2. Sensor Properties

2.0 Introduction

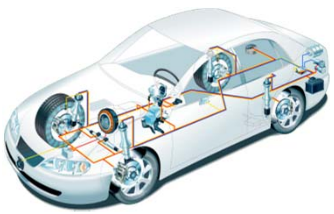
2.1 Static Properties

Sensitivity (Empfindlichkeit),
Sensitivity to influence effects (Empfindlichkeit auf Einflussgrößen),
Resolution (Auflösung),
Reproducibility (Reproduzierbarkeit),
Linearity (Linearität),
Hysteresis (Hysterese),
Drift,
Errors(Ausfall)

2.2 Dynamic Properties

Dead time (Totzeit)
Slow rate (Anstiegszeit)
Delay Time (Verschiebungszeit)
Settling Time (Einschwingzeit)

Application



Special
Requirements

Sensor?

Which criterions are important?

Sensor

Principe
Typ
Packaging
….

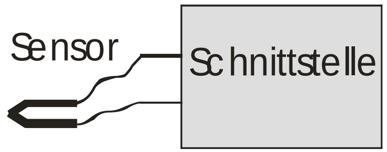
2.0 Introduction

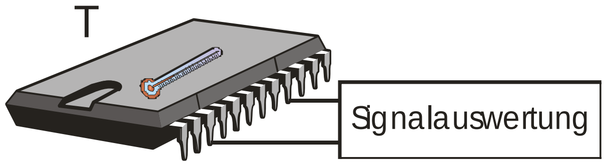
Preselection of sensors

Application conditions: Temperature, Polluants, contacting

Efficiency, long time stability, ...

Geometrical dimensions, integrability





Temperatursensor	Meßbereich in °C	Signal	Fehler
Thermoelement	- 200 ... 1600	10 µV/K	1 K
Metallwiderstand	- 270 ... 900	0,4 W/K	0,1 K
Heißleiter (NTC)	- 55 ... 330	1 KW/K	0,1 K
Kaltleiter (PTC)	- 30 ... 350	10 KW/K	1 K
Si-Diode	- 50 ... 150	2 mV/K	2 K
Si-Streuwiderstand	- 50 ... 150	2 V/K	0,5 K
Si-IC	- 55 ... 125	10 mV/K	0,5 K
Pyro-Sensor	- 50 ... 1000	10^2 V/K	1 %
Permalloy-Sensor	- 40 ... 140	3,8 mV/K	0,4 K
Quarzoszillator	- 0 ... 140	450 Hz/K	0,1 %

Typical values

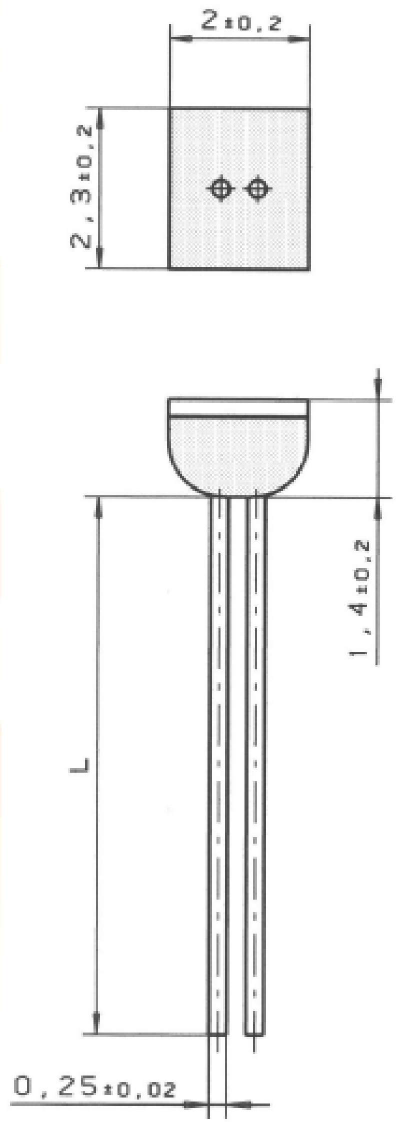
Resistance Thermometer

M - Medium Temperatureinsatzbereich (-70°C bis +600°C)

Bezeichnung	Ohmwert	Temperatur-koeffizient (TK)	Größe (mm)			Temperatur-einsatzbereich (°C)	Hauptanwendungsfeld / Beschreibung
			Länge	Breite	Höhe		
M 213	100/1000	3850	1,7	1,2	0,9	-70 bis +500	
M 219	100/1000	3750	2,1	1,9	0,9	-70 bis +500	
M 220	100	3850	2,3	1,9	0,9	-70 bis +500	
M 222	100/500/1000	3850	2,3	2,1	0,9	-70 bis +500	
M 310	100/1000	3850	3,0	1,0	0,9	-70 bis +500	
M 410 ax	100	3850	3,7	0,9	0,9	-70 bis +500	Axiale Drähte
M 416	100	3850	3,9	1,5	0,9	-70 bis +500	
M 422	100/500/1000	3850 / 3750	3,9	2,1	0,9	-70 bis +500	
M 622	1000/2000	3850	5,9	2,1	0,9	-70 bis +500	
M 622	10000	3850	5,9	2,1	0,9	-70 bis +500	
M 1020	100/500/1000	3850	9,5	1,9	0,9	-70 bis +500	
MH 220	100	3850	2,3	1,9	0,9	-70 bis +600	
MH 410 ax	100	3850	3,7	0,9	0,9	-70 bis +600	Axiale Drähte
MH 416	100	3850	3,9	1,5	0,9	-70 bis +600	
MH 420	100/500/1000	3850	4	2	1,3	-70 bis +600	
MH 1020	100/500/1000	3850	9,5	1,9	0,9	-70 bis +600	
M 220 DBS	100/1000	3850	2,3	1,9	0,9	-70 bis +500	DBS: Direct Bonding Strip ; Anschlussbänder statt Drähte
M 420 DBS	100/1000	3850	3,9	1,9	0,9	-70 bis +500	DBS: Direct Bonding Strip ; Anschlussbänder statt Drähte
M 420 DBW	100/1000	3850	3,9	1,9	0,9	-70 bis +500	DBW: Direct Bonding Wire

