

Communication

Jian-Jia Chen
(slides are based
on Peter Marwedel)
Informatik 12
TU Dortmund
Germany

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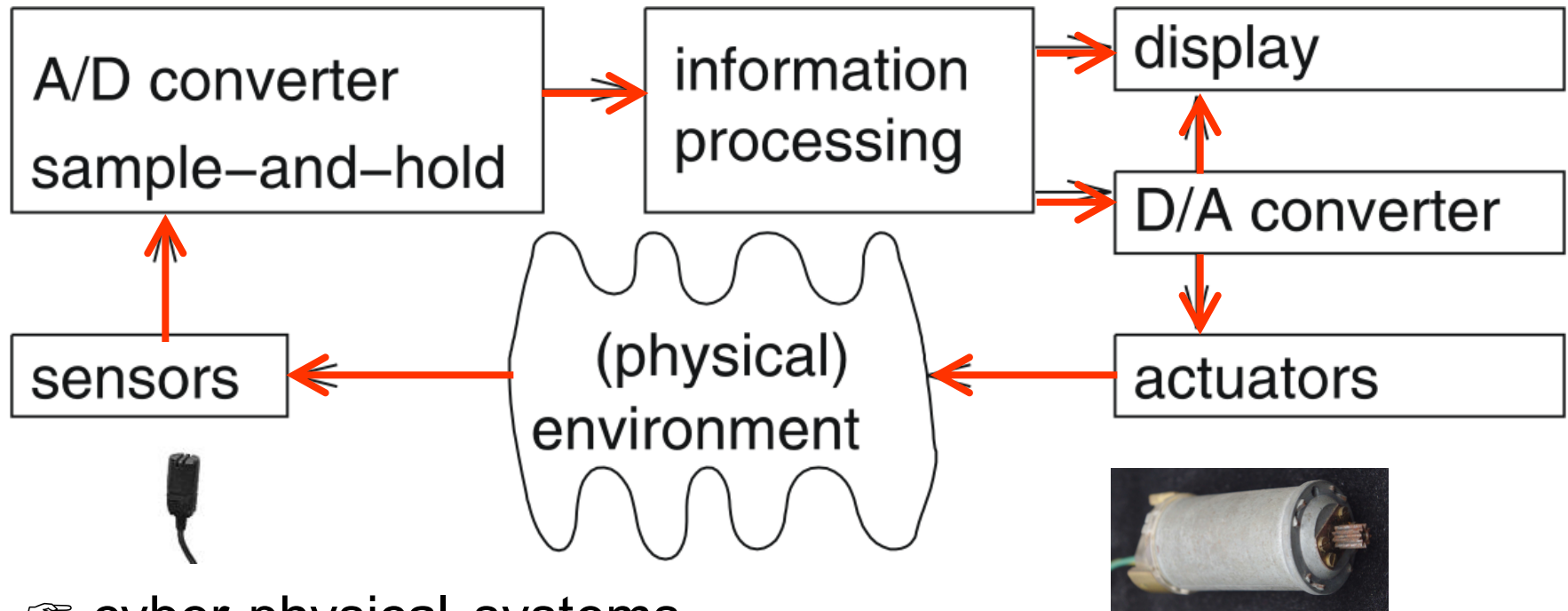


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Embedded System Hardware

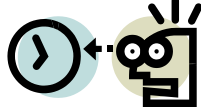

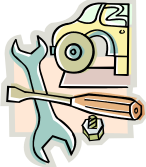


Embedded system hardware is frequently used in a loop ("**hardware in a loop**“):



👉 cyber-physical systems

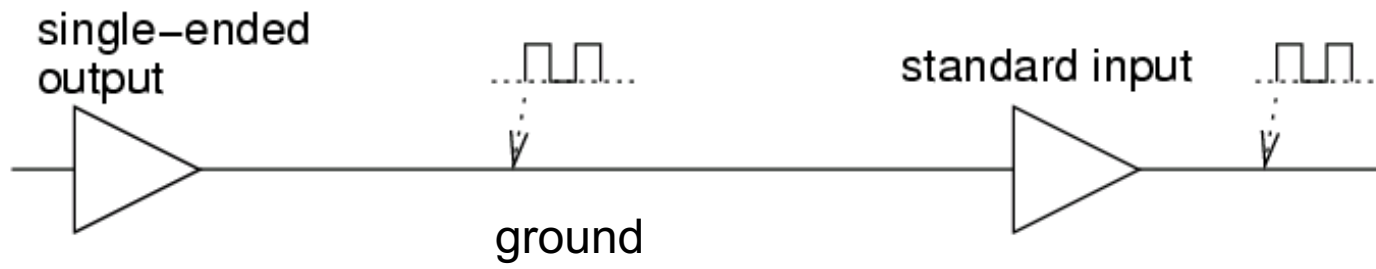
Communication

- Requirements -

- Real-time behavior 
- Efficient, economical
(e.g. centralized power supply) 
- Appropriate bandwidth and communication delay
- Robustness
- Fault tolerance
- Diagnosability
- Maintainability 
- Security 
- Safety 

Basic techniques: Electrical robustness

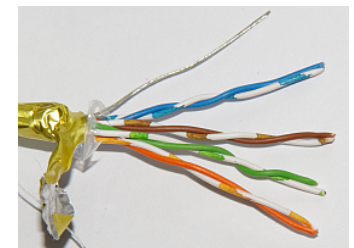
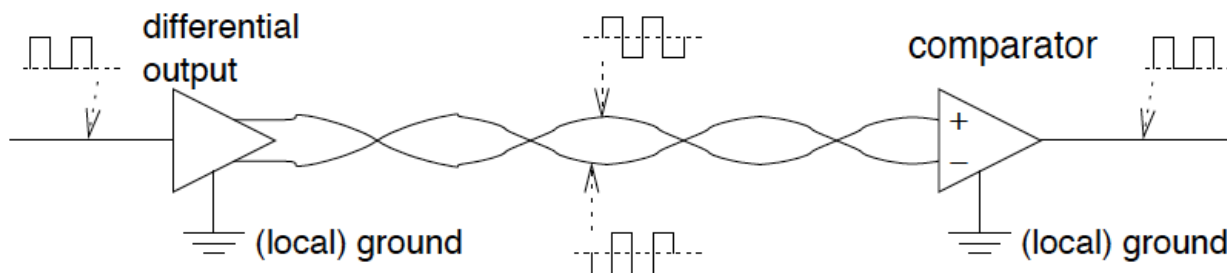
■ Single-ended signals



e.g.: RS-232

Voltage at input of Op-Amp positive → '1'; otherwise → '0'

■ Differential signals



Combined with twisted pairs; Most noise added to both wires.

Evaluation

Advantages:

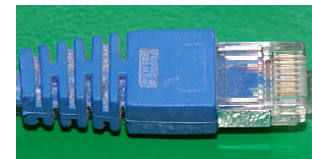
- Comparison removes most of the noise
- Changes of voltage levels have no effect
- Reduced importance of ground wiring
- Higher speed

Disadvantages:

- Requires negative voltages
- Increased number of wires and connectors

Applications:

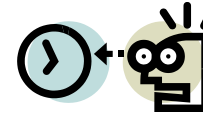
- High-quality analog audio signals (XLR)
- differential SCSI
- Ethernet (STP/UTP CAT 5/6/7 cables)
- FireWire, ISDN, USB



Communication

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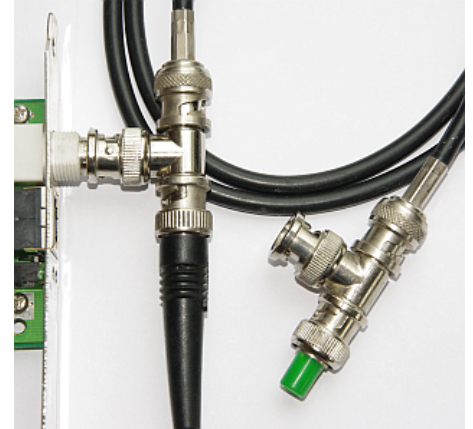


CSMA/CD vs. CSMA/CA

Carrier-sense multiple-access/collision-
detection (CSMA/CD, variants of Ethernet):
collision ➡ retries;
no guaranteed response time.

