.**



# Add Slack to Conductors in Bend Areas



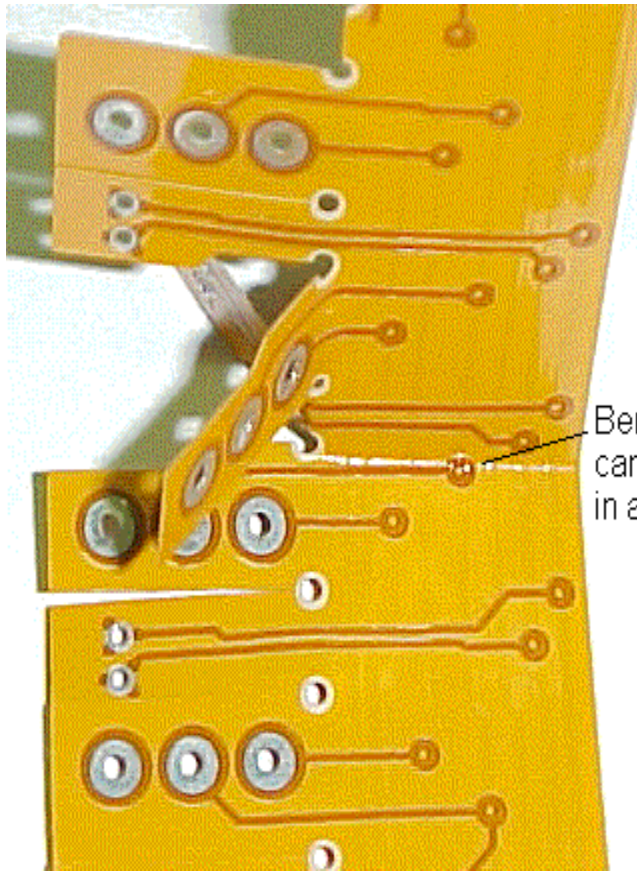
- When pads are close to bend areas, adding slack to the conductors can prevent conductor breakage by removing the stress from the conductor / pad junction.



