Microwave Laboratory
Experiment-2_B
Design of passive components based on Microstrip Line

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Software used: HFSS 15.0

- ## <u>Quarter Wave:</u>

Objective:

- To design a quarter-wavelength impedance transformer to match source impedance(100 ohm) with real load impedance(50 ohm).

Components:

- Section of microstrip line of characteristic impedance as specified on the substrate, port impedances(50 ohm,100 ohm), quarter-wave transformer design to match a 100 ohm impedance at a given frequency.

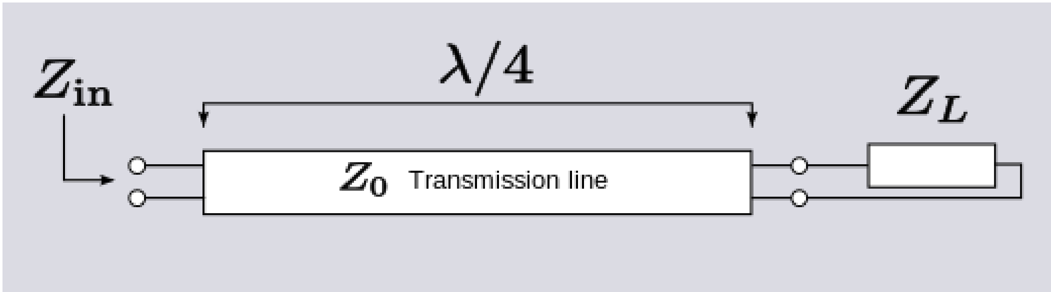
Brief theory:

A **quarter-wave impedance transformer**, often written as **λ/4 impedance transformer**, is a transmission line or waveguide used in electrical engineering of length one-quarter wavelength(λ), terminated with some known impedance. It presents at its input the dual of the impedance with which it is terminated.

It is a similar concept to a stub; but, whereas a stub is terminated in a short (or open) circuit and the length is chosen so as to produce the required impedance, the λ/4 transformer is the other way around; it is a predetermined length and the termination is designed to produce the required impedance.

The relationship between the characteristic impedance, Z_0, input impedance, Z_{in} and load impedance, Z_L is:

$$\frac{Z_{\text{in}}}{Z_0} = \frac{Z_0}{Z_L}$$



- **Schematic:**

  Port impedances: At P1 = 50Ω and At P2 = 100Ω

  Characteristic impedance of line Z0 = $\sqrt{(50 * 100)}$ = 70.71Ω

  l = 4.21mm, w = 1.6mm

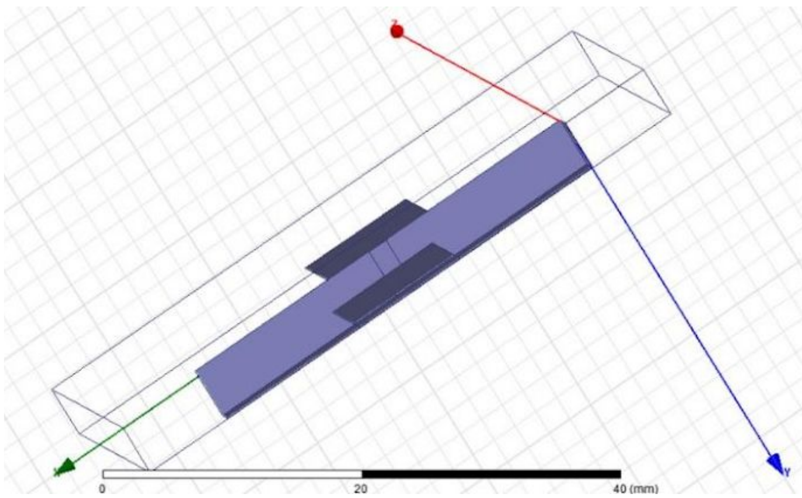


Fig.1

Link for the Quarter wave simulated HFSS file:
https://drive.google.com/file/d/11Pa1pKd5KjFhrM-9pBZPrZEiPkfntlv8/view?usp=sharing

Plots:

1.S(1,1) in dB vs Freq:-(simulated)

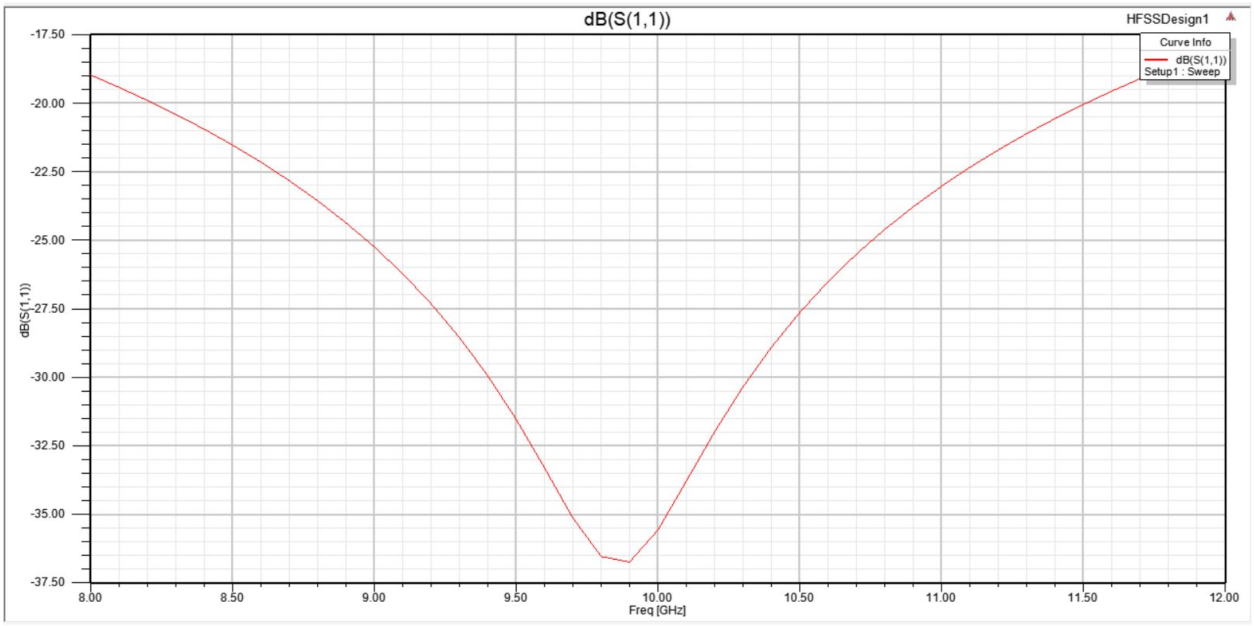


Fig.2

2.S(2,1) in dB vs Freq:-(simulated)

