Lab7 Microwave Directional Coupler

EERF – 6396

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1. Introduction

Objectives:

a. Design a 50-Ω **microstrip 3-dB quadrature branch-line coupler**. Compare the design against physical results and Axiem simulation.

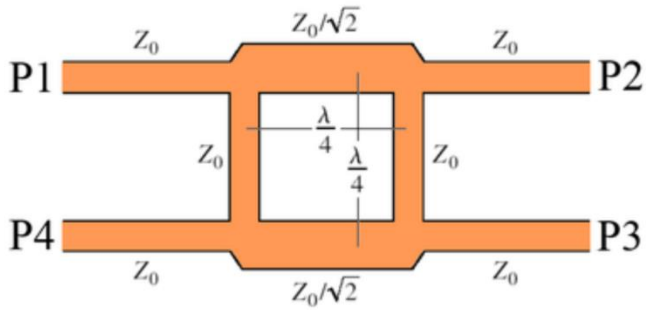
b. Design a **microstrip edge-coupled 4-port 20dB directional coupler**. Build and test your design in the lab.

2. Significance

Directional couplers are passive RF devices which split EM power to two ports to be used in different circuits. The advantage of the directional couplers is that they combine power flowing only in 1 direction. Power entering the output port is coupled only to the isolated port but not to the coupled port. Accordingly, any of the mismatch SWR from say an amplifier connected to the output port of the directional coupler will find itself at the isolated port. This results in higher return loss. Directional couplers which split power equally are called hybrid couplers. There is also at 90^{o} phase shift between the output ports. Branch line couplers have tighter coupling as compared to coupled designs but have restrictions in band width.

3. Design

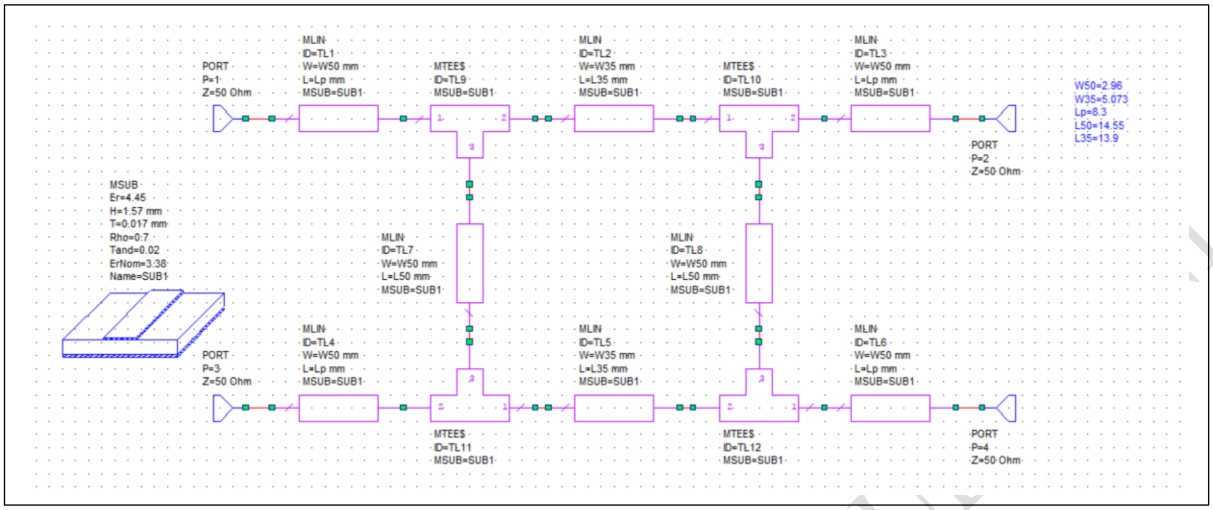
A. Branch line coupler – Omkar Kulkarni



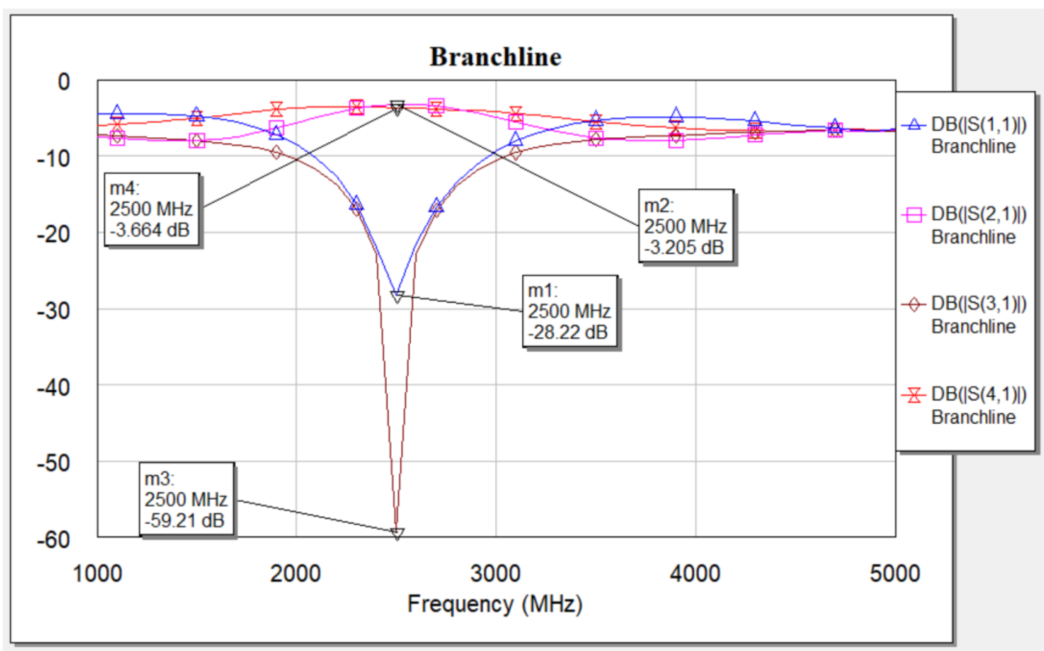
P1 – Input port
P2 – Direct port
P3 – Coupled port
P4 – Isolated port

The branch line coupler is matched at all ports with impedance $Z_0 = 50\Omega$ in this case. The central square structure has dimension of λ/4. However, there is a difference in the impedance and hence the line widths. The $Z_0/\sqrt{2}$ value comes to be 35.4Ω. The line widths are calculated from Tx line tool and are found to be $W(Z_0) = 2.96$ mm and $W(Z_0/\sqrt{2}) = 5.073$ mm at 2.5 GHz. The lengths of the lines were taken to be multiples of λ\4 and tuned for the desired results. MTEE$ elements were used to join the lines of different widths. Rest all elements used were MLIN.

