IE1206 Embedded Electronics

Charge Q-Coulomb (C)

Atom/ions have protons & neutrons & electrons.
Protons and electrons have charge (measured in coulombs.

Force
$$F = k\frac{Q_1 Q_2}{r^2}$$
charge 1&2
constant
dist from Q_1 to Q_2

oposite attract
Similar repel.

Current I-Ampere (A)

Flow of charge per second through a cross-section.

$$I = \frac{dQ}{dt}$$
current
change in charge
change in time

Electric Potential V-Volt (V)

Potential energy of a charge in an electric field

$$V = \frac{PE}{q}$$
Electric potential
Potential Energy
charge

Resistance R-Ohm (Ω)

Some materials restrict the flow of charge.

Electric potential
$$V = IR$$
current
Resistance

Property of the material
$$R = \rho\frac{L}{A}$$
Resistivity
length
Area
silver 1.6×10^{-8}
glass 10^{9}

Power P-Watt (W)

Rate that electrical energy is transferred into other form of energy

$$P = \frac{E}{t} = \frac{QV}{t} = IV$$
current
Electric potential

$P_{deliver} = P_{consumed}$

$P > 0 \Rightarrow$ Power is consumed

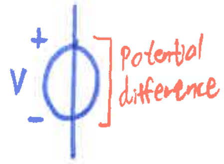
$P < 0$ Power is delivered to the circuit

Circuit Elements

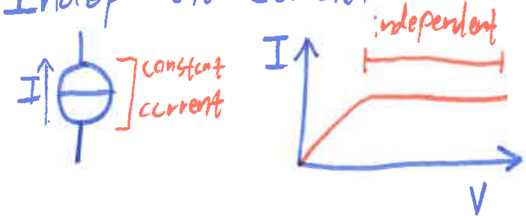
Resistor:

Passive

Independent Voltage:

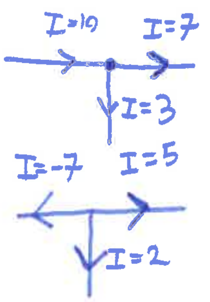


Independent Current:



Kirchoffs Current law

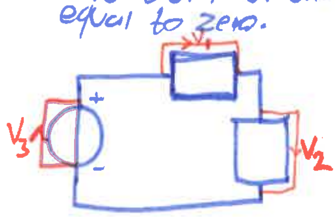
All charge flowing into a node also flows out of the node.



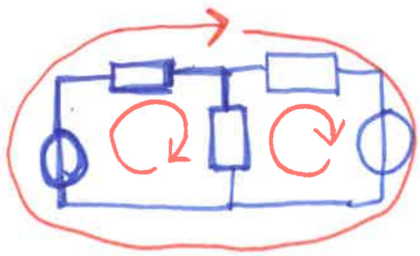
10 = 7+3

Kirchoffs Voltage law

The sum of all voltage elements in a loop is equal to zero.



$V_1 + V_2 + V_3 = 0$



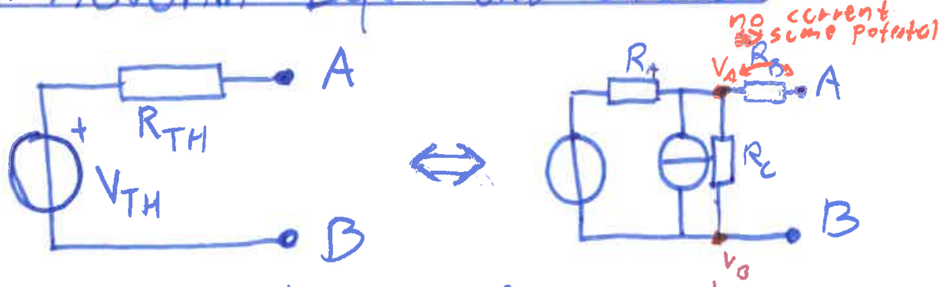
Node Voltage Method

1. Assign a potential to every node in circuit.
2. Assign ground to one of the nodes.
3. Use KCL to express current in terms of node potentials.
4. Solve equations & determine potentials.

Current Mesh Method

1. Assign current to all loops in circuit
2. Use KVL to express voltages in terms of the currents.
3. Solve equations & determine the currents.

