Western New England University
College of Engineering
ECE Department
Wave Transmission and Reception
EE 457/557
Fall 2023
Design Project #2
Due: November 13, 2023

Name:____

References:____

Design Project #2

	Score	Max
Design		200
HFSS		300
Tables		100
Presentation		100
Total		700

1. Design a 16-GHz probe-fed microstrip patch antenna. The substrate is 20-mil thick ($h = 20 \text{ mils} = 0.508 \text{ mm}$) Duroid 5880 ($\varepsilon_r = 2.2$). The probe formed by using the center conductor of a 0.085″ semi-rigid copper coax cable. The dielectric of the coax is Teflon ($\varepsilon_r = 2.1$). The inner and outer radii of the coax are 10 mils ($r_i = 10 \text{ mils}$) and 33 mils ($r_o = 33 \text{ mils}$), respectively.

2. Simulate the 16-GHz probe-fed microstrip patch antenna using HFSS.

   - Tune the patch until the input return loss at 16 GHz is better than 25 dB ($RL_{in} \geq +25 \text{ dB}$ or $|\Gamma_{in}| \leq |S_{11}| \leq -25 \text{ dB}$ |).
   - Determine a value for the gain (G) at a frequency of 16 GHz.
   - Determine a value for the E-Plane beamwidth (BW_{EP}) at a frequency of 16 GHz.
   - Determine a value for the H-Plane beamwidth (BW_{HP}) at a frequency of 16 GHz.
   - Plot $|S_{11}|$ over the range of -40 to 0 dB. Employ a frequency range of 15 to 17 GHz.
   - Determine the bandwidth and percent bandwidth for which the input return loss is better than 10 dB ($RL_{in} \geq +10 \text{ dB}$ or $|\Gamma_{in}| \leq |S_{11}| \leq -10 \text{ dB}$).

3. Complete the following tables (Table 1, Table 2, Table 3, and Table 4).

Table 1 Summary of the calculated design parameters for the 16-GHz probe-fed microstrip patch antenna.

Parameter	Calculated	
λ_g		mm
L_e		mm
ΔL		µm
W		mm
ε_r^{eff}		
ΔL		µm
L_p		mm
G_1		mS
G_{12}		µS
B_1		mS
G_{Edge}		mS
R_{Edge}		Ω
x_f		mm

Table 2 Summary of the simulated design parameters for the 16-GHz probe-fed microstrip patch antenna.

Parameter	Initial Design	Final Design	
W			mm
L_e			mm
ΔL			µm
L_p			mm
x_f			mm

Table 3 Summary of the simulated gain (at 16 GHz) for the 16-GHz probe-fed microstrip patch antenna.

