Lab 6: Design of Branch Line Coupler

Author	Name: 张皓东	Student ID: 12113010

Introduction

1.1 Experimental goal

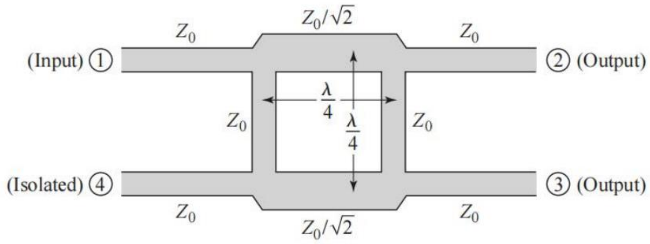
Comprehend the modeling and simulation of branch line couplers, and acquire proficiency in utilizing the Odd-Even mode analysis method for analysis. Gain skills in employing HFSS and ADS for both modeling and simulation, along with optimization techniques.

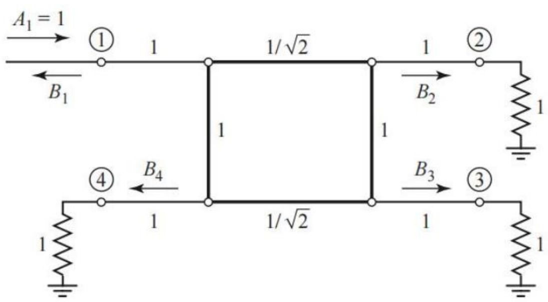
1.2 Principle of Branch Line Coupler

The branch line coupler is a type of 3 dB directional coupler featuring a 90° phase difference in the outputs of the through and coupled arms. The fundamental operation of the branch-line coupler is as follows: when all ports are matched, power entering port 1 is evenly split between ports 2 and 3, accompanied by a 90° phase shift between these outputs. Notably, no power is coupled to port 4, which serves as the isolated port. The scattering matrix has the following form:

$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}.$$

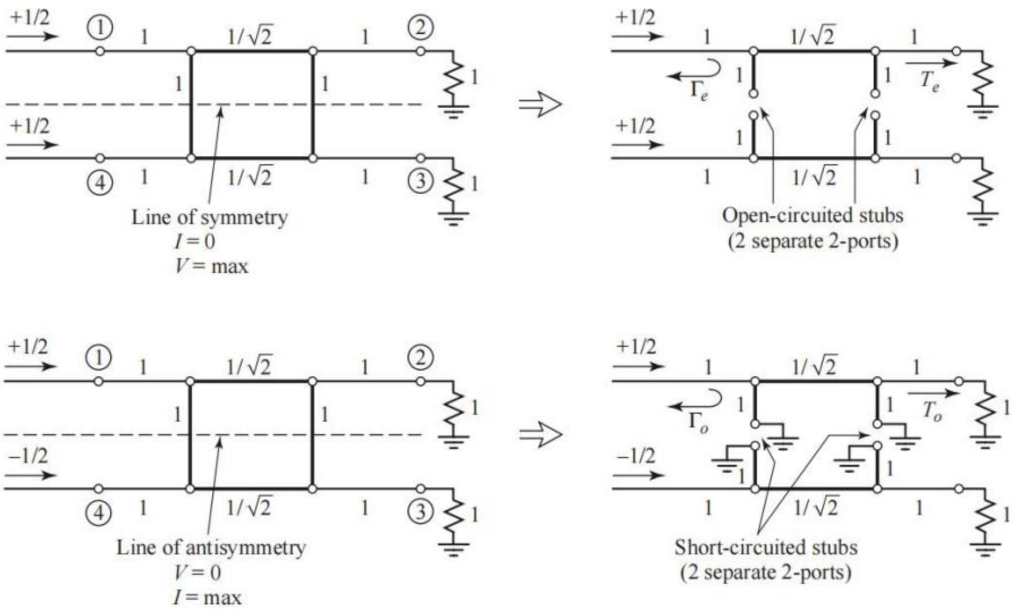
Note the pronounced symmetry in the branch-line hybrid, where any port can serve as the input port. The output ports consistently appear on the opposite side of the junction from the input port, and the isolated port aligns with the remaining port on the same side as the input port. This symmetry is evident in the scattering matrix, where each row can be derived through a transposition of the first row.





