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Resonances in power planes

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In the column "Thin Laminates: Buried Capacitance or What?" we looked at the most important benefit of thin laminates: their low inductance. To understand the potential further advantages offered by thin laminates, we need to take a broader look at power-ground plane pairs. In signal integrity we know that if we leave traces un-terminated, reflections at the two ends will create resonances. Planes behave like very wide traces and unless we do something about it, they also resonate, which in turn can increase conducted and radiated noise.

Let's look at the same figure that we used in the previous column to calculate the static capacitance of plane pairs, except now we look at it from a high-frequency perspective.

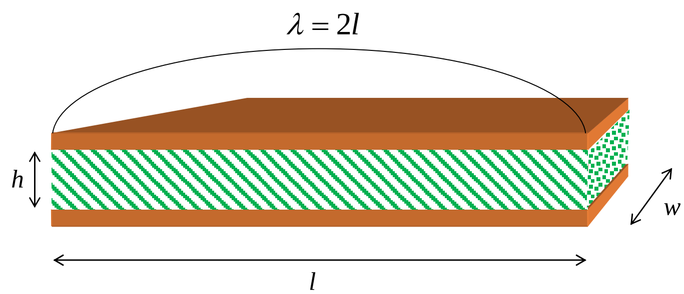

Figure 1: *A pair of metal layers forms not only a parallel-plate capacitor, but also a two-dimensional resonator.*

As we increase the frequency up to and beyond the first series resonance of the plane pair, reflections from the open boundaries will build up a frequency-dependent standing-wave pattern. Across the l length of the plane, the curved line in *Figure 1* represents one half of a sine-wave, illustrating the standing-wave pattern of the lowest modal resonance frequency. The open boundaries will create maximum voltage at the edges and minimum voltage in the middle. Integer multiples of this lowest frequency will also satisfy the boundary condition, creating an infinite series of resonances, just like in un-terminated traces. In planes, however, the w width can also be electrically large, giving rise to a similar infinite series of resonances. In case of a square plane, the lowest modal resonance frequency is the same along both l and w, and the two series of resonances will blend into one. In rectangular plane pairs we have to deal with a double series of resonances with different base frequencies in the two series. Finally, in printed circuit boards we usually assume that the h vertical dimension is much smaller than the shortest wavelength of interest, and therefore we experience no resonances along the vertical axis.

The impedance characteristics of rectangular parallel plates were analyzed and described a few decades ago by antenna designers, when planar antennas created on printed-circuit boards became popular. One of the early and very good summaries on the subject can be found in [1].

The double-infinite series of modal resonances of open-terminated rectangular plane shapes can be easily demonstrated by measurements as well. *Figure 2* shows the measured impedance magnitude of a large sheet of 1.5mm copper-clad FR4 laminate.

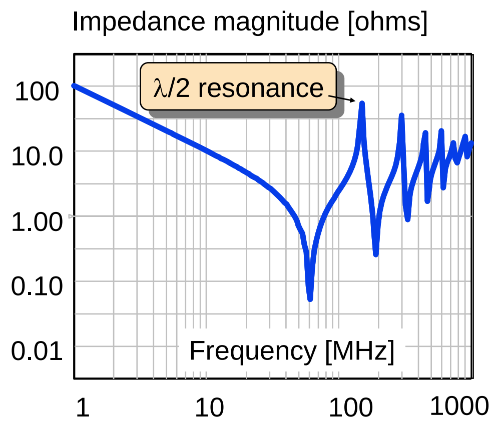

Figure 2: *Measured impedance magnitude of a 480 x 110 mm rectangular parallel plate pair with 1.5mm FR4 dielectric separation.*

The self- and transfer-impedance formulas of plane pairs from [1] can be coded in any math package. *Figure 3* shows an illustration from an Excel spreadsheet implementation [2]. The plot shows the imaginary part of the self impedance over a square pair of bare parallel plates, separated by 50um of FR4 laminate.

