ESA Activities on Fiber Optic Frequency Dissemination

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Summary of Presentation

- Political Landscape
  - Member states of ESA

- ESA Locations
  ESTEC in The Netherlands

- First ESA supported development on optical frequency transfer

- Developmental steps
  1. Ultra Stable Fiber Frequency dissemination
  2. Enhancement of range and performance

- On-going ESA studies

- Newest ESA Activities

- Conclusions and Next Steps

19 MEMBER STATES AND GROWING

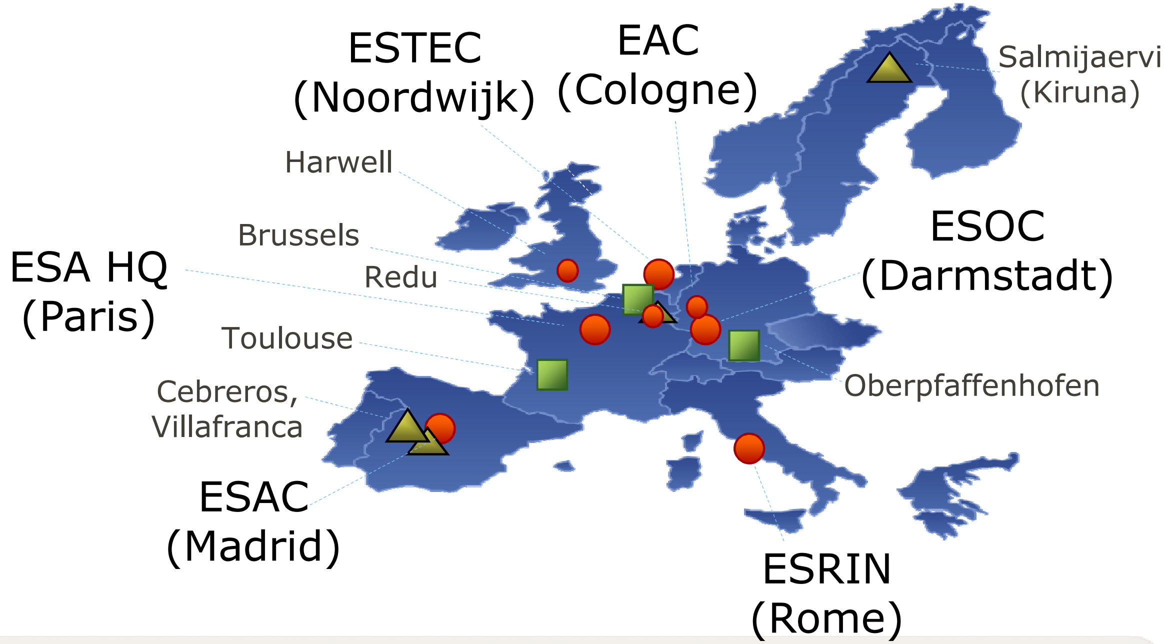
ESA has 19 Member States: 17 states of the EU (AT, BE, CZ, DE, DK, ES, FI, FR, IT, GR, IE, LU, NL, PT, RO, SE, UK) plus Norway and Switzerland.

Eight other EU states have Cooperation Agreements with ESA: Estonia, Slovenia, Poland, Hungary, Cyprus, Latvia, Lithuania and the Slovak Republic. Bulgaria and Malta are negotiating Cooperation Agreements.

Canada takes part in some programmes under a Cooperation Agreement.

ESA'S LOCATIONS

- ESA sites/facilities
- Offices
- ESA ground stations



ESTEC IN THE NETHERLANDS

Principal tasks

- Preparation studies and management of most ESA space programmes: space science and exploration, Earth science and applications, navigation, telecommunications, human spaceflight
- Engineering support to ESA project teams including preparation, coordination and management of ESA space technology R&D programmes
- Dedicated laboratories for technology development, troubleshooting pre and during missions
- Product assurance and safety responsibility for ESA space programmes
- Management of ESTEC Test Centre and coordination with other test centres in Europe
- operates a time laboratory that seeks to maintain a time scale directly traceable to UTC

