SIMULATIONS OF SERIES RESONANCE CIRCUIT

POWER ELECTRONICS

COLORADO STATE UNIVERSITY

Modified in Spring 2006

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

- 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)

Series Resonance Circuit Using OrCAD Capture

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

PROCEDURE:

Part 1: Build the schematic shown in Figure 1.

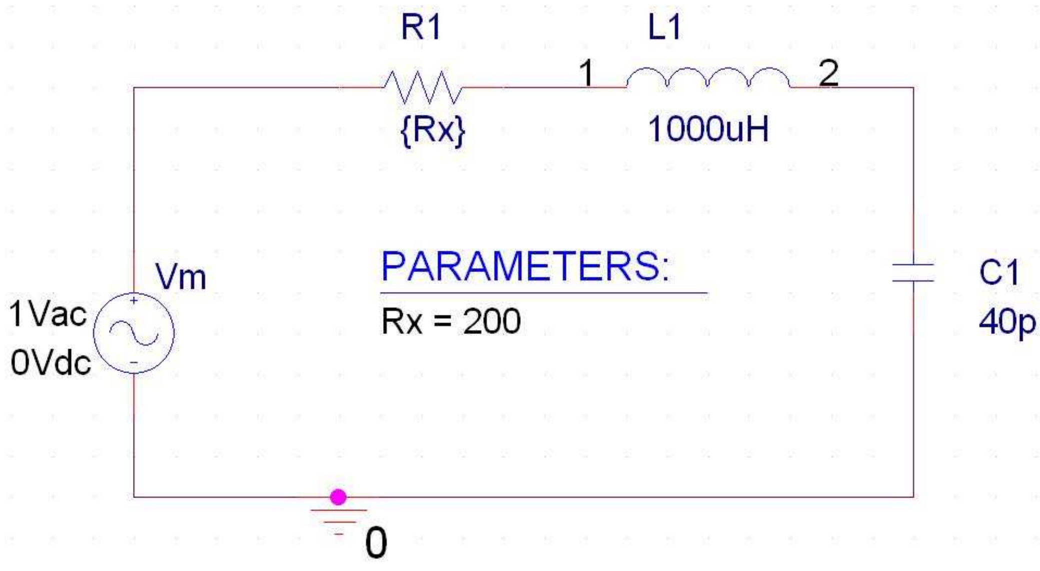
Vm is an AC voltage source (VAC) from the source library. It needs to be set for 1 volt.

L1 is an ideal inductor from the Analog Library. Set for 1000μH.

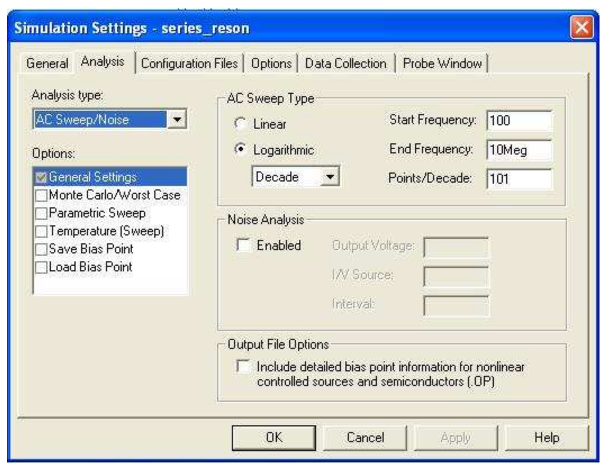
R is an ideal resistor from the Analog Library. Set value to {Rx}. Next add part named "Parameters". Then double click on part to enter edit mode. Click on new column, name = Rx, value = 200. Then click on column, select display and click on name and value.

C1 is an ideal capacitor from the Analog library. Change the value to 40pF.

Figure1. The RLC series resonance

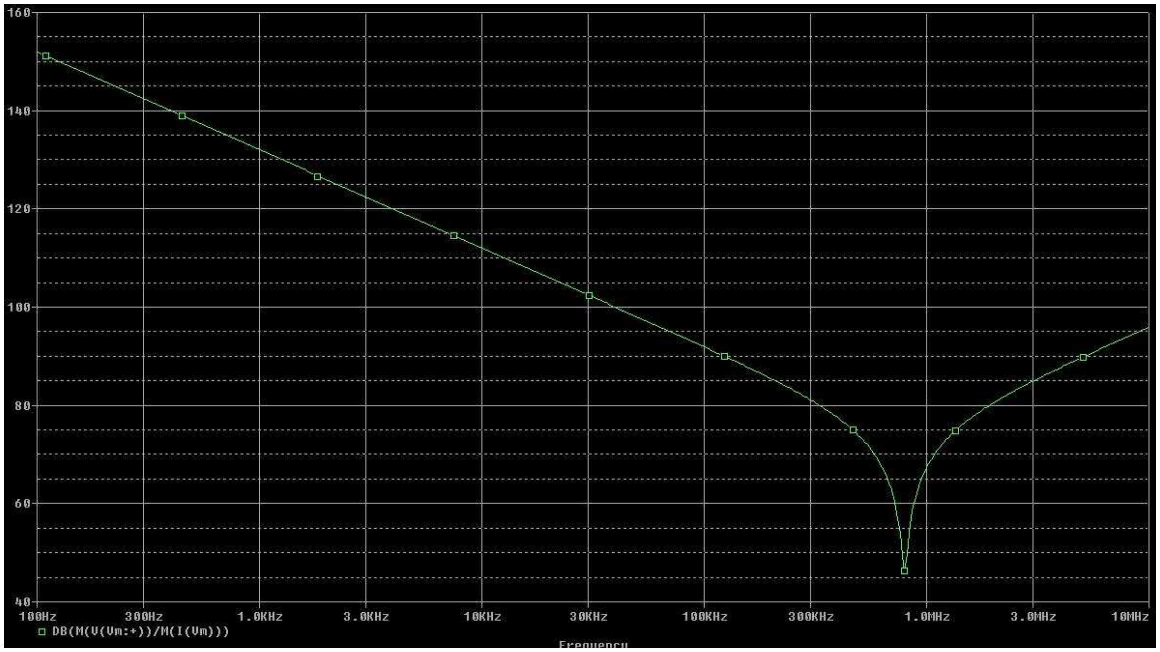


1. Do analysis setup
    a. At top of screen click on Pspice
    b. Click on New Simulations Profile
    c. Type name of profile that you wish.
    d. Under Analysis tab, select AC sweep from the Analysis type pull down menu.
    e. Under AC Sweep Type Select Logarithmic and Decade as shown.
        i. Start freq = 100
        ii. End freq = 10Meg
        iii. Points/Decade = 101

