The Facts about the Input Impedance of Power and Ground Planes

The following diagram shows the power and ground plane structure of which the input impedance is computed.

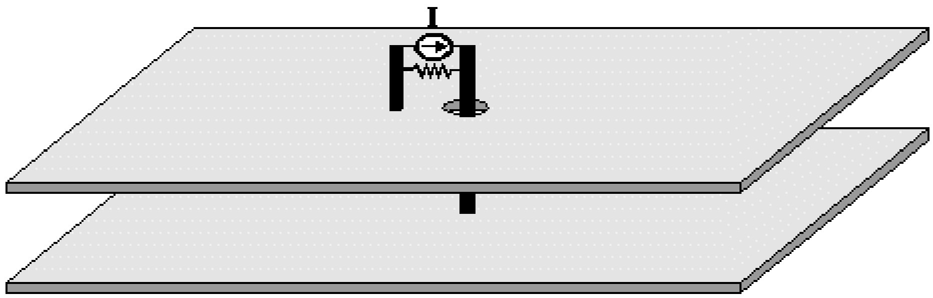

Figure 1. Configuration of the power and ground plane structure

Physical Configuration Considered:

- Two metal planes of 10 inches by 10 inches in size;
- A 2 mil thick FR4 (dielectric constant sets to 4) layer between the two metal planes;
- A pair of vias, located at the center, connected to the two metal planes from a signal layer above the upper metal plane. The radius of the vias is 200 microns.

Procedure of Computing the Input Impedance

The pair of vias are connected to a current source. The current source has a 0.5 ohm source impedance and a Gaussian pulse waveform. ***SPEED97*** computes the transient current (C1) flowing through the via passing between the two metal planes and the transient voltage (V1) across the current source. The frequency dependent input impedance is computed as the ratio of Fourier transformed V1 over Fourier transformed C1. The input capacitance is extracted as the imaginary part of (C1/V1)/(2*pi**f*), and the input inductance is extracted as the imaginary part of (V1/C1)/(2*pi**f*).

Simulation Results:

Figure 2 shows the amplitude of the input impedance from DC to 1GHz of the power and ground plane structure looking from the pair of the vias at the center. High input impedance, which corresponds to the capacitive effect, can be observed at the low frequency region. Resonance appears at around 590MHz and 830MHz. A more detailed picture of the input impedance from DC to 500MHz is shown in Figure 3. The effective input capacitance, of about 45 nF, is displayed in Figure 4. As can be seen from Figure 3, at frequencies below 50MHz, the effect of the power and ground plane structure can be approximated by a capacitor of 45 nF. However, in the frequency range beyond 50MHz, the power and ground plane structure can no longer be simply modeled as a capacitor.

