EE 483L/583L Antennas for Wireless Communications (Spring 2025) Laboratory 2- Introduction to Vector Network Analyzer and Calibration

Introduction

In this lab, you will be introduced to vector network analyzers (VNA) by conducting a 1-port calibration procedure and taking some sample measurements. The purpose of the calibration is to provide accurate measurements, and to move the measurement reference plane(s) to the end of the coaxial transmission line (TL) adaptor(s) and/or coaxial TL(s) attached to the port(s) of the VNA. After calibration, the measured data will be for the device under test (DUT) only, i.e., it does not include the transmission line effects of the adaptor(s) and/or TL(s) between the VNA and DUT. We will use a Keysight E5063A Network Analyzer as our VNA (see Figure 1). It has two ports with female type N connectors and a possible frequency range of 100 kHz to 8.5 GHz.

There are two steps to performing an S_{11} (i.e., single-port) calibration with the VNA. The first is to define/select a calibration kit. For this laboratory, the Agilent 85033E 3.5 mm Calibration Kit is used. The second step is to perform the actual calibration using known standards (e.g., open, short, and matched load) contained in the kit. Defining the calibration kit allows the VNA to collect the necessary measurements and to correctly apply these measurements in the calculation of the calibration/error coefficients.

The following designations will be used to help give instructions on operating the VNA:

- Figure 1 shows the front layout of the Keysight E5063A Network Analyzer.
- Front panel buttons will be depicted by a box outline, e.g. BUTTON.
- Boxed groups of related buttons will be referenced by the box name in quotes, e.g., “ENTRY”.
- Softkeys (i.e., software defined keys) on the VNA display will be depicted by highlighting, e.g. **SOFTKEY**.

Background

VNAs are used to measure scattering parameters (i.e., *S*-parameters). At higher frequencies, voltage and current measurements are not always possible or do not make sense (e.g., waveguides). *S*-parameters are defined in terms of incident and reflected waves on a two-port device or network as shown in Figure 2. The wave variables are defined as

$$a_1 = \frac{V_{\text{inc},1}}{\sqrt{Z_{O,1}}},\ b_1 = \frac{V_{\text{refl},1}}{\sqrt{Z_{O,1}}},\ a_2 = \frac{V_{\text{inc},2}}{\sqrt{Z_{O,2}}},\text{ and } b_2 = \frac{V_{\text{refl},2}}{\sqrt{Z_{O,2}}}$$

where $Z_{O,i}$ are the characteristic impedances of the connected transmission lines (all are 50 Ω in our case), $V_{\text{inc},i}$ are the incident voltage waves, and $V_{\text{refl},i}$ are the reflected voltage waves. For a one-port calibration or measurement, the *S*-parameter we are concerned with is $S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0}$ (no incident wave at port 2). For our purposes (i.e., one-port devices such as an antenna or terminated transmission lines), S_{11} is essentially the reflection coefficient Γ looking into port 1.

