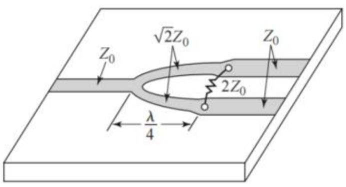
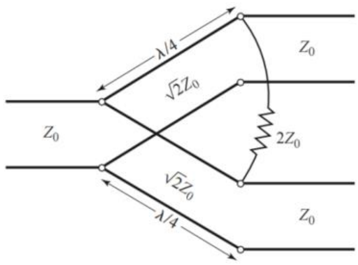
Lab 5：Wilkinson Power Divider

Author	Name：张皓东	Student ID: 12113010

Introduction

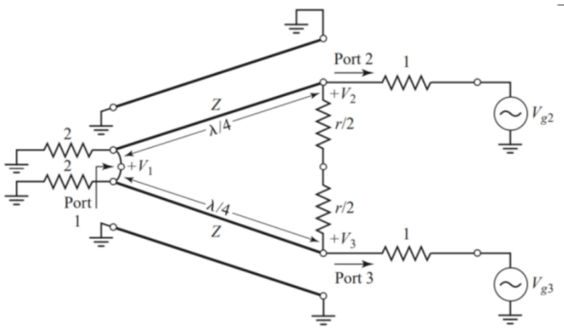
The Wilkinson Power Divider is a widely used passive microwave circuit commonly applied in wireless communication, radar systems, and microwave communication systems. Proposed by Ernest Wilkinson in 1960, it has found extensive applications in various fields. The basic structure of the Wilkinson Power Divider is a three-port network, where one port serves as the input and the other two ports act as outputs. Its distinctive feature is the ability to evenly distribute input power to the two output ports while maintaining independence between the two output ports. As the RF signal is fed into the input port, it passes through a series of networks and components, ultimately undergoing power division at the two output ports. This power division is achieved by introducing specially designed impedance transformation networks into the circuit. Through careful impedance matching, the Wilkinson Power Divider achieves uniform power distribution at its output ports while minimizing coupling between them. An important characteristic of the Wilkinson Power Divider is its phase performance. By incorporating appropriate impedance matching in the design, phase matching is achieved, ensuring stable phase relationships between the two output ports. This is crucial for systems requiring phase consistency, such as antenna arrays and phased-array radar systems. Wilkinson Power Dividers are commonly employed in wireless communication systems to distribute RF signals to different channels or antennas. In radar systems, Wilkinson Power Dividers can be utilized to distribute radar signals to different antennas or channels, facilitating beamforming and target tracking. In laboratory and testing applications, Wilkinson Power Dividers are widely used in microwave measurement systems for the precise distribution and measurement of microwave power.





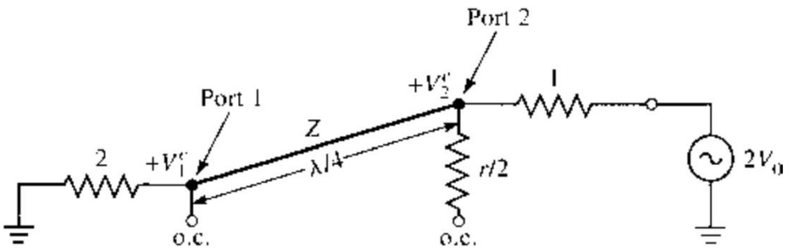
Theorical Analysis with even and odd mode

To analyze the Wilkinson Power Divider, we apply even-odd mode, in which we reduce the circuit to two simpler ones driven by symmetric and antisymmetric sources at the output ports. For simplicity, we can normalize all impedances to the characteristic impedance $Z0$, and the transmission line circuit with voltage generators at the output ports is shown below:



Now define two separate modes of excitation for the circuit the even mode, where $Vg2 = Vg3 = 2V0$, and the odd mode, where $Vg2 = -Vg3 = 2V0$. Superposition of these two modes effectively produce an excitation of $Vg2 = 4V0$ and $Vg3 = 0$, from which we find the scattering parameters of the network. We now treat these two modes separately.

For even-mode excitation, $Vg2 = Vg3 = 2V0$, so $V2e = V3e$, and therefore no current flows through the $r/2$ resistors or the short circuit between the inputs of the two transmission lines at port 1. We can then bisect the network above with open circuits at these points to obtain the network below:



Looking into port 2, we can see an impedance:

$$Z_{in}^{e} = \frac{Z^2}{2}$$

Thus, if $Z = \sqrt{2}$, port 2 will be matched for even-mode excitation, then $V2e = V0$ since $Zine = 1$. The $r/2$ resistor is superfluous in this case since one end is open-circuited. Then, we find $V1e$ from the transmission line equations. If we let $x = 0$ at port 1 and $x = -\lambda/4$ at port 2, we can write the voltage on the transmission line section as:

$$V(x) = V^{+}(e^{-j\beta x} + \Gamma e^{j\beta x})$$

Then, we have

$$V_2^e = V\left(-\frac{\lambda}{4}\right) = jV^{+}(1-\Gamma) = V_0$$

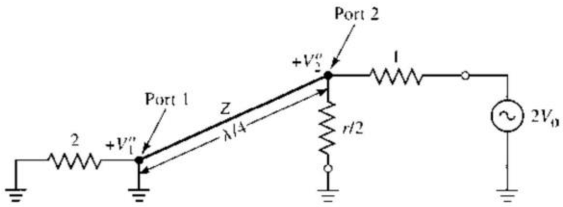
$$V_1^e = V(0) = V^{+}(1+\Gamma) = jV_0\frac{\Gamma+1}{\Gamma-1}$$

The reflection coefficient Γ is that seen at port 1 looking toward the resistor of normalized value 2, so

$$\Gamma = \frac{2-\sqrt{2}}{2+\sqrt{2}}$$

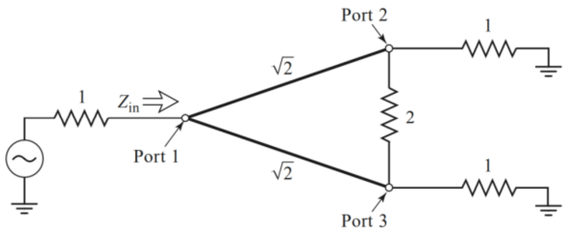
$$V_1^e = -jV_0\sqrt{2}$$

For odd-mode excitation, $Vg2 = -Vg3 = 2V0$, so $V2o = -V3o$, and there is a voltage null along the middle of the whole transmission line circuit. We can then bisect this circuit by grounding it at two points on its midplane to give the network below:

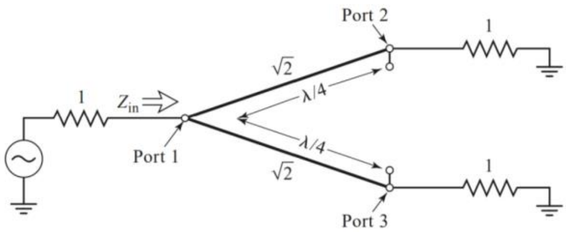


Looking into port 2, we see an impedance of $r/2$ since the parallel-connected transmission line is $\lambda/4$ long and shorted at port 1, and so looks like an open circuit at port 2. Thus, port 2 will be matched for odd-mode excitation if we select $r = 2$. Then $V2o = V0$ and $V1o = 0$, for this mode of excitation all power is delivered to the r/2 resistors, with none going to port 1.

Finally, we must find the input impedance at port 1 of the Wilkinson divider when ports 2 and 3 are terminated in matched loads. The resulting circuit is shown below.



where it is seen that this is like an even mode of excitation since $V2 = V3$. No current flows through the resistor of normalized value 2, so it can be removed, leaving the circuit:



We then have the parallel connection of two quarter-wave transformers terminated in loads of unity (normalized). The input impedance is:

$$Z_{in} = \frac{1}{2}(\sqrt{2})^2 = 1$$

In summary, we can establish scattering parameters for the Wilkinson power divider:

$$S_{11} = 0$$

$$S_{22} = S_{33} = 0$$

$$S_{12} = S_{21} = \frac{V_1^e + V_1^o}{V_2^e + V_2^o} = \frac{-j}{\sqrt{2}}$$

$$S_{13} = S_{31} = \frac{-j}{\sqrt{2}}$$

$$S_{23} = S_{32} = 0$$

Therefore, the S parameters matrix is that:

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

From the scattering matrix, we find that when the divider is driven at port 1 and the outputs are matched, no power is dissipated in the resistor. Therefore, the divider is lossless when the outputs are matched, only reflected power from ports 2 or 3 is dissipated in the resistor. Also, $S23 = S32 = 0$, so ports 2 and 3 are isolated. And as $S11 = S22 = S33 = 0$, the Wilkinson power divider is perfectly matched.

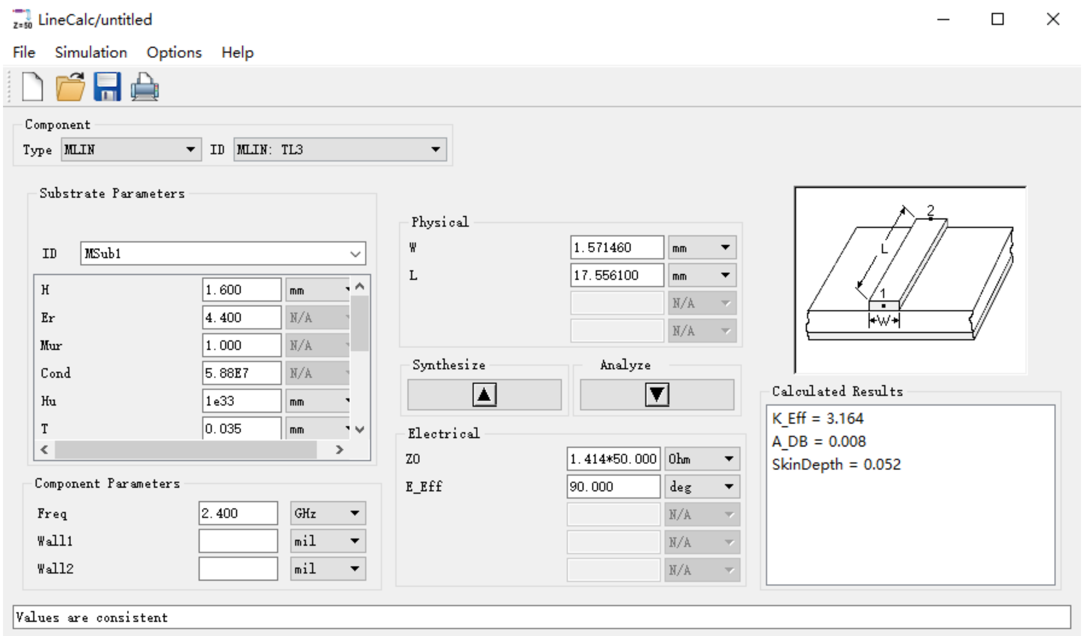
Lab results & Analysis:

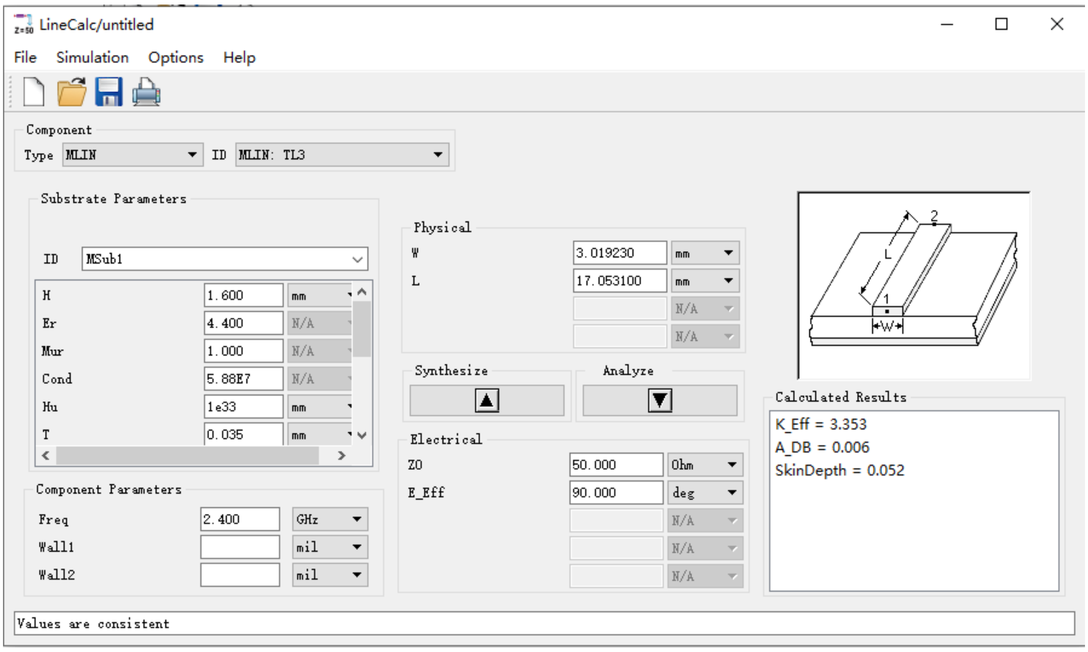
Lab objective

- Wilkinson Power Divider design in ADS and HFSS
- Freq. 2.4 GHz
- Bandwidth: 200MHz
- Substrate: FR4, thickness: 1.6mm
- S11<-20dB, S21>-3.3dB, S22<-20dB and S32<-25dB
- Optimization

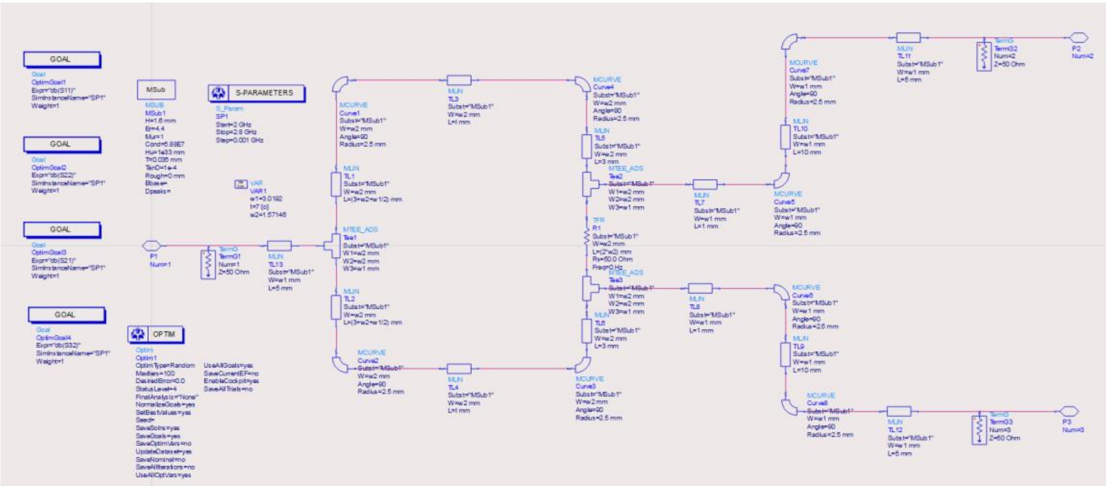
ADS:

Apply LineCalc tools to calculate the width of transmission line again. Below results are widths of $Z0 = 50\ \Omega$ and $Z0 = 50\sqrt{2}\ \Omega$ separately. So, we change the $w1 = 1.57146mm$, and $w2 =$ 3.01923mm.

