StudentZone—May 2018 ADALM1000 SMU Training Topic 5: Transient Response of RL Circuit

By Doug Mercer and Antoniu Miclaus

After the introduction of the SMU ADALM1000 in our *Analog Dialogue* December 2017 article, we want to continue our series with some small, basic measurements. You can find the previous ADALM1000 article here.



Figure 1. A schematic of the ADALM1000.

Now let's get started with the next experiment.

Objective:

The objective of this lab activity is to study the transient response of a series RL circuit and understand the time constant concept using pulse waveforms.

Background:

This lab activity is similar to another of our lab activities, Activity 4: Transient Response of an RC Circuit, except that the capacitor is replaced by an inductor. In this experiment, you will apply a square waveform to the RL circuit to analyze the transient response of the circuit. The pulse width relative to the circuit's time constant determines how it is affected by the RL circuit.

Time Constant (τ): A measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, when the elapsed time exceeds five time constants (5 τ) after switching has occurred, the currents and voltages have reached their final value, which is also called the steady-state response.

The time constant of an RL circuit is the equivalent inductance divided by the Thévenin resistance as viewed from the terminals of the equivalent inductor.

$$\tau = \frac{L}{R} \tag{1}$$

A pulse is a voltage or current that changes from one level to another and back again. If a waveform's high time equals its low time, it is called a square wave. The length of each cycle of a pulse train is its period (T). The pulse width (tp) of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency for the square wave is given by:



Figure 2. Series RL circuit.

In an RL circuit, voltage across the inductor decreases with time, while in the RC circuit, the voltage across the capacitor increased with time. Thus, current in an RL circuit has the same form as voltage in an RC circuit: they both rise to their final value exponentially according to $1 - e^{-t \times R/L}$.

The expression for the current in the inductor is given by:

$$I_L(t) = \left(\frac{V}{R}\right) \left(1 - e^{-\left(t\frac{R}{L}\right)}\right) t \ge 0$$
(3)

where V is the applied source voltage to the circuit for t=0. The response curve increases and is shown in Figure 3.



Figure 3. The current in an inductor increasing in a series RL circuit.

The expression for the current decay across the inductor is given by:

$$I_L(t) = I_0 e^{-\left(t\frac{R}{L}\right)} t \ge 0$$
(4)

where:

 $I_{\scriptscriptstyle 0}$ is the initial current stored in the inductor at t=0

 $L/R = \tau$ is the time constant.

The response curve is a decaying exponential and is shown in Figure 4.



Figure 4. The current decay through the inductor for a series RL circuit.

Since it is possible to directly measure the current through the inductor (current supplied by driving source) with the ALM1000, we will measure and compare both the current and the output voltage across the resistor. The resistor waveform should be similar to the inductor current as $V_{\text{R}} = I \times L_{\text{R}}$. From the waveforms on the scope, we should be able to measure the time constant τ , which should be equal to $\tau = L/R_{\text{total}}$.

Here, R_{TOTAL} is the total resistance and can be calculated from $R_{TOTAL} = R$ inductance + R.

R inductance is the measured value of inductor resistance and can be measured by connecting inductance to an ohmmeter prior to running the experiment.

Materials:

- ADALM1000 hardware module
- One resistor (220 Ω)
- One inductor (20 mH (two 10 mH in series))

Procedure:

- 1. Measure the combined inductor and resistor resistance R_{TOTAL} by using an ohmmeter. You can use the ALM1000 ohmmeter tool to do this. Remember that the ohmmeter tool measures resistance with respect to ground when you connect the series connected L1 and R1.
- ► 2. Set up the circuit shown in Figure 5 on your solderless breadboard with the component values R1 = 220 Ω and L1 = 20 mH. Open the ALICE oscilloscope software.



Figure 5. Experiment setup.



Figure 6. Breadboard connections.

3. Set the Channel A AWG minimum value to 0.5 V and the maximum value to 4.5 V to apply a 4 V p-p square wave centered on 2.5 V as the input voltage to the circuit. From the AWG A mode drop-down menu, select the SVMI mode. From the AWG A shape drop-down menu, select Square. From the AWG B mode drop-down menu, select Hi-Z mode.

Calculate the applied frequency using Equation 2 for tp = 5τ

4. From the ALICE curves drop-down menu, select CA-V, CA-I, and CB-V for display. From the Trigger drop-down menu, select CA-V and Auto Level. Adjust the time base until you have at approximately two cycles of the square wave on the display grid.



Figure 7. Oscilloscope configuration.

This configuration allows the oscilloscope to look at the input voltage of the circuit and the current through the inductor on Channel A and the output voltage of the circuit on Channel B. Make sure you have checked the **Sync AWG** selector.

- 5. The VR waveform has the same shape as the IL(t) waveform. From the VR waveform, measure time constant t and compare that with the one that you calculated from L/R_{TOTAL} (hint: find the time that corresponds to the 0.63 VR value). See the Background section for details.
- 6. Observe the response of the circuit and record the results again for $tp = 25\tau$ and $tp = 0.5\tau$.

Questions:

- Include the plots of IL and VR for different tp values: 2τ, 5τ, and 10τ.
- A capacitor stores energy. What do you think an inductor stores? Answer in brief.

You can find the answers at the StudentZone blog.

Notes

As in all the ALM labs, we use the following terminology when referring to the connections to the ALM1000 connector and configuring the hardware. The green shaded rectangles indicate connections to the ADALM1000 analog I/O connector. The analog I/O channel pins are referred to as CA and CB. When configured to force voltage/measure current, –V is added, as in CA-V or when configured to force current/measure voltage, –I is added, as in CA-I. When a channel is configured in the high impedance mode to only measure voltage, –H is added, as in CA-H.

Scope traces are similarly referred to by channel and voltage/current, such as CA-V and CB-V for the voltage waveforms, and CA-I and CB-I for the current waveforms.

We are using the ALICE Rev 1.1 software for those examples here.

File: alice-desktop-1.1-setup.zip. Please download here.

The ALICE desktop software provides the following functions:

- A 2-channel oscilloscope for the time domain display and analysis of voltage and current waveforms.
- ► The 2-channel arbitrary waveform generator (AWG) controls.

- The X and Y display for plotting captured voltage and current vs. voltage and current data, as well as voltage waveform histograms.
- The 2-channel spectrum analyzer for frequency domain display and analysis of voltage waveforms.
- The Bode plotter and network analyzer with built-in sweep generator.
- An impedance analyzer for analyzing complex RLC networks and as an RLC meter and vector voltmeter.
- A dc ohmmeter measures unknown resistance with respect to known external resistor or known internal 50 Ω.
- Board self-calibration using the AD584 precision 2.5 V reference from the ADALP2000 analog parts kit.
- ALICE M1K voltmeter.
- ALICE M1K meter source.
- ALICE M1K desktop tool.

For more information, please look here.

Note: You need to have the ADALM1000 connected to your PC to use the software.



Figure 8. ALICE desktop 1.1 menu.

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