Experiments with Fringe Effects in Printed Circuit Boards

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In connection with efforts to measure the dielectric constant of printed circuit boards (PCBs) using a resonant-frequency method, some experiments were conducted to determine the significance of “fringe” effects. To examine these effects, they were exaggerated by “extending” the ground plane of a double-sided PCB. The ground plane can be extended in all directions by clamping the PCB to an aluminum plate. It can be extended along two opposite sides by clamping suitable metal or PCB strips along those sides.

The extension of the ground plane of the PCB causes two effects. First, fringe capacitance is created, increasing the effective length of the PCB between the edges with the extended ground plane. This tends to reduce the associated resonant frequency. Second, additional field is created in air for signals traveling along and parallel to the edges with the extended ground plane, which reduces the effective dielectric constant, speeds propagation, and increases the resonant frequency in that direction. When the ground plane is extended all around, there is a complex netting of these counteracting forces, which can make the resonance frequency changes smaller than they would be with an extension only along two opposite sides.

We first measure the resonant frequencies of a piece of PCB, by attaching an SMA connector to one corner (edgewise, so two legs contact the bottom ground plane and the center pin contacts the top plane), and scanning reflection with a VNA (Scotty’s MSA).

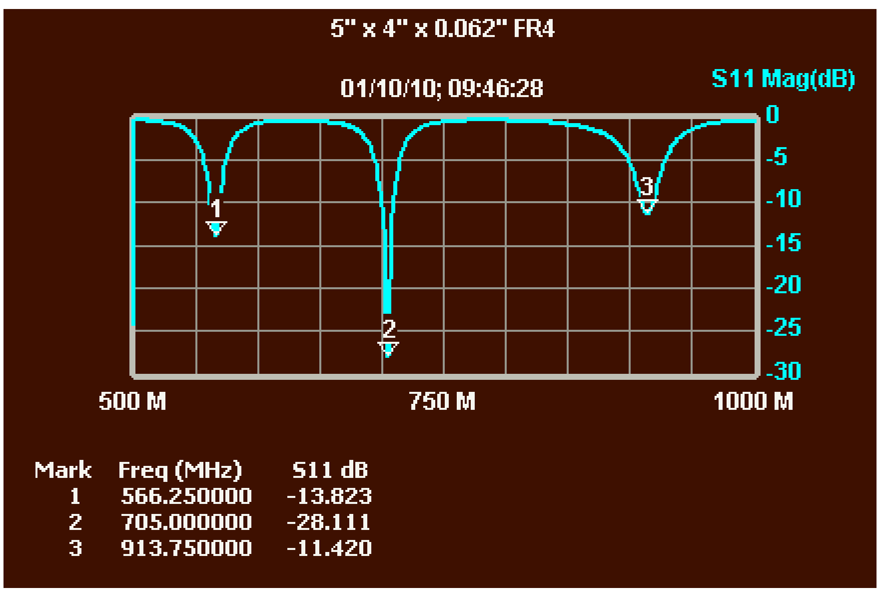

Figure 1—PCB without extensions

Figure 1 shows the resonant frequencies of the double sided board without any ground plane extensions. Frequency 1 is the resonance running the 5” length of the board. Frequency 2 is the resonance running the 4” width of the board, which requires less time and therefore has a higher frequency. Frequency 3 is a complex combination involving resonance in both directions. We will ignore frequency 3.

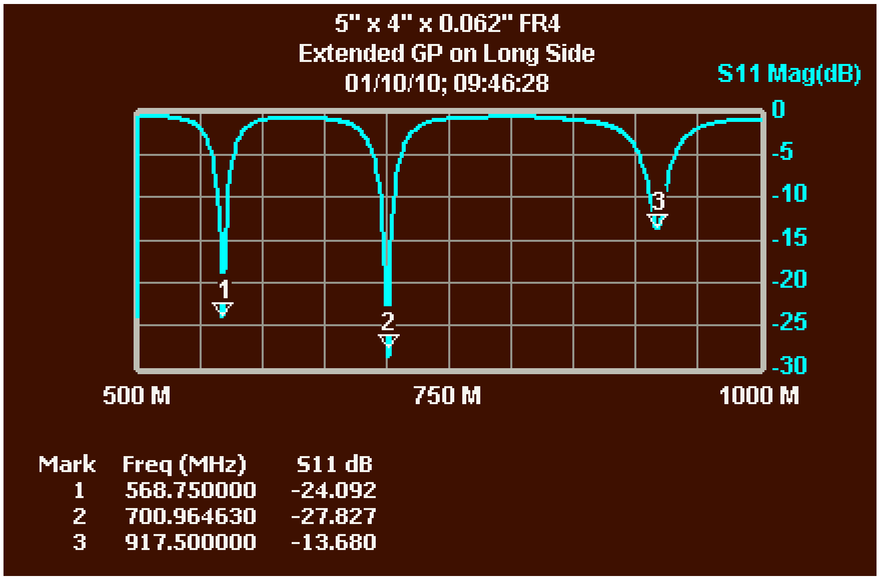

Figure 2—Extended Ground Plane on Long Side
Raises frequency 1, lowers frequency 2

Figure 2 shows the resonances with the ground plane extended along the 5" sides. This creates fringe capacitance at those sides, causing the 4" dimension to act as though it is slightly extended. This reduces the resonant frequency running in the 4" dimension (marker 2) by 0.6%. For a signal running in the 5" dimension, the extensions cause additional field in air along the edges. Because air has a dielectric constant near 1, compared to the FR4 value of about 4.3, this extra field causes the effective dielectric constant to be reduced, speeding up propagation in the 5" direction and raising frequency 1 by 0.4%.

