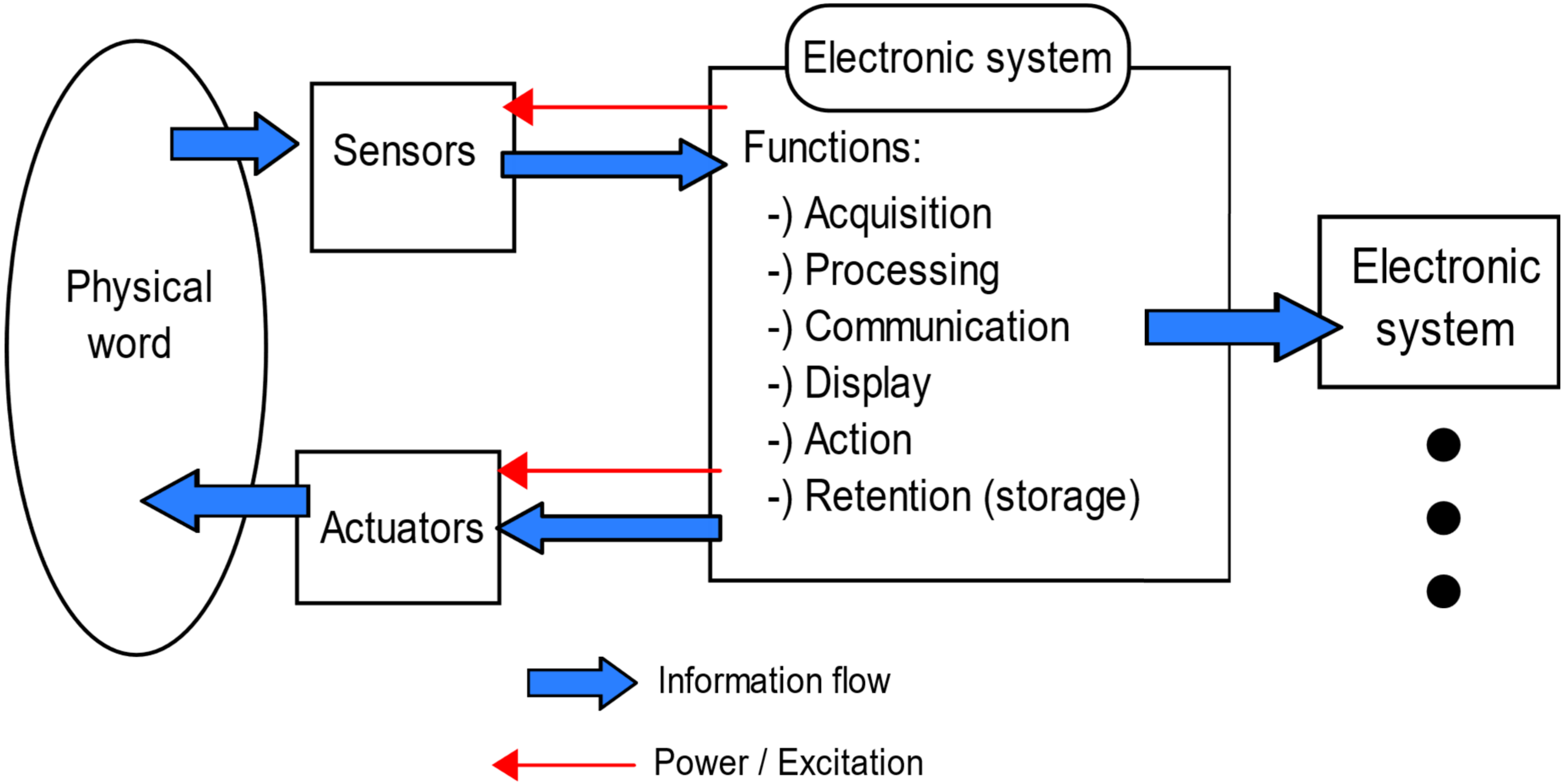
