UNIVERSITÀ DEGLI STUDI DI PADOVA

Electronic Measurements

Lecture #1
Electronic measurements
Alessandro Pozzebon

Electronic Measurements

Alessandro Pozzebon

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Office: DEI-A, Third floor, room 308

Lectures

- **Tuesday**: 16:30 – 18:00
- **Wednesday**: 12:30 – 14:00 and 14:30 – 16:00 (Laboratory)
- **Thursday**: 10:30 – 12:00

Laboratory – Organization

- Work group composition: **three persons max.**
- **2 shifts** with **12-16 groups** each (max. 72-96 students)
- Registration to be opened tomorrow – see Moodle
- Weekly schedule
  - on Wednesday: 12:30 – 14:00 and 14:30 – 16:00
  - start: next week (second week of the course)
- Laboratory activity is **an integral part of the course**
- **Laboratory reports** expected for some lab exercises

Laboratory – Safety courses

- Attendance to the laboratory is allowed only **after** the required safety certifications are obtained
- If you already have a **valid certification**, you do not need to take the course again
- If needed, **on-line courses** on safety are accessible Please, consult the Moodle page of the course:

  https://stem.elearning.unipd.it/course/view.php?id=7346
- Students are required to agree to the laboratory guidelines and provide a statement that they achieved the safety certification.
- *IMPORTANT: a signed statement of certification (autocertificazione - self-statement) is a trusted document according to Italian Law. You are reminded that any signed false statement is a criminal offense.*

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“Seminar” week

Shaping a world class university

Prof. Domenico Balsamo

Newcastle University

Newcastle, UK

Newcastle University

Three seminars

10/12/2024

Power-Aware Sensing: Intermittent Computing for Sustainable Measurement Systems

11/12/2024

Opportunistic Communication in Intermittent Sensing Networks

12/12/2024

Unlocking the Potential of EH-based IoT Systems through Intermittent Computing and Cutting-edge Energy and Time Management

Exam Schedule

Wednesday, January 21st 2026 – h. 12:00

Wednesday, February 11th 2026 – h. 10:00

Wednesday, June 17th 2026 – h. 14:00

Tuesday, September 22nd 2026 – h. 14:00

What are we going to talk about?

- Fundamental knowledge about **measuring instruments**
- **Measurement methods** for the test and characterization of electronic devices and systems
- **Laboratory**: review concepts given in lecture, strengthen awareness of quantitative issues and develop the notions of approximation and uncertainty
- Measurement provides the essential **“bridge” between reality and engineering models**

taking measurements is like taking pictures…

…unseen

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What is "Measurement"?

- **Process** of experimentally obtaining values that can reasonably be attributed to a quantity

International Vocabulary of Metrology (VIM) – 3rd edition, 2012

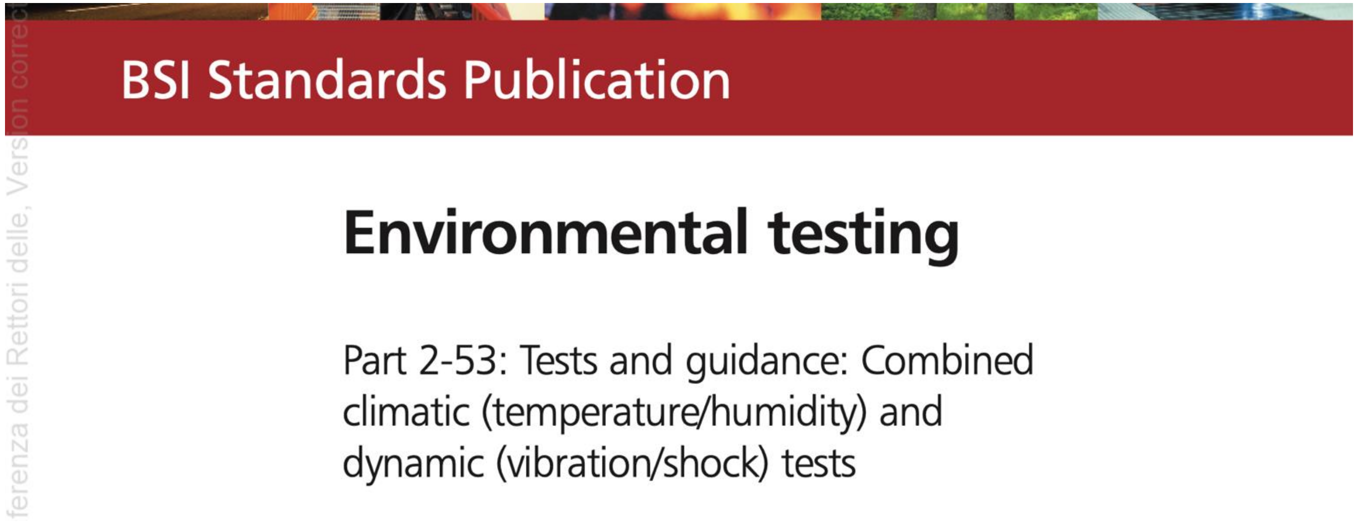
- Measurement implies a **comparison between quantities** or a **count**
- In measurement, it is assumed that:
  - A suitable **description** of the quantity that it is intended to measure ("measurand") is given
  - A measurement **procedure** has been defined
  - **Calibration** of the measuring system is ensured

Measurement "quality" assessment: how?

- Is the measurement result **meaningful**?
  - Verifiable experimental condition?
  - Measurement accuracy?
- **Repeatability**
  - Would repeated measurements of the same "object" yield comparable ("same") results?
- **Reproducibility**
  - Well-documented measurement procedure?
  - Would another laboratory measuring the same "object" obtain comparable ("same") results?

Measurement, or test?

