CPE 390: Microprocessor Systems

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Lecture 14
Analog to Digital Conversion

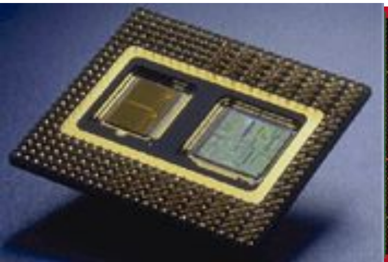
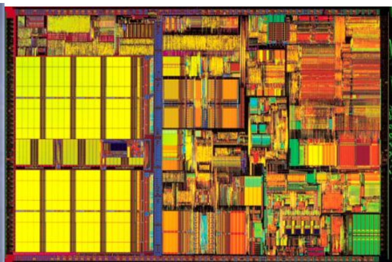
Bryan Ackland

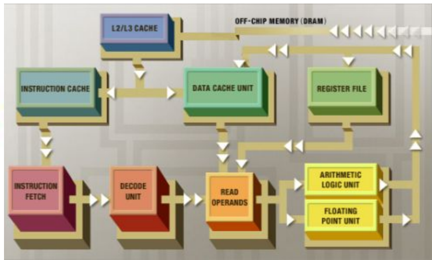
Department of Electrical and Computer Engineering

Stevens Institute of Technology

Hoboken, NJ 07030

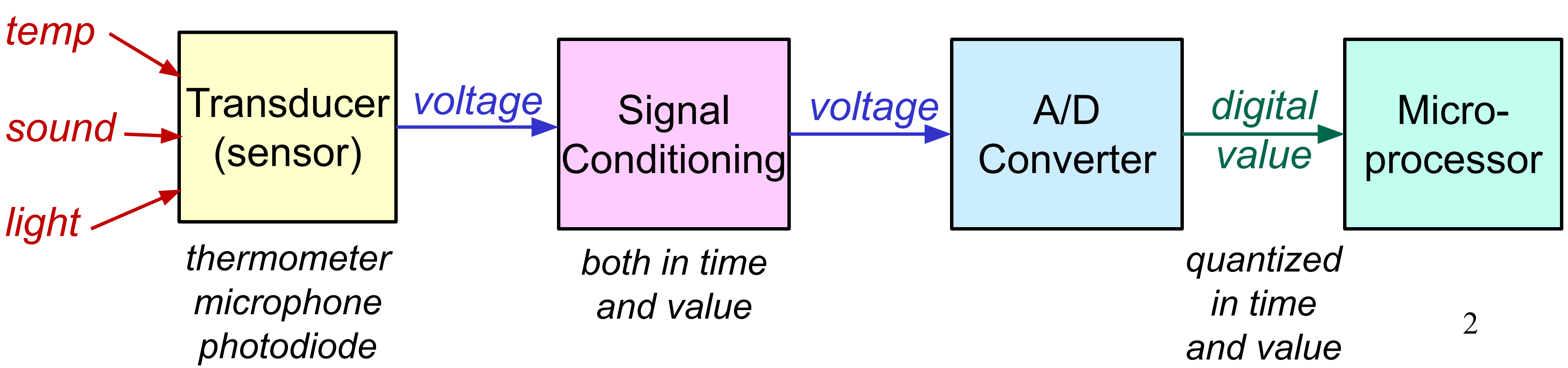
Adapted from HCS12/9S12 An Introduction to Software and Hardware Interfacing   Han-Way Huang, 2010