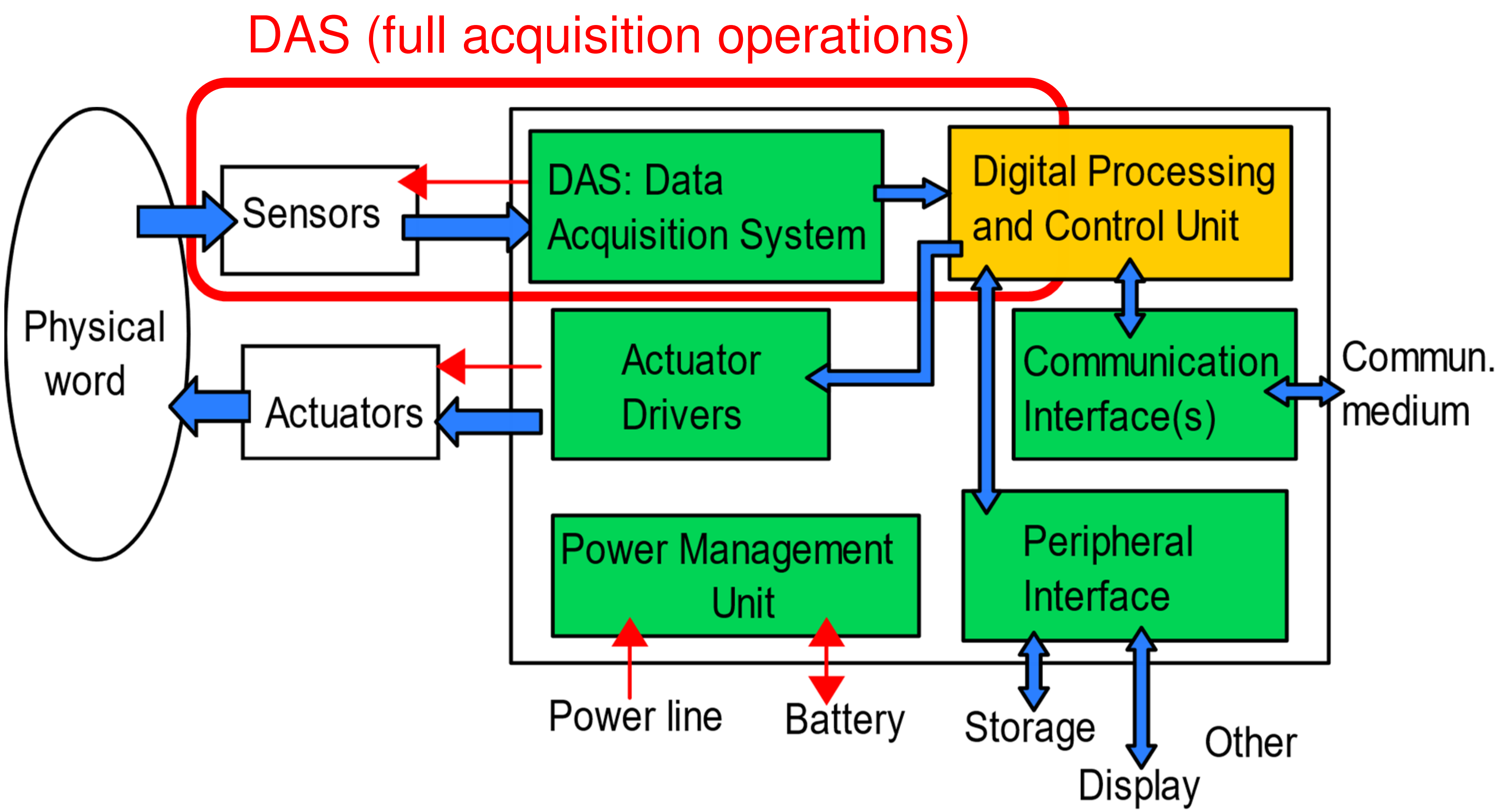
DAS: Data Acquisition Systems

