

## **Two-Way Time Transfer**

# **A Universal Tool for Metrology and Wide-Area Time Synchronisation**

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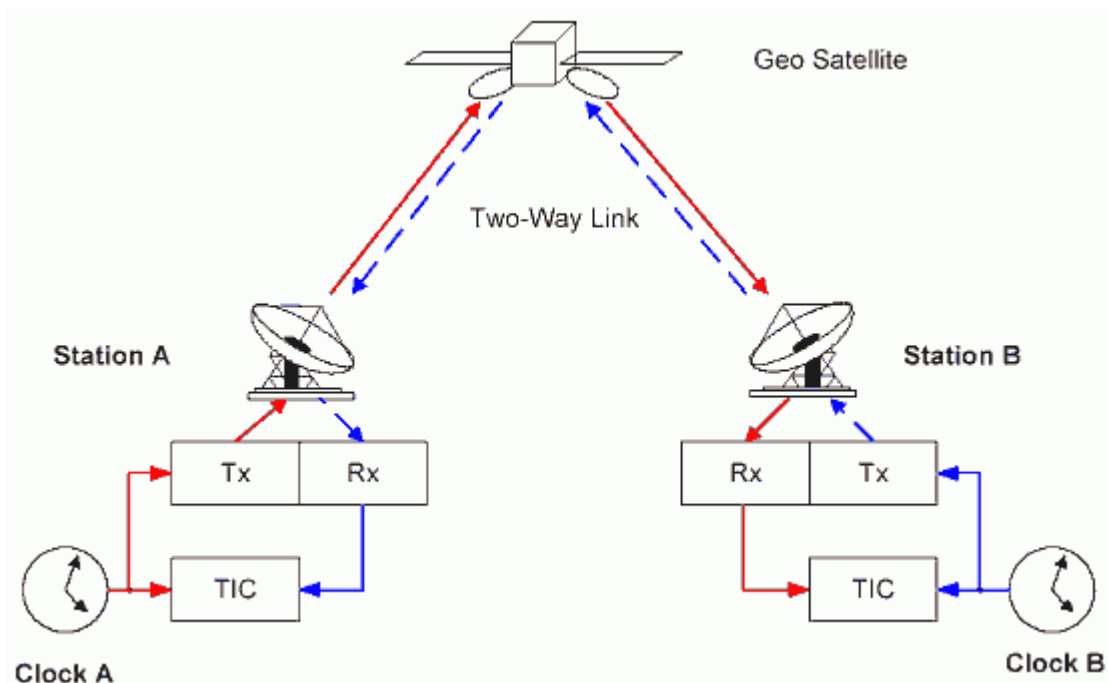
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## **1. Two-Way Time & Frequency Transfer via Satellite (TWSTFT)**



## 2. TWSTFT: Main Characteristics

### Main Benefits:

- Measure clock difference, DO NOT MODEL!
- TWSTFT Link eliminates all 1st-order errors by SYMMETRY
- Multiple links via same transponder using CDMA

### Independent from:

- Ground: Location, height, tides, tectonic movement
- Satellite: Location, velocity vector, transponder delay
- Propagation: Path geometry, Troposphere, Ionosphere (dispersive)

### Asymmetry:

- Relativistics: Sagnac
- Propagation: Different up-down frequencies, Ionosphere
- Instrumental and Calibration Errors

