

The CCTF Working Group on Advanced Time and Frequency Transfer Technology

Report to the 21th CCTF

June 2017

Feng-Lei Hong

WGATFT Chair

Invited Research Scientist of NMIJ/AIST, Tsukuba, Japan

Yokohama National University, Yokohama, Japan

Terms of reference

-
- 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

Study group on fiber links for UTC (Started in 2014)

CCTF
WGATFT

Chair: Davide Calonico (INRIM)

- 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 the 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**

Activities

CCTF
WGATFT

- WG ATFT meeting at BIPM
September 2015, with the 20th CCTF meeting
- SGOF meeting at York
April 2016, with EFTF 2016
- Support for related projects
Support letters for NEAT-FT, ITOC(EMRP), STE-
QUEST, INRIM(EMRP), ...
Project advisor for NEAT-FT
- WG ATFT meeting at BIPM
June 2017, with the 21th CCTF meeting

Summary and outcome of the 2015 BIPM WGATFT meeting

CCTF
WGATFT

- 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)
- **New recommendation**

Recommendations (CCTF2015)

CCTF
WGATFT

-
- National metrology institutes (NMIs), optical fibre network providers, space agencies, national governments, regional metrology organizations (RMOs), International Telecommunication Union (ITU) and other 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 ground to space and space to 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 provisions for these novel technologies to be transferred with the relevant accuracy to other fields of science, industry and society,
 - 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.
 - those laboratories contributing to UTC and performing continuous time comparisons via fibre links regularly submit their results to the BIPM Time Department.

Overview of the 2017 BIPM WG meeting

CCTF
WGATFT

- Transportable optical clocks (Lisdat)
- Fiber links (Calonico)
- Discussion about on going campaign of clocks comparisons between SYRTE, PTB, and NPL using fiber links, with the transportable clock coming to SYRTE from PTB.

*Report on ACES progress was not available, but Sebastien Bize was kind to give a brief status report.

Transportable optical clocks

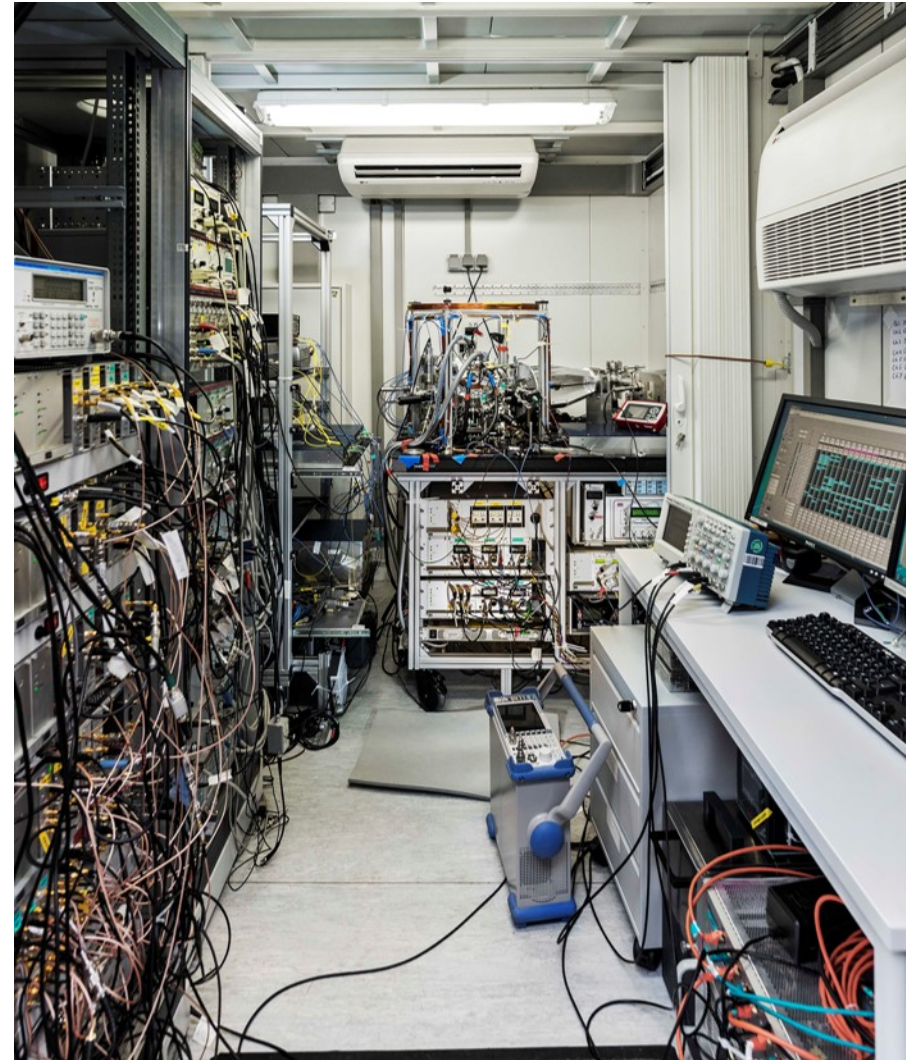


Car trailer housing the clock

View into the car trailer ►

S. Vogt *et al.*, J. Phys.: Conf. Ser. **723**, 012020 (2016)

S. Koller *et al.*, Phys. Rev. Lett. **118**, 073601 (2017)



Why optical fibre?

Optical frequency transfer over fibre has **order-of-magnitude better** stability and accuracy than satellite-based methods, and has been **demonstrated over >1000 km**. It is currently the only long-distance transfer technique adequate for **optical clocks**.

