Institut für Technik der Informationsverarbeitung

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Communication Systems and Protocols

Session 3: Physical Principles

Clicker Session: Recapitulation

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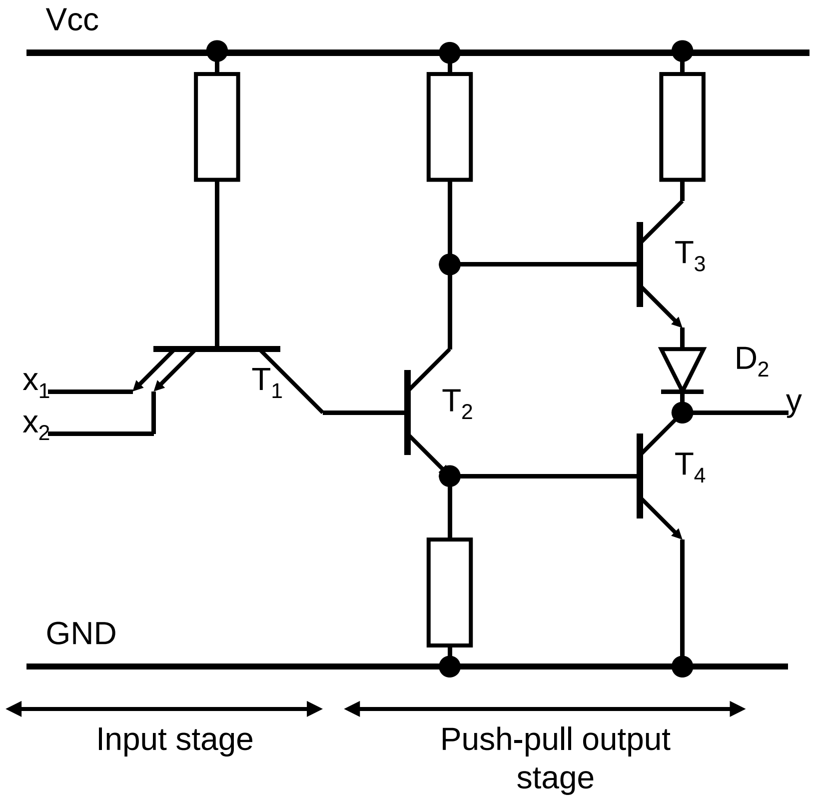
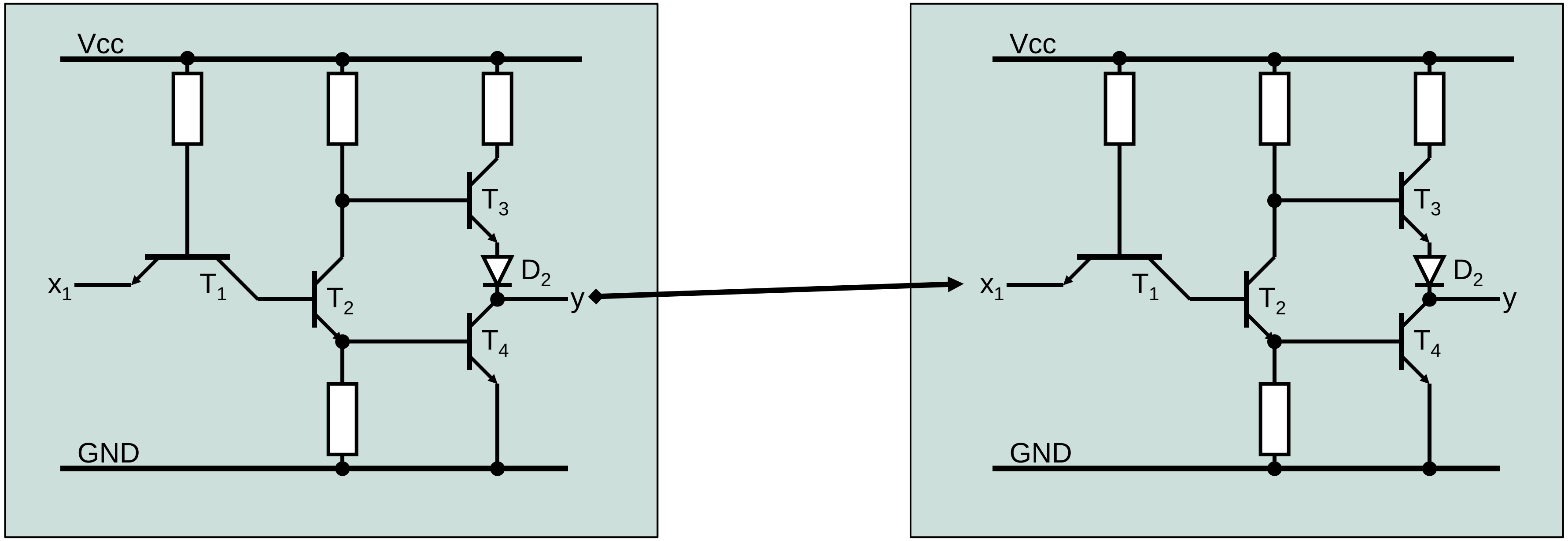
Recapitulation: TTL-Driver



TTL basic gate (i.e. SN 7400)

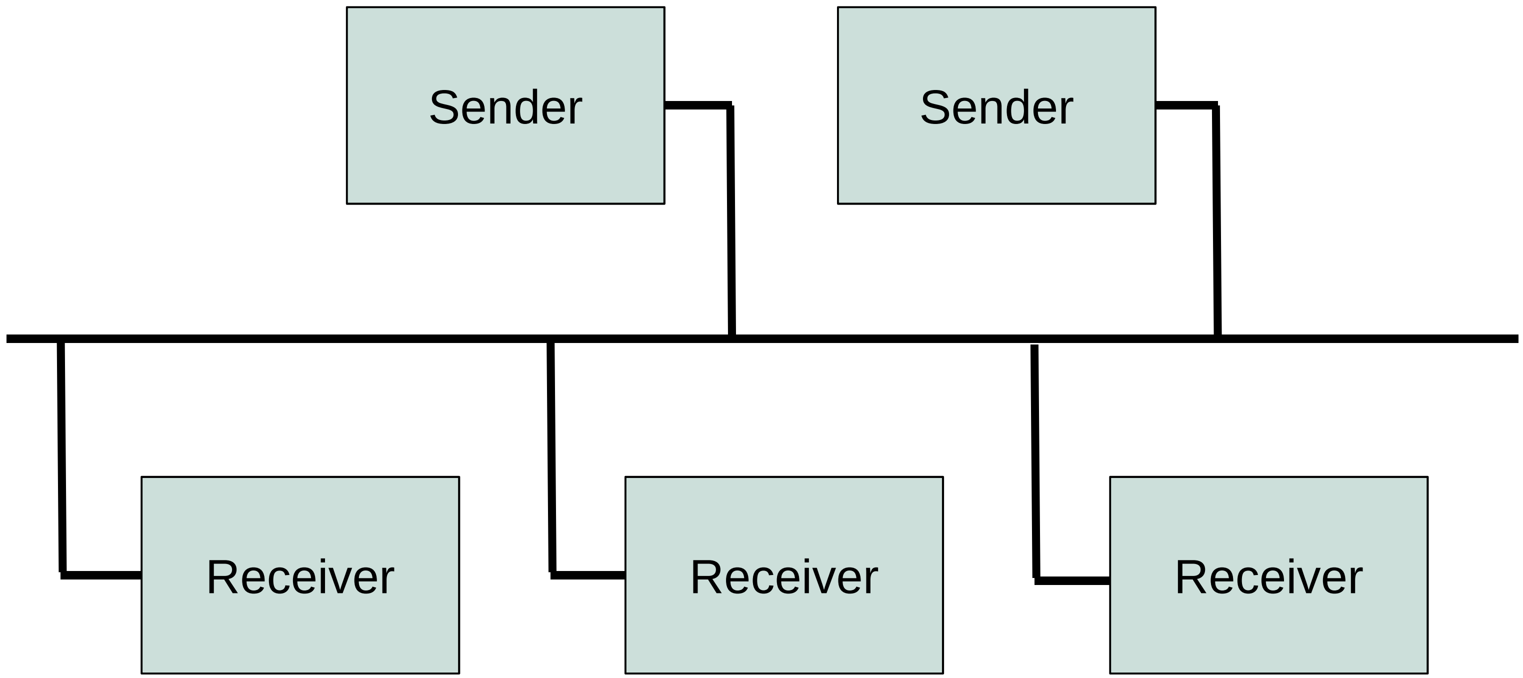
Transmission Setup with TTL Technology



Sender **Receiver**

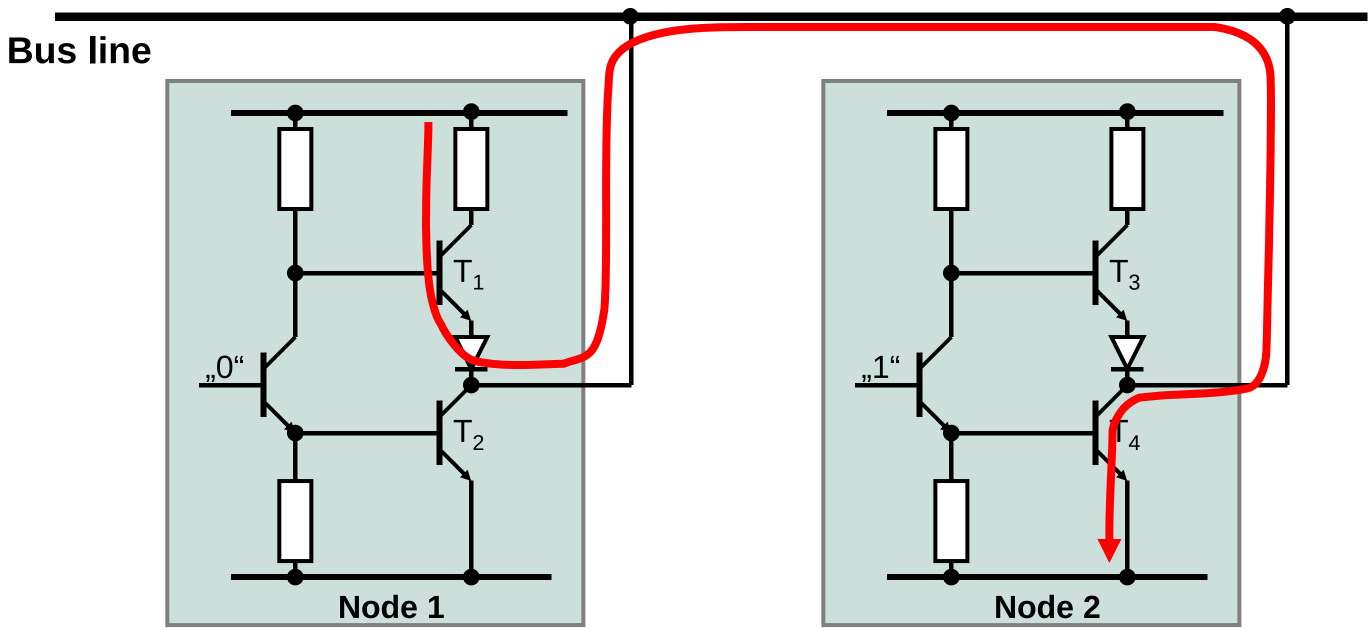
Idea of a Bus System

- Multiple Senders and receivers are connected together to the same channel for communication



Connection of multiple TTL drivers

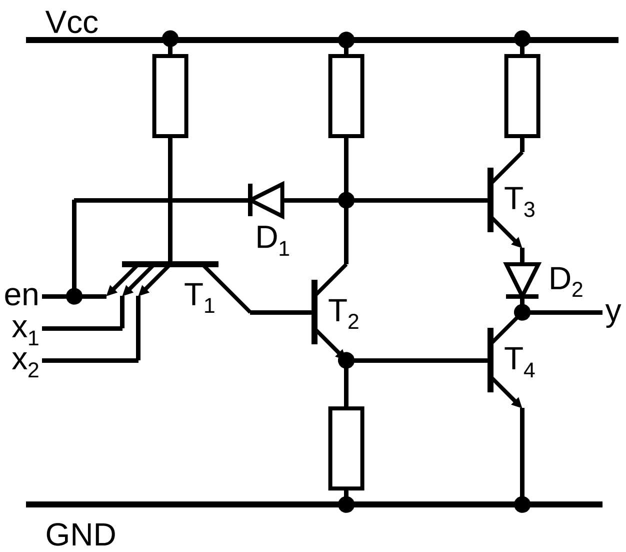
- Danger for short-circuit if the outputs of several TTL gates are connected to each other
  - If one gate is on HIGH level and another on LOW level a short-circuit current can flow via the open transistors (T1 and T4 in the figure)
- Modification of the bus coupling circuit is necessary when using driver on bus lines!