- 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.**

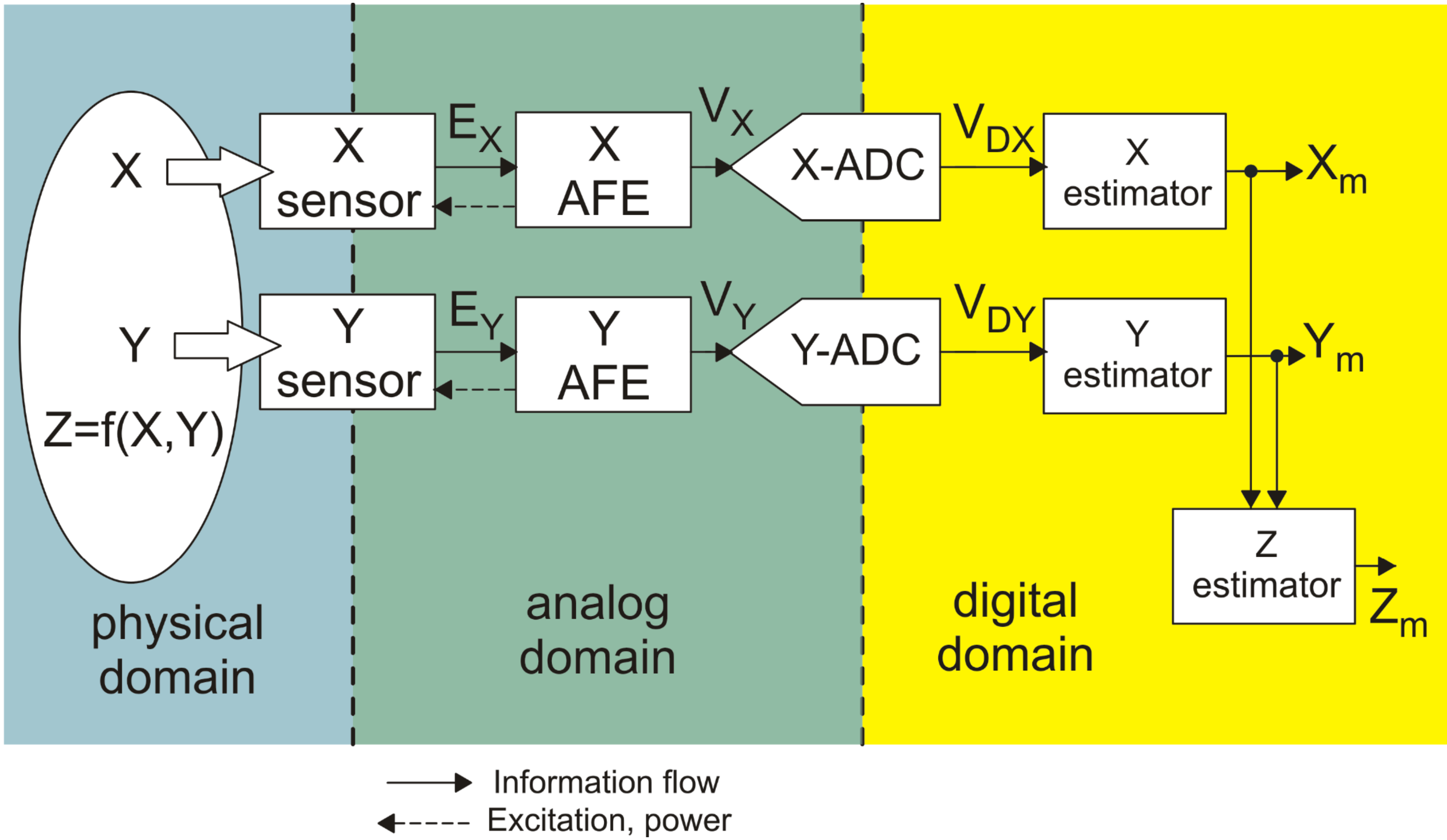
The electronic system and the enviroment



Main blocks of an Electronic System



Elements of a DAS: a two-channel case



Signal classification on the basis of quantization

<table>
<tr><th>Magnitude</th><th>Time</th></tr>
<tr><td>digital signals</td><td>discrete time</td></tr>
<tr><td rowspan="2">analog signals</td><td>discrete time</td></tr>
<tr><td>continuous time</td></tr>
</table>

Errors on the ideal transfer function

$$X \longrightarrow \boxed{\quad f \quad} \longrightarrow V$$

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

Once V is known, X can be known exactly:

$X = g(V) \qquad g(x) = f^{-1}(x)$ (inverse function)

Real case: $V = f(X) - V_e(X)$

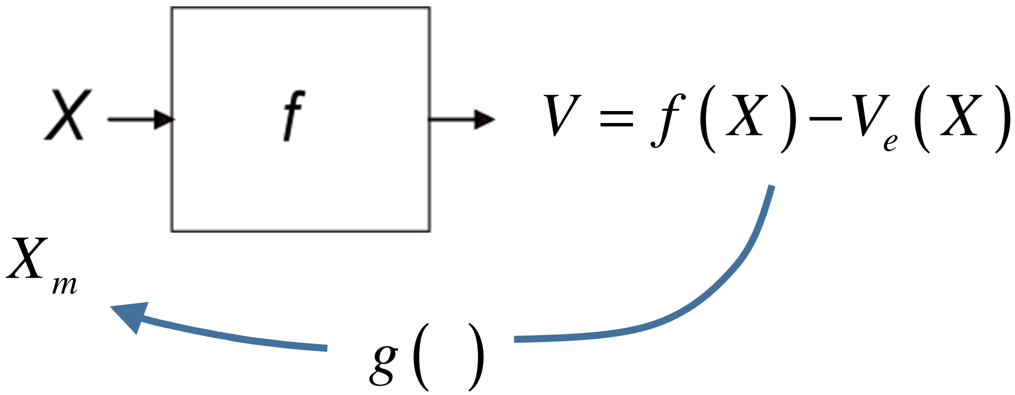
$V_e(X)$ is the **output error** defined as: $V_{ideal} - V$ $\qquad V_{ideal} = f(X)$

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 (g) of the nominal transfer function to the real output quantity (we do not know the real t.f.):

$X_m = g(V) = g\left(f(X) - V_e(X)\right)$ $\qquad X_m$ is the "measurement result"

RTI (Referred to Input) Error



Property of Inverse Functions

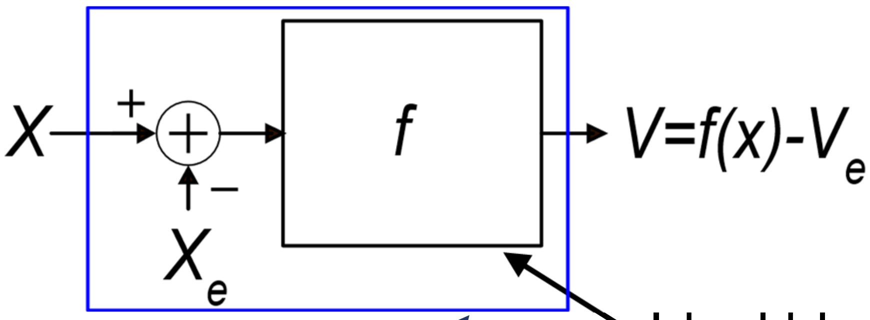
$$\frac{dg(V)}{dV} = \left[\frac{df(x)}{dx}\right]^{-1}$$

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

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



Ideal block

Equivalent representation of the real block

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

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

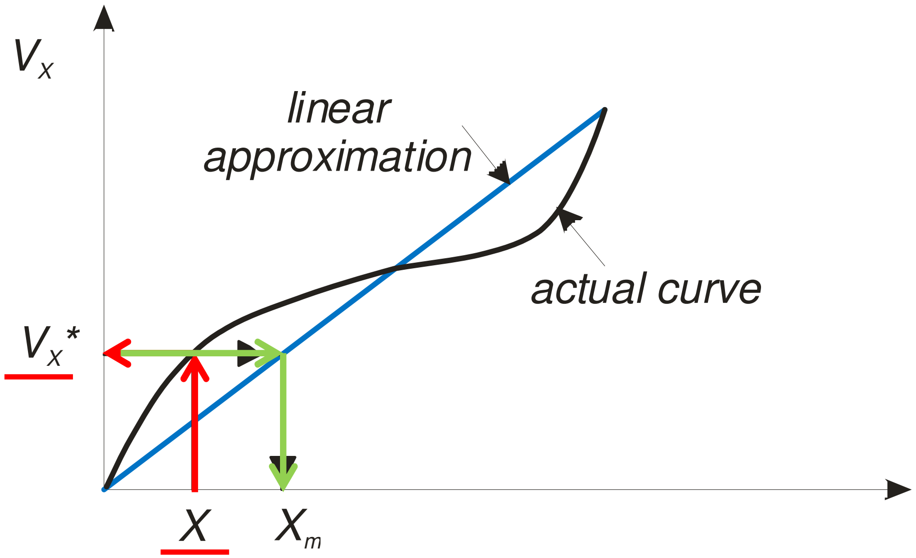
X_e is the value of the input quantity X that nulls the output

