Embedded System Application

4190.303C

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Analog and Digital Signals

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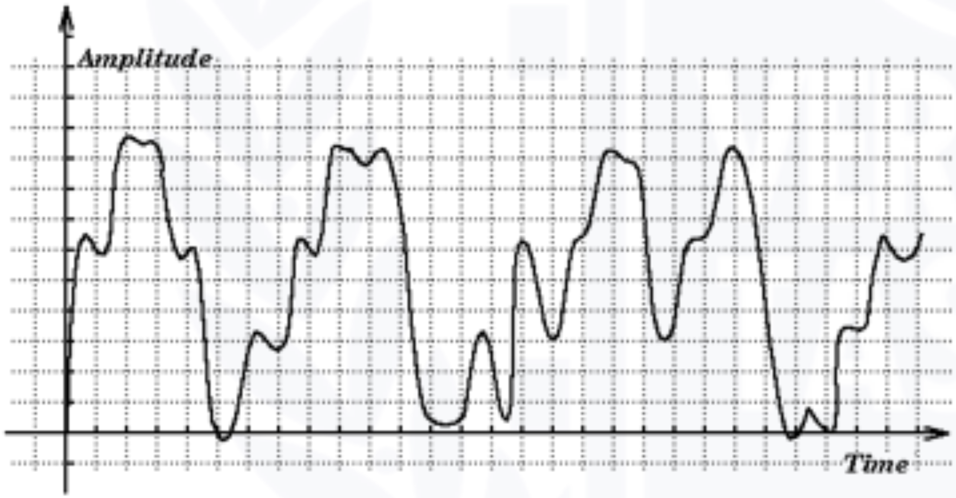
Analog and digital signals

- Continuous time and discrete time signals
  - $Y=f(t)$: t is a continuous variable
  - $Y=F(t_i)$: t_i is an index
  - Sampling converts continuous time signal to discrete time signal
- Digital signal
  - Logic 0 and logic 1
  - A group of digital signals can represent analog quantity by quantization
- Analog signals are converted to digital signals via sampling and quantization

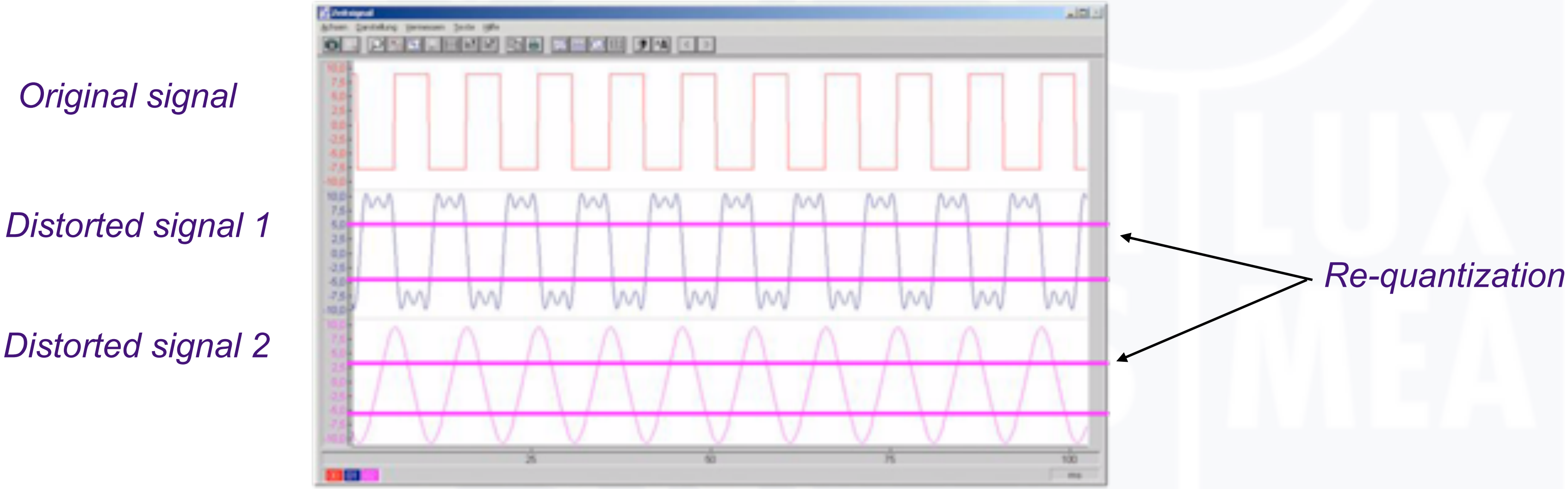
Analog and digital signals

- Analog signals
  - Continuous time signals
  - Continuous values
  - Natural signals
  - Noise prone
    - Additive noise permanently changes the original signal



