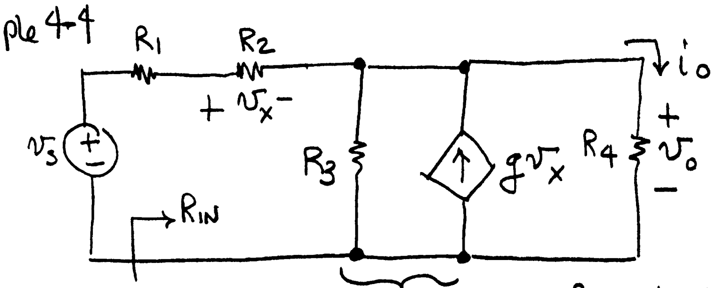
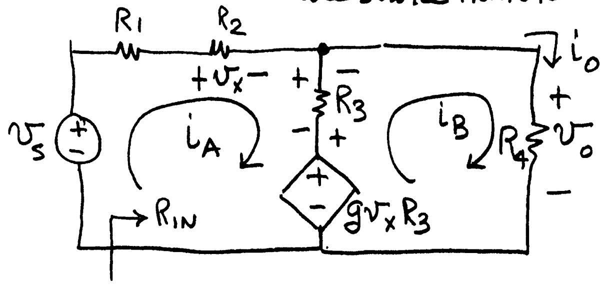
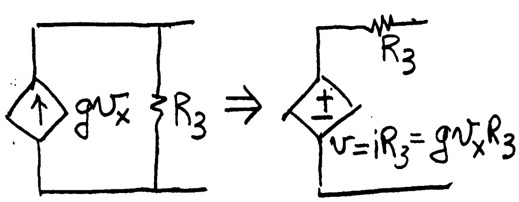
Example 4-4



use source transform to give two branches





write mesh equations

$$-v_s + i_A(R_1+R_2) + i_A R_3 - i_B R_3 + g v_x R_3 = 0$$

$$-g v_x R_3 + i_B R_3 - i_A R_3 + i_B R_4 = 0$$

Now use control constraint $v_x = i_A R_2$

$$(R_1 + R_2 + R_3 + g R_2 R_3)\, i_A \quad - R_3\, i_B = v_s$$

$$(-g R_2 R_3 - R_3)\, i_A \quad + (R_3 + R_4)\, i_B = 0$$

Can numerically solve for

$R_1 = 50$, $R_2 = 1k$, $R_3 = 100$, $R_4 = 5k$

$g = 100\,mS$

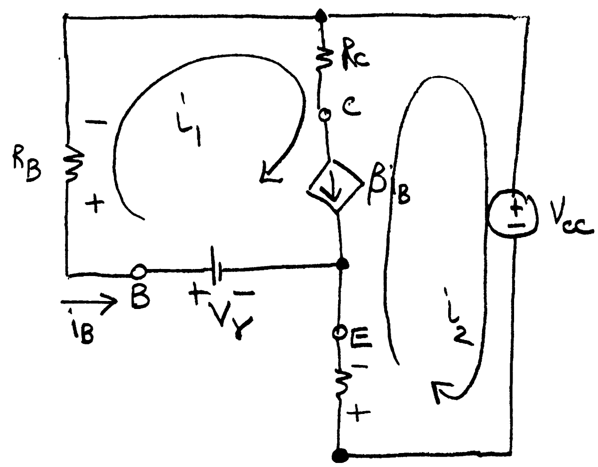
$$i_A = 0.9131 \times 10^{-4}\, v_s$$

$$i_B = 1.808 \times 10^{-4}\, v_s$$

$$\Rightarrow \quad v_o = R_4 i_B = (5\times10^3)(1.808\times10^{-4} v_s) = 0.904\, v_s$$

$$R_{IN} = \frac{v_s}{i_A} = \frac{\cancel{v_s}}{0.9131\times10^{-4}\,\cancel{v_s}} = 10.95\,k\Omega.$$