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

System performance *vs* type of errors

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

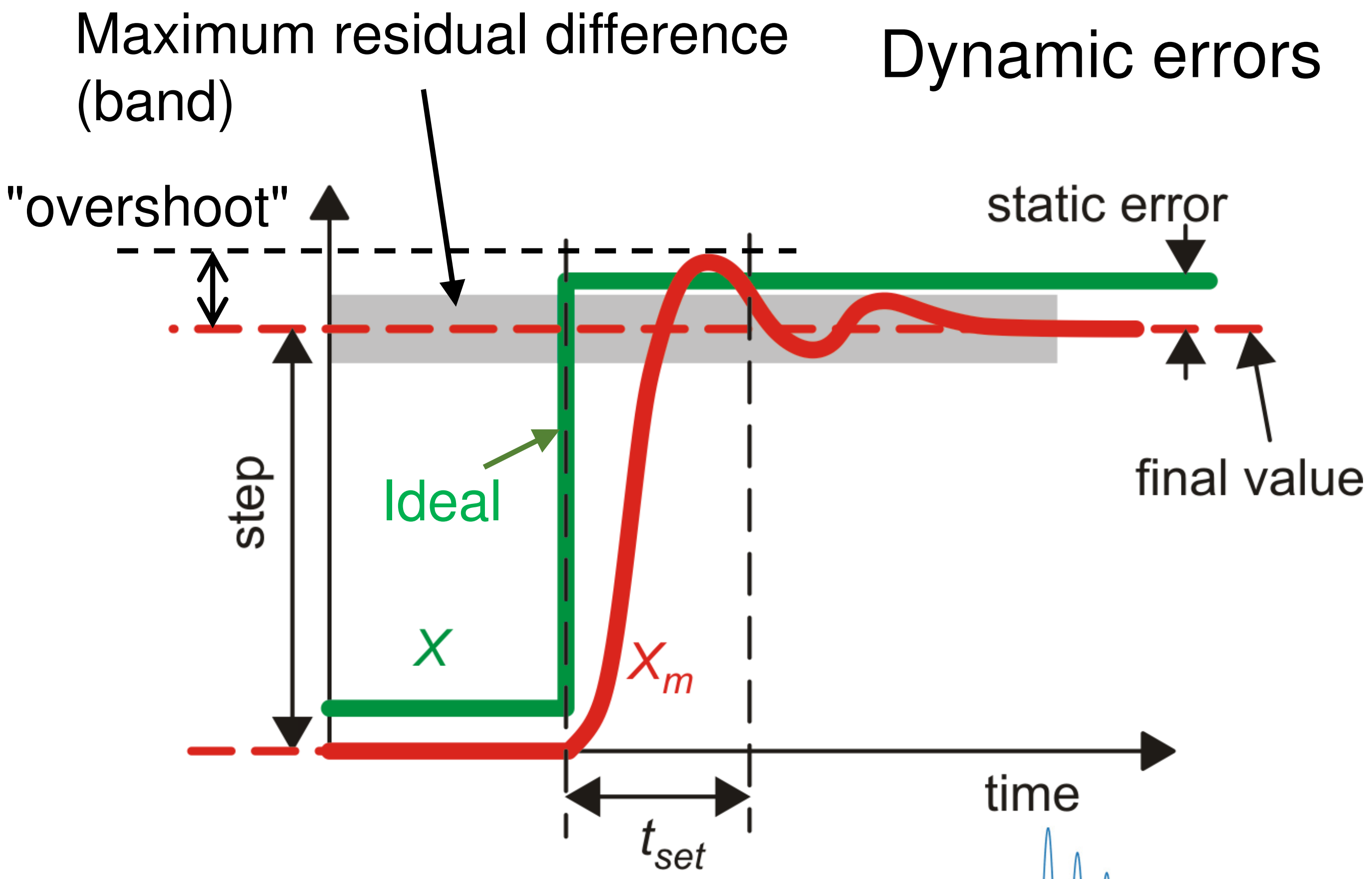
Non-linearity errors



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

- 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

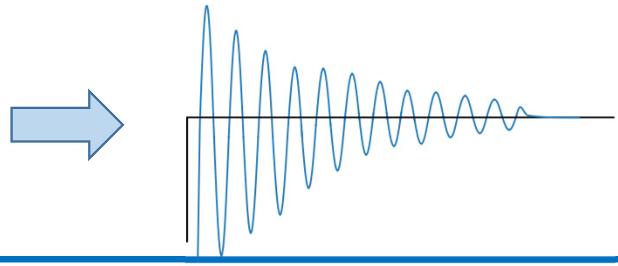


The dynamic error is the difference between the present value and the final value