- Test aims are:
  - obtain a “pass/fail” result referred to a set of **specifications**
  - be **repeatable** (homogeneous results)
  - be **reproducible** (comparable results)
- Tests **may** be based on measurements and **must** be carried out according to a **standard and documented procedure**


BSI Standards Publication

Environmental testing

Part 2-53: Tests and guidance: Combined climatic (temperature/humidity) and dynamic (vibration/shock) tests

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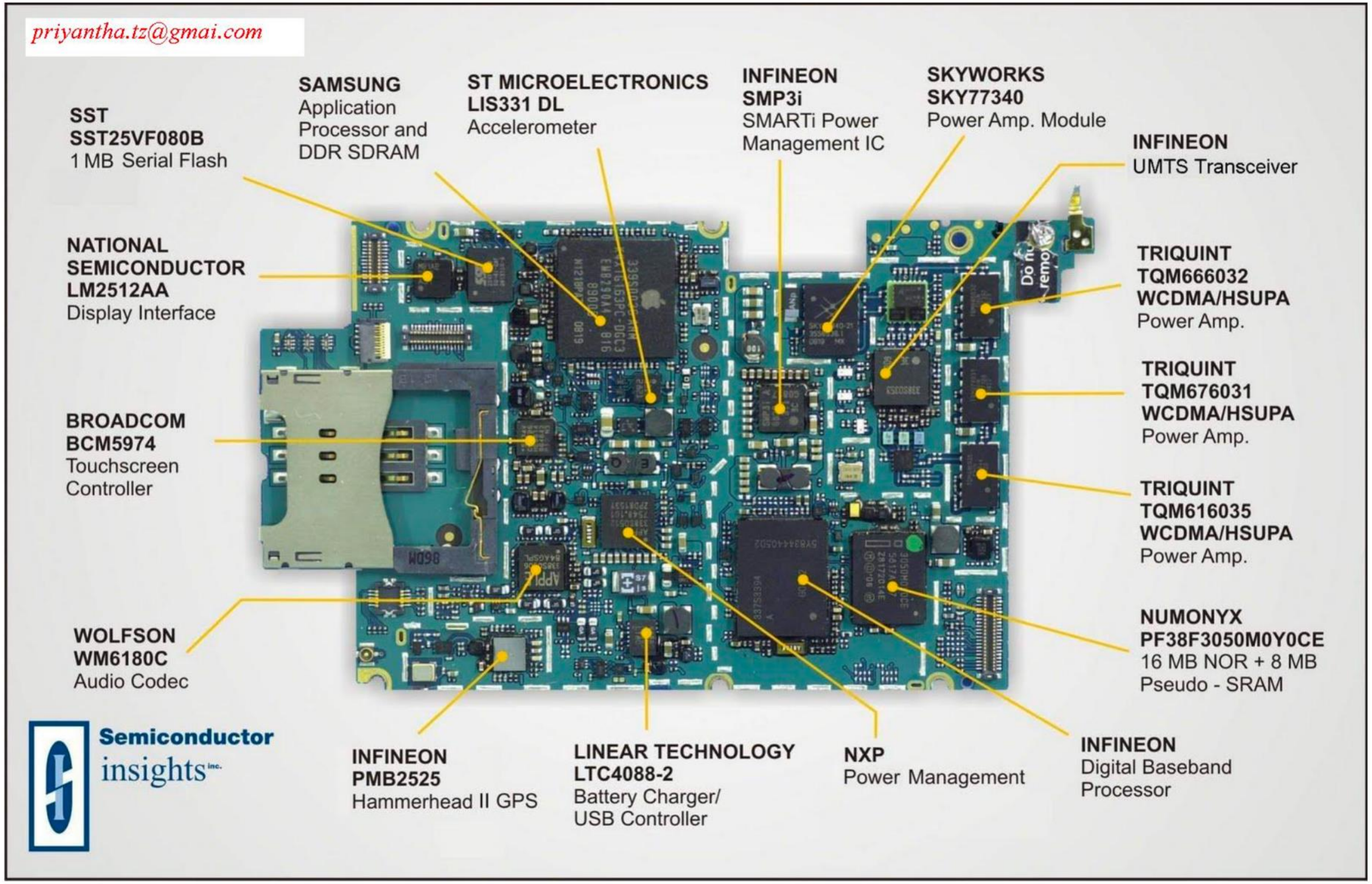
When do we measure/test – and why?

- **Design, research and development**
  - Instrumentation performance comes first
  - Interaction with CAD/CAE tools (engineering models)
  - Prototype validation and diagnostics

- **Production**
  - Test benches should be *cost-effective*
  - Interaction with production lines
  - Functional verification and testing, diagnostics and self-diagnostics

What needs to be measured/tested in electronics?

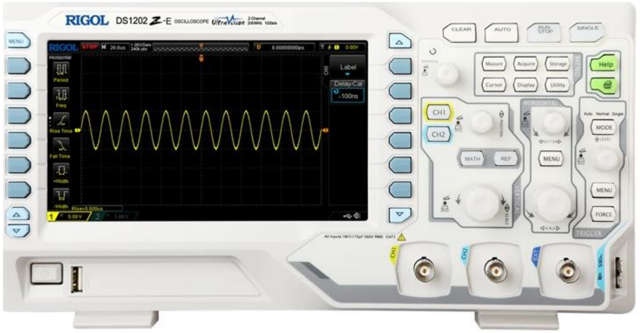


Instrument overview – what's in the Lab

- **Multimeters**

- **Signal Generators**

- **Oscilloscopes**



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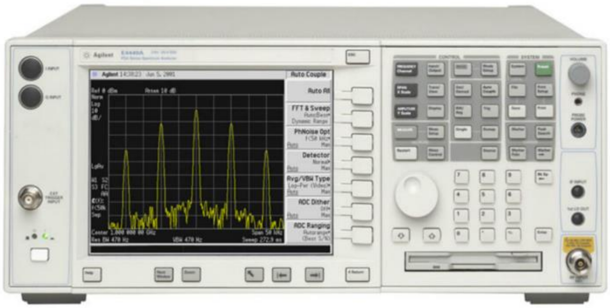
Instrument overview – what's in the Lab

- **Spectrum/signal analyzers**



Measurement automation

- Stand-alone bench instruments are typical of laboratory R&D environments
- Complex measurement **procedures** + specific **instrument setups** in industrial testing → computer-controlled **measuring system**
- Instrumentation **interfacing standards**
- Software-based **instrument drivers**
- Inherently documented procedures
- Compliance to specifications from standards