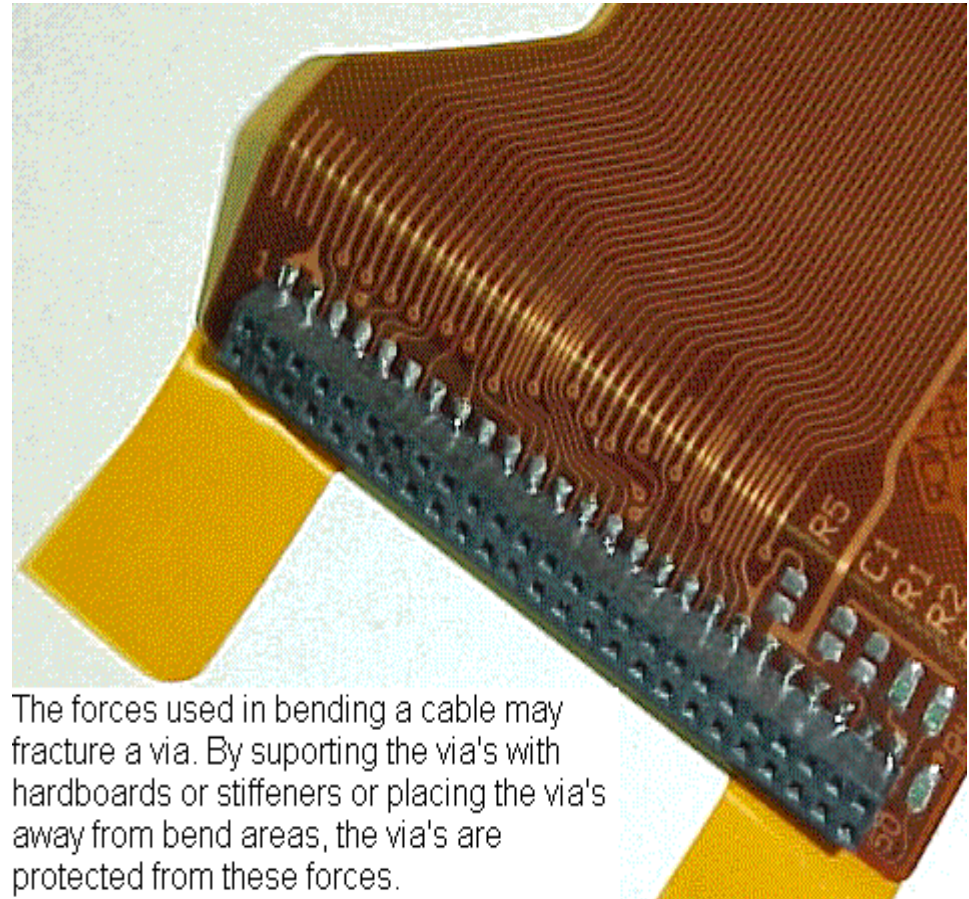
# Avoid Via's in Bend Areas



- **Protect via's from bending forces.**



Bending forces can fracture via's in a bend area.

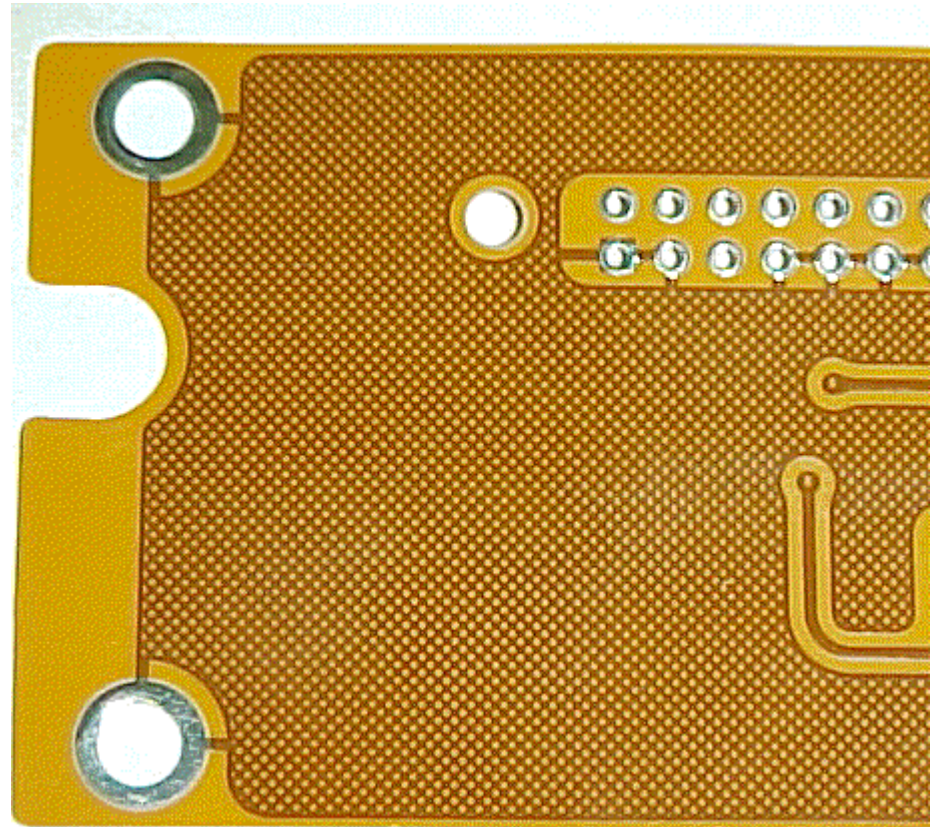
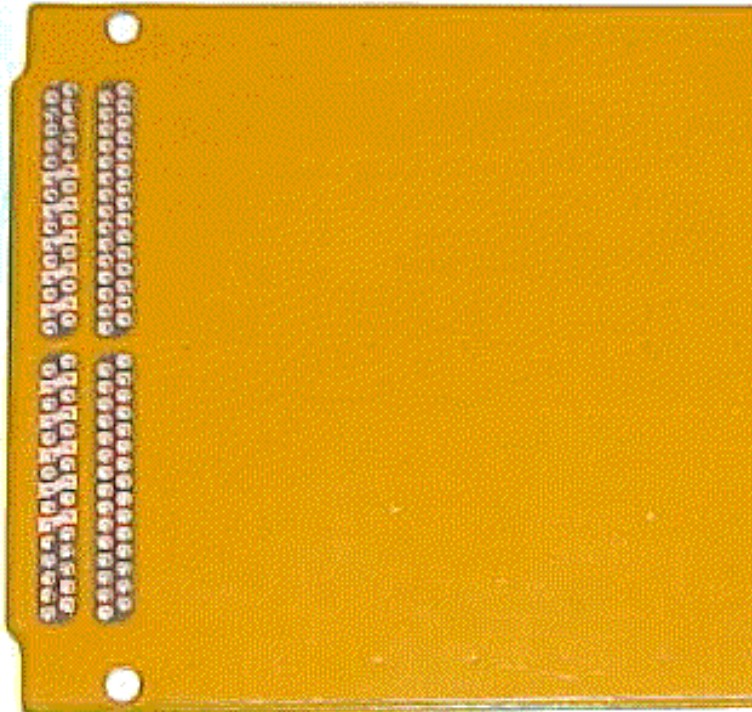


