Resistor

Energy Consuming Element

Resistor

- **Passive electric device** that **dissipates energy**
- **Resistance:** Property that opposes the flow of current
  - Symbol: **R**
  - Unit: Ohms (Ω)
  - Power Consumed $= \boldsymbol{I^2 R}$
- **Conductance**
  - Reciprocal of resistance
  - Symbol: G
  - Unit – Siemens (S)

- **Resistivity or Specific Resistance**
  - $\mathbf{R} = \frac{\boldsymbol{\rho l}}{\boldsymbol{A}}$ $\boldsymbol{\rho}$ = resistivity l = length A = cross sectional area Unit: Ohm-meter
  - The factor in the resistance which takes into account the **nature of the material**
  - It is **temperature dependent**
  - The inverse of resistivity is called **conductivity, denoted by σ**

Effect of Temperature on Resistance

Metallic conductors (Example: Cu, Al)	If temperature is increased resistance increases	Positive temperature coefficient of resistance
Electrolytes, insulators (Example: glass, mica, rubber), **and semiconductors**	Resistance decreases with the increase in temperature	Negative temperature coefficient of resistance

- At temperature T_1, resistance is R_1
- Temperature is increased from T_1 to T_2, resistance becomes R_2
- Then, $\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$
- The constant α is known as **temperature coefficient of resistance**
- Unit: 1 / ^{o}C
- Defined as increase in resistance per unit original resistance per unit rise in temperature
- **Resistivity of metallic conductors also increases with the rise in temperature and vice-versa**

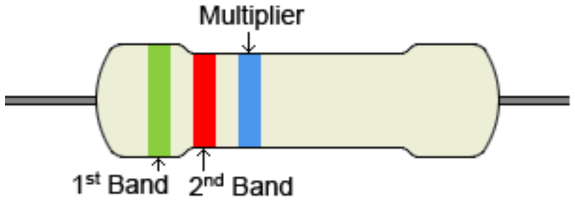
Effect of Temperature on Resistance

Typical Values of Electrical Resistivity (In Ohm-Meters) at 20^oC	
Aluminium	2.8×10^{-8}
Copper	1.7×10^{-8}
Gold	2.4×10^{-8}
Carbon (Graphite)	1×10^{-5}
Iron	1.0×10^{-7}
Nickel	7×10^{-8}
Silicon	6.4×10^{2}
Quartz	7×10^{17}

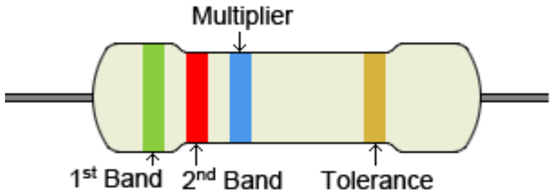
Temperature Coefficient of Resistance / ^0C (at 20^0 C)	
Aluminium	0.00429
Copper	0.00386
Gold	0.0034
Carbon (Graphite)	– 0 .0005
Iron	0.00651
Nickel	0.00641
Silicon	– 0.07
Quartz	

Resistor Value Determination

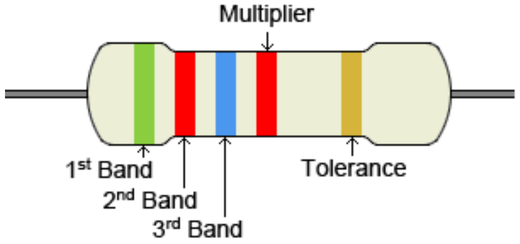
Ohm value and tolerance based on resistor color codes



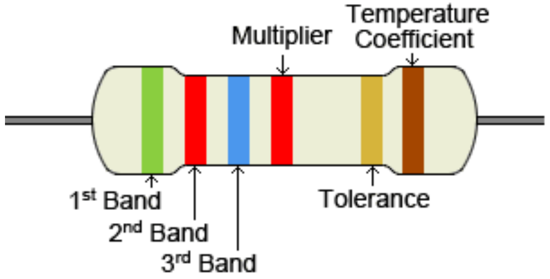
Color	1st, 2nd Band Significant Figures	Multiplier
Black	0	× 1
Brown	1	× 10
Red	2	× 100
Orange	3	× 1K
Yellow	4	× 10K
Green	5	× 100K
Blue	6	× 1M
Violet	7	× 10M
Grey	8	× 100M
White	9	× 1G
Gold		× 0.1
Silver		× 0.01



Color	1st, 2nd Band Significant Figures	Multiplier	Tolerance
Black	0	× 1	
Brown	1	× 10	±1% (F)
Red	2	× 100	±2% (G)
Orange	3	× 1K	±0.05% (W)
Yellow	4	× 10K	±0.02% (P)
Green	5	× 100K	±0.5% (D)
Blue	6	× 1M	±0.25% (C)
Violet	7	× 10M	±0.1% (B)
Grey	8	× 100M	±0.01% (L)
White	9	× 1G	
Gold		× 0.1	±5% (J)
Silver		× 0.01	±10% (K)



