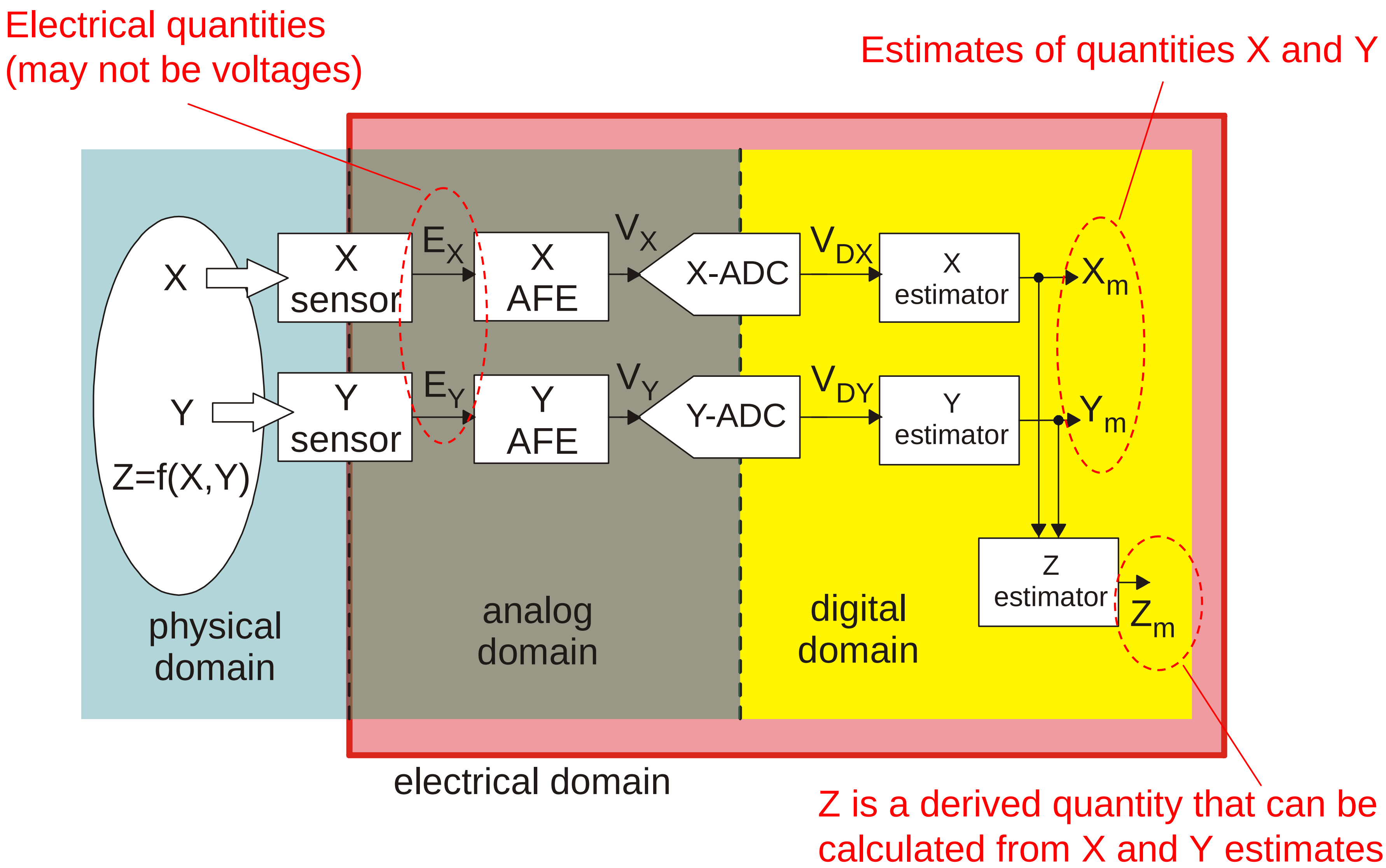
Data Acquisition System (DAS)



DAS: important parameters

Accuracy (absolute): $X-X_m$

Resolution: Minimum detectable $|X_1-X_2|$ difference.

