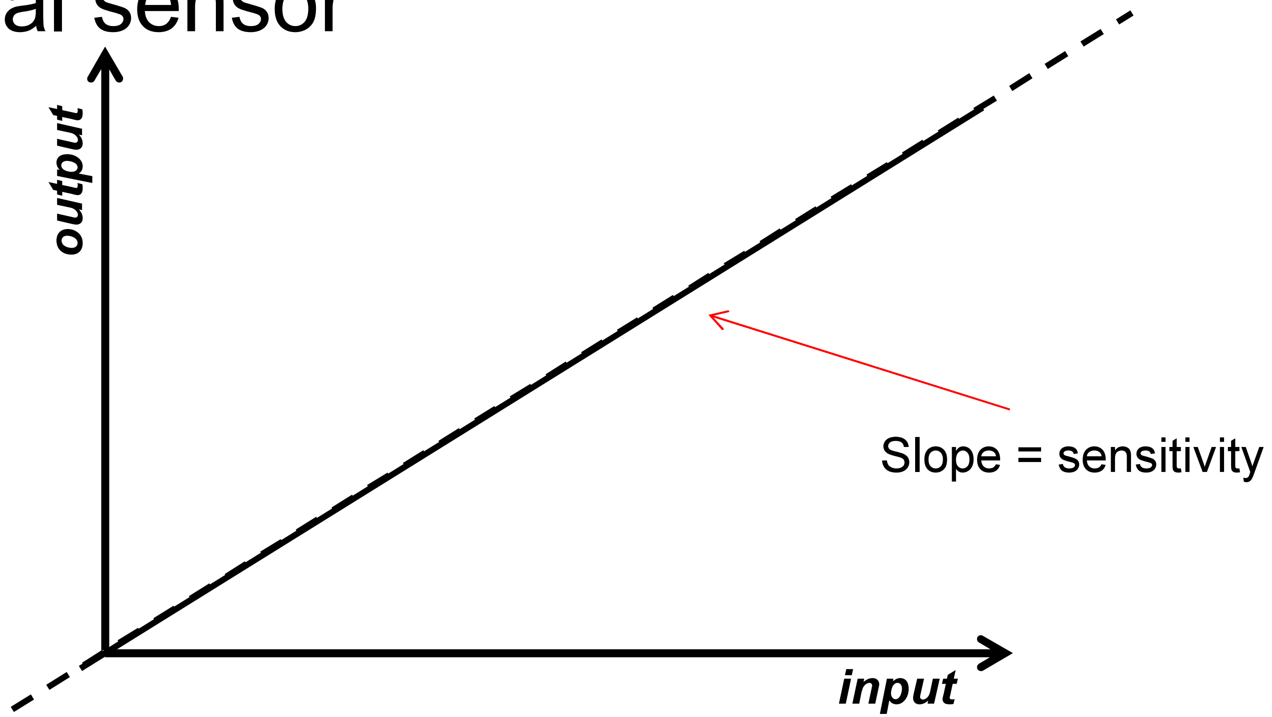
Static Sensor Characteristics

Static characteristics

- Static characteristics describe the behaviour of our sensor in steady state - when all transient behaviour has decayed.

