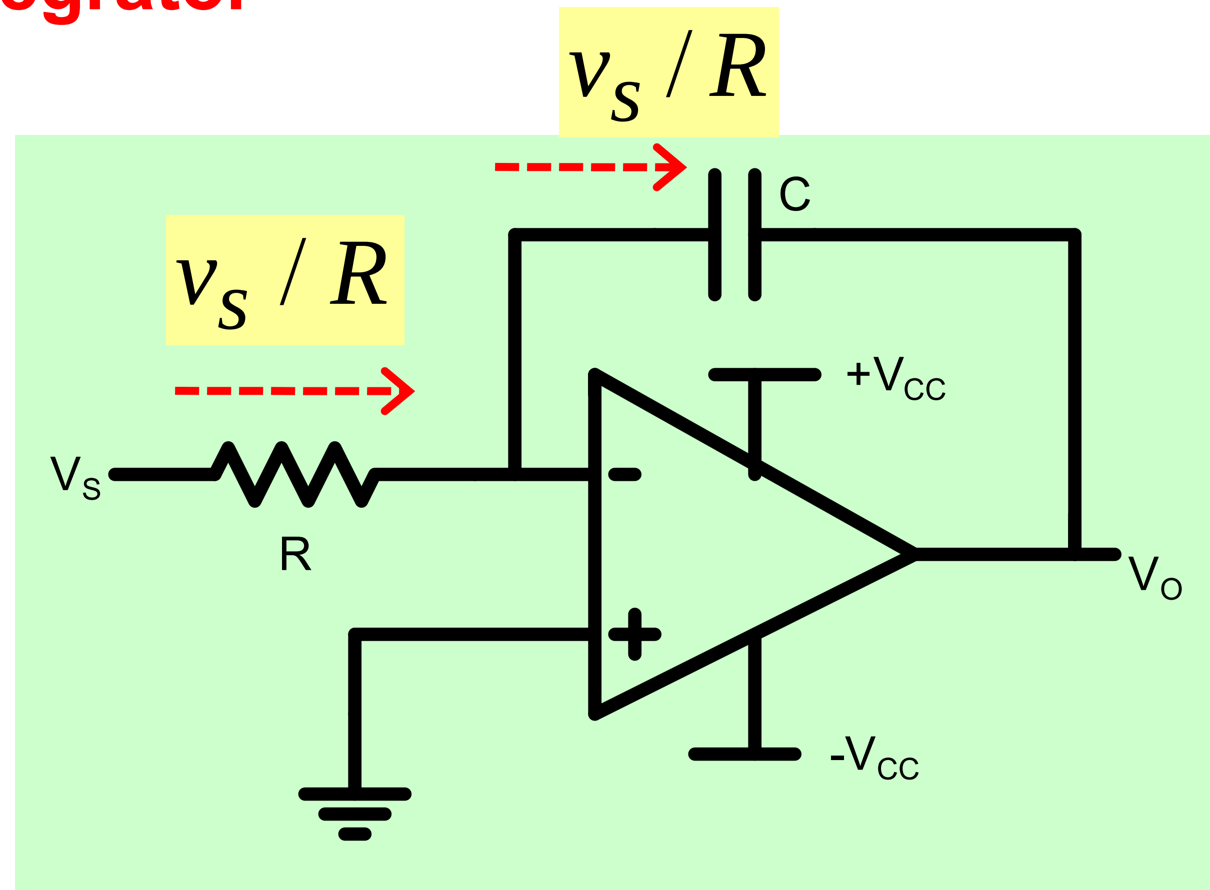
ESc201 : Introduction to Electronics

Operational Amplifier
Part-2

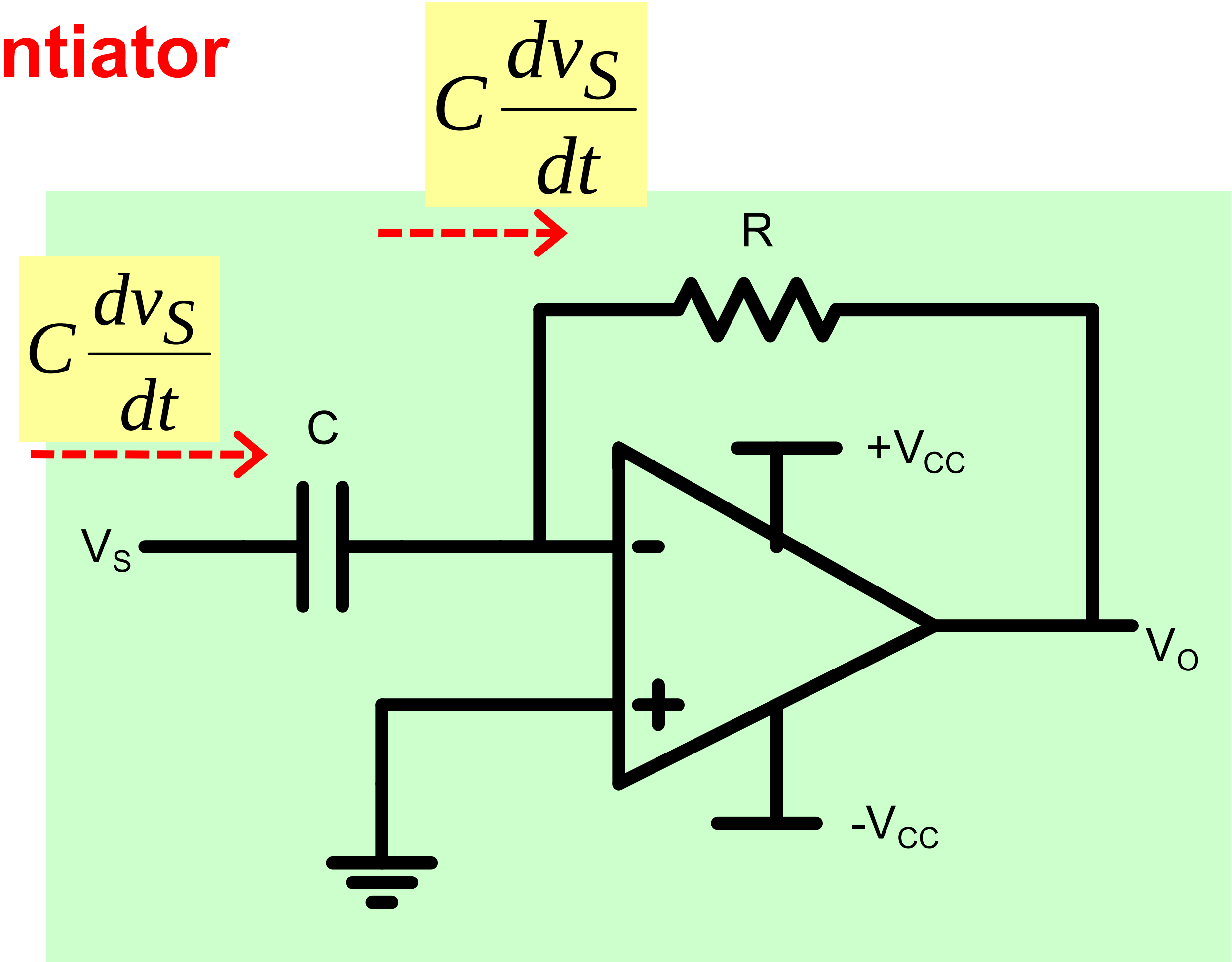
Dr. Y. S. Chauhan
Dept. of Electrical Engineering
IIT Kanpur

Integrator



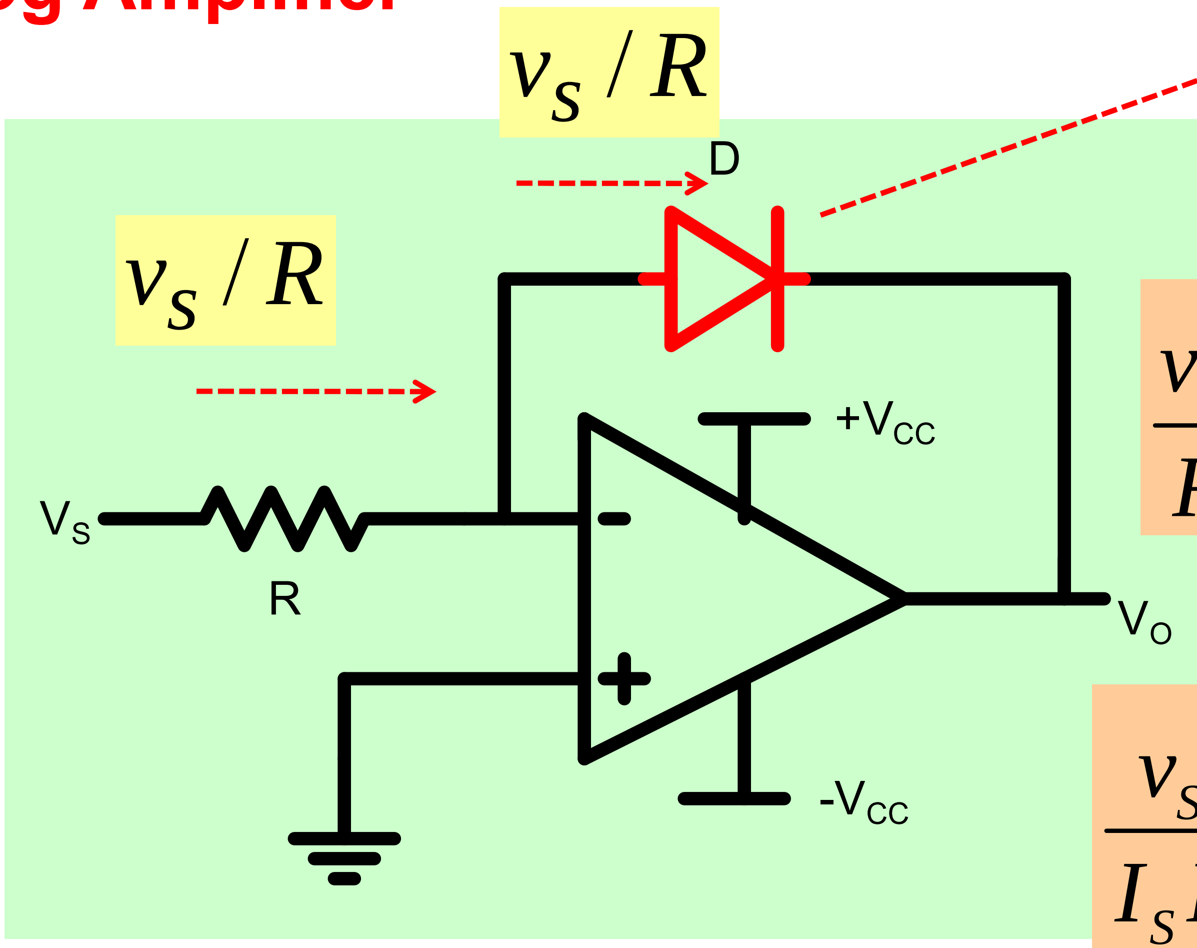
$$\frac{v_S}{R} = -C\frac{dV_O}{dt} \Rightarrow V_O(t) = -\frac{1}{RC}\int v_S dt$$

