NUST
SCHOOL OF ELECTRICAL ENGINEERING
& COMPUTER SCIENCE

- Course: **EE383 Instrumentation and Measurements**
- Session: Fall 2022
- **Lectures: Week 3**
- Course Instructor: Dr. Shahzad Younis

INSTRUMENTATION
& MEASUREMENT

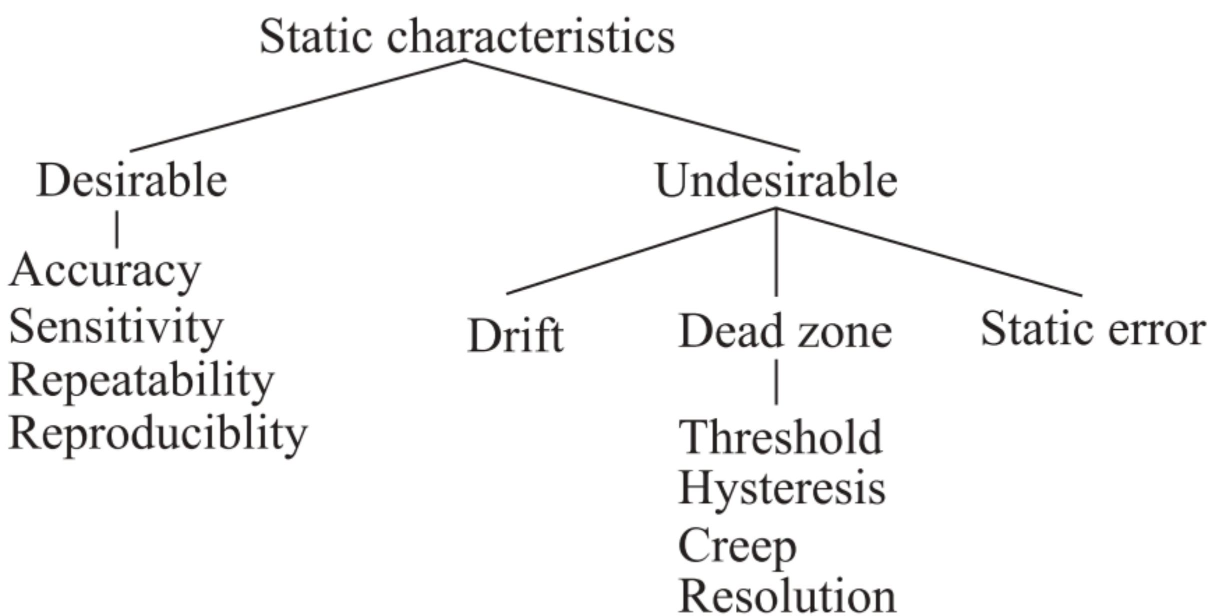
Week 3

- **Chapter 2**

Static Characteristics of Instruments

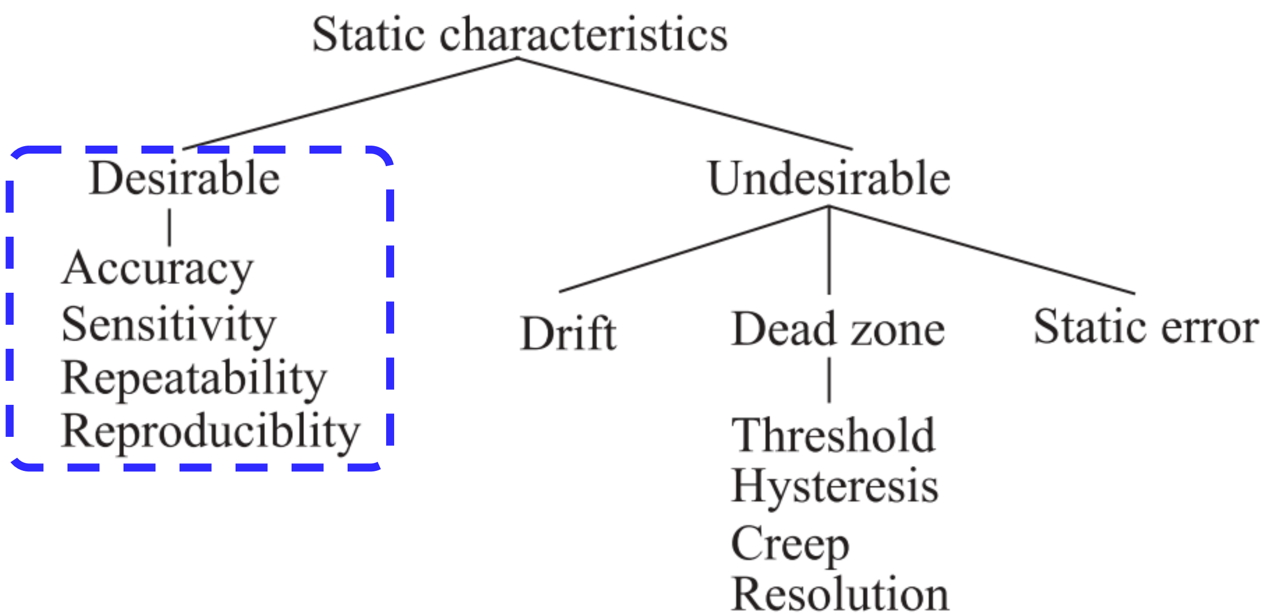
Static Characteristics Of Instrument

- **Characteristics relating the steady-state (achieved) of an instrument**
- **Measurement of quantities which are constant or vary very slowly with time**
- ***Example: EMF, resistance at constant T***



Static Characteristics Of Instrument

- **Characteristics relating the steady-state (achieved) of an instrument**



Desirable Characteristics

- Accuracy
  - Precision
  - Significant figures
- Sensitivity
  - Linearity & Non linearity
- Repeatability
- Reproducibility

Sensitivity

- **Absolute ratio of the increment of the output signal (or response) to that of the input signal (or measurand)**
- **Ratio of the output signal (measurement/response) to that of the input signal (measurand)**

Sensitivity

- **Absolute ratio of the increment of the output signal (or response) to that of the input signal (or measurand)**
  - **If q_i and q_o are input and output quantities, respectively**

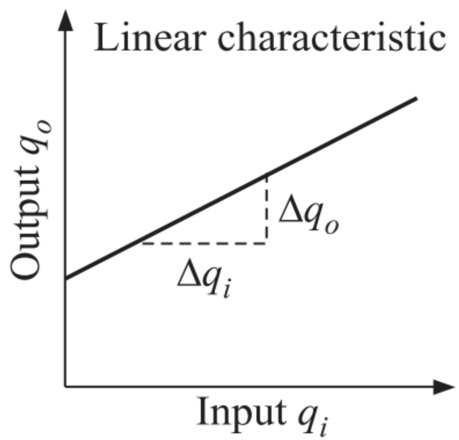
$$S = \frac{\Delta q_o}{\Delta q_i}$$

Sensitivity

- **Absolute ratio of the increment of the output signal (or response) to that of the input signal (or measurand)**
  - **If q_i and q_o are input and output quantities, respectively**

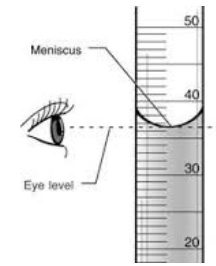
$$S = \frac{\Delta q_o}{\Delta q_i}$$

  - **Slope of the instrument's response curve**



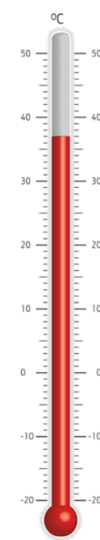
Sensitivity of Thermometer?

Example:



•In a mercury in glass thermometer, meniscus moves by 1 cm when a temperature changes by 10 ° Celsius.

- Sensitivity of the thermometer will be?



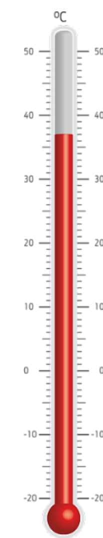
Sensitivity

- Absolute ratio of the increment of the output signal (or response) to that of the input signal (or measurand)

  - If q_i and q_o are input and output quantities, respectively

$$S = \frac{\Delta q_o}{\Delta q_i}$$

  - Mercury-in-glass thermometer
    - Meniscus movement: ΔH=1 cm for ΔT=10 ℃
    - $S = \frac{\Delta H}{\Delta T}$= 1 mm/ ℃



Temperature

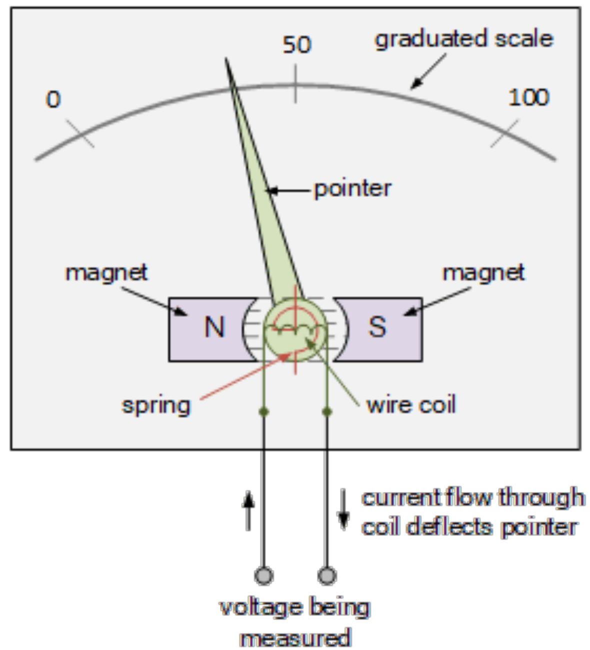
Sensitivity

- What is the sensitivity of a voltmeter

Sensitivity

- What is the sensitivity of a voltmeter

- How does it work



Sensitivity

- ❑ **Voltmeter: How does it work?**

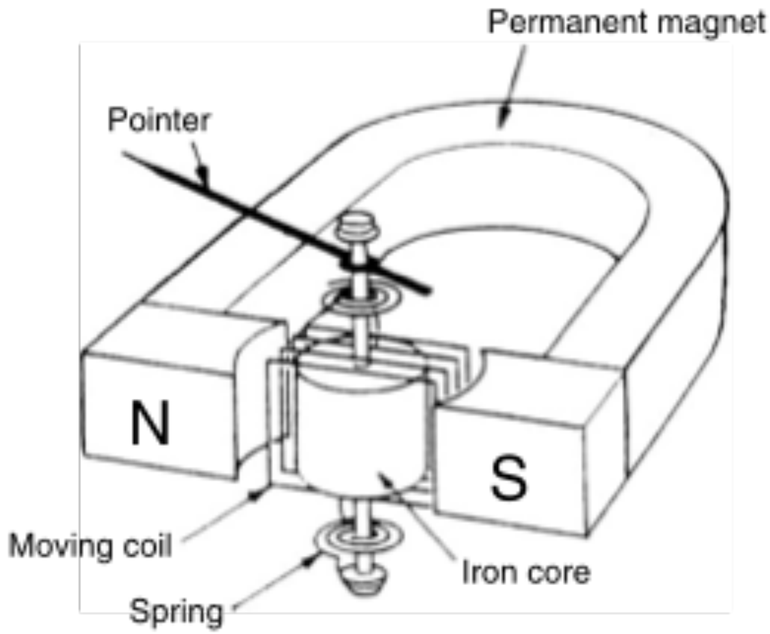


Figure 7.3
Mechanism of a moving coil meter.

Measurement and Instrumentation, Theory and Application, Alan S Morris, Reza Lengari

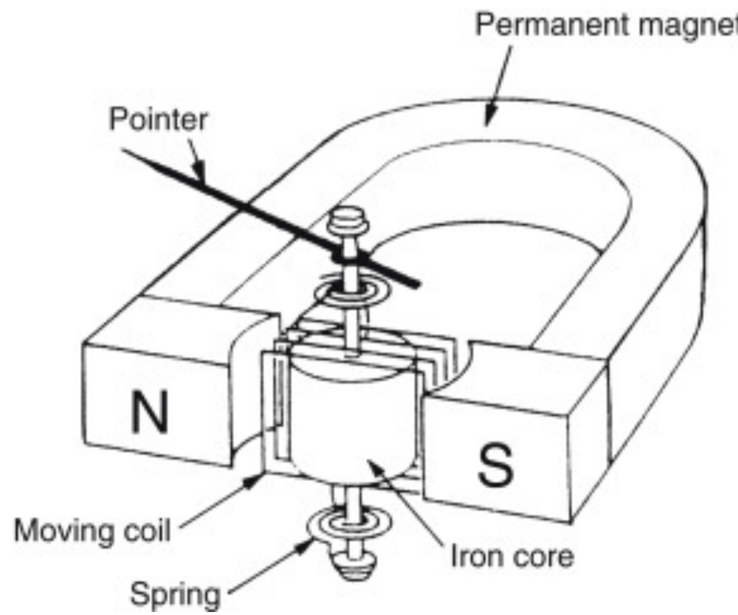
- ➢ **Interaction of the induced field with permanent magnet's field causes deflection**
  - ➢ **Rectangular coil draws current from the circuit**

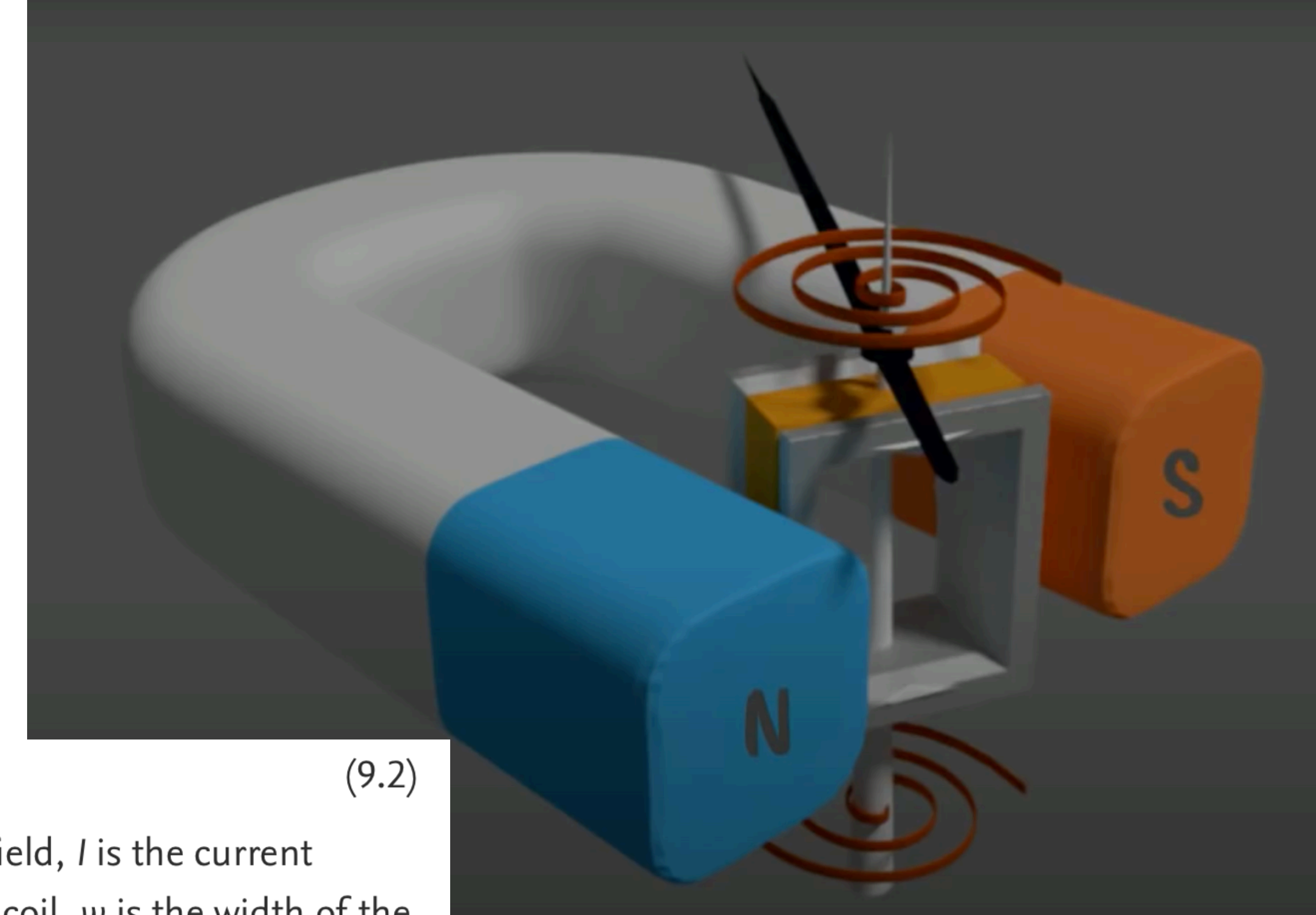
Display, Recording, and Presentation of Measurement Data

Alan S. Morris, Reza Langari, in Measurement and Instrumentation (Second Edition), 2016

Moving coil meter

A moving coil meter is a very common form of analog voltmeter because of its sensitivity, accuracy, and linear scale, although it only responds to DC signals. As shown schematically in Figure 9.3, it consists of a rectangular coil wound round a soft iron core that is suspended in the field of a permanent magnet. The signal being measured is applied to the coil and this produces a radial magnetic field. Interaction between this induced field and the field produced by the permanent magnet causes a torque, which results in rotation of the coil. The amount of rotation of the coil is measured by attaching a pointer to it that moves past a graduated scale. The theoretical torque produced is given by:





$$\boxed{T = BIhwN} \tag{9.2}$$

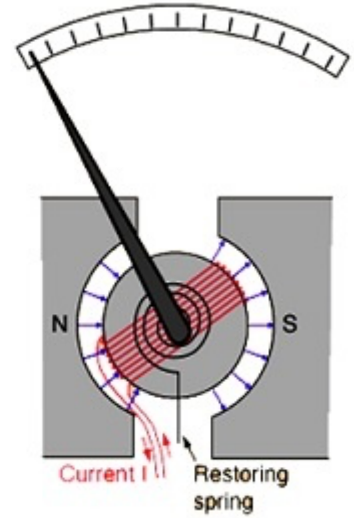
where B is the flux density of the radial field, I is the current flowing in the coil, h is the height of the coil, w is the width of the coil, and N is the number of turns in the coil. If the iron core is cylindrical and the air gap between the coil and pole faces of the permanent magnet is uniform, then the flux density B is constant, and Eqn (9.2) can be rewritten as:

$$\boxed{T = KI} \tag{9.3}$$

i.e., the torque is proportional to the coil current and the instrument scale is linear.

