Microwave Circuits Project

Semester: Fall 2025

Course: ECE 433s: Microwave Circuits and Systems

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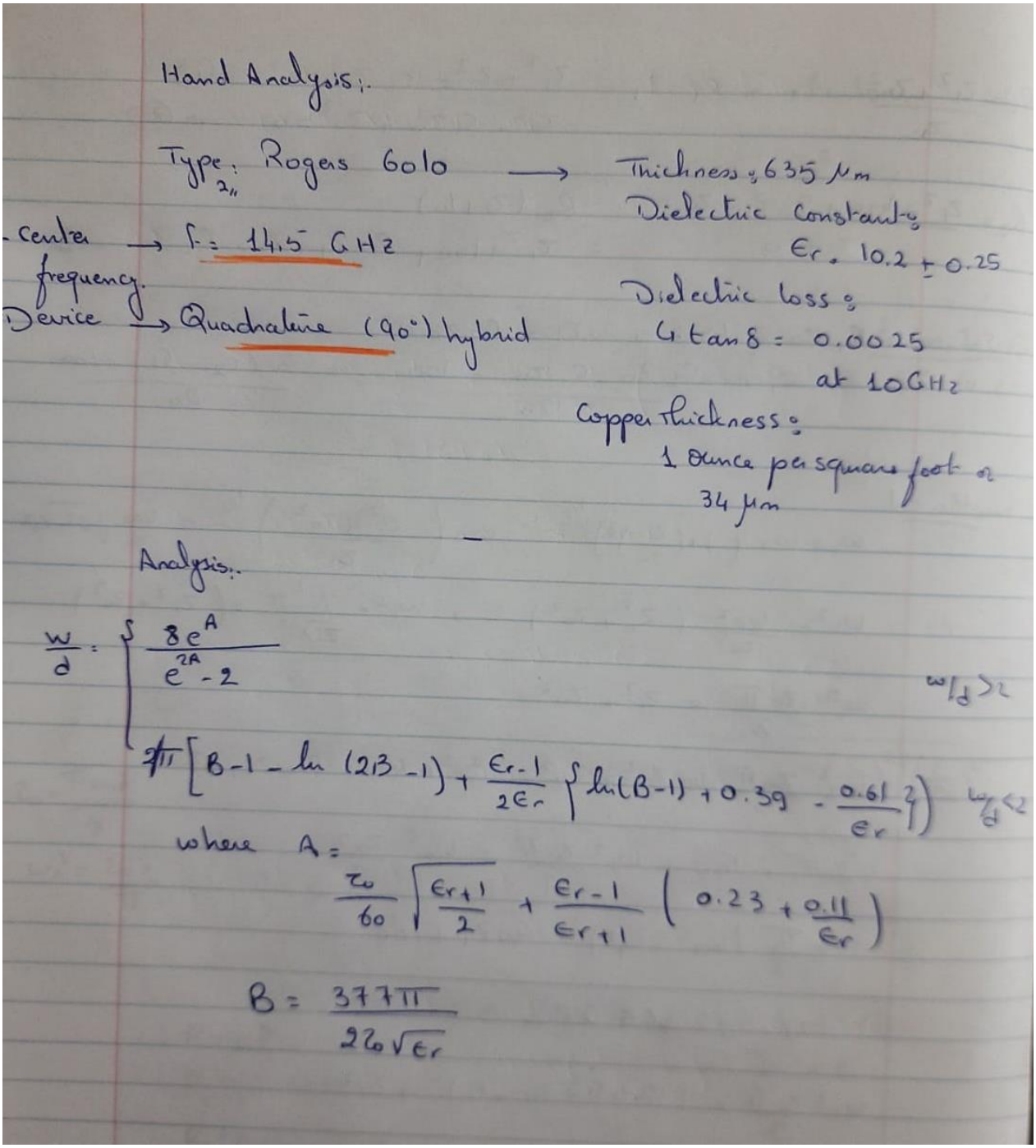
Hand Analysis:



Hand Analysis:

Type: Rogers 6010 → Thickness: 635 μm
Dielectric Constant:
ϵ_r = 10.2 ± 0.25
Dielectric loss:
tan δ = 0.0025
at 10 GHz
Copper thickness:
1 ounce per square foot or
34 μm

- Centre frequency → f = 14.5 GHz
Device → Quadrature (90°) hybrid

Analysis:

$$\frac{w}{d} = \begin{cases} \frac{8e^A}{e^{2A}-2} & w/d < 2 \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\epsilon_r-1}{2\epsilon_r}\left\{\ln(B-1)+0.39-\frac{0.61}{\epsilon_r}\right\}\right] & w/d > 2 \end{cases}$$

where $A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}\left(0.23+\frac{0.11}{\epsilon_r}\right)$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

① for $Z = \frac{Z_0}{\sqrt{2}} = 35.355\ \Omega$

$$A = \frac{50\sqrt{2}}{60}\sqrt{\frac{10.2+1}{2}} + \frac{10.2-1}{10.2+1}\left(0.23 + \frac{0.11}{10.2}\right)$$

$$\boxed{A = 1.5922}$$

$A \rightarrow (1.576 \rightarrow 1.608)$

$\epsilon_r \approx 10.2$

$\epsilon_r = 10.2 - 0.25$ $\qquad$ $\epsilon_r = 10.2 + 0.25$

$$B = \frac{377\pi}{2\left(\frac{50}{\sqrt{2}}\right)\sqrt{10.2}} = \boxed{5.2445}$$

$(5.31 \rightarrow 5.1814)$

$$\frac{w}{d} = \frac{8e^A}{e^{2A} - 2} = 1.77474 \qquad w/d < 2$$

$$\frac{w}{d} \rightarrow (1.80915 \rightarrow 1.7421)$$

Thickness $d = 635\ \mu m$

$$w_1 = 1.77474 \times 635 = 1126.96\ \mu m$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \times \frac{1}{\sqrt{1 + 12\frac{d}{w}}}$$

$$\frac{10.2+1}{2} + \frac{10.2-1}{2} \times \frac{1}{\sqrt{1 + 12\left(\frac{1}{1.77474}\right)}} = 7.25114$$

$L_1 = \frac{\lambda_g}{4}$ ← Length of transmission line

$$= \frac{\lambda_0}{4\sqrt{\epsilon_{eff}}} = \frac{c_0}{4f\sqrt{\epsilon_{eff}}}$$

$$L_1 = \frac{3\times10^8}{4\times14.5\times10^9\sqrt{7.25114}} = 1.921\ mm$$

① for $Z_0 = 50\ \Omega$

$$A = \frac{50}{60}\sqrt{\frac{10.2+1}{2}} + \frac{10.2-1}{10.2+1}\left(0.23+\frac{0.11}{10.2}\right)$$

$$= 2.16981$$

$$B_j = \frac{377\pi}{2\times50\times\sqrt{10.2}} = 3.70844$$

$$\frac{w}{d} = \frac{8e^A}{e^{2A}-2} = 0.938062 \quad \frac{w}{d} < 2$$

$$w_2 = 0.938062\times635 = 595.6693\ \mu m$$

$$\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\times\frac{1}{\sqrt{1+12\frac{d}{w}}}$$

$$\frac{10.2+1}{2} + \frac{10.2-1}{2}\frac{1}{\sqrt{1+12\left(\frac{1}{0.938062}\right)}} = 6.8386$$

$$L_2 = \frac{C_0}{4F\sqrt{\epsilon_{eff}}} = \frac{3\times10^8}{4\times14.5\times10^9\sqrt{6.8386}}$$

