VNA calibration and measurements

Microwave Design and Measurements (EERF 6396)
Prof. Dr. Randall E. Lehmann
The University of Texas at Dallas

Submitted By

Niyati Sanandiya
(2021317640)

1. Introduction

- Perform calibration of VNA and take vector impedance measurements.
- Measure s-parameters of unknown 1-port, 2-port, 3-port DUT and analyze their properties.

- The following equipment were used to perform the experiments:

a. Agilent Network Analyzer E5071C (100kHz to 8.5 GHz)
b. Calibration kit
c. 3.5 mm RF connectors
d. Dipole Antenna
e. 1 port DUT
f. 2 port DUT
g. 3 port DUT

2. Pre-lab discussion

- The basics of Vector Network Analyser were studied to get familiar with the operation of VNA and SOLT calibration methods.
- Calibration methods along with careful procedures for handling the VNA were studied.
- Emphasis on various types of errors that would occur in the absence of calibration.
- Study of proper handling and care for connectors.

3. Procedure

- The VNA was turned on and warmed up for about 10 minutes and the ESD strap was worn before conduction of any measurement or calibration.

1. 1-port Calibration:

- Set frequency range from 100 KHz to 8.5 GHz with 401 measurement points.
- Make proper connections to VNA, test equipment and calibration kit using torque wrench.
- Perform calibration using an S-O-L mechanical device from the 3.5mm calibration kit in the order: Short, Open and Load. After this, select "Done" on the "Cal" section.
- Measure Return Loss (in dB) on VNA while the port is terminated with the 50 Ω Load end of the S-O-L mechanical device. Verify RL (in dB) reading to be > 50 dB to ensure accuracy of calibration.
- Measure Return Loss (in dB) on VNA while the port is terminated with short circuit end of the S-O-L mechanical device. Verify RL (in dB) reading to be 0 dB (+/-0.2dB) to ensure accuracy of calibration.

2. Dipole Antenna:

- Design λ/2 Dipole antenna by soldering one wire (λ/4) to the center pin of the SMA connector and the second wire ((λ/4) to the ground plate of the connector.
- Connect dipole antenna to VNA and record the S11 plot readings.
- Observe its resonant frequency value and compare with design frequency.

3. 1 Port DUT:

- Connect the 1-port device to the VNA and take S11 measurements with and without 50-ohm termination load.
- Save the measurement plot in s1p format file.

4. 2-Port Calibration:

- Select 2-port calibration on VNA using 'Cal' button..
- Perform calibration of second port with open, short and load S-O-L end of mechanical device.
- Perform the "port-thru-port" calibration of the VNA using N-type connector between the ports 1 & 2. This calibrates any connection between ports 1 & 2.
- RL data (in dB) reading was verified to be > 50 dB for 50 ohm load, which shows that the calibration was satisfactory.

5. 2 Port DUT:

- Connect the 2 port RF component between port 1 and port 2 of VNA and take S11, S12, S21, S22 measurements.
- Save measurements plot in s2p format file.

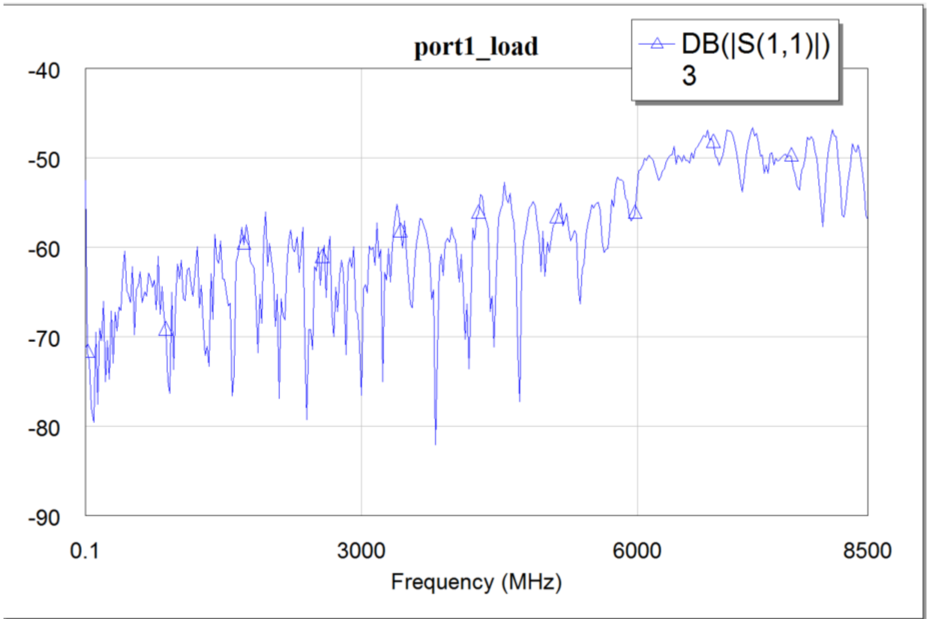
6. 3 Port DUT:

- Connect port-1 and port-2 of the 3-port device to the respective port cables in VNA and terminate the third port with 50-ohm load. Take S11, S22, S12, S21 measurements.
- Connect port-2 and port-3 of the 3-port device to the respective port cables in VNA and terminate the third port with 50-ohm load. Take S23, S32 measurements.
- Connect port-1 and port-3 of the 3-port device to the respective port cables in VNA and terminate the third port with 50-ohm load. Take S31, S13, S33 measurements.
- Save the measurements in '. S2P' file format for analysis.

