ECE 435

INTRODUCTION TO THE MICROWAVE NETWORK ANALYZER

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Introduction

A vector network analyzer (VNA) is a device capable of measuring both the magnitude and phase of a sinusoidal voltage signal. This makes it very similar to a vector voltmeter. However, a network analyzer is more advanced than a vector voltmeter in many ways. Complex RF circuitry is used to make the analyzer much more accurate, with a typical dynamic range of 70-110 dB. Microprocessor circuitry allows flexible processing of data including smoothing, averaging and a variety of displays. Most importantly, a VNA is capable of acquiring measurements over a swept band of frequencies, allowing the rapid wideband characterization of a wide range of microwave networks.

To compensate for the frequency dependent phase and amplitude characteristics of the cables and receiving system, it is necessary to calibrate using the known responses of standard loads (open, short, and $50\,\Omega$ terminations). The calibration procedure is an important part of network analysis, and must be done repeatedly (ideally, each time a new measurement is taken).

The HP 8720B network analyzer incorporates in one package each of the three components of a network analyzing system: a swept frequency source, a receiver, and an S-parameter test set. The sweeper produces a sinusoidal signal with a frequency that can be swept between 130 MHz and 20 GHz with a 100 kHz resolution. The receiver allows the measurement of complex voltage. The S-parameter test set incorporates directional couplers to send the signal into the chosen port of a two-port network while measuring either the transmitted or reflected signal. More advanced network analyzers (such as the HP 8510C) consist of separate components assembled into an analysis system.

In this lab you will characterize the reflection and transmission characteristics of a $100\,\Omega$ load, an open-ended coaxial cable, a cavity wavemeter and a 10 dB attenuator. You will be able to make in a few minutes measurements which might take days using the slotted line or vector voltmeter techniques studied in earlier labs.

NOTE: The HP 8720B network analyzer, cables and calibration kit cost about **$70,000**. Please treat the equipment KINDLY so that students may use them for years to come.

IMPORTANT NOTE ON CONNECTORS ************************************

The connectors on the 8720B S-parameter test set cables and on the standard loads are about the only things that can be easily damaged. Accurate measurements depend on the careful handling of all connectors. (HP has a special publication just on the cleaning and handling of connectors.)

PLEASE follow these rules when using connectors:

1. Do not touch the connector threads.
2. Always keep caps on unused connectors.
3. Do not force the connectors. If they don't seem to be meshing, you don't have them aligned properly.
4. Don't adjust the APC connectors. Only the N-type connectors are used by the students. (APC connectors require a torque wrench for proper adjustment.) If the APC connectors need adjusted, ask the lab instructor to do it for you.
5. Don't turn the device being connected! Only turn the sleeve on the male N-type connector.
6. Hand-tighten the N-type connectors snugly, but not so tight they can't be easily loosened.
7. Don't bang the connectors on the table top.
8. Don't bend the cables past where they move freely.

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I. REFLECTION MEASUREMENTS

A. Power-up

1. Turn on 8720B and PC.
2. Insert your formatted floppy into computer. Type SCAN A: (or B:). If there are viruses on your disk **REMOVE IT IMMEDIATELY** and see your instructor.
3. Note: all measured data should be stored with the .NDF extension (New Data Format).

B. Set instrument state

1. Run all programs from the C:\USR directory on the PC. Type NAM3 (network analyzer measurements) to start the measurement software. Control is now with the PC.
2. Push LOCAL on VNA to return it to local control.
3. Push START and set starting sweep frequency to 0.2 GHz. Push STOP and set ending sweep frequency to 2.2 GHz.
4. Push MENU and set no. pts to measure to 201.
5. Push AVG and set average to ON. The VNA will now take 16 sets of measurements and average the results. Set IF bandwidth to 300 Hz. This is the IF filter width.
6. Push MEAS and set the measurement to S_{11}.
7. Push CAL and select CAL KIT. Set to N 50Ω.

C. Save instrument state

1. From main menu of NAM3, enter instrument state menu.
2. Choose to save the instrument state.
3. Push LOCAL.
3. Push any key. The VNA will now transfer the instrument state.
4. Enter a filename. Choose something you will remember (try S11.IS). The instrument state will now be saved to disk.
5. Return to the main menu of NAM3.
6. The instrument state is now saved and can be recalled at any time.