Thévenin Equivalent Circuits

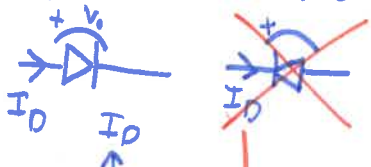


$$R_{TH} = \underset{A \text{ to } B}{\text{Total resistence}} = R_B + \frac{1}{\frac{1}{R_A} + \frac{1}{R_C}}$$

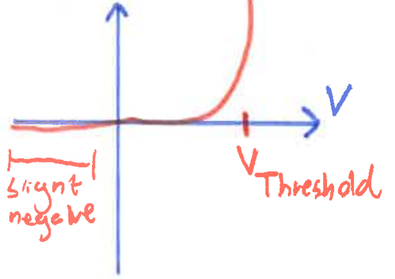
$$V_{TH} = \underset{A \text{ to } B}{\text{voltage difference}} = V_A - V_B$$

Diodes

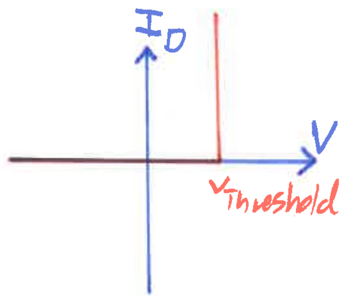
Allows current in a single direction.



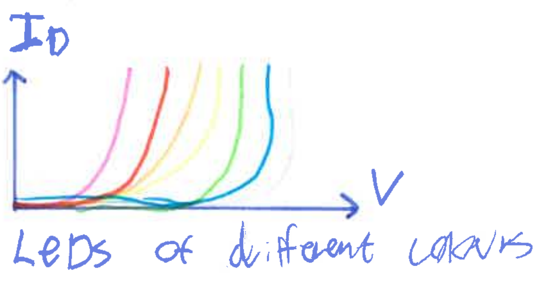
$$I_D = I_S\left(e^{\frac{qV_D}{kT}} - 1\right)$$



Real

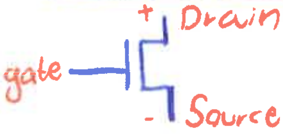


Assumed

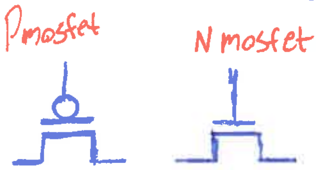


LEDs of different colours

Transistor (not part of course)

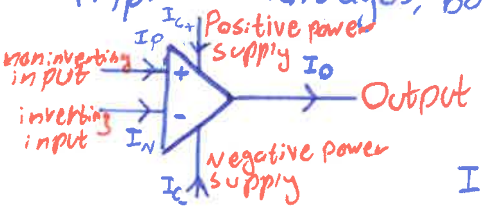


If there is a potential at the gate current may flow from drain to source or vice versa.



Operational Amplifier

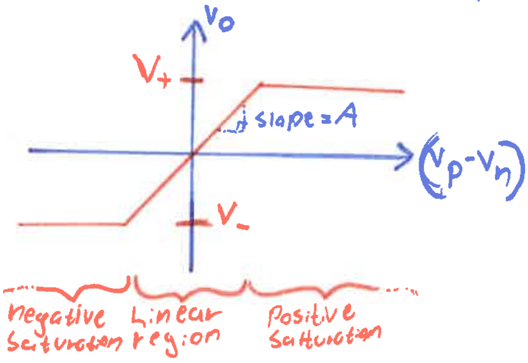
Amplifies Voltages, both up or down.

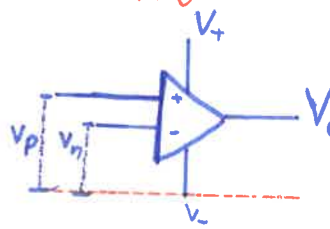


Currents going in and out of the amplifier sum up to zero.

$I_p = I_n \approx 0 \Rightarrow I_{C+} + I_{C-} = I_o$

All current comes from power supply





Operational Amp. Analysis

1 check for negative feedback $\Rightarrow$ linear region.

2 write KCL at negative input terminal.