The forces used in bending a cable may fracture a via. By supporting the via's with hardboards or stiffeners or placing the via's away from bend areas, the via's are protected from these forces.

# Utilize Cross-Hatched Shields



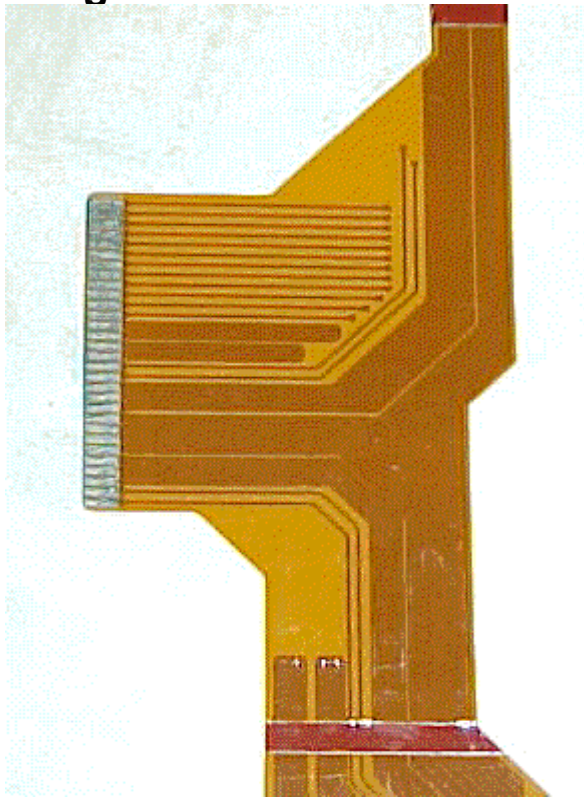
- Use Cross Hatched Shields when signal frequency permits to assist in circuits flexibility.



