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Using Network Analyzer Time-Domain Analysis to Verify and Troubleshoot Complex Components

by Afsi Moaveni, Agilent Technologies

Testing and qualifying components and systems for use in modern communications and radar systems can be a challenging task for today's RF engineers. Accomplishing that goal requires a certain level of specified performance for the various devices across the operating frequency range. Swept frequency measurements such as insertion loss or return loss are often specified for RF devices. In cases where the device or system does not meet its specifications, engineers must troubleshoot by swapping components in and out of the system until the performance meets specified requirements; a time-consuming and error-prone process. An alternative technique available to engineers today is time-domain analysis using a vector network analyzer (VNA). Time-domain measurements provide insight into the location and magnitude of problems, thereby simplifying the troubleshooting process and helping engineers better understand their device performance.

Time-Domain Measurement Basics

Time-domain measurements can play an important role in helping engineers determine the root cause of problems in today's complex electronic systems. To understand why, let's examine the relationship between frequency-domain measurements and time-domain transforms.

Time-domain analysis is useful for observing mismatch effects along a transmission line system. When an RF or microwave signal propagates along a transmission line, a portion of the signal is reflected back from any discontinuities encountered along the path. Using time-domain analysis, the location of each

Figure 1: Agilent's handheld FieldFox combination analyzer is equipped to handle everything from routine maintenance to in-depth troubleshooting. Its base function is as a cable and antenna analyzer; however, it can be configured to include a spectrum and network analyzer. Additional capabilities include a power meter, independent signal generator, vector voltmeter, interference analyzer, variable DC source, and built-in GPS receiver.

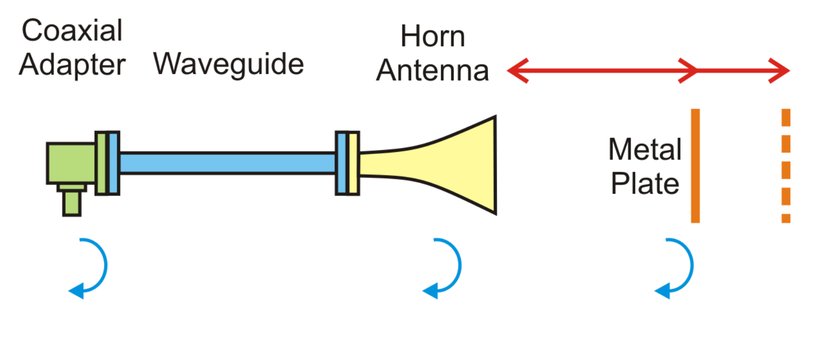

Figure 2: This configuration is used to measure frequency-domain and time-domain responses of an over-the-air measurement using an X-Band horn antenna.

discontinuity is displayed as a function of time along the x-axis and the amplitude of the reflected signal or S11, along the y-axis. Knowing the propagation velocity along the transmission line allows the time measurement to be scaled to physical distance.

The measurement from any one-port or two-port device can be represented in the time domain and/or the frequency domain. Consequently, if a measurement is made in one domain, the other domain can be calculated using a Fourier Transform (FT). The transform provides a universal problem solving method that enables engineers to examine a particular measurement from an entirely different viewpoint. If the measurement is recorded using a time-domain method, then a FT calculation will result in a frequency-domain representation of the data. Alternatively, if frequency-domain data is initially captured, an Inverse FT (IFT) will result in a time-domain representation of the data. This ability for the same data to be simultaneously displayed in both time and frequency creates a powerful analysis and problem solving tool for today's RF engineers. Accessing this capability requires use of a measurement instrument that supports such functionality.

Accessing the Time-Domain

While both the Time Domain Reflectometer (TDR) and VNA are capable of displaying the time-domain response of individual discontinuities along a transmission system, the VNA includes the IFT mathematical transformation as part of its firmware. As a result, it allows the user to display either time-domain data or frequency-domain data, or both.

The VNA is primarily a frequency-domain instrument capable of measuring the reflected and transmission characteristics of one and two-port devices. Using error-corrected data measured in the frequency domain, the response of a network to an impulse or step function can be calculated using the IFT and displayed as a function of time. Because the VNA uses narrowband measurement receivers, its dynamic range is typically higher than oscilloscope-based TDR systems. Also, the VNA includes a time-domain capability for measuring band-limited devices. Some VNAs may even be configured as cable and antenna analyzers (**Figure 1**). The cable and antenna analyzer configuration enables the instrument to perform the same frequency-to-time transformation, and also scale

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the time measurements to an equivalent physical distance. Such functionality helps technicians and engineers quickly locate faults in transmission lines in the field.