Sensitivity

- **Voltmeter: How does it work?**
  - **Voltmeter take current as input to make a voltage measurement.**



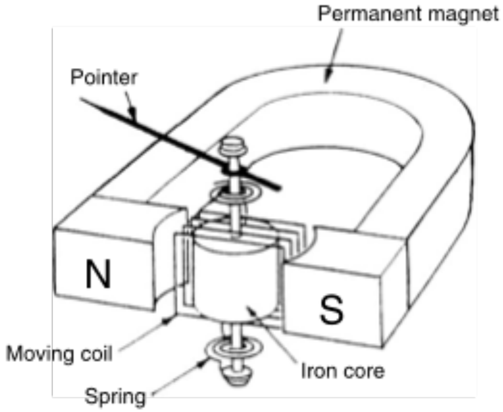
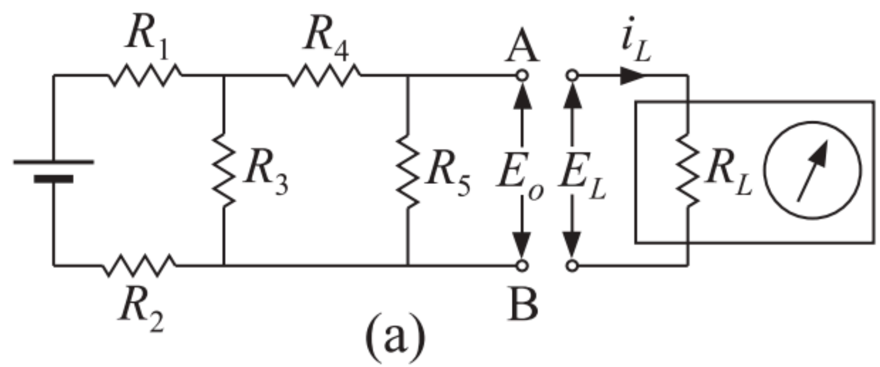


Figure 7.3
Mechanism of a moving coil meter.



Measurement and Instrumentation, Theory and Application, Alan S Morris, Reza Lengari

Sensitivity

- Voltmeter: How does it work?
  - It draws the current from the measurand's circuit
  - More sensitive, if it draws less current from the circuit
    - High resistance to be connected in parallel

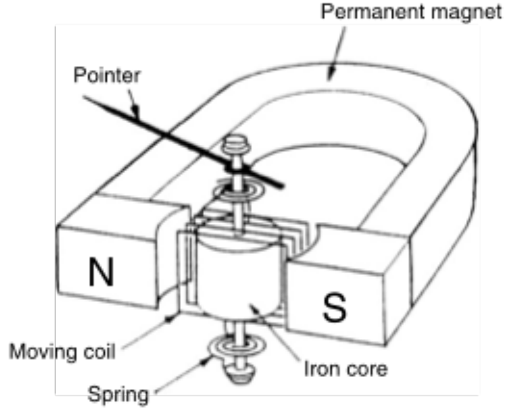
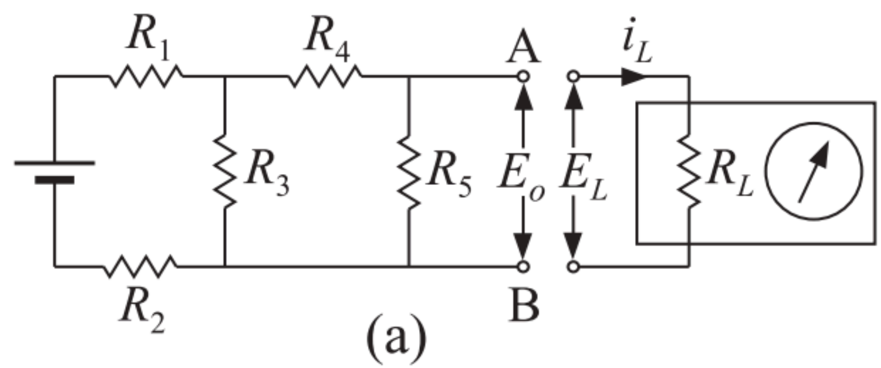


Figure 7.3
Mechanism of a moving coil meter.



Sensitivity

Sensitivity of a voltmeter

- **varies inversely with the current required for full-scale deflection (FSD)**
- **If I_{FSD} is the current required for the full-scale deflection (FSD)**

$$\text{Sensitivity} = \frac{1\ (\text{V})}{I_{\text{FSD}}\ (\text{A})}\ \text{ohm/volt}$$

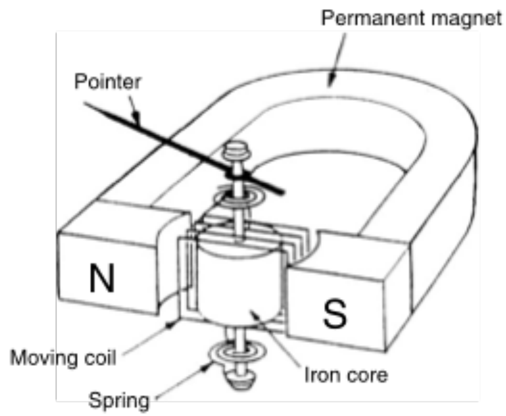


Figure 7.3
Mechanism of a moving coil meter.

Desirable Characteristics

- **Sensitivity**
  - Sensitivity of voltmeter
    - Voltmeter take current as input to make a voltage measurement.
    - Lower the current required to produce full scale deflection, more sensitive will be the voltmeter.
    - Sensitivity of voltmeter is expressed in ohm/volt.

$$\text{Sensitivity} = \frac{1}{I_{\text{FSD}}\ (\text{A})}\ \text{ohm/volt}$$

Sensitivity

Example 2.3

What is the sensitivity of a voltmeter having 50 μA FSD?

Sensitivity

Example 2.3

What is the sensitivity of a voltmeter having 50 μA FSD?

Solution

The required sensitivity is given by

$$\text{Sensitivity} = \frac{1}{50 \times 10^{-6}} = 20,000 \text{ ohm/volt}$$

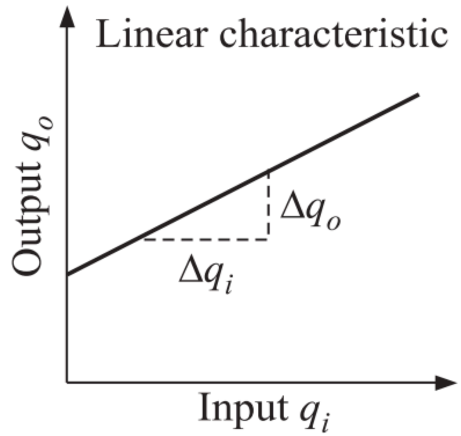
Lab quality voltmeters should have a minimum sensitivity of 20 kΩ/volt.

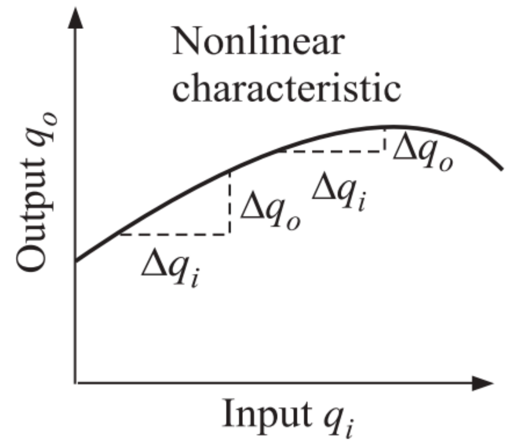
Linearity and nonlinearity

- **Why linear？**

- **Why nonlinear？**

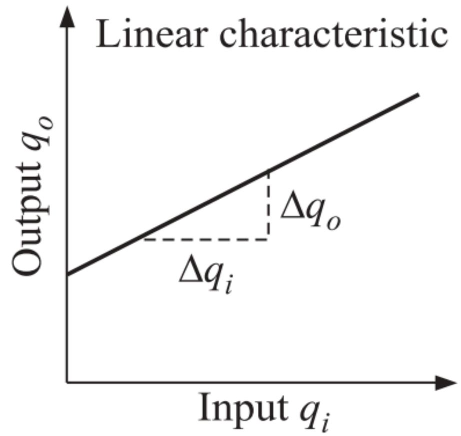
Linearity and nonlinearity





- **Linear instrument: linear relationship b/w input quantity and output reading**
  - **Sensitivity is constant**

Linearity and nonlinearity



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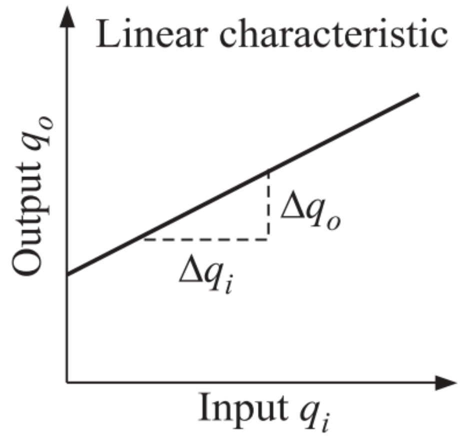
Linearity and nonlinearity



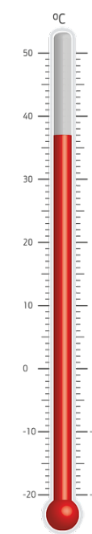
❑Linear instrument: linear relationship b/w input quantity and output reading

- Sensitivity is constant

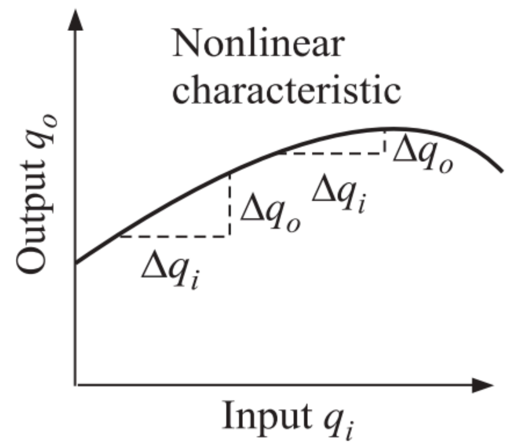
❑ Example: mercury in glass

❑ Volume change, ΔV; expansion coefficient, β; initial volume V_o; temperature change, ΔT

$$\Delta V = \beta V_o \Delta T$$



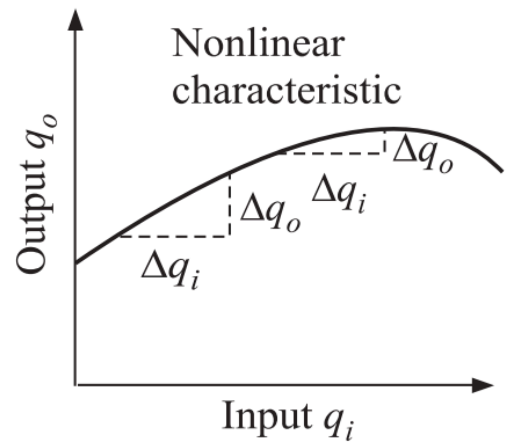
Linearity and nonlinearity



❑**Non-linear instrument: non-linear relationship between input quantity and output reading**

- **Sensitivity varies with input**

Nonlinearity



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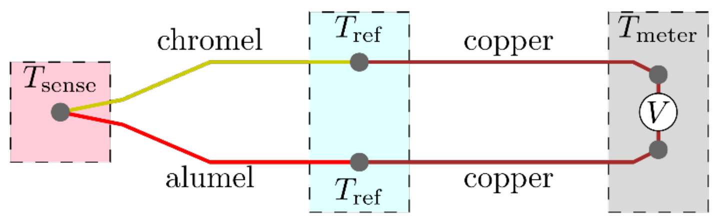
  - **Sensitivity varies with input**

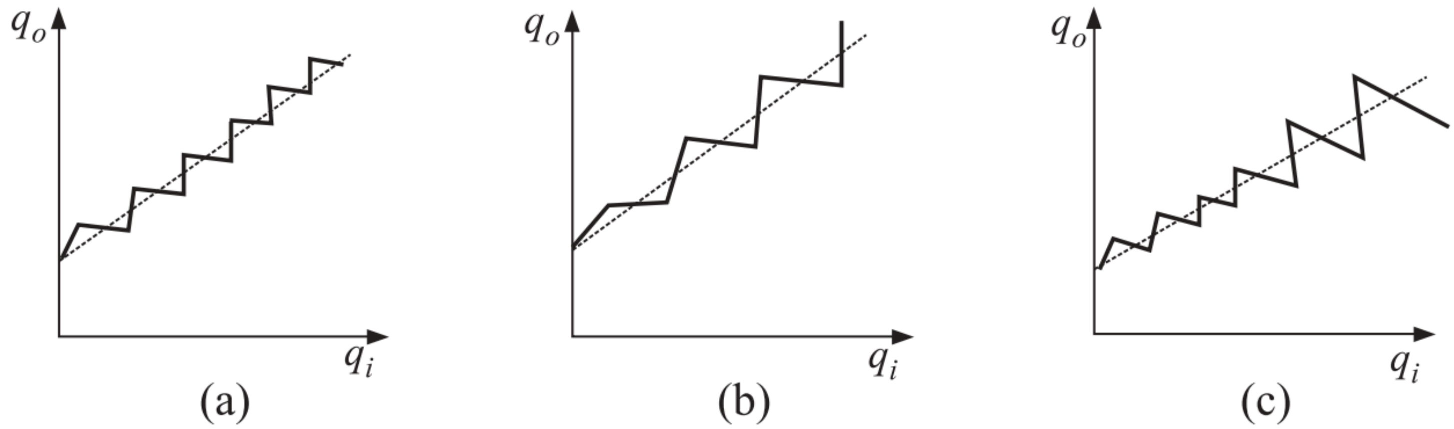
- Example: Thermocouple



$$\boldsymbol{E = \alpha T + \beta T^2}$$

E is the output voltage; $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are constants; Temperature, T

Linearity

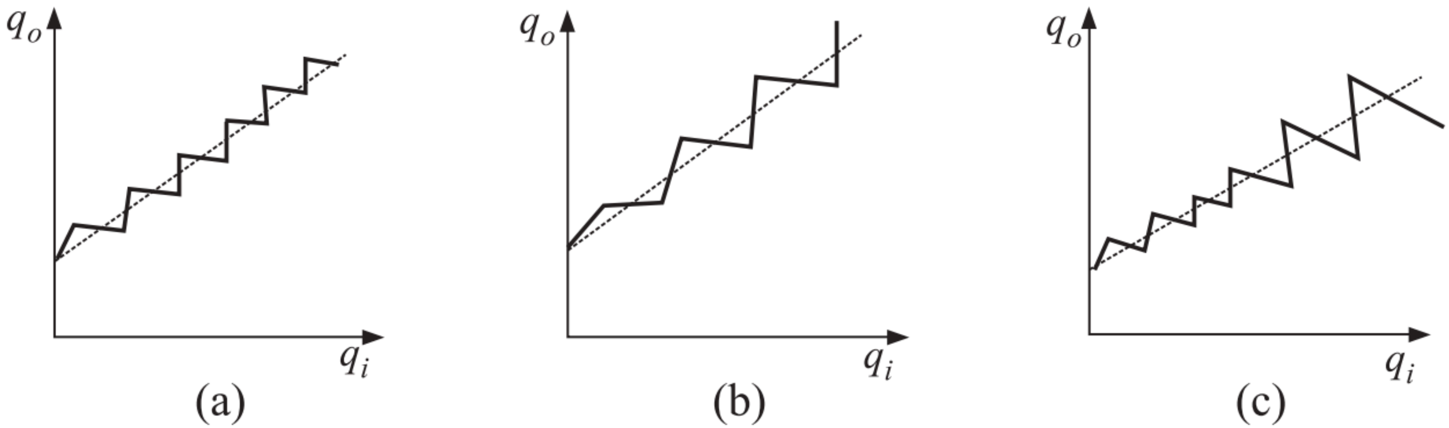


❑Deviation from linearity

- No instrument is perfectly linear

1. the output oscillate with same amplitude around the best-fit straight line
2. amplitude of oscillation varies with the input value
3. combination of the two: fixed amplitude in some part and varying amplitude in other parts

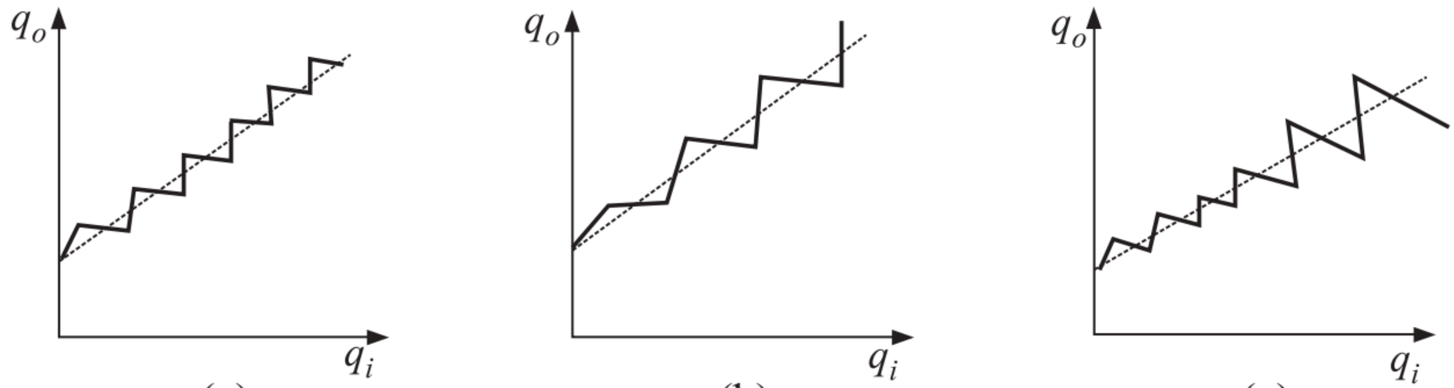
Linearity



❑Deviation from linearity

1. The actual output of the instrument may oscillate with the same amplitude around the best-fit straight line. In this case, the nonlinearity is expressed in terms of the amplitude (or maximum deviation). The amplitude is calculated as the $\pm$ of the full scale deflection (FSD).

