

Time Domain

for Vector Network Analyzers

Application Note



Vector Network Analyzers (VNA's) are very flexible measuring instruments - the microwave engineers most powerful tool. Their basic capability is to measure the S Parameters of an RF or microwave device and display the result in the frequency domain. This provides valuable data for the design engineer to develop a design and for the production engineer to substantiate the performance of the device or system. The Time Domain option is available to enhance the flexibility of the VNA by presenting data that provides insight into the time (or distance) performance of the device - valuable information for both the design and production engineer. Figure 1 shows both the time and frequency response of a microstrip circuit. The benefit of the Time Domain response is apparent.

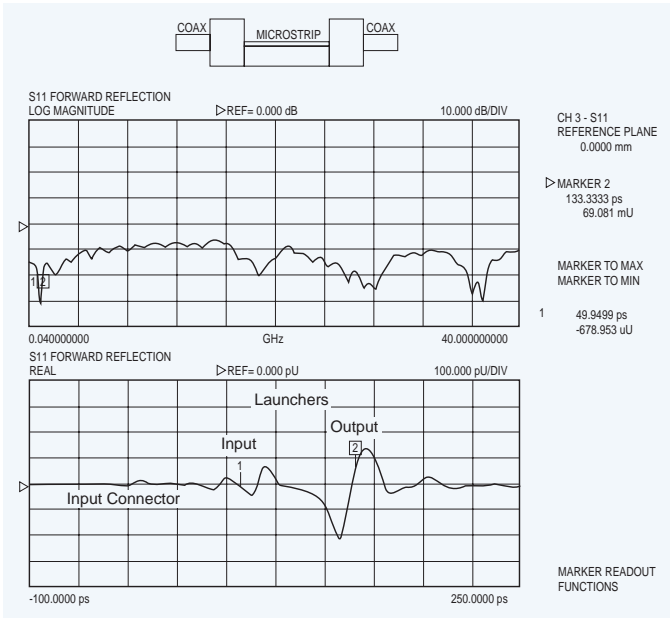


Figure 1. The Time and Frequency Response of a Microstrip Circuit

TIME DOMAIN FUNDAMENTALS

The Fourier transform has been used in many technologies and in the area of microwave measurements it provides a method for transforming frequency domain data, the VNA's basic capability, to the time domain. DSP, which is fundamental to the modern VNA by computing error correction terms, also permits convenient implementation of the FFT. Actually a type of FFT known as the Chirp Z Transform is used. This permits the user to "zoom in" on a specific time (distance) range of interest for the data display. This note will not deal with the details of either transforms or DSP; but, will address properties of the transform process and show how the various processing options can be used to obtain optimum results for a given application.

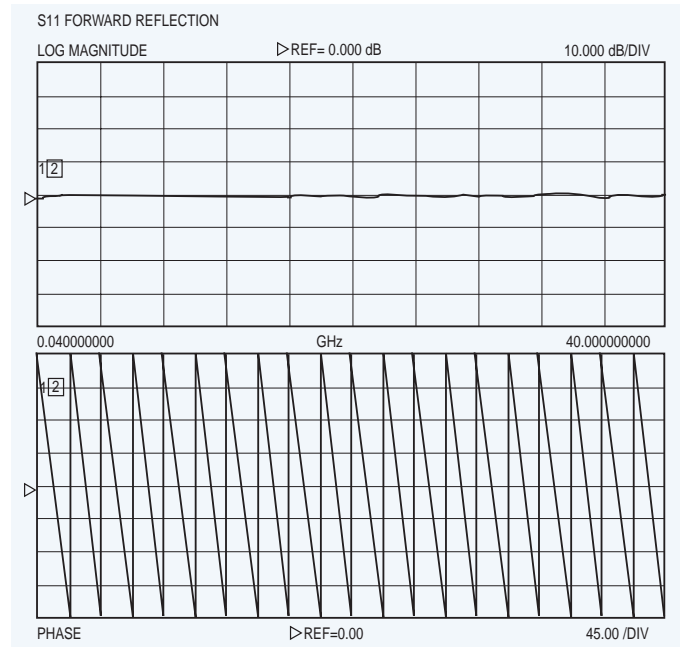


Figure 2a

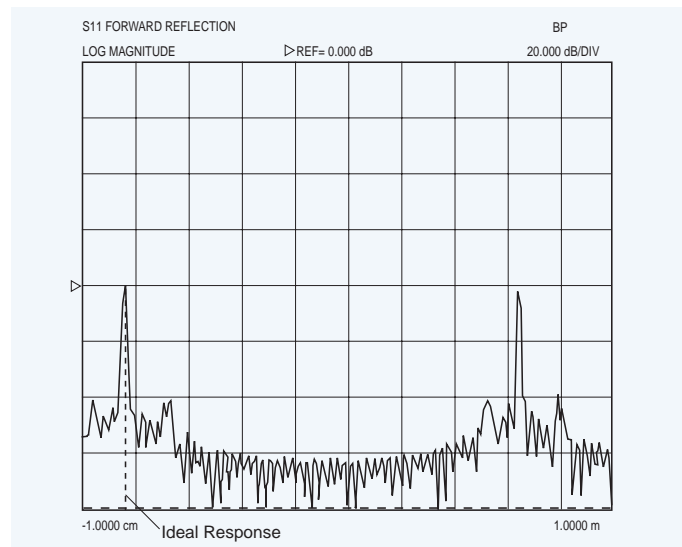


Figure 2b

A convenient place to start is to consider the transform of frequency domain data obtained from the measurement of a short at the end of an airline - see Figure 2. It is apparent that the time domain response is informative; but, it is far from the ideal time domain response, which is superimposed. This figure illustrates two of the fundamental properties (limitations) associated with the FFT - resolution and alias free range. These are due to the fact that the FFT is operating on a finite set of data rather than the theoretical infinite set.

