SIMULATION OF A SERIES RESONANT CIRCUIT
ECE562: Power Electronics I
COLORADO STATE UNIVERSITY

Modified in Fall 2011

PURPOSE: The purpose of this lab is to simulate the series resonant circuit using MATLAB® and NL5 to better familiarize the student with some of its operating characteristics. This lab will explore some of the following aspects of the series resonant circuit:

- Input impedance
- Magnitude and phase margin
- Zero frequency
- Output power
- Output current
- Plot the natural response for the output voltage
- Zero poles
- Phase of transfer function
- Input impedance for varying resistance (R)

NOTE: The simulations that follow are intended to be completed with NL5. It is assumed that the student has a fundamental understanding of the operation of NL5.

Build the schematic shown in Figure A.

- **Vm** is an AC voltage source. Set the type to 'Sin,' and the magnitude to 1 volt.
- **L1** is an ideal inductor. Set to 1000µH.
- **R** is an ideal resistor. Set to 200 Ω.
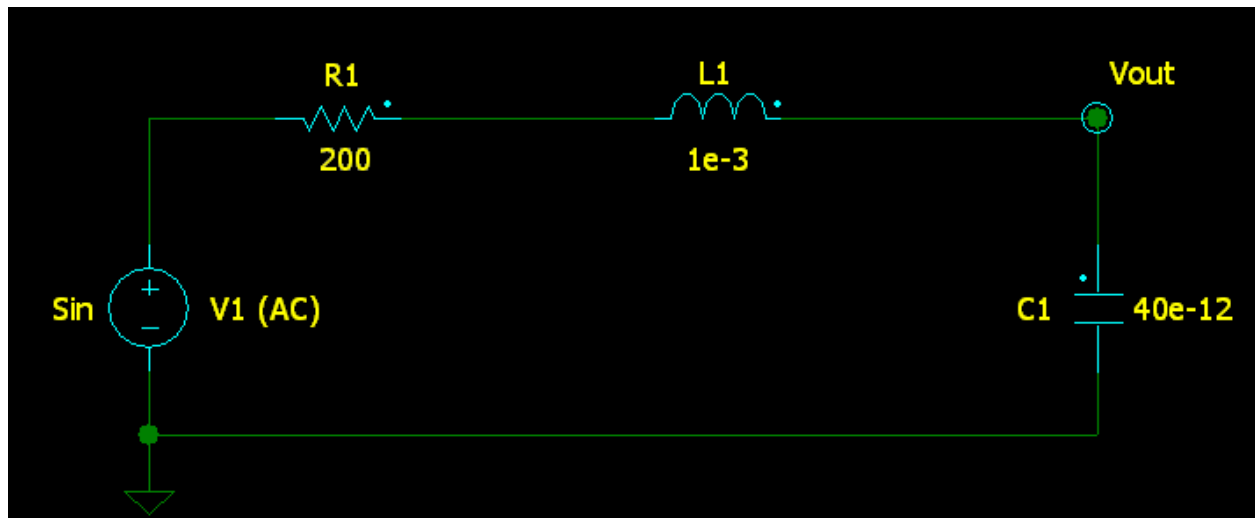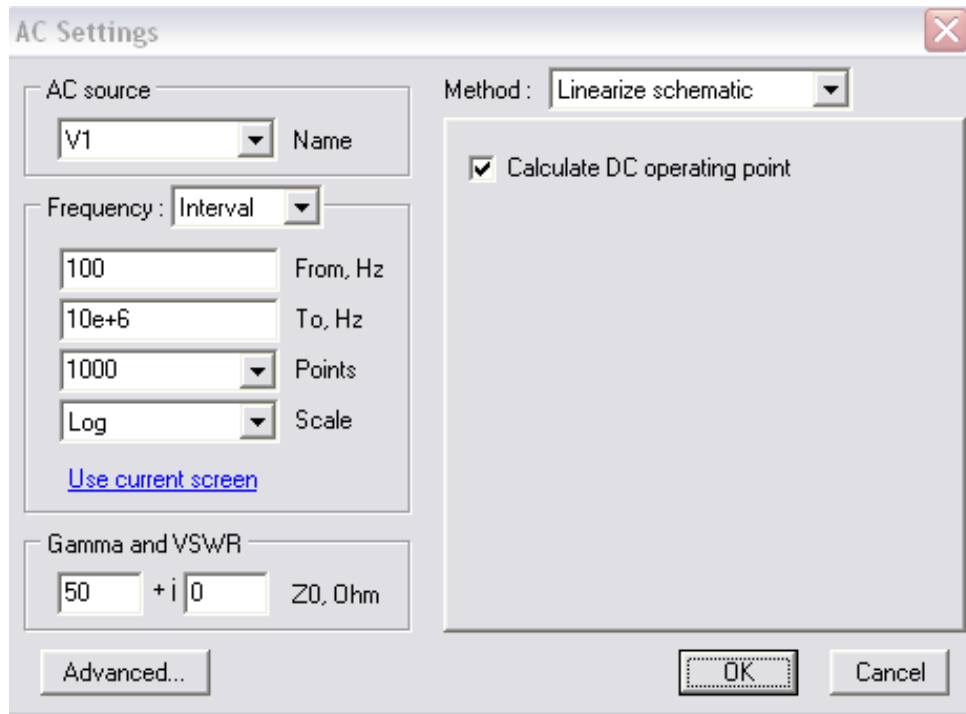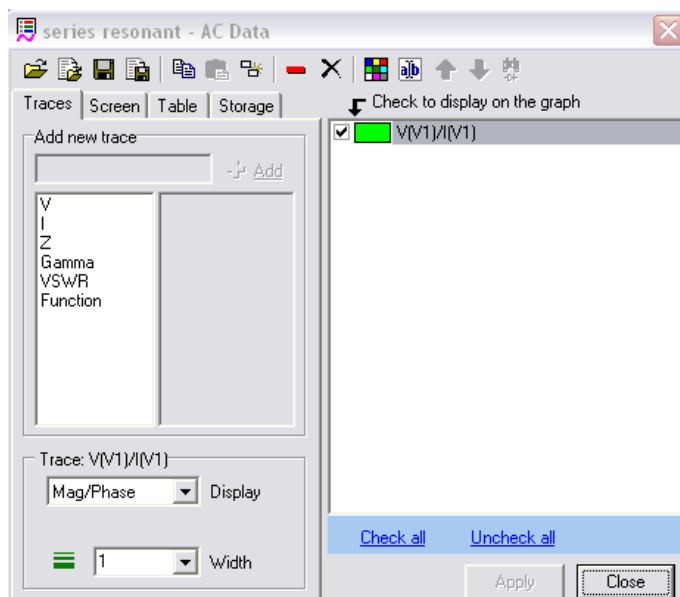- **C1** is an ideal capacitor. Set to 40pF.

Figure A – Initial schematic.

Under the 'AC Settings' tab, specify V1 as the source, a frequency range of 100 Hz to 10 MHz, 1000 points, and a logarithmic scale.

Add a trace for the input impedance by selecting AC / Data / Traces from the menu. Click on 'Function' in the 'Add new trace' section. Add the function V(V1)/I(V1).