Alternatives:

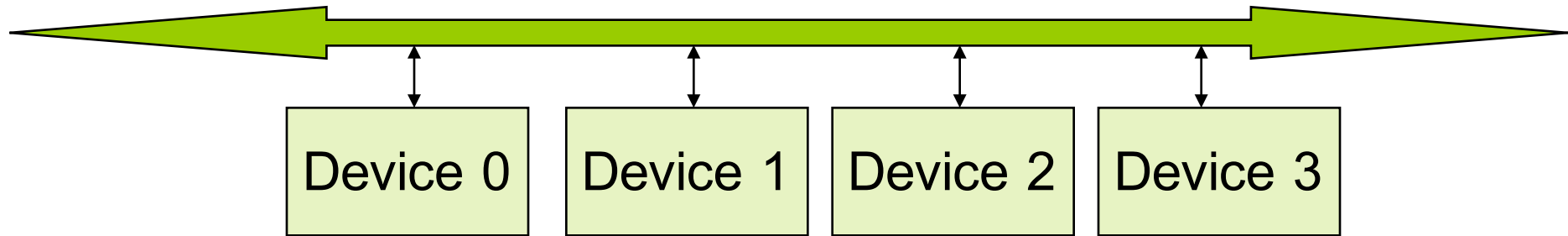
- Carrier-sense multiple-access/collision-
avoidance (CSMA/CA): IEEE 802.11, WLAN
- Carrier-sense multiple-access/collision-
resolution (CSMA/CR): CAN (controller area network)
- token rings, token busses



➡ chapter 5

Priority-based arbitration of communication media

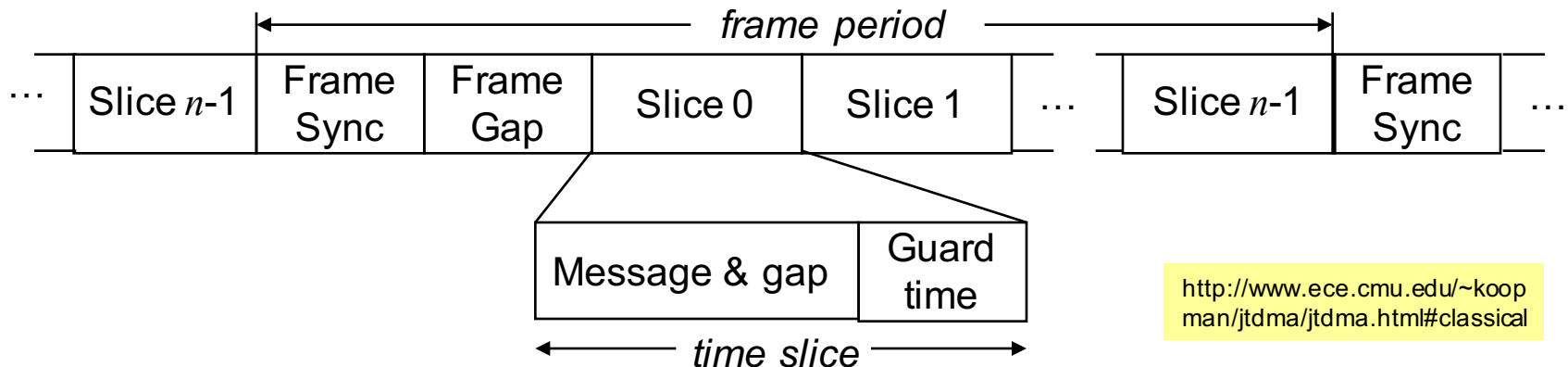
Example: bus



- Bus arbitration (allocation) is frequently priority-based
- ☞ Communication delay depends on communication traffic of other partners
- ☞ Real-time guarantees can be provided

Time division multiple access (TDMA) busses

Each communication partner is assigned a fixed time slot.
Example:



<http://www.ece.cmu.edu/~koopman/jtdma/jtdma.html#classical>

- Master sends sync
- Some waiting time
- Each slave transmits in its time slot
- \exists variations (truncating unused slots, >1 slots per slave)
- TDMA resources have a deterministic timing behavior
- TDMA provides QoS guarantees in networks on chips

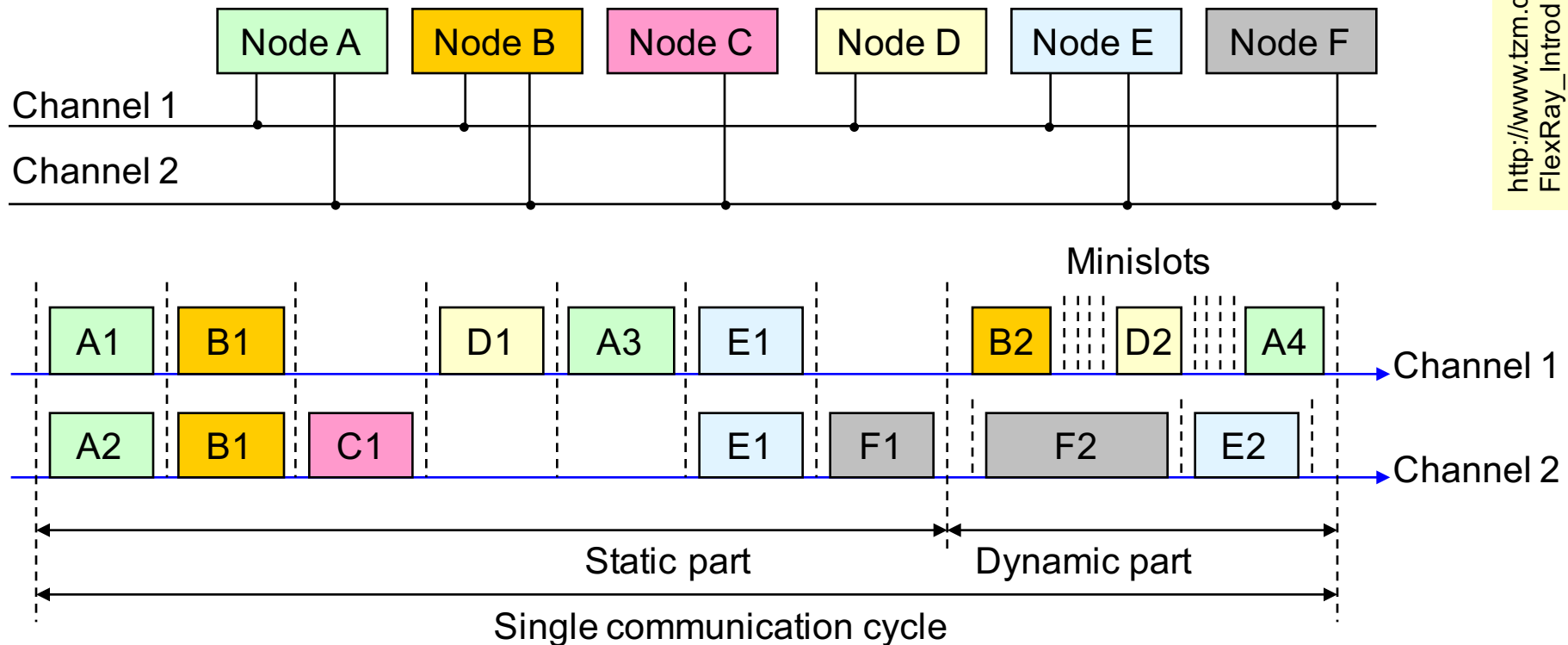
[E. Wandeler, L. Thiele: Optimal TDMA Time Slot and Cycle Length Allocation for Hard Real-Time Systems, ASP-DAC, 2006]

- Developed by the FlexRay consortium (BMW, Ford, Bosch, DaimlerChrysler, ...)
- Specified in SDL
- Meets requirements with transfer rates
High data rate can be achieved:
 - initially targeted for ~ 10Mbit/sec;
 - design allows much higher data rates
- Improved error tolerance and time-determinism
- TDMA protocol
- Cycle subdivided into a static and a dynamic segment.