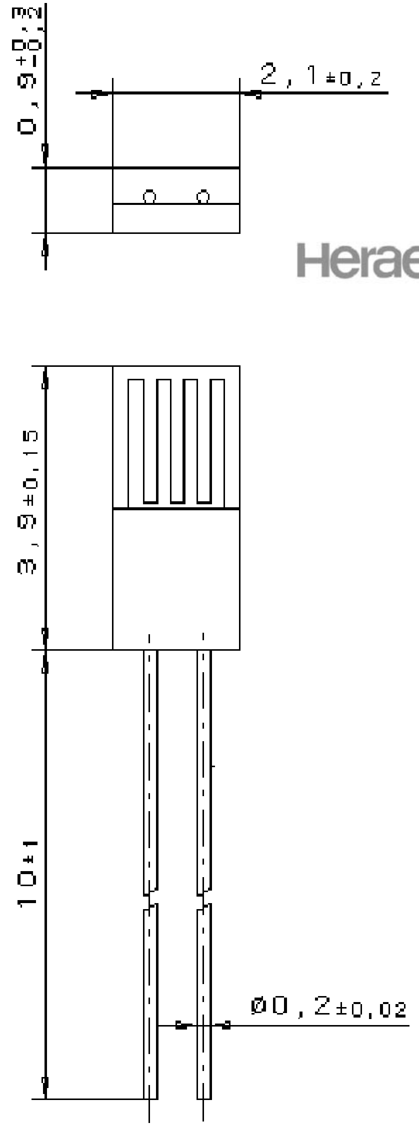
Example of a Data Sheet of a Resistance Thermometer Pt 100

Specification	DIN EN 60751 (according to IEC 751)
Temperature range	-50℃ to +400℃ (continuous operation) Tolerance class B: - 50 ℃ to + 400 ℃
Temperature coefficient	TCR = 3850 ppm/K
Leads	AuPd
Lead lengths (L)	10 mm +- 1 mm
Long-term stability	max. R_0-drift 0.04% after 1000 h at 400℃
Vibration resistance	at least 40 g acceleration at 10 to 2000 Hz, depends on installation
Shock resistance	at least 100 g acceleration with 8ms half sine wave, depends on installation
Environmental conditions	unhoused for dry environments only
Insulation resistance	> 100 MΩ at 20℃; > 2 M Ω at 500℃
Self heating	0.4 K/mW at 0℃
Response time	water current (v = 0.4 m/s): $t_{0.5}$ = 0.20 s $t_{0.9}$ = 0.30 s air stream (v = 2 m/s): $t_{0.5}$ = 3.0 s $t_{0.9}$ = 9.0 s
Measuring current	0.3 to 1.0 mA (self heating has to be considered)
Note	Other tolerances, values of resistance and wire lengths are available on request.



Beispiel: Datenblatt eines Widerstandsthermometers (Pt100)

Spezifikation	DIN EN 60751
Temperaturbereich	- 70 °C bis + 500 °C (Dauerbetrieb) (kurzzeitig bis 550 °C möglich) Gültigkeit der Klasse B: - 70 °C bis + 500 °C Gültigkeit der Klasse A: - 50 °C bis + 300 °C Gültigkeit der Klasse 1/3 DIN: 0 °C bis + 150 °C
Temperaturkoeffizient	TK = 3850 ppm/K ; 3750 ppm/K auf Anfrage
Anschlussdrähte	NiPt-Manteldraht
Langzeitstabilität	Max. R_0-Drift 0,04% nach 1000 h bei 500 °C
Erschütterungsfestigkeit	Mindestens 40 g Beschleunigung bei 10 bis 2000 Hz, abhängig von Montageart
Stoßfestigkeit	Mindestens 100 g Beschleunigung mit 8ms Halb-Sinus-Welle, abhängig von der Montageart
Umgebungsbedingungen	Ungeschützt nur in trockener Umgebung einsetzbar
Isolationswiderstand	> 100 MΩ bei 20 °C; > 2 MΩ bei 500 °C
Selbsterwärmung	0,3 K/mW bei 0 °C
Ansprechzeit	Bewegtes Wasser (v = 0,4 m/s): $t_{0,5}$ = 0,07 s; $t_{0,9}$ = 0,20 s; Luftstrom (v = 2 m/s): $t_{0,5}$ = 3,2 s; $t_{0,9}$ = 11 s;
Messstrom	100 Ω: 0,3 bis 1,0 mA 500 Ω: 0,1 bis 0,7 mA 1000 Ω: 0,1 bis 0,3 mA (Selbsterwärmung berücksichtigen)



Heraeus

M 422

Capacitive fill level sensor

Performance characteristics

Reference operating conditions

- Temperature = +68°F ± 40°F (+20°C ± 5°C)
- Pressure = 15 psia ± 0.3 psi (1013 mbar abs. ±20 mbar)
- Humidity = 65 % ± 20%
- Medium = water from mains (conductivity ≥ 180 µS/cm)
- Rod probe PFA: Probe length 3 ft (1 m)

Maximum measured error

- Linearity: 0.5 %
- Reproducibility: 0.1 %

Influence of ambient temperature

Electronic insert

< 0.06 % / 10 K related to the full scale value

Separate housing

Change in capacitance of connecting cable 0.015 pF/m per K

Startup settling time

FEI50H
14 s (stable measured value after switch-on procedure)

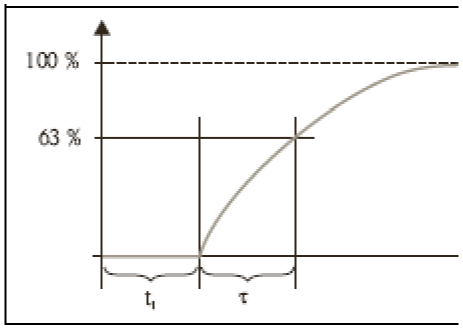
FEI57C
1.5 s (stable measured value after switch-on procedure)

