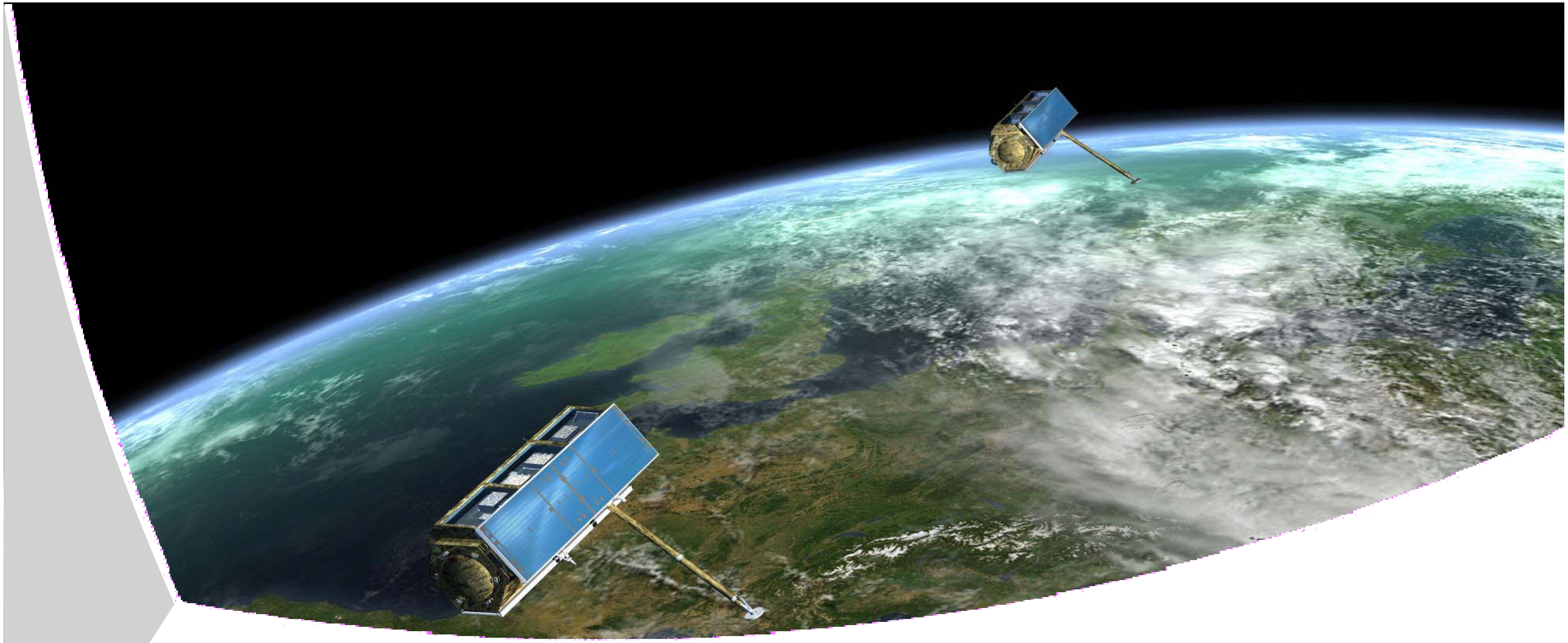

TerraSAR-X Internal Calibration Experience and Extension for TanDEM-X

TANDEM-X CALIBRATION

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Microwaves and Radar Institute

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28/11/2008

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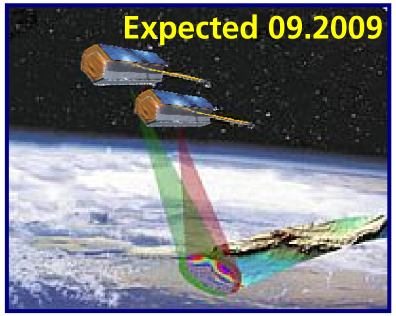
TerraSAR-X Experience

+ TanDEM-X

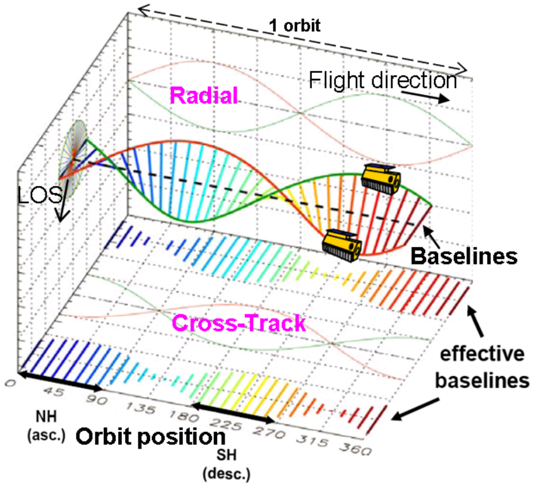


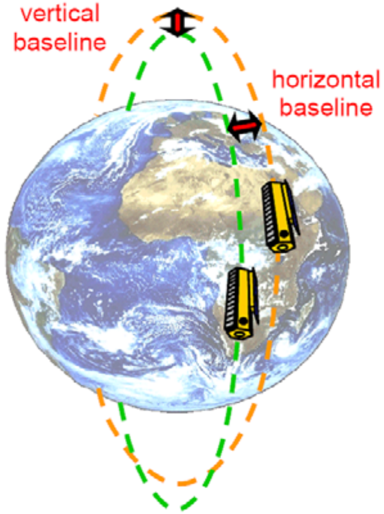
- German SAR satellite TerraSAR-X for global earth observation
- Challenges:
  - high resolution
  - flexible mode operation
  - high product quality
- Requirements achieved:
  - **Stability** of the **instrument**
  - Accurate external and **internal calibration**
- **TanDEM-X EXTENSION for DEM**
  - Second identical satellite
  - **DEM height requirements**

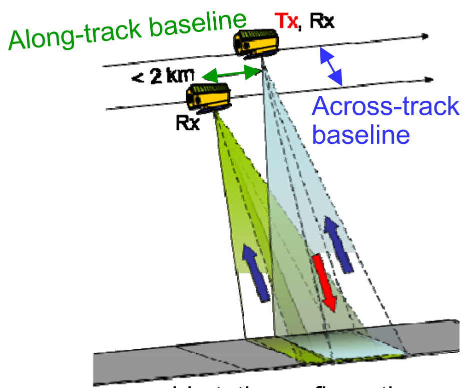
Centre Frequency	9.65 GHz
Chirp Bandwidth	max. 300 MHz
Antenna Array	12 Panels x 32 Rows (384 T/R Modules)
Polarisation	H and V
Incidence Angle Range	15°-60°
Imaging Modes	StripMap, ScanSAR, Spotlight
Radiometric Stability (since 1.5 years)	**< 0.2dB** - (spec. 0.9)
Radiometric Accuracy	**< 0.7dB** - (spec. 1.1)
Phase Drift Knowledge	**< 1°** - (spec. 5)
TanDEM-X DEM requirements – HRTI-3	
Absolute vertical accuracy (global)	10m (90%)
Relative vertical accuracy (100 km x 100 km)	**2m** (90% point-to-point)

