

# Modeling Physical Interconnects

(Part 3)

**Dr. José Ernesto Rayas Sánchez**

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## Outline

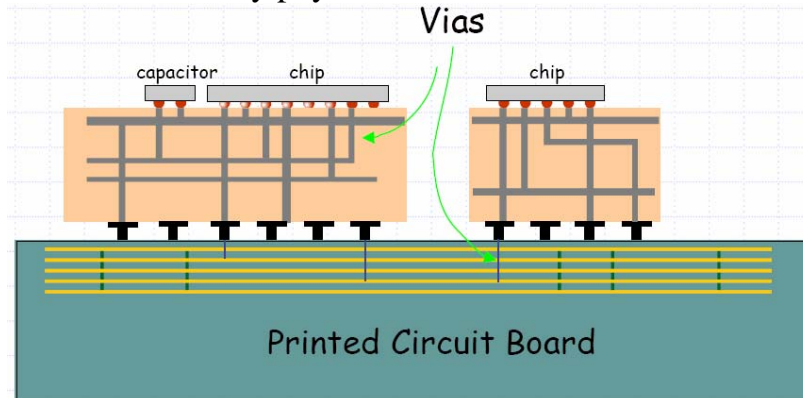
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- Vias
- Vias in PCBs
- Types of vias in PCBs
- Pad and antipad
- Nonfunctional pads
- Modeling vias
- Calculating circuit element values with formulas
- Obtaining circuit element values from EM simulations

## Vias

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- They implement the vertical connections (conductive columns to connect traces on different layers)
- Vias exist at many physical levels:



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(R. Mellitz, 2003)<sub>3</sub>

## Vias in PCBs

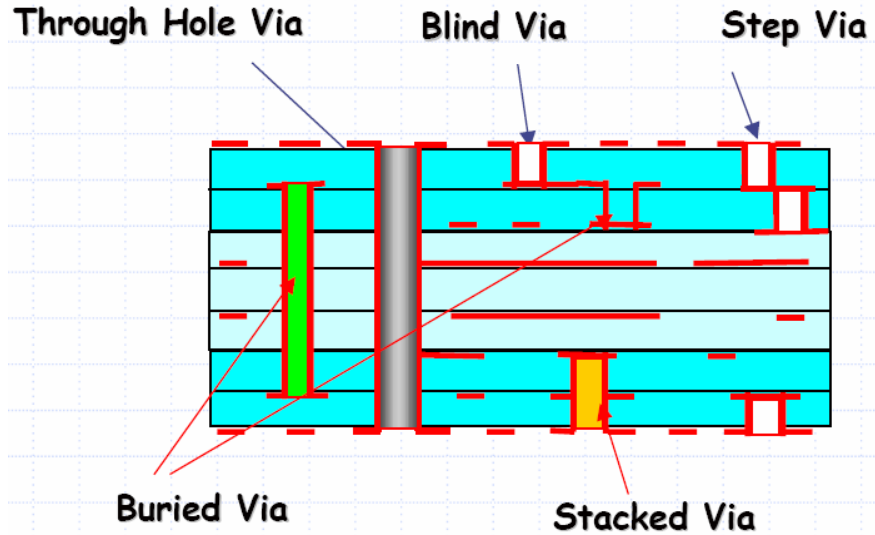
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- They are formed by drilling a hole (either mechanically or with a laser)
- Blind via: a via not passing through the complete PCB
- Through hole via: a via passing through the entire PCB stackup
- Buried via: a via connecting internal layers
- Conducting vias are “plated” with copper
- Plated through hole (PTH): conductive via passing through the entire PCB stackup

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## Types of Vias in PCBs

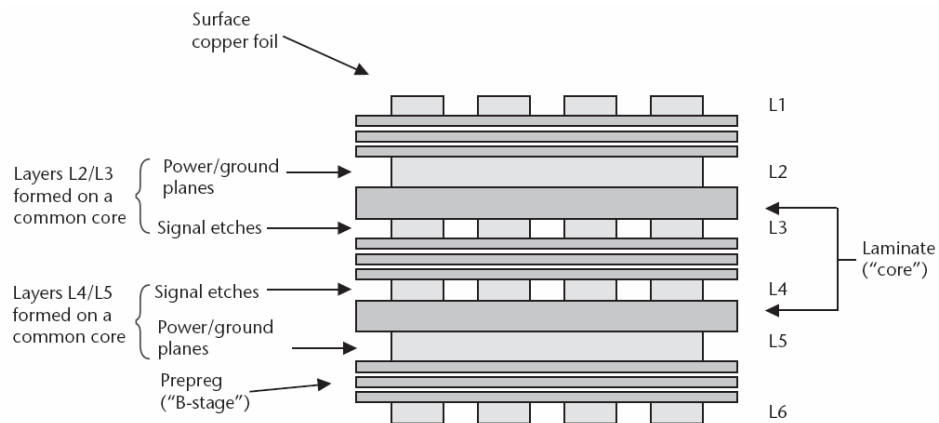


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(R. Mellitz, 2003)<sub>5</sub>

## PCB Stackup

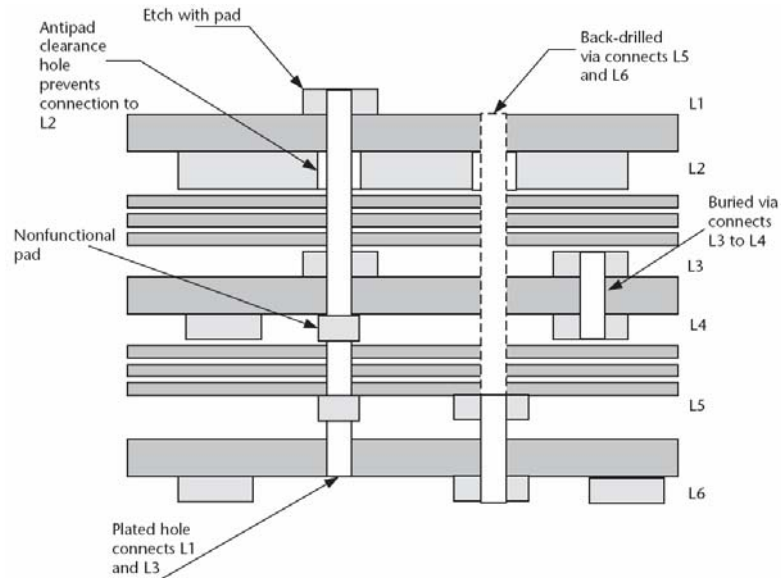
Example showing a 6-layer stackup



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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004)<sub>6</sub>

