Western New England University
College of Engineering
ECE Department
Microwave Engineering
EE 414
Spring 2024
Design Project #3
Due: April 17, 2024

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References: ____

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Design Project #3

	Score	Max
Lumped Element Design		200
MATLAB LE Simulation		100
WG Iris Design		500
WG Iris (HFSS – V1)		200
WG Iris (HFSS – V2)		100
Summary Graphs		100
Table 1		100
Table 2		100
Presentation		200
Total		1600

1. Design a lumped element bandpass filter that meets the following performance specifications:
   - $f_0 = 22$ GHz .
   - $BW_f = 1$ GHz .
   - $RL \geq 26$ dB for $f_L \leq f \leq f_H$.
   - $IL \geq 20$ dB for $f \leq f_{Ls}$ where $f_{Ls} = 21$ GHz .
   - $IL \geq 35$ dB for $f \geq f_{Hs}$ where $f \geq f_{Hs} = 23.4$ GHz .
   - The source and load impedances of the filter are $Z_0 = Z_0(f_0)$ (waveguide impedance). Assume that the waveguide is a WR42 waveguide ($a = 10.6680$ mm , $b = 4.3180$ mm , and $t_w = 1.0160$ mm).

2. Using MATLAB and ideal lumped elements, simulate the BPF. Employ a frequency range of 20.5 GHz to 23.5 GHz.
   - On the same graph, plot $|S_{11}|$ in dB and $|S_{21}|$ in dB. Employ a frequency range of 20.5 GHz to 23.5 GHz and a range of -40 dB to 0 dB for $|S_{k1}|$.
   - Plot $|S_{21}|$ in dB. Employ a frequency range of 21.4 GHz to 22.6 GHz and a range of -0.02 dB to 0 dB for $|S_{21}|$.

3. Convert the BPF into a waveguide inductive iris BPF. Assume that the waveguide is a WR42 waveguide ($a = 10.6680$ mm , $b = 4.3180$ mm , and $t_w = 1.0160$ mm) and assume that each iris has a thickness of 1 mm ($t = 1$ mm). For each impedance inverter, determine a value for K/Z_0 , X_p/Z_0 , X_s/Z_0 , ψ , ϕ , and a_g . For each resonator, determine a value for d and θ .

4. Using HFSS, simulate the waveguide inductive iris BPF. Employ a frequency range of 20.5 GHz to 23.5 GHz. In addition, assume that all metallic elements are perfect electric conductors.
   - On the same graph, plot $|S_{11}|$ in dB and $|S_{21}|$ in dB. Employ a frequency range of 20.5 GHz to 23.5 GHz and a range of -40 dB to 0 dB for $|S_{k1}|$.
   - Plot $|S_{21}|$ in dB. Employ a frequency range of 21.4 GHz to 22.6 GHz and a range of -0.02 dB to 0 dB for $|S_{21}|$.

5. Using HFSS, simulate the waveguide inductive iris BPF with conductor loss. Employ a frequency range of 20.5 GHz to 23.5 GHz. In addition, assume that all metallic elements are copper.
   - On the same graph, plot $|S_{11}|$ in dB and $|S_{21}|$ in dB. Employ a frequency range of 20.5 GHz to 23.5 GHz and a range of -40 dB to 0 dB for $|S_{k1}|$.
   - Plot $|S_{21}|$ in dB. Employ a frequency range of 21.4 GHz to 22.6 GHz and a range of -0.25 dB to 0 dB for $|S_{21}|$.

6. Summarize the results for the lumped element BPF (MATLAB), the waveguide inductive iris BPF (HFSS), and the waveguide inductive iris BPF with conductor loss.
   - On the same graph, plot $|S_{21}|$ in dB, for the three cases. Employ a frequency range of 20.5 GHz to 23.5 GHz and a range of -40 dB to 0 dB for $|S_{21}|$.
   - On the same graph, plot $|S_{21}|$ in dB, for the three cases. Employ a of frequency range 21.4 GHz to 22.6 GHz and a range of -0.25 dB to 0 dB for $|S_{21}|$.
   - On the same graph, plot $|S_{11}|$ in dB, for the three cases. Employ a frequency range of 21.4 GHz to 22.6 GHz and a range of -40 dB to 0 dB for $|S_{11}|$.

7. Complete Table 1.

8. Complete Table 2.

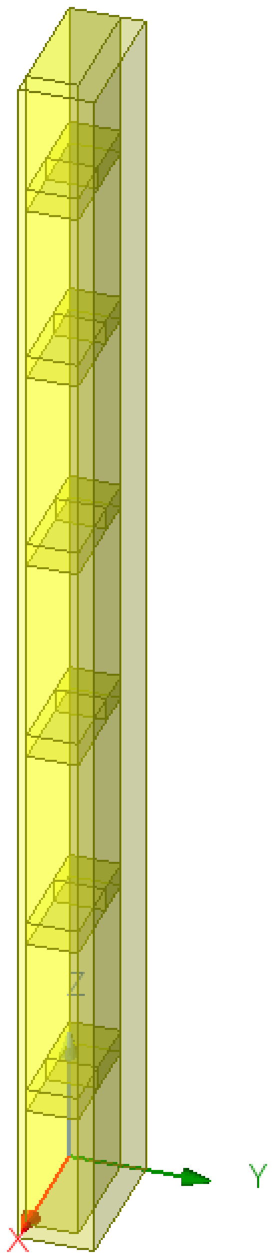
9. Present the results from the design project into a well-organized presentation.

Table 1 Summary of the impedance inverter parameters.

$k, k+1$	01	12	23	$\cdots$	N_P, N_P+1	
$K_{k,k+1}/Z_0$				$\cdots$		Ω/Ω
$X_{p(k,k+1)}/Z_0$				$\cdots$		Ω/Ω
$X_{s(k,k+1)}/Z_0$				$\cdots$		Ω/Ω
$\Psi_{k,k+1}$				$\cdots$		$\circ$
$\phi_{k,k+1}$				$\cdots$		$\circ$
a_g				$\cdots$		mm

Table 2 Summary of the resonator parameters.

k	1	2	3	$\cdots$	$N_{\text{Resonators}}$	
$\theta_{k,k+1}$				$\cdots$		$\circ$
d_k/λ_{g0}				$\cdots$		Ω/Ω
d_k				$\cdots$		mm



Design Project 3

By : Nittala Satya Surya Lakshmi Vasuki Siva Srinivas

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   - $IL \geq 20\ \text{dB}$ for $f \leq f_{Ls}$ where $f_{Ls} = 21\ \text{GHz}$.
   - $IL \geq 35\ \text{dB}$ for $f \geq f_{Hs}$ where $f \geq f_{Hs} = 23.4\ \text{GHz}$.
   - The source and load impedances of the filter are $Z_0 = Z_0\left(f_0\right)$ (waveguide impedance). Assume that the waveguide is a WR42 waveguide ($a = 10.6680\ \text{mm}$, $b = 4.3180\ \text{mm}$, and $t_w = 1.0160\ \text{mm}$).

