High Speed Material Considerations for Flex and Rigid-Flex Circuit Designs

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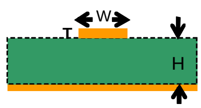
Overview

- High Speed Requirements – What is different at high speed?
- Design Trade-Offs
- Illustrations, charts and analysis of basic structures

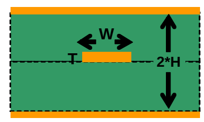
Selected Circuit Geometries

- Interconnect Geometry – Single Ended

<u>Microstrip</u>

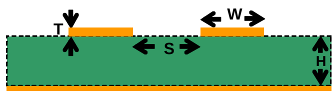


<u>Stripline</u>

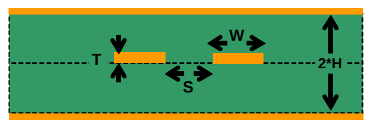


- Interconnect Geometry – Differential

<u>Edge Coupled Microstrip</u>

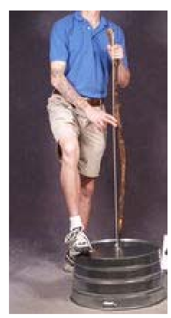


<u>Edge Coupled Stripline</u>



High Frequency - Musical Analogy

- Low Frequency – You do not have to get too precise with your lines (strings) or substrate (tub) to make bass notes. Do not need to worry about the signal quality.



A washtub bass

- High Frequency – The clarity and overtones need to be perfect. The substrate (wood in this case) matters a lot.

An antique violin

High Speed Requirements

- Minimize Effects of Noise – Use Balanced Signals
  - ❑ Differential Pairs = forward and return signals coupled together.
  - ❑ Example: Twisted pairs in telephone lines.
  - ❑ Signal routing is of critical importance.
  - ❑ Pairs need to have the same electrical length or skew will result.
- Keep Impedance Constant – Minimize Reflection
  - ❑ Minimize layers and vias.
  - ❑ Keep width and spacing of lines constant.
  - ❑ Thickness variation translates directly to impedance variation.
- Minimize Attenuation – Use lower loss materials
  - ❑ Glass weave in FR4 leads to anisotropy. If dielectric constant changes, Impedance changes. These changes effectively reduce the signal to noise ratio.
  - ❑ Effect of dielectric loss is straightforward. Most applications for high speed require material with a loss tangent of 0.005 or less.
  - ❑ At very high speeds, the copper roughness is a key factor due to the skin effect.
- Minimize Crosstalk
  - ❑ Differential pairs operate by the principle of coupling. This is GOOD coupling.
  - ❑ When signals couple to another signal line (not its pair), then this is BAD. This is called crosstalk.
  - ❑ Differential Transmit and Receive electronics also work to reduce noise and crosstalk.

Design Trade-Offs

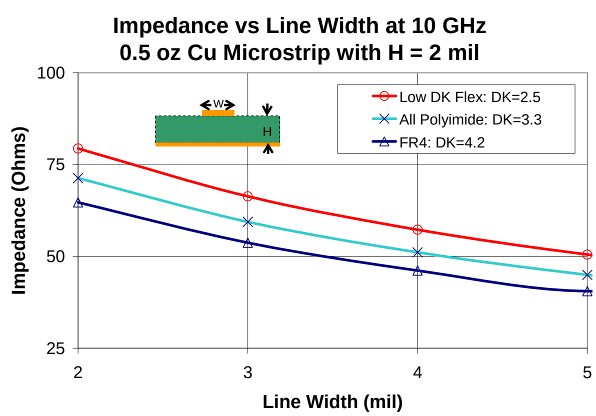
- Commonly Used Circuit Structures
  - ❑ Microstrip
  - ❑ Stripline
- Dielectric Properties
  - ❑ Effective Permittivity (Dielectric Constant = DK)
  - ❑ Loss Tangent (Dissipation Factor = DF)
  - ❑ Isotropy
  - ❑ Thickness Tolerance
- Conductor Properties
  - ❑ Feature Size and Tolerance (Line Width and Spacing - Etching, Plating, etc.)
  - ❑ Copper Type (ED & RA)
  - ❑ Roughness (Profile)

Circuit Structure Trade-Offs

- Microstrip
  - Easy to manufacture – Can make with a double sided laminate and no vias required
  - Lower loss and lower propagation delay than stripline
  - More susceptible to noise (crosstalk) – electric fields radiate
  - Generally this susceptibility to noise makes microstrip unattractive for differential signaling at high data rates.
- Stripline
  - Improved noise immunity due to shielding provided by ground planes
  - Higher loss and higher propagation delay than microstrip
  - More difficult to manufacture – bondply lamination and vias required
  - More suitable to high data rates than microstrip due to noise immunity

