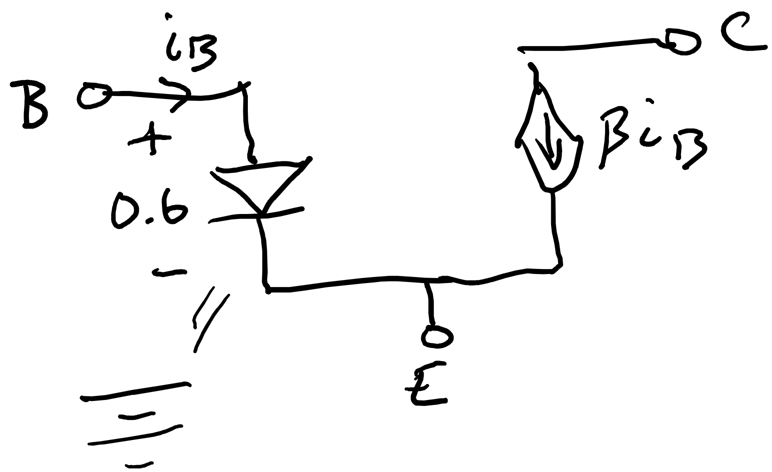
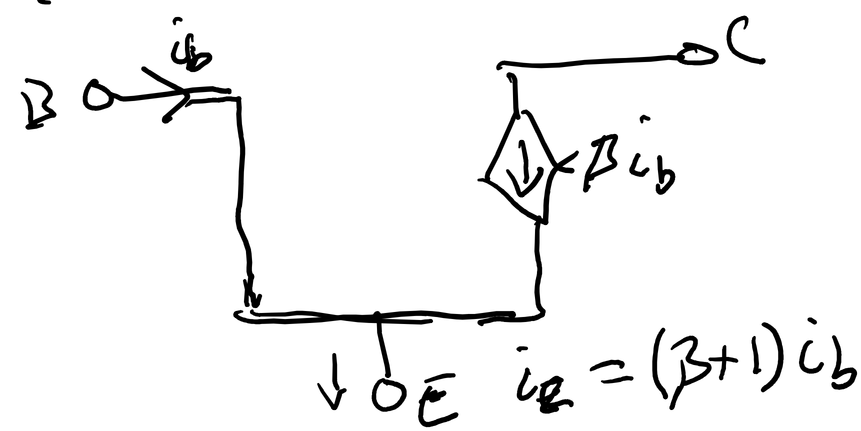
SMALL SIGNAL MODEL FOR BJT

LARGE SIGNAL



$\Longrightarrow$ S.S.

