Advanced Antenna Engineering

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I, the undersigned Tong Lin
ID n. (matricola) 287649
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By submitting this course assignment material,

I declare (*dichiarazione sostitutiva di atto notorio*) that:

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1. TL I understand that plagiarism is the presentation of the work, idea or creation of another person or organization as though it is my own. It is a form of cheating and is a very serious academic offence that will lead to disciplinary action;
2. TL The submitted material is my original work and no part of it has been copied from any other source except where due acknowledgement is made (see item 4 below on how to acknowledge use of allowed sources);
3. TL With reference to the above, in particular: I have neither used, nor taken inspiration from codes (like Matlab scripts) written by others (e.g. Classmates), or written by me in collaboration with others;
4. TL In carrying out the tasks of this submitted material I have used only: a) the material(s) provided by the official course instructor(s) via the official course webpage, that does not need referencing; b) materials publicly available[3] (published books, journal papers, etc.) as duly acknowledged below. Any material in b) above MUST be clearly listed and precisely referenced in a separate sheet, signed at bottom, to be attached to the submitted paper as an Appendix. Absence of such an Appendix is a declaration that only materials in a) have been used;
5. TL I understand that my submitted material will be compared and archived for plagiarism detection and benchmarking;
6. TL I have not communicated anything with and will not communicate with anyone concerning this assignment for any reason; exceptions: course Instructor(s) and registered course classmates;
7. TL I have discussed this assignment with the persons listed below[4],[5]; this item cannot be left blank: enter "none" if appropriate:

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TONG LIN
(Complete name, please print)

全霖. Tong Lin signature[6]

Torino, 17/12/2021 (date)

[6] If your National language is not written in Latin characters (e.g. Chinese, Arabic), you must sign both with your name in Latin characters and as you sign official documents in your National language

Assignment 4

Problem 1

1) By setting $N=4$, visible range $\psi \in [-kd+\Phi, kd+\Phi]$, to achieve that the Grating Lobe entering the visible range and a side lobe not higher than others, we can get $\frac{d}{\lambda} = 0.8043$, as plotted with Matlab.

2) ① HPBW $\approx |98.91 - 80.89| = 18.02°$
(According to Figure 1.3: Array Factor [dB]).

② SLL $= 10\log_{10}(0.2722) \approx -13.01$ dB
(According to Figure 1.1: Array Factor, where the maximum side lobe level equals to 0.2722)