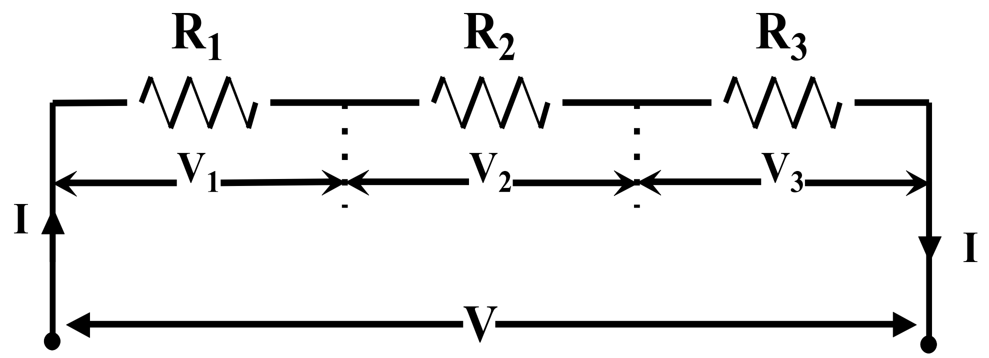
Color	1st, 2nd, 3rd Band Significant Figures	Multiplier	Tolerance
Black	0	× 1	
Brown	1	× 10	±1% (F)
Red	2	× 100	±2% (G)
Orange	3	× 1K	±0.05% (W)
Yellow	4	× 10K	±0.02% (P)
Green	5	× 100K	±0.5% (D)
Blue	6	× 1M	±0.25% (C)
Violet	7	× 10M	±0.1% (B)
Grey	8	× 100M	±0.01% (L)
White	9	× 1G	
Gold		× 0.1	±5% (J)
Silver		× 0.01	±10% (K)



Color	1st, 2nd, 3rd Band	Multiplier	Tolerance	Temperature Coefficient
Black	0	× 1		250 ppm/K(U)
Brown	1	× 10	±1% (F)	100 ppm/K(S)
Red	2	× 100	±2% (G)	50 ppm/K (R)
Orange	3	× 1K	±0.05%(W)	15 ppm/K (P)
Yellow	4	× 10K	±0.02%(P)	25 ppm/K (Q)
Green	5	× 100K	±0.5% (D)	20 ppm/K (Z)
Blue	6	× 1M	±0.25%(C)	10 ppm/K (Z)
Violet	7	× 10M	±0.1% (B)	5 ppm/K (M)
Grey	8	× 100M	±0.01% (L)	1 ppm/K (K)
White	9	× 1G		
Gold		× 0.1	±5% (J)	
Silver		× 0.01	±10% (K)	

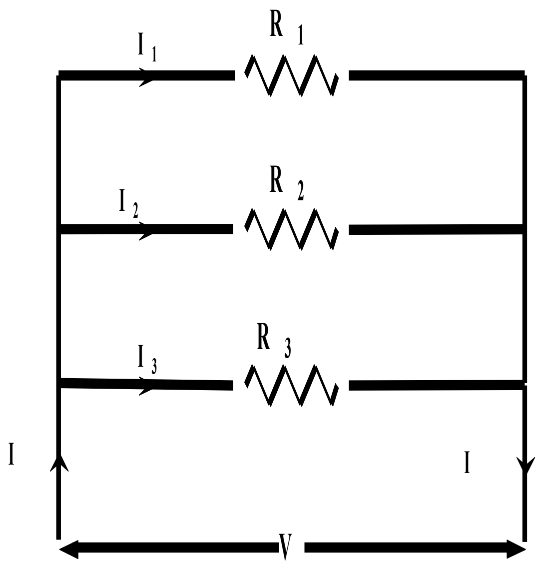
Resistors

Series connection of Resistors



- Current (I) in the all the resistors remains same
- $V = V_1 + V_2 + V_3$
- $R_{eq} = R_1 + R_2 + R_3$

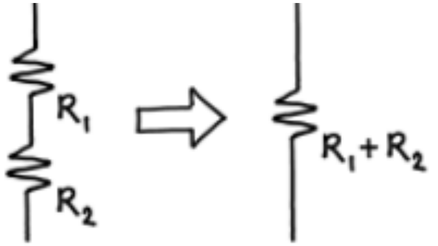
Parallel connection of Resistors



- Voltage (V) is same
- $I = I_1 + I_2 + I_3$
- $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Resistors – Voltage and Current Division

Series Resistors

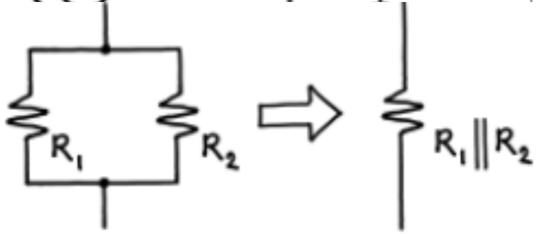


$$\text{Equivalent resistance} = R_1 + R_2$$

Voltage Divider

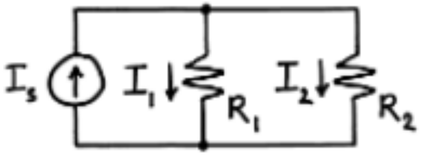
$$V_1 = \frac{R_1}{R_1 + R_2} V_s \qquad V_2 = \frac{R_2}{R_1 + R_2} V_s$$

Parallel Resistors



$$\text{Equivalent resistance} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Current Divider



$$I_1 = \frac{R_2}{R_1 + R_2} I_s \qquad I_2 = \frac{R_1}{R_1 + R_2} I_s$$

Inductor

Energy Storage Element

Inductor

- **Passive** electric device that **stores energy in its magnetic field** when current flows through it.

