ShanghaiTech

SIST

EE130P Final Report

Topic: ☑1 ☑2 ☐3 ☐4 ☑5

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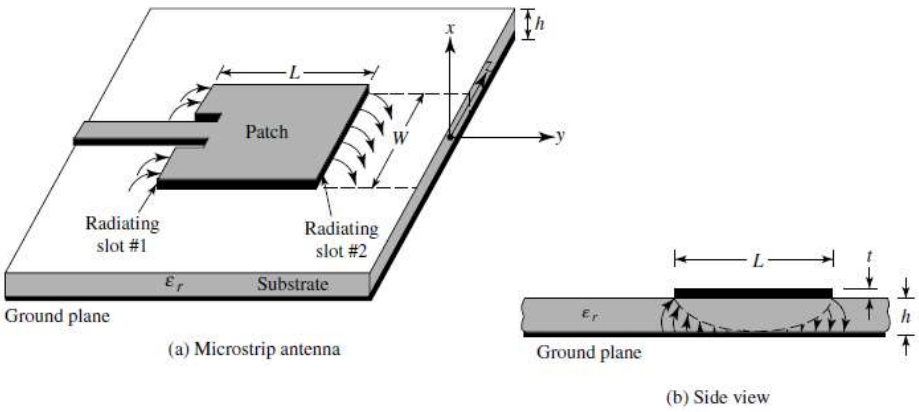
Topic1 - Part I. Objective

- Gain basic knowledge of patch antenna
- Design one patch antenna working at **3.55Ghz**

Topic1 - Part II. Data

- Parameters
  - $f = 3.55GHz$
  - $\varepsilon_r = 4.6$
  - $h = 1mm$
  - $t = 35\mu m$



(a) Microstrip antenna

(b) Side view

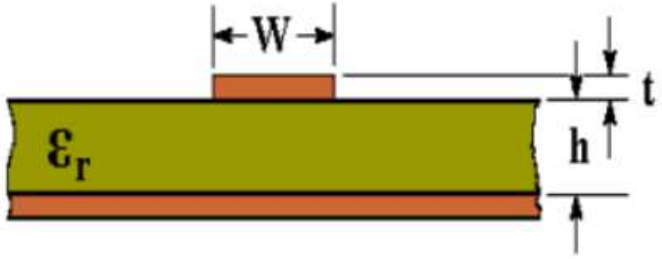
- Formulas
  - $W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$
  - $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$
  - $L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$
  - $\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$

Topic1 - Part II. Data

- Formulas
  - $W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$
  - $\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$
  - $L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$
  - $\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}$
  - $R_{in} = 90\frac{(\varepsilon_r)^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)$
  - $R_{in}(y=y_0) = Rin(y=0)cos^2(\frac{\pi}{L}y_0)$
- Results:
  - $W = 25.25mm$
  - $\varepsilon_{reff} = 4.282$
  - $L = 19.5mm$
  - $\Delta L = 0.459mm$
  - $L_e = L + 2\Delta L = 20.418mm$
  - $y_0 = 7.53mm$

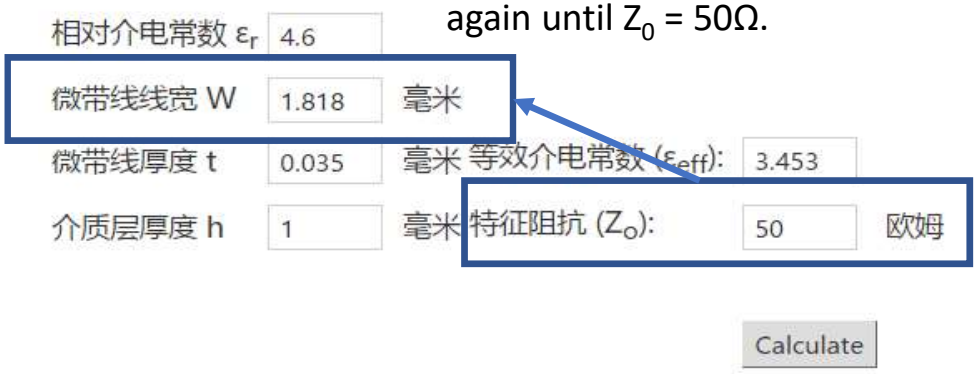
Topic1 - Part II. Data

With the help of **Microstrip line characteristic impedance calculator**...

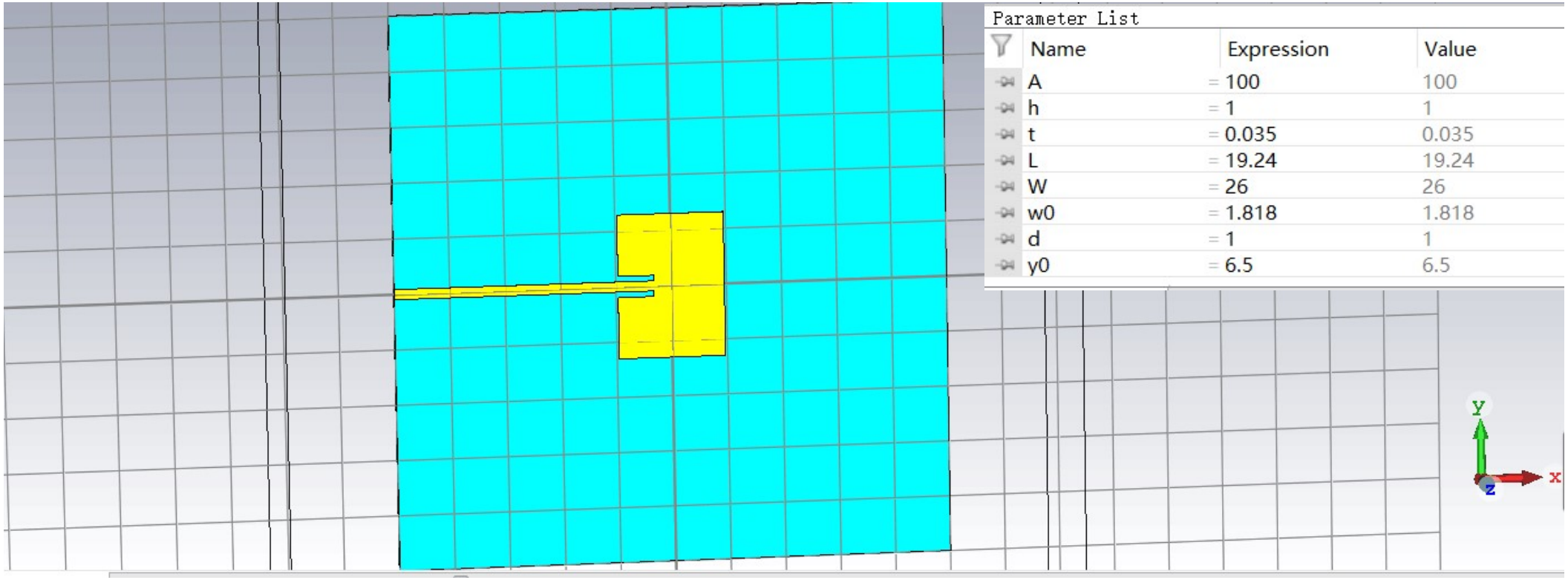


We get when the microstrip line's width is about **1.818mm**, the characteristic impedance can be **50Ω**, to meet the demand of this topic.

Find the value by changing W again and again until Z_0 = 50Ω.



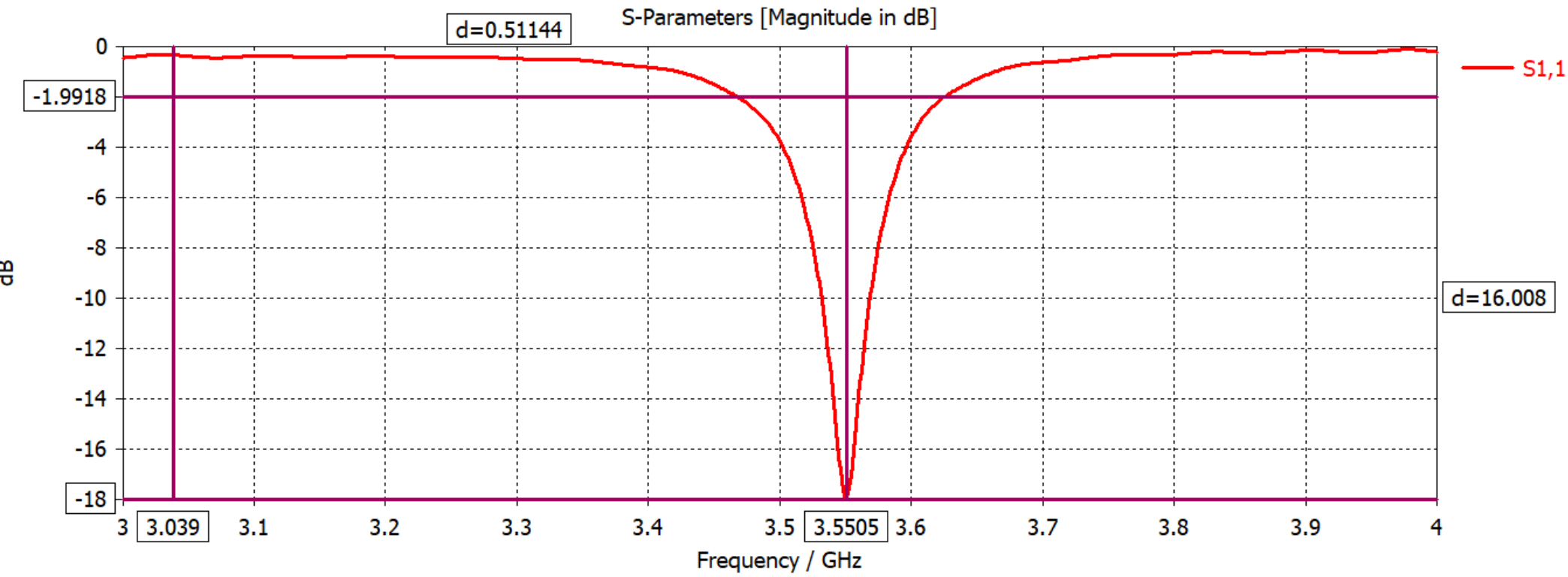
Topic1 - Part II. Data



Simulated chart & Parameters

Topic1 - Part II. Data

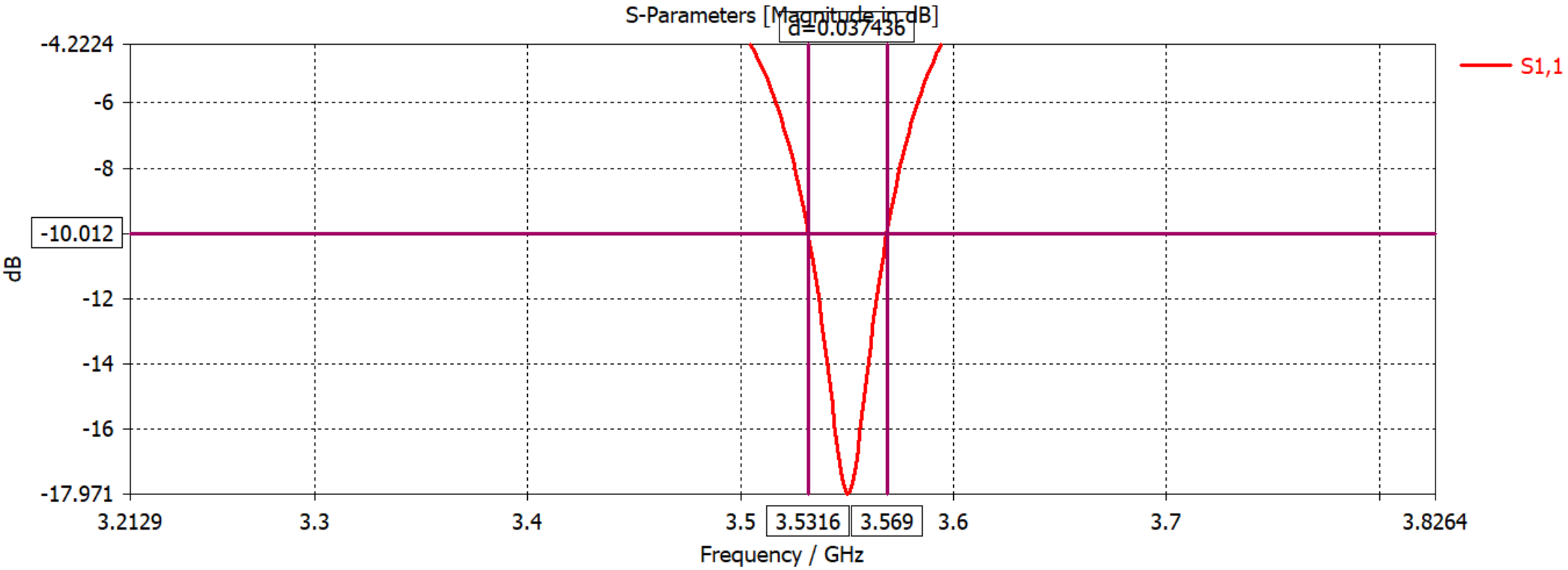
S-Parameters



By observing the position of the cursor, we can get that the working frequency is about 3.55GHz.

