Jahre genau

Don’t panic
May metrology be with you

Metrology down to Earth : what is it good for ?

Maguelonne CHAMBON / LNE

"*Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it*."

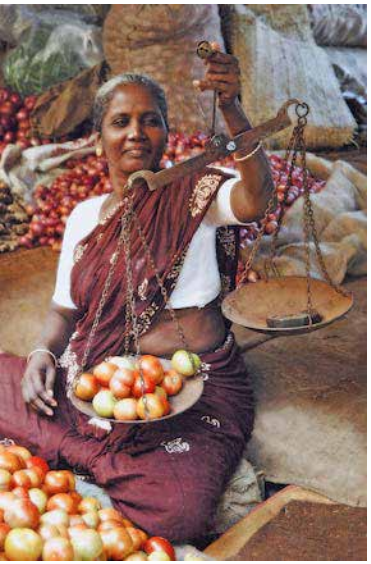
-

H. James Harrington

Metrology down to Earth : what is it good for ?

- To measure means
  - to compare two « objects » with an instrument
    - one object considered as a reference to an unknown one
  - to express the measured quantity with a value, a unit and an uncertainty
- Measurements give some clues to
  - validate a manufacturing process or to adjust parameter
  - prove the conformity or non conformity of a product with a specification
  - validate an hypothesis in R & D
  - protect environment and consumers / citizens
  - define safety conditions

Metrology down to Earth : what is it good for ?



- Metrology and measurement of quantities are part of our daily life
- Measurement and testing are referees in many cases
- Measurement allows confidence between partners
- Measurement is a way to take decision
- Measurement quantities are universal

- Means : to get a coherence world-wide on a shared planet
- To implement an ensemble of techniques and know-how comparable anywhere, anytime

Metrology down to Earth : what is it good for ?

- from 6000 BC up to now, in a huge number of case, units were always pragmatic, and linked to mankind to allow practical and easy measurements
- units were linked to usefulness
- units were defined by an authority (local, regional, national, …)
- measurements
  - strengthen the daily life, daily needs
  - were a way to control / verify trade market, to impose taxes
  - used for scientific purpose

Metrology down to Earth : what is it good for ?

Egyptian clepsydre

"Nîmes" weights used in pharmacopoeia

Egyptian cubit Toutankhamon minister of finance "Mâya". 52,3 cm divided in 28 digits of 1,86 cm

Metrology down to Earth : what is it good for ?

- a travel in the metrology world
  - transport
    - ocean, sea
    - road
    - railway, air plane
  - energy
  - ……
- what metrology brought us ?

Energy

Transport

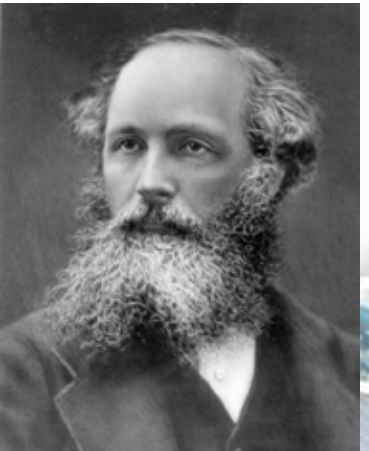
Housing

daily life

A little bit of history

- XIX century
- André-Marie Ampère
  - expressed the theory of electromagnetism in 1827, and the Ampere's law on electrodynamics
  - one of the precursors with Arago of telecommunication, with the invention of the electrical telegraph

Electromagnetism : study of electromagnetic field and interaction with electrically charged particles. Theory of James Maxwell in 1864 : light as an electromagnetic wave



A little bit of history

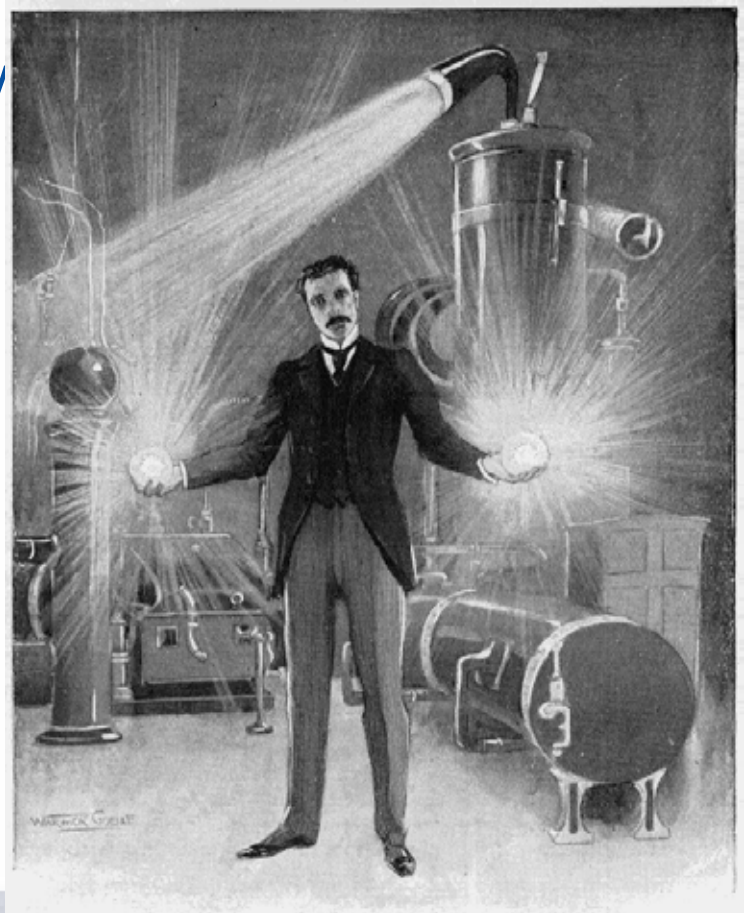
- Heinrich Rudolph Hertz
  - was born 30 years before the creation of PTB
  - performed his PhD with Hermann von Helmotz
  - realised an oscillator in 1887, and precursor of measurements of electromagnetic waves in air
  - on his major contribution : verify the theory of J. Maxwell
  - first link by electromagnetic waves between a transmitter and a receptor : opening the way of wireless telecommunication

