DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

# RF DESIGN PROJECT

ECE 671 REPORT

SUBMITTED BY

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COURSE: ECE 671

RF & MICROWAVE ENGINEERING

PROFESSOR: RAAFAT MANSOUR

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**Problem 1**

In this question a microstrip circuit was simulated using ADS with the parameters given in the problem statement. The parameter D was calculated to be 5.35 mm based on the last two digits of my student ID. First the schematic was created based on representing the circuit in terms of various sub components and junctions. Mainly, microstrip lines were used followed by T-junction to represent change in steps with the input and output port assuming to have 50-ohm impedances. Following the schematic, the layout was autogenerated and the input and output ports were labeled with arrows. The EM simulator was then setup, providing with a frequency plan of start and end frequency of 2 GHz to 8 GHz. The EM Simulator shows a magnitude S21 value 46.7 dB occurring and return loss (magnitude of S11) to be 0 dB around 5GHz frequency in Figure 4. The circuit simulator was also performed and is shown to have a S11(return loss) value of around 30dB and S21 of 0dB at 5GHz frequency in Figure 3.

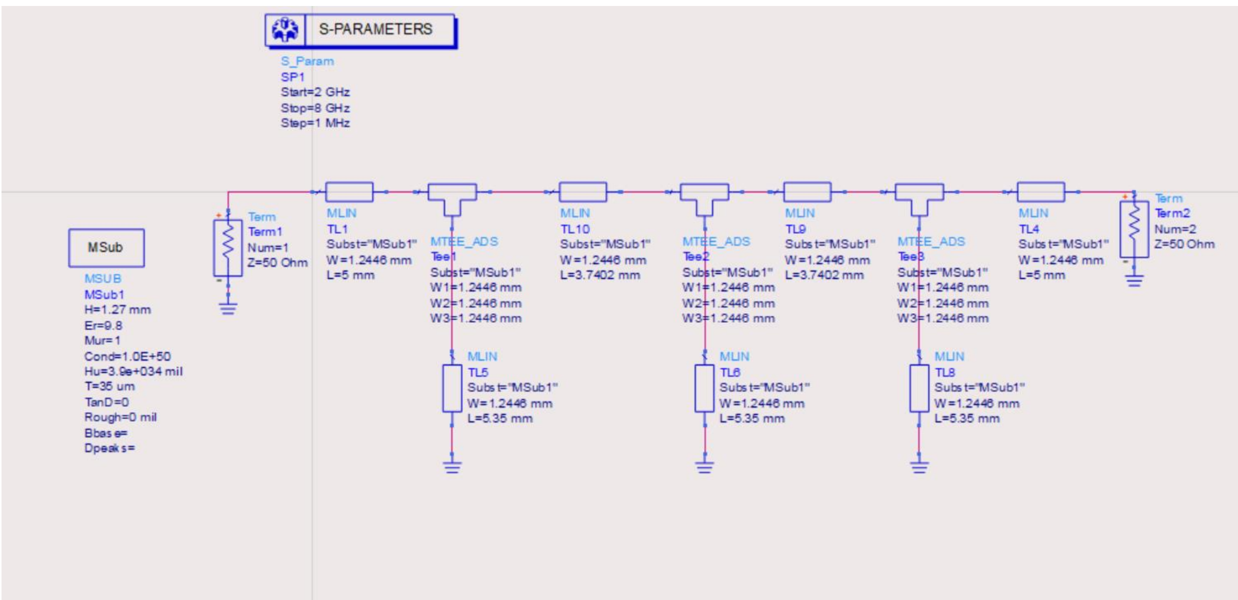



