Analogue signals acquisition

My slides are subject to change without prior notice

Choose yourself and new technologies

HUMAN CAPITAL

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Project co-financed from the EU European Social Fund

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References

- U. Tietze, Ch.Schenk, Electronics Circuits – Handbook for Design and Applications, Springer, 2010
- Advertisement materials and Application notes of:
  - Linear Technology,
  - Analog Device,
  - Texas Instruments,
  - National Semiconductors
  - NEV Corporation

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Outline

- Aquisition system –general diagram
- ADC – general information
- Isolation methods
- Multiplexing problems
- Sample & hold – sampling frequency
- Widowing

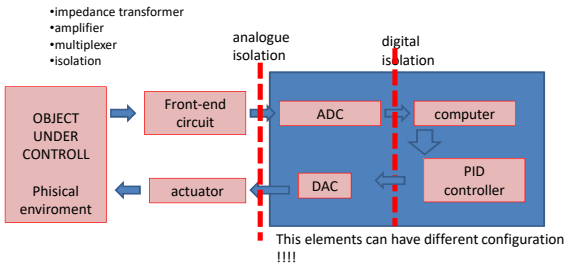
Intoduction

The intent of this and a few next lectures is to introduce the students to the most commonly used transducer interfaces and to provide practical information for dealing with the most frequently encountered transducers and their associated signals.

Transducers are available for measuring many physical quantities, such as temperature, pressure, strain, vibration, sound, humidity, flow, level, velocity, charge, pH, and chemical composition, among others. In most cases, the transducer manufacturer provides application notes on the transducer's use and principles of operation. The main questions to consider when selecting a transducer are:

- the electrical characteristics - source impedance, amplitude, frequency,
- power supply or excitation
- transducer's accuracy (taking frequency and range into account)
- calibration method
- verification of calibration
- environment of operation (temperature, humidity, vibration, pressure, etc.)

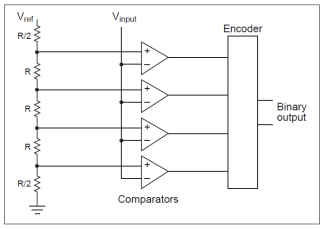
General controll schematic outline



ADC Analog to Digital Converters

- parallel converter – flash
- successive approximation
- pipeline
- voltage to frequency
- integrating converter (two, four slop)
- delta-sigma converter

ADC – parallel (flash)

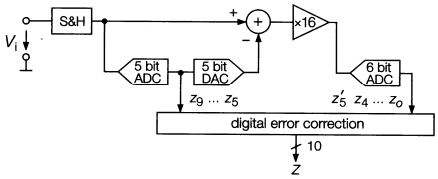


2-step converter

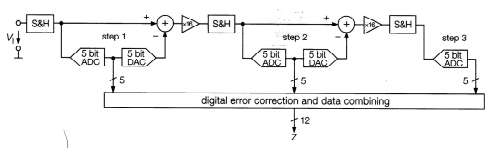
(direct, serial, pipeline)

Features (compared to „flash"):

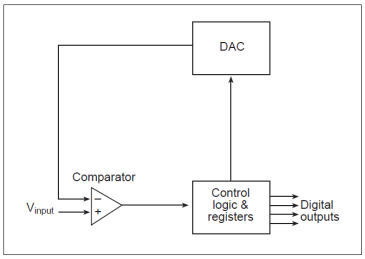
- lower number comparators
- higher conversion time
- more popular (cheaper)
- higher resolution



3-step converter
(direct, serial, pipeline)



ADC - successive approximation



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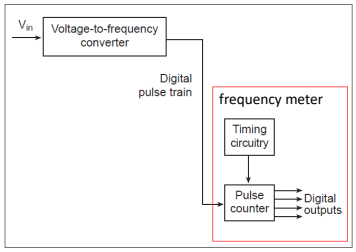
ADC - voltage to frequency



