Time keeping and distribution state-of-the-art

Training on Time and Frequency
Dissemination In Packet – Oriented Networks
DMDM Beograd, 19/20 November 2015

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Outline

Introduction

- History of time keeping
- Present developments
- UTC and European NMI practices
- Time (and frequency) dissemination options
- Time and frequency traceability
- Time and frequency laboratory
- Participants view on their development

Introduction

What does it mean to "keep" time?

- who's time are we actually keeping?
- what is UTC?
- what is GPS time?
- how good are atomic clocks?
- why do we need to keep it well?
- who needs it?

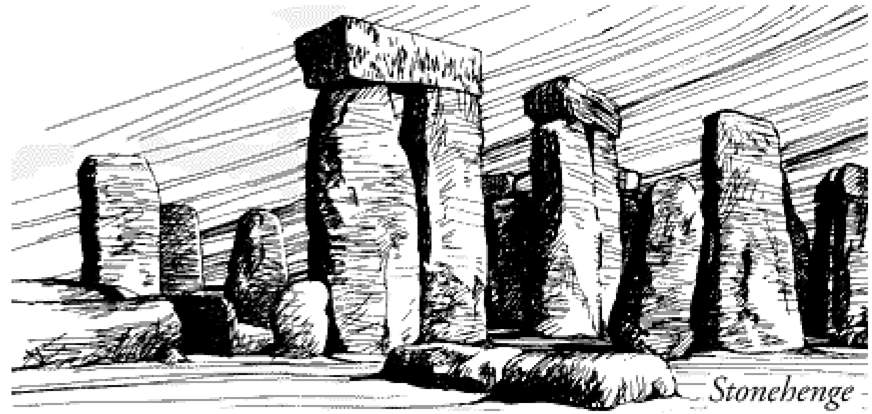
Introduction

What is the *best* clock?

- Quartz: inaccurate and drifts
- Rubidium vapor: more stable but still drifts
- Cesium beam: better still and no drift
- Hydrogen maser: most stable, (very) small drift
- UTC itself is “average” of 452 clocks (322)
- Exotic fountain, ion, optical clocks
- No one best clock, no *perfect time*

History of time keeping*

Ancient calendars



- Celestial bodies
- Ice age hunters (20 ky ago)
- Sumerians (5 ky ago: 30 d/“m“, 12 “h“, 30 „m“)
- Egyptians (3100 BCE : 365 d/y)
- Babylonians (2000 BCE: 29 ↔ 30 d in 12 m)
- Mayans, Aztecs (2600 BCE to 1500 BCE: 365 d calendars)

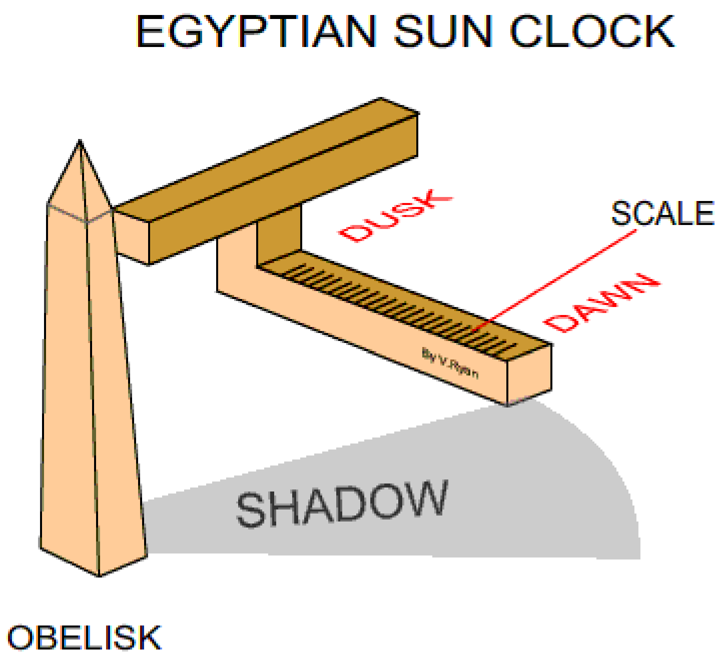
* NIST: A Walk Through Time (http://www.nist.gov/pml/general/time/)

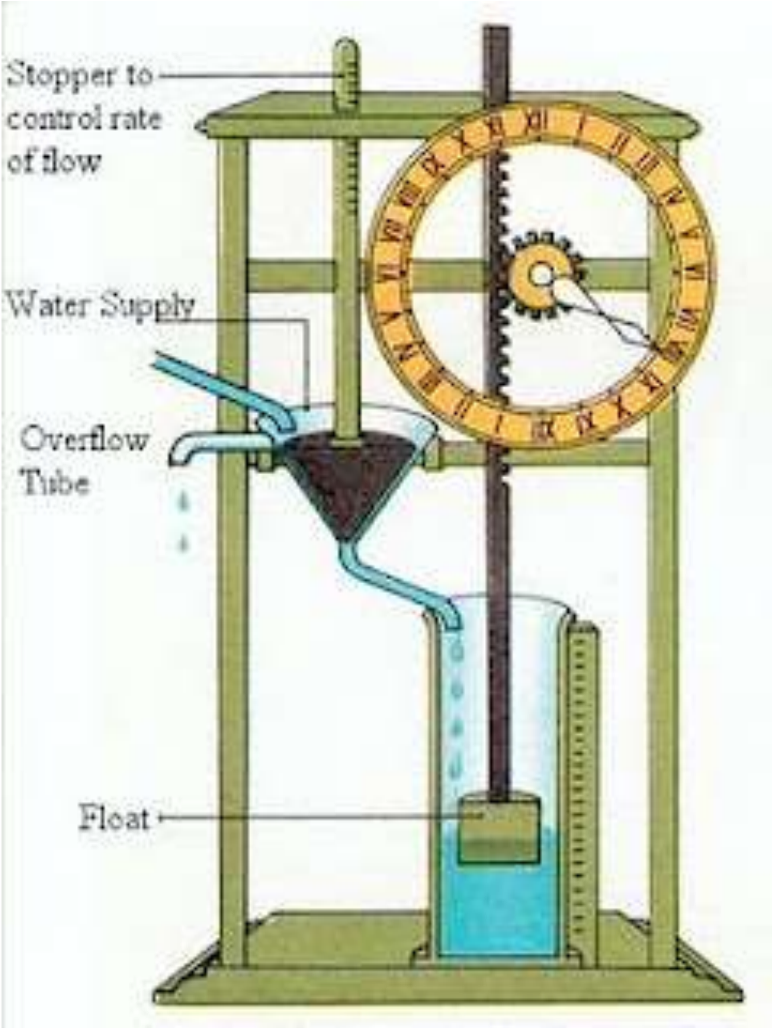
History of time keeping

EURAMET

Early clocks

- Sun clocks
- Water clocks (no celestial bodies) (1500 BCE to 1088 CE) (u = 0.02)

