Next Generation Time Domain Processing for Network Analyzers

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Time Domain Processing for VNAs

Time domain processing is a commonly selected option for Vector Network Analyzers. It gives the engineer an alternate view of the device under test's (DUT's) S-parameters. This alternate view can aid the engineer's understanding of the DUT's behavior. It is particularly useful in finding measurement problems related to connectors and fixturing. Recently, an entirely new approach to time domain processing was developed which promises to greatly enhance the engineer's ability to understand the measured S-parameters of the DUT.

The measured S-parameters are functions of frequency. Therefore the term "frequency domain" can be applied to them. Because the frequencies at which S-parameters are measured are equally spaced, it is possible to transform them using an inverse Fourier transform. The output of this operation is a function of time. Therefore the term "time domain" can be applied to the measured, inverse transformed S-parameters.

As an example, Figure 1 shows measured S11 data in the frequency domain. The data is measured from 40 MHz up to 20 GHz with 1601 points. As can be seen from Figure 1, the behavior of the DUT is quite complicated. It may not be readily apparent to an engineer what kind of DUT could cause this type of behavior.

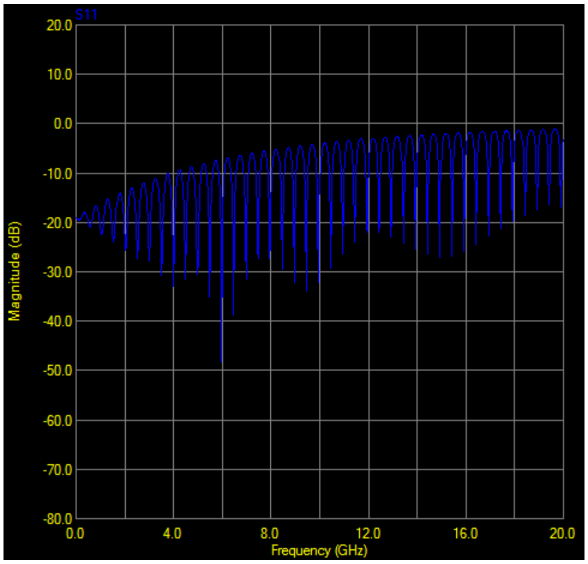

Fig. 1 Magnitude of S11 for a DUT

At this point, the engineer turns to time domain processing to better understand the DUT. Figure 2 shows the magnitude of S11 in the time domain. Because the measurement is of the reflection parameter S11, the time domain is a series of reflections off the DUT. The first reflection comes back at 2.0 nanoseconds. There are other reflections at 4, 6 and 8 nanoseconds. The shapes of the reflections appear to be subtly different from each other. However, aside from helping to show that the DUT has some distinct scattering centers, time domain processing has not greatly aided in understanding of the DUT.

Spectrographic Analysis

The problem with frequency domain and time domain views, are that they are two extremes. In the frequency domain, there is no notion of time. In the time domain, there is no notion of frequency. What is needed is a view of S11 which simultaneously displays time and frequency information. The mathematics that accomplishes this is known as joint time-frequency analysis. One particularly useful form of this math, at least as far as VNAs are concerned, is spectrographic analysis. The image created by applying spectrographic processing to a set of data, is known as a spectrogram.

Constant Wave has developed a software package called "Spectro VNA" which applies this patent pending spectrographic analysis to VNA time domain processing.

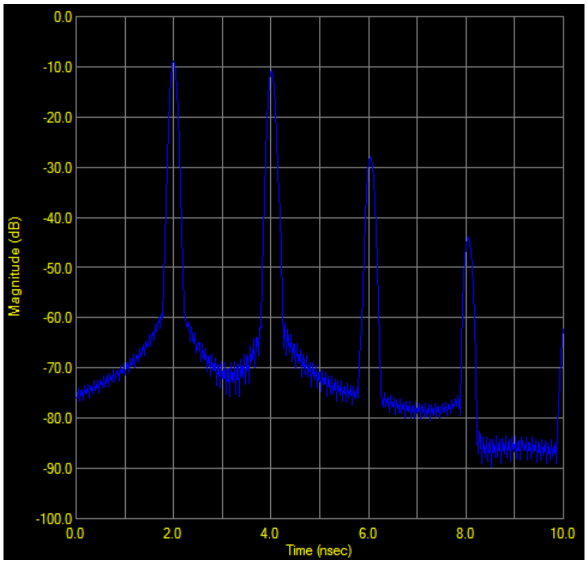

Fig. 2 Magnitude of S11 in the time domain.