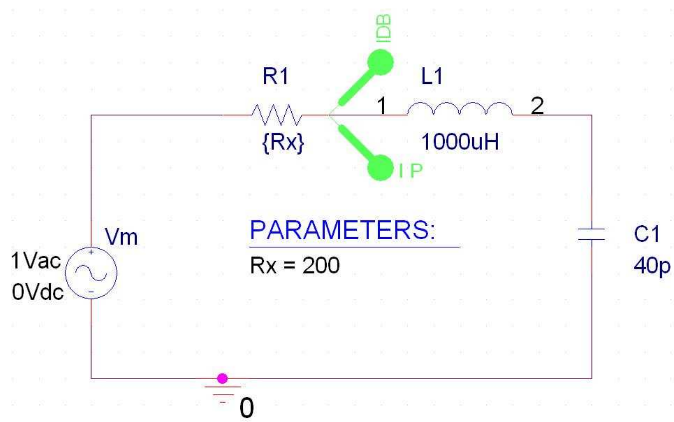


    f. Then click the run Pspice button. (Looks like a play button)
    g. After running, look at schematic file and click on trace, add trace.
    h. Next Select Db() on left, select M() on left, select V(Vm:+), then divide by M(I(Vm)).

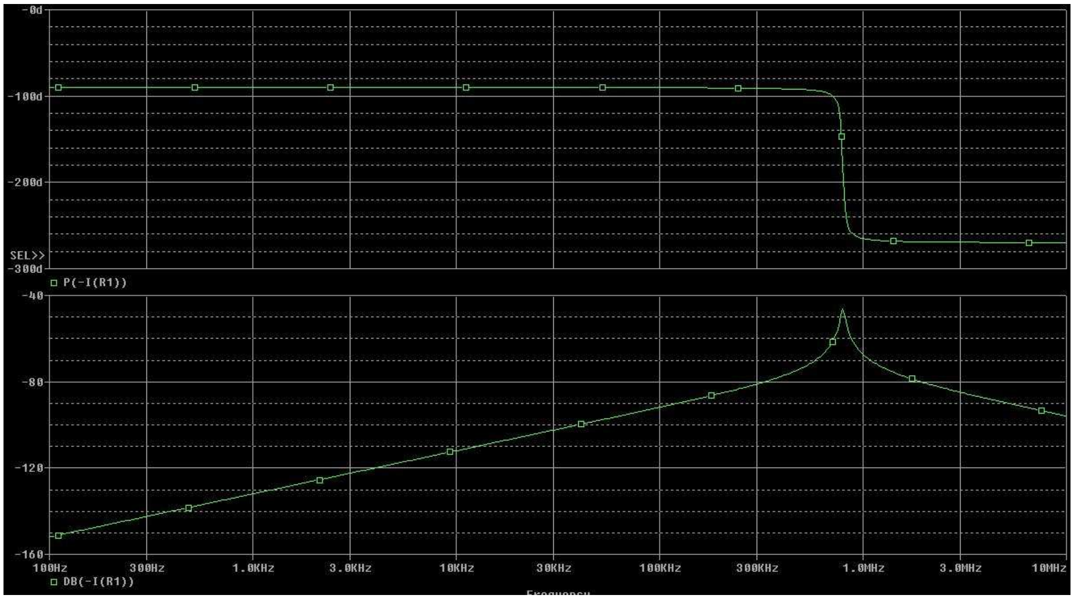
The figure below is the result of input impedance of series RLC tank circuit. What is the input impedance value of RLC circuit?



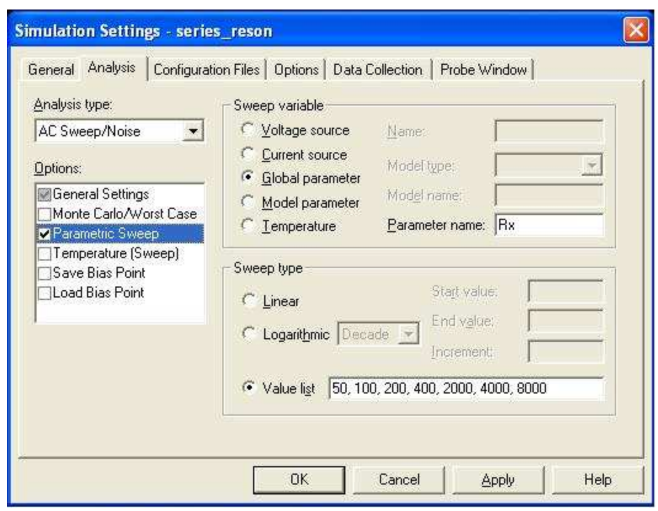
Next, we want to measure the total inductor current of RLC series resonance circuit. Use the same circuit as above, and from the Pspice button, Markers, Advanced, select "db magnitude of current marker" and "Phase of Current marker", and place in series next to L1.

