VNA calibration and measurements

EERF – 6396

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1. Introduction

Objectives:

a. Learn and perform calibration of the VNA and take vector impedance measurements.
b. Measure the s-parameters of 1-port, 2-port and 3-port devices respectively using the calibrated VNA.

Apparatus:

a. Agilent E5071C Network Analyzer (100KHz → 8.5GHz)
b. Calibration Kit
c. Dipole Antenna, one port, two ports and three ports networks

2. Pre-Lab Discussion

1) The basics of VNA working have been studied
2) SOLT method of VNA calibration and have been studied

3. Procedure

- **1 – port Calibration of VNA**
  1. Use grounded wrist straps while working with VNA to avoid ESD damage to the instrument. Make proper connections to the VNA and test equipment, calibration kit using torque wrench
  2. Set frequency range from 0.01 – 8.5 GHz with 401 measurement points
  3. Calibrate the port using Short, Open, Load combination using the 3.5 mm calibration kit
  4. Verify the correctness of the calibration by checking the Return Loss > 40 dB when the matched load is used and a return loss of 0 dB (+/- 0.2 dB) for a short circuit termination

- **Dipole Antenna**
  1. Connect the designed dipole antenna to the VNA and observe its s11 plot
  2. Determine its resonant frequency and compare to design value

- **1 – port Network Measurement**
  1. Connect the 1-port RF component to the end of VNA cable and record its s11 in dB
  2. Take reading while shorting the other end
  3. Take reading while connecting the other end to a 50 Ω termination
  4. Save measurements in s1p format

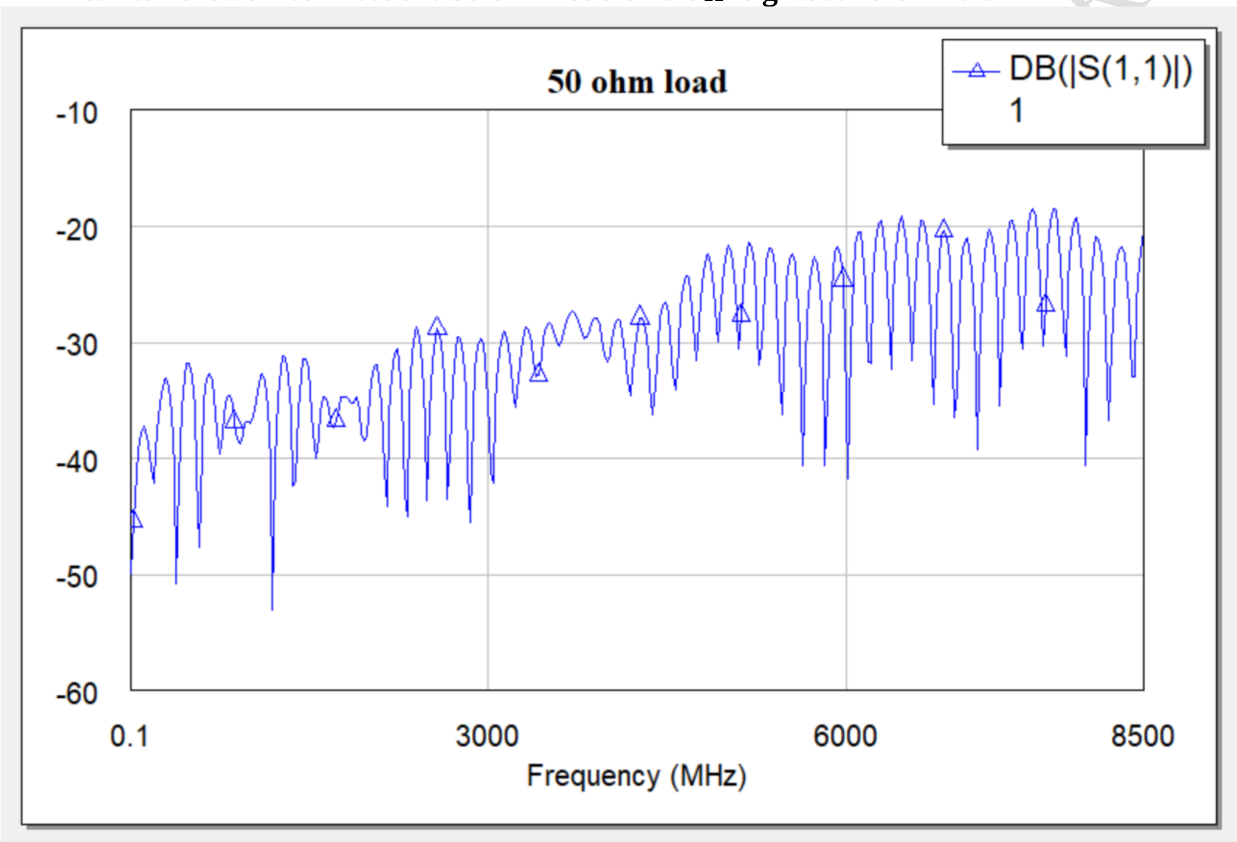
- **2 – port Calibration of VNA**
  1. Press 'CAL' button on VNA
  2. Select 2 Port Calibration
  3. Follow the Short, Open, Load and Through for 2 port calibration

- **2 – port Network Measurements**
  1. Connect the 2-port device between port 1 and 2 of the VNA and record the s-parameters
  2. Save the reading in s2p file format