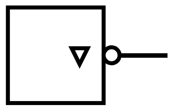
Solution 1: Tristate driver

- Parallel switching of several outputs is not possible with simple TTL gates --> danger of short-circuit
- By turning off unused output stages, several of such circuits can be connected to one bus
- Third state (Tristate): high-resistance (Z)
- In each case only one output is allowed to drive the bus, all others must show high-resistance

Example: NAND gate



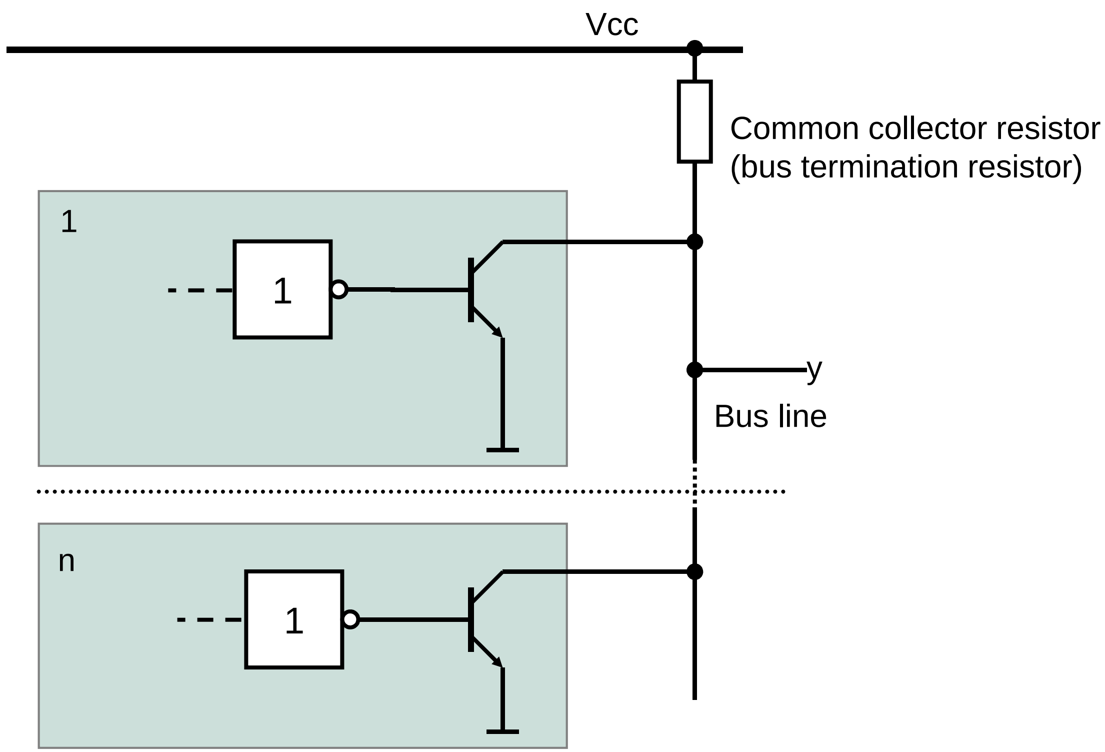
en	x_1	x_2	y
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0
0	-	-	Z

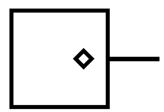


Switch symbol of a Tristate output

Solution 2: Open collector bus

- The collector of each of the output transistors remains unconnected
- All bus members share one collector resistor
- The output is only HIGH if all transistors cut off
  - low value (GND) on the bus line is dominant value

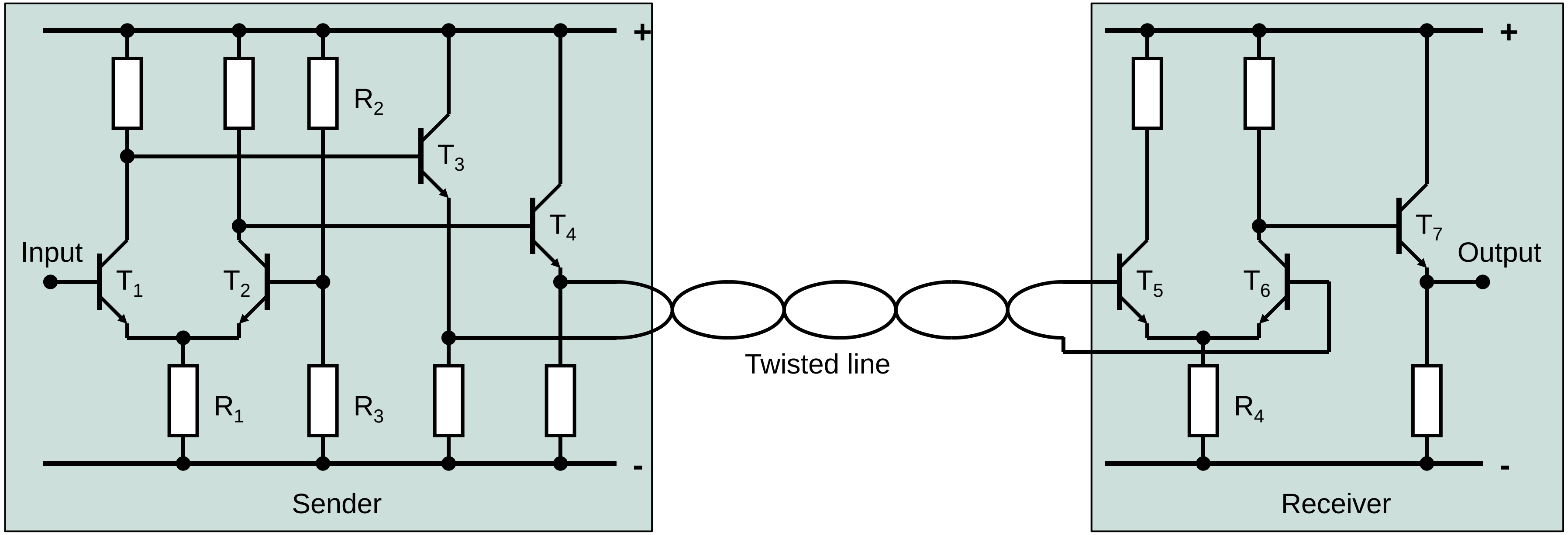




Switch symbol of a
open collector output

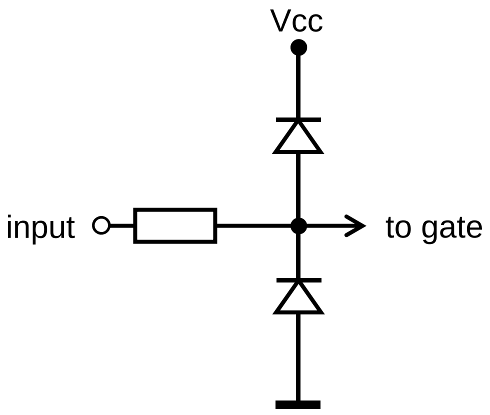
Example for differential signal generation

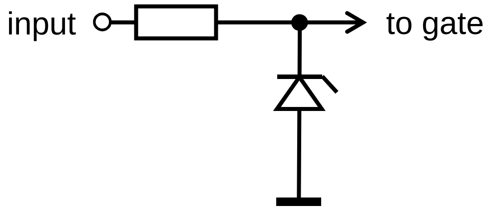
- Emitter Coupled Logic (ECL)
  - Higher speed since transistors do not go to saturation
  - With the help of the asymmetric input signal a differential signal for transmission is generated
  - The differential amplifier inside the receiver reconstructs the input signal



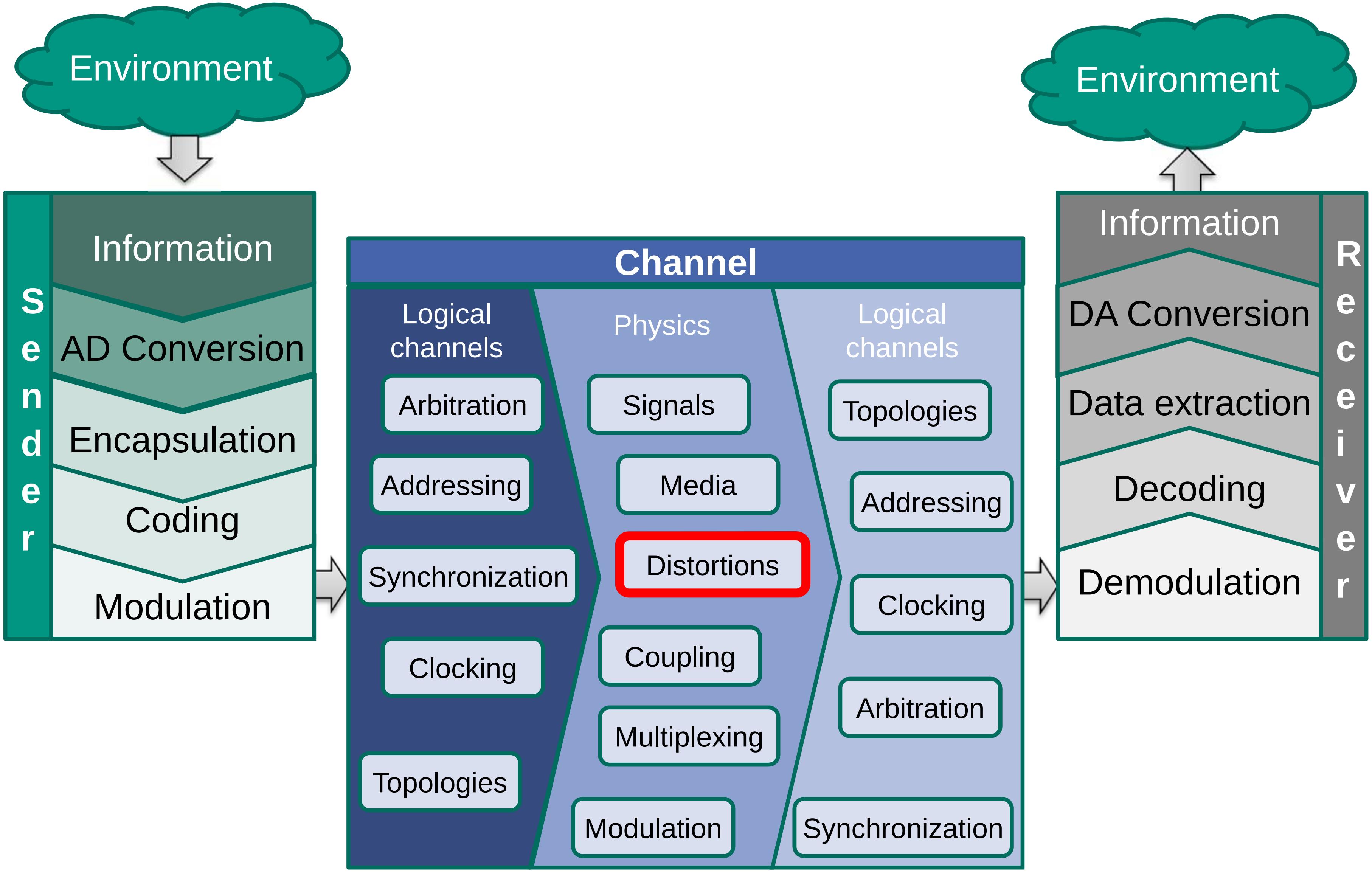
Input protection

- High voltages at the input could damage the circuit
  - Limitation to -0,7V …Vcc +0,7V using two diodes
  - Alternate solution using Z-Diode
  - Current through diode is limited with additional resistor