The principal property of time domain processing for most micro-wave applications is resolution - which relates to the ability to locate a specific signal in the presence of other signals. In practice the basic limitation is inversely related to data collection bandwidth in the frequency domain. A rule of thumb: resolution is on the order of 150 mm/Frequency Span (GHz) - that is a 40 GHz frequency span will provide resolution of about 4mm. Figure 3 illustrates the importance of a wide frequency sweep if the application calls for identifying closely spaced reflections. Resolution is also influenced by the processing method and window selection which will be described below. Another important factor is the relative amplitude of the signals being processed. A large signal can swamp a smaller signal - obviously the greater the time(distance) separation between the two the better the system will perform.

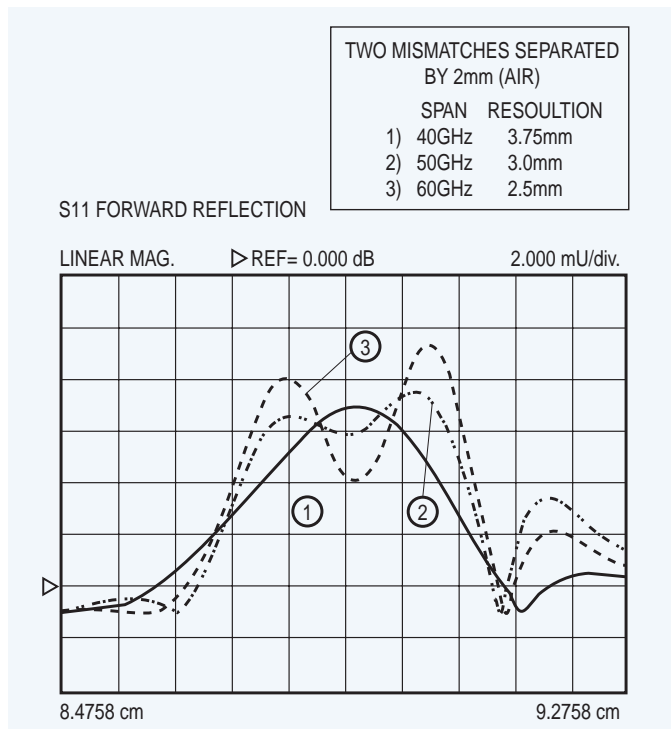


Figure 3

A second property of the transform process is the Alias Free Range. The transform is a circular function and repeats itself outside of it's inherent range which is 1/Step Size. This is not usually a factor in circuit measurements; but, does become a factor in fault location which is an important application for the Time Domain Option. For example with a 20 GHz, 401 point frequency collection the Alias Free Range is:

$$1/50 \text{ MHz} = 20 \text{ nanoseconds}$$

This is large for most circuit work and the range is usually greatly reduced for display; however, if the user wanted to locate a fault in a 100 meter cable the range is inadequate. For such applications the step size must be reduced either by decreasing the frequency span or increasing the number of points.

Processing Options:

The Time Domain option offers a number of processing options to the user. It is important that the user be aware of the feature set available as selection can have a significant effect on the end result. These "tools" include:

- Processing Method- Lowpass, Bandpass or Phasor Impulse.
- Windows
- Gating – Frequency Gated by Time Display.

Lowpass – This is the most powerful processing technique. It does require a special frequency plan: A harmonically related set of frequencies that starts at as low a frequency as possible is required. A DC term is extrapolated which provides a phase reference, so that the true nature of a discontinuity can be seen. Low pass offers two presentations: Step or Impulse response. (The step response is the integral of the Impulse response.) The Step response permits the direct display of impedance versus time or distance similar to that obtained with a Time Domain Reflectometer. The user can also obtain insight into the nature of a discontinuity: inductive, capacitive or resistive. Figure 4 shows ideal responses associated with various types of discontinuities. The default display is real which shows impedance information. (A scale of 20 mU per division is about 2 ohms per division). There is no imaginary component in the time display for Lowpass processing. The user can also choose Log Mag or a linear display format (standard for Bandpass described below) so that if the instrumentation, transmission line and DUT permit Lowpass processing, it should be used. Lowpass processing also offers the highest resolution for a given bandwidth.

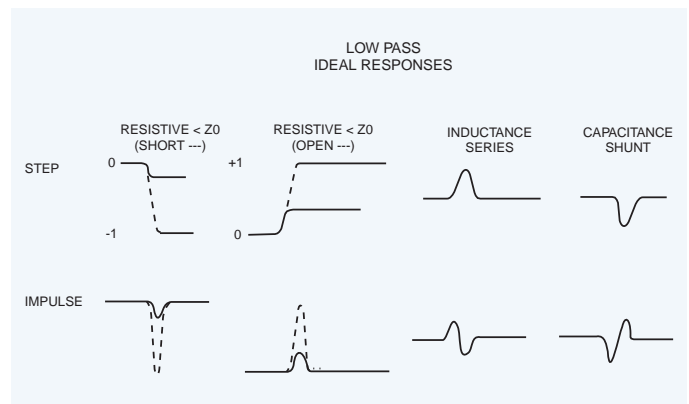


Figure 4. Ideal Responses Associated with Various Types of Discontinuities

Figure 5 shows a practical application of Lowpass Time Domain processing. An SMA line standard was constructed using solid teflon and precision connector interfaces, the response clearly shows the quality of the SMA "standard" which was used to evaluate SMA calibration performance. The standard line impedance is 49.73 ohms, which provides greater than 50dB return loss.

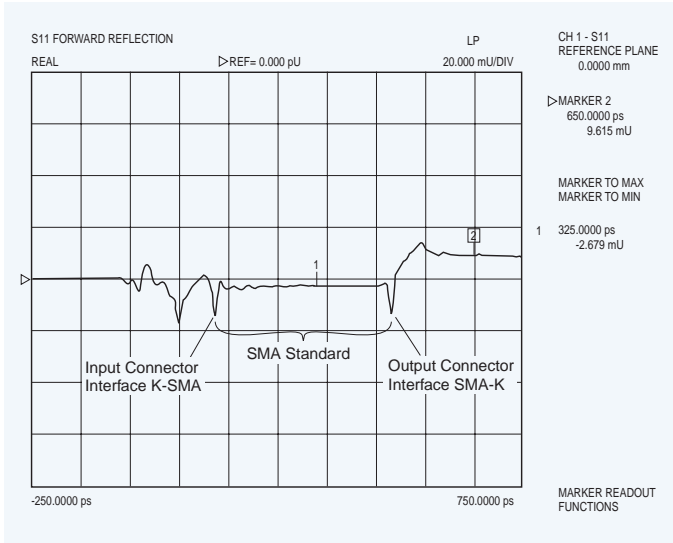


Figure 5

Bandpass – Many situations such as waveguide or band limited DUT's preclude using a broadband harmonically related frequency plan. For these cases Bandpass processing can be used. In this situation there is no phase reference, so vector information is lost; but, useful magnitude information is still available. It can be displayed in either log magnitude or linear form. Figure 6 shows the Bandpass response of the SMA "standard" which was used in Figure 5. This type of processing is common in fault location which can be used to test transmission lines. Figure 7 shows an example of this application: measuring a 2m cable with imperfections.