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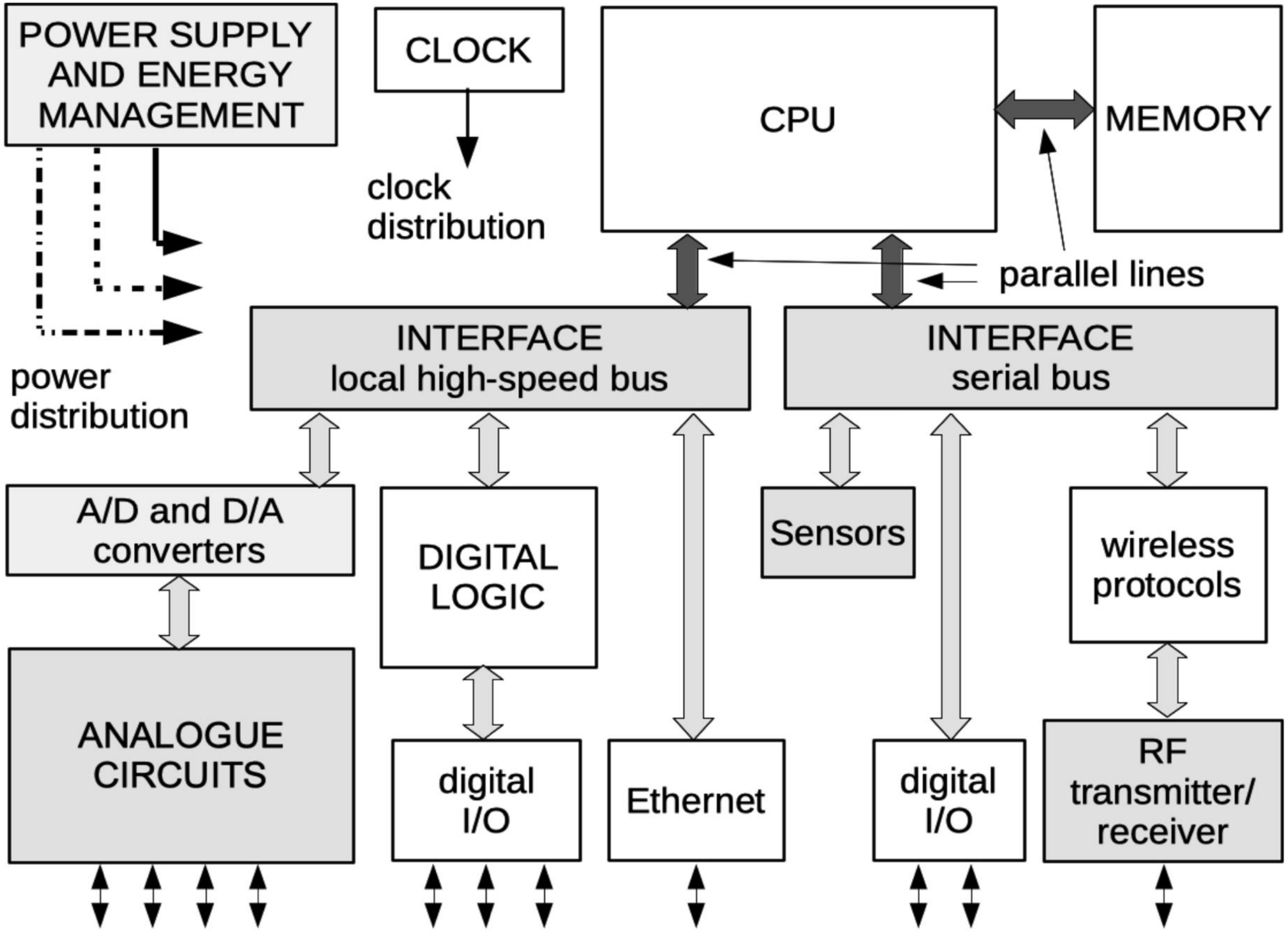
What needs to be measured in electronics?



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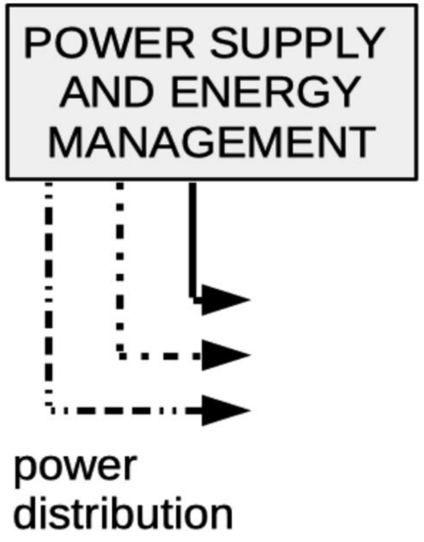
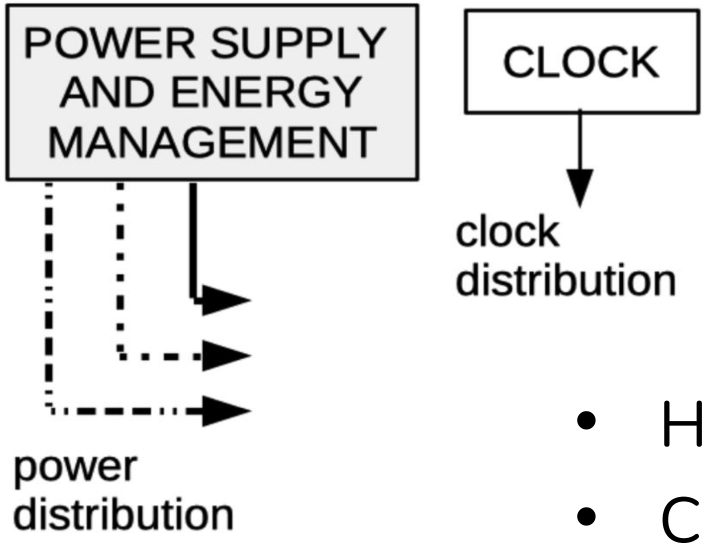
What is measured in a device?