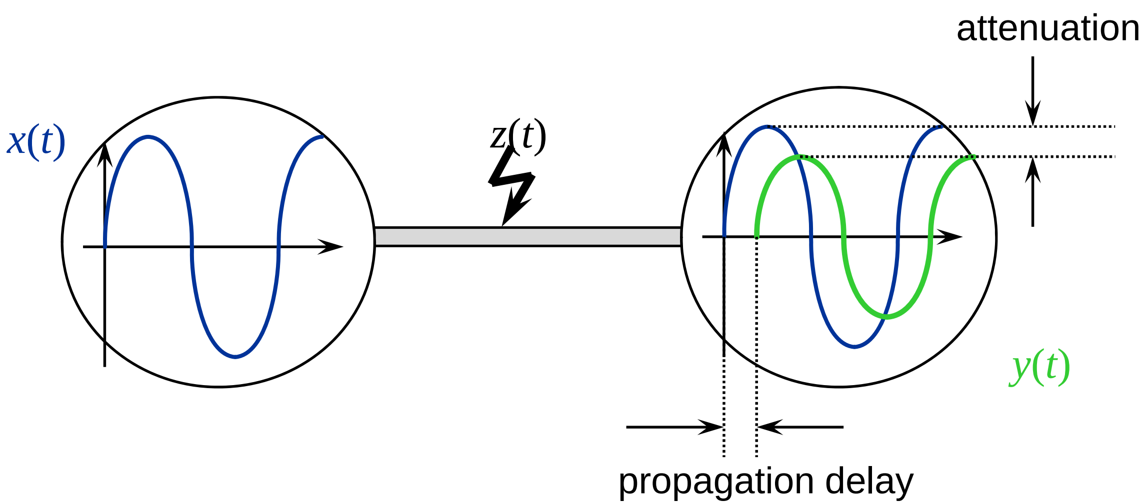
Transmission System – Effects on electrical Signal Lines



Signal Transmission over a Medium

- with
  - $x(t)$: Input signal
  - $y(t)$: Output signal
  - $z(t)$: Interference

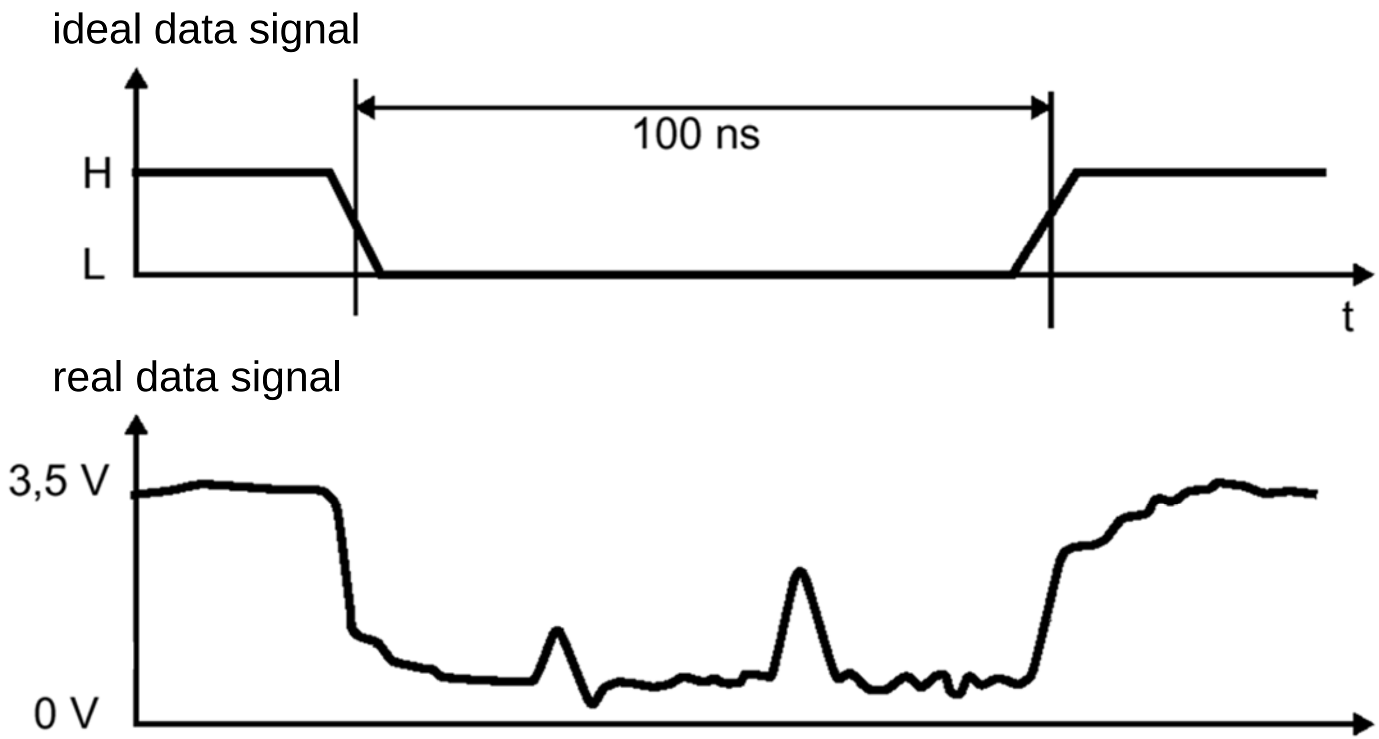
$$y(t) = F(x(t), z(t))$$



- Interferences can be caused by external sources as well as by media itself

Possible signal distortions

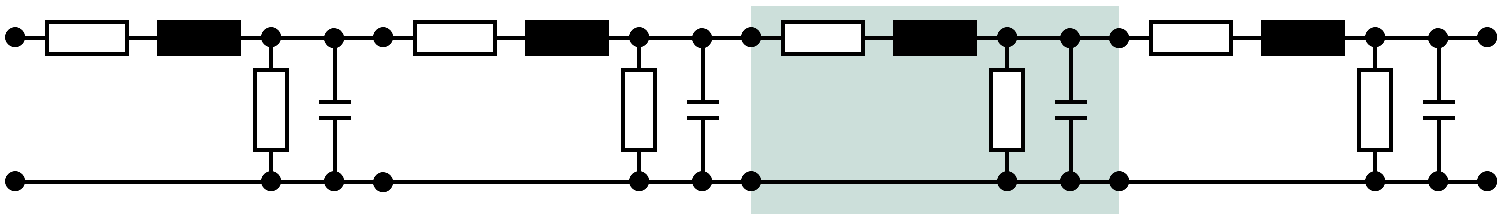
- Reflections
- Attenuation
- Glitches
- Interference
- Noise
- Cross Talk



Model of Signal Lines

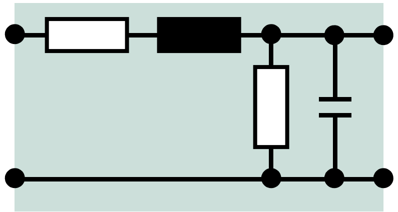
- Problem: When taking wave effects into account, signal lines can not be described by single elements any more

- Solution: Description using a distributed waveguide model → cascade of RLC quadripole



- Each segment represents an infinitesimally short segment of a transmission line

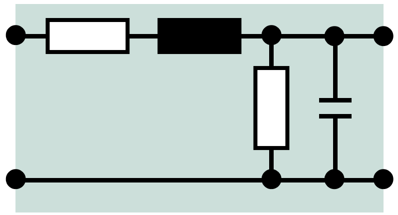
Components of the line model



- Distributed resistance **R'**, caused by resistance of the conductors is represented by a series resistor
- Distributed inductance **L'**, caused by the magnetic field around the wires is represented by a series inductor
- Distributed capacitance **C'** between the conductors is represented by a shunt capacitor
- Distributed conductance **G'**, caused by the dielectricum between the conductors is represented by a shunt resistor between the conductors

Idea: Derivation of the telegrapher‘s equation

- Boundary conditions: long, straight signal line, propagation in x-direction



- Using the laws of Kirchhoff, one can describe this system using the following equations:

$$\frac{\partial U(x,t)}{\partial x} = -L'(x)\frac{\partial I(x,t)}{\partial t} - R'(x)I(x,t)$$

$$\frac{\partial I(x,t)}{\partial x} = -G'(x)U(x,t) - C'(x)\frac{\partial U(x,t)}{\partial t}$$

Solution of the telegrapher‘s equation

- Under the assumption of constant distributed elements one can find:

$$U(x,t) = u_1 e^{i\omega t - \gamma x} + u_2 e^{i\omega t + \gamma x}$$
$$I(x,t) = i_1 e^{i\omega t - \gamma x} + i_2 e^{i\omega t + \gamma x}$$

with $\gamma = \sqrt{(R' + i\omega L')(G' + i\omega C')}$

- In the lossless case (R’=0, G’=0) the equations can be simplified:

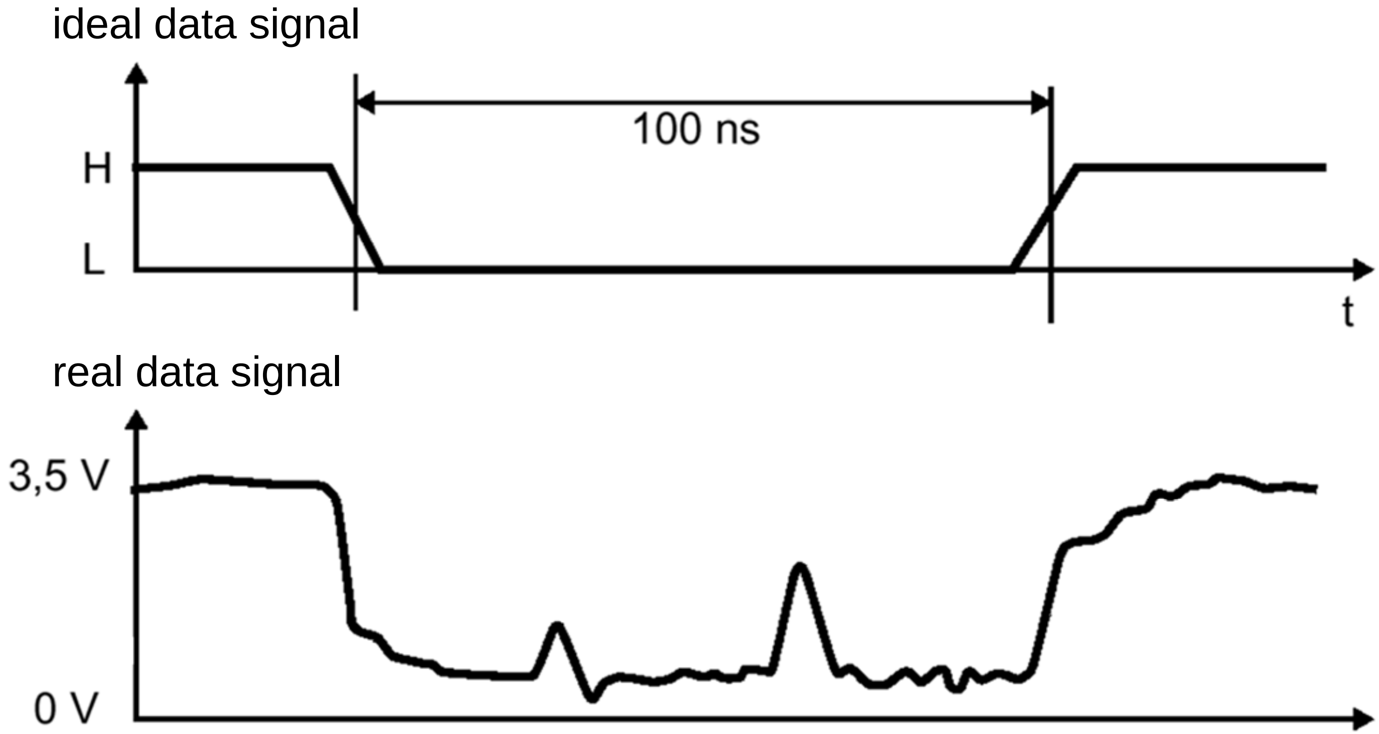
$$U(x,t) = u_1 e^{i\omega t - \gamma x} + u_2 e^{i\omega t + \gamma x}$$
$$I(x,t) = \frac{u_1}{Z_0} e^{i\omega t - \gamma x} - \frac{u_2}{Z_0} e^{i\omega t + \gamma x}$$

with $Z_0 = \sqrt{\frac{L'}{C'}}$, that is called **characteristic impedance**

→More details see lecture “Grundlagen der Hochfrequenztechnik”

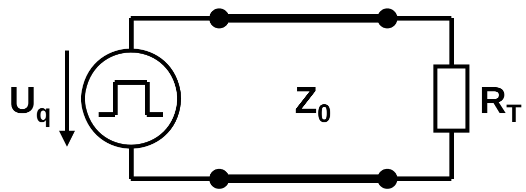
Possible signal distortions

- **Reflections**
- Attenuation
- Glitches
- Interference
- Noise
- Cross Talk



Reflection at the wire end

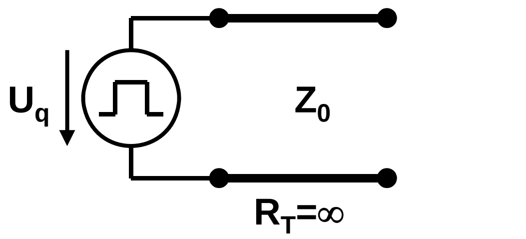
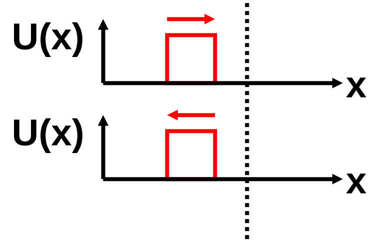
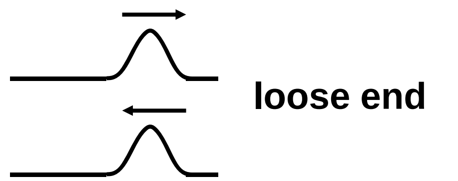
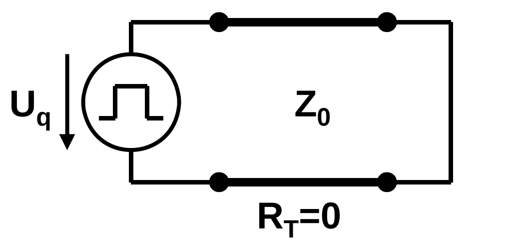
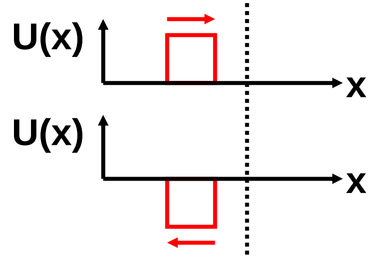
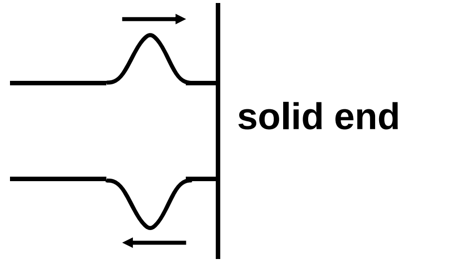
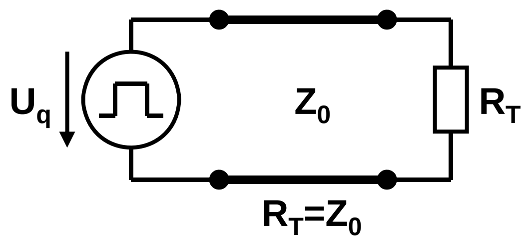
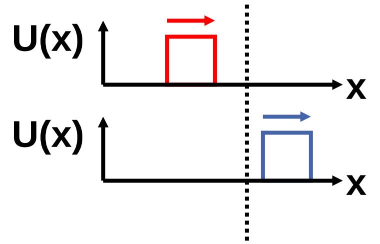
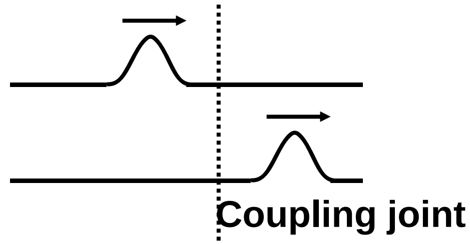
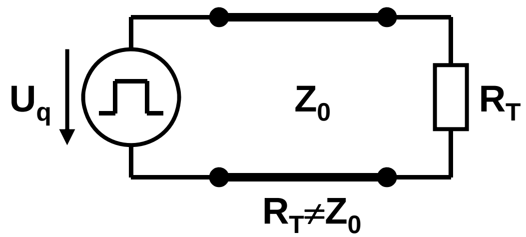
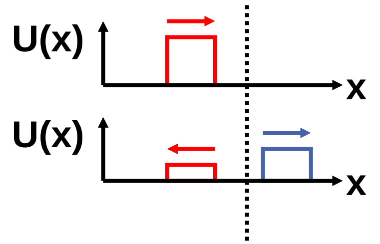
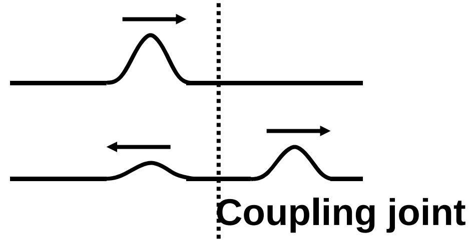
- Signals spread wavelike within long lines/wires
- There exists a forward and eventually a backward running wave that interfere on the wire
- The amplitude of the backward running wave depends on
  - The impedance of the line
  - The terminating impedance at the end of the line



- Definition of the reflection factor: $r = \frac{R_T - Z_0}{R_T + Z_0}$

R_T: Terminal Resitance
Z_0: Characteristic impedance

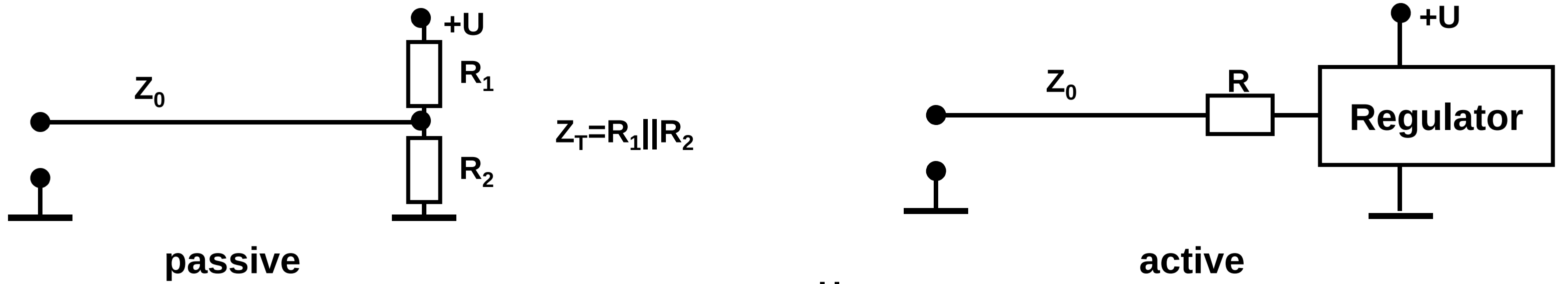
Reflection on wires

Line	Reflection factor r	Voltage curve	mechanical analogue
	r=1		
	r=-1		
	r=0		
	-1<r<1		

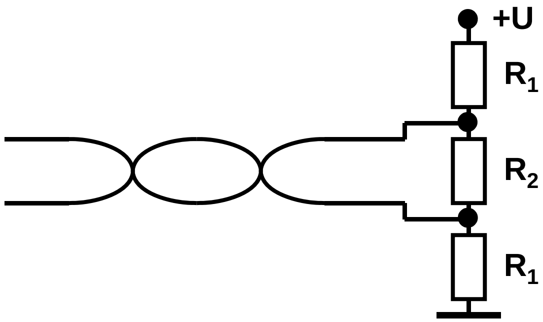
Line terminations

- Termination by using the characteristic wave resistance Z_0 to avoid reflections
- The utilization of several resistors switched in parallel is advantageous since usage of resistors of a relatively high value which provide for a lower DC charge allow for a approximation to the relatively low resistance of the line

