USAF ACADEMY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
LESSONS 15–16 LAB - Transmission Line Reflection Coefficients
Spring 2027

Learning Objective 3.8: I can measure the reflection coefficient across a range of frequencies and interpret the measurement using a network analyzer.

TEAMS: Work in teams of two or three, one team to a lab station. The team keeps the same station and the same VNA for both lab periods.

COLLABORATION POLICY: The lab is a team assignment. Each team submits **one** combined lab report covering both lab periods, with every member's name on it.

AUTHORIZED RESOURCES: Any resources are authorized.

DOCUMENTATION: You must include a documentation statement with each assignment in accordance with the course policy letter.

DUE DATES: The lab report will be due as indicated on Gradescope.

INSTRUCTIONS:

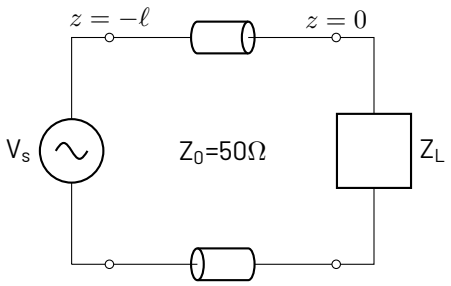
- Before lab: read the entire lab packet.
- Before lab: read the VNA user's guide.
- Before lab: work the predictions (the capacitor table in Measurement 3, and parts (a) and (e) of Measurement 5) so you arrive with them in hand.
- During lab: complete the measurements as specified.

EQUIPMENT SAFETY:

- Equipment safety rules must be observed at all times and are for the safety of the students and protection of the equipment.
- No food or drink is allowed in the ECE labs while conducting measurements. Cadets are requested to finish their snacks outside the classroom and place all trash in the trash containers before class starts, and keep all drinks off work surfaces.
- At least two people (instructor/technician/cadet) must be in the room when equipment is in use.
- Cadets should return equipment to original configuration before leaving.
- Cadets must clean up their immediate area (return wires, pick up trash, etc.) before leaving.
- Cadets are to refrain from "playing" with the equipment, parts, and wires when there is no hands-on activity underway.
- When plugging in or unplugging wires, make sure any signal sources (AC or DC) are not transmitting.

1 Purpose

The goal of this lab is to use a Vector Network Analyzer (VNA) to measure the reflection and transmission coefficients in the transmission line system shown below. You will familiarize yourself with RF measurement technique, calibrate the VNA, measure several known load impedances, and, finally, characterize an unknown device. Measurements 1 through 5 are the Lesson 15 lab period; Measurement 6 is Lesson 16.



2 Background

In this lab, we will measure the reflection and transmission coefficients of several devices over a range of frequencies, and compare them with the reflection and transmission described in class. Recall that you find the reflection and transmission coefficients at the load from:

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$
$$T_L = 1 + \Gamma_L$$

In this lab, we won't be considering the length of our transmission lines (ℓ), because we will calibrate the length out of our measurements.

3 Equipment

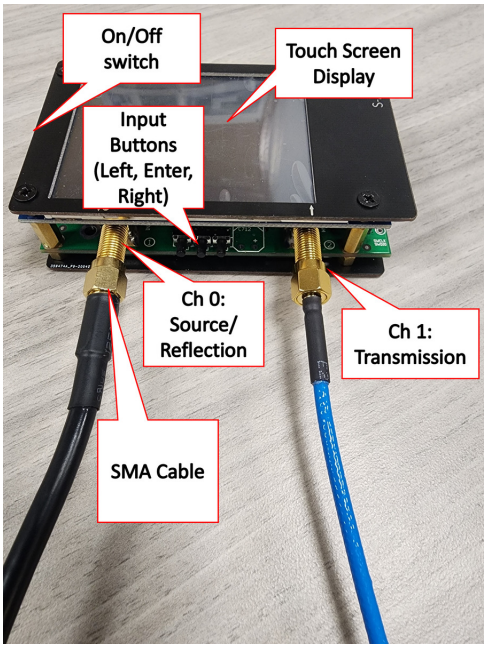
3.1 Basic Familiarization

A full user's guide for the VNA is available online. Please familiarize yourself with this guide **before** the lab period. Figure 1a shows the VNA and calls out its key components.