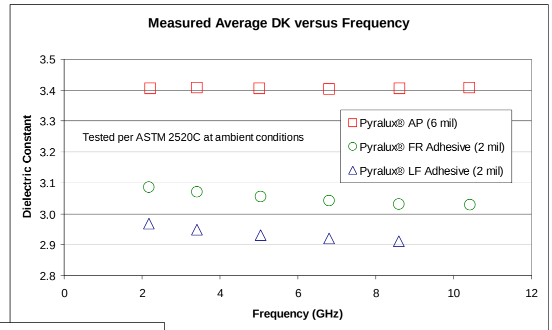
Dielectric Trade-Offs

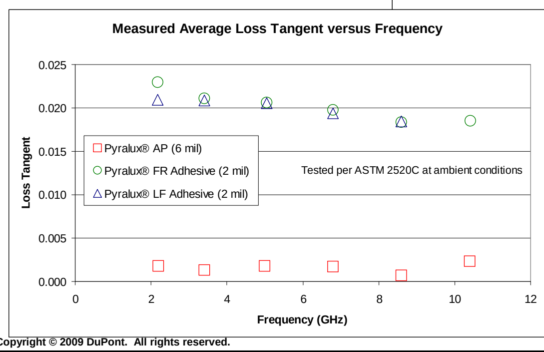
- Effective Permittivity (Dielectric Constant)
  - GOOD: Lower DK allows use of thinner materials for applications needing flexibility
  - GOOD: Lower DK allows wider lines if the dielectric thickness is kept constant (higher yields)
  - BAD: Generally, lower DK materials are more expensive for organic laminates (DK<4.2)
  - Lower dielectric constant can allow higher impedance for thinner materials
- Loss Tangent (DF)
  - Generally in the 0.02-0.03 range for acrylics and FR4
  - All Polyimide materials in the 0.003-0.004 range
  - There is demand for flex materials with low dielectric loss.



DK and DF at High Frequency

- Measured in a Waveguide Cavity newly obtained in late 2008.
- Note that Acrylic is not flat over frequency…DK = 3.6 in the 1 MHz range (this is the value on the data sheet).

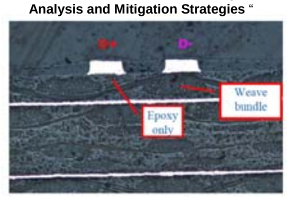




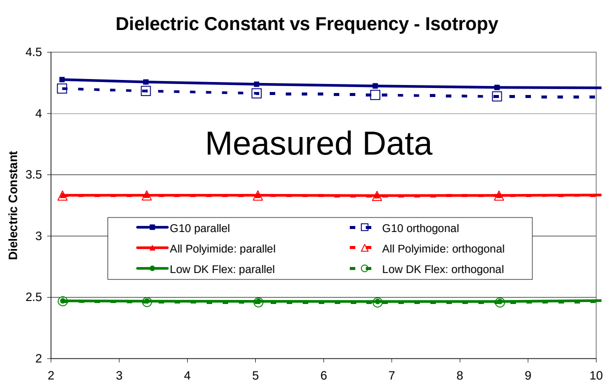
- Standard Kapton® has a DK around 3.5 in the 2-10 GHz frequency range.
- If you have a stack-up that uses acrylic adhesive, the DK will decrease as you add more acrylic.
- DF will increase as you add more acrylic to the stack-up.

Isotropy

From: Intel Whitepaper on circuitree.com "Fiber Weave Effect: Practical Impact Analysis and Mitigation Strategies "

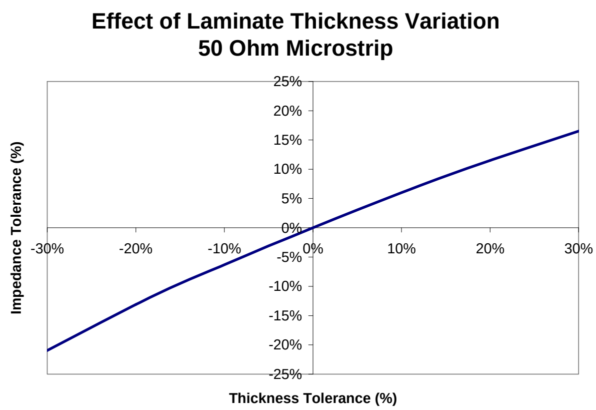


- Variations of effective dielectric constant at different locations.
- A product of the glass weave in rigid laminates.
- Dielectric constant of glass is generally higher than that of the epoxy.
- Polyimide flex laminates do not have glass weave.



