Sentinel-1 C/D Instrument:
Improvements on internal calibration and preliminary verification results

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Overview

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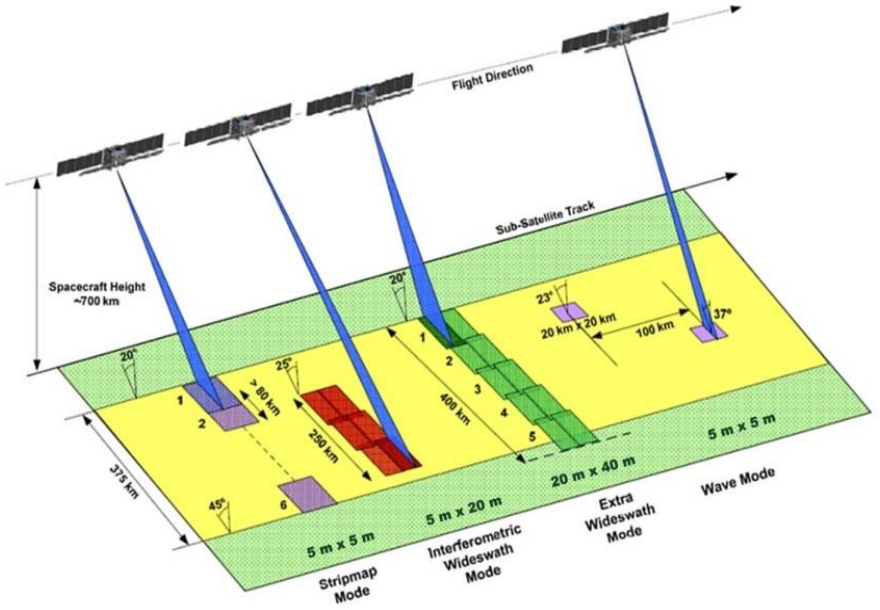
- The Sentinel-1 SAR Instrument
- S-1C&D Upgraded Antenna architecture
  - The new Tile Amplifier
  - Internal Calibration improvements
- Improvements on Noise estimation
- FM tiles on-ground test results
- Summary

Introduction

- Sentinel-1A launched on 3rd April 2014.
- Sentinel-1B launched on 25th April 2016.
- Sentinel-1C & -1D contract kicked off in 2015 to extend observations beyond the lifetime of Sentinel-1A and -1B (design lifetime: 7.25 years in orbit).
- Sentinel-1C launch is targeted for 2022*
- S-1A, B, C and D are fully compatible in terms of mode characteristics, observation geometry, resolution and burst synchronisation (interferometry).