Topic1 - Part II. Data

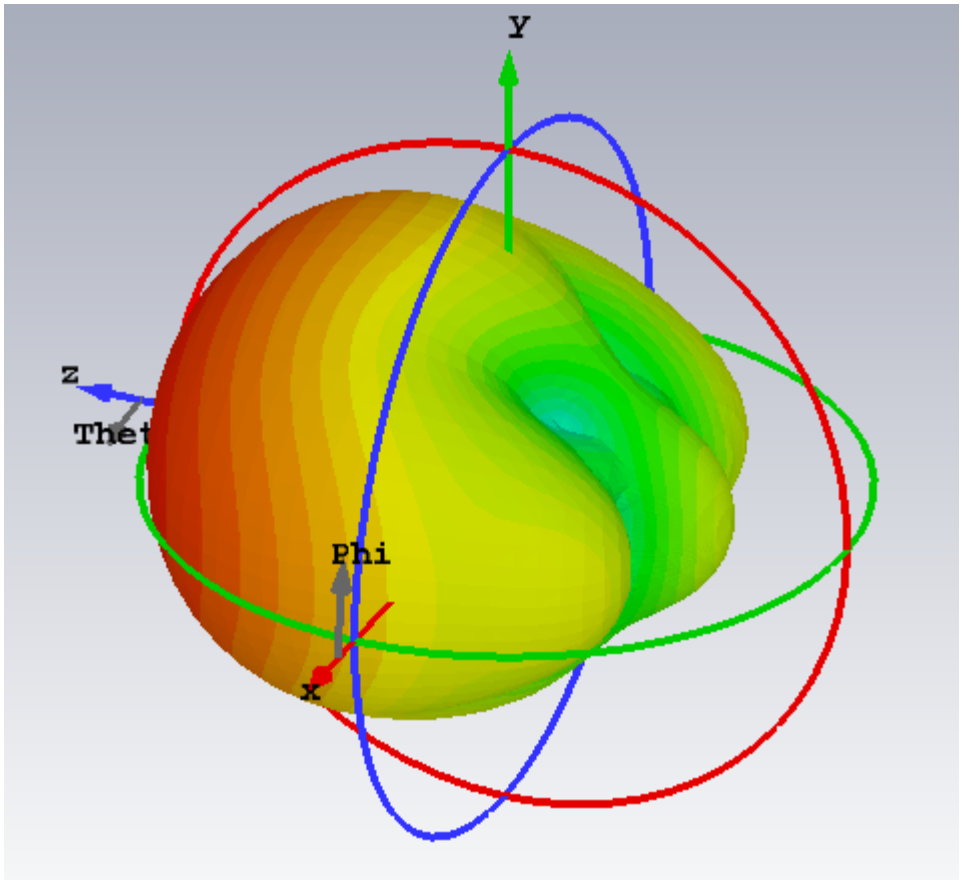
Relative bandwidth (frequency range in which |S11| is less than −10 dB)



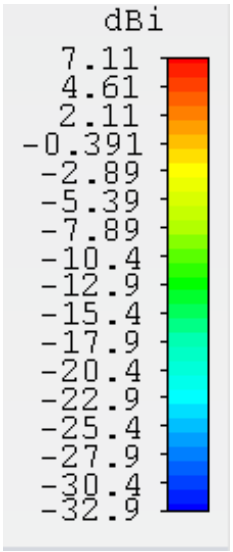
$$BW = \frac{f_{high} - f_{low}}{f_{design}} = \frac{0.037436}{3.55} * 100\% \approx 1.055\%$$

Topic1 - Part II. Data

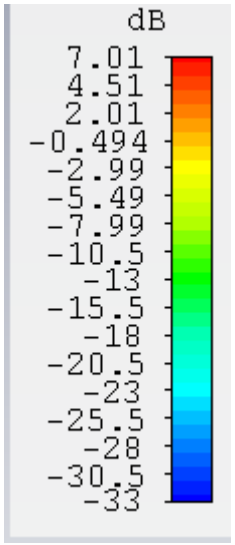
Radiation pattern(3D farfield)



Directivity



Gain



farfield (f=3.55) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-0.1030 dB
Tot. effic.	-0.1728 dB
Dir.	7.109 dBi

farfield (f=3.55) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-0.1030 dB
Tot. effic.	-0.1728 dB
Gain	7.006 dB

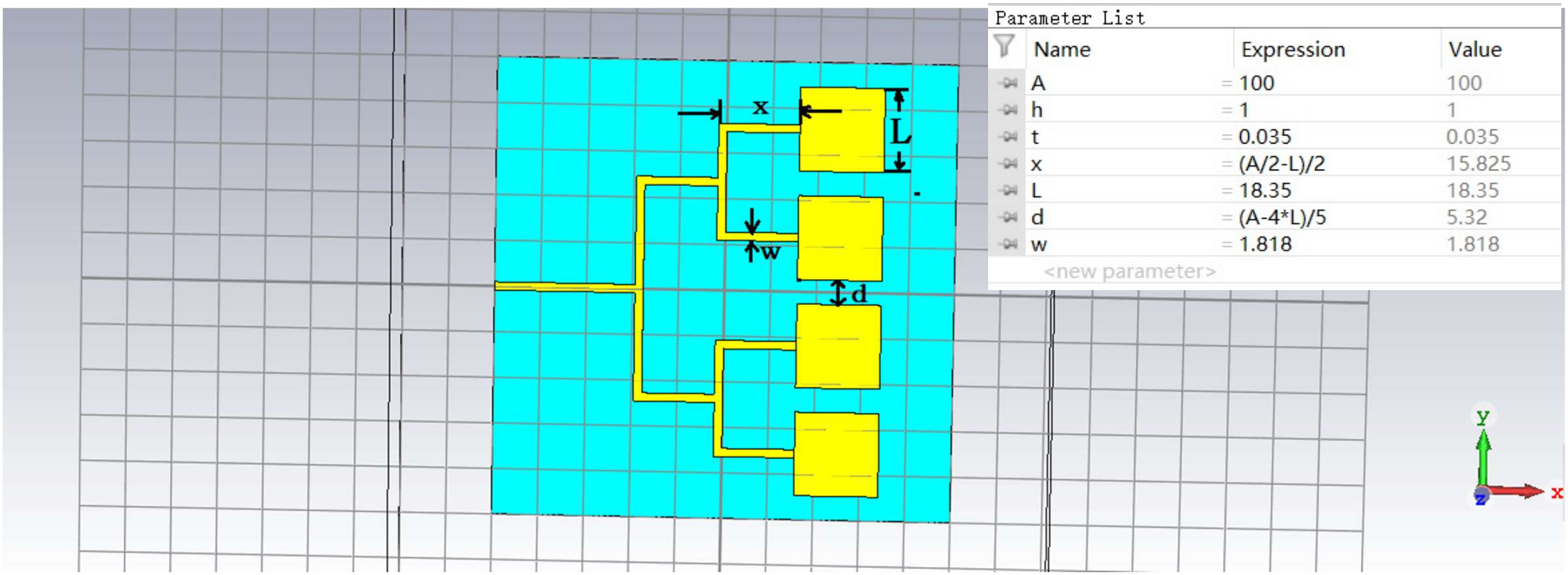
Radiation efficiency:-0.1030 dB

Total efficiency:-0.1728 dB

Topic2 - Part I. Objective

- Gain basic knowledge of patch antenna array
- Design two patch antenna arrays working at **3.55Ghz**
- Microstrip line feed method & probe feed method

Topic2 - Part II. Data(Microstrip Line Feed)



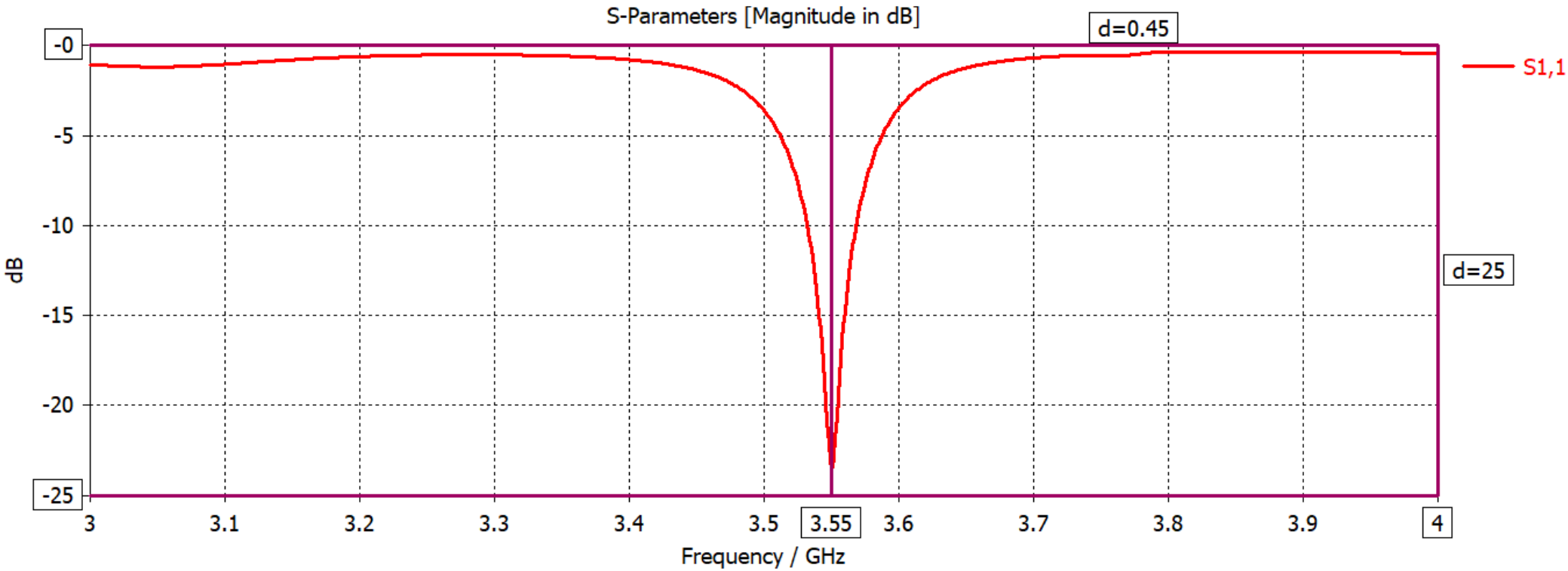
Parameter List

Name	Expression	Value
A	= 100	100
h	= 1	1
t	= 0.035	0.035
x	= (A/2-L)/2	15.825
L	= 18.35	18.35
d	= (A-4*L)/5	5.32
w	= 1.818	1.818
<new parameter>		

Simulated chart & Parameters

Topic2 - Part II. Data(Microstrip Line Feed)

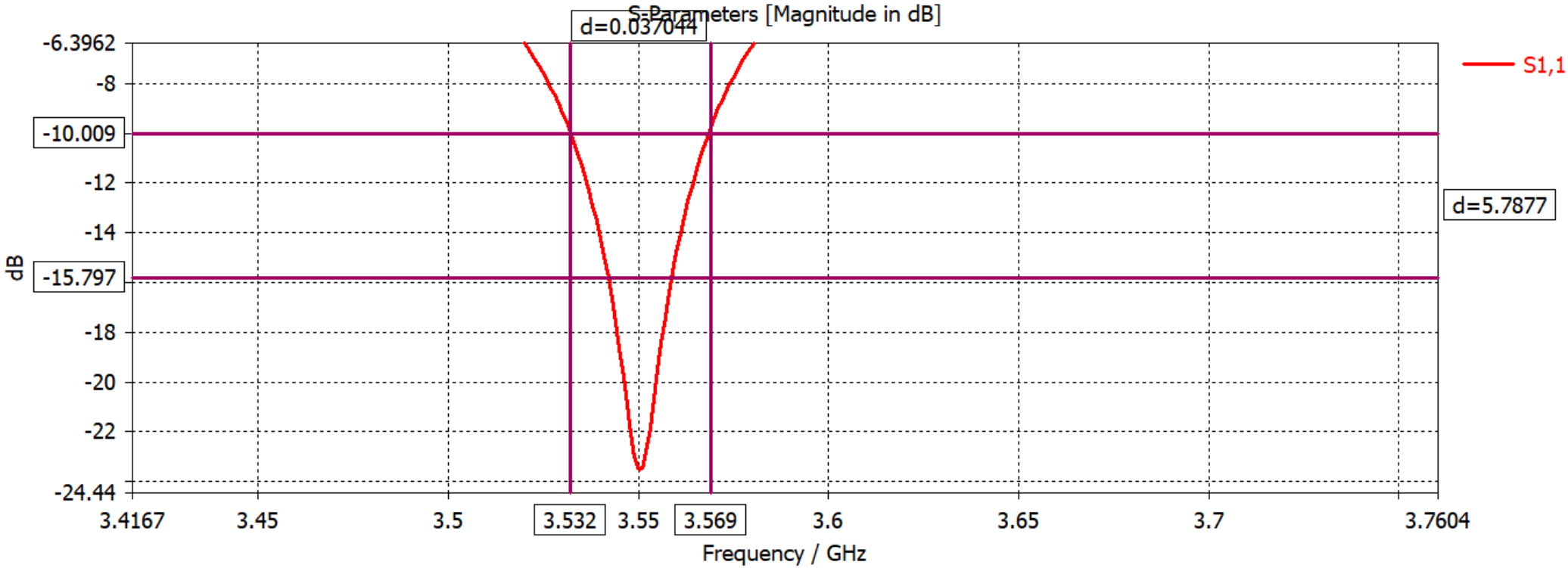
S-Parameters



By observing the position of the cursor, we can get that the working frequency is about 3.55GHz.