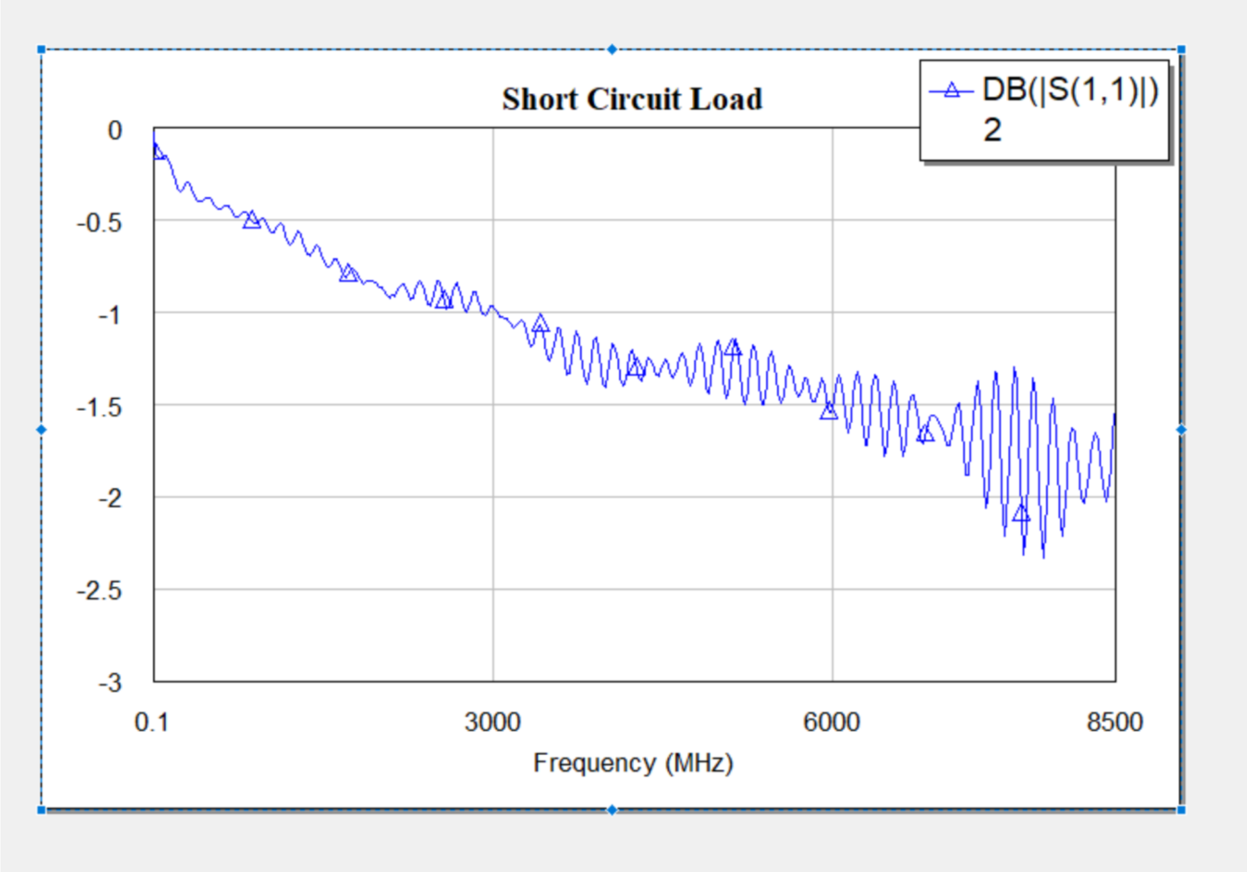
- **3 – port Network Measurements**
  1. Connect Ports 1 and 2 of the 3-port network to their respective port cables in the VNA and terminate port 3 in Z_0. The parameters measured are $s_{11}, s_{12}, s_{21}, s_{22}$
  2. Connect ports 2 and 3 of the 3-port network to the VNA and terminate port 1 in Z_0. The parameters measured are s_{23}, s_{32}
  3. Connect ports 1 and 3 of the 3-port network to the VNA and terminate port 2 in Z_0. The measured parameters are s_{31}, s_{13}, s_{33}

4. Analysis

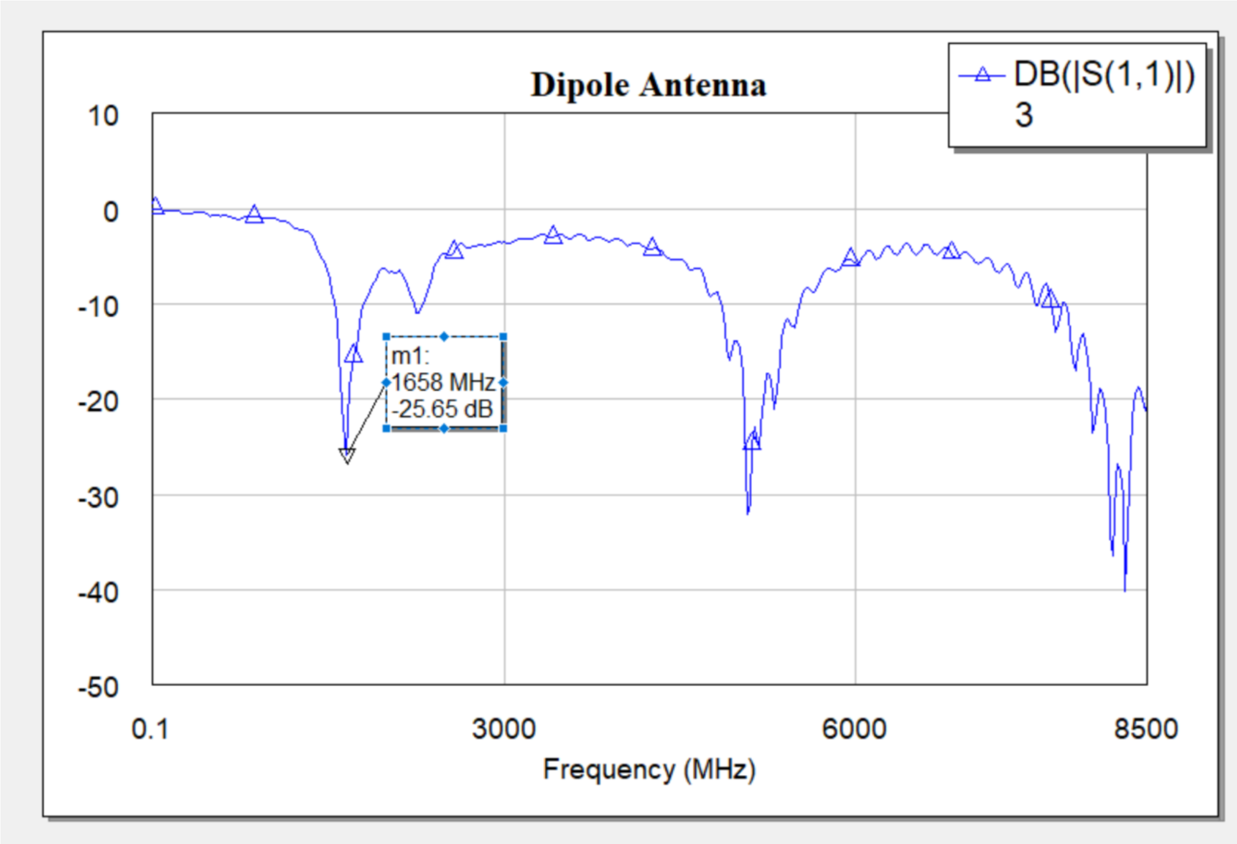
- **After calibration connect the 50 ohm load and S_{11} is greater than 40 dB**