*Figure 1: Schematic Design*

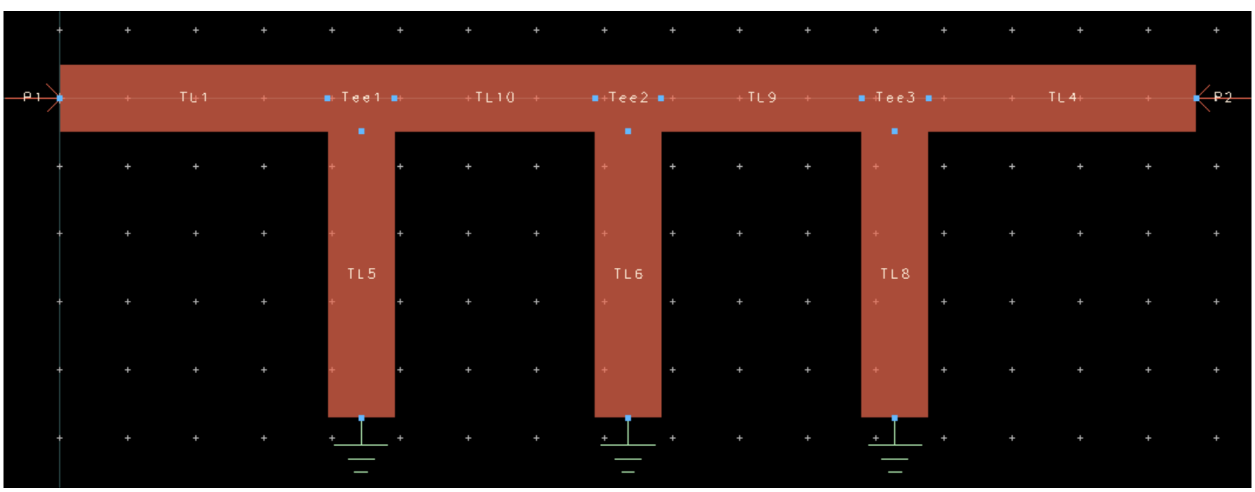



*Figure 2: Layout*

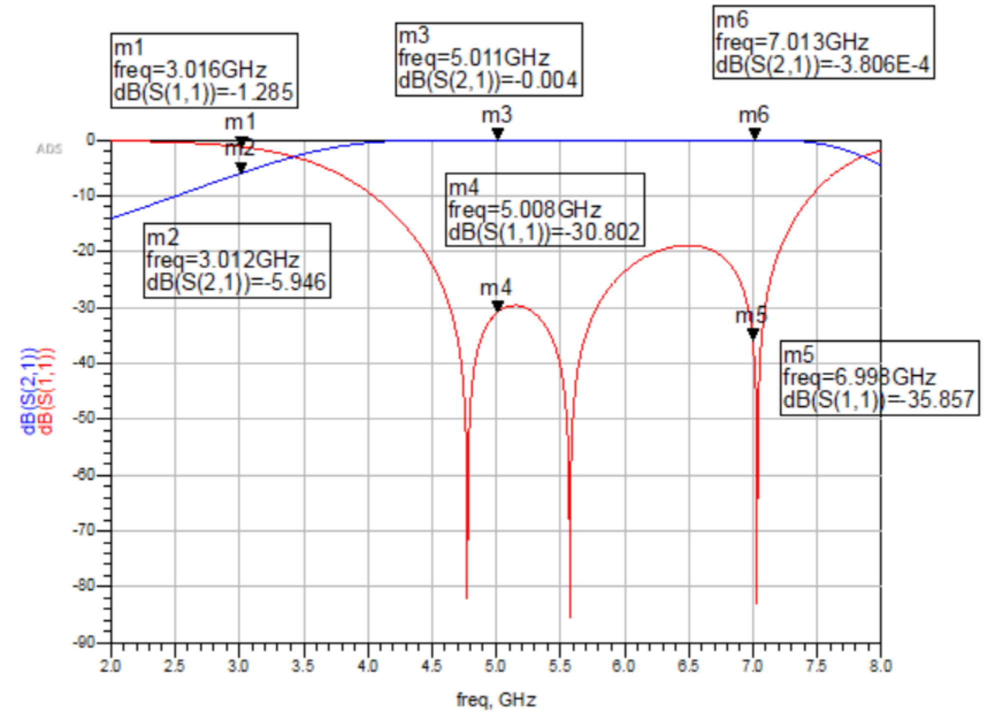



*Figure 3: Circuit Simulation Graph*

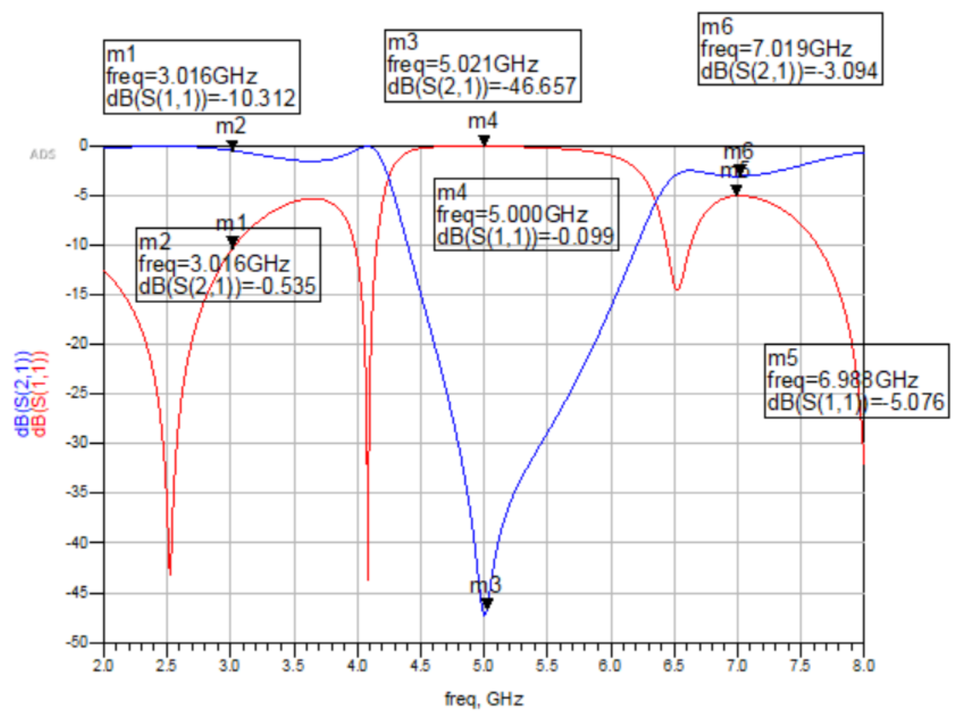



*Figure 4: EM Simulation Plot*

**Problem 2**

In this problem, the interdigital capacitor was modelled on ADS with the parameters given in the question and W3 parameter was calculated to be 6.7 mm based on my student ID. The capacitor parameter Nd was set to 7 to represent off number of turns and match the model given in the question. The generated layout for the interdigital capacitor is shown in Figure 7, which accurately models the capacitor shown in the problem statement with input and output ports directly attached to the component.  EM Simulation was setup and executed on the layout and various S parameters were plotted shown in Figure 8 and 9. It was found that across 2GHz frequency range, the magnitude of S21 is 4.3dB and S22 to be around 2dB.

Using the EM simulation, a table was generated with numerical values of the various S-parameters at 2 GHz and the S matrix is constructed show in in Figure 5. Since the S11 and S22 values are not the same, the S matrix is not symmetrical.

```
Smatrix =

  -0.5180 - 0.5950i   0.5010 - 0.3480i
   0.5010 - 0.3480i  -0.3860 - 0.6880i
```