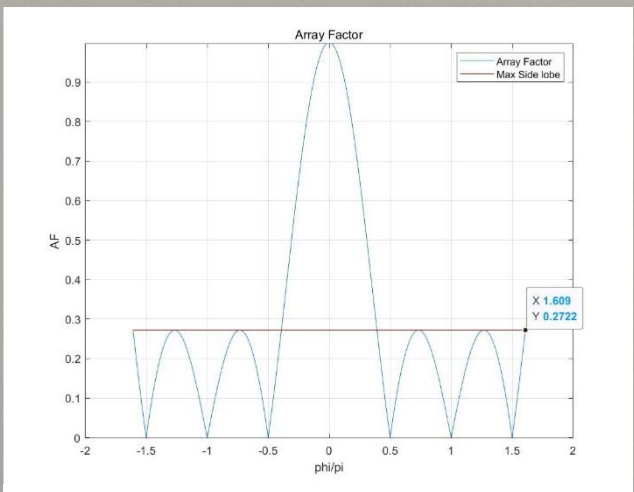


Figure 1.1: Adjusting visible range to visualize the Grating Lobes

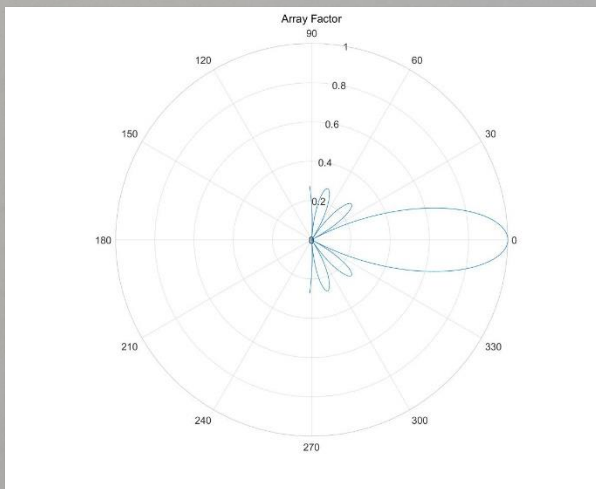


Figure 1.2: Array Factor in polar coordination

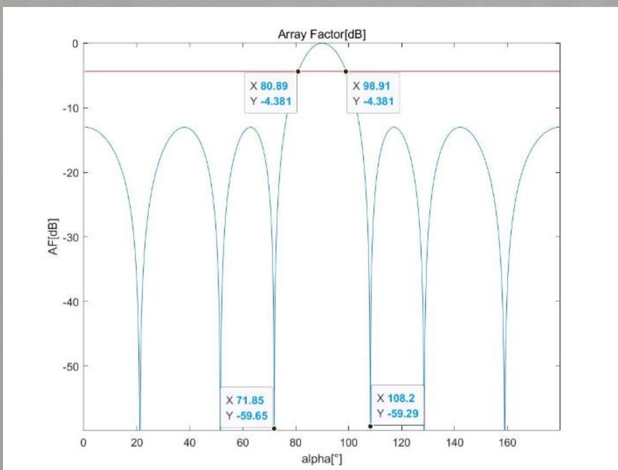
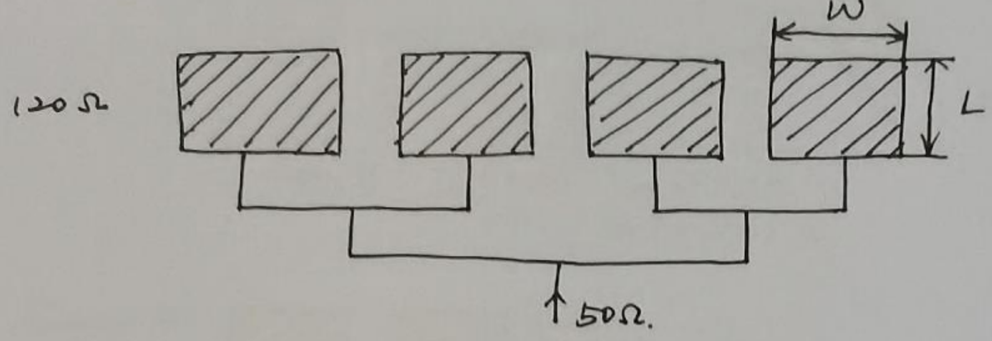


Figure 1.2: Array Factor [dB] to find HPBW

Problem 2



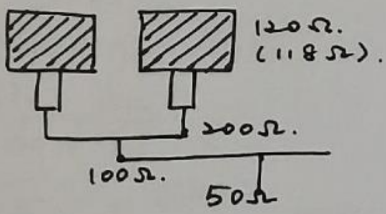
① Patch Design.

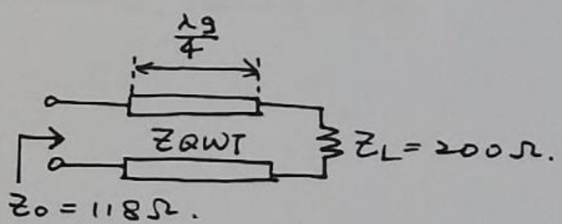
Using the parameters have already calculated in Assignment 2. problem 1, which $\begin{cases} W = 6.47\text{ cm} \\ L = 2.87\text{ cm} \end{cases}$

and the real impendance $Z_{in} = 118\ \Omega$.

