Advanced antenna engineering

Assignment 2. Patch

Student: Tong Lin

ID: S287649

Declaration:

References: Slides from the file ‘Handouts’

1. patch design 3.5.pdf
2. patch_SRTLmodel_6x5.pdf

Discussed: with student Zhang Zhifan.

Assignment 2. Patch TONG LIN S287649

Problem 1

a) Design a rectangular patch antenna: width. length.

$$L \approx 0.5 \frac{\lambda_0}{\sqrt{\varepsilon_r}} = 0.5 \frac{\frac{c}{f}}{\sqrt{\varepsilon_r}} \approx 0.0295 [m]$$

① w1

Using the formulars:

$$L = 0.0295 = \frac{1}{2} \lambda_g^p (f_R) - 2\Delta L$$

$$\lambda_g^p = \frac{\lambda_0}{\sqrt{\varepsilon_{r,eff}}}$$

$$\Delta L = 0.412 \times h \cdot \frac{(\varepsilon_{r,eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{r,eff} - 0.258)(\frac{W}{h} + 0.8)}$$

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12 \cdot \frac{h}{W}}}$$

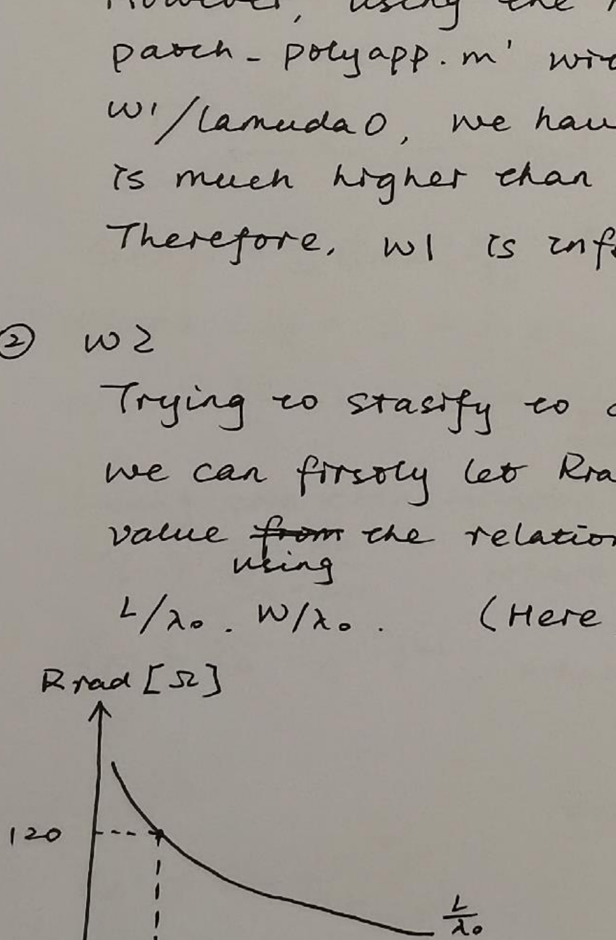
Using Matlab. we can get $w1 = 0.0263$ [m]

However, using the Matlab function of Grad. 'grad_patch_polyapp.m' with ~~the~~ values L/lamuda0, w1/lamuda0, we have $Zin(f_0) = R_0 = 1366\,\Omega$. which is much higher than $120\,\Omega$.

Therefore, w1 is infeasible.

② w2

Trying to stasify to constrain $R_0 = Zin(f_0) \le 120\,\Omega$, we can firstly let $R_{rad} = 120$ to get an approximate value ~~from~~ using the relation graph between Rrad and L/λ_0. W/λ_0. (Here, R_0 actually equals to Rrad + loss).



$$\begin{cases} R_{rad} = 120\,\Omega \\ \frac{L}{\lambda_0} = 0.2411 \end{cases}$$

We can get, $w2 = 0.0624$ [m]

Accordingly, $R_0 = 129.8\,\Omega > 120\,\Omega$, which is also infeasible.

