Project 1: A Branch line coupler operating at 2.4GHz

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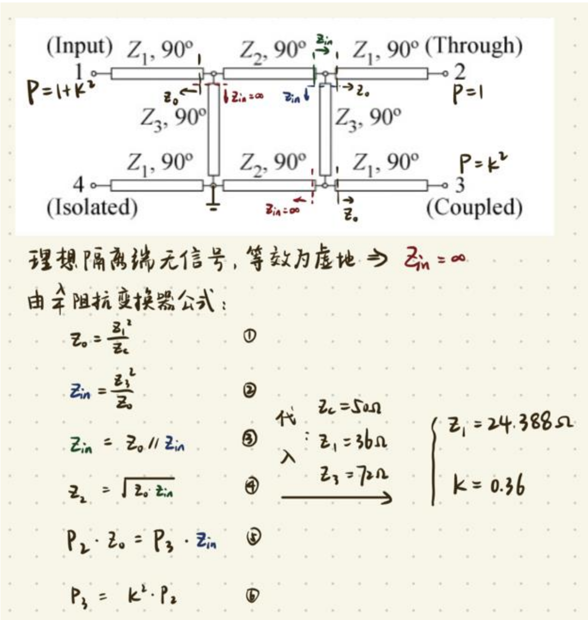
Introduction

1. Branch line directional coupler

For an ideal branch-line coupler, four initial boundary conditions are defined:

- All four ports have no reflections, and the impedances are uniformly matched to (Z_0 = 50 ohms).
- Any port can serve as an input port. This means that the topology satisfies X-axis and Y-axis mirror symmetry, and 180-degree rotational symmetry.
- The lengths of the four edges that constitute the branch-line coupler are all one-quarter wavelength.
- The total power of the input port signal is ($1 + K^2$), where the power output to the through port is ($P_2 = 1$), the power at the coupled port is ($P_3 = K^2$), and there is no signal output at the isolation port.



```
% 给定参数值
Z0 = 50;
Z1 = 36;
Zv = 72;

% 计算Z2
Z2 = sqrt((Z1^2 / Z0) * ((Z1^2 / Z0) * (Zv^2 / (Z1^2 / Z0))) ...
    / (Z1^2 / Z0 + Zv^2 / (Z1^2 / Z0)));

% 切换MATLAB输出格式为长格式
format long;

% 显示结果，保留15位小数
fprintf('解得的Z2值为：%.15f\n', Z2);
```

```
解得的Z2值为：24.387801715637398
```

2. Unbalanced Power Distribution

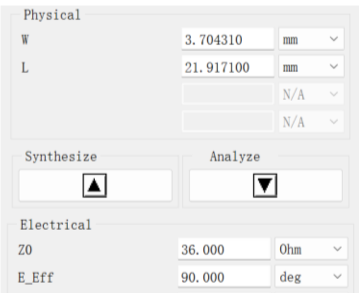
An unbalanced branch line directional coupler is a device used in microwave and RF circuits, characterized by having different power distributions between Port 2 and Port 3. Here are the basic principles of an unbalanced branch line directional coupler. By adjusting the length, width and characteristic impedance of the branch line, different power distributions can be achieved. When a microwave signal is input at Port 1, a portion of the power travels through the main line to reach Port 2, while another portion travels through the branch line to reach Port 3. Thus, the output power at Ports 2 and 3 can be tuned. The design of the unbalanced branch line directional coupler aims to introduce power imbalance between Port 2 and Port 3. This imbalance is meaningful for certain applications, such as those requiring specific power ratios between the two ports.

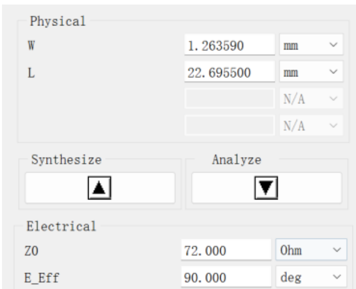
Results & Analysis

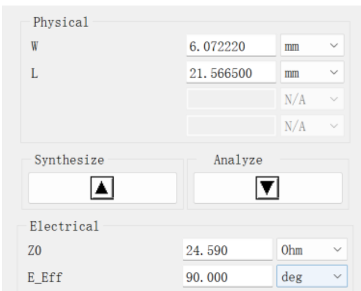
1. ADS simulation branch line coupler

In ADS, we used the path method to simulate the branch line coupler. The design and simulation result are shown below.

