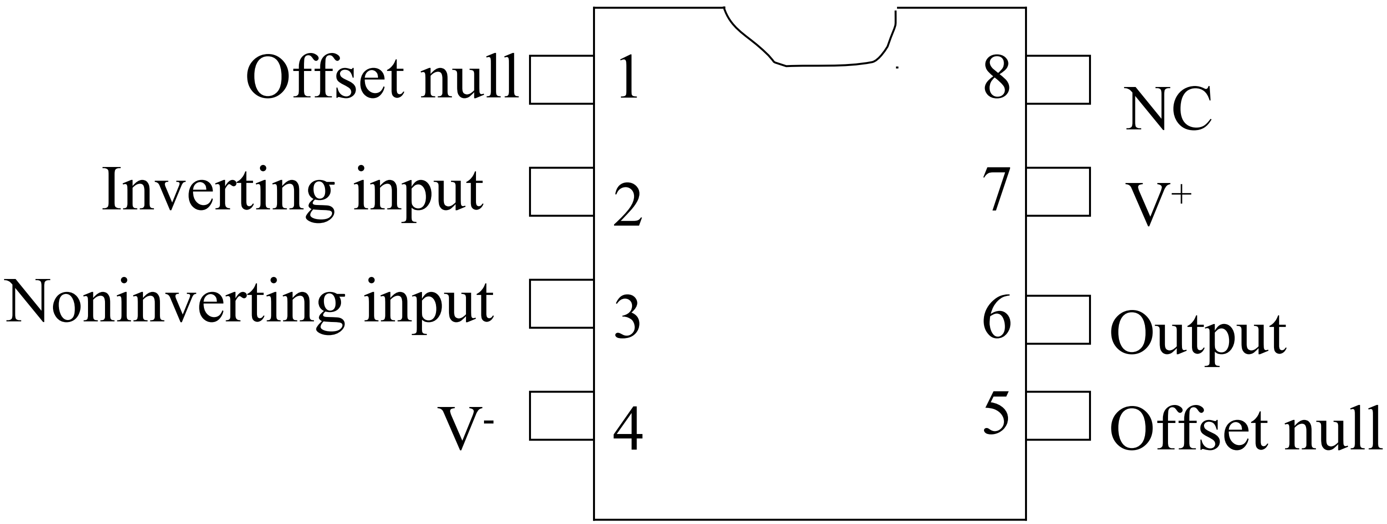
THE OPERATIONAL AMPLIFIER

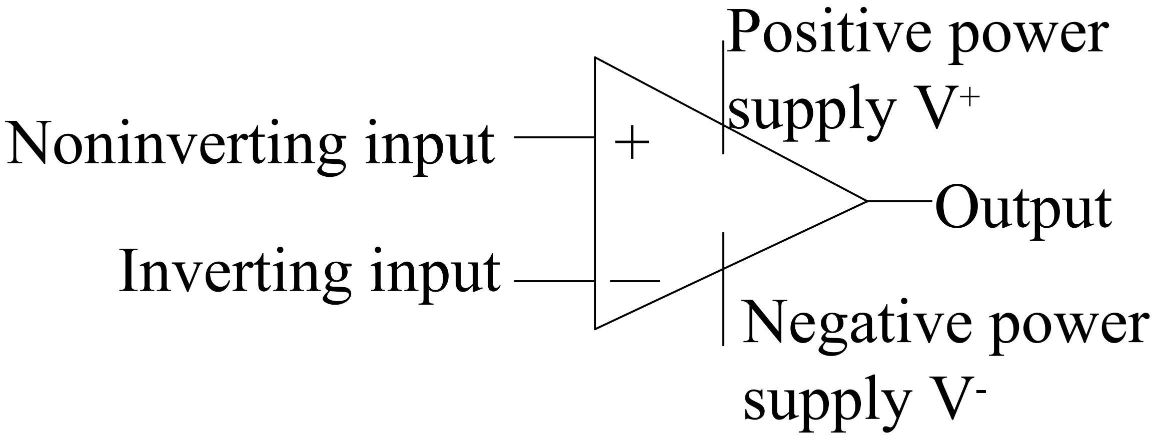
OSMAN PARLAKTUNA
OSMANGAZİ UNIVERSITY
ESKİŞEHİR, TURKEY
www.ogu.edu.tr/~oparlak

THE OP AMP

- In 1968, Fairchild Semiconductor introduced an op amp μA741.
- It is referred to as operational amplifier because it was used to implement mathematical operations such as addition, subtraction, integration, differentiation, sign changing, and scaling.