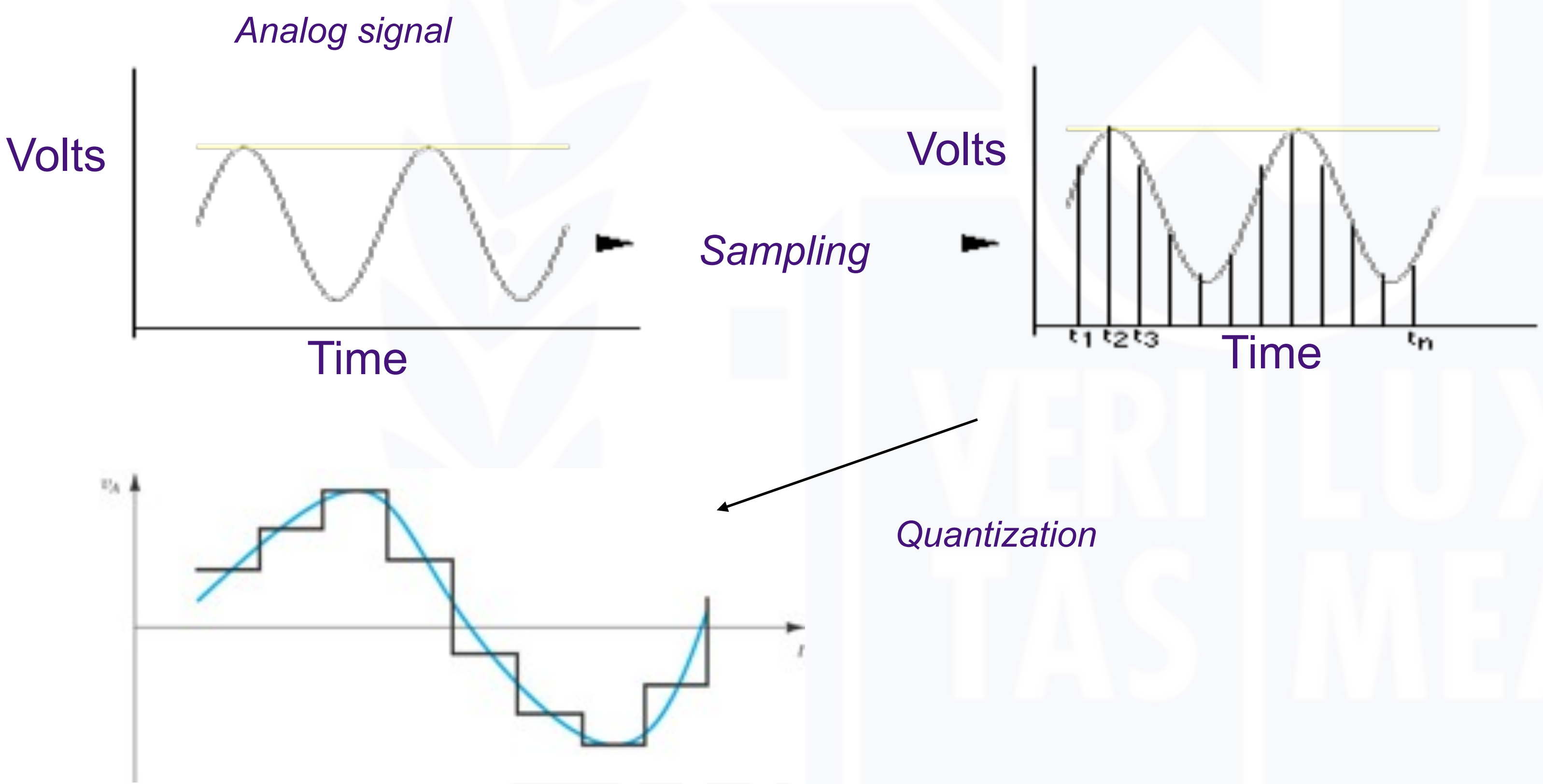
Analog and digital signals

- Digital signals
  - Discrete time signals
  - Discrete values
  - Not an original signal
    - Sampling and quantization error Noise immunity within noise margin
    - Additive noise can be canceled



