Easy trick to measure plane impedance with VNA

The measurement of a PCB plane using a vector network analyser may not be as straightforward as you might expect. One simple trick makes it easy.

By Steve Sandler

The dilemma of time vs. frequency as the most useful measurement domain has long been a controversial issue. In some cases, it leads to rather heated discussions. The argument in favour of a vector network analyser (VNA), a frequency domain instrument, is that the dynamic range and signal to noise ratio (SNR) of a VNA are much better than they are for a time domain reflectometer (TDR). The argument in favour of TDR measurements is that they tend to be lower cost and are taken from a direct reading, so there is little to interpret. Fortunately, most new TDRs can also transform measurements to S-parameters (much like a VNA) and most new VNAs can also transform to time (providing TDR equivalent data).

Having said all of this, the measurement of a PCB plane using a VNA may not be as straightforward as you might expect. One simple trick makes it easy.

A 2-sided 63mil FR4 PCB is used as an example in this article. The PCB is measured using both a VNA and a TDR. The results are compared, the error source is identified, and the trick is employed to correct the error.

The PCB is shown in **figure 1** connected to a SD-24 20GHz/17.5ps sampling head installed in a Tektronix 11801B DSO mainframe. The board is connected to the instrument via an SMA edge connector and a SMA male-SMA-male barrel adapter. The instrument cursor table is enlarged and shows a characteristic impedance of approximately 3.36Ω or 10.4dBΩ. I say approximately because the cursor resolution on this instrument is somewhat coarse, but it is pretty close to 3.36 Ω.

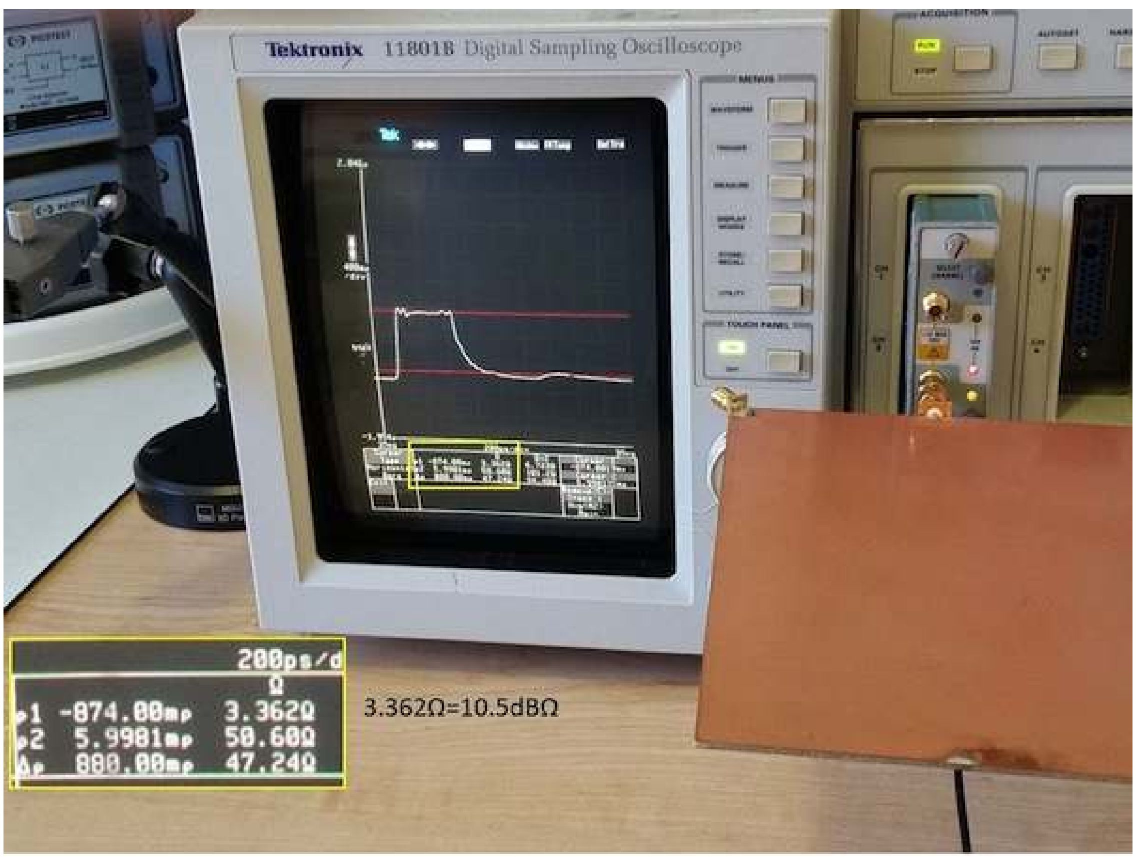

Figure 1: Tektronix 11801B DSO with a 20GHz SD-24 TDR head connected to PCB shows an approximate impedance of 3.36Ω.

