Lab 4: Design of Impedance Transformers

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Introduction

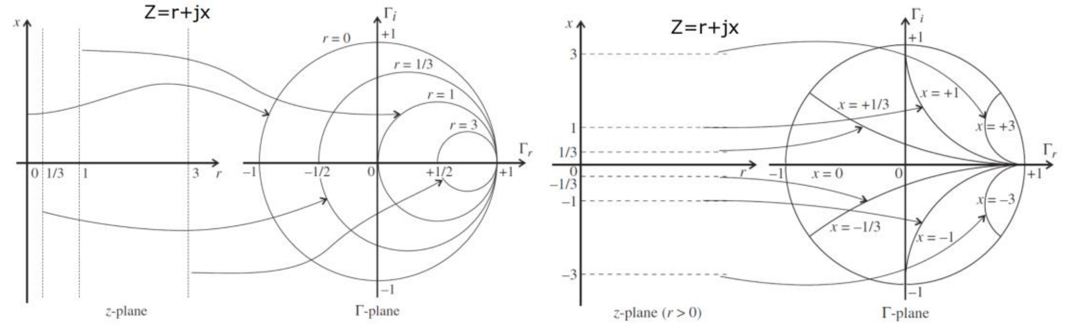
Experimental objective

The objective of this experiment is to use ADS tools to explore how to use microstrip lines for impedance matching. In this experiment, we will delve into the impedance matching issues of microwave transmission lines. We will primarily use the Smith chart as a tool to find the required component parameters. To achieve impedance matching, we will employ two main matching techniques. One is the LC network impedance matching, which primarily utilizes capacitors and inductors for impedance matching. The other is microstrip line impedance matching, which mainly utilizes microstrip lines for impedance matching. In this experiment, we will introduce and explore a novel impedance matching structure, namely the π-type network impedance matching. The principles and matching methods of this structure will be detailed in the following sections.

For this experiment, we will mainly use two tools in ADS (Advanced Design System). One is the Smith chart tool, which allows us to construct impedance matching components graphically on the Smith chart. The other is the LineCalc tool, which can automatically calculate the length and width of microstrip lines based on dielectric parameters, center frequency, characteristic impedance, electrical length, and other parameters.

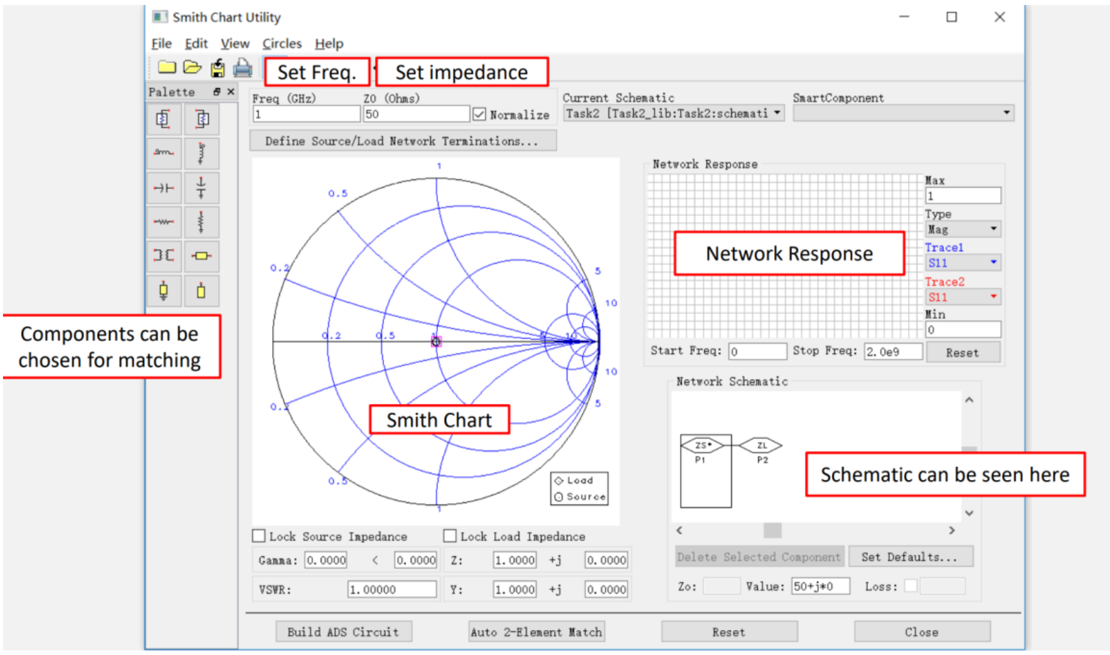
Principles of the smith chart

The Smith Chart is a graphical tool used in the field of RF (radio frequency) and microwave engineering for analyzing and designing transmission line and antenna systems. The Smith Chart is a polar plot of impedance values and is extremely useful for various impedance-matching and network analysis tasks. The Smith Chart is a graphical representation of the complex impedance plane, with the center representing the reference impedance (usually 50 ohms, standard for many RF applications). It provides a convenient way to visualize and manipulate complex impedance values, making it easier to design and troubleshoot RF circuits and transmission lines. It is a circular chart where the outer edge represents infinite impedance and the center represents zero impedance. Impedance values are plotted as points on this chart, with the real part (resistance) on the horizontal axis and the imaginary part (reactance) on the vertical axis. It has a series of concentric circles that represent constant resistance values. These circles help analyze impedance matching and transformation. Radial arcs extending from the center represent constant reactance values. These arcs help visualize the effect of components like inductors and capacitors on impedance.



The Smith Chart allows engineers to visualize how transmission lines, components, and networks affect impedance. Moving along constant resistance circles corresponds to adding series reactance, while moving along constant reactance arcs corresponds to adding shunt reactance. The position of an impedance point on the Smith Chart corresponds to the reflection coefficient (Γ), which indicates the magnitude and phase of reflected waves in transmission lines. Engineers can use the Smith Chart to design impedance matching networks by plotting the load impedance and manipulating it to match the desired source impedance, typically 50 ohms. This is done by moving the impedance point along the chart using transmission lines or matching components. This is the main usage in this experiment.

The Smith Chart tools of ADS can be shown as follows:



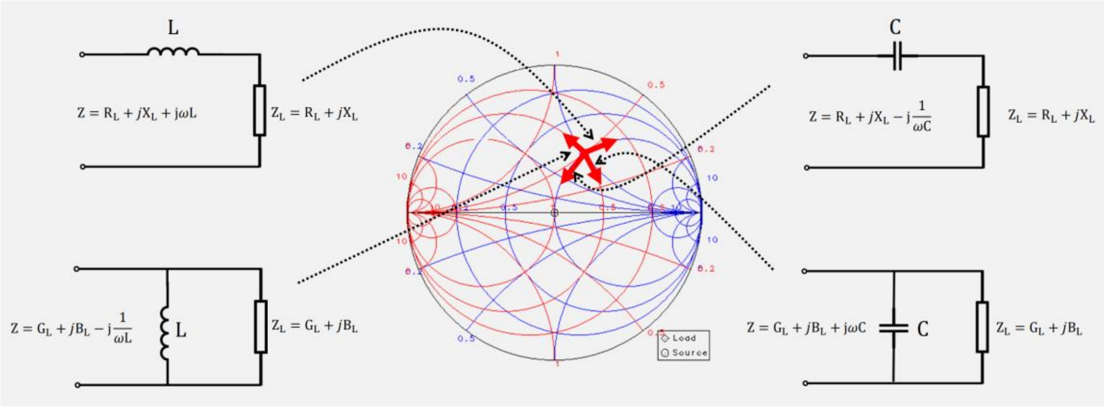
In ADS (Advanced Design System), the Smith Chart tool is employed for impedance matching purposes: We can utilize the Smith Chart tool to graphically construct impedance matching components on the chart. The Smith Chart in ADS provides a visual representation of impedance points, making it easier to locate optimal matching conditions. By leveraging the Smith Chart within ADS, designers can efficiently work towards achieving impedance matching objectives in their circuits.

