Passive Components

W. Bolton, “Mechatronics --- Electronic control systems in mechanical and electrical engineering,” 5th edition, Pearson Education Limited 2012
J. Edward Carryer, R. Matthew Ohline, Thomas W. Kenny, “Introduction to Mechatronic Design,” Prentice Hall 2011, Chap 9
線上學習網站：https://www.electronics-tutorials.ws
PowerPoint 中部分圖片擷取和修改自教科書和網路圖片

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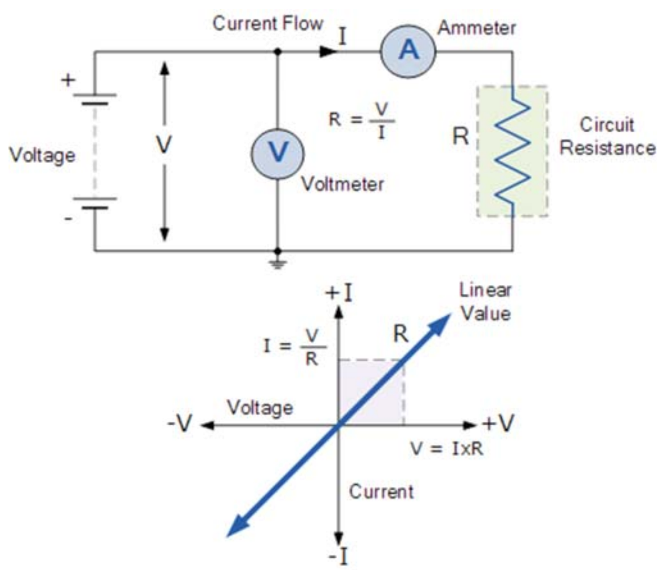
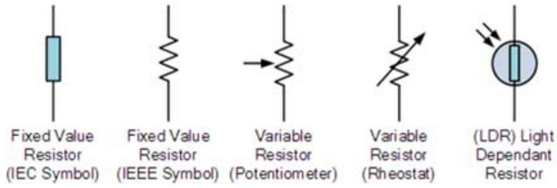
Resistor -1

- Description
  - Resistance: the capacity of a material to resist or prevent the flow of current or, more specifically, the flow of electric charge within a circuit
  - Conductance: representing the ability of a conductor or device to conduct electricity

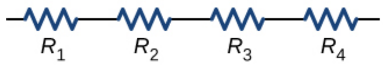


Resistor -2

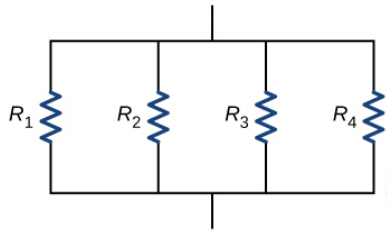
- Ideal resistor
  - Symbol:



  - Ohm's Law, $V = IR$
  - Unit: ohm ($\Omega = \frac{C}{s}$)
  - Power dissipation: $\mathrm{P} = \frac{V^2}{R} = I^2R$
  - In series: $R_{series} = \sum_{k=1}^{n} R_k$

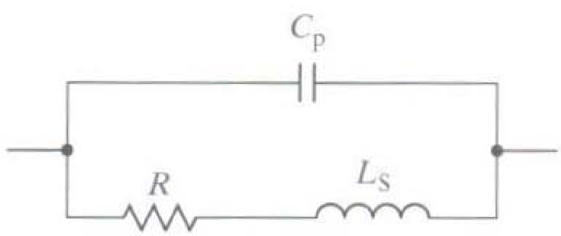


  - In parallel: $R_{parallel} = \frac{1}{\sum_{k=1}^{n}\frac{1}{R_k}}$



Resistor -3

- Real resistor
  - A more representative model
    - C_p: Negligible for general mechatronics system; non-negligible in high-frequency circuits (>1GHz)
    - L_s: Negligible in carbon or film resistors; pay attention to this inductance when using wirewound resistors