Inductance (also known as Self-Inductance, Unit: Henry or H)

- The property of a coil that opposes any change in the amount of current flowing through it.
- This property is due to the self-induced emf in the coil itself by the changing current.
- Self-inductance does not prevent the current from changing, it serves only to delay the change.

$$e = -N\frac{d\phi}{dt} = -N\frac{d\phi}{di}\cdot\frac{di}{dt} = -L\frac{di}{dt}$$

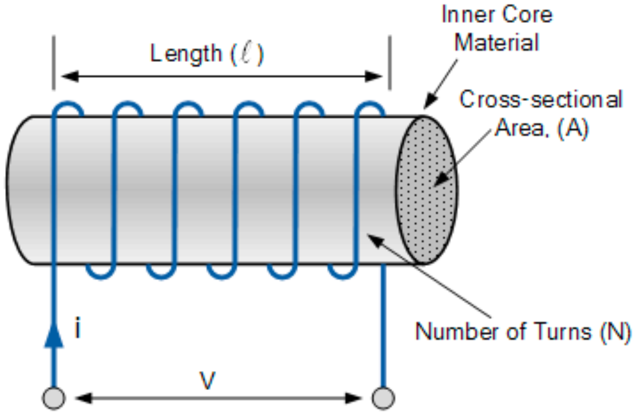
$$L = N\frac{d\phi}{di}$$

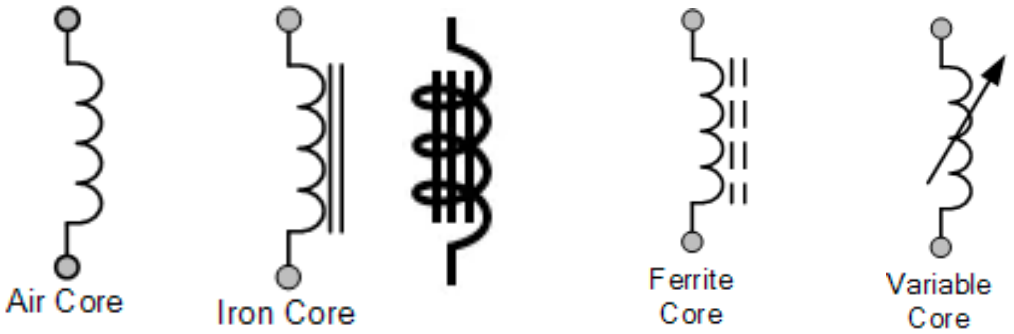
- The greater the self-induced emf, the greater the self-inductance of the coil and hence larger is the opposition to the changing current.
- Inductance of the coil depends upon: Shape and number of turns, relative permeability (μ_r) of the material surrounding the coil, and the speed at which the magnetic field changes

(i) $\mathbf{e = L\frac{di}{dt}}$ (ii) $N\,\phi = L\,I$ (iii) $\mathbf{L = \frac{N^2}{Reluctance} = \frac{N^2\mu_0\,\mu_r\,A}{l}}$

Inductor

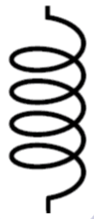
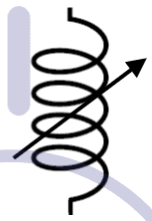
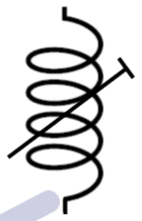
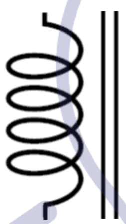
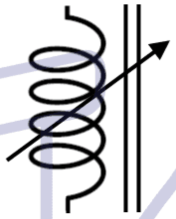
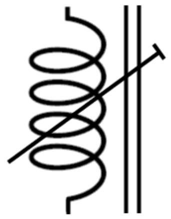
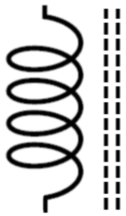
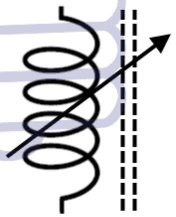
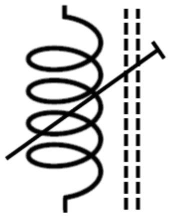
Types of Inductors	
Air-core inductor (fixed inductor)	- **Linear B-H curve, so L is the same no matter what current is in the coil.** - Since μ_r of air is 1, the values of L obtained are very low
Iron-core inductor (variable inductor)	- **Ferromagnetic core** - Provides much higher value of L (as μ_r of ferromagnetic material is very large) - **B-H curve is not linear, so inductance will vary with current.**
Practical Inductor	- All inductors are coil that have some winding resistance.