Even-Odd Mode Analysis:

The common ground return for each transmission line is not shown. We assume that a wave of unit amplitude A1 = 1 is incident at port 1. The circuit can be decomposed into the superposition of an even-mode excitation and an odd-mode excitation, as shown as below and since the circuit is linear, the actual response (the scattered waves) can be obtained from the sum of the responses to the even and odd excitations.



Due to the symmetry or anti-symmetry in the excitation, the four-port network can be broken down into a collection of two decoupled two-port networks. Since the amplitudes of the incident waves for these two-ports are ±1/2, the amplitudes of the emerging wave at each port of the branch-line hybrid can be expressed as:

$$B_1 = \frac{1}{2}\Gamma_e + \frac{1}{2}\Gamma_o,$$
$$B_2 = \frac{1}{2}T_e + \frac{1}{2}T_o,$$
$$B_3 = \frac{1}{2}T_e - \frac{1}{2}T_o,$$
$$B_4 = \frac{1}{2}\Gamma_e - \frac{1}{2}\Gamma_o,$$

This can best be done by multiplying the ABCD matrices of each cascade component in that circuit, to give:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_e = \underbrace{\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}}_{\substack{\text{Shunt} \\ Y = j}} \underbrace{\begin{bmatrix} 0 & j/\sqrt{2} \\ j\sqrt{2} & 0 \end{bmatrix}}_{\substack{\lambda/4 \\ \text{Transmission} \\ \text{line}}} \underbrace{\begin{bmatrix} 1 & 0 \\ j & 1 \end{bmatrix}}_{\substack{\text{Shunt} \\ Y = J}} = \frac{1}{\sqrt{2}} \begin{bmatrix} -1 & j \\ j & -1 \end{bmatrix}$$

Then we convert the ABCD matrix into S parameter matrix, which are equivalent to the reflection and transmission coefficients:

$$\Gamma_e = \frac{A + B - C - D}{A + B + C + D} = \frac{(-1 + j - j + 1)/\sqrt{2}}{(-1 + j + j - 1)/\sqrt{2}} = 0,$$
$$T_e = \frac{2}{A + B + C + D} = \frac{2}{(-1 + j + j - 1)/\sqrt{2}} = \frac{-1}{\sqrt{2}}(1 + j).$$

Similarly, for the odd mode we obtain:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_o = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix}$$

which gives the reflection and transmission coefficients as:

$$\Gamma_o = 0,$$
$$T_o = \frac{1}{\sqrt{2}}(1 - j)$$

Using the equation above we can get that:

$B_1 = 0$ (port 1 is matched), $B_3 =-\frac{1}{\sqrt{2}}$ (port 1 is matched),

$B_2 =-\frac{j}{\sqrt{2}}$ (port 1 is matched), $B_4 = 0$ (no power to port 4).

These results agree with the first row and column of the scattering matrix. The remaining elements can easily be found by transposition.

$$[S] = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{bmatrix}.$$

In practical applications, the bandwidth of a branch-line hybrid is constrained to 10%–20% due to the quarter-wave length requirement. However, similar to the approach taken with multi-section matching transformers and multi-hole directional couplers, cascading multiple sections can expand the bandwidth to a decade or more. Moreover, the fundamental design can be adapted for unequal power division and/or different characteristic impedances at the output ports. Another practical consideration is that discontinuity effects at the junctions of the branch-line coupler may necessitate lengthening the shunt arms by 10°–20°.