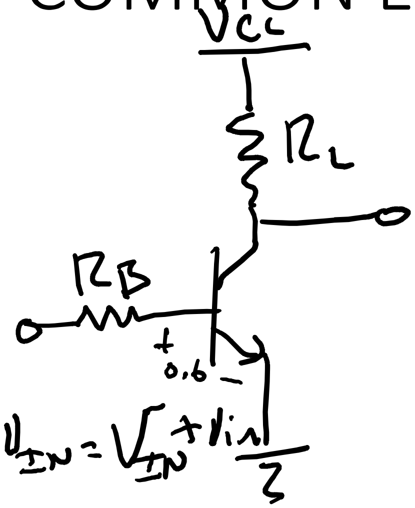


$i_e =$

$i_c =$

$=$

COMMON EMITTER AMPLIFIER



$v_{OUT} = V_{OUT} + v_{out}$

$v_{IN} = V_{IN} + v_{in}$

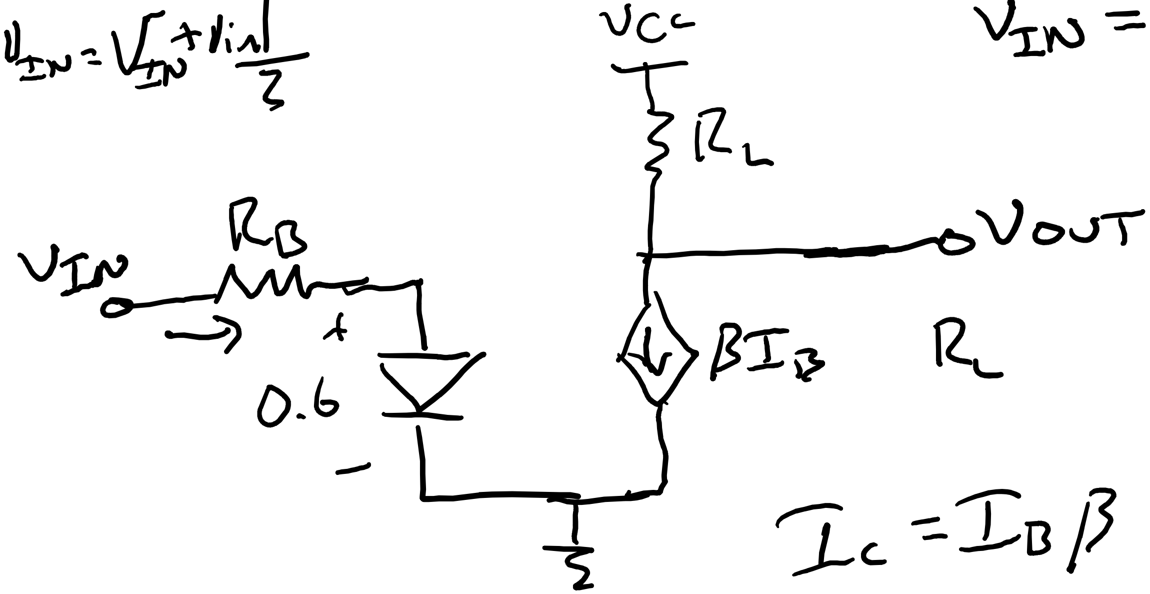
$R_B = 100k\Omega$

$R_L = 10k\Omega$

$V_{CC} = 10V$

$\beta = 100$

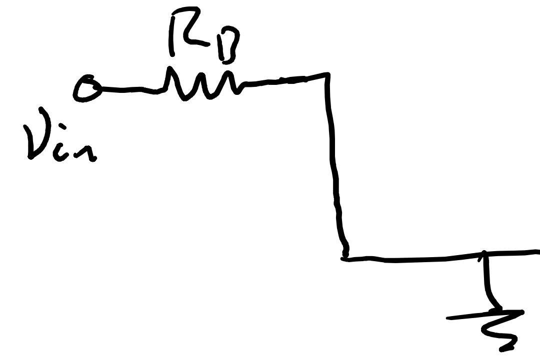
$V_{IN} = 1V$



$$I_B = \frac{V_{IN} - 0.6V}{R_B} = \frac{.4}{10^5} = 4\mu A$$

$$I_C = I_B \beta = 0.4mA$$

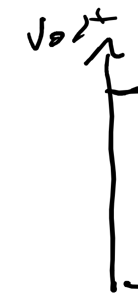
$$V_{OUT} = V_{CC} - (0.4mA)(10k\Omega) = 6V$$



$v_{out} = -\beta i_b$

$i_b = \frac{v_{in}}{R_B}$

$\frac{V_{out}}{V_{in}} = -\beta$



INPUT & OUTPUT RESISTANCE FOR C-E AMP

Input resistance $= R_B$

Output resistance

$r_{out} = R_L$

1. Zero independent sources
2. Apply v_{test}, measure i_{test}

CURRENT GAIN $=$

$$i_{test} = \frac{v_{test}}{R_B}$$

$$\beta i_b + \frac{v_{out}}{R_L} +$$

$$v_{out} = -\beta i_b ($$

$$\beta i_b - \beta i_b \frac{(R_L \|}{R}$$

$$i_b = i_{test}$$

$$\frac{i_{out}}{i_{test}} = -\beta \frac{R_L}{R_L +}$$

INPUT & OUTPUT RESISTANCE FOR C-E AMP

$$\text{Power Gain} = \frac{v_{out} \cdot i_{out}}{v_{in} \cdot i_{in}}$$

$$= \begin{pmatrix}\text{Voltage} \\ \text{Gain}\end{pmatrix} \times \begin{pmatrix}\text{Current} \\ \text{Gain}\end{pmatrix}$$

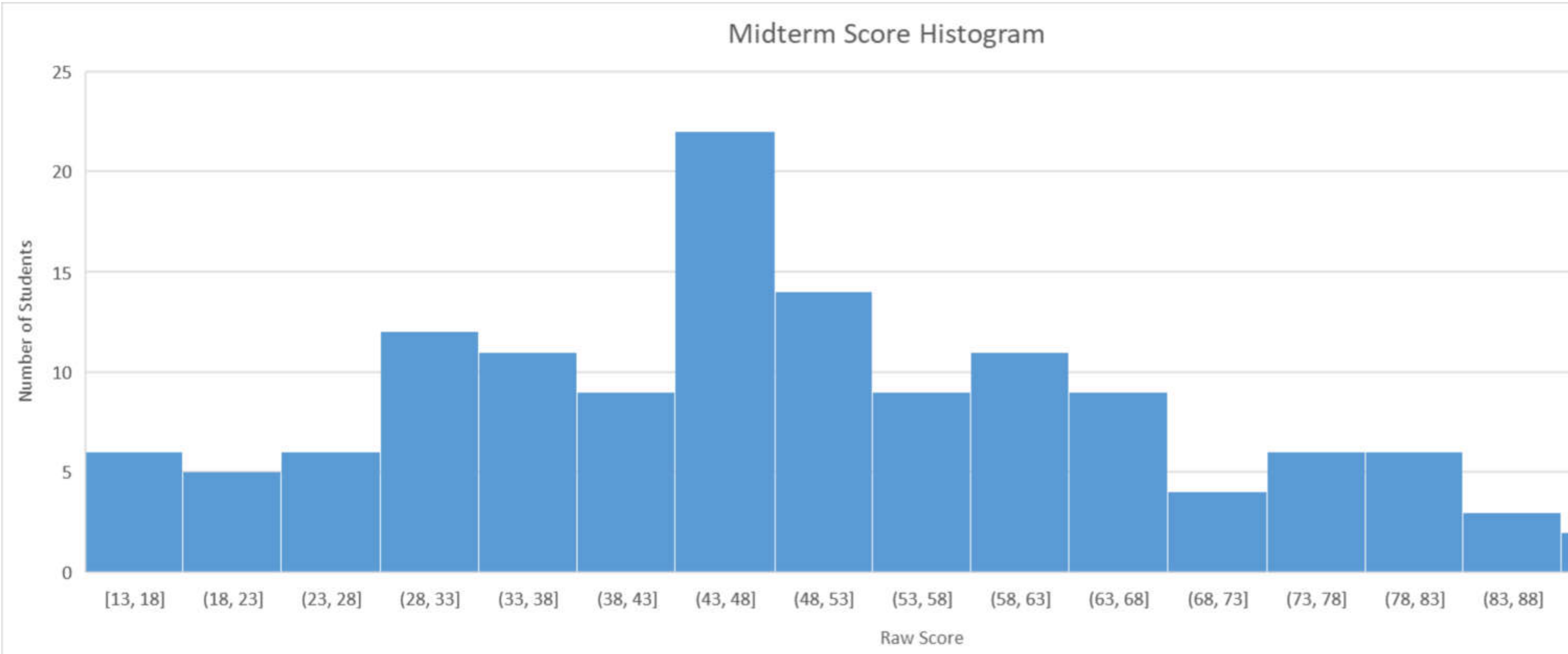
$$= -\beta\frac{(R_L \| R_o)}{R_B}\,\beta\left(\frac{R_L \| R_o}{R_o}\right) = \beta^2 \frac{(R_L \| R_o)^2}{R_o R_B}$$

