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The CCTF Working Group on Advanced Time and Frequency Transfer Technology

Report to the 20th CCTF

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Terms of reference

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- to review the status and projected evolution of the characteristics of frequency,
- standards, time scales and time and frequency transfer techniques,
- to follow and assess the evolution of microwave links in current use, based on GNSS signals and TWSTFT,
- to follow and assess other technical possibilities, including optical fibre links, optical satellite links, and transportable optical frequency standards, which could be used for comparison of high performance frequency standards,
- to establish the relevant connections and facilitate consultations with other relevant bodies, such as IGS, IUGG, IVS, ITU, etc.
- together with BIPM, to foster the spread of information on technical achievements by suitable means, e.g. workshops, and
- to propose and organize novel comparison and calibration campaigns, including multiple techniques (such as GNSS, TWSTFT, ACES microwave link, T2L2, optical fibre links).

Membership

- Chairman

  Dr Feng-Lei Hong (NMIJ/AIST)
- Secretary:

  Dr Lennart Robertsson (BIPM)
- Members:

  One representative from the CCTF-WGTAI;

  One representative from the CCTF-WG-ALGO;

  One representative from the CCTF-WGGNSS;

  One representative from the CCTF-WGTWSTFT;

  One representative from the CCTF-WGPSFS;

  Two representatives from the CCL-CCTF WGFS;

  One representative from the BIPM, who will serve as the WGATFT Executive Secretary;

  Other experts from laboratory members of the CCTF

Activities

- WG ATFT meeting at Neuchatel

  Adjoin with EFTF 2014, attendee about 30 people
- Support for related projects

  Support letters for NEAT-FT, ITOC(EMRP), STE-QUEST, INRIM(EMRP), …

  Project advisor for NEAT-FT
- Questionnaire

  A questionnaire was sent out and collected recently.
- WG ATFT meeting at BIPM

  Tuesday this week, attendee about 50 people

Summary and outcome of the Neuchâtel WG meeting

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- Decision on the establishment of a study group of fiber links for UTC

  Activities on fiber links for UTC at NMIs together with BIPM

- Status reports:

  ACES project (Philip Tuckey)

  NEAT-FT (Harald Schnatz)

  VLBI and TW satellite (Miho Fujieda)

  Transportable optical clocks (Patrick Gill)

Summary of the questionnaire

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- Answers of the questionnaire from:

  NRC, PTB, TL, NIST, NMIJ, SYRTE

- Contents:

  a) Fiber links: SYRTE-PTB (1440 km), PTB-MPQ (980 km), PTB-Hanover (146 km), NIST-USNO Colorado Springs (> 200 km), JILA-NIST (5, 30 km), NMIJ-Tokyo (120 km), RIKEN-Tokyo (30 km)

  b) Instability (uncertainty) of fiber links: 10^{-17} – 10^{-20}

  c) Fiber links for time dissemination: using telecom networks and other critical infrastructures (e.g. next generation mobile system and financial market…) in future

Overview of the 2015 BIPM WG meeting

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- Answers to Questionnaire (Hong)
- Linking aspects of SRS validation (Bize, Gill, Riehle)
  - SYRTE-PTB fiber link, 2×10^{-17} @100,000 s
  - Sr-Sr comparison, $(4 \pm 5) \times 10^{-17}$
- Accurate measurements in geodesy (Delva)
- Study group on fiber links (Hong, Arias, Calonico, Jiang)
- Fiber links (Calonico)
- ACES progress (Salomon)
- Transportable optical clocks (Lisdat)
- TW satellite between PTB and NICT (Fujieda)
- Discussion about possible recommendations

Topics 1: Fiber links

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Optical Fiber Links: a worldwide snapshot

1 Fiber Link in use

Ongoing projects

Topics 1: Fiber links

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- Fiber Links are developed worldwide
- Different techniques for different objectives: time, frequency, T&F, different performances and complexity.
- They allow to compare remote frequency standards at their best accuracy.
- They are suitable for accurate time transfer
- Efforts to be done to ensure reliable continous systems and to cope for weaknesses

Topics 2: Study group on fiber links for UTC (Planed actions)

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- Monitor the availability of new permanent links for UTC;
- Survey about the data transfer format and the experience achieved so far (OTFT);
- Investigation on further structuration of fibre time links;
- Study of possible mixed solutions with fibre and satellite links;
- Use of redundant links for UTC;
- Implementing a literature repository;
- **Continuous contact with laboratories developing fiber links**;
- **Permanent survey of non-NMI user of fiber links**.
- Proposal of a technical directive for operating procedures, formats, including hardware, software and administrative issues,
- **Study of he regulatory issues related to the availability of the services in a national context and the coordination between networks in different countries**
- **Pushing international bodies to facilitate fiber links implementation**

To properly and timely organize the workflow, the TGF plans to meet at least once per year and to organize teleconferences, at least three per
The first teleconference will be held in October.

