Portland State UNIVERSITY

DEPARTMENT OF
ELECTRICAL AND COMPUTER ENGINEERING

ECE331

Lab3: High Frequency Measurement

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1.1 EXPERIMENT (Characteristic of sound)

Objective:

The objective of this lab is for us to familiarize ourselves with the Vector Network Analyzer (VNA) measurement tool. We will also be using the tool to study the characteristic parameter of the line linet work, the reflection by various load terminations and for characterization line network of a bandpass filter design.

Theory:
Key Concepts
- Vector Network Analyzer calibration
- Standing Wave Ratio
- Reflection coefficient
- Scattering matrix

Procedure:
1. Pre-Lab
Design Bandpass filter with the following characteristic:
Center Frequency = 1.6 MHz ±10 kHz, Q = 8

We use the value of the Capacitor, Inductor, and Resistor. Given to us in the Lab, these values are the closest value to achieve the Lab packet Band Pass Filter design.

Capacitor: 100 pF
Inductor: 100 uH
Resistor: 120 Ohm

After using the realistic component value for our RLC series bandpass filter design. Our Center Frequency and Q point change slightly.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \text{ (Hz)}$$

Center Frequency = 1.591 MHz ±10 kHz,

$$Q = \frac{\omega_r L}{R} = \frac{X_L}{R} = \frac{1}{\omega_r CR} = \frac{X_C}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Q Factor = 8.333