Example 4-5



① write KVL around outer mesh

$$+i_2 R_E - V_\gamma + i_1 R_B + V_{cc} = 0$$

② use KCL at current source

$$\beta i_B = i_1 - i_2$$

③ NOTE : $i_B = -i_1 \Rightarrow \quad \beta i_B = -i_B - i_2$

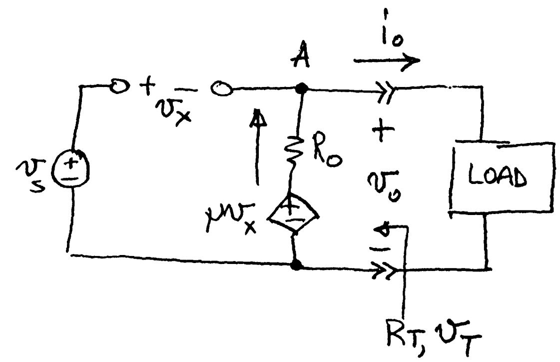
$$-i_2 = (\beta+1)\, i_B$$

$$-\underline{(\beta+1)\, i_B R_E} - V_\gamma \underline{- i_B R_B} + V_{cc} = 0$$

$$i_B\left[R_B + (\beta+1) R_E\right] = V_{cc} - V_\gamma$$

$$i_B = \frac{V_{cc} - V_\gamma}{R_B + (\beta+1) R_E}$$

Example 4-8



$$v_x = v_s - v_o$$

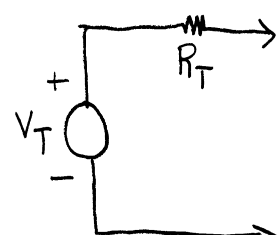
$\sum_{\text{in}} i$ @ node A $\qquad + \dfrac{\mu v_x - v_o}{R_o} - i_o = 0$

This is an output v-i relationship if we eliminate v_x

$$\frac{\mu(v_s - v_o) - v_o}{R_o} - i_o = 0$$

$$\frac{\mu v_s}{\mu+1} - \frac{\cancel{(\mu+1)} v_o}{\cancel{\mu+1}} - \frac{i_o R_o}{\mu+1} = 0$$

$$v_o = \underbrace{\frac{\mu}{\mu+1} v_s}_{V_T = \frac{\mu}{\mu+1} v_s} - \underbrace{\frac{R_o}{\mu+1}}_{R_T = \frac{R_o}{\mu+1}} i_o$$

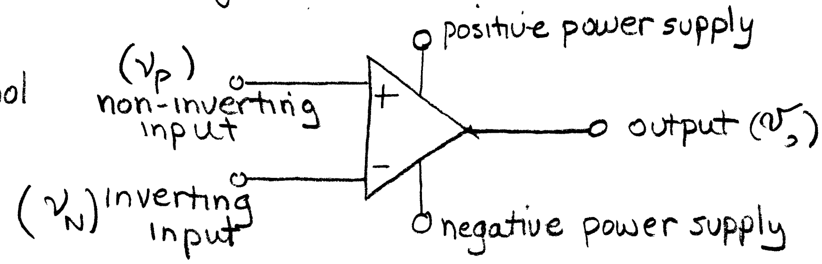


4.4 The Operational Amplifier

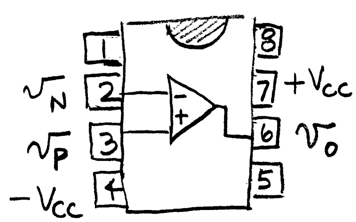
The term "operational amplifier" was first used in 1947 to describe DC high gain amplifiers which could be used to perform mathematical operations such as addition, subtraction, multiplication, division, integration, etc.

Originally built with vacuum tubes, these were implemented with transistors and then as integrated circuits in the 1960's. The OP AMP is now the most popular integrated circuit.

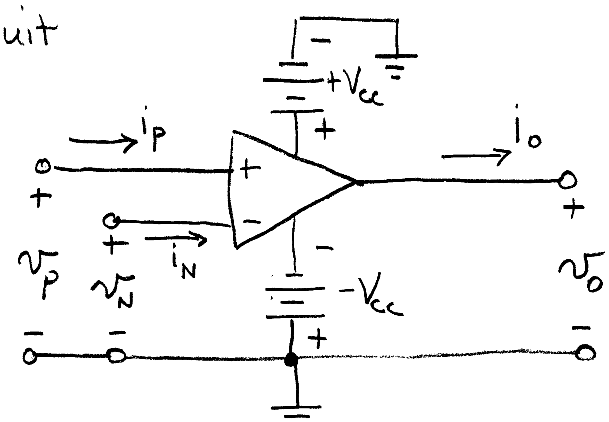
Electrical symbol



These are sold in 8-pin packages (Top view) [It is also available in other packages.]