Earliest ESA supported development on optical frequency transfer (1)

Free-space Ultra-stable Optical Link for Space Applications

F. Narbonneau, M. Lours, G. Santarelli, BNM-SYRTE (2001)

Objective

- Share ultra-stable clock signals at 100 MHz on board the International Space Station (ISS) without direct connection between the pallets:
  ↳ Free space optical communication
  ↳ RF process to correct phase fluctuations due to optical path variations (mechanical vibrations, pallet to pallet fluctuations …)

Low phase noise

Frequency stability $\sigma_y(1s) \leq 2.10^{-14}$

Maximum equivalent phase noise

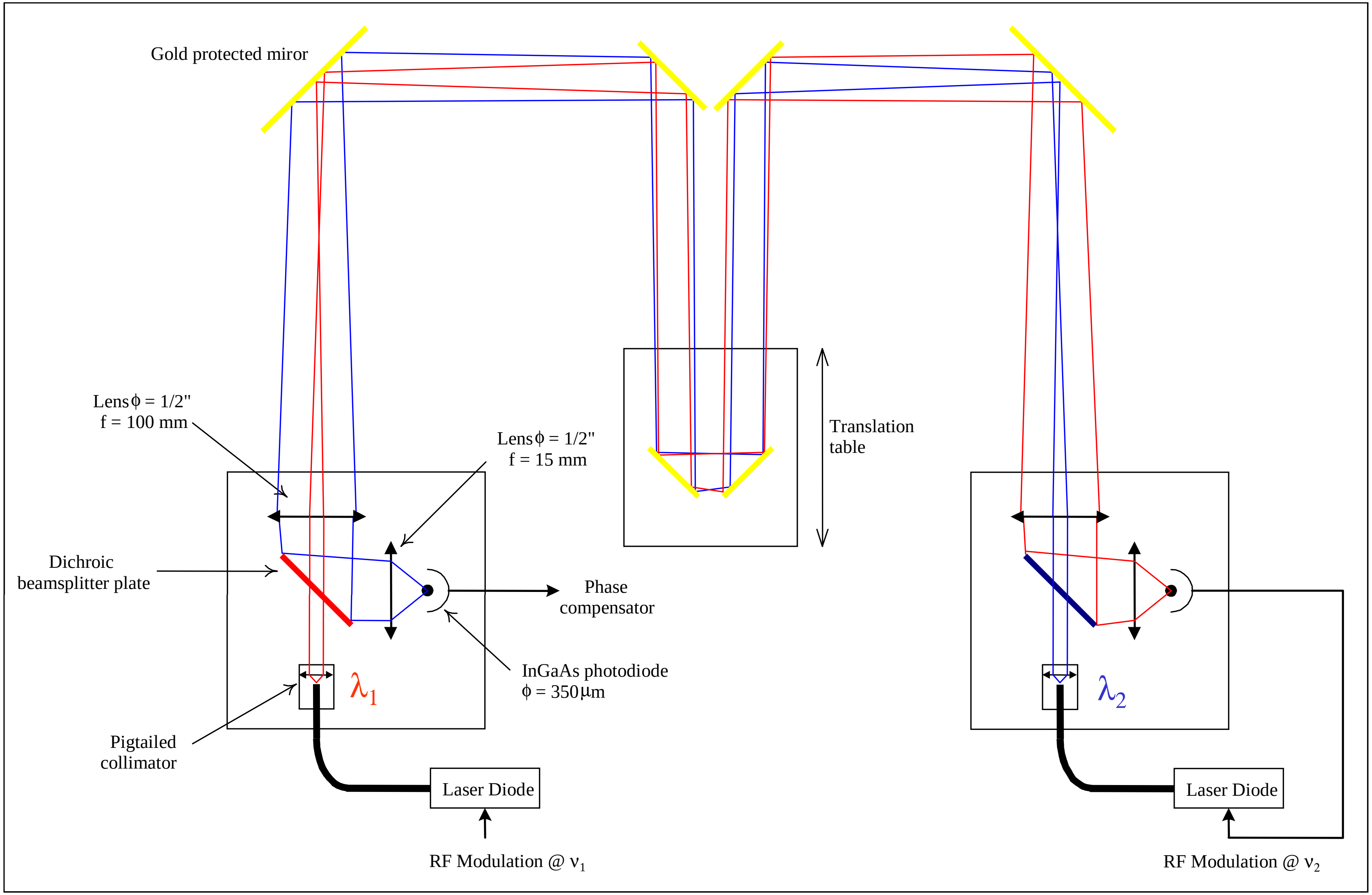
$$S_\phi(f) = 10^{-12} f^{-1} + 10^{-14} f^0 \ [rd^2/Hz] \ @ \ 100 \text{ MHz}$$

