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MT. SAN ANTONIO COLLEGE

Electronics 55:
Microwave Communications
Laboratory Experiment 1:
Laboratory-Grade Vector Network Analyzers

- OBJECTIVES:
1. To become familiar with the operating features of a laboratory-grade vector network analyzer.
 2. To confirm the significance of calibration in achieving measurement accuracy.
 3. To introduce two-port measurements of bandpass filters and other two-port devices.
 4. To introduce one-port measurements of antennas and other one-port devices.
 5. To introduce two-port measurements of cables.

MATERIALS:

Copper Mountain Technologies 2-Port 8 GHz Vector Network Analyzer and cables (USB and power)
Laptop or desktop computer with S2VNA software installed
"University Kit" suitcase with the following accessories: (2 N-SMA cables, Band Pass Filter, Wi-Fi Antenna, Torque Wrenches (Nand SMA), 2 SMA-SMA adapters, Calibration Kit N911).

INTRODUCTION:

This exercise will introduce you to the features and characteristics of a laboratory-grade vector network analyzer (VNA). The Copper Mountain Technologies instruments in our laboratory cover the frequency range 1 MHz to 8 GHz and have full S-parameter test sets, allowing for automated characterization of two-port devices under test without the need for manual connection and disconnection. Performance specifications of these instruments are on par with those from any of the major legacy test equipment manufacturers, including Keysight (formerly Hewlett-Packard/Agilent), Anritsu/Wiltron, Tektronix, and Rohde and Schwarz, all of which are the most highly regarded vendors of VNAs capable of high-precision measurements at microwave frequencies.

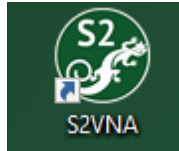
Like many newer-generation test instruments, these VNAs are designed for use with a personal computer. All display capabilities and many data-processing functions formerly found within fully self-contained and standalone instruments are now being offloaded to laptop or desktop computers. This distributed intelligence approach allows the radio-frequency "front end" of the instrument to be carefully designed and optimized for rf work even as the data analysis and display capabilities are made ever more powerful and the user interface (the "GUI" or graphical user interface) to be made more intuitive and convenient. This trend in test-equipment design and implementation is expected to continue, not only for VNAs but also for other radio-frequency test instruments such as spectrum analyzers and even oscilloscopes.

PROCEDURE:

PART I. INTRODUCTION TO VNA OPERATION

1. If not already installed, download and install the operating software for the VNA from the flash drive available from the instructor or from the following site: <https://coppermountaintech.com/university-kit/>. Operating Manual is in C:\VNA\S2VNA\Doc directory. (Note: program will have been installed if using a Mt. SAC supplied computer, so this step can be skipped.) If installing the program on your computer, select the model of VNA from the drop-down menu, and ensure that the serial number check-box is cleared.

2. The software will open and operate in a “Demo Mode” if it does not detect connected hardware (the VNA). Click on this icon to open the



program. Demo mode is very useful for becoming familiar with the menu options, display formats, and other aspects of instrument operation. Take some time to explore the menu structure and operational settings. Note in particular the calibration and display menu trees. In many respects, the menus are remarkably similar to those found in the NanoVNAs with which you are already familiar.

3. One of the most useful features of any professional-grade VNA is that it provides the ability to view multiple measurement screens at one time. These can include multiple formats for a given set of S parameter measurements (such as side-by-side S_{11} measurements displayed on a Smith chart to show impedance characteristics as well as log-magnitude displays showing return loss). Open the program in demo mode and prepare to view four traces as follows.

(a) If not already there, enter demo mode:
System – Misc Setup – Demo Mode – ON

(b) If desired, display settings, including font size, can be changed:
Display – Properties – Font Size – Choice

(c) Add traces:
Display – Num of Traces – 4

(d) Allocate traces:



Display – Allocate Traces -

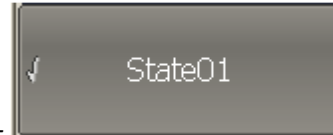
- (e) Configure 4 absolute traces
Click on Tr1, Measurement – Absolute – Receiver R1 (source port 1)
Click on Tr2, Measurement – Absolute – Receiver A (source port 1)

Click on Tr3, Measurement – Absolute – Receiver R2 (source port 2)
Click on Tr2, Measurement – Absolute – Receiver B (source port 2)

4. Prepare to edit and save your measurement files.

(a) First, add a title label
Display -Title Label

(b) Edit and save renamed title label and save state file
Enter *Absolute Measurements*



*Save the state file: Recall – Save State -
Rename State01.sta in C:\VNA\S2VNA\State
toELEC55_Lab11_YourName_Absolute_Measurements.sta*

(c) Preset VNA to the original state
System – Preset – OK

(d) Recall state file:
Save/Recall – Recall State – File

(e) Save state file: Save file with *.sta at easily accessible location.

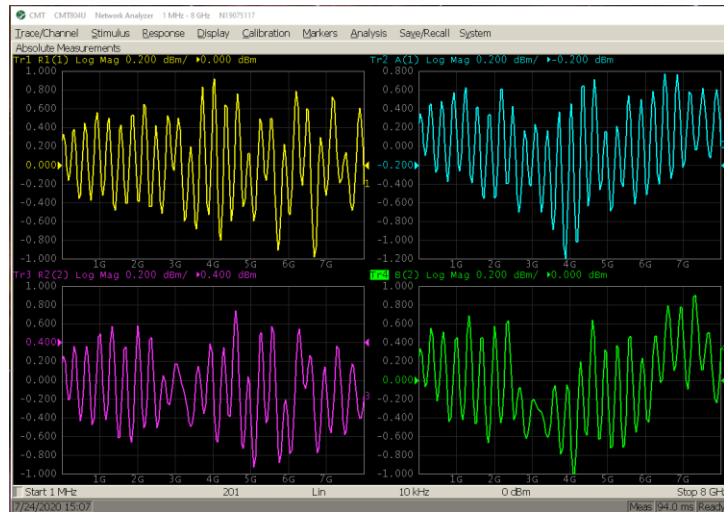
5. Connect VNA to computer and power it up (in that order). Wear ESD strap and take appropriate electrostatic discharge precautions as discussed in class.

6. Start software and recall file saved in step 4(b).



7. Use the scale function: This will cause the display to show the measurement parameters without calibration or correction factors applied.