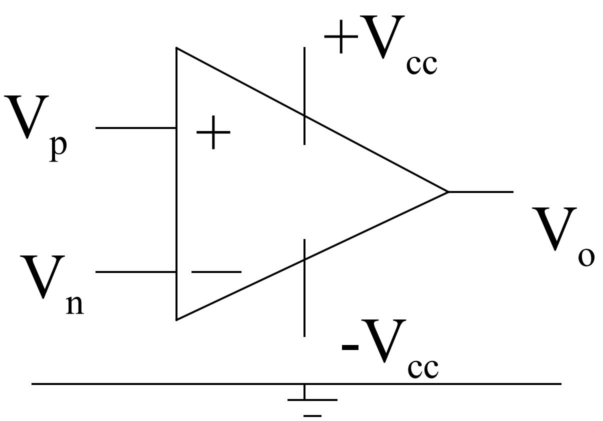
DIP PACKAGE AND SYMBOL

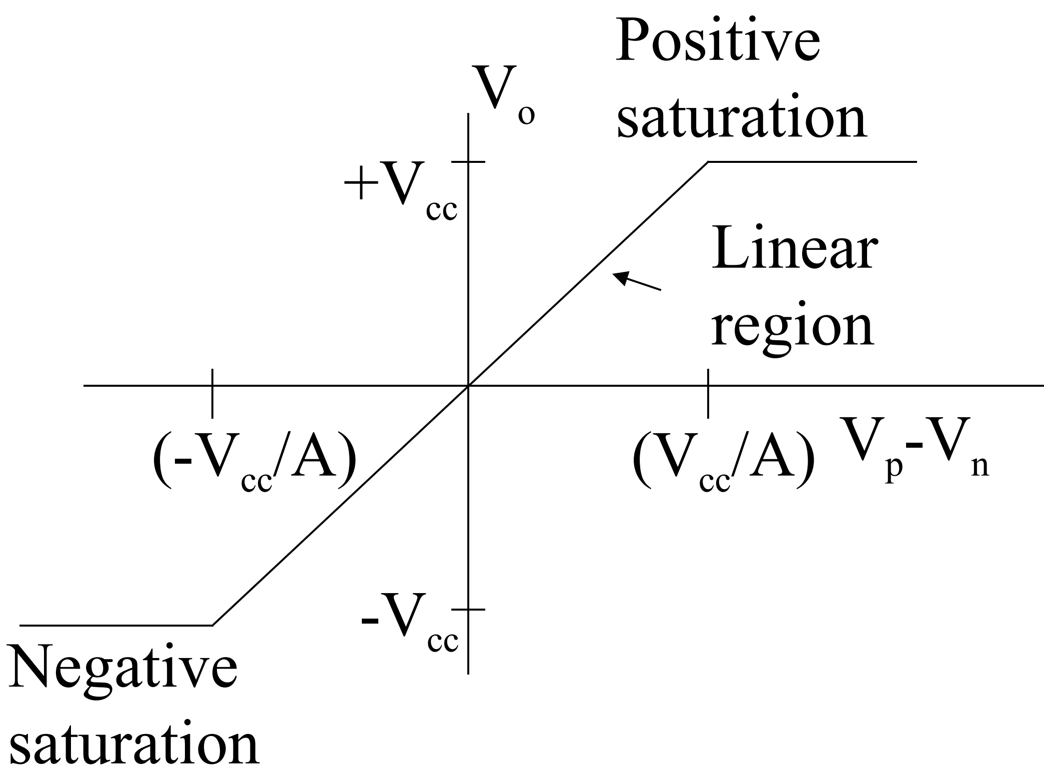




TERMINAL VOLTAGES AND CURRENTS

The terminal behavior of the op amp as a linear circuit element is characterized by constraints on the input voltages and the input currents.