Hand Calculations

Part-1

$a = 10.6680\ mm$

$b = 4.3180\ mm$

$t = 1\ mm$

$f_0 = 22\ GHz$

$Bwf = 1\ GHz$

$RL \geq 26\ dB$

$f_{LS} = 21\ GHz$

$f_{HS} = 23.4\ GHz$

$IL \geq 20\ dB$

$IL \geq 35\ dB$

Part-2

$f_0 = 22\ GHz$

$Bwf = 1\ GHz$

$f_0 = \sqrt{f_H \cdot f_L}$

$Bwf = f_0 \cdot \Delta = f_H - f_L$

$1 = 22 \cdot \Delta$

$\Delta = 1/22 = 0.0455$

$\boxed{\Delta = 0.0455}$

$f_H = ?$

$f_L = ?$

$(f_H)^2 - (f_0 \cdot \Delta) \cdot f_H - f_0^2 = 0$

$(f_H)^2 - (22)(0.0455)(f_H) - (22)^2 = 0$

$(f_H)^2 - (22)(0.0455)(f_H) - 484 = 0$

$(f(H))^2 - (f(H)(1.0010)) - 484 = 0$

$\boxed{f(H) = 22.5062}$

$Bwf = f_H - f_L$

$1 = 22.5062 - f_L$

$f_L = 22.5062 - 1$

$\boxed{f_L = 21.5062}$

Part-3

$a = 10.6680$

$b = 4.3180$

$t_w = 1.0160$

$f_0 = 22\ GHz$

$f_c = u_c / 2a$

$u = 2.997925 \times 10^8$

$f_c = \dfrac{2.997925 \times 10^8}{2 \times 10.6680 \times 10^{-3}}$

$\boxed{f_c = 14.0510\ GHz}$

$\lambda_{FSO} = u_c / f_0$

$= \dfrac{2.997925 \times 10^8}{22 \times 10^5}$

$\boxed{\lambda_{FSO} = 13.6269\ mm}$

$\lambda_{g0} = \dfrac{\lambda_{FSO}}{\sqrt{1 - (f_c/f_0)^2}}$

$= \dfrac{13.6269}{\sqrt{1 - \left(\frac{14.0510}{22}\right)^2}}$

$= \dfrac{13.6269}{\sqrt{1 - (0.4079)}}$

$\boxed{\lambda_{g0} = 17.7094}$

Part-4

$a = 10.6680$

$b = 4.3180$

$f_c = 14.0510\ GHz$

$\lambda_{FSO} = 13.6269$

$\lambda_{g0} = 17.7095$

$\eta_0 = 376.7303$

$Z_{TE} = \dfrac{\eta_0}{\sqrt{1 - (f_c/f_0)^2}}$

$Z_{TE} = \dfrac{376.7303}{\sqrt{1 - \left(\frac{14.0510}{22}\right)^2}}$

$Z_{TE} = \dfrac{376.7303}{\sqrt{1 - (0.4079)}}$

$\boxed{\cancel{Z_{TE} = 489.5905}}$

$\boxed{Z_{TE} = 489.5969}$ ***

$Z_0 = \left(\dfrac{2b}{a}\right) \cdot Z_{TE}$

$Z_0 = \left(\dfrac{2 \times 4.3180}{10.6680}\right) \times (489.5969)$

$\boxed{Z_0 = 396.3403}$

Part-5

$f_L \leq f \leq f_H$

$RL \geq 26\ dB$

$RL_{min} = 26\ dB$

$|S_{11}^{RL}|_{dB} = \leq -26$

$|S_{11}^{RL}|_{max} = 10^{(dB/20)}$

$= 10^{(-26/20)}$

$\boxed{|S_{11}^{RL}|_{max} = 0.0501}$

$|S_{21}^{RL}|_{min} = \sqrt{1-|S_{11}^{RL}|^2}$

$= \sqrt{1-(0.0501)^2}$

$\boxed{|S_{21}^{RL}|_{min} = 0.9987}$

$\boxed{|S_{21}^{RL}|_{dB} = -0.0109}$

$A_P \le -|S_{21}|^{min}_{dB}$

$A_P \le 0.0109$

$\boxed{A_P = 0.0109\,dB}$

Part-6

$f_{LS} = 21\,GHz$

$f_{HS} = 23.4\,GHz$

$IL \ge 20dB \rightarrow A_{LS} = 20dB$

$A_{LS} = 20dB \rightarrow f_{LS} = 21GHz$

$IL \ge 35dB \rightarrow A_{HS} = 35dB$

$A_{HS} = 35dB$ & $f_{HS} = 23.4\,GHz$

Part-7

$f_L = 21.5062.$

$f_H = 22.5062.$

$A_P = 0.0109\,dB$

$A_P\,w/w = 10^{(A_P/10)}$

$= 10^{(0.0109/10)}$

$\boxed{A_P(w/w) = 1.0025}$

$X_P = A_P - 1$

$X_P = 1.0025 - 1$

$\boxed{X_P = 0.0025}$

$\varepsilon = \sqrt{X_P}$

$= \sqrt{0.0025}$

$= 0.05$

$\boxed{\varepsilon = 0.0502}$

Part-8

$f_{LS} = 21\,GHz$

$A_{LS} = 20dB$

$A_{LS}(w/w) = 10^{(20/10)}$

$\boxed{A_{LS}(w/w) = 100}$

$X_{LS} = A_{LS} - 1$

$\boxed{X_{LS} = 99\,w/w}$

$\Omega_{LS} = \left(\frac{1}{\Delta}\right)\left[\left(\frac{f_{LS}}{f_0}\right) - \left(\frac{f_0}{f_{LS}}\right)\right]$

$= \left(\frac{1}{0.0455}\right)\left[\left(\frac{21}{22}\right) - \left(\frac{22}{21}\right)\right]$

$= \left(\frac{1}{0.0455}\right)\left[(0.9545) - (1.0476)\right]$

$\boxed{\Omega_{LS} = -2.0476}$

$N_{LS} \ge \frac{\cosh^{-1}\left[\left(\frac{1}{\varepsilon}\right)\left(\sqrt{X_{LS}}\right)\right]}{\cosh^{-1}(|\Omega_{LS}|)}$

$\boxed{N_{LS} = 4.4514}$

$\therefore \boxed{N_{LS} = 5}$

Part-9

$f_{HS} = 23.4\,GHz$

$A_{HS} = 35dB$

$A_{HS} = 10^{(A_{HS}/10)}$

$= 10^{(35/10)}$

$\boxed{A_{HS} = 3162.2776}\ w/w$

$X_{HS} = A_{HS} - 1$

$\boxed{X_{HS} = 3161.2776}\ w/w$

$\Omega_{HS} = \left(\frac{1}{\Delta}\right)\left[\left(\frac{f_{HS}}{f_0}\right) - \left(\frac{f_0}{f_{HS}}\right)\right]$

$= \left(\frac{1}{0.0455}\right)\left[\left(\frac{23.4}{22}\right) - \left(\frac{22}{23.4}\right)\right]$

$= \left(\frac{1}{0.0455}\right)\left[(1.0636) - (0.940)\right]$

$= 2.7162.$

$\boxed{\Omega_{HS} = 2.7162}$

$N_{HS} \ge \frac{\cosh^{-1}\left[\left(\frac{1}{\varepsilon}\right)\sqrt{X_{HS}}\right]}{\cosh^{-1}(|\Omega_{HS}|)}$

$\boxed{N_{HS} = 4.6568}$

$\boxed{N_{HS} = 5}$

Part-10

$N_P = 5$

$\therefore$ No. of Branches $= N_P$

$= 5$

No. of iris $= 5 + 1 = 6$

$\boxed{N_{iris} = 6}$

$N_{resonator} = N_{Branches}$

$\boxed{N_{resonator} = 5}$

Chebyshev 0.01 dB

Ripple. 5th order.

$g_0 = 1$
$g_1 = 0.7563$
$g_2 = 1.3049$
$g_3 = 1.5773$
$g_4 = 1.3049$
$g_5 = 0.7563$
$g_6 = 1.000$