Run the simulation by selecting 'AC' and then 'Start' from the drop down menus.
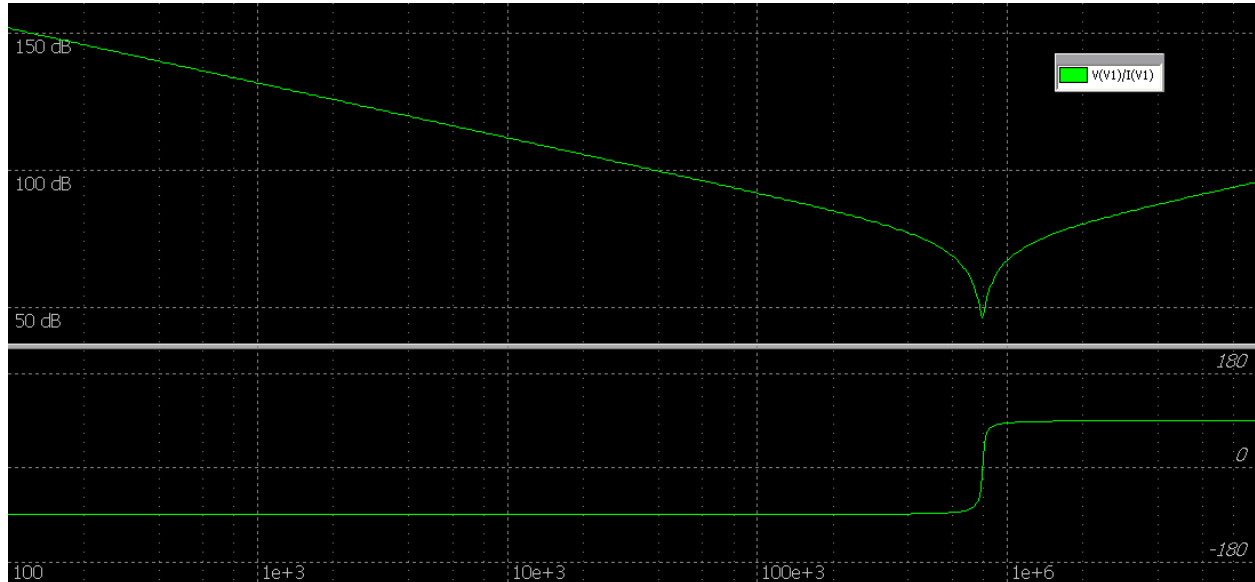

Figure B – Magnitude and phase of the input impedance.

Referring to Figure B, what is the input impedance value of RLC circuit?

Next, we want to measure the total inductor current of RLC series resonance circuit. Right click on the inductor, and select Add trace / current. Re-run the simulation and adjust the display to show the data of interest.
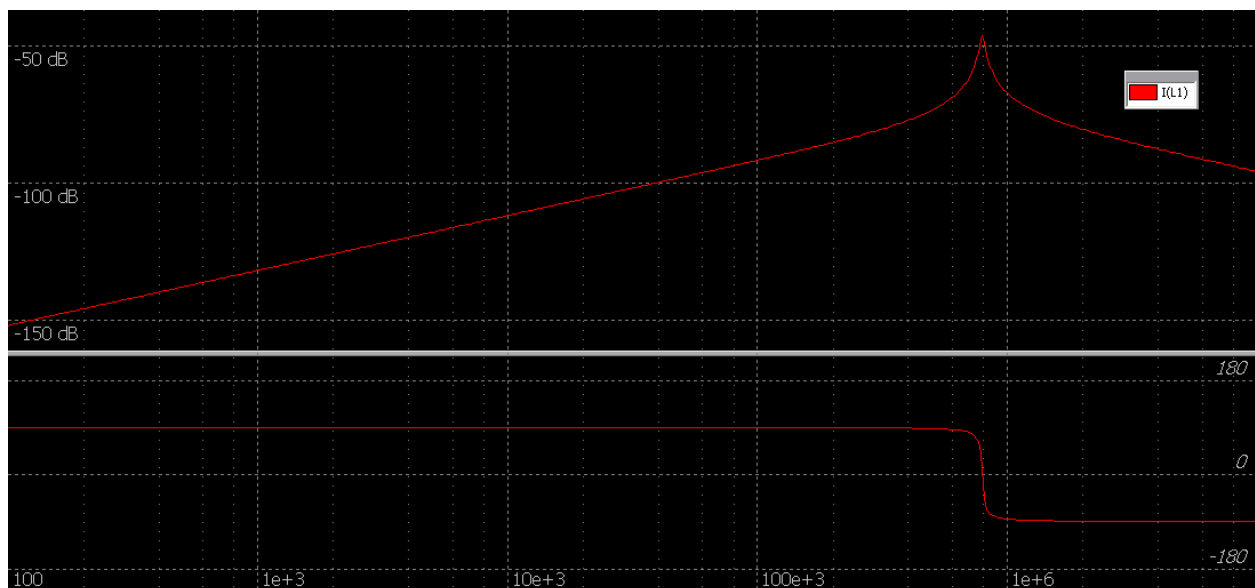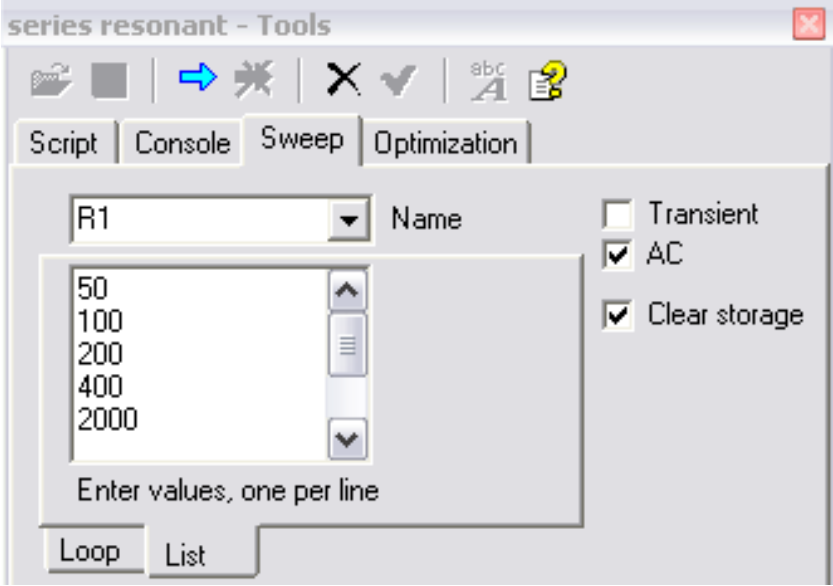

Figure C – Inductor current.

What is the value of the inductor current? Describe the phase characteristics of the inductor current.

Next, we want to simulate the input impedance of series RLC resonant circuit with a varying resistor. Use the same circuit as above, but change the resistor values to 50, 100, 200, 400, 2000, 4000, and 8000 Ω. This type of parametric sweep is accomplished in NL5 with a script. Go to Tools / Script and click on the Sweep tab. Select List instead of Loop. Enter R1 as the Name, enter the parametric values in the box, and select AC sweep. Click on the blue arrow to start the script.

What is the input impedance value of RLC circuit with varying resistances?
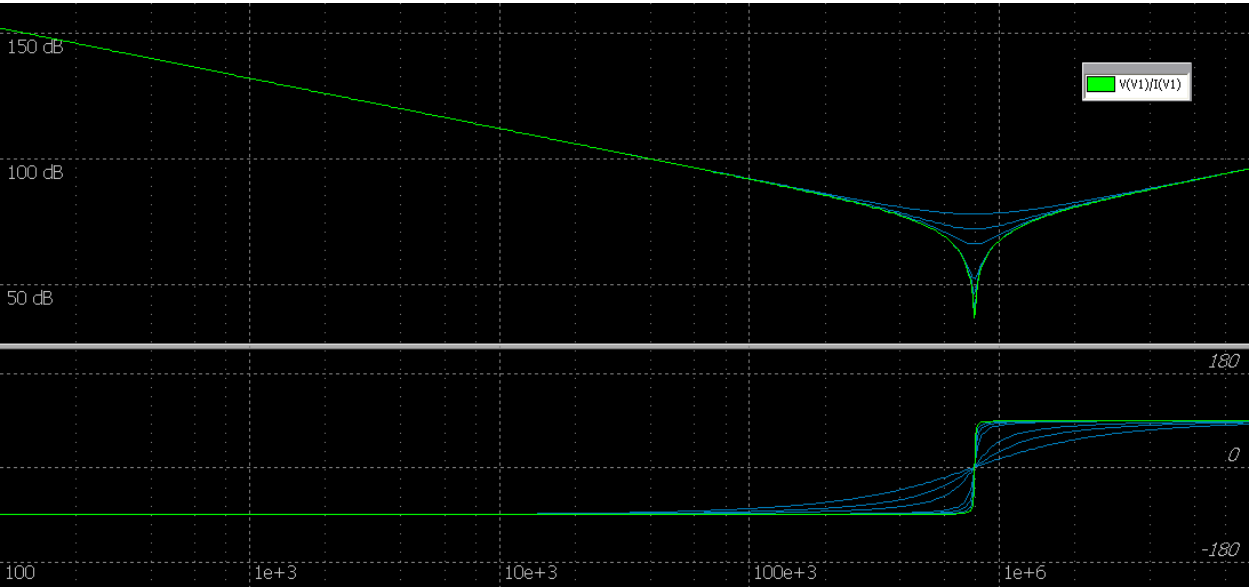
Figure D – Input impedance values of the RLC circuit.

