MEMS Switch network

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1. INTRODUCTION

The CubeSat deployable EDGES receiver requires a reduction in size and power consumption. To achieve this goal, a redesign of all sub-components is necessary, focusing on minimizing form factor and power usage. Currently, the EDGES receiver employs a co-axial mechanical switch network at the input, connecting to various calibration loads, a VNA (Vector Network Analyzer), and an LNA (Low-Noise Amplifier). Notably, these co-axial mechanical switches are among the most power-intensive elements within the entire RF chain of the EDGES receiver. After experimenting with different RF switching options, including semiconductor switches, pin diode switches, and MEMS switches, it has been observed that MEMS switches offer superior S-parameters in comparison to pin and semiconductor switches. Figure 1 shows the switch network in the EDGES-3 receiver. The configuration is 2X8 switch network. There are 8 inputs (7 calibration loads and antenna) connected to either VNA or LNA and VNA has to connect with LNA. A switch network with the same functionality is designed to replace mechanical switches in the current EDGES receiver with a small form factor and less power consumption.

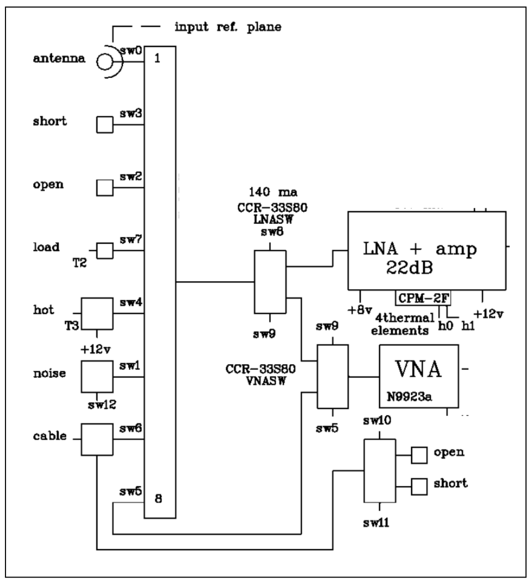

Fig. 1. EDGES switch network

2. MEMS SWITCH WORKING

MEMS switches are considered as a replacement for electromechanical relays and can revolutionize RF system design with easy-to-use and small form factor switches with similar RF performance to electromechanical relays. Figure 2 shows the functioning of a MEMS switch. The MEMS switch is a three-terminal device that is represented as the source, gate, and drain. Case A shows the representation of an open switch. When a dc voltage is applied to the gate, an electrostatic pull-down force is generated on the switch beam, which makes the cantilever switch to get in contact with the drain. Case B shows the closed position of the MEMS switch.

3. MEMS SWITCH NETWORK DESIGN

A 2x8 switch network is designed with three ADGM1004 (SP4T) Analog device IC to obtain the same functionality of the switch network in the EDGES-3 receiver. Figure 3 shows the switch

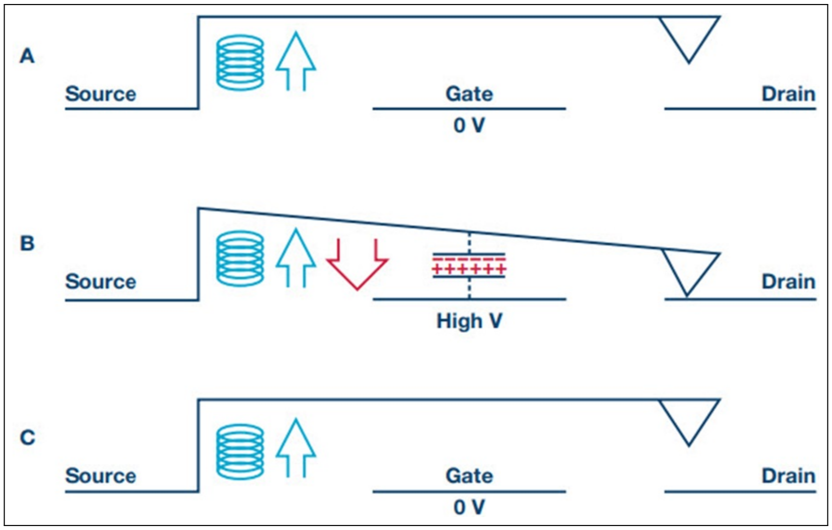

Fig. 2. MEMS switch working

network design with three SP4T MEMS switch. It is learned from the datasheet of ADGM1004 IC that it will support inter port connectivity, ie it supports the connection between RF1-RF4. Making use of this feature RFc in the design is not used, instead, VNA and LNA are connected to the two ports from RF1 to RF4 in the SP4T_1 IC. All the calibration loads can be connected to RF1-RF8. One of the added advantages of this design is the RF path delay from VNA to all calibration loads is exactly the same as LNA to calibration loads.