- *not convinced of the usefulness and on possible applications !*

A little bit of history

- Nikola Tesla
  - important contribution in term on technologies and innovation
  - depositary of more than 700 licences
  - works more in the field of electrical energy
  - convince of the added value of AC electricity : first alternator
  - allowed the development of electrical networks
  - promotion of the (electrical) energy transport means in a AC/DC way
  - discovery of the radar principle

Instrumentation becomes essential in progress development

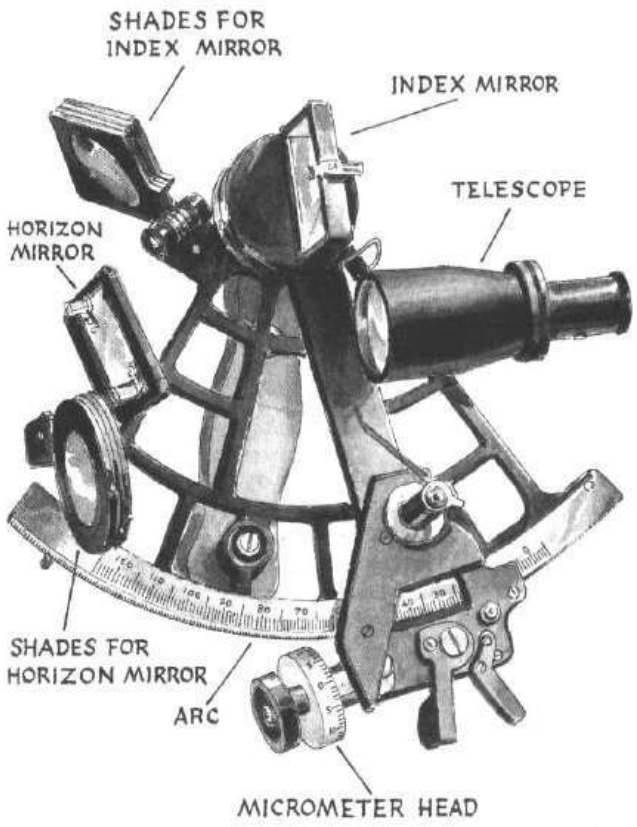


Nikola Tesla holding in his hands balls of flame

what is the relation with transport, energy and metrology ?

Shipping

- Sextant
  - navigation instrument
  - marine, aeronautic, etc..
  - to measure the angular distance between two points (e.g. angular heigth of sun at noon)
  - to give the latitude where the observer is
  - reliable instrument



- invention of John Hadley and Thomas Godfrey
  - still in use in aeronautics, navy

Shipping

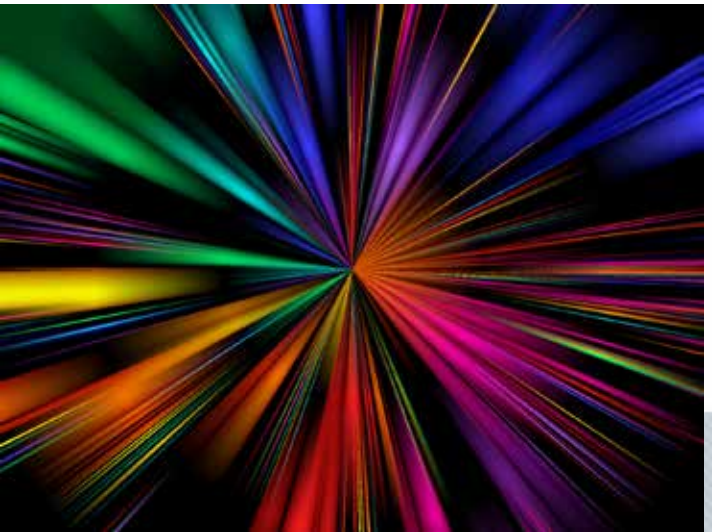
- exactitude / precision
  - 0.2’ of arc
  - around 370 m in theory
  - in practice more than 3,5 km

  (depending of the weather, sea, etc.)

- implementation of new instrumentation of navigation and positioning based on satellite constellations
  - based on more precise clocks
  - use time and frequency transfer microwave techniques
  - should provide a better accuracy on position measurements

Metrology of time and frequency

- Discovery of laser in the 1920's
  - by Albert Einstein
  - new principle of optical pumping by Alfred Kastler in the 1950's
  - allowed big improvements in the field of frequency measurements and brought a lot of innovation in instrumentation
- Development of new clocks in the 1950's by NPL
  - better knowledge and improvement on frequency measurements in RF and microwave, in atomic physics
  - development of atomic clocks : Caesium, Rubidium, …