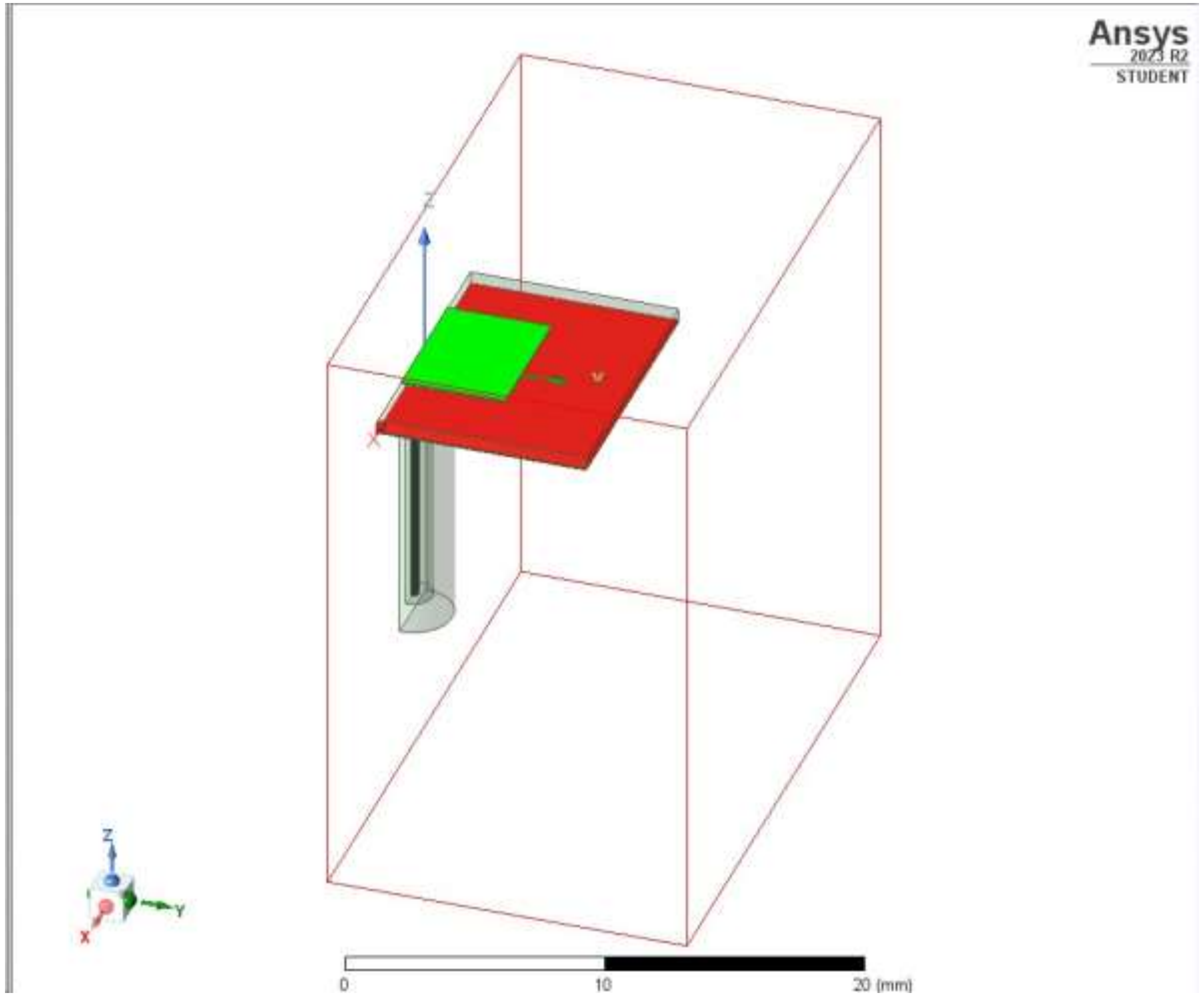
Parameter	HFSS	
G		W/W
G		dB
BW_{EP}		°
BW_{HP}		°

