Microstrip Patch antenna design

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assigned frequency f0=2.47Ghz

The aim of this lab is to design a microstrip patch antenna with resonant frequency at f_0 GHz. The structure is illustrated in Fig. 1 (transversal section view) and Fig. 2 (frontal view):

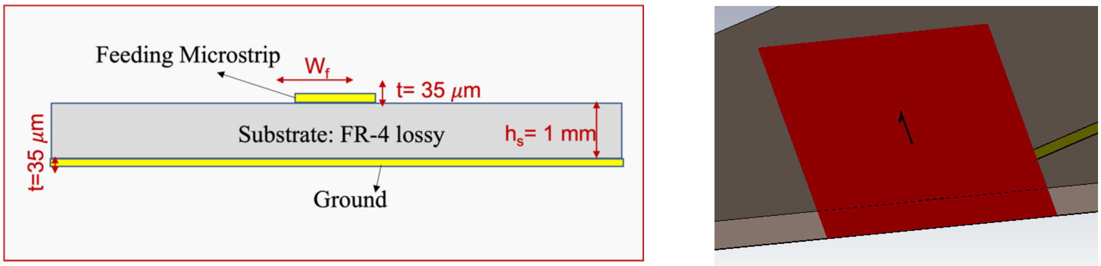


Fig. 1

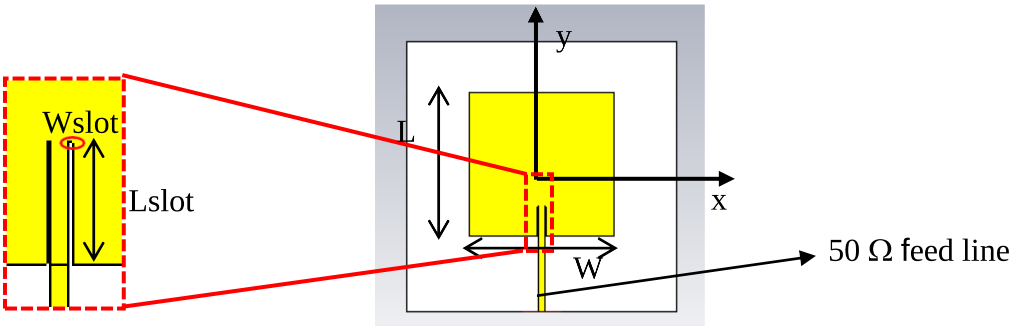
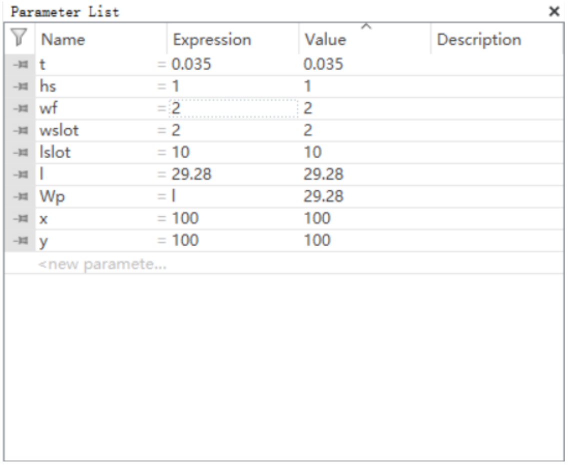


Fig. 2

The planar technology is particularly exploited for the realization of radio-frequency (high frequency) circuits. Due to the high-frequency involved, the signal is guided by means of a particular 2-wire transmission line, called microstrip line (Q-TEM is its fundamental mode)

1) **Create (and save) the project** ***patch_antenna.cst*** by selecting the template *MW&RF&Optical/Antennas/Planar/Time Domain*: select the frequency range [0.5-5] GHz, and define the field monitors (*H-field, Farfield*) at 2. 47 GHz.
   a. Create a <u>square</u> planar patch layout similar to the one shown in Fig. 2. The physical length (L=W) of the patch has to be around λ/2 @ 2. 47GHz (considering the dielectric, also), but tune it in order to have the proper resonance. Adopt the origin of the reference frame as indicated in the figure to have the patch antenna in the center of the substrate. The ideal resonant cavity is given by two (real) perfect electric conductor planes (the patch and the ground), and two (ideal) perfect magnetic conductors (at x = ± L/2) Start with the definition of the components of the antenna:



Parameter List

Name	Expression	Value	Description
t	= 0.035	0.035	
hs	= 1	1	
wf	= 2	2	
wslot	= 2	2	
lslot	= 10	10	
l	= 29.28	29.28	
Wp	= l	29.28	
x	= 100	100	
y	= 100	100	
<new paramete...			