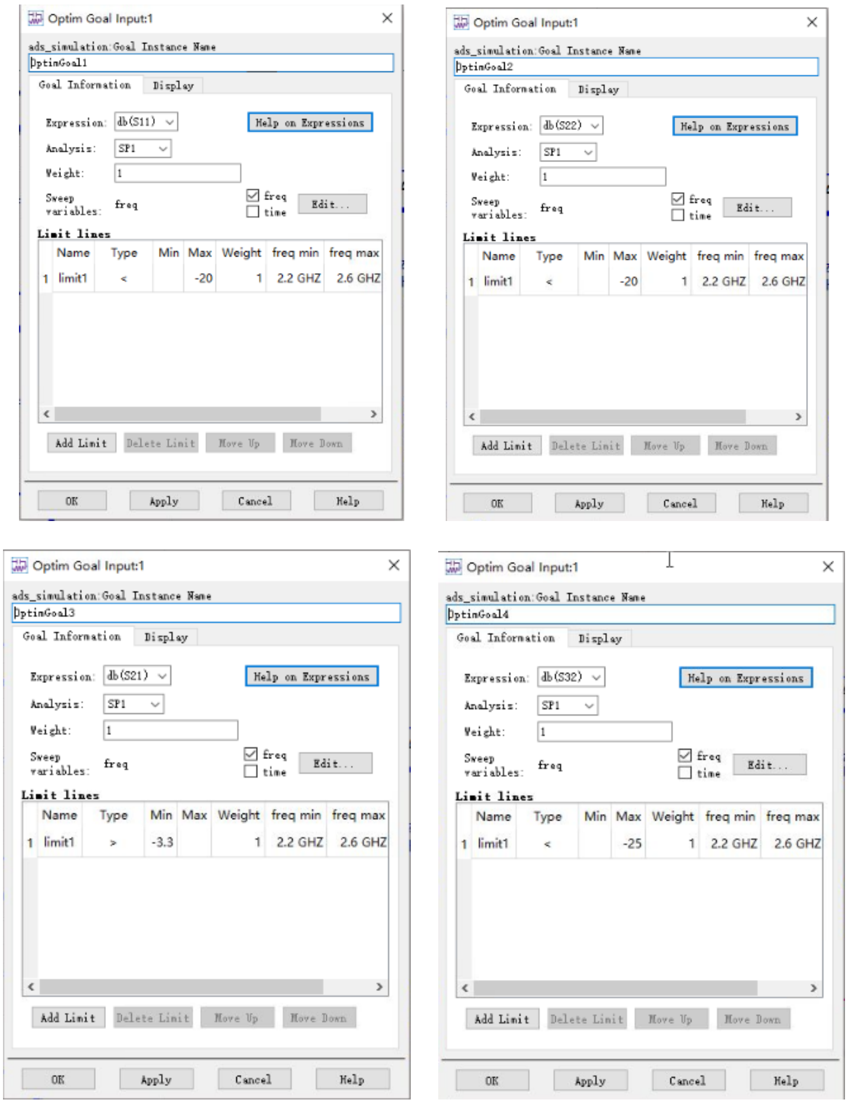




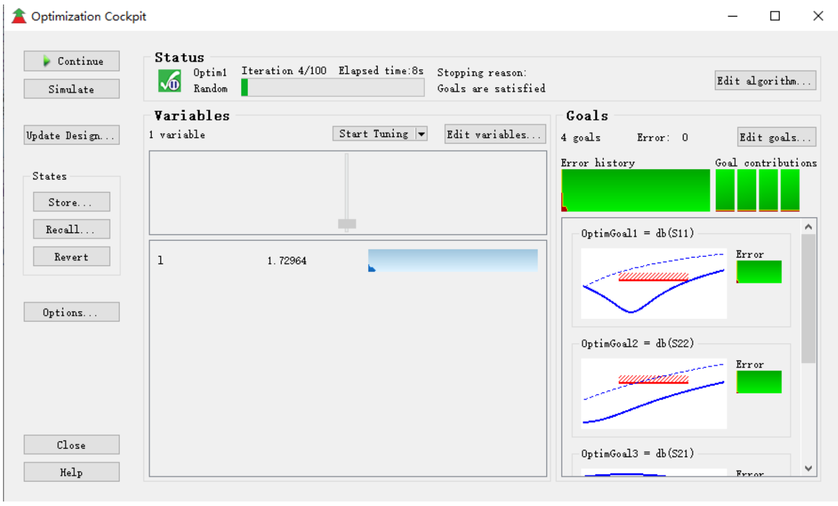
According to the principle of Wilkinson power divider, the length of $Z0 = 50\sqrt{2}\ \Omega$ should be a quarter wavelength. Adjust the microstrip line length to operate at $2.4GHz$. The ADS circuit diagram and board diagram of 3dB Wilkinson power divider are shown below, respectively.



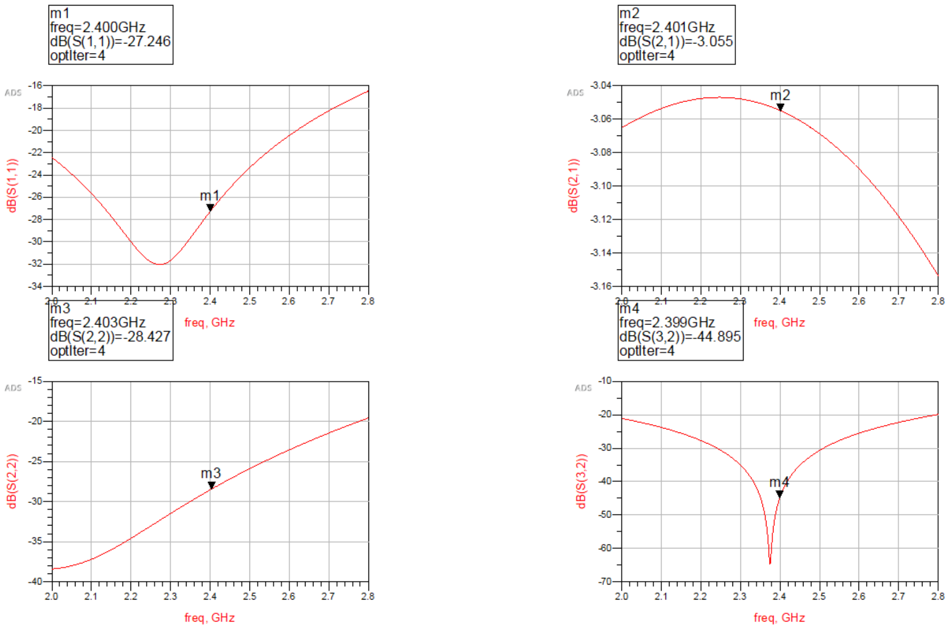
To meet the requirements of S-parameter of the power divider, we need to optimize the parameters Ls using the optimization settings of the ADS, whose optimization range of Ls is $1-20mm$. Here are the optimized settings:



The result of the optimized parameter $Ls = 1.72964mm$ is shown below:

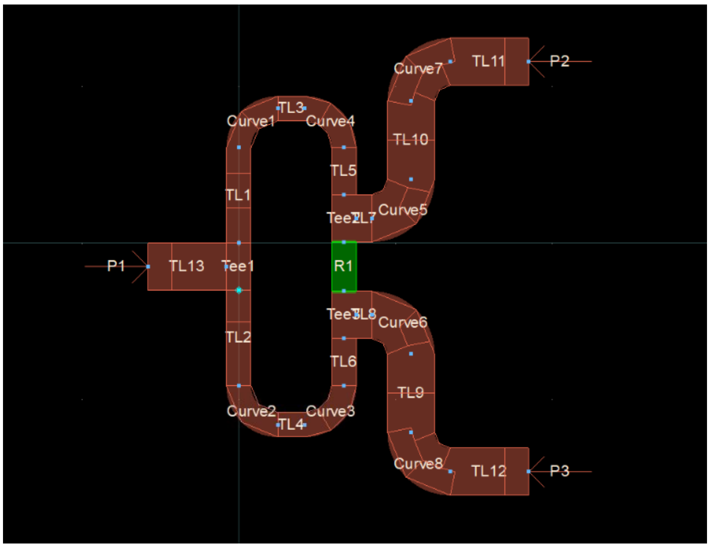


The result of $S11$, $S12$, $S13$, $S23$ after optimization in ADS is shown below.