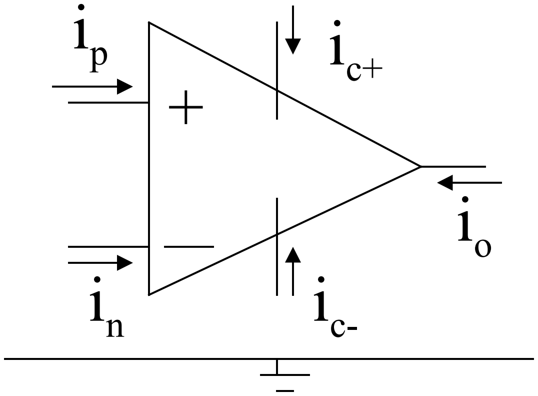




Virtual Short (virtual ground)

When the op amp operates in the linear region, a constraint is imposed on the input voltages V_p and V_n. For a typical op amp V_{cc} seldomly exceed 20V, and the gain A is rarely less than 10000. Thus, in the linear region, the magnitude of the input voltage difference ($|V_p-V_n|$) must be less than 2mV. A voltage difference less than 2mV means the two voltages are essentially equal. Then, in the linear region operation we will assume that $V_p=V_n$. This constraint on the input voltages is known as **virtual short** concept. If one of the input voltages is connected to the ground, then $V_p=V_n=0$ (**Virtual ground**)

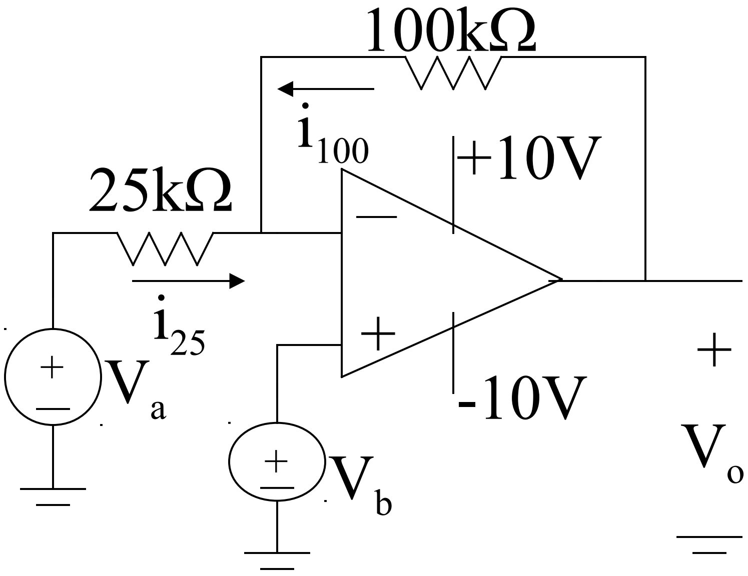
Current Constraint



The equivalent resistance seen by the input terminals of the op amp is very large, typically 1MΩ or more. Ideally, the input resistance is infinite, resulting in the current constraint $i_p = i_n = 0$.

$i_p + i_n + i_{c+} + i_{c-} + i_o = 0$. Then, $i_o = -(i_{c+} + i_{c-})$

EXAMPLE



The op amp in the circuit is idea

a) Calculate V_o if V_a=1V and V_b=0V

b) Repeat a) for V_a=1V and V_b=2V

c)If V_a=1.5V, specify the range of V_b that avoids saturation

$V_p = V_b = 0 = V_n$

$i_{25} + i_{100} = 0$

$i_{25} = (V_a - V_n)/25 = 1/25$ mA

$i_{100} = (V_o - V_n)/100 = V_o/100$ mA

$1/25 + V_o/100 = 0$

$Vo = -4V$

b) $V_p = V_n = V_b = 2V$

$$i_{25} = \frac{V_a - V_n}{25} = \frac{1-2}{25} = -\frac{1}{25} mA$$

$$i_{100} = \frac{V_o - V_n}{100} = \frac{V_o - 2}{100} mA$$

$V_o = 6V$

c)

