Lesson 6

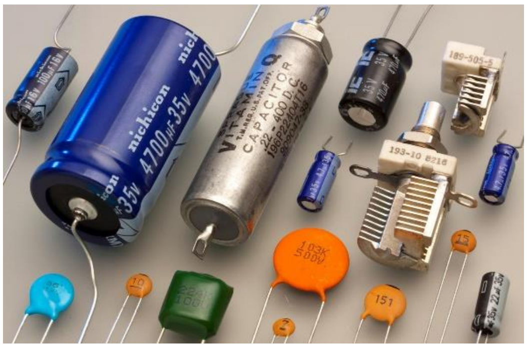
CAPACITORS AND INDUCTORS

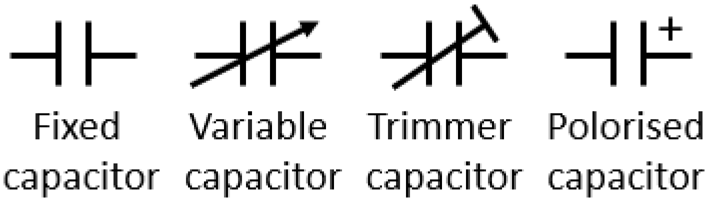
ACMA Syllabus February 2024 Chapters 2.2 and 2.3

Contents

Capacitors

Energy can be stored in an electrostatic field. This is called capacitance, and the device is a capacitor. Capacitor symbols are shown below. Capacitors are measured in Farads.





A capacitor is comprised of two conducting plates parallel to each other. These plates are separated by a non-conducting material 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 capacitor size is dependent on the plate sizes, the separation of the plates and the dielectric material between the plates. Dielectrics can be any material such as paper, air, plastic, etc. These all impact the capacitance of the product.

For information only

The value of the **Capacitor** can be determined by using the following formula.

$$C = \frac{\varepsilon \text{ x } A}{d}$$

C = capacitor size in Farads
ε = relative permittivity for the dielectric (Permittivity of air is 8.85418782 × 10^{-12}
A = the area of one plate in square metres
d = distance between the two plates in metres

Capacitance is a measure of the capacitor's ability to hold charges. The capacitance formula is:

$$C = \frac{Q}{V}$$

C is the capacitance of the element,
Q is the magnitude of the charge
V is the potential difference across the circuit element.

Capacitor sizes

Prefix Name	Abbreviation	Weight	Equivalent Farads
Picofarad	pF	10-12	0.000000000001 F
Nano farad	nF	10-9	0.000000001 F

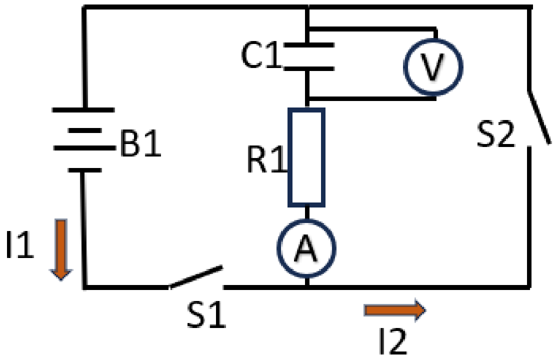
Microfarad	µF	10-6	0.000001 Fself
Millifarad	mF	10-3	0.001 F
Kilofarad	kF	103	1000 F

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

Voltage and Current

A resistor is used to control the current flow when charging and discharging a 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)

The current rises and electrons will flow anticlockwise (E1) 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 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