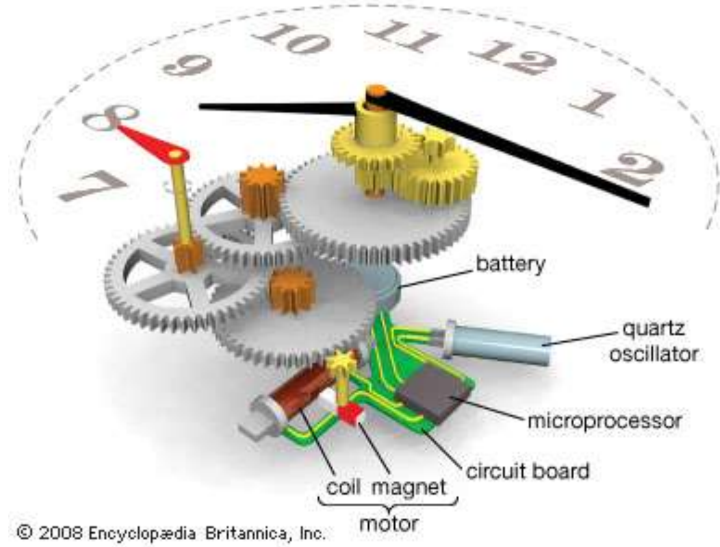




History of time keeping

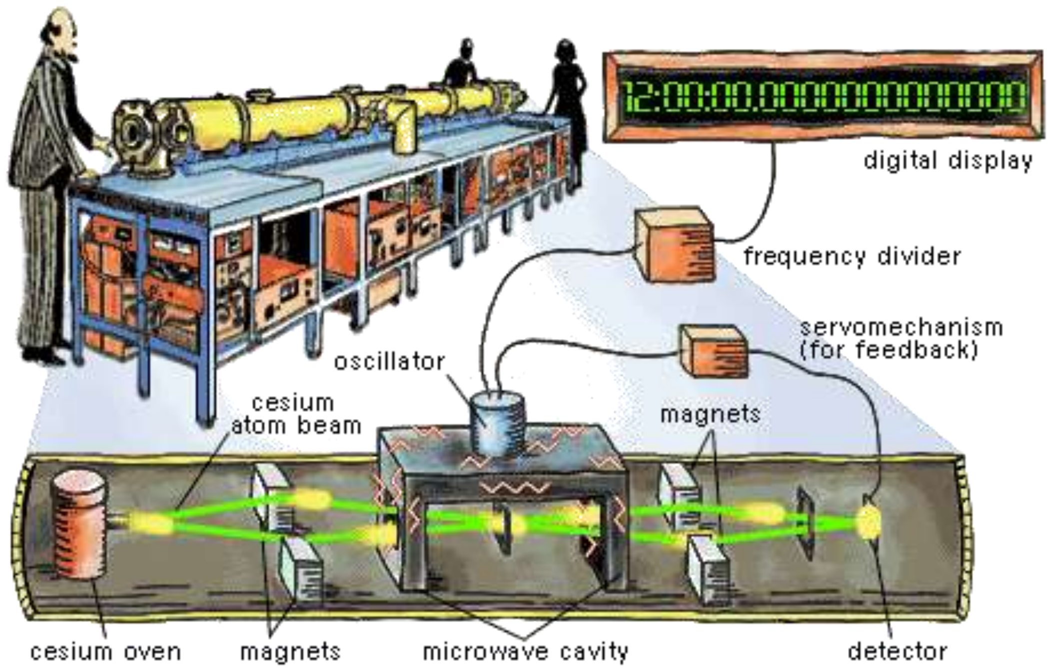
A revolution in timekeeping

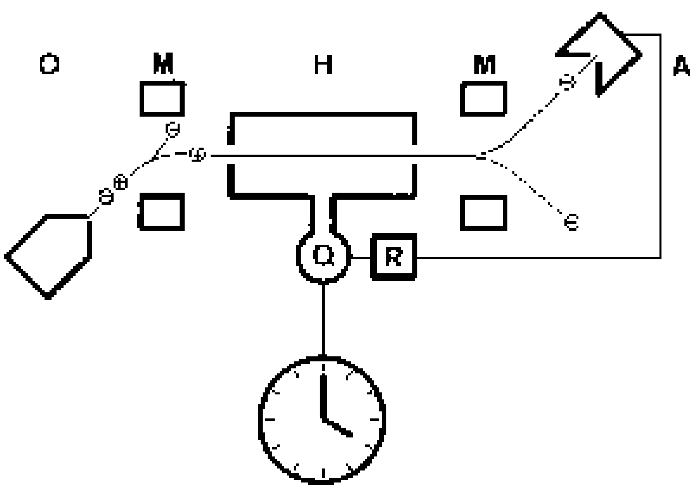
- Mechanical clocks
- Pendulum clocks
  - Huygens 1656 (u = 7.10^{-4})
  - Graham 1721 (u = 1.10^{-5})
  - Harrison 1761 (u = 2.10^{-6} on ship)
  - Riefler 1889 (u = 1.10^{-7} s/d)
  - Shortt 1921 (u = 3.10^{-8})
- Quartz clocks 1929 (u = 1.10^{-7} ... 2.10^{-10})



History of time keeping

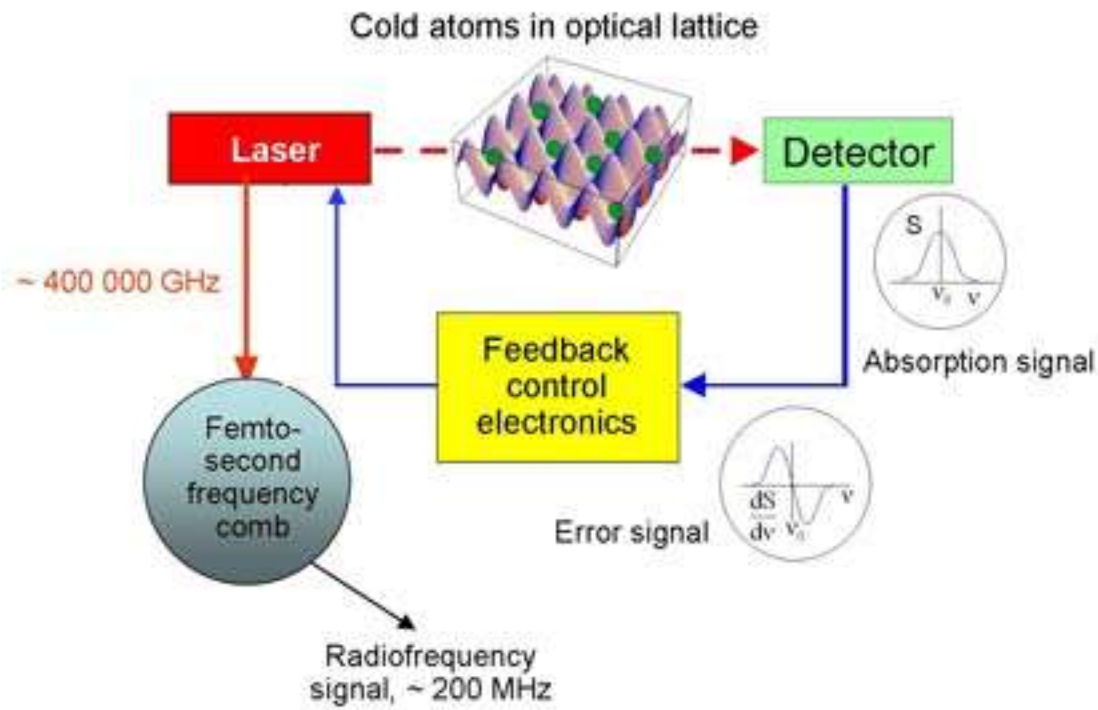
- The atomic age
  - Resonance of atoms
  - Rubidium clock
  - Caesium clock
  - Hydrogen maser





