Simulating Complex Power-Ground Plane Shapes with Variable-Size Cell SPICE Grids

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Outline

- Uniform, rectangular plane models
- Need for adaptive, non-uniform grids
- Impedance profiles with various cutouts
- Hardware correlation with adaptive grid
- Conclusions
Conductive plane pair with dielectric separation:

Upper conductor

Dielectric material

Lower conductor

Grid subcircuit model:

Subckt: L_line_e

Subckt: L_line_g

X cells

Y cells

Simulation Model for Plane Pairs

(Rectangular and Uniform)
Irregular Plane Shape with Cutouts
Symmetrical Cutout in Middle (1)

- 1/16” FR4 double-sided 4”x6” rectangular plane pair
- Transfer impedance along shorter side
- Removed copper
  - None
  - 0.5”x0.75” rectangular cutout
  - 1”x1.5” rectangular cutout
  - 2”x3” rectangular cutout
  - 3”x5” rectangular cutout
Symmetrical Cutout in Middle (2)

Impedance magnitude [ohm]

Frequency [Hz]

- full
- 0.5x0.75
- 1.0x1.5
- 2.0x3.0
- 3.0x4.5

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Symmetrical Cutout in Middle (3)

Percentage frequency change over percentage copper removed

0.5”x0.75”
1.0”x1.5”
2.0”x3.0”
3.0”x5.0”

Relative copper area removed [%]

0 10 20 30 40 50 60 70

Frequency of first modal resonance peak

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Symmetrical Slot in Middle (1)

- 1/16” FR4 double-sided 4”x6” rectangular plane pair
- Transfer impedance along shorter side
- Slot in middle, 0.125” wide
  - None
  - 0.75” rectangular cutout
  - 1.5” rectangular cutout
  - 3” rectangular cutout
  - 4.5” rectangular cutout
Symmetrical Slot in Middle (2)

Impedance magnitude [ohm]

Frequency [Hz]

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Symmetrical Slot in Middle (3)

Percentage frequency change over percentage copper removed

Relative copper area removed [%]

0 0.5 1 1.5 2 2.5 3.0" 4.5"

Frequency of first modal resonance peak

Complex plane shapes

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Cut from Side (1)

- 1/16” FR4 double-sided 3”x6” rectangular plane pair
- Transfer impedance along 1” on side
- Cut from side, 0.03” wide
  - None
  - 0.5” cut
  - 1” cut
  - 2” cut
  - 3” cut
  - 4” cut
  - 5” cut
Cut from Side (2)

Impedance magnitude [ohm]

Frequency [Hz]

- full
- 0.5" cut
- 1" cut
- 2" cut
- 3" cut
- 4" cut
- 5" cut

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Cut from Side (3)

Percentage frequency change over percentage copper removed

<table>
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<th>0</th>
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<th>0.4</th>
<th>0.6</th>
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Limitations of Rectangular Uniform Grids

- Many cells may fall outside of shape
- SPICE run-time grows sharply with node numbers
  - Unnecessary nodes increase run time
  - Cant switch to fine mesh in sensitive areas
- Modal resonances may not be captured correctly
Cell and Diamond Definitions

Node
Cell
Segment

Diamond

Diamond1
Diamond2
Diamond3
Diamond4

$F_{\text{upper}}$
$F_{\text{lower}}$
$F_{\text{pair}}$

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Definitions of Example Shape

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Grid with Adaptive Sub Gridding
Correlation on Modal Resonances (1)

Example shape from Slide 4:
- Irregular outline
- Cutouts
Correlation on Modal Resonances (2)

Self-impedance at white arrow

Uniform grid:
- Overestimates static capacitance
- Overestimates resonance frequencies

Adaptive grid:
- Good correlation

Impedance measured, simulated: adaptive grid and simulated: fixed grid [ohm]

Fixed uniform grid

Measured

Adaptive grid

Frequency [Hz]

1.E+07 1.E+08 1.E+09
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Conclusions

• Odd shapes, cutouts and perforations change
  – Static capacitance
  – Modal resonances

• Modal resonances do not scale with static capacitance

• Adaptive, non-uniform plane models can
  – Allow for finer mesh in critical areas
  – Capture modal resonances of odd shapes
  – Capture signatures of perforated planes

• Adaptive grid showed good hardware correlation
Correlation on Perforated Plane (1)

1.8”x1.6”x0.002”
Measured in the middle, front/back
Via pair: 20mil drill, 50-mil center-to-center
TDR source:
• 150psec
• 50 ohm
TDT input:
• 50 ohm
Correlation on Perforated Plane (2)

Adaptive grid captures accurately:

- Plane perforations
- Edge reflections