Division of RF Industries

Insertion Phase Errors in long lengths of coaxial cable assemblies

In this section, we will discuss the steps necessary to correct for insertion phase error as part of the calibration procedure for Vector Network Analyzers.

If you have ever tried to measure a long length of cable, you may have noticed the insertion loss (S_{21},S_{12}) display showing an abrupt change at some frequency in the negative direction or scale. I call this change in transmission loss “cliffing” as if you were looking down a cliff. If not corrected during the calibration stage, this additional loss would add to the total system loss which is erroneous to the actual insertion loss of the cable assembly.

Insertion phase error is the phase change that occurs to a signal as it propagates from one end of a coaxial cable to the other. Stated another way, it is also the time (delay) it takes for the signal to pass through transmission media from one end to the other. The delay is caused by the dielectric constant of the cable dielectric, the resistance of the conductor and the length of the cable.

Long lengths of cable will cause signal delay due to conductor length, conductor resistance and the *Vp* of the cable’s dielectric.

$$td = \frac{1.016}{V_p}$$

$$td = 1.016 \sqrt{\epsilon r}$$

$$td = \frac{l \chi \sqrt{\epsilon r}}{c}$$

Network Analyzers have a source frequency and tuned receiver that make swept measurements at the same time. The signal coming out of a coax cable opposite the receiver’s input will lag behind the VNA’s source frequency by:

$$f = t^* \, df/dt$$

Time Delay (td) is measured in seconds, nanoseconds or picoseconds. We will focus on how to select the proper *sweep time* on your VNA to compensate for this. Figure 1 illustrates the measurement error. Notice the cliffing effect occurs almost immediately at the start frequency.

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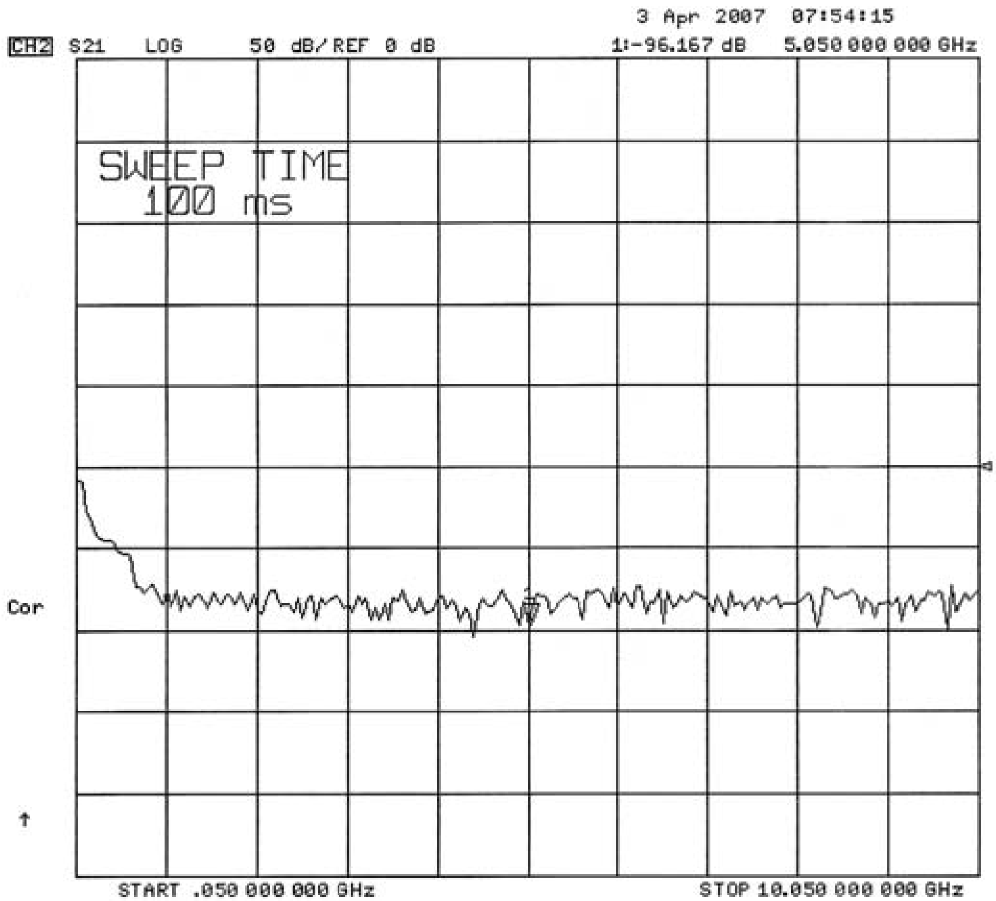