Present developments

- Optical clocks
  - stability greater than a tenth of a second over the age of the universe



- All other things being equal, the stability of an atomic clock is proportional to its operating frequency

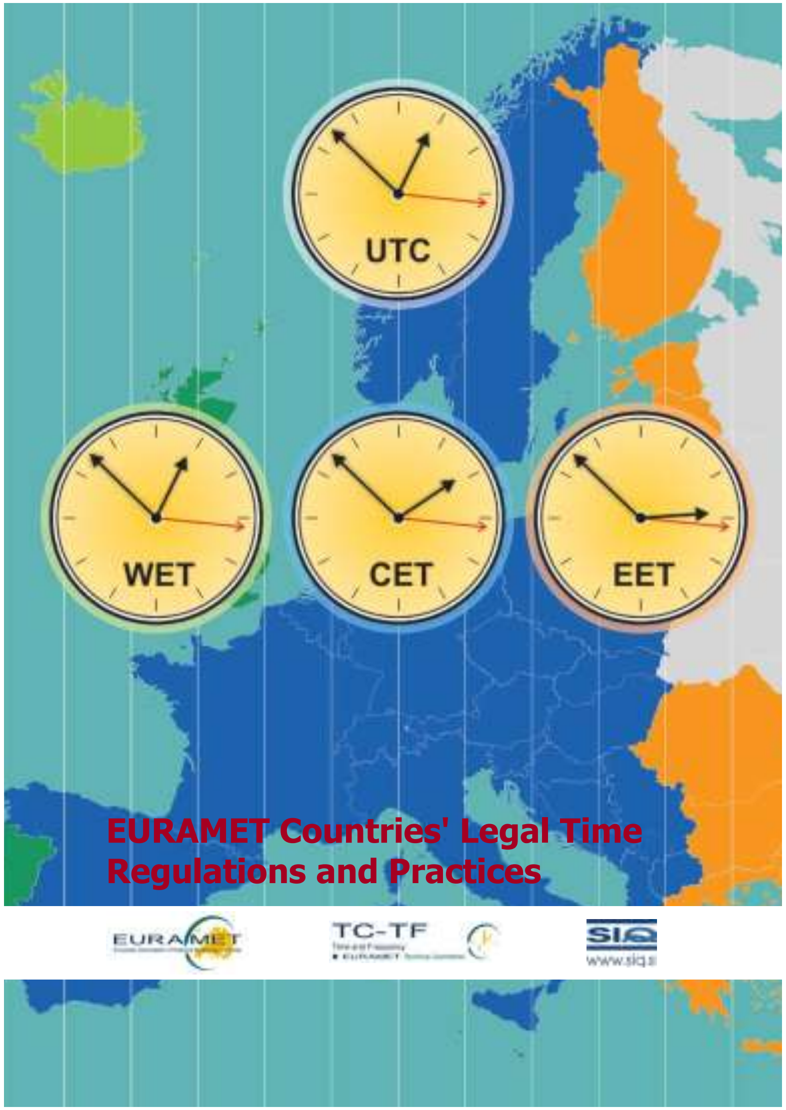
Present developments

- Where do we need such time accuracy / frequency stability
  - Satelite navigation systems
  - Telecommunications
  - High speed mobile networks
  - SI unit realisation
  - (basic) Science
  - Deep space exploration

- And not so much accuracy
  - Financial transactions
  - (almost everywhere else)

UTC and European NMI practices

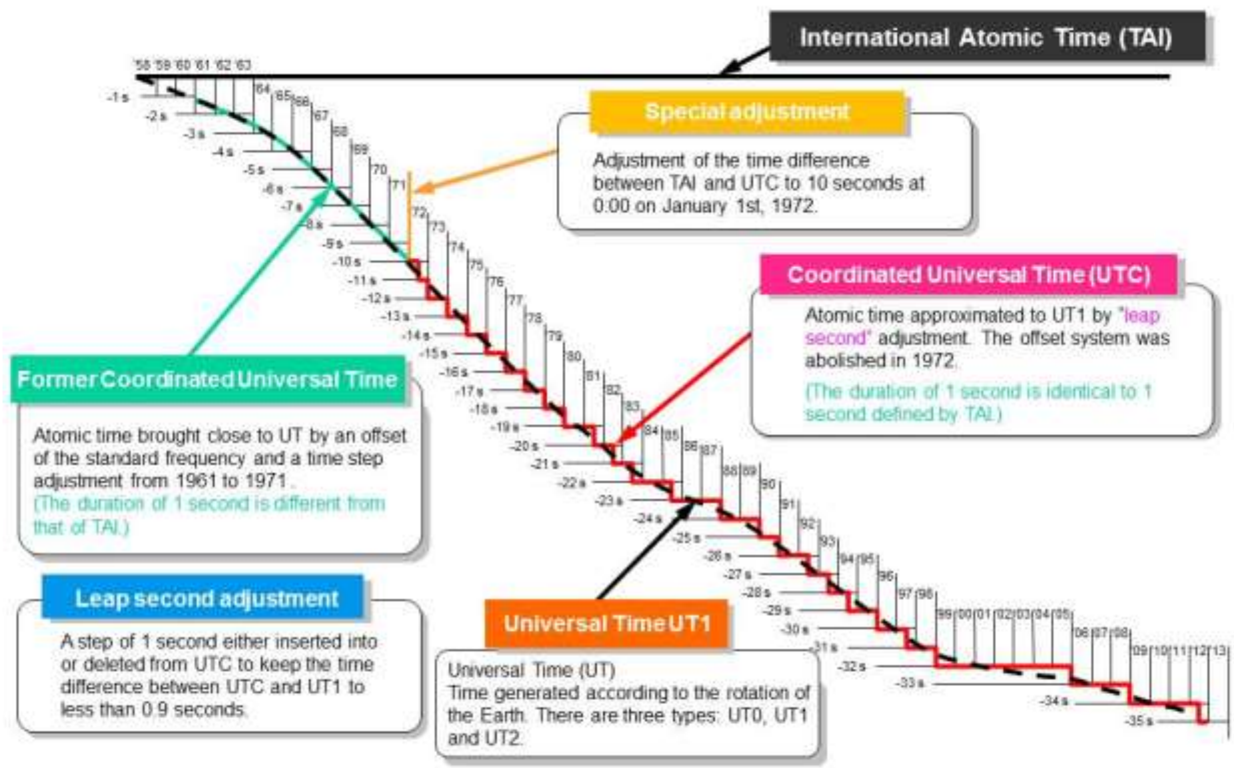
- EURAMET t&f booklet*
  - Europe t&f community
  - Time zones
  - Legal time
  - Legislation
  - Dissemination
    - radio signals
    - telephone signals
    - NTP servers
    - other means
  - Traceability
  - Other issues