Measured value reaction time

FEI50H
$t_1 \leq 0.3$ s
$t_1 \leq 0.5$ s for operating mode SIL

FEI57C
$t_1 = 0.3$ s

Note!
Observe integration time of switching unit



τ = Integration time
t_1 = Measured value reaction time

Endress+Hauser

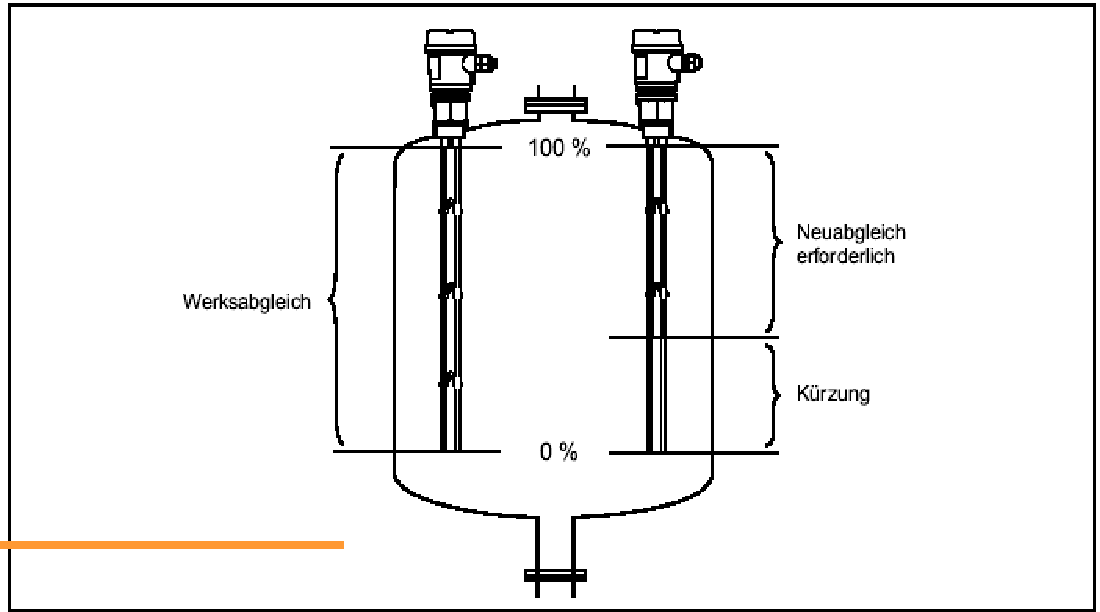
Liquicap M FMI51, FMI52

Capacitive Level Measurement
For continuous measurement in liquids

Capacitive fill level sensor

Liquicap T FMI21

Endress+Hauser

Referenzbedingungen	■ Umgebungstemperatur: 23 °C ■ Messstofftemperatur: 23 °C ■ Messstoffviskosität: Medium muss die Sonde wieder freigeben (abtropfen < 2000 cst) ■ Atmosphärischer Druck ■ Sondeneinbau: vertikal von oben
Messabweichung (Linearität)	≤ 1 % vom Messbereichsendwert (aktiver Sondenstab)
Wiederholbarkeit	0,25 % vom Messbereichsendwert
Einschalteinschwingzeit	< 2 s (Stabiler Messwert nach Einschaltvorgang)
Einfluss der Umgebungstemperatur	< 0,01 %/K (–40...+70 °C) bei einer Sondenlänge von 1 m
Integrationszeit	τ =1 s (fest eingestellt) Die Integrationszeit beeinflusst die Geschwindigkeit, mit der die Anzeige sowie der Stromausgang auf Änderungen des Füllstandes reagieren.
Werksabgleich	

2.1 Static Properties

Sensitivity

Sensitivity on influence factors

Resolution

Reproducibility

Linearity

Hysteresis

Drift

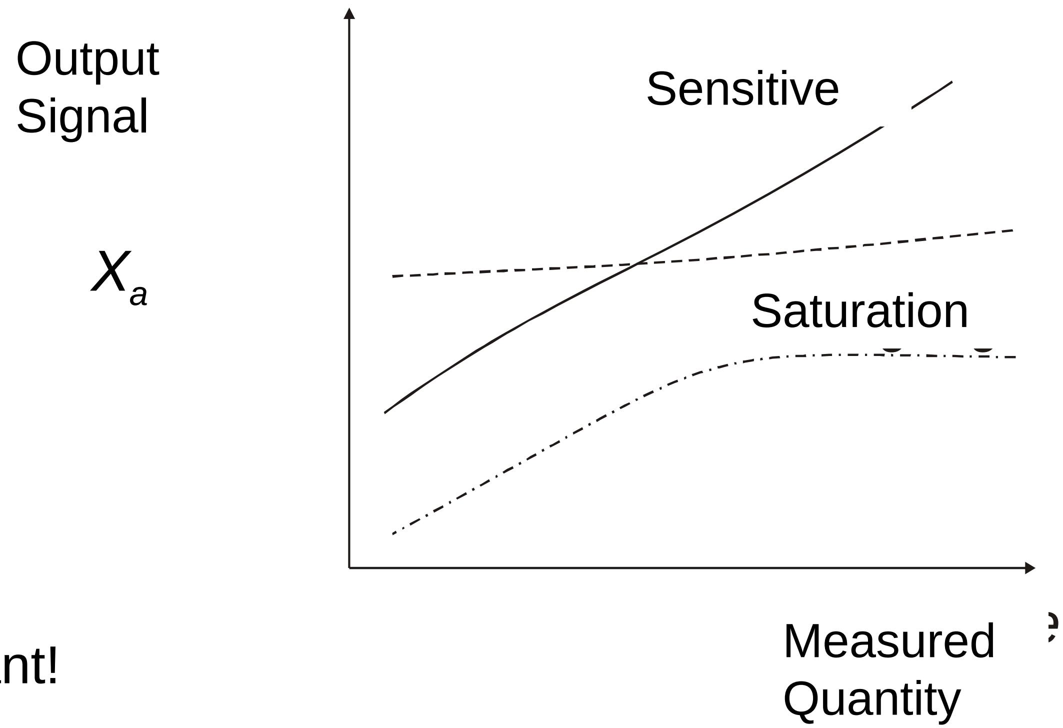
Failure

Precision

Sensitivity

Changes of the signal versus changes of the input

$$E = \frac{\partial X_a}{\partial MeasQ}$$



A high sensitivity is important!