② Adapter Position

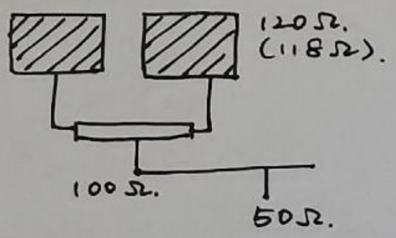
Case 1 :

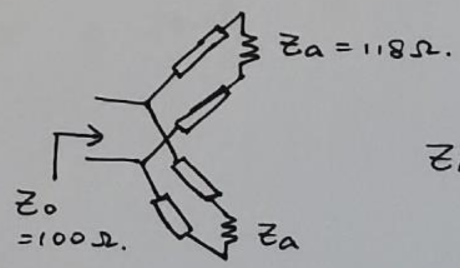




$$Z_{QWT} = \sqrt{Z_0 Z_L} = \sqrt{118 \times 200} \approx 153.62\ \Omega.$$

Case 2 :

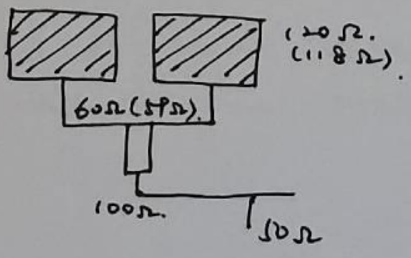


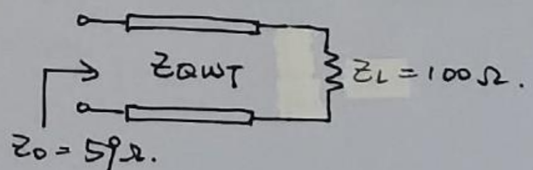


$Z_L = 2Z_a$
$= 236\ \Omega$.

$$Z_{QWT} = \sqrt{Z_0 Z_L} = \sqrt{100 \times 236} \approx 153.62\ \Omega.$$

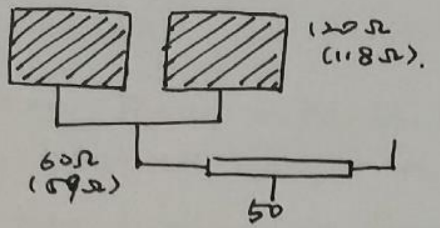
Case 3 :

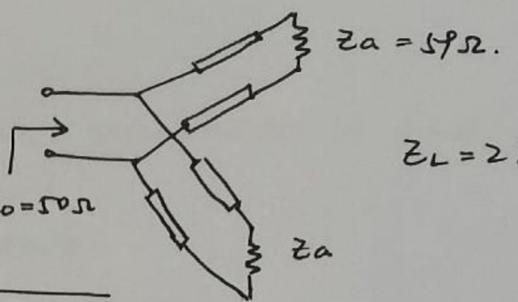




$$Z_{QWT} = \sqrt{Z_0 Z_L} = \sqrt{59 \times 100} \approx 76.81\ \Omega.$$

Case 4:

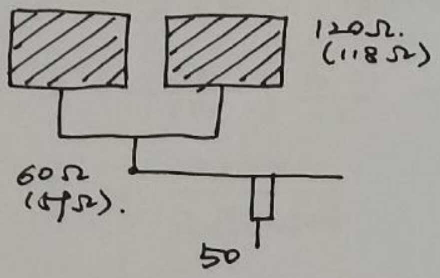


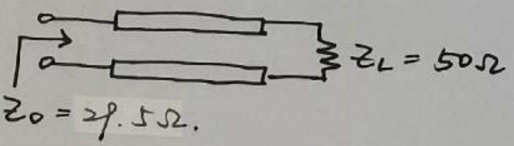


$Z_L = 2Z_a = 118\Omega.$

$$Z_{QWT} = \sqrt{Z_0 Z_L} = \sqrt{50\times 118} \approx 76.8115\Omega.$$

Case 5:





$$Z_{QWT} = \sqrt{Z_0 Z_L} = \sqrt{29.5\times 50} \approx 38.4057\Omega.$$

Verify S11 parameters of these 5 cases, using the formulars below,

$$Z_C = Z_{QWT} = \sqrt{Z_0 Z_L}$$

$$\Gamma_{B^-} = \frac{Z_0 - Z_C}{Z_0 + Z_C}$$

$$\Gamma_{A^+} = \Gamma_{B^-} \cdot e^{-2jkl}, \quad \text{where } l = \frac{\lambda_0}{4} = \frac{\frac{v_p}{f_0}}{4}, \quad k = \frac{2\pi}{\lambda} = \frac{2\pi}{\frac{v_p}{f}}$$

therefore, $\Gamma_{A^+} = \Gamma_{B^-} \cdot e^{-j\pi \cdot \frac{f}{f_0}}$.

$$z_{A^+} = \frac{1 - \Gamma_{A^+}}{1 + \Gamma_{A^+}}$$

$$Z_A = Z_C \cdot z_{A^+}$$

$$\Gamma_{A^-} = S_{11} = \frac{Z_A - Z_0}{Z_A + Z_0}$$

Using Matlab to plot the final results. where in case 1, 3, 5 have lower S11. Finally, choosing case 3 as the adapter position.

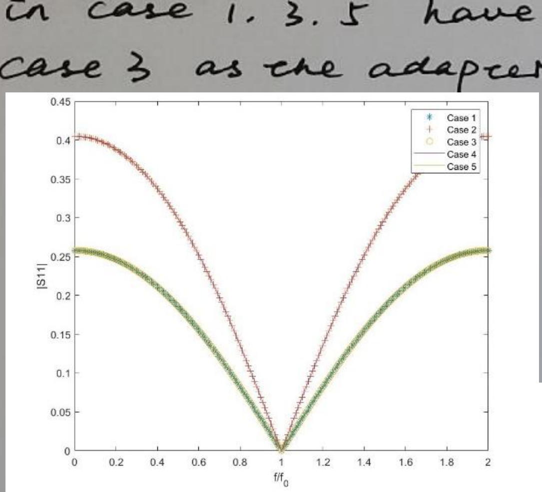


Figure 2.1: S11 parameters for the five cases

③ Adapter Design.

To achieve $Z_{QWT} = 76.815\,\Omega$, suitable W and L values should be found.

Using the microstrip formulars:

$$\frac{W}{h} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & (\frac{W}{h} < 2) \\ \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\varepsilon_r-1}{2\varepsilon_r}\cdot C\right] & (\frac{W}{h} > 2). \end{cases}$$

with $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right)$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

$$C = \ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}$$

Receiving to result: $\frac{W}{h} = 0.8686$, with $h = 1.55$ mm,

so $W = 0.0013$ m. $= 1.3$ mm.

$$L = \frac{\lambda g}{4} = \frac{1}{4}\frac{\lambda_0}{\sqrt{\varepsilon_r}} = \frac{1}{4}\frac{\frac{c}{f_0}}{\sqrt{\varepsilon_r}} = 17.3\text{ mm}.$$

④ Strip lines Design.

With the microstrip formulars, the width of the strip lines on different positions can also be calculated.

$$\begin{cases} W_{L1} = 4.3148\times10^{-4}\,\text{m} = 0.43148\text{ mm} \\ W_{L2} = 7.0599\times10^{-4}\,\text{m} = 0.70599\text{ mm} \\ W_{L3} = 0.0030\text{ m} = 3\text{ mm}. \end{cases}$$

Finally, using CST to draw the entire Beam Forming Network.

