31st Annual Precise Time and Time Interval Systems and Applications Meeting

New Trends in Two-Way Time and Frequency Transfer via Satellite

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1. Monitoring and Control, Operational Aspects

- Automatic Operation of TWSTFT modems
- Automatic schedule to cover multiple signal links
- Remote control via local area network or Internet
- Centralised monitoring and control facility
- Real-time data- and performance evaluation at control centre
- Unattended stations
- Remote transmitter shut-down
- Warnings, error reporting and error logging
- Redundancy, automatic fail-over, automatic LAN re-connect
- Compact dedicated ground station controlled by modem
- Support instrumentation controlled by modem

2. Real-Time Data Generation

- Data Exchange between stations via RF
- Real-time evaluation of TWSTFT formula: on-screen data display
- Data Reduction: 1st, 2nd and 3rd order regression
- Built-in Database and Data Storage
- Fast Time-to-Alarm for continuous operating systems:

2.5 MChip/s	3 ns @ 1 s
	1 ns @ 10 s
20 MChip/s	300 ps @ 1 s
	100 ps @ 10 s
Carrier Phase	15 ps @ 1 s

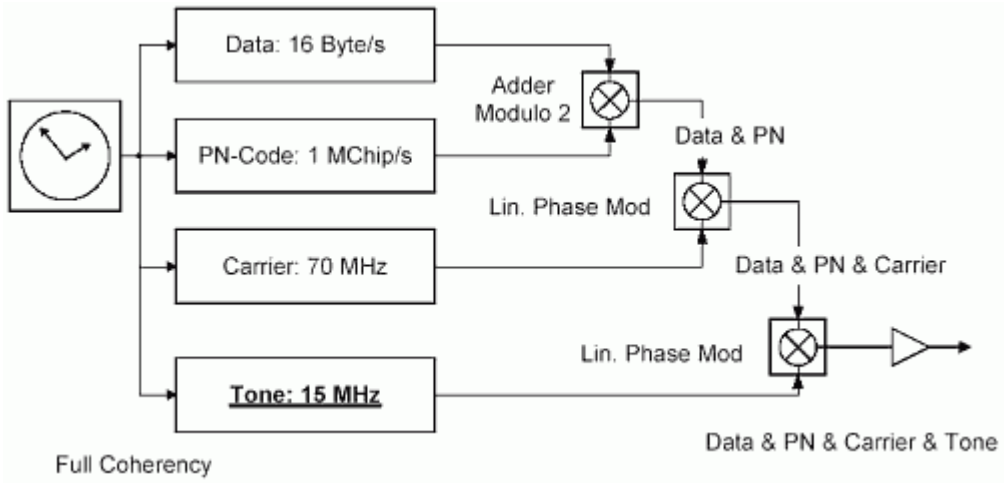
3. Co-Existence with Other Satellite Users

3.1. Higher Chipping Rates (up to 20 MChip/s)

- Max chip-rate adjusted to standard transponder bandwidth (~ 30 MHz)
- NO visible interference to Direct TV emissions at 20 MChip/s
- Direct TV Analogue FM: S/N - 30 dB
- Direct TV Digital: S/N - 23 dB
- NO interference to digital satellite services at 20 MChip/s S/N < - 20 dB

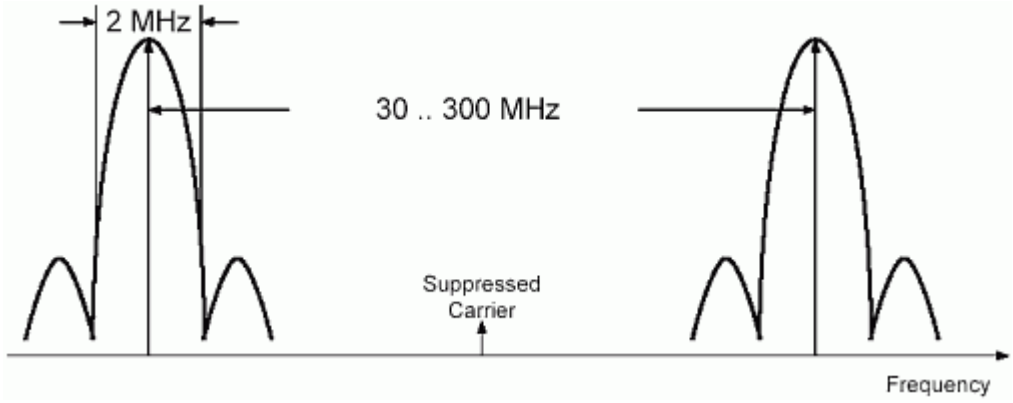
3.2. Spread-Spectrum with Tone Modulation

