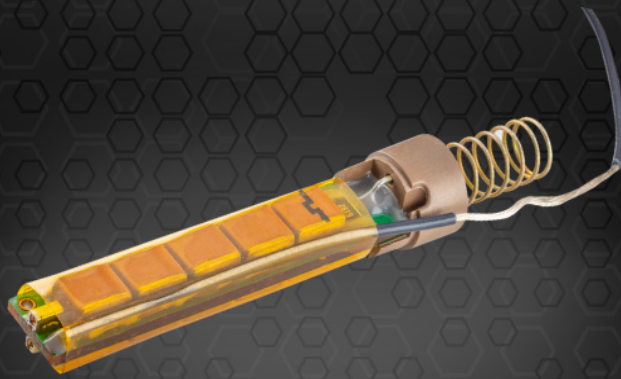


HOW DO YOU MAKE A PULSE IN AN RLC CIRCUIT?



One of the fundamental roles of capacitors is charging and discharging energy predictably. Many electronics applications leverage capacitors to store energy and release it in a controlled pulse of current or voltage. Here, we'll revisit how pulses are produced in a basic RLC circuit featuring a capacitor (C), inductor (L) and resistor (R).

Series RLC Circuit

As mentioned above, a series RLC circuit, shown in Figure 1, is made up of the three most common passive components in electronics engineering. When the capacitor is charged to an initial voltage and switched to discharge via the resistor and inductor, three types of responses can occur depending on the component values involved.

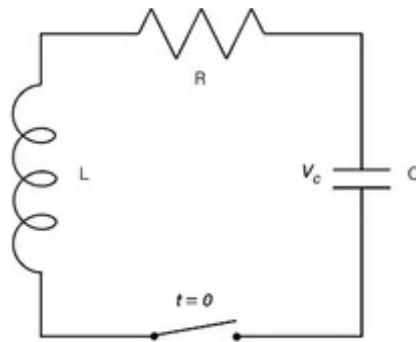


Figure 1. Series RLC circuit

When assessing current in an RLC circuit, damping dictates which equation you should use to determine how current varies over time. Is the system overdamped, critically damped or underdamped? The damping ratio, ζ , places a system into one of these categories.

Two RLC circuit parameters can be used to understand a system's damping ratio: neper frequency and resonant angular frequency.

Neper Frequency

The neper frequency refers to an exponential transience rate. In other words, how quickly is energy lost from the system?

Find the neper frequency, α , using:

$$\alpha = \frac{R}{2L}$$

Resonant Angular Frequency

The resonant angular frequency, ω_0 , indicates what frequency a system will oscillate at:

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

In combination, these parameters can be used to calculate the damping factor and identify which mathematical model would best represent the system's behavior.

Damping Factor

Refocusing on the damping factor, the value for ζ places the system into one of three categories. There are three cases to consider:

Case 1: Overdamped: $\zeta > 1$

Case 2: Critically Damped: $\zeta = 1$

Case 3: Under Damped: $\zeta < 1$

Where: $\zeta = \frac{\alpha}{\omega_0}$

[Capacitor Discharge Current Theory](#) derives solutions for current over time for each damping case. Here, we'll leverage those results for the sake of example.

Case 1: Overdamped Current Response

When $\zeta > 1$, apply the following equation:

$$i(t) = \frac{V}{L(s_1 - s_2)} e^{s_1 t} - \frac{V}{L(s_1 - s_2)} e^{s_2 t}$$

Where: $s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$

To observe an overdamped response, shown in Figure 2, charge the capacitor to 10V and set C to 2.0 μ F, L to 5.0mH and R to 200 Ω .

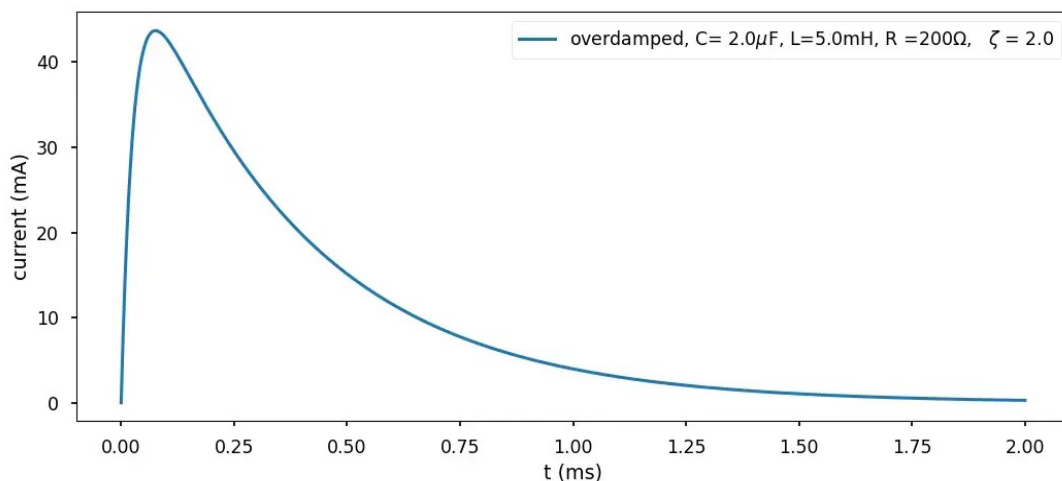


Figure 2. Current over time for an overdamped RLC circuit

Case 2: Critically Damped Current Response

When $\zeta = 1$, apply the following equation:

$$i(t) = \frac{V}{L} t e^{-\alpha t}$$

To observe a critically damped response, shown in Figure 3, keep C and L the same and set R to 100Ω. As shown, critically damped cases typically have higher peak amplitudes than overdamped cases.