LC Network Impedance Matching Principle

LC network impedance matching is a technique employed in RF (Radio Frequency) and microwave engineering to achieve optimal impedance matching between a source and a load. The primary components used in an LC network are capacitors (C) and inductors (L). The goal is to design a matching network that transforms the complex impedance of the load to the desired impedance. To finish the impedance matching, we should first determine the source impedance (Zs) and the load impedance (Zl). And then we should identify the frequency at which impedance matching is required. And then we can choose an LC network topology based on the specific impedance transformation requirements. Then we can calculate the values of the inductors and capacitors needed for the matching network using standard formulas. Finally, we construct the designed LC network and test its performance experimentally or through simulation.

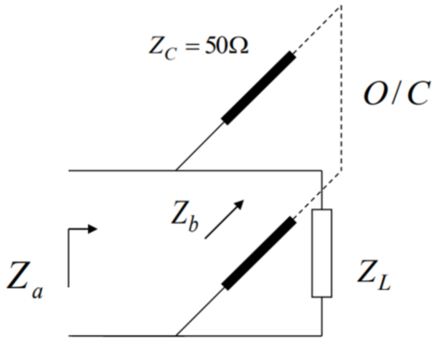
In Advanced Design System (ADS), we can utilize simulation tools to analyze and optimize LC networks for impedance matching. The Smith Chart and network analyzer functionalities in ADS assist in visualizing and fine-tuning the matching circuit for specific frequency requirements. The simulation results can guide the design process towards achieving efficient LC network impedance matching.

Specifically, the implementation principle of LC impedance matching on the Smith Chart is as follows: when L and C are connected in series, the point on the Smith Chart will move along constant resistance circles. This is because when an L or C is connected in series, only the reactive part of impedance changes, and the real part remains unchanged. Based on the positive or negative nature of reactance and susceptance, the following conclusions can be drawn: connecting an inductor in series will cause the point to move clockwise on the Smith Chart, while connecting a capacitor in series will cause the point to move counterclockwise. When L and C are connected in parallel, the point on the Smith Chart will move along constant conductance circles. This is because when an L or C is connected in parallel, only the imaginary part of admittance changes, and the real part remains constant. Depending on the positive or negative nature of reactance and susceptance, we can conclude that connecting an inductor in parallel will cause the point to move counterclockwise on the Smith Chart, while connecting a capacitor in parallel will cause the point to move clockwise. The analysis and conclusions above are intuitively illustrated in the following figure:



Parallel Dual-Stub Microstrip Line Impedance Matching Principle

Parallel dual-stub microstrip line impedance matching is a technique used in microstrip line design to achieve a structure that matches the impedance of a given system or circuit. The parallel dual-stub microstrip line structure typically consists of two parallel stubs. Each stub is composed of a section of microstrip line and an open-circuited stub. First, we should determine the input impedance of the system and the desired target impedance. This can be a complex impedance, and it may require a multi-stage matching network to achieve. And then we can design the length and width of the stubs to provide the required impedance transformation within a specific frequency range. Typically, the length of the stubs is adjusted based on the operating frequency and target impedance.



In fact, its implementation can also be achieved through ADS. By using the Smith chart tool in ADS, you can graphically obtain the impedance and electrical length of each microstrip line. Then, using the LineCalc tool, you can calculate the length and width of the microstrip line.

The advantages and disadvantages of L-type and π-type impedance matching network

L-type and π-type impedance matching network are two ways to implement the impedance matching. The L-type impedance matching network consists of two inductors and one capacitor or two microstrip lines, forming an "L" shaped topology. The values of the inductors and capacitor microstrip lines are determined based on specific impedance matching requirements. And the π-type impedance matching network is composed of one inductor and two capacitors or three microstrip lines, forming a π shaped topology. The values of the inductor and capacitors or microstrip lines are determined based on specific requirements.

L-type and π-type network has their advantages and disadvantages, respectively. For L-type network, there are many advantages, for example, L-type impedance matching networks are relatively simple, easy to understand, and suitable for basic impedance matching problems. And it typically requires only two inductors and one capacitor, reducing the number of components, lowering manufacturing costs, and simplifying the circuit. And due to the lower number of components, the occupied space is relatively small, making it suitable for applications with space constraints. However, there are also some disadvantages, firstly, L-type networks provide effective matching only within a certain frequency range, potentially performing poorly at other frequencies, limiting their application range. And compared to π-type networks, L-type networks may have lower matching precision, especially in applications that demand high matching accuracy.

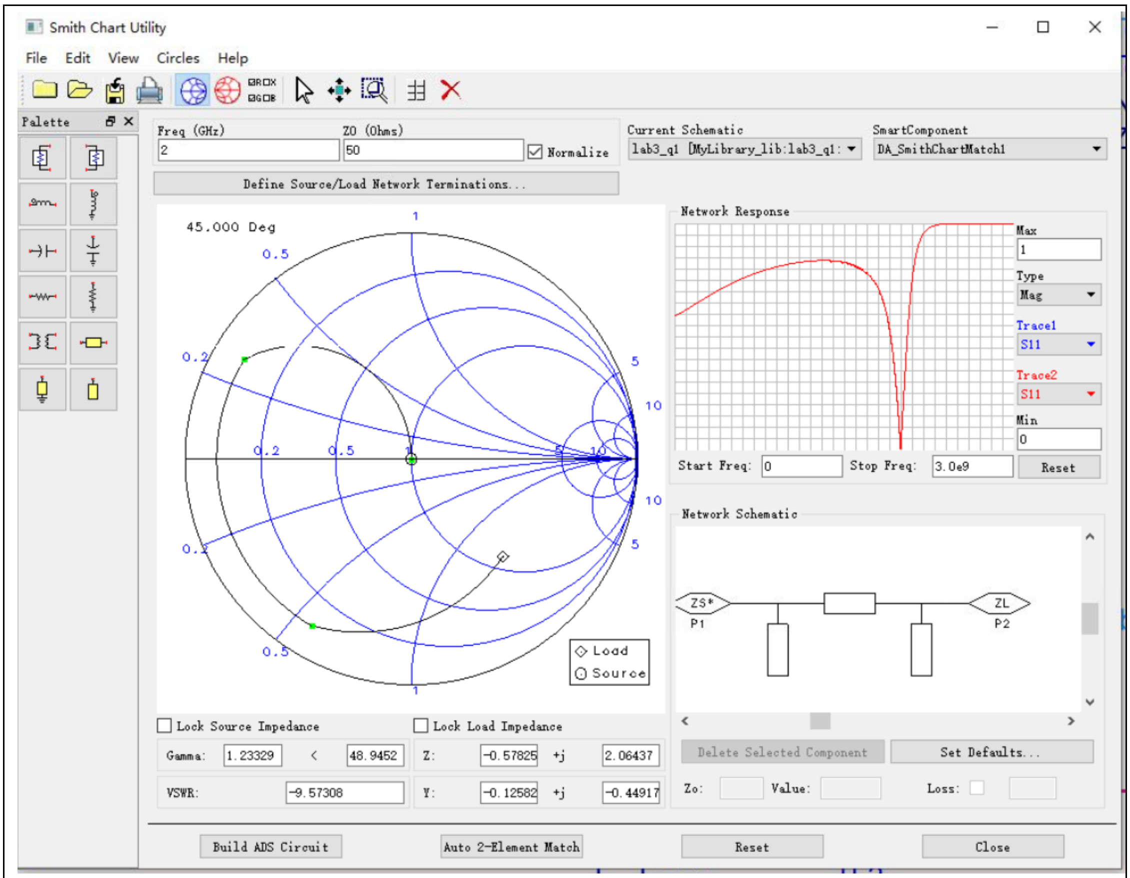
For π-type network, there are also some advantages. First and foremost, π-type networks are more flexible in solving complex impedance matching problems, adapting well to various complex circuit matching needs. It can achieve impedance matching through a variety of component combination schemes, unlike the L-type network which can only have one implementation scheme, so the options of the component are very much, that is, if the matching scheme of the L-type network can only be achieved through this fixed component, but in the π-type scheme, it is not limited to a combination of components, to provide engineers with more options. And π-type impedance matching networks can provide effective impedance matching over a broader frequency range, suitable for multi-band applications. Typically, it offers higher matching precision compared to L-type networks, making it suitable for applications with stringent matching requirements. However, π-type networks are relatively more complex, requiring more engineering work for design and adjustment, increasing development and manufacturing challenges. And it typically requires more inductors and capacitors, leading to increased circuit complexity and potentially higher manufacturing costs.

