CENG 314

Embedded Computer Systems

Lecture Notes

Data Acquisition and Digital Signal Processing

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Data Acquisition

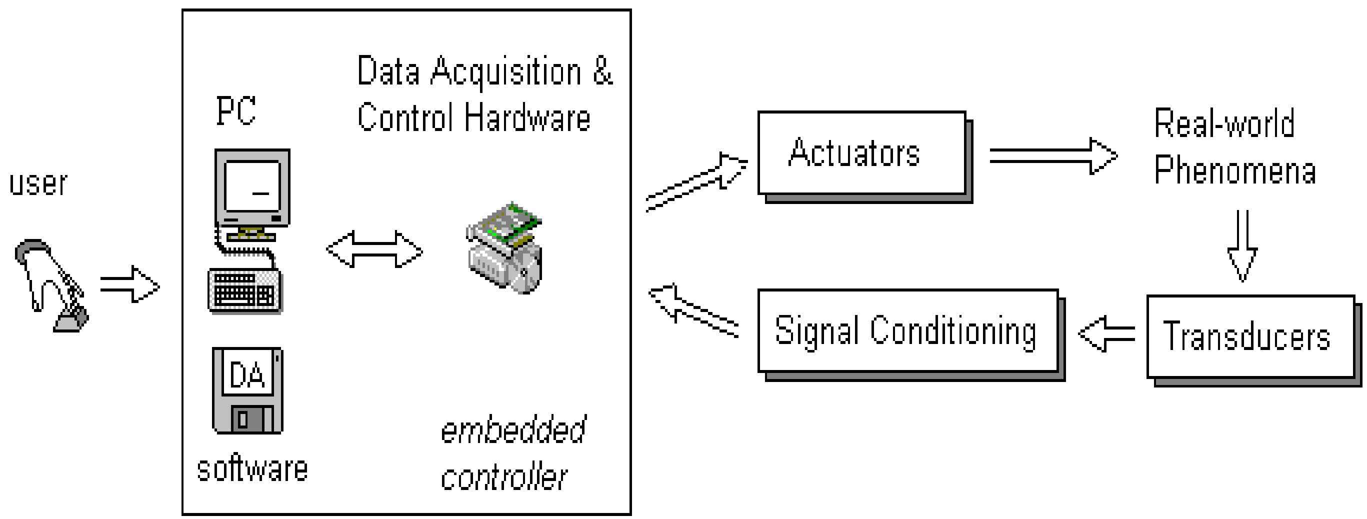
Data acquisition is the sampling of the real world to generate data that can be manipulated by a computer.

Sometimes abbreviated DAQ or DAS, data acquisition typically involves acquisition of signals and waveforms and processing the signals to obtain desired information.

The components of data acquisition systems include appropriate sensors that convert any measurement parameter to an electrical signal, which is acquired by data acquisition hardware.

Data Acquisition

Data Acquisition and Control



- Physical systems (real-world phenomena)
- Transducers and Actuators
- Signal Conditioning equipment
- Data Acquisition & Control Hardware
- Software

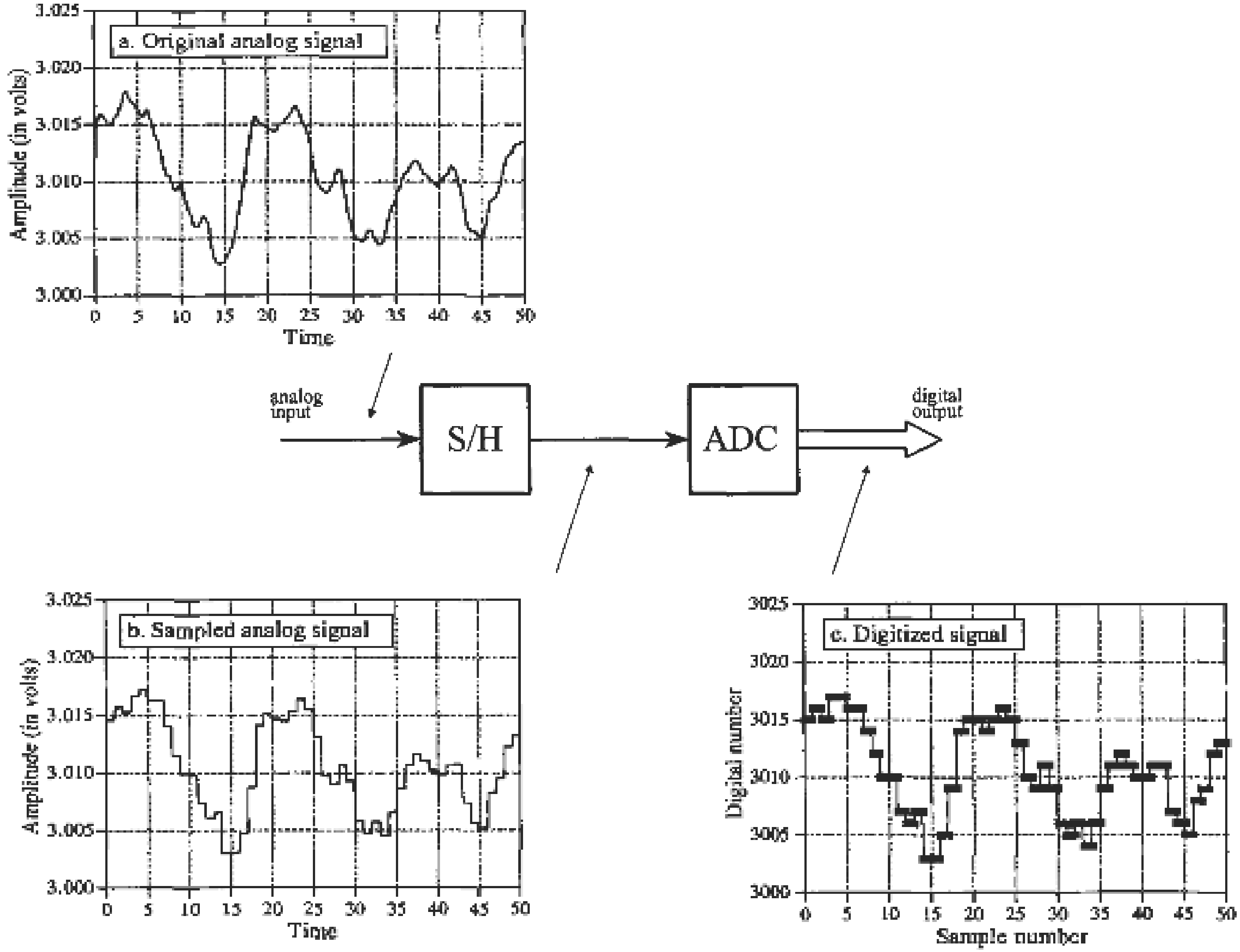
Analog-to-Digital Conversion

Analog-to-digital conversion (ADC) and digital-to-analog conversion (DAC) are the processes that allow digital computers to interact with everyday signals: voltage, current, distance, velocity, temperature, altitude, force, acceleration, pressure etc.