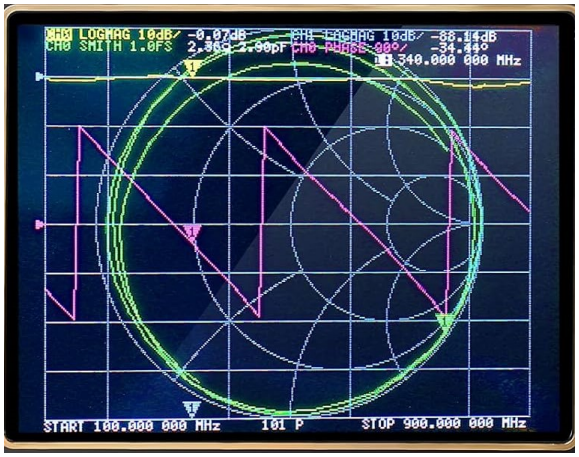
We will use a VNA to measure S-parameters, which are essentially reflection and transmission coefficients. For a two-port network (which, in our case, are Channel 0 and Channel 1), we have 4 S-parameters: S_{11}, S_{21}, S_{12}, and S_{22}. The subscripts represent the receiving port and the source port, so S_{21} means the signal received at port 2 as a result of a source at port 1 – this is the transmission coefficient from port 1 to port 2.

You can power these nano VNAs from the built-in battery or the micro-USB cable. To operate the VNA, turn on the device using the on/off slider on the left side of the device. Within a few seconds, you should see a display as shown in Figure 1b. At first, the display will appear cluttered, because you are actually looking at several plots overlayed on one another. The labels for each trace are at the very top of the screen and the default quantities are as follows:

- Yellow: Channel 0's magnitude in log format. This is the reflection coefficient, which the VNA plots on the rectangular grid. The default scale, as shown, is 10dB per division. Usually, 0dB is at the top of the screen.



(a) An annotated overview of the VNA.



(b) An initial view of the nano VNA screen.

Figure 1: Familiarization views of the nano VNA.

- Blue: Channel 1's magnitude in log format. This is the transmission coefficient, which the VNA plots on the rectangular grid. The default scale, as shown, is 10dB per division. Usually, 0dB is at the top of the screen.
- Magenta: Channel 0's phase in degrees. The default scale is 90° per division.
- Green: This is the smith chart plot of the measured complex impedance of the load (Z_L). The VNA plots it "behind" the rectangular grid, on its own scale (normalized **impedance**).

You can customize each scale – the user's manual describes how – but this lab does not need it.

3.2 VNA Setup

To bring up the menu, tap the screen (it helps to use a passive stylus) or press the middle tactile button. Your first task should be to flip the display, which will allow you to turn the ports away from you. To do this, tap the screen, then tap "Display" at the top of the menu. At the bottom, you should then see "Flip Display" – tap this button and the screen should invert. You should also tap the "Pause Sweep" button – this pauses the frequency sweep and measurement cycle of the VNA. Take some time to explore the menu structure – a full map is available in the user's guide.

3.3 Parts

Beyond the VNA and its cables, each station has three parts for Measurements 3 through 5:

Part	Used in
50Ω resistor	calibration; Measurements 4 and 5
1 kΩ resistor	Measurement 5, resistive load
470 pF capacitor	Measurements 3 and 5

Measurement 5's complex load is the 50Ω resistor and the 470 pF capacitor in series. Keep its leads short: twist one lead of each part together, and clip the grabbers to the two free ends.

4 Tasks

4.1 Calibration

When performing RF measurements, you **always** need to calibrate your device to your particular configuration. You must recalibrate every time you connect a cable or change the frequency range. First, connect the SMA cables to each port (SMA cables are the smaller coax connectors). On channel 0 (which is confusingly labeled "1" on the circuit board), connect the black SMA-BNC connector, then connect the BNC-grabber clips cable to the open end. On channel 1 (labeled "2" on the circuit board), connect the blue SMA-SMA cable. Don't worry about the different colors or lengths of the cables at this time. RF connectors are sensitive, so when connecting them **DO NOT** overtighten the connectors or cross-thread them. Finger tight is just right in this case.

Before we calibrate the device, you will need to set your frequency range.

1. Tap **Stimulus** from the main menu.
2. Set your frequency range from 50kHz to 5MHz using the **Start** and **Stop** buttons.

You will now follow the calibration procedure using an open, short, and load calibration standard.

1. Connect every calibration standard to channel 0, and leave channel 1's SMA cable disconnected.
2. Bring up the menu and tap **Cal**.
3. Reset the calibration by tapping **Reset**.
4. Leave the grabber clips disconnected from any load. This is an open circuit.
5. Now, under the **Calibration** pane, tap **Open**. The calibration is complete when the background of the text turns black.
6. Connect the grabber clips to form a short circuit.
7. Under the **Calibration** pane, tap **Short**.
8. Once the calibration is complete, move on to the **Load** calibration. In this case, you will connect the grabber clips to a matched load of 50Ω – a simple resistor.
9. Do not conduct a **Thru** measurement. This involves adding another length of transmission line between channel 0 and channel 1.
10. Tap **Done** at the bottom of the **Calibration** pane.
11. If you wish, you may save your calibration by tapping "Save 0". You will be able to recall these calibration settings later.

