

An Internal Calibration System Model for the Estimation of SAR Instrument Errors

Committee on Earth Observation Satellites Workshop
18-22 November 2019

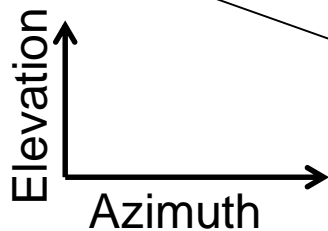
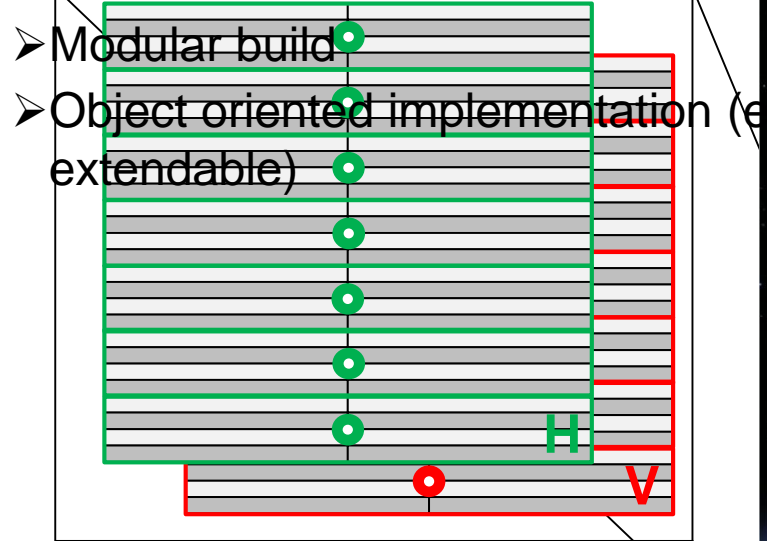
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Knowledge for Tomorrow

Future Systems

- Phase centers
- Simulation elements
- Y-polarization elements
- Performance of different calibration methods



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Scan-On-Receive (SCORE)

