Circuit Resonance

Core Concept Instructor Set

nPoints
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Frequency
Sweep

Materials:

1 Air-Core 8.2mH Inductor

1 Capacitor (Calculate)

1 Resister (Calculate)
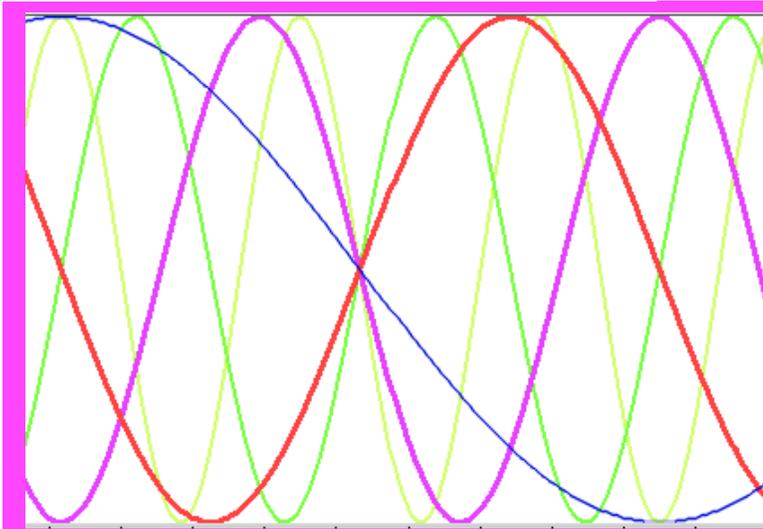
1 Op Amp

Learn It!

At the heart of every circuit are fundamental components that help with a number of needs, some being amplification and removing unwanted noise. These are capacitors, inductors and resistors, these components allow us to distribute charge in a circuit accordingly. But how do these components work in a circuit? Is there a way to understand how these components react to different signals? Inductors capacitors and resistors are found in everything that involves circuitry, even if the discrete component is not found, wires and junctions between chips contain inherent capacitance inductance and resistance. This means that it is a necessity to understand how these components react to different signals in order to properly design to avoid any difficulties. In fact, LRC (inductance, resistance, capacitance) circuits have a natural increased response to signals that oscillate at certain frequencies. This is known as a resonance frequency and when this is applied to an LRC circuit we see drastic increased output for the given input. In this module, the resonance frequency of a lightly underdamped LRC series circuit is ascertained by two methods, the first being to obtain the peak amplitude of signals at the output for different frequencies of input signals, the second is see the oscillations first hand of an LRC circuit when a transient step function is applied.

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Build It!

The Series LRC Circuit

Inductance and capacitance can be modeled in their frequency dependant complex form. In this form we reference them as impedances and they allow us to solve circuits with all three components using simple series and parallel equations. Resistance is not frequency dependant so its complex form stays the same while capacitance and inductance are modeled as $(\frac{-i}{wC})$

(iwL) respectively. This means that the series combination of all of these components is written as:

$$Z = R + iwL - i/wC$$

A commercially purchased inductor is a wirewound coil that represents an ideal inductance in series with a resistance caused by the wire used in the coil.
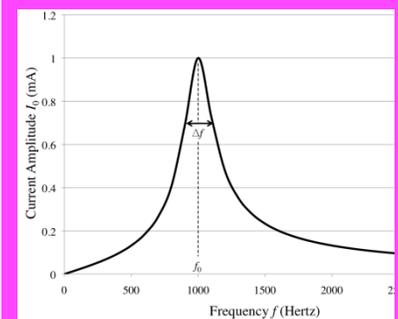

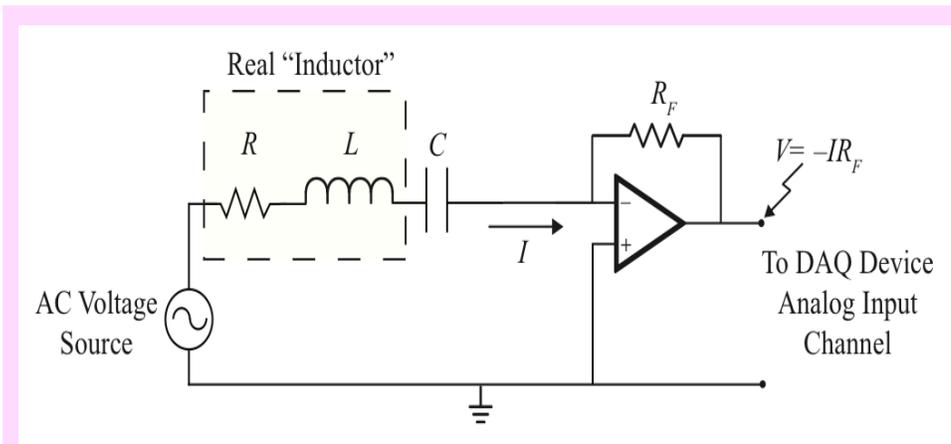Figure 1 1000 Hz resonant frequency of an LRC circuit