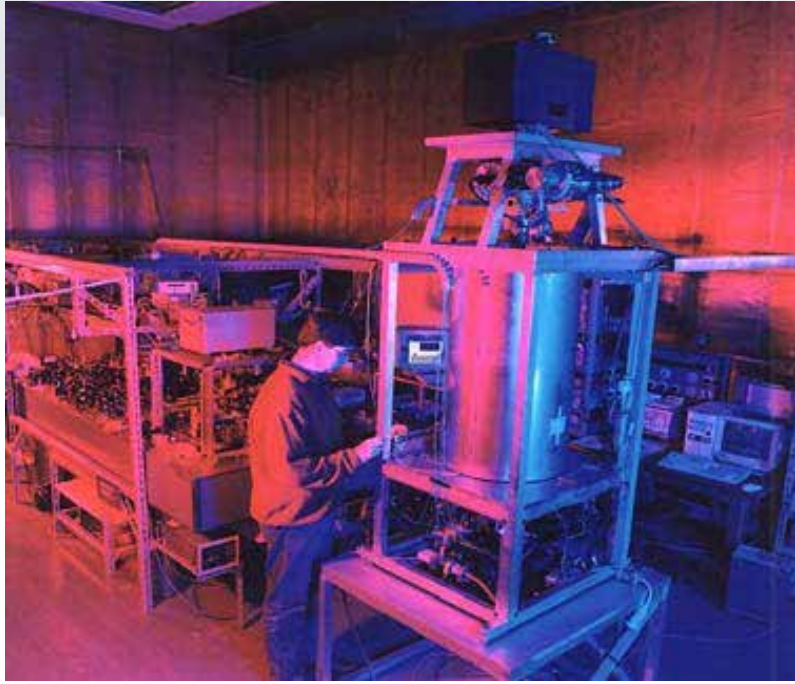


- from 1967-1968 : the unit, the second, is defined by the hyperfine transition of ^{133}Cs at ~ 9.2 GHz
- improvement of clock accuracy

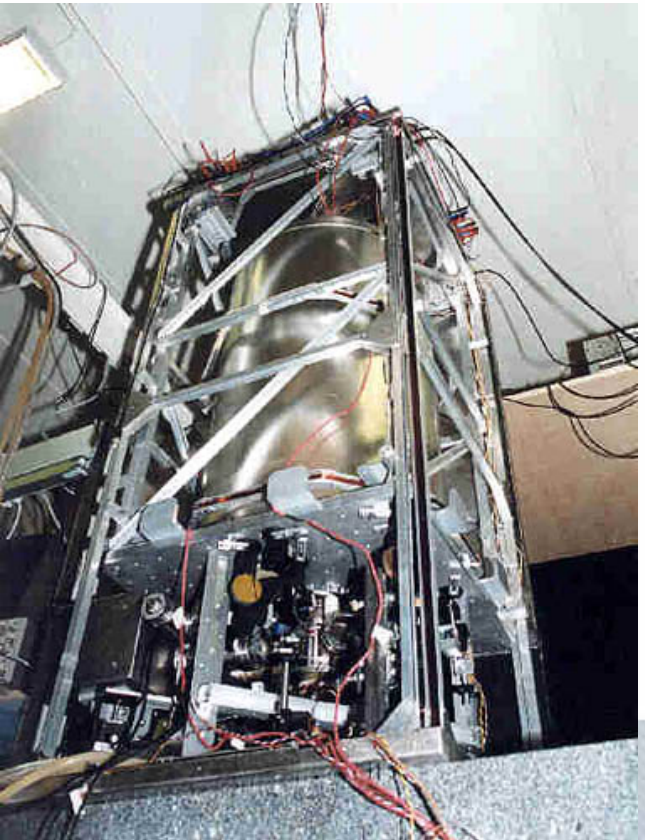
Metrology of time and frequency

1980's up to XXIe century

- accuracy of 10^{-13} / accuracy of 10^{-14}
- in the 1990's accuracy of 10^{-15}
- 2000 / 2010 accuracy of 10^{-16}



Fountain clock at PTB /DE



At the present time

new type of clocks : optical clock

- to reach an accuracy of 10^{-17}
- development at PTB
  - means that we can detect one second on 3 billion of years

Fountain clock at LNE-SYRTE /FR

Metrology of time and frequency

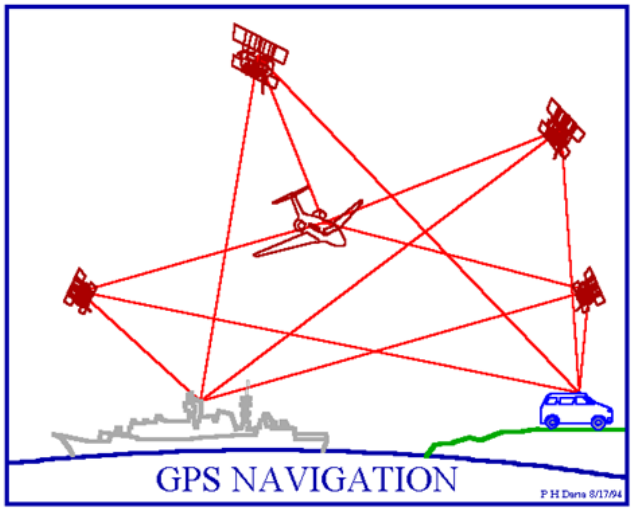
- progress on clocks implies progress in time transfer, consequently on positioning and navigation
  - permit a positioning with an accuracy at the best level of less than 1 cm.
- This allows numerous applications

  Main difficulty is the synchronisation between satellite and receiver's clocks

  1 µs corresponds to an difference of 300 m in term of position
- At the present time new instrumentation, new technologies developed with GPS system, GLONASS