Figure 3 shows a spectrogram produced using Spectro VNA. The horizontal axis is time. The vertical axis is frequency. The colors represent the intensity of the magnitude of S11. As with traditional time domain processing for VNAs, any range of time can be chosen for the output time range. In this case, the range of 0 to 10 nanoseconds was chosen, because that range of time captures the essential behavior of the DUT. Note that some of the lowest and highest frequencies are not displayed. This aspect of spectrographic processing is discussed in the Appendix.

Unlike traditional time domain processing, which has a fixed time resolution, the engineer can choose to trade off time resolution with frequency resolution. The Heisenberg Uncertainty Principle states that resolution in the frequency domain is a trade-off with respect to resolution in the time domain. For the case shown in Figure 3, the time resolution was chosen as 400 picoseconds. Spectro VNA allows the engineer to choose the time/frequency resolution trade-off which allows for the best view of the DUT's behavior.

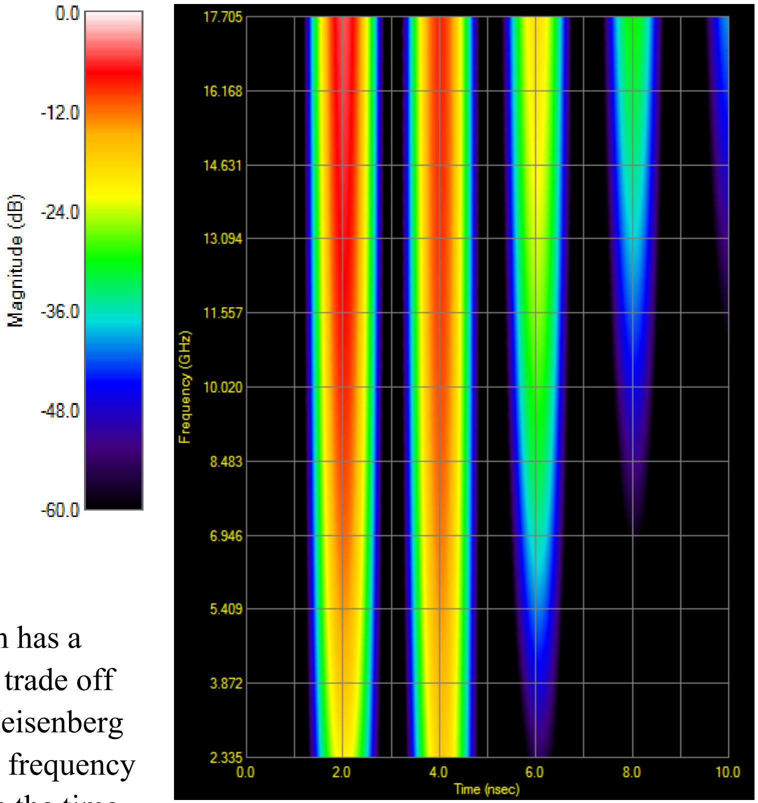

Fig. 3 Spectrogram of DUT response.

A significant enhancement which spectrographic analysis brings to VNA's, is the ability to retain frequency domain information about the reflections in the time domain. Note how the color changes for the reflection at 2 nanoseconds, when going from lower frequencies at the bottom of the plot, to higher frequencies at the top. It appears that there is more reflection at higher frequencies. By placing a cursor at 2 nanoseconds, the magnitude of S11 can be plotted as a function of frequency. This is shown in Figure 4. The reflection does indeed vary with frequency. Although Figure 4 shows the magnitude of S11 for the reflection at 2 nanoseconds, the phase, the real part and the imaginary part could also be plotted.