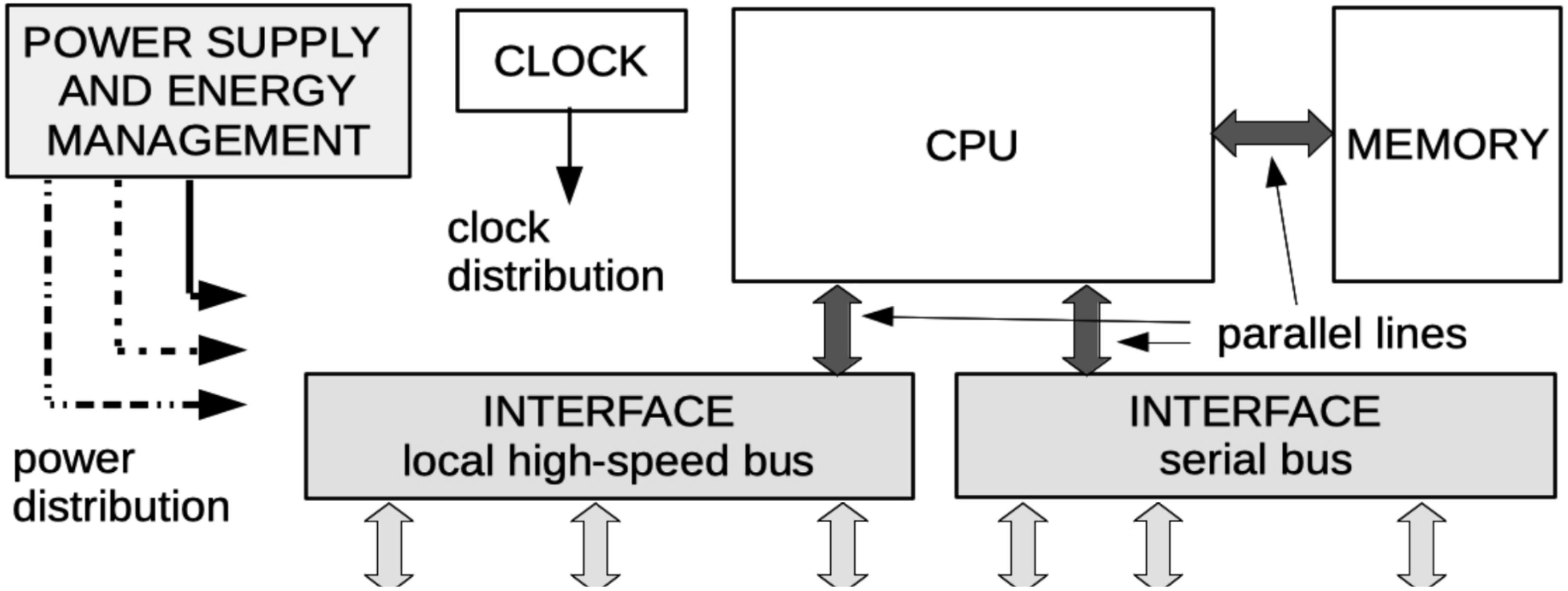
- Different power supplies
- Voltage regulation
- Power-up/down sequencing
- Energy management
- Recharging/energy harvesting
- Supply distribution lines
- Electromagnetic compatibility

What is measured in a device?



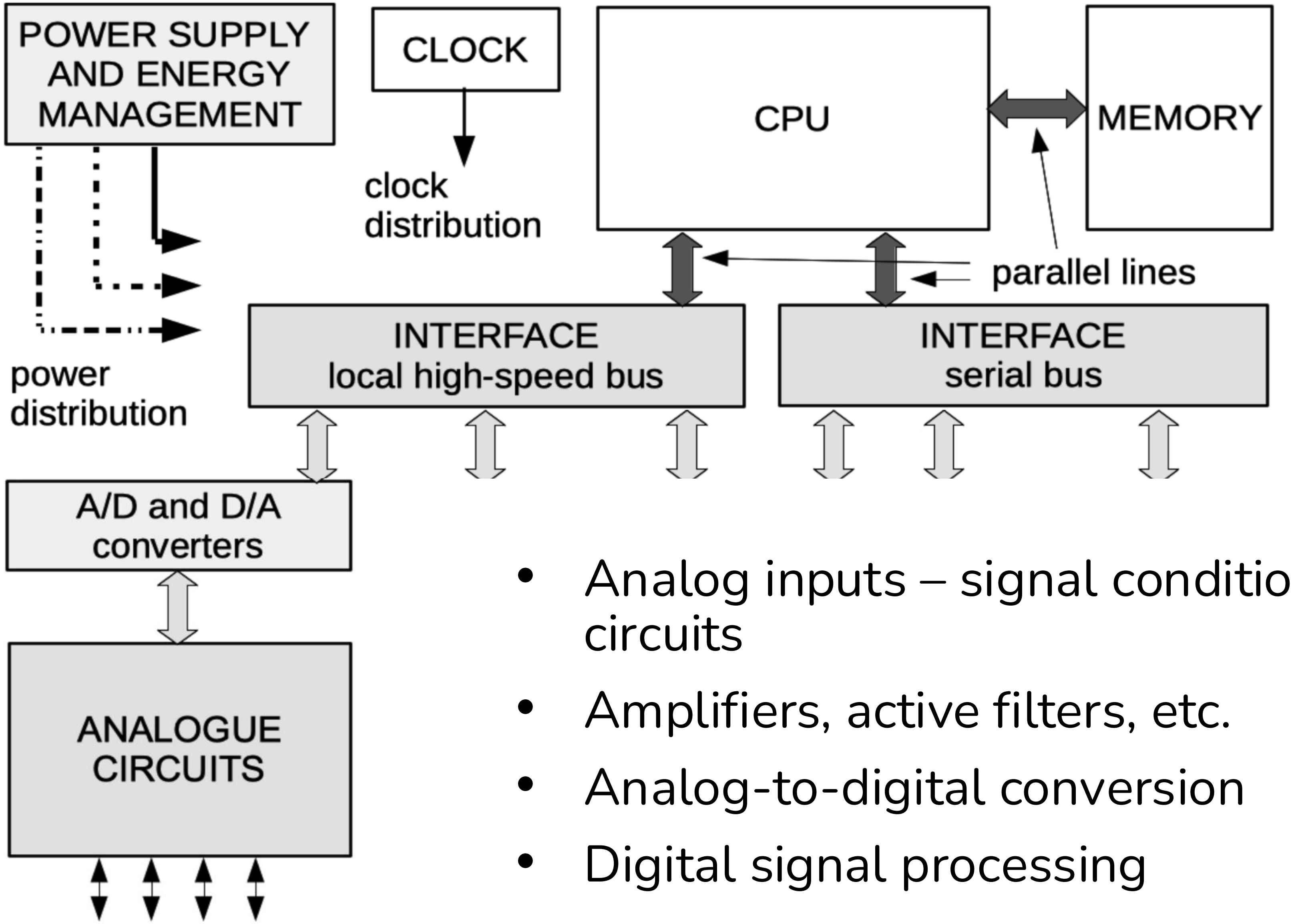
- High-frequency signal
- Clock distribution lines (high-speed)
- Propagation/reflections
- Signal integrity
- Electromagnetic compatibility

What is measured in a device?