4. Data and Analysis

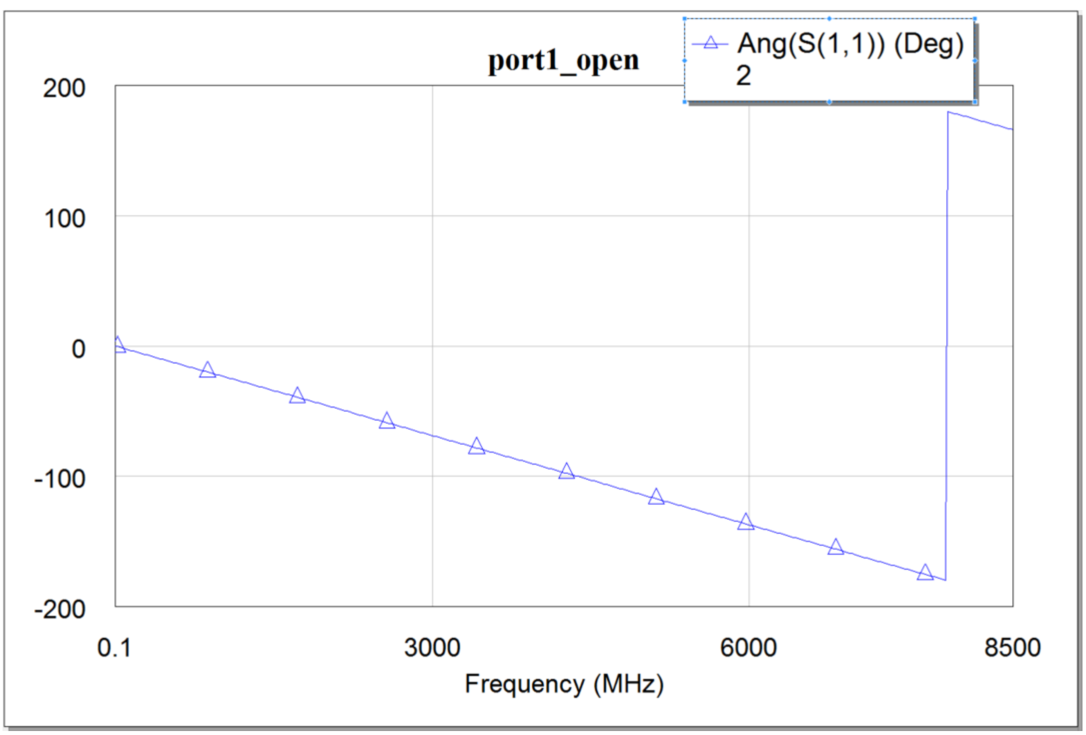
1. 1-port Calibration

1) After calibration when terminated with 50-ohm load:

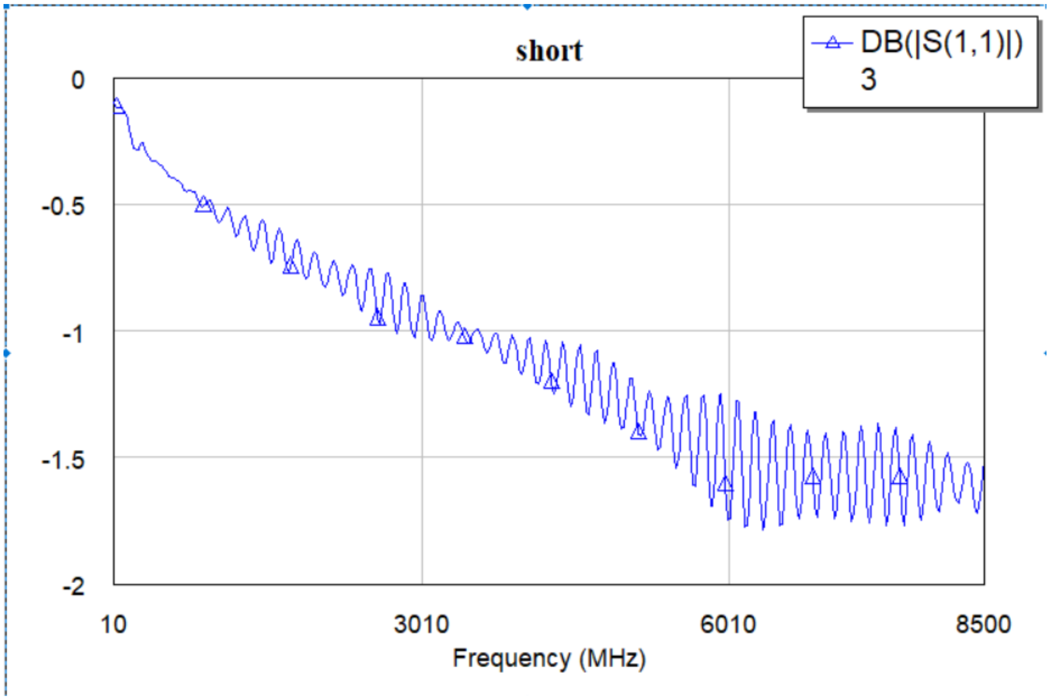


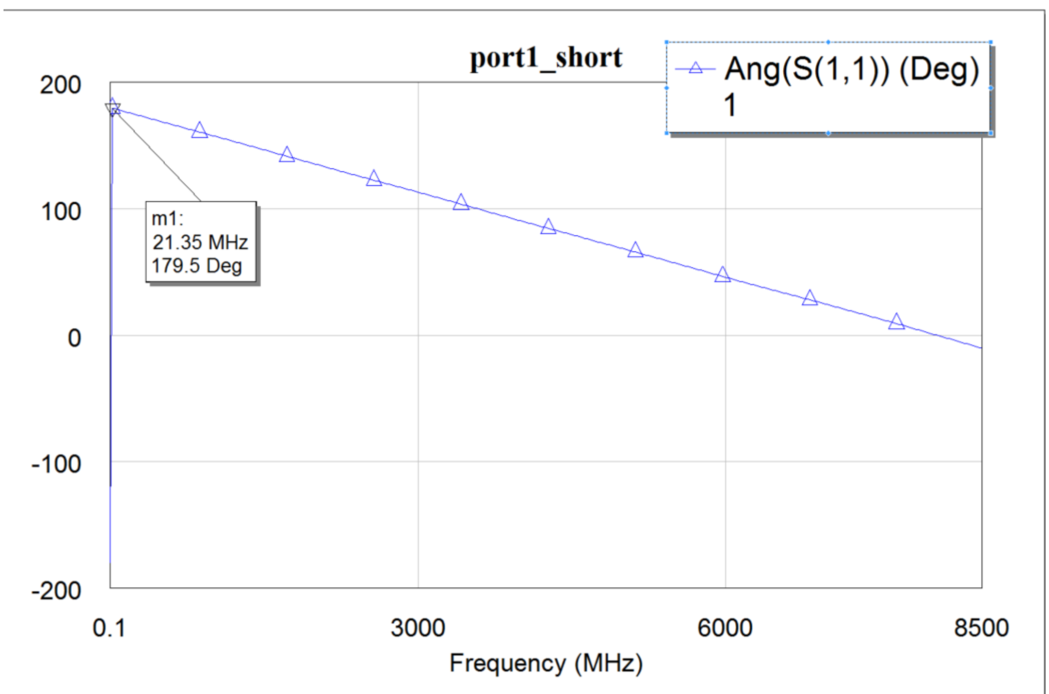
Analysis: Here, RL data (in dB) reading for 50-ohm load was verified to be > 50 dB which shows that the calibration was satisfactory.