Next, we want to simulate the inductor current of series RLC resonant circuit with varying resistance values.
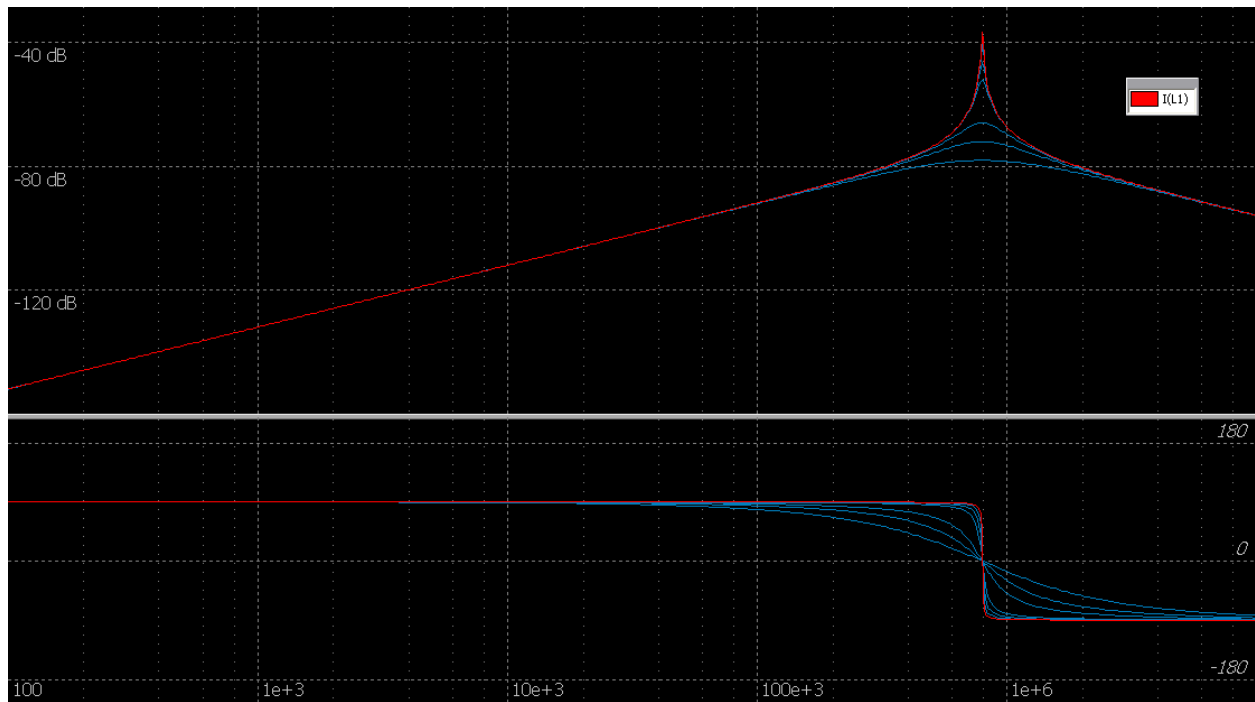
Figure E – Inductor current for varying resistor values.

What is the value of the inductor current? Describe the phase characteristics of the inductor current.

Next, simulate the output voltage as a function of varying resistance. For this example, take the voltage across the capacitor as the output voltage.

Figure F – Output voltage for varying resistor values.

What is the value of the output voltage? Describe the phase characteristics of the output voltage.

For Homework:

You need to re-solve the parallel resonant circuit with Capacitor ESR and see its effects on the magnitude and phase plots in some detail. For example choose the ratio of the C ESR to the load resistance to be in the ratio range from 0.01 to 1.
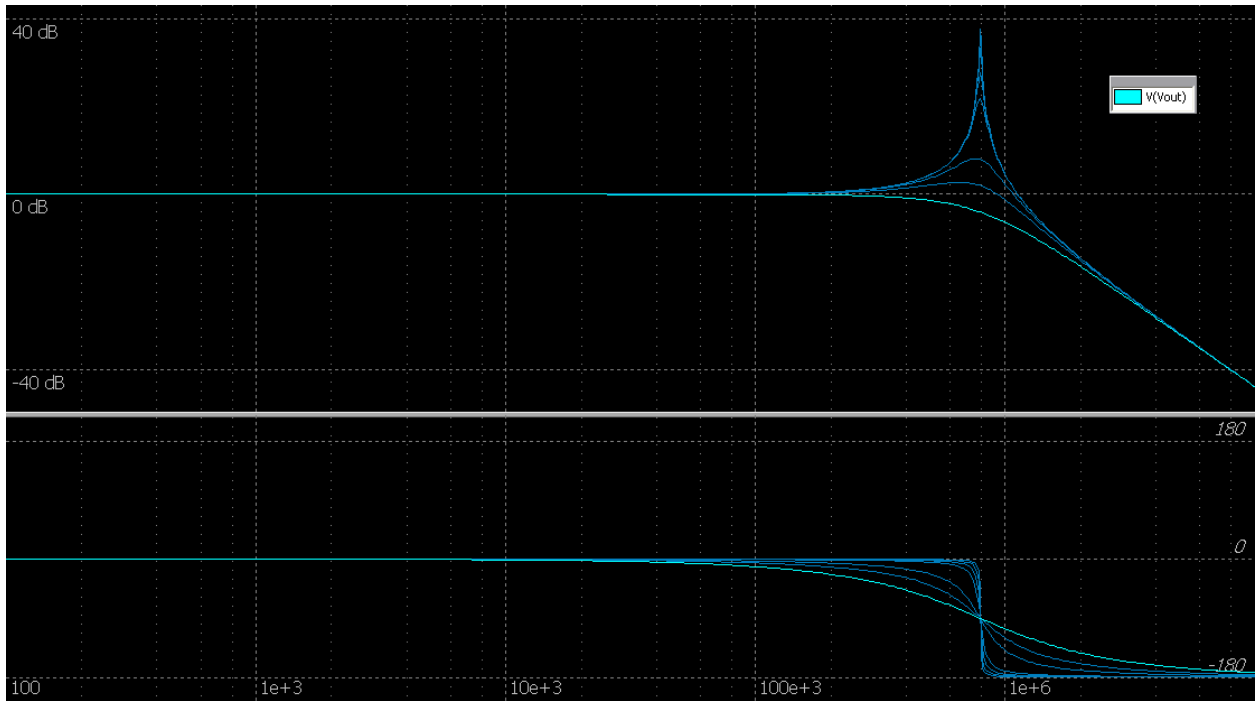
Series Resonant Circuit Using MATLAB

NOTE: The simulations that follow are intended to be completed with MATLAB®. It is assumed that the student has a fundamental understanding of the operation of MATLAB®. MATLAB® provides tutorials for users that are not experienced with its functions.

In this lab you will learn how to write a function to varying, calculating and plotting the input impedance, current and output voltage of the series RLC resonant tank circuit. You can define your own function in MATLAB. A function must start with a line.

