

StudentZone—April 2018

ADALM1000 SMU Training

Topic 4: Transient Response of RC Circuit

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After the introduction of the SMU [ADALM1000](#) in our *Analog Dialogue* December 2017 article, we want to continue with the fourth part of our series with some small, basic measurements. You can find the first ADALM1000 article [here](#).

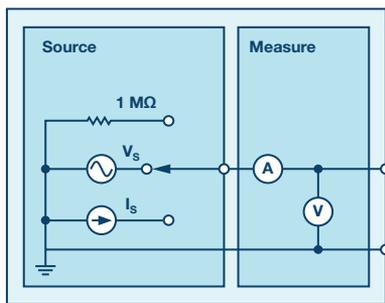


Figure 1. A schematic of the ADALM1000.

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 RC circuit and understand the time constant concept using pulse waveforms.

Background:

In this lab activity, you will apply a pulse waveform to the RC circuit to analyze the transient response of the circuit. The pulse width relative to a circuit's time constant determines how it is affected by an RC circuit.

Time Constant (τ): A measure of time required for certain changes in voltages and currents in RC and RL circuits. Generally, after four time constants (4τ), the capacitor in the RC circuit is virtually fully charged and the voltage across the capacitor is now approximately at 98% of its maximum value. This interval is considered to be the transient response of the circuit. When the elapsed time exceeds five time constants (5τ) after switching has occurred, the currents and voltages have reached their final value, which is also called steady-state response.

Table 1 shows the voltage and current percentage values for the capacitor in the RC charging circuit at a given time constant while charging.

Table 1. Voltage and Current Percentage Values for Given Time Constant

Time Constant (τ)	Percentage of Maximum	
	Voltage	Current
0.5τ	39.3%	60.7%
0.7τ	50.3%	49.7%
τ	63.2%	36.8%
2τ	86.5%	13.5%
3τ	95.0%	5.0%
4τ	98.2%	1.8%
5τ	99.3%	0.7%

Note that the capacitor will never become 100% charged in reality. Therefore, five time constants are used to consider a capacitor fully charged for all practical purposes.

The time constant of an RC circuit is the product of equivalent capacitance and the Thévenin resistance as viewed from the terminals of the equivalent capacitor.

$$\tau = R \times C \quad (1)$$

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 is its period (T).

The pulse width (t_p) of an ideal square wave is equal to half the time period.

The relation between pulse width and frequency is then given by,

$$f = \frac{1}{(2t_p)} \quad (2)$$

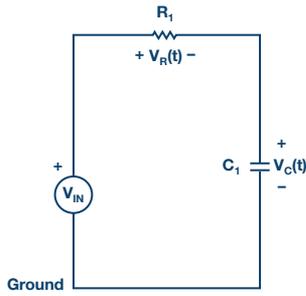


Figure 2. Series RC circuit.

From Kirchhoff's laws, it can be shown that the charging voltage $V_C(t)$ across the capacitor is given by:

$$V_C(t) = V \left(1 - e^{-\frac{t}{RC}} \right) \quad t \geq 0 \quad (3)$$

where V is the applied source voltage to the circuit for $t = 0$, and $RC = \tau$ is the time constant.

The response curve increases and is shown in Figure 3.

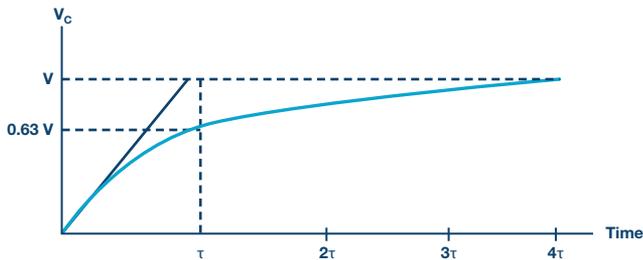


Figure 3. Capacitor charging for series RC circuit to a step input with time axis normalized by τ .