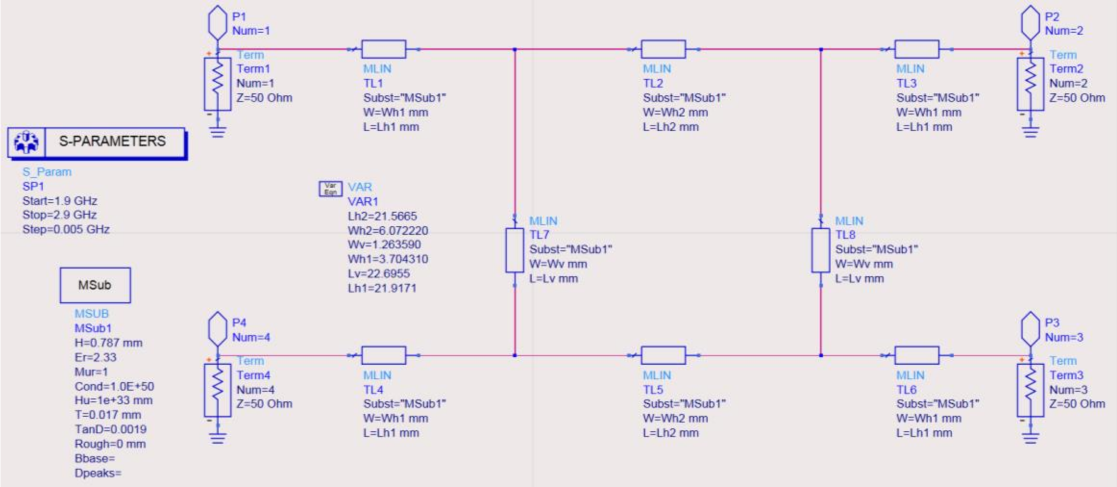
Line-Calculation:



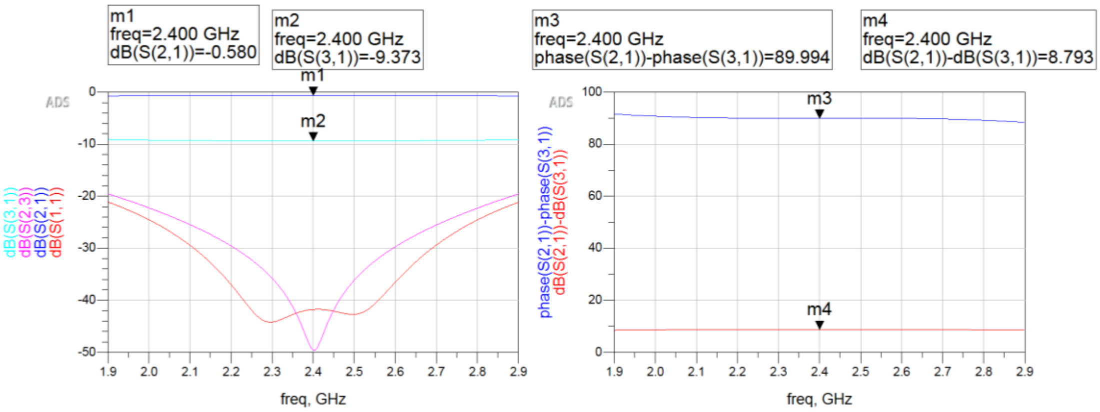




Schematic:



S-parameters:



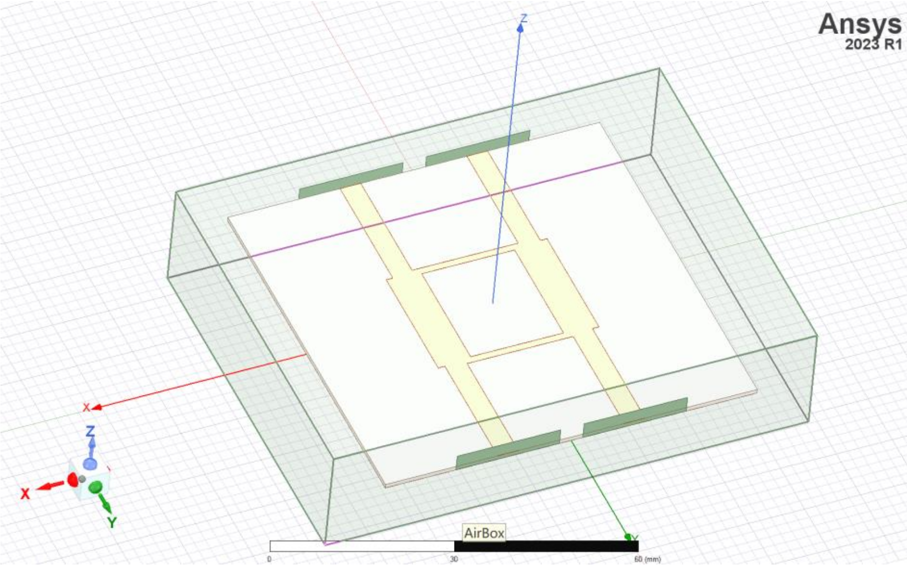
From the results, we can confirm that our design outcomes are accurate. S_{11} and S_{23} reach their lowest points near the operating frequency, both being less than -40dB. This indicates that our broadband coupler has good port input matching, and there is high isolation between ports 2 and 3. In terms of bandwidth, the range that satisfies the above requirements is greater than 300MHz, indicating that the device can operate under broadband conditions.