TDMA in FlexRay



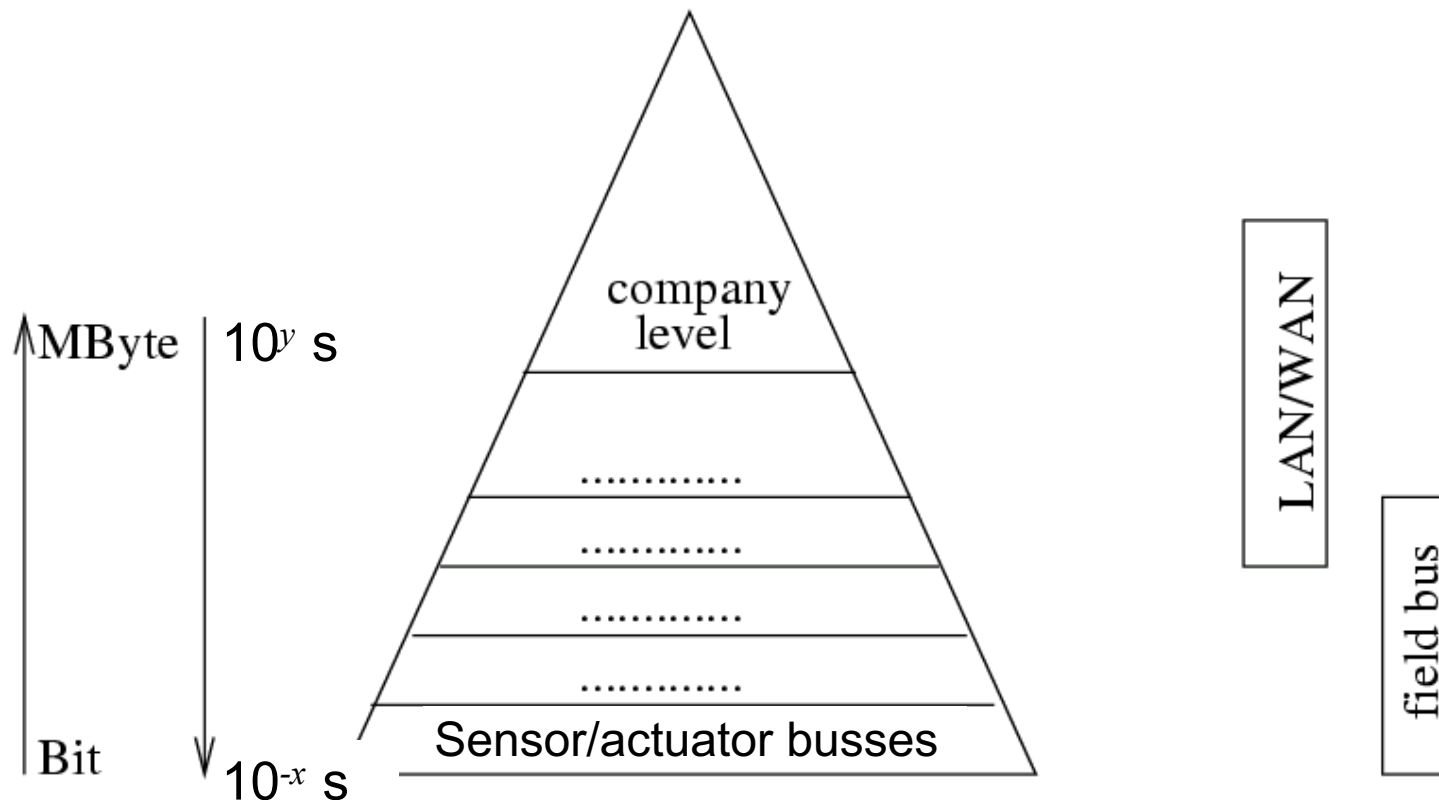
Exclusive bus access enabled for short time in each case.
Dynamic segment for transmission of variable length information.
Fixed priorities in dynamic segment: Minislots for each potential sender.
Bandwidth used only when it is actually needed.



http://www.tzm.de/FlexRay/FlexRay_Introduction.html

Communication: Hierarchy

Inverse relation between volume and urgency quite common:



Other busses

- **IEEE 488:** Designed for laboratory equipment.
- **CAN:** Controller bus for automotive
- **LIN:** low cost bus for interfacing sensors/actuators in the automotive domain
- **MOST:** Multimedia bus for the automotive domain (not a field bus)
- **MAP:** bus designed for car factories.
- **Process Field Bus (Profibus):** used in smart buildings
- **The European Installation Bus (EIB):** bus designed for smart buildings; CSMA/CA; low data rate. **Upgrade: KNX-Bus**
- Attempts to use Ethernet. Timing predictability an issue.

Wireless communication: Examples

- IEEE 802.11 a/b/g/n
- UMTS; HSPA; LTE
- DECT
- Bluetooth
- WirelessHART
- ZigBee

Timing predictability of wireless communication?

☞ chapter 5

D/A-Converts

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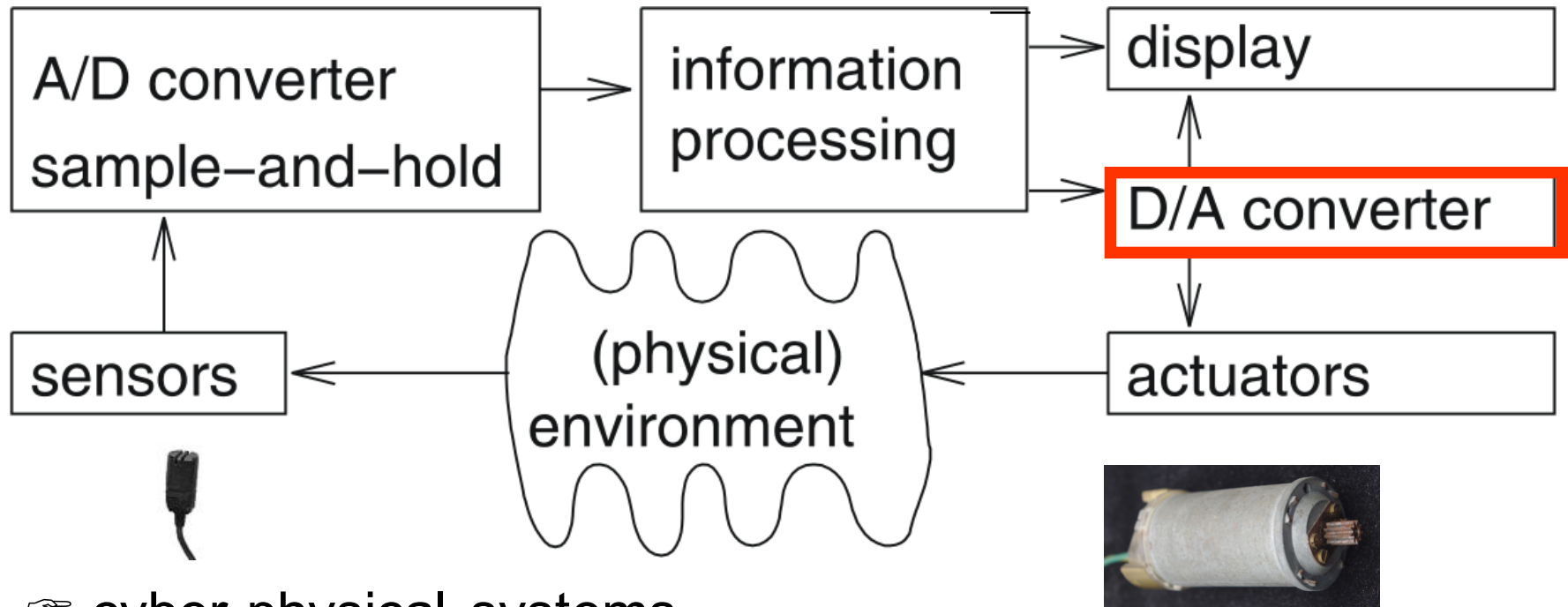


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Embedded System Hardware

Embedded system hardware is frequently used in a loop (***“hardware in a loop”***):



👉 cyber-physical systems

Kirchhoff's junction rule

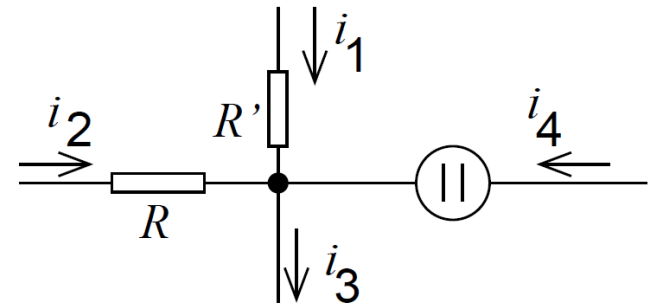
Kirchhoff's Current Law, Kirchhoff's first rule

Kirchhoff's Current Law:

At any point in an electrical circuit, the sum of currents flowing towards that point is equal to the sum of currents flowing away from that point.