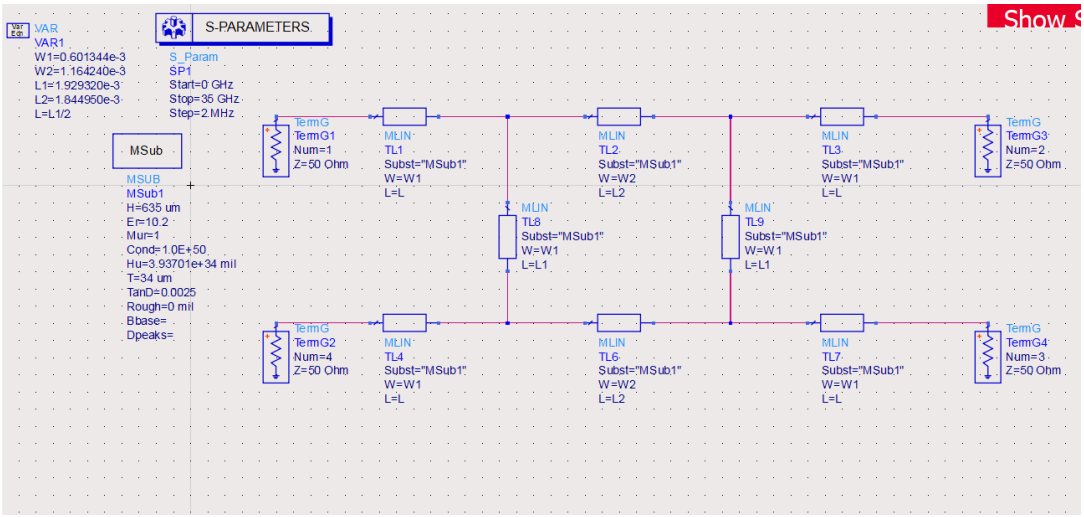
$$= 1.978\ mm$$

$w_1 = 1126.96\ \mu m$ $\quad$ $w_2 = 595.6693\ \mu m$

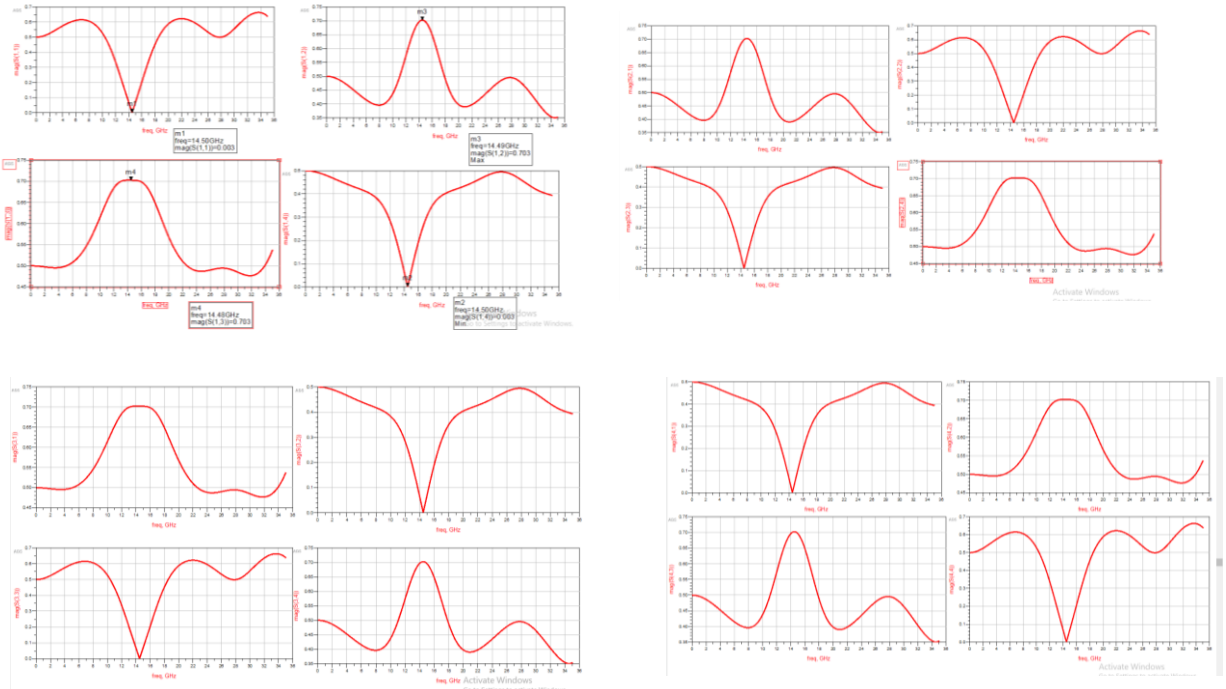
$L_1 = 1.921\ mm$ $\quad$ $L_2 = 1.978\ mm$

Case 1: Without T-Junction :

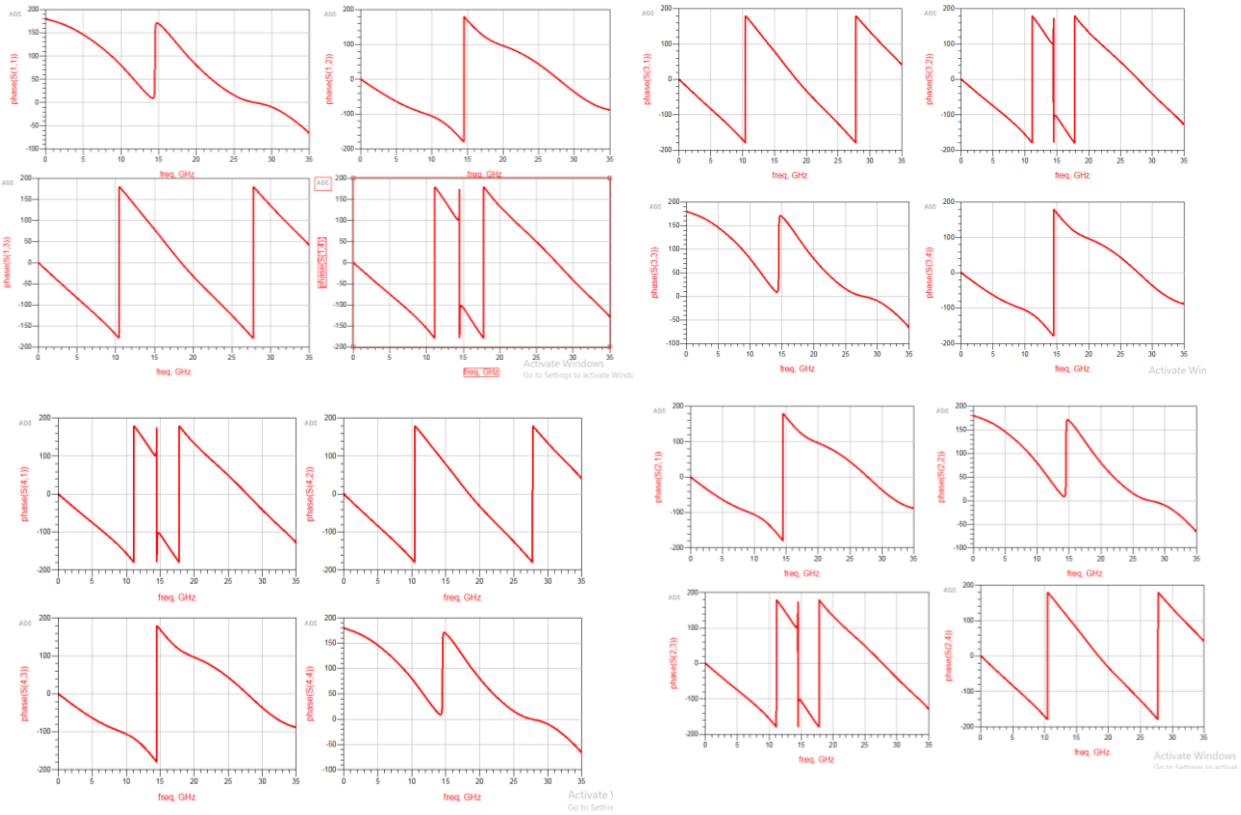
Schematic:



Magnitude Of S-Parameters:

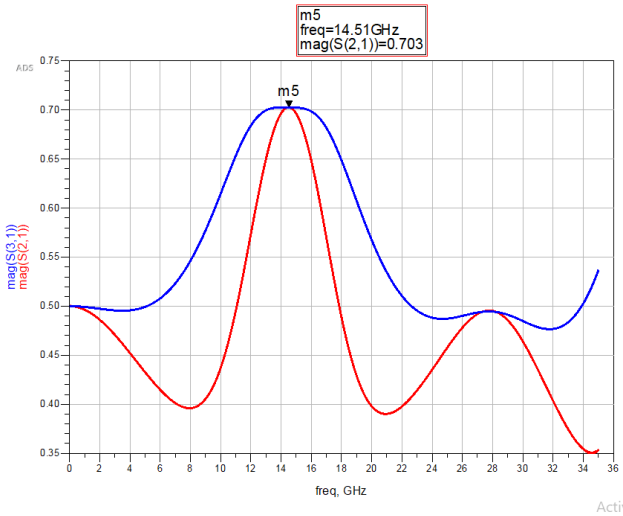


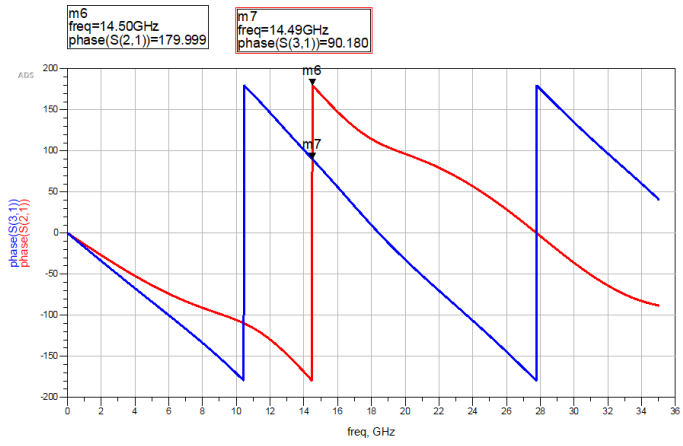
Phase of S-Parameters:



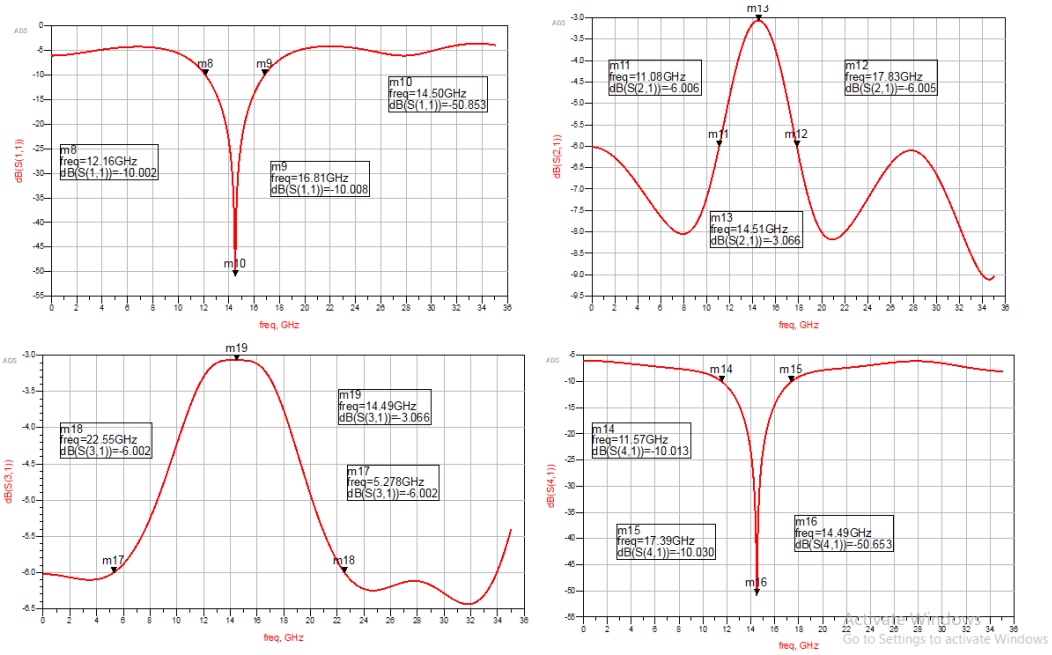
Phase and Magnitude comparison from Port 2 and 3