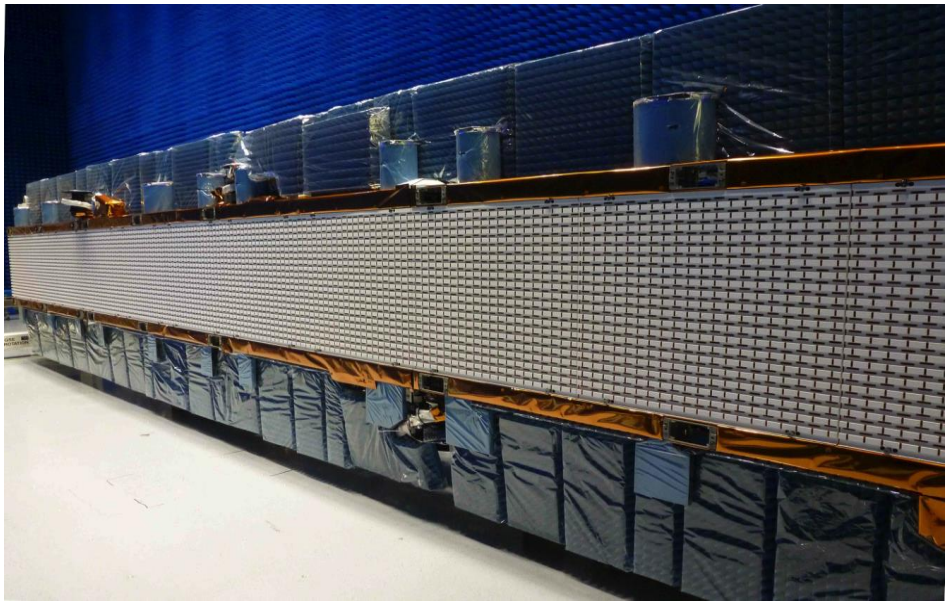


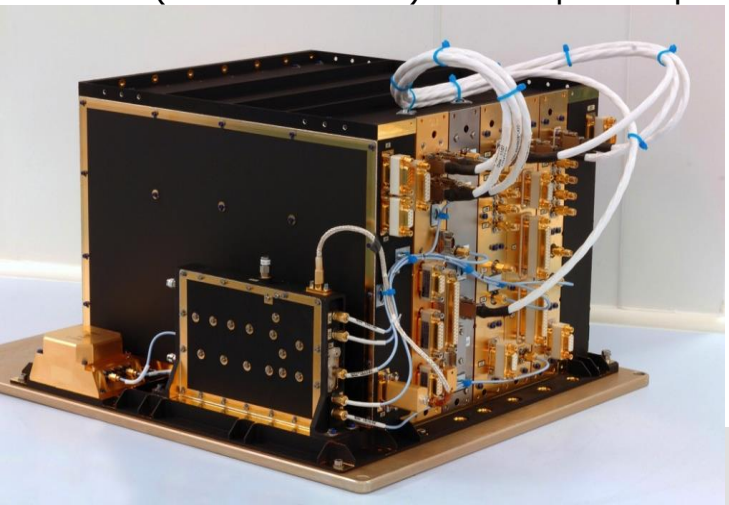
*) **See presentation from B. Duesmann** *Sentinel-1 C Model insertion into the current A/B constellation: options* (3B3)

The Sentinel-1 SAR Instrument

SAR Antenna Subsystem (SAS)

- Active phased array antenna
- 12.3 m x 0.84 m aperture
- 2 wings, 5 Panels
- 14 Tiles each with 20 H & 20 V slotted dual polarized waveguide arrays
  - 2 x 280 T/R modules
  - = 10 *Electronic Front Ends* (EFEs) per tile, each with 2 TRMs x 2 (H & V)
  - 2 (cold redundant) Tile Amplifiers per tile



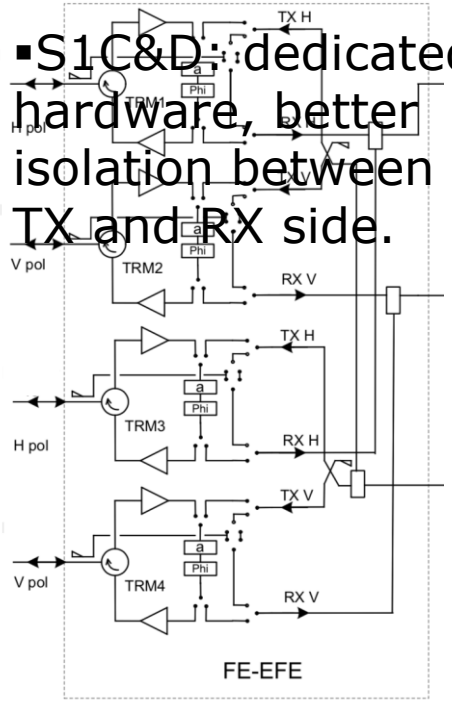


Integrated Central Electronics (ICE)
(part of the SAR Electronics Sub-system SES)

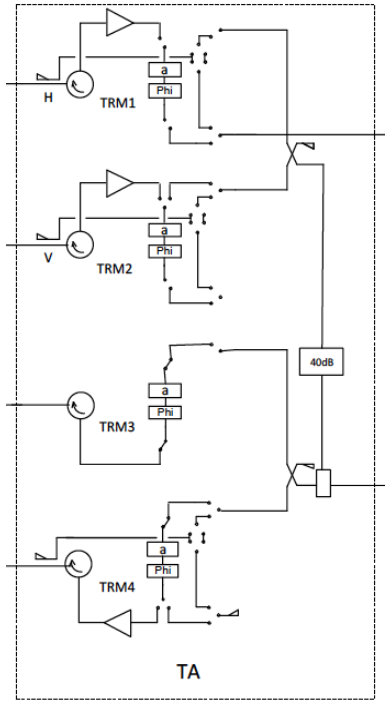
- Digital Chirp Generator
- Real sampling, Digital demodulation & filters
- Flexible Dynamic Block Adaptive Quantisation

Upgraded Antenna Architecture (1 of 2)

- S1C&D: dedicated hardware, better isolation between TX and RX side.

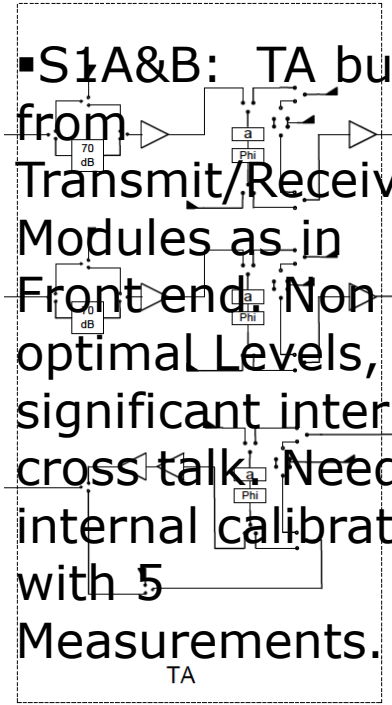


S1 EFE



S1A&B TA

- S1A&B: TA built from Transmit/Receive Modules as in Front end. Non optimal Levels, significant internal cross talk. Needs internal calibration with 5 Measurements.