Measurement Example Using a Horn Antenna

As an example, consider the test configuration in Figure 2. It is used to examine the frequency-domain and time-domain responses of an over-the-air measurement using an X-band waveguide horn antenna and a separate metal plate placed near the antenna. The high-gain horn antenna is connected to a short length of WR-90 waveguide transmission line attached to a waveguide-to-coaxial adapter for connection to the VNA. The VNA is calibrated for S11 at the plane where the adapter is connected to the instrument port. It measures the effects of all components in Figure 2, as well as effects from other items in the surrounding environment. The metal plate is a 0.3-m^2 aluminum plate mounted to a tripod and positioned in front of the antenna. The distance between the metal plate and the antenna varies to examine changes in the frequency and time responses.

Figure 3A shows the measured frequency response of the system under three test conditions: two with the metal plate near the antenna and one without. The yellow curve shows the measurement without the metal plate. There is a small ripple in the measured S11 response due to interaction between the various transmission lines and reflections from items in the surrounding environment. The blue trace shows the frequency response with the metal plate positioned at 1.7 m from the horn antenna. Note that there is a larger amount of ripple in S11 compared to the case with no plate. The orange curve shows the response when the plate is moved to a 1.2-m separation. Here, the ripple is even more pronounced as the reflected signal from the plate has larger received amplitude.

While metallic structures placed near the antenna system could have a negative effect on the system performance (causing an out-of-spec condition), examining only the frequency response will not provide sufficient insight into the root cause of any problems. An examination of the time-domain response is therefore essential.

Figure 3B shows the time-domain response of the same antenna system using a FieldFox VNA with time domain analysis capability. For the test condition without the metal plate (yellow trace), the peaks associated with signal reflections from the surrounding environment are low compared to those from the adapter and antenna. This measurement would provide a good baseline for a new system installation and would be ideal for comparison purposes as more antenna components and structures are added around the system.

Also shown in the figure is the time-domain response when the metal plate is positioned near the antenna. At 1.7 m (blue trace), the measurement shows a large peak due to the reflection from the metal plate. A smaller peak to the right represents the reflection from the legs of the tripod. When the plate and tripod are moved to 1.2 m (orange trace), the measured time-domain response shows an equivalent time shift in these peaks. From these measurements, it's possible to see the peaks associated with the adapter and antenna are static since these components were unchanged during testing. There is also a noticeable increase in the peak amplitude associated with the metal plate when the plate is moved closer to the antenna. This is due to the reduction in space loss as the signal now propagates over a shorter distance.

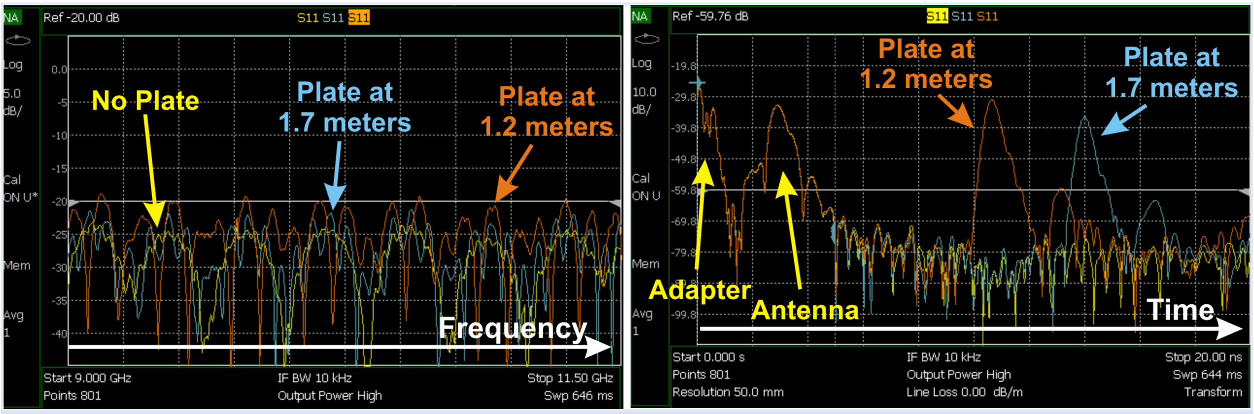

Figure 3A and 3B: Shown here is the measured frequency response (3A) and time-domain response (3B) of the X-band antenna system under three test conditions.