- High number of digital lines
- High-speed parallel communication
- Serial-line communication
- Peripheral communication protocols

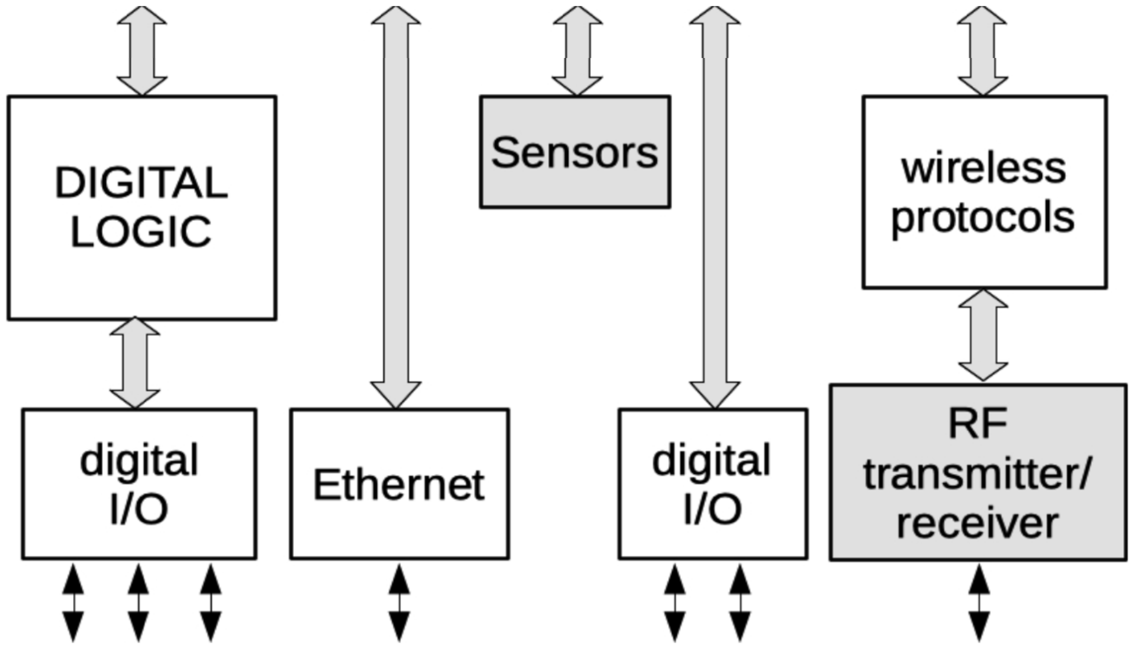
What is measured in a device?



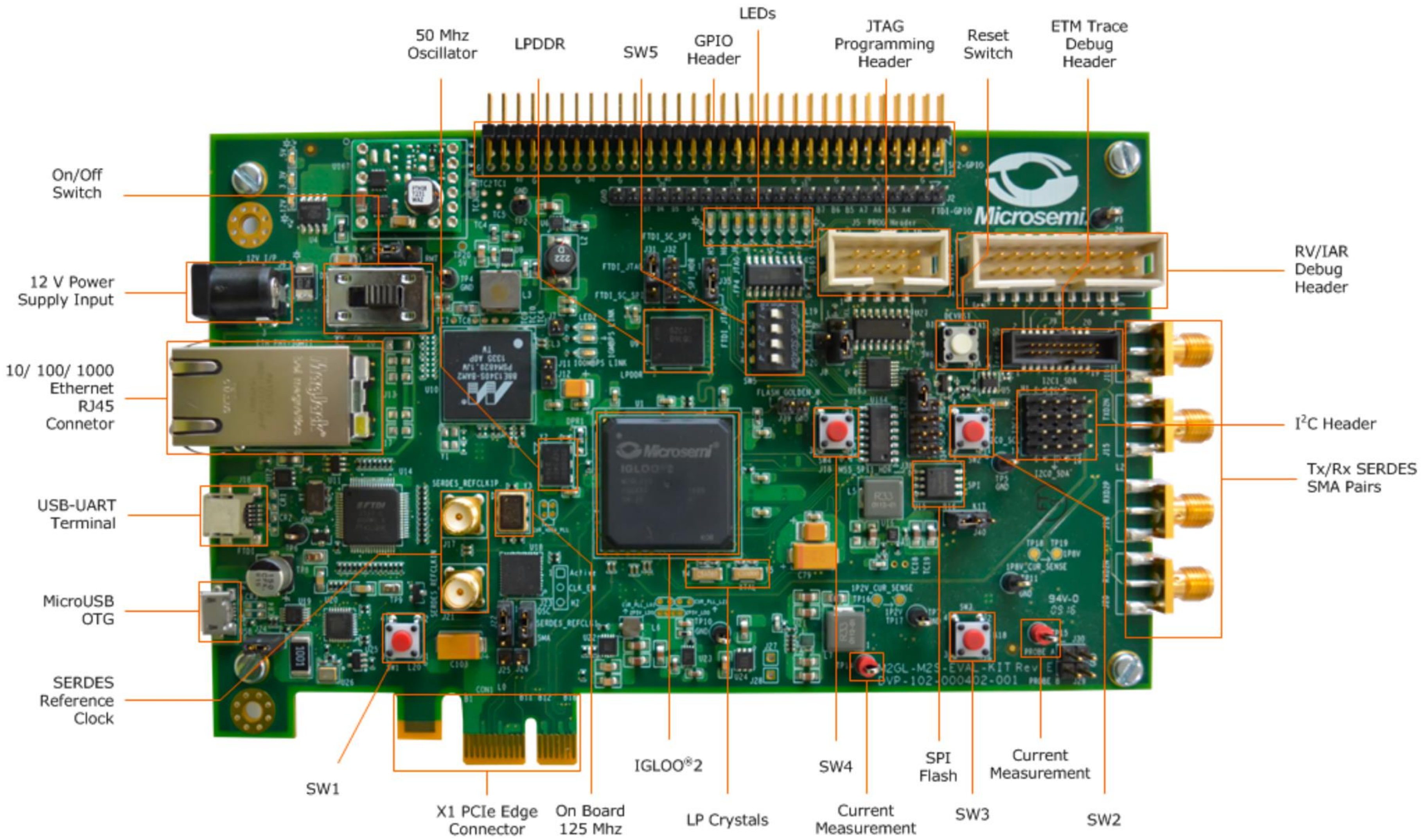
- Analog inputs – signal conditioning circuits
- Amplifiers, active filters, etc.
- Analog-to-digital conversion
- Digital signal processing

What is measured in a device?

- Digital I/O
- Field busses, Ethernet
- Wireless links
- Radio frequency devices



What needs to be measured/tested in electronics?

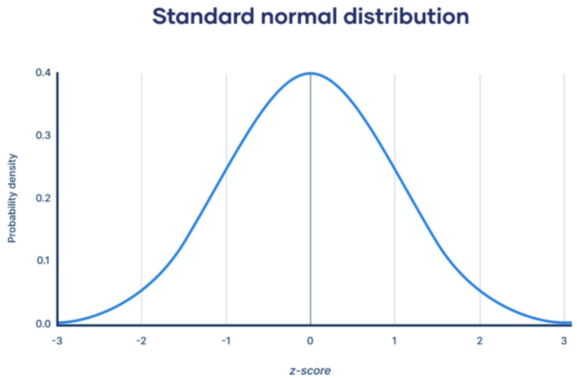


What needs to be measured/tested in electronics?

