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StudentZone—ADALM2000 Activity: Inductor Self Resonance

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Objective

The objective of this lab activity is to measure the self-resonant frequency (SRF) of an inductor and determine the parasitic capacitance from the measured data.

Background

The inductors supplied in your parts kit, like all nonideal electrical components, are not perfect. The schematic in Figure 1 shows the most common simple model of a real inductor. In addition to the desired inductance L, the real component also has a loss (modeled as a series resistance, shown in the schematic as R) and a parallel parasitic capacitance, shown as C. The smaller the resistance, which is close to 0 Ω, and the smaller the capacitance, which is close to 0 F, the more ideal the inductor becomes.

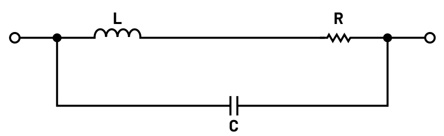


Figure 1. A 3-element LRC inductor model.

Interwinding Capacitance and Self-Resonant Frequency

The classical description of C is that it represents the turn-to-turn distributed capacitance of the inductor (and turn-to-core, etc.). At some frequency, the SRF, this turn-to-turn capacitance forms a parallel resonance with the inductance L, and the inductor becomes a tuned circuit.

3-Element LRC Model Impedance vs. Frequency

At frequencies below the SRF, the model appears to be inductive. At frequencies above the SRF it appears to be capacitive and at the SRF it is resistive, as the inductive and capacitive reactance are equal in magnitude but opposite in sign and thus cancel.

At the SRF of an inductor, all of the following conditions are met:

- The input impedance is at its peak.
- The phase angle of the input impedance is zero, crossing from positive (inductive) to negative (capacitive).
- Since the phase angle is zero, the Q is zero.
- The effective inductance is zero since the negative capacitive reactance ($X_C = 1/j\omega C$) just cancels the positive inductive reactance ($X_L = j\omega L$).
- The 2-port insertion loss (S21 dB) is a maximum, which corresponds to the minimum in the plot of frequency vs. S21 dB.
- The 2-port phase (S21 angle) is zero, crossing from negative at lower frequencies to positive at higher frequencies.

Equation 1 shows how the SRF is related to inductance and capacitance in the inductor model circuit.

$$F_{SR} = \frac{1}{(2\,\pi\,\sqrt{(LC_P)})_{in\ Hz}} \tag{1}$$

where:

L is the inductance in henries

C_p is the parasitic capacitance in farads

From Equation 1, it is clear that increasing inductance or capacitance lowers the measured SRF and reducing inductance or capacitance raises the SRF.

Prelab Simulation of a 3-Element LRC Inductor Model

The schematic in Figure 2 shows the simulation test circuit for the 3-element LRC model of the inductor. L, R, and C_P are used to model the inductor. V1 is the ideal AC test voltage source and resistor RS serves as the source resistance for V1. CL and

RL are the components of the load with CL set equal to the typical input capacitance of the ADALM2000 scope input channel. RL is either set equal to RS or can be set to some higher value such as the 1 MΩ input resistance of the scope channel.

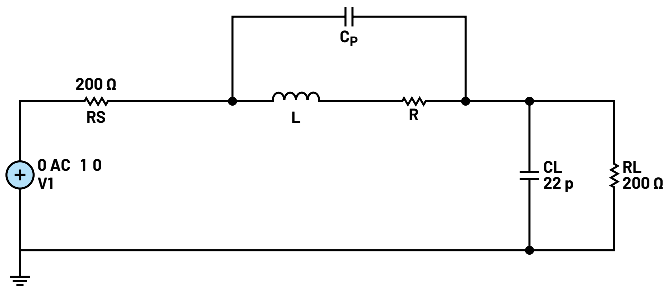


Figure 2. A simulation schematic.

You should simulate the circuit shown in Figure 2 before building the actual inductor test circuit.