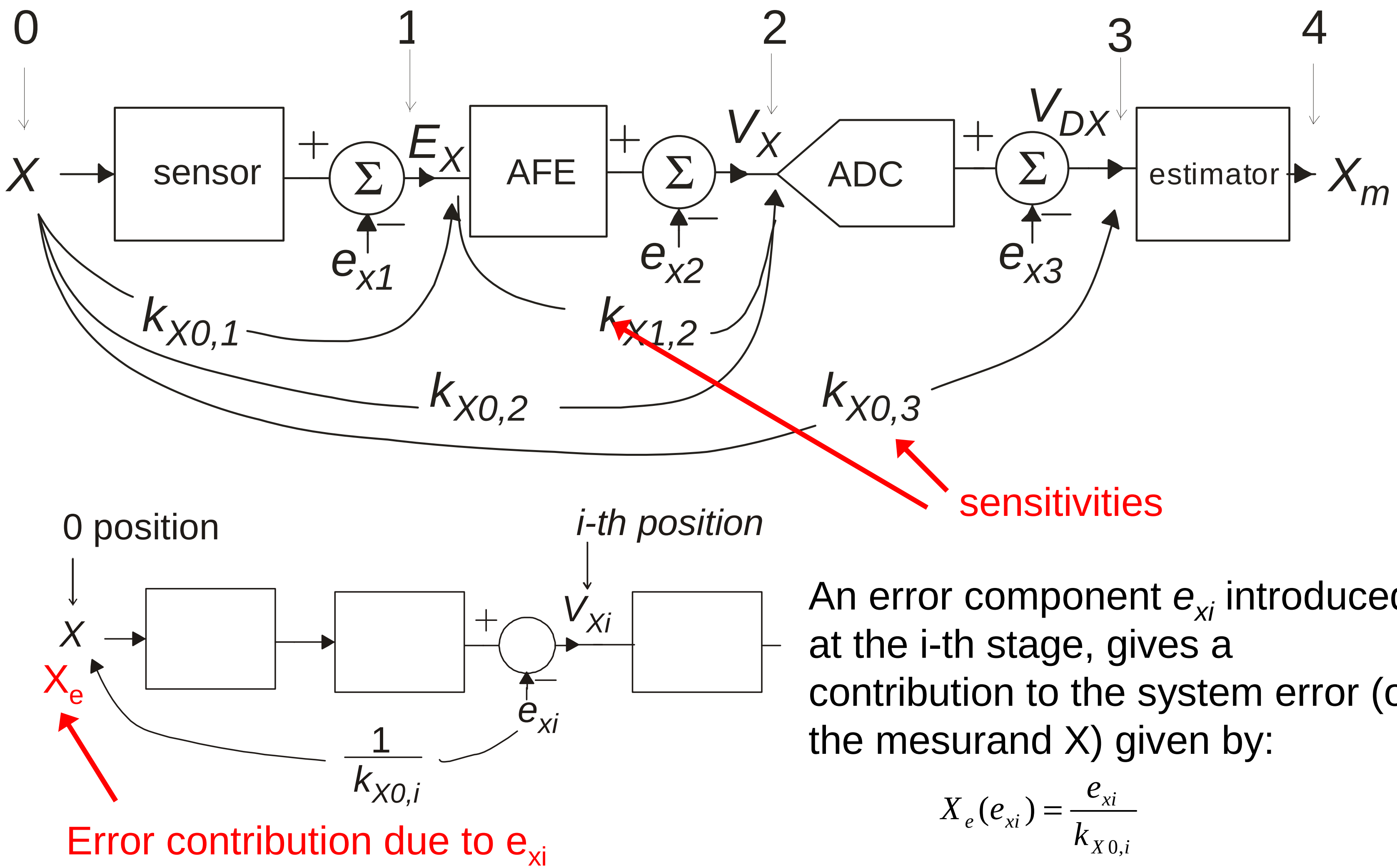
Range: X_{min}, X_{max}

Full scale range (FS): $X_{max}-X_{min}$

Dynamic range (DR) = $\dfrac{FS}{resolution}$

The dynamic range is equal to the maximum number of distinct levels of the quantity X that can be reliably discerned by the system. This concept can be applied also to an all-analog subsystem. In this case, $\log_2(DR)$ gives an "equivalent number of bits" associated to the considered analog section of the DAS. If noise cannot be reduced with further filtering operated in the digital domain (note that filtering reduces the response speed of the system), it is meaningless to convert the analog signal into a digital stream using an ACD with a resolution (number of bits) much higher than log2(DR).

Error contributions (DAS)



An error component e_{xi} introduced at the i-th stage, gives a contribution to the system error (on the mesurand X) given by:

$$X_e(e_{xi}) = \frac{e_{xi}}{k_{X0,i}}$$

Temperature sensors

- Resistive: Thermistors (semiconducting materials)
  RTDs (metals or metal alloys)
- Thermoelectric: Thermocouples, thermopiles
- P-N junctions: Simple calibrated diodes
  ΔV_{BE} circuits.

Thermistors and RTD

RTD: Resistive Temperature Detectors.
These sensors are essentially metallic resistors (wire wound or thin film type).
The resistance increases with temperature according to a relationship that can can be approximated by a linear law:

$$R(T) = R(T_0)\left[1 + \alpha\left(T - T_0\right)\right]$$

T_0=reference temperature, tipically °C.
α=temperature coefficient of resistance (TCR) for $T=T_0$.

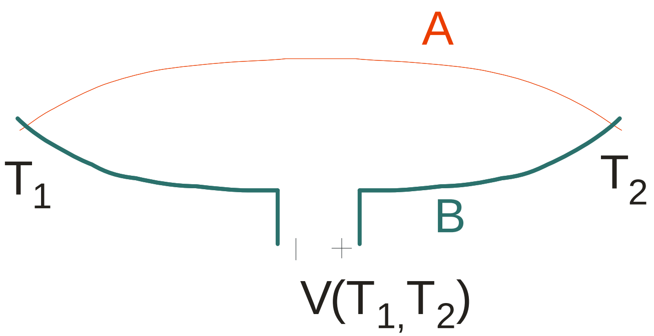
More generally:

$$TCR = \frac{1}{R}\frac{dR}{dT}$$