Long-term phase stability

Phase stability 10 ps/day

Temperature coefficient < 1 ps/° C

First ESA supported development on optical frequency transfer (2)



Dual wavelength optical system, not to scale

Developmental steps (1)
Ultra Stable Fiber Frequency Dissemination

LNE-SYRTE, Observatoire de Paris

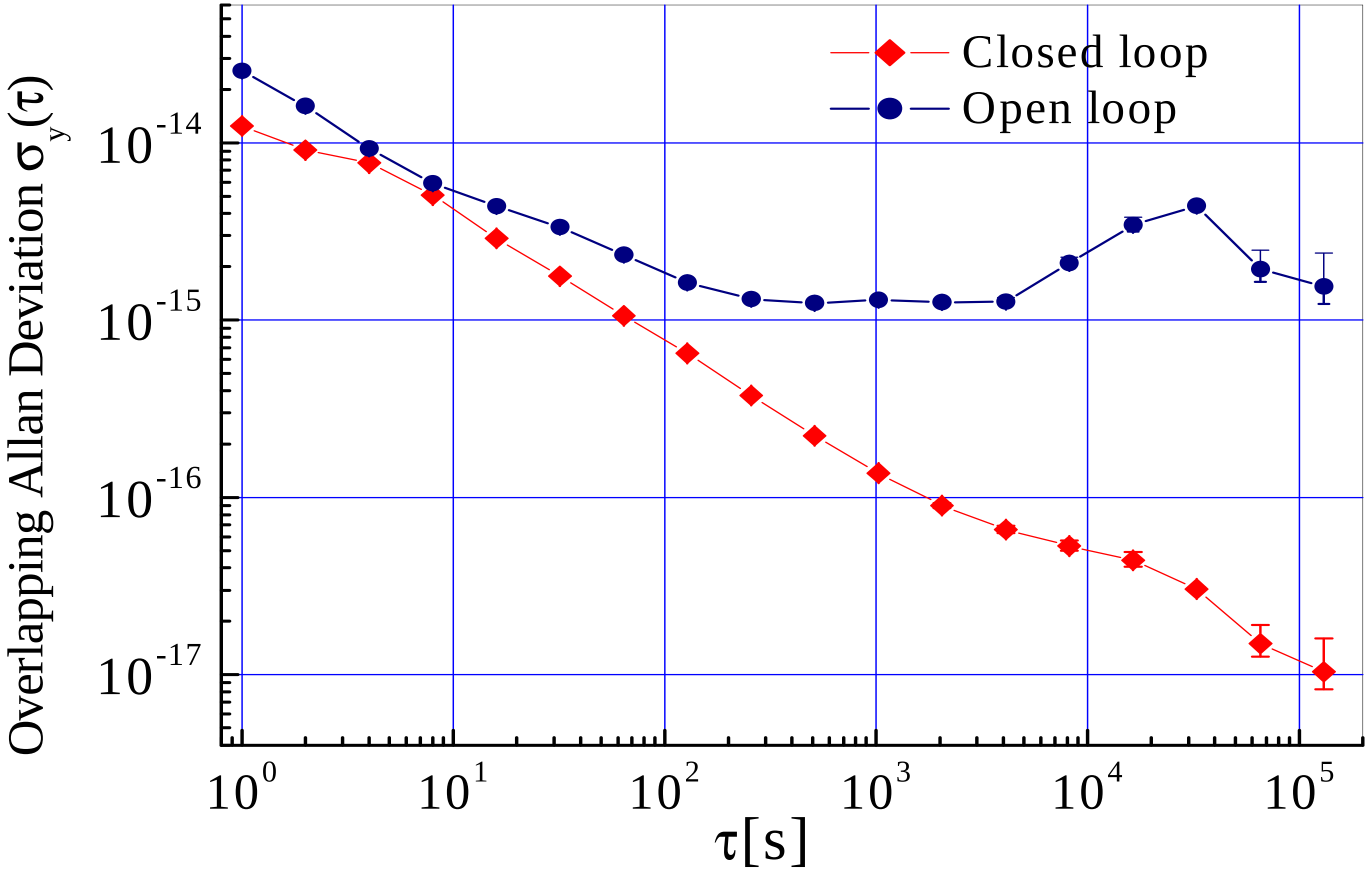
Laboratoire de Physique des Lasers,

ESA contract No:

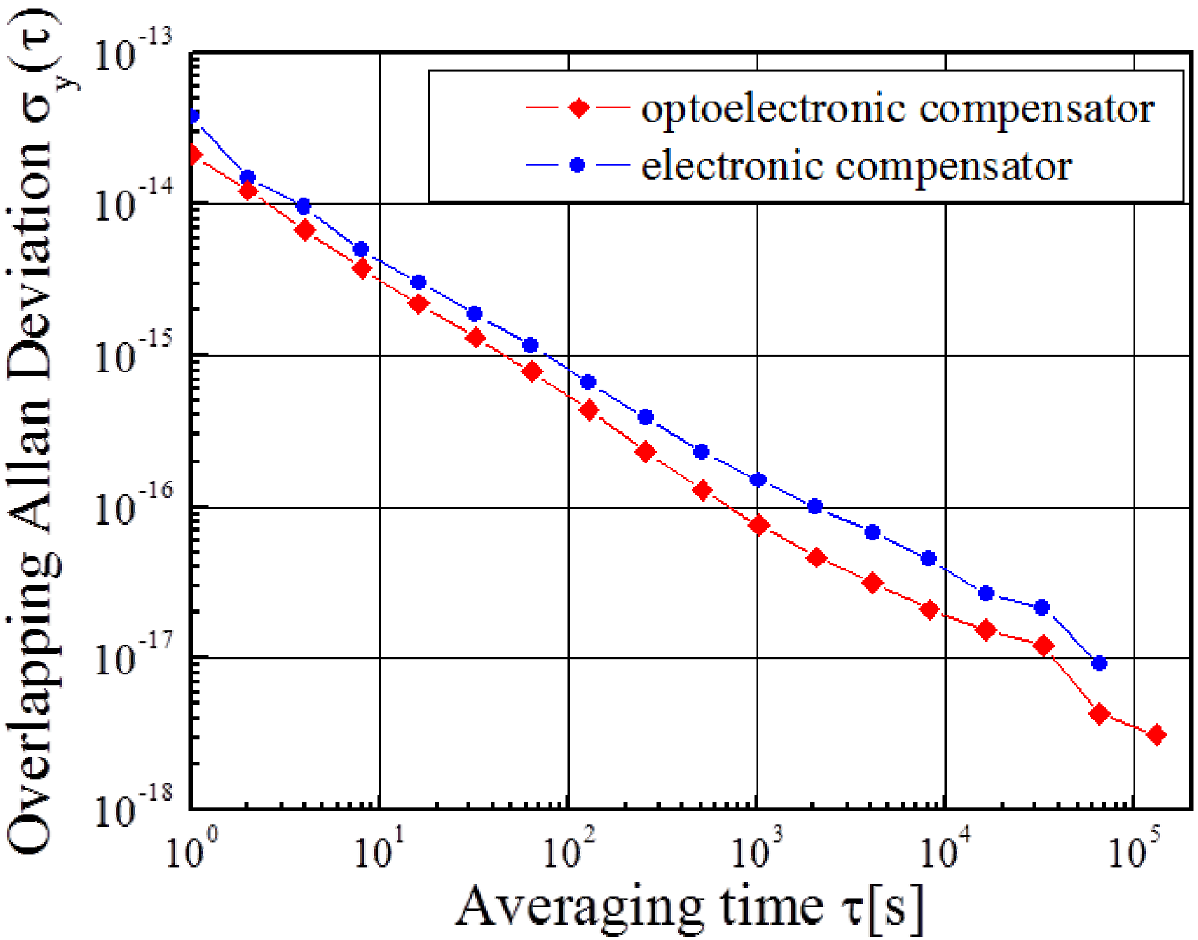
2004 – 2007

- Define the criteria for frequency distribution for stable signal in the Deep Space Network stations
- Short distances (up to 2km) within a deep space facility and 100 km links between distant antennae
- Long distance extension for an European Network

Frequency stability of the double compensated link cascaded Electronic and Optoelectronic compensators 2x43km



Extended link (186km-1GHz) with 2 EDFA.



Developmental steps (1)
Ultra Stable Fiber Frequency Dissemination

- **A full European network is fully feasible with regenerating stations (amplifiers, clean-up oscillators and segment compensation) every 180-200km.**

- **The industrialisation of this optical link needs to be done.**

- **A further factor of 2 in the bridged distance, to reach 300-400km, would be suitable for the reduction of the network complexity.**

