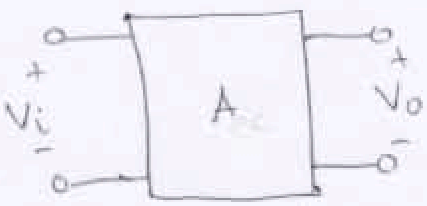
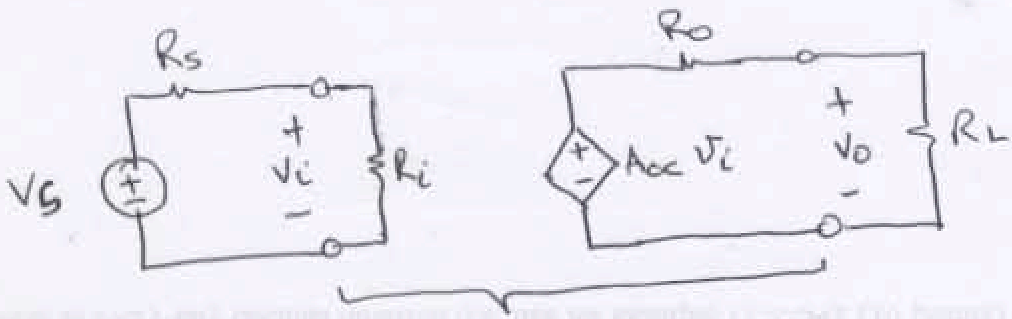
Intro



two-port device

if A is independent of v_i → linear amplifier

voltage amplifier

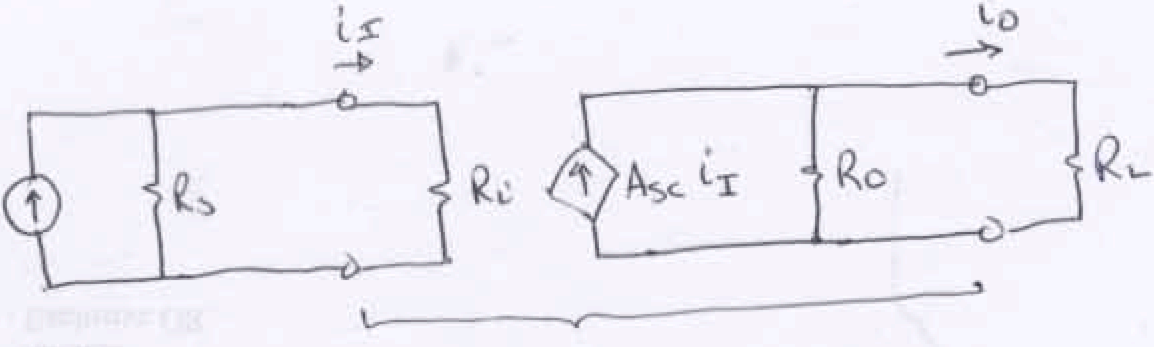


voltage amp.

$$V_o = A_{oc} v_i \frac{R_L}{R_L + R_o} \quad ; \quad v_i = \frac{R_i}{R_i + R_s} v_S$$

$$V_o = A_{oc} \frac{R_i}{R_i + R_s} \frac{R_L}{R_L + R_o} v_S$$

$$\text{gain} = A = \frac{V_o}{V_S} = A_{oc} \underbrace{\frac{R_i}{R_i + R_S}}_{\text{input loading}} \underbrace{\frac{R_L}{R_L + R_o}}_{\text{output loading}}$$



Current Amp.

$$i_O = A_{sc}\, i_I \frac{R_O}{R_O + R_L} \quad ; \quad i_I = i_S \frac{R_S}{R_S + R_i}$$