12. From the **Cal** pane, ensure **Correction** is highlighted in black.
13. Calibration is now complete – tap any portion of the plots to close the menu.

Note the reference plane. Everything you just did tells the VNA to call the *tips of the grabber clips* the place where $z = 0$. Every impedance you report from here on is the impedance seen at those clips.

4.2 Measurement

When making measurements, be sure to pause the sweep while changing physical connections. Additionally, you may read values for the marker positions at the top of the screen. You can move the markers by tapping/holding and dragging (this requires a stylus), or by choosing **Markers → Select Markers → Marker X** and then using the left/right tactile buttons to move the marker location. Figure 2 shows an annotated example.

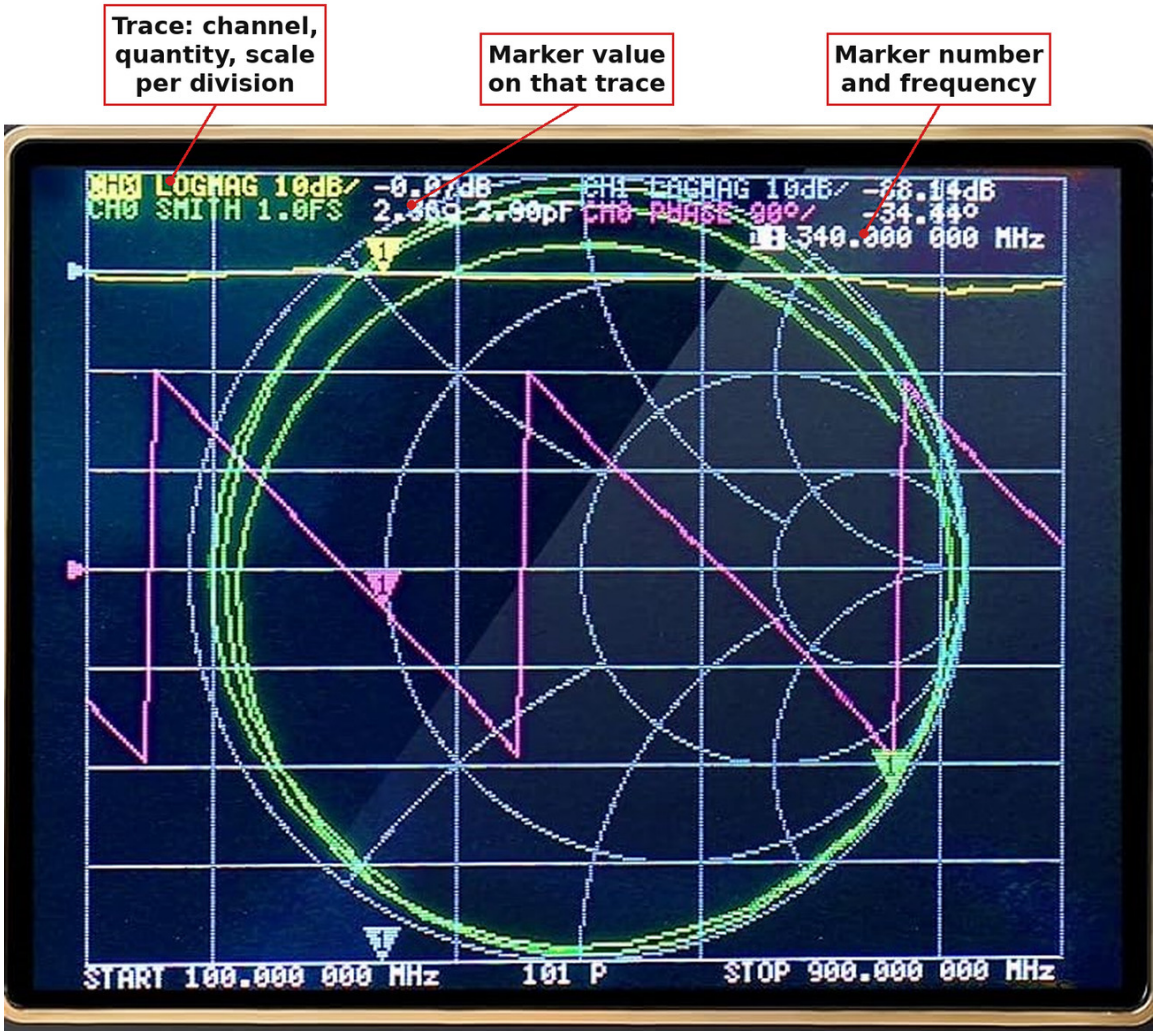


Figure 2: An example readout of a VNA measurement showing the location of Marker position information.