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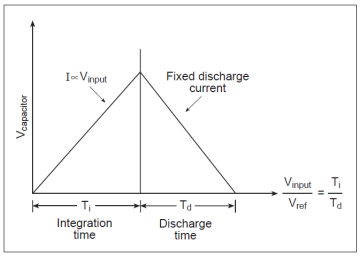
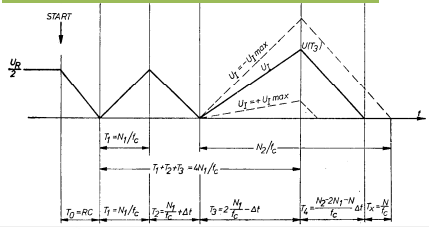
ADC - integrating converter

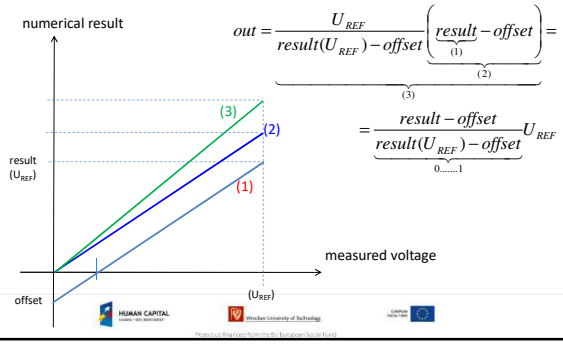


Indirect converter ---four - slope

Phase	0	1	2	3	4
	U_R	GND	U_R	U_I	U_R

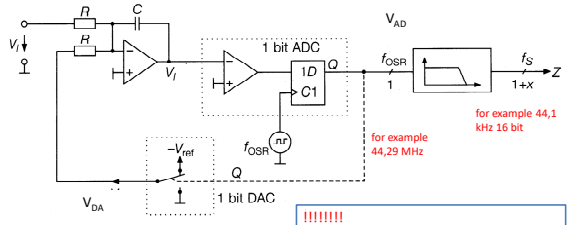


Four slope converter - „principle" of corrections



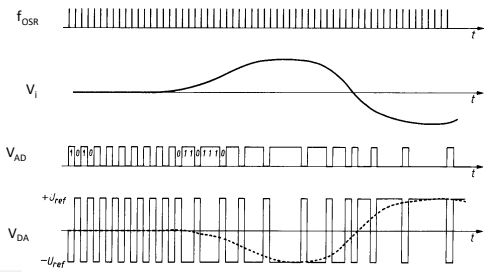
$$out = \underbrace{\frac{U_{REF}}{result(U_{REF}) - offset}\left(\underbrace{result}_{(1)} - offset\right)}_{(3)} = \underbrace{\frac{result - offset}{result(U_{REF}) - offset}}_{0.....1} U_{REF}$$

„Σ-Δ" converter
oversampling converter

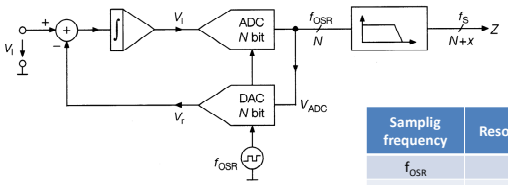


!!!!!!!
Sampling frequency f_{OSR} is much greater than reading frequency f_S

„Σ-Δ" converter - principle of operation

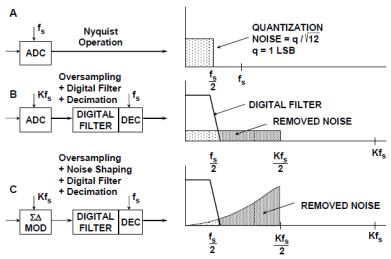


Oversampling „Σ-Δ" converter - general principle

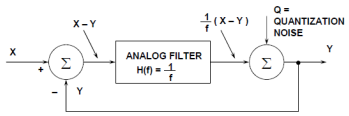


Samplig frequency	Resolution
f_{OSR}	N
$f_S << f_{OSR}$	N+x

Noise shaping in „Σ-Δ" converter



„Σ-Δ" converter – linear model



$$Y = \frac{1}{f}(X - Y) + Q$$

REARRANGING, SOLVING FOR Y:

$$Y = \frac{X}{f+1} + \frac{Q\,f}{f+1}$$

SIGNAL TERM NOISE TERM

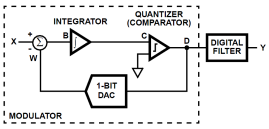
Conventional converter

$$U_{Nout} \propto \frac{1}{\sqrt{f_{OS}/f_S}}$$

$$N_{bits} = \frac{20\log\sqrt{f_{OS}/f_S}}{6dB/bit}$$

f_{OS}/f_S	bit
2	0.5
4	1
256	4

First order „Δ-Σ" converter

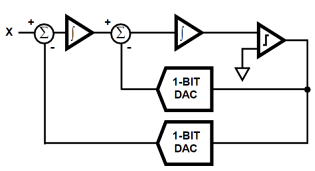


$$U_{Nout} \propto \left(\frac{1}{\sqrt{f_{OS}/f_S}}\right)^3$$

$$N_{bits} = \frac{20\log\left(\sqrt{f_{OS}/f_S}\right)^3}{6dB/bit}$$

f_{OS}/f_S	bit
2	1.5
4	3
256	12

3dr order „Δ-Σ" converter

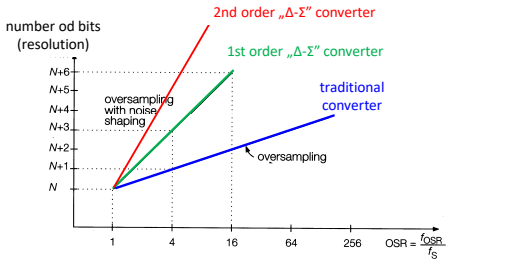


$$U_{Nout} \propto \left(\frac{1}{\sqrt{f_{OS}/f_S}} \right)^5$$

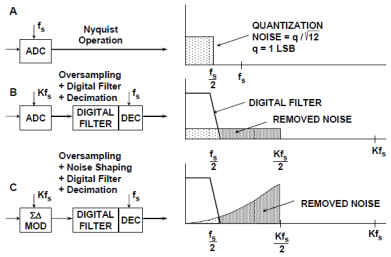
$$N_{bits} = \frac{20\log\left(\sqrt{f_{OS}/f_S} \right)^5}{6dB/bit}$$

f_{OS}/f_S	bit
2	2.5
4	5
256	20

Oversampling



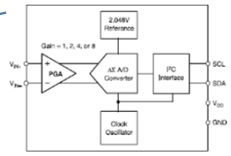
Noise shaping in „Δ-Σ" converter

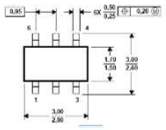


Example of „Δ-Σ" converter ADS1110

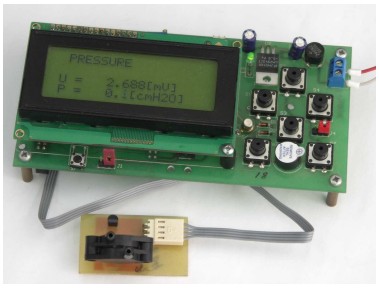
FEATURES

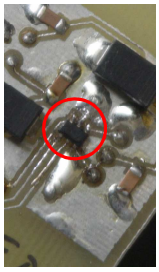
- COMPLETE DATA ACQUISITION SYSTEM IN A TINY SOT23-6 PACKAGE
- ONBOARD REFERENCE: Accuracy: 2.048V ±0.05% Drift: 5ppm/°C
- ONBOARD PGA
- ONBOARD OSCILLATOR
- 16-BITS NO MISSING CODES
- INL: 0.01% of FSR max
- CONTINUOUS SELF-CALIBRATION
- SINGLE-CYCLE CONVERSION
- PROGRAMMABLE DATA RATE: 15SPS TO 240SPS
- I²C™ INTERFACE—EIGHT AVAILABLE ADDRESSES
- POWER SUPPLY: 2.7V to 5.5V
- LOW CURRENT CONSUMPTION: 240μA