- **AWR MWO Schematic**



- **S-parameters from circuit simulations**
  Direct, Isolated and coupled port parameters



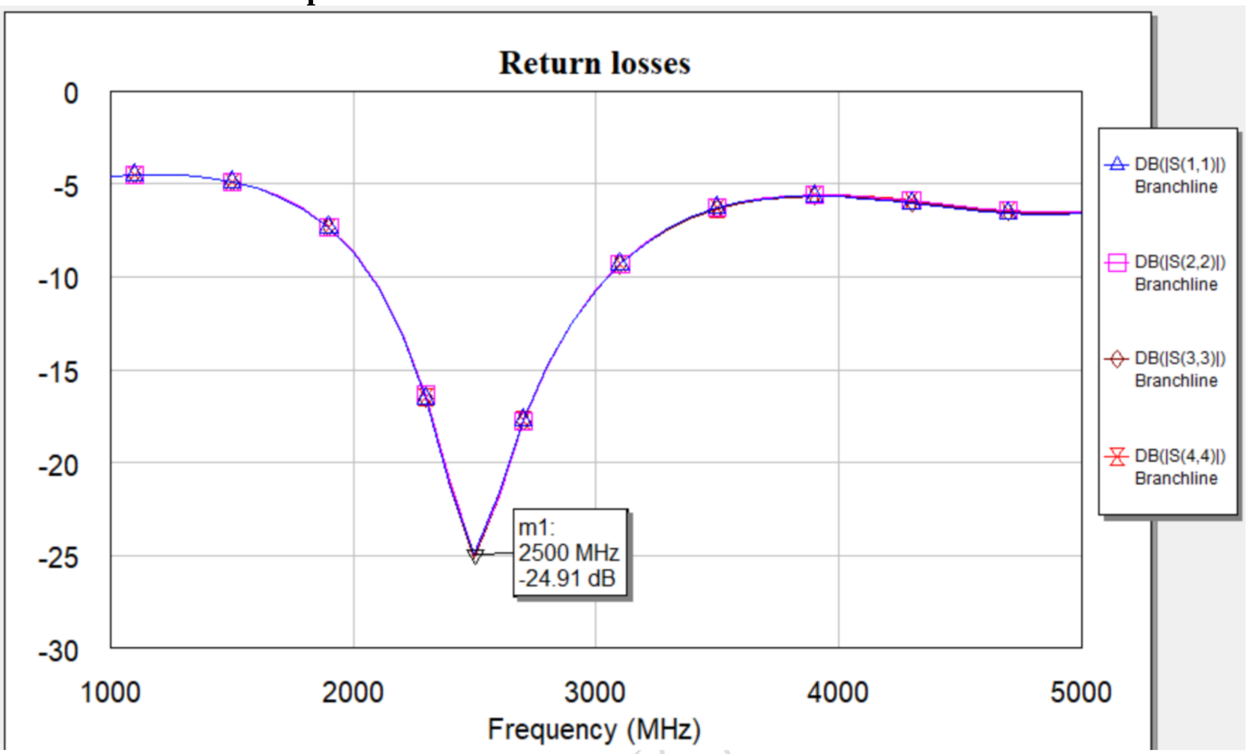
1 – Input Port

2 - Direct Port

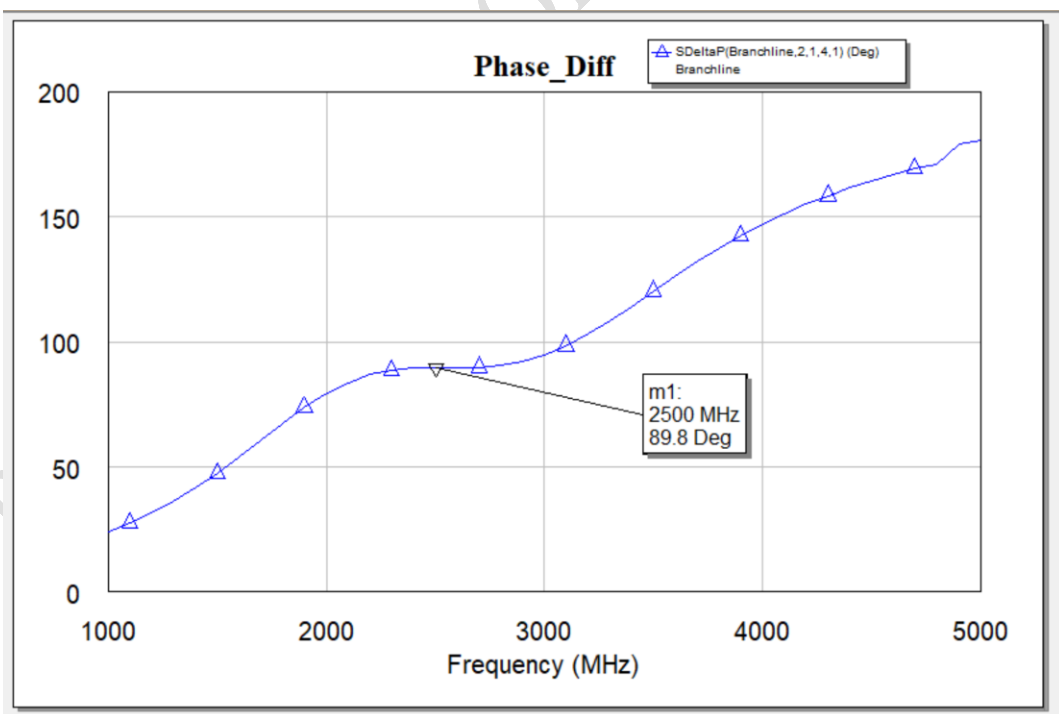
3 -Isolated Port

4 -Coupled Port

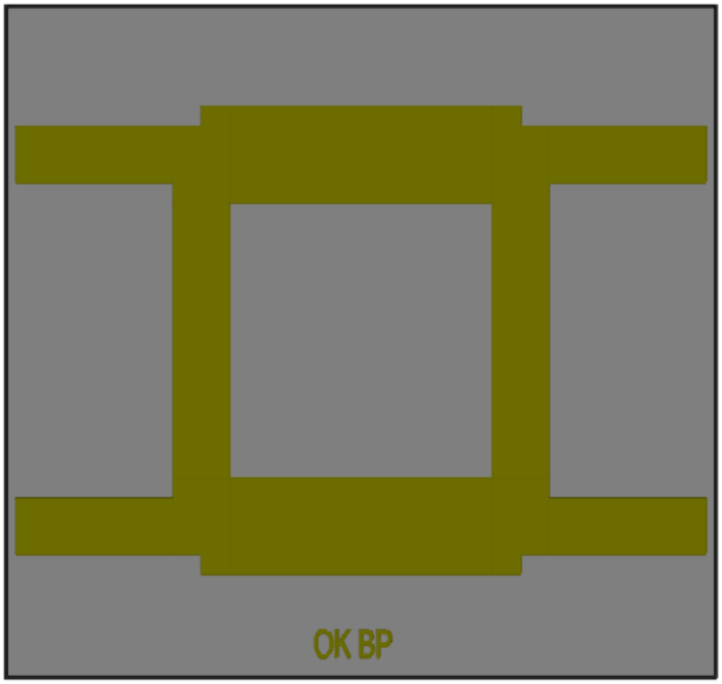
Return losses for each ports



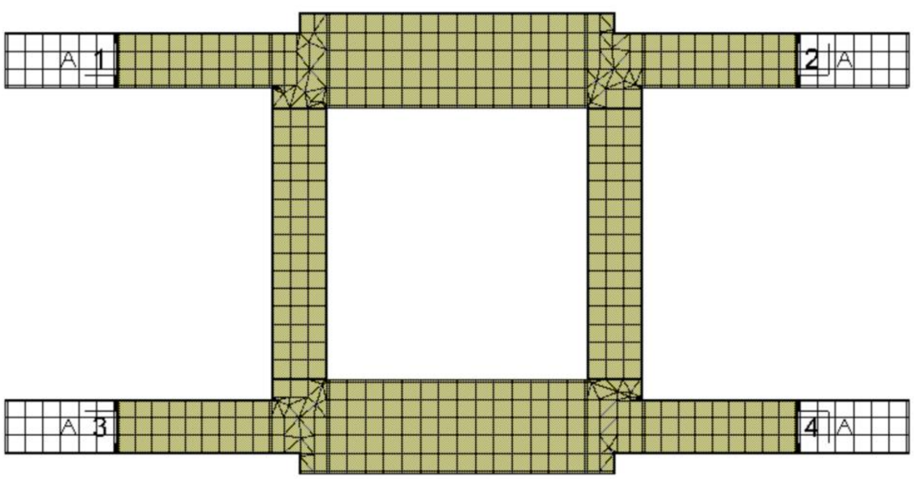
- **Phase plots from circuit simulation**