Figure 2 Navigate to Compound Arithmetic function

Task 1: Build the circuit in Figure 2. The real inductor will serve as both the ideal inductor and series resistance. Calculate the capacitance needed in order to achieve a resonant frequency of 2kHz using the equation:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The Op Amp is being used to amplify the current signal coming from the LRC circuit. The output of the Op Amp will be a voltage so we will need to convert it back to current. The resistance in the feedback leg is what we will use in our calculation to get back current.

Step 2: Choose a resistance such that a current of 1mA results in an output voltage of 1V. The Op Amp voltage rails can be driven using the +/-15V lines of your myDAQ.

Step 3: Wire the AO0 of your myDAQ to be the AC Voltage Source as shown in Figure 2. Wire the output of the Op Amp to AI0. Confirm the circuit is properly grounded and referenced to AGND as shown in Figure 3.

Guiding Questions:
- Research and explain underdamped, overdamped and critically damped systems. Explain why this circuit is underdamped.
- Research the charging and discharging characteristics of inductors and capacitors. They are considered energy storage components; discuss how each reacts to change in current and voltage.
- Write out the equation for an LRC circuit if the components were in parallel. Can this configuration be made to show the same behavior as the series circuit?

Creating a Frequency Sweep Program

A frequency sweep is used to show the response of the series circuit once it has reached a steady state after the signal has been applied. The circuit will exhibit a signal at specific amplitude based on the signal frequency applied. This method is what is used to construct a bode plot which also includes the phase response of the circuit. Let's build a frequency sweep program that can be used to study all kinds of systems.

Step 4: Open the "LCR Steady-State_Template(Frequency Scan).vi" from the LCR Circuit Templates folder and navigate to the block diagram. Place a subtract function by right clicking and navigating to **Programming>>Numeric>>Subtract.** Use this function to subtract Start(Hz) from End(Hz).

Step 5: Place a divide function using the same method from the previous step. Use this to divide the output from the subtract function by the Increment(Hz) input. This will create the number of steps needed in your frequency sweep.
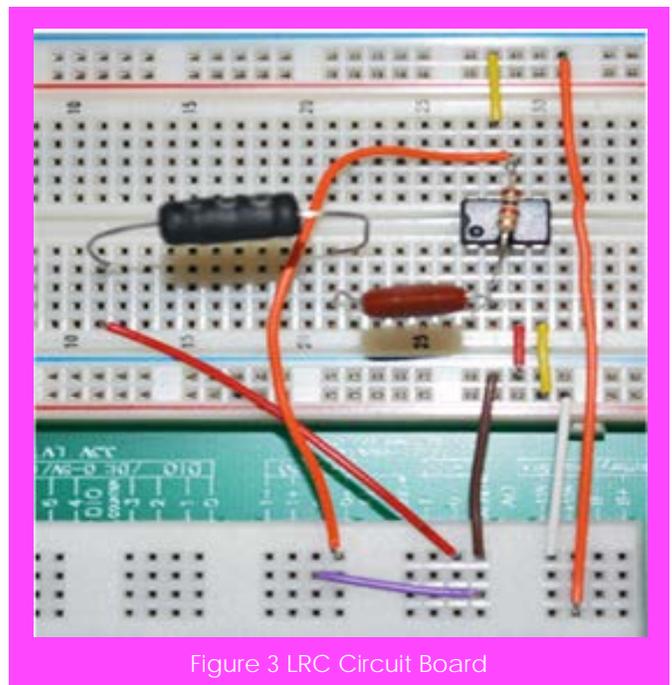

Figure 3 LRC Circuit Board

Step 6: Wire the output of the divide function into the I32 converter function and wire that output to the Loop count of the For Loop. The frequency of the signal that will be output to the LRC circuit needs to be calculated in each loop iteration. Design a way to determine the frequency by using the Start(Hz) and Increment values provided in the loop.

Step 7: Place a Simulate Signal Function by right clicking and navigating to Express>>Input>>Simulate Signal. Configure this Express VI with an appropriately high value for **Sample per second (Hz)** and, for the option **Number of samples**, check Automatic and **Integer number of cycles.**

Step 8: Place a DAQ assistant function by right clicking and navigating to **Measurement I/O>>NI-DAQmx>>DAQ Assistant,** configure the function with these parameters: **Generate Signals>>Analog Output** with the **Generation Mode>>Continuous Samples** and **Use Waveform Timing**. Wire the output of the Simulate Signal Function to the input of the DAQ assistant. Your block diagram should now look similar to Figure 4.