Platinum is often used for precision RTD, due to its high chemical stability that guarantee a constant response over life-time periods.
For platimum RTDs $\alpha=4\times10^{-3}$ °C^{-1}.

Thermistors. These sensors consist in resistors made of mixtures of semiconducting metal oxides. Their resistance decreases with temperature in a strongly non linear fahion. Their sensitivity is typically one order of magnitide higher than that of RTDs. This simplifies the design of the electronic interface (AFE), since higher noise levels are acceptable for a given temperature resolution.
On the other hand, thermistors are less precise and less stable than RTDs.

Thermoelectric sensors



Thermoelectric temperature sensors (thermocouples) consist of a conductor pair forming a circuit, as shown in the figure. The two conductors are made of different materials (A and B). The voltage measured across the cut applied to conductor B is a function of the junction temperatures T_1 and T_2.

Termocouples are widely used in industrial plants.

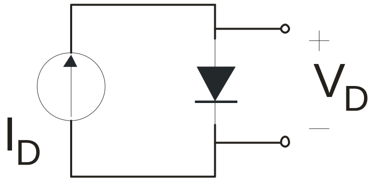
For small temperature differences, the dependence can be approximated by:

$$V = S_{AB}\left(T_2 - T_1\right)$$

where S_{AB} is the Seebeck coefficient of the couple A-B

Note: in order to use a thermocouple for measuring a single temperature (e.g. T_2), we need to know T_1. This is generally accomplished by measuring T_1 with a different sensor (i.e. a thermistor) and using this information to extract T_2 from measurement of $V(T_1,T_2)$. Note that T_1 is generally the room temperature, so that the sensor used to read it can be very simple, while T2 can vary in an extremely wide range (from cryogenic to very high (> 1000 °C) temperatures.