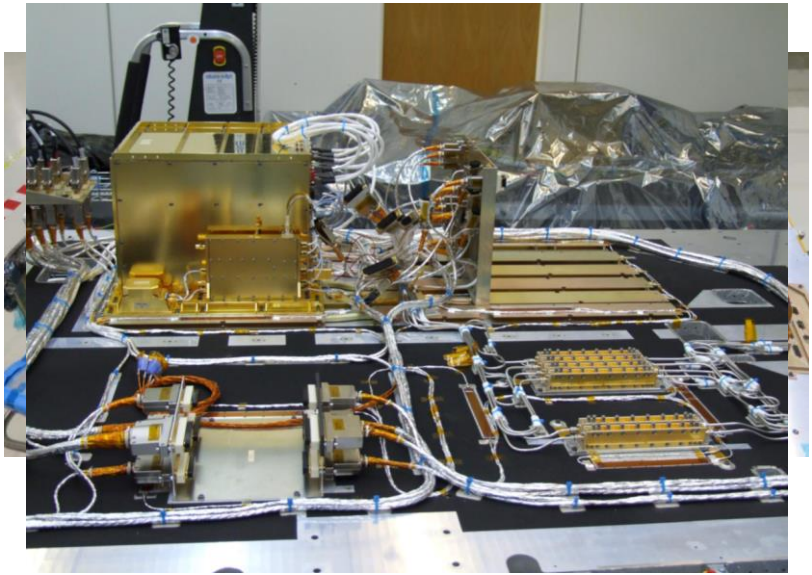
S1C&D TA

Upgraded Antenna Architecture (2 of 2)

The S1A&B instrument architecture was reviewed to identify potential improvements.

New TA design provides:

- Improved radiometric stability and accuracy.
- Simplification of internal calibration scheme.
- Reduction of RF hardware complexity. Transmit Gain Unit TGU is no longer required.
- Simplification of trimming for the long RF networks from SES to the tiles.
- Slight improvement in the instrument noise figure.



S1-C/D SES Panel

Internal Calibration Improvements

- The new Tile amplifiers simplify the internal calibration approach:

  S1A&B Status:

$$PGCal = \frac{TxCal * RxCal * TACal}{EPDNCal * APDNCal}$$

  S1C&D Status:

$$PGCal = \frac{TxCal * RxCal}{EPDNCal}$$

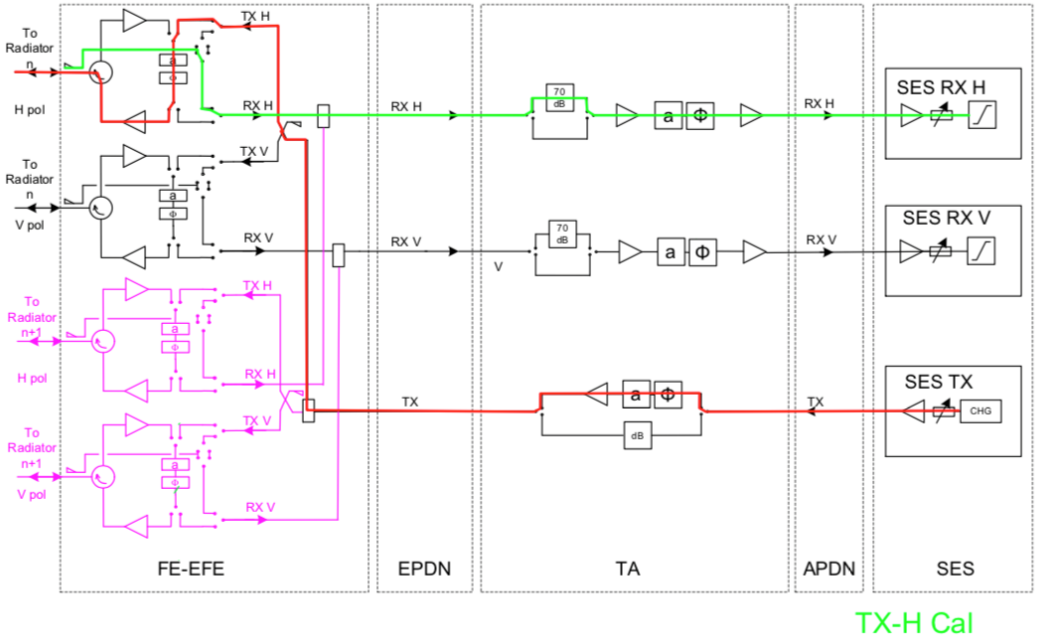
- Lower number of measurements → lower calibration inherent errors
- Reduced cross talk within new TAs → better calibration stability

- Predicted Radiometric Stability of S1A&B: 0.55 dB (3σ)
- Predicted Radiometric Stability of S1C&D: 0.40 dB (3σ)

Internal Calibration Scheme (1 of 3)