Step 9: The 200 ms timer is used to allow the circuit to reach a steady state before a measurement is taken. Using the same method as above, place a DAQ assistant function configured to acquire N Samples. Calculate the samples that need to be acquired to span a time frame of 0.1 seconds. Use a sample rate that is 20 times the frequency being output by the simulator.

Step 10: Place an Amplitude and Level Measurements function by right clicking and navigating to Express>>Signal Analysis>>Amplitude and Level Measurements. Check RMS in the configuration window. Wire the output of the DAQ assistant acquisition function to the Amplitude and Level Measurements function and wire that output to the Convert from Dynamic Data type function.

Step 11: Wire the frequency value calculated from Step 6 to the output of the For loop (the tunnel mode is automatically set to create an array). Wire the array of frequencies to the top input of the cluster being used to create "Resonance Curve" output indicator.
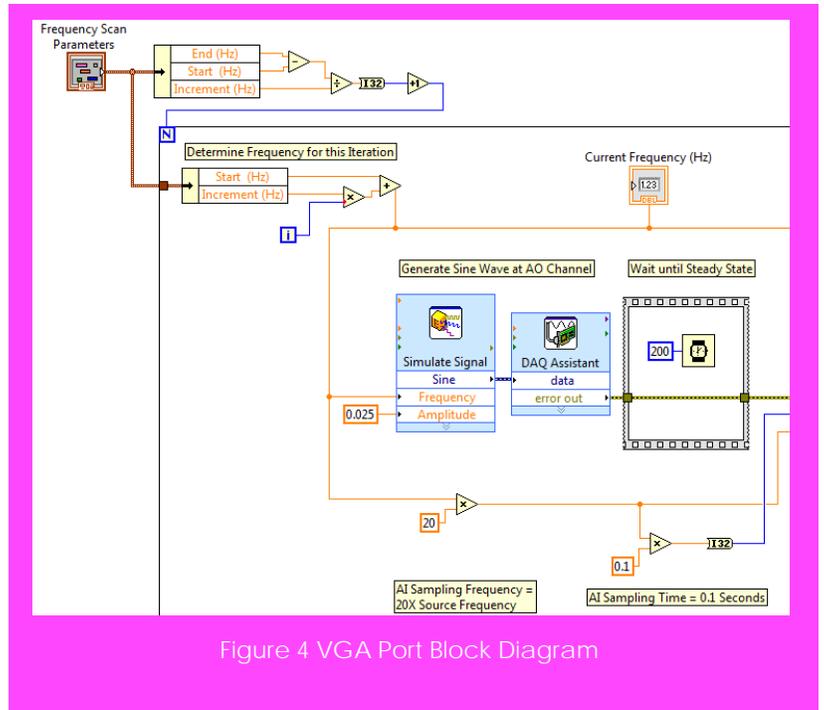

Figure 4 VGA Port Block Diagram

Step 12: Set the start and end frequencies as well as the amount to increment by (in hertz) for each iteration. Run the code and take not of the resonance curve. Does this match what you calculated?

Transient Response

When a system like the series LRC circuit is given a step function the circuit will give its response which should have a specific frequency.

Using what you learned in the previous section, design code that generates a square wave and outputs it on AO0. At the same time, read the output of the circuit with AI0. After the analog acquisition place the "Tone Measurements" function to allow you to see the peak frequency from each iteration. Run the code multiple times and see if you can get a resonant frequency as before.

Guiding Questions:
- Research and find cases where resonance played an important role in electrical circuits or man-made structures.
- Explain why the oscillations seen in a lightly underdamped system level out to a specific value.
- Suggest a way to reduce the oscillations in a system by paracitic capacitance and inductance.

Expand it!

- Design a means to implement the phase plot that is found in actual bode plots. Make this process automated as well.
- Calculate the capacitance and resistance values that would make this a critically damped system.
- Research Q factor and find wha the Q factor is of your system. Implement code that finds the Q factor of the system automatically and .

Research It!

LCR Circuit(Wikipedia)
http://en.wikipedia.org/wiki/RLC_circuit

LCR Circuit(HyperPhysics)
http://hyperphysics.phy---astr.gsu.edu/hbase/electric/serres.html

Axial Power Inductors
http://www.abracon.com/Magnetics/axial/AIAP---02.pdf

Producing Analog Waveforms Using Digital-to-Analog Converters
http://www.ni.com/white---paper/5521/en

Generating a Voltage (National Instruments Video Training)
http://www.ni.com/academic/students/learn-daq/generate/

Using Counters and Digital I/O (National Instruments Video Training)
http://www.ni.com/academic/students/learn-daq/digital