- **The PMD although controlled, could still be detrimental for our application, a wise choice of modern fibers (lower PMD) is recommended.**

- **In a long term prospect the use of very low loss fibers with well engineered lay out have the potential to further increase the single segment range up to 500km.**

Developmental steps (2)
Enhancement of range and performance

OLAF: Optical Linking of Atomic Frequency standards over large distances
HACOF: High performance Atomic frequency Comparison over Optical Fibers

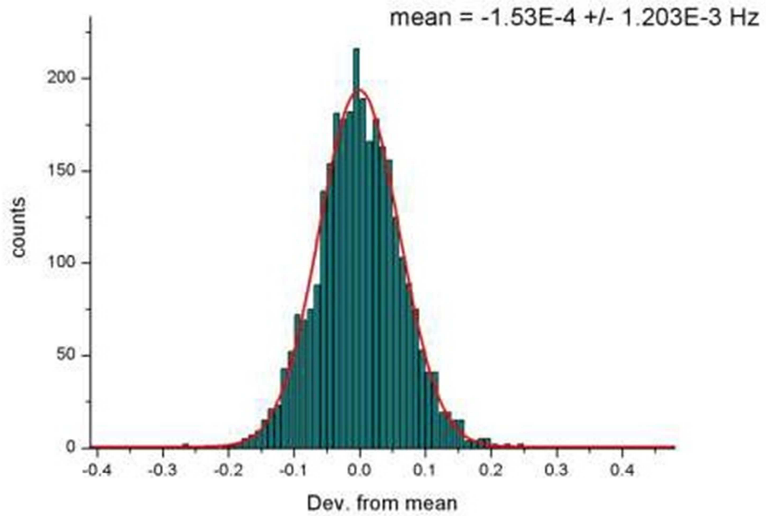
ESA-ESTEC / Contract No.21082/07/NL/PA
Completed in 2011 (after extension)

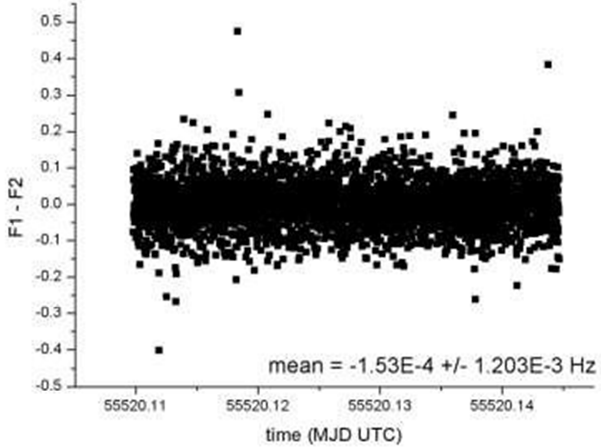
Max-Planck-Institut für Quantenoptik (MPQ)
Physikalisch-Technische Bundesanstalt (PTB)