TXCal

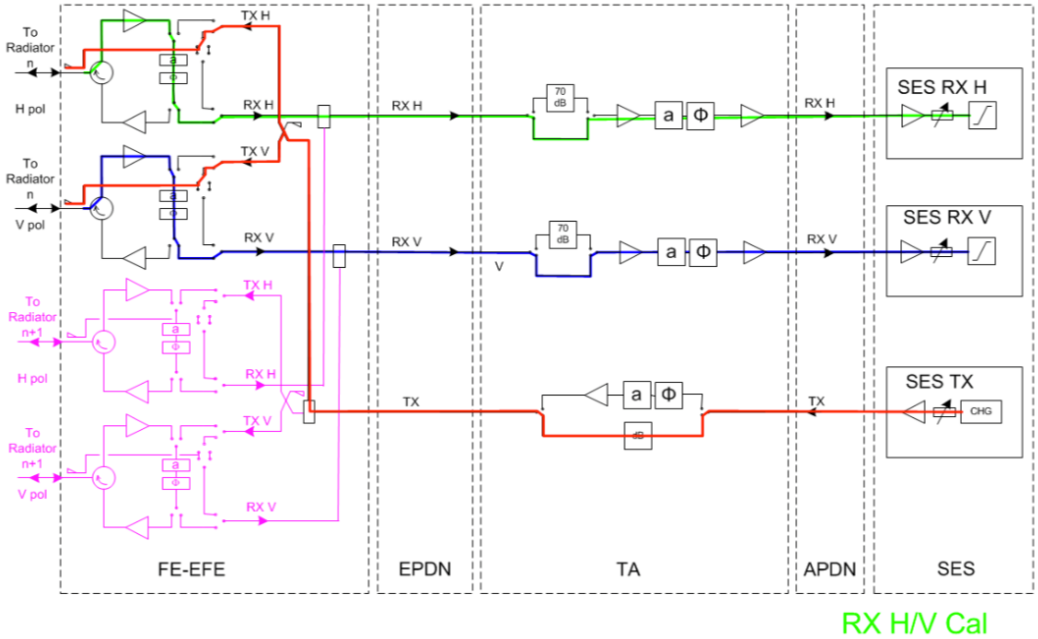
- Signal has same TX path as imaging signals (red).
- Receive path (green) includes a 70 dB attenuator in addition to the nominal RX path.
- TXCal provides useful data on one RX channel only.



Internal Calibration Scheme (2 of 3)

RXCal

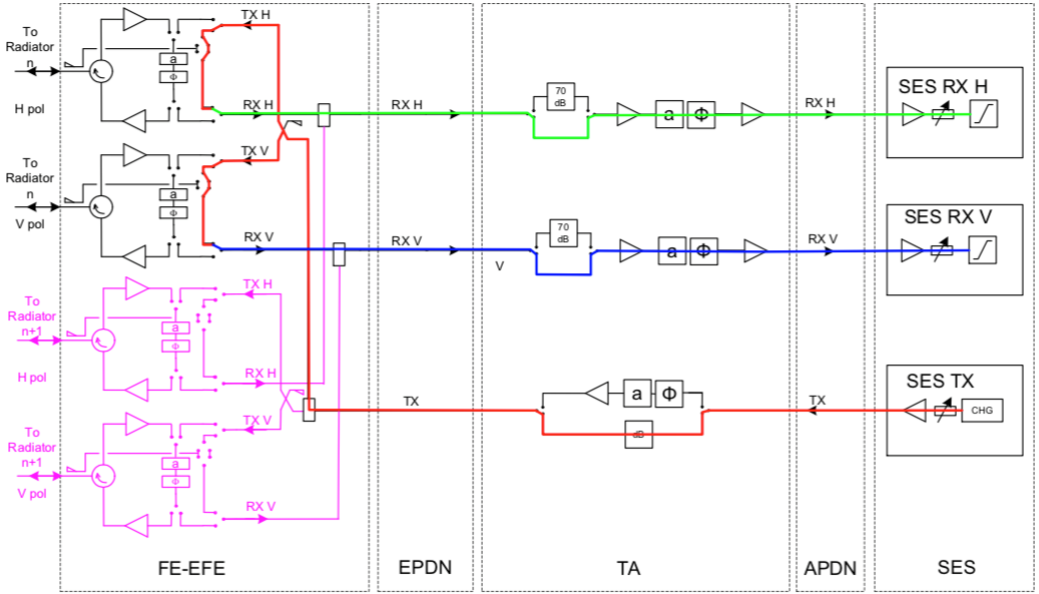
- Signal is operated with low gain on the TX path (red).
- Receive paths (green and blue) are operated with high gain, identical to imaging operation.
- RXCal provides useful data on H and V-pol RX channels



Internal Calibration Scheme (3 of 3)

EPDNCal

- operated with low gain on the TX path (red), same as for RXCal.
- Receive paths (green and blue) bypass the amplifiers within the front end.
- RX amplifiers are operated with high gain, identical to imaging operation.
- EPDNCal provides useful data on H and V-pol RX channels



EPDN-H/V Cal

Improvements on Noise estimation (1 of 3)

- Noise within the SAR signals includes significant amount of thermal radiation from ground (surface "brightness Temperature")
- Variations on thermal radiation changes overall noise levels up to 1 dB.
- Radar data takes include dedicated noise measurements in Preamble and Post-amble of data takes.
- Radiometric accuracy in images can be improved when acquiring actual noise power of the imaged scene. **

) ***Cross-Sensor Calibration of Sentinel-1 Noise Level,* N. Franceschi (2D4)

Improvements on Noise estimation (2 of 3)

- Interleaved Noise data within a data take can be extracted from first data packets acquired after internal calibration sequences
- "Clean" noise data can be acquired after RXCal and EPDNCal
- TXCal emits a boresight beam which contaminates noise in following Rank PRIs.