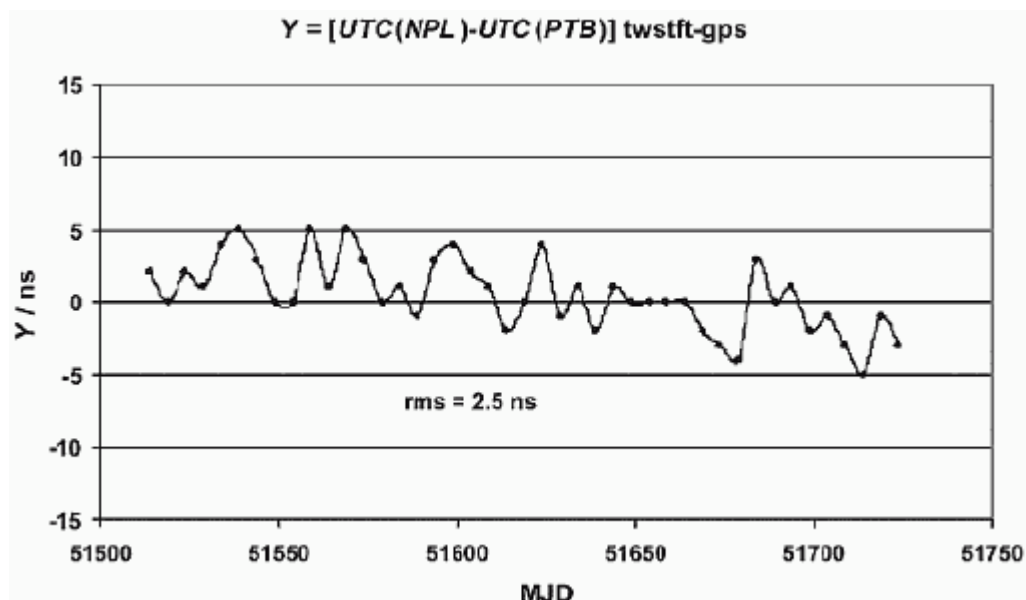
## 3. TWSTFT: Network and Operations

- Time-Transfer data contribute to generation of TAI by the BIPM
- Regular operation in Europe, U.S. and Asia
- Trans-Atlantic Links, US-Asia, Asia-Australia
- Laboratories include Australia, France, Germany, Italy Japan, Netherlands, Spain, Sweden (2002), UK, Taiwan, USNO, Washington (GPS) incl. AMC, Colorado Springs, NIST, Boulder

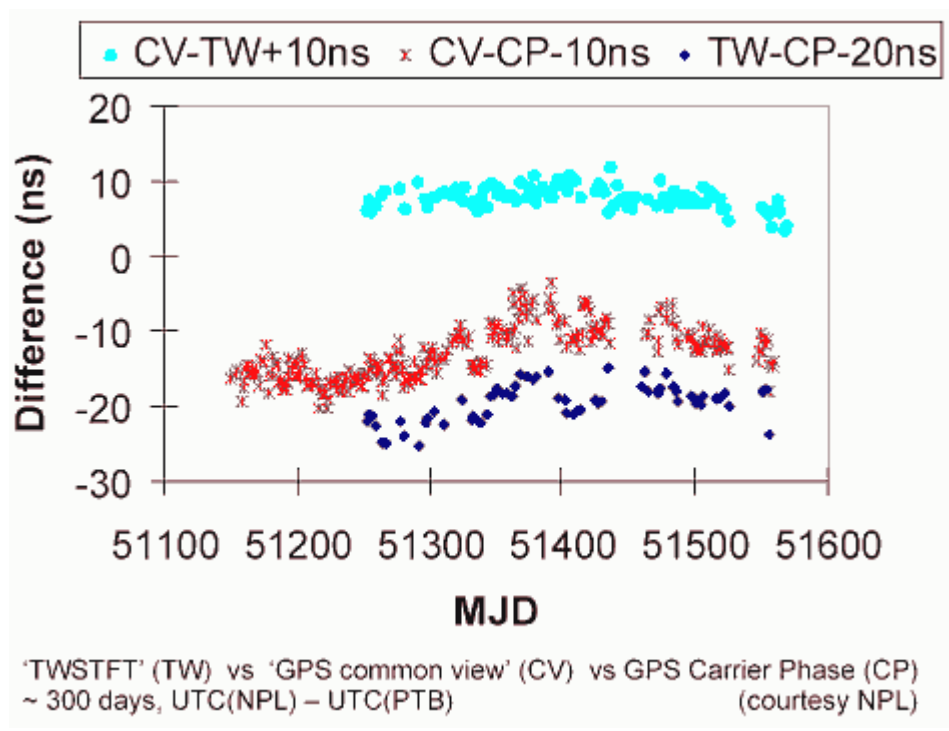
### Performance:

- Repeatability: 200 .. 300 ps
- Calibration Error: 600 ps .. 3  $\mu$ s

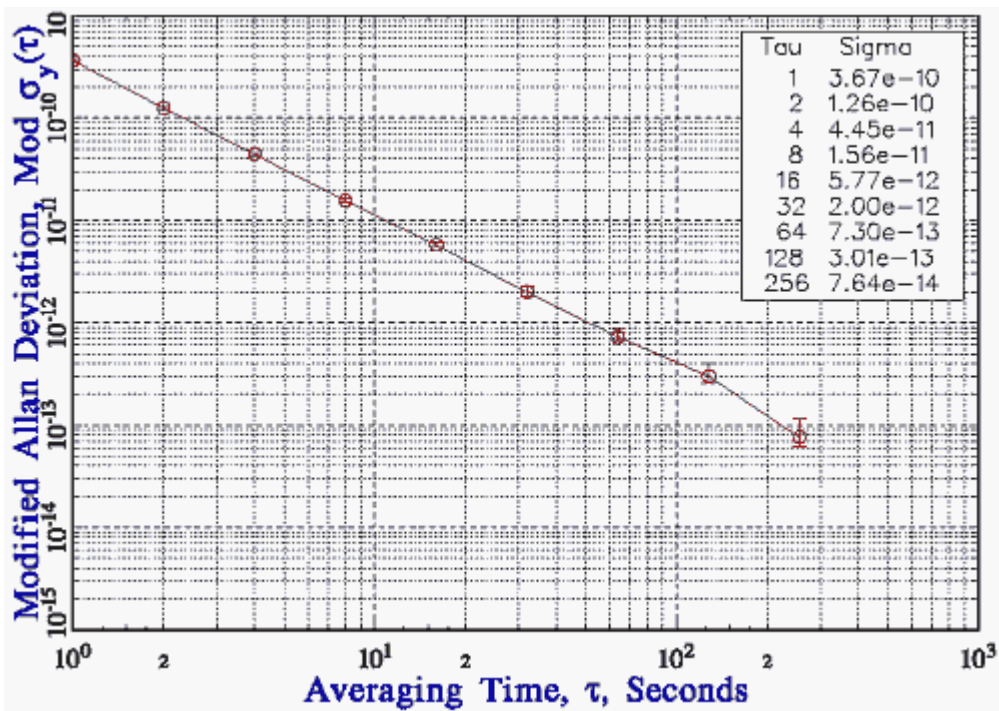
#### 4. TWSTFT Long-Term Performance between Primary Laboratories



