Microwave Directional Couplers

Microwave Design and Measurements (EERF 6396)
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Submitted By

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1. Introduction

Objectives:

- Design, simulate and build **microstrip edge-coupled 4-port 20dB directional coupler** on duroid material using AWR MWO (Axiem). Compare the measurement results and Axiem simulation results.
- Design and simulate 50-Ω **microstrip 3-dB quadrature branch-line coupler** using AWR MWO (Axiem).

2. Design

A. Design Process

Design A: 3-dB quadrature branch-line coupler:

- Branch line couplers are quadrature hybrid structures with four ports. It has one input port, two output ports and one isolated port.
- The impedance of lines connected to four ports of coupler is 50 ohm(Zo). The impedances of two remaining horizontal lines in between are kept to be 1/√2 x Zo. The impedances of two vertical lines are equal to Zo.
- Widths and lengths of all MLIN are calculated using TX line tool in AWR. Impedance value, cut off frequency, substrate properties and electric length are entered into TX line tool for individual MLIN.
- The phase difference between two output ports is 90 deg.
- Design goals were verified by using AXIEM Simulation.

Design B: 20dB Edge-coupled 4-port directional coupler:

- Edge-coupled directional coupler has four ports. It has one input port, second is direct port connected to the input port, third is coupled port and fourth is isolated port.
- The impedance for even and odd mode are calculated for length λ/4 and ϑ= 90 deg as follows:

$$C(dB) = 20\log C(lin)$$

In this design Voltage Coupling Coefficient = 20 dB, which gives C(lin) = 0.1.

$$Zoe = Zo\ x\ \sqrt{((1+Clin)}/(1-Clin))$$

$$Zoo = Zo\ x\ \sqrt{((1-Clin)}/(1+Clin))$$

So we get Zoe = 55.28 ohm and Zoo = 45.23 ohm.

- TX line tool was used to get coupled line width, length and spacing for even and odd mode.

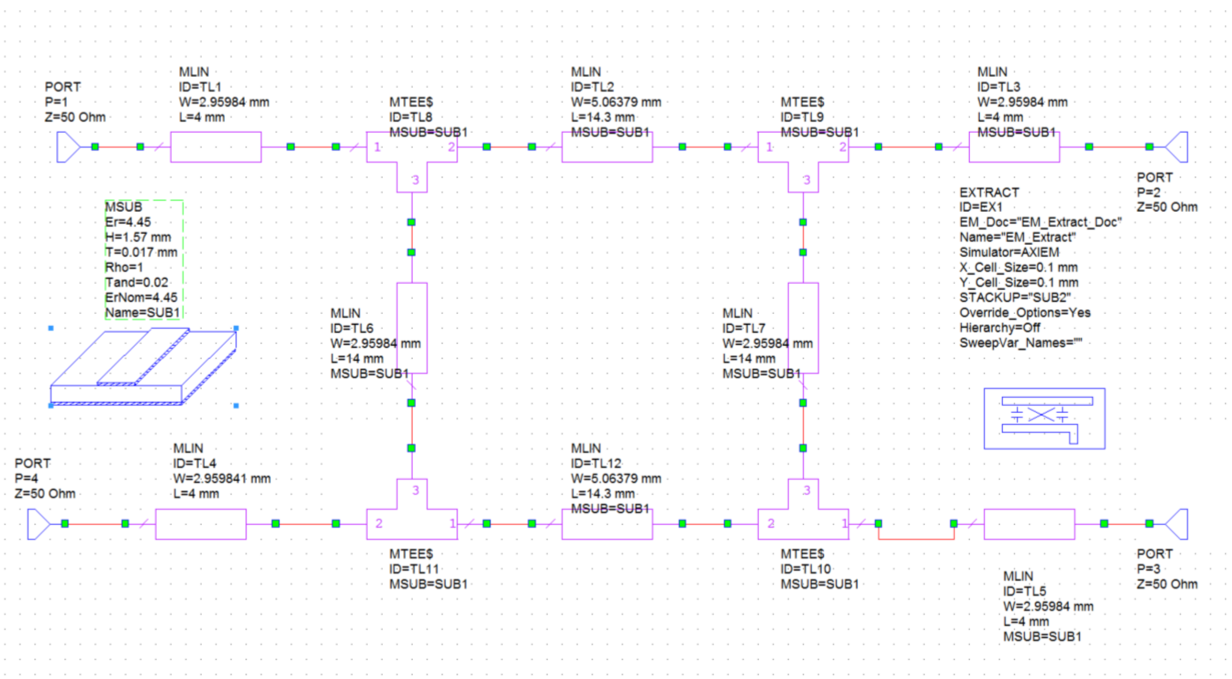
$$Zo = \sqrt{(Zoe \ x \ Zoo)}$$

- Design goals are verified by using AXIEM Simulation.

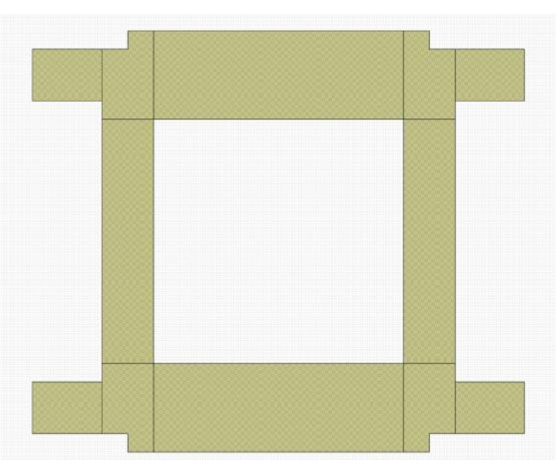
B. Figures related to design:

Design A: 3-dB quadrature branch-line coupler:

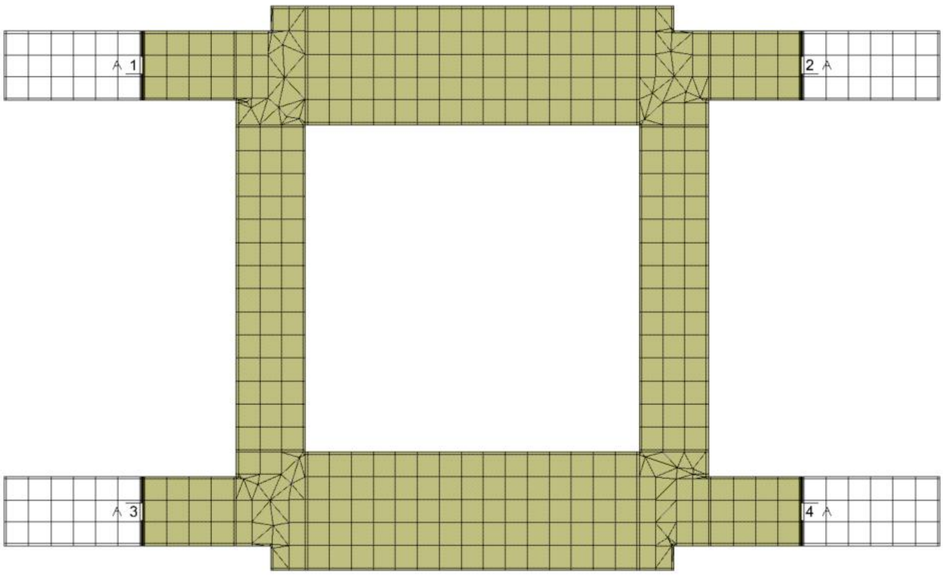
Circuit Schematic:



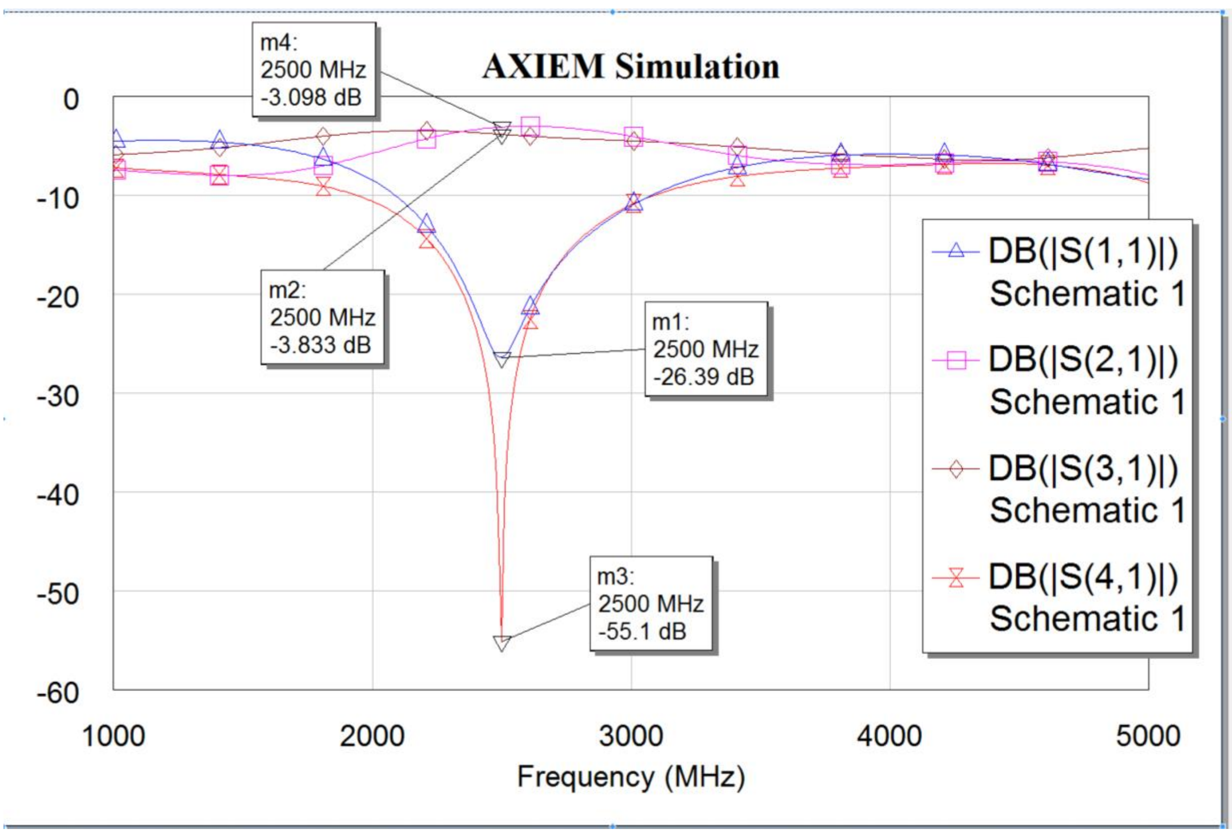
Layout:

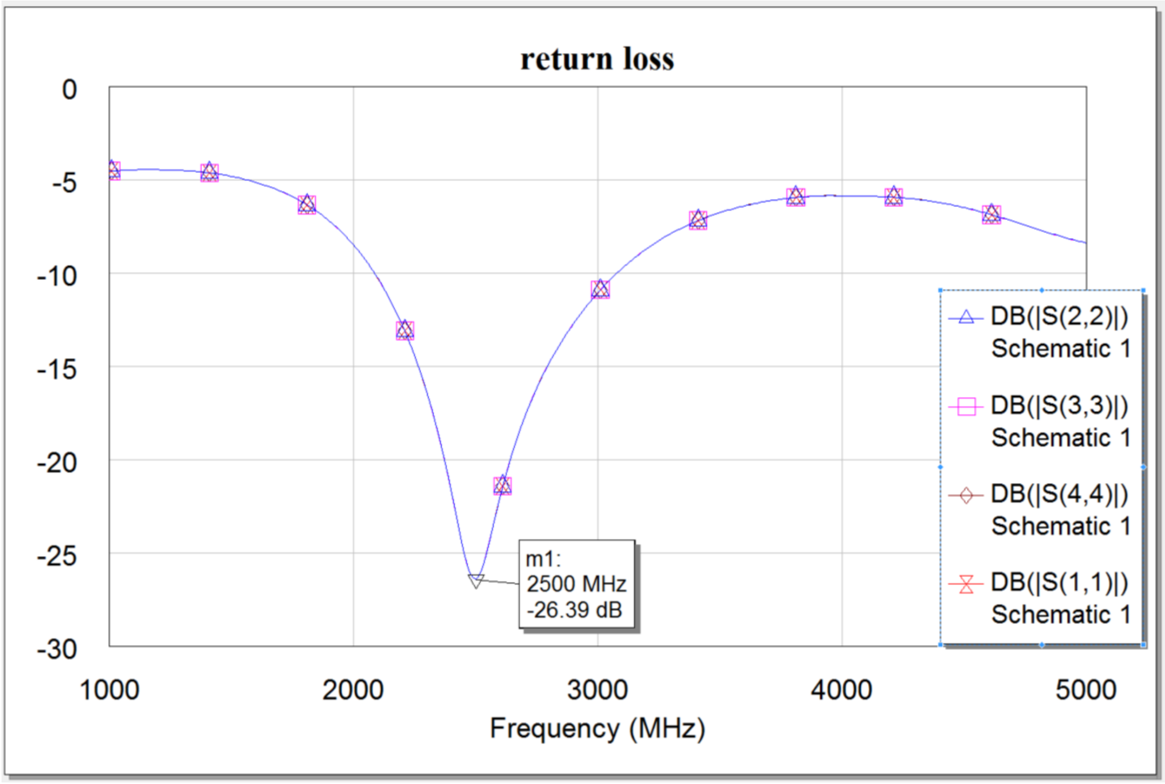


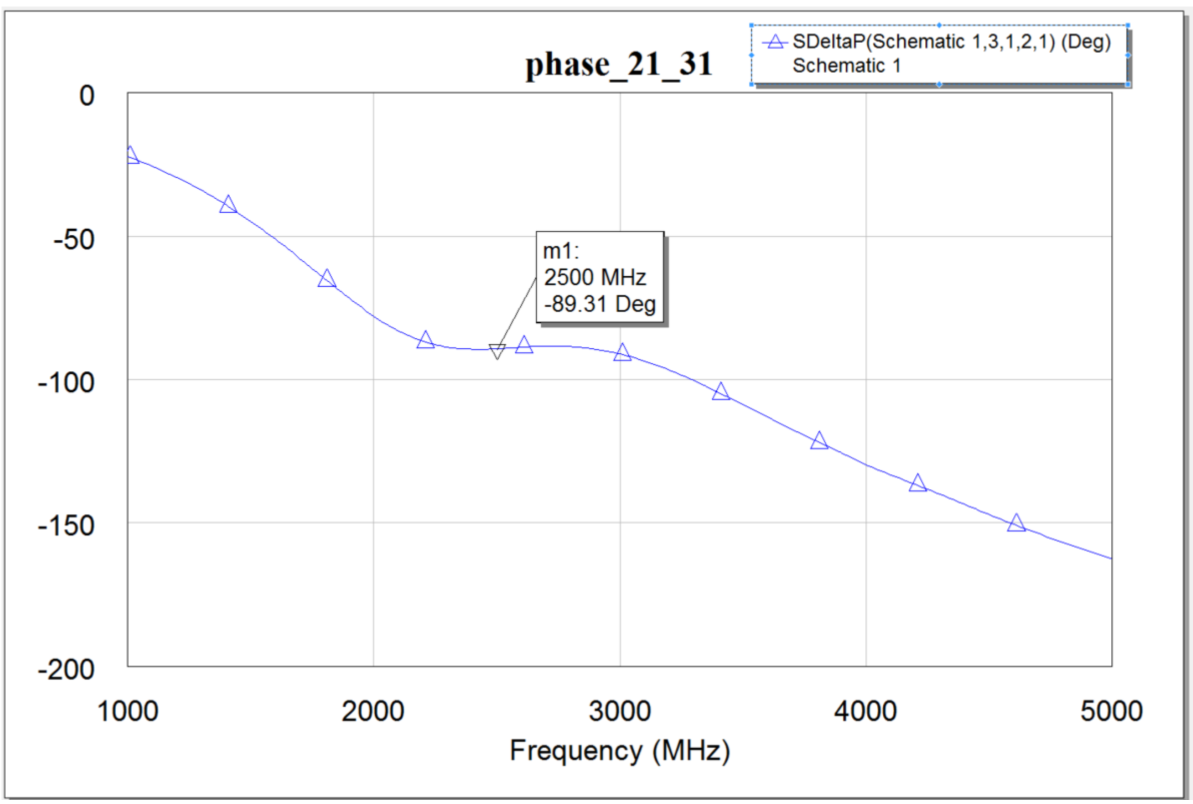
AXIEM Layout:



AXIEM Simulation:



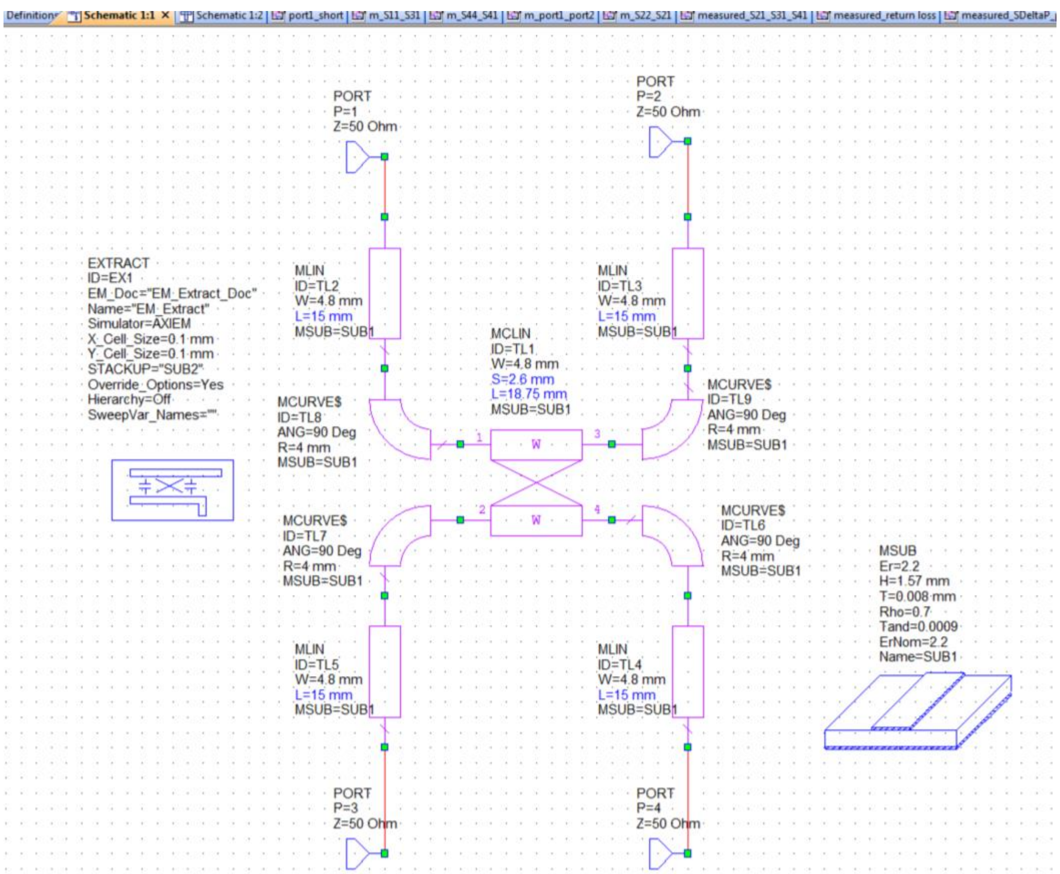

return loss
0
-5
-10
-15
-20
-25
-30
1000
2000
3000
4000
5000
Frequency (MHz)
m1:
2500 MHz
-26.39 dB
DB(|S(2,2)|)
Schematic 1
DB(|S(3,3)|)
Schematic 1
DB(|S(4,4)|)
Schematic 1
DB(|S(1,1)|)
Schematic 1


phase_21_31
SDeltaP(Schematic 1,3,1,2,1) (Deg)
Schematic 1
0
-50
-100
-150
-200
1000
2000
3000
4000
5000
Frequency (MHz)
m1:
2500 MHz
-89.31 Deg

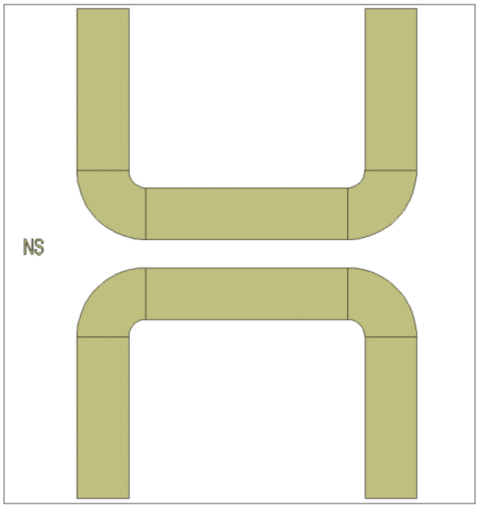
Parameter	Goal	Predicted
Center Frequency f_o (GHz)	2.5	2.5
Coupling (dB) at port 2	3.0	3.098
Coupling (dB) at port 3	3.0	3.833
Relative Phase (between output ports)	90	89.31
Input Return Loss at port 1@ f_o (dB)	>20	26.39
Output Return Loss at port 2 @ f_o (dB)	>20	26.39
Output Return Loss at port 3 @ f_o (dB)	>20	26.39
Output Return Loss at port 4 @ f_o (dB)	>20	26.39
Isolation between output ports 1 and 4@ f_o (dB)	> 20	55.1

Design B: 20dB Edge-coupled 4-port directional coupler

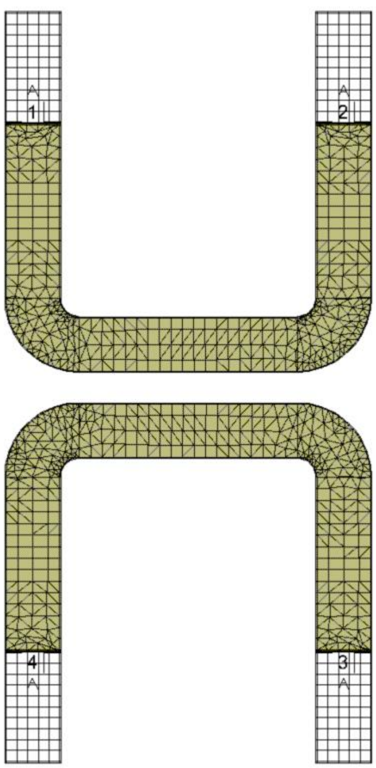
Circuit Schematic:



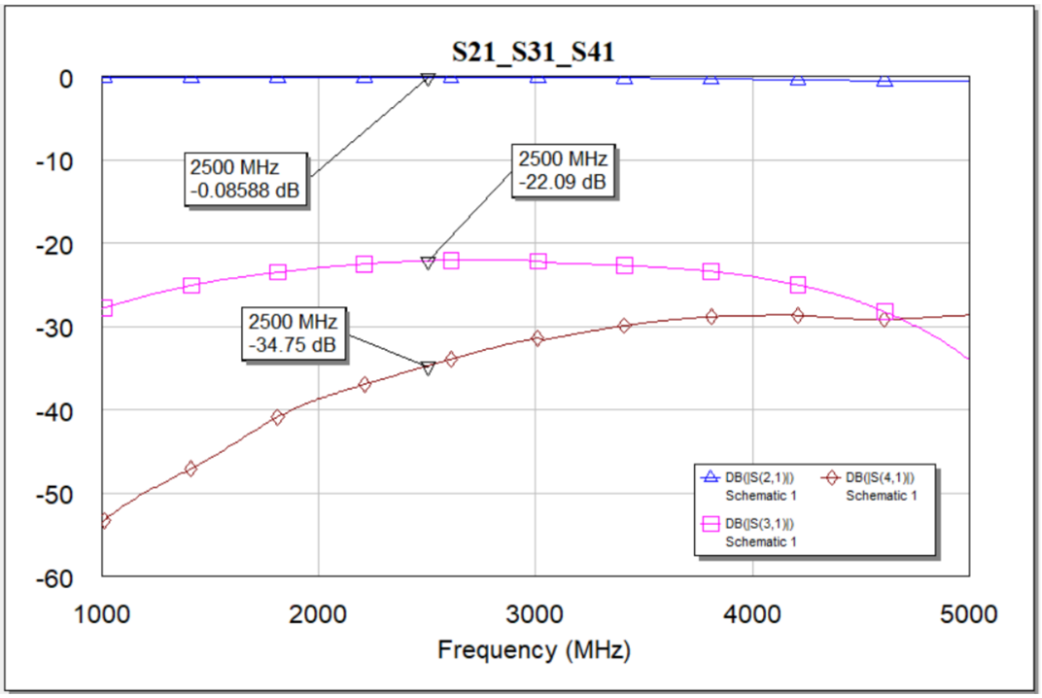
Layout:

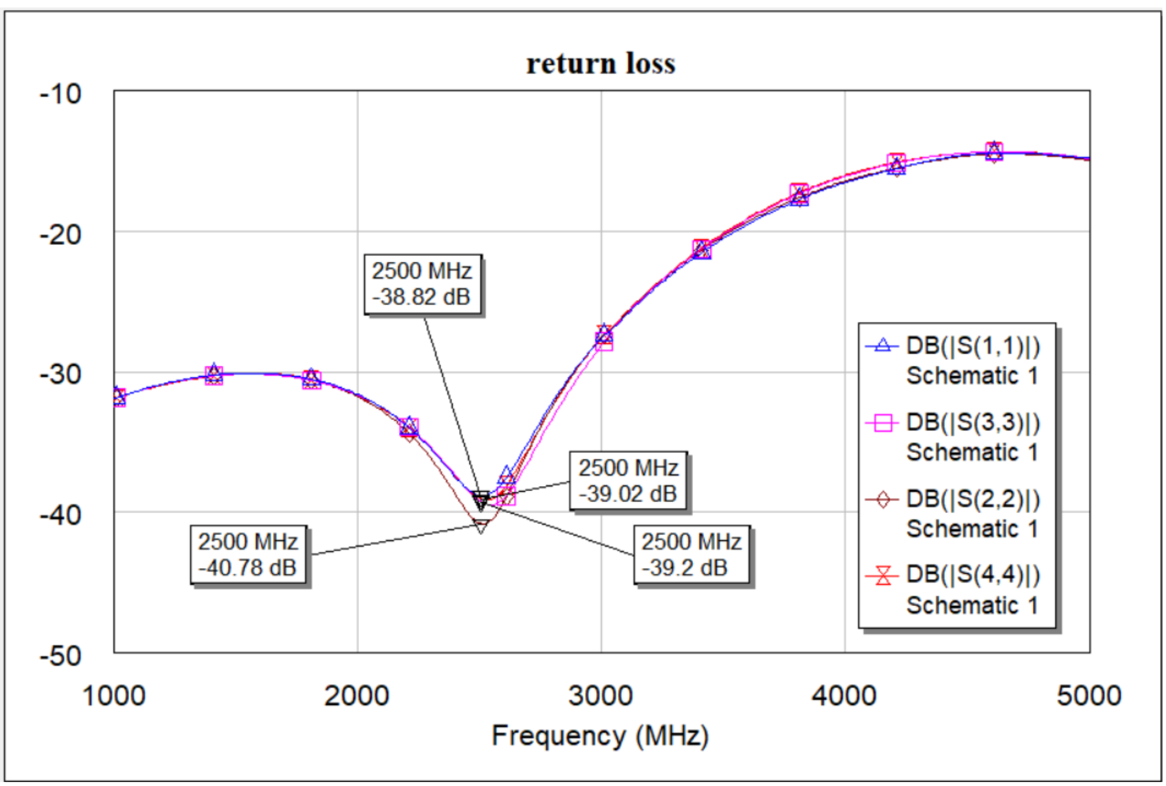


AXIEM Layout:

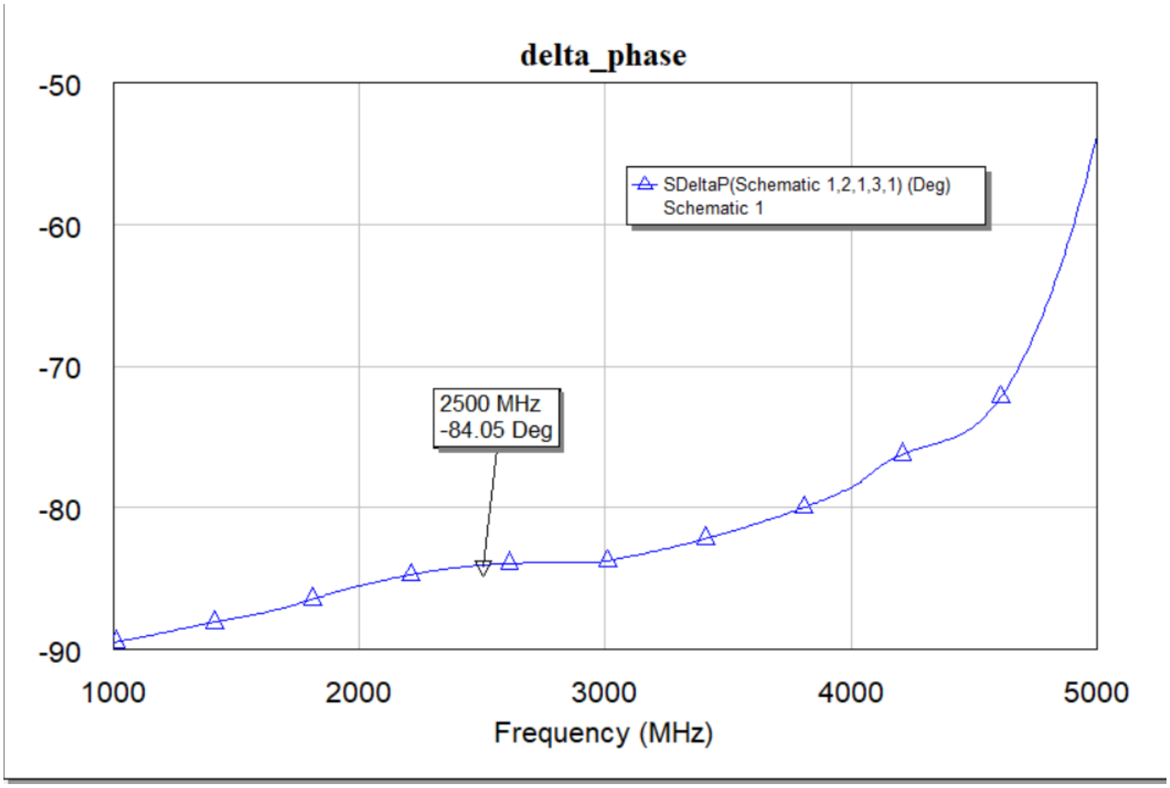


AXIEM Simulation:





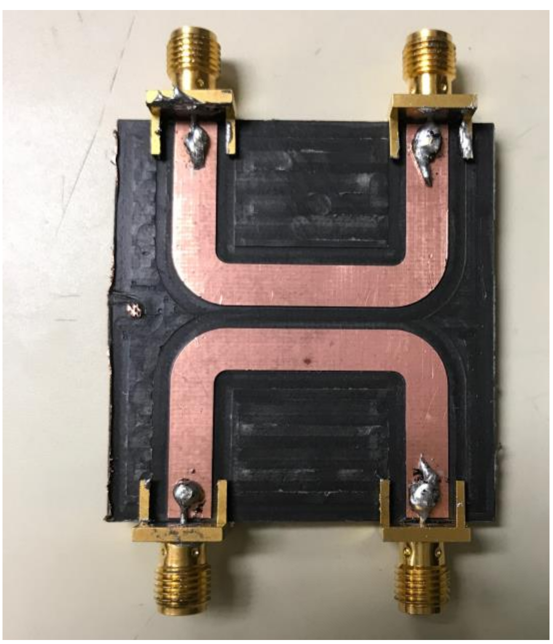
From the above graph, S11= -38.83dB, S22= -40.78 dB, S33= -39.2 dB, S44= -39.02 dB



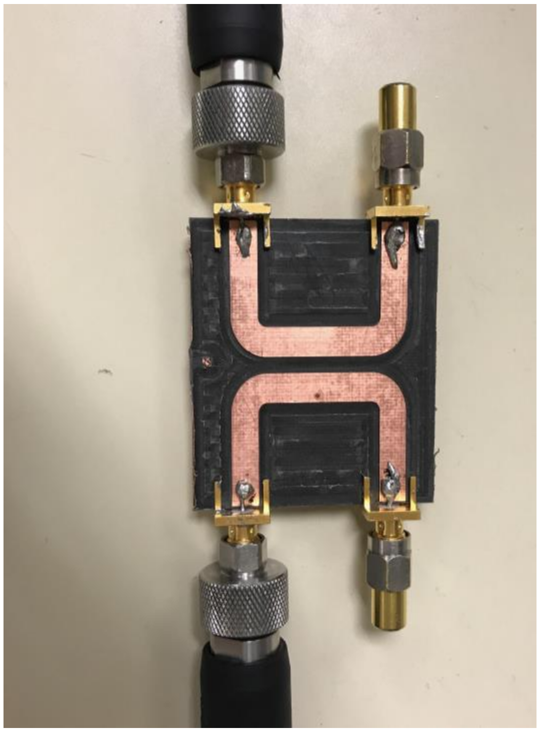
3. Measurement

A. Photographs of measured circuit:

Design B: 20dB Edge-coupled 4-port directional coupler

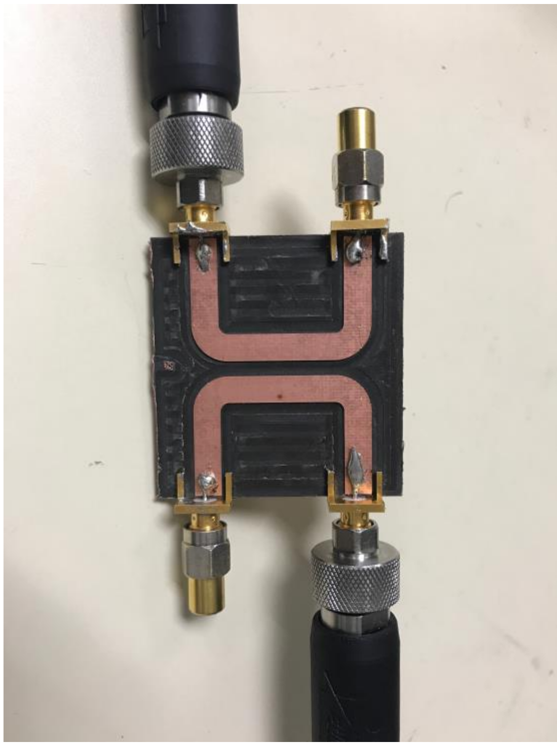


Port 1 and Port 3 measurement:



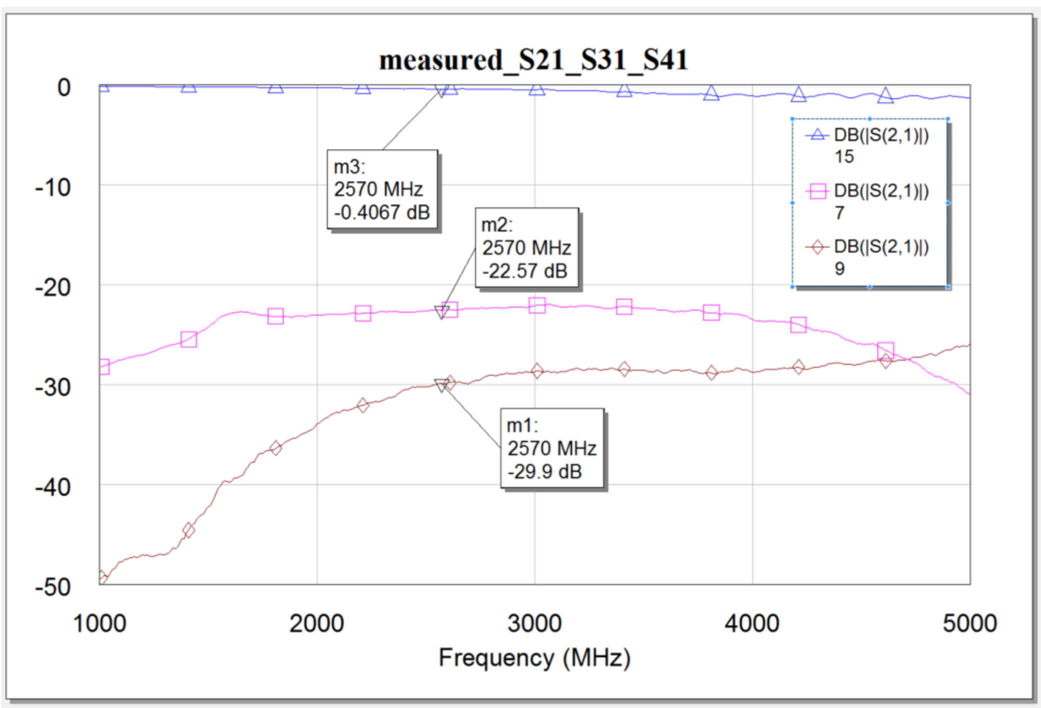
Port 1 and Port 2 measurement:

Port 1 and Port 2 measurement:



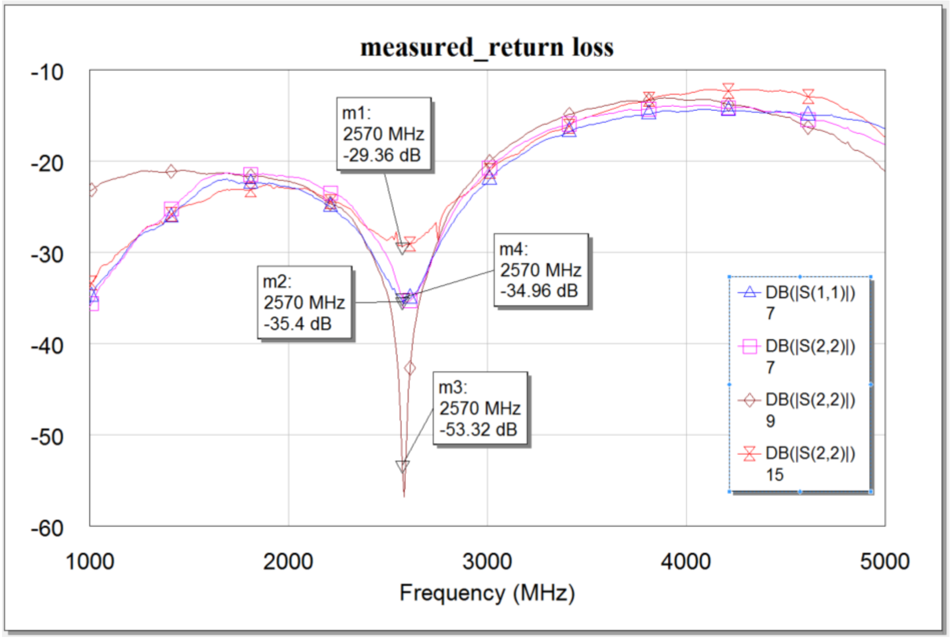
B. Plots of Measured Data

Plot 1: magnitude (in dB) for the direct, coupled and isolated ports



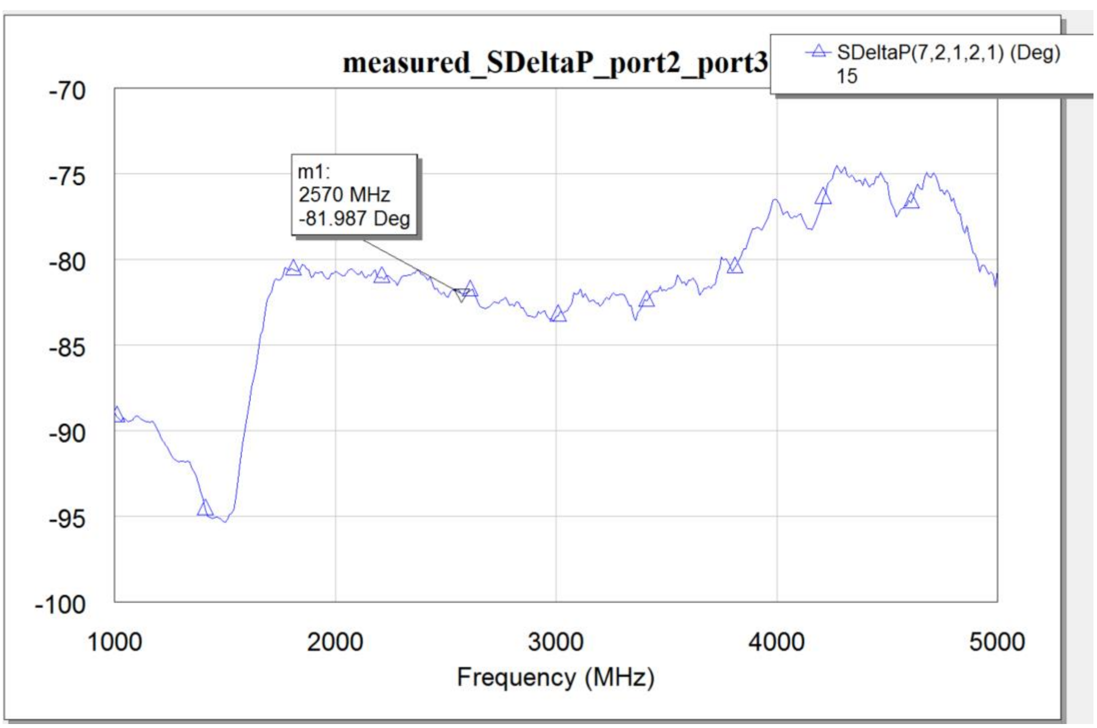
From the above graph, S21 = -0.4067 dB, S31 = -22.57 dB   and S41 = -29.9 dB.

Plot 2 : return loss (in dB) for each of the four ports



From the above graph, S11 = -35.4 db, S22 = -29.36 dB, S33 = -34.96 dB, S44 = -53.22 dB.

Plot 3: Δ-phase response (SDeltaP measurement) between ports 2 & 3



C. Summary

Board Size: 43.7 mm x 46.1 mm

Board thickness = varies from 1.4 mm to 1.5 mm.

Length of MLIN = 17.5 mm.

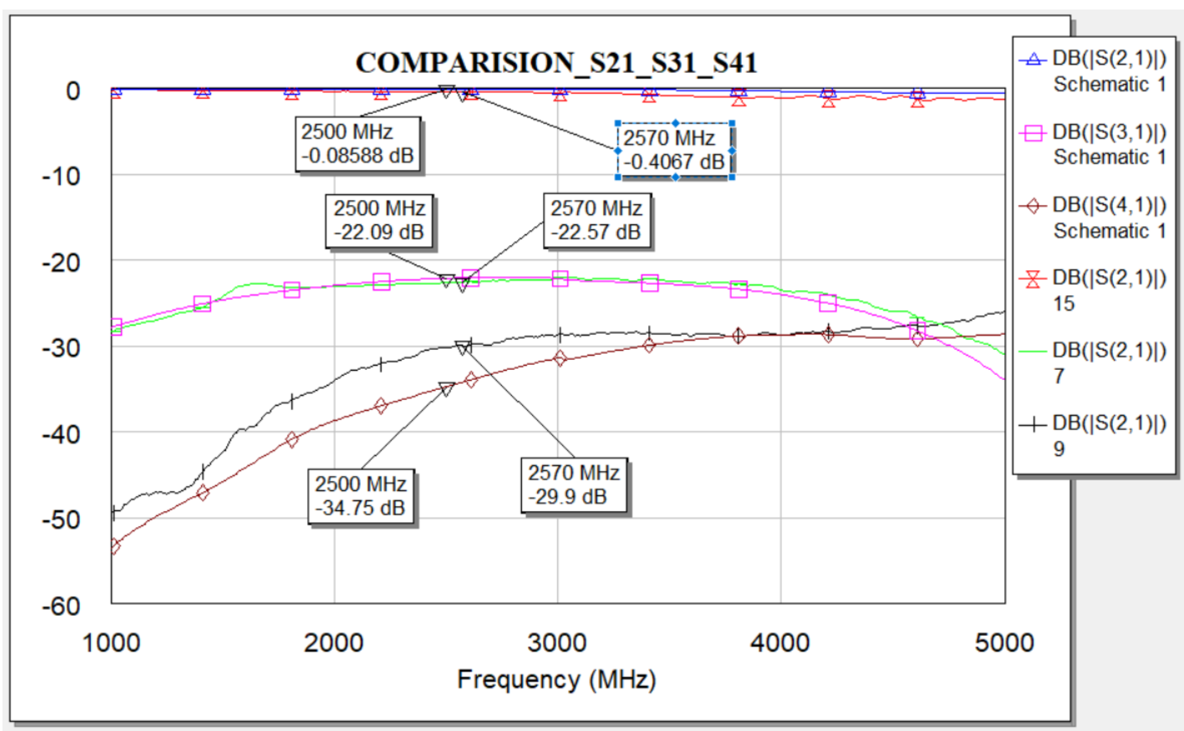
Spacing between the coupled lines to satisfy odd and even ode impedance is extremely important for achieving desired design goals.

4. Analysis

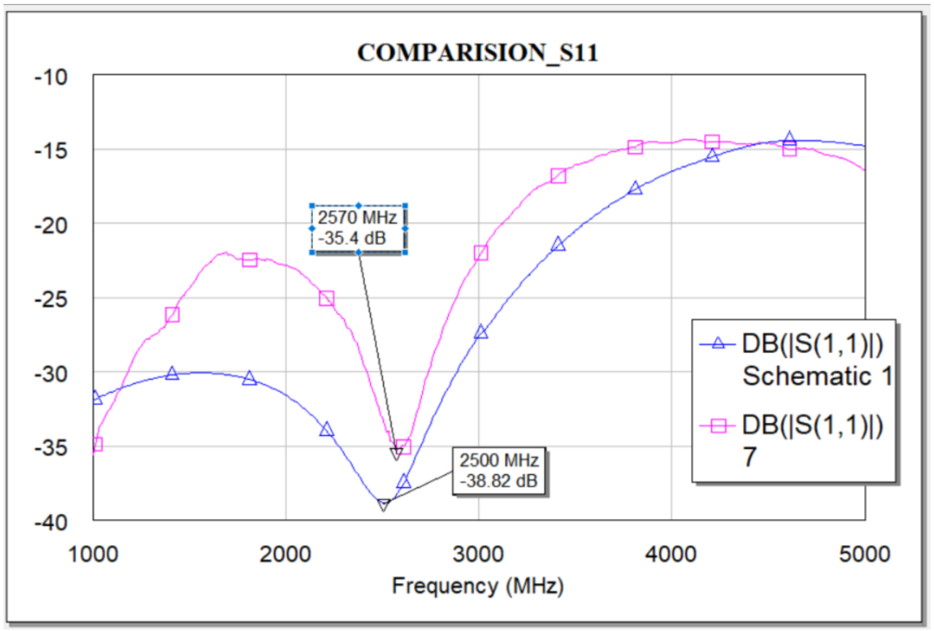
A. Comparison graph of predicted and measured graph