- New modulation scheme: PN-modulated Tone



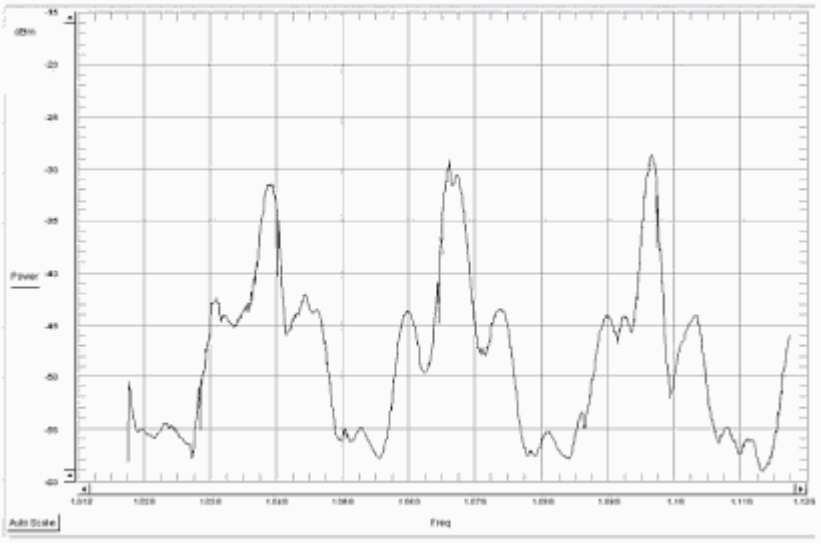
Spread Spectrum with Tone Modulation (continued)

- Tone: high precision, poor ambiguity: 30 ..300 MHz . 30 .. 3ns
- PN: full ambiguity resolution 1 MChip/s . 1µs
- Minimise spectrum requirements, optimise performance



Spread Spectrum with Tone Modulation (continued)

- PN-modulated tones may be located in guard bands between transponders



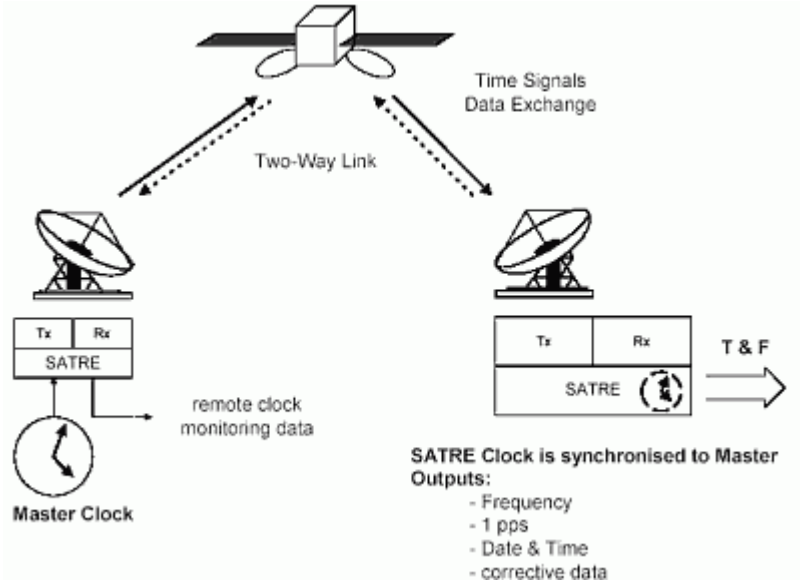
3.3. Combination with Satellite Services

- Ranging and Orbit Determination: Benefit to Sat-Operator
- Ground Segment and Network Synchronisation: Benefit to Sat-Users