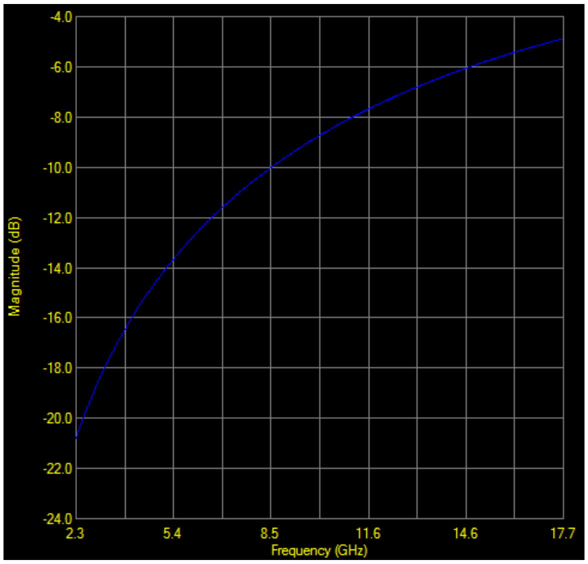

Fig. 4 Frequency response of the reflection at 2 nanoseconds.

Take a moment to compare the data shown in Figures 2, 3 and 4 with regard to what is revealed about the characteristics of the reflection at 2 nanoseconds. Traditional time domain processing, shown in Figure 2, does not retain frequency information about discontinuities. From Figure 2, we know where the discontinuity resides, how much signal reflected off it, but very little about its frequency domain characteristics. Spectrographic processing makes it possible to view both time and frequency behavior. This is a powerful new tool for the engineer. We will see this power as we proceed with the example.

Modeling Parts of the DUT

Constant Wave's patent pending implementation of spectrographic processing for VNA's not only gives the engineer a new way of visualizing reflections, but it also can be used to model them. Because frequency domain information has been retained about the discontinuity at 2 nanoseconds, it is possible to determine an equivalent circuit for that part of the DUT. In Spectro VNA this is known as Discontinuity Modeling. Let's ask Spectro VNA to model the discontinuity at 2 nanoseconds as a shunt inductance. The result is shown in Figure 5. The blue trace is the same data shown in Figure 4. The green trace is the best fit data for a shunt inductor. An inductor is clearly not a good representation of the data. Let's try a shunt capacitance. The result is shown in Figure 6. As with Figure 5, there are both blue and green traces, but this time, the agreement is so good, that it looks like one trace. Spectro VNA reports that the best fit capacitor is 0.25 pF. Thus, the

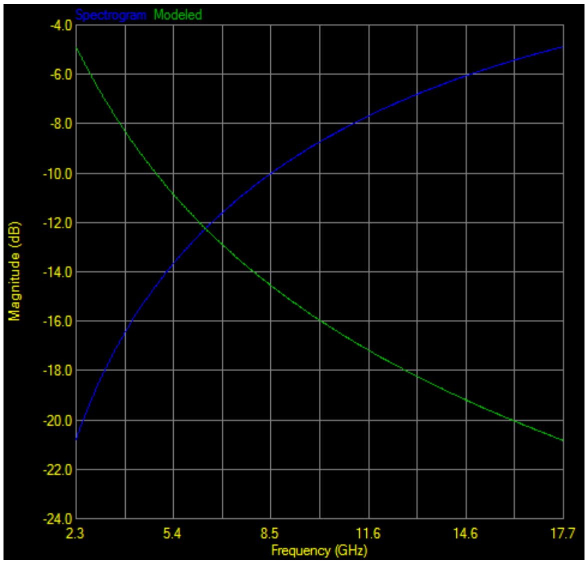

Fig. 5 Modeling the reflection at 2 nsec as a shunt inductor.

first reflection at 2 nanoseconds is due to a 0.25 pF shunt capacitance.

