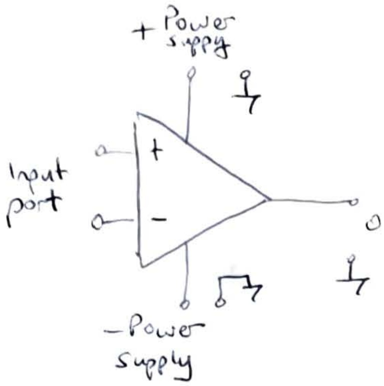
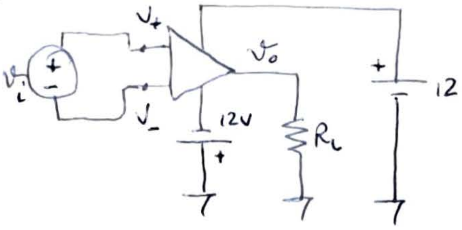
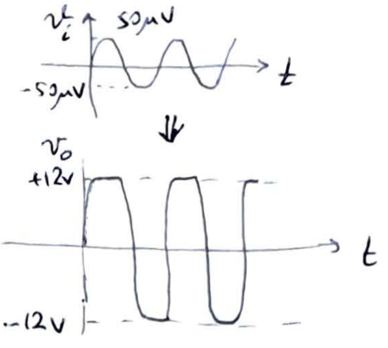
$\boxed{\text{OPAMP}}$ (Operational Amplifier) Abstraction

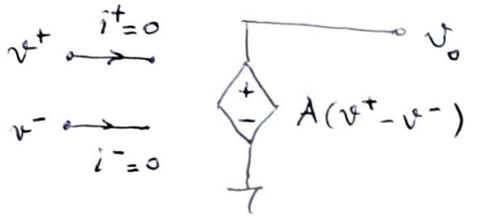


It's an impotat device for electronic circuit design. Four-port device. The input impedance is too high, the output impedance is too low. The gain is about 300,000 etc.





The gain is too high and unreliable. Generally used with feedback.
The idealized opamp (voltage controlled voltage source) is as follows:



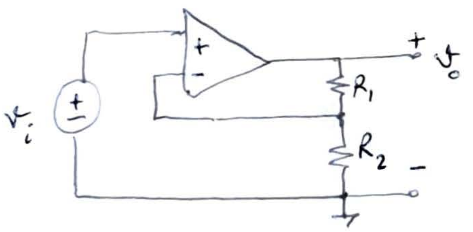
$$v_o = A(v^+ - v^-)$$

$$A \to \infty$$

$i^+ = i^- = 0 \Rightarrow$ input resistance is infinite.

The output resistance is ϕ.

Non-inverting opamp: (Negative feedback)



$$v^+ = v_i$$

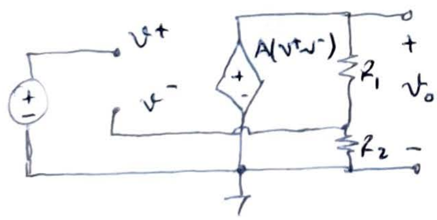
$$\frac{v^-}{R_2} + \frac{v^- - v_o}{R_1} = 0 \quad \text{or} \quad v^- = \frac{R_2}{R_1+R_2} \cdot v_o$$

$$v_o = A(v^+ - v^-) \Rightarrow v_o = Av_i - Av^-$$

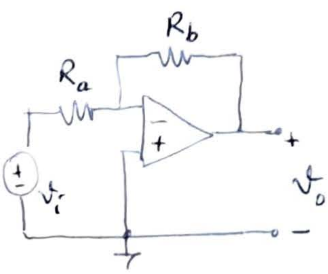
$$v_o + A \cdot \frac{R_2}{R_1+R_2} v_o = A v_i \Rightarrow v_o = \frac{A v_i}{1 + A \frac{R_2}{R_1+R_2}}$$

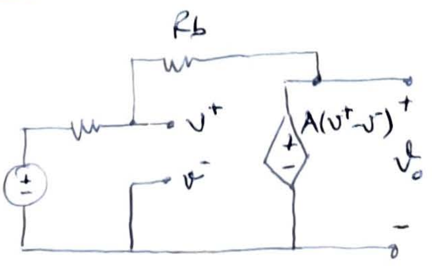
$$\lim_{A\to\infty} v_o = \left(1 + \frac{R_1}{R_2}\right) v_i$$

The model:



Inverting connection:





$$v^+ = 0$$

$$\frac{v_i - v^-}{R_a} + \frac{v_o - v^-}{R_b} = 0$$

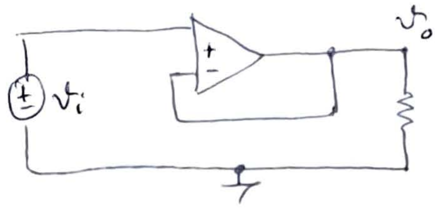
$$v_o = A(v^+ - v^-)$$

$$\Rightarrow v_o = \frac{-AR_b/(R_a+R_b)}{1 + AR_a/(R_a+R_b)} \cdot v_i$$

$$\lim_{A\to\infty} v_o = -\frac{R_b}{R_a} \cdot v_i$$

OPAMP

The voltage follower :