Topics 3: ACES

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- Laser cooled cesium clock on satellite with stability of 1 10^{-13} at 1 second and 1 10^{-16} at 10 days
- Test of red shift at 2ppm; search for drift of fundamental constants
- Time transfer: continental and intercontinental frequency comparisons between 9 Institutes including 7 NMI. < 1ps at 300 s, 7 ps at 1 day and 23ps at 10 days.
- 10^{-17} frequency resolution at one week of measurements. Very low noise but only 5-7 measurements per day. Comparison with fiber links, GPS and TWSTFT.
- Laser Time transfer with 10 ps noise: ELT.

Topics 3: ACES

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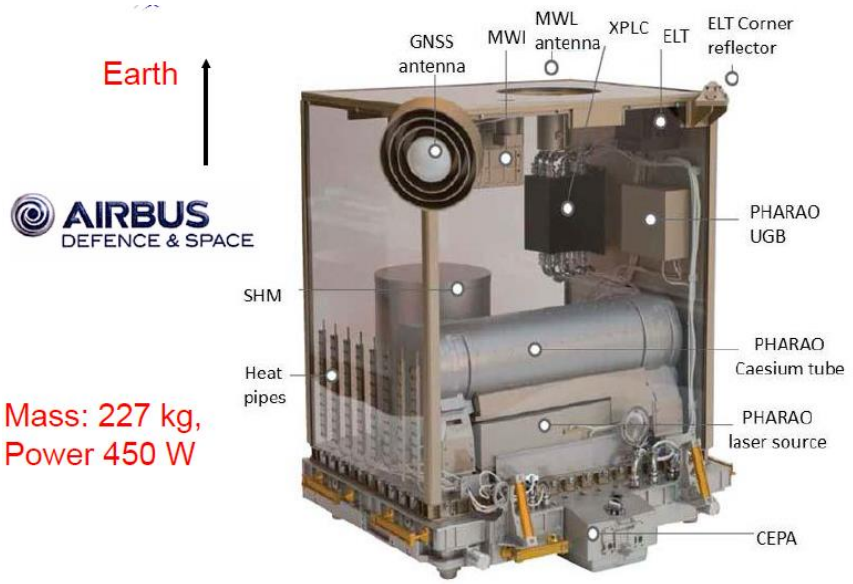
- Most Flight models finished. On ground testing in 2015-2016. Launch first semester of 2017. Mission duration: 18 months guaranteed, 3 years most likely.
- Perspectives: improved redshift test with optical clock in elliptical orbit; SOC2 ESA project.
- permanent MWL

  time transfer in space.
- Future time definition

  from space !



Topics 4: Transportable optical clocks

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- 4 – 5 transportable clocks under development (Sr lattice, Al^+ quantum logic)
- Two Sr systems close to operation (SOC2, PTB), probably most advanced ones (no info about NIST Al^+)
- Uncertainty of $<10^{-17}$ to be expected at ~3 hours
- So far, two development branches:
  moderate compactification, ‘metrological systems’
  mass/volume optimized, ‘space systems’
- These clocks will be used in measurements joint with geodesists (EMRP ITOC, CRC geo-Q)

