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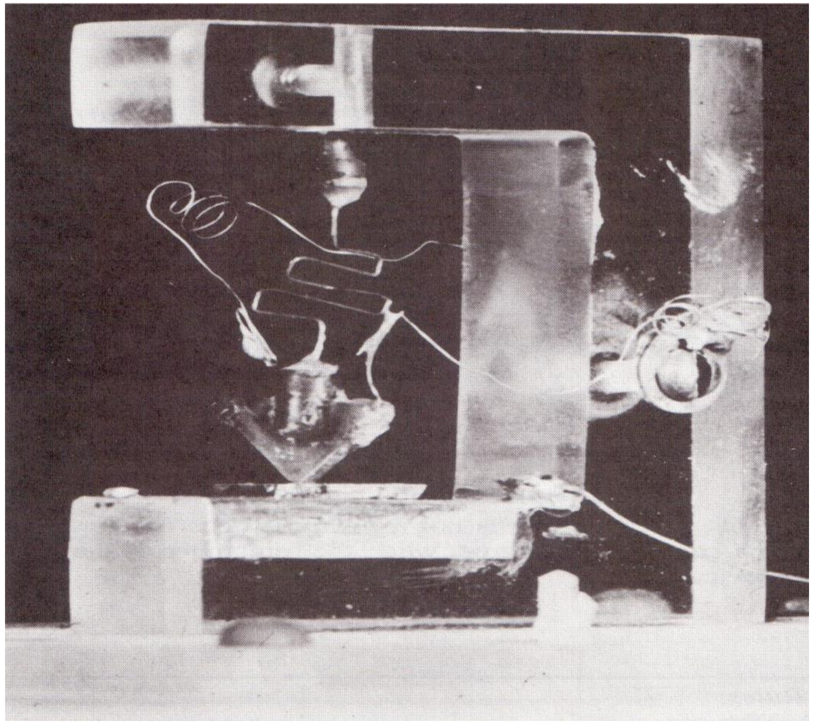
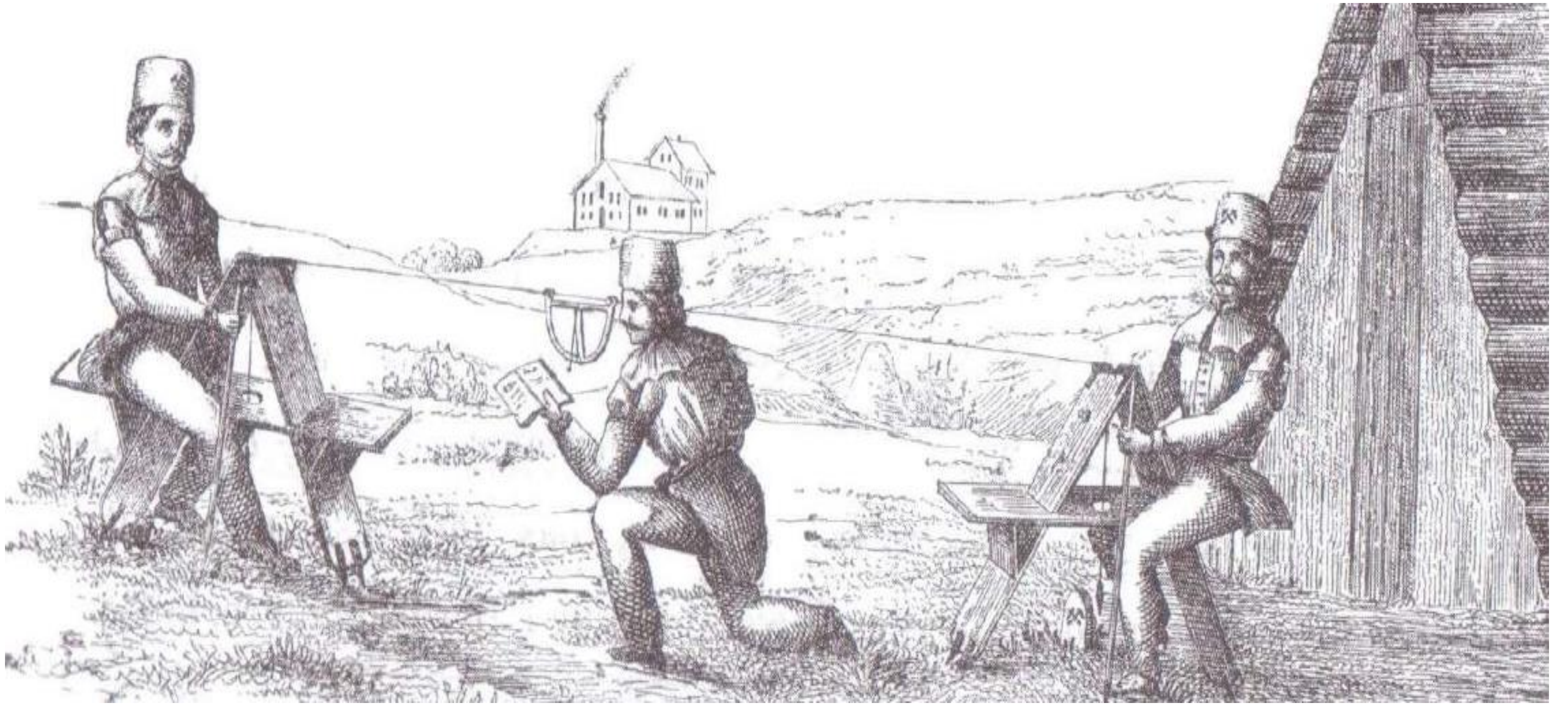
Electronic Devices and Measurements

MATERIAL 1





Coordinator: **Raul Ionel** (raul.ionel@upt.ro)

1. Basic Electrical and Electronic Engineering Principles and Terminology.

1.1 Measurement Units & Systems. Definition of Measurements (True Value, Conventional True Value, Measured Value, Absolute & Relative Errors etc.).
1.2 Defining units of Charge, Force, Energy, Power, Electrical potential, Resistance, Conductance etc.
1.3 Introduction to electronic circuits (block diagrams, schematics, symbols of circuit components etc.).