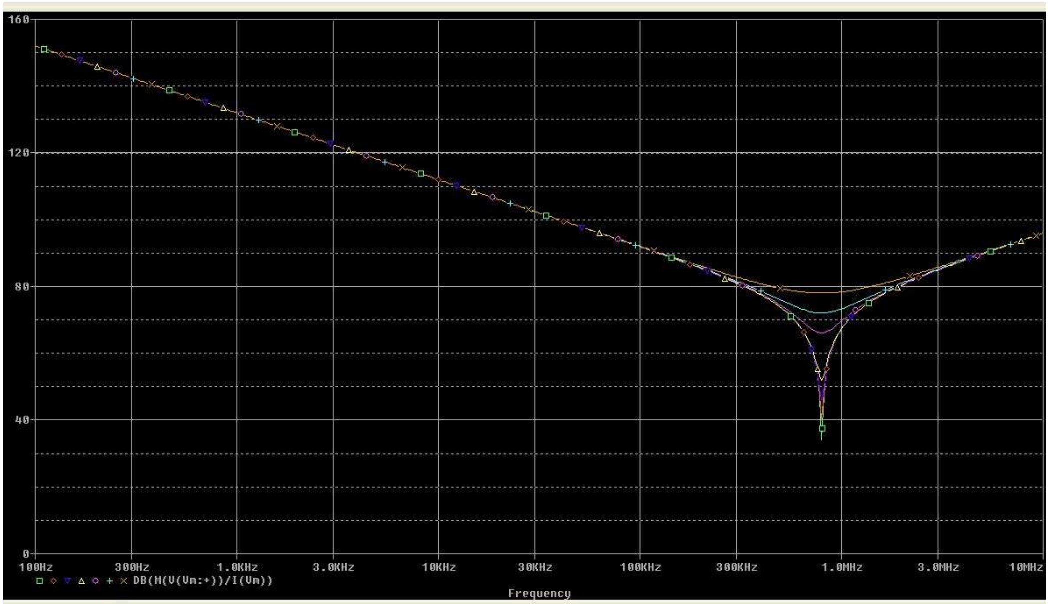


The figure below is the result of inductor current of series RLC tank circuit. Hint: to add a second window in the simulations result window select plot, add plot window. What is the value of inductor current of series RLC circuit? What is the phase value of inductor current of series RLC circuit?

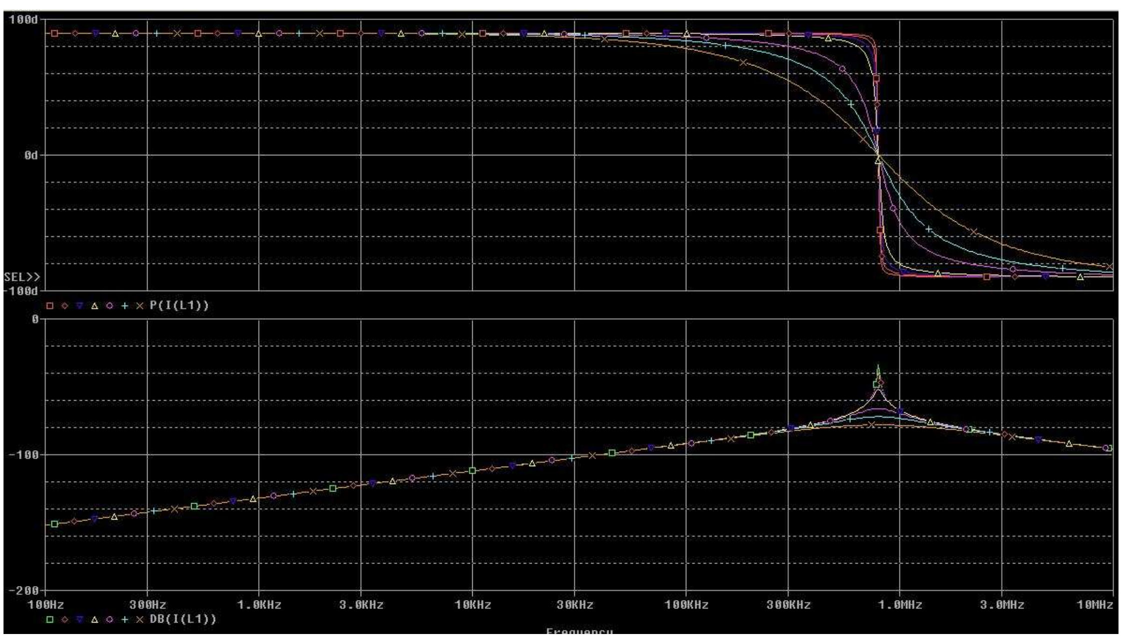


Next, we want to simulate the input impedance of series RLC resonant circuit with a varying Resistor. Use the same circuit as above, but change the resistor values to 50, 100, 200, 400, 2000, 4000, and 8000 Ohms. The way this can be done is to do a "parametric sweep", select Edit Simulation Profile, Parametric Sweep, Global Parameter, enter value name, select value list, and enter resistor values. The figure on the next page is the result of input impedance of series RLC tank circuit. What is the input impedance value of RLC circuit with varying resistors value?

