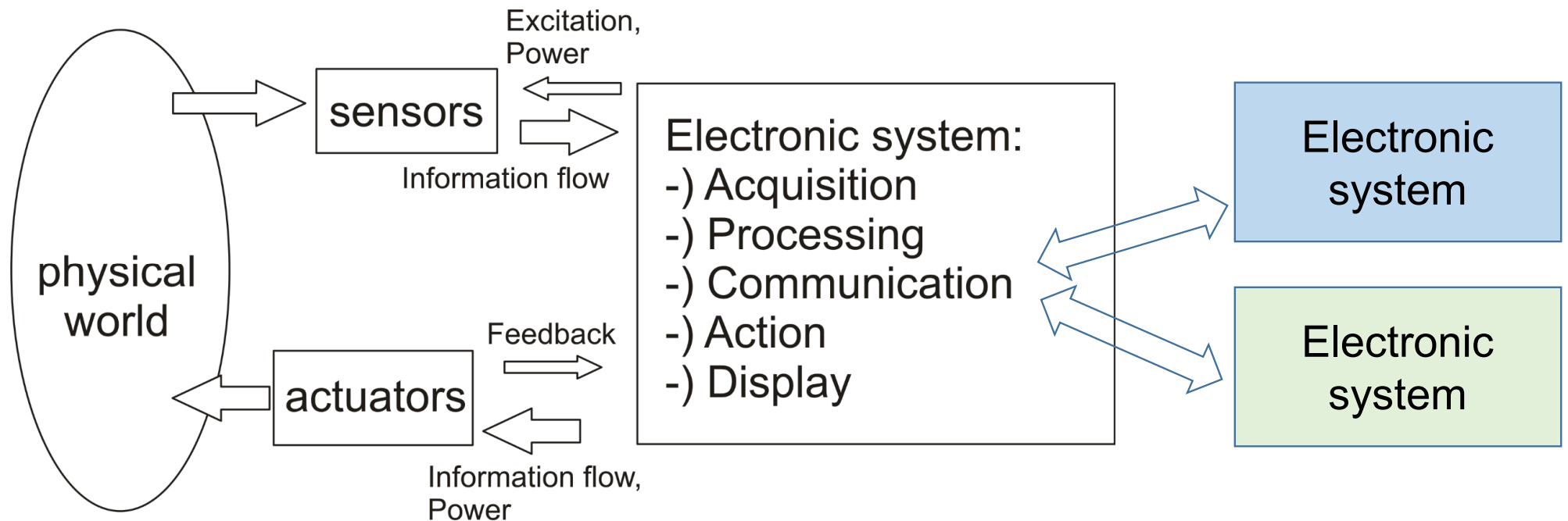# DAS: Data Acquisition Systems

- A DAS is required to allow an electronic system to get information on the external environment

- The development of extremely miniaturized DASs capable of detecting a large number of different and inhomogeneous quantities is currently urged by emerging fields, such as robotics, security and health care.

- This is giving a significant contribution to the request for analog and mixed signal integrated SoCs

- **The design of a DAS involve architectures and specifications that recur in many other branches of analog and mixed signal microelectronic circuits.**

The electronic system and the enviroment

Excitation, Power

sensors

Information flow

physical world

Feedback

actuators

Information flow, Power

Electronic system:
-) Acquisition
-) Processing
-) Communication
-) Action
-) Display