At 2.4GHz, the value of S_{21} is -0.580dB, and it is used as the primary energy output port. At the same frequency, the value of S_{31} is -9.373dB, essentially meeting our requirement for a 10dB coupling level, serving as the secondary energy output port. P21=K^2*P31, S21=K*S31， dB(S21)-dB(S31)=20*lg(1/K)=8.793 dB, we obtained K=0.3634, close to the expected value of 0.36.

In terms of phase, the phase difference between the output ports of port 2 and 3 is about 90 degrees as expected.

2. HFSS simulation branch line coupler

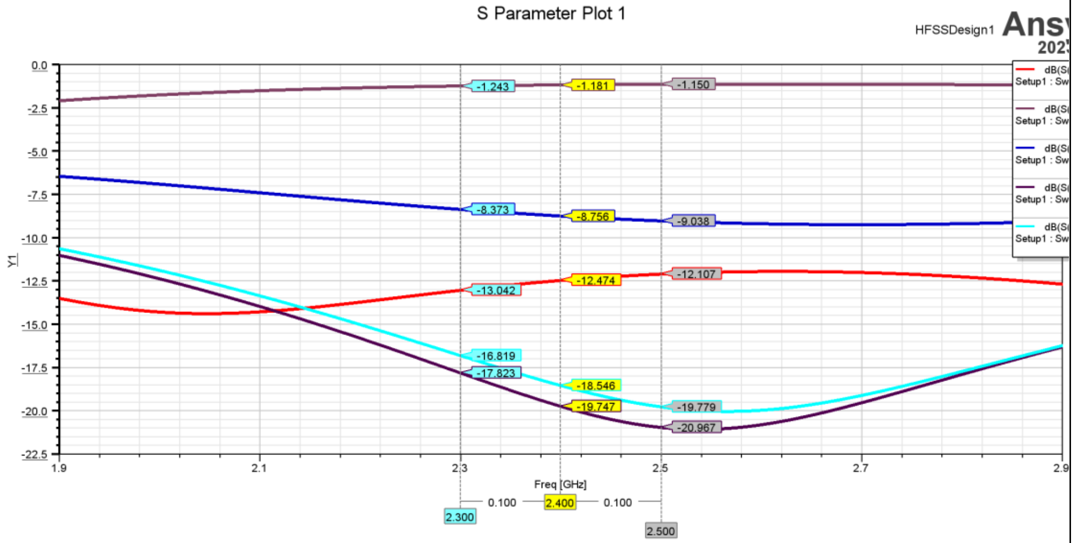
In HFSS, we completed the modeling of branch line coupler, as shown below.