* https://www.euramet.org/publications-media-centre/documents-and-publications/

UTC and European NMI practices

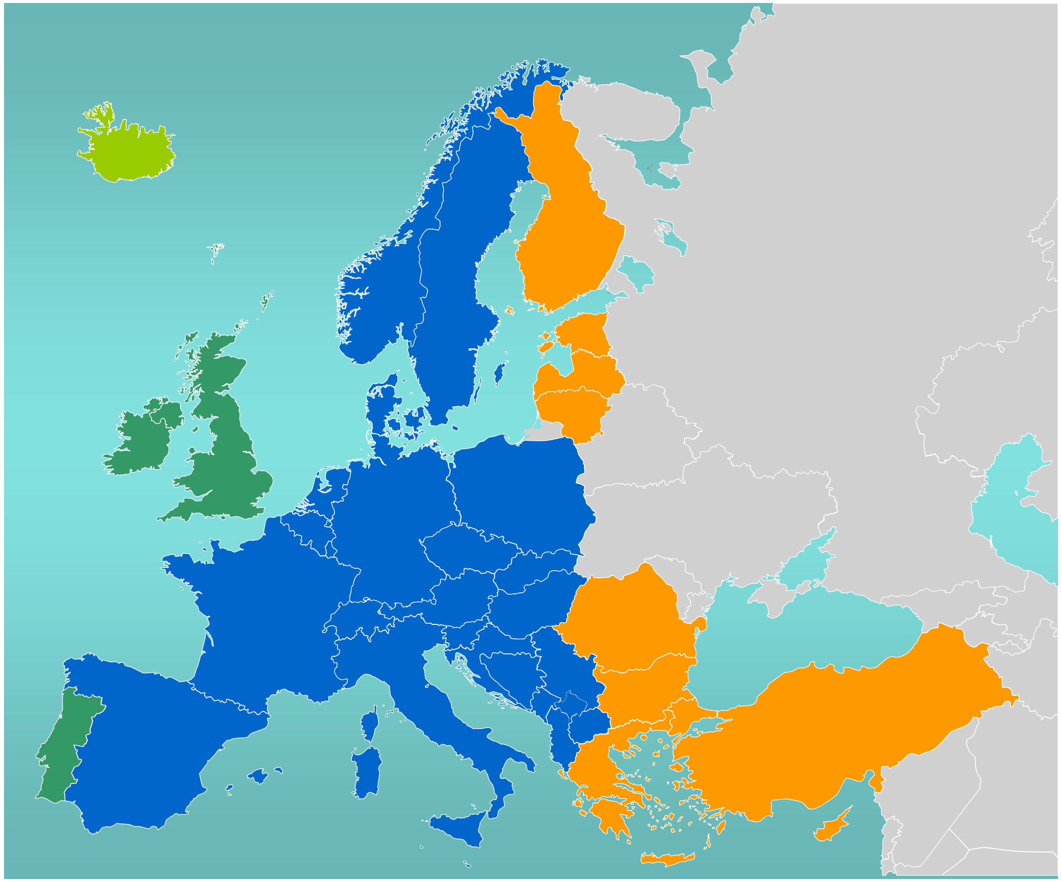
- UTC time (Universal Time Coordinated
- Based on the best clocks data of countries participating in the Circular-T comparison (BIPM).
- BIPM calculates the actual international time scale (TAI→UTC) based on this data.
- Official or legal time is defined by particular country legislation.



UTC and European NMI practices

EURAMET

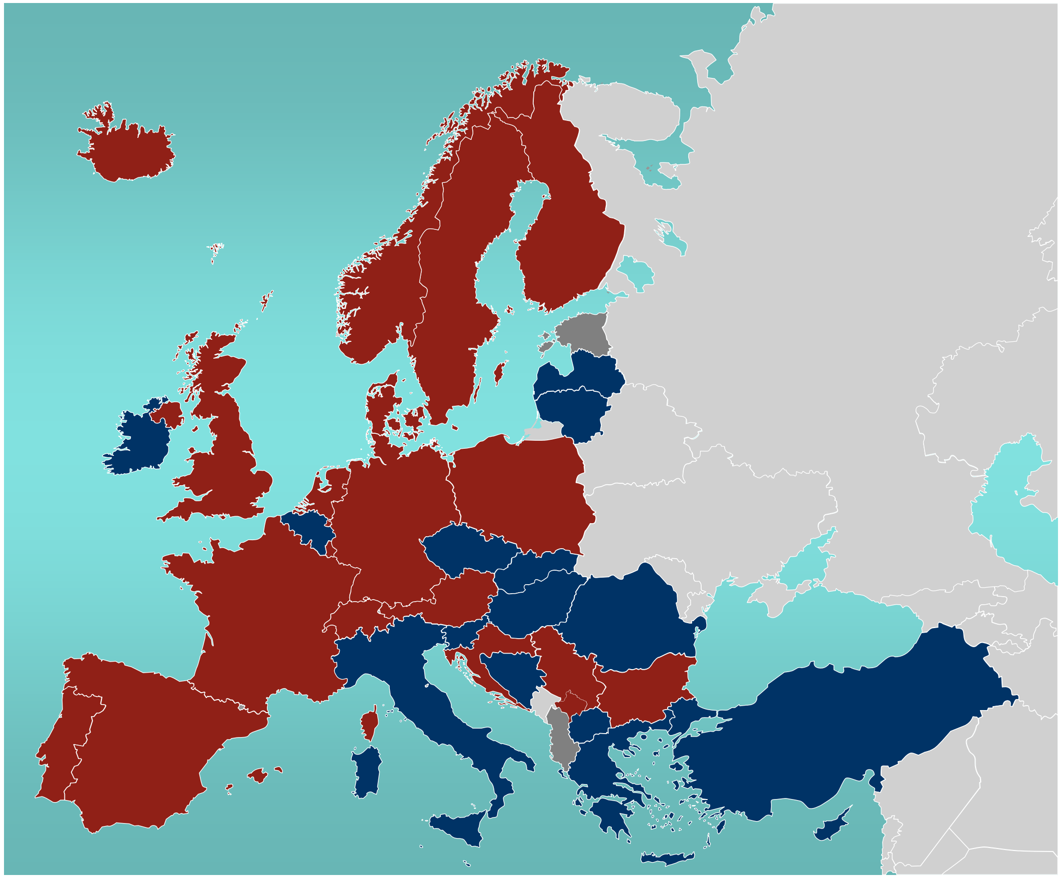
- Time zones



- UTC (WET)
- UTC (WET), BST (WEST) = UTC + 1 h during summertime
- CET (UTC + 1 h), CEST (UTC + 2 h) during summertime
- EET (UTC + 2 h), EEST (UTC + 3 h) during summertime