with R_o

$$\frac{v_{out}}{v_{in}} = -\beta\left(\frac{R_L \| R_o}{R_B}\right)$$

$$\frac{i_{out}}{i_{test}} = -\beta\,\frac{(R_L \| R_o)}{R_o} = -\beta\,\frac{\frac{R_L R_o}{R_L + R_o}}{R_o}$$

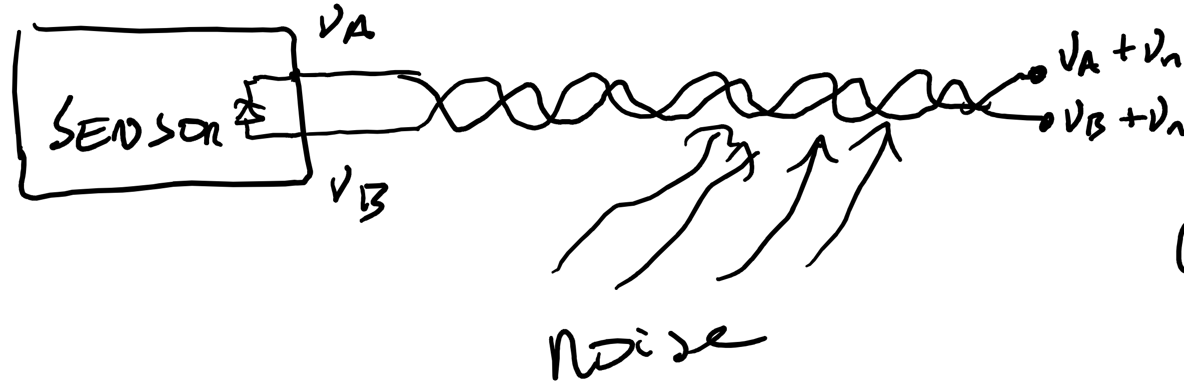
$$= -\beta\,\frac{R_L}{R_L + R_o}$$



Rough Breakdown

Grade	Range	# Students	%
A+	>86	4	3
A	68-86	19	14
B	50-68	36	26
C	32-50	52	38
D	<32	27	20

DIFFERENTIAL AMPLIFIERS



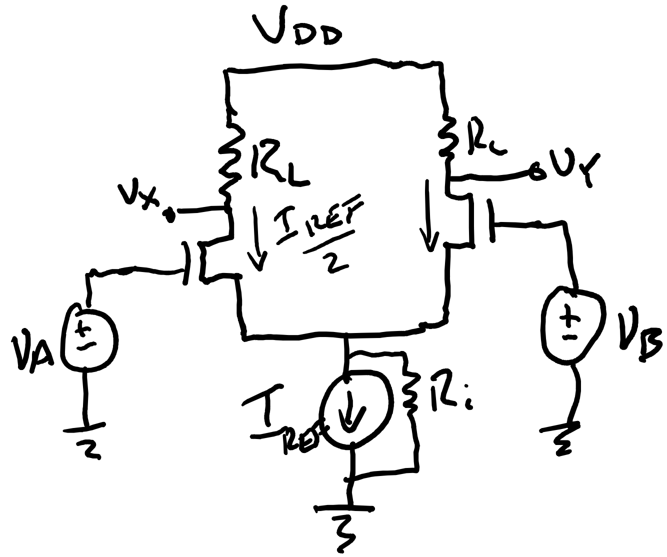
common
rejection

CMRR

DEFINE:

Difference Mode component $v_D = v_A - v_B$

Common mode component $v_{CM} = \frac{v_A + v_B}{2}$



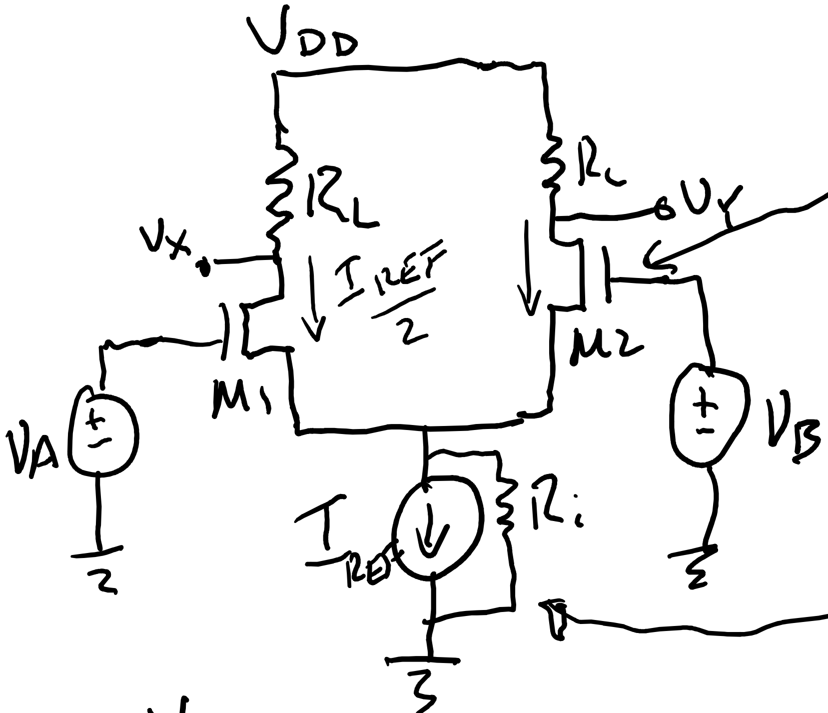
A_D = DIFFERENTIAL

→ SIGNAL

A_{CM} = COMMON - MODE

→ NOISE

DIFFERENTIAL AMPLIFIERS



SOURCE COUPLED PAIR

CURRENT SOURCE w/ finite output resistance

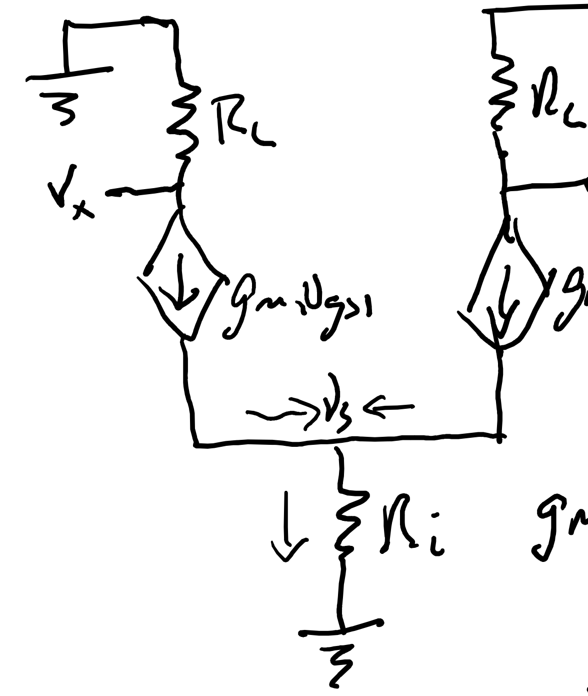
V

$V_A = V_{cm} + \frac{V_D}{2}$

$B = V_{cm} - \frac{V_D}{2}$

$V_a \to \frac{V_d}{2}$

DIFFERENCE



g_m

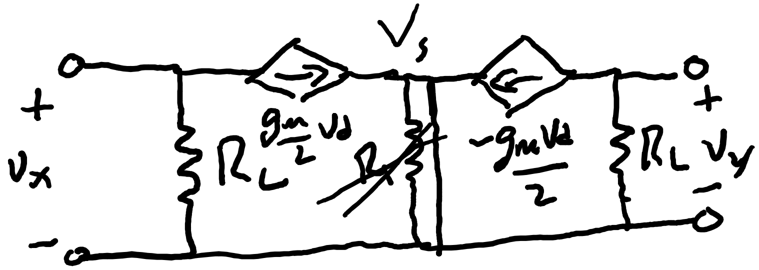
$g_m v_{gs1} + g_m v_{gs2} = \frac{V}{R}$