## Vias in the PCB Stackup

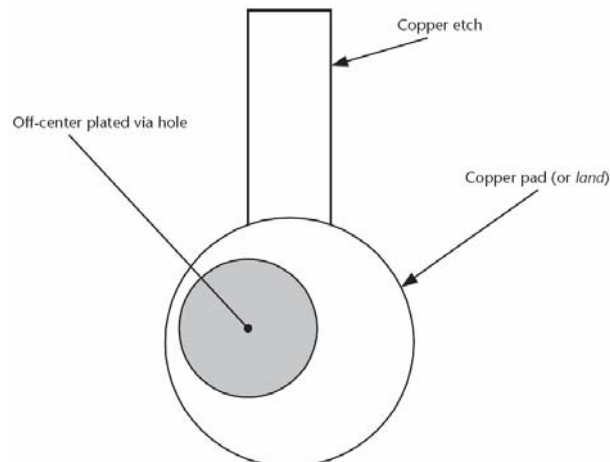


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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004) <sub>7</sub>

## Pad or Land

A ring of copper that surrounds a plated via (to ensure electrical contact to traces even if there is some misalignment)



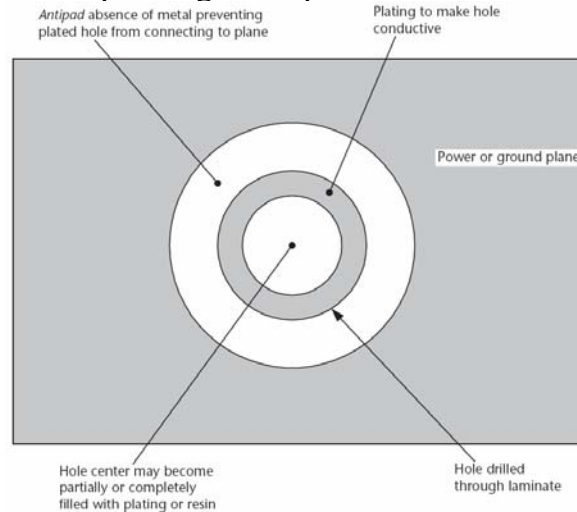
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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004) <sub>8</sub>

## Antipad

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A hole in the power/ground plane to avoid electrical contact



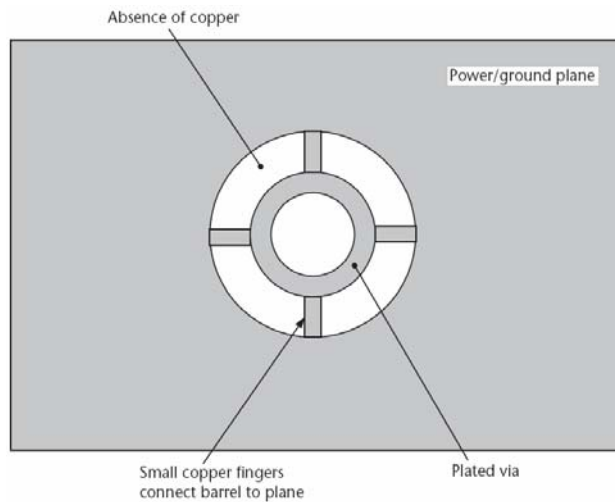
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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004)<sub>9</sub>

## Vias Connecting to Power/Ground Planes

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Small copper fingers are used for thermal isolation

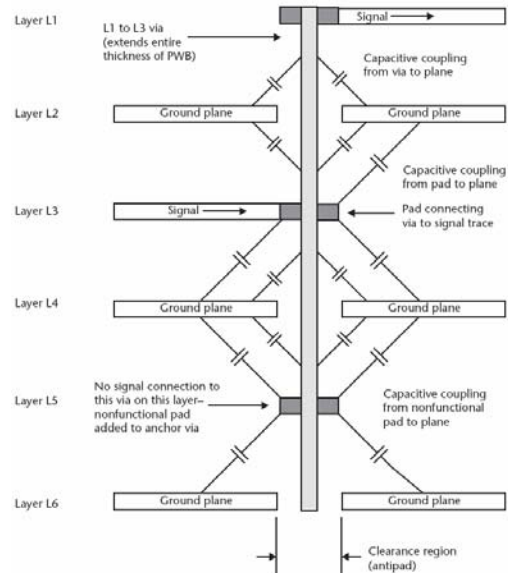


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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004)<sub>10</sub>

## Nonfunctional Pads

- They are used to anchor the via to the laminate
- ☹ They increase unwanted capacitive coupling to ground/power planes
- ☺ Increasing the antipad decreases the coupling

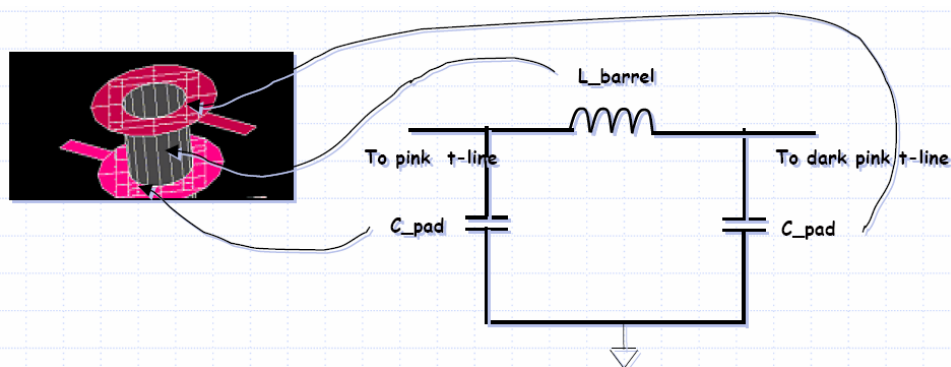


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(S. C. Thierauf, *High-Speed Circuit Board Signal Integrity*, Artech, 2004) <sub>11</sub>

