# Circuit Characterization with the Agilent 8714 VNA

**By:** Larry Dunleavy
Wireless and Microwave Instruments
University of South Florida

## Objectives

1) To examine the concepts of reflection, phase shift, attenuation, filtering and amplification.
2) To gain experience with the use of a two-port vector network analyzer for transmission measurements.
3) To become proficient at importing and manipulating VNA data within MATHCAD.

## Equipment

1) PC running Mathcad.
2) Agilent8714VNA, with cables and adapters to provide SMA connector test ports
3) 1 Filter with SMA connectors
4) 1 MiniCircuits Amplifier
5) 1 section of semi-rigid cable (3-6" in length).
6) DC Bias Supply
7) Digital Multi-Meter
8) Banana to alligator clip dc bias wires (qty. 2)

1) 1 male-male SMA adapter
2) 1 female-female SMA adapter (barrel)
3) 1 male-female SMA adapter
4) 1 female SMA short.
5) 1 male SMA load
6) 1 20dB attenuator (pad)
7) 1 10dB or 1 30dB attenuator (pad)
8) 1 6dB Attenuator (pad)
9) 1 3dB Attenuator (pad)

## *TA NOTES:*

*Check all lab kits for completeness. Perform reflection calibration on channel 1 of all VNAs. Demonstrate calibration to all at beginning of lab.*

## Reference

⇒ HP Application Note 154, pp 1-9, Hewlett Packard Company(5952-1087), 1990.

⇒ HP Application Note 95-1, pp11-12. Hewlett Packard Company (5952-1130.

⇒ HP8711B/12B/13B/14B RF Network Analyzers User's Guide, pp2-2 to 3-64.

⇒ "Student's Introduction to the HP8714 RF Network Analyzer," USF WAMI Lab Document.

**Lab Assignment Summary - (**Detailed Procedures Below)

In this lab you will do the following:

***Part I: Reflection Measurements.***

Use a TA performed reflection calibration, to measure the complex reflection coefficient of the following items:

- SMA female short circuit
- SMA female short on end of F-M adapter
- SMA female short on end of 3”-4” semi-rigid cable.
- SMA 50 ohm load.
- Output cable used in transmission measurements.
- 6 dB attenuator attached to output cable.

***Part II: Transmission Calibration and Measurements of Passive Components:***

Perform a transmission calibration, with a thru connection and 6dB pad attached to output cable, and measure the complex transmission coefficient of:

- 3 and 20 dB attenuators.
- F-M Adapter
- 3”-4” semi-rigid cable.
- a supplied filter

***Part III: Transmission Coefficient of the Supplied MiniCircuits Amplifier***

With a 6 dB pad connected to the output cable, and 30 dB of attenuation on the input cable, lower the VNA power setting to -5dBm and re-calibrate for transmission. Using this set-up, measure the transmission coefficient (gain/phase) of the amplifier.

***Part IV: Simulations and additional analysis*.**

Some of the above measurements will be stored to a floppy disk for post measurement analysis and plotting within MATHCAD. A standard procedure for doing this is included in the Appendices. This stored data will be used for post-lab analysis and plotting.
Plots requested are specified in the write-up below.

## Equipment Set-up - General

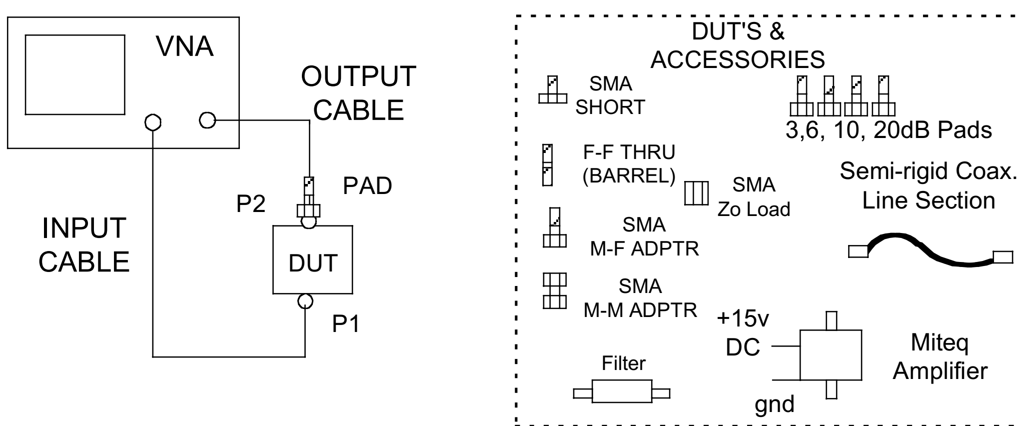



**Figure 1.** General Equipment configuration for measurement. For reflection measurements, P2 will not always be connected.