$\frac{V_d}{2} - v_{gs1} = V_s = -\frac{V}{}$

$g_m\left(\frac{V_d}{2} - V_s\right) + g_m\left(-\frac{V_d}{2}\right.$

$-2 g_m V_s = \frac{V}{R}$

DIFFERENCE MODE AND COMMON MODE



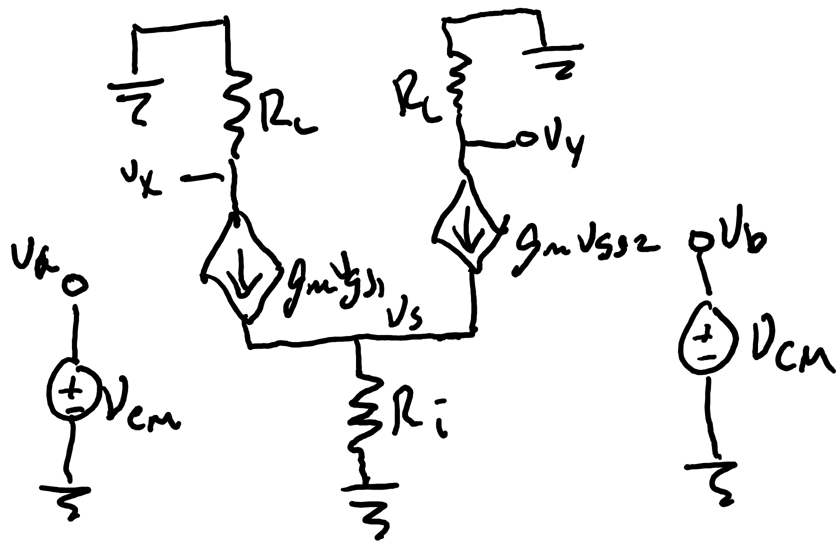
$$V_x = -\frac{g_m v_d}{2} R_L$$

$$v_y = \frac{g_m v_d}{2} R_L$$

$$V_{out} = v_x - v_y$$

$$= -g_m R_L v_d$$

COMMON-MODE



$$v_{gs1} = v_{gs2} = v_{gs}$$

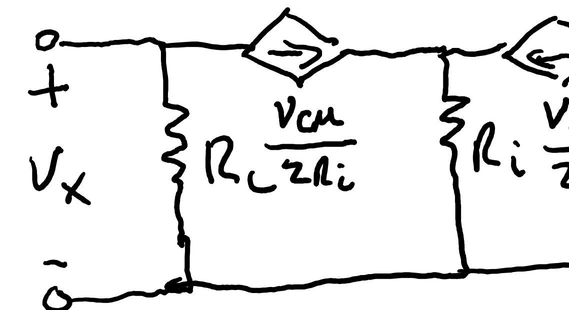
$$v_{gs} = v_{cm} - v_s$$

$$g_m v_{gs} + g_m v_{gs} = \frac{v_s}{R_i}$$

$$2 g_m v_{gs} = \frac{v_{cm} - v_{gs}}{R_i}$$

$$v_{gs} = \frac{1}{2 g_m R_i + 1} v_{cm}$$

$$v_{gs} \simeq \frac{v_{cm}}{2 g_m R_i}$$



$V_x = V_y = -$

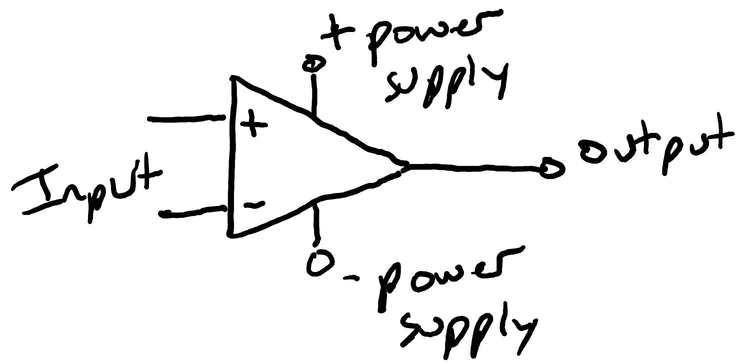
$$\boxed{V_{out} = V_x - V_y}$$

Assume R_i is lar
(good current
$2 g_m R_i >> 1$

CHAPTER 15: OP-AMPS

Multi-stage two-input differential amplifier

Voltage controlled voltage source

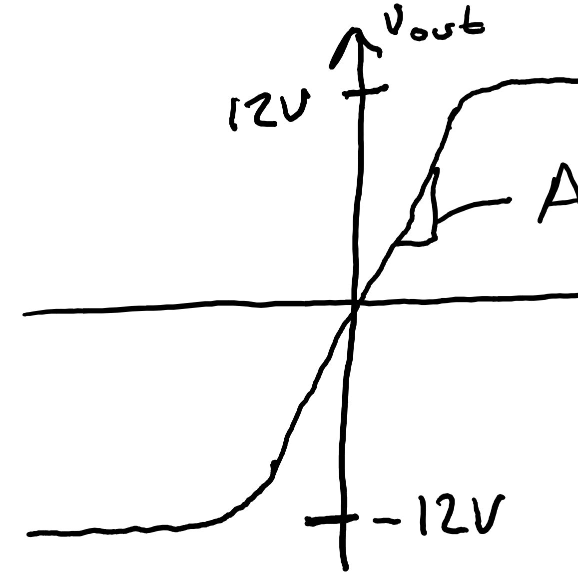


IDEAL

$R_{in} = \infty$

$R_{out} = 0$

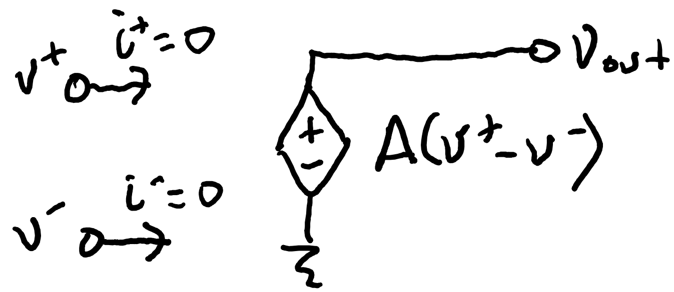
$A = \infty$ ← open loop gain



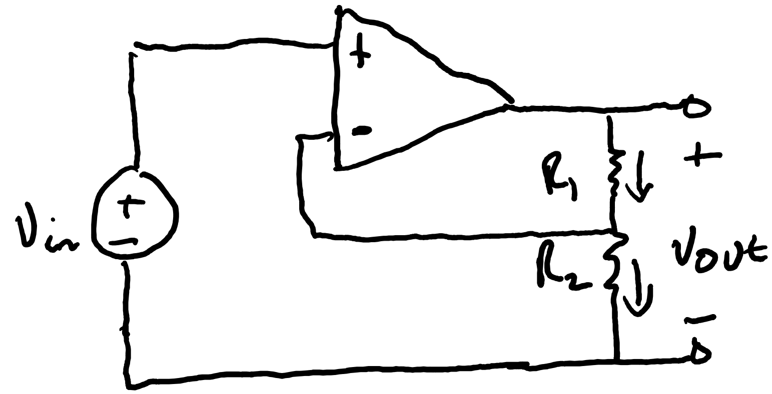