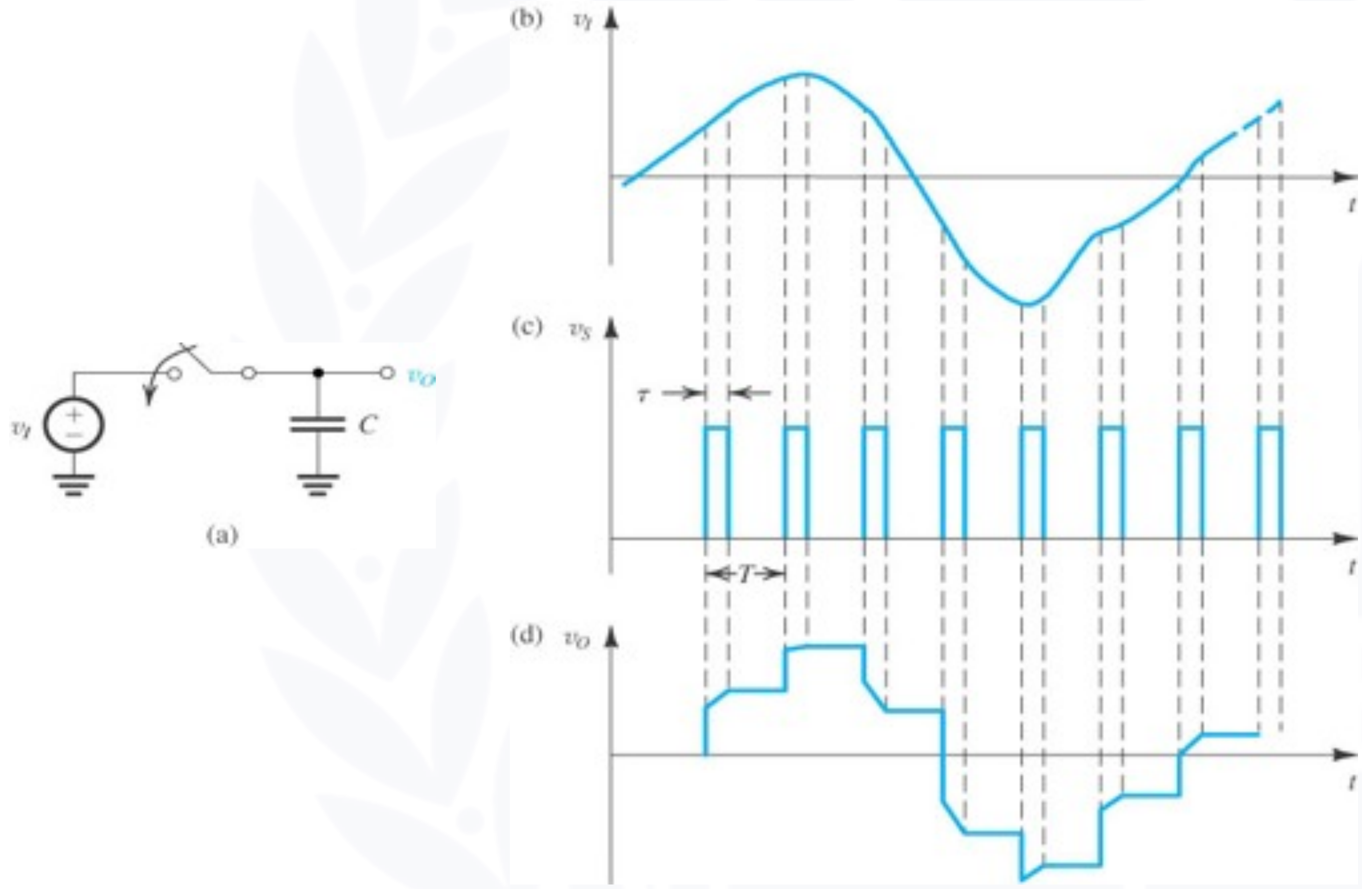
Analog and digital signals

- Signal translations



Sampling

- Sample and hold



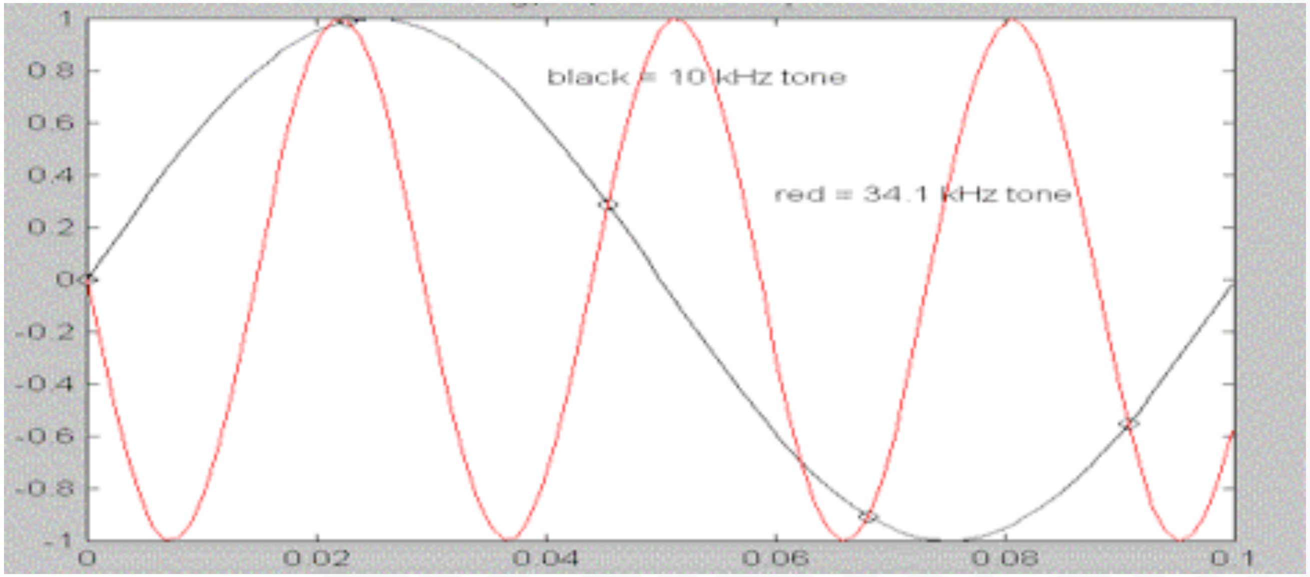
Sampling

- Sampling rate
  - Sampling Rate or Conversion Rate: Data is acquired by the ADC by using a process called sampling
  - Instantaneous values from the analog signal are sampled at discrete time intervals
  - The rate at which signals are sampled is called the sampling frequency
  - Higher the rate of sampling, better is the quality of conversion
  - Nyquist Rate
    - The minimum sampling frequency must be at least twice the maximum frequency of the input analog signal
  - Sampling at a lower rate will lead to aliasing
    - Example of aliasing – an unlucky student

Aliasing

- Red wave: Original Signal (34.1 KHz)
- Black wave: Undersampled waveform (Fs=10KHz)

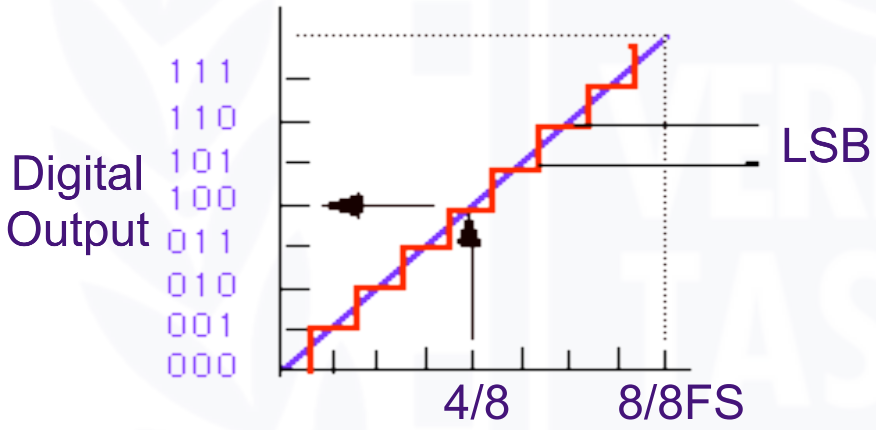
Voltage



Time

Resolution (quantization)

- Resolution: The number of bits the ADC uses to represent the digital data determines the resolution
  - Example: A 3-bit ADC. For a full-scale voltage of 10 volts, the resolution will be $10/(2^3)=1.25$ V.
  - However, if we increase the number of bits to 12, then resolution becomes $10/(2^{12})=2.44$ mV.

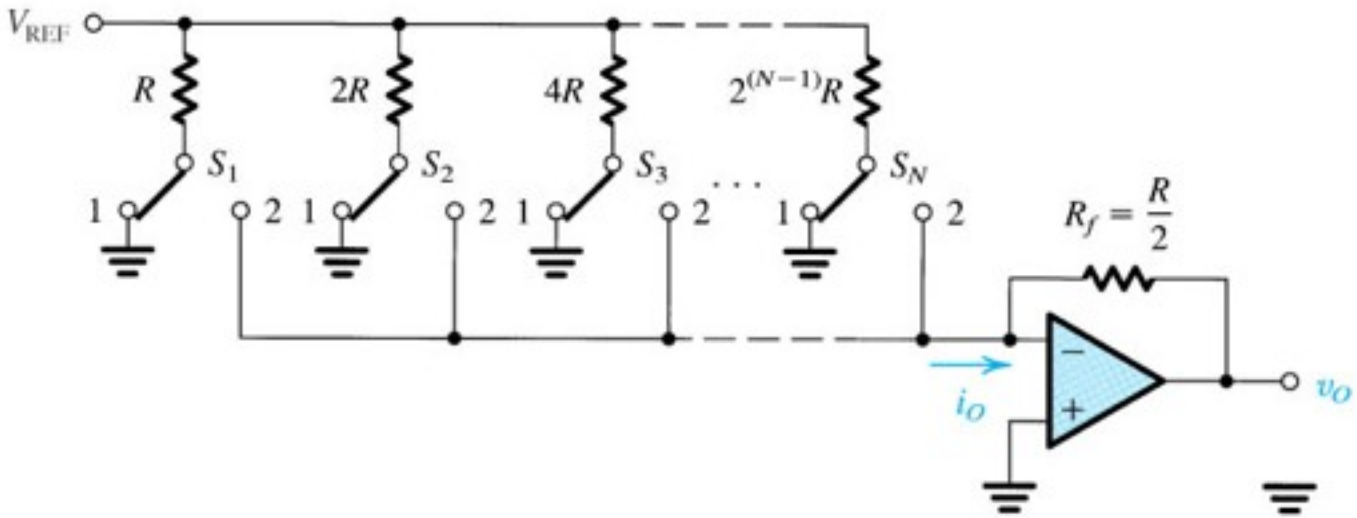


Resolution (quantization)