Temperature sensors based on junctions



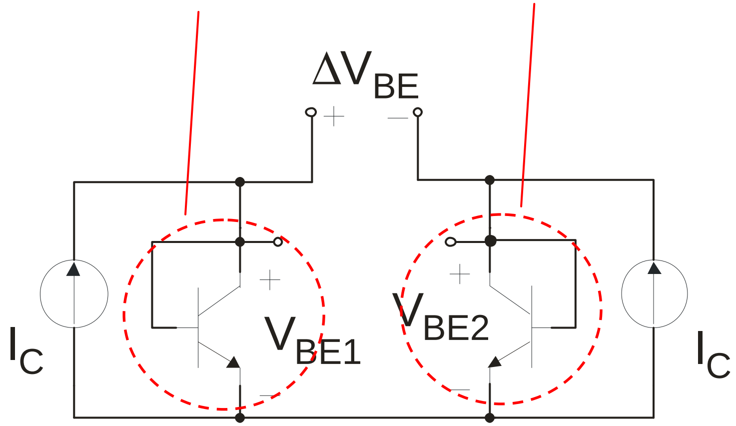
Diodes (p-n silicon junctions) can be used as temperature sensors by biasing them with a constant current and measuring the diode voltage, given by:

$$V_D = \frac{kT}{q} \ln\left(\frac{I_D}{I_S}\right) \quad \text{where } I_S = f(T)$$

The temperature dependence is due to the kT/q factor and by I_S (exponentially increasing with temperature). The dominant factor is I_S, so that voltage V decreases with temperature. Calibrated diode sensors can be used for precise temperature measurements over wide ranges. The voltage variation is of the order of -2.5 mV/°C.

Junction temperature sensors: ΔV_{BE} sensors

Diode implemented with bipolar transistors (BJT)



$$\Delta V_{BE} = \frac{kT}{q}\left[\ln\left(\frac{I_{S2}}{I_{S1}}\right)\right]$$

The dependence on I_S can be eliminated with the circuit in the figure. The output signal is the difference between the voltages measured across two diodes biased with the same current I_C. The diodes have different saturation currents I_{S1} and I_{S2}.

The I_{S2}/I_{S1} ratio is equal to the ratio of emitter areas of the two BJTs. This ratio can be made precise and completely temperature independent, so that ΔV_{BE} becomes linearly dependent on temperature.

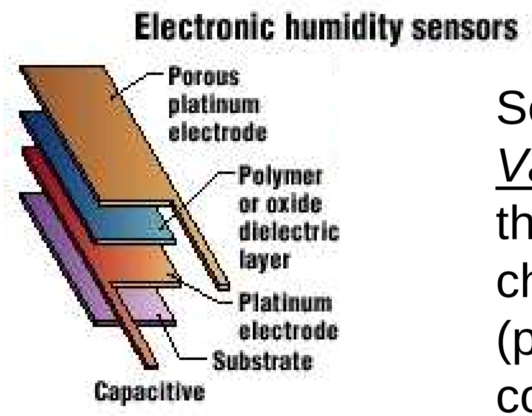
Commercial sensors that exploit this principle are available (e.g.the AD590, where the ΔV_{BE} voltage is applied to a resistor in order to obtain a current that varies linearly with temperature). The same principle is often used to monitor the chip temperature in microprocessors units.

Humidity sensors

Generally they measure the relative humidity (RH %).