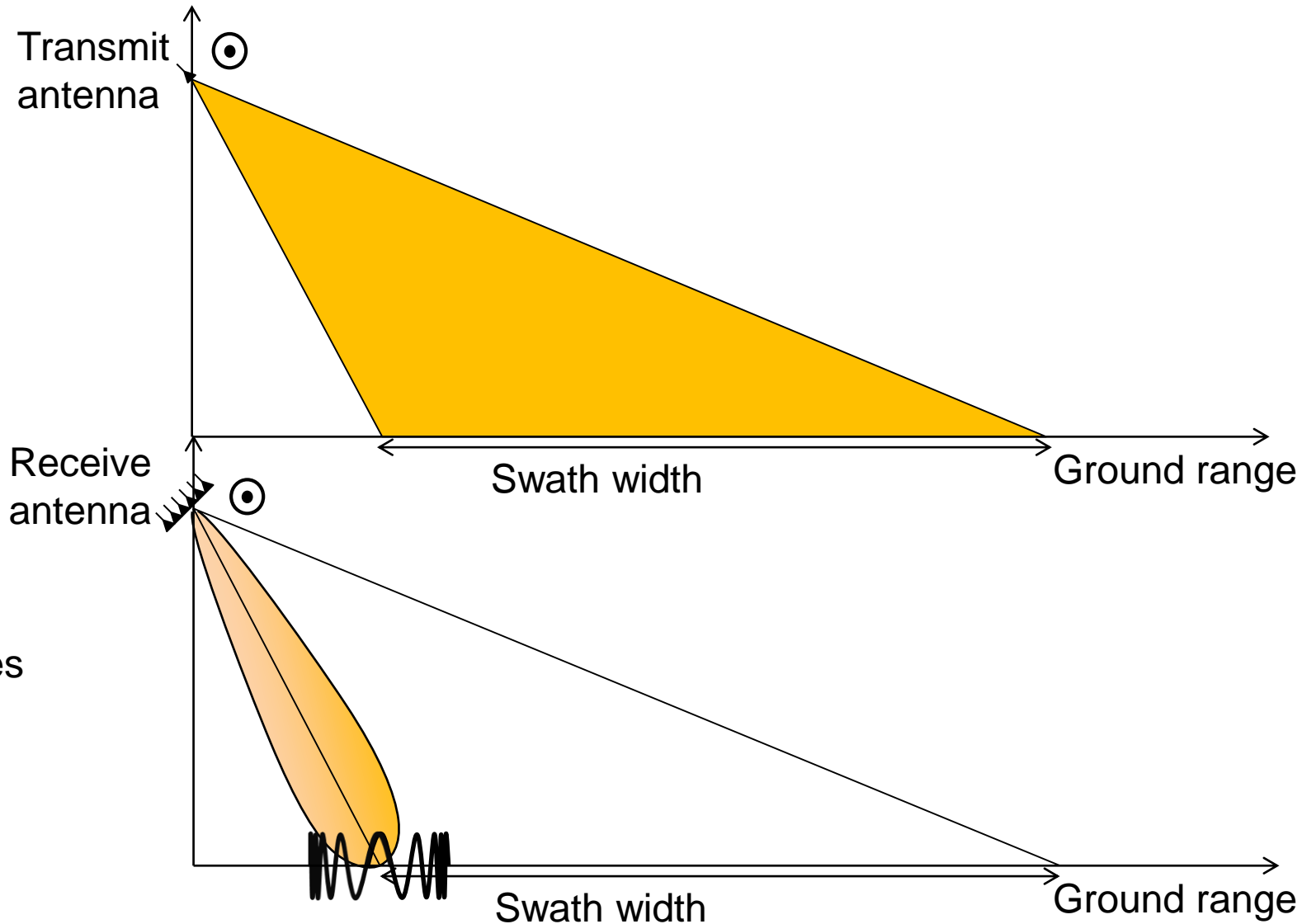
Transmit:

- Transmitter illuminates the whole swath

Receive:

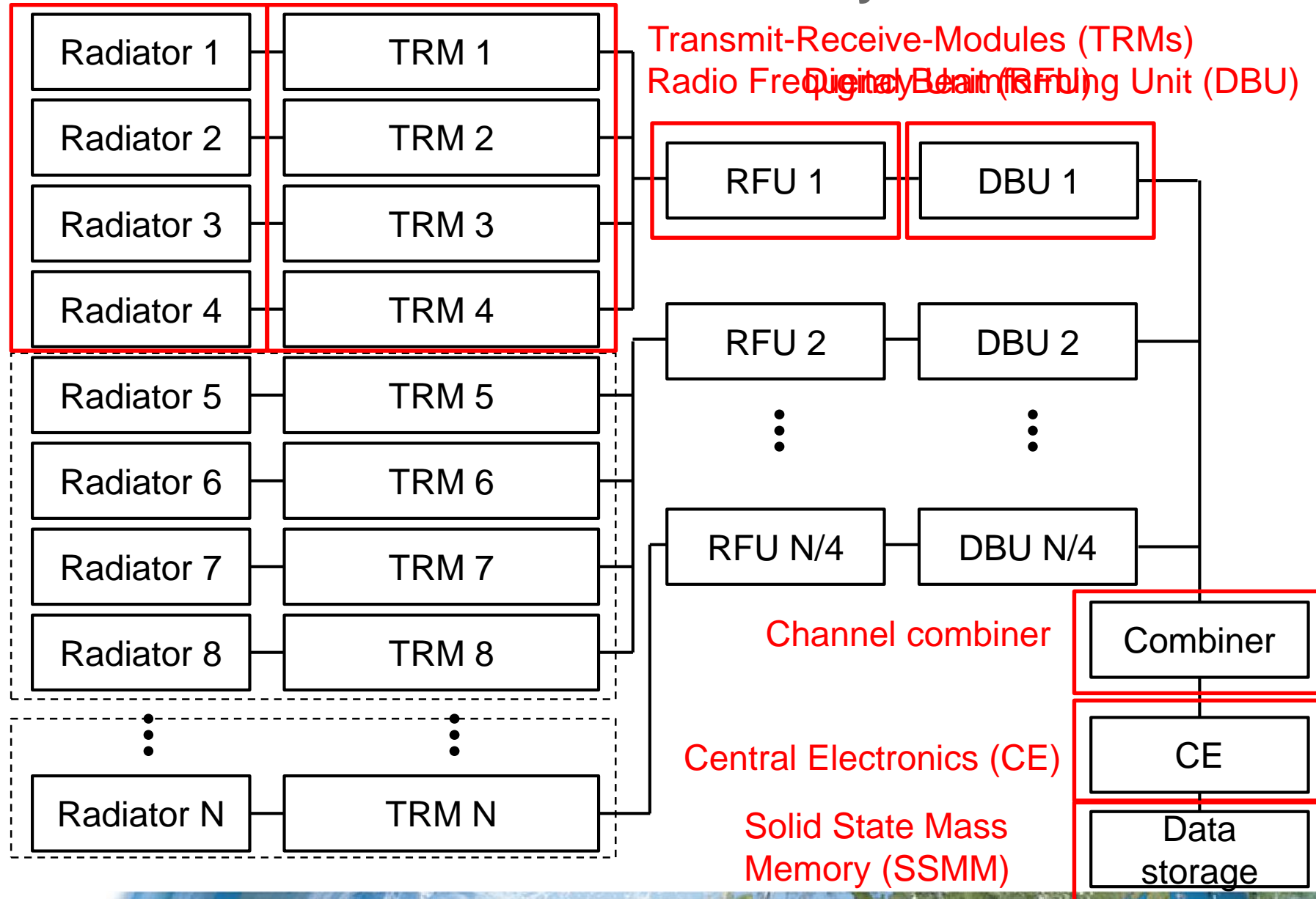
- Narrow receive beam
- Digital beamforming steers beam to signal on ground
- Advantages:
 - High resolution, wide swath
 - Improved Signal-to-Noise Ratio (SNR)
 - Suppression of range ambiguities