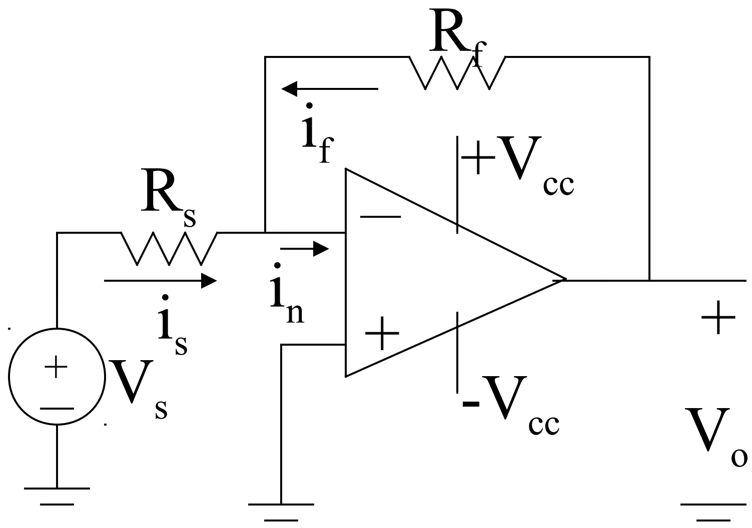
$$V_n = V_p = V_b$$

$$i_{25} = -i_{100}$$

$$\frac{1.5 - V_b}{25} = -\frac{V_o - V_b}{100} \Rightarrow V_b = \frac{1}{5}(6 + V_o)$$

$$-10V \le V_o \le 10V \Rightarrow -0.8V \le V_b \le 3.2V$$

THE INVERTING-AMPLIFIER CIRCUIT



$$i_s + i_f = i_n \qquad V_p = V_n = 0$$

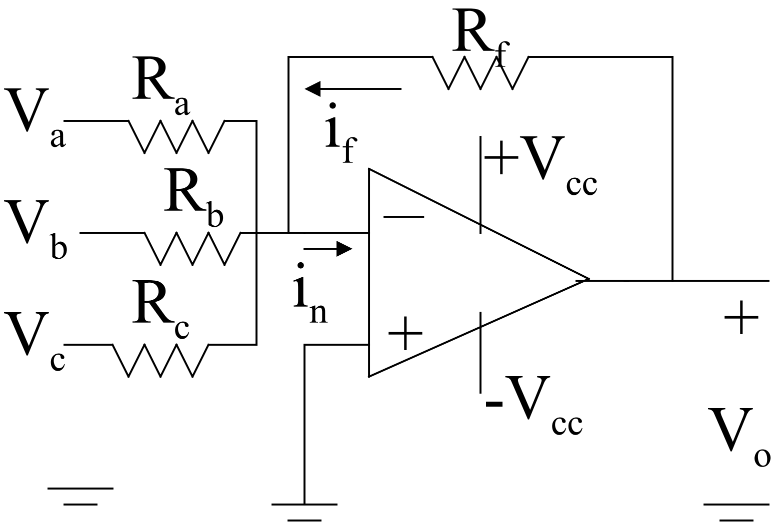
$$i_s = \frac{V_s}{R_s} \qquad i_f = \frac{V_o}{R_f}$$

$$i_n = 0 \qquad V_o = -\frac{R_f}{R_s} V_s$$

For a linear region operation, $|V_o| < V_{cc}$. Then

$$\left| \frac{R_f}{R_s} V_s \right| < V_{cc} \Rightarrow \frac{R_f}{R_s} < \left| \frac{V_{cc}}{V_s} \right|$$

THE SUMMING-AMPLIFIER CIRCUIT



$$V_p = V_n = 0 \qquad i_n = 0$$

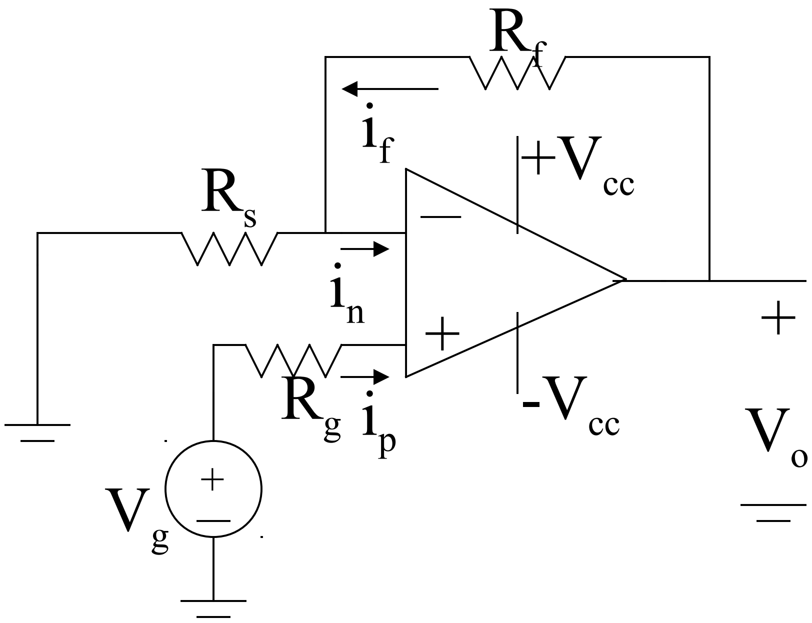
$$\frac{-V_a}{R_a} + \frac{-V_b}{R_b} + \frac{-V_c}{R_c} + \frac{-V_o}{R_f} = 0$$