Lab results & Analysis：

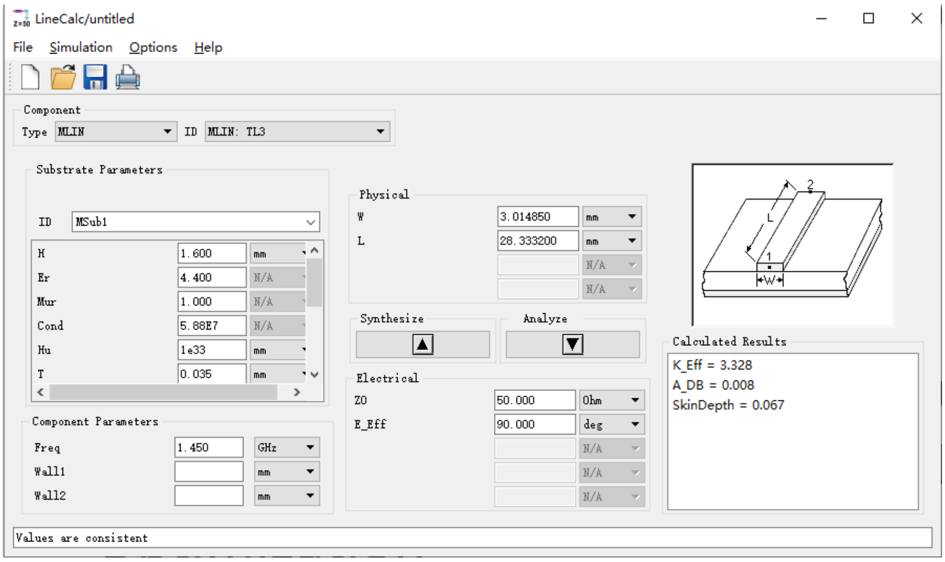
Requirement:

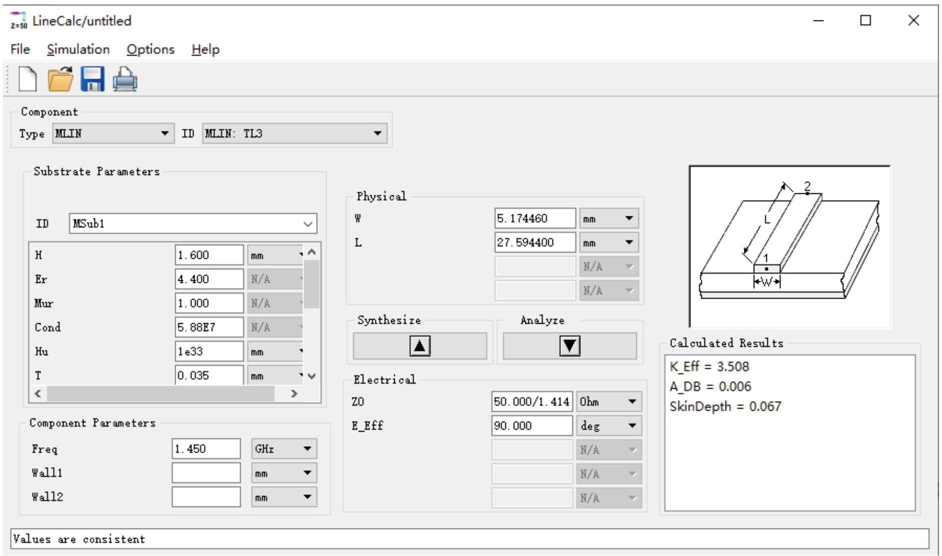
- Design a Branch Line Coupler in ADS and HFSS
- Center Frequency: 1.45 GHz
- Bandwidth: 100MHz
- Substrate: FR4, thickness: 1.6mm
- S11<-15dB, S21>-3.3dB, S31>-3.3dB, S41<-20dB
- abs(S31-S21)<0.1dB at center frequency
- 89°<|phase(S31)-phase(S21)|<91° at center frequency
- Optimization