The PCB is then connected to a Rohde & Schwarz ZNB 20GHz VNA using the same connectors as shown in **figure 2**. The general method of determining the characteristic impedance of the plane is to measure the open circuit capacitance and the short circuit inductance. The characteristic impedance is then computed as:

$$Z_o = \sqrt{\frac{L}{C}}$$

Rather than calculating the inductance and the capacitance, which takes time and effort, there is an easier way. Since the capacitive impedance is falling at 6dB/octave and the short circuit inductance is increasing at 6dB/octave, we can average the short circuit and open circuit impedance at any frequency. The result is also shown in **figure 2** as 12dBΩ or 3.98Ω.

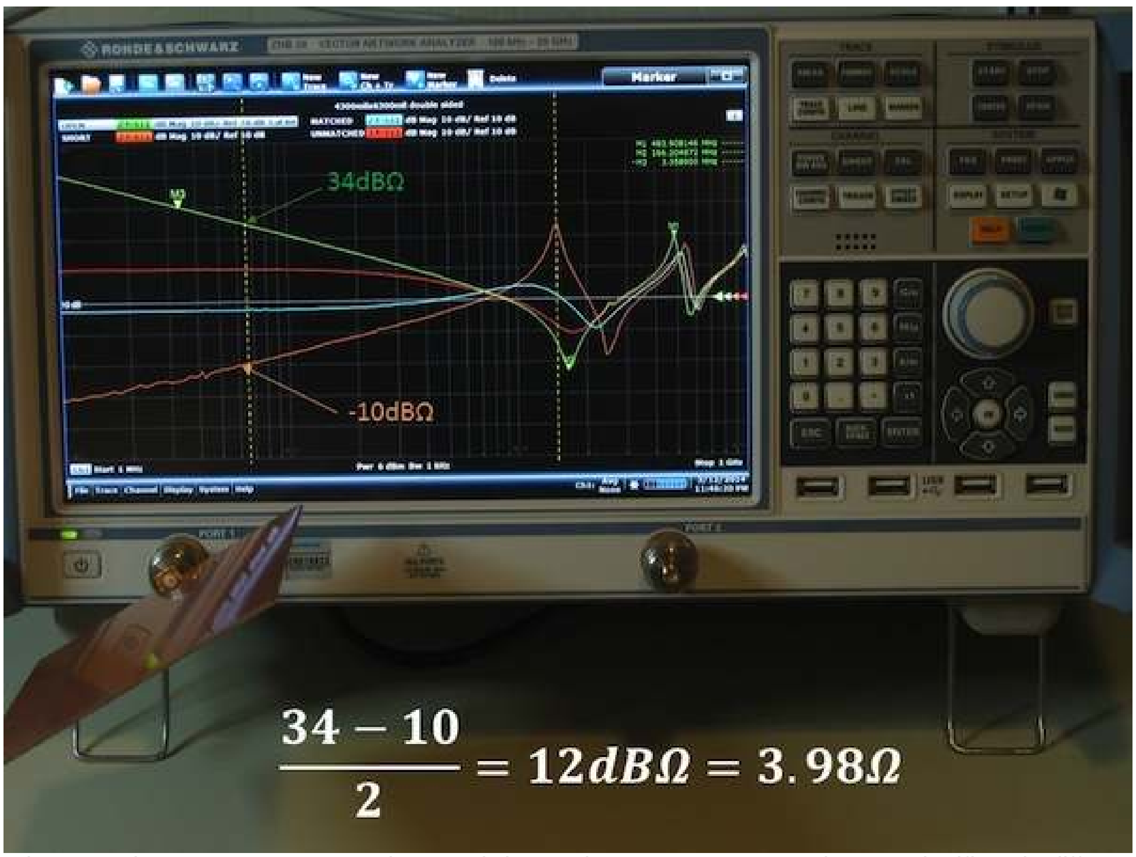

Figure 2: The same PCB mounted to a Rohde & Schwarz ZNB 20 VNA shows a significantly different result. Note the resonant peak of the shorted (orange) trace is at a lower frequency than the open (green) trace.

