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

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Abstract:

Power and ground planes can be simulated with rectangular uniform SPICE grids, or by analytically evaluating the double series of modal resonances. For nonrectangular shapes, Transmission Matrix Method can be used. For odd shapes, irregular outlines, cutouts and perforations, a variable-size cell grid is shown to be effective and sufficiently accurate. The adaptive grid preserves the static capacitance of the planes, calculates the modal resonances accurately in the presence of cutouts, and can also account for the perforations of planes.

I. Introduction

Impedance vs. frequency profiles of power-ground plane pairs can be obtained in several different ways. For rectangular shapes, SPICE grids with square or rectangular unit cells are effective [1], or the double modal resonance series can be analytically evaluated [2]. For non-rectangular shapes, the Transmission Matrix Method was introduced [3]. Complicated perforated odd shapes and cutouts of the planes, however, have not yet been reported having been analyzed with the above methods.

II. Limitations of uniform grids

As an example, lets consider the power-ground plane shape of Figure 1. Figure 2 shows the outline of the highlighted plane shape with a 0.25” geometrically uniform square grid fitted over its envelope. The uniform grid has 28 cells horizontally and 20 cells vertically, totaling 28*20=560 cells and (28+1)*(20+1)=609 nodes.

There are several limitations related to the uniform rectangular grid.

- Dependent on the actual outline and cutouts, there may be unnecessary cells and nodes in the uniform grid. In this example, out of the total of 560 cells (and 609 nodes), altogether there are 91 cells outside of the actual plane shape
- In SPICE, run-time grows sharply as the number of nodes increases. This imposes limitations in several ways:
    - Unnecessary nodes increase the run time without the benefit of higher resolution/accuracy.
    - There may be areas where smaller grid cells may be necessary: for instance around odd-shaped outline contours, or in perforated areas. If the entire plane is meshed with the smallest grid size, the total grid number may increase unnecessarily
- Modal resonances may not be captured correctly with uniform grids. One of the major roles of SPICE models of planes is to capture modal resonances so that bypass capacitors can be applied properly to smooth out the impedance profile. Modal resonance frequencies depend on the possible standing-wave patterns, which is determined by the actual boundary shapes and cutouts, and if not captured accurately, the simulated resonance frequencies are in error.

III. Adaptive grid

To handle complex outline shapes, results are shown below with an adaptive, variable-size cell SPICE grid, featuring the following major characteristics:

- Grid nodes stay on rectangular grids with square unit cells

- The SPICE grid uses varying degree of coarser grid in solidly filled areas, and gradually converges into finer mesh around the shape's outline and (possible) inner cutout contours
- The resulting SPICE grid preserves the actual static plane-capacitance by
  - Dropping cells completely, which are not at least partly on the plane shapes, and
  - Adjusting the electrical parameters of unit cells, which are either not entirely on the plane shape or are not solidly filled (e.g., due to antipads). See Figure 3 for illustration.

In each unit cell, the amount of metal within the unit cell's area is calculated separately for the two conductive planes, and the conductive loss values are adjusted according to those fill ratios. The common set of the two planes' metal contents is also calculated (as shown in Figure 3), and it is used to adjust the transmission characteristics of the SPICE grid elements.

To further preserve the static capacitance value of planes, as indicated in Figure 4, compensating capacitors are introduced in the SPICE grid to account for the missing coverage on the boundary of different-size unit cells.

Finally, following the same procedure, multiple plane pairs connected in parallel by vias can be handled as separate pairs first, then the SPICE grids of individual pairs can be linked.

IV. Results

Figure 5 shows the adaptive grid for the example plane shape. Figure 6 shows the measured impedance profile compared to the simulated responses with uniform and adaptive variable-size cell grid.

Note that the adaptive grid captures the static capacitance and the modal resonances accurately. The uniform rectangular grid following the outer envelope of shape overestimates the static capacitance (as it does not account for the cutouts and missing portions along the jagged outline), and also overestimates the first modal resonance frequency. However, with the rectangular uniform grid, both conditions cannot be met at the same time by adjusting the envelope of the rectangular uniform grid: any attempt to decrease the outline to better match the static capacitance would further increase the predicted first modal resonance frequency, and vice versa.

The first modal resonance from the propagation delay along the longer side of the rectangular envelope can be calculated: it is 800MHz for the first peak. Note that there is a small glitch at around 800MHz in the impedance simulated with rectangular uniform grid. It is not pronounced because of the location of the test point. If the plane had no cutout, and were to follow the rectangular outline of the envelope, at this same location the modal resonance would be highly suppressed. However, due to the odd outline and cutout, the actual plane cut has a much lower first modal frequency, at about half of the frequency that we get from the uniform grid.

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References:

[1] H. H. Wu, J. W. Meyer, K. Lee, A. Barber, "Accurate Power Supply and Ground Plane Pair Models," Proceedings of the 7th Topical Meeting on Electrical Performance of Electronic Packaging, October 26-28, 1998, pp.163-166.