$$V_o = -\left(\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \frac{R_f}{R_c} V_c \right)$$

If $R_a = R_b = R_c = R_s$

$$V_o = -\frac{R_f}{R_s}(V_a + V_b + V_c)$$

THE NONINVERTING-AMPLIFIER CIRCUIT



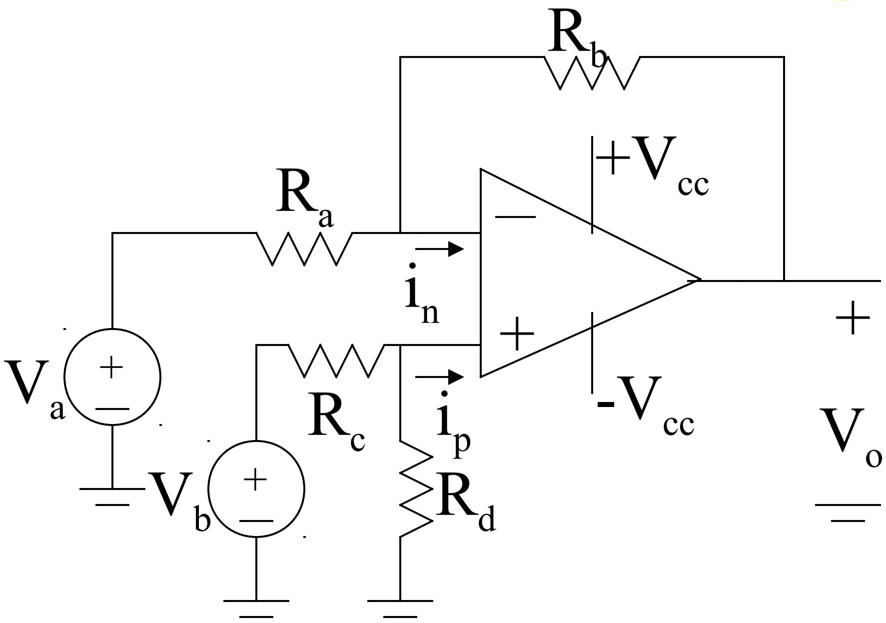
Because $i_p = i_n = 0$, $V_p = V_g = V_n$

$$\frac{V_g}{R_s} + \frac{V_g - V_o}{R_f} = 0$$

$$V_g = \frac{R_s + R_f}{R_s} V_g$$

$$\frac{R_s + R_f}{R_s} < \left| \frac{V_{cc}}{V_g} \right|$$

THE DIFFERENCE-AMPLIFIER CIRCUIT



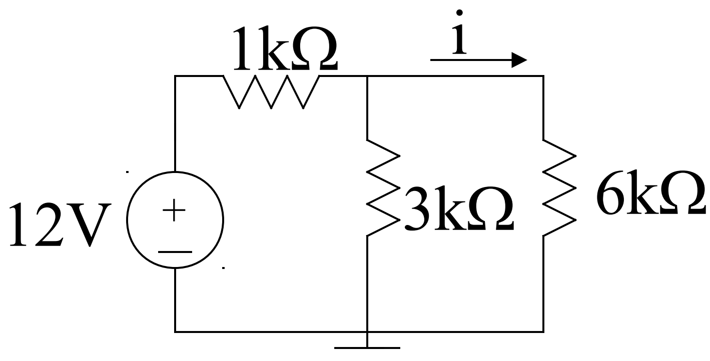
$$V_p = V_n = \frac{R_d}{R_c + R_d} V_b$$

