SIMULATIONS OF LCC RESONANT CIRCUIT

POWER ELECTRONICS

COLORADO STATE UNIVERSITY

Modified in Spring 2006
**PURPOSE:** The purpose of this lab is to simulate the LCC circuit using MATLAB® and CAPTURE CIS to better familiarize the student with some of its operating characteristics. This lab will explore some of the following aspects of the buck converter:

- Input impedance
- Output impedance
- Zero frequency
- Output power
- Output current
- Output voltage
- Zero poles
- Phase of transfer function
- Stable circuit
- Unstable circuit

**Simulation of LCC Resonant Circuit Using CAPTURE CIS**

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

**PROCEDURE:**

**Part 1:** Build the schematic shown in Figure below.

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

\( L_1 \) is an ideal inductor from the Analog Library. Set for 25\( \mu \)H.

\( R \) is an ideal resistor from the Analog Library. Set for 25.
Cs is an ideal capacitor from the Analog library. Change the value to 200nF.
Cp is an ideal capacitor from the Analog library. Change the value to 66nF.

-use the student version Capture CIS that install on CSU computer lab to simulation the given circuit above. Here are some steps:

1. Draw the circuit given above
2. Apply the VAC, because we want to plot the frequency response
3. Do analysis setup
   a. Go to analysis/setup
   b. D-click on AC sweep
   c. Set all the values for the frequency as following
   d. And click on decade
4. Analysis/run probe

The figure below is the result of impedance of series RLC tank circuit. What is the input impedance value of LCC circuit?
Next, we want to run the simulation of the output voltage of the LCC circuit. Use the same circuit as above, and place voltage markers as shown in the schematic below.

This figure shows the output voltage of LCC circuit. What is the output voltage of LCC circuit?
Now remove voltage markers from the circuit, and place the “db magnitude of voltage marker” in series next to output resistor. The figure below is the result of output voltage of series LCC tank circuit. What is the value of output voltage of LCC circuit? What is the phase value output voltage of LCC circuit?
Use the same circuit as above and remove the “db magnitude of voltage marker” from the circuit. Place the “db magnitude of current marker” and the “Phase of current” in series next to L1.
The figure below is the result of inductor current of series LCC tank circuit. What is the value of inductor current of LCC circuit? What is the phase value of inductor current of LCC circuit?

Next, find the zero crossing of phase of inductor current. Use the same circuit as above and remove the “db magnitude of current marker” from the circuit. Keep the “Phase of current” in series next to L1.
The figure below is the result of zero crossing of phase of inductor current of series LCC tank circuit. What is the value the zero crossing of phase of inductor current?
Use the same circuit as above and remove the “db magnitude of current marker” and “Phase of current” from the inductor. Place the “db magnitude of current marker” and the “Phase of current” in series next to Cs. The figure below is the result of capacitor current of series LCC tank circuit. What is the value of input capacitor Cs current of LCC circuit? What is the phase value of input capacitor (Cs) current of LCC circuit?

![Graph of capacitor current of LCC circuit](image)

Use the same circuit as above and remove the “db magnitude of current marker” and “Phase of current” from the input capacitor (Cs). Place the “db
magnitude of current marker” in series next to output resistor. The figure below is the result of power of series LCC tank circuit. What is the value of power of LCC circuit?

For Homework:

You need to re-solve the LCC 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 Cs and Cp ESR to the load resistance to be in the ratio range from 0.01 to 1.
Simulation of LCC 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.

PROCEDURE:
Part 1: write an m file shown in Figure 1.

Vm is a variable voltage. Set to 1 volts
L is a variable inductor. Set to 25µH.
R is a variable ideal resistor. Set to 25Ω.
Cp is a variable ideal capacitor. Change the value to 66nF.
Cs is a variable ideal capacitor. Change the value to 200nF.
% C L C  Resonant R L C circuit
% Minh Anh Thi Nguyen
% Colorado State University
% Electrical and Computer Engineering student
% ***********************************************************************

% define all the component values and units for Tank
    % unit
    Vm=1; % Volts
    R=25; % Ohms
    Cs=200e-9; % Farads
    Cp=56e-9; % Farads
    L=25e-6; % Henrys

% define the input impedance
    Z1=tf([L 0],[0,1]);
    Zcs=tf([0 1],[Cs 0]);
    Zcp=tf([0 1],[Cp 0]);
% the total resistor and/or capacitor connected in parallel
    Zparallel=1/(1/R+1/Zc);
% the total resistor and/or capacitor connected in series
    Zseries=Zcs+Z1;
% the input transfer function
    Zinput=Zparallel+Zseries