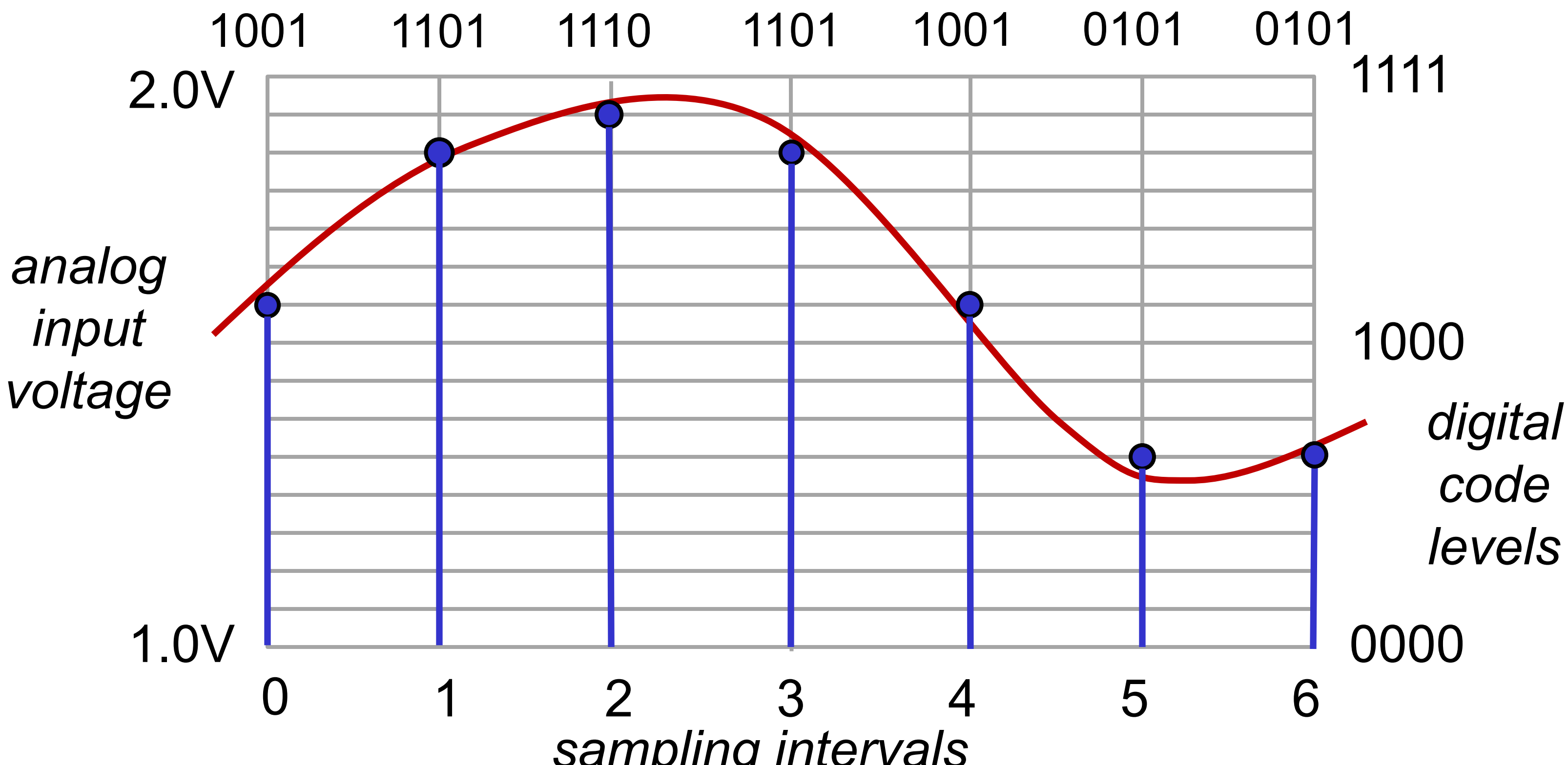
The Real World of Analog

- A microprocessor deals exclusively with digital data
  - finite precision representations of external real world and internal computational data
- A microcontroller in an embedded application takes inputs from real-world sensors
  - some of these are already digital (e.g. switches, keyboard, mouse)
  - many are analog (e.g. pressure, temperature, light intensity, microphone, airflow, engine speed, oxygen level)
- Analog-to-Digital converter (A/D) transforms analog signal into digital representation usable by microprocessor



Analog to Digital Conversion

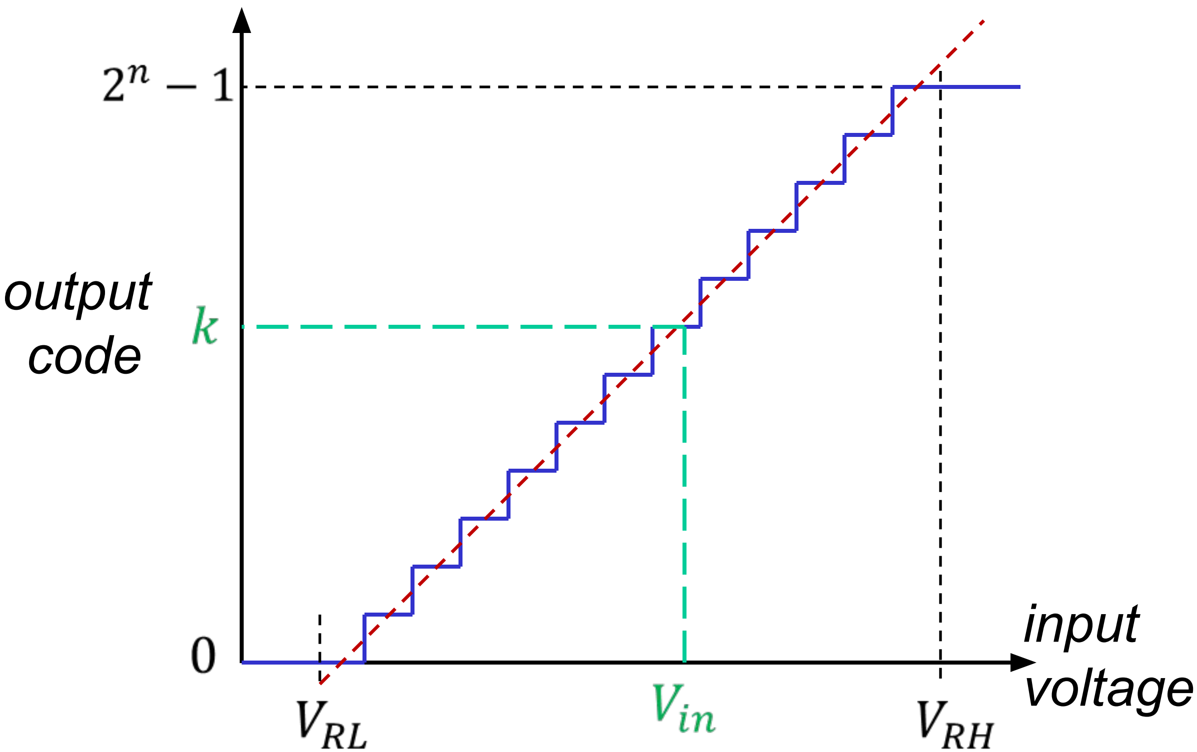
- An A/D converter samples an analog signal at regular intervals and generates a digital code which is its best (closest) approximation to the analog value at that instant