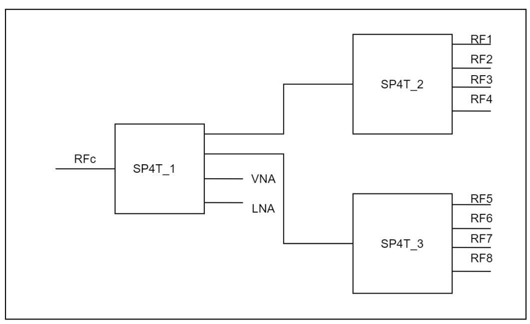

Fig. 3. MEMS switch network

A. PCB design

PCB is designed using 4 layer FR4 board with 1.6mm thickness. 50-ohm GCPWG (grounded co-planar waveguide) is used as the transmission line between the ports and IC. A through transmission line with two different SMA connector is included to see the comparison of S11 with different connectors. The VNA port is slightly extended outside the board to make the path length the same from VNA and LNA to all RF ports. Figure 4 shows the images of the 3D rendered design file and fabricated PCB. There are ten RF ports in the network two ports are named as VNA and LNA. The remaining ports are named as RF-1 to RF-8.

4. MEASUREMENTS

To understand the switching performance it is important to characterize the switch performance over a frequency ranging from 40MHz to 200MHz. S-parameter measurements will give an overall performance of switch w.r.t frequency. The reflection, as well as transmission parameters, are extracted from S-parameter measurements. S-parameter measurements are taken between VNA-port to all RF-ports, LNA-port to all RF-ports, and between VNA-port and LNA-port. Before taking the measurement 2-port calibration is done with the VNA.

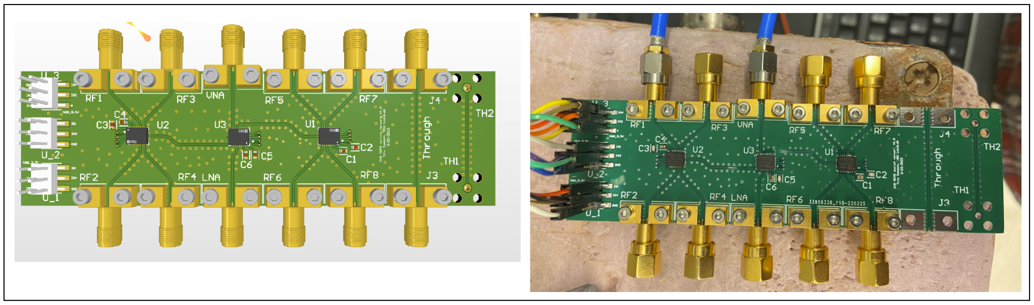

Fig. 4. MEMS switch network Altium 3D rendering (left) and connectorized (Right)

A. S-parameter measurements

There are ten RF ports in the switch network which are designed to function as a 2x8 switch network. To characterize all RF channels three sets of measurements are taken VNA-port to LNA port, VNA-port to all RF-ports, and LNA-port to all RF-ports. The settings of VNA are shown in the appendix tableS1.

A.1. VNA-LNA

In the EDGES receiver, all RF ports are connected to either VNA or LNA as shown in figure 1. The port connecting to VNA is named as VNA port and the port connecting to the LNA is named as LNA port in the switch network. During the EDGES receiver calibration process it is required to take the S-parameter of LNA, for that VNA-LNA channel is activated. VNA port on the switch is connected to port-1 of VNA and the LNA port on the switch is connected to port-2 of VNA. Figure 5 shows the measured s-parameters between VNA-port and LNA-port. S21 varies from 0.28dB to 0.56dB and S11 varies from -31.95dB to -27.55dB over a frequency of 40 MHz to 200 MHz.