TanDEM-X Mission

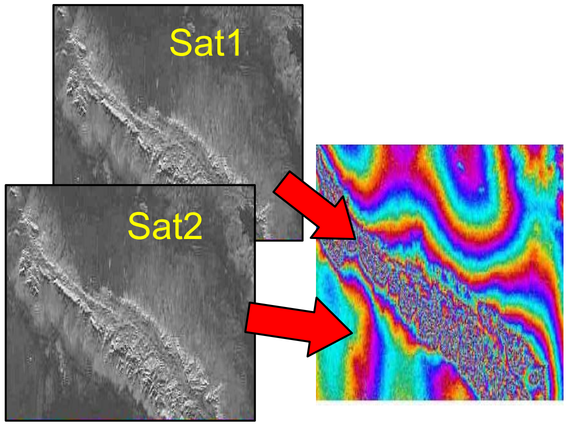
- Characteristics:
  - Close helix formation for X-track interferometry: baselines ~250m
  - Collision avoidance → orbits never cross: Δvertical separation in poles, Δhorizontal in equator



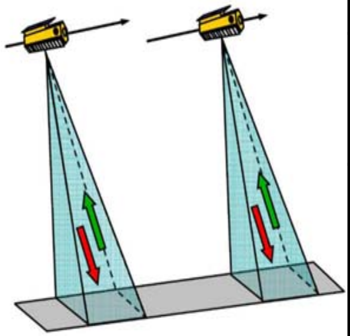




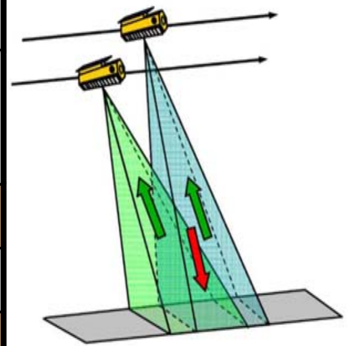
- Objectives
  - Global acquisition of X-track bi-static images
  - Coherent interferogram generation → **synchronisation**
  - DEM with HRTI-3 accuracy → **DEM Calibration** and **phase drift reduction** to correct height errors
  - Both satellites capable TSX mono-static acquisitions → experience TerraSAR-X



TanDEM-X Operation and Height Error



	Mono-static operation	Bi-static operation
SAR operation	TSX: Tx+Rx, TDX: Tx+Rx	Sat 1: Tx+Rx, Sat 2: Rx only
Accuracy requirements	Same as TSX: geometric, radiometric and phase	Additional effort due to DEM requirements
Average DT duration	~5-10s	~140s
Replica	Mono-static like TSX	Bi-static
Cal-network phase drift	< 1°	> 2°



- Height error budget →

Relative height error requirement	2m (90%)
Performance losses	~1.8m (90%)
DEM adjustment	0.53m (σ)

height references accuracy < 0.4m (σ)

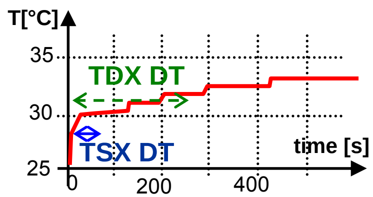
- Residual ICAL phase drift → DEM height error
  - h_{amb} = 35m, $\Delta\varphi$ = 2°, **Δh = 0.2m**

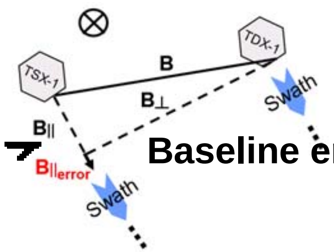
$$\Delta h = \frac{h_{amb}}{2\pi} \cdot \Delta\varphi$$

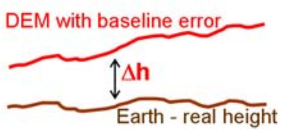
- Avoid fast changes
- Limit of budget

Phase Error Nature TanDEM-X – DEM Errors

Error Sources	Magnitude	Phase variation speed relative to DT duration	Correction methods
Phase Noise and **Performance** losses Residual errors of ICAL, Baseline and Sync	~1.4m	Fast Random	After **Averaging** pixels and DTs **Multilooking**
Instrument drifts	~dm	Medium-Fast Systematic Medium-Slow	☆ **Special effort ICAL** **DEM Calibration** least-squares adjustment model and height references
Baseline errors	~m	Very slow Constant offsets	On-ground/in-flight characterization DEM Calibration and GCP