1

③ W_3

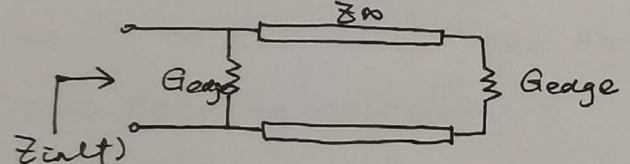
Try with a square patch this time, where $W_3 = L = 0.0295\,m$, then $R_0 = Z_{in}(f_0) = 744.7\,\Omega > 120\,\Omega$, which is also infeasible.

Finally, to achieve the condition $Z_{in}(f_0) = R_0 \leq 120\,\Omega$, from the plotted graph in problem 1, question b1, of $Z_{in}(f)$, a more suitable value can be found, which $W = 0.066\,m$, where $Z_{in}(f_0) = R_0 = 118.8\,\Omega \leq 120\,\Omega$.

Therefore, in this case: $\begin{cases} L = 0.0295\,m \\ W = 0.0660\,m \end{cases}$

b1) $Z_{in}(f)$

The transmission line model is shown as,



$$G_{edge} = \frac{1}{2} G_{rad}\left(\frac{W}{\lambda_0}, \frac{L_{eff}}{\lambda_0}\right)$$

where $L_{eff} = L + 2 \cdot \Delta L$

With $\frac{W}{h} \geq 1$, $Z_\infty = \dfrac{120\pi}{\sqrt{\varepsilon_{r,eff}}\left[\frac{W}{h} + 1.393 + 0.667\ln\left(\frac{W}{h} + 1.444\right)\right]}$

Using the transmission line formulars:

$$\Gamma_{B^-} = \frac{Z_s - Z_\infty}{Z_s + Z_\infty}, \quad \text{where } Z_s = \frac{1}{G_{edge}}$$

$$\Gamma_{A^+} = \Gamma_B^- \cdot e^{-2jkl}, \quad \text{where } k = \frac{2\pi f}{v_p} = \frac{2\pi f\sqrt{\varepsilon_r}}{c}$$

$$l = 0.5\,\frac{\frac{c}{f_0}}{\sqrt{\varepsilon_r}}$$

$$\text{so, } kl = \pi \cdot \frac{f}{f_0}$$

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

$$Y_{A^+} = \frac{1}{Z_{A^+}}$$

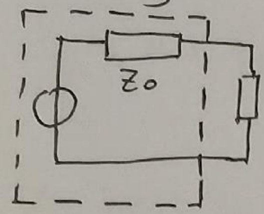
$$Y_{in} = Y_{A^+} + G_{edge}$$

$$Z_{in} = \frac{1}{Y_{in}}$$

The figure of $\frac{f}{f_0} - Z_{in}(\frac{f}{f_0})$ can be plotted using Matlab.

b2) Return loss RL ; Bandwidth (VSWR ≤ 2).

① Using the follow formulars to compute RL,



$$Z_0 = R_0 = Z_{in}(f_0) = 120\,\Omega$$

$$S_{11}(f) = \frac{Z_a(f) - Z_0}{Z_a(f) + Z_0}, \quad \text{where } Z_a(f) = Z_{in}(f).$$

$$RL(f) = |S_{11}(f)|^2$$

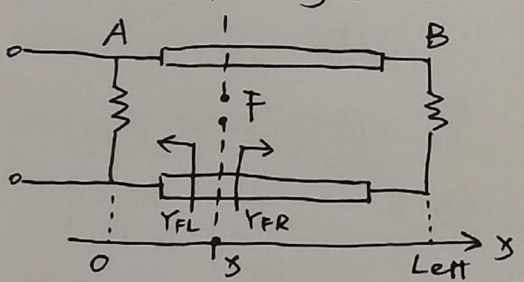
The figure of $\frac{f}{f_0}$ - $RL(\frac{f}{f_0})$ can be plotted by Matlab. At centerband frequency, $RL = -46.25$ dB.

② As $VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \leq 2$

Using Matlab to plot the figure $\frac{f}{f_0}$ - $VSWR(\frac{f}{f_0})$, finding where VSWR = 2 in the figure, we can then get the bandwidth $[0.889 f_0, 1.11 f_0]$, which the absolute value is [2178.05 MHz, 2719.5 MHz], which is approximately ±11%.