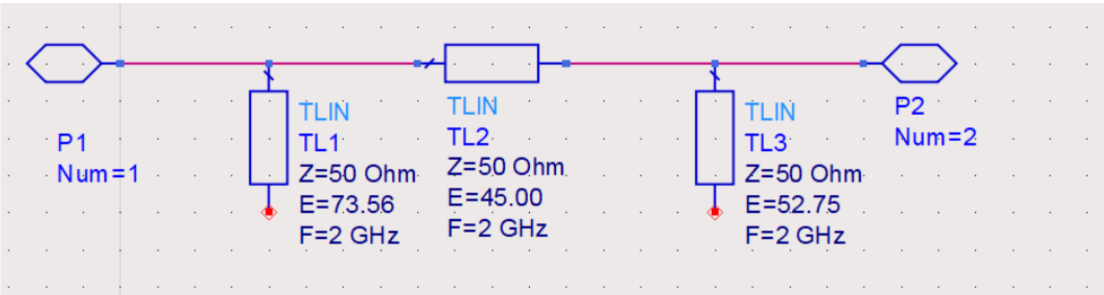
Lab results & Analysis：

ADS circuit diagram

Part I: Double stub microstrip line impedance matching

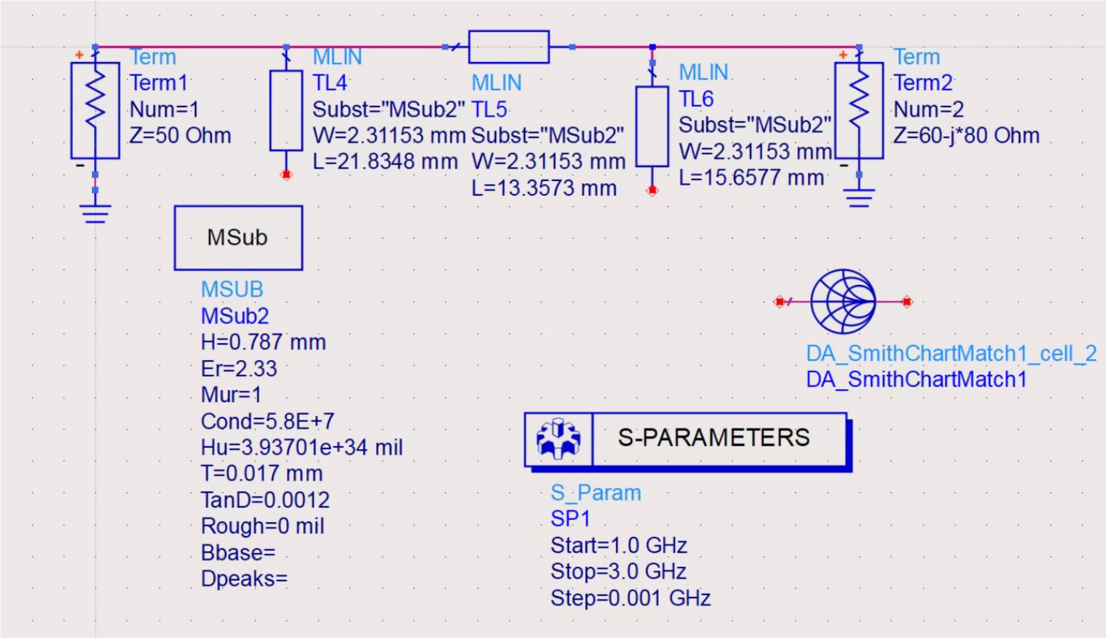
First, we use the Smith chart tool to design the microstrip line matching structure according to the given requirements. It is important to fix the length of the second microstrip line to λ/8, corresponding to an electrical length of π/4. The matching operation and results using the tool are as follows:





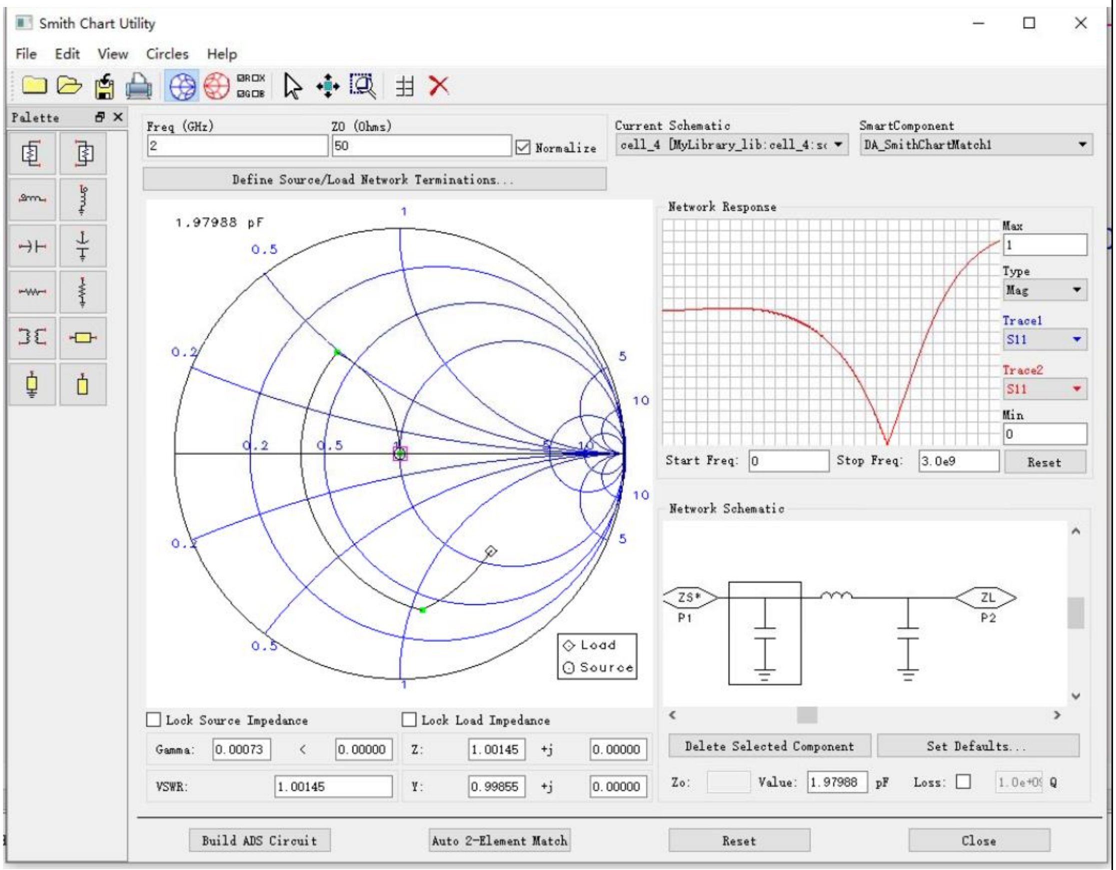
At this point, the generated microstrip lines are ideal. We need to transform them into actual microstrip lines. Choose the substrate as Msub and set the parameters accordingly.