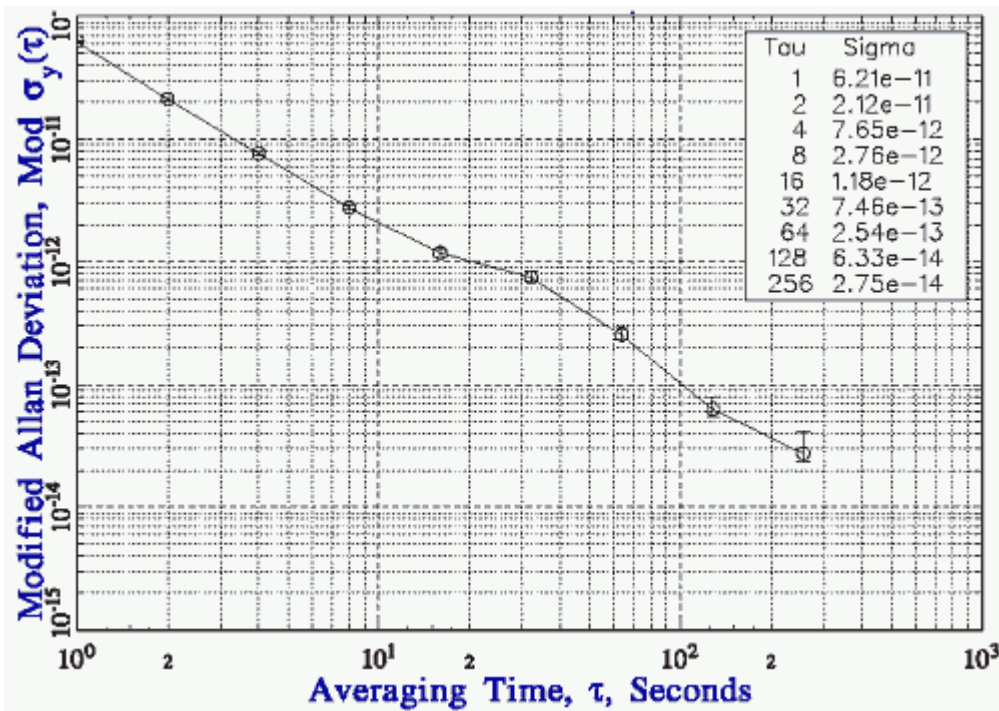
#### 5. TWSTFT: Comparison to GPS-Links



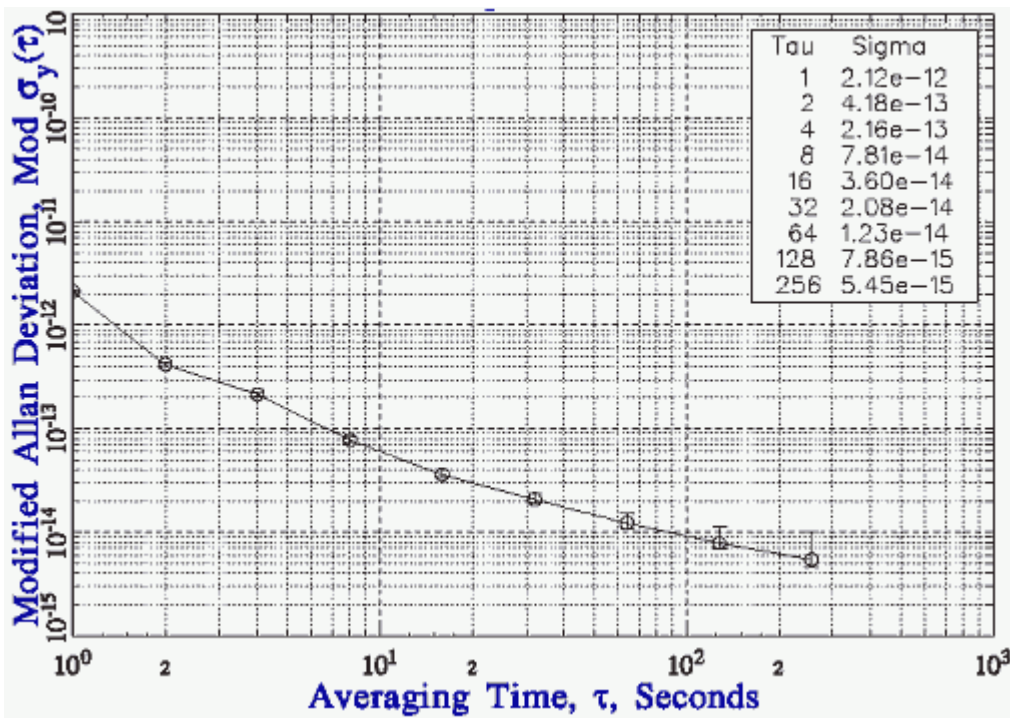
#### 6. TWSTFT: Modified Allan Deviation (Link USNO – NIST) 2.5 MChip/s