## Modeling Vias

If the via is electrically small (if  $t_{d(\text{via})} > 0.1t_t$ ), it can be modeled with a lumped circuit

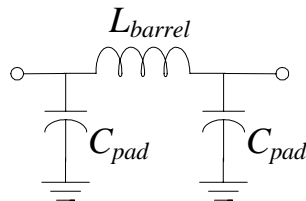


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(R. Mellitz, 2003) <sub>12</sub>

## Modeling Vias (cont)

If the via is electrically small (if  $t_{d(\text{via})} > 0.1t_t$ ), it can be modeled with a lumped circuit



$$L_{\text{barrel}} = 5.08h[\ln(4h/d) + 1] \text{ (nH)}$$

$$C_{\text{pad}} = \frac{1.41\epsilon_r D_1 T}{D_2 - D_1} \text{ (pF)}$$

$D_1$  : pad diameter (in)

$D_2$  : antipad diameter (in)

$T$  : thickness of PCB (in)

$\epsilon_r$ : relative permeability of the PCB

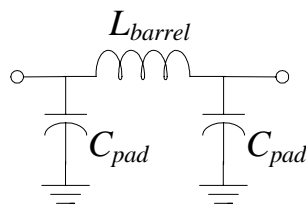
$h$ : via length (in)

$d$ : via diameter (in)

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## Alternative Formula for the Via Inductance

If the via is electrically small (if  $t_{d(\text{via})} > 0.1t_t$ ), it can be modeled with a lumped circuit



$$L_{\text{barrel}} = \frac{\mu_0}{2\pi} \left[ h \ln \left( \frac{h + \sqrt{r^2 + h^2}}{r} \right) + r - \sqrt{r^2 + h^2} \right]$$

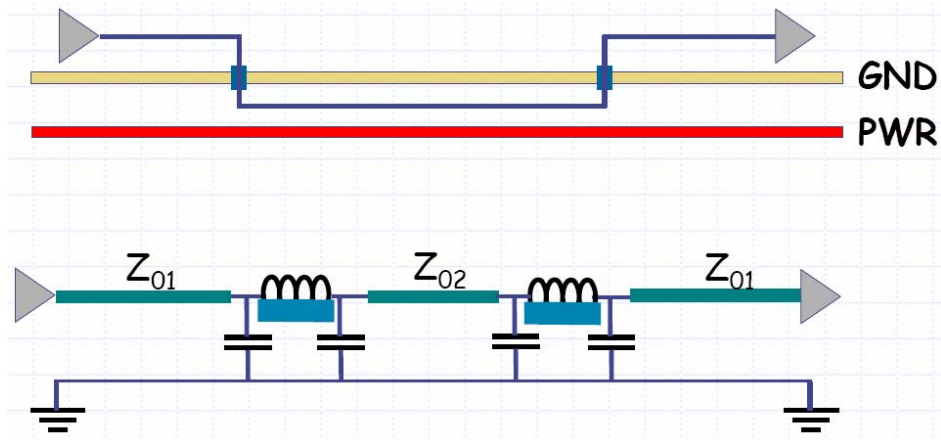
$h$ : via length (m)

$r$ : via radius (m)

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(M.E. Goldfarb and R.A. Pucel, 1991)<sub>14</sub>

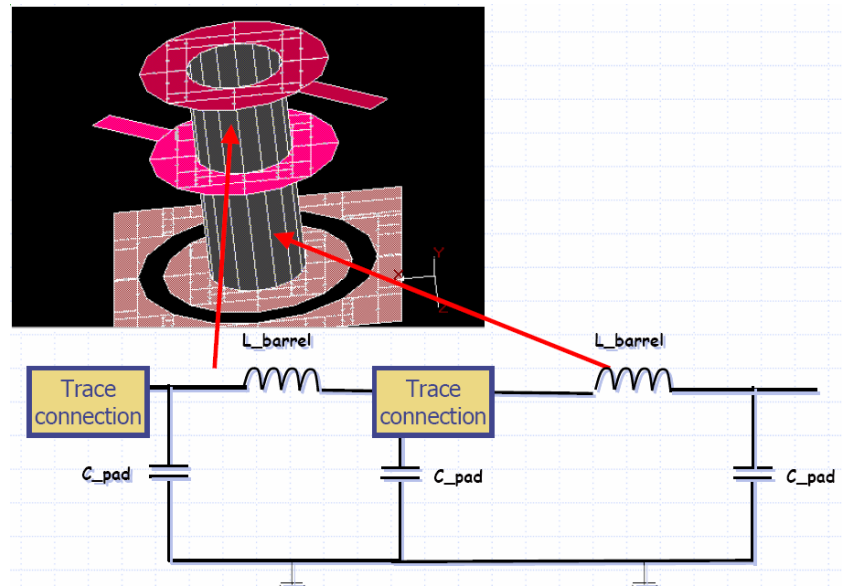
## Modeling Vias – Example



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(R. Mellitz, 2003)<sub>15</sub>

## Modeling a Plated Through Hole Via (PTH)



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(R. Mellitz, 2003)<sub>16</sub>