MATLAB Calculations

```
f0 = 22.0000 GHz

Bwf = 1.0000 GHz

fL = 21.5000 GHz

fH = 22.5000 GHz

delta = 0.0455

S21_min (RL) = 0.9987 W/W

S21_min (RL) = -0.0109 dB

Ap (RIPPLE) = 0.0109 dB

fc = 14.0510 GHz

lambda_fs0 = 13.6269 mm

lambda_g0 = 17.7095 mm

ZTE = 489.5969  Ohms

Z0 = 396.3403  Ohms

NLS = 4.4514

NHS = 4.6568

w0 = 138.2301  Grad/s
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C1 = 303.7008 fF

L1 = 172.3253 pH

L2 = 82.3125 nH

C2 = 635.8128 aF

C3 = 633.3826 fF

L3 = 82.6283 pH

L4 = 82.3125 nH

C4 = 635.8128 aF

C5 = 303.7008 fF

L5 = 172.3253 pH

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lambda_fs = 13.9438 mm

lambda_g_fL = 18.4224 mm

lambda_fs_f0 = 13.6269 mm

lambda_g_f0 = 17.7095 mm

lambda_fs_fH = 13.3241 mm

lambda_g_fH = 17.0596 mm

Delta_Lambda = 0.0770

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K01_Z0 = 0.3998

K12_Z0 = 0.1217

K23_Z0 = 0.0843

K34_Z0 = 0.0843

K45_Z0 = 0.1217

K56_Z0 = 0.3998
```
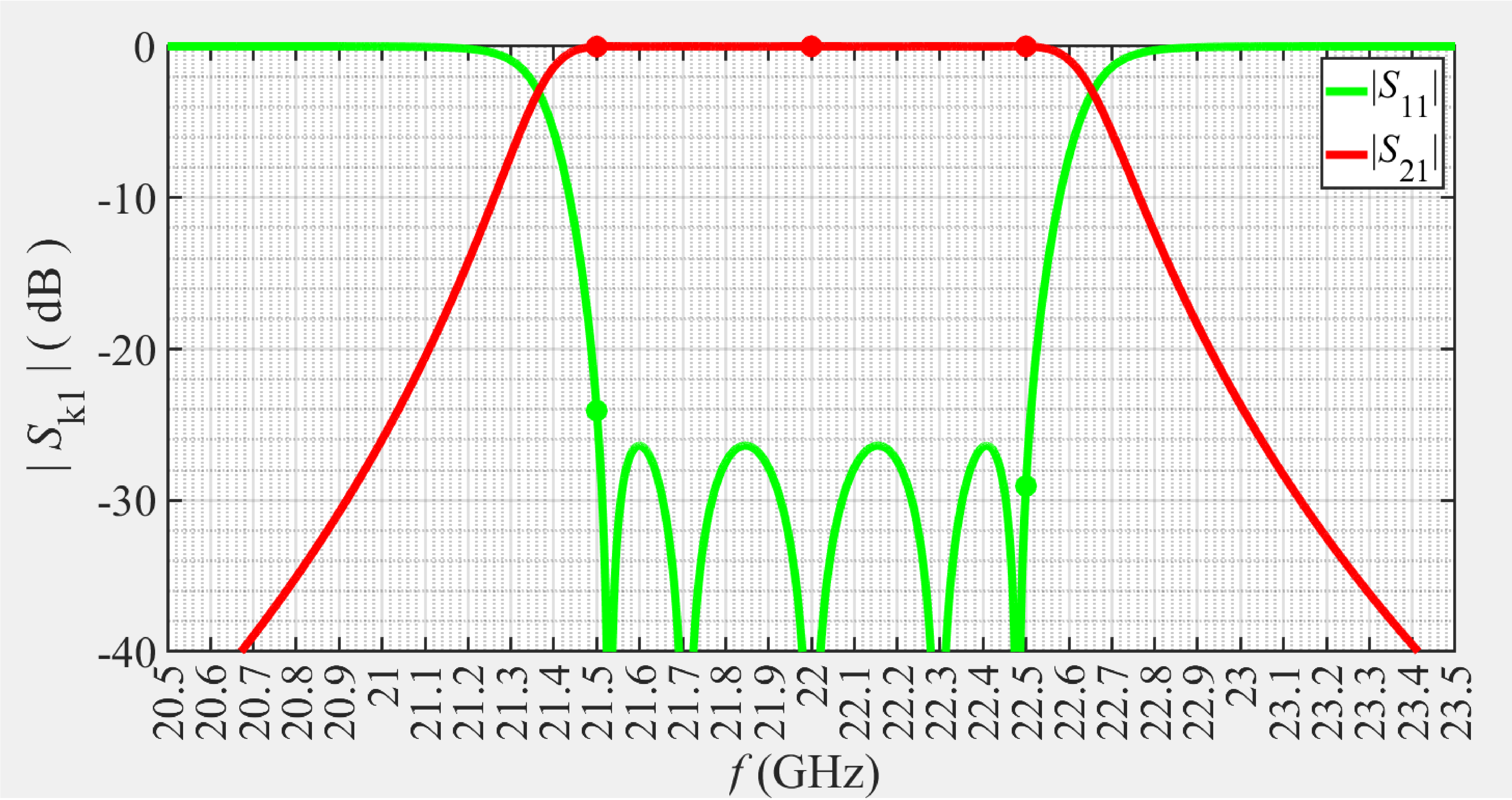
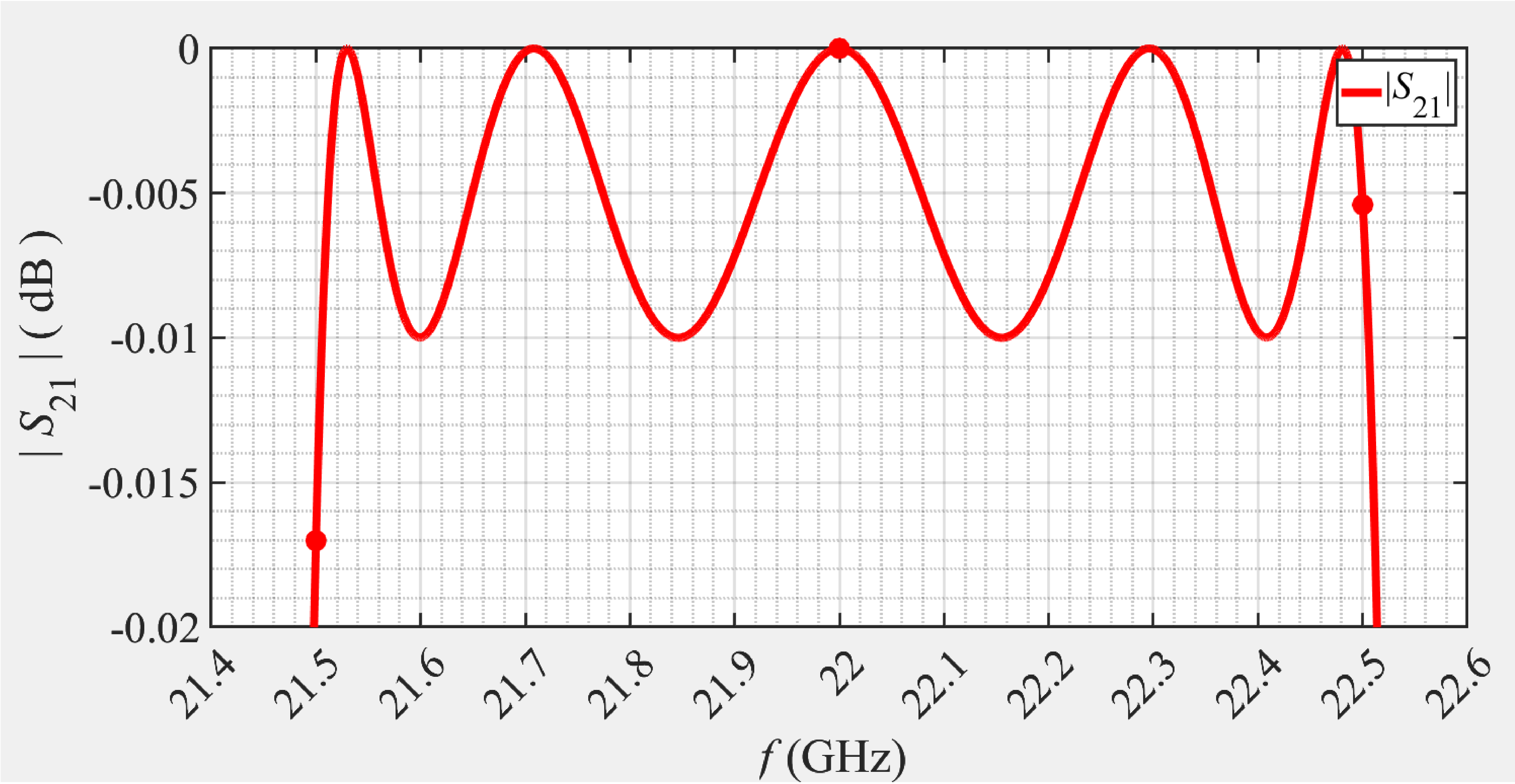
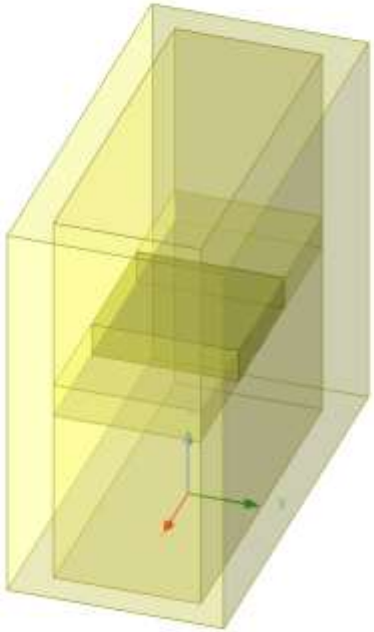

MATLAB Ideal Lumped Elements





0
-0.005
-0.01
-0.015
-0.02
| S_{21} | (dB)
21.4
21.5
21.6
21.7
21.8
21.9
22
22.1
22.2
22.3
22.4
22.5
22.6
f (GHz)
$|S_{21}|$

Waveguide inductive iris BPF Design



BPF Full Model Iris Sweep

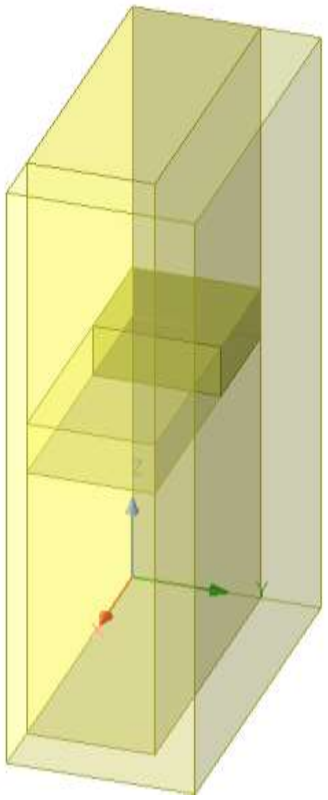
Properties

Name	Value	Unit	Evaluated Value	Type
a	10.668	mm	10.668mm	Design
b	4.318	mm	4.318mm	Design
tw	1.016	mm	1.016mm	Design
t_iris	1	mm	1mm	Design
dp	(1/2)*a		5.334mm	Design
L	2*dp+t_iris		11.668mm	Design
ag_0	4	mm	4mm	Design
aw	a+2*tw		12.7mm	Design
bw	b+2*tw		6.35mm	Design