Center Frequency = 1.5926 Mhz	**Bandwidth =190.69669 khz**

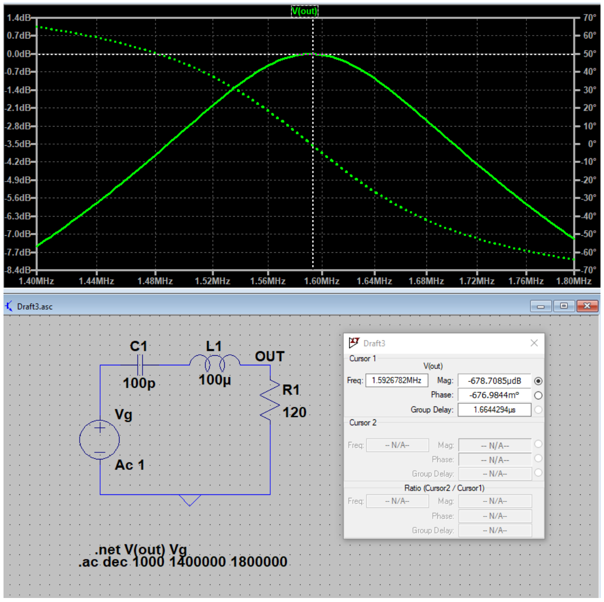


Figure 1-1, Fc

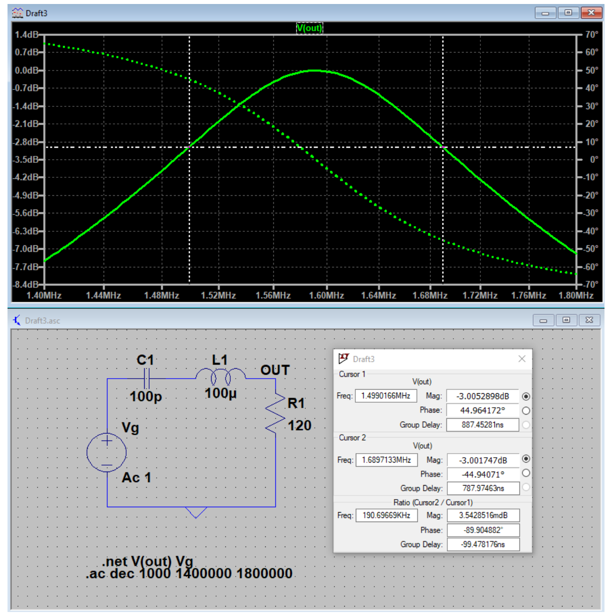


Figure 1-2, Bw

Return Loss =S11 = -4.7348 dB
Phase =54.8594

Insertion Loss = S21 = -1.81964 dB
Phase=35.4341

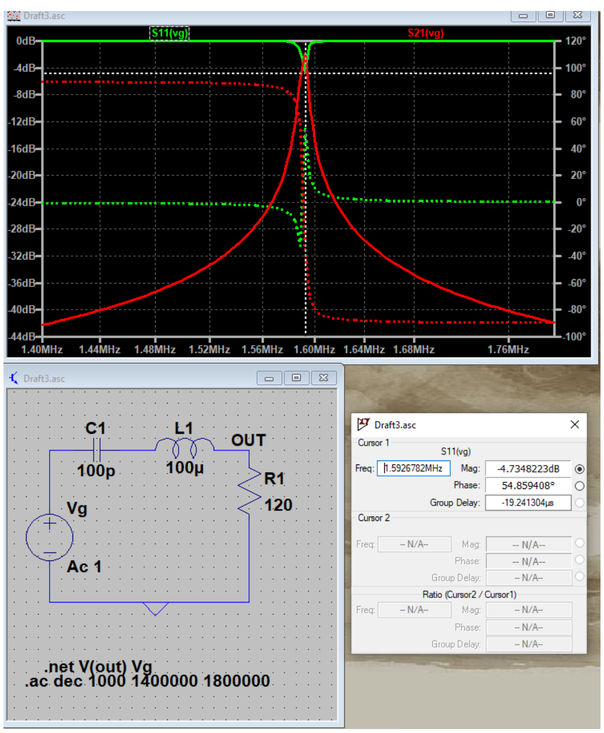


Figure 1-3, S11

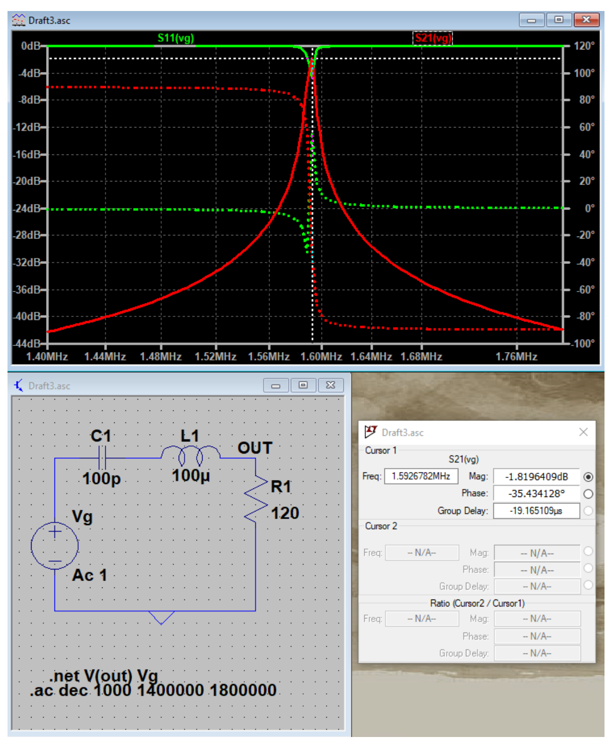


Figure 1-4, S21

<u>2.1 Vector Network Analyzer</u>

Introduction

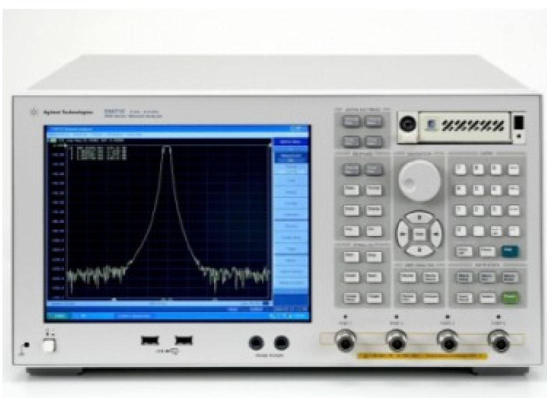
One method for providing links between remote sites is to use transmission lines. Transmission lines can be: telephone lines, coax lines for cable television, and even electrical lines.

The length of the wires or transmission lines are an appreciable fraction of the wavelength or longer, the output signal changes phase compared to the input signal, and at impedance discontinuities, reflections can occur.

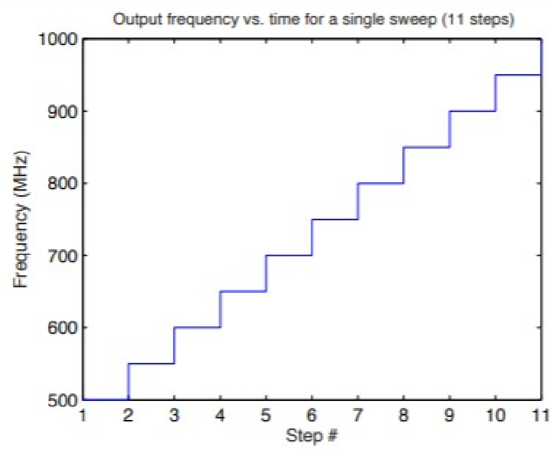
In this section of the lab, we will explore the characteristic parameters of transmission lines and the reflections caused by different load terminations. We will be introduced to our new tool for analyzing transmission lines.

The VNA is used for a variety of device and component characterization tasks in both laboratory and production environments. This highly accurate instrument can evaluate both active and passive components. A VNA can filter out unwanted responses during measurements.

The VNA is a measurement tool for making phase and magnitude measurements. The VNA (Agilent E5071C) we will use is capable of making phasor (magnitude and phase) measurements in the frequency range from 300 kHz - 20 GHz.



(a) Agilent E5071C ENA



(b) Frequency vs. time plot for the output of the network analyzer.

