DAQ – data acquisition systems

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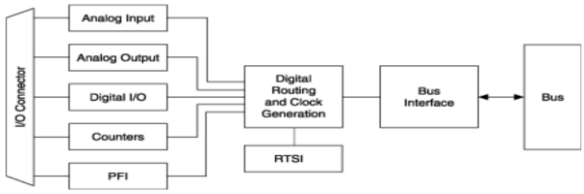
Data Acquisition Systems

- Measurement (and control) in industry:
  - Electrical and nonelectrical quantities
  - Relatively slow signals (kHz, ms)

What is multifunction board?

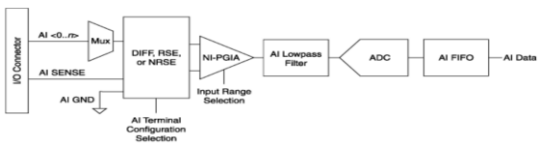
- Multifunction board - a modul allowing sensing and generating analogue and digital signals by a computer (PC)
- Connection with PC:
  - Internal bus (PCI, PCIe)
  - Modular system (PXI, PXIe)
  - USB
  - Ethernet
  - …
- Software is needed for using (driver + application)
  - General (universal) – usually for checking the basic functions
  - Software developed for required applications given by user

Typical block diagram

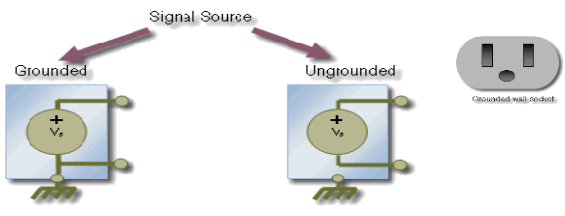


Analog inputs

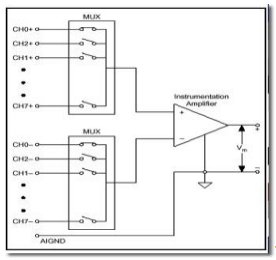
- Usually multiplexed (8, 16, 32, …)
- Input voltage ranges from cca. 1V up to 10V in unipolar or bipolar mode
- Differential or single ended with referenced or non-referenced ground
- Max. sampling frequencycca. 1MHz, resolution 12 – 18bits (typ. 16)



Grounding and shielding



Differential input

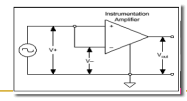


High noise and disturbance immunity – proper for small signals (mV)

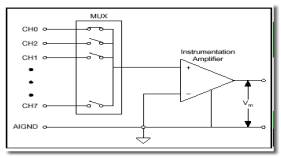
More complex electronics and cabling

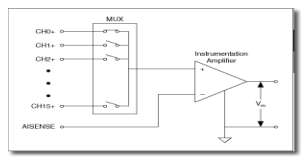
!!! common mode voltage – the same voltage on both inputs:

- Cross talk on output
- Damage of input



Grounded inputs





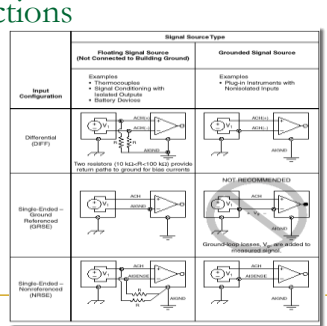
Reference ground

Referenced single ended

Non-reference ground

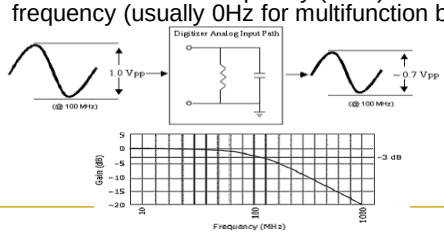
Non-referenced single ended

Connections



Basic parameters

- Bandwidth – max. frequency (-3dB) – min. frequency (usually 0Hz for multifunction board)