UTC and European NMI practices

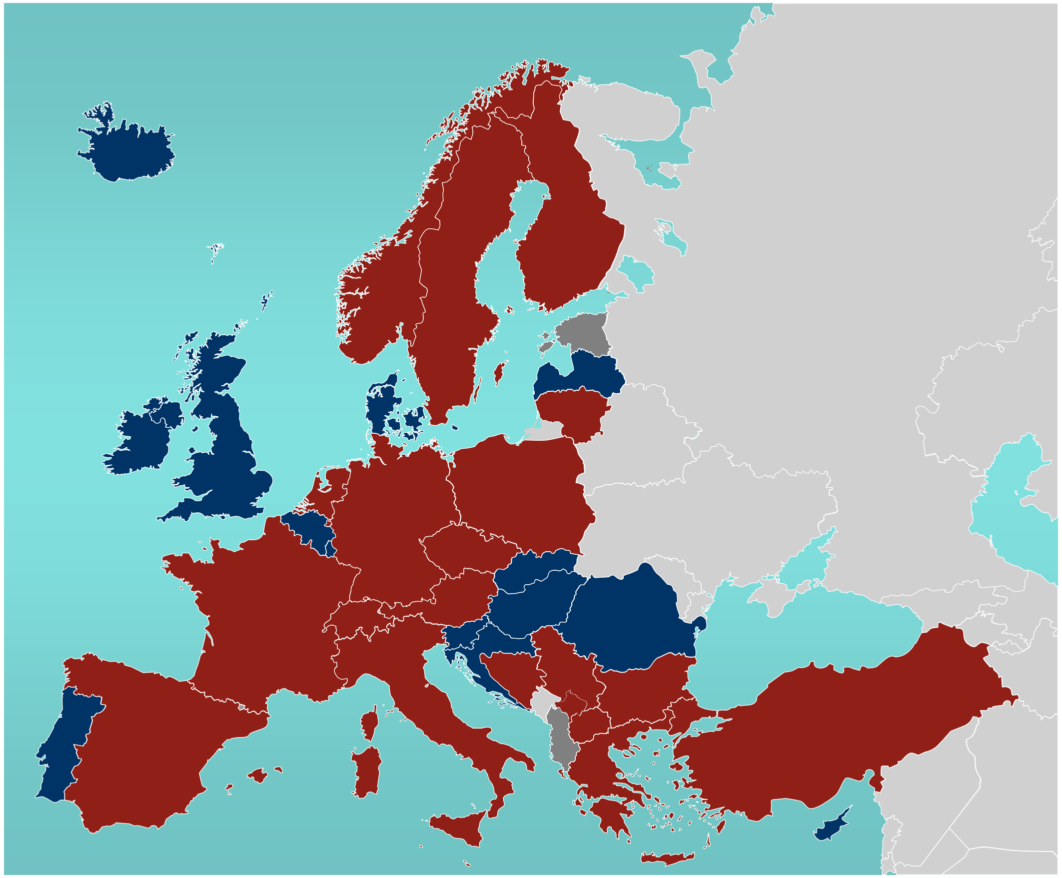
- Countries in the EURAMET region where legal time is defined by legislation



- Countries where legal time is defined by legislation
- Countries without legal definition of their time

UTC and European NMI practices

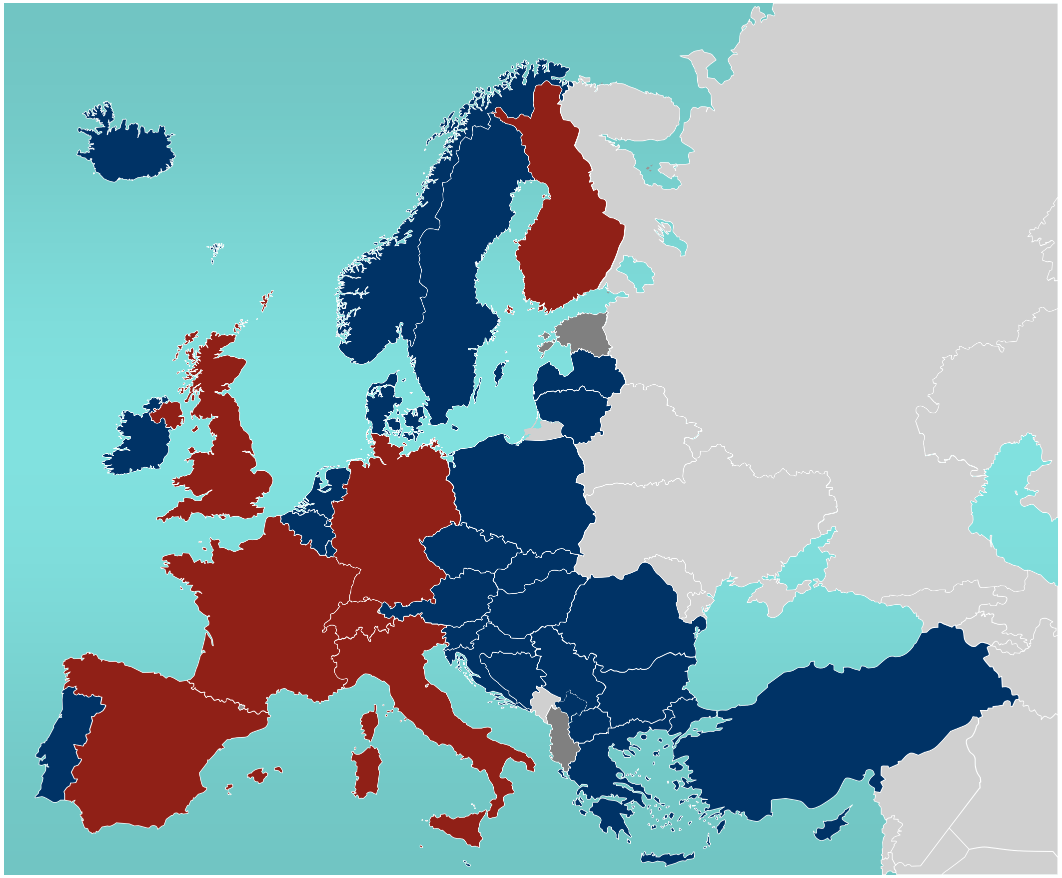
- Countries in the EURAMET in which the NMI or DI is responsible for legal time dissemination



