Jules' Workshop

Standard

Unit 7

CAPACITORS AND INDUCTORS

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Capacitors

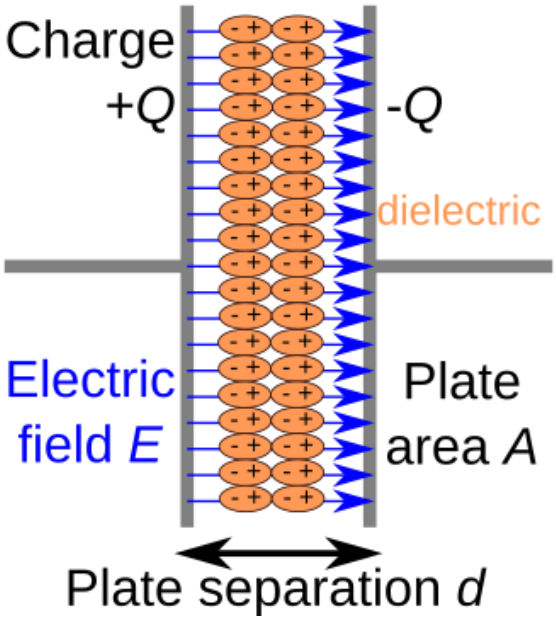
A capacitor is a two-terminal component that can store electrical energy in an electric field by accumulating charge on two closely spaced parallel conductive plates. These plates are separated by an insulator called a dielectric.

If a voltage potential is placed across these plates, the plates will achieve the same voltage as the power source. If the voltage source is removed. The capacitor will retain the charge and discharge over time. A capacitor blocks DC current.

The capacitance is dependent several factors.

- The plate sizes (A).
- The plate separation (d)
- The dielectric material between the plates. Dielectrics can be any material such as paper, air, plastic, etc.

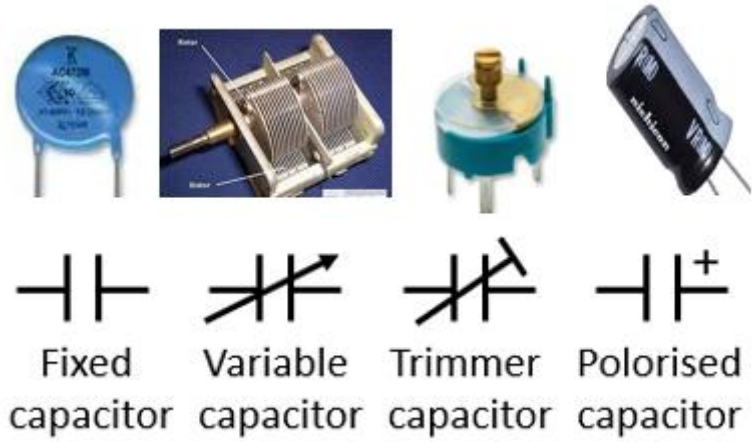
Capacitors are measured in Farads (F) named after the English physicist and chemist Michael Faraday. Most common capacitors are measured in microfarads (µF) or picofarads (pF)



Capacitor sizes

Prefix Name	Abbreviation	Weight	Equivalent Farads
Picofarad	pF	10-12	0.000000000001 F
Nano farad	nF	10-9	0.000000001 F
Microfarad	µF	10-6	0.000001 F
Millifarad	mF	10-3	0.001 F

Symbols

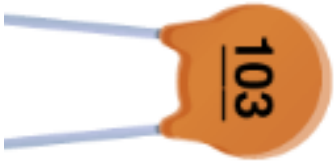


- A fixed capacitor has a predefined capacitance.
- A variable capacitor can be mechanically or electronically changed over a predefined range of capacitance.
- A trimmer capacitor is a set and forget device. The capacitor has a small range and once set is not altered.
- A polorised capacitor is used for high capacitance values in power filtering and energy storage.

WARNING: If a polorised capacitor is connected to the incorrect polarity, the capacitor may heat up and leak or explode.

Types of capacitors

Ceramic capacitors – A ceramic capacitor is a fixed-value capacitor where the ceramic material is the dielectric. Two or more alternating layers of ceramic and a metal layer act as the electrodes. Ceramic capacitors can be used as a general-purpose capacitor, since they are not polarized.