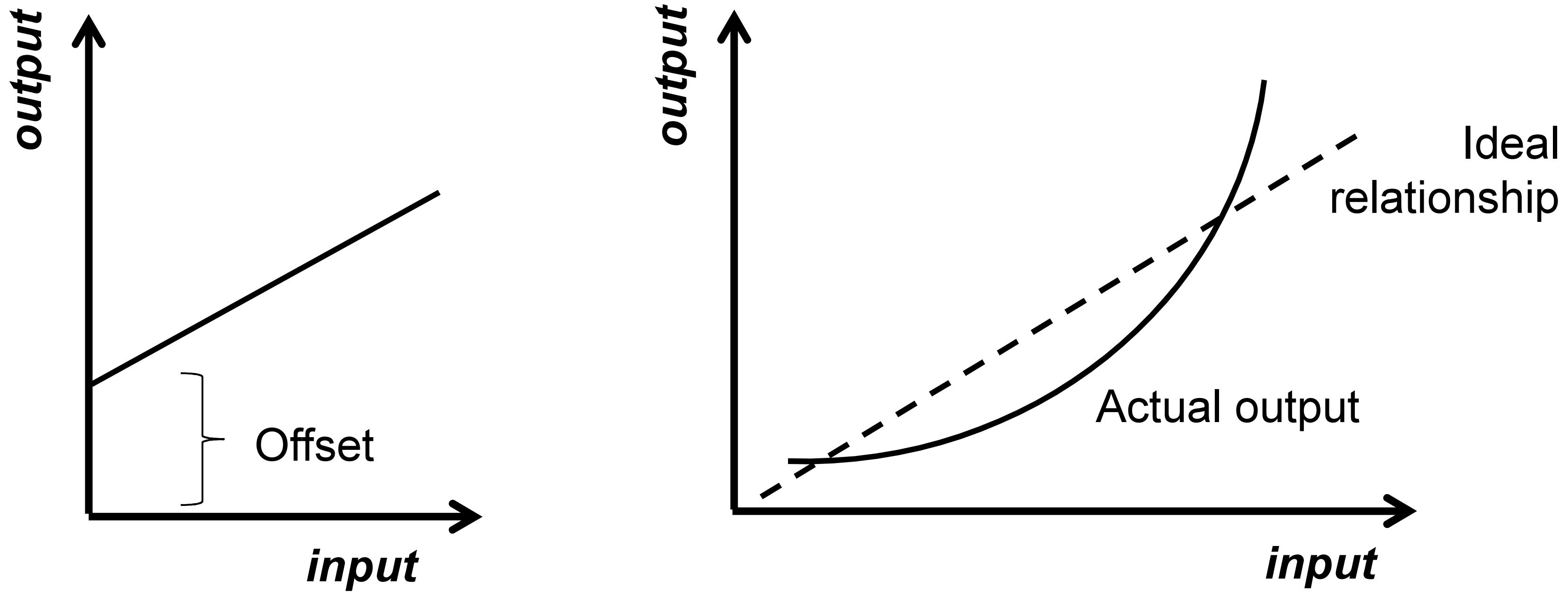
- The transient or dynamic behaviour describes how the sensor responds to changing input.
  - Influenced by energy storage elements – mass, compliance, inductance, capacitance etc.

The ideal sensor



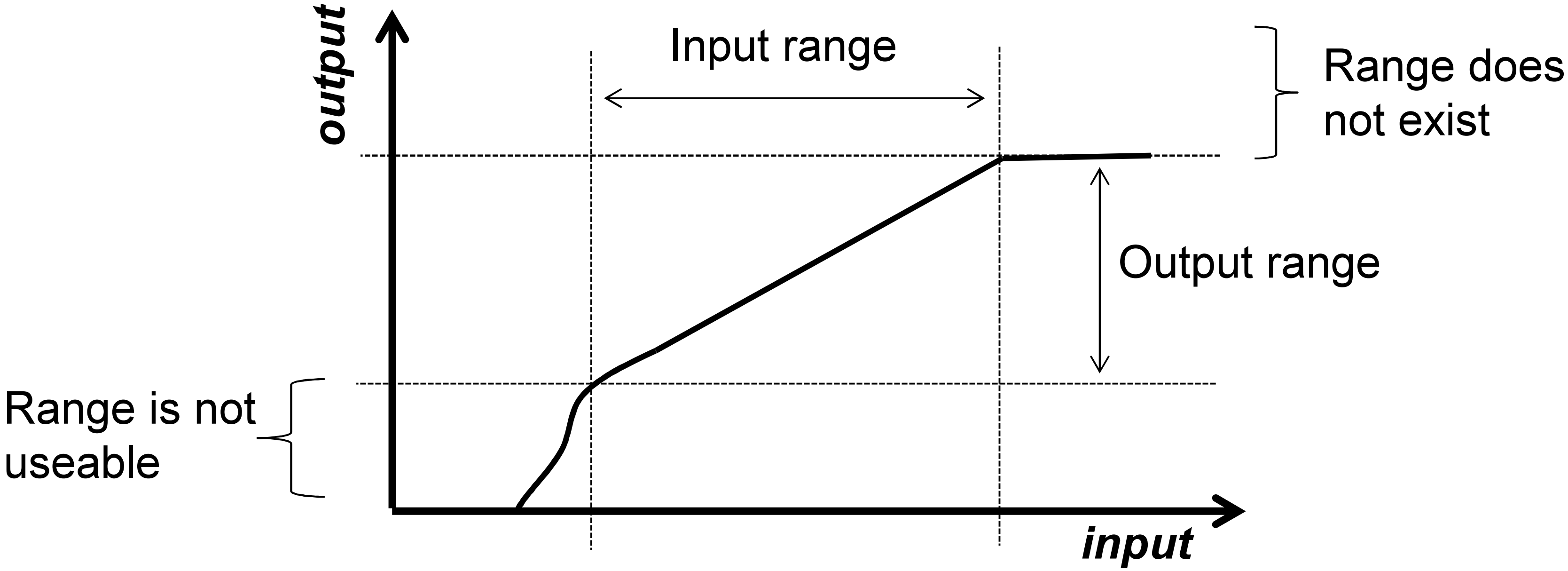
- An ideal sensor has a linear relationship between input/output.
- *Sensitivity* is the constant of proportionality relating input and output.

Real sensors: offset, non-linearity



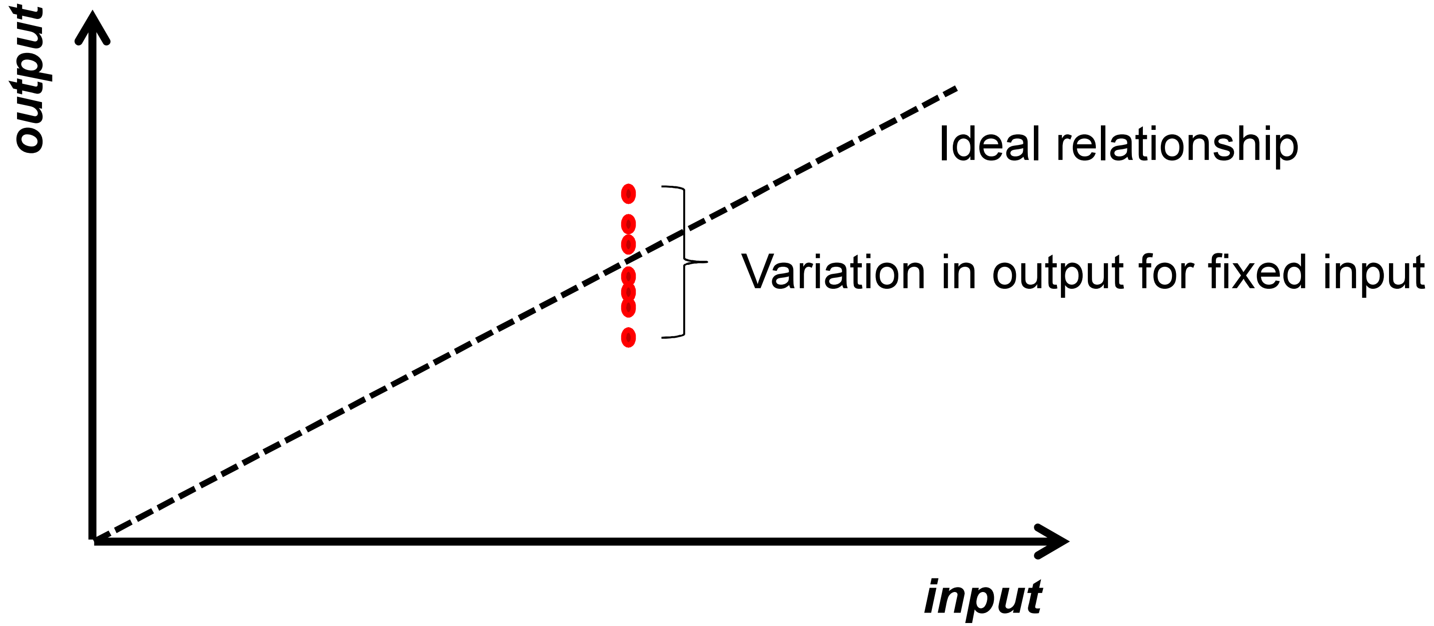
- Offset describes a fixed additional component of the output, irrespective of the input.
- Linearity describes how close the actual output response is compared to the ideal linear response.