● Countries where NMI or DI is responsible for legal time dissemination

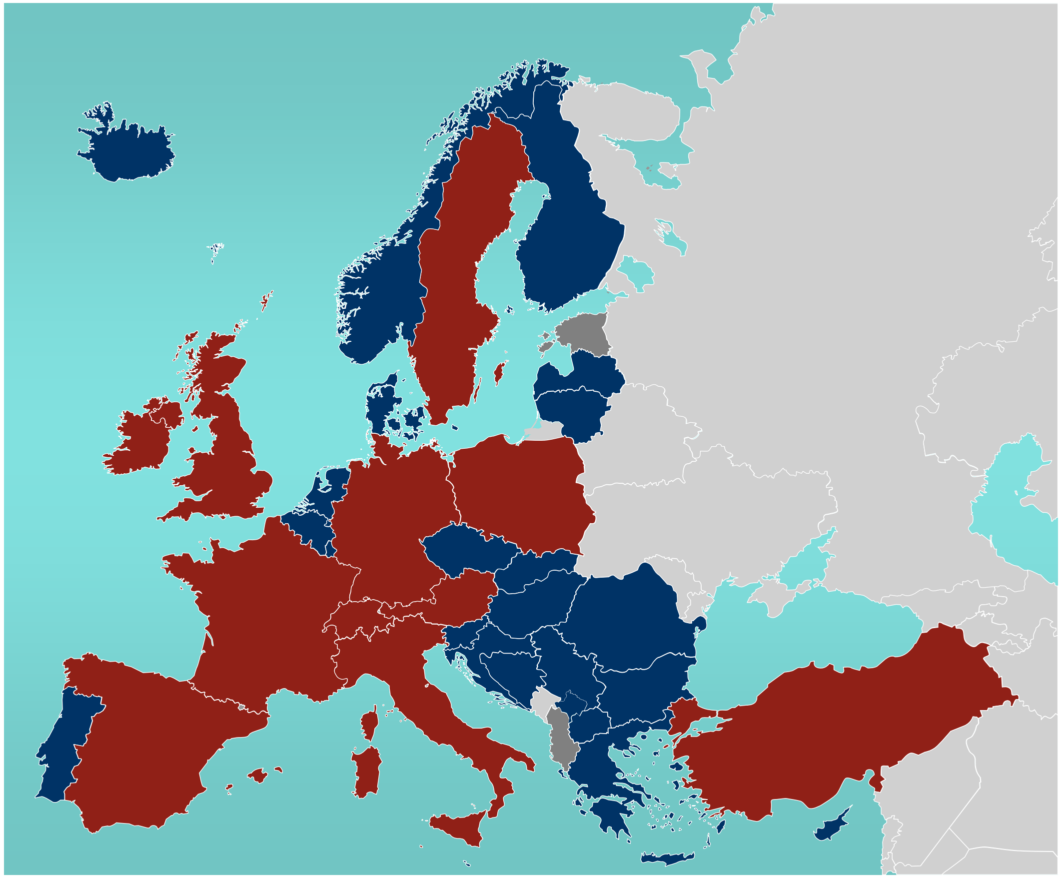
UTC and European NMI practices

- Legal time dissemination via radio signals
  - DCF 77



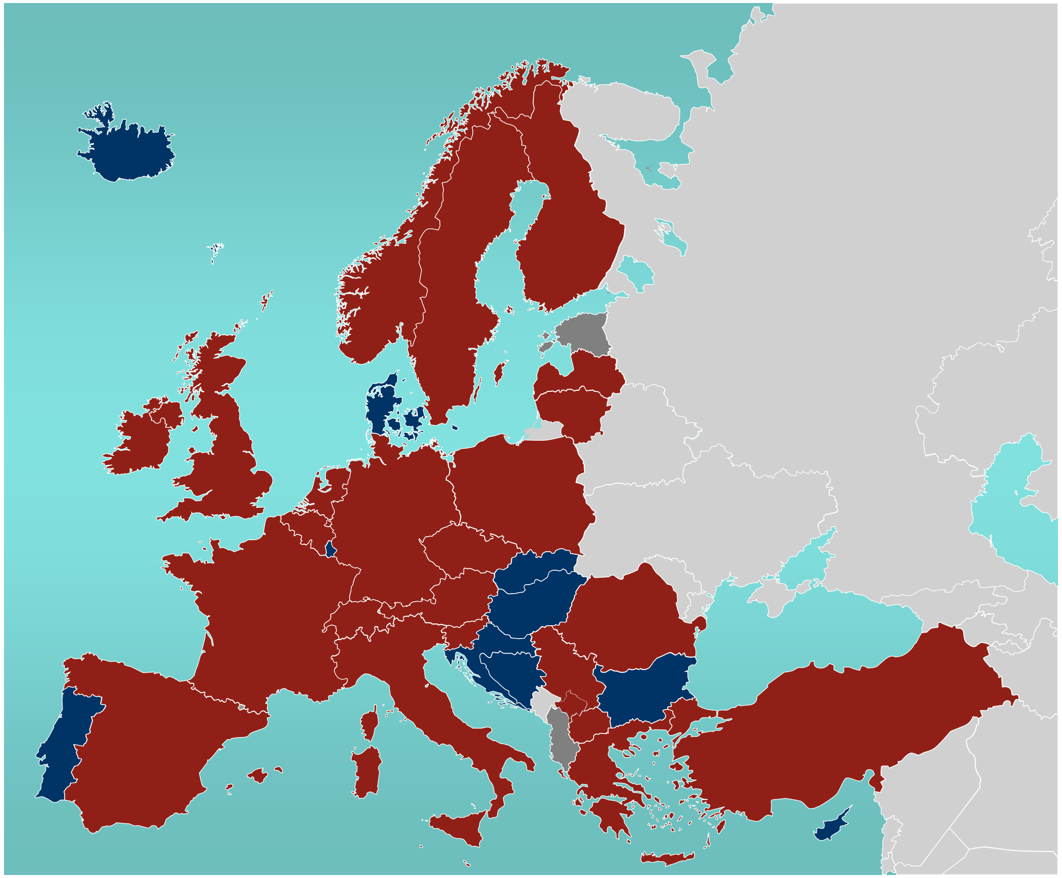
UTC and European NMI practices

- Legal time dissemination via telephone signals



UTC and European NMI practices

- Legal time dissemination using NTP servers

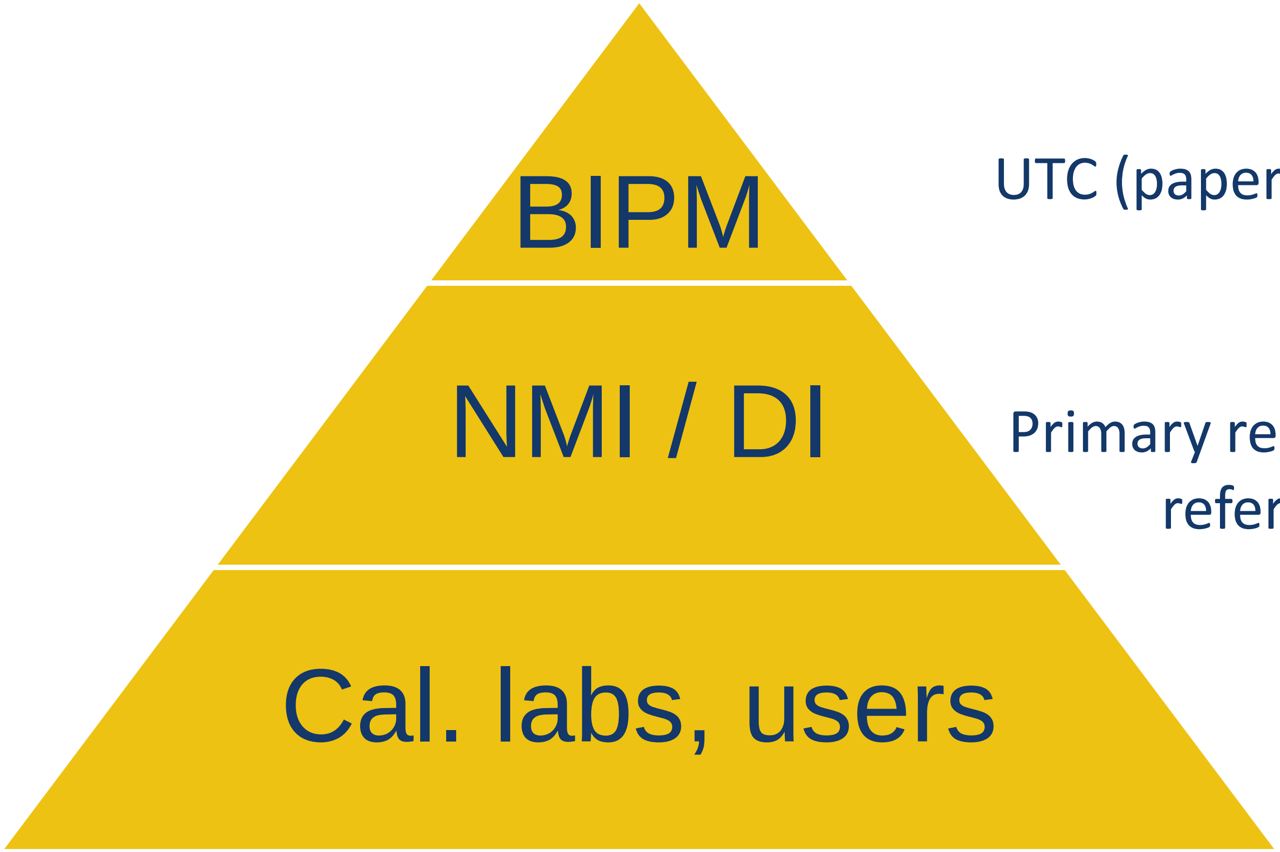


Time (and frequency) dissemination options

- Radio signals (5.5 µs) (2×10^{-12} rel. to UTC)
- TV signals (not useful due to digital emission delays)
- Telephone time services (few ms)
- Internet time services (few ms to few µs)
  - NTP : network time protocol
  - IRIG : inter-range instrumentation group
  - PTP : precision time protocol
- GPS common view (10 ns to 20 ns) (5×10^{-14} rel. to UTC)