**IMPORTANT INFORMATION ABOUT MEASUREMENT CHANNELS FOR REFLECTION AND TRANSMISSION MEASUREMENTS**:

There are two measurement channels on the HP8714 VNA, which can be thought of as having two VNAs in one. **To keep things straight, you will be using Channel 1 for reflection measurements and Channel 2 for transmission measurements. Keep this straight!!** [Note: The reason for this is that if procedures are followed correctly, Channel 2 will not be properly calibrated for reflection, likewise Ch1 will not be properly calibrated for transmission].

For this laboratory a reflection calibration will be performed on Channel 1, by the TA's, prior to the lab. You will be doing a quick verification of this calibration as part of your reflection measurements. You will perform transmission calibrations yourself, using Channel 2, first to calibrate and then to measure several "DUT's" (Devices Under Test).

It is best to look at just one channel at a time. That is, when you are looking at transmission measurements, turn Ch 1 off, and when you are doing reflection measurements turn Ch 2 off. You may need to set the display to "Full" after doing this: Display => More display => Full. When viewing signals, the Scale and Format and Marker menus will be most helpful. Under Scale, the Autoscale button can be quite handy at first, but you will likely use it less and less as you get more comfortable with manipulating the display.

Finally, **if you hit PRE-SET your reflection calibration may remain valid, but your transmission calibration will need to be re-done. You can verify your calibration at anytime with a short for reflection and a thru for transmission. For this particular lab please ask the TA for assistance on re-calibrating for reflection if necessary. (Pre-set also sets the "calibration kit" selection to the default kit which generally does not correspond to the SMA cal. components you will use.)**

## Lab Assignment

Using the procedures and hints provided below along with information in the reference material, and the Appendices, carry out the following measurements and analysis.

### ***PART I. Reflection Measurements***

A. SMA Female short circuit: Connect the female short circuit to the test port, P1 (Fig. 1). [Note: P2 will not be connected]. Push Ch1 => Reflection. Set format to Smith Chart (Format => Smith Chart) and view the Smith Chart. Turn on a marker and set it with the knob or key pad to correspond to 3GHz. The trace should start at the short circuit position and travel along the edge of the Smith chart in a clockwise direction. With the marker on 3GHz, record the value of the reactive part of the impedance displayed as a marker read out below. Another number is shown in units of pH. Record this value as well. Switch the format to Phase, and with the marker still set at 3GHz record the value of the reflection phase. **If the reflection phase is not approximately 150 degrees, or if the magnitude in Smith Chart format does not trace along the edge of the chart ask for assistance before proceeding.** Switch the format to log mag and change the scale to clearly view the residual measurement ripple in the magnitude. It should be less than +/- 0.2dB. If it is not, try turning averaging on (AVERAGE menu) and re-calibrate (with TA assistance).

### OBSERVATIONS / DATA RECORDING

Does the Smith Chart trace follow along the outside edge of the Smith Chart? (If no ask for assistance) ______

3GHz Marker Values of (read from Smith Chart FORMAT):

Resistance: ________Ω Reactance _____ Ω, Equiv. Inductance _____ pH

Change FORMAT to read:

3GHz Marker Value of Reflection Phase_______ degrees.

Max/min. ripple in reflection magnitude of short circuit +/- ________ dB

Use the disk save procedures in Appendix A to store reflection coefficient in polar format (linear mag/phase). The file name will automatically be assigned by the VNA record the file name for your data below (e.g. Trace0.prn):

File name for measurement: ___________

B. SMA female short on end of F-M adapter: Connect a F-M adapter between the short used in part A and the test port P1. Set the format to Smith Chart and view the reflection coefficient measurement.

**OBSERVATIONS/DATA RECORDING:**

Describe how the Smith Chart representation of the reflection coefficient differs from Part A, do the differences make sense (explain)?