*Figure 5: S-Matrix*

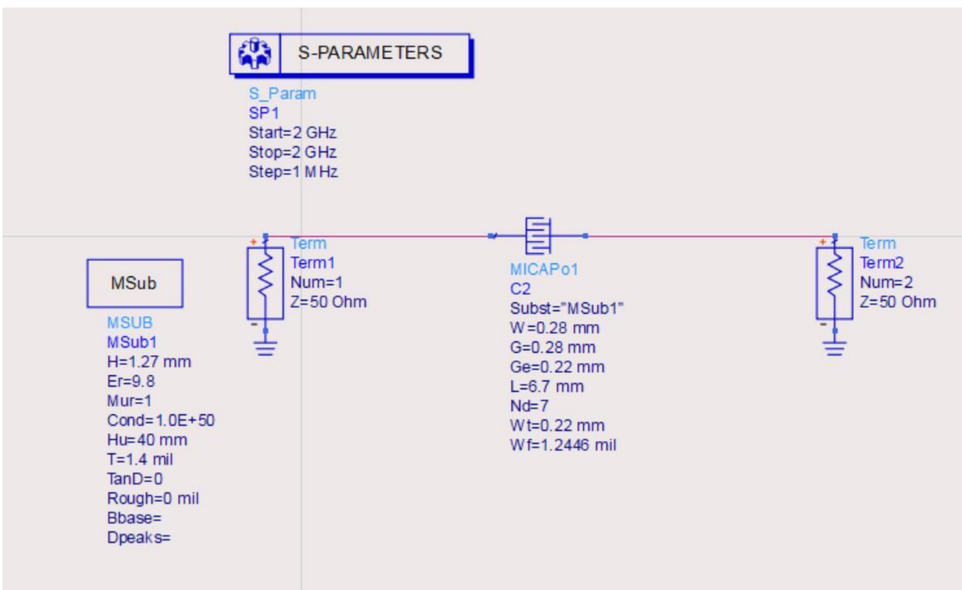



*Figure 6: Interdigital Capacitor Schematic*

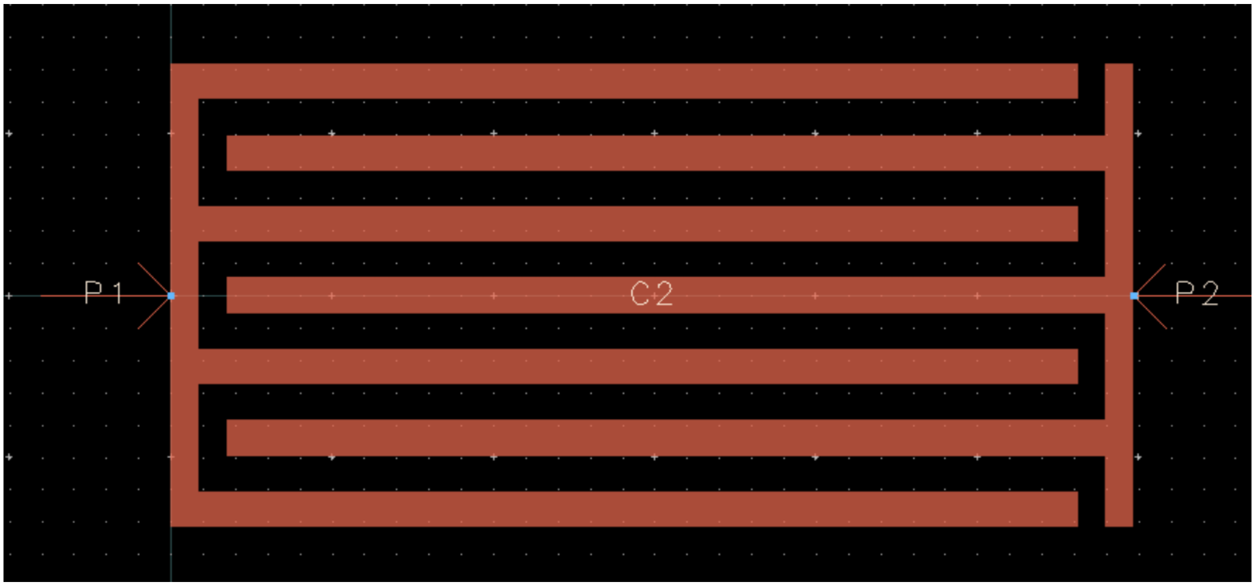



*Figure 7: Interdigital Capacitor Layout*

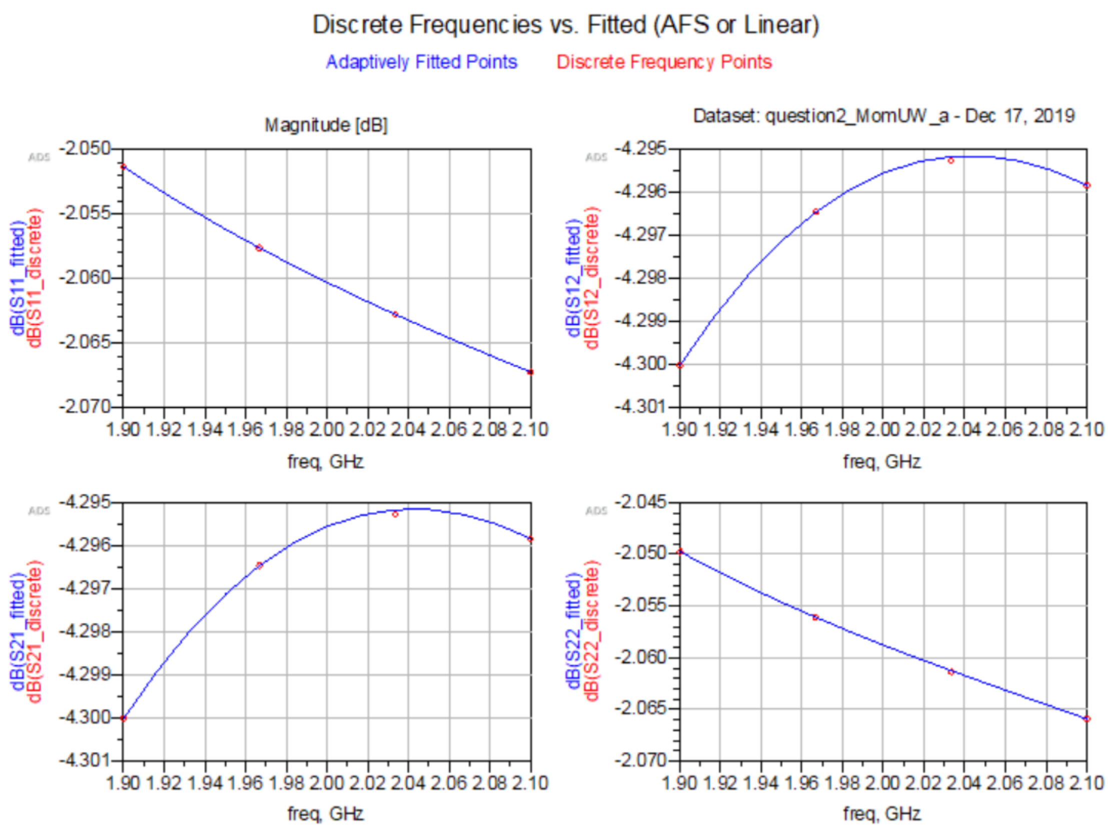



*Figure 8: Phase Plot*

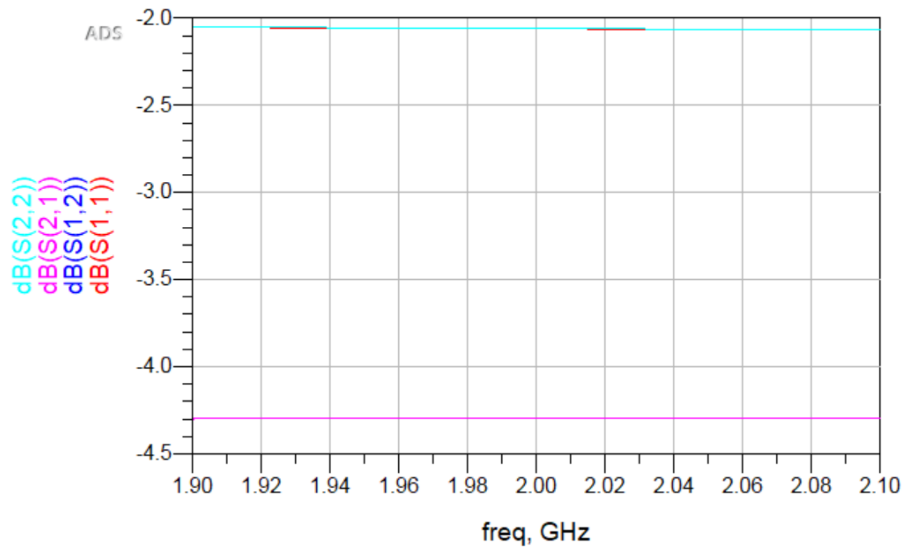



*Figure 9: Magnitude Plot*

| freq | S(1,1) | S(1,2) | S(2,1) | S(2,2) |
|---|---|---|---|---|
| 1.900 GHz | -0.483 - j0.625 | 0.521 - j0.316 | 0.521 - j0.316 | -0.339 - j0.714 |
| 1.917 GHz | -0.489 - j0.620 | 0.518 - j0.322 | 0.518 - j0.322 | -0.347 - j0.710 |
| 1.933 GHz | -0.495 - j0.615 | 0.514 - j0.327 | 0.514 - j0.327 | -0.355 - j0.705 |
| 1.950 GHz | -0.501 - j0.610 | 0.511 - j0.333 | 0.511 - j0.333 | -0.362 - j0.701 |
| 1.967 GHz | -0.507 - j0.605 | 0.508 - j0.338 | 0.508 - j0.338 | -0.370 - j0.697 |
| 1.983 GHz | -0.513 - j0.600 | 0.504 - j0.343 | 0.504 - j0.343 | -0.378 - j0.693 |
| 2.000 GHz | -0.518 - j0.595 | 0.501 - j0.348 | 0.501 - j0.348 | -0.386 - j0.688 |
| 2.017 GHz | -0.524 - j0.590 | 0.497 - j0.354 | 0.497 - j0.354 | -0.393 - j0.684 |
| 2.033 GHz | -0.529 - j0.585 | 0.493 - j0.359 | 0.493 - j0.359 | -0.401 - j0.679 |
| 2.050 GHz | -0.535 - j0.580 | 0.490 - j0.363 | 0.490 - j0.363 | -0.408 - j0.675 |
| 2.067 GHz | -0.540 - j0.575 | 0.486 - j0.368 | 0.486 - j0.368 | -0.416 - j0.670 |