2. Introduction to Measurement and Instrumentation Principles.

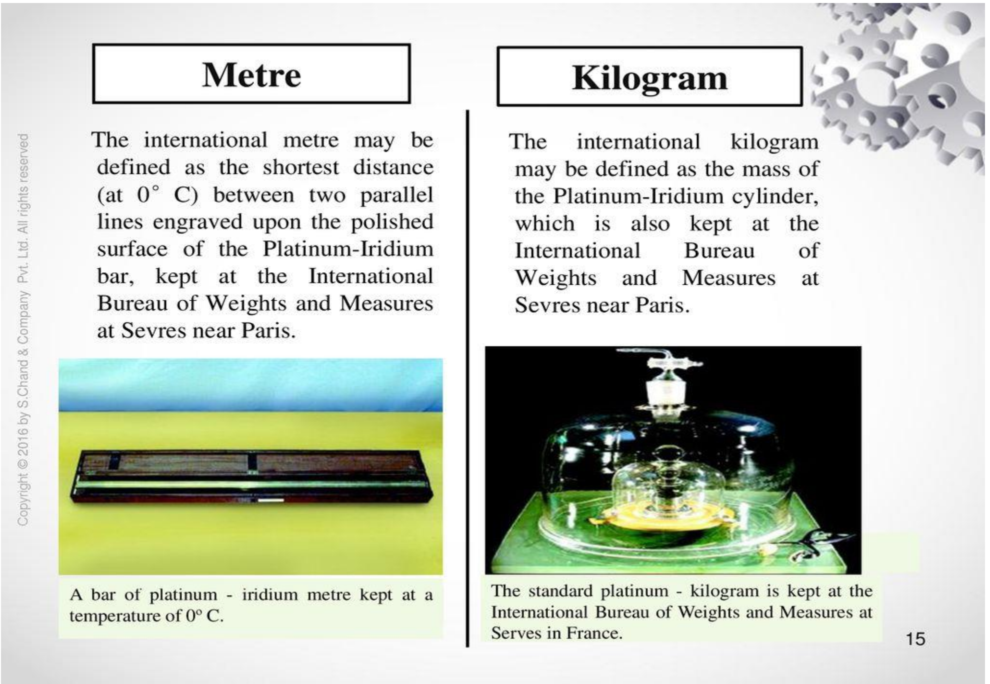
2.1 Measurement methods classification (direct, indirect, deflection methods, comparison methods, Null methods or zero methods, Differential methods, Coincidence methods).
2.2 Elements of a Measurement System.
2.3 Classifications of measurement instrumentation (Primary & Secondary, Analog & Digital, Null Type or Deflection Type, Stand Alone or PC Based, Smart vs Non-Smart, Active or Passive).
2.4 Measurement instruments characteristics (Static & Dynamic characteristics).

3. Questions & exercises.

1.1 Measurement Units & Systems.

The **International System of Units** (**SI, 1960**) is built on **seven basic (class of base units) units of measurement**, each representing a fundamental physical quantity. These units include the **meter** (**m**) for **length**, the **kilogram** (**kg**) for **mass**, the **second** (**s**) for **time**, the **ampere** (**A**) for **electric current**, the **kelvin** (**K**) for **thermodynamic temperature**, the **mole** (**mol**) for the **amount of substance**, and the **candela** (**cd**) for **luminous intensity**. These base units serve as the foundation for all other derived units used in science and engineering. In the framework of the SI it is considered that the base quantities have independent dimensions, that is, none of the base units can be obtained from the others.

Quantity	Measurement Unit (Abbreviation)
Length	Meter (m)
Mass	Kilogram (kg)
Time	Second (s)
Electric Current	Ampere (A)
Thermodynamic Temperature	Kelvin (K)
Amount of Substance	Mole (mol)
Luminous Intensity	Candela (cd)



1.1 Measurement Units & Systems.

[How France created the metric system]
[Historic vote to redefine the kilogram changes forever the way we measure mass]

Derived units are combinations of the seven base units of the International System of Units (SI) that are used to express other physical quantities. These units are formed through mathematical relationships, such as multiplication or division of base units. For example, **velocity** is measured in meters per second (**m/s**), which combines the base units of length (meter) and time (second). Other examples include **frequency (Hz)** derived from the unit of time (1/s), **acceleration** (**m/s²**) derived from the base units of length (meter) and time (second) or the **force** measured in Newtons **(N)**, which is derived from the units of mass, length, and time (kg·m/s²).

Replica of the International Prototype kg at the International Bureau of Weights and Measures (BIPM) in Sevres, Paris.

For plane (2D) and solid angles (3D), the SI includes two additional derived units.

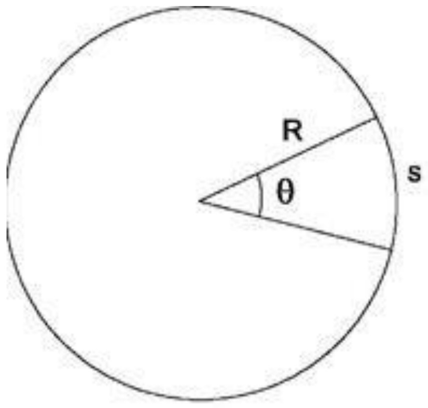
Quantity	Measurement Unit (Abbreviation)
Plane Angle	Radian (rad)
Solid Angle	Steradian (sr)

The **plane angle** is considered dimensionless because it is defined as the ratio of two lengths, which results in a quantity that has no physical dimension. Specifically, a plane angle measures the ratio of the length of the arc of a circle (subtended by the angle) to the radius of that circle.

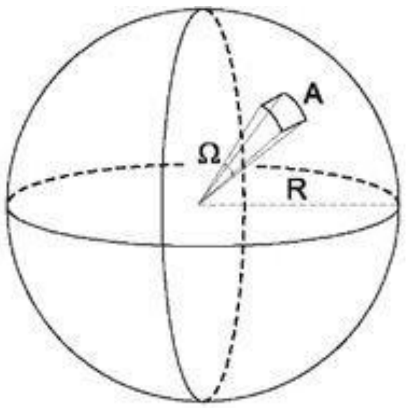
1.1 Measurement Units & Systems.