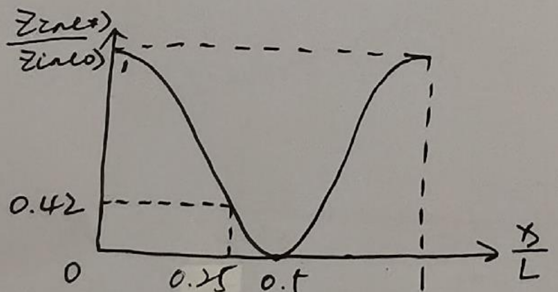
b3) $L_{eff} = L$ to plot $Z_{in}(f)$, the figure scale is slightly smaller.

c) Probe feeding position: x.

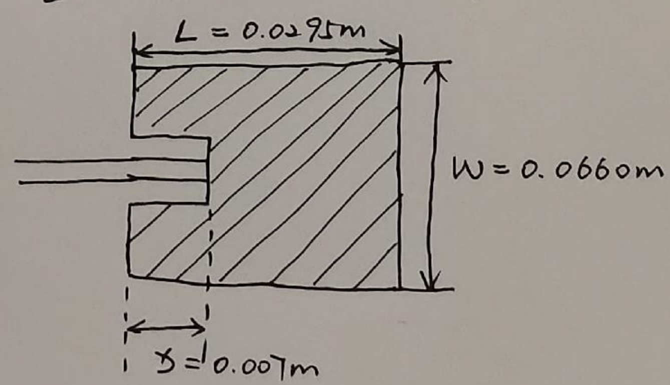


Using the grap $\frac{x}{L}$ - $\frac{Z_{in}(x)}{Z_{in}(0)}$, where $Z_{in}(x) = 50\,\Omega$,

$Z_{in}(0) = R_0 = 118.8\,\Omega$, so $\frac{Z_{in}(x)}{Z_{in}(0)} = \frac{50\,\Omega}{118.8\,\Omega} \approx 0.42$.