→ We can see that while the magnitude resonance frequency is shifted from the 14.5GHz (-3dB is shifted to 3GHz approximately), the phase shift is approximately equals to 90 degrees (179.999-90=89.8)





Bandwidth:



Bandwidth (from S11) $= 16.81 - 12.16 = 4.65\ GHz$

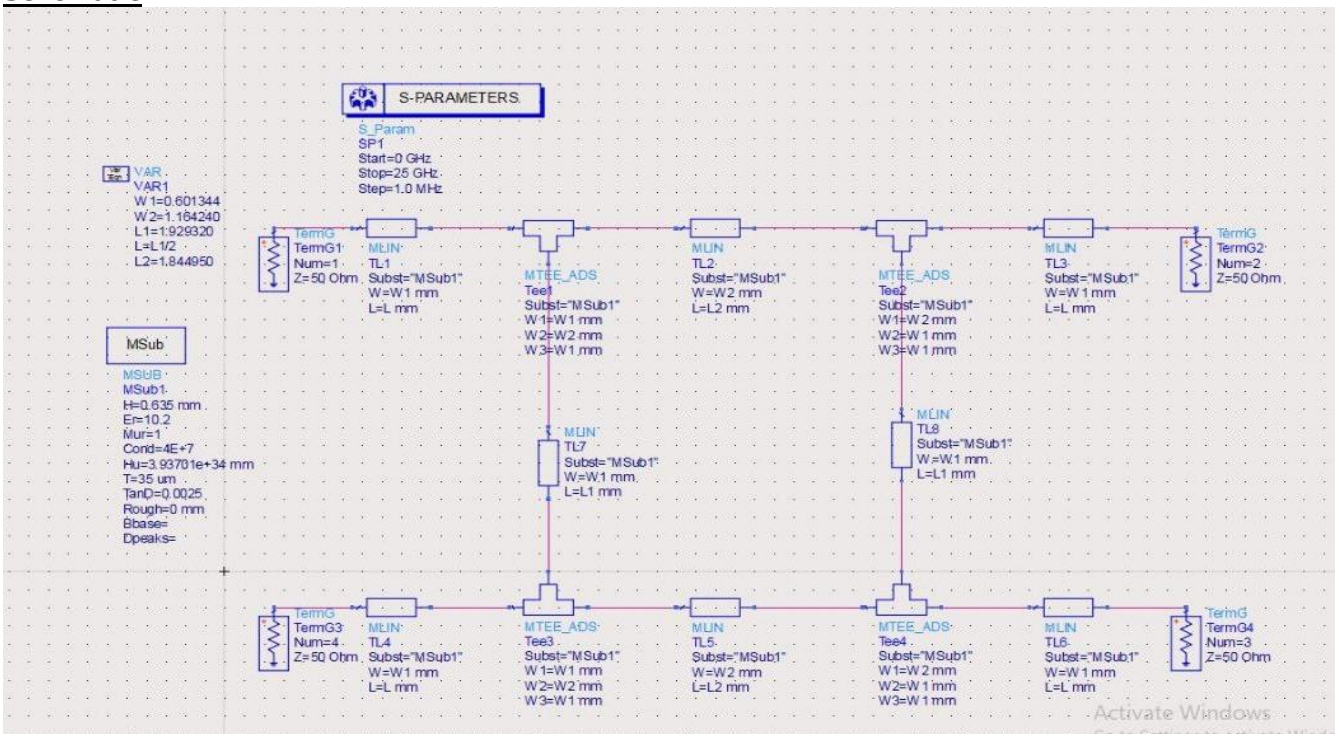
Bandwidth (from S21) $= 17.83 - 11.08 = 6.75\ GHz$

Bandwidth (from S31) $= 14.49\text{-}5.278 = 9.212\ GHz$

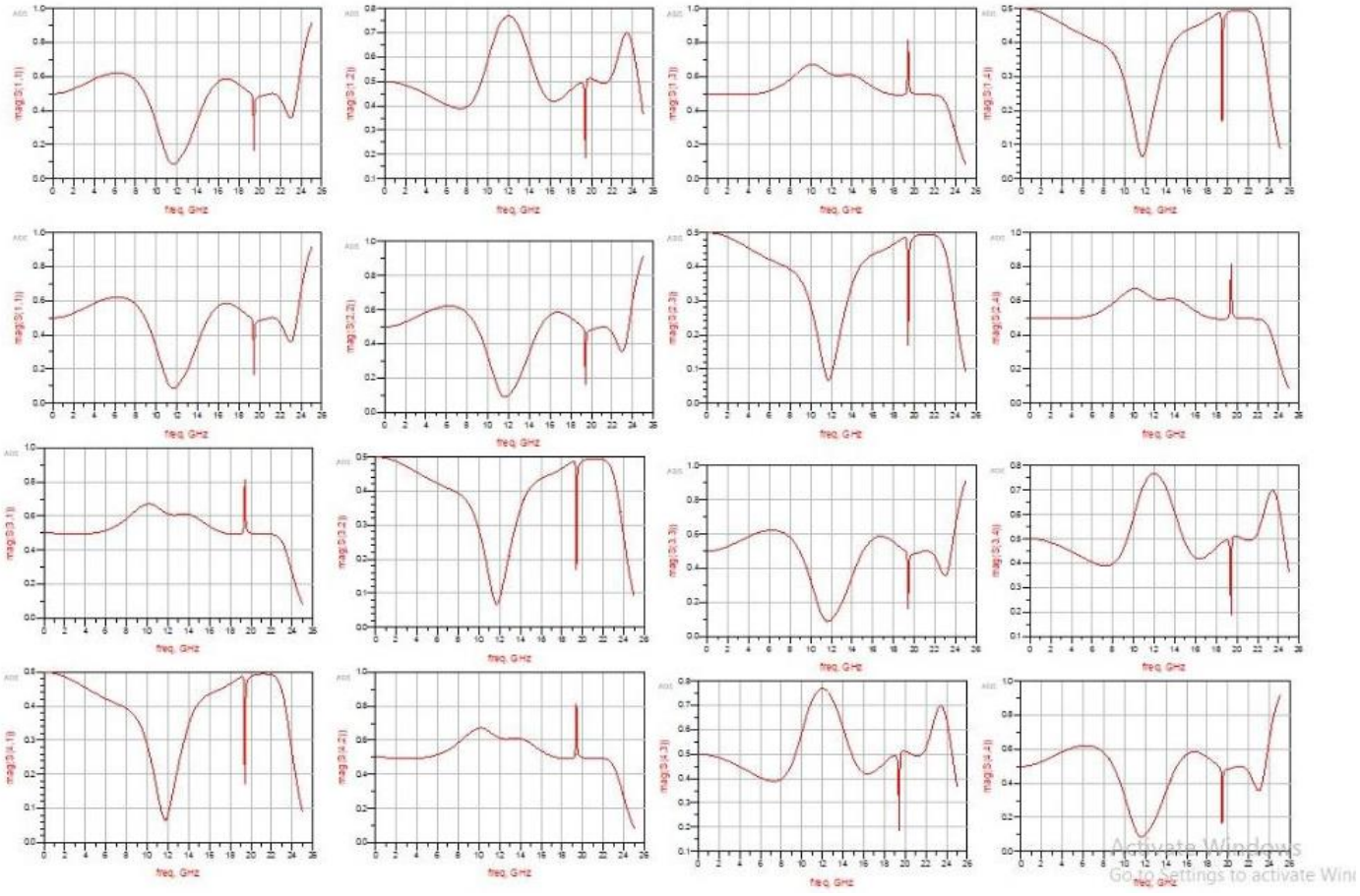
Bandwidth (from S41) $= 17.39\text{-}11.57 = 5.82\ GHz$

Case 2: With T-Junction (Unoptimized)