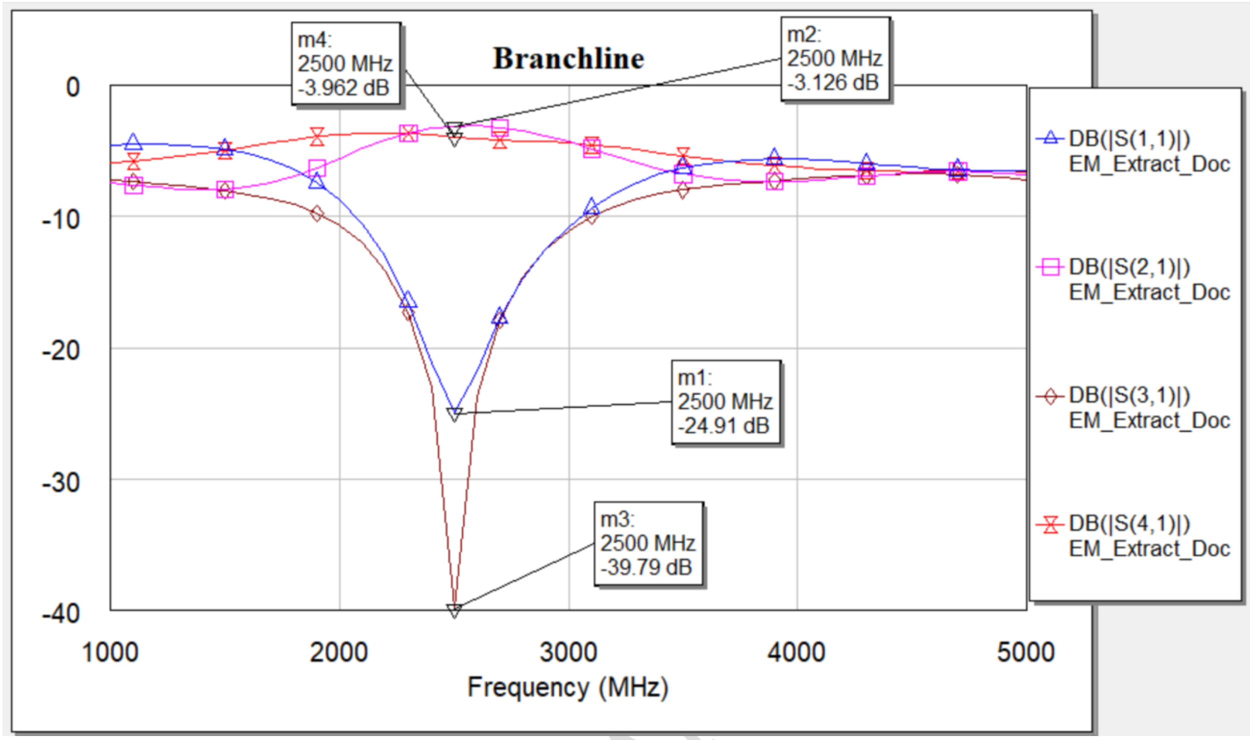
- **Board layout**



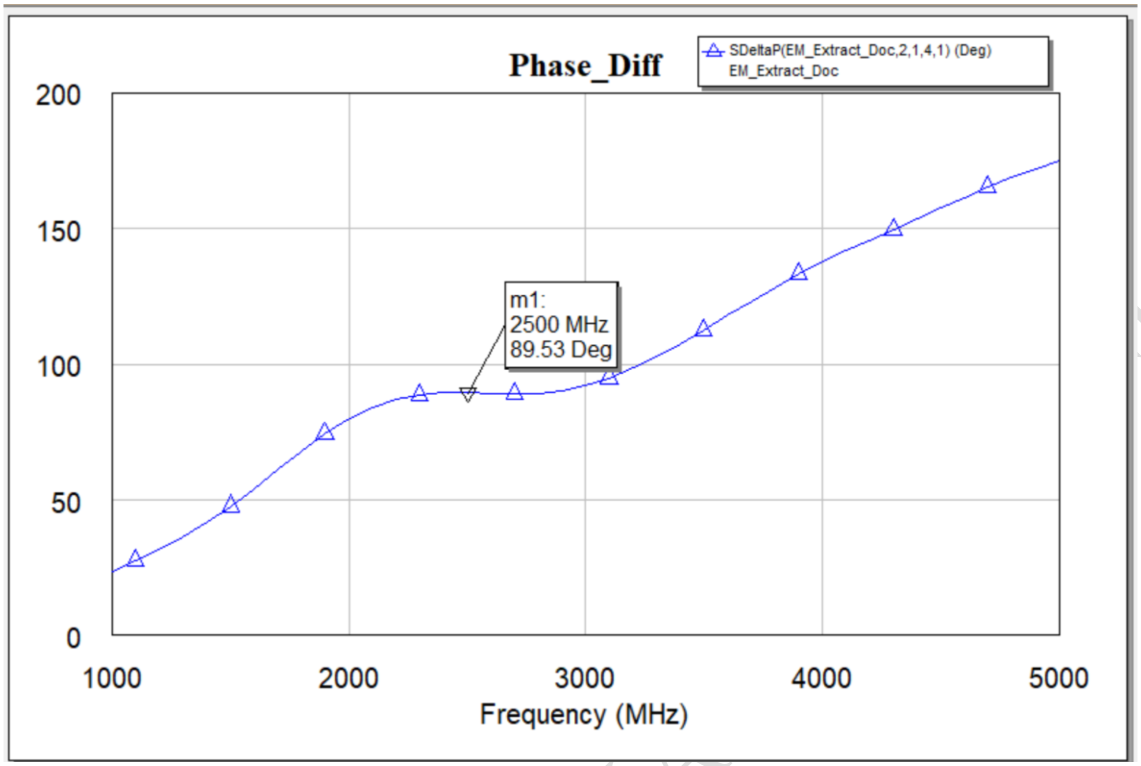
- **Axiem mesh**



- **Axiem mesh simulation results**



- **Phase difference from Axiem mesh simulation**

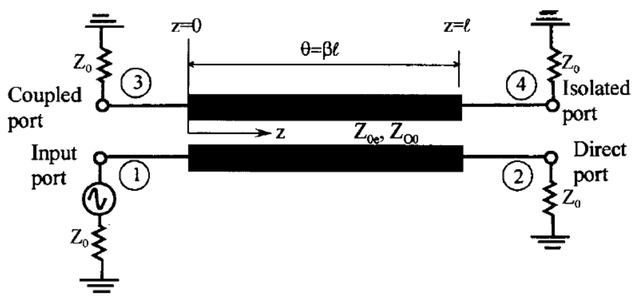


- **Design Compliance**

Parameter	Design Goal	Simulated Performance	Compliance
Center Frequency (GHz)	2.5	2.5	Yes
Coupling @ f_o (dB)	3.0	3.962	No
Relative Phase @ f_o (between ports 2 & 3) (deg)	90	89.53	Yes
Input Return Loss @ f_o (dB) (each port)	>20	S_{11} = 24.91 S_{22} = 29.56	Yes
Isolation @ f_o (between ports 1 & 4) (dB)		37.79	Yes

- **Summary:**
The results obtained from the circuit simulation and Axiem simulation are close to each other. Initially the design values didn't lie near the objectives. After tuning the design goals were achieved.

B. Edge coupled directional coupler – Behnam Pouya



Source: RF and Microwave Coupled-Line Circuits by Mongia

The edge coupled directional coupler has the port layout like the branch line coupler. The design is consummated by placing transmission lines close to each other which results in linking between the 2 transmission lines.

The design uses even odd mode analysis to calculate Even (Z_{0e}) and odd mode (Z_{0o}) impedances.

Calculations for a 20 dB coupler:

$C = 10 \log c^2$ …Where C = 20dB

$\therefore c = 0.1$

$Z_{0e} = Z_0\sqrt{\frac{1+c}{1-c}} = 55.28\ \Omega$ $Z_{0o} = Z_0\sqrt{\frac{1-c}{1+c}} = 45.23\ \Omega$ … with $Z_0 = 50\Omega$

The λ_{ms}, ϵ_{eff} are calculated from Tx line tool and the corresponding width is fixed.

To obtain the spacing between the MCLIN various values were run through the Tx line Coupled MS Line to obtain close values to $Z_{0e} = 55.28\ \Omega$ and $Z_{0o} = 45.23\ \Omega$.

Accordingly, the value of s = 1.811 mm was fixed.

