3 Sensor signals and disturbing effects

3.1 Definitions

3.2 Classification of analog signals

3.3 Modulation and demodulation

3.4 Influences of faults

- 3.4.1 Network faults
- 3.4.2 Switch faults
- 3.4.3 High-frequency faults

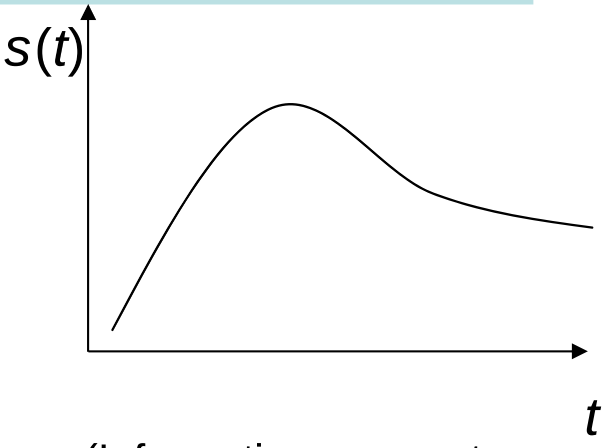
3.5 Precautions

- 3.5.1 Protection ground
- 3.5.2 Shielding against magnetic fields
- 3.5.3 Shielding against electric fields

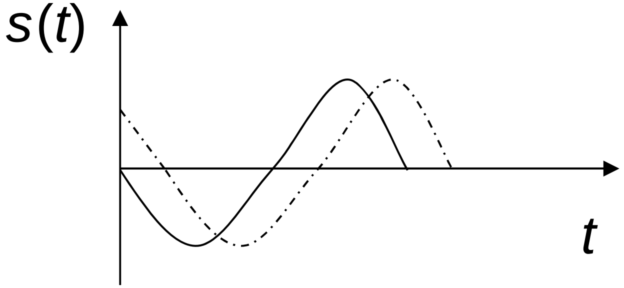
3.1 Definitions

Signal parameters: value , course, frequency, phase

continuous analog signals

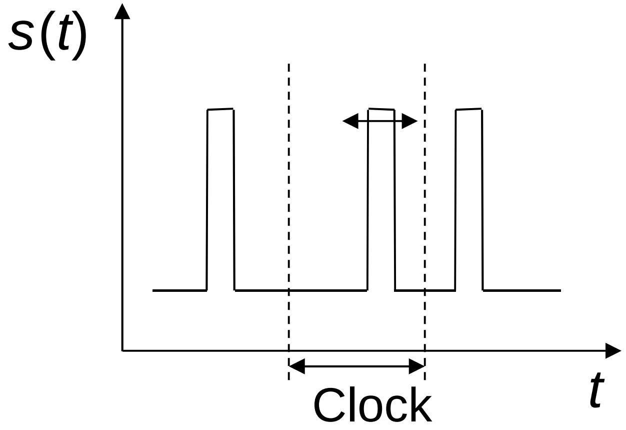


(Information-parameter:
signal amplitude)

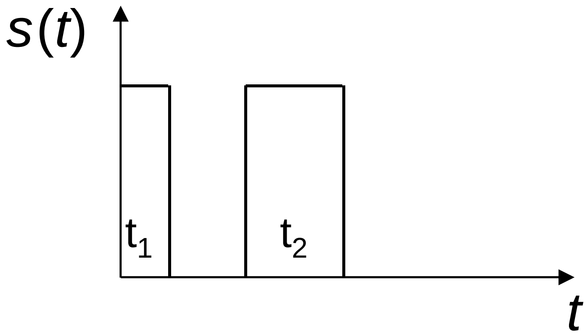


(Information-parameter:
phase relation)

discontinuous analog signals



(Information-parameter:
phase relation of impulses)



(Information-parameter:
impulse-length or impulse-width)

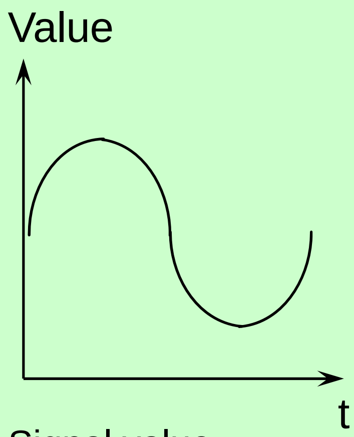
3.2 Classification of Signals

- Which kind of signals do you already know?

6 – 8 – 12 – …

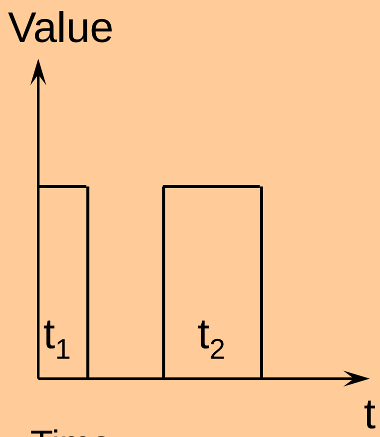
A measured quantity can be described by different signal parameters

amplitude analog



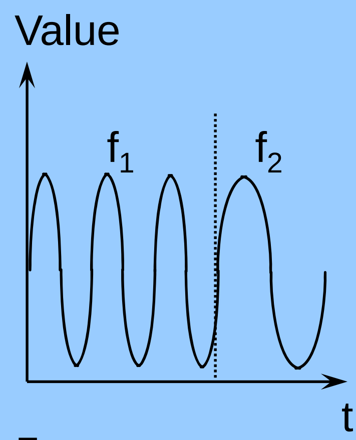
Signal value
~ Measured quantity

time analog



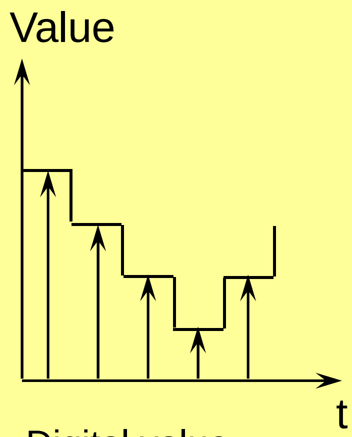
Time
~ Measured quantity

frequency



Frequency
~ Measured quantity

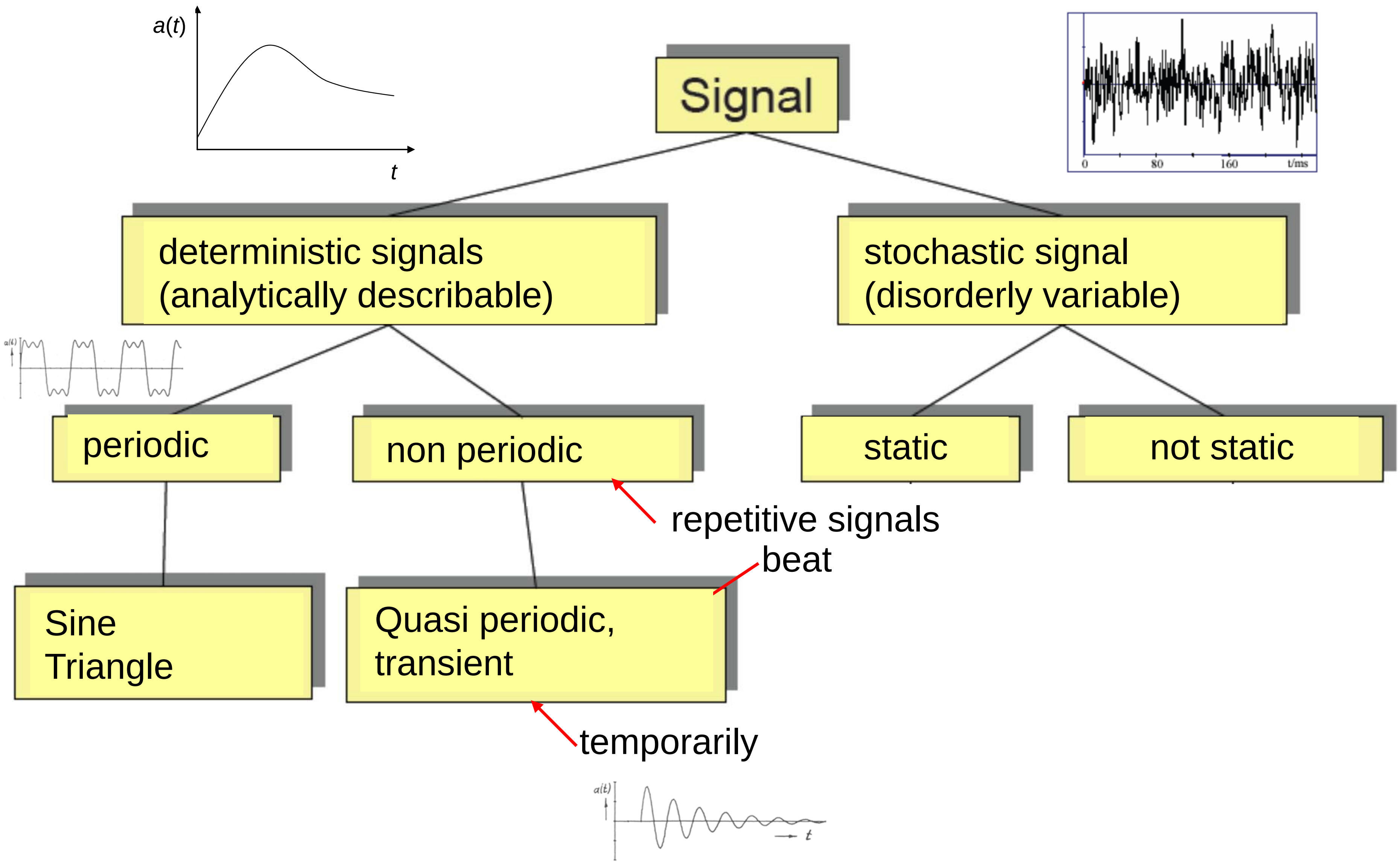
digital



Digital value
~ Measured quantity

- Which signal parameter should we prefer, if we assume that sensor signals can be affected with noise?