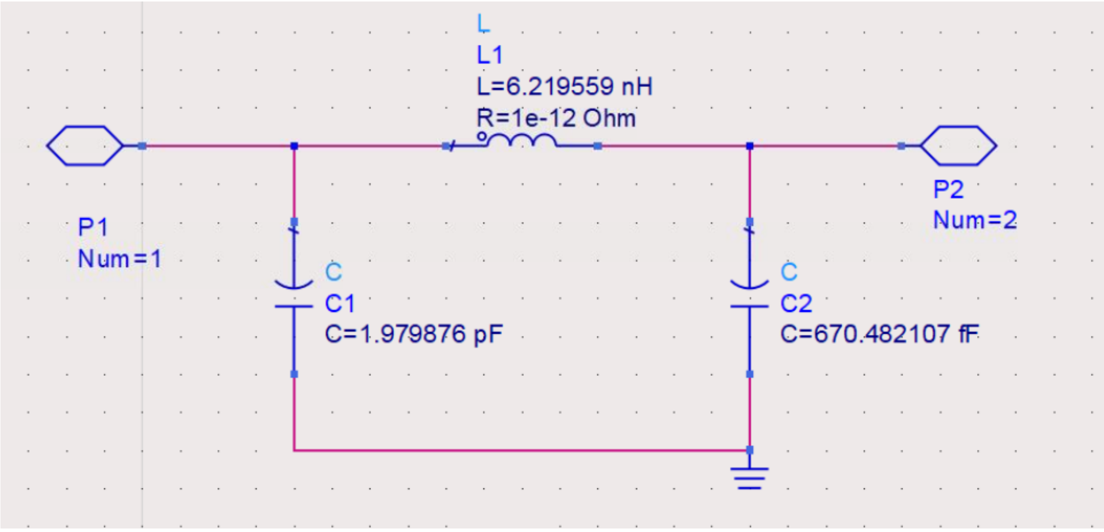
Then, using the LineCalc tool (which will be present in next section) and incorporating the electrical length and impedance values exported from the Smith chart tool, along with the substrate parameters, we calculate the length and width of the microstrip line. The final circuit diagram is as follows:



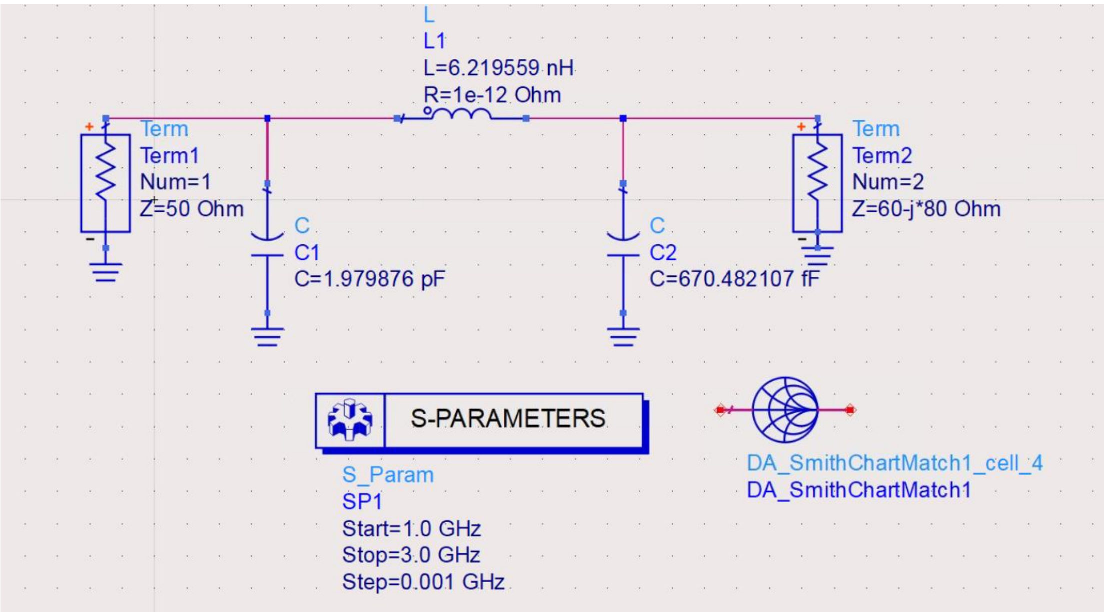
Part II: LC network impedance matching

Using the same principle, we will utilize the Smith chart tool for impedance matching design of the LC network. The design process and the final results are as follows:





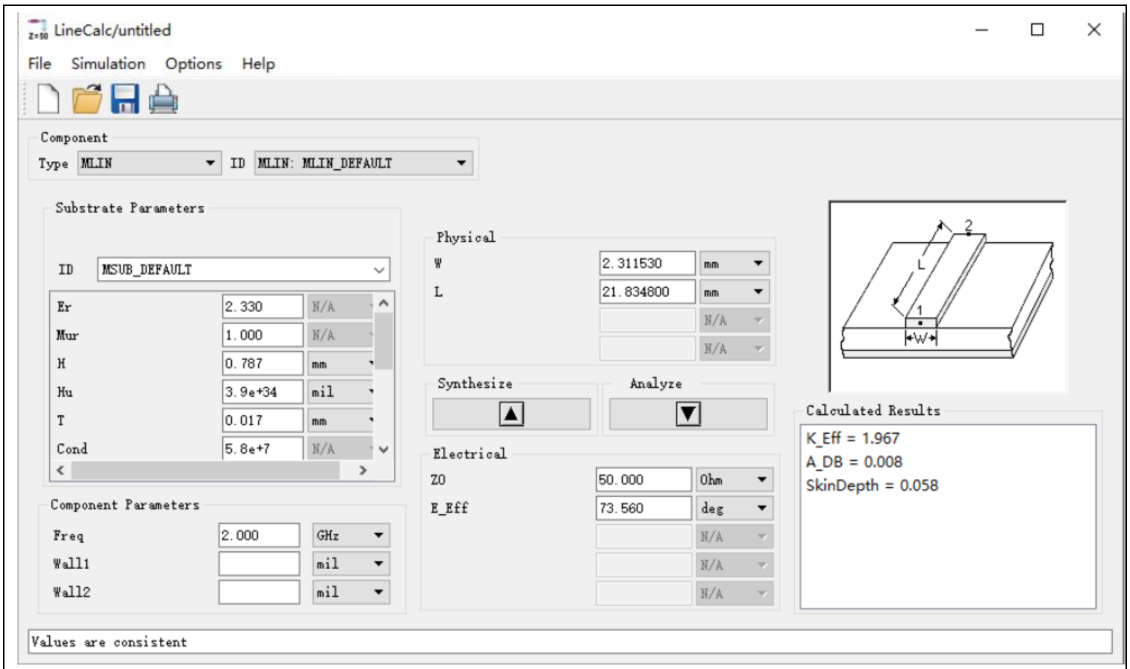
The final circuit diagram is as follows:



LineCalc tool calculation result graph

LineCalc tool is a handy tool in ADS for calculating the length and width of microstrip lines, which can be automatically calculated based on Msub dielectric parameters, characteristic impedance, and electrical length. The calculation result graphs of each part are shown as follows:

Part I: Double stub microstrip line impedance matching


LineCalc/untitled
File
Simulation
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MLIN
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ID
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Er 2.330 N/A
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H 0.787 mm
Hu 3.9e+34 mil
T 0.017 mm
Cond 5.8e+7 N/A
Component Parameters
Freq 2.000 GHz
Wall1 mil
Wall2 mil
Physical
W 2.311530 mm
L 21.834800 mm
N/A
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Synthesize
Analyze
Electrical
Z0 50.000 Ohm
E_Eff 73.560 deg
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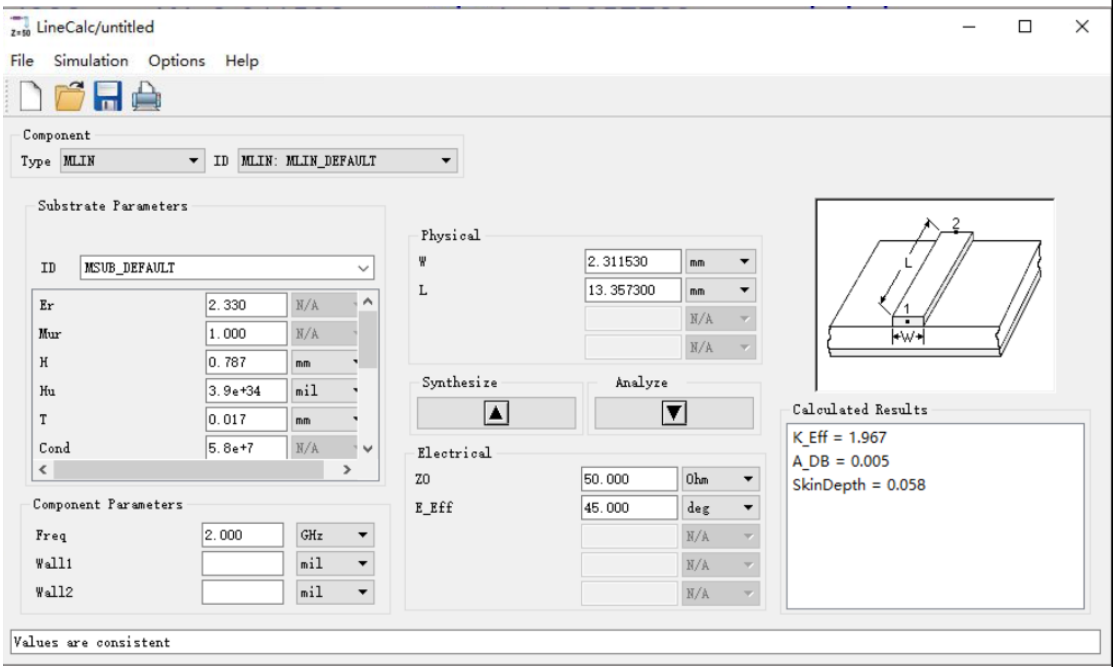
1
2
Calculated Results
K_Eff = 1.967
A_DB = 0.008
SkinDepth = 0.058
Values are consistent

LineCalc/untitled
File
Simulation
Options
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Component
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MLIN
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ID
MSUB_DEFAULT
Er 2.330 N/A
Mur 1.000 N/A
H 0.787 mm
Hu 3.9e+34 mil
T 0.017 mm
Cond 5.8e+7 N/A
Component Parameters
Freq 2.000 GHz
Wall1 mil
Wall2 mil
Physical
W 2.311530 mm
L 13.357300 mm
N/A
N/A
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Analyze
Electrical
Z0 50.000 Ohm
E_Eff 45.000 deg
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Calculated Results
K_Eff = 1.967
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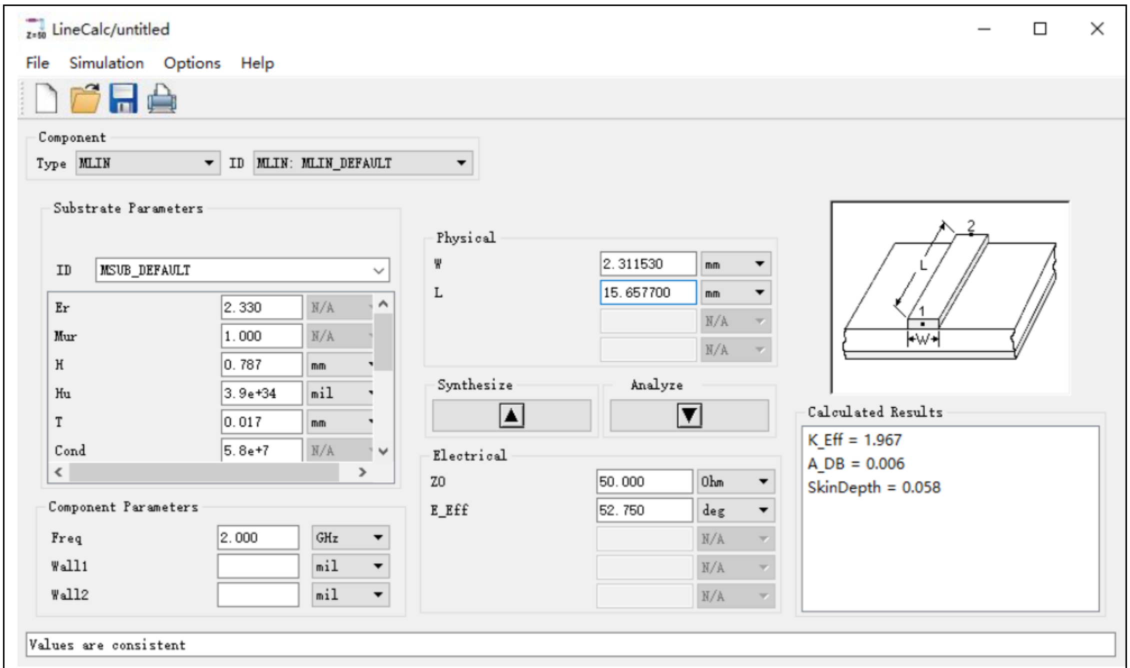
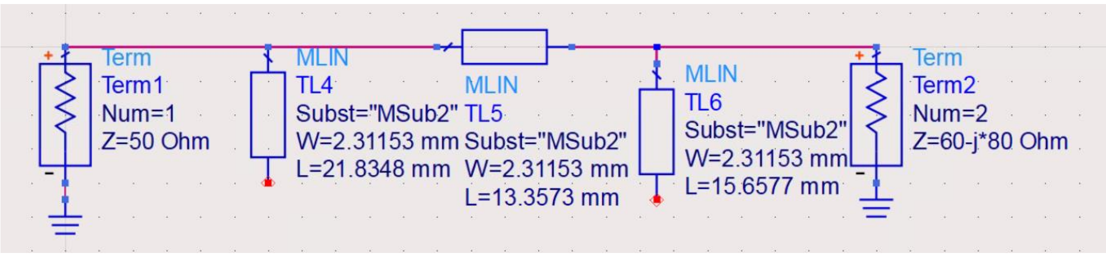
SkinDepth = 0.058
Values are consistent



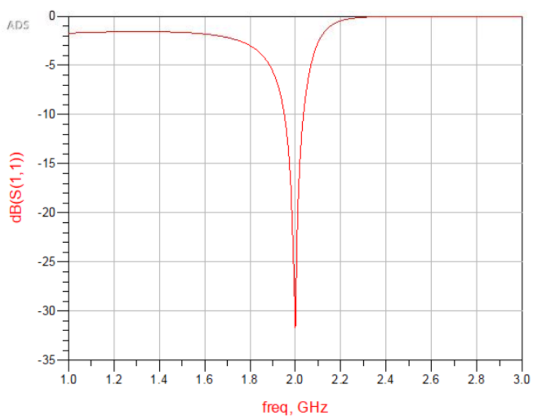
The results are as follows:

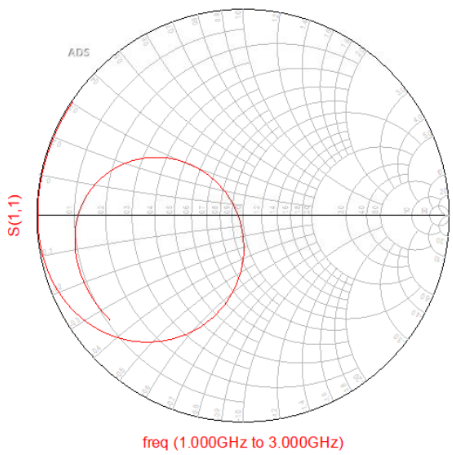


S11 parameter diagram and smith chart

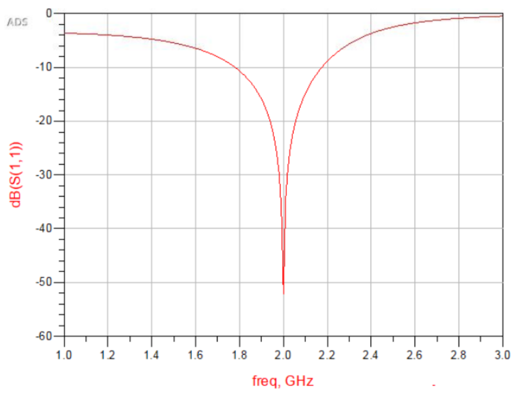
In this experiment we mainly examine the effect of impedance matching by observing the S11 parameter, the simulation results of the S11 parameter for the above experiment are shown below:

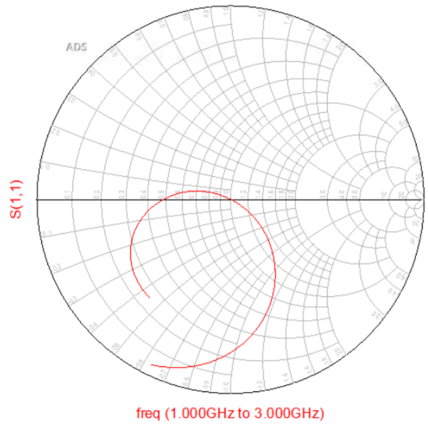
Part I: Double stub microstrip line impedance matching



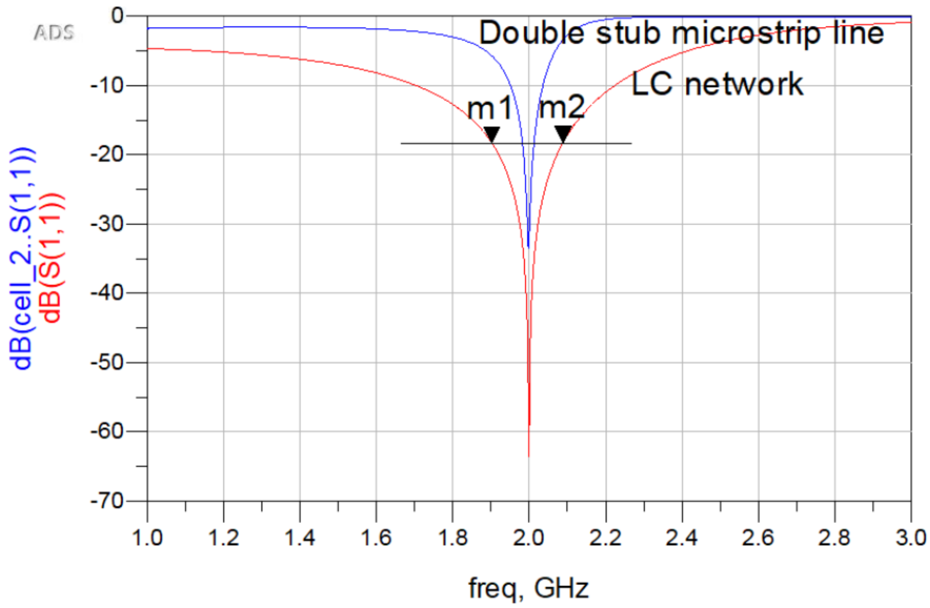


Part II: LC network impedance matching



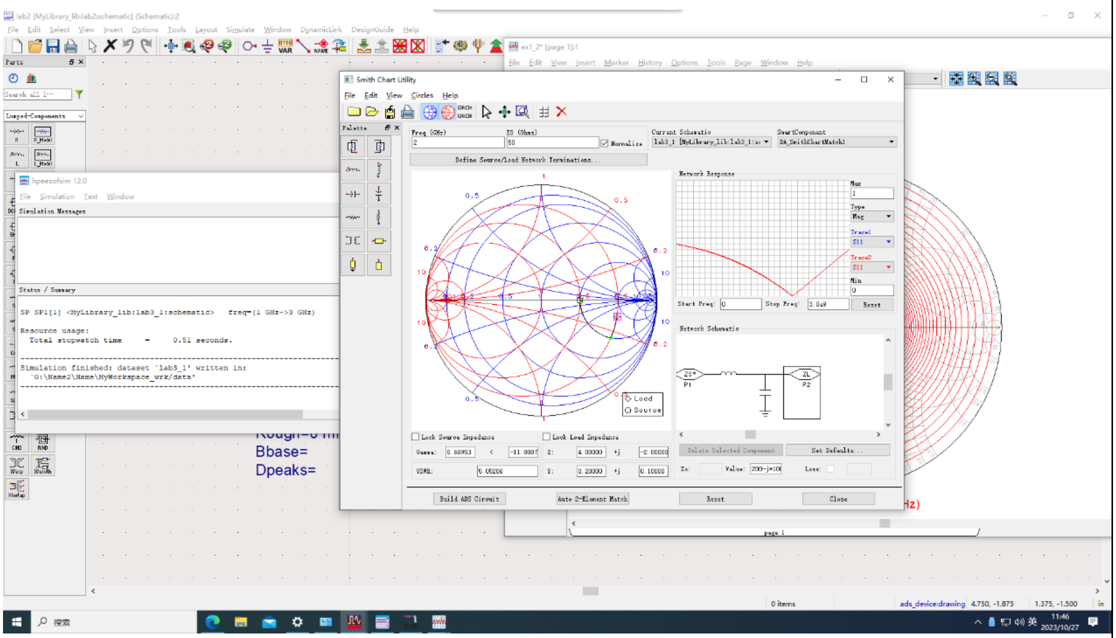


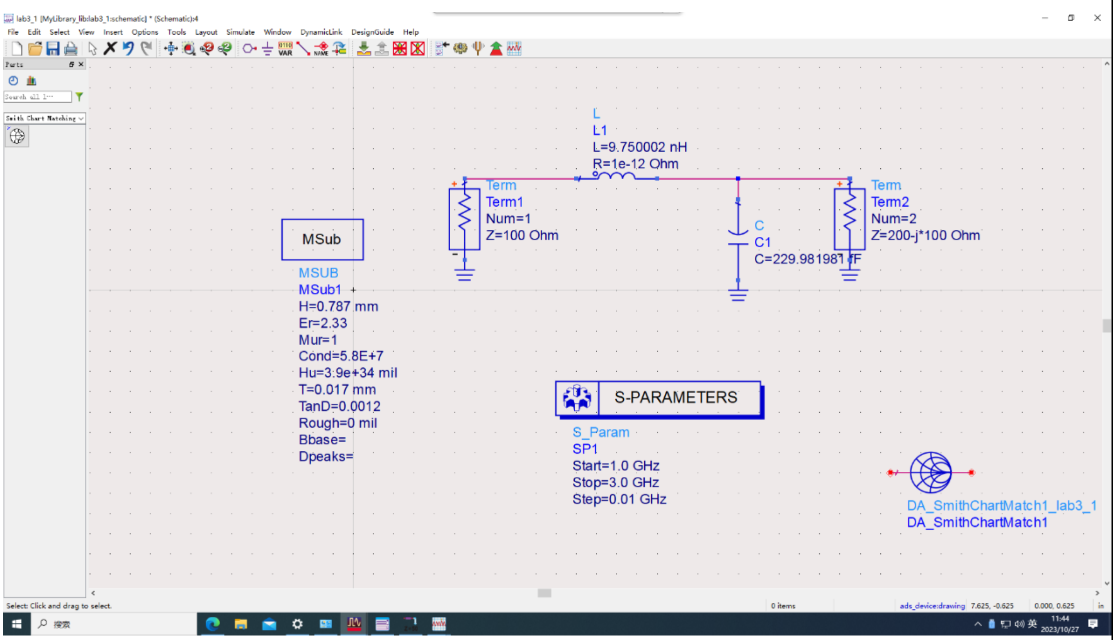
Based on the simulation results above, it can be observed that the bandwidth obtained by the LC-implemented π-type network is significantly larger than that obtained using the double stub network. Combining both in the graph makes this phenomenon more apparent. Additionally, the LC network's π-type configuration offers relatively greater flexibility in component selection. Although both configurations have multiple combinations for achieving impedance matching, the double stub network imposes constraints on the length of the intermediate microstrip line, resulting in comparatively reduced flexibility. Furthermore, different combinations correspond to varying microstrip line lengths and widths. Designing such diverse microstrip lines is more challenging compared to designing capacitors and inductors. Therefore, overall, the LC-implemented π-type network demonstrates superior performance. It's worth noting that these advantages are attributed to the π-type configuration; the L-type network does not exhibit the same benefits mentioned above.