2) After calibration when terminated with open load:



3) After calibration when terminated with short circuit:

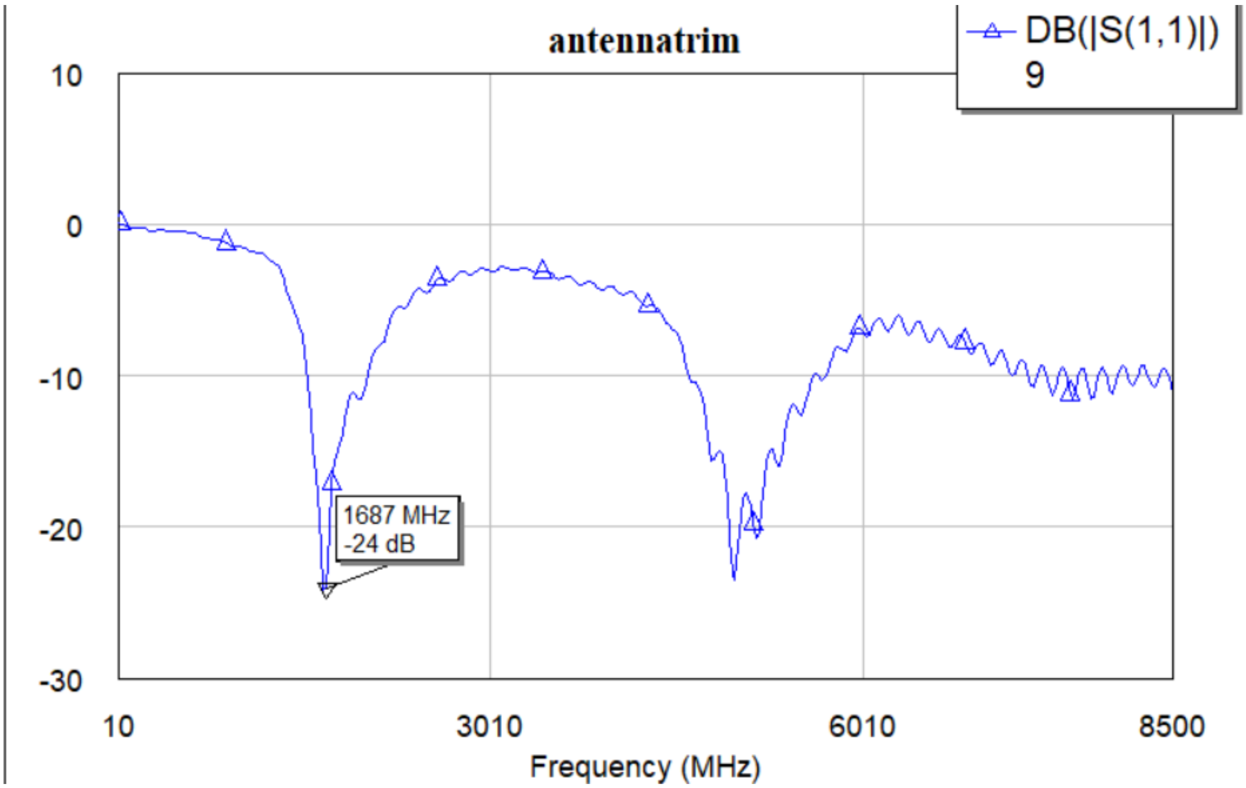




- **Analysis**: The angle of the reflected wave with respect to the incident wave at the short circuit is almost 180 degrees.
- RL data (in dB) reading for short circuit load was verified to be close to 0 dB which shows that the calibration was accurate.

2. Dipole Antenna Measurement

The graph below shows the S11 (in dB) over the measured frequency range:

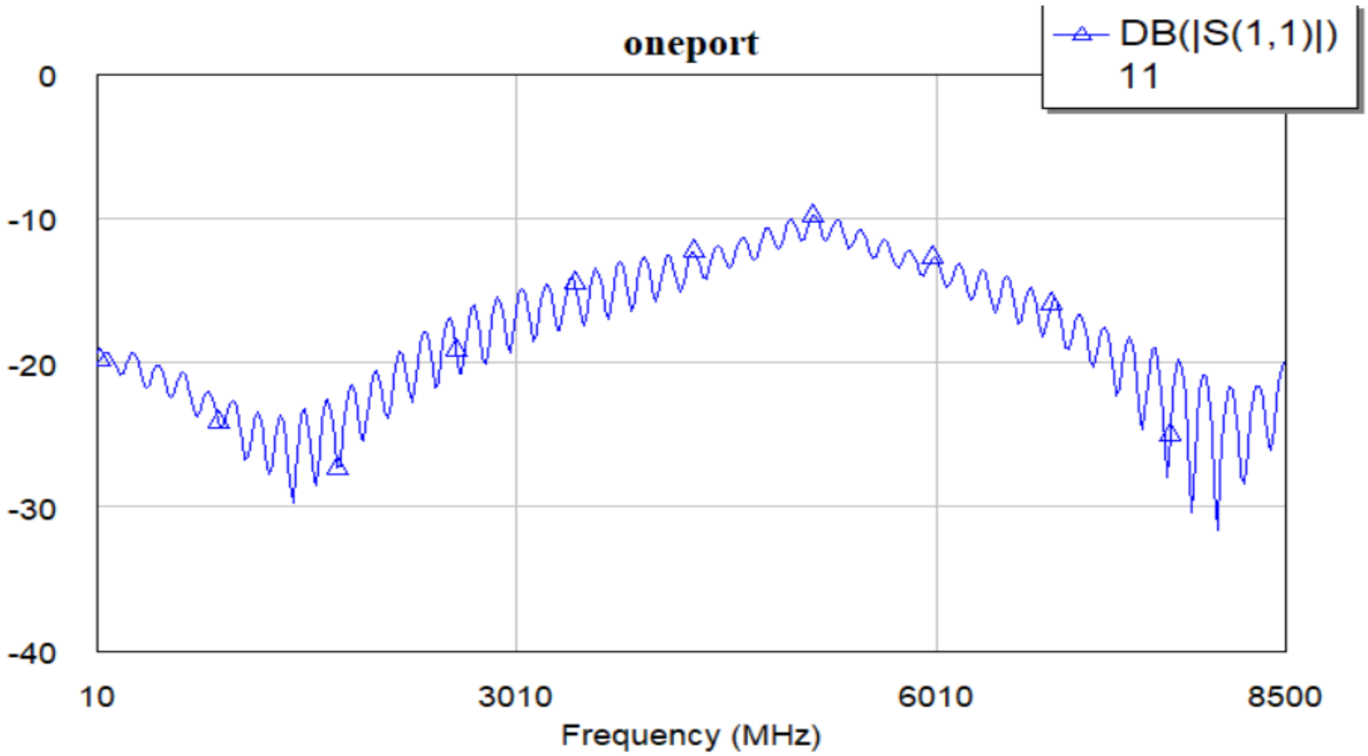


Analysis:

- Here, observed resonant frequency of dipole antenna is 1.687 GHz, while it should be 1.75 GHz.
- This deviation is due to the fringing effect which increases the effective length which leads to increased wavelength. Thus, we can observe drop in resonant frequency due to increased wavelength.
- For wire length 4.5 cm, the Resonant frequency was measured to be 1.39 GHz.

3. 1-port DUT Measurement

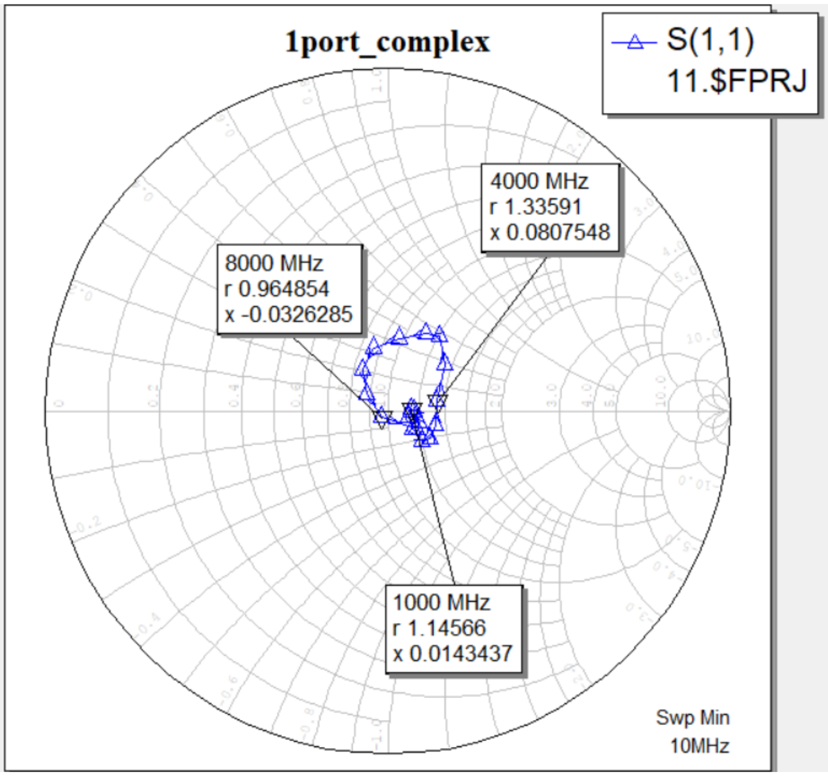
1) Rectangular plot over frequency range 0.01GHz to 8.5GHz:



Analysis:

- The given 1-port RF component is a **10 dB SMA Attenuator**.
- Without a terminating load of 50 Ω, a Return Loss of 20 dB is observed. The 10-dB attenuator sees an open circuit load due to which there will be a forward loss of 10 dB and a reverse loss of 10 dB, resulting in a Return Loss of 20 dB.
- The S11 values can be improved by terminating with 50-ohm. Due to which, the impedance will be matched and reflections will be much less.

2) The actual input impedance determined from S11 measured data, Z = R+jX, (in ohms) of the component at f = 1GHz, 4GHz, & 8GHz.



The Impedance (Zin) values at f = 1 GHz, 4 GHz & 8 GHz are as follows:

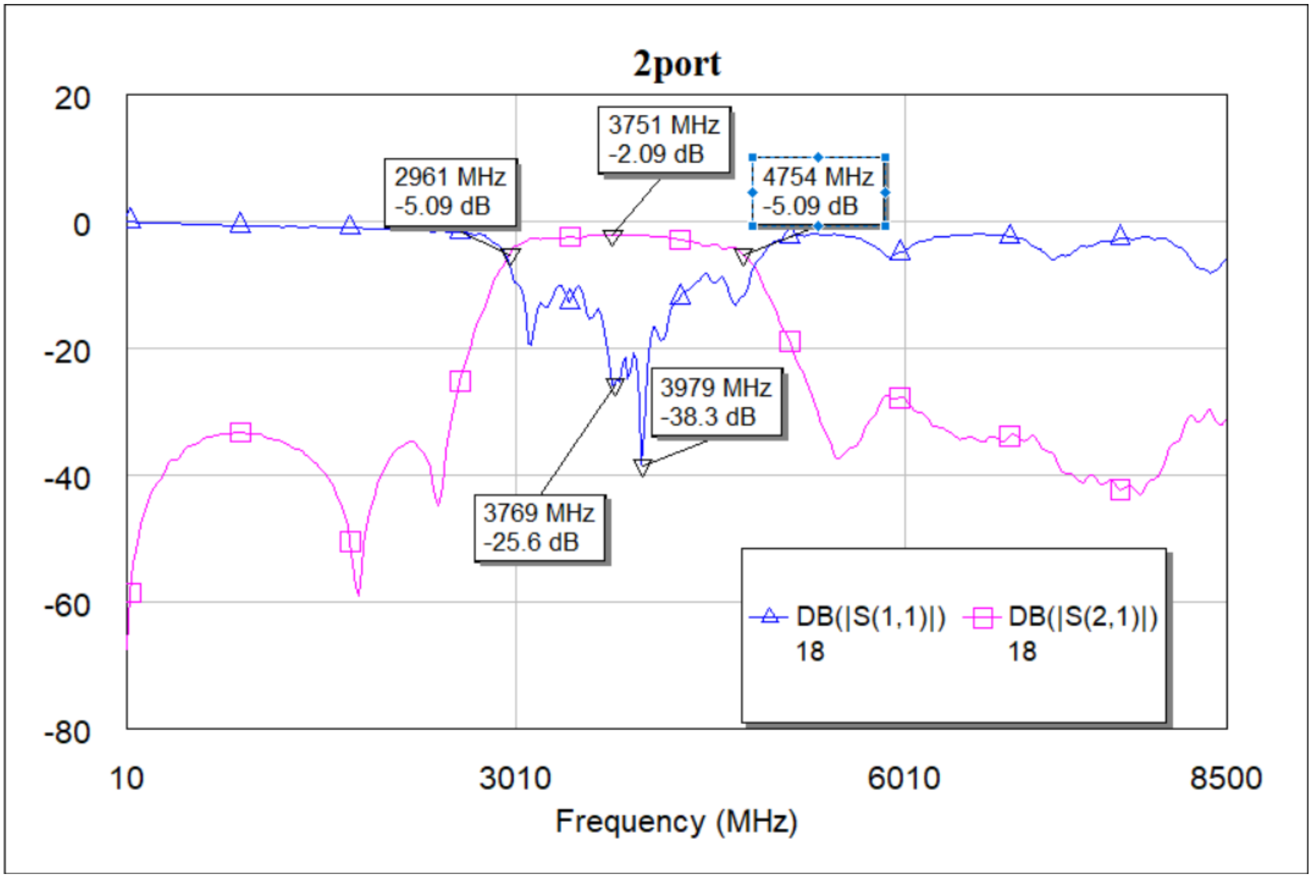
Frequency (GHz)	Zin (R+jX) (Real and imaginary part)	Zin (R+jX, Ohm)
1	1.1456 + 0.01434j	57.28 + 0.717j
4	1.33591 + 0.0807j	66.79 + 4.037j
8	0.9648 – 0.0326j	48.24 – 1.631j