Dielectric Thickness Tolerance

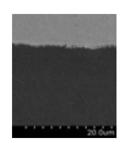
- If the thickness of the dielectric varies, the impedance of signal lines will vary.
- Typical laminates specify thickness tolerance of ±10%. This is generally insufficient for applications in which impedance must be closely controlled.
- A 10% thickness tolerance results in more than a 6% impedance variation while a 5% thickness tolerance results in less than a 3% variation in impedance.
- Having discrete thickness choices also enhance design flexibility.



Conductor Trade-Offs

Cross Sections of Copper/Dielectric Interfaces

ED Copper with Surface Treatment

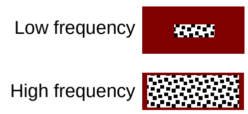


Low Profile RA Copper

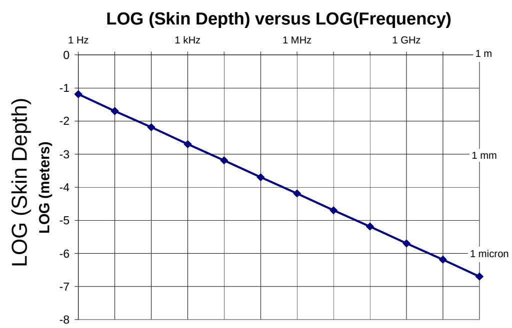
- Conductor Properties
  - Copper Type
    - Electrodeposited (ED)
    - Rolled Annealed (RA)
  - Roughness – Surface Profile
    - Generally, RA has about the same roughness on both sides while ED is generally much rougher on the laminate side than on the surface. The rougher side faces the dielectric to improve Cu adhesion.
    - Surface treatments to improve dielectric adhesion to copper will increase roughness and affect high frequency performance
      - Average (RMS) roughness (R_{avg}) for adhesion treated copper can result in R_{avg} = 36 microinch (0.9 microns)
      - For high performance applications, can result in R_{avg} values between 8-16 microinches (0.2 – 0.4 microns)

Conductor Trade-Offs

Cu Trace Cross Sections
(dark areas show highest current density)

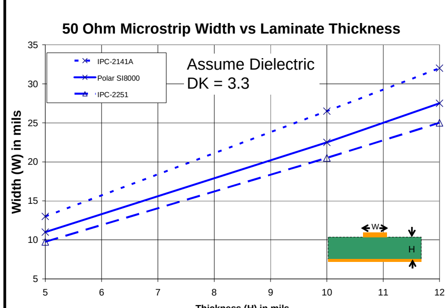


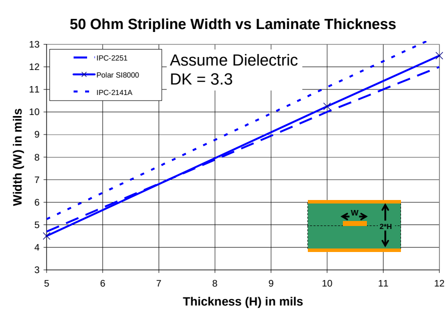
- Why Does Roughness Matter?
  - The Skin Effect
    - As frequency increases, current tends to flow on the surface (or skin) of the conductor.
    - Centrifuge analogy – as it rotates faster, things inside are collected around the edge.
    - Surface condition affects signal transmission since current is concentrated on the surface
  - Frequency Dependence
    - At 100 MHz, copper skin depth is about 10 microns so roughness makes no difference
    - At 10 GHz, copper skin depth is less than 1 micron so Cu roughness has a very big effect