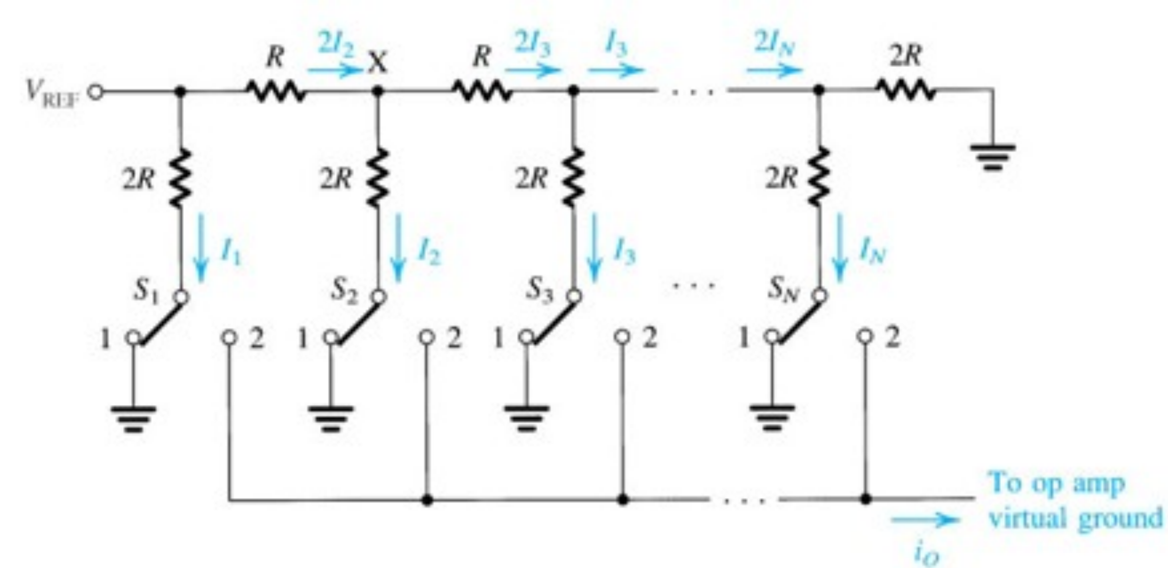
- Full-Scale Voltage Range
  - The difference between the maximum voltage and minimum voltage that the ADC is converting.
- Differential sensing:
  - In the regular single sensing mode, the ADC samples the difference between the applied signal and ground pin.
  - In differential mode, the input signal is applied between a signal line and its own special reference, the signal return path is through this reference signal and not the regular ground pin.
  - Differential mode is used when noise on input line is high, or the voltages are extremely low (< 1 V).