Resistor -4

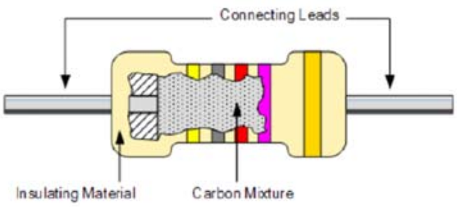
- Characteristics
  - Resistance
  - Power
  - Physical size (i.e. Package)
  - Tolerance (precision): it does not make sense to add small resistors to large resistors in hopes of achieving higher precision
  - Temperature coefficient
  - Voltage coefficient
  - Noise
  - Frequency response
  - Temperature rating
  - Reliability

Resistor -5

- E series resistors and their values
  - EX: Having X values in each decade
  - E6 values (20% tolerance)
    - 1.0, 1.5, 2.2, 3.3, 4.7, 6.8
  - E12 values (10% tolerance)
    - 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2
  - E24 values (5% tolerance)
    - 1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1
  - E48 values (2% tolerance) - different set of values
    - 1.00, 1.05, 1.10, 1.15, 1.21, 1.27, 1.33, 1.40, 1.47, 1.54, 1.62, 1.69, 1.78, 1.87, 1.96, 2.05, 2.15, 2.26, 2.37, 2.49, 2.61, 2.74, 2.87, 3.01, 3.16, 3.32, 3.48, 3.65, 3.83, 4.02, 4.22, 4.42, 4.64, 4.87, 5.11, 5.36, 5.62, 5.90, 6.19, 6.49, 6.81, 7.15, 7.50, 7.87, 8.25, 8.66, 9.09, 9.53

Resistor -6

- Types of resistors
  - Carbon resistor: a cheap general purpose resistor
    - Generally prefixed with a "CR" notation (eg, CR10kΩ)
    - Available in E6 (± 20% tolerance), E12 (±10% tolerance) and E24 (± 5% tolerance) packages
    - Power ratings: 1/4 Watt up to 5 Watts



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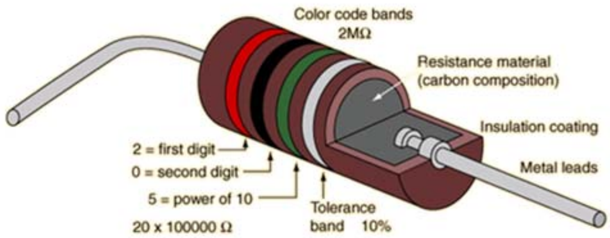
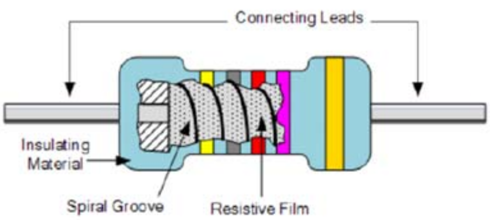


Resistor -7

- Types of resistors
  - Film resistor: generally made by depositing pure metals onto an insulating ceramic rod or substrate
    - Types: metal film (prefixed with a "MFR"), carbon film (prefixed with a "CR") and metal oxide film
    - Available in E24 (±5% tolerance), E48 (±2% tolerance), E96 (±1% tolerance) and E192 (±0.5%, ±0.25% & ±0.1% tolerances)
    - Power ratings: 1/20 Watt up to 1/2 Watt



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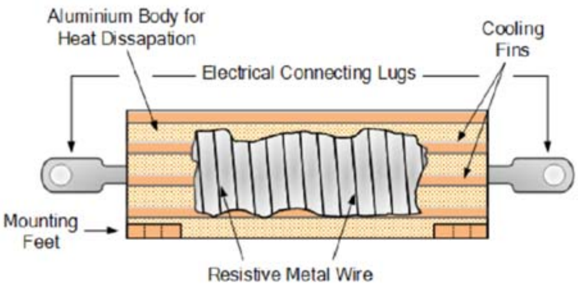
Resistor -8

- Types of resistors
  - Wirewound Resistor: winding a thin metal alloy wire onto an insulating ceramic former in the form of a spiral helix
  - Only available in very low ohmic high precision values (from 0.01Ω to 100kΩ)





