EECS 42 Introduction to Electronics for Computer Science
Andrew R. Neureuther

Lecture # 14 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/

Game Plan 03/19/03

Monday 03/17/04
- Monday: Circuit analysis with dependent sources (4.1-4.2)

Wednesday 03/19/03:
- Comparators and op-amps (Comparator handout)

Next (10th) Week: After Spring Recess
- Monday: 3/31/03 Logic with State Dependent Device 593-595, 604-605
- Wednesday: 4/02/03 Logic Static: Voltage Transfer Characteristic 606, Handout

Problem set #8: Half-Set - out Monday 3/17 and due at 2:30 4/02 in box in 240 Cory – input/output impedance, comparators
NEGATIVE FEEDBACK

Familiar examples of negative feedback:
- Thermostat controlling room temperature
- Driver controlling direction of automobile
- Photochromic lenses in eyeglasses

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 stability

Fundamentally pushes toward instability or bi-stability

CASCADE OP-AMP CIRCUITS

How do you get started on finding $V_0$?

Hint: Identify Stages

Hint: $I_{\text{IN}}$ does not affect $V_{01}$

See the further examples of op-amp circuits in the reader
CASCADE OP-AMP SOLUTION

FIRST STAGE IS “SUMMING JUNCTION” AMPLIFIER

Solution:

\[ i_{IN} \equiv 0 \text{ and } V(-) \equiv V_+ = 0 \]

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

\[ V_{02} = -\frac{R_2}{R_1} V_{IN2} \]

INTEGRATING OP-AMP

How do you get started on finding \( V_o \)?

Hint: \( i_{IN} \equiv 0 \) and \( V(-) \equiv V_+ = 0 \)

Hint: KCL at \( V \) node with \( I_{IN} = 0 \)
INTEGRATING OP-AMP

\[ 0 - V^N_{\text{IN}} + C \frac{d}{dt}(0 - V^O) = 0 \]

Integrate from \( t_0 \) to \( t \) to get \( V^O(t) \)

\[ V^O(t) = -\frac{1}{R_1 C} \int_{t_0}^{t} V^N(t) \, dt \]

Example: Amplifier with gain of \( 10^5 \), with max \( V^O \) of 3V and min \( V^O \) of -3V.

Circuit model (ideal op-amp) gives the essential linear part

But \( V^O \) cannot rise above some physical voltage related to the positive power supply \( V_{CC} \) ("upper rail") \( V^O < V_{+RAIL} \)

And \( V^O \) cannot go below most negative power supply, \( V_{EE} \) i.e., limited by lower "rail" \( V^O > V_{-RAIL} \)

OP-AMP I-V CHARACTERISTICS WITH RAILS

Example: Amplifier with gain of \( 10^5 \), with max \( V^O \) of 3V and min \( V^O \) 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 $V_o$ vs $V_{IN}$ characteristics on two different scales.

(c) Same $V_o$ vs $V_{IN}$ over even wider range.

(b) I-V over wide range.

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”.

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 to 10^5)

\[ V_{\text{IN}} \rightarrow V_0 \]

\[ V_0 = \begin{cases} 2 & \text{if } V_{\text{IN}} > 1.010 \text{ V} \\ 0 & \text{if } V_{\text{IN}} < 0.99 \text{ V} \end{cases} \]

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.

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 \( V_{\text{IN}} > V_{\text{THRESHOLD}} \) and to –rail if \( V_{\text{IN}} < V_{\text{THRESHOLD}} \).

What would this circuit do?

\[ 1V \rightarrow V_0 \]

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

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<th>Binary number</th>
<th>Analog output (volts)</th>
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<td>0</td>
</tr>
<tr>
<td>0 0 0 1</td>
<td>.5</td>
</tr>
<tr>
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<tr>
<td>1 1 1 1</td>
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</tr>
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</table>

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

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

CHARACTERISTIC OF A 4-BIT DAC

Analog Output (V)

Digital Input