Electronic system

Electronic system

Main blocks of an Electronic System

DAS (full acquisition operations)
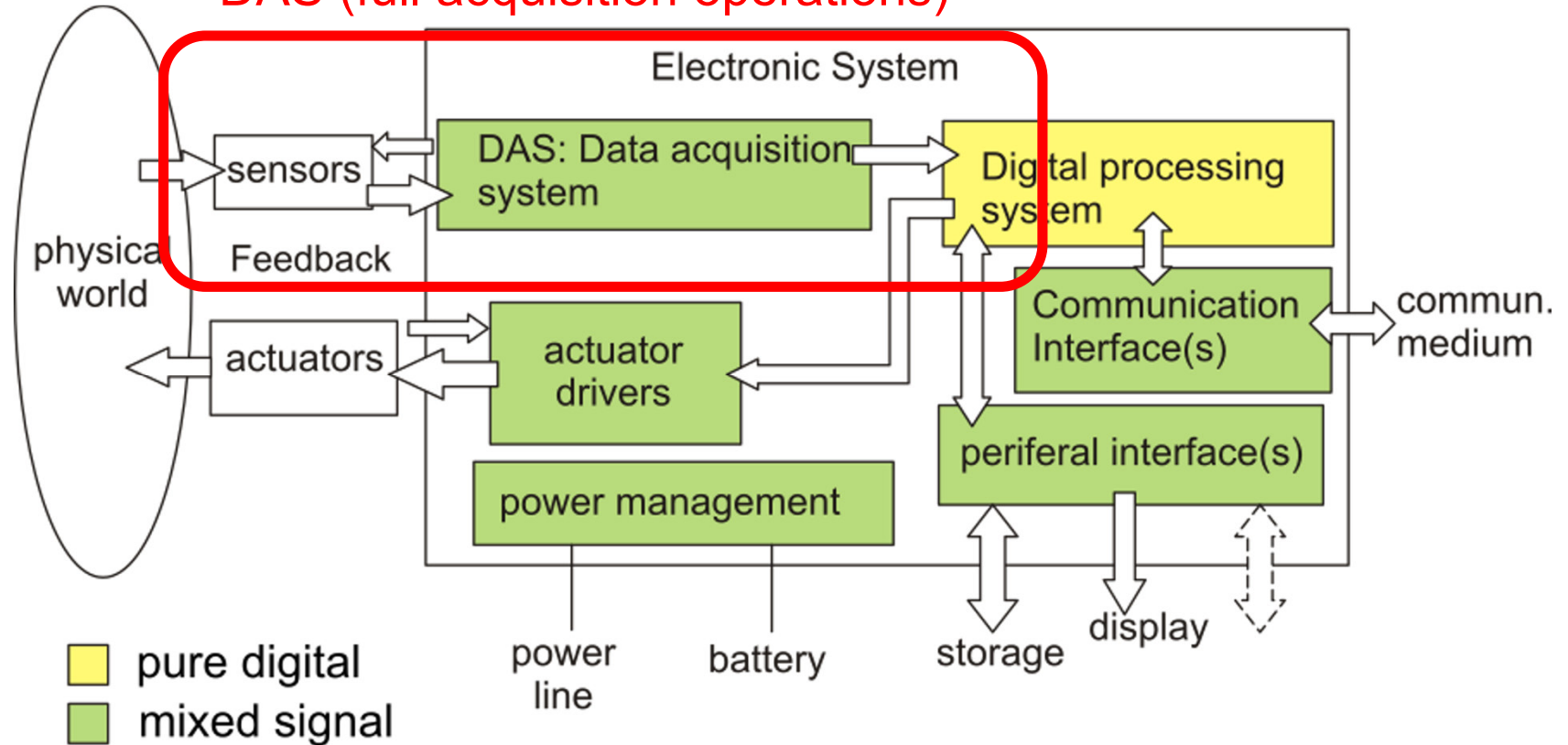
Elements of a DAS: a two-channel case
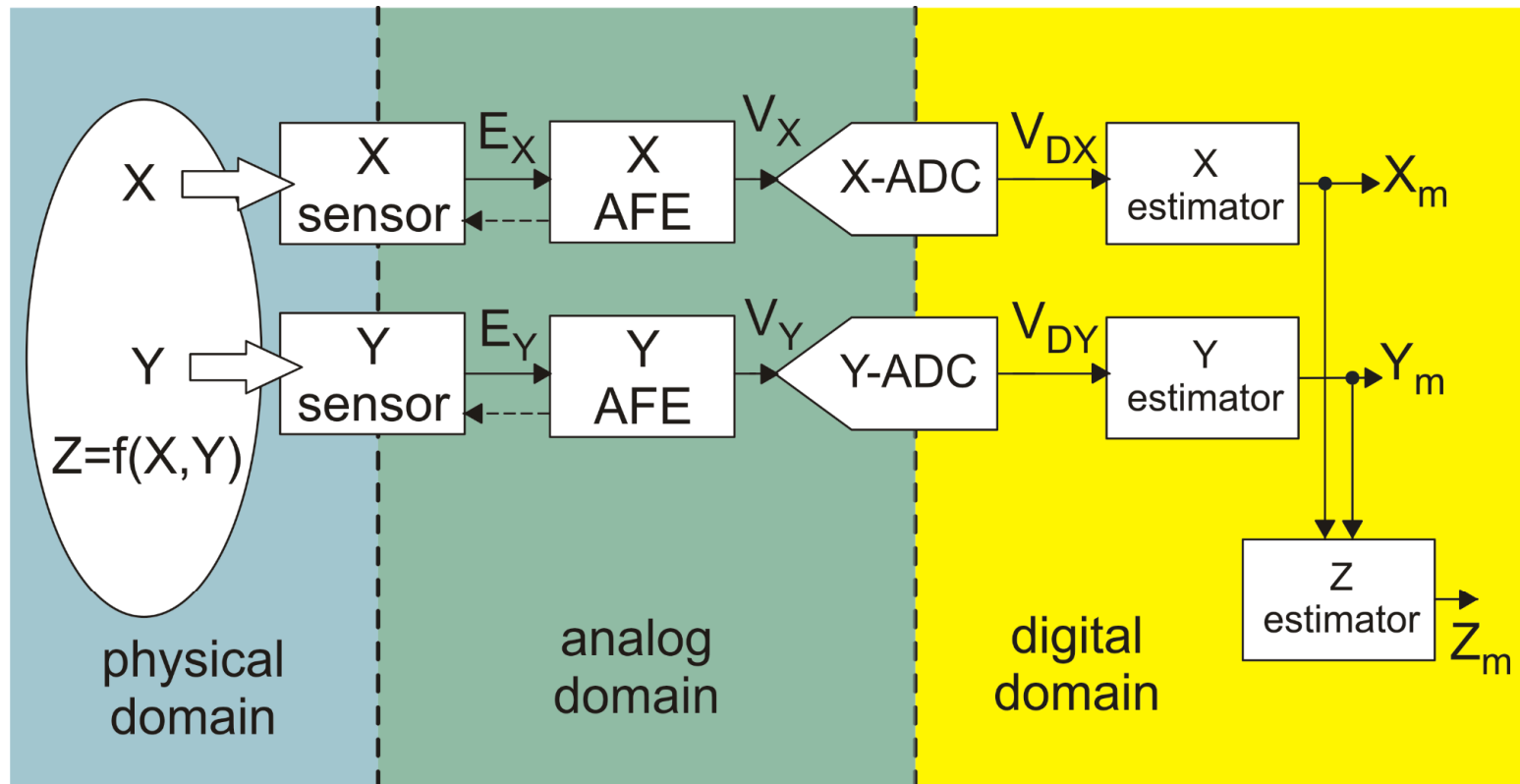
Signal classification on the basis of quantization