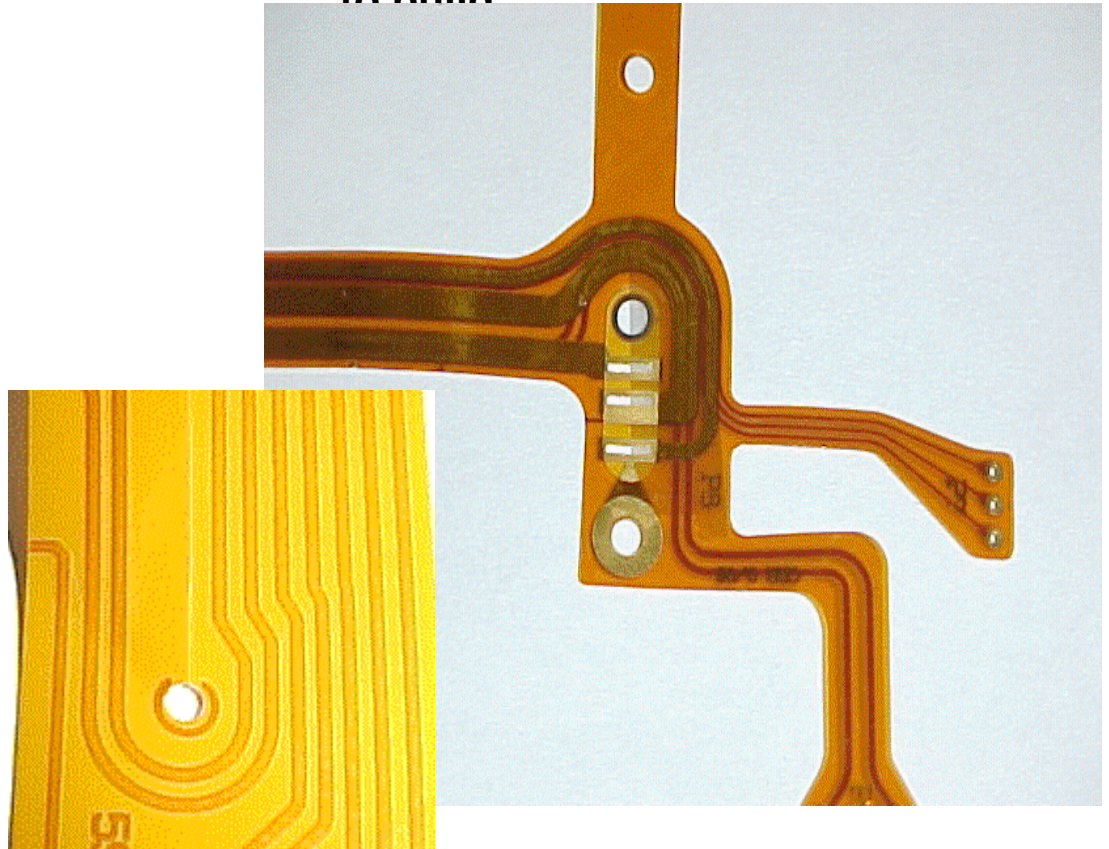
# Radius Cut-lines



- Flex circuit materials resist tearing very well but they do not resist tear migration well.



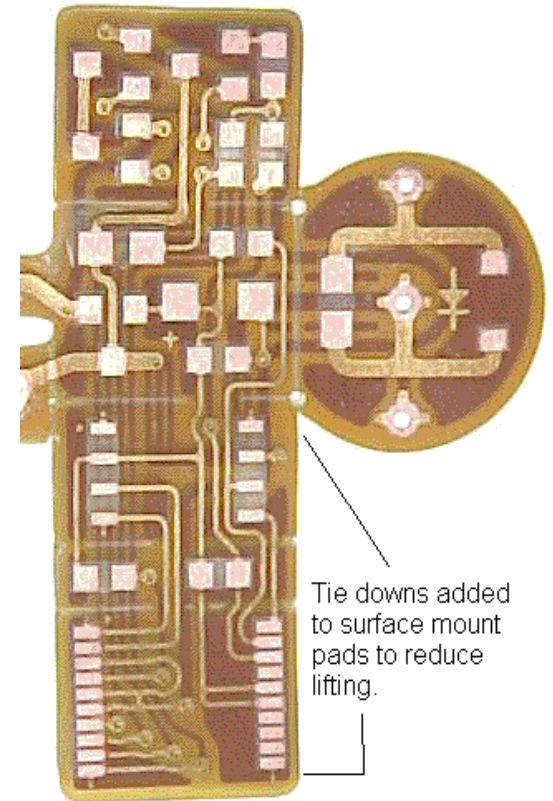
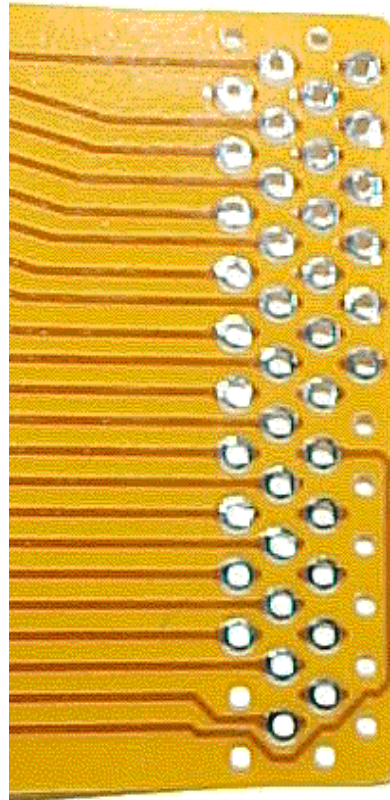
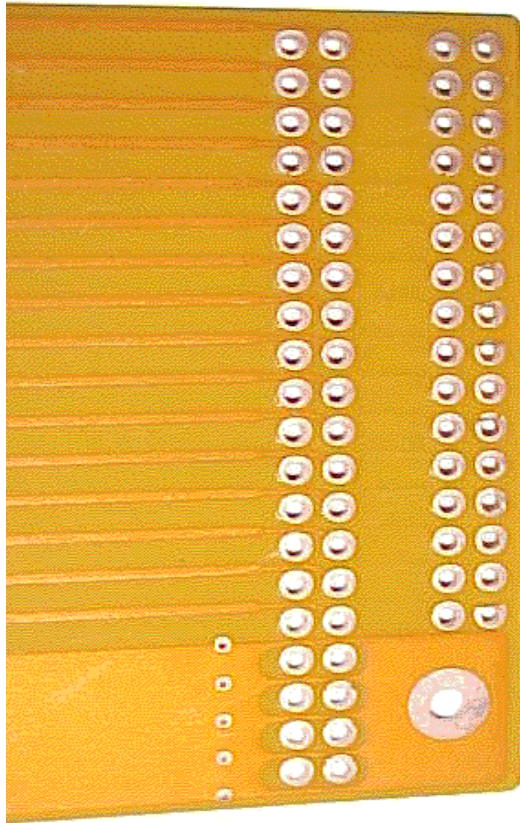
- Radiused Corners resist tearing and their tools are less expensive to build



