Development of DLR's Next Generation C-band Calibration Transponders for future SAR Missions

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DLR SAR Calibration Center

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DLR SAR Calibration Center - Supported Missions

Mission	Year	Band	Purpose	Cooperation
ERS-1/2	1991-1996	C-Band	External Calibration	**ESA / ESTEC**
SIR-C / XSAR	1994	L-/C-/X-Band	Overall System Calibration (X-Band)	**JPL / NASA**
SRTM	2000	C- / X-Band	First DEM by Single Pass Interferometry	**JPL / NASA**
ASAR / ENVISAT	2002	C-Band	ScanSAR Calibration	**ESA / ESTEC**
PalSAR / ALOS	2006	L-Band	Polarimetric Calibration, Product Validation	**ESA / ESRIN**
TerraSAR-X	Since 2007	X-Band	Overall System Calibration	**Astrium GmbH**
TanDEM-X	Since 2010	X-Band	Overall System Calibration	**Astrium GmbH**
PAZ	2010-2013	X-Band	Calibration S/W Tools	**INTA**
Sentinel-1A/B	Since 2007	C-Band	Overall System Calibration (Copernicus)	**ESA, TAS-I**
Sentinel-1C/D	Since 2017	C-Band	Overall System Calibration (Copernicus)	**ESA, TAS-I**
RCM Transponder	Since 2015	C-Band	Transponder for Radar Constellation Mission	**CSA**
NewSpace	Since 2020	X-Band	Corner Reflector Alignments	**Capella, Synspective**
KOMPSAT-6	Since 2021	X-Band	Calibration Support	**KARI**
ROSE-L	Since 2021	L-Band	Overall System Calibration (Copernicus)	**ESA, TAS-I**
SARah	Since 2022	X-Band	Corner Reflector Alignments	**BMVg**

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DLR SAR Calibration Field

Calibration site at DLR Oberpfaffenhofen

120 x 15 km

Corner reflector

Remote-controlled reflector / C-band transponder

X/L-Band transponder

DLR‘s present C-Band Calibration Sites

Sentinel-1 (S-1)

- Three C-band transponders („Kalibri“) and three remote-controlled corner reflectors were commissioned for ESA‘s Sentinel-1 mission in 2014
- Independent SAR system calibration of Sentinel-1A (2014) and Sentinel-1B (2016) satellites
- Since start of S-1 routine operation performance has been monitored by regular overpasses
- All six reference targets are forseen as central calibration sites for the upcoming Sentinel-1C and -1D satellites

RADARSAT Constellation Mission (RCM)

- In-house development of two transponders from DLR SAR Calibration Center for RCM and RADARSAT-2
- Delivered to CSA and installed in 2017
- Operation/maintenance support by DLR

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Remote-Controlled Reference Targets

Status since start of operation (April 2014 – End 2023)