(Principle of conservation of electric charge)

Example:



$$i_1 + i_2 + i_4 = i_3$$

Formally, for any node in a circuit:

$$i_1 + i_2 - i_3 + i_4 = 0$$

$$\sum_k i_k = 0$$

Count current flowing away from node as negative.

[Jewett and Serway, 2007].

Kirchhoff's loop rule

Kirchhoff's Voltage Law, Kirchhoff's second rule

The principle of conservation of energy implies that:

The sum of the potential differences (voltages) across all elements around any closed circuit must be zero

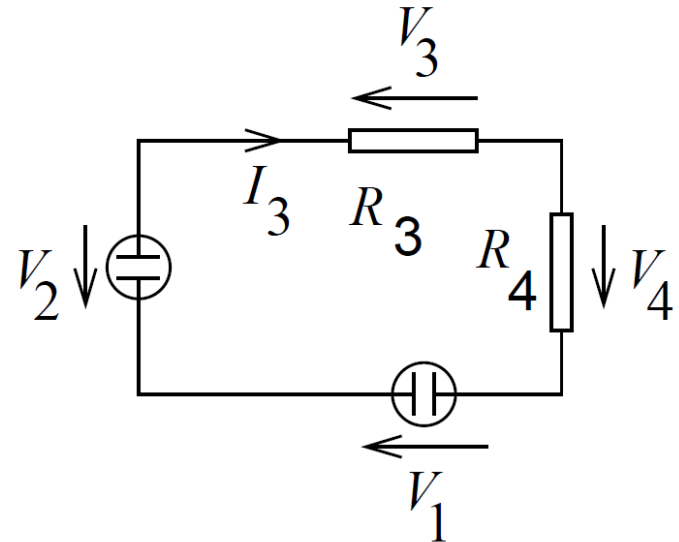
[Jewett and Serway, 2007].

Formally, for any loop in a circuit:

$$\sum_k V_k = 0$$

Count voltages traversed against arrow direction as negative

Example:



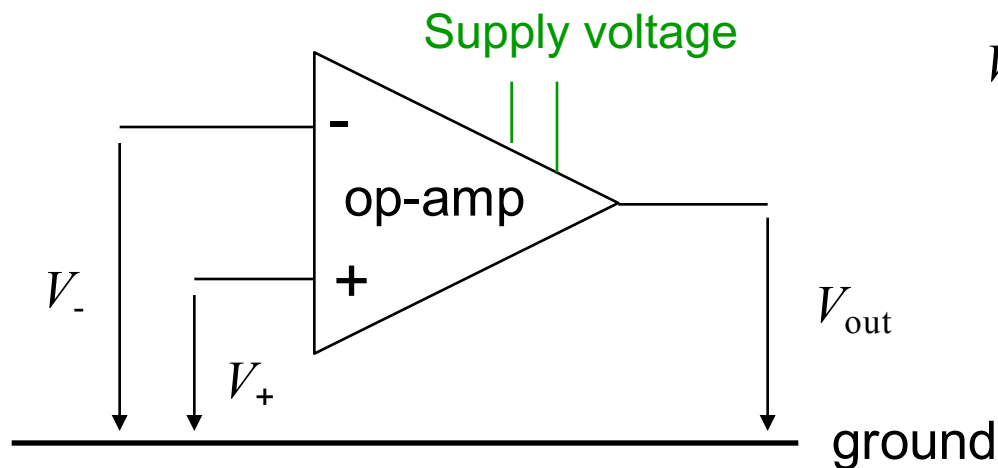
$$V_1 - V_2 - V_3 + V_4 = 0$$

$V_3 = R_3 \times I_3$ if current counted in the same direction as V_3

$V_3 = -R_3 \times I_3$ if current counted in the opposite direction as V_3

Operational Amplifiers (Op-Amps)

Operational amplifiers (op-amps) are devices amplifying the voltage difference between two input terminals by a large gain factor g

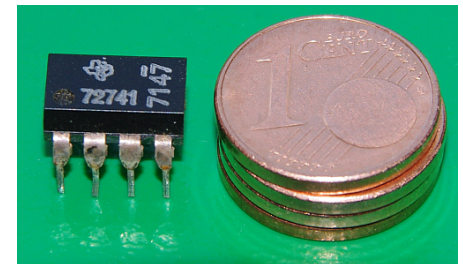


$$V_{out} = (V_+ - V_-) \cdot g$$

For an **ideal** op-amp: $g \rightarrow \infty$

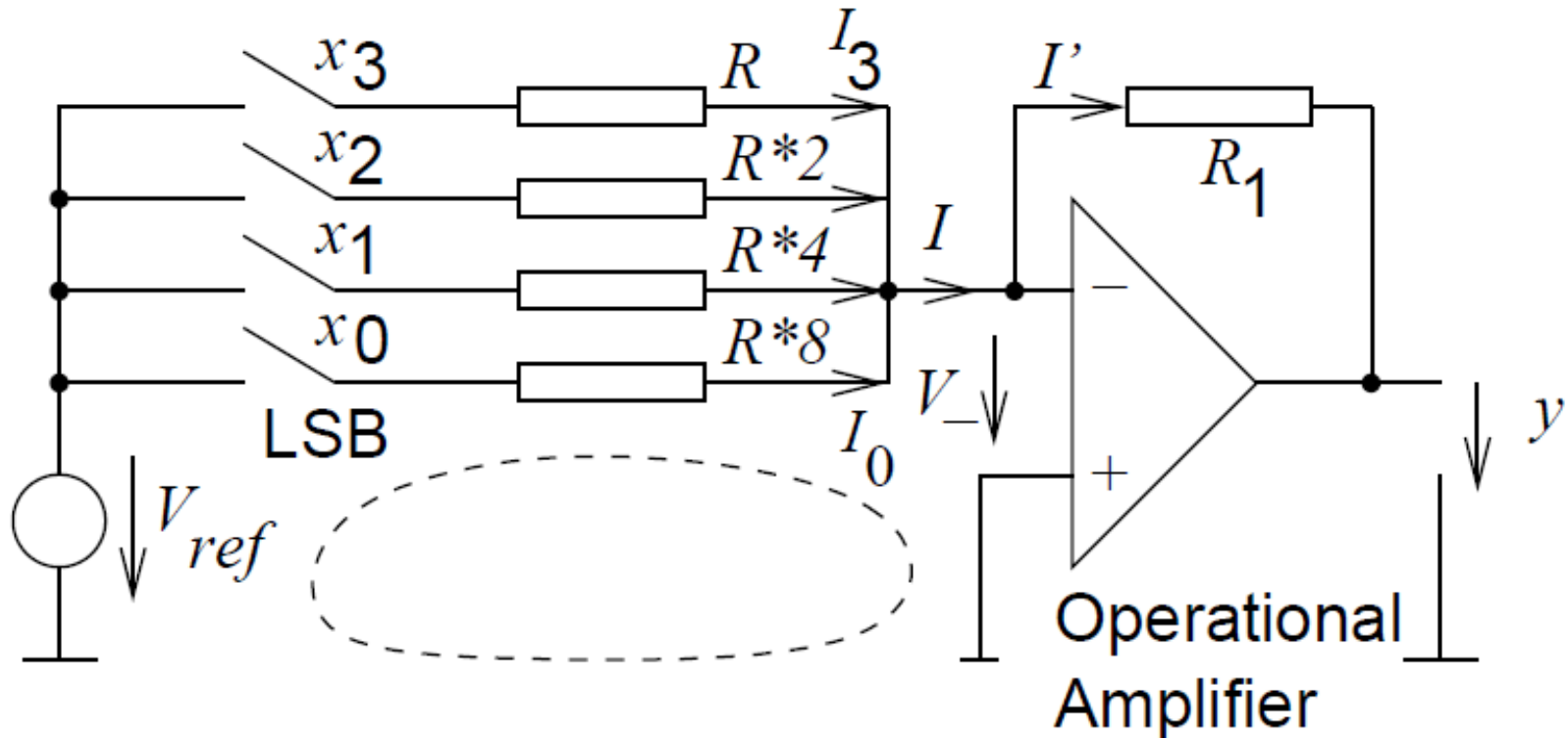
(In practice: g may be around $10^4 \dots 10^6$)