The TDR and VNA characteristic impedance measurements are almost 20% apart, which can result in degraded signal and/or power integrity. Note that the peak resonance in the short circuit trace is at a lower frequency than the resonance of the open circuit trace. The reason is simple. There is no perfect short circuit. The short at the far end of the PCB is inductive, increasing the impedance measurement and reducing the resonant frequency.

PCB simulation model

In order to better illustrate the error, a simulation model of the PCB is constructed. The model is simultaneously simulated with the PCB open, shorted, and with a 1nH inductor. The 1nH is estimated based on the PCB thickness of 62mils thick and the ¼” wide solder wick used to short the planes is approximately 15nH/inch. This is only used for illustration purposes and does not need to be exact. The simulation models are shown in **figure 3**.

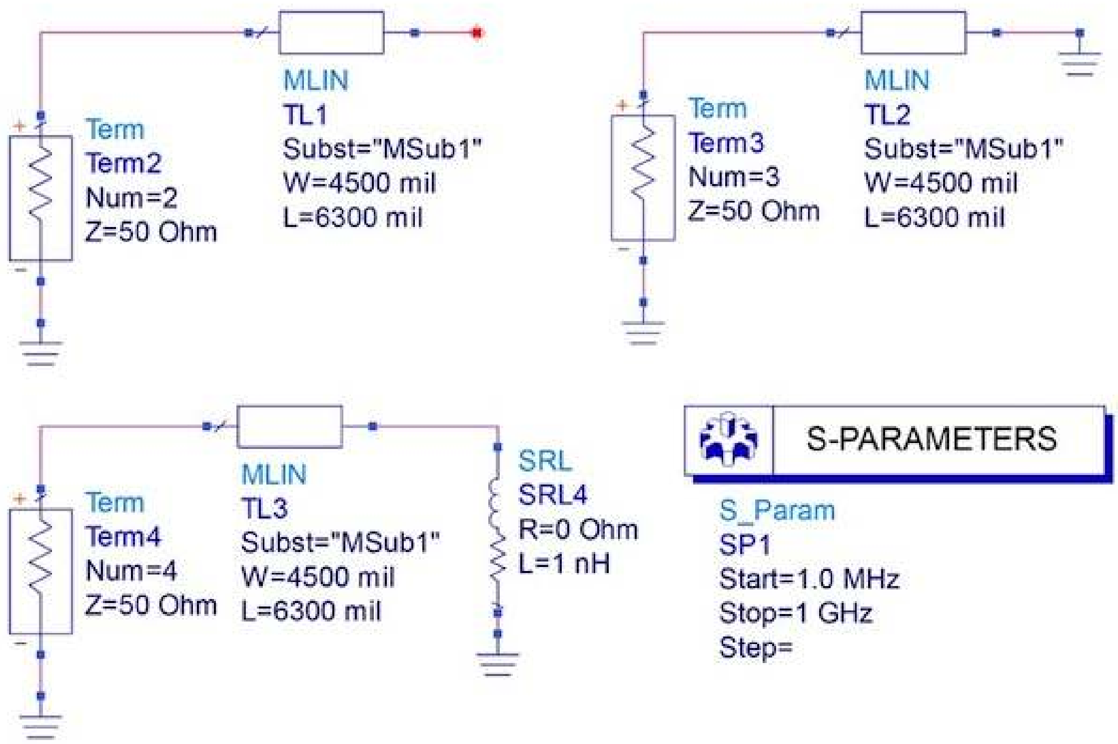

Figure 3: Impedance simulation model of the PCB with shorted, open and 1nH short terminations.

The simulation results, shown in **figure 4**, clearly show the frequency shift and impedance shift resulting from the 1nH shorting inductance. Without knowing the precise inductance of the short circuit, it is difficult to determine the exact answer.