Done on-board



One Azimuth Channel Of A Multi-Channel SAR System

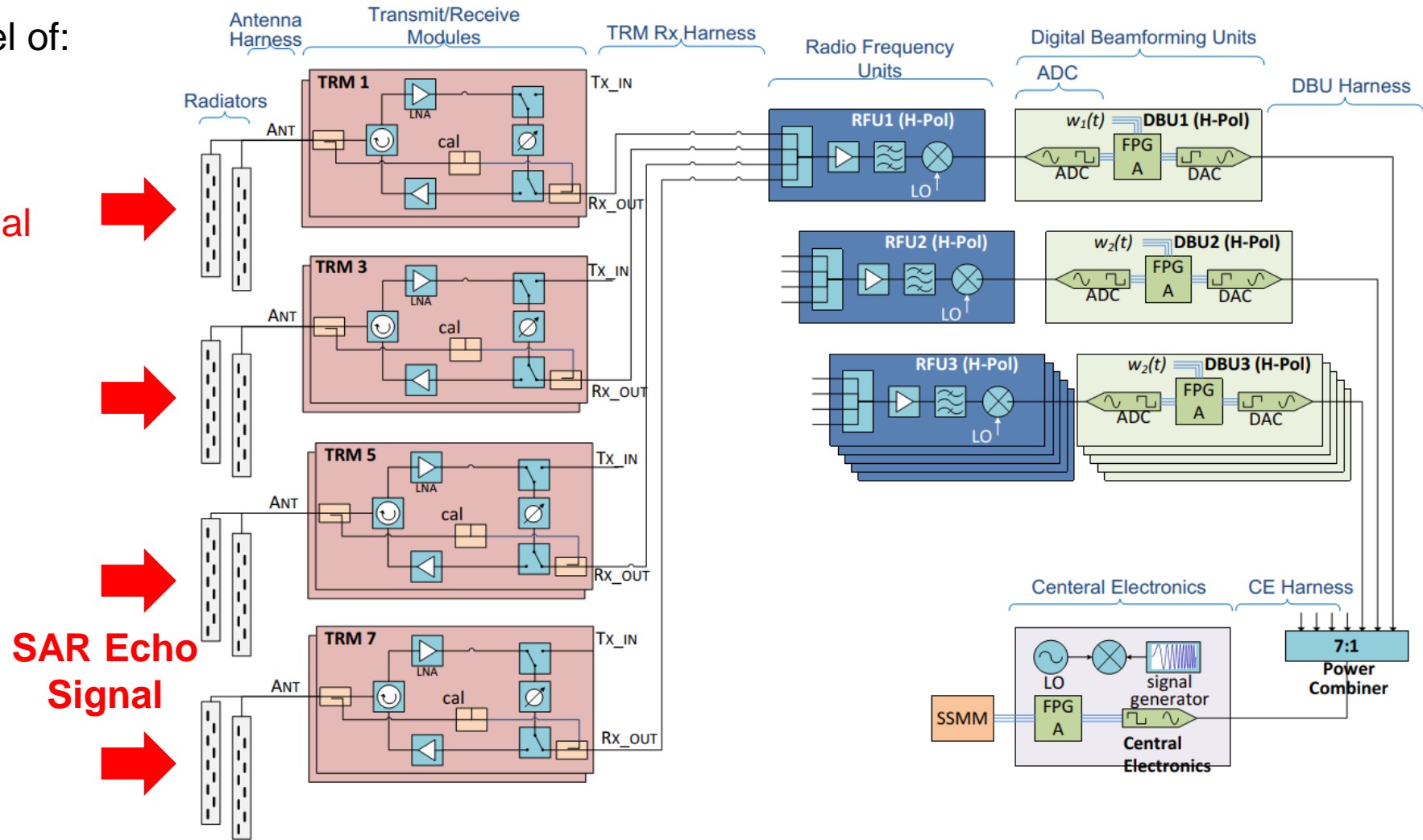
- Radiators**
- Transmit-Receive-Module (TRM)
 - Radio Frequency Unit (RFU)
 - Digital Beamforming Unit (DBU)
 - Combination of elevation channels



System Model

➤ Mathematical model of:

- Signals
- System
- Errors
- SAR echo signal



Error Sources

- Coupling
 - Antenna elements
 - Signal paths
- Temperature drift
- Random walk
- Transfer function drift
- Noise