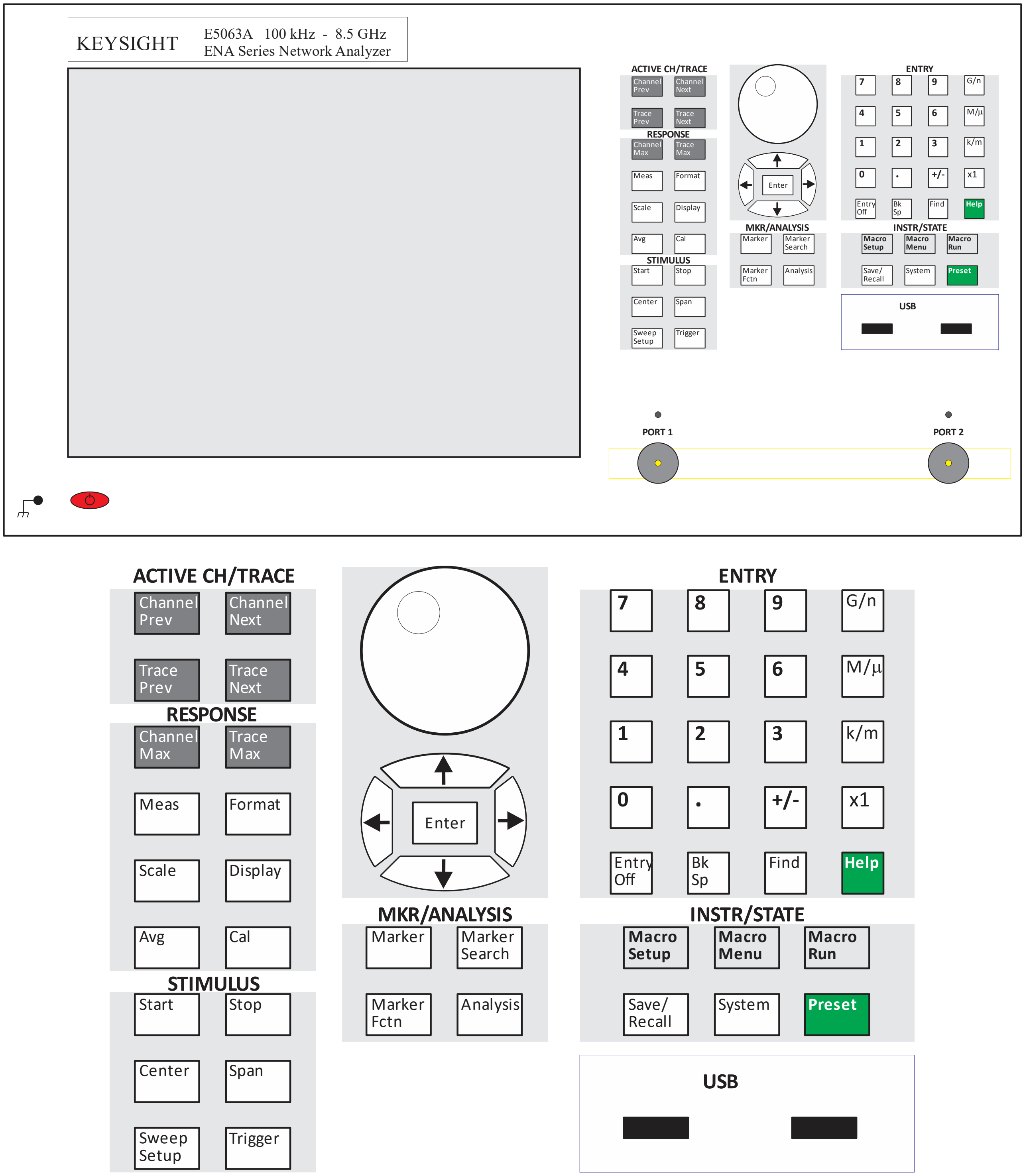

Figure 1 Keysight E5063A Network Analyzer front panel (top) and close-up (bottom)

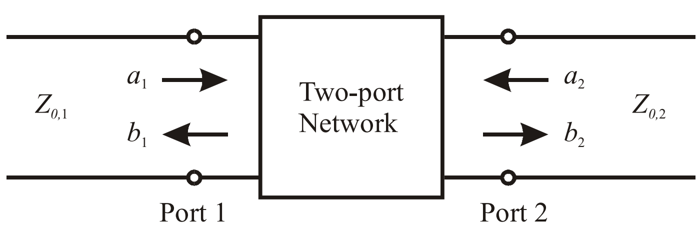

Figure 2 Two-port Network

Procedure

Note 1: Review connector_care_guide.pdf under the 'Labs' link. Always gently start RF/µwave connectors (w/ threads aligned!) by hand and turn clockwise to a *gentle* 'finger tight.'

Note 2: Always wear a grounding wrist strap when using the VNA to mitigate the effects of electrostatic discharge, which can easily damage a VNA. Ensure the wrist strap is connected to the grounding lug on the VNA.

1) If the VNA is not already turned on, press the power button (lower left hand corner) so that it is backlit green. Wait for the VNA to 'boot up.' For best results, a VNA should be allowed to warm up for several minutes.

2) If necessary, connect a male type N to female SMA adaptor to PORT 1 (finger tight is adequate). Next, connect a six foot long Mini-Circuits 50 Ω coaxial TL with male SMA connectors (CBL-6FT-SMSM) to the adaptor, i.e., 'finger tight' followed by the **5 in-lbs torque wrench**.

3) To give a familiar display, press [Format] under the "RESPONSE" menu. This will activate a softkey menu with several choices. Use the mouse to select the **Smith** softkey and select the **R+jX** softkey option. Note that the trace on the Smith chart is not on the outer rim ($|\Gamma| = 1$) as could be expected for a lossless TL with an open circuit termination. The TL as well as the adaptor and connectors are imperfect, we need to correct for this by calibrating the VNA.