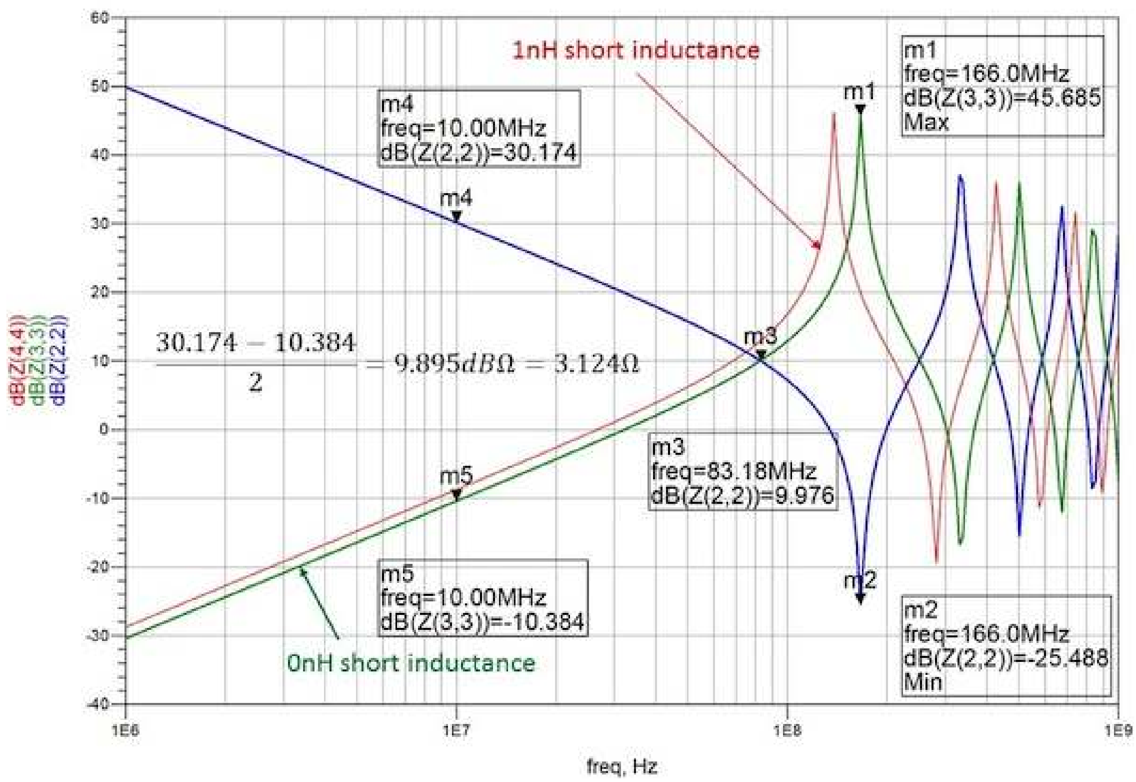

Figure 4: The simulation results show the impact of the inductance of the short on the resonant frequency and also in the characteristic impedance, identified by the intersection of the open and shorted traces.

This is where we employ the trick and make the measurement both easier and more accurate. Note that with a 0nH shorting inductance, the resonance frequency of the short and the open are the same at 166MHz. Also note that the intersection of the open and 0nH short intersect at precisely half the resonant frequency.
The exact impedance is obtained by averaging the open trace and the 0nH short trace at 10MHz, shown by markers m4 and m5 respectively or 3.124Ω. The trick is to measure only the open circuit impedance. Place the marker at precisely half the frequency of the first resonance (or 83MHz in this measurement). The measurement result is approximately 9.976dBΩ or 3.14Ω shown by marker, m3 or within 1% of the exact answer.
In order to demonstrate this method with a well-defined characteristic impedance an additional simulation model is created. The model, shown in **figure 5**, has a defined 5 Ohm characteristic impedance. A single impedance simulation is performed with the plane open and the simulation result is shown in **figure 6**.

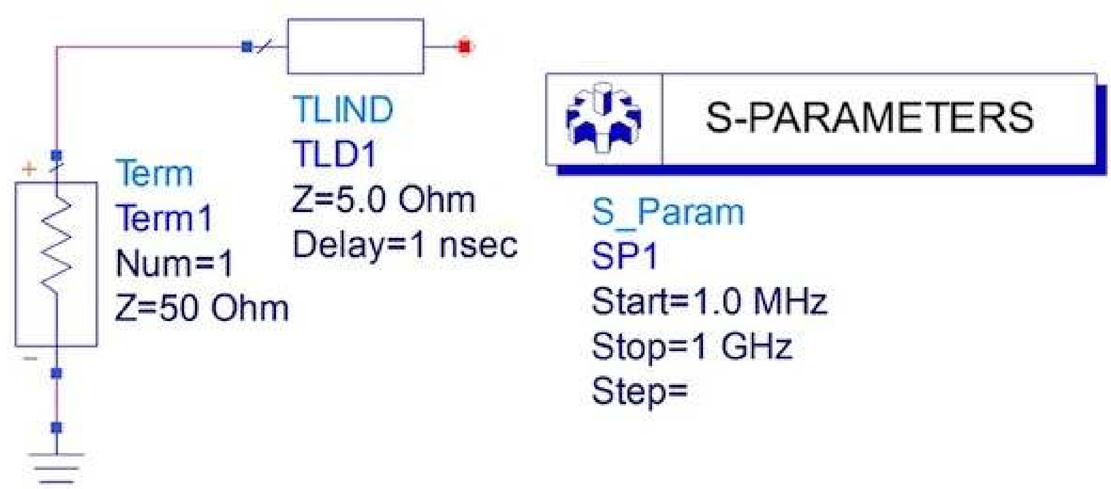

Figure 5: A simulation model with a well-defined 5Ω characteristic impedance.