Function return-value = function-name (arguments)

So that MATLAB will recognize it as a function. Each function must have its own file and the file must have the same as the function.
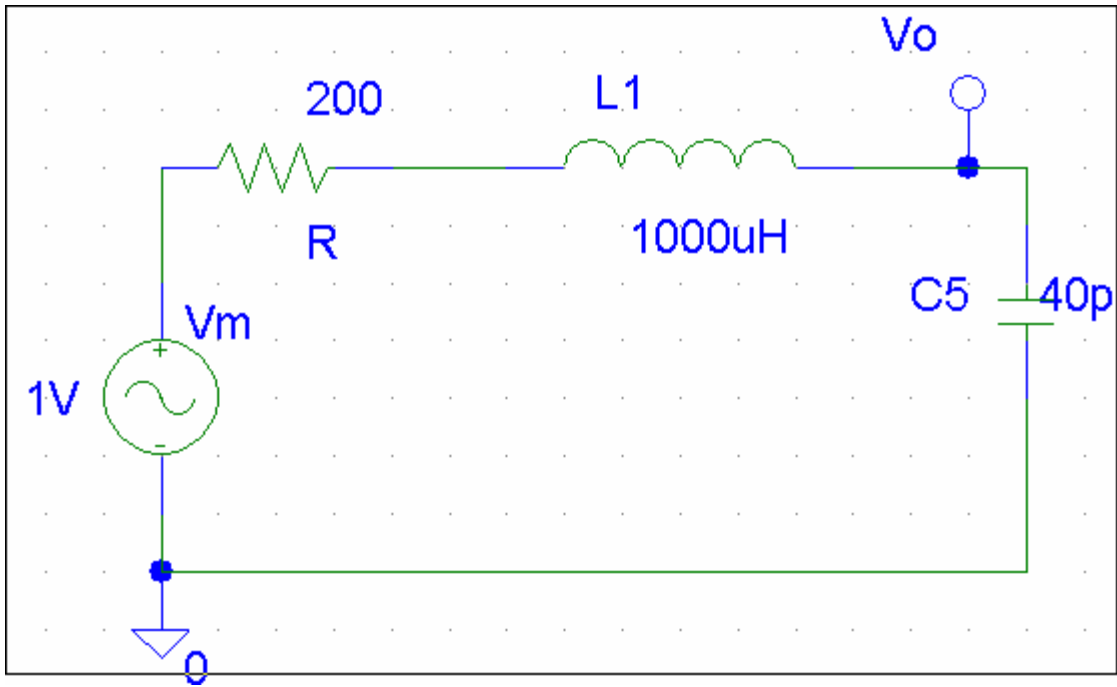
PROCEDURE:

Part 1: Write a function to calculate the total input impedance of series RLC resonant circuit as shown in Figure 1.

Vm is a variable voltage. Set to 1 volts

L is a variable inductor. Set to 1000μH.

R is a variable ideal resistor. Set to 200Ω.

C is a variable ideal capacitor. Set to 40pF.

```matlab
%************************************************************************
% Series RLC Resonant circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% ************************************************************************


function [Zinput]=Zinput_seriesRLC1()   %is the function declaration.  Note:

%The word "function" must be the first (non-comment) word of the program.
%"Zinput " is the value that this function returns, or calculates, a.k.a. the output.
%"radius" is the name of the variable taken as input.
%"Zinput_seriesRLC1" should be both the name of the function and the name
%that you use to save the file.

disp('Starting the function of Zinput_seriesRLC1');
%define all the component values and units for Tank
                        %unit
Vm=1;                   %Volts
R=200;                   %ohms
C=40e-12;                %Farads
L=1000e-6;               %henrys

% define the input impedance
Zin_numb=[L*C R*C 1];
Zin_de=[0 C 0];
Zinput=tf(Zin_numb,Zin_de)
figure(1)
bode(Zinput)
title('Input impedance of series RLC tank circuit')

% calculating important parameters of the tank

[z,p,k]=zpkdata(Zinput,'v');

wo=sqrt(1/L/C)
Beta=R/L
Q=wo/Beta

disp('finishedthe function of Zinput_seriesRLC1');
```

Figure 1: The input impedance of series RLC tank circuit.

Once the above m file is captured, the simulations can be run.   First, go to your directory. Find your m file and then run your file. If there is a red message on

your MATLAB window, then you need to correct your error.   Otherwise, you will see the solution as show in figure 2.

```
Command Window

>> Zinput_seriesRLC1
Starting the function of Zinput_seriesRLC1

Transfer function:
4e-014 s^2 + 8e-009 s + 1
-------------------------
        4e-011 s


wo =

     5000000


Beta =

      200000


Q =

    25

finishedthe function of Zinput_seriesRLC1

Transfer function:
4e-014 s^2 + 8e-009 s + 1
-------------------------
        4e-011 s
```

Figure2: The output of input impedance of series RLC tank circuit.

Next, plot the total input of the series resonant RLC tank circuit.   Write another function to calculate the total input current of series RLC tank circuit as shown in Figure 3. All the initial variables and values are remained the same.

Vm is a variable voltage. Set to 1 volts

L is a variable inductor. Set to 1000μH.

R is a variable ideal resistor. Set to 200Ω.

C is a variable ideal capacitor. Set to 40pF

```matlab
%**********************************************************************
% Series Resonant of RLC tank circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% **********************************************************************


function []=Zinput_seriesRLC2(Zin)
%"Zin" is the name of the variable taken as input.
%define all the component values and units for Tank

disp('Starting the function of Zinput_seriesRLC2');


                        %unit
Vm=1;                   %Volts
R=200;                   %ohms
C=40e-12;                %Farads
L=1000e-6;                %henrys

Zin=Zinput_SeriesRLC1;
Im=1/Zin
figure(2)
bode(Im)
title('Input current of series RLC tank circuit')

% calculating important parameters of the tank

[z,p,k]=zpkdata(Zin,'v');

wo=sqrt(1/L/C)
Beta=R/L
Q=wo/Beta

disp('finishedthe function of Zinput_seriesRLC2');
```

Figure 3: the function to calculate the total input current of series RLC tank circuit