- Time Labs shall NOT pay for transponder use

- Detailed negotiations with Satellite Operators and Satellite Owners required

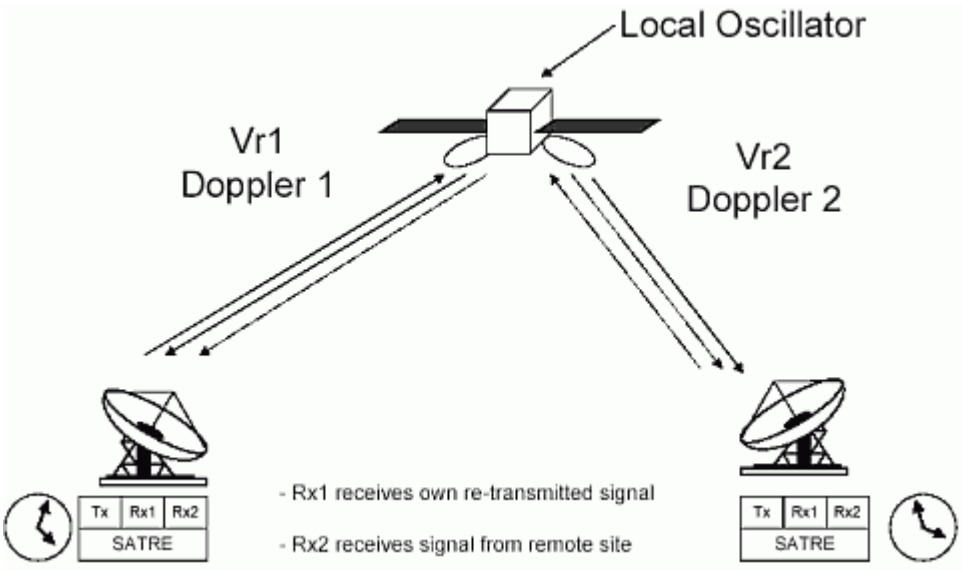
4. Two-Way Time Synchronisation via Satellite



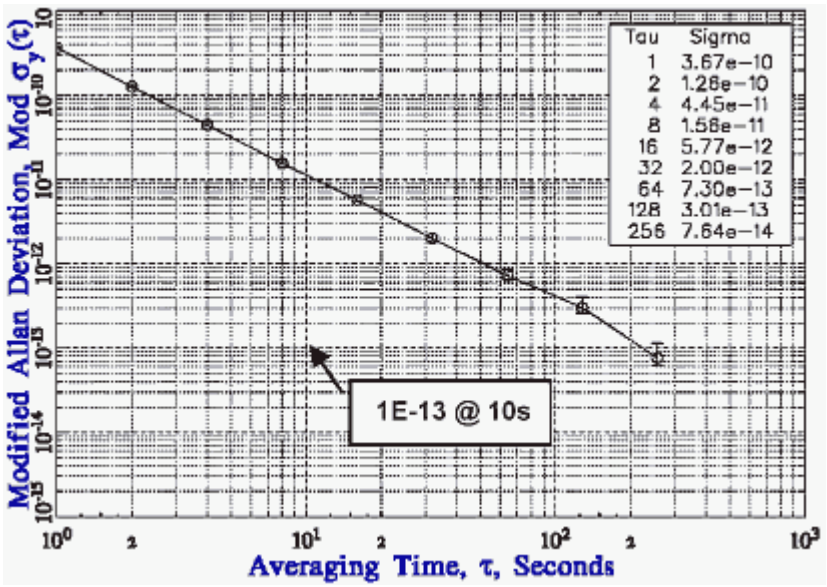
Two-Way Time Synchronisation (continued)

- Real-time application of TWSTFT method
- Clock at slave station may be internal or external to modem
- Reduce clock costs at slave station (crystal instead of atomic clocks)
- Maximise knowledge about clock at slave station
- Continuous / frequent operation maximises performance
- Time to alarm: 1 .. 10 s