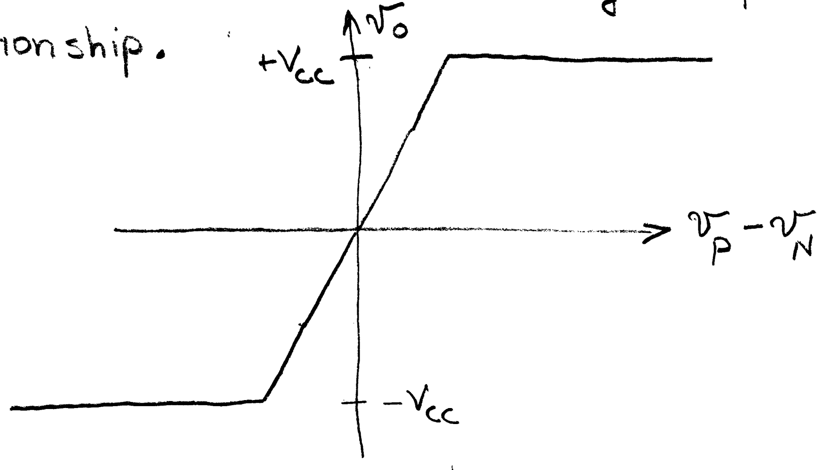
Basic circuit



$$v_o = A(v_P - v_N)$$

We often don't draw the power supply connections but all OPAMPS require them.

The OP AMP can be characterized by its input–output relationship.



$\underbrace{\qquad\qquad}_{\text{– saturation}}$ $\underbrace{\qquad\qquad}_{\text{linear region}}$ $\underbrace{\qquad\qquad}_{\text{+ saturation}}$

– saturation

$v_o = -V_{cc}$
when $A(v_P - v_N) < -V_{cc}$

linear region

+ saturation

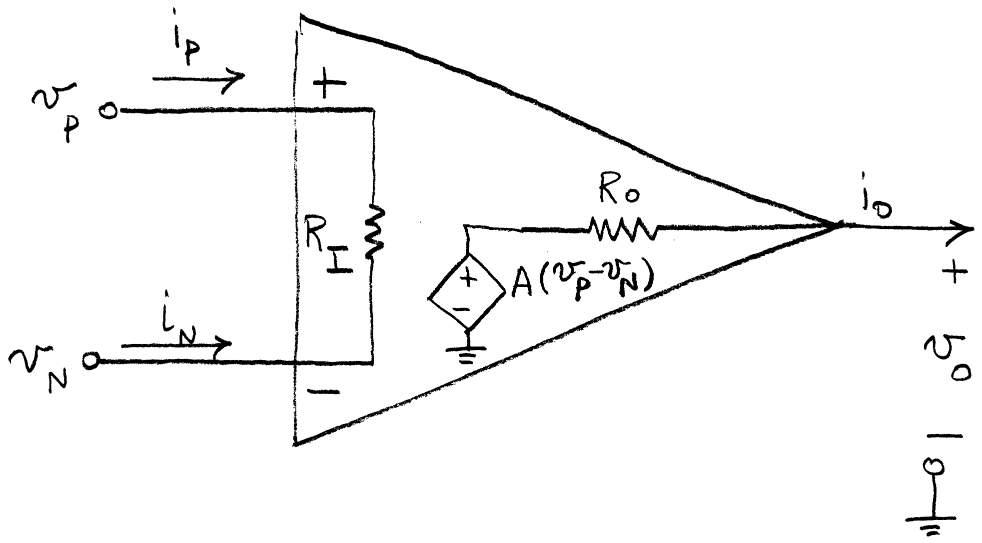
$v_o = +V_{cc}$
when $A(v_P - v_N) > V_{cc}$

in the linear region

$$v_o = A(v_P - v_N)$$

This is the normal range of operation.

What is inside the OP AMP?



For modern integrated circuit OP AMPS

$$10^6 < R_I < 10^{12}\ \Omega$$

$$10 < R_o < 100\ \Omega$$

$$10^5 < A < 10^8$$

A is called the open loop gain

We can write

$$-V_{cc} \le v_o \le +V_{cc}$$

$$-V_{cc} \le A(v_P - v_N) \le +V_{cc}$$

$$-\frac{V_{cc}}{A} \le v_P - v_N \le +\frac{V_{cc}}{A}$$

Since A is so large

$$v_P - v_N \approx 0$$

or $\boxed{v_P = v_N}$

Since R_I is so large $\boxed{i_P = i_N \approx 0}$