Fig. 3 parameter list

a) *Substrate of the Patch*, containing the brick of material *FR-4 lossy* ($\varepsilon_r = 4.3$) taken from the material library, with thickness (h_s) of 1 mm, width *x=10 cm* and length *y=x*.

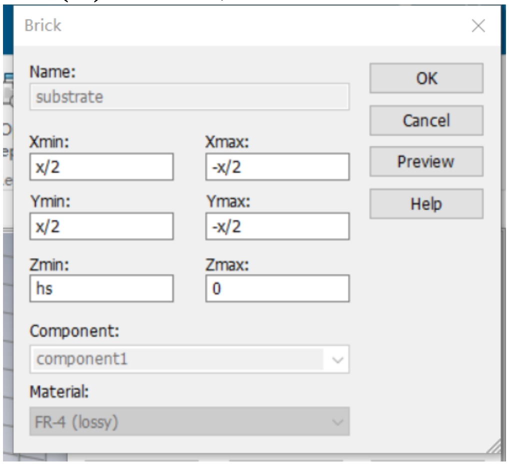


Fig. 4 parameter of substrate

b) *Ground*, containing the brick of material *Copper annealed* taken from the material library, with thickness (*t*) of 35 µm, width *x* and length *y* (same dimension of the substrate). The ground acts as a p.e.c. for the image theorem, and also as a reflector.

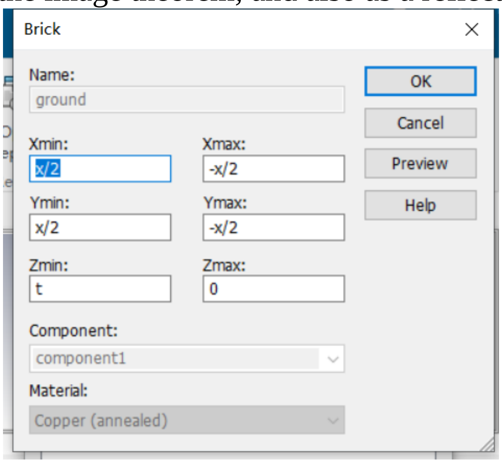


Fig. 5 parameter of ground

c) *Patch Antenna*, containing the brick of material *Copper annealed* with width (*W*) = length (*L*).

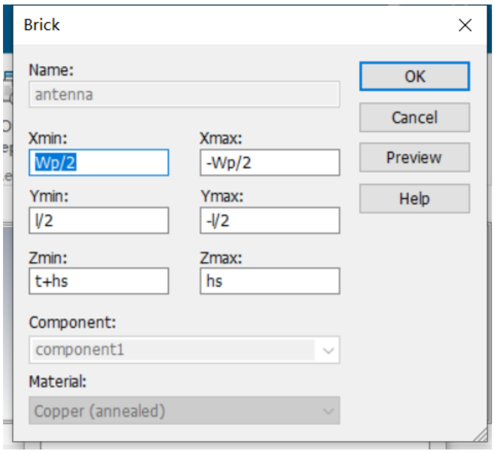


Fig. 6 parameter of patch antenna

$$l = \frac{\lambda}{2} = \frac{c}{2*f_0\sqrt{\varepsilon_r}} = 28.29mm \qquad (1)$$

Formula 1 Calculation of l

*C is the speed of light which is equal to 3*10^8 m/s, f0 is the design frequency which is equal to 2.47Ghz, and* ε_r *is the substrate dielectric constant.*

d) *Feeding Microstrip line*, containing the brick of material *Copper annealed* with width (W_f) corresponding to a 50Ω line (use the Home/Macros/Calculate/Analytical line impedance/Thin Microstrip to define the proper width: put the value of h and ε_r changing the width of the line w until we reach 50 Ω characteristic impedance). The theory of microstrip transmission line is valid for: W<<l, h<<l