Figure 2-1 VNA equipment used for experiment

The signal transmitted by the vector network analyzer (VNA) is a stepped frequency signal. With this measurement, we can look at a plot of the frequency output of the VNA versus time, instead of a continuous line (called a ramp), you will see a discrete line (called a discrete ramp)

2.2 Scattering Matrix

Introductions

To measure voltages and currents at high frequencies because the direct measurement usually involves the magnitude (inferred from the power) and phase of a traveling (or standing) wave. The equivalent voltages and currents become somewhat of an abstraction when dealing with high frequency networks. A representation of a direct measurements of the ideas of incident and reflected waves is given by the scattering S parameter

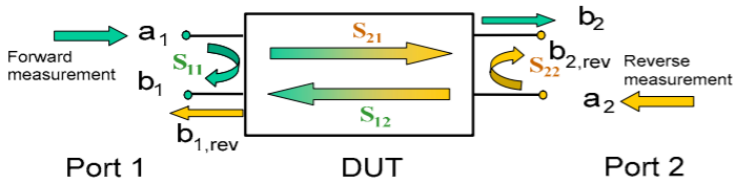


Figure 2-2 relationship between forward and reflected measurements

Figure 2-2, the S parameters relate the incident and reflected voltages from their respective ports. To determine the S parameter we use the matrix notation and solve for Spq:

$$[\mathbf{V}^-] = [\mathbf{S}]\,[\mathbf{V}^+]$$
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{pq} = \left. \frac{V_p^-}{V_q^+} \right|_{V_k^+ = 0 \text{ for } k \neq q}$$

Figure 2-3 Equation for Spq

Figure 2-3-Equation shows above that Spq is found by driving port q with an incident wave of voltage V+q and measuring the reflected wave V—p coming out of port p. The incident waves on all other ports except the qth port are set to zero. Spq is equivalent to the reflection coefficient Γ seen looking into port i when all other ports are terminated in matched loads and Spq is equivalent to the transmission coefficient τ from port q to port p when all other ports are terminated by matched loads.

2.3 Calibration

Introductions

We have to calibrate the test equipment to improve accuracy. There are three categories of errors: Drift, Random and Systematic.

Theory

Drift Errors

Drift errors are deviations in the performance of the measuring instrument which happen after calibration. This error is caused by the thermal expansion of connecting cables and thermal drift of the frequency converter within the measuring instrument. These errors are reduced by frequently calibrating the ambient temperature or by maintaining a stable ambient temperature.

Random Errors

Random errors occur irregularly. Since it is unpredictable, they cannot be eliminated by calibration. Cause by Instrument noise errors. These errors are reduced by increasing the power of the signal, narrowing the Intermediate Frequency (IF) bandwidth, or enabling sweep averaging.

Switch repeatability errors

These errors occur because of the mechanical Radio Frequency (RF) switch that is used in the measuring instrument. We can reduce these errors by carrying out measurements under conditions where we do not change the operations.

Connector repeatability errors

These errors are caused by fluctuations in the electrical characteristics of connectors. These errors can be reduced by handling connectors with care and using the same connector.

Systematic Errors

Systematic errors are caused by imperfections in the measuring instrument and the test setup Assuming that the errors are repeatable, it is possible to eliminate them by determining the characteristics of these errors through calibration. There are six types of systematic errors:

- Errors caused by signal leaks in the measuring system:
  - – Directivity : Directivity errors are caused by the fact that, in a reflection measurement, signals other than the reflection signal from the DUT are received by the receiver through the directivity coupler.
  - – Isolation (cross-talk) : Isolation errors are caused by signals other than the transmission signal of the DUT leaking to the test receiver of the transmission measurement port.
- Errors caused by reflections in the measuring system:
  - – Source match : A source match error is caused when the reflection signal of the DUT reflects at the signal source and enters the DUT again.
  - – Load match : A load match error is caused when part, but not all, of the signal transmitted in the DUT reflects at a response port and is measured by the receiver of the response port.

• Errors caused by the frequency response of the receiver within the measuring instrument:

– Reflection tracking : A reflection tracking error is caused by the difference in frequency response between the test receiver and the reference receiver of a stimulus port.

– Transmission tracking : A transmission tracking error is caused by the difference in frequency response between the test receiver of a response port and the reference receiver of a stimulus port.

The calibration method used depends on the type of measurement. Fortunately, the experiments we will be using the Agilent N4619B auto calibration kit. This type of auto calibration kit can calibrate the VNA to the end of the SMA cables, without the need for the operator to define their own calibration standards.

For these experiments we will perform a 1-Port calibration and a Full 2-Port calibration (see Table 1).

Calibration Method	Standard(s) Used	Corrected Error Factor	Measurement Parameter	Characteristics
No Calibration	None	None	All parameters	Low accuracy. Calibration not required.
1-Port Calibration	Short, Open, Load (SOL)	Directivity. Source Match, Reflection Tracking	S_{11} (Reflection characteristics at 1 port)	Highly accurate 1-port measurements.
Full 2-Port Calibration	Thru, Short, Open, Load (TSOL)	Directivity, Isolation, Source Match, Load Match, Transmission Tracking, Reflection Tracking	S_{11},S_{21},S_{12},S_{22} (All S-parameters at 2 ports)	Highly accurate 2-port measurements.