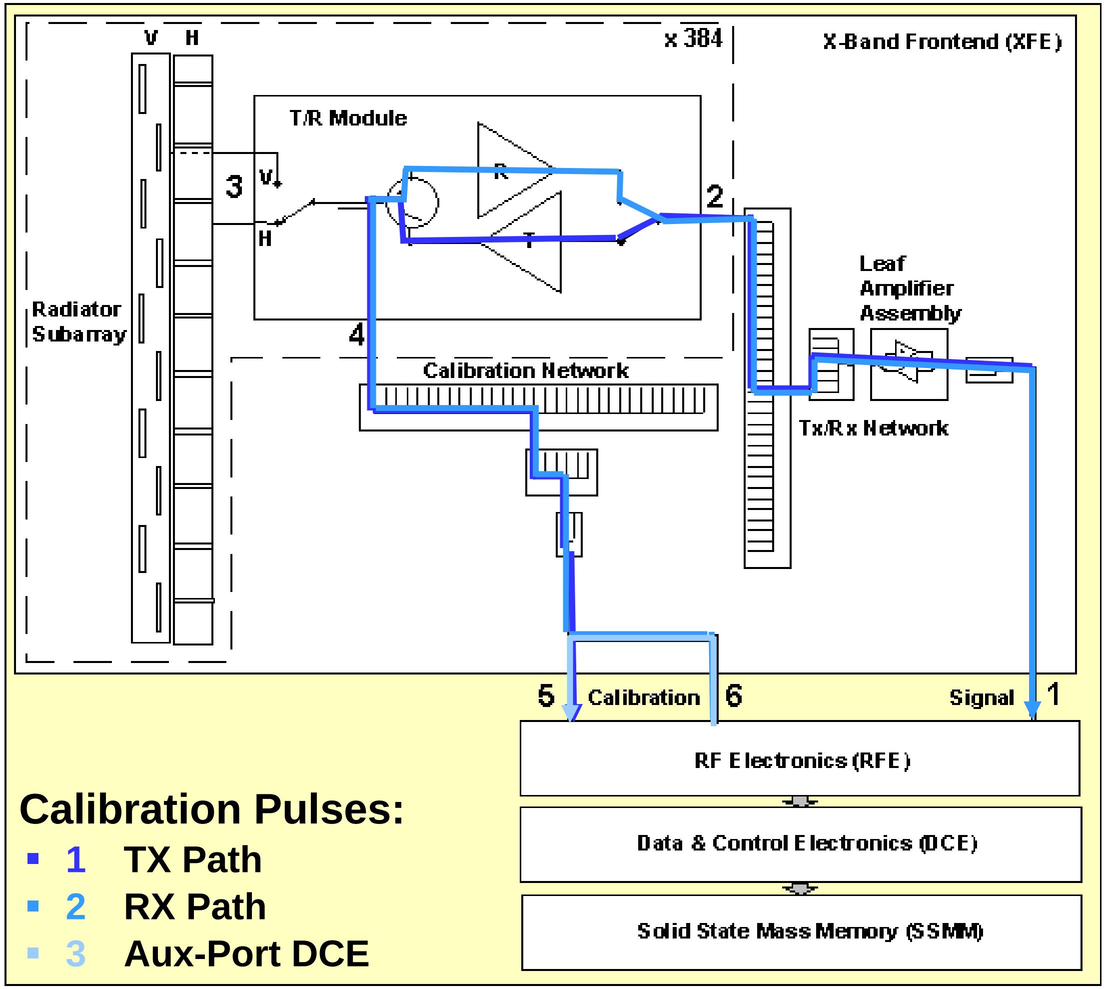


Internal Instrument Calibration

- T/R Modules can be adjusted in gain and phase for **beam steering**/shaping
- Radar pulses can be looped via calibration network to **characterise the radar path** under nominal conditions

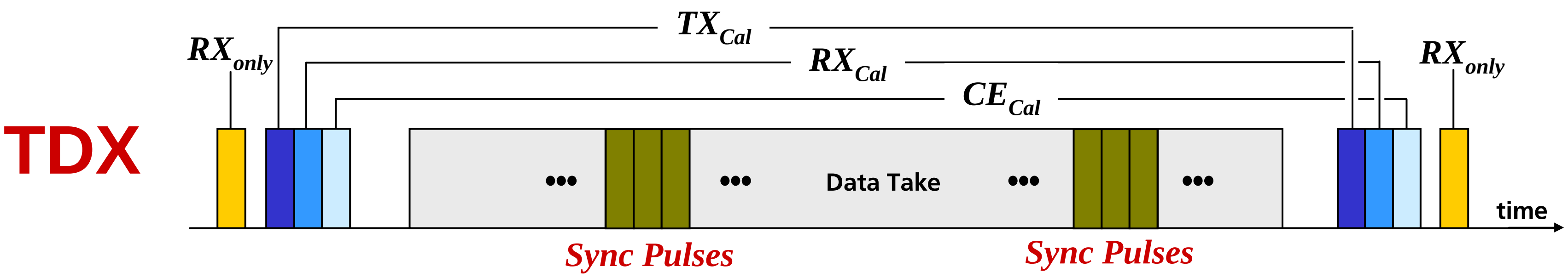
Compensation of Radar Instrument Drift

Individual T/R Module Characterisation



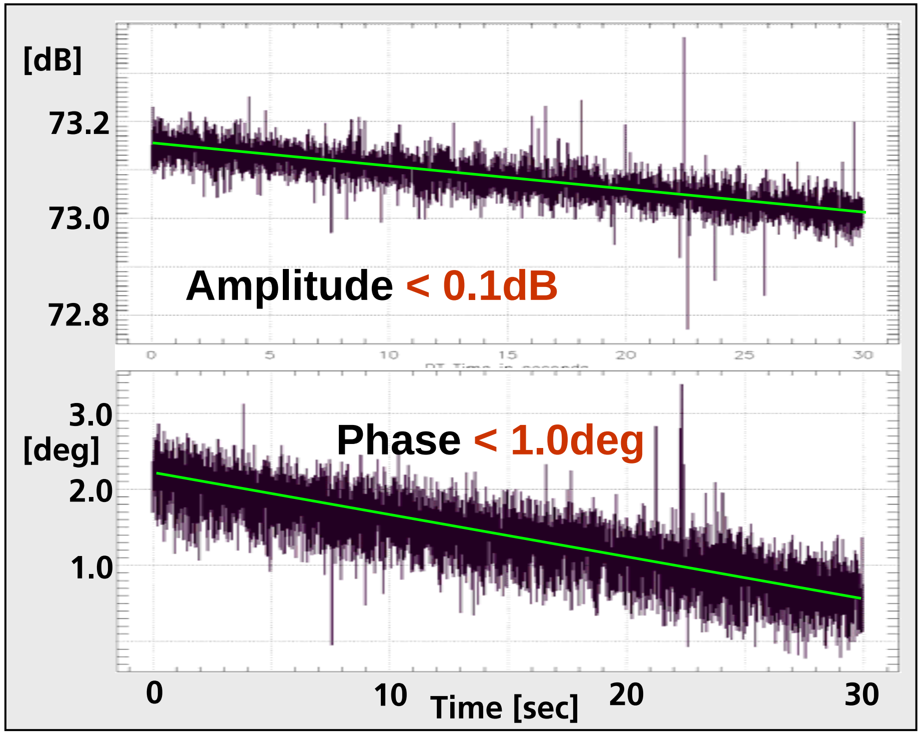
Calibration Pulses:
- 1 TX Path
- 2 RX Path
- 3 Aux-Port DCE