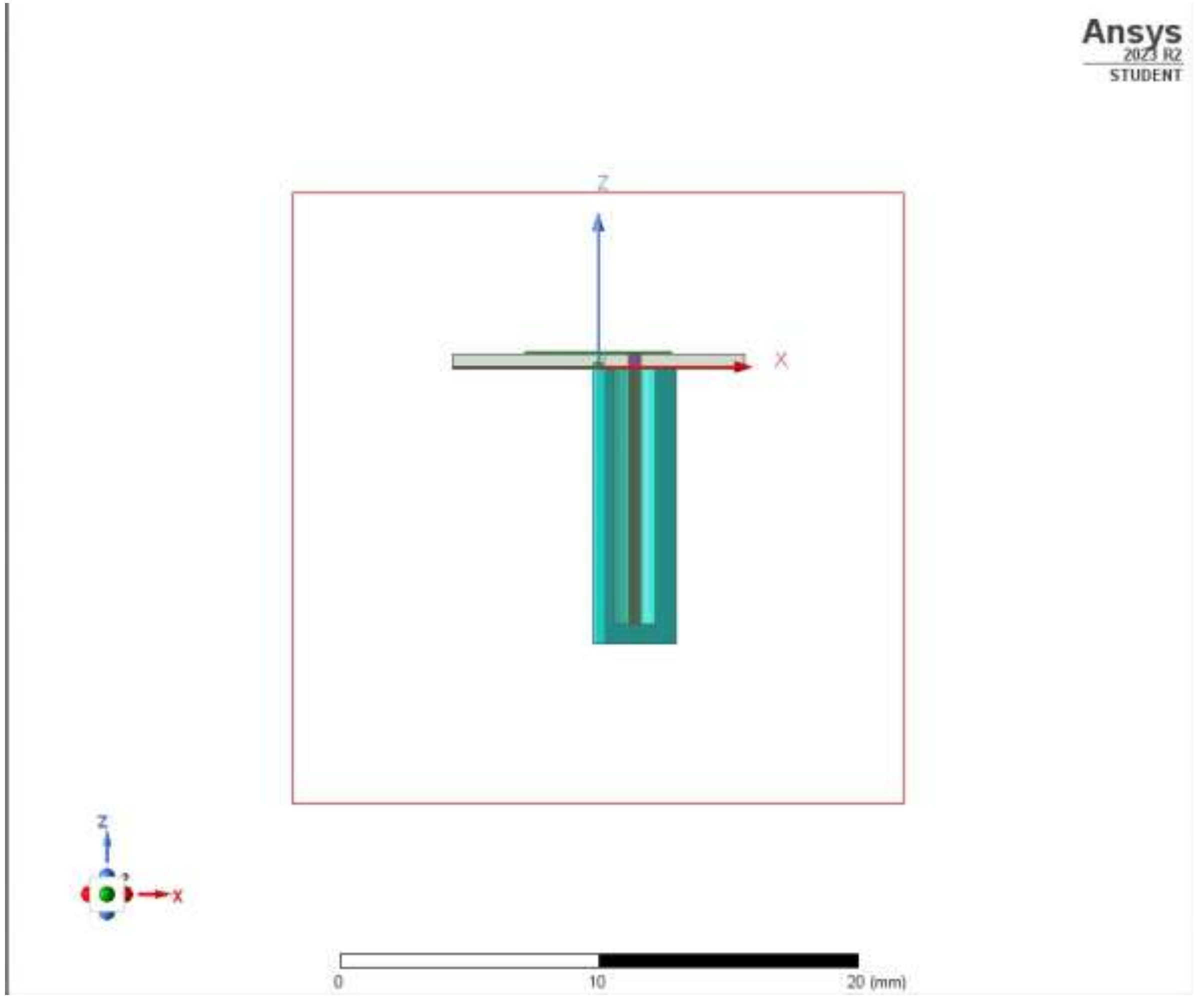
Table 4 Summary of the calculated and simulated frequency response for the 16-GHz probe-fed microstrip patch antenna.