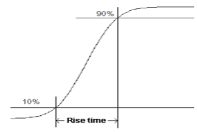


Rising and falling time

- Electronic circuits decrease pulse slopes

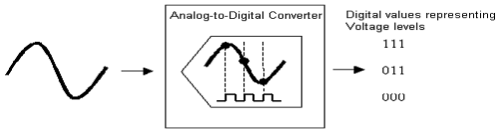
$$Tr_m = \sqrt{Tr_d^2 + Tr_s^2}$$

$$T_{rd} \cong \frac{0.35 \text{ až } 0.45}{B}$$



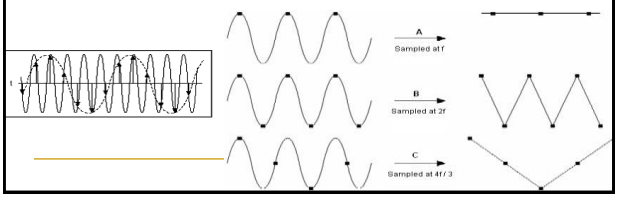
Sampling rate

- Sampling rate (frequency) – rate of conversion of analog signal to numbers (rate of measurements of analog signal)



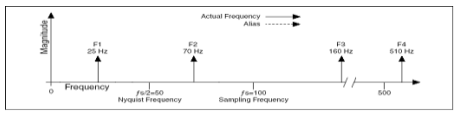
Sampling frequency

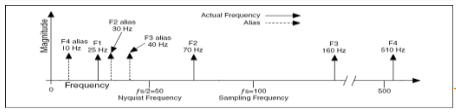
- Sampling frequency must be at least twice higher than the highest frequency in the spectrum of sampled signal (Niquist frequency) – not easy and always fulfilled in praxis



Aliasing

- Signal spectral componets are moved to new positions (freqencies) $f_{alias} = ABS(\text{the nearest } N.f_s - f_{in})$





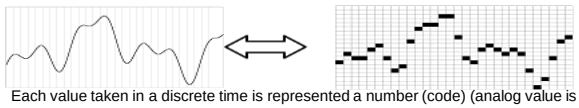
F_{2alias}= ABS (100-70) =30

F_{3alias}= ABS (2.100-160) =3

40

F_{4alias}= ABS (5.100-510) =10

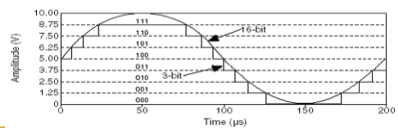
Conversion of analog value to number (quantization)



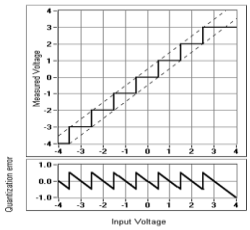
Each value taken in a discrete time is represented a number (code) (analog value is rounded – quantized) by analog to digital convertor (ADC)

ADC resolution:

- Given by number of bits and input full scale (FS)
- Number of quantization steps N= 2^N -1
- Δ=FS/(2^N -1)



Quantization error = quantization noise



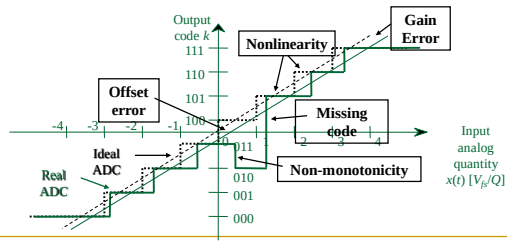
The difference between real and discrete (digitized) values

Uniform distribution is usually supposed (not generally true)

Effective (RMS) value:

$e_{rms}=\Delta/\mathrm{sqr}(12)$

ADC error parameters



DNL a INL

- DNL – differential nonlinearity – relative error of real quantization step for code k

$$DNL(k)=\frac{\Delta_{real}-\Delta}{\Delta}=\frac{T(k)-T(k-1)}{\Delta}-1$$

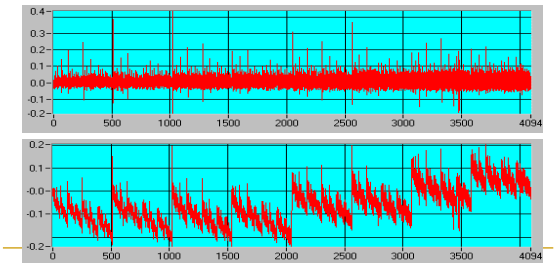
- INL – integral nonlinearity – relative error of real transition (quantization) level of code k

$$INL(k)=\frac{T_{real}(k)-T_{ideal}(k)}{\Delta}=DNL(k)+INL(k-1)$$

Nonlinearity consequences:
- Erroneous code = increasing quantization noise = number of valid bit < nominal number of bits

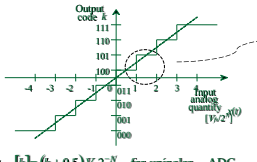
Measurement of real quantization level is difficult because of stochastic behavior or real ADC