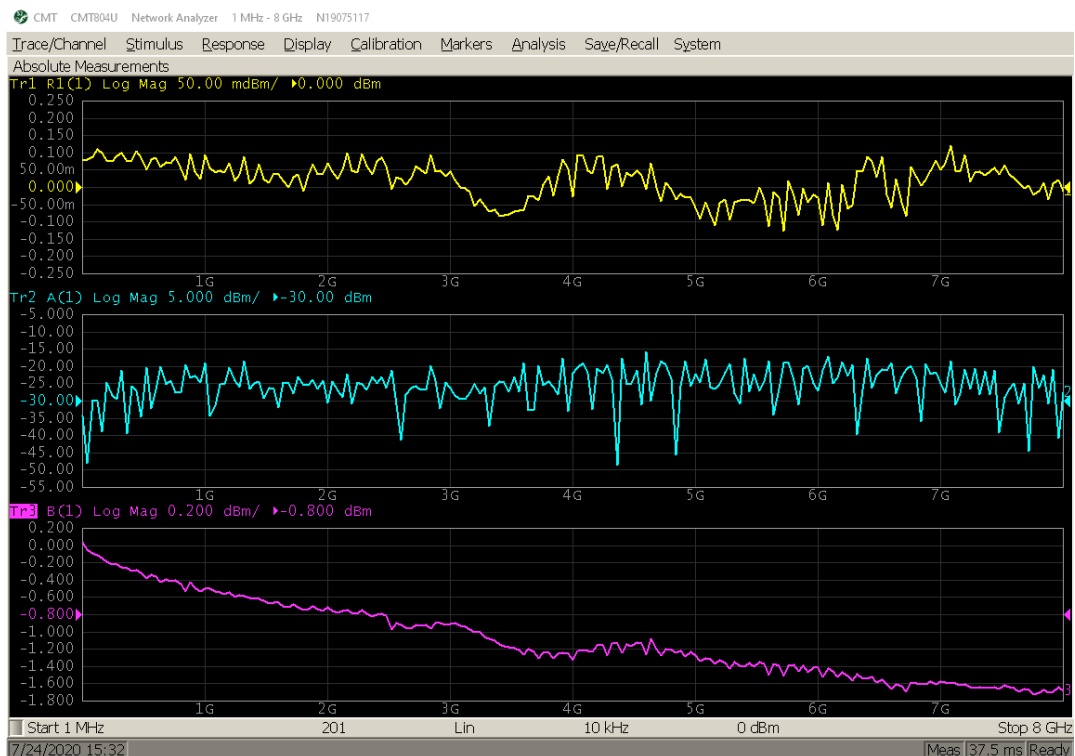
8. Save this image, similar to the one shown below, for later reference. This image shows measurements made for all four S parameters available from both ports for the instrument in its uncalibrated state.



9. Connect the cables from the University Kit suitcase to the ports. Use the TW-N torque wrench. (Note: Torque wrenches are calibrated tools. As soon as the handle bends torquing should stop.)

10. Connect SMA – SMA adapter between cables. Use TW-S SMA torque wrench.

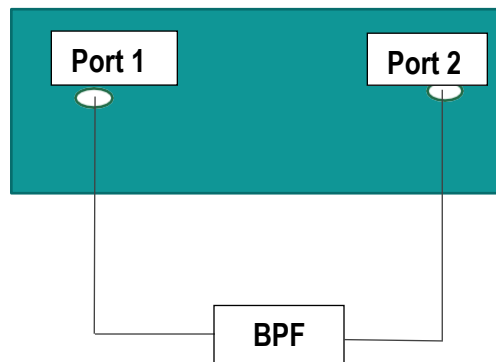
11. Modifying the steps from 3(c) as needed, configure the software to show three traces, similar to that shown below. Save the image you obtained.



12. Configure display to show 4 different traces with 4 S-parameters.
13. Change IFBW (intermediate frequency bandwidth), number of points, trace format, scale, power levels, start/stop frequencies.
14. Experiment with IFBW and number of points changes. Observe how changing IFBW and number of points changes measurement speed.

PART II: SIGNIFICANCE OF CALIBRATION

15. Use the N to SMA cables in the University kit suitcase to connect to ports 1 and 2 of the VNA. Connect the bandpass filter, also in the kit, as shown in the figure below:



16. Set up the display to show the characteristics of the bandpass filter by following these steps:
 - (a) Add traces: Go to "Display," click on "Num of Traces," and change to 2.
 - (b) Allocate traces: Select "Display" option, click on "Allocate Traces," and select third option.

Either plot can be shown in full size by double clicking on it. Double clicking again will return to the split screen. Click on the plot once before performing any action you want to have apply to that plot.
17. Measure both the S_{11} and S_{21} of the device in log magnitude. Take a screenshot of the results for reference.
18. Calibrate the instrument.
 - (a) Click on Stimulus. If not already set, set the start and stop frequencies to 1 MHz and 8 GHz, respectively. Set points to 201 and the IF bandwidth to 10 kHz.
 - (b) Begin calibrating the instrument with the known standard in the University Kit.

- (i) Go to Calibration on the sidebar menu and click on Cal kit.
 - (ii) Select N911 as the calibration kit by checking the box in the drop-down menu. Be sure “N911” appears as the selected cal kit in the menu button.
19. Perform full 2-port calibration:
- (a) Go to Calibration -> Calibrate -> Full 2-port Cal.
 - (b) Connect the “Open” standard to the end of the cable on Port 1. Use the SMA torque wrench to tighten.
 - (c) Click the “Open” button on the screen. It should say “calibration in progress...” followed shortly by a checkmark on the left part of the button.
 - (d) Repeat the previous two steps with the “Short” and “Load” standards with the cable attached to Port 1.
 - (e) Repeat the previous steps for Port 2. When all steps have been completed, click “Apply.” The program will process the measurements, computing differences between the measured characteristics and the known correct characteristics provided in the calibration kit definition. These differences are due to non-idealities of the VNA itself and losses in the cables and adaptors used. The error correction will automatically be enabled.
20. Verify that corrections are turned on. Under the calibration menu, the Correction option should say “on.” If it is off, click once to activate. This will apply the current calibration settings to the measurements being made.
21. Connect the bandpass filter used earlier and make the same measurements again. Is there a difference in your S_{11} and S_{21} measurements in comparison to the ones made without calibration. Make notes of any differences you see between the two results.

PART III. BANDPASS FILTER MEASUREMENTS (2-PORT)

Attached to this handout is a short summary, provided by Copper Mountain Technologies, describing filter characteristics and types. You will be making measurements of a bandpass filter. You may also review a video link showing the filter characterization here:

<https://coppermountaintech.com/video-measuring-a-filter-with-the-university-kit/>

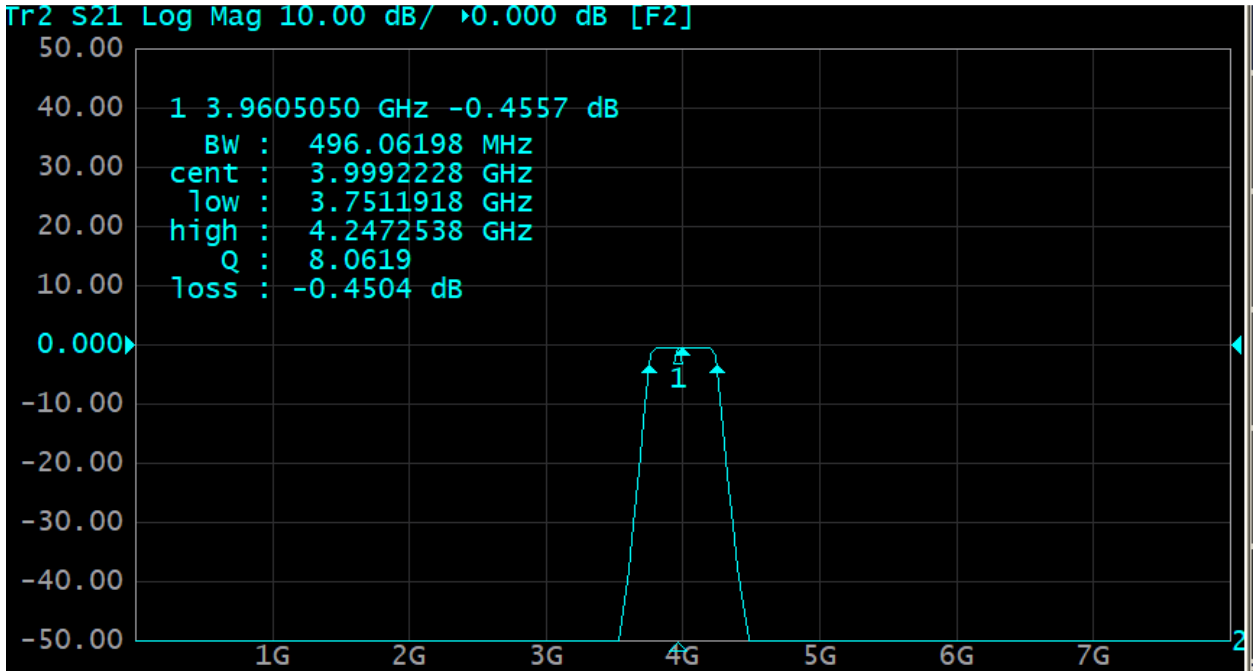
22. If not previously performed during this laboratory session, then complete the full two-port calibration described in step 19. Both N-to-SMA cables should be connected to the VNA and torqued with the appropriate wrenches and the calibration standard used to establish the open, short, and load measurements in turn.