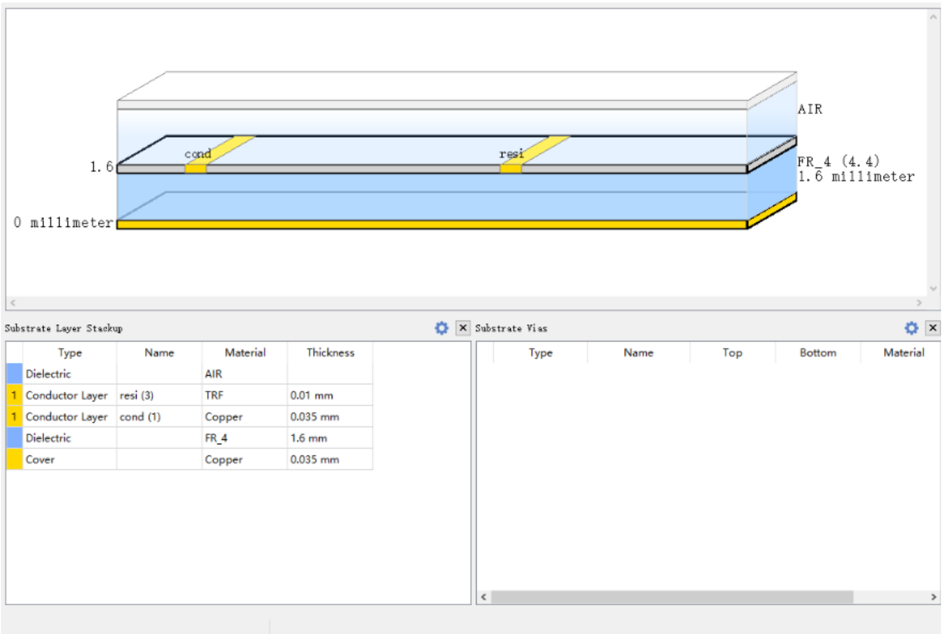


Which meets our requirements.

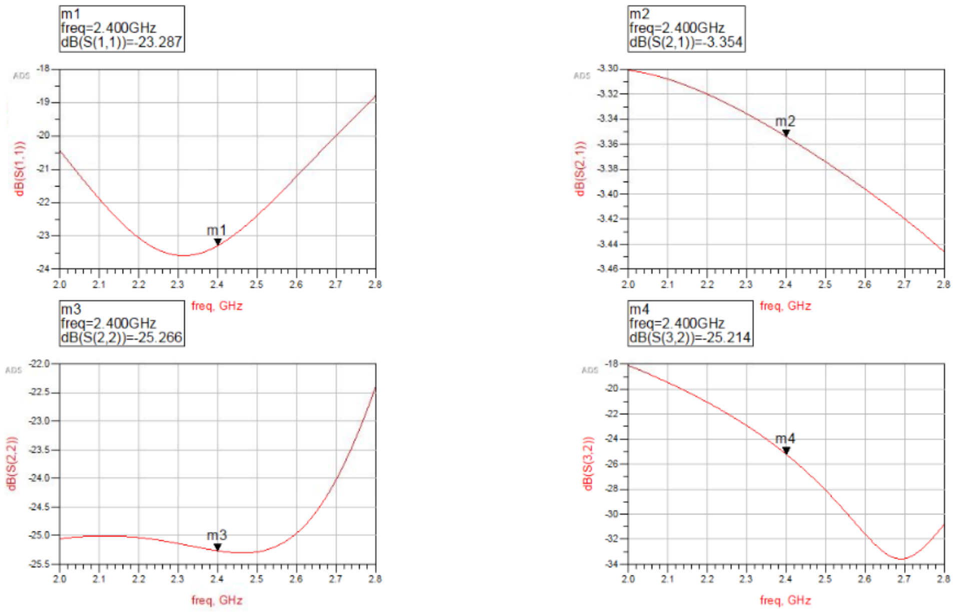
Then, we can generate the layout as follows:



And the substrate is:



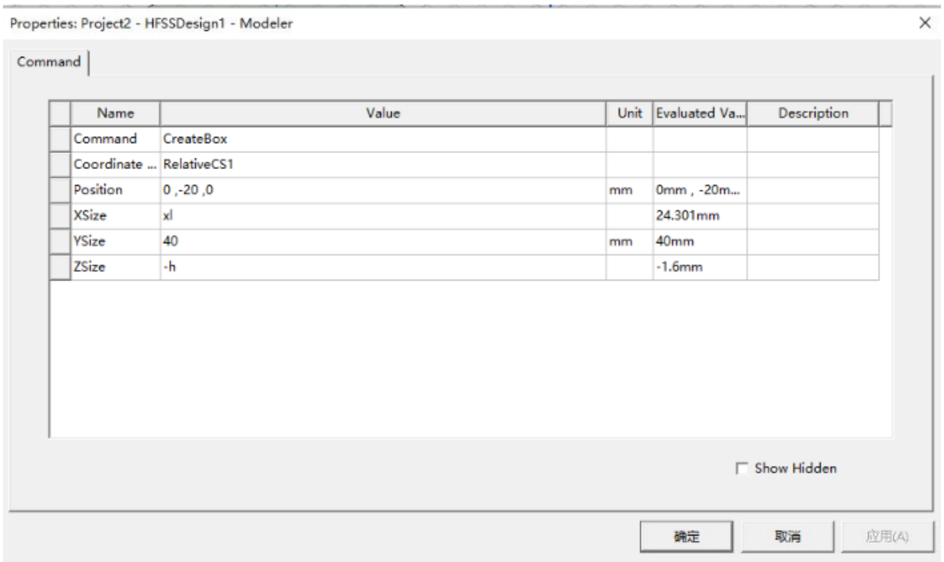
The S parameters through the EM simulation is as follows, which differs from the simulated ideal S-parameters mentioned earlier, showing some degradation. This is because the EM simulation in the layout considers spatial effects and the influence of parasitic parameters, which is normal.