## Via Modeling through EM Simulation

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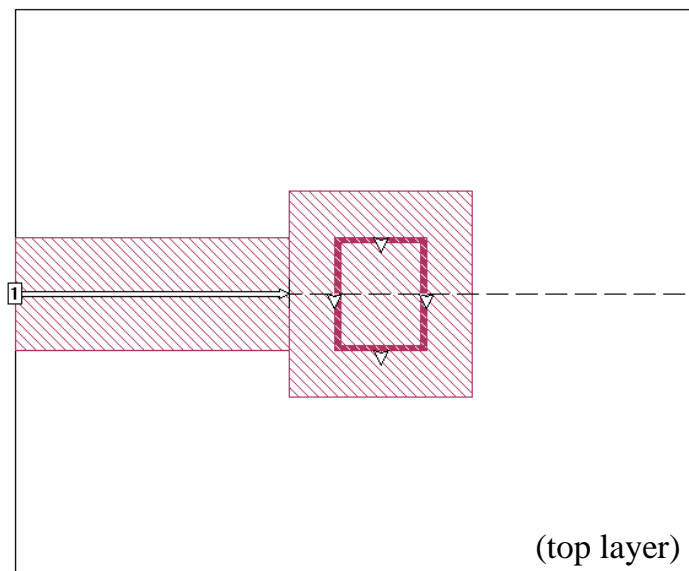
- Some electromagnetic simulators have the capability of automatically synthesizing a lumped circuit model using inductors, capacitors, resistors and mutual inductors
- The equivalent circuit is usually provided in SPICE format
- This method is intended for any electrically small circuit (small with respect to the wavelength at the highest frequency of excitation)
- By using this approach, we can develop very accurate models of vias (with arbitrary geometries), without relying on empirical formulas

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## Modeling a Squared Grounded Via Using Sonnet

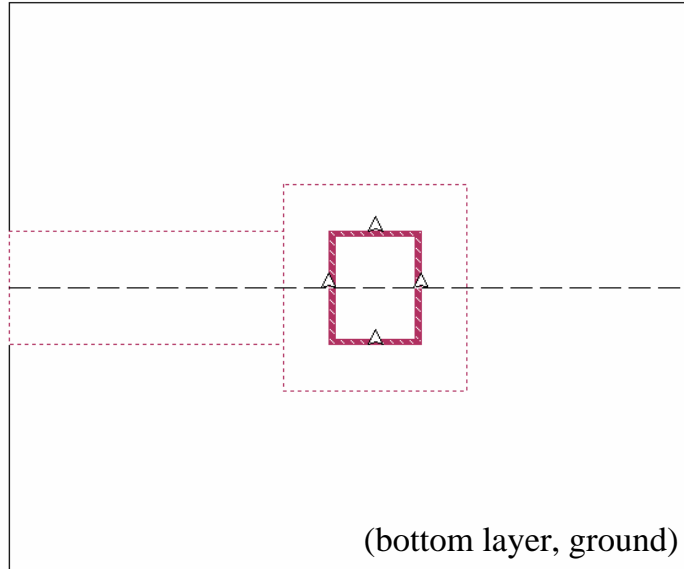
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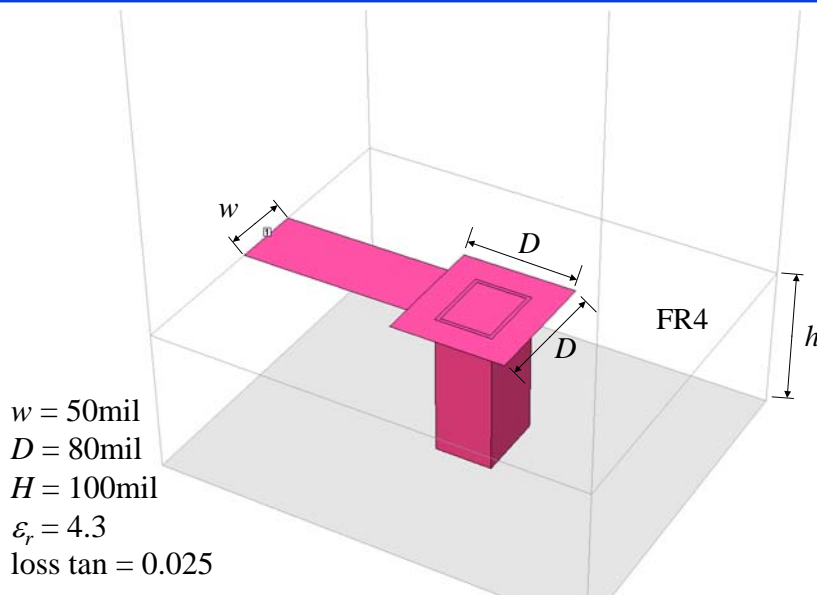
## Modeling a Squared Via Using Sonnet (cont)



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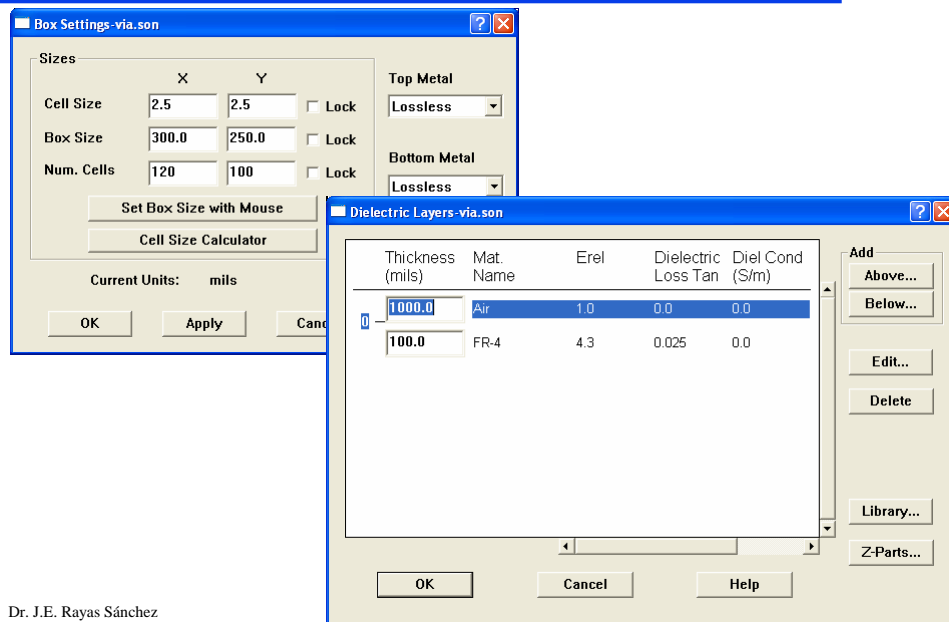
## Modeling a Squared Via Using Sonnet (cont)