% The bode plot of input impedance
    bode(Zinput)
    title('input impedance LCC tank circuit')
% calculate zero frequency, beta and Q factor of the tank

% z is zero frequency
% p is poles
% k is static gain
    [Z,p,k]=zpkdata(Zinput,'y');

Figure 1. Input impedance for LCC 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.

```
Transfer function:
3.3e-019 s^3 + 2e-013 s^2 + 2.66e-007 s + 0.04
-------------------------------------------
1.32e-014 s^2 + 8e-009 s

z =
1.0e+005 *
-2.2037 + 8.2743i
-2.2037 - 8.2743i
-1.6532

p =
1.0e+005 *
0
-5.0605

k =
2.5000e-005
```
Next, plot the output voltage of the LCC circuit by adding the output voltage equation to the LCC m file. Then rerun the LCC m file.

```matlab
% define the output voltage function
Voutput=Vm*Zparallel/(Zparallel+Zseries)
% bode plot for the output voltage
figure(2)
bode(Voutput)
% write the title of the bode plot for output voltage
title('Output voltage of LCC tank circuit')
% z is zero frequency
% p is poles
% k is static gain
[z,p,k]=zpkdata(Voutput,'y')
wn=sqrt(p(1)*p(2))
```
Transfer function:

\[
\frac{1.32e-014 \ s^2 + 8e-009 \ s}{2.178e-026 \ s^4 + 2.64e-020 \ s^3 + 2.556e-014 \ s^2 + 1.328e-008 \ s + 0.0016}
\]

\[
z = 1.0e+005 \ *
\]
\[
0 -6.0606
\]

\[
p = 1.0e+005 \ *
\]
\[
-2.2037 + 8.2743i -2.2037 - 8.2743i -6.0606 -1.6532
\]

\[
k = 6.0606e+011
\]

\[
wn = 8.5627e+005
\]
Now plot the inductor current of the LCC circuit by adding the inductor current equations to the LCC m file. Then rerun the LCC m file.

```matlab
Iinductor=(Vm-Voutput)/Zseries;
% bode plot for the inductor current
figure(3)
bode(Iinductor)
% write the title of the bode plot for output voltage
title('inductor current of LCC tank circuit')
% z is zero frequency
% p is poles
% k is static gain
[z,p,k]=zpksdata(Iinductor,'y')
wn=sqrt(p(1)*p(2))
[A,B]=damp(Iinductor)
```
<table>
<thead>
<tr>
<th>Command Window</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>z =</strong></td>
</tr>
<tr>
<td>1.0e+005 π</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>-0.0000 + 4.4721i</td>
</tr>
<tr>
<td>-0.0000 - 4.4721i</td>
</tr>
<tr>
<td>-6.0606</td>
</tr>
<tr>
<td>-6.0606</td>
</tr>
<tr>
<td><strong>p =</strong></td>
</tr>
<tr>
<td>1.0e+005 π</td>
</tr>
<tr>
<td>-2.2037 + 8.2743i</td>
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<tr>
<td>-2.2037 - 8.2743i</td>
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<tr>
<td>0.0000 + 4.4721i</td>
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<tr>
<td>0.0000 - 4.4721i</td>
</tr>
<tr>
<td>-1.6532</td>
</tr>
<tr>
<td><strong>k =</strong></td>
</tr>
<tr>
<td>40000</td>
</tr>
<tr>
<td><strong>wm =</strong></td>
</tr>
<tr>
<td>8.5627e+005</td>
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<tr>
<td><strong>A =</strong></td>
</tr>
<tr>
<td>1.0e+005 π</td>
</tr>
<tr>
<td>1.6532</td>
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<tr>
<td>4.4721</td>
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<tr>
<td>4.4721</td>
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<td>6.0606</td>
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<tr>
<td>8.5627</td>
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<td>8.5627</td>
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</tbody>
</table>
Now find the zero crossing of phase of inductor current. First define the input impedance as a vector. Write a loop function to do the zero crossing of the phase. Then rerun the simulation. 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

\[
B = \\
\begin{bmatrix}
1.0000 \\
-0.0000 \\
-0.0000 \\
1.0000 \\
0.2574 \\
0.2574 \\
\end{bmatrix}
\]
% zero cross of the phase of inductor current