Parameter	Calculated	HFSS	
BW_f			MHz
BW_f			%

Design Project 2

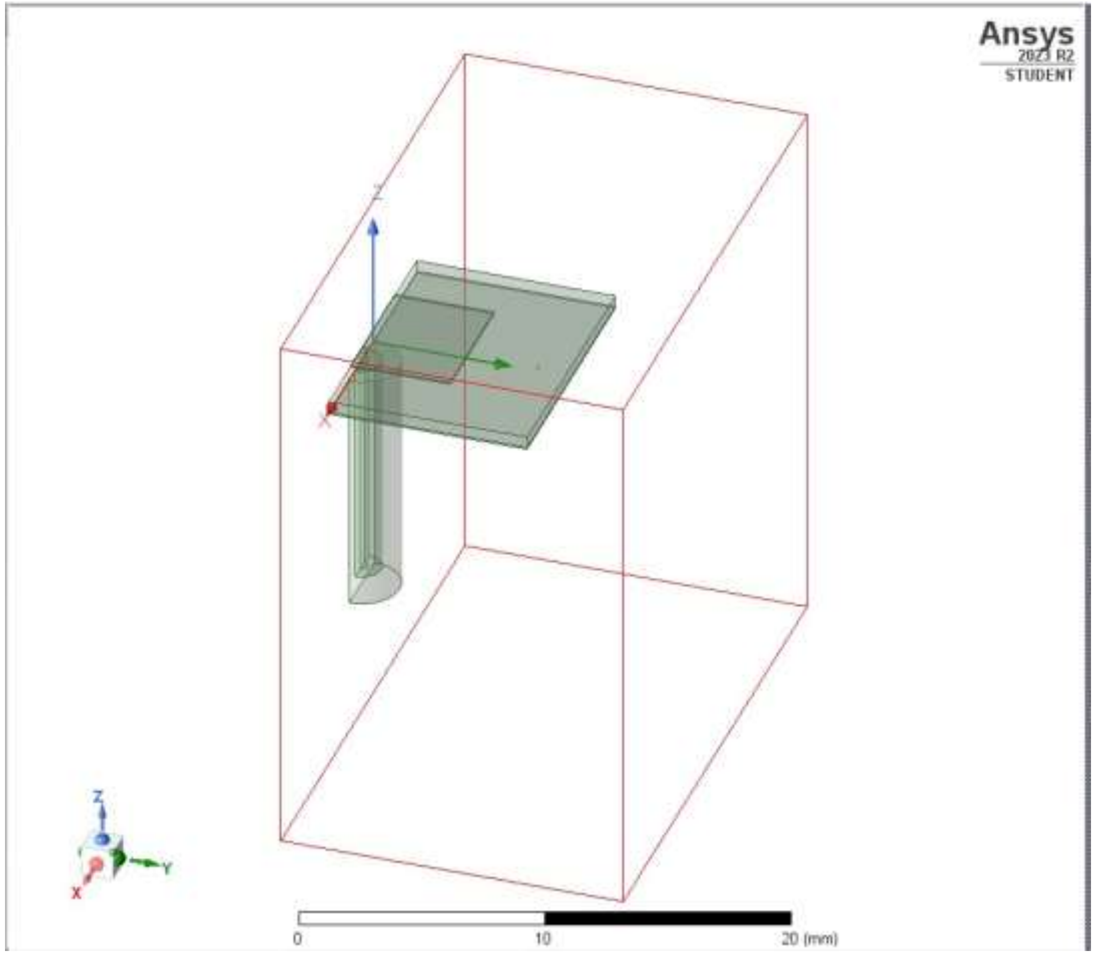
16GHz Patch Antenna


Ansys
2023 R2
STUDENT
Z
X
Y
0
10
20 (mm)


Ansys
2023 R2
STUDENT
Z
X
0
10
20 (mm)

Properties

Name	Value	Unit	Evaluated V...	Type
h	0.508	mm	0.508mm	Design
Le	6.262947717	mm	6.2629477mm	Design
del_L	266.272104	um	266.2721um	Design
L	Le - 2*del_L		5.7304035mm	Design
W	1.5*L		8.5956053mm	Design
Ls	2*L		11.460807mm	Design
Ws	2*W		17.191211mm	Design
t	80	um	80um	Design
SCALE	0.825		0.825	Design
Xf	2.07*SCALE	mm	1.70775mm	Design
X0	(1/2)*Le-Xf		1.4237239mm	Design
r_i	10	mil	10mil	Design
r_o	33	mil	33mil	Design
r_o2	r_o+10*t		1.6382mm	Design
Lc	10	mm	10mm	Design
d_cap	10*t		800um	Design



Calculations

(1) $\lambda_{FS} = \mu c / f_0$

$$= \frac{2.99792 \times 10^8 \times 10^3}{16 \times 10^9} = \frac{2.99792 \times 10^{11}}{16 \times 10^9} = 0.18737 \times 10^2$$

$$\lambda_{FS} = 18.737$$

(2) $\lambda_g = \frac{18.737}{\sqrt{2.2}} = 12.632482 \text{ mm.}$

(3) $L_e = \frac{1}{2} \cdot \lambda_g$

$$= \frac{1}{2} \times 12.632482$$

$$= 6.316241 \text{ mm.}$$

(4) $W' = 1.5 \times L_e$

$$= 1.5 \times 6.316241$$

$$= 9.4743615 \text{ mm.}$$

(5) $\varepsilon_r^{eff} = \left[\left(\frac{1}{2}\right)(\varepsilon_r + 1)\right] + \left[\left(\frac{1}{2}\right)(\varepsilon_r - 1)\right]\left[1 + 12\left(h/w'\right)\right]^{-1/2}$

$$= \left[\left(\frac{1}{2}\right)(2.2+1)\right] + \left[\left(\frac{1}{2}\right)(2.2-1)\right]\left[1 + 12\left(\frac{0.508}{9.4743615}\right)\right]^{-1/2}$$

$$= 1.6 + 0.6\left[1.643420\right]^{-1/2}$$

$$= 2.068033$$

(6) $\Delta L = 0.412h \left[\frac{\varepsilon_r^{eff} + 0.3}{\varepsilon_r^{eff} - 0.258}\right]\left[\frac{(w'/h) + 0.264}{(w'/h) + 0.8}\right]$

