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# Pros & Cons of Thin Laminates in Power Distribution

Istvan Novak

# Outline

- The role and history of thin laminates
- Laminates in power distribution
- Two misconceptions about thin laminates
- Inductance of laminates
- Modal resonances of power planes
- Suppression of modal resonances
- Low-pass filtering
- Summary of benefits of thin laminates
- Downsides of thin laminates
- Lumped resonance of plane capacitance and capacitor inductance
- Summary

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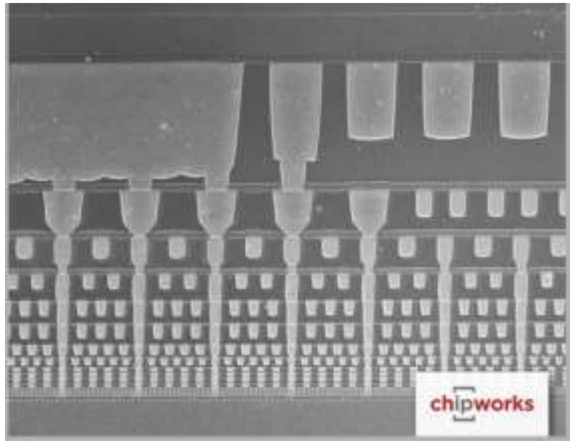
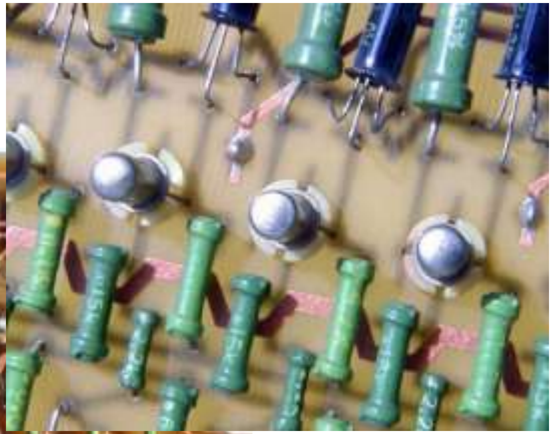
# The Place of Laminates in PDN

- Laminates are used in Printed Circuit Boards
- Did not have in the early days of electronics
- Did not have in the early days of PCBs
- Do not have them in semiconductors




https://www.extremetech.com/computing/193200-intels-14nm-broadwell-chip-reverse-engineered-reveals-impressive-finfets-13-layer-design

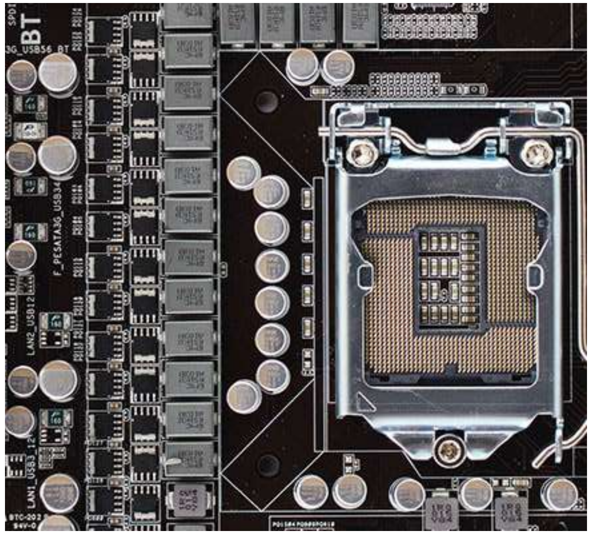


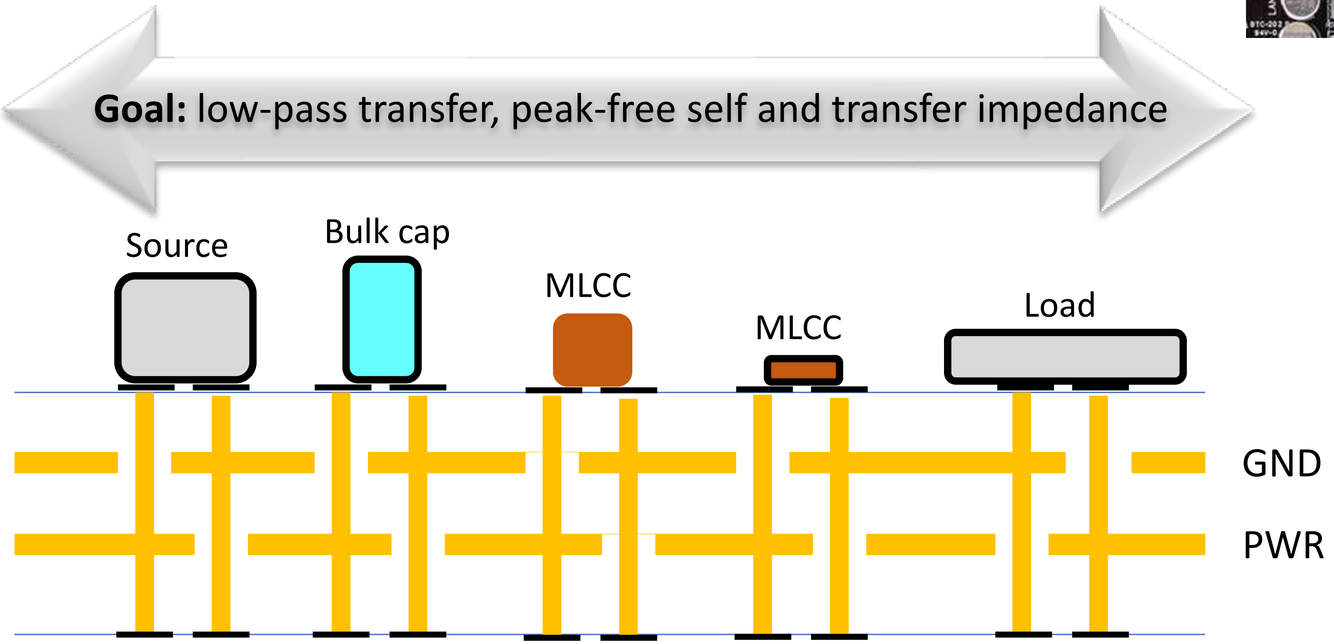
https://www.printedcircuits.com/wp-content/uploads/the-history-of-pcbs-new2.png samtec gEEk spEEk