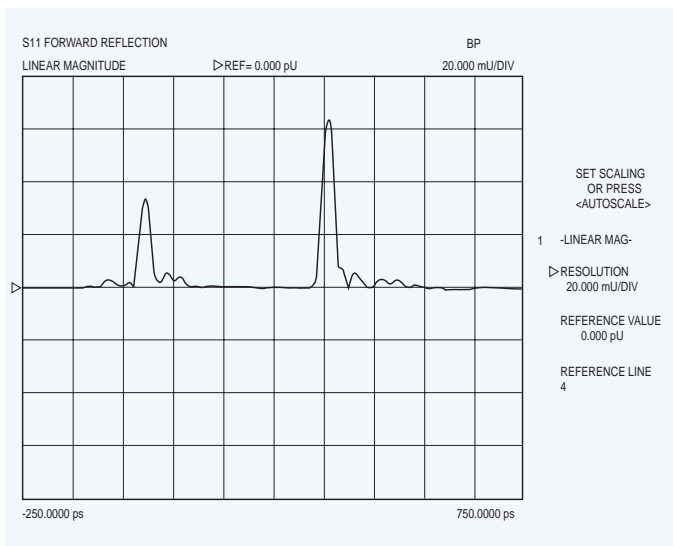


Figure 6

Phasor Impulse – This technique which is exclusive to Anritsu VNA's enables the user to extract impedance information for a specific discontinuity from a Bandpass display.

The discontinuity of interest must be positioned in the center of the screen and it should fill about 50% of the time range being displayed. Then when the Phasor Impulse processing is applied the resulting display, usually Real, Imaginary or Linear Polar provides the desired impedance information. Figure 8 shows the shunt Capacitance associated with a waveguide iris.

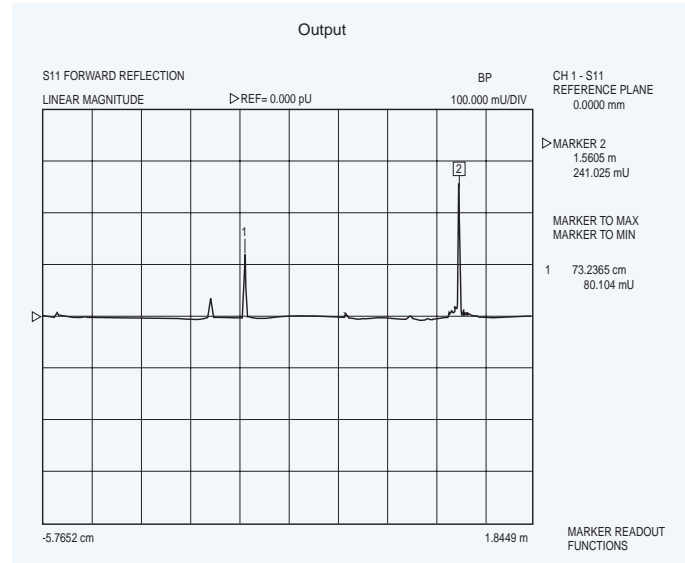


Figure 7

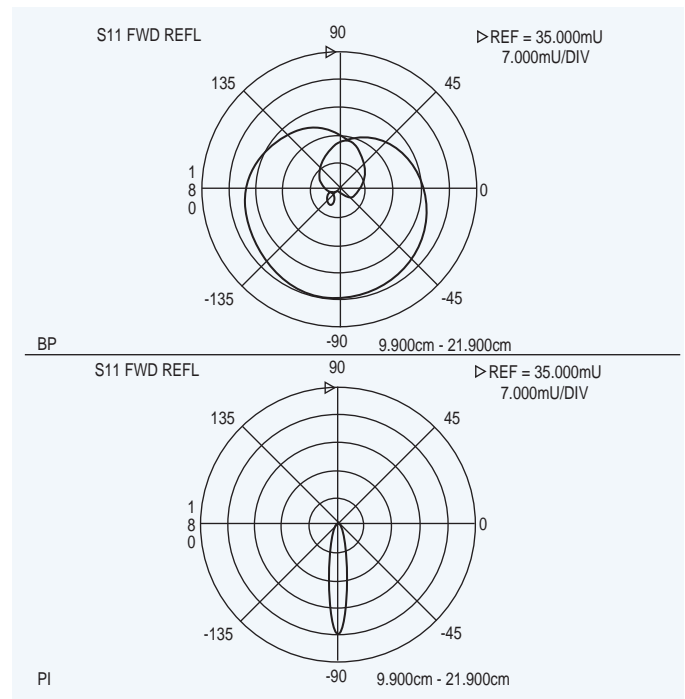
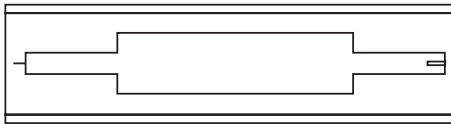


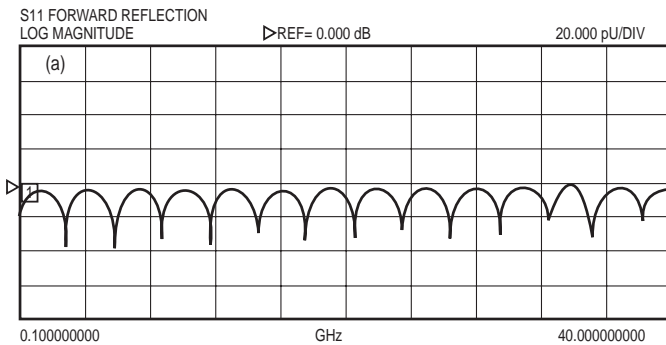
Figure 8. Normal Bandpass Display and the Phasor Impulse Display of Waveguide Iris

Figure 9 is a summary of the above processing types. It should be apparent that if Lowpass processing is possible it should be used as it offers the highest performance, and most versatile set of displays.