- **After calibration connect short circuit load and S_{11} is close to 0 dB**

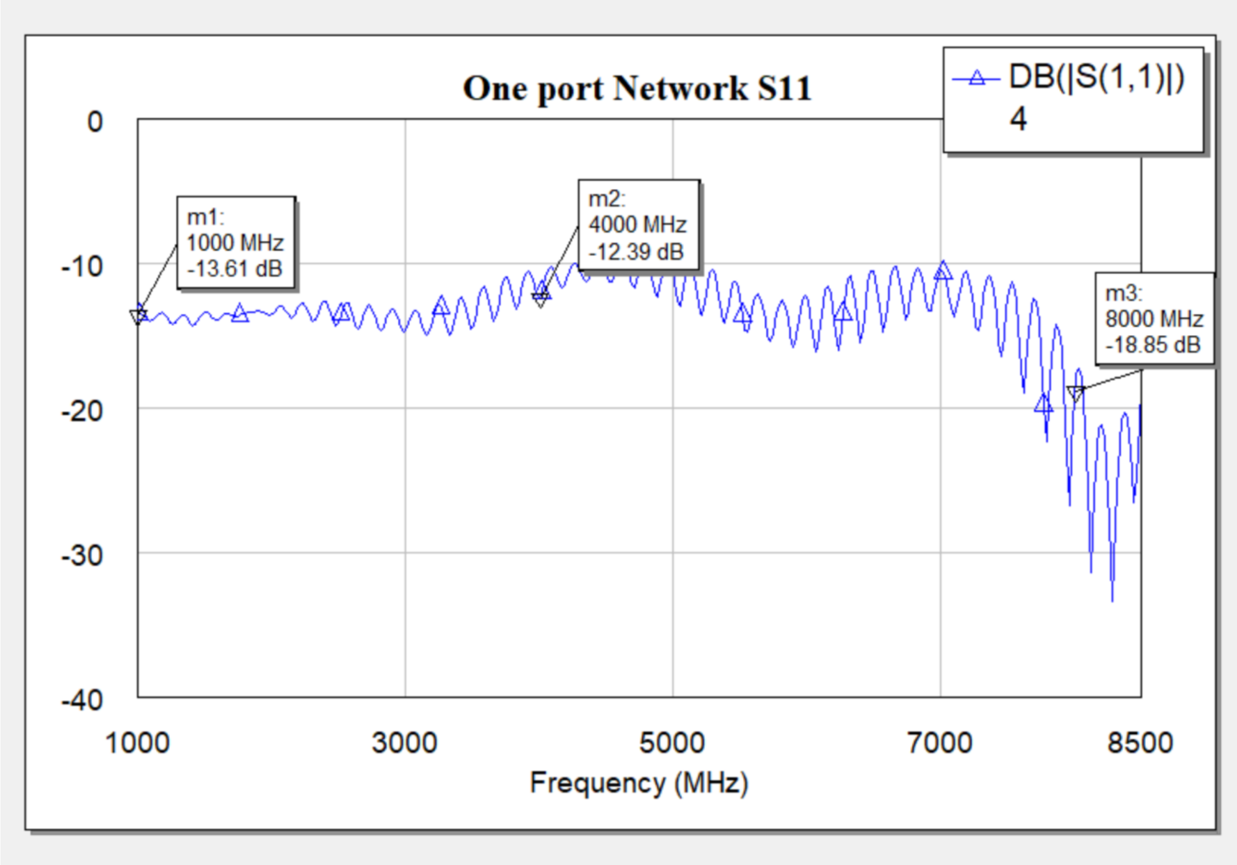


- **Dipole antenna measurements**

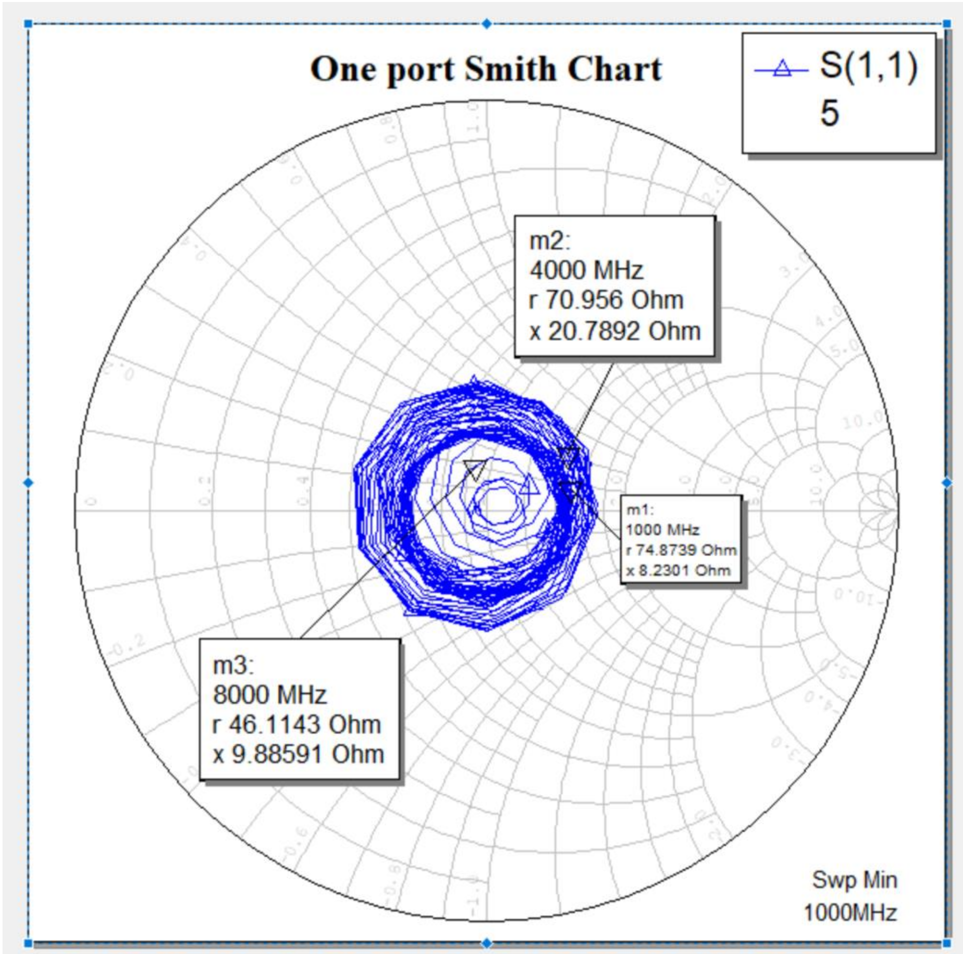


The observed resonant frequency of the dipole antenna is 1658 MHz while the actual frequency should be 1710 MHz. Which is -3% from the ideal value. This observation can be reasoned by fringing fields at the end of the dipole antenna which increase the effective length which in-turn increases the wavelength. This increased wavelength leads to lesser resonating frequency.
Accordingly, to have the resonating frequency exactly at 1710 MHz we should take into consideration of these parameters and reduce the length of the dipole antenna.