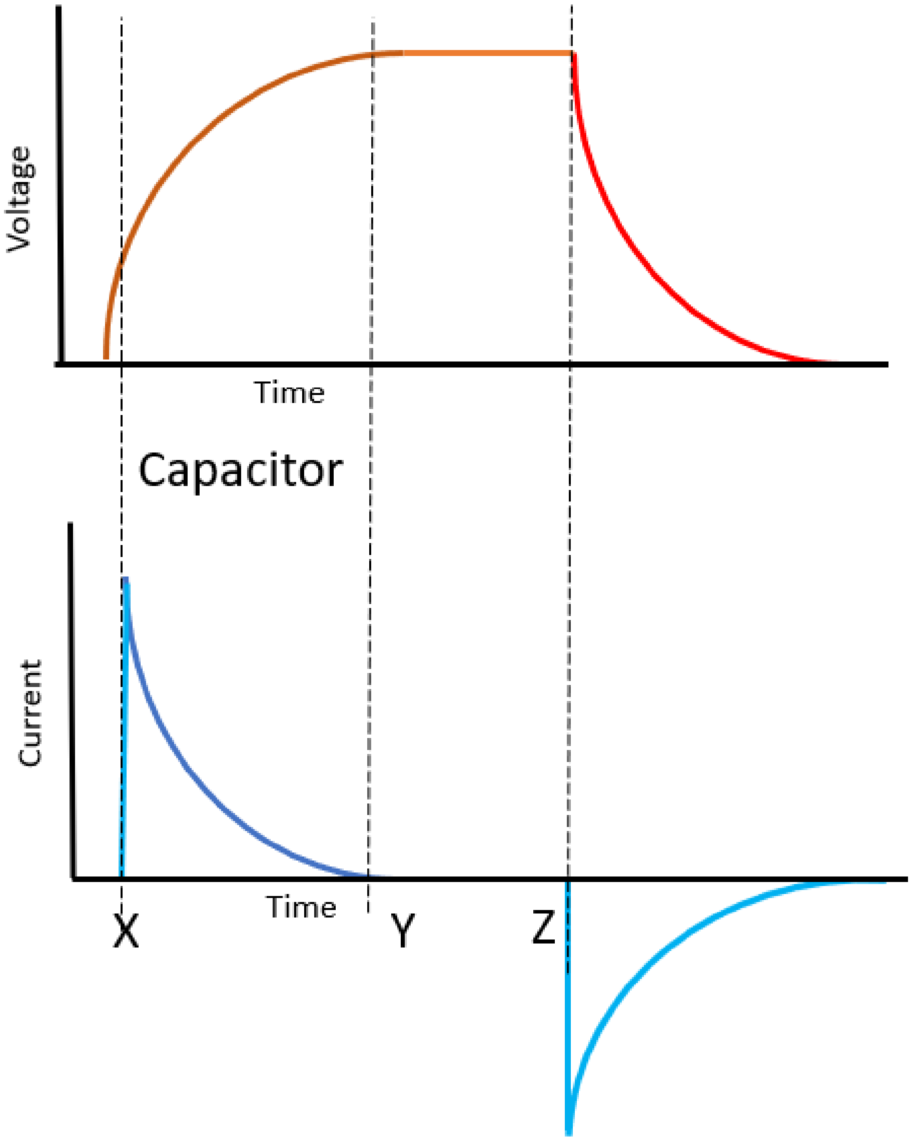
The capacitor will retain the charge but will eventually discharge over an extended time.

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.



Types of capacitors

Ceramic capacitors –	A ceramic capacitor is a fixed-value capacitor in which ceramic material acts as the dielectric with two or more alternating layers of ceramic and a metal layer acting 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 is a capacitor that 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.
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,

Capacitor in series

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

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

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.

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

Example: The capacitors in parallel are 3mF, 6mF and 9 mF what is the total capacitance?
CT = 0.003 + 0.006 + 0.009
CT = 0.18 F or 180 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 just like resistance (R). The capacitive reactance can be calculated. More on this in tuned circuits.

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

$$X_C = \frac{1}{2\pi f C}$$

X_C = Capacitive reactance in Ohms
f = frequency in hertz (Hz)
C = capacitance in Farads
π = 3.141

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.

Inductors

An inductor usually is made of insulated wire wound into a coil. Sometimes called a coil, choke, or reactor. The inductor energy in a magnetic field when electric current flows through it.
The inductance (L) of the device is measured in Henries (H). An inductor inhibits AC current.

The inductance of a coil depends on several factors.

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

For information only

$$H = \frac{0.4\ x\ \pi\ x\ N\ x\ I}{\varepsilon}$$

H = inductance in Henries
π = Pi = 3.141
N = number of turns
I = Current in amperes
Ɛ = mean magnetic path length in cm.

Example: Coil with 20 turns, 0.5 A and length of 5 cm, what is the inductance?
H = (0.4 x 3.141 x 20 x 0.5) / 5
H = 12.564 / 5
H = 2.51 H

Energy

The energy stored in an inductor is measured in Joules.

$$W = \frac{I^2\ x\ L}{2}$$

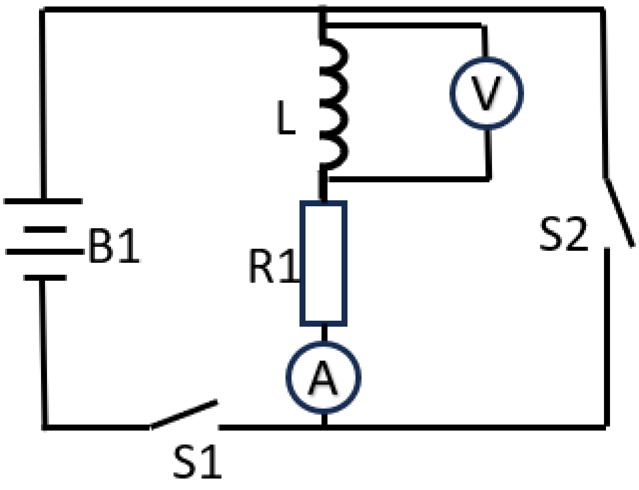
W = Energy in Joules
I = current in amperes
L = inductance in Henries