- 1471 overpasses
- 7616 targets aligned
- **reliability 94,42 %**

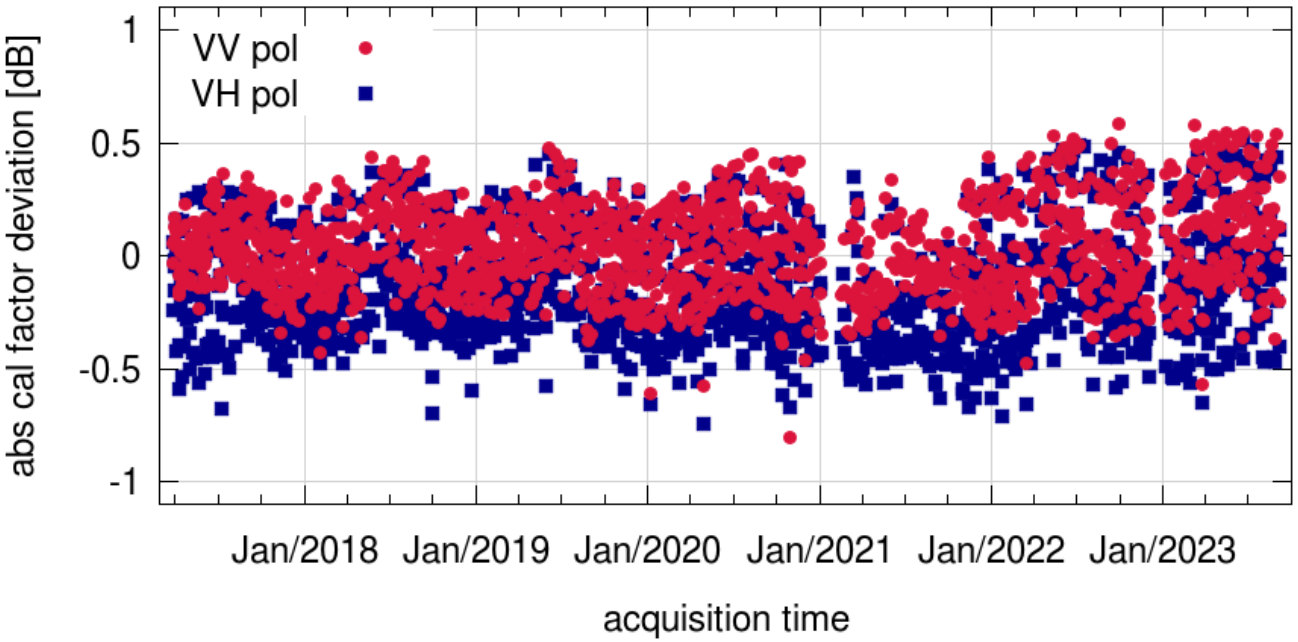
3 Corner Reflectors

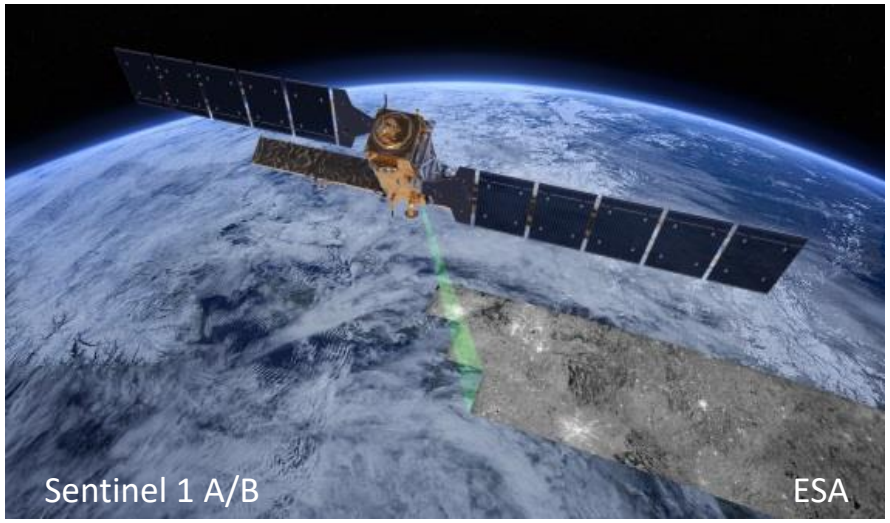
- 2.8 m leg length,
- RCS: 49.2 dBm² (C-band)
- ≤ 1.0 mm mech. form tolerance
- 0.2 dB abs. rad. accuracy

3 C-Band “Kalibri” Transponders

- 5.405 GHz, 100 MHz BW
- 60 dBm² RCS
- Adjustable polarization
- ≤ 0.1 rad. stability
- 0.2 abs. rad. Accuracy

„Kalibri“ Transponders – Performance





Radiometric stability of ESA’s Sentinel-1A satellite measured by “Kalibri” transponders over six years

- Constant mean
- Standard deviation: 0.22 dB (0.19 VV, 0.24 VH)
- This deviation includes all contributions arising from satellite/instrument, the targets, the different acquisition geometries, and propagation effects
- Stability of transponders is likely much better (< 0.1 dB due to one housing concept and temperature management system)