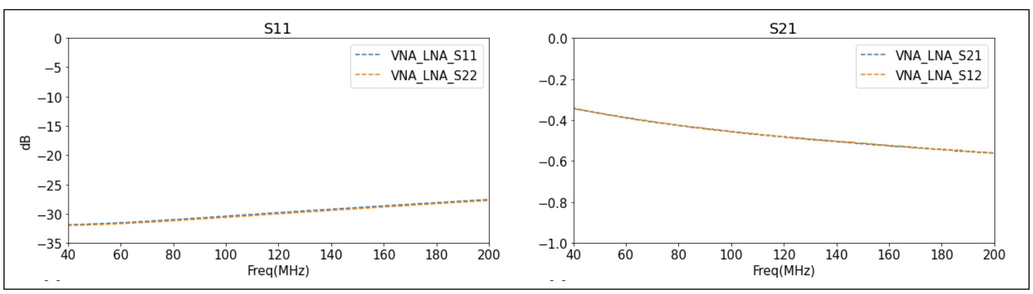

Fig. 5. S-parameter measurement of VNA-port connected to LNA-port

A.2. LNA-RFx

S-parameter of LNA-port connected to all RF ports is taken by activating each channel sequentially. Figure 6 shows the measured S-parameters. The S11 varies from -28dB to -24dB and the S21 varies from 0.5dB to 1dB over a frequency range of 40 MHz to 200 MHz.

A.3. VNA-RFx

S-parameter of VNA-port connected to all RF ports is taken by activating each channel sequentially. Figure 7 shows the measured S-parameters. The S11 varies from -28dB to -24dB and the S21 varies from 0.5dB to 1dB over a frequency range of 40 MHz to 200 MHz.

B. ON-OFF isolation

Isolation is the amount of signal attenuation between the two ports of the switch when the active channel is in the off state. In the MEMS switch network, there are four ports on the left side and four ports on the right side of the PCB. The two sides are divided by the VNA port and the LNA port at the center. Isolation measurement is taken only for one channel VNA to RF1. Figure 8 shows the measured S21 of the VNA-RF1 path while it is on and off. The off isolation is better than -80dB because S21 of off shows the noise floor of VNA.