$\frac{x}{L} = 0.25$, $x = 0.0077$ m



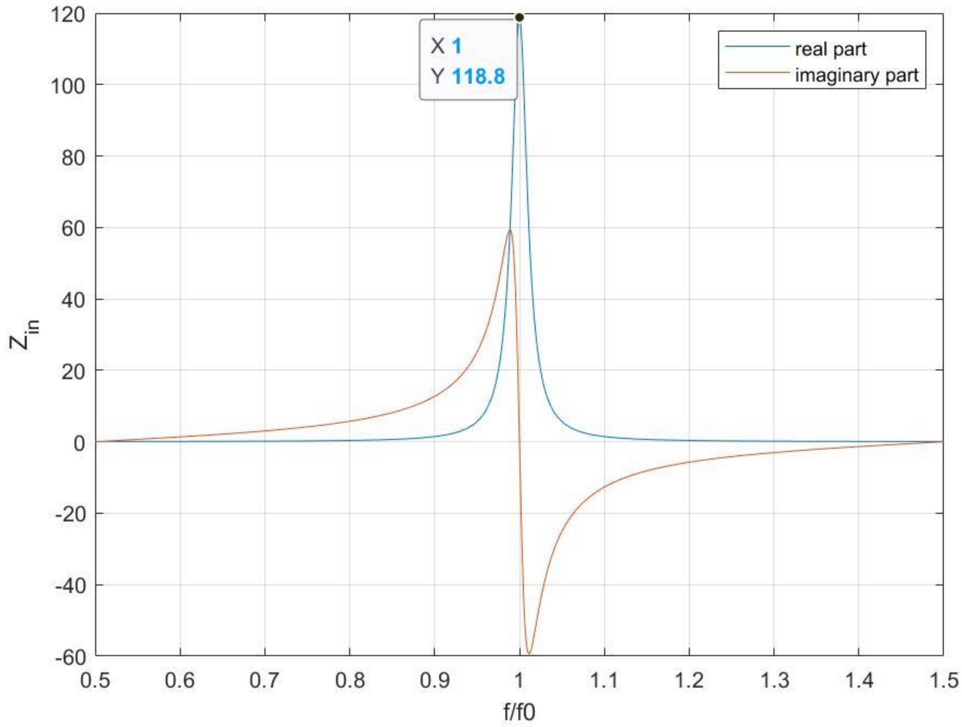


Figure 1. Problem1,Question b1) – Real and Imaginary part of input impendence

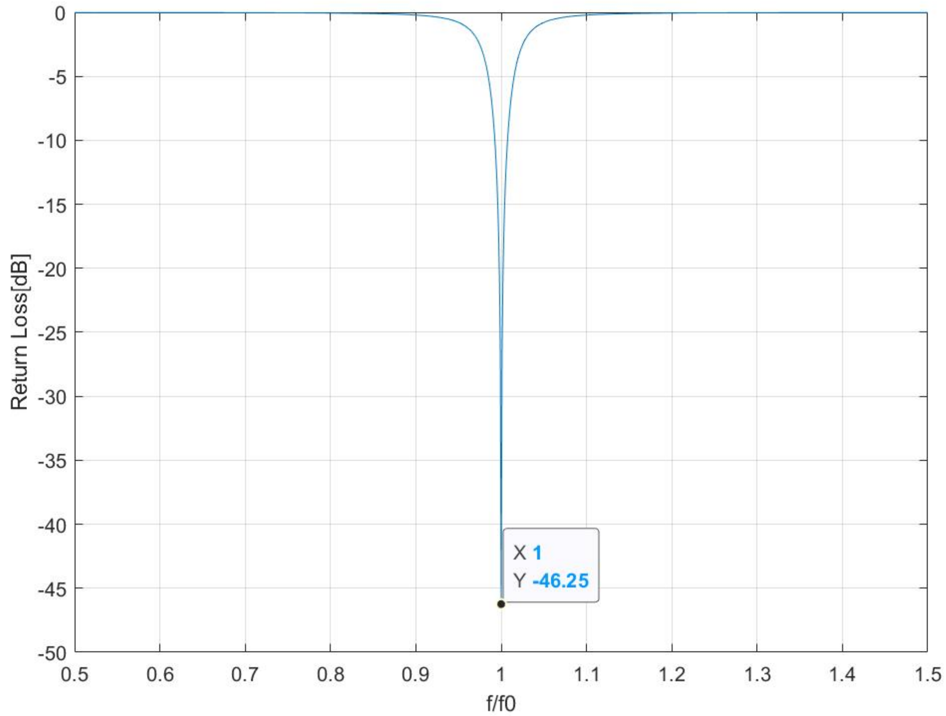


Figure 2. Problem 1, Question b2) – Return Loss

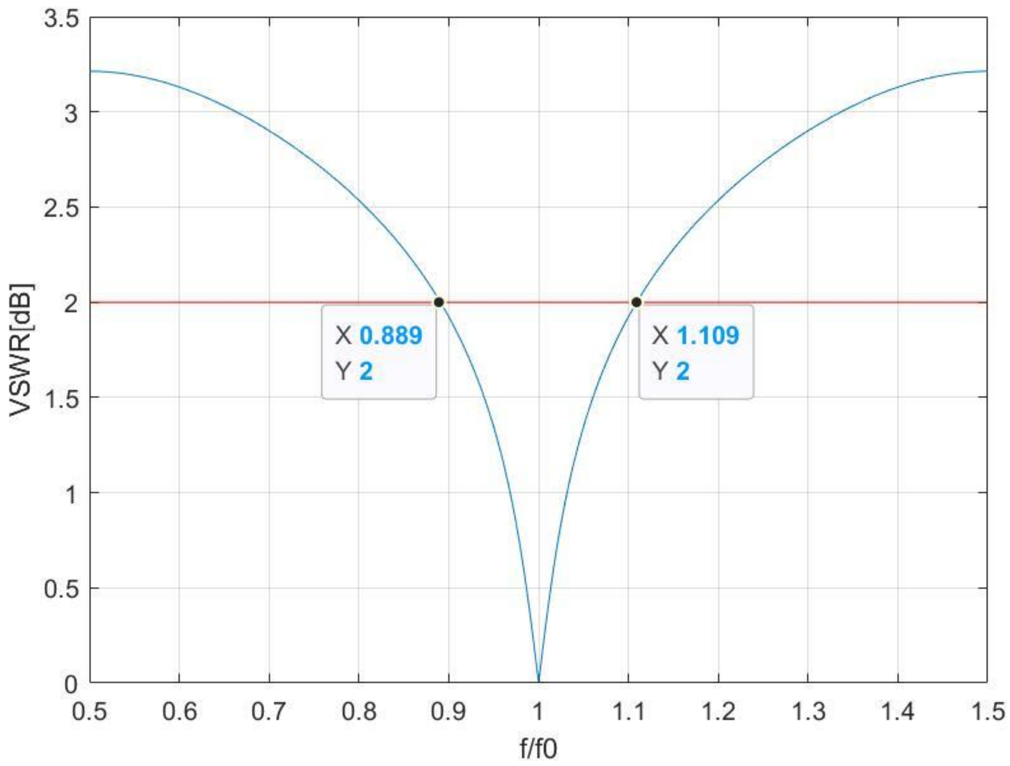


Figure 3. Problem 1, Question b2) – VSWR