$$= 0.412\,(0.508)\left[\frac{2.068033 + 0.3}{2.068033 - 0.258}\right]\left[\frac{18.65031 + 0.264}{18.65031 + 0.8}\right]$$

$$= 0.209296\left[1.308281\right]\left[0.972442\right] \times 10^3$$

$$= 0.266272104 \times 10^3$$

$$= 266.272104 \ \mu m.$$

(7) $L_p = L_e - 2\Delta L$

$$= 6.316241 - \left[2(0.266272104)\right]$$

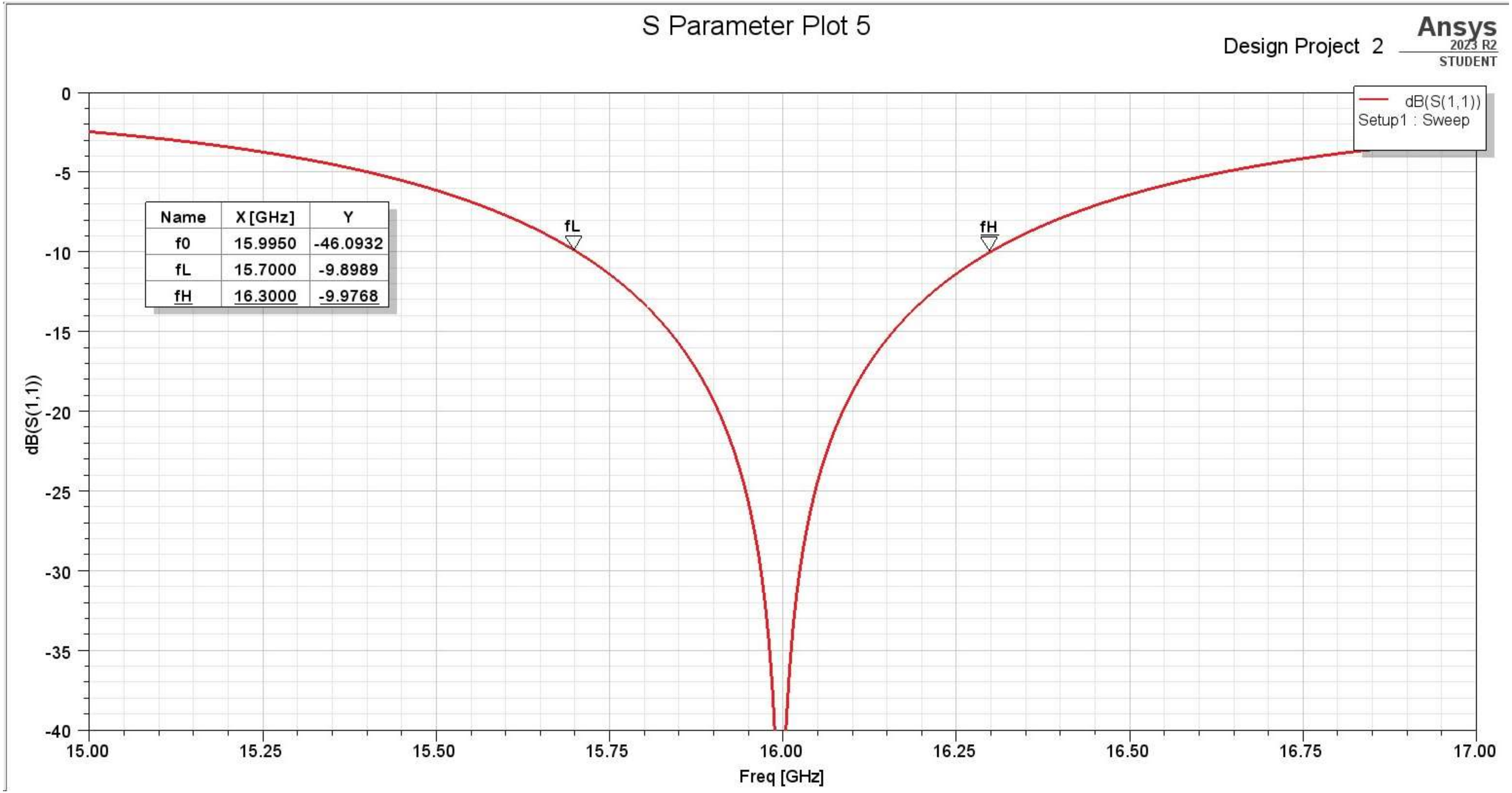
$$= 6.316241 - 1.065088$$

$$= 5.78369 \text{ mm.}$$

(8) $W = 1.5 \times L_p$

$$W = 1.5 \times 5.78365$$

$$= 8.67554 \text{ mm}$$


S Parameter Plot 5
Design Project 2
Ansys
2023 R2
STUDENT
dB(S(1,1))
Setup1 : Sweep
Name | X [GHz] | Y
f0 | 15.9950 | -46.0932
fL | 15.7000 | -9.8989
fH | 16.3000 | -9.9768
fL
fH
0
-5
-10
-15
-20
-25
-30
-35
-40
dB(S(1,1))
15.00
15.25
15.50
15.75
16.00
16.25
16.50
16.75
17.00
Freq [GHz]