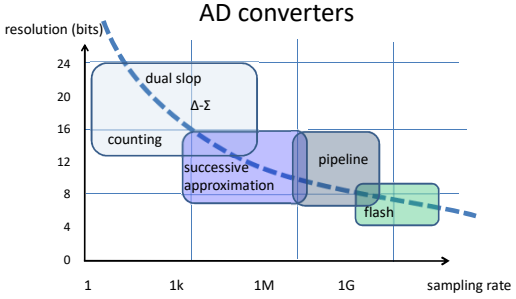


Lab setup of pressure sensor

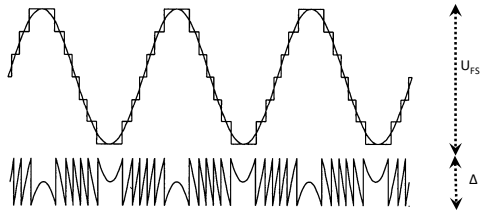




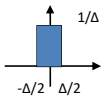
General comparison of AD converters



Resolution



ADC – resolution and SNR



$$P_N = \int_{-\infty}^{\infty} x^2 p(x)dx = \frac{1}{\Delta}\int_{-\frac{\Delta}{2}}^{\frac{\Delta}{2}} x^2 dx = \frac{\Delta^2}{12} = \frac{\left(U_{FS}/2^n\right)^2}{12}$$

$$SNR = 10\log\frac{P_S}{P_N} = 10\log\left(\frac{\frac{\left(U_{FS}/2\right)^2}{2}}{\frac{\left(U_{FS}/2^n\right)^2}{12}}\right) = 6{,}02\cdot n + 1{,}76 \quad [dB]$$

ADC ----SNR

$$SNR = 10\log\frac{P_S}{P_N} = 10\log\left(\frac{\frac{\left(U_{FS}/2\right)^2}{2}}{\frac{\left(U_{FS}/2^n\right)^2}{12}}\right) = 6{,}02\cdot n + 1{,}76 \quad [dB]$$

$$SNR = 20\log 2 = 6{,}02\,[dB]$$

For every bit of resolution SNR increases by 6dB !!!!!!!!

For every bit of resolution, SNR increases by 6dB !!!!!!!!

Channel Capacity [bit / second]

$$CC[bits/\sec] = f_{sampl} n_{bits} = 2B\log_2\left(\frac{U_{amp}}{\Delta U}\right) =$$

$$= 2B\frac{\log_{10}\left(\frac{U_{amp}}{\Delta U}\right)}{\log_{10}(2)} = 2B\frac{\left\{20\log_{10}\left(\frac{U_{amp}}{\Delta U}\right)\right\}}{20\log_{10}(2)} = B\frac{SNR}{10\log_{10}(2)} = \frac{B\cdot SNR}{3}$$

$$CC = \frac{B\cdot SNR}{3}[bits/\sec]$$

Shannon–Hartley theorem

ADC Errors

- offset
- linearity
- gain
- missing codes
- noise (interferences)

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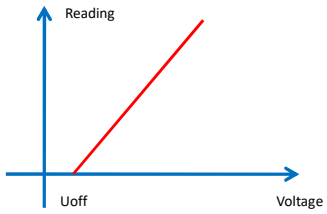
ADC Errors - offset



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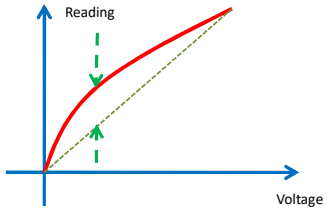
ADC Errors – nonlinearity



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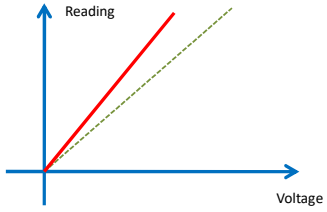
ADC Errors – gain



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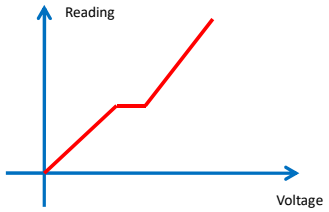
ADC Errors – missing codes



ADC Errors - noise (interferences)

Controlling noise is first step to measure anything.

Spending money for accurate and high resolution ADC can be worthless when measuring signal is interfered by high level noise.

noise level should be smaller than resolution

Digital to analog conversion

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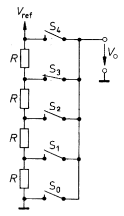
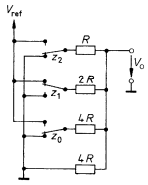
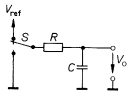
Digital to Analogue Conversion



the parallel method



the weighting method



computing method

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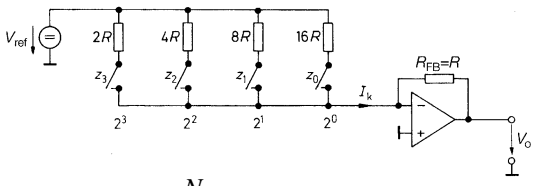
Weighting conversion



$$U_{out} = -U_{ref}\frac{N}{N_{max}+1}$$

TIP:
difficult for manufacturing because of different R;
U_{ref} is loaded depending N;
stray capacitance of switches are charged or dis-every change;