Table 1: Some different calibration types and their features.

3.1 Line Parameters of a Lossless Line

Introduction:

For Experiment 1, the goal was to be able to use a Vector Network Analyzer (VNA) to help us determine the transmission line characteristics of a coaxial cable. By the end of the experiment, we hope to find the velocity propagation (µp), the relative permittivity (εr), the inductance per unit length (L'), the capacitance per unit length (C'), and the phase constant (β).

Set up:

The setup for this experiment is fairly simple. After measuring the length of our coaxial cable, the end of the cable would be short circuit terminated, and a range of signal frequencies would be sent and reflected back in order to make a smith chart on the VNA.

Procedure:

Once the setup is completed, and the RF power is turned on, we would then adjust the electrical delay setting on the VNA, in order to get a point like response on the smith chart. With this added electrical delay, the values for the transmission line can be calculated using the equations below.

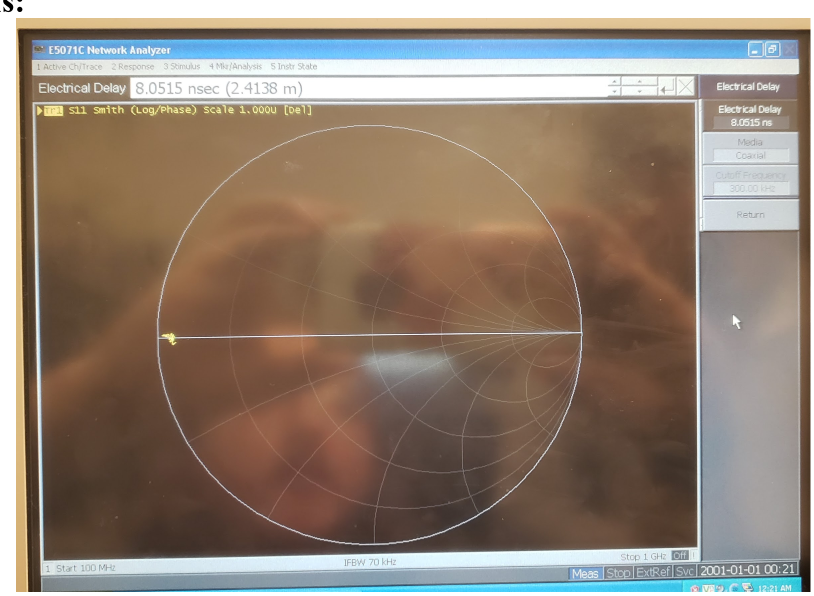
$$u_p = \frac{2l}{\Delta t}(m/s). \qquad \beta = \omega/u_p \quad = \omega\sqrt{\mu\epsilon} \quad = \omega\sqrt{L'C'}$$

$$\epsilon_r = (c/u_p)^2$$

$$\lambda = u_p/f \qquad Z_0 = \sqrt{L'/C'}$$

Equations (4)-(8) used in experiment 3.1

Data Collections:



Point response after electrical delay

(All data taken assumed that μ=μ0, frequency=800MHz, and Z0=50Ω)

SMA Cable length	**0.91 (m)**
Added Electrical Delay	**8 (ns)**
μp	**227.5E6 (m/s)**

εr	**1.739**
β	**22.095 (rad/m)**
L'	**2.2E-7 (H/m)**
C'	**8.8E-11 (F/m)**

Table 5: Experiment 3.1 - Transmission line characteristic parameters

Questions

1. No measurements were made to compute R' and G'. Explain why?

Under the assumption that we are testing a lossless transmission line as stated in the lab description, the R' and G' would both simply equal zero.

2. What is the difference between a lossless line and a dispersionless (distortionless) line? Would this technique for measuring the line parameters work for a dispersionless line? Explain why or why not.

Every lossline is a distortionless, but it is not true vice versa. If the R=G=0, the attenuation constant and phase constant are linearly frequency dependent. It is not the same for the distortionless.

3. When performing the electrical delay measurements, why did we choose the short to terminate the cables instead of the matched load?

Because, with a short we already know the wavelength and reflection coefficient. So we can calibrate the cable to be zeros. For the load match, we would need to know the exact load impedance and phase shift to make the line match exactly.

4. When computing up using the electrical delay technique, why did we have to use twice the length of the cable?

Due to the fact that we needed to use the delay to match the time that the output signal, and the reflected signal would match, the time needed for the reflected signal would be based on twice the length of the cable (travel to the end AND back).

3.2 Reflection Coefficient

Introduction:
In this experiment, we learn how to calibrate the VNA procedures by measuring the reflection coefficient of three standard impedances.

