Association Connecting Electronics Industries

Impedance in a Flex Application: What Happens to the Signal?

Robert Sheldon,
Applications Engineering Manager
Pioneer Circuits, Inc.

About the Author

Robert Sheldon,
Applications Engineering Manager
Pioneer Circuits, Inc.

Bob Sheldon, a graduate of the University of South Florida, has over thirty years experience in flexible printed wiring and rigid-flex product development. He has held management positions in Engineering and Quality and supported both fabrication and design activities. Bob is an active participant in IPC Standards Development and has presented a variety of seminars on flexible printed wiring design and best practices. He is Director of Operations and Technology at Pioneer Circuits, Incorporated.

Pioneer Circuits, Inc.

Association Connecting Electronics Industries

IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

Revision 6/7/2010

Designing for --

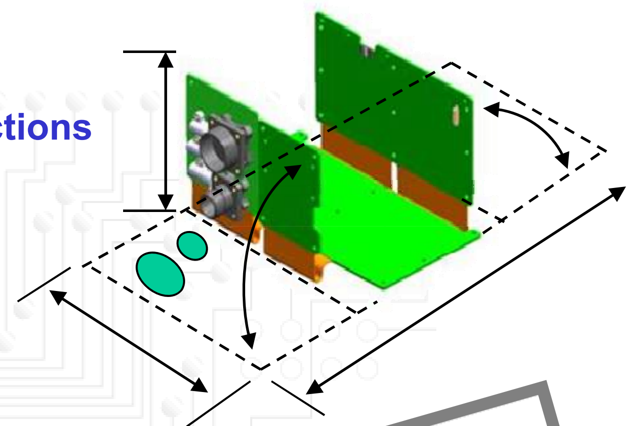
Controlled Impedance Rigid Flex

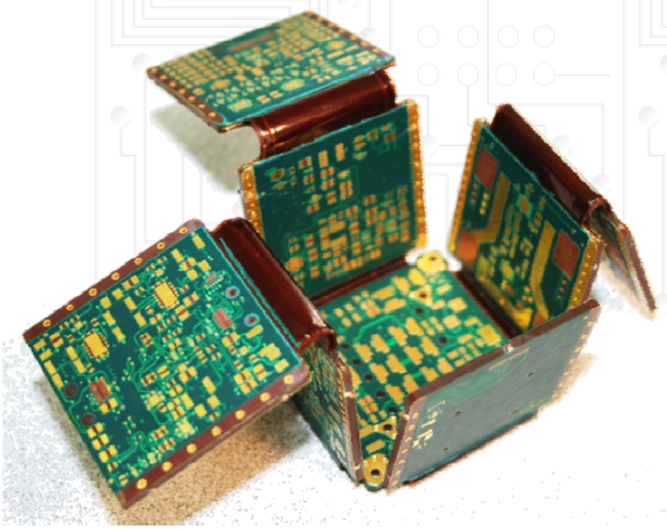
Signal Analysis / Simulation provided by DuPont

Why Rigid –Flex?

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

- "3D" – Electronic Packaging
- Weight Saving
- Eliminate connectors for rigid to rigid area routing
- Signal Integrity
    - Device to Device Controlled Impedance - even across Flex Sections
- Effective Use of Board Real Estate
- Consistent Assembly (vs round wire)
- Reliability – Fewer Solder Joints / Interconnects
- When Evaluating Cost Must Review Best Total Value
    - (Total Cost Of Ownership)
- Part (Panel) Size Capability

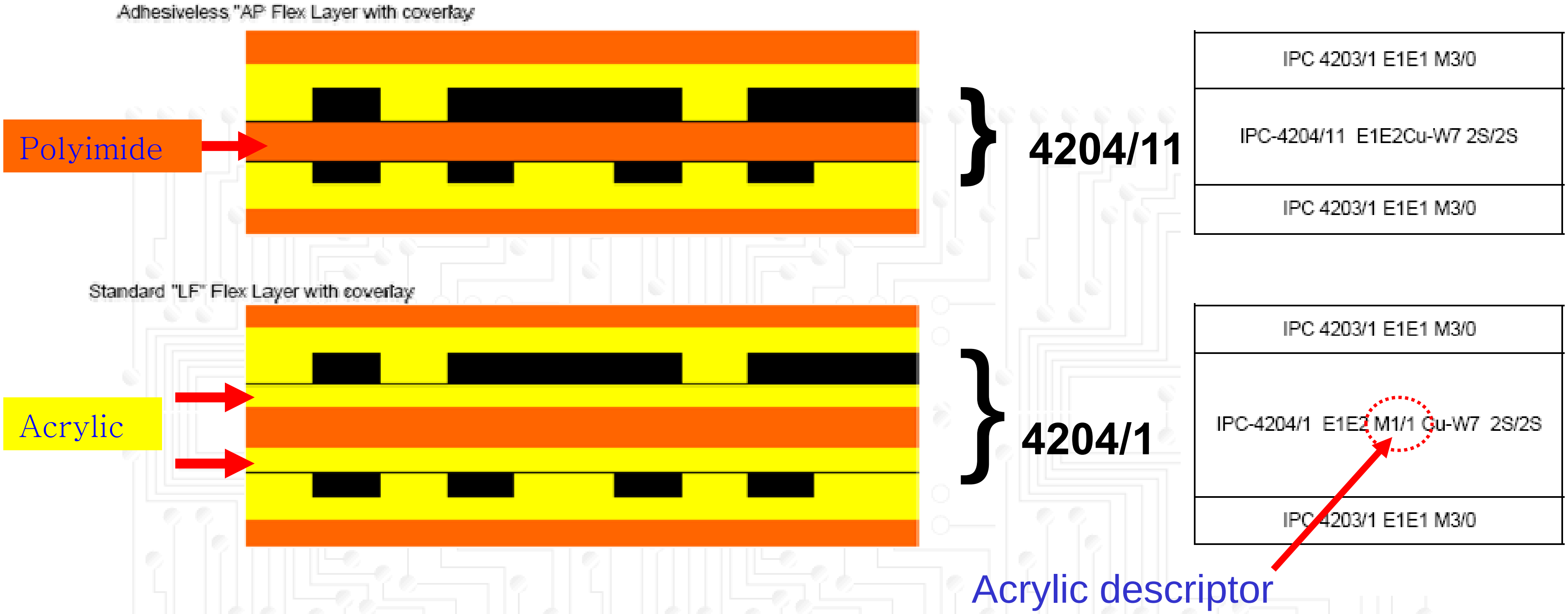




Designing for Rigid-Flex?
- IPC-2223

Flexible Clad Substrates

Adhesiveless vs Standard Flex:



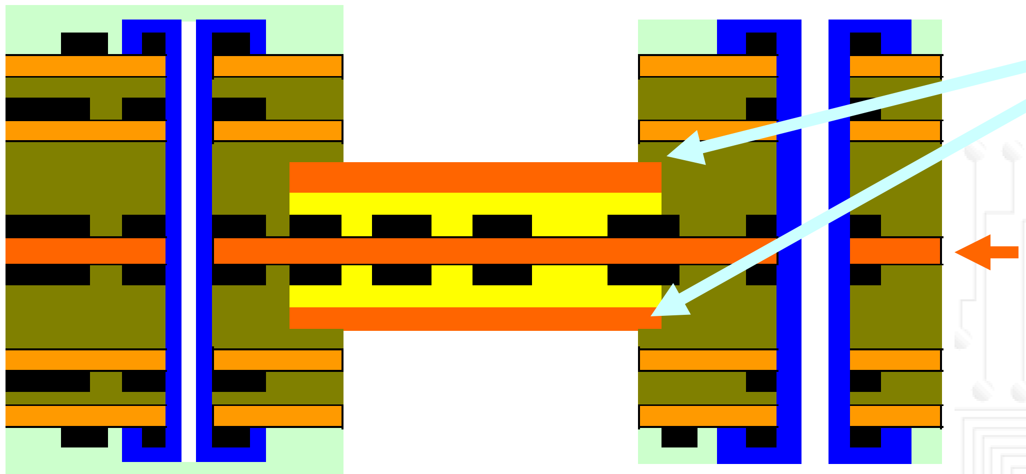
"ADHESIVELESS" simply means acrylic layers are ***not*** used to bond to the copper onto the polyimide core dielectric. On adhesiveless constructions, the copper is bonded directly to the polyimide film substrate. AP is DuPont's product code for their adhesiveless polyimide (IPC-4204/11) clad substrates. LF is DuPont's product code for their standard – acrylic / Kapton® (IPC-4204/1) clad substrates.

Flexible Clad Substrates

Adhesiveless vs Standard Flex:

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

No acrylic is present in plated holes



IPC 4203/1
Coverlay slightly "tucked" into rigid area

IPC 4204/11
Adhesive-less Flex Layer

In adhesiveless rigid-flex (Type 4) constructions, the flexible coverlay outer insulation (which uses a Kapton® polyimide / acrylic dielectric layer) is present ONLY in the flex region and is slightly tucked into the rigid section. No plated through holes should be present in the area where the coverlay patch slightly extends in the rigid section – about .125 inside the flex / rigid transition edge. Acrylic has a very high CTE, coefficient of thermal expansion, - (400 ppm/deg c) versus other pwb / adhesiveless materials (30- 40 ppm / deg C). The high CTE can translate to a very high z—axis expansion well as PTH reliability concerns. Also the high CTE of acrylic (vs rigid material) results in internal stresses that may create internal delamination.

"Why is acrylic BAD in rigid sections?"