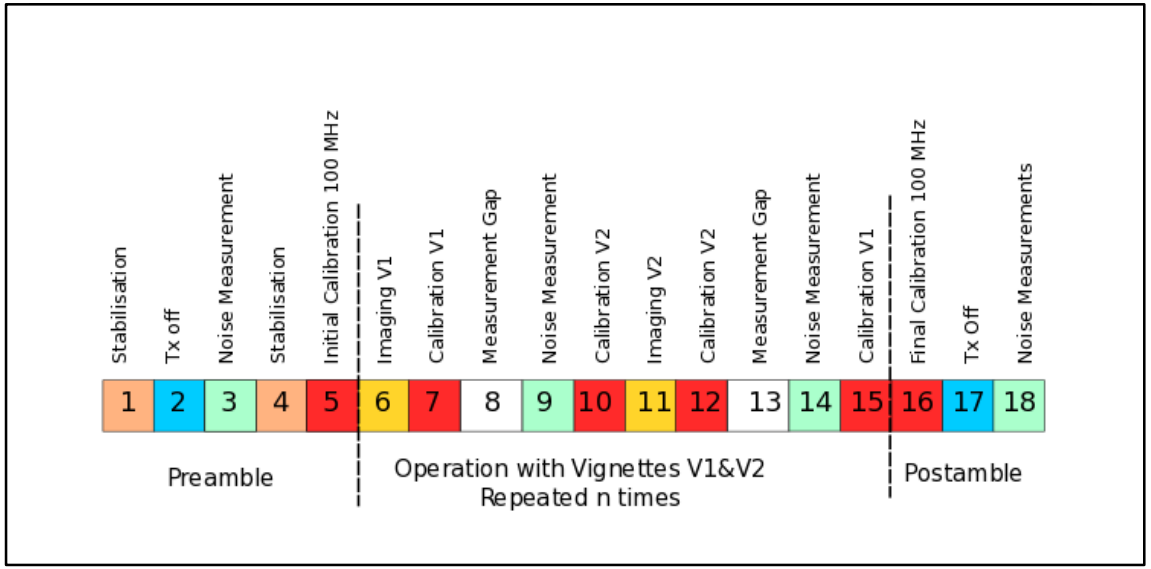
Updates for S-1C&D:

- Wave Mode: dedicated noise acquisitions added to each vignette
- Stripmap: typically short data takes without interleaved calibration pulses, no extra noise measurements added.
- IW and EW modes: Two approaches have been considered:
  - Continue using Rank Echoes: Changed the calibration sequence to minimise the impacts of TXCal signals.
  - Interleaving Noise Measurements with BAQ-5.

Improvements on Noise estimation (3 of 3)

Wave Mode: dedicated noise measurements before each imaging vignette.

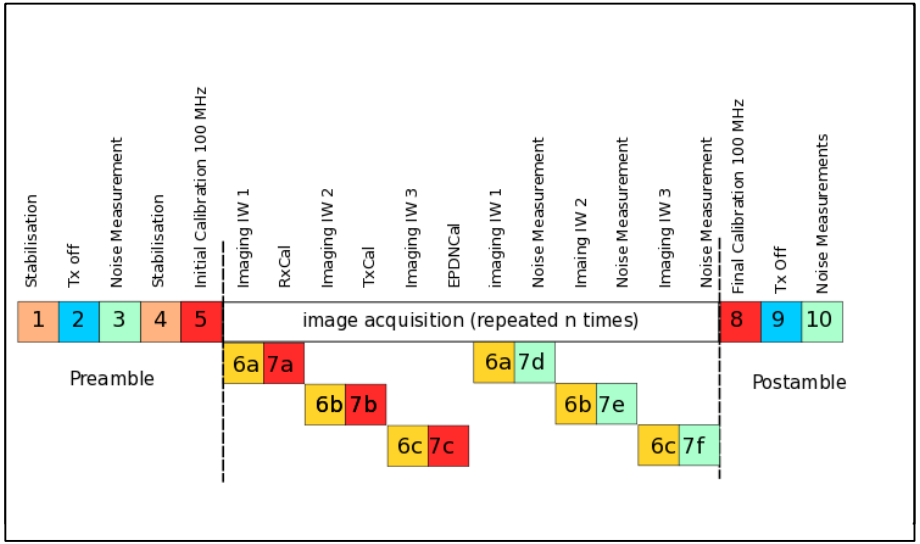
S1-A/B S1-C/D



Improvements on Noise estimation (3 of 3)

IW Mode: The reduction on the number of internal calibration signals permits the accommodation of dedicated noise measurements.