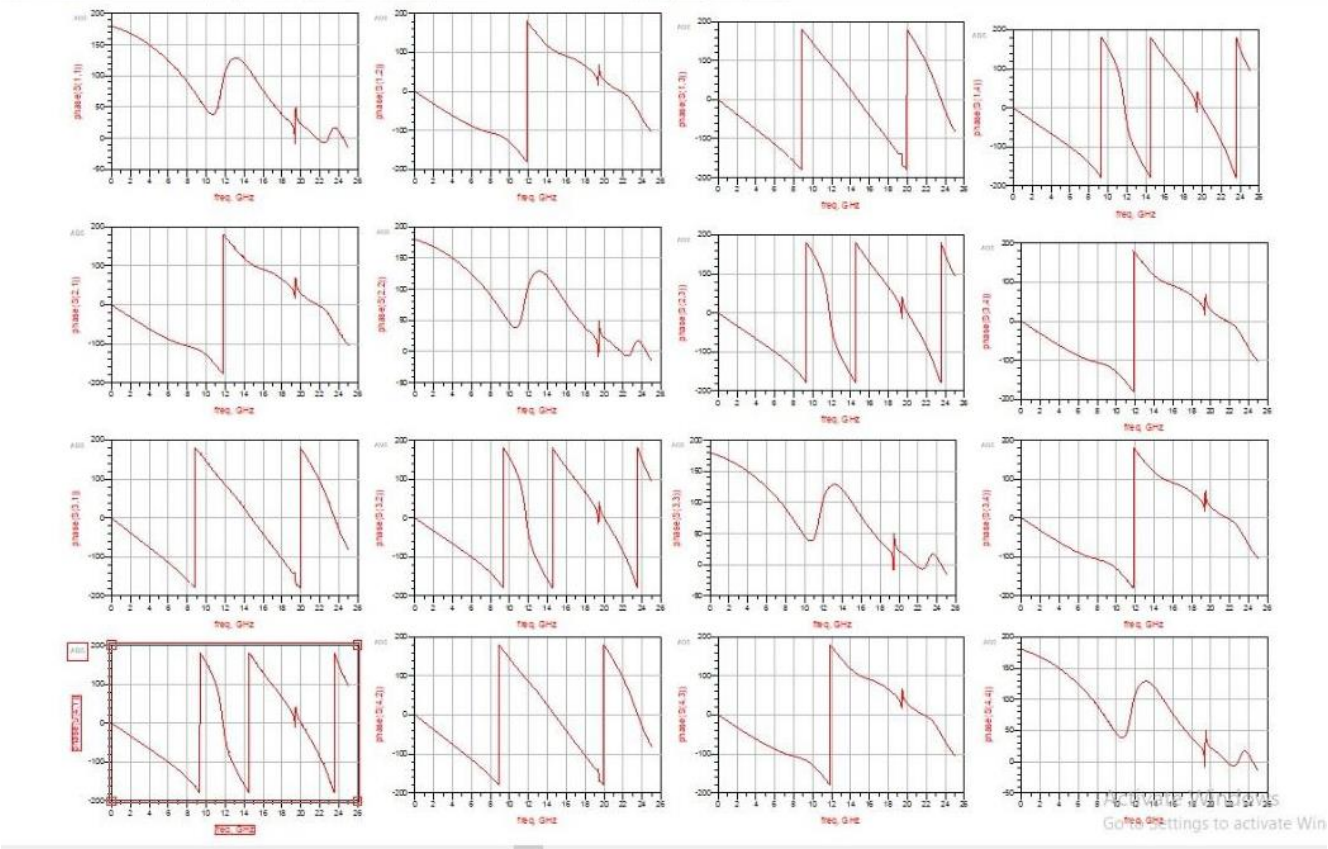
Schematic



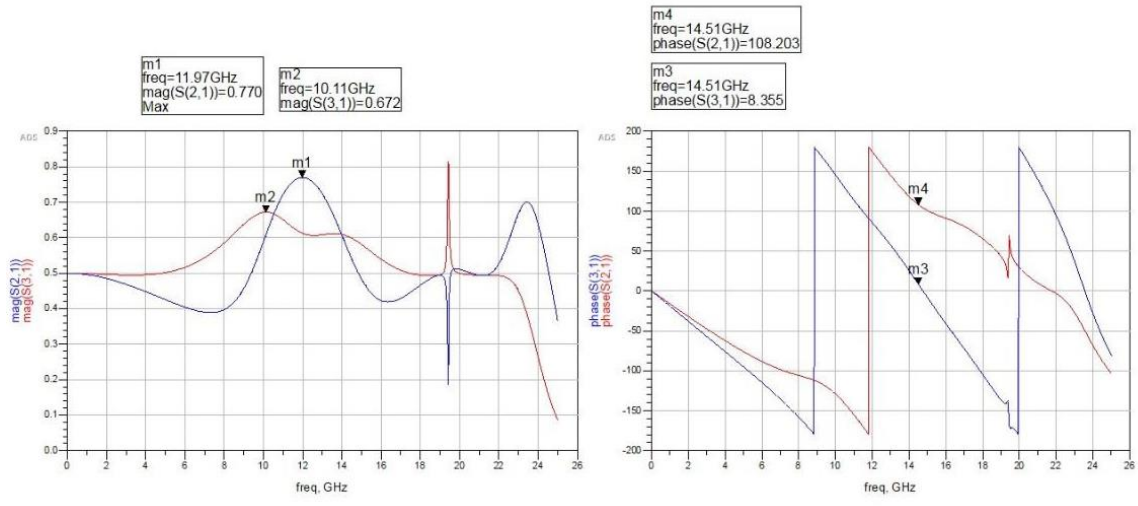
Magnitude Of S-Parameters:



Phase of S-Parameters:

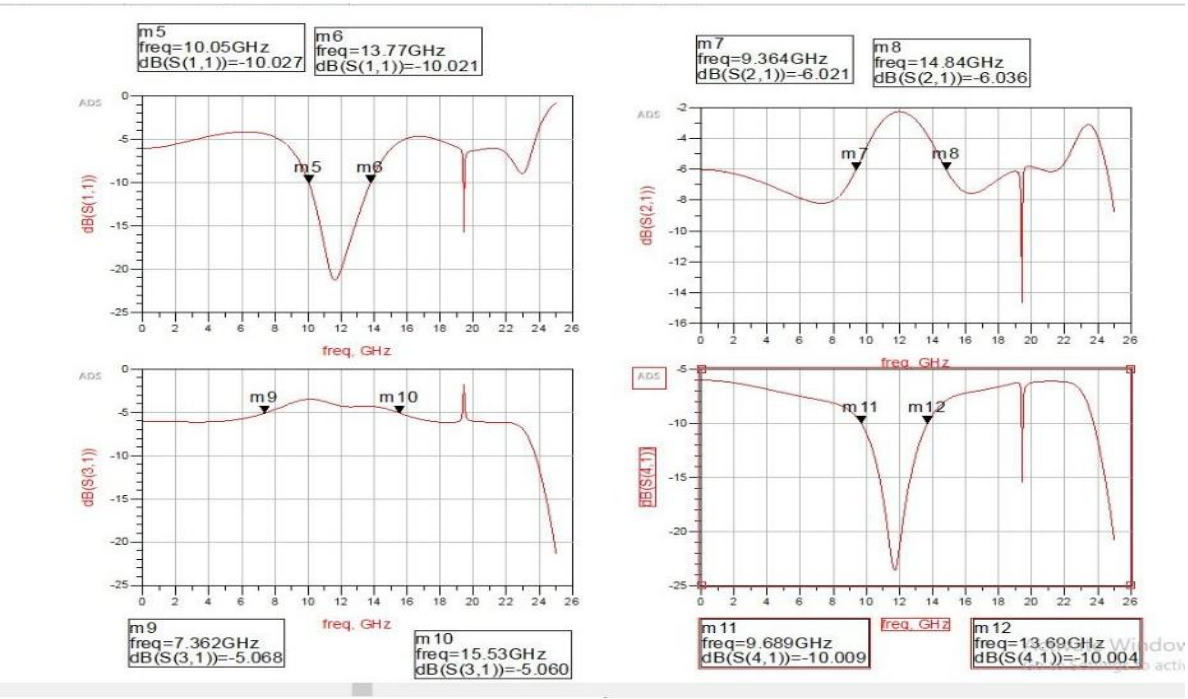


Phase and Magnitude comparison from Port 2 and 3



→ We can see that while the magnitude resonance frequency is shifted from the 14.5GHz (-3dB is shifted to 3GHz approximately), the phase shift is more than 90 degrees between both ports m it needs optimization..

Bandwidth:



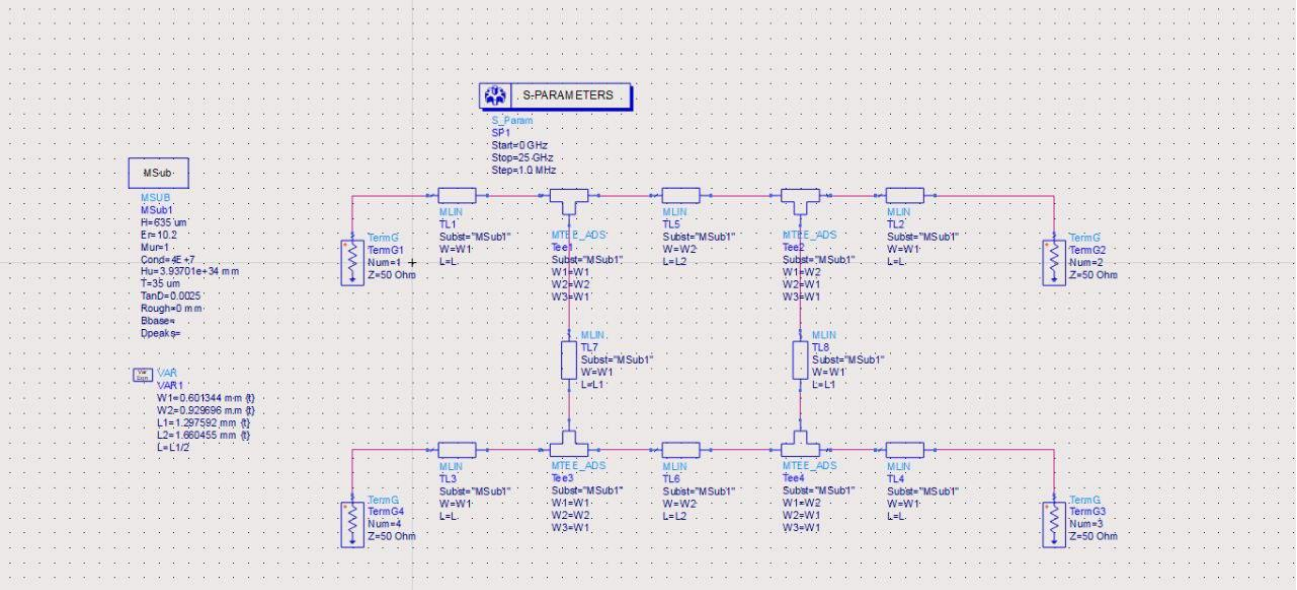
Bandwidth (from S11) $= 13.77 - 10.05 = 3.75\ GHz$
Bandwidth (from S21) $= 14.84 - 9.364 = 5.476\ GHz$
Bandwidth (from S31) $= 15.53 - 7.362 = 8.168\ GHz$