[2] Eged, Balogh, "Analytical Calculation of the Impedance of Lossy Power/Ground Planes," Proceedings of the Instrumentation and Measurement Technology Conference, May 21-23, 2001, Budapest, Hungary

[3] Kim, Swaminathan, "Modeling of Irregular Shaped Power Distribution Networks Using Transmission Matrix Method," ," Proceedings of the 9th Topical Meeting on Electrical Performance of Electronic Packaging, October 23-25, 2000.

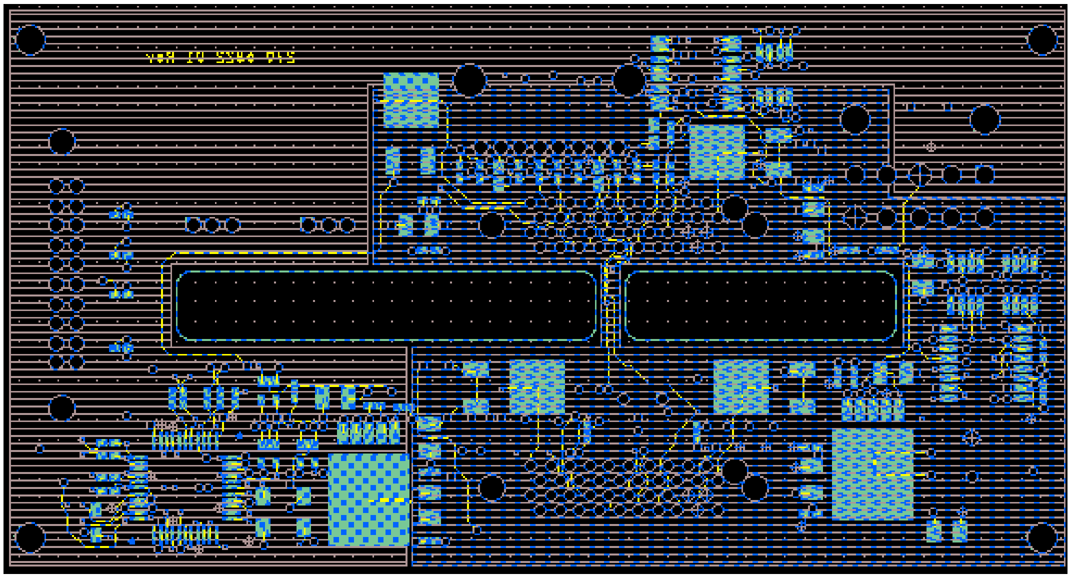


Figure 1.: Odd-shaped power-ground plane pair with cutouts. Within the rectangular board outline, there is an odd-outline plane shape with varying degree of perforations due to smaller and larger holes, as well as with a large cutout.

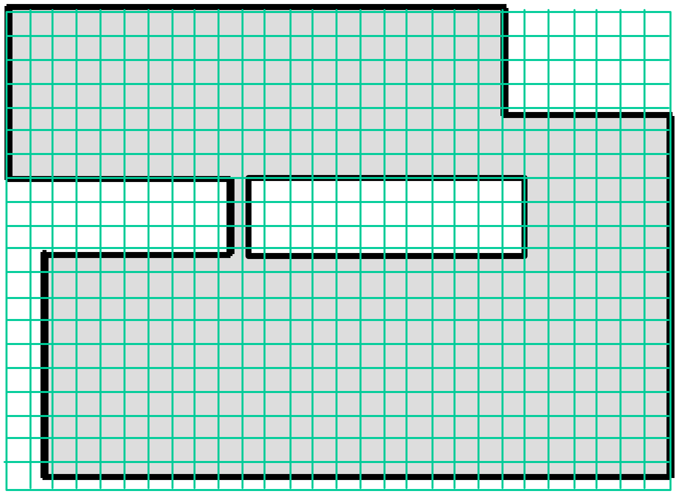


Figure 2.: Outline of the highlighted plane pair of Figure 1, with a uniform square-unit-cell SPICE grid laid over it. Each side of the overlaid grid cells represents one piece of transmission line in the equivalent SPICE circuit.

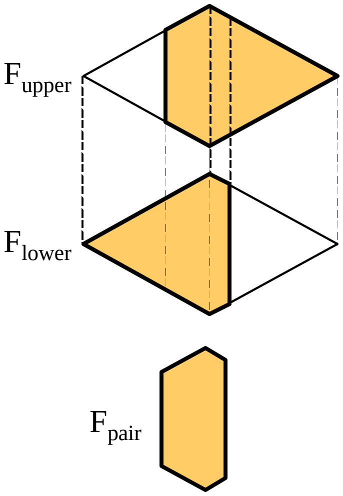
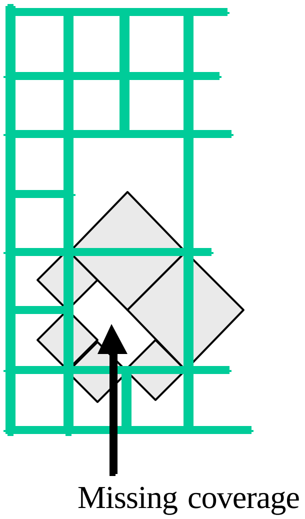