Sensitivity: Example NTC-Resistance

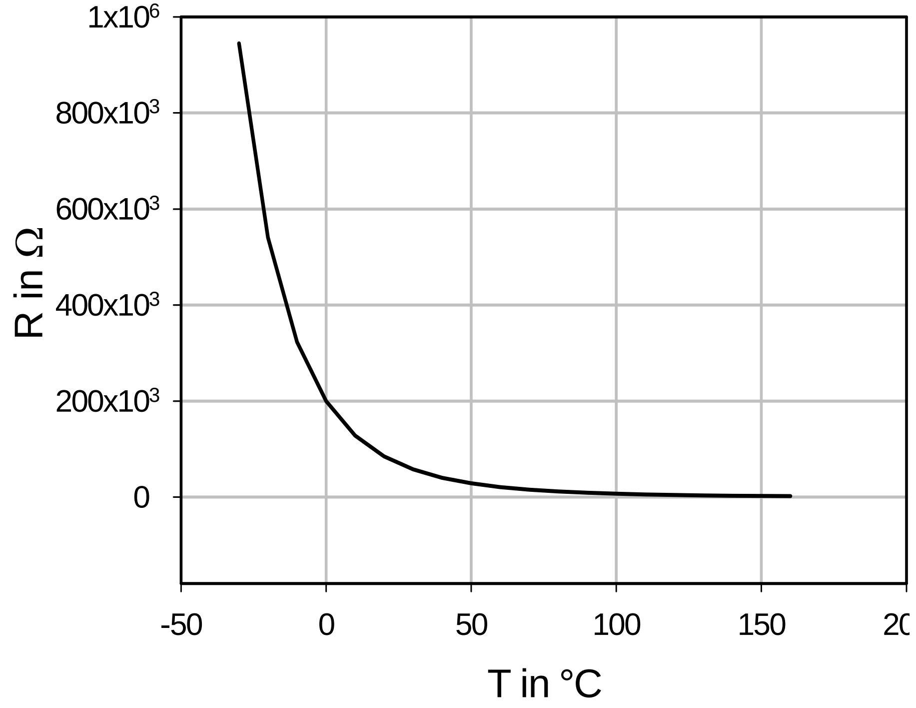
$$R = R_0 \cdot e^{b\left(\frac{1}{T}-\frac{1}{T_0}\right)} = R_0 \cdot e^{\frac{-b}{T_0}} e^{\frac{b}{T}}$$

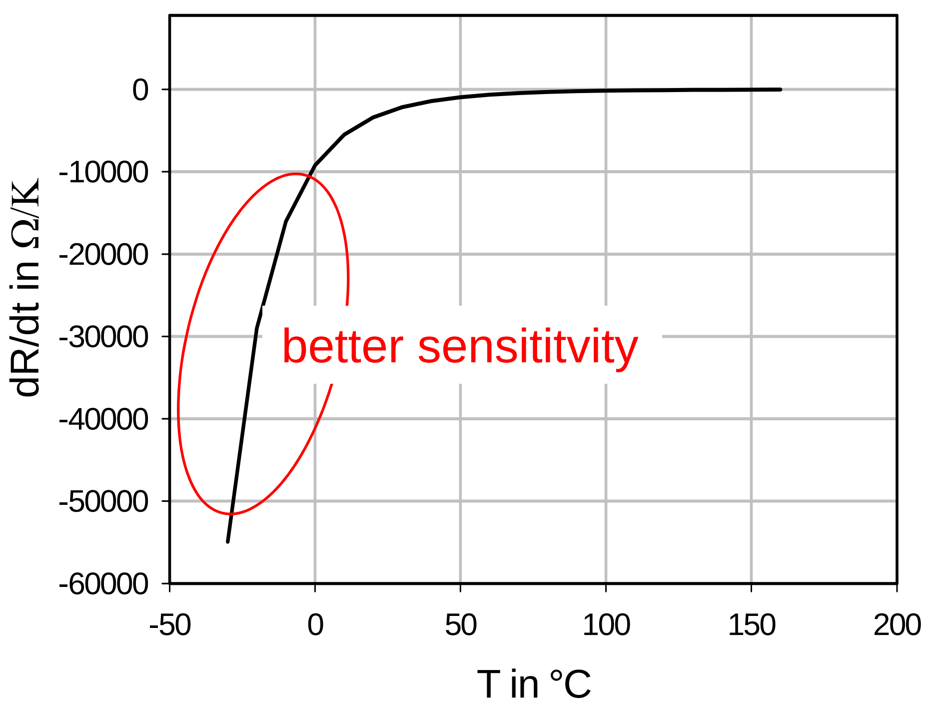
$$E = \frac{dR}{dT}$$

$$= R_0 \cdot e^{\frac{-b}{T_0}} e^{\frac{b}{T}} \cdot \left(-\frac{b}{T^2}\right) = -\frac{b}{T^2} R$$