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 dimension:

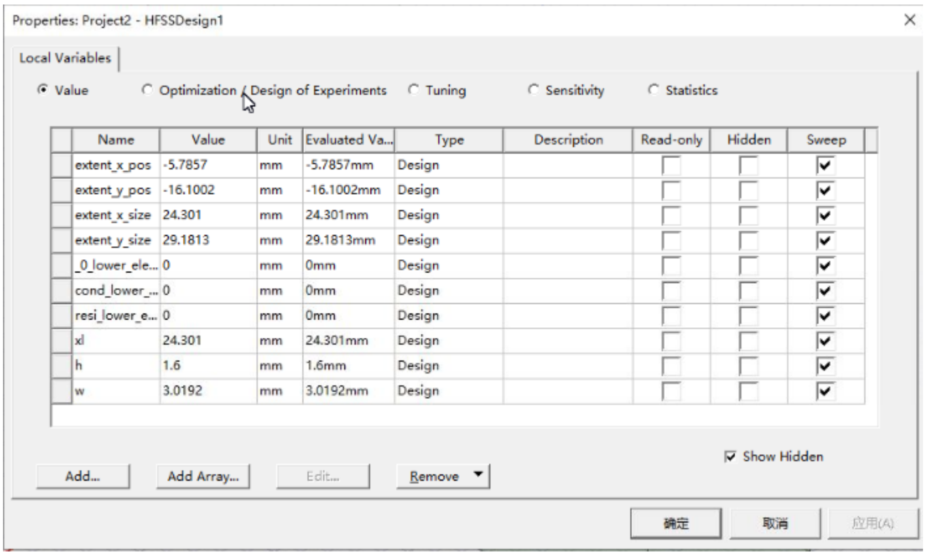


Properties: Project2 - HFSSDesign1 - Modeler

Command

Name	Value	Unit	Evaluated Va...	Description
Command	CreateBox			
Coordinate ...	RelativeCS1			
Position	0 ,-20 ,0	mm	0mm , -20m...	
XSize	xl		24.301mm	
YSize	40	mm	40mm	
ZSize	-h		-1.6mm	

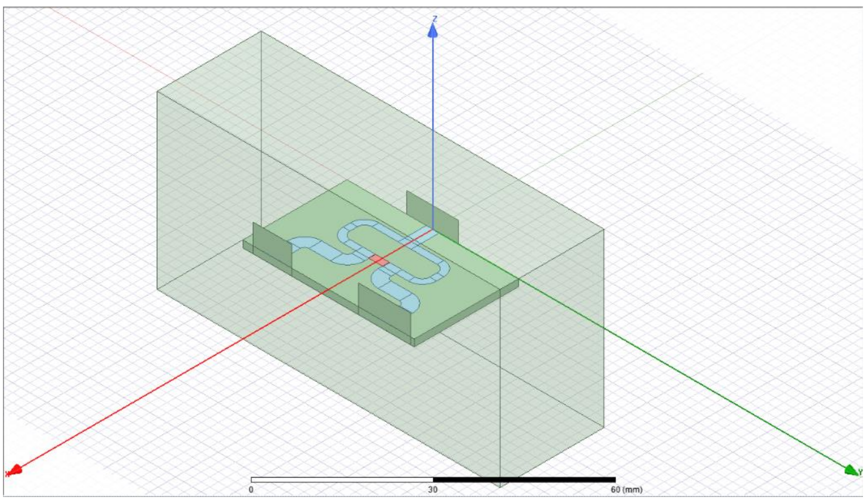
The variables:

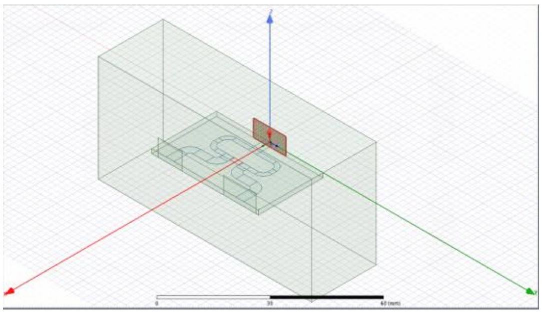
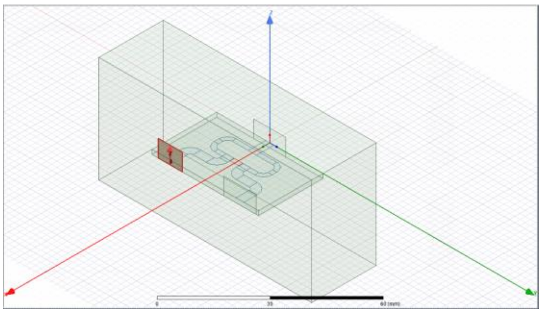
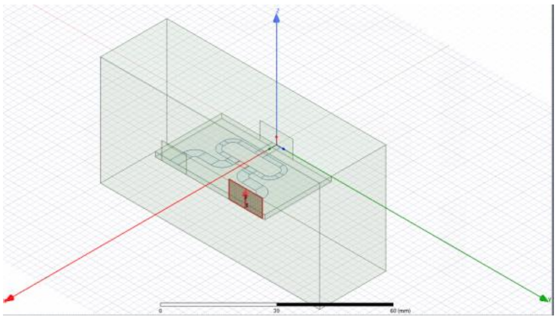


Properties: Project2 - HFSSDesign1

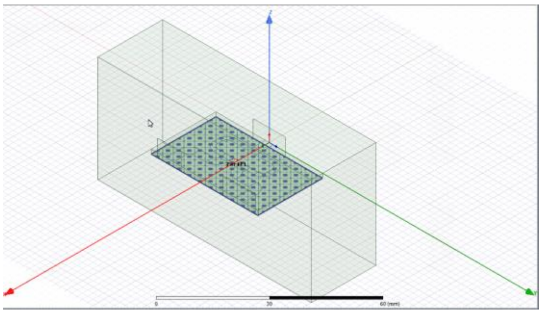
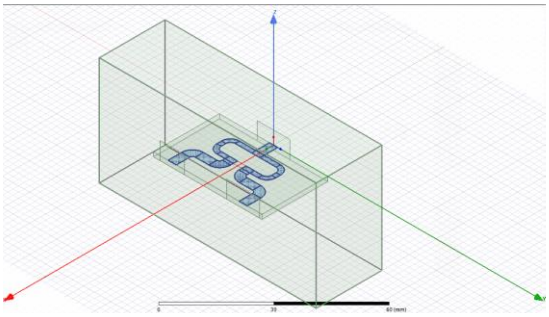
Local Variables