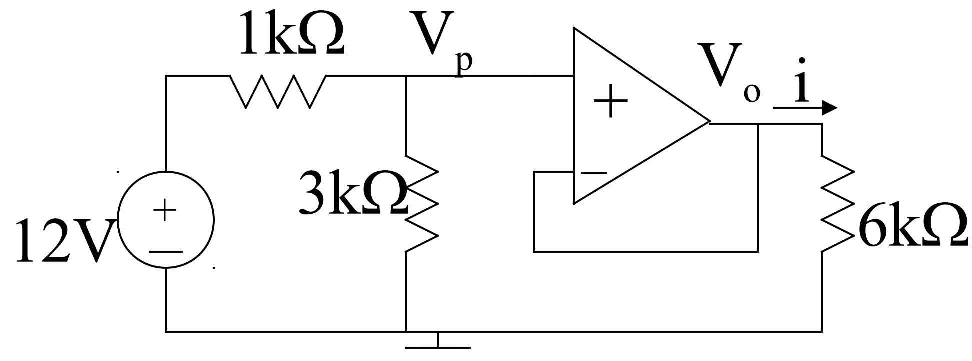
$$\frac{V_n - V_a}{R_a} + \frac{V_n - V_o}{R_b} = 0$$

$$V_o = \frac{R_d(R_b + R_a)}{R_a(R_c + R_d)} V_b - \frac{R_b}{R_a} V_a$$

If $\quad \frac{R_a}{R_b} = \frac{R_c}{R_d} \Rightarrow V_o = \frac{R_b}{R_a}(V_b - V_a)$

EXAMPLE





Calculate i for both circuits, compare the results.

$$3||6 = 2k\Omega$$

$$V = \frac{2}{2+1}12 = 8V$$

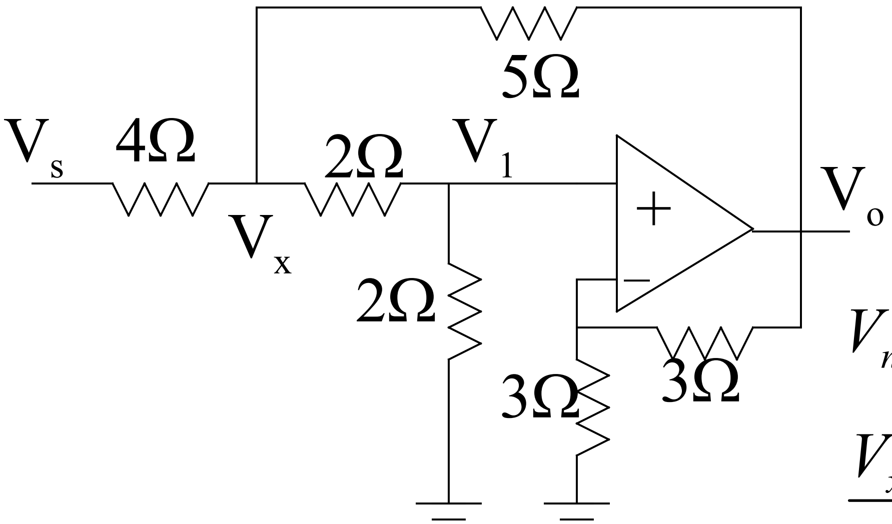
$$i = \frac{8}{6}mA$$

$$V_p = \frac{3}{3+1}12 = 9V$$

$$V_o = V_p = 9V \text{ (Voltage follower)}$$

$$i = \frac{9}{6}mA$$

EXAMPLE



Find V_o in terms of V_s

$$V_n = \frac{3}{3+3}V_o = \frac{V_o}{2} = V_p = V_1$$

$$\frac{V_x - V_s}{4} + \frac{V_x - V_1}{2} + \frac{V_x - V_o}{5} = 0$$

$$\frac{V_1 - V_x}{2} + \frac{V_1}{2} = 0 \Rightarrow V_x = 2V_1 \Rightarrow V_o = V_x$$

$$\frac{V_o - V_s}{4} + \frac{V_o - \frac{V_o}{2}}{2} + \frac{V_o - V_0}{5} = 0 \Rightarrow V_o = \frac{V_s}{2}$$