- **One Port Network Measurements**
  The given 1 port component is a 6 dB attenuator

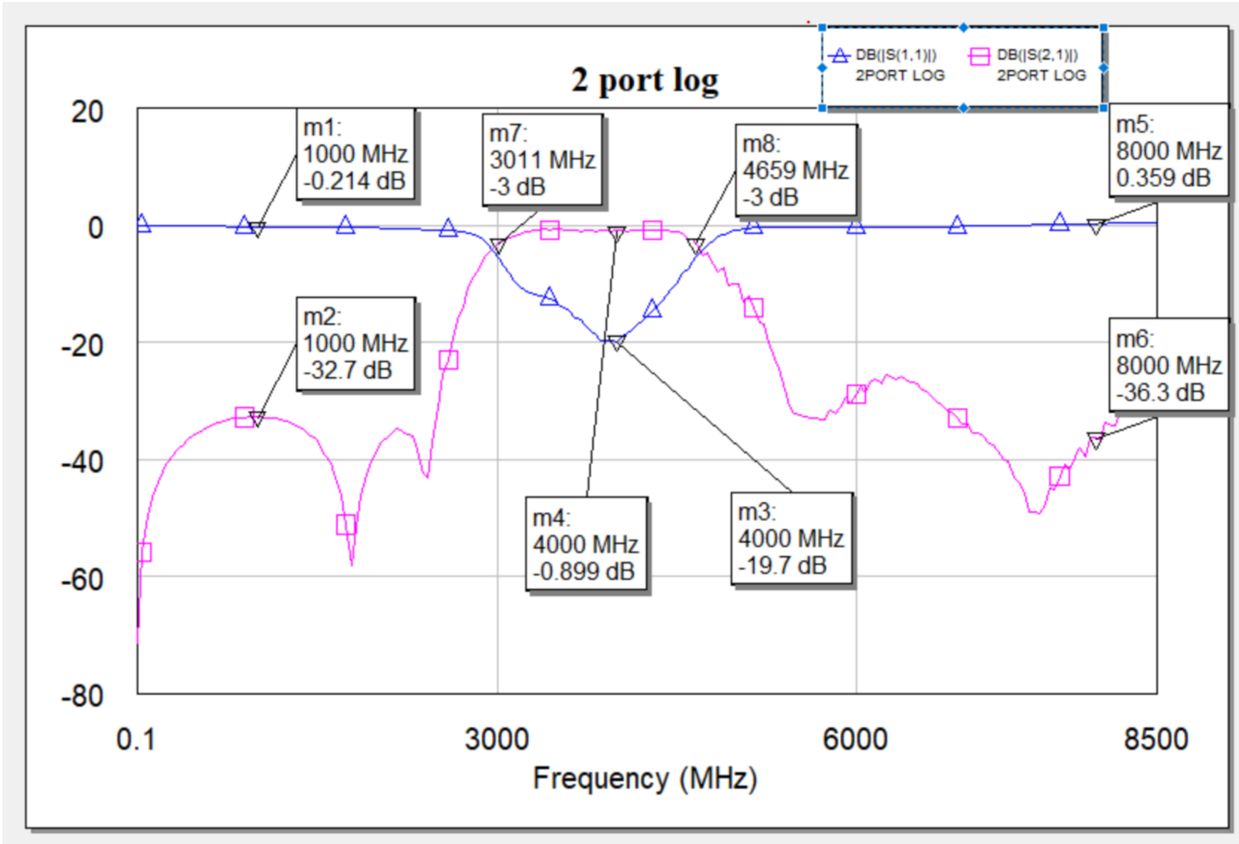


Frequency (GHz)	Attenuation (dB)
1	-13.61
4	-12.39
8	-18.85



Frequency (GHz)	Input Impedances (ohm)
1	74.78+j8.23
4	70.95+j20.98
8	46.11+j9.88

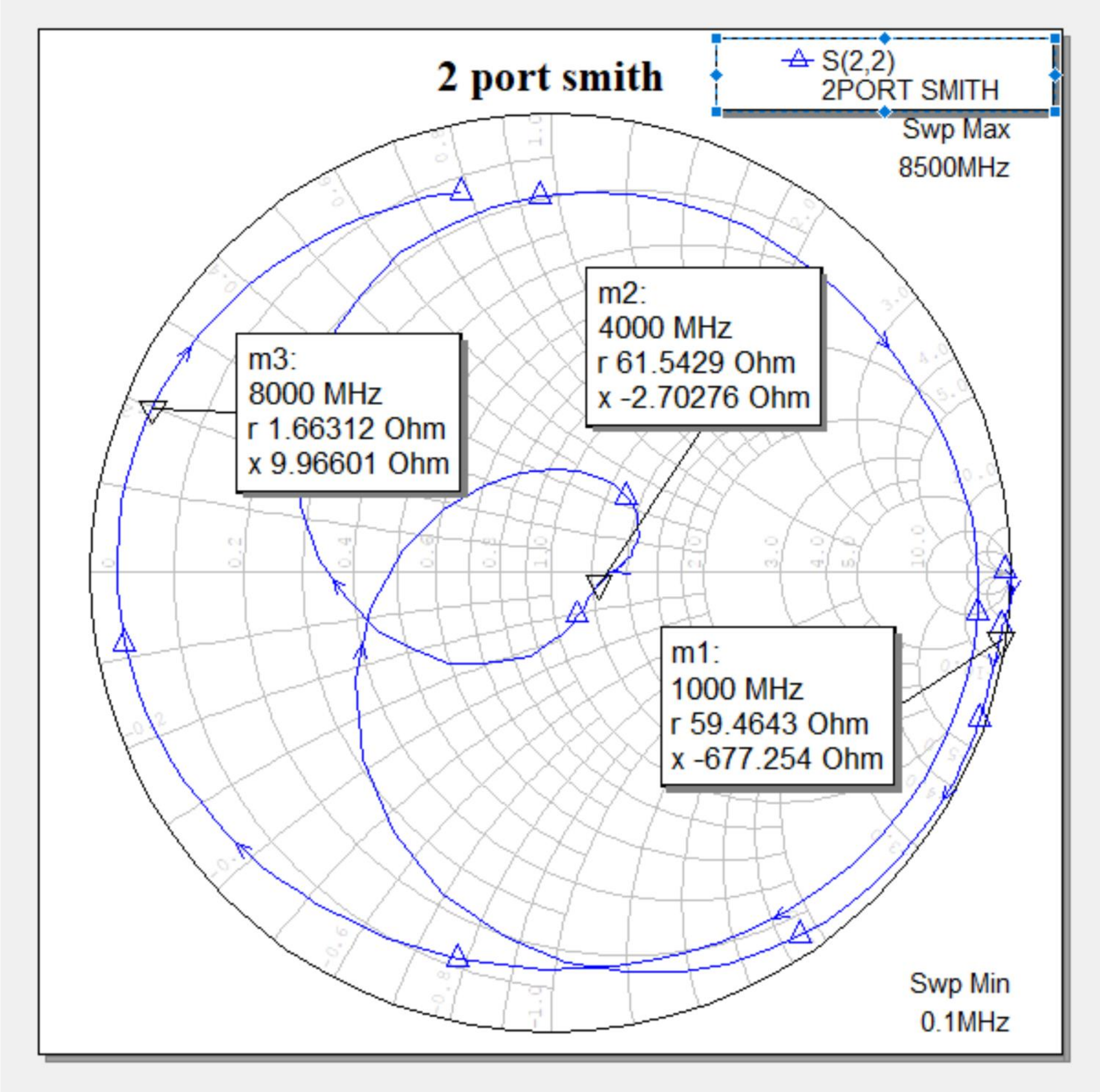
- **Two Port Network Measurements**
  The component is a band pass filter