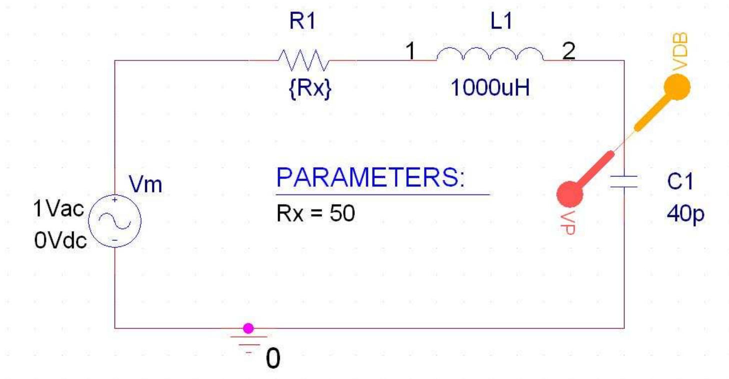




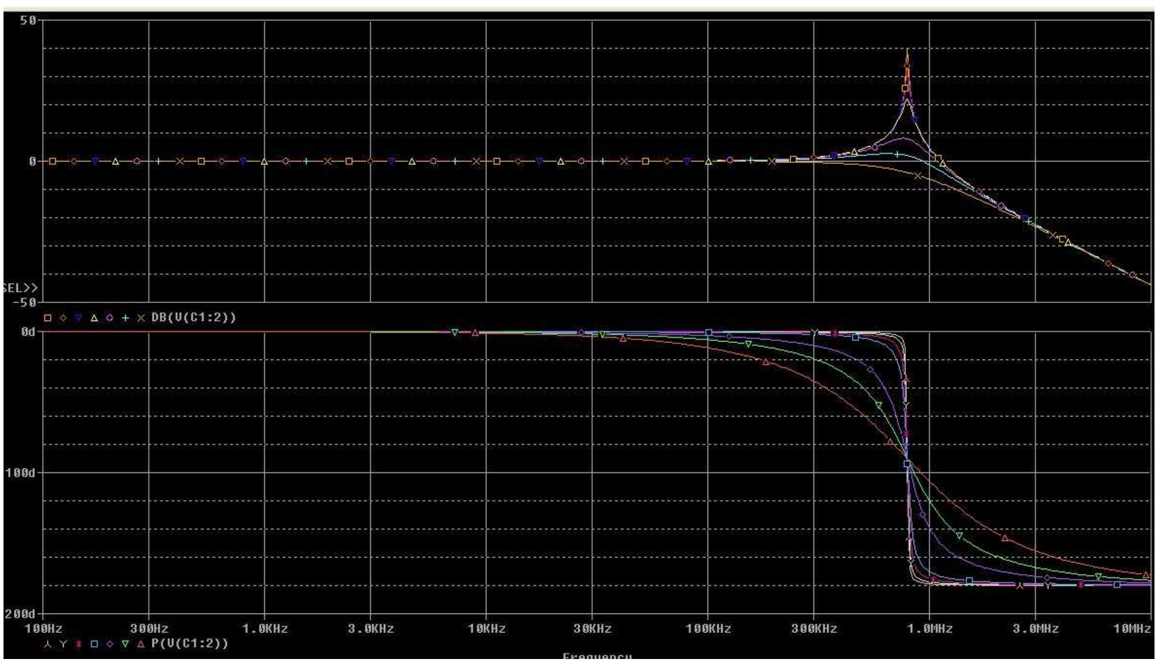
Next, we want to simulate the inductor current of series RLC resonant circuit with varying Resistor. Use the same circuit as above, place the "db magnitude of current marker" in series next to L1, and perform a parametric sweep with the same varying resistor values. The figure below is the result of input impedance of series RLC tank circuit. What is the value of inductor current of RLC circuit varying with resistors value? What is the phase value inductor current of RLC circuit with varying resistors value?



Next, we want to simulate the output voltage of series RLC resonant circuit with varying Resistor. Use the same circuit as above, place the "**db magnitude of voltage marker**" and the "phase of voltage marker" in series next to output capacitor, with the same varying resistor values.



The figure below is the result of output voltage of series RLC tank circuit. What is the value of output voltage of series RLC circuit with varying resistors? What is the phase value of output voltage of series RLC circuit with varying resistors?



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:

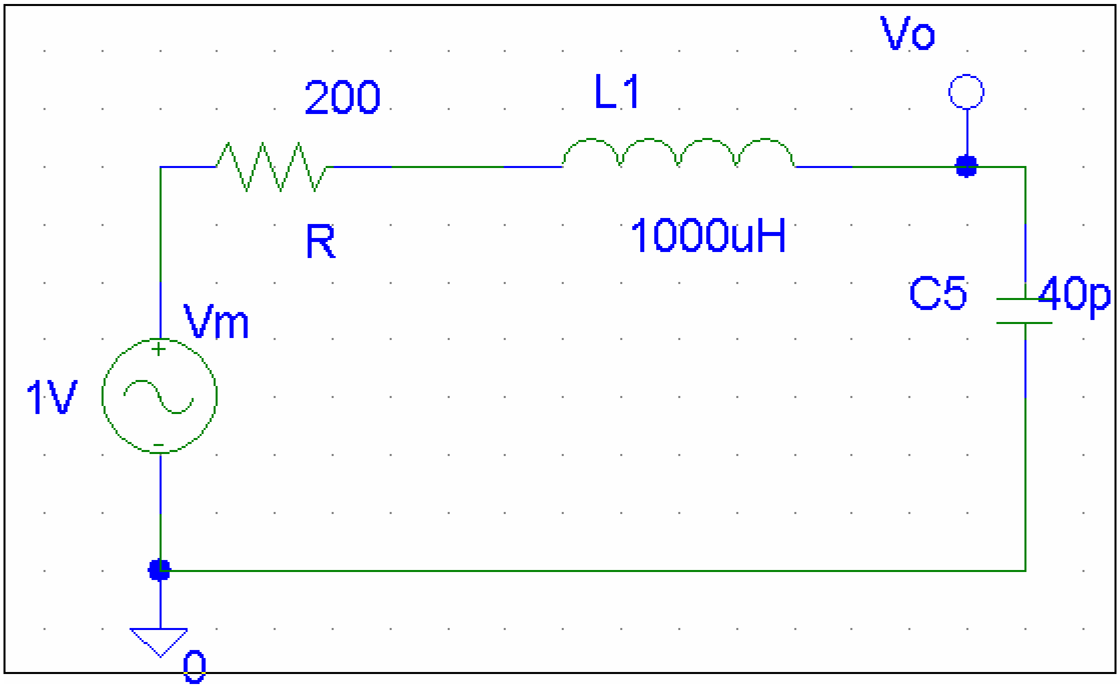
Part 1: Write a function to calculate the total input impedance of series RLC resonant circuit as shown in Figure 1.

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.


