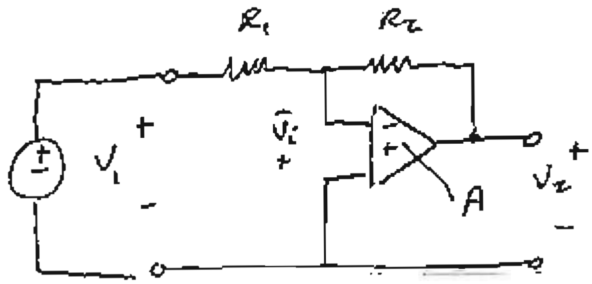
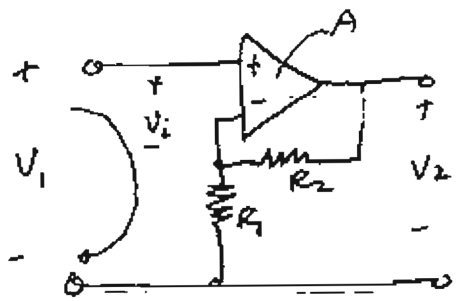


$$\frac{V_2}{V_1} = \frac{-\left(\frac{R_2}{R_1+R_2}\right)A}{1+\left(\frac{R_2}{R_1+R_2}\right)A} \quad \text{finite } A$$

$$\lim_{A\to\infty} \left[\left(\frac{R_2}{R_1+R_2}\right)A \gg 1\right];\ \frac{V_2}{V_1} = -\frac{R_1}{R_2} \quad \underline{\text{inverting}} \text{ configuration}$$



$$-V_1 + V_i + \left(\frac{R_1}{R_1+R_2}\right)V_2 = 0\ ;\ V_i = \frac{V_2}{A}$$

$$V_2\left(\frac{1}{A} + \frac{R_1}{R_1+R_2}\right) = V_1$$

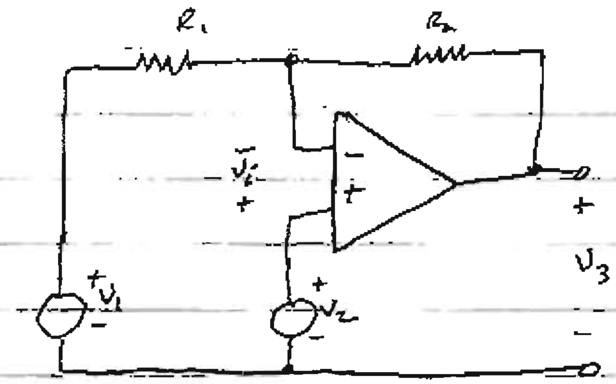
$$\frac{V_2}{V_1} = \frac{1}{\frac{1}{A} + \frac{R_1}{R_1+R_2}} \quad \underline{\text{non-inverting}} \text{ configuration}$$

$$\lim_{A\to\infty} \frac{V_2}{V_1} = \frac{R_1+R_2}{R_1} \geq 1$$

<u>Notice:</u>

For $R_1 = R_2$ inverting gain $= -1 = \frac{1}{2}\cdot(-2) = -1$

non-inverting gain $= 2 = 1\cdot(2) = 2$



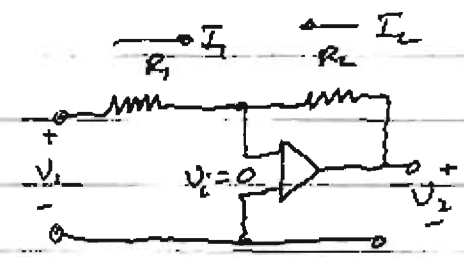
By Superposition:

with $A \to \infty$

$$V_3 = -V_1\left(\frac{R_2}{R_1}\right) + V_2\left(\frac{R_1+R_2}{R_1}\right)$$

Virtual Ground

$V_i = 0$



$$\frac{V_1}{R_1} = I_1, \quad \frac{V_2}{R_2} = I_2, \quad I_1 = -I_2$$

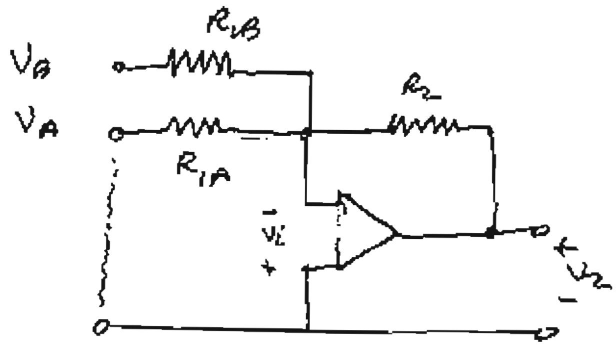
$$\frac{V_1}{R_1} = -\frac{V_2}{R_2} \Rightarrow \frac{V_2}{V_1} = -\frac{R_2}{R_1}$$ Same as before

Finite $\neq 0$ value for V_2

$V_i = \frac{V_2}{A}$, $A \to \infty$, $V_i \to 0$ but

never ever $= 0$.

weighted sums



$V_A = 0$, $V_B \neq 0$, V_i across $R_1A \Rightarrow i_{1A} = 0$

$$\frac{V_2}{V_B} = -\frac{R_2}{R_1B}$$

$$\frac{V_2}{V_A} = -\frac{R_2}{R_1A}$$

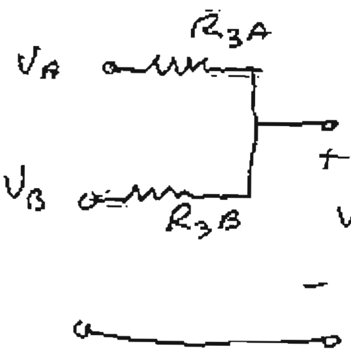
$$V_2 = -\left[\left(\frac{R_2}{R_1A}\right)V_A + \left(\frac{R_2}{R_{1B}}\right)V_B + \dots + \left(\frac{R_2}{R_1n}\right)V_n\right]$$

negative gain (inverting) weighted summer

Ex

$$V_2 = -\left[2V_a + 3V_b + 5V_c\right]$$

- Resistors make a non-unity summer

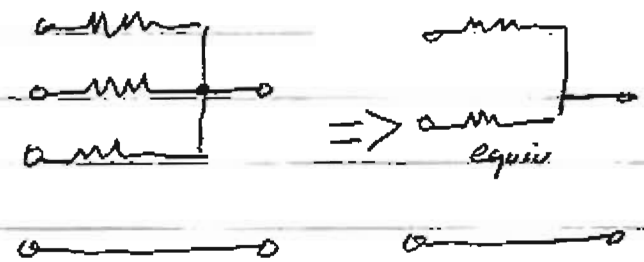


By superposition

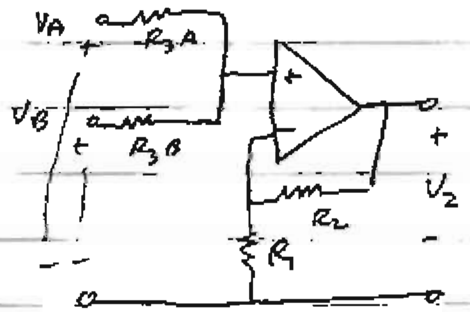
$$V_2 = V_A\left(\frac{R_{3B}}{R_{3A}+R_{3B}}\right) + V_B\left(\frac{R_{3A}}{R_3A+R_3B}\right)$$

≤ 1 ≤ 1

$$V_2 = \frac{1}{2}V_A + \frac{1}{2}V_B = \frac{1}{2}(V_A + V_B)$$



any number of branches



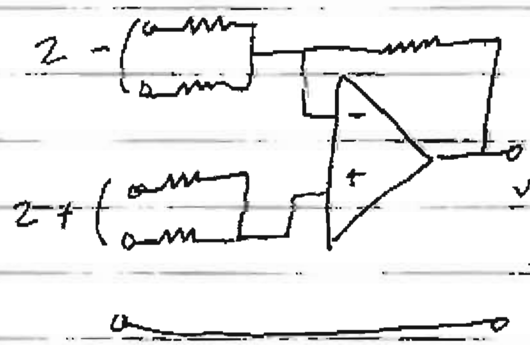
$$V_2 = \left(\frac{R_1+R_2}{R_1}\right)\left[\left(\frac{R_{3B}}{R_{3A}+R_{3B}}\right)V_A + \left(\frac{R_{3A}}{R_{3A}+R_{3B}}\right)V_B\right]$$

determine proportion

overall gain

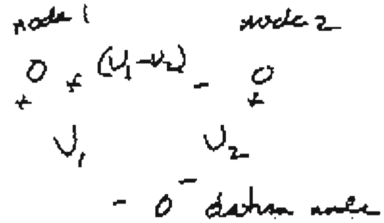
$$V_2 = 6V_A + 9V_B$$

$$= (9)\left[\frac{2}{3}V_A + V_B\right]$$



$v_2^+ = +sum - sum$

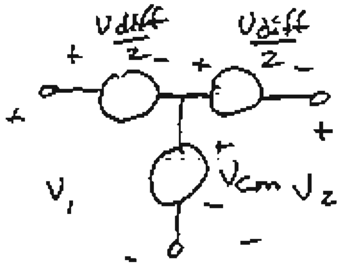
New Concept:



Propose

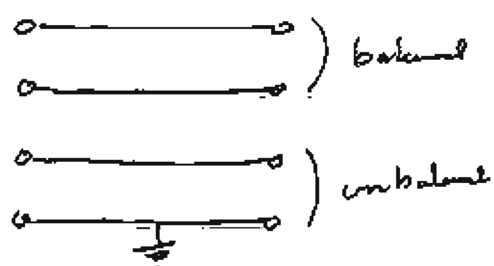
$$V_1 = V_{cm} \pm V_{diff}/2$$
$$V_2 = V_{cm} \mp V_{diff}/2$$

V_{cm} = common-mode voltage
V_{diff} = differential-mode voltage



$$V_1 = V_{cm} + \frac{V_{diff}}{2}$$
$$V_2 = V_{cm} - \frac{V_{diff}}{2}$$
$$V_1 - V_2 = V_{diff}$$

Balanced vs Unbalanced connection:



Unbalanced connection: power 120VAC

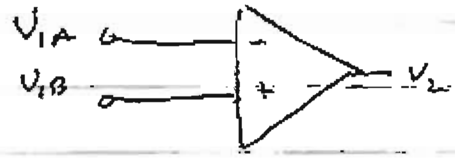
balanced connection: telephone twisted pair, 300Ω twin lead

75Ω
coax
Unbalanced

300Ω
twin lead
balanced

balun

balanced - unbalanced



$V_1A = V_{cm} + \frac{V_{diff}}{2}$

$V_1B = V_{cm} - \frac{V_{diff}}{2}$

$V_2 = ?$ Ideally,

$V_2 = K\, V_{diff}$ Reality

$V_2 = \underbrace{K_1 V_{cm}}_{\text{reject}} + \underbrace{K_2 V_{diff}}_{\text{preserve}}$

measure of Goodness:

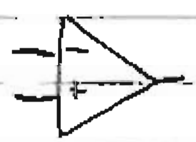
$\frac{\text{good}}{\text{bad}}$ 0 —— ∞ bad good

Common-Mode Rejection Ratio (CMRR)

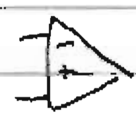
$\frac{\text{differential gain}}{\text{common-mode gain}}$

Typically (1000 – 10,000):1

differential Amplifier -vs- difference amplifier



input identical



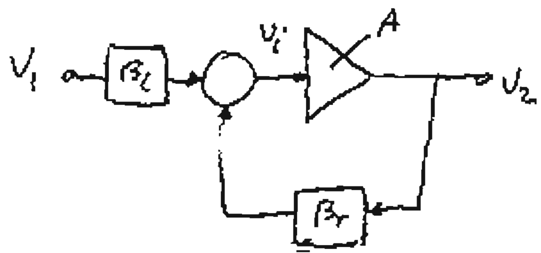
inputs are not identical

Refer to gain expression:

$$\frac{V_2}{V_1} = \frac{-\left(\frac{R_2}{R_1+R_2}\right)A}{\underbrace{1+\left(\frac{R_1}{R_1+R_2}\right)A}} \quad \& \quad \frac{V_2}{V_1} = \frac{A}{\underbrace{1+\left(\frac{R_1}{R_1+R_2}\right)A}}$$

(denominator same)

Block Diagram

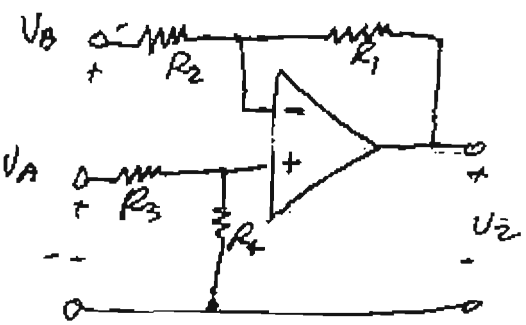


$$\frac{V_2}{V_1} = \frac{A\beta_i}{1 + A\beta_r}$$

inverting $\beta_i = -\left(\frac{R_2}{R_1+R_2}\right)$

non-inverting $\beta_i = +(1)$

$$\beta_r = \frac{R_1}{R_1+R_2}$$



$$V_2 = \left[\frac{A\beta_i V_B + A\beta_i V_A}{1+\beta_r A}\right]$$

$$V_2 = A\left[\frac{\beta_{iB} V_B + \beta_{iA} V_A}{1+\beta_r A}\right]$$

want $V_2 = K(V_A - V_B)$

Establish amp gain with R_1 & R_2
compensate for gain with R_3 & R_4

Example $R_1 = R_2 = R_3 = R_4$

$$V_2 = V_B\left(\frac{-1}{1}\right) + V_A\left(\frac{1}{2}\right)(2)$$

$= V_A - V_B$ difference amp