Developmental steps (2)
Enhancement of range and performance

- **Implemented Carrier Phase**
  - **Better phase resolution and instability**
  - **Fewer non-linear processes(PMD/CD)**
  - **Reduced AM/PM conversion**
- **Select optimum carrier wavelength for fiber compatibility**
  - – <30 dB/km, better 20 dB/km
- **Establish good thermal, seismic and acoustic isolation**
  - **Go underground**

Developmental steps (2)
Enhancement of range and performance





Full Link: Accuracy

Approx. 1 h of data: 6.1 E-18

Cycleslips sorted out

High Performance Frequency Dissemination Technologies

1. Ground to space & space to ground
2. **Ground to ground & space to space**
3. GETRIS – Geodesy and Time Reference In Space

On-going ESA Studies (1)

3 ESA studies

- **High Performance Frequency Dissemination Technologies, Phase 1**
  2 parallel activities as precursors to Phase 2
  -> Proof of Concept Demonstrator
  - **Ground to ground & space to space**
    ESTEC, D/TEC, TO: Christoph Voland, Start: July 2011, 18 months
    AO/1-6567/10/NL/NA
    Ref.: T216-033MM-B, Contr.No.: 4000103705

High Performance Frequency Dissemination Technologies – Phase 1 space to space & ground to ground

Objectives

- Design a **frequency dissemination** system for Optical Atom Clock signals between spacecraft or between ground clocks to allow for frequency comparison of optical atom clocks **without compromising the clock performance**.

- High Performance Frequency Dissemination **Infrastructure in space**
    - a **master** optical atom clock at L1 / L2 (1.5 million km link distance) to provide the (time and) frequency reference to
    - a secondary (**slave**) optical atom clock in LEO and
    - one **relay** spacecraft (out of three) in GEO that allows uninterruptible link between the two clocks
    - with all links being of **optical nature**

- **Contractor: TimeTech (de)**

  NPL (UK), PTB (de), SYRTE (FR), TESAT (de)

Motivation for the baseline scenario

- Various link distances
- Master clock at Lagrange Point:
  - Earth independent time frame
  - Minimised gravity impact on clock performance
    (in awareness of the performance of optical atom clocks)
  - Long range link distance (1.5 million kilometres)
- Secondary clock in LEO
  - Application spacecraft (navigation, Earth observation, science, etc.)
  - Transfer from/to ground clocks is assumed to go via LEO
    (ground to space links investigated in parallel study)
- Relay spacecraft at GEO
  - ensure uninterruptible link
    (between master and secondary clock)

High Performance Frequency Dissemination Technologies – Phase 1 space to space & ground to ground

Behind the scenes

- Physical and technological limitations of methods, techniques and components
- Identify technologies and subsystems that need development
- Possibility of upgrading optical communication links
- Fibre links as template and performance target

Newest ESA Studies

ESA-ESOC
AO/1-6648/10/NL/
Ultra-Stable Frequency reference Dissemination across commercially deployed fiber networks
NTUA, OTE
[expect to focus on time transfer][Will test on OTE 200km field circuit]

ESA-ESOC
AO/1-6418/10/NL/
High Performance Frequency Dissemination Techniques
UCC Department of Electrical Engineering
[will focus on frequency transfer][Will test on UCC external fiber test grid]

Opportunities

Intercontinental link

- Which satellites have high coherence lasers on board or will do so soon?
- What detailed studies have been done in this domain
- Optical Pre-cursor experiments abound: SYRTE, DLR-OP

Satellite dissemination possibilities

- ESA Sentinels will introduce a new standard for data downlink for EO missions [Optical link via GEO]

Tests using existing infrastructure

- Combined mode test [RF, ACES, Fiber, Free-space]

Conclusions and Next Steps (1)

Optical transfer is outperforming GNSS Satellite links in stability and accuracy. How to maximise this capability [Presentation by Jeroen Koelemeij]

Explore Geoid determination using ultra high performance ground clocks and fiber distribution networks: LOFAR, SKA…

Conclusions and Next Steps (2)

Please tell ESA how it can be more proactive ?