| 2.083 GHz | -0.545 - j0.569 | 0.482 - j0.373 | 0.482 - j0.373 | -0.423 - j0.665 |
| 2.100 GHz | -0.550 - j0.564 | 0.479 - j0.378 | 0.479 - j0.378 | -0.430 - j0.660 |

*Figure 10: S Parameter over Frequency Range Table*

Once the S-matrix is found, it is transformed to Y-matrix to find the impedance value of capacitor. The equivalent Y-Matrix is shown in Figure 11 using matrix transformation function on MATLAB.

```
y_matrix =

  -0.0000 + 0.0845i   0.0002 - 0.0574i
   0.0002 - 0.0574i  -0.0001 + 0.0693i
```

*Figure 11: Y Matrix*

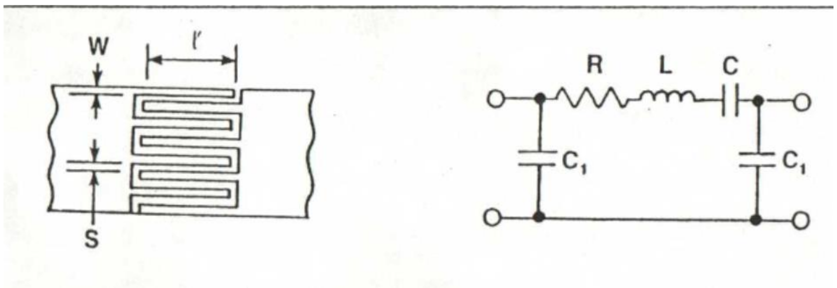



*Figure 12: Interdigital Equivalent Circuit*

The interdigital capacitor can be modelled by the equivalent lumped components in Figure 12. This model shown in Figure 12 can be simplified to admittance Y-based equivalent circuit shown in Figure 13 in order to calculate the C values. Using the Y circuit model, we can find three capacitor values, C and two C1s shown in the interdigital equivalent circuit.

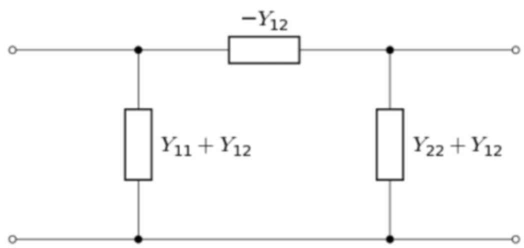



*Figure 13: Equivalent Circuit for Y Parameters*

This is done with the capacitance reactance equation:

$$X_C = \frac{1}{2\pi\mathcal{F}C}$$

C can be isolated and solved for given all other parameters and Z=1/Y from above. Using these equations and given Y matrix, a MATLAB Script was made to calculate the appropriate capacitator values on each side shown in Figure 14.