Although the unit used to express plane angles is the **radian (rad)**, the radian is a dimensionless derived unit because it represents the ratio of two lengths. The radian is used for convenience in labeling angles but does not introduce a physical dimension. Therefore, plane angles are considered dimensionless.

The **steradian** is considered dimensionless for a similar reason to the radian: it is defined as a ratio of two areas, which cancels out any physical dimensions. It represents the ratio of two areas, and thus, like the radian, is considered **dimensionless** in the SI system. The unit "steradian" helps in practical communication, but it does not imply any physical dimension.



$\theta = \frac{s}{R}$ radians



$\Omega = \frac{A}{R^2}$ steradians (sr)

Reference from Quora.

Popular examples of derived quantities commonly used in measurement and instrumentation.

Electric Power, SI unit - Watt (W), where 1 W = 1 J/s = 1 kg·m²/s³.
Energy (Work), SI unit - Joule (J), where 1 J = 1 N·m = 1 kg·m²/s².
Pressure, SI unit - Pascal (Pa), where 1 Pa = 1 N/m².
Force, SI unit - Newton (N), where 1 N = 1 kg·m/s².
Speed, SI unit - Meters per second (m/s).

1.1 Measurement Units & Systems.

Other measurement systems.

The **Imperial System of Measurement (1824)**, also known as the British Imperial System, is a traditional system of weights and measures that was used in the British Empire and is still in use today in a few countries like the United States. It includes units such as the **inch**, **foot**, and **yard** for length, **pound** and **ounce** for weight, and **gallon** and **pint** for volume.

Length/Distance: Measured in **inches**, **feet**, **yards**, or **miles -> USA, UK. Ex.** to estimate the height of a person (5 feet 9 inches).
Volume (liquids): Measured in **gallons**, **quarts**, **pints**, or **fluid ounces -> USA, UK. Ex.** to estimate pints for beer.
Temperature: Measured in **degrees Fahrenheit (°F) -> USA.**
Weight: Measured in **pounds** (lbs) and **ounces -> USA, UK. Ex.** to estimate body weight (150 lbs).
And so on…..

USA example of combined measurement units Metric vs. Imperial.

Volume, used in medicine, often expressed in **milliliters (mL)** or **liters (L)**.
Length, used in sports, ex. running, often expressed in **meters (m).**
Temperature, used in science, expressed in **degrees Celsius (°C)**.
Length, used to describe road distance, expressed in **miles (mi)**.
Weight, used to describe a person's weight, expressed in **pounds (lbs).**
Length, used in some sports, ex. football, expressed in **yards (yd).**

One pint of US beer or about 473mL.

1.1 Measurement Units & Systems.

Other measurement systems.

The **traditional Chinese Measurement System** uses units such as the “li” for distance, "jin" for weight or "shi" volume.
The **traditional Japanese Shakkan-hō Measurement System** uses units such as the “shaku” for length or "kan" for weight.

In scientific and international contexts, the **metric system** is **overwhelmingly dominant**. Even in the US, SI units are used in fields like science, engineering, and medicine. There is a gradual shift toward metrication in many countries that historically used imperial or customary units, driven by globalization and the need for standardization.

The **Metric System (General Term)** originated in France in the late 18th century (1790s) as a standardized system of measurement based on powers of ten. Its primary units were the **meter** for **length** and the **gram** for **mass**. The **SI system**, formalized in **1960** by the General Conference on Weights and Measures (CGPM), is the modern, internationally accepted version of the metric system.

- The **SI system** is the official and modernized version of the Metric System with specific standards.
- The **SI system** has a defined set of base and derived units with precise definitions, often based on fundamental physical constants. Older metric systems lacked this degree of precision and universality.
- The **SI system** is the globally recognized standard for scientific and technical work, while "metric" can refer to any of the early decimal-based systems.

1.1 Measurement Units & Systems.

SI units may be made larger or smaller by using prefixes which denote multiplication or division by a particular amount.

Prefix	Symbol	Factor	Meaning
Yotta	Y	10^{24}	multiply by 1,000,000,000,000,000,000,000,000
Zetta	Z	10^{21}	multiply by 1,000,000,000,000,000,000,000
Exa	E	10^{18}	multiply by 1,000,000,000,000,000,000
Peta	P	10^{15}	multiply by 1,000,000,000,000,000
Tera	T	10^{12}	multiply by 1,000,000,000,000
Giga	G	10^{9}	multiply by 1,000,000,000
Mega	M	10^{6}	multiply by 1,000,000
Kilo	k	10^{3}	multiply by 1,000
Hecto	h	10^{2}	multiply by 100
Deca	da	10^{1}	multiply by 10

1.1 Measurement Units & Systems.

SI units may be made larger or smaller by using prefixes which denote multiplication or division by a particular amount.

Prefix	Symbol	Factor	Meaning
Deci	d	10^{-1}	multiply by 0.1
Centi	c	10^{-2}	multiply by 0.01
Milli	m	10^{-3}	multiply by 0.001
Micro	µ	10^{-6}	multiply by 0.000001
Nano	n	10^{-9}	multiply by 0.000000001
Pico	p	10^{-12}	multiply by 0.000000000001
Femto	f	10^{-15}	multiply by 0.000000000000001
Atto	a	10^{-18}	multiply by 0.000000000000000001
Zepto	z	10^{-21}	multiply by 0.000000000000000000001
Yocto	y	10^{-24}	multiply by 0.000000000000000000000001

1.1 Measurement Units & Systems.

Some interesting observations.

- The **Calories**, belonging to the Imperial Systems are frequently used in diet menus, weight loss regimes etc. The term originates from the Latin word *calor* or heat, suggesting a form of energy caused by chaotic movement of molecules. A person who takes on such a weight loss regime receives indications described in Calories, not **Joules** (J, belonging to the SI).

- The **HP or Horsepower**, belonging to the Imperial Systems is frequently used to describe the power output of **car engines**, **motorcycles**, and **trucks**. It helps consumers understand the performance of a vehicle—higher horsepower generally translates to greater speed and acceleration potential. It is equivalent to about 746 **Watt** (W, belonging to the SI).

Measurement units for Length.