DNL and INL example



ADC conversion characteristics

Deterministic model

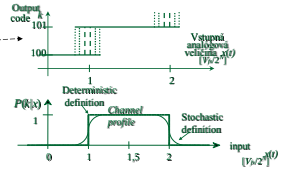


$T_{nom}[k] = (k + 0{,}5)\,V_{fs}\,2^{-N}$ for unipolar ADC

$T_{nom}[k] = (k - 2^{N-1} + 1)\,V_{fs}\,2^{-N}$ for bipolar ADC

$k = 0, 1, \ldots, 2^N - 1$

Stochastic model



$T[k]: \quad P(k|T[k]) = P((k+1)|T[k]) = 0{,}5$

$T[k]$ - Transition (quantization) level of code k

V_{fs} – ADC full scale

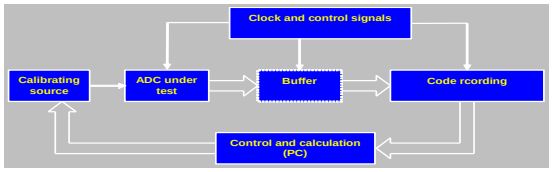
N – Nominal number of bits

DNL and INL testing

- Standadized methods
  - IEEE Std. 1057 - 1994, "IEEE Standard for Digitizing Waveform Recorders",
  - IEEE Std. 1241, "IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters koncept
  - DYNAD – SMT4-CT98-2214, „Methods and draft standards for the DYNamic characterisation of Analogue to Digital converters“,
  - IEC std.

Static method

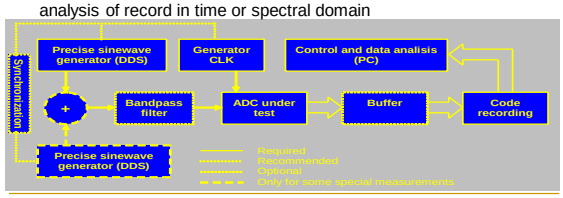
- Based on stochastic ADC model



- Disadvantage: time consuming, e.g.. 12bits ADC, f_s=100kHz ~ 30hours, f_s=10Hz ~ 300000 hours ~ 521years

Dynamic method

- Fast determination of DNL and INL based on histogram analysis
- Determination of dynamic parameters (SINAD, ENOB, THD, ...) by analysis of record in time or spectral domain



Histogram test

- Probability density of sinewave $p(x)=2\left|\frac{d}{dx}\left(\frac{1}{2\pi}\arccos\frac{x}{A}\right)\right|=\frac{1}{\pi\sqrt{A^2-x^2}}$
- Probability of code k at ADC output

$$P[k]=\int_{\frac{V_{fs}((k-1)-2^{N-1})}{2^N}}^{\frac{V_{fs}(k-2^{N-1})}{2^N}}\frac{1}{\pi\sqrt{A_1^2-x^2}}\,dx=\frac{1}{\pi}\left(\arcsin\frac{V_{fs}(k-2^{N-1})}{A.2^N}-\arcsin\frac{V_{fs}((k-1)-2^{N-1})}{A.2^N}\right)$$

- For idel ADC and pure sinewave

$$H^{id}[k]=\frac{M}{\pi}\left(\arcsin\frac{V_{fs}(k-2^{N-1})}{A\,2^N}-\arcsin\frac{V_{fs}((k-1)-2^{N-1})}{A2^N}\right)$$

- Result
- Disadvantages:
  - - Extremely high purity of sinewave is needed
  - - Parameters of sinewave must be known

$$DNL[k]=\frac{H[k]-H_{id}[k]}{H_{id}[k]}$$

Common dynamic parameters

- Signal to noise and distortion $SINAD_{dB} = 20 \log \frac{A_{1rms}}{\eta_{rms}}$
- Signal to noise ratio $SNR_{dB} = 10 \log \frac{A_{1rms}^2}{\eta_{rms}^2 - \sum_{h=2}^{H} A_h^2}$
- Effective number of bits $ENOB = N - \log_2 \frac{\eta_{rms}}{\sigma_{rms}} \doteq \frac{SINAD - 1{,}76}{6{,}02}$
- Spurious free dynamic range $SFDR_{dB} = 10 \log \frac{|Y_{avm}(f_1)|}{\max\left(|Y_{avm}(f_h)|, |Y_{avm}(f_{sp})|\right)}$
- Harmonic distortion $THD = \frac{\sqrt{\sum_{h=2}^{H} A_h^2}}{A_1}$