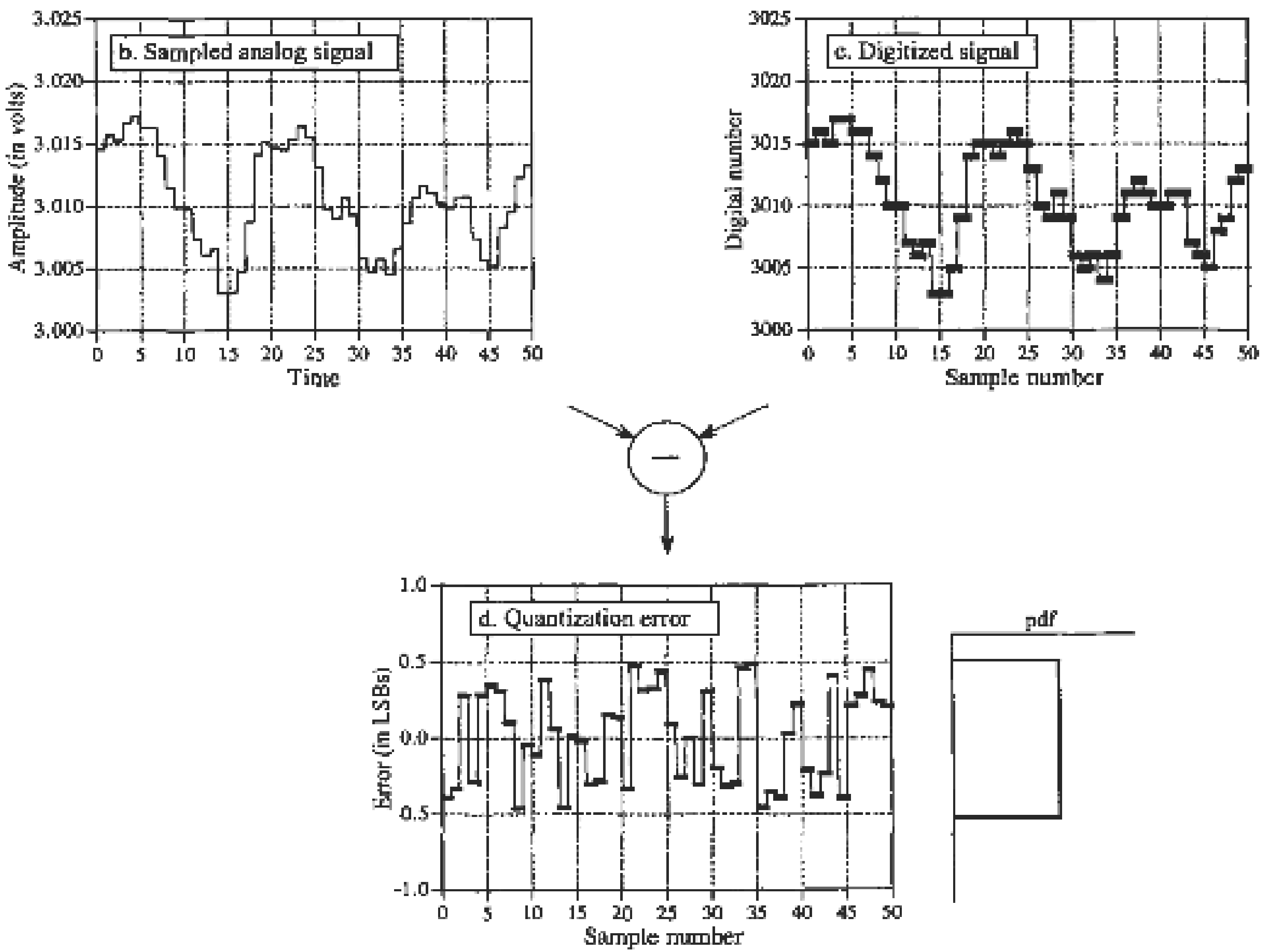
Digital information is different from its analog counterpart in two respects:

- it is *sampled*
- it is *quantized*

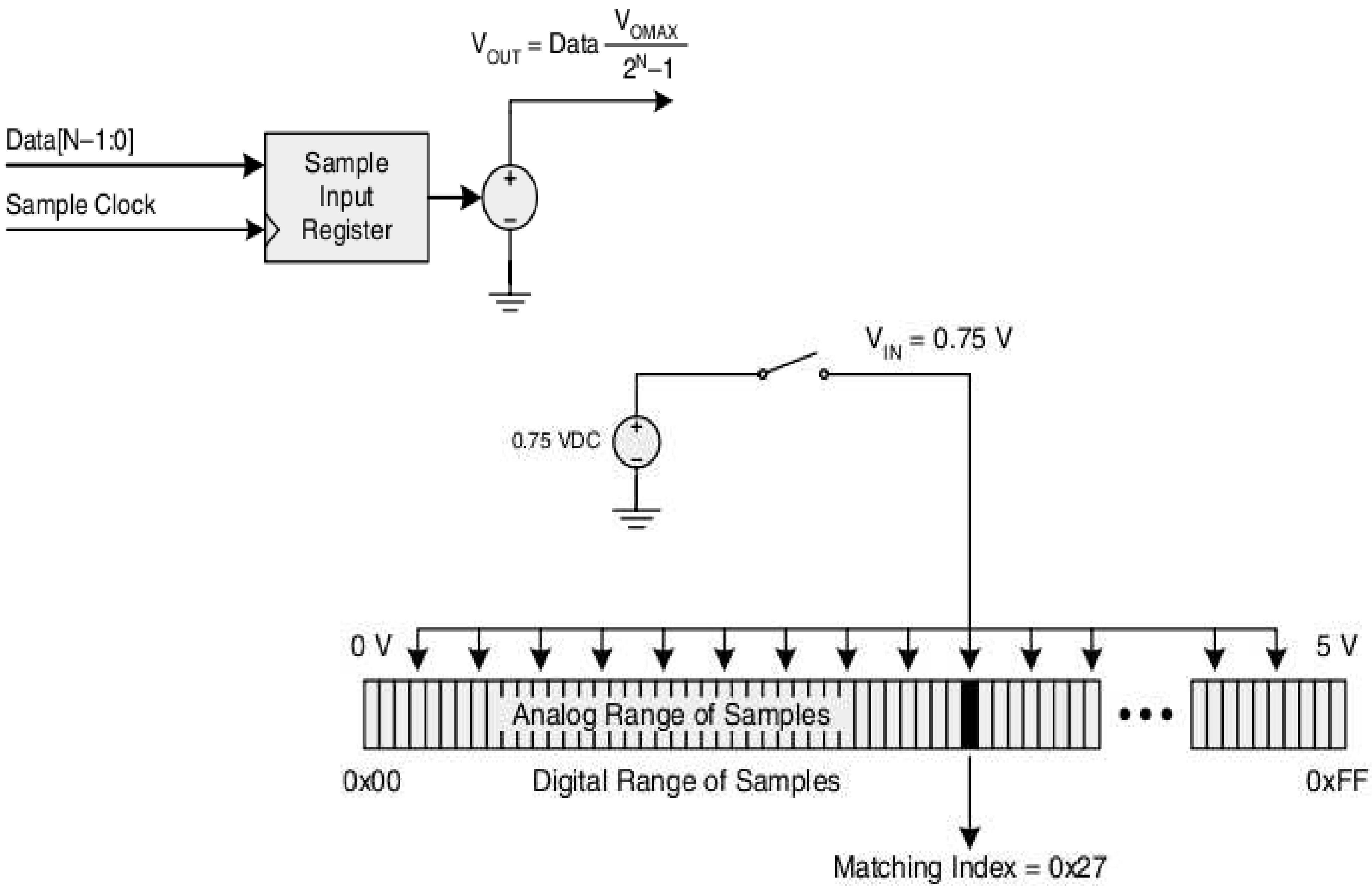
ADC Principles: S/H and Quantization



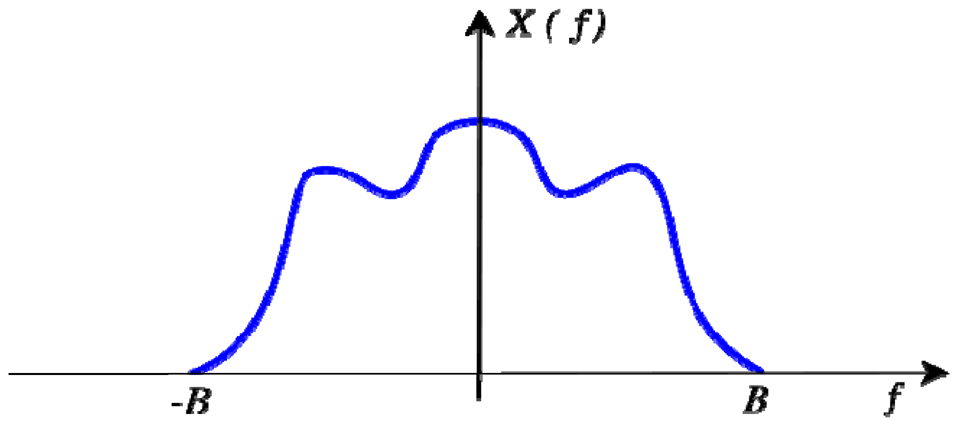
Quantization Error



Analog-to-Digital Conversion



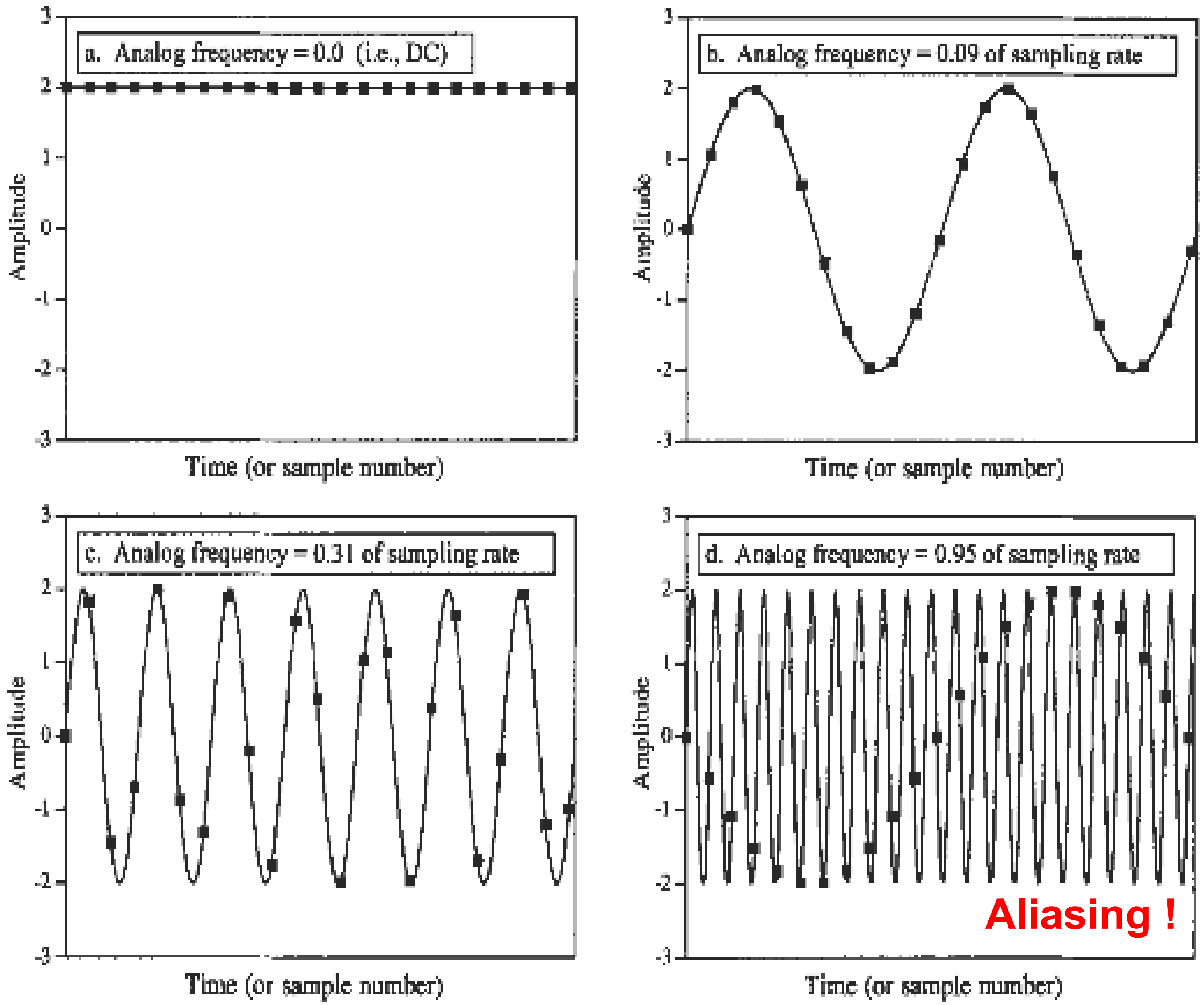
Sampling Theory



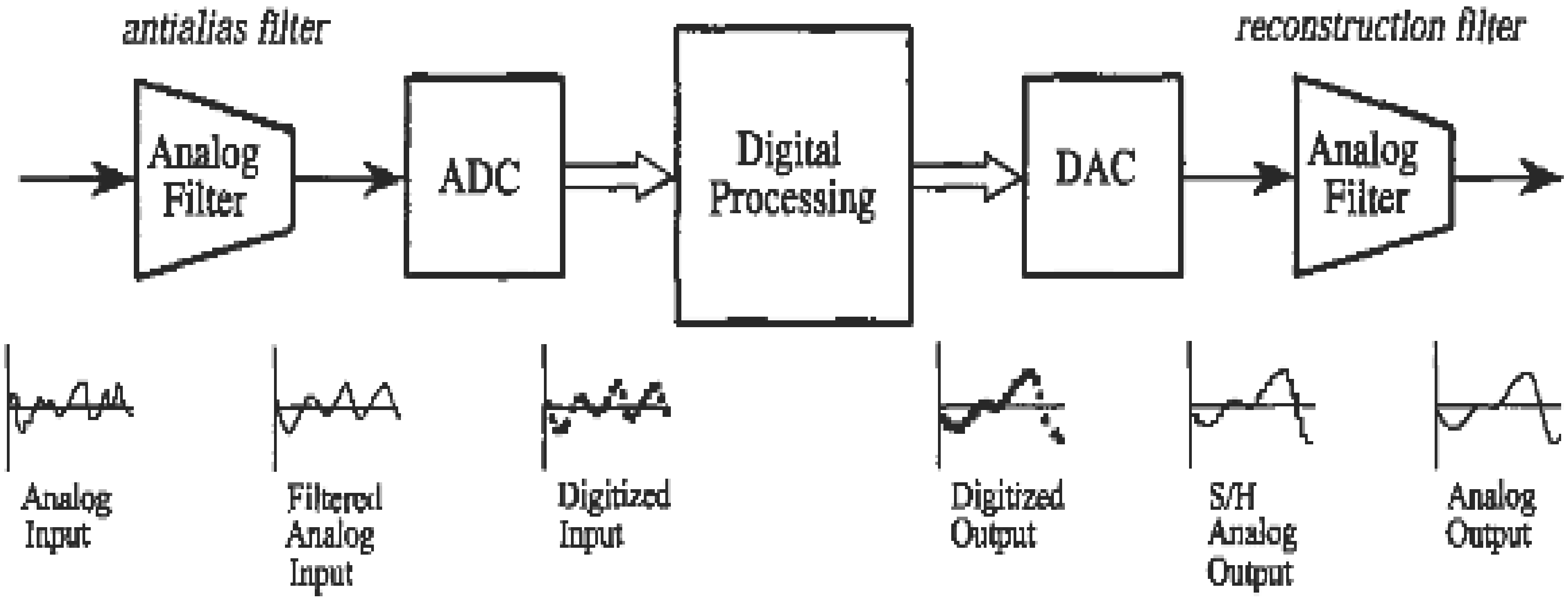
Nyquist theorem:

