New Trends in R&D

PC data logging (with LabView)
Data-acquisition and signal filtering

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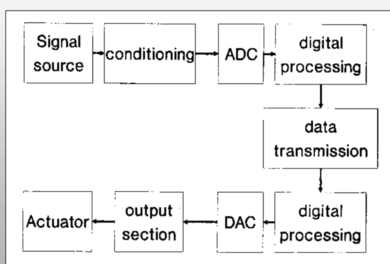
The Key Diagram



Measurement Principles

→ all signals = electrical signals (small amplitude)

4 groups of signals:

- low voltage (< 1 µV)
- low current (< 1 µA)
- low resistance (< 100 mΩ)
- high resistance (> 1 GΩ)

Low level signals: $V_S = 1\mu A \times R_S$

e.g. V_S = 0.02 pH x 0.059 V/pH = 1.18 mV

<< 1 µA x 250 MΩ = 250 V

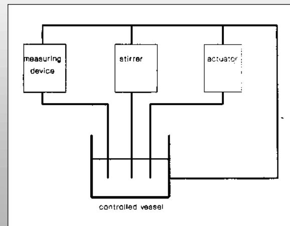
Signal Conditioning

Remark: *galvanic isolation*

Ground loops!

→ common ground

→ galvanic isolation



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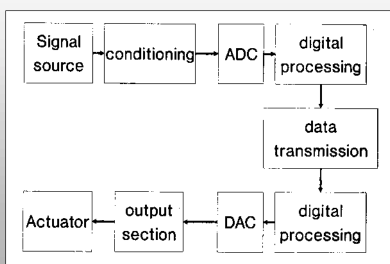
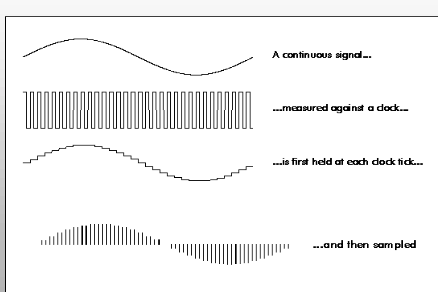


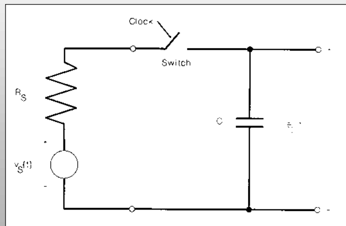
Data conversion



Data conversion

BIOMATH

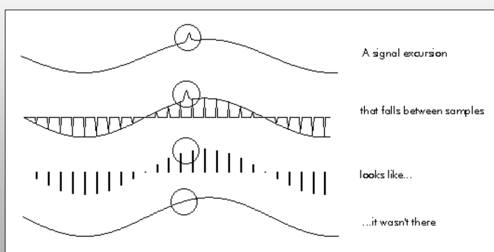
→ Sample and hold circuit



Data conversion

BIOMATH

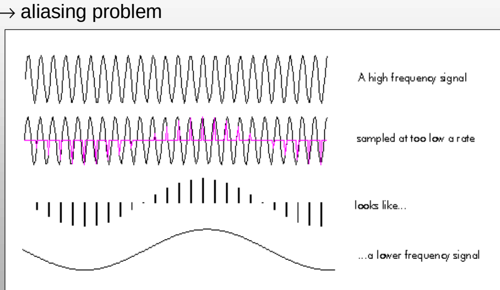
→ Sampling frequency > highest signal frequency (Nyquist)



Data conversion

BIOMATH

→ aliasing problem



Data conversion (ADC)

BIOMATH

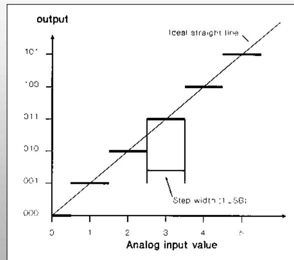
- speed [meas./sec]
- resolution [bits]

  e.g. *8-bit converter*: 256 discrete states
  → accuracy: 1/256 = 0.4%

  10-bit converter:
  → accuracy: 1/1024 = 0.1%

  resolution=2^{bits}

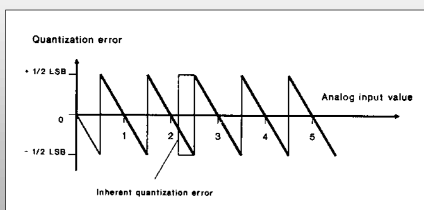
- Least Significant Bit (LSB)



Data conversion (ADC)

BIOMATH

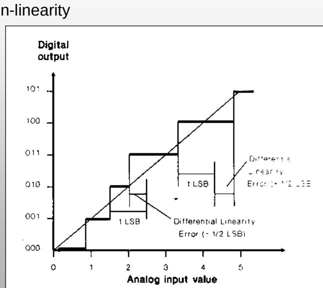
Quantization error inherent to ADC = 1/2 LSB



Data conversion (ADC)

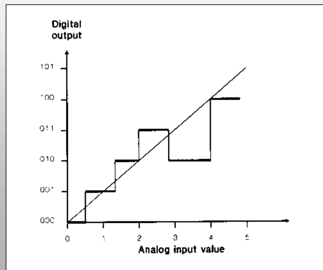
BIOMATH

Error of non-linearity



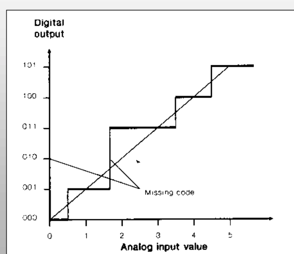
Data conversion (ADC)

Error of non-monotonicity

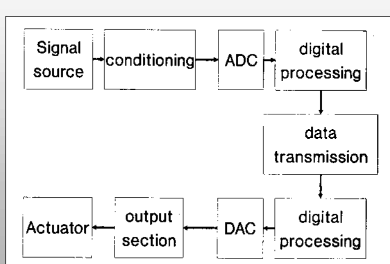


Data conversion (ADC)

Error of missing codes



The Key Diagram



Data conversion (DAC)

BIOMATH

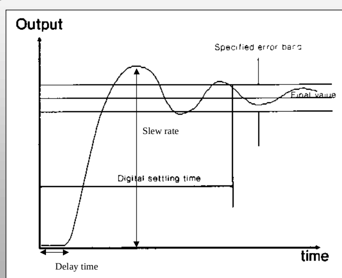
- X = k.A.B with: X = analog signal
  k = constant
  A = analog reference voltage or current
  B = binary signal

- DAC characteristics → step response

Data conversion (DAC)

BIOMATH

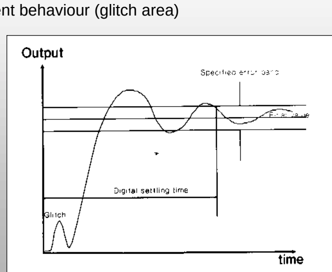
Step response



Data conversion (DAC)

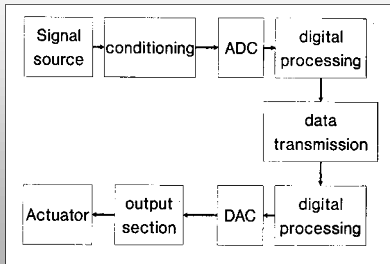
BIOMATH

Glitch → transient behaviour (glitch area)



The Key Diagram

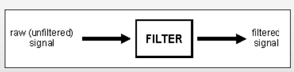
BIOMATH

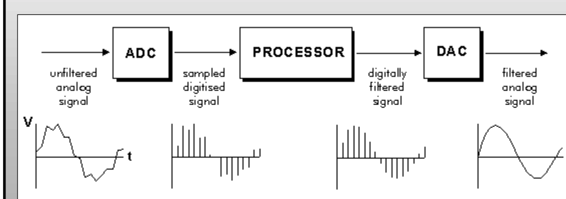


Filtering

BIOMATH

Analog and digital filters



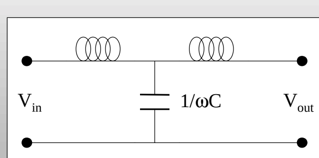


Analog Filtering

BIOMATH

Analog filters

e.g. low-pass filter



Digital Processing

Digital filters

- history *'60* *→ DSP (Digital Signal Processor): embedded controllers; focussed on specific functions*

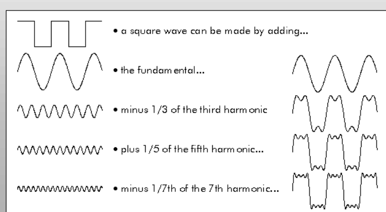
  → PC: series of general functions
- advantages digital filters
  - *programmable*
  - *simple and compact*
  - *stabile (no drift)*
  - *low signal frequencies*
  - *adaptive digital filters*
- disadvantages digital filters
  - *aliasing*

Digital Processing

Signal conditioning in FREQUENCY DOMAIN

Fourier → signal = series of sine functions
→ only 3 characteristics: amplitude, phase and frequency
→ reduction of information

e.g. block wave



Digital Processing

- *mathematical technique*

  Fourier Transform (TF) → integral form!

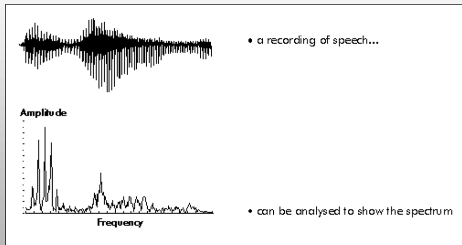
  Discrete Fourier Transform (DFT) → discrete equivalent

  Fast Fourier Transform (FFT) → practical calculation method

$$f(t) = \sum_{k=1}^{\infty} b(k)\sin(k\varpi t) + a(k)\cos(k\varpi t)$$

Digital Processing

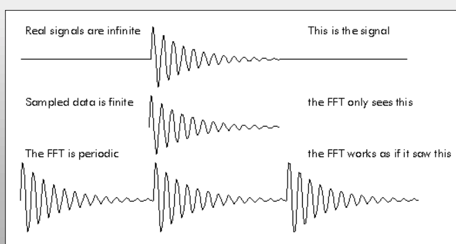
e.g.



Digital Processing

! Remark: FFT only works properly if the signal is periodic

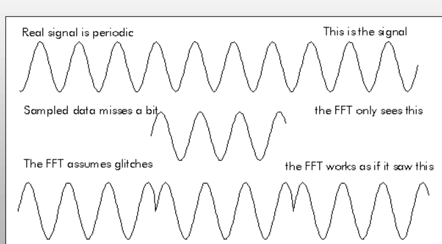
e.g. 1



Digital Processing

! Remark: FFT only works properly if signal is complete

e.g. 2

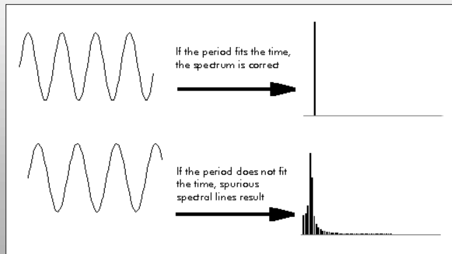


Digital Processing

BIOMATH

! Remark: FFT only works properly if signal is complete

e.g. 2



Digital Processing

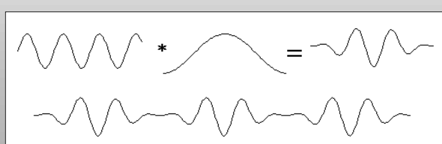
BIOMATH

To narrow the spectrum one needs to reduce the *glitches* artificially by smoothly connecting the signal ends

→ multiply the signal with a *window function*:
one forces the signal to go to zero at the signal's end

Consequence: more narrow spectrum, but distortion of signal occurs so, necessity of correct choice of window function

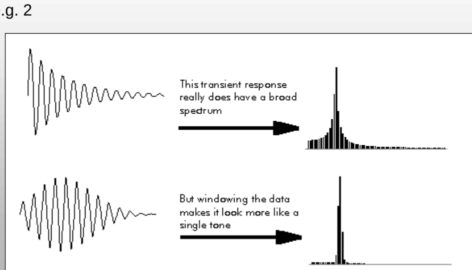
e.g. 1



Digital Processing

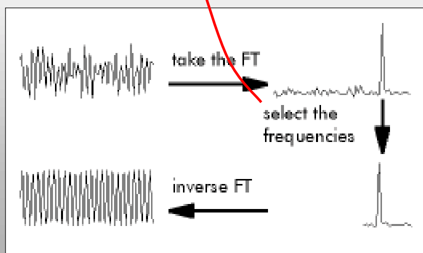
BIOMATH

e.g. 2



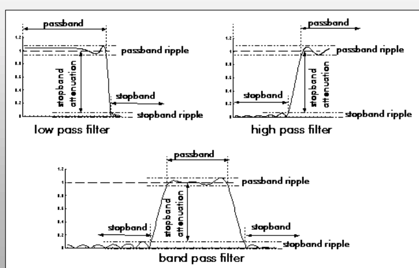
Digital Processing

Fourier filtering $f(t)=\sum_{k=1}^{\infty} b(k)\sin(k\varpi t)+a(k)\cos(k\varpi t)$



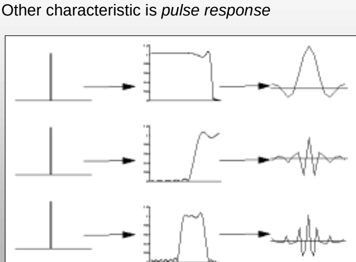
Digital Processing

Digital filter characteristics = choice of frequencies



Digital Processing

Other characteristic is *pulse response*



low-pass filter

high-pass filter

band-pass filter

Digital Processing

BIOMATH

Signal conditioning in TIME DOMAIN

- take averages: y'(k) = [y(k-1) + 2 y(k) + y(k+1)]/4
- for very noisy signals with "outliers": take MEDIAN[y(k-j) … y(k+j)]

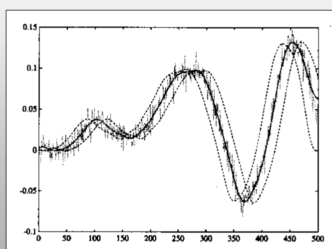
- for on-line application: y'(k) = [y(k-2) + 2 y(k-1) +4 y(k)] / 7

PROBLEM: ***Data shift in time***

Digital Processing

BIOMATH

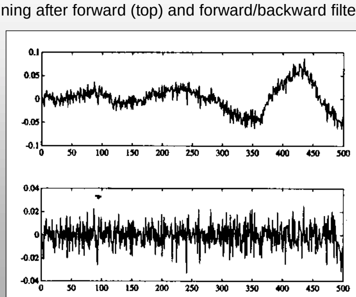
Phase shift from forward, backward and forward/backward low-pass filter



Digital Processing

BIOMATH

Noise remaining after forward (top) and forward/backward filter (bottom)



Digital Processing

Peak shaving

noise peaks introduced by the sensor or the transmission lines
(e.g. by on/off switching of devices)

→ need for <u>peak shaving</u>!

a) Clipping the signal amplitudes

$$\tilde{s}_k = f_k . s_k \qquad \text{with}: f_k = \begin{cases} s_{max} \cdot \frac{1}{s_k} & \text{if } s_k \geq s_{max} \\ 1 & \text{if } s_{min} < s_k < s_{max} \\ s_{min} \cdot \frac{1}{s_k} & \text{if } s_k \leq s_{min} \end{cases}$$

Digital P

a) clipping the signal amplitudes

b) computation of trend signal $\bar{s}_k$ of $\tilde{s}_k$

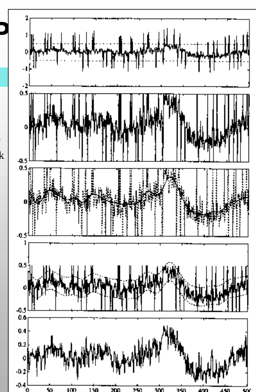
c) computation of standard deviation

$$\sigma = \sqrt{\sum_{k=1}^{N} [(\tilde{s}_k - \bar{s}_k) - s_a]^2}$$

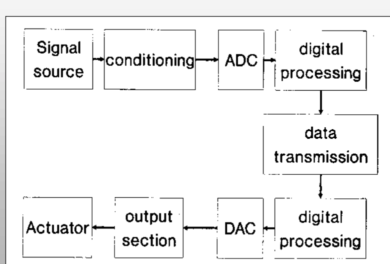
with s_a = average of $\tilde{s}_k - \bar{s}_k$

d) interpolation of samples outside the band defined as

$$s_k = \begin{cases} \bar{s}_k + \alpha\sigma & \text{upper limit} \\ \bar{s}_k - \alpha\sigma & \text{lower limit} \end{cases}$$



The Key Diagram



Data Transmission

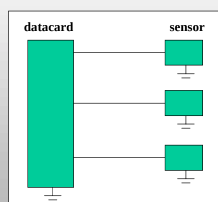
Introduction

single ended - differential signals

analog - digital signals

Data Transmission

Single ended data transmission



Advantages:

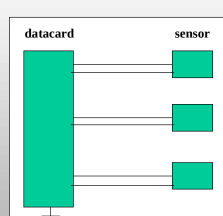
- low cost
- simple

Disadvantages:

- noise sensitive
- low transmission speed
- short lines
- grounding

Data Transmission

Differential data transmission



Advantages:

- fast transmission speed
- long transmission lines
- noise insensitive
- no grounding

Disadvantages:

- more costly

Data Transmission

BIOMATH

Analog data transmission

→ signal amplification

<u>A-signal</u>: 0-20 mA and 4-20 mA (4mA ↔cable rupture)

± immune to noise

total resistance < 600 Ω

<u>V-signal</u>: 0-1 V, 0-5 V and 0-10 V

sensitive to noise

total resistance > 100 kΩ

Data Transmission

BIOMATH

Digital data transmission

Only 2 signal levels: 0 and 1 => low noise sensitivity

Synchronization of sender-receiver needed

Fault detection possible:
- parity
- check of sums
- redundancy

Transfer speed (baudrate) [bits/s]

→ digital speed > real information speed:
(due to fault detection needs)

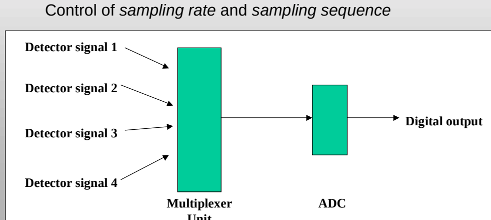
Data Transmission

BIOMATH

Multiplexing of digital data

Multichannel data-acquisition with single ADC
! *Crosstalk*: interchannel interference → loss of data integrity

Control of *sampling rate* and *sampling sequence*



Data Transmission

BIOMATH

Parallel and serial data communication for digital data

a) **Parallel communication**

Distribute bytes over several transmission lines

! Need for synchronization

! Limited cable length

Data Transmission

BIOMATH

b) **Serial communication** bits are sent sequentially over 1 cable

→ **RS-232 interface** (single ended)

devices with a standard RS-232 interface can *not* be connected to each other without any problems due to:

- existence of many "232" norms (EIA-232, RS-232-C, RS-232-D, EIA/TIA-232-F)
- existence of many connector types (DB25, DB9, OEM)
- speed of transmission
- number of bits per byte
- number of stop bits: 1 or 2? Parity bit?
- protocol of data transmission: direct transmission after data generation *or* data storage

Data Transmission

BIOMATH

→ **RS-422** and **RS-485** (differential)

advantages over RS-232: higher transmission speed
longer transmission lines
less noise sensitive

Data Transmission

BIOMATH

Internal data transport

data is transported to RAM or CPU of control device

How?

- ADC has memory location characteristics for CPU
- port address

→ last available data, does not have to be the most recent one

Data Transmission

BIOMATH

CPU copies data to another location to avoid eventual overwriting. To do so, there exist several possibilities:

- *polling*: continuous CPU monitoring of the memory location
- *hardware or software protocol*: data exchange at specific times
- *interrupt driven strategy*: data exchange at every moment
  (disadvantage: no other tasks during data logging)
- *Direct Memory Access*: DMA-chip realizes data transfer
  (advantage:CPU can execute other tasks meanwhile)
  (disadvantage: costly)

Control Devices

BIOMATH

- **Control devices**

\- *PC*

speed not only dependent on hardware, but also on the OS
(DOS vs. MS Windows)

\- *PLC* (Programmable Logic Controllers)

program is run sequentially and repeated

skipping lines or jumping back is impossible

advantage: infinite loops are impossible
a fixed run time

disadvantage: little flexible
no complete control algorithms