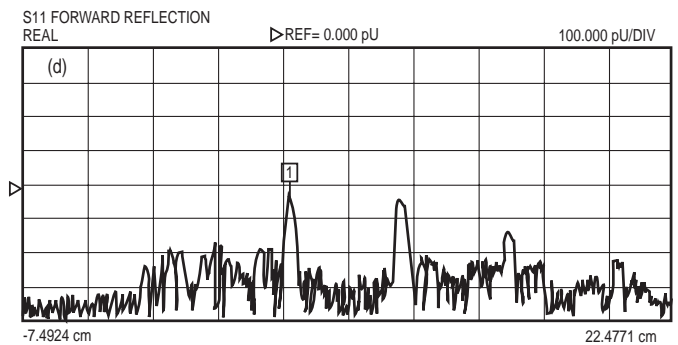
BEATTY STANDARD



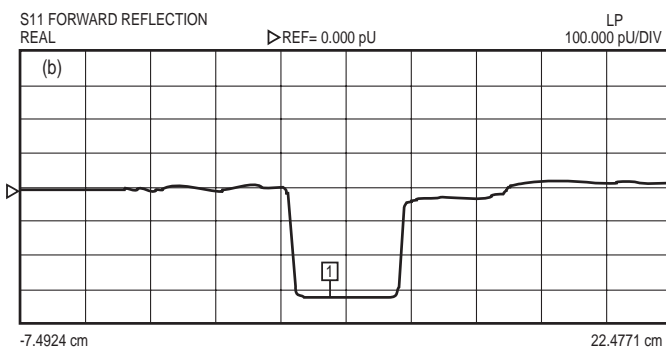
FREQUENCY RESPONSE



LOW PASS MAGNITUDE

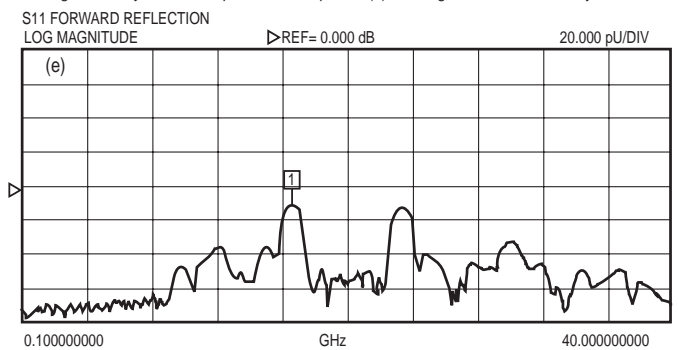


LOW PASS STEP RESPONSE

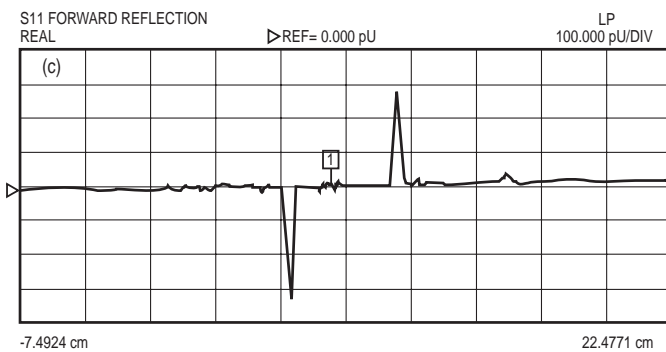


BAND PASS RESPONSE

Note: Magnitude only & broad response with respect to (d) showing reduced resolution by a factor of 2!



LOW PASS IMPULSE RESPONSE



PHASOR IMPULSE - FOCUSED ON FIRST RESPONSE

Note: The impedance (lower than Z0) as shown in (b) has been regained.

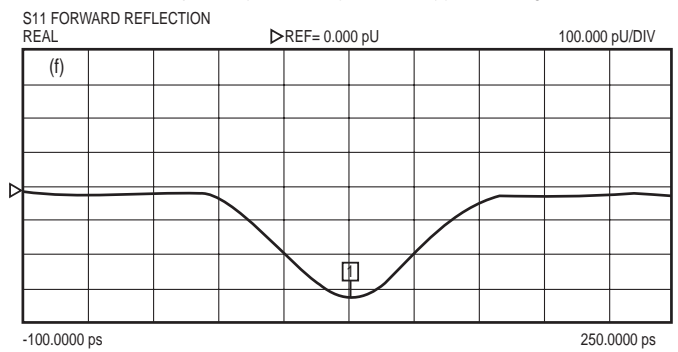


Figure 9

PROCESSING OPTIONS

Processing options are also available to enhance the value of time domain processing for a specific application.

Windows:

Windows are used to "condition" data prior to transformation. They are used to get around the Fourier transforms basic; but, impractical - to + form and are used to mitigate edge effects associated with a finite data set..The application of what is called a "window" function to the frequency domain data will accomplish this. The window is a curve derived from a mathematical function (many are available - see reference 4) that tapers off from unity gain at the center of the frequency domain data to a low value at the ends Figure 10a and 10b shows the effect of applying the widely used two term Hamming window to the data array obtained measuring the short circuit shown earlier. The resulting time domain displays are shown in 11a and 11b. This is not without a price,since the window has the effect of widening the main lobe, thus decreasing the effective resolution. For this reason it is good to have a range of different window types available so that a compromise, appropriate for the application, between resolution and sidelobe level can be reached. The Anritsu VNA's offer the window choices described in Table 1. Resolution has been normalized to the Default Nominal window which is adequate for most applications.