3.2 Classification of analog signals



3.2.1 Deterministic signals
Periodic signals

$x(t) = x(t + T_0)$ T_0 : period

<u>Typical forms:</u>
Sine, cosine, rectangle, pulsed, triangle, saw tooth

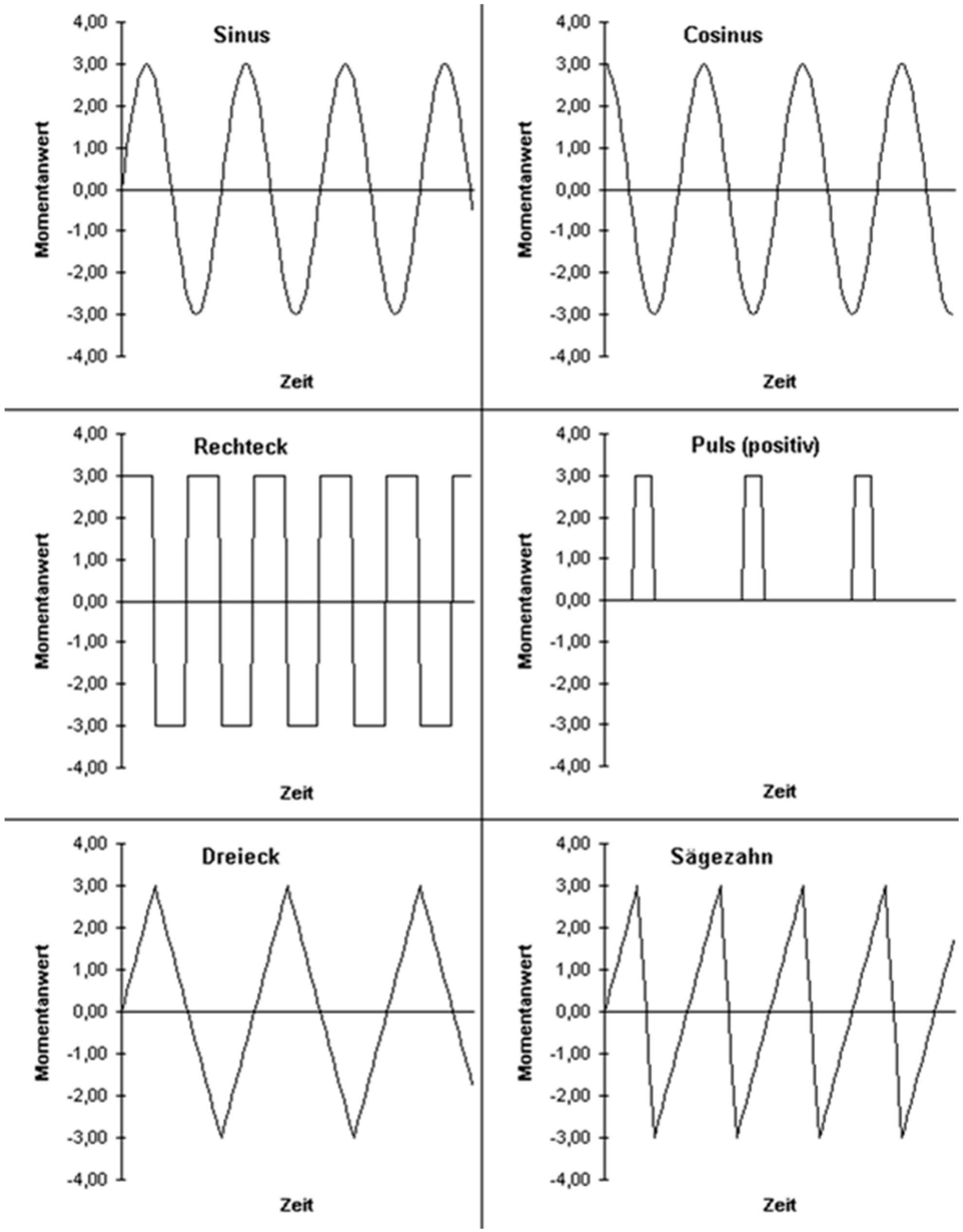
<u>Features:</u>
amplitude, frequency, period, symmetry

linear mean-value $\bar{x} = \frac{1}{T}\int_0^T x(t)dt$

rectifying-value $|\bar{x}| = \frac{1}{T}\int_0^T |x(t)|\, dt$

effective value $X_{eff} = \sqrt{\frac{1}{T}\int_0^T (x(t))^2 dt}$

Signal-power $P = X_{Eff}^2 = \frac{1}{T}\int_0^T (x(t))^2 dt$



3.2.1 Deterministic signals

Periodic non-sine-shaped signals

$$s(t) = S_0 + \sum_{k=1}^{\infty} S_k \cdot \cos(k \cdot \omega t + \varphi_k)$$ (Fourier-sequence-presentation)

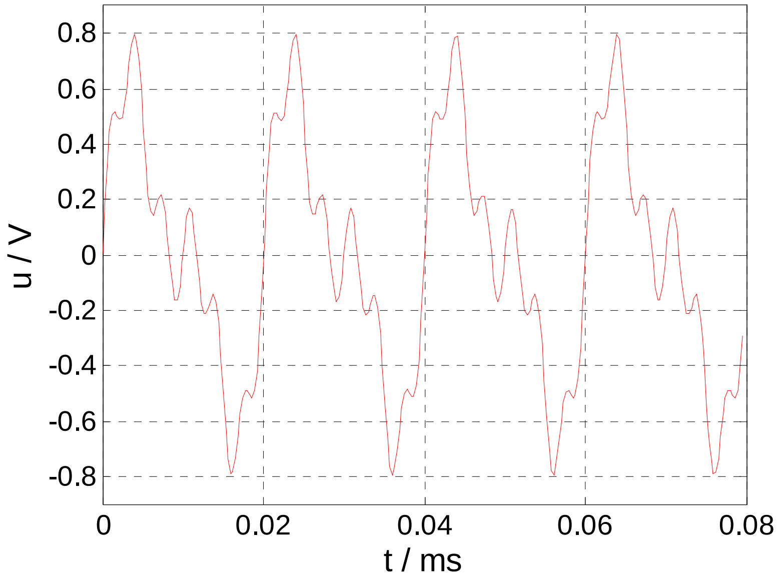
S_0: Constant component (Gleichanteil)

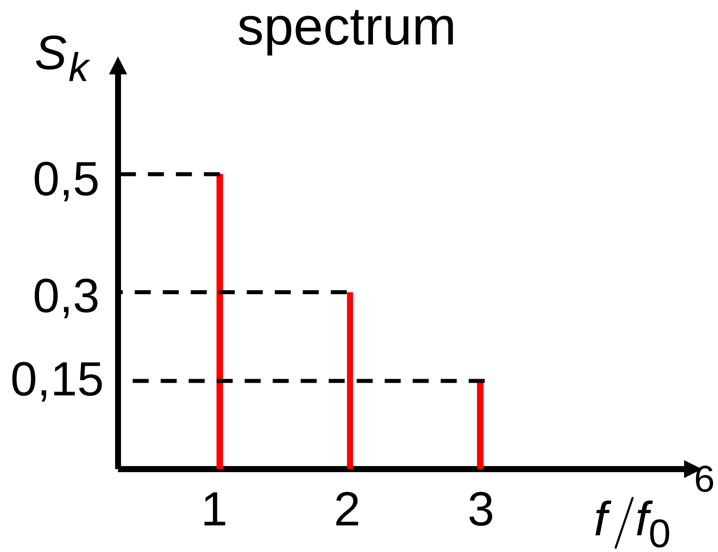
S_1: Amplitude of the fundamental wave ω

S_k: Amplitude of harmonics

Example: $s(t) = 0{,}5 \cdot \cos(\omega t) + 0{,}3 \cdot \cos(2\omega t) + 0{,}15 \cdot \cos(3\omega t)$

time-function



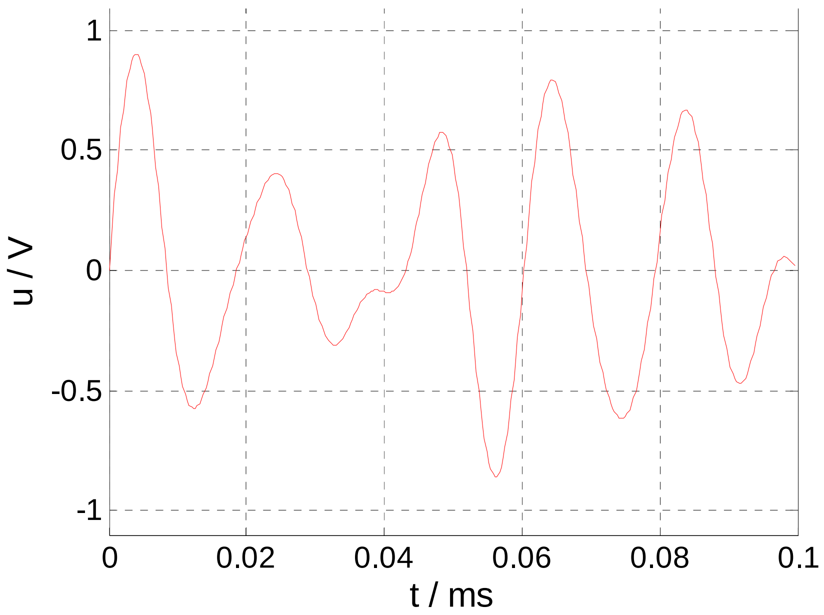


3.2.1 Deterministic signals
Quasi-periodic signals

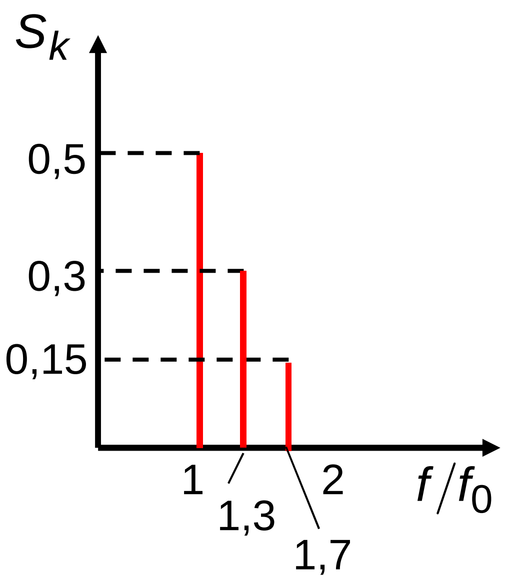
$$s(t) = S_0 + \sum_{k=1}^{\infty} S_k \cdot \cos(\omega_k t + \varphi_k)$$

