## ECE 100 Lab 1 RLC Circuit Analysis with Matlab

The scripting language Matlab is very widely used in engineering and physical sciences. It is particularly useful in system analysis and statistics, both important in electrical engineering. Matlab can produce professional plots quickly and easily. Experience shows that one can write applications about 10 times faster in a scripting language than in a lower level language like C. The code typically runs 10 times slower, but usually run time is not the limiting factor. The student version of Matlab is not expensive and every electrical engineer should have it.

You can run Matlab on all ACS machines. The TA's will be available in the Pspice lab room during the regularly scheduled lab sections to help with Matlab problems.

We will run similar Matlab scripts in future projects so make sure you comment your work and save it.

**1. Lowpass Analysis:** The RLC low-pass circuit drawn to the right, is easily analyzed because it is a single loop. In circuit analysis we use the complex frequency  $s = j\omega$  more than  $\omega$  itself. So the transfer function would be written as a ratio of polynomials in s, i.e.  $H(s) = 1/(1 + sCR + s^2LC)$ . In normalized form  $H(s) = 1/(1 + 2\zeta (s/\omega_0) + (s/\omega_0)^2)$  and of course  $H(\omega) = 1/(1 + j 2\zeta (\omega/\omega_0) - (\omega/\omega_0)^2)$ .



(a) Write the equations for  $\omega_0$  and  $\zeta$  in terms of R, L and C.

(b) Plot the magnitude and phase of the transfer function using the Matlab script ece100lab1.m, for  $\omega_0 = 1$  and  $\zeta = [0.1 \ 0.3 \ 0.707 \ 1.0 \ 3.0 \ 10.0]$ . In this script the substitution  $s = j\omega$  was done by hand. Then a vector of sample frequencies w was created. The complex transfer function H(w) was evaluated at each sample frequency creating another vector h. The magnitude and phase of h were then plotted in various ways. Read the script carefully because you will need to make similar calculations and plots throughout ECE 100. You will see that the first plot, on linear axes, is very difficult to read. That's why the standard form of plotting transfer functions is with magnitude in dB vs log frequency and phase in degrees vs log frequency. When both the magnitude in dB and phase in degrees are plotted on the same figure, as in plot 3, it is called a Bode plot. Change the titles of figures 2 and 3 to include your name and save copies of plots 2 and 3 only for your report.

(c) When the damping factor  $\zeta < 0.707$  a peak occurs in  $|H(\omega)|$ . It is easy to calculate that the peak frequency is  $\omega_{PK} = \omega_0 (1 - 2 \zeta^2)^{0.5}$  and  $|H(\omega_{PK})| = 1/(2\zeta (1 - \zeta^2)^{0.5})$ . Do these expression agree with the peaks that you read off the figure 2 for  $\zeta = 0.1$  and 0.3 using the cursor?

**2. Bandpass and Highpass:** The bandpass topology is obtained by switching the capacitor with the resistor in the schematic above. The highpass topology is given by switching the inductor with the capacitor.



(a) Write the transfer functions  $H_{BP}(s)$ 

and  $H_{HP}(s)$  in terms of R, L, and C. Put them in normalized form so the denominator is the same as  $H_{LP}(s)$  and the numerator is written in terms of s,  $\omega_0$  and  $\zeta$ . Of course  $\omega_0$  and  $\zeta$  are the same (in terms of R, L, and C) as for the lowpass circuit because the loop current is unchanged by changing the order of the elements. All that happens is you read the voltage across a different element. This changes the numerator.

(b) Modify the script ece100lab1.m to make Bode plots of  $H(\omega)$  for both bandpass and highpass filters. That is, plot the modified figure 3 only. Be careful how you use the "." operators. Do not make plots 1 or 2 for these filters. Save copies for your report.

**3. Other?:** What happens if you take the output across both C and L together, rather than just one of them? Write the transfer function H(s) and plot  $H(\omega)$  on a Bode plot as you did for the bandpass and highpass filters. Save a copy for your report. What could you use this circuit for?



4. Linear Systems Tools: Matlab can also do symbolic algebra including Laplace transforms, and it has a number of tools that are very useful for analyzing linear systems. For example the code below will produce Bode plots and step response plots for the type of circuits you have analyzed above: s = tf(`s'); %defines s as a transfer function variable w0 = 2\*pi\*15.9e3; zeta = 1/sqrt(2); %define parameters h = 1/(1 + 2\*zeta\*s/w0 + (s/w0)^2); %define a transfer function bode(h); % create a bode plot with "nice" scales step(h); % create a step response plot nicely scaled stepinfo(h) % computes rise time, overshoot, etc.

(a) Use these tools to create a single plot with all the step responses for the transfer functions in Part 1 (b).

(b) Find the % overshoot for each step response above and plot % os vs damping factor (as a series of symbols, not a solid line). There is a closed form expression for the overshoot for a second-order step-response of low-pass form, % os =  $100 \exp(-\pi\zeta/\operatorname{sqrt}(1-\zeta^2))$  for  $0 < \zeta < 1$  and % os = 0 for  $\zeta > 1$ . Overplot the theoretical value as a solid line on your plot.

**Report:** Your report should be sequential giving the results of parts 1a through 4b in order. Always include a schematic of the circuit(s) you are analyzing. Report should be concise, but the "audit-trail" should be complete enough that another engineer could repeat what you have done, including any errors you might have made. Append listings of any Matlab scripts you have created. If in doubt about what to include, ask the instructor or the TA.