EECS 42 Introduction Digital Electronics
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Lecture # 15 Op-Amp Circuits and Comparators 4.3-4.4 (light on non-ideal)

A) Cascade Op-Amps
B) Integration/Differentiation Op-Amps
C) I vs. V of Op-Amps – Source Limits
D) Comparator Circuits
E) D to A Converters

http://inst.EECS.Berkeley.EDU/~ee42/

NEGATIVE FEEDBACK

Familiar examples of negative feedback:

- Thermostat controlling room temperature
- Driver controlling direction of automobile
- Photochromic lenses in eyeglasses

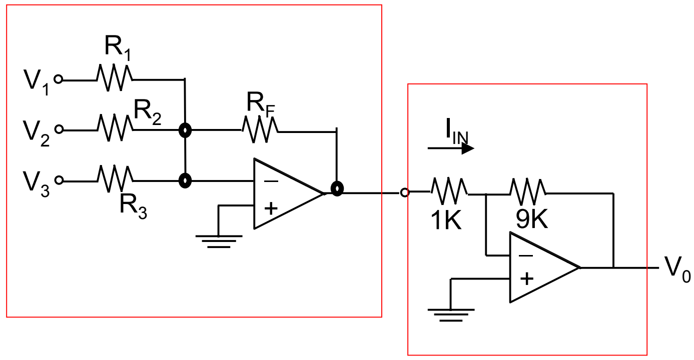
→ Fundamentally pushes toward stability

Familiar examples of positive feedback:

- Microphone “squawk” in room sound system
- Mechanical bi-stability in light switches
- Thermonuclear reaction in H-bomb

→ Fundamentally pushes toward instability or bi-stability

CASCADE OP-AMP CIRCUITS



How do you get started on finding V_O?

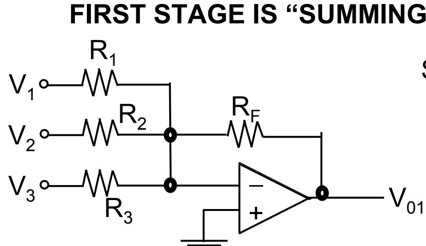
Hint: Identify Stages

Hint: I_{IN} does not affect V_{O1}

See the further examples of op-amp circuits in the reader

CASCADE OP-AMP SOLUTION

FIRST STAGE IS "SUMMING JUNCTION" AMPLIFIER



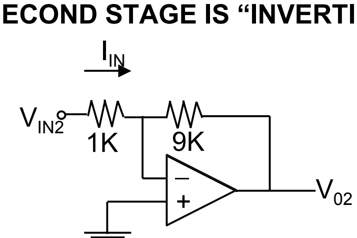
Solution:

$$i_{IN} \cong 0 \text{ and } V_{(-)} \cong V_+ = 0$$

$$\text{KCL}: \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_0}{R_F} = 0$$

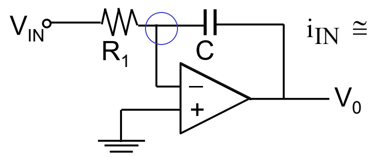
$$\Rightarrow V_{01} = -\frac{R_F}{R_1}V_1 - \frac{R_F}{R_2}V_2 - \frac{R_F}{R_3}V_3$$

SECOND STAGE IS "INVERTING" AMPLIFIER



$$V_{02} \cong \frac{-R_2}{R_1} V_{IN2}$$

INTEGRATING OP-AMP



$i_{IN} \cong 0$ and $V_{(-)} \cong V_{+} = 0$

How do you get started on finding V_O?

Hint: $i_{IN} \cong 0$ and $V_{(-)} \cong V_{+} = 0$

Hint: KCL at V_- node with $I_{IN-} = 0$

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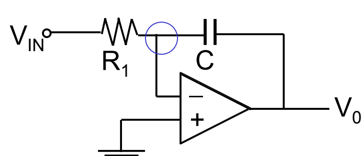
INTEGRATING OP-AMP

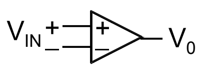


$$\frac{0 - V_{IN}}{R_1} + C\frac{\partial(0 - V_O)}{\partial t} = 0$$

Integrate from t_0 to t to get $V_O(t)$

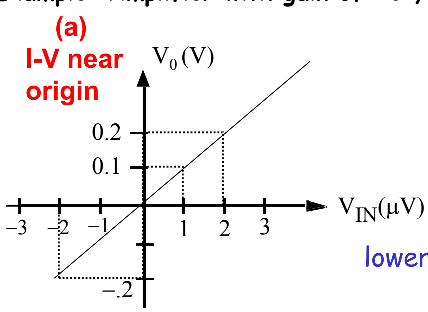
$$V_O(t) = \frac{-1}{R_1 C}\int_{t_0}^{t} V_{IN}(t)dt'$$

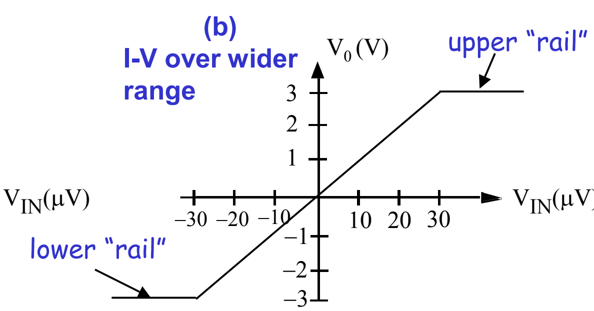
OP-AMP I-V CHARACTERISTICS WITH RAILS



- Circuit model (ideal op-amp) gives the essential linear part
- But V_0 cannot rise above some physical voltage related to the positive power supply V_{CC} (" upper rail") $V_0 < V_{+RAIL}$
- And V_0 cannot go below most negative power supply, V_{EE} i.e., limited by lower "rail" $V_0 > V_{-RAIL}$

Example: Amplifier with gain of 10^5, with max V_0 of 3V and min V_0 of –3V.