The cut-off frequencies are

fc1	3.01GHz
fc2	4.659GHz

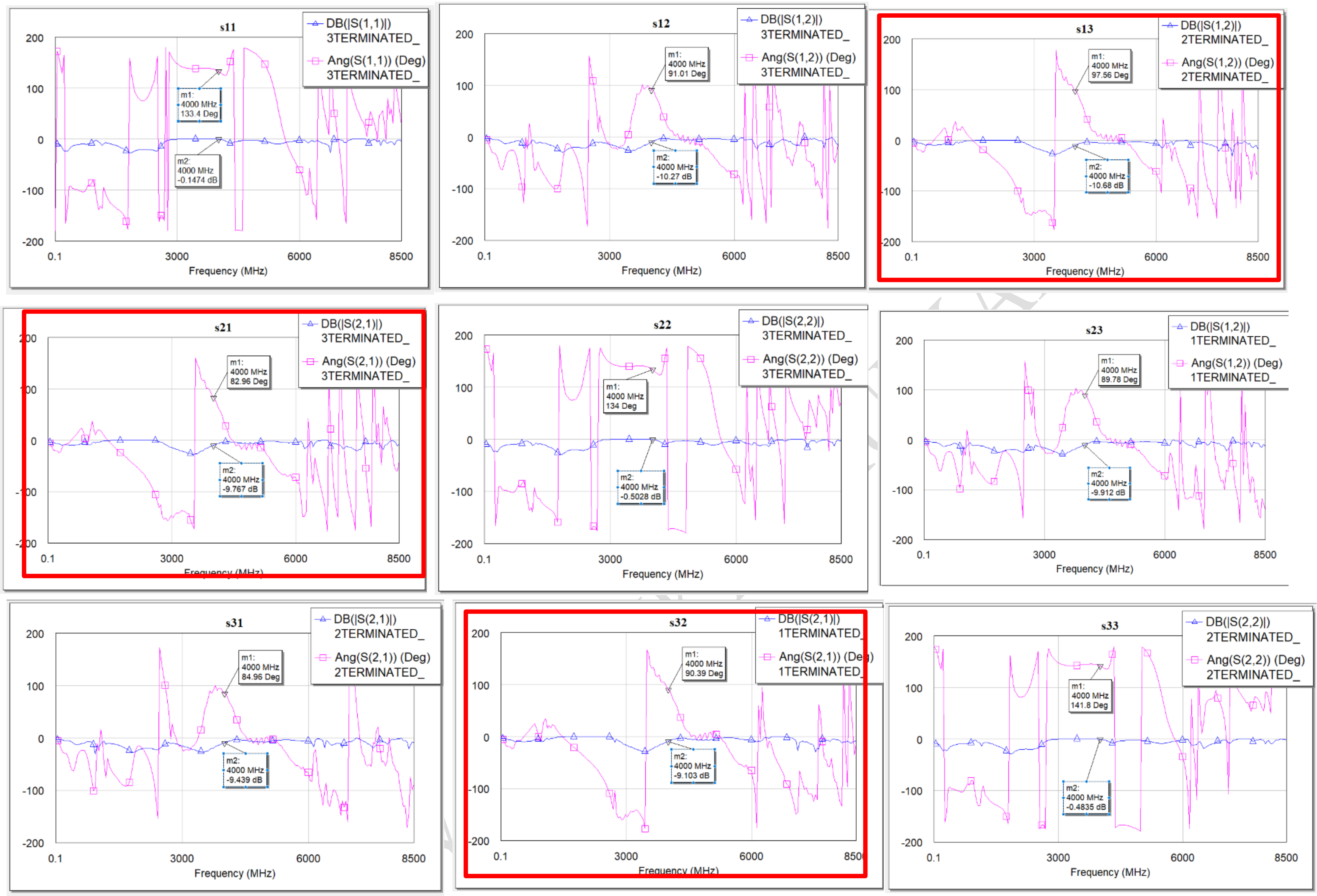
Bandwidth = 1.648GHz



Output Impedance Measurements:

Frequency (GHz)	Impedance (ohm)
1	59.46 – j677.25
4	61.54 – j2.70
8	1.66 + j9.96

3 Port parameters: Representing S parameters graphs in matrix format for easy visualization

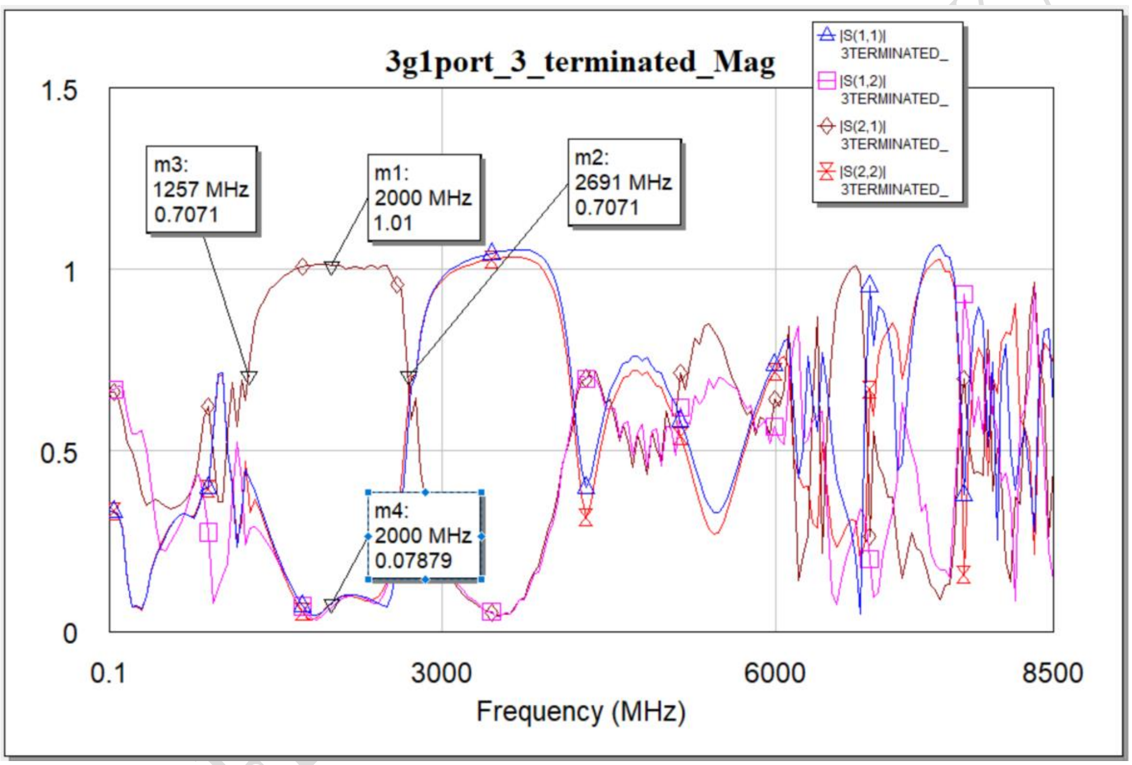


Constructing S parameter matrix from above data at 4 GHz:

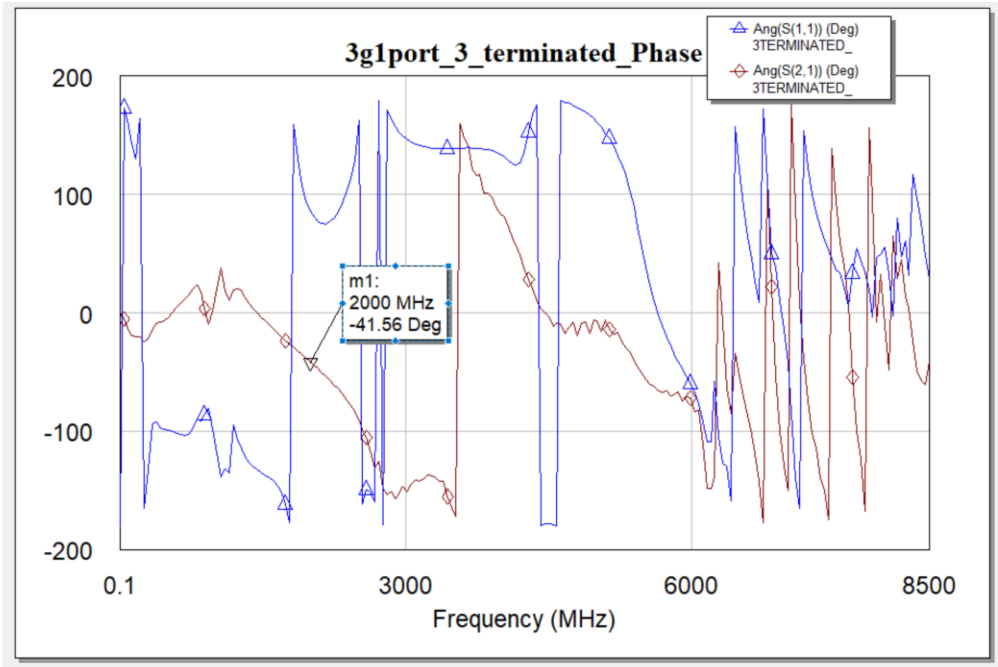
$$\begin{matrix} S11 & S12 & S13 \\ S21 & S22 & S23 \\ S32 & S32 & S33 \end{matrix} = \begin{matrix} 0.98\measuredangle 133.4 & 0.31\measuredangle 91.01 & 0.29\measuredangle 97.56 \\ 0.32\measuredangle 82.96 & 0.94\measuredangle 134 & 0.10\measuredangle 89.78 \\ 0.33\measuredangle 84.96 & 0.35\measuredangle 90.39 & 0.95\measuredangle 141.8 \end{matrix}$$

The given device is a circulator with operating frequency range of 1.7 to 2.4 GHz. Hence, plotting the S-parameters at 4GHz won't describe its properties correctly. The following help understand the device characteristics. **The following show the properties over its intended frequency usage.**

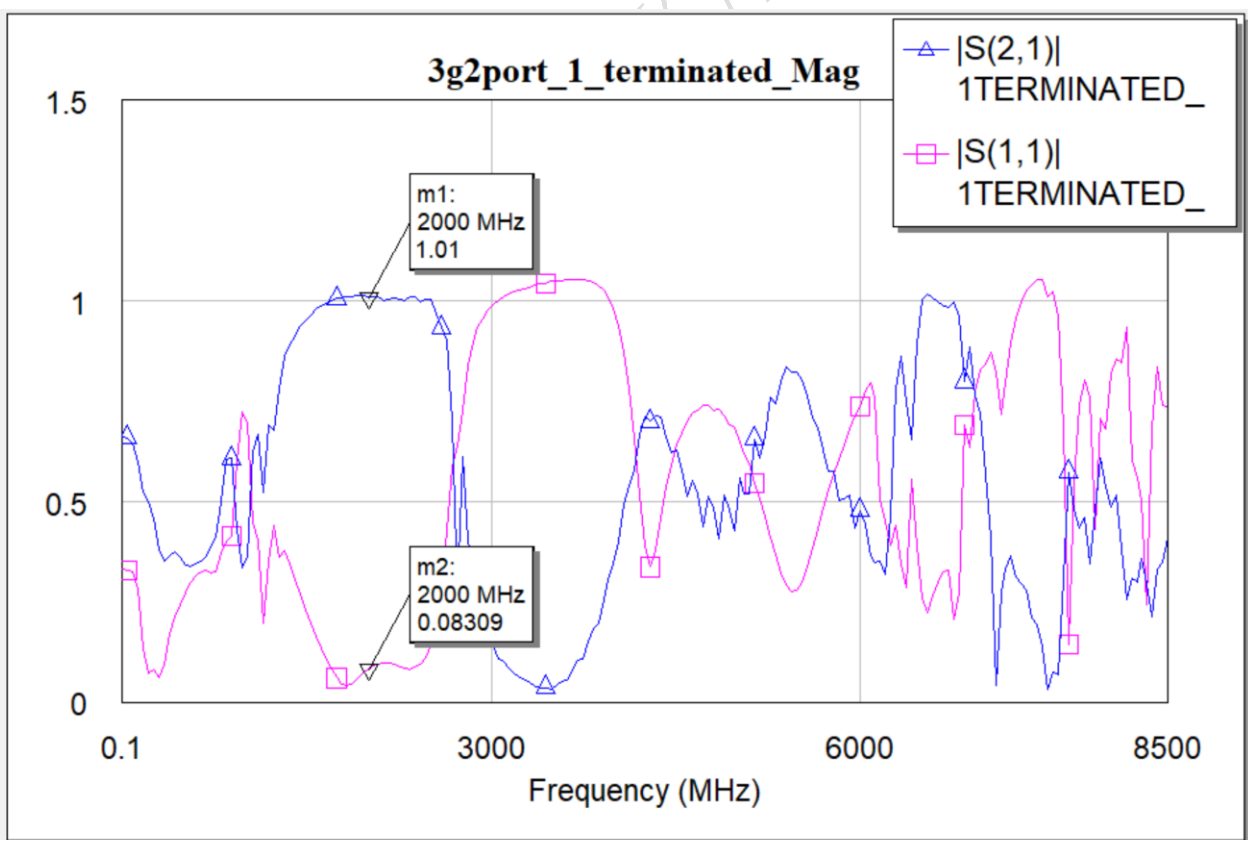
- Magnitude when terminal 3 is terminated in Z_0