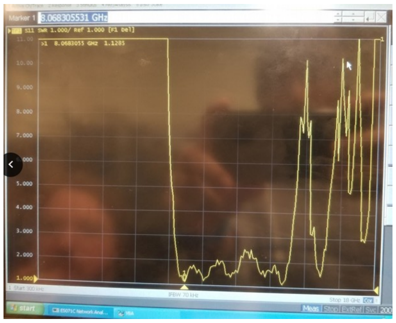
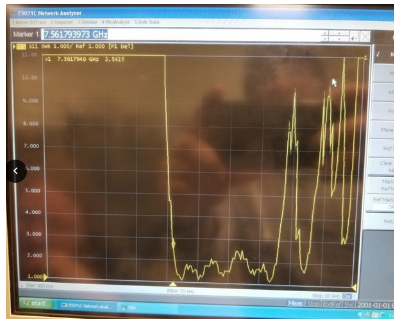
Set up:

- Turn RF power
- Connect the SMA cable to Channel 1 on the VNA.
- Configure the VNA: Set the windowing and calibrate the equipment

Procedure:
Procedure - Load Impedance Measurements
1. Connect the short circuit termination to the end of the SMA cable using the SMA/F to SMA/F adapter.
2. Turn RF power on (turn on display)
3. Record the magnitude and phase of the short circuit reflection coefficient at 500 MHz in Table 6.
4. Take a screen capture of the short circuit reflection coefficient.
5. Turn RF power off
6. Connect the SMA/F to SMA/F Adapter to the end of the SMA cable.
7. Do not connect any termination to the end of the adapter (open circuit load).
8. Turn RF power on..
9. Record the magnitude and phase of the open circuit reflection coefficient at 500 MHz in Table 6.
10. Turn RF power off
11. Connect the 50 termination to the end of the SMA cable using the SMA/F to SMA/F adapter.
12. Turn RF power on.
13. Record the magnitude and phase of the matched load reflection coefficient at 500 MHz in Table 6.
14. Turn RF power off
15. Turn on device calibration:
16. Turn RF power off
17. Repeat steps 1 - 13 with device calibration enabled.

Procedure - Antenna Bandwidth Measurement
1. Turn RF power off
2. Connect the SMA cable to the horn antenna with the SMA-N adapter.
3. Maximize Trace 1.
4. Change Trace 1 format to SWR.
5. Turn measurement conversion off
6. Turn RF power on.
7. Place a marker on Trace 1.
8. Using the position knob on the front panel of the VNA, move the marker to the frequency where the SWR is a minimum. Record this frequency and the corresponding SWR in Table 7.

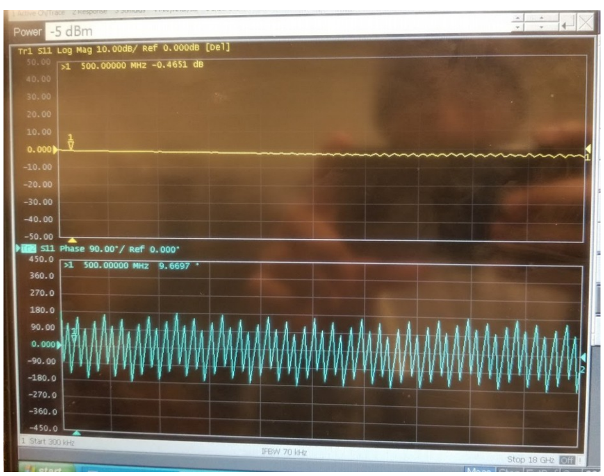
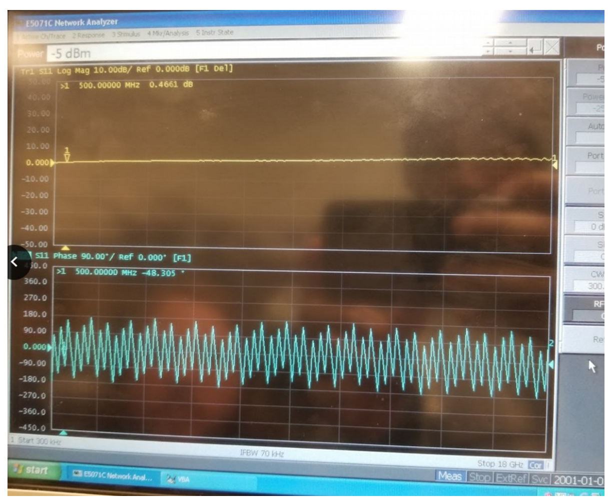
Frequency of SWR Minimum	**(lower) Frequency of SWR**	**(higher) Frequency of SWR**

 Figure 3.2-1 SWR Min	 Figure 3.2-2 SWR Min (L)	 Figure 3.2-3 SWR Min(H)

9. Using the marker, locate the two frequencies nearest the minimum where the SWR becomes 2.5. Record these two frequencies in Table 7.

Collected Data:
-Screen captures of the uncalibrated and calibrated short circuit load.
-Measured values at 500 MHz:

- Calibrated and uncalibrated reflection coefficient for the short circuit load.

Uncalibrated reflection coefficient for the short circuit load	Calibrated reflection coefficient for the short circuit load
 Figure 3.2-4 Uncalibrated short circuit load	 Figure 3.2-5 Calibrated short circuit load

- Calibrated and uncalibrated reflection coefficient for the open circuit load.