Name	Value	Unit	Evaluated Va...	Type	Description	Read-only	Hidden	Sweep
extent_x_pos	-5.7857	mm	-5.7857mm	Design		☐	☐	☑
extent_y_pos	-16.1002	mm	-16.1002mm	Design		☐	☐	☑
extent_x_size	24.301	mm	24.301mm	Design		☐	☐	☑
extent_y_size	29.1813	mm	29.1813mm	Design		☐	☐	☑
_0_lower_ele...	0	mm	0mm	Design		☐	☐	☑
cond_lower_...	0	mm	0mm	Design		☐	☐	☑
resi_lower_e...	0	mm	0mm	Design		☐	☐	☑
xl	24.301	mm	24.301mm	Design		☐	☐	☑
h	1.6	mm	1.6mm	Design		☐	☐	☑
w	3.0192	mm	3.0192mm	Design		☐	☐	☑

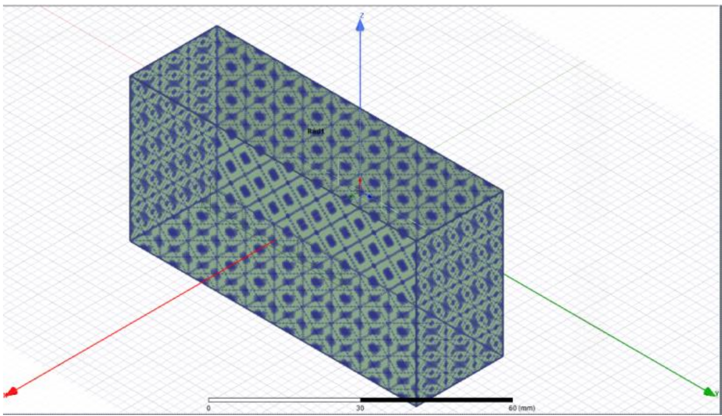


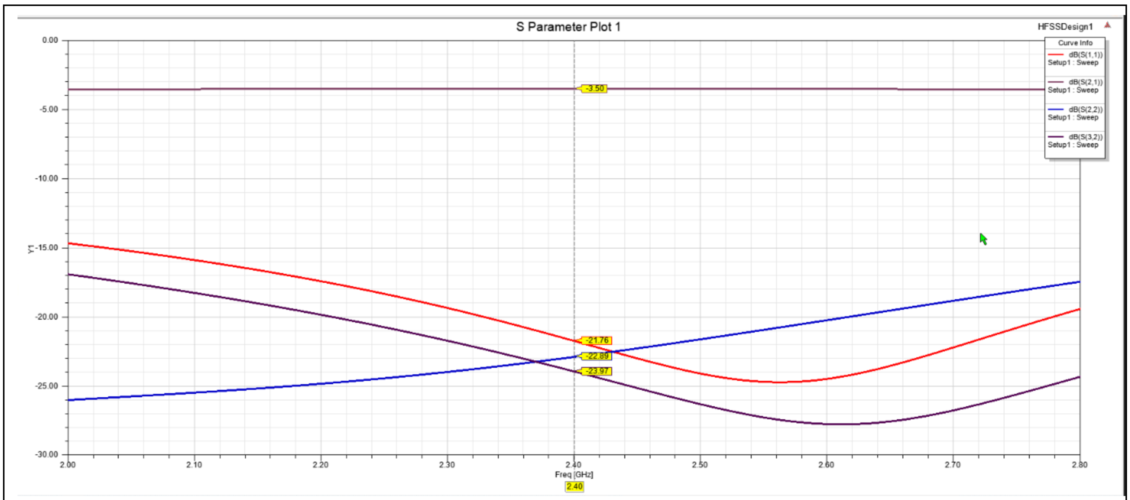
The perfect E:

The radiation:

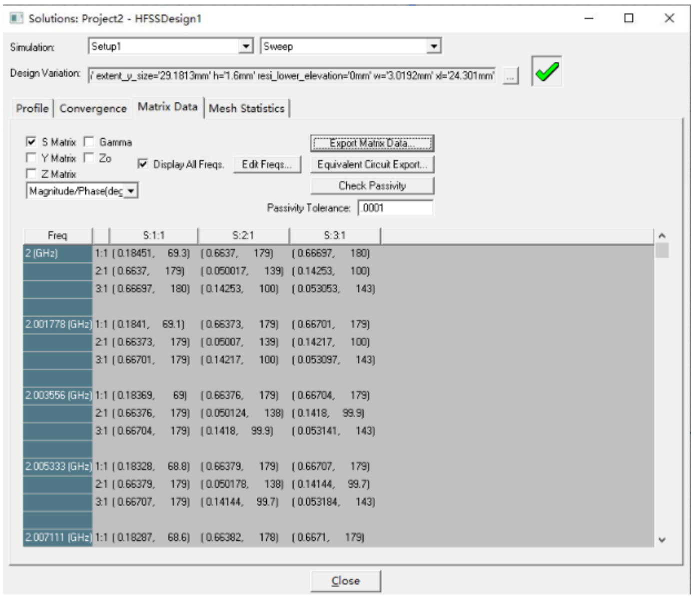


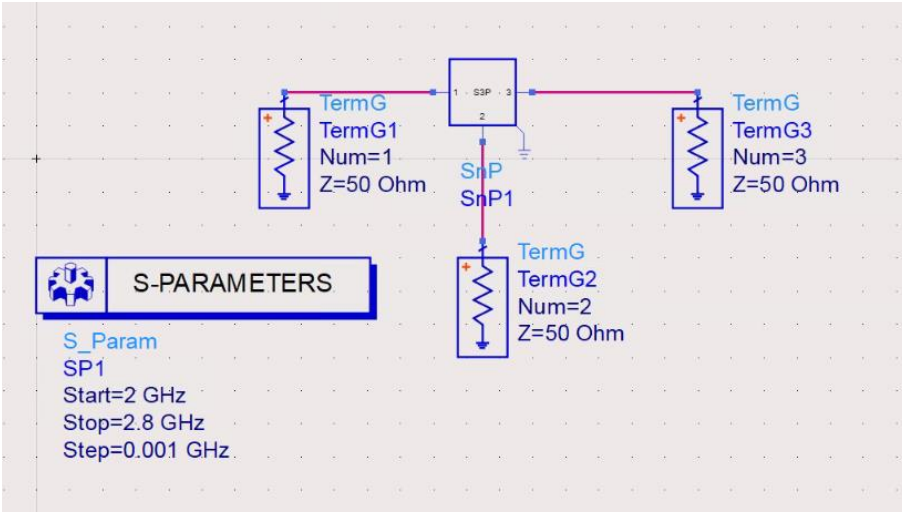
The S parameters after simulation is as follows:



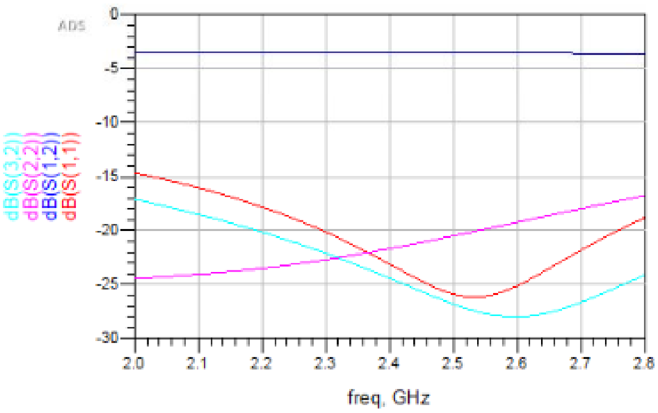
It can be observed that although satisfactory S-parameter curves can be obtained through simulation in ADS, similar results are not achieved in HFSS. Therefore, further optimization is still required in HFSS to find the optimal dimensions that meet the requirements.

And then we can export SNP data from HFSS to ADS



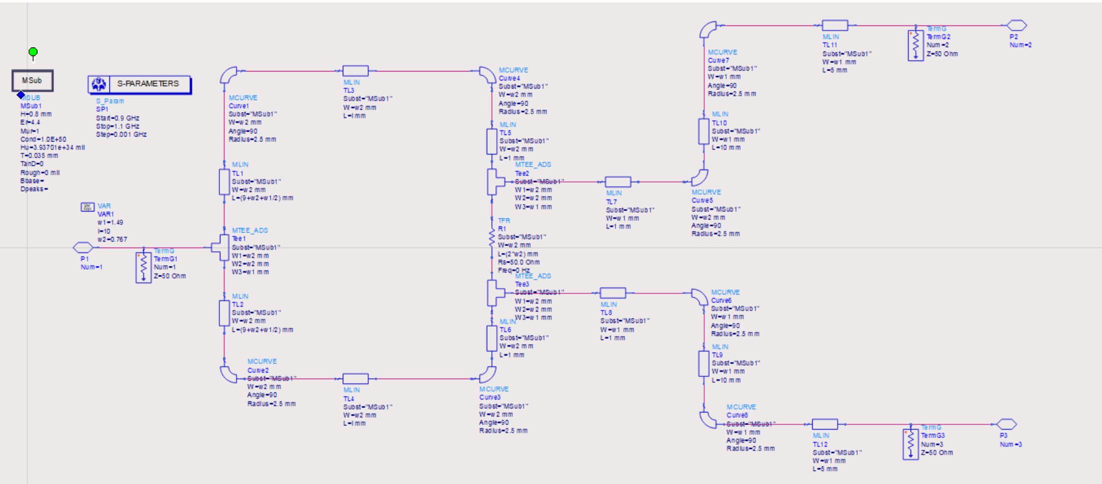


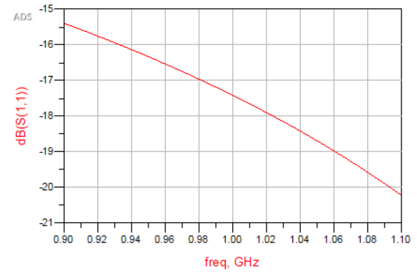
The results are as below which is same as that presented above.

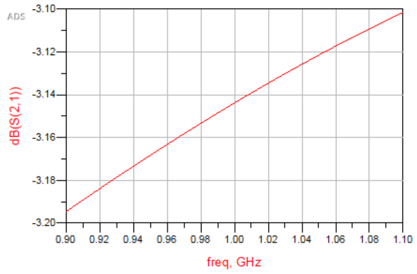


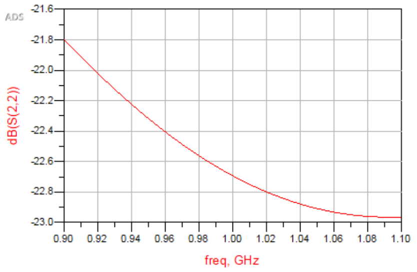
Experience

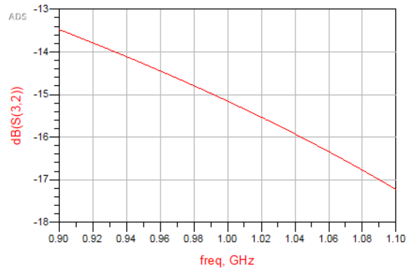
In-class lab screenshot











Experience

Through this experiment, I have deepened my understanding of the Wilkinson Power Divider, gained a better grasp of its theoretical knowledge, and learned how to simulate it in HFSS and ADS. Additionally, I have acquired the skills to optimize parameters in ADS to obtain the most suitable line lengths. I observed that even though ADS can provide parameters that perfectly meet the design requirements, the results obtained from layout simulation and HFSS simulation are not identical. This discrepancy arises due to the difference between theory and practice. Layout simulation and HFSS simulation need to consider many practical parameters, leading to varied results. The final outcomes may not perfectly align with our requirements. Therefore, it is necessary to conduct further optimization in HFSS. However, I am currently not familiar with the optimization process in HFSS. In my ongoing studies, I will continue to learn and subsequently optimize the results obtained in HFSS for this experiment, aiming to achieve the optimal dimensional parameters.

Score	98