Once the above function file is captured, the simulations can be run.   First, go to
your directory. Find your function file and then run your file. If there is a red
message on your MATLAB window, then you need to correct your error.
Otherwise, you will see the solution as show in figure 4.

```
>> Zinput_seriesRLC2
Starting the function of Zinput_seriesRLC2
Starting the function of Zinput_seriesRLC1

Transfer function:
4e-014 s^2 + 8e-009 s + 1
-------------------------
         4e-011 s


wo =

      5000000


Beta =

       200000


Q =

     25

finishedthe function of Zinput_seriesRLC1

Transfer function:
        4e-011 s
-------------------------
4e-014 s^2 + 8e-009 s + 1


wo =

      5000000


Beta =

       200000


Q =

     25

finishedthe function of Zinput_seriesRLC2
```
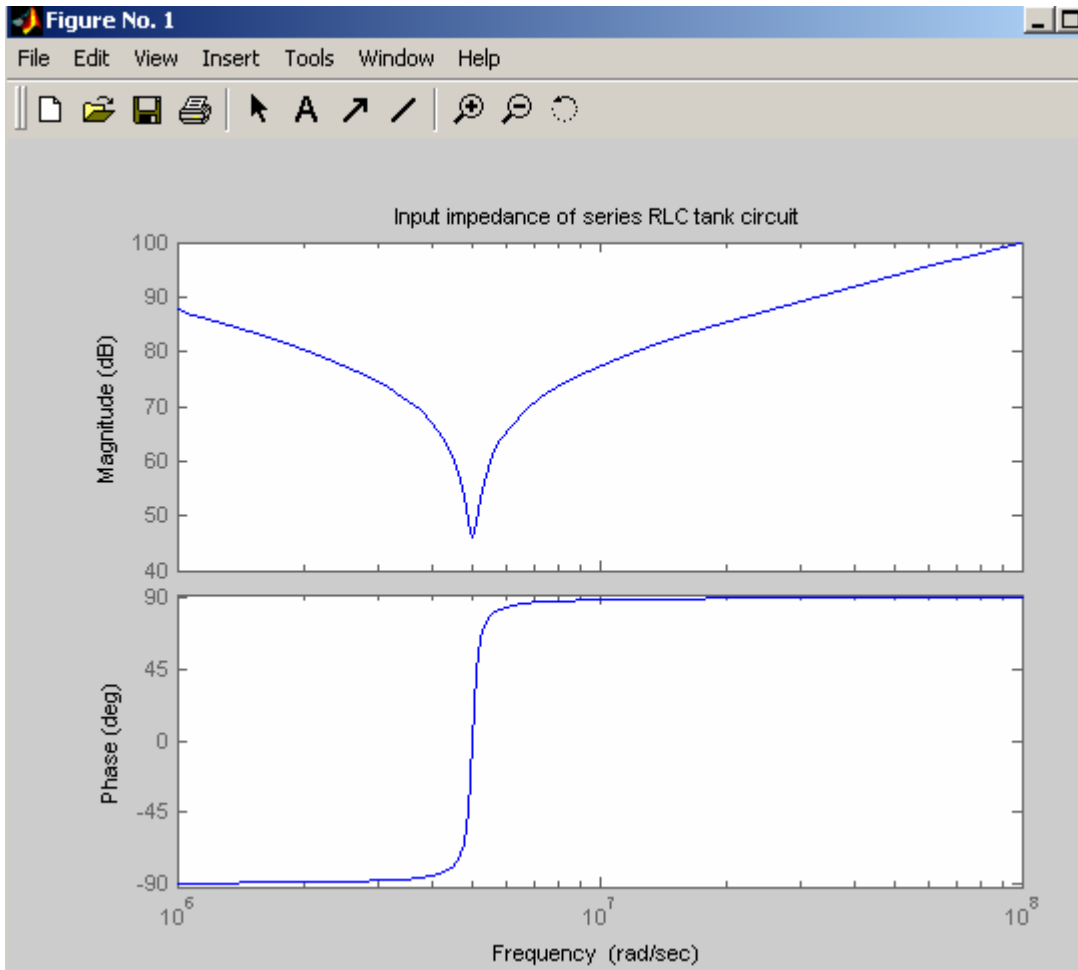
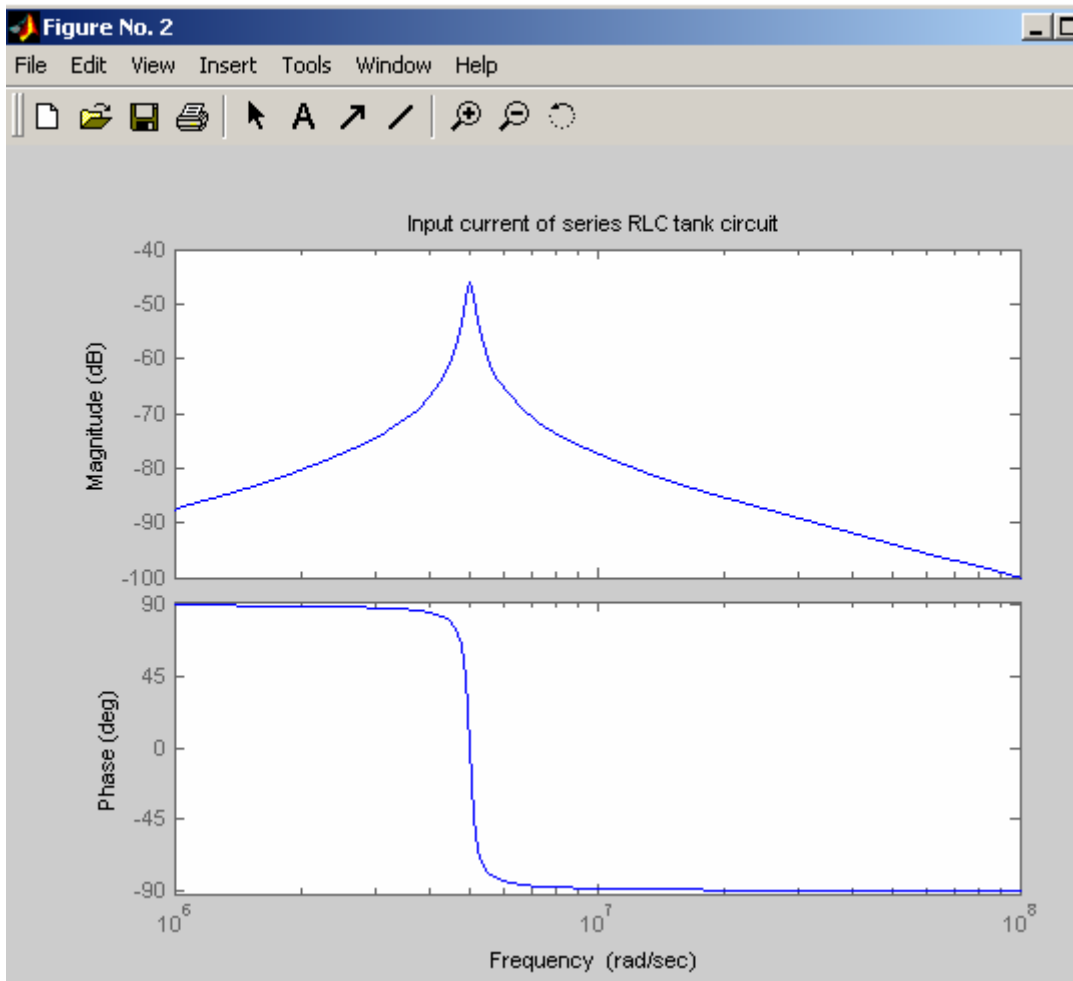*Figure 4: the output and plot of the total input current of series RLC tank circuit*

Now write a function to varying R of the input impedance of series RLC resonant circuit by adding an array of Resistors (R) value. Again all the initial variables and values are remain the same.

Vm is a variable voltage. Set to 1 volts

L is a variable inductor. Set to 1000μH.

R is a variable ideal resistor. Set to 200Ω.

C is a variable ideal capacitor. Set to 40pF

Write a loop function to do the varying resistors value, calculate and plot the output of total input impedance of series RLC resonant circuit.   When the function to varying R of the input impedance of series RLC resonant circuit function file is captured, the simulations can be run. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the result as show below

```matlab
%*********************************************************************
% Series RLC Resonant circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% ********************************************************************

function [Zinput]=Zinput_seriesRLC3()

disp('Starting the function of Zinput_seriesRLC3');
%define all the component values and units for Tank
                    %unit
Vm=1;               %Volts
R=200;               %ohms
C=40e-12;            %Farads
L=1000e-6;            %henrys

% define the varying loads value
R=[R/4 R/2 R R*2 R*10 R*20 R*40]

% define the input impedance for varing Rs

for i=1:7
    Zin_numb=[L*C R(i)*C 1];
    Zin_de=[0 C 0];
    Zinput=tf(Zin_numb, Zin_de);
    figure(3)
    bode(Zinput)
    if i==1,
        hold,
    end
end
title('Input impedance of series RLC tank circuit for varing R')
disp('finishedthe function of Zinput_seriesRLC3');
```

Figure 5: A function of the input impedance of series RLC resonant circuit with varying Resistor

```
>> Zinput_seriesRLC3
Starting the function of Zinput_seriesRLC3

R =

          50          100          200          400          2000          4000          8000

Current plot held
finishedthe function of Zinput_seriesRLC3

Transfer function:
4e-014 s^2 + 3.2e-007 s + 1
---------------------------
         4e-011 s
```
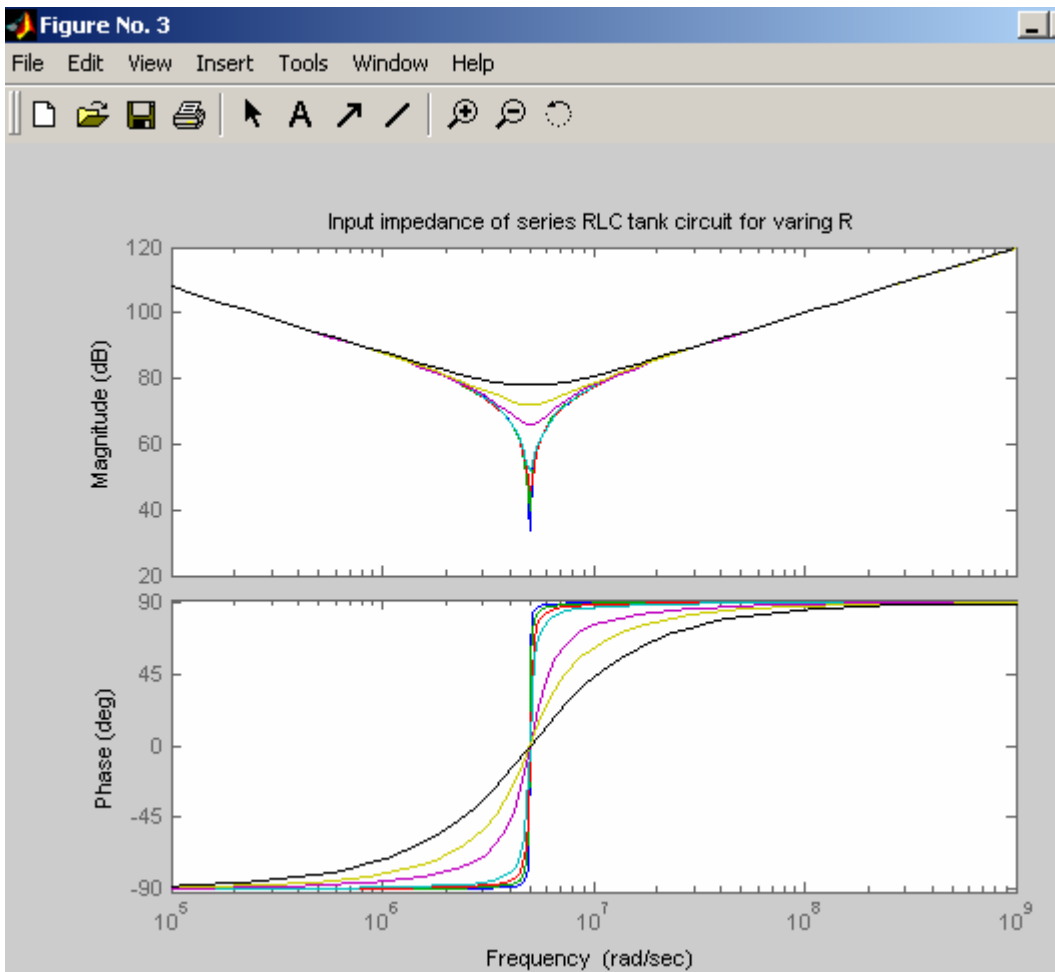
Figure 6: Output of the input impedance of series RLC resonant circuit with varying Resistor