23. Connect the bandpass filter between the two ports of the VNA.
24. View all four S parameters (S_{11} , S_{12} , S_{21} , and S_{22}) simultaneously by selecting the Display option of the menu and changing the “Num of Traces” to 4.
25. Click on Allocate Traces and select the option as shown below:

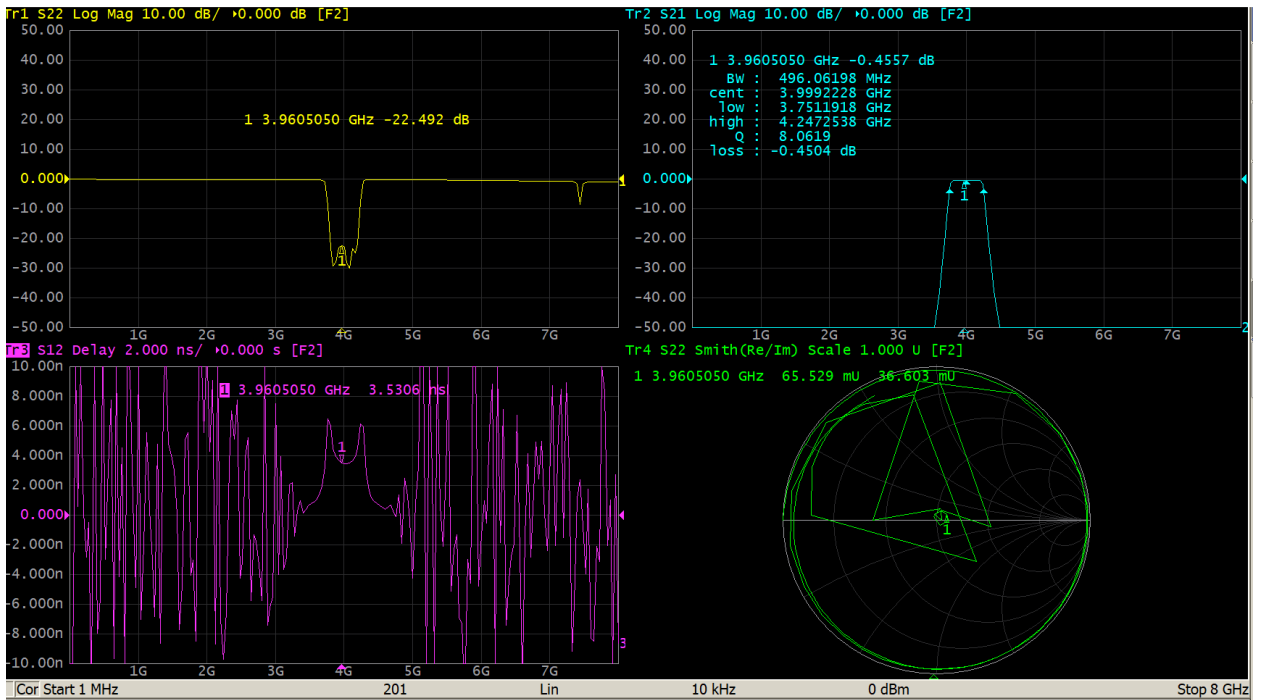


26. Four traces should be visible on the screen. The formats should be those established in step 24. The formats for various S parameters are: S_{11} and S_{21} is Log Mag, S_{12} is Phase and S_{22} is Smith Chart.
27. Enable bandwidth measurements for the S_{21} measurements. (Recall that the S_{21} parameter is a transmission-loss measurement, suitable for showing insertion loss and bandwidth-related parameters of filters.) To enable the marker readings for S_{21} , click on the S_{21} marker first and then click Markers>Marker Math > Bandwidth search ON.

Once enabled, bandwidth readings, similar to those shown in the figure below, should be visible.



28. The graphs of the S parameters measured and displayed in the formats shown in step 26 should resemble those in the figure below:

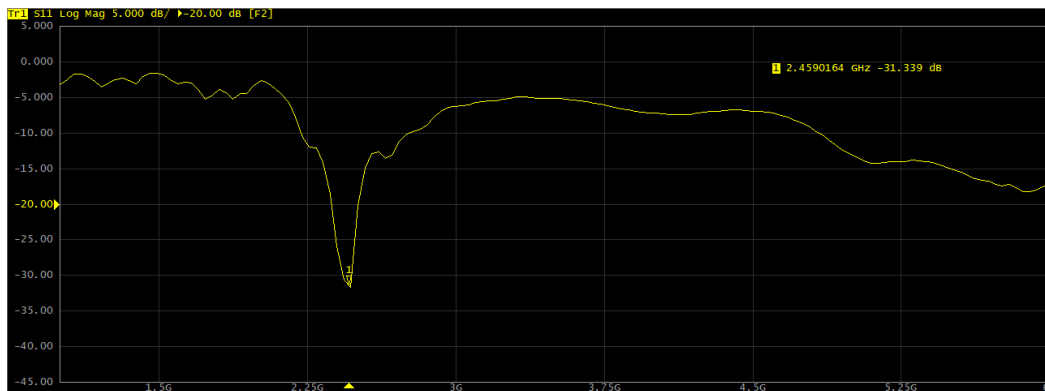


PART IV. ANTENNA MEASUREMENTS

Read the material at the end of this handout for additional information pertaining to antenna measurements. In particular, keep in mind that all antenna measurements are one-port measurements of S_{11} parameters. The following video, produced by Copper Mountain Technologies, demonstrates many of the concepts employed in this part of the exercise: You can access the video using the link