Fig 1

The “cliffing” effect can be seen at the start frequency, 50MHz (.050GHz). The VNA settings for figure 1 are the default sets when calibration constants are loaded. The number of data points (NOP) is 201 and the sweep time is 100ms. In this example, I swept a cable assembly composed of TNC male connectors on 262 feet of Times Microwave LMR-195. I increased the power output to the VNA ports to -5dBm to facilitate some of the resistive loss due to the long length. The marker is set to the center frequency of 5.050 GHz. The I.L. value is -96.1dB. Notice the linear loss characteristic is absent from this graph. (Fig 1) The specification from Times Microwave should have an I.L. value of -72.7dB @ 5.050 GHz.

I performed a new calibration and set the NOP to 801. A *sweep time* setting of 1 - 5 seconds usually corrects the cliffing effect. (Fig 2) Notice here the linear loss characteristic. It is important to note that foamed dielectric cables have a faster Vp than solid dielectric cables therefore, you would need to increase the sweep time if you are measuring insertion loss on solid dielectric cables.

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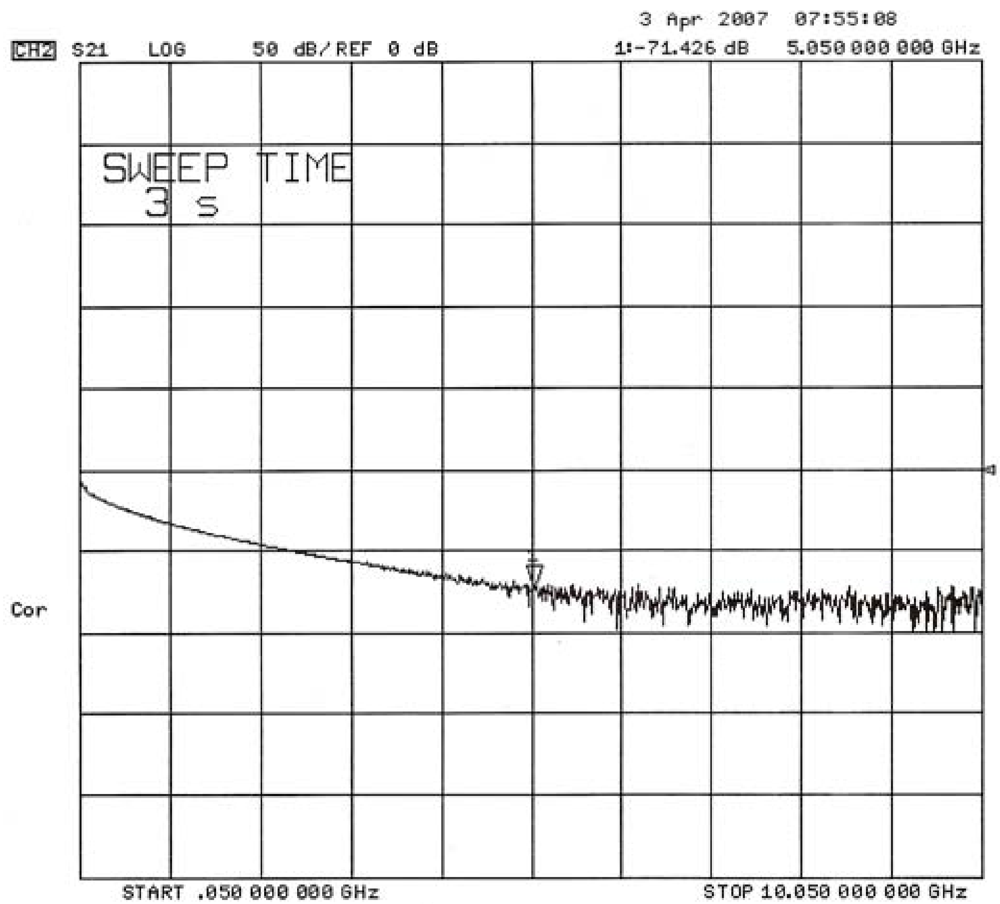

Fig 2

Although foamed dielectric cables have faster Vp, you would still need to increase the sweep time if you are experiencing measurement errors. Your VNA has the ability to manually change the sweep time. The default sweep time is typically derived from the bandwidth between the start and stop frequencies and the number of points. (NOP) Increasing the NOP will increase the sweep time based on the frequency span.