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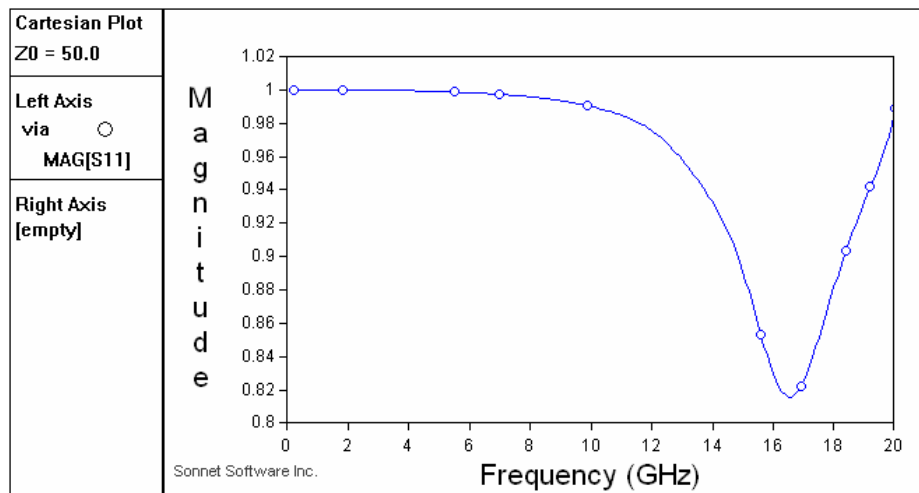
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## Modeling a Squared Via Using Sonnet (cont)



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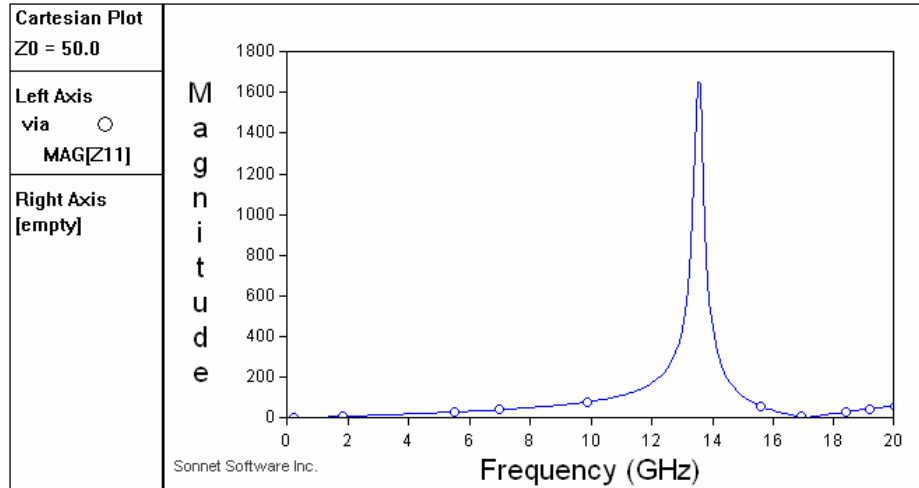
## Modeling a Squared Via Using Sonnet (cont)



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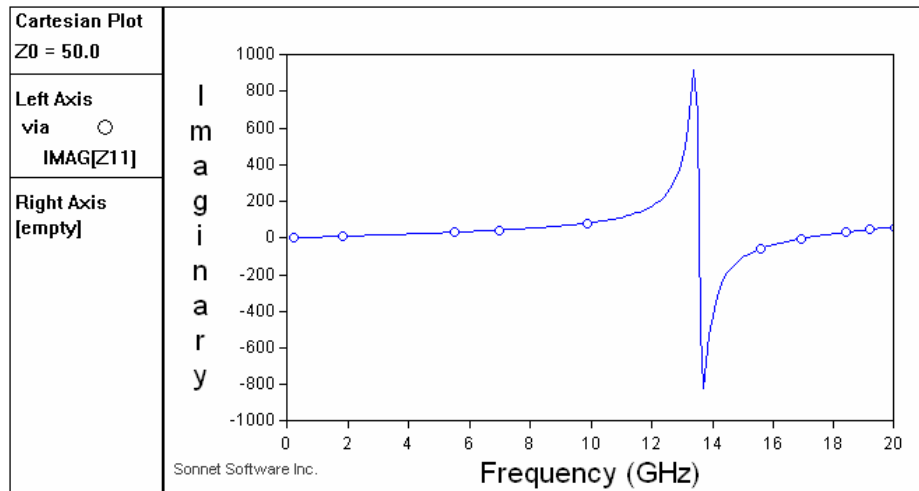
## Modeling a Squared Via Using Sonnet (cont)



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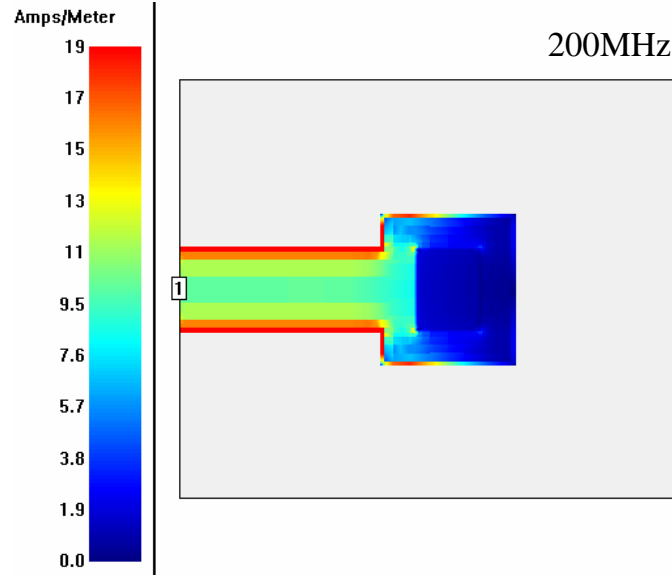
## Modeling a Squared Via Using Sonnet (cont)