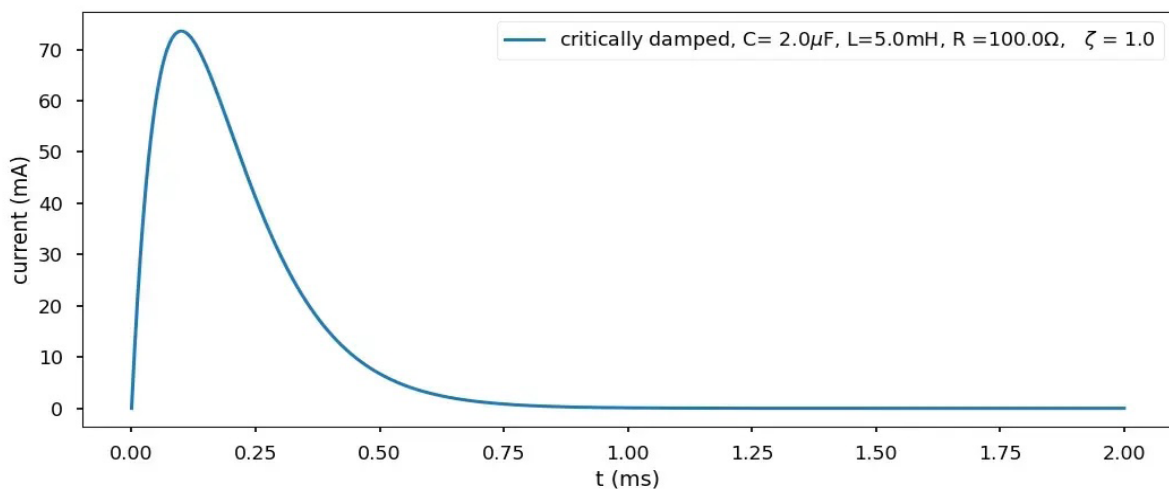


Figure 3. Current over time for an overdamped RLC circuit

Case 3: Underdamped Current Response

When $\zeta < 1$, apply the following equation:

$$i(t) = \frac{V}{L\sqrt{\omega_0^2 - \alpha^2}} e^{-\alpha t} \sin\left(\sqrt{\omega_0^2 - \alpha^2} t\right)$$

To observe an underdamped response, shown in Figure 4, keep C and L the same and set R to 50Ω. With all other variables remaining constant over time, resistance drives damping. As resistance decreases, the damping ratio decreases and peaks get larger. In this case, oscillation and decay, a pair known as ringing, become more pronounced too. The damping ratio determines the rate at which decay occurs.

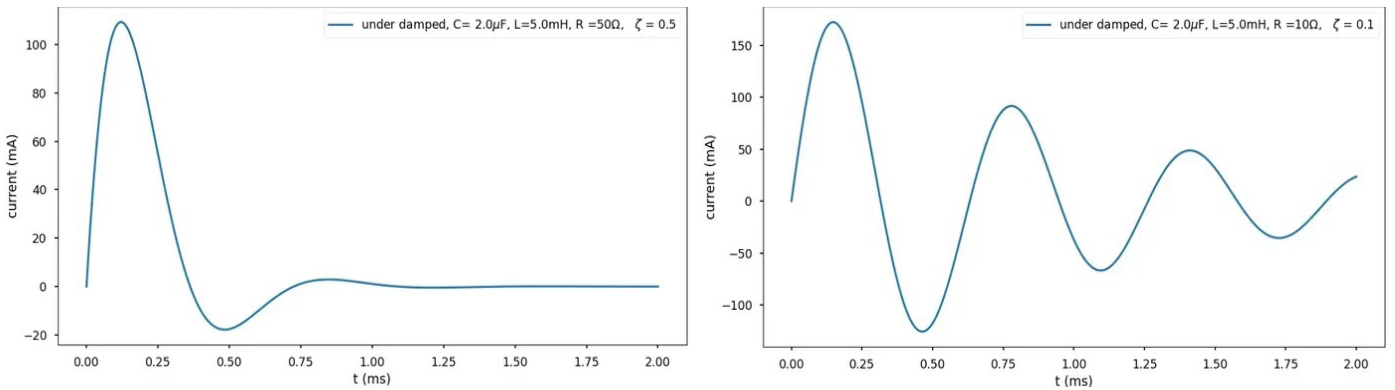


Figure 4: Current over time for an underdamped circuit with 50Ω resistance (left) vs. 10Ω resistance (right)

Peak current varies among damping cases, which is best observed on a single plot, Figure 5.