Change the FORMAT as needed and use markers to record the magnitude and phase of the reflection coefficient at the three frequencies indicated: **[Hint: You can turn on several markers at once and set them to the desired frequencies where numeric data is desired.]**

| 100 MHz Mag. dB | 100MHz Phase deg. | 1000 MHz Mag. DB | 1000MHz Phase deg. | 3000 MHz Mag. DB | 3000MHz Phase deg. |
|---|---|---|---|---|---|
| | | | | | |

How many zero crossings are there in the phase response [Note a zero crossing should correspond to the trace crossings of the horizontal axis on the RIGHT HAND SIDE (RHS) of the Smith Chart?

Use the disk save procedures in Appendix A to store reflection coefficient in **polar format** (which will store linear magnitude and phase in degrees).

File name for measurement: ___________

Additional Comments:

C. SMA female short on end of 3" to 4" semi-rigid (S-R) cable: Connect the F short to one end of the semi-rigid cables provided and connect the other to the test port P1. You will need to connect a f-f barrel to the other end of the S-R cable to enable a connection. Set the format to Smith Chart and view the reflection coefficient measurement. Place a marker at 3GHz again and repeat the observations and data recording steps performed in part B.

**OBSERVATIONS / DATA RECORDING:**

Describe how the Smith Chart representation of the reflection coefficient differs from Part A and B. Explain why the differences occur:

Use multiple markers to record the phase at different frequencies in the band indicated below: File name for measurement _____________

| 50MHz Phase deg. | 0.1GHz Phase deg. | 1GHz Phase deg. | 3GHz Phase deg. |
|---|---|---|---|
| | | | |

How many zero crossings (RHS of Smith Chart) are observed in the phase response (0.3-3000MHz), excluding +/- 180 degree phase transitions (which occur on the LHS of Smith Chart)? ________

What is the magnitude of the reflection coefficient in dB at 3GHz __________ DB

What is responsible for the difference in magnitude for this measurement as compared to the short measured at the test port in Part I a?

D. SMA load: Connect the 50 ohm SMA male load provided on the end of the F-F barrel to the port 1 connector. View the result on SWR format and then switch the results to log-magnitude and then Smith Chart to make the observations indicated below

**OBSERVATIONS/DATA RECORDING:**

With format set to SWR set a marker on the maximum value of SWR in the frequency band and record its value and the frequency at which it occurs:

Max. SWR = ______:1 at __________ MHz.

Leaving the marker set at the frequency corresponding to max SWR, switch format to Log-mag and record the corresponding reflection coefficient in dB:

Max. S11 = ______ dB at __________ MHz

Leaving the marker set at the frequency corresponding to max SWR, switch format to Smith chart and record the corresponding impedance values:

Equivalent load impedance = _________ Ω + j __________ Ω

Describe how the Smith Chart representation of the reflection coefficient differs from Parts I. A-C, do the differences make sense to you (explain)?

What SWR and reflection coefficient (in dB) would you expect to see from a perfect $Z_0$ load?

What SWR and reflection coefficient (in dB) would you expect to see from a perfect short?

E. Output cable: Connect P1 to P2 directly (without the pad shown in Figure 1). View the result on SWR format and then switch the results to log-magnitude and then Smith Chart to make the observations indicated below.

**OBSERVATIONS/DATA RECORDING:**

With FORMAT set to SWR, set a marker on the maximum value of SWR in the frequency band and record its value and the frequency at which it occurs:

Max. SWR = ______:1 at __________ MHz.

Leaving the marker set at the frequency corresponding to max SWR, switch FORMAT to Log-mag and record the corresponding reflection coefficient in dB:

Max. S11 = ______ dB at __________ MHz

Leaving the marker set at the frequency corresponding to max SWR, switch format to Smith chart and record the corresponding impedance values:

Equivalent load impedance = _________ Ω + j __________ Ω

Does the cable represent more favorable or less favorable conditions, as compared to the SMA load, in terms of ideal Zo conditions?

Additional Comments:

F. Output cable with 6dB pad: Connect a 6dB attenuator (pad) between P1 and P2 as shown in Figure 1 (pad is DUT). View the result on SWR format and then switch the results to log-magnitude and then Smith Chart to make the observations indicated below.

**OBSERVATIONS/DATA RECORDING:**

With format set to SWR, set a marker on the maximum value of SWR in the frequency band and record its value and the frequency at which it occurs:

Max. SWR = ______:1 at __________ MHz.