The discharge voltage for the capacitor is given by:

$$V_C(t) = V_0 e^{-\frac{t}{RC}} \quad t \geq 0 \quad (4)$$

Where V_0 is the initial voltage stored in capacitor at $t = 0$, and $RC = \tau$ is time constant. The response curve is a decaying exponential as shown in Figure 4.

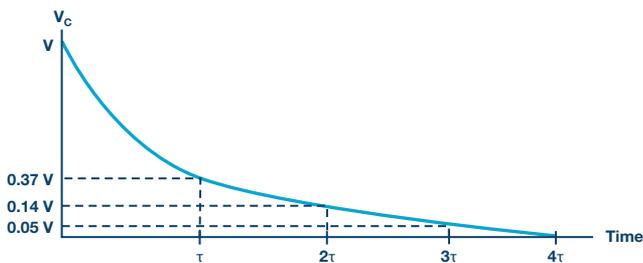


Figure 4. Capacitor discharging for series RC circuit.

Materials:

- ▶ ADALM1000 hardware module
- ▶ Resistors (2.2 k Ω , 10 k Ω)
- ▶ Capacitors (1 μ F, 0.01 μ F)

Procedure:

- ▶ 1. Set up the circuit shown in Figure 5 on your solderless breadboard with the component values $R_1 = 2.2 \text{ k}\Omega$ and $C_1 = 1 \mu\text{F}$. Open the ALICE Oscilloscope software.
- ▶ 2. Set the Channel A arbitrary waveform generator (AWG) **Min** value to 0.5 V and the **Max** 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 menus select **Square**. From the AWG B **Mode** drop down menu, select the **Hi-Z** mode.

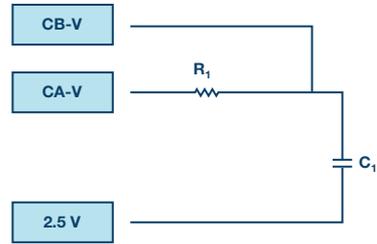


Figure 5. Breadboard diagram of an RC circuit.

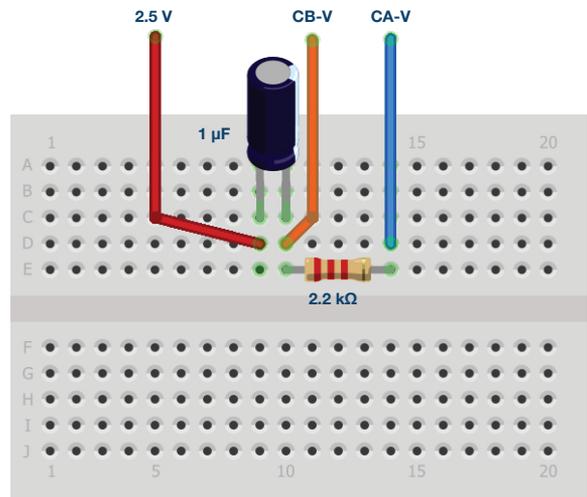


Figure 6. Breadboard connections for RC circuit $R_1 = 2.2 \text{ k}\Omega$ and $C_1 = 1 \mu\text{F}$.

- ▶ 3. From the **ALICE Curves** drop down menu, select **CA-V** 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 uses the oscilloscope to look at the input of the circuit on Channel A and the output of the circuit on Channel B. Make sure you have checked the **Sync AWG** selector.

- ▶ 4. Observe the response of the circuit for the following three cases and record the results.
 - a. Pulse width $\gg 5\tau$: Set the frequency of AWG A output such that the capacitor has enough time to fully charge and discharge during each cycle of the square wave. Let the pulse width be 15τ and set the frequency according to Equation 2. The value you have found should be approximately 15 Hz. Determine the time constant from the waveforms obtained on the screen if you can. If you cannot obtain the time constant easily, explain possible reasons.
 - b. Pulse width = 5τ : Set the frequency such that the pulse width = 5τ (this should be approximately 45 Hz). Since the pulse width is 5τ , the capacitor should just be able to fully charge and discharge during each pulse cycle (see Figure 3 and Figure 4).