Linearity

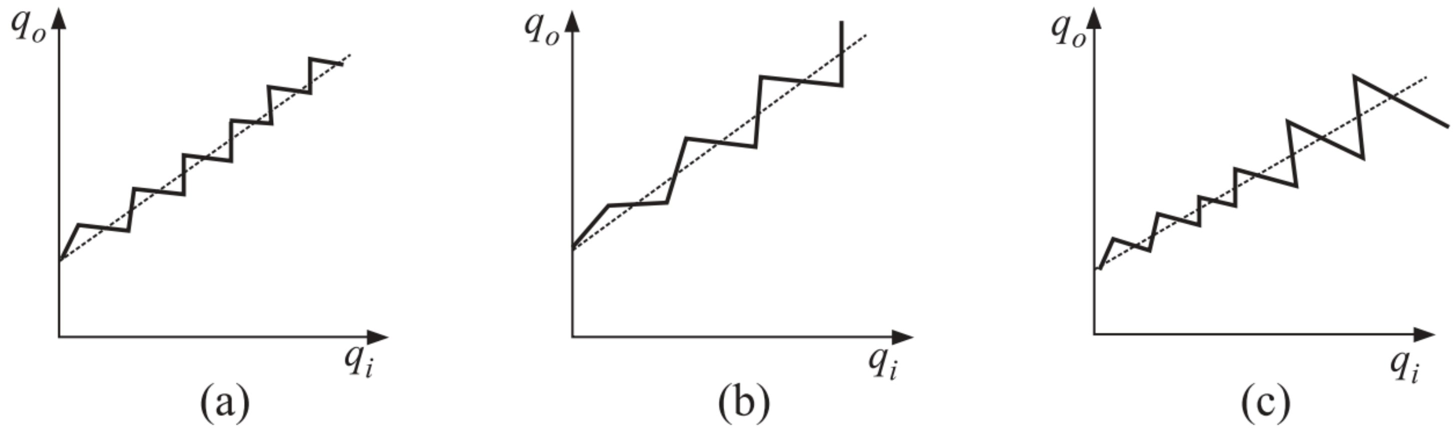


(a) (b) (c)

❑Deviation from linearity

2. The actual output of the instrument may oscillate around the best-fit straight line, but the amplitude of oscillation varies with the input value. Here, the nonlinearity is expressed as a function of the input value. Actually, the slopes of lines connecting positive and negative deviations are determined and the one with a higher deviation from the best-fit line is used to express the per cent nonlinearity with respect to the input value.

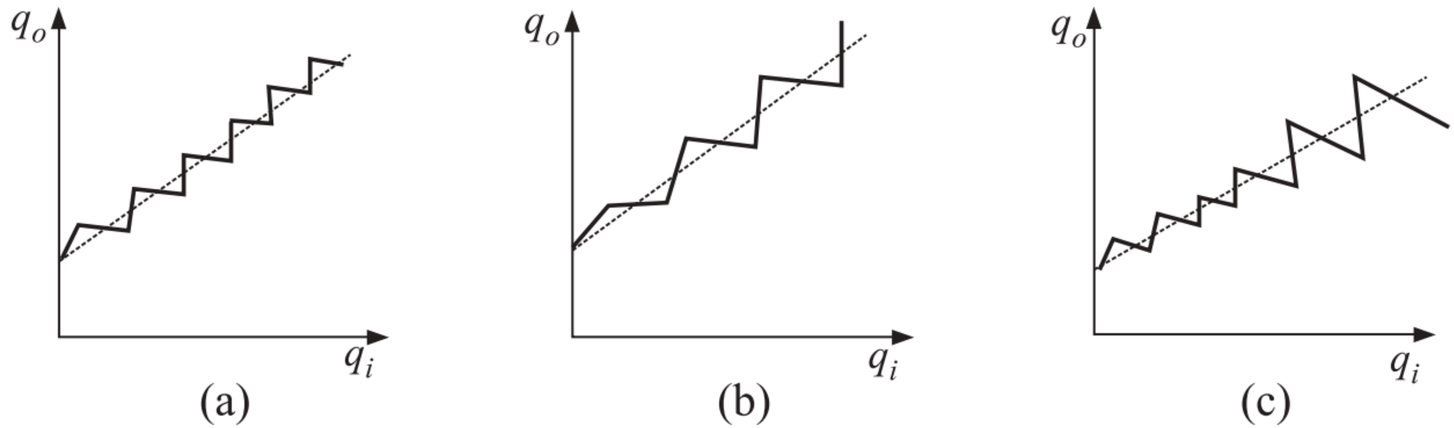
Linearity



❑**Deviation from linearity**

2. The actual output of the instrument may oscillate around the best-fit straight line, but the amplitude of oscillation varies with the input value. Here, the nonlinearity is expressed as a function of the input value. Actually, the slopes of lines connecting positive and negative deviations are determined and the one with a higher deviation from the best-fit line is used to express the per cent nonlinearity with respect to the input value.

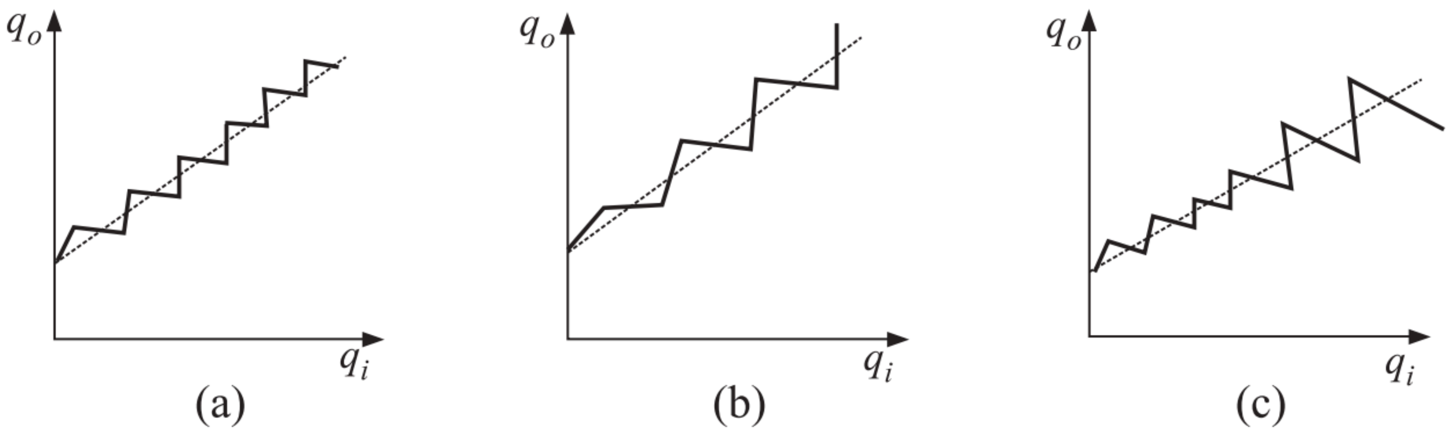
Linearity



❑Deviation from linearity

3. The actual output may oscillate with a fixed amplitude around the best-fit straight line over a certain range and then the amplitude may become a function of the input over the rest. In that case, two computations are made—one for the fixed amplitude part and expressed as ±% of the FSD, and another for the varying amplitude part, expressed as ±% of the input value. Nonlinearity is expressed in terms of the higher value.

Linearity



❑Deviation from linearity

- **max deviation of the reading from the linear fit**
- **as a percentage of full scale reading (FSD); D is the deviation**

$$\Delta L = \frac{100D}{FSD}$$

Nonlinearity

Example 2.4

The output of a temperature transducer is recorded over its full-scale range of 25°C as shown below:

Calibration temperature (°C)	0.0	5.0	10.0	15.0	20.0	25.0
Output reading (°C)	0.0	5.0	9.8	14.8	19.9	25.0

Determine (a) the static sensitivity of the device, and (b) the maximum nonlinearity of the device.

Nonlinearity

Example 2.4

The output of a temperature transducer is recorded over its full-scale range of 25°C as shown below:

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Output reading (°C)	0.0	5.0	9.8	14.8	19.9	25.0

Determine (a) the static sensitivity of the device, and (b) the maximum nonlinearity of the device.

Solution

Let q_i be the calibration temperature in °C

q_o be the output reading in °C

S be the sensitivity $= \Delta q_o / \Delta q_i$

D be the deviation from the calibration temperature

Δl be the nonlinearity $= 100D/\mathrm{FSD} = 4D$ since FSD = 25°C.

Then, we have

q_i (°C)	Δq_i (°C)	q_o (°C)	Δq_o (°C)	S	D (°C)	Δl (%)
0.0		0.0			0.0	0.0
5.0	5.0	5.0	5.0	1.0	0.0	0.0
10.0	5.0	9.8	4.8	0.96	–0.2	0.8
15.0	5.0	14.8	5.0	1.0	–0.2	0.8
20.0	5.0	19.9	5.1	1.02	–0.1	0.4
25.0	5.0	25.0	5.1	1.02	0.0	0.0

Thus $S_{\min} = 0.96$ and maximum nonlinearity $= 0.8\%$

Nonlinearity

emf-temperature relation of a thermocouple can be written to a first approximation as

$$E = \alpha T + \beta T^2 \tag{2.1}$$

where, α and β are constants for a given thermocouple and T is the temperature of the hot junction, the cold junction being kept at 0°C. For such a thermocouple, if we assume emfs are E_1 and E_2 at temperatures T_1 and T_2 and that a linear relationship exists between emf and temperature, then

$$E_{\text{linear}} = \left(\frac{E_1 - E_2}{T_1 - T_2}\right) T \equiv \alpha' T \tag{2.2}$$

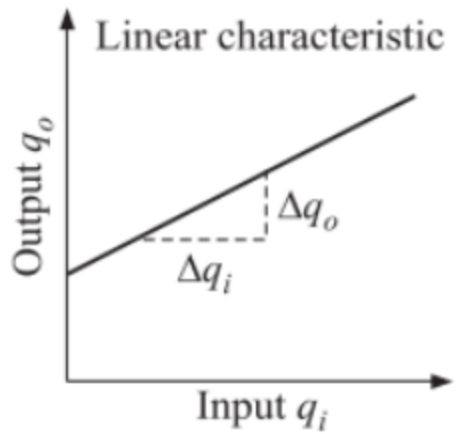
where, $\alpha' = \dfrac{E_1 - E_2}{T_1 - T_2}$. In this case, the nonlinearity N may be expressed as

$$N = E_{\text{actual}} - E_{\text{linear}} = (\alpha - \alpha')T + \beta T^2 \tag{2.3}$$

Alternatively, the nonlinearity may be defined in terms of the nonlinear term βT^2 in expression (2.1). We will consider a case in Example 10.1.

2.1 Desirable Characteristics

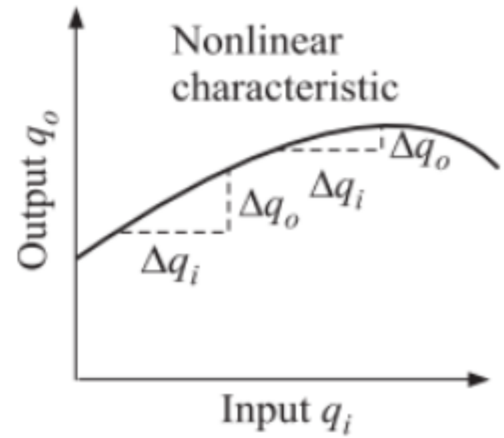
- **Linearity and nonlinearity**



(a)

Sensitivity remains the same over the entire range of instrument

e.g. a thermometer



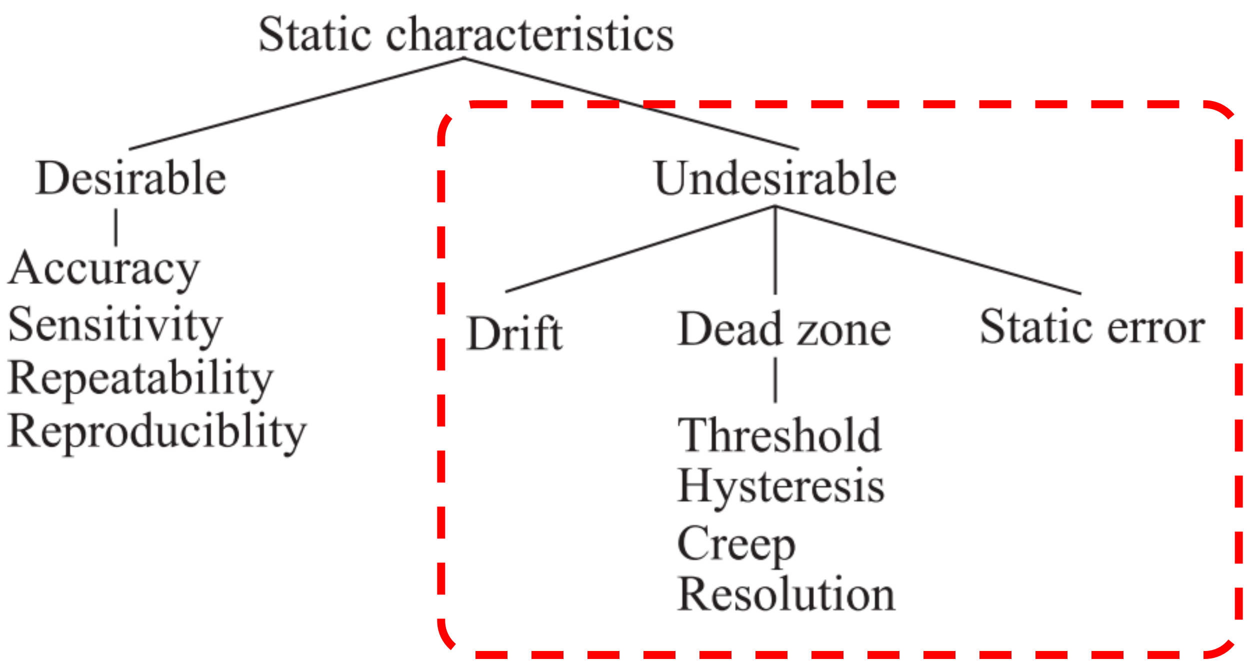
(b)

Sensitivity varies over the range of instrument

e.g. a thermocouple

Static Characteristics of Instruments

- **Characteristics relating the steady-state (achieved) of an instrument**



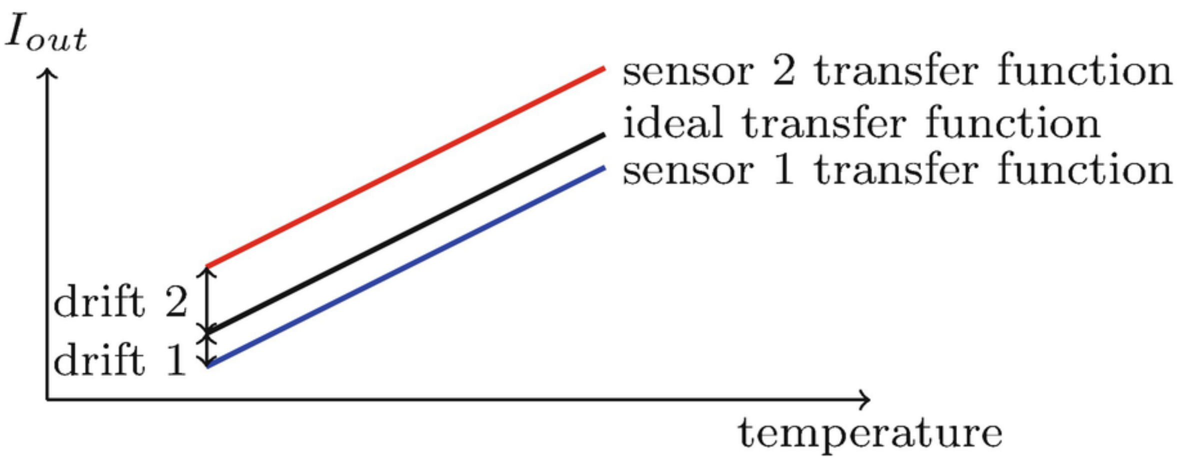
2.2 Undesirable Characteristics

- Drift
- Dead Zone
  - Hysteresis
  - Threshold
  - Creep
  - Resolution
- Static Errors
  - Human
  - Random
  - Systematic

Drift

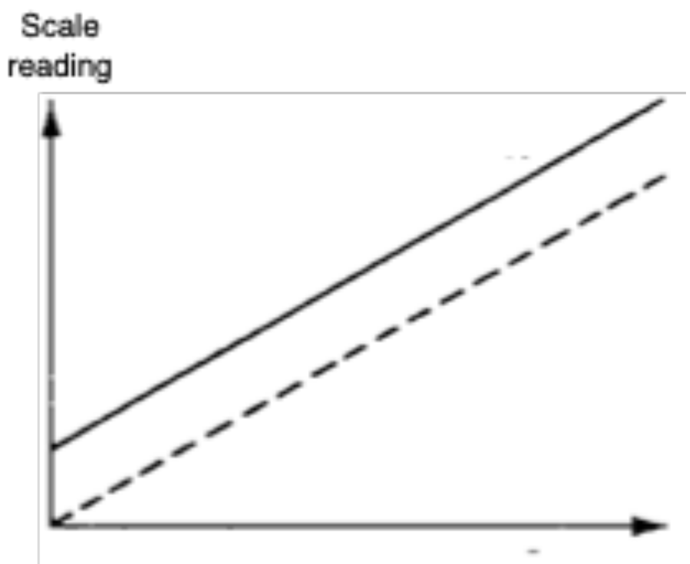
- When the process of measurement takes place there are some changes taking place in the environment such as changes in the temperature ,pressure etc .