Practical Inductor

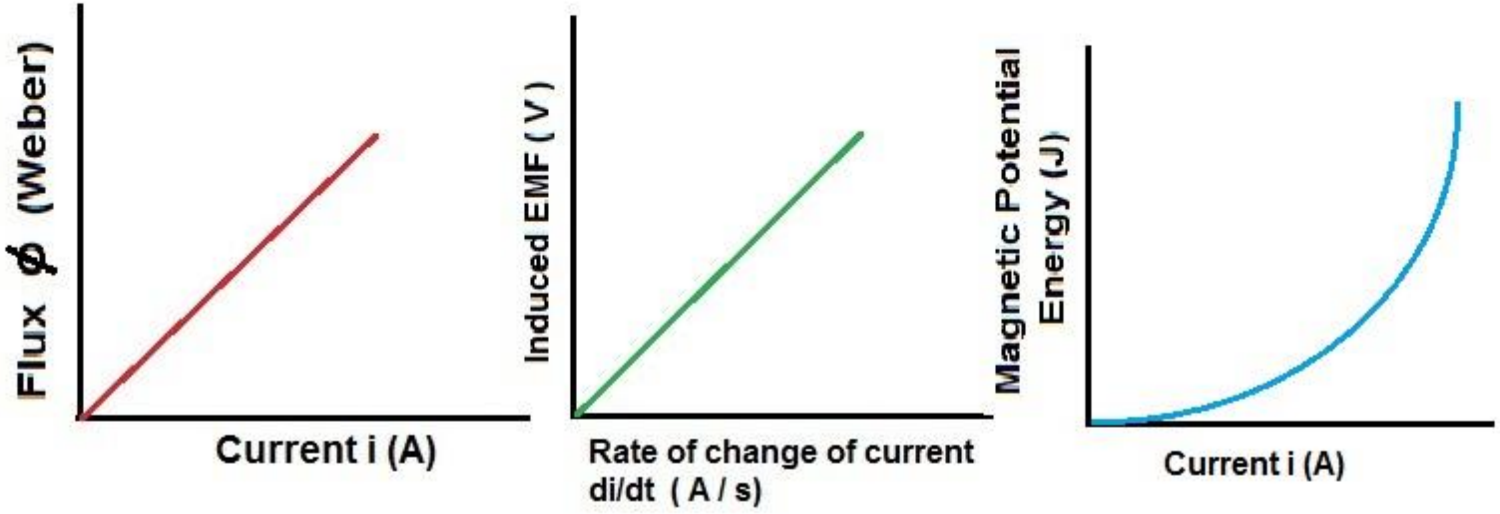
Inductor

Inductor	Fixed	Variable	Pre-set	Shape
Air Core				
Iron Core				
Ferrite Core				

Energy Stored in an Inductor

- Instantaneous power,

$$\mathbf{p = \ v_L . i = L\, i \frac{di}{dt}}$$



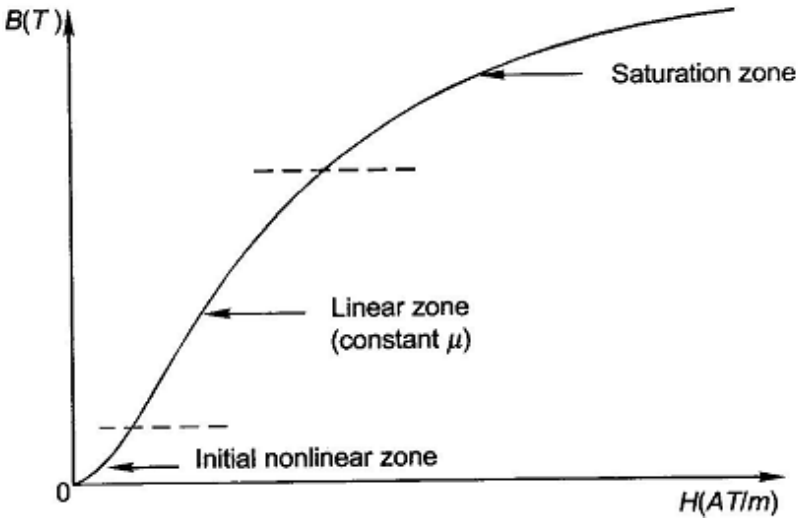
- Energy absorbed in '$\mathbf{dt}$' time is