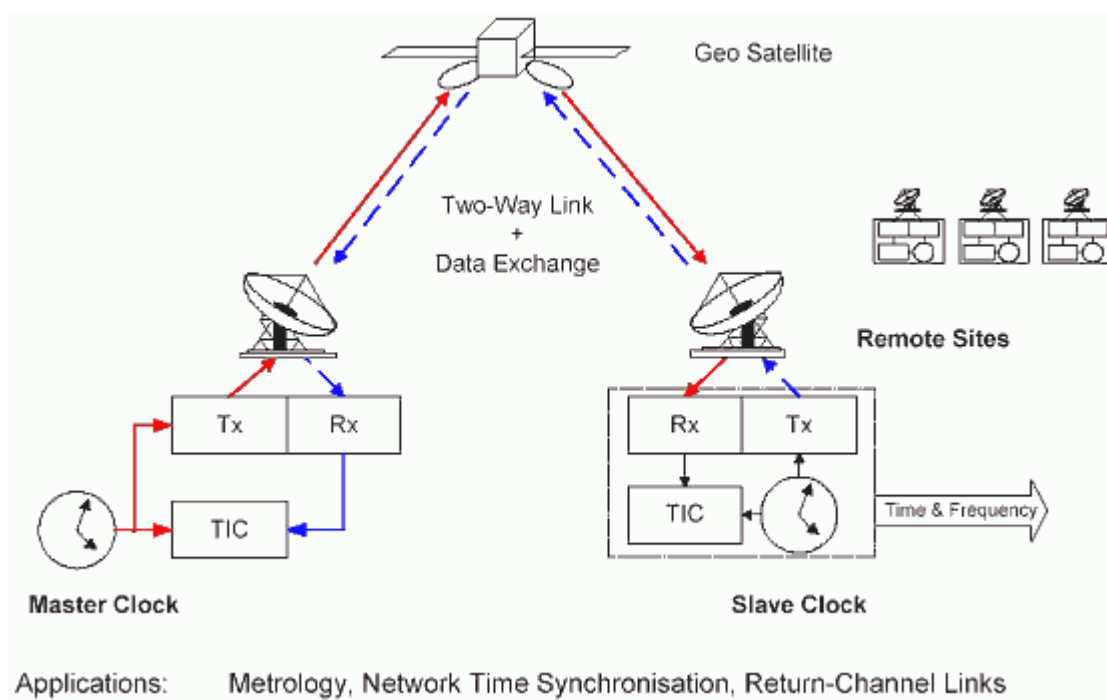
### 7. TWSTFT: USNO – NIST, 20 MChip/s (Experimental)



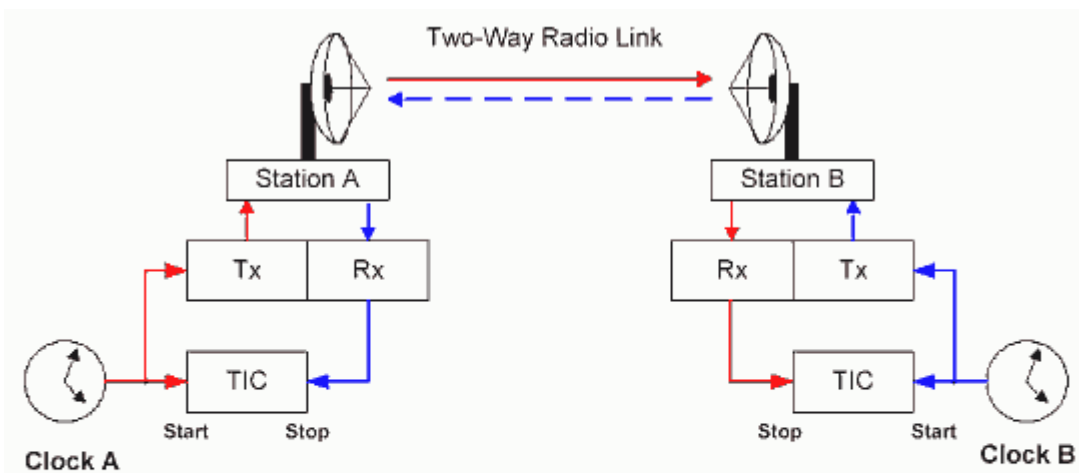
### 8. Frequency Transfer using 2-Way Carrier Phase (Experimental)



