Inductors and Time-Dependent Signals

Concept

The purpose is to learn about time-dependent (AC) analysis of RL circuits using a function generator and an oscilloscope. The transient response of an RL circuit will be studied in the time-domain using the combination of square-wave from a function generator and an oscilloscope. Frequency-domain behavior will be measured as well, and the response function of RL circuits will be determined. Complex impedance of inductors will be introduced, and Fourier analysis of complicated waveforms will be presented.

An inductor has very little DC resistance, but can have a large AC impedance. This is a consequence of Faraday's Law of Induction, which relates the rate of change of the magnetic field within the coil to an electric field. Hence, the relationship between the rate of change of current through the coil and the potential across it is $\Delta\Phi = LdI/dt$, where L is the inductance in Henrys. From the complex amplitude analysis of these circuits, the complex impedance of an ideal inductor when the frequency of the applied signal is ω is $Z = i\omega L$.

Helpful hints and warnings

The "ground symbol" in a circuit implies that the grounds (outer conductors or shields) of the signal generator and the oscilloscope are connected to the circuit at this point. Unlike the DMM, the signal generator and oscilloscopes grounds can be connected only to the circuit ground. Thus, in the high-pass RL circuit, the oscilloscope can be used only to measure the potential across the inductor. Conversely, in the low-pass LR circuit, the scope can be used only to measure the potential across the resistor.

To read the inductance on the encapsulated inductors, look for three numbers such as 151. The first two digits are the real first two digits of the inductance. The third digit is the order of magnitude or power of ten. So, 151 means an inductance of 150 something. To figure out what "something" is, the type and size of the inductor needs to be considered. For the encapsulated inductors in the laboratory, the unit is microHenry or μH. So, 150 μH = 0.15 mH. Measure both the inductance and resistance of your inductor using the LRC meter.

For measurements, be sure to vary the frequency of the applied signal over a wide range, such as 100 Hz to 1MHz, to make sure that you are working in the right range for your choice of R and L.

Experimental Instructions

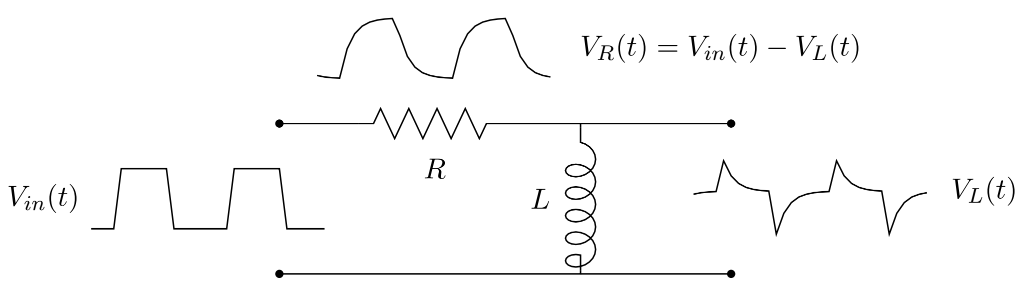
1. Inductor demonstrations

a. Listen to the TA describe different types of inductors.

b. Watch the demonstrations, and perform the simple, qualitative experiments described by the TA.

2. Time-dependent analysis of RL circuits

a. Square waves and the RL circuit:



(a) Construct an RL circuit, choosing the theoretical *time constant* $\tau = L/R$ to be about 0.0001 seconds.

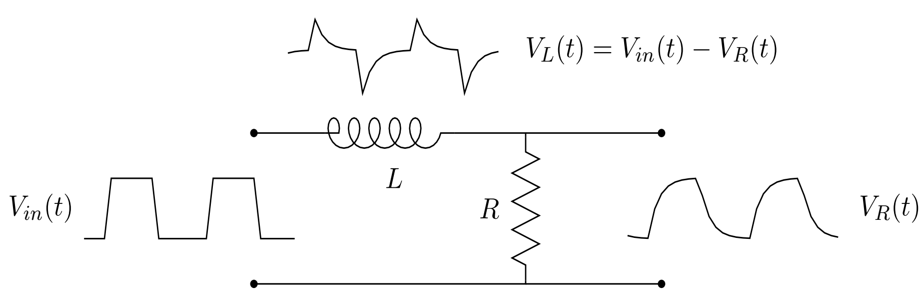
(b) Apply a 100 Hz square wave signal and view the output using channel 1 of the oscilloscope. With the scope input switch for channel 1 set to "gnd" (ground), adjust the vertical position of the trace so that it is centered vertically. Switch to the "DC" position to view the signal. Be sure the triggering is set correctly. Ask for help if you are uncertain.

(c) Measure τ by determining the time for the output to drop to $1/e$ of the maximum and to rise to $1 - 1/e$ of the maximum. Are these two values of τ equal? Does either equal t0 L/R? Explain any differences you observe.

(d) Vary the frequency from 0 to 1 MHz and determine the frequency range over which the behavior of the circuit is similar to the 100 Hz behavior.

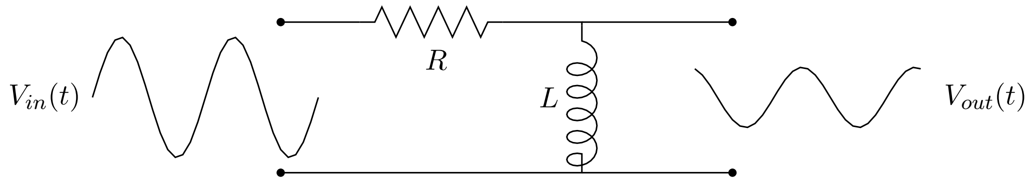
(e) Apply different waveforms, such as triangle and sine waves. Describe the behavior of this circuit over the range of frequencies applied.

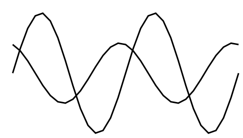
b. Square waves and the LR circuit:



(a) Repeat the same measurements for the LR circuit.

3. Frequency response of both configurations



Amplitude and phase change 

a. Apply a sine-wave signal to each configuration and sweep the frequency from 0 to 1 MHz. Make at least 20 measurements. Since you will be plotting your data versus the $\log \nu$, make at least two measurements per decade of frequency. Determine the transmission function $A(\omega)$ by dividing the output amplitude by the input amplitude. Be sure to measure the input amplitude from the function generator at each frequency, since the combination of your circuit and the limitations of the generator will lead to a signal that will generally decrease in amplitude with frequency. The applied frequency should be determined by taking the reciprocal of the period measured on the scope. Measure the phase difference between the output and input signals. A good point on the waveform to use for such measurements is the point at which the trace crosses the 0 Volts line. If the period of the input signal is T and the displacement of the output signal is t, then the phase difference is $\phi = 2\pi t/T$.

b. For each configuration, plot the data and theoretical curves for phase and amplitude together as $20 \log A(\nu)$ vs. $\log \nu$. Determine the *breakpoint* or *characteristic* frequency from the data plot by identifying the -3dB point, and compare this to the theoretical value. Draw conclusions about the behavior of both circuits.