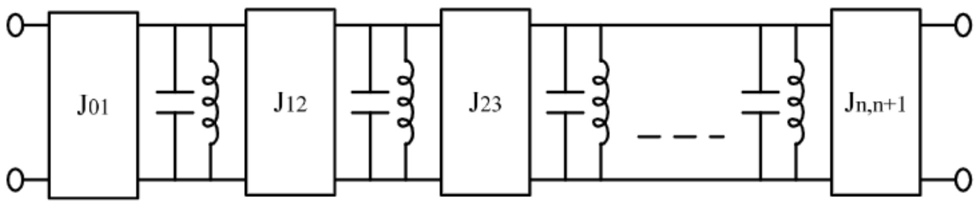
```
C =

   4.5706e-12

C1 =

   2.1532e-12

C2 =

   9.4330e-13
```

*Figure 14: Capacitor Values for Interdigital Model*

The equivalent capacitor on the top side is found to be C= 4.57pF. The left-hand side capacitor C1= 2.15 pF and right-hand side equivalent capacitor is C2= 0.943pF. These values were found using the MATLAB code seen in Appendix. Since the matrix is not symmetrical, the right and left side capacitor values are not the same (C1 ≠ C1) on the interdigital equivalent circuit diagram. Instead C1 and C2 represent those new values on the left- and right-hand shunt sides respectively.

**Problem 3**

In this question, a bandpass microstrip 5-pole filter is designed on ADS. A centre frequency of 3.7 GHz and filter bandwidth of 3.7% is calculated based on student number ID. The first step for design is to use the J-Admittance inverter model for bandpass filter shown in the Figure 15 with the appropriate equations.




$$\frac{J_{j,j+1}}{Y_o} = \frac{\pi\Delta}{2\sqrt{g_j g_{j+1}}} \qquad j = 1,2\ldots\ldots,N-1$$

$$\frac{J_{01}}{Y_o} = \sqrt{\frac{\pi\Delta}{2 g_o g_1}} \qquad \frac{J_{N,N+1}}{Y_o} = \sqrt{\frac{\pi\Delta}{2 g_N g_{N+1}}}$$

*Figure 15: J-Admittance Inverter Model for Bandpass Filters*

The deltas are the filter bandwidth value in percentage, which is 0.037. These equations require finding the g values, which were found using low pass filter of 0.0138 dB equal ripple table. Since this filter is of order 5, the following g values were extracted as shown in Figure 16.

| g Parameter | Values |
|---|---|
| g1 | 0.765 |
| g2 | 1.3249 |
| g3 | 1.6211 |
| g4 | 1.3249 |
| g5 | 0.765 |
| g6 | 1 |

*Figure 16: g Parameter Values for Filter Design Equal Ripple*

Using the g-values, J values can be found using the given equations shown in Figure 17.

| J Parameter | Equations |
|---|---|
| J01 | sqrt((pi*delta)/(2*g0*g1))*y0 |
| J12 | pi*delta/(2*sqrt(g1*g2))*y0 |
| J23 | pi*delta/(2*sqrt(g2*g3))*y0 |
| J34 | pi*delta/(2*sqrt(g3*g4))*y0 |
| J45 | pi*delta/(2*sqrt(g4*g5))*y0 |
| J56 | sqrt((pi*delta)/(2*g5*g6))*y0 |

*Figure 17: Equations for calculating J values*

Plugging the g values into J equation, the following J parameters values are calculated seen in Figure 18.

| J Parameter | Values |
|---|---|
| J01 | 0.005512645668825 |
| J12 | 0.001154594087300 |
| J23 | 7.931496625976632e-04 |
| J34 | 7.931496625976632e-04 |
| J45 | 0.001154594087300 |
| J56 | 0.005512645668825 |

*Figure 18: J Values*

Next, the gap distance and phi values needed to be modeled and calculated. The modelling of the gap was done on ADS using parameter sweep technique shown in Figure 19. Based on the model, ADS generated a look-up table for gap versus J and phi shown in Figure 20. The gap distance d and phi were found based on the corresponding J values seen in Figure 21.