Vo
200
L1
R
1000uH
C5
40p
Vm
1V
0

```
%***********************************************************************
% 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
```

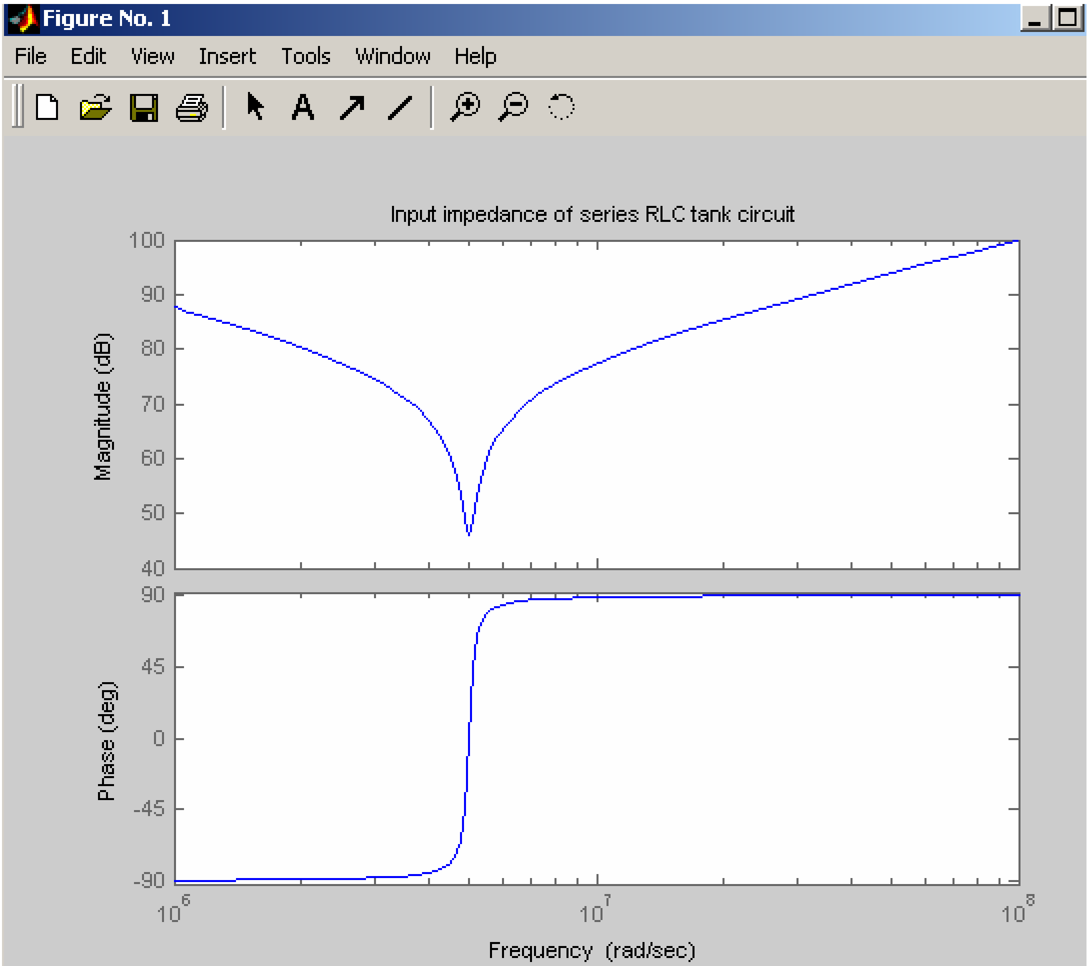


Figure2: The output of input impedance of series RLC tank circuit.

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.

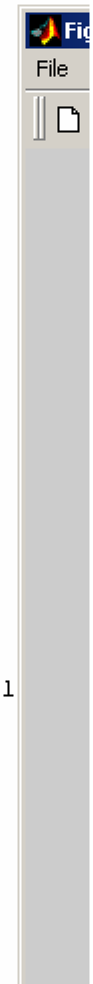
C is a variable ideal capacitor. Set to 40pF

```
%*************************************************************************
% 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
```



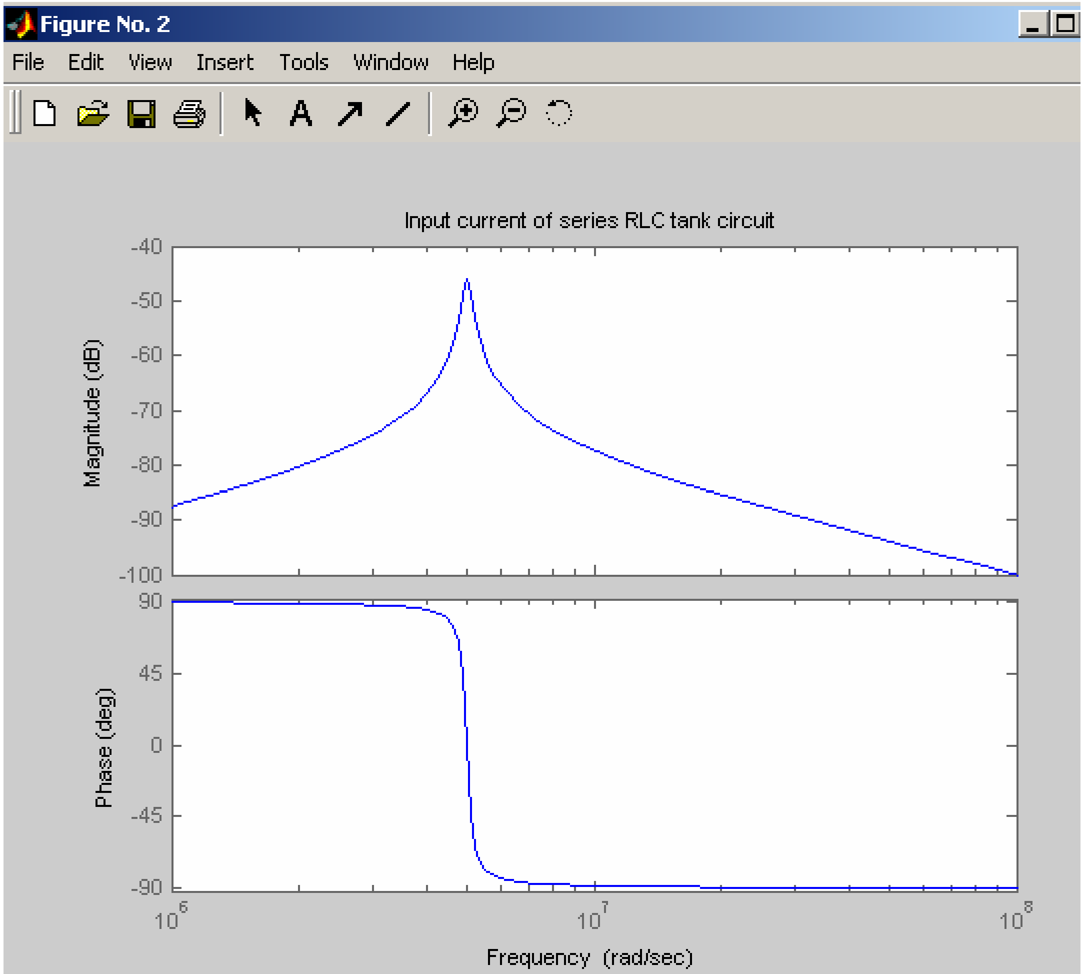


Figure 4: the output and plot of the total input current of series RLC tank circuit