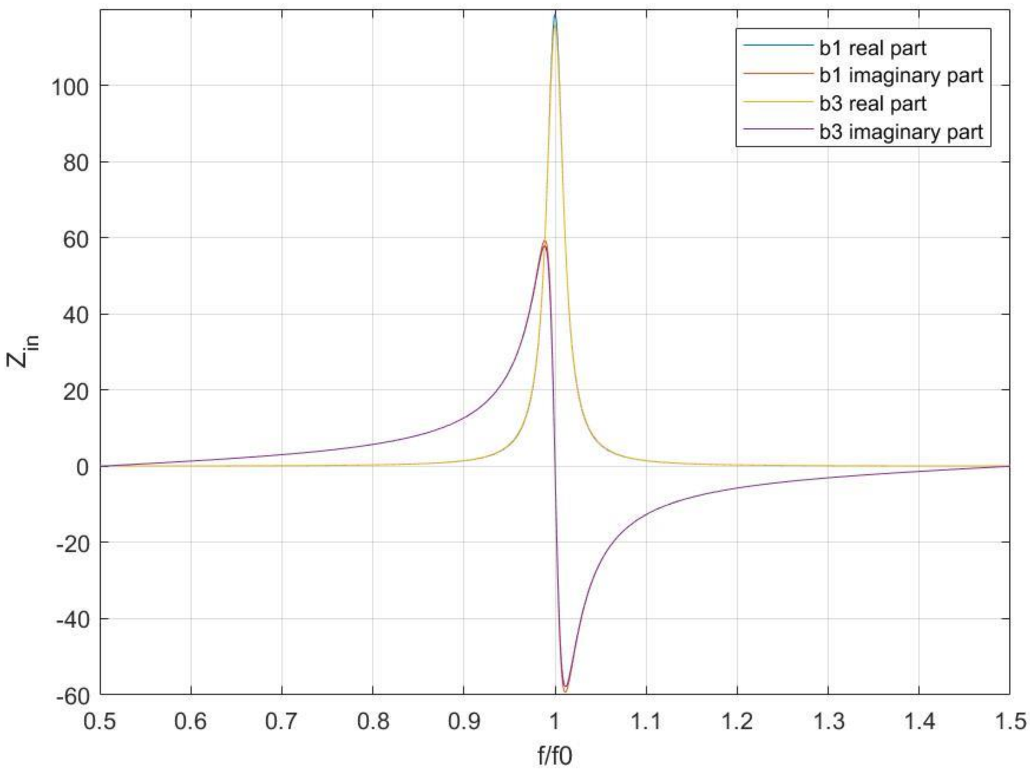


Figure 4. Problem 1, Question b3) – Input impendence with Leff = L

Problem 2

a) Design : width & length

$$L \approx 0.5 \frac{\lambda_0}{\sqrt{\varepsilon_r}} \quad , \text{where } \lambda_0 = \frac{c}{f_0}$$

$$\varepsilon_{r,air} = 1$$

As this is a square patch, so $W = L$.