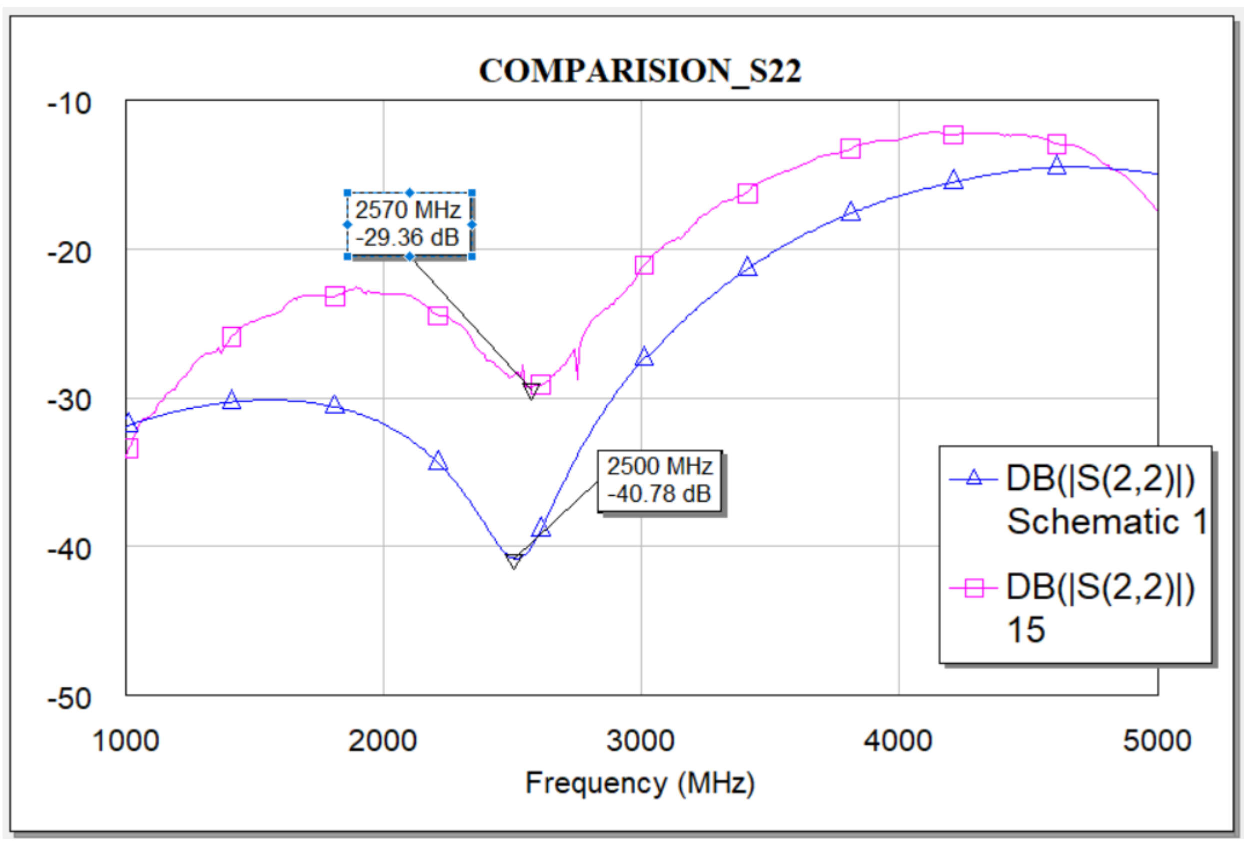
Design B: 20dB Edge-coupled 4-port directional coupler (My design was milled)

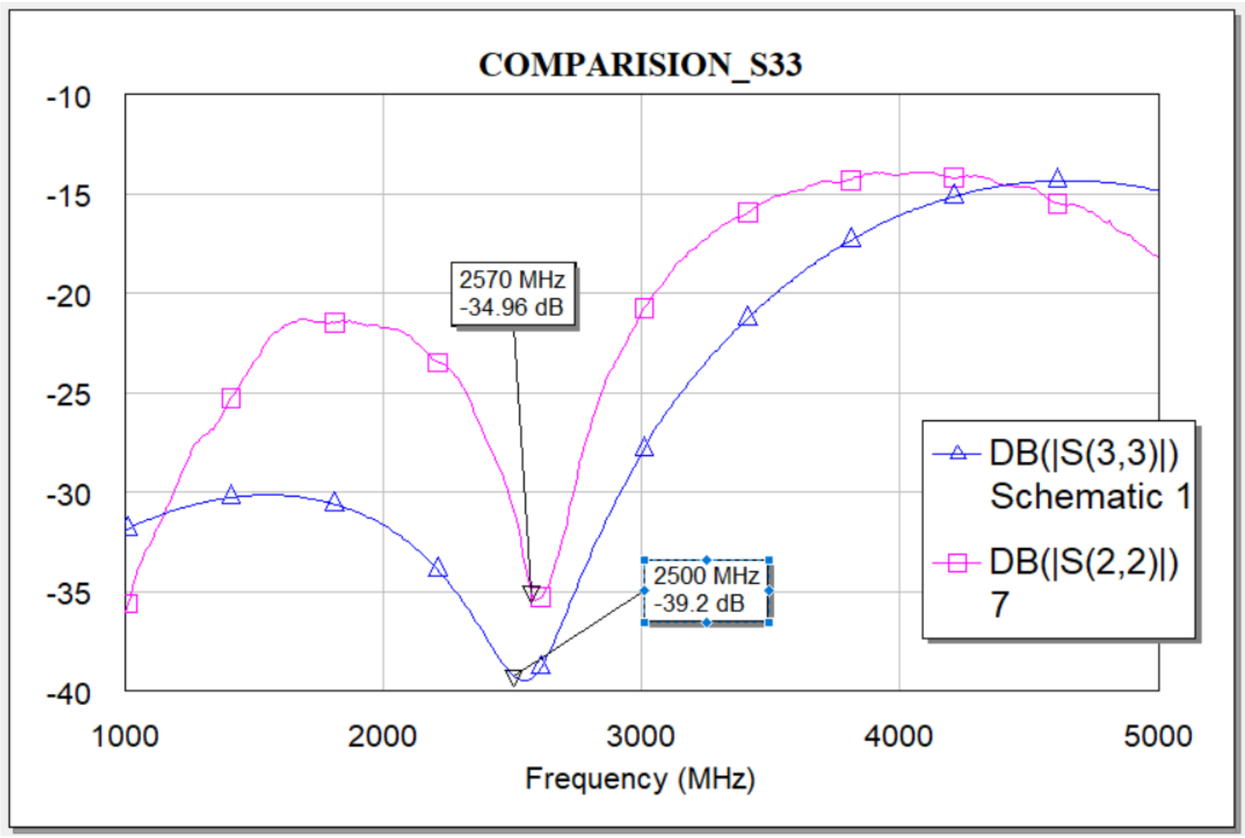
Magnitude (in dB) for the direct, coupled and isolated ports:

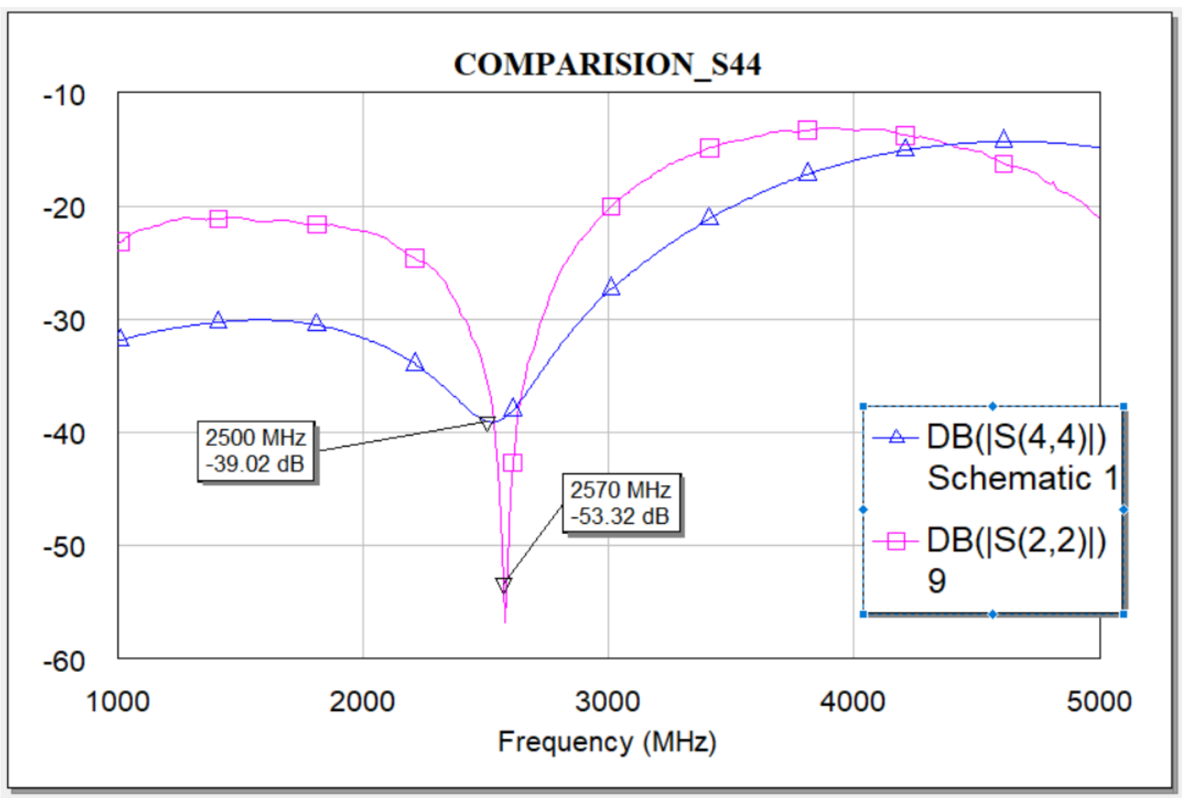


Return loss (in dB) for each of the four ports:

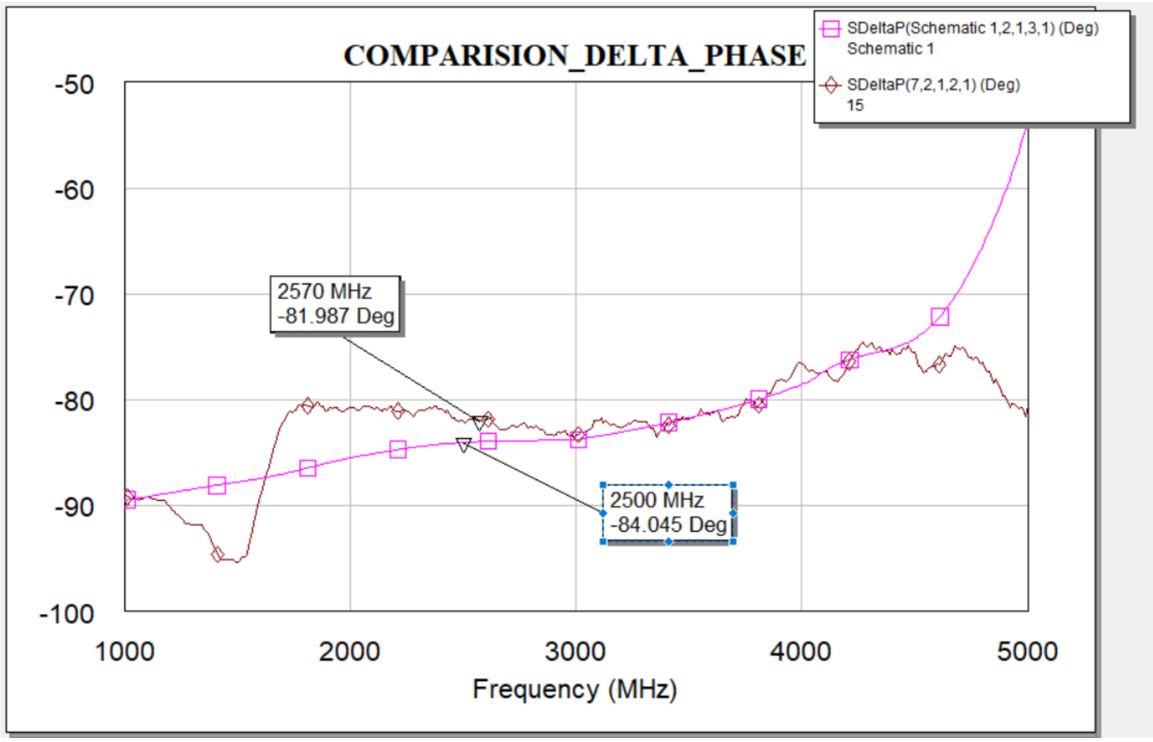

COMPARISION_S11
-10
-15
-20
-25
-30
-35
-40
1000
2000
3000
4000
5000
Frequency (MHz)
2570 MHz
-35.4 dB
2500 MHz
-38.82 dB
DB(|S(1,1)|)
Schematic 1
DB(|S(1,1)|)
7


COMPARISION_S22
-10
-20
-30
-40
-50
1000
2000
3000
4000
5000
Frequency (MHz)
2570 MHz
-29.36 dB
2500 MHz
-40.78 dB
DB(|S(2,2)|)
Schematic 1
DB(|S(2,2)|)
15


COMPARISION_S33
2570 MHz
-34.96 dB
2500 MHz
-39.2 dB
DB(|S(3,3)|)
Schematic 1
DB(|S(2,2)|)
7
Frequency (MHz)


COMPARISION_S44
2500 MHz
-39.02 dB
2570 MHz
-53.32 dB
DB(|S(4,4)|)
Schematic 1
DB(|S(2,2)|)
9
Frequency (MHz)

Δ-phase response (SDeltaP measurement) between ports 2 & 3:



B. Compliance matrix

Parameter	Goal	Predicted	Measured	Complaint
Center Frequency f_o (GHz)	2.5	2.5	2.57	Yes
Coupling (dB)	20.0	22.09	22.57	No
Input Return Loss at port 1@ f_o (dB)	>20	38.82	35.4	Yes
Output Return Loss at port 2 @ f_o (dB)	>20	40.78	29.36	Yes
Output Return Loss at port 3 @ f_o (dB)	>20	39.2	34.96	Yes
Output Return Loss at port 4 @ f_o (dB)	>20	39.02	53.32	Yes
Isolation between output ports 1 and 4@ f_o (dB)	> 20	34.75	29.9	Yes

C. Summary

Design A: 3-dB quadrature branch-line coupler

Design B: 20dB Edge-coupled 4-port directional coupler

1. What is the measured phase difference between the direct and coupled ports at the design frequency?

A1: The phase difference between two output ports is 89.31° (measured in AXIEM Simulation).
B1: The measured phase difference between the direct port and coupled port is 81.987°.

2. If your design does not appear to be centered at the design frequency what is the most likely cause?

B2: In edge coupler design, the measured center frequency is 2.57 GHz which was measured to be 2.5 GHz in AXIEM Simulation. The reason behind this shift could be defects in the material and inaccuracy in the milling process.

5. Conclusion

A. Was the design successful? Why or why not?

All the design parameters were met except |S31| was measured to be 22.57 dB which means that the design was under-coupled. This is because the spacing between the coupling lines was too large. Spacing between the coupled lines to satisfy odd and even ode impedance is extremely important for achieving desired design goals.

B. What lessons did you learn from the lab?

From this lab, I learned that it is important to find precise spacing between coupling lined in order to avoid under-coupling or over-coupling.
Unlike FR-4, Duroid causes low losses which needs to be taken into consideration while designing the circuit.