Real sensors: limited range



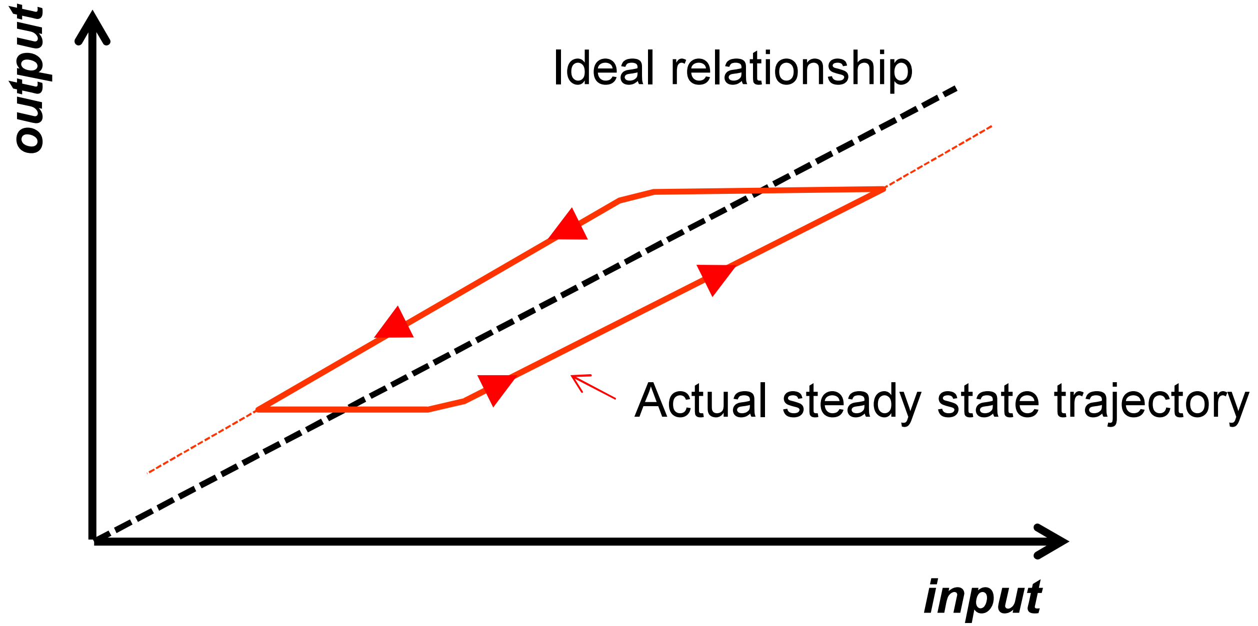
- A sensor has a *range* – limited since at some point the input/output relationship breaks down. Could be caused by;
  - *Deviation from linear relationship*
  - *Physical limit on input/output*