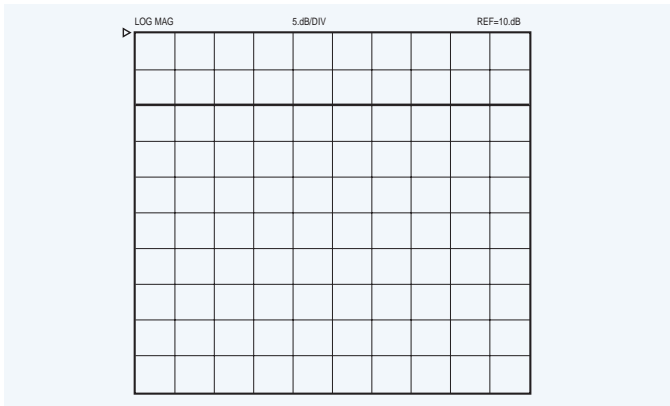


Figure 10a. Frequency Domain Data Before Application of Hamming Window

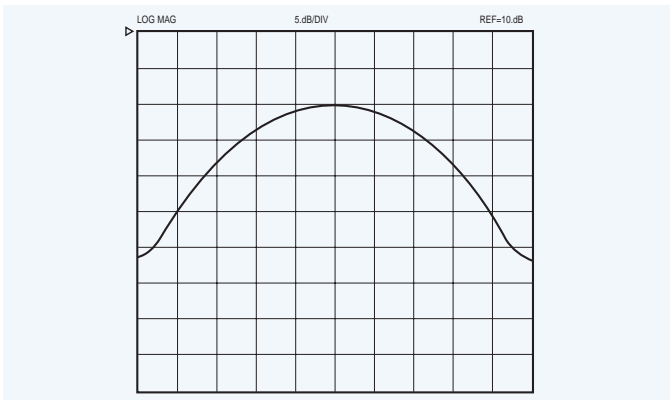


Figure 10b. Frequency Domain Data After Application of Hamming Window

Gating – Frequency Gated by Time:

The Gate is essentially a filter in the time domain. It is set by the operator while observing the time domain response to select a given discontinuity or in some cases to select those responses that can be attributed to given DUT such as a cable which has principal reflections at both ends. It can also be used to Gate out a specific discontinuity thus observing the performance of a microwave circuit with an imperfection removed. This permits observing the selected range without the influence of unwanted elements, such as connectors or in the case of transmission measurements: multipath signals.

The Gating process also involves a "conditioning" Gate Shape. This is similar; but, not identical to the Window function described above. In looking at previous time domain displays it is apparent that there are ripples associated with a specific reflection that extend over a range of time all of which are necessary to obtain a good representation of that reflection in the frequency domain. The gating process can eliminate some of this necessary data which can introduce errors or ripple in the frequency domain response. As in Windowing the solution is to provide a selection of Gate functions so the user can obtain the best tradeoff of resolution versus ripple.

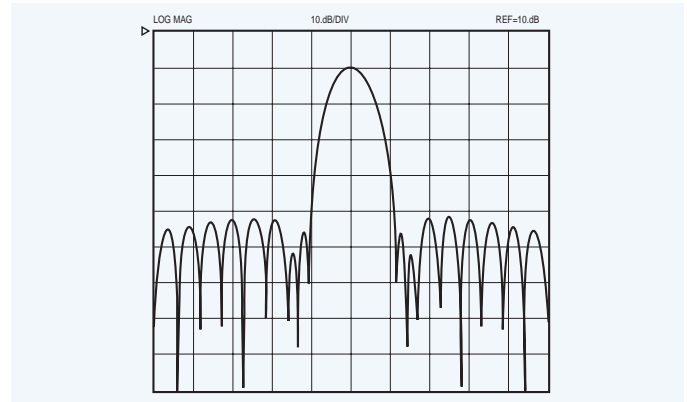


Figure 11b. Time Domain Data After Application of Hamming Window

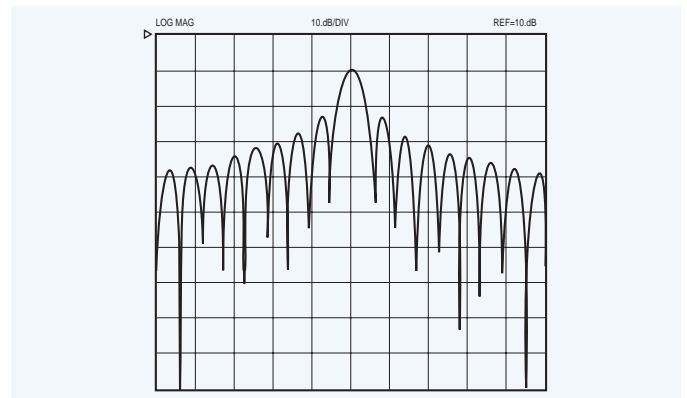


Figure 11a. Time Domain Data Before Application of Hamming Window

Window Type	Main Lobe Width Lowpass	Main Lobe Width Bandpass	Sidelobe Level (dB)
Rectangular	0.5 / BW	1 / BW	-13
Nominal	1 / BW	2 / BW	-42
Low sidelobe	1.5 / BW	3 / BW	-70
Min sidelobe	2 / BW	4 / BW	-90

