Embedded Systems Hands-On 1: Design and Implementation of Hardware/Software Systems

Electrical Engineering Brief

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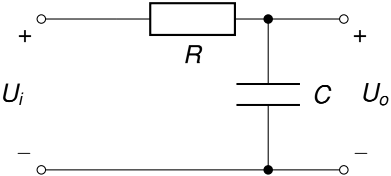


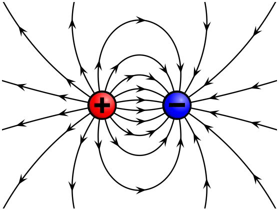
Content

- Basic terms of electrostatics
- Passive components in electronic circuits
- Semiconductors

Electric Charge

- **Q** [As] or [Coulomb]
- Multiple of elementary charge $Q = z \cdot e_0, z \in \mathbb{Z}, e_0 = 1.6 \cdot 10^{-19} As$

$$F \propto \frac{Q_1 Q_2}{r^2}$$

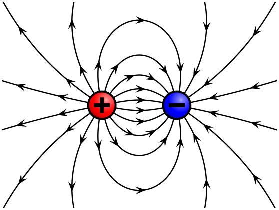


Electric Field

- Force per Charge

$$E = \frac{F_C}{q}, \left[\frac{V}{m}\right]$$

- Vectoral field quantity
- Visualized by field lines
  - Positive to negative
  - Orthogonal to surface
  - Density $\propto$ intensity



Electric Potential

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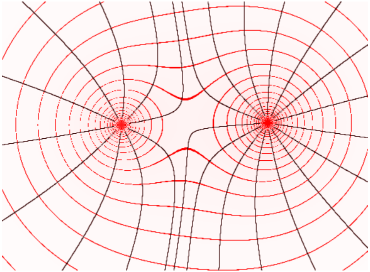
- Specific energy required to move the test charge *into* electric field

$$\varphi = \frac{W}{Q}, [V]$$

- Scalar field quantity
- Visualized by lines of equal potential



Electric Voltage

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- Specific energy required to move the test charge *inside* the electric field

$$U = \triangle\varphi, [V]$$

- Difference in potentials

Electric Capacity

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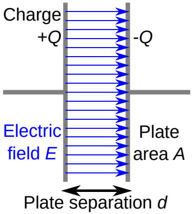
$$C = \frac{Q}{U}, \left[\frac{As}{V}\right], [F]$$

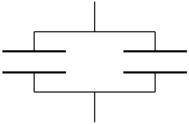


- Parallel-plate capacitor

$$C \propto \frac{A}{d}$$

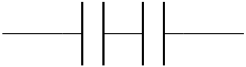
- Parallel circuit

$$C = C_1 + C_2$$



- Series circuit

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \Leftrightarrow C = \frac{C_1 C_2}{C_1 + C_2}$$



Electric Current

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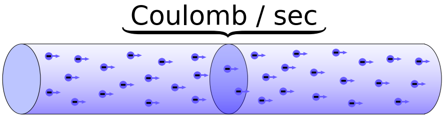
- Flow of electric charge through a region

$$I = \frac{\triangle Q}{\triangle t}, [A]$$

- Current flow: $+ \rightarrow -$
- Electron movement: $- \rightarrow +$



Electrical Resistance

- Ohm's law

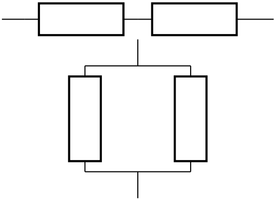
$$R = \frac{U}{I}$$

- Conductor type
  - Metallic $R \propto \sigma l A^{-1}$
  - Isolator $R \to \infty$
  - Semiconductor *non-linear*
- Series circuit

$$R = R_1 + R_2$$

- Parallel circuit

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Leftrightarrow R = \frac{R_1 R_2}{R_1 + R_2}$$



Electrical Power

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- Work done per unit time

$$P = \frac{UQ}{t} = UI$$

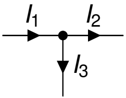
- For resistive loads

$$P = I^2 R = \frac{U^2}{R}$$

Kirchhoff's circuit laws

- Junction rule (charge conservation)

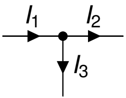
$$\sum_k I_k = 0$$



Kirchhoff's circuit laws

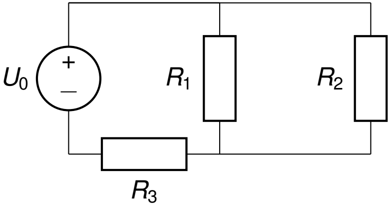
- Junction rule (charge conservation)

$$\sum_k I_k = 0$$



- Mesh rule (potential conservation)

$$\sum_k U_k = 0$$



- Mesh 1: $U_0 = U_{R1} + U_{R2}$
- Mesh 2: $U_{R1} = U_{R2}$
- Mesh 3: $U_0 = U_{R2} + U_{R3}$

Voltage divider

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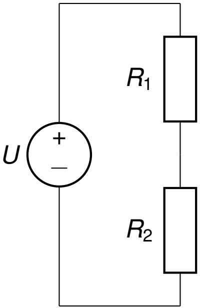
- Junction rule $I = I_{R_1} = I_{R_2}$
- Ohm's Law $U_{R_x} = R_x \cdot I_{R_x}$
- Series circuit $U = (R_1 + R_2) \cdot I$
- Mesh rule $U = U_{R_1} + U_{R_2}$