20 dB coupler

$C = 10 \log c^2$

$\therefore -20 = 10 \log c^2$

$\therefore -2 = \log c^2$

$\therefore 10^{-2} = c^2$

$\therefore \frac{1}{100} = c^2$

$\therefore \boxed{c = 0.1}$

$Z_{0e} = Z_0 \sqrt{\frac{1+c}{1-c}} = 55.28$

$Z_{00} = Z_0 \sqrt{\frac{1-c}{1+c}} = 45.23$

3 dB coupler

$-3 = 10 \log c^2$

$\therefore \frac{-3}{10} = \log c^2$

$\therefore c^2 = 10^{-3/10}$

$\therefore c = 0.70794$

$\therefore Z_{0e} = Z_0 \sqrt{\frac{1+c}{1-c}} = 120.913$

$Z_{00} = Z_0 \sqrt{\frac{1-c}{1+c}} = 20.675$

W = 4.5 mm

1.) S = 3.9 mm
$Z_{0e} = 53.37\ \Omega$
$Z_{00} = 48.8326\ \Omega$

2.) S = 3.5 mm
$Z_{0e} = 53.6155$
$Z_{00} = 48.3744$

3.) S = 2.7 mm
$Z_{0e} = 54.3005$
$Z_{00} = 47.1843$

4.) S = 2.5 mm
$Z_{0e} = 54.5275$
$Z_{00} = 46.8152$

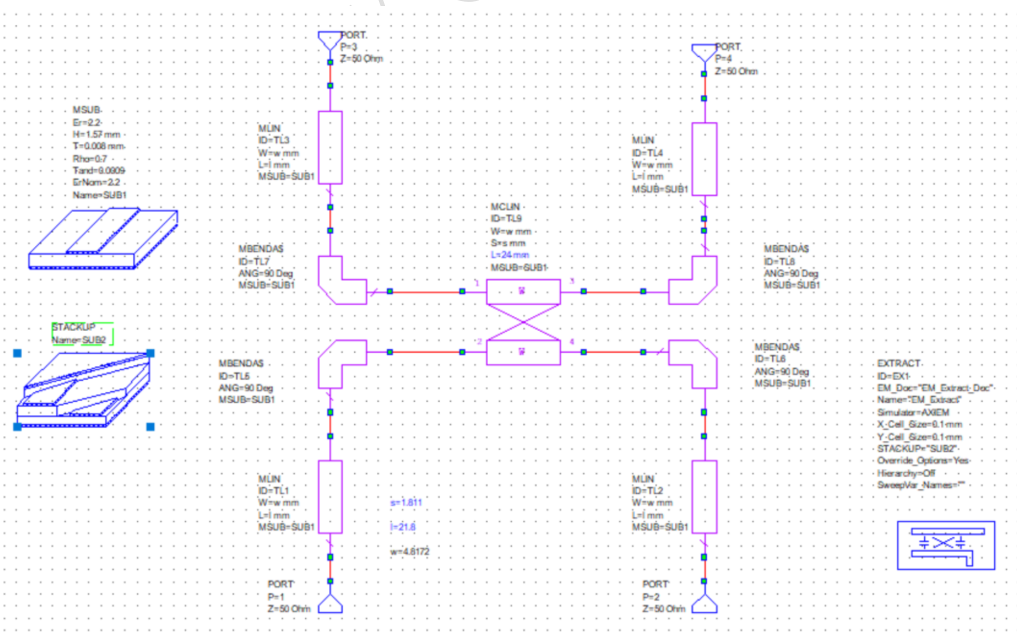
5.) S = 2.3 mm
$Z_{0e} = 54.7832$
$Z_{00} = 46.4085$

6.) S = 2 mm
$Z_{0e} = 55.2207$
$Z_{00} = 45.7131$

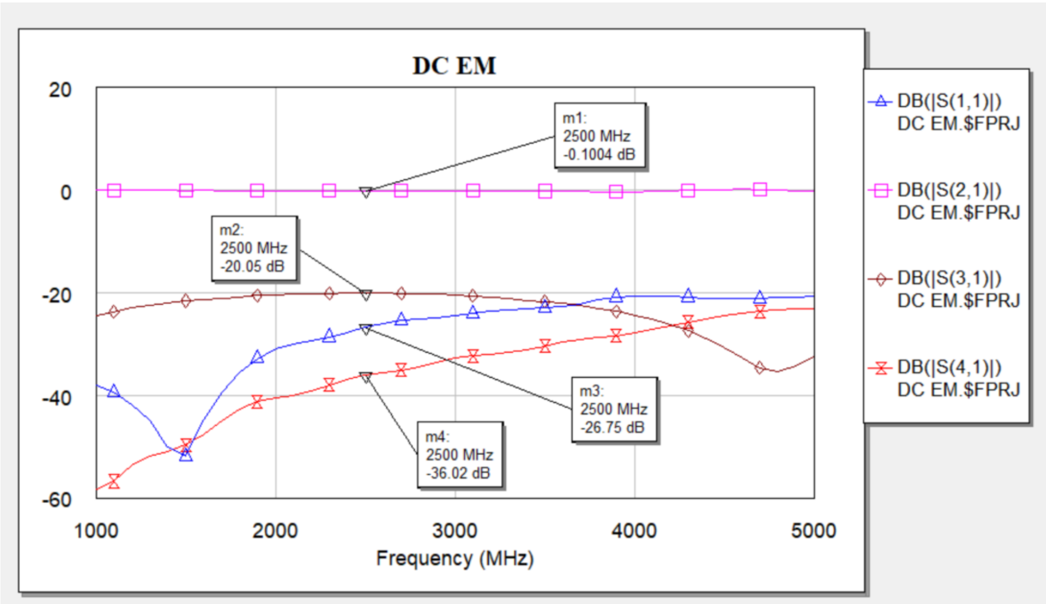
7.) S = 1.9 mm
$Z_{0e} = 55.3978$ → C
$Z_{00} = 45.5481$ → 0.09