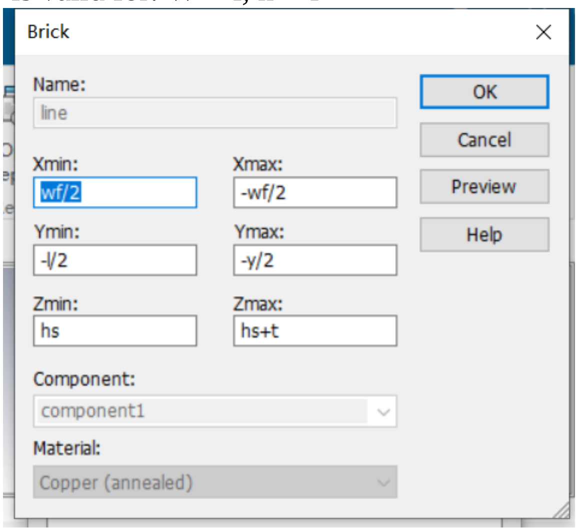


Fig. 6 parameter of feeding line

2) **Define the port**: It allows us to solve the antenna-line matching issue. By moving from the edge towards the centre of the patch (design parameter S) it is possible to find the right length providing the antenna impedance (real at the resonance) equal to the characteristic impedance of the line pick the edge of the feeding line in the back side of the structure (*Simulation/Pick/Pick edge*). Then select *Ports/New Waveguide port* and define a port in the positive y direction (as in Fig. 2), with width 3*W_f at the left and right side of the X range, h_s at Zmin (it must touch the ground), and 5*h_s at Zmax (in order to have a sufficiently big rectangle as in the Fig. 1).

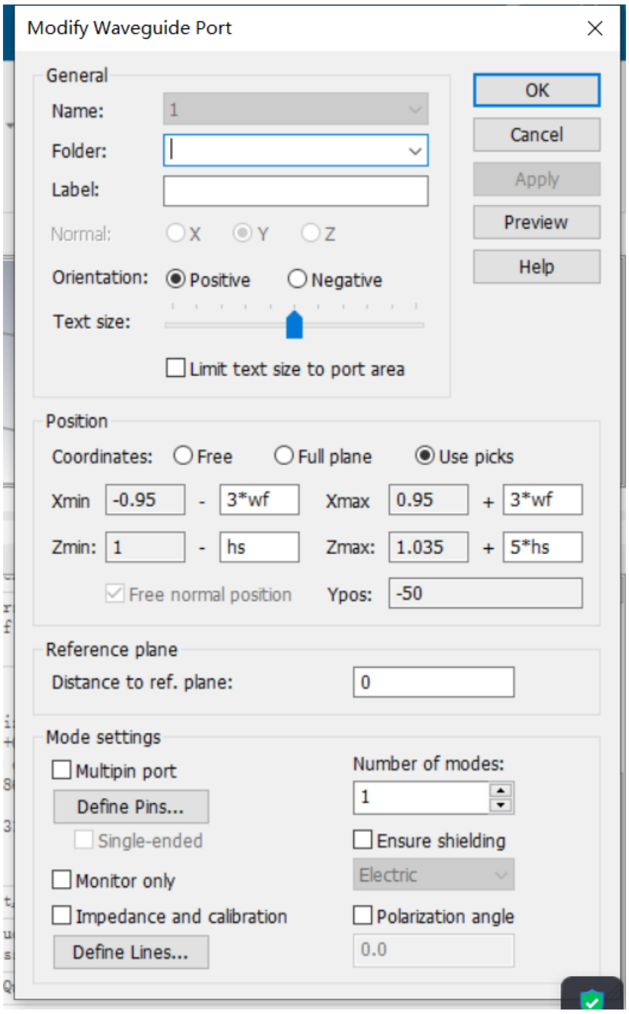


Fig. 7 parameter of waveguide prot

3) **Insert a *symmetry plane*** (*Solve/Boundary conditions*) for the yz plane, in order to halve the mesh dimension and thus the solving system dimension. Choose the proper symmetry plane kind.

4) **Perform a *Transient analysis*** with a mesh with 10 lines per wavelength and Energy=-40dB. If needed, reduce the mesh (reduce no. lines per wavelength in the *Mesh Options*)
   a. View the S_{11}(dB) behavior.