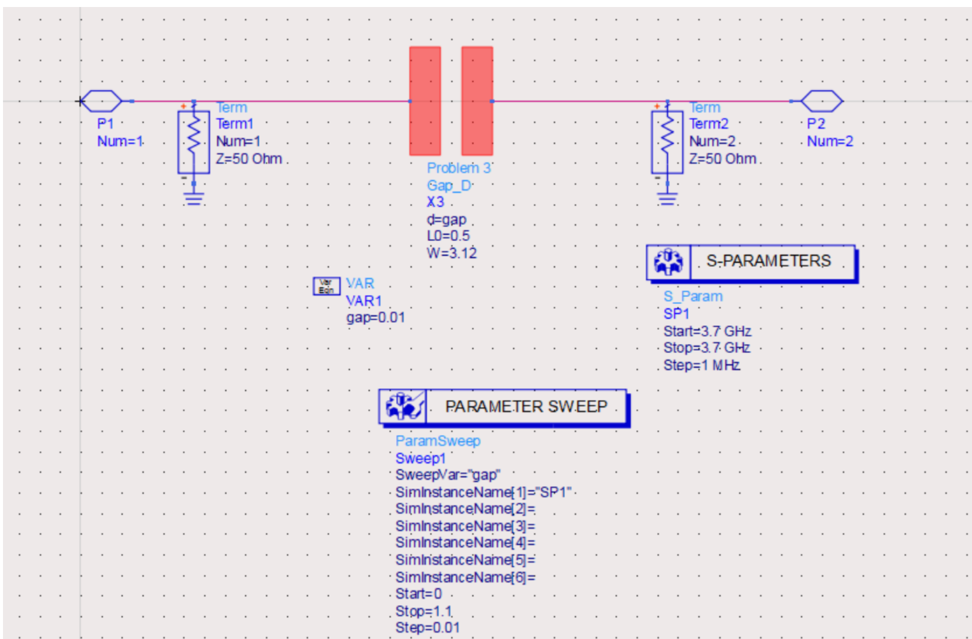



*Figure 19: Schematic for Single Gap Modelling*

| - S(1,2)*S(2,1))))) / (1/50) ) | ...) - S(1,2)*S(2,1))))) / (1/50)) )*(1/50)) |
|---|---|
| 700000000.0000000 | freq=3700000000.0000000 |
| 1.2176025 | 0.0270904 |
| -1.1953993 | 0.0055110 |
| -1.1319600 | 0.0047959 |
| -1.1044632 | 0.0044696 |
| -1.0871284 | 0.0042524 |
| -1.0742516 | 0.0040836 |
| -1.0638105 | 0.0039415 |
| -1.0548207 | 0.0038166 |
| -1.0470059 | 0.0037034 |
| -1.0400333 | 0.0035997 |
| -1.0334816 | 0.0035008 |
| -1.0277144 | 0.0034104 |
| -1.0261361 | 0.0033386 |
| -1.0212373 | 0.0032584 |
| -1.0166753 | 0.0031820 |
| -1.0124286 | 0.0031091 |
| -1.0063888 | 0.0030407 |
| -1.0009060 | 0.0029606 |
| -0.9973760 | 0.0028969 |
| -0.9940610 | 0.0028360 |
| -0.9909305 | 0.0027774 |
| -0.9879817 | 0.0027211 |
| -0.9852097 | 0.0026672 |
| -0.9825839 | 0.0026151 |
| -0.9800967 | 0.0025649 |
| -0.9777338 | 0.0025164 |
| -0.9754875 | 0.0024695 |
| -0.9733347 | 0.0024238 |
| -0.9712729 | 0.0023794 |
| -0.9692976 | 0.0023362 |
| -0.9673938 | 0.0022939 |
| -0.9655615 | 0.0022526 |
| -0.9638041 | 0.0022124 |
| -0.9621136 | 0.0021730 |
| -0.9604935 | 0.0021347 |
| -0.9589406 | 0.0020973 |
| -0.9574557 | 0.0020610 |
| -0.9560282 | 0.0020255 |
| -0.9546594 | 0.0019908 |
| -0.9533491 | 0.0019571 |
| -0.9520896 | 0.0019240 |
| -0.9508808 | 0.0018918 |
| -0.9497215 | 0.0018604 |
| -0.9486039 | 0.0018296 |

*Figure 20: ADS Generated Look-Up Table*

From the generated table, values of phi and gap distance were found for the nearest J values. This is extracted in to table below in Figure 21.

| Gap distance(mm) | Phi | J value |
|---|---|---|
| 0.01 | -1.1953993 | 0.0055110 |
| 0.72 | -0.9267960 | 0.11581 |
| 0.98 | -0.9189037 | 0.0007889 |

*Figure 21: Gap vs Phi vs J values*

Once the gap distance was found, the lengths for the transmission line were needed to be found. This required finding an E_eff for given impedance of 50-ohms. Using Line-Calc tool on ADS in Figure 22, the E_eff was found to be 6.666 and the transmission line width was found to be 1.203m mm.

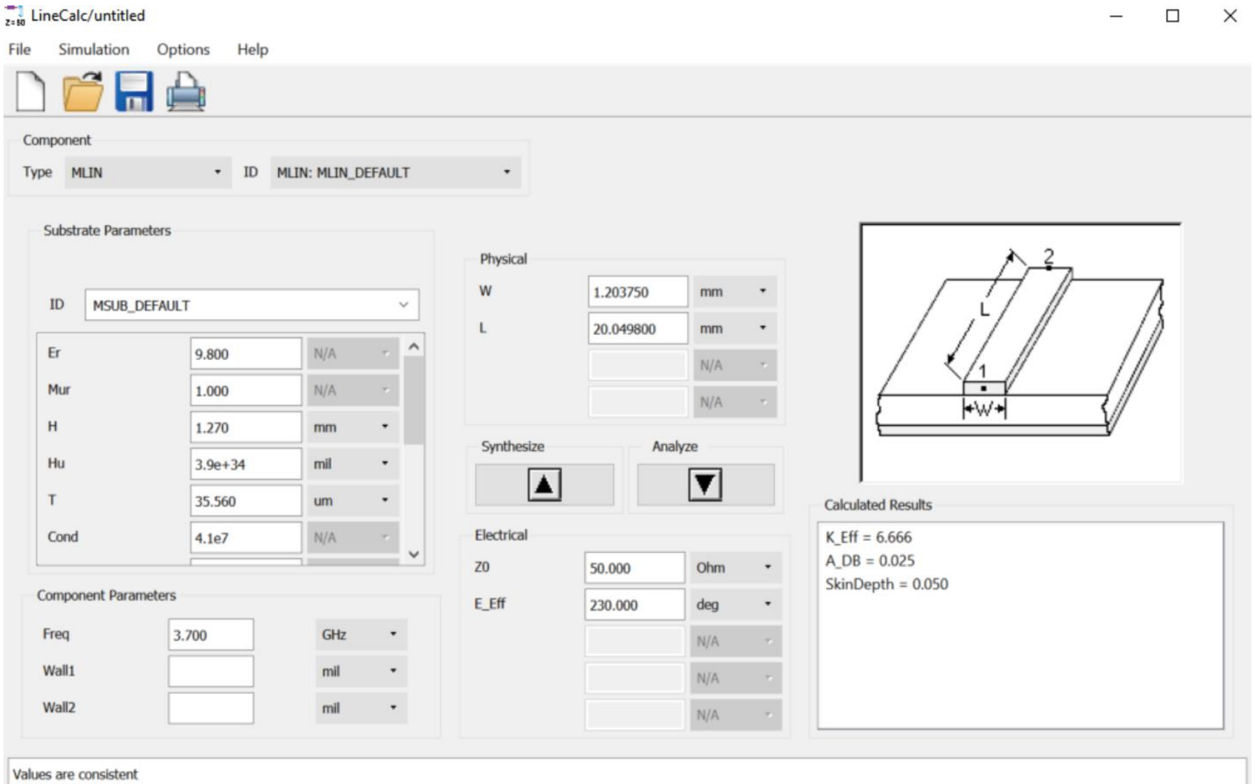



*Figure 22: Line Cal*

Now, all the parameters have been calculated and so the entire 5 pole network can be modeled. As seen in the Figure 23, the schematic for a single pole was created and duplicated multiple time to create the 5-pole network. Then a layout was generated showing all 5 poles in the Figure 24.