# Pad Tie Downs



- **Pad Tie Downs add surface area to a pad and increase its peel strength reducing lifted pads.**



Tie downs added to surface mount pads to reduce lifting.

# Flexible Circuitry Layout Guidelines

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- Avoid abrupt changes in conductor size and direction.
- Rout conductors uniformly and perpendicular to fold lines.
- Keep copper in the neutral axis at bend areas. Avoid I beams.
- Add slack to conductors running between pads near bend areas.
- Avoid placing via's near bend areas.
- Crosshatch Shields whenever signal frequency permits.
- Radius all cut-lines
- Add pad tie down when ever space permits.
- Ridgidize component areas.
- Avoid specifying conductor widths  $< 3$  times conductors thickness.
- Use 3D modeling when laying out your flex.
- Get your vendor involved as early in the design process as possible.

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# What is Impedance?

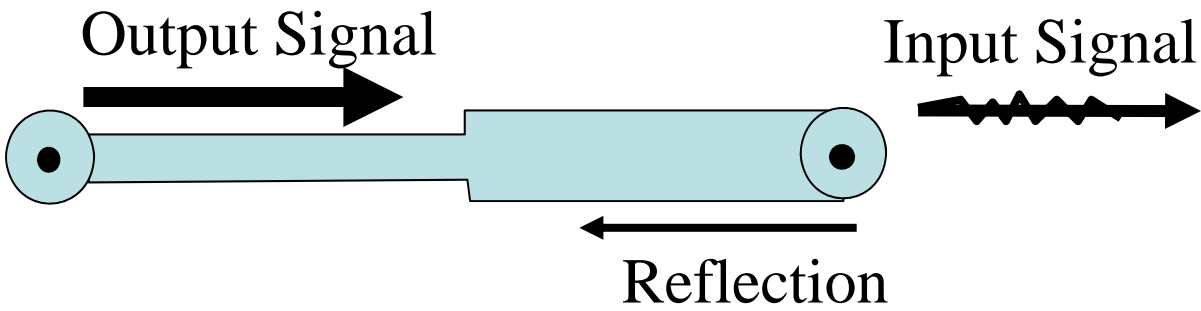


- Impedance is the combination of Resistance, Capacitance and Inductance creating an Electric and magnetic field defined in Ohms.
  
- It is called Characteristic Impedance because it depends solely on the characteristics of the materials used and spatial relationship.
  