Uncalibrated reflection coefficient for the open circuit load	Calibrated reflection coefficient for the open circuit load

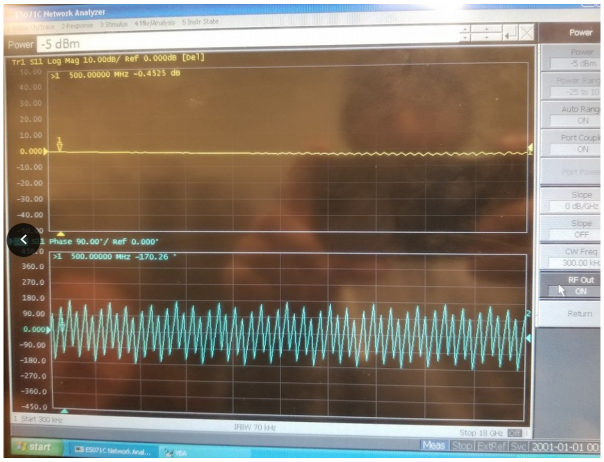


Figure 3.2-6 UnCalibrated open circuit load

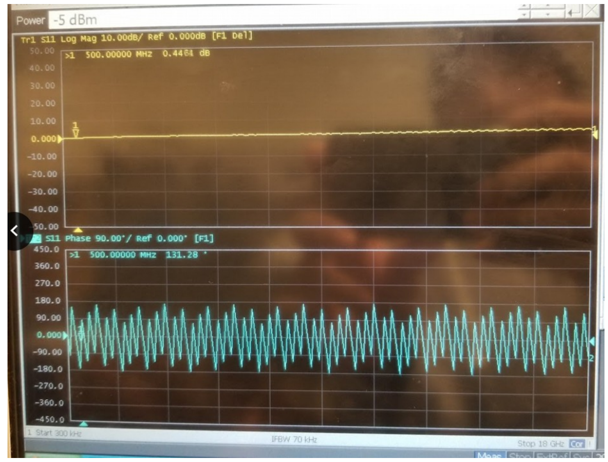


Figure 3.2-7 Calibrated open circuit load

- Calibrated and uncalibrated reflection coefficient for the matched (50) load.

Uncalibrated reflection coefficient for the matched (50) load	Calibrated reflection coefficient for the matched (50) load

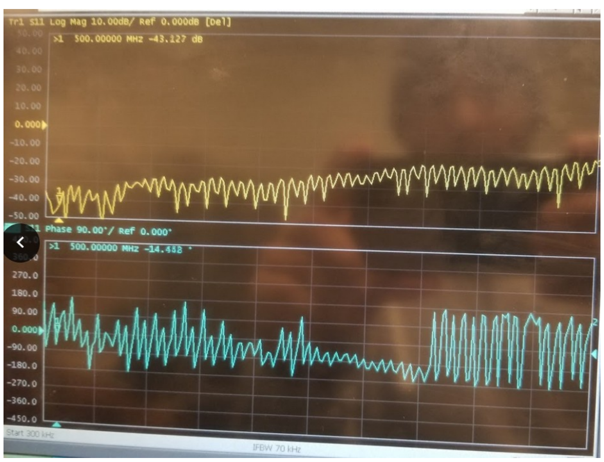


Figure 3.2-8 Uncalibrated matched (50) load

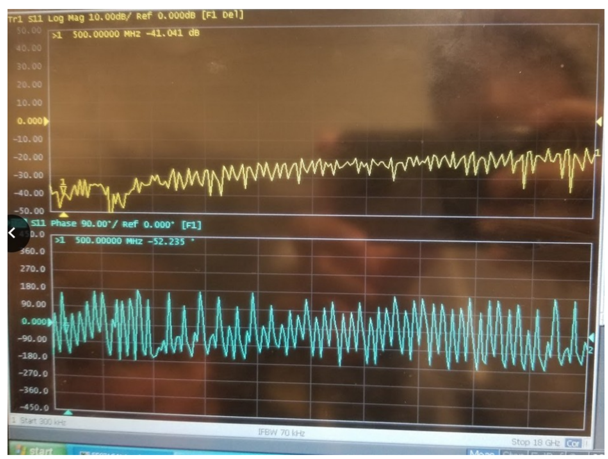


Figure 3.2-9

-For each of the loads measured (short, open, matched), calculate the theoretical reflection coefficient. Since the VNA performs a power measurement, the conversion to a linear scale is given by (9). Record these values in your logbook.

$$|\Gamma_{linear}| = 10^{\frac{|\Gamma|}{20}}$$

-Calculate the magnitude of the input impedance at the frequency where the SWR minimum occurred. Record this value in Table 7. For your calculations, assume that the reflection coefficient is real.

$$SWR = S = \frac{1+|\Gamma|}{1-|\Gamma|}$$

$$|\Gamma| = \frac{S-1}{S+1}$$

$$Z_{\text{in}} = Z_0\frac{1-|\Gamma|}{1+|\Gamma|}$$

Load	$\lvert\Gamma\rvert$ (dB)	$\angle\Gamma$ (°)	$\lvert\Gamma\rvert$ (dB)	$\angle\Gamma$ (°)
	Uncal.		Cal.	
Short	-0.46	9.6	0.4	-48
Open	-0.46	170.2	0.44	131.2
50Ω(matched)	-43	-14	-41	50

Table 6: Experiment 3.2 - Reflection coefficient for known load impedances.

