Objective:

In this exercise you will investigate the swept frequency network analyzer measurement, including impedance, return loss, and gain. You will measure transmission line terminations and other devices.

Introduction:

Network analyzer swept-frequency measurement techniques use s-parameters to characterize linear networks. These parameters are measured at the device under test's (DUT) terminals (ports) without regard to the contents of the networks. Once the parameters are determined, the network's behavior in any external environment can be predicted. S-parameters are used in microwave design because they are easier to measure and work with than other kinds of parameters. Recall that open and short circuits were used in h-, y-, and z-parameter measurements. These impedances are difficult to achieve at RF frequencies, but real (purely resistive) impedances can be realized quite easily. The figure below shows the quantities associated with linear two-port networks.

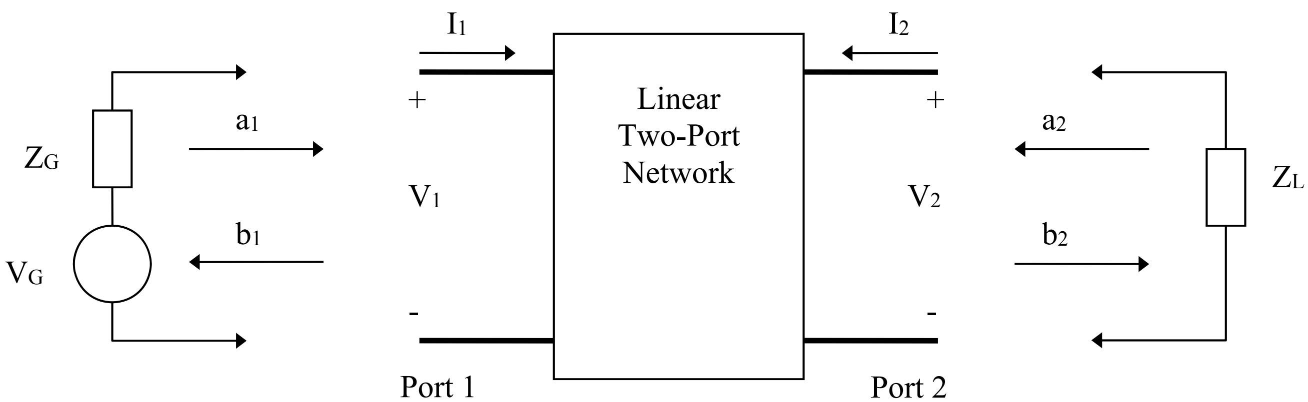

Figure 1. Linear two-port network and the associated input and output quantities.

If the characteristic impedance (Z_0) is real and positive, the following expressions can be written for the normalized incident and reflected waves seen at the input and output ports.

$$a_1 = \frac{V_{i1}}{Z_0} \quad a_2 = \frac{V_{i2}}{Z_0}$$
$$b_1 = \frac{V_{r1}}{Z_0} \quad b_2 = \frac{V_{r2}}{Z_0} \tag{2}$$

The linear equations describing the network are then:

$$b_1 = s_{11}a_1 + s_{12}a_2$$
$$b_2 = s_{21}a_1 + s_{22}a_2 \tag{3}$$

where the S-parameters are :

$s_{11}= b_1/a_1$ ($a_2 = 0$) [input reflection coefficient with the output terminated with matched impedance]
$s_{22}= b_2/a_2$ ($a_1 = 0$) [output reflection coefficient with the input terminated with matched impedance]
$s_{21}= b_2/a_1$ ($a_2 = 0$) [forward insertion gain with the output terminated with matched impedance]
$s_{12}= b_1/a_2$ ($a_1 = 0$) [reverse insertion gain with the input terminated with matched impedance]

The S-parameters can easily be related to power gain and mismatch loss, most often the quantities of interest in RF measurements.

$|s_{11}|^2$ = Power reflected from input / Power incident at input
$|s_{21}|^2$ = Power delivered to Z_0 load / Power available from Z_0 source = Device's power gain or loss

In this lab exercise, you will be looking at the s_{11} (return loss) and the s_{21} (forward power gain) parameters.