- GPS signal via GPSDO (few ns) (5×10^{-14} rel. to UTC)
- Coax cables
- Optic cables
- ...

Time and frequency traceability

Definition of a SI second



UTC (paper time scale)

Primary realisations & reference clocks

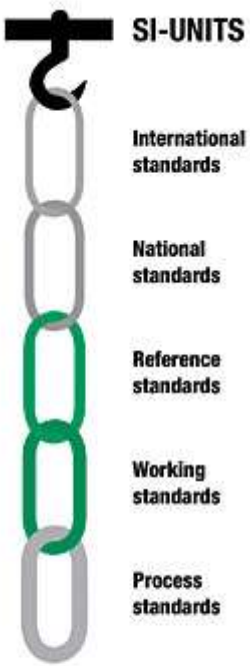
Working standards

Time and frequency traceability

- **Traceability defined:** The property of a result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

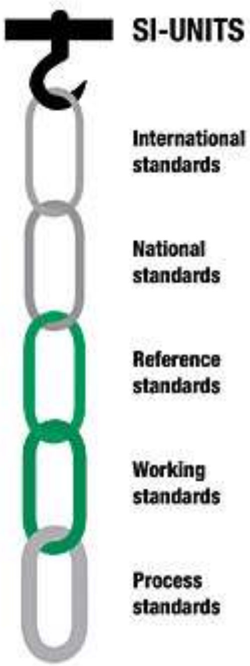
- The NMI is required to show traceability to the SI system (or to another NMI).

- The metrologists are required to complete traceability chain by stating their measurement uncertainty with respect to the reference (NMI or SI).



Time and frequency traceability

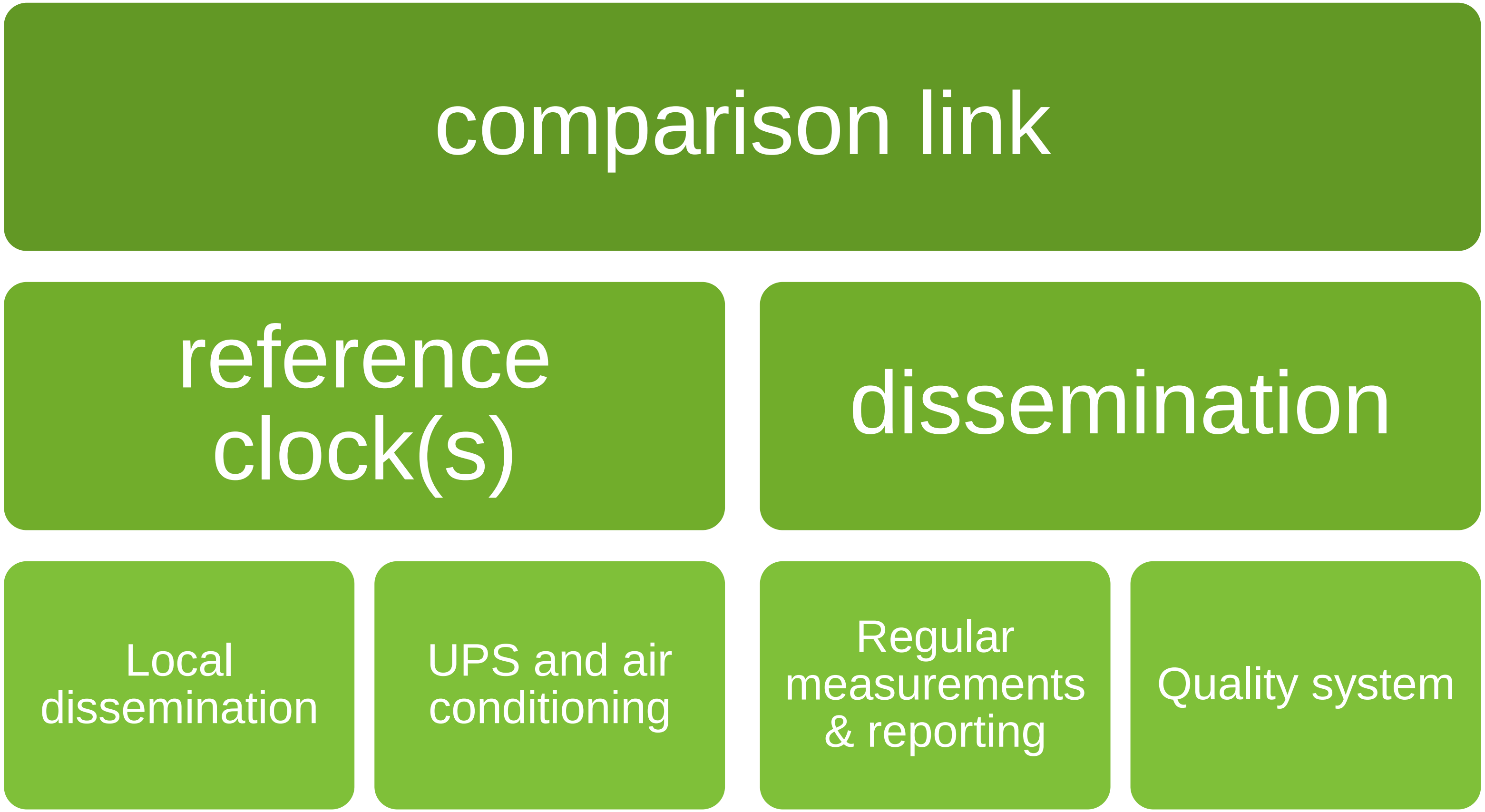
- **Is the Caesium clock traceable?**
- Is the GPSDO traceable?
- Is the GNSS receiver traceable?