We can then get $\begin{cases} L = 0.0612 \text{ m} \\ W = 0.0612 \pm 5\% \text{ m} \end{cases}$

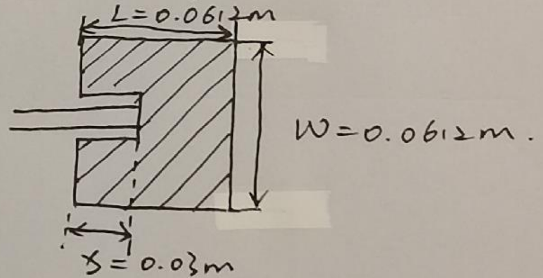
b) Probe Position : x

Using the relationship $\frac{R_{rad}(x)}{R_{rad}(0)} \approx \cos^4(\pi \frac{x}{L})$

where $R_{rad}(x) = 50\,\Omega$

$$R_{rad}(0) = \frac{1}{G_{rad}(\frac{W}{\lambda_0}, \frac{L_{eff}}{\lambda_0})} \approx 420.89\,\Omega.$$

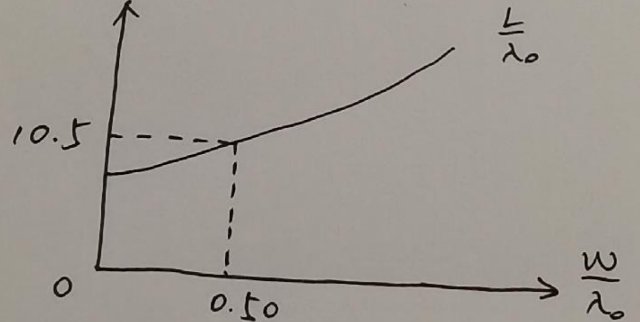
Therefore, $\frac{x}{L} \approx 0.3880$, $x = 0.03\text{m}$



c) Max gain : G_{max}.

Using the grap $\frac{W}{\lambda_0} - G$ to find G_{max},

where $\begin{cases} \frac{L}{\lambda_0} = 0.63 \\ \frac{W}{\lambda_0} = 0.50 \end{cases}$



We can get an approximate value, $G_{max} \approx 10.5\,dB$.