Table 1. Window Lobe Widths and Maximum Sidelobe Levels

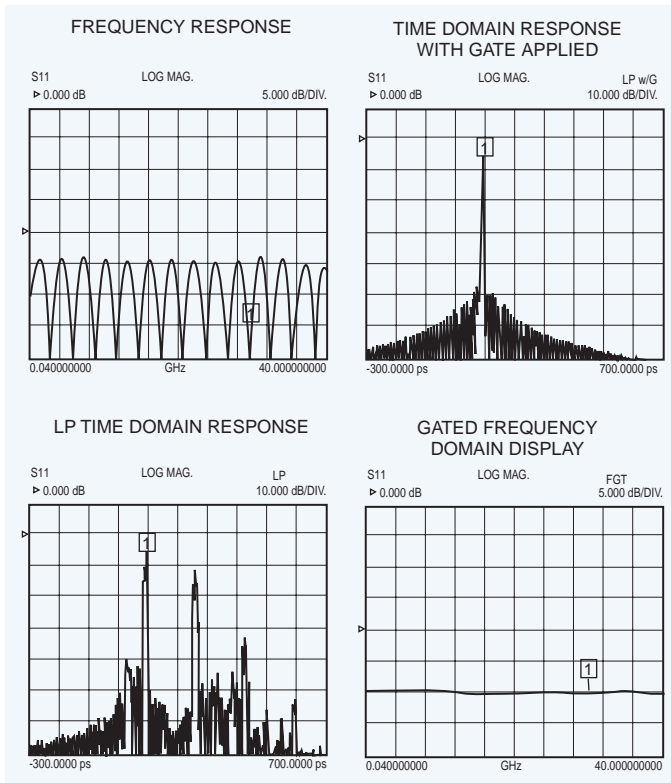


Figure 12

Figure 12 shows the application of a Gate and the Frequency Gated by Time display of the initial discontinuity of the Beatty standard used in Figure 9 above. This figure also illustrates the processing sequence which can be observed when a four channel display is available. Each channel is set to S11 and each is set up with a different process, the final in the lower right showing the frequency gated by time response of an impedance step which is reasonably flat with frequency as expected.

USER INTERFACE

The user interface for time domain is designed to give the user a simple but flexible way of selecting processing options and controlling the display. All of the controls required are grouped together in a few menus. The menus also include full screen HELP displays for each major area. During the calibration process the recommended harmonic frequency plan can be selected and it is automatically established. The instrument, which offers a four channel display, permits the user to display data with up to four different types of processing which permits viewing the effects of the processing steps (as shown in Figure 12 above) or to observe the effects of a change in several different ways. The user can select whether the annotation of each display and it's associated markers is given in units of time or distance.

WHAT TIME DOMAIN CAN DO FOR YOU

Time domain is most useful when analyzing broadband low loss devices. This includes transmission lines, connectors, test fixtures and similar components. Narrowband devices such as filters, isolators or matching networks are not good candidates for Time Domain measurements. A few "Helpful Hints":

A harmonic frequency set is most desirable as this permits low pass processing. In any application use the widest frequency range possible.

The VNA should be calibrated; but, the calibration doesn't have to be perfect. As long as the cable environment is intact "old" calibrations will provide good results. Figure 13 shows the measurement of an offset termination measured with a precision calibration, a typical OSLT calibration using a broadband termination, and a frequency response calibration.

When interpreting the return loss value of a time domain response it must be noted that the response is the average of the return loss over the entire frequency range.

When using frequency gated by time it is important to center the gate around the discontinuity, or circuit being analyzed. In general the gate should be as wide as possible; but, not too close to responses that the user wants to eliminate.

The selection of window and gate shapes can have a significant effect on the result. For most applications the default values will provide good results. For some applications the user can establish a set of window and gate shapes that optimize a result. In these cases if correlation with other's measurements becomes an issue it's important that the same window and gate shapes are used.

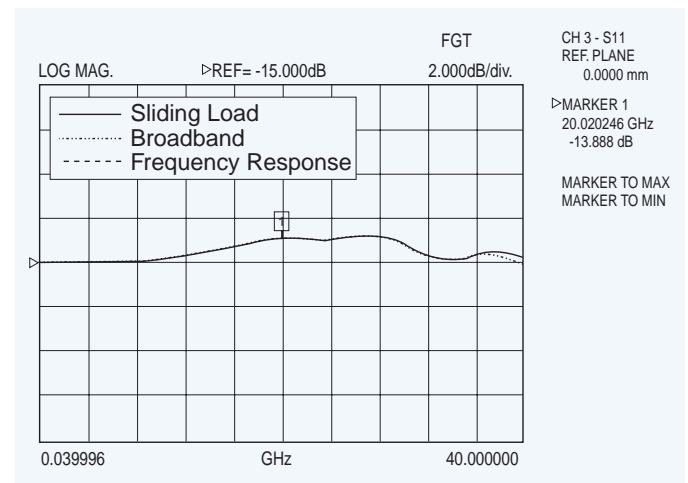


Figure 13

Assurance Airlines

Time domain work is greatly enhanced when the reflection(s) to be studied are well separated from other reflections. This is readily accomplished if a high quality transmission line can be included in the system to be measured. In a coaxial system this would be an airline with connectors that interfaced to the other components with minimum reflections. This performance can be realized by airlines with a beaded interface at one end and a floating center interface at the other end. The bead insures an accurate pin depth at the precision interface, and also supports the center conductor so the airline can be easily installed. Such airlines are available with GPC-7, N, 3.5mm and K connectors. They were used in two of the example applications.

The following examples show a number of practical applications for Time Domain processing:

Designing a Test Fixture – In test fixture design it's often desirable to have an input coaxial connector, and a launch to the microstrip medium being used for circuit design. This launch should be designed for minimum SWR so that it will be transparent when the device design is being evaluated. This can be accomplished by starting with a short length (several centimeters is a good choice) of microstrip line and connecting it to the initial launcher design, leaving the other end open. Figure 14 shows a coaxial to Duroid microstrip design. The reflection from the launch is clearly distinguished from the open end. The designer can make modifications to the launch design and easily see their effect until a satisfactory launch interface is obtained.