Topics 5: TW satellite

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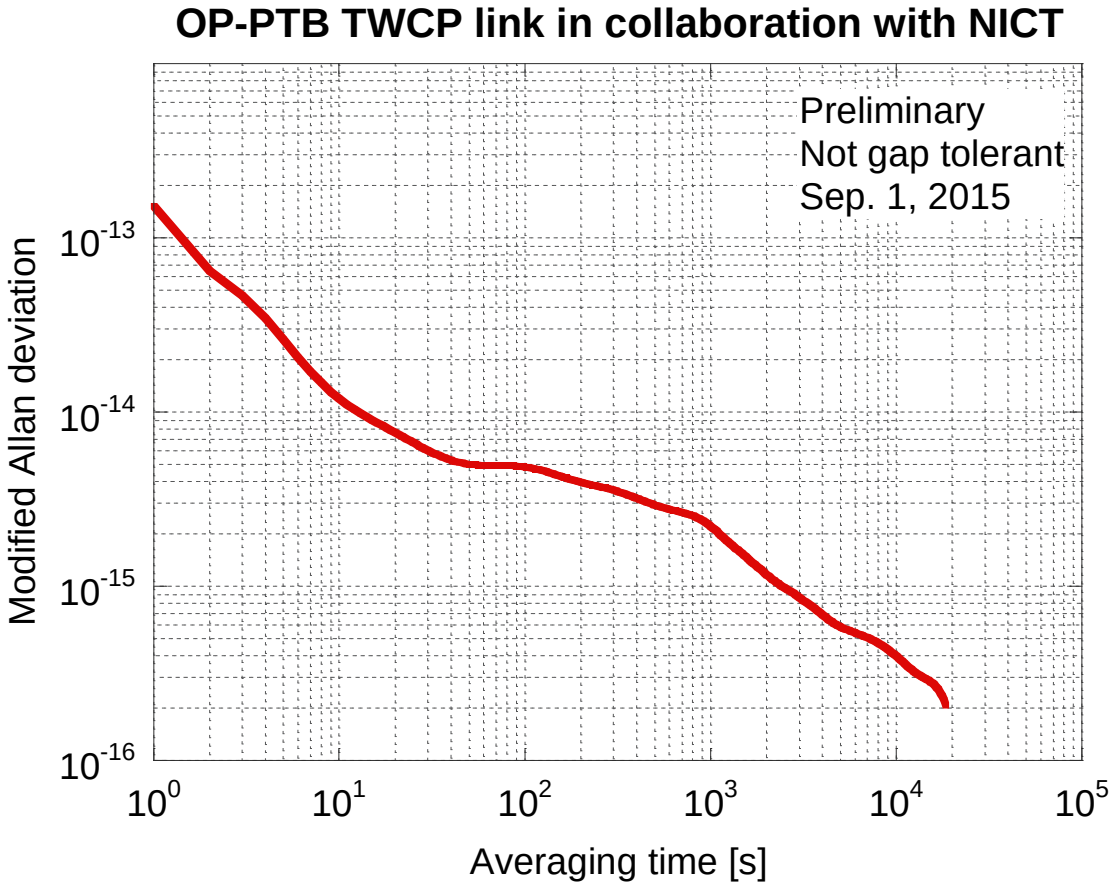

- Frequency comparison at the 10^{-16} level is promising by TWCP.
- Availability of carrier-phase measurement will be increased.

Topics 6: Geodesy

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- The flow of time depends on the velocity of a clock and on the space-time metric. By comparing the frequencies of two clocks it is therefore possible to **directly measure gravity potential differences**: this is **chronometric geodesy**.
- The **chronometric observable is very different in nature** than all other classical observables in geodesy (gravimetry, gradiometry, …), and the accuracy of optical clocks begins to be **competitive** with classical methods in geodesy which have accuracies up to a few centimeters for the static potential.
- **Several projects** study the benefits of chronometric observables for geodesy: comparison with classical methods in the ITOC EMRP project with a large-scale experiment, new theoretical definition of the TAI based on the chronometric geoid, applications in geophysics and for the high resolution geopotential, time-varying phenomena, etc...
- All these applications foster the need for **transportable optical clocks** and **highly stable links over inter-continental distances**.

Recommendations

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- Recommendation 1

1) Relevant bodies:

- Vigorously support research and development of time and frequency transfer techniques matching the stability and uncertainty of the most advanced frequency standards. These techniques may include optical fibre links, advanced satellite microwave links, optical space links and transportable frequency standards, and advanced space clocks.
- Help secure sustainable infrastructure of selected continental and intercontinental links forming a global time and frequency metrology backbone for these novel technologies.
- Make provision that these novel technologies are transferred with the relevant accuracy to other fields of science, industry and society.

2) the BIPM participates actively in these developments, notably by making preparations for exploiting, in time scale realization, clock comparison data issued from new time and frequency transfer methods.