# The Electrical Role of Laminates in PDN

We want to transmit DC, want to block AC

- Series elements should have low Rdc, can have high Rac

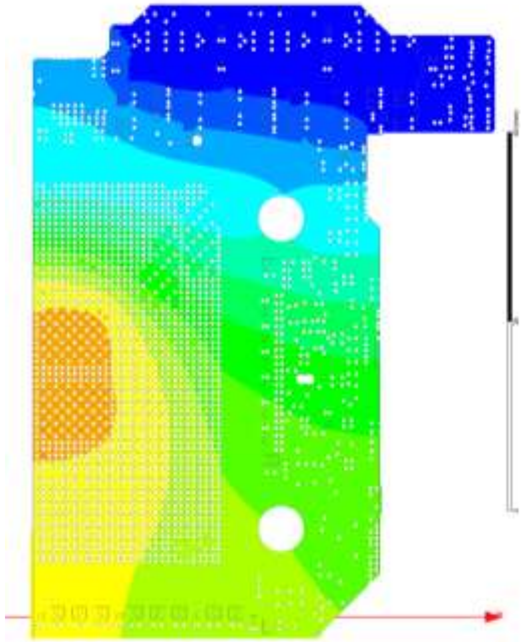




# The Laminates in PDN

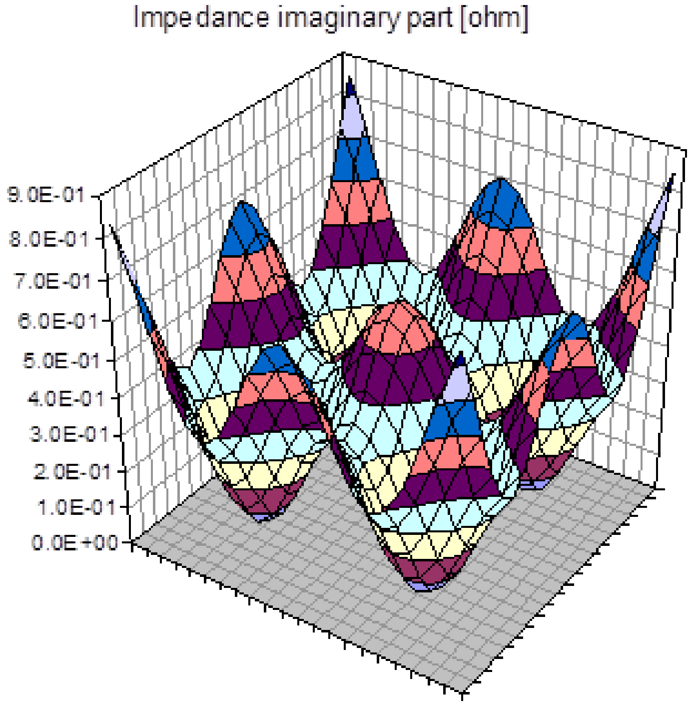
- The DC and AC resistance depends on the conductive layers
- The high-frequency impedance also depends on the modal resonances and losses

DC potential on CPU core power plane



Blando, Bakleh, DeLap, McMorrow, Koether, Novak, "Etch Factor Impact on SI & PI ," DesignCon 2019

Simulated imaginary part of impedance of a 25x25 cm plane pair with open boundaries, separated by 50 µm of FR4 dielectric separation. Impedance surface is shown at 533 MHz.