Acrylic is a great adhesive for flexible applications with desirable properties such as-

- **High Peel strength**
- **Low modulus / good flexibility**
- **Excellent chemical resistance to acids, oils**

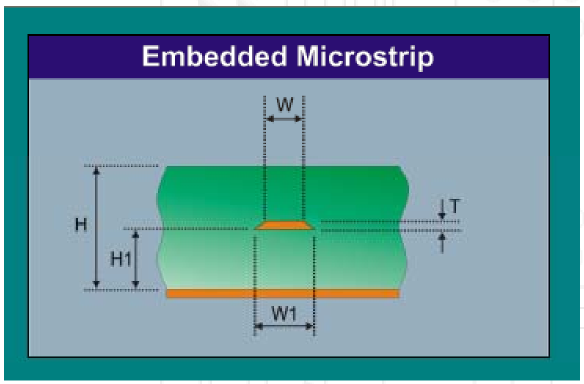
Acrylic is a poor adhesive for rigid applications with undesirable properties such as-

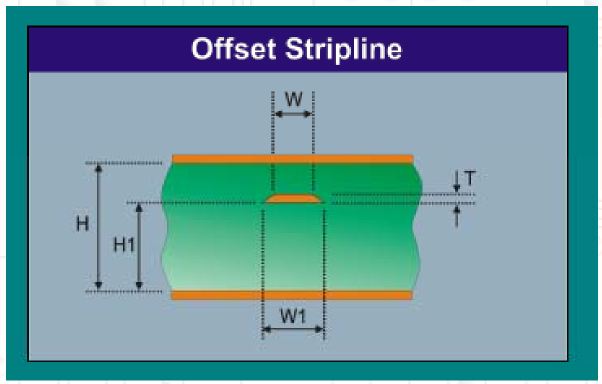
- **High CTE X-Y (400 ppm/deg C) vs polyimide glass (18 ppm/deg C)**
  --- Can result in laminate voiding and small area of delamination due to CTE mismatch between flex & rigid materials
- **High CTE Z (400ppm/deg C) vs polyimide glass (30 ppm/deg C)**
  --- Can result in premature pth failures to work hardening of copper in multiple thermal excursions
- **Low Tg - 105 deg F – but it behaves more like a thermal adhesive vs. thermoset (Classical thermoset definitions do not apply)**

Controlled Impedance Rigid Flex

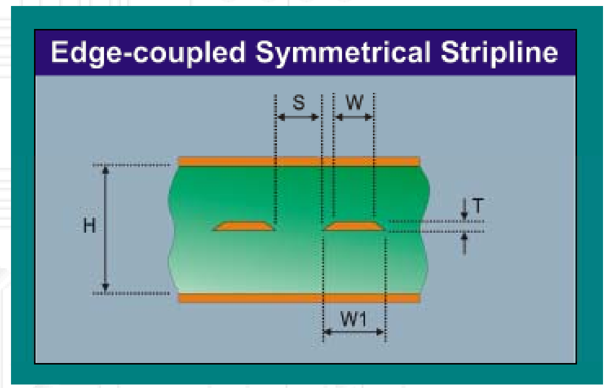
Any Controlled Impedance Model used in rigid PWBs can be accommodated in Rigid Flex Designs:

Single-ended examples:

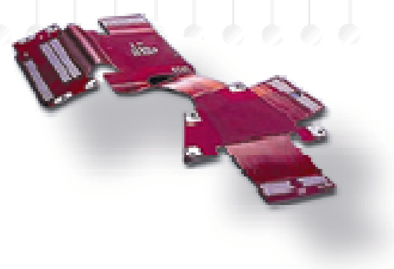




Differential example

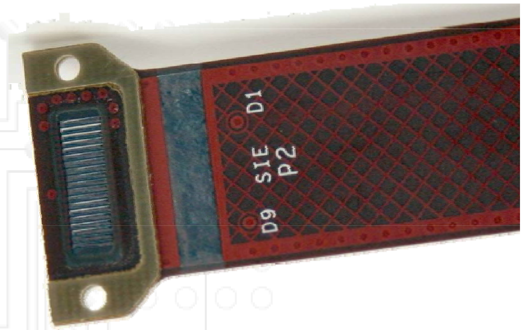


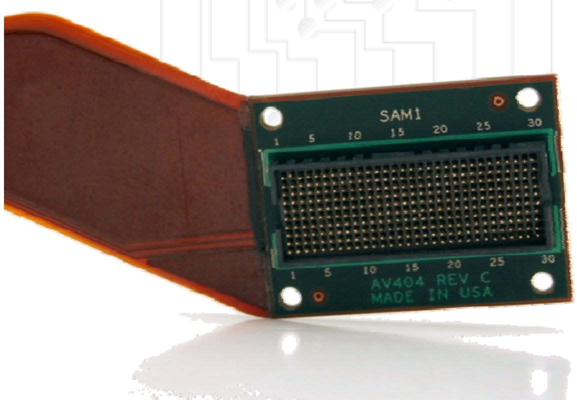
Polar ® Software Graphics

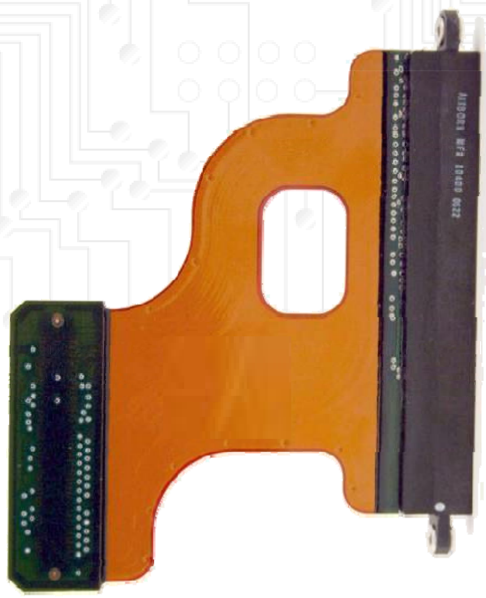


Reference / EMI Planes – Conductive Materials

- **Full Copper**
- **Copper Cross-Hatch (Mesh)**
- **Full Copper – Stitched Vias (Button Plate)**
- **Silver Epoxy**
- **Silver Epoxy – 360 Degree**
- **Sputtered (Thin) Conductive Finishes (Ni Au)**
- **EMI Shielding Films**