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

```
%****************************************************************************
% 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
```

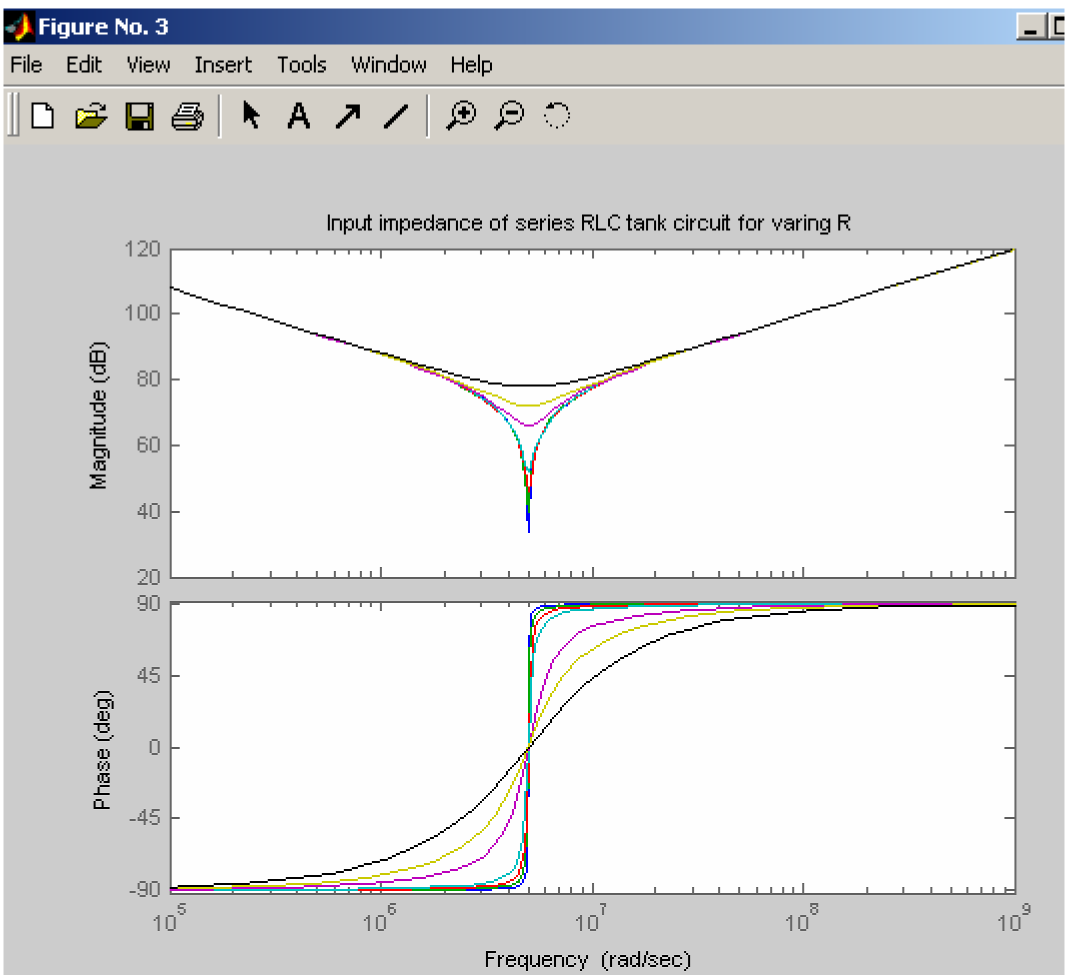


Figure 6: Output of the input impedance of series RLC resonant circuit with varying Resistor

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
```

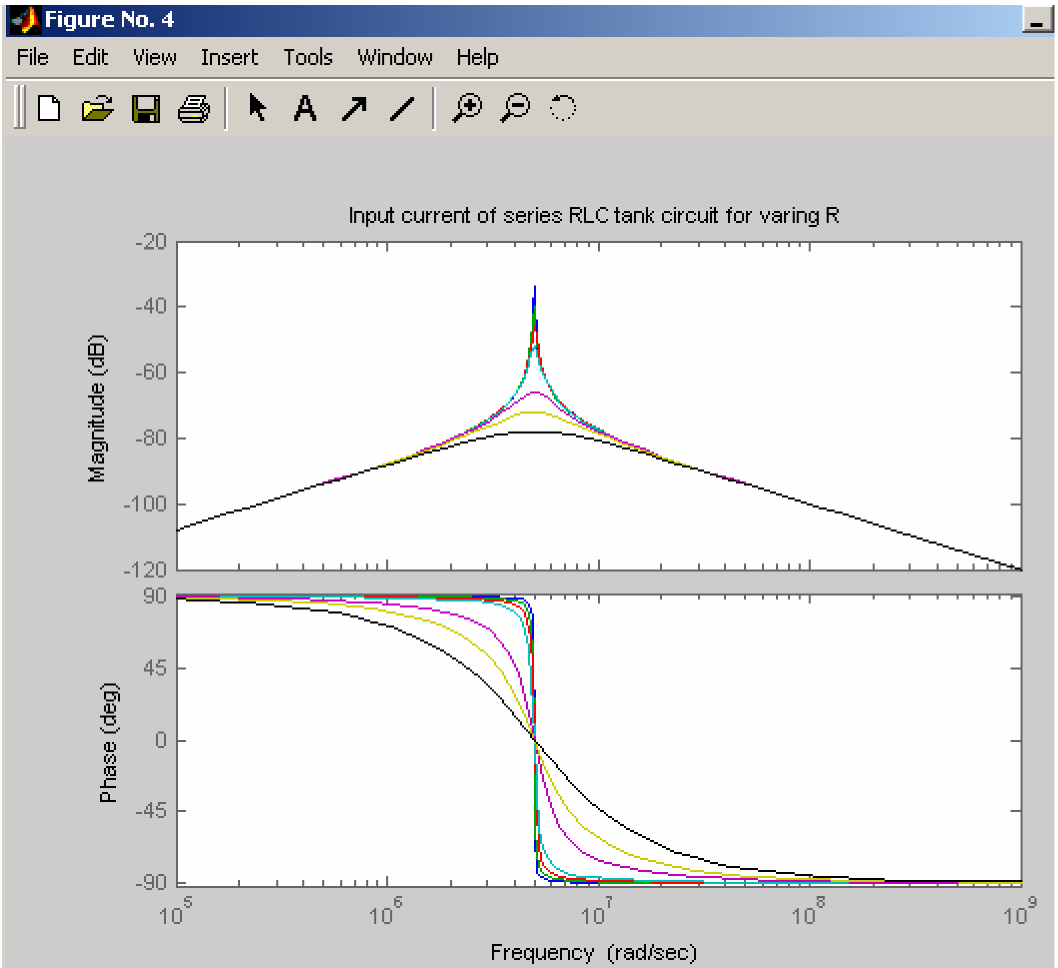


Figure 8: Output of the input current of series RLC resonant circuit with varying Resistor

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