Comment:

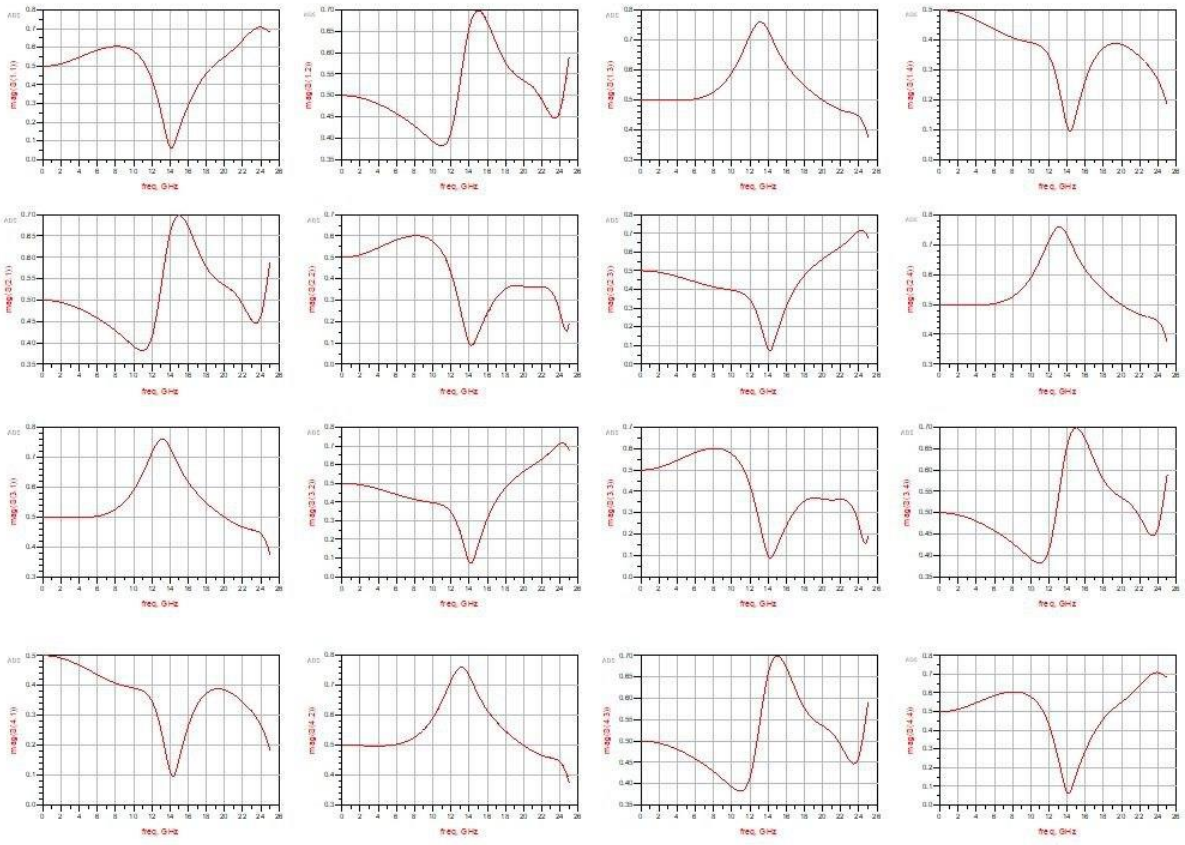
- The difference between the two bandwidth values is because each method has a different idea of what power level is acceptable.
- In the first method (signal below -10 dB), it means that more than 90% of the input power is still being passed through. Most of the power makes it to ports 2 and 3, either as the main output or as a coupled signal.
- In the second method (signal above -6 dB), it assumes that half of the power is already lost before reaching the receiving port. Since the signal starts weaker, this method sets the acceptable level at about a quarter of the original input power. This shows that some power may be lost to the isolated port or used up inside the circuit.

Case 3: With T-Junction (Optimized)

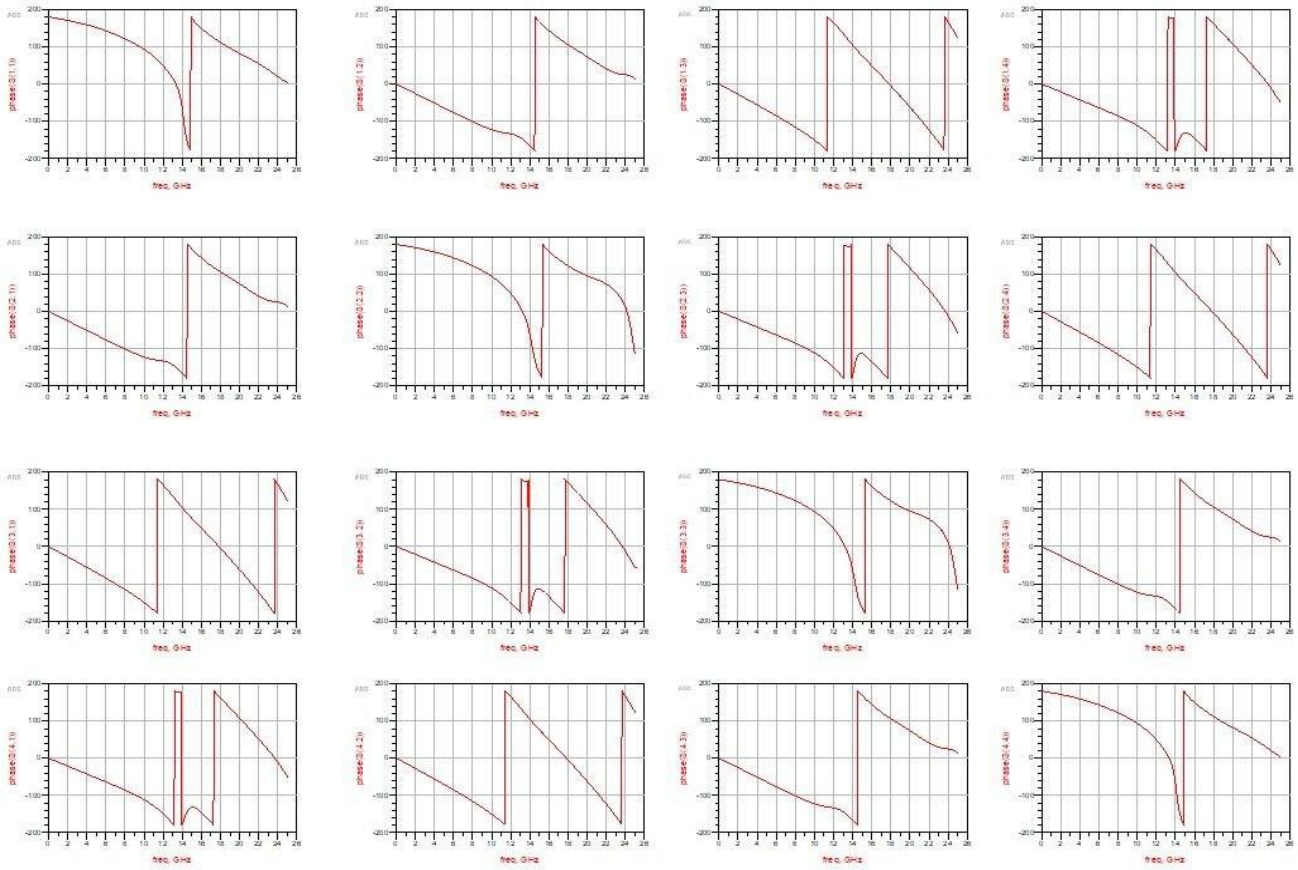
Schematic:



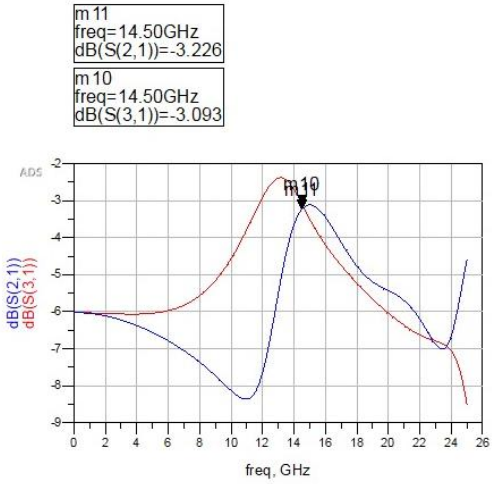
Magnitude of S-Parameters:

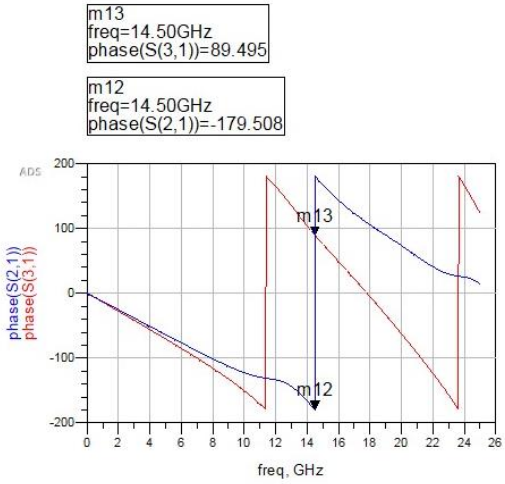


Phase of S-Parameters:



Phase and Magnitude comparison from Port 2 and 3:

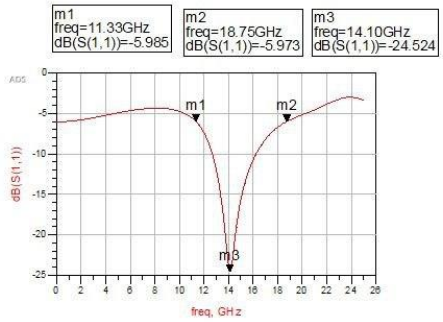


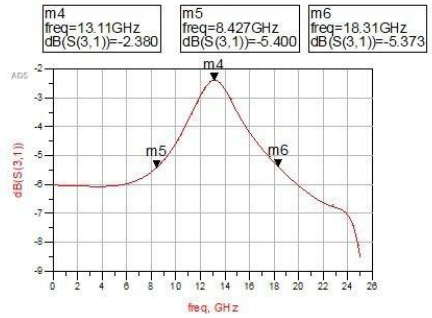


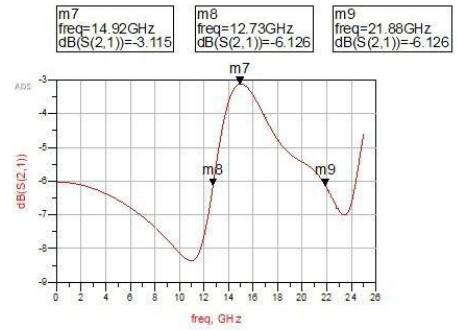
→ We can see that the optimization moved the resonance to the required frequency (14.5GHz) and the phase shift is kept 90 degrees.(179.508-89.495=90.013)

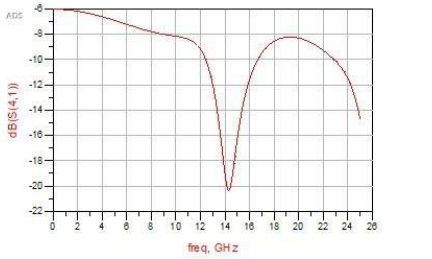
→ However, the S31 parameter isn't exactly on the desired frequency, it's shifted up.

Bandwidth







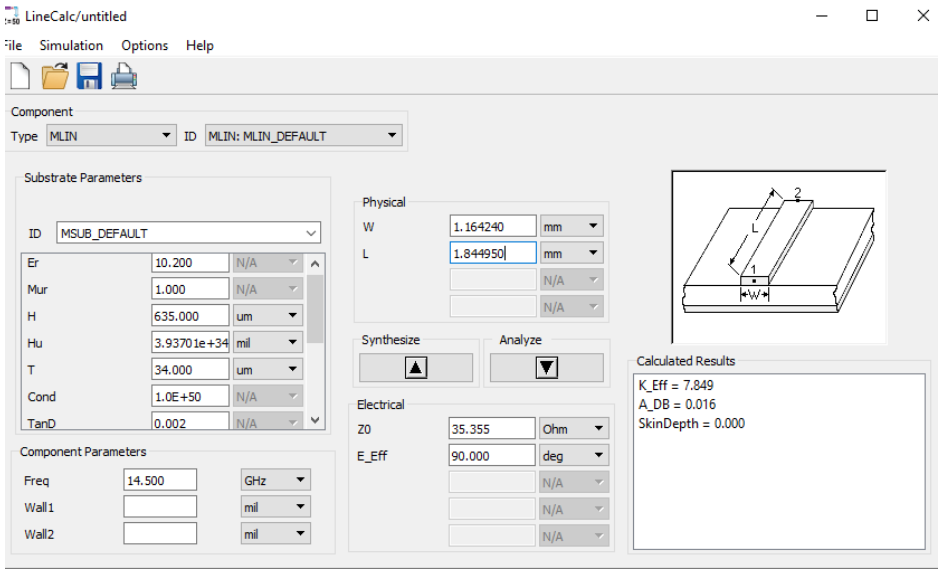


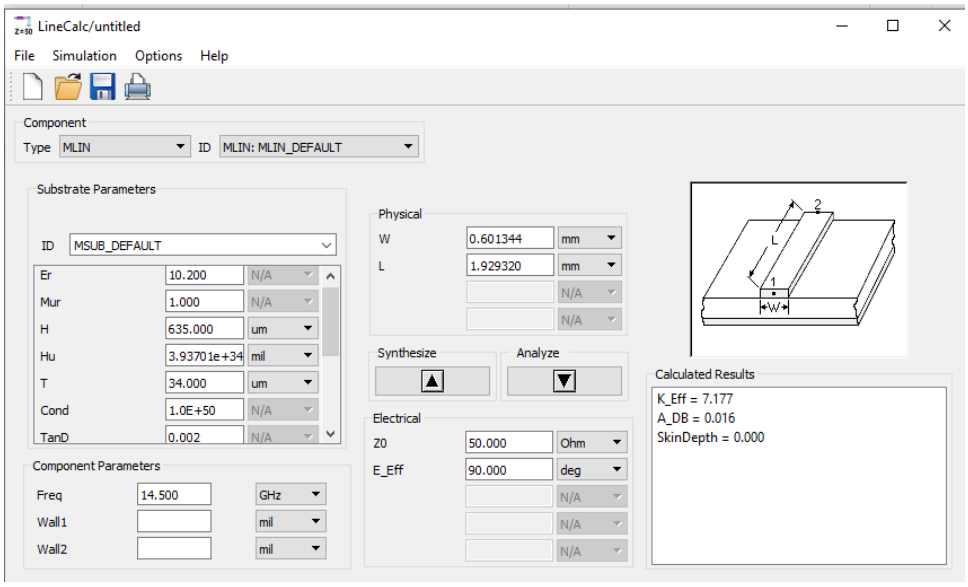
Bandwidth (from S11) $= 18.75 - 11.33 = 7.42\ GHz$
Bandwidth (from S21) $= 18.31 - 8.427 = 9.883\ GHz$
Bandwidth (from S31) $= 21.88 - 12.73 = 9.15\ GHz$

Comment:
It's important to mention that the S21 value going above -3 dB could be because of double reflections. Some of the power that was reflected back from port 2 toward port 1 got reflected again from port 1 back to port 2. This second reflection adds more power to what was already reflected, causing interference.
Most of the power went this way: $P1 \rightarrow P2$
Some of the power went this way: $P1 \rightarrow P2 \rightarrow P1 \rightarrow P2$

Summary of Length and Widths of all transmission lines

Parameter	Hand Analysis	Case 1 (without T) and Case 2 (With T – Unoptimized)	Case 3 (With T – Optimized)
L1_50	1.978 mm	1.929320 mm	1.297592 mm
L2_35.355	1.921 mm	1.844950 mm	1.660455 mm
W1_50	0.5956693 mm	0.601344 mm	0.601344 mm
W2_35.355	1.12696 mm	1.164240 mm	0.99696 mm
L	0.989 mm	0.96466 mm	0.648796 mm