Op-amp in a DIL package



Digital-to-Analog (D/A) Converters

Various types, can be quite simple, e.g.:



$$I = x_3 \times \frac{V_{ref}}{R} + x_2 \times \frac{V_{ref}}{2 \times R} + x_1 \times \frac{V_{ref}}{4 \times R} + x_0 \times \frac{V_{ref}}{8 \times R} = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^3 x_i \times 2^i$$

Current I proportional to the number represented by x

Loop rule:

$$x_0 \cdot I_0 \cdot 8 \cdot R + V_- - V_{ref} = 0$$



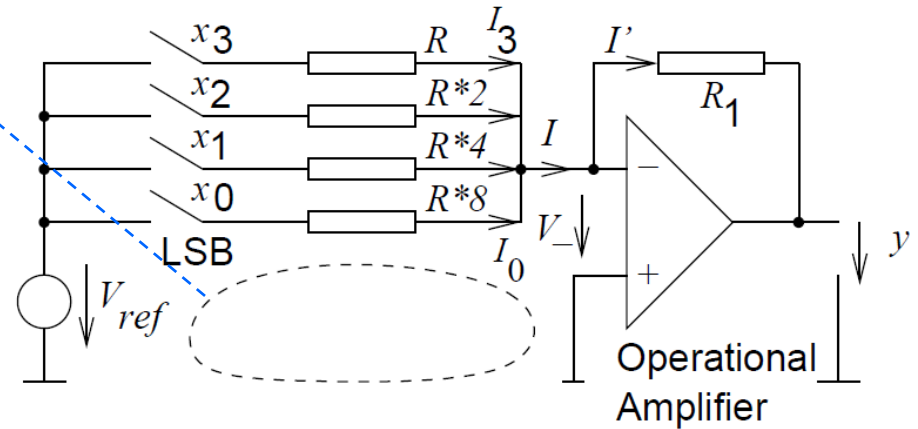
$$I_0 = x_0 \times \frac{V_{ref}}{8 \times R}$$

In general:

$$I_i = x_i \times \frac{V_{ref}}{2^{3-i} \times R}$$

Junction rule:
$$I = \sum_i I_i$$

Hand icon
$$I = x_3 \times \frac{V_{ref}}{R} + x_2 \times \frac{V_{ref}}{2 \times R} + x_1 \times \frac{V_{ref}}{4 \times R} + x_0 \times \frac{V_{ref}}{8 \times R} = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^3 x_i \times 2^i$$



$I \sim nat(x)$, where $nat(x)$: natural number represented by x ;

Output voltage proportional to the number represented by x

Loop rule*: $y + R_1 \times I' = 0$

Junction rule[◡]: $I = I'$

☞ $y + R_1 \times I = 0$

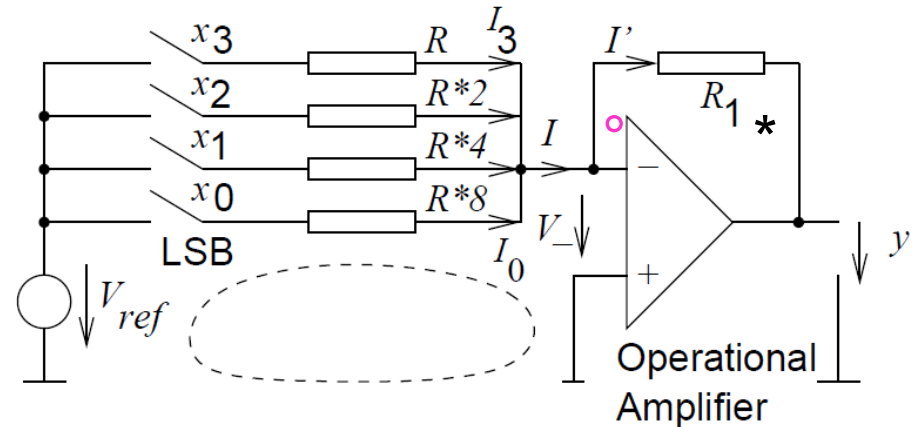
From the previous slide

$$I = \frac{V_{ref}}{8 \times R} \times \sum_{i=0}^3 x_i \times 2^i$$

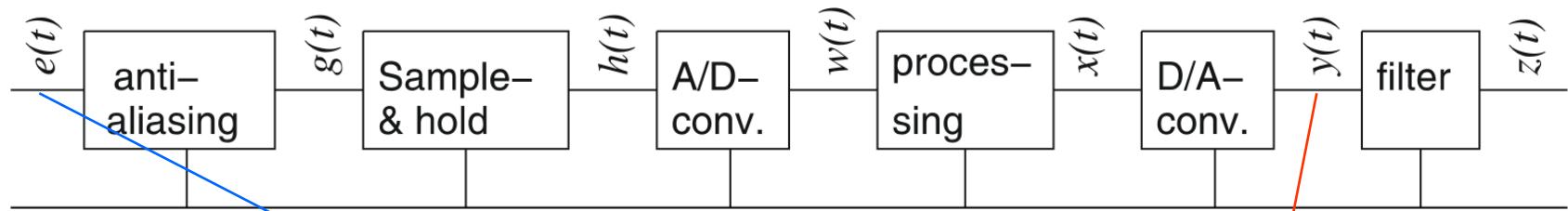
Hence:

$$y = -V_{ref} \times \frac{R_1}{8 \times R} \sum_{i=0}^3 x_i \times 2^i = -V_{ref} \times \frac{R_1}{8 \times R} \times nat(x)$$

Op-amp turns current $I \sim nat(x)$ into a voltage $\sim nat(x)$

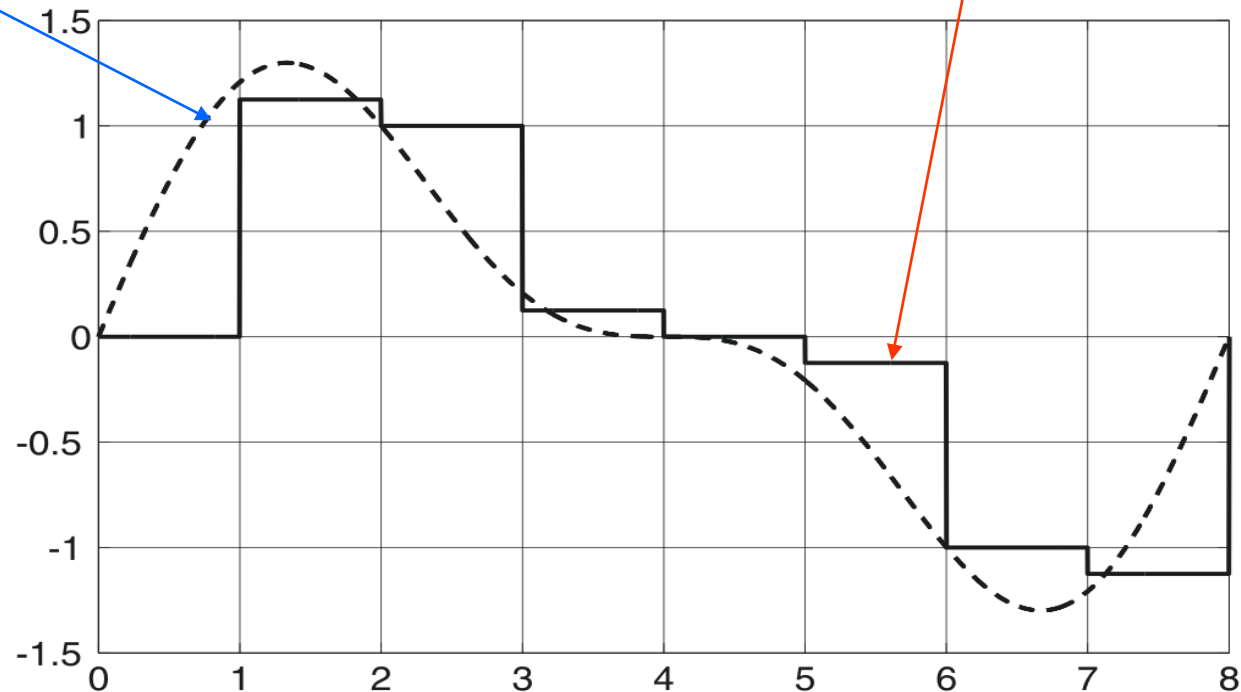


Output generated from signal $e_3(t)$



* Assuming
“zero-order
hold”

Possible to
reconstruct
input
signal?