Now, let's instead extend the ground plane along the 4" edges.

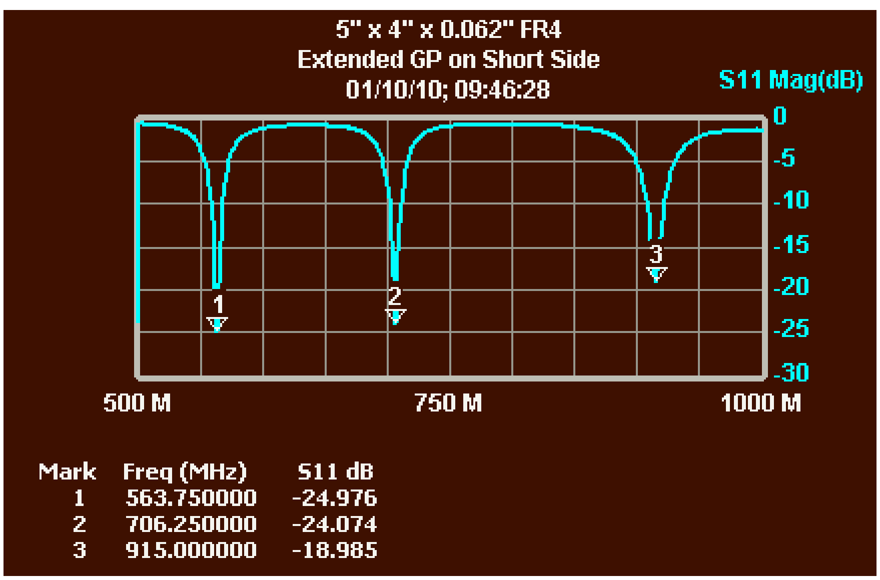

Figure 3—Extended Ground Plane on Short Side
Raises frequency 2, lowers frequency 1

Compared to Figure 1, the fringe capacitance along the short sides lowers the frequency for resonance in the 5” dimension (1) by 0.4 %. The increased propagation velocity in the 4” direction raises frequency 2 by 0.2%. As one might expect, the significance of extending the ground plane along the short side is less than that of extending it along the long side.

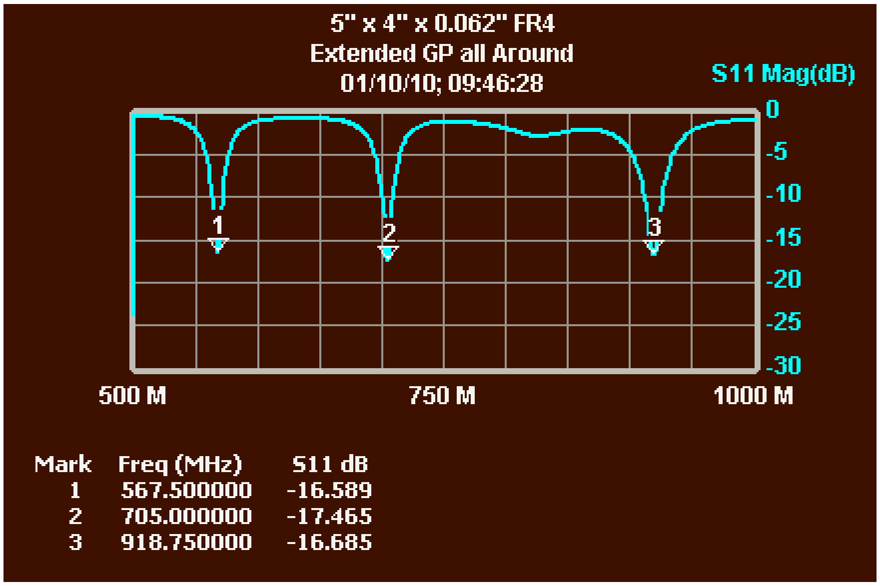

Figure 4—Extended Ground Plane on All Sides

Figure 4 shows the resonant frequencies with the ground plane extended on all sides, by clamping it to an aluminum plate. Compared to Figure 1, the resonant frequency in the long direction (1) increases by 0.4%, and that in the short direction (2) is unchanged.

Conclusions

The most important conclusion is that the effects of the extended ground plane are relatively small. The maximum change in resonant frequency in these experiments was only 0.6%. With extensions in all directions, the maximum effect was only 0.4%. If those frequencies were used to calculate the dielectric constant, the frequency is squared so the error would be doubled to 0.8%.

There are fringe effects along the edges of PCB even without the ground plane extensions, but one would expect them to be smaller than the effects of extending the ground plane. Therefore, these experiments suggest that the dielectric constant calculated from the resonant frequencies of the PCB without ground plane extensions would be affected less than 0.8% by fringe effects. Other experiments have shown that fringe effects are very small if the relevant dimension of the board is at least 1.5”.

A convenient way to measure the dielectric constant of a single-sided board is to make it a double-sided board by clamping it to a piece of metal, which becomes the ground plane and is likely to extend beyond the edges of the PCB. These experiments suggest that the error caused by the extended ground plane will be small. In actual practice, these effects will be far smaller than the error introduced by the presence of air between the PCB and the metal to which it is clamped.