Calculations

Time domain

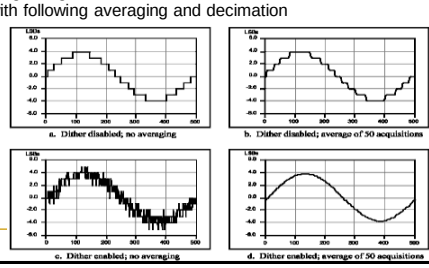
- Fitting record:
  - Three parameters method – the frequency is exactly know – easy for calculation but commonly not applicable
  - Four parameters fit – exact but difficult (numerical iteration with threads of local minima
- Difference of codes and fit is quantization noise
- Application of parameters definition (ENOB, SINAD)

Spectral domain

- Spectrum calculation by DFT from record
- Spectrum analysis and application of parameters definitions (ENOB, SINAD, SNR, THD, …)

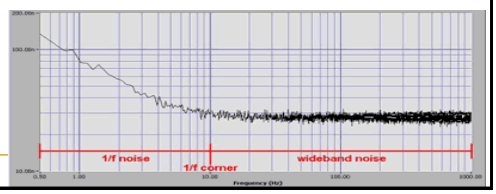
Dithering

Oversampling of signal with added noise with uniform distribution in 1LSB range with following averaging and decimation



Noise

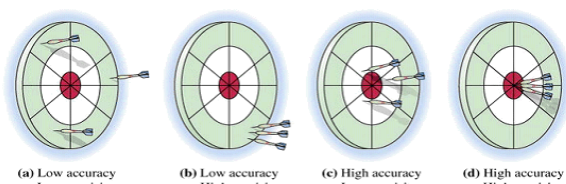
- All fluctuation in signal
- Zdroje šumu:
  - Thermal noise –R: $(V_n)^2 = 4KTRB$ [V^2/Hz]
  - Flicker, 1/f noise, … – PN in semiconductor
  - ...



Noise suppression strategies

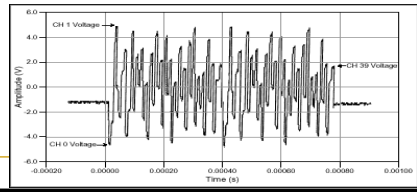
- Small impedances
- Narrow bandwidth
- Grounding, shielding, ...
- Low noise components
- Low power voltage
- Digital signal processing

„Precision“ or „accuracy“?



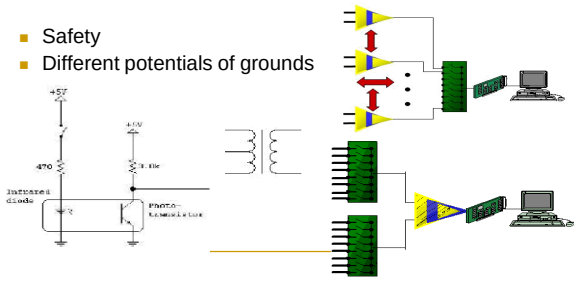
Analog multiplexers

- Ron, Roff
- Settling time
- Cross-talk, noise, parasitic capacity, ...

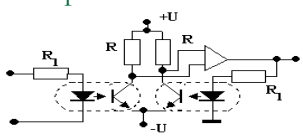


Galvanic isolation

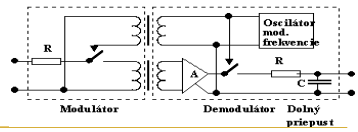
- Safety
- Different potentials of grounds



Principles

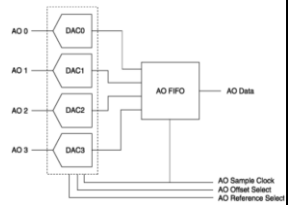


Modulating amplifier



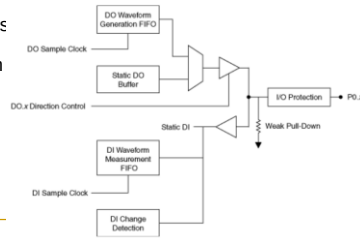
Analog outputs

- Usually 2 or 4
- Typ. 10V in unipolar or bipolar mode
- Sampling rate up to MHz
- Resolution 12 – 16 bits
- Single ended (GND in PC)



Direct digital inputs/outputs

- TTL levels
- Programmable in groups (ports) or bit by bit
- Programmable direction
- Handshake and buffer



Timers

- Measurement of time parameters of pulse or pulse train
- Generating individual pulses or pulse trains with given parameters
- Based on programmable counters