## 9. Time Synchronisation using TWSTFT

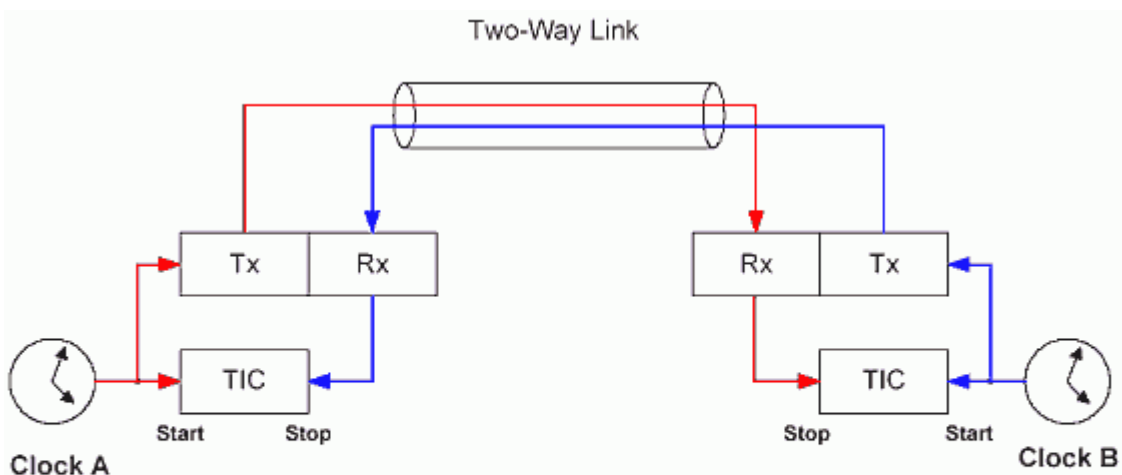


## 10. TWSTFT: Ground-to-Ground, Space-to-Ground, Space-to-Space



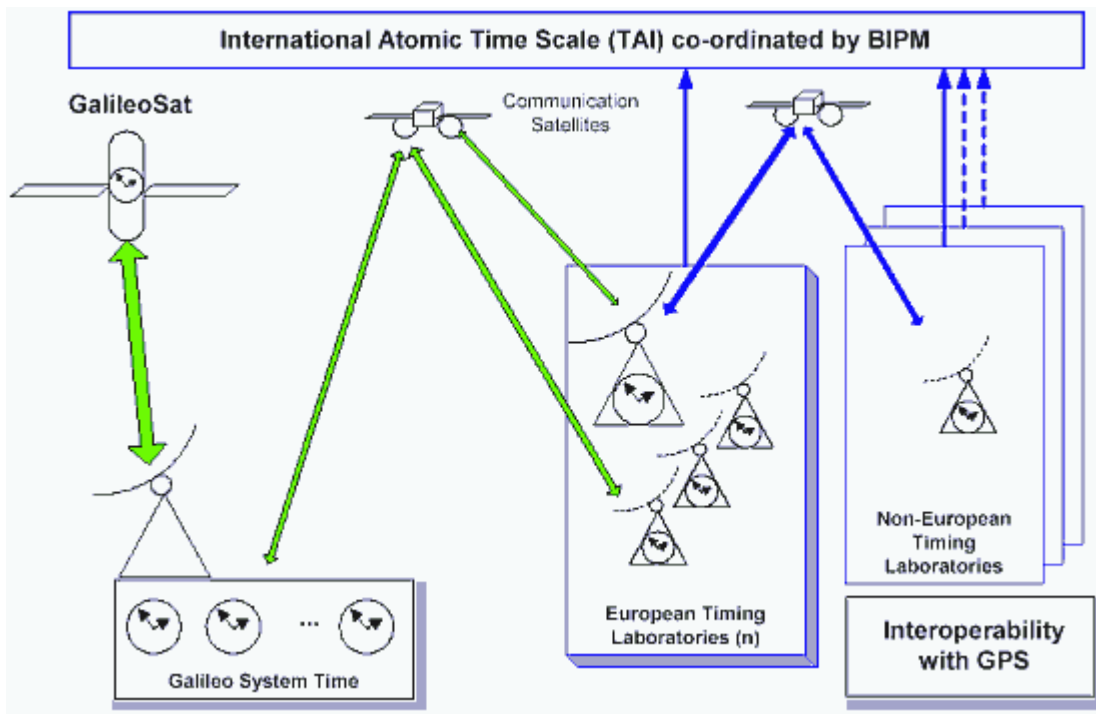
- Ground-to-Ground: TV- and Communication Feeder Links
- Space-to-Ground: GLONASS, PRARE, ACES (sub-ps stability), GALILEO (?)
- Space-to-Space: GPS inter-satellite links, Optical Links (SILEX)
- LEO-GEO-Ground: ISS – TDRSS – Ground