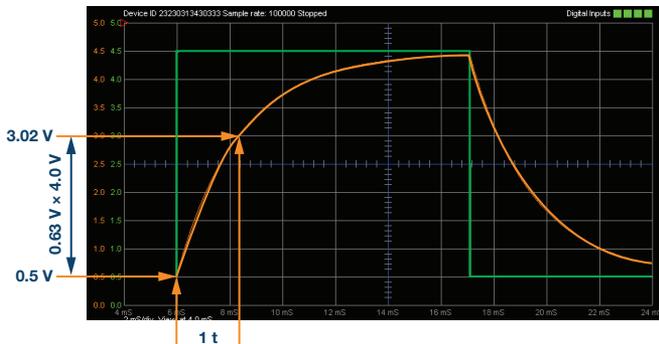


Figure 8. Measuring the time constant t approximately by counting the number of squares.

- c. Pulse width $\ll 5\tau$: In this case the capacitor does not have time to charge significantly before it is switched to discharge, and vice versa. Let the pulse width be only 1.0τ in this case and set the frequency accordingly.
- ▶ 5. Repeat the procedure using $R1 = 10\text{ k}\Omega$ and $C1 = 0.01\text{ }\mu\text{F}$ and record the measurements.

Questions:

- ▶ 1. Calculate the time constant (τ) using Equation 1 and compare it to the measured value from 4b ($R = 2.2\text{ k}\Omega$ and $C = 0.01\text{ }\mu\text{F}$).
- ▶ 2. Repeat this for another set of values, $R = 10\text{ k}\Omega$ and $C = 0.01\text{ }\mu\text{F}$.

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 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 $50\text{ }\Omega$.
- ▶ 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.

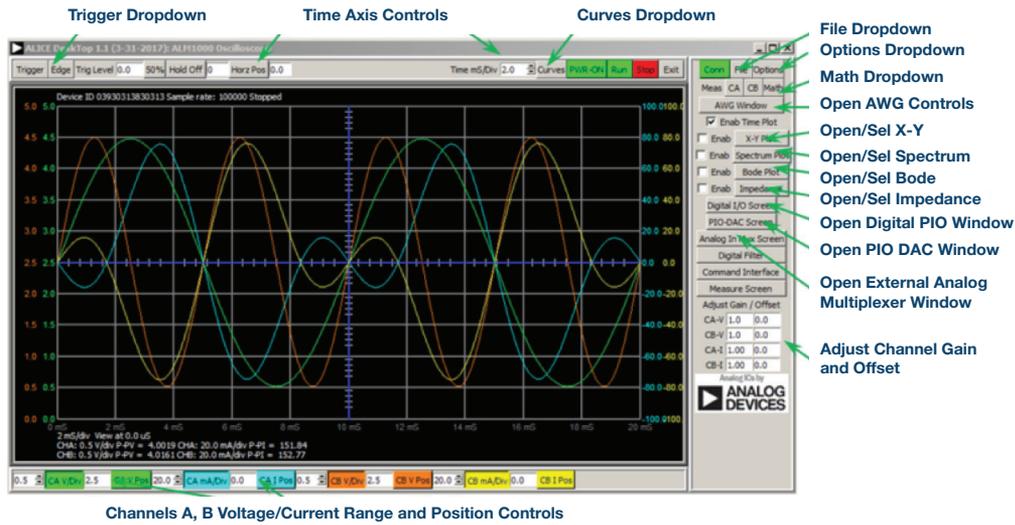


Figure 9. ALICE desktop 1.1 menu.

Doug Mercer [doug.mercer@analog.com] 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 he 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.



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Also by this Author:

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[StudentZone—March 2018](#)

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He is currently an M.Sc. student in the software engineering master's program at Babes-Bolyai University and he has a B.Eng. in electronics and telecommunications from Technical University of Cluj-Napoca.



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