As shown in Figure 3, two frequency sweep simulations were run from 10 kHz to 10 MHz as an example of a 1 mH inductor, L, with C_P set to 15 pF and R set to 100 mΩ. The red curve is with RL set to the same 200 Ω as RS. The amplitude seen at RL has a sharp dip at the SRF when the impedance of the inductor is at its maximum. The blue curve is with RL set to the 1 MΩ of the scope input. Again, we see the sharp null when the impedance is maximum. We also see a sharp peak in the amplitude seen at RL about one octave below the notch. This peaking occurs when the source and load resistances are not matched.

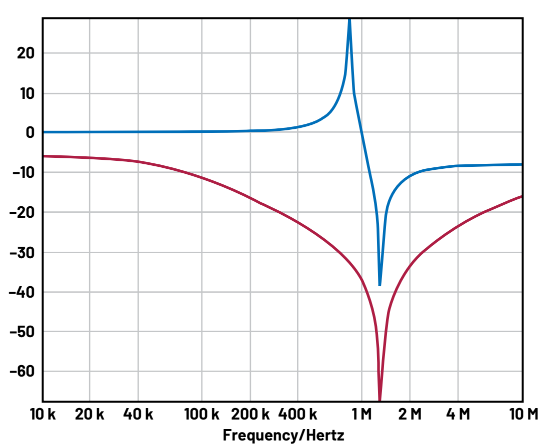


Figure 3. Simulation results: Red curve RL = 200 Ω, blue curve RL = 1 MΩ.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard and jumper wire kit
- One 1 mH inductor
- Various other value inductors
- Two 200 Ω resistors (may be made from two 100 Ω resistors in series)

Directions

Build the inductor test circuit as shown in Figure 4 on your solderless breadboard. The blue squares indicate where to connect the ADALM2000 AWG and scope channels.

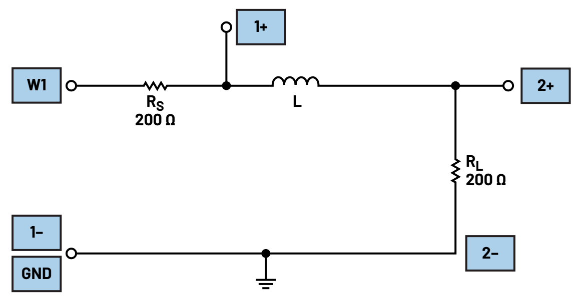


Figure 4. An inductor test circuit.

Hardware Setup

The connections to the ADALM2000 AWG output and scope channel inputs are as indicated by the blue boxes in Figure 4. Your parts kit should contain a number of inductors with different values. Insert each inductor, one at a time into your test circuit.

Procedure

Open the network analyzer software instrument from the Scopy window. Configure the sweep to start at 100 kHz and stop at 30 MHz. Set the amplitude to 1 V and the offset to 0 V. Set the magnitude range from –60 dB to +40 dB for the bode plot. Set the phase top to +180° and bottom to –180°. Under scope channels, click on Channel 1 as the reference. Set the number of steps to 100.

Run a single sweep for each inductor in your kit of parts. You should see amplitude and phase vs. frequency plots that look very similar to your simulation results. Be sure to export the data to a .csv file for further analysis in either Excel or MATLAB®.

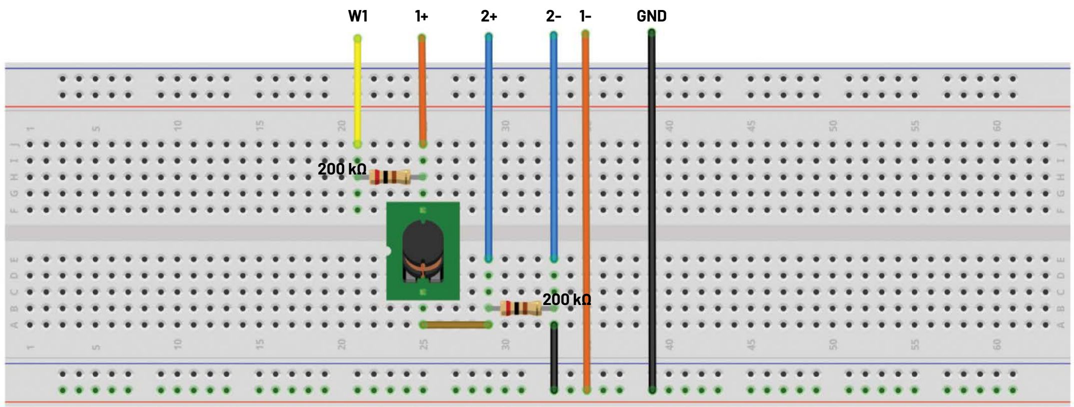


Figure 5. Inductor test circuit breadboard connections.