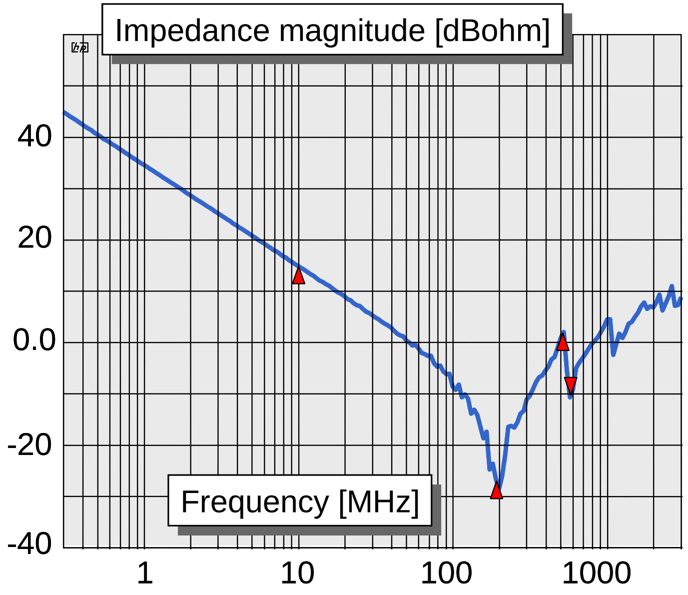



REFERENCE

# History and Evolution of Thin Laminates



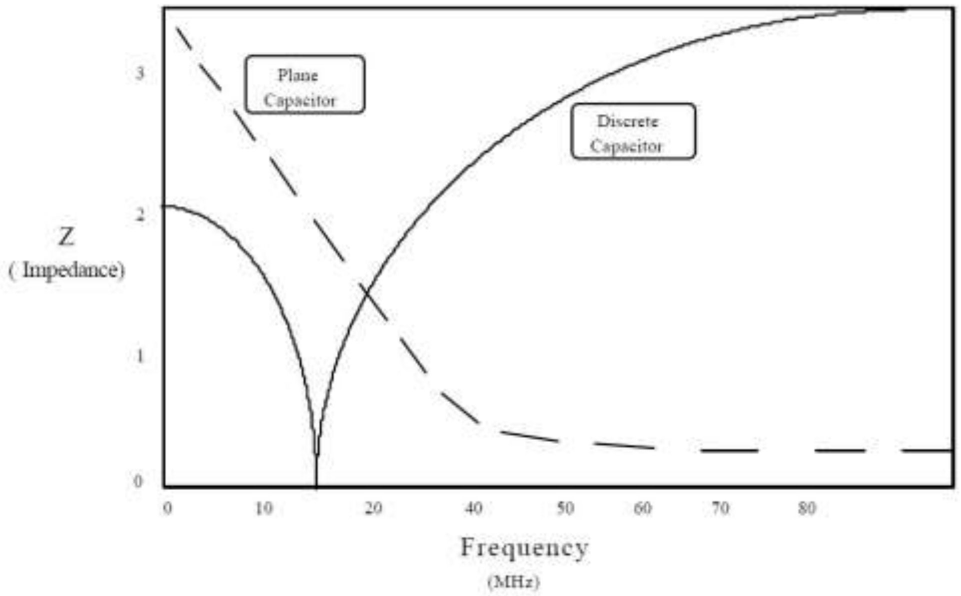


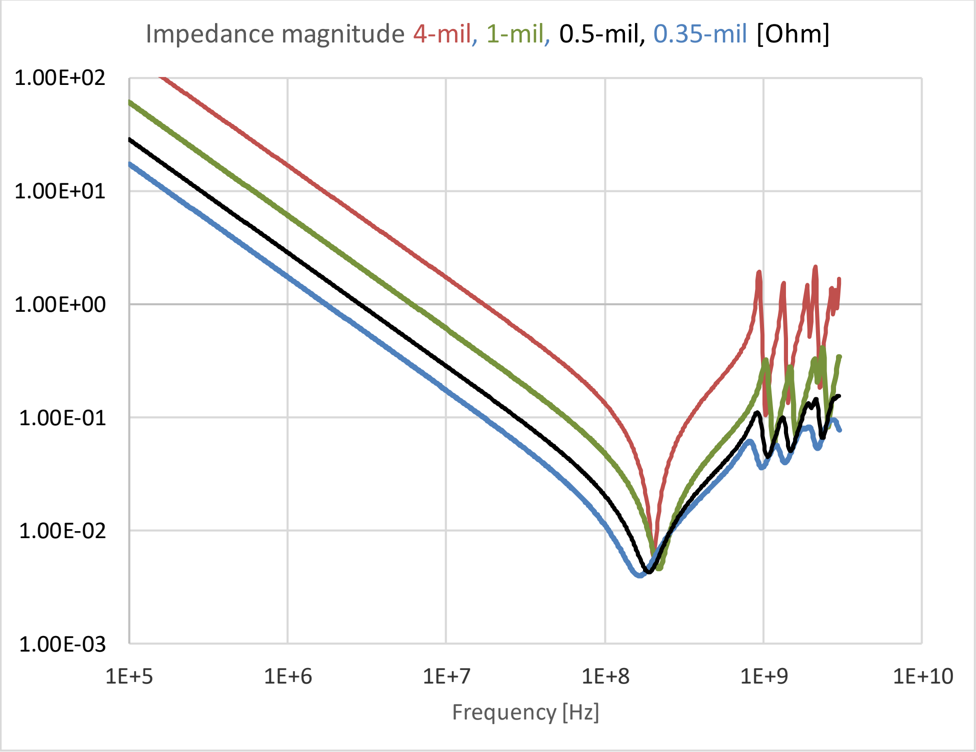


# Misconception 1 About Thin Laminates

## Thin Laminate Impedance Stays Low at High Frequencies

Technical marketing material about thin laminates from 1995.




**Truth:** Self impedance becomes inductive at high frequencies

**Spreading inductance: $\mu_0$*th**

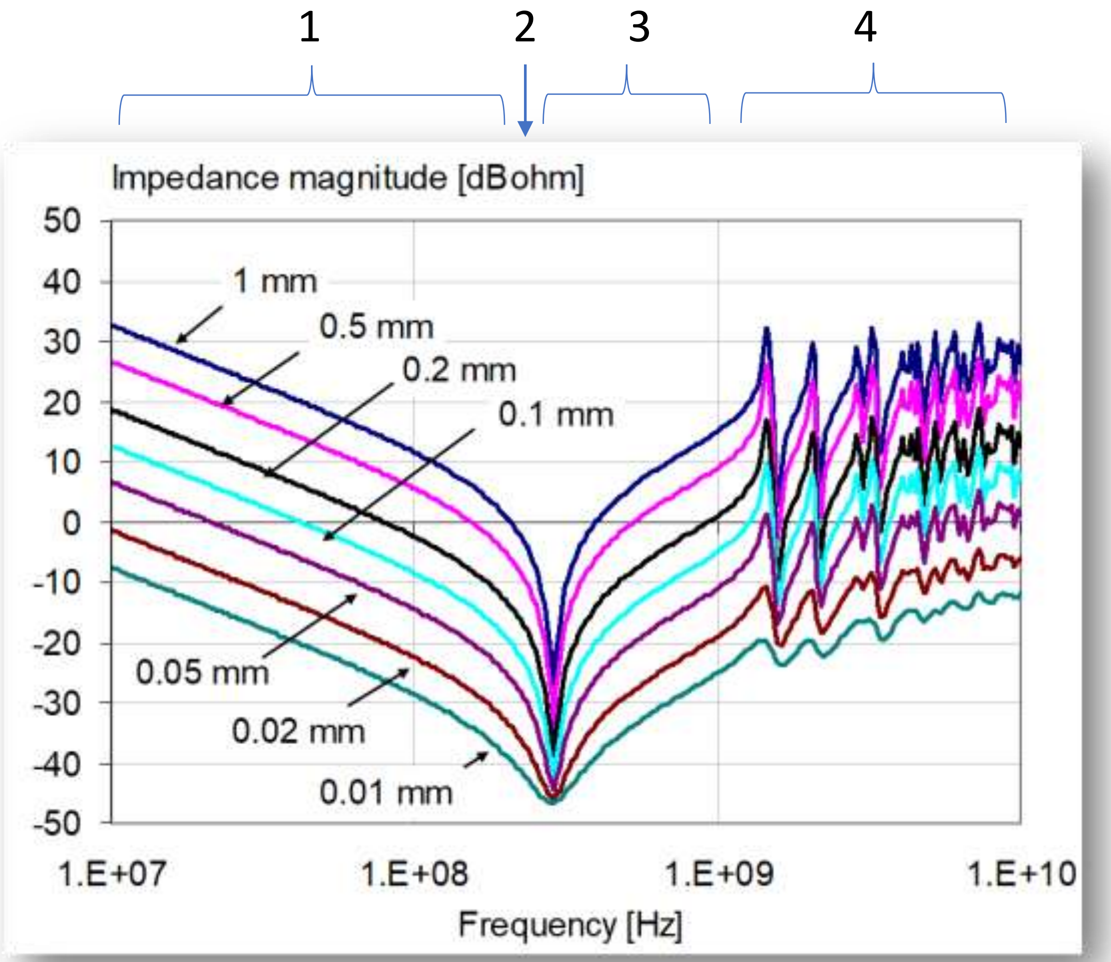
# Benefit 1: Thin Laminates Have Low Inductance

Laminates are like discrete capacitors, they have:

1) A capacitive region
2) Series Resonance
3) An inductive region

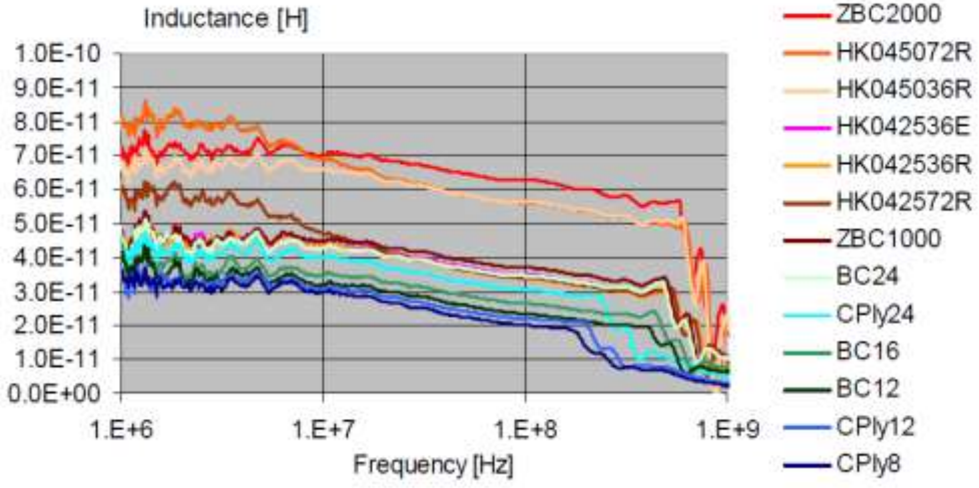
Laminates are unlike discrete capacitors, they have:

1) Modal resonances

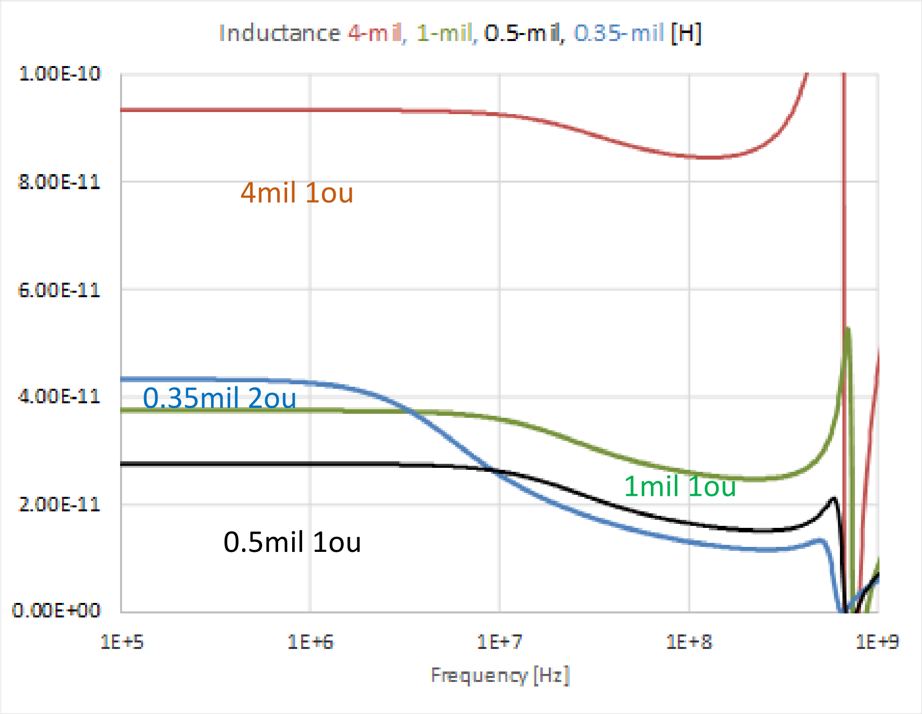


# Benefit 1: Thin Laminates Have Low Inductance

Thin laminate impedance does ‘bounce back’ after the series resonance




“SUN’s Experience with Thin and Ultra Thin Laminates for Power Distribution Applications,” http://www.electrical-integrity.com/Paper_download_files/DC06_TF-THA2_SUN.pdf

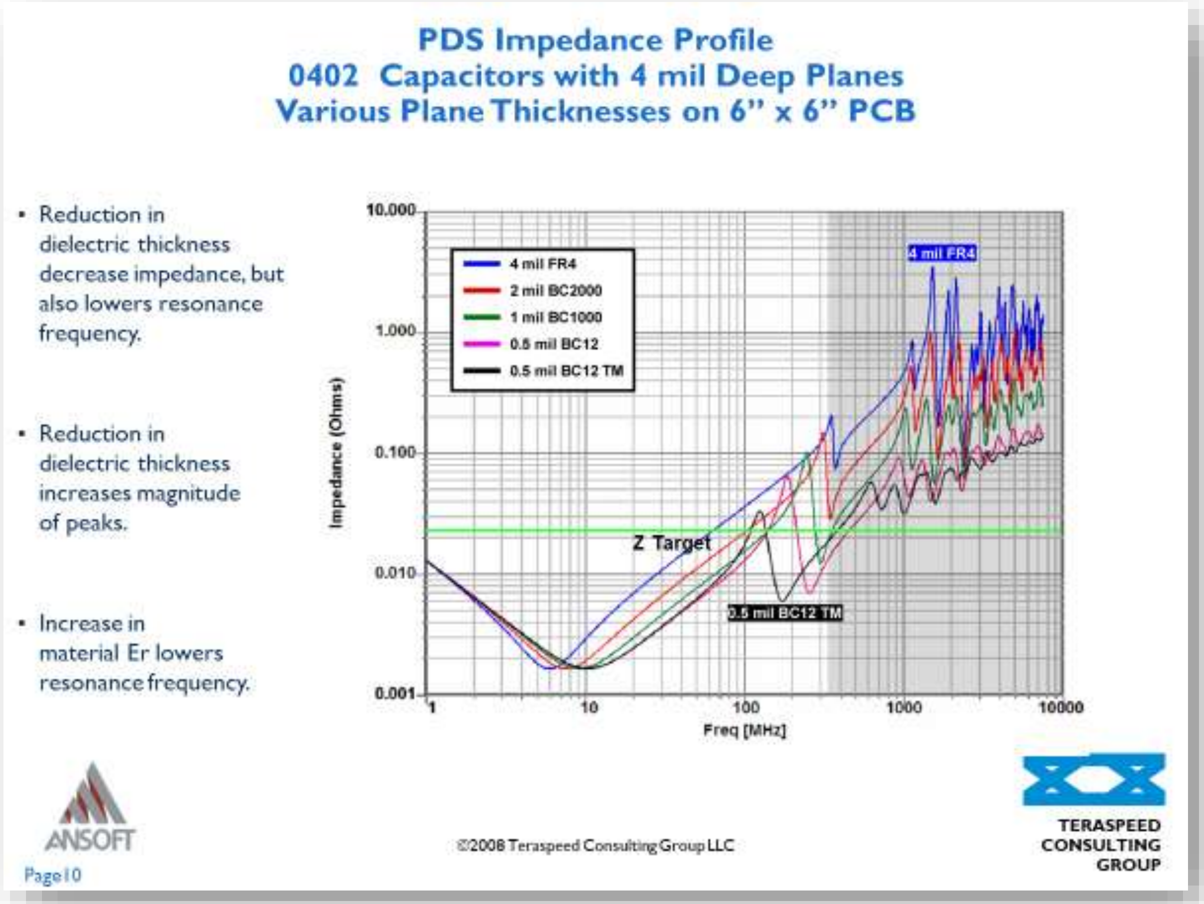



“Measurement to Simulation Correlation on Thin Laminate Test Boards,” http://www.electrical-integrity.com/Quietpower_files/QuietPower-47.pdf

Inductance at low frequencies also depends on copper thickness

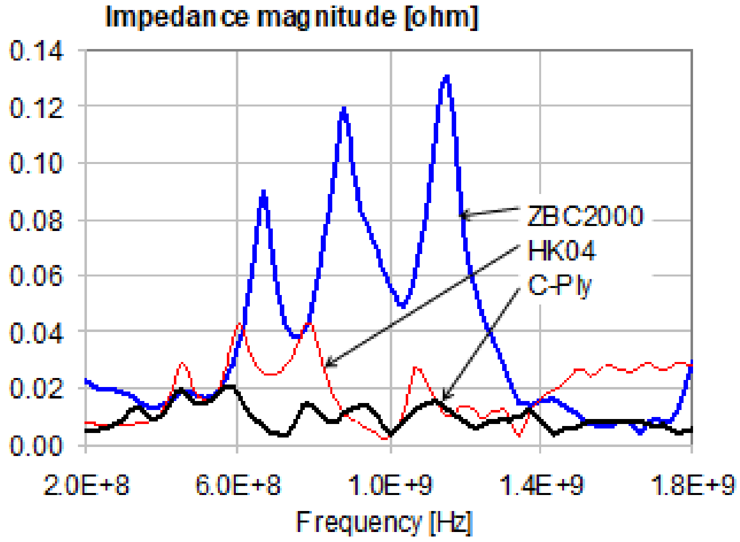
# Benefit 2: Thin Laminates Suppress Modal Resonances

## The rare case: what is bad for SI, good for PI




Scott McMorrow, Steve Weir, Chris Herrick, Steve Pytel, "High Bandwidth Modeling and Simulation of SSO Effects on Single-Ended Switching Performance of Complex FPGA System," DesignCon 2008.

