Laboratory 3.2	**Signals, Filters, & Amplifiers**
Name	**Section**

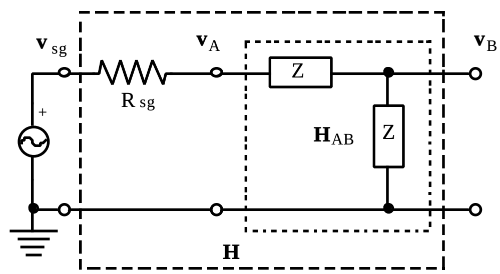
PURPOSE

1. Investigate the low-pass *RC* circuit.
2. Investigate the high-pass *RC* circuit.
3. Investigate the parallel *LCR* circuit.

COMMENTS

In this lab you will compare the frequency domain and time domain responses of several circuits. The frequency domain response is determined by applying sine waves at a number of frequencies and determining the relative amplitude of the output signal at each frequency. The corresponding time domain response can be observed by applying a low frequency square wave and observing the output waveform associated with one of the sharp edges of the square wave.

Some care is needed to make the frequency domain results properly correspond to those determined from the time domain. A typical circuit is shown here.



The transfer function $\mathbf{H}_{AB}$ can be measured without concern for the signal generator's output impedance because both $\mathbf{v}_A$ and $\mathbf{v}_B$ can be observed. However, other considerations enter when we use the square or triangle waveforms of the signal generator. These waveforms contain many frequencies and most circuits will have an input impedance that changes with frequency. The result is that even though $\mathbf{v}_A(\text{open}) = \mathbf{v}_{sg}$ is set and observed to be a square wave, a different waveform may be seen at $\mathbf{v}_A$ because the current through R_{sg} varies with frequency.

We can avoid this problem by measuring the overall transfer function $\mathbf{H}$ from $\mathbf{v}_{sg}$ to $\mathbf{v}_B$ because $\mathbf{v}_{sg}$ does not change when a circuit is connected. Note however that $\mathbf{v}_{sg}$ can only be measured when the signal generator is open (disconnected from the circuit). Measuring $\mathbf{H}$ is actually easier than $\mathbf{H}_{AB}$ in the frequency domain because there is no need to divide by a possibly variable amplitude signal at *A*. To measure $\mathbf{H}$ you can simply set $\mathbf{v}_{sg}(\text{open})$ to some convenient value and assume that the amplitude and shape of this signal remains constant.

SPECIAL EQUIPMENT

You will once again need an inductor of the type used in Lab 2.1 so you need to know the values of *L* and *R* that you found in that lab.

PRELIMINARY WORK

Reduce the output impedance of your signal generator as described in the introduction to this manual, then set the output to some convenient value: 1 volt makes the divisions easy, but your modified generator my not be able produce an undistorted sine wave of this amplitude. This modification is not essential to the following exercises, but it is a good idea to get into the habit of reducing this hidden resistance to a minimal value.

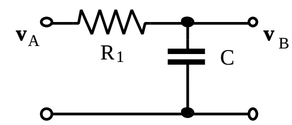
A. Low-pass RC Filter

1. Preliminary calculations

Do the work in this section before you come to lab.

a. Modify the following figure to include a Thevenin's equivalent circuit driving the network shown. Label the actual sizes of $|\mathbf{v}_{Th}|$ and R_{Th} that apply to this lab.

b. Write the transfer function **H** of this circuit in terms of $R = R_{Th} + R_1$.



c. Write the low and high frequency single-term approximations to $|\mathbf{H}|$, intersect them to find ω_c, then show that $|\mathbf{H}(j\omega_c)| = 0.707|\mathbf{H}_{low}|$. Note this is also the point where $|\mathbf{Z}| = R$.

d. Now write an expression for the pole of this transfer function and express it in terms of ω_c.

2. Build the circuit and measure its frequency domain response.

a. Use a capacitance of 0.1 μF, and a value for R_1 that will yield a corner frequency slightly less than 1500 Hz. Write and expression and value for R_1.

$R_1 =$

b. Using a sine wave input, scan the frequency spectrum to verify the behavior of this circuit, then measure its corner frequency.

measured $f_c =$ $\omega_c =$

3. Observe the transient response to a square wave edge.

a. Switch the function generator to a square wave of fundamental frequency no higher than $f_c/10$, trigger on a rising edge of the A channel, and measure the time constant τ of the rising signal at the output of the filter. Use the method outlined in the introduction to this manual. Compare this value with $1/\omega_c$ using the value found above.