Look again at Figure 4, the frequency characteristics of the discontinuity at 2 nanoseconds. As frequency increases, a capacitor increasingly looks like a short circuit. A short circuit has total reflection. Figure 4 shows that as the frequency increases, the magnitude of the reflection off this discontinuity increases. Spectrographic analysis has been used to identify the discontinuity and to increase our understanding of the nature of discontinuities.

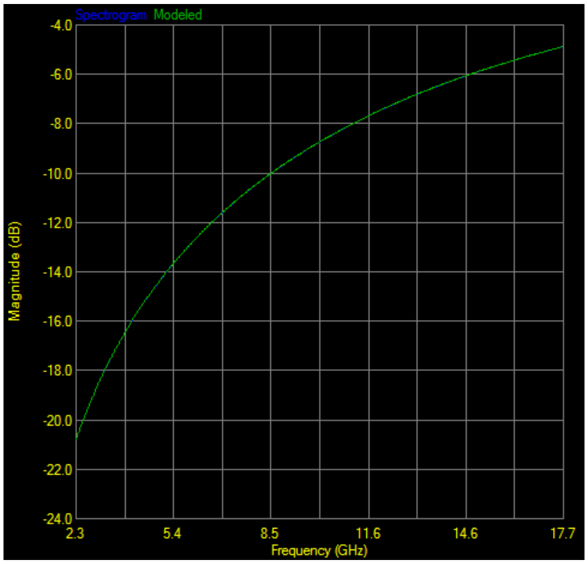

Fig. 6 Modeling the reflection at 2 nsec as a shunt capacitor.

De-Embedding

Now that we have determined the value of the capacitance, we can remove its effect from the measured data. We do this by de-embedding a capacitor from our DUT's S11 response. In Spectro VNA this is known as Discontinuity De-Embedding. The result of de-embedding the capacitor from the original measured S11 data is shown in Figure 7. Naturally, Spectro VNA handles all the de-embedding mathematics for the engineer. Just to be clear, Figure 7 shows what the measurement of the DUT would look like if the capacitance at 2 nanoseconds did not exist. The data shown in Figure 7 can be saved as an s1p file.

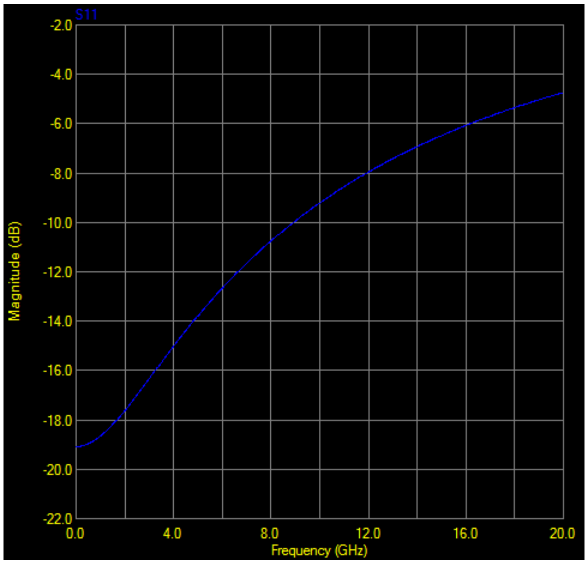

Fig. 7 Magnitude of S11 for the DUT with the discontinuity at 2 nsec deembedded.

Let's now perform the same type of spectrographic analysis on the s1p file we saved from Figure 7. The result is shown in Figure 8. Note the absence of the reflection at 2 nanoseconds. The de-embedding process has removed this discontinuity from the DUT response data. Notice also that the reflection at 6 nanoseconds has also been removed. This was a re-reflection off the capacitance. Because the capacitance was removed by de-embedding, the re-reflection off it no longer exists.