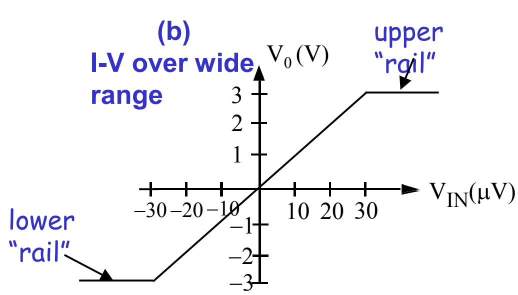


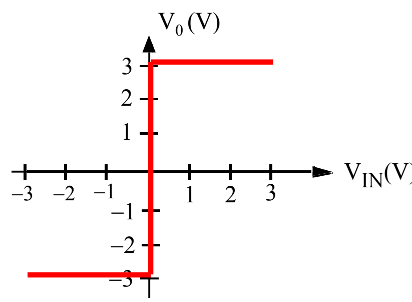


OP-AMP I-V CHARACTERISTICS WITH RAILS (cont.)

Example: Amplifier with gain of 10^5, with upper rail of 3V and lower rail of –3V. We plot the V_0 vs V_{IN} characteristics on two different scales

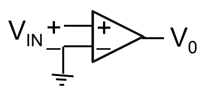
(c)
Same V_0 vs V_{IN} over even wider range

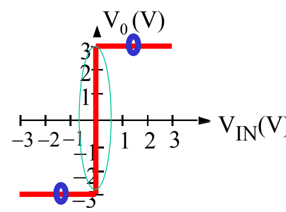




SIMPLE A/D CONVERTER

I-V with equal X and Y axes



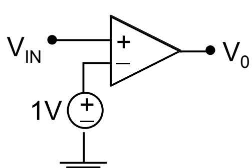


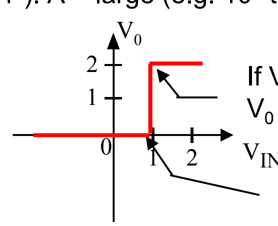
Note:

- (a) displays linear amplifier behavior ($|V_{IN}| < 30\ \mu V$) and stops at rails
- (b) shows comparator decision function (1 bit A/D converter centered at $V_{IN} = 0$) where lower rail = logic "0" and upper rail = logic "1"

OP-AMP USE AS COMPARATOR (A/D) MODE

Simple comparator with threshold at 1V. Design lower rail at 0V and upper rail at 2V (logic "1"). A = large (e.g. 10^2 to10^5)

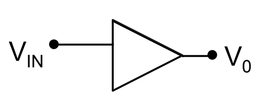




If $V_{IN} > 1.010$ V, $V_0 = 2V$ = Logic "1"

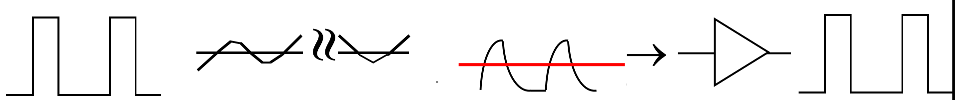
If $V_{IN} < 0.99$ V, $V_0 = 0V$ = Logic "0"

NOTE: The actual diagram of a comparator would not show an amplifier with "offset" power supply as above. It would be a simple triangle, perhaps with the threshold level (here 1V) specified.



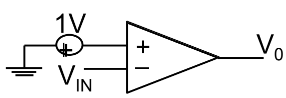
Comparator

ONE-BIT A/D CONVERSION
REQUIRED IN DIGITAL SYSTEMS



As we saw, we set comparator threshold at a suitable value (e.g., halfway between rails) and comparator output goes to +rail if $V_{IN} > V_{THRESHOLD}$ and to –rail if $V_{IN} < V_{THRESHOLD}$.

What would this circuit do?



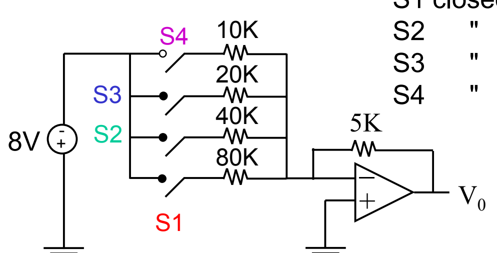
The inverse pulse shaped function is generated by applying the input voltage to V- and setting V+ to the threshold voltage.

D/A CONVERSION

Example: Digital representation of sound to analog (so you can hear it!) → D/A conversion

The summing junction op-amp provides a simple means of D/A conversion via **weighted-adder D/A converter**

S1 closed if LSB =1
S2 " if next bit = 1
S3 " if " " = 1
S4 " if MSB = 1



4-Bit D/A

Another way (not shown) is to sum **charges** instead of current with capacitor networks

Binary number	Analog output (volts)
0 0 0 0	0
0 0 0 1	.5
0 0 1 0	1
0 0 1 1	1.5
0 1 0 0	2
0 1 0 1	2.5
0 1 1 0	3
0 1 1 1	3.5
1 0 0 0	4
1 0 0 1	4.5
1 0 1 0	5
1 0 1 1	5.5
1 1 0 0	6
1 1 0 1	6.5
1 1 1 0	7
1 1 1 1	7.5

↑ MSB ↑ LSB

CHARACTERISTIC OF A 4-BIT DAC