Analysis:

- For the open load, input impedance is not 50-ohm constant over the frequency range, as it depends on frequency.
- For input impedance to be 50-ohm constant over the entire frequency range, 50-ohm load should be used for termination.

4. 2-port DUT

1) Rectangular plot over frequency range 0.01GHz to 8.5GHz:

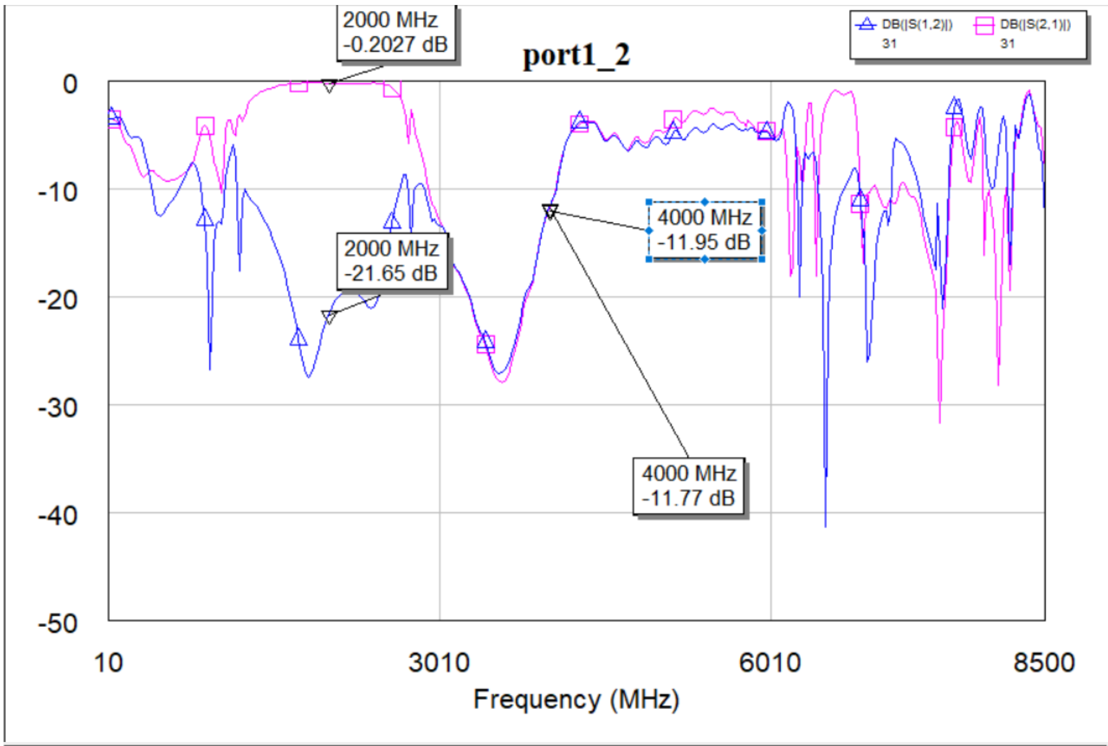


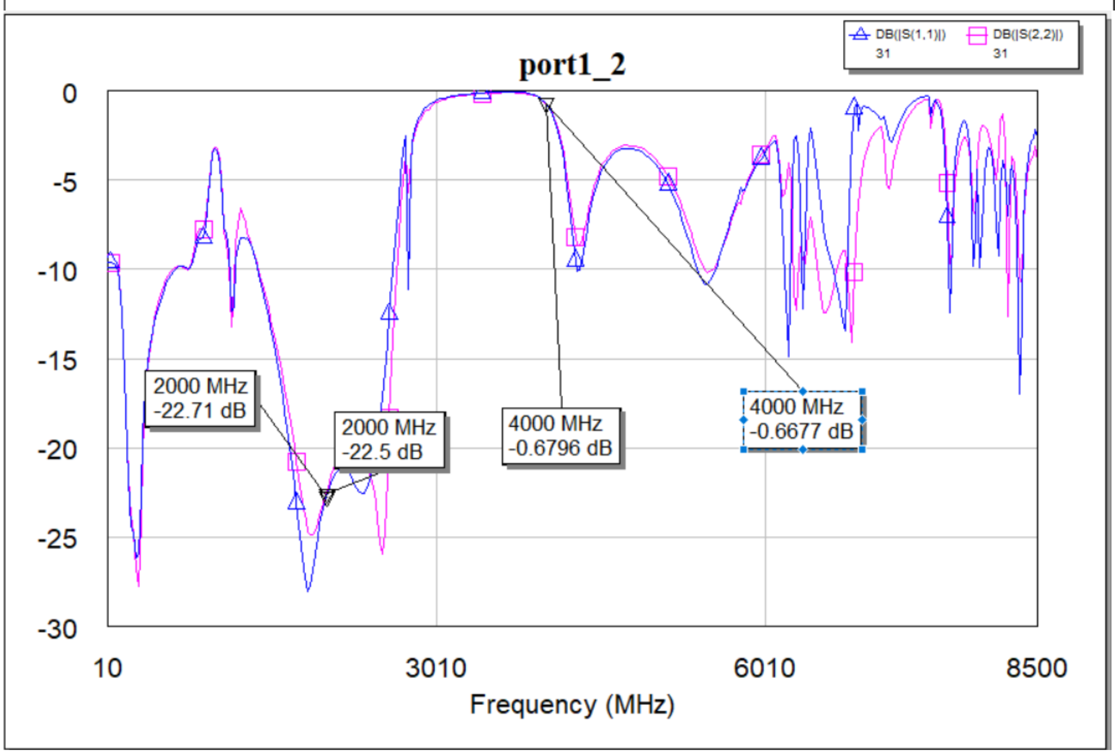
Analysis:

- S21 is close to -2.09 dB for a small range of frequencies. S21 falls to -5.09 dB (-3 dB below) at 2.961 GHz and 4.754 GHz.
- Thus, from S21 we can say that the component is a filter with pass band 2.9 GHz to 4.7 GHz.
- S11 is ranging from -25.6 dB to -38.3 dB. Hence, for these frequencies the S11 is very low and hence reflections are less, Therefore, the signals are being transmitted.

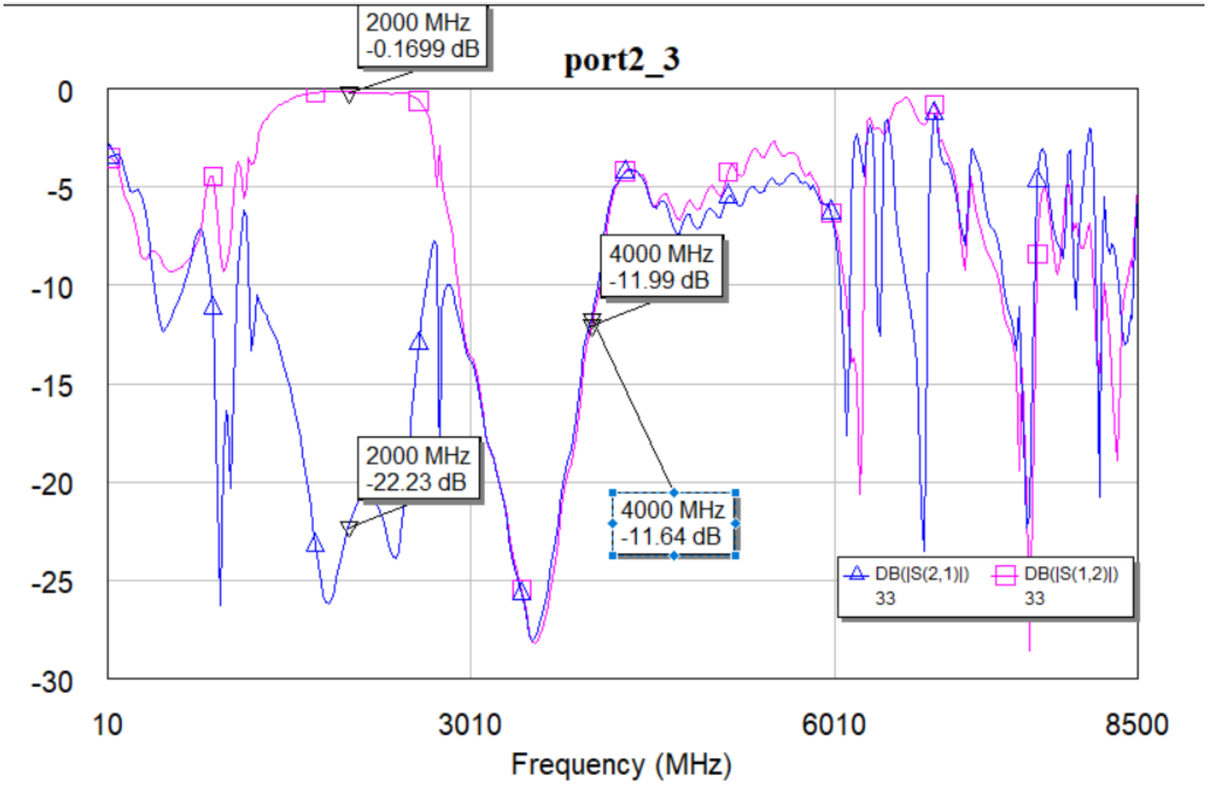
5. 3-port DUT

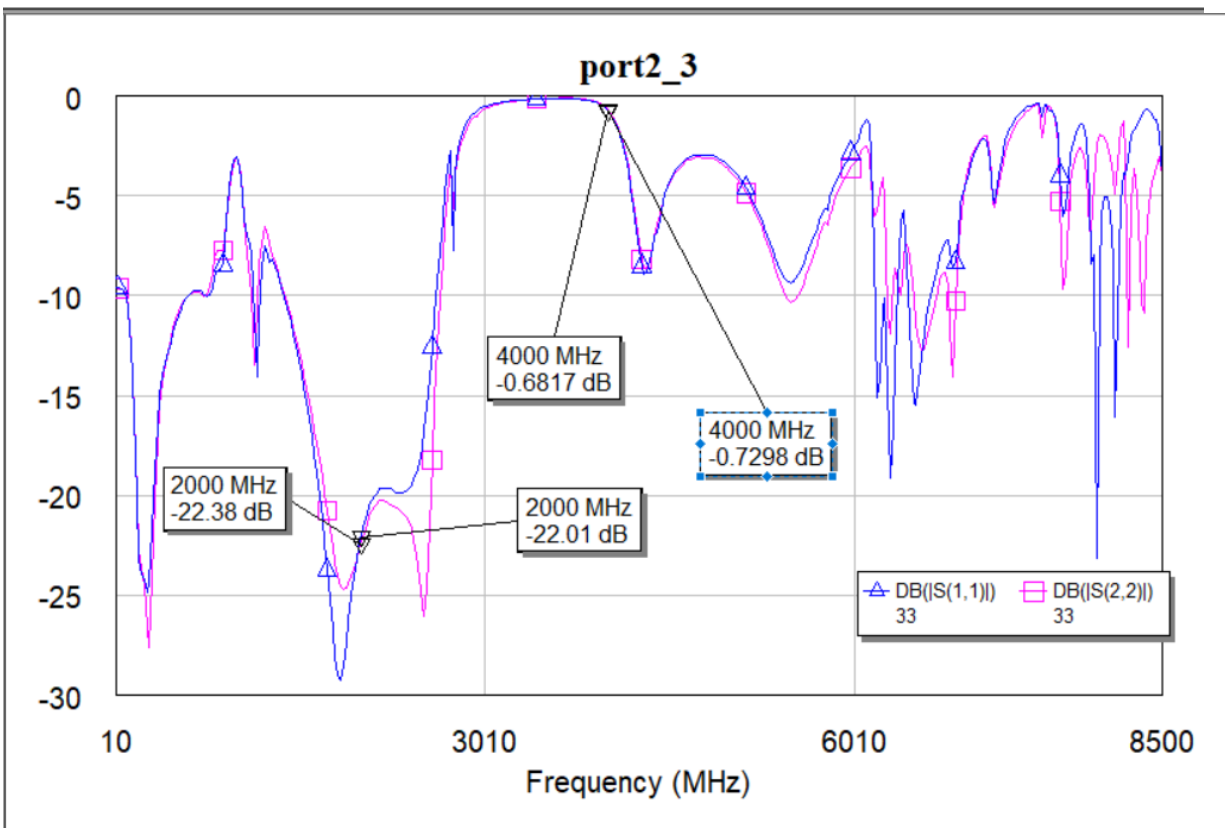
Input at port 1, output at port 2, port 3 is terminated with 50-ohm load:



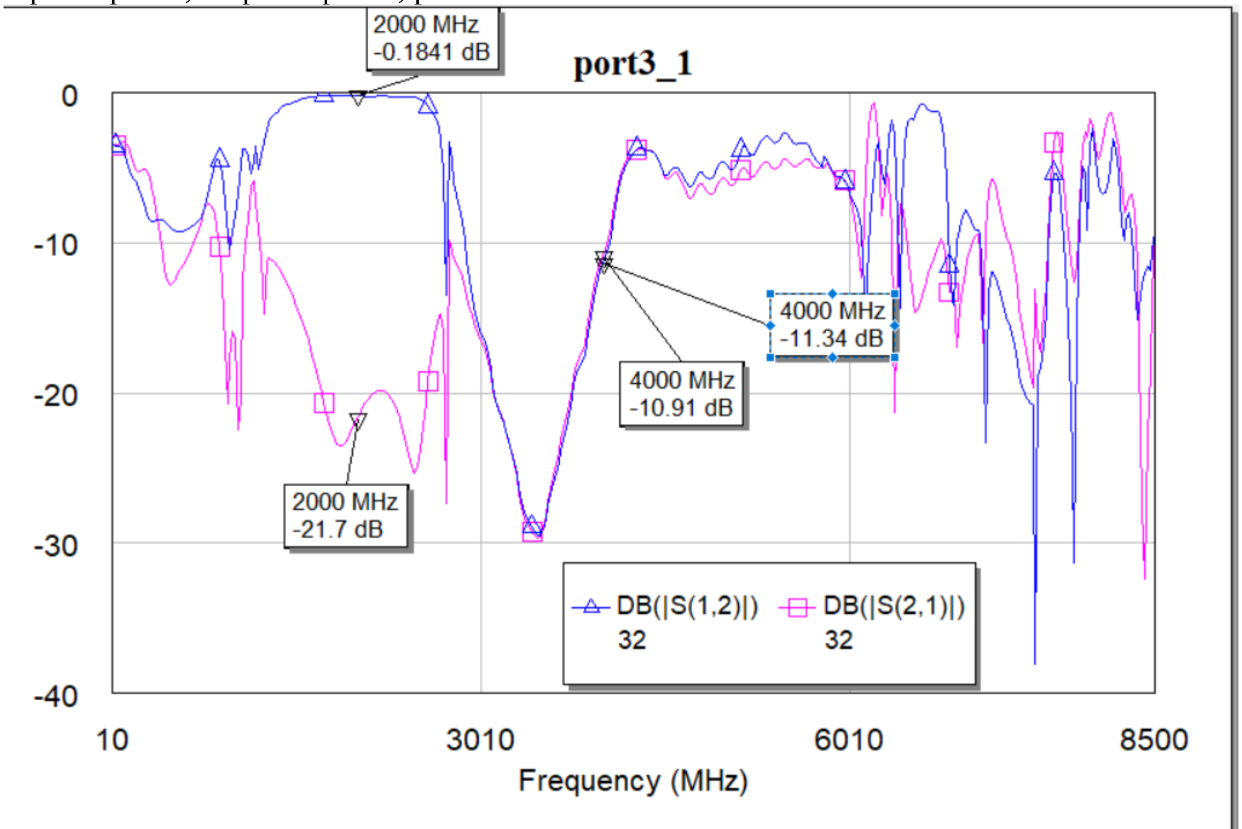


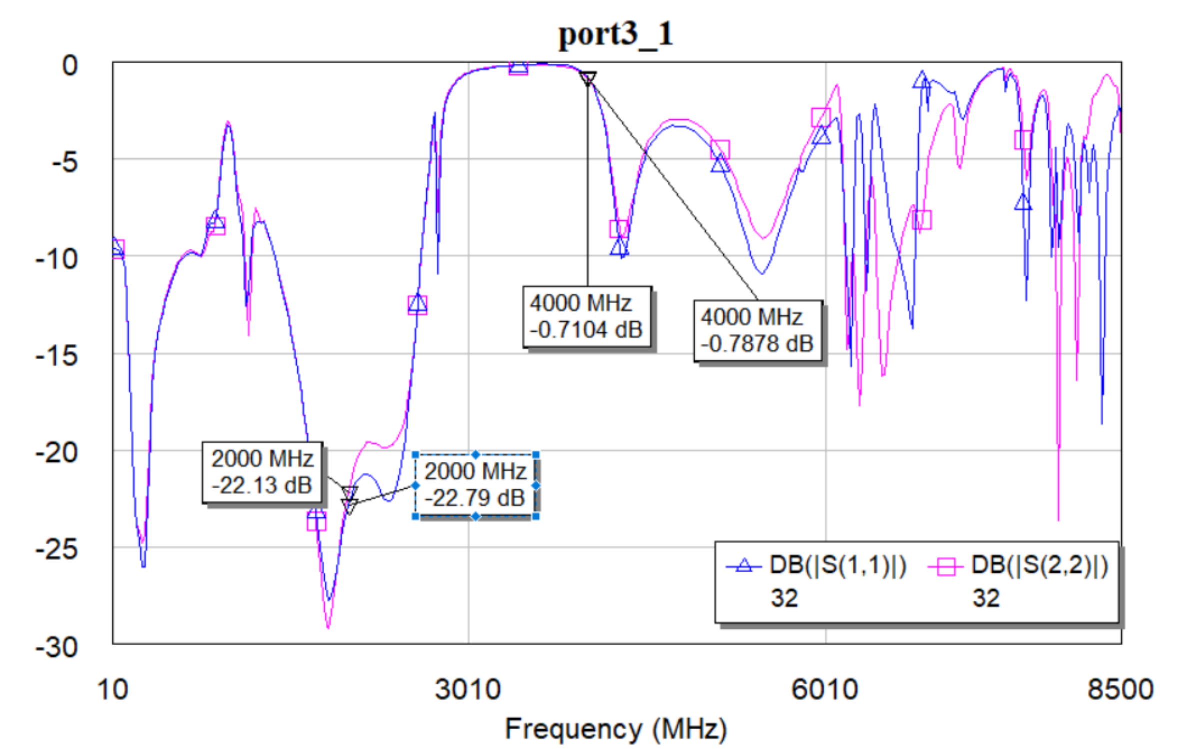
Input at port 2, output at port 3 , port 1 is terminated with 50 ohm load:





Input at port 3, output at port 1, port 2 is terminated with 50 ohm load:





S-parameter matrix for 2 GHz frequency:

S(dB)= [-22.71 -21.65 -0.1841
-0.2027 -22.5 -22.23
-21.7 -0.1699 -22.38]

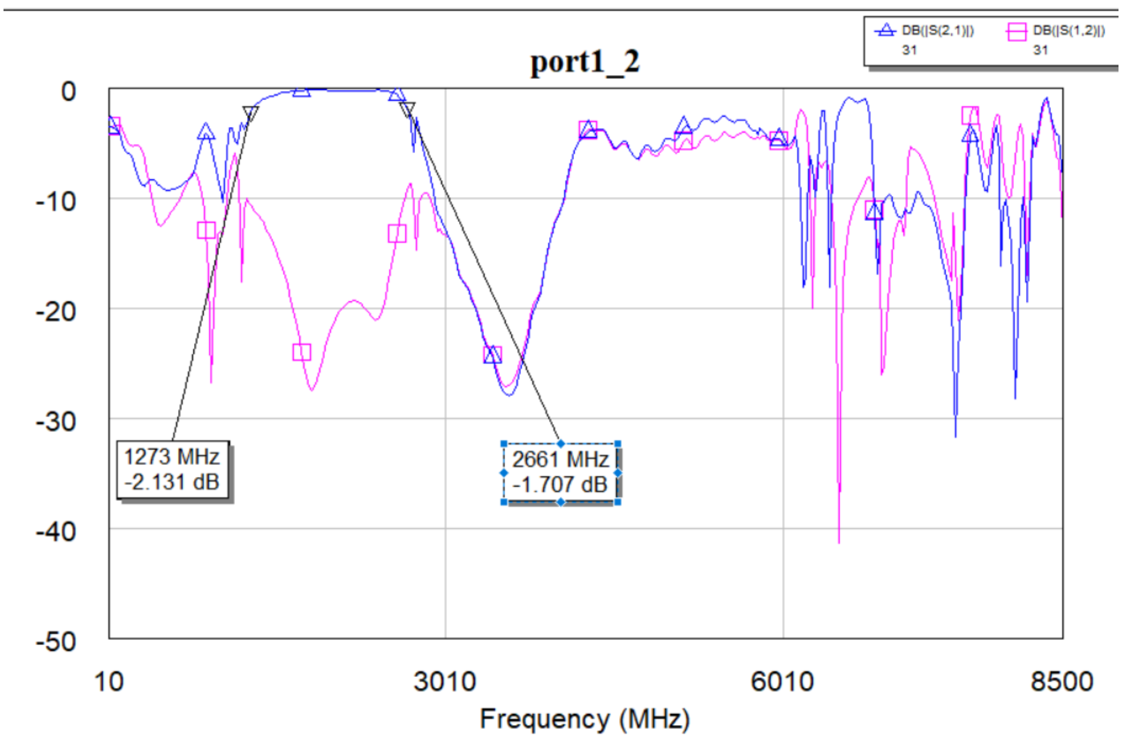
S = [0.005 0.007 0.958
0.954 0.006 0.006
0.007 0.962 0.006]

S-parameter matrix for 4 GHz frequency:

S(dB)= [-0.6677 -11.77 -11.34
-11.95 -0.6796 -11.99
-10.91 -11.64 -0.6817]

S = [0.857 0.067 0.073
0.064 0.855 0.063
0.081 0.069 0.855]

Rectangular plot clearly shows the pass band of the RF component: 1.27 GHz to 2.66 GHz



Analysis:

- From the rectangular plots, it can be observed:

1. Signal is being transmitted in directions: S21, S13, S32.
2. Signal is not allowed to flow in the opposite direction: S12, S31, S23 so they are close to 0. Hence it is not reciprocal.
3. Reflections (S11, S22, S33) are minimum, hence it is matched.

- S-parameter matrix is calculated for pass band frequency 2 GHz. From the S-parameter matrix, we find that the S21, S32, S13 values are high indicating that 3 port component allows the signal to flow only in one direction, i.e from port 1 to port 2, 2 to 3 or 3 to 1.
- Hence **the 3-port component is a circulator**.
- The 3-port component works as a circulator in range of 1.27 GHz to 2.66 GHz.
- S-parameter matrix is also calculated for 4 GHz frequency. The circulator does not operate on this frequency value, so it can be seen that S11, S22, S33 values are high which says that reflections are more and the remaining parameters (S21, S32, S13) with less values indicate that signal is not being transmitted.

4. Summary

- The given 1-port device is a 10-dB attenuator as it S11 plot shows around 20dB when left open circuited.
- The given 2-port device is a band pass filter with pass band 2.9 GHz to 4.7 GHz.
- The given 3-port device is a circulator which allows power flow in S21, S13, S32 directions and does not allow power flow in S12, S31, S23 directions.

Lessons learned:

- Accuracy of calibration of VNA highly affects reliability of the measurement data.
- Quality of measurements can be improved by using torque wrench for the connections.
- Learned to analyze S parameters of unknown DUT to understand their properties.