S1-A/B S1-C/D



Improvements on Noise estimation (3 of 3)

EW Mode: Noise samples taken during the redundant EPDNCal slots

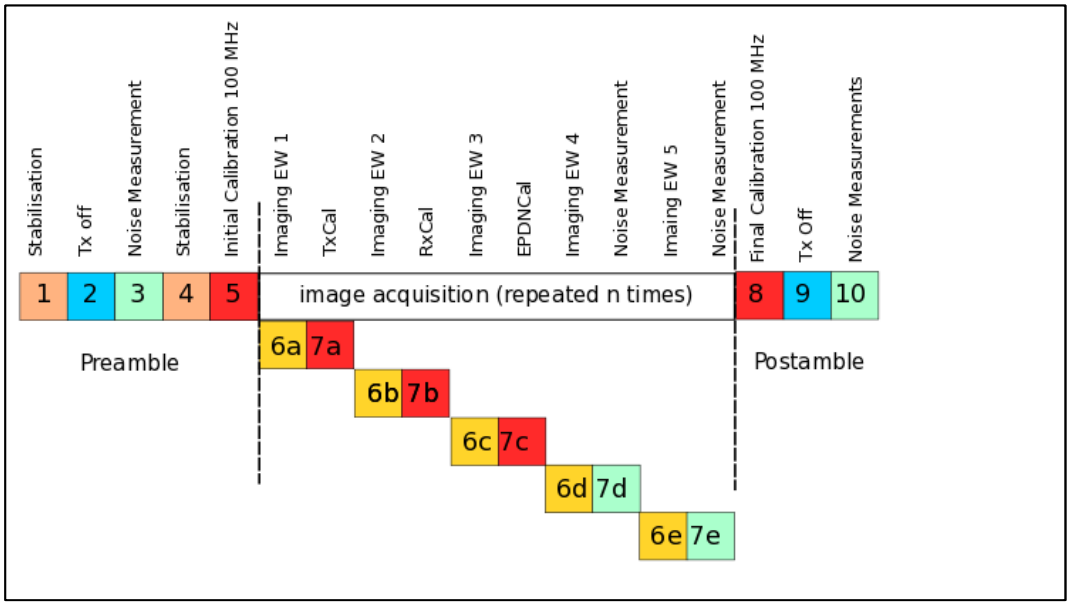
7d

PRI 1 to 11	PRI 12 to 14	PRI 15 to 17	PRI 18 to 20
Rank Echoes	Noise EW 1	Noise EW 2	Noise EW 3

7e

PRI 1 to 11	PRI 12 to 14	PRI 15 to 17	PRI 18 to 20
Rank Echoes	not used	Noise EW 4	Noise EW 5

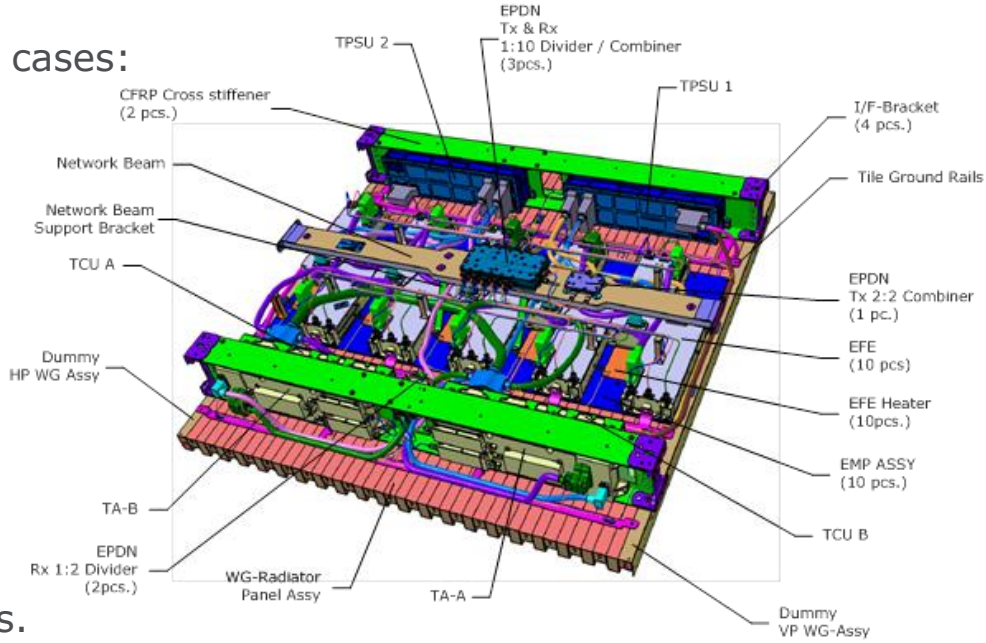
S1-A/B S1-C/D



Tile FM on-ground test results (1 of 4)

The nominal test flow covers the following test cases:

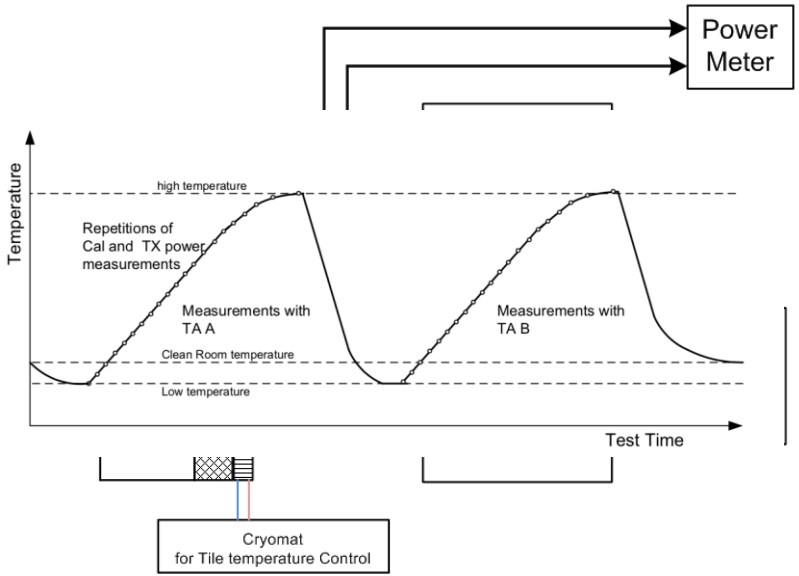
- Functional
- Performance
- Temperature Compensation
- Mechanical/Vibration
- Thermal Cycling



PFM vs. FM:

- PFM-C used to qualify the new tile design.
- FM acceptance test showed excellent results.

Tile FM on-ground test results (2 of 4)



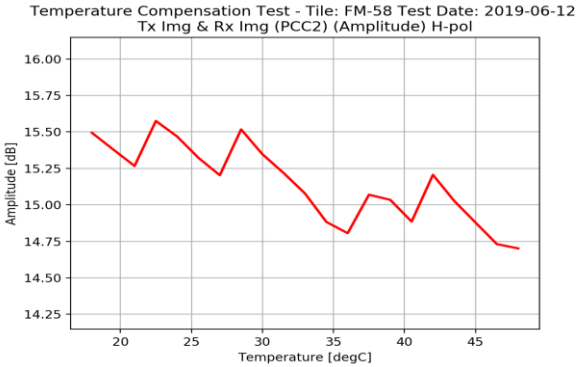
Tile FM on-ground test results (3 of 4)

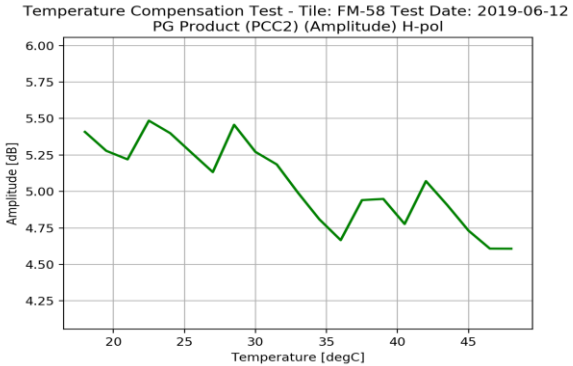
TA-A H-pol

Red: Gain changes of TX and RX path (Imaging)

Green: Gain changes measured by internal calibration

Blue: Imaging normalized by Internal calibration

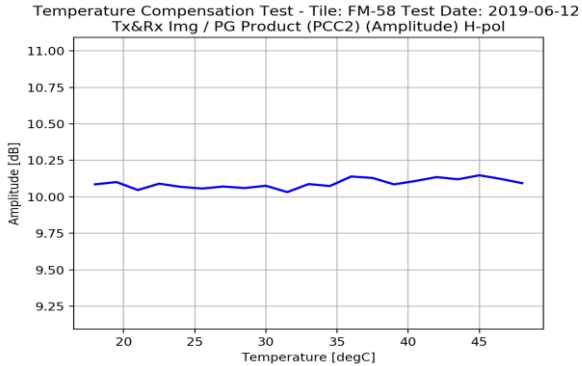




Radiometric Stability

$$IMG = TXPow * RXGain$$

$$PG\_product = \frac{TxCal * RxCal}{EPDNCal}$$



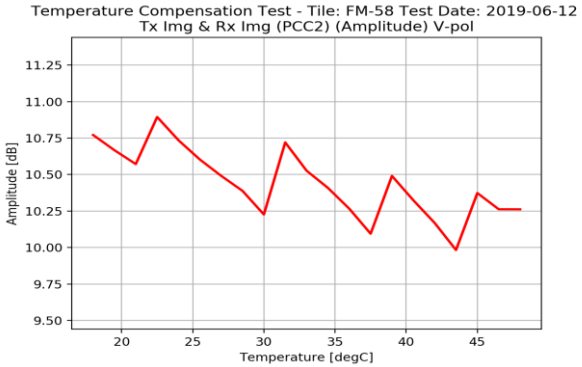
Tile FM on-ground test results (3 of 4)