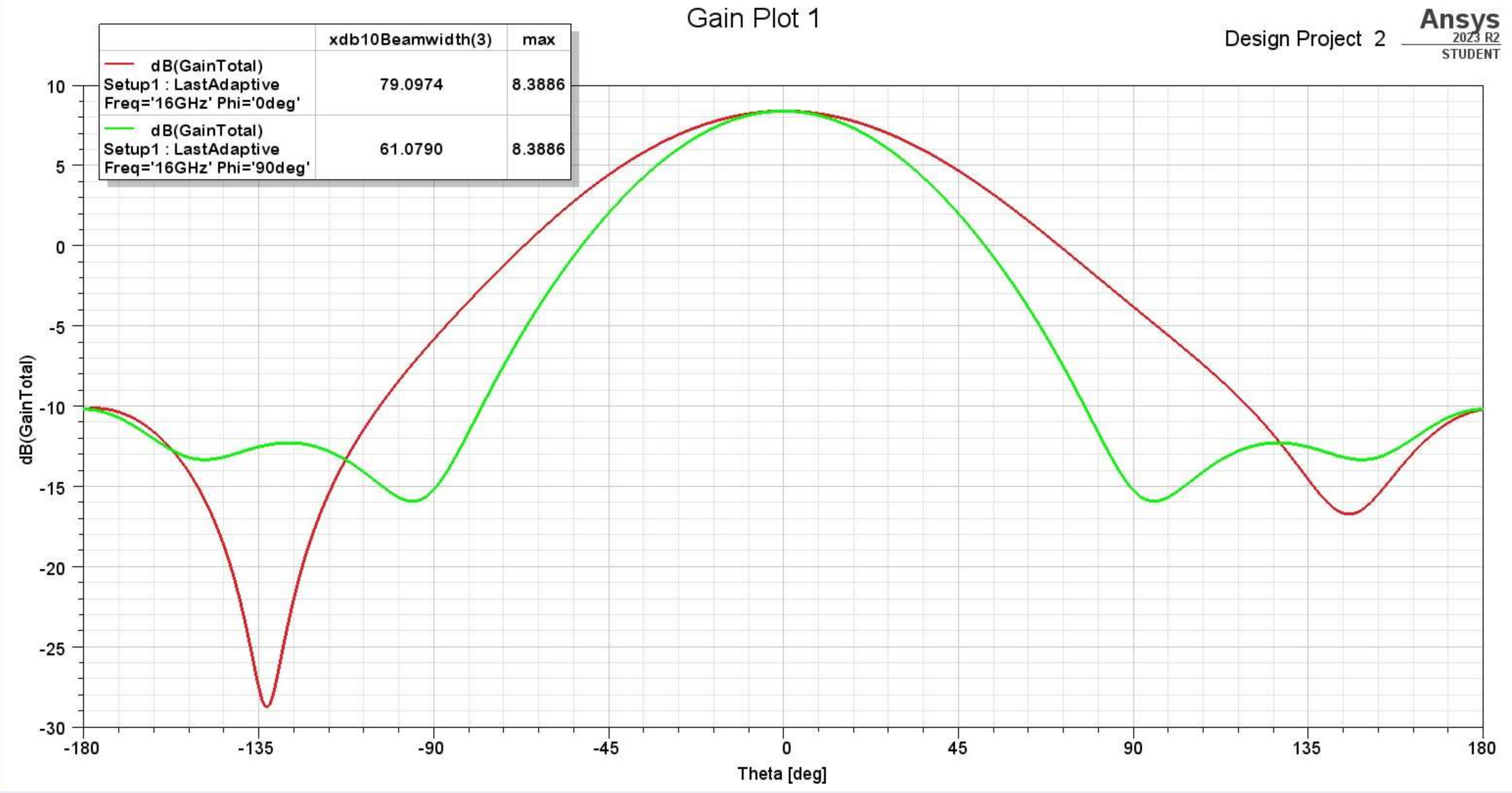

Gain Plot 1
Design Project 2
Ansys
2023 R2
STUDENT
xdb10Beamwidth(3)
max
dB(GainTotal)
Setup1 : LastAdaptive
Freq='16GHz' Phi='0deg'
79.0974
8.3886
dB(GainTotal)
Setup1 : LastAdaptive
Freq='16GHz' Phi='90deg'
61.0790
8.3886
10
5
0
-5
-10
-15
-20
-25
-30
dB(GainTotal)
-180
-135
-90
-45
0
45
90
135
180
Theta [deg]

Table 1

Parameter	Calculated	
f_0	16	GHz
h	0.508	mm
ε_r	2.2	
λ_g	12.632482	mm
L_e	6.316241	mm
W'	9.4743615	mm
ε_r^{eff}	2.068033	
ΔL	266.272104	μm
L_p	5.78369	mm
W	8.67554	mm
R_{edge}	189.33921	Ω
x_f	0.270	mm

Table 2

Parameter	Initial Design	Final Design	
W	8.67554	8.5956033	mm
L_e	6.316241	6.262947717	mm
ΔL	266.272104	266.2721	μm
L_p	5.78369	5.7304033	mm
x_f	0.270	1.70775	mm

Table 3

Parameter	HFSS	
G	6.9002	W/W
G	8.3886	dB
BW_{EP}	61.0790	$\circ$
BW_{HP}	79.0974	$\circ$

Table 4

Parameter	Calculated	HFSS	
BW_f	628.492714	625.00000	MHz
BW_f	3.92807	3.8824	%

① $\lambda_{FS} = \mu c / f_0$

