CENG4480
Lecture 05 Review

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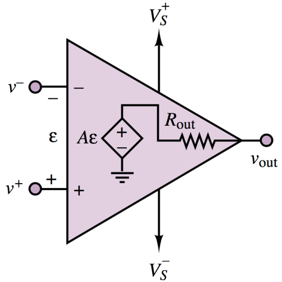
Op-Amp Comparator

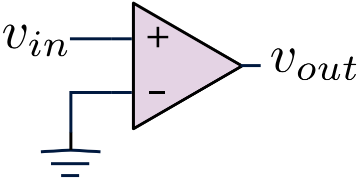


Open-Loop Mode

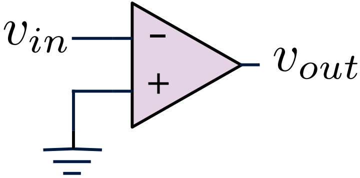
$$v_{out} = A_V(v^+ - v^-)$$

- Extreme large gain
- Any small difference ϵ will cause large outputs.

Noninverting & Inverting Comparator

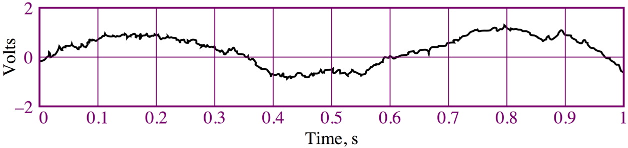


(a) Noninverting comparator

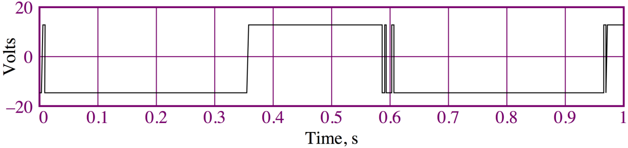


(b) Inverting comparator

Limitation of Conventional Comparator



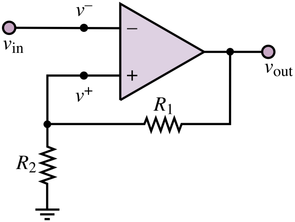
Noisy input waveform

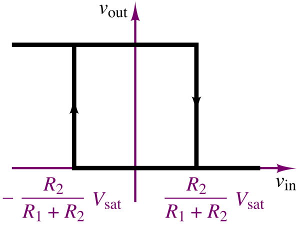


Comparator output waveform

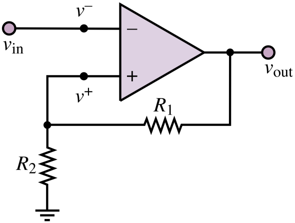
- In the presence of noisy inputs
- Cross the reference voltage level repeatedly
- Cause multiple triggering

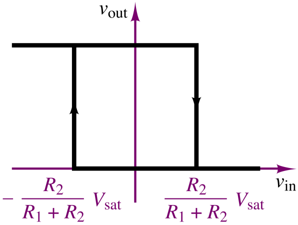
Schmitt Trigger



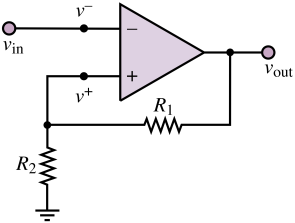


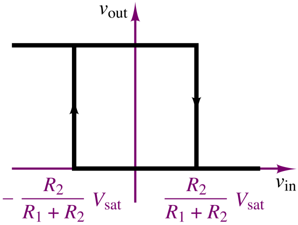
- Based on Inverting comparator
- Positive feedback
- (+) Increase the switching speed
- (+) Noise immunity





Question: prove two reference voltages of schmitt trigger.





Question: prove two reference voltages of schmitt trigger.