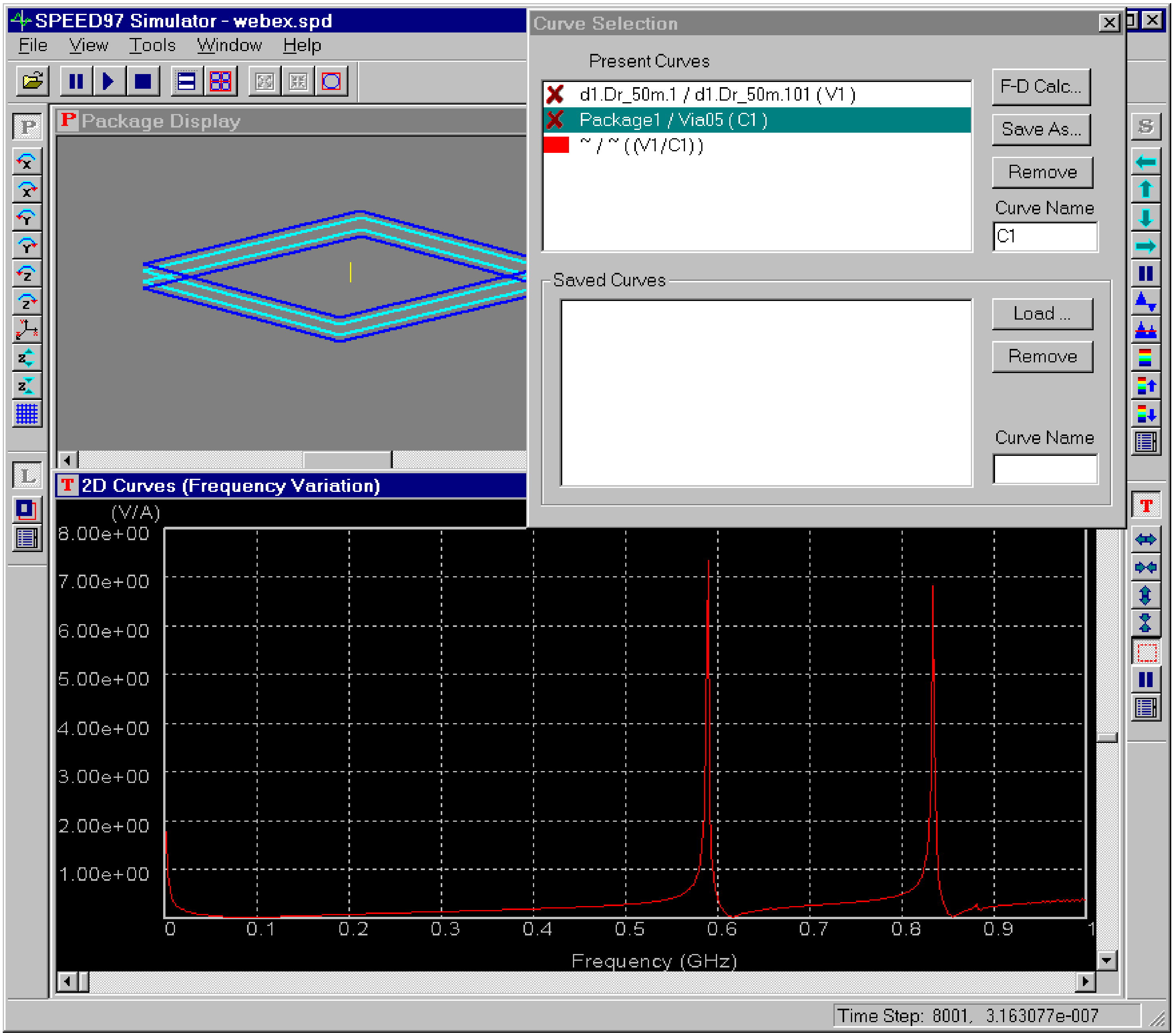

Figure 2. Amplitude of the input impedance of the power and ground plane structure.