ADS

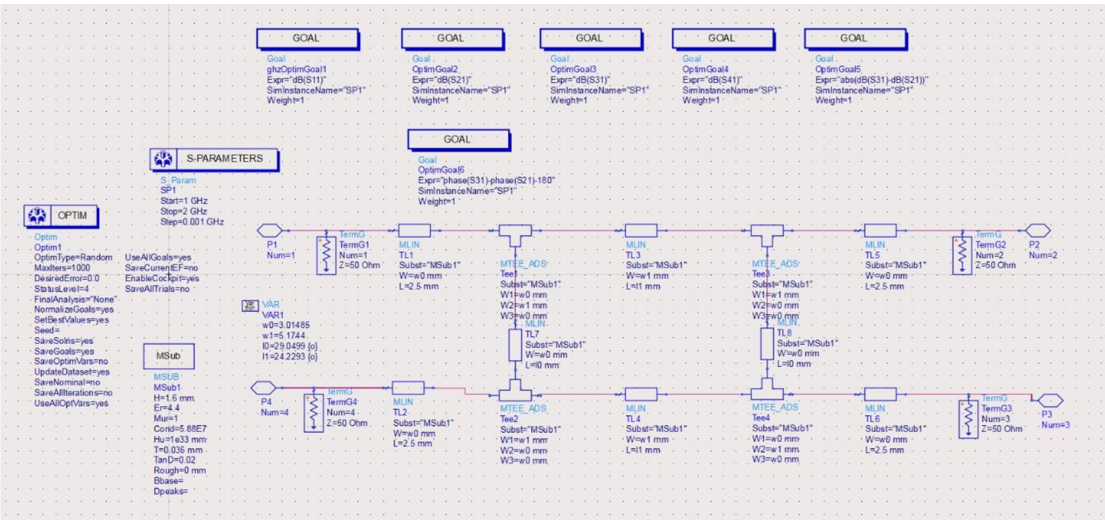
Apply LineCalc tools to calculate the width of transmission line again. Below results are widths of $Z0$ = 50 Ω and $Z0$ = 50/√2 Ω separately. So, we change the $w1$ = 5.17446mm, and $w2$ =

3.01485mm

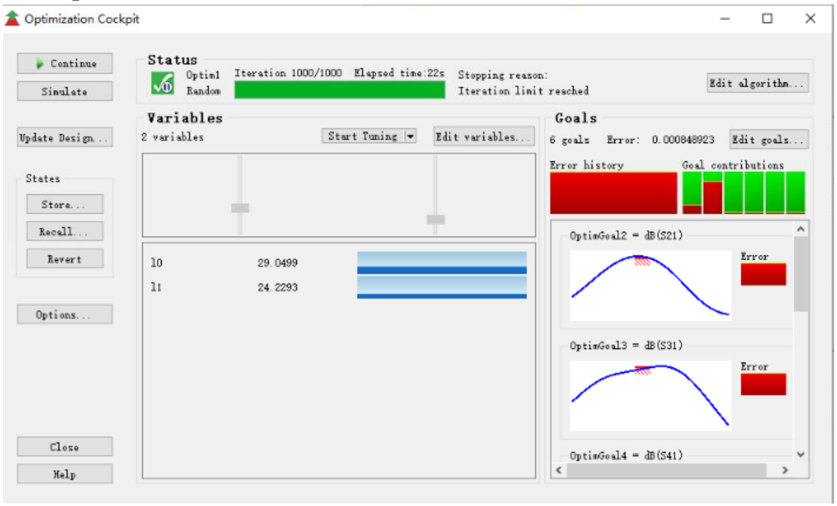




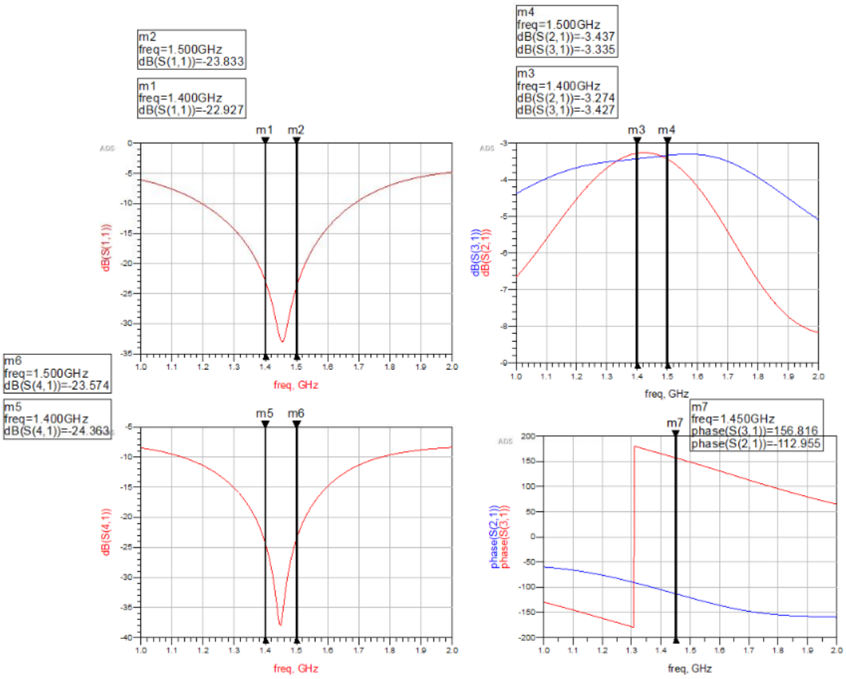
According to the principle, the length should be a quarter wavelength. Adjust the microstrip line length to operate at 1.45GHz. The ADS circuit diagram is shown below.



