# Lab 2: Microstrip Line for Impedance Matching

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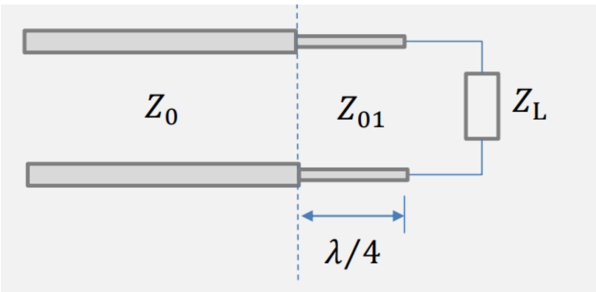
## Introduction

### Experimental purpose

The purpose of this experiment is to use ADS tools to explore how to use microstrip lines for impedance matching. In this experiment, the electrical length of the microstrip line is taken as 1/4 wavelength. The length and width of the microstrip line are calculated under different situations to achieve impedance matching. The S11 parameters of the simulation results are observed to observe the impedance matching effect. This experiment consists of two small experiments. In the first experiment, we used 2, 3, and 4 sections of microstrip lines to achieve impedance matching respectively. Then, through simulation, we observed the impedance matching effects corresponding to the above different situations through the S11 parameter diagram. In the second experiment, we achieved impedance matching through the series and parallel connection of microstrip lines. Here we used the Smith original diagram tool to solve the parameters of the microstrip lines, and simulated and observed the S11 parameters to verify the matching results.

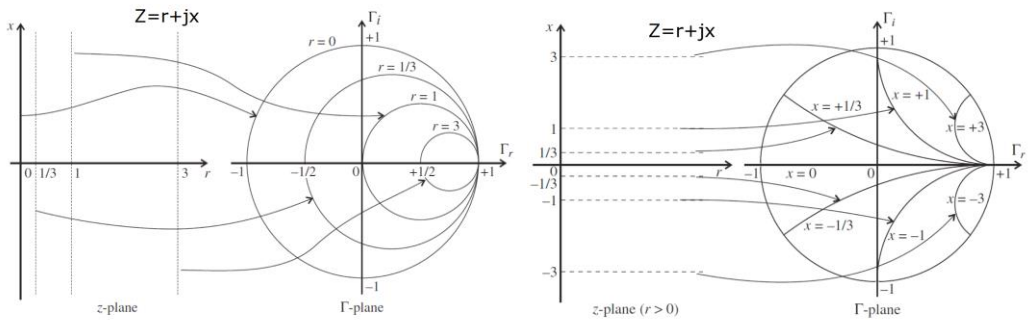
### 1/4 wavelength impedance matching converter principle

A quarter-wavelength microstrip line is a widely used component in microwave and RF engineering for impedance matching. Its principle is based on the concept of electromagnetic wave propagation and the characteristic impedance of transmission lines. The quarter-wavelength microstrip line acts as a transformer that matches the impedance between a source and a load. A quarter-wavelength line has a length equal to one-quarter of the wavelength of the signal it is designed for. When a signal travels along this line, it undergoes a 180-degree phase shift because it travels a quarter-wavelength, which is half of a full wavelength. Additionally, the characteristic impedance of the microstrip line, Z0, is chosen to be the geometric mean between the source and load impedances ($Z_0$ and $Z_L$). The 180-degree phase shift is critical for impedance matching. When the signal reaches the load, the reflected wave from the load combines with the incident wave to create either constructive or destructive interference. If the load impedance is not equal to the characteristic impedance of the transmission line, there will be a reflection at the load. By adjusting the characteristic impedance, the reflected wave can be made to interfere constructively with the incident wave, resulting in maximum power transfer to the load. By properly designing the quarter-wavelength microstrip line, the impedance at the load end can be matched to the source impedance. This is achieved when the quarter-wavelength line's characteristic impedance is the square root of the product of the source and load impedances, i.e., $Z_{01} = \sqrt{(Z_0 * Z_L)}$.



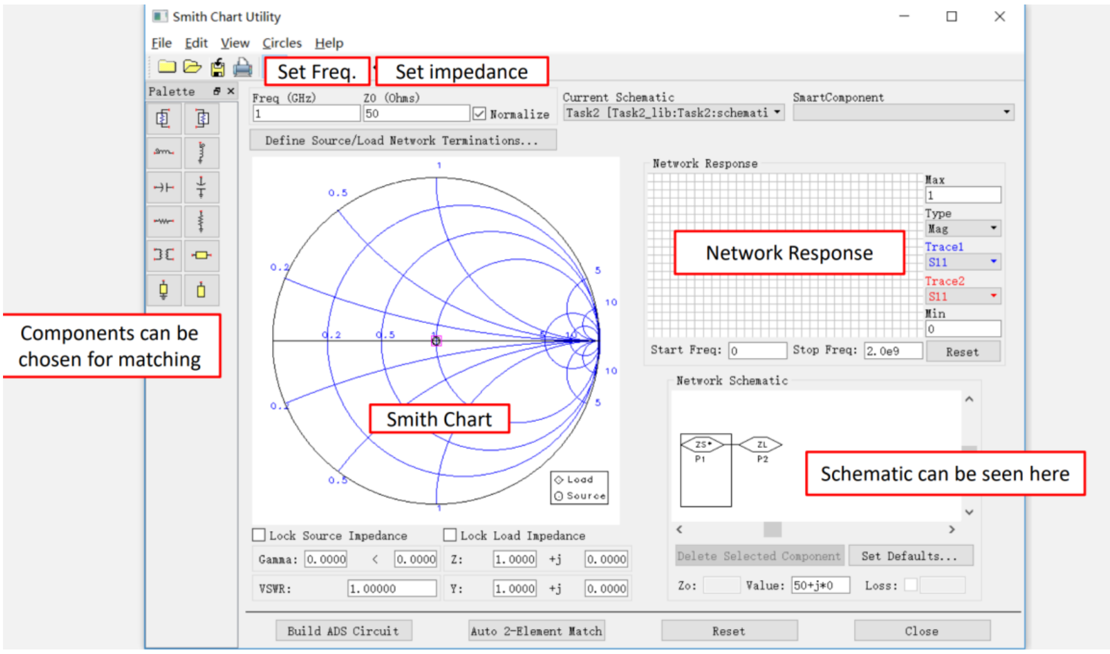

## Smith Chart Principle

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:

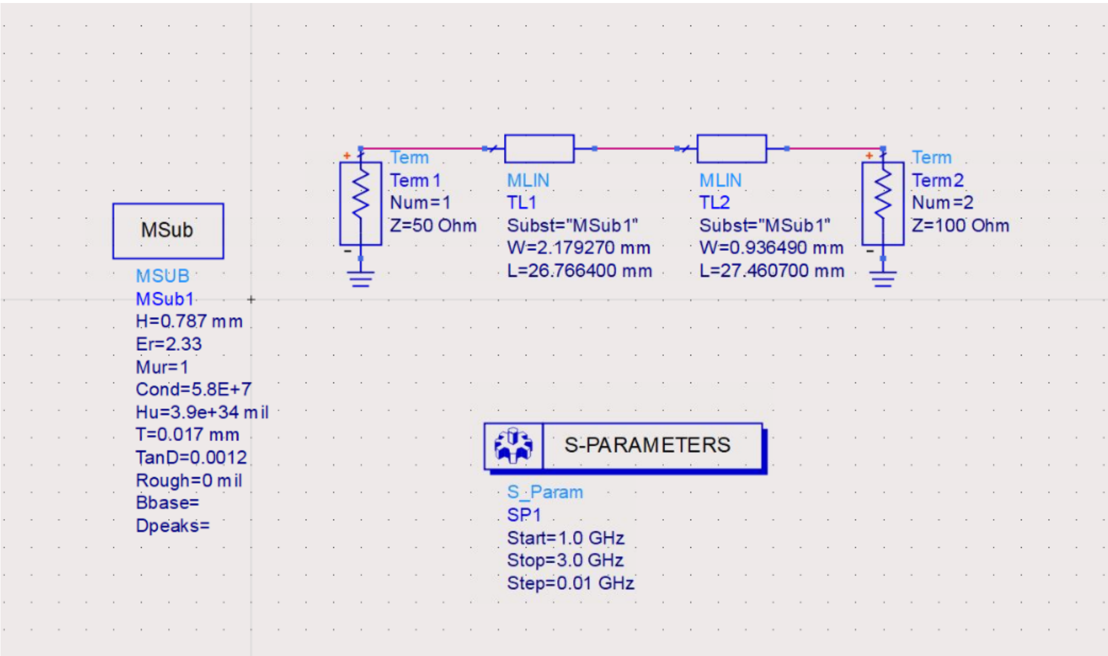



# Lab results & Analysis:

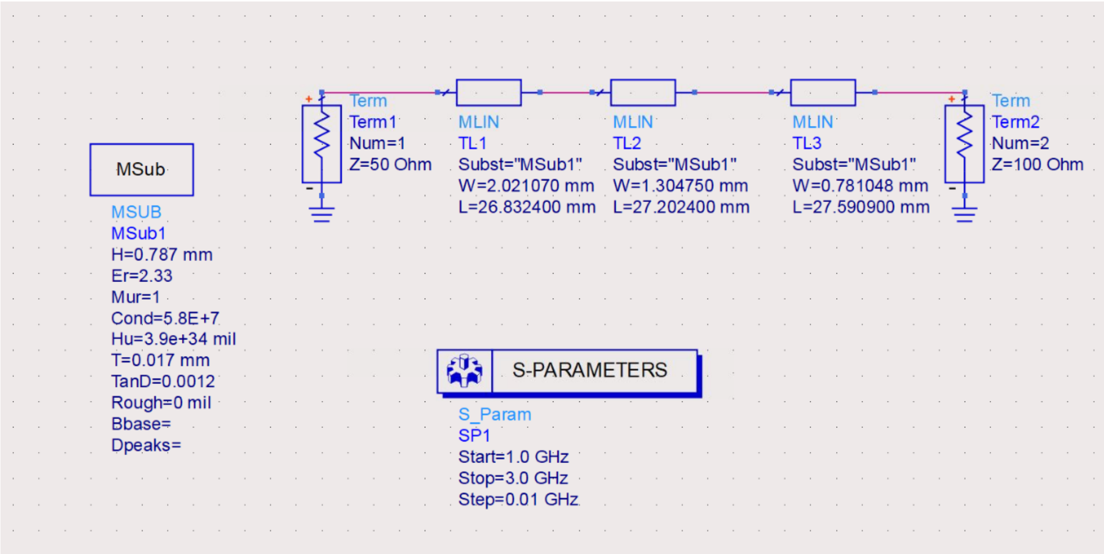
## ADS circuit diagram

### Part I

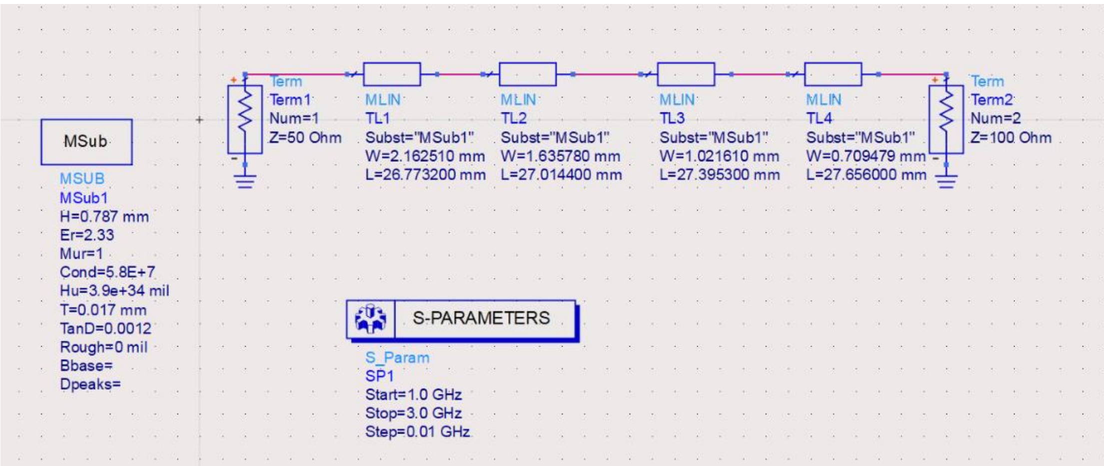
According to the request, the impedance of the source is 50Ω, the impedance of the load is 100Ω, the electrical length of a microstrip line is a quarter wavelength, or 90°, and the characteristic impedance of the microstrip line is labeled. According to the above requirements, we can design the circuit diagram using 2, 3 and 4 sections of microstrip line in ADS software, respectively.
For 2 sections case:




For 3 section case:

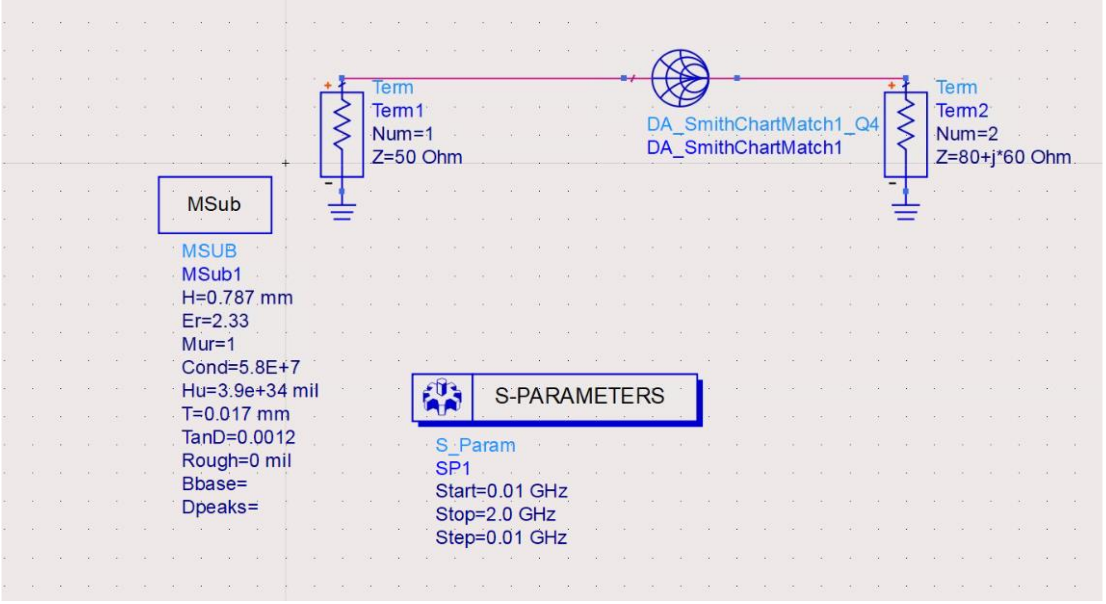


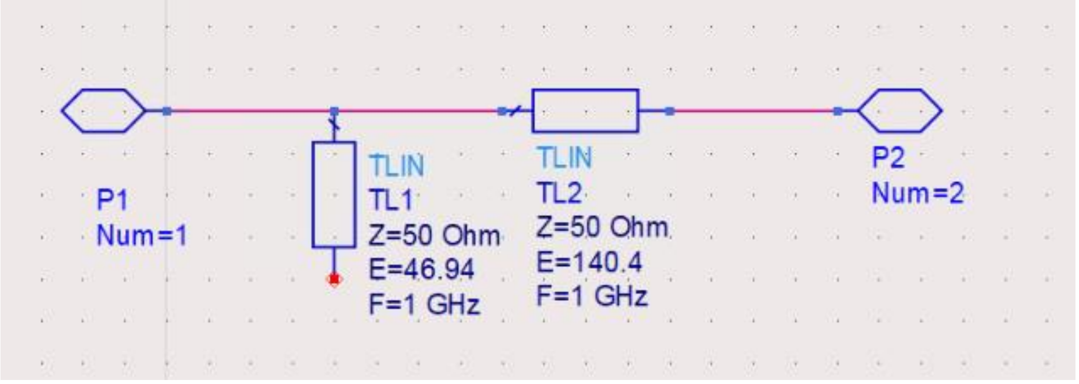

For 4 section case:



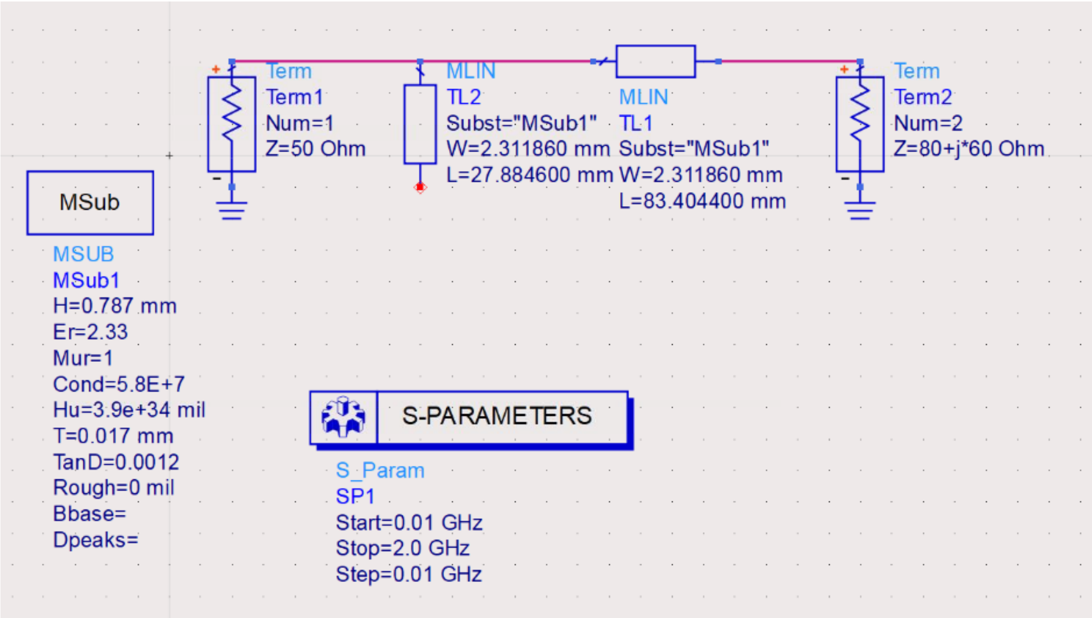
**Part II**

The impedance of source is 50Ω, the impedance of the load is 80+j*60Ω, and the characteristic impedance of the microstrip line is 50Ω. According to the above requirements, we can design the circuit diagram. Firstly, we use the Smith's Circle Diagram Analysis tool in ADS to perform an analysis to determine the electrical lengths of the microstrip lines in series and parallel that can be realized for impedance matching.




Note that the parameters generated here are those of an ideal microstrip line, and we need to convert the ideal microstrip line into actual microstrip line parameters using the tools for calculating the length and width of the line, the real circuit diagram:

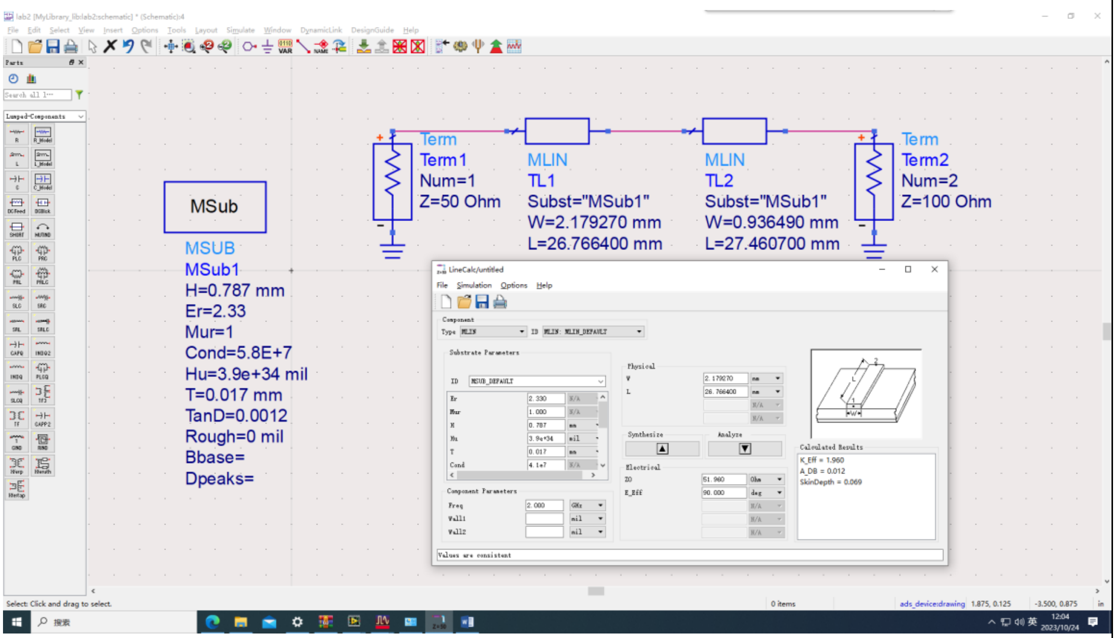


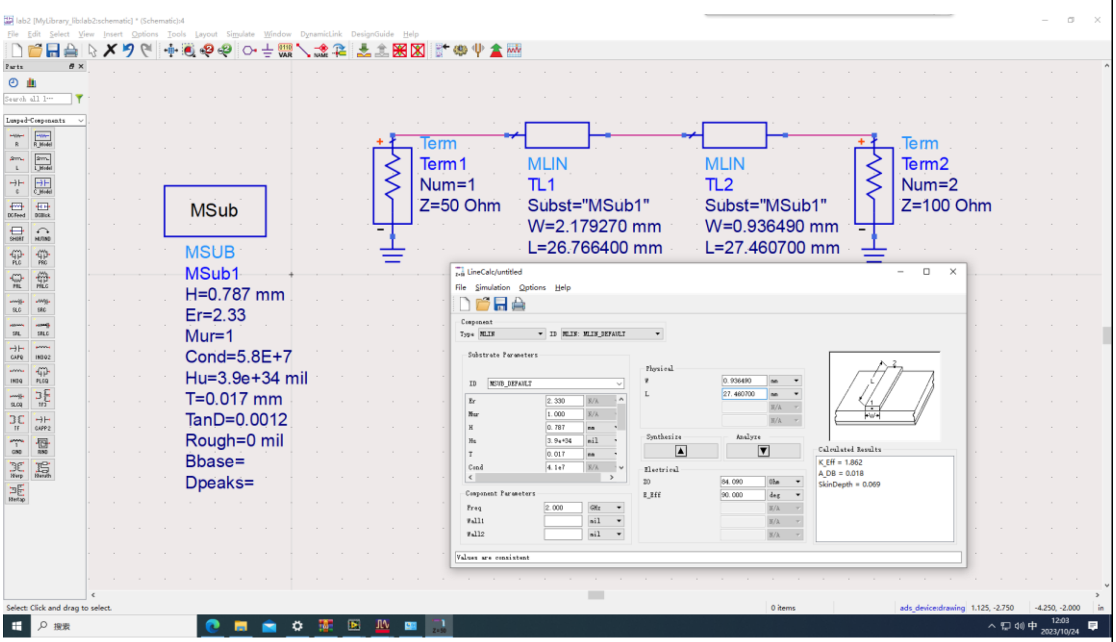

## LineCalc tool calculation result graph

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:

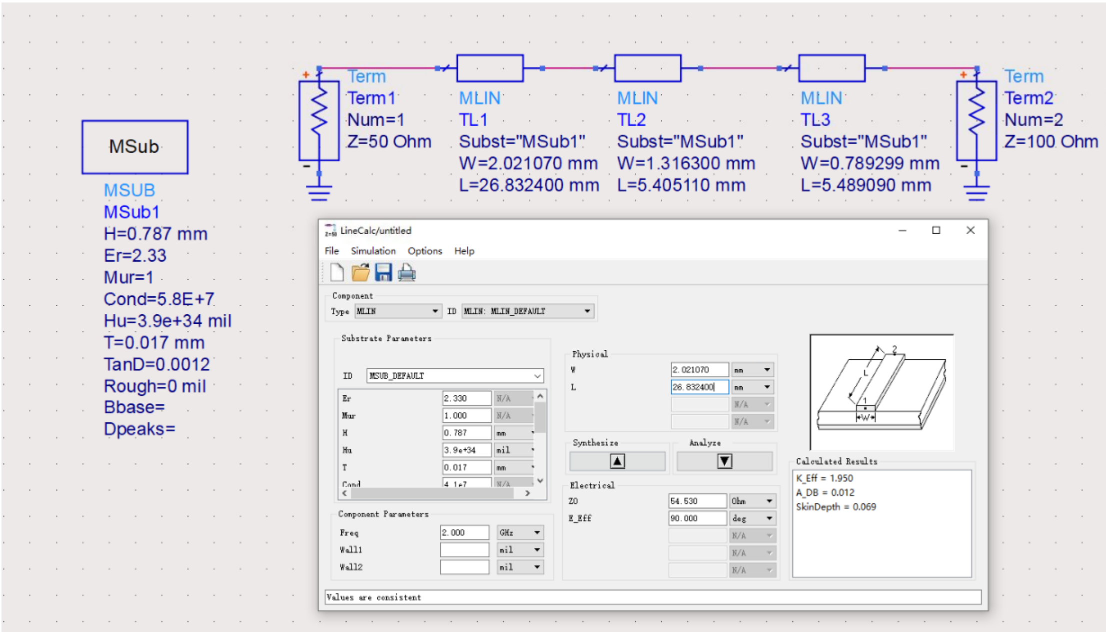
**Part I:**

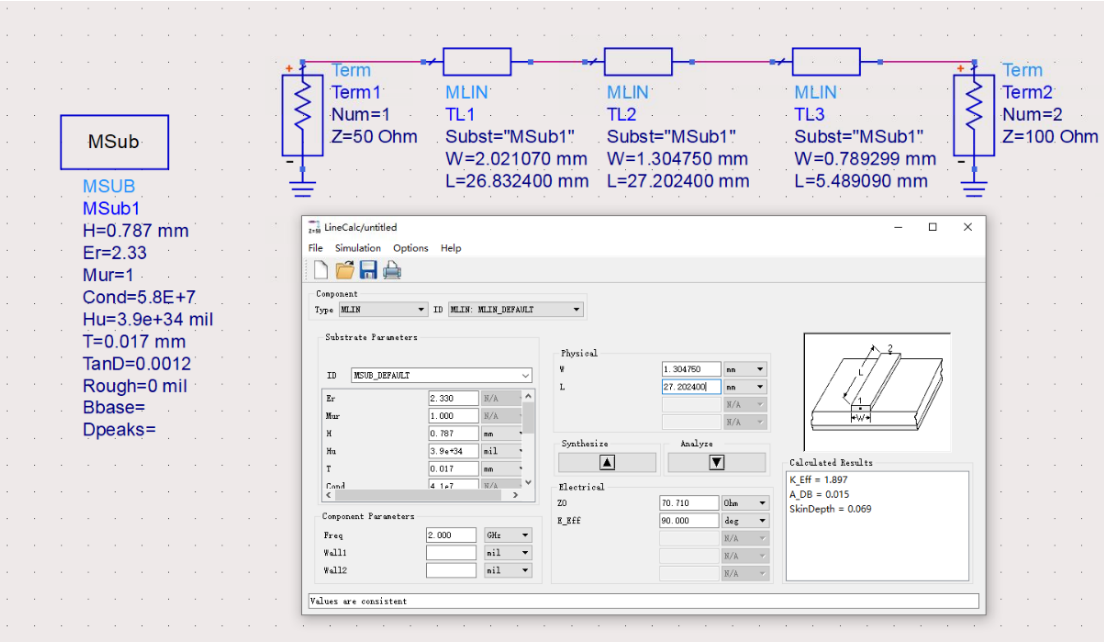
For two sections:

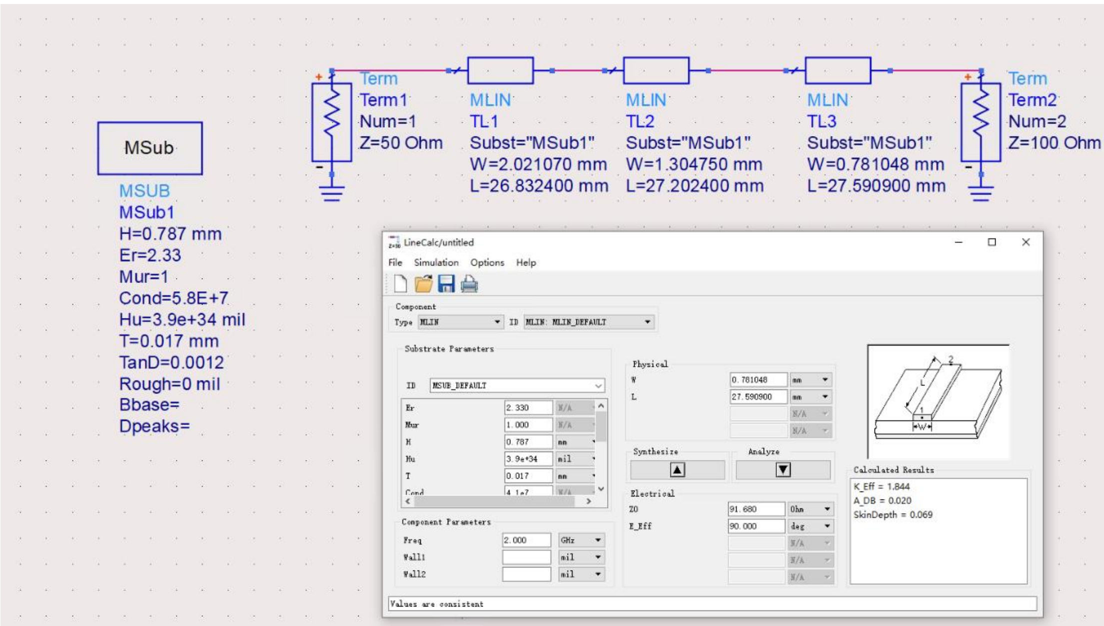




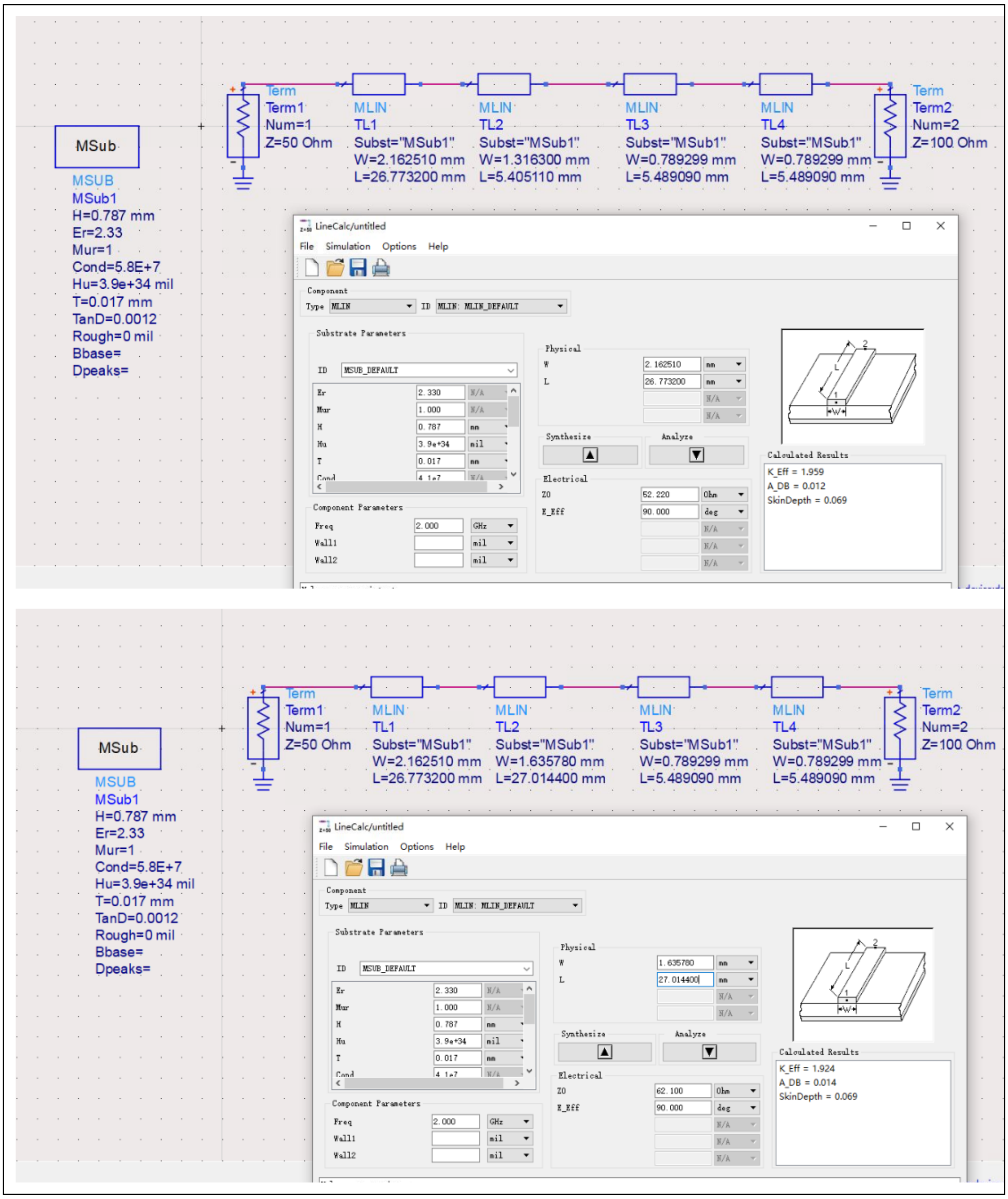

For three sections:



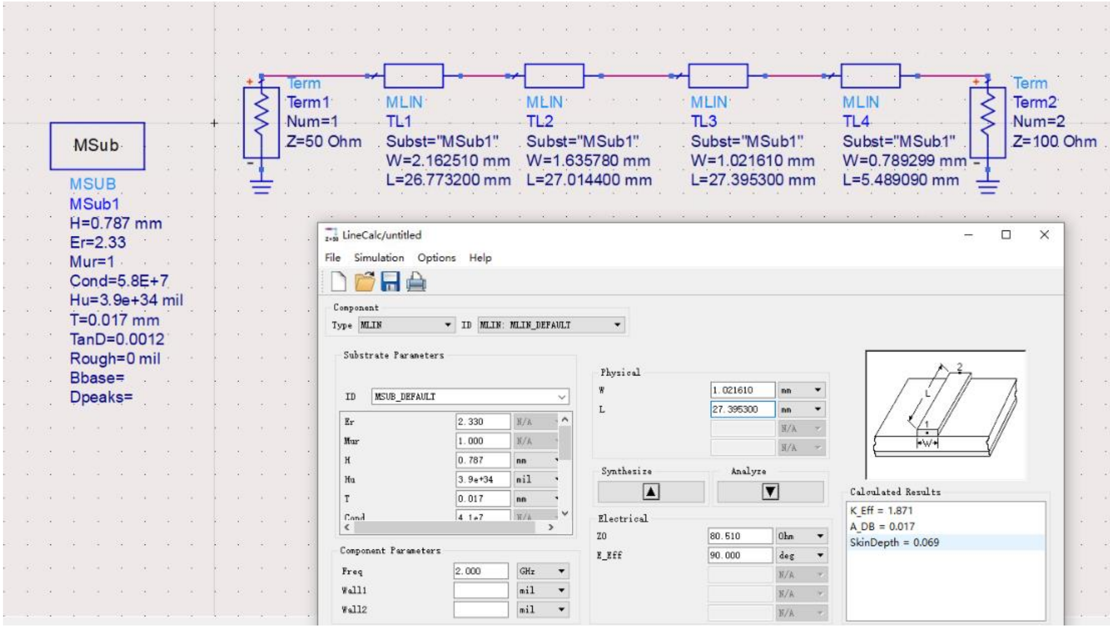


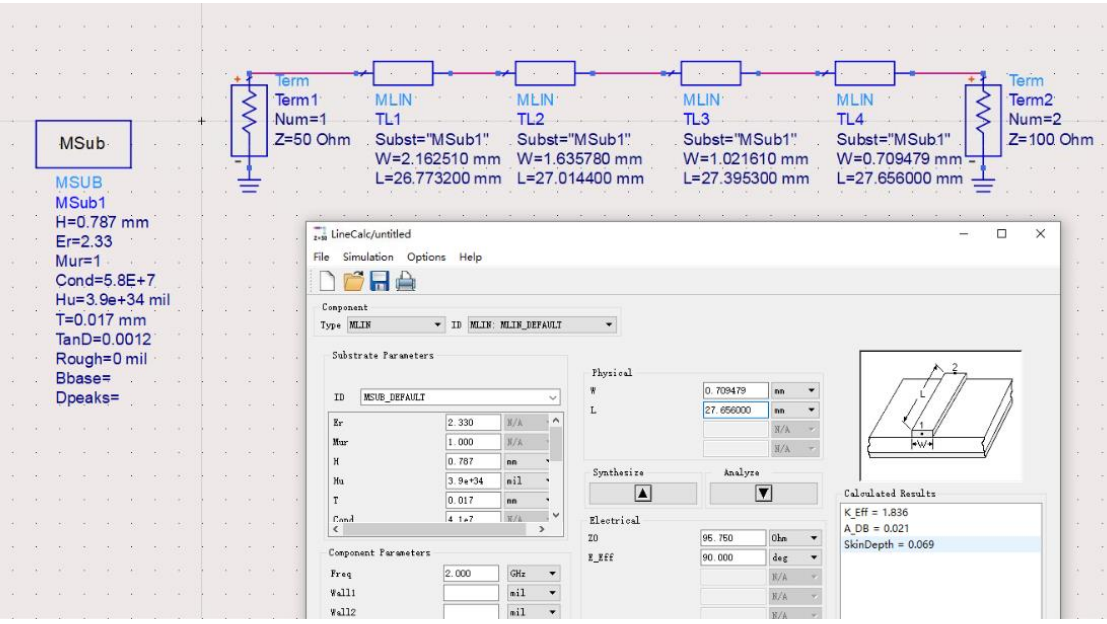




For four sections:

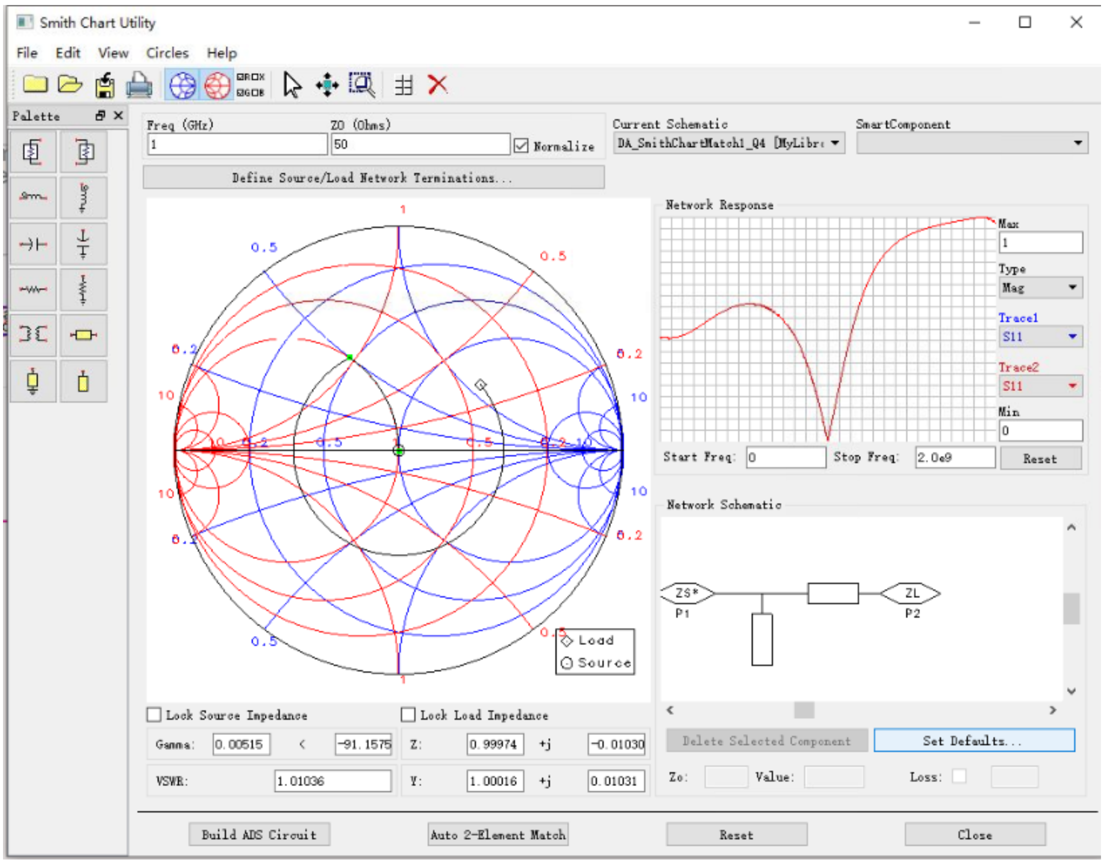
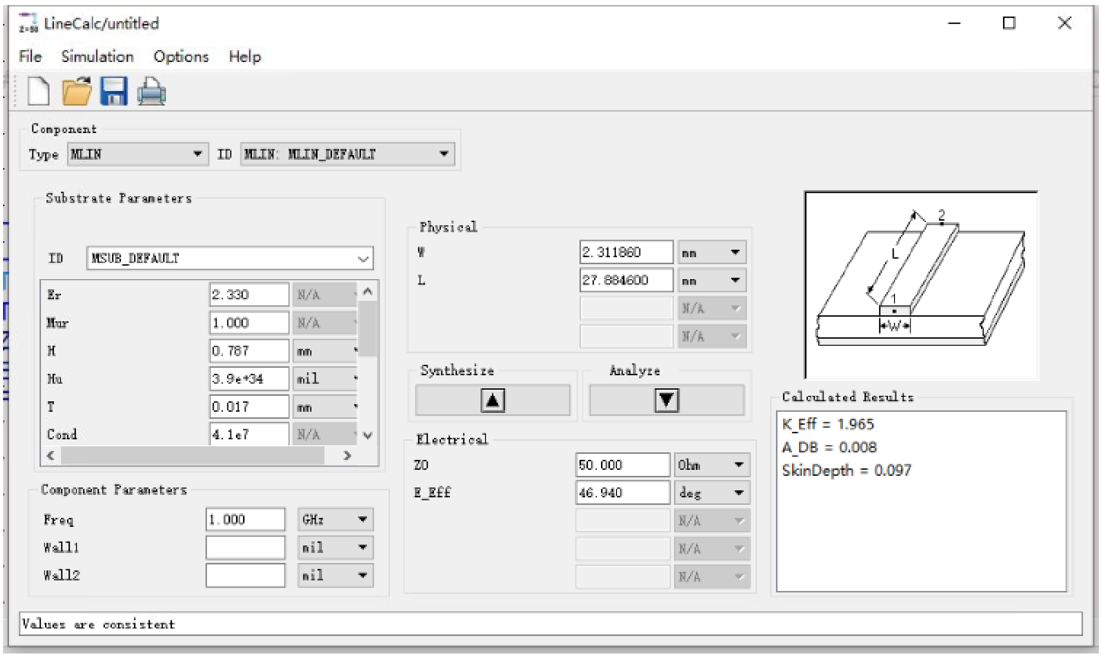


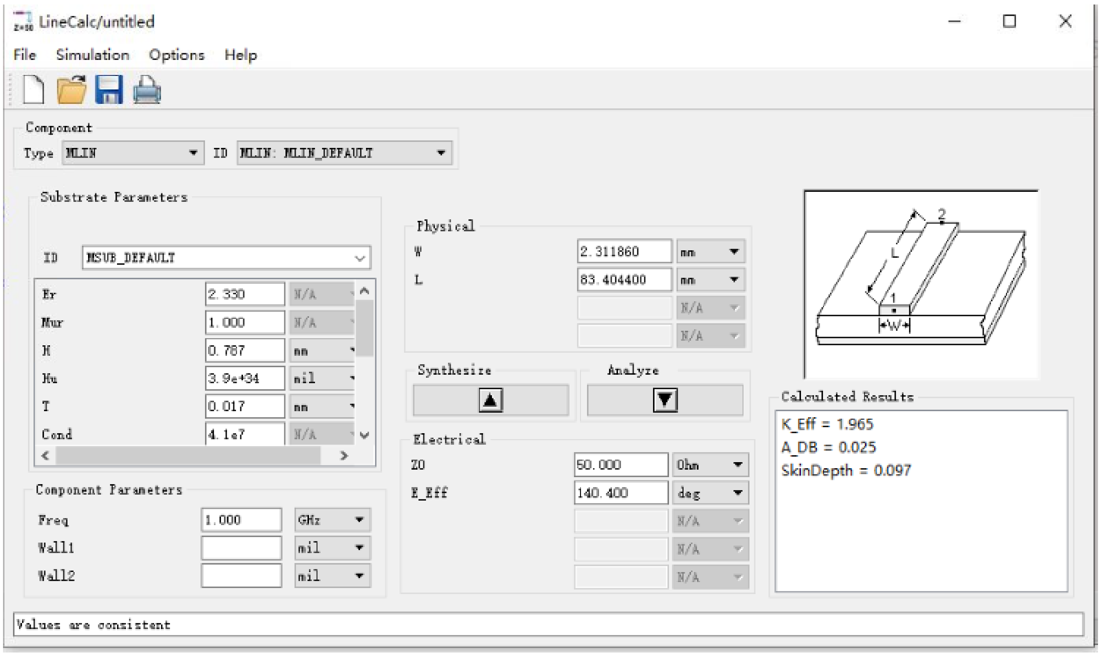
MSub
MSUB
MSub1
H=0.787 mm
Er=2.33
Mur=1
Cond=5.8E+7
Hu=3.9e+34 mil
T=0.017 mm
TanD=0.0012
Rough=0 mil
Bbase=
Dpeaks=
Term
Term1
Num=1
Z=50 Ohm
MLIN
TL1
Subst="MSub1"
W=2.162510 mm
L=26.773200 mm
MLIN
TL2
Subst="MSub1"
W=1.316300 mm
L=5.405110 mm
MLIN
TL3
Subst="MSub1"
W=0.789299 mm
L=5.489090 mm
MLIN
TL4
Subst="MSub1"
W=0.789299 mm
L=5.489090 mm
Term
Term2
Num=2
Z=100 Ohm
LineCalc/untitled
K_Eff = 1.959
A_DB = 0.012
SkinDepth = 0.069
MLIN
TL2
Subst="MSub1"
W=1.635780 mm
L=27.014400 mm
K_Eff = 1.924
A_DB = 0.014
SkinDepth = 0.069