Electrolytic capacitors - Electrolytic capacitors are polarized and must be connected to the voltage supply correctly. An electrolytic capacitor uses an oxide film made of aluminium, tantalum or other oxidizable metal as a dielectric. This type of capacitor is used extensively in power supply circuits and similar applications.

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Film capacitors - Most common capacitor and are non-polarized. Polypropylene (PP) film capacitors are used for high-frequency high-power applications such as induction heating, pulsed power energy discharge applications and as AC capacitors for electrical distribution. The AC voltage ratings of these capacitors can range up to 400 kV.

Variable capacitors - The capacitance is variable through a defined range.

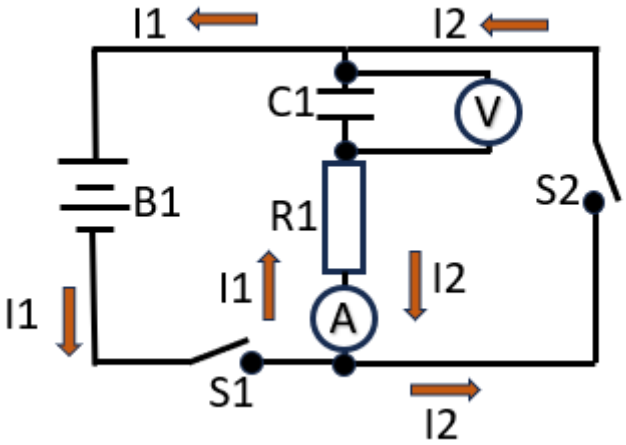
Dielectric Loss

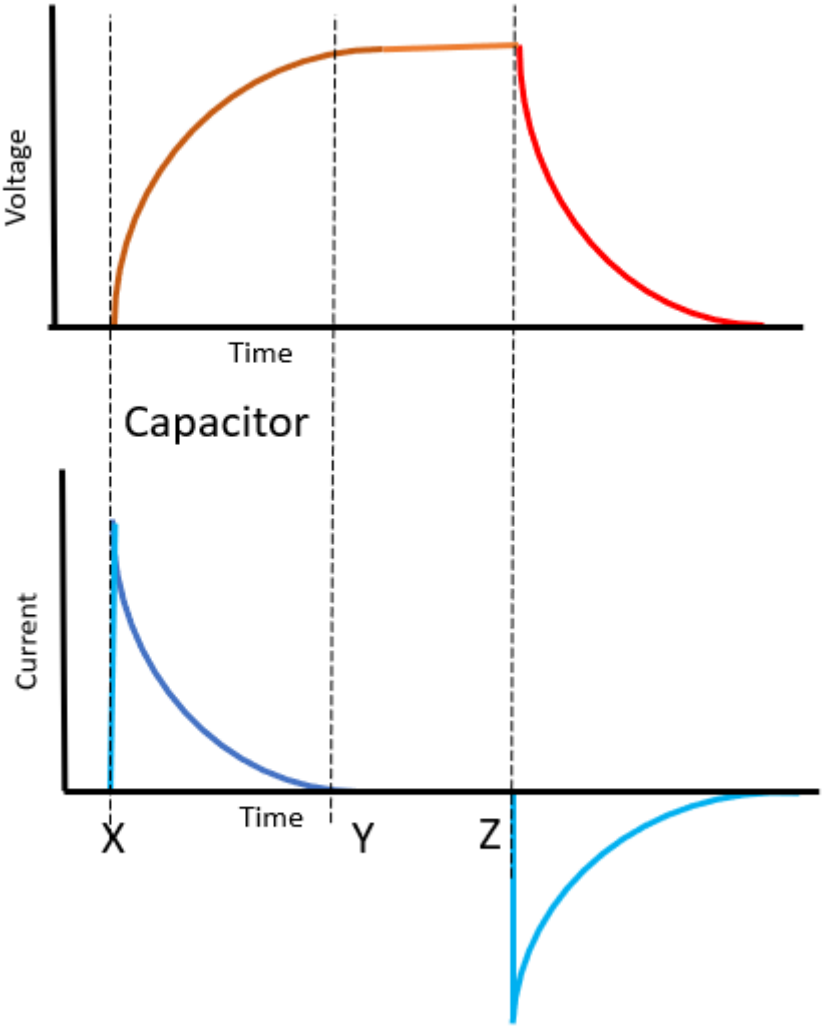
Dielectric loss is the loss of energy in heating a dielectric material in a varying electric field between two plates of the capacitor.