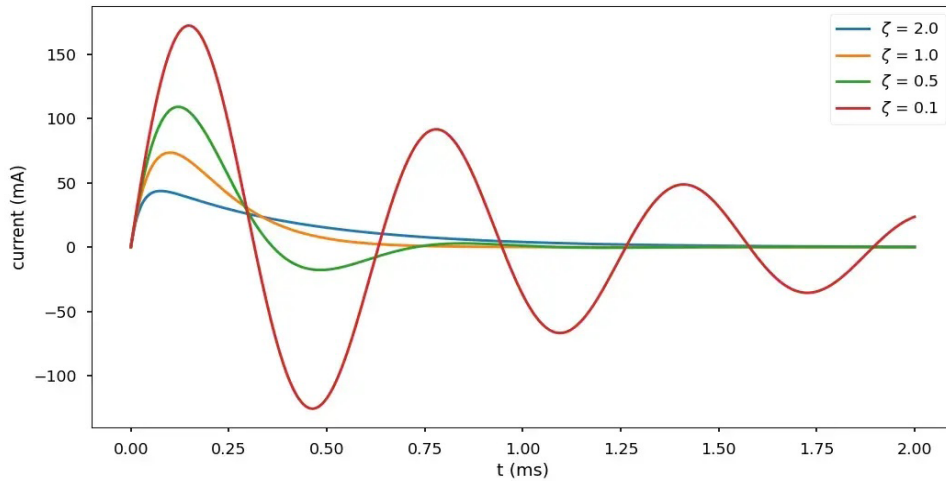


Figure 5: Current over time for various damping ratios in an RLC circuit

The Impact of Capacitance on Circuit Response

Changing resistance (Figure 3) has the most significant impact on damping ratio; however, changes in capacitance and inductance can also change the shape of the system response.

Consider the earlier equation: $\zeta = \frac{\alpha}{\omega_0}$

Where:

$$\alpha = \frac{R}{2L}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

By rewriting ζ in terms of α and ω , you have:

$$\zeta = \frac{R}{2} \sqrt{\frac{C}{L}}$$

The damping ratio was 2.0 when values were set to $C = 2.0\mu\text{F}$, $L = 5.0\text{mH}$ and $R = 200\Omega$. By changing C to $1.0\mu\text{F}$, the damping ratio is approximately 1.41. Since this is still considered an overdamped condition, you can use the equation for an overdamped case to compare $2.0\mu\text{F}$ and $1.0\mu\text{F}$ of capacitance, Figure 6.

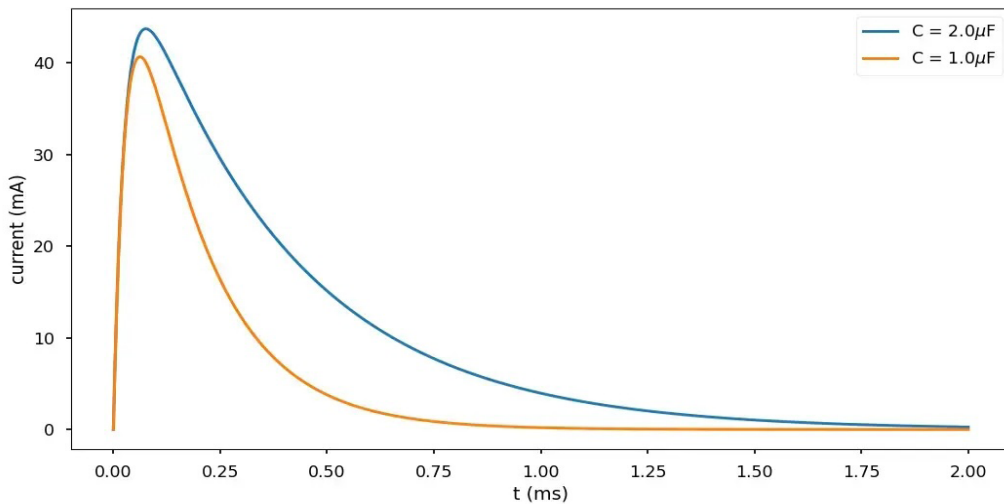


Figure 6: Current over time for an overdamped circuit with different capacitor values in an RLC circuit

The area under $1.0\mu\text{F}$ capacitance case is smaller, which is reasonable to expect from a smaller capacitor that stores less charge.

Here, we've explored:

- The three relevant equations for current waveform in an RLC circuit
- The cases in which those equations are valid (depending on the damping ratio range)
- How adjusting the capacitance value in the RLC circuit changes the shape of the waveform

Looking forward, we'll discuss real-world applications for this simple circuit and the kinds of capacitors responsible for making pulses. In the meantime, read about pulse capacitors in [external defibrillators](#) and [detonation](#).

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