If we place a cursor on the discontinuity at 4 nanoseconds, the frequency domain response can be determined and is shown in Figure 9. We again desire to generate an equivalent circuit for this part of the DUT. From basic knowledge of the circuit topology, we know that this is the last element in our DUT. We therefore model it as a load using Spectro VNA. The mathematics of modeling a circuit element in the middle of a transmission line, and one at the end of the line, are slightly different. From our basic understanding of our DUT, we know that this element should be our load, so we model it that way.

We can choose several different equivalent circuits for the load. Spectro VNA makes it easy to experiment to find the best fit. By choosing a series resistor and inductor we get the fit shown in Figure 11. There are two lines plotted on Figure 11, the trace from Figure 10 and that obtained from a resistance of 40 Ohms in series with an inductance of 500 picoHenries. We have determined that our load is not the 50 Ohms that was desired, and that there is a slight inductive component to it.

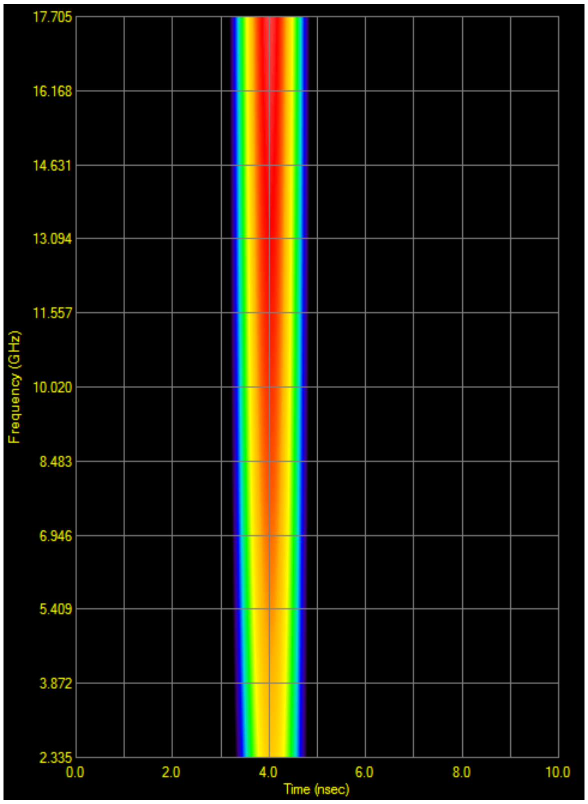

Fig. 8 Spectrogram for the data in Figure 7.

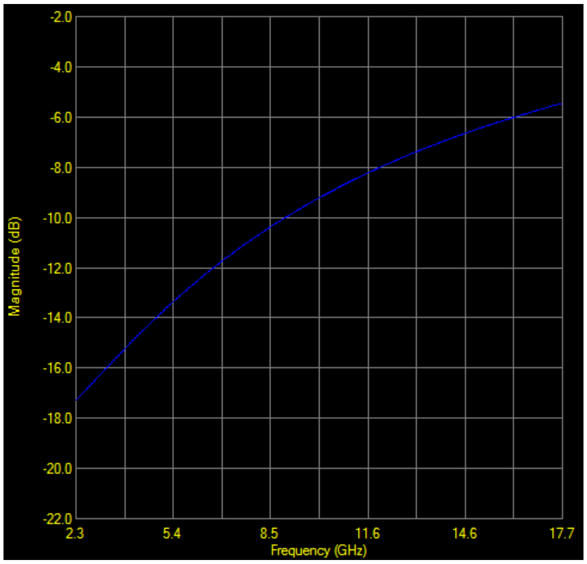

Fig. 9 Frequency response of the reflection at 4 nanoseconds.