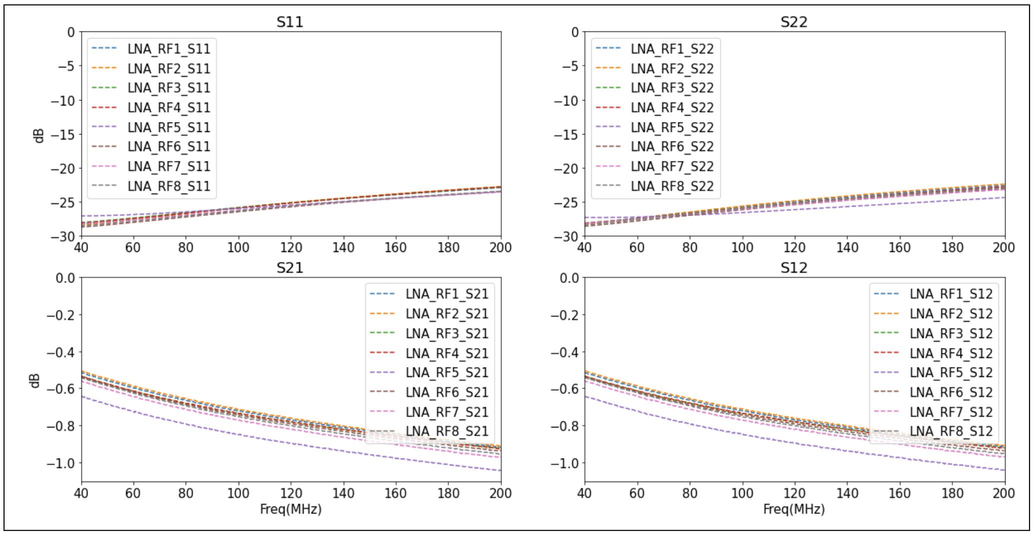

Fig. 6. S-parameter measurement of LNA-port connected to all RF-ports

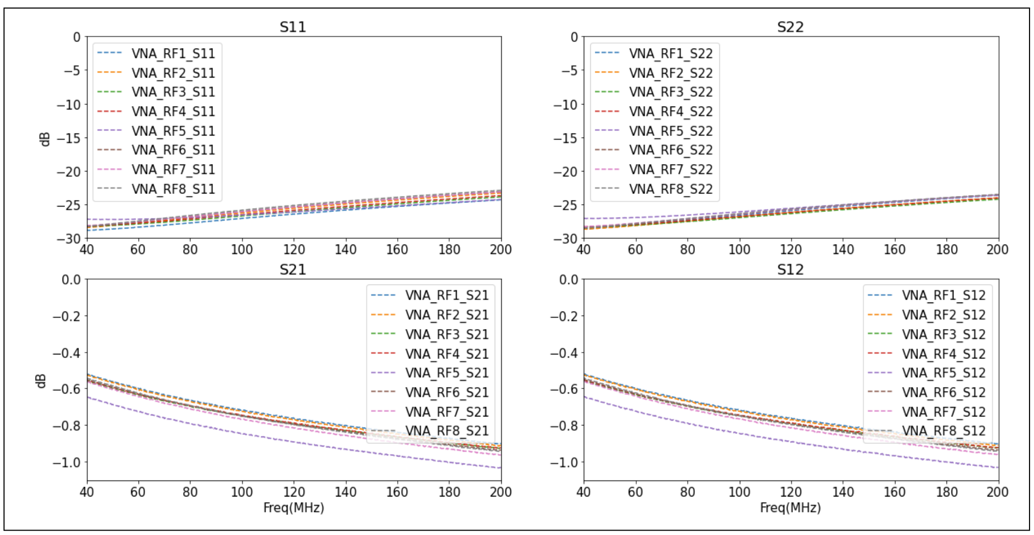

Fig. 7. S-parameter measurement of VNA-port connected to all RF-ports

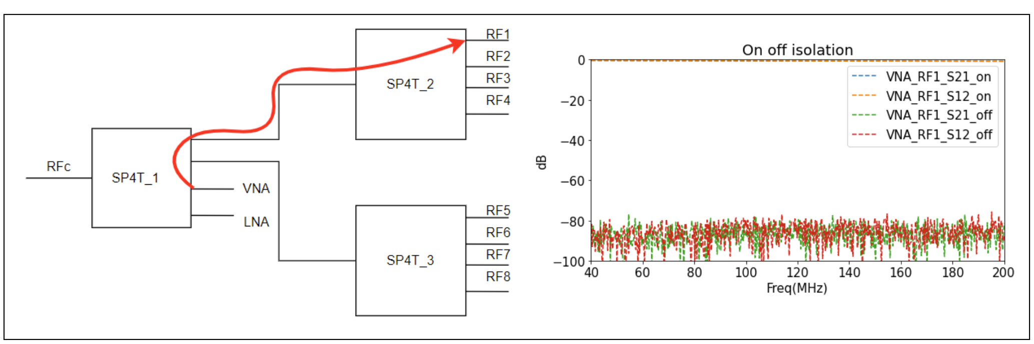

Fig. 8. ON-OFF isolation measurement of VNA-port connected to RF1

C. Cross-coupling

Cross-coupling refers to the signal leaking to the neighboring ports. For this measurement, S21 is measured between RF3-RF1 and RF7-RF1. RF3 is on the same side of RF1 and RF7 is on the other side of RF1. Figure 9 shows the representation of active channel, measured channel, and results. Cross-coupling on the same side is from -45dB to -40dB and below -80 dB on the other side.

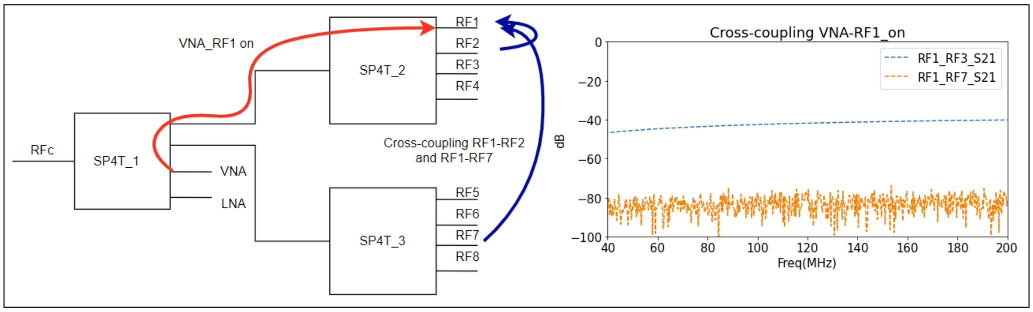

Fig. 9. Cross-coupling measurement while VNA-port connected to RF1

D. Channel to Channel isolation

Channel to channel isolation refers to the signal coupling from the neighboring ports. For this measurement, S21 is measured between VNA-RF3 and VNA-RF7 while VNA-RF1 is active. RF3 is on the same side and RF7 is on the other side of the active channel. Figure 10 shows the representation of active channel, measured channel, and results. Channel to channel isolation on the same side is from -55dB to -45dB and below -80 dB on the other side.