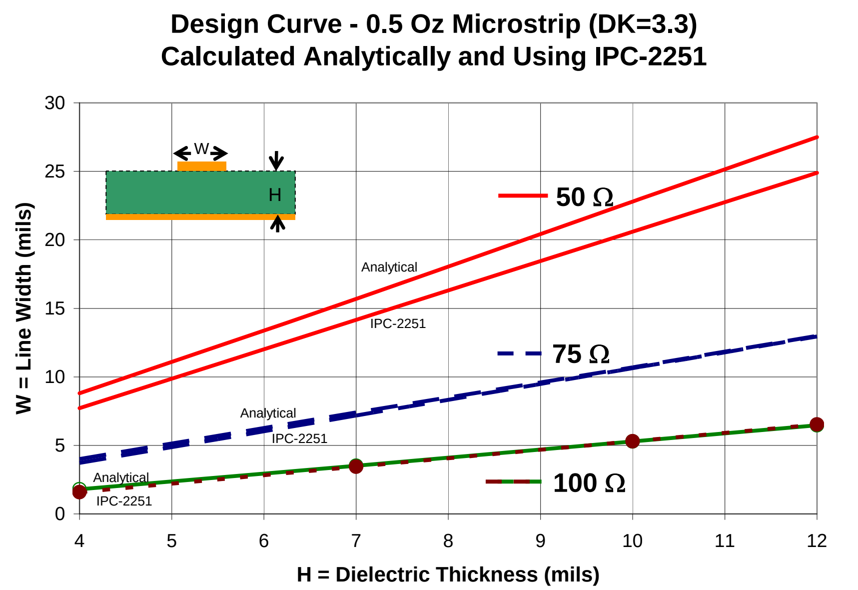
Resources – Estimating Impedance

- IPC-2141A Design Guide for High-Speed Controlled Impedance Circuit Boards
- IPC-2251 Design Guide for the Packaging of High Speed Electronic Circuits
- Analytical Methods Analytical solutions like those available at Polar Instruments closest to true electromagnetic solution
- Although IPC-2141A focuses on controlled impedance applications, the formulas developed in IPC-2251 to estimate impedance are more realistic than those in IPC-2141A.

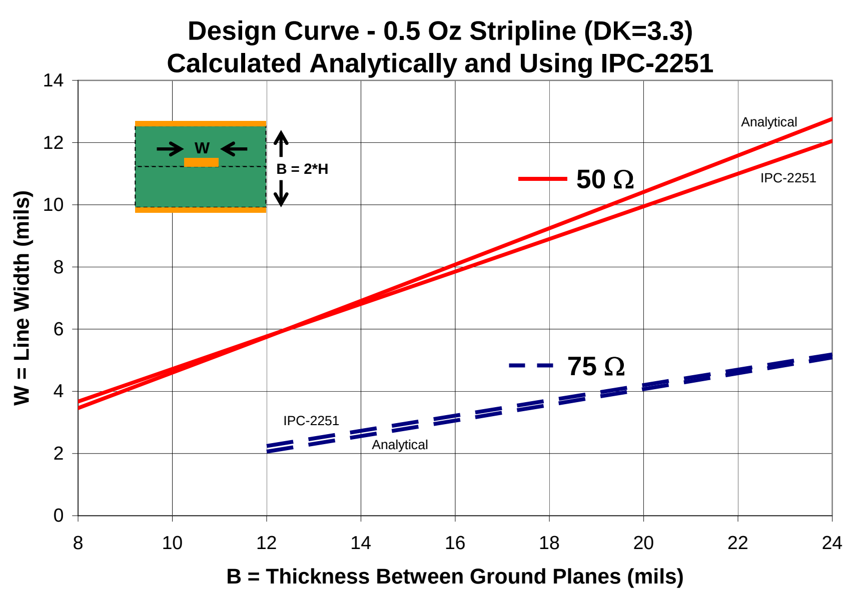




Analysis - All Polyimide Microstrip Design



Analysis - All Polyimide Stripline Design



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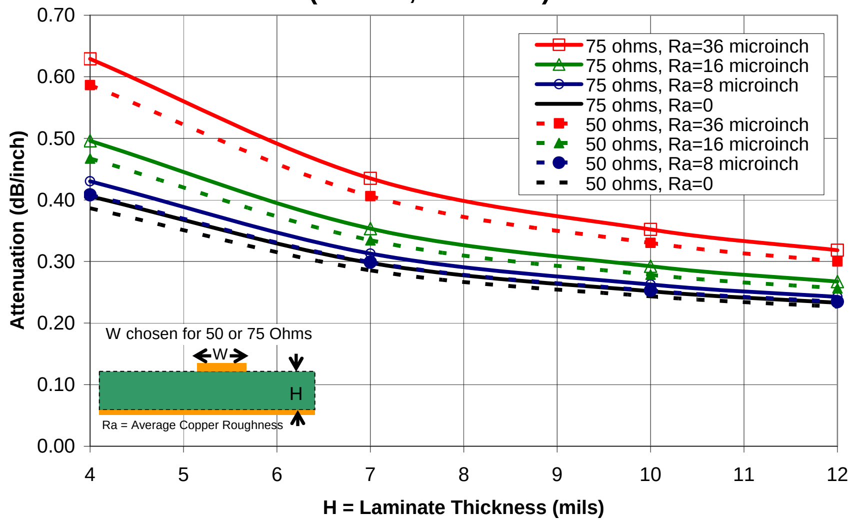
All Polyimide Attenuation Estimates – 0.5 oz Cu