Topic2 - Part II. Data(Microstrip Line Feed)

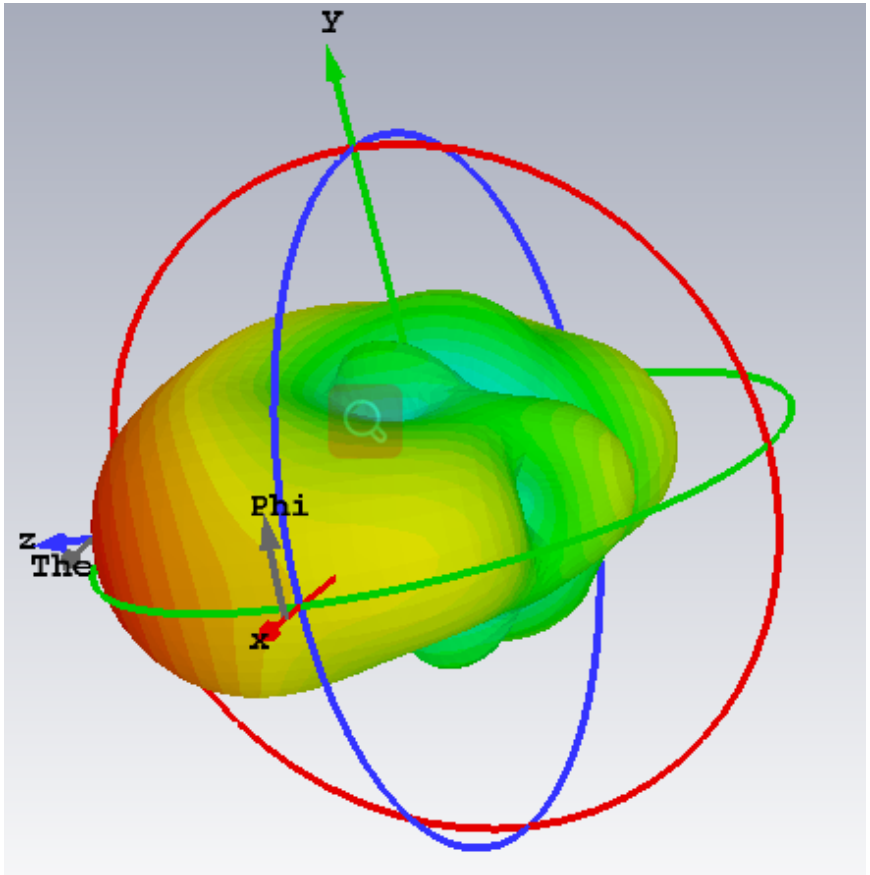
Relative bandwidth (frequency range in which |S11| is less than −10 dB)



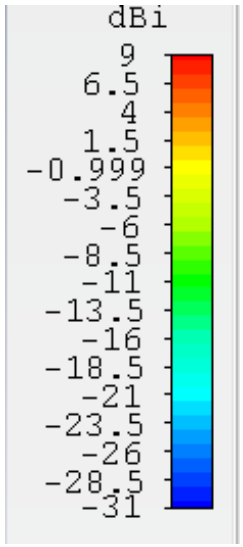
$$BW = \frac{f_{high} - f_{low}}{f_{design}} = \frac{0.037044}{3.55} * 100\% \approx 1.043\%$$

Topic2 - Part II. Data(Microstrip Line Feed)

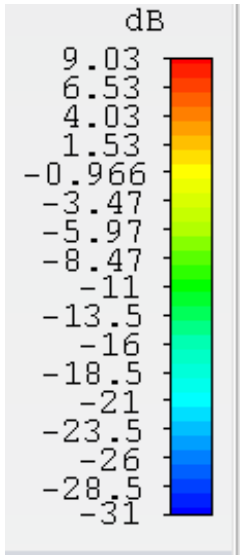
Radiation pattern(3D farfield)



Directivity



Gain



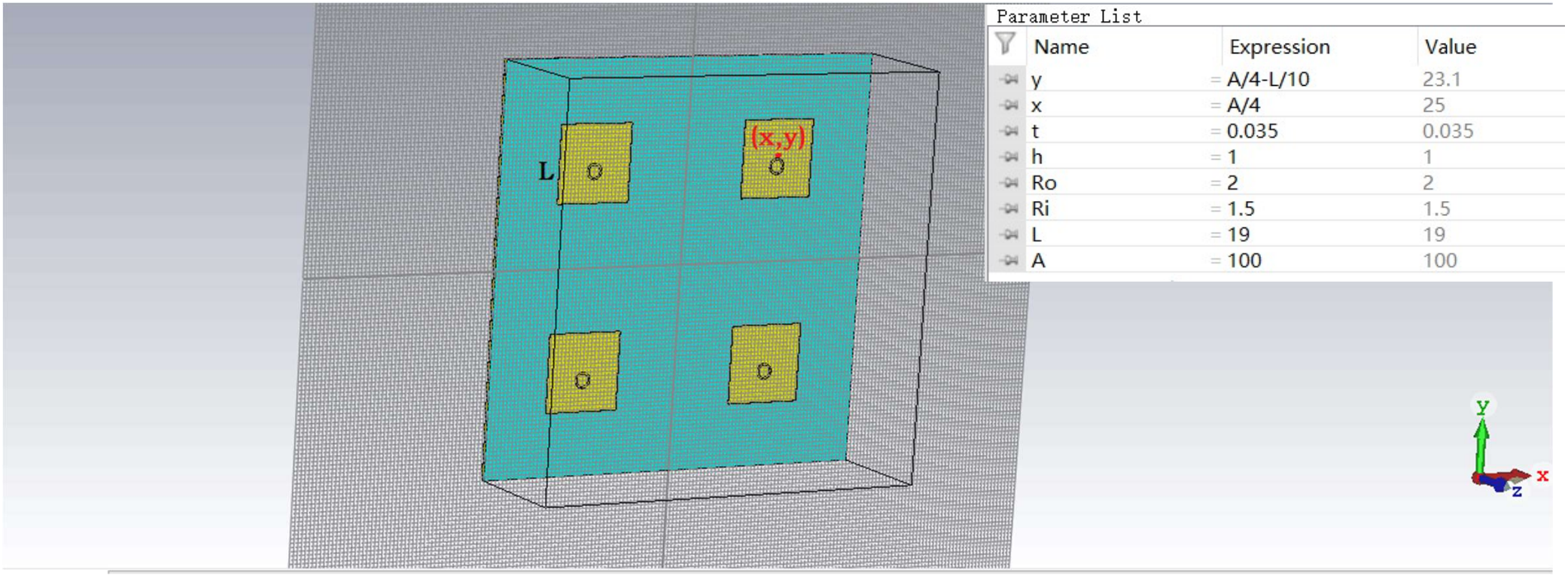
farfield (f=3.55) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	0.03227 dB
Tot. effic.	0.01295 dB
Dir.	9.001 dBi

farfield (f=3.55) [1]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	0.03227 dB
Tot. effic.	0.01295 dB
Gain	9.034 dB

Radiation efficiency:-0.03227 dB

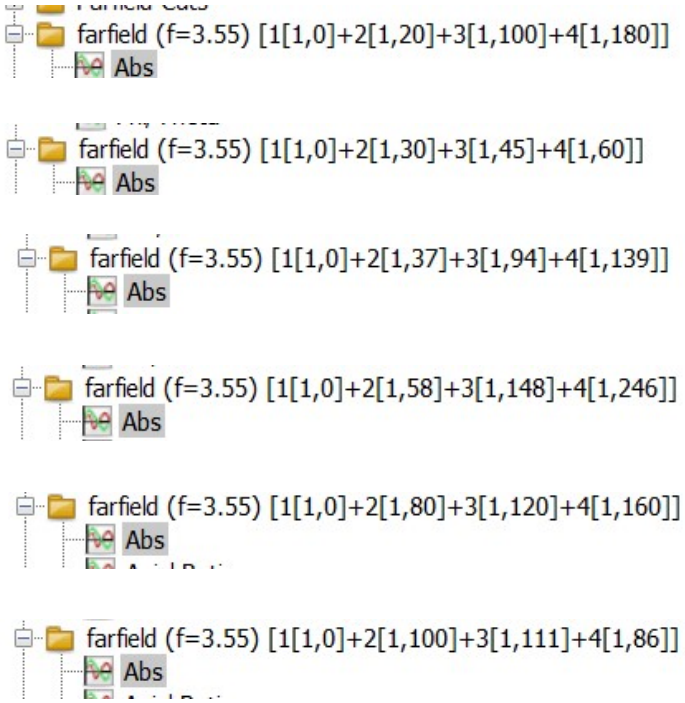
Total efficiency:-0.01295 dB

Topic2 - Part II. Data(Probe Feed)



Simulated chart & Parameters

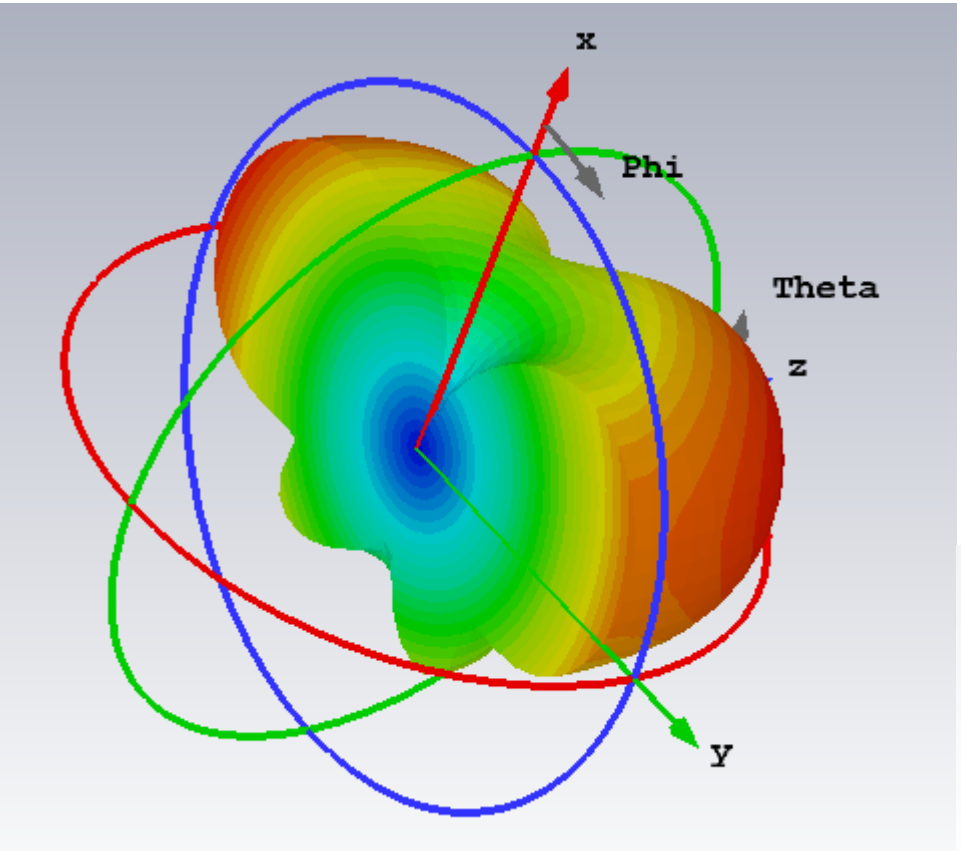
Topic2 - Part II. Data(Probe Feed)



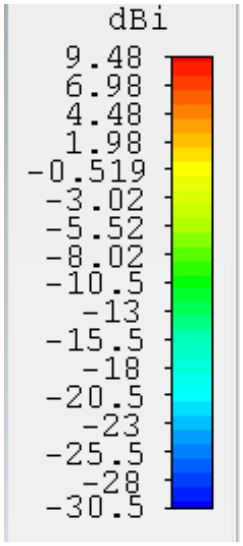
	Amp	Phase1	Phase2	Phase3	Phase4
Ang1	1	0	20	100	180
Ang2	1	0	30	45	60
Ang3	1	0	37	94	139
Ang4	1	0	58	148	246
Ang5	1	0	80	120	160
Ang6	1	0	100	111	86

Topic2 - Part II. Data(Probe Feed)

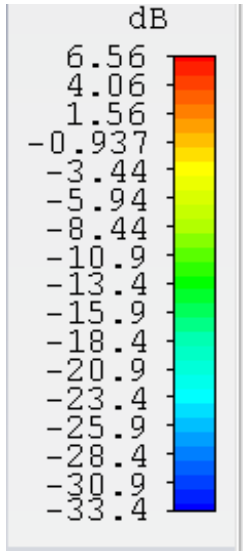
Ang1. Radiation pattern(3D farfield)