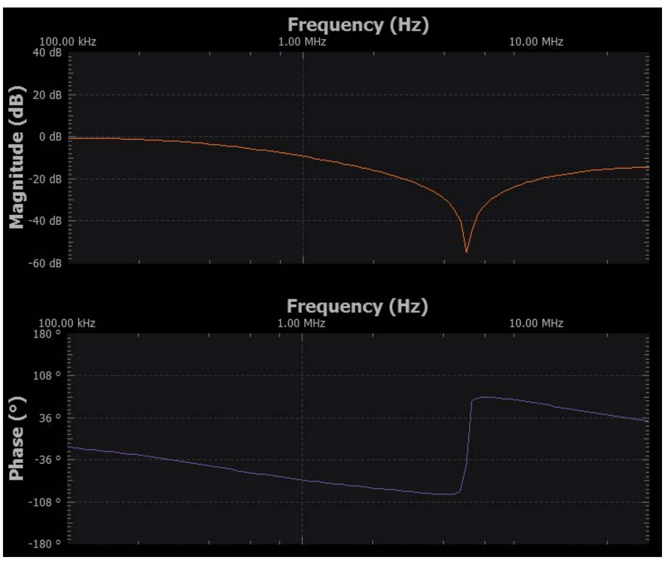


Figure 6. Scopy shot, L = 100 µH, RL = 200 Ω.

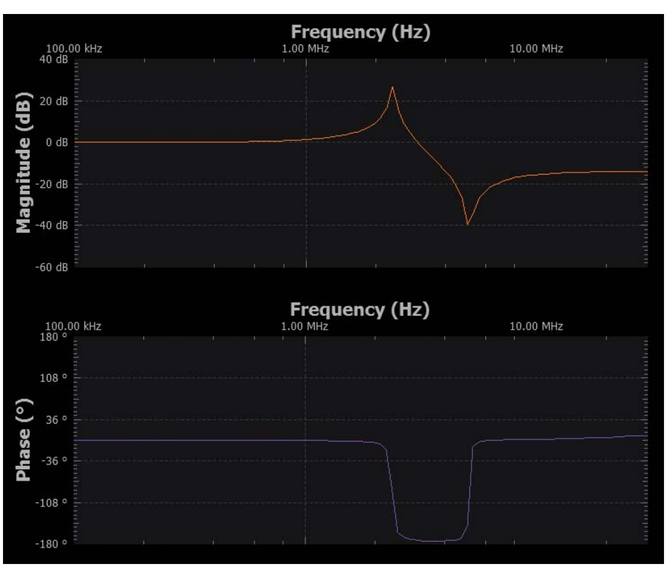


Figure 7. Scopy shot, L = 100 µH, RL = 1 MΩ.

Question:

Use the formula for the SRF to calculate the value for the turn-to-turn parasitic capacitance of the inductor used in your experimental setup.

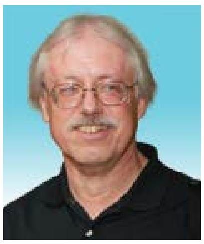
You can find the answers at the StudentZone blog.

Extra Experiments

To further explore this resonance, connect external 39 pF and/or 100 pF capacitors in parallel with the inductor and remeasure the frequency response. You will now have additional resonance frequencies that you can use to also calculate and confirm the inductance L as well as C_P in our simple model by using the resonance formula.

About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab®, QA automation, and process management. He started working at ADI in February 2017 in Cluj-Napoca, Romania. He currently holds an M.Sc. degree in software engineering from the Babes-Bolyai University and a B.Eng. degree in electronics and telecommunications from the Technical University of Cluj-Napoca.



About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a fellow emeritus contributing to the Active Learning Program. In 2016, he was named engineer in residence within the ECSE department at RPI.