- Such environmental changes affect the output of an instrument and this is termed as drift.



Drift

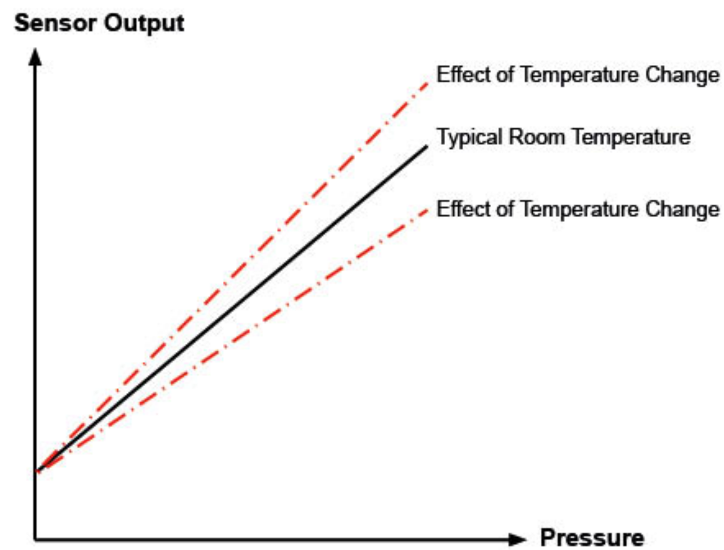
- Drift denotes the change in the indicated reading of an instrument over time when the value of the measurand remains constant.
- If there is no drift, the reproducibility is 100%



Drift

❑Why drift？

❑**Stray electromagnetic fields, mechanical vibrations, changes in ambient temperature or pressure, Joule heating of the components of the instrument, etc. are some of the causes**



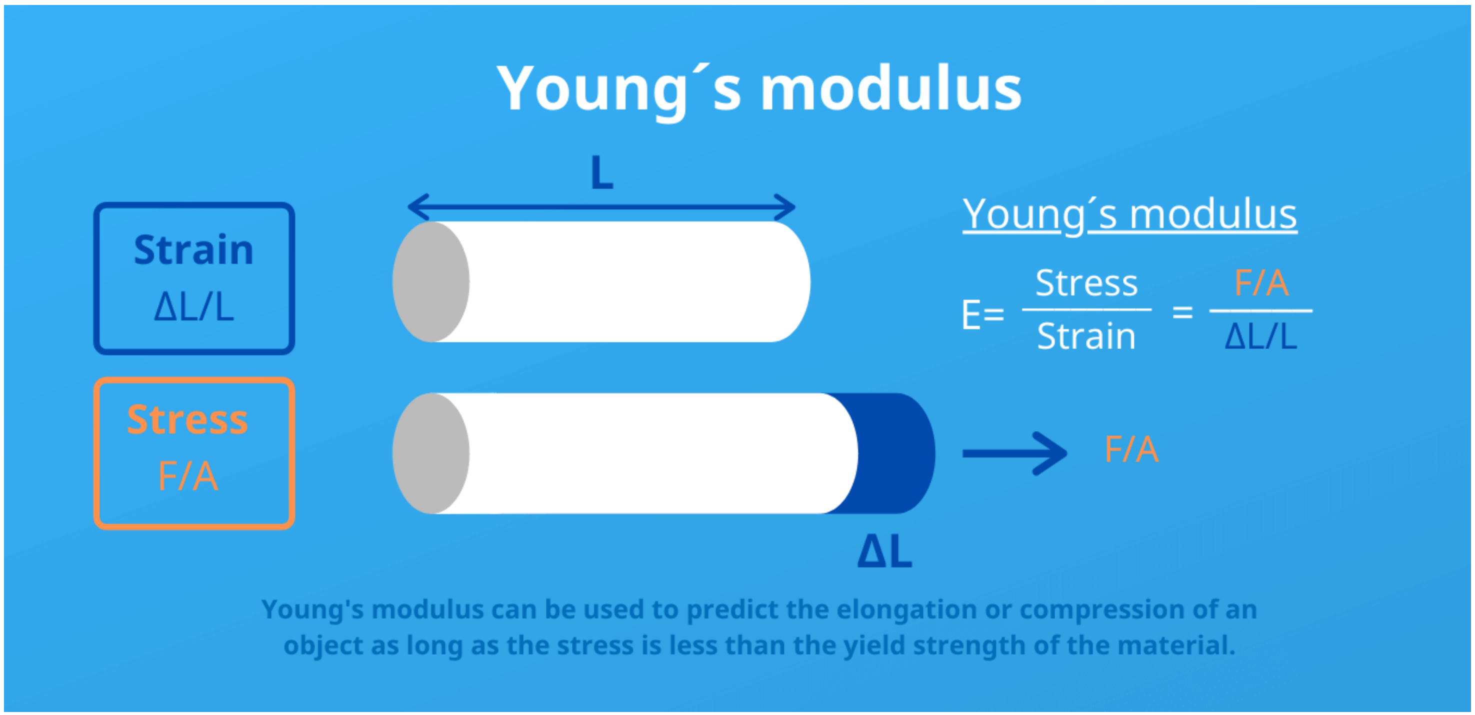
❑Why drift？

- ❑Stray electromagnetic fields, mechanical vibrations, changes in ambient temperature or pressure, Joule heating of the components of the instrument, etc. are some of the causes.
- ❑e.g., many components within an instrument are affected by environmental fluctuations: such as temperature change
  - ✓ Modulus of elasticity of a spring is temperature dependent
  - ✓ Electrical resistance is temperature dependent

Concept: Review

Modulus of elasticity: resistance to being deformed elastically when a stress is applied to it.

$$\lambda = \frac{\text{stress}}{\text{strain}}$$



Drift

- drift or zero drift or bias
    - change in the zero setting

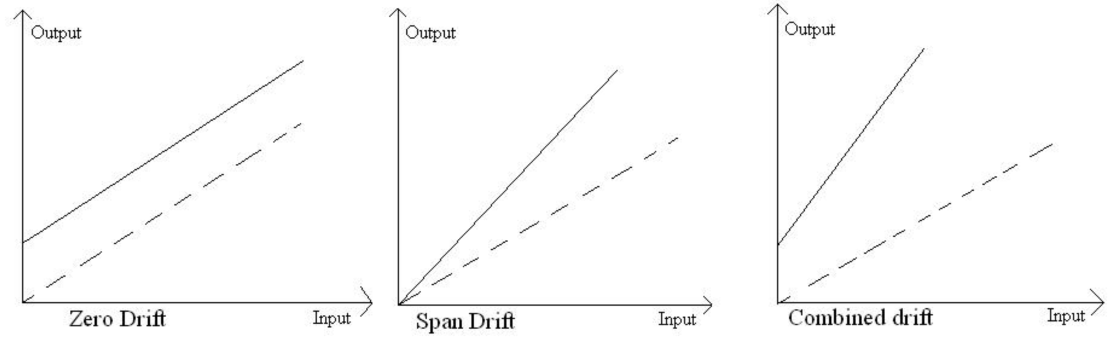
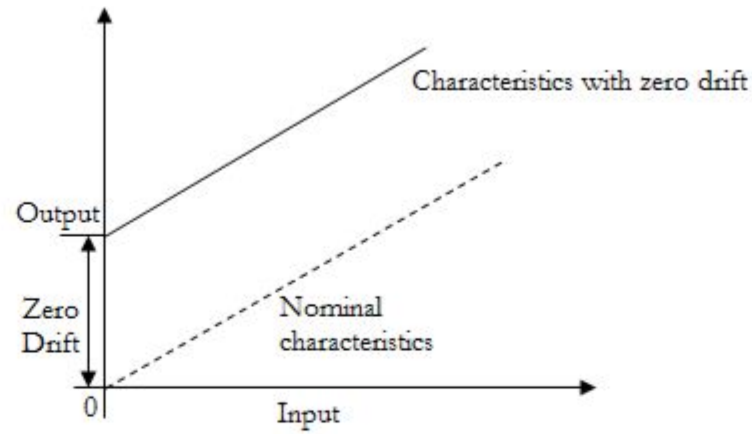
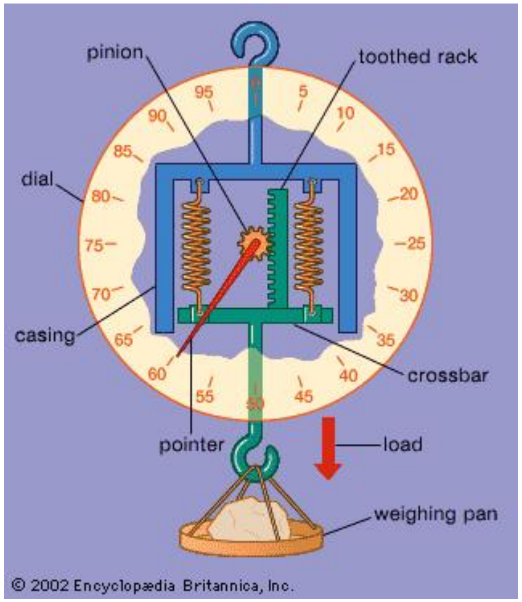


Fig. Types of Drift





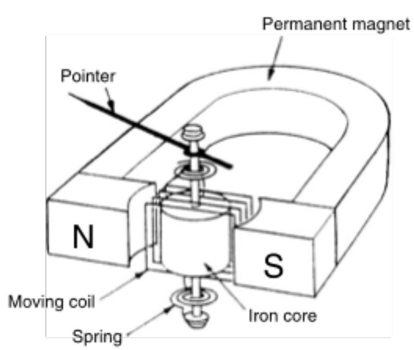


Figure 7.3
Mechanism of a moving coil meter.

Dead zone

- Range of input values over which there is no change in output value

Dead zone: Hysteresis

❑ **The loading and unloading curves do not coincide**

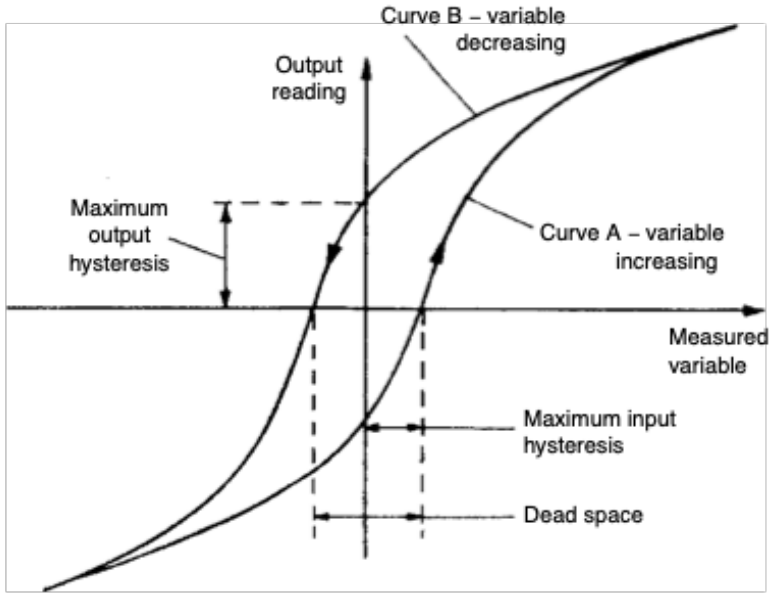
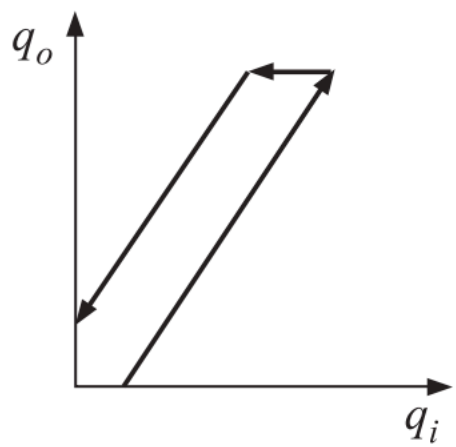


Figure 2.8
Instrument characteristic with hysteresis.

Dead zone: Hysteresis

- The loading and unloading curves do not coincide
  - spring balance: one set of readings when the weight is increased and another set of readings when the weight is decreased
    - Consumption of some energy by the friction
    - Different friction forces depending upon the direction of the movement



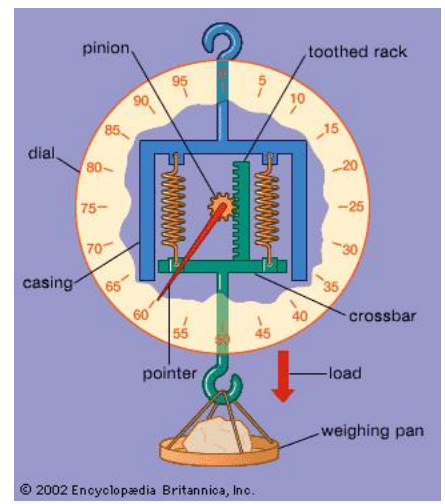
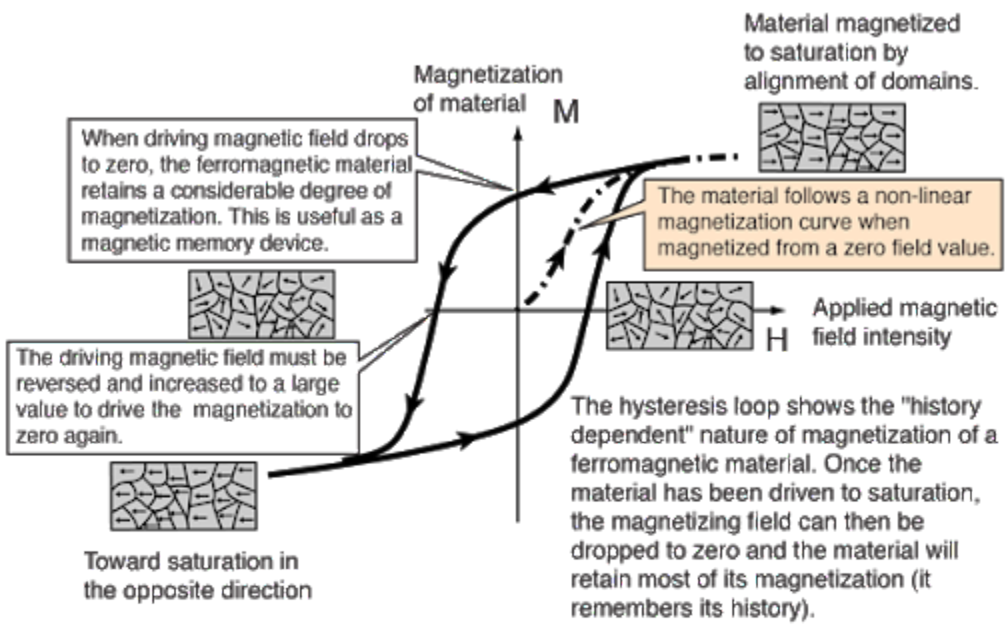


Fig. 2.4 Hysteresis effects shown in an exaggerated way.

Dead zone: Hysteresis

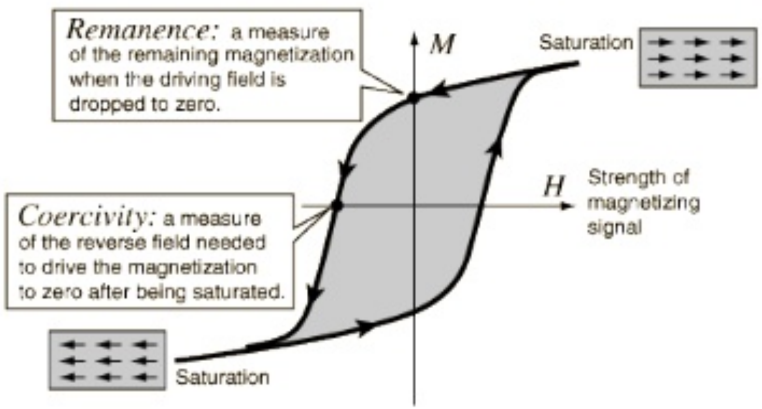
- ❑Electrical instruments: magnetic hysteresis
  - ❑ variable inductance displacement transducer, linear variable differential transformer, rotary differential transformer etc.



Concept: Review

Coercivity and Remanence

When a ferromagnetic material is magnetized in one direction, it will not relax back to zero magnetization when the imposed magnetizing field is removed. The amount of magnetization it retains at zero driving field is called its **remanence**.



