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Working group on coordination of the development of advanced time and frequency transfer techniques

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Plan

Summarise current situation of clock and long distance comparison characteristics and discuss future prospects.

Limit to the highest performance clocks: Cs and Rb fountains, optical clocks which are (or are potential) secondary representations of the second.

Emphasis on frequency comparisons.

Frequency standards: current status – microwave clocks

Fountain clocks:

- several Cs fountains accuracy better than 10^{-15}
- best estimated accuracy 2×10^{-16}
- at least 1 Rb fountain similar characteristics
- best fountain stability 2×10^{-14} @ 1 s
- local comparisons achieve statistical uncertainties of 10^{-16} at 1 day

Frequency standards: current status – optical clocks

- Hg+ and Al+ single-ion clocks have estimated systematic uncertainties of 2×10^{-17}
- stabilities of 3×10^{-15} @ 1 s
- local comparisons achieve statistical uncertainties of 4×10^{-17} after a few hours
- several other optical clocks already rival the microwave standards and are in rapid evolution

Frequency standards: future prospects

- in addition to the single-ion clocks, the optical lattice clocks are evolving rapidly
- expect systematic uncertainties in the 10^{-18} range
- stability: depends on the ultra-stable laser oscillators –> into the 10^{-16} @ 1 s range

Transfer techniques: current status – operational methods

TWSTFT and GNSS

- **the mainstays of long-distance comparisons**
- TWSTFT stability ~ 2×10^{-15} @ 1 day
- GPS phase methods comparable
- stabilities continue to decrease at longer times

Transfer techniques: current status – operational methods

Local optical fibre links

- consider links carrying ultra-stable optical references
- in routine use for local and “semi-local” links, up to 10s of km
- demonstrations up to O(100 km): stability of 2x10-16 @ 1 s to below 10^{-18} @ 1 day

Transfer techniques: current status – operational methods

Transportable references

- require excellent stability and repeatability, not accuracy
- transportable Cs fountain
  - stability 10^{-13} @ 1 s
  - accuracy 7×10^{-16}
  - a primary standard

Transfer techniques: current status – experimental methods

T2L2 – time transfer by laser link

- was launched on Jason-2 in 2008
- expected stability in common view: 10^{-16} at 1 day
- degraded by on-board oscillator in non-common view

Transfer techniques: future prospects

TWSTFT chip rate increase and carrier phase

- stability ~ 10^{-16} at 1 day plausible

PHARAO/ACES

- launch in 2013
- on-board microwave link + clock ensemble: tool for long-distance clock comparisons
- intercontinental (non-common view) comparison design stability: 5×10^{-17} at 1 day

Transfer techniques: future prospects

Optical fibre links over continental distances

- need for repeaters
- suppose stability scales with sqrt distance
- estimate of stability for a 1000 km link:
  10^{-15} at 1 s, down to few 10^{-18} at 1 day

Transportable standards

- european space agencies supporting transportable optical frequency standard development (initially Sr lattice)

Discussion

Reliability/dead-time problem => we need long distance comparison methods which reach clock stability rapidly.

The current situation is not satisfactory.

Essential point for building up the international consensus which will be needed as part of a move to a new definition of the second.

Discussion

Optical fibre links hold the promise of very significantly improving frequency comparisons up to continental distances.

- not yet demonstrated at 1000 km
- much work remains
- technology choices
- practical and cost implications for fibre access

Discussion

For inter-continental comparisons satellite-based methods remain obligatory:

- TWSTFT chip rate/carrier phase
- T2L2 and follow-on
- PHARAO/ACES mission and micro-wave link follow-on

Discussion

Other considerations

- geoid uncertainty/fluctuations, at 10^{-17} (10 cm) level
- comparison method frequency accuracy limitations?

Proposed recommendations

- recommend vigorous development of optical fibre link methods for comparisons between optical clocks in support of a future change in the definition of the second
- recommend vigorous development of improved methods for intercontinental comparisons between optical clocks in support of a future change in the definition of the second, for example: TWSTFT chip rate increase and carrier phase, ACES MWL, T2L2.