PDN impedance of small populated server board

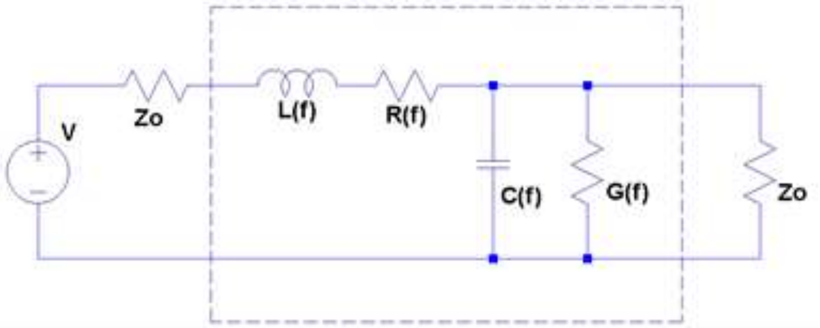



SUN's Experience with Thin and Ultra Thin Laminates for Power Distribution Applications, DesignCon 2006

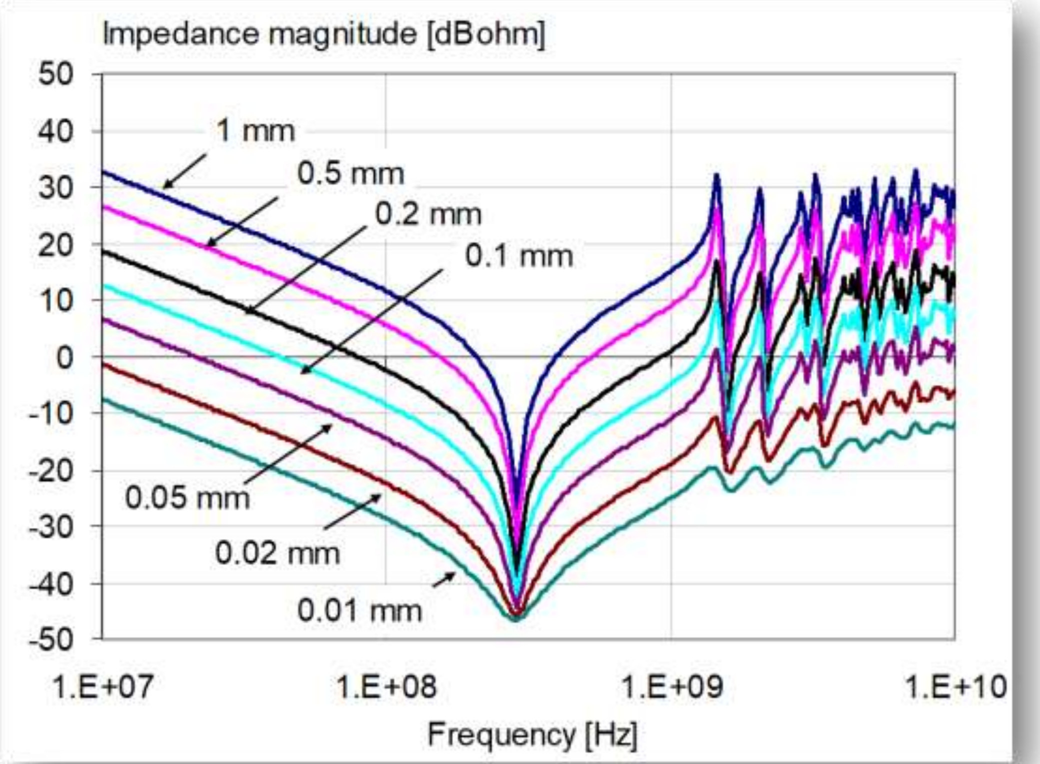
# Benefit 2: Thin Laminates Suppress Modal Resonances

## The rare case: what is bad for SI, good for PI

$$A^{[dB]} = 4.35\left[G(f)Z_0 + \frac{R(f)}{Z_0}\right]$$

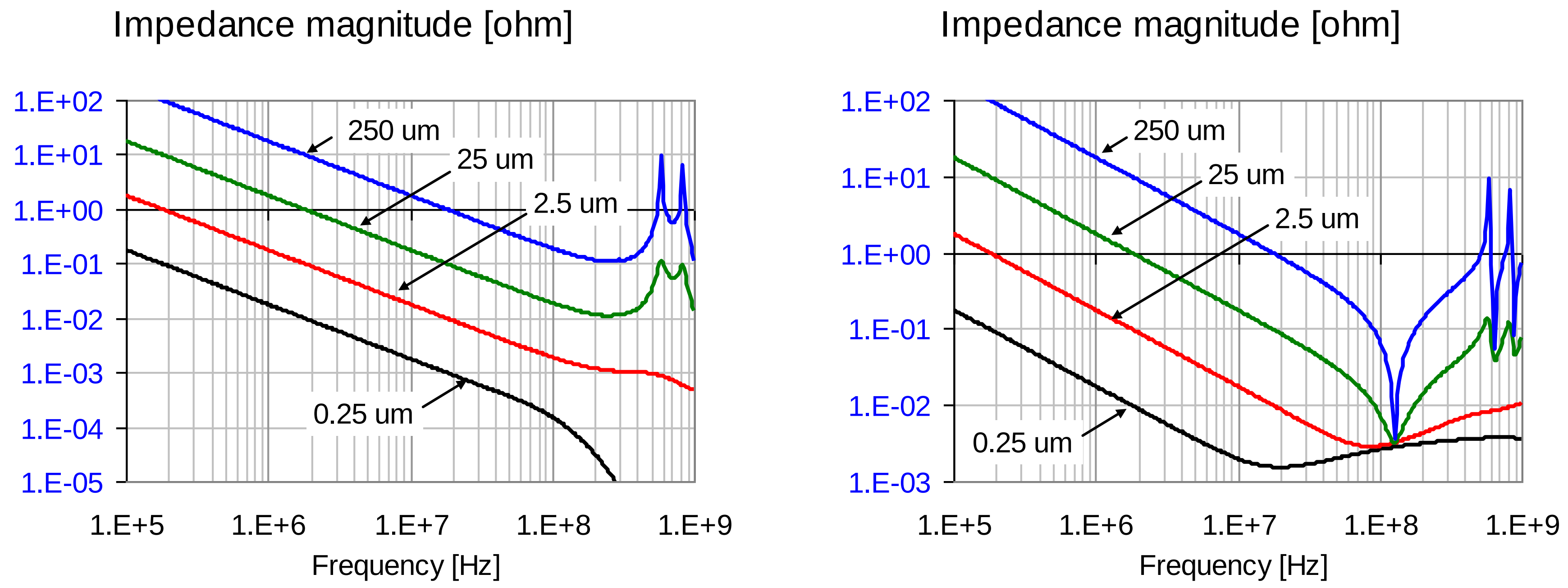



$$Z_p = \frac{532}{\sqrt{\varepsilon_r}}\frac{h}{P} \qquad Z_0 = \sqrt{\frac{L}{C}}$$