8.) S = 1.7 mm
$Z_{00} = 55.7174$
$Z_{0e} = 44.8865$

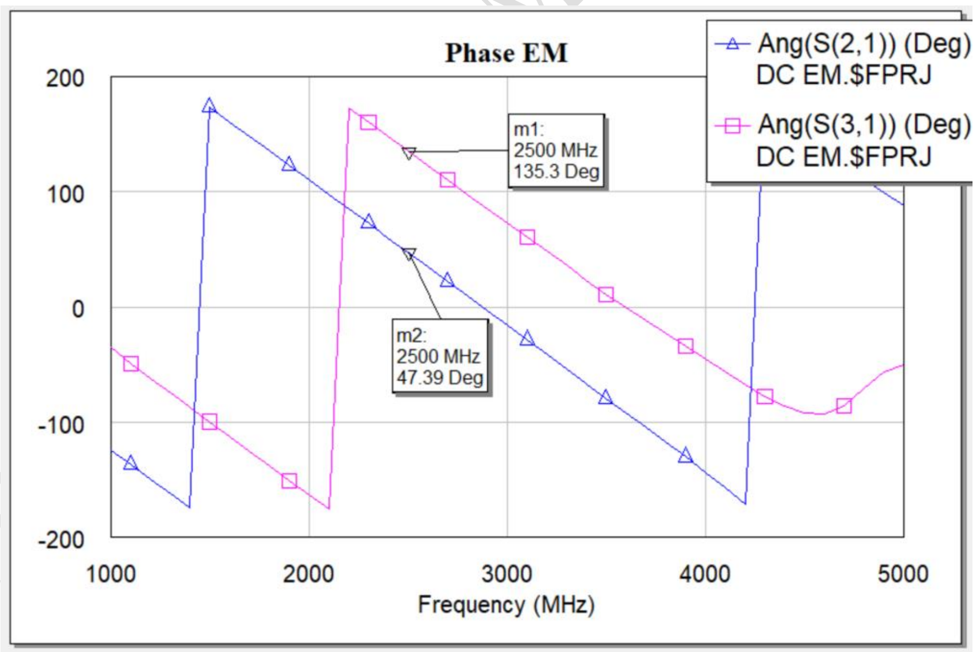
- **AWR MWO Schematic**



- **S-parameters from Axiem simulations**

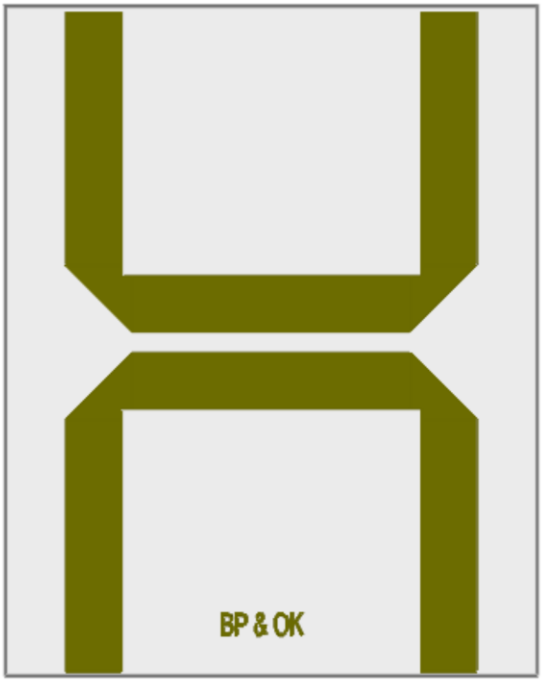


- **Phase difference between output ports**



Phase difference = 87.91°