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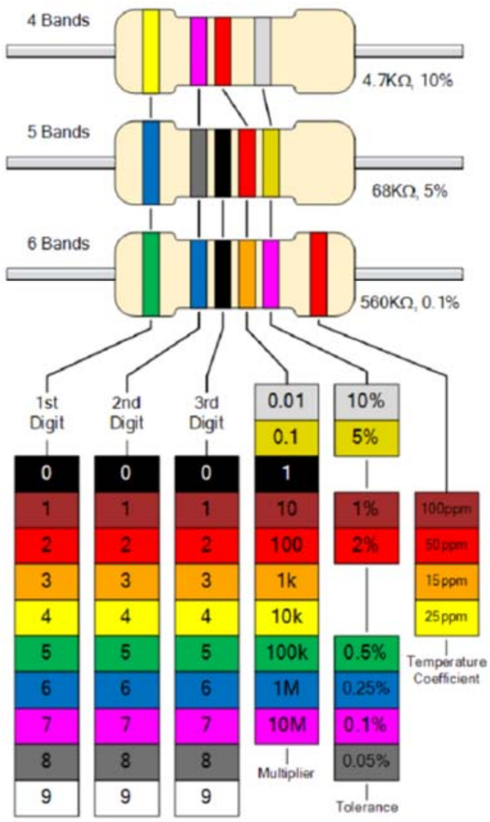
Resistor -9

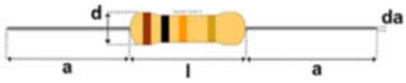
- Color code
  - Yellow Violet Red $= 4.7\ k\Omega$

Colour	Digit	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1%
Red	2	100	± 2%
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	± 0.5%
Blue	6	1,000,000	± 0.25%
Violet	7	10,000,000	± 0.1%
Grey	8		± 0.05%
White	9		
Gold		0.1	± 5%
Silver		0.01	± 10%
None			± 20%



Resistor -10

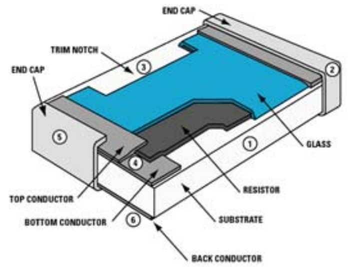
- Sizes & package



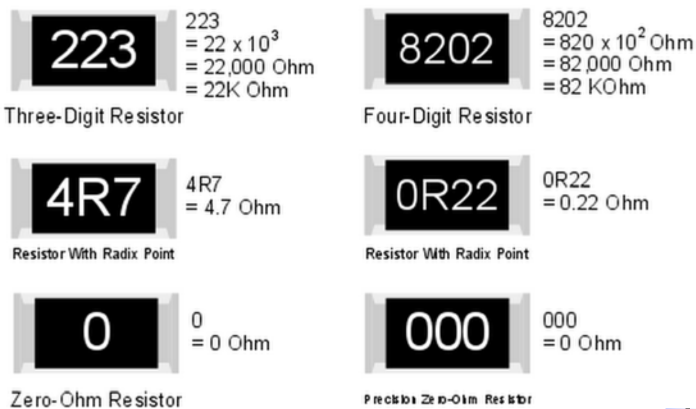
Power rating	Body length (l)	Body diameter (d)	Lead length (a)	Lead diameter (da)
Watt	mm	mm	mm	mm
1/8 (0.125)	3.0 ± 0.3	1.8 ± 0.3	28 ± 3	0.45 ± 0.05
1/4 (0.25)	6.5 ± 0.5	2.5 ± 0.3	28 ± 3	0.6 ± 0.05
1/2 (0.5)	8.5 ± 0.5	3.2 ± 0.3	28 ± 3	0.6 ± 0.05
1	11 ± 1	5 ± 0.5	28 ± 3	0.8 ± 0.05

Resistor -11

- Surface mount (SMD) resistors
  - Very small rectangular shaped metal oxide film resistors designed to be soldered directly onto the surface of a circuit board
  - Highly accurate low tolerance resistors, down to 0.1%