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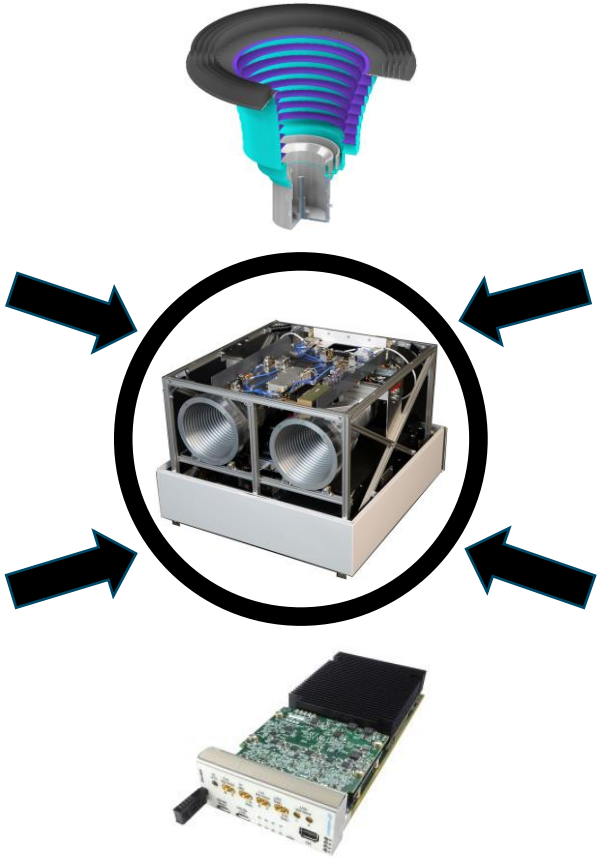
Motivation for C-Band Transponder Upgrade

- Kalibri transponders have been in uninterrupted operation for 10 years
- Nominal life cycle of several components has been exceeded. Spare parts not longer available
- Maintenance effort increased within the last years
- Minimising risk of longer outages by hardware replacement/upgrade
- Ensuring C-band transponder availability for next decade of future SAR missions
- Transponder hardware and software should evolve to fulfil the increased requirements of follow-on missions, e. g. ESA‘s Sentinel-1 Next Generation (S1-NG)



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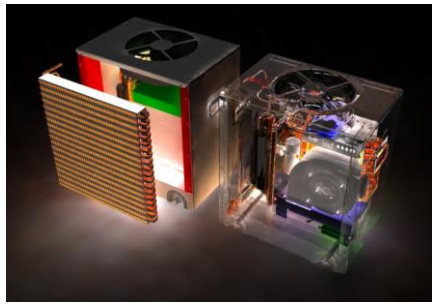
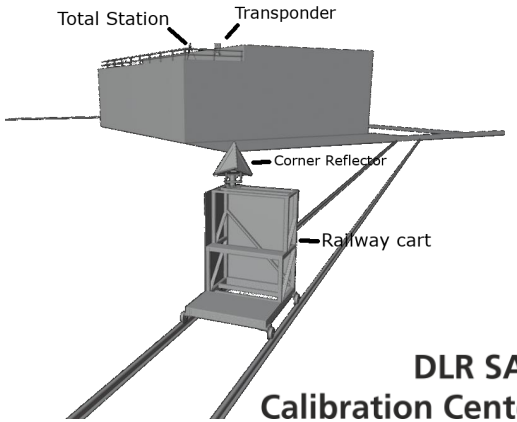
Technical Enhancement of upgraded Transponders

- Upgrade to a fully polarimetric dual-channel system:
  - Dual-polarization feeding system for RX and TX antenna
  - Two RF chains in both receive and transmit
  - Dual-channel digital unit
- Adaption of decoupling concept between receiving and transmitting antenna
- Bandwidth increase up to 320 MHz
- New digital unit with increased processing power
- Enhanced active cooling system for improved temperature management.
- Redesign of the transponder housing.
- RCS determination according to the novel “Three Transponder Method” (3TM)