Digital to analog conversion

- Ladder network for DA conversion

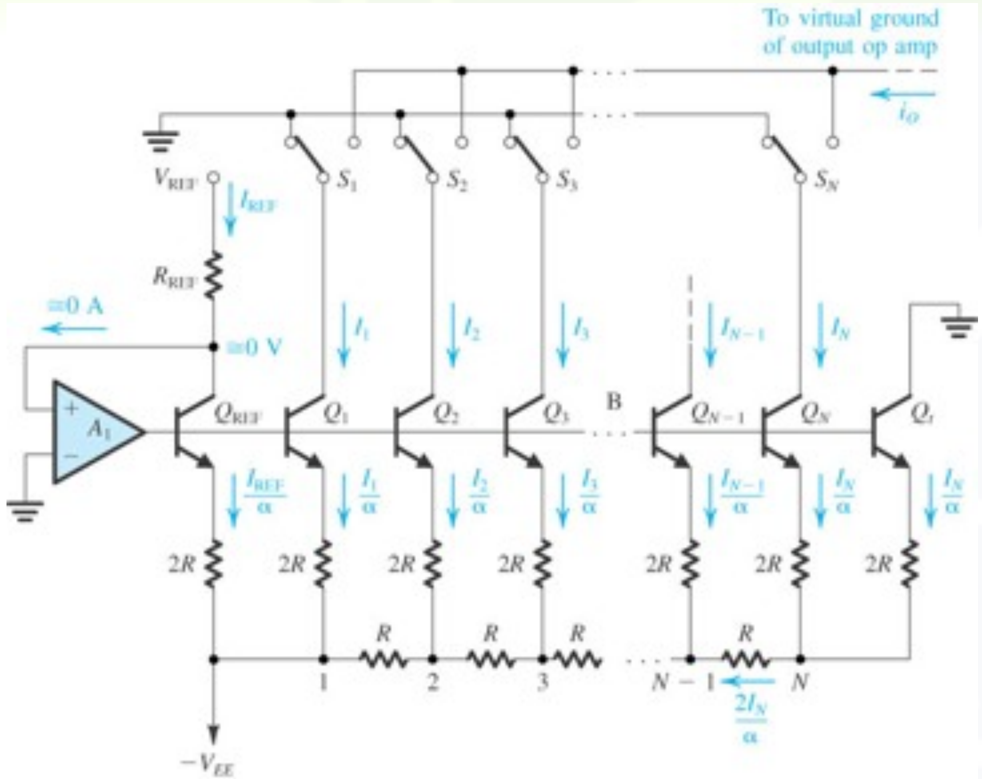


Digital to analog conversion



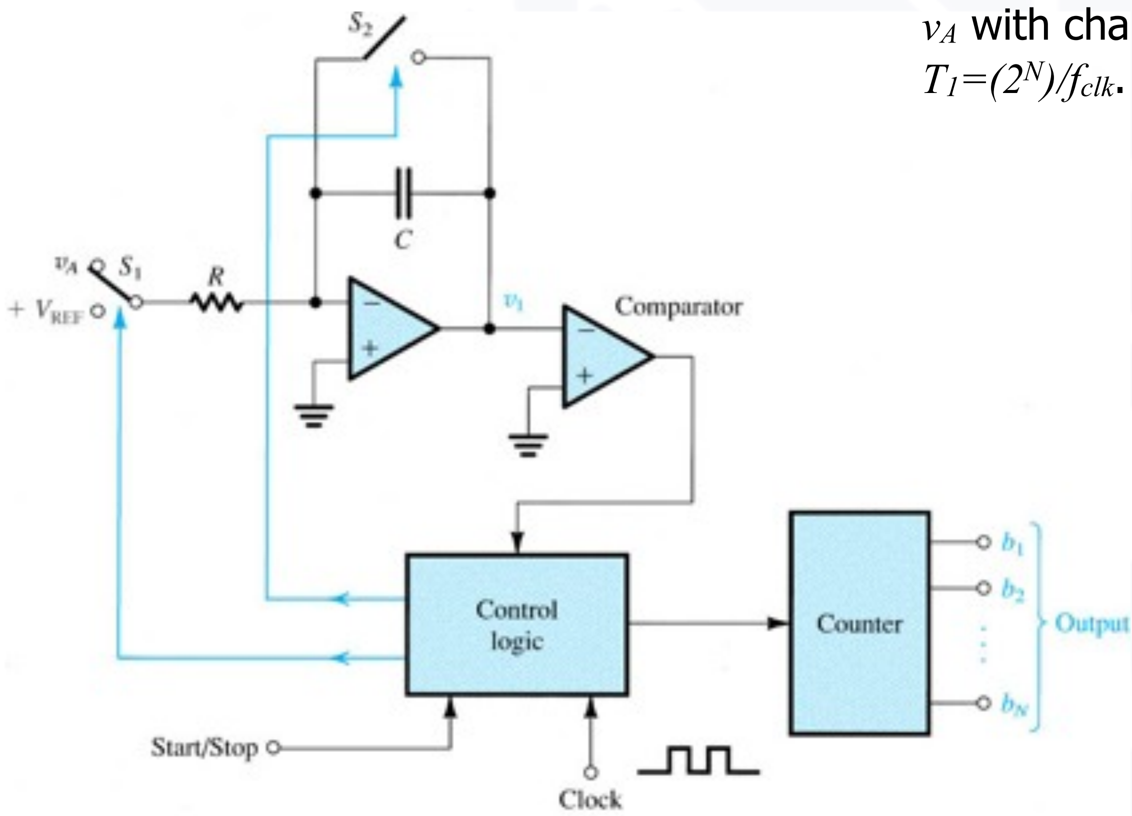
- Practical DAC Circuit - R-2R Ladder
  - When the above ladder circuit is analyzed, we can see that the resistance "as seen" at the arrows shown, is always 2R irrespective of the number of stages.
  - This gives the current relationships shown.
  - Thus, the ladder circuit can be used to obtain binary weighted currents.

Digital to analog conversion



- The ladder circuit connected to an Op-amp to perform D/A conversion.
- The switches are controlled by the digital value. The switch positions are shown when bit equals one.

Dual-Slope Integrating ADC - Operation

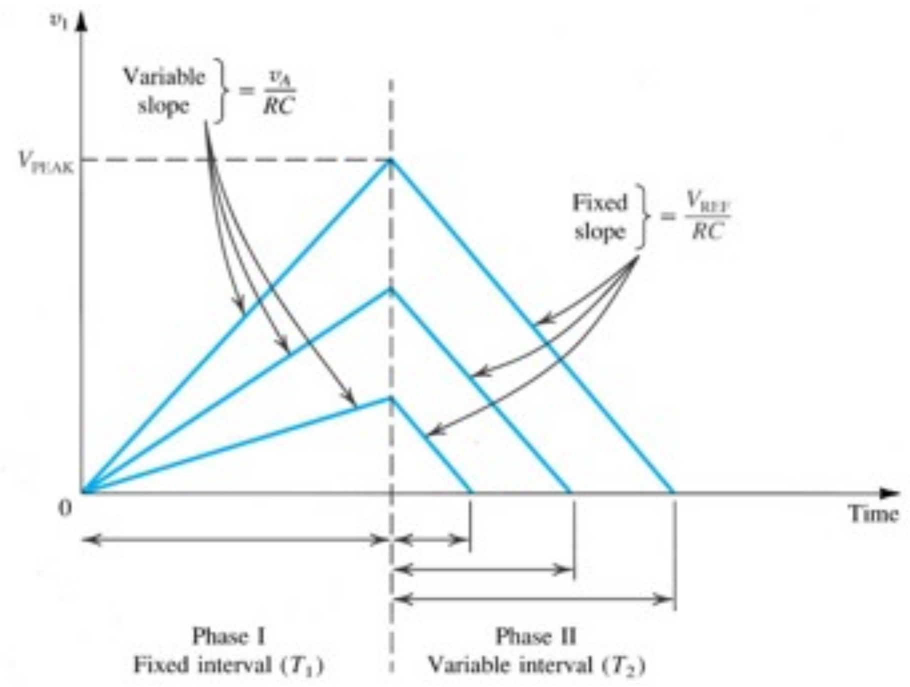


(a)

- Phase I:
  - C1 is charged with S1 connected to v_A with charging duration equal to $T_1=(2^N)/f_{clk}$.

Dual-Slope Integrating ADC - Operation

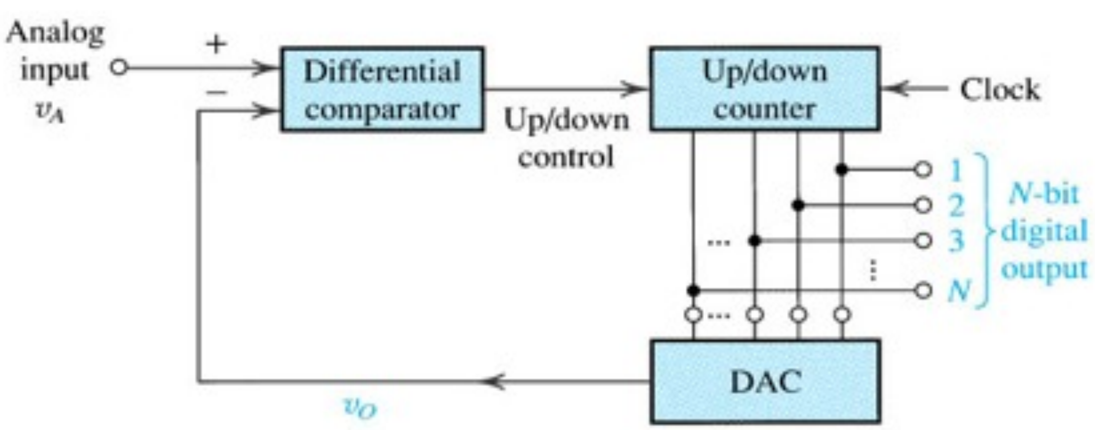
- Phase II :
  - Counter is reset and S1 is connected to Vref
  - C1 discharges in time T2, proportional to the value it was charged in Phase I
  - Counter counts until Vx is less than zero
  - The counter output is proportional to Vin, all other quantities in the above equation are constant.
- Merits and Demerits:
  - 100 µs (slow), Very Accurate, Low Cost, Long life
  - Digital multi-meters