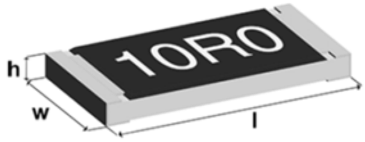
ANATOMY OF A HIGH RELIABILITY THICK FILM CHIP RESISTOR



shorting link

Resistor -12

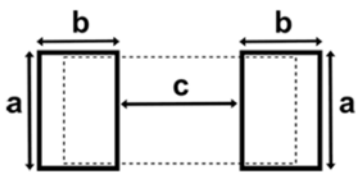
- Sizes & package



Code		Length (l)		Width (w)		Height (h)		Power
Imperial	Metric	inch	mm	inch	mm	inch	mm	Watt
0201	0603	0.024	0.6	0.012	0.3	0.01	0.25	1/20 (0.05)
0402	1005	0.04	1.0	0.02	0.5	0.014	0.35	1/16 (0.062)
0603	1608	0.06	1.55	0.03	0.85	0.018	0.45	1/10 (0.10)
0805	2012	0.08	2.0	0.05	1.2	0.018	0.45	1/8 (0.125)
1206	3216	0.12	3.2	0.06	1.6	0.022	0.55	1/4 (0.25)
1210	3225	0.12	3.2	0.10	2.5	0.022	0.55	1/2 (0.50)
1218	3246	0.12	3.2	0.18	4.6	0.022	0.55	1
2010	5025	0.20	5.0	0.10	2.5	0.024	0.6	3/4 (0.75)
2512	6332	0.25	6.3	0.12	3.2	0.024	0.6	1

Resistor -13

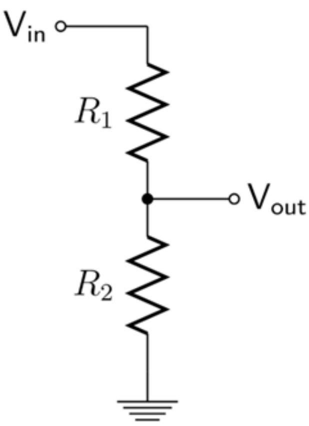
- Sizes & package

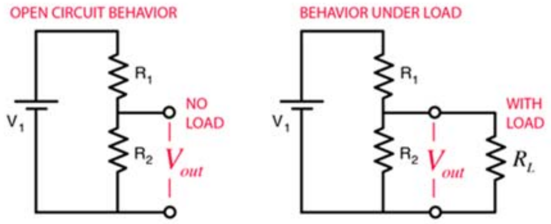


Code		Pad length (a)		Pad width (b)		Gap (c)		Power
Imperial	Metric	inch	mm	inch	mm	inch	mm	Watt
0201	0603	0.012	0.3	0.012	0.3	0.012	0.3	1/20 (0.05)
0402	1005	0.024	0.6	0.020	0.5	0.020	0.5	1/16 (0.062)
0603	1608	0.035	0.9	0.024	0.6	0.035	0.9	1/10 (0.10)
0805	2012	0.051	1.3	0.028	0.7	0.047	1.2	1/8 (0.125)
1206	3216	0.063	1.6	0.035	0.9	0.079	2.0	1/4 (0.25)
1218	3246	0.19	4.8	0.035	0.9	0.079	2.0	1/2 (0.50)
2010	5025	0.11	2.8	0.059	0.9	0.15	3.8	1
2512	6332	0.14	3.5	0.063	1.6	0.15	3.8	3/4 (0.75)
2512	6332	0.25	6.3	0.12	3.2	0.024	0.6	1

Resistor -14

- Voltage divider





$$V_{out} = V_1 \frac{IR_2}{I(R_1+R_2)} = \frac{V_1R_2}{(R_1+R_2)}$$

OUTPUT VOLTAGE UNDER "NO LOAD" CONDITION (open circuit)