Leaving the marker set at the frequency corresponding to max SWR, switch format to Log-mag and record the corresponding reflection coefficient in dB:

Max. S11 = ______ dB at __________ MHz

Leaving the marker set at the frequency corresponding to max SWR, switch format to Smith chart and record the corresponding impedance values:
Equivalent load impedance = _________ Ω + j __________ Ω

Does the cable w/pad represent more favorable or less favorable conditions, as compared to the cable measurement of part E, in terms of ideal Zo conditions? What about as compared to the SMA load measurement?

Additional Comments:

## ***Part II. Transmission Measurements of Cables and Attenuators:***

A. Transmission calibration with simple thru: Turn Ch1 off and and make a thru connection between P1 and P2 leaving the 6dB pad connected to the output cable (i.e. consider 6dB pad to be part of the output cable for the rest of the lab). Perform a response calibration on Channel 2. Press Preset, then Ch2 => Transmission. Then press CAL => Transmission => Response => Measure Std.. This will establish a transmission calibration on Ch2. The reflection calibration on Ch1 will remain valid.

B. Thru verification: Note that proper calibration removes the loss and phase delay of the cables so that the thru measurement should ideally be 0dB and 0 degrees across the band. With the thru still connected, set FORMAT to Log-mag and hit Autoscale. Estimate the residual ripple in the magnitude measurement (record below), it should be less than +/- 0.1dB (turning AVERAGING on during calibration and measurement can help reduce the ripple). Change format to Phase and hit Autoscale, record the phase ripple, it should be less than +/- 1 degrees. You may notice some instability in the phase even if you are not moving anything. This instability can be stabilized, or reduced, with other settings of the VNA that we will not get into here. However, you should also notice that the phase will change if you move the cable, and this is something you can keep in mind. It is always a good practice to minimize cable movement between calibration and measurement. You can re-calibrate at this point if your phase did not return to nominally zero degrees after movement.

**OBSERVATION:**

Residual magnitude ripple with thru measurement: +/- _____ dB

Residual phase ripple with thru measurement: +/- _____ deg.

Additional comments:

A note on use of barrel adapters during transmission calibration: When the measurement cables both have male test ports an adapter (in this case f-f) is required to enable a thru connection. This adapter may need to be removed when measuring a DUT, depending on the sex of the DUT connectors. When this is necessary there will be an error in the phase of the measurement (and to a lesser extent the magnitude) due to the fact that the adapter was present during calibration but absent during DUT measurement. This effect can be corrected for with a knowledge of the adapters characteristics (e.g. having a simple transmission line model for it), which is one of the motivations for the post lab exercise related to modeling an adapter. For our purposes in this lab, we will neglect the effects of adding or removing an adapter during the DUT measurements to follow (if it is present in the same position during calibration and measurement there is no associated error).

C. Transmission measurement of F-M adapter: Connect the F-M as the DUT (Fig.1), and make the following observations. Switch formats as appropriate, keeping measurement as Ch2 - transmission at all times, and leaving Ch1 - off, to avoid confusion.

**OBSERVATIONS:**

Using markers and appropriate settings of Format and Scale functions, fill in the following table

| 100 MHz Mag. dB | 100MHz Phase deg. | 1000MHz Mag. DB | 1000MHz Phase deg. | 3000MHz Mag. DB | 3000MHz Phase deg. |
|---|---|---|---|---|---|
| | | | | | |

How many zero crossings are there in the phase response?

Use the disk save procedures in Appendix A to store transmission coefficient data in polar format (linear mag/phase). The file name will automatically be assigned by the VNA record the file name for your data below (e.g. Trace0.prn):

File name for measurement: ___________

Additional Observations (Do the results make sense?)

D. Transmission measurement of semi-rigid cable. Connect the S-R cable as the DUT (Fig.1), and make the following observations. Switch formats as appropriate, keeping measurement as transmission on Ch2 at all times. (You may need to use one or 2 f-f adapters to make the connections)

**OBSERVATIONS:**

Using markers obtain the following information.

Count the number of zero crossings in the Phase response and compare to the number of zero crossings in the corresponding reflection measurement from part I. Number of phase zero crossings _________

What is the magnitude of the transmission coefficient in dB at 3GHz __________ DB. Compare to the corresponding reflection measurement of the shorted line in part I. C. Can you explain the difference?

Additional Observations: Do the results make sense to you? Why/why not?)