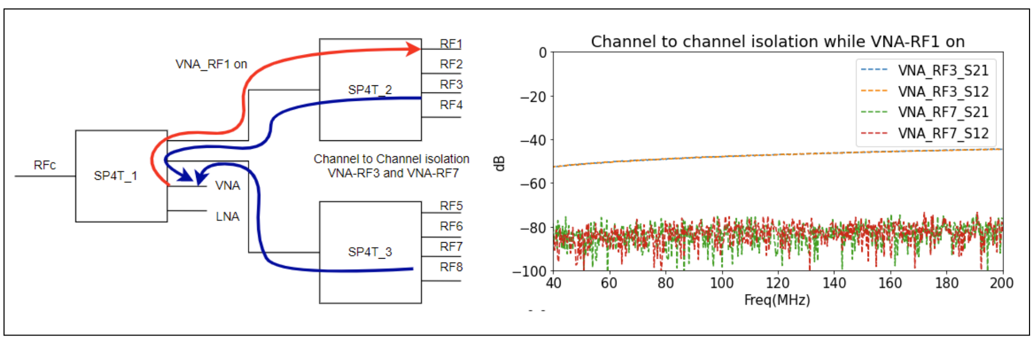

Fig. 10. Channel to channel isolation measurement while VNA-port connected to RF1

E. stability measurements

To understand the variation in S-parameters over time, stability measurements are done. For this measurement channel, VNA to RF1-RF4 is used. Calibration standards are connected to the RF1-RF3 ie. Open, Short, and Load. RF4 is connected with a 6dB attenuator. S11 of all loads is measured sequentially and calibrated as the S11 of the 6dB attenuator. This cycle is repeated for approximately 2 hours. The delta variation of calibrated S11 of 6dB attn is plotted over time for three frequencies (40MHz, 100MHz, 200MHz). From the plots stability is similar for the SP4T evaluation board and switch network. RF power output from VNA for stability measurements is kept at -30dBm.

5. SIMULATION

A. comparison of simulation with measured

Figure 12 shows the comparison of measured with the simulation of an active channel. By activating RFc to RF1 and RF1 to RF2 of the Evaluation board two separate s2p files are generated. These files are connected together in AWR to simulate the scenario of LNA connected to RF1 in

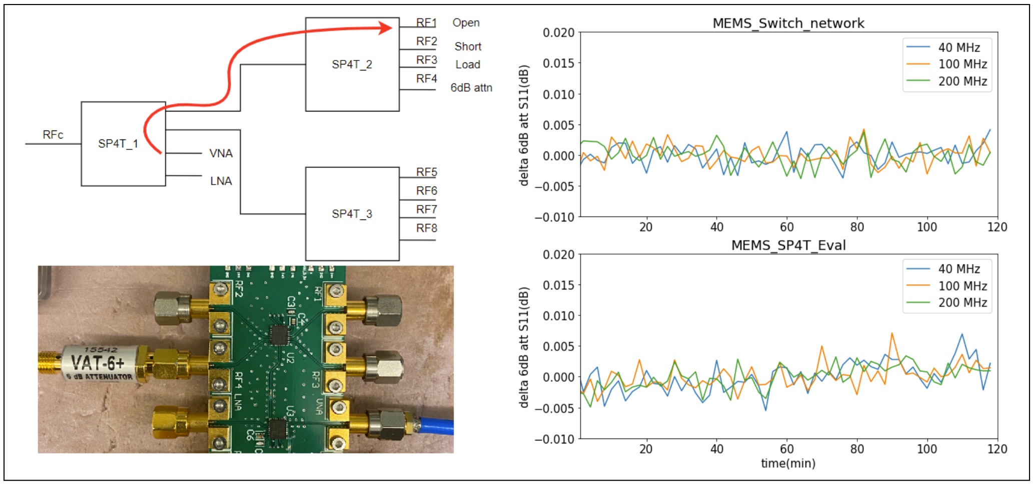

Fig. 11. Comparison of S11 stability of switch network with SP4T evaluation board over time

start freq	40 MHz
stop freq	200 MHz
IF BW	100 Hz
no. of points	641
output power	-15 dBm
no. of averaging	1

Table S1. VNA settings for S-parameter measurement

the network. The S21 in the figure 12 shows that the switch network is lossy when compared with the simulation this is due to the insertion loss of a long transmission line in the network. S11 in the figure 12 shows an improvement in network switch from simulation. This improvement is because there are no unwanted transmission line stubs connected to the active channel. When s2p of RF1 to RF2 is measured there is a transmission line connected to RFc which act as a stub connected to the active channel of RF1 to RF2. In the switch network design it is avoided.

B. simulation of new network design

To see the possibilities of S11 improvement of the switch network two different networks are simulated. Figure 13 shows a switch network configuration and its simulated S11 and S21. From the simulation, there is no improvement in s11 when compared with the current design. Figure 14 shows another design and its simulated S11 and S21. From the simulation, S11 is showing a slight improvement compared to the current switch network.

B.1. design 1

Figure 13 shows a network design in which RFc of three SP4T is connected together.

B.2. design 2

Figure 14 shows a different network design with four SP4T ICs.