To meet the requirements of S-parameter, we need to optimize the parameters Ls using the optimization settings of the ADS, whose optimization range of Ls is $10-50mm$. The result of the optimized parameter $Ls = 1.72964mm$ is shown below:

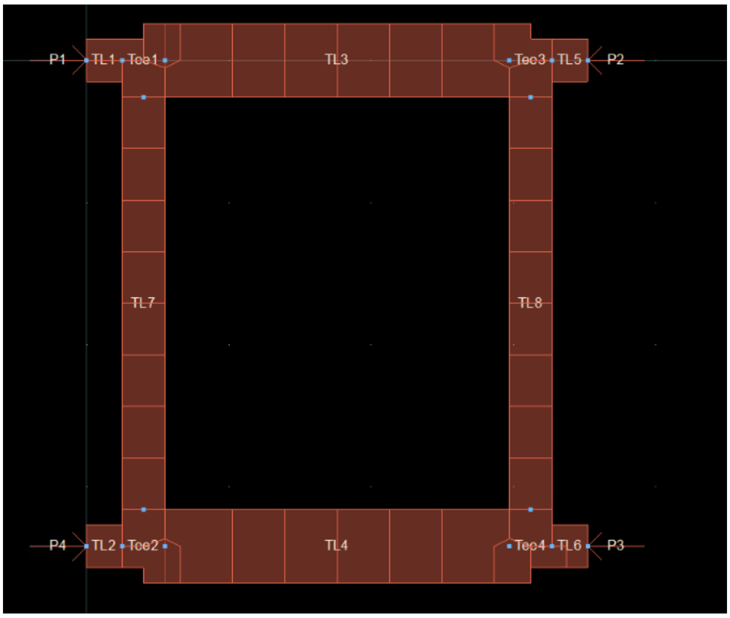


The result of $S11$, $S12$, $S13$, $S23$ after optimization in ADS is shown below.

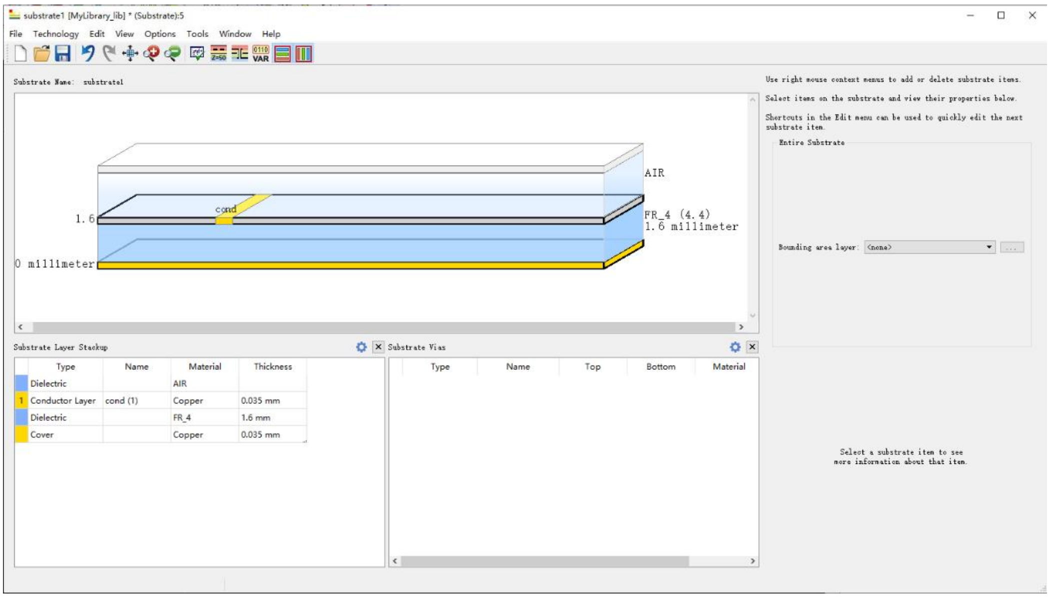


Which meets our requirements mostly.