Instrumentation:

Agilent 8714ES RF Network Analyzer
Open Circuit, 50 Ω, and other coaxial terminations
Short section of 50 Ω coaxial cable
Assorted coaxial adapters

PROCEDURE: Perform the following tasks. Instructions for the **8714ES** network analyzer are included.

1. Set up the **8714ES** network analyzer for coaxial termination $\mathbf{S_{11}}$ measurements:

- **i.** Power on the network analyzer and wait for it to finish booting.
- **ii.** Under MEAS, press **MEAS 1** > **S11**. (choose S11 from the on-screen menu)
- **iii.** Under CONFIGURE, press **FORMAT** > **Smith Chart**.
- **iv.** Under SOURCE, press **FREQ** > **Stop** and set the stop frequency to **3 GHz**. Then select **Start** and set the start frequency to **300 kHz**.
- **v.** Under SOURCE, press **POWER** > **LEVEL** and set the level to **0 dBm**. Set the RF to on.
- **vi.** Under SOURCE, press **Menu** > **Number of Points** and select **801**.
- **vii.** You will now perform an open circuit response calibration, which for this analyzer will be a normalization. Connect the **Type-N Male to BNC Female adapter** to Port 1.

  Under CONFIGURE, press **DISPLAY** > **Normalize**. The trace should collapse to a dot on the right side of the Smith chart at Z = ∞Ω, where an open circuit should be.

2. Perform the following coaxial termination $\mathbf{S_{11}}$ measurements:

- **a.** Connect a BNC **50Ω** load to Port 1. A perfect 50Ω load should result in the entire sweep collapsed in a dot in the center of the Smith chart. Your load will not create such a display.

  Calculate the theoretical **reflection coefficient magnitude** and **VSWR** for an **ideal 50Ω load**.

  $|\Gamma_R|$: ________________ VSWR: ____________

b. Under CONFIGURE, press **MARKER** and use a marker to locate the **frequencies** at which the curve is closest to and farthest from the center of the chart (50Ω) and the **impedances** at these frequencies. Calculate the **reflection coefficient magnitudes** and **VSWRs** based on the measured impedances. Note that Z_o = 50Ω.

Closest to 50Ω: Frequency: ____________ Impedance: ____________________

(calc)➔ $|\Gamma_R|$: ________________ VSWR: ____________

Furthest from 50Ω: Frequency: ____________ Impedance: ____________________

(calc)➔ $|\Gamma_R|$: ________________ VSWR: ____________

c. Under the CONFIGURE buttons, press **FORMAT** > Lin. Mag. to change the Format to magnitude of reflection coefficient.

Determine the $|\Gamma_R|$ at the frequency where the load is closest to 50Ω and the $|\Gamma_R|$ at the frequency where the load is furthest from 50Ω. Compare these values to the ones determined in step 2b.

Closest to 50Ω: $|\Gamma_R|$: ____________

Furthest from 50Ω: $|\Gamma_R|$: ____________

d. Now, under the CONFIGURE buttons, press **FORMAT** > SWR to change the Format to SWR.

Determine the **VSWR** at the frequency where the load is closest to 50Ω and the VSWR at the frequency where the load is furthest from 50Ω. Compare these values to the ones determined in step 2b.

Closest to 50Ω: VSWR: ____________

Furthest from 50Ω: VSWR: ____________

3. Change the FORMAT back to **Smith Chart** and replace the 50Ω load with the **200Ω** load provided by the instructor.

a. Calculate the theoretical **reflection coefficient magnitude** and **VSWR** for an **ideal 200Ω load**.

$|\Gamma_R|$: ________________ VSWR: ____________

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b. Under CONFIGURE, press **MARKER** and use a marker to locate the **frequencies** at which the curve is closest to and farthest from the center of the chart (200Ω) and the **impedances** at these frequencies. Calculate the **reflection coefficient magnitudes** and **VSWRs** based on the measured impedances. Note that Z_o = 50Ω.

Closest to 200Ω: Frequency: ____________ Impedance: ____________________

(calc)➔ $|\Gamma_R|$: ________________ VSWR: ____________

Furthest from 200Ω: Frequency: ____________ Impedance: ____________________

(calc)➔ $|\Gamma_R|$: ________________ VSWR: ____________

c. Under the CONFIGURE buttons, press **FORMAT** > Lin. Mag. to change the Format to magnitude of reflection coefficient.

Determine the **$|\Gamma_R|$** at the frequency where the load is closest to 200Ω and the **$|\Gamma_R|$** at the frequency where the load is furthest from 50Ω. Compare these values to the ones determined in step 2b.

Closest to 50Ω: $|\Gamma_R|$: ____________

Furthest from 50Ω: $|\Gamma_R|$: ____________

d. Now, under the CONFIGURE buttons, press **FORMAT** > SWR to change the Format to SWR.

Determine the **VSWR** at the frequency where the load is closest to 200Ω and the VSWR at the frequency where the load is furthest from 200Ω. Compare these values to the ones determined in step 3b.

Closest to 50Ω: VSWR: ____________

Furthest from 50Ω: VSWR: ____________

4. Remove both the **200Ω** load and the **Type-N Male to BNC Female adapter** from Port 1 and change the FORMAT back to **Smith Chart**.

Under CONFIGURE, press **DISPLAY** > **Normalize**. The trace should collapse to a dot on the right side of the Smith chart at Z = ∞Ω, where an open circuit should be.

Place a "high quality" **Type-N 50Ω load** on port 1 and compare the results to those in Step 2.

5. Configure the **8714ES** network analyzer for forward insertion gain **S_{21}** measurements:

a. After the system boots up, under **CONFIGURE** press **FORMAT** and select **Log Mag** if not already selected.

b. Under **MEAS** press **MEAS 1** and select **S21 Fwd Trans**.

c. Under **SOURCE** press **FREQ**, select **Start** and set the start frequency to 100 MHz, then select **Stop** and set the frequency to 1600 MHz.

4. Perform the following forward insertion gain S_{21} measurements:

a. Interconnect **PORT 1** to **PORT 2** with the calibration cable provided with the network analyzer. If no calibration cable is available, utilize a short piece of RG 58/U cable.

b. To perform meaningful measurements, the instrumentation must first be calibrated. Under **CONFIGURE**, press **DISPLAY** and select **NORMALIZE** to calibrate the system. The forward transmission loss should be 0 dB across the frequency range. If not, press **Normalize** again. You may have to change the reference level to 0 dB to get accurate results. Move the cable gently with your hand. Notice that simply moving the cable around affects the forward power.

c. Disconnect the calibration cable from **PORT 2.** Place the ***5-meter section of RG 58/U*** cable that was used during experiment 1 between the calibration cable and Port 2 using adapters as needed.

d. Under **CONFIGURE** press **SCALE** and select **Autoscale**.

e. Under **CONFIGURE** press **MARKER** and select **MKR 1>**. Using the dial (or the keypad) to adjust the frequency of marker 1, determine the attenuation in the cable at frequencies ranging from 100 MHz to 1600 MHz in 100 MHz intervals. Note that the attenuation in the cable is the negative of the Fwd Trans coefficient as shown on the display. Record the attenuation values.

f. Replace the 5-meter cable with the ***long section of RG 58/U*** (>100 feet long) that was used during experiment 1.

g. Under **CONFIGURE** press **SCALE** and select **Autoscale**.

h. Under **CONFIGURE** press **MARKER** and select **MKR 1>**. Determine the attenuation in the cable at frequencies ranging from 100 MHz to 1600 MHz in 100 MHz intervals. Note that the attenuation in the cable is the negative of the Fwd Trans coefficient as shown on the display. Record the attenuation values.

i. Remove the test cable from the analyzer, place the protective caps on the ports, and turn the analyzer **OFF**.