6. APPENDIX

A. VNA settings

Table S1 shows the VNA settings for all measurements in this memo except stability measurements. For stability measurements, only difference is the output power of VNA is kept at -30dBm.

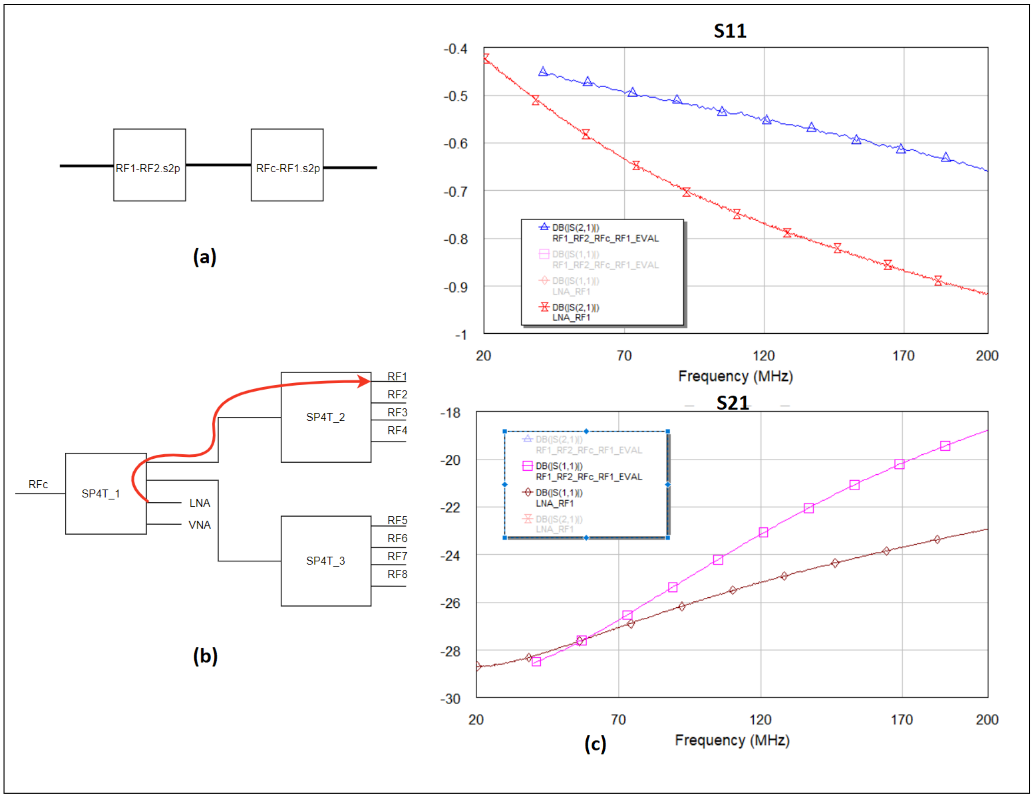

Fig. 12. Comparison of simulation vs measured S-parameter of LNA-RF1

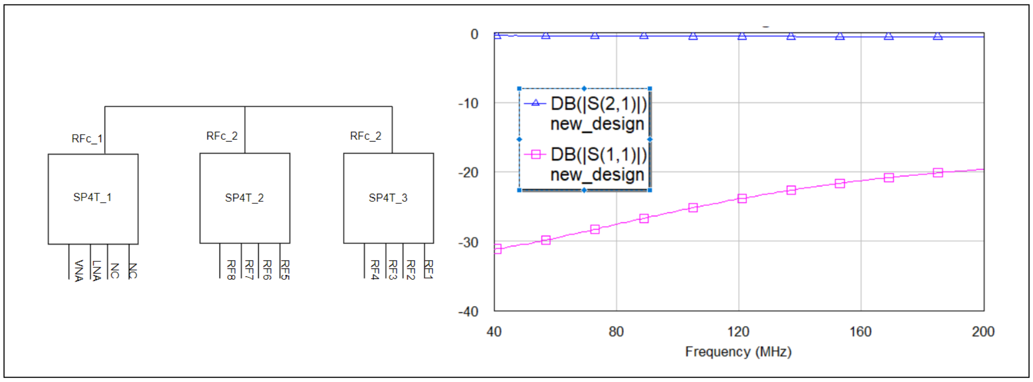

Fig. 13. Simulated S-parameter of LNA-RF1

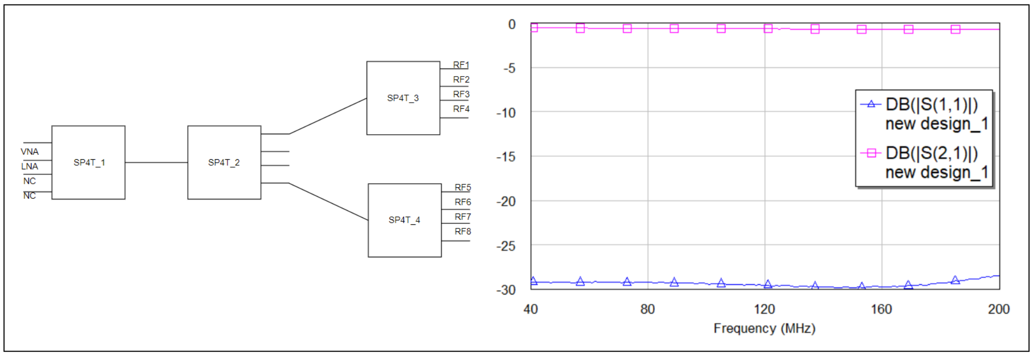

Fig. 14. Simulated S-parameter of LNA-RF1

B. Through transmission line

The insertion loss and reflection of PCB trace lines depend on many parameters like trace width, length, dielectric constant, material,etc. To get an understanding of transmission lines a through-line is placed in the same PCB and connected with the same connectors. On the switch network board, an additional transmission line with a through-hole vertical SMA connector is added along with the edge SMA connector to understand the variation of the S-parameter when there is a change in SMA connector orientation. S-parameter of through-line on evaluation board