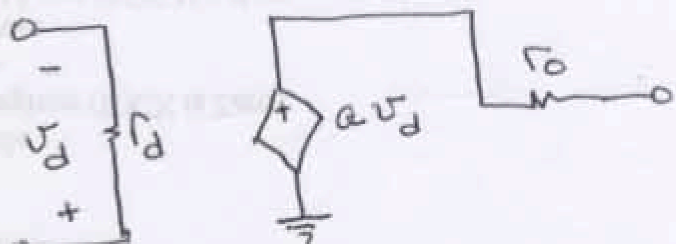
$$A_i = \frac{i_O}{i_S} = A_{sc} \frac{R_S}{R_S + R_i} \frac{R_O}{R_O + R_L}$$

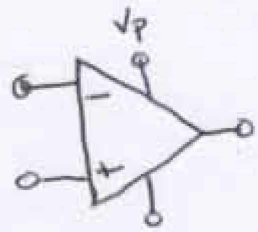
The are also:

Transconductance amplifier → v_i, i_O

Transresistance amplifier → i_I, v_O

OP AMP





Typical numbers (741)

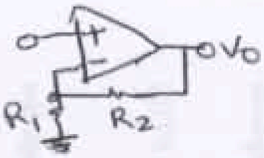
$r_d = 2 M\Omega$

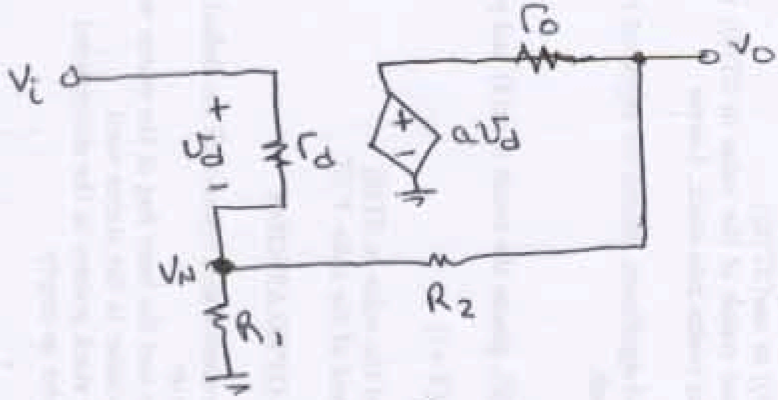
$r_o = 75 \Omega$

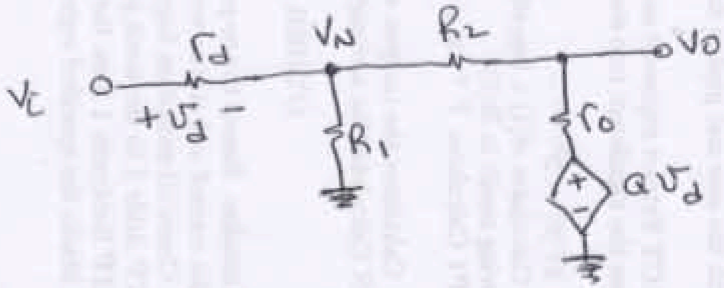
$a = 200\ V/mV$

Basic config.

non-inverting.







KCL at v_N: $$\frac{v_i - v_N}{r_d} = \frac{v_N}{R_1} + \frac{v_N - v_O}{R_2} \quad (1)$$

KCL at v_O: $$\frac{v_N - v_O}{R_2} = \frac{v_O - a v_d}{r_o} \quad (2)$$

$$v_d = v_i - v_N$$

from (2)

$$r_o v_N - r_o v_O = R_2 v_O - a(v_i - v_N) R_2$$

$$r_o v_N - r_o v_O = R_2 v_O - a R_2 v_i + a R_2 v_N$$

$$v_N (r_o - a R_2) = (r_o + R_2) v_O - a R_2 v_i$$

$$v_N = \frac{a R_2 v_i - (r_o + R_2) v_O}{a R_2 - r_o}$$

Let $r_o \ll R_2 \ll a R_2$

$$v_N \simeq \frac{aR_2 v_i - R_2 v_0}{aR_2} = v_i - v_0/a$$

From (1)