Differentiator



$$-\frac{V_O}{R} = C\frac{dv_s}{dt} \Rightarrow V_O(t) = -RC\frac{dv_s}{dt}$$

Log Amplifier



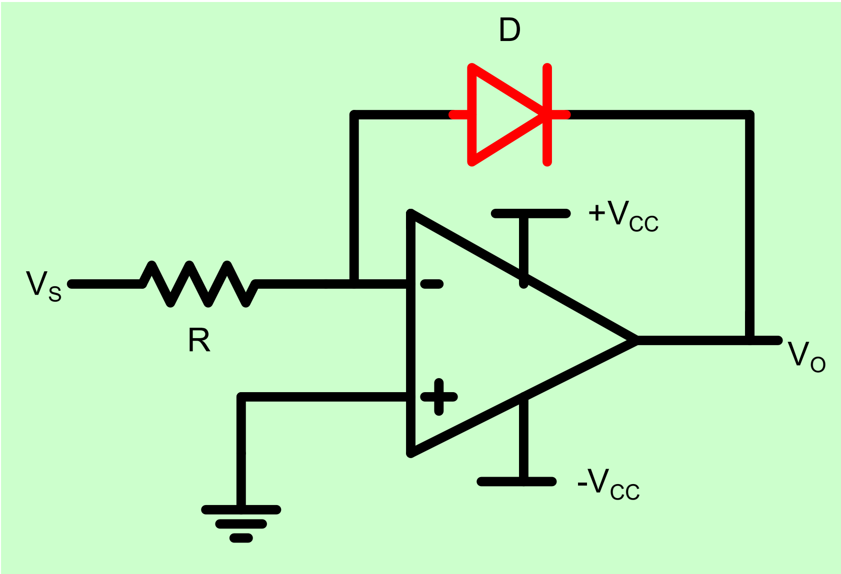
$$I = I_S(e^{\frac{V}{V_T}} - 1)$$

$$\frac{v_S}{R} = I_S(e^{-\frac{V_O}{V_T}} - 1)$$

$$\frac{v_S}{I_S R} + 1 = e^{-\frac{V_O}{V_T}}$$

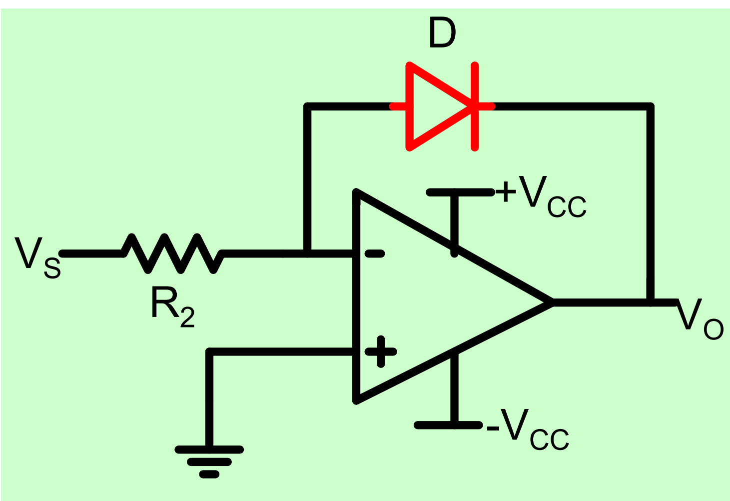
$$\Rightarrow \quad -V_O = V_T \times \ln(1 + \frac{v_S}{RI_S}) \cong V_T \times \ln(\frac{v_S}{RI_S})$$

Temperature Sensor ?

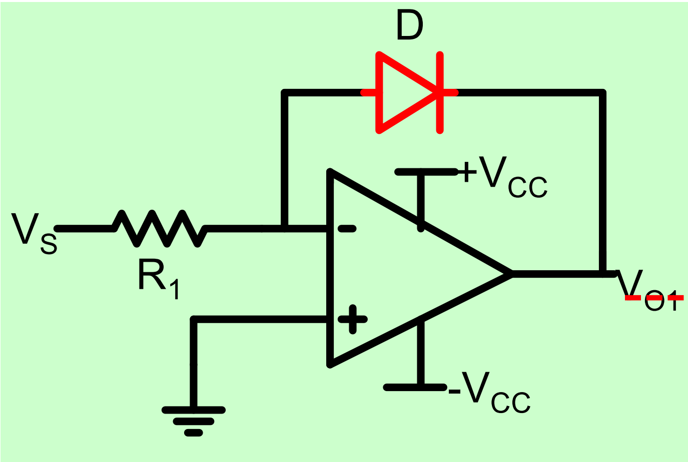


$$V_O = -V_T \times \ln\left(\frac{V_S}{RI_S}\right); \; V_T = \frac{k_B T}{q}$$

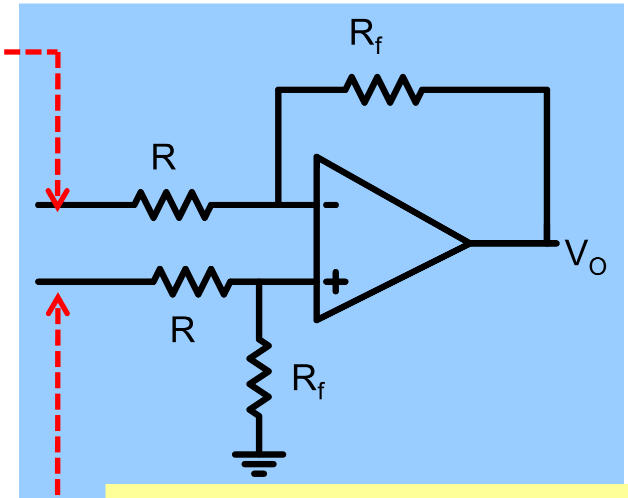
But I_S is a function of temperature as well.

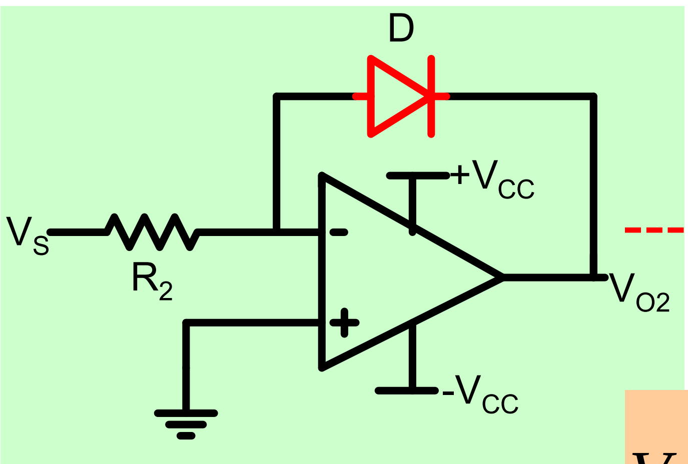


$$V_O = -V_T \times \ln\left(\frac{V_S}{R_2 I_S}\right)$$



$$V_{O1} = -V_T \times \ln\left(\frac{V_S}{R_1 I_S}\right)$$



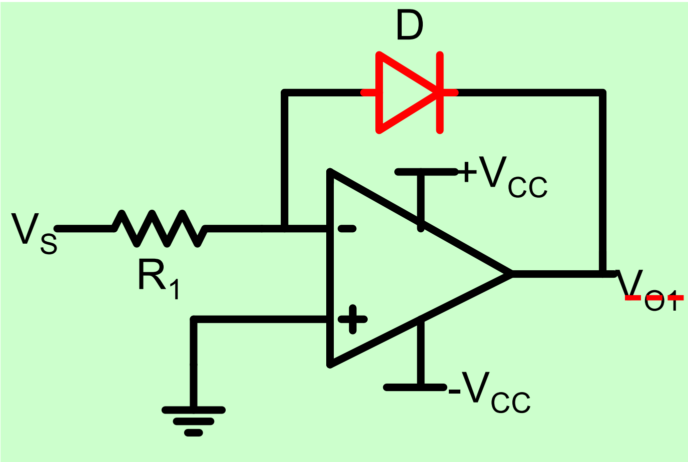


$$V_O = -\frac{R_f}{R} V_{01} + \left(1 + \frac{R_f}{R}\right) \times \frac{R_f}{R_f + R} V_{02}$$

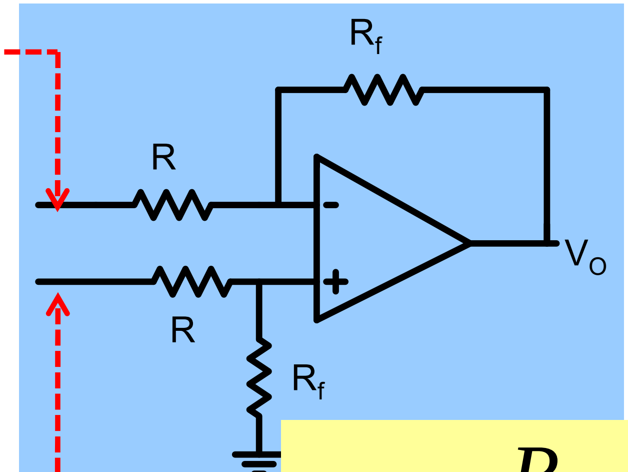
$$V_{O2} = -V_T \times \ln\left(\frac{V_S}{R_2 I_S}\right)$$

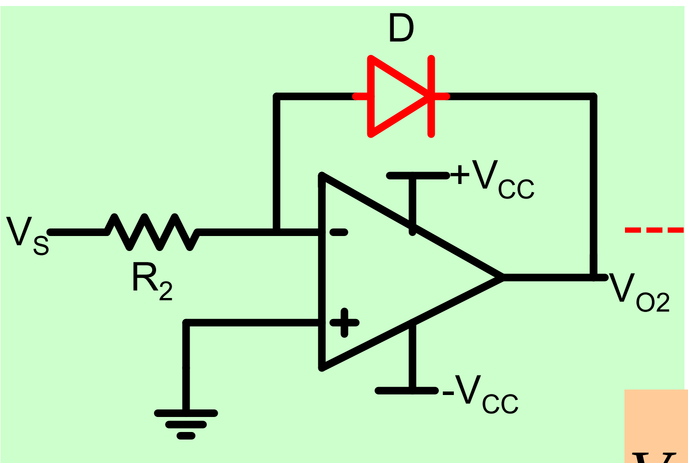
$$V_O = \frac{R_f}{R}\left(V_{02} - V_{01}\right)$$

$$V_O = \frac{R_f}{R} V_T \left(-\ln\left(\frac{V_S}{R_2 I_S}\right) + \ln\left(\frac{V_S}{R_1 I_S}\right) \right)$$



$$V_{O1} = -V_T \times \ln\left(\frac{V_S}{R_1 I_S}\right)$$





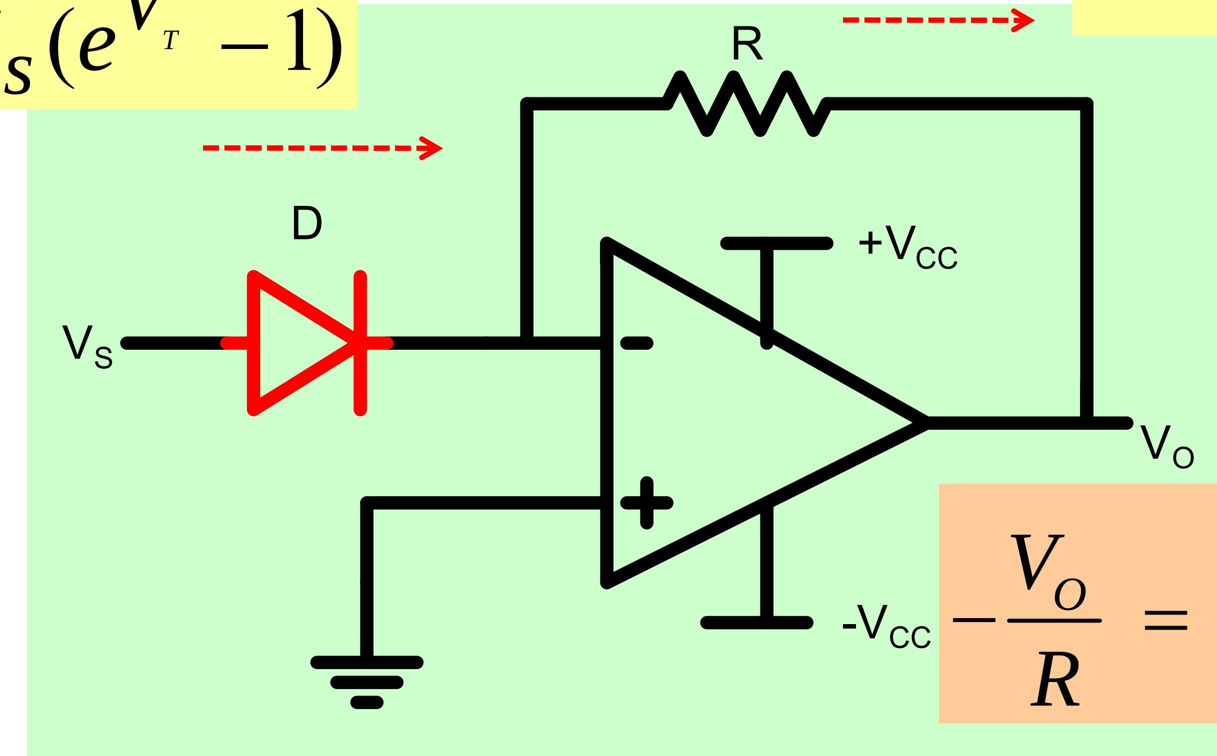
$$V_O = \frac{R_f}{R} V_T \times \ln\left(\frac{R_2}{R_1}\right)$$