Internal Calibration TSX – TDX

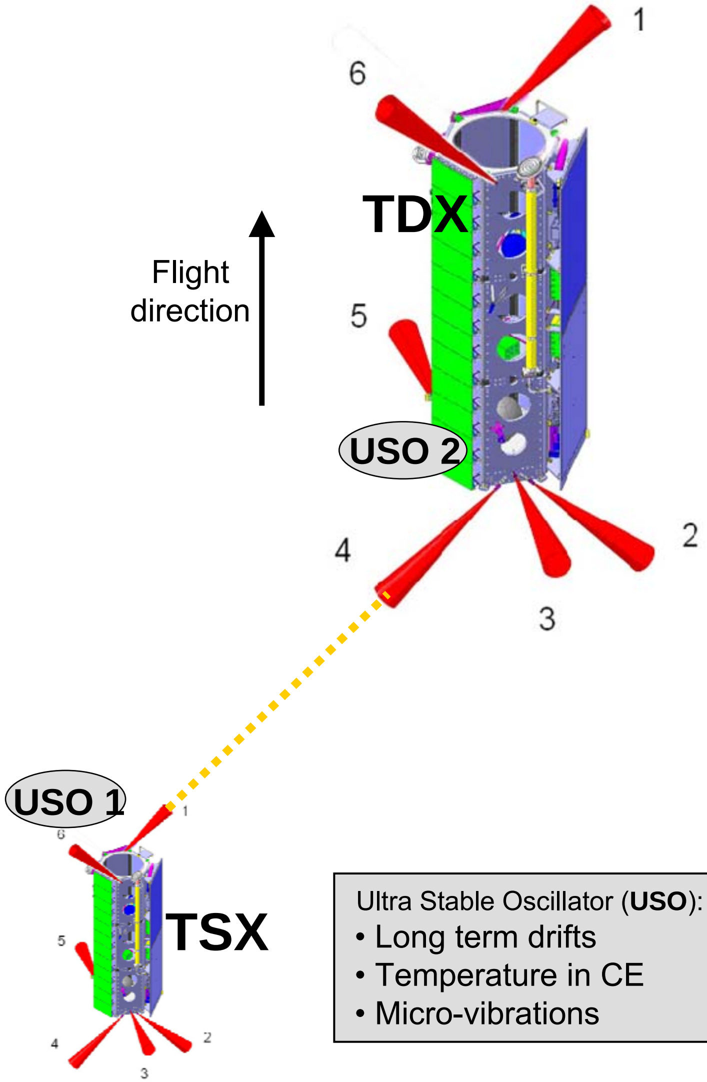


- **Replica** for range compression
- **Gain/Phase behaviour** of instrument over time

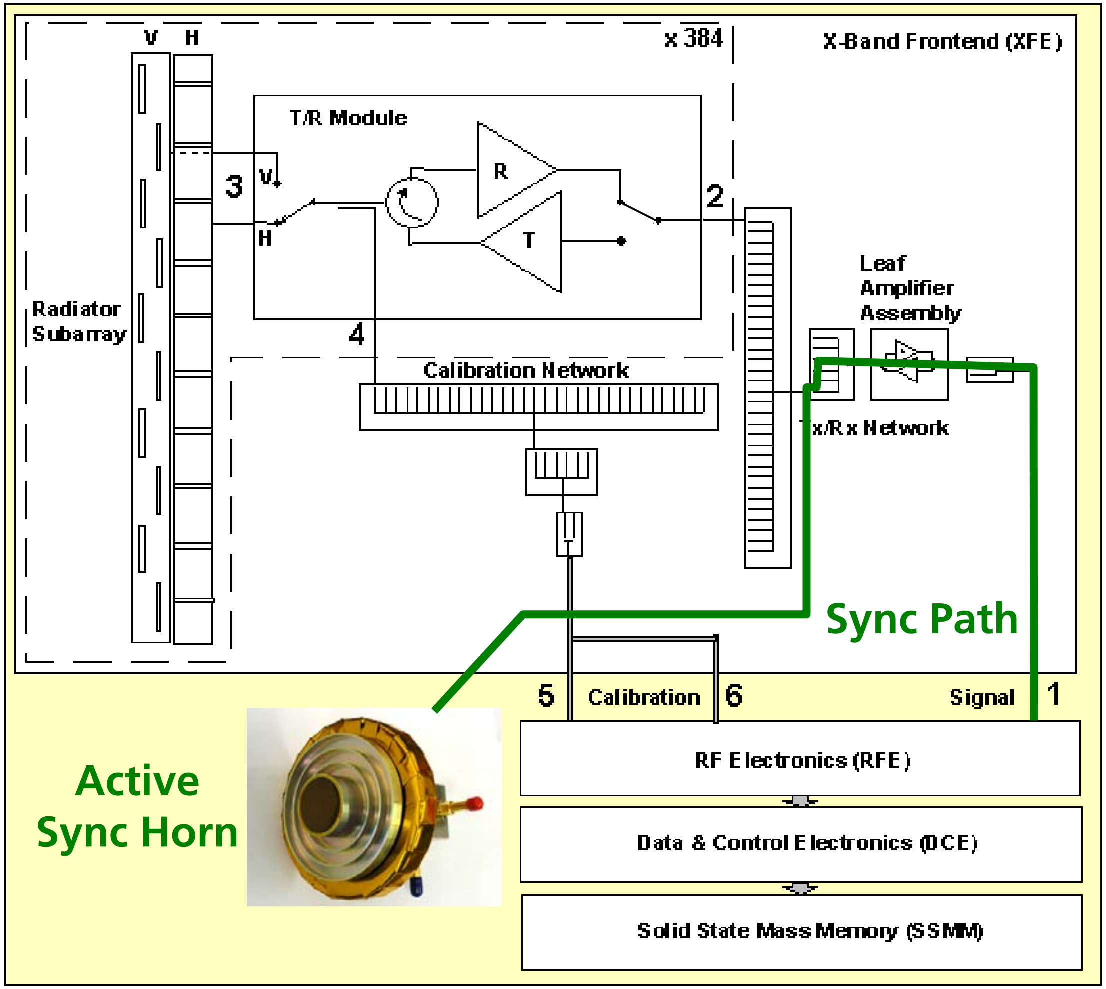
- **Stable Performance** of TerraSAR-X instrument
- Residual instrument drift is compensated by **high Internal Calibration Accuracy**