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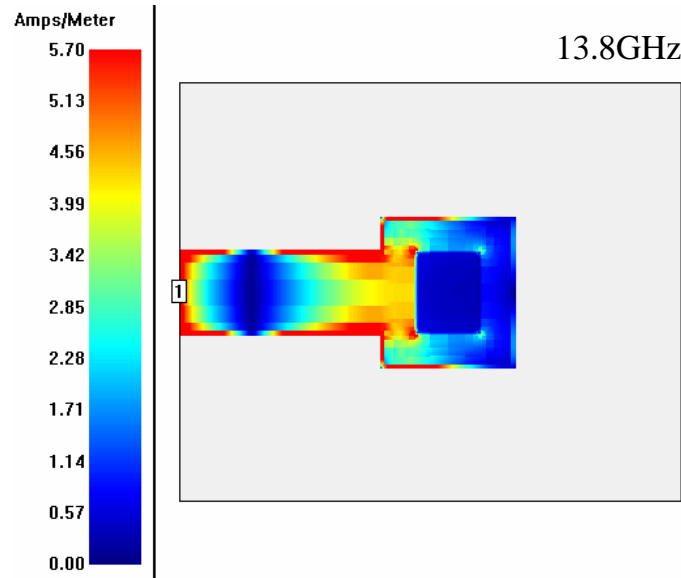
## Modeling a Squared Via Using Sonnet (cont)



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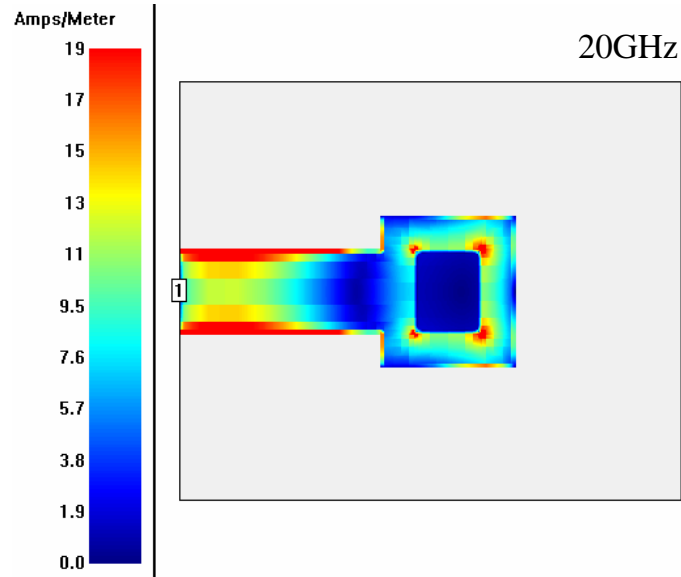
## Modeling a Squared Via Using Sonnet (cont)



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## Modeling a Squared Via Using Sonnet (cont)



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## Modeling a Squared Via Using Sonnet (cont)

```
# Sonnet Data File
# From: emgraph Version : 10.52
# From Emgraph Data: via
# Data File Written: 05/01/2006 20:50:51
# < HDATE 05/01/2006 20:22:31
# < MDATE 05/01/2006 20:22:31
# Spice Data
# Limits: C>0.01pF L<100.0nH R<1000.0Ohms K>0.01
# * Analysis frequencies: 200.0, 300.0 MHz
.subckt SON3_0 1 GND
L_L1 1 GND 0.809395nh
.ends SON3_0

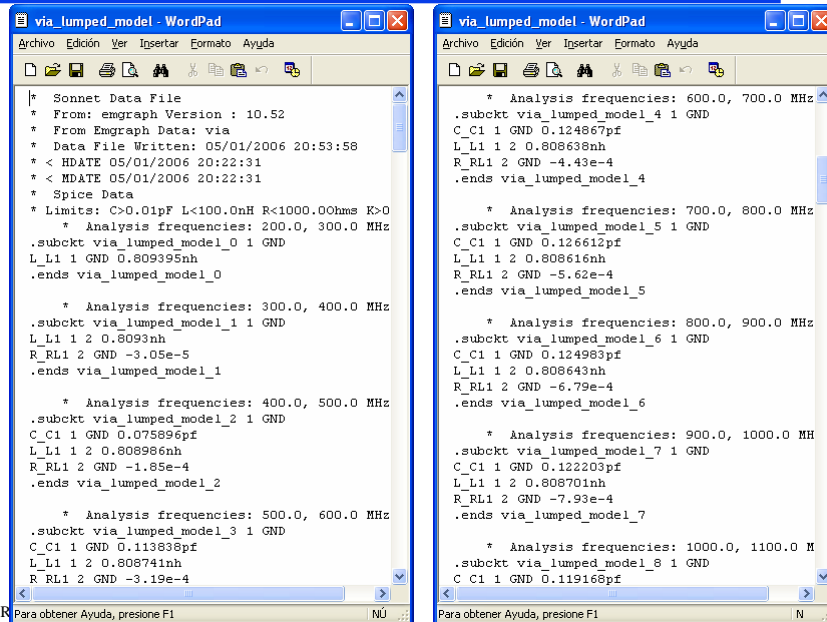
# * Analysis frequencies: 300.0, 400.0 MHz
.subckt SON3_1 1 GND
L_L1 1 2 0.8093nh
R_RL1 2 GND -3.05e-5
.ends SON3_1

# * Analysis frequencies: 400.0, 500.0 MHz
.subckt SON3_2 1 GND
C_C1 1 GND 0.075896pf
L_L1 1 2 0.808986nh
R_RL1 2 GND -1.85e-4
.ends SON3_2
```