is compared with the through lines in switch network with two different connectors. Figure 15 shows the picture of different transmission lines and their S-parameters. From the S-parameter, it is observed that the edge SMA connector will give a better S11 when compared with vertical connectors. Insertion loss is comparable for all cases.

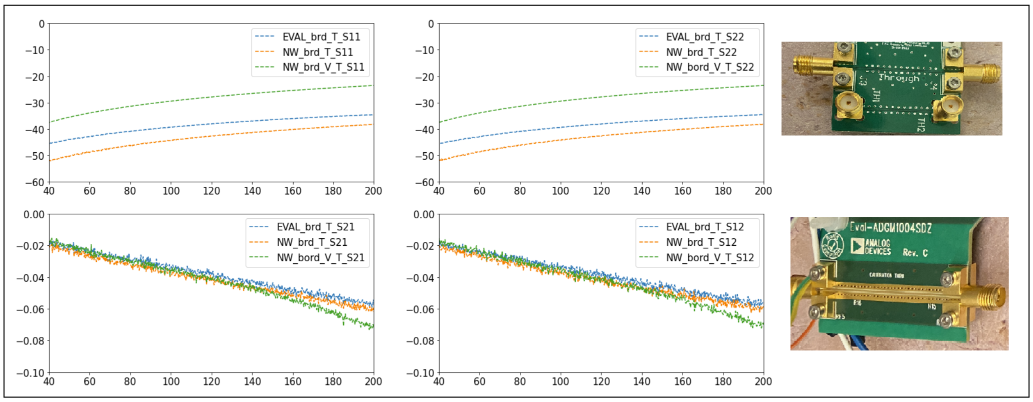

Fig. 15. Transmission line analysis

C. ADGM1004 Evaluation board measurements

C.1. RFc-RFx

S-parameter of RFc-port connected to all RF ports is taken by activating each channel sequentially. Figure 16 shows the measured S-parameters. The S11 varies from -38dB to -35dB and S21 varies from 0.2dB to .25dB over a frequency range of 40 MHz to 200 MHz.

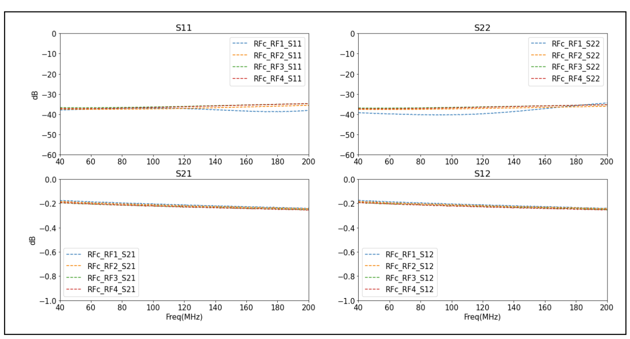

Fig. 16. Evaluation board RFc to RFx

C.2. RF1-RF2

S-parameter of RF1-port connected to all RF2 port is taken by activating two channels at the same time. Figure 17 shows the measured S-parameters. The S11 varies from -30dB to -20dB and S21 varies from 0.25dB to .3dB over a frequency range of 40 MHz to 200 MHz.