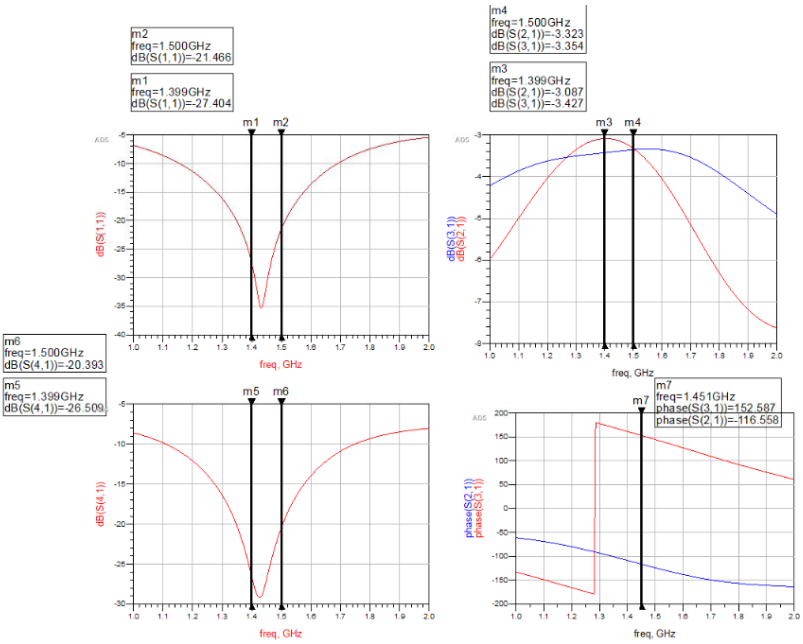
Then, we can generate the layout as follows:



And the substrate is:

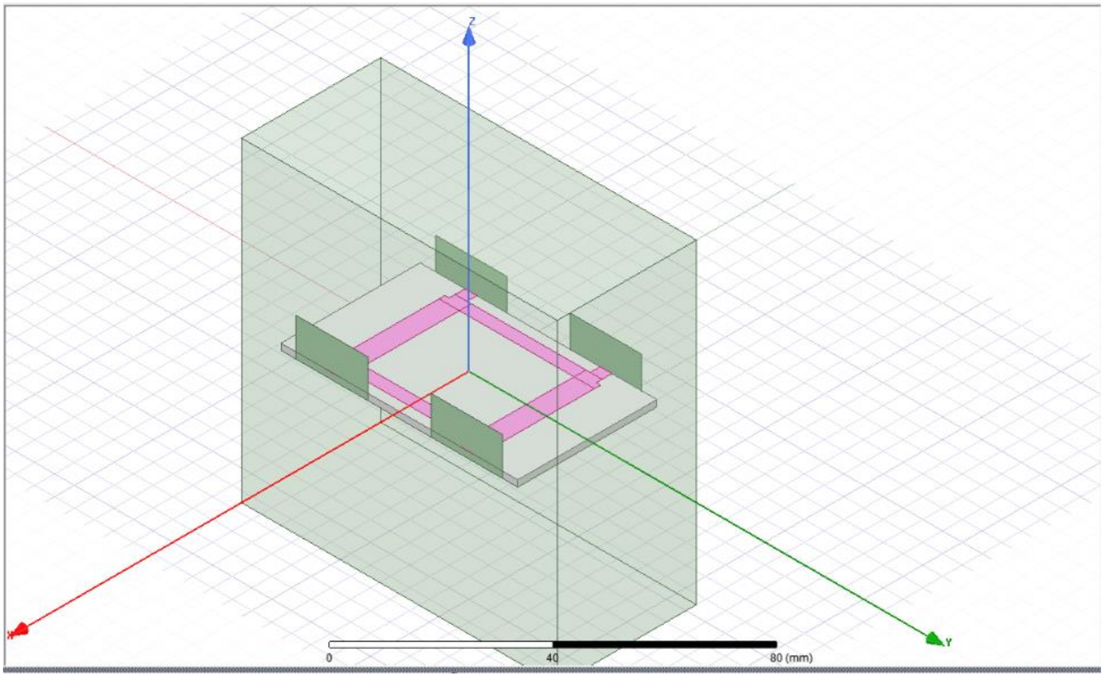


The S parameters through the EM simulation is as follows, which differs from the simulated ideal S-parameters mentioned earlier, showing some degradation. This is because the EM simulation in the layout considers spatial effects and the influence of parasitic parameters, which is normal but they are meets our requirements nearly.