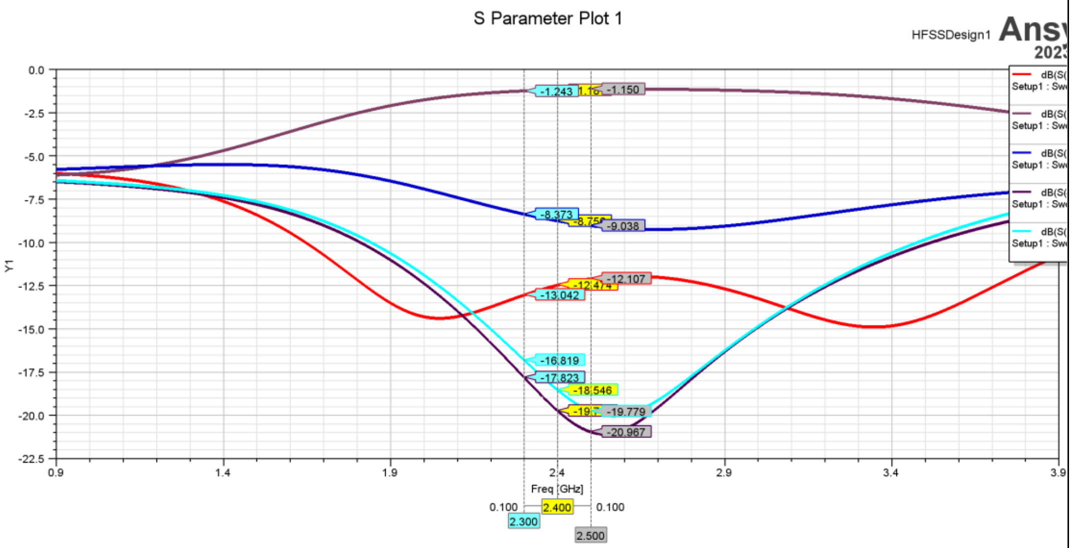
Design Properties:

Name	Value	Unit	Evaluated Val...	Type	Descripti...	Rea...	Hid...	Swe...
Lf	21.9171	mm	21.9171mm	Design		☐	☐	☑
L1	22.6955	mm	22.6955mm	Design		☐	☐	☑
L2	21.5665	mm	21.5665mm	Design		☐	☐	☑
hs	0.787	mm	0.787mm	Design		☐	☐	☑
hc	0.017	mm	0.017mm	Design		☐	☐	☑
Wf	3.70431	mm	3.70431mm	Design		☐	☐	☑
W1	1.26359	mm	1.26359mm	Design		☐	☐	☑
W2	6.07222	mm	6.07222mm	Design		☐	☐	☑

S-Parameters:

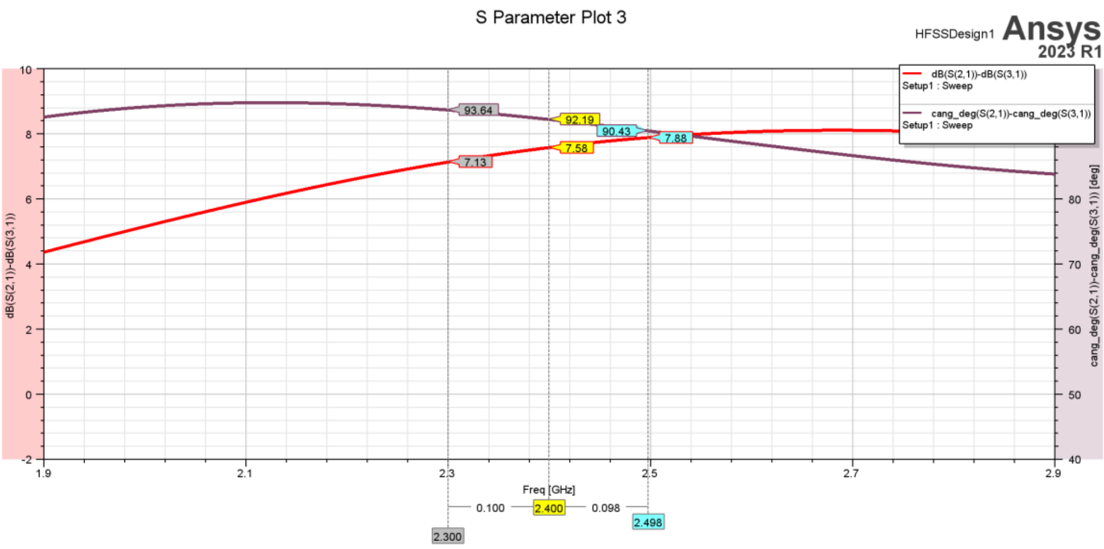


Set the solution frequency to 2.4 GHz, set sweep frequency in the range of 1.9 GHz to 2.9 GHZ, and the S parameter is as shown in the figure below. Through observation, The HFSS simulation is similar to ADS in terms of coupling and insertion loss. S31 is -8.756 dB, approximately -10 dB, while S21 is -1.181 dB, slightly worse than the simulation in ADS but generally meeting the requirements. K=0.4178. However, the return loss of S11 and S23, namely the input port, and the isolation between ports 2 and 3 are poor, only about -12.474 dB and -18.546 dB, significantly worse than the ideal performance in the ADS simulation.