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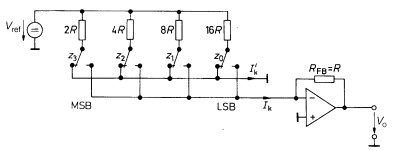
Weighting conversion



TIP:
difficult for manufacturing because of different R;
~~U_{ref} is loaded depending N;~~
~~stray capacitance of switches are charged or dis-every change;~~

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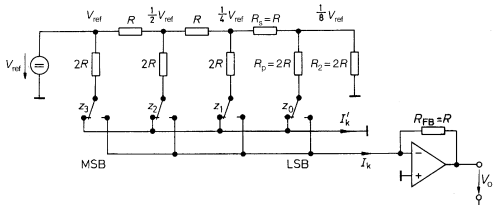
Ladder network



TIP:

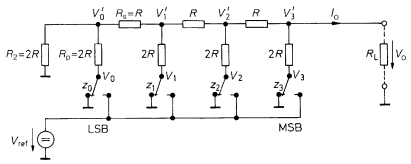
~~difficult for manufacturing because of different R;~~

~~U_{ref} is loaded depending N;~~

~~strai capacitance of switches are charged or dis- every change;~~

$$U_{out} = -U_{ref}\frac{N}{N_{max}+1}$$

Ladder network converter without any amp

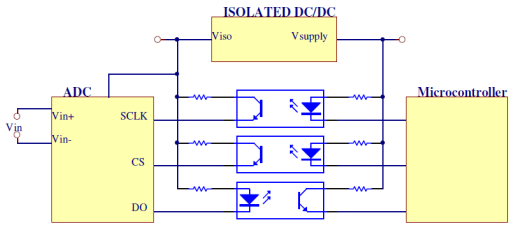


Isolation

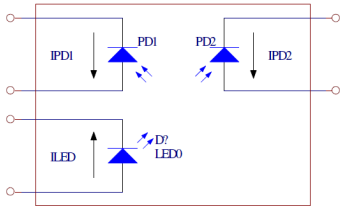
- Optical
- Magnetic
- Capacitive

- Analogue
- Digital

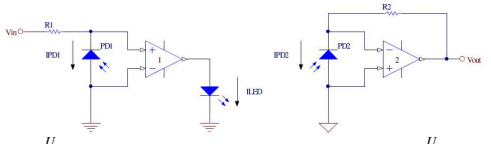
„Digitaly" isolatet analog signals



Opto-Isolation of analog signals



Analog opto-isloation

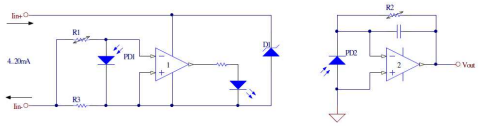


$$I_{PD1} = \frac{U_{in}}{R_1} \qquad I_{PD2} = \eta I_{PD1} \qquad I_{PD2} = \frac{U_{out}}{R_2}$$

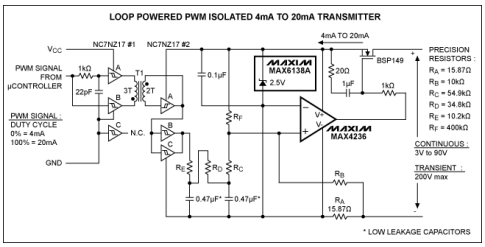
$$U_{out} = U_{in} \frac{R_2}{R_1} \eta$$