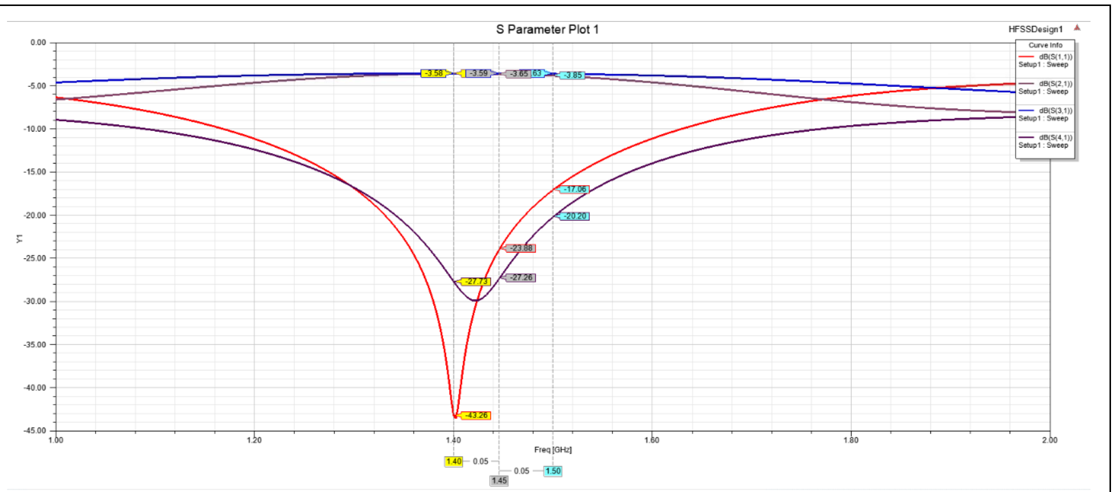


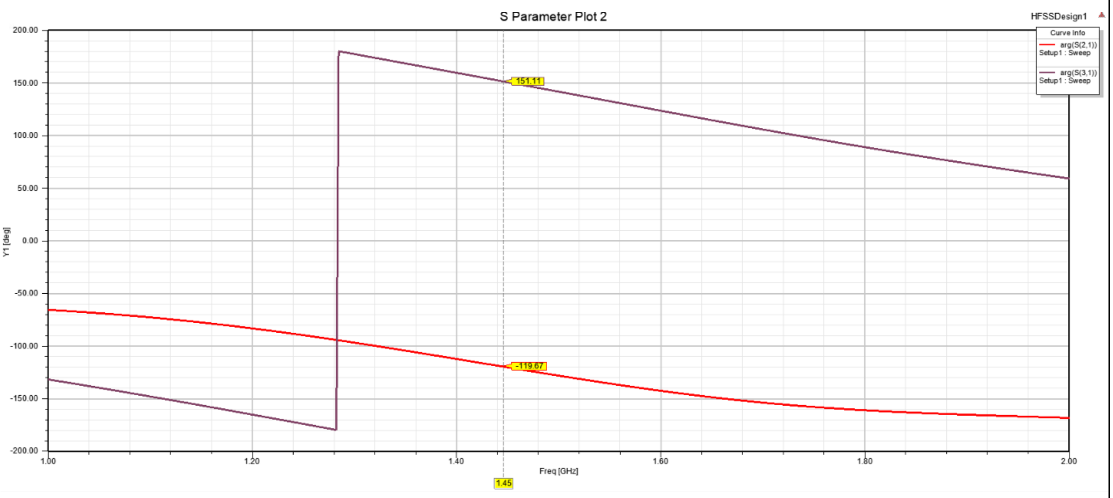
HFSS

And then we can export this to the HFSS to do the EM simulation. We add the substrate with FR4 and the radiation box. The whole model is shown as below. And we should assign excitation by adding the wave port for the three ports. The mode is as follows:



The S-paraments are:





From the above figure, it can be observed that the S-parameters generally meet our requirements, except that S31 and S21 don't completely fulfill our expectations, but the difference is not significant. Therefore, we can achieve better results through optimization.