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## Modeling a Squared Via Using Sonnet (cont)



```
via_lumped_model - WordPad
* Sonnet Data File
* From: emgraph Version : 10.52
* From Emgraph Data: via
* Data File Written: 05/01/2006 20:53:58
* < HDATE 05/01/2006 20:22:31
* < MDATE 05/01/2006 20:22:31
* Spice Data
* Limits: C>0.01pF L<100.0nH R<1000.0Ohms K>0
* Analysis frequencies: 200.0, 300.0 MHz
.subckt via_lumped_model_0 1 GND
L_L1 1 2 0.809395nh
.ends via_lumped_model_0

* Analysis frequencies: 300.0, 400.0 MHz
.subckt via_lumped_model_1 1 GND
L_L1 1 2 0.8093nh
R_RL1 2 GND -3.05e-5
.ends via_lumped_model_1

* Analysis frequencies: 400.0, 500.0 MHz
.subckt via_lumped_model_2 1 GND
C_C1 1 GND 0.075896pf
L_L1 1 2 0.808986nh
R_RL1 2 GND -1.85e-4
.ends via_lumped_model_2

* Analysis frequencies: 500.0, 600.0 MHz
.subckt via_lumped_model_3 1 GND
C_C1 1 GND 0.113838pf
L_L1 1 2 0.808741nh
R_RL1 2 GND -3.19e-4

via_lumped_model - WordPad
* Analysis frequencies: 600.0, 700.0 MHz
.subckt via_lumped_model_4 1 GND
C_C1 1 GND 0.124867pf
L_L1 1 2 0.808638nh
R_RL1 2 GND -4.43e-4
.ends via_lumped_model_4

* Analysis frequencies: 700.0, 800.0 MHz
.subckt via_lumped_model_5 1 GND
C_C1 1 GND 0.126612pf
L_L1 1 2 0.808616nh
R_RL1 2 GND -5.62e-4
.ends via_lumped_model_5

* Analysis frequencies: 800.0, 900.0 MHz
.subckt via_lumped_model_6 1 GND
C_C1 1 GND 0.124983pf
L_L1 1 2 0.808643nh
R_RL1 2 GND -6.79e-4
.ends via_lumped_model_6

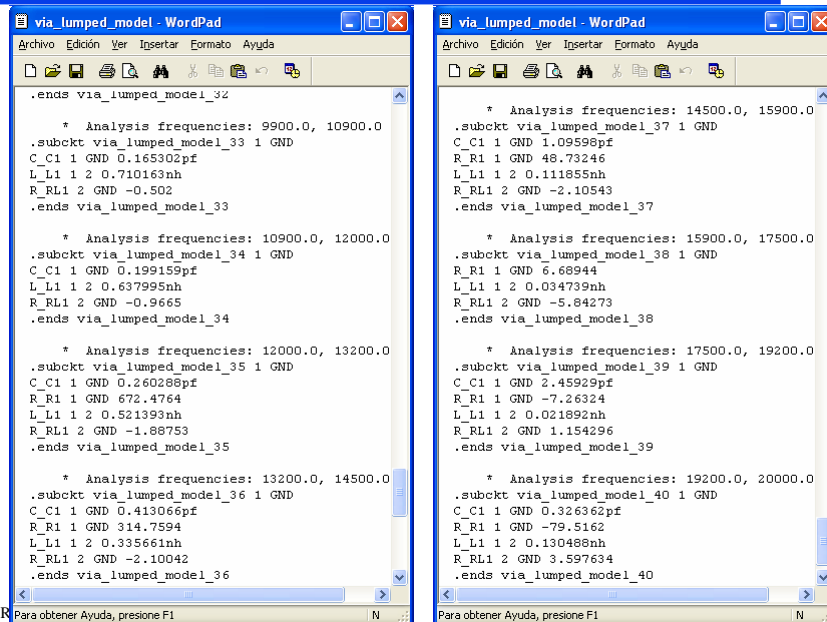
* Analysis frequencies: 900.0, 1000.0 MHz
.subckt via_lumped_model_7 1 GND
C_C1 1 GND 0.122203pf
L_L1 1 2 0.808701nh
R_RL1 2 GND -7.93e-4
.ends via_lumped_model_7

* Analysis frequencies: 1000.0, 1100.0 MHz
.subckt via_lumped_model_8 1 GND
C_C1 1 GND 0.119168pf
```

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## Modeling a Squared Via Using Sonnet (cont)



```
via_lumped_model - WordPad
.ends via_lumped_model_32

* Analysis frequencies: 9900.0, 10900.0
.subckt via_lumped_model_33 1 GND
C_C1 1 GND 0.165302pf
L_L1 1 2 0.710163nh
R_RL1 2 GND -0.502
.ends via_lumped_model_33

* Analysis frequencies: 10900.0, 12000.0
.subckt via_lumped_model_34 1 GND
C_C1 1 GND 0.199159pf
L_L1 1 2 0.637995nh
R_RL1 2 GND -0.9665
.ends via_lumped_model_34

* Analysis frequencies: 12000.0, 13200.0
.subckt via_lumped_model_35 1 GND
C_C1 1 GND 0.260288pf
R_R1 1 GND 672.4764
L_L1 1 2 0.521393nh
R_RL1 2 GND -1.88753
.ends via_lumped_model_35

* Analysis frequencies: 13200.0, 14500.0
.subckt via_lumped_model_36 1 GND
C_C1 1 GND 0.413066pf
R_R1 1 GND 314.7594
L_L1 1 2 0.335661nh
R_RL1 2 GND -2.10042
.ends via_lumped_model_36

via_lumped_model - WordPad
* Analysis frequencies: 14500.0, 15900.0
.subckt via_lumped_model_37 1 GND
C_C1 1 GND 1.09598pf
R_R1 1 GND 48.73246
L_L1 1 2 0.111855nh
R_RL1 2 GND -2.10543
.ends via_lumped_model_37

* Analysis frequencies: 15900.0, 17500.0
.subckt via_lumped_model_38 1 GND
R_R1 1 GND 6.68944
L_L1 1 2 0.034739nh
R_RL1 2 GND -5.84273
.ends via_lumped_model_38

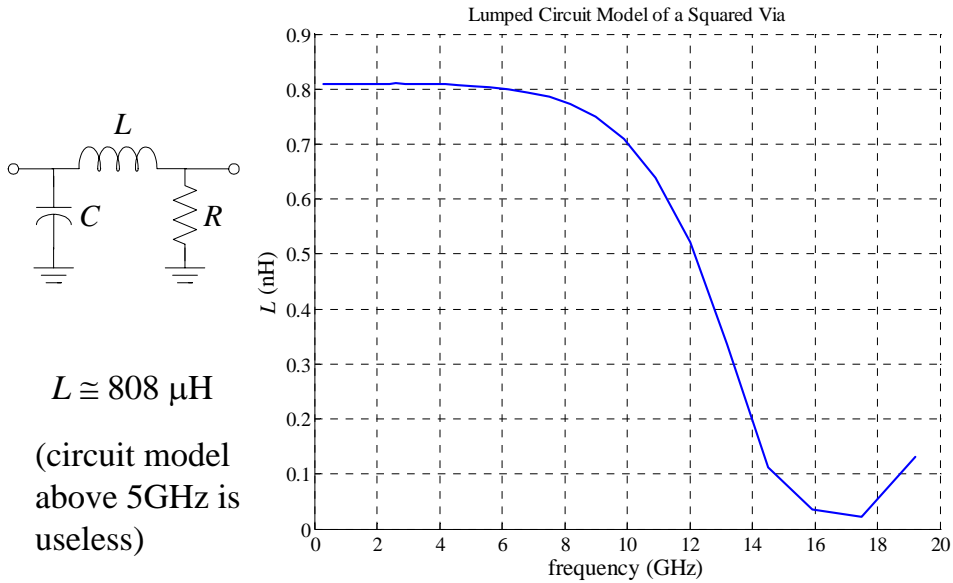
* Analysis frequencies: 17500.0, 19200.0
.subckt via_lumped_model_39 1 GND
C_C1 1 GND 2.45929pf
R_R1 1 GND -7.26324
L_L1 1 2 0.021892nh
R_RL1 2 GND 1.154296
.ends via_lumped_model_39

* Analysis frequencies: 19200.0, 20000.0
.subckt via_lumped_model_40 1 GND
C_C1 1 GND 0.326362pf
R_R1 1 GND -79.5162
L_L1 1 2 0.130488nh
R_RL1 2 GND 3.597634
.ends via_lumped_model_40
```