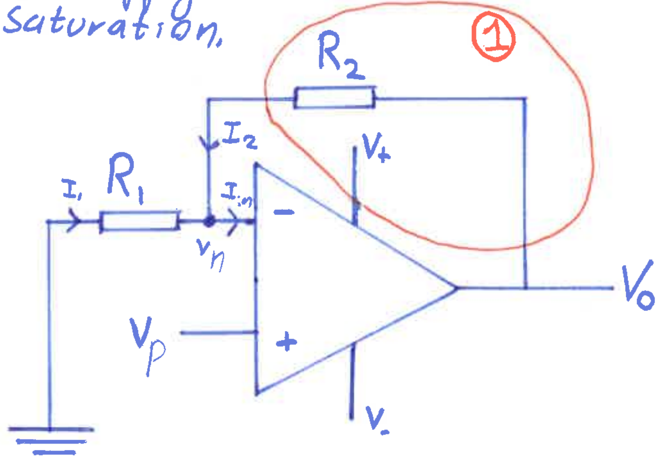
3 solve KCL, Remember $V_p \approx V_n$ in the linear region

4 Compare Vout to the supply to determine saturation.

In the linear region:

$V_o = A(v_p - v_n)$ A is usually very large $\sim 10^4$

Negative feedback is used to stay in the very narrow linear region.



2

$I_1 + I_2 = I_{in} \quad \{I_{in} = 0\}$

$I_1 + I_2 = 0$

3

$$I_1 = \frac{0 - V_n}{R_1}; \quad I_2 = \frac{V_o - V_n}{R_2}$$

$$\frac{-V_n}{R_1} + \frac{V_o - V_n}{R_2} = 0 \qquad \{V_n = V_p\}$$

$$\frac{V_o}{R_2} - V_p\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 0$$

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V_p$$

4

Determine value of R_2, R_1, V_p and solve V_o

determine the linear region

Inductance & Capacitance

Geometrical effects, cause delays in changes in voltage and current.

Capacitance: $Q = CV$ [F farad]

↳ Voltage created by separation of charges is proportional to capacitance.

Inductance: $\Phi_B = L \cdot I$ [H henry]

↳ Magnetic field created by a current is proportional to the Inductance.

Capacitor cont.

$I = C \cdot \frac{dV}{dt}$ ⇒ Current = 0 if V is constant

$$V(t) = \frac{1}{C} \underbrace{\int_{t_0}^{t} (I \cdot dt)}_{\text{total current flowing into capacitor}} + V(t_0)$$

$V(t) = V_0 \cdot e^{-\frac{t}{RC}}$ $RC := \tau$ } discharge towards zero

Between voltages

$V(t) = V(\infty) + (V(0) - V(\infty)) e^{-\frac{t}{\tau}}$ } charge/discharge between voltages

$\cancel{I_c(t) = \frac{V(t)}{R} = \frac{V_0}{R} e^{-\frac{t}{\tau}}}$?

$P(t) = IV = \frac{V_0^2}{R} e^{-\frac{2t}{\tau}}$

In series: $\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2} \dots$

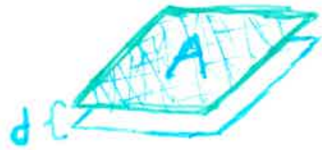
In paralell: $C_{tot} = C_1 + C_2 + \dots$

$E = \frac{1}{2} C V^2$

Capacitor

A device designed to have a large capacitance.

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



Inductor

A device designed to have a large Inductance.

$L = \mu_0 N^2 A L$

Inductor Cont

$V = L \frac{dI}{dt}$ ⇒ Voltage drop (resistances) is zero if I is constant

$$I(t) = \frac{1}{L} \int_{t_0}^{t} (V dt) + I(t_0)$$

$I(t) = I(\infty) + (I(0) - I(\infty)) e^{-\frac{t}{\tau}}$, $\tau = \frac{L}{R}$

$I(t) = I_0 e^{-\frac{t}{\tau}}$ } discharge towards zero

$\cancel{V = IR = I_0 R e^{-\frac{t}{\tau}}}$?

$P(t) = IV = I_0^2 R e^{-\frac{2t}{\tau}}$

In series: $L_{tot} = L_1 + L_2 + \dots$

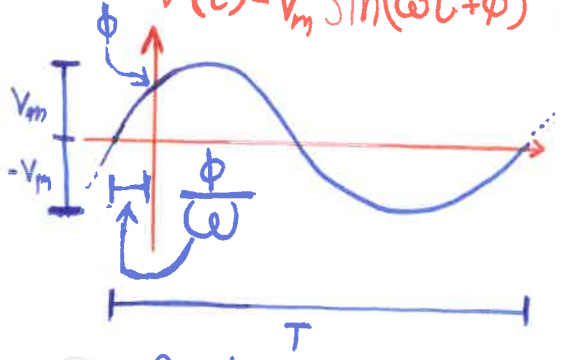
In paralell: $\frac{1}{L_{tot}} = \frac{1}{L_1} + \frac{1}{L_2} + \dots$

$E = \frac{1}{2} L I^2$

Sinusoidal Sources.