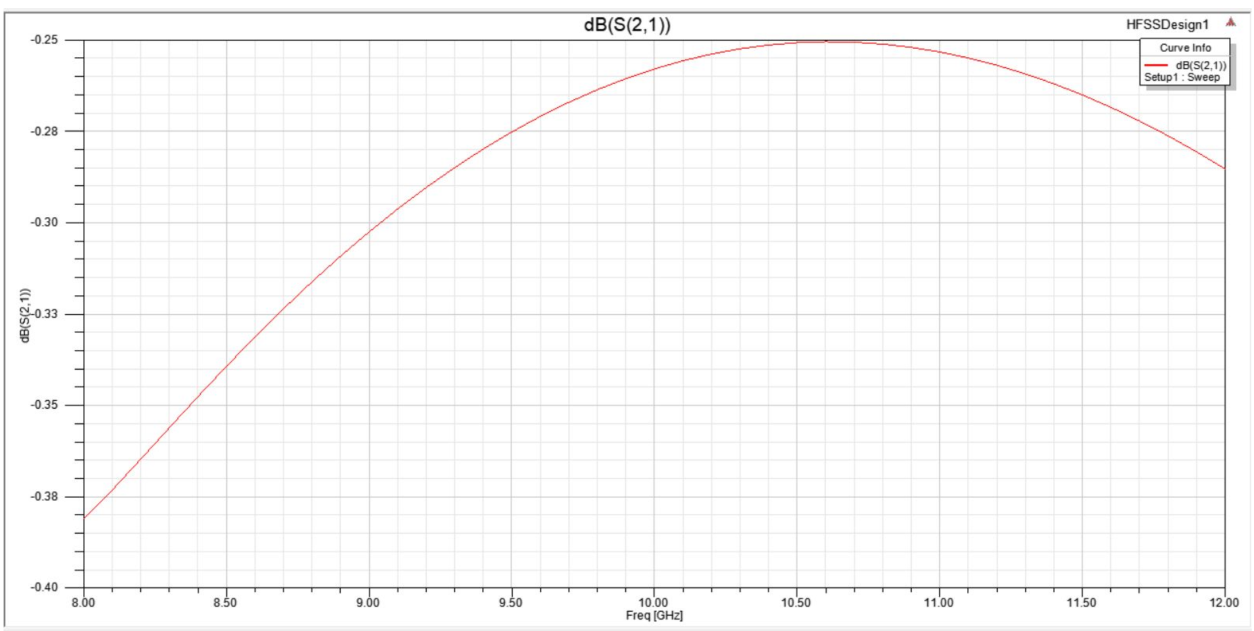


Fig.3

Calculations:

The formula for calculating S(1,1) is:

$$S11 = |\Gamma| = (1 + (\frac{2\sqrt{Z_0 Z_l}}{Z_L - Z_0} sec(\theta))^2)^{\frac{-1}{2}} \ where\ \theta = \frac{\pi f}{2 f_0}$$

For S21 it is nothing but 1+|S11| and since S11 si very small S21 is nearly equal to1 thus we observe it mostly equal to 0 dB.

3.S(1,1) in dB[calculated] vs Freq:-(MATLAB)

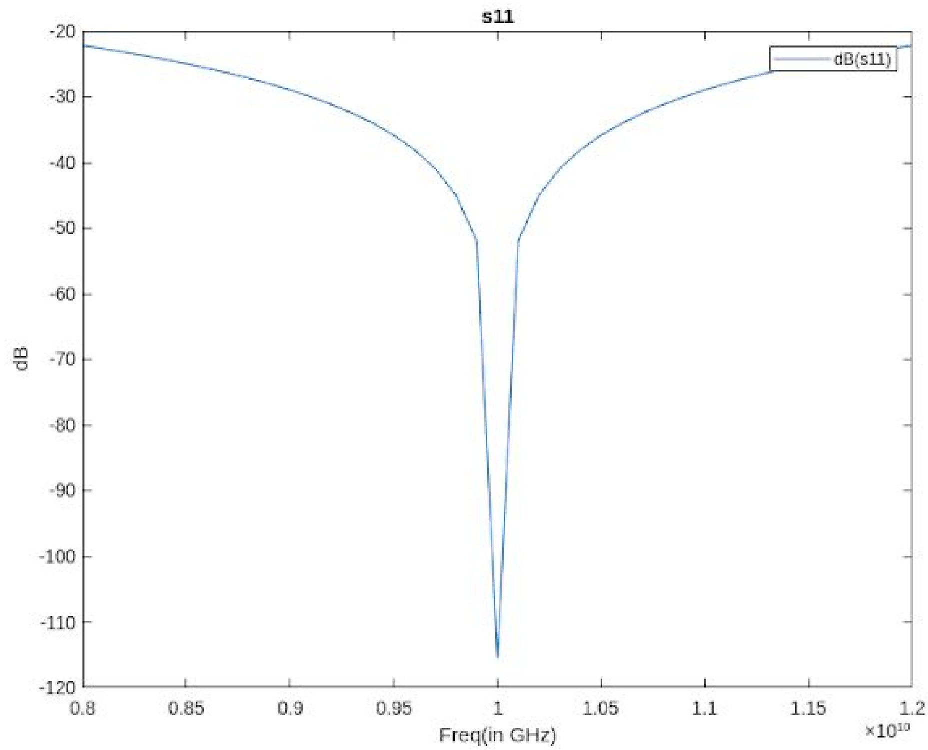


Fig.4

- **Single Stub matching:**

Objective:

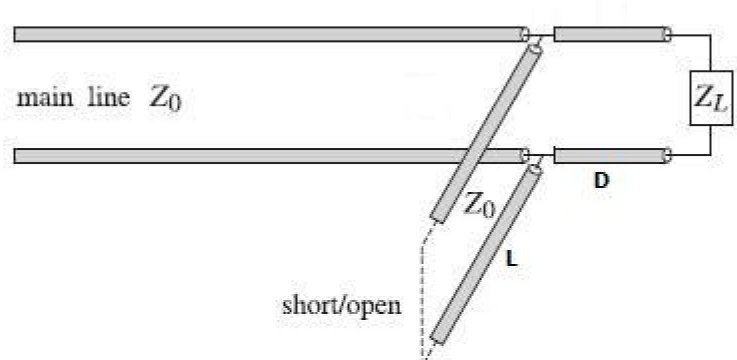
- To design a single stub matching section for a specified load impedance at a given frequency.
- To obtain S and ABCD parameters.
- to fine tune for minimum reflection at f_0.