OUTPUT VOLTAGE UNDER LOAD

$$V_{out} = V_1 \frac{IR_2}{I(R_1+R_2)} = \frac{V_1(R_2 \parallel R_L)}{(R_1+R_2 \parallel R_L)}$$

$$V_{out} = \frac{R_2(i_{in} - i_{out})}{R_1 i_{in} + R_2(i_{in} - i_{out})} V_{in}$$

$$if\ i_{out} \to 0, \qquad V_{out} \to \frac{R_2}{R_1+R_2} V_{in}$$

Resistor -15

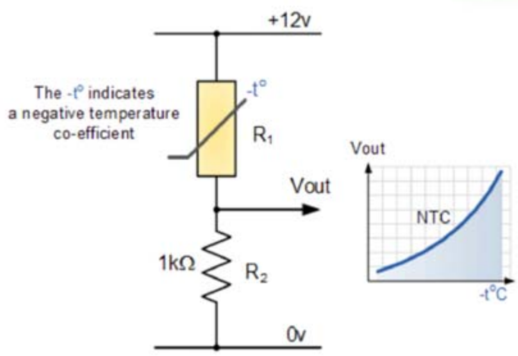
- Thermistor (熱敏電阻) Circuit
  - Ex: 10KΩ at 25°C and 100Ω at 100°C

    Calculate the output voltage (V_{out}) for both temperatures

$$V_{out} = \frac{R_2}{R_1+R_2} V_{in} = \frac{1k}{10k+1k} 12 = 1.09V$$

$$V_{out} = \frac{R_2}{R_1+R_2} V_{in} = \frac{1k}{100+1k} 12 = 10.9V$$

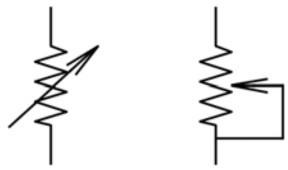
$temp \uparrow \qquad R_1 \downarrow \qquad V_{out} \uparrow$

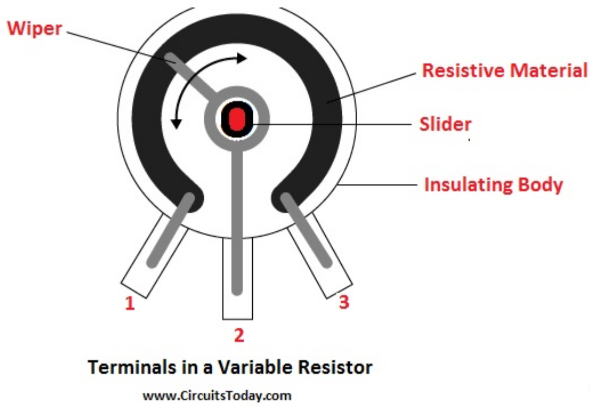


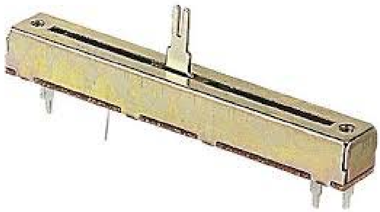
How to clamp V_{out}?

Resistor -16

- Variable resistor & potentiometer



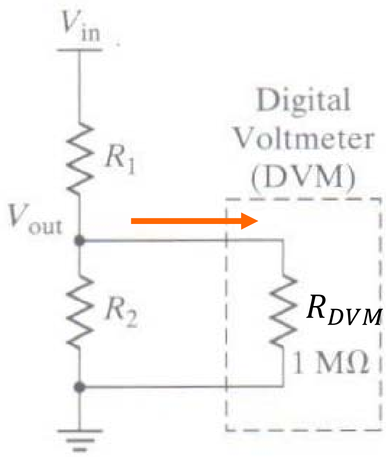




Real Measurement -1

- Voltage measurement

“loading” – need $R_{DVM} \gg R_2$ to reduce loading



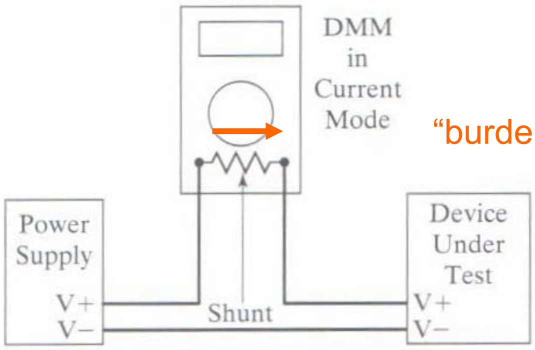
Assume $R_2 = 100k \rightarrow \frac{1}{11}$ current diverted