Example: How much energy is stored in a 5H inductor fed by 2 A,
W = ((2 x 2) x 5) / 2
W = 20 / 2
W = 10 Joules

Voltage and Current

A resistor is used to control the current flow when charging and discharging an inductor. The charging and discharging times for combination of the inductor and resistor can be calculated.

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, inductor appears 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.

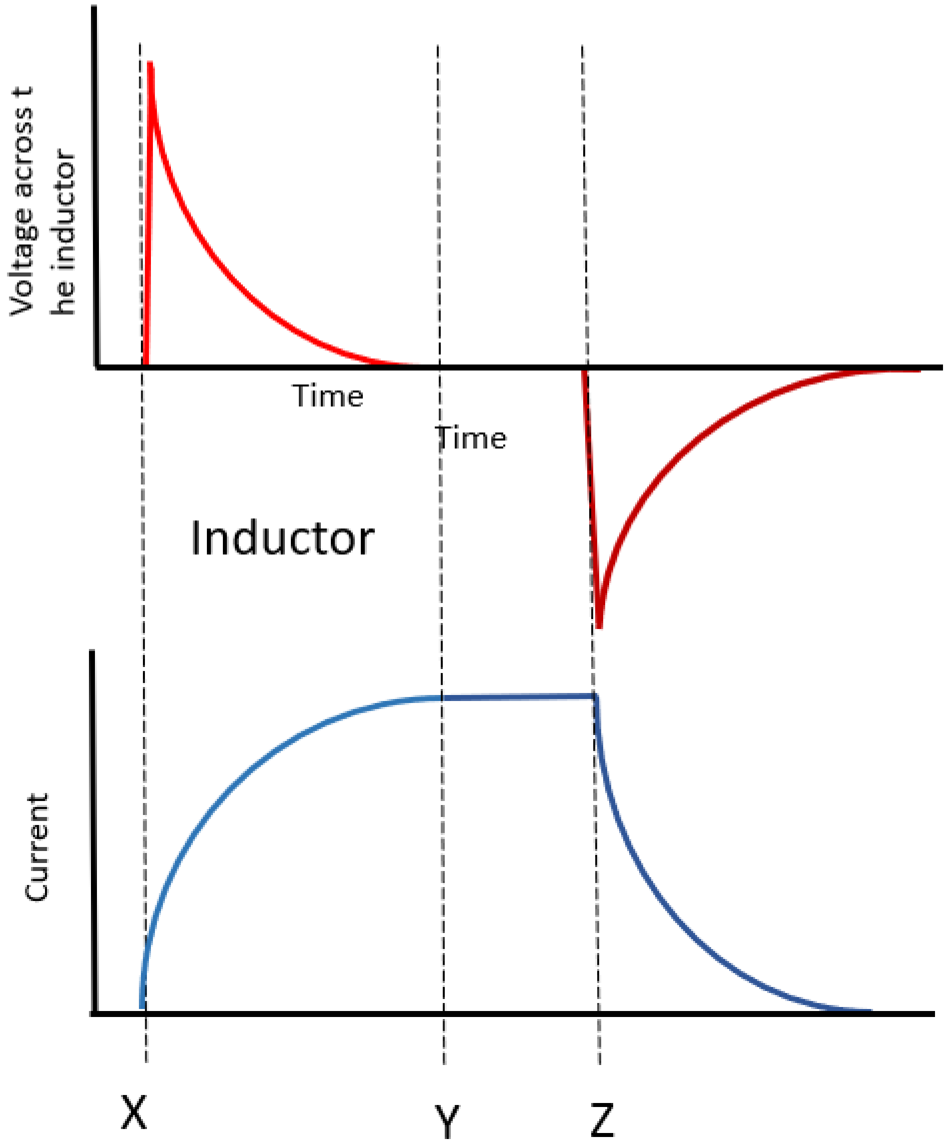
Time Y to Z

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.



Symbols

Inductor symbols are shown below.

Air core inductor

Iron core inductor

Ferrite core inductor

Variable core inductor

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
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

$$X_L = 2 \times \pi \times f \times L$$

X_L = Inductor reactance in Ohms
f = frequency in hertz (Hz)
L = Inductance in Henries
π = 3.141

Go to Lesson 6 questions.