Tip:
accuracy can be is not satisfactory

Opto-isolatin of 4-20mA loop

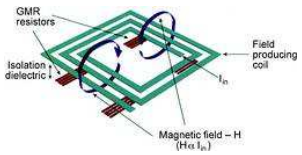


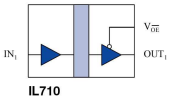
PWM to 4-20mA isolation



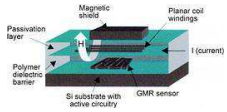
MAXIMy advertisement materials

Magneto - Isolation





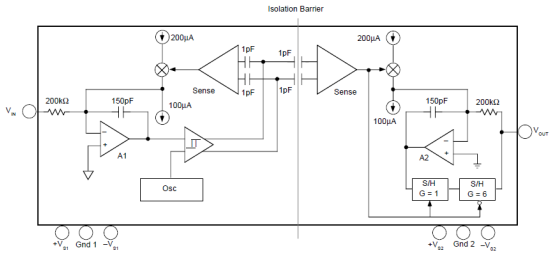
IL710



NVE corporation Advertisement materials

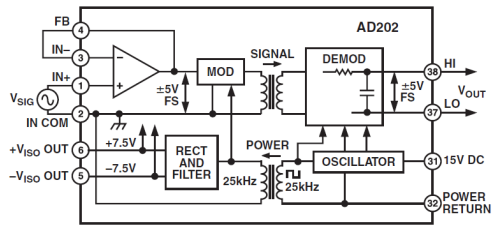
Isolation by Pulse With Modulation (PWM)

(Burr Brown – advertisement materials)

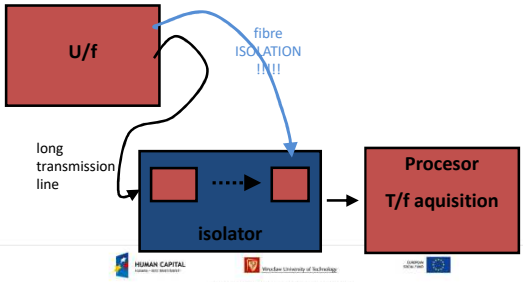


Isolation by modulation

(Analog Device – advertisement materials)



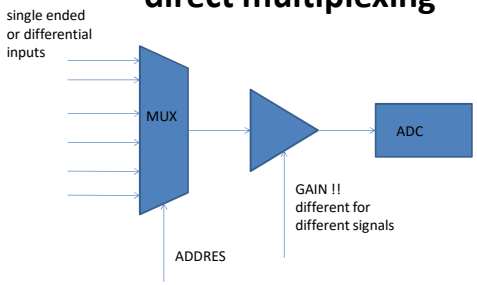
Voltage-frequency modulation in transmission and isolation



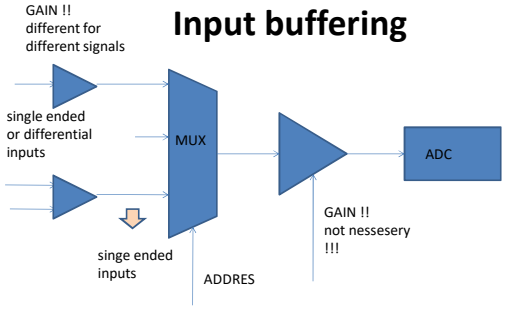
Multiplexing

- direct (small signal) multiplexing
- buffering – multiplexing
- simultaneous s/h
- digital multiplexing