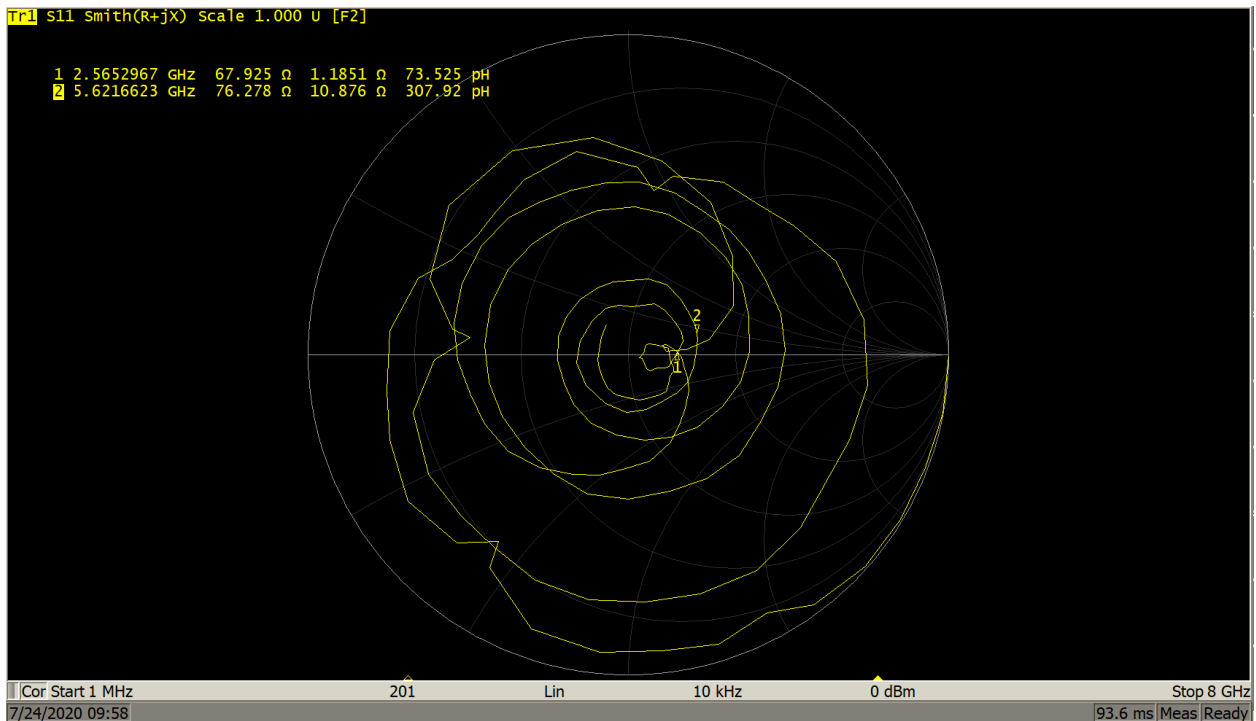
<https://coppermountaintech.wistia.com/medias/ksy2yacsya>

29. Connect a cable to Port 1 of the VNA and secure the connection with the torque wrench.
30. Set Stimulus settings as follows: Select Stimulus, start frequency 1 MHz, stop frequency 8 GHz, points 201, IF bandwidth 10 kHz.
31. Perform a one-port calibration: Calibration > Calibrate > Full 1-port Cal.
32. Keep Select Port as 1 (S_{11}).
33. Connect open standard to your port (port 1) and use torque wrench to secure connection. Click on “open” option on menu.
34. Repeat step 33 for short and load standard. When complete, click “apply.”
35. Remove the load and connect the Wi-Fi antenna provided in the University kit to the port 1 cable with the SMA-SMA connector.
36. Adjust software settings as needed to produce a display in log-magnitude (log-mag) format for the parameter measurement of S_{11} . Your graph should look similar to that shown below, but your response may look different based on the position of the antenna. This display shows a measurement of the return loss of the antenna.



The frequency at the “dip” in the screenshot is the frequency of the antenna. As you know, the resonant frequency is the frequency at which maximum radiation can be expected.

37. Change the format of the S_{11} measurement displayed from Log Magnitude to SWR. The plot will look somewhat like that below. Compare the SWR plot with that for return loss at the frequency expected to show resonance. What statements can be made about both?
38. Compare the previous readings with the corresponding Smith chart representation. Change the format of S_{11} from SWR to Smith ($R + jX$) to produce a plot similar to that shown below. The point for a matched load in a Smith chart is at the very center.



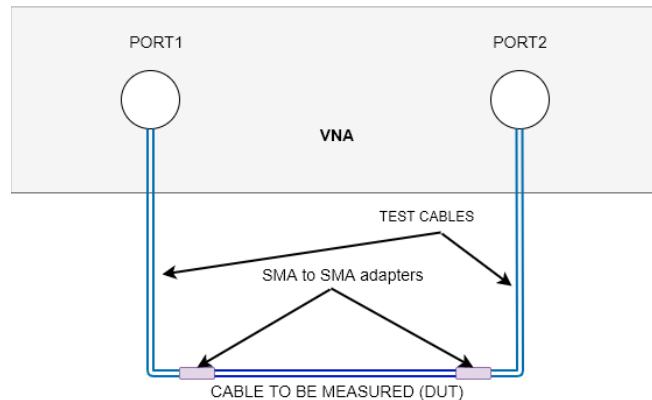
PART V. CABLE MEASUREMENTS

A video showing the complete calibration procedure is available here:

<https://coppermountaintech.wistia.com/medias/90gsd3yb3x>

39. If not already performed during the same lab session, perform a full 2-port calibration (step 19) with start frequency of 1 MHz, stop frequency of 8 GHz, number of points set to 401 and IF bandwidth of 10 kHz. Be sure the Cal Kit selected is N911. When calibration is complete, check that Correction is ON.

40. The characteristics of the cable to be measured are those of the SMA to SMA cable in the University kit suitcase. It will be the DUT. Make the connections as shown in the picture below.



41. If needed, change the number of traces to 4: Display > Num of Traces > 4.
42. Allocate traces: Click on the 8th option (x4 traces, two side by side, as shown after step 25).
43. Set traces to S11, S21, S12, and S22. Formats should be as follows: S11 and S21 (Log Magnitude), S12 (Delay), and S22 [Smith (R + JX)].
44. Use the marker search function and determine the value of return loss by setting to maximum. The value of insertion loss can be read by using a marker search set to minimum. The cable return loss should be around -20 dB and the insertion loss around -1.7 dB. Delay must be close to 2.8 ns and the impedance approximately 50 Ω .

Introduction

What is a filter?

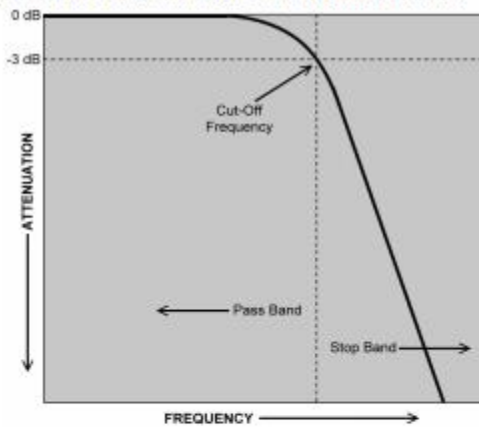
Filters are two-port networks that are used to remove or propagate, certain frequencies depending on the application. For example, in RF receiver applications, filters are frequently used to select an intermediate frequency and reject other signals before the filtered signal is processed by a demodulator.

Types of filters

There are four basic types of filters: low-pass, high-pass, bandpass and bandstop. A visual description of the filters can be shown below.