  Europe : in the future with Galileo

other applications of positioning - navigation



- synchronisation and localisation
  - in telecommunication (spatial, mobile phone,..)
  - for energy transport
  - for space agency
  - public transport : localisation of car, bus,
  - localisation of airplane
- migration of wild animals, to learn about their habits
- geodesy, surveillance of Earth : mountains, earthquakes, continent drift
- transport,

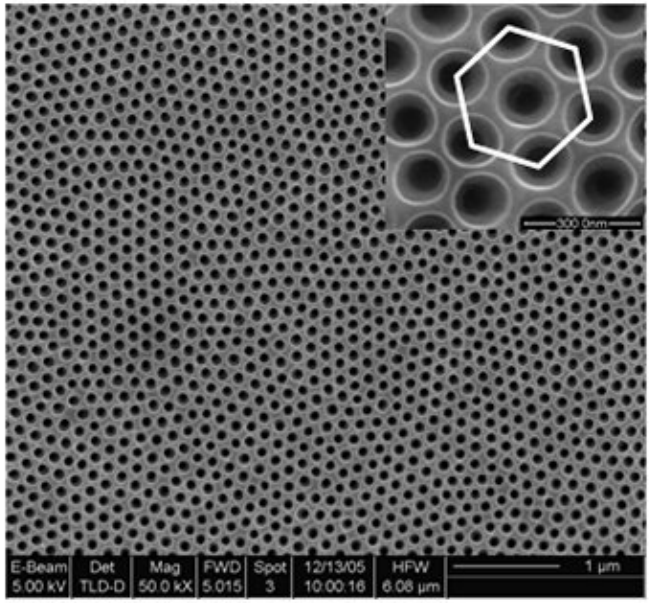
road transport

- Two main issues
  - the vehicles used : car, bus, trucks, …
  - road infrastructure
- Vehicles : Car, bus, trucks
  - using more and more electronics
  - surveillance of pollutant emission
  - mechanical developments, and hybrid engine
- road infrastructure
  - bridge, tunnels,
  - quality of road
  - security and safety

road transport - vehicles

- mechanics
  - not so far, car was being run it
  - manufacturing of motor, car structure, needed mechanical adjustments
  - progress on dimensional metrology permit to get a better reliable vehicles
  - accuracy from 10 µm down to 50 - 100 nm on gauge blocks (standards to calibrate mechanical « elements »
  - new materials needed to get « light » vehicles
- micro & nano-electronics
  - development of new technologies (more components in smaller space)
  - characterisation of materials, better knowledge of the behaviour, capabilities

