Lecture 23 Analog/Digital conversion

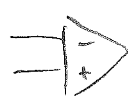
Real world signals are generally analog

Need to convert analog → digital for measurements "ADC"

convert digital → analog for control "DAC"

Many methods.

Simplest: comparator



Like op-amp without feedback

If $V_+ > V_-$, V_{out} = + supply

$V_+ < V_-$, V_{out} = − supply

Make supply voltages +5 V, 0V:

get one-bit ADC

Or make $V_- = 2.5\,V$, supplies = desired analog levels

get one-bit DAC

Often, one bit is sufficient

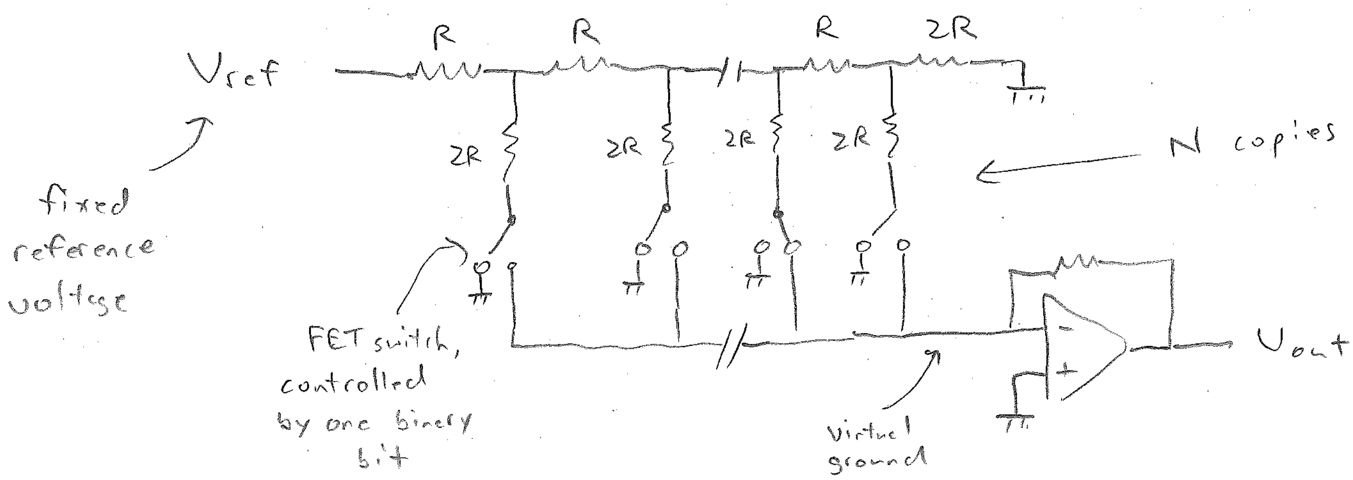
Just need yes/no answer

or do/don't command

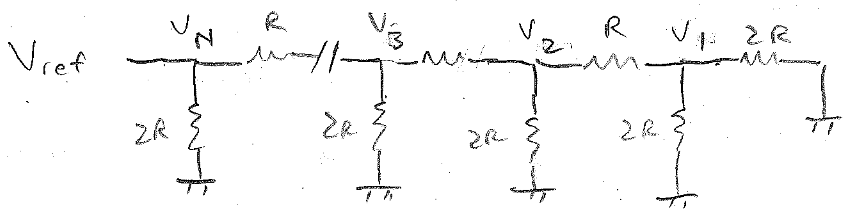
When more than one bit is required, use fancier techniques

DAC = digital to analog converter

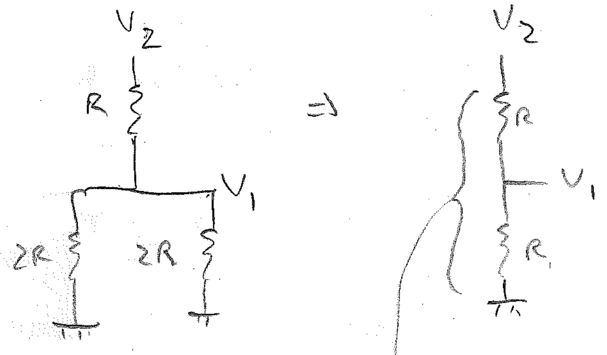
Common method = R-2R ladder



Input network acts like:

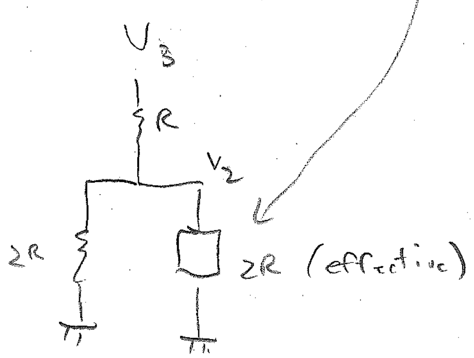


Compare V_2 & V_1



$$V_1 = \frac{V_2}{2}$$

Compare V_3 & V_2



$$\Rightarrow \quad V_2 = \frac{V_3}{2}$$

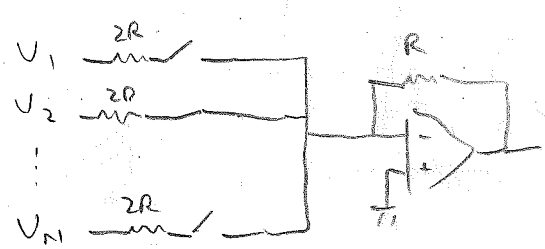
Same for each stage: $V_{n+1} = 2V_n \qquad n = 1 \text{ to } N-1$

$$= 2^n V_1$$

So $V_N = 2^{N-1} V_1$, but $V_N = V_{ref}$

$$\Rightarrow V_1 = \frac{V_{ref}}{2^{N-1}}, \qquad V_n = \frac{V_{ref}}{2^{N-n}}$$