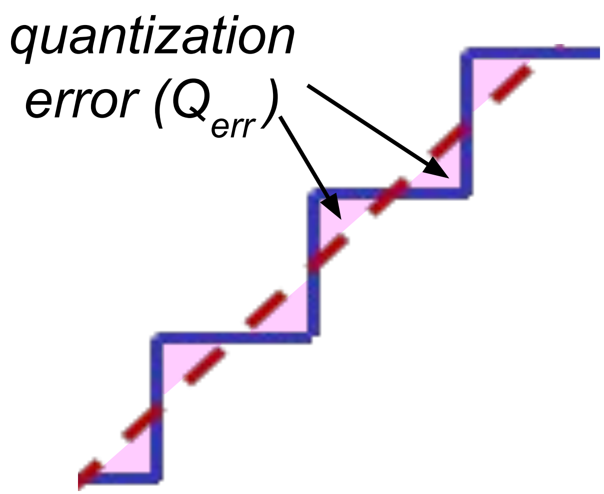


- Analog signal: continuous in time and value
- Digital signal: quantized in time and value

A/D Transfer Function

- An n-bit A/D converter has 2^n possible output codes
- Input voltage range typically defined by two reference voltages V_{RL} and V_{RH}





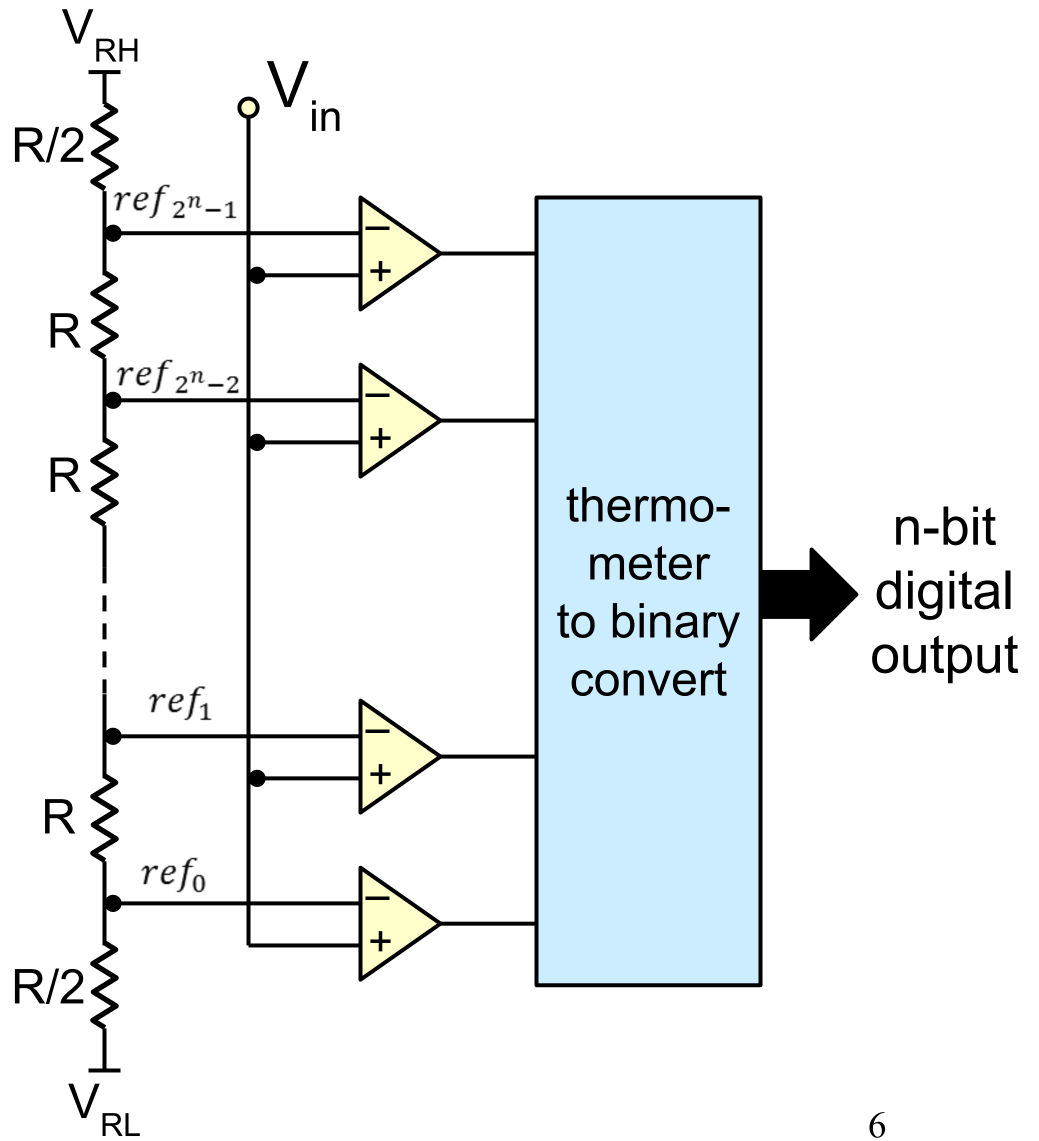
$$V_{in} = V_{RL} + \frac{(V_{RH} - V_{RL}).\,k}{2^n - 1} \pm Q_{err}$$