- Asymmetric line

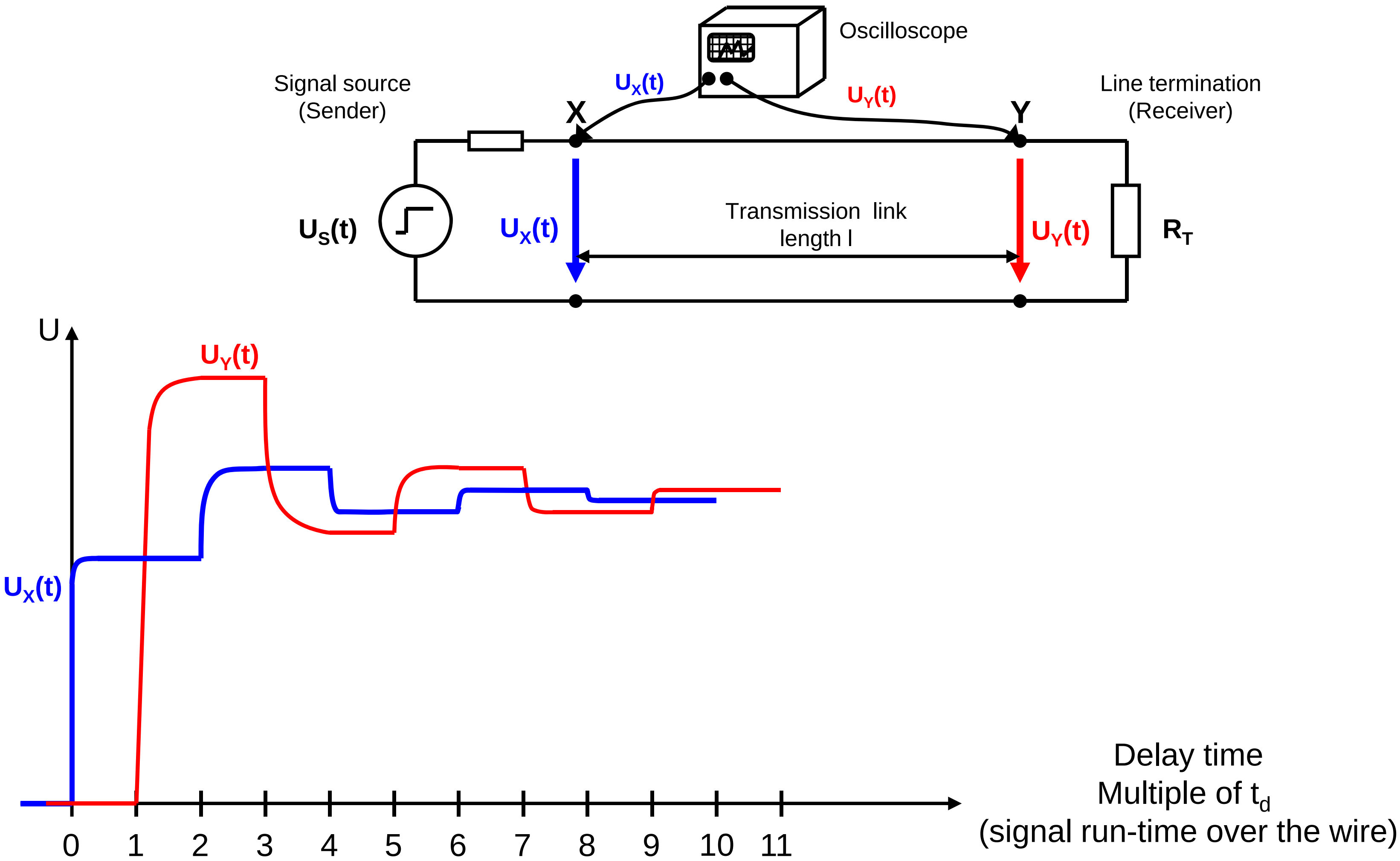


- Symmetric line



Outlook to exercises: Reflection on wires

- Measurement setup for the determination of the reflection on the lines:



Clicker Session: Reflection on wires

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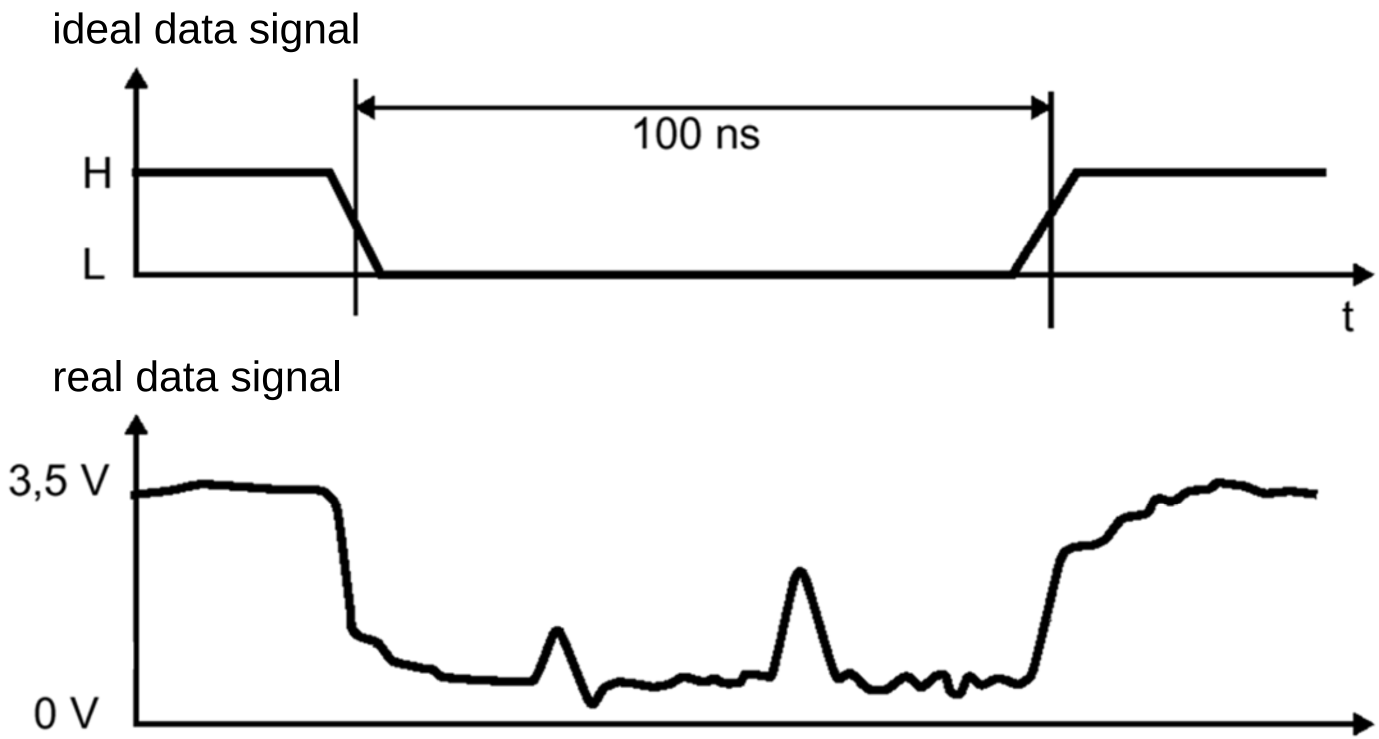
Possible signal distortions

- Reflections
- **Attenuation**
- Glitches
- Interference
- Noise
- Cross Talk



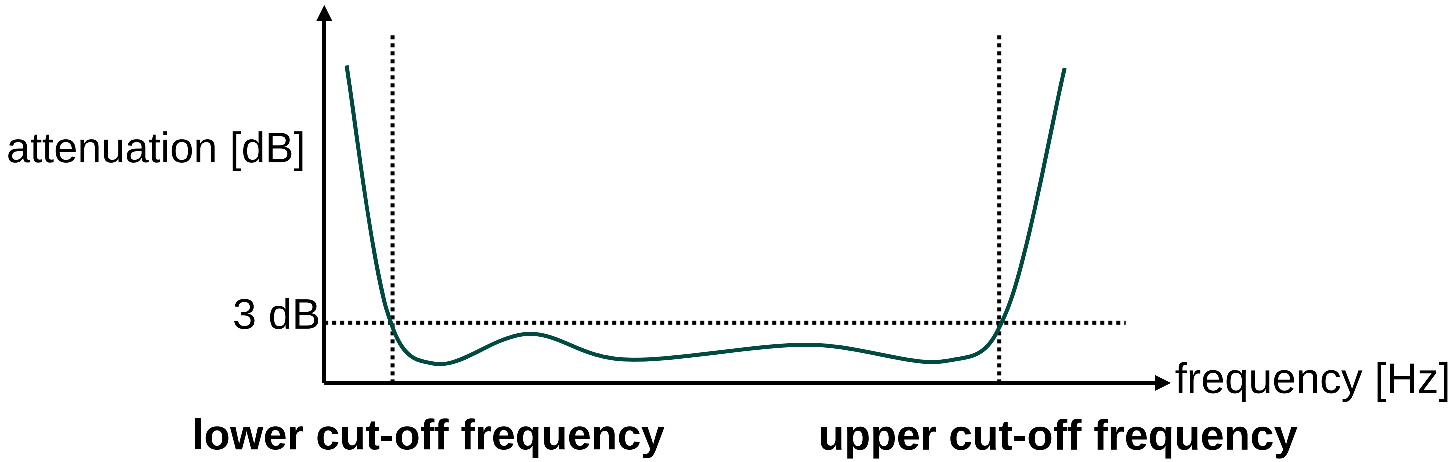
Attenuation (media dependend)

- Attenuation of signals is caused by:
  - Ohmic loss
  - Dielectric loss
  - Radiation loss
  - Reflections

- Attenuation $G = 10\log\left(P_{in}/P_{out}\right) = 20\log\left(U_{in}/U_{out}\right)\left[\text{dB}\right]$
  - additive properties of single cable sections
  - Depends on length/distance
  - Depends on frequency of transmitted signal

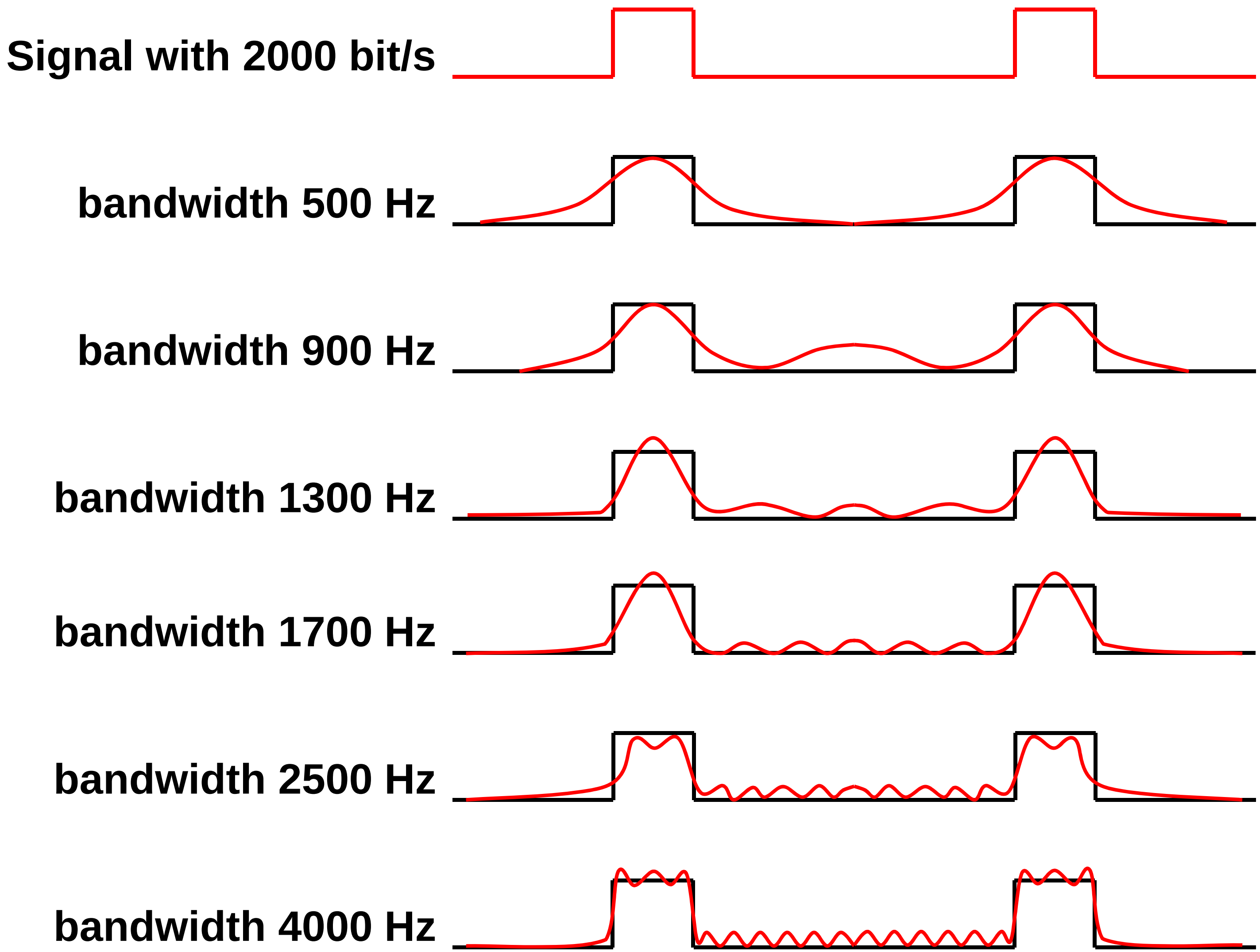
Bandwidth

- Cut Off frequency
  - Frequency at with the signal amplitude has dropped by 3dB compared to the output value
- Interval between upper and lower cut-off frequency
  - Between the frequencies almost uniform attenuation