$$V_{O2} = -V_T \times \ln\left(\frac{V_S}{R_2 I_S}\right)$$

Output voltage is directly proportional to temperature

AntiLog Amplifier

$$I = I_S\left(e^{\frac{V_S}{V_T}} - 1\right)$$



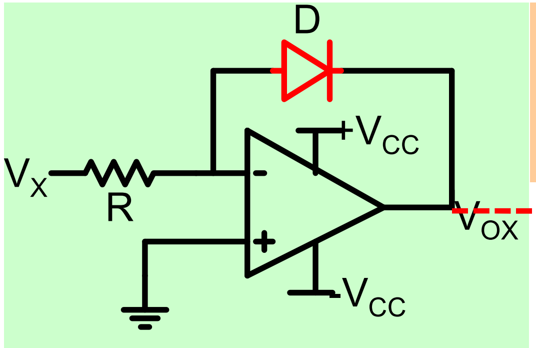
$$I = I_S\left(e^{\frac{V_S}{V_T}} - 1\right)$$

$$-\frac{V_O}{R} = I_S\left(e^{\frac{V_S}{V_T}} - 1\right)$$

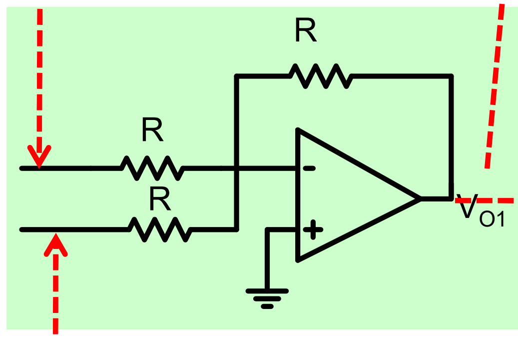
$$\Rightarrow \; V_O = -RI_S\left(e^{\frac{V_S}{V_T}} - 1\right) \cong -RI_S \times e^{\frac{V_S}{V_T}}$$

Multiplier

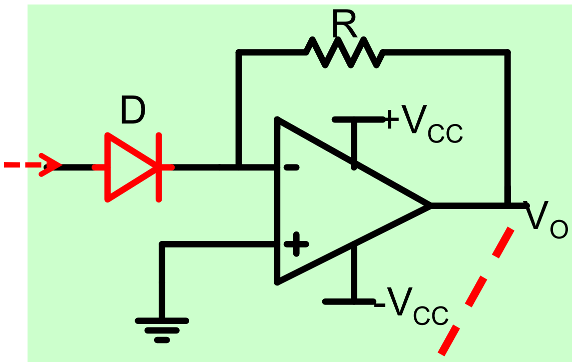
$$V_{O1} = V_T \times \left(\ln\left(\frac{V_X}{RI_S}\right) + \ln\left(\frac{V_Y}{RI_S}\right)\right)$$

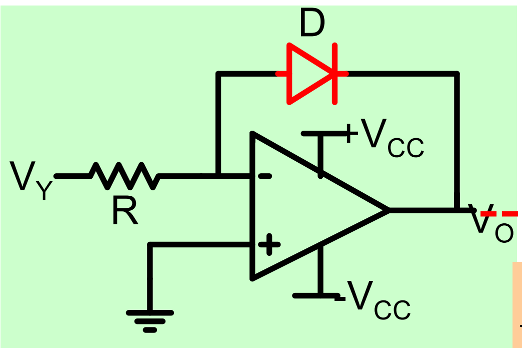


$$V_{OX} = -V_T \times \ln\left(\frac{V_X}{RI_S}\right)$$



$$V_{O1} = V_T \times \ln\left(\frac{V_X V_Y}{R^2 I_S^2}\right)$$

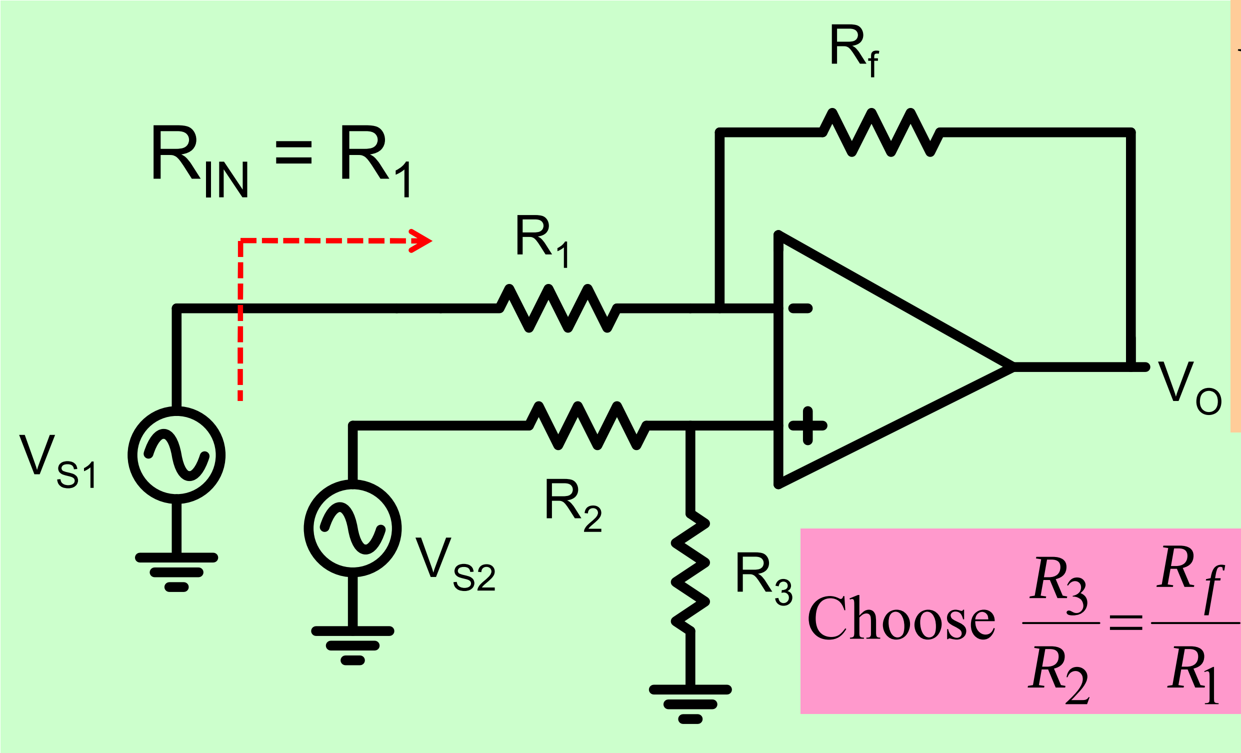




$$V_{OY} = -V_T \times \ln\left(\frac{V_Y}{RI_S}\right)$$

$$V_O \cong -RI_S \times e^{\frac{V_{O1}}{V_T}} = -\frac{V_X V_Y}{RI_S}$$

Difference Amplifier



$$v_o = v_{s2}\frac{\frac{R_3}{R_2}}{(1+\frac{R_3}{R_2})}(1+\frac{R_f}{R_1}) - (\frac{R_f}{R_1})v_{s1}$$

Choose $\frac{R_3}{R_2} = \frac{R_f}{R_1}$

$$v_o = \frac{R_f}{R_1}(v_{s2} - v_{s1})$$

Need to be checked input resistance

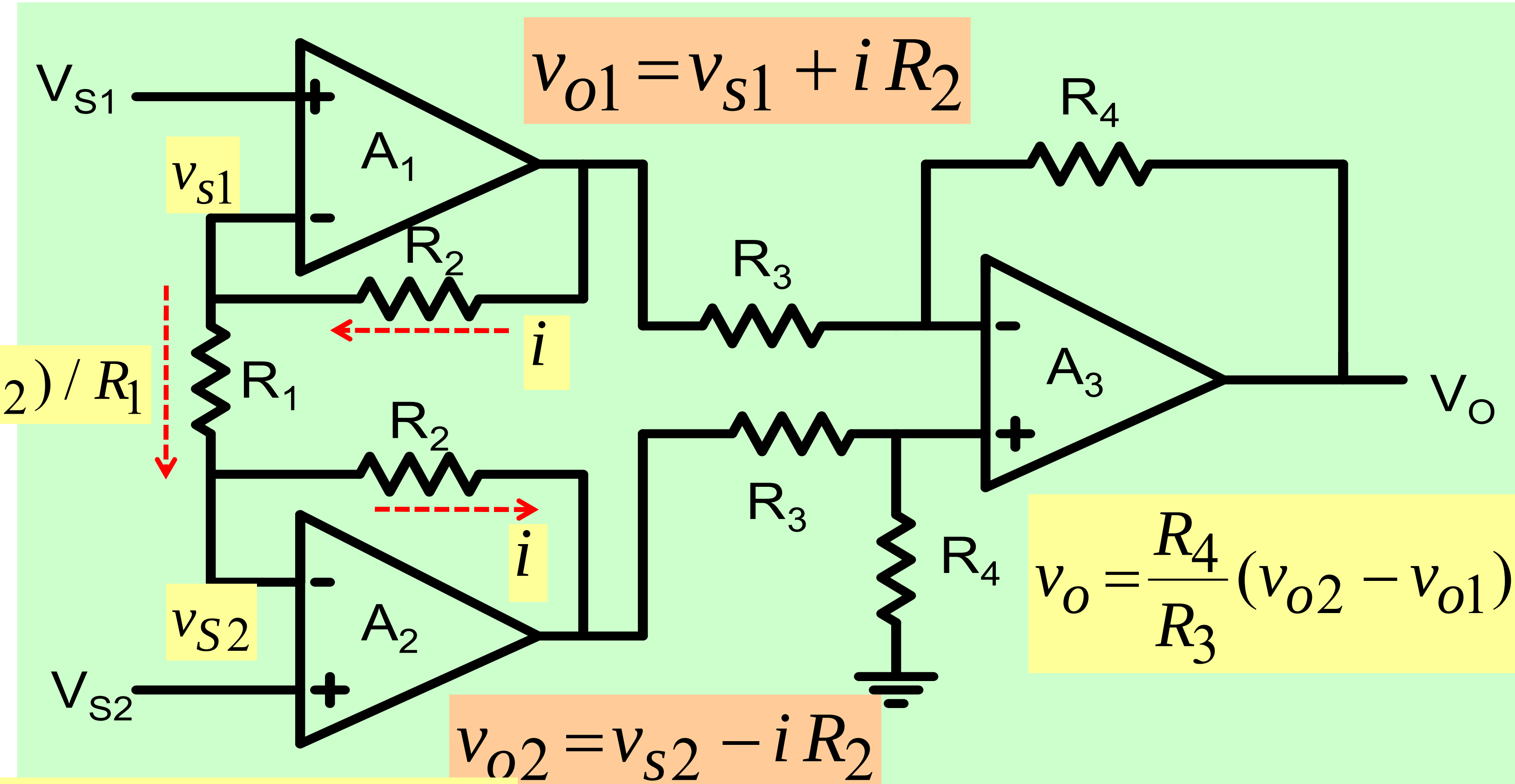
A drawback is that input resistance is relatively Lower