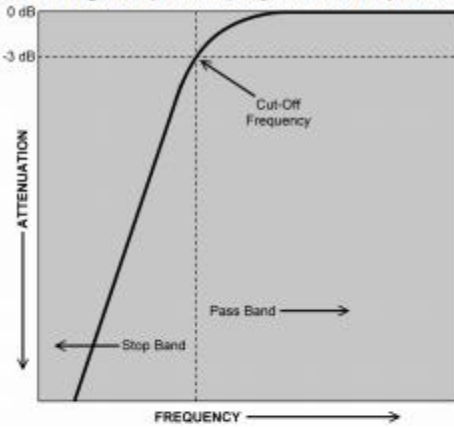
Lowpass Filters:

Passes low frequencies, rejects high frequencies



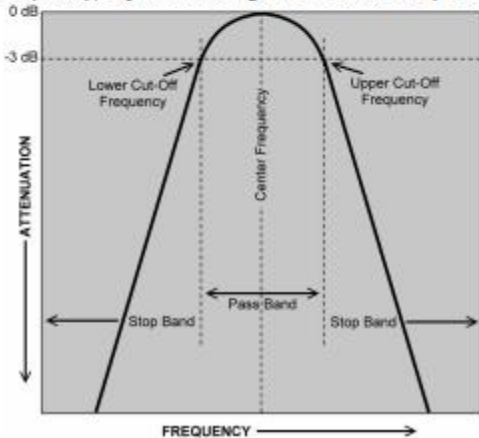
Highpass Filters:

Passes high frequencies, rejects low frequencies



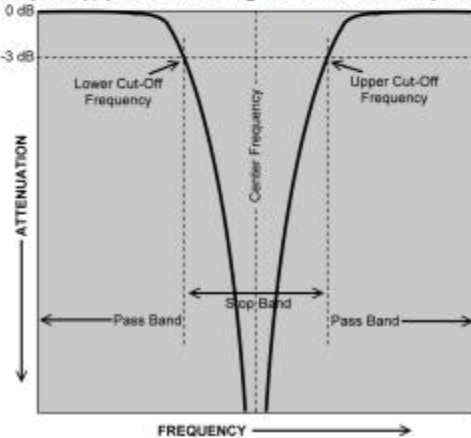
Bandpass Filters:

Passes a band of frequencies centered on a center frequency, rejects both higher and lower frequencies



Bandstop / Band Reject Filters:

Rejects a band of frequencies centered on a center frequency, passes both higher and lower frequencies



Types of filter design

Different filter designs have different response characteristics and are chosen to meet varied requirements.

Listed below the different filter designs and their characteristics:

1. Butterworth Design: A ripple free pass band and a smooth stop band characterize this design. Increased attenuation is achieved as you move away higher in frequency. The downside for this design is that it uses more components than Chebyshev or Elliptical designs, which makes it less economical in applications that do not require a ripple free pass band.

2. Chebyshev Design: A predetermined amount of pass band ripple is used to design filters that meet Chebyshev characteristics. The roll off and the stop band is smooth and approaches infinity as the frequency moves away from the band edges. It requires lesser number of elements to achieve similar shape factor as compared to a Butterworth design. Therefore, it is more economical and hence used more commonly used in filter designs. A good quality factor is required for such filters, typically a Q of 250 for inductors and 500 for capacitors.

3. Elliptical Design: This also requires a predetermined amount of pass band ripple along with stop band ripple. Although these use the least number of elements required in achieving a desired shape factor compared to Chebyshev or Butterworth designs, the quality factor required for the elements are very high. As a result, the dynamic range of frequency elliptical filters can be used are limited by the elements' Q. These filters are ideal for applications that require a very sharp roll off. Roll off ratio as lower than 1.01 at 40dB can be achieved using this.

4. Bessel Design: Bessel filters are a kind of linear filters with maximally flat group delay and hence maximally linear phase response. For lowpass and narrow bandpass filter designs, the delay is flat throughout the pass band, but for wider band pass filters, special designs are used to achieve the group delay flatness. The downside of this is that the roll off is horrible with ratio of 2 at 13dB and has a very poor VSWR.

5. Gaussian Design: The step and impulse response of a Gaussian filter has ZERO overshoot while minimizing the rise and fall time. The delay response is almost similar to that of a Bessel filter, except that it has a bump at the center frequency. The cutoff frequency for Gaussian is usually specified as the 6dB cutoff or 12dB cutoff.

What is an Antenna?

An antenna is a device which is used to transmit and/or receive electromagnetic waves. Electromagnetic waves are often referred to as radio waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned (matched) to the same frequency band as the radio system to which it is connected, otherwise reception and/or transmission will be impaired.

Why do we need antennas?

There are several reasons as to why we need or why we use antennas, but an important reason as to why we use antennas is that they provide a simple way to transfer signals (or data) where other methods are impossible.

For example, take the case of an airplane. The pilot needs to frequently communicate with the ATC personnel. It would not make any sense if we tie up a cable (of dynamically variable length) to the tail of the plane and connect it to the ATC. Wireless communication is the only feasible option and antennas are the gateway for that.

How does an antenna work?

The antenna at the transmitter generates the radio wave. A voltage at the desired frequency is applied to the antenna. The voltage across the antenna elements and the current through them create the electric and magnetic waves, respectively. At the receiver, the electromagnetic wave passing over the antenna induces a small voltage. Thus, the antenna becomes the signal source for the receiver input.

Types of Antennas

There are various types of antennas and their sub-classifications. Some of the common types of antennas are: Wire Antenna, Log Periodic Antenna, Aperture Antenna, Microstrip Antenna, Reflector Antenna, Lens Antenna, Travelling wave Antenna and Array Antenna

NAME: _____

MT. SAN ANTONIO COLLEGE

Electronics 55:
Microwave Communications
Laboratory Experiment 2:
Network Analysis in the Time and Frequency Domains

- OBJECTIVES:
1. To use the Copper Mountain VNA to perform both two-port and one-port measurements.
 2. To characterize the parameters of a quarter-wave vertical antenna, including trimming it to optimal length.
 3. To explore the time-domain properties of the vector network analyzer for purposes of characterizing cables and determining distances to faults.

MATERIALS:

Copper Mountain Technologies 2-Port 8 GHz Vector Network Analyzer and cables.
Laptop or desktop computer with S2VNA software installed
Coaxial bandpass filter
SO-239 coaxial connector
#12 gauge solid copper wire, soldering iron, and mounting hardware
Wire cutters
Safety glasses
SMA to open-ended RG-174 cable of unknown length
SMA to N between-series adaptor
6-ft. SMA-male to UHF connector coaxial cable

INTRODUCTION:

In this experiment we will explore further the capabilities of vector network analyzers (VNAs) in both the time and frequency domains. In the frequency domain, VNAs allow for the characterization of transmission-related parameters of two-port devices such as bandpass or band-reject filters or the reflection characteristics of one-port DUTs such as antennas. In the time domain, VNAs can perform reflectometry measurements to determine propagation velocities, phase shifts, time delays, and can also characterize faults in transmission lines.

PROCEDURE: **PART I: Two-Port Filter Measurements**

1. Calibrate the VNA. Perform a full 2-port calibration. Use the frequency range 15 MHz to 30 MHz. Set points to 201 and the IF bandwidth to 10 kHz. The calibration steps are as shown in steps 18 and 19 of Experiment 11 and are repeated below for convenience:
 - (a) If not already shown, define the known standard in the University Kit accessory suitcase by selecting Calibration on the sidebar menu and clicking on Cal kit. Select S911 as the calibration kit by checking the box in the drop-down menu. Be sure "S911" appears as the selected cal kit in the menu button.