Voltage variations over time can be expressed by:

$$v(t) = V_m \sin(\omega t + \phi)$$



$$f = \frac{1}{T} \quad \omega = 2\pi f$$

RMS: Root Mean Squared

$$V_{RMS} = \frac{V_m}{\sqrt{2}}$$ -> only dependent on V_m.

Implications:

$V = IR$

$V = L\frac{dI}{dt}$

$I = C\frac{dV}{dt}$

not equal to zero

Phasor Transform

Writing sin & cos using e

$j = \sqrt{-1}$

$$e^{jx} = \cos(x) + i\sin(x)$$

$$\Rightarrow RE(e^{ix}) = \cos(x)$$

$$IM(e^{ix}) = \sin(x)$$

This means:

$$I = I_m \cdot \cos(\omega t + \phi)$$

$$\Leftrightarrow RE\{I_m e^{i(\omega t + \phi)}\}$$

$$\Leftrightarrow RE\{\underbrace{I_m e^{i\phi}}_{\text{Phasor } \hat{I}} \cdot \underbrace{e^{i\omega t}}_{\text{Frequency}}\}$$

Amplitude
Phase angle

Impedance

Unit is ohm.

$$\hat{V} = \underset{\uparrow}{Z} \cdot \hat{I}$$

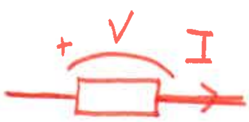
impedence

Only dependent on ω

Resistor
$Z = R$

Inductor
$Z_L = i\omega L$

Capacitor
$Z_C = \frac{1}{i\omega C}$



$I = I_m \cos(\omega t + \phi)$

$\hat{I} = I_m e^{i\phi} = I_m \angle \phi$

$V = IR = R_m \cos(\omega t + \phi)$

$\hat{V} = R\hat{I}$

$\hat{I} = I_m \angle \phi$

$V = L\frac{dI}{dt} = LI_m(-\sin(\omega t + \phi))\omega$

$= -\omega L I_m \sin(\omega t + \phi)$

$\hat{V} = -\omega L I_m \angle \phi - 90 = -\omega L I_m e^{i\phi} \cdot e^{i\frac{\pi}{2}}$

$\hat{V} = i\omega L \hat{I}$

$\hat{V} = V_m \angle \phi$

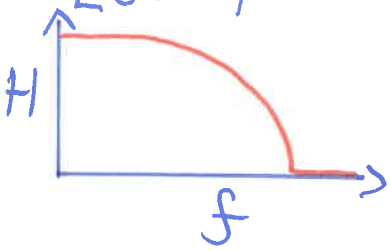
$\hat{I} = C\frac{d\hat{V}}{dt} = C V_m (-\sin(\omega t + \phi))\omega$

$= -\omega C V_m \sin(\omega t + \phi)$

$\Rightarrow \hat{I} = i\omega C \hat{V}$

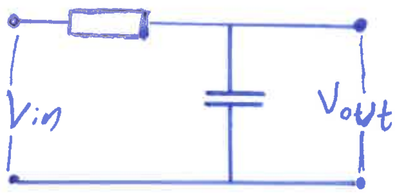
Filters

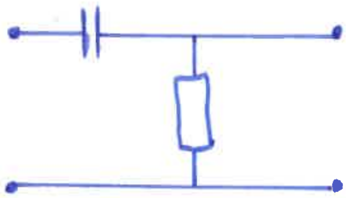
Low pass

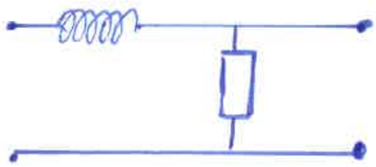


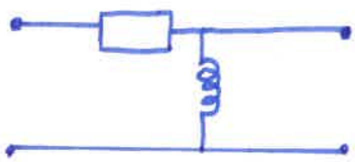
High pass

Bandpass









Combination of a high and Low pass in Series.

Band reject

Combination of high and Low pass in Parallel

$$H = \frac{V_{out}}{V_{in}}$$

f_{cutoff} ⇒ frequency where $H = \frac{1}{\sqrt{2}}$

for capacitor

$$f_c = \frac{1}{RC} \cdot \frac{1}{2\pi}$$

for Inductor

$$f_c = \frac{R}{L} \cdot \frac{1}{2\pi}$$