  - Limits not ideal
    - No vertical signal edges
    - Frequencies are attenuated at different degrees

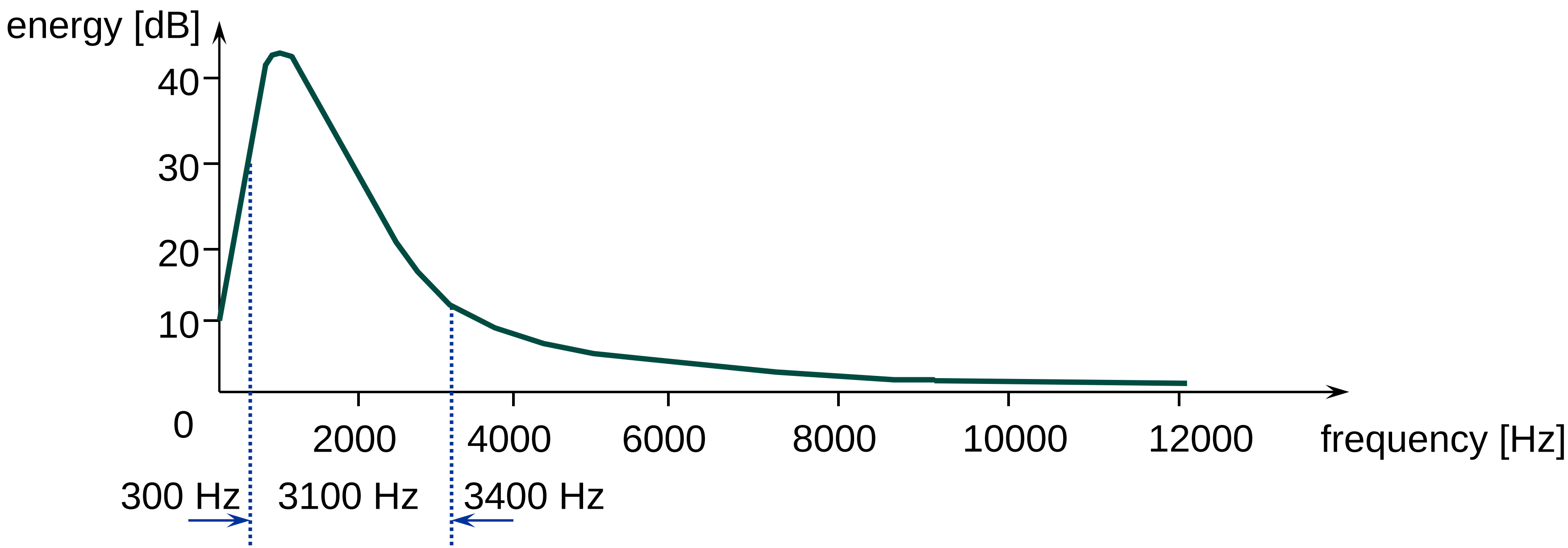
Influence of the Bandwidth on a digital Signal



source: University Ulm

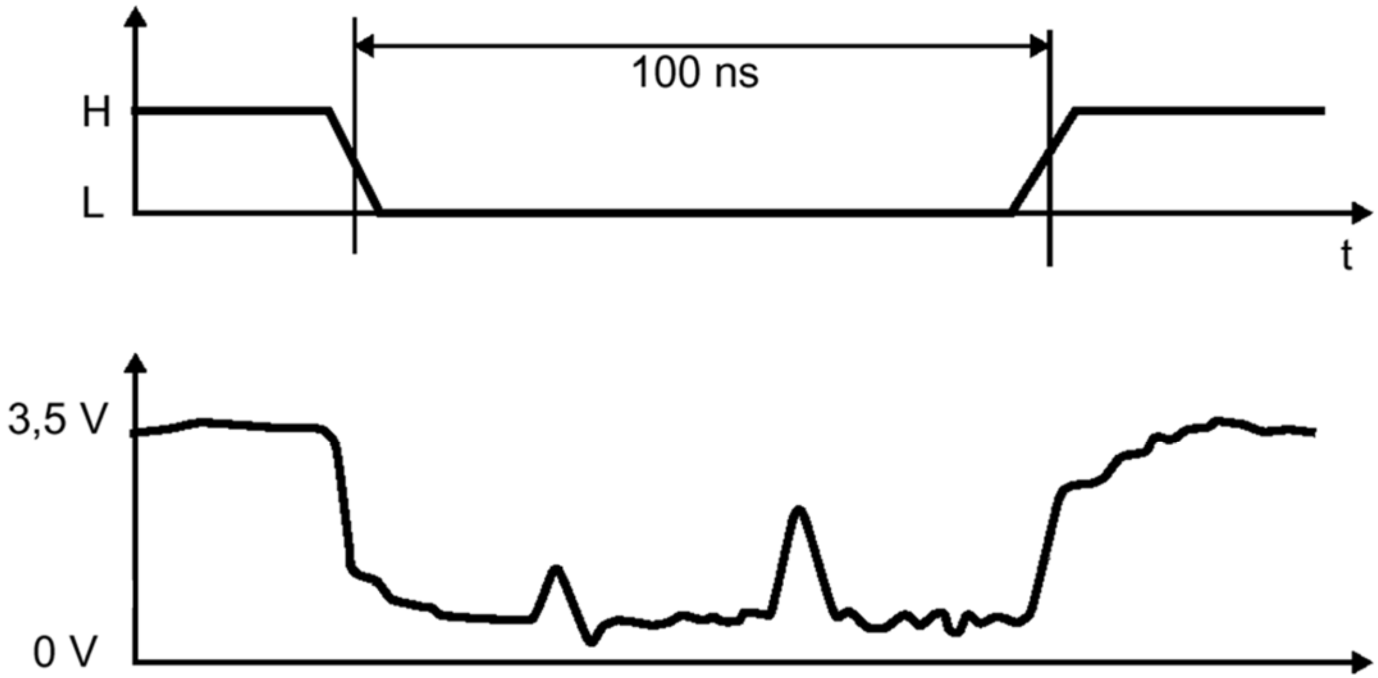
Example: Frequency Spectrum of a Signal

- Band limited signal: signals can comprise a “naturally” limited frequency spectrum or can be limited to a section of a spectrum through technical means (bandwidth)
  - Example: ITU-Standard telephone channel
    Frequency spectrum of the human voice

