

LAST TIME:

SEMICONDUCTORS

DIODES

BIPOLAR JUNCTION TRANSISTORS

COMMON EMITTER AMPLIFIER

TODAY: CH. 28

OPERATIONAL AMPLIFIERS

NEGATIVE FEEDBACK

GOLDEN RULES FOR THE OP AMP

NON-IDEAL BEHAVIORS — A FEW EXAMPLES OF "REALISTIC" PARAMETERS

NEXT TIME: CH. 29

OP AMP APPLICATIONS IN ANALOG ELECTRONICS

• AMPLIFIER

• INVERTING AMP

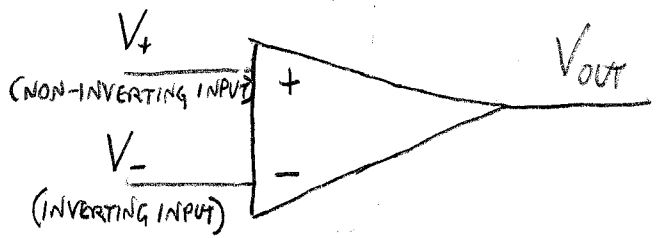
• ADDITION & SUBTRACTION OF SIGNALS

OPAMP

THE OPERATIONAL AMPLIFIER IS A CIRCUIT MADE OF MANY (DOZENS) OF TRANSISTORS. ITS PURPOSE IS TO BEHAVE IN A VERY SIMPLE WAY. I AM NOT GOING TO TEACH YOU HOW THEY WORK. BUT I WANT YOU TO UNDERSTAND BOTH THE IDEAL NOTION (HOW THE PERFECT OP AMP IS SUPPOSED TO BEHAVE) AND A FEW OF THE SHORTCOMINGS OF REAL OP AMPS. IT IS DIFFICULT TO DESIGN A GOOD OP AMP, AND GENERALLY YOU (DON'T) GET WHAT YOU (DON'T) PAY FOR.

SAMPAG

IDEAL OP AMP



$$V_{OUT} = A(V_+ - V_-)$$

↑
"OPEN LOOP" GAIN

IDEALLY:

- LARGE (INFINITE) GAIN, $A \rightarrow \infty$.
- V_+ AND V_- SENSE VOLTAGES WITHOUT DRAWING ANY CURRENT (INFINITE INPUT IMPEDANCE).
- V_{OUT} IS INDEPENDENT OF THE LOAD — CAN SUPPLY AS MUCH CURRENT AS NEEDED (ZERO OUTPUT IMPEDANCE).
- V_{OUT} RESPONDS INSTANTLY TO CHANGES IN $V_+ - V_-$ (INFINITE SLEW RATE).
- $V_{OUT} = 0$ IF $V_+ = V_-$ (ZERO OFFSET).

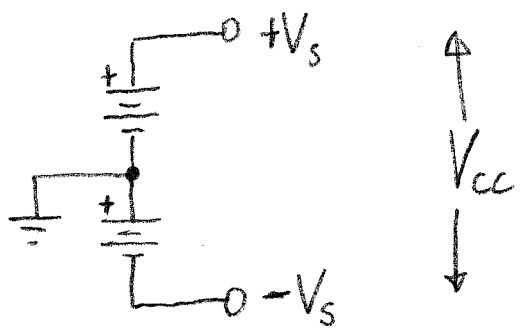
REAL OP AMPS VIOLATE THESE ASSUMPTIONS:

<u>PARAMETER</u>	<u>IDEAL</u>	<u>TYPICAL</u>
GAIN, A	∞	10^5 , BUT DEPENDS ON FREQUENCY
OUTPUT IMPEDANCE	0	10Ω
INPUT IMPEDANCE	∞	$10 M\Omega$
SLEW RATE	∞	$1 V/\mu s$
OFFSET	0	MAY REQUIRE EXTERNAL ADJUSTMENT

WHERE DOES THE POWER COME FROM?

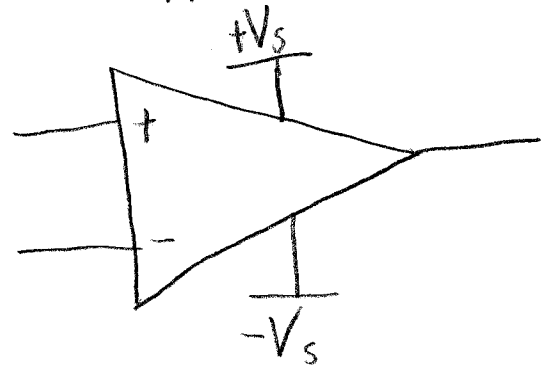
THE SUPPLY IS OFTEN OMITTED IN CIRCUIT DIAGRAMS. DON'T FORGET THAT IT'S THERE!