E. Transmission measurement of attenuators (pads): Connect the 3dB pad as the DUT (Fig.1). Use markers and appropriate format and scale settings to obtain the data indicated in the table below. Repeat for the 20dB pad. **[Hint: You can turn on several markers at once and set them to the desired frequencies where numeric data is desired.]**

**OBSERVATIONS:**

Let's look briefly at phase. What is the Phase in degrees of the 3dB attenuator at 1GHz? _____ degrees.

How does the phase response of the 3dB attenuator compare to the F-M adapter measured earlier (look at the recorded phase values in the transmission measurement for the F-M adapter) ?

| PAD VALUE dB | 100 MHz<br>Mag. dB | 1000MHz<br>Mag. DB | 3000MHz<br>Mag. DB |
|---|---|---|---|
| 3 | | | |
| 20 | | | |

Additional Comments:

F. Transmission Measurement of filter: Now connect the supplied filter between P1 and the 6dB pad connected to P2. With the format in magnitude mode adjust Scale and markers to make the following observations.

**OBSERVATIONS:**

What type of filter is this (band pass, low-pass, high-pass, or not-sure):

Find the frequency at which the minimum attenuation for the filter occurs

Minimum loss ______ dB at _______ GHz

Find the 3dB cut-off frequency (ies) for the filter, defined as that frequency (ies) where the transmission coefficient is reduced by 3dB from the minimum attenuation. (If high or low pass you will have one cut-off frequency, if bandpass you will have two. )

$f_{c1}$ = _______ GHz $f_{c2}$ =__________

Display the phase response. How does the general shape of the phase response compare to transmission phase of some of the other components measured earlier in the lab?

Use the disk save procedures in Appendix A to store the trans. coefficient in polar format (linear mag/phase). The file name will automatically be assigned by the VNA record the file name for your data below (e.g. Trace0.prn):

File name for measurement: ___________

## *Part III. Transmission Coefficient of Supplied MiniCircuits Amplifier*

In measuring a high gain amplifier, we have two concerns. One is overdriving the amplifier input causing it to saturate, demonstrate significant non-linearity, and possibly damaging the unit. The second concern is possible damage to the test equipment. While damage would be unlikely in this experiment, we will take appropriate precautions to address both concerns. **PLEASE DO NOT CONNECT THE AMPLIFIER WITHOUT DOING THE FOLLOWING!**

A. High gain amplifier measurement set-up: Connect the 30dB of attenuation to the input cable (use 30 dB pad or combination of 10dB and 20dB pads and the 6dB pad to the end of the output cable. Reduce the VNA power level to a setting of -5dBm. This will give an input power of ~ -35dBm. Make a thru connection and perform a new response calibration. Use the configuration shown below.

B. Amplifier transmission coefficient measurement: Connect the amplifier in the DUT position (Fig.2). You may need to add or remove an adapter in doing this (we will neglect adapter affects for our purposes here). **Before connecting bias to the amplifier adjust the dc power supply voltage for 15 v using a multi-meter to verify 15v.** Turn off the supply then hook the leads to the amplifier: +15 v (wire) and ground - case. Bias up the amplifier by turning on dc bias supply back on.