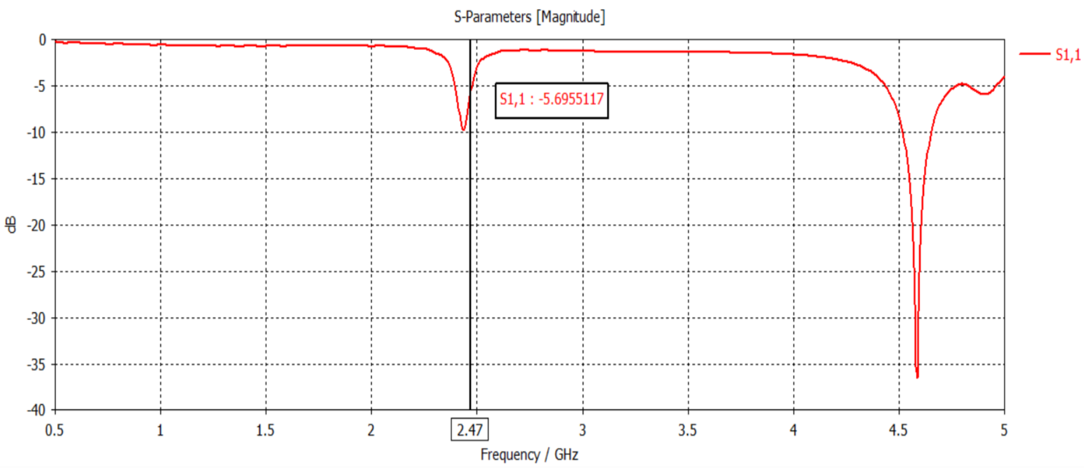


Fig. 7 S11(dB) behavior

S parameter is used to measure the reflection loss at the input of the antenna, which is the lower the better at the designed frequency. The value of S reflects how much power is radiated by the antenna and how much power is reflected back to the signal source. In theory analysis, the model is in the ideal case, we omitted some phenomena, so the result does not meet the requirement. From the picture shown above, we can find that there is a notch near 2.47Ghz, the real part of Z-parameter is 45 Ω , and the image part of the Z- parameter is 56 Ω , which means too much power are wasted and this behavior is not good enough.

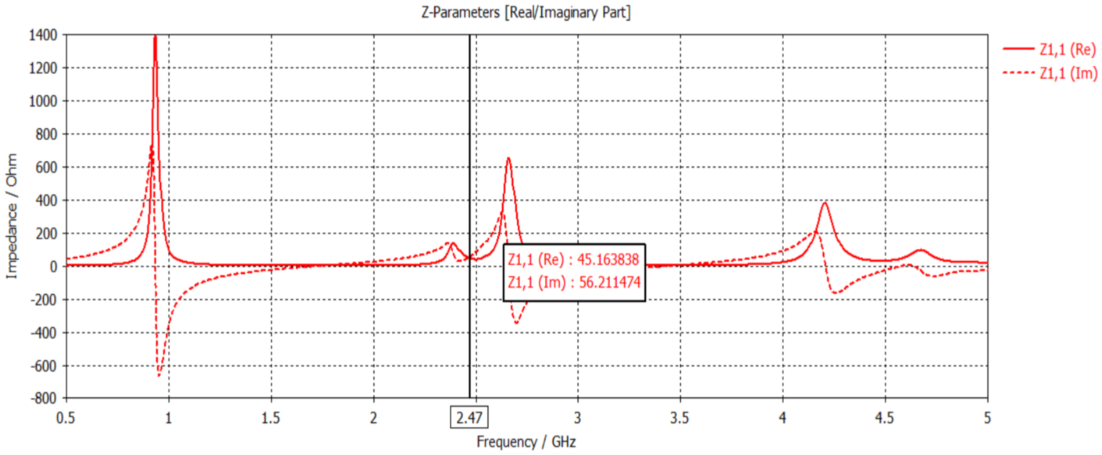


Fig.8 Z parameter behavior

5) Use the previous information to properly **tune** the patch length (through the L variable previously defined) and achieve the resonance (hence *Im(Z_{11})*=0) at 2. 47GHz. To do this, in *Time Domain Solver*, click on ***Par. Sweep*** and define the parameter to be swept and the number of passes of the sweep.

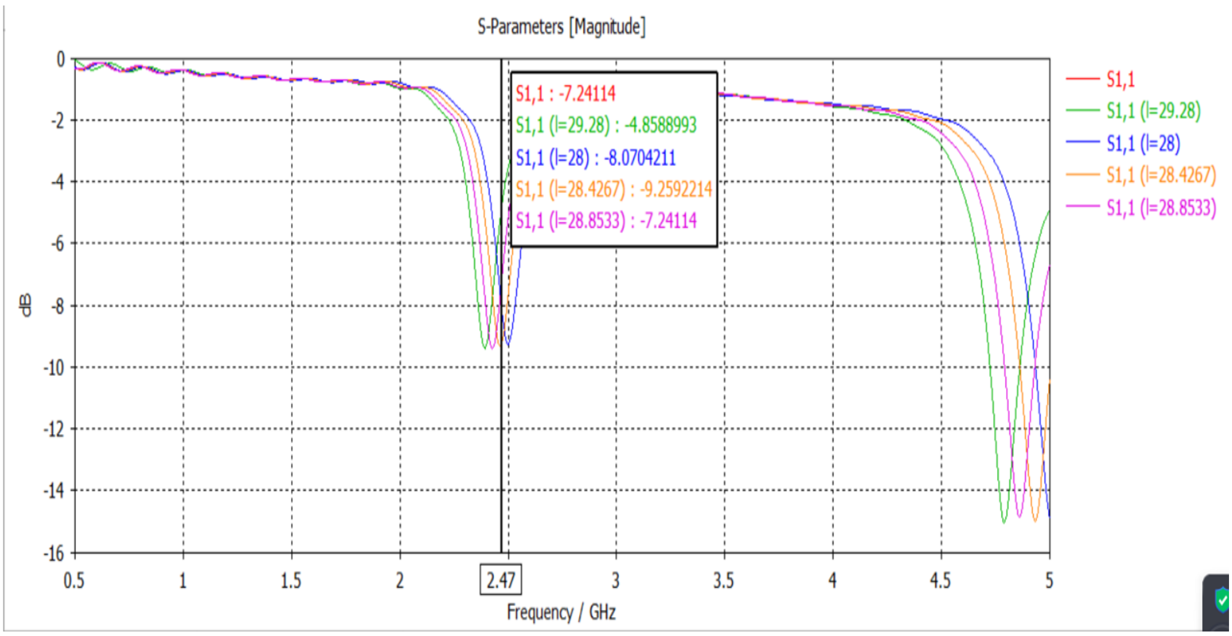


Fig.9 S parameter tuning

After tuning the l parameter and comparing its behavior, we find a better performance near l=28.4mm.

6) Since typically a patch antenna is not well matched to a 50 Ω feed line, we have now to introduce the feeding slots (slot width **Wslot** = 2 mm and starting value of slot length **Lslot** = 10 mm) on the line sides, inside the patch (as in Fig. 2).
To begin with, we need to create the slots: create two symmetrical bricks superimposed to the patch metallization, then subtract them to the metallization (by the Boolean operator *Subtract:* first select the patch metallization, then the operator Subtract, then the slots we have to subtract). After this we have to perform a *Sweep Analysis* (*Par. sweep* in *Transient Solver*) by using the length of the feeding slots (**Lslot**) as a parameter (e.g. 4 steps from 5 to 15 mm).

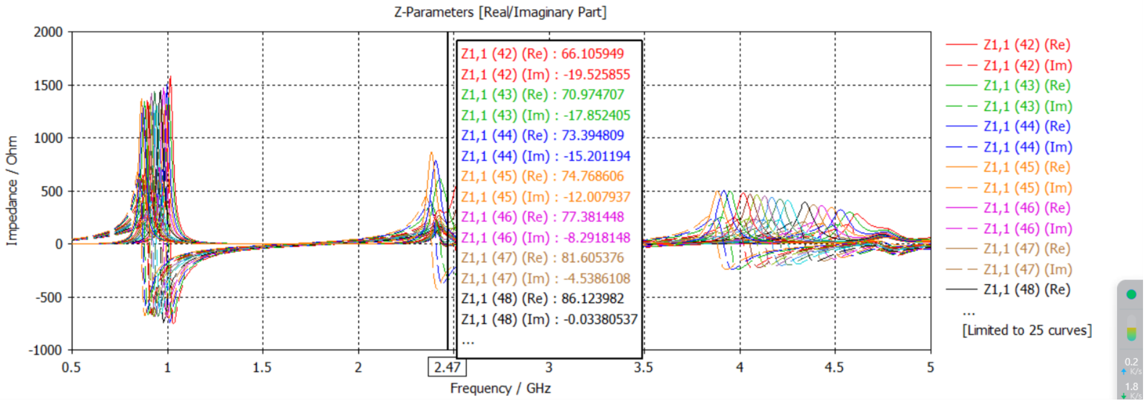


Fig.9 impedance tuning

To achieve a precise Lslot length we set the step is 0.5. According to the result of the parameter sweep, we find that with the length increased from 5mm to 15mm, the real part impedance increased from 66 Ω to 359 Ω then decreased to 78 Ω. The image part of impedance increased from -19 Ω to 105 Ω then jumped to -359 Ω then increased to -256 Ω, the drawback of patch antenna is difficult to match. The performance is still not good enough to meet the requirement. When the Lslot is in the range of 5mm-8mm the impedance increases smoothly, and since the real part of the impedance is 66 Ω at 5mm, it can be assumed that the right value of Slot is in the range of 4mm-8mm.

7) Once the topology has been defined:
   a. Re-simulate the antenna with a ***Transient analysis*** in order to have a look at the radiation properties of the patch (*Farfield* and *Surface currents*).
   b. View the Z port behavior (*Re*(Z_{11}) and *Im*(Z_{11}))
   c. Evaluate the relative bandwidth of the selected topology by referring to the maximum acceptable reflection coefficient magnitude = -10 dB.

Finally, we find a better trade-off between the impedance matching and the reflection coefficient magnitude, the details and parameters are shown below.

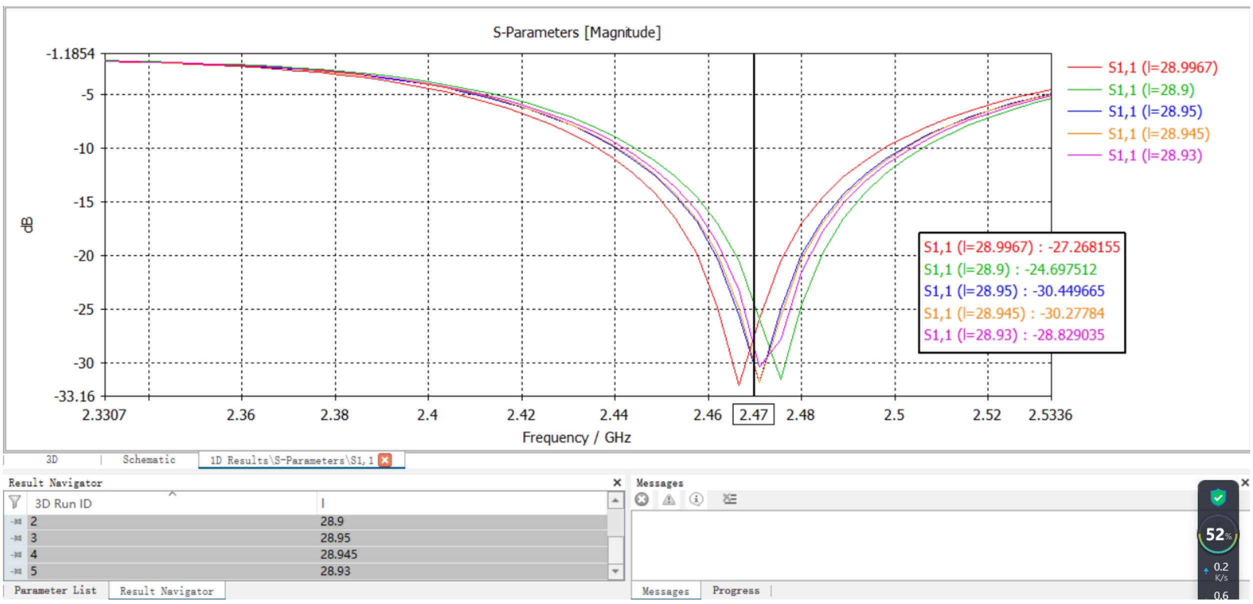


Fig.10 S parameter retuning

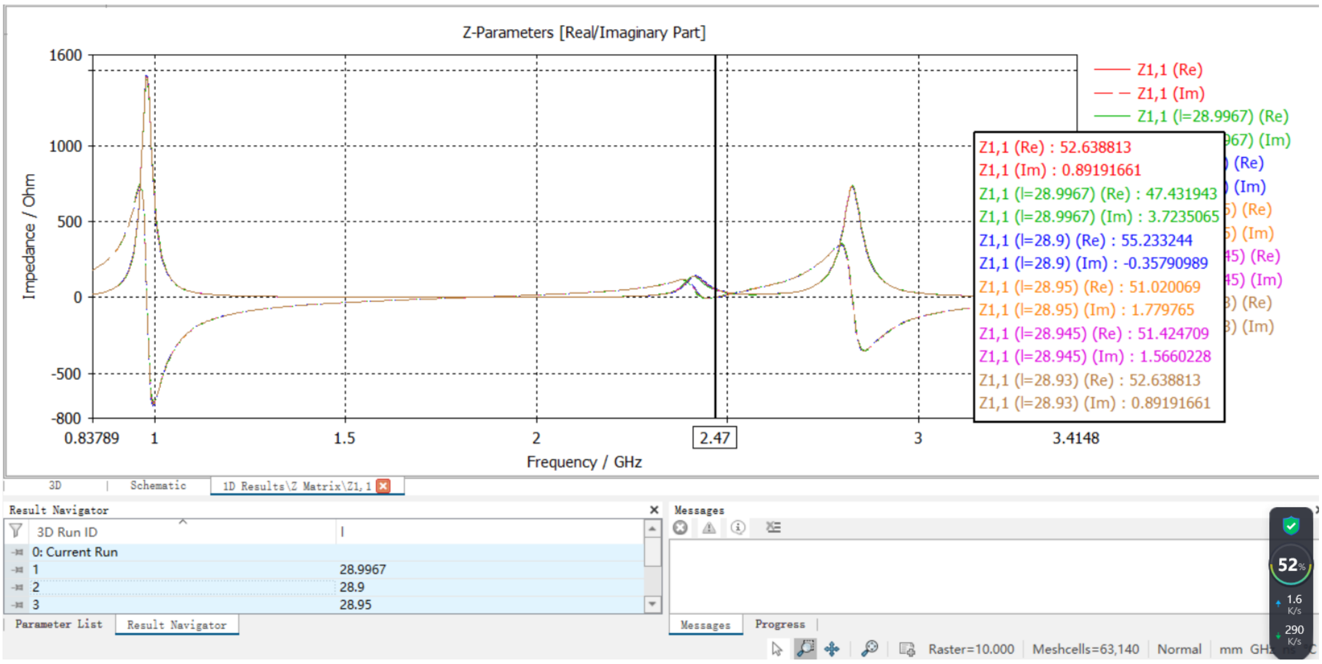
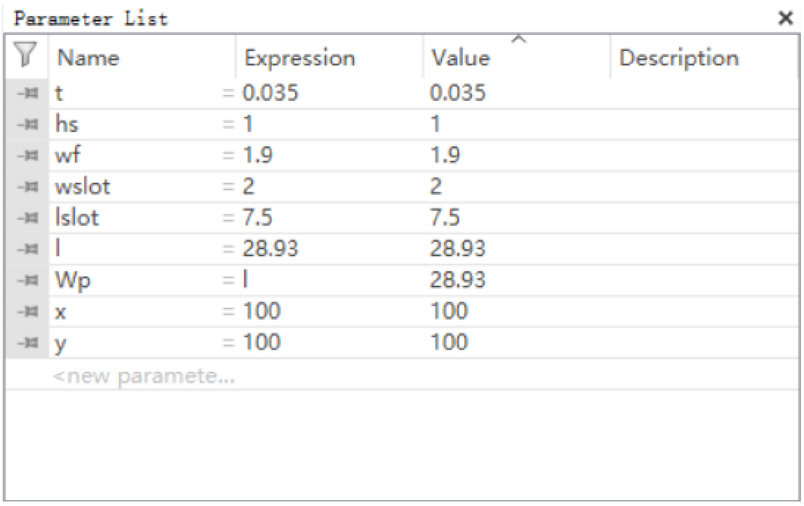


Fig.11 Z parameter returning



Parameter List

	Name	Expression	Value	Description
	t	= 0.035	0.035	
	hs	= 1	1	
	wf	= 1.9	1.9	
	wslot	= 2	2	
	lslot	= 7.5	7.5	
	l	= 28.93	28.93	
	Wp	= l	28.93	
	x	= 100	100	
	y	= 100	100	
	<new paramete...			