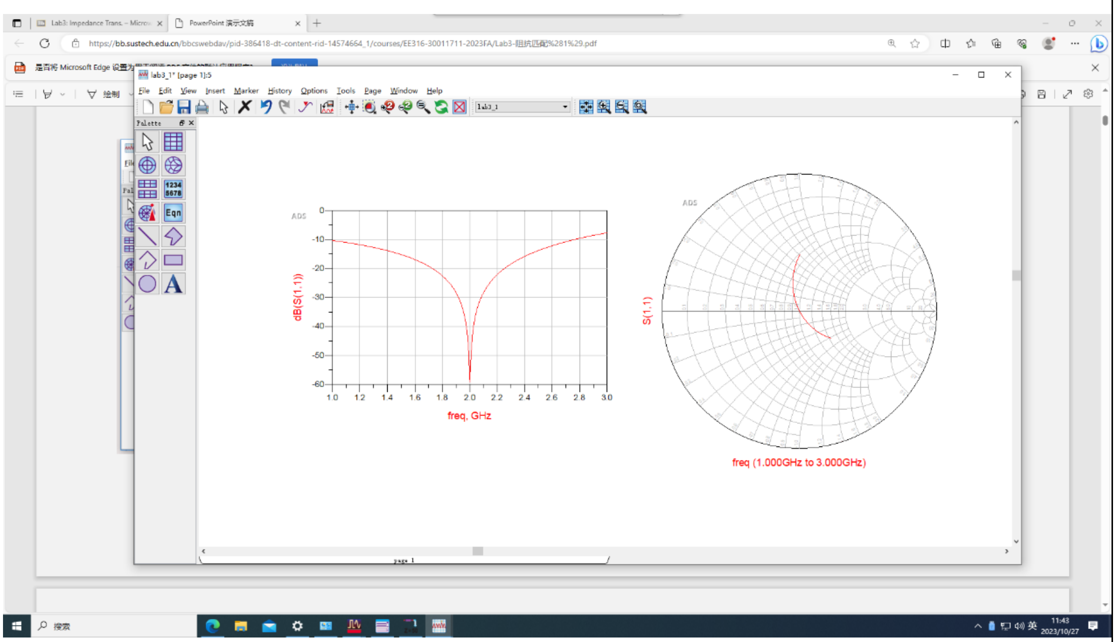


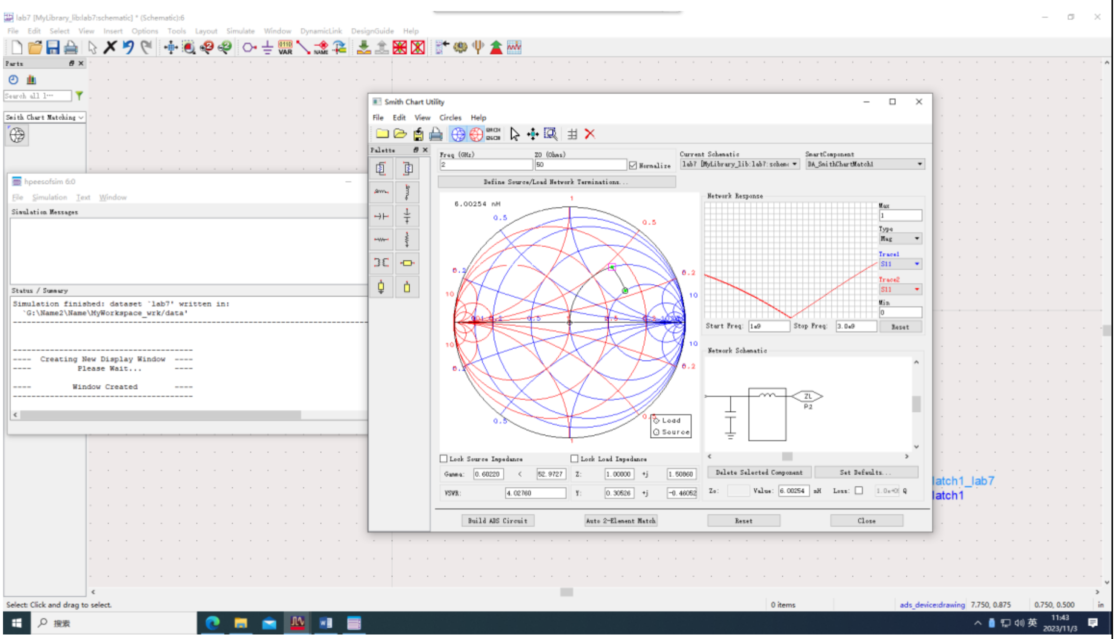
Experience

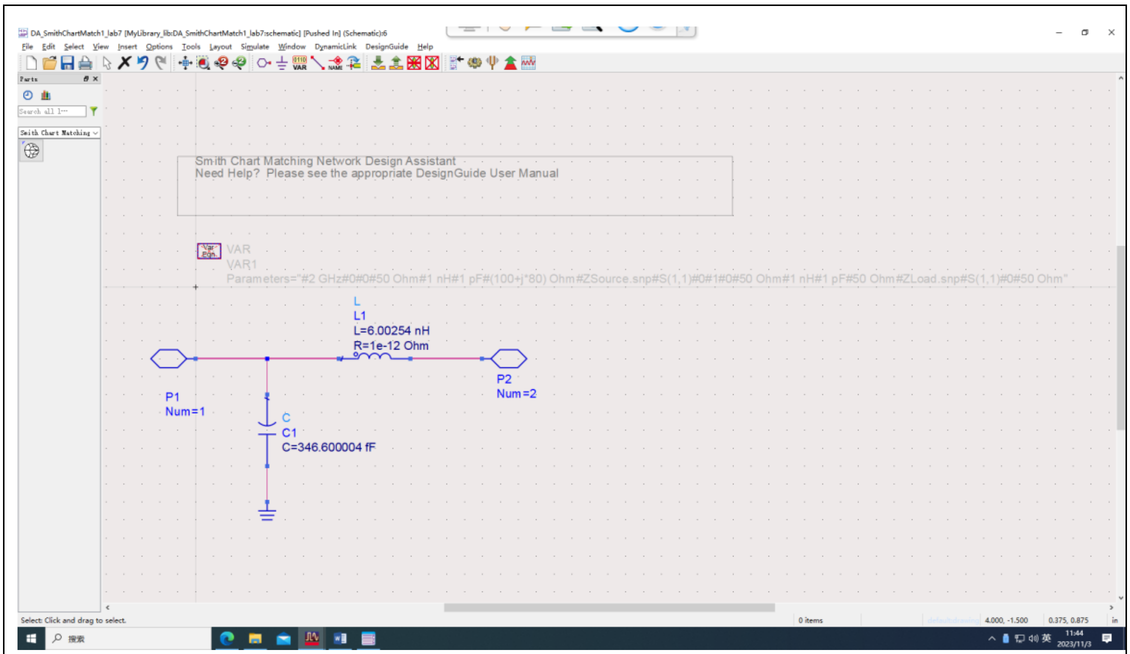
1. Screenshot on course






dB(S(1,1))
freq, GHz
S(1,1)
freq (1.000GHz to 3.000GHz)


Smith Chart Utility
Simulation Messages
Creating New Display Window
Window Created