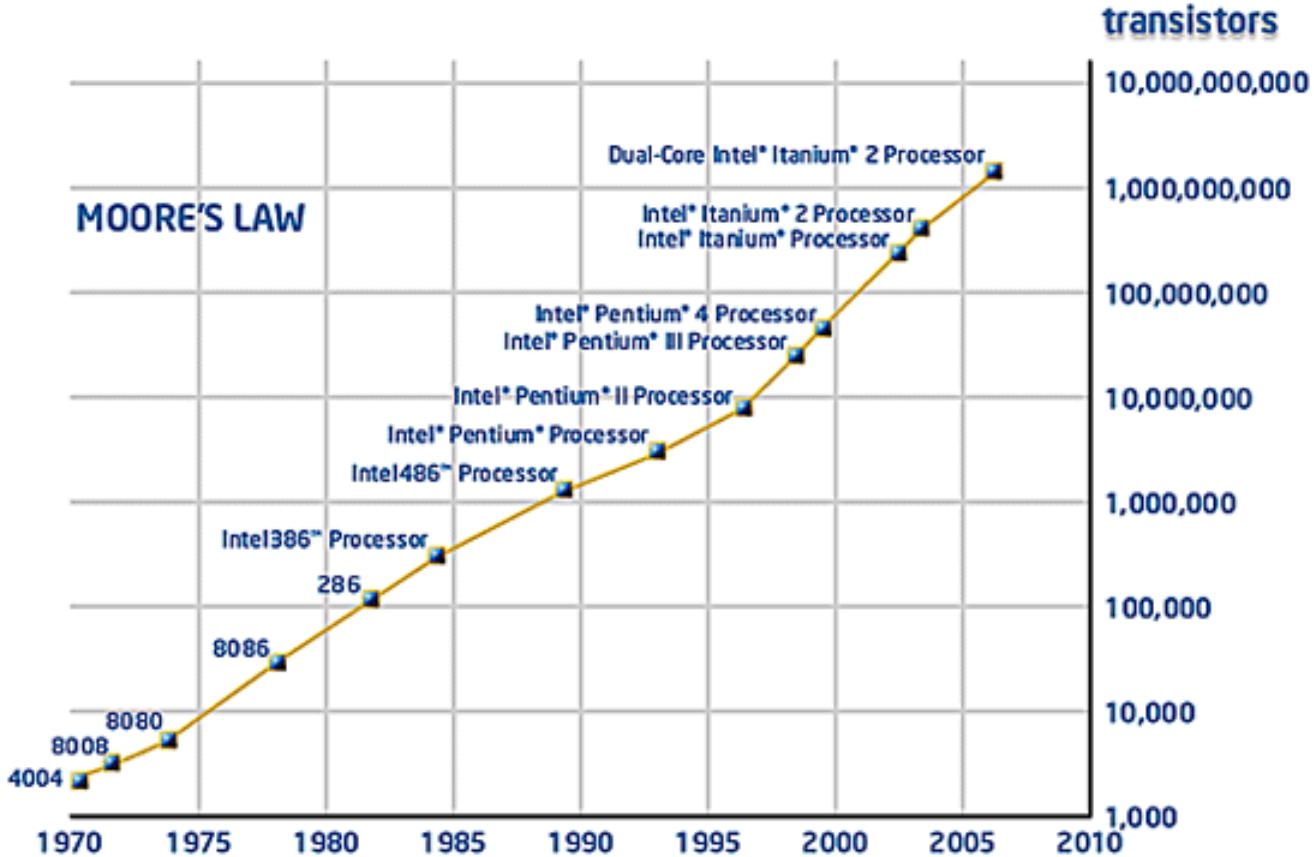
micro & nano-electronics



- Moore Law / Conjecture
  - empiric law to follow the evolution of computer, taking into account evolution on semi-conductor evolution
  - true up to 2015 ?
  - Silicon substrat (wafer) used in electronic industries to manufacture components (more than 10 000 patterns on 20 layers)
  - application in optics, electronics, mechanics for telecommunication, energy, transport, …
- micro-electronic industries
  - to increase constantly the possible data capacity of electronic devices

micro & nano-electronics

- in 1971, a processor in computer was composed of about 2300 transistors
- in 2003, it was composed of around more than 1 billion of transistors ...

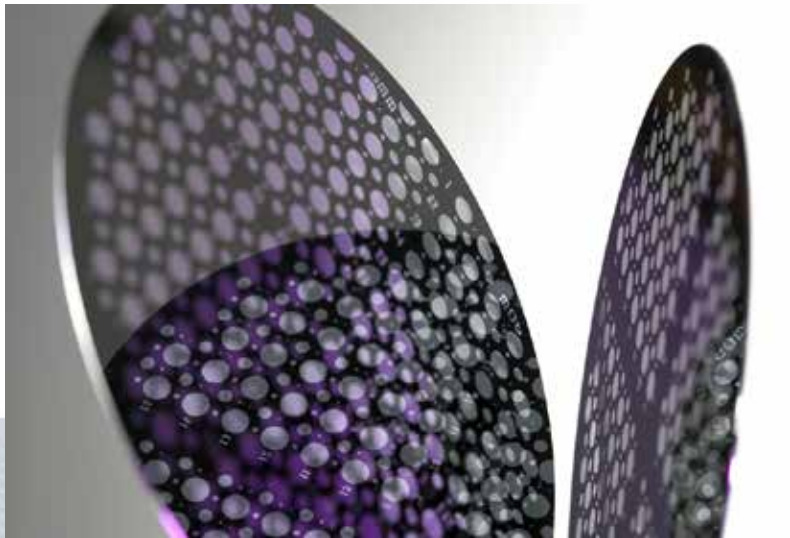


micro & nano-electronics

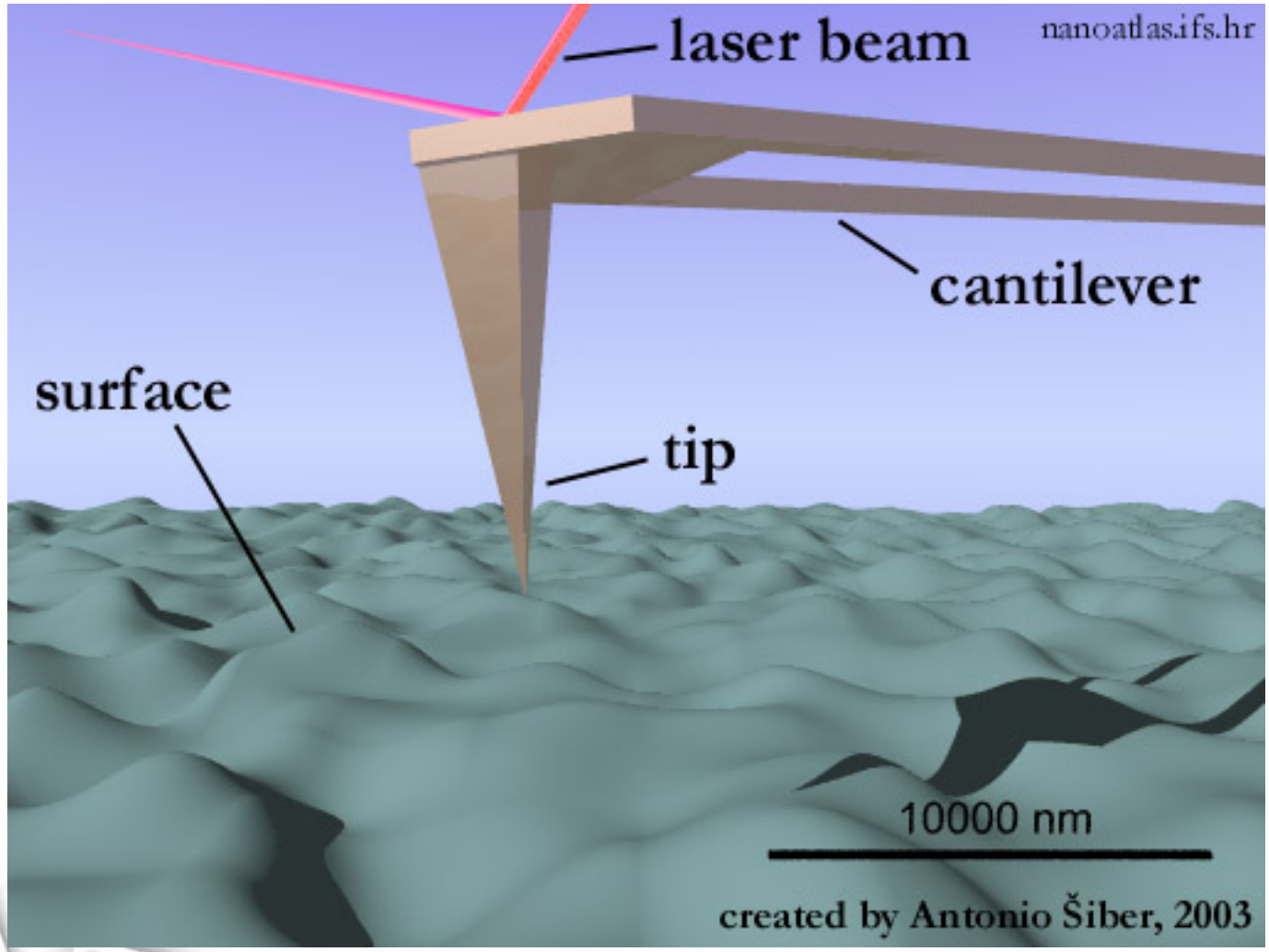
- Metrology to answer to
  - accuracy of measurement on such small devices
  - for all the innovation chain from R&D to nano-object manufacturing
  - to the needs of specific instrumentation
    - to link and find the correlation between dimensional measurement and new physical properties of this materials
    - to be able to measure at the nanometre level, with a good reproducibility
    - reliable measurements