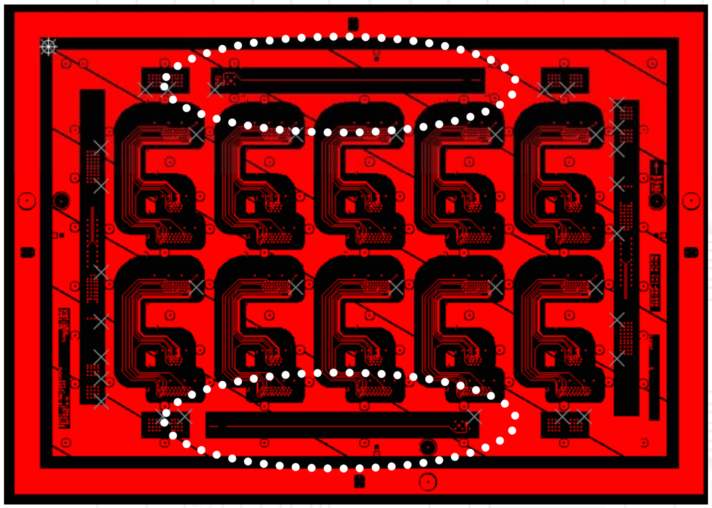


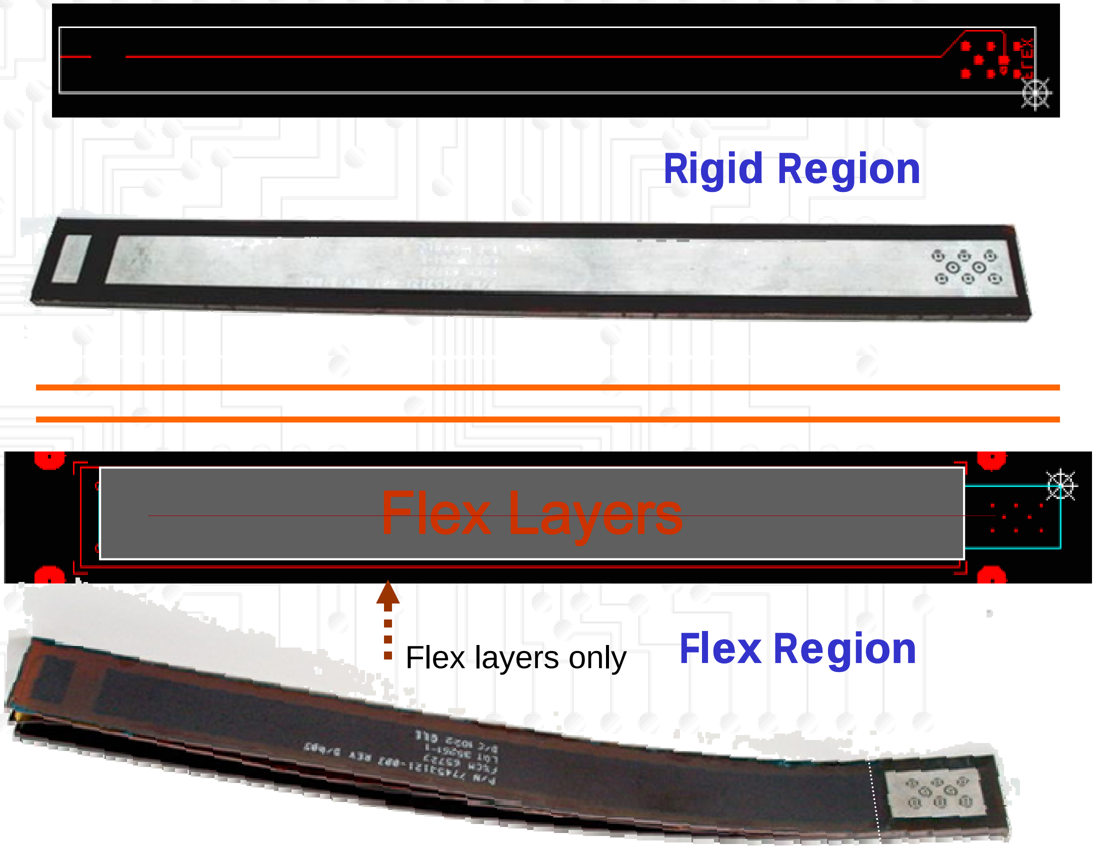




Controlled Impedance Rigid Flex

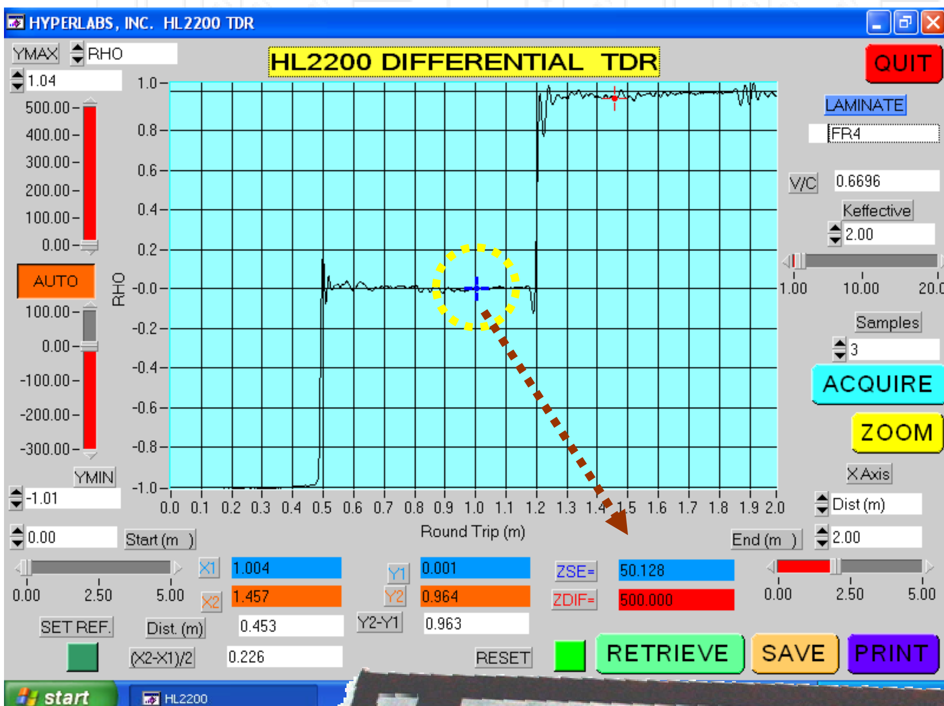
During CAM Panelization separate TDR coupons are created to Characterize the flex AND rigid sections.





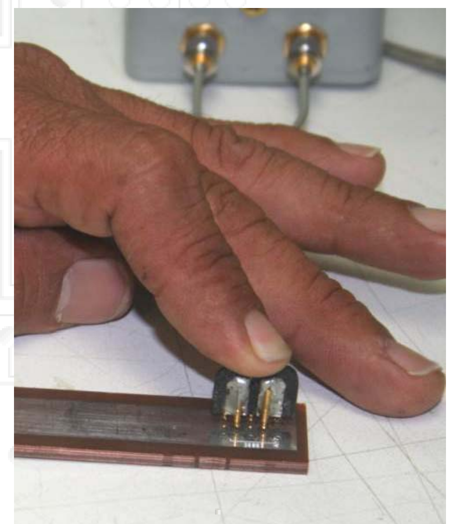
Controlled Impedance Rigid Flex

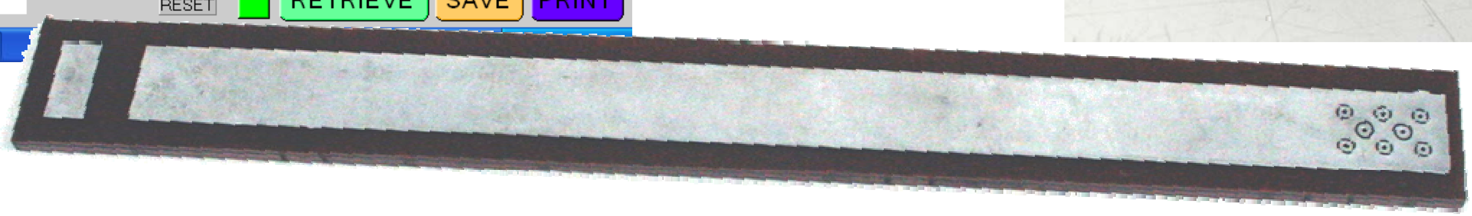
Controlled Impedance Coupons are Tested on a Time Domain Reflectomoter (TDR)



HL2200 Test Head

HYPERLABS, Inc. Ultrafast Sampler/TDR Instruments





Controlled Impedance Rigid Flex

Dielectric Constants (Dk) are *different* for rigid and flexible materials.

During Material Selection and “Stack-up” Determination, The controlled impedance criteria is evaluated using Transmission Line Field solver / modeling software.

Dielectrics Values (i.e. Material Thickness) and line widths are determined for both the Rigid and Flexible sections.

Controlled Impedance Rigid Flex

Dielectric Constants for Various Dielectric Materials
(Values Empirically Derived from Impedance Testing)

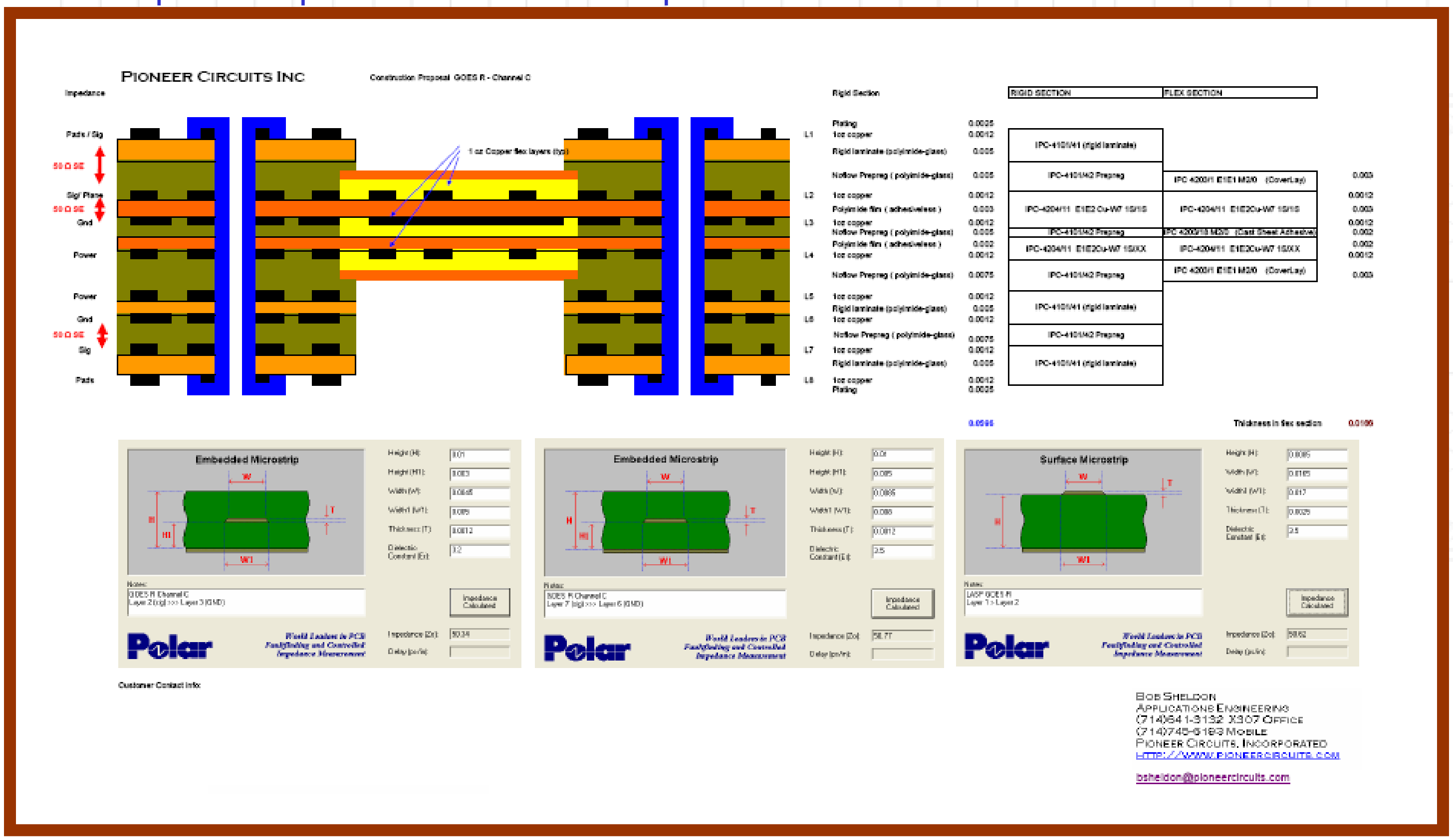
Dk

Polyimide-Glass IPC-4101/41 & 42 [Arlon 85N & Hitachi 671N no-flow] 3.5
FR Epoxy Glass IPC-4101/24 and /26 [Arlon 45N]....................................... 4.0
Adhesiveless Flex (Dupont AP]... 3.0
Standard Flex (Dupont LF Kapton® / Acrylic).. 3.2
FR Epoxy Thermount [Arlon 45NT]... 4.0
Polyimide Thermount [Arlon 85-NT]:.. 3.8

Pay attention to where REFERENCE Planes are located in the data and modeling. The Dk values may need to be approximated based on mixed dielectrics, especially if the reference planes are not on adjacent layers: If the signal layer is on a adhesiveless layer, but reference planes are "some" distance away through GF laminate for instance, it may be more appropriate to use a higher Er of 3.8 or even 4.0.