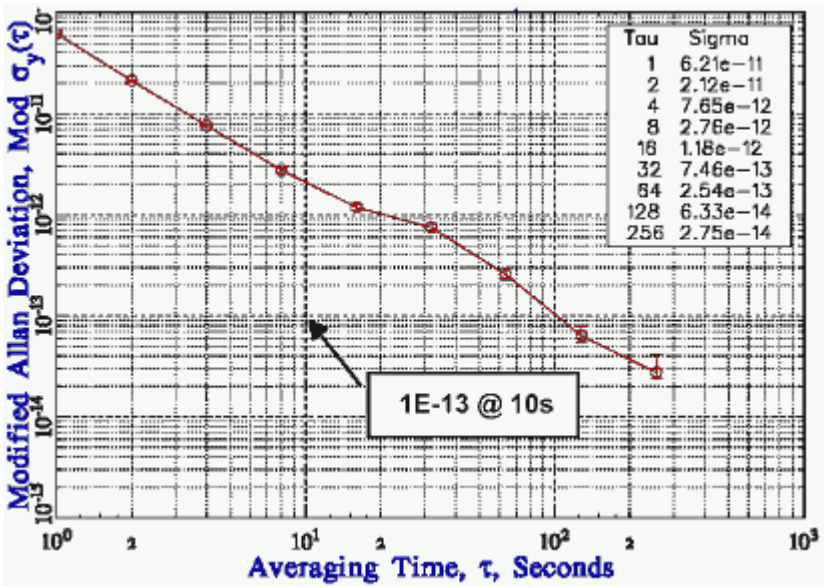
5. Two-Way Frequency Transfer using Carrier Phase



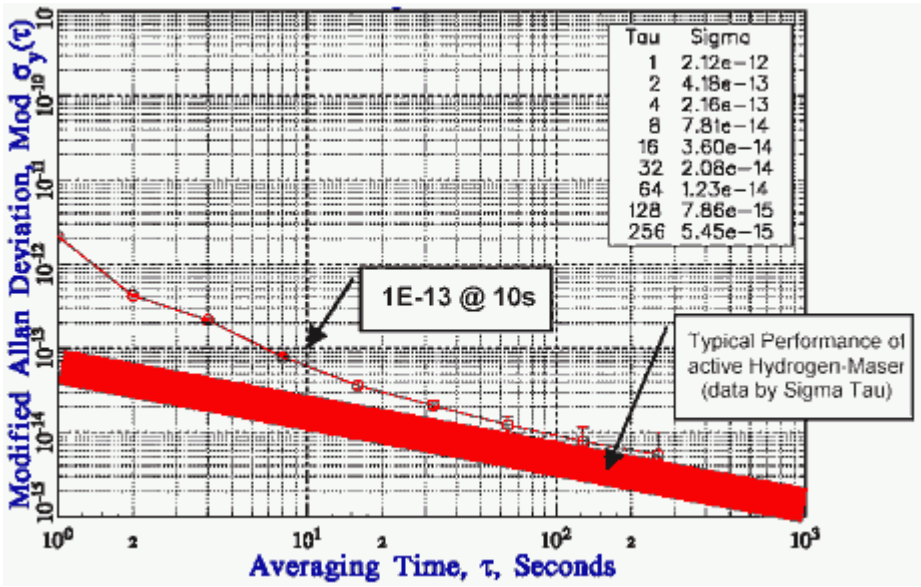
6. MDEV, PN-code 2.5 MChip/s, USNO <-> NIST



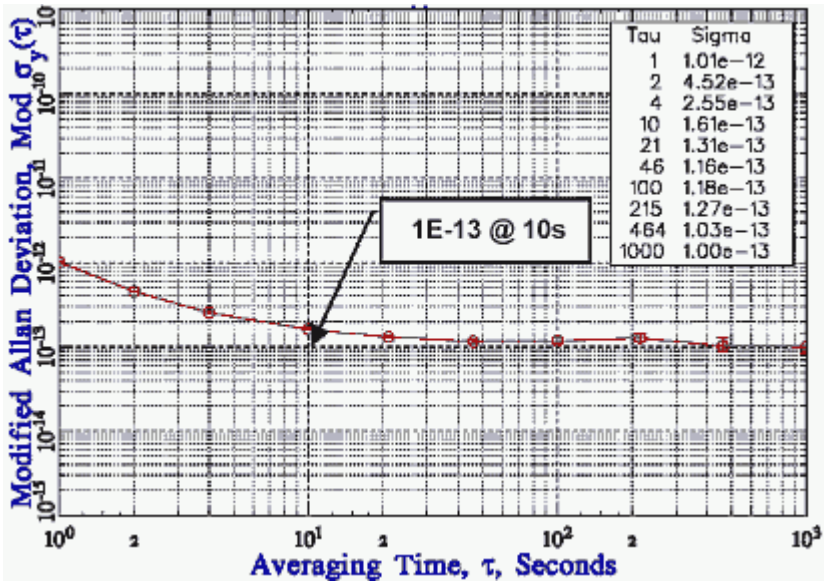
7. MDEV, PN-code 20 MChip/s, USNO <-> NIST