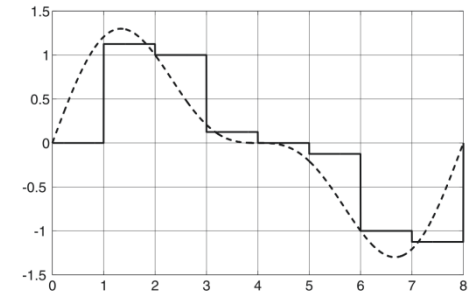
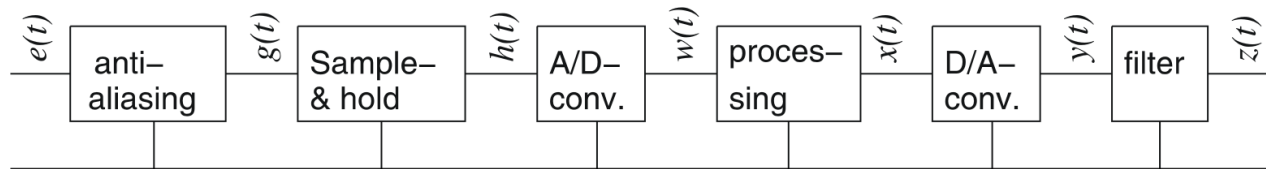
Sampling Theorem



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Possible to reconstruct input signal?



- Assuming Nyquist criterion met
- Let $\{t_s\}, s = \dots, -1, 0, 1, 2, \dots$ be times at which we sample $g(t)$
- Assume a constant sampling rate of $1/p_s$ ($\forall s: p_s = t_{s+1} - t_s$).
- According sampling theory, we can approximate the input signal as follows:

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) \sin \frac{\pi}{p_s} (t - t_s)}{\frac{\pi}{p_s} (t - t_s)}$$

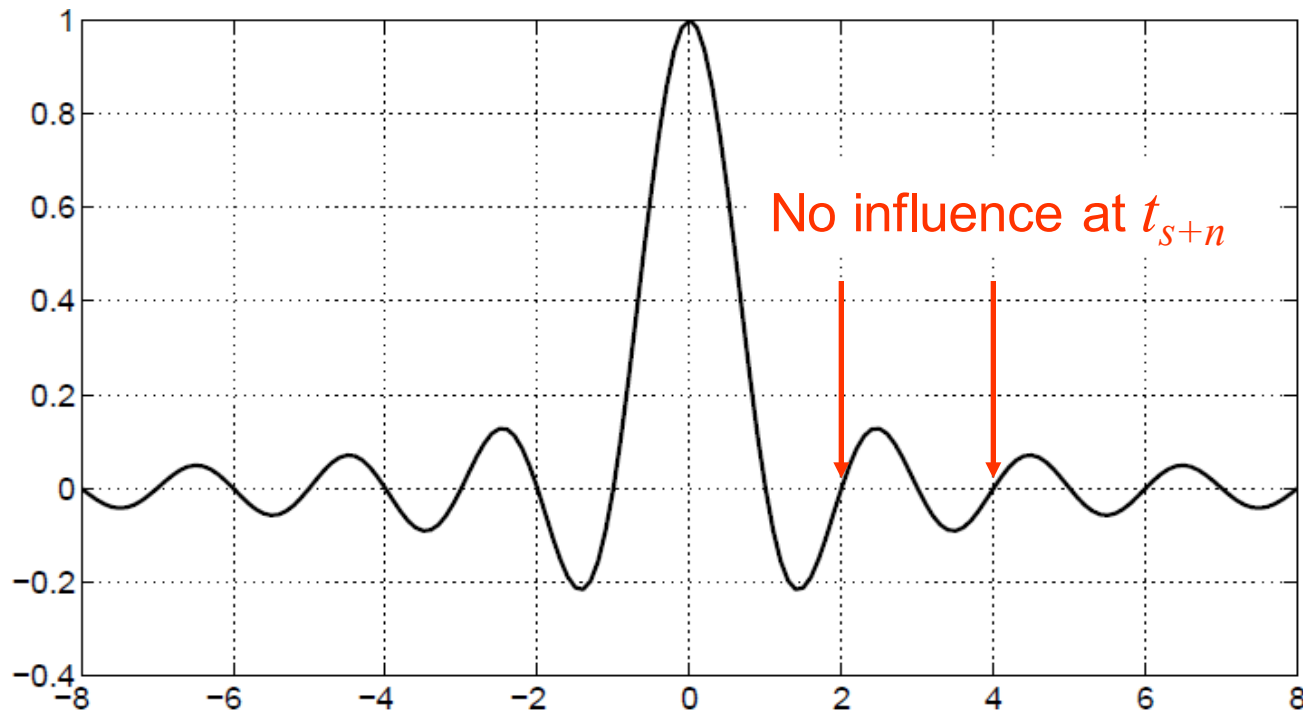
Weighting factor for influence of $y(t_s)$ at time t

Called sinc function

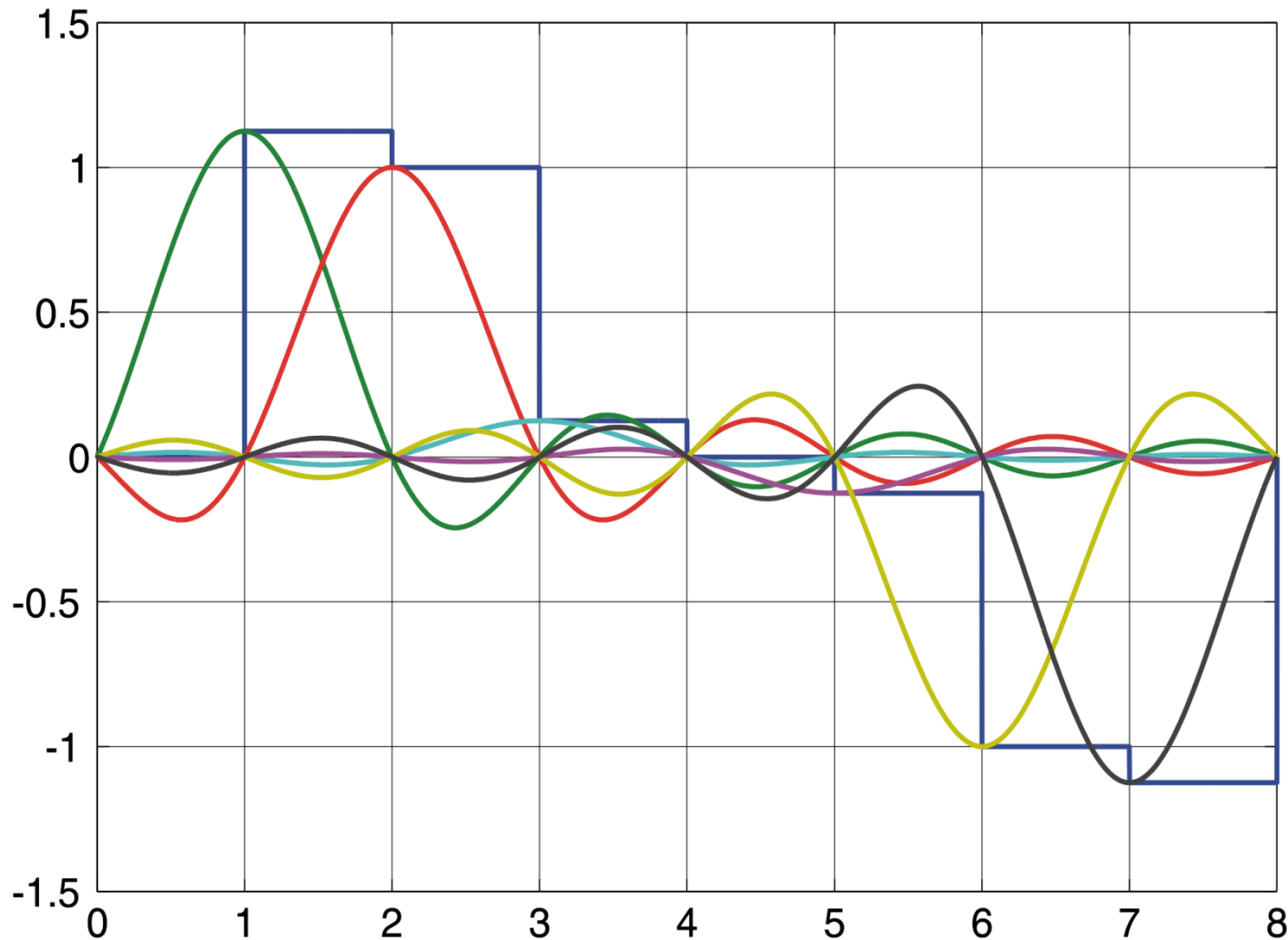
[Oppenheim, Schafer, 2009]