Real sensors: Noise



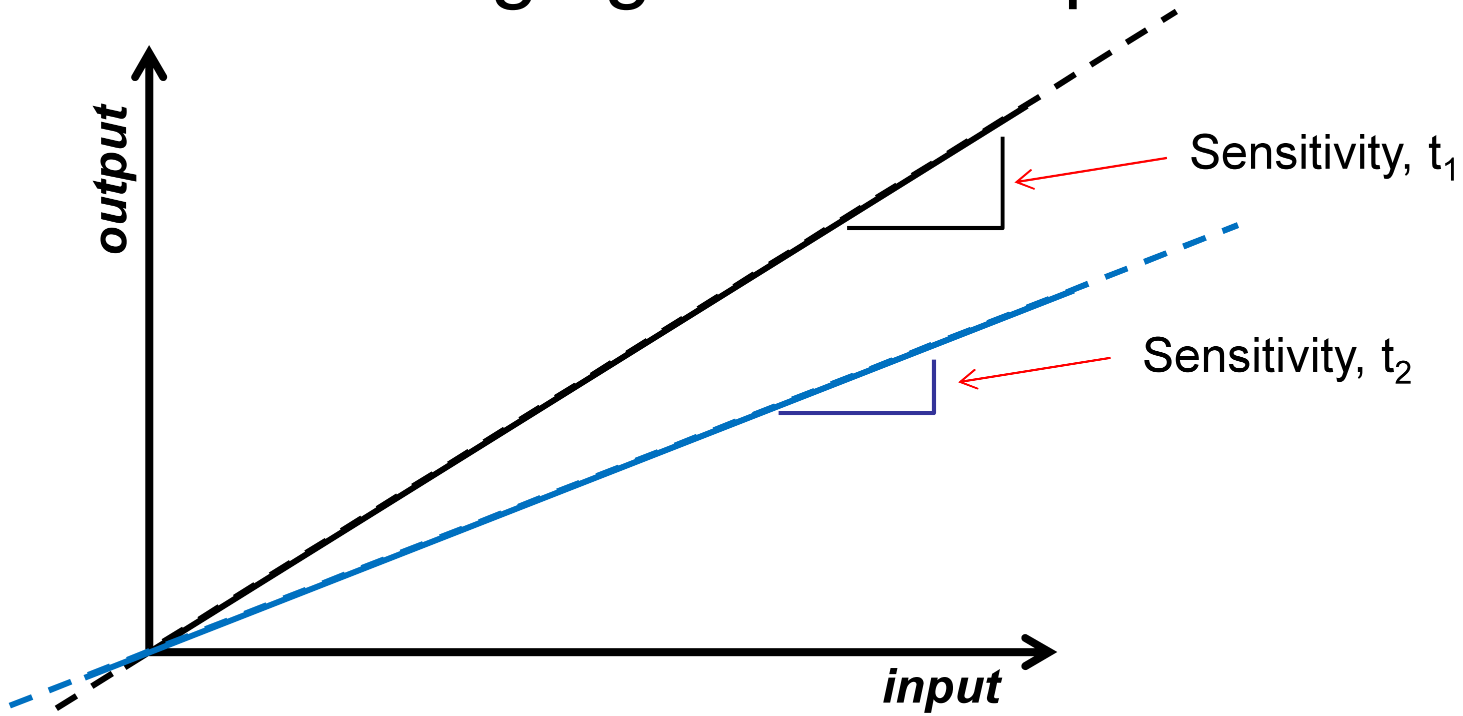
- *Noise* is used to describe a random variation in the output that is not a function the input.

Real sensors: Hysteresis



- Hysteresis can be thought of as a delay or an offset with sign determined direction of change of input.
- Friction or backlash can create hysteresis.

Real sensors: changing relationship



- Some sensors feature a sensitivity (or offset etc) that is a function of some other variable. Temperature is a common cause of this type of effect.

Quantifying real sensors: Accuracy

- *Accuracy* is the ability of the sensor to output a measured value close to the real value. It is described in terms of error.
  - *Can be absolute;*

$$\textit{Absolute error} = \textit{measured value} - \textit{real value}$$

  - *Or relative;*

$$\textit{relative error} = \frac{\textit{absolute error}}{\textit{real value}}$$

Quantifying real sensors: Precision

- *Precision* describes the agreement between successive readings i.e. If repeatedly given the same input conditions, how close are the outputs.