- (b) Select the “2-port SOLT Cal” option. (“SOLT” stands for “short, open, load, through.”) Connect the “Open” standard to the end of the cable on Port 1. Use the SMA torque wrench to tighten.
 - (c) Click the “Open” button on the screen. It should say “calibration in progress...” followed shortly by a checkmark on the left part of the button.
 - (d) Repeat the previous two steps with the “Short” and “Load” standards with the cable attached to Port 1.
 - (e) Repeat the previous steps for Port 2. For the “Thru” calibration, connect N to SMA cables from the University kit to each of the two ports and connect the SMA ends together with the SMA barrel adaptor, also found in the University kit. When the connection has been made, click on “Thru.”
 - (f) When all steps have been completed, click “Apply.” The program will process the measurements, computing differences between the measured characteristics and the known correct characteristics provided in the calibration kit definition. These differences result from non-idealities of the VNA itself and losses in the cables and adaptors used. The error correction will automatically be enabled.
2. Follow the steps shown below to perform a two-port insertion-loss measurement of the 21.4-MHz bandpass filter checked out to you. (The term “two-port” indicates that both the input and output ports of the filter are connected at the same time to the analyzer. This configuration is in contrast to the “one-port” measurements of return loss and distance-to-fault made when only Port 1 of the analyzer is used.) Two-port insertion-loss measurements accurately quantify the amount of loss or gain a signal will incur as it passes through a device. In S-parameter terms, insertion loss is referred to as an S_{21} measurement.

- (a) Connect PORT 1 of the analyzer to the SMA-M (male or plug) input connector on the SBP-21.4+ bandpass filter using the appropriate cable from the University kit and SMA-F to SMA-F barrel adaptor provided. Connect the SMA-F (female or jack) output of the filter to PORT 2 using the second SMA-to-SMA cable.
- (b) Set up the analyzer to perform an S_{21} measurement of insertion loss. Position the cursor over the displayed S parameter measurement label. An underline should appear along with options for the four possible S parameter measurements that can be selected. If necessary, select the S_{21} measurement option.

Insertion loss is a measure of attenuation caused by a device placed within in a signal path. For a bandpass filter, the insertion

loss should be minimum in the passband (the frequency region of minimum attenuation, usually defined at the -3-dB points at both the low and high frequencies for a bandpass or band-stop filter) and maximum in the stopband (the frequency region of maximum attenuation).

- (c) Enable a marker with the Markers menu by selecting Add Marker. Move the marker to observe the insertion loss within the passband. Refer to the supplied data sheet for this filter to determine the manufacturer's specified frequency range for the passband of this filter. What is the maximum measured insertion loss of this filter in the passband?

_____ dB.

- (d) The *critical frequency* of a filter (also called the *cutoff frequency*, f_c) is generally defined as the frequency at which the filter output amplitude decreases by 3 dB from the maximum output seen in the passband. Because this is a bandpass filter there will be two critical frequencies, f_1 and f_2 , one at the lower frequency (f_1) and one at the higher frequency (f_2). You can determine the critical frequencies by moving the marker and observing the insertion loss versus frequency characteristics displayed on the screen. The critical frequencies are those on either side of center where insertion loss is 3 dB greater than the minimum insertion loss in the passband.

What are the critical frequencies, f_1 and f_2 ?

f_1 : _____ MHz; f_2 : _____ MHz

What is the filter bandwidth ($f_2 - f_1$)? _____ MHz

- (e) Compare your measured values for insertion loss in the passband and for 3-dB bandwidth with those for each parameter published in the manufacturer's data sheet. Do your measurements confirm whether your filter meets specifications in this regard? Discuss.

- (f) The *stopband* defines the frequency range on either side of the passband response where the output amplitude has been attenuated by some substantial amount, usually 20 dB below the reduction at the critical frequencies, from the output seen in the passband. Use the markers to determine the upper and lower stopband frequencies for this filter. Do your measurements agree with those provided for 20-dB stopbands in the manufacturer's data sheet?

The manufacturer of the bandpass filter you have (Mini-Circuits) also provides a specification for stopband responses at 35-dB reduction from the passband. (Not all manufacturers do so.) Notice in particular that stopbands so defined are substantially farther from the cutoff frequencies than those specified for 20-dB stopband reduction.

Compare the VNA display of S_{21} insertion loss with the graph of insertion loss versus frequency provided on the manufacturer data sheet. Why does the graph appear “upside down” compared with the display?

3. We will now perform a return loss measurement on the filter. *Return loss* is a measure of the reflection characteristics of a DUT. It is defined as the ratio of forward to reflected power and can also be derived from the reflection coefficient, which, recall, is the ratio of the reflected voltage to the incident voltage at any port of the DUT. Return loss is a scalar quantity, whereas reflection coefficient, when represented by the Greek letter gamma (Γ), is “complex” in that it consists of both magnitude and phase information. The magnitude of the reflection coefficient is represented by the Greek letter rho (ρ), and the return loss, RL, is related to ρ as $RL = -20 \log \rho$. In S-parameter terms, return loss and reflection coefficient are both S_{11} measurements.

Leave the filter connected. Select the Display option of the menu and change the “Num of Traces” to 2. Click on Allocate Traces and select the x2 side by side option (either vertical or horizontal, as desired). Select the windows to select the display formats. One trace should still show the S_{21} trace from the previous steps. The other trace should show the S_{11} (return loss) measurement.

Look at the insertion loss and return loss measurements at the same time. Is the return loss maximum or minimum in the passband? How about the insertion loss in the passband? Explain why these would be the expected results:

4. The number of S parameters equals the square of the number of ports. Thus, for a 2-port device, there will be four S parameters (S_{11} , S_{12} , S_{21} , and S_{22}) to be defined and measured to characterize the DUT

fully. All measurements can be made simultaneously if the VNA has an “S-parameter test set” installed because the radio-frequency source within the analyzer can be automatically switched between VNA ports 1 and 2. Without such capability the DUT would have to be manually disconnected and reconnected if signals originally characterized from port 1 to port 2 are to be recharacterized from port 2 to port 1. Such measurements would be needed to determine whether DUTs are bidirectional or to determine their directional characteristics.

Select the Display option of the menu and change the “Num of Traces” to 4. Click on Allocate Traces and select the x4 (four squares) option. Four traces should be visible on the screen. The formats for all screens should be Log Mag. Set each of the possible S parameters to be visible in one of the visible squares by positioning the cursor over each displayed S parameter in turn and selecting the desired one for each square. Now look at the S_{11} and S_{21} (reflection and transmission-related characteristics as viewed from port 1 to port 2) and the S_{22} and S_{12} measurements (port 2 to port 1). Is this filter bidirectional? Discuss how the DUT exhibits (or does not exhibit) transmission or reflection-related characteristics from signals applied to port 1 and passed through to port 2 that are similar to those applied to port 2 and obtained from port 1.

5. The return-loss/reflection coefficient measurements of a two-port device like the bandpass filter can also be performed as a one-port test, provided that the second port of the DUT is terminated with a load in its characteristic impedance. The return loss measurement described in this step is an example of a “one-port” test because only one of two ports of the DUT is connected to the analyzer. A directional coupler RF bridge inside the instrument detects both the forward and reflected signals produced by the DUT. Disconnect the filter from PORT 2 while leaving it connected to PORT 1. Set the display option “Num of Traces” to 2, with the format of one Log Mag trace established as S_{11} and the other as S_{21} . Terminate PORT 2 with the load provided and observe the results. Does the S_{11} trace appear the same as from the previous step?