important in the manufacturing chain

for quality of the product



Atomic Force Microscopy



transport

- challenges
  - seems that no new equipment without micro-nanoelectronic devices
  - new architecture concept for electronics
  - go to « more than Moore law », new technologies
  - molecular electronics
  - power sensor, magnetic circuit
  - information technology
- Metrology to be present to ensure reliable measurements and comparability in these new devices

- Road Infrastructure example of bridge

  Viaduct of Millau

  (Tarn valley)

- cable stayed bridge
  - length : 2460 m
  - high : 343 m
  - width : 32 m
  - stay : 154

concentration of know-how
& high performance
instrumentation
- to built
- to the daily surveillance

road infrastructure

making-up

- to pilot at milli-metric level the making-up of the bridge
  - drop by translation in the the empty space elements of the bridge (translator)
  - speed of 9 m/ h
  - traceable measurements needed using GPS, laser interferometry, each drop being guiding by GPS and laser
- stay
  - each stay constituted of 45 to 91 monotorons (diameter of 150 mm²)
  - should support a force of 12,5 MN to 25 MN

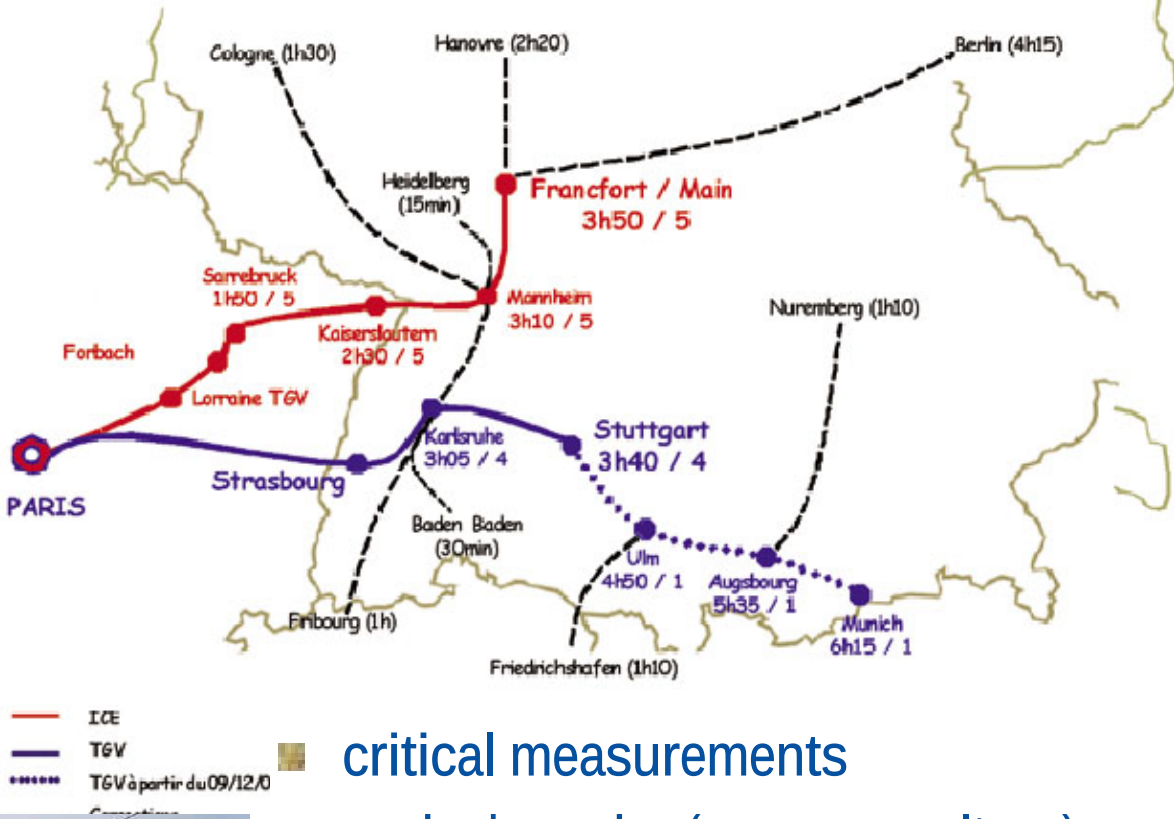
road infrastructure

- bridge on constant surveillance
  - equipped with a huge numbers of sensors
  - to detect all the different movements of the bridge
  - to measure the daily wearing (in particular stays)
  - anemometer, accelerometer, temperature sensor, inclinometer, optical traction sensor
    - to detect bridge movement at the level of 0,001 mm

- to look at the behaviour of the viaduct when strong wind
- to control random oscillations which can affect the metallic structure (accelerometer)

railways, ….