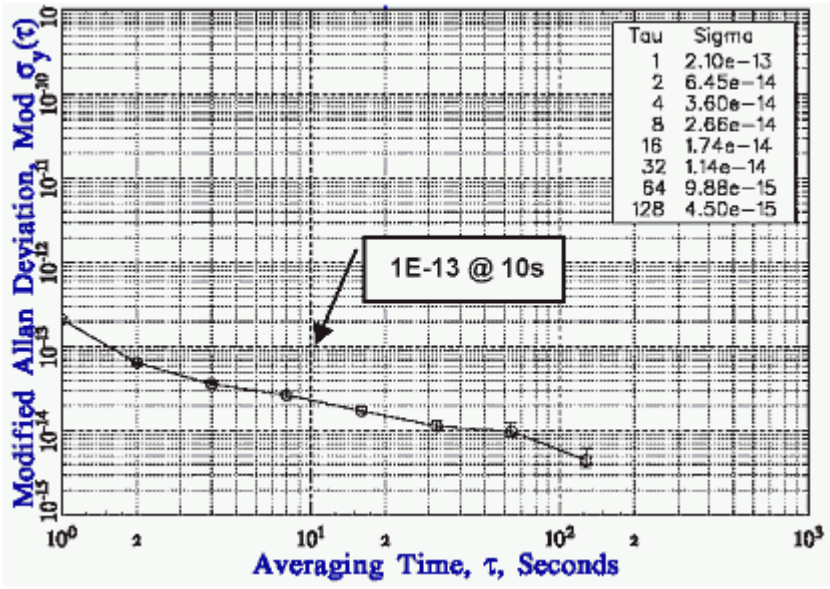
8. MDEV, Carrier Phase, Signal 2.5 MChip/s, USNO <-> NIST



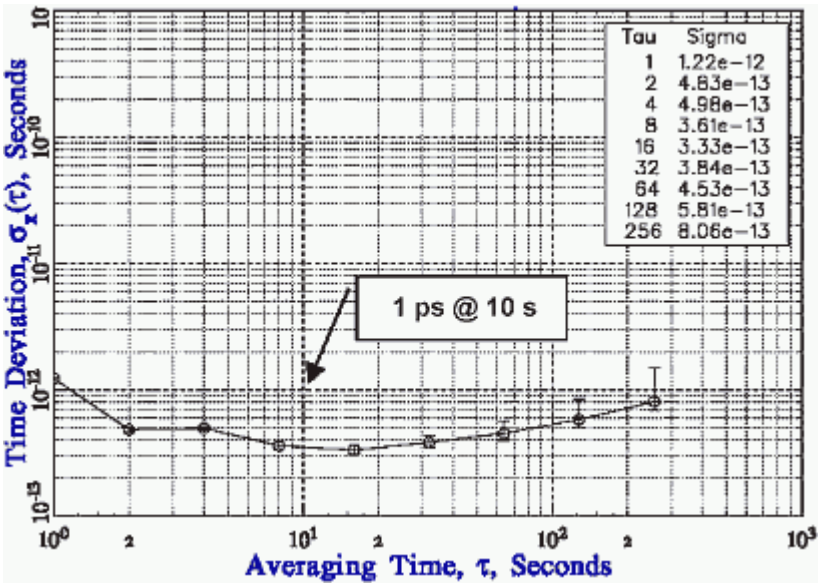
9. MDEV, Carrier Phase, Signal 5 MChip/s, PTB <-> DLR, Spring 1999