Settling time t_{set}:
Time required to have the output voltage stay close to the final value within a given residual difference

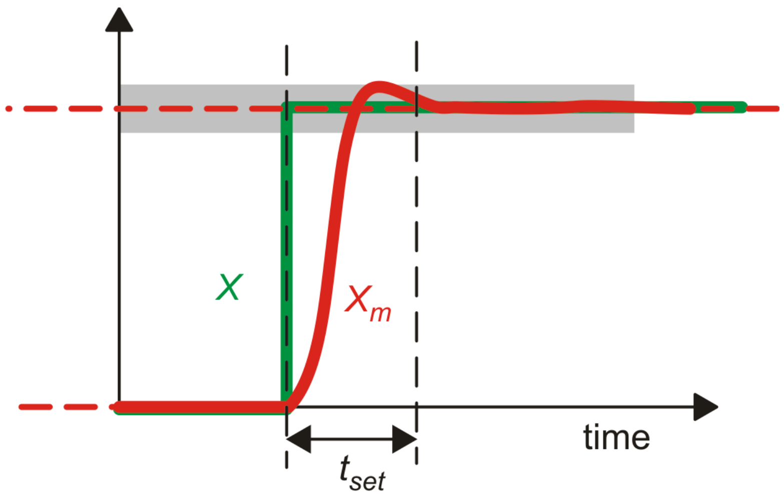
Typical settling specs:
1 % (low accuracy)
0.01 % (high accuracy)

damped oscillation: "ringing"



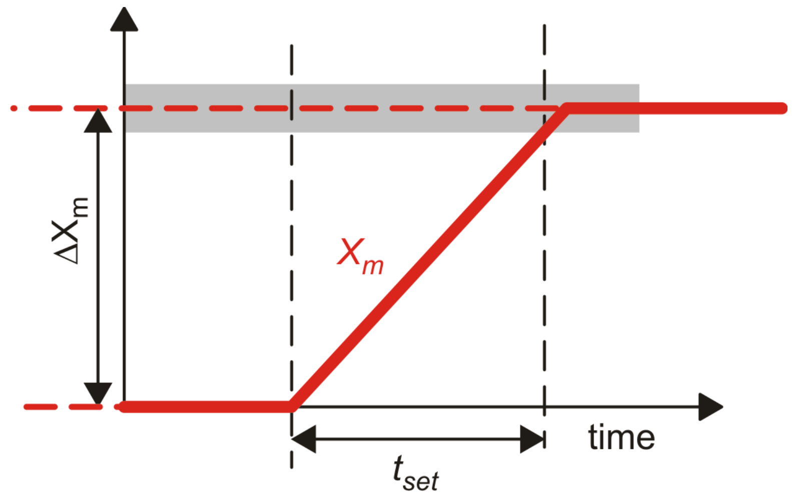
Linear time and slew-rate time

Linear-time only
(all stages behave linearly)