- Impedance is a function of:
  - Dielectric constant of the medium.  
(How well magnetic waves travel in a medium)
  - Size of the signal path.  
(Height & width of conductor)
  
- $Z_0 = \text{Square root } (L/C)$

# Why is Impedance Important?



- Today's high speed digital devices demand minimum signal losses and distortion between the output of one device to the input of other devices. By matching the Characteristic impedance of an interconnect with the impedance of the loss at the output device, the interconnects appear transparent. Electrically there will be no power reflection. Power reflections are signals reflected back to the transmitter end. These reflections reduce the signal strength and induce noise into the signal.



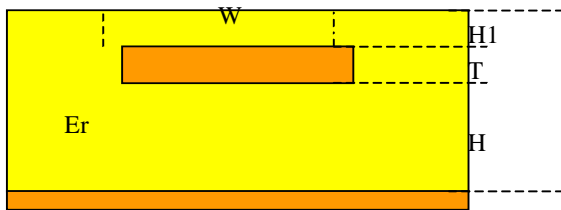
# CC&E - IPC Impedance Formulas



## ■ Embedded Microstrip

$$Z_o = \frac{76}{\sqrt{Er'}} * \ln \left( \frac{5.98H}{0.8W + T} \right) \text{ Ohms}$$

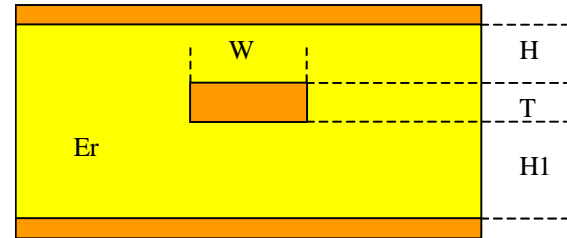
$$Er' = Er(1 - e^{-155 H1 / H})$$



IPC-D-317A 5.34 & 5.35

## ■ Stripline

$$Z_o = \frac{80}{\sqrt{Er}} \ln \left( \frac{1.9(2H + T)}{.8W + T} \right) \left( 1 - \frac{H}{4 \times H1} \right) \text{ Ohms}$$



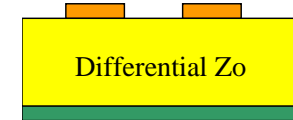
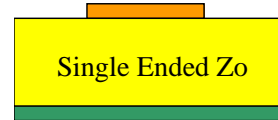
IPC-D-317 5.38a

Characteristics Effecting Impedance		
Description		Increased (Zo) Impedance
W	Conductor Width	↓
H	Dielectric Thickness	↑
ER	Dielectric Constant	↓
S	Shield Coverage	↓
T	Conductor Thickness	↓
H1	Coverlay Dielectric Thickness	↓

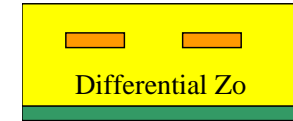
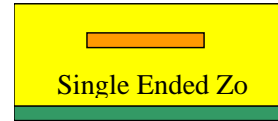
# Impedance Configurations



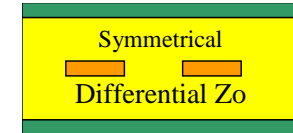
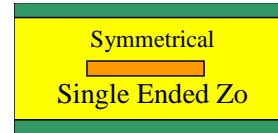
## ■ Surface Microstrip:



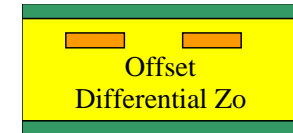
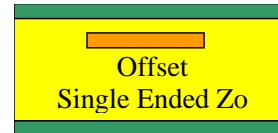
## ■ Embedded Microstrip:



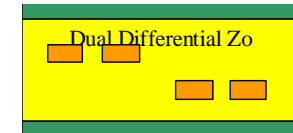
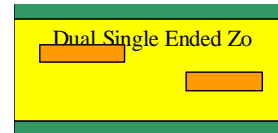
## ■ Symmetrical Stripline:



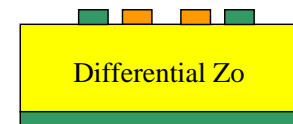
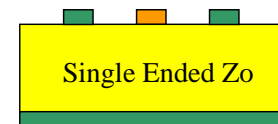
## ■ Offset stripline:



## ■ Dual stripline:

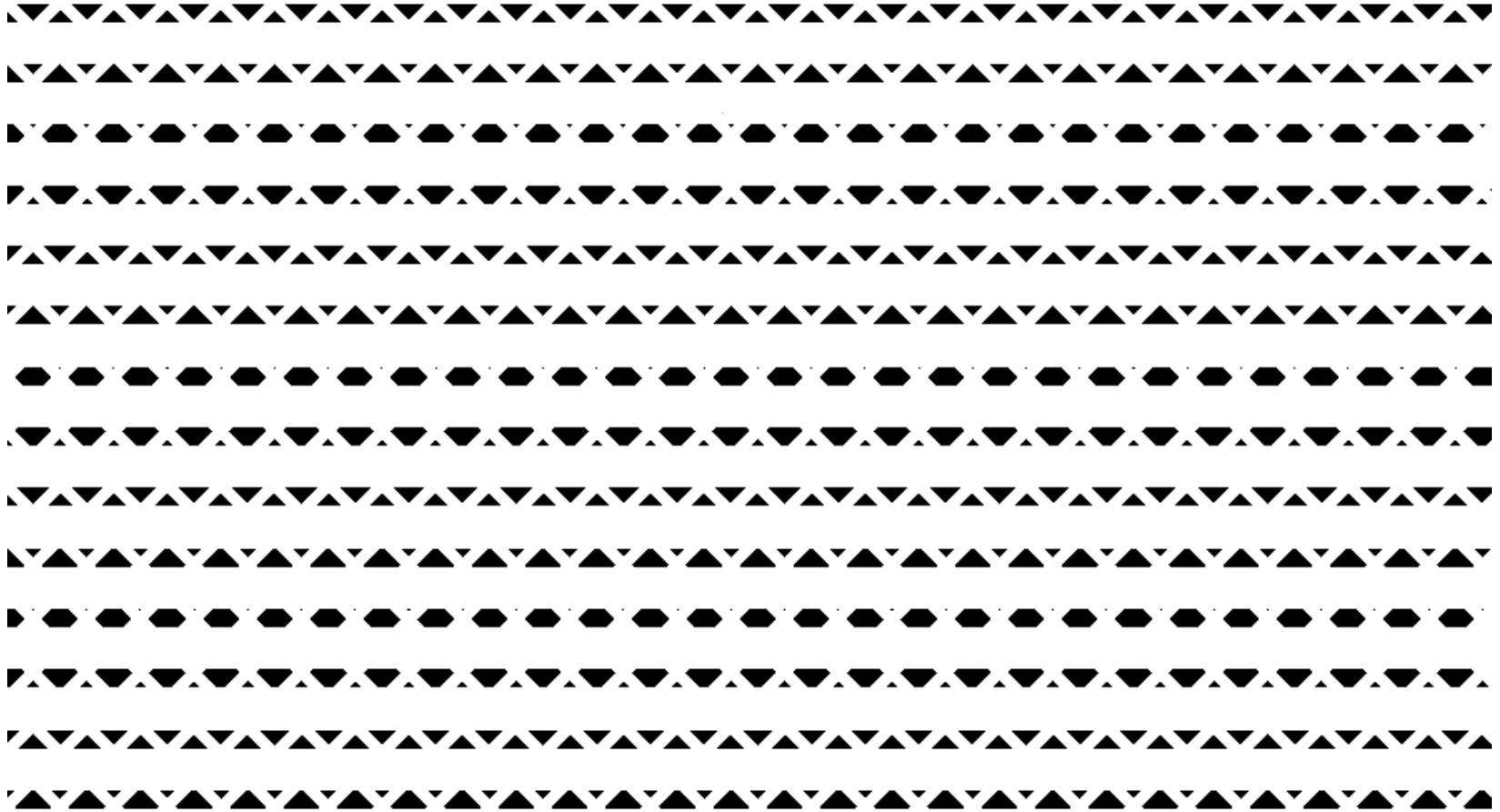


## ■ Coplanar:

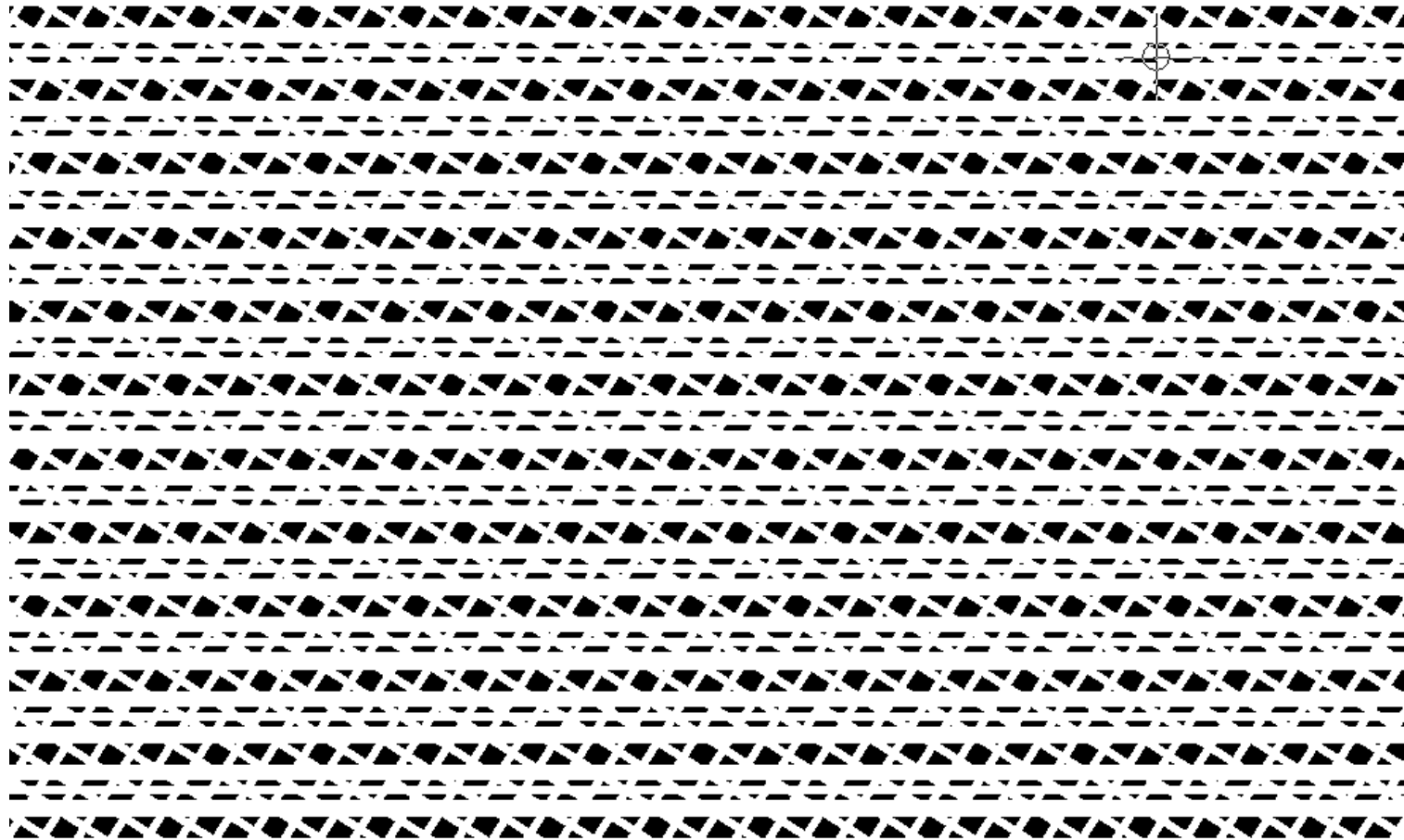


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# 45 Degree X-Hatch Angle



# 57.5 Degree X-hatch Angle



## Involve Flex Vendor Early



### *Final thought...*

Flex designs are typically left until the very end of the design process when less design options are possible, leading to higher costs and more stringent/complex designs.

- Your Flex Vendor can assist you in tackling your difficult design problems while reducing costs. Don't hesitate to involve your flex vendor in your designs as soon as possible.
- Let us get grey hair so you don't have to.....

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# QUESTIONS?



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**Thank You for your Time**