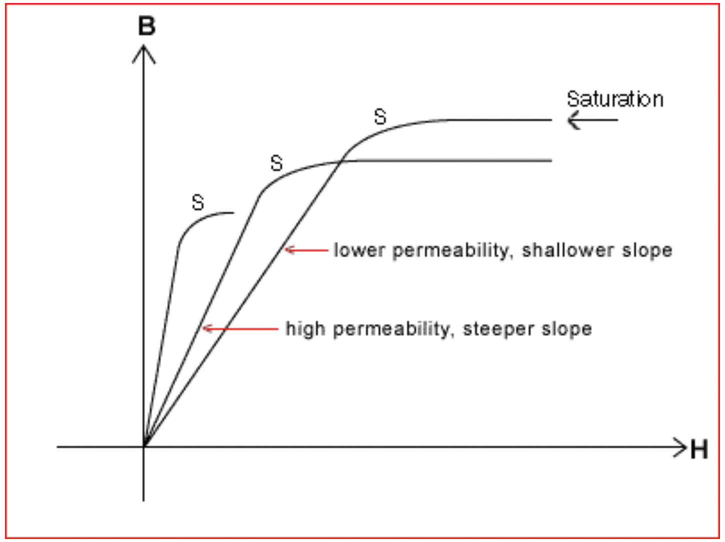
$$\mathbf{dw = L\, i\, di}$$

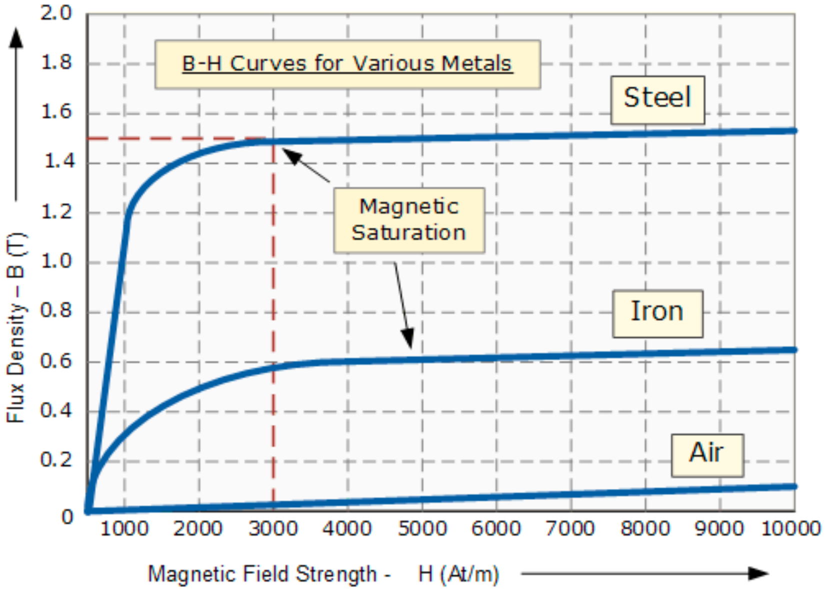
- Energy absorbed by the magnetic field when current increases from $\mathbf{0}$ to $\mathbf{I}$ amperes, is

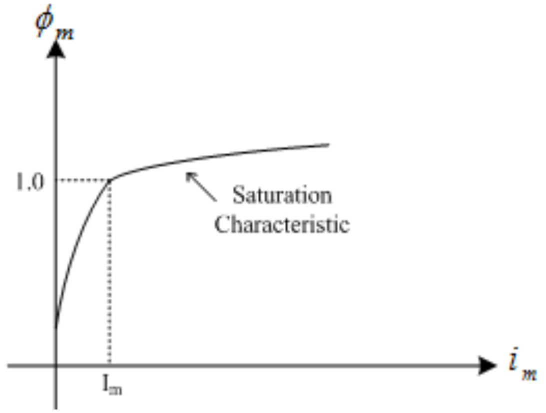
$$\mathbf{W = \ \int_0^I L\, i\, di = \frac{1}{2} L\, I^2}$$

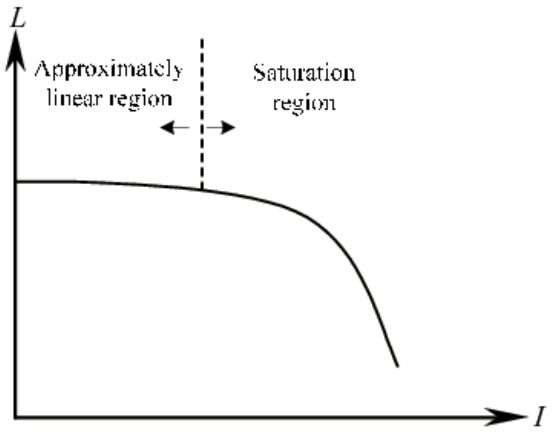
Inductance and Saturation Current







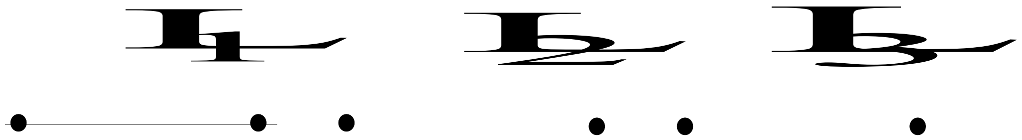




Equivalent Inductance

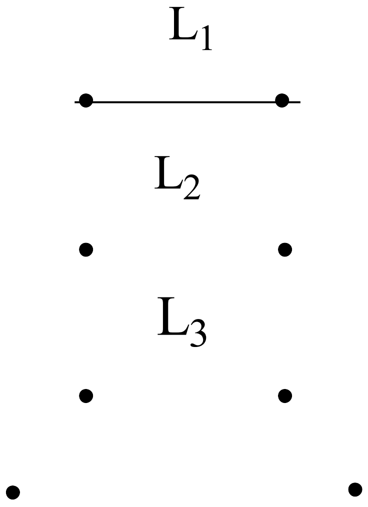
Inductors in series

$$\mathbf{L_{eq} = L_1 + L_2 + \ldots\ldots + L_n}$$



Inductors in Parallel

$$\mathbf{\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots\ldots. + \frac{1}{L_n}}$$