D. Recall instrument state

1. From the main menu of NAM3, choose to exit the program.
2. Press LOCAL and PRESET on the VNA to return instrument state to its initial setting.
3. Start NAM3.
2. From main menu of NAM3, enter instrument state menu.
3. Choose to upload the instrument state to the VNA from disk.
4. Enter your filename. The VNA should return to your instrument state.

5. Return to main menu of NAM3.

E. Calibrate the VNA

1. Press LOCAL on the VNA.
2. Press CAL to enter the CAL menu.
3. Press CALIBRATE MENU.
4. Choose S_{11} 1-PORT.
5. Calibrate by connecting the following standard loads in succession. (Be sure to read the section on connector care.)

    a. Attach the open.
    b. Press OPENS.
    c. Indicate the sex of the connector. (Male N-type connectors have the rotating sleeve).
    d. Wait until averaging is finished and OPEN is underlined.
    e. Press DONE: OPENS.
    f. Repeat for short and $50\,\Omega$ load. For the load indicate BROADBAND.
    g. If you make a mistake, start the calibration procedure from the beginning.
    h. When done, press DONE 1-PORT CAL.
    i. The VNA will now compute the CAL coefficients it will use to make phase and amplitude compensation.

F. Save CAL coefficients

1. From the main menu of NAM3, enter the CAL coefficient menu.
2. Choose to save the CAL coefficients to disk.
3. Enter your filename (try S11.CAL). The CAL coefficients will be downloaded to the PC.
4. Return to main menu of NAM3.

G. Recall CAL coefficients

1. If you goof up something and have to start over, you do NOT have to recalibrate (unless a day or more has elapsed since your last calibration). Just recall the instrument state and CAL coefficients from disk. (Don't do this unless you have to).

H. Swept-frequency reflection measurements

1. Attach the $100\,\Omega$ load to port 1 (i.e. to the port 1 cable).
2. From the main menu of NAM3, choose to perform swept-frequency measurements.
3. Press any key to take the measurements. Enter your filename (try

100S11.NDF).

4. Return to the main menu of NAM3.
5. From the main menu of NAM3, choose UTILITY, load your data go to the menu.
6. Choose to plot linear magnitude. Plot the entire frequency range, 0.2-2.2 GHz.
7. Look at the display and comment on what you see.
8. Also look at the displays for the phase and log magnitude.
9. Return to the main menu of NAM3.
13. Push LOCAL on VNA.
14. Press FORMAT.
15. Choose LIN MAG to display the magnitude of S_{11} on a linear scale.
16. Press MKR and record $|S_{11}|$ at 300 MHz, 750 MHz, 1 GHz, 1.5 GHz, and 1.8 GHz. Do the measured values match the value expected for a $100\,\Omega$ load? How good a $100\,\Omega$ load do you think this is?
17. Observe the display.
18. Choose PHASE from FORMAT to display the phase of $S_{11.}$ Does the phase match what is expected for the $100\,\Omega$ load? Record the value of the phase at 1 GHz and 1.5 GHz.
19. Choose DELAY from FORMAT and record the value at 1 GHz and 1.5 GHz. What is this a measure of? Relate this value mathematically to the phase measured above.
20. Choose SMITH CHART from FORMAT. Explain the shape of the displayed curve.
21. To see a polar plot choose POLAR.
22. To see a plot of $|S_{11}|$ in dB, choose LOG MAG. Record $|S_{11}|$ in dB at 300 MHz and 1.8 GHz. Compare to your measurements in (16) above.
23. To see a plot of the VSWR choose SWR. Record SWR at 300 MHz and 1.8 GHz and compare to (16). Get a screen dump.