Figure 3.: Illustration of metal fill ratios used for the adaptive grid



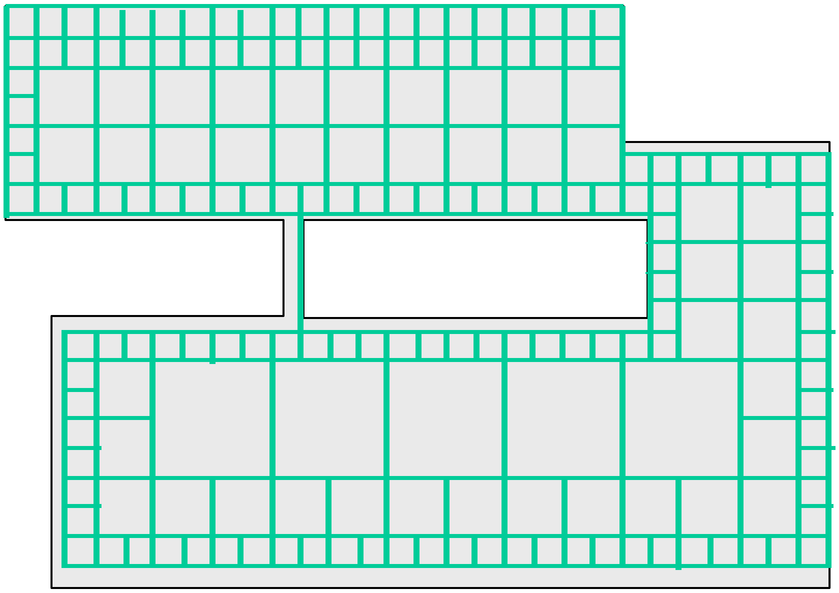


Figure 4.: Compensation for missing unit-cell coverage.

Figure 5.: Illustration of adaptive grids.

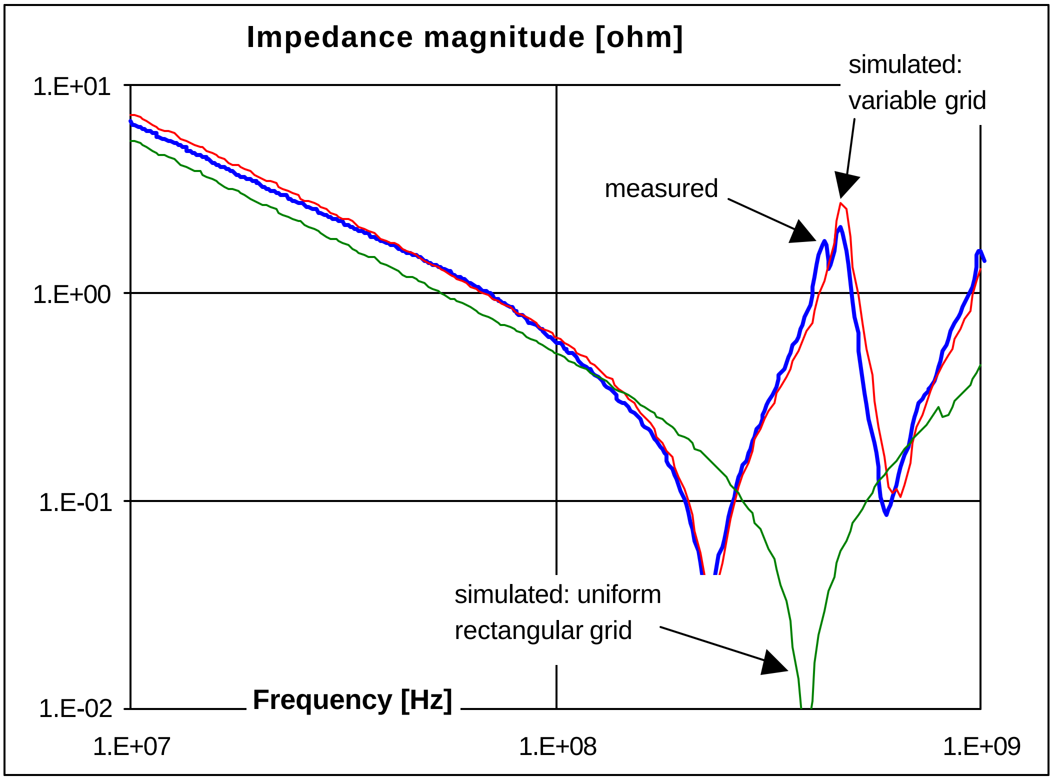


Figure 6.: Impedance profiles of the plane shapes shown in Figure 1 and 2.: a) measured, b) simulated with rectangular uniform grid, and c) smulated with adaptive grid.