TYPICAL SUPPLY:



- ZERO POINT (GROUND) IS DEFINED HALFWAY BETWEEN THE "RAILS" AT $\pm V_s$.
- THE SYMBOL V_{CC} IS OFTEN USED FOR THE TOTAL SUPPLY VOLTAGE ($2V_s$).

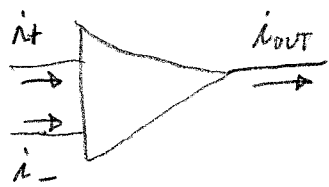
SUPPLY TO OP AMP:



IMPLICATIONS

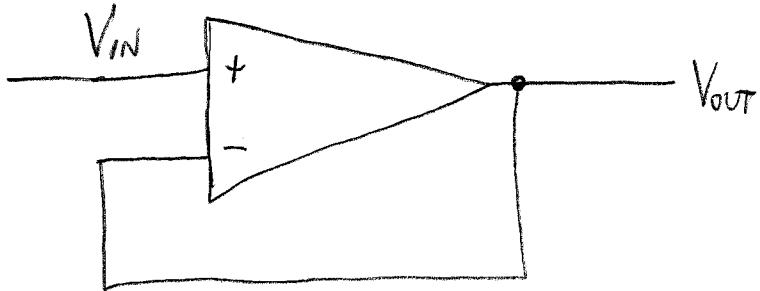
I. $-V_s < V_{out} < V_s$ (V_{out} "BETWEEN THE RAILS")

II. KCL: $i_+ + i_- - i_{out} \neq 0$



Q: WHAT IS THE OP AMP GOOD FOR?

A: THIS IS BEST ANSWERED WITH AN EXAMPLE USING NEGATIVE FEEDBACK.



"LINE DRIVER" OR
 "VOLTAGE FOLLOWER"
 OR "BUFFERED OUTPUT"
 ... A WIDELY USED
 APPLICATION FOR THE
 OP AMP.

ANALYSIS:

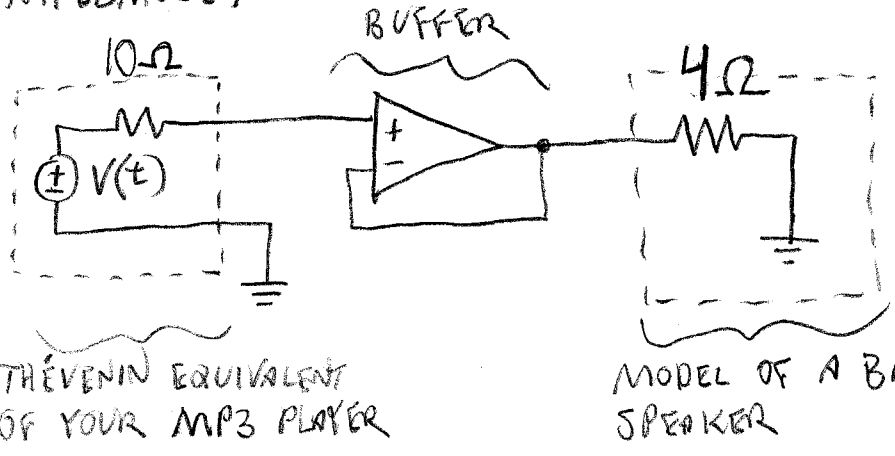
$$V_{OUT} = A(V_+ - V_-) = A(V_{IN} - V_{OUT})$$

$$V_{OUT} = \left(\frac{A}{1+A} \right) V_{IN}$$

For $A \gg 1$, $V_{OUT} = V_{IN}$

Q: WHY USE A BUFFER?

A: TO CONNECT A HIGH OUTPUT IMPEDANCE TO A LOW INPUT IMPEDANCE:



THEVENIN EQUIVALENT OF YOUR MP3 PLAYER

MODEL OF A BIG SPEAKER

★ STABILITY: WHAT IF V_{IN} CHANGES? IS EQUILIBRIUM MAINTAINED?