A/D Characteristics

- **Resolution**
  - often quoted in terms of # bits (e.g. 12-bit converter)
  - analog resolution is $(V_{RH} - V_{RL})/2^n$

Flash (Parallel) A/D Converter

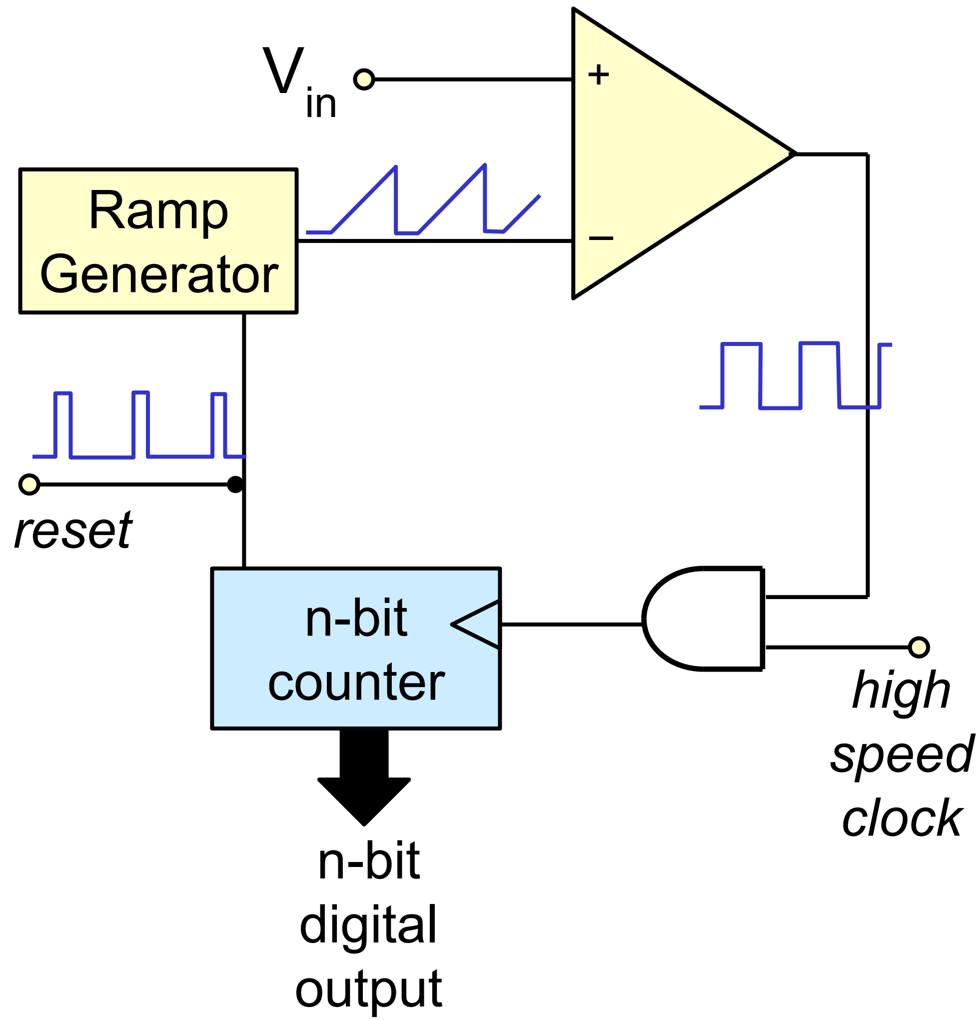
- Resistor ladder generates 2^n reference voltages
- 2^n comparators simultaneously compare input with each reference
- Comparator output k is high if Vin > ref_k
- Conversion logic generates code indicating greatest value of k for which comparator output is high
- Very high speed
- Expensive in area & power
- Limited to ~ 8-bits



Single Slope A/D Converter

- Compares input to linear ramp to generate a pulse width proportional to V_{in}
- Pulse used to gate clock to high speed digital counter
- Simple hardware – popular in low speed applications
- High resolution possible
- Performance limited by:

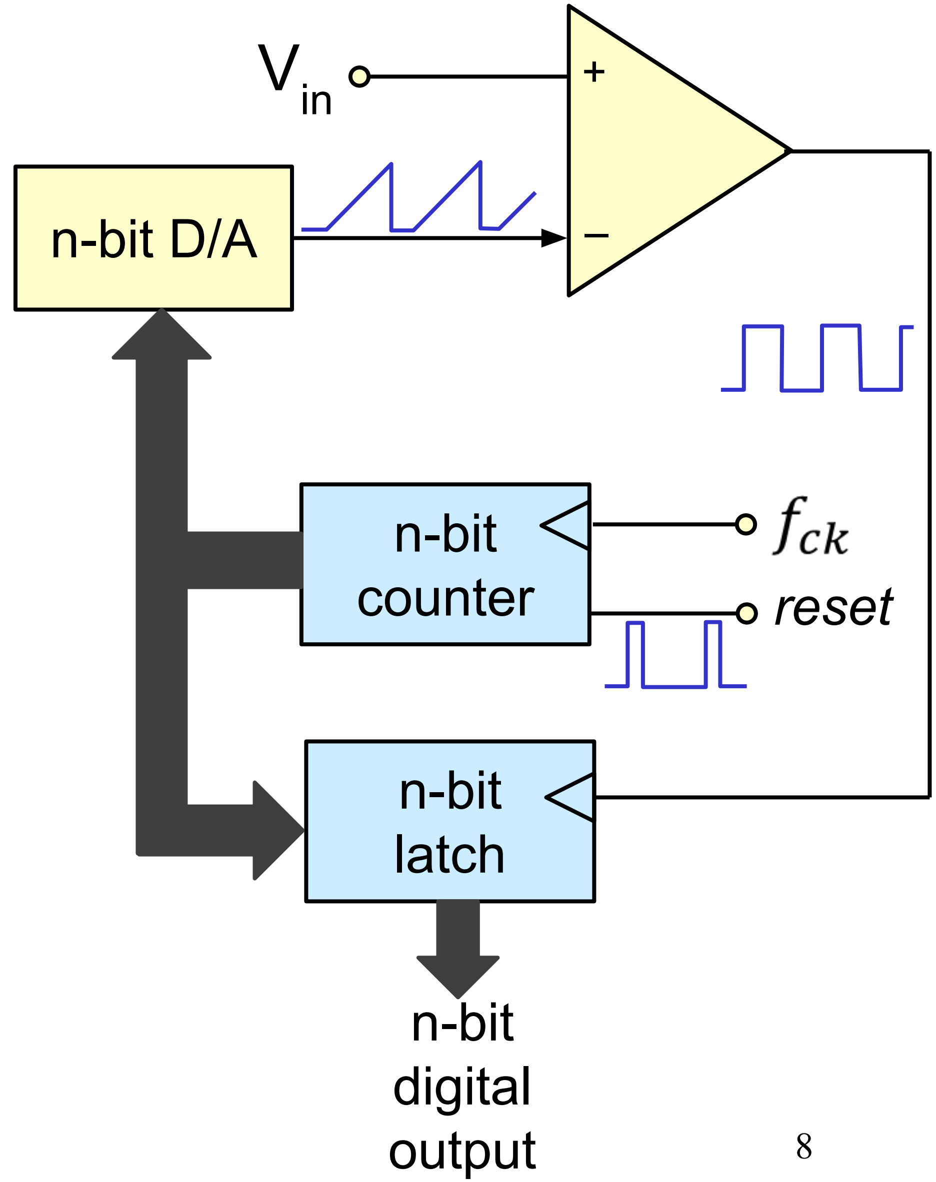
$$f_{ck} = f_{samp} \times 2^n$$



e.g. for f_{samp} = 1 MHz, a 12-bit converter requires f_{ck} = 4 GHz

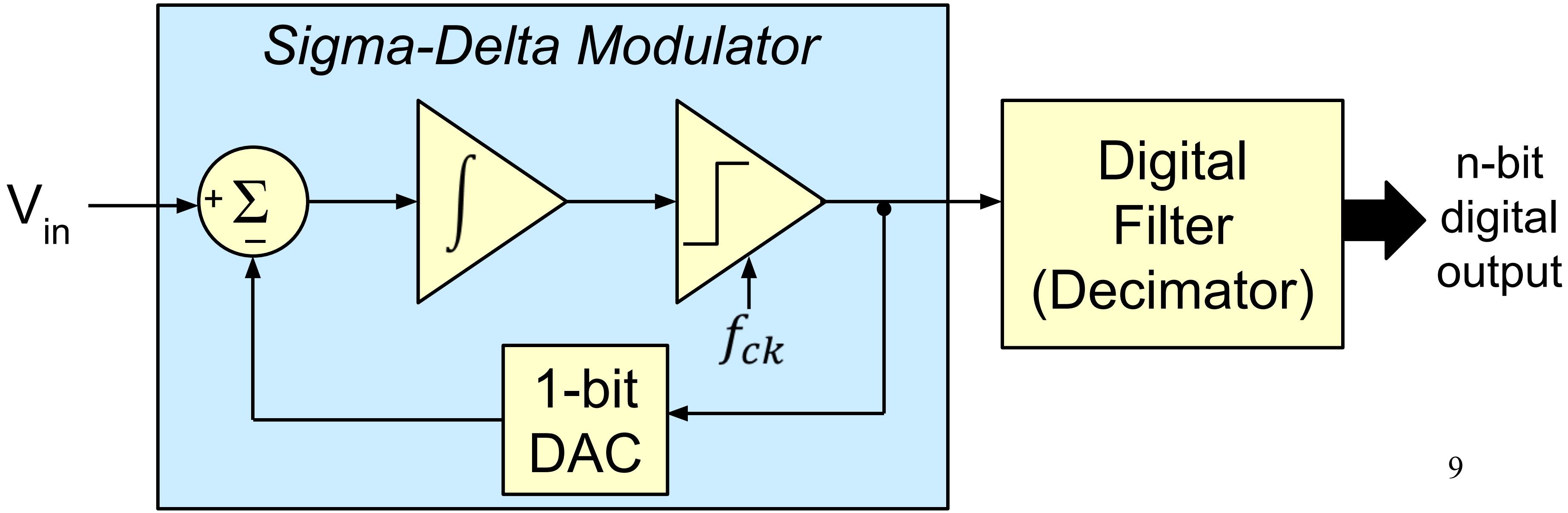
Counter Ramp A/D Converter

- Variant on single-slope converter
- Ramp is generated by counter driving a D/A converter
- When D/A output ramp crosses V_{in}, counter value is captured in n-bit latch
- Does not require precision analog ramp generation
- Precision limited by linearity of D/A