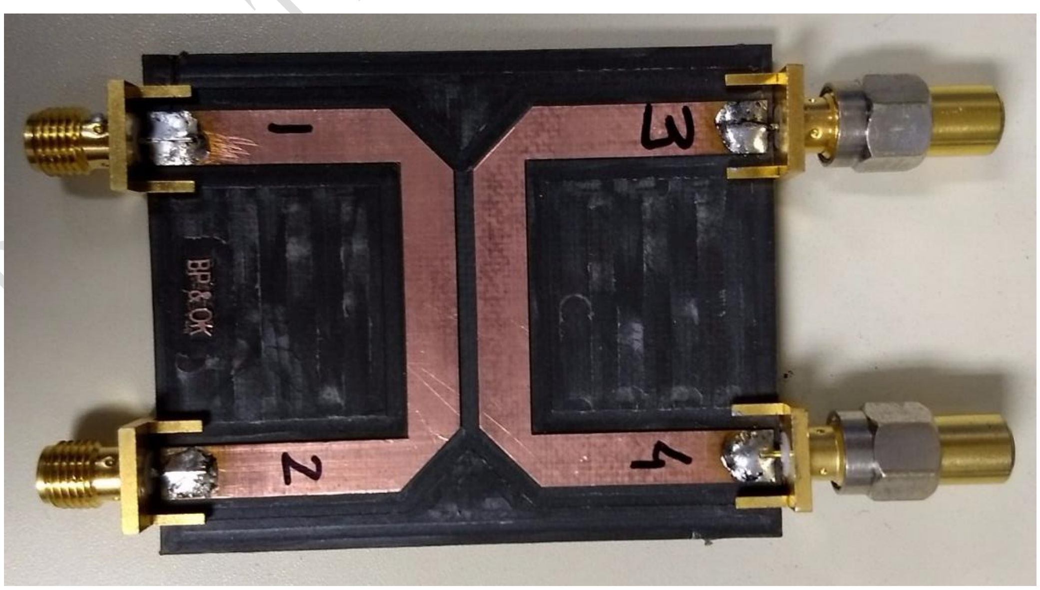
- **Axiem Board layout**

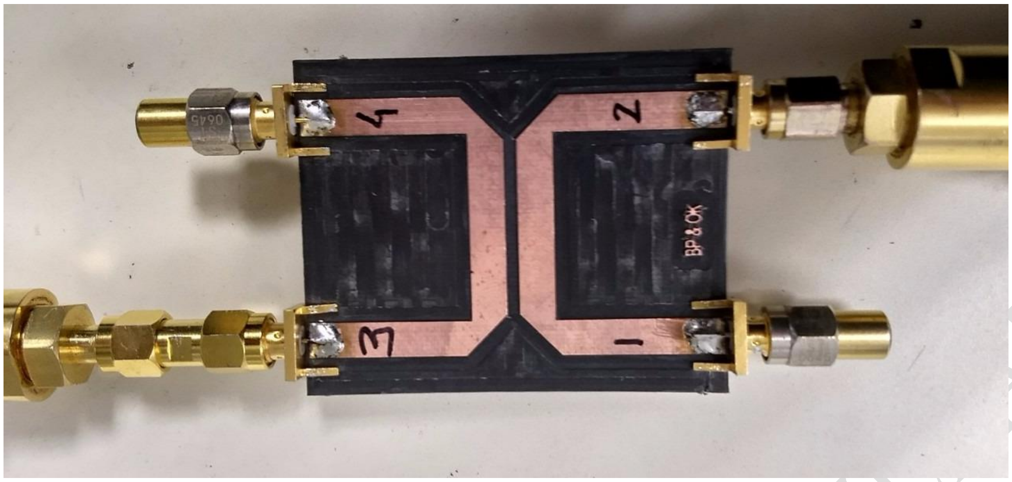


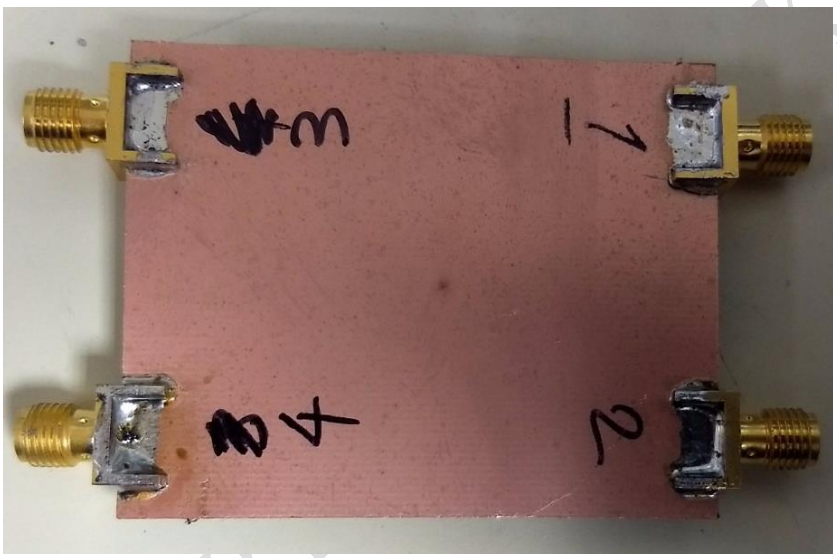
- **Summary:**
  Finding the spacing "s" between the coupled lines to satisfy the odd and even mode impedance is a crucial aspect in achieving the desired performance.