D. ON-OFF isolation

Isolation is the amount of signal attenuation between the two ports of the switch when the switch is in the off state. S-parameter is measured between RFc and RF1 while on and off. Figure 8 shows

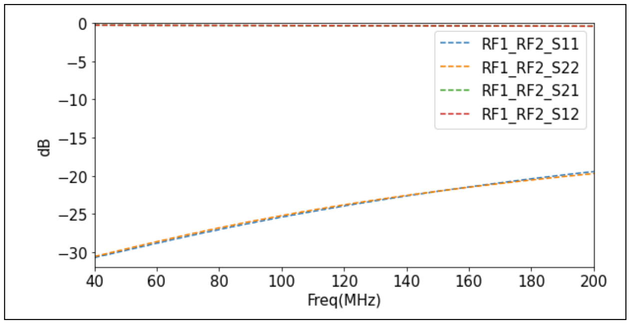

Fig. 17. Evaluation board RF1-RF2

the measured S21 of RFc-RF1 path while it is on and off. The off isolation varies from -56dB to -45dB.

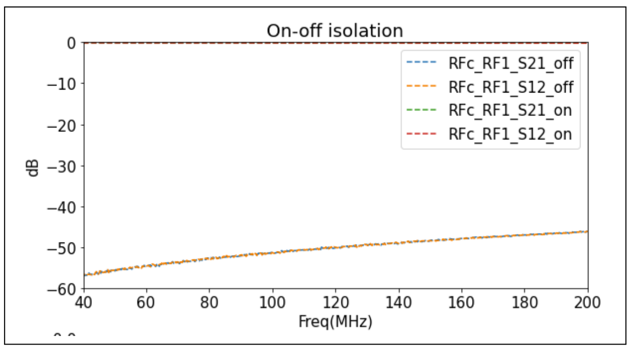

Fig. 18. Evaluation board RFc-RF1 on off isolation

E. Cross-coupling

Cross-coupling refers to the signal leaking to the neighboring ports. For this measurement, S21 is measured between RF1-RF2 and RF3-RF1 while RFc to RF1 in on. Figure 19 shows the representation of active channel, measured channel, and results. Cross-coupling varies from -55dB to -45dB.

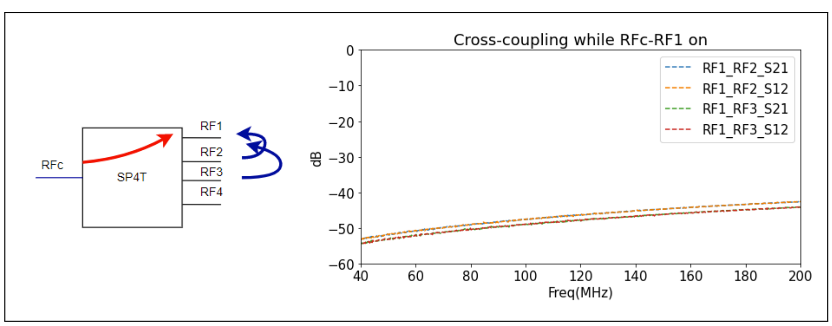

Fig. 19. Evaluation board cross-coupling while RFc-RF1 is on

F. Channel to channel isolation

Channel to channel isolation refers to the signal coupling from the neighboring ports. For this measurement, S21 is measured between RFc-RF2 and RFc-RF3 while RFc-RF1 is active. All the unused ports are terminated by 50ohm. Figure 20 shows the representation of active channel, measured channel, and results. Channel to channel isolation varies from -60dB to -50dB.

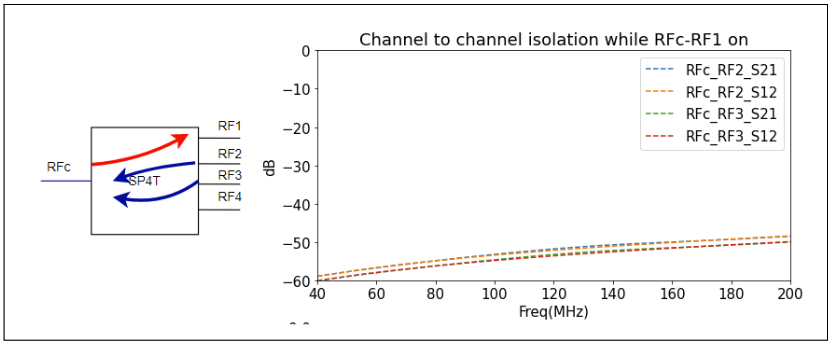

Fig. 20. Evaluation board channel to channel isolation while RFc-RF1 is on

G. stability measurements

Refer section 5.A for comparison results.

H. Data location