- Related to the variance of a set of readings

- Similar terms are ‘repeatability’ and ‘reproducibility’

Quantifying real sensors: Precision

- *Precision* is somewhat harder to define than accuracy
- In statistics it is formally the inverse of the variance
  - Large variance = low precision
  - But units are awkward – $1 / units\_of\_measurement^2$
  - Also may not have enough measurement points for this to be valid

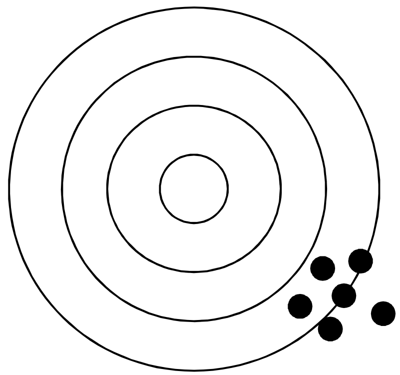
- Maybe better to quote range e.g. Max – min
- or the greatest deviation from average.

Quantifying real sensors: Precision

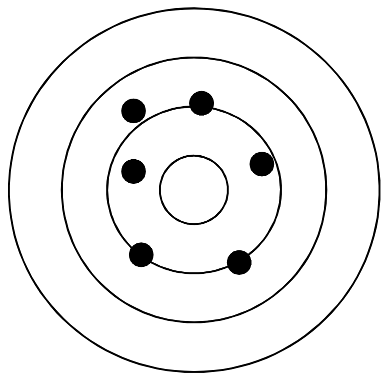
- *Repeatability*
  - *Normally describes when the same measurement is made by the same person, with the same equipment at short time intervals.*

- Reproducibility
  - Describes the situation where measurements are made sometime apart, perhaps by differing people with differing equipment.

Target Analogy



- High precision
- Poor accuracy



- Higher accuracy
- Lower precision

Drift

- *Drift* describes a slow change in indicated value or sensor characteristics.

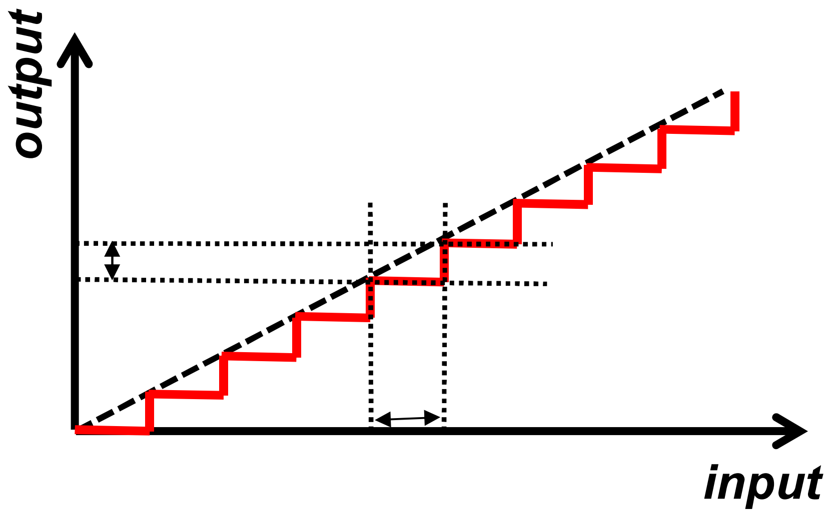
- Some sensors feature drift in the medium term due to thermal effects and require a period of stabilization before a reading can be taken.

- Over longer timescales components ‘age’ and their characteristics change over time. Old equipment tends to be less accurate for this reason

Resolution

- *Resolution* is the smallest change in input that is detectable at the output.
- A sensor with poor accuracy can have high resolution – *(many consumer devices behave like this)*
- Sensor resolution will generally be limited by random errors.

Resolution with Digital Systems



- Systems incorporating analogue to digital conversion have a maximum accuracy determined by the number of bits and maximum range, e.g. 8 bits give 256 discrete levels.

Systematic errors

- Error caused by effects such as non-linearity, offset or influence of temperature are repeatable and predictable.
- These are described as *systematic errors*
  - *Compare with 'systematic failures' in safety analysis*
- It is possible to compensate for these errors if they are known.