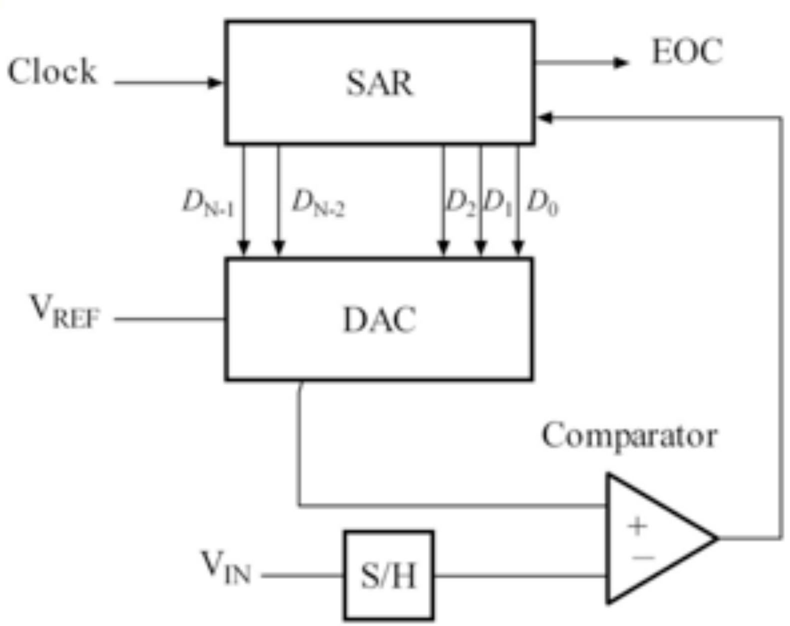
(b)

Continuous conversion

- Counter continuously up or down counts
- Simple and cheap
- Conversion time is variable
  - If signal changes fast, longer conversion time occurs
  - Useful for continuous signal, voice, etc.



Successive Approximation-Operation



- Follows the concept of Binary Search Algorithm
- Begins by comparing analog input with midpoint voltage, i.e., SAR sets MSB to 1. If analog input is greater, MSB remains unchanged and in the next cycle, the SAR sets the next bit in line and the cycle repeats until all the bits are covered

Successive Approximation - Example

- A simple example:

- Step 1>
- Step 2>
- Step 3>

1	0	0
0	1	0
0	1	1

- Final Value:

0	1	0

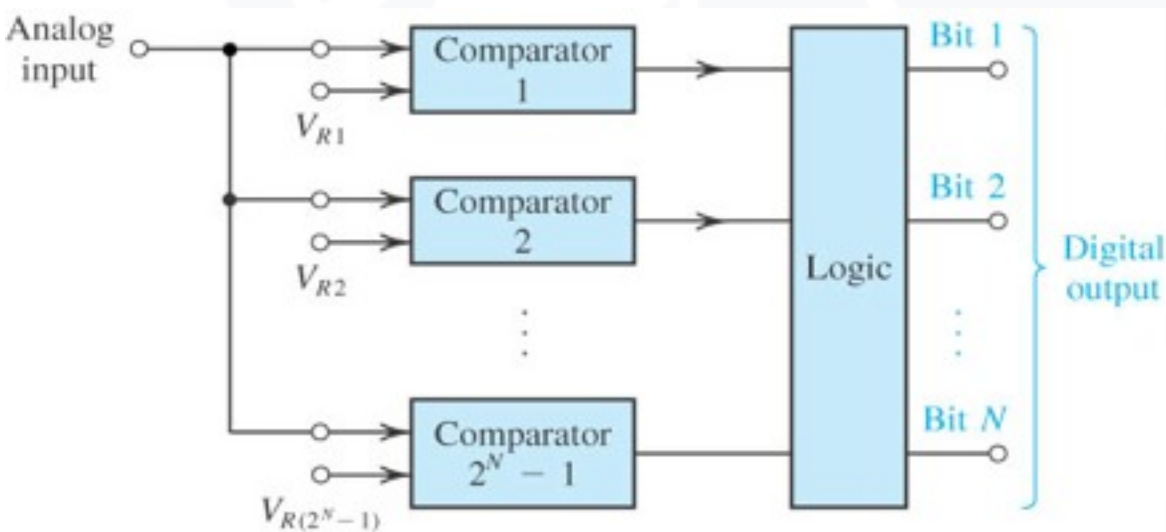
D/A Value	Analog Value
(4*0.625v)=2.5 V	1.7 V
(2*0.625v)=1.25 V	1.7 V
(3*0.625v)=1.875 V	1.7 V

0	0	0
0	1	0
0	1	0

- Merits and Demerits:
  - Good combination of simple circuit and reasonable conversion time
  - 1-10 microseconds
  - May result in inconsistent conversion

Flash (Parallel) ADC - Circuit

- Extremely expensive
- Extremely fast
- For high-speed instrumentation or video applications
- For 8-bit converter, 256 comparators are used



Data Acquisition

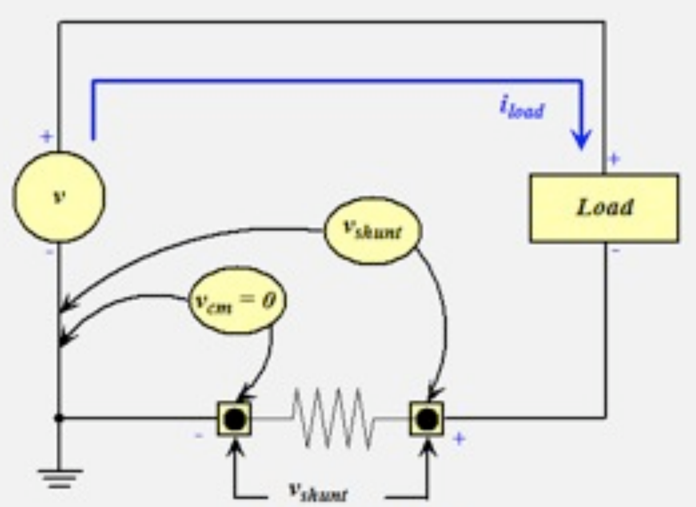
- Data acquisition (DAQ) refers to the process of capturing data from a real-world physical system (Eg., Transducers) and presenting the data in a form that is readily available to a digital processing system.