ground-vibration multiplied by a non whole number

time-function



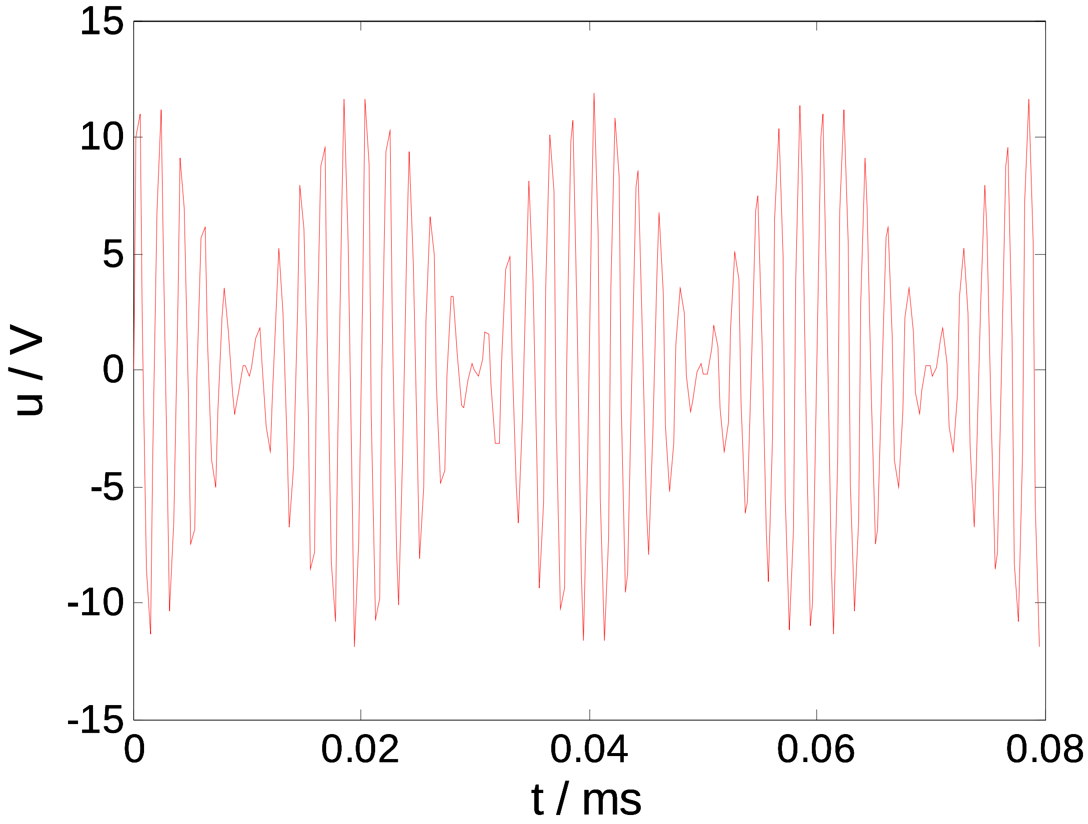
spectrum



3.2.1 Deterministic Signals

Example: Beat

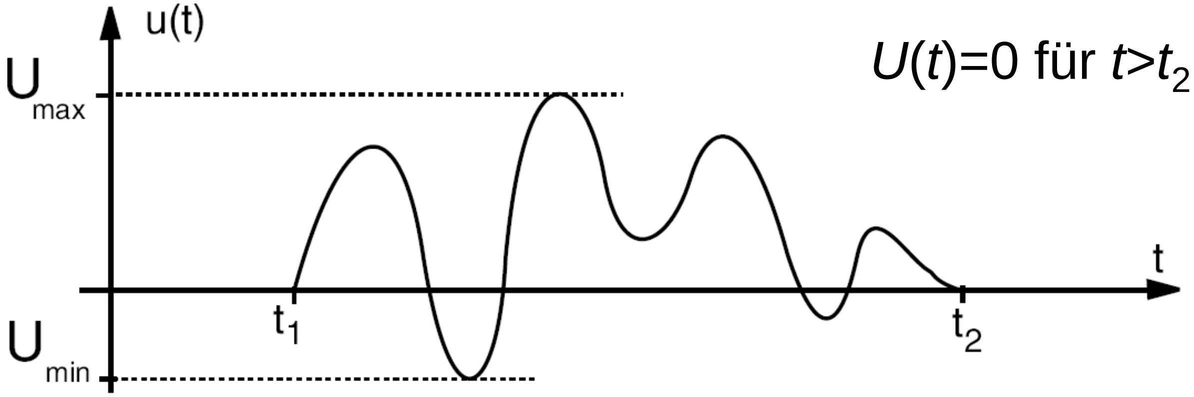
$$u(t) = \hat{u} \cdot \sin(2\pi f_1 \cdot t) + \hat{u} \cdot \sin(2\pi f_2 \cdot t)$$



f_1 = 500 Hz	f_1 = 500 Hz	f_1 = 500 Hz	f_1 = 500 Hz	f_1 = 500 Hz
f_2 = 500 Hz	f_2 = 510 Hz	f_2 = 520 Hz	f_2 = 530 Hz	f_2 = 550 Hz

3.2.1 Deterministic signals
Transient signals

temporary non recurring signals

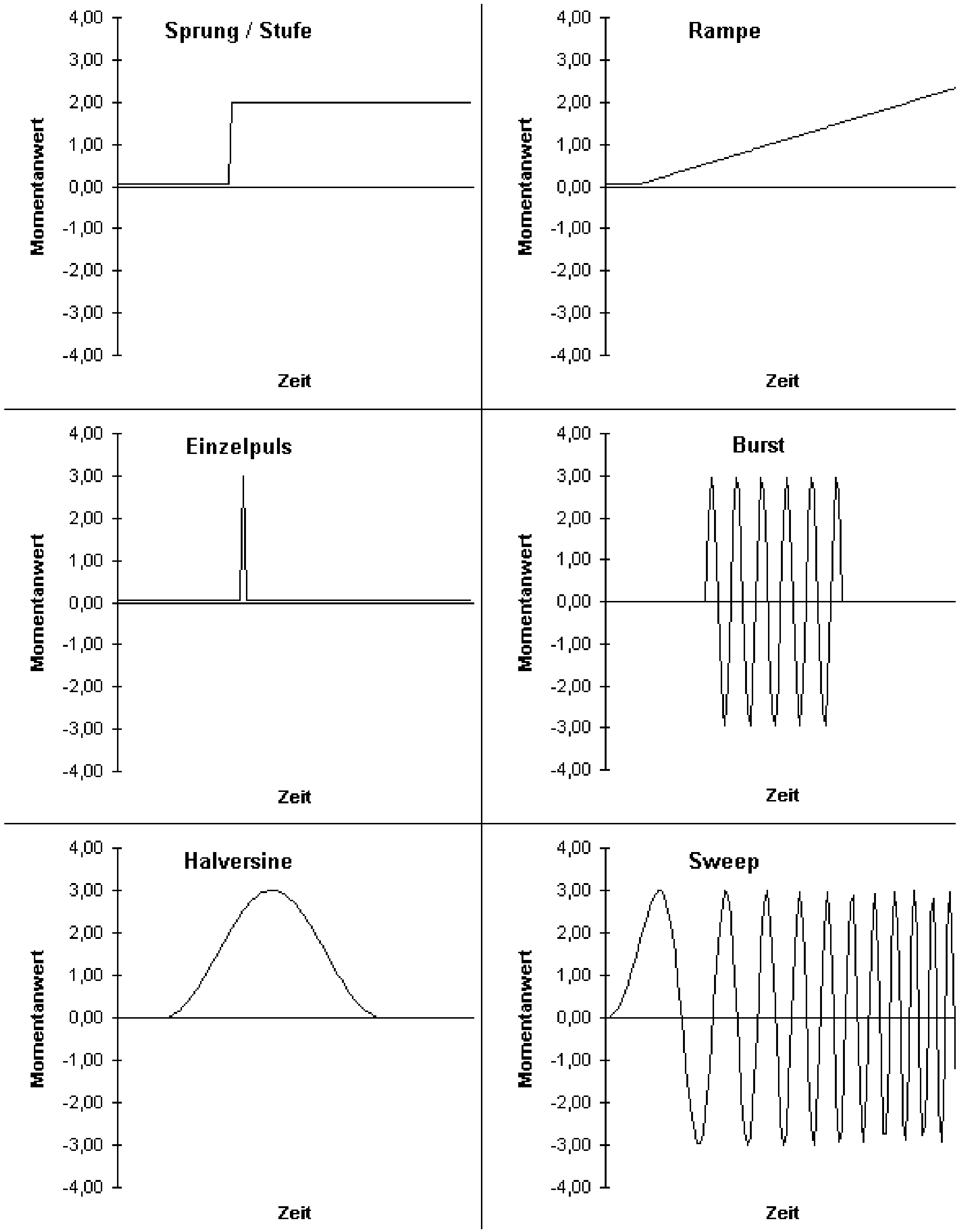


$U(t)=0$ für $t>t_2$ und $t<t_1$

Transient signals have a continuous spectrum and are described by a Fourier-integral

$$s(\omega) = \int_{-\infty}^{+\infty} s(t)\, e^{-j\omega t}\, dt$$

3.2.1 Deterministic signals
Non-periodic signals

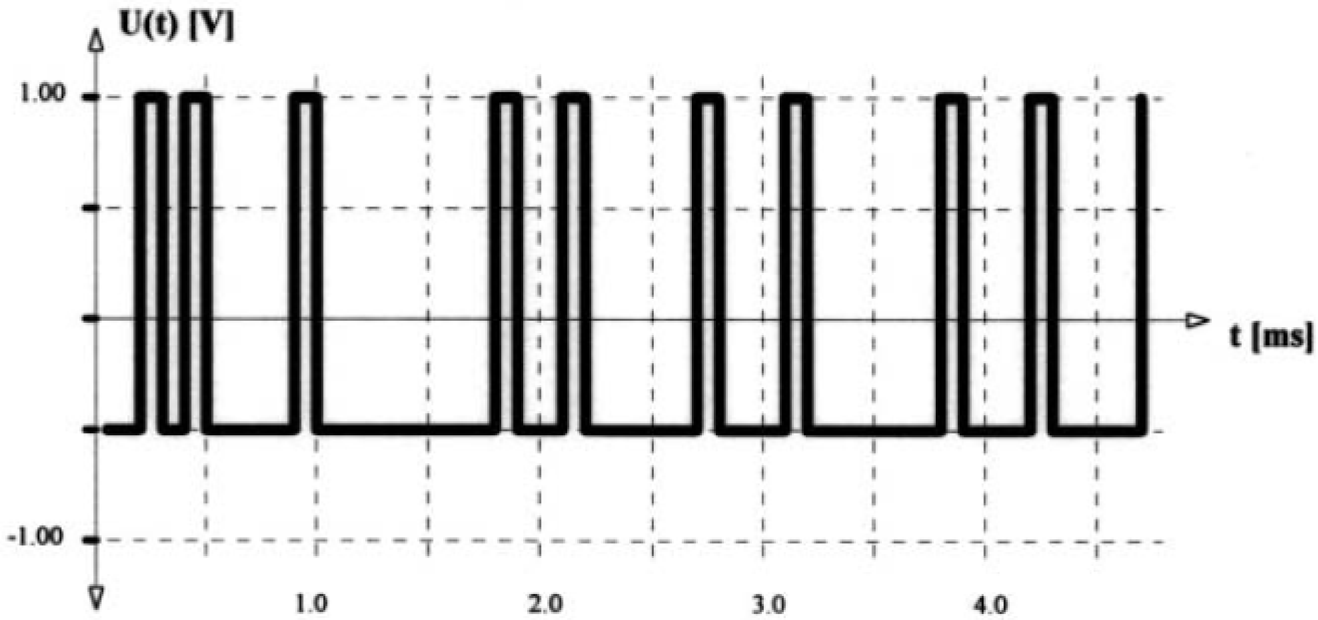


<u>Typical forms:</u>

- Step, ramp, pulse, monocycle (a Sine-cycle)
- Burst, Halversine (half a Sinus),
- Chirp / Sweep (frequency-modulated, sine, frequency-change mostly linear or logarithmic)
- Spike (outlier in positive or negative direction)
- Glitch (two consecutive outliers with different omen)