- ① $V_{IN} > V_{OUT} \Rightarrow V_+ > V_- \xrightarrow{\text{GAIN}} V_{OUT} \uparrow \text{ RAPIDLY}$
 - ② $V_{IN} < V_{OUT} \Rightarrow V_+ < V_- \xrightarrow{\text{GAIN}} V_{OUT} \downarrow \text{ RAPIDLY}$
- } EQUILIBRIUM MAINTAINED!

GOLDEN RULES FOR ANALYZING IDEAL OP AMPS IN CIRCUITS WITH NEGATIVE FEEDBACK*

I. V_{out} DOES WHATEVER IT MUST TO MAKE $V_+ = V_-$.

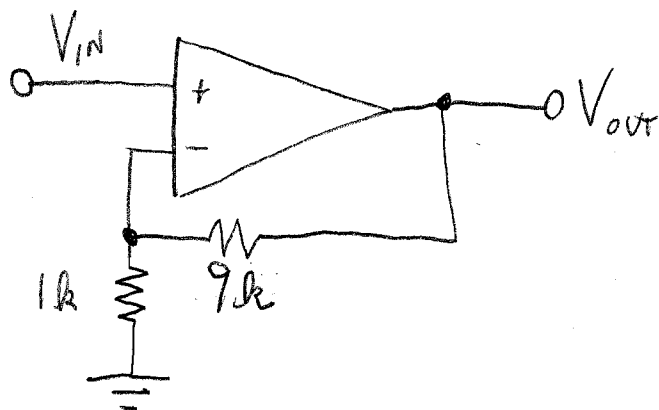
II. CURRENT = 0 AT BOTH INPUTS.

THAT'S ALL!

* NEGATIVE FEEDBACK MEANS THE OUTPUT IS CONNECTED, SOMETIMES THROUGH RESISTORS OR OTHER COMPONENTS TO THE INVERTING INPUT.

BRUNNEN

EXAMPLE — A SIMPLE AMPLIFIER



GIVEN V_{IN} , WHAT IS V_{OUT} ??

USE THE GOLDEN RULES:

I. $V_{IN} = V_+ = V_-$

II. NO CURRENT AT INVERTING INPUT \Rightarrow

$$V_- = V_{OUT} \cdot \frac{1k}{1k + 9k} = \frac{1}{10} V_{OUT}$$

\therefore $V_{OUT} = 10 V_{IN}$

Q: WHAT IF GAIN $A = 100$? ASSUME THE AMPLIFIER IS OTHERWISE IDEAL.

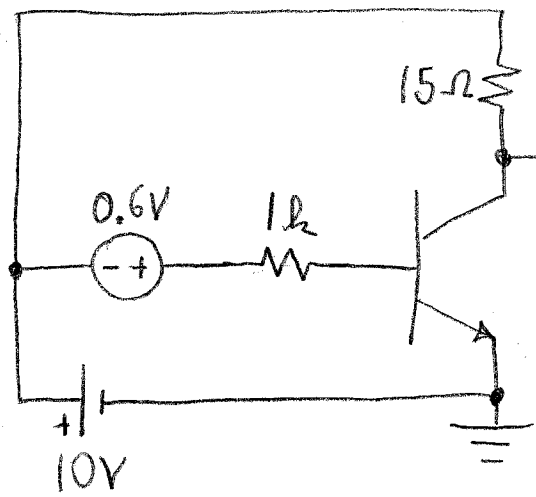
A: $V_{OUT} = 100 (V_+ - V_-) = 100 (V_{IN} - \frac{1}{10} V_{OUT}) = 100 V_{IN} - 10 V_{OUT}$

$\Rightarrow V_{OUT} = \frac{100}{11} V_{IN} = 9.1 V_{IN}$

IF TIME PERMITS — AN EXAMPLE BJT CIRCUIT.

(a) FIND V_1 .

(b) FIND i_e .



ASSUME $\beta = 100$,
 $V_T = 0.6V$

ASSUME ACTIVE MODE:

$$i_b = \frac{10V + 0.6V - 0.6V}{1k} = 10 \text{ mA}$$

$$i_c = \beta i_b = 1A$$

(IF THIS IS TRUE, $V_1 = 10V - 15\Omega \cdot 1A = -5V$.)

IS IT IN ACTIVE MODE?

- $i_b > 0$, SO NOT IN CUTOFF.
- MAX $i_c = \frac{10V}{15\Omega} = \frac{2}{3}A$. ← UH-OH! $< 1A$.

\Rightarrow SATURATION. $i_c = 2/3A$. $\Rightarrow V_1 = 0$ (a)

(b) $i_e = 10 \text{ mA} + \frac{2}{3}A = 0.677A$.

DIPLOMA