Trusting instruments: calibration

- Operation that, under specified conditions:
  - **In a first step**, establishes a relation between the values provided by measurement **standards** and corresponding instrument **indications** with associated measurement uncertainties
  - **In a second step**, uses this information to establish a relation for obtaining a **measurement result** from an indication

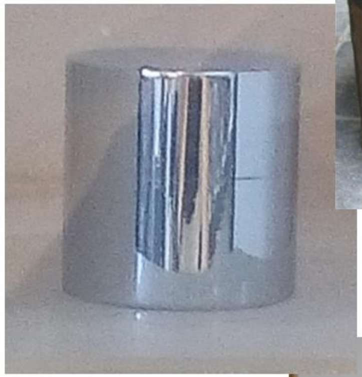
*WARNING: two meanings of the word **standard***



Standard
Normale

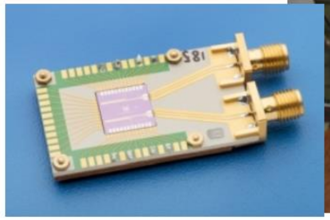
Standard
Campione

Standards

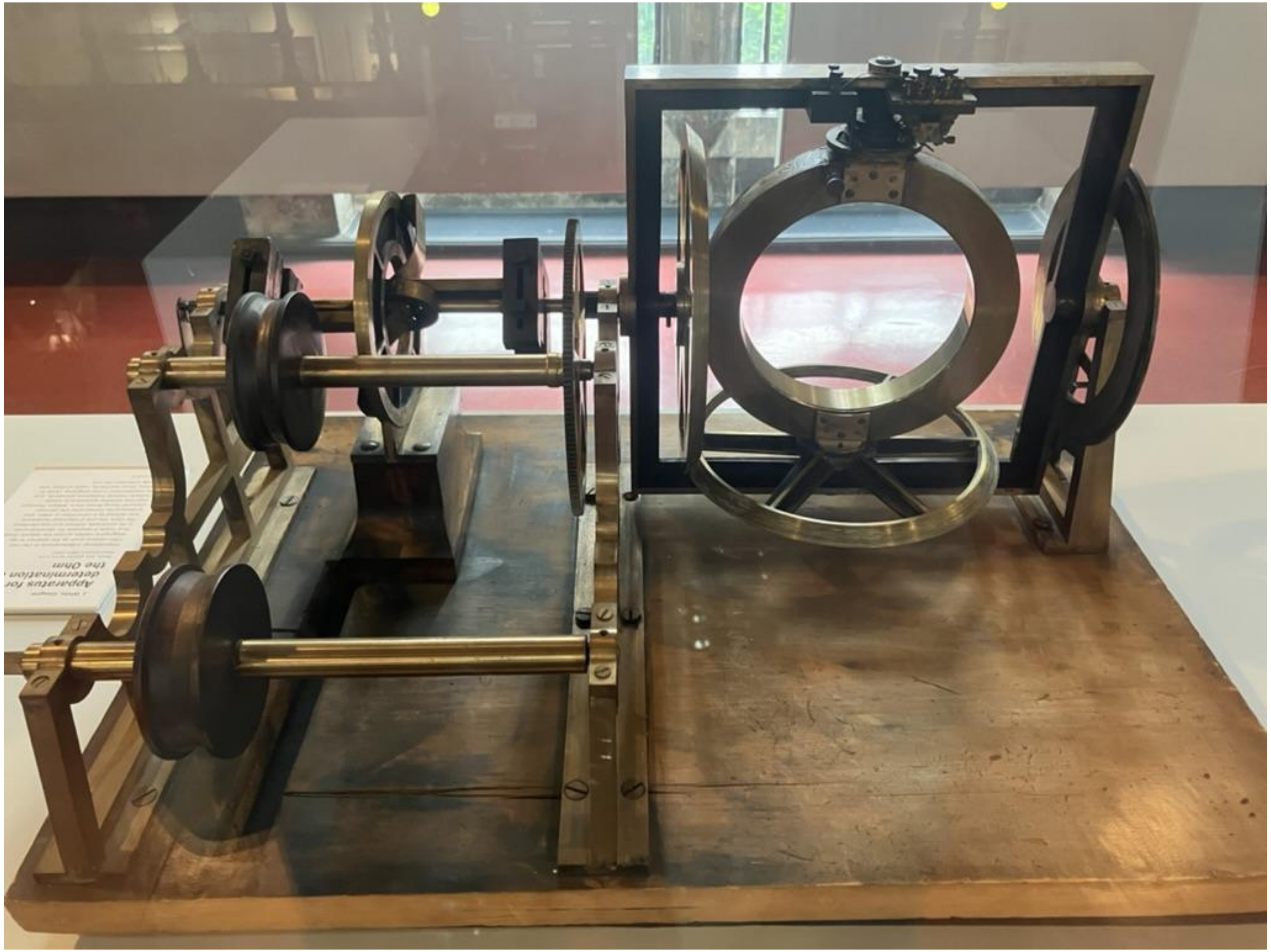



METRO
ALTEZZA LIMITE
TRASPORTO GRATUITO
BAMBINI


MESVRE DE PEDRE CVPPI ET ALTRI LAVORI
COTTI ET MESVRE ESTESE DEL COMVNE
DE RIMINO · M · D · XXXXIIII
QVADRELO
QVADRO
PIEDE COMVNE
PASSO DA LEGNE ET DA PALLATE