"How thin laminates suppress resonances," http://www.electrical-integrity.com/Quietpower_files/QuietPower-15.pdf

# Benefit 3: Thin Laminates Create Low-Pass Filtering




Effect of dielectric thickness on the transfer impedance (left) and self impedance (on the right) of a pair of 25 cm by 25 cm planes, with 35 micron copper on either side. The self impedance magnitude is measured at the center of planes, transfer impedance is between the center and corner.

Frequency-Domain Characterization of Power Distribution Networks. Artech House, 2007, Ch 4.

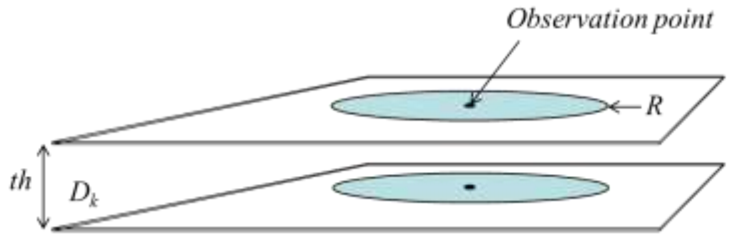
# How About Charge Available for Transients?

## Service Area vs. Thickness and $\varepsilon_r$

How much charge is available for sudden transients?

Capacitance within radius *R*:

$$C = \varepsilon_0 \varepsilon_r \frac{R^2 \pi}{th}$$




*R* radius is determined by how far the charge can travel within $t_r$ time:

$$v = \frac{c}{\sqrt{\varepsilon_r}} \qquad R = v{*}t_r$$

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

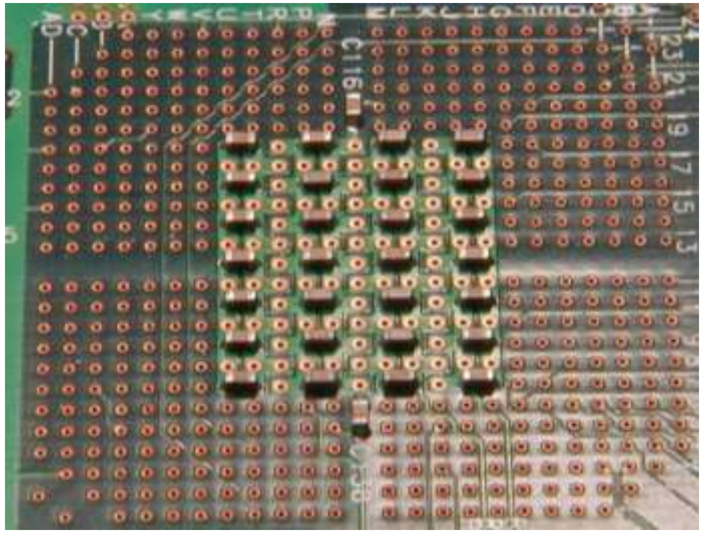
$$C = \varepsilon_0 \varepsilon_r \frac{\left( \frac{t_r}{\sqrt{\varepsilon_r \varepsilon_0 \mu_0}} \right)^2 \pi}{th} = \varepsilon_0 \varepsilon_r \frac{(t_r)^2 \pi}{\varepsilon_0 \mu_0 th} = \frac{\pi}{\mu_0} \frac{t_r^{\,2}}{th}$$

**The available capacitance (and charge) does not depend on $\varepsilon_r$**

# Misconception 2 About Thin Laminates

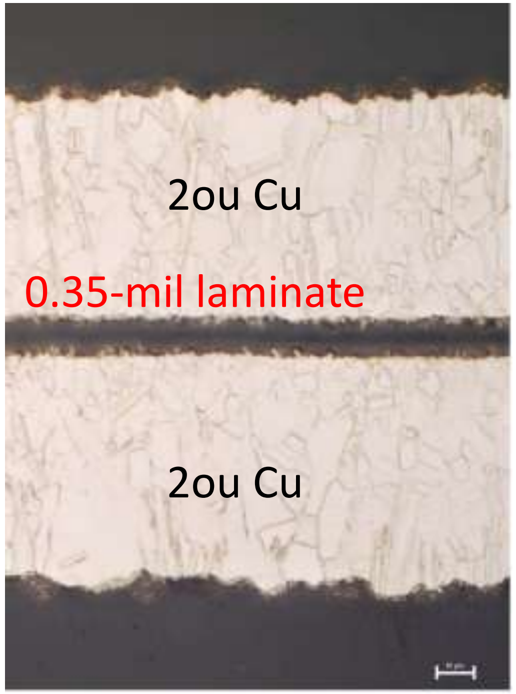
Thin laminates help to reduce the number of capacitors on the board

- The static capacitance of a 2-mil glass-reinforced laminate is approximately 500 pF/inch$^2$.
- A 10" x 10" (25 cm x 25 cm) 2-mil laminate has approximately 50 nF capacitance.
- A 1uF MLCC is a fraction of a penny.
- Many MLCCs on a board may be used for their inductance, not for their capacitance.

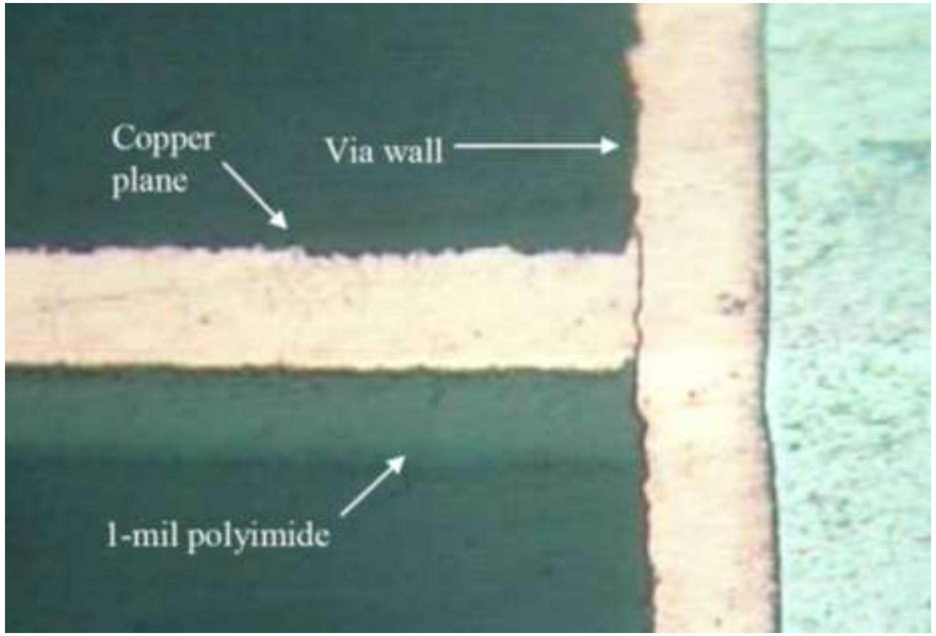


# How About Surface Roughness?

- Copper roughness is bad for SI
- Roughness **would be** good for PI
- But, to avoid shorting and CAF, we can't afford much roughness




Test board courtesy of DuPont



# Benefits of Thin Laminates

- Overall thinner stack-up  >> SI advantage
  - Shorter stubs without back drilling
  - Less discontinuity when signal traces cross power splits
- Lower PDN impedance (lower inductance)
- Higher plane capacitance (important in very low power circuits)
- Lower edge coupling between adjacent power domains
- Lower Q of modal resonances
- Lower edge emission
- Lower lumped resonance magnitude
- Relaxed component placements (lower horizontal inductance)
- Low-pass transfer function
- Overall thinner stack up >> mechanical advantage

# Challenges and Negatives of Thin Laminates

## Electrical

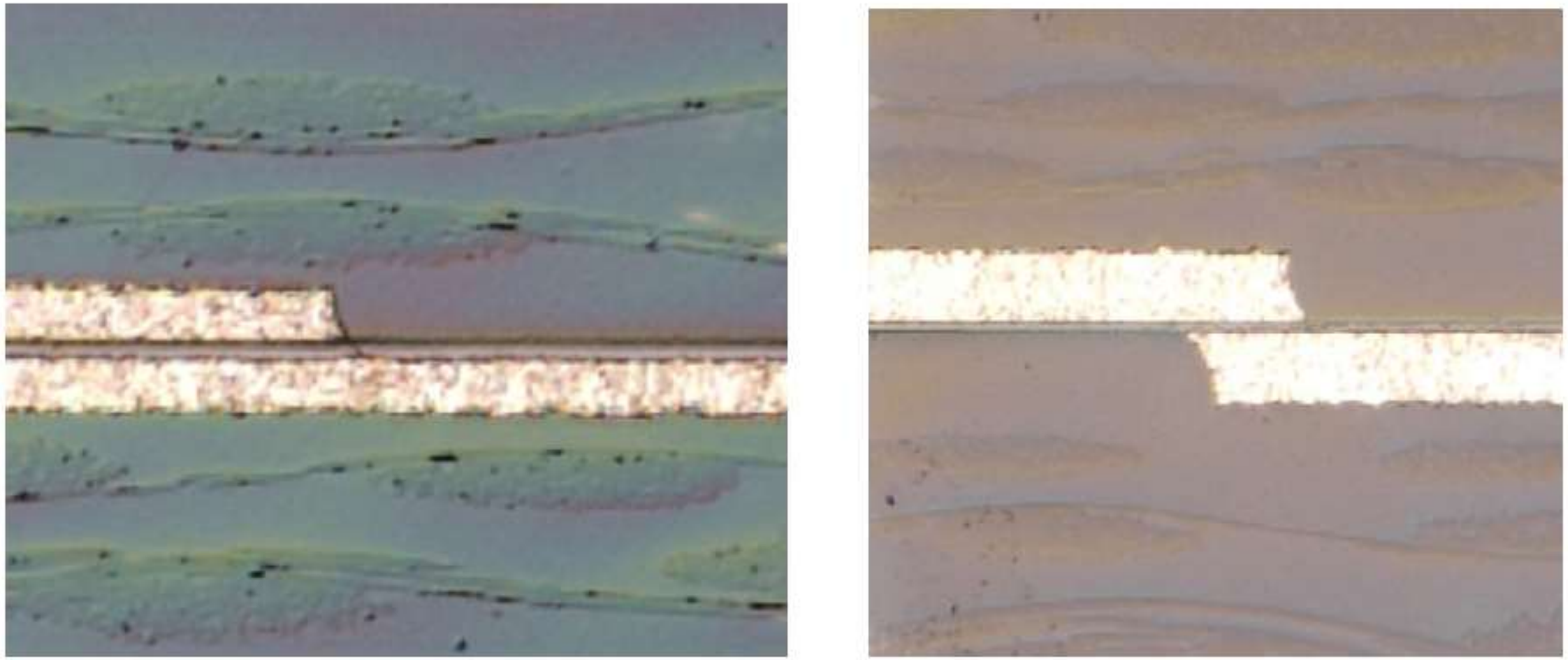
- Single lumped resonance frequency goes lower
- Need lower ESL capacitors for the same effectiveness

## Non-electrical

- Higher laminate cost
  - Applies to the full board
  - Stack up has to be symmetric, need to add laminates in pairs (mostly)
- Higher processing cost (extra steps, potentially lower yield)
- Sequential lamination is needed for the thinnest laminates