Term
Term1
Num=1
Z=50 Ohm
MLIN
TL1
Subst="MSub1"
W=2.162510 mm
L=26.773200 mm
MLIN
TL2
Subst="MSub1"
W=1.635780 mm
L=27.014400 mm
MLIN
TL3
Subst="MSub1"
W=1.021610 mm
L=27.395300 mm
MLIN
TL4
Subst="MSub1"
W=0.789299 mm
L=5.489090 mm
Term
Term2
Num=2
Z=100 Ohm
MSub
MSUB
MSub1
H=0.787 mm
Er=2.33
Mur=1
Cond=5.8E+7
Hu=3.9e+34 mil
T=0.017 mm
TanD=0.0012
Rough=0 mil
Bbase=
Dpeaks=
LineCalc/untitled
File Simulation Options Help
Component
Type MLIN
ID MLIN: MLIN_DEFAULT
Substrate Parameters
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
Component Parameters
Freq 2.000 GHz
Wall1 mil
Wall2 mil
Physical
W 1.021610 mm
L 27.395300 mm
Synthesize
Analyze
Electrical
Z0 80.510 Ohm
E_Eff 90.000 deg
Calculated Results
K_Eff = 1.871
A_DB = 0.017
SkinDepth = 0.069


Term
Term1
Num=1
Z=50 Ohm
MLIN
TL1
Subst="MSub1"
W=2.162510 mm
L=26.773200 mm
MLIN
TL2
Subst="MSub1"
W=1.635780 mm
L=27.014400 mm
MLIN
TL3
Subst="MSub1"
W=1.021610 mm
L=27.395300 mm
MLIN
TL4
Subst="MSub1"
W=0.709479 mm
L=27.656000 mm
Term
Term2
Num=2
Z=100 Ohm
MSub
MSUB
MSub1
H=0.787 mm
Er=2.33
Mur=1
Cond=5.8E+7
Hu=3.9e+34 mil
T=0.017 mm
TanD=0.0012
Rough=0 mil
Bbase=
Dpeaks=
LineCalc/untitled
File Simulation Options Help
Component
Type MLIN
ID MLIN: MLIN_DEFAULT
Substrate Parameters
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
Component Parameters
Freq 2.000 GHz
Wall1 mil
Wall2 mil
Physical
W 0.709479 mm
L 27.656000 mm
Synthesize
Analyze
Electrical
Z0 95.750 Ohm
E_Eff 90.000 deg
Calculated Results
K_Eff = 1.836
A_DB = 0.021
SkinDepth = 0.069

**Part II:**


Smith Chart Utility
File Edit View Circles Help
Palette
Freq (GHz)
1
Z0 (Ohms)
50
Normalize
Current Schematic
DA_SmithChartMatch1_Q4 [MyLibr
SmartComponent
Define Source/Load Network Terminations...
Network Response
Max
1
Type
Mag
Trace1
S11
Trace2
S11
Min
0
Start Freq:
0
Stop Freq:
2.0e9
Reset
Network Schematic
ZS*
P1
ZL
P2
Load
Source
Lock Source Impedance
Lock Load Impedance
Gamma:
0.00515
-91.1575
Z:
0.99974
+j
-0.01030
VSWR:
1.01036
Y:
1.00016
+j
0.01031
Delete Selected Component
Set Defaults...
Zo:
Value:
Loss:
Build ADS Circuit
Auto 2-Element Match
Reset
Close

LineCalc/untitled
File Simulation Options Help
Component
Type MLIN
ID MLIN: MLIN_DEFAULT
Substrate Parameters
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 4.1e7 N/A
Component Parameters
Freq 1.000 GHz
Wall1 mil
Wall2 mil
Physical
W 2.311860 mm
L 27.884600 mm
N/A
N/A
Synthesize
Analyze
Electrical
Z0 50.000 Ohm
E_Eff 46.940 deg
N/A
N/A
N/A
Calculated Results
K_Eff = 1.965
A_DB = 0.008
SkinDepth = 0.097
Values are consistent

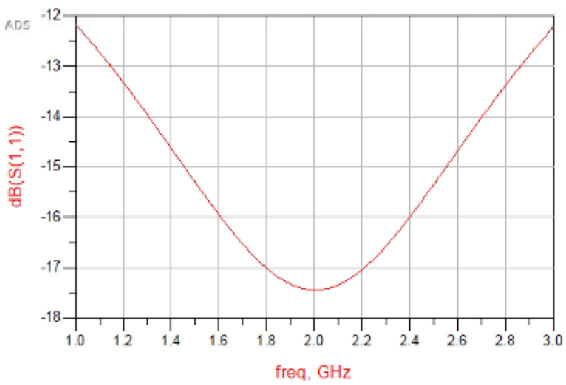



## S11 parameter diagram

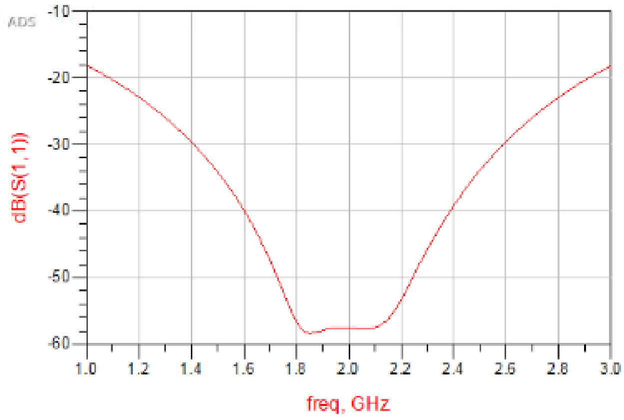
In this experiment we mainly examine the effect of impedance matching by observing the S11 parameter, the simulation results of the S11 parameter for the above experiment are shown below:

**Part I:**

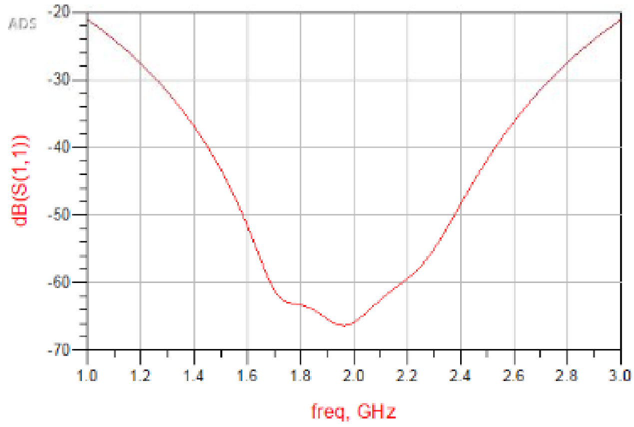
For two sections:



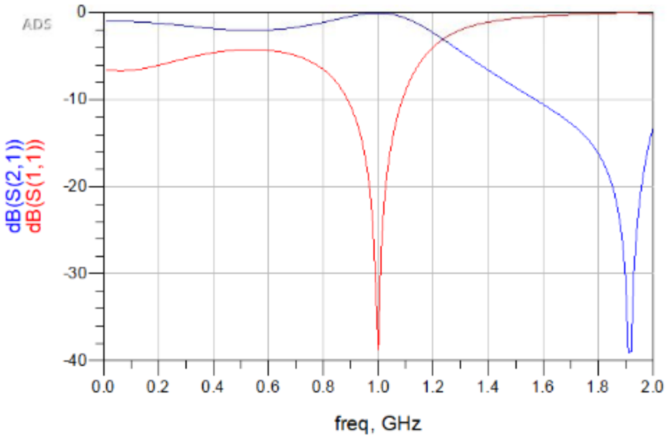

For three sections:




For three sections:




**Part II:**

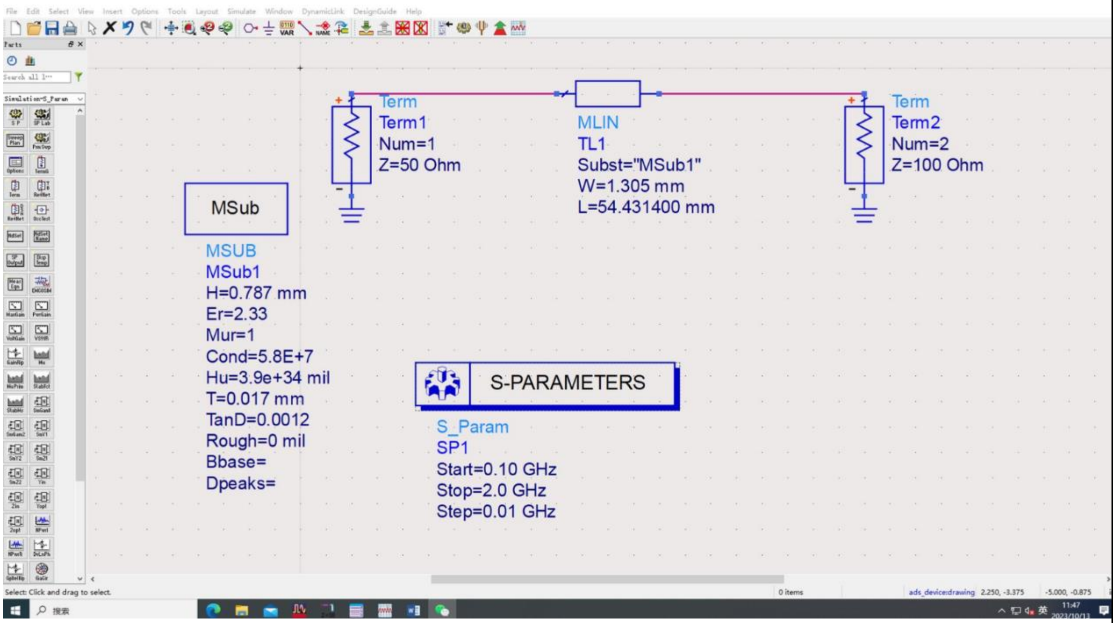


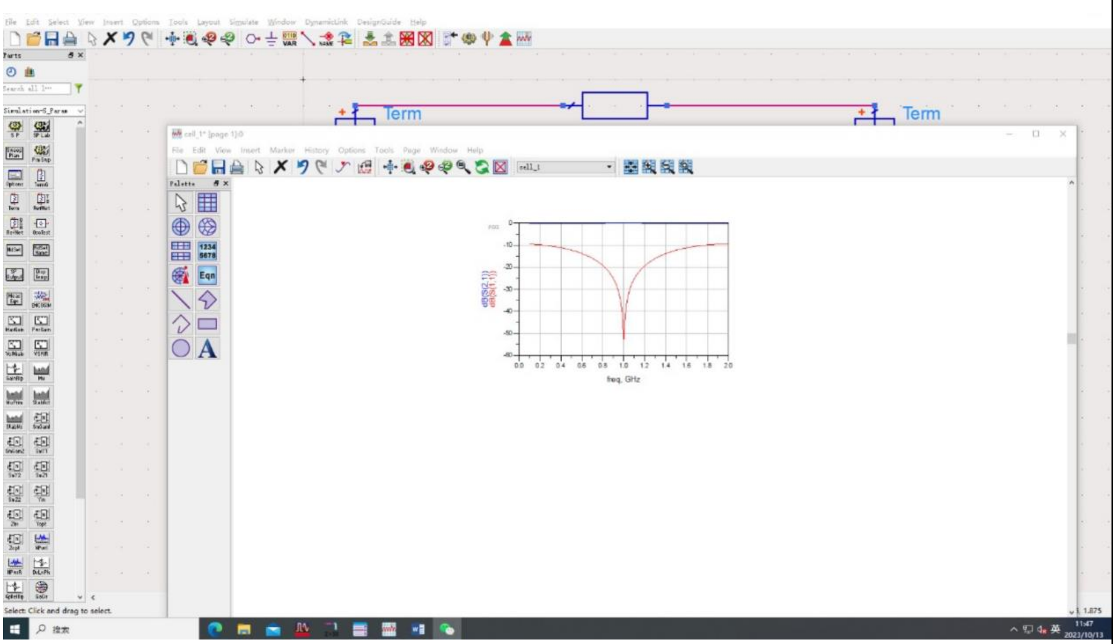

As can be seen from the above simulation result plots of S11 parameters, all the above experiments are at the center frequency where the S11 parameters drop to the lowest point, which indicates that the impedance matching is successful.

For part I, through the ADS simulation, we can find that the S11 parameter map of 2 sections will reach the minimum value at the center frequency and is smoother, the corresponding 3 sections are equal and minimum near the center frequency, that is, the bottom is flat, and the corresponding 4 sections of the S11 parameter map has a more obvious jitter at the bottom, which is not so smooth. For the above phenomenon, the possible reasons are: for two-section microstrip line impedance matching: the smoother S11 parameter curve indicates a wider bandwidth. This is because the bandwidth of the two-band match is relatively narrow and therefore provides better matching performance around the center frequency. For three-band microstrip line impedance matching: equal and minimum values of the S11 parameter around the center frequency generally indicate a wider bandwidth. This is because a three-section matching network usually includes a microstrip line section that further smooth the impedance transition to ensure better matching performance over a wider frequency range. The flatter S11 parameter curves indicate that the three-section matches typically provide a wider bandwidth because they provide a better match at and around the center frequency. For four-band microstrip line impedance matching: The apparent jitter at the bottom of the S11 parameter plot may be due to the more complex frequency response resulting from the multiple microstrip line sections in the four-section matching network. Four-section matching networks typically include more impedance transition sections, which can lead to irregular impedance reflections near the center frequency and fluctuations at the bottom of the S11 parametric plot. The main advantage of a four-section matched network is that it provides a wider bandwidth and higher performance, but may exhibit fluctuations in certain frequency ranges.

# Experience

## 1. Screenshot on course






## 2. Problems we meet and the experience

Through the study of this experiment, I became more familiar with the use of ADS software, and gained a deeper understanding of how to perform impedance matching based on source impedance and load impedance, how to use the tool for calculating line length in ADS to calculate the length and width of the microstrip line, how to utilize Smith's circle diagrams for impedance matching, and how to use the Smith's Circle Diagram tool in ADS, and I also gained a deeper understanding of the Smith's Circle Diagrams principles of Smith Circle Diagrams. I also encountered certain problems in this experiment, more in the details. First of all, the center frequency must not be taken wrongly, otherwise the whole result will be wrong. The center frequency is set in many places, which must be paid attention to, including the tool of calculating line length, the tool of Smith's Circle Chart, and the setting of the simulator, and so on. In addition, we must pay attention to the unit, especially when calculating the length of the line, the general unit is mm, the default unit is mill, we must mainly change the unit, otherwise the calculation must be wrong.

| | |
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| **Score** | 98 |