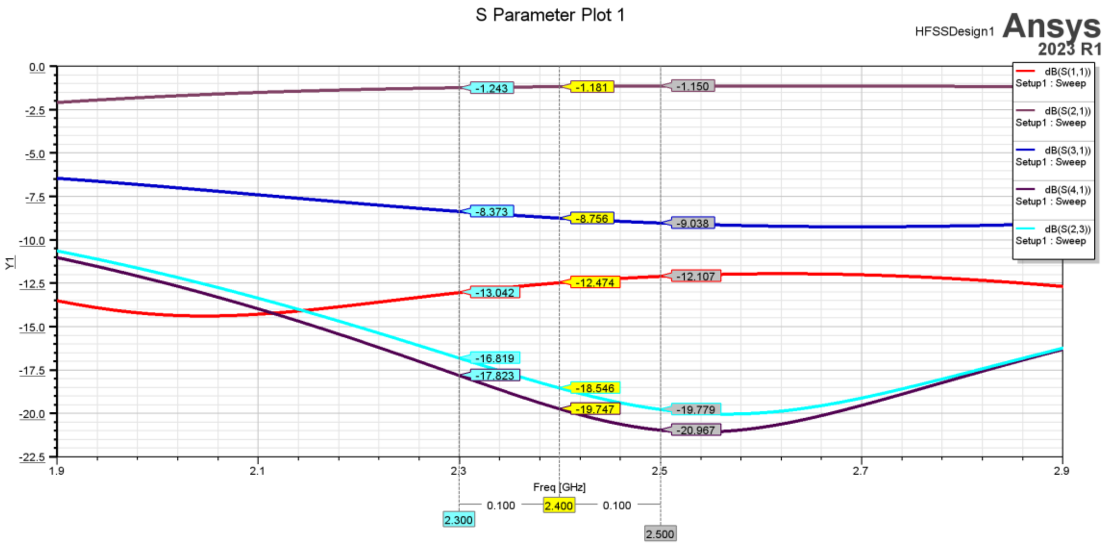


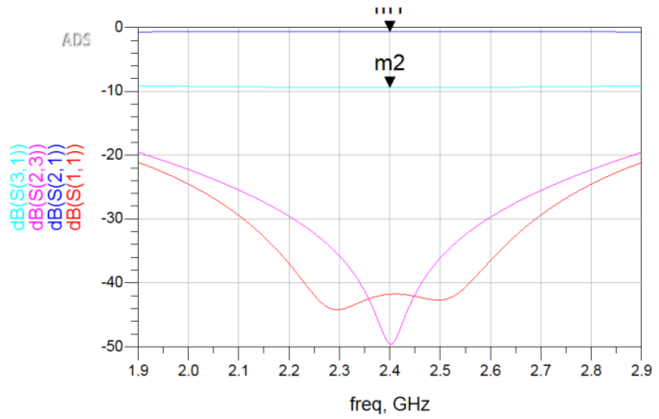
Expanding the frequency sweep range, as indicated by the trend of the S11 curve, suggests an attempt to achieve a wide operating bandwidth in the design. However, due to the presence of ripples, the return loss of S11 at the center frequency of 2.4 GHz is excessively large, making the design less than ideal.

By observing the phase diagram of S parameter, we found that the phase angle of S21 and S21 differ by about 90 degrees.



3. Comparison of HFSS and ADS simulation results





HFSS and ADS exhibit similarities in terms of coupling and directivity, but differences exist in some aspects of isolation and insertion loss.

4. Q&A

- **Q1:** Do these results indicate that your designs are correct? Explain why you think so.

  A1: From the results in ADS, it can be observed that the design is correct. Both the directivity and coupling meet the specified requirements, and a relatively wide operating frequency range has been achieved.

- **Q2:** Compare these values between the ADS simulation results and HFSS simulation results. Some of these values are close, while some values are quite different. Explain why this is so.

  A2: HFSS simulations consider the **overlap between microstrip lines** and consider parasitic effects. In comparison to HFSS, ADS simulations involve fewer actual parameter settings and operate as circuit simulations, whereas HFSS focuses on electromagnetic simulations. Hence, HFSS tends to be more representative of real-world scenarios.

- **Q3:** How this coupler is different than the conventional branch-line coupler.