4) Next, you will set the frequency range over which to measure S_{11} from 2.4 to 2.5 GHz. To set the lower frequency (start of sweep), press [Start] under the "STIMULUS" menu. Then, press [2], [.], [4], and [G/n] under the "ENTRY" menu. To set the upper frequency (end of sweep), press [Stop] under the "STIMULUS" menu. Then, press [2], [.], [5], and [G/n] under the "ENTRY" menu.

5) To collect S_{11} data at equally spaced 0.5 MHz frequencies (both in calibration and for experimental measurements), press [Sweep Setup] under the "STIMULUS" menu. This will activate a softkey menu. Use the mouse to select the **Points** softkey. Then, press [2], [0], [1], and [x1] under the "ENTRY" menu. [Alternate method: use keyboard.] Why? Dividing the 100 MHz frequency range/span by 0.5 MHz gives 200, add 1 to account for starting data point at 2.4 GHz.

6) To reduce the effects of random noise on our calibration and measurements, we will use data averaging (remember the discrete-time N-point Moving Average filter from EE 313?). Press [Avg] under the "RESPONSE" menu to activate a softkey menu. Use the mouse to select the **Avg Factor** softkey. Press [1], [0], and [x1] under the "ENTRY" menu to set N = 10. Next, use the mouse to click the **Averaging** softkey to toggle it from **OFF** to **ON**.

7) To define the calibration kit, press [Cal] in the "RESPONSE" menu, which will activate a softkey menu. Confirm the **Correction** softkey shows **OFF** and the **Set Z0** softkey shows **50 Ω**. If not, use the mouse to fix these settings. To confirm/set the VNA to use the Agilent 85033E 3.5mm Calibration Kit, confirm the **Cal Kit** softkey shows **85033E**. If not, use the mouse to click the **Cal Kit** softkey to activate the drop-down menu and click on **85033E**.

8) Next, select **CALIBRATE** softkey with mouse, which will activate another softkey menu. Using mouse, select **1-Port Cal**, which will activate another softkey menu. Confirm the **Select Port** softkey shows **1**. From the Agilent 85033E 3.5 mm Calibration Kit, take the standard (see Figure 3) with the three female 3.5 mm connectors. Connect the open "O" standard to the 3.5 mm male connector at the end of the coaxial TL by hand to 'finger tight.' Then, use the **5 in-lbs torque wrench** on the coaxial TL SMA connector and a **5/16" open wrench** to support the open standard

to finish tightening, done when torque wrench 'breaks.' Using the mouse, click the **OPEN** softkey. The VNA will beep and place a check mark to the left of the **OPEN** softkey to indicate the data was collected. Using wrenches, disconnect the open "O" standard. Repeat process for the short "S" and load "L" standards. [Note: You may repeat any of these steps, new measurements will overwrite old ones. Further, these measurements can be done in any order.]

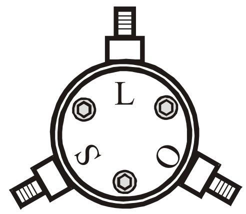

Figure 3 Calibration Standard from Agilent 85033E 3.5 mm Calibration Kit

9) When the VNA detects that you have made measurements for all three standards, the **Done** softkey appears below the softkeys for the standards. Use the mouse to click the **Done** softkey. The VNA will calculate the calibration/error coefficients at each frequency and beep when finished. Use the mouse to click the **Return** softkey (at bottom) twice to go back to the original **CALIBRATE** softkey menu. Confirm the **Correction** softkey now shows **ON.**

10) The VNA is now ready to take measurements. Connect the DUT (a rectangular microstrip patch) provided using a torque wrench and a pliers (mechanical support for end launch SMA connector). Place DUT in a location where it will not be disturbed with ground plane down. The VNA will measure S_{11} for the DUT with the effects of systematic errors removed from the measurements. The VNA can compute and display quantities related to S_{11}. Press Format under the "RESPONSE" menu to bring up the softkey menu with these quantities. Record the top five options in your logbook. Click each of them to observe how the display changes. Before proceeding, use the mouse to select the **Smith** softkey and select the **R+jX** softkey option to return to the Smith chart display option.

11) Draw a block diagram of the test set-up in your logbook and create an 'Equipment List' table. The list should include all relevant equipment information, i.e., description, manufacturer, and model number (sensitive measurements might also include serial numbers).