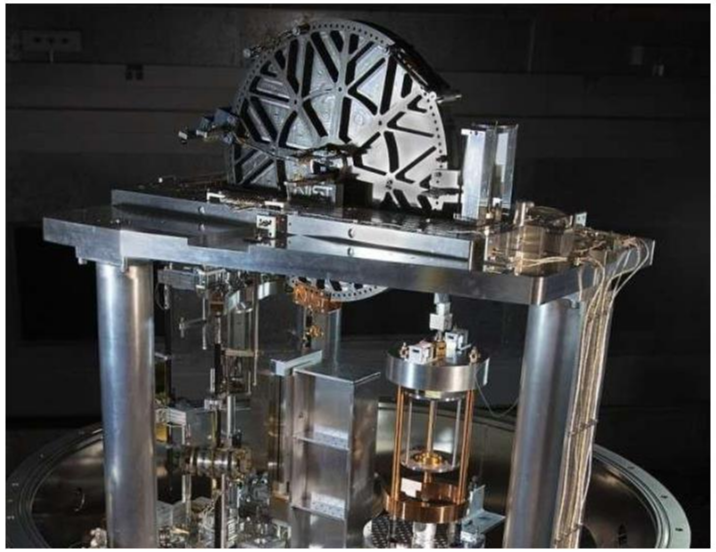


Standards

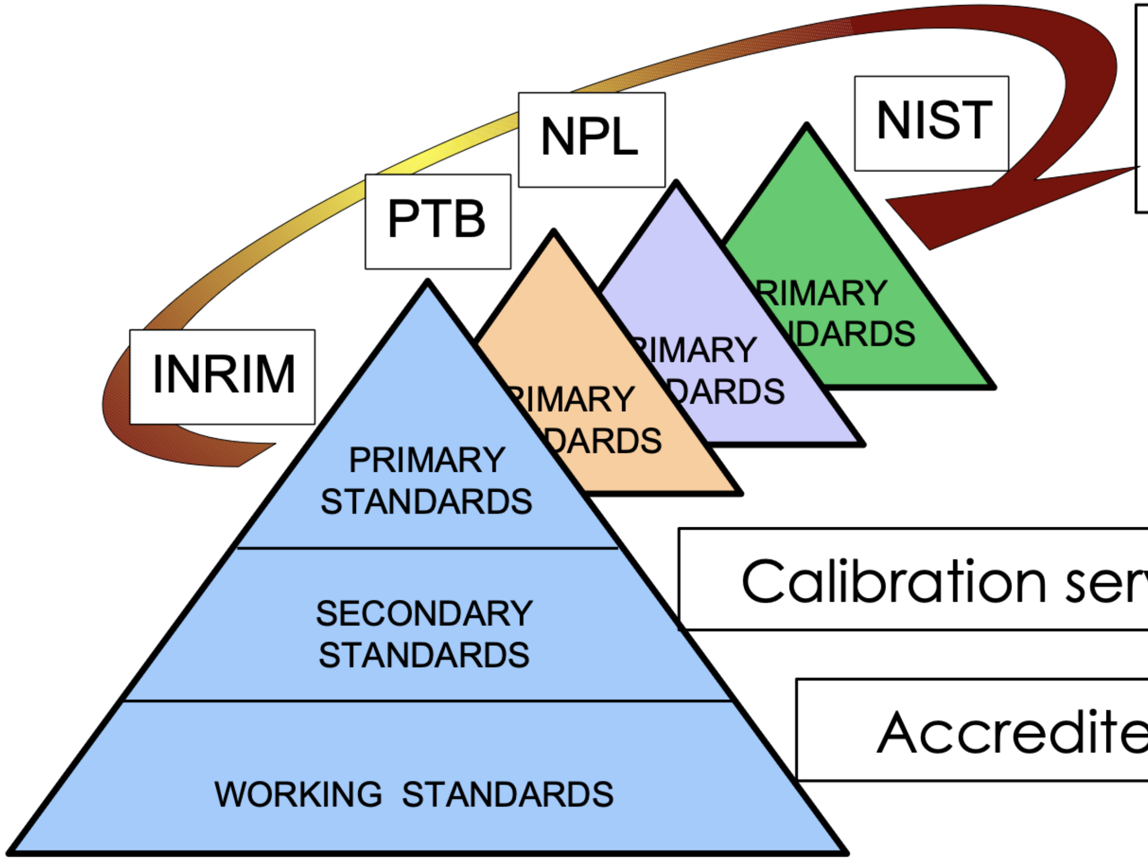


20 May 2019 – new definition of the kg

- The kilogram, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the **Planck constant** h to be 6.626 070 040 ×10–34 when expressed in the unit J s, which is equal to kg m^2 s^{-1}
- Inverting this relation gives an exact expression for the kilogram in terms of the three defining constants h, ΔνCs and c
- (...) with the present definition **primary realizations can be established**, in principle, at any point in the mass scale



Trusting instruments: traceability



Intercomparisons (round robins, travelling standards)

Calibration services (DKD, UKAS, COFRAC, ...)

Accredited labs (Accredia, NAMAS, ...)

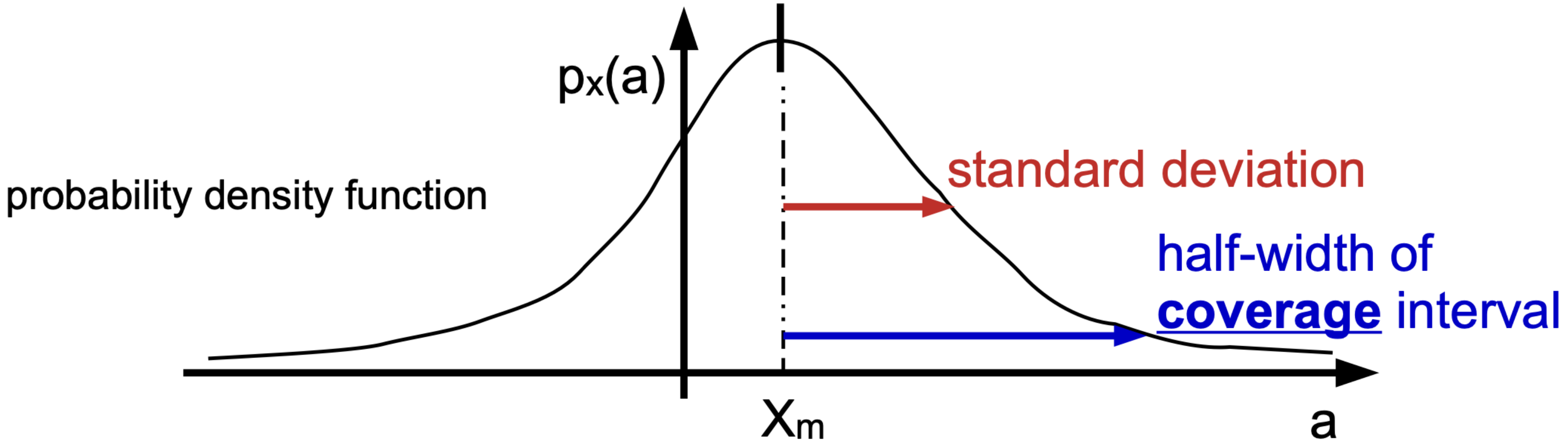
Measurement uncertainty

- (…) when all components of error have been **evaluated** and the appropriate corrections have been applied, there still remains an **uncertainty** about the correctness of the stated result…
- … that is, a **doubt** about **how well the result of the measurement represents** the value of the quantity being measured
- **Measurement result** – may be reported as a **probability distribution** on a set of values being attributed to a measurand

