IGS WORKSHOP
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Compensation of Ionospheric Effects for Frequency and Time Comparison using the ACES Microwave Link

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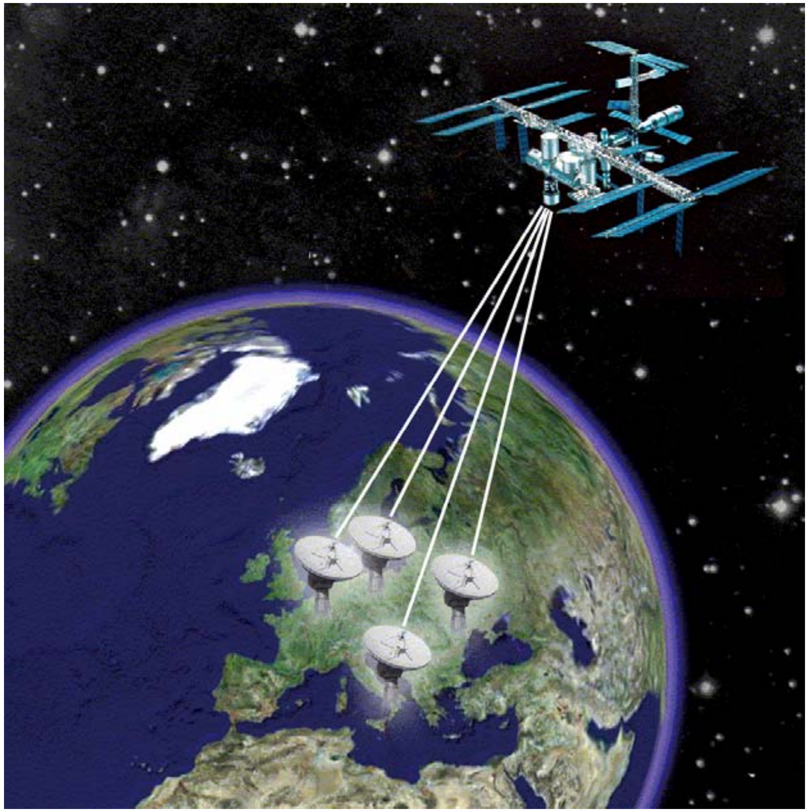
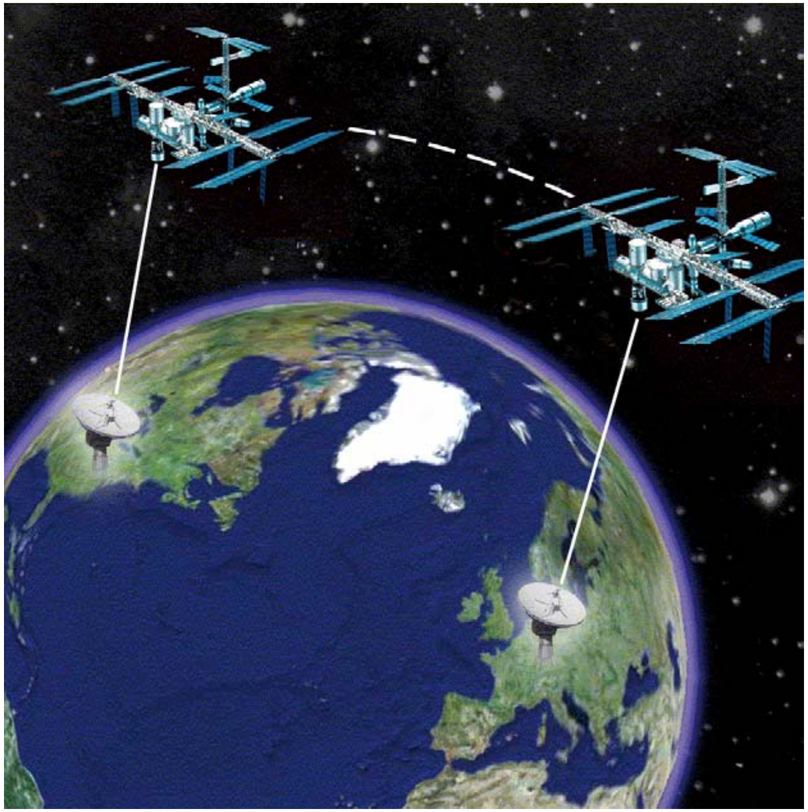
MWL Applications

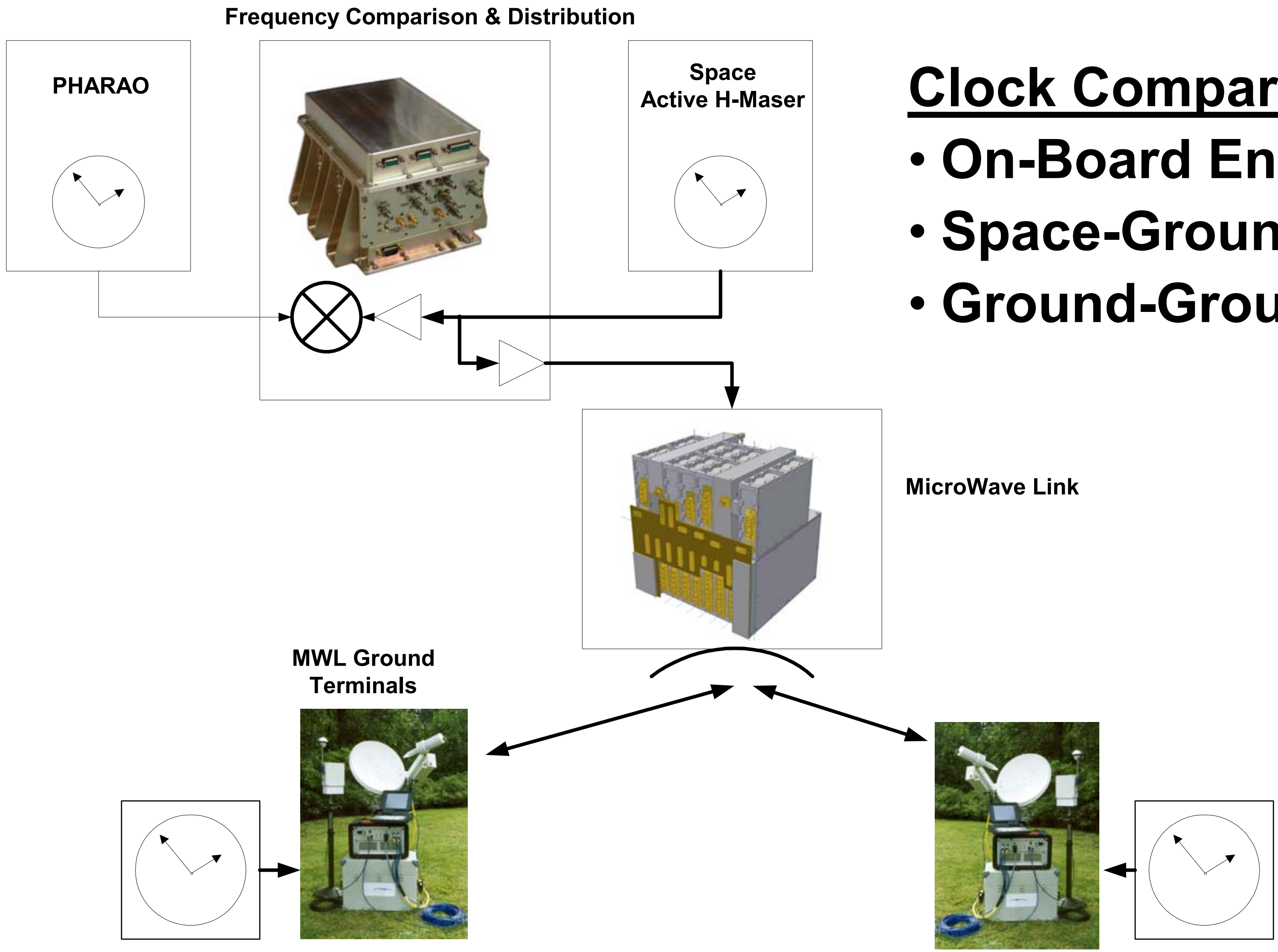




- Space-Ground
- Ground-Ground Common View

- Ground-Ground Non-Common View

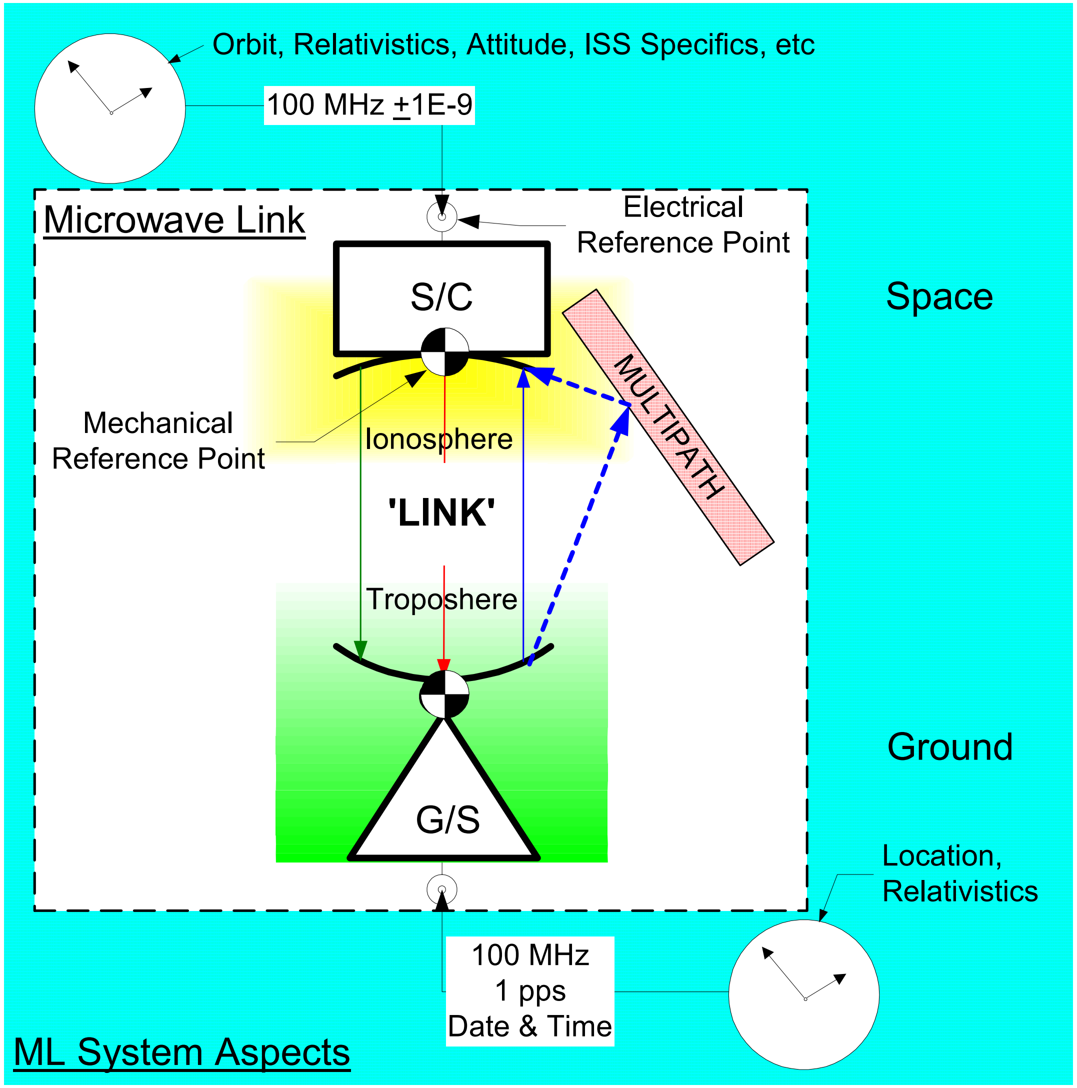
ACES: Clocks Involved



Clock Comparisons

- On-Board Ensemble
- Space-Ground
- Ground-Ground

MWL System Aspects



- Clocks „as is"
- Orbit
  - Distance
  - Velocity
  - Acceleration
- Signal Link
  - Ionosphere
  - Troposphere
  - Multipath
- Environment
  - Temperature

Performance Requirements (TDEV)

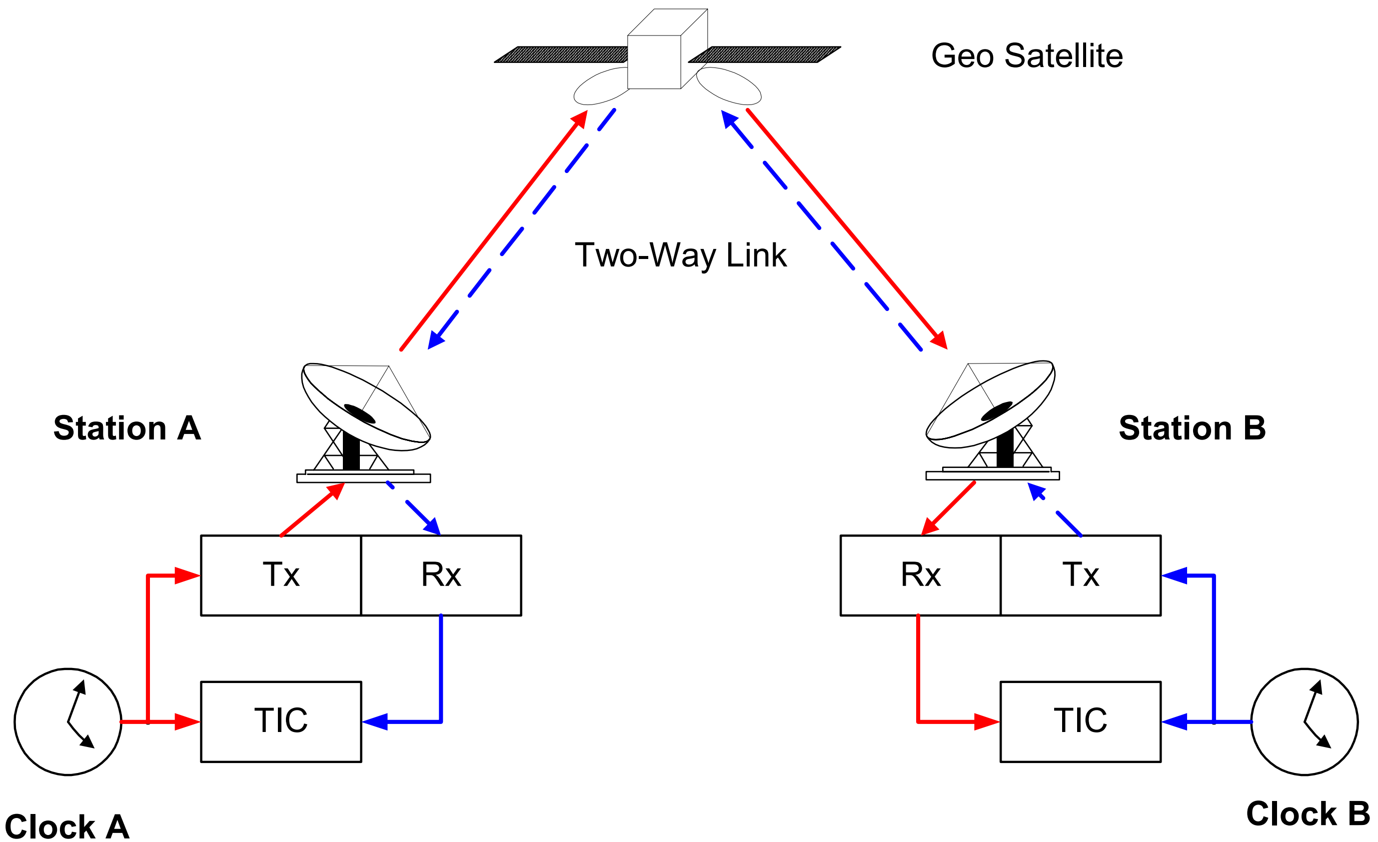
- Short Term: **230 fs / pass**
  - Driven by Maser: one pass (300s)

$$\sigma_x(10\ s \leq \tau \leq 300\ s)_{MWL} \leq 4{,}1 \times 10^{-12} \times \tau^{-1/2}$$

- Long Term: **5.5 ps / orbit**, 16 ps / 10 d
  - Driven by Pharao: > 1 orbit

$$\sigma_x(1orbit < \tau < 15\ days)_{MWL} \leq 1{,}7 \times 10^{-14} \times \tau^{+1/2}$$

Principle of TWSTFT (Ground – Ground)



Double Difference between simultaneous measurements

Direct read-out of time-dfference between remote clocks

Well established method for ground-ground and ground-space

Benefits from Bi-directional Link

- Directly measure Time Difference (do not model)
- Works equally well for Ground-Ground and Ground-Space Links
- Allows for Clock Monitoring without knowledge of the orbit
- Provides (precise) Time- and (accurate) Frequency comparison
- Independent from relative
  - Location
  - Distance
  - Velocity
- Inherently includes Ranging function (sum of up- und down-link)
- Elegant separation between Clock- and Orbit Errors
- Residual Errors are due to Link- and other Asymmetries
- Design Tasks:
  - Minimise amount and value of Asymmetries to best extent
  - Detect and correct for each Asymmetry
  - Perform direct measurements rather then rely on modelling
  - Do not rely on orbit data (attitude data is required only, S- vs. Ku)

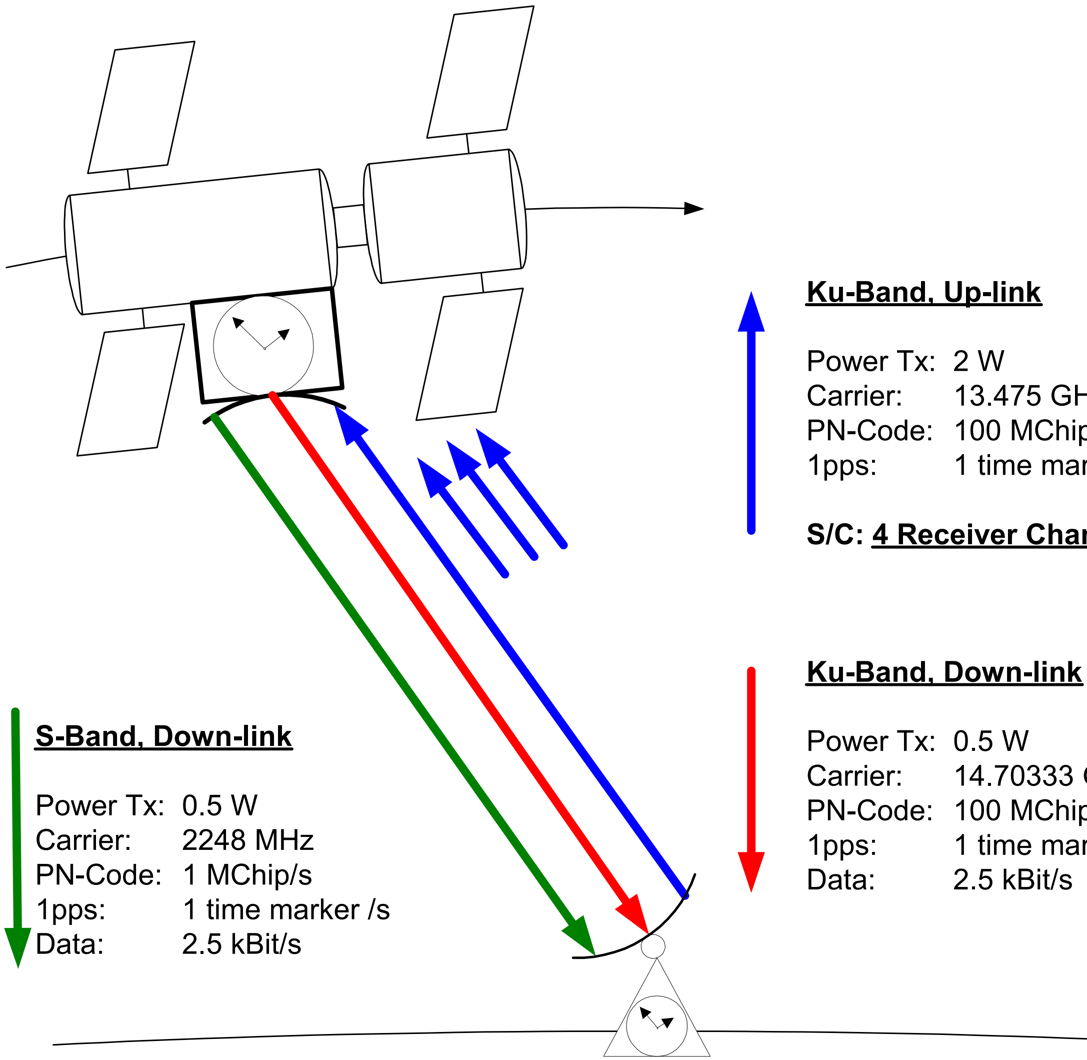
Measurement Method

Extend TWSTFT to operate in dynamic environment

- Continuous PN coded emissions and signal reception
- Fully coherent signals: code, carrier & measurements
- High Chip-rate 100 MChip/s to suppress potential Multi-path
- High Carrier Frequencies
- High **ratio** between the two frequency bands

1. Ku Code + Carrier phase (at both ends)
2. S Code + Carrier phase (at ground)
3. Count carrier cycles differentially (ground)
4. Perform Carrier Cycle Identification
5. Time-tag all data w.r.t. local clock
6. Evaluate asymmetries

Signal Links, Ku up/down + S-band



Ku-Band, Up-link

Power Tx: 2 W
Carrier: 13.475 GHz
PN-Code: 100 MChip/s
1pps: 1 time marker /s

S/C: 4 Receiver Channels

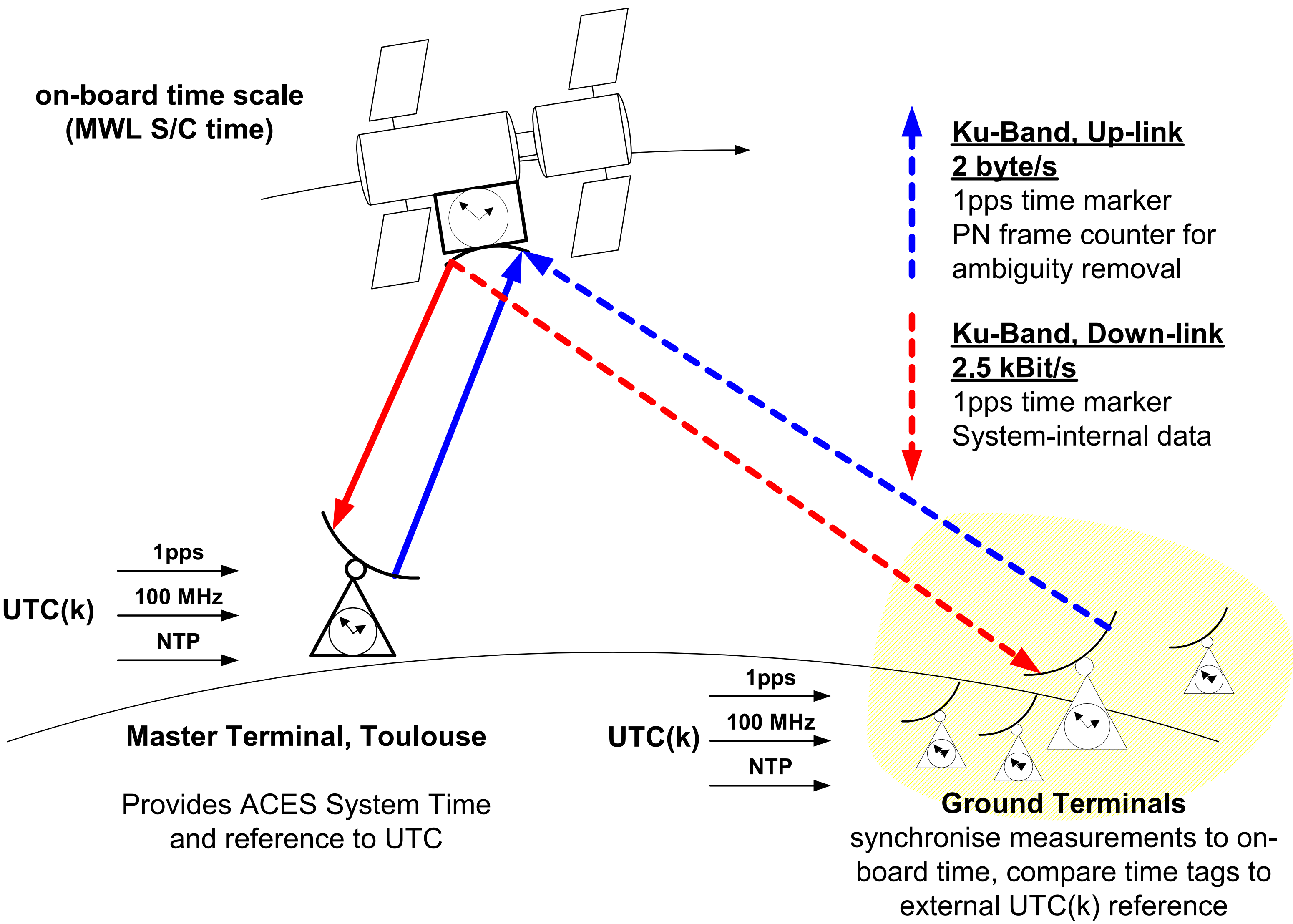
Ku-Band, Down-link

Power Tx: 0.5 W
Carrier: 14.70333 GHz
PN-Code: 100 MChip/s
1pps: 1 time marker /s
Data: 2.5 kBit/s

S-Band, Down-link

Power Tx: 0.5 W
Carrier: 2248 MHz
PN-Code: 1 MChip/s
1pps: 1 time marker /s
Data: 2.5 kBit/s

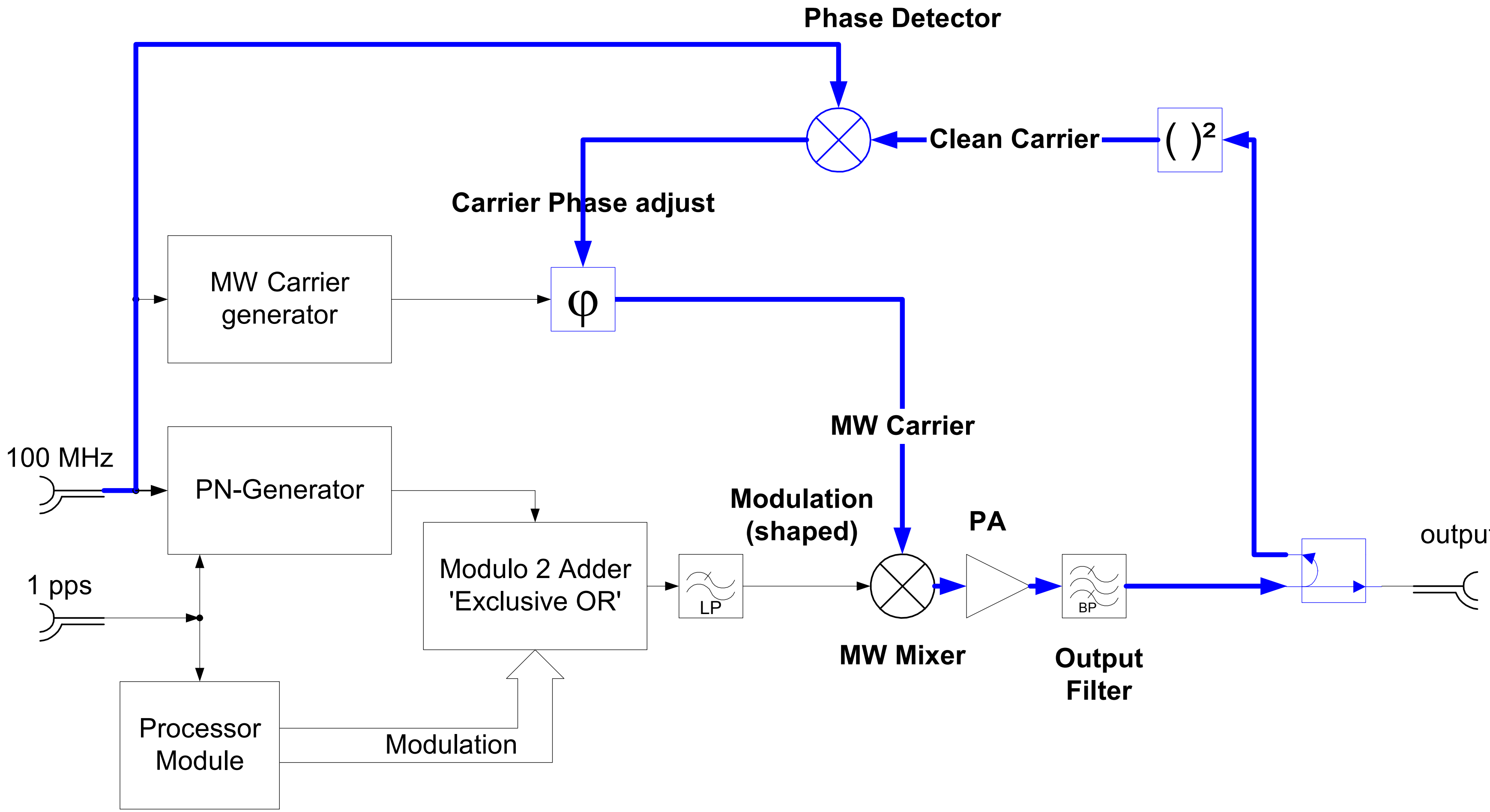
Operations and Time-Tagging



Link Characteristics

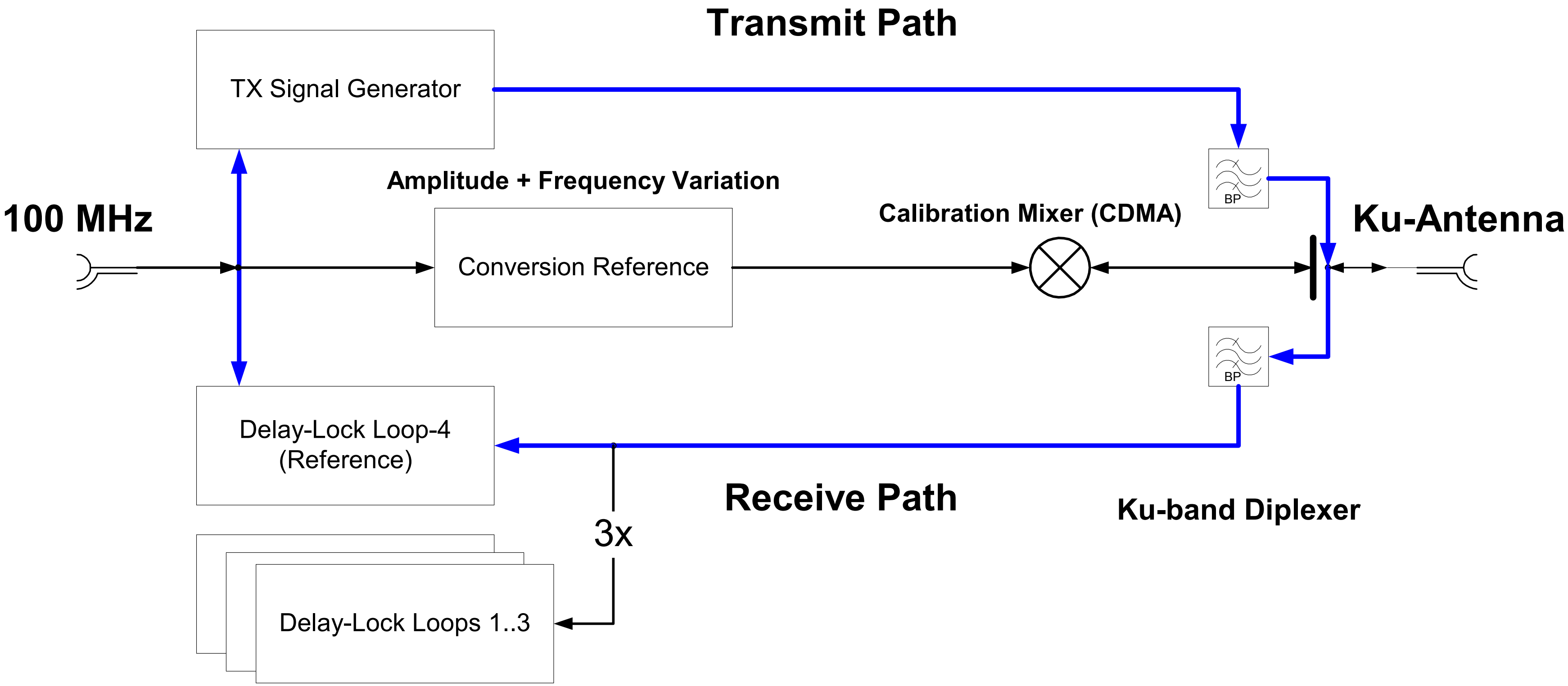
Band	Ku-Band	S-Band
Received C/No @ 10°	~47.8 dBHz	~50 dBHz
Carrier noise @ 1s, 10°	0.09 ps	0.45 ps
Carrier Doppler, max.	+/- 400 kHz	+/- 58 kHz
Carrier Doppler rate, max.	6.5 kHz/s	1 kHz/s
Code noise @ 1s, 10°	29 ps	2.23 ns
Code Doppler, max	+/- 2700 Hz	+/- 27 Hz
Code Doppler rate, max	44 Hz/s	0.4 Hz/s

Coherent Signal Generation



Full coherency to ext. reference & carrier phase stabilisation scheme

Continuous Delay Monitoring



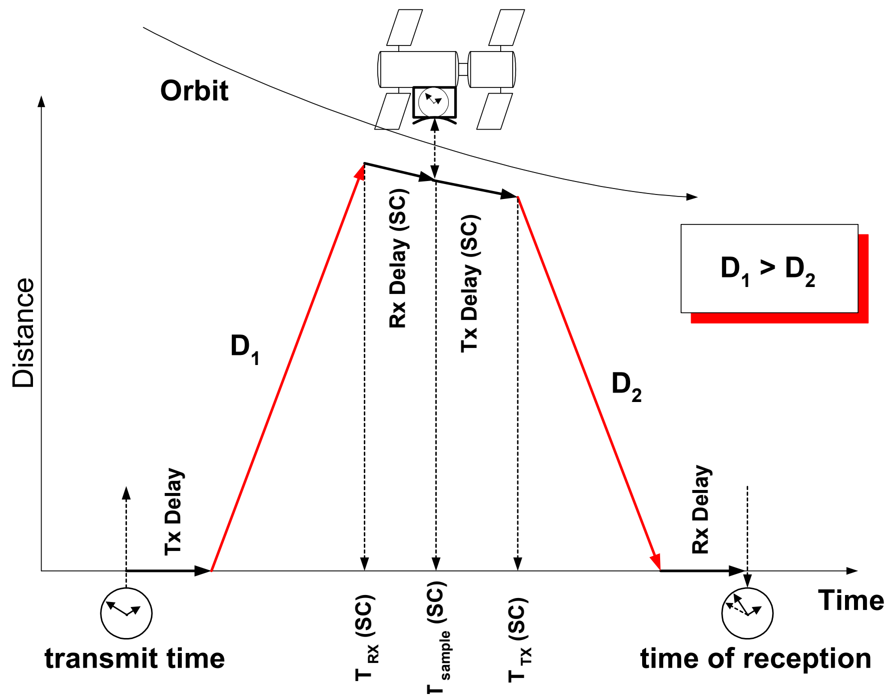
Calibration Mixers in each equipment (Space and Ground)

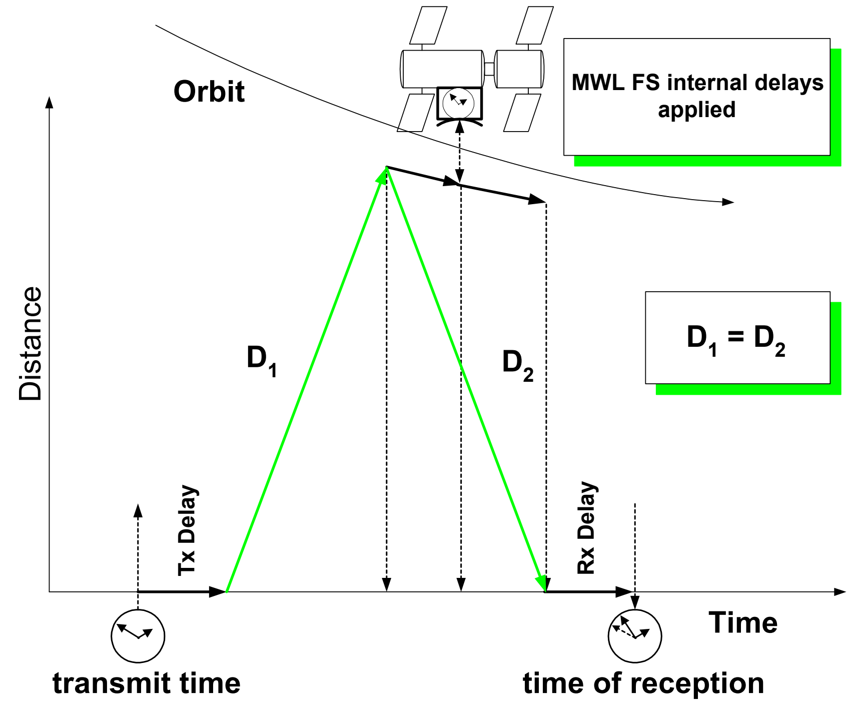
Continuous monitoring of equipment delay, even during pass

Covers code- and carrier phase

Allows in-flight (re-)calibration of AM/PM and delay vs Doppler

Match Up- and Downlink Paths





Asymmetry due to mismatch between Up- and Downlink path lengths

Asymmetry corrected by post-processing (Lambda Configuration)
a) Delay Variation (curvature)
b) proper shifting of time tags along orbit

Ionosphere Detection and Removal

ONLY the Difference between Ku-band Up- and Down-link is relevant

- Total Effect in Ku-Band: 800 .. 1100 ps
- Difference between Up/Down: 150ps (max), 22ps (avg)
- Total electron content (TEC) affects **time transfer** pass-to-pass

Measure TEC by S-band versus Ku-band code-phase

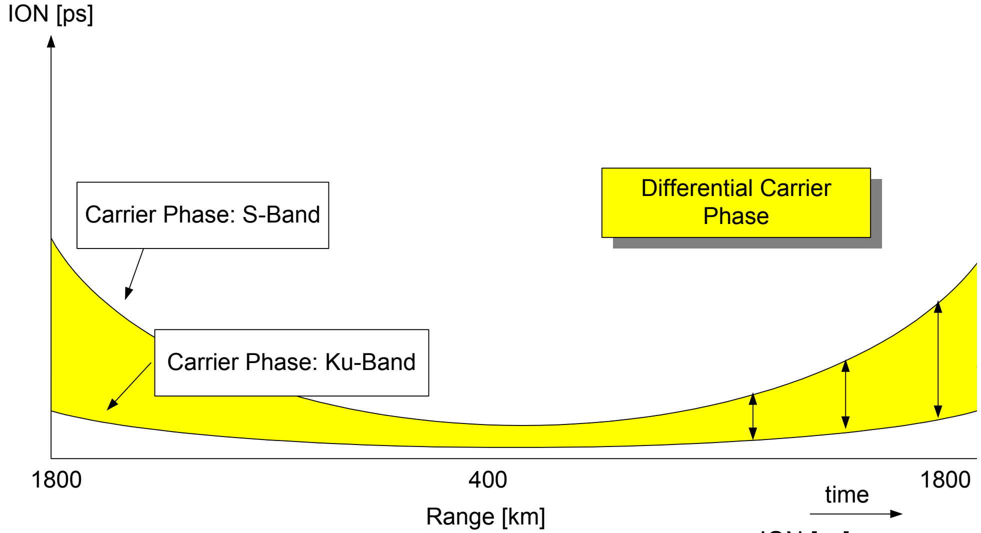
- Change of TEC affects **frequency transfer stability** within one pass
- Use two independent methods to measure **TEC variation**

S-band versus Ku-band differential carrier-phase (dual band)

DRVID: Differenced Range vs Integrated Doppler (single band)

- Corrections are derived for each signal link, separately for each G/T
- DRVID detects multi-path (presence & level) at the same time

Dual Frequency Differential Phase vs DRVID



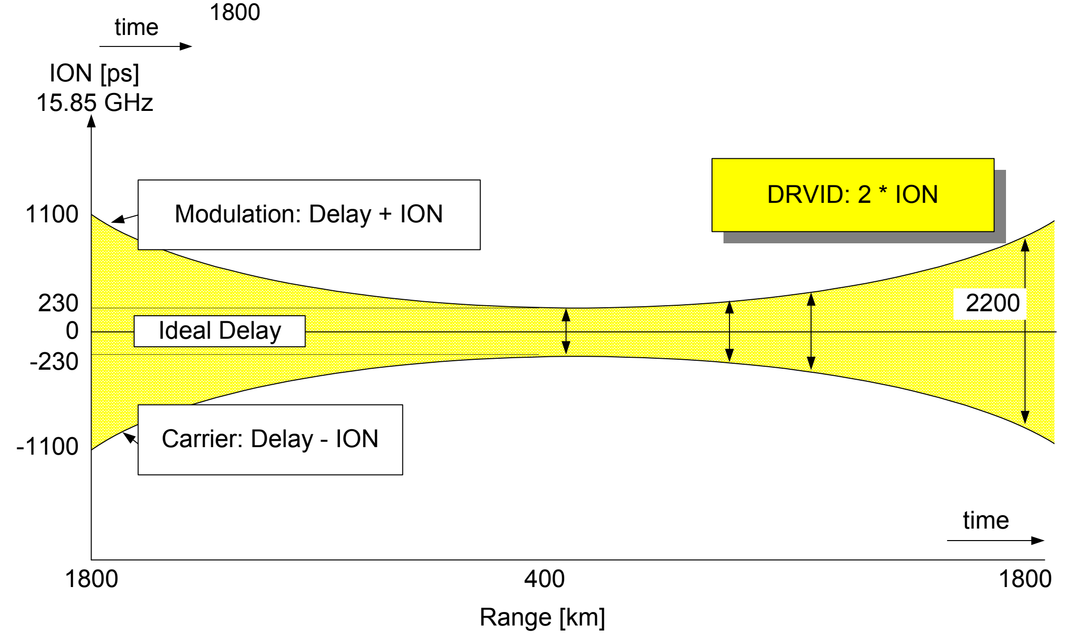
Dual-Band (left)

TEC

Code vs Code

TEC variation

Carier vs Carrier

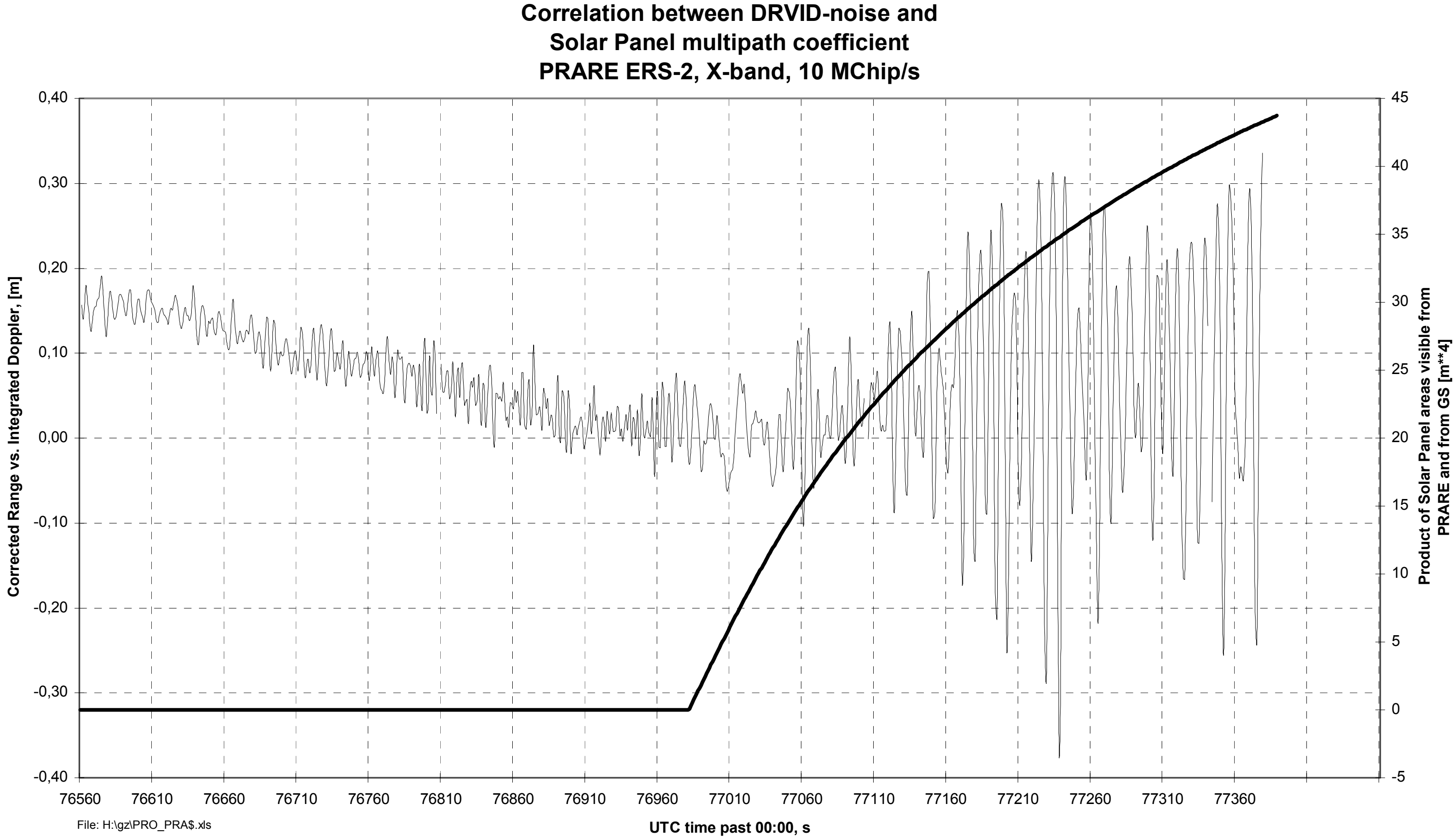


Single-Band (right)

- **TEC variation**

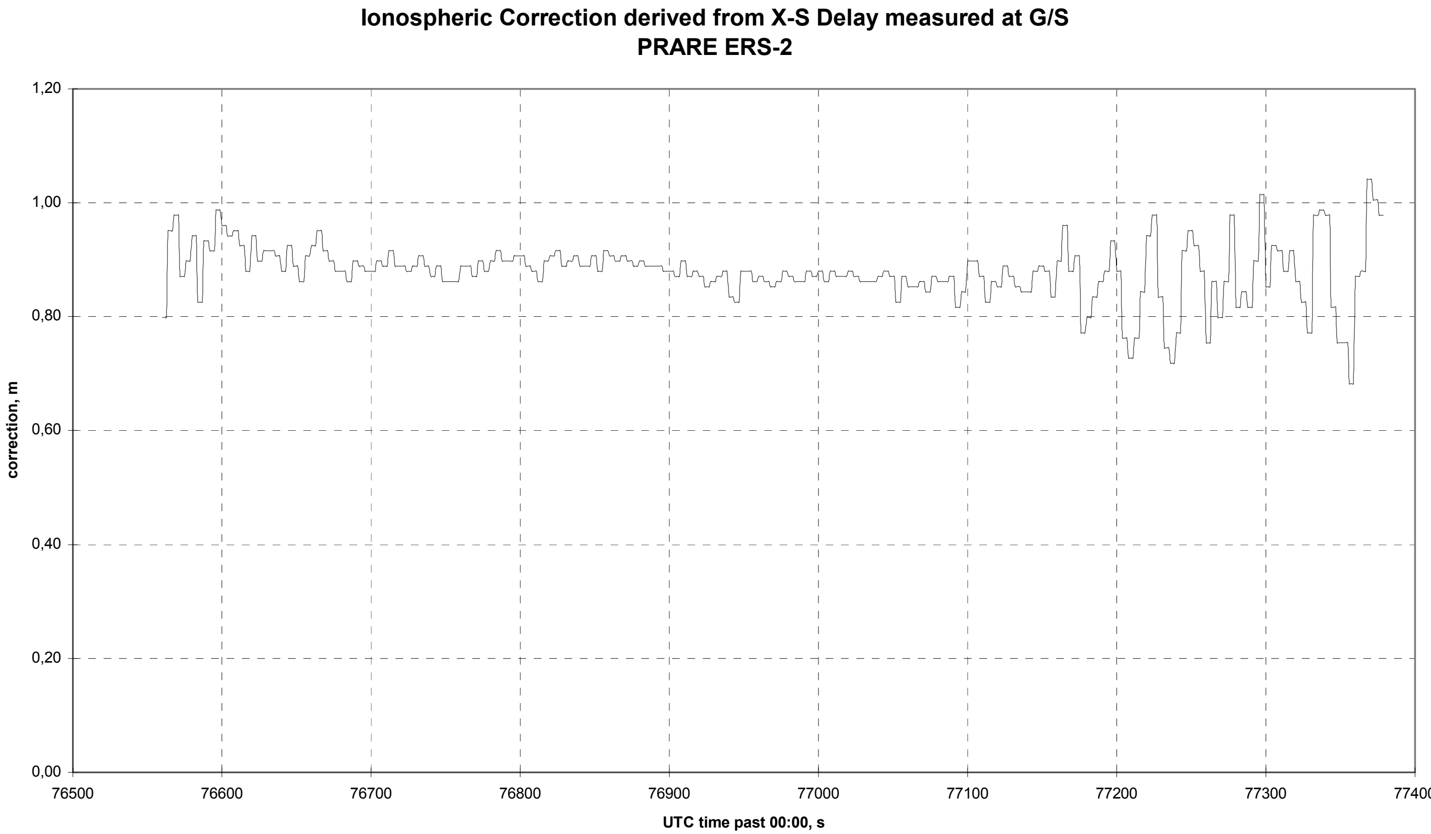
  Carrier Phase vs Code Phase
- **Effect doubled**

Use of DRVID to detect Signal MP (PRARE ERS-2)



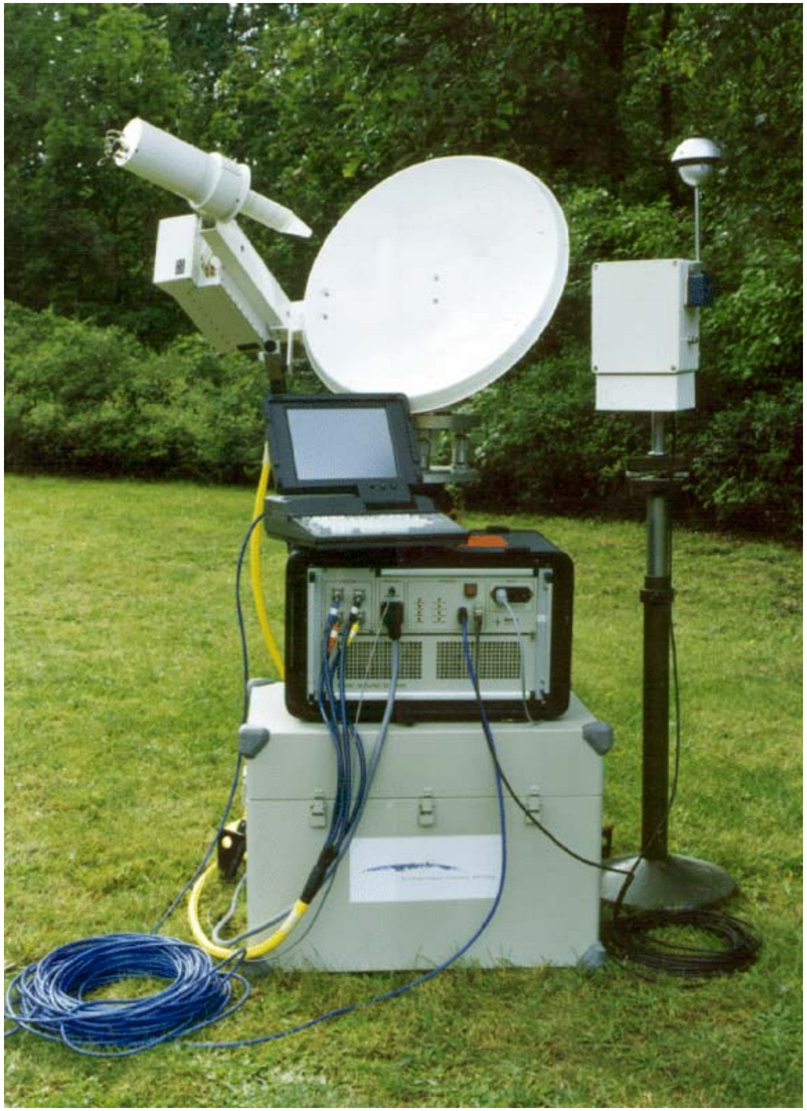
- Measured date, single pass, left to right
- General curvature, start to end of pass: **TEC variation**
- Noise increase mid to end of pass: MP due to solar panel

Determine absolute S vs X Delay (PRARE, ERS-2)



- **Absolute Dealy Calibration** in flight for each Ground Station
- Use curve fitting between measured Range- and TEC variation
- Value is constant during mission: Long integration time

Ground Terminal Layout (PRARE)

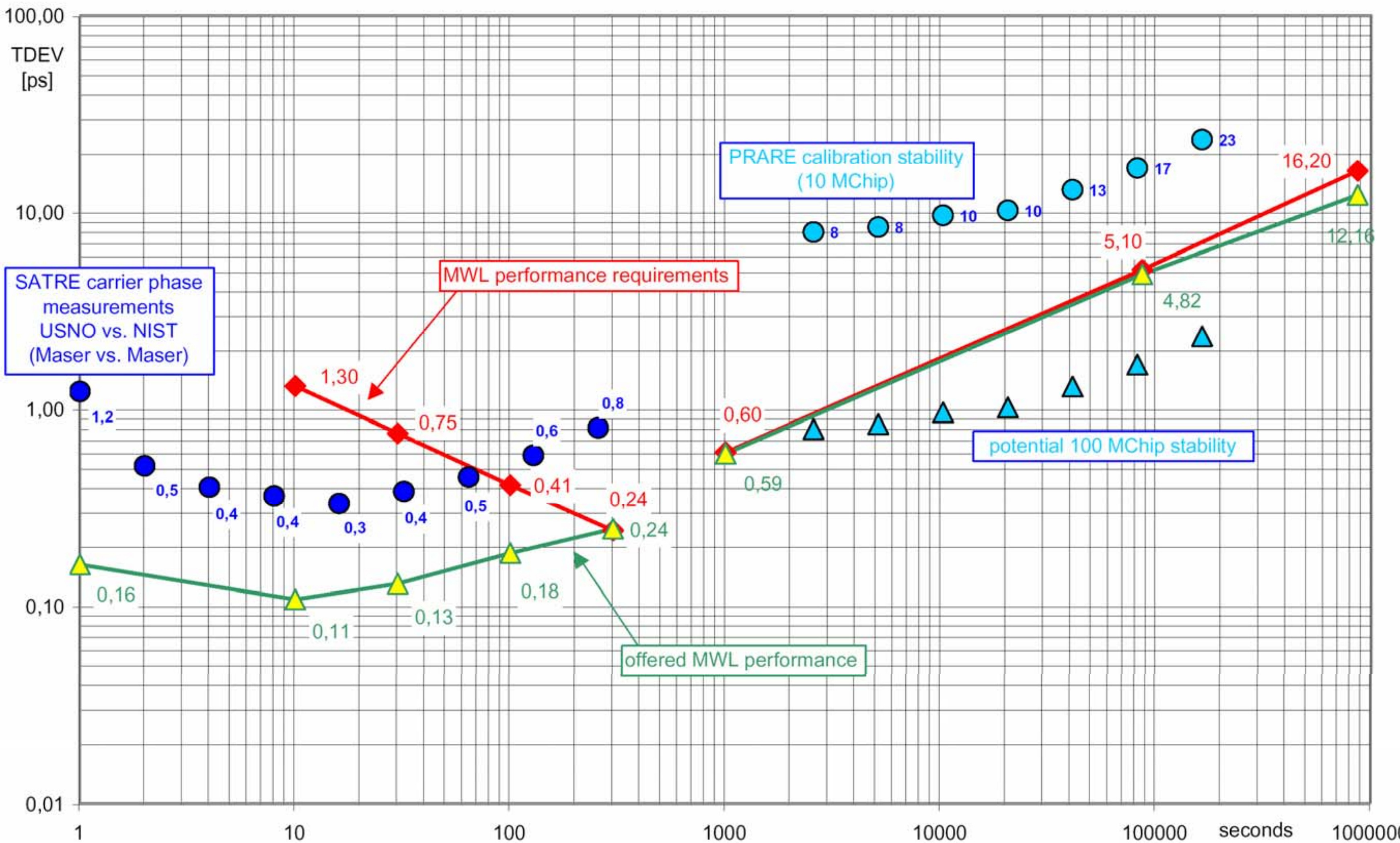


- Antenna 40 cm dia
- T&F reference
  - 100 MHz
  - 1pps
  - NTP & LAN
- **Local Sounding of lower Ionosphere**

  even without good ground clock

  receive-only mode possible

Performance Perspective: TDEV [ps]



Conclusions

- Key Elements and concepts verified during previous Missions (PRARE) and
  TWSTFT / Ranging Applications (SATRE)
- ACES MWL Phase B finalised
- MWL-FS Demonstration Model built, presently under functional and performance verification
- No major showstoppers found
- Next Phase until Spring 2007 leads to the Engineering Model

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