3.2.1 Deterministic signals
Non-periodic signals

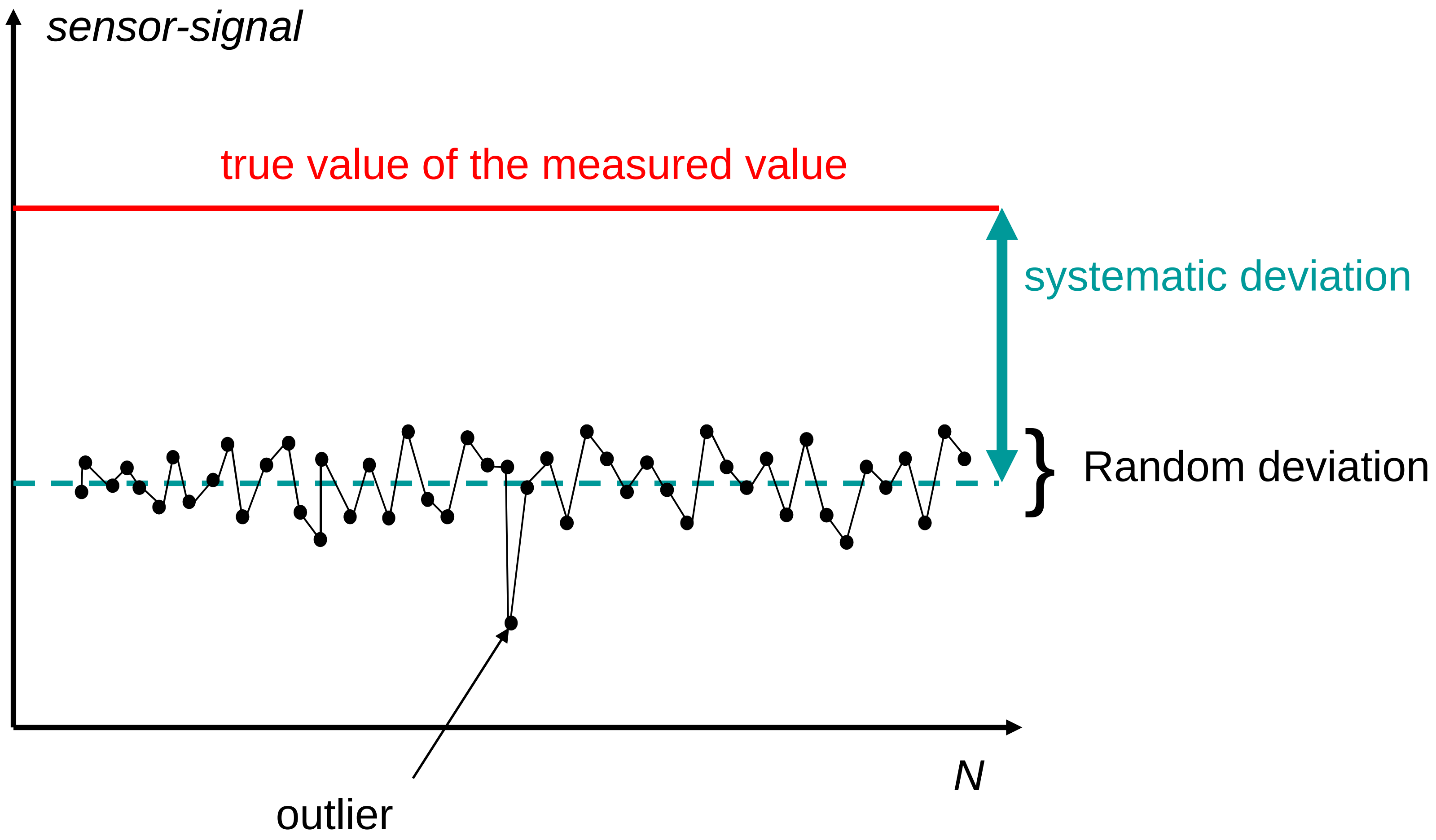
Repetitive Signals



3.2.2 Stochastic signals

Stochastic signals are not predictable, not computable

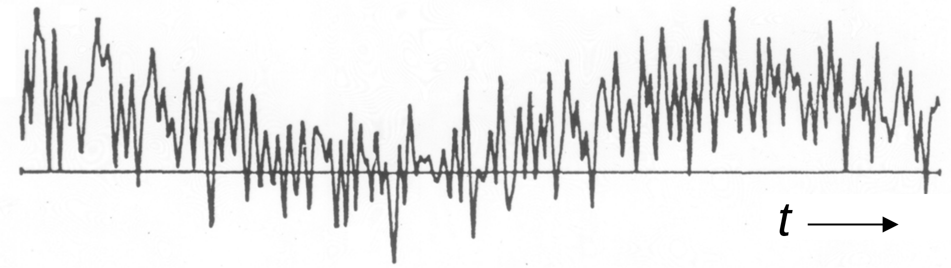
Example: random deviation is a stochastic signal



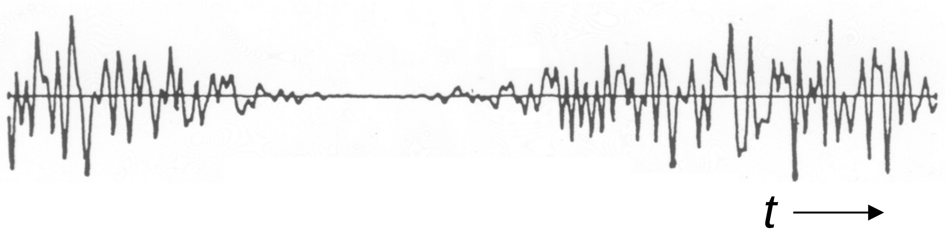
3.2.2 Stochastic signals

The course of a stochastic signal is dependent on statistic properties
Stationarity is given by the temporal behaviour of statistic signal-parameter

Stationary wideband noise with negligible linear mean value



Non stationary wideband noise with time dependent quadratic mean value



Stationary wideband noise with time dependent linear mean value

3.2.2 Stochastic signals

Amplitude-density-distribution or distribution-density-function

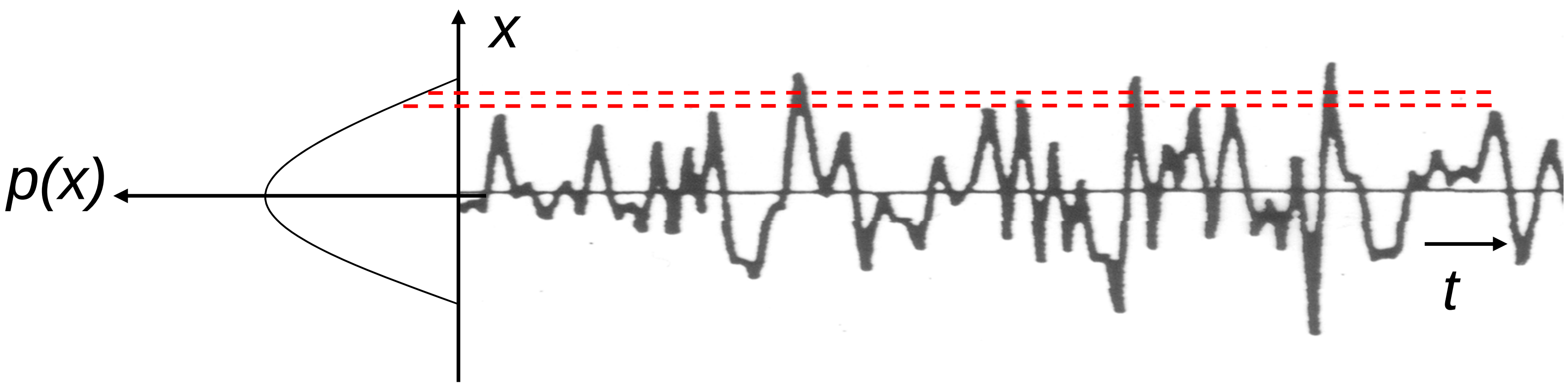
probability for the reaching of a specific signal-amplitude x

$$p(x) = \lim_{N\to\infty} h(x) = \lim_{N\to\infty} \frac{n(x)}{N}$$

$h(x)$: incidence of the amplitudes x

$n(x)$: number of amplitudes x

N : number of all amplitudes



3.2.2 Stochastic signals
Distributions function

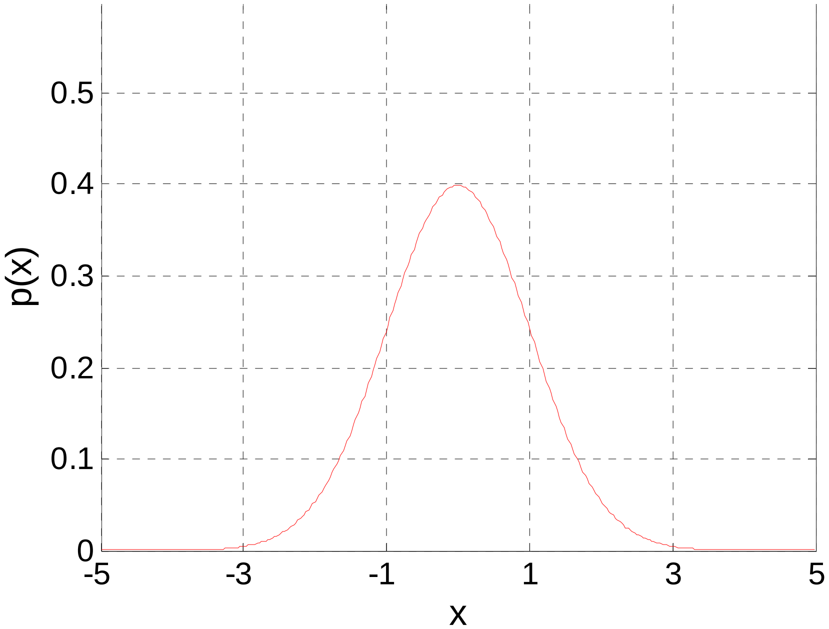
probability, that an amplitude *x happens*, which is less or even of a predetermined upper limit x_0