Setup Sweep Analysis

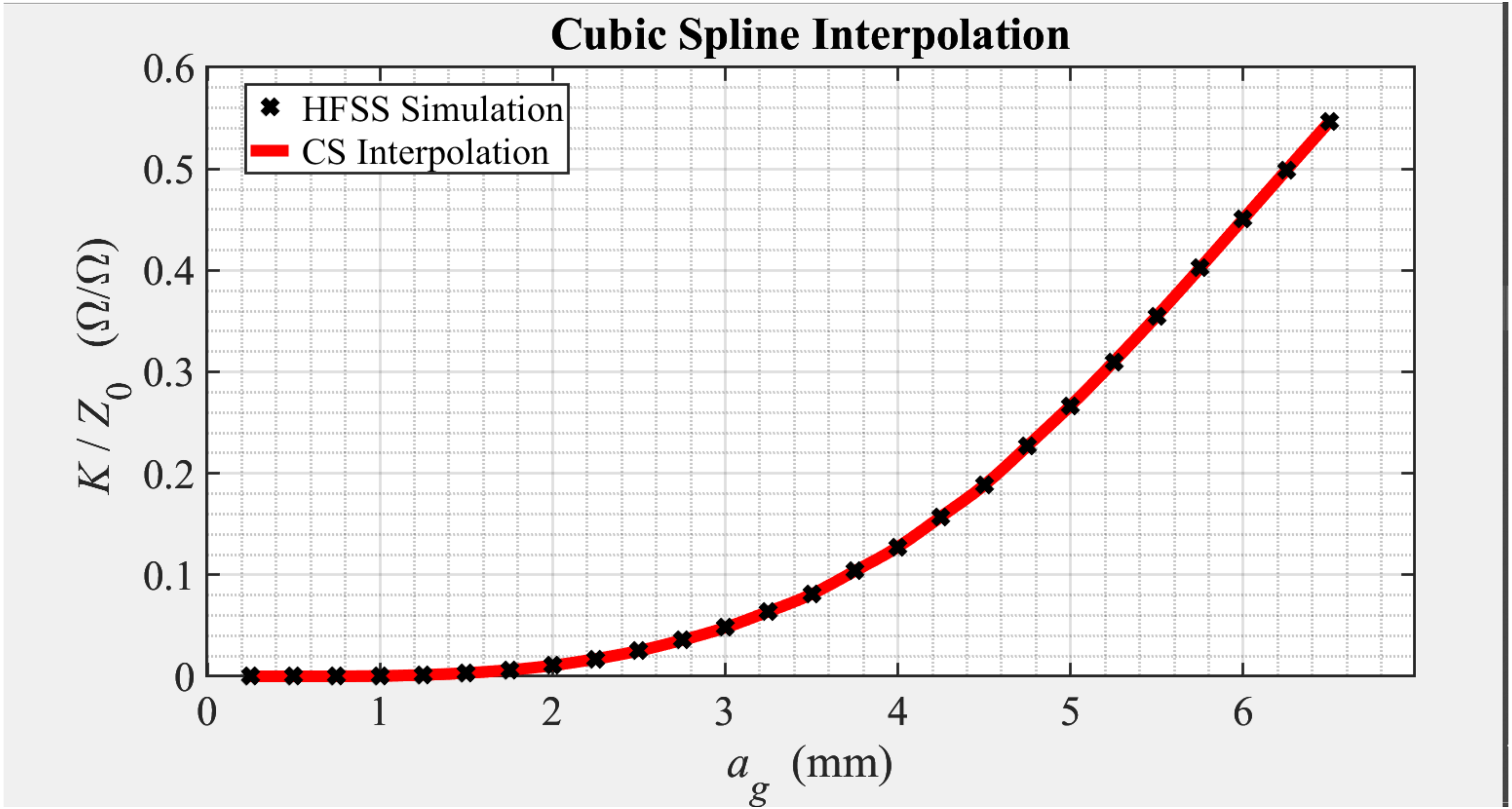
Sweep Definitions | Table | General | Calculations | Options

Sync #	Variable	Description
	ag_0	Linear Step from 0.25mm to 6.5mm, step=0.25mm

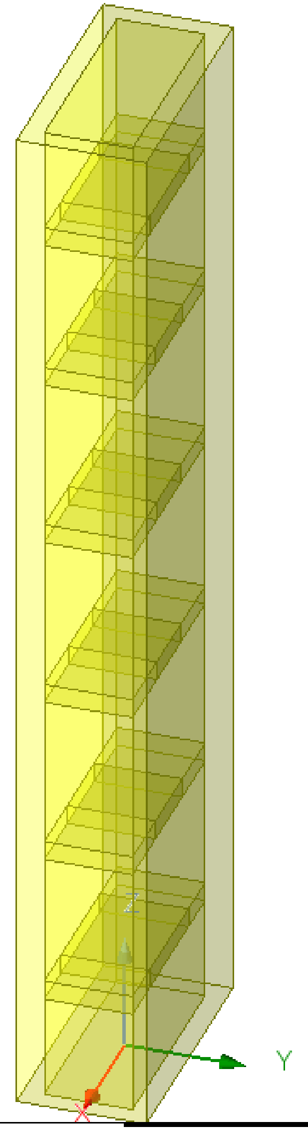


BPF Quarter Model Iris Sweep

Iris Sweep - Cubic spline Interpolation



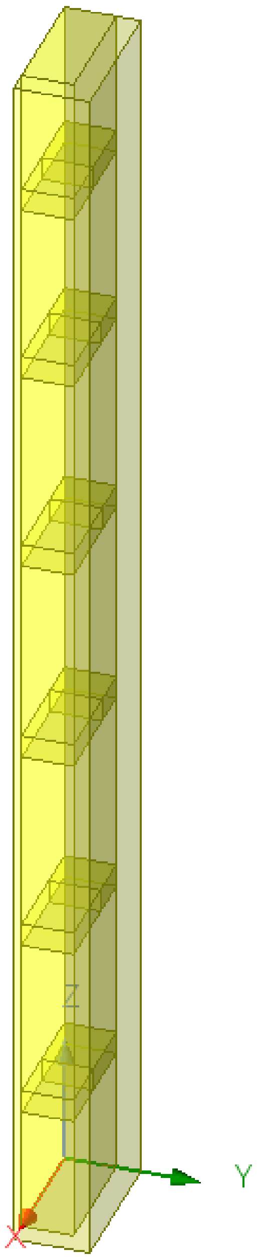
WG iris BPF HFSS (PEC)



BPF iris Full Model Pec

Name	Value	Unit	Evaluated Value	Type
a	10.668	mm	10.668mm	Design
b	4.318	mm	4.318mm	Design
tw	1.016	mm	1.016mm	Design
t	1	mm	1mm	Design
ag	[0, 5.737, 3.9424, 3.5427, 3.5427, 3.9424, 5.737, 0]	mm	[0, 5.737, 3.942...	Design
zk	[0, 5.334, 13.1594, 21.9746, 30.9249, 39.7401, 47.5655, 53.8995]	mm	[0, 5.334, 13.15...	Design
L	53.8995	mm	53.8995mm	Design
dp	(1/2)*a		5.334mm	Design
aw	a+2*tw		12.7mm	Design
bw	b+2*tw		6.35mm	Design

- Model
  - Solids
    - pec
      - Iris_pec_1
        - CreateBox
      - Iris_pec_2
        - CreateBox
      - Iris_pec_3
        - CreateBox
      - Iris_pec_4
        - CreateBox
      - Iris_pec_5
        - CreateBox
      - Iris_pec_6
        - CreateBox
      - WG1
        - CreateBox
    - vacuum
      - Iris_air_1
      - Iris_air_2
      - Iris_air_3
      - Iris_air_4
      - Iris_air_5
      - Iris_air_6
      - WG
- Coordinate Systems
- Planes
- Lists