It must be driven back to zero by a field in the opposite direction; the amount of reverse driving field required to demagnetize it is called its **coercivity.**

Dead zone: Hysteresis

- The loading and unloading curves do not coincide
  - Electrical instruments: magnetic hysteresis
    - variable inductance displacement transducer
      - Change in mutual inductance due to “d”
      - $I = V/(\omega L)$

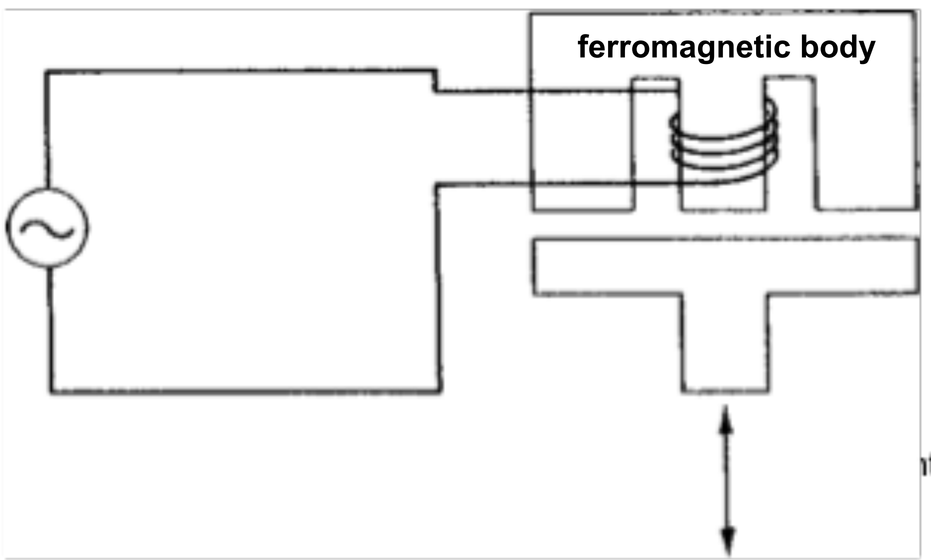
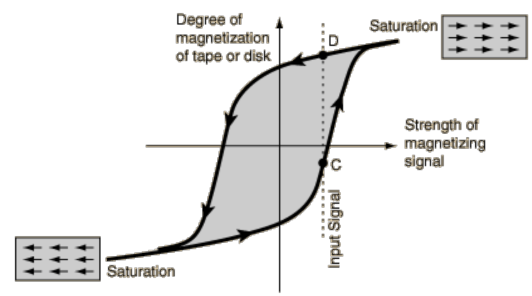


Figure 13.1
Inductive displacement sensor.



Dead zone: Threshold

- The minimum input required to activate an instrument to produce an output
    - Example: a car speedometer typically has a threshold of about 15 km/h

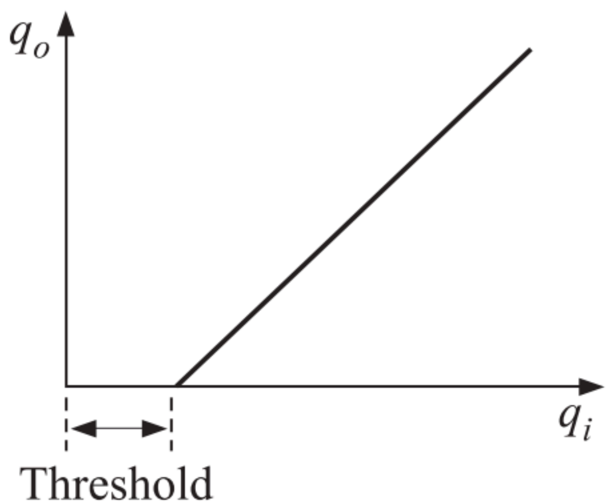


Fig. 2.5 Threshold effect.

Dead zone: Threshold

❑The minimum input required to activate an instrument to produce an output

- MOSFET and the threshold voltage

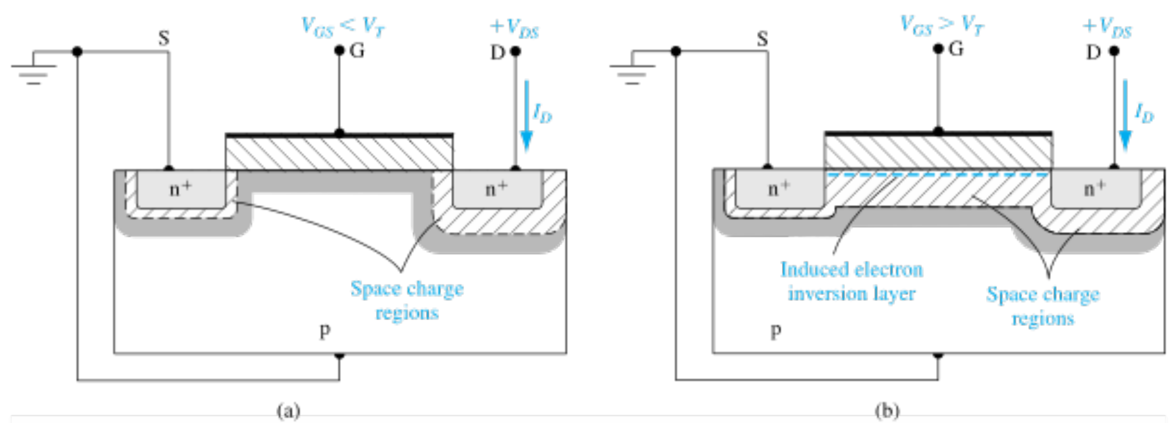
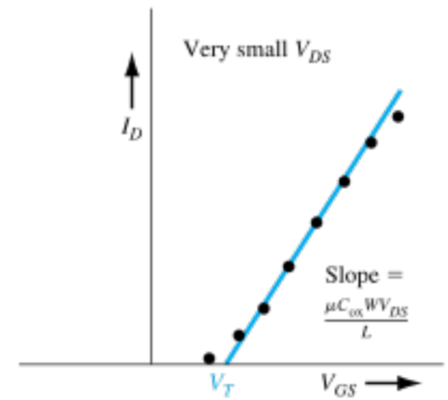


Figure 10.37 | The n-channel enhancement mode MOSFET (a) with an applied gate voltage $V_{GS} < V_T$ and (b) with an applied gate voltage $V_{GS} > V_T$.

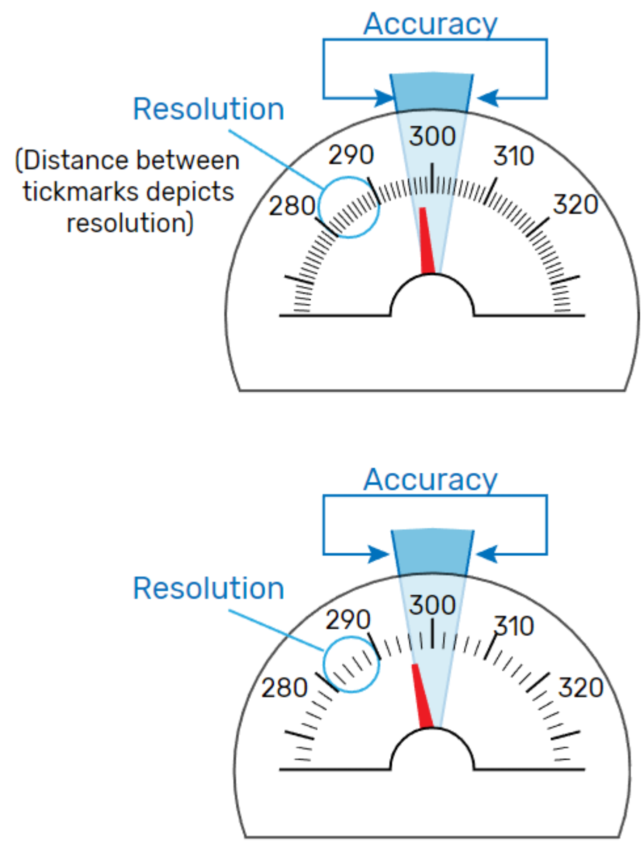


Ref: Semiconductor Physics and Devices: Basic Principles by Donald A. Neamen

Dead zone: Resolution

❑**Minimum input required to activate an instrument to produce an output**

- **Resolution is the smallest measurable change in input**
- **Expression: absolute value or percentage of the full-scale reading/ deflection**



Dead zone: Resolution

Example 2.5
An analogue ammeter has a linear scale of 50 divisions. Its full-scale reading is 10 A and half a scale division can be read. What is the resolution of the instrument?

Solution
1 scale division = $10/50$ A = 0.2 A. Thus, resolution = $1/2$ scale division = $(0.2/2)$ A = 0.1 A.

Dead zone: Resolution

Example 2.6
The dead-zone in a pyrometer is 0.125% of the span. The instrument is calibrated from 800 to 1800°C. What temperature change must occur before it is detected?

Solution
The span is $(1800 - 800) = 1000°C$. The dead zone is 0.125% of 1000°C, i.e. 1.25°C. Hence, no change in temperature below 1.25°C can be detected.

Dead zone: Resolution

- Minimum input required to activate an instrument to produce an output
  - Resolution is the smallest measurable change in input
  - Expression: absolute value or percentage of the full-scale reading/ deflection

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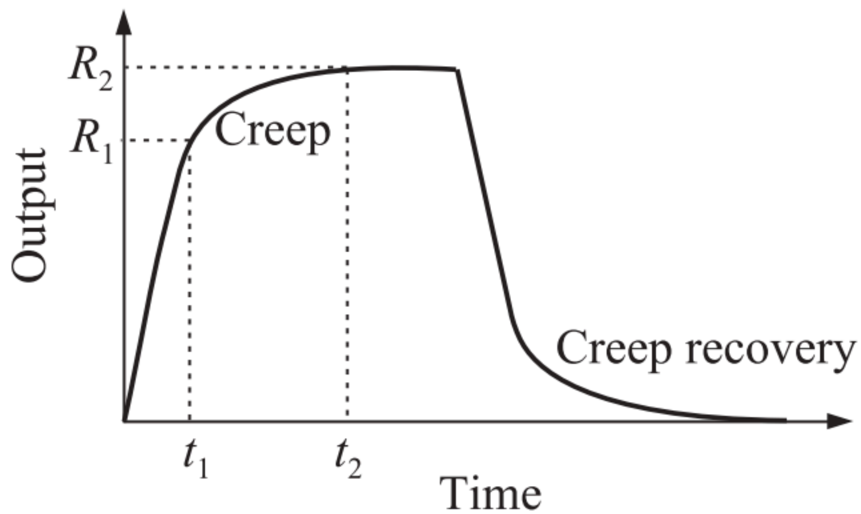
The span is $(1800 - 800) = 1000$°C. The dead zone is 0.125% of 1000°C, i.e. 1.25°C. Hence, no change in temperature below 1.25°C can be detected.

Dead zone: Creep

- Creep: change of output with time following a step increase in the input from one value to another.

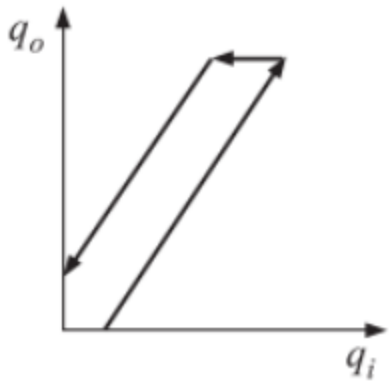


- Creep recovery: change of output following a step decrease in the applied input to the transducer.

2.2 Undesirable Characteristics

- Dead Zone (Summary)

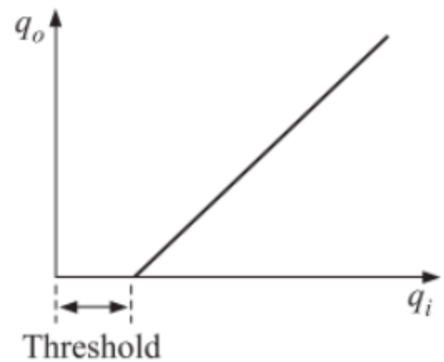
Hysteresis



Loading and unloading curves do not coincide

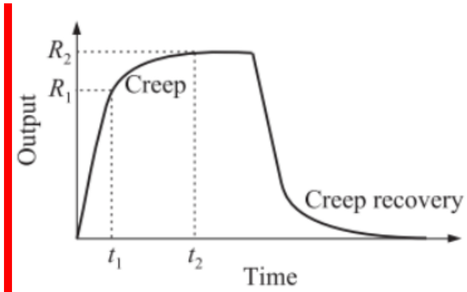
→Due to consumption energy by internal components of instrument/friction etc.

Threshold



Minimum input required by instrument to produce an output.

Creep



There is a step increase in input, however the output changes very slowly. Lets say from t1 to t2 the output changes by 0.03% of the rated output in 30 minutes..

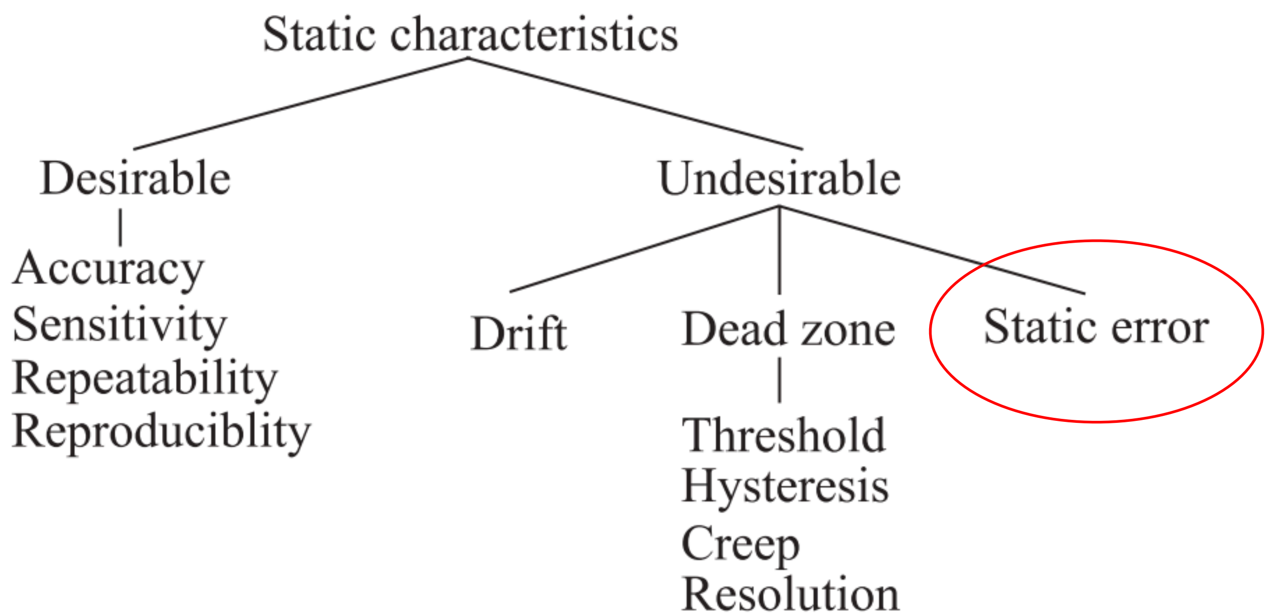
Resolution

A minimum change in input is required to change a perceptible change in output.

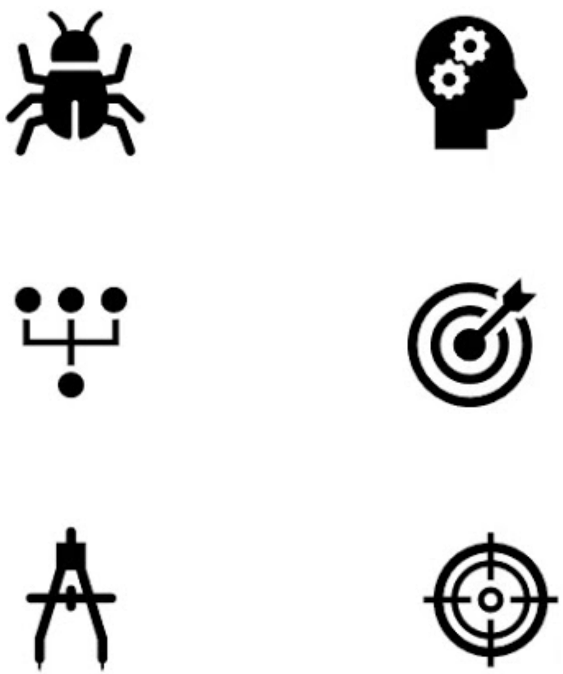
→if a resolution of a digital voltmeter is 1 V, a smaller change in voltage (e.g., 0.1 V) could not be observed by the user.