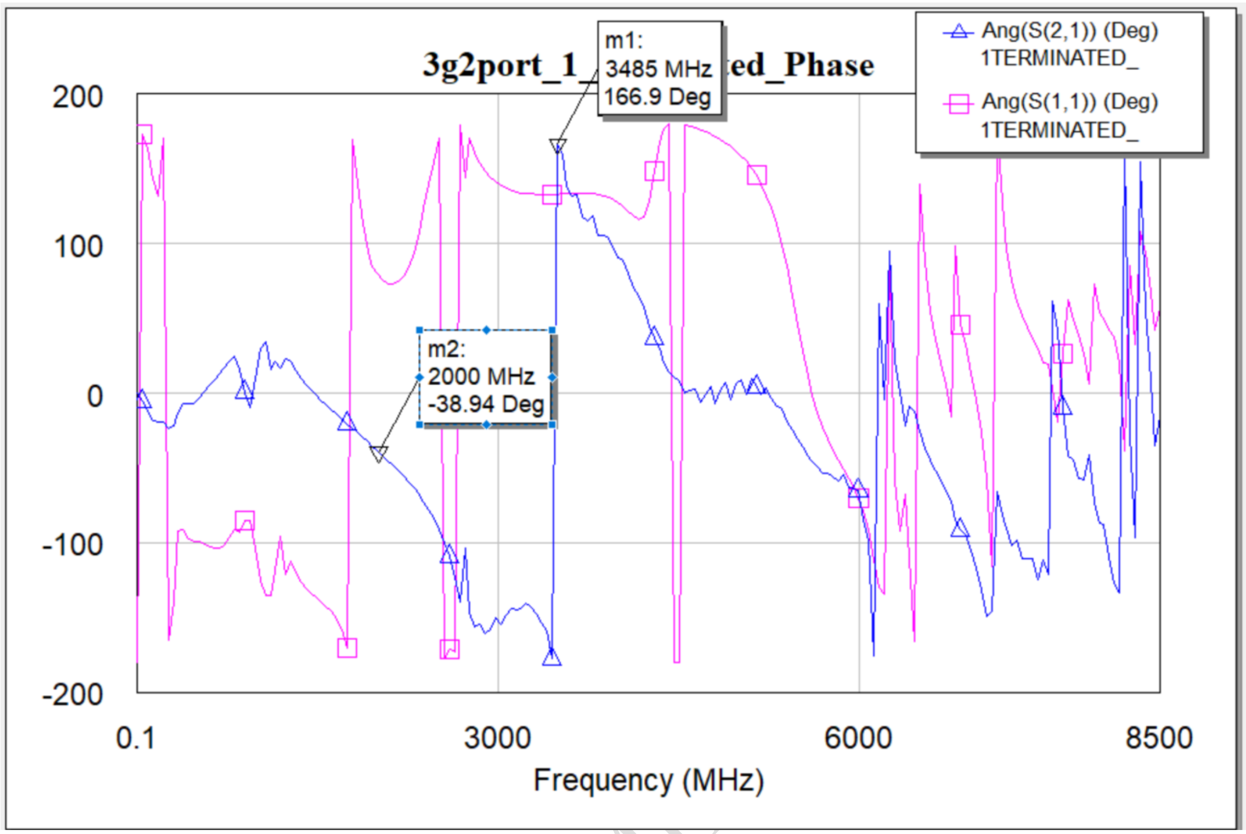
- Phase when terminal 3 is terminated in Z_0



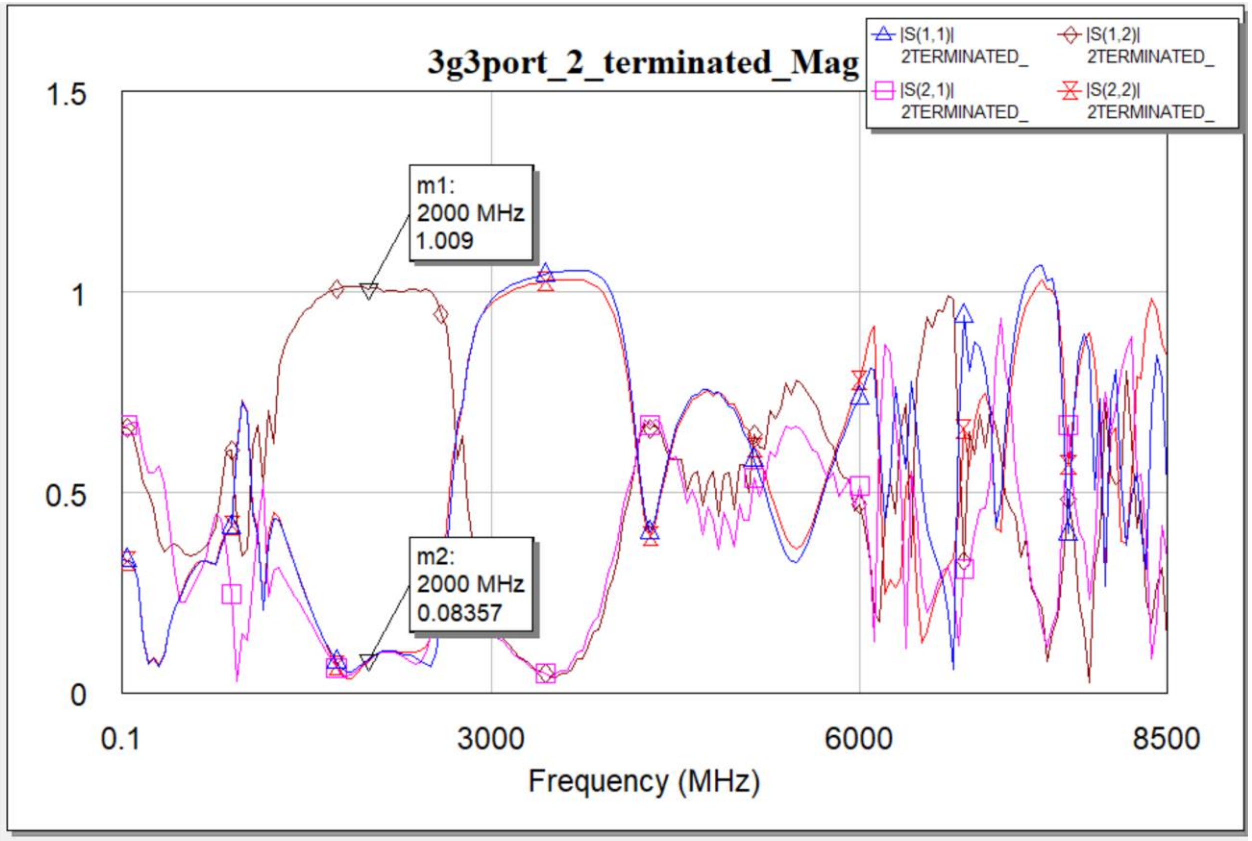
- Magnitude when terminal 1 is terminated in Z_0