Components:

- Copper microstrip line filled with FR4_epoxy,microstripline stub

Brief theory:

A stub is a short-circuited section of a transmission line connected in parallel to the main transmission line. A stub of appropriate length is placed at some distance from the load such that the impedance seen beyond the stub is equal to the characteristic impedance. Suppose we have a load impedance connected to a transmission line with characteristic impedance.The objective here is that no reflection should be seen by the generator. In other words,even if there are standing waves in the vicinity of the load , the standing waves must vanish beyond a certain distance from the load. Conceptually this can be achieved by adding a stub to the main line such that the reflected wave from the short-circuit end of the stub and the reflected wave from the load on the main line completely cancel each other at point B to give no net reflected wave beyond point B towards the generator.



Link for HFSS Design File:(tuned):-

https://drive.google.com/file/d/1DJtGcbbb265npzw1Bbm38VyJmXEYJQ5N/view?usp=sharing

Schematic:

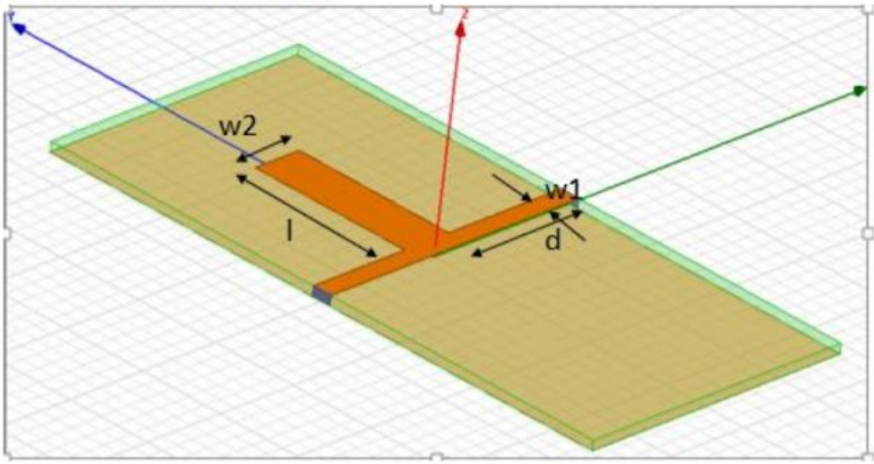


Fig.5

Initial solution:

Source impedance = 100 Ω

Load impedance = 70 + 100j Ω

Line characteristic impedance = 50 Ω

Stub characteristic impedances Zsh: 100 Ω

w1=1.819mm

w2=4.83mm

d=13.6mm

l=16.25mm

Calculations:

❖ ABCD parameter of shunt stub:

$$\mathbf{A} = 1,\ \mathbf{B} = 0,\ \mathbf{C} = Y = jY_{sh}\tan(\beta l),\ \mathbf{D} = 1$$

❖ ABCD parameter of the line:

$$\mathbf{A} = \cos(\beta d),\ \mathbf{B} = jZ_0\sin(\beta d),\ \mathbf{C} = jY_0\sin(\beta d),\ \mathbf{D} = \cos(\beta d)$$

➢ $[ABCD] = [A_1B_1C_1D_1] \times [A_2B_2C_2D_2]$

❖ ABCD parameter of the overall line:

$\mathbf{A} = \cos(\beta d)$,

$\mathbf{B} = jZ_0\sin(\beta d)$,

$\mathbf{C} = j(Y_{sh}\tan(\beta l)\cos(\beta d) + Y_0\sin(\beta d))$,

$\mathbf{D} = \cos(\beta d) - Y_{sh}Z_0\tan(\beta l)\sin(\beta d)$

Plots:with the initial values

1.|S11| and |S21| in dB vs Freq(calculated and plotted in MATLAB):-

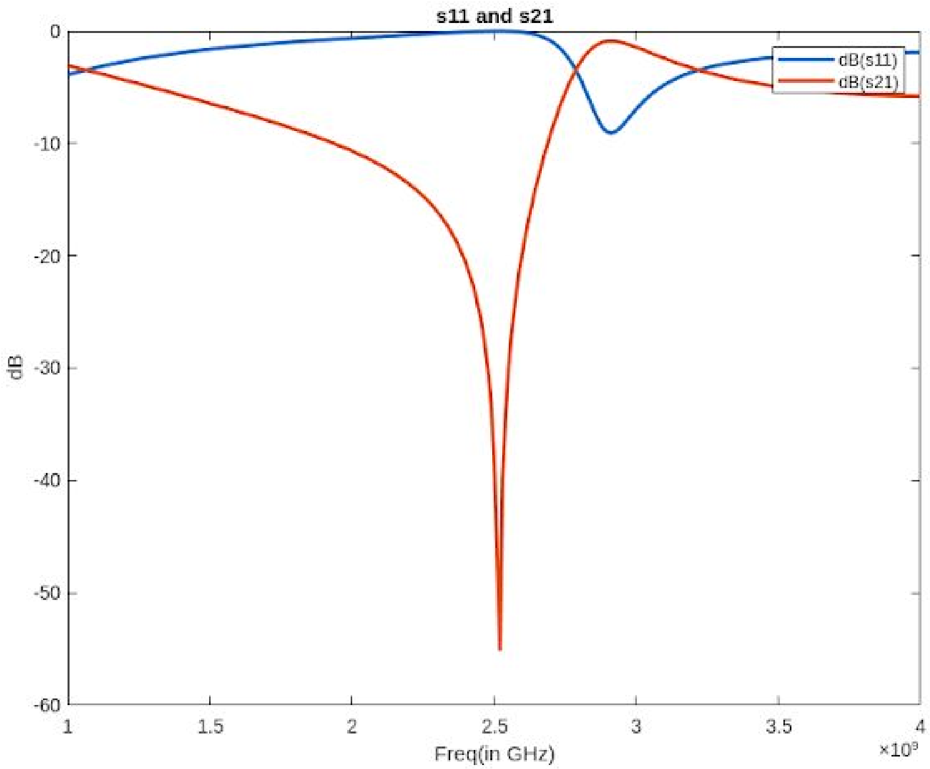


Fig.6

2.|S11| and |S21| in dB vs Freq(Simulated in HFSS):-

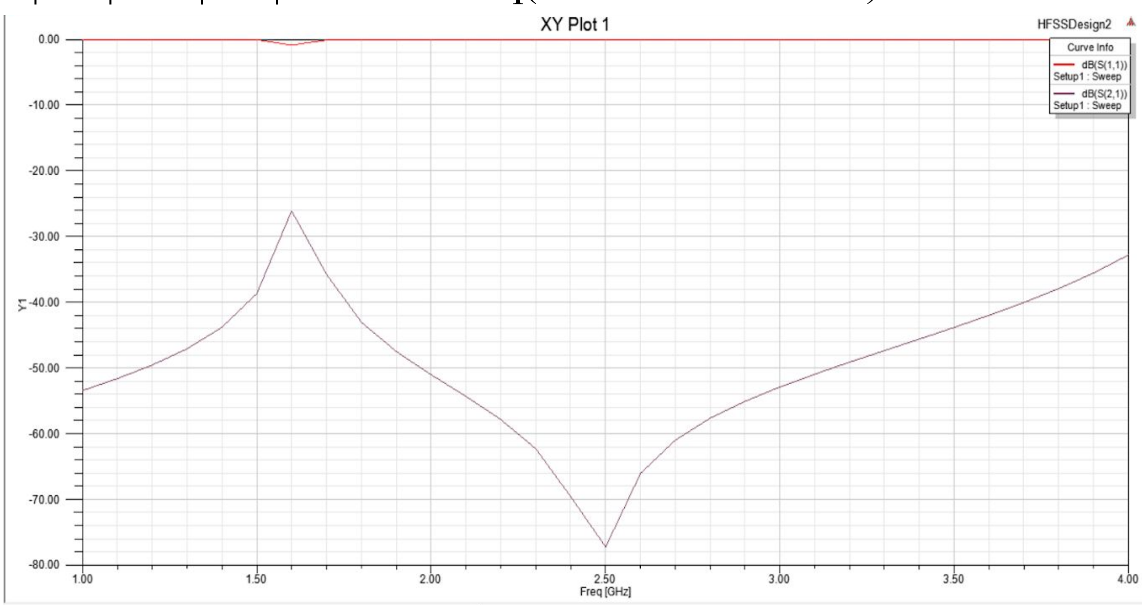


Fig.7

Tuned solution:

Source impedance = 100 Ω

Load impedance = 70 + 100j Ω

Line characteristic impedance = 50 Ω

Stub characteristic impedances Zsh: 100 Ω

w1=1.819mm

w2=4.83mm

d=13.6mm

l=16.75mm

3.|S11| and |S21| in dB vs Freq(calculated and plotted in MATLAB):-

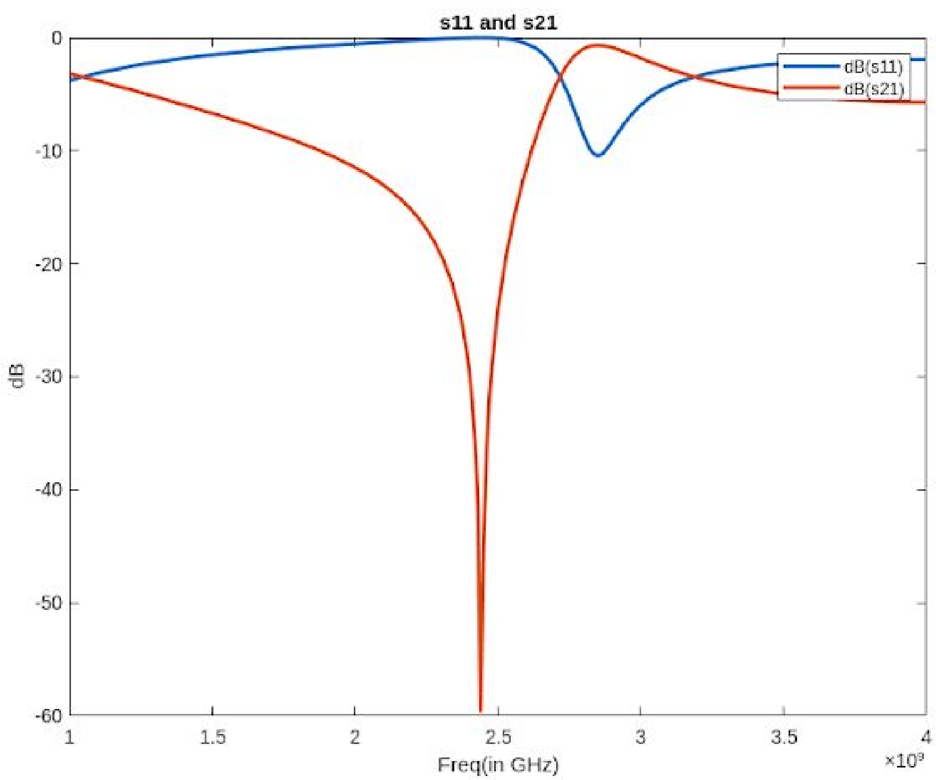


Fig.8

4.|S11| and |S21| in dB vs Freq(Simulated in HFSS):-

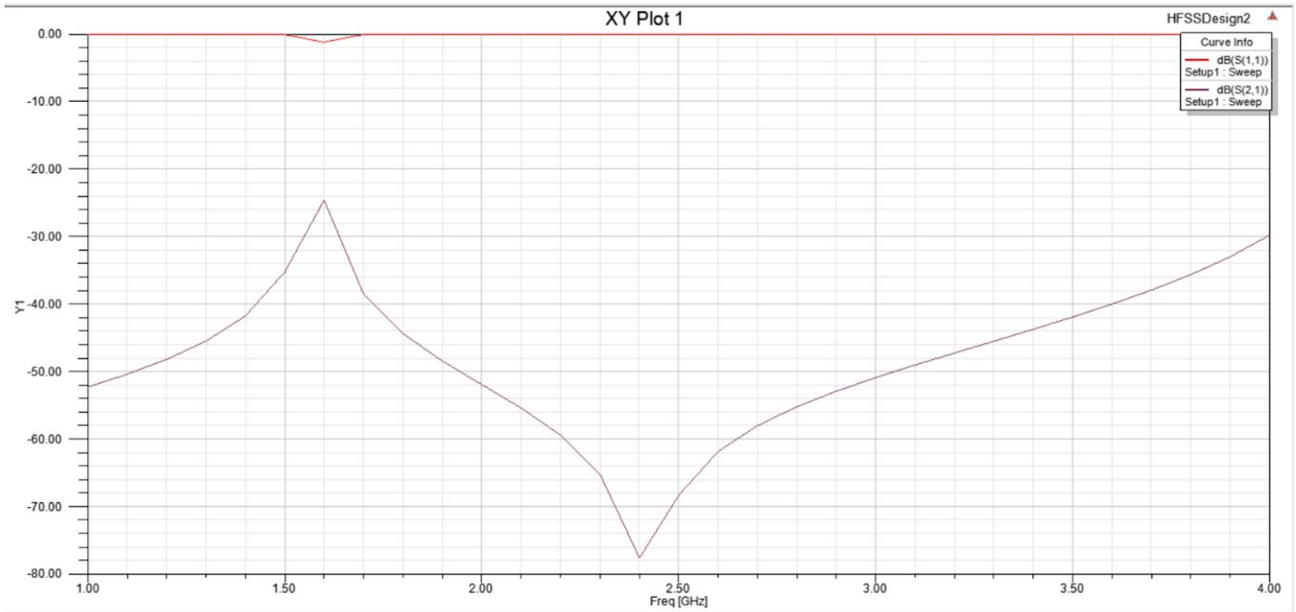


Fig.9

- **Band stop Filter:**

Objective:

- To implement BSF in the full wave simulator using the specified substrate.
- To fine tune the parameters to place transmission zero at fo

Components:

- Micro strip line of U section stub filled with FR4_epoxy medium
- Shunt arm.

Brief theory:

Bandstop filter (BSF):

A U-section stub behaves as a BSF with maximum rejection at f_0 when the series and shunt arm lengths are 90°. A straightforward method to obtain the complex S-parameters of the BSF shown in Fig. 4 is by calculating overall ABCD matrix. The BSF is first divided into three regions. Then, the overall ABCD matrix is

$$[ABCD] = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_{se} & jZ_{se}\sin\theta_{se} \\ jY_{se}\sin\theta_{se} & \cos\theta_{se} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}, \tag{4}$$

where the shunt open-stubs are represented by their equivalent input saucepances Y, and the connecting section as a section of transmission line. The characteristic impedance Z_{sh} should be as low as possible. Similarly, Z_{se} should be as high as possible. Their values are limited by fabrication limit, higher order mode excitation, and loss. The electrical lengths are 90° at the design frequency f_0. Then, at any a frequency f,

$$\theta_{sh,se} = \frac{\pi}{2}\left(\frac{f}{f_0}\right). \tag{5}$$

The corresponding S-parameters are

$$S_{11} = \frac{A + B/Z_0 - CZ_0 - D}{A + B/Z_0 + CZ_0 + D}, \quad \text{and} \quad S_{21} = \frac{2}{A + B/Z_0 + CZ_0 + D}. \tag{6}$$

Link for HFSS Design File:(tuned):-

https://drive.google.com/file/d/193CTaHTN2dxjBnke5VEVd6EdUbdjC7NH/view?usp=sharing

Schematic:

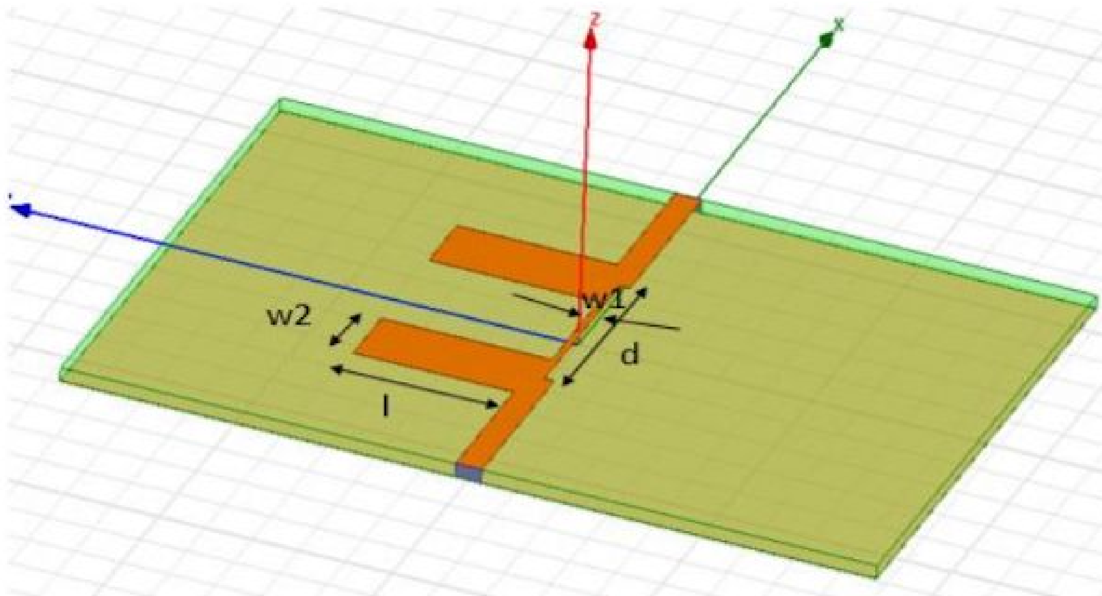


Fig.10

Initial solution:

Port impedances: Port1 = 50 and Port2 = 50Ω

Characteristic impedance of line Z_0= 50Ω

Characteristic impedance of series line Z_{se}= 100Ω

Characteristic impedance of shunt lines Z_{sh}= 25Ω

d = 21mm, l = 18.49mm, w1 = 0.276mm, w2 = 2.55mm

Calculations:

- ABCD parameter of the shunt stub:

  A = 1, **B** = 0, **C** = Y = $jY_{sh}\tan(\beta l)$, **D** = 1

- ABCD parameter of the line:

  A = $\cos(\beta d)$, **B** = $jZ_0\sin(\beta d)$, **C** = $jY_0\sin(\beta d)$, **D** = $\cos(\beta d)$

  ❖ $[ABCD] = [A_1B_1C_1D_1] \times [A_2B_2C_2D_2] \times [A_3B_3C_3D_3]$

- Overall ABCD parameter:

A = $\cos(\beta d) - Z_{se}Y_{sh}\sin(\beta d)\tan(\beta l)$

B = $jZse\sin(\beta d)$

C = $j(2Y_{sh}\tan(\beta l)\sin(\beta d) + Yse\sin(\beta d) - Y_{sh}^2 Z_{se}\tan^2(\beta l)\sin(\beta d)$