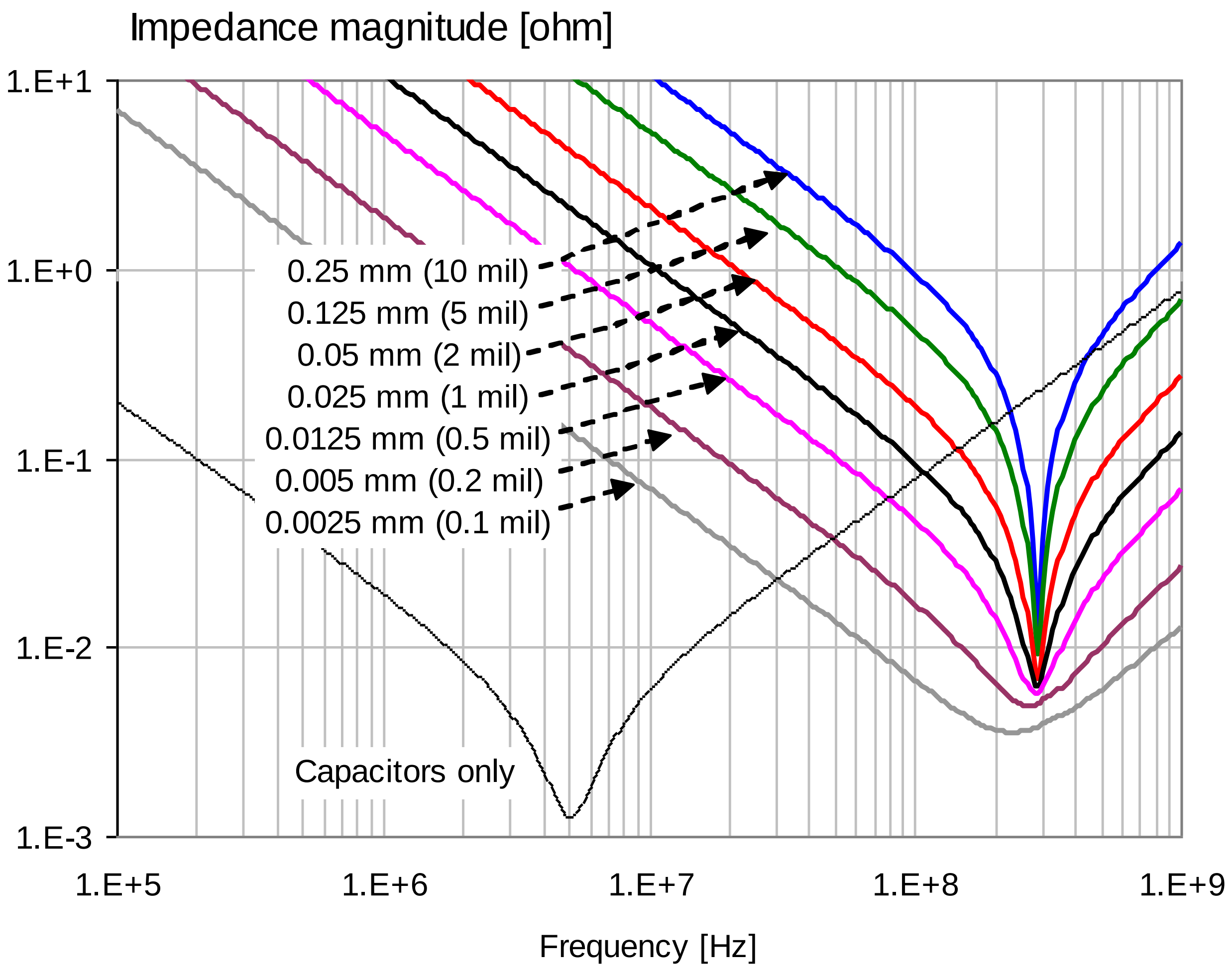
# Challenge: Need Careful Design and Handling

Straight plane edges on top and bottom of laminate should not line up



Copper edge cross-section photos on inner layers with 1-mil dielectric. One-ounce copper (left), two-ounce copper (right). Test boards and cross sections courtesy of DuPont.

# Challenge: Lumped Resonance with Bypass Capacitors

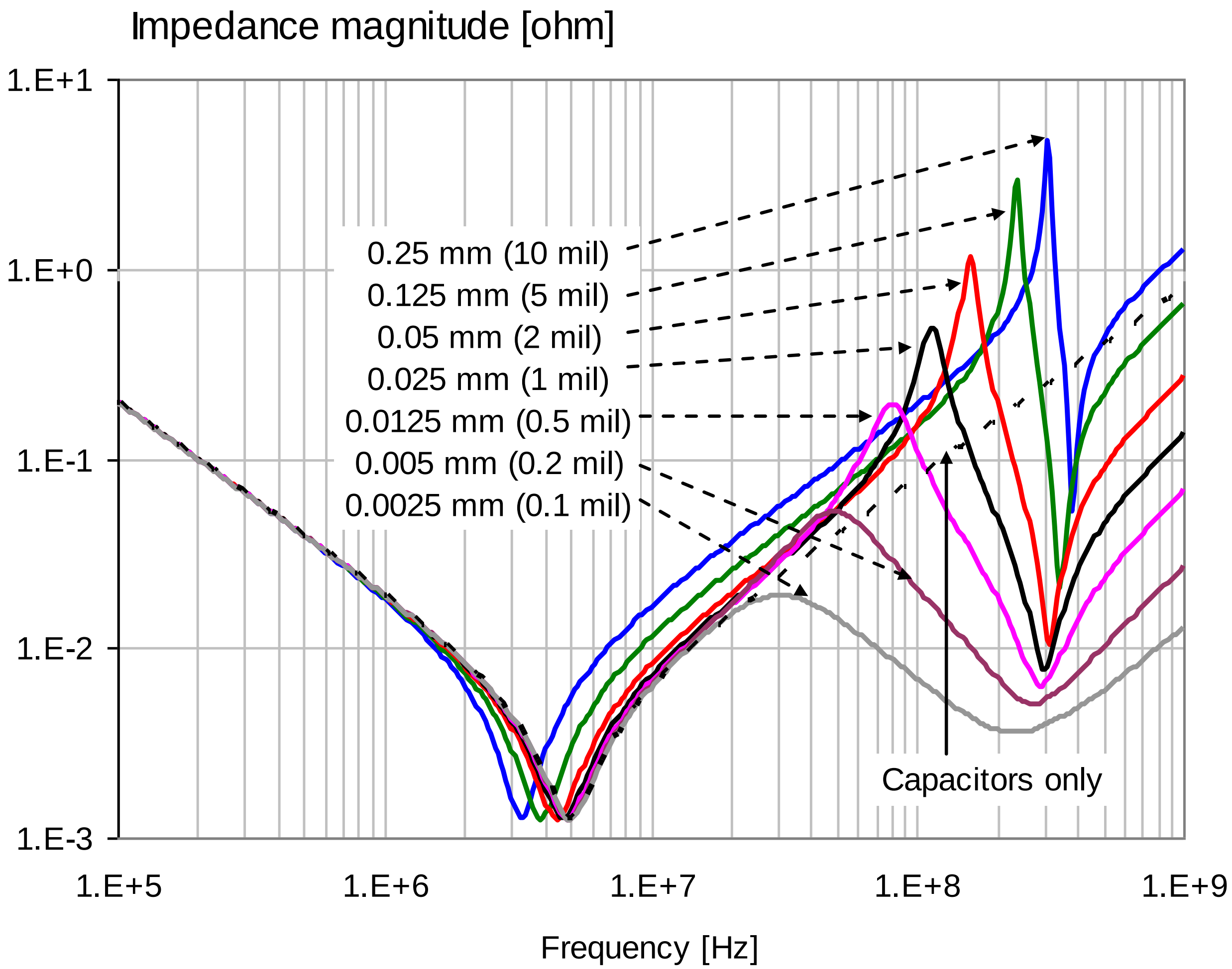



10 x 10 cm FR4 plane

Self impedance in the middle of bare planes

8 pieces of MLCCs 1 μF 10 mΩ 1 nH around 2 x 2 cm square in middle

# Challenge: Lumped Resonance with Bypass Capacitors




10 x 10 cm FR4 plane

Self impedance in the middle with capacitors

8 pieces of MLCCs 1 µF 10 mΩ 1 nH around 2 x 2 cm square in middle

Smaller plane shapes push resonance out.

# Summary

- In high-power PDNs, the main electrical benefits of thin laminate are:
  - Low distribution inductance
  - Suppression of modal resonances
  - Low-pass transfer function
- Thin laminates add cost to the design and are more challenging to process
- Designers need to make an educated decision weighing the pros and cons

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