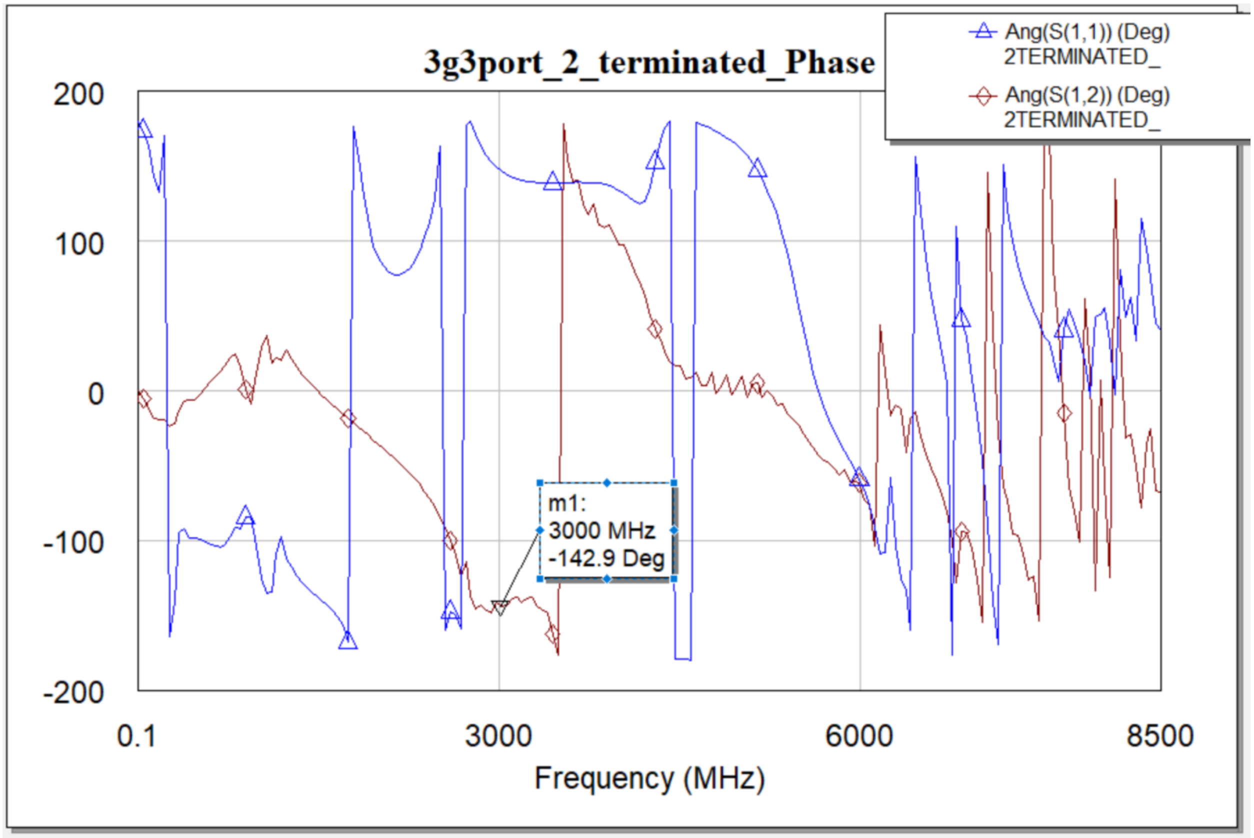
- Phase when terminal 1 is terminated in Z_0



- Magnitude when terminal 2 is terminated in Z_0



- Phase when terminal 2 is terminated in Z_0



Summary:

- Give a brief summary of how a vector network analyzer works.

The VNA is a RF test device that measures **Magnitude and Phase** of RF components, devices, circuits and sub components. It has transmitter as well as receiver block inbuilt as opposed to a spectrum analyzer which only has a receiver block. This means VNA is mainly used to measure known signal sent by its transmitter circuit. VNA measures S parameters which are easy to interpret and have practical application. VNA are particularly useful to optimize the circuit parameters.

One of the most fundamental concepts of high-frequency network analysis involves incident, reflected and transmitted waves travelling along transmission lines. It is helpful to think of travelling waves along a transmission line in terms of a light-wave analogy. We can imagine incident light striking some optical component like a clear lens. Some of the light is reflected off the surface of the lens, but most of the light continues on through the lens. If the lens were made of some lossy material, then a portion of the light could be absorbed within the lens. If the lens had mirrored surfaces, then most of the light would be reflected and little or none would be transmitted through the lens. This concept is valid for RF signals as well, except the electromagnetic energy is in the RF range instead of the optical range, and our components and circuits are electrical devices and networks instead of lenses and mirrors. Network analysis is concerned with the accurate measurement of the ratios of the reflected signal to the incident signal, and the transmitted signal to the incident signal. [1]

[1] Agilent Network Analyser basics Manual

- Summarize your measurements. What RF principles did you use to determine what your "unknown" components were? Were your measurements reasonable, and did they make sense? What did you observe about the measured performance of each of the components over frequency?

The given 1 port device is a 6-dB attenuator. The graph shows S11 of around -12 dB when left open circuited.
The two-port device test is a band pass filter with a measured bandwidth of 1.648GHz and cut-off frequencies of 3.01 GHz to 4.659GHz.
The three port device is a circulator that allows power flow in from port 1 to 2. Port 2 to 3 and from port 3 to 1 but not other way round which is evident from the S_{13} S_{21} S_{32} parameters. These values at 2GHz are close to 1. The other values are near to zero. The measurements are close to the ideal circulator S parameter matrix which is:

$$\begin{matrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{matrix}$$

The concept used to measure the parameters were S parameters and return loss. As the frequency increased the conductor and dielectric loss increased which decreased the return loss. The measured parameters were within reasonable limit.

- Summarize lessons learned.

The most important lesson learnt was that calibrating the VNA properly is of utmost importance. The noise floor and other disturbances affect the quality of measurements. Using a torque wrench at the connectors help to increase the quality of measurements.

Conclusion:

The calibrating of VNA has been done and the s parameter readings have been taken for the given 1, 2 and 3 port devices.