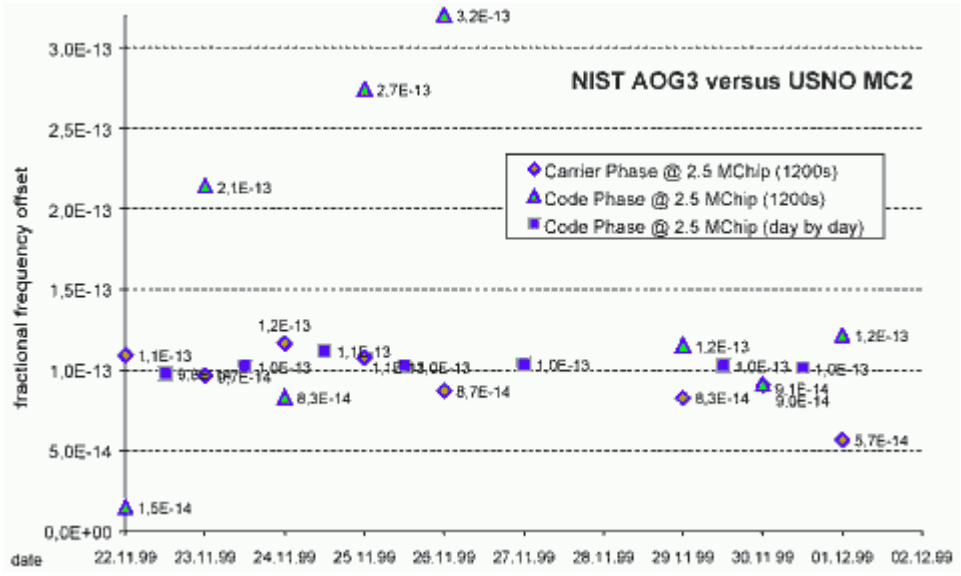
10. MDEV, Residual between Receiver Channels, at USNO



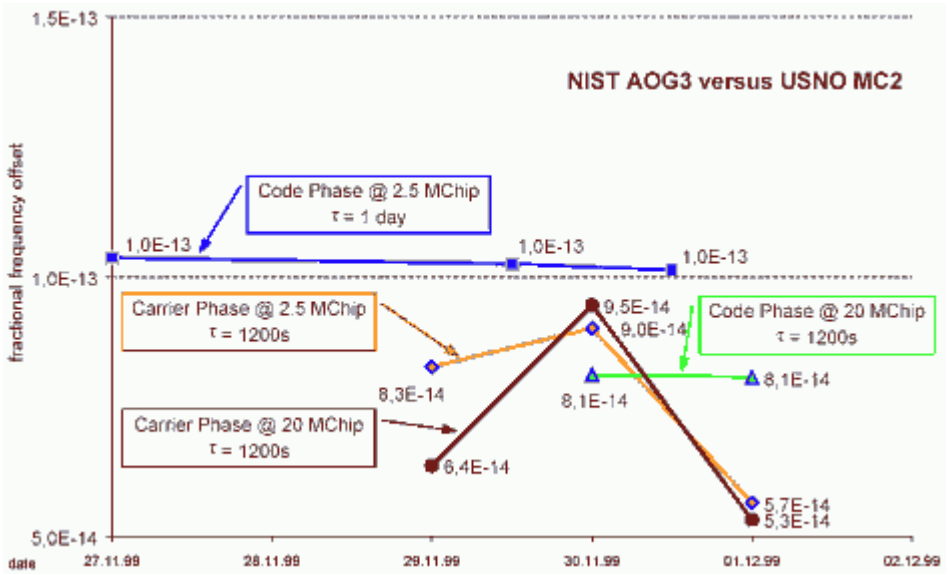
11. TDEV, Carrier Phase, Signal 2.5 MChip/s, USNO <-> NIST



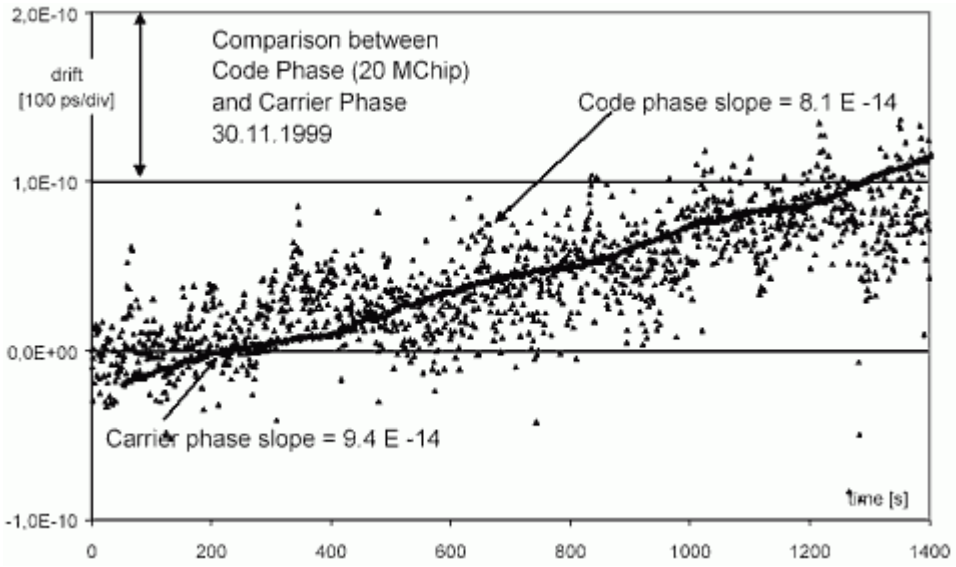
12. Frequency Transfer, PN versus Carrier Phase