Analog signal that has been digitized can be perfectly reconstructed if the sampling rate was 1/(2W) seconds,
where W is the highest frequency in the original signal.

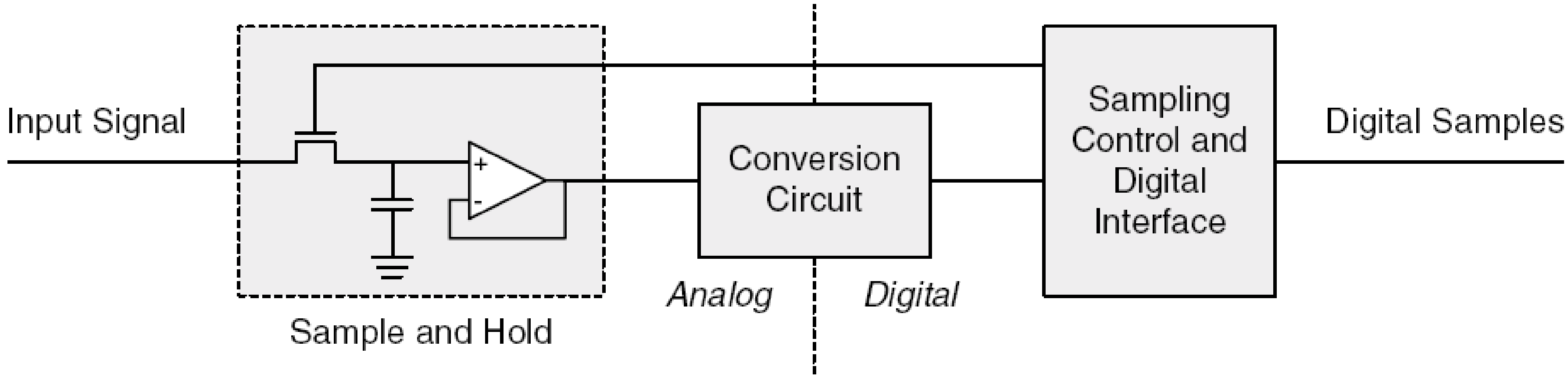
Sampling Theory



Using Analog Filters



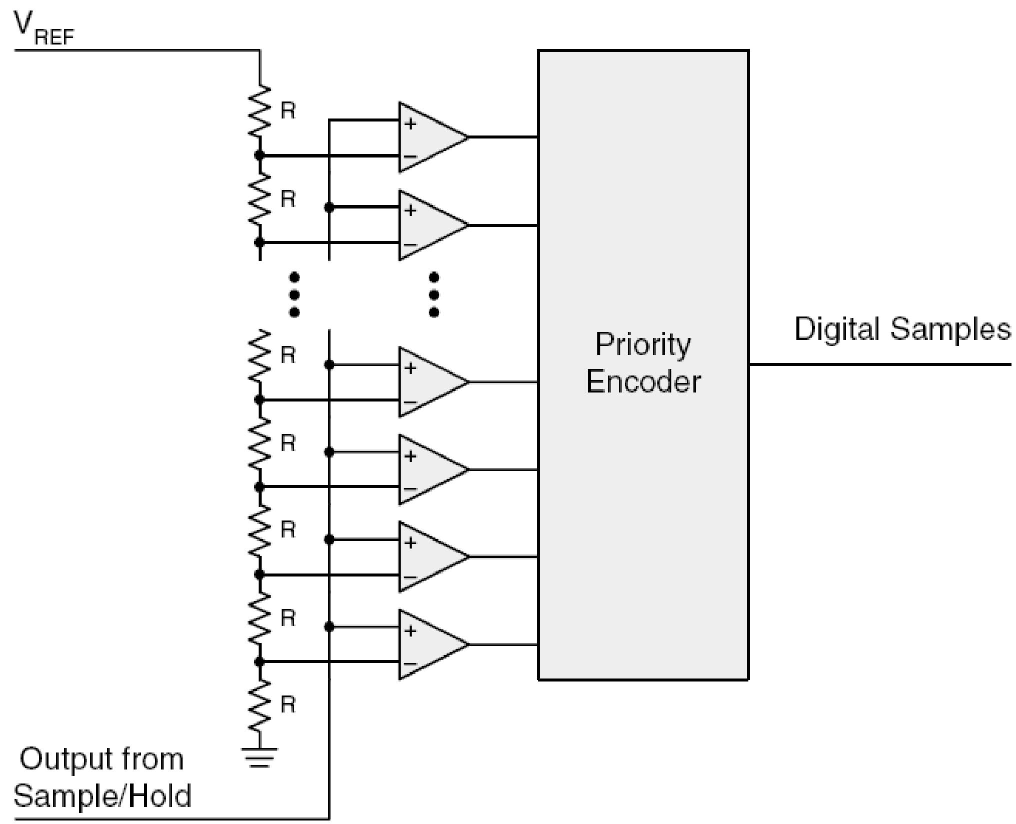
Basic A/D Architecture



ADC Types:

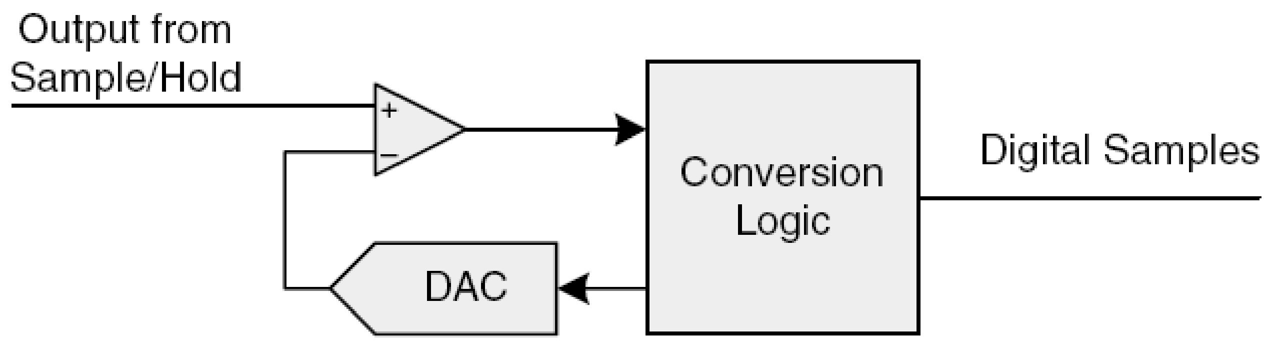
- Flash ADC
- Succesive-approximation ADC
- Sigma-delta ADC

Flash ADC



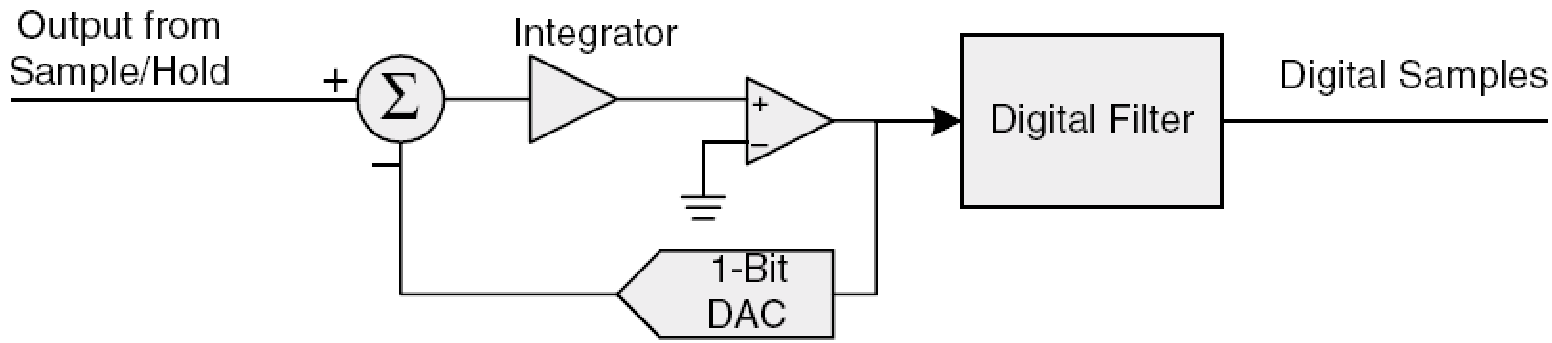
- Requires 4095 parallel comparators for 12-bit.
- Very fast, conversion is done in one step.
- Complexity doubles with each added bit of resolution.

Succesive-approximation ADC



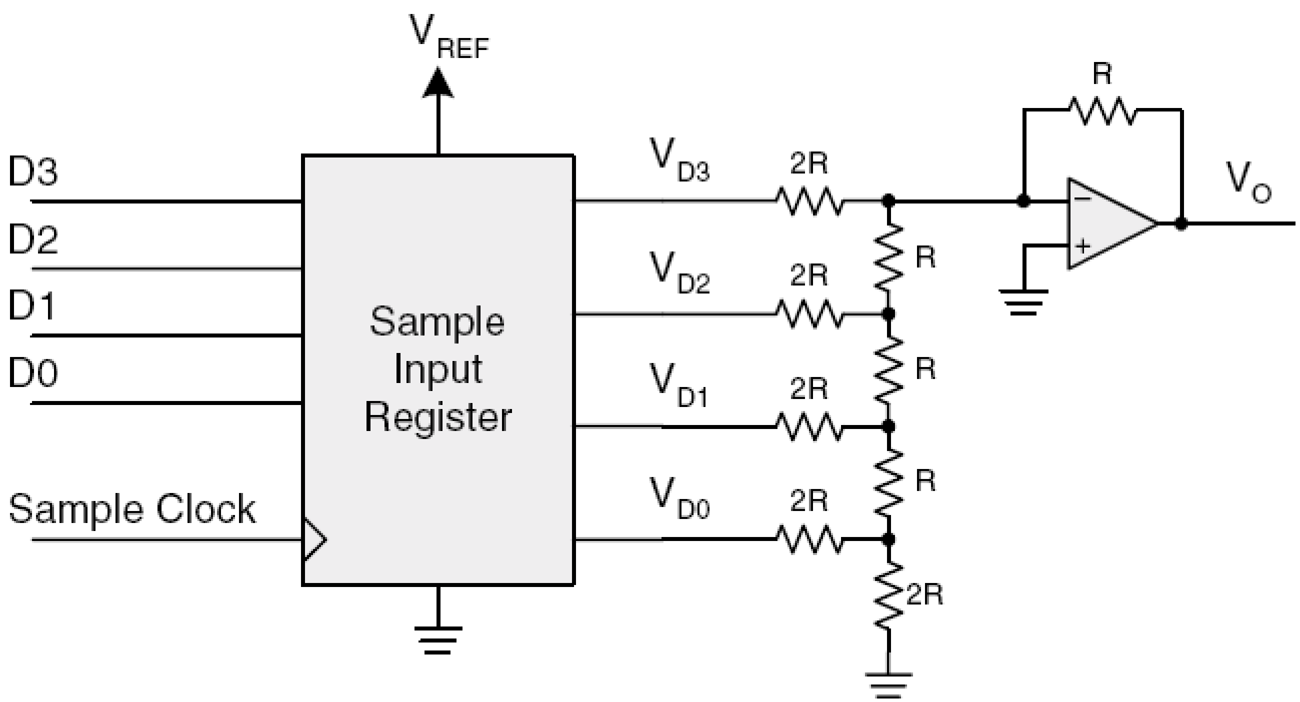
- Uses an internal n-bit DAC
- Conversion logic is a simple n-bit counter
- N-bit ADC requires 2^n cycles to perform a conversion in worst case.

Delta-sigma ADC



- Requires 1-bit DAC: less susceptible to noise
- Requires high sampling rate, suitable for audio applications
- It has digital filter, so no need for expensive low-pass filters at input
- Resolution can be very high.