Static Characteristics of Instruments

- Characteristics relating the steady-state (achieved) of an instrument



Static Errors



- Gross
- Systematic error
- Random Error

Static Errors

- **Classification of errors**

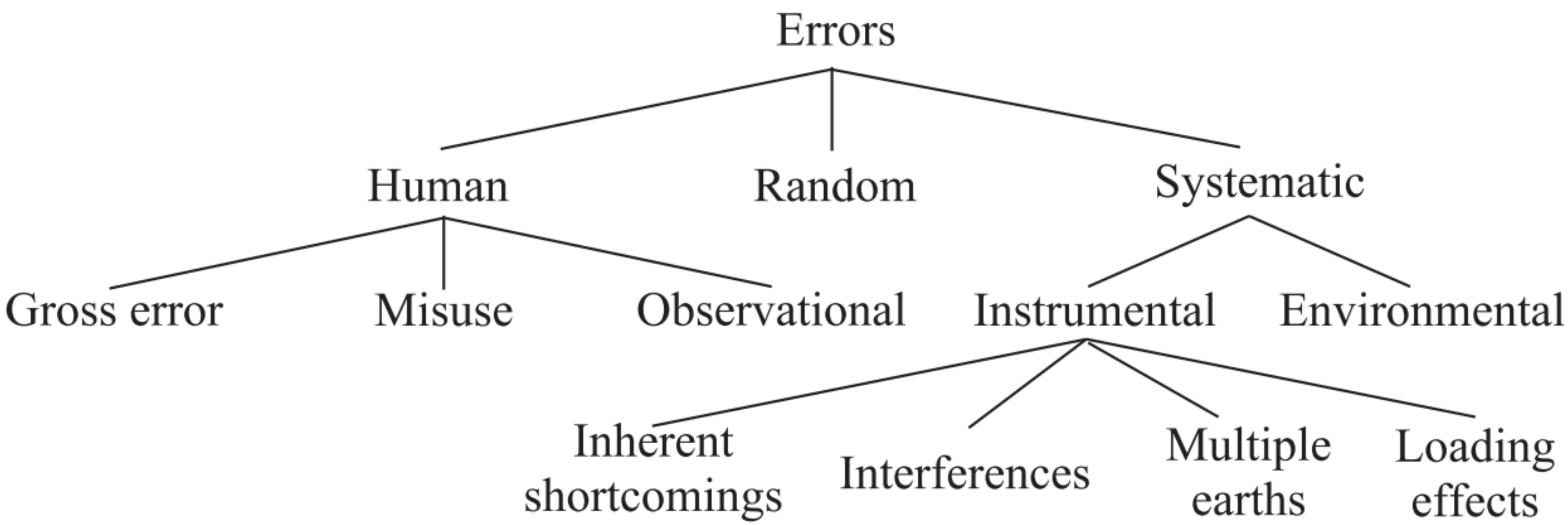


Fig. 2.7 The error tree.

Static Errors

- ❑ **Classification of errors**

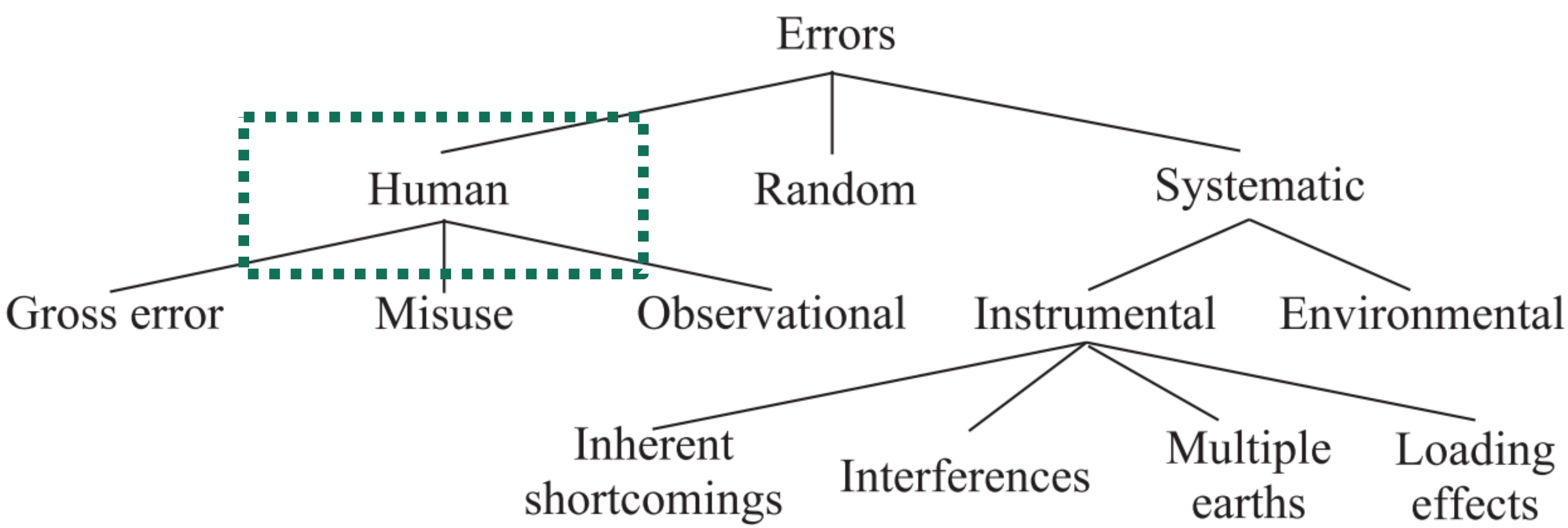


Fig. 2.7 The error tree.

Human Errors: Gross and Observational Errors

- Gross errors
  - Mistakes while reading or recording
    - Example: True value: 47.0; Reading 42.0 or Recording:41.0
  - Eliminated by automation or reduced by taking multiple readings of the same value at different times and by different observers

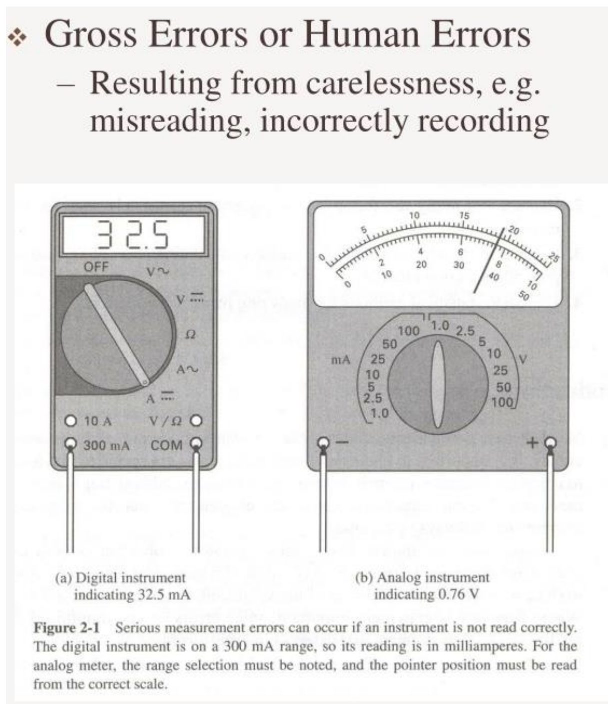
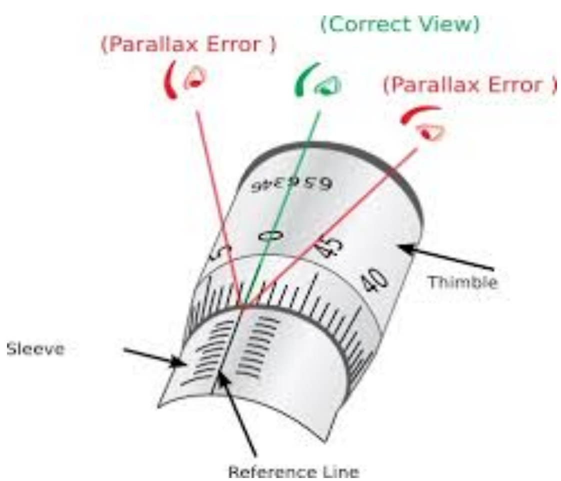
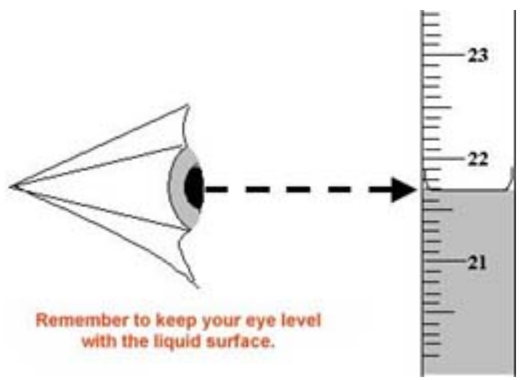


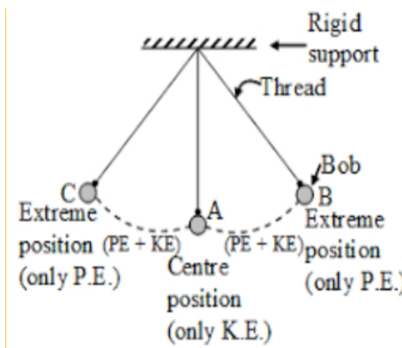
Figure 2-1 Serious measurement errors can occur if an instrument is not read correctly. The digital instrument is on a 300 mA range, so its reading is in milliamperes. For the analog meter, the range selection must be noted, and the pointer position must be read from the correct scale.

Human Errors: Gross and Observational Errors

- **Observational errors**
  - **Parallax, eye estimation or human reflexes etc.**
  - **Example: measurement of the time period of the pendulum by a stop watch; precision depends upon the reflexes of the observer who clicks stopwatch (ON or OFF)**

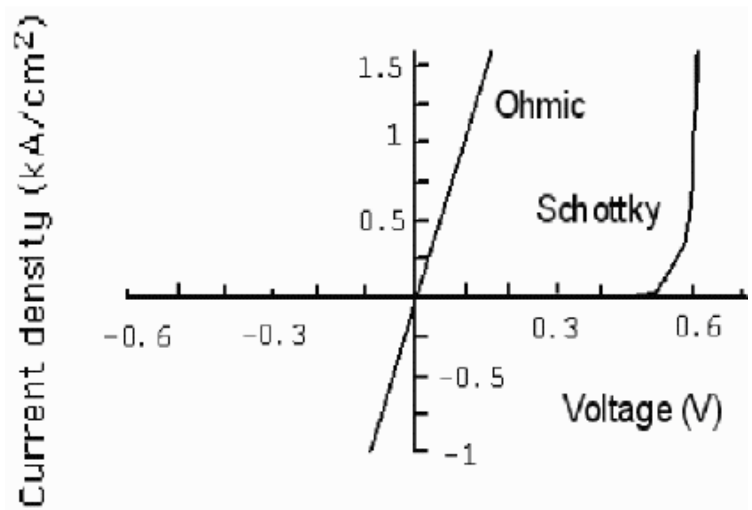






Human Errors: Misuse

- **Errors arising due to casual approach**
- **Examples**
  - **Electrical measurements: poor leads connection or lack of ohmic contact**



Human Errors: Misuse

- Errors arising due to casual approach
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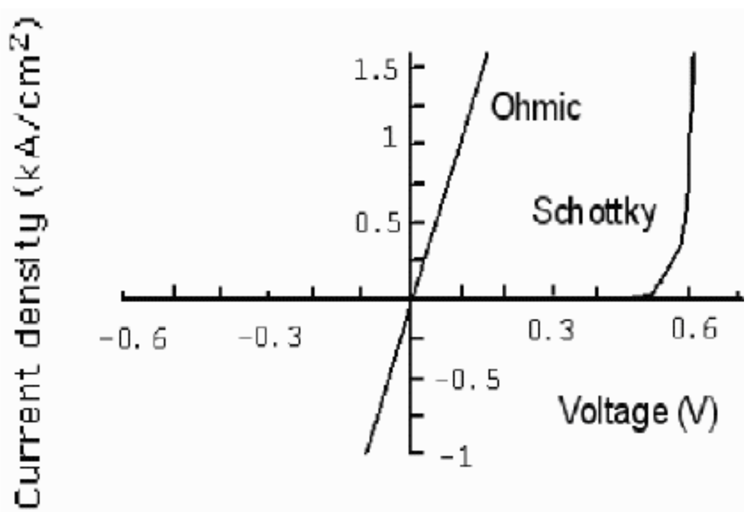
    - Electrical measurements: poor leads connection or lack of ohmic contact



Rectifying or Schottky contact

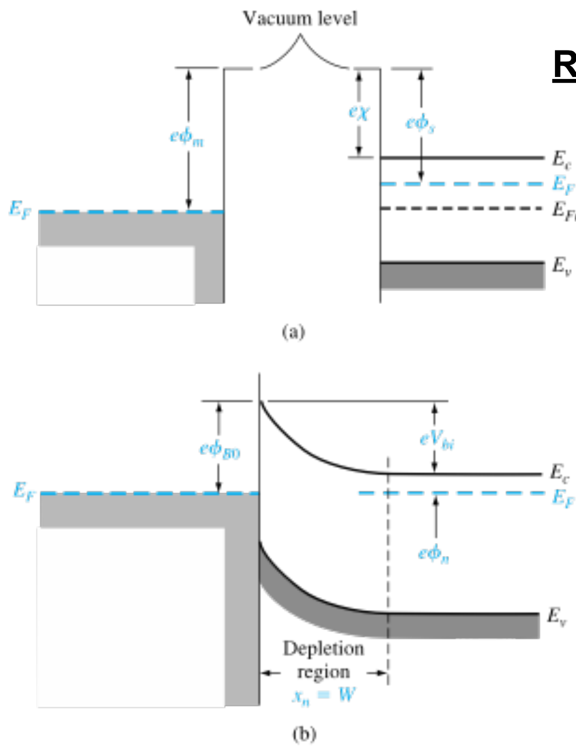


Figure 9.1 | (a) Energy-band diagram of a metal and semiconductor before contact; (b) ideal energy-band diagram of a metal–n-semiconductor junction for $\phi_m > \phi_s$.

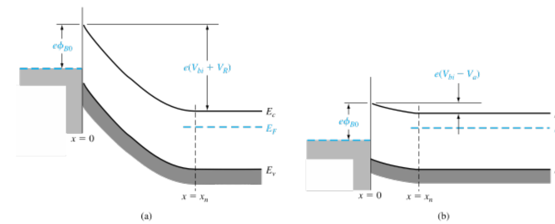
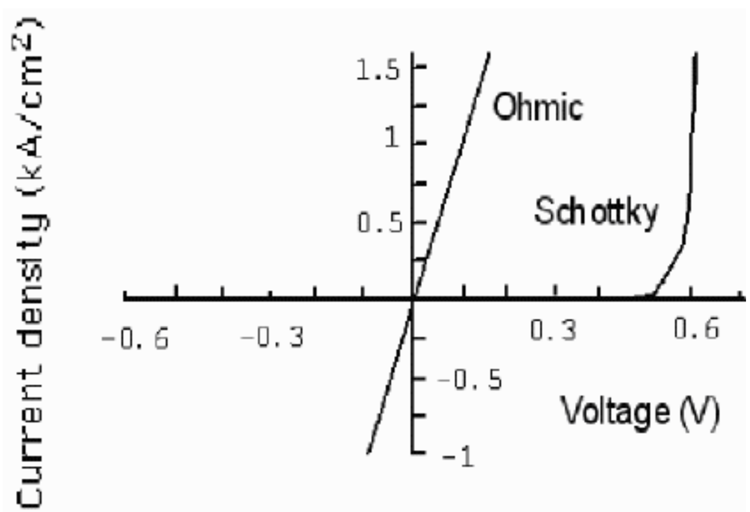


Figure 9.2 | Ideal energy-band diagram of a metal–semiconductor junction (a) under reverse bias and (b) under forward bias.

Ref: Semiconductor Physics and Devices: Basic Principles by Donald A. Neamen

Human Errors: Misuse

- Errors arising due to casual approach
- Examples
  - Electrical measurements: poor leads connection or lack of ohmic contact



Ohmic contact

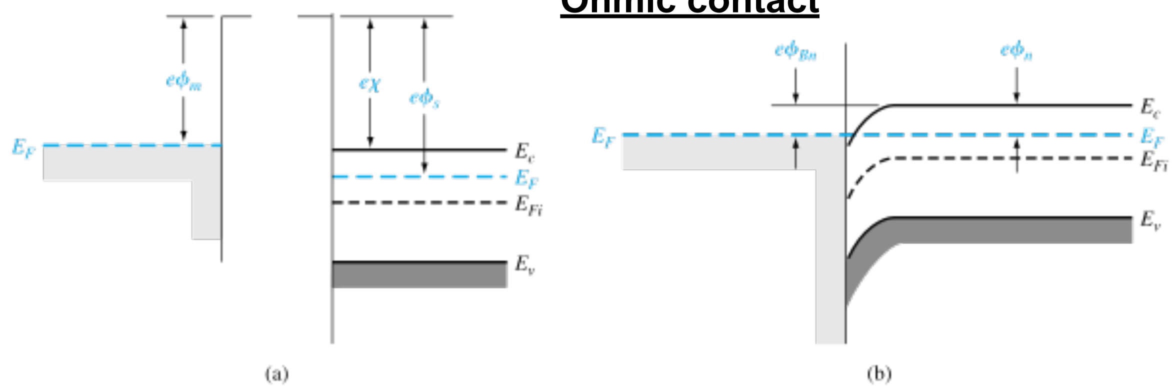


Figure 9.11 | Ideal energy-band diagram (a) before contact and (b) after contact for a metal-n-type semiconductor junction for $\phi_m < \phi_s$.

Ref: Semiconductor Physics and Devices: Basic Principles by Donald A. Neamen

Human Errors: Misuse

- **Errors arising due to casual approach**
- **Examples**
  - **Microvolt measurements: thermo-emfs arising from junctions of dissimilar metals**

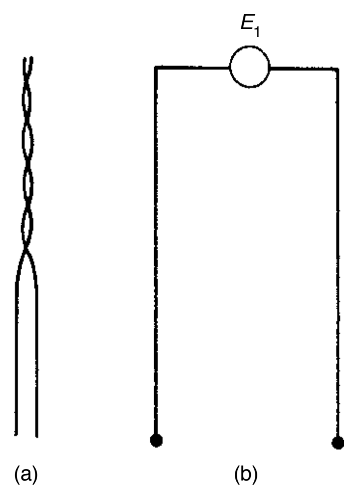


Figure 14.2
(a) Thermocouple and (b) equivalent circuit.