$A = 200{,}000$

input currents low

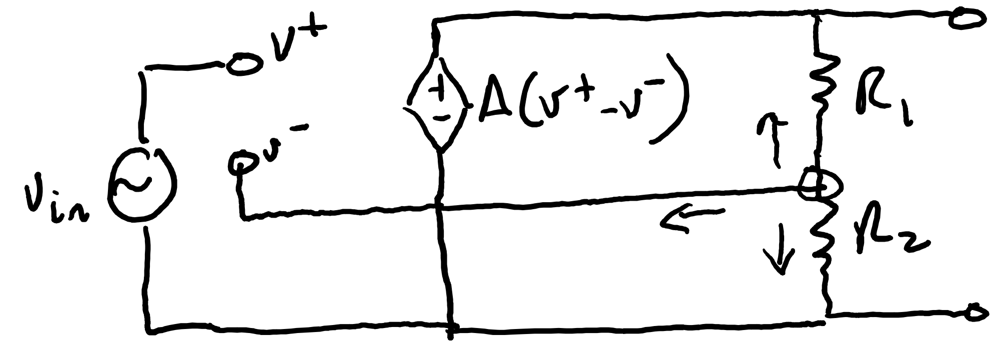
$V_{out} = A(v^+ - v^-)$



NON INVERTING CONNECTION



$\Rightarrow$



IDEAL with $V^+ = V^-$

$V^- = V_{in}$

$$\frac{V_{in}}{R_2} = \frac{V_{out} - V_{in}}{R_1}$$

$$V_{in} R_1 = R_2 (V_{out} - V_{in})$$

$$V_{in} (R_1 + R_2) = R_2 V_{out}$$

$$V_{out} = \frac{(R_1 + R_2)}{R_2} V_{in}$$

$$V_{out} = A(V^+ - V^-)$$

$$V^+ - V^- = \frac{V_{out}}{A}$$

$$A = \infty$$

$$V^+ = V^-$$

$V^+ = V_{in}$

$$V^- = \frac{R_2}{R_1 + R_2} V_{out}$$

$$\frac{V^-}{R_2} + \frac{V^- - V_{out}}{R_1} = 0$$

$$V_{out} = A(V^+ - V^-)$$

$$V^- = V^+ - \frac{V_{out}}{A}$$

$$V^+ - \frac{V_{out}}{A} = \frac{R_2}{R_1 + R_2} V_{out}$$

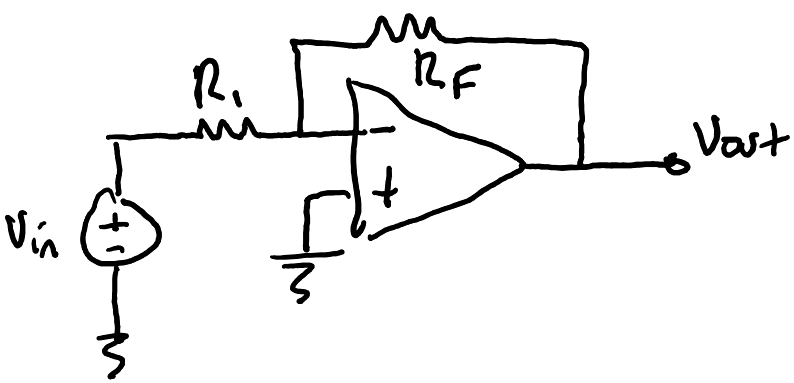
AV_{i}

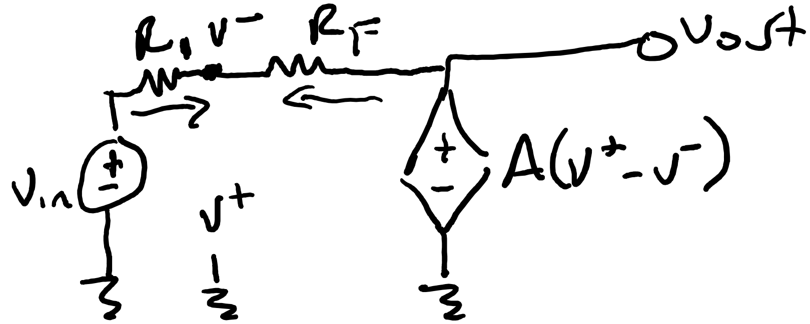
$V_{out} =$

$A($

V_{ou}

INVERTING CONNECTION





$$v^+ = 0$$

$$\frac{v_{in} - v^-}{R_1} - \frac{v^- - v_{out}}{R_F} = 0$$

$$v^- = \frac{R_F}{R_1 + R_F} v_{in} - \frac{R_1}{R_1 + R_F} v_{out}$$

$$V_{out} = A(v^+ - v^-) = -Av^-$$