Directivity



Gain

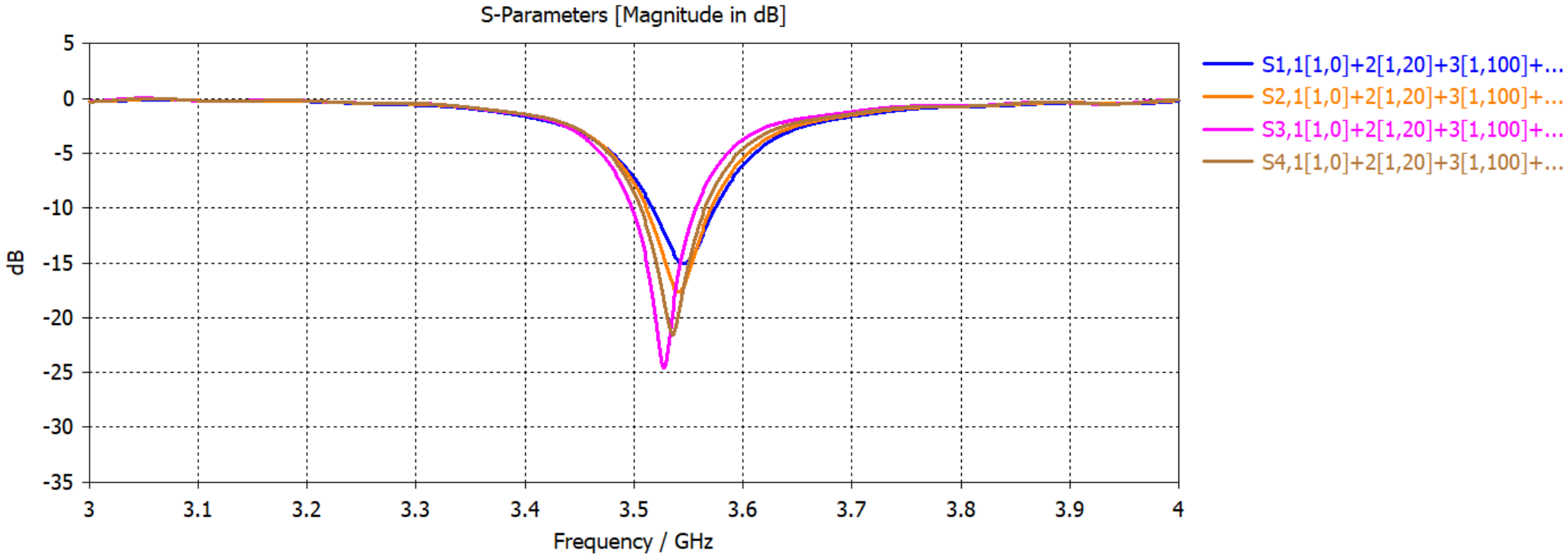


farfield (f=3.55) [1…]+3[1,1		farfield (f=3.55) [1…]+3[1,100]+4[1,180]]	
Type	Farfield	Type	Farfield
Approximation	enabled (kR >> 1)	Approximation	enabled (kR >> 1)
Component	Abs	Component	Abs
Output	Directivity	Output	Gain
Frequency	3.55 GHz	Frequency	3.55 GHz
Rad. effic.	-2.918 dB	Rad. effic.	-2.918 dB
Tot. effic.	-3.084 dB	Tot. effic.	-3.084 dB
Dir.	9.481 dBi	Gain	6.563 dB

Radiation efficiency:-2.918 dB

Total efficiency:-3.084 dB

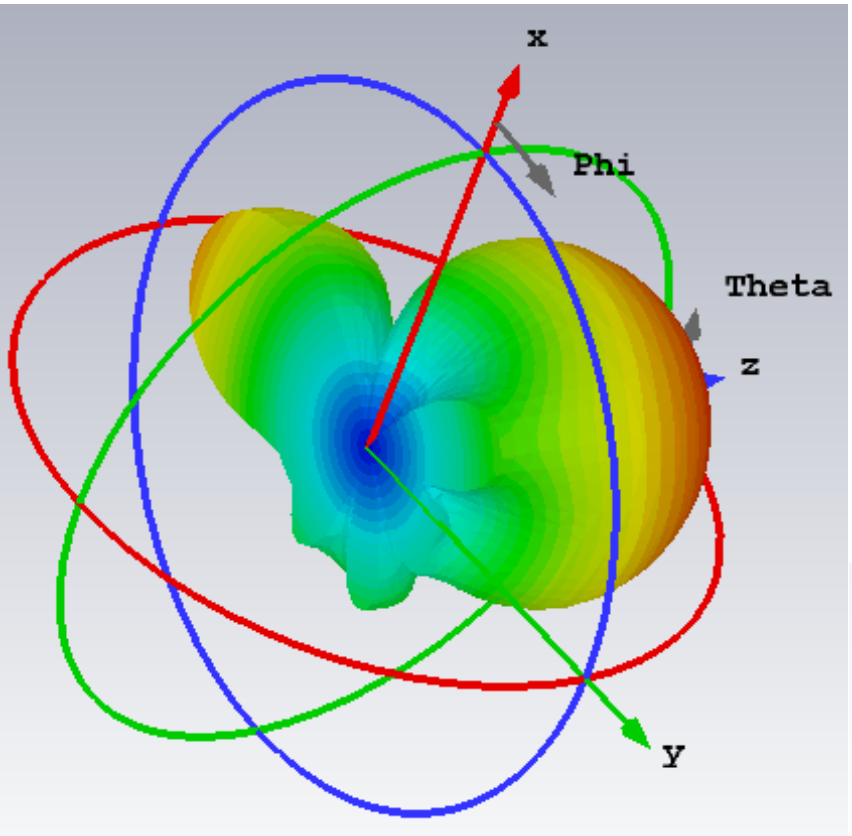
Topic2 - Part II. Data(Probe Feed)



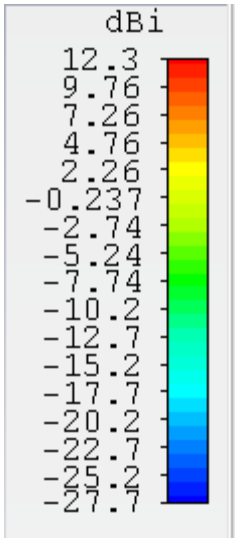
Ang1. S-parameters

Topic2 - Part II. Data(Probe Feed)

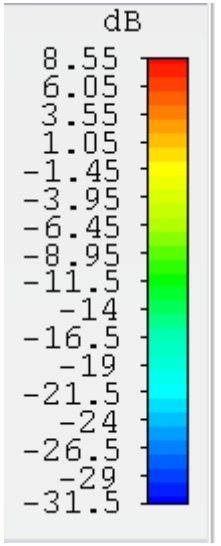
Ang2. Radiation pattern(3D farfield)



Directivity



Gain



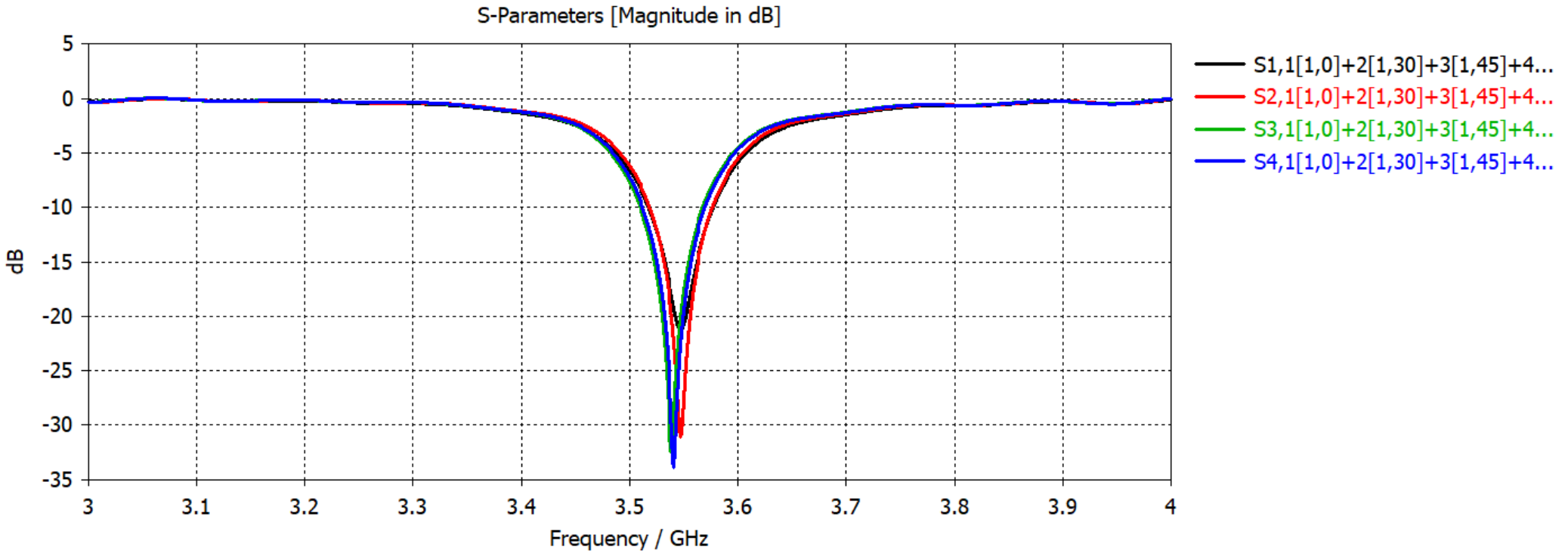
farfield (f=3.55) [1···30]+3[1, 45]+4	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-3.717 dB
Tot. effic.	-3.758 dB
Dir.	12.26 dBi

farfield (f=3.55) [1···30]+3[1, 45]+4[1, 60]]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-3.717 dB
Tot. effic.	-3.758 dB
Gain	8.547 dB

Radiation efficiency:-3.717 dB

Total efficiency:-3.758 dB

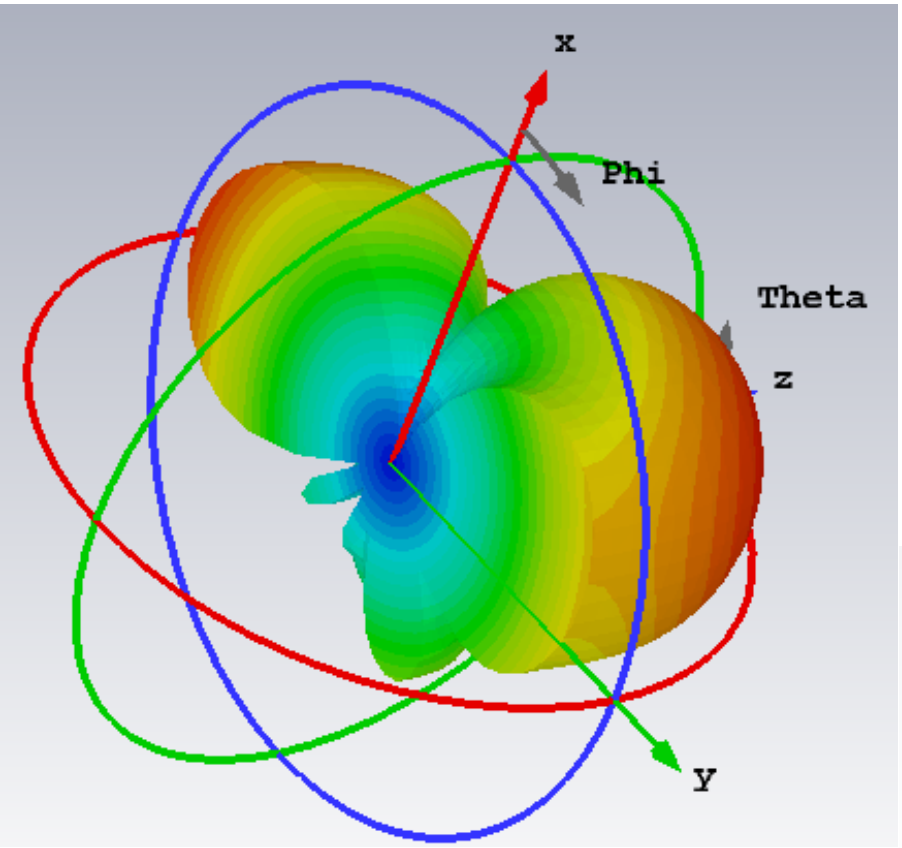
Topic2 - Part II. Data(Probe Feed)



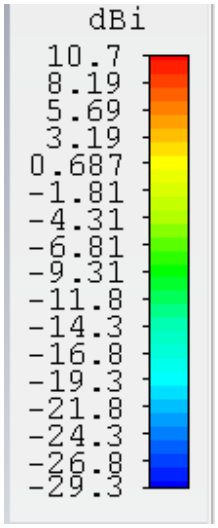
Ang2. S-parameters

Topic2 - Part II. Data(Probe Feed)

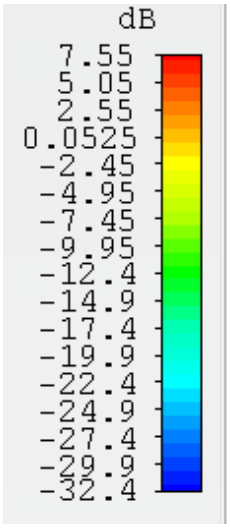
Ang3. Radiation pattern(3D farfield)



Directivity



Gain



farfield (f=3.55) [1…7]+3[1, 94]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-3.134 dB
Tot. effic.	-3.259 dB
Dir.	10.69 dBi

