Illustration of Plane Extension for the MSA

10/21/09

In VNA Transmission and Reflection modes, the MSA sweep parameters window allows the user to specify a Plane Extension value. That value is intended to eliminate the effect of a transmission line on the measurements made by the VNA. More specifically, it is intended to extend the calibration plane from one end of that transmission line to the other.

Transmission Mode

Consider a similar 2 foot cable in transmission mode, lying between the calibration plane and the DUT. It causes a phase delay of an amount that increases with frequency, as shown in Figure 1.

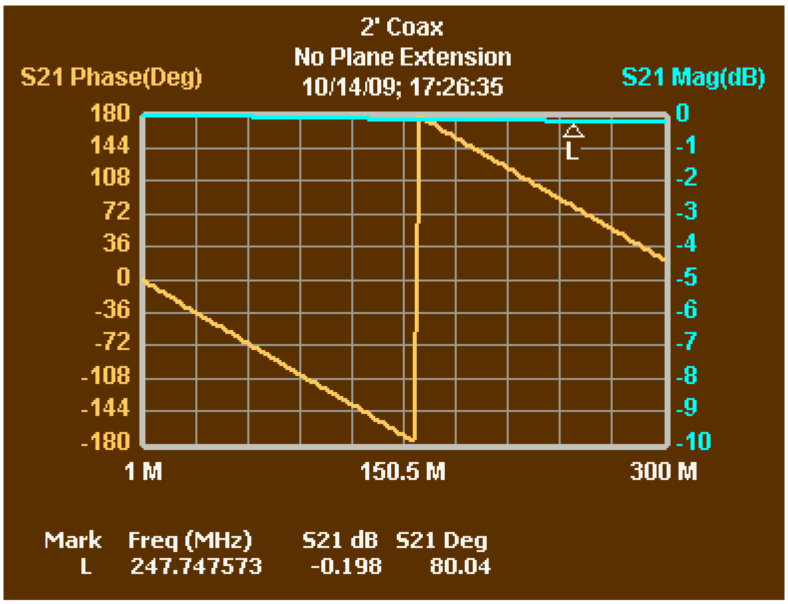

Figure 1—Coax in transmission mode, without plane extension

In Figure 1, the fixed length of the coax creates a phase delay that is proportional to frequency (because the higher the frequency, the shorter one degree is), so the phase becomes more and more negative until it hits -180 degrees and wraps around to the top of the chart. This creates the familiar sawtooth pattern. This pattern makes it appear that something abrupt happened at the wraparound point, but in fact the phase just continues its linear change.

In transmission mode, our objective is to eliminate the phase delay caused by the cable. With an actual cable, we could just calibrate with the cable in place. But in the real world we might have a DUT mounted on a PCB, and want to adjust for the length of the PCB. We are using the cable just for illustration. Not that to make the plane extension adjustment, the MSA must assume that the transmission line has a characteristic impedance equal to the reference impedance of the measurement, normally 50 ohms.

The trick is to figure out what value of plane extension to specify. If we know the characteristics of the transmission line, we can measure its length (approximately) and find the (approximate) time delay by applying the formula time=length/velocity. A typical adjustment for coax cable would be 1.5 ns/ft. At best, though, this will just give us a value to start with. We still need to refine it.

By starting with a 3 ns value, and adjusting from there, we produced Figure 2:

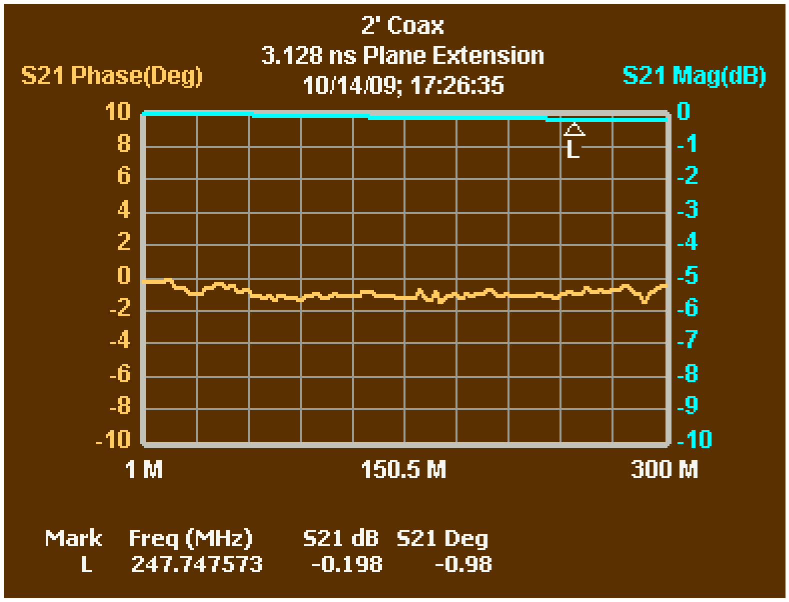

Figure 2—Transmission through coax with plane extension

In the MSA sweep parameters window, you can change the plane extension value and immediately recalculate, to see the effect of the change. This makes it easy to make successive adjustments to flatten the phase line.

Note that in Figure 5 there is still a slight tilt at low frequency; then things flatten out. This probably indicates a very slight change in the cable propagation velocity as the frequency increases. Nevertheless, the error here is very small; a slight increase in the plane extension value would virtually eliminate the error up to about 60 MHz.

Reflection Mode

Next, consider a measurement in Reflection mode. In calibration, standards are attached to the test fixture. The test fixture may even include a transmission line, with the calibration standards attached to the end of the line. A calibration plane is thereby established (at the front or back of the standards, depending how they are described) at the end of the line where the standards are attached. In this case, the calibration process itself takes into account the effects of the transmission line. Plane extension is not needed to deal with that line.

Now, suppose that line is attached to a connector attached to a PCB, on which is located the actual device we want to test; perhaps a mixer or IC. The path through the connector to the DUT creates a second transmission line. Ideally, we would like to calibrate right at the DUT, to eliminate the effects of that second line, but that is not practical. Instead, we extend the calibration plane through the connector to the input of the DUT. We do so by specifying the time delay experienced by the signal in following that path. The MSA can then mathematically adjust the measurement to put us in the same position as if we had calibrated at the DUT input.

To create a goal for making the plane extension adjustment, we short the transmission line at the point to which we are trying to extend the calibration plane. We know that if we extend the plane to that point, the point will appear as an exact short, meaning its reflection coefficient will be -1, or S11 will be 0 db at 180 degrees. We can watch for this on the regular graph or the Smith chart as we adjust.

Let's put a short at the end of a coax cable and try to extend the calibration plane to that point. In reality, with a simple cable, we would just calibrate at the end of that cable. But pretend it is some sort of transmission line for which we have access to the far end, but it is awkward to attach the regular Open, Short and Load at that point. But it is usually a simple matter to create a short.

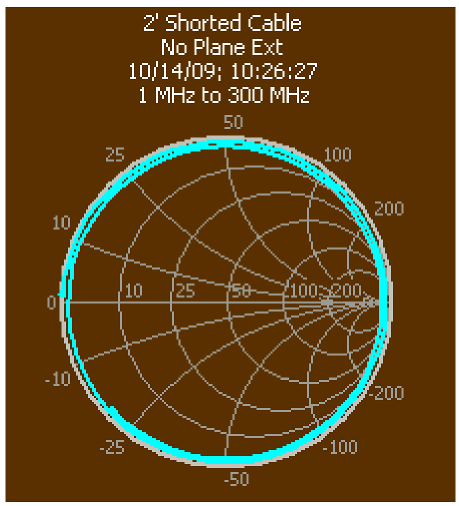

Figure 3—Cable S11 without plane extension

The short at the end of the coax graphs on the Smith chart as a reflection with magnitude near 1 (not quite 1, due to losses), which starts near 180 degree at low frequency and rotates around and around as we increase frequency, as shown in Figure 3. To get this to look like the short that is at the end of the cable, we have to get rid of all the rotation, and end up with a dot near the zero point at the left of the Smith chart.