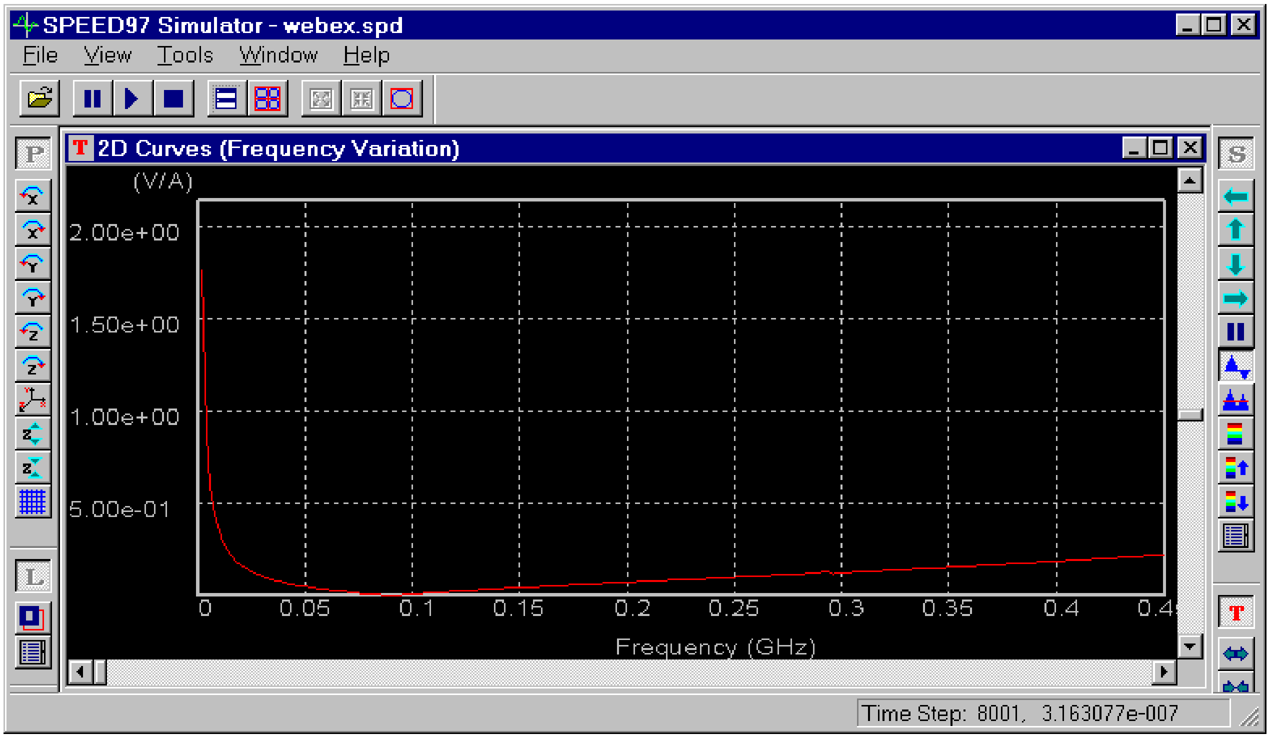

Figure 3. A detailed look at the amplitude of the input impedance of the power and ground plane structure

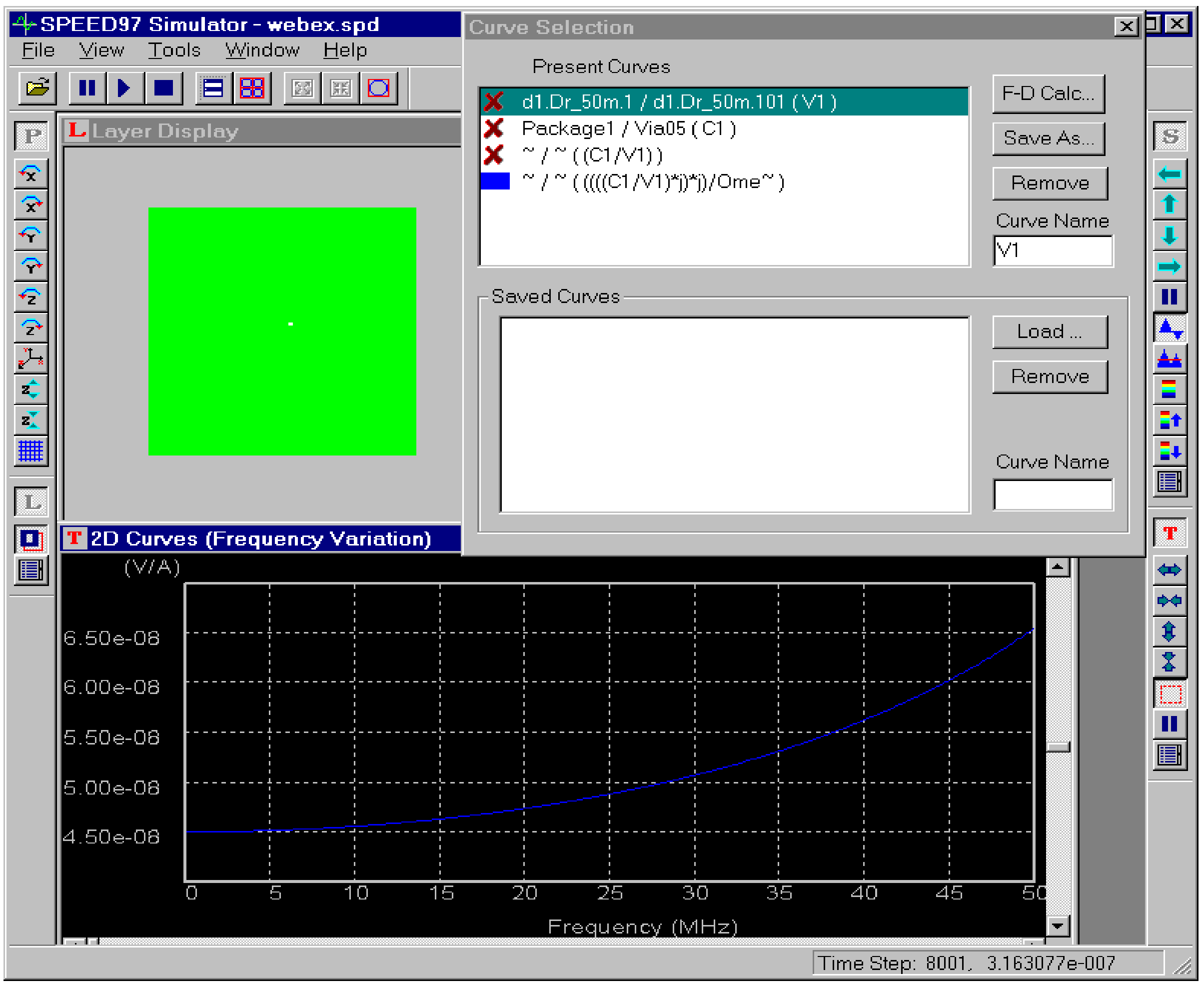

Figure 4. Effective capacitance of the power and ground plane structure at low frequencies.