☑ ☒ related to stated reference

☑ ☒ stated and documented uncertainty

Time and frequency laboratory



Time and frequency laboratory

Comparison link

- Circular-T (ultimate link to SI second)
- GSP Common view
- Two-way sattelite link
- Optical link
- Calibration
- ...

Time and frequency laboratory

Reference clock(s)

- Self built Caesium clock (NIST-F2, PTB-CSF2)
- (Ensemble of) Caesium clock(s) (5071A)
- Stand alone GPSDO*
  - using GNSS Comon view
  - using GNSS bulletin**
  - using regular calibration
- ...

* EURAMET Technical Guide: Guidelines on the use of GPS disciplined oscillators for frequency or time traceability (to be published)

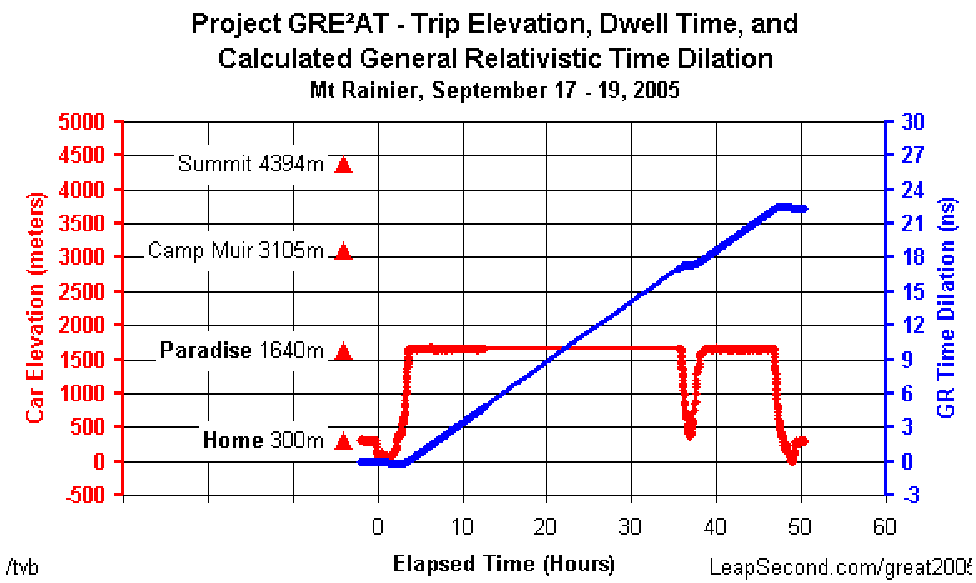
** (http://www.npl.co.uk/science-technology/time-frequency/)

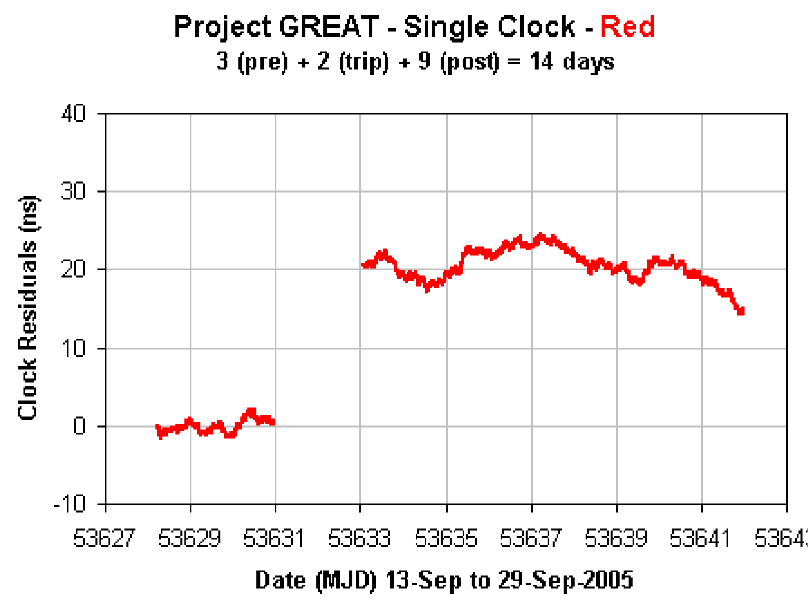
Time and frequency laboratory

Reference clock relativity effects

- Gravitational shift of $\Delta f/f \approx 1.09 \times 10^{-16}$ Hz/Hz/m.

  23.2 ns in two days at 1340 m height difference





* Tom van Baak: Extreme Amateur Timekeeping: From Harrison to Einstein, Pasadena, November 2013

Participants view on their development (as reported at the training)

NMI	Traceability	Dissemination	Equipment	TC-TF	CMC
NSAI	NPL (common view)	-	Fluke GPSDO (Rb)	yes	yes
BoM	UME (common view)	NTP	2×5071A hp GPS receiver	yes	no
HMI / IFS	-	-	-	-	-
BIM	BIPM (Circular-T)	-	5071A GPS receiver	yes/no	yes
MBM	BIPM (Circular-T)	NTP (plan)	OQ caesium GPS receiver	yes	no
IMBiH	BIPM (Circular-T)	NTP	2×5071A GPS receiver	yes	in 2016
DPM	-	-	-	-	no

Thank you for your attention!

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