Now write a function to varying R of the input current of series RLC resonant circuit by adding an array of Resistors (R) value. Again all the initial variables and values are remain the same.

Vm is a variable voltage. Set to 1 volts

L is a variable inductor. Set to 1000µH.

R is a variable ideal resistor. Set to 200Ω.

C is a variable ideal capacitor. Set to 40pF

Write a loop function to do the varying resistors value, calculate and plot the output of total input current of series RLC resonant circuit. When the function to varying R of the input current of series RLC resonant circuit function file is captured, the simulations can be run. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the result as show below

```matlab
%************************************************************************
% Series RLC Resonant circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% ************************************************************************

function []=Zinput_seriesRLC4(Zinput)
disp('Starting the function of Zinput_seriesRLC4');
%define all the component values and units for Tank
                    %unit
Vm=1;               %Volts
R=200;               %ohms
C=40e-12;            %Farads
L=1000e-6;            %henrys

% define the varying loads value
R=[R/4 R/2 R R*2 R*10 R*20 R*40]

% define the input impedance for varing Rs

for i=1:7
    Zin_numb=[L*C R(i)*C 1];
    Zin_de=[0 C 0];
    Zinput=tf(Zin_numb, Zin_de);
    Im=Vm/Zinput
    figure(4)
    bode(Im)
    if i==1,
        hold,
    end
end
title('Input current of series RLC tank circuit for varing R')
disp('finishedthe function of Zinput_seriesRLC4');
```

Figure 7: A function of the input current of series RLC resonant circuit with varying Resistor

```
Starting the function of Zinput_seriesRLC4

R =

          50          100          200          400          2000          4000          8000


Transfer function:
        4e-011 s
    ------------------------
    4e-014 s^2 + 2e-009 s + 1

Current plot held

Transfer function:
        4e-011 s
    ------------------------
    4e-014 s^2 + 4e-009 s + 1


Transfer function:
        4e-011 s
    ------------------------
    4e-014 s^2 + 8e-009 s + 1


Transfer function:
         4e-011 s
    --------------------------
    4e-014 s^2 + 1.6e-008 s + 1


Transfer function:
        4e-011 s
    ------------------------
    4e-014 s^2 + 8e-008 s + 1


Transfer function:
         4e-011 s
    --------------------------
    4e-014 s^2 + 1.6e-007 s + 1
```

```
Transfer function:
        4e-011 s
---------------------------
4e-014 s^2 + 3.2e-007 s + 1

finishedthe function of Zinput_seriesRLC4
```
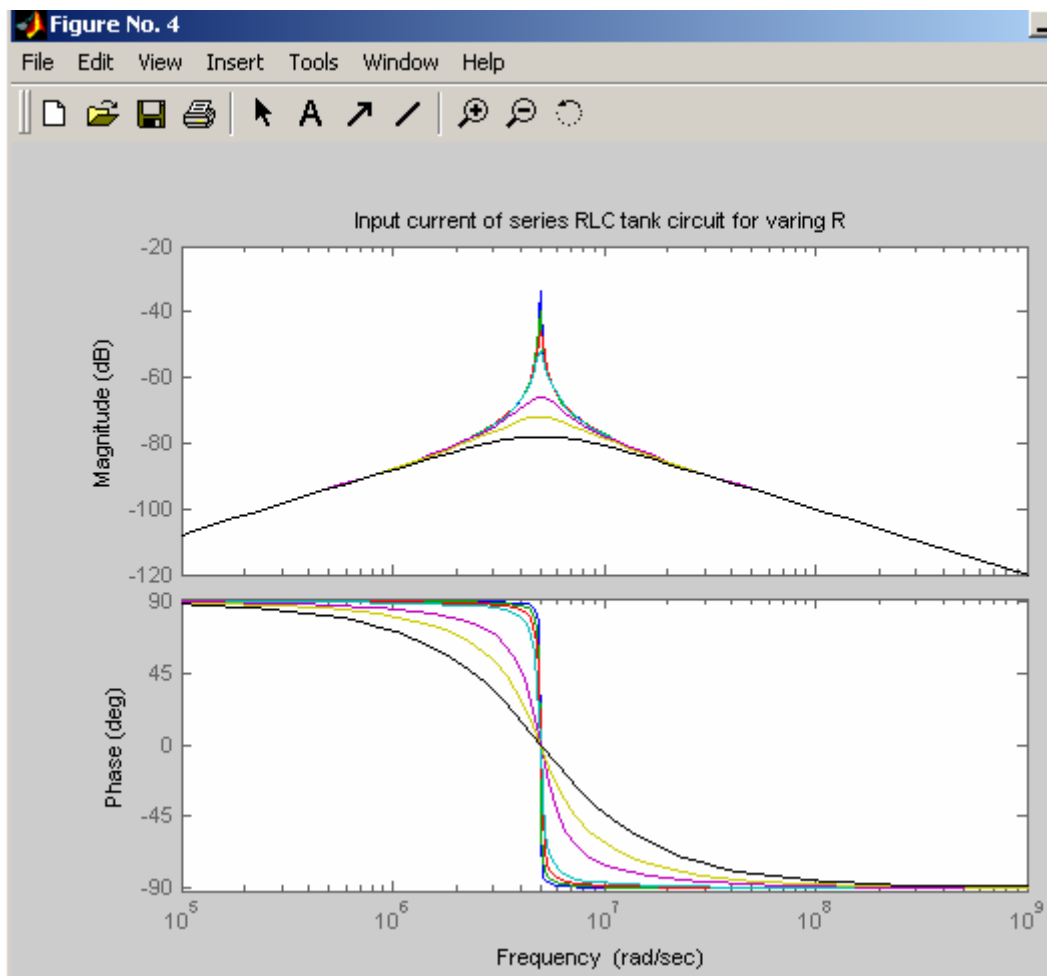

Figure 8: Output of the input current of series RLC resonant circuit with varying Resistor

Now write a function to varying R of the output voltage of series RLC resonant circuit by adding an array of Resistors (R) value. Again all the initial variables and values are remain the same.

Vm is a variable voltage. Set to 1 volts

L is a variable inductor. Set to 1000µH.

R is a variable ideal resistor. Set to 200Ω.