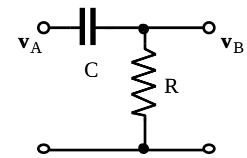
$\tau =$ $1/\omega_c =$

b. In the follow space, make a rough sketch of this circuit's frequency domain transfer function |**H**| and its response to the rising edge of a square wave signal.

B. High-pass *RC* Filter

1. Build the circuit and measure its frequency domain response.

a. First, complete the following circuit by adding a Thevenin equivalent of your signal generator just as you did for the low-pass filter.



b. Build the circuit using the same components that you used for the low-pass filter, sweep the frequency spectrum, note the behavior of $\mathbf{H}(j\omega)$, then determine this circuit's corner frequency ω_c.

measured f_c = ω_c =

3. Observe the transient response.

a. Again switch to a square wave whose fundamental is no greater than frequency $f_c/10$, trigger on a rising edge of this signal on the *A* channel, and measure the fall time *t* of the output signal. Note that the rise time is now very short because the capacitor passes the high frequency components that make up the edge.

τ = $1/\omega_c$ =

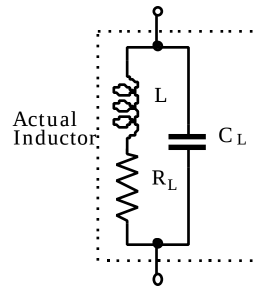
b. In the following space make a rough sketch of this circuit's frequency domain transfer function $|\mathbf{H}|$ and its response to the rising edge of a square wave. Compare these with those of the low-pass filter.

C. Parallel *LCR* Circuit

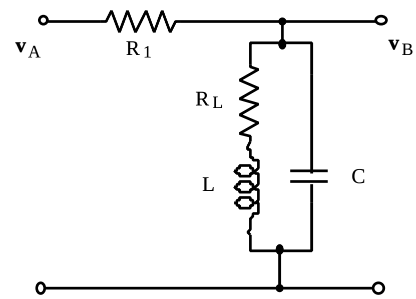
The analysis of laboratory circuits containing an inductor is complicated by the less than ideal nature of the typical inductive component. In part *B* of Lab 2.1 you measured and plotted |**Z**| for an inductor of the type used in this lab and found that it could be represented by the combination of ideal elements shown at the right. The circuit and component choices in this section were chosen to allow algebraic approximations that minimize the effect of the R_L and C_L elements but it is still necessary to include an R_L in order to get even approximately correct equations.

1. Preliminary calculations

Do the work in Section 1 before lab.



a. Add the Thevenin's equivalent representation of your signal source to the following schematic.



b. Write the transfer function for the complete circuit under the assumption that R_{sg} can be neglected then find an expression for the poles of this transfer function. This latter part entails a fair amount of algebra, but you can neglect R_L whenever it appears in a sum with R_1 and you can neglect L when it appears in a sum with RR_2C. The notation is easier if you use **s** rather than $j\omega$.

c. Set the real (in some circuits it will be the imaginary) part of the denominator of **H**(*j*w) to zero to obtain an expression for the resonant frequency ω_r.

2. Build the circuit and measure its frequency domain response.

a. Use an inductor like the one in Lab 2.1, 100 kΩ for R_1, and 0.01 μF for C. Connect the scope probes to points A and B as usual and adjust the scope to display both A and B channels while triggering on channel A.

b. Using a sine wave signal, scan the frequency spectrum and note the general behavior of the signal at B. You should see an obvious resonant behavior in the mid frequency region. Note the phase shift of the output with respect to the input in the neighborhood of the peak.

c. Measure the frequency of this resonant peak and compare it with the expected value.

measured f_r = ω_r =

expected ω_r =

d. Refer to Equation 2.99 and 2.100 in your text, make the necessary measurements (points where |**H**| falls to 0.7 of its peak value), and determine the Q of this circuit.

Q =

3. Observe the transient response.

a. Switch to a square wave signal whose frequency is **less than** $f_r/10$, trigger on the rising edge of the A channel, and sketch the response seen at B. Verify that the signal shape following a square wave rising edge does not depend on the frequency of the signal generator as long as the rising and falling edges do not interfere.