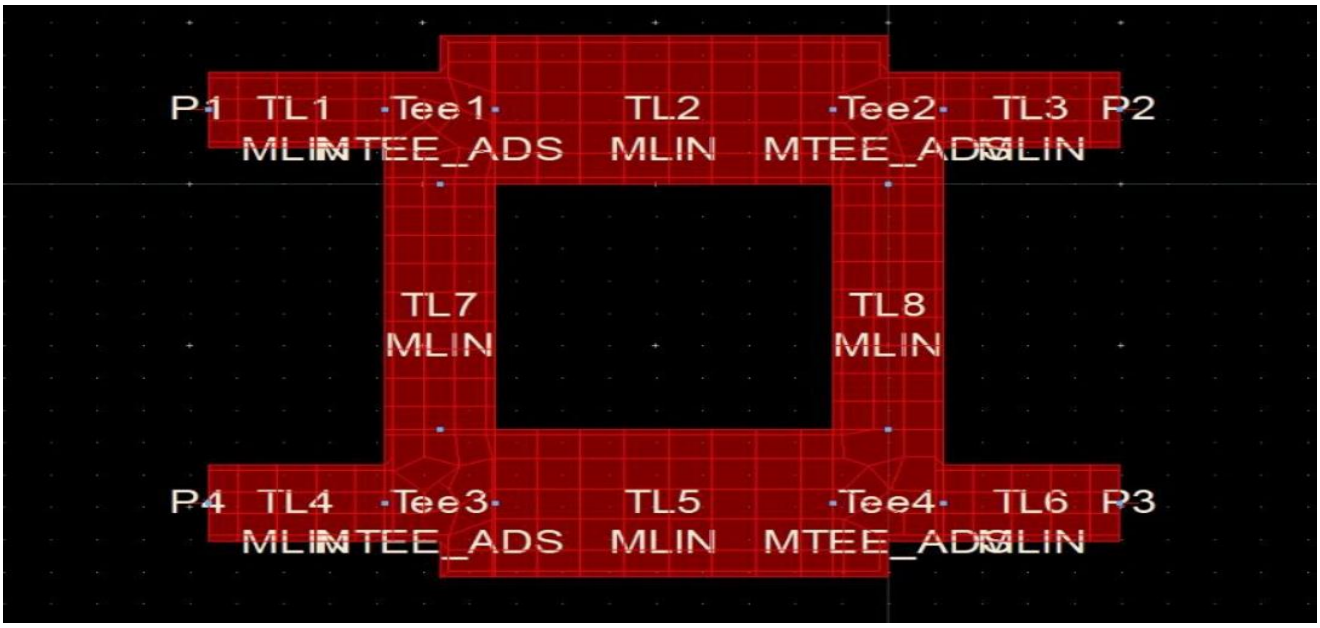




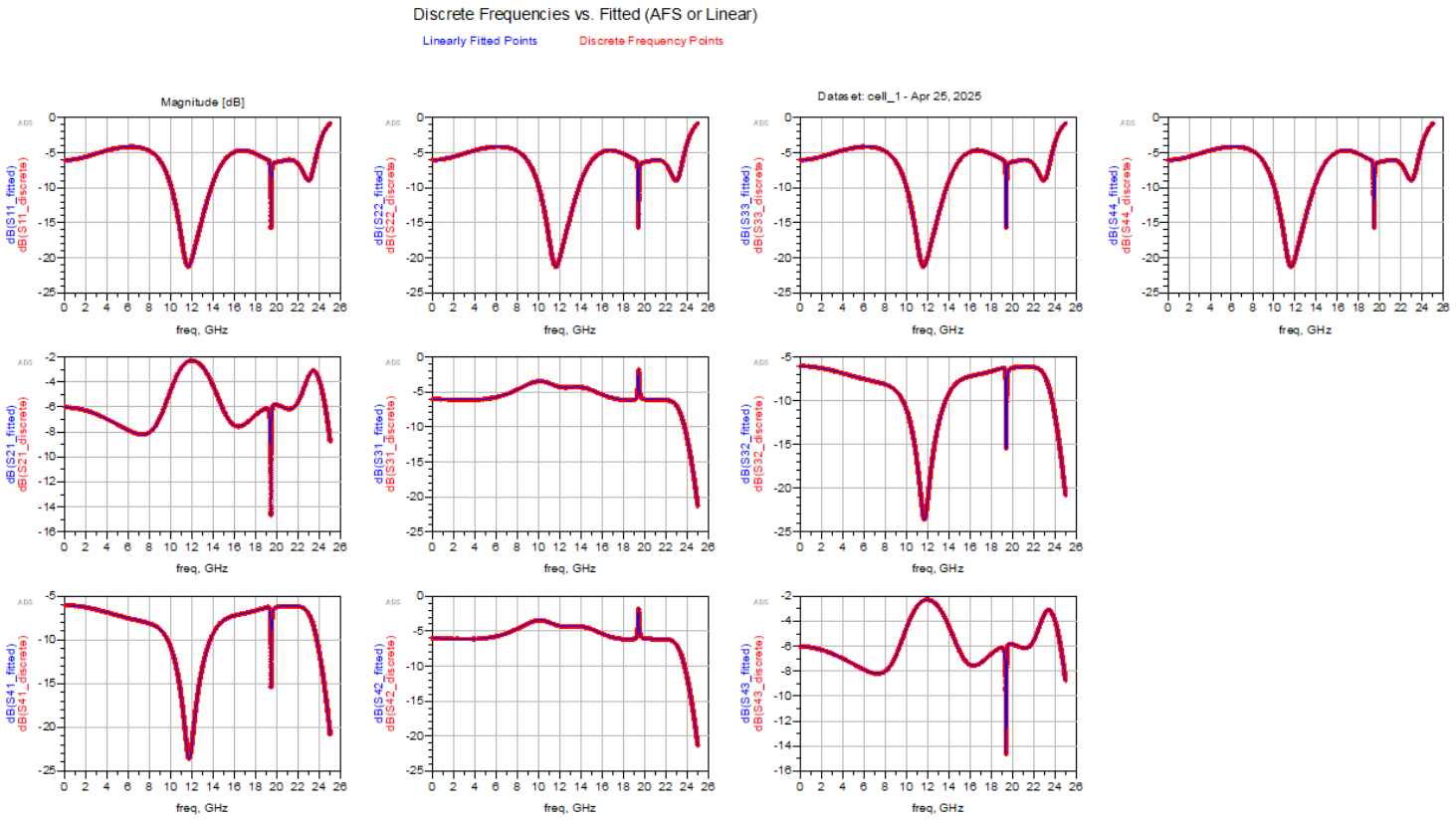
Layout Schematic

Case 2: With T-Junction (Unoptimized)

Layout:



S-Parameters:



Comments :

At Operating frequency 14.5 GHz,Figures show how the power is divided equally between the other two ports and get isolated at the adjacent port to input port

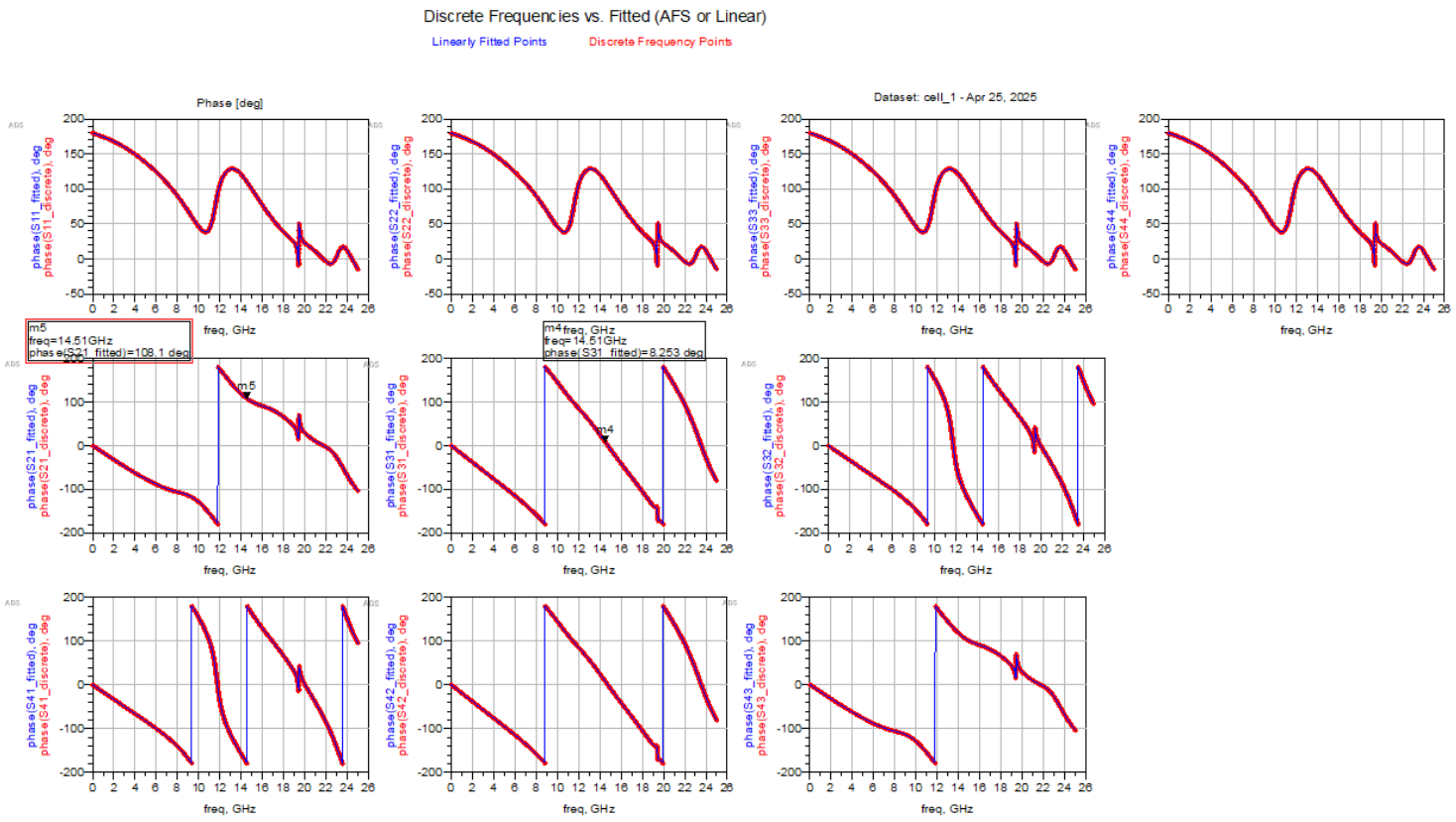
− Figures show recioprical characteristic .

− At Operating frequency 14.5 GHz,figure of S21 and S31 shows how power divided between ports 2,3 but it need optimization to adjust it to be equal -3 dB.

− At Operating frequency 14.5 GHz,figure of S41 show isolation between port 1 and port 4

− Figure of S11, S22 , S33 , S44 as expected as it is matched at all ports so only small fraction of input return back at the input port Phase:

Phase of S-Parameters:

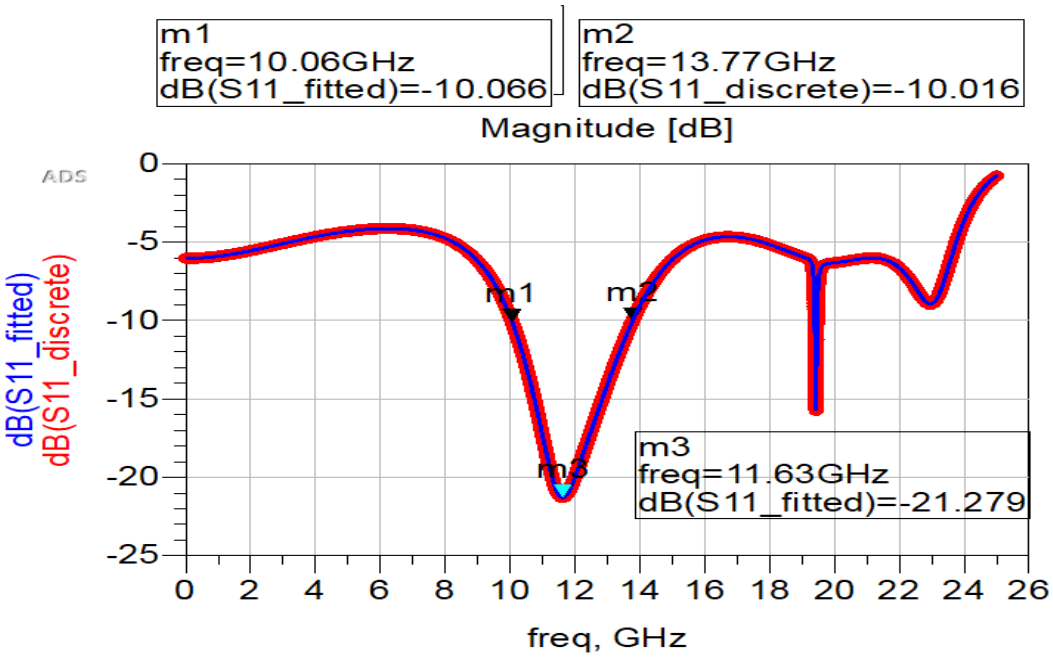


Comment:

The difference between the phase of S21 and S31 = 108.1-8.253 = 99.847◦

− It's expected to be 90◦ so we need optimization.

Bandwidth:



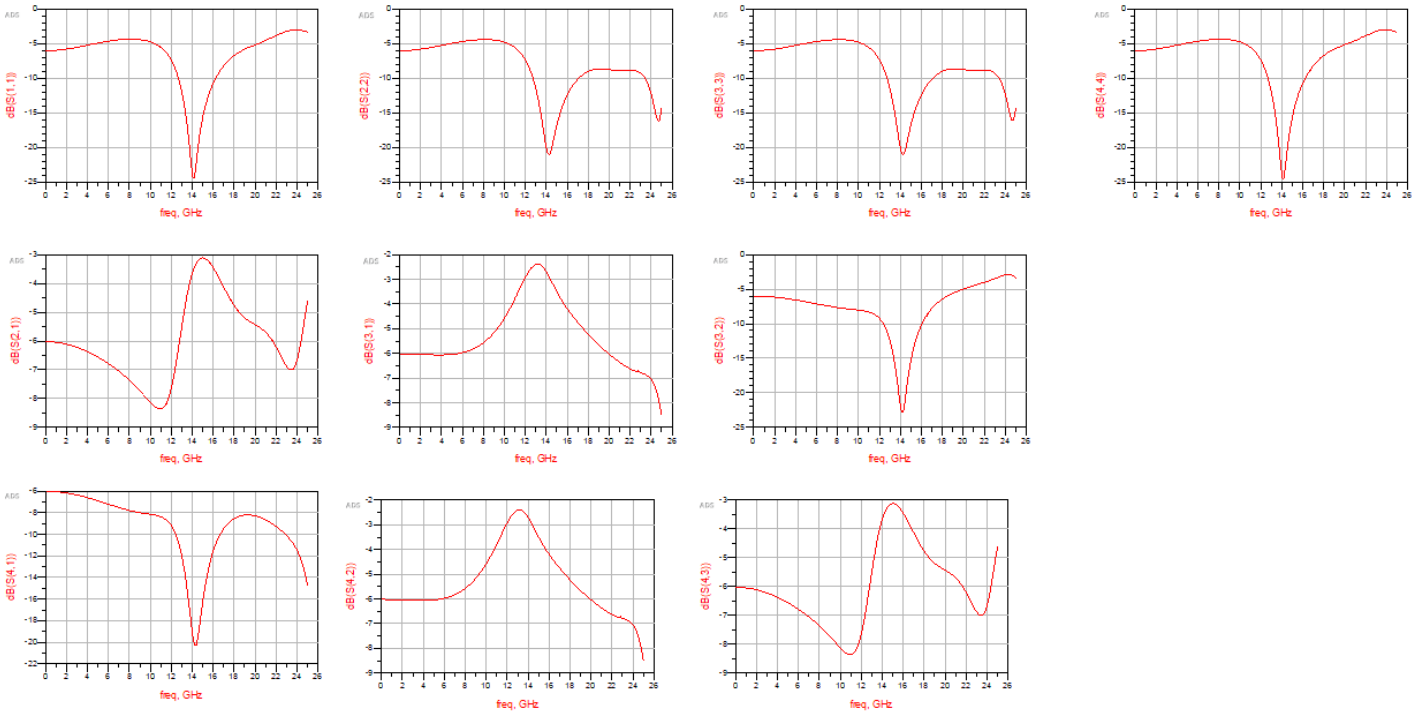
The Bandwidth equal to range of frequemcies where S11 < -10 db

− The Bandwidth = 13.77 – 10.06 = 3.71 GHz

Case 3: With T-Junction (Optimized)

Layout:

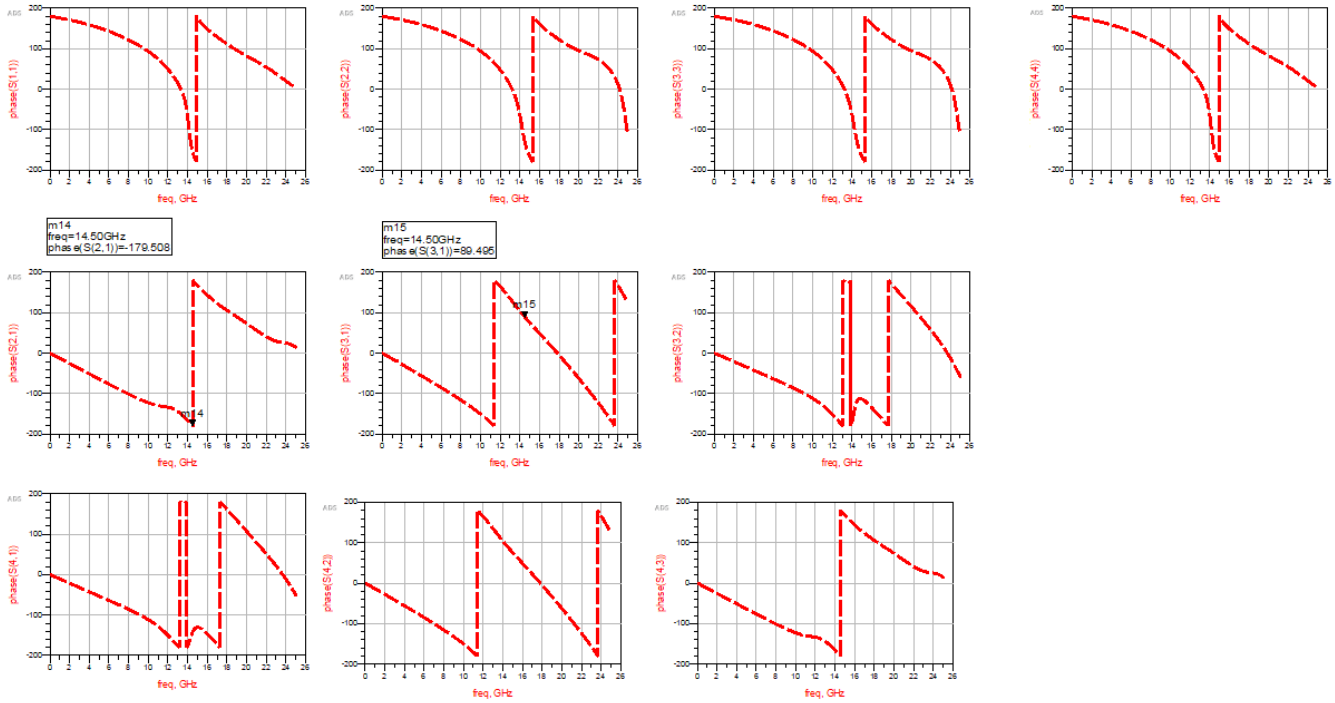
Magnitude of S-Parameters:



Comments:

-S21 and S31 values are more close to -3db

Phase of S-Parameters:



Comments:

- Phase difference between S21 and S31 = 179.508 – 89.495 = 90.013
- Approximately 90 degrees

Bandwidth:

Bandwidth where frequencies range of S11 < -10db

Bandwidth = 16.21 Ghz – 12.68 Ghz = 3.53 Ghz