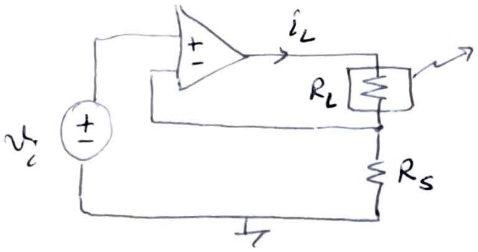


$$v_o = A(v_i - v_o)$$

$$v_o(A+1) = A v_i$$

$$v_o = \frac{A v_i}{1+A} \Rightarrow \lim_{A \to \infty} v_o = v_i$$

The current source :



circuit being driven by opamp.

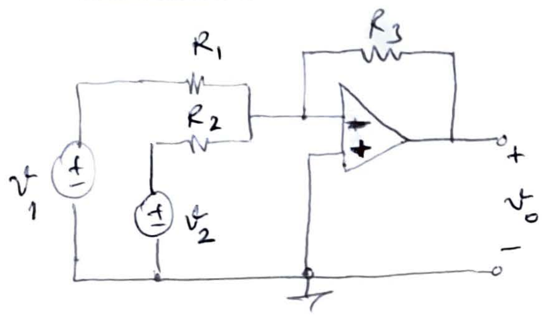
$$v^+ = v_i$$

$$v^- = i_L \cdot R_s$$

$$v^+ \simeq v_i \Rightarrow i_L \cong \frac{v_i}{R_s}$$

(independent of load, R_L)

Adder :

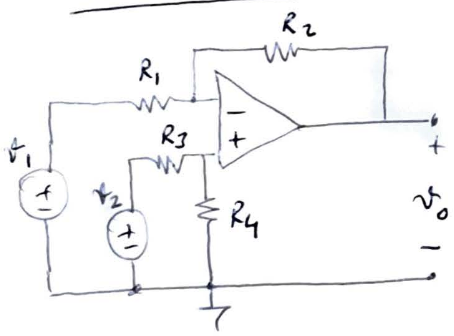


KCL @ v^- : $\frac{v_1}{R_1} + \frac{v_2}{R_2} + \frac{v_o}{R_3} \cong 0$

$v_+ = 0 \cong v^-$

$$v_o \cong -\left(\frac{R_3}{R_1} v_1 + \frac{R_3}{R_2} v_2 \right)$$

Subtracter :



$$v^+ = \frac{v_2}{R_3+R_4} \cdot R_4 = a \qquad \frac{v^+ - v_1}{R_1} + \frac{v^+ - v_o}{R_2} = 0$$

$$R_2(a v_2 - v_1) + R_1(a v_2 - v_o) = 0$$

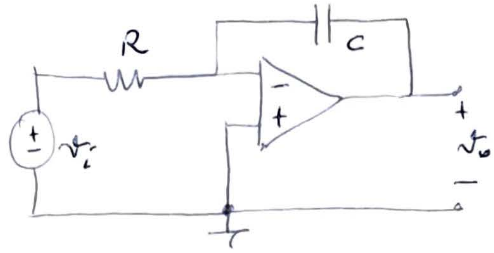
$$v_o = \frac{a\left[R_2(v_2 - v_1) + R_1 v_2 \right]}{R_1}$$

$$v_o = \left(\frac{R_3}{R_3+R_4} \right)\left(\frac{R_1+R_2}{R_1} \cdot v_2 - \frac{R_2}{R_1} v_1 \right)$$

Taking $R_3 = R_1$, $R_4 = R_2$ $\Rightarrow$ $v_o = \frac{R_2}{R_1}(v_2 - v_1)$

OPAMP

Opamp Integrator

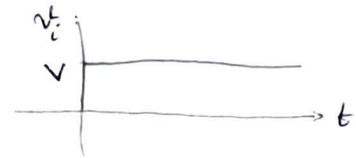


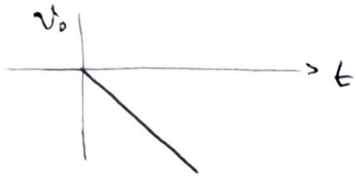
$$\frac{v_i - v^-}{R} + C\frac{d(v_o - v^-)}{dt} = 0$$