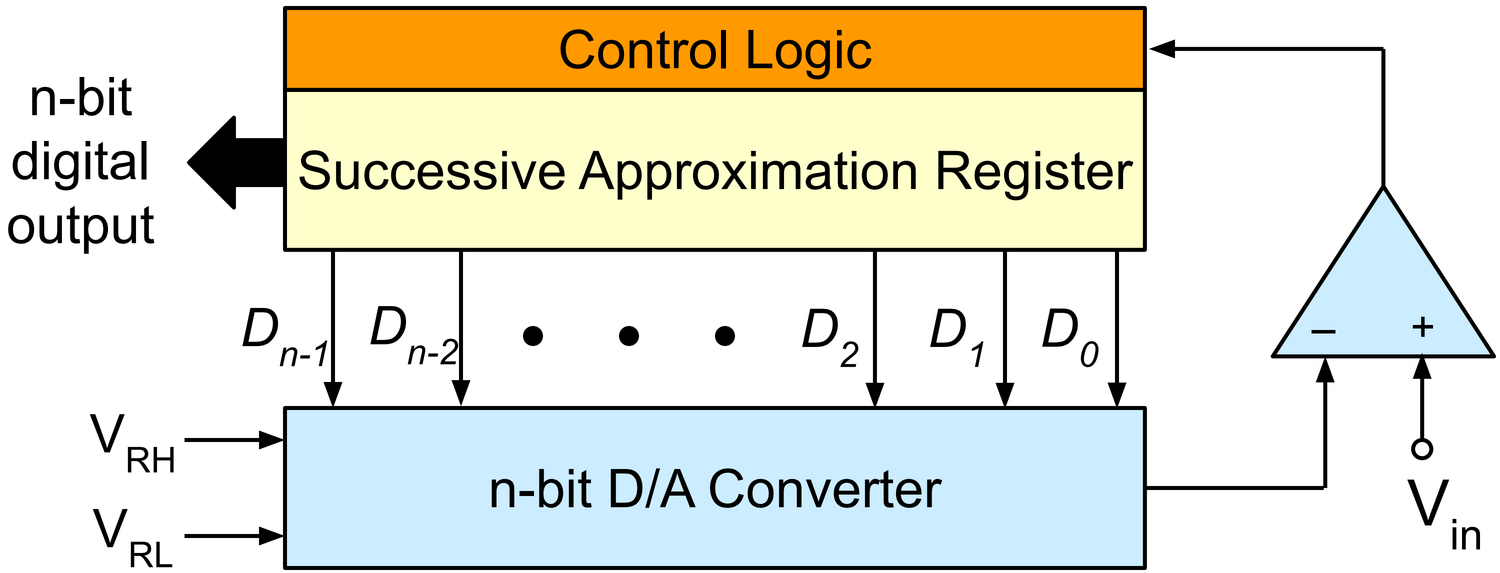
Sigma Delta (Oversampling) A/D Converter

- Sigma-delta modulator consists of summer, integrator, clocked comparator and a 1-bit DAC
- Modulator runs at many times (e.g. 16x – 1000x) the required sampling frequency to produce very high speed 1-bit waveform
- Digital filter coverts this to much slower n-bit digital output
- Since 1-bit DAC is perfectly linear, can produce very high resolution (up to 24-bit)
- Sampling frequency is limited by need to over-sample