Fig.12 final parameter list

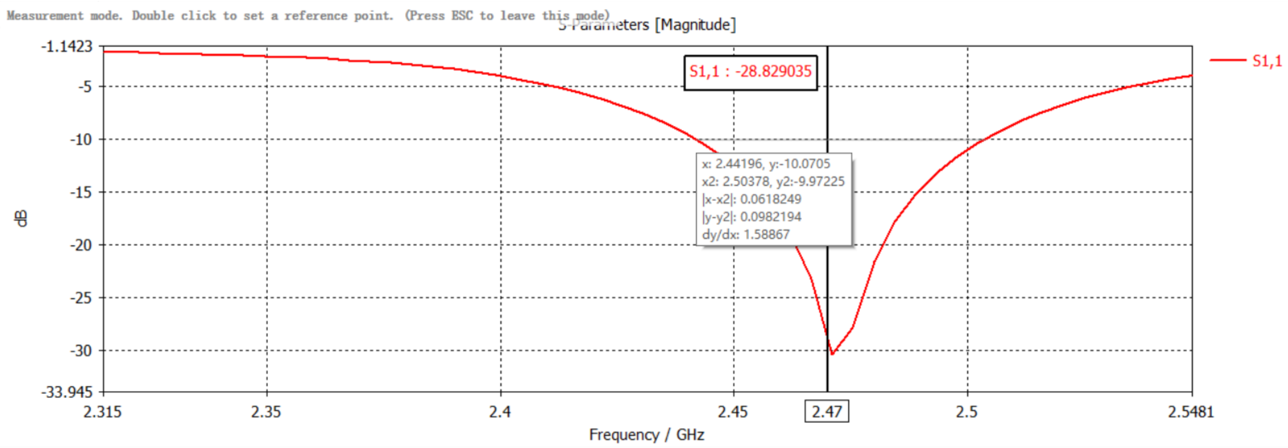


Fig.13 final S11(dB) behavior
bandwidth=60Mhz

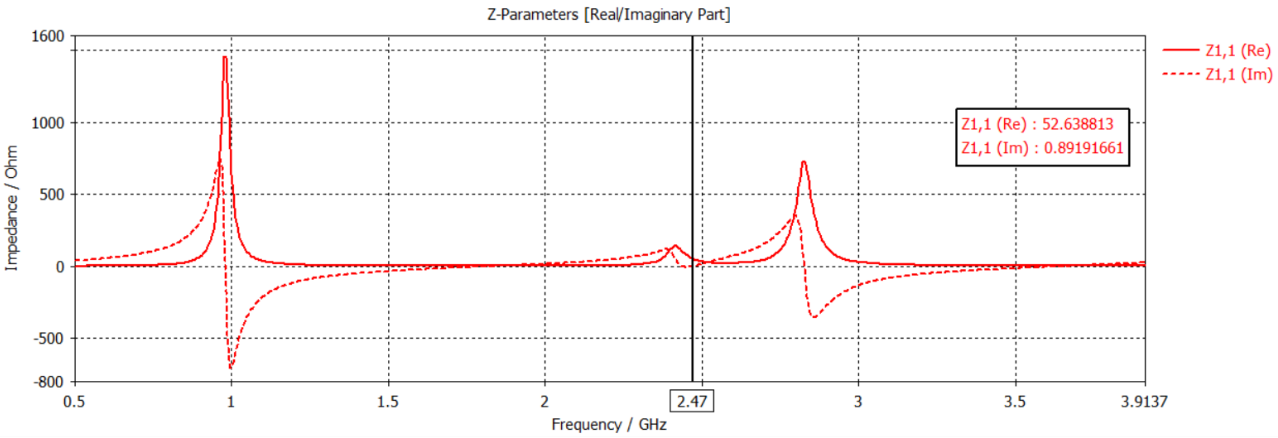


Fig.14 final Z parameter behavior

From the experimental results above, we can draw the following conclusion: at the frequency of 2.47 GHz, the minimum reflection coefficient is -30 dB, with a real impedance of 52 ohms and an imaginary impedance of 0.89 ohms, and the bandwidth is approximately 60 MHz. This is an acceptable value.