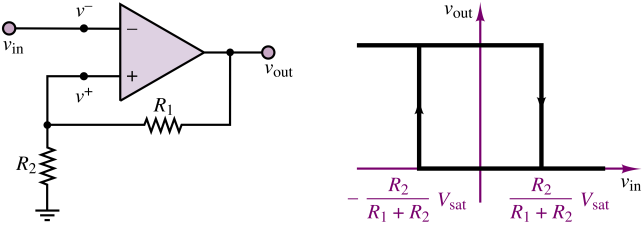
Case 1: $v_{out} = V_{sat}$, then

$$v^+ = \frac{R_2}{R_1 + R_2} V_{sat}$$

$$\epsilon = v^+ - v^- = \frac{R_2}{R_1 + R_2} V_{sat} - v_{in}$$

Therefore, the condition for switching ($\epsilon < 0$) is that

$$v_{in} > \frac{R_2}{R_1 + R_2} V_{sat}$$



Question: prove two reference voltages of schmitt trigger.

Case 2: $v_{out} = -V_{sat}$, then

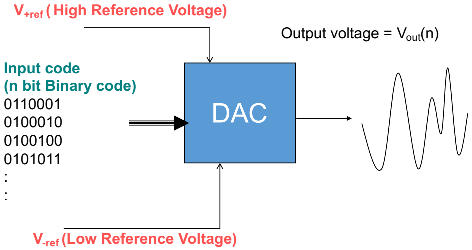
$$v^+ = -\frac{R_2}{R_1 + R_2}V_{sat}$$

$$\epsilon = v^+ - v^- = -\frac{R_2}{R_1 + R_2}V_{sat} - v_{in}$$

Therefore, the condition for switching ($\epsilon > 0$) is that

$$v_{in} < -\frac{R_2}{R_1 + R_2}V_{sat}$$

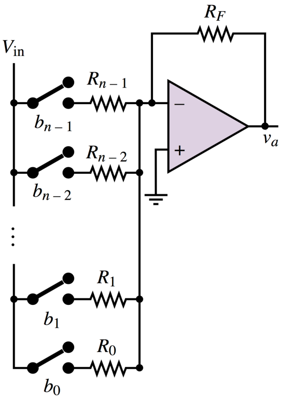
Digital-to-Analog Converter (DAC)



$$
\begin{aligned}
V_{out} &= (b_3 b_2 b_1 b_0)_2 \\
&= (b_3 \cdot 2^3 + b_2 \cdot 2^2 + b_1 \cdot 2^1 + b_0 \cdot 2^0)_{10} \\
&= (8b_3 + 4b_2 + 2b_1 + b_0)\Delta v + V_{-ref}
\end{aligned}
$$

Δv: smallest step size by which voltage can increase

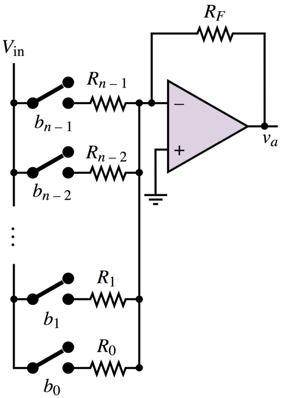
DAC Type 1: Weighted Adder DAC



Similar to summing amplifier:

$$v_a = -(\frac{R_F}{R_i} \cdot b_i \cdot v_{in})$$

DAC Type 1: Weighted Adder DAC



Similar to summing amplifier:

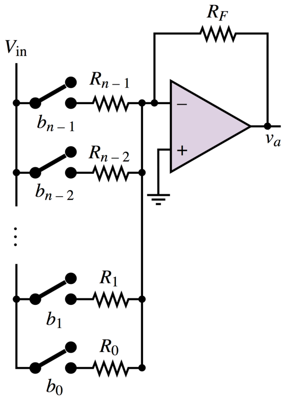
$$v_a = -\left(\frac{R_F}{R_i} \cdot b_i \cdot v_{in}\right)$$

If we select $R_i = \dfrac{R_0}{2^i}$:

$$v_a = -\frac{R_F}{R_0}\left(2^{n-1} b_{n-1} + \cdots + 2^1 b_1 + 2^0 b_0\right) \cdot v_{in}$$

Note here V_{-ref} is 0 (ground)