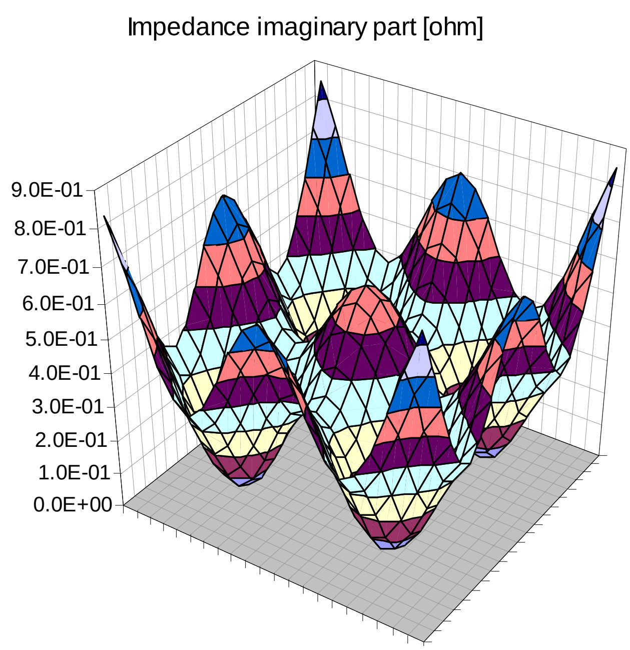

Figure 3: *Simulated imaginary part of impedance of a 25x25cm plane pair with open boundaries, separated by 50um of FR4 dielectric separation. Impedance surface is shown at 533 MHz.*

The standing-wave pattern, shown here at 533 MHz, captures the multiple resonances along both axes.

So far we assumed that the periphery of the planes is left open. What happens if we short the edges? Will this prevent resonances? Unfortunately not, even if we use perfect short, something that we could not use anyway if there is a supply voltage connected between the two planes. There is a difference though: by changing the boundary conditions from open to short, we flip the standing-wave pattern and along the periphery we force minimum voltage. The same plane pair we used for *Figure 3*, just now with short along its periphery, at 383 MHz exhibits the impedance profile shown in *Figure 4*. The positive imaginary part of the impedance indicates the inductive nature of the impedance.

As a summary, plane shapes with extreme termination (open or short) along their periphery do resonate and they exhibit impedance peaks at the parallel resonances. Unfortunately placing regular low-ESR bypass capacitors along the plane edge will not help either: a low-ESR capacitor is almost a pure reactance, which can not absorb the bouncing waves. The good news is that as opposed to high-speed signal traces, where the only practical way to suppress the resonances is to use matched terminations, with power planes we have other options as well. In future columns one of those options will bring us back to the thin laminates.

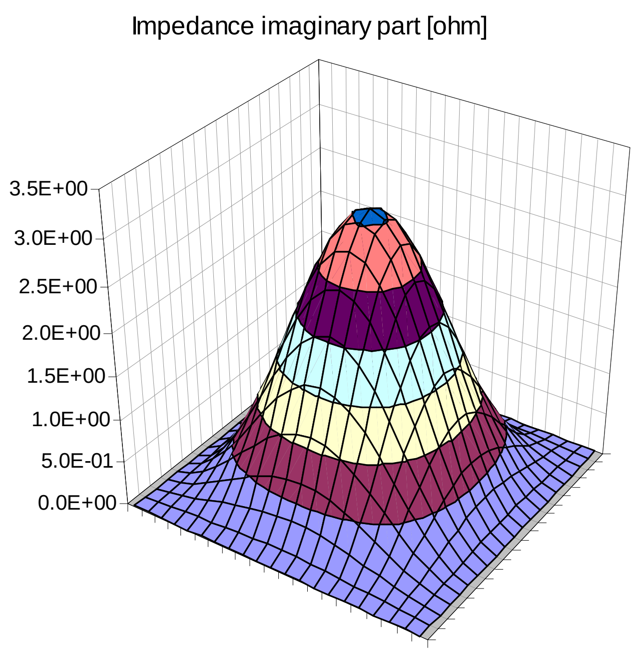

Figure 4: *Simulated imaginary part of impedance of a 25x25cm plane pair with shorted boundaries, separated by 50um of FR4 dielectric separation. Impedance surface is shown at 383 MHz.*

References:

[1] K. R. Carver, J. W. Mink, "Microstrip antenna technology," IEEE Transactions on Antennas and Propagation, AP-29, 1981, pp. 2-24.

[2] Plane_SelfZ_v-w01.xls illustration file, available at http://www.electrical-integrity.com/