Smith Chart Matching Network Design Assistant
Need Help? Please see the appropriate DesignGuide User Manual
VAR
VAR1
L
L1
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R=1e-12 Ohm
P1
Num=1
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C1
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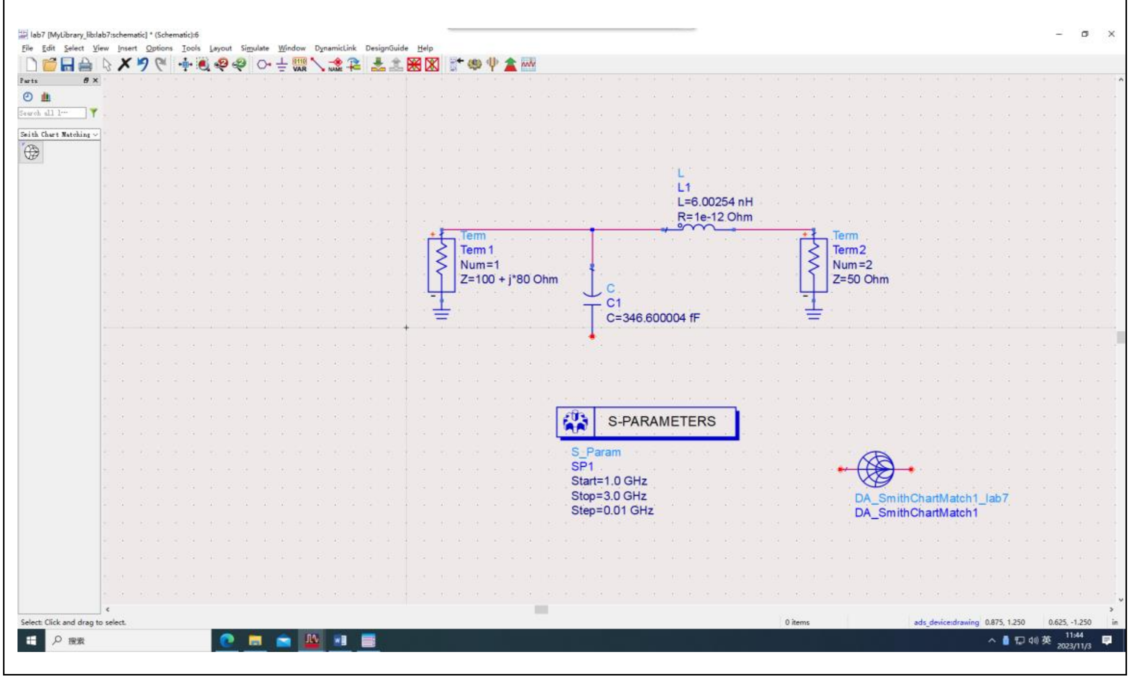
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Term2
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C
C1
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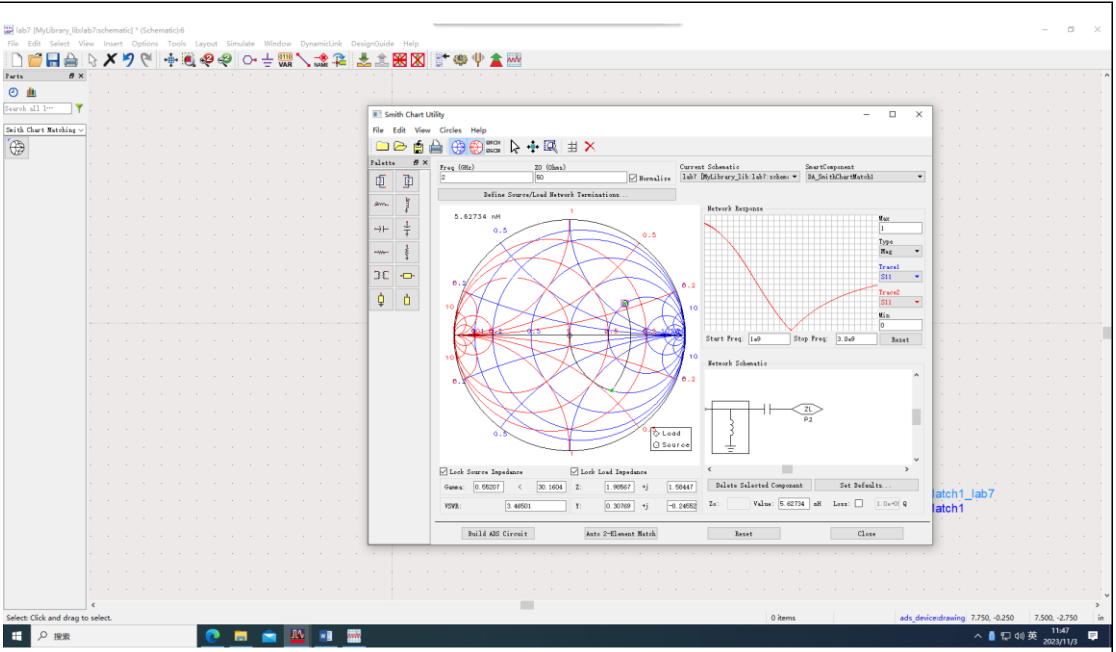
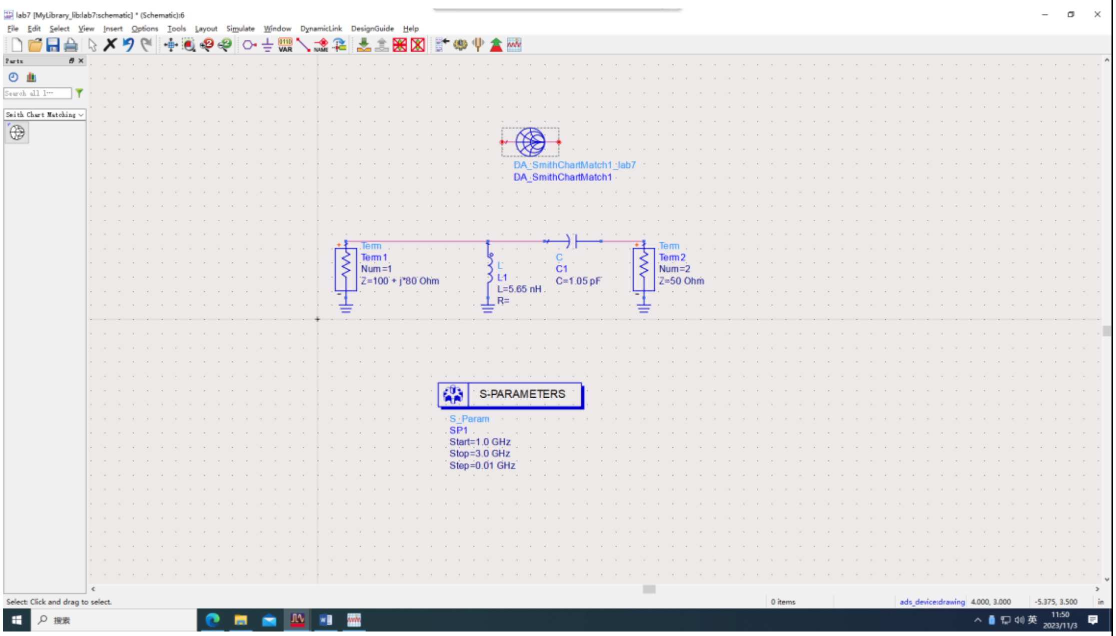
DA_SmithChartMatch1





2. Problems we meet and the experience

Through this experiment, I have gained a deeper understanding of using ADS, especially in terms of utilizing the Smith chart tool and LineCalc tool. The use of these tools and simulations has enhanced my theoretical knowledge in this field. Additionally, this experiment has reinforced my comprehension of impedance matching, involving both the utilization of LC networks and microstrip lines for matching purposes.

Furthermore, I have explored a new matching structure, namely the π-type network matching structure. I have grasped its advantages and disadvantages, understanding how its structure can increase bandwidth and enhance component flexibility. The

experimental simulations have further solidified this understanding. In conclusion, I have become more proficient in using ADS, deepened my theoretical knowledge, and gained insights into impedance matching using different techniques. In particular, the comparison between the double stub network and LC π-type network in terms of S11 parameters has revealed that the LC network achieves slightly better performance. During the experimental process, I encountered some challenges, including issues with setting the center frequency. Placing the results obtained from the Smith chart tool turned out to be entirely incorrect. Additionally, when calculating line lengths and widths, it is crucial to input the parameters of the substrate into the tool to obtain accurate results. Furthermore, attention must be given to unit consistency, particularly with mill and mm. If incorrect units are entered into the tool, it may yield erroneous results or result in an error, making it impossible to calculate.	
Score	98