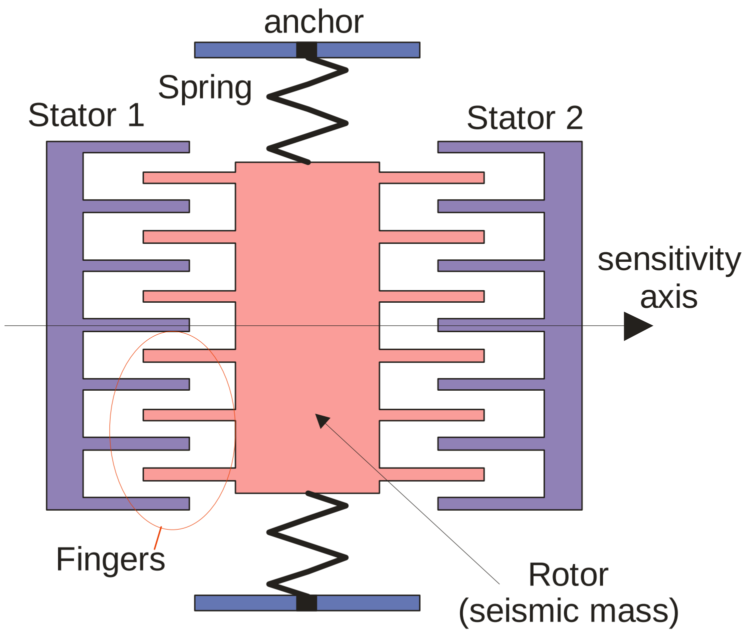
Types: Capacitive (most used, polymer dielectric)
Resistive (salts, conducting polymers etc).

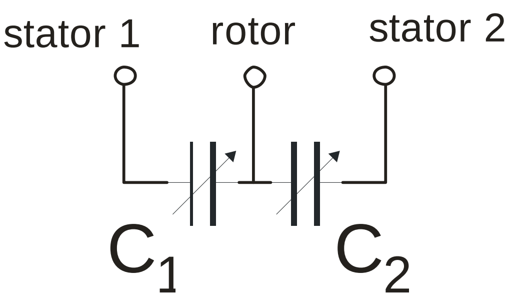
The most common RH sensors are based on the capacitive approach. Humidity is adsorbed by special dielectrics, that vary their dielectric constant according to the water molecule content. Materials used for the dielectric can be either polymeric or inorganic. Particular importance is assumed by materials that are compatible with integrated circuit fabrication processes (e.g, polyimides, silicon dioxide)



Several methods can be used to read the capacitance. *Variable oscillators*: the capacitance is connected to the resonant circuit. *Charge amplifiers*: the capacitor is charged at a constant voltage, then the stored charge (proportional to the capacitance) is transferred to a constant reference capacitor, obtaining a voltage.

Accelerometers





Integrated accelerometers consist of a seismic mass (called “rotor”), suspended by means of elastic elements (springs), connected to the substrate at points called “anchors”. Any linear acceleration applied to the substrate is sensed by the mass as a proportional apparent force. The force cause the displacement of the seismic mass (called rotor). As a result, the capacitances between the rotor and the stators (fixed to the substrate) change, producing a differential capacitance C1-C2 proportional to the acceleration. Various methods can be sed to sense the differential capacitance, the simplest of which is the charge amplifier.

Light sensors: photodiodes and photoresistors

Photodiodes are formed of a p-n junction that has to be biased in reverse region. In this way, a large electrical field is resent in the depletion zones of the junctions. If a photon with sufficient energy reaches the depletion region, a hole-electron pair is generated. These charge carries are swept by the electrical field towards opposite quasi-neutral zones, producing a current. The higher the phto arrival rate, the higher the current. A small current flows also when the diode is kept in the dark due to the diode saturation current ("dark current"). Photodiode are very fast devices, that are used also in the so called "CMOS" imagers. When used as visible light detectors, silicon photodiodes should be provided of optical filters to compensate for the sensitivity peak exhibited at long wavelengths (red and near infrared regions).

Photoresistors are intrinsic semiconductor substrates. In the absence of light, the carrier concentration is very low and the resistance is high (typically a few MΩ). When the light hits the semiconductor surface, hole-electron pairs are generated and the resistance gets much lower (< 1kΩ). Often CdTe composite semiconductor is used for its sensitivity that is well matched with that of human eye (much more than photodiodes). .These devices are generally much slower than photodiodes due to slow recombination of carriers following light intensity reductions. Times of the order of tens of ms can be necessary to recover from an intense light exposure.