Weighting factor for influence of $y(t_s)$ at time t

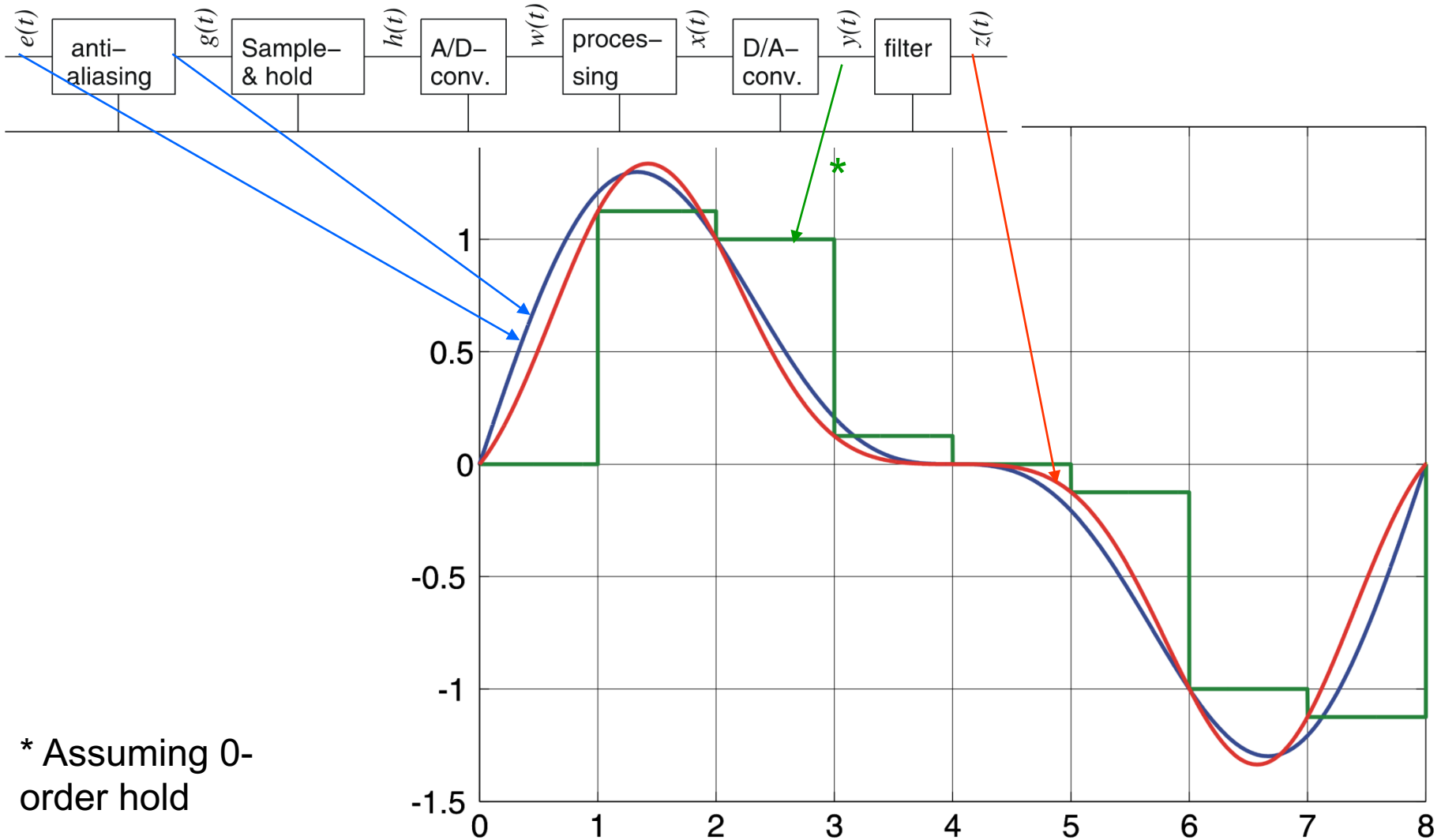
$$\text{sinc}(t - t_s) = \frac{\sin\left(\frac{\pi}{p_s}(t - t_s)\right)}{\frac{\pi}{p_s}(t - t_s)}$$



Contributions from the various sampling instances



(Attempted) reconstruction of input signal



* Assuming 0-order hold

How precisely are we reconstructing the input?

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) \sin \frac{\pi}{T_s} (t - t_s)}{\frac{\pi}{T_s} (t - t_s)}$$

- **Sampling theory:**

- **Reconstruction using *sinc* () is precise**

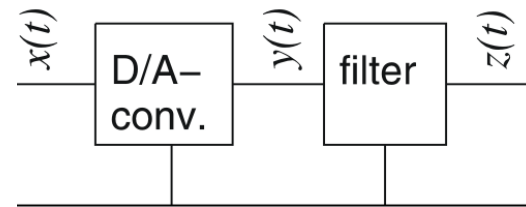
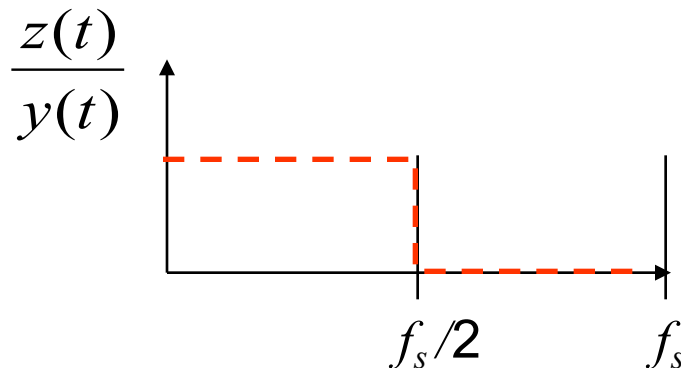
- However, it may be impossible to really compute $z(t)$ as indicated



How to compute the *sinc*() function?

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) \sin \frac{\pi}{T_s} (t - t_s)}{\frac{\pi}{T_s} (t - t_s)}$$

- **Filter theory:** The required interpolation is performed by an ideal low-pass filter (*sinc* is the Fourier transform of the low-pass filter transfer function)



Filter removes high frequencies present in $y(t)$

Limitations

$$z(t) = \sum_{s=-\infty}^{\infty} \frac{y(t_s) \sin \frac{\pi}{T_s} (t - t_s)}{\frac{\pi}{T_s} (t - t_s)}$$

- Actual filters do not compute $\text{sinc}()$
In practice, filters are used as an approximation.
Computing good filters is an art itself!
- All samples must be known to reconstruct $e(t)$ or $g(t)$.
☞ Waiting indefinitely before we can generate output!
In practice, only a finite set of samples is available.
- Actual signals are never perfectly bandwidth limited.
- Quantization noise cannot be removed.