Capacitor Voltage and Current

When a voltage is placed across a capacitor, the capacitor will charge to the applied voltage. A resistor is used to control the current flow when charging and discharging the capacitor. The charging and discharging times for combination of the capacitor and resistor can be calculated.

Looking at the circuit below, the capacitor and resistor are in the circuit with a battery, ammeter and voltmeter.





Close S1 at time X (Capacitor charging)

Electrons will flow anticlockwise (I1) and deposit electrons on the bottom side of the capacitor. This makes the bottom side of the capacitor negative compared to the top side. The capacitor will charge, between time X and Y, and when the capacitor is charged, the electron flow will stop. The capacitor blocks DC. The ammeter will rise quickly then taper off. The voltmeter will rise to the charged voltage.

Open S1 at time Y

The capacitor will retain the charge but will eventually discharge over an extended time.

Close S2 at time Z (Capacitor discharging)

As the capacitor was charged and the bottom side is now negative, the current will flow in the opposite direction (E2). The voltage and current will drop to zero.

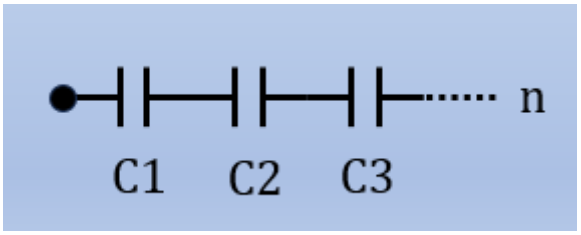
See the graphs below to demonstrate this charging and discharging.

A good video demonstrating this effect can be seen HERE.

Capacitor in series

Capacitors in series are treated the same way as resistors in parallel.

$$\frac{1}{Ct} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3} \ldots n$$



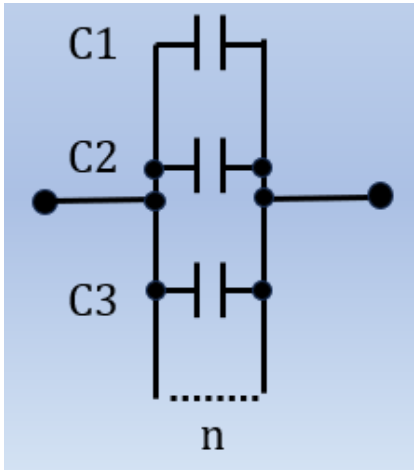
Example: The capacitors in series are 3mF, 6mF and 9 mF what is the total capacitance?

1/Ct = 1 / 0.003 + 1 / 0.006 + 1/ 0.009
1/Ct = 333.33 + 166.66 + 111.11
1/Ct = 611.1
Ct = 0.0016 F or 1.6 mF

Capacitors in parallel

Capacitors in parallel are treated the same way as resistors in series.

$$Ct = C1 + C2 + C3 \ldots n.$$



Example: The capacitors in parallel are 3mF, 6mF and 9 mF what is the total capacitance?

Ct = 0.003 + 0.006 + 0.009
Ct = 0.018 F or 18 mF

Reactance

The capacitor's opposition to alternating current is called Reactance. Reactance is symbolized by the capital letter "X" and is measured in ohms.

At DC, the capacitor resistance is infinitely high. As the frequency increases, the reactance of the capacitor to the AC signal decreases.

- Low frequencies – High capacitive reactance
- High frequencies – Low capacitive reactance

Capacitive reactance is Xc.

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Q Factor

A capacitor has a Q (Quality) Factor which measures a capacitor's efficiency, specifically the ratio of energy stored to energy dissipated as heat. A high Q factor means the capacitor wastes very little energy and behaves closer to an ideal component.

$$\mathbf{Q = X_C \div ESR}$$

ESR is the equivalent series resistance of the capacitor.

An excellent Q factor often ranges from 1,000 to 10,000. This means the energy stored is thousands of times greater than the energy lost as heat.