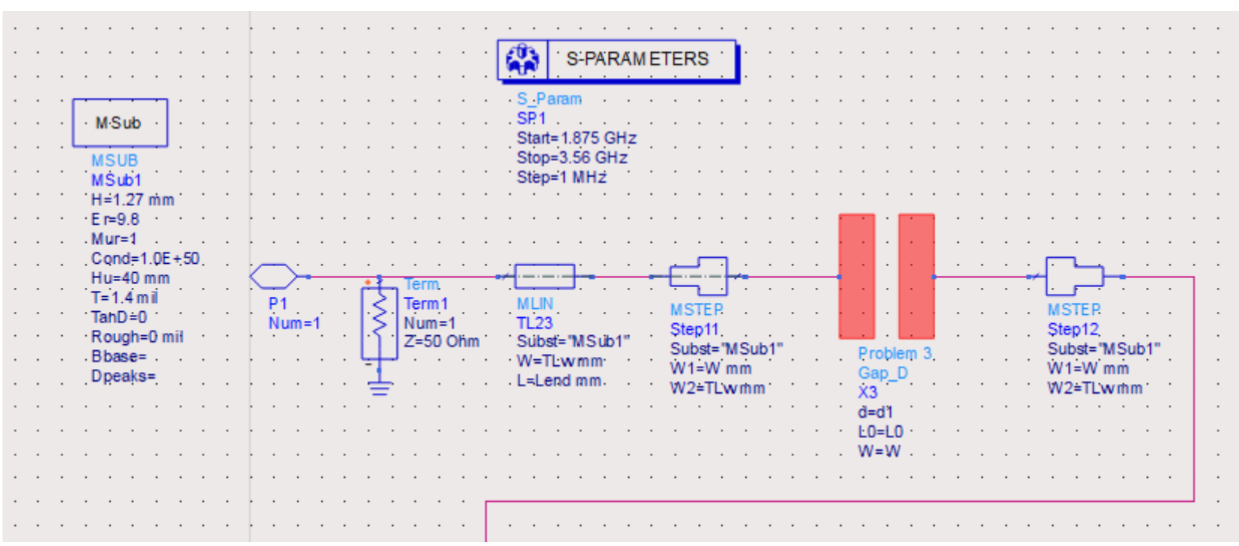



*Figure 23: Single Pole Schematic*

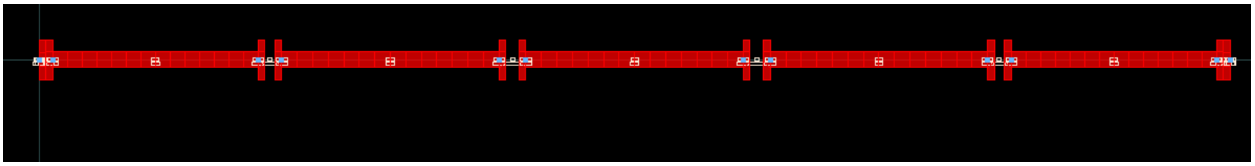


*Figure 24: 5 Pole Layout*

The final schematic representation can be shown in Figure 25 with poles condensed to 5 pole network band passes connected to input and output and terminating with 50-ohm impedance. Here, the gap distances are shown along with the lengths, transmission line width and L0 and W value for the poles. Initially, when circuit simulation was performed, the transmit power around 3.7GHz frequency was very poor and not centred. As a result, multiple iterations of fine tuning the filter parameters needed to be done to achieve desired outputs.