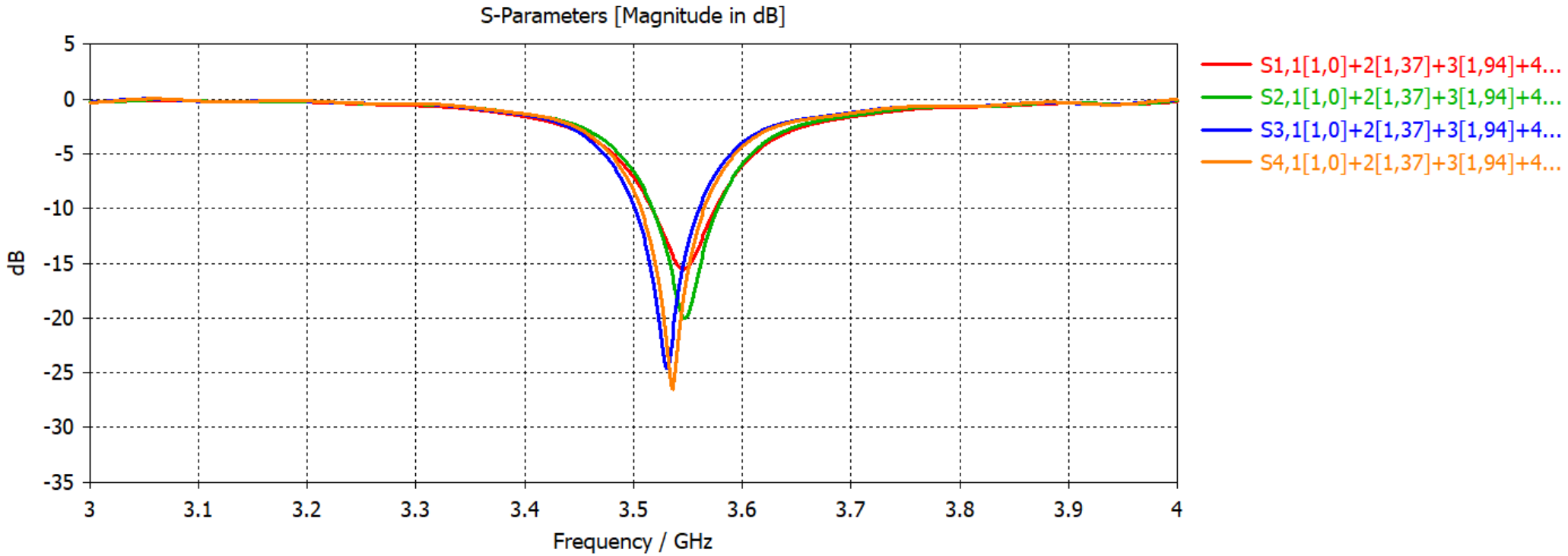
farfield (f=3.55) [1…7]+3[1, 94]+4[1, 139]]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-3.134 dB
Tot. effic.	-3.259 dB
Gain	7.553 dB

Radiation efficiency:-3.134 dB

Total efficiency:-3.259 dB

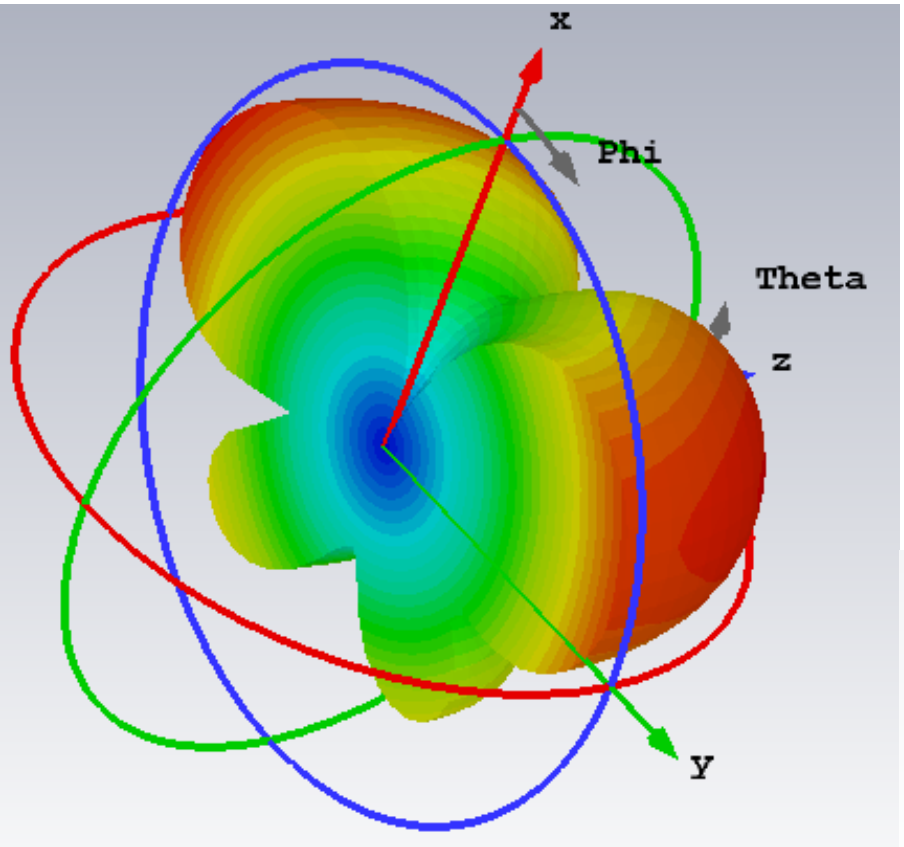
Topic2 - Part II. Data(Probe Feed)



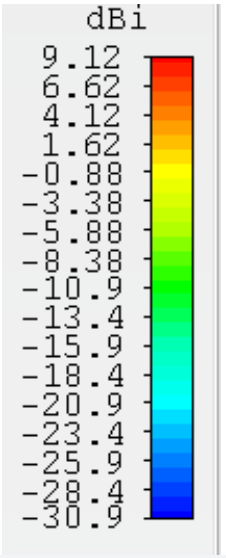
Ang3. S-parameters

Topic2 - Part II. Data(Probe Feed)

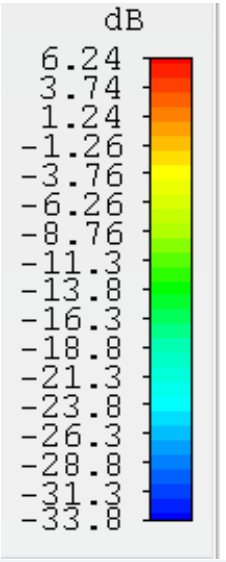
Ang4. Radiation pattern(3D farfield)



Directivity



Gain



farfield (f=3.55) [1…]+3[1, 148]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-2.882 dB
Tot. effic.	-3.090 dB
Dir.	9.120 dBi

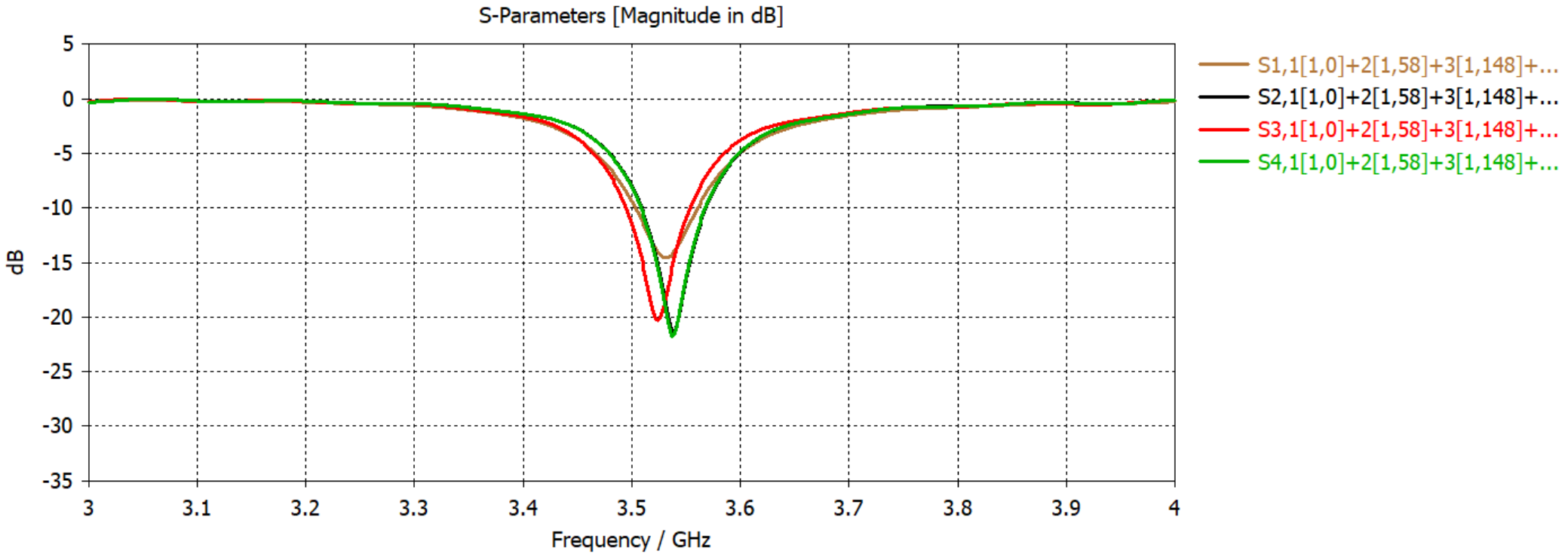
farfield (f=3.55) [1…]+3[1, 148]+4[1, 246]]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-2.882 dB
Tot. effic.	-3.090 dB
Gain	6.238 dB

Radiation efficiency:-2.882 dB

Total efficiency:-3.090 dB

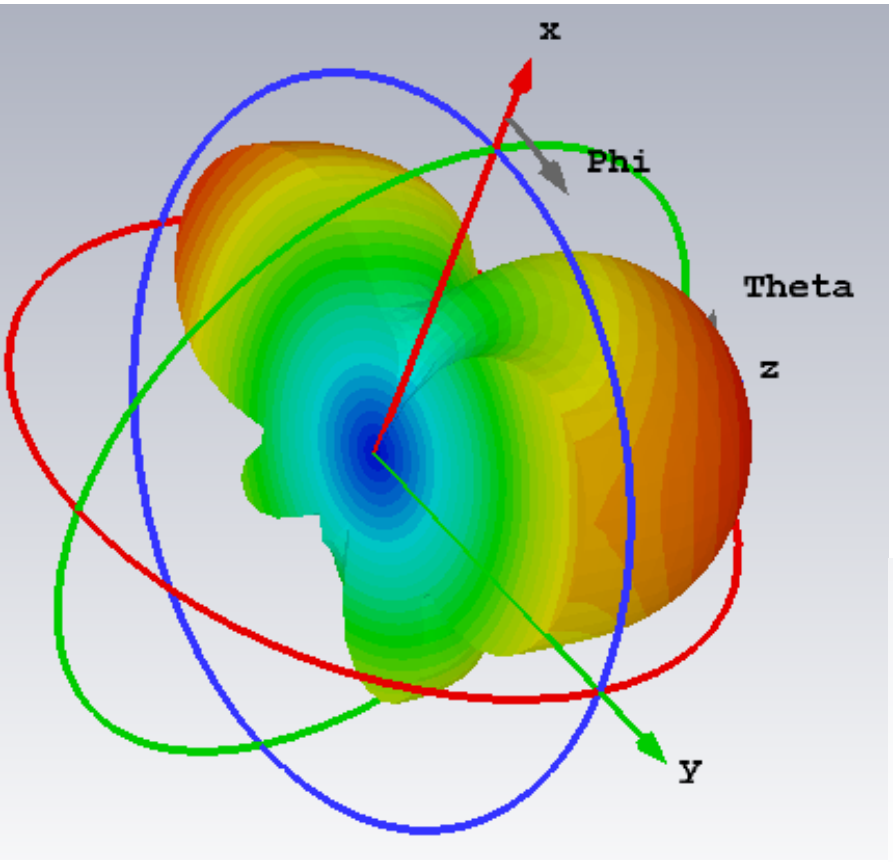
Topic2 - Part II. Data(Probe Feed)



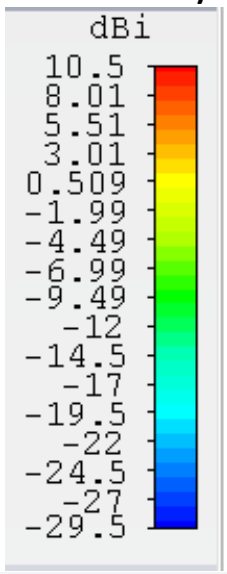
Ang4. S-parameters

Topic2 - Part II. Data(Probe Feed)

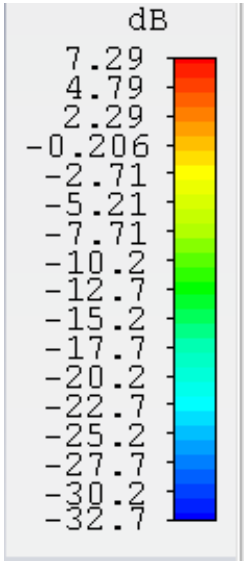
Ang5. Radiation pattern(3D farfield)



Directivity



Gain



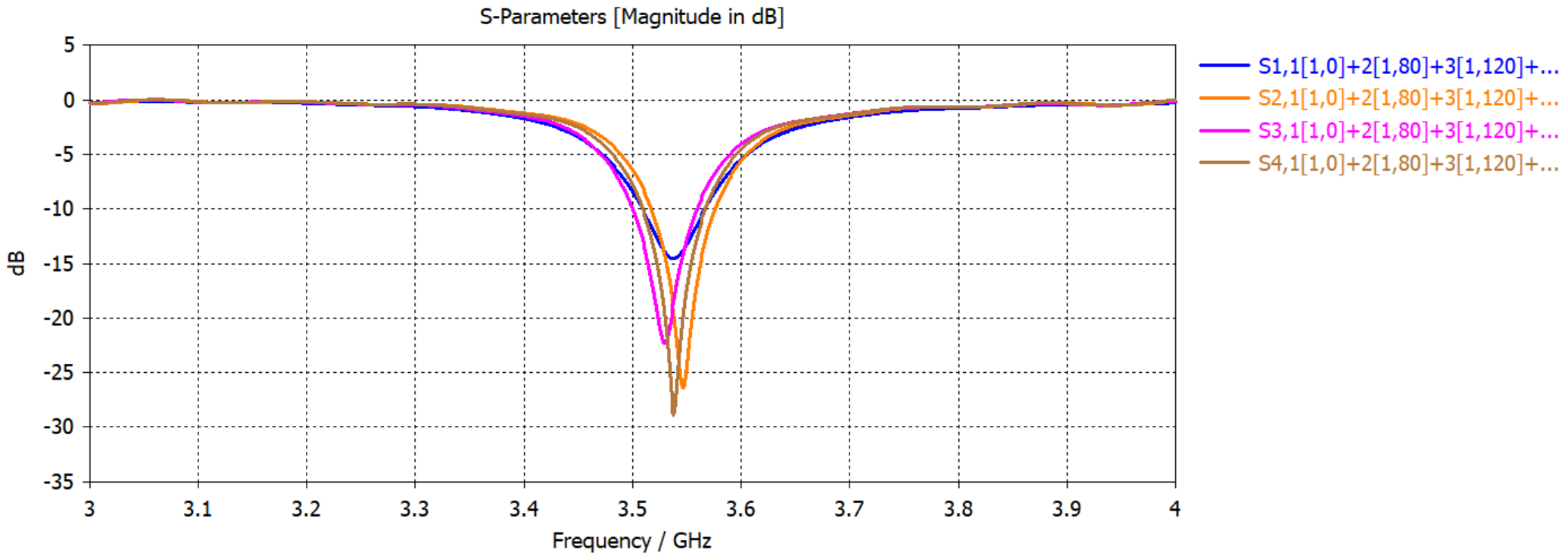
farfield (f=3.55) [1…]+3[1, 120]+	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-3.215 dB
Tot. effic.	-3.350 dB
Dir.	10.51 dBi

farfield (f=3.55) [1…]+3[1, 120]+4[1, 160]]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-3.215 dB
Tot. effic.	-3.350 dB
Gain	7.294 dB

Radiation efficiency:-3.215 dB

Total efficiency:-3.350 dB

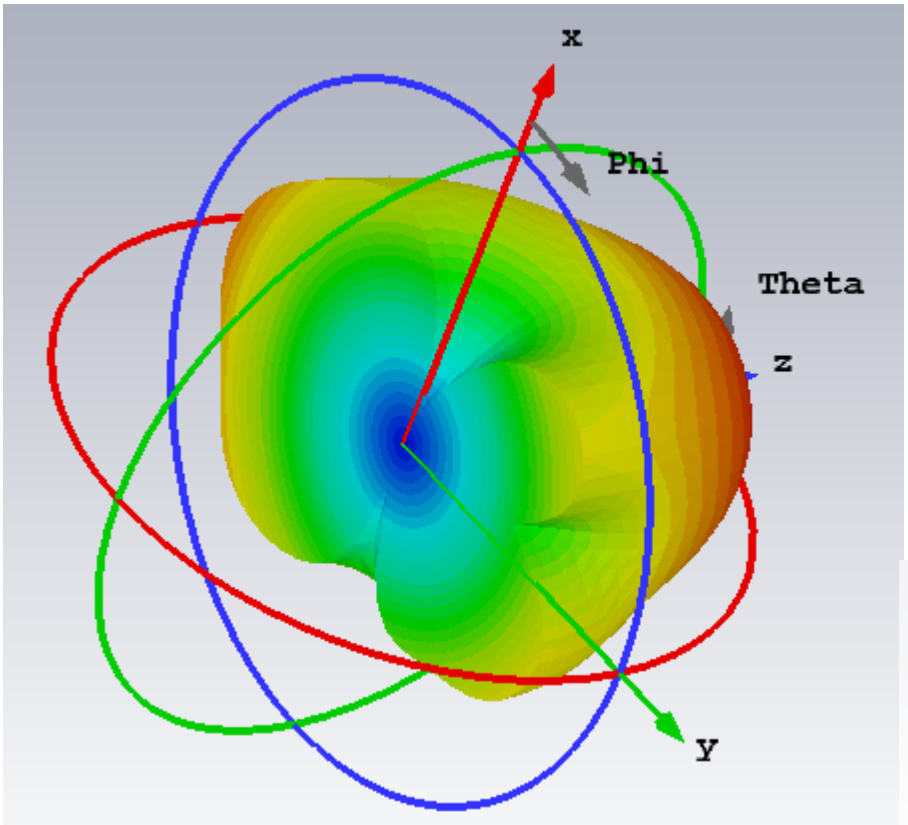
Topic2 - Part II. Data(Probe Feed)



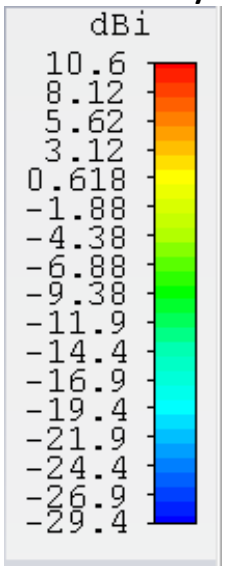
Ang5. S-parameters

Topic2 - Part II. Data(Probe Feed)

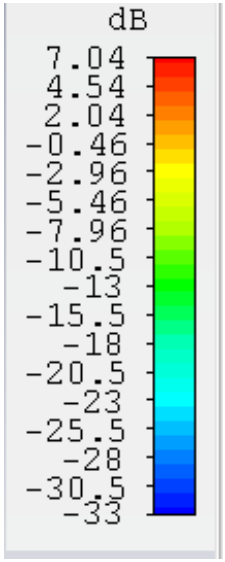
Ang6. Radiation pattern(3D farfield)



Directivity



Gain



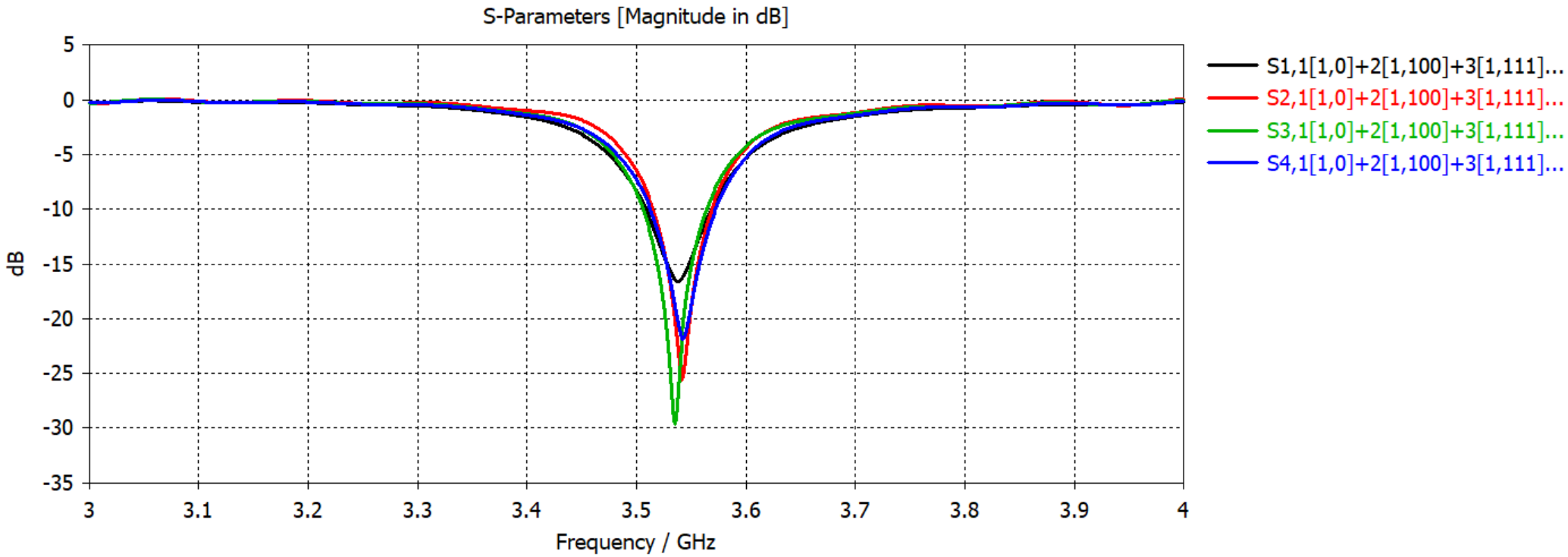
farfield (f=3.55) [1…0]+3[1,111	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	3.55 GHz
Rad. effic.	-3.578 dB
Tot. effic.	-3.675 dB
Dir.	10.62 dBi

farfield (f=3.55) [1…0]+3[1,111]+4[1,86]]	
Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Gain
Frequency	3.55 GHz
Rad. effic.	-3.578 dB
Tot. effic.	-3.675 dB
Gain	7.040 dB

Radiation efficiency:-3.578 dB

Total efficiency:-3.675 dB

Topic2 - Part II. Data(Probe Feed)



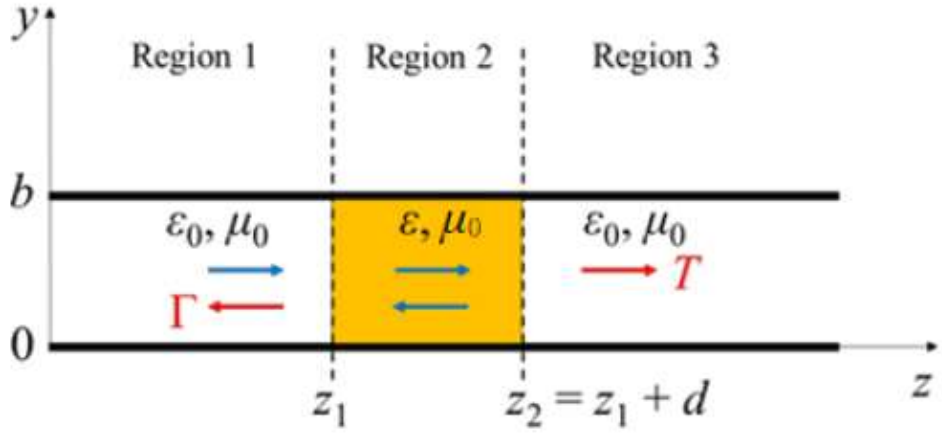
Ang6. S-parameters

Topic5 - Part I. Objective

- Use rectangular waveguide to measure dielectric property
- Gain knowledge of using VNA

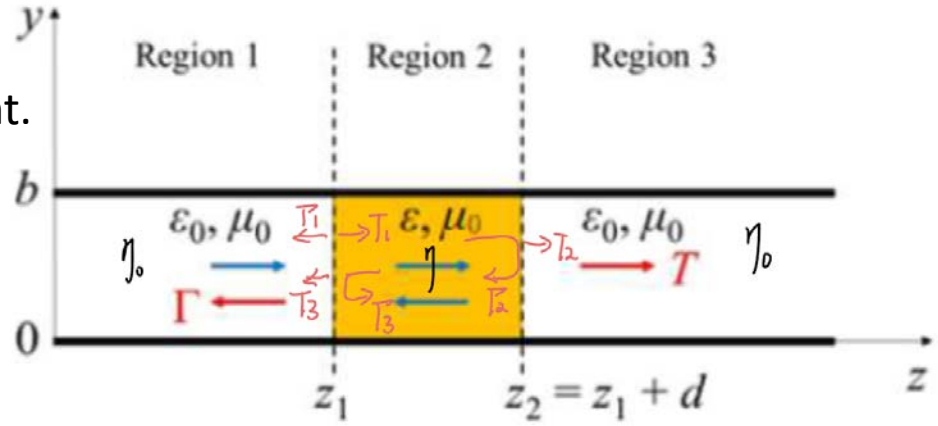
Topic5 - Part II. Data

- Parameters
  - $f = 3.95 \sim 5.85 GHz$
  - $\mathrm{WR} - 187$
  - $L * W = 47 * 22 mm$
  - $\mathrm{H} = 19.6 mm / 15.6 mm$



Topic5 - Part II. Data

Let the incident wave E=1 and z1 is the origin point.
We have



$$\Gamma = \frac{\eta_1 - \eta_2}{\eta_1 + \eta_2} e^{j\gamma z} \qquad T = \frac{2\eta_2}{\eta_1 + \eta_2}$$

Then,

$$\Gamma_1 = \frac{\eta - \eta_0}{\eta + \eta_0} = \frac{\frac{1}{\sqrt{\epsilon}} - 1}{\frac{1}{\sqrt{\epsilon}} + 1} = \frac{1 - \sqrt{\epsilon}}{1 + \sqrt{\epsilon}}$$

$$\Gamma_2 = \frac{\eta_0 - \eta}{\eta + \eta_0} e^{j\gamma d} = -\Gamma_1 e^{j\gamma d} = \Gamma_4 = \Gamma_6 = \cdots$$

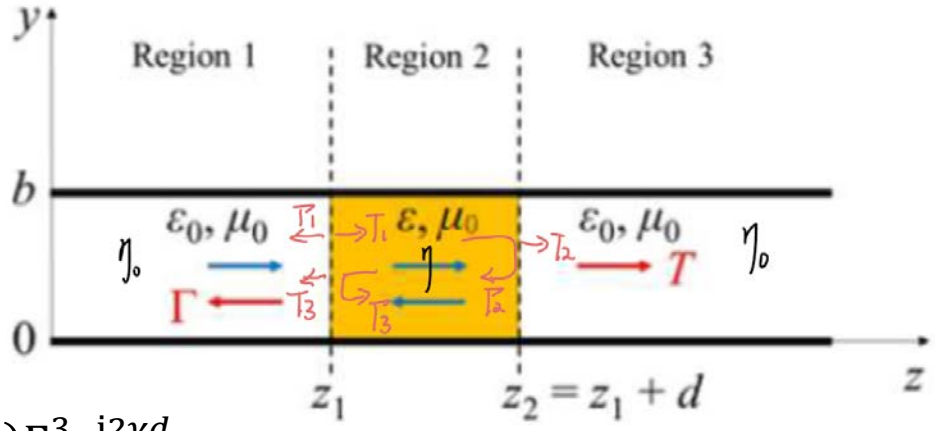
$$\Gamma_3 = \frac{\eta_0 - \eta}{\eta + \eta_0} = -\Gamma_1 = \Gamma_5 = \Gamma_7 = \cdots$$

$$\mathrm{T}_1 = \frac{2\eta}{\eta + \eta_0} = \frac{\frac{2}{\sqrt{\epsilon}}}{\frac{1}{\sqrt{\epsilon}} + 1} = \frac{2}{1 + \sqrt{\epsilon}}$$

$$\Gamma_2 = \frac{2\eta_0}{\eta + \eta_0} e^{j\gamma d} = (2 - \mathrm{T}_1) e^{j\gamma d} = \mathrm{T}_4 = \mathrm{T}_6 = \cdots$$

$$\mathrm{T}_3 = \frac{2\eta_0}{\eta + \eta_0} = (2 - \mathrm{T}_1) = \mathrm{T}_5 = \mathrm{T}_7 = \cdots$$

Topic5 - Part II. Data



At z=z1, we can get

$$
\begin{aligned}
S_{11} = \Gamma &= \Gamma_1 + \mathrm{T}_1\Gamma_2\mathrm{T}_3 + \mathrm{T}_1\Gamma_2\Gamma_3\Gamma_4\mathrm{T}_5 \\
&\quad + \mathrm{T}_1\Gamma_2\Gamma_3\Gamma_4\Gamma_5\Gamma_6\mathrm{T}_7 + \cdots\cdots \\
&= \Gamma_1 - \mathrm{T}_1(2-\mathrm{T}_1)\Gamma_1 \mathrm{e}^{\mathrm{j}\gamma d} - \mathrm{T}_1(2-\mathrm{T}_1)\Gamma_1^3 \mathrm{e}^{\mathrm{j}2\gamma d} \\
&\quad - \mathrm{T}_1(2-\mathrm{T}_1)\Gamma_1^5 \mathrm{e}^{\mathrm{j}3\gamma d} + \cdots\cdots \\
&= \Gamma_1 - \mathrm{T}_1(2-\mathrm{T}_1)(\Gamma_1 \mathrm{e}^{\mathrm{j}\gamma d} + \Gamma_1^3 \mathrm{e}^{\mathrm{j}2\gamma d} + \Gamma_1^5 \mathrm{e}^{\mathrm{j}3\gamma d} \\
&\quad + \Gamma_1^7 e^{j4\gamma d} \cdots\cdots) \\
&= \Gamma_1 - \frac{\mathrm{T}_1(2-\mathrm{T}_1)\Gamma_1 \mathrm{e}^{\mathrm{j}\gamma d}}{1 - \Gamma_1^2 e^{j\gamma d}}
\end{aligned}
$$

In the same way, we can get the expression of S_{22}, S_{12}, S_{21} .
Then substituting the measured value into the expression, we can get the ϵ

Topic5 - Part II. Data

$$S_{11} = R_1{}^2 \left[\frac{\Gamma - (1 - \mathrm{T}^2)}{1 - \Gamma^2\mathrm{T}^2}\right]$$

$$S_{22} = R_2{}^2[\frac{\Gamma - (1 - \mathrm{T}^2)}{1 - \Gamma^2\mathrm{T}^2}]$$

$$S_{21} = R_1 R_2{}^2[\frac{\mathrm{T} - (1 - \Gamma^2)}{1 - \Gamma^2\mathrm{T}^2}]$$

$$R_i = e^{-\gamma_0 L_i}$$

$$\mathrm{T} = e^{-\gamma D}$$

$$\Gamma = \frac{\gamma_0/\mu_0 - \gamma/\mu}{\gamma_0/\mu_0 + \gamma/\mu}$$

Topic5 - Part II. Data

$$S_1 = S_{11} + S_{21}$$
$$S_2 = S_{21} - S_{11}$$
$$X = \frac{1 - S_1 S_2}{S_1 - S_2}$$

$$\Gamma = X \pm \sqrt{X^2 - 1} \quad (|\Gamma| \leq 1)$$
$$\mathrm{T} = \frac{(S_{11} + S_{21}) - \Gamma}{1 - (S_{11} + S_{21})\Gamma}$$

$$\mu_r{}^2 = \left(\frac{1+\Gamma}{1-\Gamma}\right)^2 \left(\frac{1}{\lambda_0{}^2}\mu r \varepsilon r - \frac{1}{\lambda c^2}\right) / \left(\frac{1}{\lambda_0{}^2} - \frac{1}{\lambda c^2}\right)$$

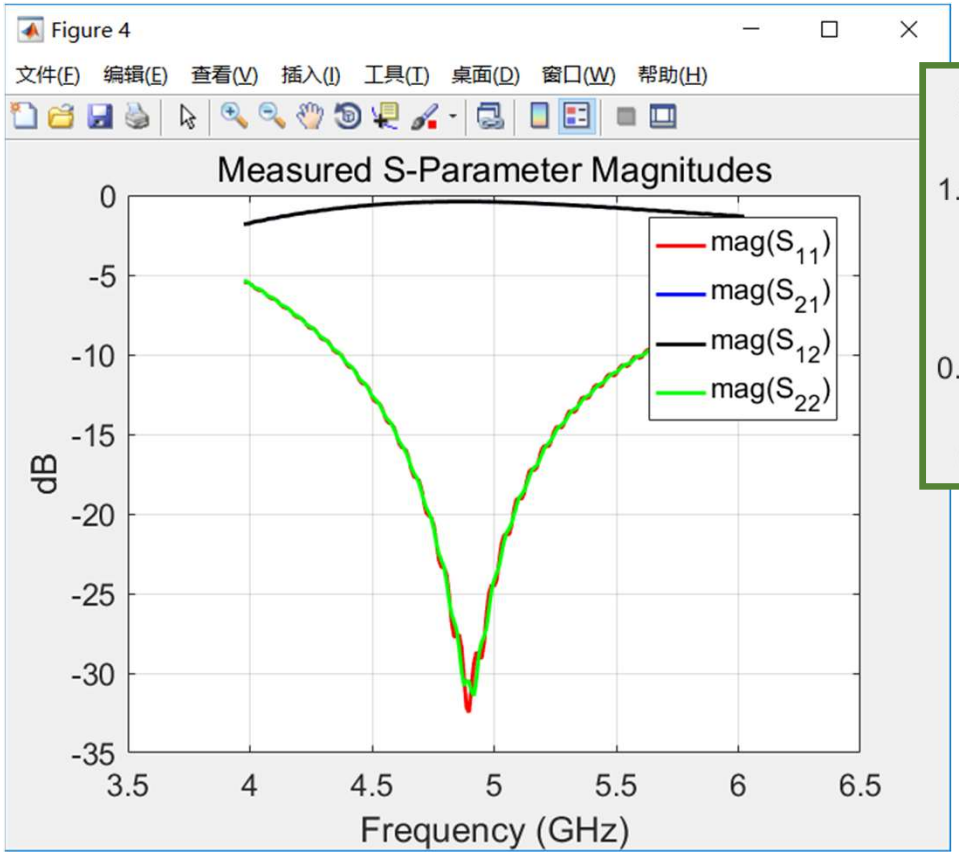
$$\frac{1}{\Lambda^2} = \frac{1}{\lambda_0{}^2}\mu_r \varepsilon_r - \frac{1}{\lambda c^2} = -\left\{\frac{1}{2\pi D}\ln\left(\frac{1}{T}\right)\right\}^2$$

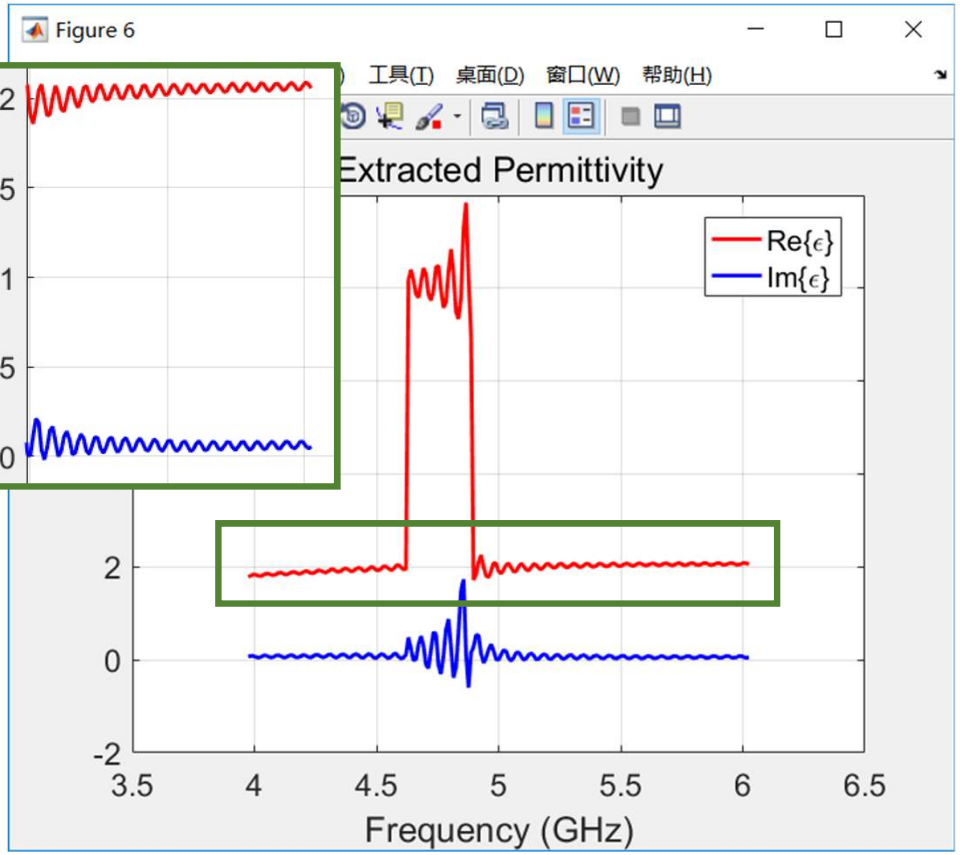
$$\mu_r = \left(\frac{1+\Gamma}{1-\Gamma}\right)\frac{1}{\Lambda}\frac{1}{\sqrt{\frac{1}{\lambda_0{}^2} - \frac{1}{\lambda c^2}}}$$

$$\varepsilon_r = \left(\frac{1}{\Lambda^2} + \frac{1}{\lambda c^2}\right)\lambda_0{}^2/\mu_r$$

Topic5 - Part II. Data

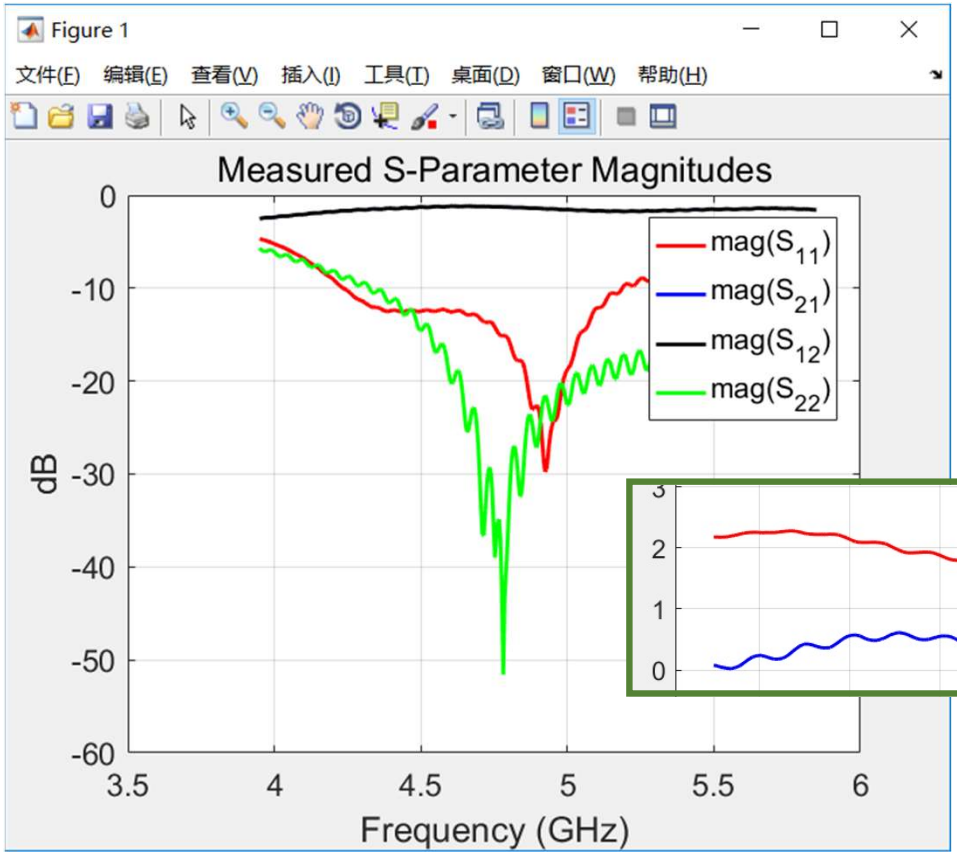
Data A(All, H=19.6mm) **(We've tried many times, here we will show the best two of them.)**

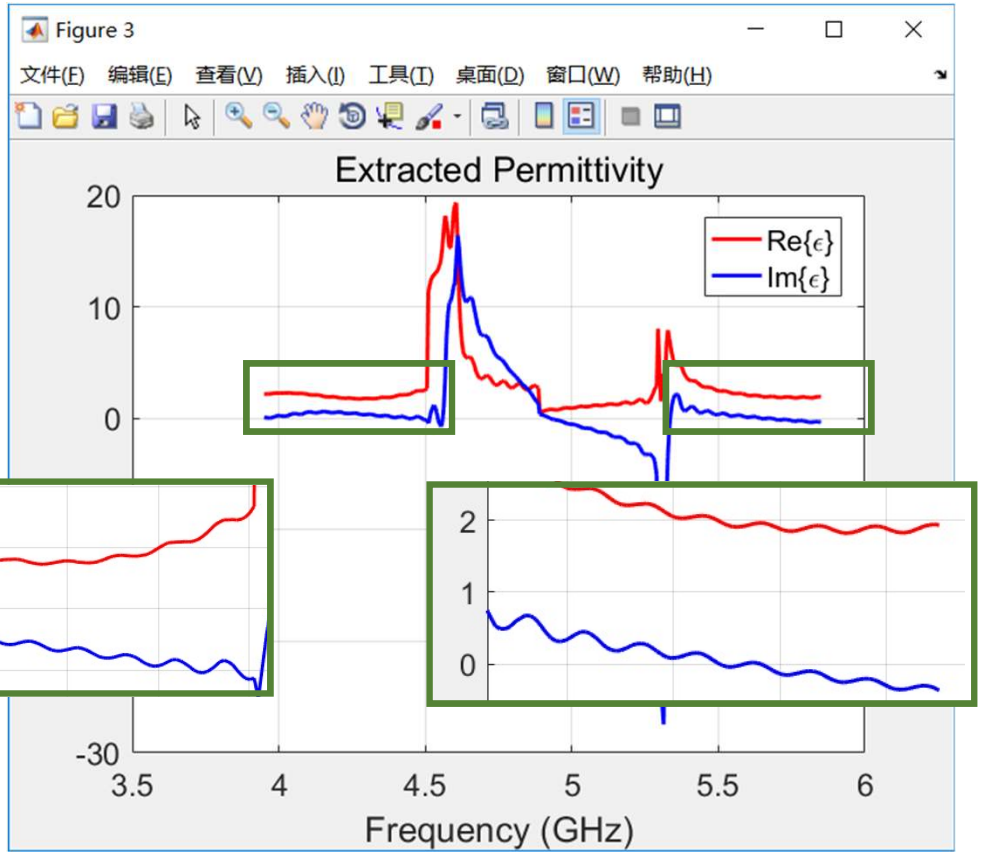




Topic5 - Part II. Data

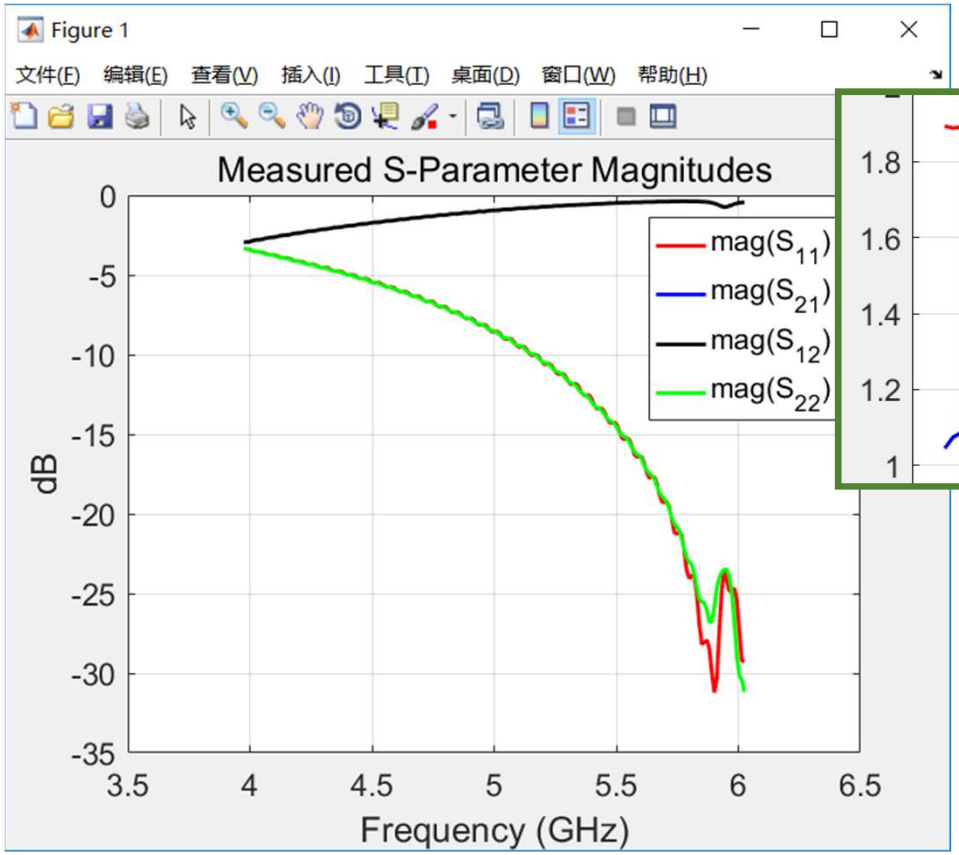
Data B(All, H=19.6mm) **(We've tried many times, here we will show the best two of them.)**

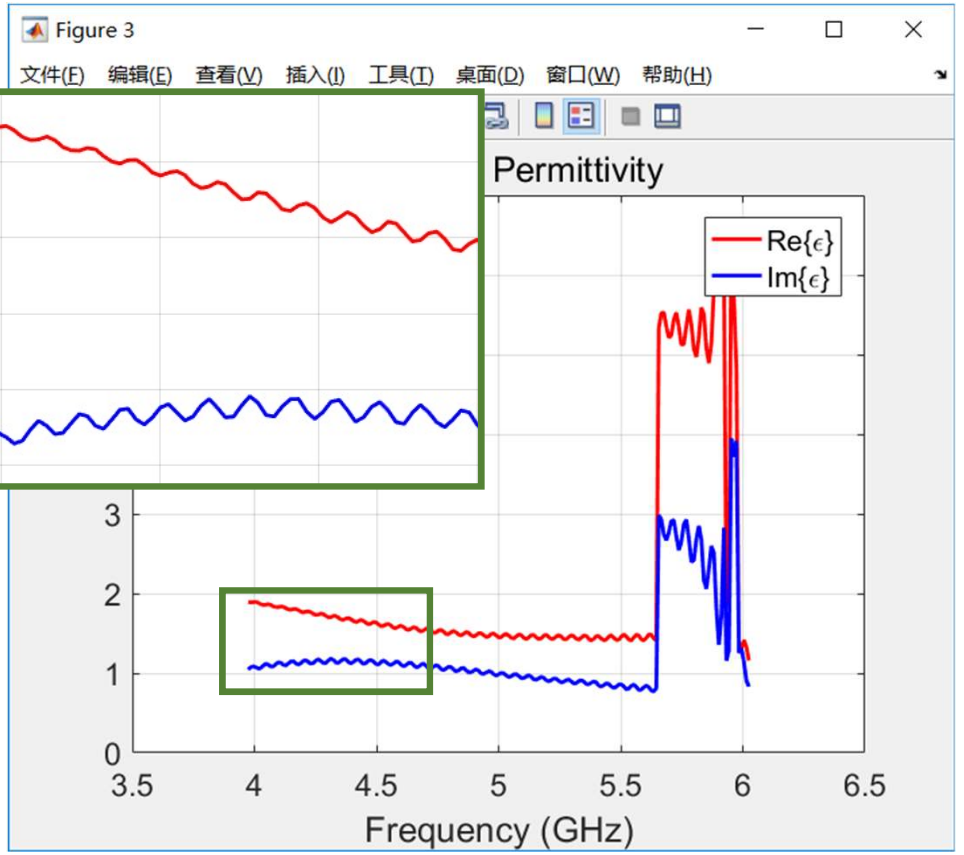




Topic5 - Part II. Data

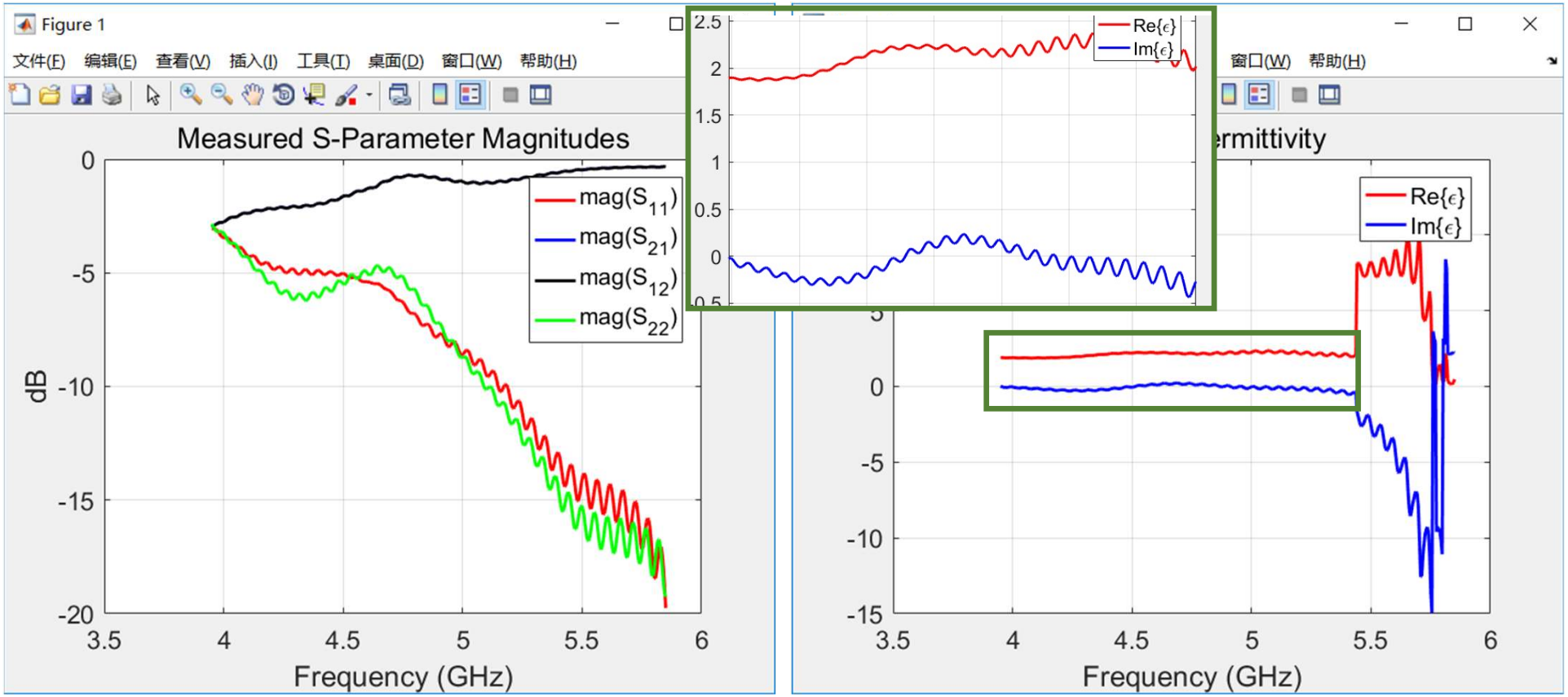
Data A(Half, H=15.6mm) **(We've tried many times, here we will show the best two of them.)**





Topic5 - Part II. Data

Data B(Half, H=15.6mm) **(We've tried many times, here we will show the best two of them.)**



Topic5 - Part II. Data

According to above, the extracted permittivity is about 1.9~2.5.

The relavant codes, images and data can be view at

https://github.com/Mine4ever/Electromagnetics-Project.git