$v^+ \simeq v^- \Rightarrow$ $\quad \frac{v_i}{R} + C\frac{dv_o}{dt} = 0$

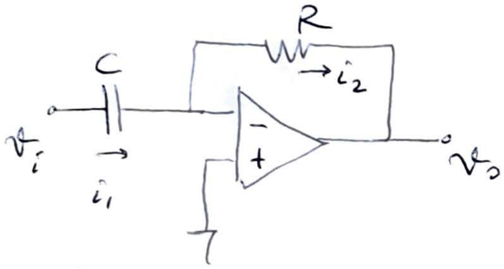
$v^+ = 0$

$$v_o \simeq -\frac{1}{RC}\int v_i \, dt$$



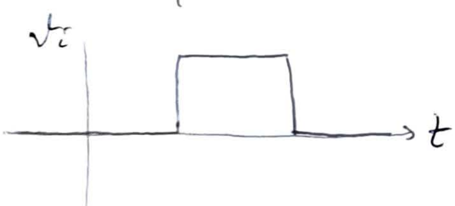


Opamp Differentiator



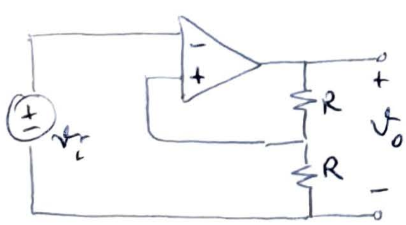
$i_1 = C\frac{dv_i}{dt}$ $\quad v_o = -R i_1$ $\quad (i_1 = i_2)$

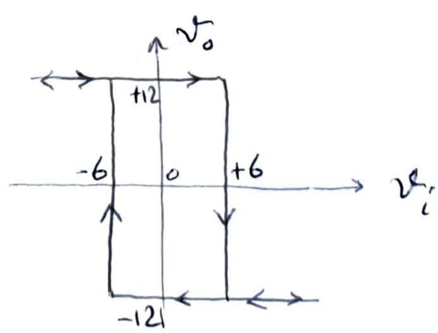
$$v_o = -RC\frac{dv_i}{dt}$$



$\Rightarrow$

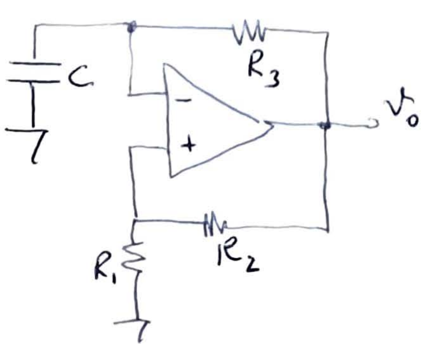
Positive Feedback :





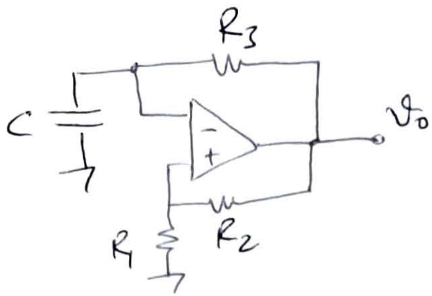
opamp works in saturation regions and shows hysteresis.

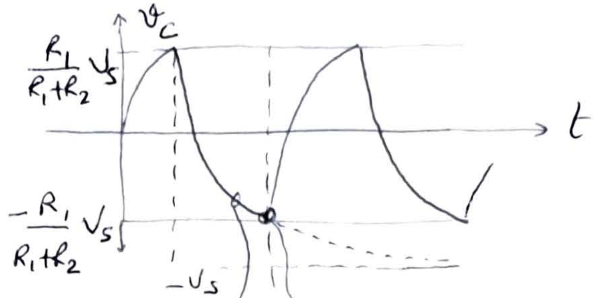
RC Oscillator :

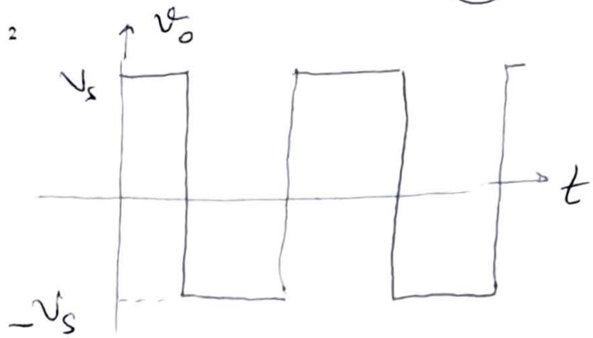


OPAMP

RC-oscillator cont'd:







$$v_c = -v_s + \left(\frac{R_1}{R_1+R_2} + 1\right) v_s\, e^{-t/R_3 C} \qquad \left(\begin{aligned} v_c(0) &= v_s \frac{R_1}{R_1+R_2} \\ v_c(\infty) &= -v_s \end{aligned} \right)$$

find this time : T_{Low} :

$$v_c = -v_s + \left(\frac{R_1}{R_1+R_2} + 1\right) v_s\, e^{-t/R_3 C} \leq -\frac{R_1}{R_1+R_2} v_s$$

$$-v_s + \left(\frac{R_1}{R_1+R_2} + 1\right) v_s\, e^{-T_{Low}/R_3 C} = -\frac{R_1}{R_1+R_2} \cdot v_s$$

$$\Rightarrow \quad T_{Low} = R_3 C \ln\left(1 + \frac{2R_1}{R_2}\right)$$

$T_{high} = T_{Low}$, so $\quad T = 2R_3 C \ln\left(1 + \frac{2R_1}{R_2}\right)$