C is a variable ideal capacitor. Set to 40pF

 Write a loop function to do the varying resistors value, calculate and plot the output voltage of series RLC resonant circuit.   When the function to varying R of the input current of series RLC resonant circuit function file is captured, the simulations can be run. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the result as show below

```matlab
%**************************************************************************
% Series RLC Resonant circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% **************************************************************************


function [Zinput]=Zinput_seriesRLC5()
disp('Starting the function of Zinput_seriesRLC5');

%define all the component values and units for Tank
                    %unit
Vm=1;               %Volts
R=200;               %ohms
C=40e-12;            %Farads
L=1000e-6;            %henrys

% define the varying loads value
R=[R/4 R/2 R R*2 R*10 R*20 R*40]

% define the input impedance for varing Rs

for i=1:7
    Zc=tf([0 1],[C 0]);
    Zp=tf([L R(i)], [0 1]);
    Vout=Vm*Zc/(Zc+Zp);
    figure(5)
    bode(Vout)
    if i==1,
        hold,
    end
end
title('Ouput voltage across Capacitor of series RLC tank circuit for varing R')
disp('finishedthe function of Zinput_seriesRLC5');
```

Figure 9: A function of the output voltage of series RLC resonant circuit with varying Resistor

```
Starting the function of Zinput_seriesRLC5

R =

        50          100          200          400         2000         4000         8000

Current plot held
finishedthe function of Zinput_seriesRLC5
```
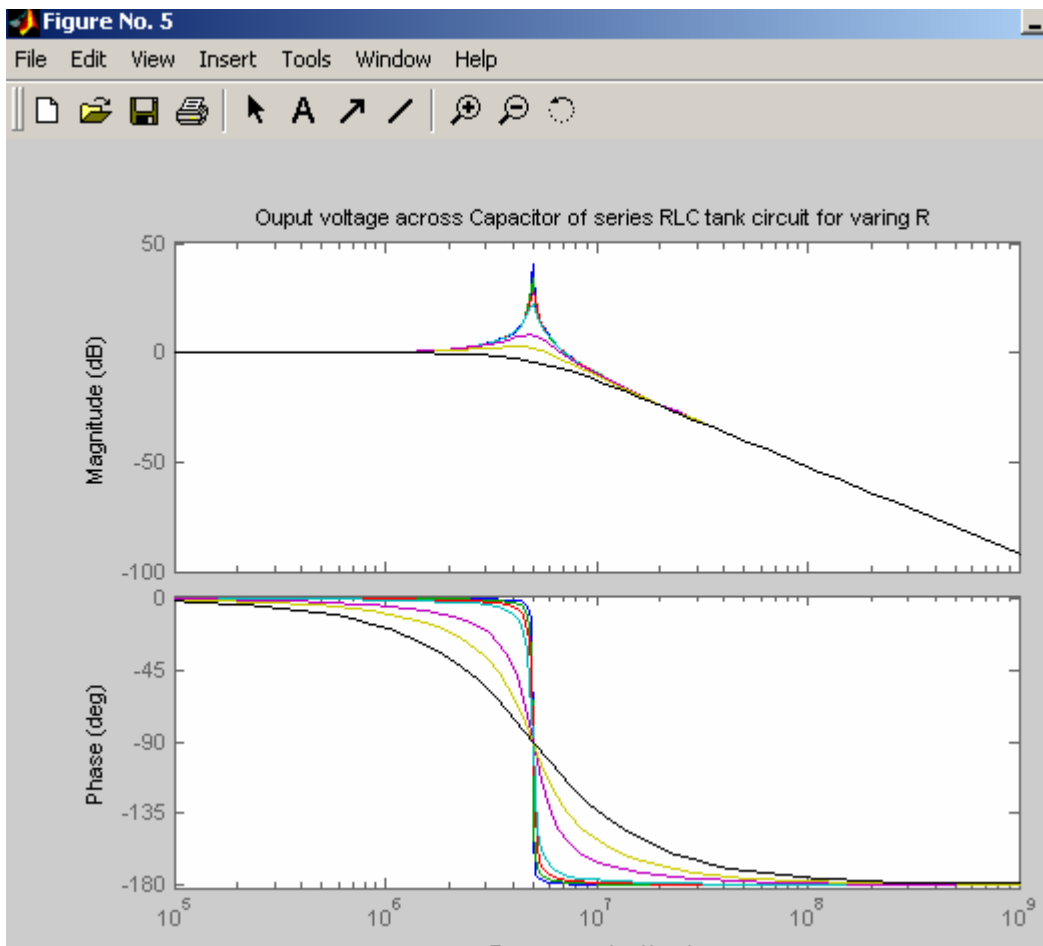

Figure 10: This figure is shown the output voltage of series RLC resonant circuit with varying Resistor

For Homework:

You need to re-solve the parallel resonant circuit with Capacitor ESR and see its effects on the magnitude and phase plots in some detail. For example choose the ratio of the C ESR to the load resistance to be in the ratio range from 0.01 to 1.

Now write m file to varying R of the natural response of current in series RLC resonant circuit by adding an array of Resistors (R) value. Again all the initial variables are remain the same but change their values.

Vm is a variable voltage. Set to 0 volts

L is a variable inductor. Set to 5mH.

R is a variable ideal resistor. Set to 8Ω.

C is a variable ideal capacitor. Set to 200μF

Io is a variable ideal of inductor current. Set to 2 amps.

Vo is a variable ideal of capacitor voltage. Set to -5 volts.

Write a loop function to do the varying resistors value, calculate and plot the natural response of current for series RLC resonant circuit. When the function to varying R of the natural response of current in series RLC resonant circuit file is captured, the simulations can be run. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the result as show below

```matlab
%****************************************************************************
% Series RLC Resonant circuit circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% ****************************************************************************

% clear all the windows
clc;
disp('Starting the natural response of current')

%define all the component values and units for Tank
                    %unit
Vm=0;               %Volts
R=8;                %ohms
C=200e-6;           %Farads
L=5e-3;             %henrys
Io=2;               %amps (initial Ic on inductor)
Vo=-5;              %Volts ( initial Vc on capacitor)

% transfer function of tank current with initial conditions

numb=[0 Vm+Io*L -Vo];
de=[L R 1/C];
% define the current of series curcuit
i=tf(numb,de)
% plot the impulse current of the circuit
impulse(i)

% define varying loads
R=[4 8 10 16]
m=size(R);
jmax=m(2)

hold off

% defining the input impedance for varying Rs.

for i=1:jmax
    numb=[0 Vm+Io*L -Vo];
    de=[L R(i) 1/C];
    Il=tf(numb,de)
    impulse(Il)
    if i==1,
        hold,
    end;
end
grid

disp('finished the function natural response of current');
```

Figure 11: the m file to calculate and plot the natural response of current in series RLC resonant circuit with varying Resistor

```
Command Window
Starting the natural response of current

Transfer function:
     0.01 s + 5
------------------------
0.005 s^2 + 8 s + 5000


R =

     4      8     10     16


jmax =

     4


Transfer function:
     0.01 s + 5
------------------------
0.005 s^2 + 4 s + 5000

Current plot held

Transfer function:
     0.01 s + 5
------------------------
0.005 s^2 + 8 s + 5000


Transfer function:
     0.01 s + 5
------------------------
0.005 s^2 + 10 s + 5000


Transfer function:
     0.01 s + 5
------------------------
0.005 s^2 + 16 s + 5000


finished the function natural response of current
```
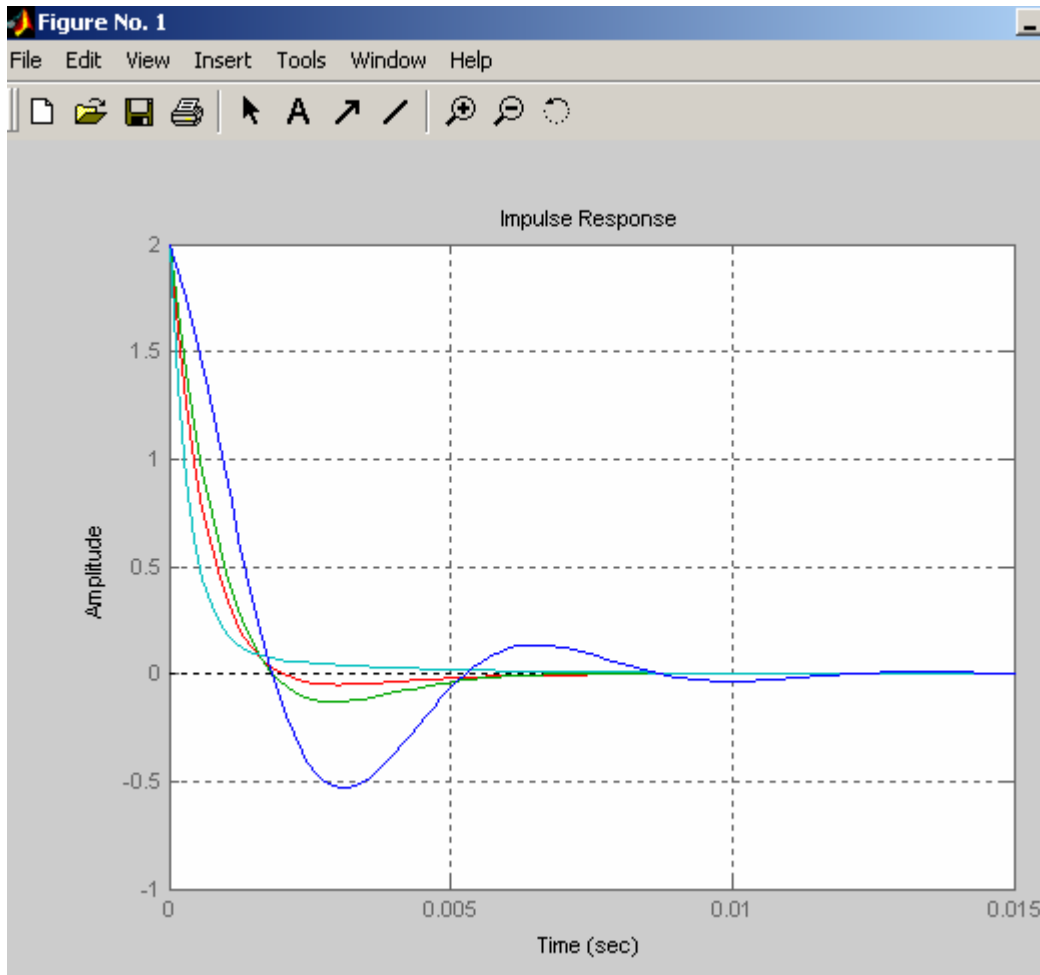
Figure 12: This figure is shown the output of the natural responses of current in series RLC resonant circuit with varying Resistor