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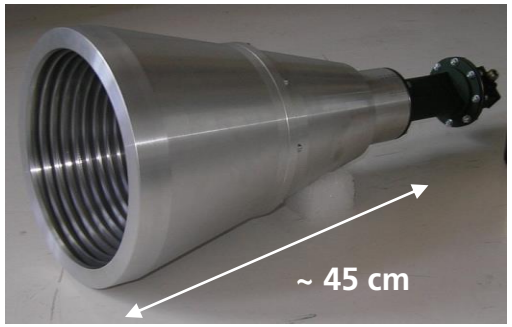
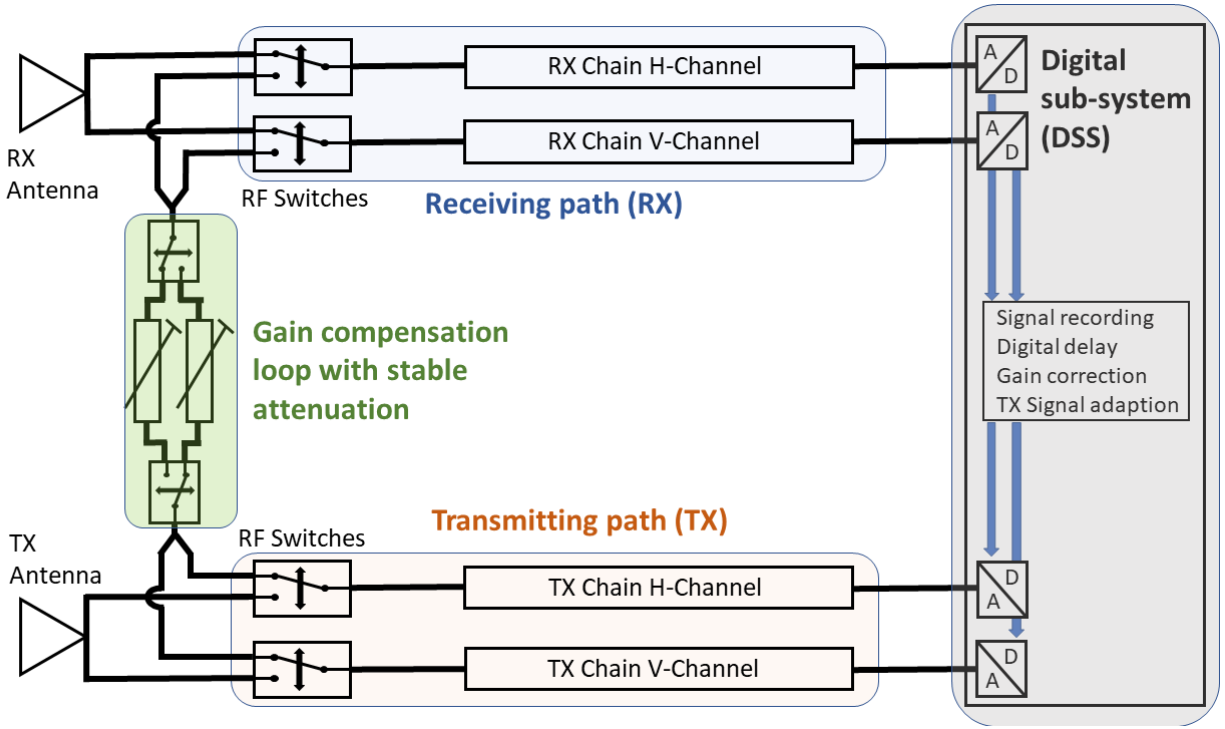
Dual Channel Architecture



- Fully polarimetric RX and TX corrugated horn antennas with dual-channel feeding system
- Separate RF chain for H- and V-polarization on receive and transmit
- Individual data processing of each channel by a new dual-channel digital subsystem