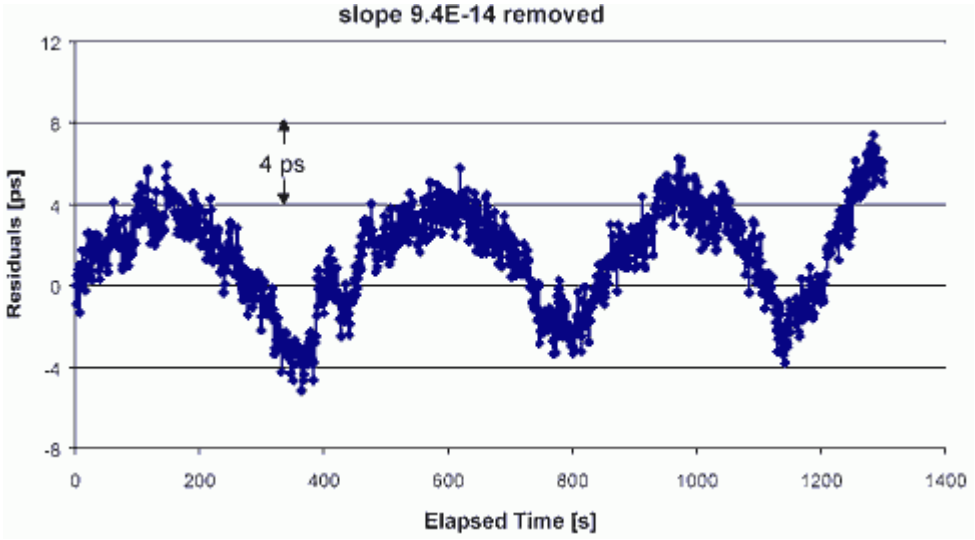
13. Frequency Transfer, PN 2,5 and 20 MChip versus Carrier Phase



14. Frequency Transfer, PN 20 MChip/s versus Carrier Phase, Detail



15. Frequency Transfer, Carrier Phase Residuals, 20 MChip signal



16. Summary, Frequency Transfer

MDEV	1s	100s
PN @ 2.5 MChip/s	4 E-10	4 E-13
PN @ 20 MChip/s	6 E-11	1 E -13
Carrier Phase	2 E-12	1 E -14

- 2-Way Carrier Phase Frequency Transfer
  rough accuracy: ~ 2 E – 14 @ 1200 s TWSTFT
  TDEV < 0.5 ps @ 2..100s
- Ground station and distribution systems become crucial for system performance

17. Conclusions

- TWSTFT ready to provide self-contained means for T&F transfer
- Operation and data handling fully automatic
- TWSTFT may be integrated into larger operational systems
- Satellite operators and time laboratories may benefit from each other
- Real-time operation allows very short time-to-alarm
- New modulation schemes reduce / eliminate transponder costs
- Accuracy may be improved by advanced modulation schemes
- 2-Way Carrier Phase: improvement of 10 w.r.t. code phase @ 20 MChip/s
- Satellite systems with ‘return-channel’ lead to very low-cost ground stations

18. Acknowledgements

This work was only possible due to invaluable support and continuous contributions by:

- USNO, United States Naval Observatory, Washington
- NIST, National Institute of Standards and Technology, Boulder
- SES, Société Européenne des Satellites, Luxembourg, Link PTB <-> DLR
- PTB, Physikalisch-Technische Bundesanstalt, Braunschweig
- DLR, Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen