

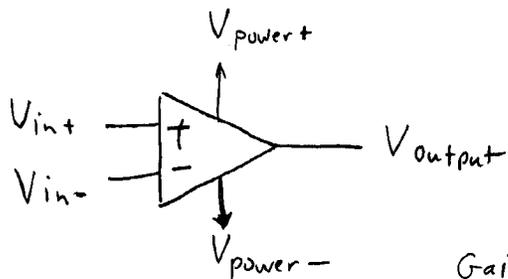
Introduction to op-amps

"operational amplifier"

What is it?

→ An amplifier with differential input and VERY high gain

We use negative feedback to lower the gain.



Gain = A

$$V_{output} = A (V_{in+} - V_{in-})$$

1B
①

Read
~~Surv ON A~~
Hambley 2-1, 24

Talk about:
2.1 1, 2, 3, 4
2.2 5, 6, 7, 8
~~2.3~~ Do:
2.3:
9, 10, 14, 15, 18
2.4
19, 20, 21, 22,
23, 24, 26,
27

Example:

Let $A = 100,000$

$V_{p+} = +15$
 $V_{p-} = -15$

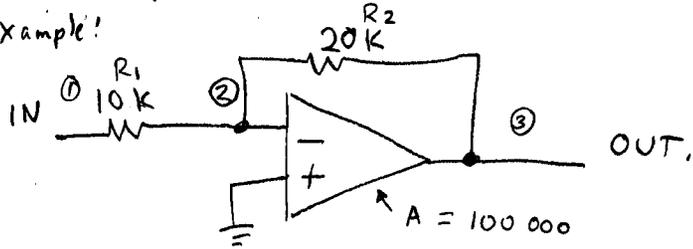
1B
②

- (a) $V_{in+} = 1 \mu V$
 $V_{in-} = 0$ $V_{out} = \underline{\hspace{2cm}}$
- (b) $V_{in+} = 0$
 $V_{in-} = 1 \mu V$ $V_{out} = \underline{\hspace{2cm}}$
- (c) $V_{in+} = 1 \mu V$
 $V_{in-} = 1 \mu V$ $V_{out} = \underline{\hspace{2cm}}$
- (d) $V_{in+} = 1 V$
 $V_{in-} = 1 V$ $V_{out} = \underline{\hspace{2cm}}$
- (e) $V_{in+} = 1.000001 V$
 $V_{in-} = 1.000000 V.$ $V_{out} = \underline{\hspace{2cm}}$
- (f) $V_{in+} = 1 \mu V$
 $V_{in-} = -1 \mu V$ $V_{out} = \underline{\hspace{2cm}}$
- (g) $V_{in+} = 1 V$
 $V_{in-} = 0$ $V_{out} = \underline{\hspace{2cm}}$

Practical uses of op-amp:

Apply "negative feedback"

Example!



What does this do? What is $\frac{V_{out}}{V_{in}}$?

Do nodal analysis:

$$V_3 = -A V_2 \quad \leftarrow V_2 = \frac{-V_3}{A}$$

$$\frac{V_1 - V_2}{R_1} + \frac{V_3 - V_2}{R_2} = 0$$

$$\frac{V_1 + \frac{+V_3}{A}}{R_1} + \frac{V_3 + \frac{+V_3}{A}}{R_2} = 0$$

$$\frac{AV_1 + V_3}{R_1} + \frac{AV_3 + V_3}{R_2} = 0$$

$$\frac{V_3}{R_1} + \frac{AV_3 + V_3}{R_2} = \frac{-AV_1}{R_1}$$

$$V_3 \left(\frac{A+1}{R_2} + \frac{1}{R_1} \right) = V_1 \left(\frac{-A}{R_1} \right)$$

$$\frac{V_3}{V_1} = \frac{-\frac{A}{R_1}}{\frac{A+1}{R_2} + \frac{1}{R_1}}$$

1B
③

$$\frac{V_3}{V_1} = \frac{-A}{\frac{R_1(A+1)}{R_2} + 1}$$

$$\frac{V_3}{V_1} = \frac{-AR_2}{R_1(A+1) + R_2}$$

Substitute values:

$$\begin{aligned} \frac{V_3}{V_1} &= \frac{-(100000)(20K)}{10K(100000+1) + 20K} \\ &= -1.999940002 \\ &\approx -2 \end{aligned}$$

Observe: if A is large

$$A \approx A+1$$

$$\frac{V_3}{V_1} = \frac{-R_2}{R_1}$$

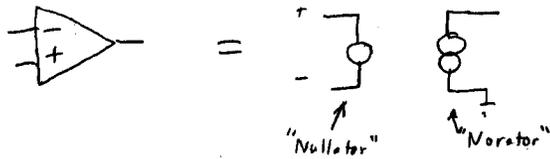
$$\frac{V_3}{V_1} = \frac{-AR_2}{R_1A + R_1 + R_2} = \frac{-R_2}{R_1 + \underbrace{\frac{R_1 + R_2}{A}}}$$

↑ This term $\rightarrow 0$
as $A \rightarrow \infty$

1B
④

"Nullor" model of op-amp

1B
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"Nullator" = $V = 0$
 $I = 0$ (magic!)

"Norator" = $V = \text{arbitrary}$
 $I = \text{arbitrary}$.

Nullator is like a short ($V=0$)
 and like an open ($I=0$)

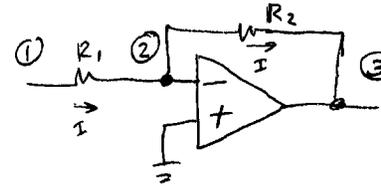
recall:
 voltage source
 $V = \text{value}$
 $I = \text{arbitrary}$
 current source
 $I = \text{value}$
 $V = \text{arbitrary}$.

"Virtual short circuit"

Gives good approximation assuming
ideal op-amp.

Same example using "nullor" approach.

1B
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Do nodal analysis:

$$\frac{V_1 - V_2}{R_1} + \frac{V_3 - V_2}{R_2} = 0$$

$$V_2 = 0 \quad (\text{by virtual short circuit})$$

so... $\frac{V_1}{R_1} + \frac{V_3}{R_2} = 0$

$$\frac{V_3}{R_2} = -\frac{V_1}{R_1}$$

$$\frac{V_3}{V_1} = -\frac{R_2}{R_1}$$

Intuition approach:

If $V_2 = 0$, then $I_{R1} = \frac{V_1}{R_1}$

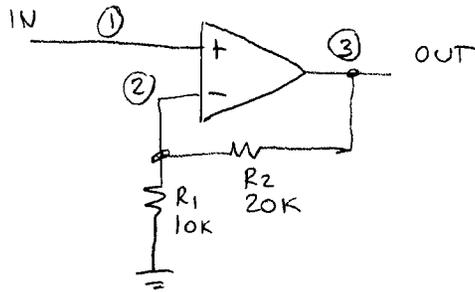
since $I = 0$, then $I_{R2} = I_{R1} = \frac{V_1}{R_1}$
↑ into op-amp

$$\text{so } -V_3 = I_{R2} R_2 = \frac{V_1}{R_1} R_2$$

$$\frac{V_3}{V_1} = -\frac{R_2}{R_1}$$

The non-inverting configuration

(15/7)



What is $\frac{V_{out}}{V_{in}}$?

Nodal analysis using nullor approach..

$V_1 = V_2$ by summing point constraint. (Virtual short circuit)

Node ②: $\frac{V_2 - V_3}{R_2} + \frac{V_2}{R_1} = 0$

$$\frac{V_2}{R_2} + \frac{V_2}{R_1} = \frac{V_3}{R_2}$$

$$R_1 V_2 + R_2 V_2 = R_1 V_3$$

$$V_2 (R_1 + R_2) = V_3 (R_1)$$

$$\frac{V_3}{V_2} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

Since $V_1 = V_2$..

$$\frac{V_3}{V_1} = 1 + \frac{R_2}{R_1}$$

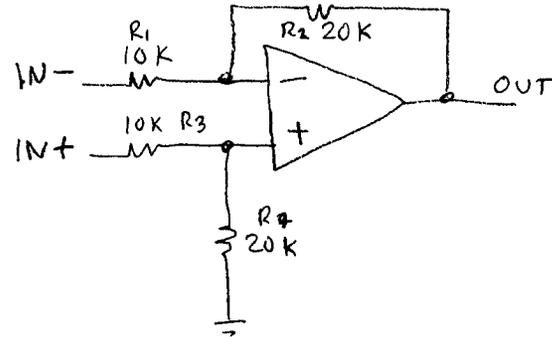
For this example:

$$\frac{V_3}{V_1} = 1 + \frac{20K}{10K} = 1 + 2 = 3$$

(positive)

The differential configuration ..

(18/8)



Combine inverting and non-inverting.

Analyze by superposition.

(What is the purpose of R_3 and R_4 ?)

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

$$\frac{V_{out}}{V_{IN+}} = \left(\frac{R_1 + R_2}{R_1}\right) \left(\frac{R_4}{R_3 + R_4}\right) = \left(\frac{R_1 + R_2}{R_1}\right) \left(\frac{R_2}{R_1 + R_2}\right) = \frac{R_2}{R_1}$$

Let $R_3 = R_1$, $R_4 = R_2$

Combine them:

Non-inverting: $V_{out} = \frac{R_2}{R_1} V_{IN+}$

inverting: $V_{out} = -\frac{R_2}{R_1} V_{IN-}$

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

Try: "Differential mode"
 $V_{IN+} = -V_{IN-}$
call it V_{IN}

$$V_{out} = \frac{R_2}{R_1} V_{IN} - \frac{R_2}{R_1} (-V_{IN}) = 2 \frac{R_2}{R_1} V_{IN}$$

"Common mode"
 $V_{IN+} = V_{IN-}$
call it V_{IN}

$$V_{out} = \frac{R_2}{R_1} V_{IN} - \frac{R_2}{R_1} V_{IN} = 0$$