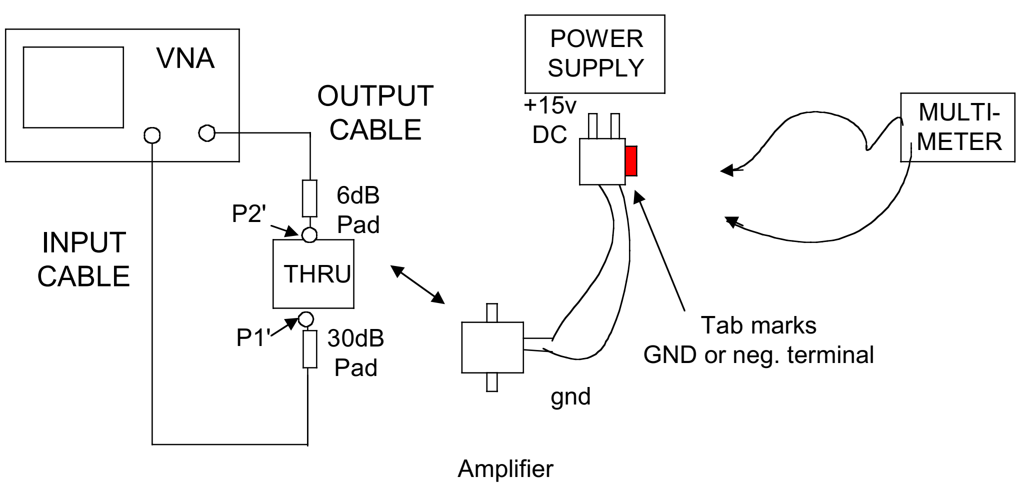



**Figure 2.** Equipment configuration for measurement of Amplifier. The attenuation on the input helps reduce the input power to a level that will not saturate (overdrive) the amplifier. The input pad(s) also improve the input cable VSWR (or Zo condition). The 6dB output pad helps improve the cable VSWR (or Zo condition) as well as reduces the output power from the amplifier.

**OBSERVATIONS:**

Find the maximum gain, and the frequency at which it occurs?

Gmax = _____ dB at ______GHz

Find the frequency below this at which the gain is reduced by 3dB from the maximum gain.

Gmax - 3dB occurs at _____ GHz.

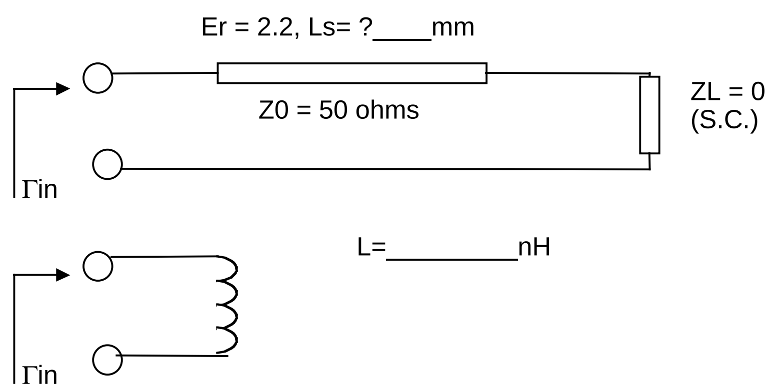
Display the phase response. How does the general shape of the phase response compare to transmission phase of some of the other components measured earlier in the lab.

Additional Comments:

## *IV. Simulations, Additional Analysis and Data Plotting*

A. Import the short circuit SMA reflection coefficient data into MATHCAD (Appendix B). Plot the magnitude and phase data for this measurement.

B. Using your pre-lab work as a starting point, and your measured data as a basis, model the short using the following two networks. That is model it as both an ideal short with an offsetting transmission line length (find the length), or as an inductance (find L). Compare the inductance to the inductance value read off of the Smith Chart in the OBSERVATIONS in Part I. **It is best to get the physical length from a low enough frequency, e.g. 1GHz, such that the reflection phase has not gone completely around the Smith Chart.** You should verify and refine, as necessary the physical length for good fit to the measured phase response over the entire bandwidth of interest.




Show the fit of your two models to the measured phase data in a MATHCAD plot.

C. Obtain plots of the (dB) magnitude and phase (deg) data corresponding to the shorted F-M adapter and shorted semi-rigid cable.

D. Obtain plots of the S21 magnitude dB and phase response (degrees) over 0.3 to 3GHz for the filter measured. Use an appropriate scale of the magnitude that will capture the entire response of the DUT while displaying good sensitivity.

**APPENDIX A: Agilent 8714 DISK SAVE OPERATION**
(Written for Agilent 8714B, differs slightly for Agilent 874C)**:**

For this lab: The following conventions are followed.

Reflection Data - Ch1 Measurement Transmission Data - Ch2 Measurement.

Assuming the desired data is displayed on Ch1. Procedure is identical but substitute Ch2 for Ch1 in below for Ch2 data save.

- **Press Format => More format => Polar!**
- Put a DOS formatted 3.5" floppy in the drive (please try to remember to bring one with you.)
- Press SAVE RECALL - Select Disk - Internal 3.5" drive. This should catalog the disk and give you a display of what is currently on the disk.
- Now press SAVE RECALL again, then Define Save, Set Inst State to off, Cal to off, Data to On, then hit Save ASCII - Save Ch1. This will save the data to a file that the analyzer will automatically name (e.g. Trace0.prn, Trace1.prn, and so on as you add files).
- The data stored will consist of Frequency, linear magnitude and phase in degrees.

**APPENDIX B: To be handed out or otherwise supplied.**