- High speed train
  - infrastructure adapted to high speed (tunnel, bridge, tracks)
  - catenaries with high voltage, strong mechanical constraints,
  - information transmission ground-train



- critical measurements
  - in dynamics (pressure, voltage)
  - mechanics (force, torque, catenary, tracks, ..)
  - high voltage (engine, catenary, transport of energy)
  - energy consumption (linked to the mechanical stability)

"*When dealing with numerical data, approximately right is better than precisely wrong*."

-

Carl G. Thor

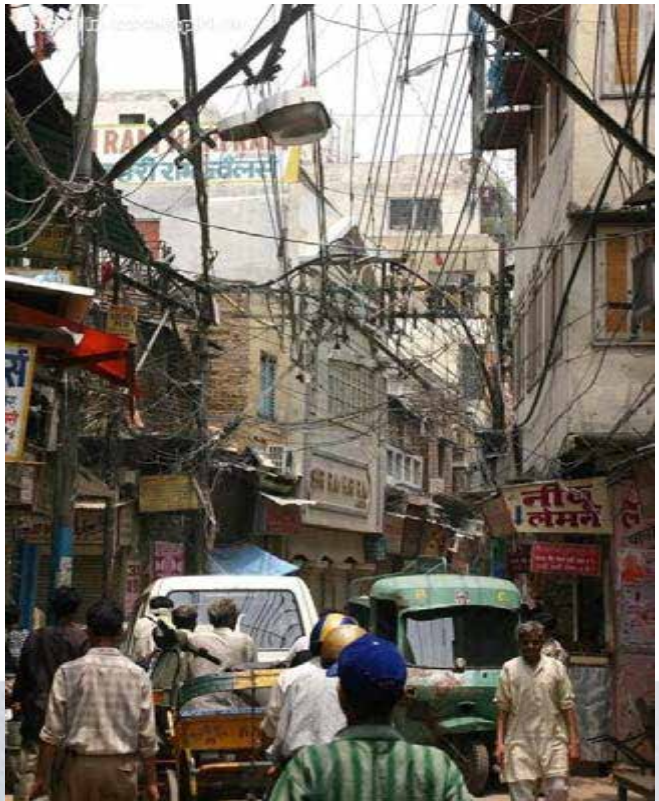
Metrology : to be as accurately right as possible

energy

- Society will face big challenges in this area
  - to find new and sustainable kind of energies (solar, photovoltaic, geothermal energy, nuclear new generation, from biomass, …)
  - to improve energy efficiency
    - to reduce the greenhouse effect and to allow a better monitoring of the climate
    - to face economic situation and the diminution of Earth fossil resources
    - to have a better “consumption”
  - to improve the energy transport and storage

smart grids

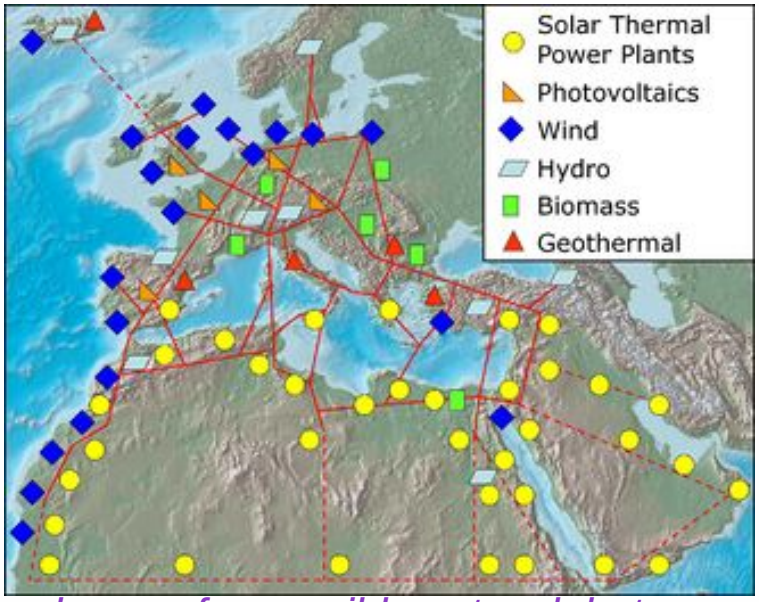
- an example for electricity transport and distribution
  - system able to integrate in an “intelligent way”, the actions done by consumers / producers / users
  - to maintain the quality of delivered power and energy
    - communication systems (production, control of distribution, ..)
    - smart “power-meter”, able to exchange information with the network
  - to be able to store energy with the minimum energy losses
  - to provide a more secure network
  - to reduce cost, by improving the energy efficiency



smart grids

metrology objectives

- to develop metrological tools for manufacturers, operators / distributors
  - to control and make a surveillance of energy delivered in the electricity network
  - to improve the reliability and safety by integration of components
    - phase-meter
    - smart counter
    - portable system to measure the quality on the mart grid
    - development of modelling tools
    - comparability between countries essential



scheme of a possible network between Europe, North Africa and Middle-East countries

energy efficiency

- lightning used around 20 % of energy
  - reduction of the total energy related to lightning is essential
  - reduction of the most consumable energy
  - alternative is the development of LED and OLED (Light Emitting Diode)
    - security link to this new light (retinal perception, power, ...)
    - efficiency and quality of the light source
    - visual perception
      - ✗ new photometric and radiometric references
      - ✗ definition of pertinent parameter to qualify this kind of sources
      - ✗ comparability between countries essential

renewable energy

- Solar energy
  - photovoltaic energy
  - thermal solar energy
- windmill energy
- biomass
- geothermal energy
- sea / ocean / hydraulic energy