$$= \frac{2.99792 \times 10^{8} \times 10^{3}}{16 \times 10^{9}} = \frac{2.99792 \times 10^{11}}{16 \times 10^{9}} = 0.18737 \times 10^{2}$$

$\lambda_{FS} = 18.737$

② $\lambda_g = \frac{18.737}{\sqrt{2.2}} = 12.632482$ mm.

③ $L_e = \frac{1}{2} \cdot \lambda_g$

$= \frac{1}{2} \times 12.632482.$

$= 6.316241$ mm.

④ $W' = 1.5 \times L_e$

$= 1.5 \times 6.316241$

$= 9.4743615$ mm.

⑤ $\varepsilon_r^{eff} = \left[\left(\frac{1}{2}\right)(\varepsilon_r + 1)\right] + \left[\left(\frac{1}{2}\right)(\varepsilon_r - 1)\right]\left[1 + 12\left(h/w'\right)\right]^{-1/2}$

$= \left[\left(\frac{1}{2}\right)(2.2 + 1)\right] + \left[\left(\frac{1}{2}\right)(2.2 - 1)\right]\left[1 + 12\left(\frac{0.508}{9.4743615}\right)\right]^{-1/2}$

$= 1.6 + 0.6\,[1.643420]^{-1/2}.$

$= 2.068033$

6. $\Delta L = 0.412h \left[\frac{\varepsilon_r^{eff} + 0.3}{\varepsilon_r^{eff} - 0.258}\right]\left[\frac{(w'/h) + 0.264}{(w'/h) + 0.8}\right]$

$= 0.412\,(0.508)\left[\frac{2.068033 + 0.3}{2.068033 - 0.258}\right]\left[\frac{18.65031 + 0.264}{18.65031 + 0.8}\right]$