Effects of Connection to a Power Supply

The power and ground planes in a PCB are typically not isolated. They are somewhere connected to a power supply which has a low internal impedance. Assume the power and ground planes are connected to an ideal power supply at the location 1.0 inch from the left edge and 5.0 inches from the lower edge of the metal planes. In the simulation below, a shorting via is placed at that position to connect the power and the ground planes.

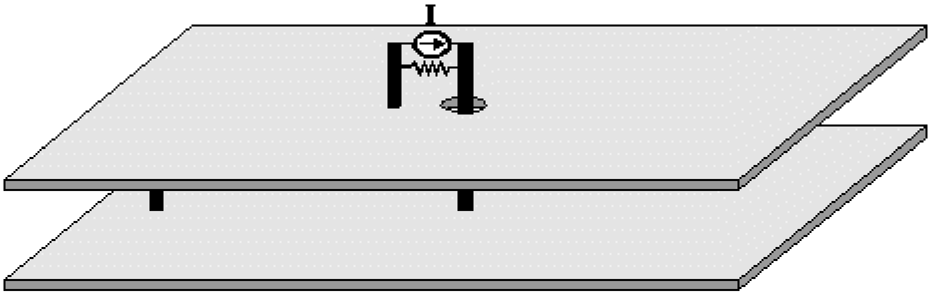

Figure 5. The power and ground planes connected to a shorting via.

The amplitude of the input impedance from DC to 1GHz of the power and ground plane structure looking from the pair of the vias at the center is shown in Figure 6. High input impedance no longer exists at the low frequency region, which means that the power and ground plane structure is not capacitive at low frequencies. Besides resonances at around 590MHz and 830MHz, a resonance under 100MHz is also observed. The effective input inductance, of about 0.15 nH at the low frequency limit, is displayed in Figure 7. As can be noticed from Figure 6, the effective inductance model is only valid at low frequencies.