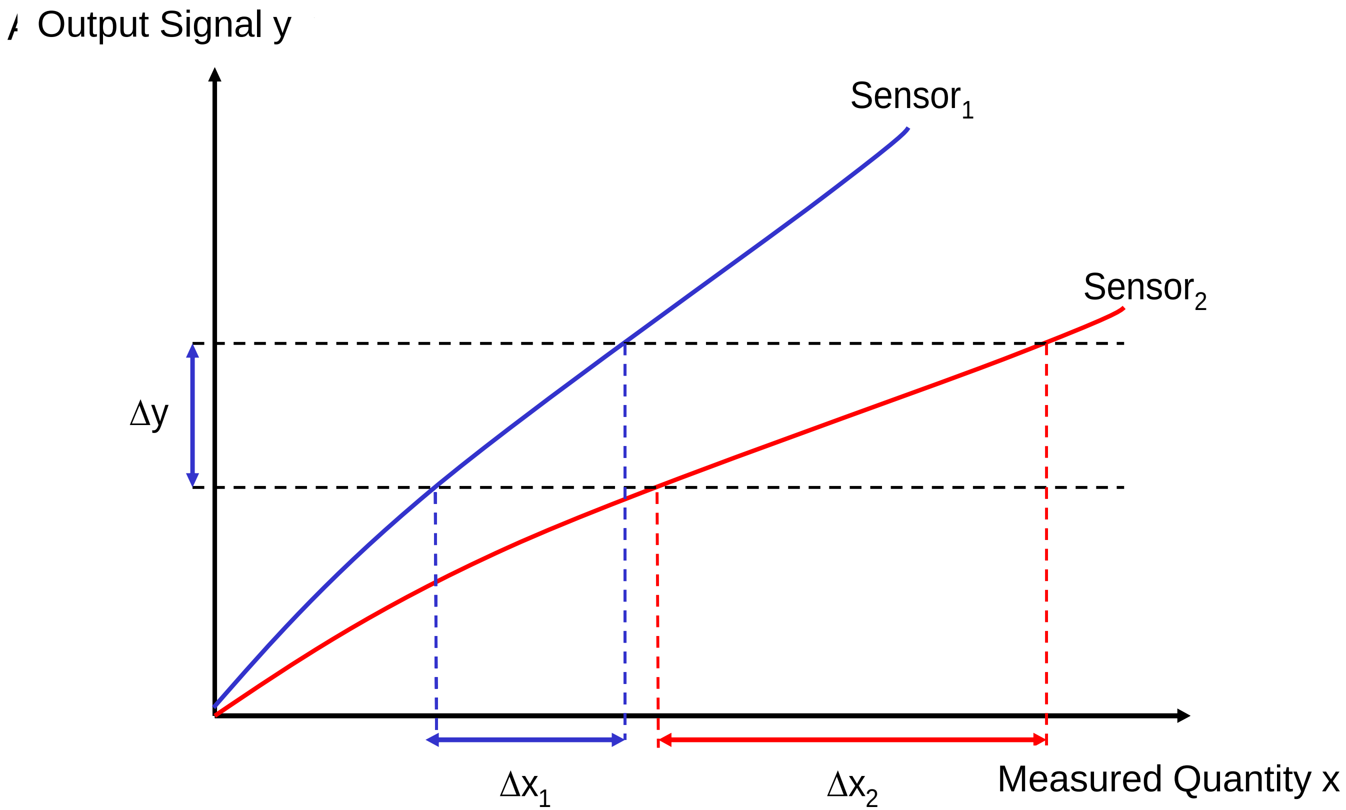
b: Material Constant

R_0: Resistance at the Temperature T_0





Sensitivity and Accuracy



For a more sensistive sensor an observed change of the sensor signal Δy corresponds to a smaller change Δx of the measured quantity

A measurement deviation at the output signal leads to a smaler deviation of the measurement quantity

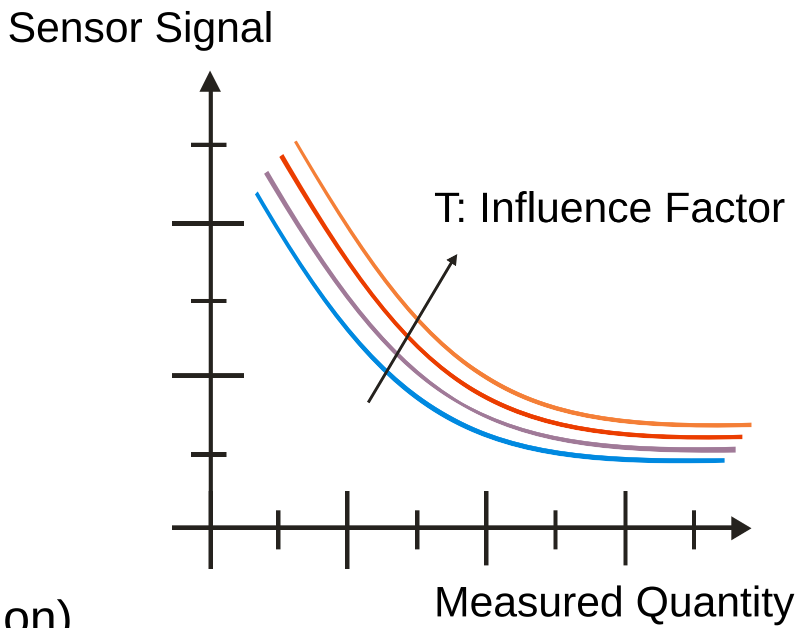
Sensitivity to Influence Factors

Sensitivity on modifying input

Sensor signal changes depending on variable which different to the measurement quantity

e. g. Influence of temperature on

- Changes of material properties
- Changes of activation energies
- Changes of transport mechanisms (Diffusion)



Cross Sensitivity

Sensitivity to Interfering inputs

Sensor reacts on the same way on the measurand and the interfering inputs

e. g.: A gas sensor for oxygen shows sensitivity to other gases

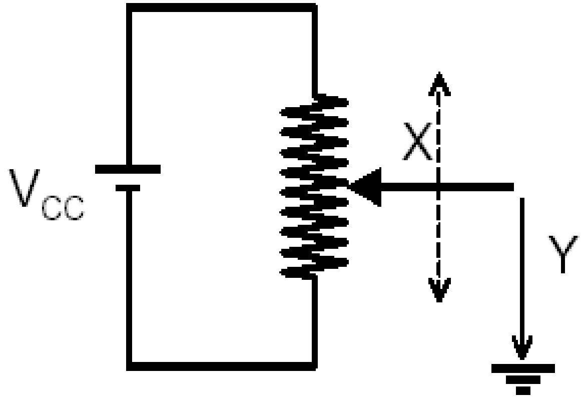
Resolution

..smallest change of the input signal leading to an observable change of the output signal

Typical Description xx Measurand

xx % of the upper range value

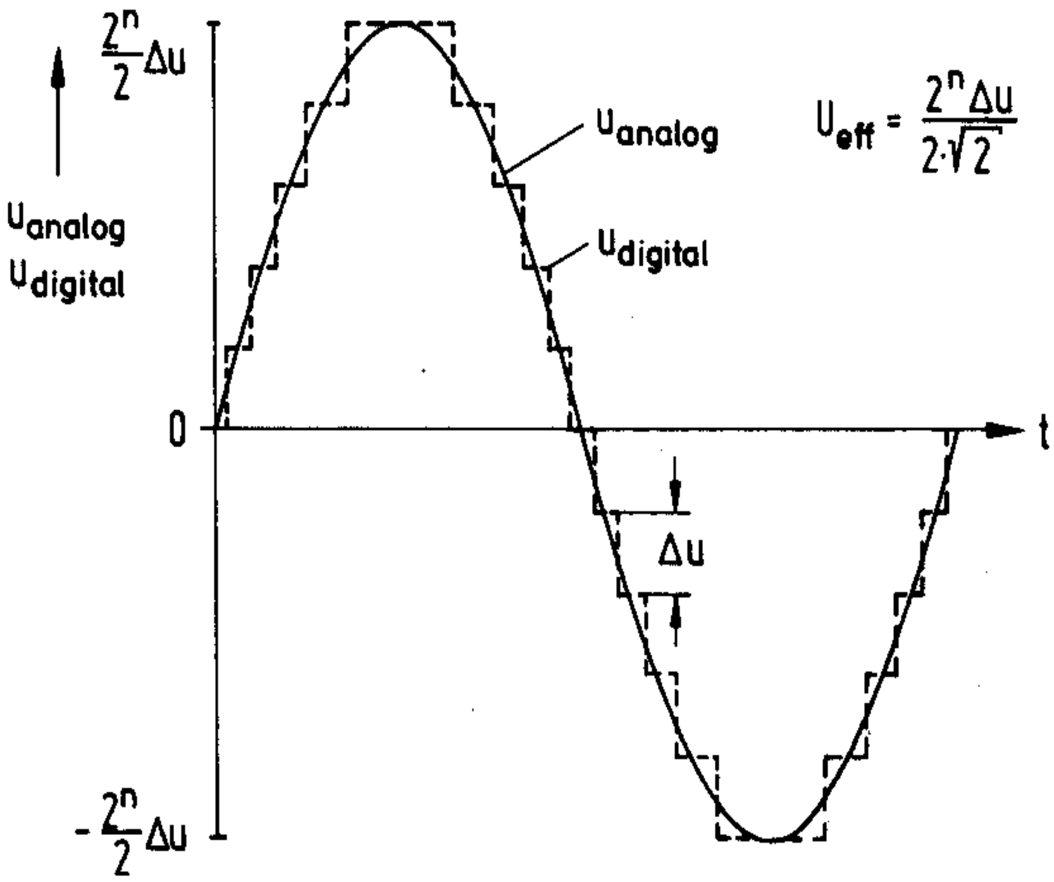
Example: Resolution of a Person Scales: 100 g