In the next example, I swept a cable assembly composed of N male connectors on 50 feet of Times Microwave LMR-400 cable. (Fig 3) Per the Times specification, the I.L. value at 9.0 GHz should be -7dB. The NOP and sweep time are the same as the previous example. I increased the power output to -5dBm. The only difference is the frequency start and stop bands. The cliffing effect is very pronounced in this example probably due in part to the limited operating band of this cable assembly.

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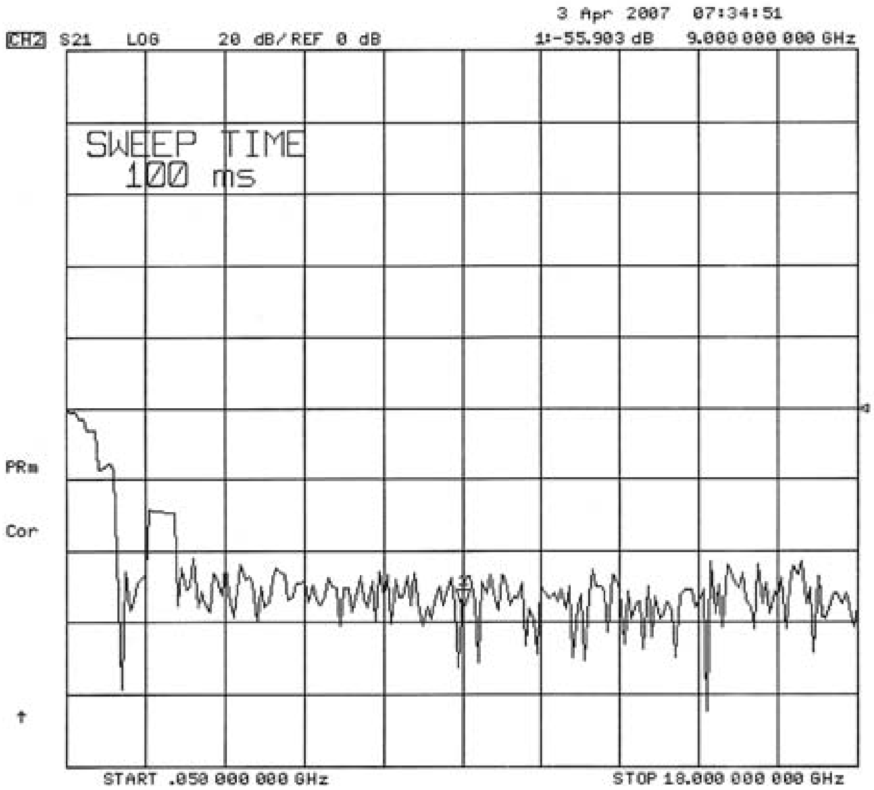

Fig 3

Again, I performed a new calibration, increased the power out, the NOP and for example purposes, I set the sweep time to 1 second. (Fig 4) The effects can still be seen and considered erroneous. The last graph shows the improved insertion phase by increasing the sweep time to 2 seconds. It now represents the Times Microwave I.L. specification with the connectors adding the extra -.5dB. (Fig 5)