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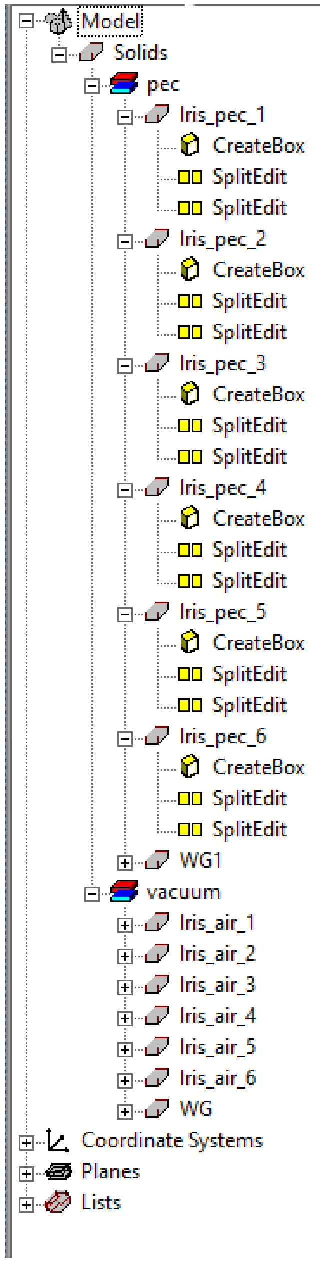
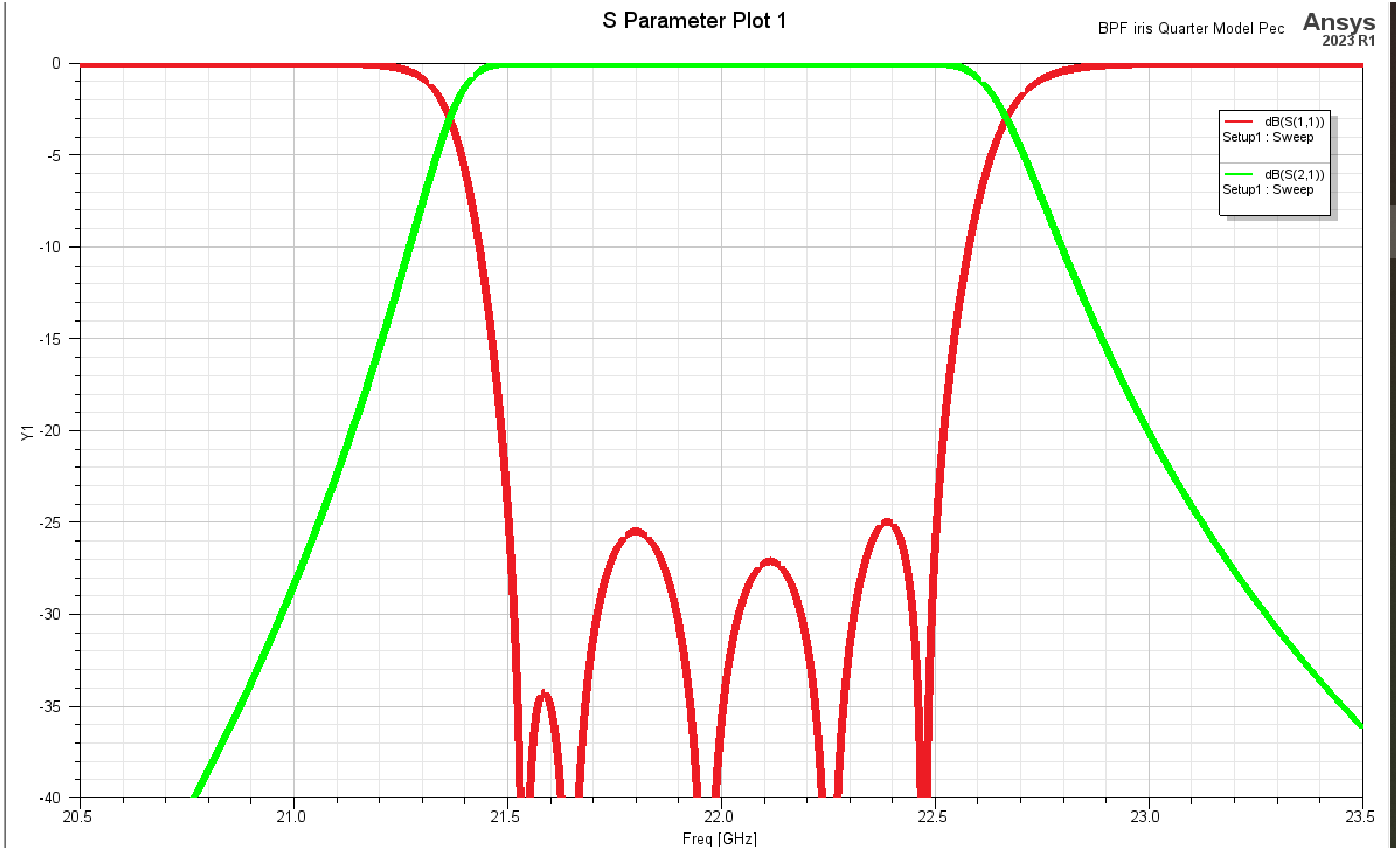
zk	[0, 5.334, 13.1594, 21.9746, 30.9249, 39.7401, 47.5655, 53.8995]	mm	[0, 5.334, 13.15...	Design
L	53.8995	mm	53.8995mm	Design
dp	(1/2)*a		5.334mm	Design
aw	a+2*tw		12.7mm	Design
bw	b+2*tw		6.35mm	Design

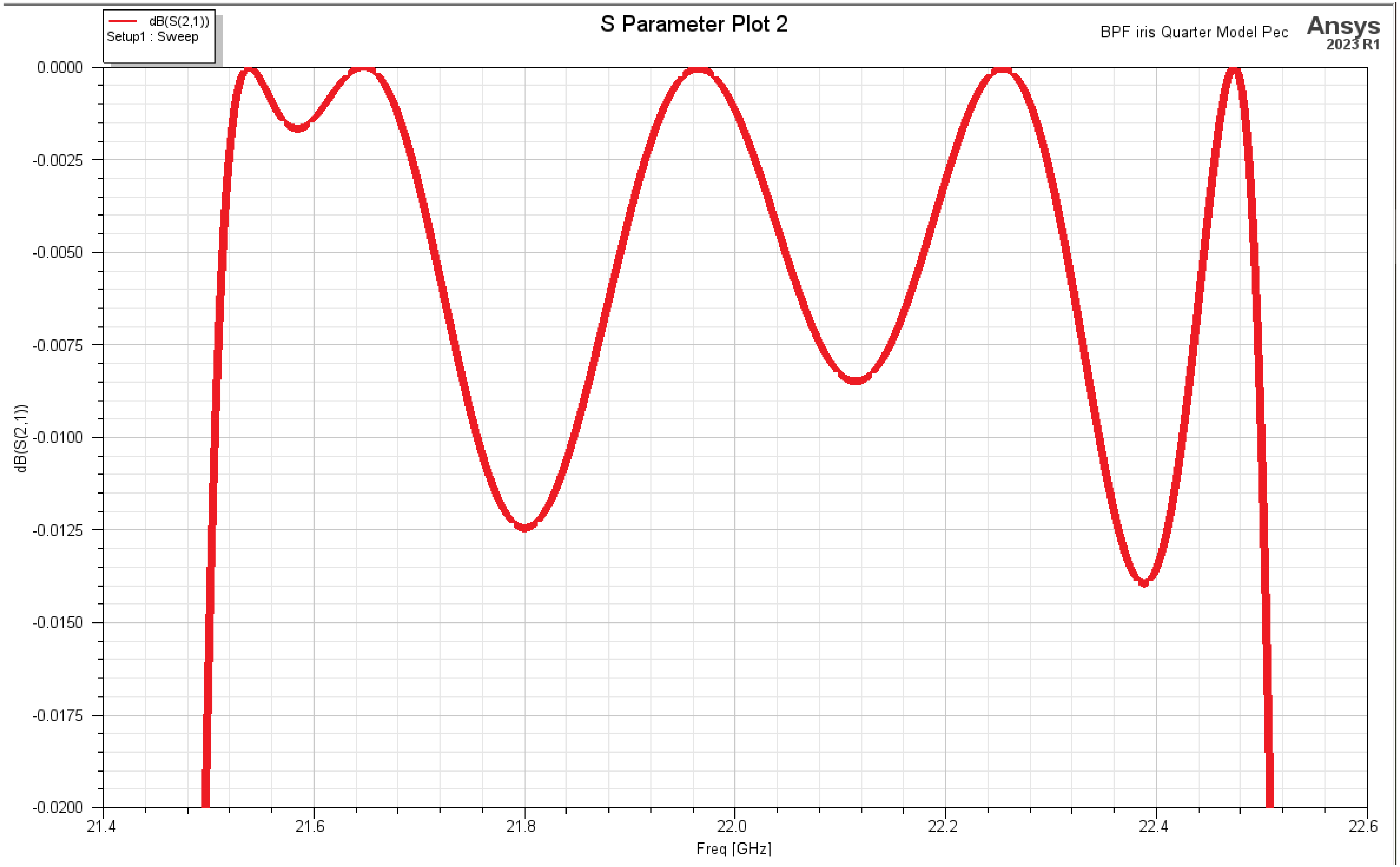
BPF iris Quarter Model Pec



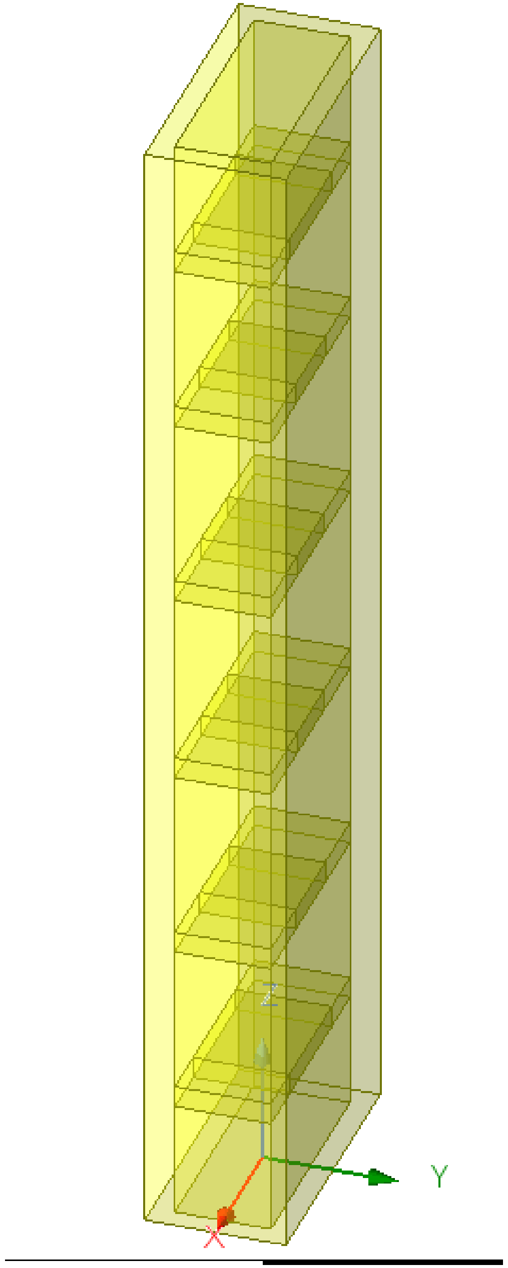
WG iris BPF HFSS (PEC) $|S_{11}|$ and $|S_{21}|$