To change gain, we have to change two resistors and a slight mismatch can drastically reduce common mode rejection ratio

Instrumentation Amplifier

$$v_{o1} = v_{s1} + i\,R_2$$

$$i = (v_{s1} - v_{s2})\,/\,R_1$$



$$v_{o2} = v_{s2} - i\,R_2$$

$$v_o = \frac{R_4}{R_3}(v_{o2} - v_{o1})$$

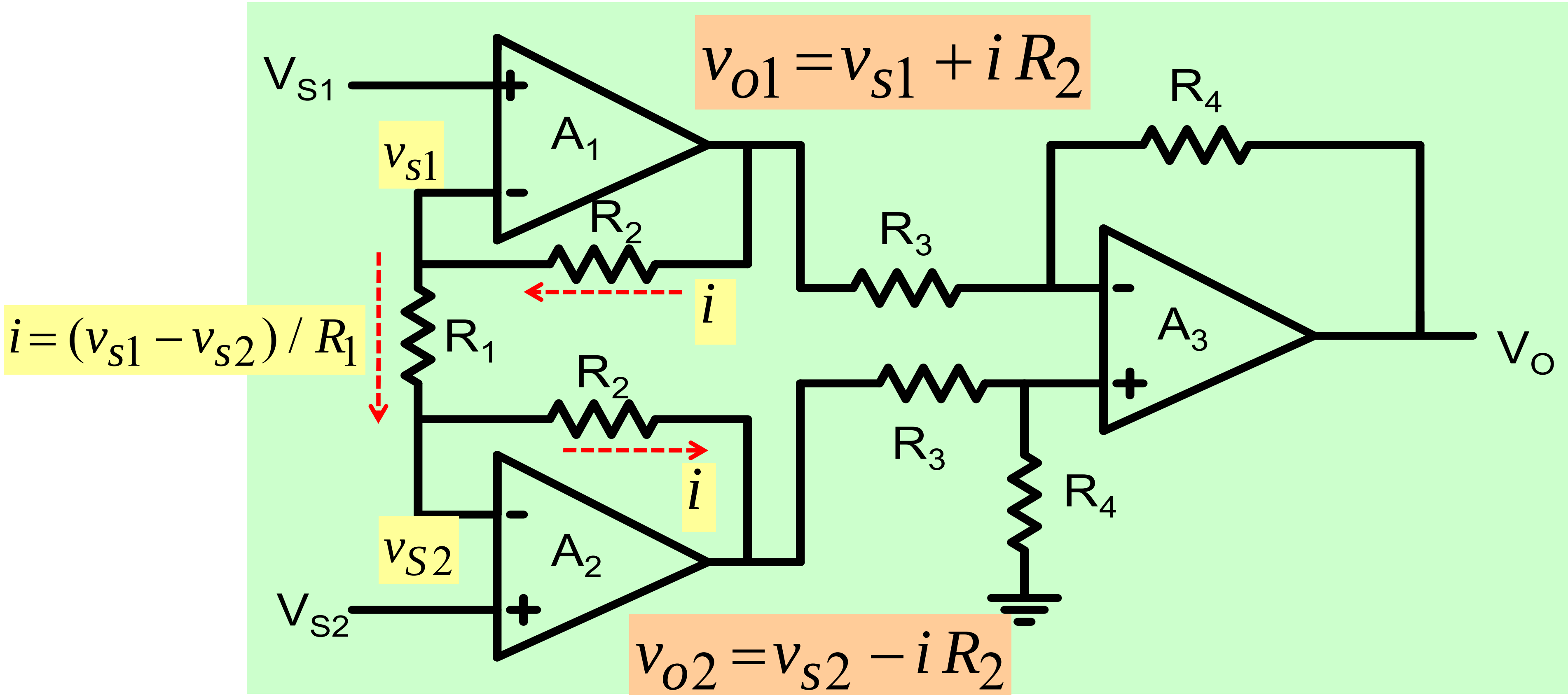
$$v_o = \frac{R_4}{R_3}(v_{s2} - iR_2 - v_{s1} - iR_2)$$

$$v_o = \frac{R_4}{R_3}(\{v_{s2} - v_{s1}\} - 2R_2\{(v_{s1} - v_{s2})\,/\,R_1\})$$

$$v_o = \frac{R_4}{R_3}(v_{s2} - v_{s1} - 2iR_2)$$

$$v_o = \frac{R_4}{R_3}\left(v_{s2} - v_{s1}\right)(1 + 2\frac{R_2}{R_1})$$

Instrumentation Amplifier

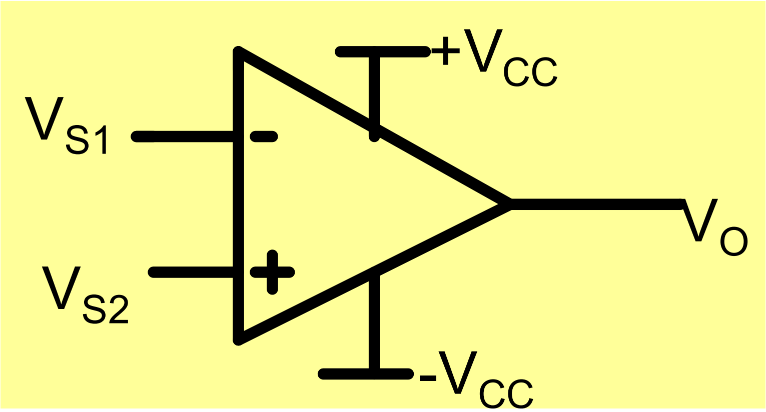


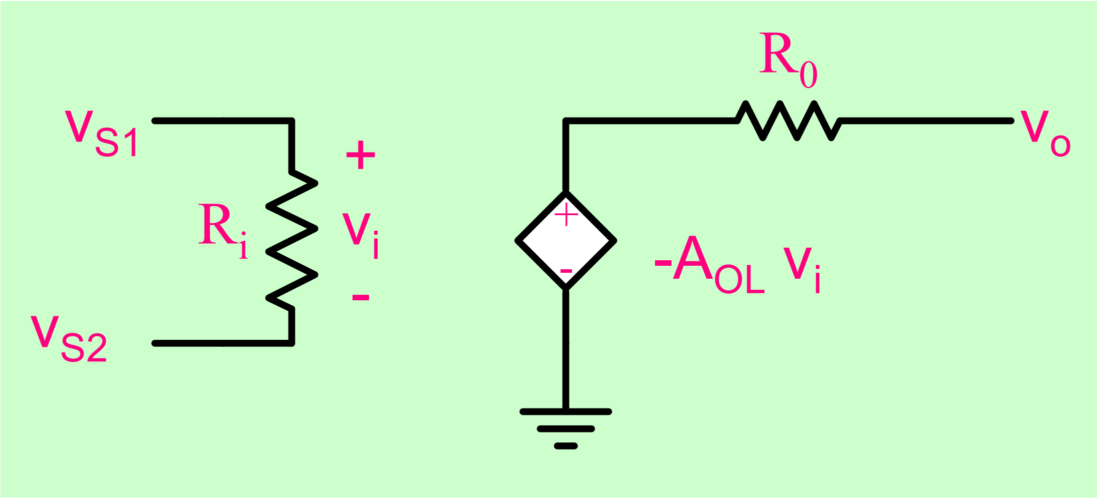
$$v_o = \frac{R_4}{R_3} \times \left(1 + \frac{2R_2}{R_1}\right) \times (v_{s2} - v_{S1})$$

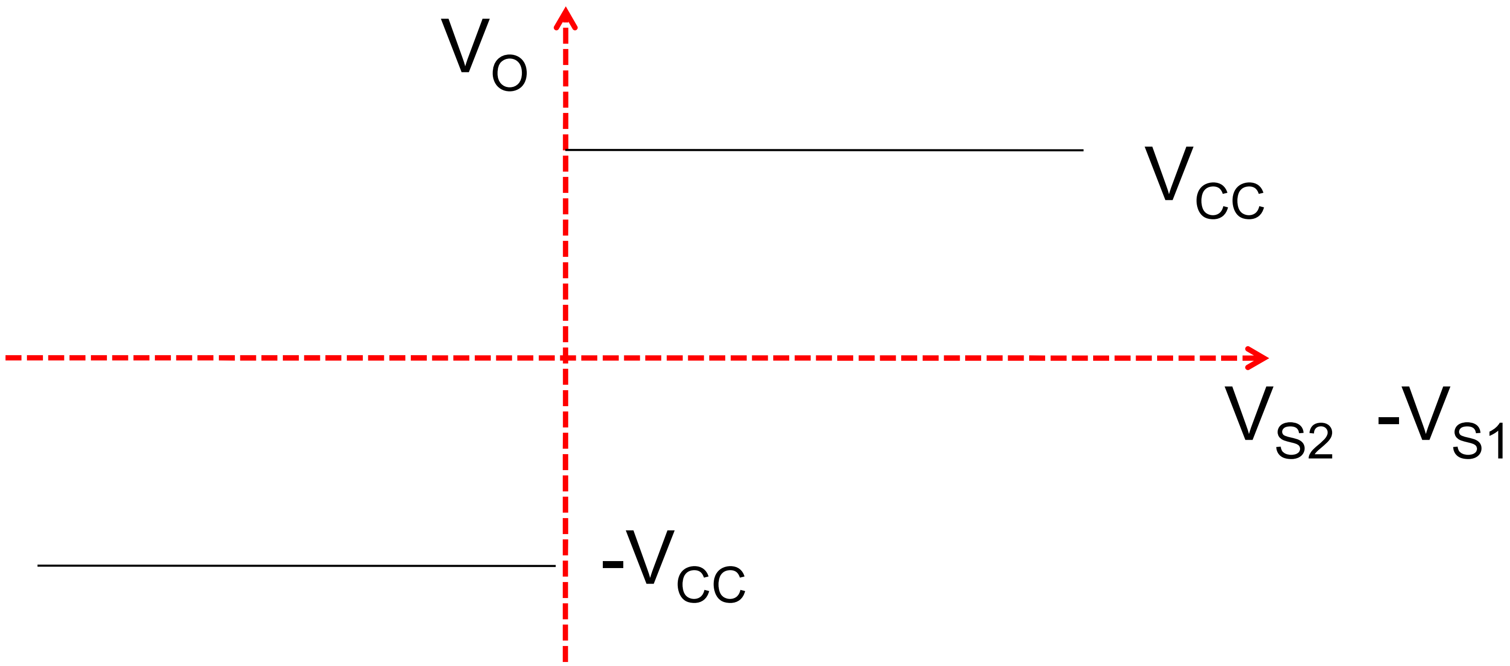
Very high input Resistance

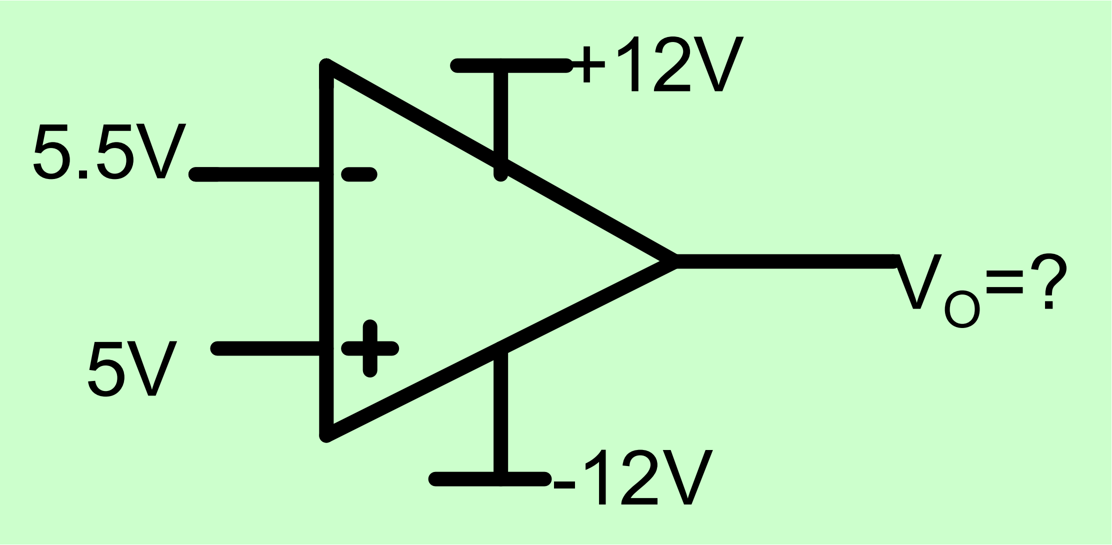
Can change one resistor R_1 and change gain