$$t_{set} \cong \frac{1}{B_{-3dB}} \quad \text{(for 1 \% error no-ringing)}$$

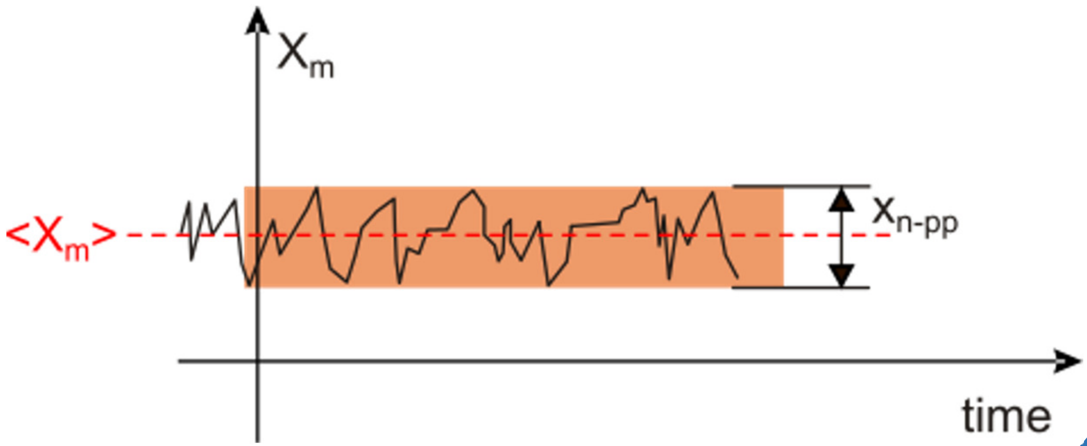
Slew-rate only
(most of the transition time at least one stage is saturated)

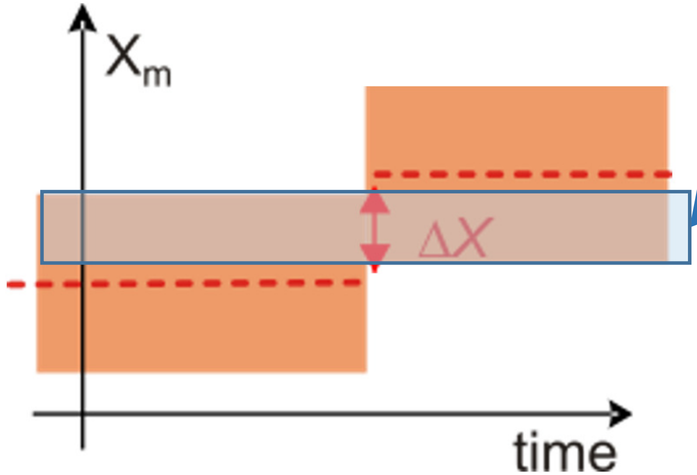


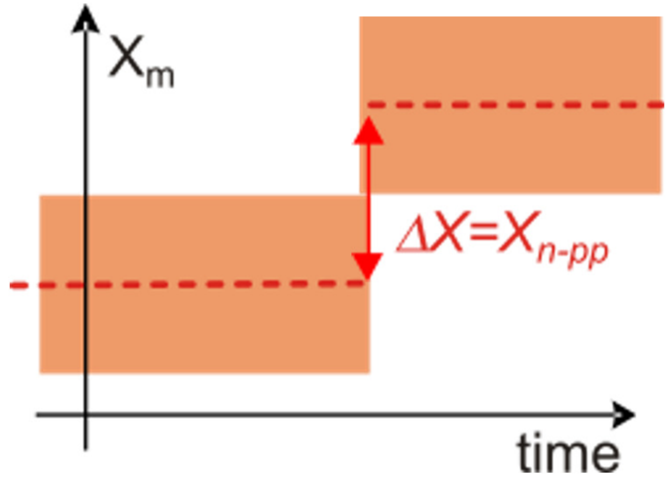
$$t_{set} \cong \frac{0.99 \cdot \Delta X_m}{s_r} \cong \frac{\Delta X_m}{s_r} \cong \frac{\Delta X}{s_r}$$