Now, op amp is configured as summing amplifier with gain ½



Say b_n = bit value for n th stage

$b_n = 0$ or 1

Then $$V_{out} = \frac{1}{2} \times \sum_{n=1}^{N} b_n \cdot V_n = \frac{1}{2} \sum_{n=1}^{N} b_n \frac{V_{ref}}{2^{N-n}}$$

$$= \frac{V_{ref}}{2^N} \sum_{n=1}^{N} b_n 2^{n-1}$$

Now $\sum_n b_n 2^n$ is just binary value of $\{b_n\}$

b_1 = 1s place
b_2 = 2s place
b_3 = 4s place etc

So $V_{out} = \Delta V \times$ value $\{b_n\}$

$\Delta V = \frac{V_{ref}}{2^N}$ = minimum voltage step

So if $N = 10$ (values = 0 to 1023)

and $\Delta V = 1\,mV$, can get output value from 0 to 1.023 V as specified by data

Typical values are $N = 8, 12, 16$
V_{ref} > 1 to 10 V

ΔV = voltage resolution
typically 1 to 10 mV

ADC = analog to digital converter

measure voltage V, output binary values $\{b_n\}$

with value $\{b_n\} = \frac{V}{\Delta V}$

Larger N ⇒ more bits ⇒ smaller ΔV ⇒ more resolution

Three common techniques:

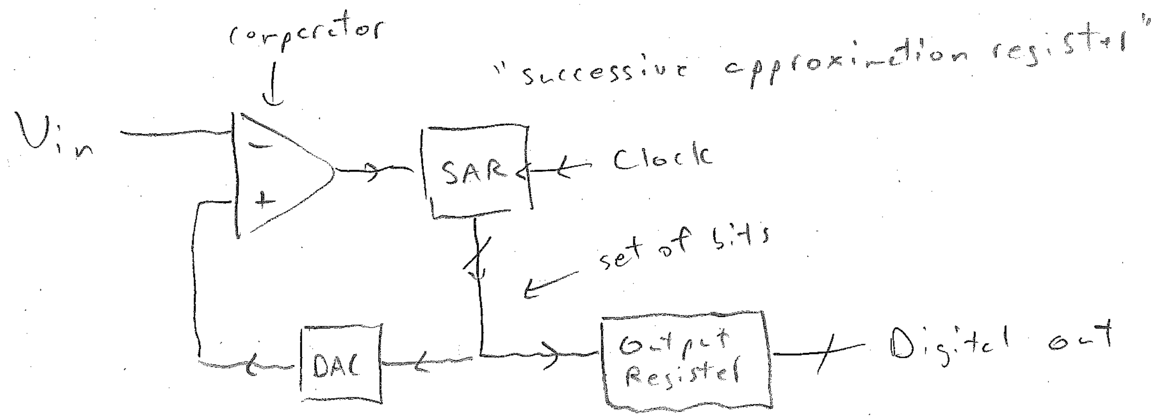
- Flash: accurate & very fast, but limited to small N
  Often used for digital scopes

- Integrating: very accurate but slow, works at large N
  Often used for digital voltmeters

- Successive Approximation: fairly fast & fairly accurate
  ⇒ medium N

  Common general purpose method

Technique:



SAR generates one bit at a time

Initial output = middle of range = "guess" for right value

(repeat N times:)

DAC converts to voltage in middle of range

Comparator says whether guess is high or low

If guess is high, SAR rises to middle of upper half
low, SAR drops to middle of lower half

Clock controls timing for new guesses

Register holds output until conversion complete

Each cycle gives one more bit

Example: $N = 8$ $V_{ref} = 5\ V$ $\Rightarrow$ $\Delta V = \frac{5}{2^8} = 19.5\ mV$

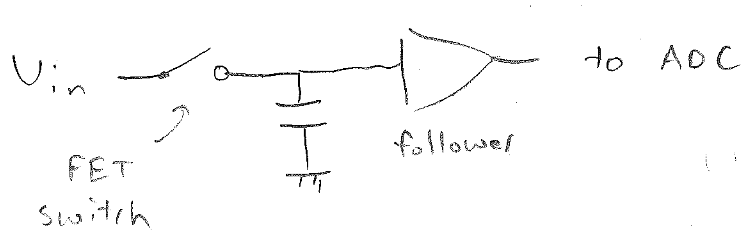
Say $V_{in} = 1.330\ V$

Cycle	Guess	Value	DAC	Comparator
1	1000 0000	128	2.496 V	H
2	0100 0000	64	1.248 V	L
3	0110 0000	96	1.872 V	H
4	0101 0000	80	1.560 V	H
5	0100 1000	72	1.404 V	H
6	0100 0100	68	1.326 V	L
7	0100 0110	70	1.365 V	H
8	0100 0101	69	1.346 V	H

Final output either 0100 0101
or 0100 0100, depending on circuit details

Might worry: what if V_{in} changes during measurement?

Solve with "sample and hold" circuit



When switch is open, voltage on ADC held ~ constant

Important for all ADC techniques