In the simulation, I used $\begin{cases} W = 0.067\text{m} = 67\text{mm} \\ L = 0.027\text{m} = 27\text{mm} \end{cases}$ to achieve a more suitable radiation pattern.

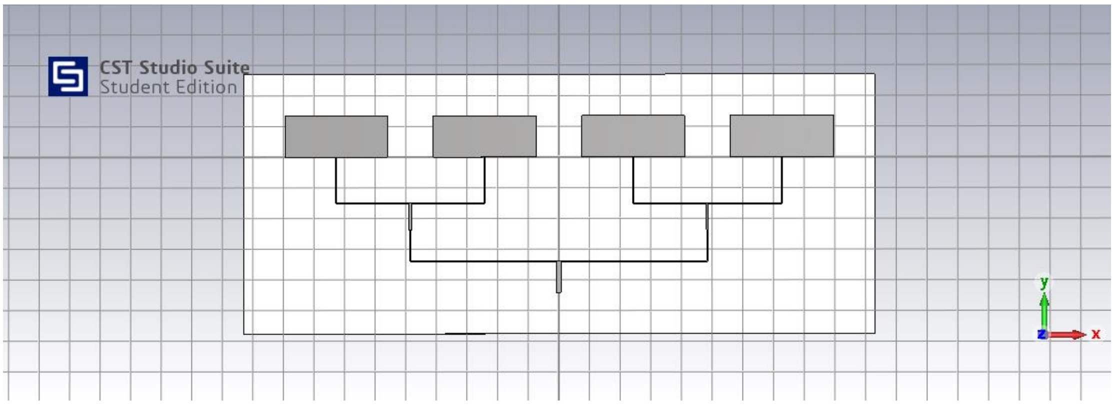


Figure 2.2: Beamform Network Figure drawn in CST

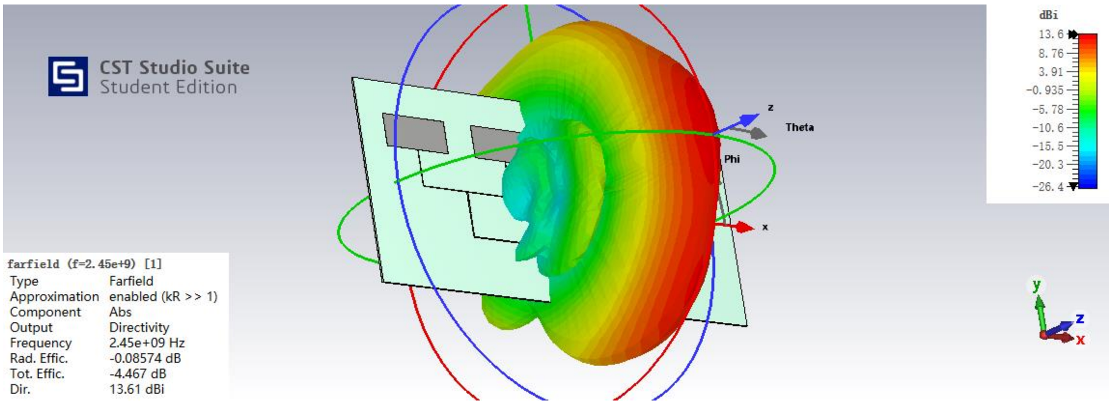


Figure 2.3: Radiation Pattern of Simulation

Name	Expression	Value	Description
lamuda0	= 3e8/2450e6	0.122448979591837	
W	= 0.067	0.067	
L	= 0.027	0.027	
gap	= 0.03	0.03	
Wl1	= 4.3148e-4	4.3148e-4	
Wl2	= 7.0599e-4	7.0599e-4	
Wl3	= 0.0030	0.0030	
Ll1	= 0.03	0.03	
Ll2	= 0.02	0.02	
Ll3	= 0.02	0.02	
Wad	= 0.0013	0.0013	
Lad	= 0.0173	0.0173	
t	= 0.1e-3	0.1e-3	
h	= 1.55e-3	1.55e-3	