% define input impedance as a vector
w=1e5:100:1e6;
% define interesting of v
an=size(w);
% setting for the loop up
jmax=an(2);

% now do the for loop
for i=1:jmax
    % sample impedance of each elements
    Zinductor(i)=G+j*w(i)*L;
    ZCs(i)=0-j*(1/(w(i)*tauCs));
    ZCp(i)=0-j*(1/(w(i)*Cp));
    ZR(i)=R;

    % inductor connected in series with Capacitor Cs
    Zs(i)=ZCs(i)+Zinductor(i);

    % Resistor connected in parallel to the capacitor Cp
    Zp(i)=1/(1/ZR(i)+1/ZCp(i));

    % the output of the circuit. To find the output voltage of the circuit using
    % voltage divider
    Vout(i)=Vm*Zp(i)/(2p(i)+Zs(i));

    % inductor current
    Il(i)=(Vm-Vout(i))/Zs(i);
end

% find the resonant frequency is by looking for the zero crossing point.
for i=1:jmax
    if phase(Il(i))<0, x=i;
        break;
    end
end
wo=x+(x(x)-x(x-1))/2;

% plot the inductor current in degree
figure(4)
semilogx(w,phase(Il)*180/pi)
title('Inductor current phase LCC tank circuit')
grid
sprintf('the resonant frequency is %d.', wo)
Now calculate and plot the output of capacitor current by adding the capacitor current equations to the LCC m file. Then rerun the LCC m file. Then rerun the simulation. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the results as show below.

```
ans =
```

the resonant frequency is 753750.
% calculate the current through the parallel circuit
% again using voltage divider method to calculate the output capacitor
% current
Icapacitor =Iinductor *(R/(Zcp+R))
figure(5)
bode(Icapacitor)

% write the title of the bode plot for output capacitor current
title('Output Capacitor current of LCC tank circuit')
% z is zero frequency
% p is poles
% k is static gain
[z,p,k]=zpksdata(Icapacitor,'r')
wn=sqrt(p(1)*p(2))
Transfer function:
\[ 7.187e-039 \ s^6 + 6.712e-033 \ s^5 + 4.077e-027 \ s^4 + 1.742e-021 \ s^3 + 5.20e-016 \ s^2 \]
\[ \quad + 1.797e-043 \ s^7 + 3.167e-037 \ s^6 + 3.798e-031 \ s^5 + 3.027e-025 \ s^4 + 1.462e-019 \ s^3 \]
\[ + 5.547e-014 \ s^2 + 1.592e-008 \ s + 0.0016 \]

\[ z = 1.0e+005 \quad * \]
0
0
-0.0000 + 4.4721i
-0.0000 - 4.4721i
-6.0606
-6.0606

\[ p = 1.0e+005 \quad * \]
-2.2037 + 8.2743i
-2.2037 - 8.2743i
0.0000 + 4.4721i
0.0000 - 4.4721i
-6.0606 + 0.0000i
-6.0606 - 0.0000i
-1.5532

\[ k = 4.0000e+004 \]

\[ on = 8.5827e+005 \]
Now calculate and plot the output power of LCC circuit by adding the output power equations to the LCC m file. But the output power is a vector function. First define the input impedance as a vector. Write a loop function to do the zero crossing of the phase. Then rerun the LCC m file. If there is any error message on your MATLAB windows, then correct your error and then rerun the simulation. Otherwise, you will see the results as show below
% Calculated the output power of LCC circuit

% define input impedance as a vector
w=1e5:1000:1e7;
% define interesting of w
en=size(w);
% setting for the loop up
jmax=en(2);

% now do the for loop

for i=1:jmax
    % simple impedance of each elements
    Zinductor(i)=0+j*w(i)*L;
    ZCS(i)=0-j*(1/(w(i)*Cs));
    ZCp(i)=0-j*(1/(w(i)*Cp));
    ZR(i)=R;

    % inductor connected in series with Capacitor Cs
    Zs(i)=ZCS(i)+Zinductor(i);

    % Resistor connected in parallel to the capacitor Cp
    Zp(i)=1/(1/ZR(i)+1/ZCp(i));

    % the output of the circuit. To find the output voltage of the circuit using
    % voltage divider
    Vout(i)=Vm*Zp(i)/(Zp(i)+Zs(i));

    % output power
    P(i)=(Vout(i))^2/2p(i);
end

% plot the output power
max(abs(P))
figure(6)
semilogx(w,abs(P))
title('Output power of LCC tank circuit')
grid
ans =

0.1769