Thermocouple: Thermo-emfs

2.2 Undesirable Characteristics

- Human Errors

Gross Error

Suppose an ohmmeter shows resistance of a resistor as 47 Ω

→ observer reads it as 42 Ω

→observer reads it correctly but record it as 41 Ω

Remedy?

→By automating the recording process

→ Taking multiple readings of the same quantity by different observers

Misuse

Due to casualness of operator

→improper lead connection

→forgetting to adjust zero error

→generation of thermos emf due to connection of dissimilar metals.

Remedy?

→Carefulness of operator

Observational

Examples:

→Parallax

→Measurement of time period of a pendulum by stop watch. Human reflexes may lead to inaccurate measurements.

Static Errors

- **Classification of errors**

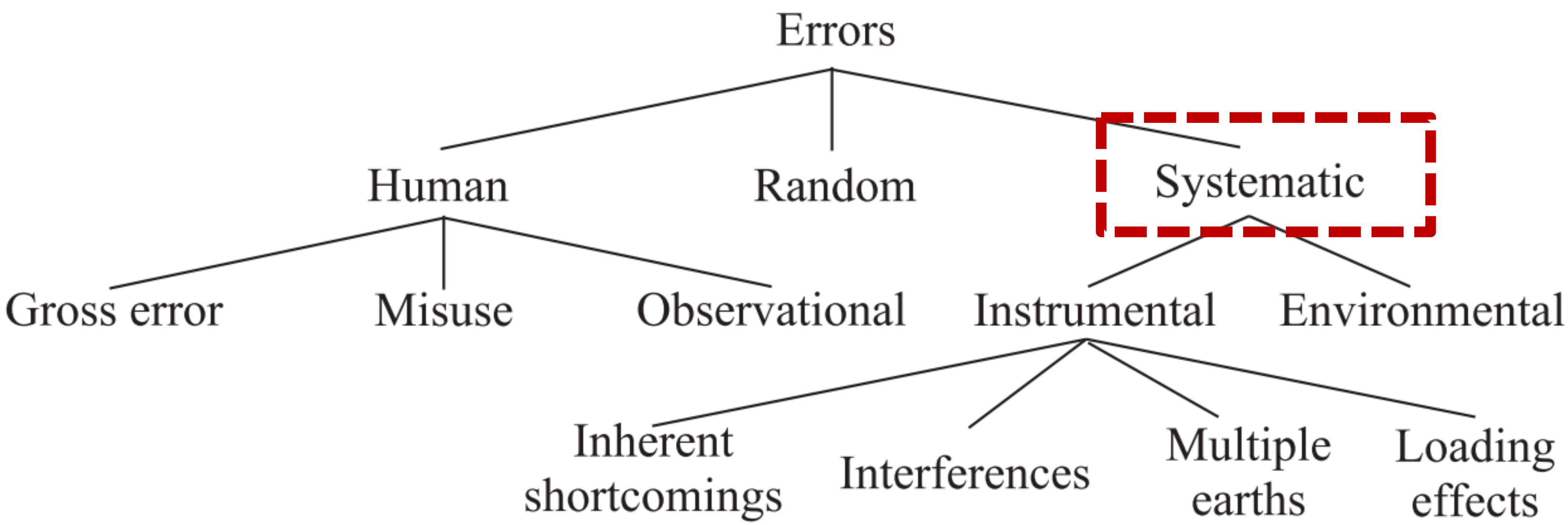
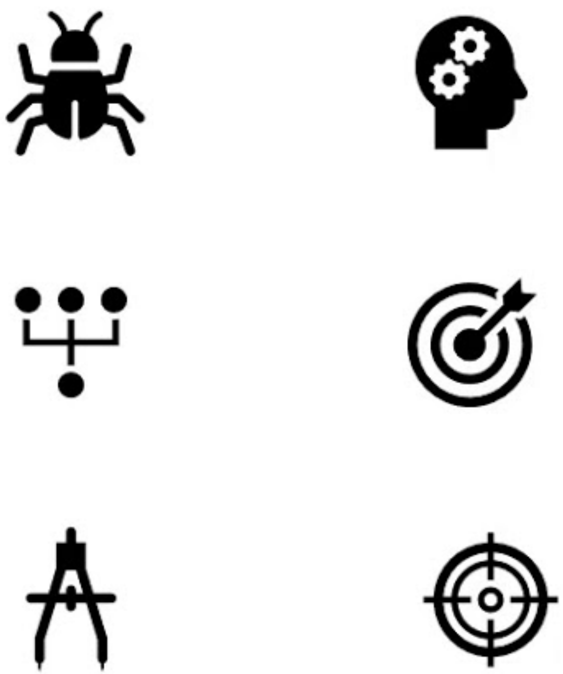


Fig. 2.7 The error tree.

Static Errors



- Gross
- Systematic error
- Random Error

2.2 Undesirable Characteristics

- **Environmental Error**
  - Atmospheric pressure, temperature and humidity may cause error in measurements
  - Examples
    - Plastic scales → change length in humid condition
    - Metal scales → affected by change in temperature
    - Electromagnetic instruments e.g. based om galvanometer are affected by stray electromagnetic fields
  - Remedy
    - Air conditioning
    - Hermitically sealing the equipment

Environmental Error

- ❑ **Change in the environmental conditions from those during calibration: pressure, temperature, humidity etc.**
- ❑ **electromagnetic fields, vibrations,…**

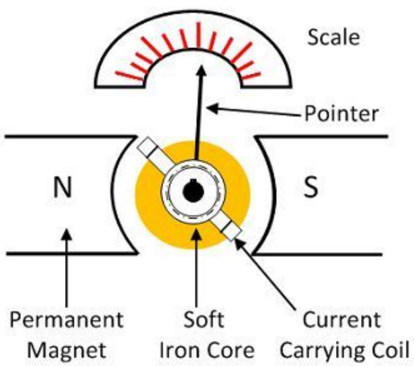
- **Examples**
  - **Plastic scales → change length in humid condition**
  - **Metal scales → affected by change in temperature**
  - **Electromagnetic instruments e.g. galvanometer are affected by stray electromagnetic fields**

❑***Remedy***

- ❑ **controlling temperature, pressure and humidity (Air conditioning)**
- ❑ **vibration-free mounting**
- ❑ **shielding against electromagnetic fields**
- ❑ **Hermitically sealing the equipment**

Review

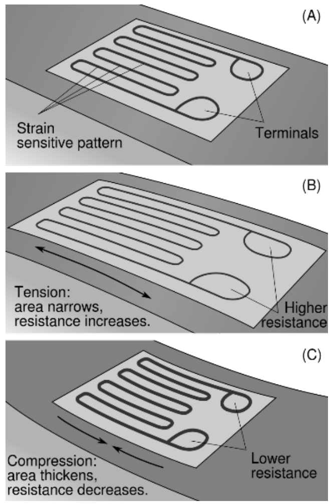
Galvanometer	Ammeter	Voltmeter
It is an instrument used to detect the flow of current in the circuit.	It is an instrument used to show the amount of current in the circuit.	It is an instrument used to show the amount of potential difference across two points in the circuit.
It tells the direction of current in the circuit.	It doesn't tell about the direction of current in the circuit.	It tells nothing about the current in the circuit.
It is connected in series in a circuit.	It is connected in series in a circuit.	It is connected in parallel in a circuit.
It has moderate resistance (10-100 ohms)	An ideal ammeter should have zero resistance, hence resistance of an ammeter is very small.	An ideal voltmeter should have infinite resistance, hence resistance of a voltmeter is very high.
Magnetic Field is required for Galvanometer to work	Ammeter can work with or without magnetic field	Voltmeter can work with or without magnetic field
It measures only direct current	It measures both direct and alternating current	It tells nothing about current in the circuit



Galvanometer

Environmental Error

- **Change in the environmental conditions from those during calibration: pressure, temperature, humidity etc.**
- Remedy
  - Example: Temperature dependence of resistance
  - Instrument design to reduce sensitivity to environmental inputs
    - Strain gauge using a material with a low "temperature coefficient of resistance"



Strain Gauge: strain sensor

Static Errors

- ❑ **Classification of errors**

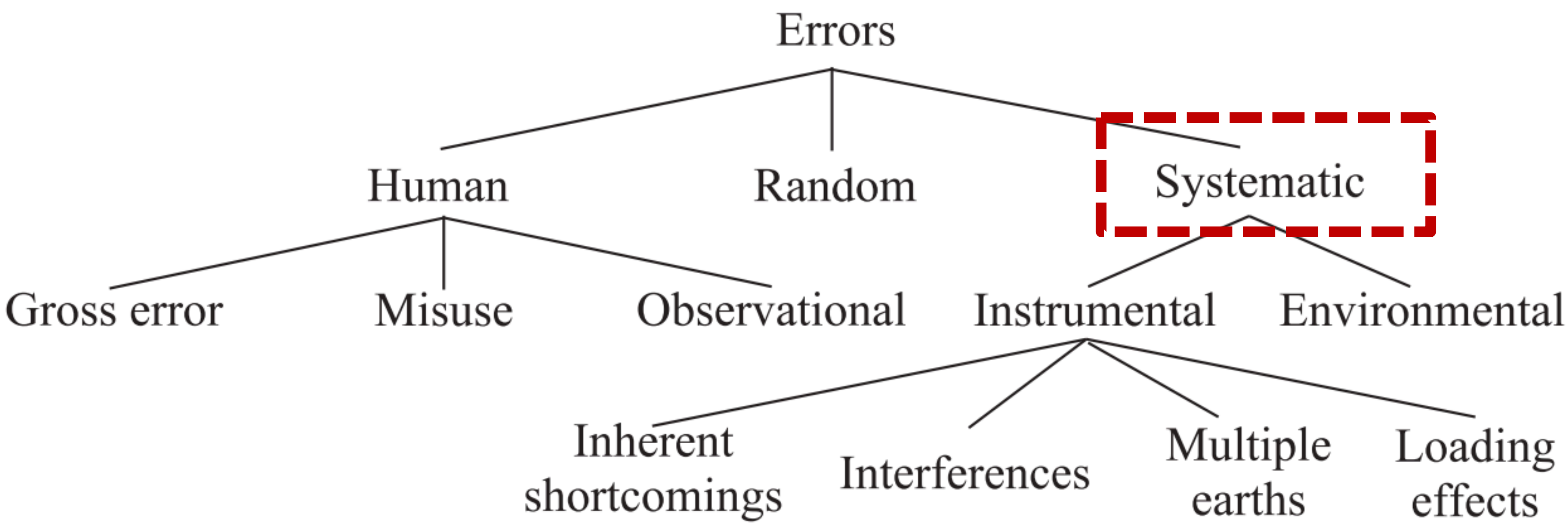


Fig. 2.7 The error tree.

Instrumental Errors

1. **Inherent shortcomings**
2. **Interference**
3. **Multiple earths**
4. **Loading effects**

Instrumental Errors: Inherent shortcomings

- **Malfunctioning of components due to ageing or wear**
  - **Spring of a galvanometer may become weak with time and changes calibration**
- **How to remove?**
  - **Calibration from time to time**

Instrumental Errors

1. **Inherent shortcomings**
2. **Interference**
3. **Multiple earths**
4. **Loading effects**

What is Interference?

Noise and interferences

Noise Vs Interference

Noise and interferences

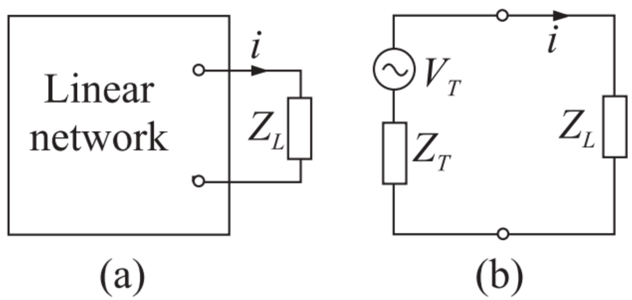
In a measurement system, we usually have a **wanted signal** (the measurement signal) and some **unwanted signal**

The magnitude of the unwanted signal can sometimes be higher than that of the desired measurement signal!

- An unwanted deterministic signal is often referred to as an **interference signal**.
- An unwanted random signal is often referred to as a **noise signal**.

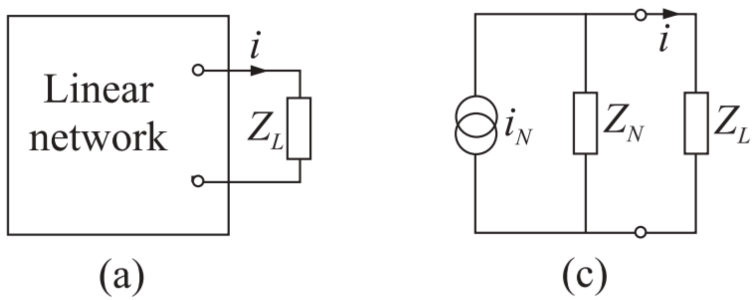
Instrumental Errors: Interference

- **Thevenin's theorem**
  - **A linear network can be replaced with an equivalent circuit having a voltage source and a series impedance**



Instrumental Errors: Interference

- **Norton's theorem**
  - **A linear network can be replaced with an equivalent circuit having a current source in parallel with an impedance**



and (c) Norton equivalents.

Instrumental Errors: Interference

Interference. Thevenin's theorem states that a network consisting of linear impedances and voltage sources can be replaced with an equivalent circuit having a voltage source and a series impedance, while Norton's theorem states that such a network can be replaced with an equivalent circuit consisting of a current source in parallel with an impedance (Fig. 2.8).

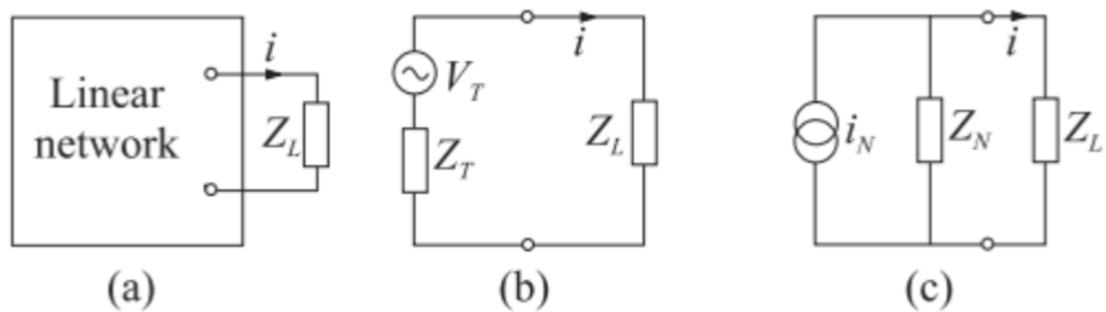
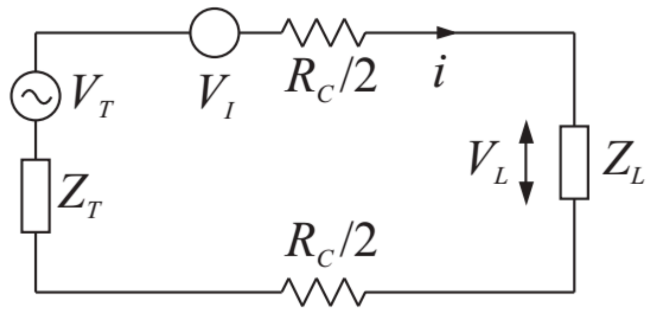


Fig. 2.8 (a) A linear circuit and its (b) Thevenin, and (c) Norton equivalents.

Instrumental Errors: Interference

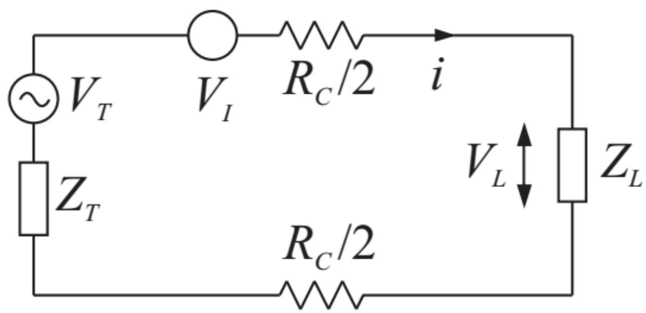
- **Voltage transmission system**

  - **Thevenin voltage source V_T , thevenin impedance Z_T , load impedance Z_L , cable resistance R_C and interference voltage V_I in series**



Instrumental Errors: Interference

- **Voltage transmission system**
  - **Thevenin voltage source V_T , thevenin impedance Z_T , load impedance Z_L , cable resistance R_C and interference voltage V_I in series**



$$i = \frac{V_T + V_I}{Z_T + R_C + Z_L}$$

$$V_L = \frac{V_T + V_I}{Z_T + R_C + Z_L} \cdot Z_L$$

- **For *ZL*≫(*R_C* + *Z_T*) to ensure maximum voltage transfer to the load**

$$V_L = V_T + V_I$$

- **Signal-to-noise ratio**
- **W_S and W_N, signal and noise powers**

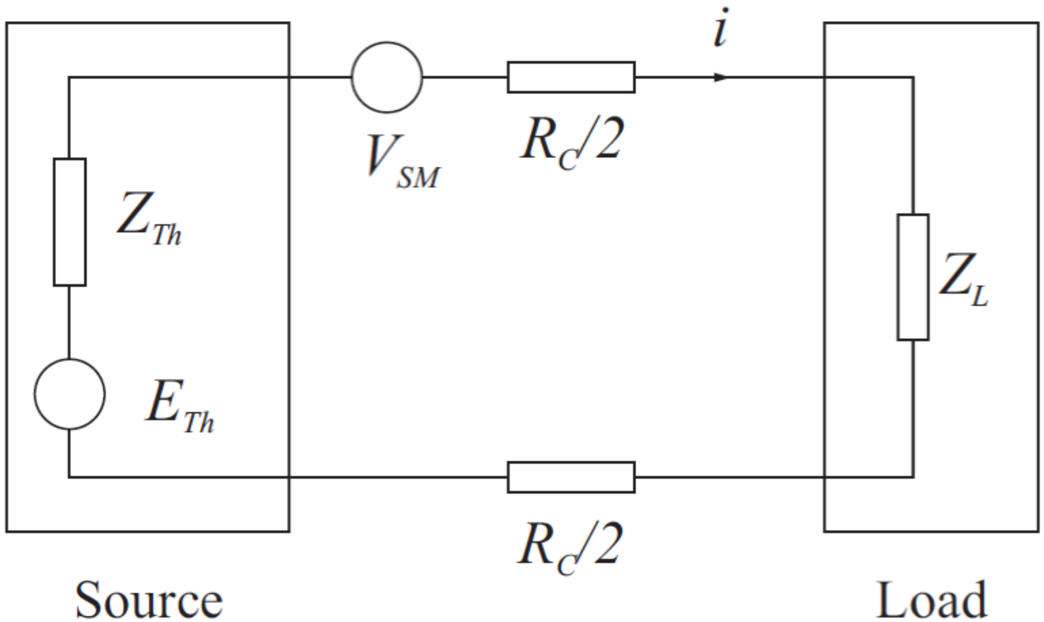
$$\frac{S}{N} = 10\log\frac{W_S}{W_N}\ \mathrm{d}B = 20\log\frac{V_T}{V_I}\ \mathrm{d}B$$

where, W_S and W_N indicate signal and noise powers respectively. Thus, if $V_T = 1$ mV and $V_I = 0.1$ mV, $S/N = 20$ dB.