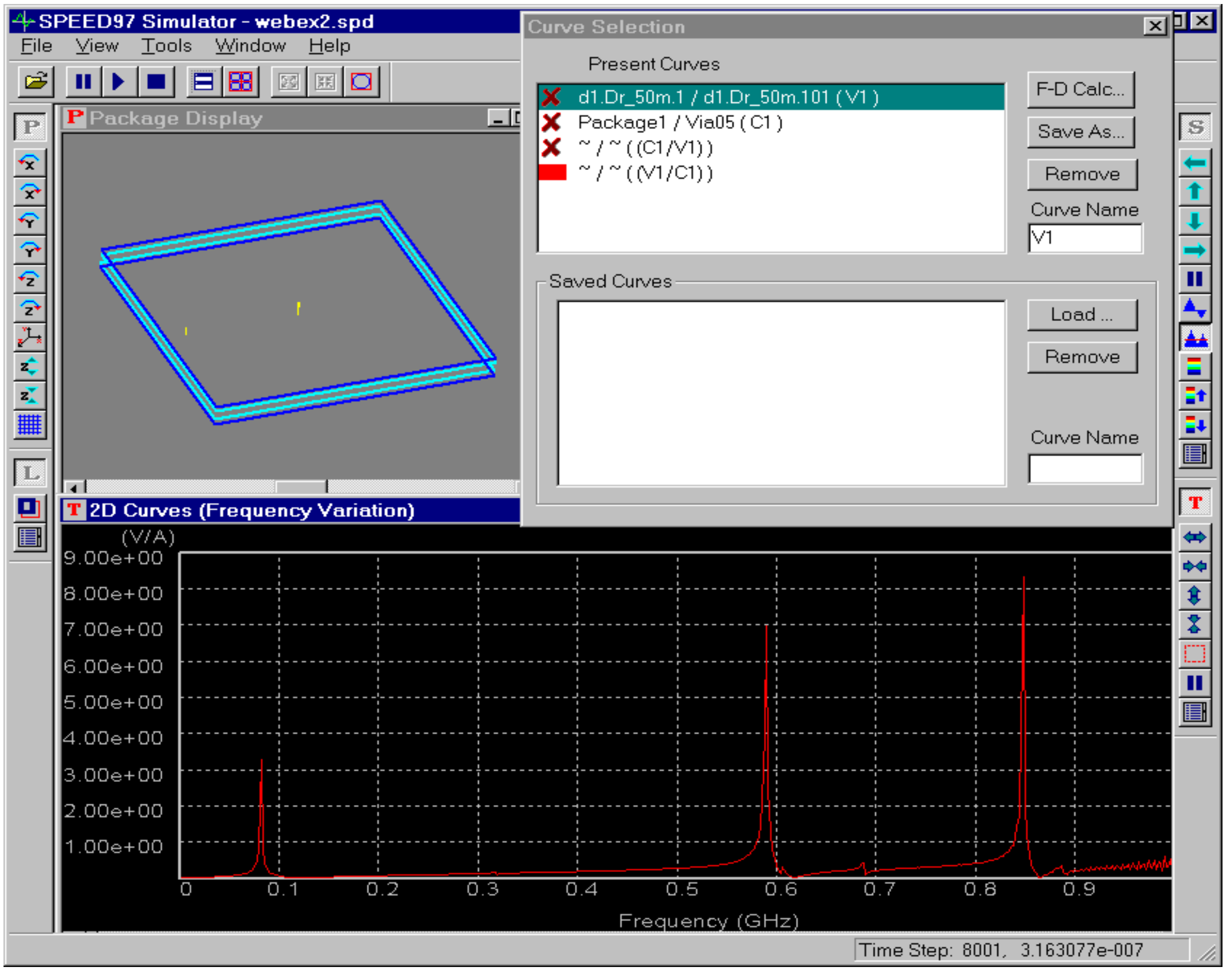

Figure 6. Amplitude of the input impedance of the power and ground plane structure.