<u>Example: Potentiometer</u>

Sensor signal changes is steps

Resolution of Analog/Digital-Converters



Example:
A/D-converters of 8 Bit resolution

$$\overbrace{11001001}^{n=8\text{ Bit}}$$

LSB: Least Significant Bit

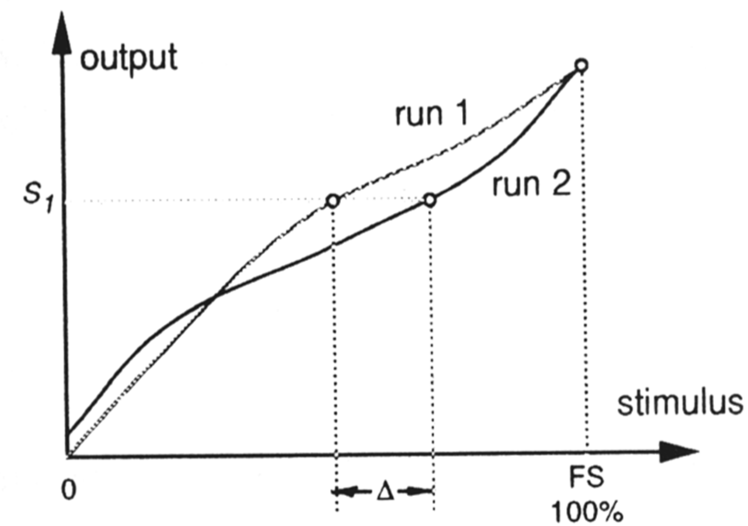
$U_{min} \equiv 00000001$

$U_{max} \equiv 11111111$

$$\Delta U_{LSB} = \frac{U_{max} - U_{min}}{2^n}$$

Reproducibility /Repeatability

Sensor system delivers not the same value, even if the measurement conditions remain the same



Measurand

Possible Causes:

- Thermal Noise
- Material elasticity
- Contamination of Bio and Gas Sensors

Typical description:

$$\Delta = \frac{\Delta y_{\max}}{MBE}$$

$\Delta y_{\max}$: Maximal deviation of the output signal

MBE: end value of the measurement range

Linearity

The transfer behaviour of a system is not linear

Cause: measurement principle

Examination by linearization or numerical differenciation

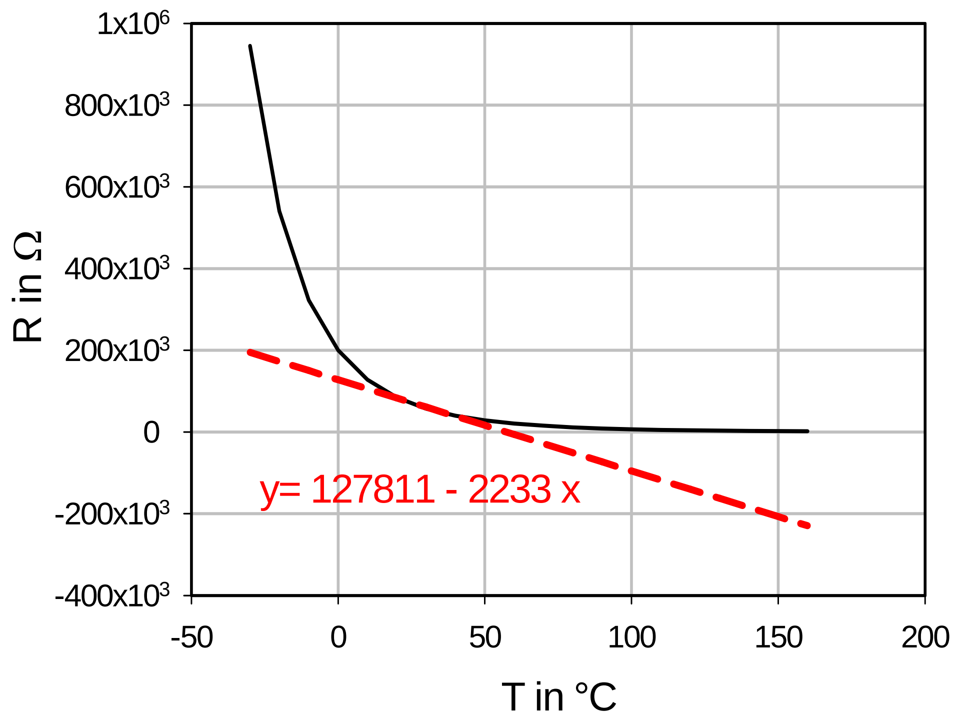
typical description:

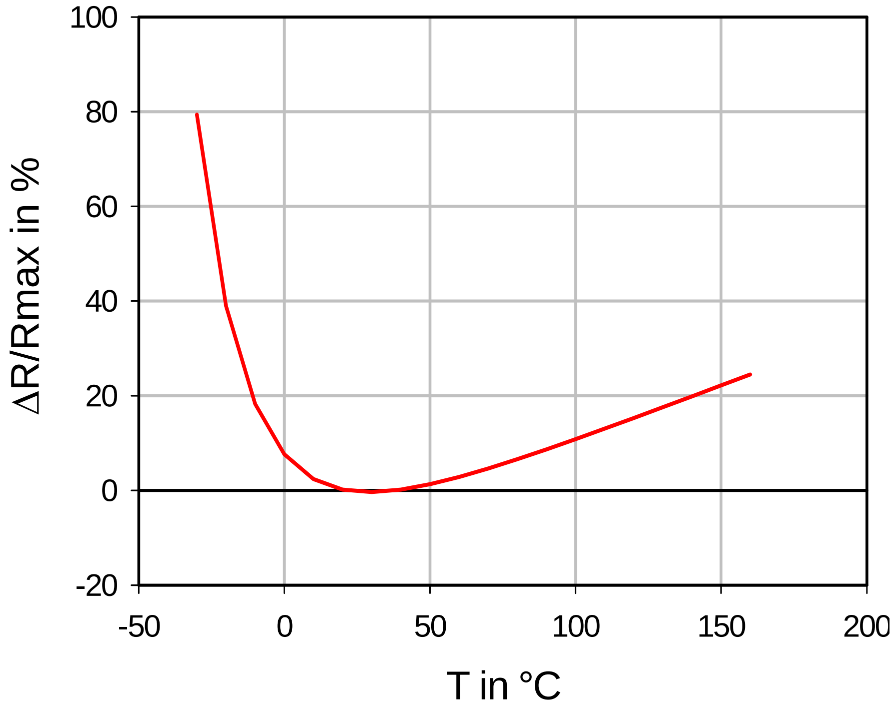
$$\Delta y_{\max}$$

$$\Delta = \frac{\Delta y_{\max}}{MBE}$$

Example: Linearity Deviation of an NTC-Resistance

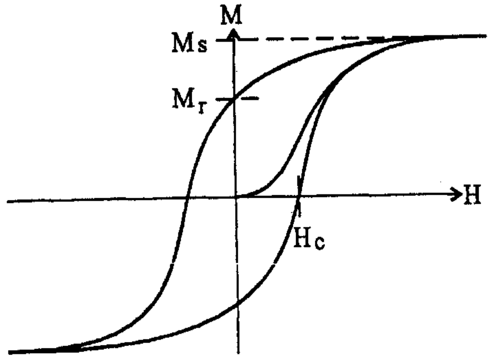
$$R = R_0 \cdot e^{b\left(\frac{1}{T}-\frac{1}{T_0}\right)} = R_0 \cdot e^{\frac{-b}{T_0}} e^{\frac{b}{T}}$$





2.1 Static Properties
Hysteresis

Sensor output signal is dependent on previous values of the input



→ Sensor signal is dependent of the history

→ The dependence of the output signal from input signal is not unique!

typ. Angabe:

$$\Delta = \frac{\Delta y_{\max}}{MBE}$$

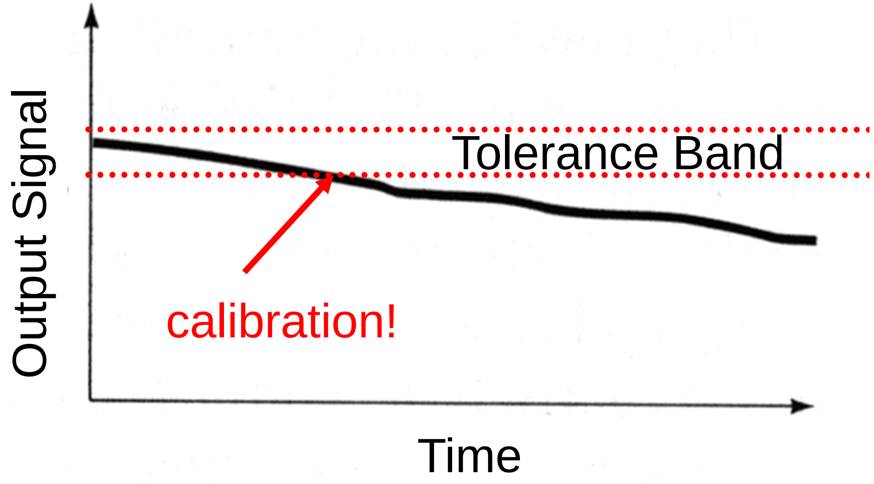
<u>Causes</u>

- Hysteresis of Materials like ferromagnetics
- Friction and settlement of multipart (Screwed or clamped) messurement setups
- Plastic deformation of the assmbly between chip and packaging

2.1 Static Properties
Aging/Drift

Properties of the sensor system change with time.

Drift: is a special type of aging describing:
slow changes with time



Causes, e. g. :
- of Materials
- Setting of atoms in the cristal grid

Ageing is dependent on the application conditions

Linear Sensors:
→ Drift of the zero point
→ Drift of sensitivity

2.1 Static Properties

Failure

MTBF (Mean Time between Failures)

MTTR (Mean Time to Repair)

Availability of a sensor system

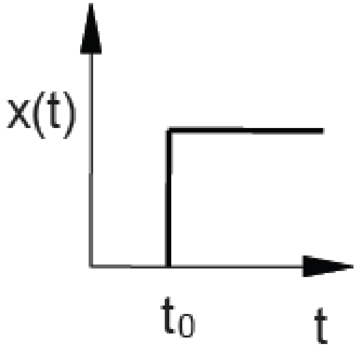
$$V = \frac{MTBF}{MTBF + MTTR}$$

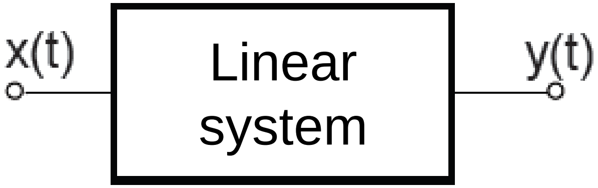
[→DIN EN/IEC61709]