Digital-to-Analog Converter (DAC)

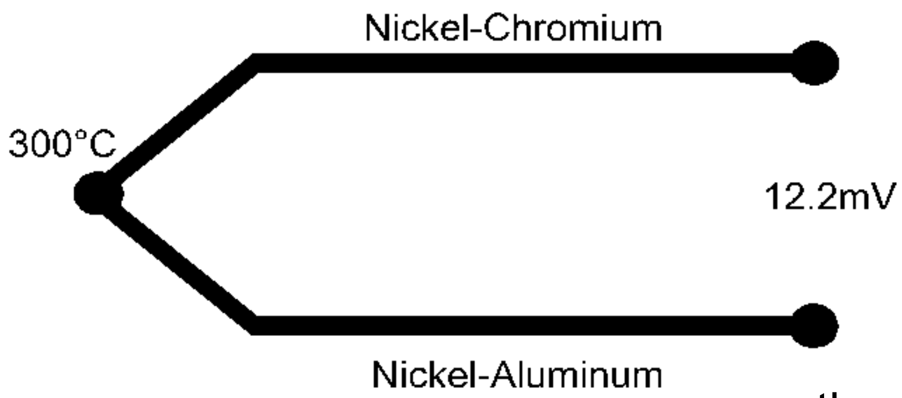


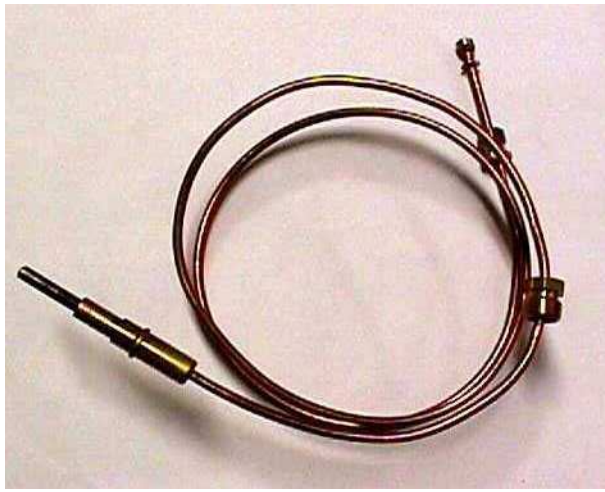
$$V_O = -V_{REF}\left[\frac{D3}{2} + \frac{D2}{4} + \frac{D1}{8} + \frac{D0}{16}\right]$$

Transducers

- Converts physical properties such as temperature, pressure, force etc. to electrical signals.

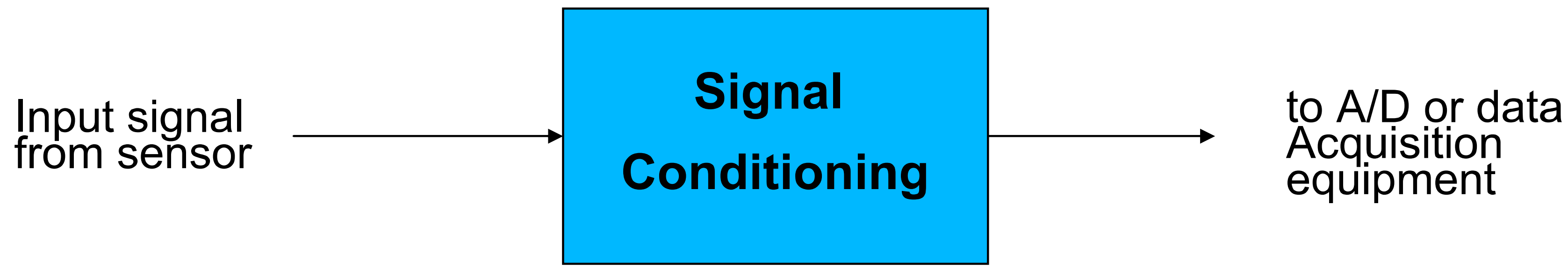
Pt-100





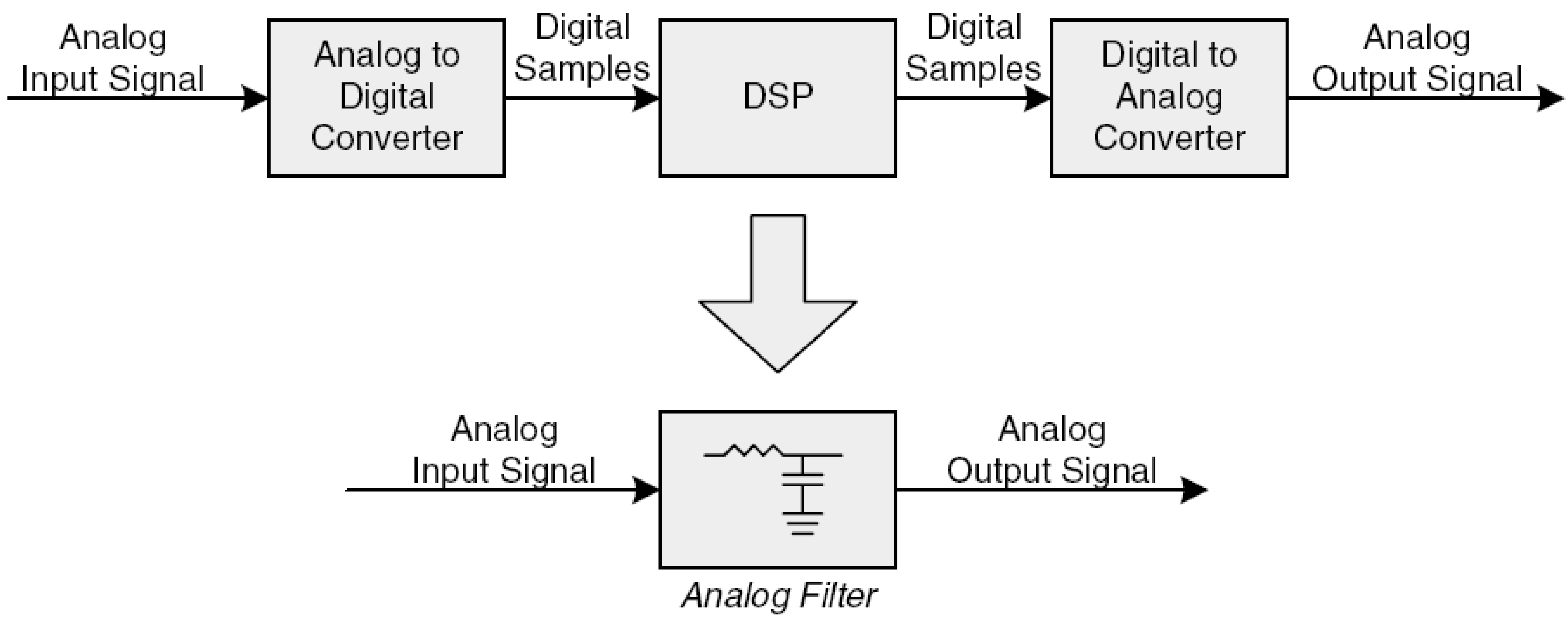
thermocouple

Signal Conditioning



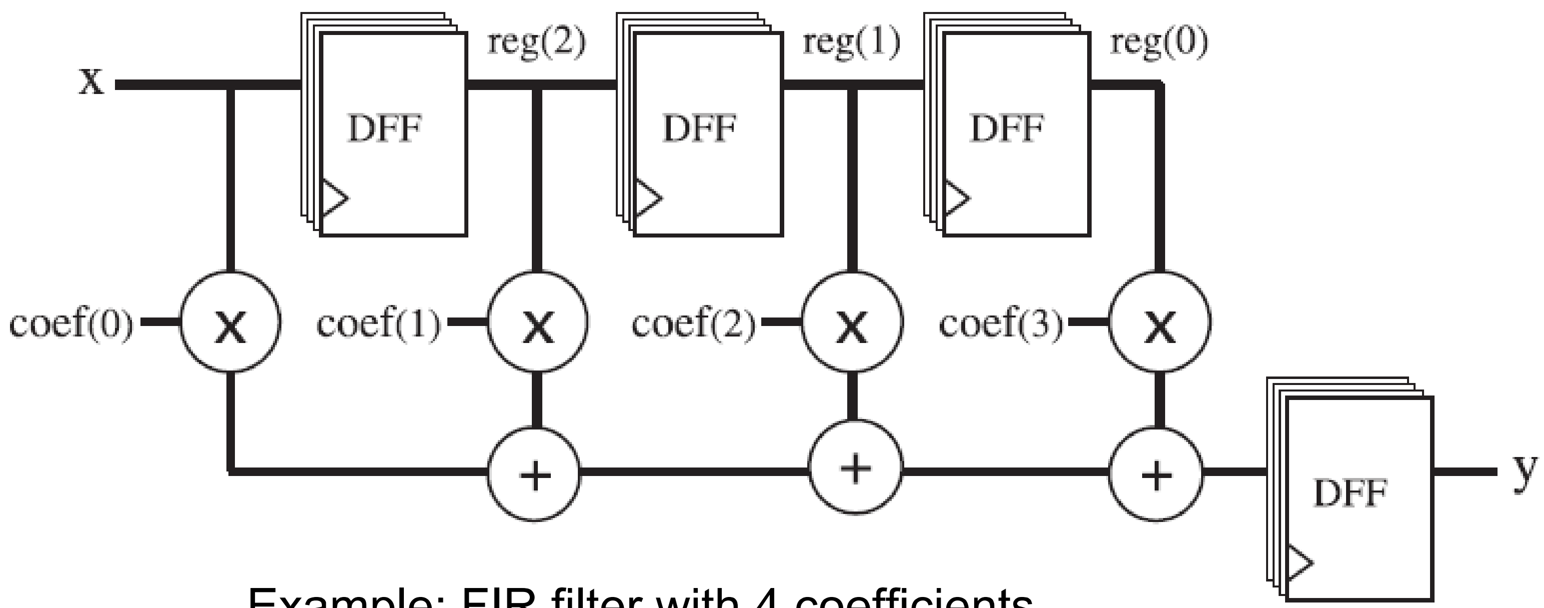
- Amplifying
- Scaling
- Offsetting
- Filtering
- Linearization
- Isolation

Digital Signal Processing



1) Specialized microprocessors (DSP)
2) Digital Signal Controllers (DSC)
3) FPGA, ASIC
4) Powerful general purpose microprocessors

Example: Digital Filters

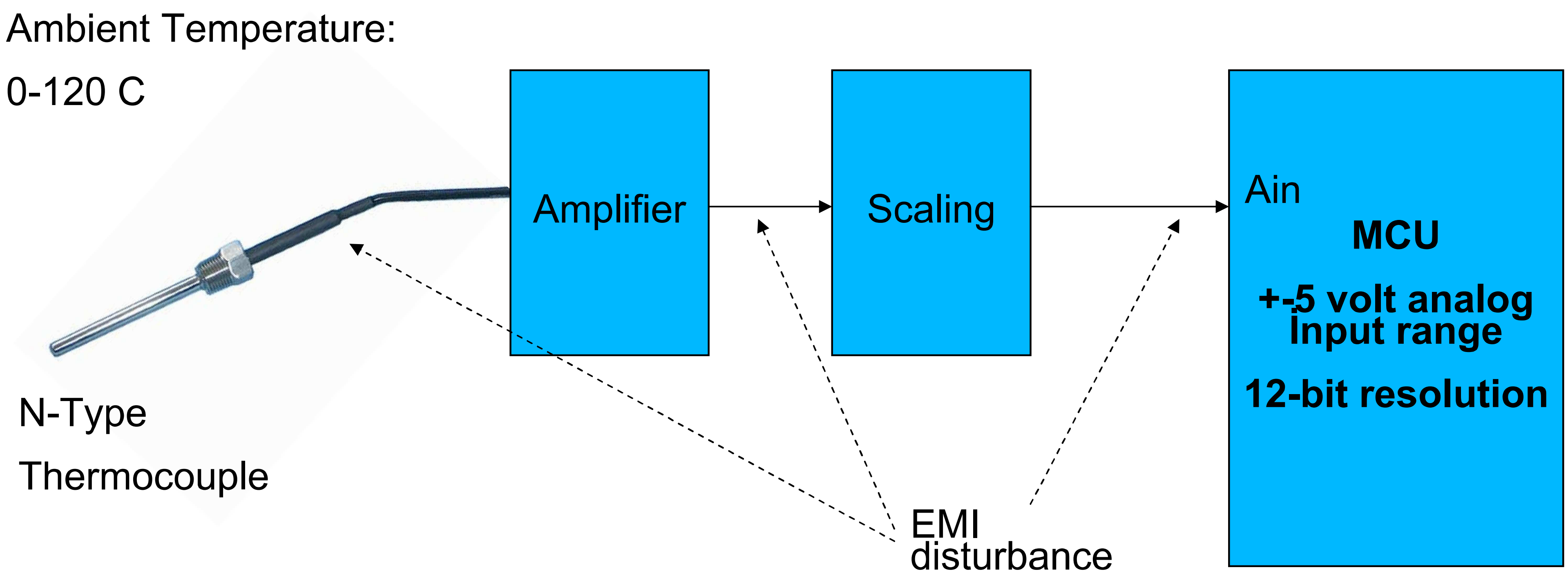


Example: FIR filter with 4 coefficients

- Reproducable response
- Temperature insensitive
- Programmable

- Unable to pass power
- Requires a power supply
- Frequency range limitations

Case Study



Getting the most from an ADC means scaling the maximum signal from each sensor to match the maximum input of the ADC. Therefore, we have to use an amplifier along with a scaling circuit. We may left the noise filtering on the acquired temperature to the program.

Table for Thermocouple

ISE, Inc.

ITS-90 Table for Type N Thermocouple (Ref Junction 0°C)