- Acronyms: ADC → Analog to Digital Converter
  DAC → Digital to Analog Converter

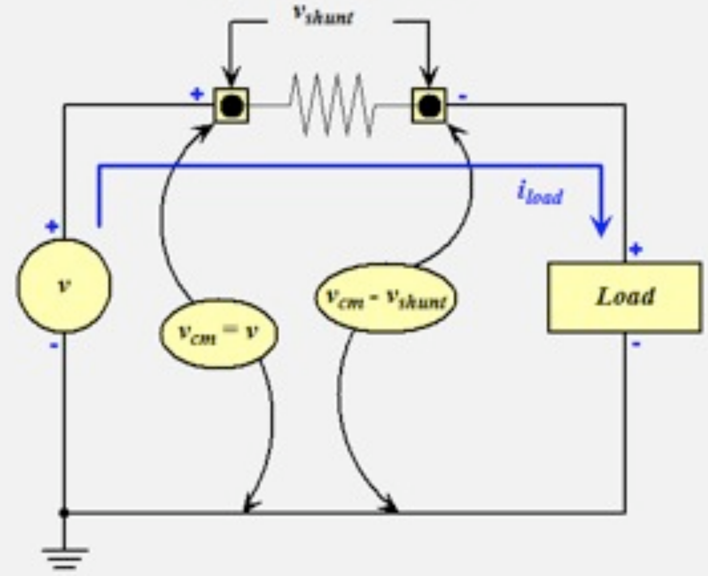
- Topics Covered:
  - Architecture of a typical DAQ System
  - Range, Resolution, Conversion Rate, Data Transfer, Differential Non-Linearity etc.
  - Circuits: ADC (Dual-Slope Integrating, Successive Approximation, Flash (Parallel)) and DAC (R-2R Ladder)

Current shunt measurements

- Current shunt
  - A low resistance precision resistor
  - Placed in series with the load
  - The voltage drop across the shunt is proportional to the current flowing through it



Low-side current shunt

High-side current shunt


Low-side (return path) current shunt

- Advantage
  - Eliminate common mode voltage
  - Common mode voltage can create complications for the instrument used to measure shunt voltage
  - Often recommended, especially in high voltage situations
- Drawbacks
  - The load is removed from a direct path to ground, which may create problems for control circuitry
  - Only current directly returned to the supply by the load is measured
  - Current leaking to ground are not measured

High-side (supply path) current shunt

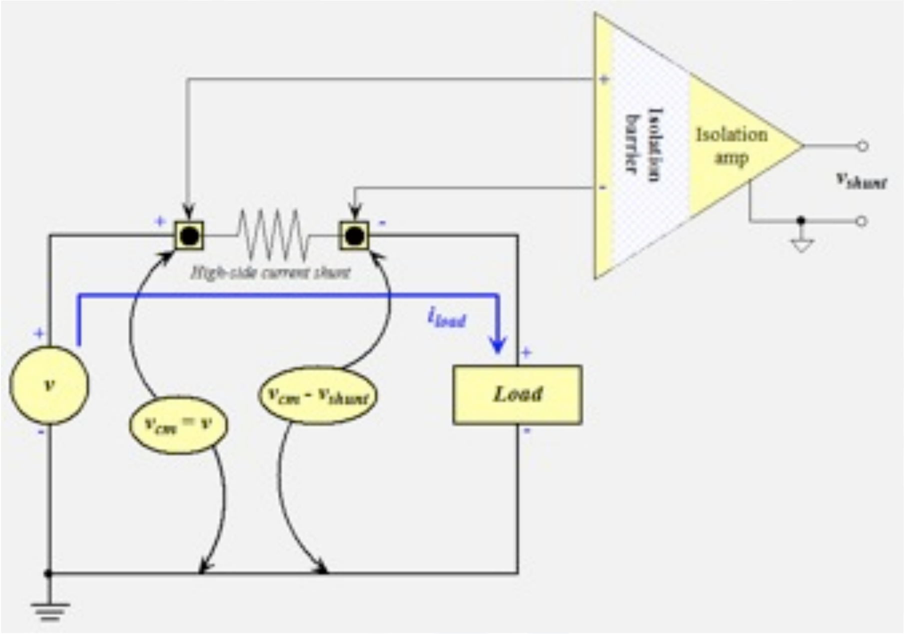
- Advantage
  - Improve drawbacks of low-side current shunt
- Drawbacks
  - Common mode voltage is virtually guaranteed to be present
    - Complicate the instrument used to make the measurement
    - In high voltage applications, can have dire consequences that include explosive destruction of the instrument

Safe high-side current shunt measurements

- Apply a voltage divider to each input of a differential amplifier
  - The divider is sized to reduce the magnitude of the common mode voltage to within the range of the amplifier
- Drawbacks
  - The resistors that make up the divider must be almost perfectly matched
    - Result in accuracy-destroying offsets
  - Require that the differential amplifier be designed to provide substantial gain
    - Leads to a noisy representation of the current signal
  - Increases source resistance
  - Divider resistors may be difficult to locate and implement for higher common mode voltages

Safe high-side current shunt measurements

- Isolation amplifier
  - An electrically floating front end
    - Rise or fall in response to the magnitude of the applied common mode voltage
  - The amplifier's input and output ground references are free to remain at independent potentials
  - The breakdown voltage of the isolation barrier is as high as ±1,000 V