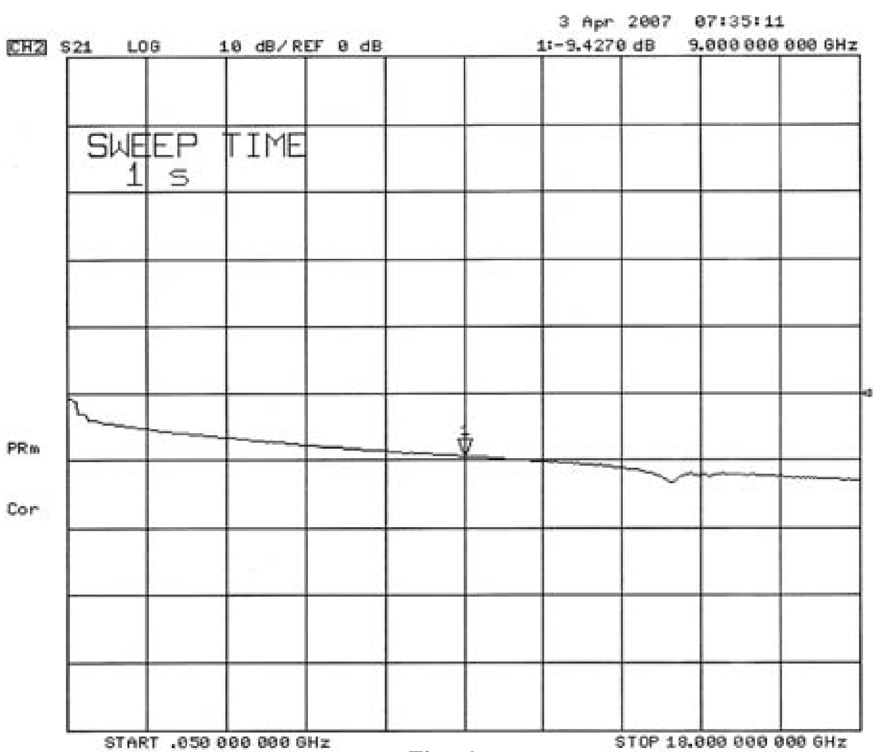

Fig 4

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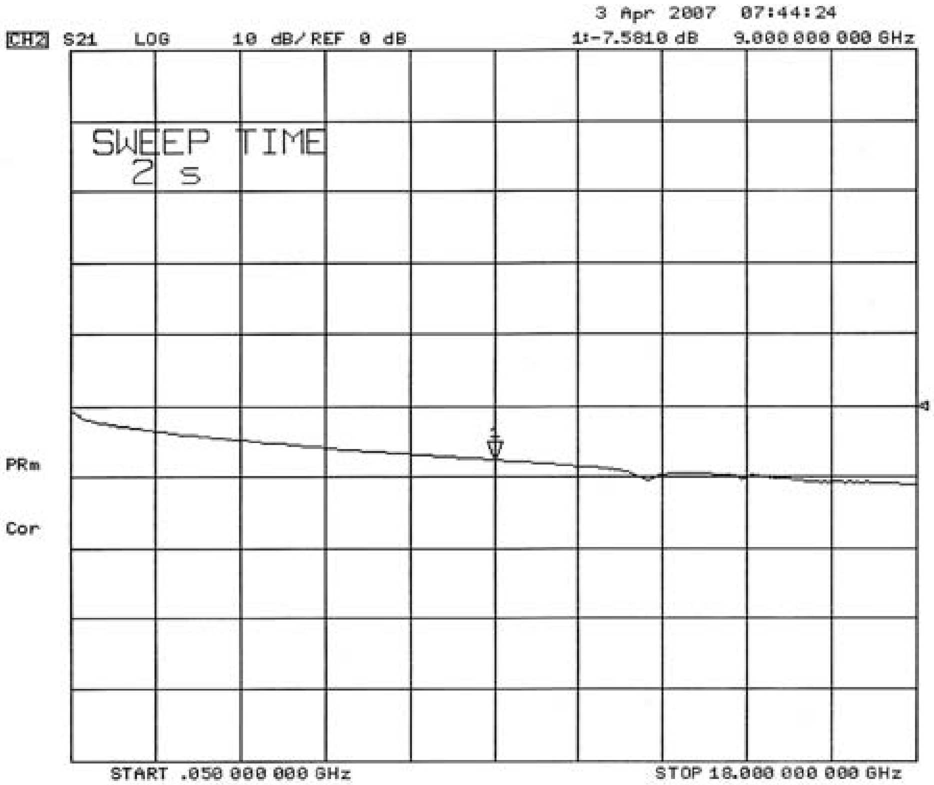

Fig 5

Conclusion:

If the frequency shift is out of phase to the VNA's IF detection bandwidth, then the measured result will display erroneous data due to the lag from the signal source to the VNA's detector. Sweeping long lengths of cable with fast sweep times will display incorrect insertion loss values. Correcting for cable delay is a must when sweeping cable assemblies with long lengths on a VNA especially if the coax cable uses a solid dielectric. When working with loss budgets, this can be a very important detail that is commonly overlooked.

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For a more in-depth explanation on insertion phase and frequency shift error read:

Coaxial cable insertion phase measurement and analysis by Carl Dole, Belden Cable Engineer

10 hints for better VNA measurements by Agilent, App note 1291-1B

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