D = $\cos(\beta d) - Z_{se}Y_{sh}\sin(\beta d)\tan(\beta l)$

Plots:with the initial values

1.|S11| and |S21| in dB vs Freq(calculated and plotted in MATLAB):-

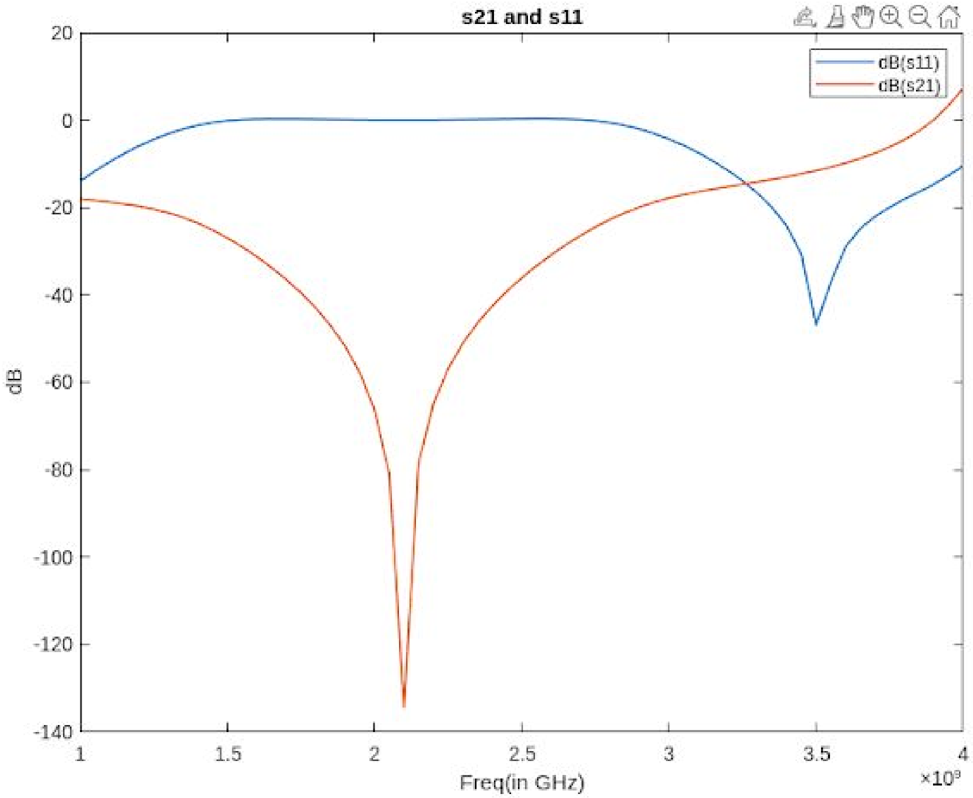


Fig.11

2.|S11| and |S21| in dB vs Freq(Simulated in HFSS):-

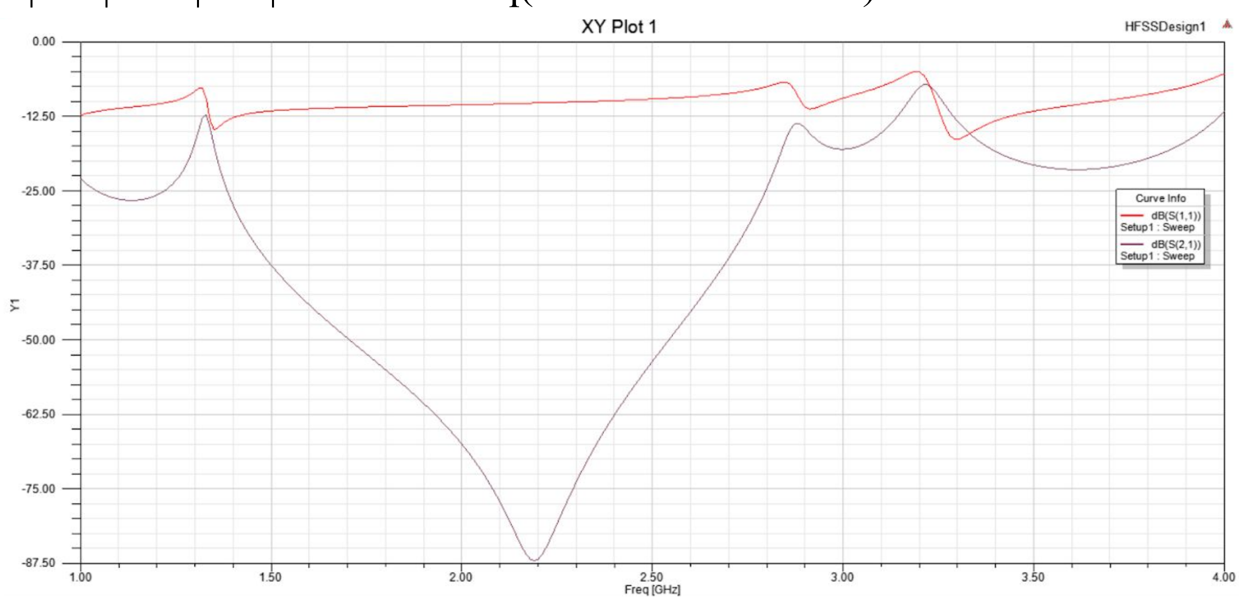


Fig.12

Tuned solution:

Port impedances: Port1 = 50 and Port2 = 50Ω

Characteristic impedance of line Z_0= 50Ω

Characteristic impedance of series line Z_{se}= 100Ω

Characteristic impedance of shunt lines Z_{sh}= 25Ω

d = 22mm, l = 16.59mm, w1 = 0.276mm, w2 = 2.55mm

3.|S11| and |S21| in dB vs Freq(calculated and plotted in MATLAB):-

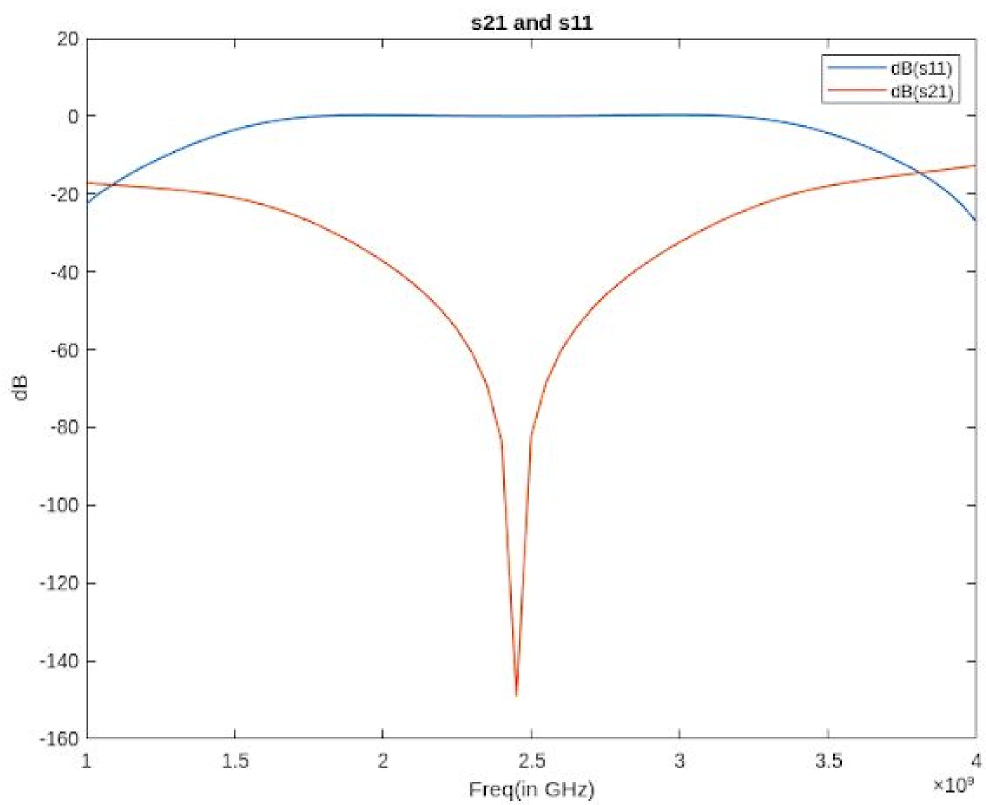


Fig:13

4.|S11| and |S21| in dB vs Freq(Simulated in HFSS):-

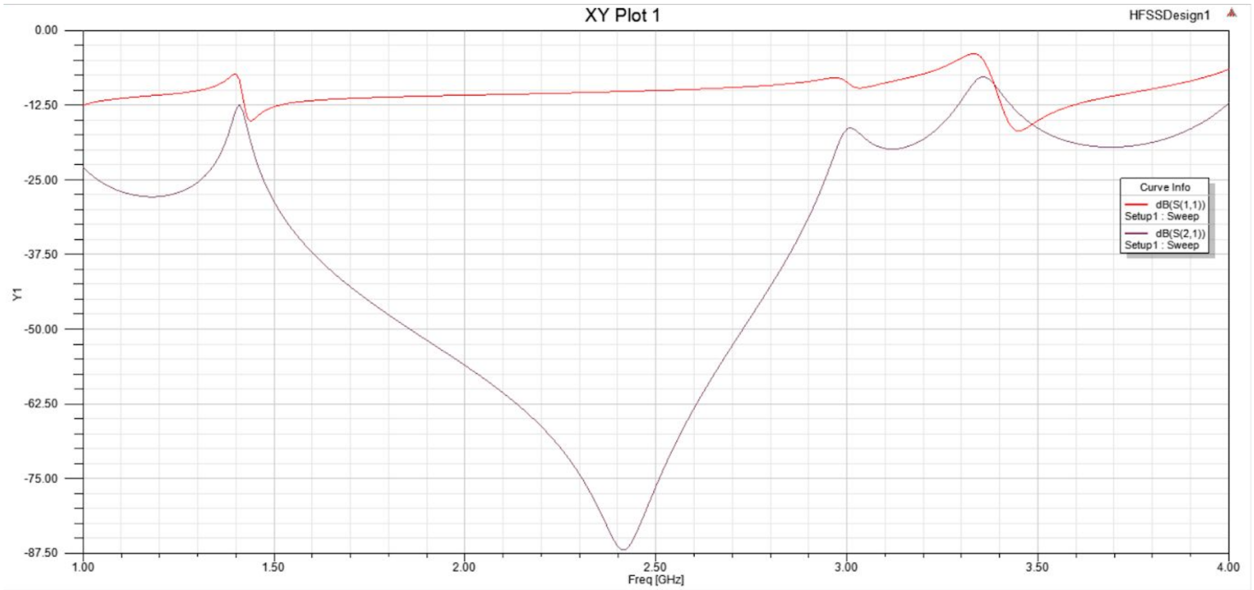


Fig.14

MATLAB codes:-

Quarter wave:

```
clc
close all
clear all
f0=10*10^9;
ff=0.8*f0:0.1*10^9:1.2*f0;
Z0=70.71;
Z2 = 50;
Z1=100;
betal=pi*ff/(2*f0);
for ii=1:length(ff)
  betal1=90*ff(ii)/(f0);
  T2=[cosd(betal1) 1i*Z0*sind(betal1);1i*sind(betal1)/Z0 cosd(betal1)];
  T3=[1 0;1/Z1 1];
  T0 =[1 Z2;0 1];
  T1=T2*T3;
  Sparam = abcd2s(T1,Z2);
  S21(ii) = (T1(1,1)-T1(2,1)*Z2)/(T1(1,1)+T1(2,1)*Z2);
  S11(ii) = abs(S21(ii));
  Zin = Z0*((Z1+1i*Z0*tand(betal1))/(Z0+1i*Z1*tand(betal1)));
end
S11_db = 10*log(S11);
plot(ff,S11_db)

xlabel("Freq(in GHz)");
ylabel("dB");
legend("dB(s11)");
title("s11");
```

Single Stub Matching:

Code for Initial solution:

```
clc
close all
clear all

l=16.25;
f = 1e9:0.1e8:4e9;
theta0 = 0.399*pi;
f0 = 24e8;
theta = theta0*f/f0;
theta1 = l*theta/13.6;

Z0 = 50;
Y0 = 0.02;
Ysh = 0.01;
Z1 = 100;
Z2 = 70+100i;

A = cos(theta);
B = complex(0,Z0*sin(theta));
C = complex(0,Ysh*tan(theta1).*cos(theta)+Y0*sin(theta));
D = cos(theta) - Ysh*Z0*tan(theta1).*sin(theta);

s11 = abs((Z2*A + B - Z1*Z2*C - Z1*D)./(Z2*A + B + Z1*Z2*C + Z1*D));
s21 = abs((2*sqrt(real(Z2)*Z1))./(Z2*A + B + Z1*Z2*C + Z1*D));

s11 = 10*log(s11);
s21 = 10*log(s21);

plot(f,s11,'LineWidth',2);
hold on;
plot(f,s21,'LineWidth',2);
xlabel("Freq(in GHz)");
ylabel("dB");
legend("dB(s11)","dB(s21)");
title("s11 and s21");
```