$$P(x_0) = \int_{-\infty}^{x_0} p(x)\, dx$$

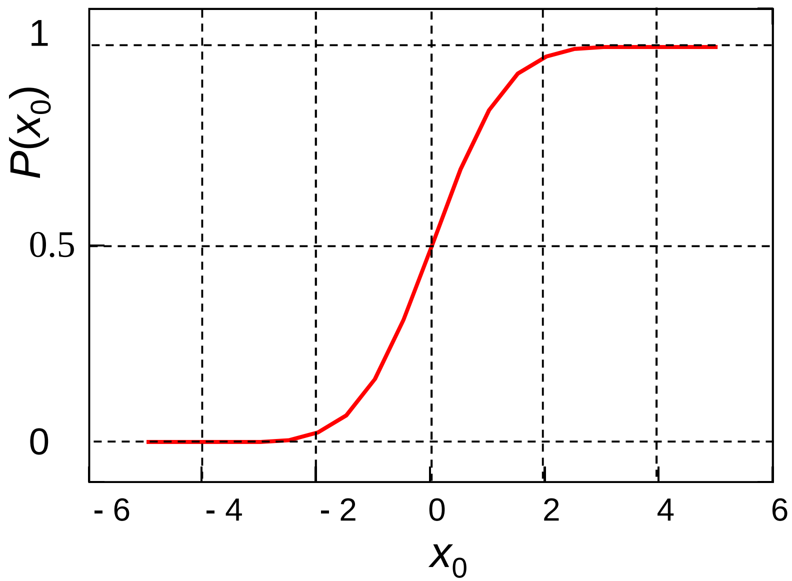
integration →

differentiation ←

Standardized distribution density



Standardized distribution function



3.2.2 Stochastic signals
Further properties

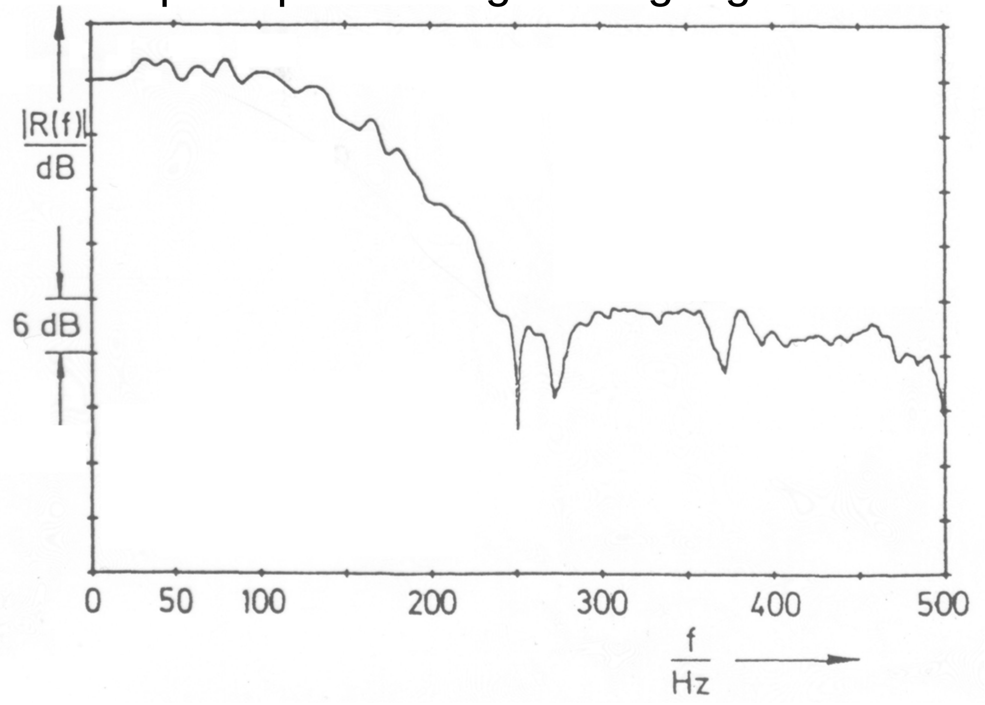
Stochastic signals have a continuous spectrum with statistical fluctuating phase

power density-spectrum

$$W(\omega) = |S(\omega)|^2 = \left| \int_{-\infty}^{+\infty} s(t)\, e^{-j\omega t}\, dt \right|^2$$

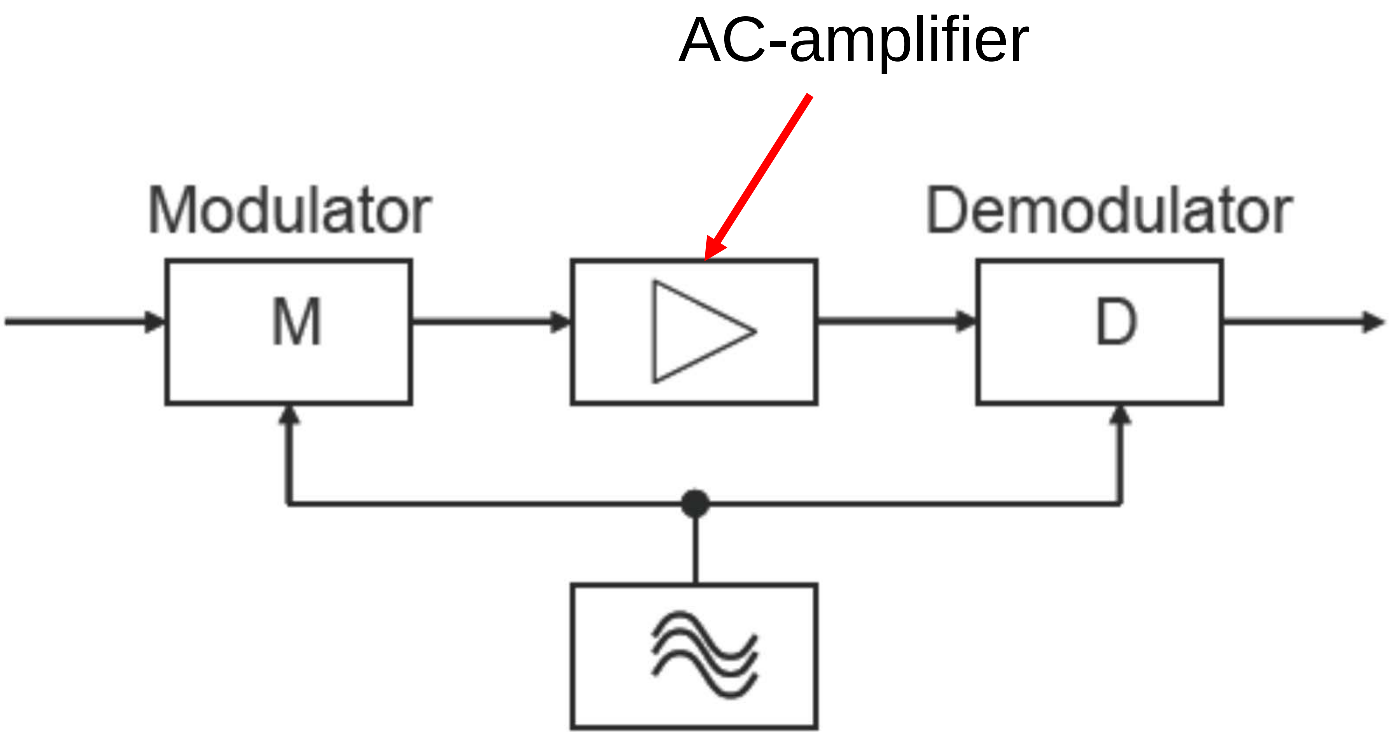
phase-less

Power density-spectrum of a low-pass-percolating hissing-signals



3.3 Modulation/Demodulation

<u>Problem:</u> errors on little measurement signals

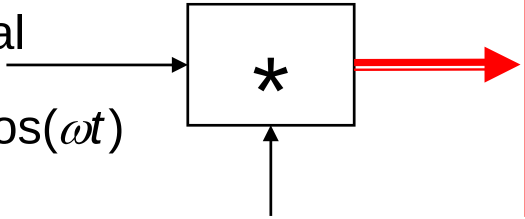


carrier-frequency generator

Amplitude modulation

Measured-signal

$$u(t) = U_0 + \hat{u} \cdot \cos(\omega t)$$

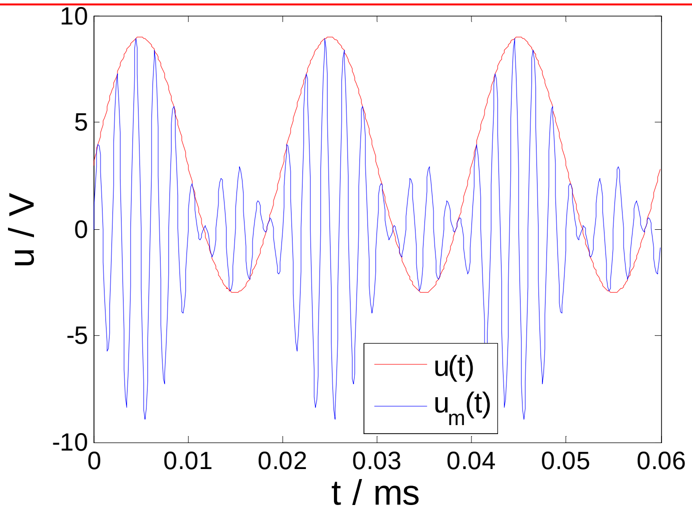


Carrier-frequency generator

$$u_T(t) = \cos(\omega_T t)$$

Amplitude modulated signal

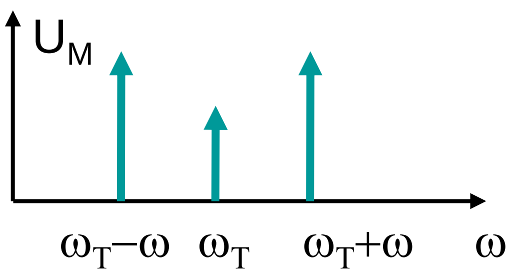
$$u_M(t) = \left(U_0 + \hat{u} \cdot \cos(\omega t)\right) \cdot \cos(\omega_T t)$$
$$= U_0 \cdot \cos(\omega_T t) + \hat{u} \cdot \cos(\omega t) \cdot \cos(\omega_T t)$$



$$2\cos\alpha \cdot \cos\beta = \cos(\alpha + \beta) + \cos(\alpha - \beta)$$

$$u_M(t) = U_0 \cdot \cos(\omega_T t) + \frac{\hat{u}}{2}\left[\cos((\omega_T + \omega)t) + \cos((\omega_T - \omega)t)\right]$$