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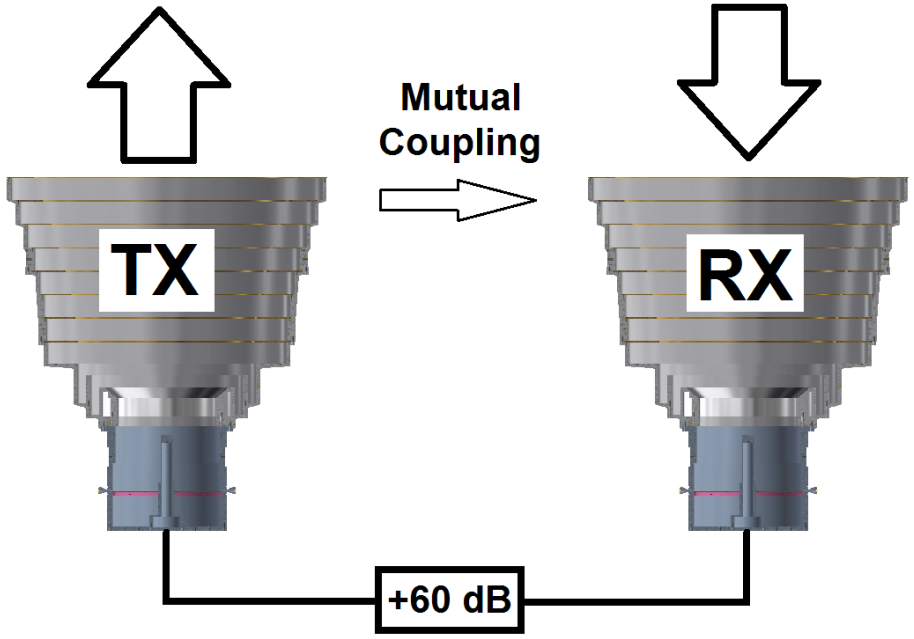
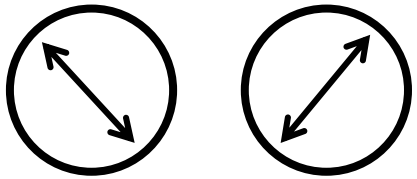
Surpression of Mutual Coupling

Mutual Coupling in Transponders

- DLR‘s transponder design uses a two antenna concept (receive and re-transmit)
- Due to the high intrinsic amplification (60dB) sufficient decoupling of the antennas is essential

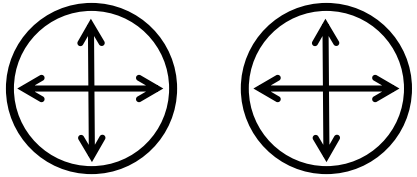


Single-Pol Transponders

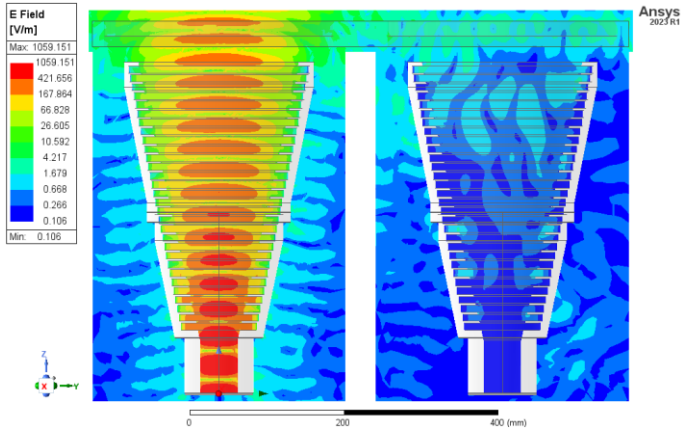


- 90° design (+45°/-45° orientation)
- Decoupling through maximum polarization mismatch

Fully polarimetric Transponders



- two channel design
- No decoupling through polarization mismatch possible
- Analysis of alternative decoupling concepts necessary