Controlled Impedance Rigid Flex

Stack-Up and Impedance Model - Sample



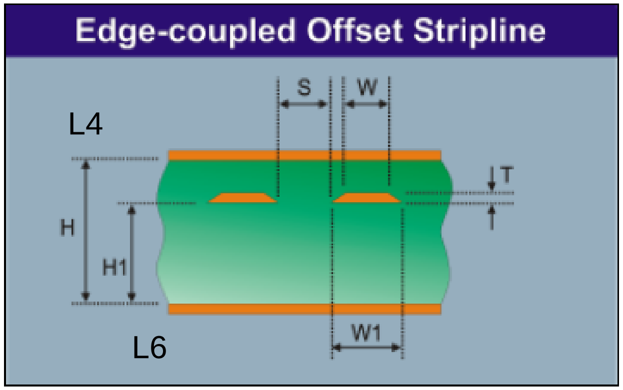
Layer stack-up and Material Specifications

Impedance Models

Controlled Impedance Rigid Flex

Differential Impedance Model - Sample

Polar Si6000 - Controlled Impedance Quick Solver August 04, 2006



Height	H	0.015
Height1	H1	0.006
Width	W	0.0045
Width1	W1	0.005
Separation	S	0.01
Thickness	T	0.0014
Dielectric	Er	3.1

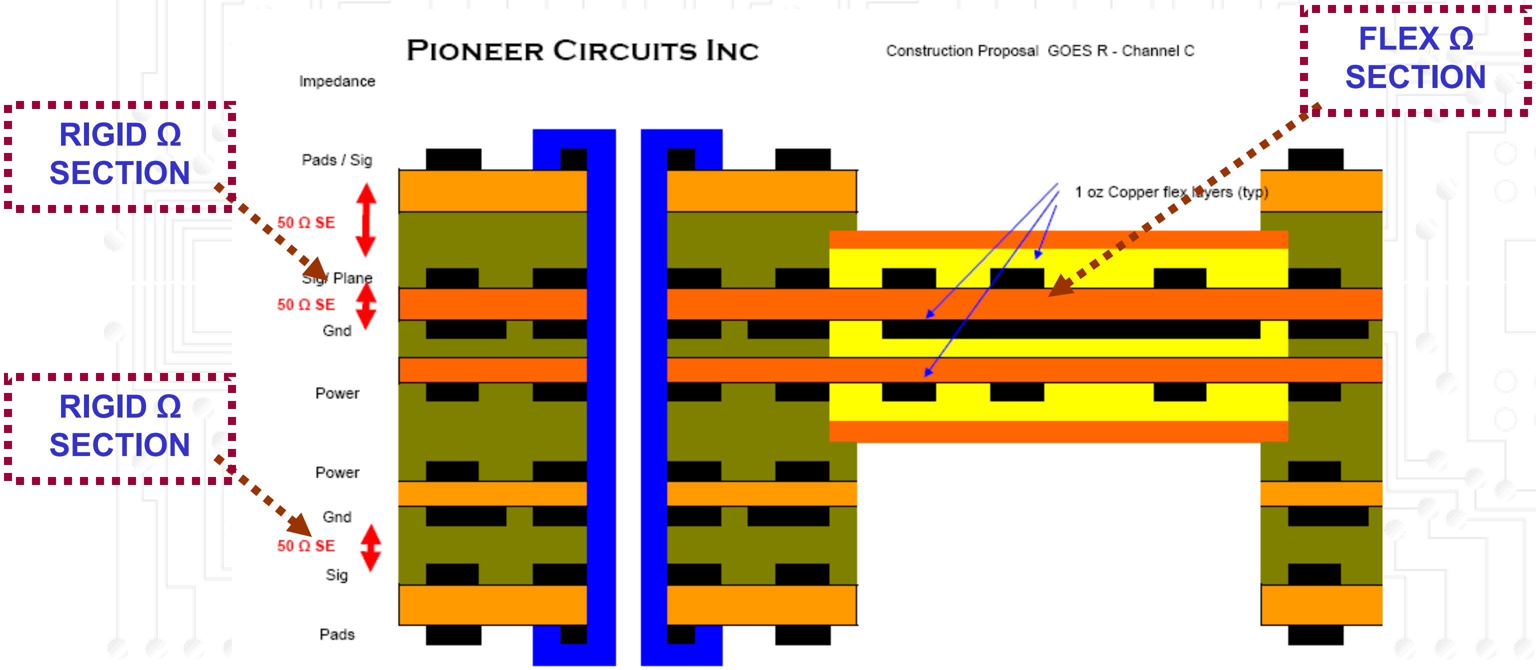
Diff. Impedance	Zo	109.01
Delay (ps/in)	D	149.174
Odd Mode	Zodd	54.5

Notes
Flex Section - 110 ohm Differential - Layer 5
1 oz Copper on .006 AP

Differential lines at .015 pitch

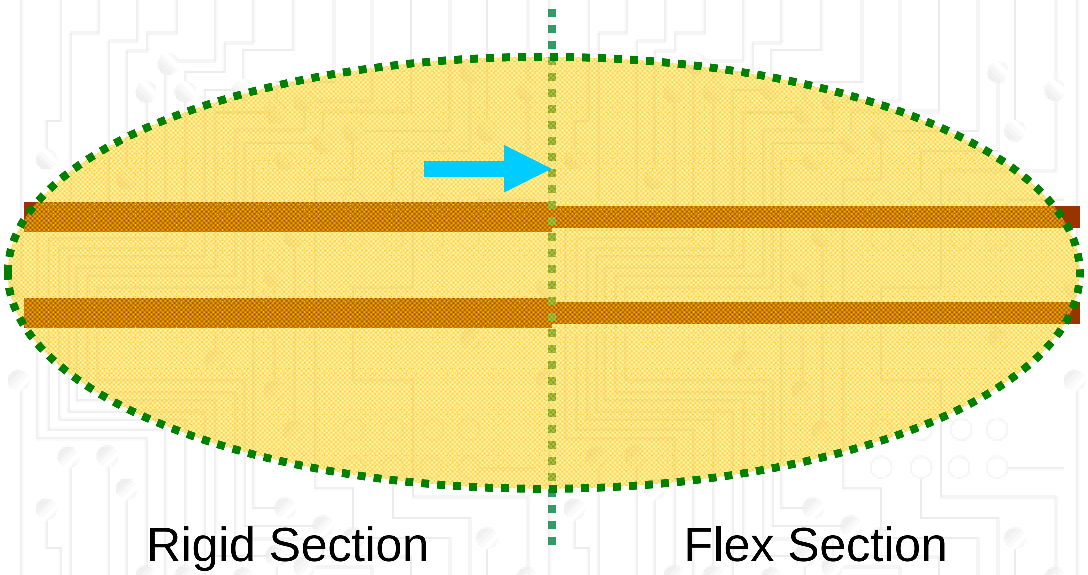
Controlled Impedance Rigid Flex

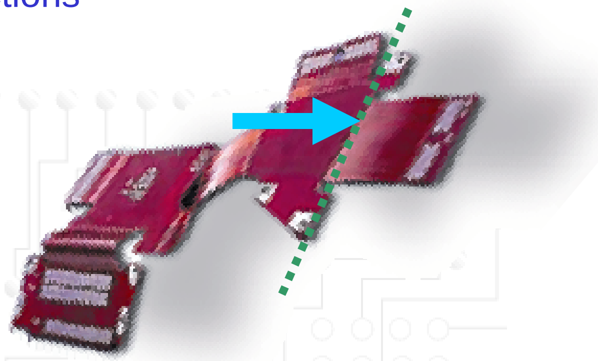
Stack-Up and Impedance Model - Sample



Controlled Impedance Rigid Flex

Impedance Matching: Line Width Transitions – Rigid To Flex Sections

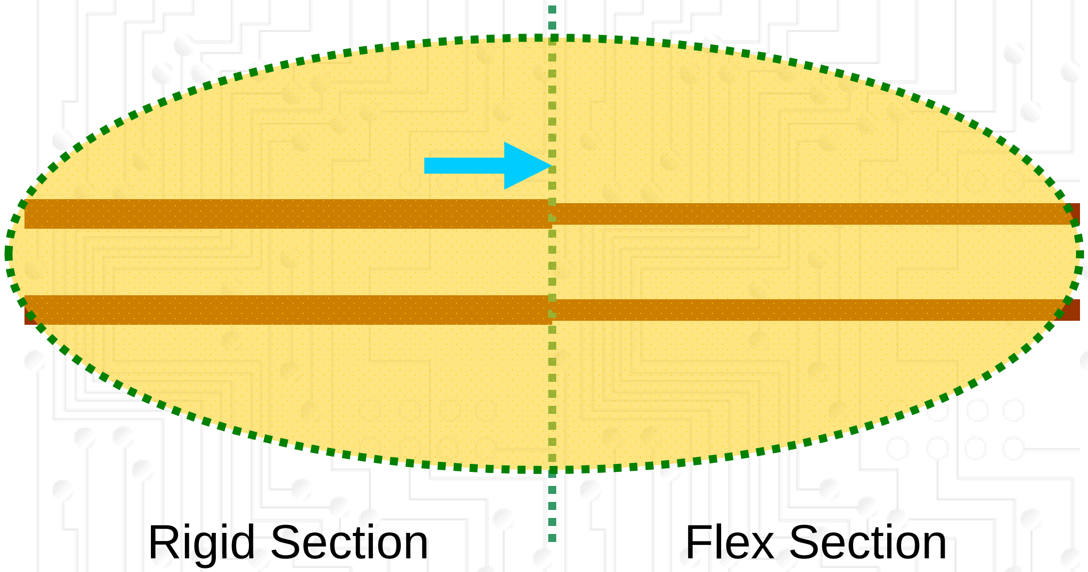


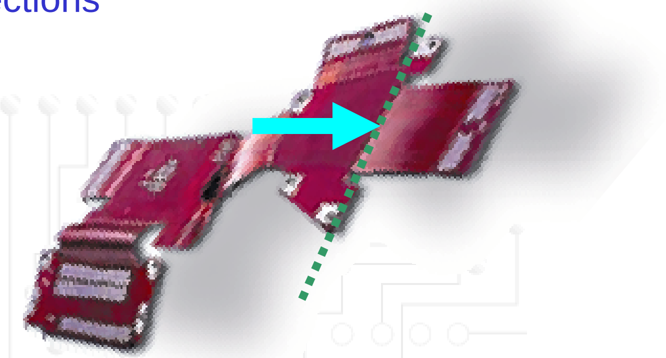


Based on the impedance model, permit the fabricator to adjust line widths. As signal lines transition from a rigid section to a flex section line widths will usually require adjustment based on different Dk (Er) values and different dielectric spacing to reference plane(s).

Controlled Impedance Rigid Flex

Impedance Matching: Line Width Transitions – Rigid To Flex Sections





$f = 30gHz$

What happens to the signal?

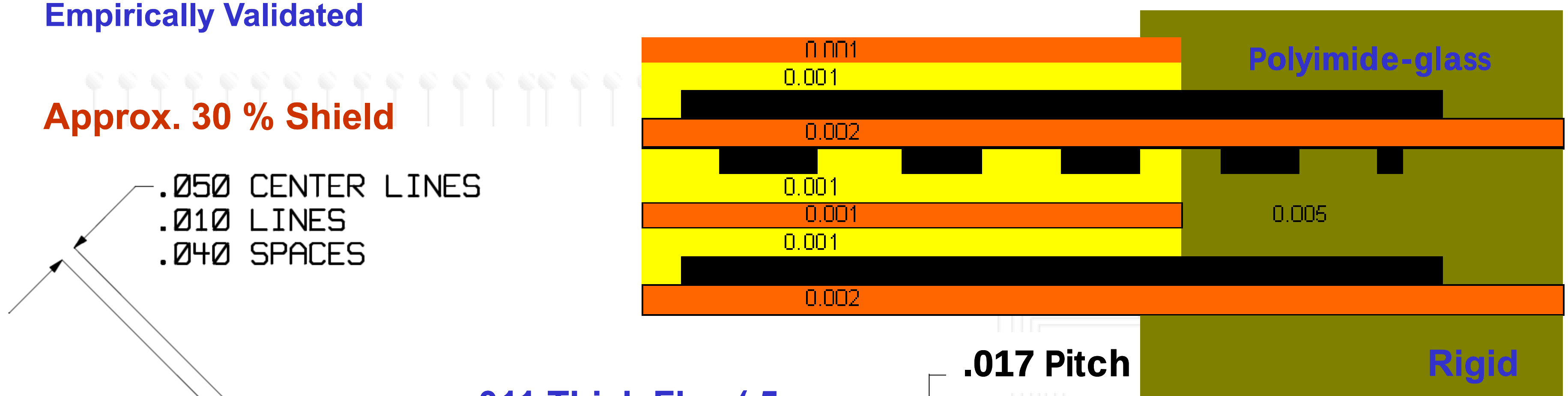
Discontinuities have less impact at low frequencies.
Most Important: Match the impedance as closely as possible between rigid and flex.
As frequencies increase, the more closely the impedance needs to be matched.
Poor impedance matching leads to unwanted reflected signal (a.k.a. NOISE).

Controlled Impedance Rigid Flex

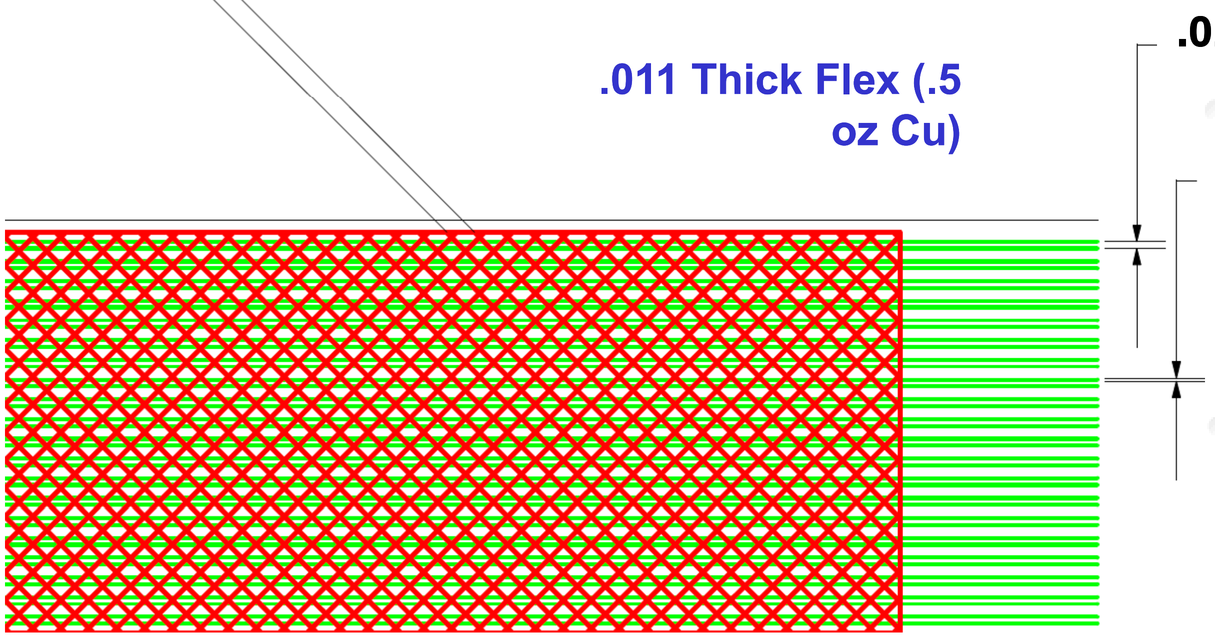
Cross-Hatch Plane

Specific Cross Hatch Copper Plane Designs Must Be Empirically Validated

Approx. 30 % Shield



.011 Thick Flex (.5 oz Cu)



.007 in Flex Region
(with .002 Flex / .003 Flex Dielectric)
Dk about 3.1

.006 in Rigid Region
(with .002 Flex / .005 Rigid Dielectric)
Dk about 3.3

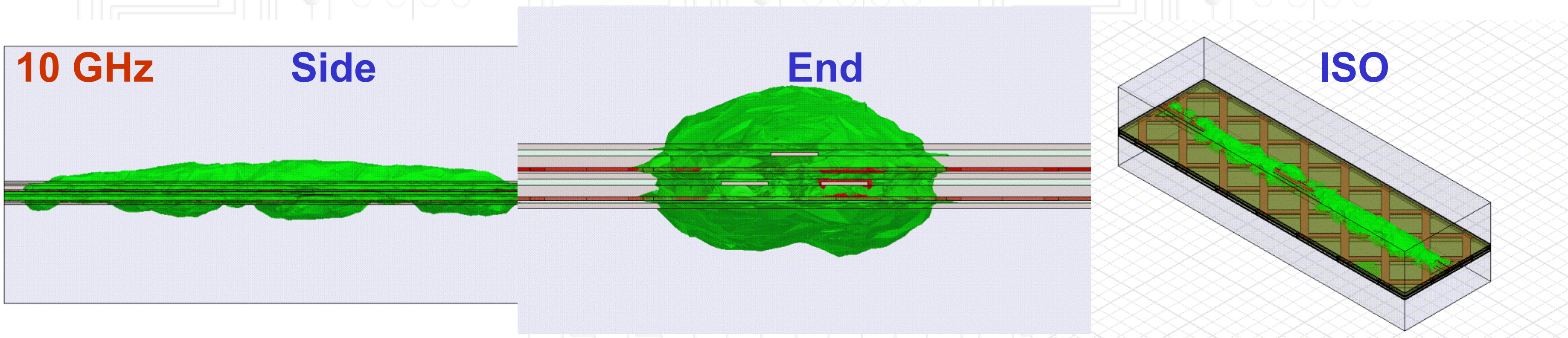
Crosshatch layout courtesy of Raytheon Missile Division

Cross-Hatch Plane - Field Radiation Effects - Strip Line
(Phase Angle 0° - 180°)

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

Sonnet Model Simulation

HFSS Models - AANSOFT



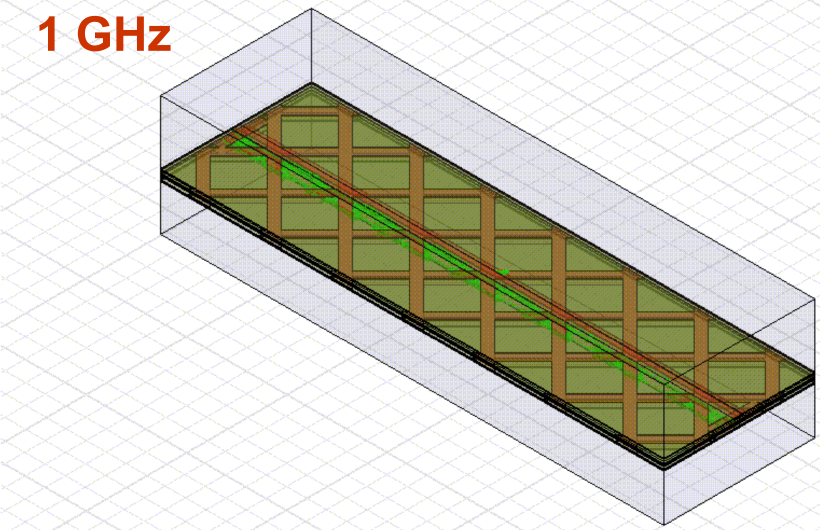
* Signal applied to strip line signals, but not to the microstrip line on top.
* You can see energy coupling from inside (strip line) to outside (microstrip) at high frequency, but not at low frequency.

Model Simulation provided by DuPont

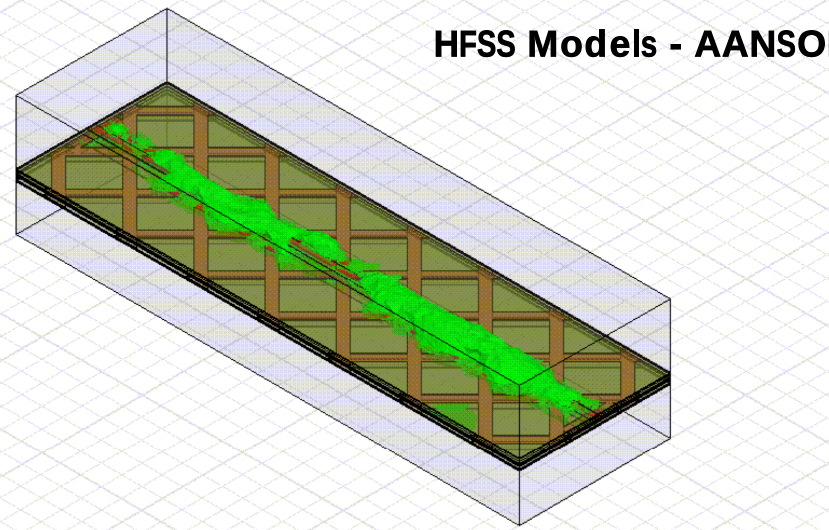
Cross-Hatch Plane - Field Radiation Effects - Strip Line
(Phase Angle 0° - 180°)

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

1 GHz



10 GHz



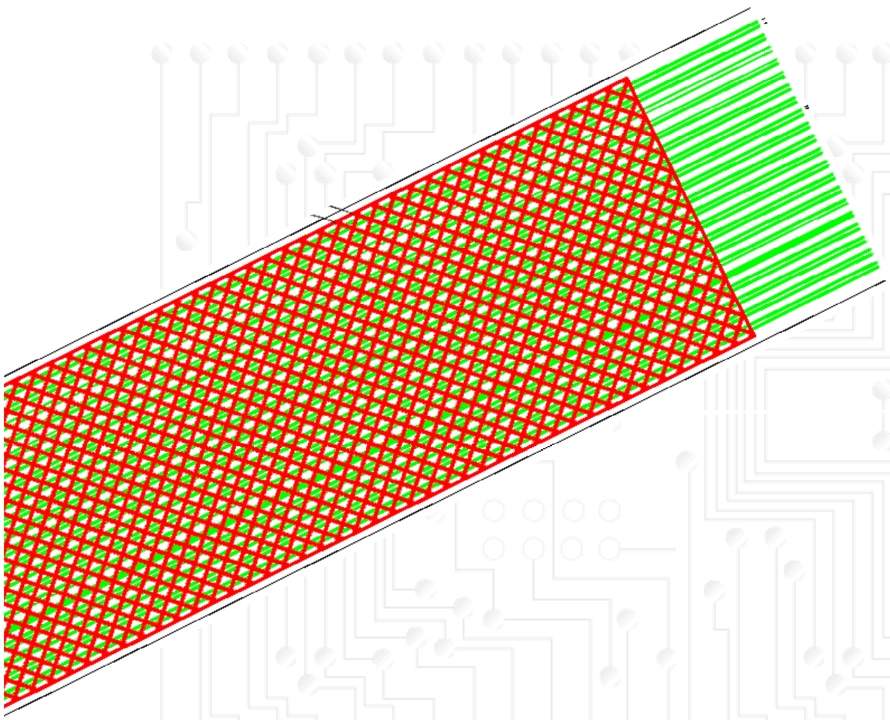
Cross hatch plane effects:

- EMI performance looks good at 1 G Hz:
  Energy mostly contained within the strip line.
- At 10 GHz, signal couples to signal line external to the strip line
  Would need a finer pitch grid or a solid ground plane.

Model Simulation provided by DuPont

Controlled Impedance Rigid Flex

Cross-Hatch Plane



Use of a Cross- Hatch shield :

•Will Improve Flexibility in the flex section

•May Significantly Reduce thickness of flexible sections

•Controlled Impedance Models May Not Be effective with X-Hatch

•> Check with your EE for EMI & Emissivity Concerns

•Effective up to 1 GHz and maybe Higher

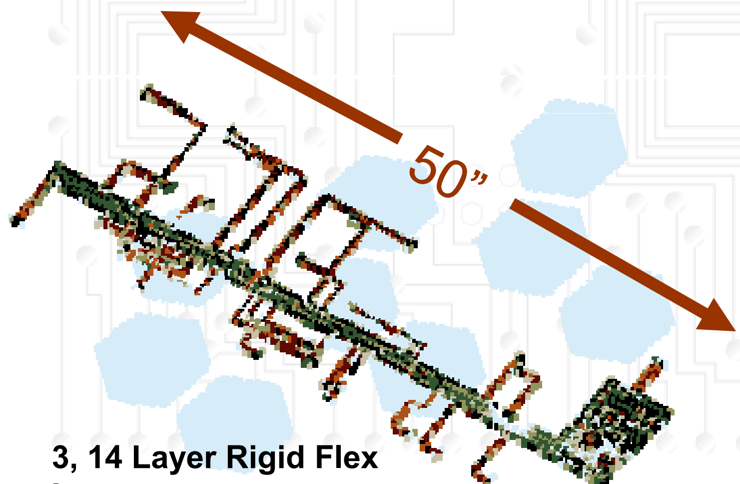
Do not align signal routing parallel with cross-hatch!

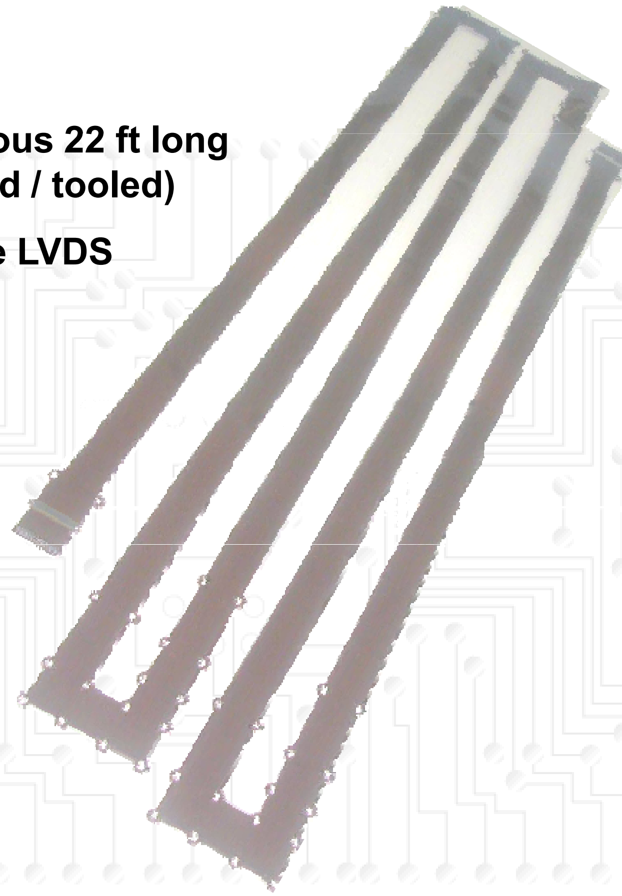
Extended Length Flex
Loss Effect Of Frequency Vs Length - -

f=?

Continuous 22 ft long
(Unfolded / tooled)