How many peaks can you distinguish before the ringing damps out?

b. Measure the time interval T between peaks of the decaying signal and compare $1/T$ with f_r.

$1/T$ = f_r =

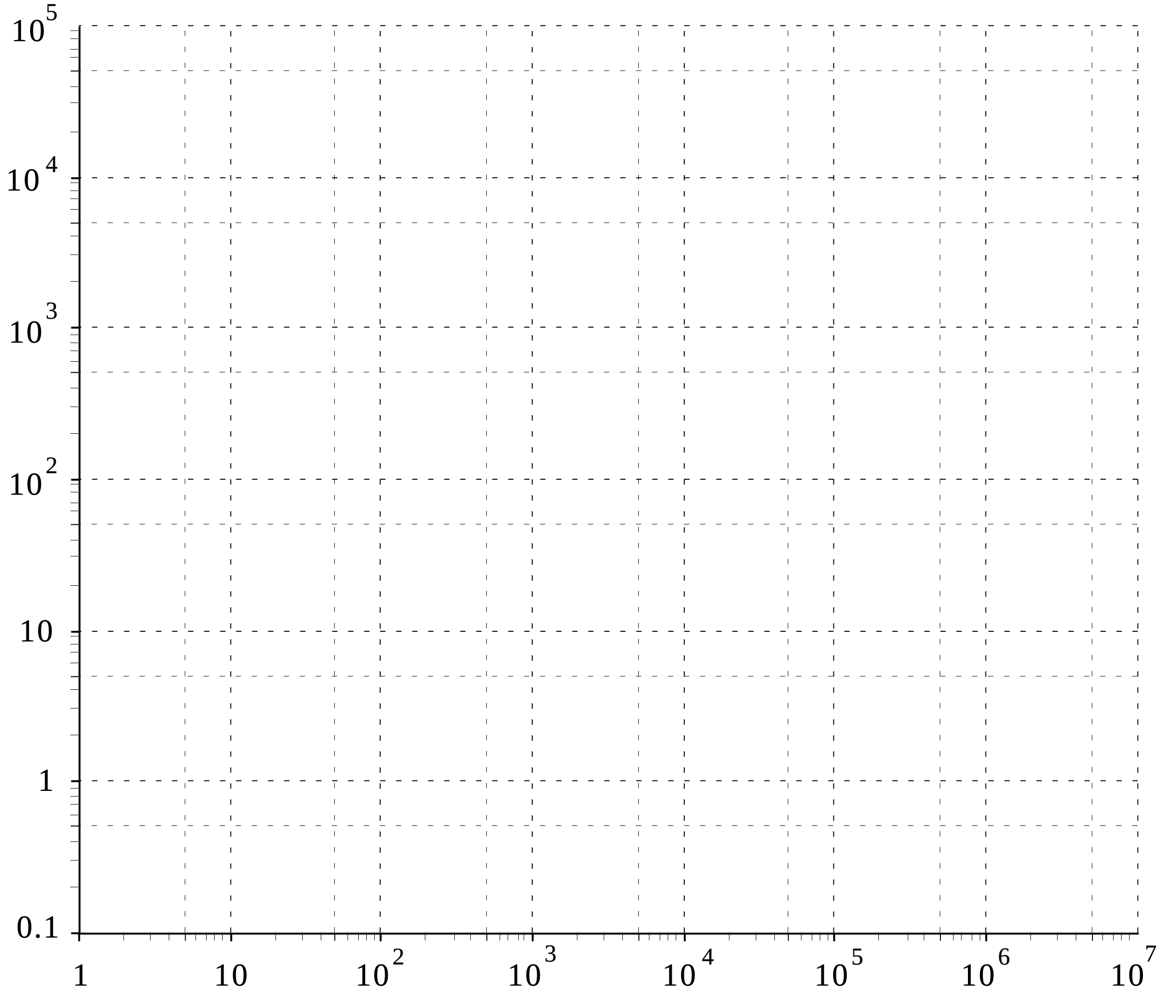
4. Change the damping

Put a 1 kΩ resistor in series with the inductor and repeat the measurement of Q and the observation of the transient response. In general terms, what connection do you see between the Q value and the ringing of the response?

Now how many peaks can you distinguish?

From your display estimate

Q = $1/T$ =


10^5
10^4
10^3
10^2
10
1
0.1
1
10
10^2
10^3
10^4
10^5
10^6
10^7