$= 0.209296\,[1.308281]\,[0.972442] \times 10^{3}$

$= 0.266272104 \times 10^{3}$

$= 266.272104\ \mu m.$

7. $L_p = L_e - 2\Delta L$

$= 6.316241 - [2(0.266272104)]$

$= 6.316241 - 1.065088$

$= 5.78369\ mm.$

8. $W = 1.5 \times L_p$

$W = \cancel{8}\,1.5 \times 5.78365$

$= 8.67554\ mm$

```
%------------------------------------------------------
% Srinivas N EE-457 DP 2
%------------------------------------------------------
clearvars
clc
close all
%------------------------------------------------------
G = 10^9;
M = 10^6;
c = 10^-2;
m = 10^-3;
u = 10^-6;
n = 10^-9;
p = 10^-12;
f = 10^-15;
%------------------------------------------------------
f0 = 16*G;
substrate_Thickness = 0.508*m;
er = 2.2; % Duroid 5880
er_t = 2.1; % Teflon
uc = 2.99792458 *10^8; % m/s
n_0 = 376.7303; % Ohms
Z0 = 50;
%------------------------------------------------------
lfs = uc/f0; % Freespace wavelength
ko = 2*pi / lfs; %
hmax = (0.3/(2*pi*sqrt(er)))*lfs; % maximum thickness
%------------------------------------------------------
Print_Real_Unit('lfs',lfs,'m')
Print_Real_Unit('ko',ko,'rad/m')
Print_Real_Unit('hmax',hmax,'m')
```

```
Print_Break
%-------------------------------------------------------
% Design 01
%-------------------------------------------------------
%h = 1.5748*m; %design param
h = 0.508*m;
%-------------------------------------------------------
lambda_g = lfs/sqrt(er);
Le = (1/2)*lambda_g;
W_prime = 1.5*Le;
%-------------------------------------------------------
Er_eff = [(1/2)*(er+1)]+[((1/2)*(er-1))]*[(1+12*(h/W_prime))]^-(1/2);
delta_L = 0.412 * h * ((Er_eff + 0.3) / (Er_eff - 0.258)) * (((W_prime / h) +
 0.264) / ((W_prime / h) + 0.8));
Lp = Le - 2*delta_L;
W = 1.5*Lp;
%-------------------------------------------------------
Print_Real_Unit('Er_eff',Er_eff,'')
Print_Real_Unit('delta_L',delta_L,'m')
Print_Real_Unit('Lp',Lp,'m')
Print_Real_Unit('W',W,'m')

%-------------------------------------------------------
Print_Break
Print_Real_Unit('lambda_g',lambda_g,'m')
Print_Real_Unit('Le',Le,'m')
Print_Real_Unit('W_prime',W_prime,'m')
%-------------------------------------------------------
[Gedge,G1,G12,B1,~,~]=...
 EE457_Microstrip_Patch_Conductance(Le,W,h,ko,lfs,n_0);
Rin = Z0;
```

```
Redge = 1/Gedge;

xf = (Le/pi)*acos(sqrt(Rin/Redge));

x0 = (1/2)*Le - xf;

Gedge = 2*(G1+G12);

%-----------------------------------------------------

Print_Break

Print_Real_Unit('G1',G1,'S')

Print_Real_Unit('G12',G12,'S')

Print_Real_Unit('B1',B1,'S')

Print_Real_Unit('Gedge',Gedge,'S')

Print_Real_Unit('Redge',Redge,'Ohm') % Resistance at the edge of the patch

Print_Real_Unit('xf',xf,'m')

 lfs = 18.7370 mm

 ko = 335.3352 rad/m

 hmax = 603.1575 um

 ---------------------------------------------------------------

 Er_eff = 2.0680

 delta_L = 266.272104 um

 Lp = 5.78369 mm

 W = 8.67554 mm

 ---------------------------------------------------------------

 lambda_g = 12.632482 mm

 Le = 6.316241 mm

 W_prime = 9.4743615 mm

 ---------------------------------------------------------------

 G1 = 2.0849 mS

 G12 = 569.1455 um

B1 = 4.4371 mS

Gedge = 5.3081 mS

 Redge = 189.33921 Ohm

 xf = 2.0700 mm
```

```
lambda0 = lfs;

f0 = 16*G;

BWf = 3.7771 * ((er - 1) / (er^2)) * (h / lambda0) * ( W/Lp) * f0;

BWp = (BWf*100)/f0;

Print_Real_Unit('BWf',BWf,'Hz')

Print_Real_Unit('BWp',BWp,'%')

 BWf = 628.492714 MHz

 BWp = 3.92807 %
```