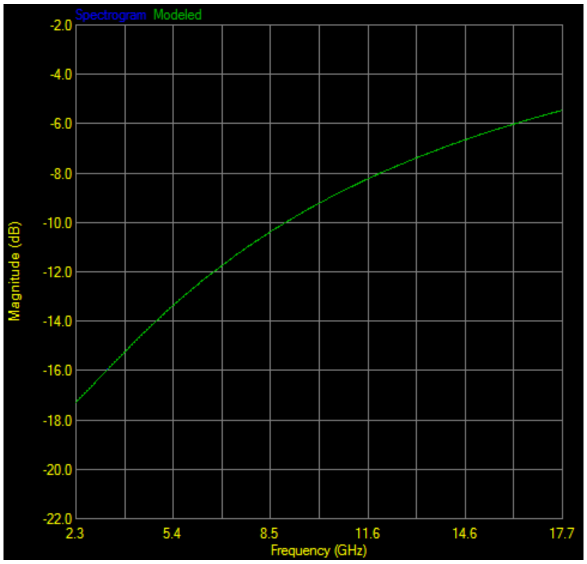

Fig. 10 Modeling the reflection at 4 nsec as a resistor and inductor.

Conclusion

Constant Wave's patent pending spectrographic analysis brings a powerful new tool to VNAs. It presents the engineer with new ways of viewing the behavior of the DUT. Spectro VNA allows the engineer more control over time/frequency resolution trade-offs than does traditional time domain processing. With its powerful modeling tool, Spectro VNA gives the engineer the ability to determine equivalent circuit models for different parts of the DUT. With its de-embedding tool, these equivalent circuit models can be removed from the DUT response. All these benefits to the engineer mean that a new era in time domain processing for VNAs has arrived.

Appendix: The reduced frequency range of spectrogram displays.

As shown in Figure 1, the original S11 data spanned the range from 40 MHz to 6 GHz. When this data is processed to produce a spectrogram, a windowing function must be applied. This is shown in Figure 11. The blue trace is the S11 data, while the red trace is the windowing function. This is the alignment of the windowing function for the computation of the lowest frequency component in the spectrogram. The peak of the window is near 2.3 GHz. Only the data within the range of the window is included in the computation of the time domain response for this frequency.

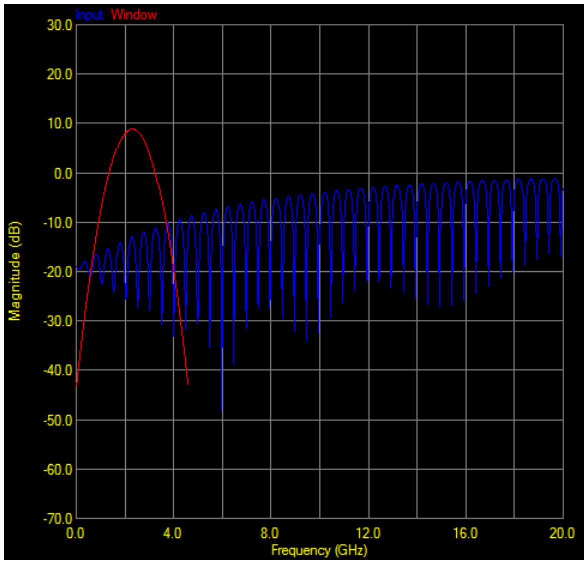

Fig. 11 Input S11 data and the windowing function.

When the time domain data is computed, it is plotted in the spectrogram as being associated with the frequency 2.335 GHz. Thus, the lowest frequency in the spectrogram is not 40 MHz, as in the input data, but 2.335 GHz, the center of the window which first fits fully within the data. The last window which fits the data has its center at 17.705 GHz. Therefore the spectrogram only displays data for frequencies between 2.3 and 17.7 GHz.

This loss of data at the extremes of the frequency range is dictated by the trade-off between time and frequency resolutions. For the case shown here, the time resolution was chosen as 400 picoseconds. Other choices are possible which opt for better time resolution, at the expense of frequency resolution, or for worse time resolution, to the benefit of frequency resolution. The resolution plot shown in Figure 11 is always made available by Spectro VNA.

While the display of the spectrogram is limited by the choice of resolution, de-embedding is not. Once an equivalent circuit has been determined which best fits a discontinuity, the de-embedding occurs at all frequencies in the input data. So, while the engineer can control the trade-off of time/frequency resolution, de-embedding occurs at all points in the input and, thus, incurs no loss of data.