$$\frac{1}{r_d} v_i - \frac{1}{r_d} v_N = \frac{1}{R_1} v_N + \frac{1}{R_2} v_N - \frac{1}{R_2} v_0$$

$$\frac{1}{r_d} v_i = v_N\left(\frac{1}{r_d} + \frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_2} v_0$$

if $r_d >> R_1, R_2$, $\frac{1}{r_d} << \frac{1}{R_1}, \frac{1}{R_2}$

$$\therefore \quad \frac{1}{r_d} v_i \simeq v_N\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{1}{R_2} v_0$$

$$= v_N\left(1 + \frac{R_2}{R_1}\right) - v_0$$

$$= \left(1 + \frac{R_2}{R_1}\right)v_i - \left(1 + \frac{R_2}{R_1}\right)\left(\frac{1}{a}\right)v_0 - v_0$$

$$\left(\frac{1}{r_d} - 1 - \frac{R_2}{R_1}\right)v_i \simeq -\left(1 + \frac{R_2}{R_1}\right)v_i = -\left(1 + \frac{R_2}{R_1}\right)\left(\frac{1}{a}\right)v_0 - v_0$$

$$\boxed{\frac{v_0}{v_i} = \frac{1 + R_2/R_1}{1 + \left(1 + R_2/R_1\right)\left(\frac{1}{a}\right)}}$$

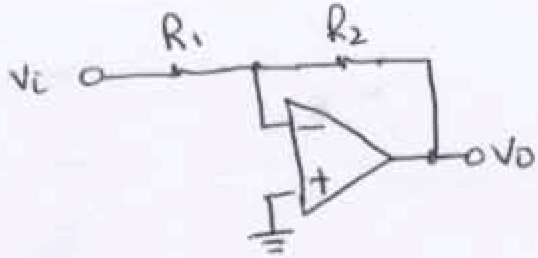
This shows the effect of having a finite open loop-gain.

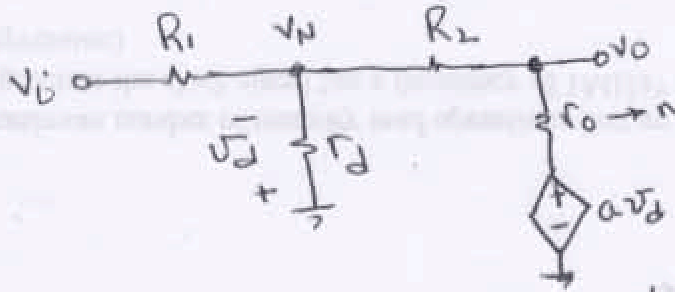
Example: $R_2 = 100 R_1$; $1/a = 1/10^4$ (very small)

$$\frac{v_0}{v_i} = \frac{101}{1 + \frac{101}{10^4}} = \frac{101}{1.0101} = 99.99$$

about 1% error in gain.

inv. amp.





$r_o \rightarrow$ neglect so $v_d = \frac{v_o}{a}$

$$v_N = -v_d = -v_o/a$$

$$\frac{v_i + v_o/a}{R_1} + \frac{v_o/a}{r_d} = \frac{-v_o/a - v_o}{R_2} = \frac{-v_o(1 + 1/a)}{R_2}$$

$$\frac{v_i}{R_1} = -v_o\left(\frac{1}{aR_1} + \frac{1}{ar_d} + \frac{1}{R_2} + \frac{1}{aR_2}\right)$$

$$= -v_o\left[\frac{1}{R_2} + \frac{1}{a}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{r_d}\right)\right]$$

$$= -\frac{v_o}{R_2}\left(1 + \frac{R_2}{a}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{r_d}\right)\right)$$

$$\boxed{\frac{v_o}{v_i} = -\frac{R_2}{R_1}\,\frac{1}{1 + \left(1 + R_2/R_1 + R_2/r_d\right)/a}}$$