Magnitude	Time
digital signals	discrete time
analog signals	discrete time
	continuous time

Errors on the ideal transfer function

Nominal (ideal) case: $V = f(X)$

Once V is known, X can be known exactly:

$$X = g(V) \quad g(x) = f^{-1}(x) \ \text{(inverse function)}$$
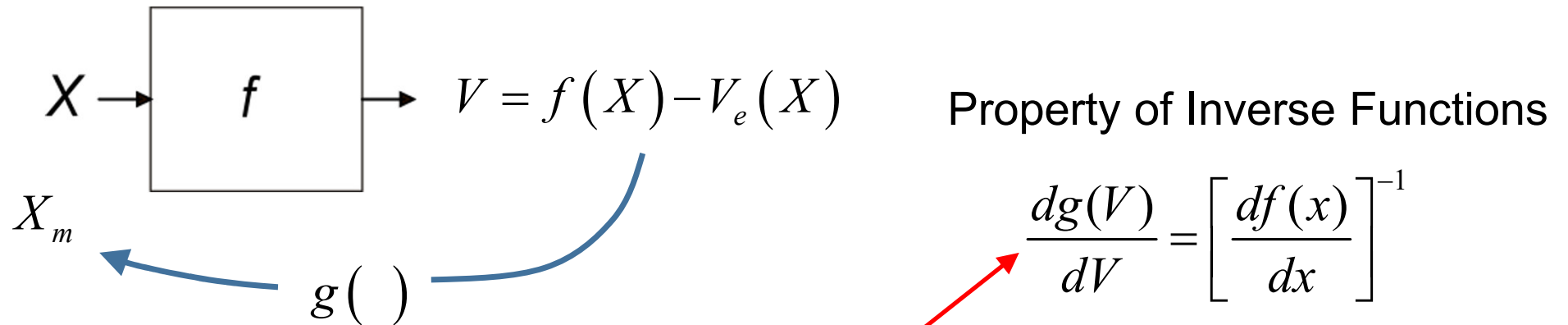
Real case: $V = f(X) - V_\varepsilon(X)$

$V_\varepsilon(X)$ is the **output error** defined as: $V_{ideal} - V$ $\quad$ $\underline{V_{ideal} = f(X)}$

In an acquisition system, the error is not known in a deterministic way.

To find the input quantity (X) we can only apply the inverse of the nominal transfer function to the real output quantity (we do not know the real t.f.):

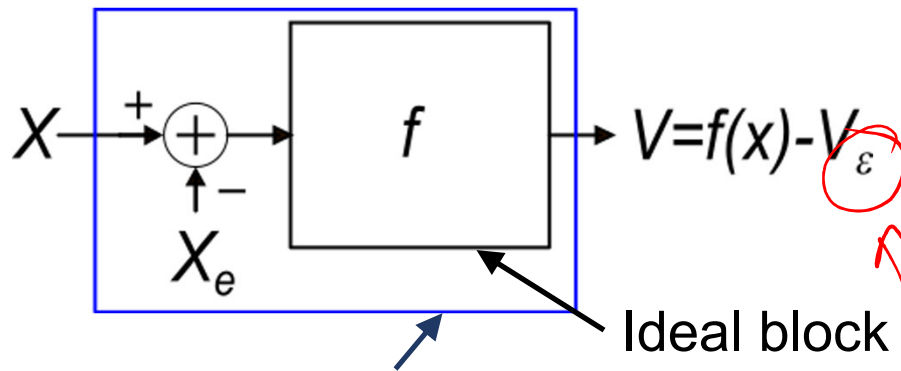$$X_m = g(V) = g\big(f(X) - V_\varepsilon(X)\big)$$