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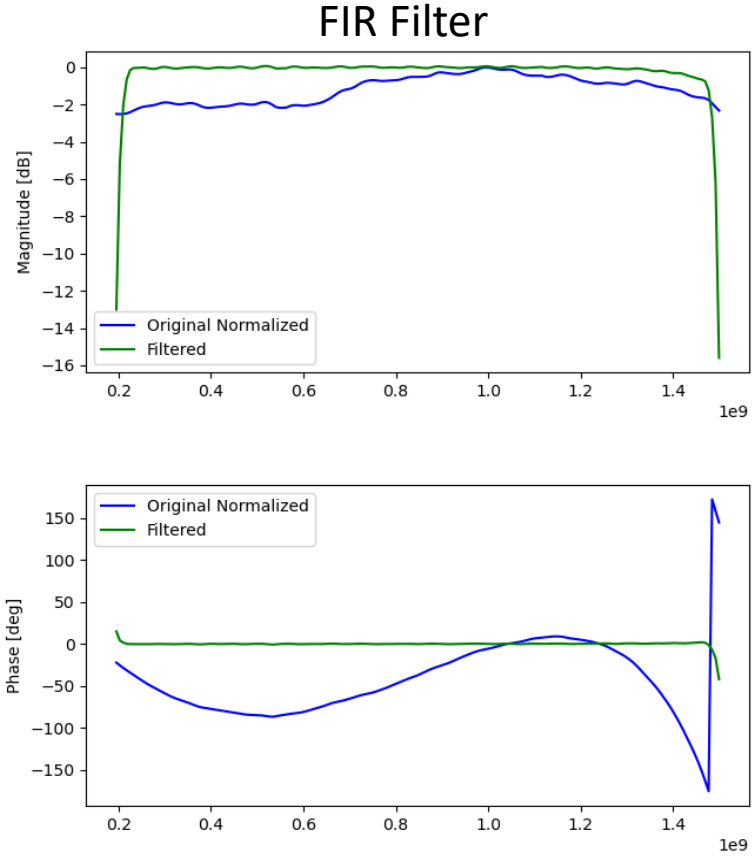
Digital Electronics

- Dual-channel FPGA Transceiver 6.4 GSPS
- Full sampling of received chirps
- Support of the full 320 MHz bandwidth
- Dual-channel operation for polarimetric calibration purposes
- GPS synchronized timestamps
- Adjustable delay of impulse response
- Internal calibration - Fine tuning of RCS
- FIR filtering (compensation of frequency response variations)



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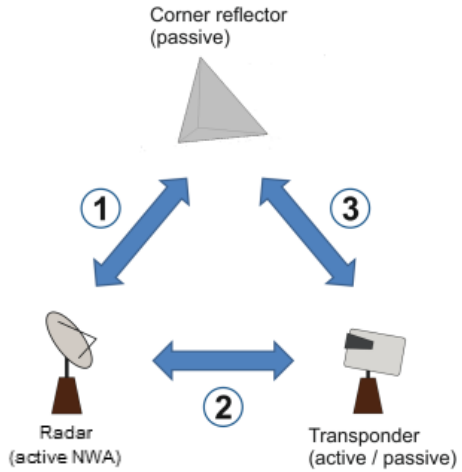
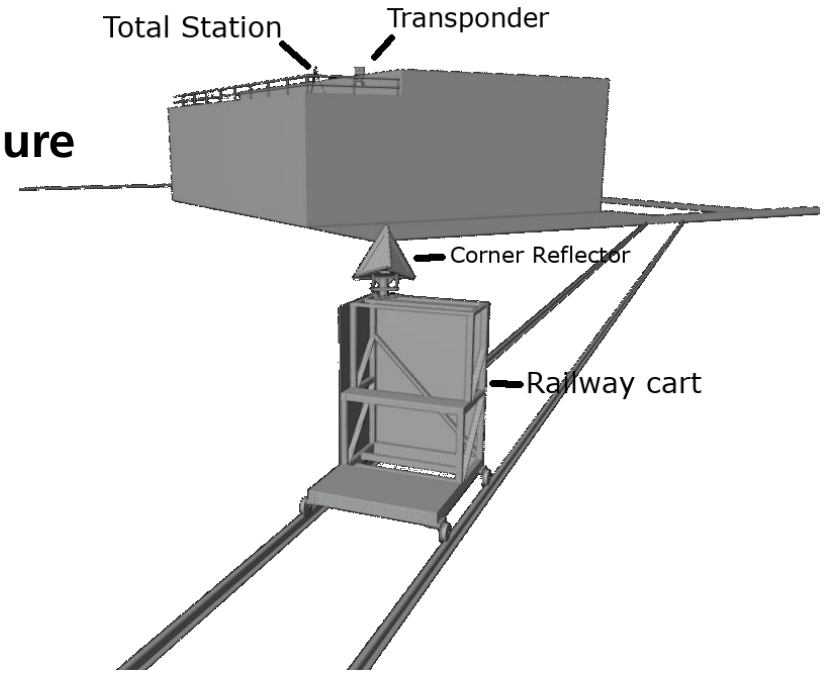
Transponder‘s RCS Determination via “Three Transponder Method“ (3TM)