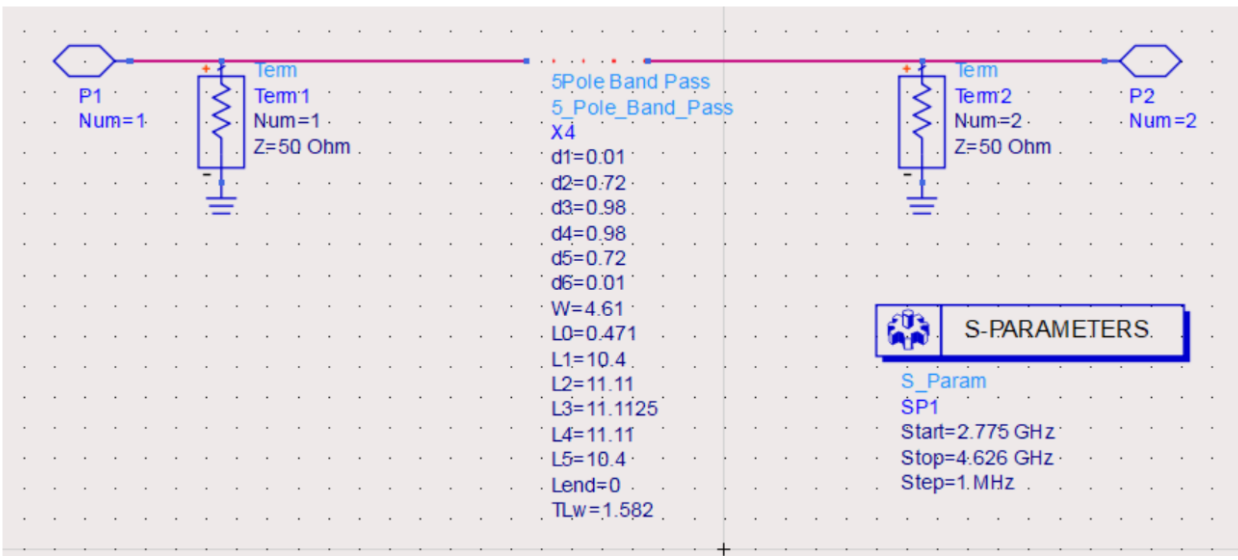



*Figure 25: Overall 5 Pole Band Pass Schematic*

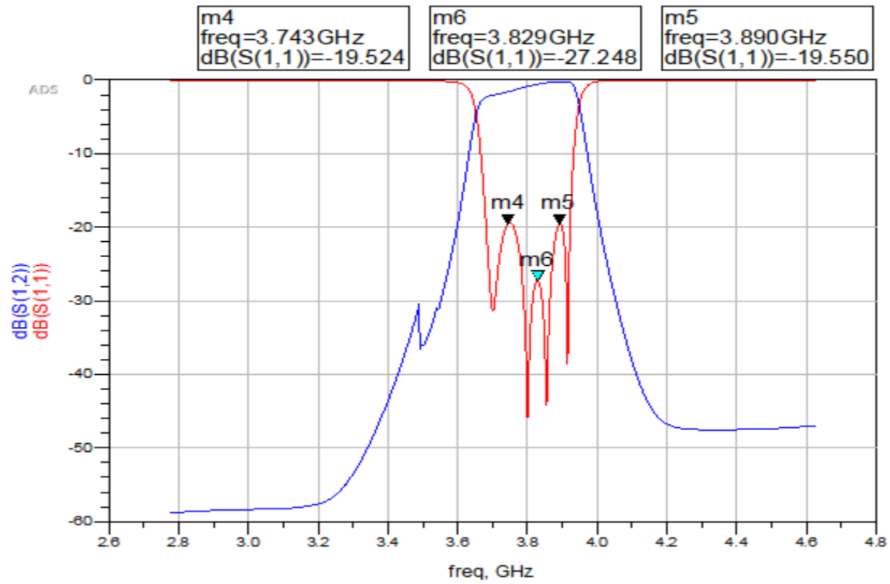



*Figure 26: Final Magnitude Plot*

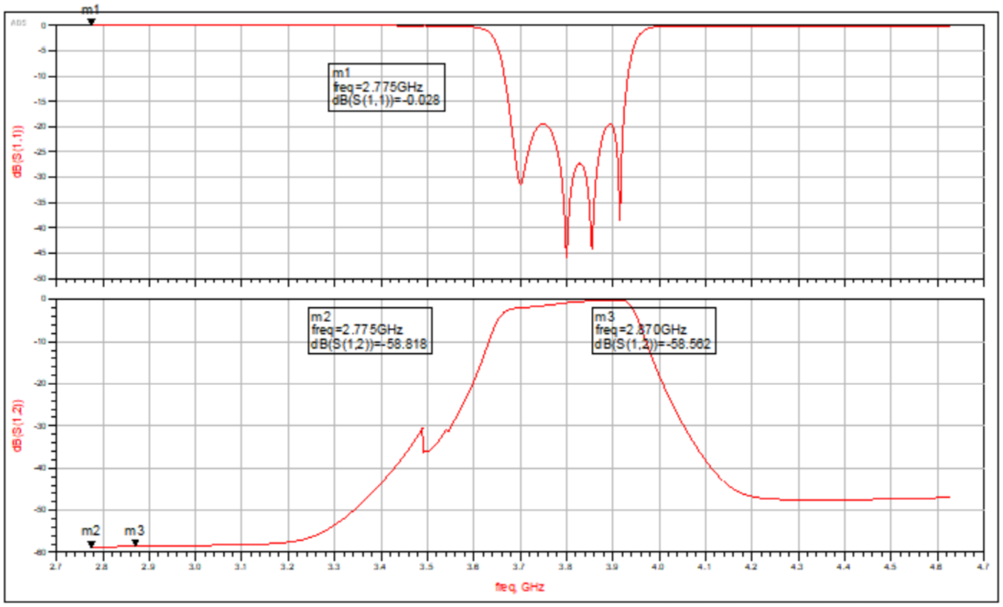



*Figure 27 Magnitude of S11 and S12 Plots*

From Figure 26 and 27, the final magnitude of S11(return loss) value for the filter is around 19.5 dB and S12 value is near 0 dB. This makes sense as we want max negative (minimum) return loss and more throughput transmission going to port 2, resulting in small or no reflection from port 2 back to port 1. This is shown with magnitude of S12 near 0 dB on the graph. This filter is designed to meet the required specs at centre frequency of around 3.7 GHz. Ultimately, it was through trial and error of tweaking gap distance and width value to achieve minimum return loss, the magnitude of S11 value on the graph.

## Appendix

**Problem 2 MATLAB Code:**

```
%Problem 2
s11= -0.518 -j*0.595 ;
s12= 0.501-j*0.348;
s21= 0.501-j*0.348 ;
s22= -0.386-j*0.688 ;
Smatrix = [s11 s12; s21 s22];
y_matrix = s2y(Smatrix,50);

y11 = y_matrix(1);
y12 = y_matrix(2);
y21 = y_matrix(3);
y22 = y_matrix(4);

-y12;
y11 + y12;
y22 + y12;
z12 = 1/-y12;
xc = -imag(z12);
C = 1/(2*pi*2e9*xc)
zLHS = 1/(y11 + y12);
xc1 = -imag(zLHS);
C1 = 1/(2*pi*2e9*xc1)

zRHS = 1/(y22 + y12);
xc2 = -imag(zRHS);

C2 = 1/(2*pi*2e9*xc2)
```

**Problem 3:**

```
clear all
close all
clc
format long

z0 = 50;
y0 = 1/z0;

delta = 0.037;
f0 = 3.7e9;
c = 3e8;

g0 = 1;
```

```
g1 = 0.765;
g2 = 1.3249;
g3 = 1.6211;
g4 = 1.3249;
g5 = 0.765;
g6 = 1;

J01 = sqrt((pi*delta)/(2*g0*g1))*y0
J12 = pi*delta/(2*sqrt(g1*g2))*y0
J23 = pi*delta/(2*sqrt(g2*g3))*y0
J34 = pi*delta/(2*sqrt(g3*g4))*y0
J45 = pi*delta/(2*sqrt(g4*g5))*y0
J56 = sqrt((pi*delta)/(2*g5*g6))*y0

phi1 = -1.1953993;
phi2 = -0.9267960;
phi3 = -0.9189037;
phi4 = phi3;
phi5 = phi2;
phi6 = phi1;

W = 0.5; %mm
h = 1.27; %mm
er = 9.8;

F = (1+(12*h/W))^(-0.5) + 0.04*(1-(W/h))^2; %W/h <1
eff_0 = (er+1)/2 + F*(er-1)/2;

z_0 = 60/sqrt(eff_0)*log(8*h/W + 0.25*W/h);

%At f = 3.7 Ghz
f = 3.7*10^9;
c = 3*10^8;
v_p = c/sqrt(1);
lamda_1_5 = v_p/f*1000;%convert wavelength from meters to mm

F_1_5 = 4*h*sqrt(er-1)/lamda_1_5*(0.5+(1+2*log10(1+W/h))^2);

eff_3_7 = (((sqrt(er)-sqrt(eff_0))/(1+4*F_1_5^(-1.5))) + sqrt(eff_0))^2

v_p = c/sqrt(6.666);
lamdag = v_p/f0;
L1 = (pi + phi1/2 + phi2/2)*lamdag/(2*pi)*1000
L2 = (pi + phi2/2 + phi3/2)*lamdag/(2*pi)*1000
L3 = (pi + phi3/2 + phi4/2)*lamdag/(2*pi)*1000
L4 = (pi + phi4/2 + phi5/2)*lamdag/(2*pi)*1000
L5 = (pi + phi5/2 + phi6/2)*lamdag/(2*pi)*1000
```