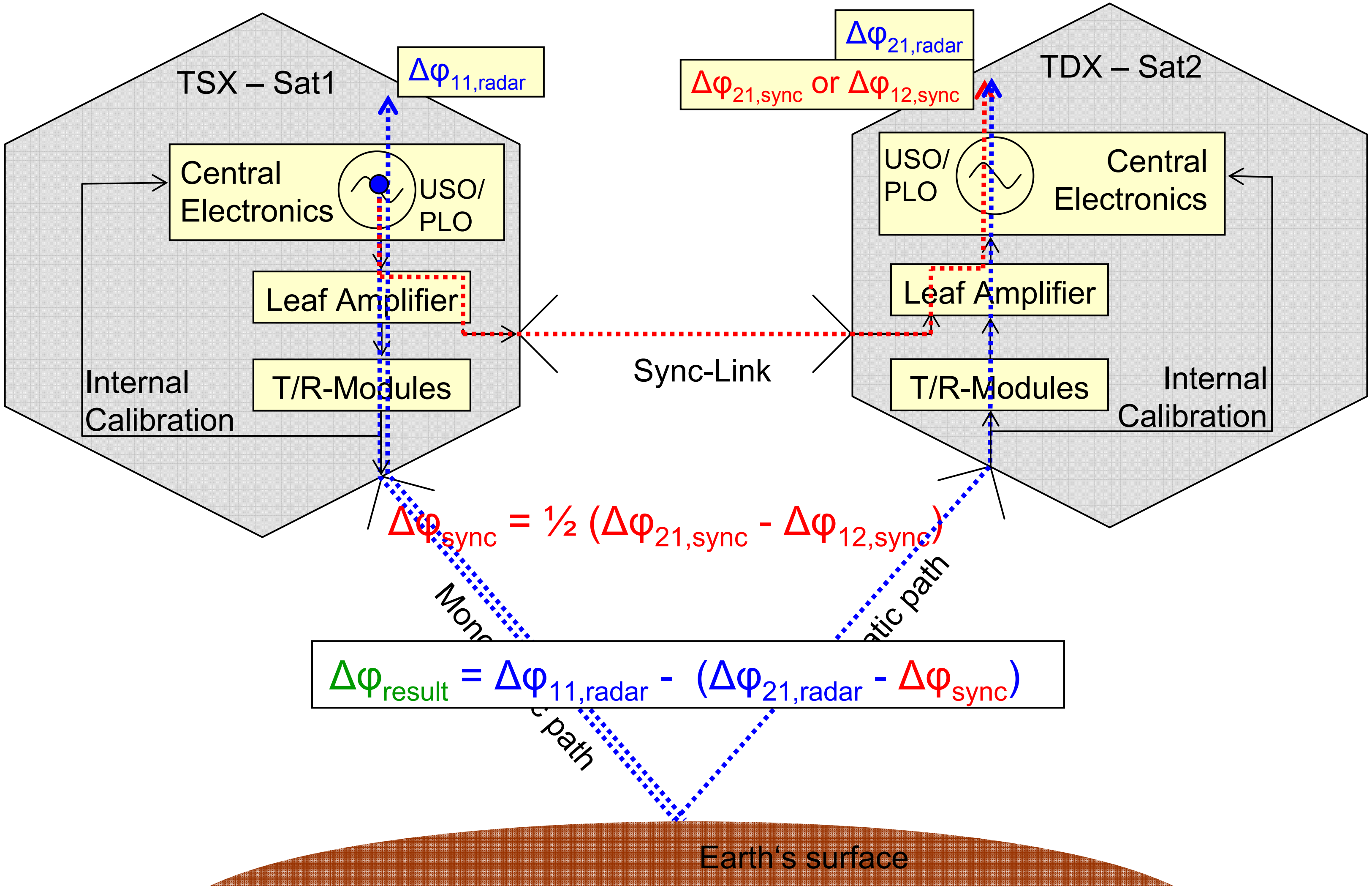
Sync Path Instrument



Ultra Stable Oscillator (**USO**):
- Long term drifts
- Temperature in CE
- Micro-vibrations

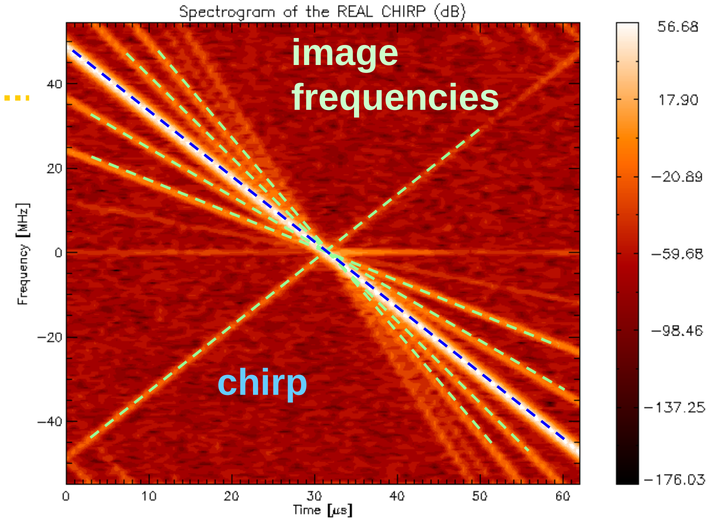


Instrument Phase Error - Overview



Mono-static and Bi-static Instrument Replica

- Mono-static instrument replica:
  - Range compression
  - Cancels losses and phase drifts in the instrument
  - Valid for both satellites in mono-static operation
- Bi-static operation:
  - Sat 1 transmits, Sat 2 receives
  - Two satellites/instruments/temperatures
  - Cal Pulses from both satellites have to be combined
  - Bi-static replica

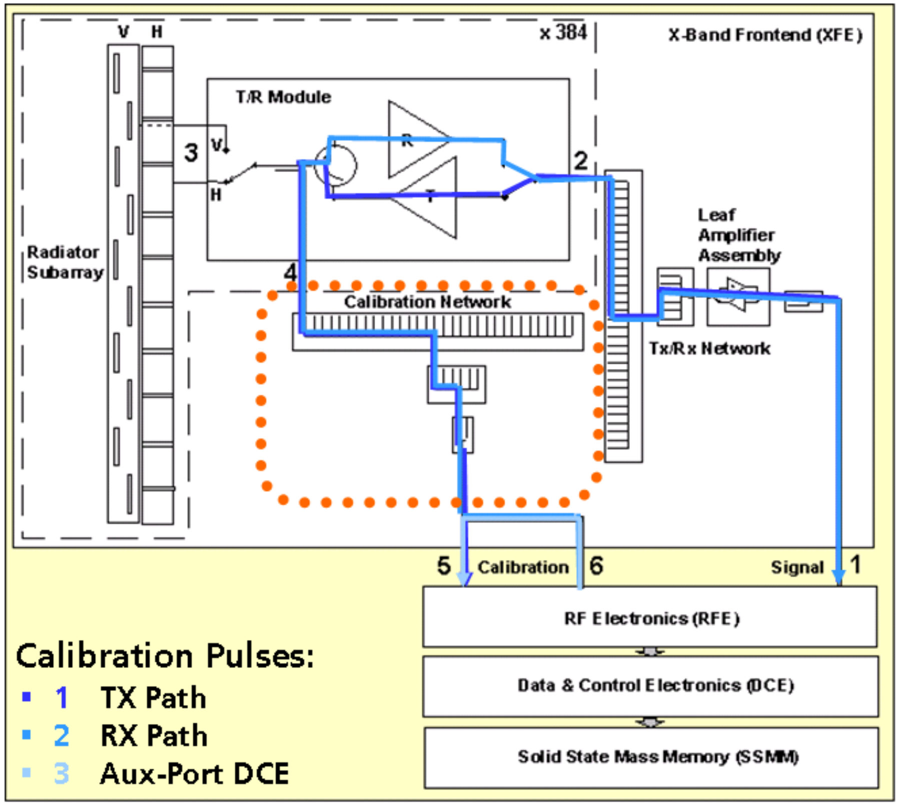


$$Inst_{Cal\_Bi} = \frac{Tx_{Cal\_1} \cdot Rx_{Cal\_2}}{\sqrt{CE_{Cal\_1} CE_{Cal\_2}}}$$

- Assumptions:
  - **Chirp spectrums** very similar for both satellites – identical circuits
  - Chirps have high time stability – verified
  - Calibration paths very similar for both satellites – passive network
  - Calibration paths **phase drift and losses constant** for both satellites during DT

ICAL: Compensation Calibration Network

- Calibration network is passive and relatively stable
- Part not covered by the CE pulse
  → not cancelled
- Mono-static: almost constant loss and phase shift
- TSX: 1 amplitude correction value/DT
  no phase compensation
- Bi-static: phase correction should be implemented
- Several values per datatake
- Characterisation curves provided by OGC tests in Astrium

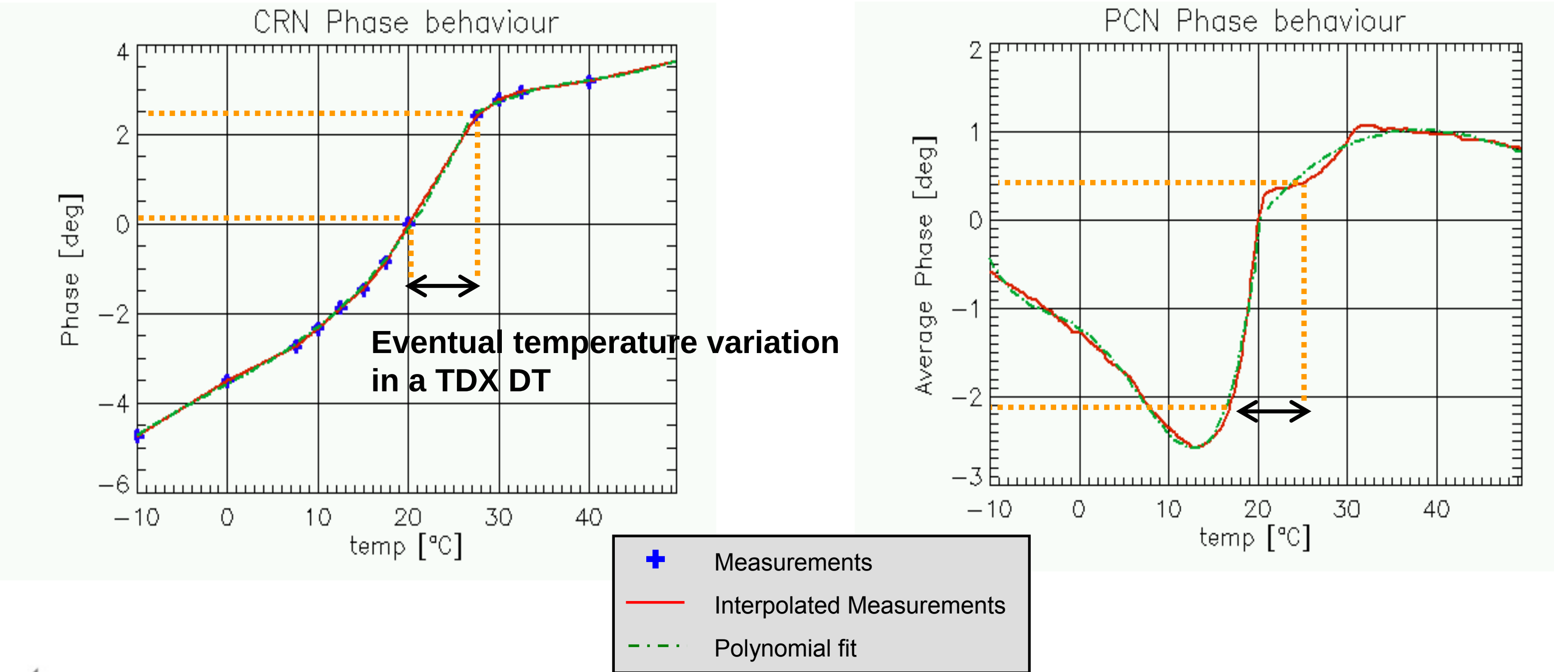


ICAL: Calibration Network Phase Polynomial Fits

- Elements not covered by Cal pulses characterised on-ground
- Satellite Housekeeping data (HK)

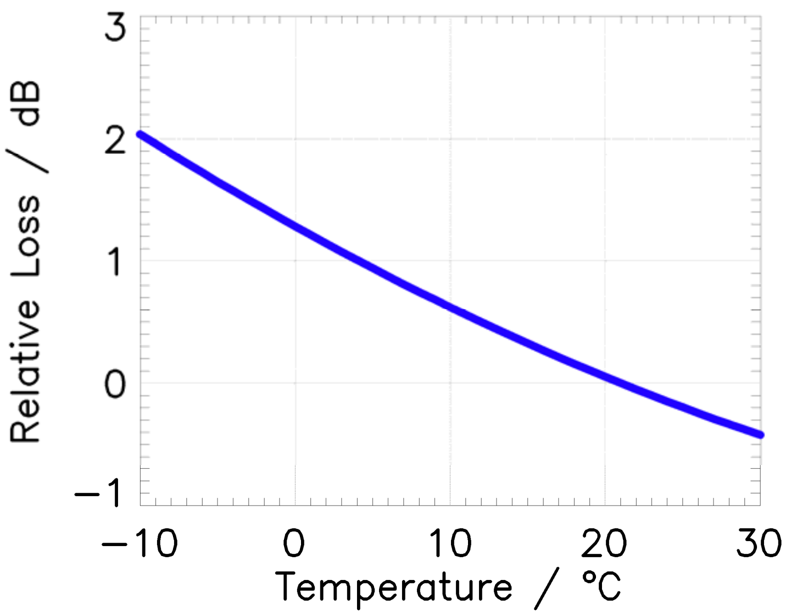
  → polynomial models for the losses and phase drifts

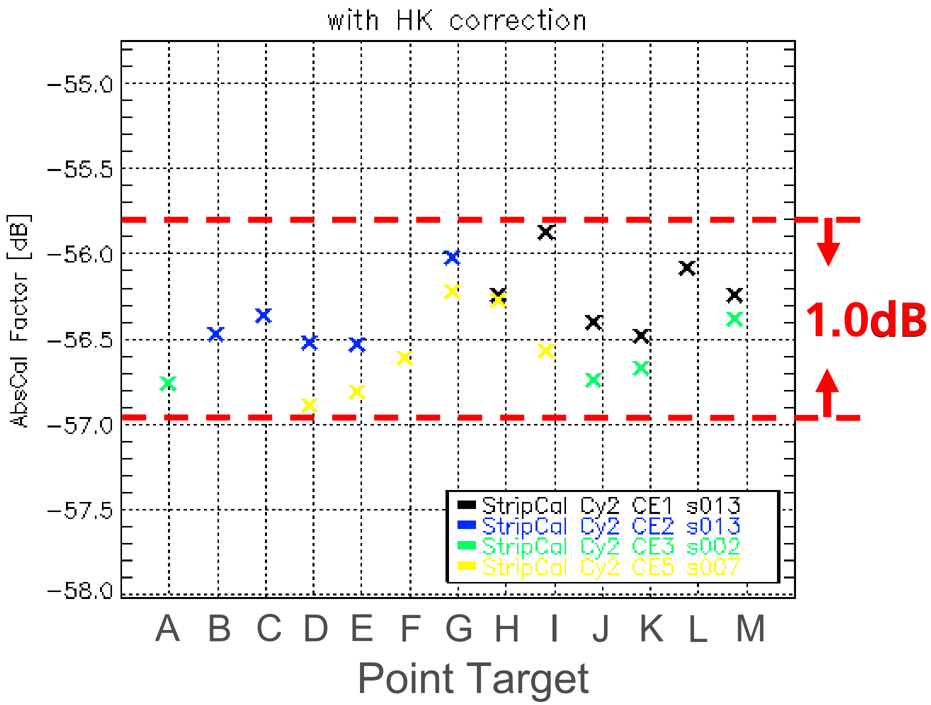
$$\Delta\varphi(T) = a_0 + a_1 \cdot T + a_2 \cdot T^2 + a_3 \cdot T^3 + a_4 \cdot T^4$$



ICAL: Compensation Loss of Calibration Network

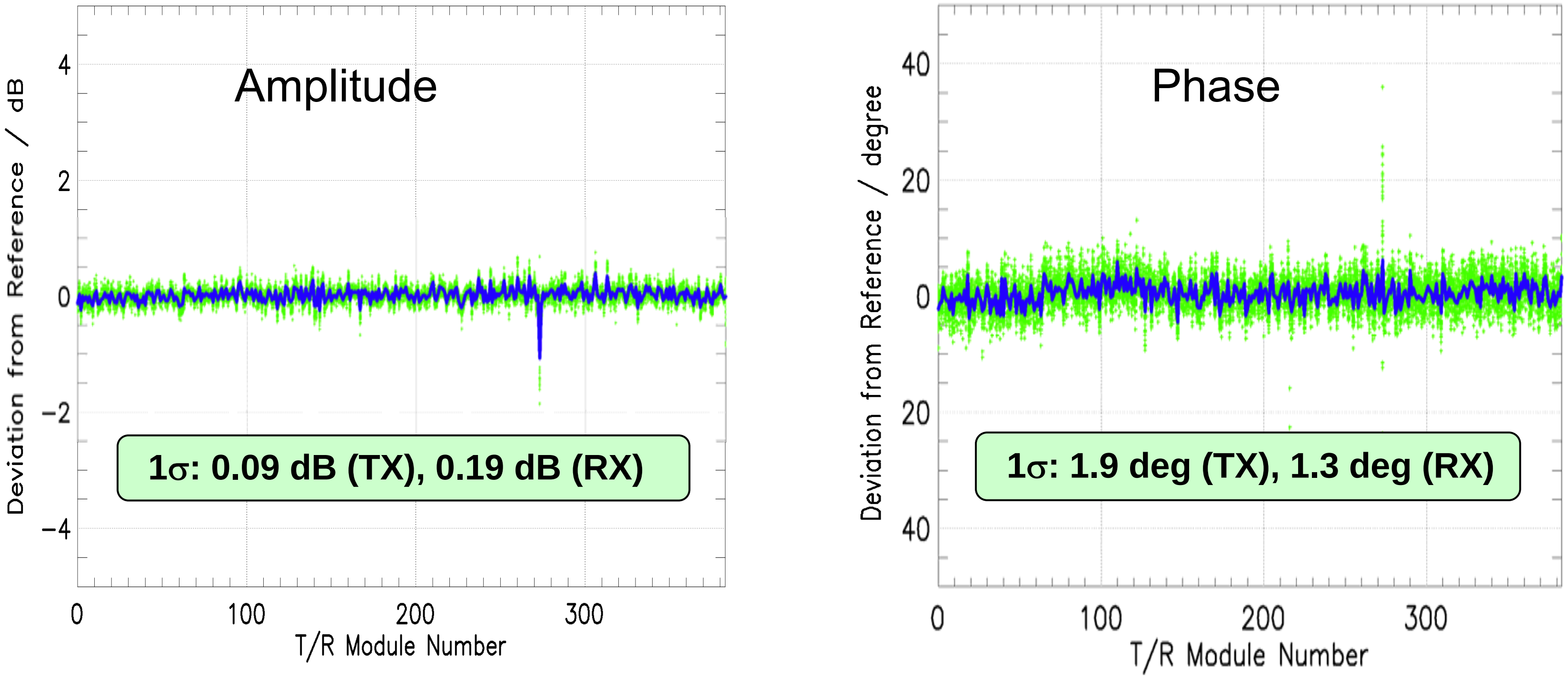
- Insertion Loss of **Calibration Network** depends on **temperature**
- Amplitude and phase **stable during data take**, but **not over long-term**
- Absolute RCS needs insertion loss correction for every SAR image





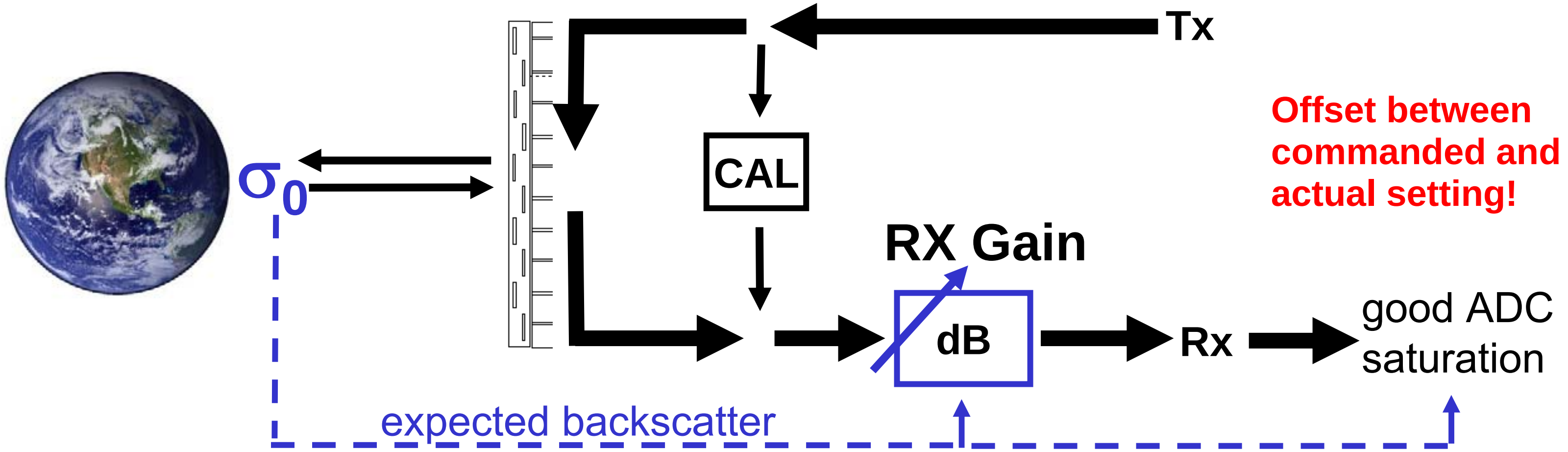
PN Gating – TRM Characterisation

- TRM are regularly checked to monitor actual performance
- Innovative method for simultaneous characterisation of all modules
- TSX In-Flight Measurements (42)



CE RX Gain Correction

- TSX: in flight
- TDX: on-ground

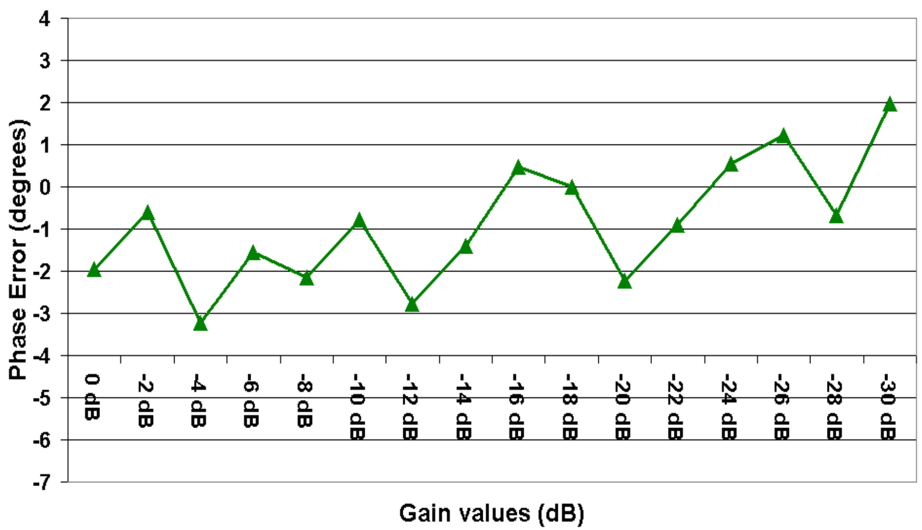


Correct actual Rx-Gain in amplitude and phase

Maximum deviation of commanded gain to actual gain:

Amplitude **0.4dB**

Phase **5°**



Drift Compensation

- TempComp: automatic temperature compensation of the TRM to stabilize performance
- Linear approximation drift at start and end of DT
- Interpolation residual error

- Idea 1: exponential fit of drift
  - eventually specific OGC for TDX and in-flight characterisation of TSX needed

- Idea 2: longer warm-up phase
  - less error due to linear approximation
  - increase in power and acquisition time consumption

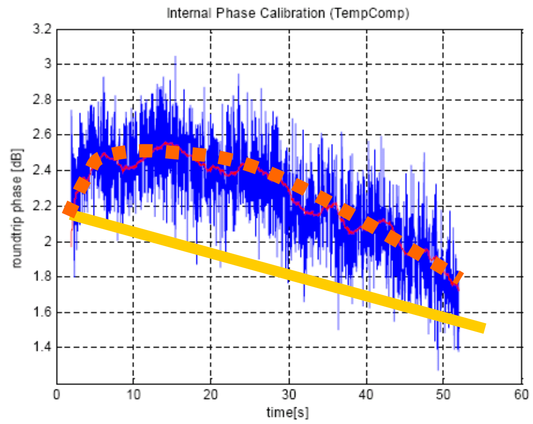


Figure 7.2.6-9: Roundtrip phase in temperature compensation mode within the first 50s calibration interval starting at 2s and linear approximation

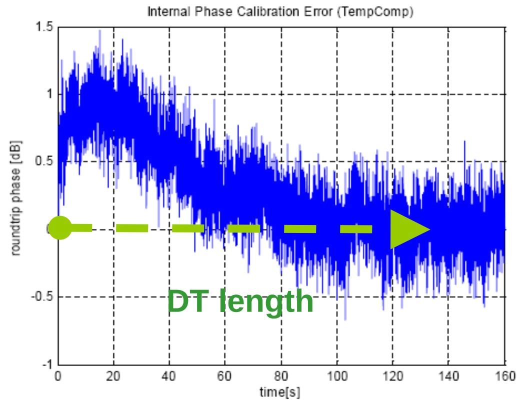


Figure 7.2.6-10: Residual error of roundtrip phase being the difference between measured roundtrip phase and linear approximation

Summary and Conclusions

- **TSX Internal Calibration** of Radar Instrument**:**
  - Radar instrument is very stable: 0.7dB radiometric accuracy, 1° phase drift knowledge
  - Results exceed expectations

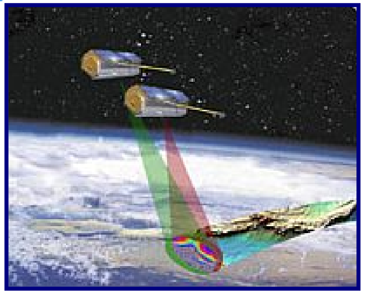
- **Mono-static Calibration of TDX** is expected to give similar results as for TSX

- **Bi-static Operation and ICAL**
  - Accurate **synchronisation** needed: remaining random error ~ 0.2°
  - New **replica** equations derived
  - Dynamic HK phase correction of the calibration network needed: error < 1°
  - Phase drift correction method under study; potential improvements
  - Verification of assumptions and new features during Commissioning Phase

- **On Ground Characterisation**
  - Ongoing for TDX
  - Validate assumptions

- **Commissioning Phase**

End of the Presentation



Questions?

Suggestions?