WG iris BPF HFSS (PEC) $|S_{21}|$



WG iris BPF HFSS (Copper(Loss))



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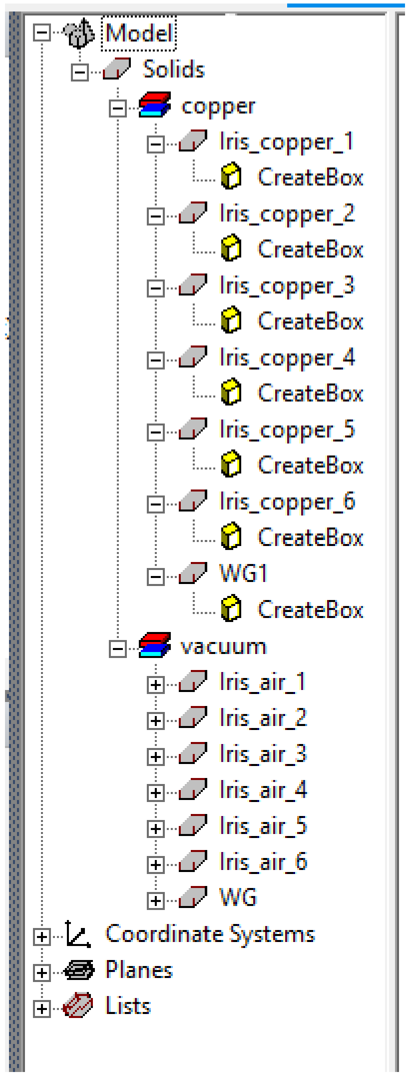
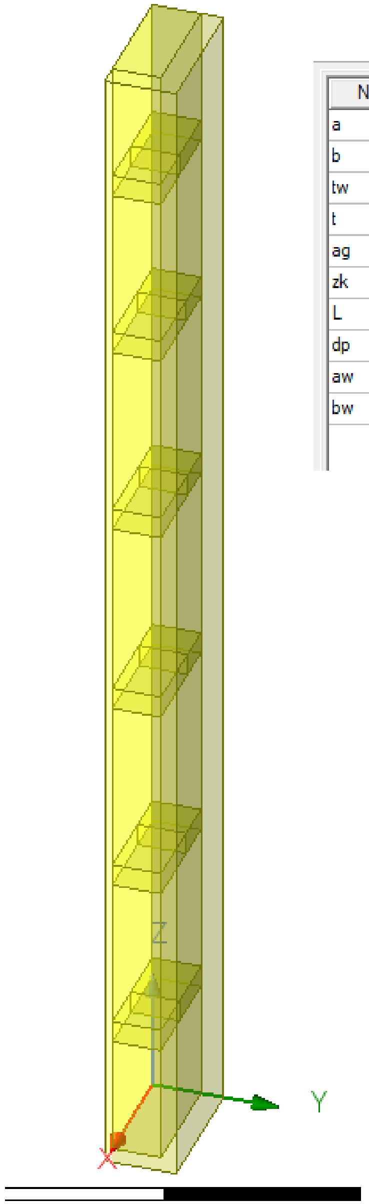
tw	1.016	mm	1.016mm	Design
t	1	mm	1mm	Design
ag	[0, 5.737, 3.9424, 3.5427, 3.5427, 3.9424, 5.737, 0]	mm	[0, 5.737, 3.942...	Design
zk	[0, 5.334, 13.1594, 21.9746, 30.9249, 39.7401, 47.5655, 53.8995]	mm	[0, 5.334, 13.15...	Design
L	53.8995	mm	53.8995mm	Design
dp	(1/2)*a		5.334mm	Design
aw	a+2*tw		12.7mm	Design
bw	b+2*tw		6.35mm	Design

BPF iris Full Model Copper





Name	Value	Unit	Evaluated Value	Type
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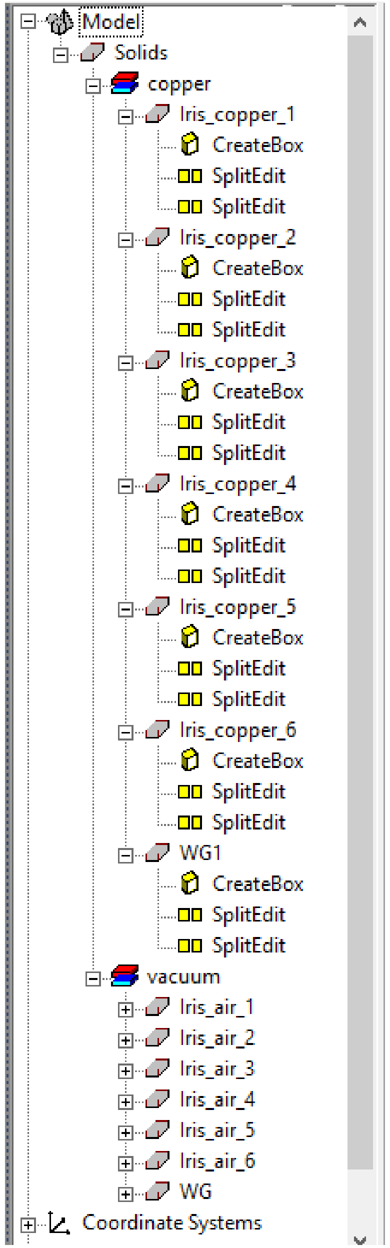
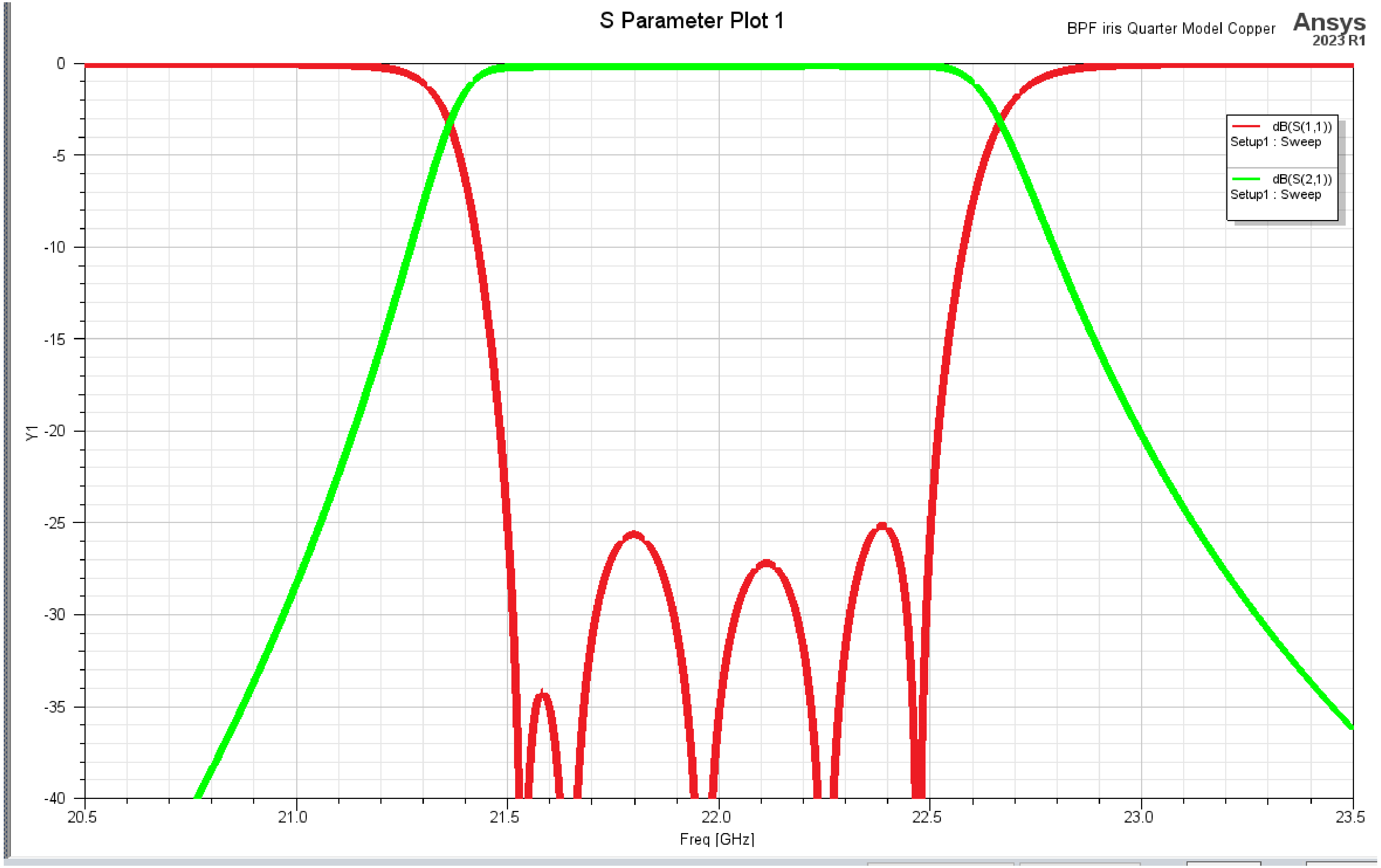
b	4.318	mm	4.318mm	Design
tw	1.016	mm	1.016mm	Design
t	1	mm	1mm	Design
ag	[0, 5.737, 3.9424, 3.5427, 3.5427, 3.9424, 5.737, 0]	mm	[0, 5.737, 3.942...	Design
zk	[0, 5.334, 13.1594, 21.9746, 30.9249, 39.7401, 47.5655, 53.8995]	mm	[0, 5.334, 13.15...	Design
L	53.8995	mm	53.8995mm	Design
dp	(1/2)*a		5.334mm	Design
aw	a+2*tw		12.7mm	Design
bw	b+2*tw		6.35mm	Design

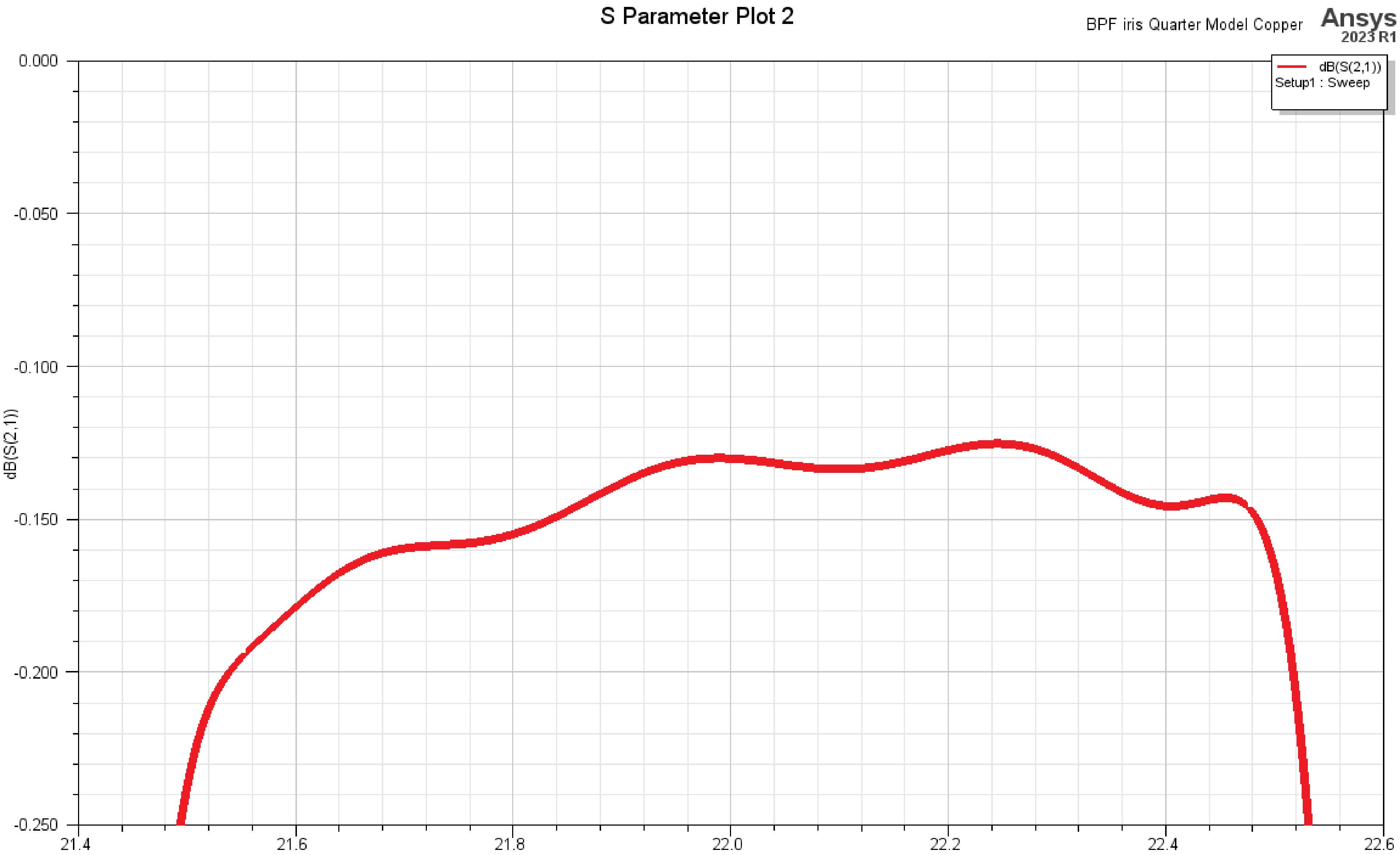
BPF iris Quarter Model Copper



WG iris BPF HFSS (Copper(Loss)) $|S_{11}|$ and $|S_{21}|$

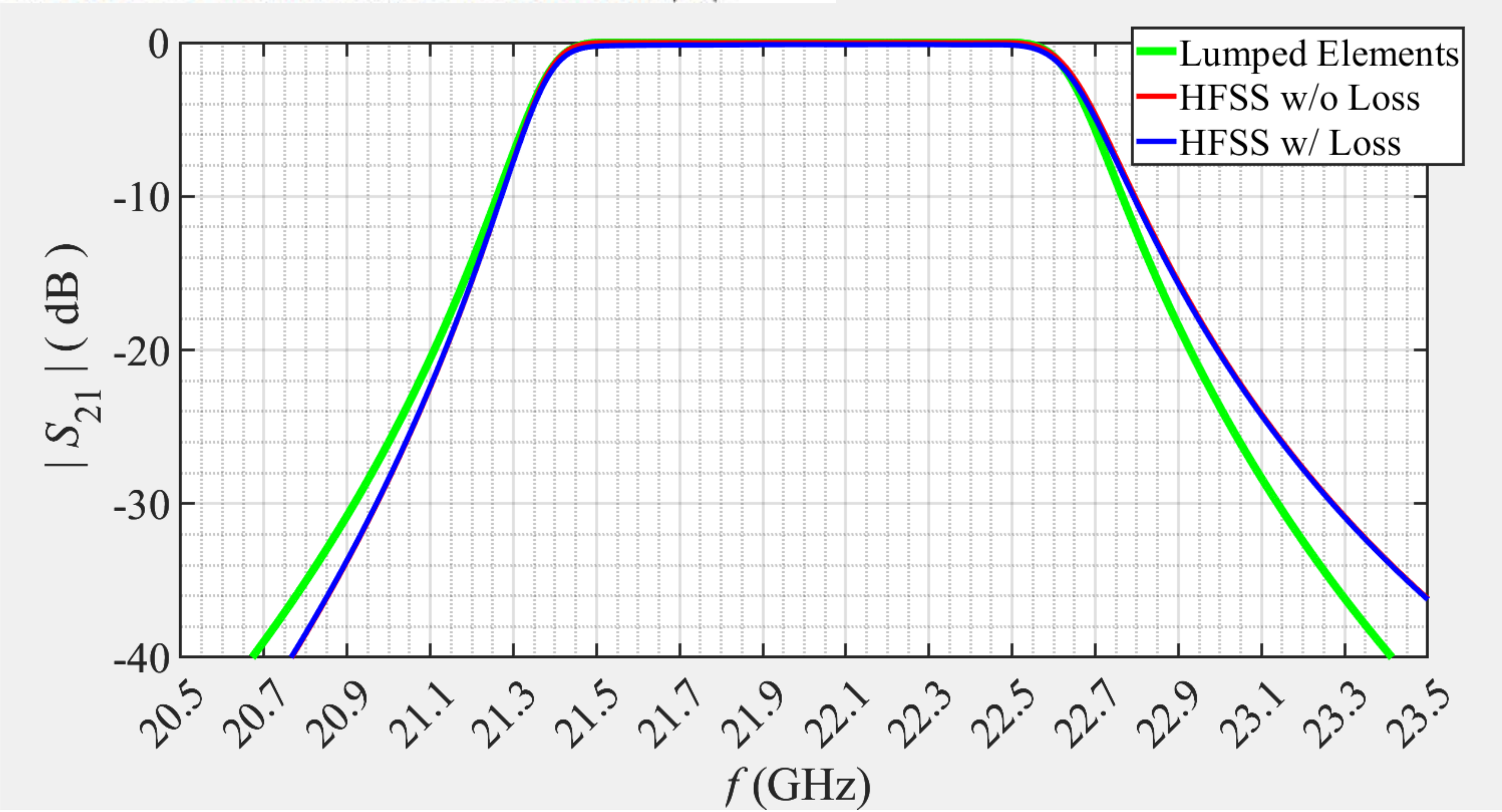


WG iris BPF HFSS (Copper(Loss)) $|S_{21}|$

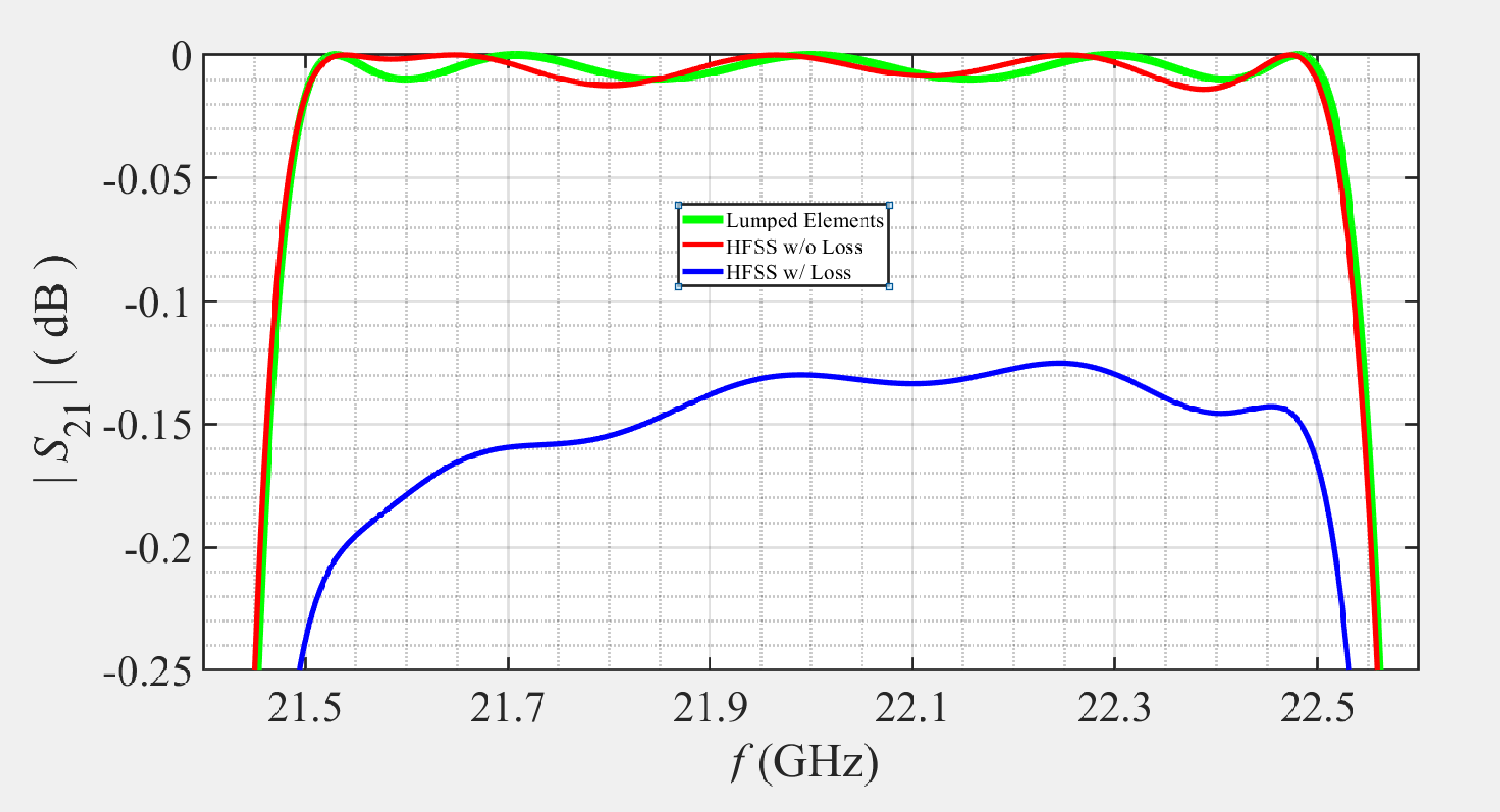


Summary of the outcomes.

On the same graph, plot $|S_{21}|$ in dB, for the three cases. Employ a frequency range of 20.5 GHz to 23.5 GHz and a range of -40 dB to 0 dB for $|S_{21}|$.



On the same graph, plot $|S_{21}|$ in dB, for the three cases. Employ a of frequency range 21.4 GHz to 22.6 GHz and a range of -0.25 dB to 0 dB for $|S_{21}|$.



On the same graph, plot $|S_{11}|$ in dB, for the three cases. Employ a frequency range of 21.4 GHz to 22.6 GHz and a range of -40 dB to 0 dB for $|S_{11}|$.

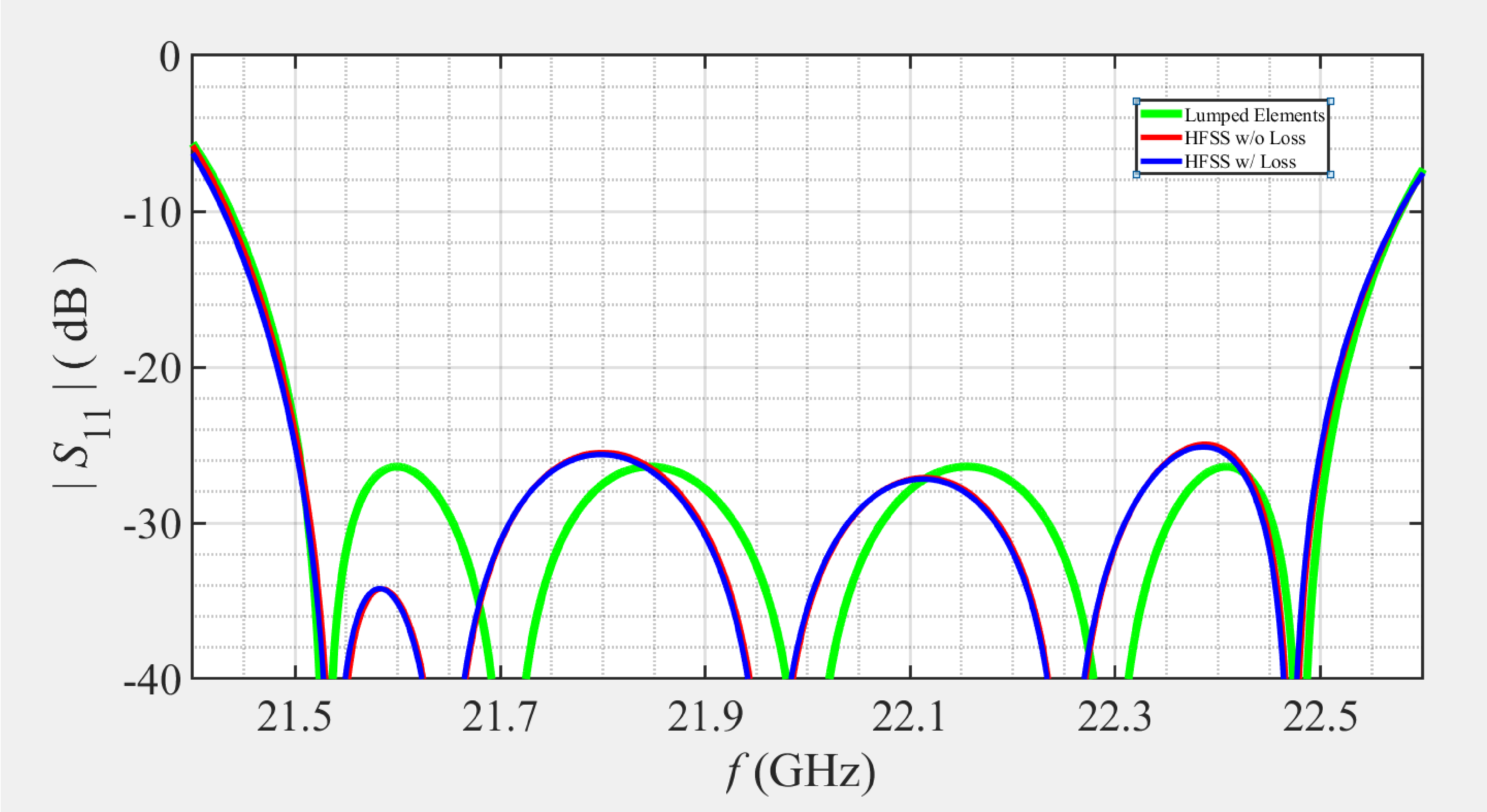


Table 01

k,k+1	01	12	23	34	45	56	
$K_{k,k+1}/Z_0$	0.3998	0.1217	0.0843	0.0843	0.1217	0.3998	Ω/Ω
$X_{p(k,k+1)}/Z_0$	0.5538	0.1270	0.0867	0.0867	0.1270	0.5538	Ω/Ω
$X_{s(k,k+1)}/Z_0$	0.1321	0.0876	0.0763	0.0763	0.0876	0.1321	Ω/Ω
$\Psi_{k,k+1}$	7.5244	5.0091	4.3654	4.3654	5.0091	7.5244	°
$\emptyset_{k,k+1}$	-58.6319	-23.8746	-18.3867	-18.3867	-23.8746	-58.6319	°
a_g	5.737	3.9424	3.5427	3.5427	3.9424	5.737	mm

Table 02

k	1	2	3	4	5	
$\theta_{k,k+1}$	138.7467	158.8693	161.6133	158.8693	138.7467	°
d_k/λ_{g0}	0.3854	0.4413	0.4489	0.4413	0.3854	Ω/Ω
d_k	6.8254	7.8153	7.9502	7.8153	6.8254	mm

Appendices

- HFSS
- MATLAB
- MS Excel

THE END