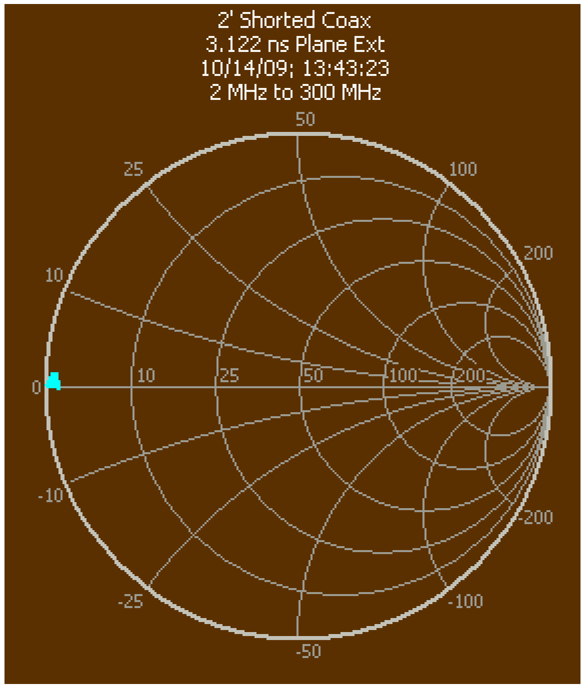

Figure 4—Coax after plane extension

The cable is two feet long, so we started with plane extension of 3 ns (1.5 ns/ft), and adjusted from there. This makes it easy to squeeze the graph down to a small area. It is not perfect, because of the losses in the coax.

Figure 5 shows a regular graph of the data in Figure 4, to illustrate the imperfections in the plane extension approach.

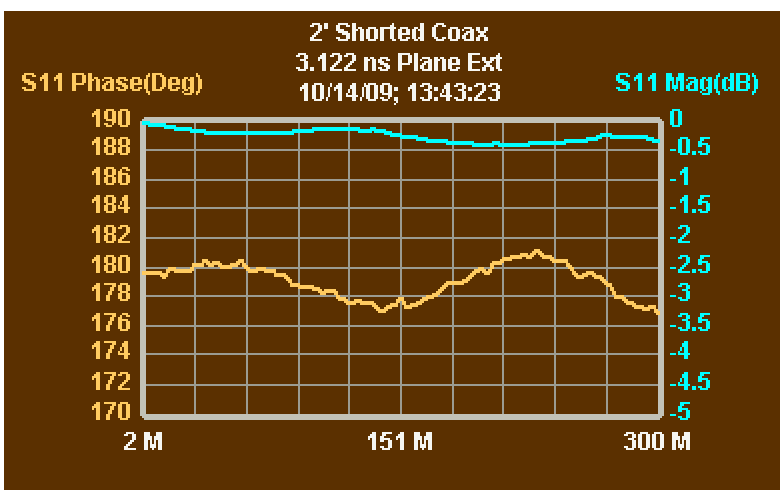

Figure 5—Residual error after plane extension.
Both lines should be flat, blue at zero and orange at 180 degrees

While we don't have a photo of it, without plane extension the phase line is wiggly and sharply tilted down to the right. As you add plane extension, the tilt goes away. For the final adjustment, it is actually easier to be precise using the regular graph of Figure 5 than the Smith chart of Figure 4. But the Smith chart gives a better intuitive feel for the fact that you are "unrotating" the graph.

Figure 6 shows that plane extension leaves a possible error of a couple of degrees, and magnitude error of almost 0.5 dB. The error is greatest at the higher frequencies. It can be reduced by shortening the cable length. The error results primarily from (1) losses in the coax and (2) the fact that the coax characteristic impedance is likely not exactly the assumed 50 ohms. If plane extension is used with long connections, it is bound to create some error. Note that the error shown in Figure 3, if translated into impedance error, is significant if you are measuring near the edge of the Smith chart (i.e. S11 values near 0 dB, meaning very high or very low impedances), but not especially significant near the center of the chart (meaning impedances near 50 ohms).