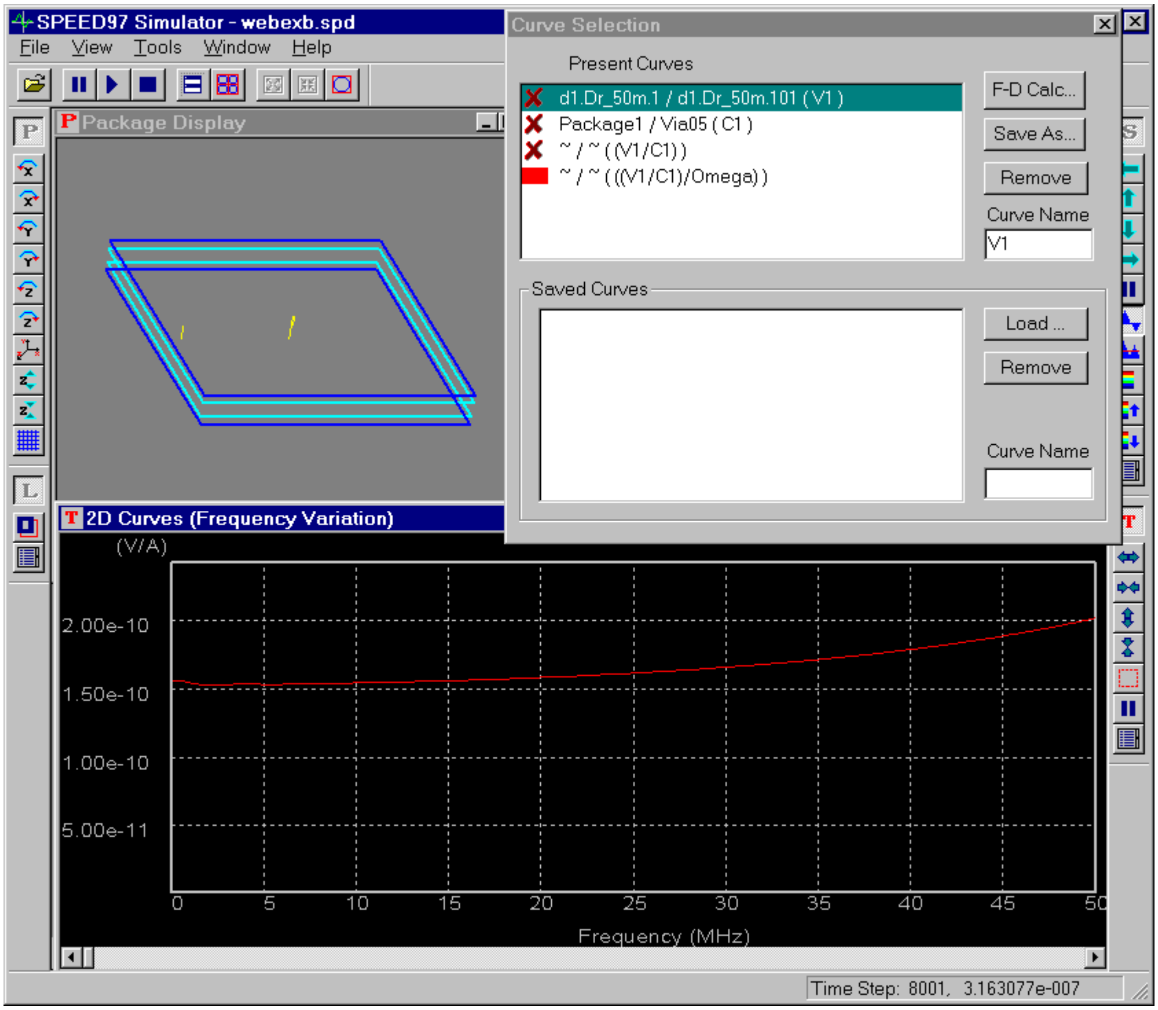

Figure 7. Effective inductance of the power and ground plane structure at low frequencies.

When the shorting via is moved closer to the source via, the current loop becomes smaller, and the effective input inductance in the low frequency range will also be smaller. Let the shorting via be moved to the location 4 inches from the left edge and 5 inches from the lower edge of the metal planes as shown in Figure 8, the effective input inductance, of about 0.12 nH at the low frequency limit, is shown in Figure 9.

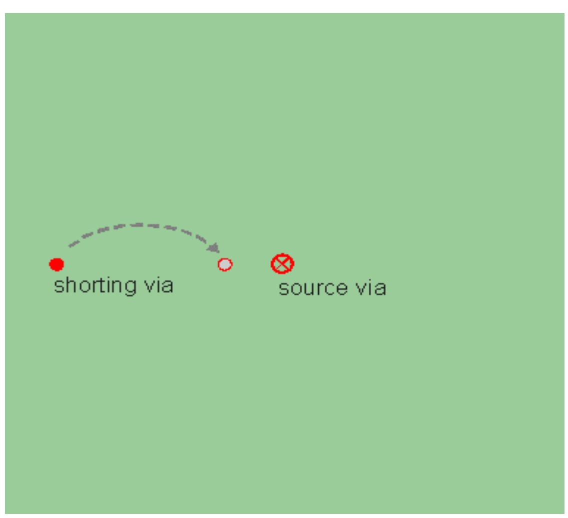

Figure 8. The shorting via is moved closer to the source via.