Frequency of SWR Minimum	**8068 MHz**
Minimum SWR value	**1.13**
(lower) Frequency of SWR = 2.5	**7562 MHz**
(higher) Frequency of SWR = 2.5	**11433 MHz**
Zin	**44.25 Ω**

Table 7: Experiment 3.2 - Antenna bandwidth.

Questions:

1. **Compare the printouts of the short termination before and after calibration. What was the effect of the calibration? There are three types of errors: drift, systematic and random. In your own words, explain how calibration affects each of these types of errors.**

We think that these issues are both systematic and drift. The difference between the calibrated and non-calibrated measurement in the short are the phase in degree. Which can be a factor of the system reading the length of the cable incorrectly or the phase reference of the cable drifting.

2. **Compare each of the loads measured (short, open, matched) to the theoretic reflection coefficient value. Explain any discrepancies, if they exist.**

There are a lot of discrepancies that can exist. Based on the effect of equipment error and human error which can cause; frequency drift, Phase Drift, Power switch, improper cable connection. All play a part of the result of our measurements.

3. What range of frequencies does the antenna that you measured operate over (i.e. what band was it designed for)?

Based on our measurements, it looks like the antenna was designed to have a 4GHz bandwidth from 7.5GHz to 11.5GHz

4. Is the antenna that you measured good for broad-band communication systems (20 MHz - 2 GHz)? Explain why or why not. (Hint: recall the connection between the reflection coefficient and the SWR) (5 pts)

According to the measurement from the antenna, we think that the best possible frequency to use with antenna is theoretical when the SWR is 1. But, Because of the cause of the other added element like cable and connector it changes the phase shift in the reflected frequency within the wire. The best rating for this antenna is about 8068 MHz with a SWR being 1.13.

3.3 Filter Characterization

Introduction:

In this experiment, we validate your bandpass filter design using the VNA to take measurements of common lter characteristics. Both the magnitude and phase behavior of a component can be critical to the per- formance of a system.

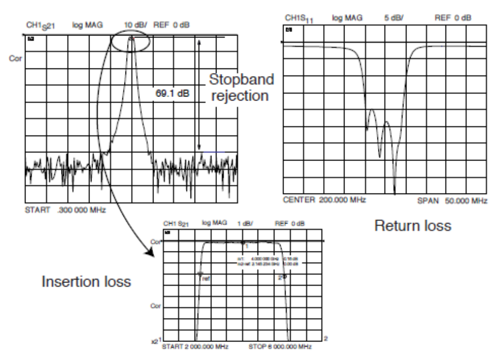


Figure 3.2

In Figure 3.2 the frequency responses of a bandpass lter. On the left and bottom the transmission response is shown in log magnitude format, and on the right we see the reflection response S11 (return loss).

The most commonly measured lter characteristics are insertion loss S21 and bandwidth, shown on the lower plot with an expanded vertical scale. Another common measured pa- rameter is out-of-band rejection. This is a measure of how well a lter passes signals within its bandwidth while simultaneously rejecting signals well outside that same bandwidth.

Set up/Procedure:

- Build the bandpass filter we designed in Section 1 (using standard component values.)
- Turn RF power on
- Connect one end of an SMA cable to Channel 1 on the VNA.
- Connect one end of the second SMA cable to Channel 2 on the VNA.

- Turn on device Calibration: Calibrate
- Configure the VNA: Test the Band-pass filter

Data Collections:

<u>Measured values:</u>

- Center frequency fc of the filter.
- Bandwidth changes f of the filter.
- Insertion loss (S21) of the filter .
- Return loss (S11) of the filter.

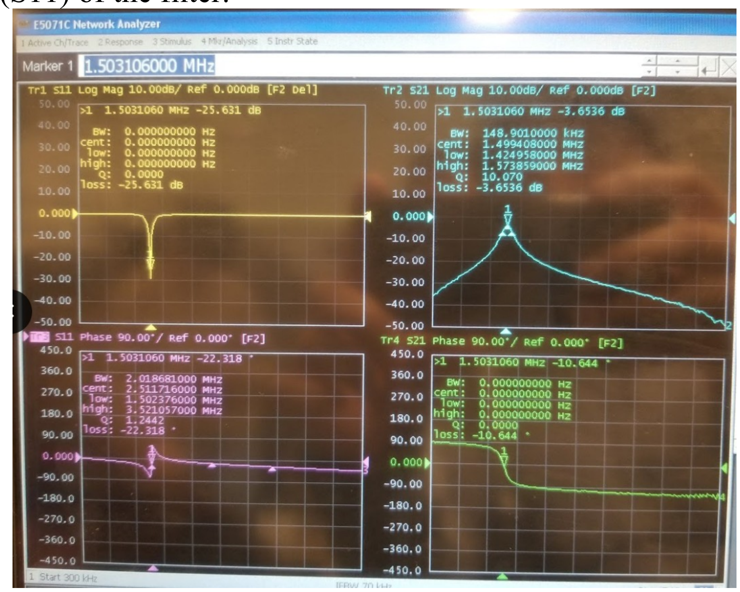


Figure 3.3-1 Final Measurement

<u>Calculate the quality factor Q of the filter and Calculate the input impedance Zin of the filter</u>