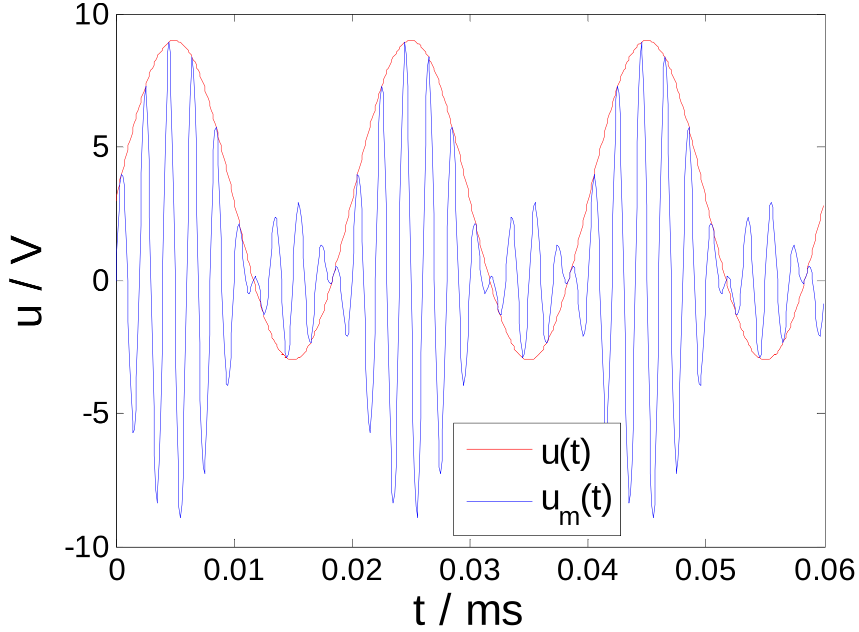
carrier — upper side band — lower side band

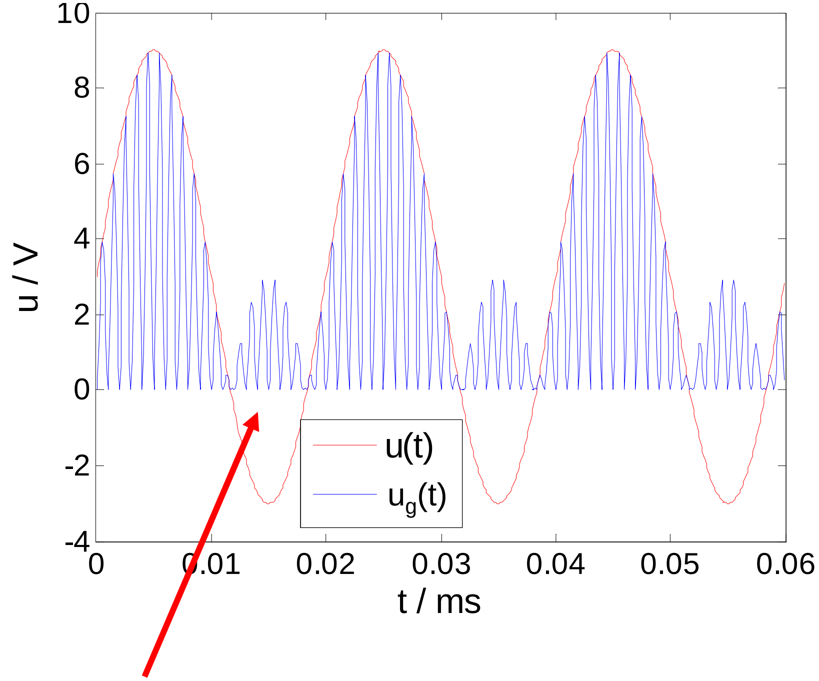


$$u_M(t) = U_0 \cdot \cos(\omega_T t) + \frac{\hat{u}}{2}\left[\cos((\omega_T + \omega)t) + \cos((\omega_T - \omega)t)\right]$$

Demodulation → cover signal is to be reconstructed

Demodulation by two-way rectification and low-pass filtering





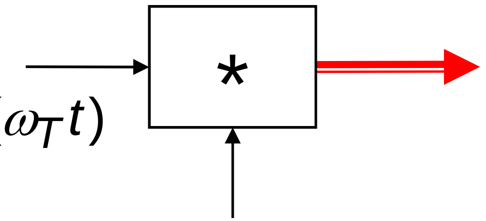
but: phase-selective rectification!

3.3 Modulation/Demodulation

Demodulation by further multiplication

modulated signal

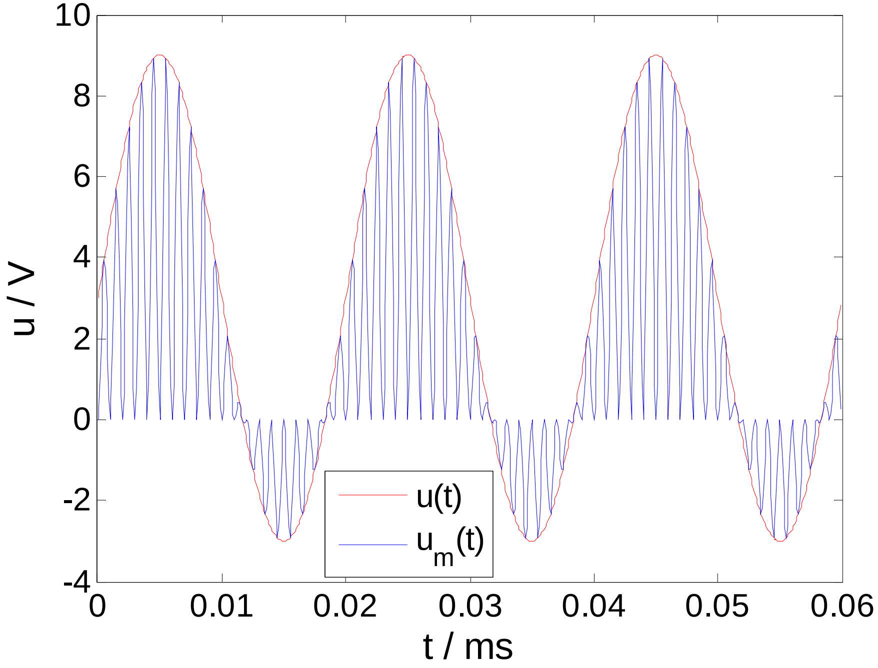
$$u_M(t) = u(t) \cdot \cos(\omega_T t)$$



$$u_{Dem}(t) = u(t) \cdot \cos(\omega_T t) \cdot \cos(\omega_T t)$$
$$= u(t) \cdot \frac{1}{2}\left(1 + \cos(2\omega_T t)\right)$$

carrier-frequency generator

$$u_T(t) = \cos(\omega_T t)$$



Low-pass filtering of the double carrier frequency

$$\overline{u_{Dem}} = \frac{1}{T}\int_0^T u_{Dem} \cdot dt = \frac{1}{2} \cdot \overline{u(t)}$$

3.4 Influence of disturbances

- Which kind of disturbances can happen on a sensor signal, sensor system, measurement system?

- Which measures do you know for avoiding disturbances in measurement and sensor systems

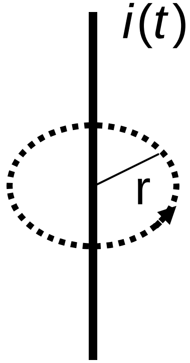
3.4 Influence of disturbances

3.4.1 network faults

(f=)50 Hz-faults become interlink inductively

field of a even line

$$i(t) = \hat{i} \cdot \sin(\omega t)$$



$$B(r) = \mu_0 \cdot H(r) = \frac{\mu_0 \cdot i}{2\pi r} \qquad \phi = B \cdot A_{Fl}$$

Induction-law

$$u(t) = \frac{\partial \phi}{\partial t} = A_{Fl} \frac{\partial B}{\partial t} = A_{Fl} \frac{\mu_0}{2\pi r} \frac{\partial i(t)}{\partial t} =$$

$$= A_{Fl} \frac{\mu_0}{2\pi r} \cdot \hat{i} \cdot 2\pi f \cdot \cos(\omega t) = \overbrace{\frac{\mu_0 \sqrt{2} \cdot I \cdot f \cdot A_{Fl}}{r}}^{\hat{u}} \cdot \cos(\omega t)$$

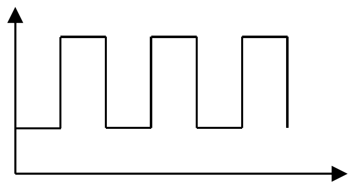
fault $\hat{u} = 5\ mV$

$A_{Fl} = 1 m^2$

$$\frac{r_k}{cm} = 2{,}21 \frac{I}{A}$$

I=10 A → r_k=22 cm

3.4.2 Switch disturbances



$$\phi = B \cdot A_{fl} = A_{fl} \cdot \mu_0 \cdot H = A_{fl} \frac{\mu_0 \, i}{2\pi \, r}$$

$$u = \frac{\Delta\phi}{\Delta t} = A_{fl} \frac{\Delta B}{\Delta t} = A_{fl} \frac{\mu_0}{2\pi r} \frac{\Delta i(t)}{\Delta t} = 2 \cdot 10^{-7} \cdot \frac{1}{r} \cdot \frac{\Delta i(t)}{\Delta t}$$

disturbance $u = 5\,mV$

$A_{Fl} = 1m^2$

change of current $\frac{\partial i(t)}{\partial t} = 10^6 \, A/s$

$r_k = 40m$

- Avoid switching
- Separate analog and digital ground
- Measuring systems install as far as possible from relay and contactors