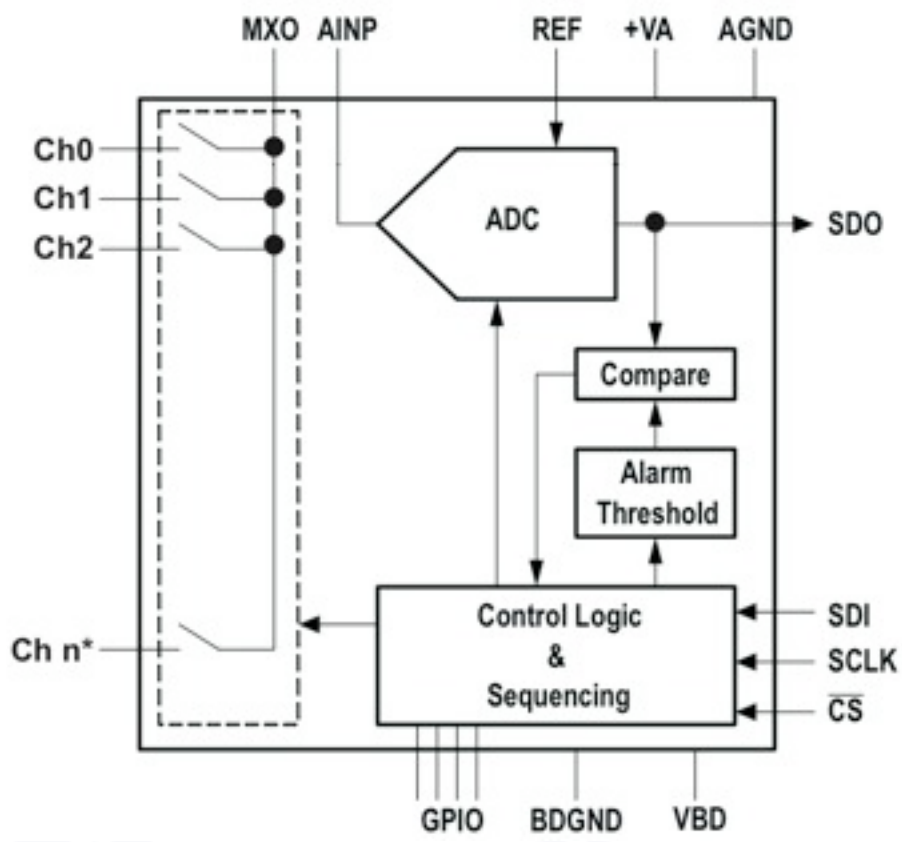


External ADC

- What is an external ADC?
  - An extra ADC IC outside of microprocessor.
  - Interfacing with microprocessor with digital interface such as SPI and I2C.
- Why do we need external ADCs?
  - Internal ADCs have limited number of channels, resolution, and sampling rate.
  - We use external ADCs for one or more reasons of
    - more input channels,
    - higher resolution,
    - faster sampling,
    - and so on.
- Limitation of external ADCs
  - Sampling rate may be limited by transmit rate of the digital interface.

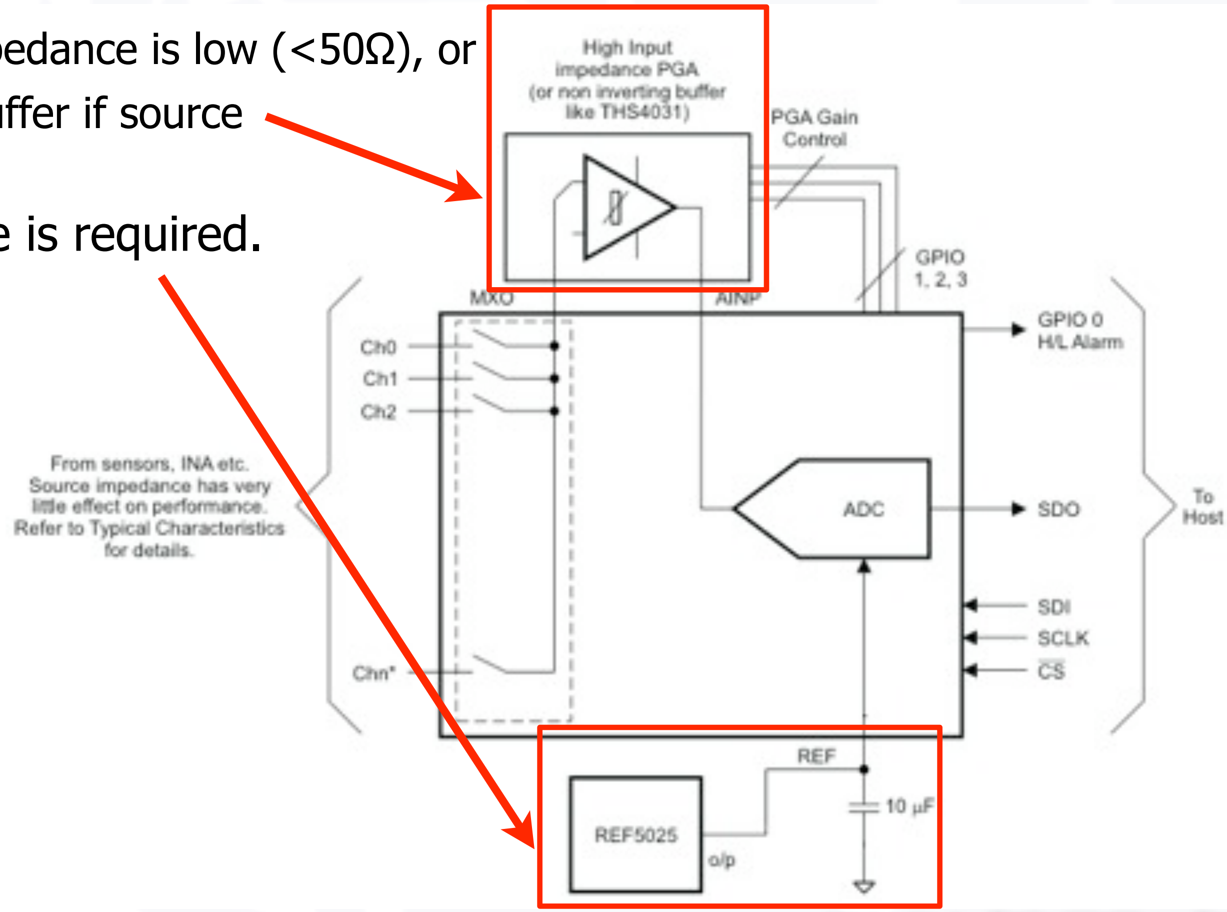
External ADC Example

- Texas Instruments ADS7953 (ADC79xx series)
  - 1 MHz sample rate
  - 16 channels
    - 16:1 MUX + 1 ADC
  - 12-bit resolution
  - 20 MHz SPI interface
  - 0 to 2.5V or 0 to 5V input range



Operation of ADS7953

- MXO (MUX output) pin outputs voltage of the selected input channel.
- ADC converts the analog voltage at AINP pin to the digital value.
- MXO and AINP is
  - shorted if source impedance is low (<50Ω), or
  - connected though buffer if source impedance is high.
- 2.5V reference voltage is required.



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SPI Interface of ADS7953

- SPI read/write functions
  - Write: select an input channel
  - Read: read conversion result of the previously selected channel
- For sporadic read, two SPI read/write required to read one channel
  - First operation
    - Read: dummy
    - Write: select an input channel
  - Second operation
    - Read: read conversion result of the selected channel of the first operation
    - Write: dummy
- For periodic read, one SPI read/write required to read one channel
  - n-th operation
    - Read: read conversion result of selected channel of (n-1)-th operation
    - Write: select the next input channel
  - Invoked from the timer interrupt handler.