Example: A capacitor with an X_C of 20Ohms at frequency and an ESR of 0.005Ohms. What is the Q?

$$Q = X_C \div ESR$$
$$Q = 2 \div 0.005$$
$$Q = 4000$$

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Inductors

An inductor is made with insulated wire wound into a coil. Sometimes called a coil, choke, or reactor.

The inductor stores energy in a magnetic field when electric current flows through it.

The inductance (L) of the device is measured in Henrys (H), named after Joseph Henry.
A Henry is the amount of inductance that generates one voltage when the current is changing at a rate of one ampere per second.

An inductor inhibits AC current.

The inductance of a coil depends on several factors.

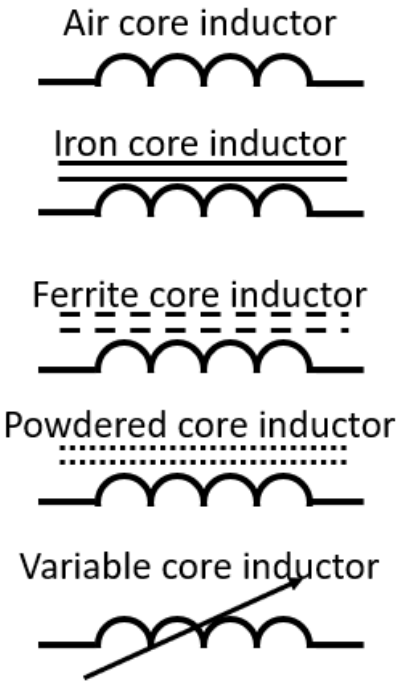
- Coil diameter.
- Cross sectional area
- Number of turns
- Type of material at the core.

Inductor sizes

Prefix Name	Abbreviation	Weight	Equivalent Henrys
Pico Henry	pH	10-12	0.000000000001 H
Nano Henry	nH	10-9	0.000000001 H
Micro Hery	µH	10-6	0.000001 H
Milli Henry	mH	10-3	0.001 H

Symbols

Inductor symbols are shown below.



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Types of Inductors

Air-Core Inductors – These inductors are open coil offering low inductance making them ideal for high-frequency (RF) applications.

Ferrite-Core Inductors- Inductor core is ferromagnetic material for high permeability and high inductance. These inductors are suitable for high-frequency, low-loss applications.

Iron-Core Inductors - Iron or steel cores are used for high-inductance, low-frequency, and high-power applications.

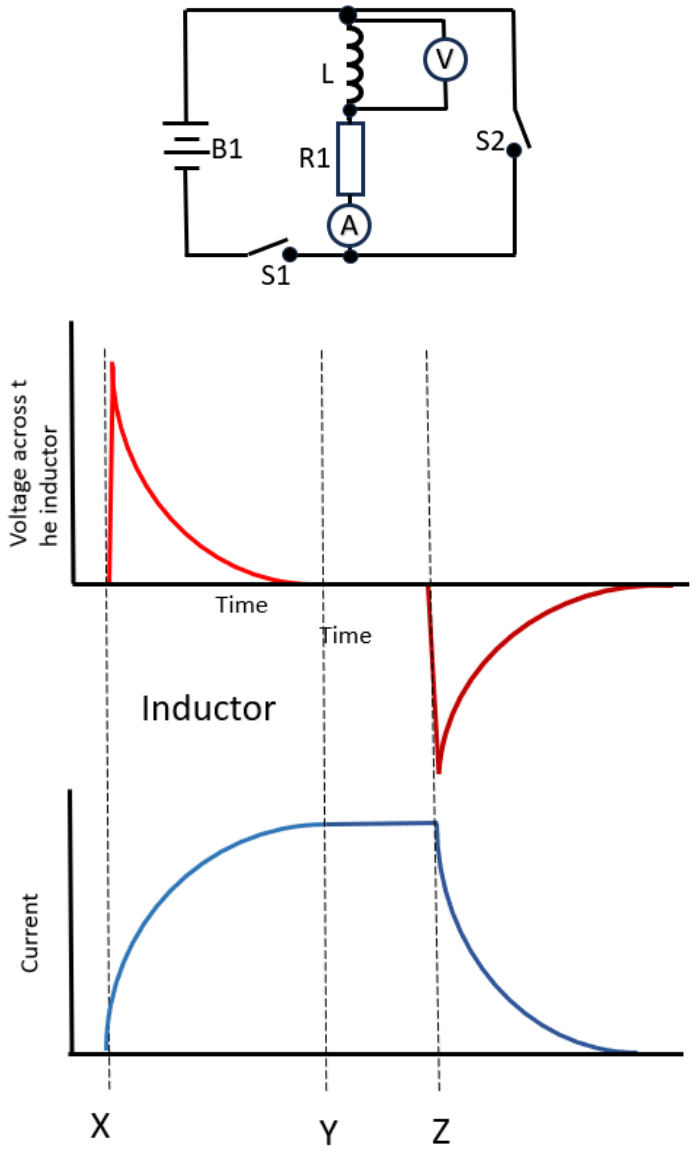
Powdered Iron Core Inductors – The inductor core is iron powder to store more energy and features low eddy current losses.