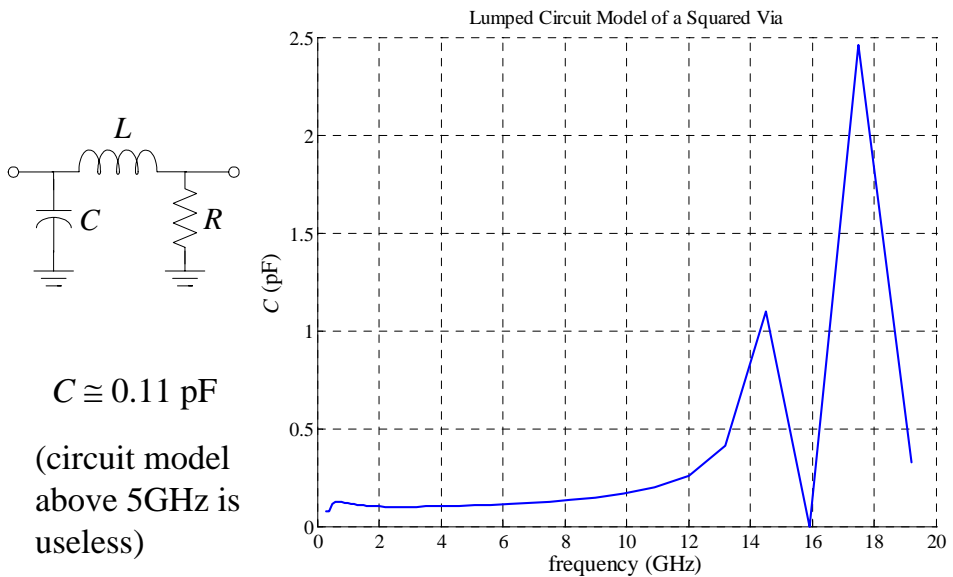
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## Modeling a Squared Via Using Sonnet (cont)

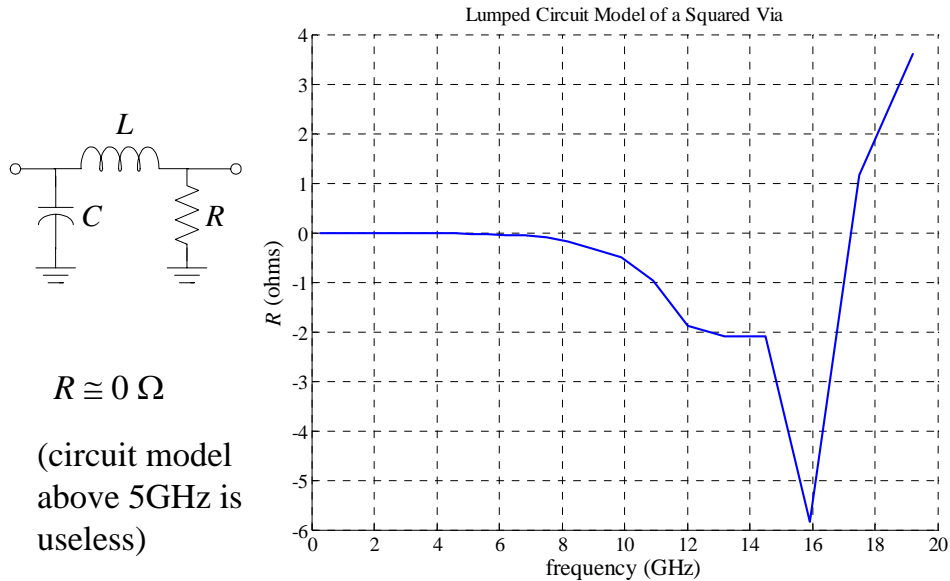


## Modeling a Squared Via Using Sonnet (cont)





## Modeling a Squared Via Using Sonnet (cont)



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## Estimating $L$ with Formulas

Taking  $h = 100\text{mil}$ ,  $d = 50\text{mil}$

- Using Johnson's formula:

$$L_{\text{barrel}} = 5.08h[\ln(4h/d) + 1] = 1.5644 \text{ nH}$$

- Using Goldfarb's formula: ( $r = d/2$ )

$$L_{\text{barrel}} = \frac{\mu_0}{2\pi} \left[ h \ln \left( \frac{h + \sqrt{r^2 + h^2}}{r} \right) + r - \sqrt{r^2 + h^2} \right] = 0.6675 \text{ nH}$$

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