Comparator: Opamp under open Loop condition

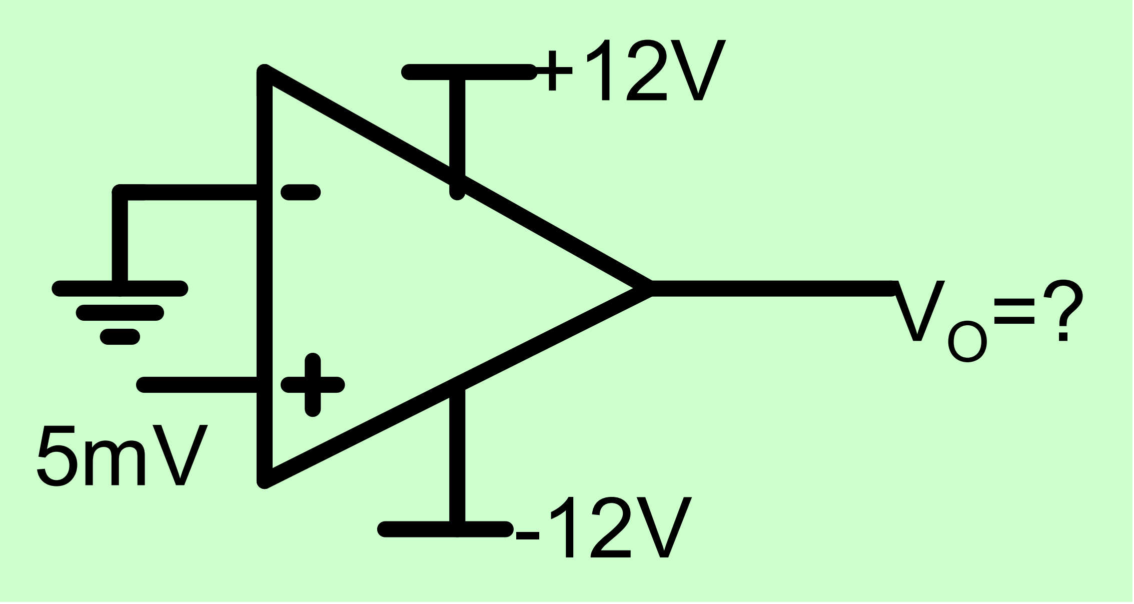








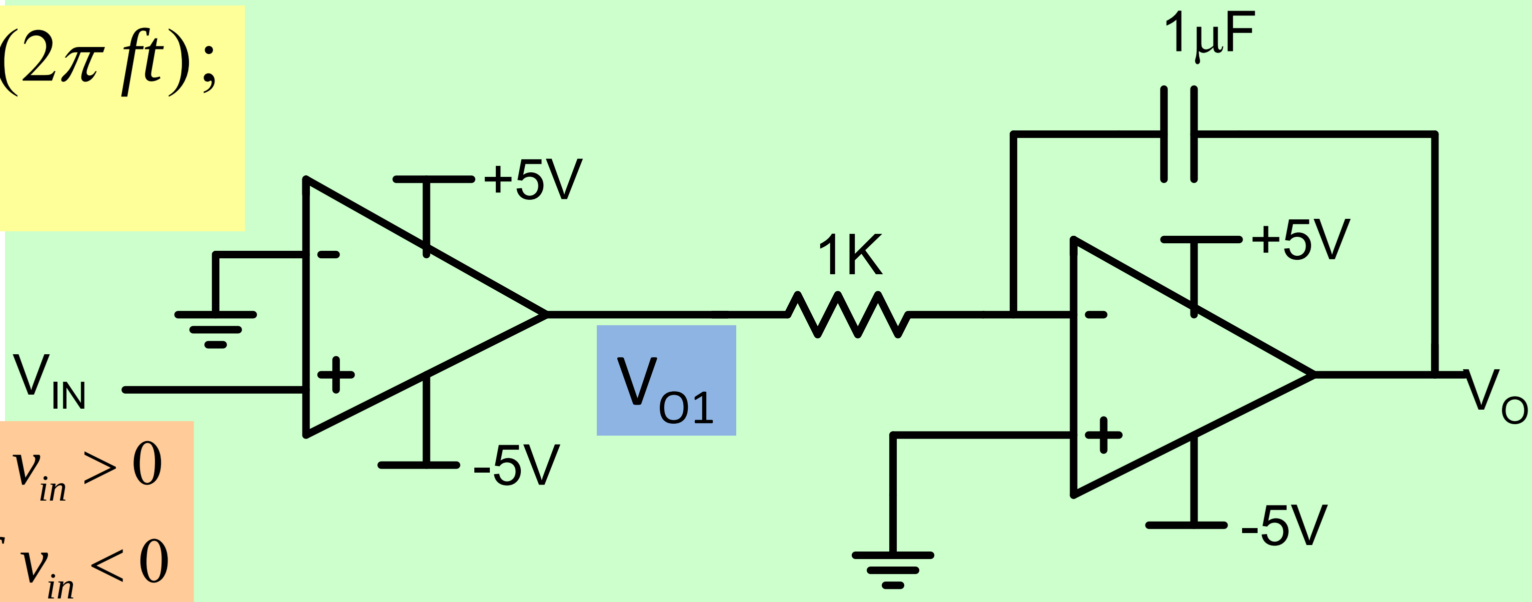
~ -12V



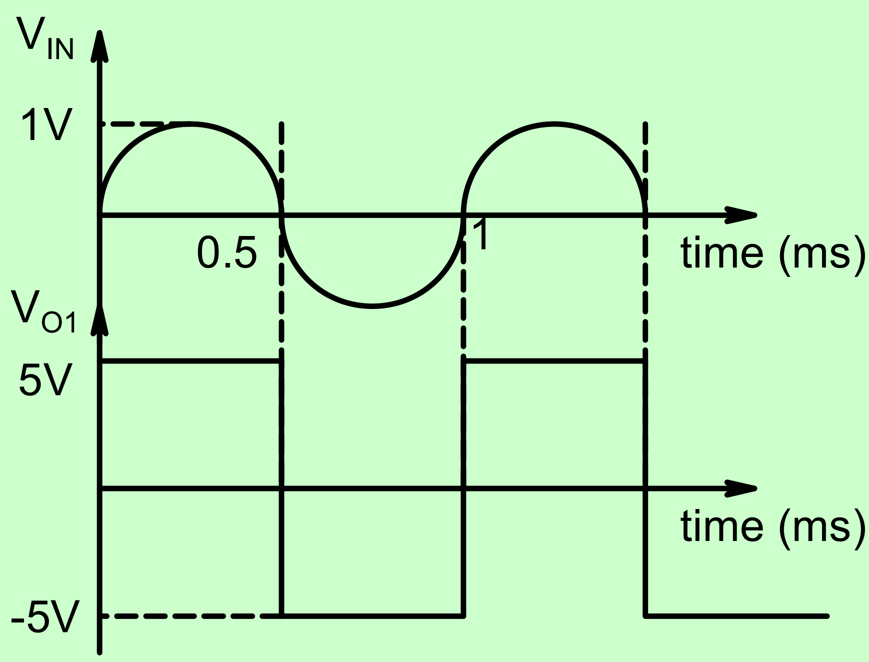
~ +12V

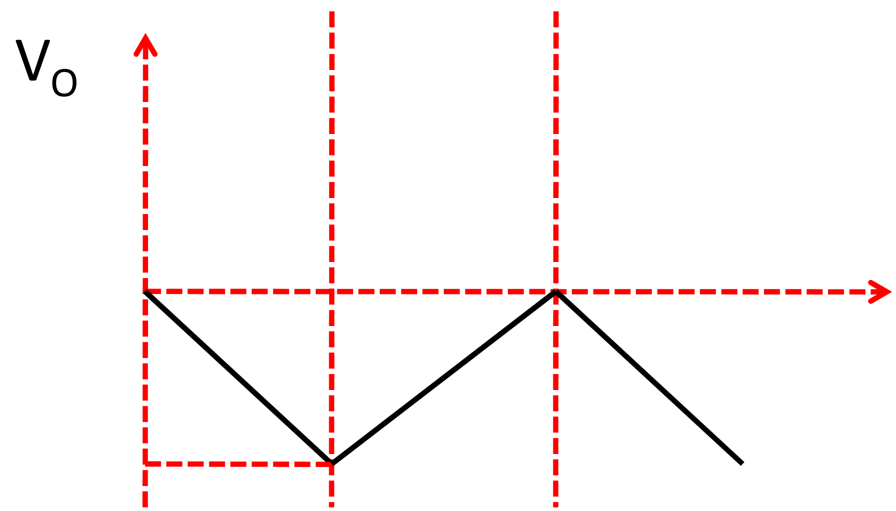
Example

$$v_{in} = 1V\ Sin(2\pi ft);$$
$$f = 1KHz$$

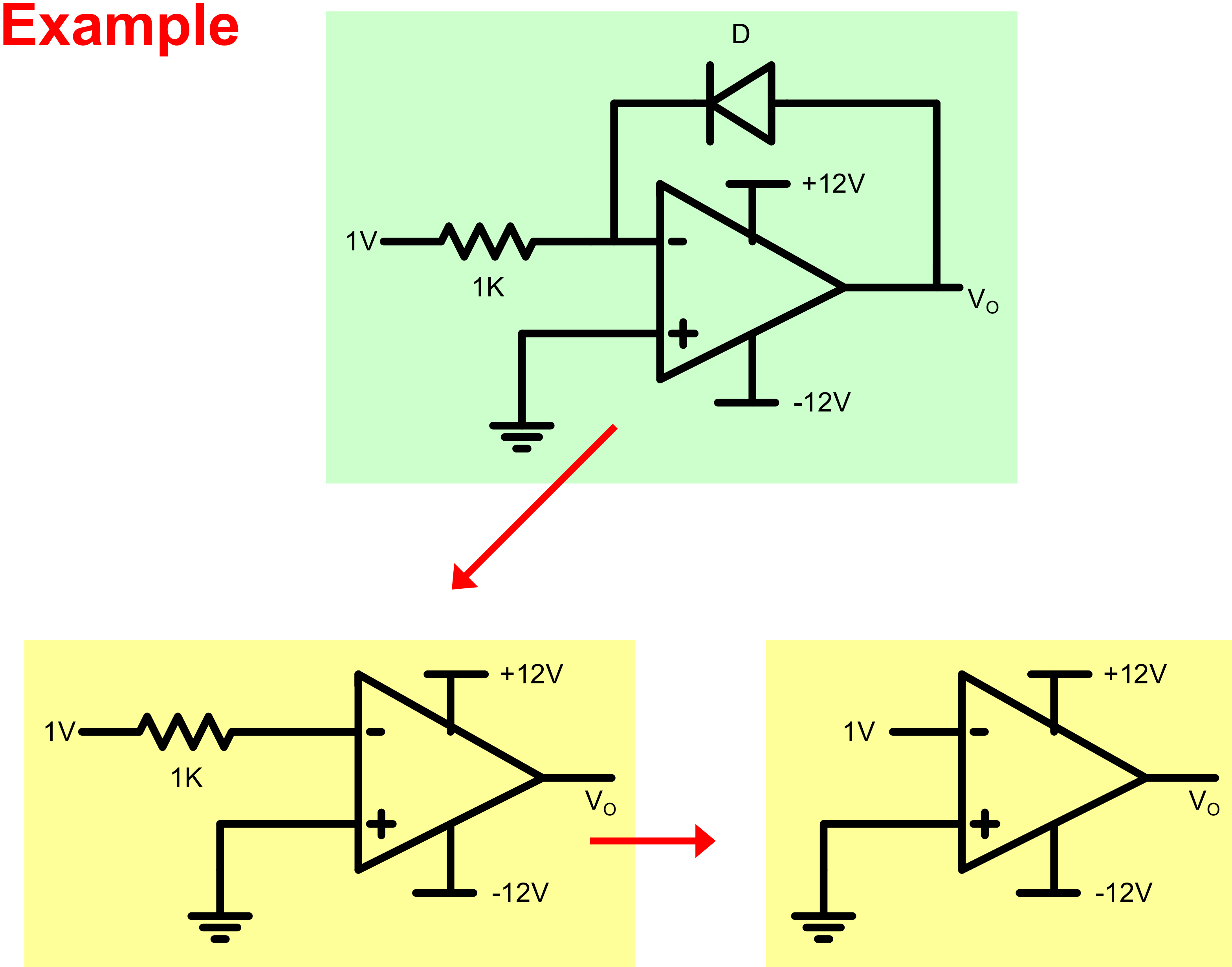


$$V_{O1} = +5V\ if\ v_{in} > 0$$
$$= -5V\ if\ v_{in} < 0$$





Example

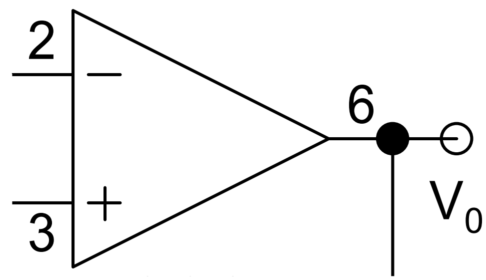


~ -12V

Comparator

$$V_2 > V_3 \Rightarrow V_0 = -V_{sat}$$
$$V_2 < V_3 \Rightarrow V_0 = +V_{sat}$$

$$V_0 = A_v\left(V_3 - V_2\right)$$

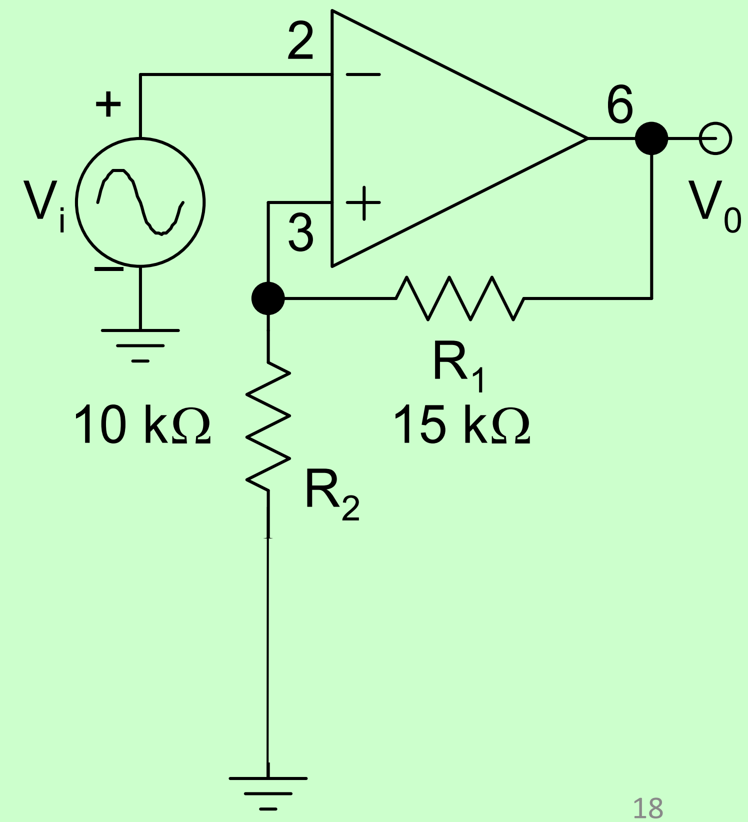