Capacitor

Energy Storing Element

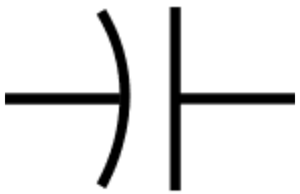
Capacitors

- **Passive electric device** that **stores energy in the electric field** between a pair of closely spaced conductors

- **Capacitance**: Property which opposes the rate of change of voltage
  - Symbol: **C**
  - Unit: Farad (F)

- The capacitive current is proportional to the rate of change of voltage across it

$$\mathbf{i_c = C\frac{dv_c}{dt}}$$



- Charge stored in a capacitor whose plates are maintained at constant voltage:

$$\mathbf{Q = CV}$$

Terminologies

- Electric field strength,

$$\mathbf{E} = \frac{\mathbf{V}}{\mathbf{d}} \ \mathbf{volts/m}$$

- Electric flux density,

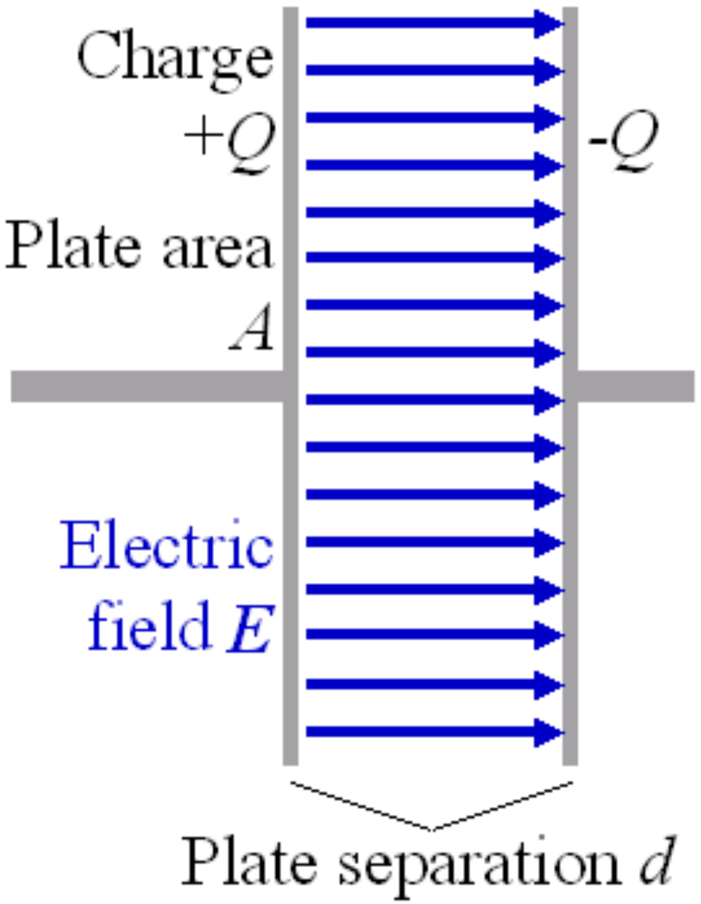
$$\mathbf{D} = \frac{\mathbf{Q}}{\mathbf{A}} \ \mathbf{C/m^2}$$

- Permittivity of free space,

$$\boldsymbol{\varepsilon_0} = \mathbf{8.854 \times 10^{-12} \ F/m}$$

- Relative permittivity, $\boldsymbol{\varepsilon_r}$
- Capacitance of parallel plate capacitor

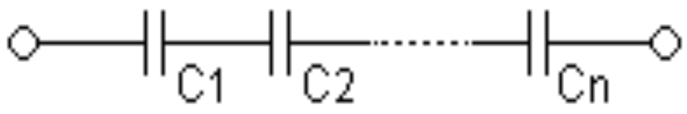
$$\mathbf{C} = \frac{\boldsymbol{\varepsilon_0 \varepsilon_r} \mathbf{A}}{\mathbf{d}}$$



Equivalent Capacitance

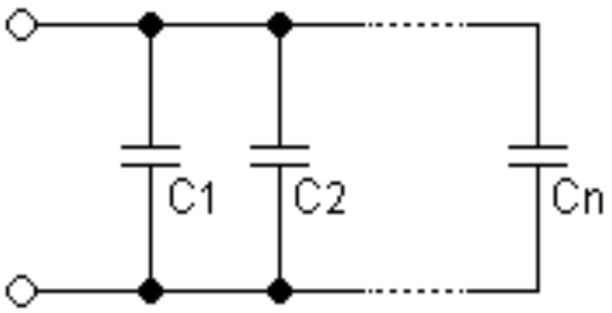
Capacitors in Series

$$\frac{1}{C_{eq}} = \frac{1}{C1} + \frac{1}{C2} + \ \ldots \ldots + \frac{1}{Cn}$$