Appendix: Matlab Codes

Matlab Code for Problem 1:

```
clear all;
close all;
clc

%P1-a: design
j = sqrt(-1);
c = 3e8;    %[m/s]
f0 = 2450e6;    %[Hz]
lamuda0 = c/f0;
ypr = 4.3;
L = 0.5*lamuda0/sqrt(ypr);
h = 1.55e-3;    %[m]

syms w_h1
ypr_eff = (ypr+1)/2+(((ypr-1)/2)*(1/sqrt((12/w_h1)+1)));
lamuda_g = lamuda0/sqrt(ypr_eff);
delta_L = 0.412*h*(ypr_eff+0.3)*(w_h1+0.264)/((ypr_eff-0.258)*(w_h1+0.8));
eq = L == (0.5*lamuda_g)-(2*delta_L);
x = solve(eq,w_h1);
w_h1 = double(x);
w1 = w_h1*h;

%find the optimum width
L_lamuda0 = L/lamuda0;
w2 = 0.51*lamuda0;      %0.51 -- from the graph
w3 = L;
W_L = [w1 w2 w3]/L;
W_lamuda0 = [w1 w2 w3]/lamuda0;         %try all 3 results to verify the condition of
R0<=120 Ohm
W = 0.066;                  %opt: width=0.066 R0=118.8
W_h = W/h;

%P1-b1: plot Zin
ypr_eff0 = (ypr+1)/2+(((ypr-1)/2)*(1/sqrt((12*h/W)+1)));
delta_L = 0.412*h*(ypr_eff0+0.3)*(W/h+0.264)/((ypr_eff0-0.258)*(W/h+0.8));
L_eff1 = L+2*delta_L;
f_f0 = 0.5:0.001:1.5;
kl = pi*f_f0;
G_rad1 = grad_patch_polyapp(W/lamuda0,L_eff1/lamuda0);
G_edge1 = 0.5*G_rad1;
```

```
Z_C1 = 120*pi/(sqrt(ypr_eff0)*(W/h)+1.393+0.667*log(1.444+W/h));
Z_S1 = 2/G_rad1;
gamma_B1 = (Z_S1-Z_C1)/(Z_S1+Z_C1);
gamma_A1 = gamma_B1*exp(-2*j*kl);
Z_A1 = Z_C1*(1+gamma_A1)./(1-gamma_A1);
Y_A1 = 1./Z_A1;
Y_in1 = Y_A1 + G_edge1;
Z_in1 = 1./Y_in1;

figure
plot(f_f0,real(Z_in1));
hold on
plot(f_f0,imag(Z_in1))
xlabel('f/f0');
ylabel('Z_{in}');
legend('real part','imaginary part');
grid on

%P1-b3 plot the two Zin on the same plot
L_eff3 = L;
G_rad3 = grad_patch_polyapp(W/lamuda0,L_eff3/lamuda0);
G_edge3 = 0.5*G_rad3;
Z_C3 = 120*pi/(sqrt(ypr_eff0)*(W/h)+1.393+0.667*log(1.444+W/h));
Z_S3 = 2/G_rad3;
gamma_B3 = (Z_S3-Z_C3)/(Z_S3+Z_C3);
gamma_A3 = gamma_B3*exp(-2*j*kl);
Z_A3 = Z_C3*(1+gamma_A3)./(1-gamma_A3);
Y_A3 = 1./Z_A3;
Y_in3 = Y_A3 + G_edge3;
Z_in3 = 1./Y_in3;

figure
plot(f_f0,real(Z_in1));
hold on
plot(f_f0,imag(Z_in1))
hold on
plot(f_f0,real(Z_in3));
hold on
plot(f_f0,imag(Z_in3));
xlabel('f/f0');
ylabel('Z_{in}');
legend('b1 real part','b1 imaginary part', 'b3 real part','b3 imaginary part');
grid on
```

```
%P1-b2 Return loss
Z0 = 120;
S11 = (Z_in1-Z0)./(Z_in1+Z0);
RL = 10*log10((abs(S11)).^2);
figure
plot(f_f0,RL);
xlabel('f/f0');
ylabel('Return Loss[dB]');
grid on
%VSWR
VSWR = log10((1+abs(S11))./(1-abs(S11)));
level = 2*ones(1,1001);
figure
plot(f_f0,VSWR);
xlabel('f/f0');
ylabel('VSWR[dB]');
hold on
plot(f_f0,level,'r');
grid on

%P1-c: probe feeding position
R0 = Z_in1(f_f0==1);
position_int = 50/R0;           %find the position x in the graph
x = 0.25*L_eff1                 %x/L = 0.25
```

Matlab Code for Problem 2:

```
clear all;
close all;
clc

%P2-a: design
j = sqrt(-1);
c = 3e8;    %[m/s]
f0 = 2.45e9;    %[Hz]
lamuda0 = c/f0;
ypr = 1;                %air
L = 0.5*lamuda0/sqrt(ypr);
h = 0.1*lamuda0;
W = L;
W_h = W/h;

%P2-b: probe feeding position
ypr_eff0 = (ypr+1)/2+(((ypr-1)/2)*(1/sqrt((12*h/W)+1)));
delta_L = 0.412*h*(ypr_eff0+0.3)*(W/h+0.264)/((ypr_eff0-0.258)*(W/h+0.8));
L_eff = L+2*delta_L;
G_rad = grad_patch_polyapp(W/lamuda0,L_eff/lamuda0);
R_rad = 1/G_rad;
x_cos = 50/R_rad;
x_L = acos(sqrt(x_cos))/pi;
x = x_L*L_eff;

%P2-c: max gain
L_lamuda0 = L_eff/lamuda0;
W_lamuda0 = W/lamuda0;          %Use the graph to find Gmax
```