## 11. TWSTFT: Ground-to-Ground

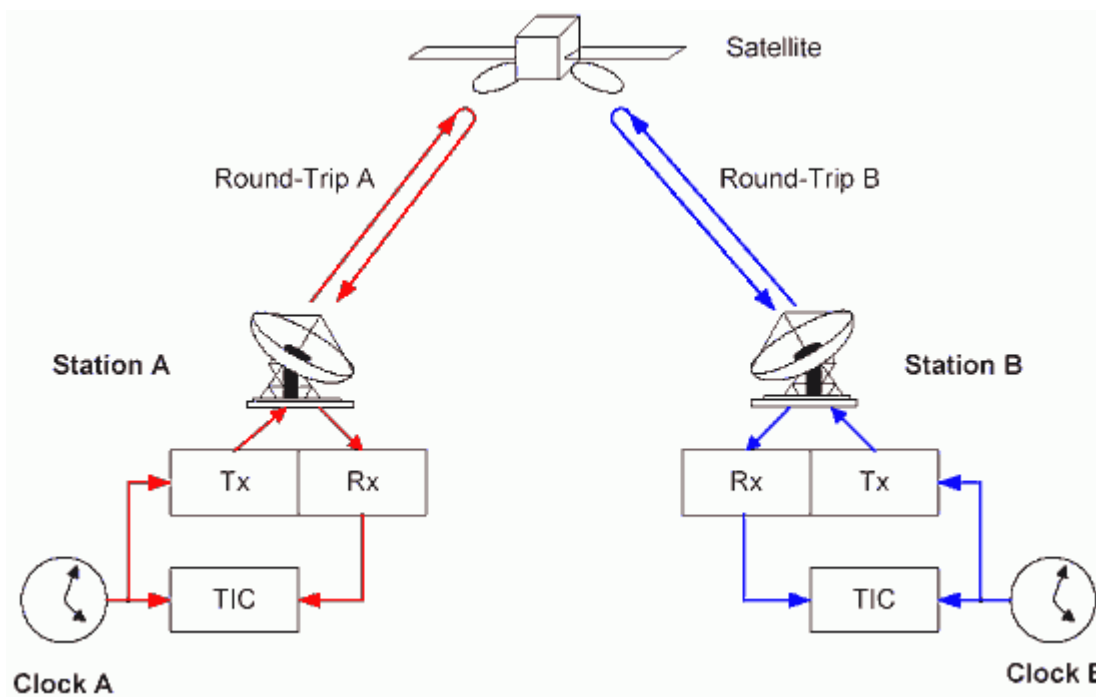


- Fibre-Optical Systems: 1 ns and better (short distance to inter-continental links)
- LANs (NTP): 0.1 .. 10 ms
- Telephone Lines: 1 .. 100 ms

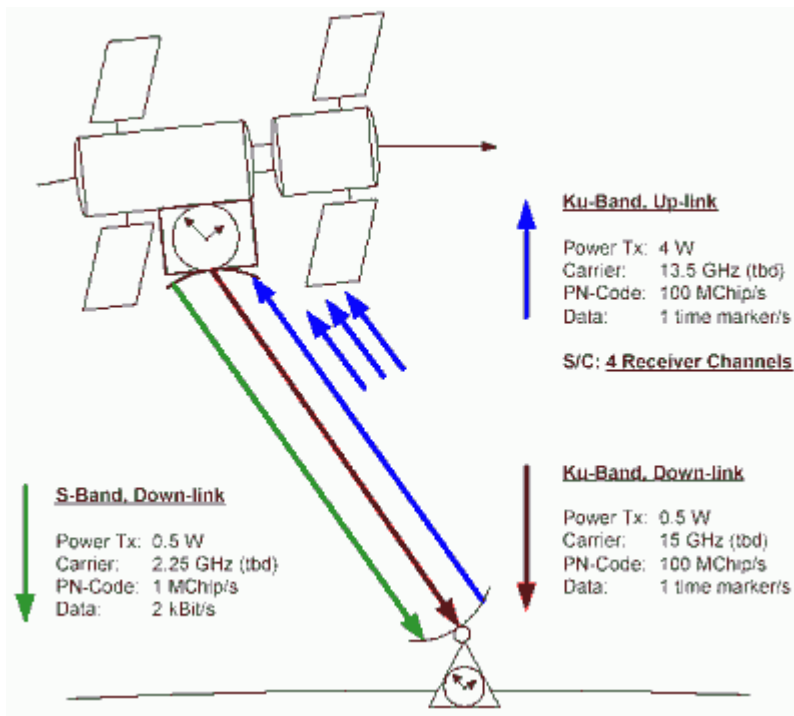
## 12. GALILEO: Time Service Augmentation