L	mm	m	km
mm	1	10^{-3}	10^{-6}
m	10^{3}	1	10^{-3}
km	10^{6}	10^{3}	1

Measurement units for Volume.

V	mm^3	ml	l	m^3
mm^3	1	10^{-3}	10^{-6}	10^{-9}
ml	10^{3}	1	10^{-3}	10^{-6}
l	10^{6}	10^{3}	1	10^{-3}
m^3	10^{9}	10^{6}	10^{3}	1

Measurement units for Area.

A	mm^2	m^2	km^2
mm^2	1	10^{-6}	-
m^2	10^{6}	1	10^{-6}
km^2	-	10^{6}	1

Measurement units for Mass.

M	g	kg	t
g	1	10^{-3}	10^{-6}
kg	10^{3}	1	10^{-3}
t	10^{6}	10^{3}	1

1.1 Measurement Units & Systems.

Measurement units for Power.

P	W	kW	HP
W	1	10^{-3}	$1{,}341\cdot10^{-3}$
kW	10^{3}	1	1,341
HP	745,7	0,7457	1

Measurement units for Energy.

E	J	kWh	cal
J	1	$2{,}778\cdot10^{-7}$	0,2388
kWh	$3{,}6\cdot10^{6}$	1	859680
cal	4,1868	$1{,}163\cdot10^{-6}$	1

Measurement units for Current Intensity.

I	μA	mA	A
μA	1	10^{-3}	10^{-6}
mA	10^{3}	1	10^{-3}
A	10^{6}	10^{3}	1

Measurement units for Voltage.

U	mV	V	kV
mV	1	10^{-3}	10^{-6}
V	10^{3}	1	10^{-3}
kV	10^{6}	10^{3}	1

Measurement units for Frequency.

F	Hz	kHz	MHz
Hz	1	10^{-3}	10^{-6}
kHz	10^{3}	1	10^{-3}
MHz	10^{6}	10^{3}	1

A few words on Temperature measurement…

The usual measurement unit for temperature is the **Celsius degree (℃)**, after the Swedish astronomer **Anders Celsius (1701-1744)**. He set the origin of the temperatures scale to the triple point of water. The **triple point of water** is the unique combination of temperature and pressure at which water can simultaneously exist in three phases: solid (ice), liquid (water), and gas (water vapor). For water this is 0.01°C ≅ 0°C. At the triple point, the three phases are in thermodynamic equilibrium, meaning they coexist stably without one phase converting into another.

On the other hand, the absolute temperature scale, or the **Kelvin scale** (after the British physicist **William Thomson alias Lord Kelvin, 1824 – 1907**), has the fixed origin to the temperature value at which the molecules of a perfect gas do not have energy to move. This happens at -273.15 °C or 0 °K.

Since they have the same increment size (1°K is equal to 1°C in terms of scale division or absolute value), you can convert between Celsius and Kelvin simply by adding or subtracting 273.15.

1.1 Measurement Units & Systems.

A few words on Temperature measurement…

Another popular temperature scale, in daily usage (for example in the USA), is the **Fahrenheit scale**. It was defined by the German physicist **Daniel Gabriel Fahrenheit** (1686 - 1736). He set the origin of his scale, 0 °F, at the freezing point of a mixture (ice, water, and ammonium chloride) that he could produce in his laboratory. The 32 °F point was defined at the freezing point of pure water. Finally, the point of the human body temperature was defined at 96 °F (later refined at 98.6 °F). Consequently, one can conclude that water freezes at 32 °F and boils at 212 °F at standard atmospheric pressure.

To convert from Celsius to Fahrenheit: F = (C x 9/5) + 32. To convert from Fahrenheit to Celsius: C = (F - 32) x 5/9.

- **The Ice-Point Paradox in the Celsius Scale** – the scale originally defined 0 °C as the **freezing point of water** and 100 °C as the **boiling point** at standard atmospheric pressure. However, water's freezing point can change with pressure, so "standard" conditions are essential for consistency. In extremely pure water under very controlled conditions, water can remain liquid slightly below 0 °C, a phenomenon known as **supercooling**.

- **Absolute Zero: The Coldest Possible Temperature** – the scale originally defined 0 °C as the **freezing point of water** and 100 °C as the **boiling point** at standard atmospheric pressure. However, water's freezing point can change with pressure, so "standard" conditions are essential for consistency. In extremely pure water under very controlled conditions, water can remain liquid slightly below 0 °C, a phenomenon known as **supercooling**.

1.1 Measurement Units & Systems.

In summary, important for us…

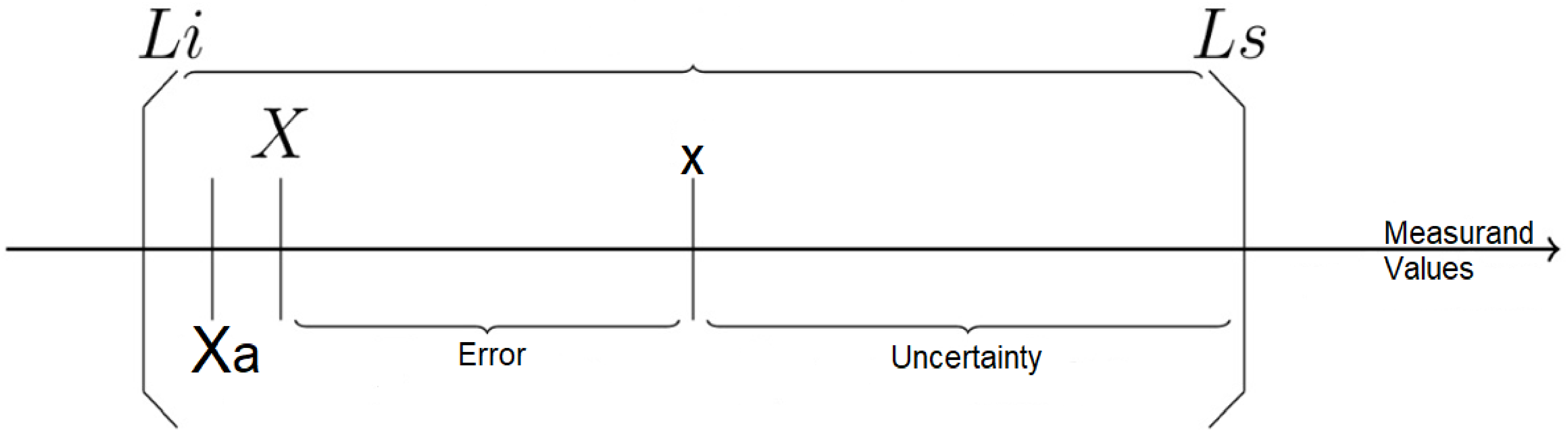
Quantity	Measurement Unit (Abbreviation)
Length, l	Meter (m)
Mass, m	Kilogram (kg)
Time, t	Second (s)
Electric Current, I	Ampere (A)
Force, F	Newton (N)
Electrical quantity/charge, Q	Coulomb (C)
Resistance, R	Ohm (Ω)
Velocity	Meters per second (m/s)
Acceleration	Meters per second squared (m/s^2)
Conductance, G	Siemens (S)
Potential difference, V	Volt (V)
Electromotive force, E	Volt (V)

Quantity	Measurement Unit (Abbreviation)
Work, W	Joule (J)
Energy, E or W	Joule (J)
Power, P	Watt (W)
Frequency, f	Hertz (Hz)
Capacitance, C	Farad (F)
Inductance, L	Henry, (H)
Pressure, P	Pascal (N/m^2)
Magnetic flux, Φ	Weber (Wb)
Electric Field Strength, E	Volt per Meter (V/m)
Magnetic Flux Density, B	Tesla (T or Wb/m^2)
Permeability, µ	Henry per meter (H/m)
Magnetic Field Strength, H	Ampere per meter (A/m)

1.1 Measurement Units & Systems.

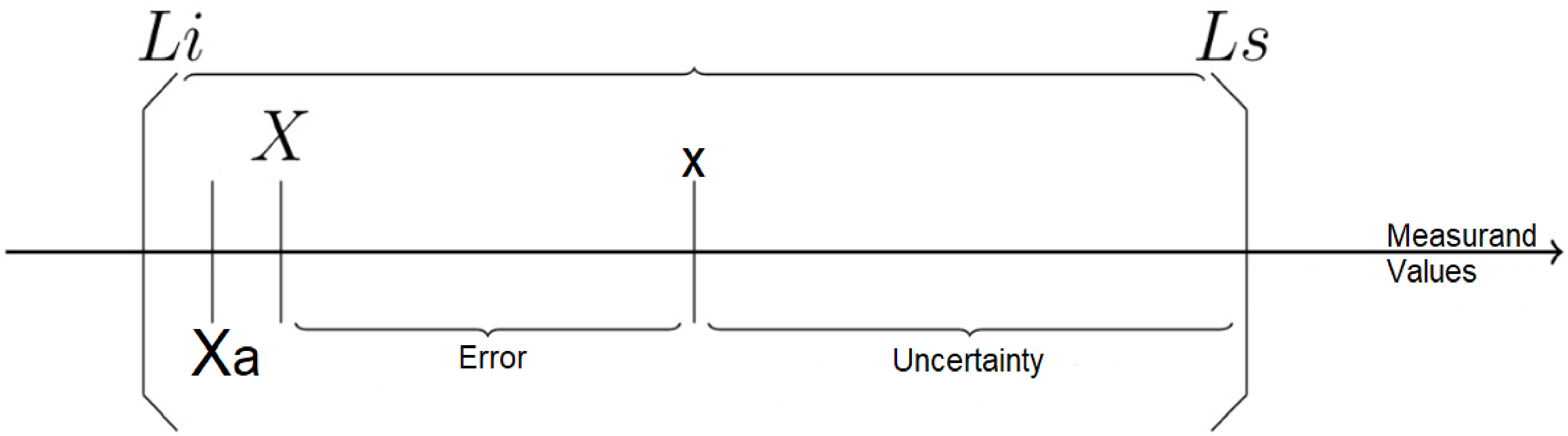
The **Measurand** is the name of the quantity that we need to evaluate. Measurands are of two types. **Electrical** such as Current, Voltage, Resistance, Capacitance. **Nonelectrical** such as Temperature, Pressure, Light intensity, and others.

Most of the times, when **we evaluate** a measurand we present 2 parameters. First, **a value** that makes sense. Second, **a unit** of measurement. For example, a voltage of 300mV has two components. 300 is the value. mV or millivolts is the measurement unit.



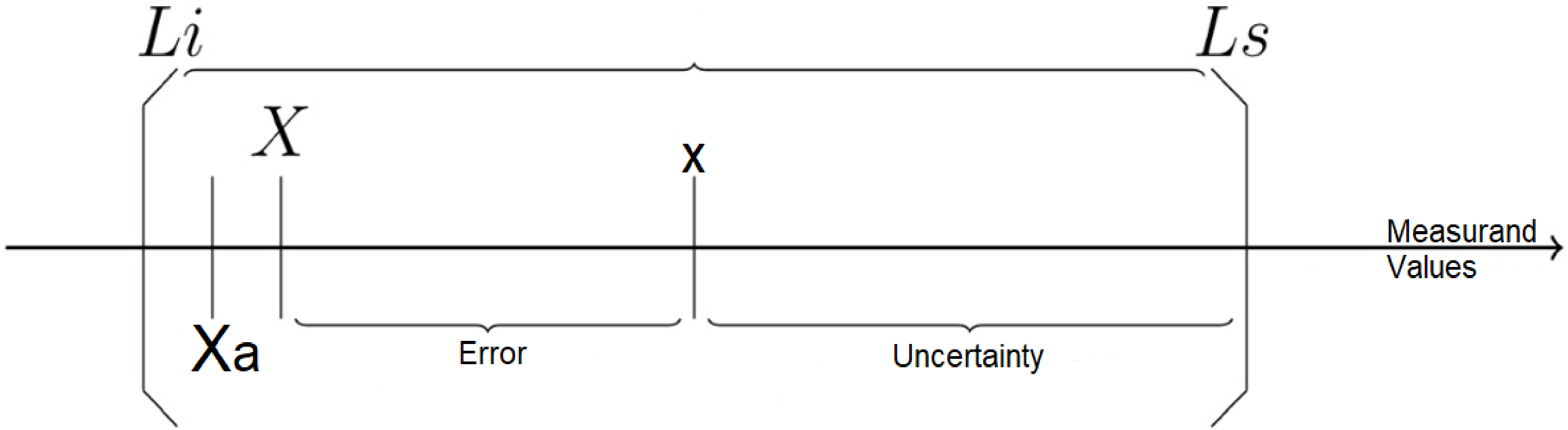
Every quantity has a **true value Xa,** not measurable due to different constrains, such as instrumentation imperfections. However, If we use a very expensive, calibrated and accurate instrument we can measure the **conventional true value X**. We accept that X is somehow a compromise in the evaluation of Xa. We can accept the conventional true value as our reference or nominal value. To this conventional true value, we can relate all other measurements that we take.

1.1 Measurement Units & Systems.



In daily practice we use **laboratory instruments**. These are not very expensive, they are general use, and they are not that accurate. However, they provide an indication that describes, with sufficient confidence, the measured quantity. And this indication is what we call the measured value **x**. We can accept that a conventional true value is the actual description of the true value. And that **there will always be a difference between the measured value and the conventional true value**. Because instruments are imperfect, we can never COMPLETELY trust the measured value! But it provides a good indication of what the measurand state is.

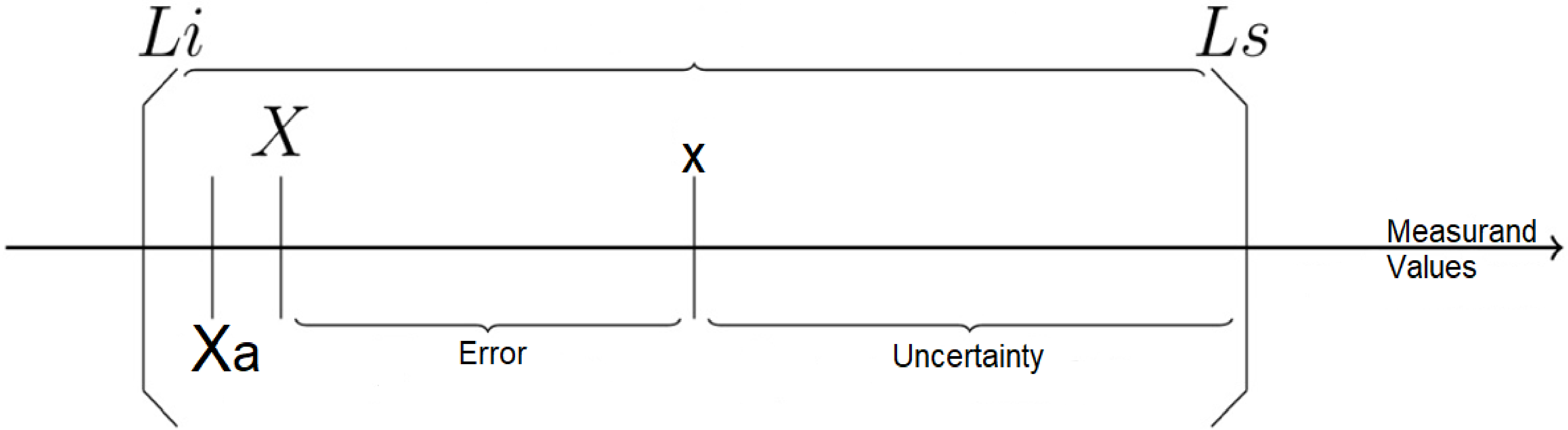
1.1 Measurement Units & Systems.



The **Absolute Error** is the simplest form of evaluation of distance between the measured value and the conventional true value. When using the absolute error evaluated quantities must be of the same class or type. For example, we evaluate 2 voltages measured over the same resistance, in the same experimental conditions, with the same measurement device. When presenting this type of evaluation, we conclude it has a sign ± and unit of measurement (V, A,℃ etc.).

$$\Delta = x - X_a \cong x - X.$$

1.1 Measurement Units & Systems.



The **Relative Error** is defined as follows:

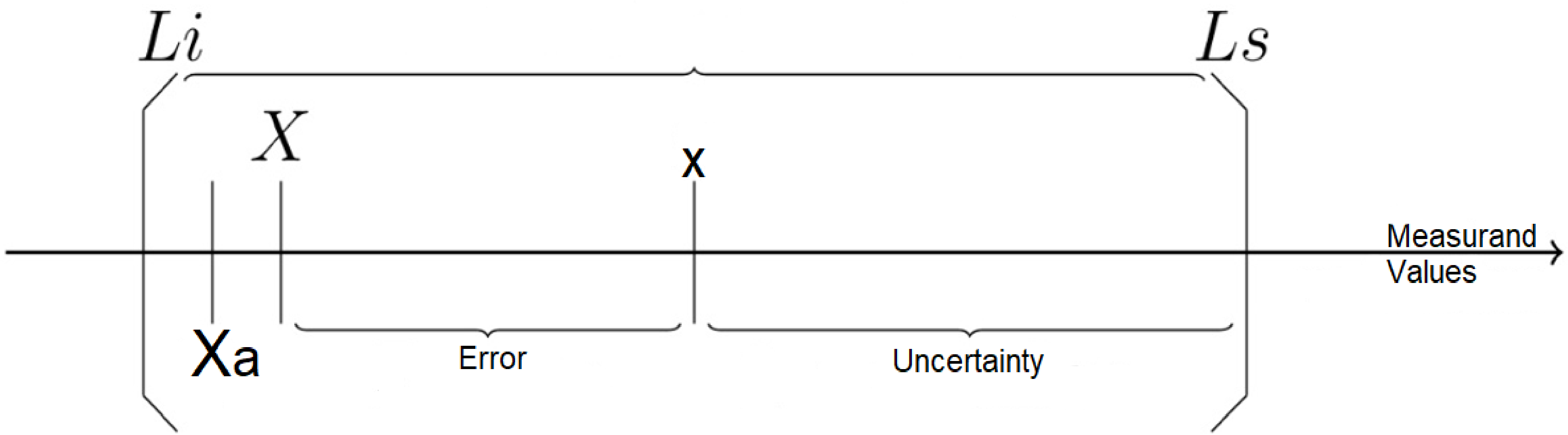
$$\delta = {}^{\Delta}/_{X} \cong {}^{\Delta}/_{x}\,.$$

If $|\Delta| \ll |X|$ the relative error is presented with an extended number of decimals. For convenience, the presentation format of the relative error should be in % or ppm. With the adjusted calculations as:

$$\delta_{\%} = \delta \cdot 100 = \delta \cdot 10^{2}[\%],$$

$$\delta_{ppm} = \delta \cdot 1000000 = \delta \cdot 10^{6}[ppm].$$

1.1 Measurement Units & Systems.



The image presents the notions of **Uncertainty** with respect to the measured value **x**. Such details are important for daily practice in our engineering work. The **accuracy** of a measurement is presented in relation to an interval which includes the conventional true value. If such an interval is constructed **by means of rigorous statistical analysis** (to be discussed later) and presents details on **the probability** that the conventional true value is within its limits, then this interval is called **confidence interval** and half of it defines the **measurement Uncertainty**.

Assuming this image presents the confidence interval, note the limits (*Li – inferior/lower confidence limit & Ls – superior/upper confidence limit*) are positioned symmetrically with respect to the measured value. The significance of this interval is that the conventional true value is within the limits, with a certain probability, or confidence level/degree, presented as $P \cdot 100\ [\%]$.

1.1 Measurement Units & Systems.

The **Measurement Uncertainty** is an important concept associated with the degree of dispersion of the measured values which we can reasonably present. Note that the measured value **x**, can suffer modifications from one measurement to the next. Our measuring tool/instrument is subject to aging, hysteresis errors, lack of calibration etc. The measurement method or process are subjected to systematic or random errors, mistakes in reading the measurement results, inconsistencies in the operations performed with a specific device and other factors, all add up to support the statement that **we can never completely trust the measured value!** The Uncertainty, by evaluating the dispersion of measured values under the same experimental conditions, defines the acceptance limits for our measurement procedures. But remember, it always includes statistical analysis, multiple measurements, probability presentation etc.

In practice, most of our measurements are of single type. In the sense that we measure once and then we present the value and the unit. However, each instrument present, in the documentation resources, the so-called *Accuracy Characteristics/Specifications.* These include different tables (depending on the measurand) defining relations to calculate the accuracy or confidence intervals for a specific measurement. In other words, **always try to present the measured value together with the associated confidence interval resulting from the instrument accuracy specifications.** It is of best practice that the conventional true value falls within the presented limits, while the absolute error remains, for repeated measurements, reduced.

1.1 Measurement Units & Systems.

Any measurement system is affected by errors generated by numerous sources. Instrumentation errors are generated by malfunctions or low-quality instruments or limited performance of instruments. Interaction errors are generated by the fact that when the instrument is connected to a system/circuit to be investigated, the values of the measurands of interest are affected/distorted by the very instrument that is used. Errors of method are created by the wrong usage of the measurement method (Ex. selection of the wrong range) or by the fact that the system/circuit generates a modified value of the measurand. We do not ignore operation errors when the person in charge of taking a measurement erroneously uses the measurement device. Errors of influence are caused by external factors affecting the instruments (Ex. environmental temperature, humidity etc.). **A GENERAL CLASSIFICATION OF ERRORS, DEPENDING ON THEIR CAUSE IS PRESENTED BELOW**.

- **Gross errors** are errors caused by human mistakes during experimentation, measurement, or data recording. Ex. misreading a scale or instrument indication, incorrectly recording a measurement, using the wrong units or formulas etc.
- **Systematic errors** are errors which do not modify under the same measuring conditions. *The source of these errors is known and because of this the measuring process can be corrected*. These errors have no or slow variation in time and they are either positive valued or negative valued. Some causes of such errors are connectivity faults (cabling issues), drift, wear in instrumentation components or lack of calibration.
- **Random errors** are errors which modify in an unpredictable manner (changes in value and sign) under the same measuring conditions. These errors appear because of factors which rapidly change and influence both the measurand and the measuring equipment (poor repeatability). Averaging those measurements will improve the indication. For example, electrical noise can be a source of random errors.

1.1 Measurement Units & Systems.

- Problem to emphasize the different use cases for Δ and $\boldsymbol{\delta}$;

Consider the width of a building entrance reported as conventional true value $X_a \cong X = 80cm$. By evaluating the width by means of a measuring tape we obtained $x = 81cm$. We are also considering the evaluation of a larger, secondary building entrance, reported as conventional true value $X_a \cong X = 7m$. By evaluating the width by means of a measuring tape we obtained $x = 6.95m$. Provide an analysis emphasizing which measurement procedure is most affected by errors.

- Discussion on Accuracy and Precision, as static characteristics, with the example of current measurements in a circuit;

The current intensity in a circuit is measured 10 times by a secondary type (laboratory) ammeter and the following results are obtained (mA): 5.383, 5.377, 5.378, 5.382, 5.380, 5.383, 5.379, 5.377, 5.380 and 5.381. Next, a primary type calibrated ammeter is used to measure the same circuit current. The value of 5.375mA is obtained. (a) What is the measurement precision of the laboratory ammeter?
(b) What is the maximum measurement inaccuracy of the laboratory ammeter?

- Example with pressure transducer and presentation of results – maximum expected error related to Range;

A relative pressure transducer with a measurement range of 0 - 15 bar has an inaccuracy of ±1% of the Full-Scale Range.
(a) What is the expected maximum measurement error? (b) What is the possible measurement error expressed as a percentage of the output reading if this pressure gauge is measuring a pressure of 1.5 bar?

- What is the introduced error is related to the device accuracy specifications related to the reading value?

We are measuring a signal frequency using a multimeter model 175. Accuracy specifications are presented in the following image. The conventional true value of the frequency is X = 133.5 Hz. The multimeter indicates x = 133.9 Hz. Present your measurement result including the absolute tolerated error, calculate Relative Error δ%. Does this measurement provide necessary accuracy for the measurement of X?