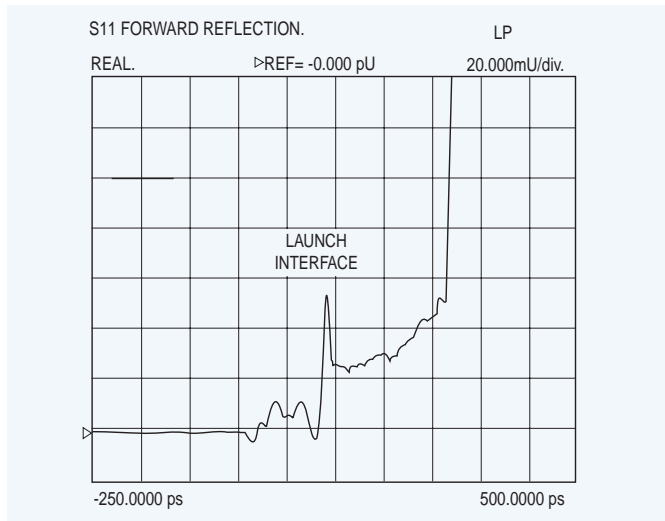


Figure 14

Measurement of VNA Directivity and Port Match – The accuracy of a VNA reflection measurement is primarily related to the effective directivity and port match after calibration. These parameters are usually specified in data sheets; but, are dependent upon calibration standards and user technique. In some cases it would be nice to know the value of these parameters. This information can be readily obtained if an Assurance Airline is available. It is installed at the calibrated test port and terminated with a short circuit. Figure 15 shows by diagram what is happening, the port match, directivity and the short reflection are clearly separated in time and can be distinguished and evaluated quantitatively. The results show the result of an OSLT calibration using a broadband termination.

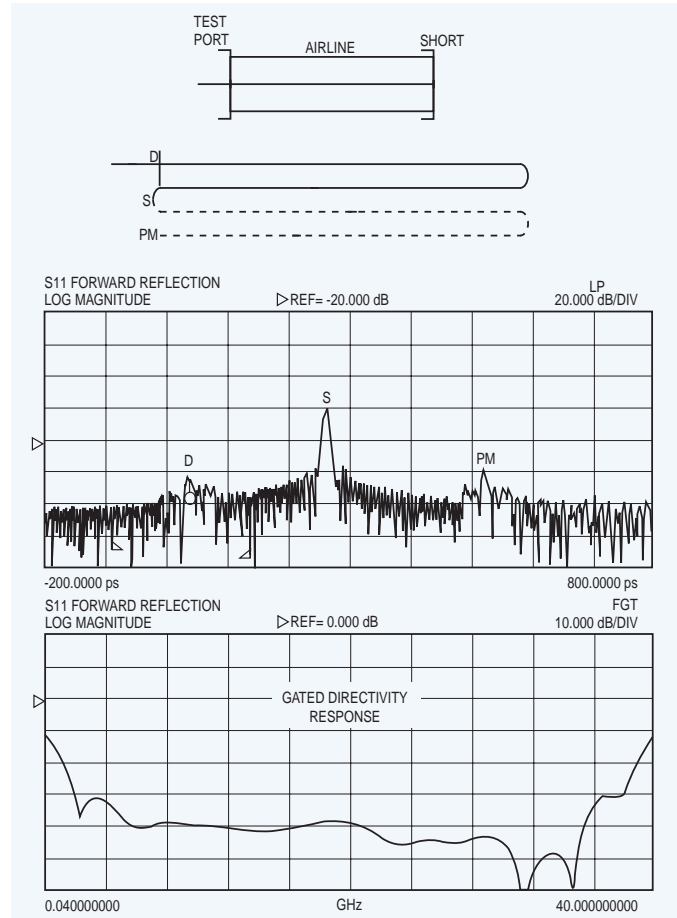


Figure 15

Antenna and RCS measurements.(Previous AN including Figures 32(16) and 33(17))

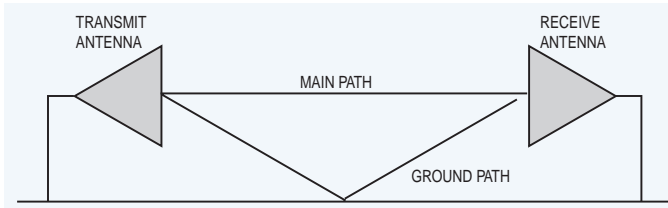


Figure 16. The Frequency Response of an 8 to 12.4 GHz Horn Antenna pair.

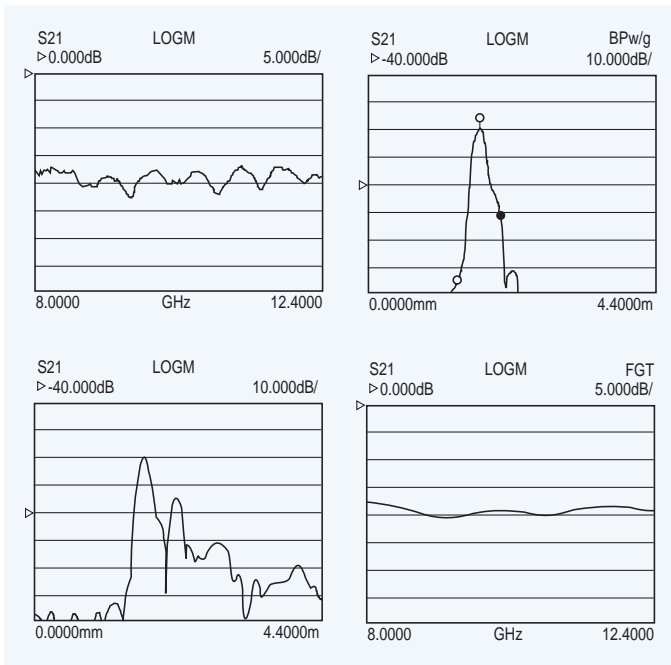


Figure 17. The Time Domain Provides a Perfect Method of Eliminating the Effects of Multi-Path Reflections

ANTENNA AND RCS MEASUREMENTS

Antenna and RCS measurement systems are all subject to multi-path reflections. Multi-path reflections are caused by the transmitted signal bouncing off objects such as the ground, walls, and other objects (Figure X). Time Domain provides a perfect method of eliminating the effects of multi-path reflections, and display the information in time gated frequency domain. The result is the true DUT performance without the distortion of multi-path reflections. Figure Y shows the frequency response of an 8 to 12.4 GHz horn antenna on the Model 360. Channel 1 is the un gated frequency response. Channel 3 is the time domain response showing the main signal and the multi-path reflections. Channel 2 is the time domain response with the multi-path reflections removed by gating. Channel 4 is the time gated frequency response. Note the distortion and ripples from the multipaths are removed.