What happened to the S_{21} trace? Why?

Part II: One-Port Antenna Measurements

Another very useful application of a return loss measurement is to detect problems in an antenna feedline system or in the antenna itself. A portion of the incident power will be reflected back to the source from each transmission line fault as well as from the antenna. An S_{11} measurement will also reveal critical antenna parameters such as resonant frequency and bandwidth.

The VNA is an excellent tool for characterizing antenna parameters. An antenna with good performance characteristics, particularly in mobile applications, is the quarter-wave ($\lambda/4$) vertical. From some copper wire, an SO-239 UHF connector, and a few pieces of mounting hardware, one can easily construct a prototype antenna similar to that shown in Figure 1. The vertical radiating element (shown as "A" in the figure) will be half the length of a dipole (half-wave antenna). Dipole length at frequencies above 30 MHz or so can be determined from the following rule-of-thumb formula:

$$L = \frac{468}{f_{(MHz)}},$$

where L = length in feet of half-wave dipole, and

f = resonant frequency in megahertz.

The constant 468 in the above expression is found by initially computing the wavelength in free space with the expression $\lambda = c/f$ and then converting the result from meters to feet, dividing by two to produce the half-wavelength dipole distance (again in free space), and then multiplying the latter result by 0.95 to represent the typical velocity factor of a wire conductor in air. The result is an initial approximation of the physical length of the conductors needed for resonant operation at the frequency f . The length will be further reduced to a small extent by the thickness of the conductors and other factors. The conductors should initially be cut a little longer than the calculated length and trimmed by observing the VNA Smith chart or SWR display until an optimal match is found.

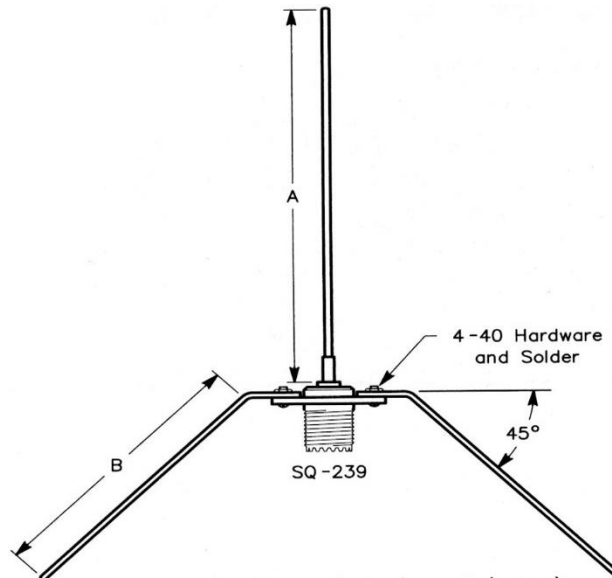


FIGURE 1. Construction diagram of quarter-wave vertical antenna with ground plane.

6. Construct a quarter-wave vertical antenna similar to that shown in Figure 1 for a resonant frequency of **200 MHz** as follows:
 - (a) Using the expression shown earlier, compute the expected length in feet of a half-wave dipole for operation at 200 MHz and cut a section of #12 AWG solid copper wire that is an inch or so longer than one-half the computed value. (Recall that the dipole length is one half wavelength, so for a quarter-wave vertical, the radiating element is half the dipole length. This will be the “A” length shown in the above figure.)
 - (b) Remove ½-inch of insulation from one end of the cut wire and solder it to the center-conductor lug on the SO-239 connector. This will be the vertical radiating element.
 - (c) Prepare four ground radials, each of the same length as that computed in (a). Remove about an inch of insulation (if present) from one end and form a small loop at the inside end of each radial and attach them to the four mounting holes of the coaxial connector with no. 4-40 hardware (machine screws, flat washers, and nuts). Initially leave the radials perpendicular to the radiating element rather than bent as shown in the figure.
7. Attach the antenna to the microphone stand by holding the antenna in place at the top of the extended stalk and with the threaded part of the SO-239 connector facing down. Wrap a cable tie around both the stand and the connector to hold the antenna in place temporarily. At this point the radiating element should be facing up and the four ground radials should be positioned perpendicular to the radiating element and roughly 90 degrees from each other.

8. Before connecting the antenna to the VNA, recalibrate the instrument for a full 1-port calibration over the frequency range 180 MHz to 220 MHz (start and stop frequencies), using the cal kit supplied.
 9. Connect the antenna to the VNA using the N-to-SMA between series adaptor and SMA to UHF cable provided. Using the menus as needed, set up the instrument to display a single window with an S_{11} (reflection) measurement with Smith chart display.
 10. Locate the antenna and stand as far from objects and people as possible. Describe what you see on the Smith chart display. In particular, is the antenna resonant at any frequency within the range displayed? Is the antenna impedance matched?
-
-

11. Now bend the four ground radials downward to form a 45° angle from the perpendicular. Your antenna should now look somewhat like the one shown in Figure 2. Is there a frequency at which the antenna now appears more closely matched to the 50- Ω transmission line characteristic impedance than it did in the previous step?
-

The “drooping” radials cause the characteristic impedance at the antenna feed point to become very close to 50 Ω . Lower or raise the radials by a small amount to see if the matched state improves. Move the marker to the point on the Smith chart nearest the matched state and record the frequency at that point here: _____

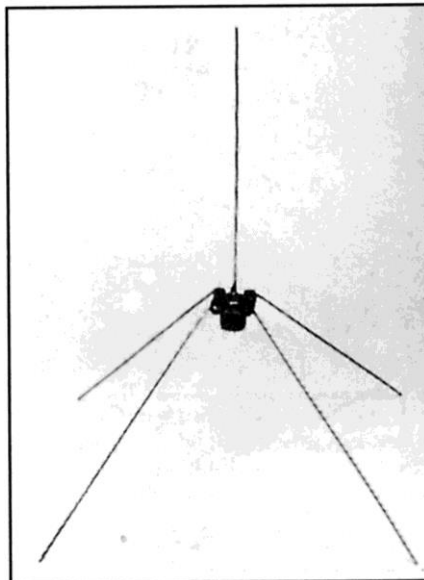


FIGURE 2. Image of $\lambda/4$ antenna with “drooping” radials.