http://iseinc.com

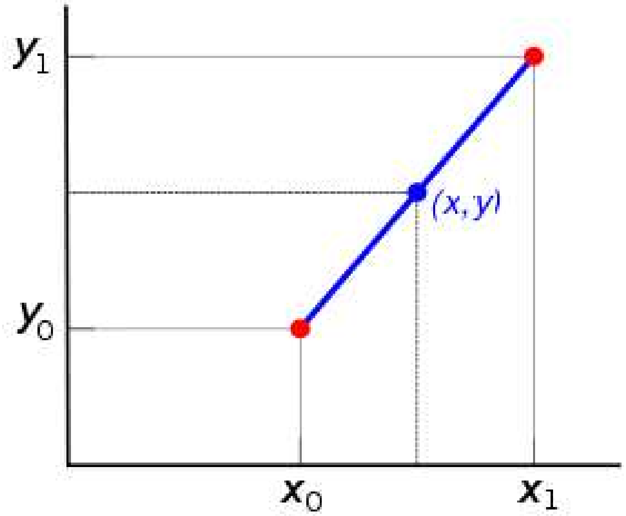
Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.026	0.052	0.078	0.104	0.130	0.156	0.182	0.208	0.235	0.261
10	0.261	0.287	0.313	0.340	0.366	0.393	0.419	0.446	0.472	0.499	0.525
20	0.525	0.552	0.578	0.605	0.632	0.659	0.685	0.712	0.739	0.766	0.793
30	0.793	0.820	0.847	0.874	0.901	0.928	0.955	0.983	1.010	1.037	1.065
40	1.065	1.092	1.119	1.147	1.174	1.202	1.229	1.257	1.284	1.312	1.340
50	1.340	1.368	1.395	1.423	1.451	1.479	1.507	1.535	1.563	1.591	1.619
60	1.619	1.647	1.675	1.703	1.732	1.760	1.788	1.817	1.845	1.873	1.902
70	1.902	1.930	1.959	1.988	2.016	2.045	2.074	2.102	2.131	2.160	2.189
80	2.189	2.218	2.247	2.276	2.305	2.334	2.363	2.392	2.421	2.450	2.480
90	2.480	2.509	2.538	2.568	2.597	2.626	2.656	2.685	2.715	2.744	2.774
100	2.774	2.804	2.833	2.863	2.893	2.923	2.953	2.983	3.012	3.042	3.072
110	3.072	3.102	3.133	3.163	3.193	3.223	3.253	3.283	3.314	3.344	3.374
120	3.374	3.405	3.435	3.466	3.496	3.527	3.557	3.588	3.619	3.649	3.680

N

Take these twelve points to construct a look-up table in the microcontroller

Linear Interpolation



$$y = y_0 + (x - x_0)\frac{y_1 - y_0}{x_1 - x_0}$$

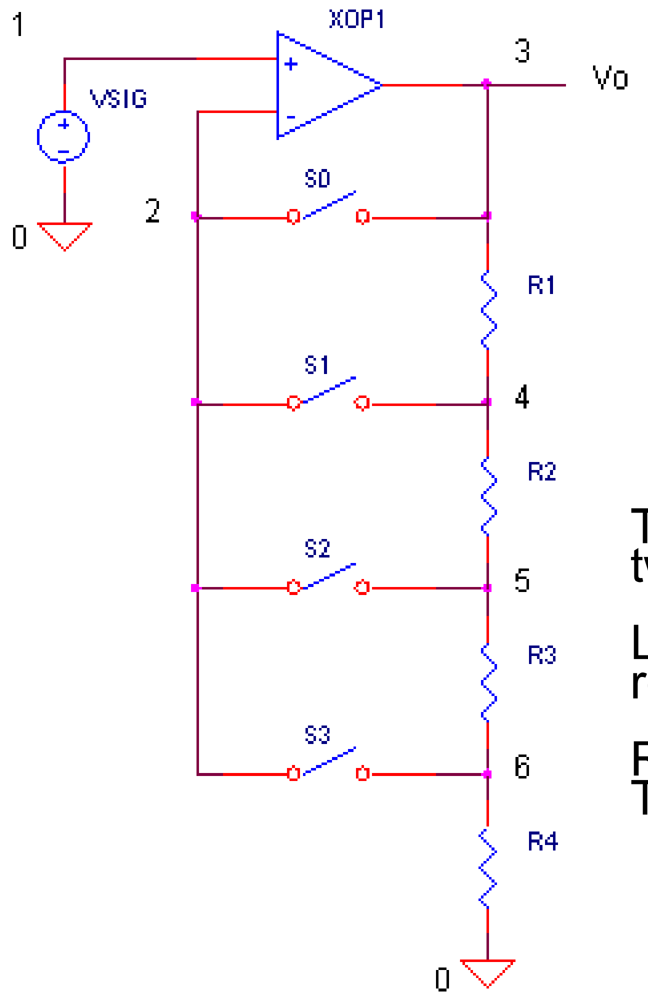
Calculate the output of N-type thermocouple at 3 °C.

We will use two points: (0, 0) and (10, 0.261).

f(3)=0+(3-0)(0.261-0)/(10-0)=0.0783

(In the table, f(3) is given as 0.078)

Programmable Gain Amplifier



Switch	Gain
S0 = ON	1
S1 = ON	(R1) / (R2 + R3 + R4) + 1
S2 = ON	(R1 + R2) / (R3 + R4) + 1
S3 = ON	(R1 + R2 + R3) / (R4) + 1

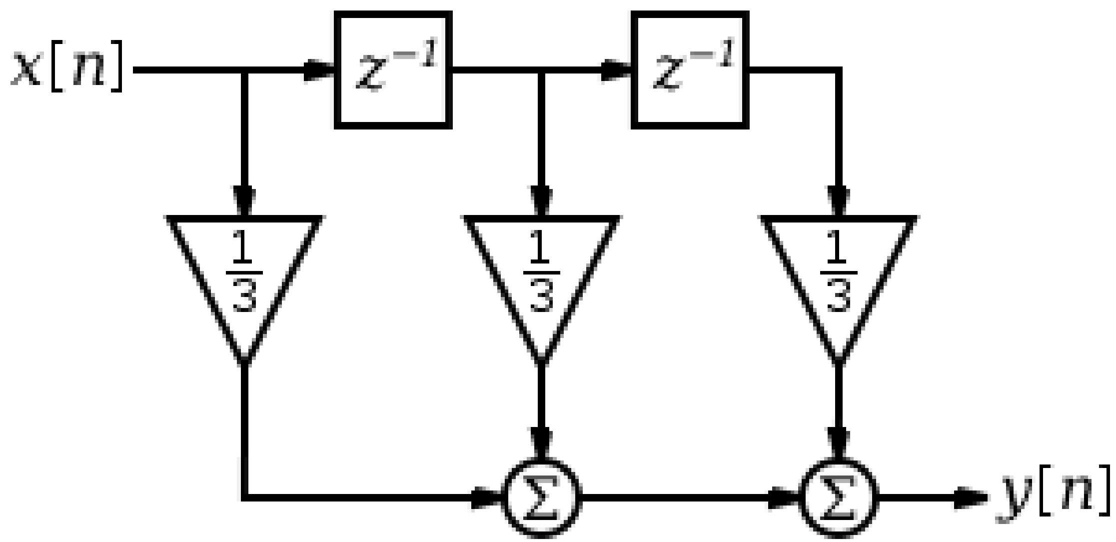
Typically, PGAs are designed in two varieties: powers of two (G = 1,2,4,...) and powers of ten (G = 1,10,100,...).

Let's piece one together for gains of 1,2,4 and 8. What resistor collection provides these gains? One solution is:

R1 = 2 kΩ, R2 = 1 kΩ, R3 = 500 Ω and R4 = 500 Ω.
This pattern can be extended to any number of gain ranges.

Digital Filtering

- A very simple FIR filter (moving average filter) attenuating the high frequencies:



A Solution

- Amplify the signal such that the output of the signal is approximately 10 volts at 120 C.
- Shift the signal 5 volts downwards.
- Implement a look-up table in the microcontroller
- Implement a digital Low Pass Filter to reduce EMI disturbance.

- Assume that ADC take the following samples (Sampling rate is 10 ms):
  - (2.81v, 2.94v, 2.68v, 2.56v, 2.78v, 2.12v, 2.48v, ...)

- What would be the current temperature according to your design?