Achievable fract instability

Fibre < 10⁻¹⁸ in 1 min

Satellite > 10⁻¹⁶ in 1 d

Towards an international optical clock comparison between NPL and SYRTE using an optical fibre network

J. Kronjäger¹, G. Marra¹, W.-K. Lee^{2,8}, P.-E. Pottie², A. Amy-Klein³, O. Lopez³, Fatima Spahic⁴, D. Calonico⁵, G. Roberts⁶ and H. Schnatz⁷

¹NPL—UK, ²LNE-SYRTE—France, ³LPL—France, ⁴IMBiH—Bosnia and Herzegovina, ⁵INRIM—Italy, ⁶GÉANT—UK, ⁷PTB—Germany, ⁸KRISS—Korea

Applications

Optical clock evaluation—redefinition of the SI Second

Test the reproducibility of prospective optical primary standards.

Clock-based geodesy—gravitational red-shift

Measure height differences at the cm level by comparing optical clocks through fibre links.

Atomic Clock Ensemble in Space (ACES) support

Characterise MicroWave Link (MWL) and European Laser Timing (ELT) optical link by simultaneously comparing clocks over fibre.

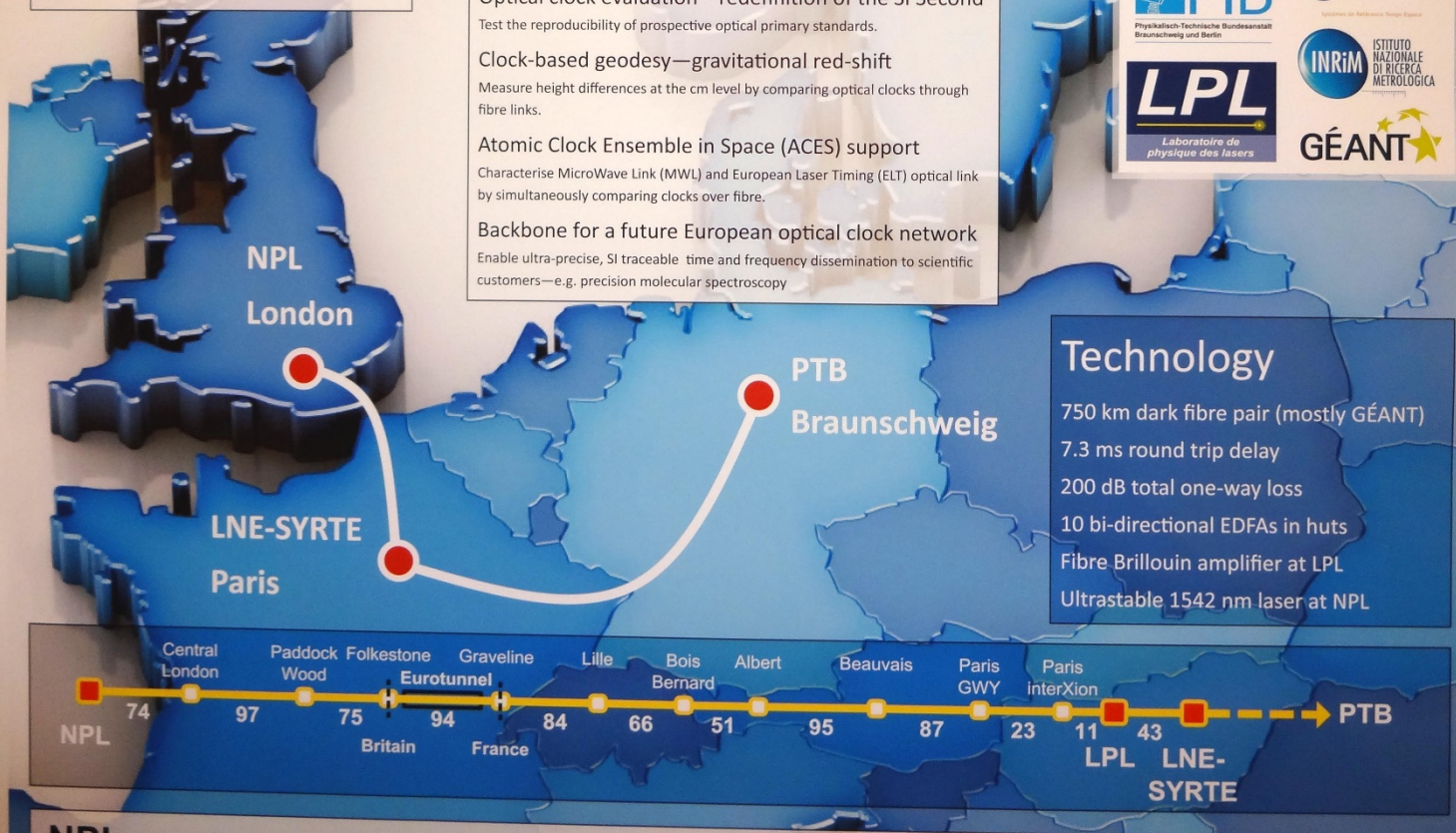
Backbone for a future European optical clock network

Enable ultra-precise, SI traceable time and frequency dissemination to scientific customers—e.g. precision molecular spectroscopy



Technology

750 km dark fibre pair (mostly GÉANT)
7.3 ms round trip delay
200 dB total one-way loss
10 bi-directional EDFAs in huts
Fibre Brillouin amplifier at LPL
Ultrastable 1542 nm laser at NPL



New chairpersons & thank you

CCTF
WGATFT

- New chairperson after the CCTF
Davide Calonico (INRIM)
- Thank you for your support during the last five years!