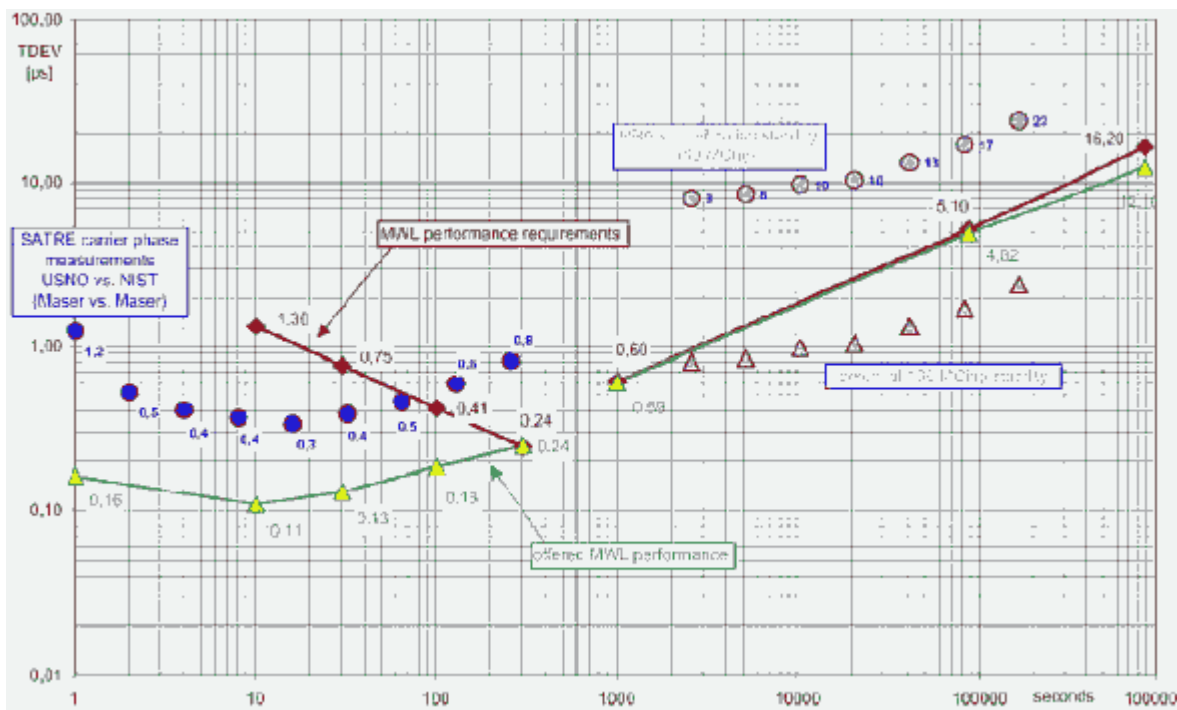
### 13. GALILEO: Support of Navigation Service (Ranging)



### 14. Future of TWSTFT: MWL for ACES (Atomic Clock Ensemble in Space)



## 15. Summary and Outlook (Atomic Clock Ensemble in Space)



## 16. Conclusions

- Method designed to achieve specified end-to-end accuracy
- TWSTFT relies mostly on direct measurements
- Residual errors can be minimised with simple models
- Time-proven and established operational reliability
- Fully recognised by national timing laboratories, incl. USNO (GPS) and BIPM
- Long-term experience and extensive performance characterisation available
- Covering: G/S equipment, real hardware, system operations, data evaluation etc.

### Applications



- Wide-Area (Computer) Time Synchronisation using Return-Channel Links
- Augmentation / Contribution to GALILEO's Time- and Navigation Services
- Time-Scale in space for worldwide use: (ACES, PARCS)
- Ideal means for Harmonisation of Time in Europe
  - Goal: Accuracy + Reliability comparable to GPS