3TM principle



Measurement procedure



- Corner reflector as passive target
- Prototype as transponder & radar
- Network analyzer as radar

No RCS knowledge of **absolute reference** necessary

Uncertainty analysis for X-band
0.066 dB (1σ)

based on ISO “Guide to the Expression of Uncertainty in Measurement” (GUM)

Milestone in
Absolute Radiometric Calibration of Reference Targets < 1/10 dB

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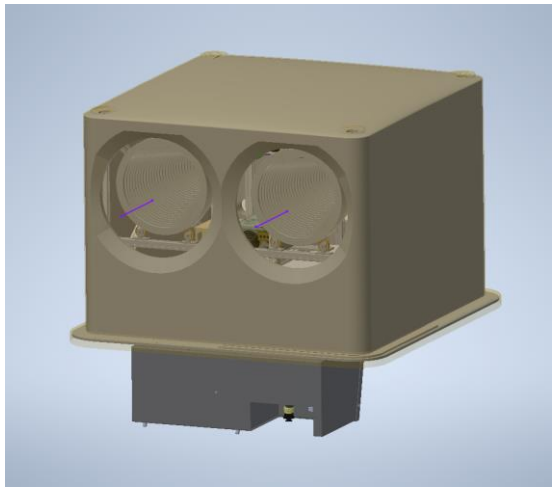
Roadmap for Uninterrupted Upgrade

1. Development of additional C-band transponder with new hardware and software

2. Testing and external calibration via 3TM

3. Circular exchange:
   - Replacement of one „Kalibri“ transponder with new developed device
   - Hardware upgrade, Testing, and external calibration



- All transponders can be upgraded one by one without interrupting the routine operation of all three devices

- Additional transponder available for further developments, experiments, and as test device for maintenance activities

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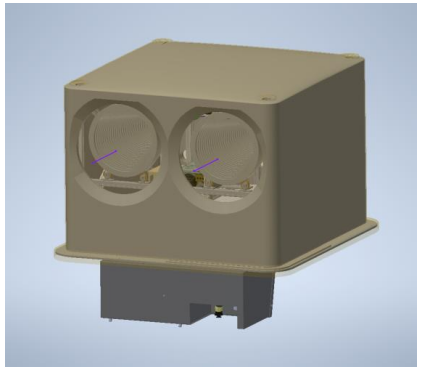
DLR's Active Reference Target Repertoire

This session:
Anna Maria Büchner,
Polarimetric calibration of DLR's dual band transponder and first polarimetric L-band SAR measurements



	Kalibri	Kalibri NG - X	Kalibri NG – L(X)	Kalibri Facelift - C
Frequency band	C-Band	X-Band	L-Band	C-Band
Bandwidth	100 MHz	1200 MHz	85 MHz	320 MHz
Polarization	Single adjustable	Single adjustable	Quad pol	Quad pol
RCS	62 dB/m²	57-68 dB/m²	52-62 dB/m²	~65 dB/m²
Abs. radiometric accuracy (1 σ)	0.2 dB	0.07 dB	Expected < 0.1 dB	Expected < 0.1 dB
Radiometric stability (1 σ)	< 0.1 dB	< 0.05 dB	< 0.05 dB	< 0.05 dB

In operation since 2014

E2E testing since 2021

Prototype installed

In design phase

Conclusion

- DLR SAR Calibration Center provides a facility of several active and passive reference targets for different frequency bands

- The „Kalibri“ C-band transponders have been in operation since 2014
  - Provide the backbone of SAR system calibration and monitoring for Sentinel-1 mission
  - Two similar transponders were delivered to CSA for RCM and have been in operation since 2017
  - Transponder operation also foreseen for Sentinel-1C and -1D

- Increased requirements of future SAR mission demand C-band transponder upgrade with new hardware
  - Fully polarimetric dual-channel system
  - Increased processing power for dual-channel operation

- Accuracy of transponder RCS is expected ≤ 0.1 dB – determination via “Three Transponder Method“

- Facelift of „Kalibri“ transponders can be executed without interrupting the transponders‘ routine operation

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