Measurement result and uncertainty

- A measurement result can be reported as a single measured **value** and a measurement **uncertainty**
- **Measurement uncertainty** – parameter characterizing the **dispersion of the values**, based on the information used
- If uncertainty is negligible (in comparison with target uncertainty), the result is sometimes expressed as a **single value**. In this case **only significant digits** should be reported

Probability and uncertainty



- Single value is often the “most likely”, that is, the “mode” of **assumed** probability density function
- **Different** parameters can characterize dispersion:
  - standard deviation
  - (half) width of suitably defined **interval**

Errors

some lessons learned…

…the hard way

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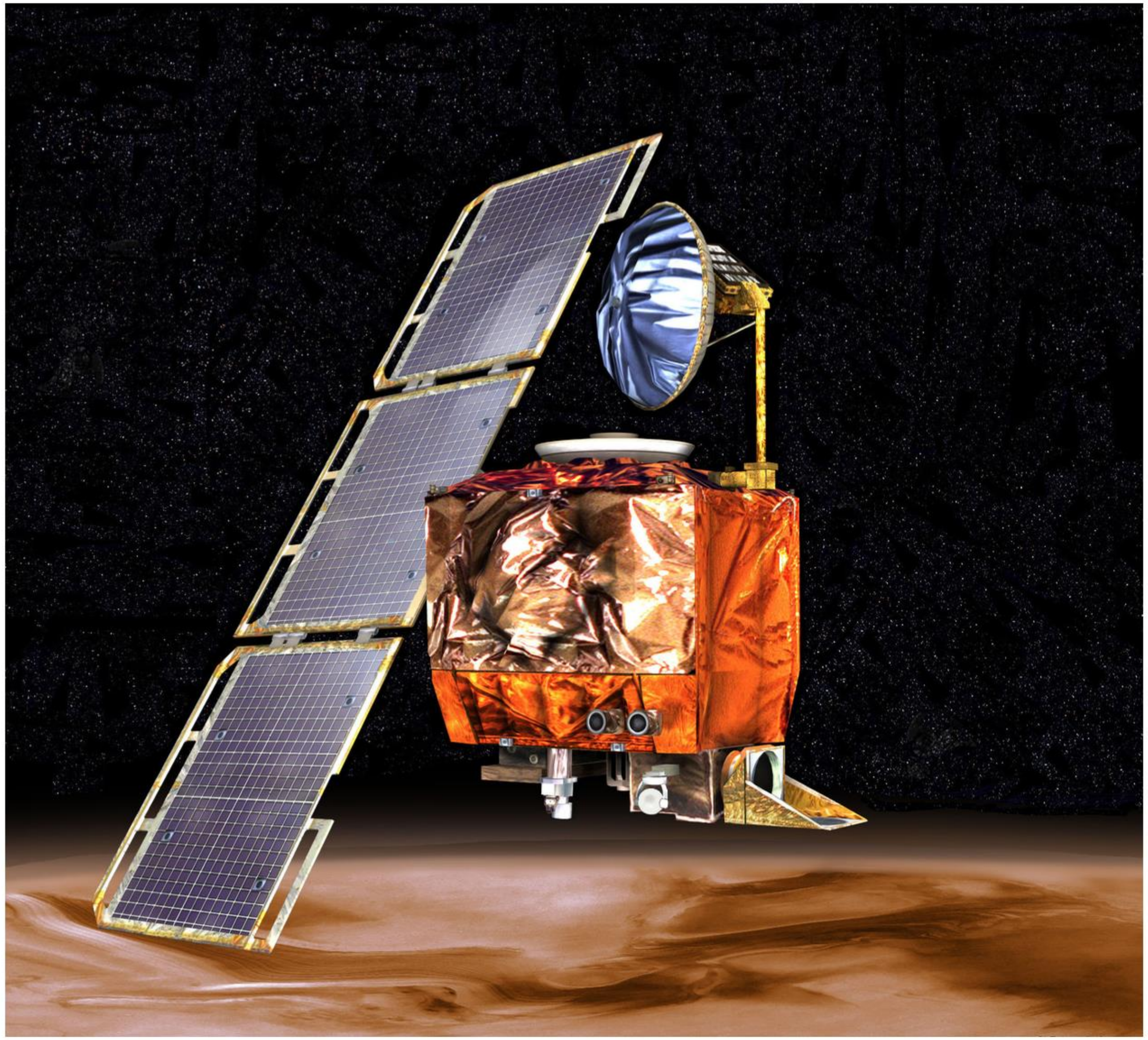
Units and orders of magnitude
Mars Climate Orbiter, 1999



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Units and orders of magnitude
Mars Climate Orbiter, 1999

- Due to "complications arising from human error" the Orbiter was lost, either destroyed in Mars atmosphere or wandering in space after leaving it
- Ground software supplied by Lockheed Martingave gave results in "pounds per square inch" (psi, or lb/in^2)
- NASA **expected** results to be in SI units (kg/m^2)
- Software that calculated total impulse produced by thruster firings gave results in "pound-force seconds"
- Trajectory calculation software **expected** them to be in "newton seconds" (incorrect by a **factor of 4.45**)

Units, orders of magnitude…
… and something more

- NASA was at fault for **failing to make the appropriate checks and tests** that would have caught the discrepancy: Lockheed Martin failed to read specifications, but it was NASA that issued them
- Discrepancy between calculated and measured position (…) noticed **by at least two trajectory software operators**
- Concerns were reportedly dismissed because they **failed to "follow the rules** about filling out form to document their concerns"
- A trajectory correction manoeuvre was possibly agreed, but ultimately not done

Corrections and compensation *Laufenburgbrücke*

- Laufenburg (**Germany**) and Laufenburg (**Switzerland**) are twin towns facing each other across the Rhine

- Bridge size: 225 m long, 11.2 m wide
- Cost: 12 million Swiss Francs, shared equally by Baden-Württemberg (D) and Canton Aargau (CH)

Corrections and compensation *Laufenburgbrücke*

- Sea level reference for Germany is taken from Amsterdam (**North Sea**), whereas the Swiss reference is set to 373.6 m above the sea level at Marseilles (**Mediterranean**)
- A height difference of 27 cm exists between these two references – this **was known** by bridge planners of Laufenburg…
- Unfortunately, **the minus sign was missed** and the 27 cm ‘correction’ was made in the wrong direction
- A routine construction control discovered a **54 cm height difference** between the two sides

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