Systematic error mitigation

- If the output is non-linear we could:
  - *Apply compensation algorithm*
    - *Useful if relationship follows simple form*

  - *Use a 'look-up' table*
    - *Useful if relationship is complex or cannot easily be described mathematically*

    + *Can be executed quickly by a computer*

    - *Limited by size of table - number of input/outputs*

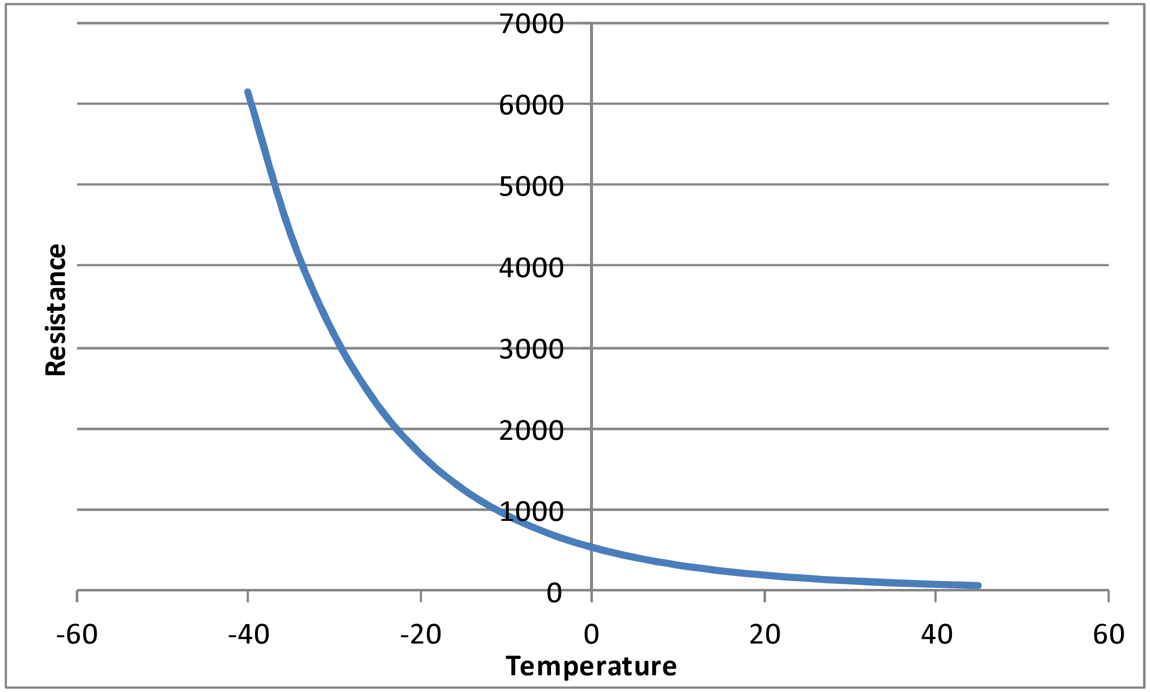
Systematic error mitigation

- If the output is influenced by temperature we could:

  - *Measure temperature also and apply compensation*

  - *As in the case of a strain gauge, combine outputs that they negate the effect of temperature*

Thermistor non-linearity



Thermistors have a very non linear temperature response and manufactures provide tables to allow compensation to be applied.

Random errors

- Errors caused by noise are random
  - *Compare with random failure*

- Can arise from;
  - Electrical interference e.g. Mains pick-up.
  - Physical variations in sensing devices, etc.

- Random errors can sometimes be reduced by signal processing, e.g. filtering, but always at the expense of information.

Random errors

- Averaging is a form of filtering – if we have lots of measurements we can average to gain a more accurate estimate.

- If we assume our measurements are subject to random error it will have a normal distribution and we can estimate the standard error (how close the SD of our data is the true SD)

$$\sigma_{SE} = \frac{\sigma}{\sqrt{n}}$$

Where n = number of samples

- To make our estimate twice as good we need to average 4X as many samples

- Averaging reduces the apparent sampling rate – frequency information is lost

Target Analogy – random / systematic