Using Gating to View Frequency Response Without Environmental Effects

In the horn antenna example, environmental reflections introduced a ripple in the frequency-domain response. In some cases, it may be useful to confirm system performance without any environmental effects. Under this test requirement, a gating function configured in the time domain to filter out specific reflections may be particularly useful. Essentially, gating introduces a time filter to remove unwanted reflections from a time-domain response. Once the undesired responses are removed, the frequency-domain response of the remaining devices can be observed.

To continue with the antenna example, Figure 4A shows the time-domain response with and without a gating function. Here, a bandpass gate is configured to remove the effects of the metal plate and the environment. The yellow trace is the original measurement including the peak from the metal plate reflection. The blue trace shows the time-domain response with the bandpass gate configured to filter any response to the right of the antenna. With the bandpass gate applied, the time response only includes the effects of the coaxial adapter and the antenna. It is also possible to remove a single peak, or group of adjacent peaks, using a notch gate.

Figure 4B shows a comparison between the original frequency response, including the plate and environmental reflections (shown in yellow), and the response when the gate is applied (shown in blue). With the gated response, there is a reduction in the ripple across the measured frequency span since reflections from the environment have been filtered out from the measurement. Gating is a very powerful tool to examine the reflection and transmission properties of a component or system by selectively removing specific responses from the measurements in any domain.

Conclusion

While frequency-domain measurements are useful for obtaining information regarding the proper functioning of a system, time-domain measurements are critical to finding the root cause (e.g., location and

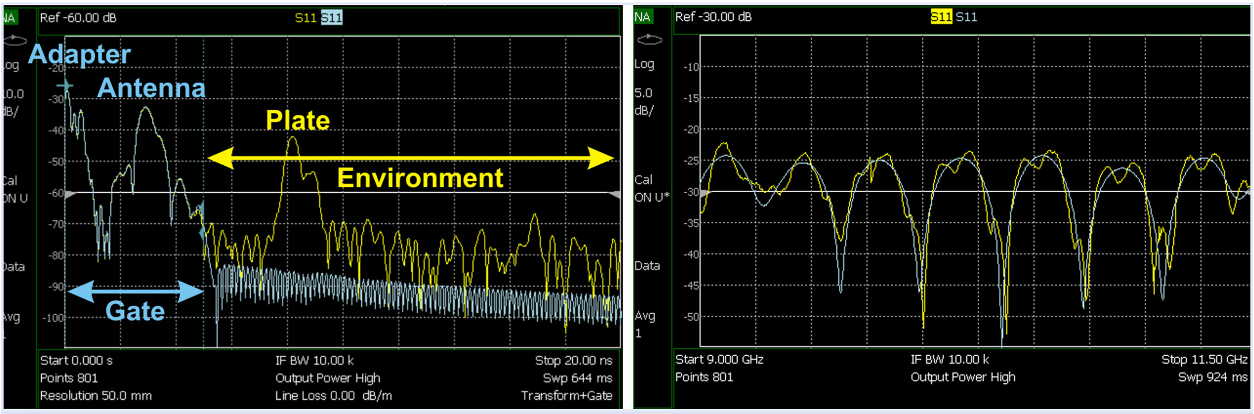

Figure 4A and 4B: Shown here are the time (4A) and frequency (4B) domain responses of the X-band antenna system with and without a gate function applied to the measured data.

magnitude) of any problems. Fortunately, the handheld VNA instrument is fully capable of displaying time-domain and frequency-domain data, as well as the time-domain characteristics of one- and two-port components and systems, all while operating in the field. Such capabilities are invaluable for RF engineers verifying and troubleshooting complex components and systems for use in modern communications and radar systems.

Download Agilent's application note, *Techniques for Time Domain Measurements* and listen to a pre-recorded webcast, *Techniques for Precise Time Domain Measurements* in the Field at www.agilent.com/find/fieldfox.

About the Author

Afsi Moaveni is a senior applications engineer working in Agilent Technologies' Component Test Division in Santa Rosa, California. Afsi has worked at Agilent for eighteen years, as a microelectronics manufacturing engineer, product marketing and applications engineer. She holds a BSEE from University of Colorado and a masters in MS&E from Stanford University.

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