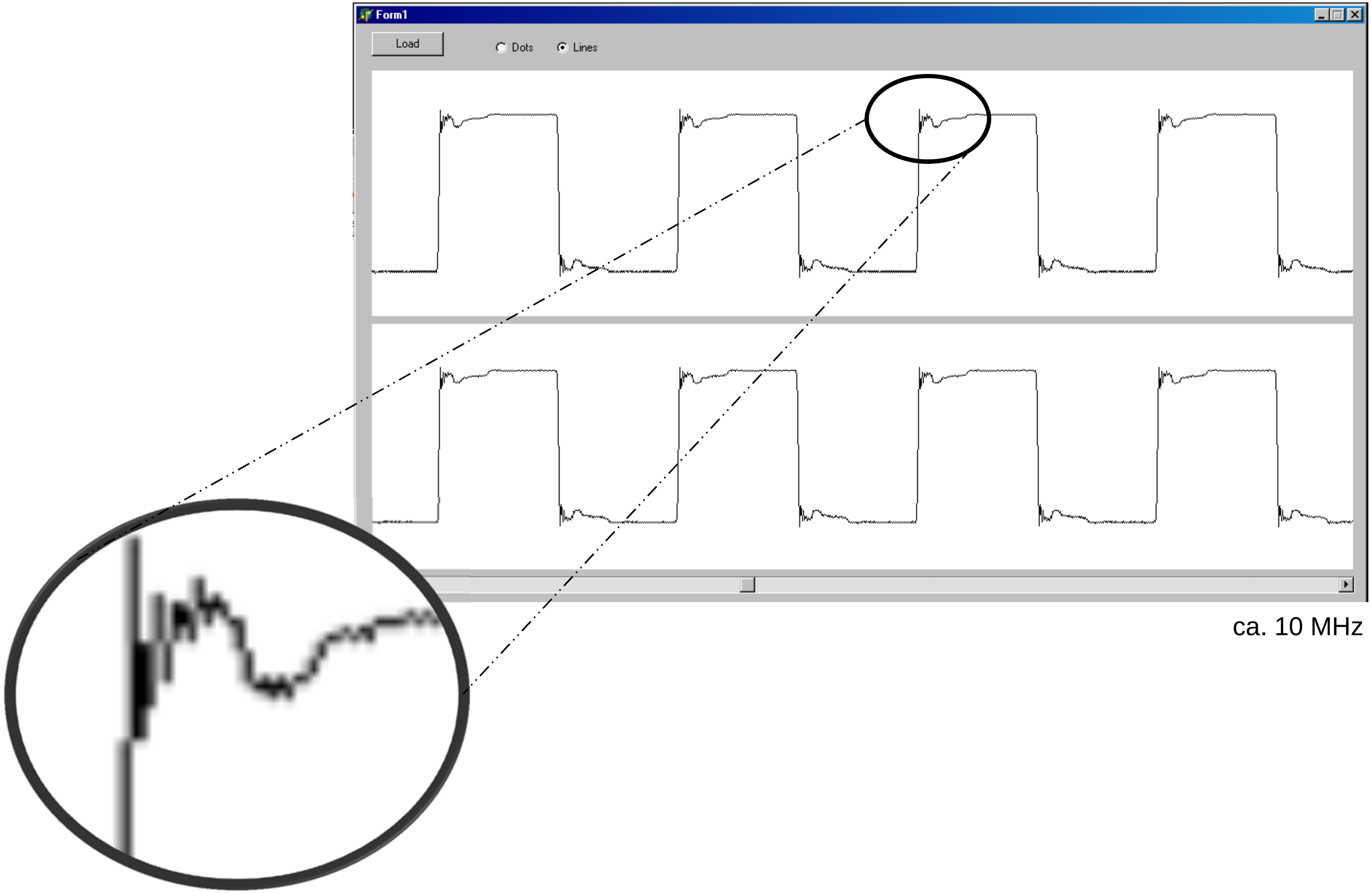


Possible Signal Distortions

- Reflections
- Attenuation
- Glitches
- Interference
- Noise
- Cross Talk



Real Signal

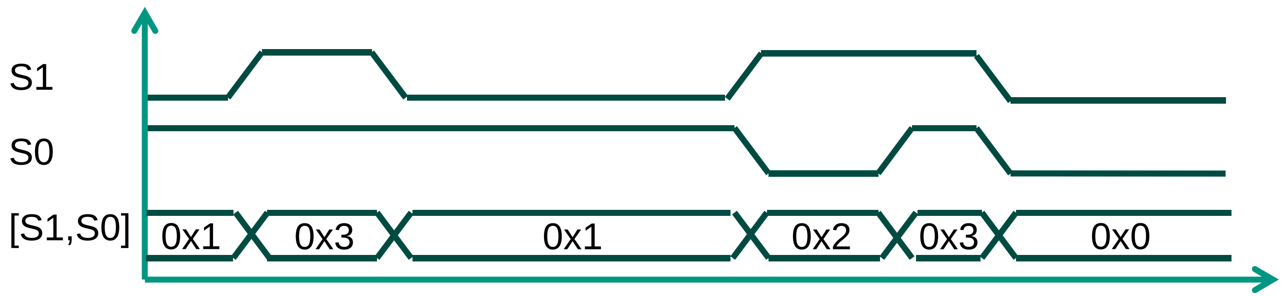


ca. 10 MHz

Excursus: Representation of Signals

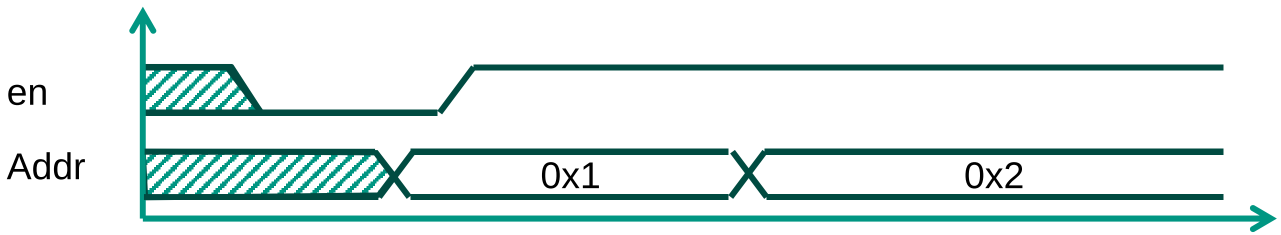
- Ideal vs. realistic edges
  - Raise and fall time is approximated by slanted edges

- Combination of individual lines (busses)
  - Signal is drawn as a ribbon with the combined value as text
  - Every change on one of the signals results in a change of the bus



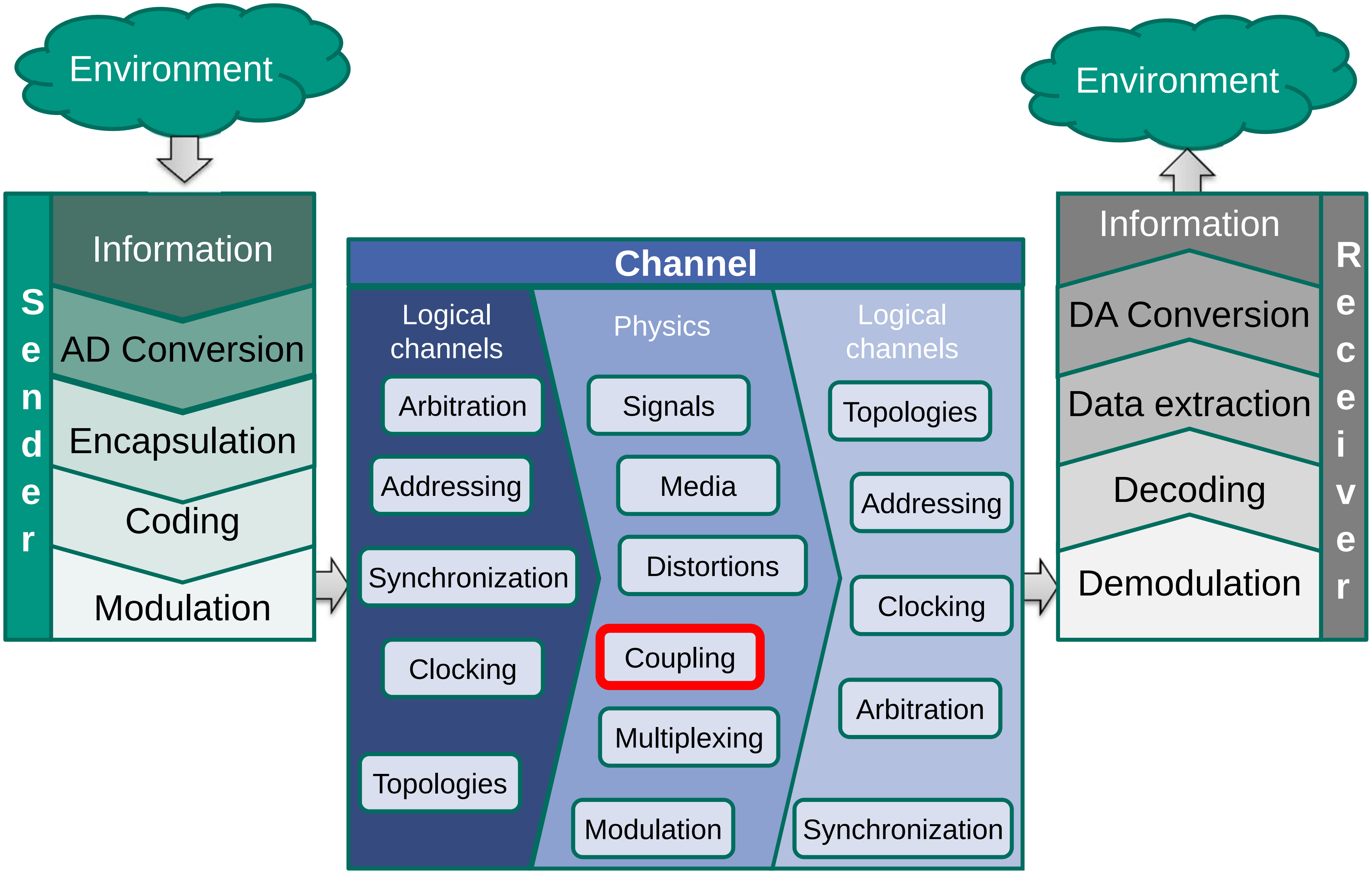
Excursus: Representation of Signals II

- Undefined value
  - In specifications, a signal might not be determined for every point in time
  - Undefined region is depicted as shaded area



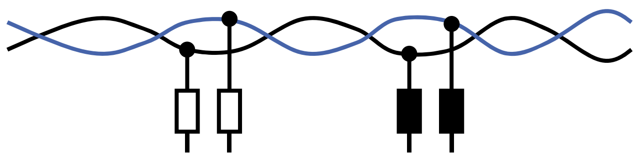
- Inverted Logic (LOW active)
  - Signals with inverted logic can be marked as follows:
    - nSignal
    - *Signal
    - $\overline{\text{Signal}}$

Transmission System – Media Coupling

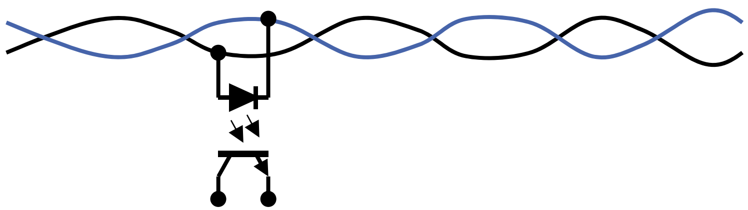


Media coupling

- Galvanic coupling
  - Ohmic resistors for protection
  - Series inductance when having an interfering source voltage



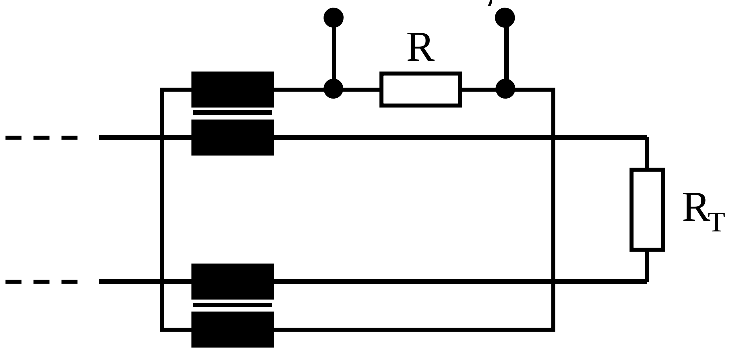
- Galvanically separated coupling
  - Avoidance of disturbances by interference on great distances

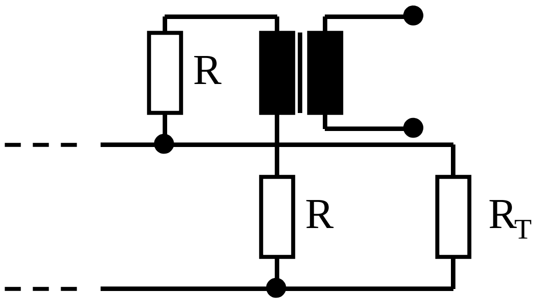


  - Optic coupling by using optoelectronic couplers
    - Luminous intensity is quasi-statically controlled
      →no lower cut-off frequency