37000/360 FAMILY

HIGH SPEED TIME (DISTANCE) DOMAIN MEASUREMENT CAPABILITY (OPTION 2A)

Option 2A, High Speed Time (Distance) Domain software allows the conversion of reflection or transmission measurements from the frequency domain to the time domain. Measured S-parameter data is converted to the time domain by application of a Fast Fourier Transform (FFT) using the Chirp Z-Transform technique. Prior to conversion any one of several selectable windowing functions may be applied. Once the data is converted to the time domain, a gating function may be applied to select the data of interest. The processed data may then be displayed in the time domain with display start and stop times selected by the user or in the distance domain with display start and stop distance selected by the user. The data may also be converted back to the frequency domain with a time gate to view the frequency response of the gated data.

Lowpass Mode: This mode displays a response equivalent to the classic "TDR" (Time Domain Reflectometer) response of the device under test. Lowpass response may be displayed in either the impulse or step mode. This type of processing requires a sweep over a harmonic series of frequencies and an extrapolated or user-entered DC value.

Bandpass Mode: This mode displays a response equivalent to the time response of the device under test to a band limited impulse. This type of processing may be used with any arbitrary frequency sweep range, limited only by the test set range or device under test response.

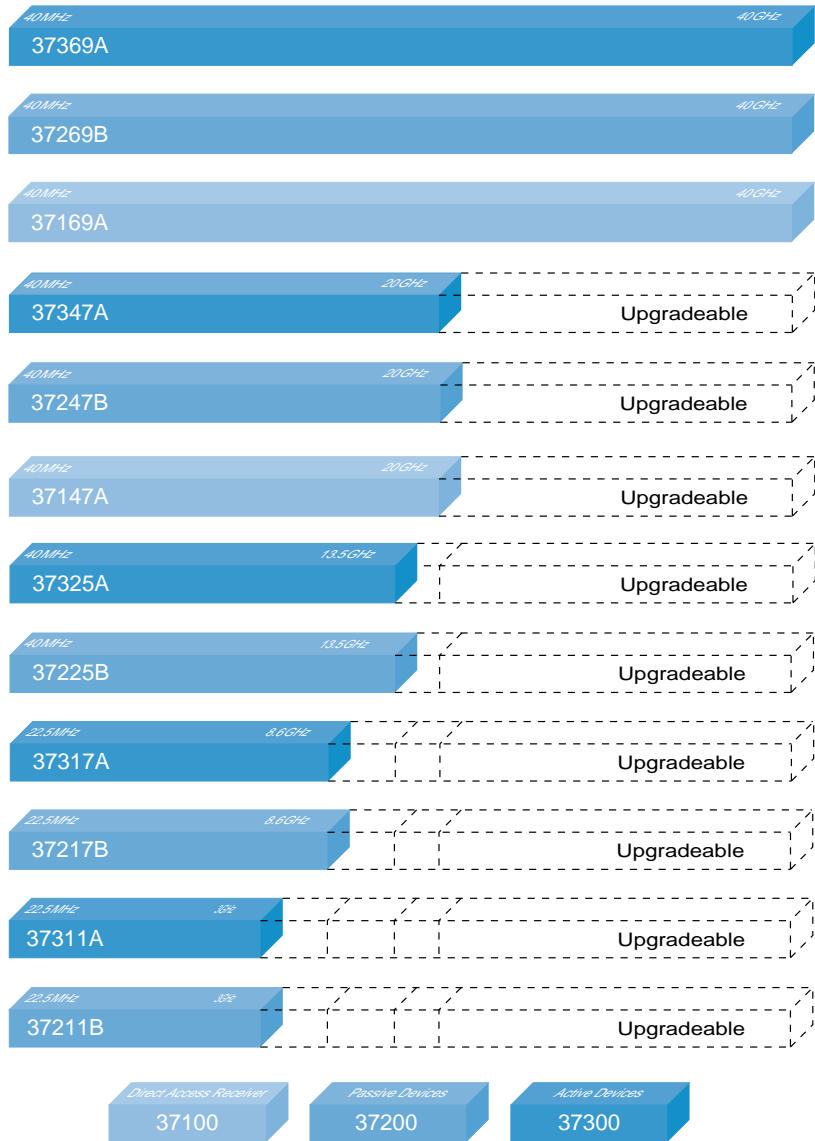
Phasor Impulse Mode: This mode displays a response similar to the Lowpass impulse response, using data taken over an arbitrary (band limited) sweep range. Detailed information, similar to that contained in the lowpass impulse response may be used to identify the nature of impedance discontinuities in the device under test. Now, with Phasor Impulse, it is possible to characterize complex impedances on band-limited devices.

Windowing: Any one of four window functions may be applied to the initial frequency data, to counteract the effects of processing data with a finite bandwidth. These windows provide a range of tradeoffs of main lobe width versus sidelobe level (ringing). The general type of function used is the Blackman-Harris window with the number of terms being varied from one to four. Typical performance follows:

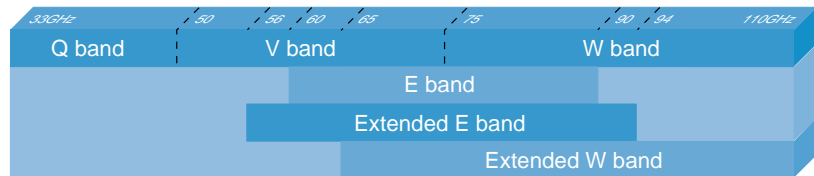
Type of Window (Number of Terms)	First Side Lobe Relative to Peak	Impulse Width ¹
Rectangular (1)	-13 dB	1.2W
Nominal-Hamming (2)	-43 dB	1.8W
Low Side Lobe, Blackman-Harris (3)	-67 dB	2.1W
Minimum Side Lobe, Blackman-Harris (4)	-92 dB	2.7W

¹W(Bin Width) = 1/2Δf sweep width.

Example. When Δf = 40 MHz to 40 GHz, W = 12.5 ps



37100A based mmWave Systems



¹W(Bin Width) = 1/2Δf sweep width.

Example. When Δf = 40 MHz to 40 GHz, W = 12.5 ps

References

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