Figure 2.4: Simulation Parameters

Appendix: Matlab codes

Problem 1

```
clear all;
close all;
clc

%---------------p1.1----------------
j = sqrt(-1);
N = 4;            %4
d_lamuda = 0.8043;    %0.8043
PHI = 0;        %0
alp = 0:0.001:pi;

phi_v = (-2*pi*d_lamuda+PHI):0.001:(2*pi*d_lamuda+PHI);
alp_v = acos(phi_v/(2*pi*d_lamuda));
phi = 2*pi*d_lamuda*cos(alp)+PHI;
F_N = (1/N)*abs(sin(N*phi_v/2)./sin(phi_v/2));
F_Ndb = 10*log(F_N);
figure
plot(phi_v/pi,F_N);
xlabel('phi/pi');
ylabel('AF');
title('Array Factor');
grid on
hold on
y = zeros(1,10108)+0.2722;
plot(phi_v/pi,y,'r');
legend('Array Factor','Max Side lobe');
figure
plot(alp_v*180/pi,F_Ndb);
axis([0 180 -60 0]);
xlabel('alpha[¡ã]');
ylabel('AF[dB]');
title('Array Factor[dB]');
hold on
ydb = zeros(1,10108)-4.381;
plot(alp_v*180/pi,ydb,'r');
figure
polarplot(phi_v/pi,F_N);
title('Array Factor');
```