$$Q = f_c/\Delta f$$

$$\Gamma_g = \frac{Z_{\text{in}} - Z_0}{Z_{\text{in}} + Z_0}$$

	fc (MHz)	Δf (kHz)	Q	S11 (dB)	S11 (◦)	S21 (dB)	S21 (◦)
Simulated	1.5926	190.69	8.197	-4.735	54.859	-1.819	-35.434
Measured	1.5031	148.901	10.070	-25.631	-22.318	-3.6536	-10.644

<u>**Table 8: Experiment 3.3 - Bandpass filter characterization**</u>

Questions:

1. Explain why it was necessary to perform a Full 2-port calibration in order to measure the frequency response of your filter.

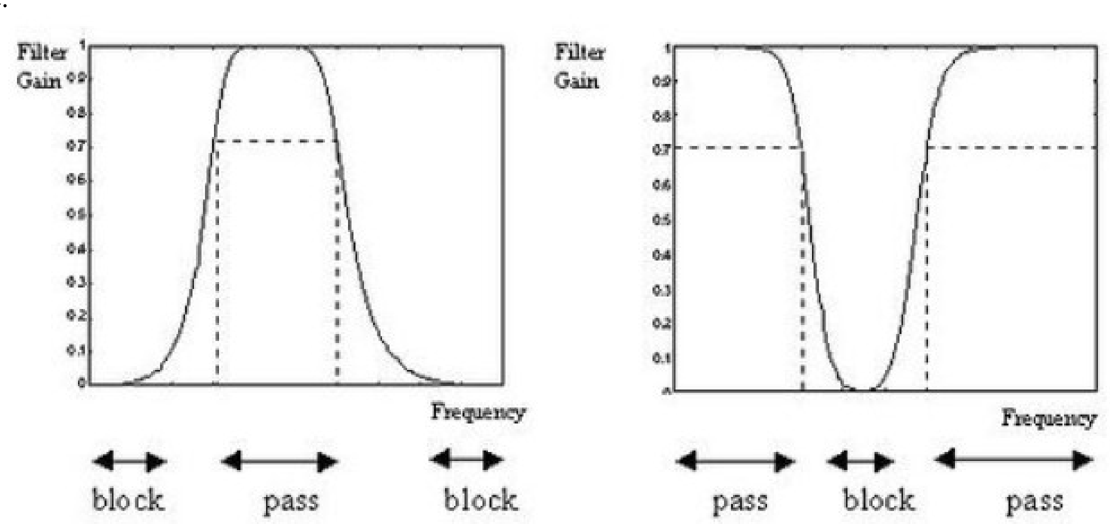
Yes it is necessary to do a full 2 port calibrations in order to get the best measure *frequency response of the filter. This calibration effectively eliminates the directivity error, crosstalk, source match error, frequency response reflection tracking error, and frequency*

2. Using what you know about the meaning of S11 and S21, describe in your own words the meaning of S12 and S22.

S-parameters describe the input-output relationship between ports in an electrical system. Since, we have 2 ports (Called Port 1 and Port 2)
S11 then would be the reflected power radio 1 is trying to deliver to antenna 1.
S12 represents the power transferred from Port 2 to Port 1.
S21 represents the power transferred from Port 1 to Port 2.
S22 would be the reflected power radio 2 is attempting to deliver to antenna 2.

3. What are the in-band and out-of-band rejection of your filter design? Is it possible to make these calculations using SPICE? Explain why or why not.

The band-in and band-out, can be calculated from the Spice simulations. The value that we get from the Lower frequency and the Upper frequency; the bandpass and band reject cutoff point.



Left : Bandpass filter Right: Bandreject

4. Compare the measured to the simulated values in Table 8. Does your filter meet the design constraints? Explain possible discrepancies if they exist.

______*The simulated value and the experimental values do meet the design constraints. The discrepancies could have been an issue with the human error or the actual material. The frequency center, the change in frequency, and the o point all work out. To less than 20 percentage error rate. Even Though, we approximate the Capacitor value and the Inductance value of the bandpass filter.*

Conclusion/Discussions:

Overall the lab was pretty easy. There were some parts where we did ask for help for the calibrations and calculations of the reflection coefficient. We were able to complete the Lab before the lab hours were up.

We also had 3 people to complete all the given tasks, having 3 people really help distribute the Lab work loads. So, we were able to complete the lab in a timely manner.