Now write m file to varying R of the natural response of capacitor voltage in a series RLC resonant circuit by adding an array of Resistors (R) value. Again all the initial variables are remain the same but change their values.

Vm is a variable voltage. Set to 0 volts

L is a variable inductor. Set to 5mH.

R is a variable ideal resistor. Set to 8Ω.

C is a variable ideal capacitor. Set to 200μF

Io is a variable ideal of inductor current. Set to 2 amps.

Vo   is a variable ideal of capacitor voltage. Set to -5 volts.

 Write a loop function to do the varying resistors value, calculate and plot the natural response of capacitor voltage in a series RLC resonant circuit.   When the function to varying R of the natural response of series RLC resonant circuit file is captured, the simulations can be run. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the result as show below

```matlab
%*************************************************************************
% Series RLC Resonant circuit
% Minh Anh Thi nguyen
% Colorado State University
% Electrical and Computer Engineering student
% *************************************************************************
 % clear all window

disp('Starting the natural response of capacitor voltage')
%define all the component values and units for Tank
                    %unit
Vm=0;               %Volts
R=4;                %ohms
C=200e-6;          %Farads
L=5e-3;             %henrys
Io=2;                %amps (initial Ic on inductor)
Vo=-5;               %Volts ( initial Vc on capacitor)


% transfer function of tank current with initial conditions

numb=[0 Vm+Io*L -Vo];
de=[L R 1/C];
% define the current of series curcuit
I=tf(numb,de)
% plot the impulse current of the circuit
Z=tf([L R],[0 1]);
Vcap=Vm-I*Z
impulse(Vcap);

% define varying loads
R=[4 8 10 16]
m=size(R);
jmax=m(2)

hold off

% defining the input impedance for varying Rs.

for i=1:jmax
    numb=[0 Vm+Io*L -Vo];
    de=[L R(i) 1/C];
    I=tf(numb,de)
    Z=tf([L R(i)], [0 1]);
    Vcap=Vm-I*Z
    impulse(Vcap)
    if i==1,
        hold,
    end;
end
grid
```
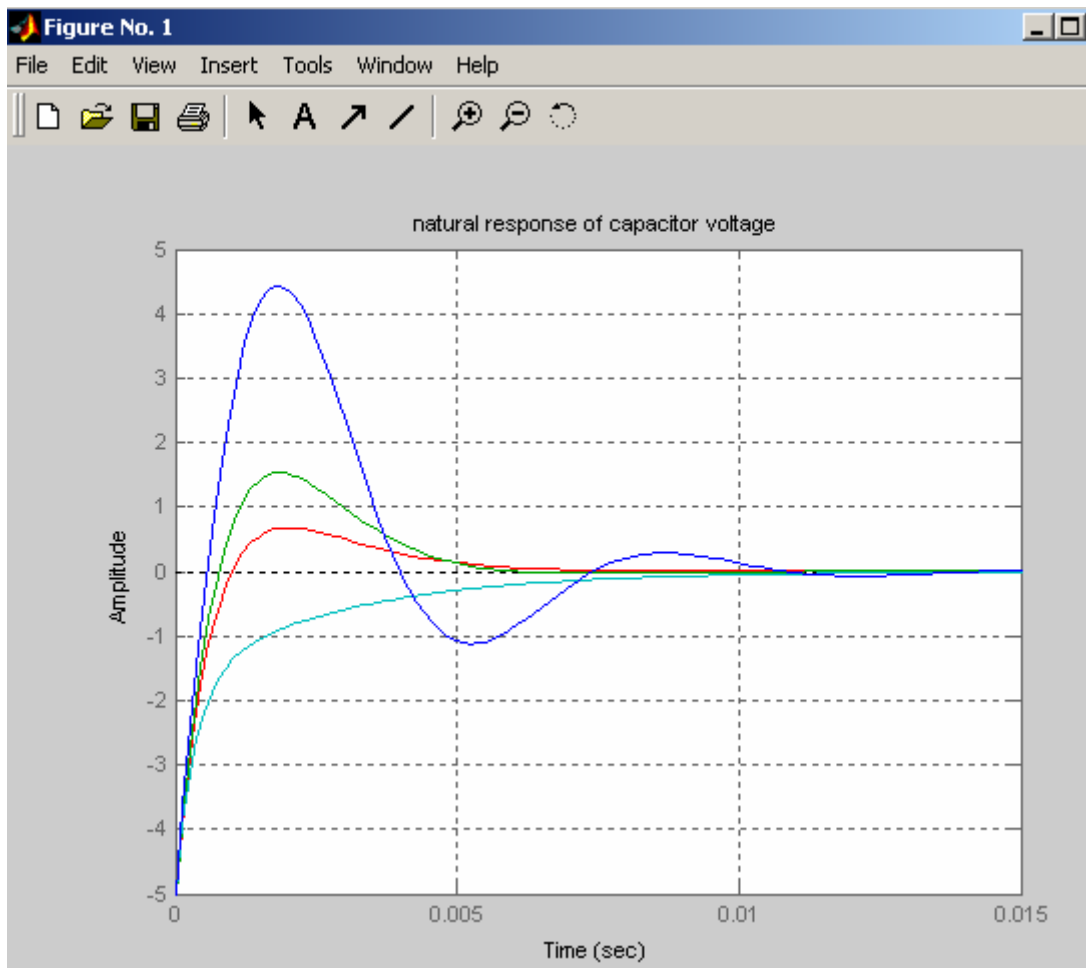
```
disp('finished the function natural response of capacitor voltage');
```

Figure 13: the m file to calculate and plot the natural response of current in a series RLC resonant circuit with varying Resistor

```
Command Window

Transfer function:
      0.01 s + 5
----------------------
0.005 s^2 + 4 s + 5000


Transfer function:
-5e-005 s^2 - 0.065 s - 20
--------------------------
  0.005 s^2 + 4 s + 5000

Current plot held

Transfer function:
      0.01 s + 5
----------------------
0.005 s^2 + 8 s + 5000


Transfer function:
-5e-005 s^2 - 0.105 s - 40
--------------------------
  0.005 s^2 + 8 s + 5000


Transfer function:
      0.01 s + 5
----------------------
0.005 s^2 + 10 s + 5000


Transfer function:
-5e-005 s^2 - 0.125 s - 50
--------------------------
 0.005 s^2 + 10 s + 5000


Transfer function:
      0.01 s + 5
----------------------
0.005 s^2 + 16 s + 5000


Transfer function:
-5e-005 s^2 - 0.185 s - 80
--------------------------
 0.005 s^2 + 16 s + 5000


finished the function natural response of capacitor voltage
```

Figure 14: the output of the natural response of capacitor voltage in a series RLC resonant circuit with varying Resistor