Function	Range [1]	Resolution	Accuracy ±([% of Reading] + [Counts])		
			175	177	179
Hz (AC- or DC- coupled, V or A [8] [9] input)	99.99 Hz 999.9 Hz 9.999 kHz 99.99 kHz	0.01 Hz 0.1 Hz 0.001 kHz 0.01 kHz	0.1 % + 1	0.1 % + 1	0.1 % + 1

1.1 Measurement Units & Systems.

IMPORTANT TERMS IN MEASUREMENT AND INSTRUMENTATION TECHNOLOGY

We can define the instrument measurement range as the upper and lower limits between which it can measure a quantity (amps, volts, ohms) or signal. The range is divided into fixed intervals presented as resolution. For digital instruments, most common in laboratory practice, the resolution is defined as the smallest increment of the input measurand that the instrument can detect and display. Basically, it is the smallest variation of the input variable that produces an observable change in the instrument output/display.

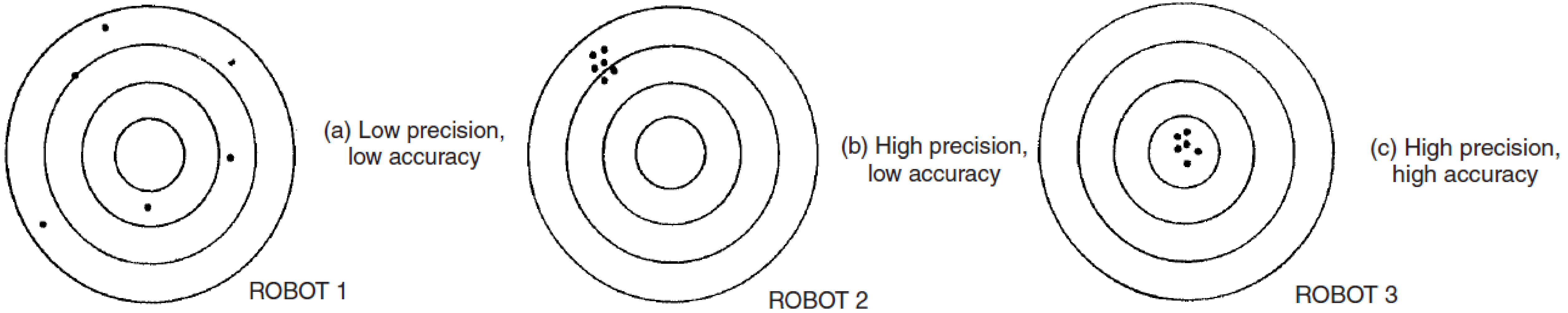
Precision (sometimes called repeatability) is another static characteristic which shows the ability of an instrument to display closely valued results when multiple measurements are taken under the same experimental conditions. Component aging, battery condition, temperature and warm-up time may all affect repeatability. Repeatability is also a measure of instrumental stability. In other words, instrumental precision/repeatability is evaluated after a higher number of readings, under the same experimental conditions (temperature, humidity etc.), when there are similar results at the output. Reduced data spread accounts for good precision.

Reproducibility describes the closeness of output readings for the same input when there are changes in the method of measurement, observer, measuring instrument, location, and conditions of use.

Accuracy (sometimes called exactness) of an instrument is a measure of how close the output reading of the instrument is to the conventional true value. Sometimes, the instruments inaccuracy is quoted rather than the accuracy. Inaccuracy is the extent to which a reading of the results might be wrong. Accuracy is a static characteristic of the instrument reflecting the imperfection in indicating a result as close as possible to the conventional true measurand value.

1.1 Measurement Units & Systems.

IMPORTANT TERMS IN MEASUREMENT AND INSTRUMENTATION TECHNOLOGY



1.1 Measurement Units & Systems.

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A high accuracy translates to a tight accepted error interval, but accuracy is not to be confused with error. The presented error interval is the numerical form in which we express the instrument accuracy characteristics. A measurement is said to be more accurate when it offers a smaller absolute measurement error. In other words, the closeness of agreement between measured quantity values that are being attributed to the measurand and the true value of the measurand, denotes the measurement accuracy. Suffice to say that one instrument is more accurate than another if under the same conditions and for the same measurand it delivers a result with a smaller absolute error.

The larger number of counts should translate into higher resolution and generally higher accuracy. If many readings are taken of the same quantity by a high-precision instrument the spread of readings will be very small.

Precision is not accuracy! A high-precision instrument may have a low accuracy (caused by a bias in the measurements, which is removable by recalibration). In international vocabulary, precision is defined as closeness of agreement between replicate measurements on the same, or similar, objects under specified conditions.

Digits and Counts define instrumental resolution. Resolution helps determine accuracy.

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Digits define the number of digits an instrument can display. A 4-Digit multimeter can display 4 digits with values from 0 to 9. Thus, it can display measurement values in the interval ±9999. This becomes complicated when the most significant digit cannot display values from 0 to 9. For example, a 3 - and 1/2-digit multimeter, shows for the most significant digit as either 1 or 0, while the other 3 values can be from 0 to 9. Thus, it can display measurement values in the interval ±1999.
For example, a value of 21V can be presented as 021.0V since the first digit can only be 0 or 1.
There is no standardized way to determine how we could express the characteristics of the display based on digits. It gets more complicated when the most significant digit can have values of combinations between 0,1,2,3 etc.
To minimize this confusion, the term **Counts** was introduced. It defines the number of readings an instrument can display within a range.
For example, the multimeter that can display measurement values in the interval **±1999** is a **2000 counts device**. It can count from 0 to 1999, regardless of the sign. The value of 1 count is determined by the least significant digit. For a reading of 18.2**5**V, **each count represents 0.01V or 10mV**. For a reading of 1.89**9**V, **each count represents 0.001V or 1mV**. For a reading of 021.**5**V, **each count represents 0.1V or 100mV**.
When calculating the absolute tolerated error interval, the selection between % of Range and % of Reading is significant.
Consider a 1000 Counts multimeter (shows values in the Range **±999**) should display a value of 100V. 1% of Range is about 10V, 1% of Reading is 1V. Make sure you verify if the absolute tolerated error is expressed as % of Range or as % of Reading. It makes a great difference. Modern multimeters have accuracy specifications expressed as % of Reading.