```
%***************************************************************************
% 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
```

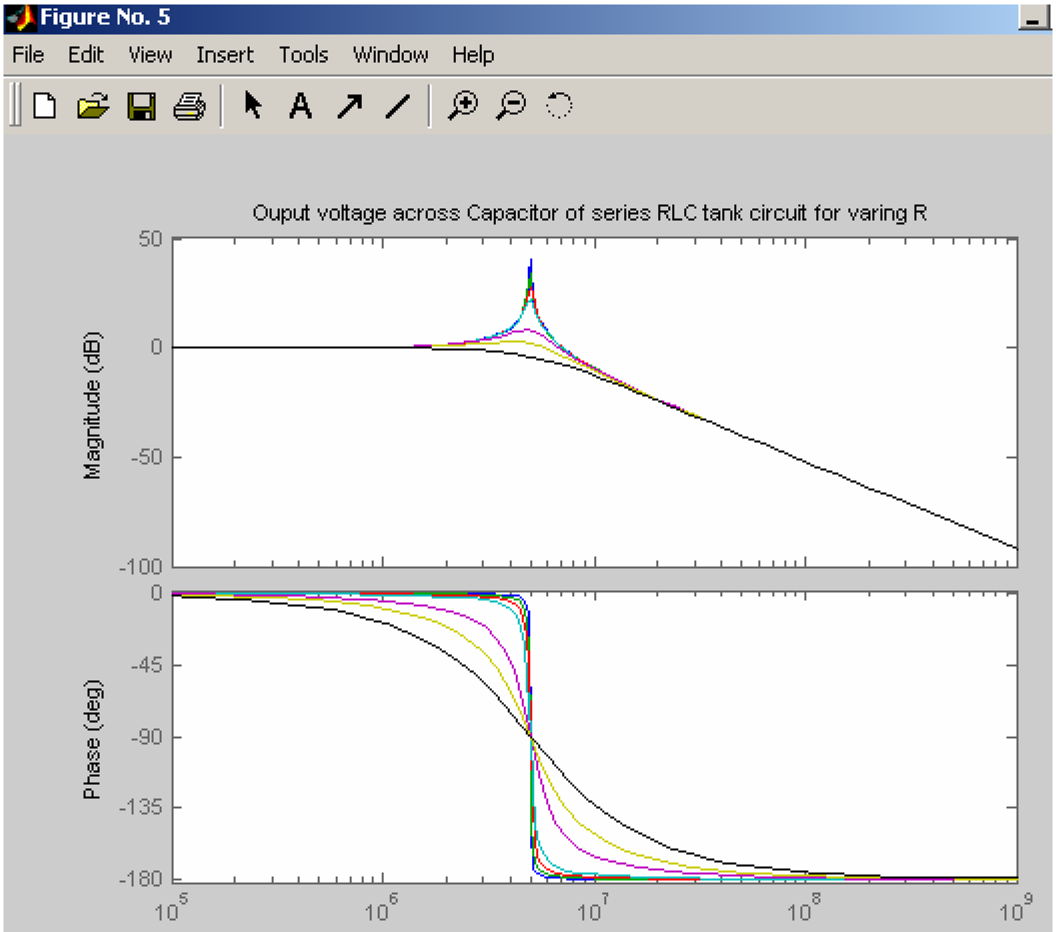


Figure 10: This figure is shown the output voltage of series RLC resonant circuit with varying Resistor

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