If $R_1 = R_2 = 100k \rightarrow V_{out} = \frac{\frac{10}{11}}{1+\frac{10}{11}} = \frac{10}{21} V_{in} = 0.476 V_{in} \rightarrow 4.8\%$ error

If $R_1 = 10R_2 = 1M \rightarrow V_{out} = \frac{\frac{10}{11}}{10+\frac{10}{11}} = \frac{1}{12} V_{in} = 0.083\ V_{in} \rightarrow 8.3\%$ error

Real Measurement -2

- Current measurement



“burden” – use shunt resistor: $m\Omega \sim \Omega$, $0.1 \sim 1\%$

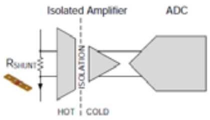


Figure 1.
Isolated Amplifier

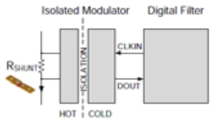


Figure 2.
Isolated Modulator

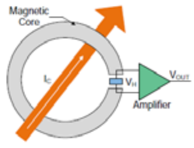


Figure 3.
Open-Loop Hall Sensor

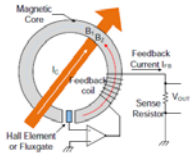


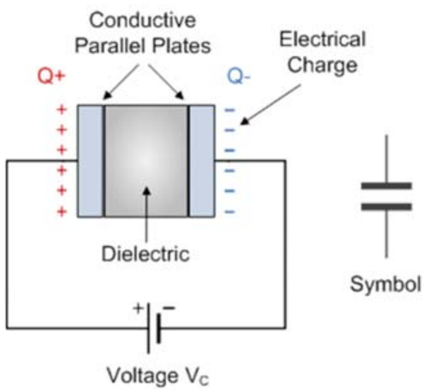
Figure 4.
Closed-Loop Hall Sensor

Table 1. Difference Between Shunt- and Hall-Based Isolated Current Sensing

CATEGORY	SHUNT-BASED	HALL-BASED
Solution size	Similar	Similar
offset	Very low	Medium
Offset drift over temperature	Low	Medium
Accuracy	<0.5% after calibration	<2% after calibration
Noise	Very low	High
Bandwidth	Similar	Similar
Latency	Similar	Similar
Nonlinearity	Very low	High
Long-term stability	Very high	Medium
Cost	Similar	Similar
Vibration impact	Very low	Low
Power dissipation	Low	Very low
Customization	Flexible	Limited

Capacitor -1

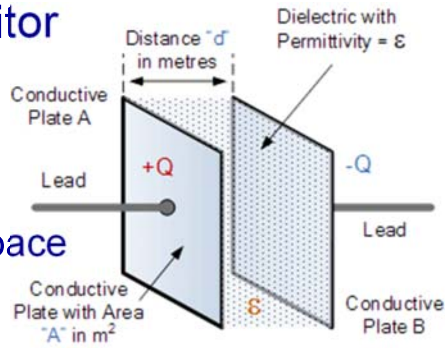
- Description
  - A component which has the ability to store energy in the form of an electrical charge producing a potential difference across its plates
  - Cannot pass an unvarying, steady current; can pass oscillating current

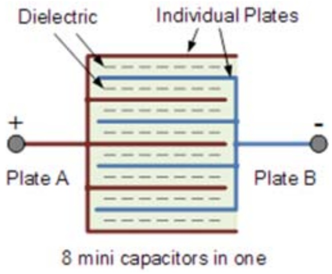


- Applications
  - Timing: transient, time constant
  - Filtering: Low-pass / high-pass filter
  - Coupling: focusing on blocking DC while passing AC
  - Bypassing / decoupling