Actuators/Display

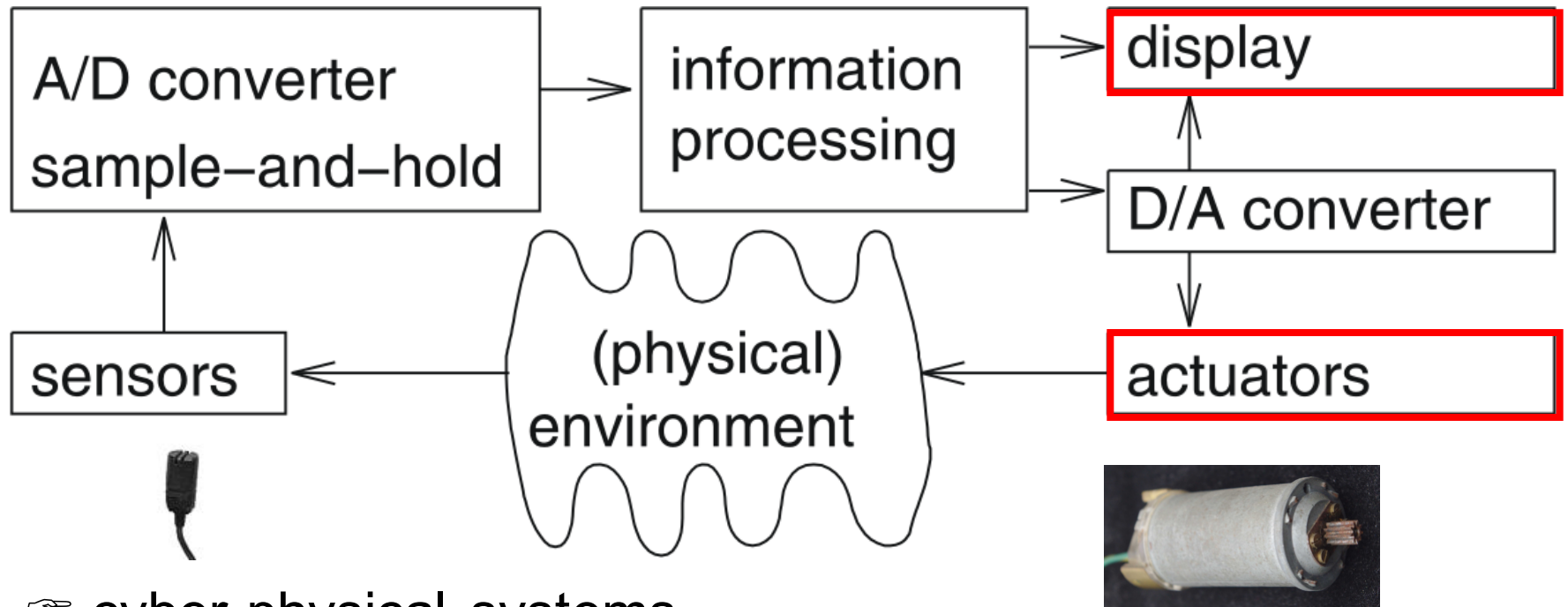


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👉 cyber-physical systems

Output

Output devices of embedded systems include

- **Displays:** Display technology is extremely important. Major research and development efforts
- **Electro-mechanical devices:** these influence the environment through motors and other electro-mechanical equipment. Frequently require analog output.



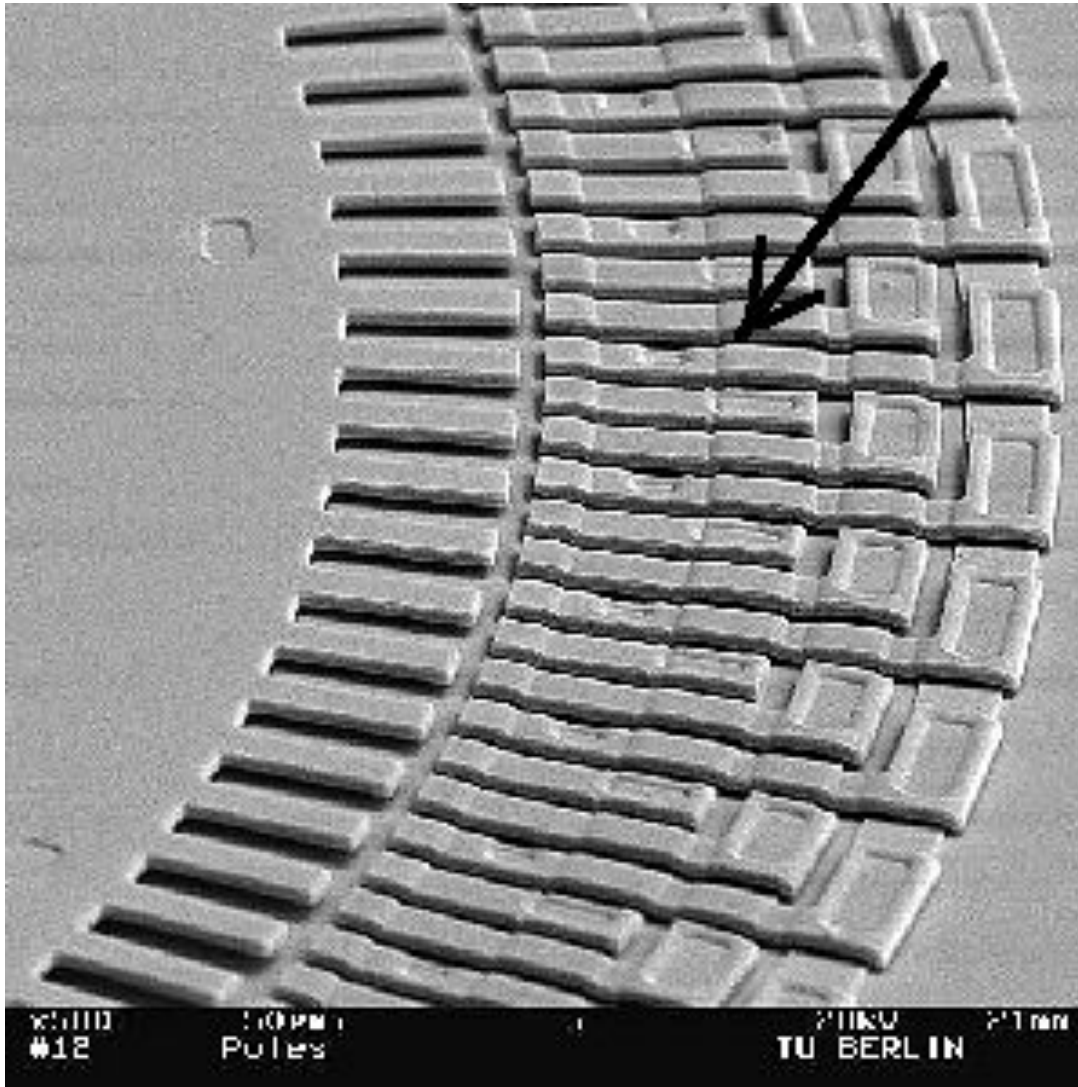
Actuators

Huge variety of actuators and output devices,
impossible to present all of them.

Motor as an example



Actuators (2)



Courtesy and ©: E. Obermeier,
MAT, TU Berlin

<http://www.piezomotor.se/pages/PWtechnology.html>

http://www.elliptec.com/fileadmin/elliptec/User/Produkte/Elliptec_Motor/Elliptecmotor_How_it_works.h

Secure Hardware



- Security needed for communication & storage
- Demand for special equipment for cryptographic keys
- To resist side-channel attacks like
 - measurements of the supply current or
 - Electromagnetic radiation.

Special mechanisms for physical protection (shielding, sensor detecting tampering with the modules).

- Logical security, using cryptographic methods needed.
- Smart cards: special case of secure hardware
 - Have to run with a very small amount of energy.
- In general, we have to distinguish between different levels of security and knowledge of “adversaries”

Summary

Hardware in a loop

- Sensors
- Discretization
- Information processing
 - Importance of energy efficiency, Special purpose HW very expensive, Energy efficiency of processors, Code size efficiency, Run-time efficiency
 - Reconfigurable Hardware
- Communication
- D/A converters
- Sampling theorem
- Actuators (briefly)
- Secure hardware (briefly)