RW = random walk

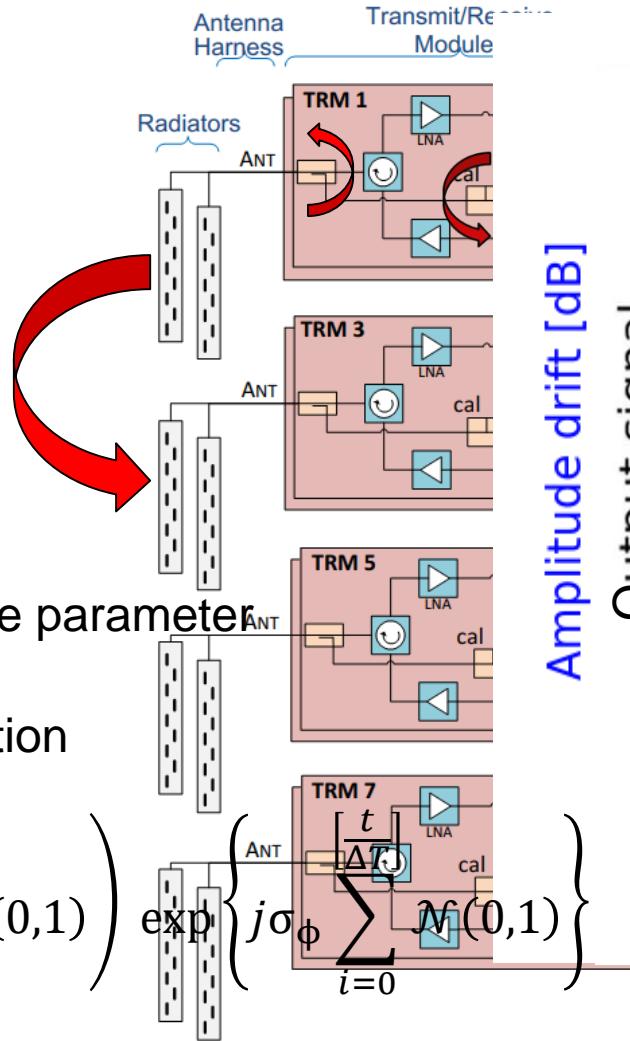
t = time

$\sigma_A; \sigma_\phi$ = amplitude, phase parameter

ΔT = time step

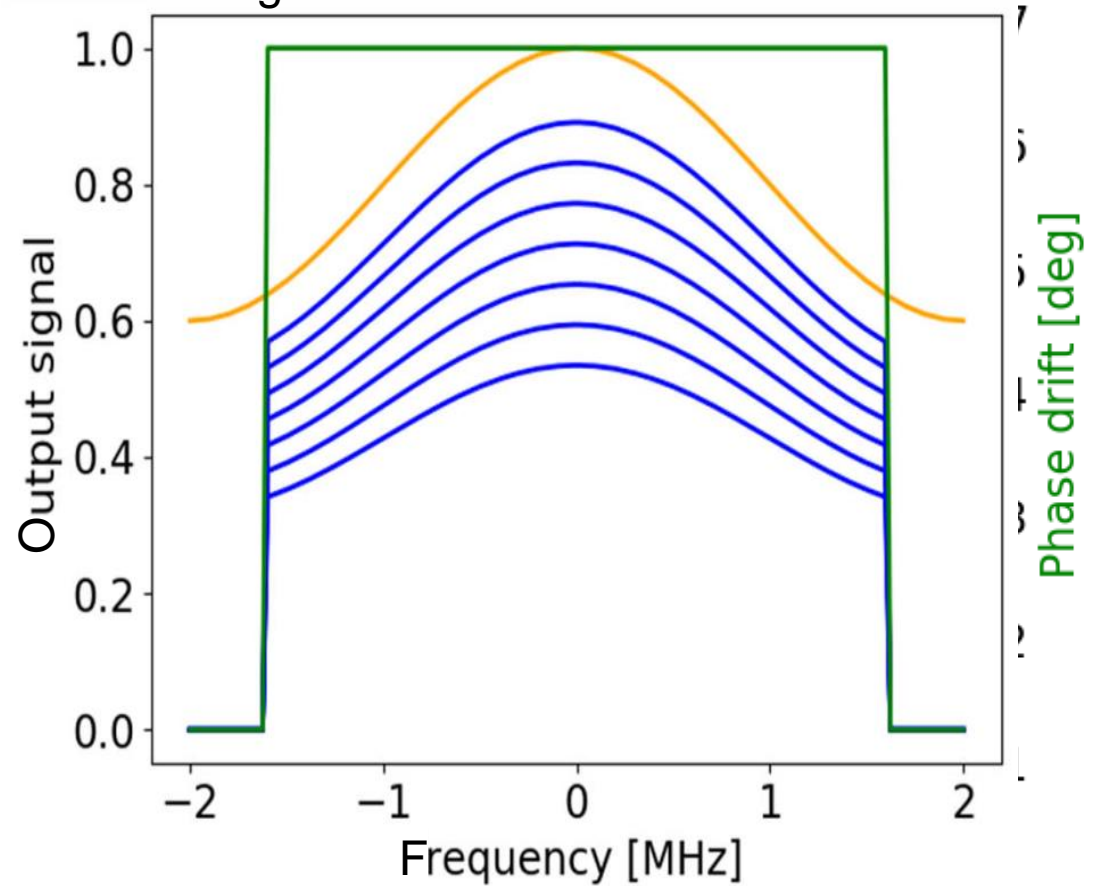
$\mathcal{N}(\mu, \sigma)$ = normal distribution

$$RW(t) = \left(1 + \sigma_A \sum_{i=0}^{\lfloor \frac{t}{\Delta T} \rfloor} \mathcal{N}(0,1) \right) \exp \left\{ j \sigma_\phi \sum_{i=0}^{\lfloor \frac{t}{\Delta T} \rfloor} \mathcal{N}(0,1) \right\}$$