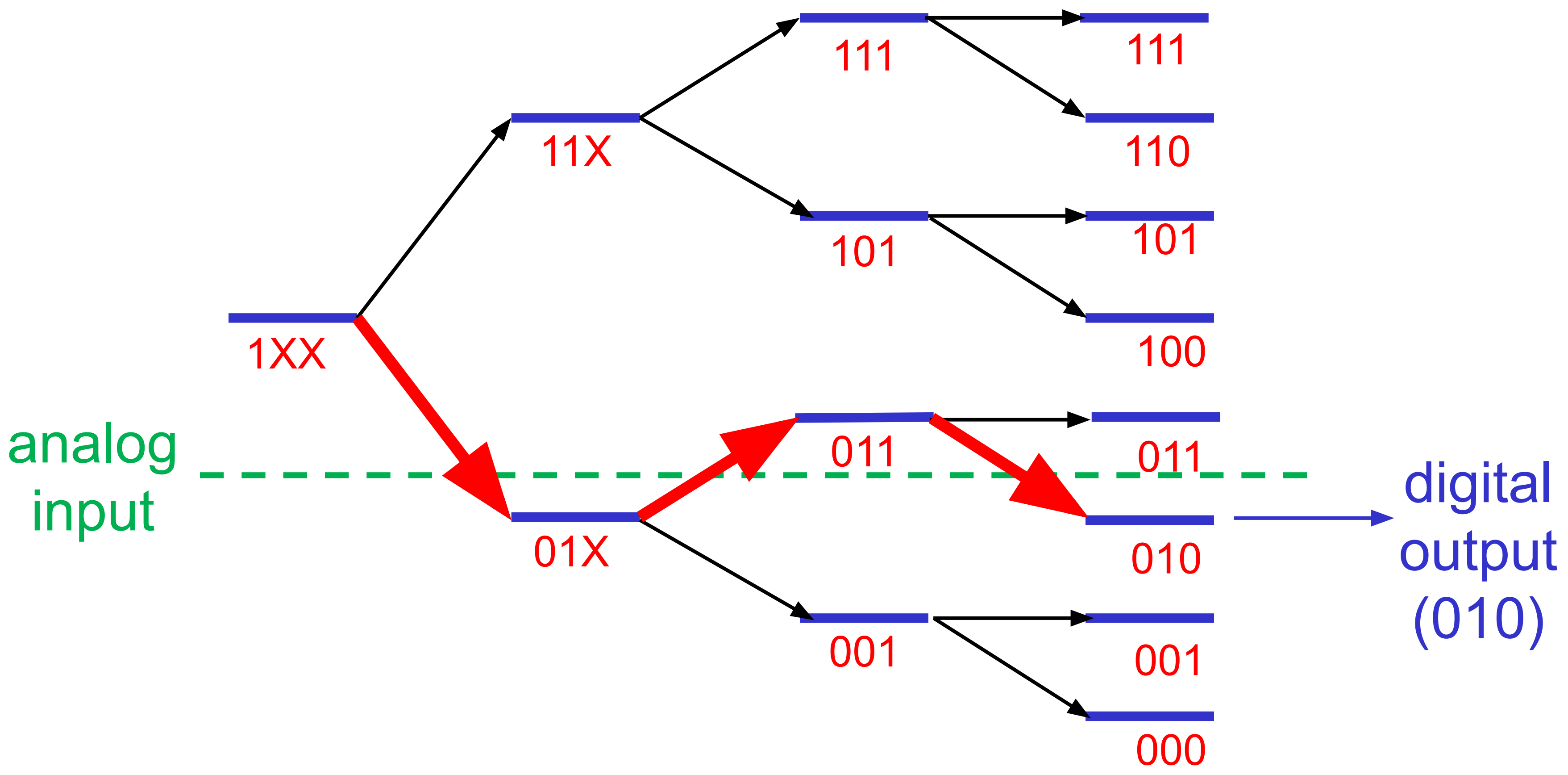
Successive Approximation A/D Converter

- Guesses and then corrects digital code in SAR one bit at a time



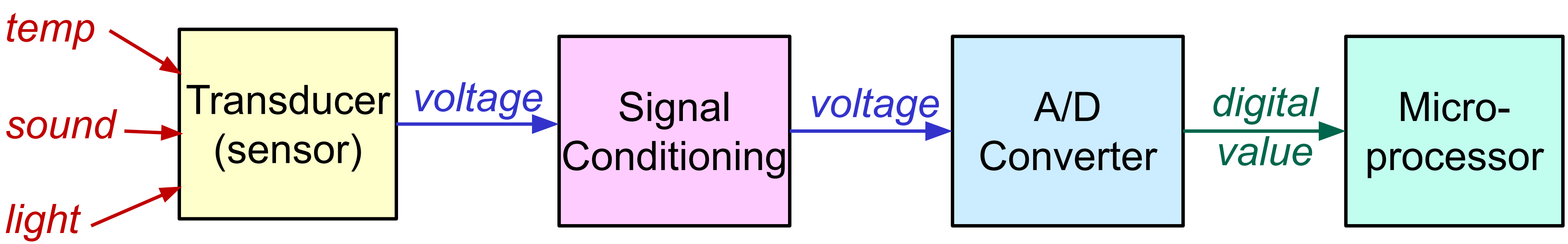
- Initially sets all bits in SAR to ‘0’
- Then starting with MSB, for each bit:
  - set bit to ‘1’ and convert output of SAR to analog value with D/A
  - compare output of D/A to input voltage
  - if D/A is larger, set this bit back to ‘0’ and go on to next (lesser sig.) bit
  - if input is larger, retain ‘1’ for this bit and go on to next bit

Successive Approximation Process



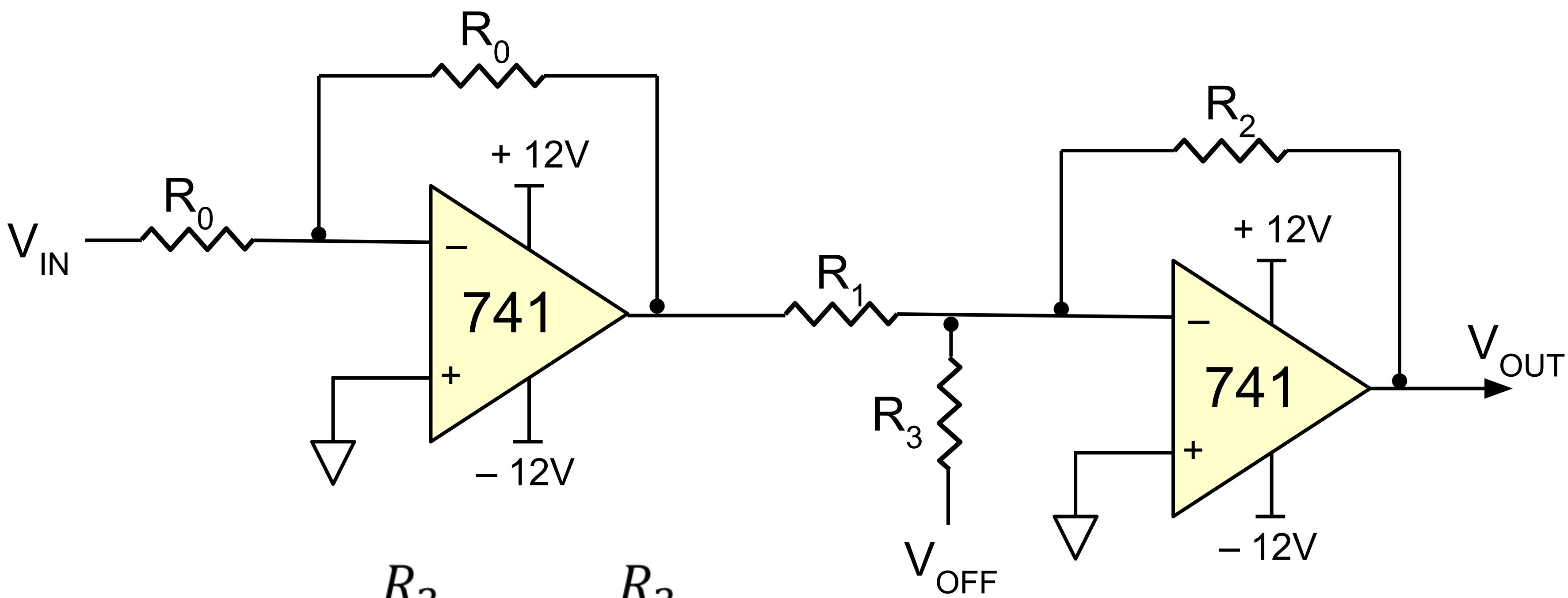
- SAR gives a good tradeoff between speed and precision
- One of most popular A/D techniques in embedded systems
- Used in HCS12