1. Given an open circuit load, what type of reflection would you expect to see, in terms of the reflection magnitude and phase? Use the reflection coefficient equation to inform your answer. It may also help to include a screenshot of the resultant plot.

(a) What amplitude and phase do you observe?

Amplitude = Phase =

(b) What position is the open circuit indicating on the Smith Chart? Does this make sense, based on your understanding of the Smith Chart?

2. Given a short circuit load, what type of reflection would you expect to see, in terms of the reflection magnitude and phase? Use the reflection coefficient equation to inform your answer. It may also help to include a screenshot of the resultant plot.

(a) What amplitude and phase do you observe?

Amplitude = Phase =

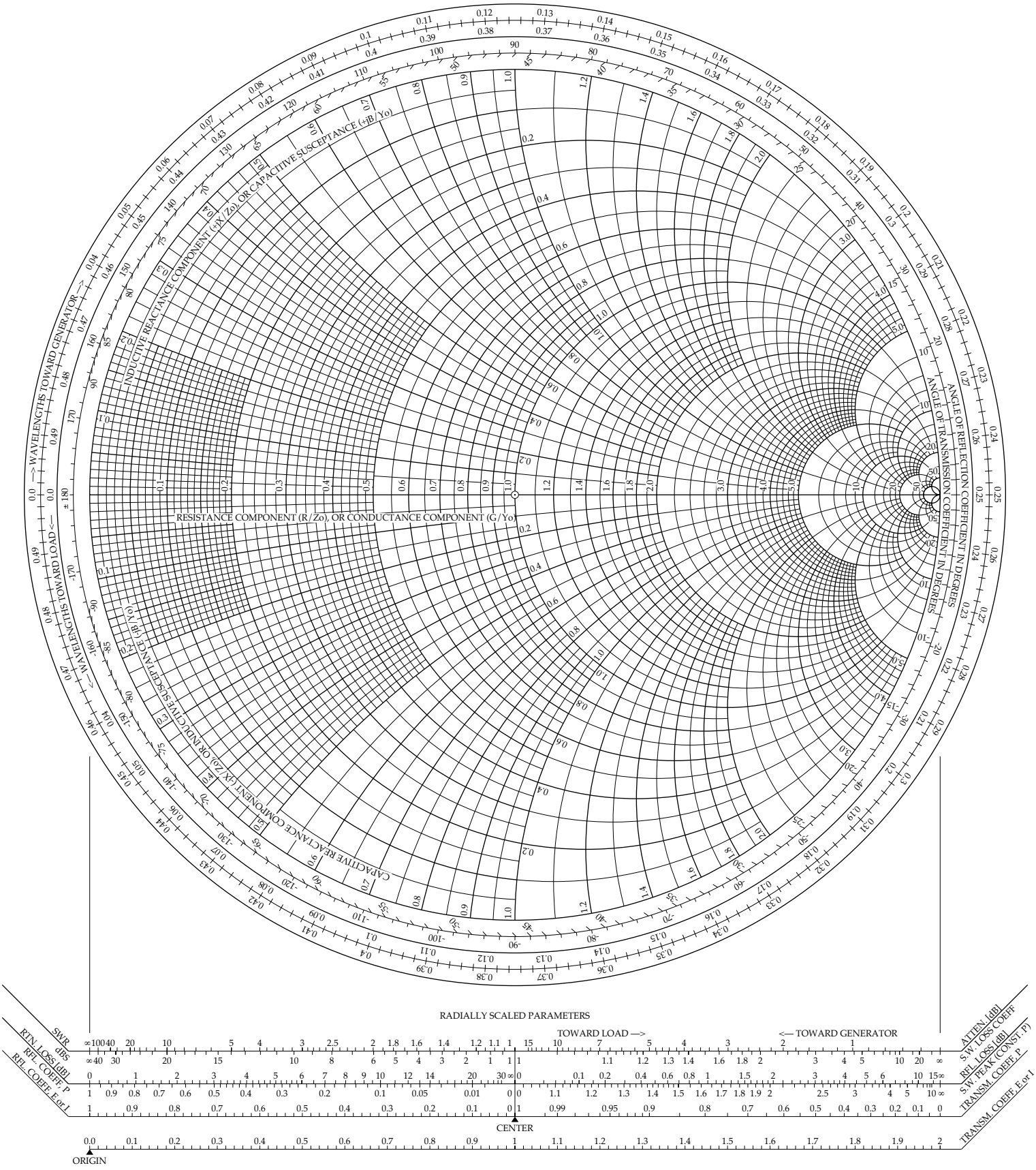
(b) What position is the short circuit indicating on the Smith Chart? Does this make sense, based on your understanding of the Smith Chart?