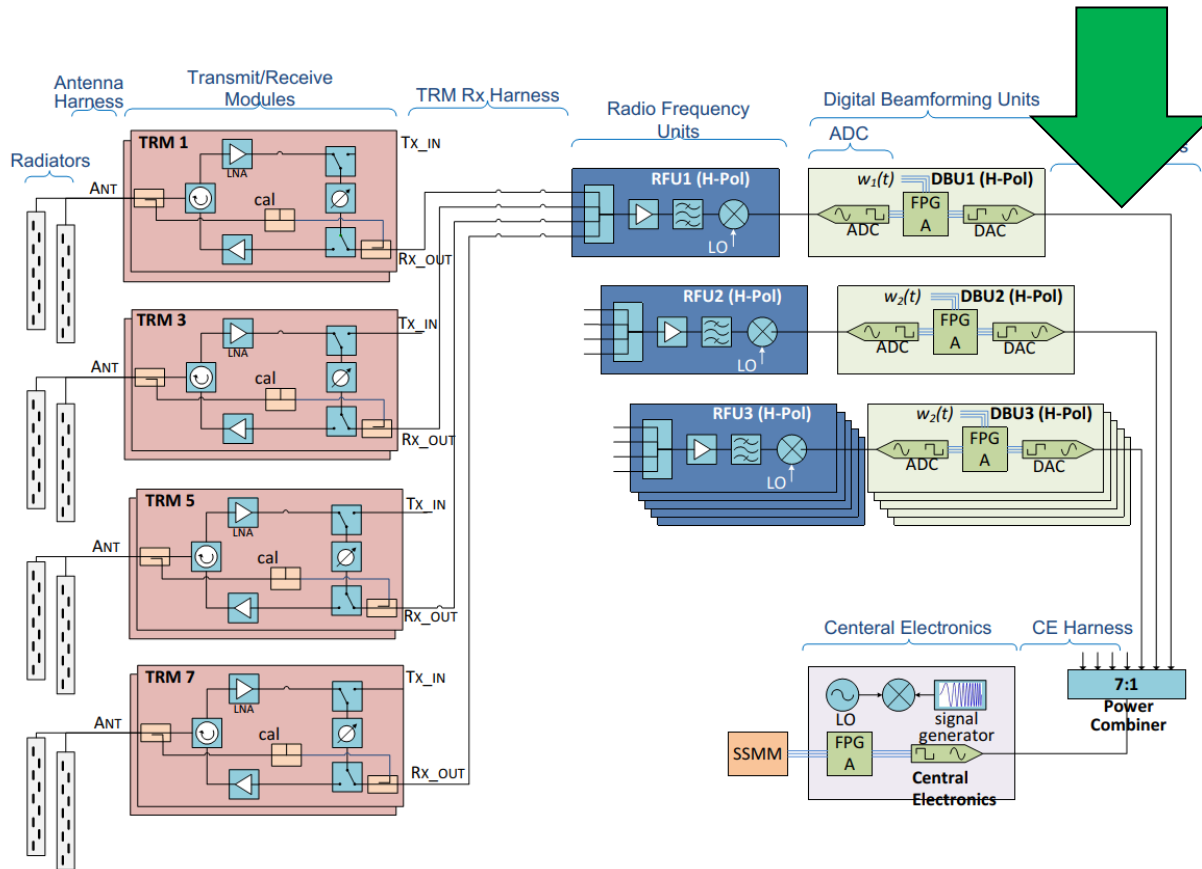
Amplitude drift [dB]