RTI (Referred to Input) Error

$$V = f(X) - V_e(X)$$

$$X_m$$

$$g(\ )$$

Property of Inverse Functions

$$\frac{dg(V)}{dV} = \left[\frac{df(x)}{dx}\right]^{-1}$$

$$X_m = g\big(f(X) - V_e(X)\big) \cong g\big(f(X)\big) - \frac{dg(V)}{dV}V_e(X) = X - V_e\left(\frac{df}{dX}\right)^{-1}$$

$$X_e = X - X_m = V_e\left(\frac{df}{dX}\right)^{-1} \qquad \text{RTI Error}$$

RTI Error: Equivalent block diagram for small errors

If the first order approximation that we have seen holds, it is possible to use the following equivalent representation:

Equivalent representation of the real block

Ideal block

$\text{if:} f(0) = 0$

X_e is the value of the input quantity X that nulls the output

In this case, the dc value of Xe is the input offset

Verification:

$$V = f(X - X_e) \cong f(X) - \left(\frac{df}{dX}\right) X_e$$

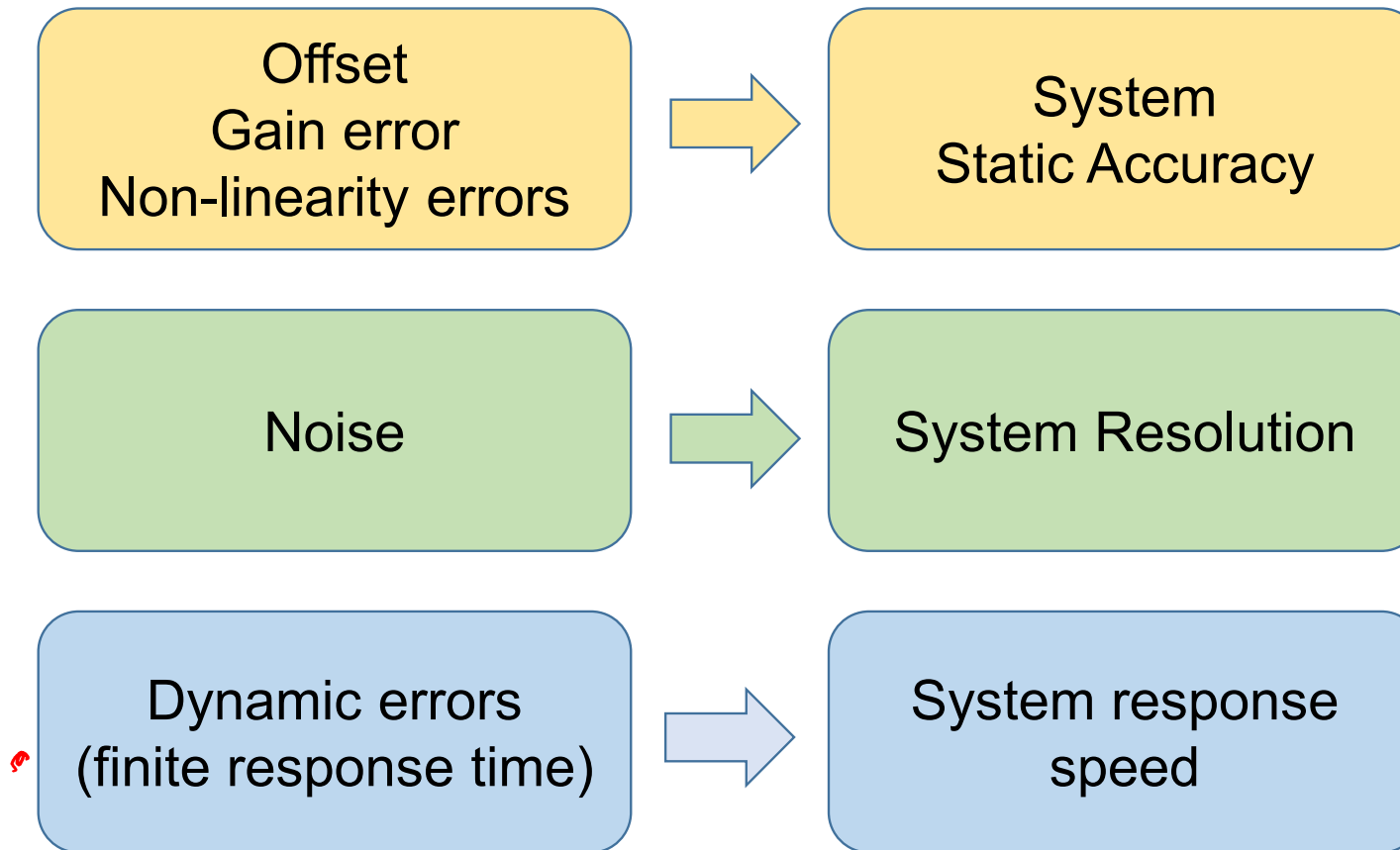$$\text{since:} X_e = V_e \left(\frac{df}{dX}\right)^{-1}$$