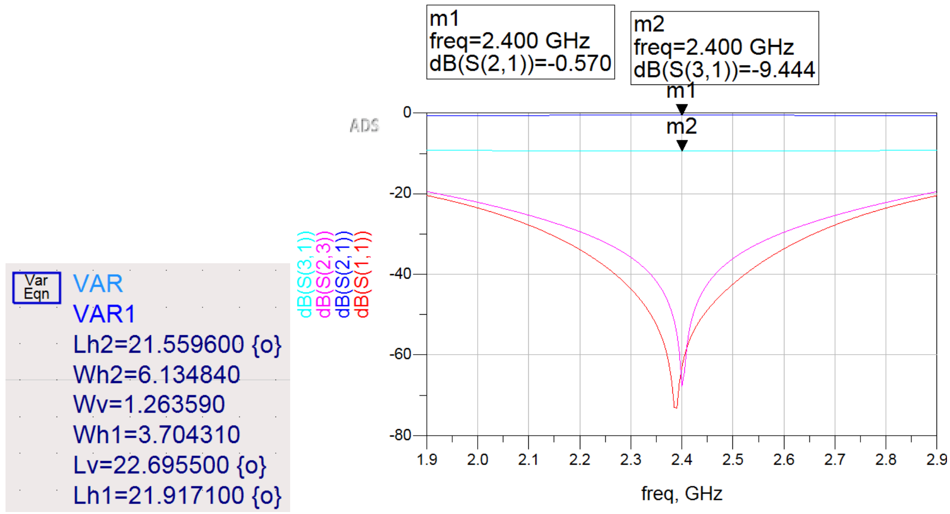
  A3: Traditional branch-line couplers are often impedance matched to achieve optimal performance at certain frequencies. However, in this experiment, we were tasked with designing a broadband coupler.

  We utilized **mismatch** to achieve a larger bandwidth, and the following theoretical calculations also confirm this:

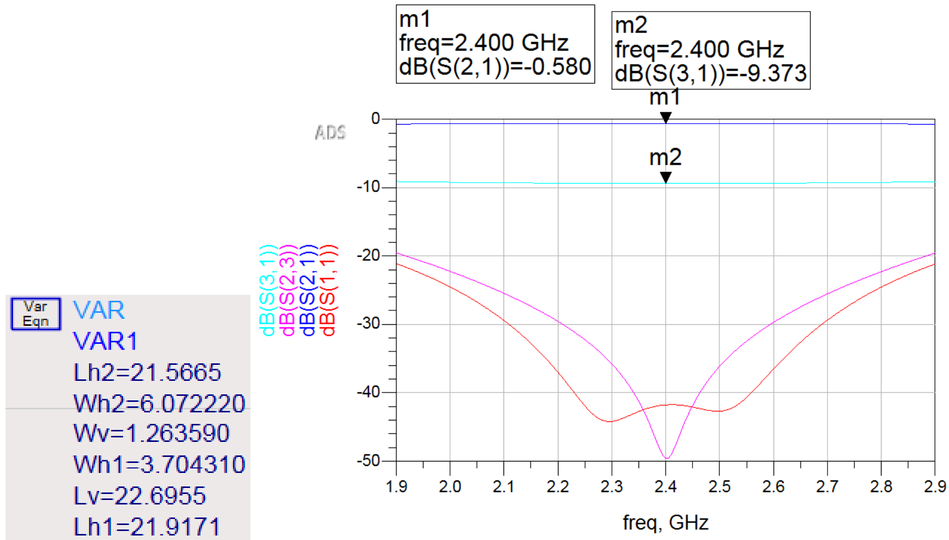
  For the branch-line coupler we designed, we utilized boundary conditions, circuit analysis theory, and quarter-wavelength transmission line impedance transformation theory to calculate the impedances on each branch line. The obtained results are shown in the figure below. According to our findings, the calculated theoretical value of Z_{h1} is 24.388 ohms, smaller than the designed value of 24.59 ohms. Therefore, what we have is a slightly **mismatched** branch-line coupler.

  By intentionally designing a mismatched coupler, it is possible to further enhance the bandwidth, similar to a Chebyshev multi-stage impedance transformer. Specifically, mismatch introduces multiple reflections and interferences of frequency components, leading to the widening of the signal spectrum in terms of frequency. This can enhance the circuit or system's response to signals at different frequencies, thereby increasing the bandwidth. ADS simulation proves the result:

- Matching Circuit:



- Mismatching Circuit:



Experience

Gives us a deeper understanding of Branch Line Coupler.

Score	100