Post Analysis Display

OptimizationSetup1

Options...

Result | Profile

View: Table
Plot

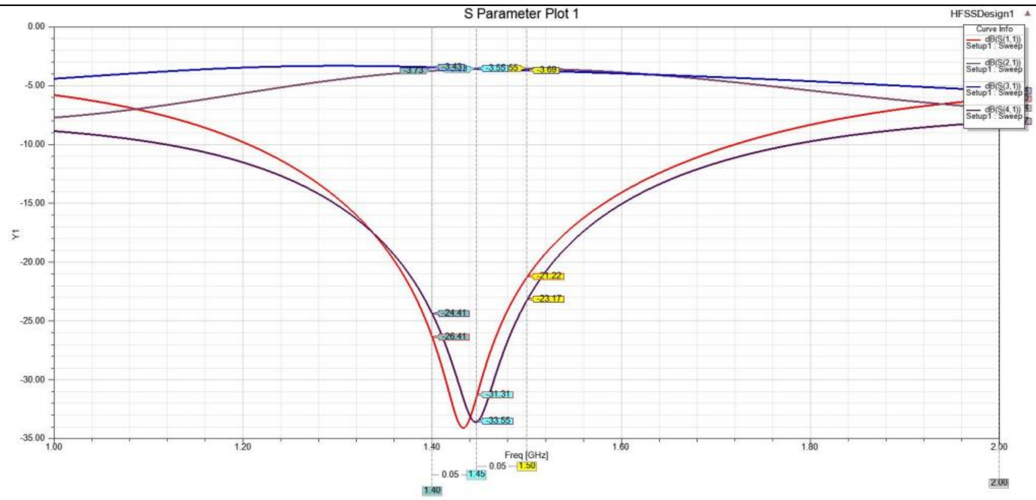
Evaluation	L1	L2	Cost
9	30.81mm	29.53mm	0.16332
17	30.82mm	29.52mm	0.16419
1	30.81mm	29.71mm	0.16453
8	30.61mm	29.71mm	0.16589
13	30.81mm	29.69mm	0.16796
12	31.04mm	29.53mm	0.17797
15	30.81mm	29.36mm	0.18794
16	30.93mm	29.45mm	0.2155
14	30.58mm	29.53mm	0.22215
10	30.75mm	29.6mm	0.24602
7	30.81mm	28.09mm	0.33631
11	30.8mm	29.7mm	0.34955
5	30.54mm	29.47mm	0.38575
2	32.45mm	29.71mm	0.39003
6	29.16mm	29.71mm	0.4931
3	30.81mm	31.33mm	0.60224
4	28.09mm	27.27mm	18.493

Export...

Apply

Revert

The results:



It can be seen that the results have improved somewhat, but S31 and S21 still do not meet our requirements. This may be related to the parameters of the actual board material in HFSS and may not yield as satisfactory results as the simulation in ADS.

Experience

Through this experiment, I have enhanced my comprehension of the Branch Line Coupler, developed a more robust understanding of its theoretical foundations, and acquired proficiency in simulating it using both HFSS and ADS. Furthermore, I have cultivated the expertise to fine-tune parameters in ADS to achieve the most optimal branch lengths. It was noted that, despite ADS providing parameters that perfectly align with the design specifications, there exists a disparity between the results obtained from layout simulation and HFSS simulation. This discrepancy is attributed to the nuances between theory and practical implementation. Layout simulation and HFSS simulation necessitate the consideration of numerous practical parameters, resulting in diverse outcomes that may not precisely meet our requirements. Consequently, further optimization in HFSS becomes imperative.

Throughout all these processes, numerous details come into play, and each step demands accuracy; otherwise, entirely incorrect results may be obtained. This underscores the need for attentiveness. For instance, during this experiment, when I initially set constraints for optimization, I forgot to include "dB," resulting in the inability to optimize the correct outcomes. Hence, we must be meticulous to ensure the accuracy of each step.

Score	98