L still expensive, and efficiency to be improved / J clean

J a few hundred km² of surface in desert can satisfy energetic needs of the planet / L need sun!

J transform mechanic energy in electricity, good energetic efficiency / L noisy, need space

J new energy / L take care that spent energy not higher that production

J clean, natural / L underground pressure can have an impact on seismic activity

production of energy

- Solar energy
  - photovoltaic energy
    - metrological qualification and certification of module cells & photovoltaic systems. Need calibration and conformity assessment on a wide number of criteria : optical (radiation, spectral sensitivity), electrical, thermal and mechanical
  - thermal solar energy
    - measurement of thermal absorption of materials used
- biomass
  - characterisation of new gas and fuel from biomass
    - energetic power (taking into account the level of water vapour)
    - production of CO_2 (after combustion)

production and transport of energy

- Windmill energy
  - exploring new sites (inshore and offshore) with the highest productivity
  - anemometry (air flow measurement, high speed)
  - dynamic measurements and modelling (e.g. characterisation of turbulence)
- Thermal energy
  - improvement of energy efficiency
  - to raise the temperature to increase the productivity
  - new heat resistant materials
  - better knowledge of thermo-physical properties (conductivity, diffusivity, emissivity, thermal dilatation,...)
- Liquefied Natural Gas
  - measurement of volume, mass and calorific capacity
  - specific flowmeter (laser Doppler velocity)

Metrology down to Earth : what is it good for ?

- Future ?
  - new technologies, new sensors
    - for control, piloting
    - treatment and transport of information (micro, nano, sub-nano electronic, telecommunication)
    - more and more “small” objects to use, to measure (at the atom levels)
    - more and more fast (transfer and transport of information)

      small time and space scale

- Metrology ?
  - to control complex nanostructure and properties of new systems
  - modelling interaction object with environments
  - multi - disciplinary

- Go back to galaxy
  - solar system (Earth – Sun)
  - stars – galaxy
  - exoplanet – inter galaxy
  - cosmic sensors
  - plasma detectors
  - low energy particle sensor

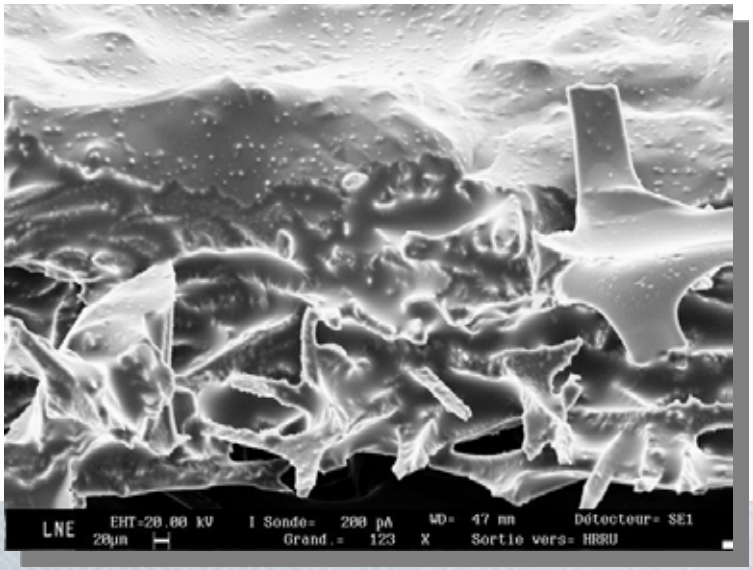
  studies of cosmic radiation, sun wind, ..
  - RF and microwave measurement

  to “listen” the planets and stars
  - interferometer, IR radiometer, for

  temperature measurement, and detection of specific materials …

Conclusion

- why metrology is good for ?
  - metrology strengthens the commerce and trade, if international comparability is established
  - metrology strengthens regulation
  - is a support to industry : innovation and technological developments
  - metrology is essential element in the quality of life



Conclusion

- why metrology is good for ?
  - Environment : measurement of pollutants in air, water, soils, measurement of climate change, …
  - Health : diagnosis, medical devices, medical imagery, therapy,
  - Security : cryptography, scanner,
  - Transport : road, railways, aircraft, shipping
  - Spatial and astronomy : positioning, telecom
  - Technologies : new materials, bio-tech, nanotechnologies,

Jahre genau

LNE
Le progrès, une passion à partager

in 1963, president Charles de Gaulle and chancellor Konrad Adenauer signed the Élysée treaty to have a real daily German-French co-operation.

In the frame of the European metrology association (Euromet, now Euramet), relationships between Germany and France have been continuously strengthened and consolidated for more than 20 years

On behalf of Jean-Luc Laurent, Managing Director of LNE, I wish the best to PTB in their mission for metrology, and for many more years....

« In all things we should considered the end…”

Jean de la Fontaine

Thank you for you attention