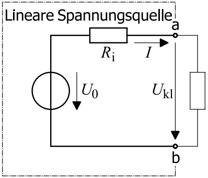


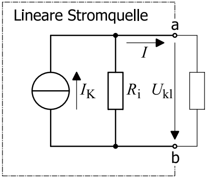
- Divider relation

$$U_{R_x} = U \frac{R_x}{R_1 + R_2}$$

Electrical sources

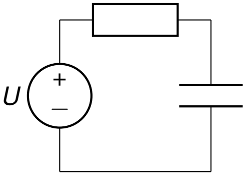
- Voltage source
  - Constant voltage, independent of current
- Current source
  - Constant current, independent of voltage
- Real world
  - Linear power supply (due to internal resistance)
  - Switched-mode power supply
- Bench power supply
  - Set voltage, limit current to avoid damage

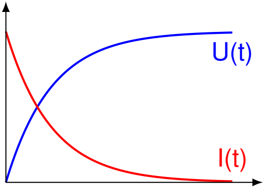




Charging a Capacitor

- Mesh rule $U_0 = U_R(t) + U_C(t)$
- Capacitor $U_C(t) = \frac{1}{C} Q(t)$
- Ohm's law $U_R(t) = RI(t)$
- Current flow $I(t) = \frac{\triangle Q(t)}{\triangle t}$
- Substitute $\frac{U_0}{R} = \frac{\triangle Q(t)}{\triangle t} + \frac{Q(t)}{RC}$
- Differential equation ...
- Charge voltage $U_C(t) = U_0 \left(1 - e^{-\frac{t}{RC}}\right)$
- Charge current $I_C(t) = \frac{U_0}{R} e^{-\frac{t}{RC}}$





Impedance

- Complex quantity

$$Z = R + jX$$

- Angular frequency $\omega = 2\pi f$
- Capacitor

$$Z_C = \frac{1}{j\omega C}$$

- Inductor

$$Z_L = j\omega L$$

Filter

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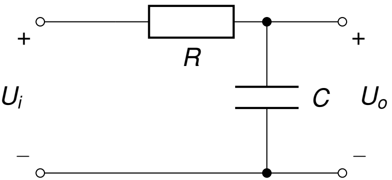
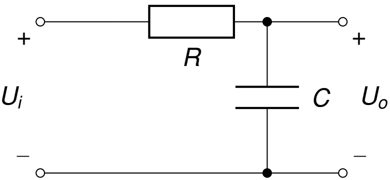
- Example: First order low-pass



Filter

- Example: First order low-pass

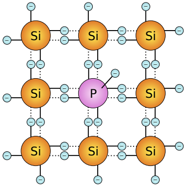


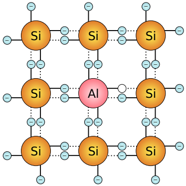
- Complex voltage divider

$$U_o = U_i \left| \frac{\frac{1}{j\omega C}}{\frac{1}{j\omega C} + R} \right| = U_i \left| \frac{1}{1 + j\omega CR} \right| = U_i \frac{1}{\sqrt{1 + (\omega CR)^2}}$$

Semiconductor

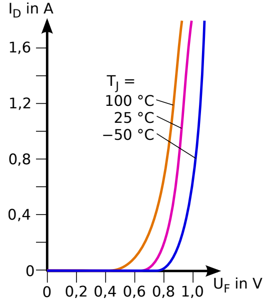
- Silicon, Germanium, ...
- Strong covalent bonding
  - No free movable charge for current flow
- Electric conductivity increases with
  - Temperature
  - n-type doping with donator
  - p-type doping with acceptor





Diode

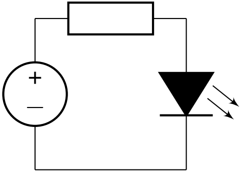
- PN junction



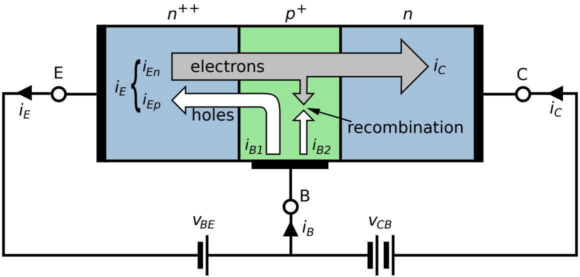
LED

- MULTICOMP 703-0090
  - Forward voltage 1.8 V
  - Operating current 20 mA
  - Reverse voltage –4 V
- Required series resistor for $U = 5\,\text{V}$

$$R = \frac{U_R}{I_D} = \frac{U - U_D}{I_D} = 160\,\Omega$$

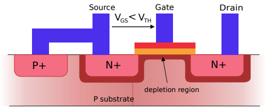


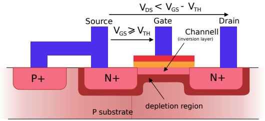
Bipolar-Junction-Transistor



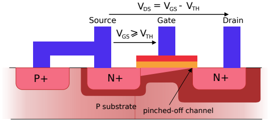
NPN PNP

MOSFET

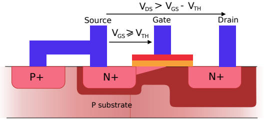




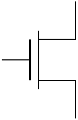
Linear operating region (ohmic mode)



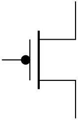
Saturation mode at point of pinch-off



Saturation mode



NMOS



PMOS

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