Signal Conditioning



- Signal Conditioning is process of matching transducer output to input characteristics of A/D
  - Need to match in voltage and time (frequency)

Shift & Scale Circuit



$$V_{OUT} = \frac{R_2}{R_1}.V_{IN} - \frac{R_2}{R_3}.V_{OFF}$$

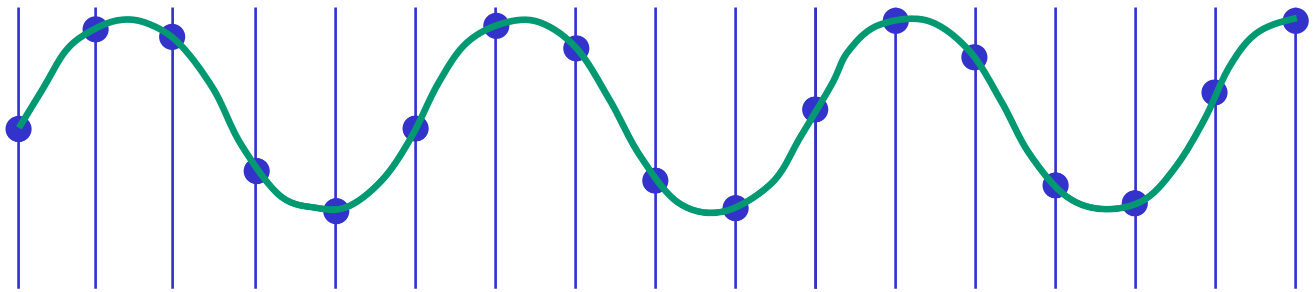
- From previous example, if $R_1 = R_3 = 10k\Omega$, $R_2 = 20k\Omega$, $V_{OFF} = -1V$:

$$V_{OUT} = (2 \times V_{IN}) + 2$$

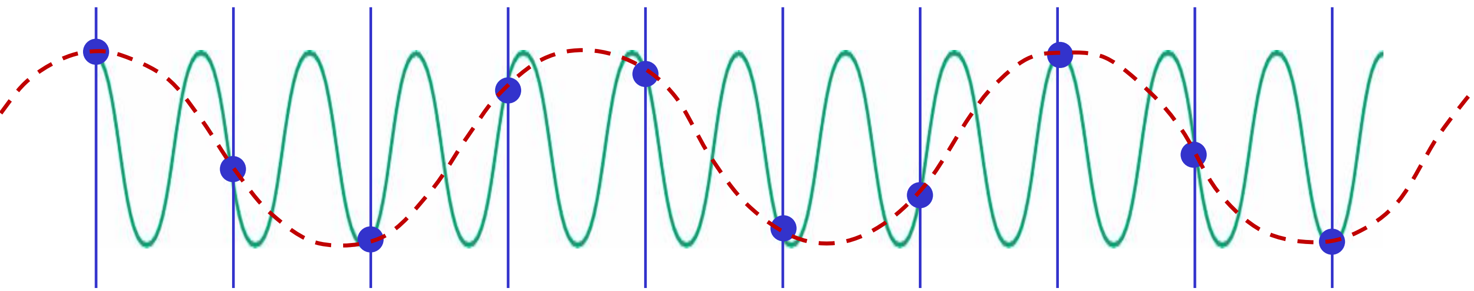
Nyquist Frequency

- If f_s is the sampling frequency, $f_s/2$ is known as Nyquist frequency

Aliasing



$f_{sig} < f_s/2$



$f_{sig} > f_s/2$

- Even if desired signal does not contain components > Nyquist, there may be high frequency noise components which must be removed
- Signal conditioning circuits frequently include a sharp low-pass filter to take out any signal components > Nyquist

A/D Conversion on Arduino Due

- Basic Arduino has 6 A/D channels, 10-bit about 7700hz
- The Due has
  - 12 bit accuracy (1 part in 4096)
  - 1MHz sample rate
  - 16 input channels
  - The basic Arduino can be run faster than rated A/D conversion less accurately.