$$V \cong f(X) - V_e$$

Then, the equivalent block behaves as the real block

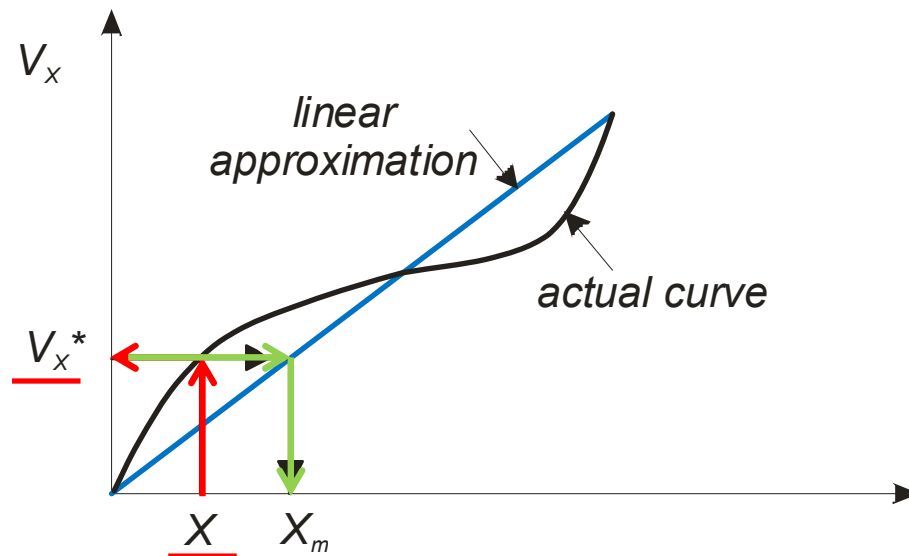# System performance *vs* type of errors

|	
Offset **Gain error** **Non-linearity errors**	→	**System** **Static Accuracy**
Noise	→	**System Resolution**
Dynamic errors **(finite response time)**	→	**System response speed**

Non-linearity errors

$$x_{e-nl} = X - X_m$$

- Generally, the maximum non-linearity error in the whole range of the input quantity X is indicated in the specifications

- If the non-linear curve is well reproducible, the non-linearity error can be compensated for by means of a non-linear estimator.