Variable Inductors- Can change inductance over a defined range.

Voltage and Current

DC passed through an inductor will generate a magnetic field around the inductor. A resistor is used to control the current flow when charging and discharging an inductor.

Looking at the circuit below, the inductor and resistor are in the circuit with a battery, ammeter and voltmeter.



Close S1 at time X

The initial flow of current will generate a magnetic field in the inductor, and a self-induced voltage will initially resist any change. (Lenz's Law) At this time, the inductor will present as high resistance and the voltage of B1 will be seen across the voltmeter. As the current reaches a steady state at point Y, the magnetic flux will remain steady and the resistance across the inductor will approach zero. No voltage drop will be measured across the inductor.

Time Y to Z

The current remains at a steady state as the inductor does not block DC.

Open S1 and Close S2 at time Z

As the current flow drops, the magnetic flux will collapse causing a back EMF voltage in the opposite direction. This will then taper off as the current flow stops.

See the graphs below to demonstrate this.

Inductor in Series

Inductors in series are the same as resistors in series.

$$\mathrm{Lt} = \mathrm{L1} + \mathrm{L2} + \mathrm{L3} \ldots \mathrm{n}$$

Example: Three inductors in series. 3mH, 5 mH and 10 mH. What is the total inductance?

Lt = 3 + 5 + 10
Lt = 18 mH

Inductors in Parallel

Inductors in parallel are the same as resistors in parallel.

$$\frac{1}{Lt} = \frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3} \ldots n$$

. **Example:** Three inductors in parallel. 3mH, 5 mH and 10 mH. What is the total inductance?

1/Lt = 1/3 + 1/5 + 1/10
1/Lt = 0.33 + 0.2 + 0.1
1/Lt = 0.63
Now flip.
Lt = 1.58 mH

Q Factor

The quality factor (or Q) of an inductor is the ratio of its inductive reactance to its resistance at a given frequency and is a measure of its efficiency. The higher the Q factor of the inductor, the closer it approaches the behaviour of an ideal inductor.

Reactance

An inductor has a DC resistance measured in Ohms.
The inductor's opposition to alternating current is called Reactance. Reactance is symbolized by the capital letter "X" and is measured in ohms just like resistance (R). The inductive reactance can be calculated. More on this in tuned circuits.
An inductor passes low frequencies and presents a high reactance to high frequencies.

At DC, the inductor resistance is that of the wire only. As the frequency increases, the reactance of the inductor to the AC signal also increases.

- Low frequencies – Low inductor reactance
- High frequencies – High inductor reactance

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Q Factor

The quality factor (or Q) of an inductor is the ratio of its inductive reactance to its resistance at a given frequency and is a measure of its efficiency. The higher the Q factor of the inductor, the closer it approaches the behaviour of an ideal inductor.

$$\mathbf{Q = X_L \div R}$$

Example: An inductor has an internal resistance of 2 Ohms and a reactance of 125 Ohms at frequency. What is the Q of the inductor?

$$\mathbf{Q = X_L \div R}$$
$$= 125 \div 2$$
$$Q = 62.5$$

A "good" inductor Q factor ranges from 50 to several hundred, depending on your application.

Go to Unit 7 Questions.

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