Strip line LVDS



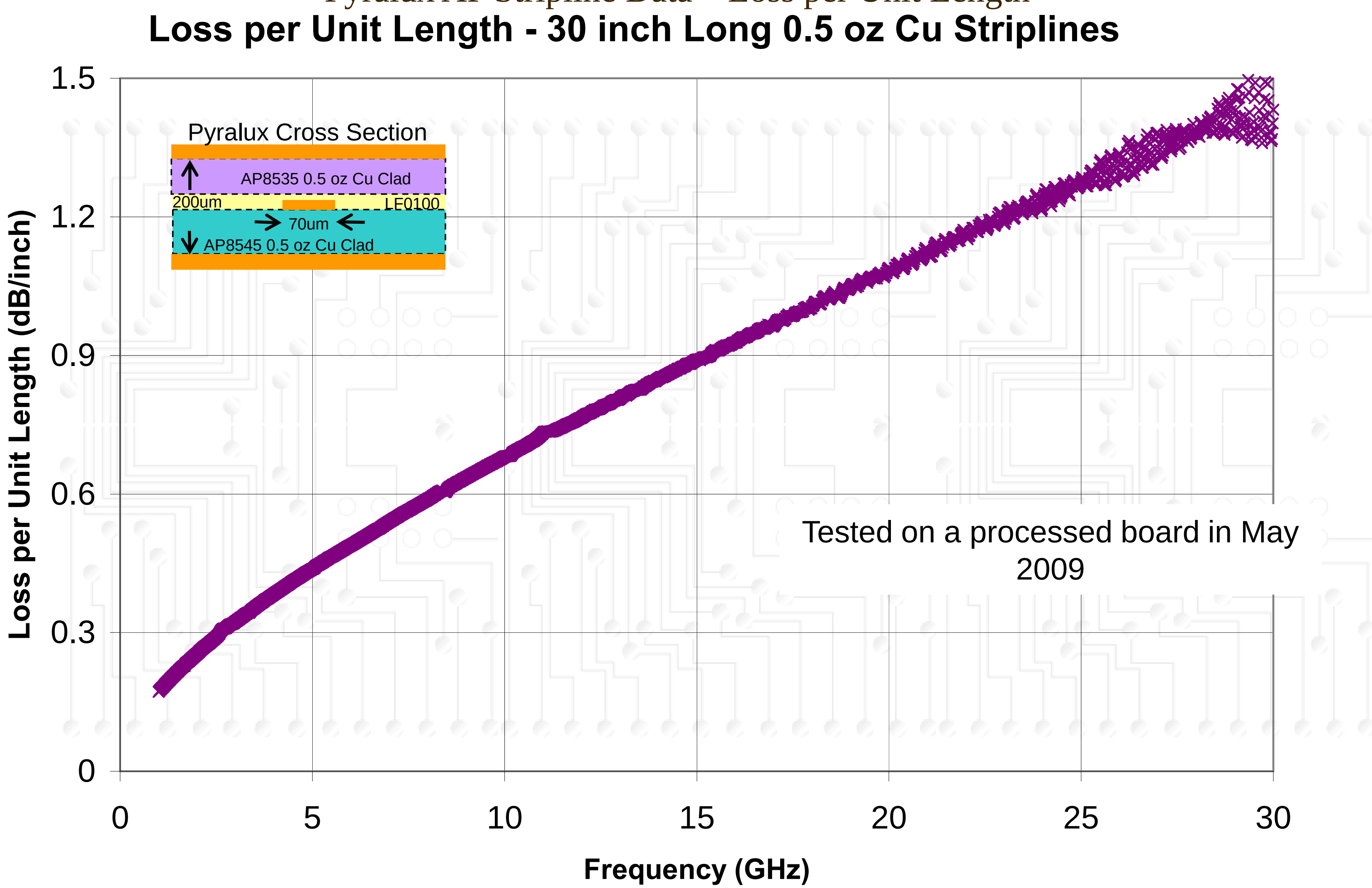


3, 14 Layer Rigid Flex
Interconnect

Extended Length Flex
Effect Of Frequency Vs Length - - on Loss

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

Pyralux AP Stripline Data – Loss per Unit Length

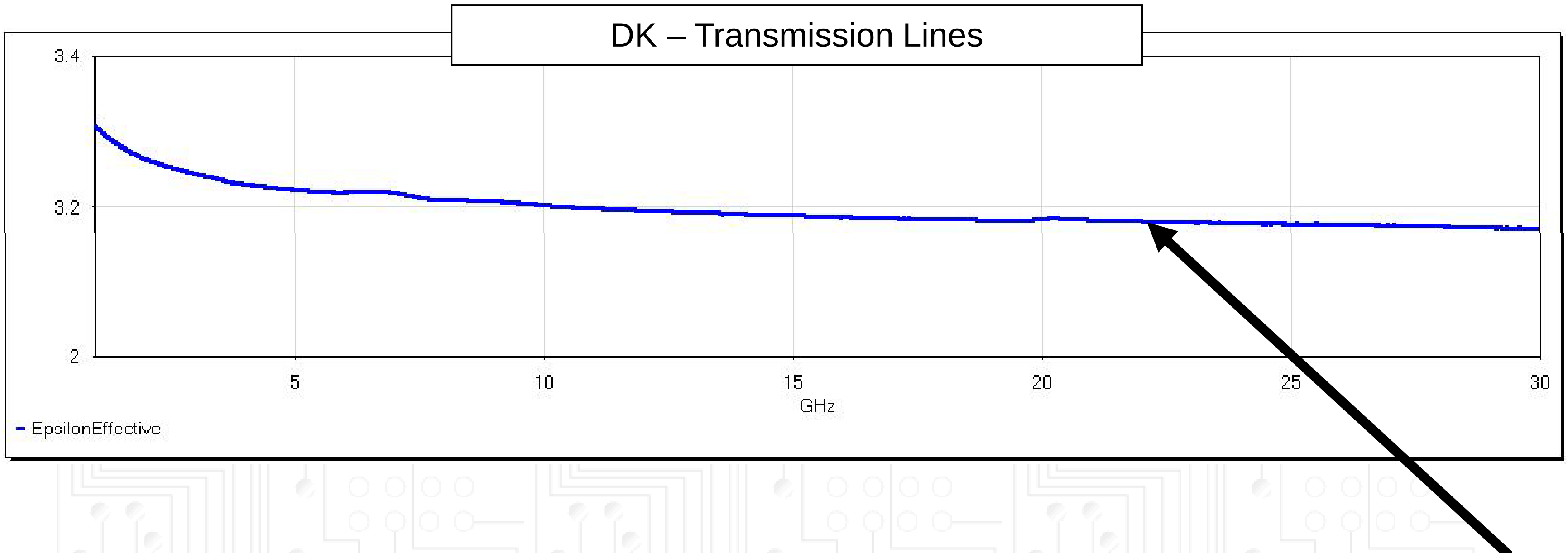


Data Supplied by DuPont

Association Connecting Electronics Industries
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

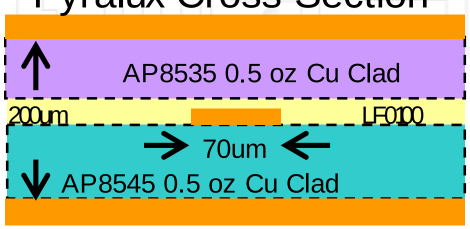
Adhesive-less Flex
Effect Of Frequency on Dk

Pyralux AP – Dielectric Constant of Striplines



Stripline Transmission Lines
(most representative data for flex interconnect)

Pyralux Cross Section



Tested on a processed board in May 2009

Adhesive-less Flex
Effect Of Frequency on Dk

For High Frequency Applications effective impedance may be higher than typical TDR measurement & Zo models may suggest.

For critical high frequency applications, impedance models and TDR test requirements should be referenced to the expected measurements using industry “standard” test equipment.

(TDR rise time / frequency band can vary depending on equipment)

- Polar -- 200pS rise time or 1.7GHz
- Hyperlabs (HL 2200) -- 50pS rise time or 7.0GHz
- Agilent -- 45pS rise time or 7.7GHz
- TEK (SD24 or 80E04) – 35 pS rise time or 10 GHz

TDR -3dB bandwidth can be calculated from rise time
BW= 0.35 / rise time

Controlled Impedance Rigid Flex

Association Connecting Electronics Industries
IPC®
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

Dielectric Constants & Dissipation Factor for Various Flexible Dielectric Materials
(Values Obtained from Base Material Testing)

Test Values Reported by DuPont ®

- **LF Adhesive (IPC 4203/18)**

- 1 MHz Dk = 3.5 Df = 0.030
- 1 GHz Dk = 3.0 Df = 0.025
- 10 GHz Dk = 2.8 Df = 0.020

- **FR Adhesive (IPC 4203/1)**

- 1 MHz Dk = 3.6 Df = 0.030
- 1 GHz Dk = 3.1 Df = 0.025
- 10 GHz Dk = 2.9 Df = 0.020

- **Kapton® (IPC 4202/1)**

- 1 MHz Dk = 3.8 Df = 0.003
- 1 GHz Dk = 3.5 Df = 0.009
- 10 GHz Dk = 3.3 Df = 0.012

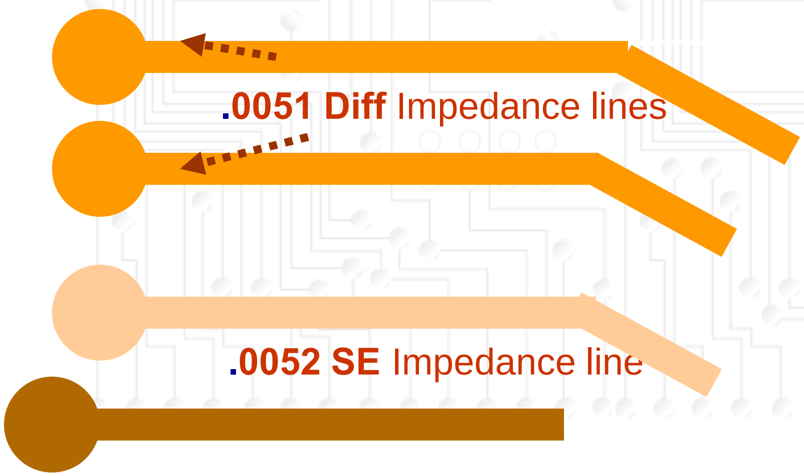
- **Pyralux® AP (IPC 4204/11)**

- 1 MHz Dk = 3.4 Df = 0.001
- 1 GHz Dk = 3.3 Df = 0.002
- 10 GHz Dk = 3.3 Df = 0.002

Controlled Impedance Rigid Flex

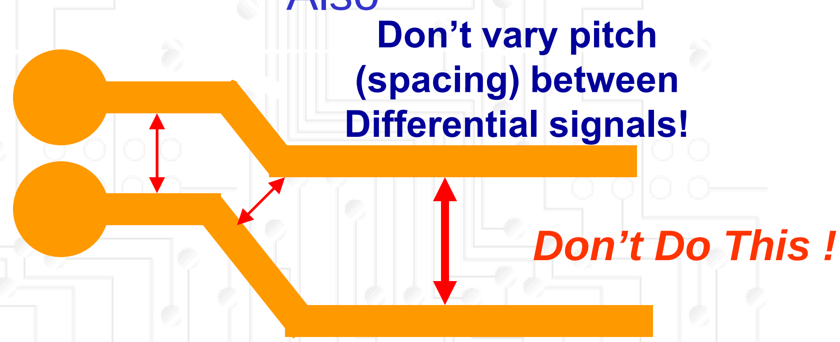
Layout HINTS (Controlled Impedance 101):

Use unique aperture (width) assignments for each different controlled impedance signal and list these in a readme.txt file in the data package. Also- provide the manufacturer sufficient spacing real estate to make adjustments for line width to:
(1) Accommodate the supplier's impedance models and …
(2) To allow for the supplier to add etch compensation, growing the line width in the production film and still have sufficient spacing.

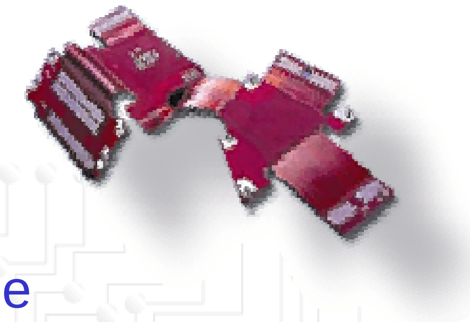


.005 Non-Impedance line

Also-



Controlled Impedance Rigid Flex



More Hints

- Edge-coupled differential modeling is preferred. Use broadside coupled differential impedance only when the signals share the same core.
- For critical impedance applications use signal line widths of <u>at least</u> .005 on .5 oz copper or less to reduce effects of etch line width variation.
- For bookbinder applications, use only micro-strip (signal & single reference plane) models. Strip-line models require at least three layers and these may not be effectively produced in bookbinder applications

Solutions for

- High Frequency Applications
- Thinner Dielectric Possible
- Low Loss
- High Temperature

DuPont Pyralux* TK

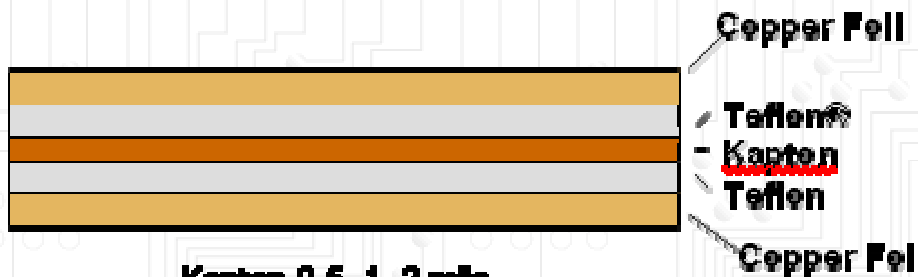
Teflon*-Kapton*-Teflon*

Next Generation Materials

Dupont ® TK

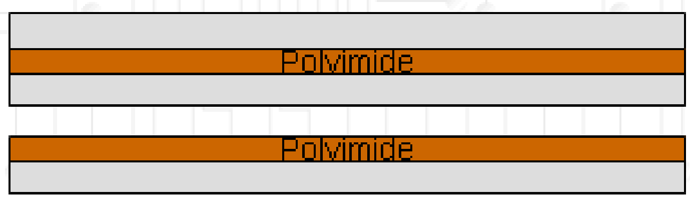
Kapton® core with Teflon® outer layers.

RA copper foil



Kapton 0.6, 1, 2 mils
Teflon 0.6, 1, 2, 3, mils

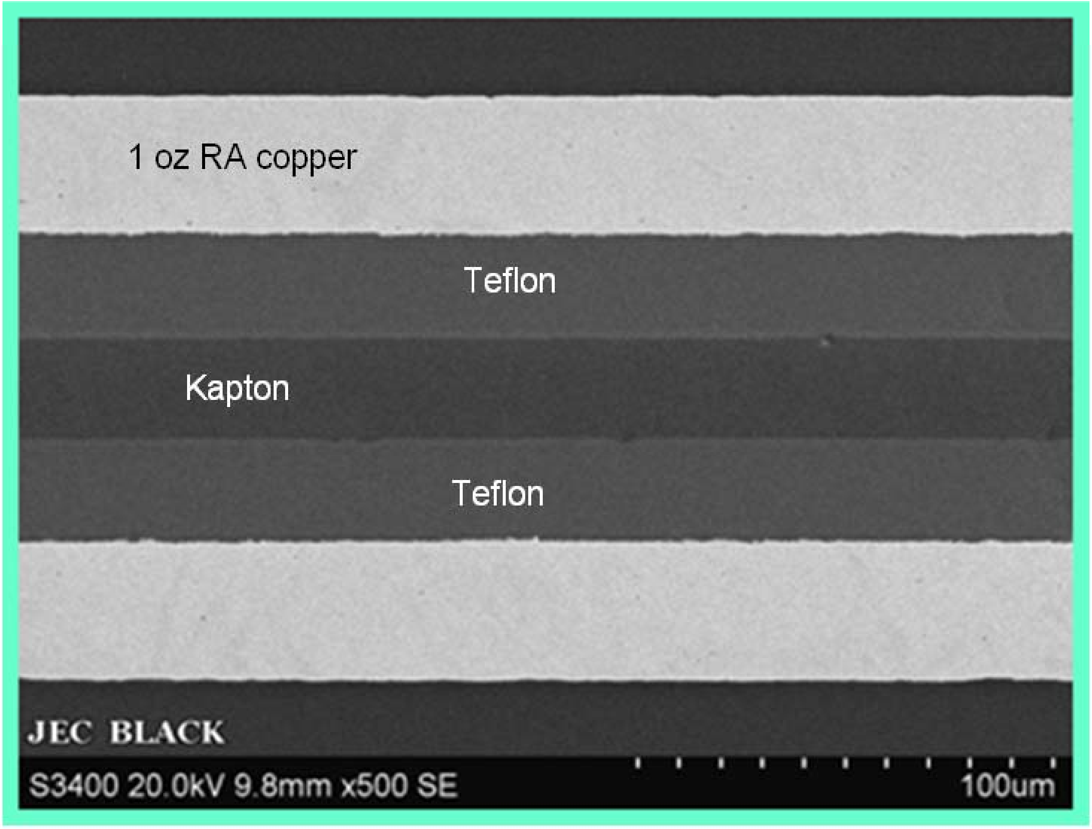
Coverlay and bonding film based on Kapton and lower melt point Teflon® . (Will require high temperature lamination >280 C.)



Next Generation Materials

Dupont ® TK "Daytona"

High Speed Flex Cross-Section. 3 mil thickness



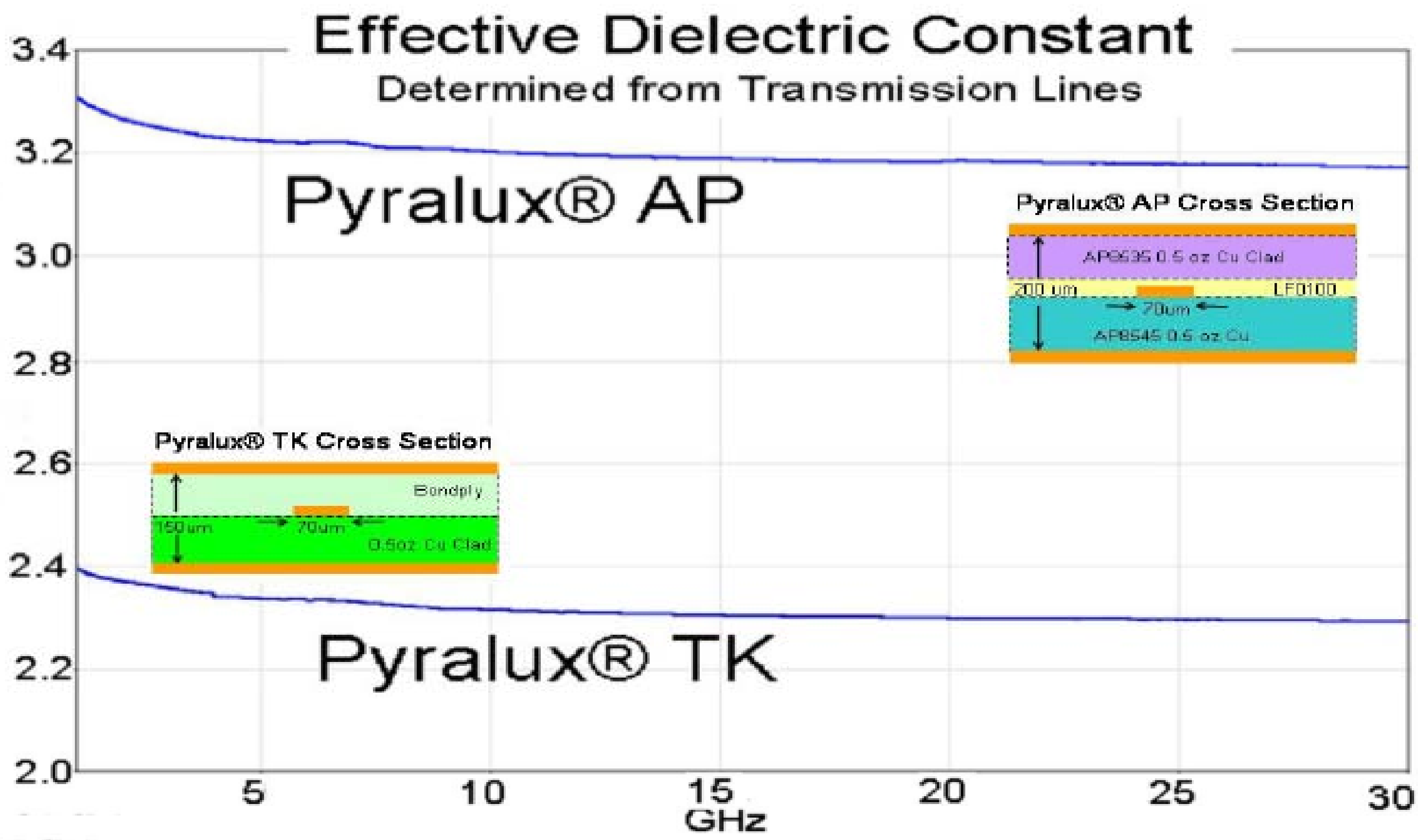
Next Generation Materials

Dupont ® TK

Summary Chart for 3 mil Clad

Property	3 mil	Pyralux AP 9131	Pyralux LF 9111
Dielectric Constant 10 GHZ	2.5	3.4	3.2
Dissipation Factor 10 GHz	0.002	0.003	0.013
Dielectric Constant 10 GHz, 85/85	2.5	3.6	
Dissipation Factor 10 GHz. 85/85	0.005	0.005	
Peel Strength AR, pli	13	20	11
Peel Strength AS, pli	12	20	10
Peel Strength After HAST, pli	10	20	6
UL Flame, Internal Testing	V-0 Internal test	V-0	None
Moisture Absorption, %	0.3	1.1	2.7
Blister Test, 3 min solder 288C	Pass	Pass	
CTE, ppm/C (50 to 250C)	30	25	

Next Generation Materials



Pioneer Circuits, Inc.

Association Connecting Electronics Industries

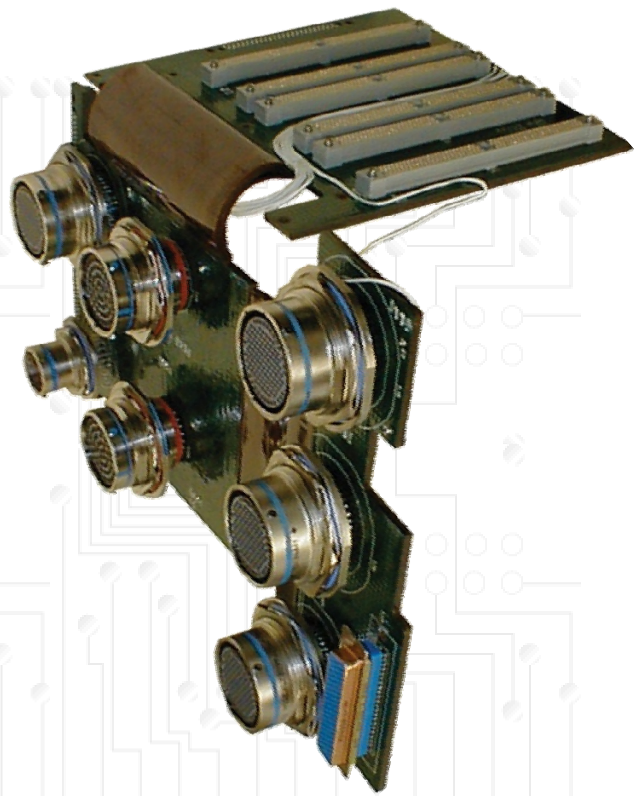
IPC INTERNATIONAL CONFERENCE ON FLEXIBLE CIRCUITS

3000 S. Shannon St
Satan Ana, CA 92704

Bob Sheldon
Director of Operations & Technology

bsheldon@pioneercircuits.com

(714)641-3132



Thank You

Simulation Models Courtesy of DUPONT

Glenn Oliver
Electrical Engineer