Problem 2

```
clear all;
close all;
clc

%1
Z0 = 118;
ZL = 200;
ZC = sqrt(Z0*ZL);

f_f0 = 0:0.01:2;
j = sqrt(-1);
kl = f_f0*pi/2;
gammaBjian = (Z0-ZC)/(Z0+ZC);
gammaAjia = gammaBjian*exp(-j*pi*f_f0);
xishu = (1-gammaAjia)./(1+gammaAjia);
ZA = ZC*xishu;
S11 = (ZA-Z0)./(ZA+Z0);
S11dB = 10*log(abs(S11));
plot(f_f0,abs(S11),'*');
hold on

%2
Z0 = 100;
ZL = 236;
ZC = sqrt(Z0*ZL);

f_f0 = 0:0.01:2;
j = sqrt(-1);
kl = f_f0*pi/2;
gammaBjian = (Z0-ZC)/(Z0+ZC);
gammaAjia = gammaBjian*exp(-j*pi*f_f0);
xishu = (1-gammaAjia)./(1+gammaAjia);
ZA = ZC*xishu;
S11 = (ZA-Z0)./(ZA+Z0);
S11dB = 10*log(abs(S11));
plot(f_f0,abs(S11),'+');
hold on

%3--chosen
Z0 = 59;
ZL = 100;
ZC = sqrt(Z0*ZL);
```

```
f_f0 = 0:0.01:2;
j = sqrt(-1);
kl = f_f0*pi/2;
gammaBjian = (Z0-ZC)/(Z0+ZC);
gammaAjia = gammaBjian*exp(-j*pi*f_f0);
xishu = (1-gammaAjia)./(1+gammaAjia);
ZA = ZC*xishu;
S11 = (ZA-Z0)./(ZA+Z0);
S11dB = 10*log(abs(S11));
plot(f_f0,abs(S11),'o');
hold on

%4
Z0 = 50;
ZL = 118;
ZC = sqrt(Z0*ZL);

f_f0 = 0:0.01:2;
j = sqrt(-1);
kl = f_f0*pi/2;
gammaBjian = (Z0-ZC)/(Z0+ZC);
gammaAjia = gammaBjian*exp(-j*pi*f_f0);
xishu = (1-gammaAjia)./(1+gammaAjia);
ZA = ZC*xishu;
S11 = (ZA-Z0)./(ZA+Z0);
S11dB = 10*log(abs(S11));
plot(f_f0,abs(S11));
hold on

%5
Z0 = 29.5;
ZL = 50;
ZC = sqrt(Z0*ZL);

f_f0 = 0:0.01:2;
j = sqrt(-1);
kl = f_f0*pi/2;
gammaBjian = (Z0-ZC)/(Z0+ZC);
gammaAjia = gammaBjian*exp(-j*pi*f_f0);
xishu = (1-gammaAjia)./(1+gammaAjia);
ZA = ZC*xishu;
S11 = (ZA-Z0)./(ZA+Z0);
S11dB = 10*log10(abs(S11));
plot(f_f0,abs(S11));
```

```
hold on
legend('Case 1','Case 2','Case 3','Case 4','Case 5');
xlabel('f/f_0');
ylabel('|S11|');
%Width of the adapter
Zinf = 76.8115;
ypsr = 4.3;
A = Zinf*sqrt((ypsr+1)/2)/60+(ypsr-1)*(0.23+0.11/ypsr)/(ypsr+1);
B = 377*pi/(2*Zinf*sqrt(ypsr));
C = log(B-1)+0.39-0.61/ypsr;
W_h_xiaoyu2 = 8*exp(A)/(exp(2*A)-2);         %this one
W_h_dayu2 = 2*(B-1-log(2*B-1)+(ypsr-1)*C/(2*ypsr))/pi;
h = 1.55e-3;
W = W_h_xiaoyu2*h;
%length of the adapter
ypsreff = (ypsr+1)/2+(ypsr-1)*(1+10*h/W)^(-0.5)/2;
lamuda0 = 3e8/2450e6;
lamudag = lamuda0/sqrt(ypsreff);
L = lamudag/4;

%Width of l1
Zl1 = 118;
A = Zl1*sqrt((ypsr+1)/2)/60+(ypsr-1)*(0.23+0.11/ypsr)/(ypsr+1);
B = 377*pi/(2*Zl1*sqrt(ypsr));
C = log(B-1)+0.39-0.61/ypsr;
W_h_xiaoyu2 = 8*exp(A)/(exp(2*A)-2);         %this one
W_h_dayu2 = 2*(B-1-log(2*B-1)+(ypsr-1)*C/(2*ypsr))/pi;
Wl1 = W_h_xiaoyu2*h;

%Width of l2
Zl2 = 100;
A = Zl2*sqrt((ypsr+1)/2)/60+(ypsr-1)*(0.23+0.11/ypsr)/(ypsr+1);
B = 377*pi/(2*Zl2*sqrt(ypsr));
C = log(B-1)+0.39-0.61/ypsr;
W_h_xiaoyu2 = 8*exp(A)/(exp(2*A)-2);         %this one
W_h_dayu2 = 2*(B-1-log(2*B-1)+(ypsr-1)*C/(2*ypsr))/pi;
Wl2 = W_h_xiaoyu2*h;

%Width of l3
Zl3 = 50;
A = Zl3*sqrt((ypsr+1)/2)/60+(ypsr-1)*(0.23+0.11/ypsr)/(ypsr+1);
B = 377*pi/(2*Zl3*sqrt(ypsr));
C = log(B-1)+0.39-0.61/ypsr;
W_h_xiaoyu2 = 8*exp(A)/(exp(2*A)-2);         %this one
```

```
W_h_dayu2 = 2*(B-1-log(2*B-1)+(ypsr-1)*C/(2*ypsr))/pi;
Wl3 = W_h_xiaoyu2*h;
```

Reference:

1. linear_AF_7x3.pdf, in section ‘Handouts’;
2. microstrip_formulas_v2x0.pdf, in section ‘Handouts’;
3. BFN_v4x6.pdf, in section ‘Handouts’;
4. AAE_Assignment 0;
5. AAE_Assignment 2;
6. AAE_Assignment 3;
7. AAE_Lab2

Discussed with student Zhang Zhifan.