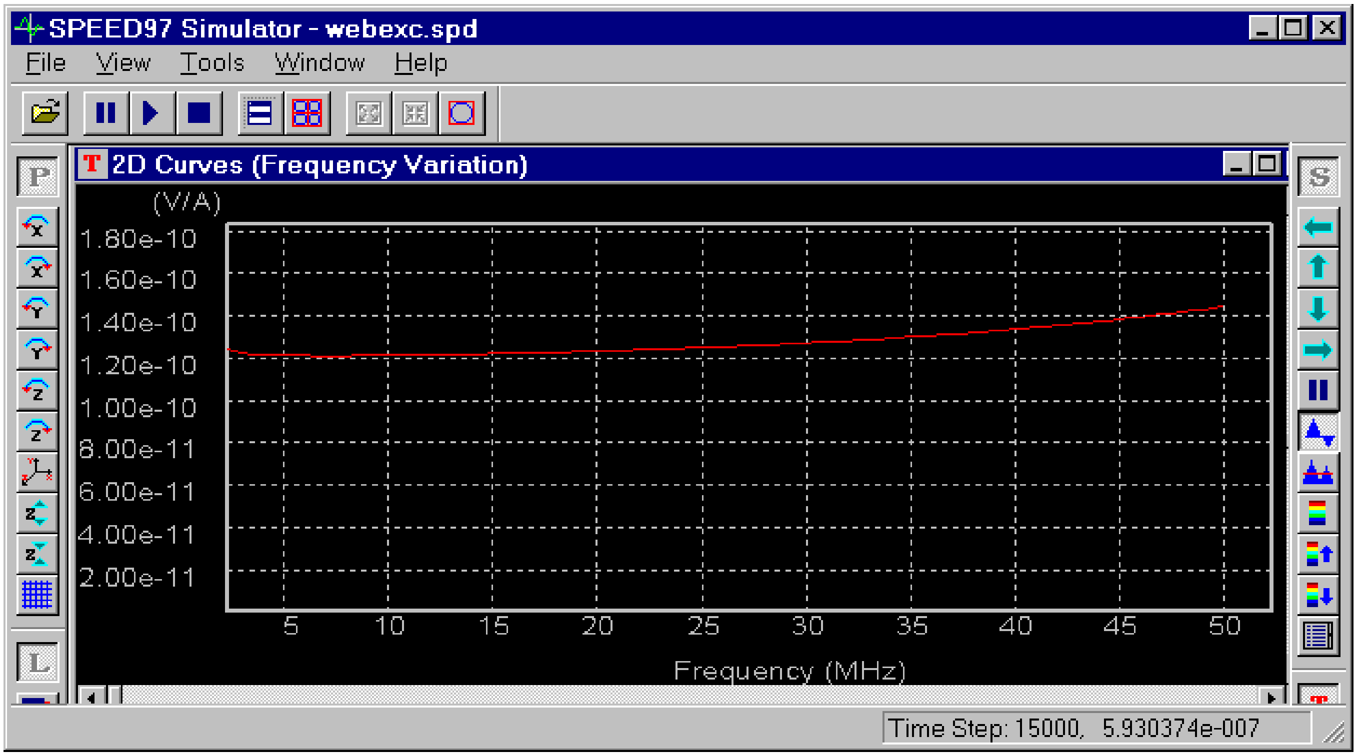

Figure 9. Amplitude of the input inductance of the power and ground plane structure.

Let's place two shorting vias, one on the left hand side and the other one on the right hand side of the source via. The distance from the source via and the two shorting vias is 1 inch. The input impedance is shown in Figure 10, and the effective input inductance in the low frequency range is displayed in Figure 11. It can be seen from Figure 10 that the first resonant frequency is shifted upward from under 100 MHz for the case shown in Figure 6 to over 100MHz. The effective input inductance in the low frequency limit is about 0.10 nH, not half of 0.12 nH shown in Figure 9 as one may expect.