Capacitor -2

- Capacitance of a parallel plate capacitor
  - $C = \frac{\epsilon_r \epsilon_0 A}{d}$; unit $farad(F) = \frac{Coulomb}{Volt}$
  - $\epsilon_0 = 8.85 \times 10^{-12} \frac{F}{m}$: permittivity of free space
  - ϵ_r: relative permittivity
    - $\epsilon = 1$ pure vacuum; $\epsilon = 1.0006$ in air
  - If n plates, $C = \frac{\epsilon_r \epsilon_0 (n-1) A}{d}$



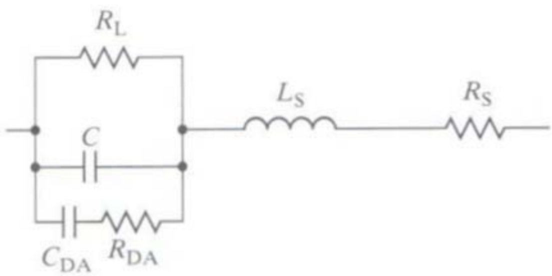


Capacitor -3

- Ideal capacitor
  - $v(t) = \frac{1}{C}\int_0^t i(\tau)d\tau = \frac{Q(t)}{C}$; $i(t) = C\frac{dv(t)}{dt}$
  - Capacitance C; unit $farad(F) = \frac{Coulomb}{Volt}$
    - $F, \mu F, nF, pF$
  - $E_c = \int Pdt = \int vidt = \int vC\frac{dv}{dt}dt = \int vCdv = \frac{1}{2}Cv^2$
  - In series $C_{series} = \frac{1}{\sum_{k=1}^{n}\frac{1}{C_k}}$
  - In parallel $C_{parallel} = \sum_{k=1}^{n} C_k$

Capacitor -4

- Real capacitor
  - A more representative model for a real capacitor
    - R_S: Equivalent series resistance (ESR)
    - L_S: Equivalent series inductance (ESL)
    - R_L: A parallel resistor, serving to leak charge off the capacitor
    - R_{DA} & C: Dielectric absorption, result of a migration of charge away from the electrodes and into the dielectric material



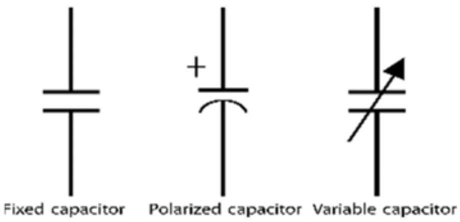
Capacitor -5

- Characteristics
  - Capacitance
    - As a general rule of thumb, never touch the leads of large value capacitors once the power supply is removed
  - Working Voltage (WV)
    - Usually referred to DC; for AC, times 1.414
  - Tolerance (±%)
  - Polarization
  - Leakage current, usually in the region of nano-amps
  - Working temperature
  - Temperature coefficient, PPM/°C
  - Equivalent series resistance (ESR)

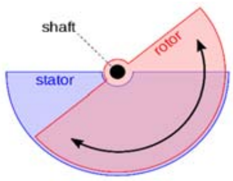
	Letter	B	C	D	F	G	J	K	M	Z
Tolerance	C <10pF ±pF	0.1	0.25	0.5	1	2				
	C >10pF ±%			0.5	1	2	5	10	20	+80 -20

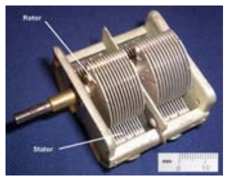
Capacitor -6

- Polar vs. nonpolar
  - Former: Using materials that require a specific electrical polarity be maintained between the two terminals of the capacitor