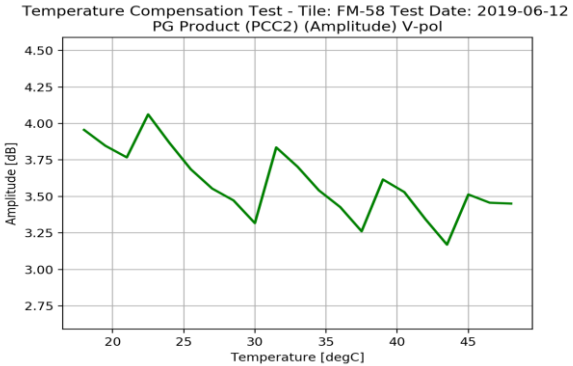
TA-B V-pol

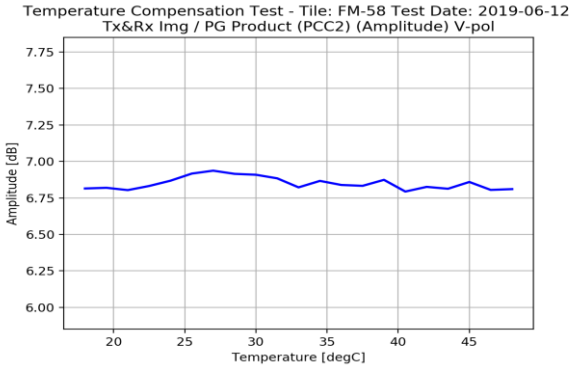
Red: Gain changes of TX and RX path (Imaging)

Green: Gain changes measured by internal calibration

Blue: Imaging normalized by Internal calibration







Radiometric Stability

$$IMG = TXPow * RXGain$$

$$PG\_product = \frac{TxCal * RxCal}{EPDNCal}$$

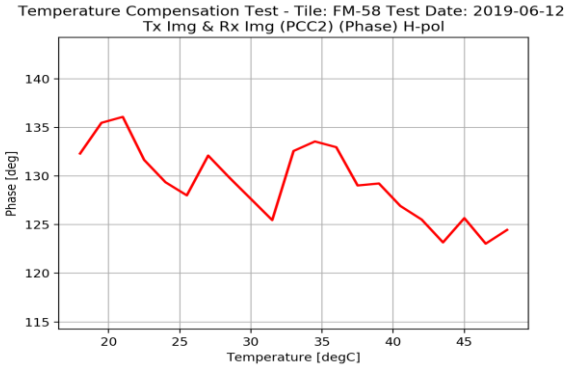
Tile FM on-ground test results (3 of 4)

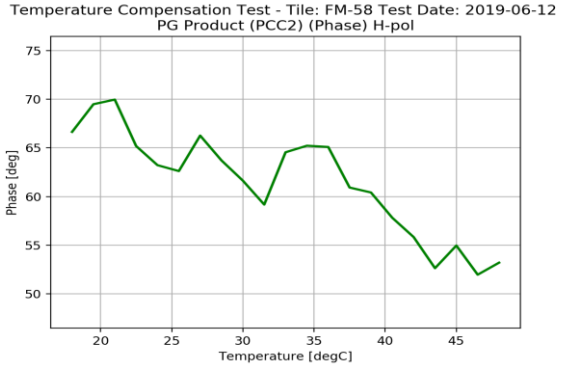
TA-A H-pol

Red: Phase changes of TX and RX path (Imaging)

Green: Phase changes measured by internal calibration

Blue: Imaging normalized by Internal calibration

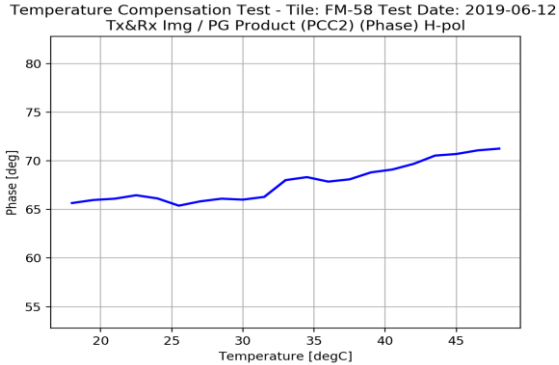




Radiometric Stability

$$IMG = TXPow * RXGain$$

$$PG\_product = \frac{TxCal * RxCal}{EPDNCal}$$



Summary

- S-1C&D ensures continuity of data products with S-1A&B.
- Antenna architecture of S-1C&D is updated with dedicated Tile Amplifiers.
- New TA simplifies internal calibration measurements.
- Instrument operation for S-1C&D is updated to improve noise acquisitions within IW, EW and WV mode.
- Eight FM Tiles have been successfully tested.
- Tile Test results show good calibration stability.
- New architecture is expected to provide improved SAR level radiometric stability and accuracy.