Schmitt Trigger

$$V_2 > V_3 \Rightarrow V_0 = -V_{sat}$$
$$V_2 < V_3 \Rightarrow V_0 = +V_{sat}$$

$$V_0 = A_v\left(V_3 - V_2\right)$$

$$V_3 = V_0 \frac{R_2}{R_1 + R_2}$$



$$R_2 = 10k$$

$$V_3 = \pm V_{sat} \frac{10}{10+15}$$

$$= \pm 12 \times \frac{2}{5} = \pm 4.8V$$

Schmitt Trigger

$$V_2 > V_3 \Rightarrow V_0 = -V_{sat}$$
$$V_2 < V_3 \Rightarrow V_0 = +V_{sat}$$

$$V_0 = A_v\left(V_3 - V_2\right)$$

$$V_3 = \pm 4.8V$$

$$V_{IH} = +\,4.8V$$
$$V_{IL} = -\,4.8V$$

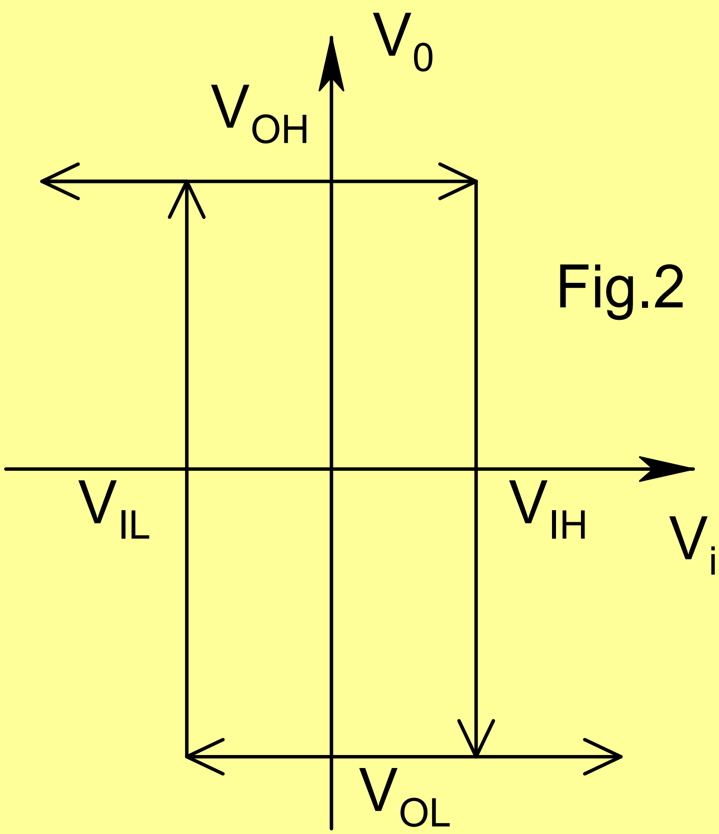
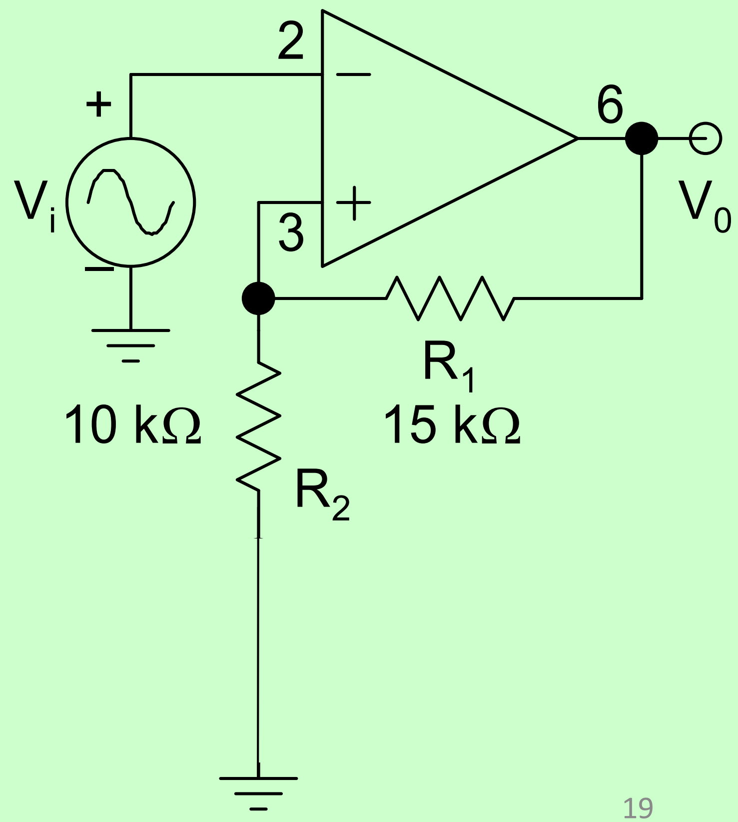
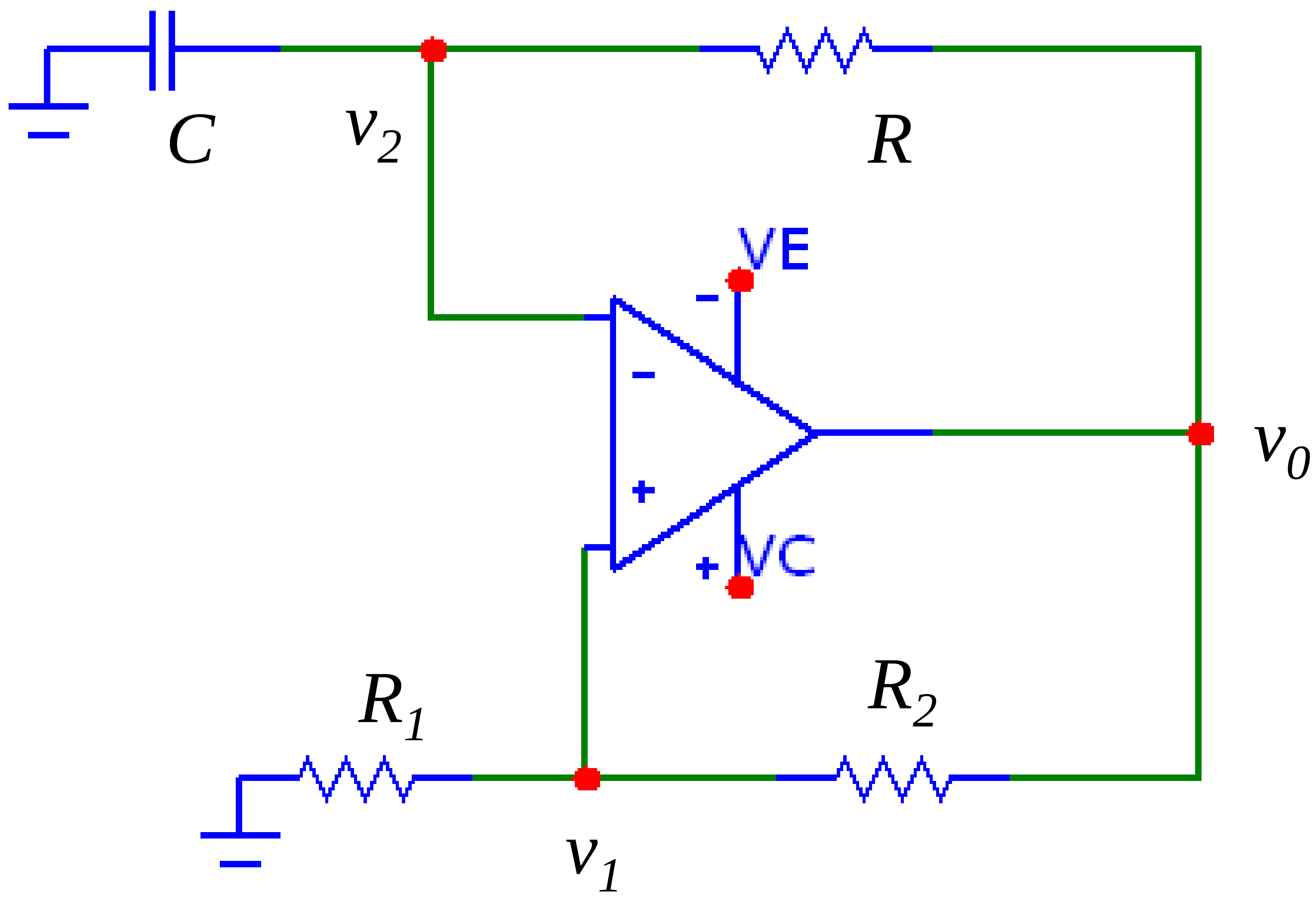