3.4.3 High-frequency disturbances

$E = \hat{E} \cdot \sin(\omega t)$ HF-disturbance

$$E = Z_0 \cdot H = Z_0 \frac{B}{\mu_0}$$

Wave impedance of the room

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\,\Omega$$

$$\phi = B \cdot A_{fl} = \frac{\mu_0 \cdot A_{fl}}{Z_0} E$$

$$u = \frac{\partial \phi}{\partial t} = \frac{\mu_0 \cdot A_{fl}}{Z_0} \cdot \hat{E} \cdot \omega \cdot \cos(\omega t) = \hat{u} \cos(\omega t)$$

$$\hat{u} = \frac{\mu_0 \cdot 2\pi f \cdot A_{fl}}{Z_0} \cdot \hat{E}$$

$$\hat{E} = 1 mV / m$$

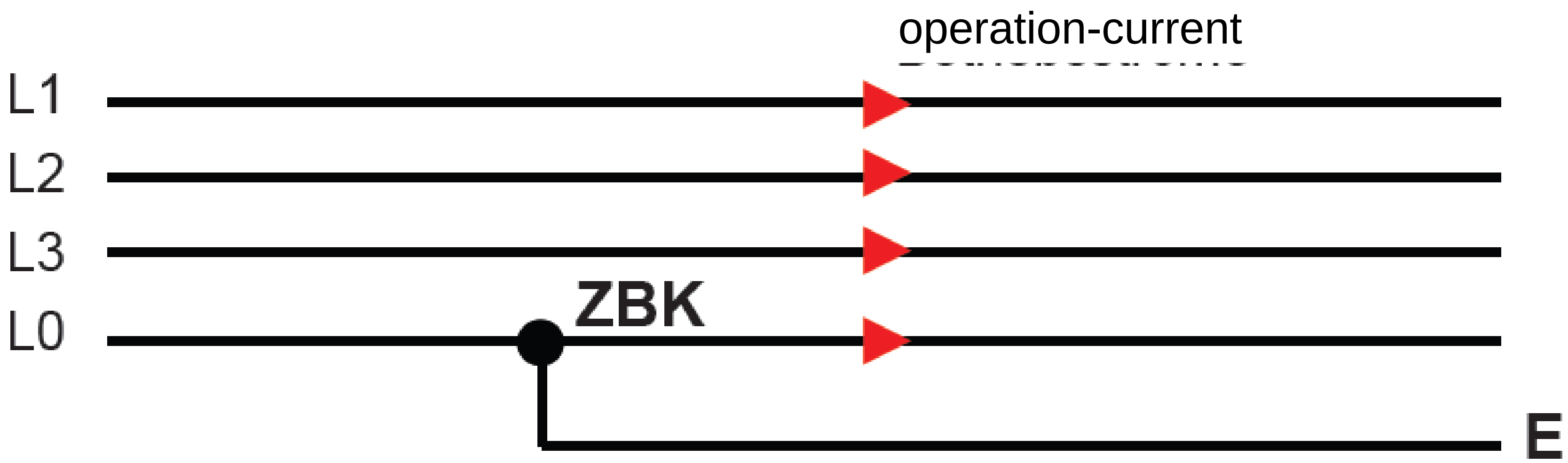
$$f = 100\, MHz (UKW - range)$$

$$A_{Fl} = 1 m^2$$

$\Rightarrow$ $\hat{u} = 2\, mV$

3.5 Precautions

3.5.1 Protection ground



Neutral lead without current as
neutral reference point

- Additional signal ground is not necessary
- makes more errors
- loss are more than added value

3.5 Precautions

3.5.1 Protection ground

Single-point series grounding

$$U_A = (I_1 + I_2 + I_3) \cdot Z_1$$

$$U_B = (I_1 + I_2 + I_3) \cdot Z_1 + (I_2 + I_3) \cdot Z_2$$

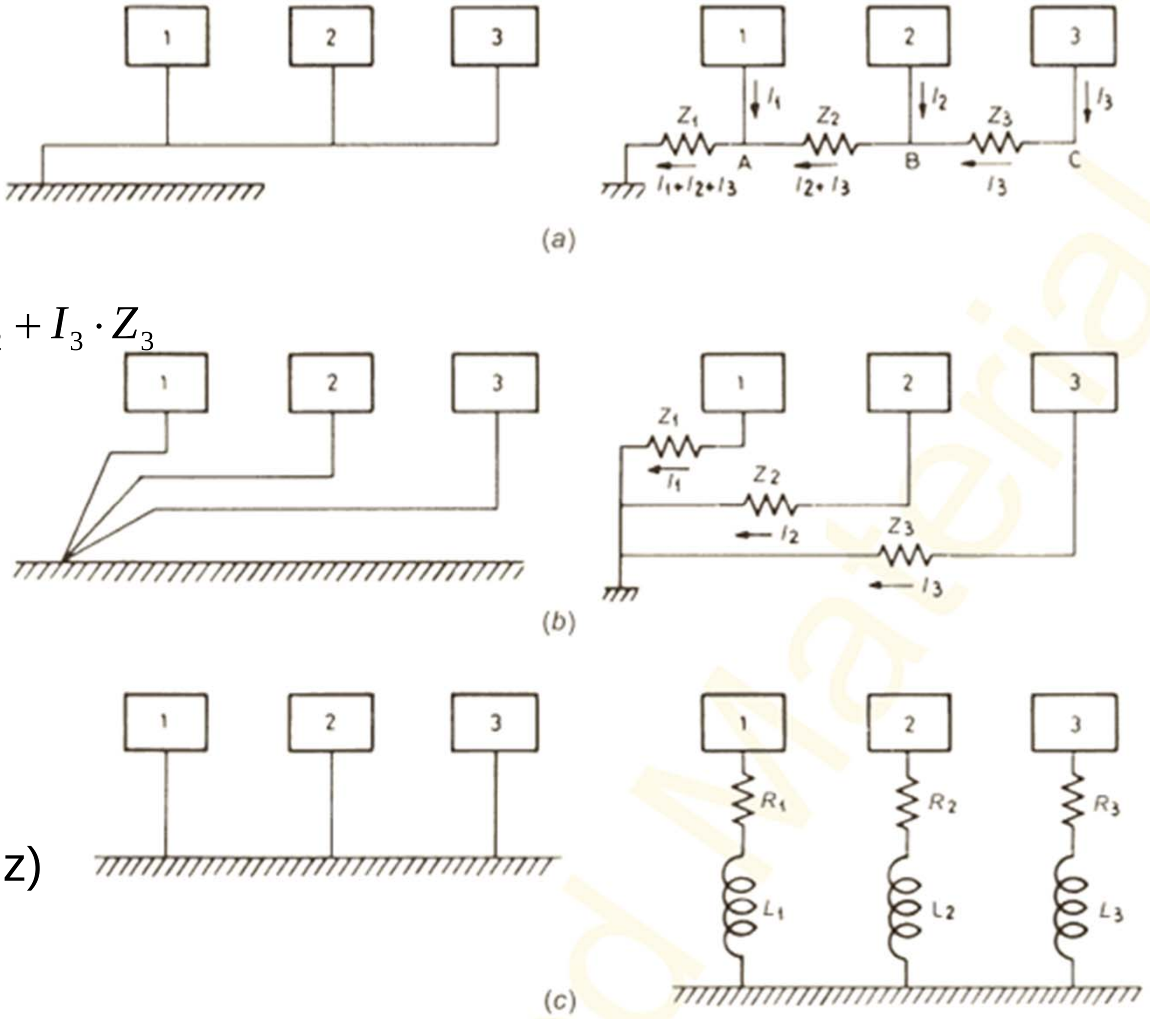
$$U_C = (I_1 + I_2 + I_3) \cdot Z_1 + (I_2 + I_3) \cdot Z_2 + I_3 \cdot Z_3$$

Single-point parallel grounding

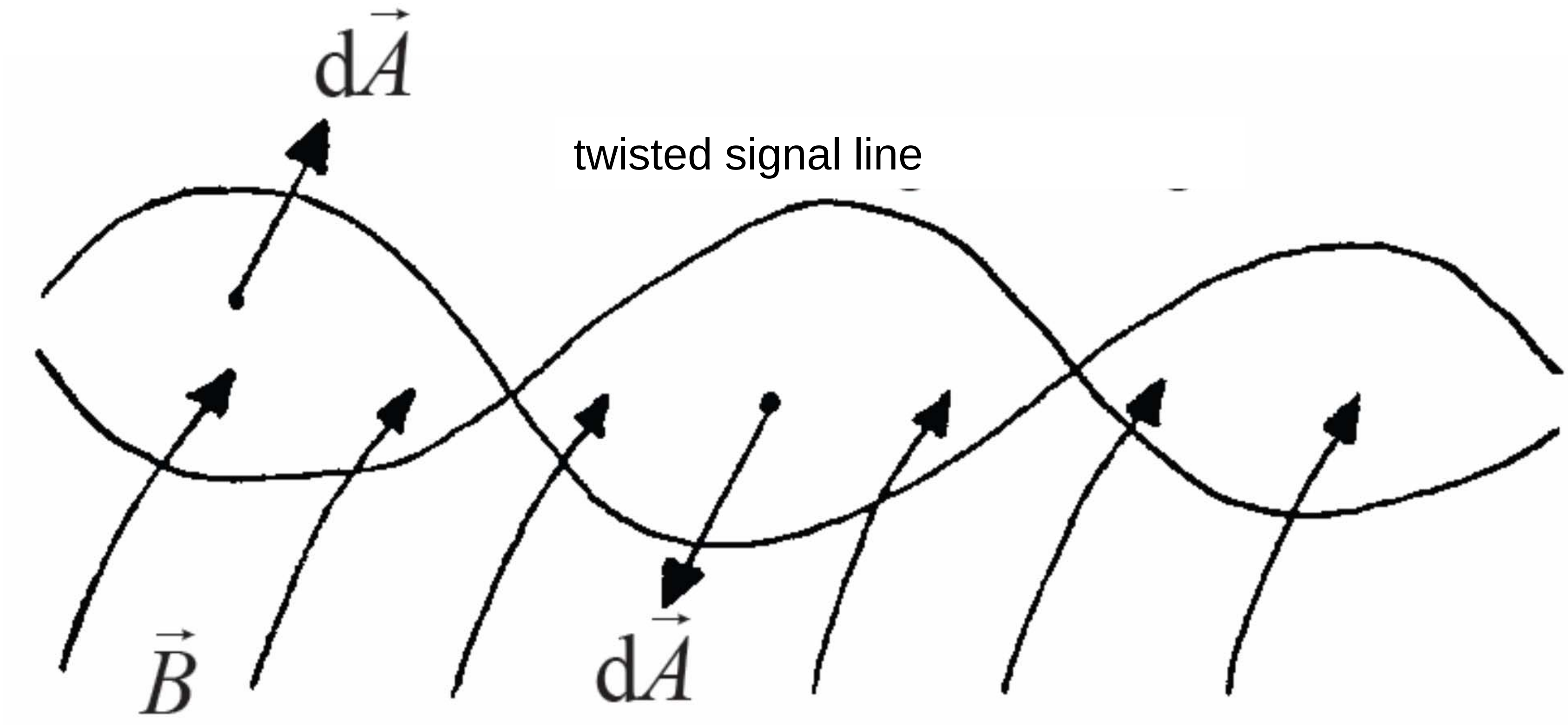
For low frequency

Multi-point parallel grounding

For high frequency (>10 MHz)