DAC Type 1: Weighted Adder DAC



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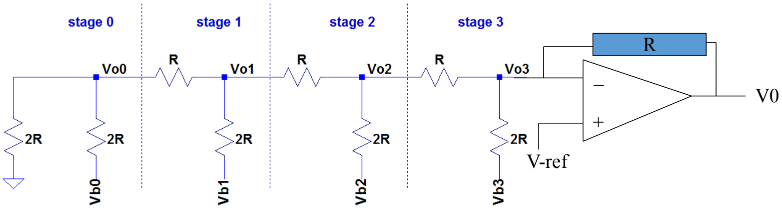
Note here V_{-ref} is 0 (ground)

Limitations:

- Impossible to fabricate a wide range of resistor values in the same IC chip

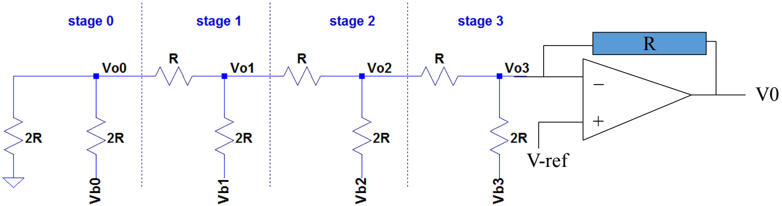
DAC Type 2: R-2R DAC



Motivations:

- Use only two values of resistors which make for easy and accurate fabrication and integration
- At each node, current is split into 2 equal parts
- The most popular DAC

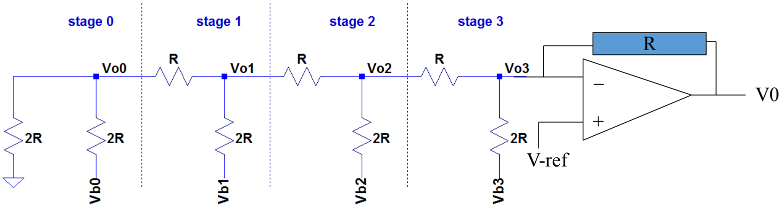
DAC Type 2: R-2R DAC



Reference:

http://www.tek.com/blog/tutorial-digital-analog-conversion--r-2r-dac

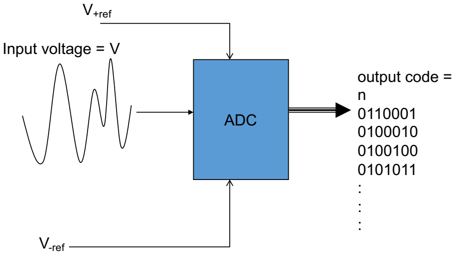
DAC Type 2: R-2R DAC



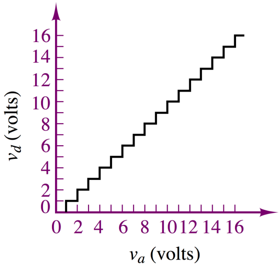
Given I as input value (n bit):

$$V_{o3} = V_{-ref} + I \cdot \frac{V_{+ref} - V_{-ref}}{2^n},$$

Analog-to-Digital Converter (ADC)



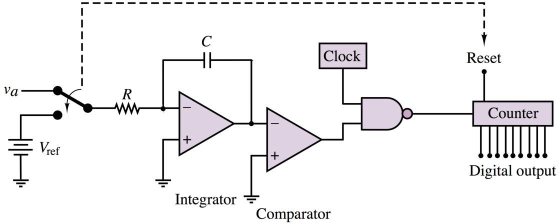
Quantization



Quantized voltage v_d	Binary representation b_3	b_2	b_1	b_0
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
⋮		⋮		
14	1	1	1	0
15	1	1	1	1

- Convert an analog level to digital output
- Employ $2^n - 1$ intervals (n: bit#)
- v_a: analog voltage
- v_d: output digital voltage

ADC Type 1: Integrating ADC



- Accumulate the input current on a capacitor for a fixed time
- Then measure time (T) to discharge the capacitor
- When cap is discharged to 0 V, comparator will stop the counter