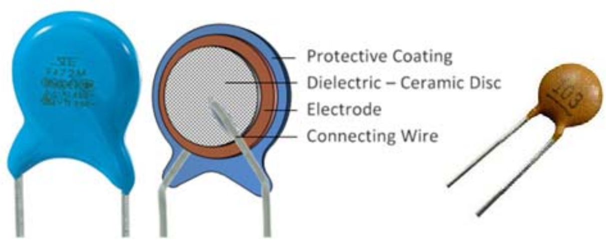
- Variable capacitor





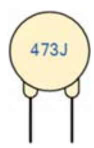
Capacitor -7

- Types of capacitors
  - Ceramic disk capacitor



    - Least expensive
    - $pF - \mu F$
    - Maintaining capacitance fro signals from low freqency to very high frequency
    - Capacitance depends on temperature / voltage
    - High part-to-part variation, up to 25%
    - Also having multi-layer ceramic (MLC) -> small package
    - Code: 154 -> $15 \times 10^4 pF = 0.15\mu F$

      473J -> $0.047\mu F \pm 5\%$



Capacitor -8

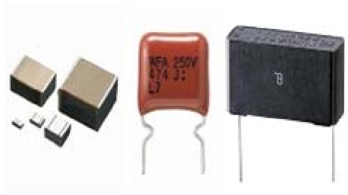
- Aluminum electrolytic capacitors
  - Aluminum 2-5nm very thin oxide on the metal's surface
    -> Easy to make large capacitance in a small package
  - $nF - mF$
  - Polarized
  - Disadvantages: large inductance, high-leakage currents (low Rc), relatively low voltage rating, temperature dependence, not good for high-frequency applications (above 20kHz), stable for one polarity only (decompose for the opposite polarity)

Capacitor -9

- Tantalum (鉭) capacitors
  - Using a thin dioxide layer to form the insulator, similar to aluminum electrolytic capacitors
  - Large permittivity -> smaller package
  - Polarized
  - Relatively low accuracy, $\pm 20\%$
  - Good performance at frequency up to 100kHz

Capacitor -10

- Film capacitors
  - Vapor depositing a metal layer onto the plastic film
  - Better accuracy, up to $\pm 1\%$
  - Low temperature coefficient, $\pm 2\%\ from\ -40℃ \sim 80℃$
  - Disadvantages: larger package, higher in cost



Inductor -1

- Description
  - A passive electrical component consisting of a coil of wire which is designed to take advantage of the relationship between magnetism and electricity as a result of an electric current passing through the coil

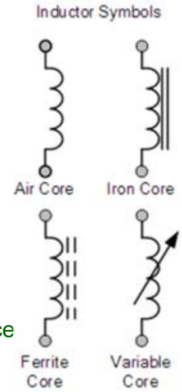
Inductor -2

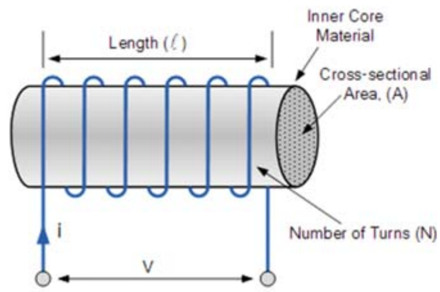
- Ideal inductor
  - Inductance (L)
    - Henry ($H = \frac{w_b}{A}$)
  - Self-inductance
    - $L = \mu_0 \frac{N^2 A}{l}$

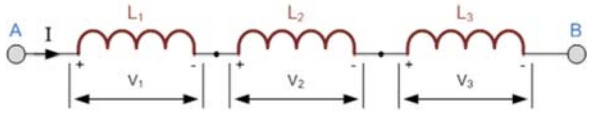
      Permeability of Free Space
      $\mu_0 = 4\pi \times 10^{-7}$
  - In series

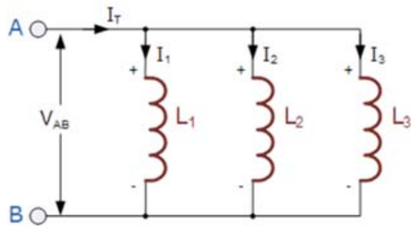
    $$L_{series} = \sum_{k=1}^{n} L_k$$
  - In parallel

    $$L_{parallel} = \frac{1}{\sum_{k=1}^{n} \frac{1}{L_k}}$$









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- Questions?