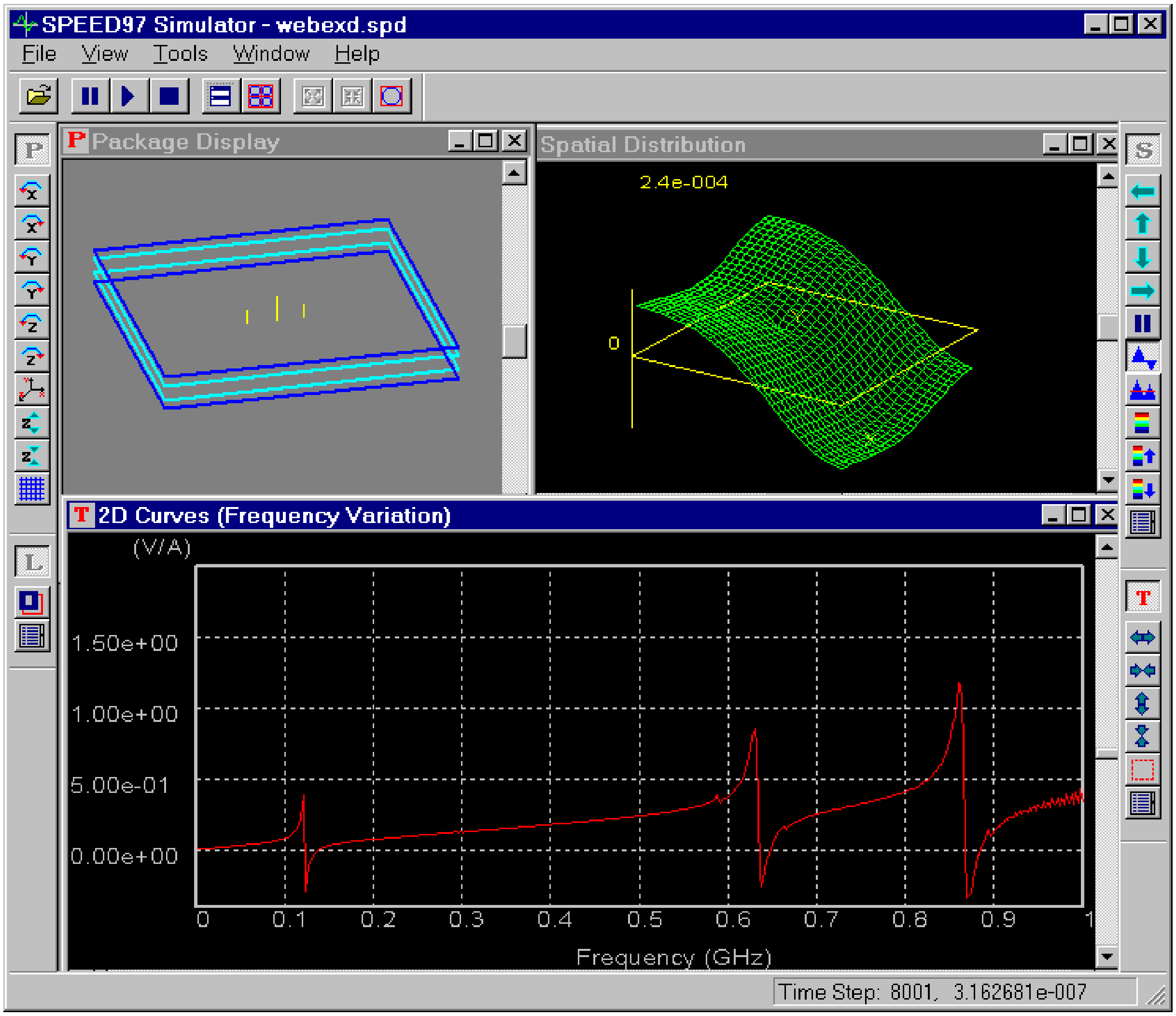

Figure 10. Amplitude of the input impedance of the power and ground plane structure.

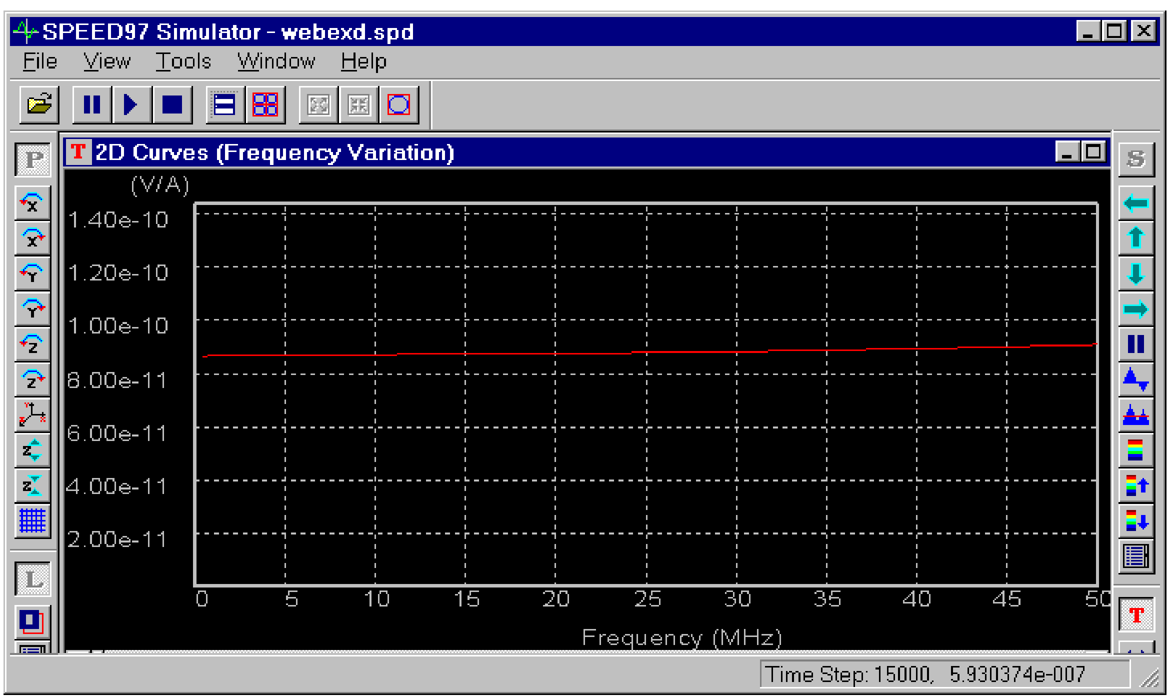

Figure 11. Amplitude of the input inductance of the power and ground plane structure in the low frequency range.

Observations

Power and ground planes in a printed circuit board may connect to the power supply at several locations. Moreover, a number of decoupling capacitors may be connected to the power and ground planes. As one can expect, it is not an easy task to estimate the input inductance of the power and ground plane structure at the low frequency limit, not to say the input impedance in a wide frequency range. Therefore, software tools are essential for accurate modeling of power and ground plane structures. The capability of handling multiple power and ground planes is just one of the many powerful features that ***SPEED97*** has.