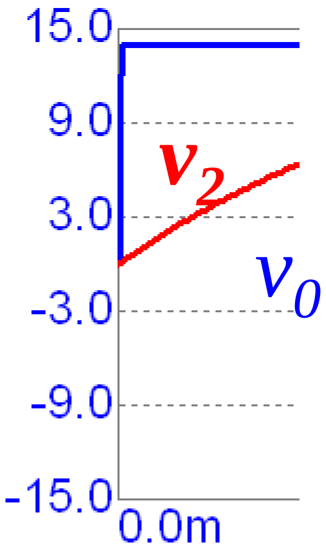
Fig.2

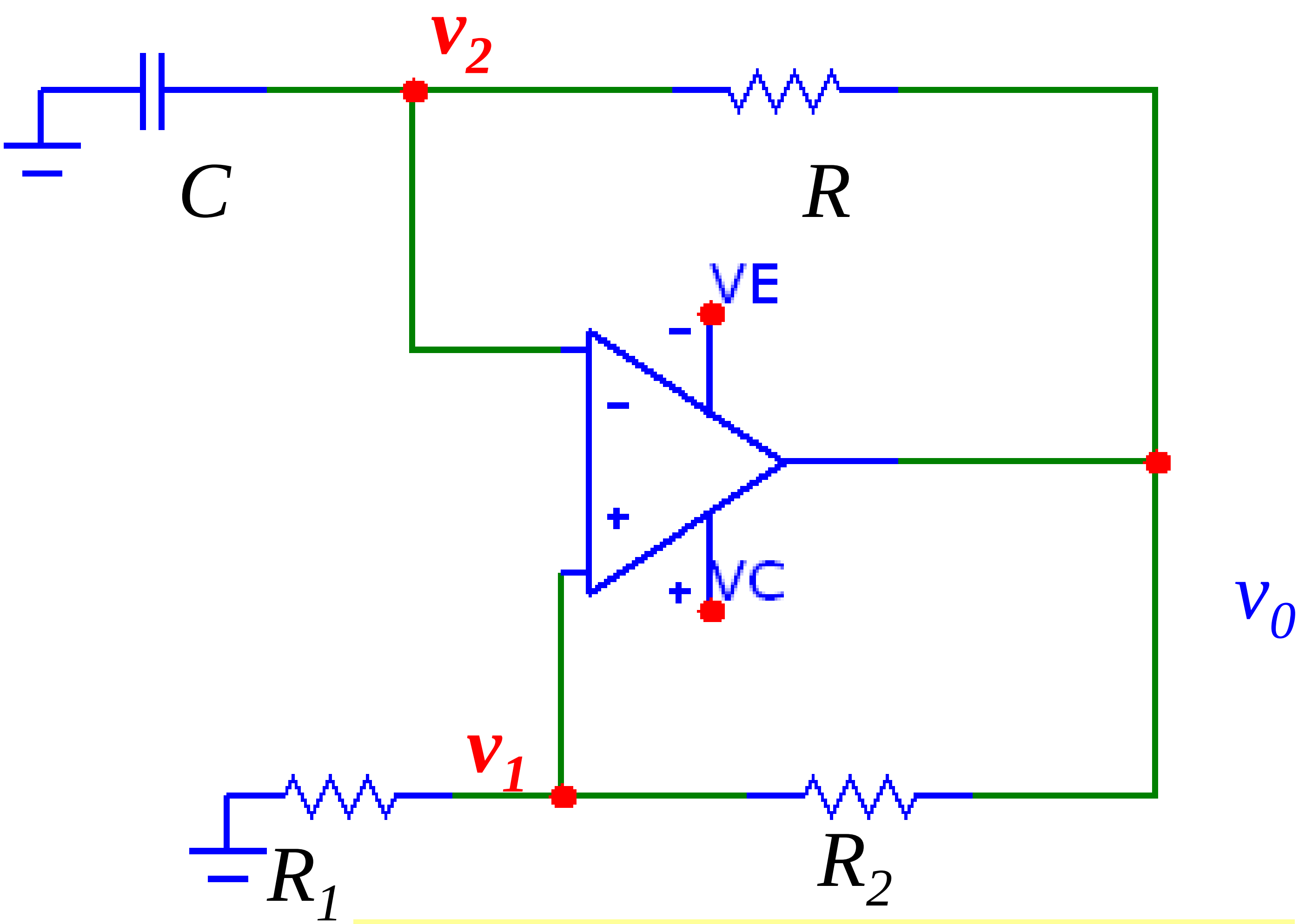


Bring in a Capacitor



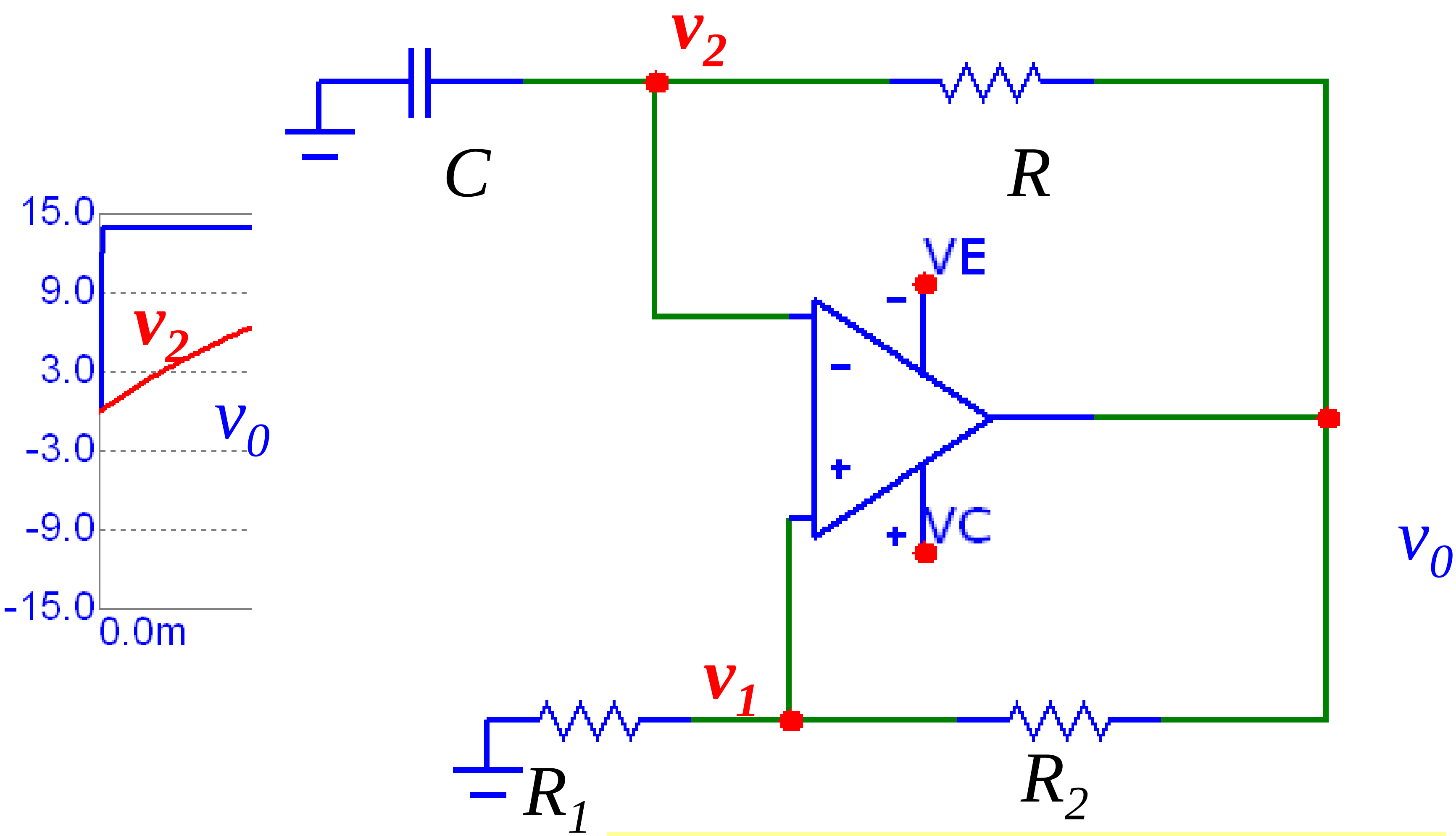
Square Wave Generator





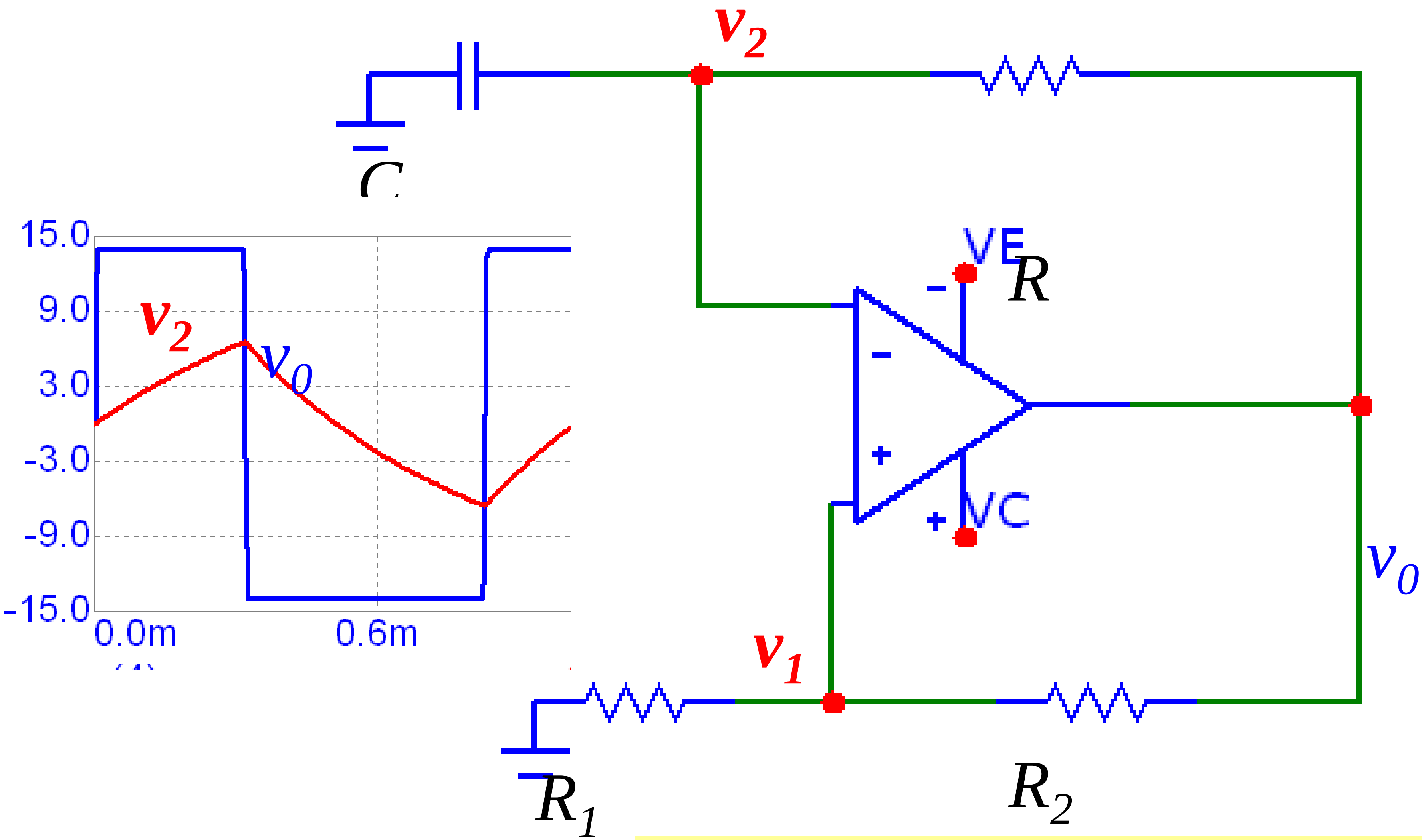
$$v_1 = v_0 \frac{R_1}{R_1 + R_2} = +V_{sat} \frac{R_1}{R_1 + R_2}$$

Square Wave Generator



$$v_1 = v_0 \frac{R_1}{R_1 + R_2} = -V_{sat} \frac{R_1}{R_1 + R_2}$$

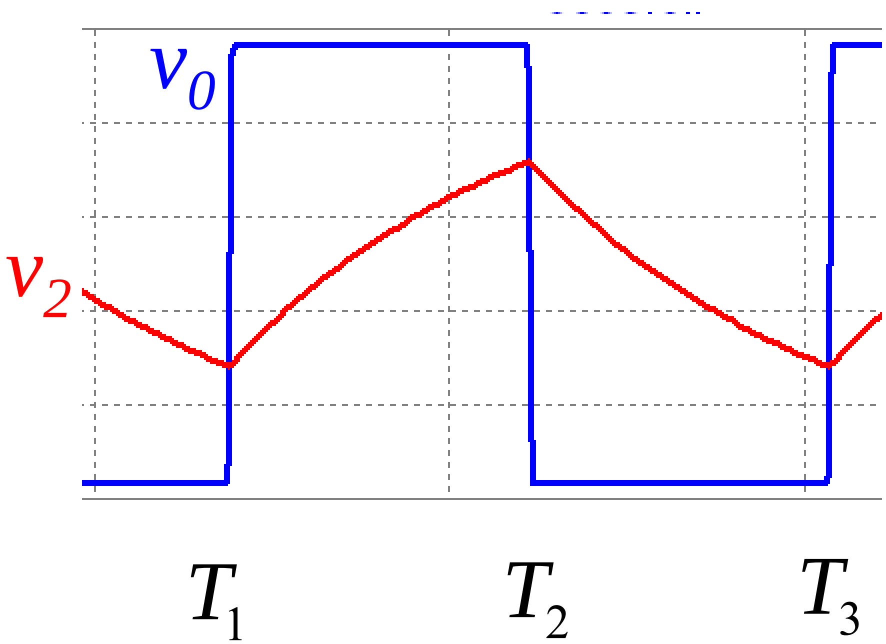
Square Wave Generator

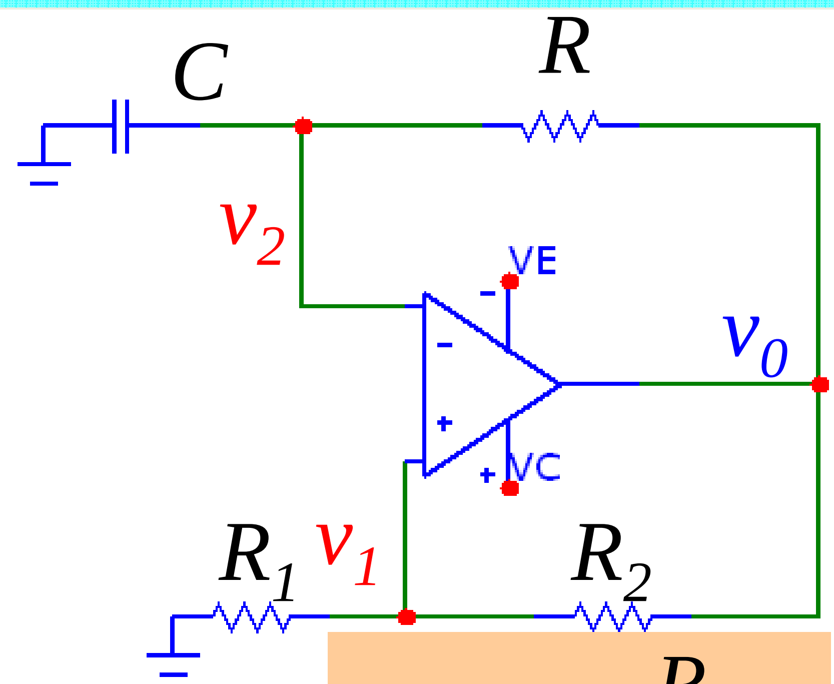


$$v_1 = v_0 \frac{R_1}{R_1 + R_2} = -V_{sat} \frac{R_1}{R_1 + R_2}$$

Square Wave Generator

$$v_C(t) = v_C(\infty) + \{v_C(0^+) - v_C(\infty)\}\ e^{-\frac{t}{RC}}$$



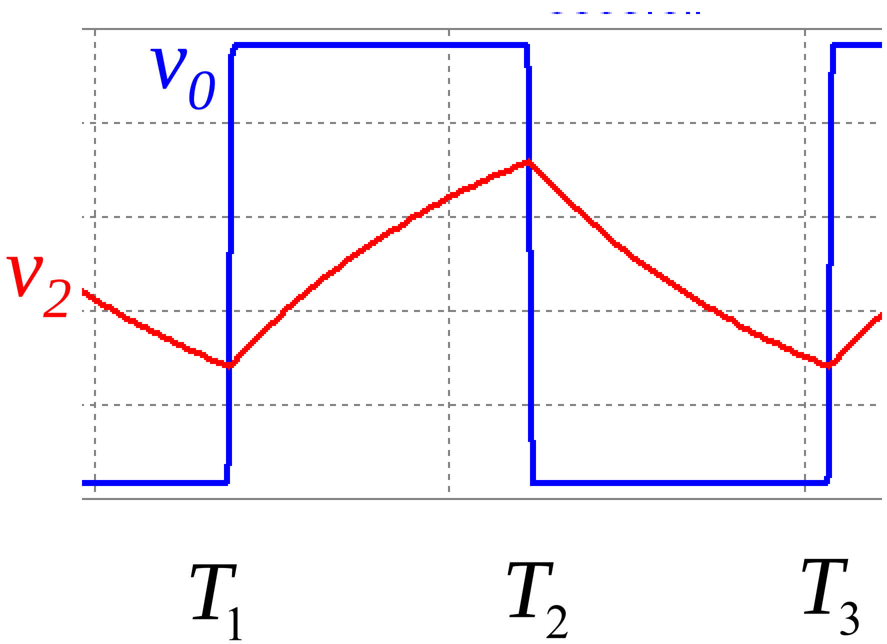