Attenuation for 0.5 oz Cu Microstrip Lines at 10 GHz (DK=3.3, DF=0.004)



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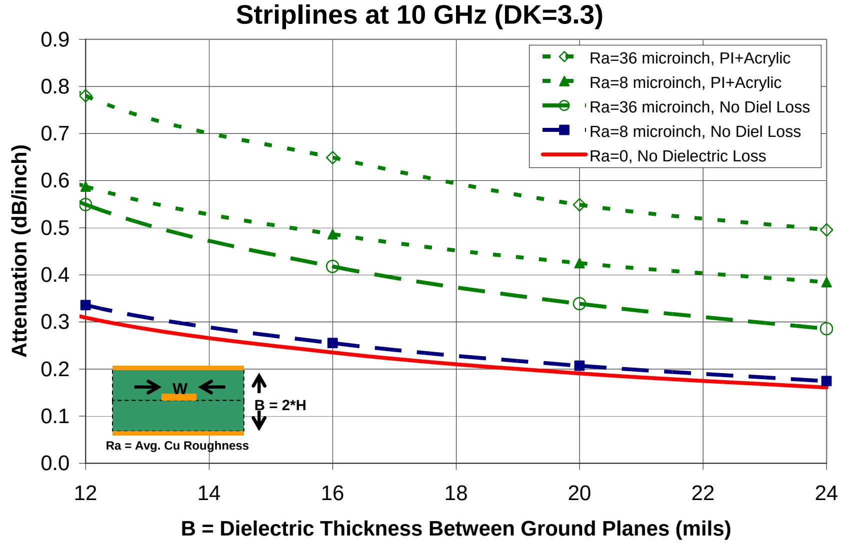
All Polyimide Attenuation Estimates - 50 Ohm

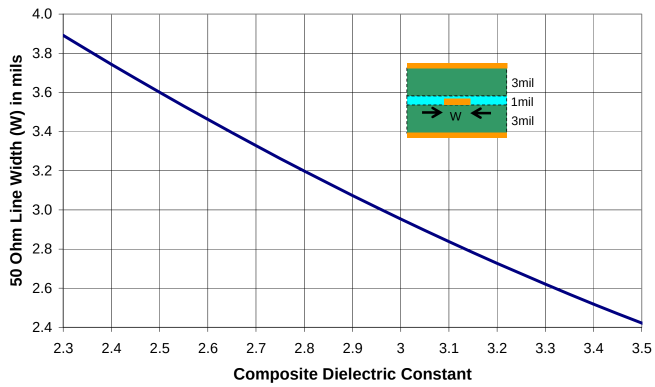
Attenuation for 50 Ohm 0.5 oz Cu Striplines at 10 GHz (DK=3.3)



Thin Options

- For applications with flex specifications, is important to have stripline circuits that are as thin as possible to meet bending requirements.
- Possible stack-up for thin applications.
- Lower DK greatly enhances the yields due to wider lines.
- Another benefit of lower DK is the ability to make thinner circuits with the same line widths.

Design Curve for 7 mil Thick Stripline
0.5 oz Cu, 1 mil Adhesive, 3 mil Thick Laminates (x2)



Conclusion

- High Speed Circuits – Performance requirements are increasing, need to understand the effect of material/electrical interactions to succeed.
  - Consider Circuit Structure
    - Microstrip geometry has faster signal propagation and wider lines resulting in lower loss, but is more susceptible to noise
    - Stripline is shielded from noise, but has higher loss and signals propagate slower than microstrip
    - Microstrip circuits are usually thinner than stripline circuits…thus are more bendable
  - Minimize Impedance Variation
    - Use isotropic materials (no glass weave)
    - Use dielectrics with tight thickness tolerance
    - Lower DK materials enables wider lines or thinner dielectrics
  - Lower Attenuation
    - At low frequencies, electrical resistance is primary concern
    - Dielectric loss is most significant factor at intermediate frequencies
    - Conductor loss becomes dominant at high frequencies

The End

THANK YOU!

Questions?

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