14.7: RLC Series Circuits

Learning Objectives

By the end of this section, you will be able to:

- Determine the angular frequency of oscillation for a resistor, inductor, capacitor (RLC) series circuit
- Relate the RLC circuit to a damped spring oscillation

When the switch is closed in the RLC circuit of Figure \(\PageIndex{1a}\), the capacitor begins to discharge and electromagnetic energy is dissipated by the resistor at a rate \((i^2 R)\). With \(U\) given by Equation 14.4.2, we have

\[
\frac{dU}{dt} = \frac{q}{C} \frac{dq}{dt} + Li \frac{di}{dt} = -i^2 R
\]

where \(i\) and \(q\) are time-dependent functions. This reduces to

\[
L\frac{d^2q}{dt^2} + R\frac{dq}{dt} + \frac{1}{C}q = 0. \quad \text{(Label 14.44)}
\]

Figure \(\PageIndex{1}\): (a) An RLC circuit. Electromagnetic oscillations begin when the switch is closed. The capacitor is fully charged initially. (b) Damped oscillations of the capacitor charge are shown in this curve of charge versus time, or \(q\) versus \(t\). The capacitor contains a charge \((q_0)\) before the switch is closed.
This equation is analogous to

\[ m\frac{d^2x}{dt^2} + b\frac{dx}{dt} + kx = 0, \]

which is the equation of motion for a damped mass-spring system (you first encountered this equation in Oscillations). As we saw in that chapter, it can be shown that the solution to this differential equation takes three forms, depending on whether the angular frequency of the undamped spring is greater than, equal to, or less than \( b/2m \). Therefore, the result can be underdamped \((\sqrt{k/m} > b/2m)\), critically damped \((\sqrt{k/m} = b/2m)\), or overdamped \((\sqrt{k/m} < b/2m)\). By analogy, the solution \(q(t)\) to the RLC differential equation has the same feature. Here we look only at the case of underdamping. By replacing \(m\) by \(L\), \(b\) by \(R\), \(k\) by \(1/C\), and \(x\) by \(q\) in Equation \ref{14.44}, and assuming \((\sqrt{1/LC} > R/2L)\), we obtain

Note

\[
q(t) = q_0 e^{-Rt/2L} \cos(\omega't + \phi) \quad \text{\ref{14.45}}
\]

where the angular frequency of the oscillations is given by

Note

\[
\omega' = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \quad \text{\ref{14.46}}
\]

This underdamped solution is shown in Figure \ref{PageIndex 1b}). Notice that the amplitude of the oscillations decreases as energy is dissipated in the resistor. Equation \ref{14.45} can be confirmed experimentally by measuring the voltage across the capacitor as a function of time. This voltage, multiplied by the capacitance of the capacitor, then gives \(q(t)\).

Note

Try an interactive circuit construction kit that allows you to graph current and voltage as a function of time. You can add inductors and capacitors to work with any combination of \(R\), \(L\), and \(C\) circuits with both dc and ac sources.

Note

Try out a circuit-based java applet website that has many problems with both dc and ac sources that will help you practice circuit problems.

Exercise \ref{PageIndex 1}]

In an RLC circuit, \((L = 5.0 \ \mu H)\), \((C = 6.0 \ \mu F)\), and \((R = 200 \ \Omega)\). (a) Is the circuit underdamped, critically damped, or overdamped? (b) If the circuit starts oscillating with a charge of \((3.0 \times 10^{-3} \ \text{C})\) on the capacitor, how much energy has been dissipated in the resistor by the time the oscillations cease?

Answer

a. overdamped; b. 0.75 J
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