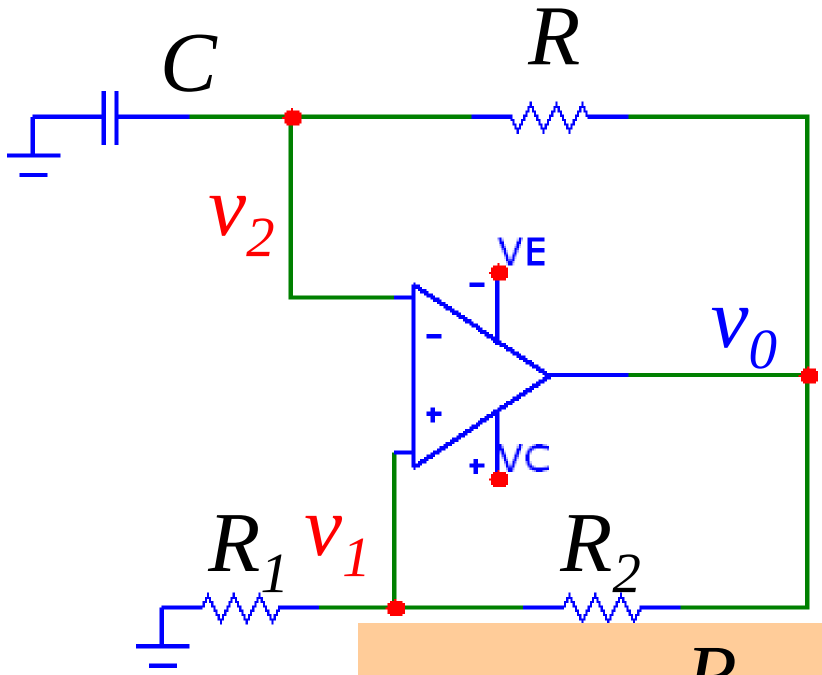
$$v_1 = v_0 \frac{R_1}{R_1 + R_2}$$

$$v_2(t) = +V_{sat} - [V_{sat} - v_2(T_1)]e^{-\frac{(t-T_1)}{\tau}}$$

$$v_2(T_2) = +V_{sat} - [V_{sat} - v_2(T_1)]e^{-\frac{(T_2-T_1)}{\tau}}$$

Square Wave Generator





$$v_1 = v_0 \frac{R_1}{R_1 + R_2}$$

$$v_2(T_2) = +V_{sat} - [V_{sat} - v_2(T_1)]e^{-\frac{(T_2 - T_1)}{\tau}}$$

$$v_2(T_1) = -V_{sat} \frac{R_1}{R_1 + R_2}$$

$$v_2(T_2) = +V_{sat} \frac{R_1}{R_1 + R_2}$$

Square Wave Generator

$$T_2 - T_1 = \tau \ln\left[1 + 2\frac{R_1}{R_2}\right]$$

Similarly,

$$T_3 - T_2 = \tau \ln\left[1 + 2\frac{R_1}{R_2}\right]$$

$$T = T_3 - T_1 = 2\tau \ln\left[1 + 2\frac{R_1}{R_2}\right]$$