Capacitors in Parallel

$$C_{eq} = C_1 + C_2 + \ \ldots\ldots + C_n$$



Energy stored in a Capacitor

- Instantaneous power

$$\mathbf{p = \ v_c \ \times i = C\, v_c \frac{dv_c}{dt}}$$

- Energy supplied during '$\mathbf{dt}$' time is:

$$\mathbf{dw = C\, v_c\, dv_c}$$

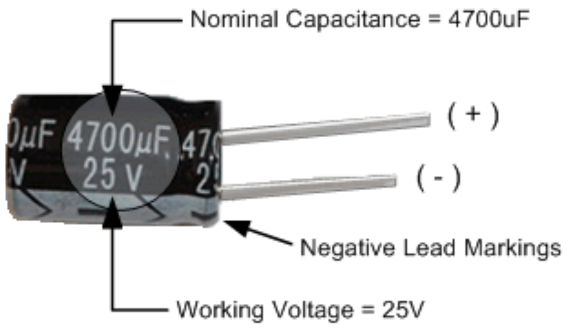
- Energy stored in the electric field when potential rises from $\mathbf{0}$ to $\mathbf{V}$ volts is,

$$\mathbf{W = \ \int_0^V C\, v_c dv_c = \frac{1}{2} CV^2 \ \ Joules}$$

Types of Capacitors and their Applications

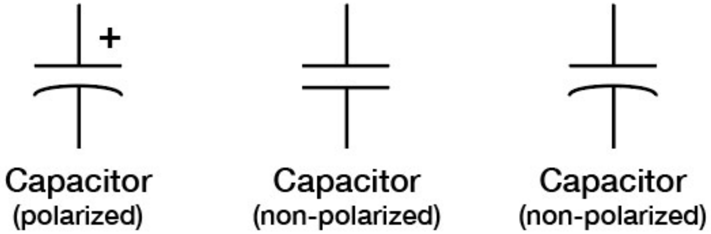
Electrolytic Capacitor

- Used when large capacitor values are required
- Used generally in the DC power supply circuit
- Typical values ranges from 1 μF up to 47,000 μF



Mica Capacitor

- Mica is the dielectric material
- A stable, reliable, low loss capacitor of small value
- Used in high-frequency applications
- Typical values: under 100 nF



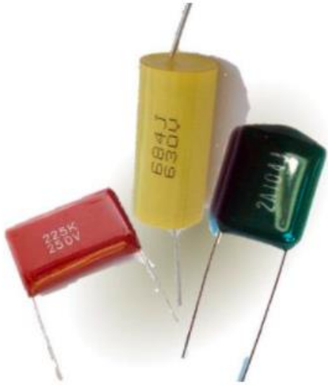
Paper Capacitor

- Typical values: Ranges from 0.001 to 2 μF
- Used in electronic noise filtering, signal processing applications, etc.

Types of Capacitors and their Applications

Film Capacitor

- Thin plastic is used as dielectric material
- It is heat resistant and used in aerospace and military technology
- Typical values: ranging from 1 nF to 30 μF



Ceramic Capacitor

- Ceramic is used as dielectric material
- Applications: Power circuit breakers, induction furnaces, also printed circuit boards in electronics
- Typical values: ranging from 1 nF to 1 μF