$$\frac{-V_{out}}{A} = \frac{R_F}{R_1 + R_F} V_{in} - \frac{R_1}{R_1 + R_F} V_{out}$$

$$V_{out}\left(\frac{R_1}{R_1 + R_F} - \frac{1}{A}\right) = \frac{R_F}{R_1 + R_F} V_{in}$$

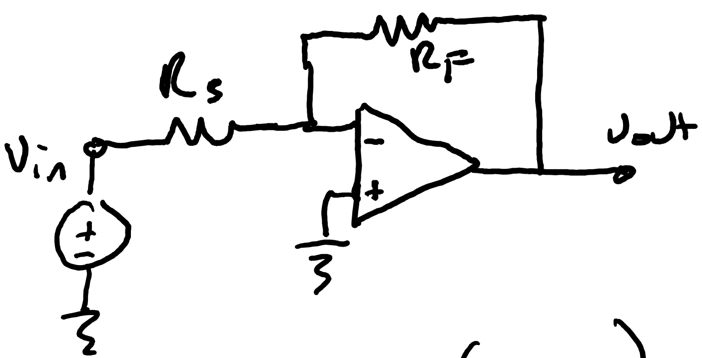
$$V_{out} = \frac{-AR_F/(R_1 + R_F)}{1 + A\,R_1/(R_1 + R_F)} V_{in}$$

IF A is large $\Rightarrow$ IDEAL

$$V_{out} = -\frac{R_F}{R_1} V_{in}$$

INVERTING OUTPUT RESISTANCE

INVERTING



A large (or ∞)

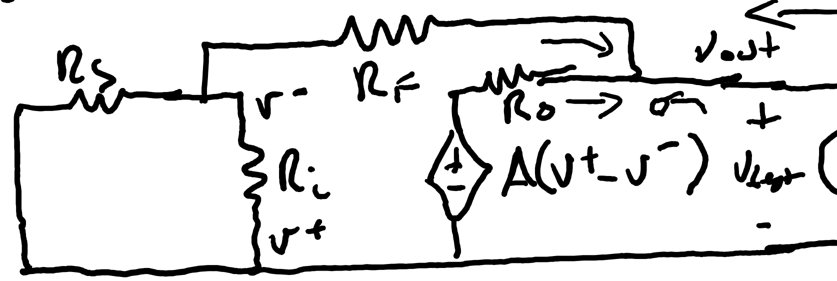
$$G_{OUT} = G_O\left(1 + \frac{A G_F}{G_F + G_S}\right)$$

$$G_{OUT} = G_O\left(1 + \frac{A R_S}{R_S + R_F}\right)$$

$$R_{OUT} = \frac{R_O}{\underbrace{1 + A\left(\frac{R_S}{R_S + R_F}\right)}_{1 + \text{LOOP GAIN}}}$$

Assume R_i, R_{out}

OUTPUT RESISTANCE



USE CONDUCTANCES

$G_i = \frac{1}{R_i}$; $G_S = \frac{1}{R_S}$; $G_F = \frac{1}{R_F}$

$v^+ = 0$

$$v^- = \frac{G_F}{G_F + G_S + G_i} v_{test}$$

$$i_{test} + \left[A(v^+ - v^-) - v_{test}\right] G_O + (v^- -$$

$$\frac{i_{test}}{v_{test}} = G_{OUT} = \underbrace{\frac{A G_F G_O}{G_F + G_S}}_{\text{EFFECT OF FEEDBACK}} + \underbrace{G_O}_{\text{op-amp alone}} +$$