I. VNA time-domain measurements

1. Push PRESET on the VNA.
2. Begin NAM3 from the C:\USR directory.
3. Upload your S_{11} instrument state.
4. Upload your S_{11} calibration coefficients.
5. Attach the open-ended 2 meter BNC cable to port 1 of the VNA.
6. Choose swept frequency measurements from main menu of NAM3. Press any key to begin.
7. Enter a filename (try CABLE.NDF).
8. Return to main menu of NAM3.
9. Enter the UTILITY menu, load CABLE.NDF, and choose 5, "Weighting and Shifting." Choose 2, "Amplitude Weighting" and 9, "Cosine Taper" with n=8 d m=2. Return to the main menu.
10. Enter the FOURIER TRANSFORM menu and transform data set.
11. Choose 1, “Calculate transform”. The computer will perform an FFT and

convert your wideband frequency domain measurements to an equivalent time domain impulse response.

12. Plot from 0 to 40 ns. Get a hard copy of this plot.
13. Do you see peaks at about 0, 10, 20 and 30 ns? Explain these features in terms of reflections from various points along the cable. Calculate where these reflections should occur and compare.
14. Return to main menu in NAM3.
15. Press LOCAL on VNA.
16. Press FORMAT.
17. Choose DELAY.
18. Measure the delay at 1 GHz and at 1.5 GHz. How does this compare to the peaks you saw in (13)? Why do you think the delay varies with frequency?

II. TRANSMISSION MEASUREMENTS

A. Set instrument state

1. Recall your S_{11} instrument state from disk.
2. Press LOCAL.
3. Change starting frequency to 1.79 GHz. Change stopping frequency to 1.81 GHz.
4. Save this new instrument state to disk (try filename THRU.NAS).

B. Calibrate the VNA

1. Push LOCAL.
2. Enter CAL menu.
3. Choose CALIBRATE MENU.
4. Choose FULL 2-PORT.
5. CHOOSE REFLECT'N.
6. **Calibrate Port 1 as before.**
7. Calibrate port 2.
8. Press REFLECT'N DONE.
9. The VNA will compute CAL coefficients.
10. Choose TRANSMISSION.
11. **Connect the port-1 cable directly to the port-2 cable.**
12. Choose FWD TRANS THRU.
13. Choose FWD MATCH THRU.
14. Choose REV TRANS THRU.
15. Choose REV MATCH THRU.
16. Choose TRANS DONE.
17. Choose ISOLATION.
18. Choose OMIT ISOLATION.
19. Choose ISOLATION DONE.
20. Choose DONE 2-PORT CAL.

21. The VNA will calculate the CAL coefficients.
22. Save CAL coefficients to disk (try THRU.CAL).

C. Cavity Q measurements

1. Insert the cavity wavemeter between ports 1 and 2. You will have to use a sex changer on port 1.
2. Set the wavemeter to exactly 1.8 GHz. (Put RED line on 1.8, read freq. on strip between the horz. red lines)
3. Choose S_{11} from MEAS.
4. Push MEASURE RESTART.
5. Choose LIN MAG from FORMAT.
6. Choose AUTOSCALE from SCALE REF.
7. Turn on the marker and record the maximum value and its frequency. Does the resonant frequency match the cavity wavemeter?
8. Find the frequencies of the half-power points. Calculate the cavity Q.
9. The 8720B can only measure in increments of 100 kHz. To get a better estimate of the Q, and interpolate to find the Q. How does this compare to the Q found above?
10. Explain the shape of the curve.
11. Choose S_{12} in MEAS.
12. Press AUTOSCALE in SCALE REF.
13. Observe S_{12}.
14. Calculate the Q using S_{12}. How does this compare to the Q found using S_{11}?
15. Measure the magnitude and phase of EACH of the four S-parameters at 1.79, 1.8 and 1.81 GHz. Write down the **S-parameter matrix** at each frequency. Is the S-parameter matrix symmetric at these frequencies? Is it unitary? What does this say about the wavemeter?

D. Attenuation measurements

1. Remove the cavity wavemeter and attach a 10 dB attenuator in its place.
2. Measure the S-parameters at 1.8 GHz. Explain the meaning of the results.
3. Is the S-parameter matrix symmetric? Is it unitary? What does this say about the attenuator?

You have completed the lab! Turn off the VNA and make sure to transfer all your measured data (including instrument state information) to your floppy.

<u>Report</u>

Prepare a report with aims and procedure sections. In an ORGANIZED fashion, present the results taken during the lab. Include the graphs in the spots where you discuss them. Be sure to answer ALL questions asked in the procedure section.