Non-Polarized Capacitor

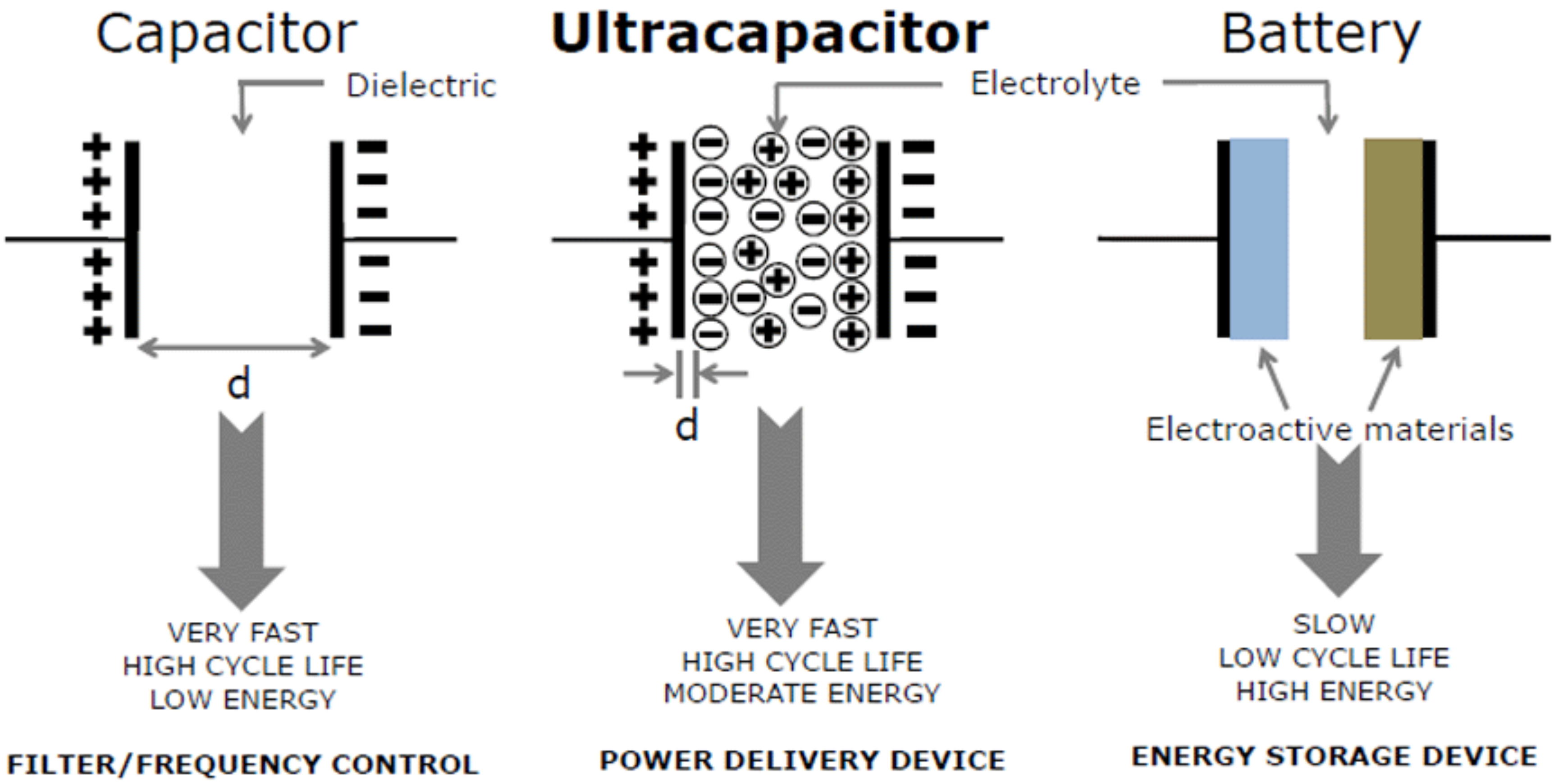
- It can be of two types: plastic foil or electrolytic.
- Used in AC applications with signal or power supply
- Typical values ranges from 1 μF up to 47,000 μF

Types of Capacitors and their Applications

Ultracapacitor (Also known as Supercapacitor or Electrochemical Capacitor)

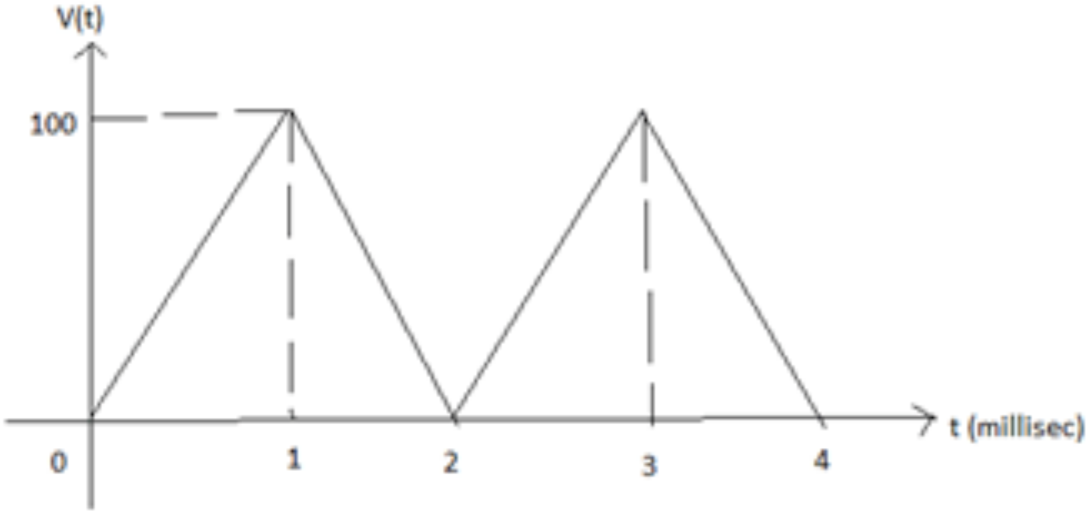
- Store energy electrostatically
- Much higher energy storage density (high-capacity capacitor) than a normal capacitor
- Can release energy much quicker than the battery and can be used many times over without degradation
- Possess high energy density, short charging cycle, and a wide range of operating temperatures
- Applications: Ranges from large-scale energy storage to small portable/wearable watches
- Has the potential to replace or augment battery and fuel cell systems in many areas of technology
- Rated in Farads - typically be found in the 100 F to 500 F range (individual cells)

Capacitor Vs Supercapacitor Vs Battery



Exercise 1

The following voltage is applied to a capacitor of **50 µF.** Determine the current for **0 – 1 ms** duration.



A) - 5 A

B) 5 mA

C) 5 A

D) 1 A

Hint: $i_c = C\frac{dV_c}{dt}$

Ans: 5 A

Exercise 2

A **100 mH** inductor is supplied with a voltage of $\mathbf{v(t) = 25\ e^{-5t}\ V}$. Determine the inductor current.

Hint: $i_L = \frac{1}{L}\int_0^t v\,dt$

Ans: - 50 e^{-5t} A