```
%**************************************************************************
% 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];
    I1=tf(numb,de)
    impulse(I1)
    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
```

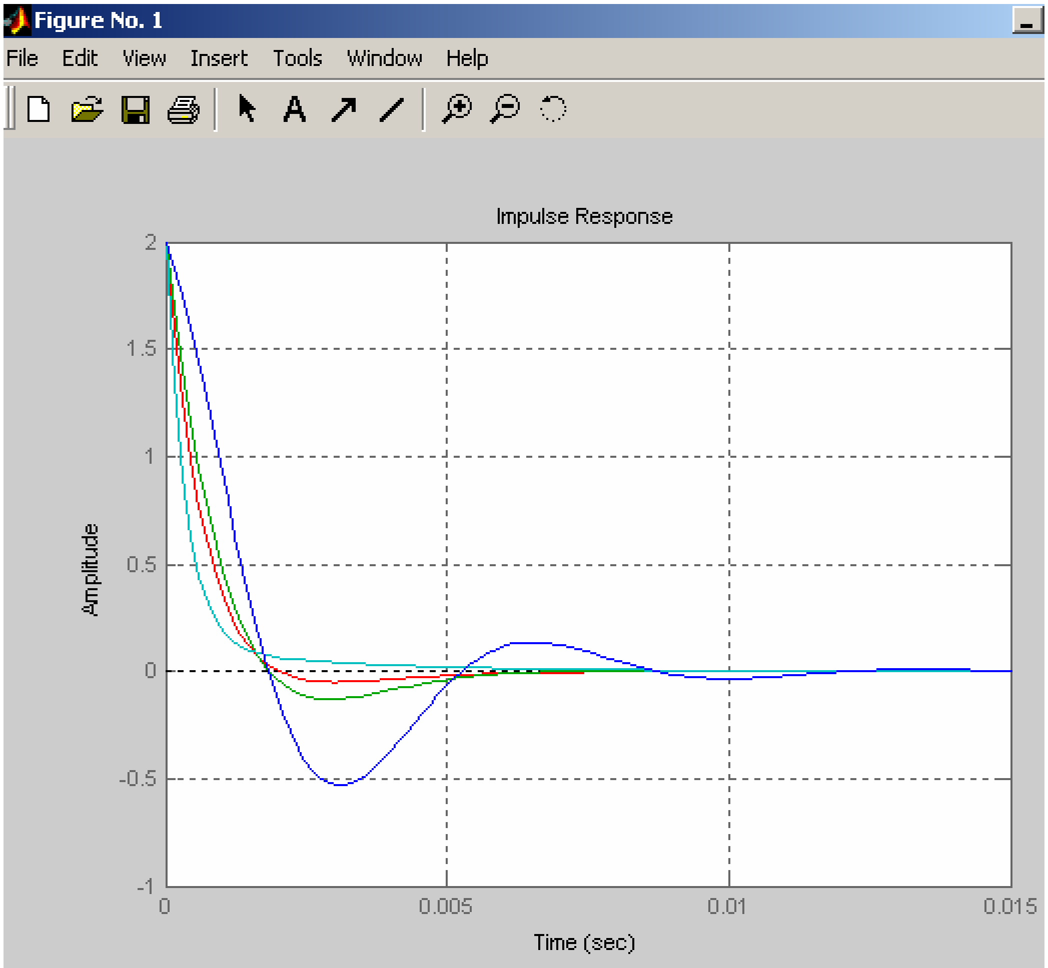


Figure 12: This figure is shown the output of the natural responses of current in series RLC resonant circuit with varying Resistor

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.

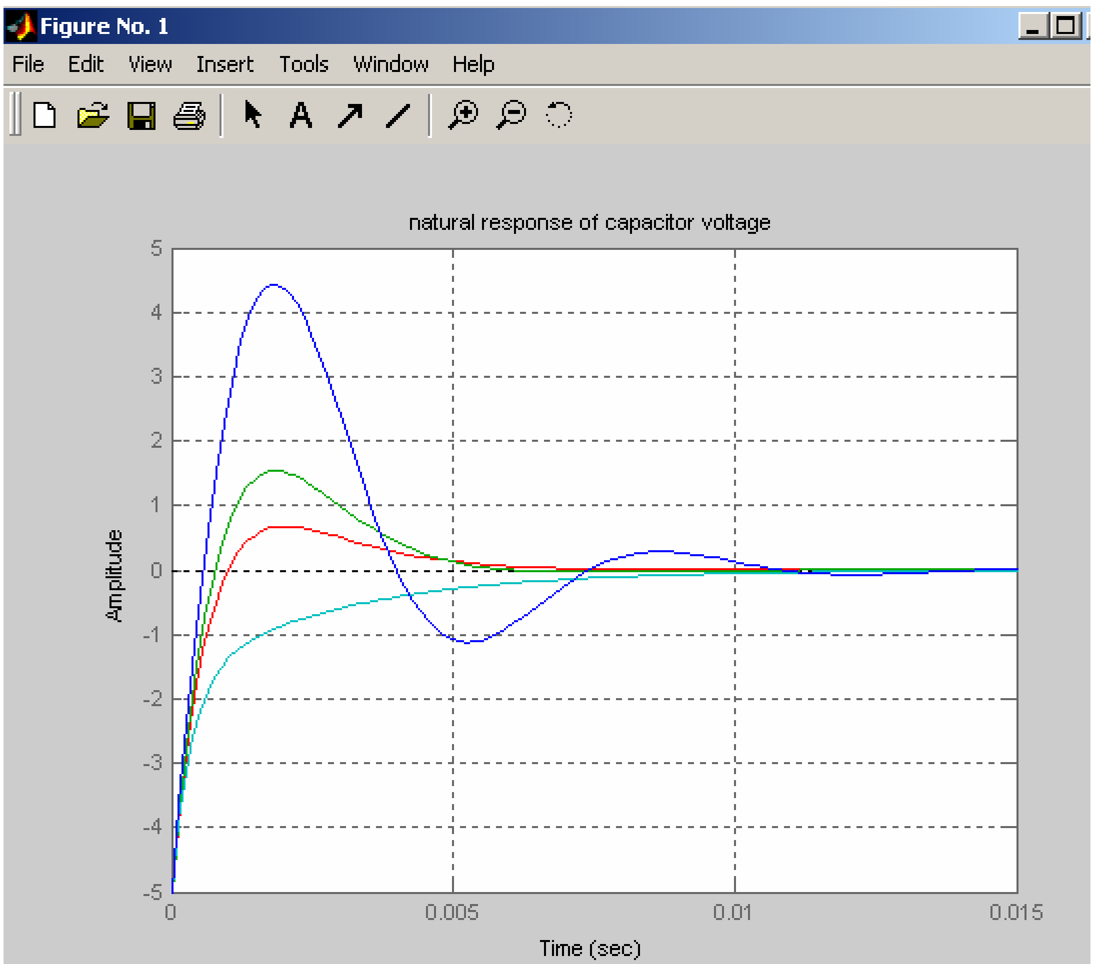
Vo is a variable ideal of capacitor voltage. Set to -5 volts.

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

```
%***************************************************************************
% 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