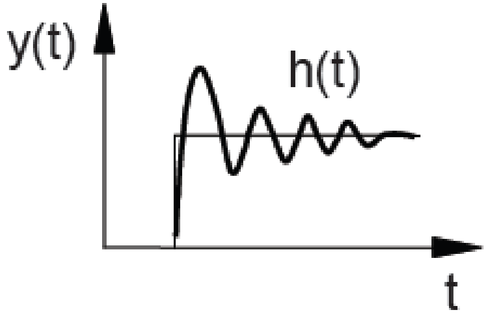
2.2 Dynamic Properties

Characterization of dynamic behaviour

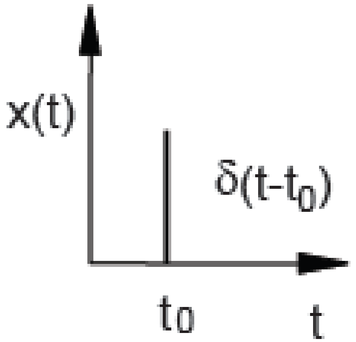
Step-Function

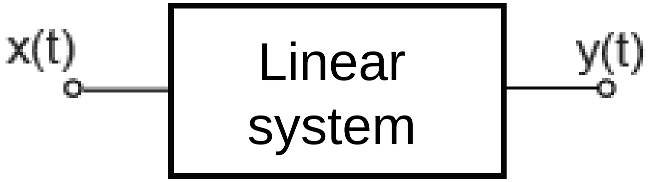


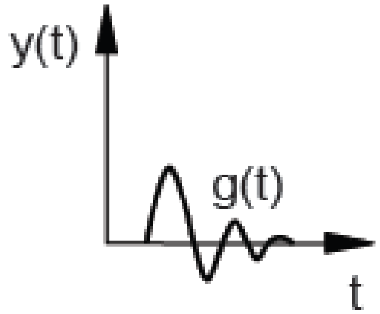




Impulse

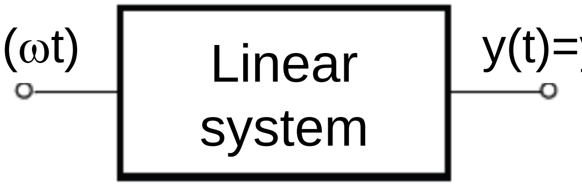






Frequency excitation

$x(t)=x_0\sin(\omega t)$



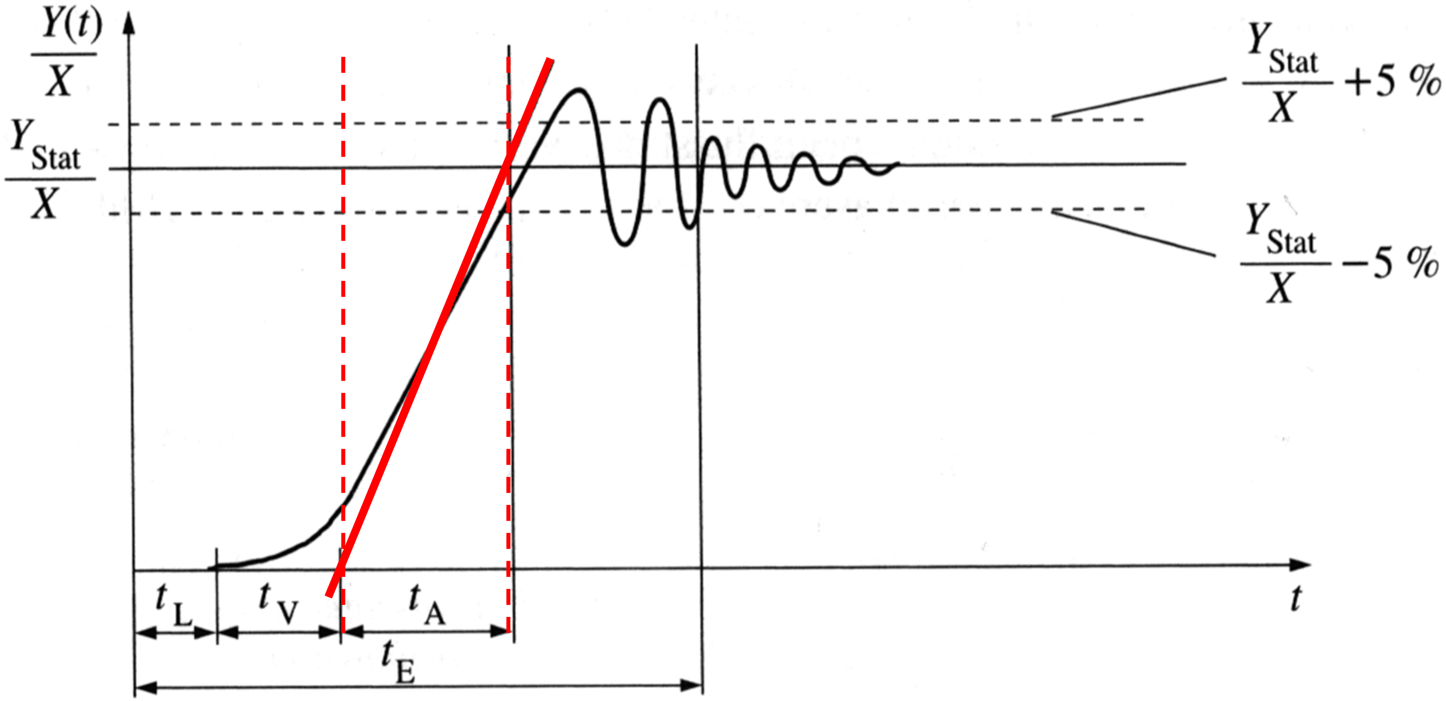
$y(t)=y_0\sin(\omega t+\varphi)$

$H_0(\omega)$ Amplitude

$\varphi(\omega)$ Phase

2.2 Dynamic Properties

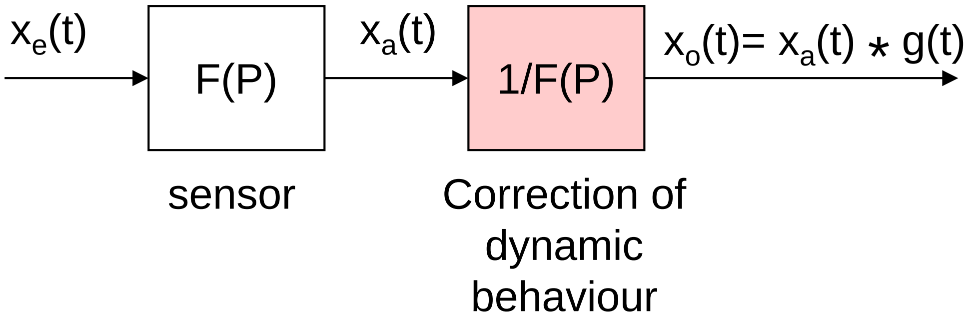
Step Response of a Sensor System (general case!)



t_L: Dead time (Totzeit)
t_A: Slow rate, rise time (Anstiegszeit)
t_V: Delay time (Verschiebungszeit)
t_E: Settling time (Einschwingzeit)

2.2 Dynamic Properties

Dynamic Correction of Linear Systems



$$x_o(t) = \int_0^t x_a(t-\tau)\, d\tau = x_a(t) * g(t)$$

Transferfunktion:

$$g(t) = L^{-1}\left[1/F(P)\right]$$

→ see chapter applications of amplification circuits