- For random non-linearities, individual multi-point trimming is necessary.
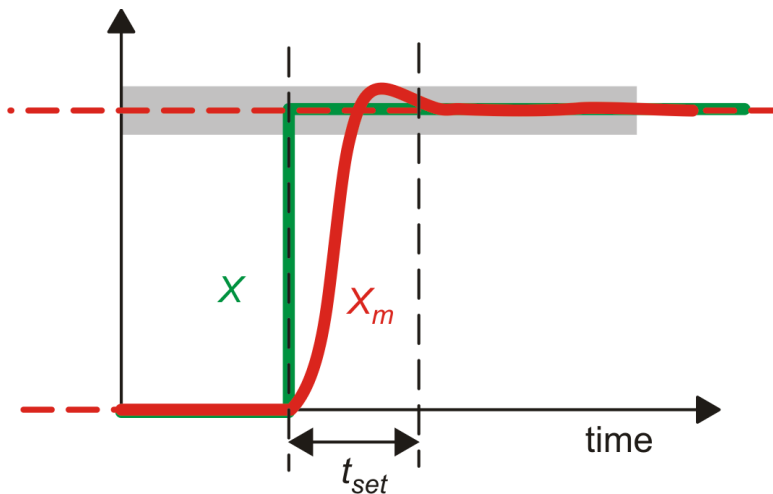
Dynamic errors
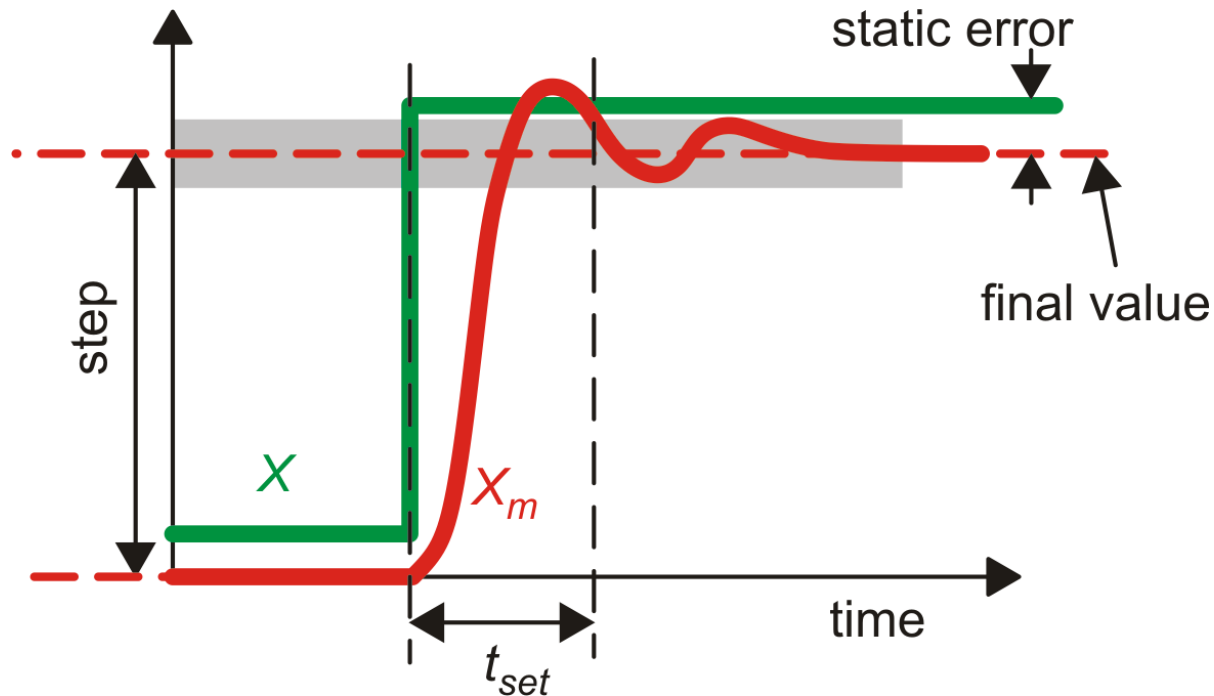
Settling time t_{set}:
Time required to have the
output voltage stay close
to the final value within
a given relative error

Typical error specs:
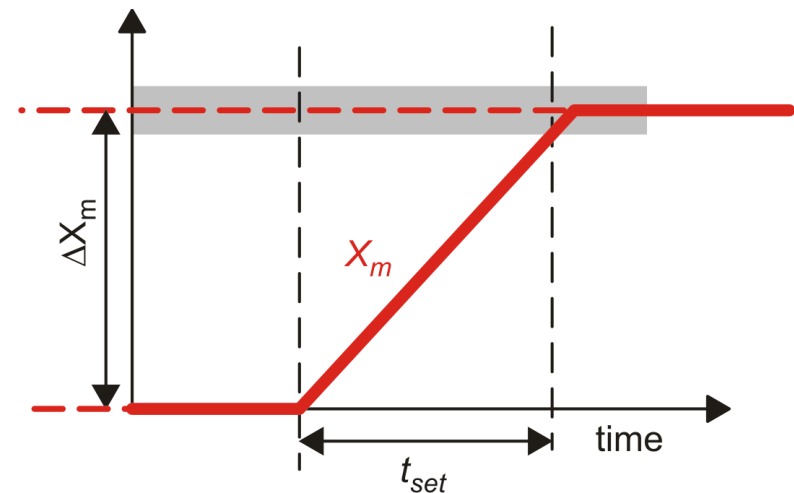1 % (low accuracy)
0.01 % (high accuracy)

Linear time and slew-rate time

Linear-time only
(all stages behave linearly)