✓ **Output contains unabated interference or noise voltage**

Series mode interference

Voltage transmission system



✓ **Output contains unabated interference or noise voltage**

Instrumental Errors: Interference

❑ Current transmission system

- **Norton current source i_N , Norton impedance Z_N , load impedance Z_L , cable resistance R_C and interference voltage V_I in series**

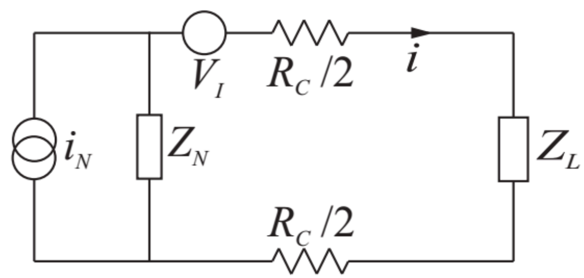


Fig. 2.10 Current transmission with series mode interference.

Instrumental Errors: Interference

- **Current transmission system**
  - **Norton current source i_N, Norton impedance Z_N, load impedance Z_L, cable resistance R_C and interference voltage V_I in series**

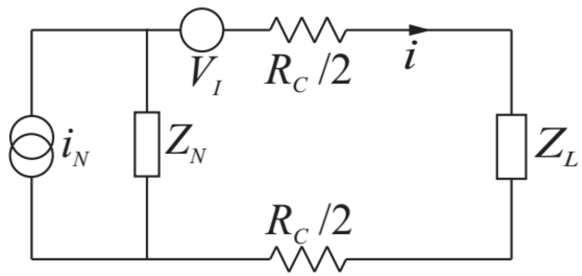


Fig. 2.10 Current transmission with series mode interference.

Then according to the rule of current division, current i through the load is

$$i = i_N \frac{Z_N}{Z_N + R_C + Z_L}$$

And the interference current through the load due to interference voltage is

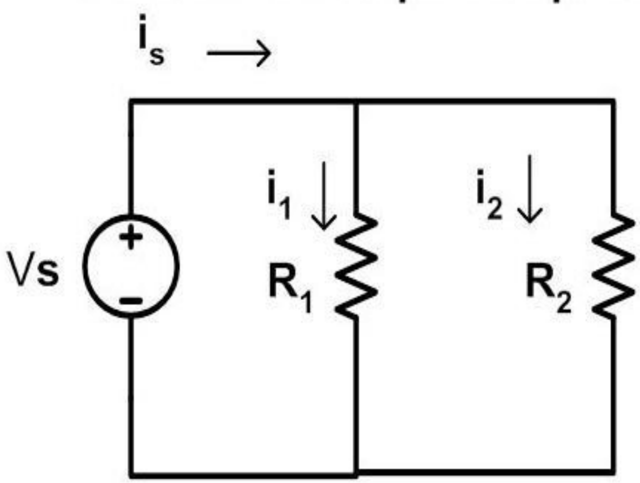
$$i_I = \frac{V_I}{Z_N + R_C + Z_L}$$

Therefore, the total voltage across the load is

$$V_L = (i + i_I)Z_L = i_N Z_L \frac{Z_N}{Z_N + R_C + Z_L} + V_I \frac{Z_L}{Z_N + R_C + Z_L}$$

Review

- Whenever current has to be divided among resistors in parallel, use current divider rule principle.



$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$

$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$

Instrumental Errors: Interference

- **Current transmission system**
  - **Norton current source i_N , Norton impedance Z_N , load impedance Z_L , cable resistance R_C and interference voltage V_I in series**

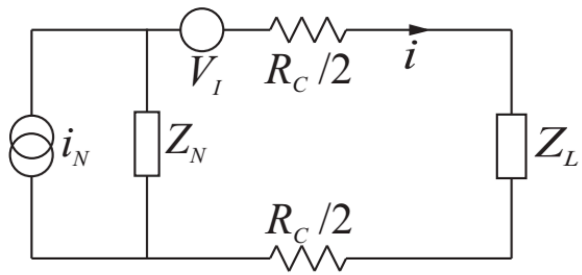


Fig. 2.10 Current transmission with series mode interference.

$$\boxed{i = i_N \frac{Z_N}{Z_N + R_C + Z_L}}$$

$$\boxed{i_I = \frac{V_I}{Z_N + R_C + Z_L}}$$

Therefore, the total voltage across the load is

$$V_L = (i + i_I)Z_L = i_N Z_L \frac{Z_N}{Z_N + R_C + Z_L} + V_I \frac{Z_L}{Z_N + R_C + Z_L}$$

The normal practice is to make $Z_N \gg (R_C + Z_L)$ so that maximum current is transferred to the load. Then

$$\boxed{V_L = i_N Z_L + V_I \frac{Z_L}{Z_N}}$$

Since, $Z_L \ll Z_N$, the contribution of noise voltage to the output voltage is negligible in current transmission.

Instrumental Errors: Interference

- **Current transmission system**

  - **Norton current source i_N, Norton impedance Z_N, load impedance Z_L, cable resistance R_C and interference voltage V_I in series**

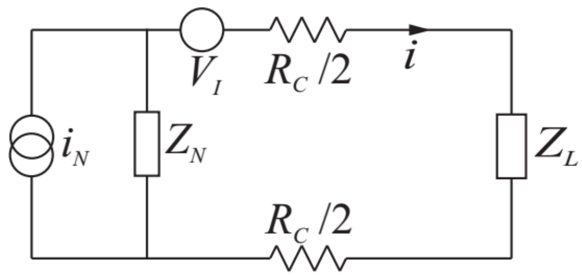


Fig. 2.10 Current transmission with series mode interference.

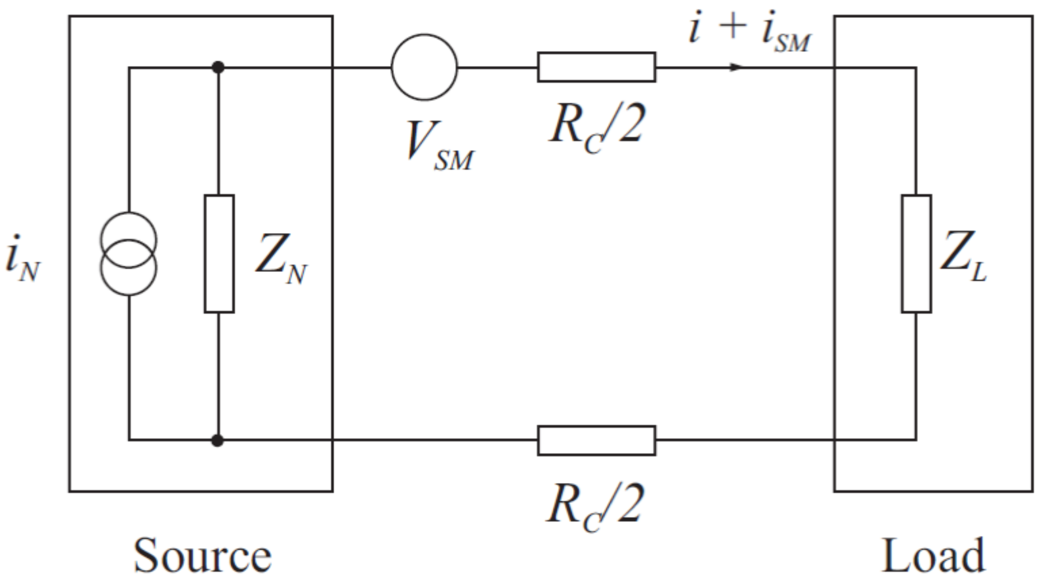
$$V_L = i_N Z_L + V_I \frac{Z_L}{Z_N}$$

✓ **Normally $Z_L \ll Z_N$, for max current transfer**

✓ **the contribution of noise voltage to the output voltage is negligible in current transmission**

Series mode interference (cont'd...)

Current transmission system



- ✓ **Normally $Z_L \ll Z_N$, for max current transfer**
- ✓ **the contribution of noise voltage to the output voltage is negligible in current transmission**

Instrumental Errors: Interference

- **Common mode interference**

  - **Common voltage V_c is added to both sides of the signal circuit**

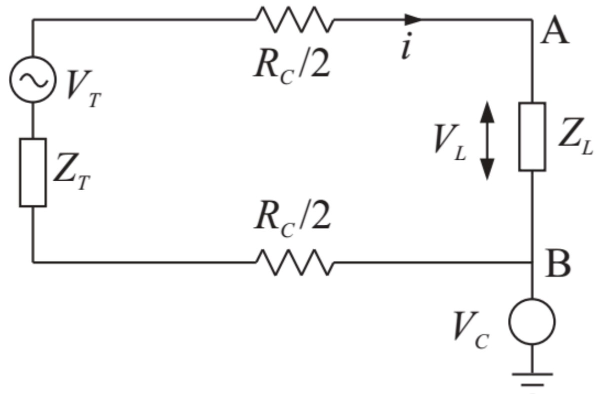


Fig. 2.11 Signal transmission with common mode interference.

Instrumental Errors: Interference

- **Common mode interference**

  - **Common voltage V_c is added to both sides of the signal circuit**

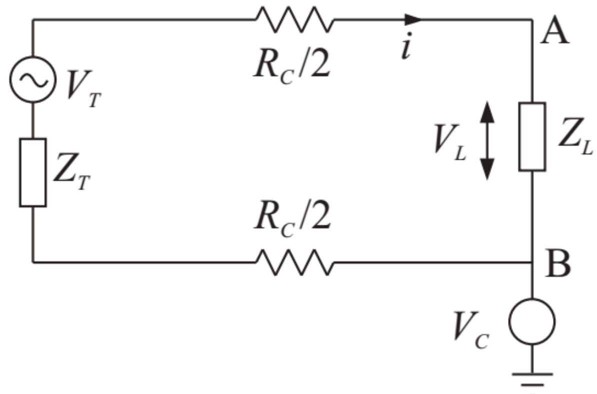


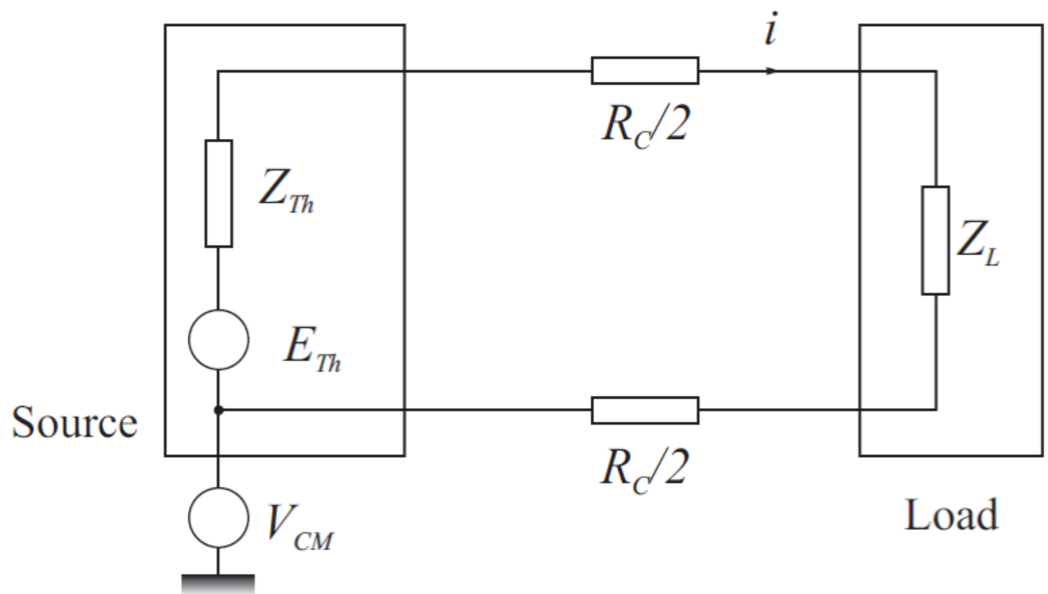
Fig. 2.11 Signal transmission with common mode interference.

$$V_A = V_c + V_T$$
$$V_B = V_c$$
$$V_L = V_A - V_B = V_T$$

✓ **Common mode interference voltage V_c does not affect the voltage across the load**

Instrumental Errors: Interference

Common mode interference

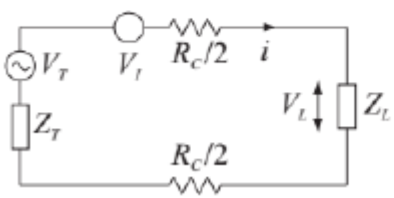


- A common mode interference is caused by a potential offset on both sides of the circuit, relative to the common ground.
- If the impedance of the load is much higher than of the equivalent circuit, the voltage across the load is not significantly affected.

2.2 Undesirable Characteristics

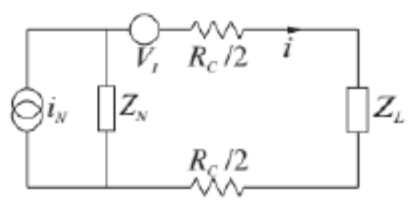
- **Instrumental Error**
  - Interference

Series Mode Interference



$$V_L = V_T + V_I$$

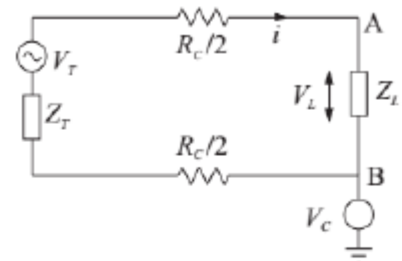
Affects voltage transmission



$$V_L = i_N Z_L$$

Do not affect current transmission

Common Mode Interference



$$V_A = V_c + V_T$$
$$V_B = V_c$$
$$V_L = V_A - V_B = V_T$$

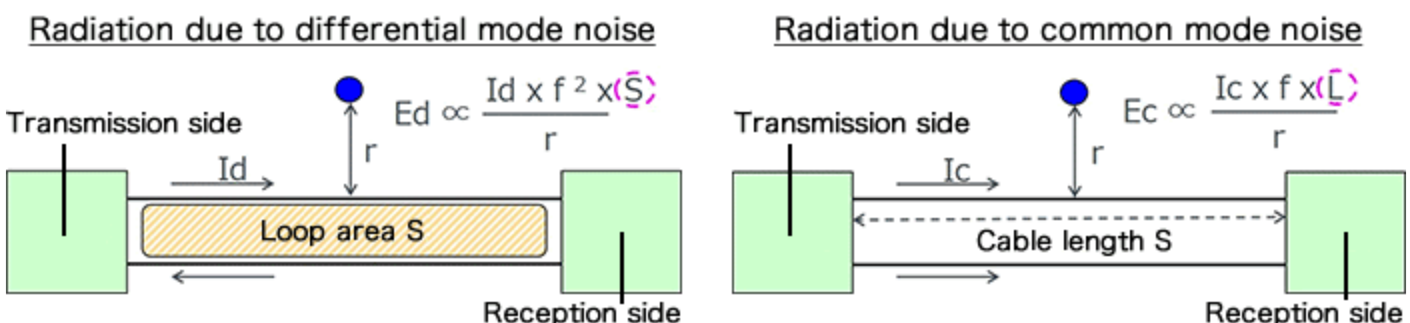
Have no effect

Common Mode Interference and Radio Reception

01-06-2020 | | By Nnamdi Anyadike

The high switching frequency of current data lines has made common mode (CM) interference a problem for radio reception. In normal or differential (single) mode, current travels on one line in one direction from the source to the load and in the opposite direction on the return line. This completes the circuit. However, in CM, the noise current travels on both lines in the same direction. Inductors create magnetic fields that oppose changes in current. An electrical filter, the CM choke, blocks the high frequency noise common to two or more data or power lines while allowing the desired DC or low-frequency signal to pass.

CM noise current is typically radiated from sources such as unwanted radio signals, unshielded electronics, inverters and motors. If left unfiltered, this noise presents interference problems in electronics and electrical circuits. Key players in the global CM choke market include AKEMET Corporation, EPCOS, Murata,



Queries

Thanks!