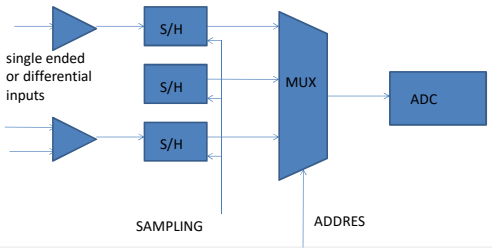
direct multiplexing



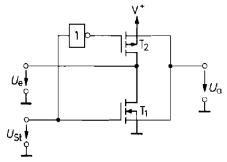
Input buffering

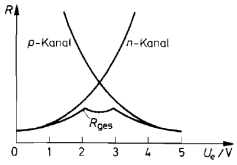


multiplexing with simultaneous reading



Switches to be continued during next lectures

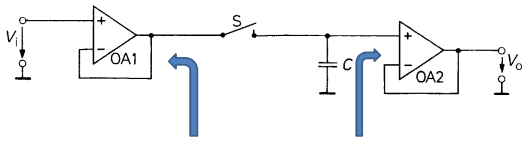




U_{CON}=VCC
U_{COFF}=0
R_{ON}<100Ω

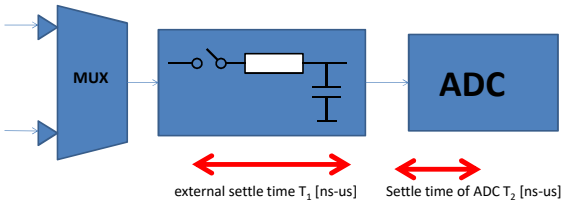
SH – sample and hold – basic circuit

to be continued during next lectures



R_{out}=0 R_{in}=∞

Time acquisition channel



$$T_{sample} \geq \sqrt{T_1^2 + T_2^2} = T_{settle} \qquad f_{acq} = \frac{1}{N_{channel} \cdot T_{sample}}$$

Summary

- Aquisition system –general diagram
- ADC – general information
- isolation methods
- Multiplexing problems
- Sample & hold – sampling frequency

Test questions (an example):

- In digital to analog conversion, what is the signal to quantization noise ratio ?
- What is the relationship between SNR and Channel Capacity ?
- Describe relationship between sampling ratio and resolution of AD converters.
- What are basic principles (methods) of galvanic isolation in analog and digital systems ?

Multiplexers & switches – more about in „AD/DA converters lecture”

Windowing (facultative)

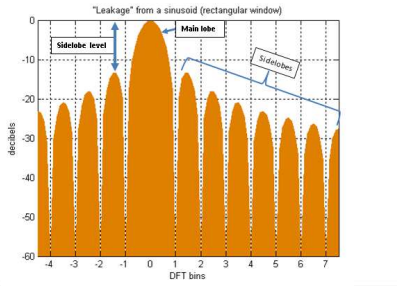
High- and moderate-resolution windows
1 Rectangular window
2 Hann window
3 Hamming window
4 Tukey window
5 Cosine window
6 Lanczos window
7 Triangular windows
8 Gaussian windows
9 Bartlett–Hann window
10 Blackman windows
11 Kaiser windows

Windowing

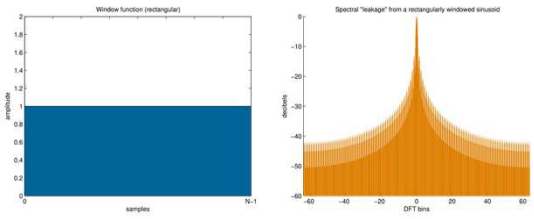
Low-resolution (high-dynamic-range) windows
1 Nuttall window, continuous first derivative
2 Blackman–Harris window
3 Blackman–Nuttall window
4 Flat top window

Windowing

Main and side lobes



Windowing rectangular window



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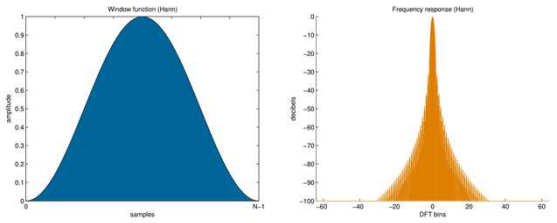
Windowing
Hann window



HUMAN CAPITAL

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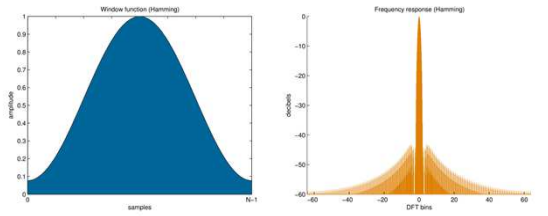
Windowing
Hamming window



HUMAN CAPITAL

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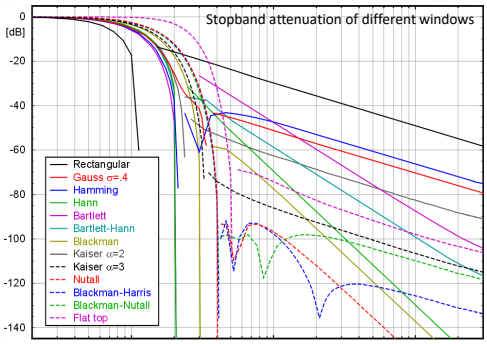

HUMAN CAPITAL