12) We can use 'Markers' to see values of the selected quantity at specific frequencies. Press Marker under the "MKR/ANALYSIS" menu to bring up the marker softkey menu. By default the **Marker 1** softkey should be selected as indicated by a check mark on the left of the softkey. A display line will appear on the upper lefthand side of the VNA screen showing the quantity value at the low end of the set frequency range, e.g., '1 2.4000000 GHz xxx Ω xxx Ω xxx F or H.' Use the mouse to click the **Marker 2** softkey and move it to 2.45 GHz using the "ENTRY" menu buttons. Use the mouse to click the **Marker 3** softkey and set it to 2.5 GHz using the "ENTRY" menu buttons. [Note: Markers can be cleared/removed using the options brought up by clicking the **Clear Marker Menu** softkey.]

13) Next, we will learn how to save data and screen shot images from the VNA to a USB flash drive. Start by inserting your USB flash drive into one of the two USB ports on the front of the VNA. A flashing icon should appear on the lower left hand side of the screen. Click on this 'Autoplay' icon to activate a pop-up window for 'Removable Drive (F:)' and click on the 'Open folder to view files' option. Select, create, … the folder to which to save your data files like you would on any MS-Windows computer. Then, **minimize** the pop-up (do NOT close).

14) To save a bitmap (*.bmp file format) screen shot image of the Smith chart display, press System under "INSTR STATE" to bring up a softkey menu. Ensure the **Invert Image** softkey is **ON**. Then, click the **Dump Screen Image…** softkey to activate a pop-up 'Save As' window. Ensure it shows 'Removable Drive (F:)' and navigate to desired folder. Use the keyboard to type in a *filename*, e.g., 'Smith_chart_lab_2,' and click **Save** in the lower right hand corner of the pop-up window to save your bitmap screen shot image, e.g., 'Smith_chart_lab_2.bmp,' to your USB flash drive. The VNA will beep when done and you can verify by clicking your minimized 'Removable Drive (F:)' window. Leave room for screen shot in logbook.

15) To save the data (*.csv file format) associated with the Smith chart display, press Save/Recall under "INSTR STATE" to bring up a softkey menu. Click the **Save Trace Data…** softkey to activate a pop-up 'Save As' window. Ensure it shows 'Removable Drive (F:).' Use the keyboard to type in a *filename*, e.g., 'Smith_chart_lab_1,' and click **Save** in the lower right hand corner of the pop-up window to save your data, e.g., 'Smith_chart_lab_1.csv,' to your USB flash drive. The VNA will beep when done and you can verify by clicking your minimized 'Removable Drive (F:)' window. Leave a blank page in logbook for to insert this data.

16) Change the display format to SWR. [Hint: Press Format under the "RESPONSE" menu to bring up the softkey menu with display options.]
    - Adjust the display so that an SWR of 1 is at the bottom and the scale is 0.5/div. [Hint: Press Scale under the "RESPONSE" menu to bring up the softkey menu with options.]
    - Place Marker 1 is at the lowest frequency where SWR = 2. [Hint: Press Marker under the "MKR/ANALYSIS", click **Marker 1** softkey, press Marker Search and explore softkey menu options <u>or</u> use dial on front of VNA.]
    - Place Marker 2 at the frequency where the SWR is lowest.
    - Place Marker 3 at the highest frequency where SWR = 2.
    - Save a screen shot of the SWR display. Leave room for screen shot in logbook.
    - Return to impedance Smith chart display and record impedance for marker 2.

17) Just pull the USB flash drive from the USB port when done. [Note: To power off VNA, follow typical computer procedure, i.e., press Ctrl, Alt, & Delete on keyboard and click red power off icon on lower right hand corner of screen. The instructor/last group will power off the VNA.]

Post Lab

1) Print out bitmap screen shot images of the Smith chart and SWR displays and put in logbook in saved places. [Suggestions: Use a photo/image editing program to **invert** colors to save ink. Insert both images on a single MS-Word document page to control size and save paper.]

2) Print out data from *.csv data file (Header plus data to whatever frequency will fit on a single page). Put in logbook on saved page. [Hint: You can open *.csv files using MS-Excel or Notepad.]

3) Import data into a plotting software package (e.g., MS-Excel, MATLAB, …) and create rectangular plots of resistance versus frequency (R vs f) and reactance versus frequency (X vs f). Insert these plots in the logbook. What is the resistance and reactance at the frequency where the SWR is lowest?

Turn-in one (1) logbook per group at class on Monday 2/10/2025.