3.5.2 Shielding against magnetic fields



$$\partial\phi = \vec{B} \cdot \partial\vec{A}$$

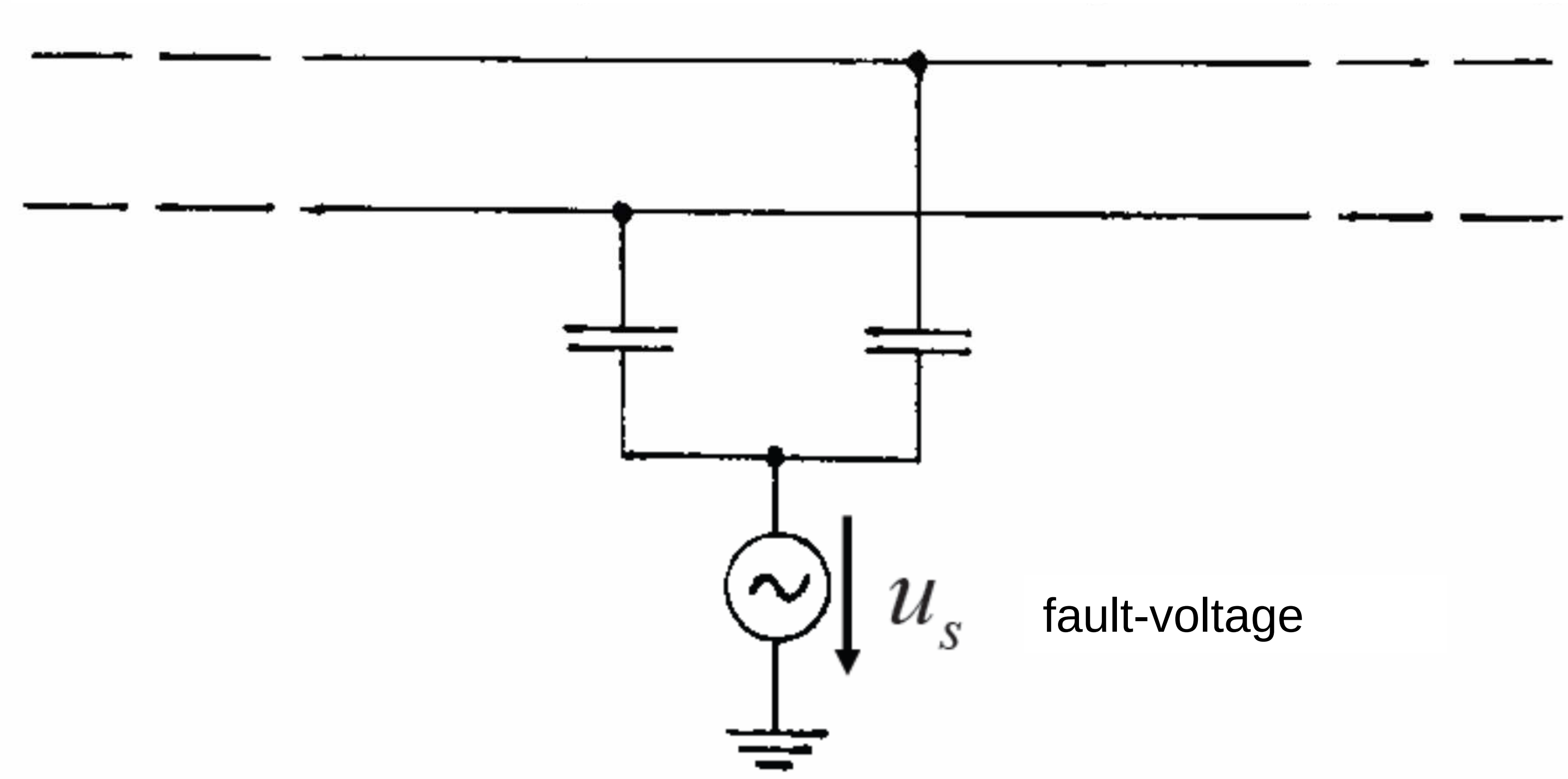
$$\boxed{\phi = \sum \partial\phi = 0}$$

<u>condition:</u> homogeneously distributed magnetic field

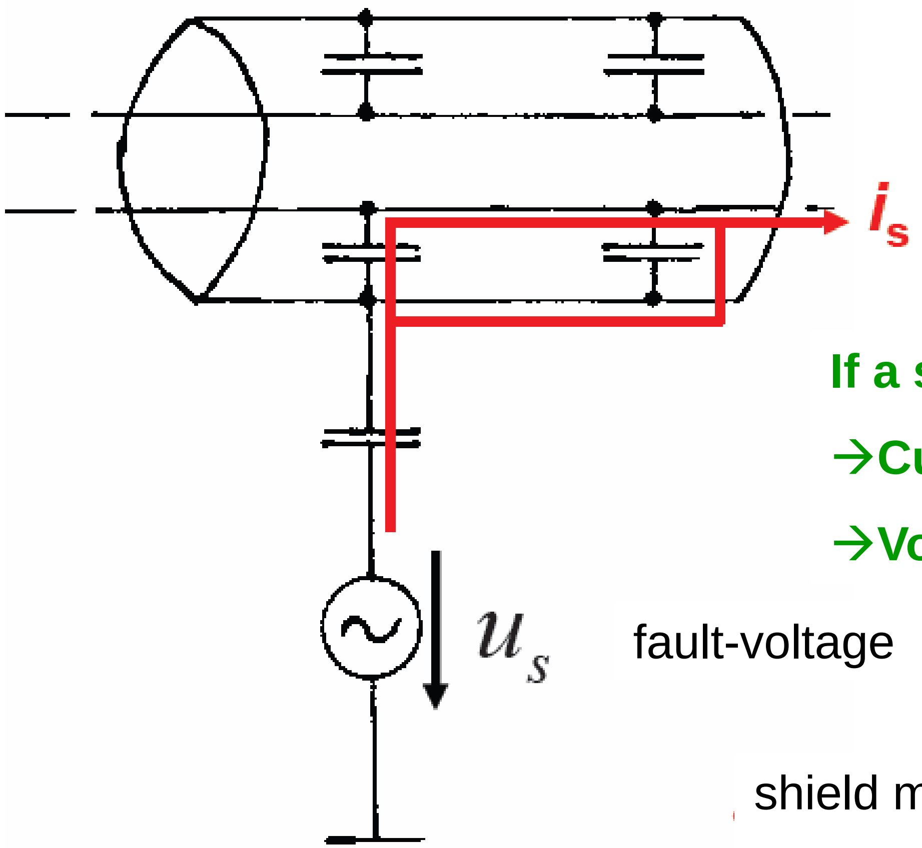
<u>Practical rule:</u> 30 twist/metre

3.5.3 Shielding against electric fields

compensation-schematic of the capacitive dispersal at doublel-line



3.5.3 Shielding against electric fields (2)



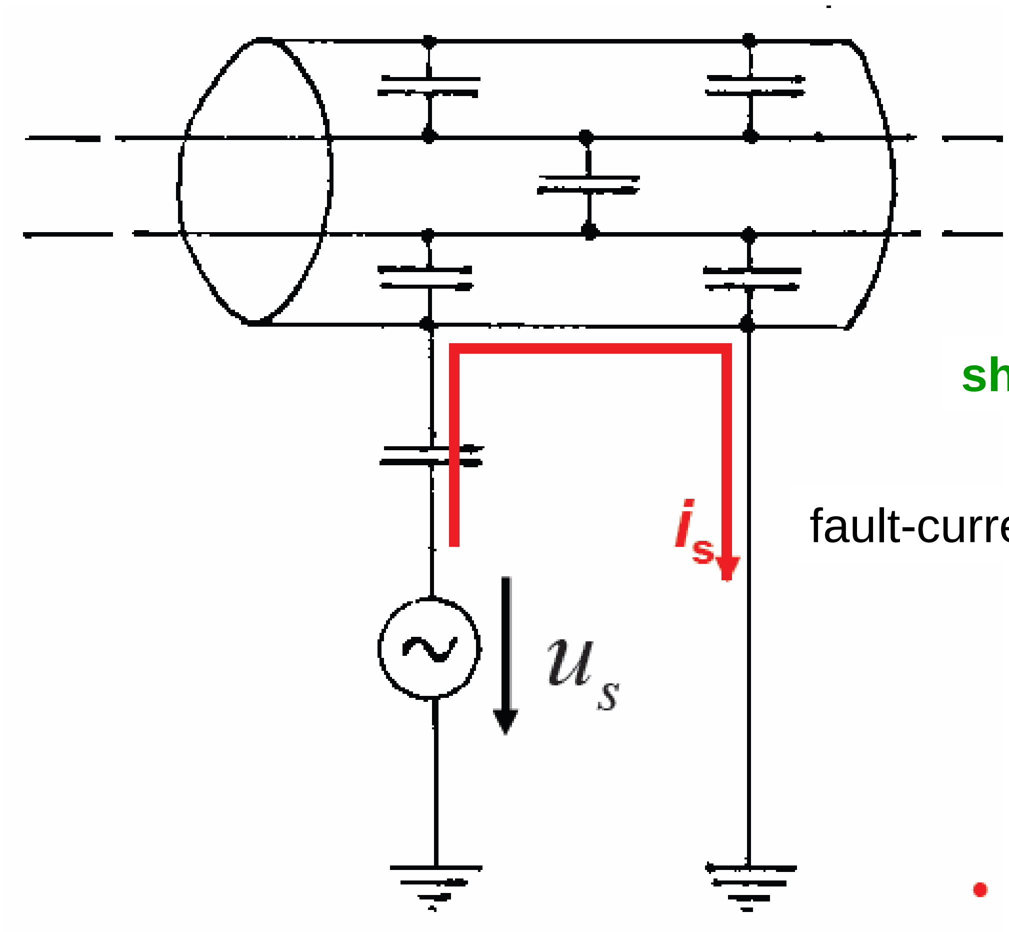
If a shield is not grounded

→Current flows within the shield

→Voltage differences

- shield must be grounded
- problem: to state the reference-potential
- To avoid hum-grinding

3.5.3 Shielding against electric fields (3)



- A shield, who is not grounded, is useless

What did we learn?

Modulation and Demodulation is important for **weak signals**. It is robust and not needing a lot of effort.

Prerequisites:

- Carrier frequency signal with a higher frequency (e. g. 100 times more)
- The new signal hast signal part at: ω_t, : $\omega_t - \omega$ and $\omega_t + \omega$
- The new signal is useful if we have a slow equipment which should measure high frequency
- Demodulation can be done by phase sensitive rectification and Low pass filtering, but also by multiplication and low pass filtering.

Disturbing effects are in general Magnetic fields, electric fields, switching, cables, noise, …

Against magnetic fields:

- To hold a certain distance from sources
- Reduce the surface of layout, measurement set-up, …
- To use twisted cables

What did we learn?

Against disturbances by electric fields
- Using grounded shields
- Without grounding, a shield is useless

Against cable effects
- To use a direct connection to ground
- For high frequencies: To limit the length of cables/connectors

Against switching effects:
- Separate analog and digital ground in a system.

Against reflections:
- Maintain the cable impedances matching the inner resistance of the corresponding port