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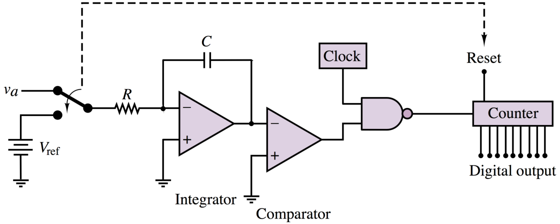

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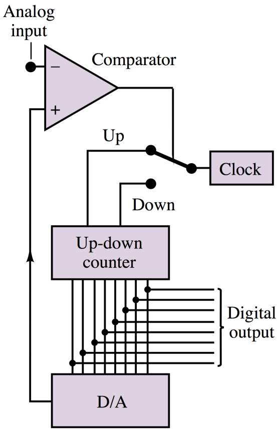
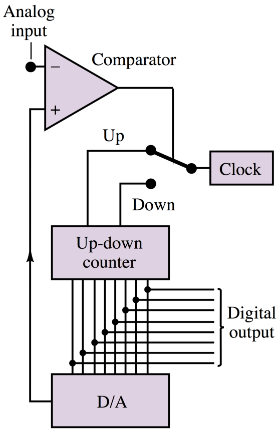
Limination: Slow

ADC Type 2: Tracking ADC



- ADC repeatedly compares its input with DAC outputs
- Up/down count depends on input/DAC output comparison

ADC Type 2: Tracking ADC



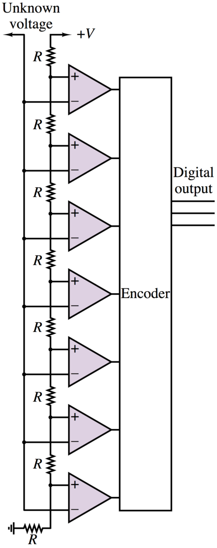
- ADC repeatedly compares its input with DAC outputs
- Up/down count depends on input/DAC output comparison

Limination: Slow

ADC Type 3: Successive Approximation

- Replace “Up-down counter” by “control logic”
- Binary search to determine the output bits
- still slow although faster than types 1 & 2

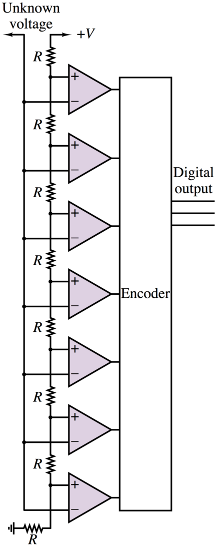
ADC Type 4: Flash ADC



- Divide the voltage range into $2^n - 1$ levels
- Use $2^n - 1$ comparators to determine what the voltage level is
- Fully parallel

Pros:

ADC Type 4: Flash ADC



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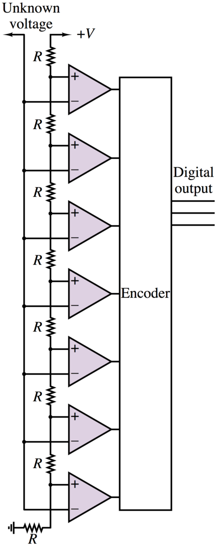
Pros:

- Very fast for high quality audio and video
- Sample and hold circuit **NOT** required

ADC Type 4: Flash ADC



- Divide the voltage range into $2^n - 1$ levels
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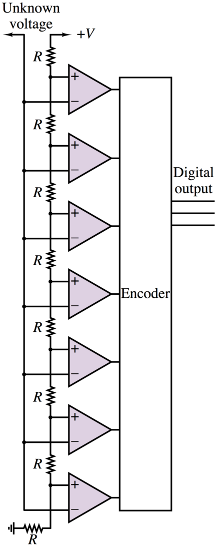
Cons:

ADC Type 4: Flash ADC



- Divide the voltage range into $2^n - 1$ levels
- Use $2^n - 1$ comparators to determine what the voltage level is
- Fully parallel

Pros:

- Very fast for high quality audio and video
- Sample and hold circuit **NOT** required

Cons:

- Very expensive for wide bits conversion