Noise and resolution

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



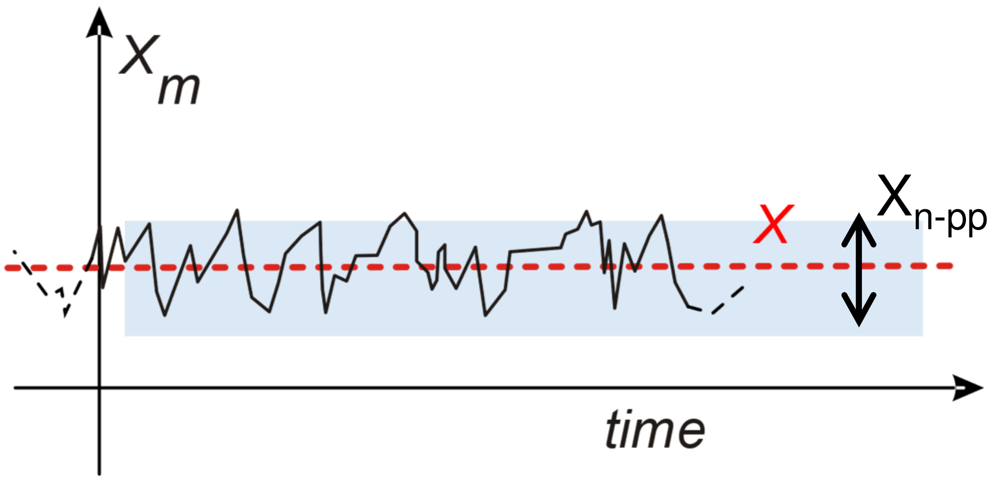




Minimum difference ΔX that can be reliably detected:

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

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

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}

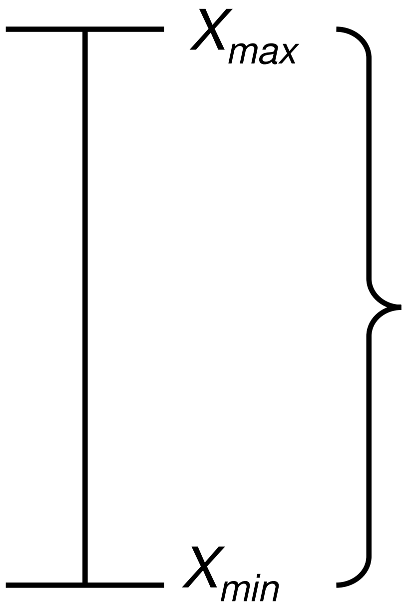
If we sample the noise x_n, then the standard deviation of the samples is:

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

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

The Dynamic Range (DR)

Signal range



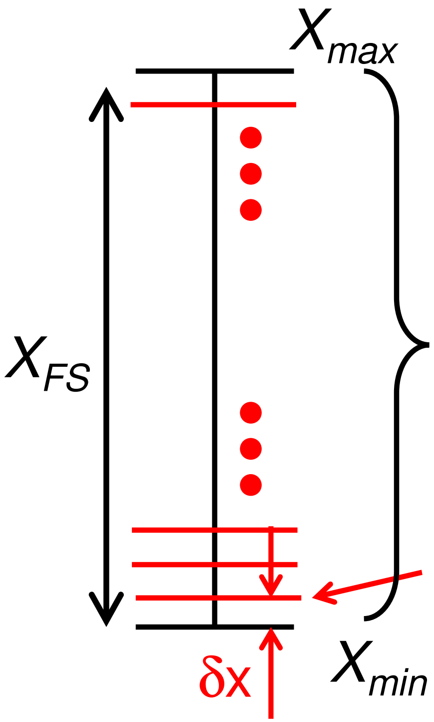
$$\boxed{DR \equiv \frac{X_{FS}}{\delta X}}$$

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

Full scale (excursion)

δx generally is the resolution

DR and maximum number of significant levels



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

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}

For a digital signal coded with *n* bits: Number of levels = 2^n

For an analog signal: Effective Number Of Bits $ENOB = \ln_2 (DR)$