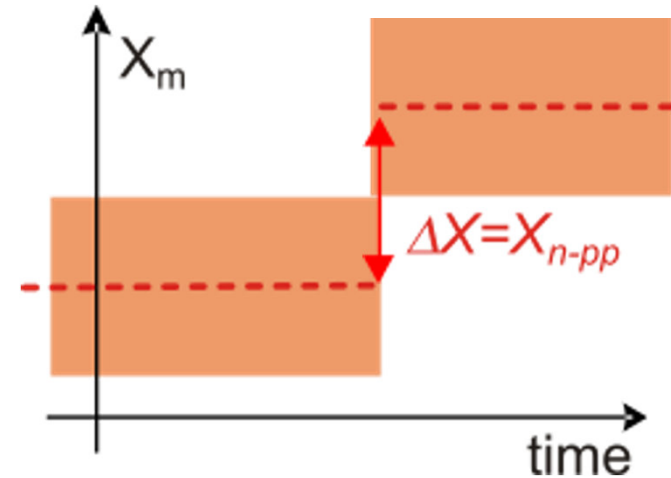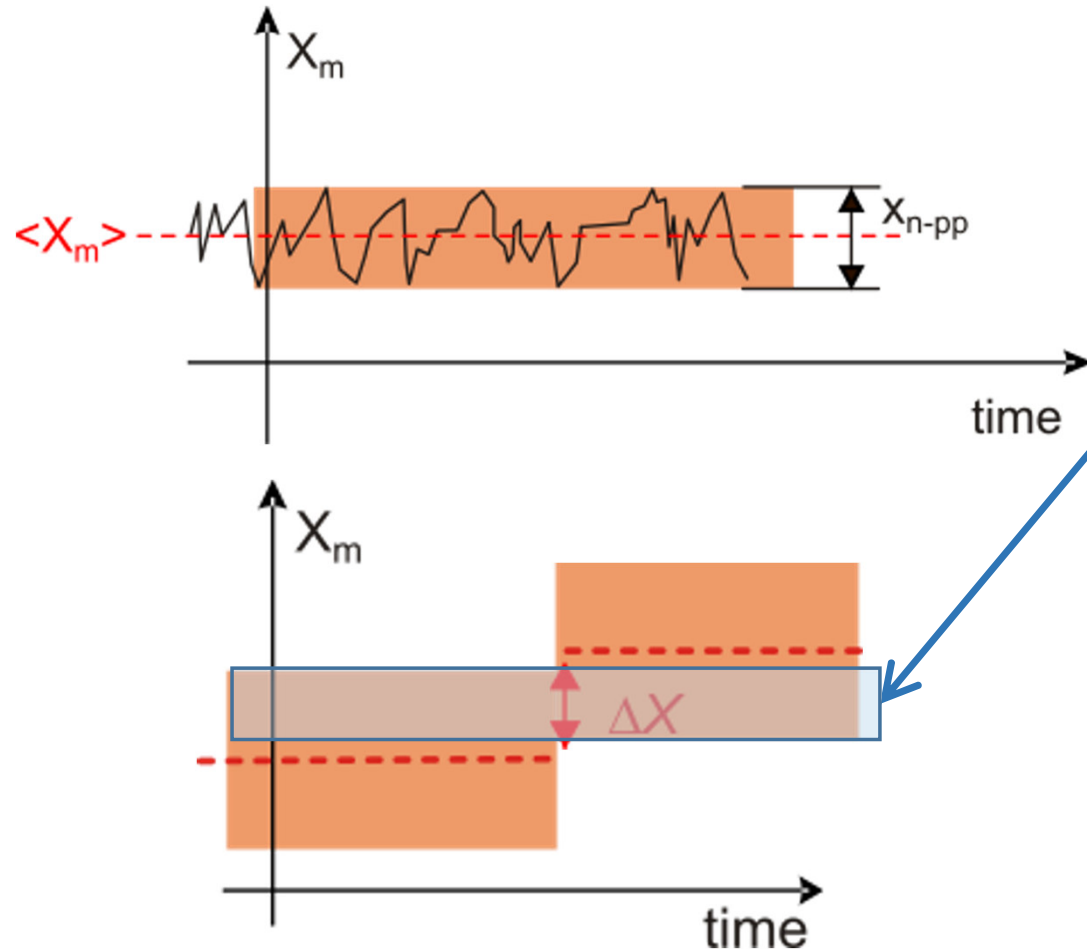$$t_{set} \cong \frac{1}{B_{-3dB}} \qquad (1\%)$$

Slew-rate only
(most of the transition time at least one stage is saturated)

$$t_{set} \cong \frac{0.99 \cdot \Delta X_m}{s_r} \cong \frac{\Delta X_m}{s_r} \cong \frac{\Delta X}{s_r}$$
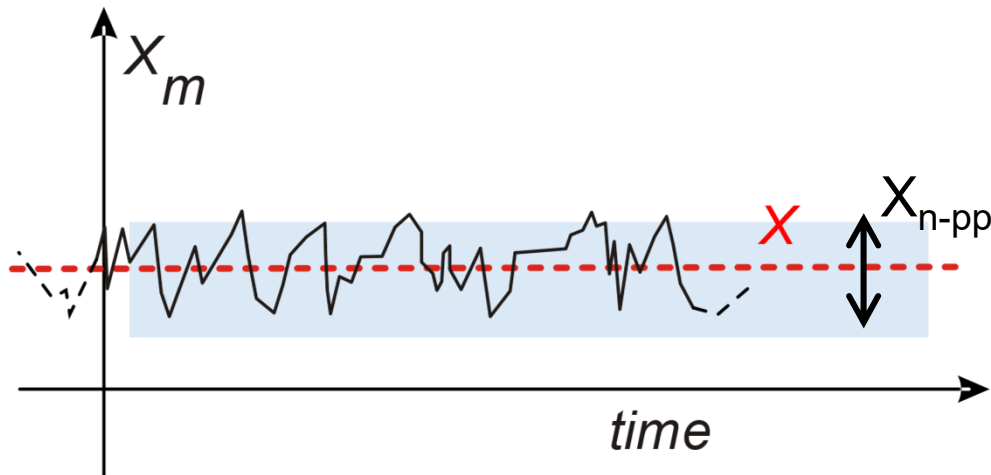
Noise and resolution