3. **Impedance Measurement:** Given a capacitor of value 470 pF, calculate the impedance for the frequency ranges shown in the table below. Plot these values on the smith chart and compare the measurement results – do they agree?

Frequency	**Expected Z_C**
50 kHz	
100 kHz	
500 kHz	
700 kHz	
900 kHz	
1 MHz	
2 MHz	
3 MHz	
4 MHz	
5 MHz	

The Complete Smith Chart

Black Magic Design



4. **Matched Load Measurement:** Now, you will measure a matched load of 50Ω . Simply connect the grabbers to each side of the same 50Ω resistor used during calibration.

   (a) What is the predicted magnitude of the matched load reflection coefficient, in dB? Remember, you are measuring **Voltages**.

   (b) What is the measured magnitude of the matched load reflection coefficient.

   (c) Identify the resistance value from the marker readout and the Smith Chart.

   (d) Make at least one observation about your measurements.

5. **Mismatched Load Measurements:** Now you will measure two mismatched loads, one purely resistive and one complex. First, connect the 1 kΩ resistor to the mini grabbers and answer the following questions.

   (a) What is the predicted magnitude (in dB) and phase of the reflection coefficient for this load? Remember, you are measuring **voltages**.

   (b) What is the measured magnitude and phase of the load reflection coefficient?

   Amplitude = Phase =

   (c) Identify the resistance value from the marker readout and the Smith Chart.

   (d) Make at least one observation about your measurements.

Now replace the 1 kΩ resistor with the **complex load**: the 50Ω resistor and the 470 pF capacitor in series (Section 3.3).

(e) Find the load impedance at 2MHz, and from it the predicted magnitude (in dB) and phase of the reflection coefficient.

(f) Set a marker at 2MHz. What is the measured magnitude and phase of the load reflection coefficient, and what impedance does the marker report?

Amplitude = Phase =

Z_L =

(g) Sweep the marker from 50kHz to 5MHz. Which way does the trace move on the Smith Chart as the frequency rises, and along which circle? Explain both from Z_L.

(h) Make at least one observation comparing the two mismatched loads.

6. Black Box Measurement

Now, you will measure an unknown device, often called the "Device Under Test" (DUT). Tape covers the DUT's label – do not remove it! Also, note the DUT has SMA connectors – disconnect the BNC cable with the minigrabbers. Due to the operational bandwidth of the DUT, you will need to adjust the frequency range to correlate to your specific filter and recalibrate. The calibration procedure is slightly different, in that SMA cables use different calibration standards (as shown in Figure 3). Please use the short, open, and load connectors. This time, you may also perform a thru calibration by connecting channel 0 and channel 1 using a coupler, but this is optional. Now, connect the DUT to the VNA using the appropriate cables and restart the sweep.

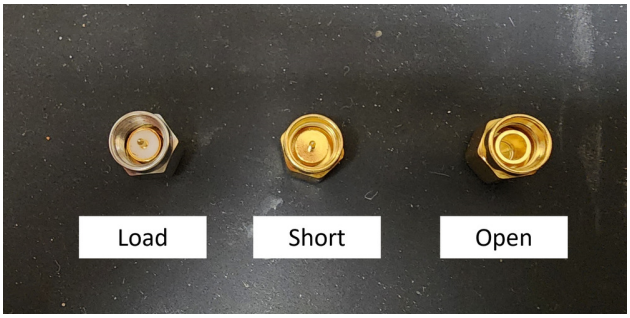


Figure 3: The RF calibration standards for this VNA, used in Measurement 6.

(a) Looking at the plot of the transmission and reflection coefficient, what type of filter do you have? How do you know?

(b) Determine the cutoff frequency (or frequencies) of the filter (remember, this is the -3dB point).

(c) Using the Smith Chart display, observe whether the DUT is capacitive or inductive over certain frequency ranges. If you move the Smith Chart marker, you will see the reactance change – can you correlate that change with a value of capacitance or inductance?

(d) Make at least one additional observation about your measurements.