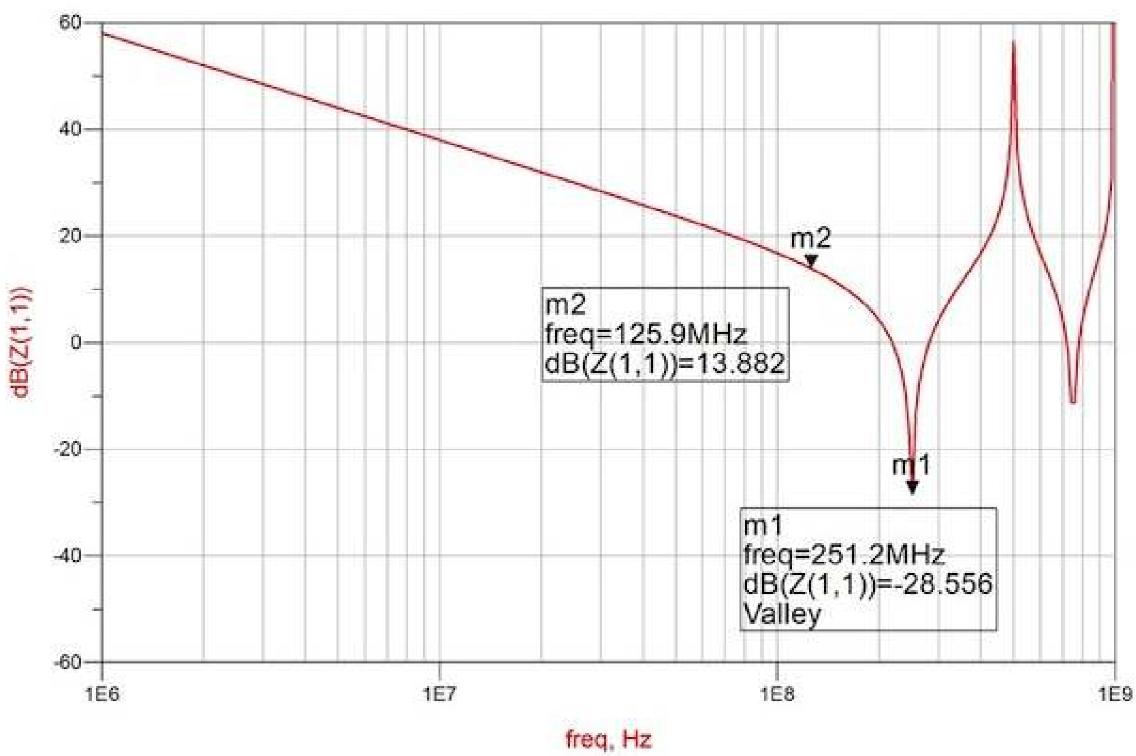

Figure 6: The single open circuit sweep shows a resonance at 251.2MHz. Measuring at half this frequency (limited by marker resolution) indicates 13.9dBΩ or 4.96Ω, within 1% of the exact impedance.

The simulation of the open plane has a first resonance at 251.2MHz, so the impedance is measured at 125.9MHz, which is as close to this frequency as the simulation allows. The resulting 13.9dBΩ or 4.96Ω is within 1% of the exact characteristic impedance.

In conclusion, measuring the impedance from a short and open plane can have a significant error due to the inductance of the short. Rather than making the measurement more complicated by attempting to include the short inductance, the measurement is simplified using a single open sweep. The simplified measurement has been shown to be within 1% of the exact answer. This small error is likely due to the accuracy at which the cursors can be placed. ■

About the author

Steve Sandler is the founder and former CEO of Analytical Engineering, Inc., the predecessor of AEi Systems. He has over 30 years experience in the design and analysis of power conversion equipment for military and space applications. Mr. Sandler is also the CEO of Picotest.com, a company that distributes test equipment including the Signal Injector product line designed for testing linear and switching power supplies, a Test & Measurement World "Best in Test" Finalist.