$\langle X_m \rangle$

X_m

$X_{n\text{-}pp}$

time

X_m

ΔX

time

Samples in this range are compatible with both the X and X+ΔX input. Therefore, it is not guaranteed that a difference ΔX can be recognized

X_m

$\Delta X = X_{n\text{-}pp}$

time

Minimum difference ΔX that can be reliably detected:

$$\Delta X_{min} = resolution = x_{n-pp}$$

Noise: peak-to-peak, rms and standard deviation

$$x_{n-pp} = 2x_{n-p} = 2c_f x_{n-rms}$$

C_f = crest factor

$$x_{n-rms} = \sqrt{<x_n^2>} = \sqrt{\int_{f_{min}}^{f_{max}} S_{xn}(f)df}$$

For gaussian noise

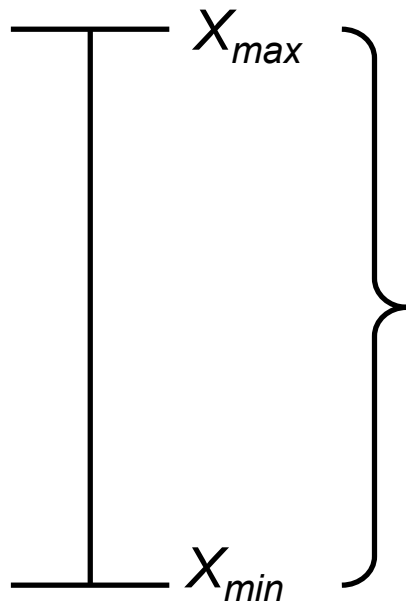If we sample the noise x_n, then the standard deviation of the samples is:

Interval	Total interval width (x_{np-p})	Probability	1 − probability
±σ	2 σ	0.683 (68.3 %)	0.317
±2σ	4 σ	0.954 (95.4 %)	0.046
±3σ	6 σ	0.997 (99.7 %)	0.003
±4σ	8 σ	0.999936 (99.9936 %)	6.4×10⁻⁵

$$\sigma_X = \sqrt{\left\langle \left(x_n - x_{n-\mu}\right)^2 \right\rangle} = x_{rms}$$

Our choice: $x_{n-pp} \cong 4\sigma_X = 4x_{rms}$

The Dynamic Range (DR)

Signal range

X_{max}

X_{min}

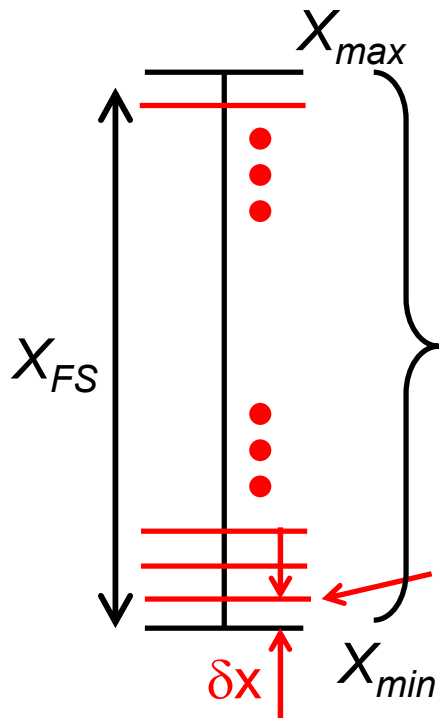$$DR \equiv \frac{\Delta X_{FS}}{\delta X}$$

$X_{max} - X_{min} = X_{FS}$

Full scale (excursion)

δx generally is the resolution

DR and maximum number of significant levels

$$DR \equiv \frac{\Delta X_{FS}}{\delta X}$$

X_{max}

X_{FS}

X_{min}

δx

Number of distinguishable levels = *DR*

The presence of noise cause a sort of quantization of the analog signal, at least in terms of usable levels

Fist level that the system can distinguish from X_{min}