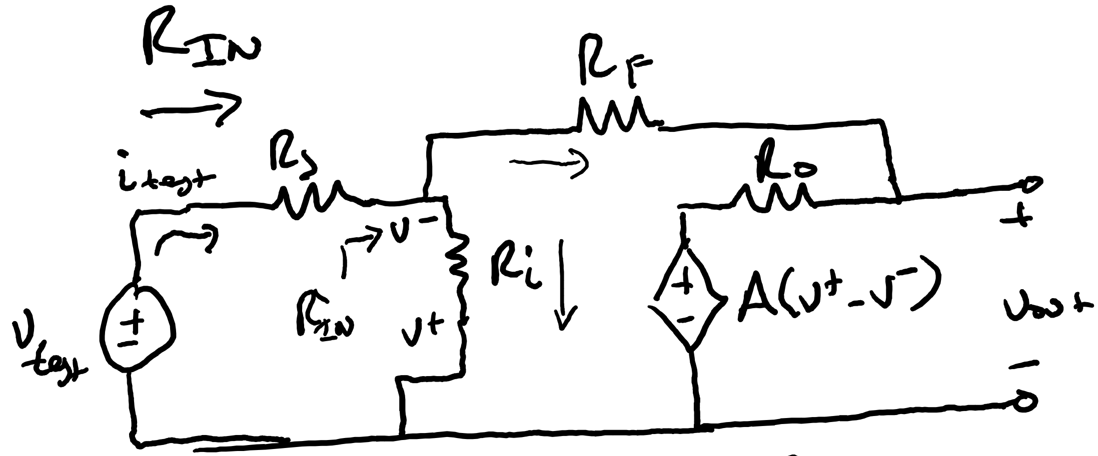
$$G_T = \frac{G_{TF}\, G_{TB}}{G_{TF} + G_{TB}}$$

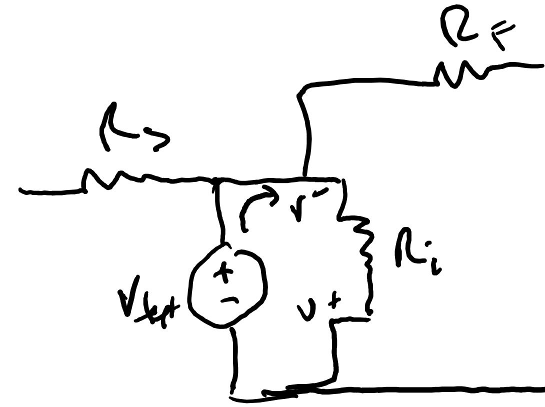
$$\frac{R_F\, R_S}{R_F + R_S} = \left(R_F \,//\, R\right.$$

$$G_T = \frac{\frac{1}{R_F}\left(\frac{1}{R_S}\right)}{\frac{1}{R_S} + \frac{1}{R_F}} = \frac{1}{R_F + R_S}$$

$$R = R_F + R_S$$

INVERTING INPUT RESISTANCE





$$R_{IN} = R_s + R_{IN}' \Longrightarrow R_{EFF} \text{ to the right of } R_s$$

$$v^+ = 0$$

$$v^- = v_{test}$$

$$i_{test} = \frac{v_{test}}{R_i} + \frac{v_{test} - A(\overset{0}{\cancel{v^+}} - \overset{v_{test}}{v^-})}{R_F + R_o} = V_{test}\left(\frac{1}{R_i} + \frac{1}{R_F + R_o} + \ldots\right.$$

$$\frac{v_{test}}{i_{test}} = R_{IN}' = \underbrace{R_i}_{\text{op-amp input}} // \underbrace{(R_F + R_o)}_{R's} // \underbrace{\left(\frac{R_F + R_o}{A}\right)}_{F/B}$$

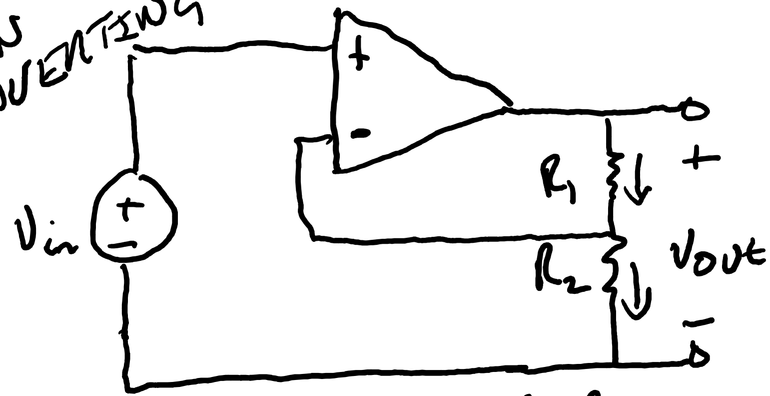
For LARGE A

$$R_{IN}' \simeq \frac{R_F \ldots}{A}$$

$$R_{IN} = R_s + R_{IN}' \ldots$$

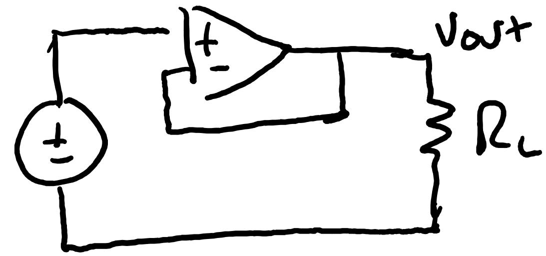
VOLTAGE FOLLOWER

NON INVERTING



$$V_{out} = \frac{R_1 + R_2}{R_2} V_{in}$$

VOLTAGE FOLLOWER



$R_1 = 0$

$V_{out} \cong V_{in}$

buffer

$V^- = V$

$V^+ = V$

$V_{in} = V$