4. Lab Measurements

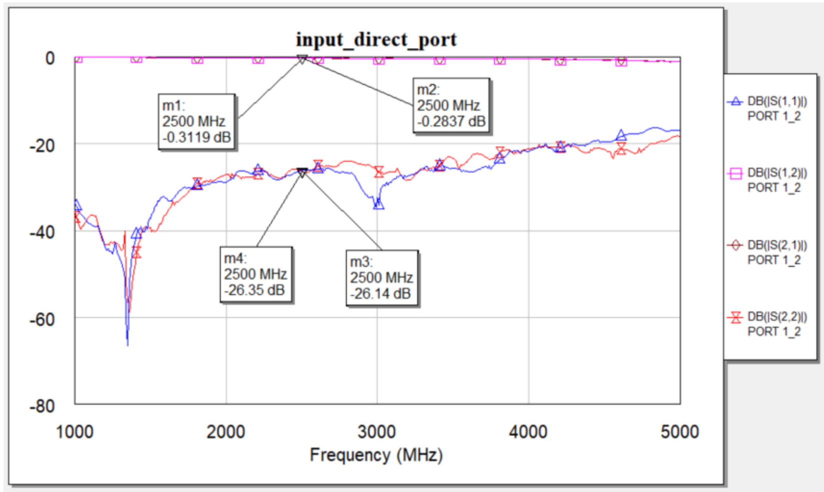
- **Lab setup photographs**



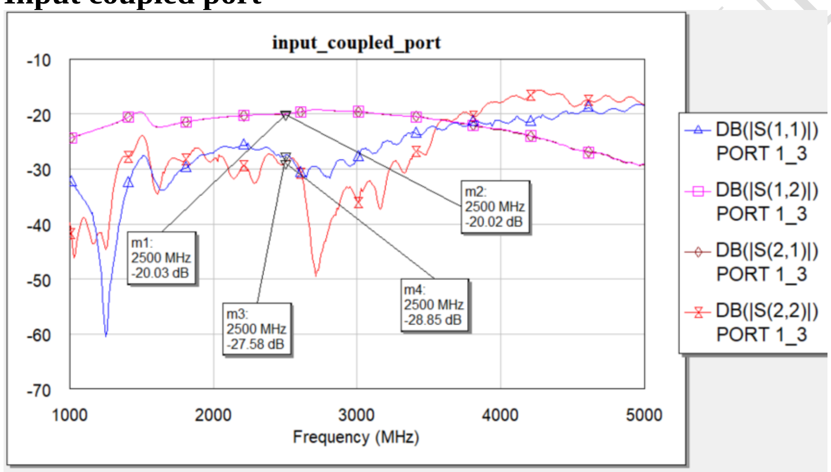




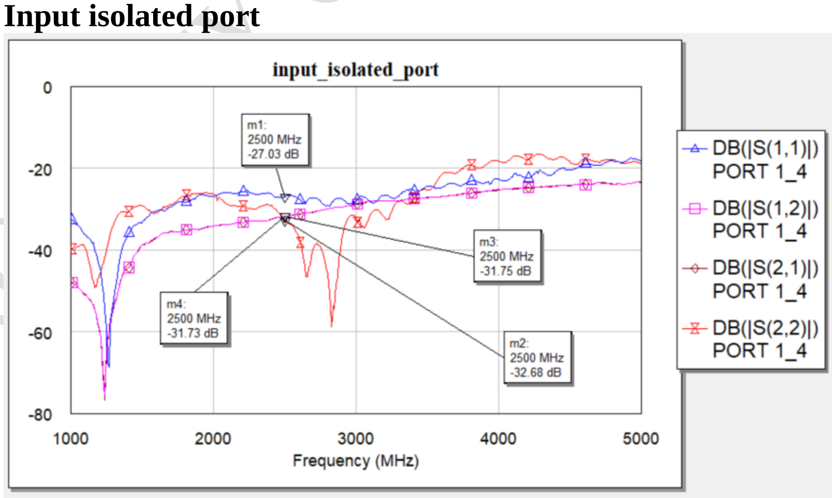
- **Lab Measurements**
  1. **Input and direct port**