Single Stub Matching:-

Code for Tuned solution:-

```
clc
close all
clear all

l=16.75;
f = 1e9:0.1e8:4e9;
theta0 = 0.399*pi;
f0 = 24e8;
theta = theta0*f/f0;
theta1 = l*theta/13.6;

Z0 = 50;
Y0 = 0.02;
Ysh = 0.01;
Z1 = 100;
Z2 = 70+100i;

A = cos(theta);
B = complex(0,Z0*sin(theta));
C = complex(0,Ysh*tan(theta1).*cos(theta)+Y0*sin(theta));
D = cos(theta) - Ysh*Z0*tan(theta1).*sin(theta);

s11 = abs((Z2*A + B - Z1*Z2*C - Z1*D)./(Z2*A + B + Z1*Z2*C + Z1*D));
s21 = abs((2*sqrt(real(Z2)*Z1))./(Z2*A + B + Z1*Z2*C + Z1*D));

s11 = 10*log(s11);
s21 = 10*log(s21);

plot(f,s11,'LineWidth',2);
hold on;
plot(f,s21,'LineWidth',2);
xlabel("Freq(in GHz)");
ylabel("dB");
legend("dB(s11)","dB(s21)");
title("s11 and s21");
```

Band stop Filter:

Code for Initial solution:

```
clc
close all
clear all

l=18.49;
d=21;
f = 1e9:0.5e8:4e9;
theta0 = pi* 0.65;
f0 = 24e8;
theta1 = theta0*f/f0;
theta=theta1*l/d;
Zse = 100;
Yse = 0.01;
Ysh = 0.04;
Z0 = 50;

A = complex(cos(theta)-Zse*Ysh*sin(theta).*tan(theta0),0);
B = complex(0,Zse*sin(theta));
C =
complex(0,2*Ysh*tan(theta).*cos(theta)+Yse*sin(theta)-Ysh*Ysh*Zse*tan(theta)
.*tan(theta).*sin(theta));
D = complex(cos(theta)-Zse*Ysh*sin(theta).*tan(theta0),0);

s11 = abs((A + B./Z0 - C*Z0 - D)./(A + B./Z0 + C*Z0 + D));
s21 = abs(2./(A + B./Z0 + C*Z0 + D));

s11 = 10*log(s11);
s21 = 10*log(s21);

plot(f,s11,'LineWidth',1);
hold on;
plot(f,s21,'LineWidth',1);
xlabel("Freq(in GHz)");
ylabel("dB");
legend("dB(s11)","dB(s21)");
title("s21and s11");
```

Band stop Filter:-

Code for Tuned solution:-

```
clc
close all
clear all

l=16.59;
d=22;
f = 1e9:0.5e8:4e9;
theta0 = pi* 0.65;
f0 = 24e8;
theta1 = theta0*f/f0;
theta=theta1*l/d;
Zse = 100;
Yse = 0.01;
Ysh = 0.04;
Z0 = 50;

A = complex(cos(theta)-Zse*Ysh*sin(theta).*tan(theta0),0);
B = complex(0,Zse*sin(theta));
C =
complex(0,2*Ysh*tan(theta).*cos(theta)+Yse*sin(theta)-Ysh*Ysh*Zse*tan(theta)
.*tan(theta).*sin(theta));
D = complex(cos(theta)-Zse*Ysh*sin(theta).*tan(theta0),0);

s11 = abs((A + B./Z0 - C*Z0 - D)./(A + B./Z0 + C*Z0 + D));
s21 = abs(2./(A + B./Z0 + C*Z0 + D));

s11 = 10*log(s11);
s21 = 10*log(s21);

plot(f,s11,'LineWidth',1);
hold on;
plot(f,s21,'LineWidth',1);
xlabel("Freq(in GHz)");
ylabel("dB");
legend("dB(s11)","dB(s21)");
title("s21 and s11");
```

Discussion:

Quarter wave:

- The quarter-wave transformer is a very important component in terms of impedance matching whenever there is an impedance mismatch at the load and the input side a quarter-wave transformer can be used to remove this mismatching.
- S-parameters describe the input-output relationships between the ports in an electrical system.
- In the graph of S(2,1) we can say that it is almost near to 0dB for each frequency,(i,e, equal to 1) which shows that there is complete transmission with minimum reflectance which only happens when there is impedance matching.
- Although the values are nearly equal we can observe that the nature of the curve is the same and if we put practical constraints we will observe the experimental graph.
- From the calculations and from the plots for S(1,1) we can see that the values for simulated and calculated are almost equal except at f_0 because we considered that angle to be nearly equal to 90^o which is not the case with practical approach where in practical approach it is 18^o,due to this the value for S(1,1) at f_0 is equal to -333 in calculated,apart from this the graphs of both calculated and simulated are similar to each other.

Single Stub Matching:

- We have constructed the open shunt stub,and plotted S(1,1) and S(2,1) and also we have calculated the A,B,C,D parameters using MATLAB and from those parameters we have plotted the S(1,1) and S(2,1) in MATLAB.
- First we had found some initial values for length of the stub(l) and length of the transmission line from load(d),from that initial values we got minimum reflection at 2.5GHz.
- Impedance matching was done to ensure minimum reflection at f_0.
- By varying length of stub, we can get various values of susceptance for the transmission line which can be made useful for minimum reflection by impedance matching

- With changing the impedances of stub (changing d and l) and microstrip transmission we have found the minimum reflection at our desired f_0=2.4GHz

Band stop Filter:

- BSF is designed to have minimum transmission in a bandwidth.
- We have constructed the U-section stub(2-shunt stubs),and plotted S(1,1) and S(2,1) and also we have calculated the A,B,C,D parameters using MATLAB and from those parameters we have plotted the S(1,1) and S(2,1) in MATLAB.
- We observed how a u-section stub behaves as a band stop filter with minimum reflection at f_0 when series and shunt arm lengths are 90^0.
- First we had found some initial values for length of the series stub(l [l3 in HFSS file]) and length of the transmission line from load(d[l1 in HFSS file]),from that initial values we got minimum reflection at 2.2GHz.
- Impedance matching was done to ensure transmission=0 at f_0.
- By varying d,l we can obtain that frequency at our desired value f_0=2.4GHz,we call it tuning.
- With changing the impedances of stub (changing d and l) and microstrip transmission we have found the transmission=0 at our desired f_0=2.4GHz.