12. Remeasure the total length of the vertical radiator, including the center lug of the SO-239 coaxial connector (the "A" length in Figure 1) and note it here: _____ (inches). Using the frequency recorded in step 11, recalculate the expected length of the vertical radiator and compare with the measurement just made. (Remember to divide your calculated length by 2 to obtain the quarter-wave length; multiply by 12 to convert to inches.) Does the calculation agree with the measured length? _____ What could account for any discrepancy? _____
13. Use the Display option to activate a second window to be viewed alongside the Smith chart display. Select Format, then SWR. The S_{11} display in the newly opened window will then show SWR versus frequency. Confirm that the SWR measurements are S_{11} measurements or redefine as necessary.
14. If the vertical radiator wire was initially cut longer than the calculated length at the intended frequency of operation (200 MHz) as instructed in step 6(a), then the radiator will need to be shortened to provide an optimal match. With wire cutters trim the length of the vertical radiator in small (1/8 to 1/4 inch) increments while observing the VNA displays. (Note: hold the top of the conductor and wear safety glasses whenever cutting wire.) Shorten the vertical radiator until the antenna appears most closely impedance-matched at or near 200 MHz. What is the lowest SWR you obtained? _____
15. Determine the antenna bandwidth, which is a measure of the frequency range over which the antenna exhibits an acceptably low SWR. What is considered acceptable is situation specific. Many manufacturers specify bandwidth over a maximum SWR of 1.5:1 (meaning about 4% reflected power) for transceivers, whereas some antennas intended for low-power or receive-only applications may have bandwidths specified at 2:1 SWR (10% reflected power). Use the markers and SWR display to determine the lower (f_1) and upper (f_2) frequencies at both SWR points and record the bandwidths for each:

BW (1.5:1 SWR): _____

BW (2:1 SWR): _____

Part III: Time-Domain Measurements

Many VNAs, including the Copper Mountain Technologies units, can perform time-domain reflectometry measurements with a mathematical operation known as an inverse Fourier transform (IFT). The IFT essentially converts the frequency-related information collected by the VNA to time-associated information such as would be viewed on an oscilloscope. In the time domain many important parameters of DUTs, including the velocity

factors of transmission lines and the times or distances to faults, can be computed and other impedance-related characteristics can be revealed.

One of the most useful applications of time-domain reflectometry (TDR) measurement is cable fault detection. The impedance mismatch presented by a discontinuity such as an open or short will cause an applied pulse to be reflected back to the measuring instrument. With knowledge of the cable velocity factor (or velocity of propagation expressed as a percentage), the VNA can easily compute the distance to the fault or the cable length.

16. Calibrate the instrument over the frequency range 1 MHz to 1 GHz.
17. Place the VNA in time domain mode. From the main menu, select "Analysis," then "Time Domain." Define the trace as an S_{11} Log Mag trace if not continuing from previous steps.
18. The first cable whose length we will measure will be the SMA to UHF cable used for the antenna measurements in Part II. Disconnect the antenna from the cable if still connected. Connect the cable to Port 1 of the instrument with the supplied N to SMA adapter. Use the data sheet for this cable (Times Microwave Systems LMR-240), also supplied, to determine the velocity of propagation and then select Cable Correction. In the Velocity Factor area, enter the velocity factor determined from the data sheet as a decimal equivalent to the propagation velocity expressed as a percentage. For example, 70% velocity of propagation should be entered as .7. (Note: the terms "velocity factor" and "velocity of propagation" or "propagation velocity" are sometimes used interchangeably, but the first is often expressed as a decimal fraction of the velocity of light, whereas the latter terms are usually expressed as percentages. For the VNA to compute distance to fault correctly, the propagation velocity must be entered as a decimal fraction.)
19. Go back to the Time Domain menu options. For measurement units, select either feet or meters as desired. Select 0 for Start, 10 ft or 3 m for stop, One Way for Reflection Type, turn on Time Domain, and confirm that the BANDPASS filter option is selected. The horizontal axis now becomes a time scale. A large, upward-facing pulse should be clearly visible. Move the marker to the top of that pulse, read the distance to the end of the cable, and note the reading here: _____. Confirm the length of the cable by direct measurement. (Note: if converting to feet and inches, recall that 1 m = 39.37 in. A convenient way to determine cable length is to use the linoleum floor tiles in the room; these are 12 in. on a side.) How closely in percentage terms to the displayed distance is the actual length of the cable?

Toggle "Cable Correction" on and off. What happened? Why?

-
-
20. The propagation velocity (or velocity factor) can be confirmed experimentally from the data sheet parameters for inductance and capacitance using the expressions shown as equations 2.3 and 2.4 in the text and shown below:

If the cable inductance and capacitance per unit length expressed in meters is known, the velocity is computed as

$$v = \frac{1}{\sqrt{LC}} ,$$

where v = velocity (m/s),

L = inductance (H/m),

C = capacitance (F/m).

The result will need to be divided into the constant c (3×10^8 m/s) to express the reduction of wave velocity as a percentage or decimal fraction of free-space velocity.

Using the appropriate inductance and capacitance values, show below the calculations needed to confirm the velocity of propagation specified in the data sheet.

21. The propagation velocity is influenced primarily by the dielectric constant of the insulating material used in the line. If known, the dielectric constant (also known as permittivity, ϵ_r) can be used to determine the velocity factor, v_f , in decimal form as follows:

$$v_f = \frac{1}{\sqrt{\epsilon_r}} .$$

Note in particular that computations involving dielectric constant produce results that show the velocity factor as a decimal fraction of the speed of light directly; they do not need further modification. These results can be converted to percentage form if needed for entry into the TDR or VNA.

Using the data sheet, determine the velocity factor of the LMR-240 cable from the dielectric constant:

-
22. Recall from Experiment 3 that the delay time through a transmission line can be determined from the expression \sqrt{LC} , where the inductance and capacitance values are per unit length (either feet or meters). This calculation determines how long it will take for the pulse to travel to the end of the line. Use the data sheet values to calculate the delay time per unit length for the cable provided. Use either the directly measured length or the displayed, calculated length to determine the total delay time and compare with the result in nanoseconds shown by the VNA. Do the calculated results agree with the displayed delay times? If not, what is happening to account for the discrepancy?
-

23. Determine the length of a “mystery cable.” Choose one of the mystery cables available and set up the VNA to determine its length. The velocity factor of the RG-174 cable supplied is 0.7, corresponding to a 70% propagation velocity. Navigate to the Cable Correction menu within Time Domain and enter the new velocity factor if needed.

With the instrument configured similarly to the options outlined in step 19, connect the cable with the appropriate adaptor to Port 1 and move the marker to the pulse corresponding to the largest reflection. What is the measured length? _____. Measure using the “floor-tile” method described for step 19 to confirm the physical length of cable. How well did the instrument determine the length of your mystery cable? Where would such a capability be useful in a real-world maintenance context?

24. The pulses produced by the Log Mag display reveal the presence of a discontinuity in the cable but say nothing about its composition, for example, whether the discontinuity represents an open-circuit condition such as from a cable break, or, conversely, a short circuit created, perhaps, from moisture penetrating into the lines. Alternatively, the load can be terminated in an impedance greater than or less than Z_0 but stopping short of a full open- or short circuit. A $Z < Z_0$ situation might result, for example, from an unauthorized “tap” into a network, thereby creating a parallel-connected impedance. Polarity information can be revealed by changing the filters used to create the time-domain display and by having the

instrument reveal the “real” characteristics of the pulse, including its polarity.

From the Time Domain menu, change the filter setting from Bandpass to Low Pass Impulse. The low-pass mode must be selected if it is desired to show the correct sign and amplitude of the reflection coefficient (and to reveal the presence of an open versus a short, for example). Replace the mystery cable with one of the SMA cables. Leave the cable unterminated. Next, go back to the main menu, and under Format, select Real. Is there a positive-going pulse at the unterminated end? In the space below and referring back to Experiment 3 as necessary, explain why this would be the expected result for a voltage pulse applied to an open-circuited transmission line:

25. Use the supplied SMA barrel adaptor and short circuit to terminate the cable. Does the displayed pulse polarity change? If so, how? Referring back to Experiment 3 as necessary, explain why this is the expected result for a voltage pulse in the short-circuited condition.