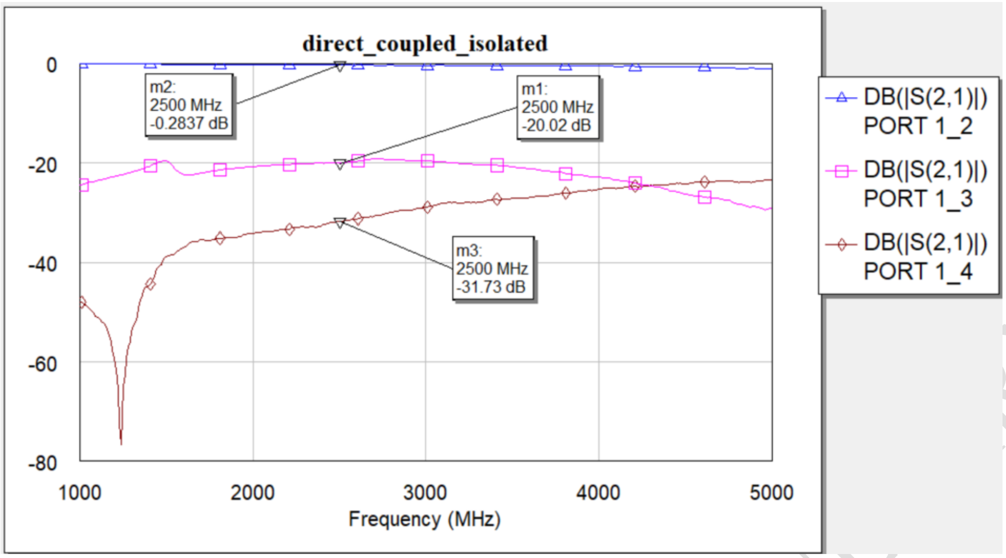
2. Input coupled port



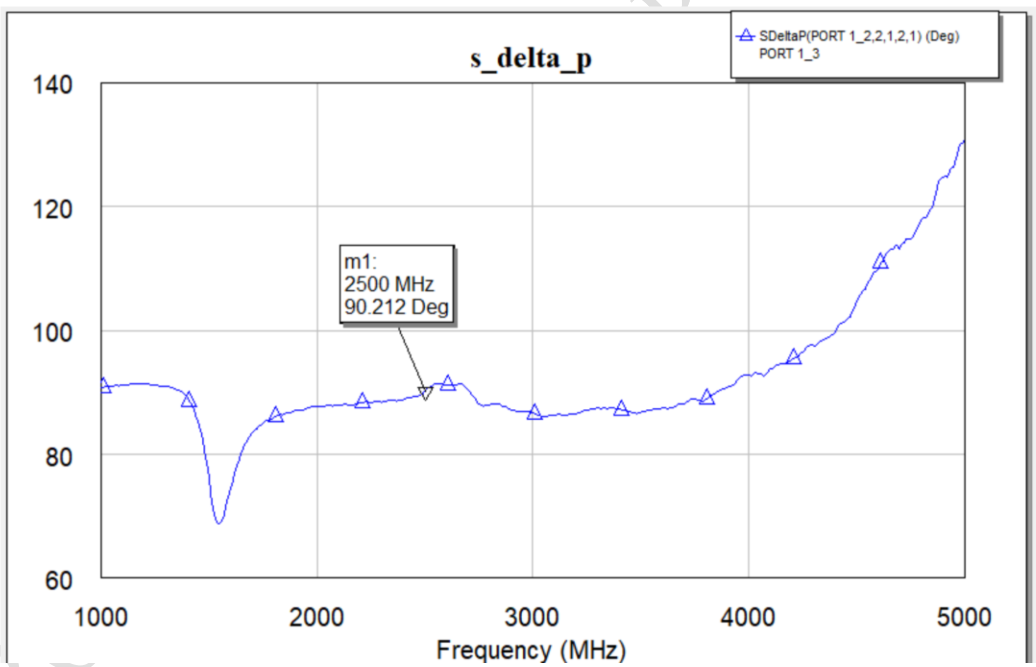
3. Input isolated port



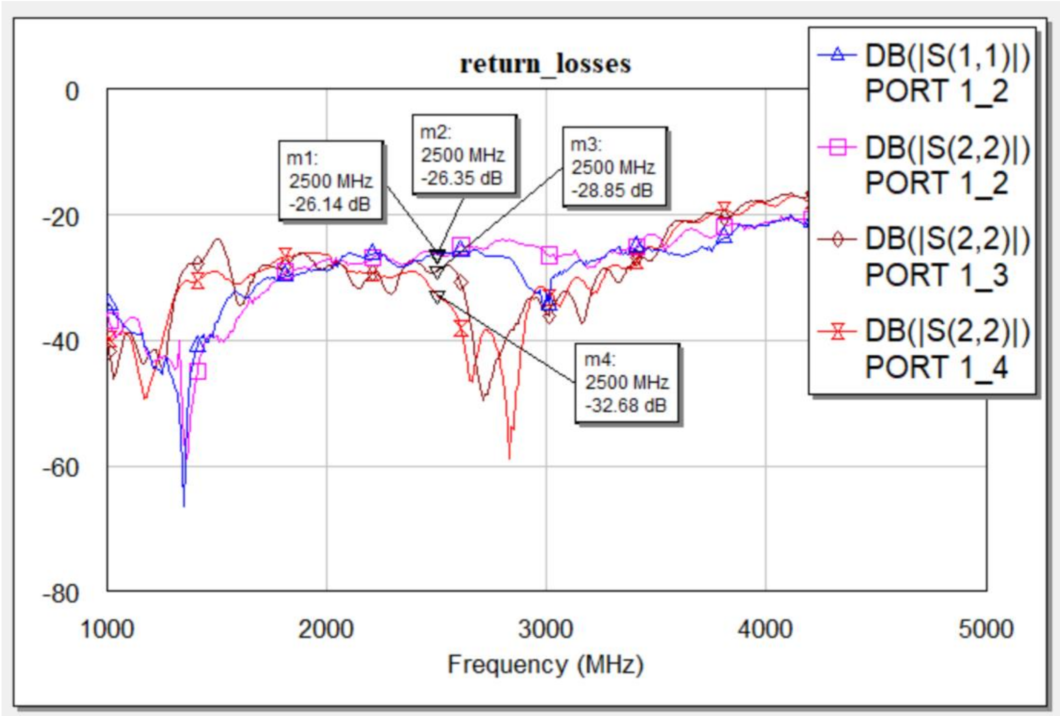
- **Plot of coupled, directed and isolated ports**



- **Phase difference between output ports**



- **Return losses**



Parameter	Design Goal	Simulated Performance	Measured Performance Built	Compliant (Yes/No)
Center Frequency (GHz)	2.5	2.5	S_{21} = 2.71	No
Coupling (dB)	20.0	S_{31} = 20.05	S_{31} = 20.02	Yes
Relative Phase (between ports 2 & 3) (deg)	90	87.91	90.212	Yes
Input Return Loss @ f_o (dB) (each port)	>20	S_{11} = 26.85 S_{22} = 24.12 S_{33} = 27.15 S_{44} = 31.25	S_{11} = 26.14 S_{22} = 26.35 S_{33} = 28.85 S_{44} = 32.68	Yes
Isolation @ fo (between ports 1 & 4) (dB)	>20	S_{41} = 36.02	S_{41} = 31.73	Yes

Summary: All dimensions of compliance are within acceptable variance.

Analysis:

Q1. What is the measured phase difference between the direct and coupled ports at the design frequency?

- Branch Line
  S∆P = 89.53°

- Edge coupled
  S∆P = 90.212°

Q2. If your design does not appear to be centered at the design frequency what is the most likely cause?

- The lossy nature of dielectric material, the inhomogeneities in the material, the oxide film on the copper, inherent inaccuracies in the milling process all cause deviation in the practical performance.

Summary:

All the design goals were within accepted variance as reflected from the compliance matrices.

The practical performance was not the same as the simulated one due to the complexities involved in practical implementation like junction capacitances, non-ideal bends and fringing effects.

Conclusion:

I. **Was your design successful? Why or why not?**
All of the design goals were met except for the center frequency.
The effect of these stray capacitances and undesirable fringing effects cause the practical results to be deviated from the ideal value.

II. **What lessons did you learn from the lab?**

The lossy nature, the inhomogeneities in the material, the oxide film on the copper, inherent inaccuracies in the milling process all cause deviation in the practical performance. Having knowledge of effective dielectric constant will be helpful to attain desired results.