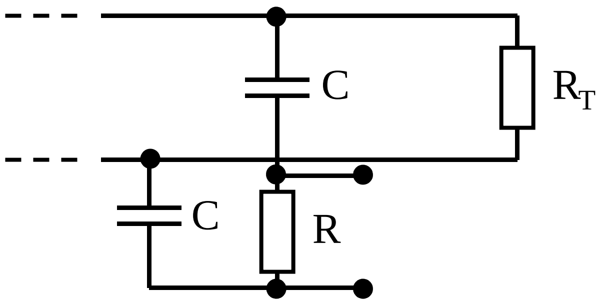
Media coupling

- Galvanically separated
  - Inductive with transformer, serial und parallel



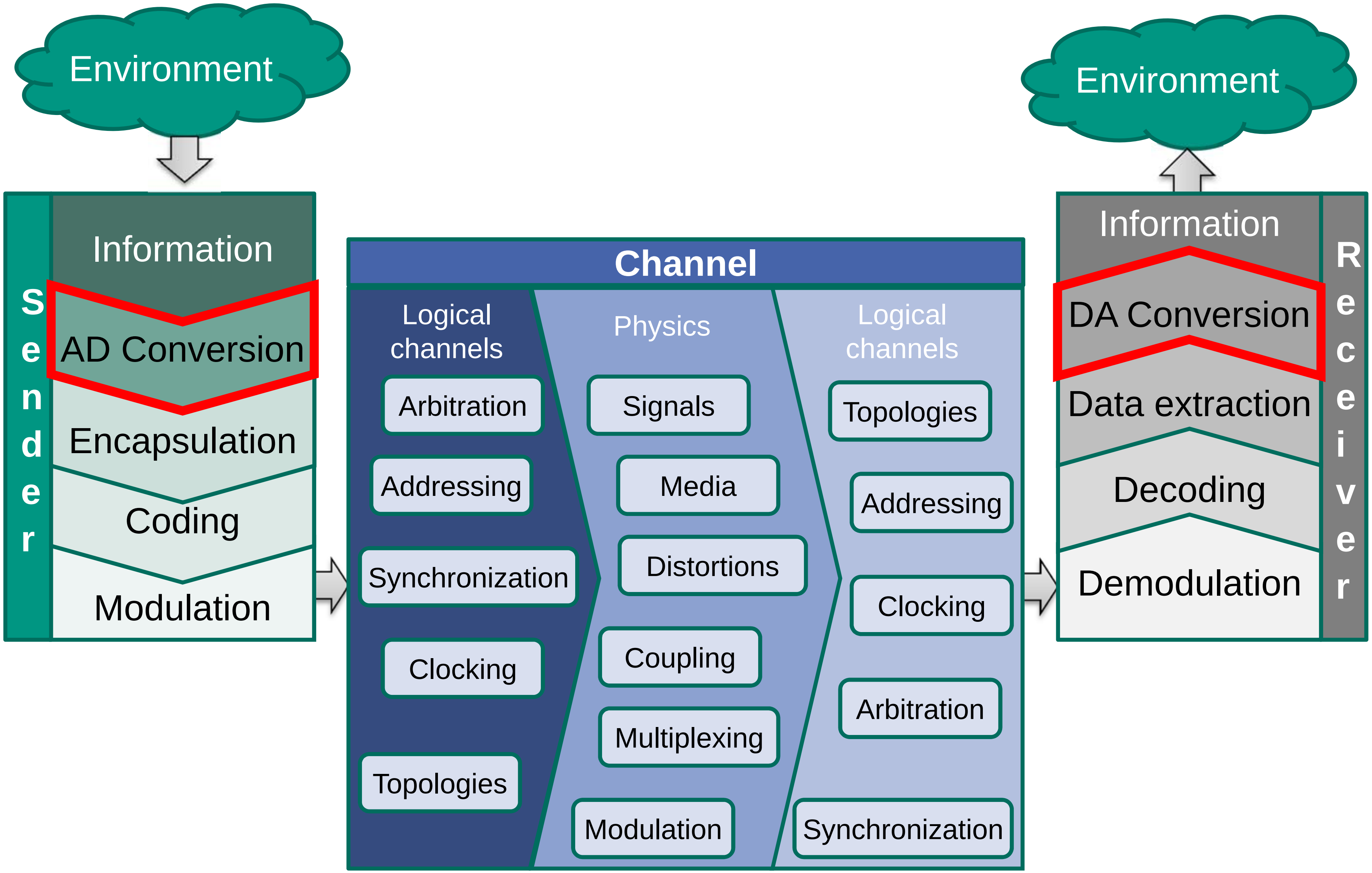


  - Capacitive



- Couplings are DC free
  - long sequences of the same value can not be detected
  - a minimal frequency of signal changes must appear on medium to be transmittable into the receiving node

Transmission System – Signal Conversion



Clicker Session: Signal classes

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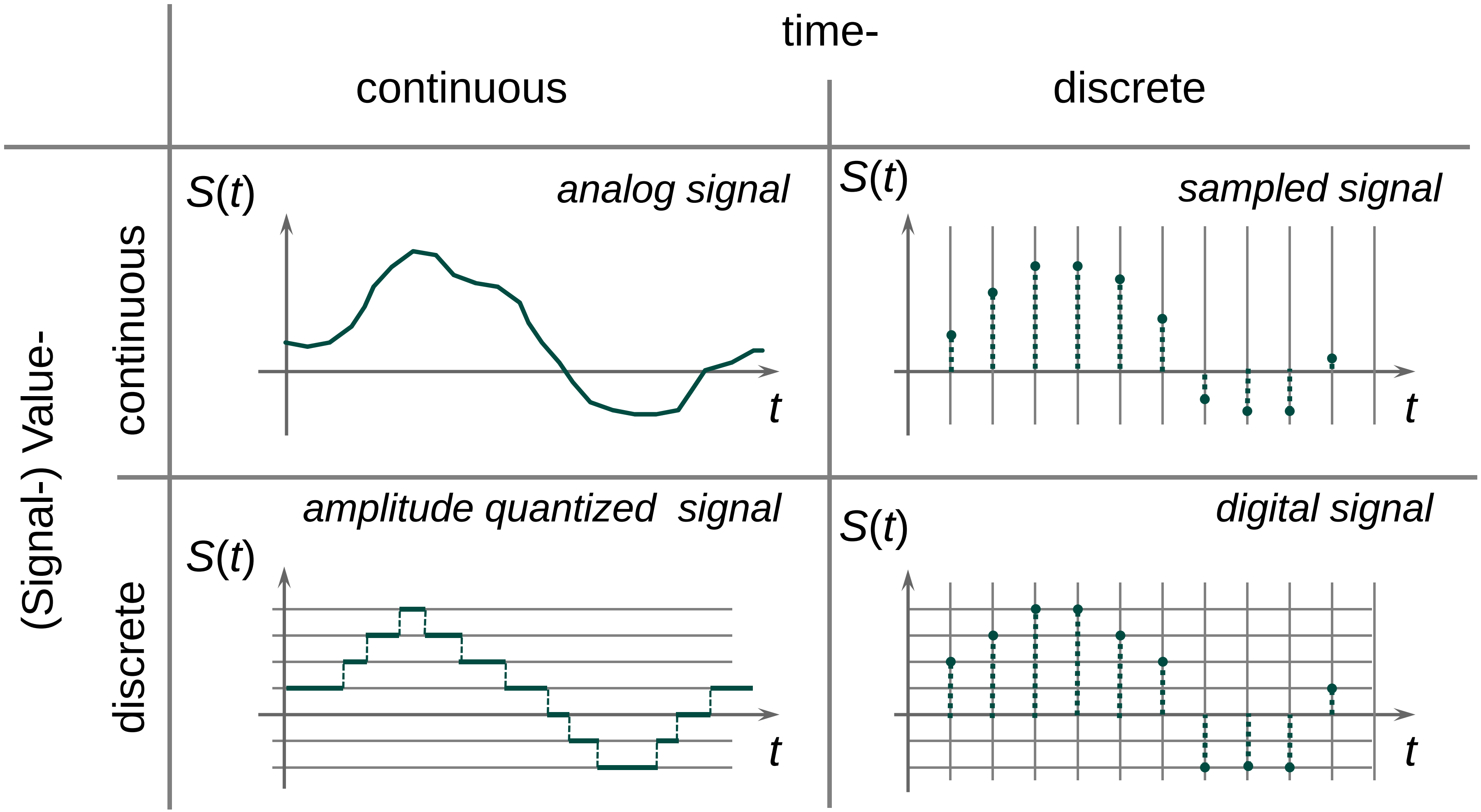
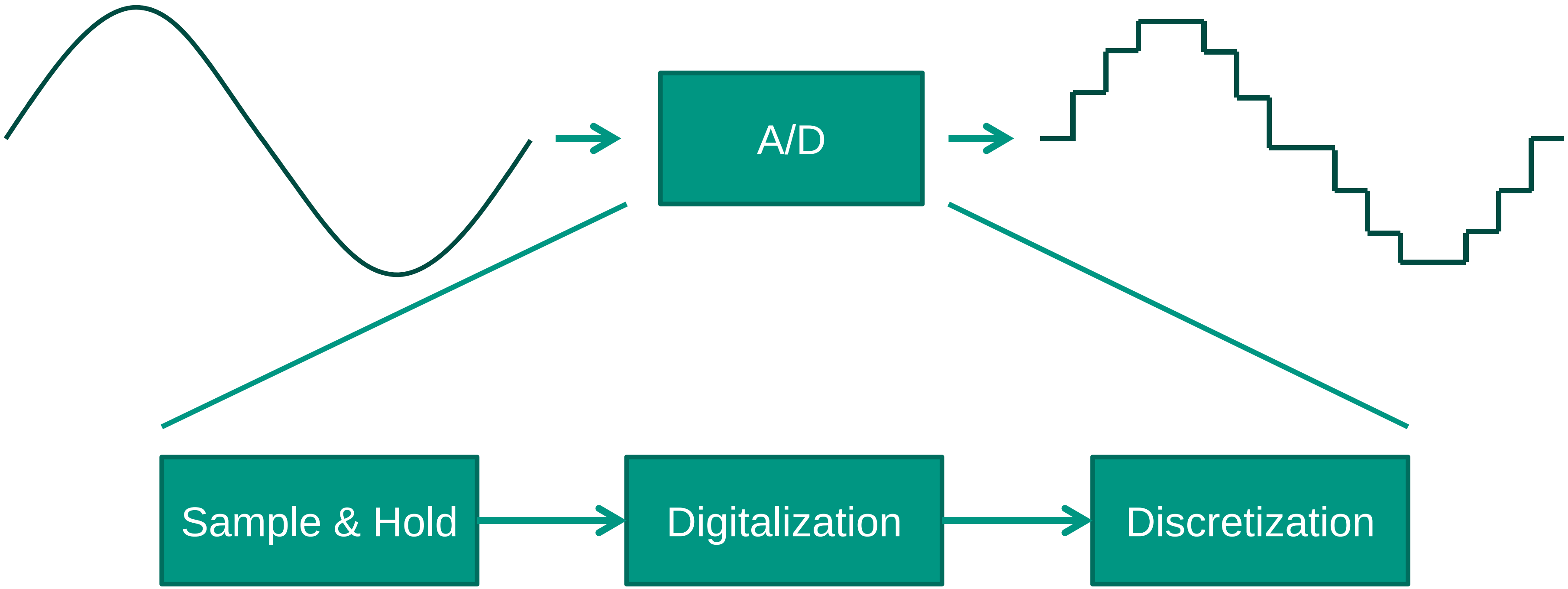
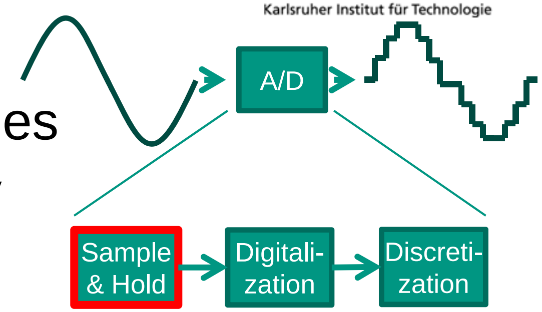
Classes of Signals



Analog-Digital Conversion



Sampling of Signals



- Transforming a continuous signal into discrete values
  - Signal shall be reconstructable unambiguously

- Prerequisites:
  - Signal limited in frequency with a maximum frequency f_{max}
  - Equidistant sampling points

- Nyquist-Shannon-Sampling Theorem

  A continuous signal has to be sampled with a frequency at least double the maximum frequency of the signal itself f_{max} in order to be able to unambiguously reconstruct the original signal.

$$f_{Sample} \geq 2 \cdot f_{max}$$

  To keep this condition it may be necessary to filter the signal prior to sampling with a low-pass filter. This prevents artefacts otherwise caused by high frequencies.

Outlook for next lecture

- Circuits for sampling
- Transmission capacity
- Line codes
- Multiplexing