Change of transfer function

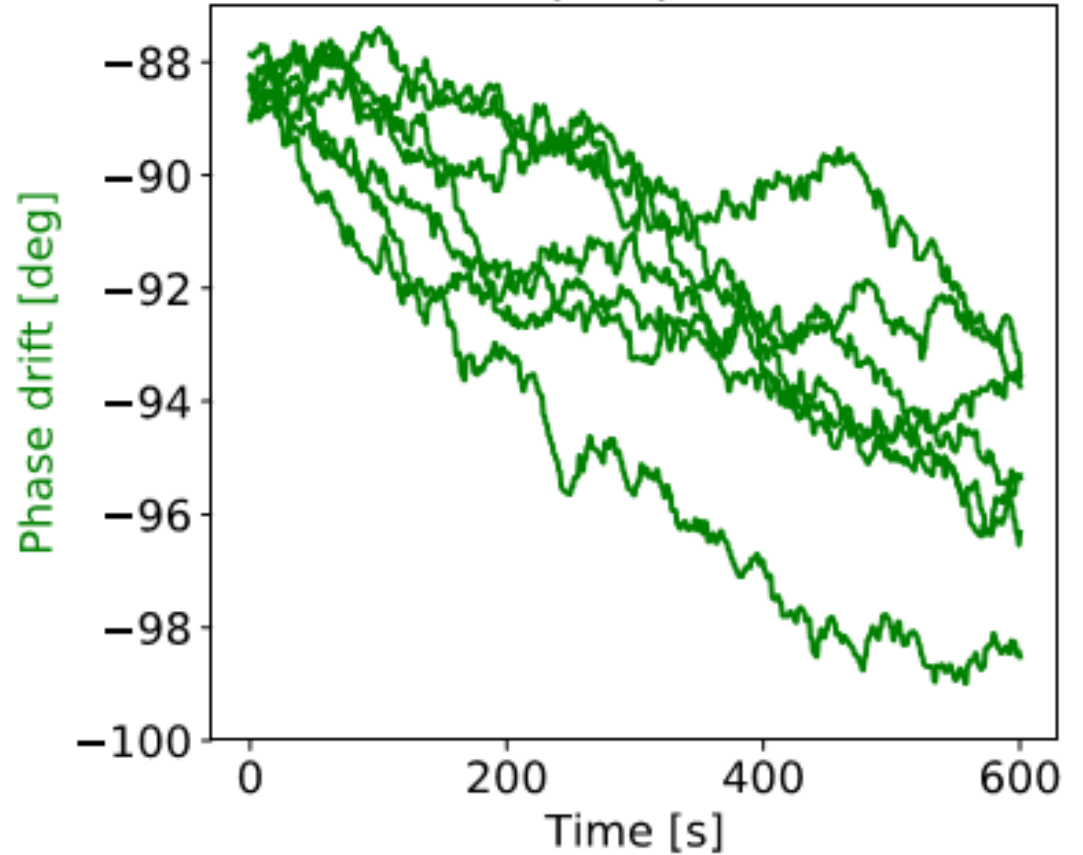


Total Error

➤ Different element parameters

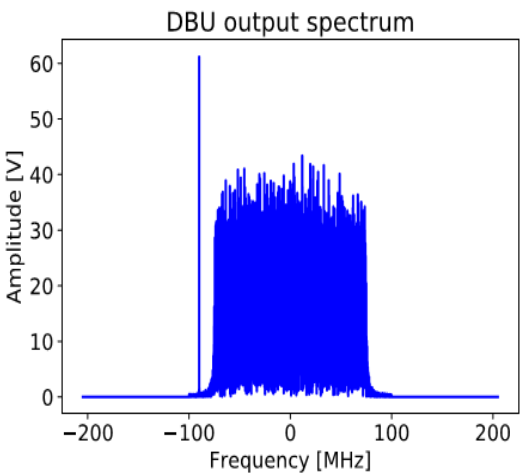
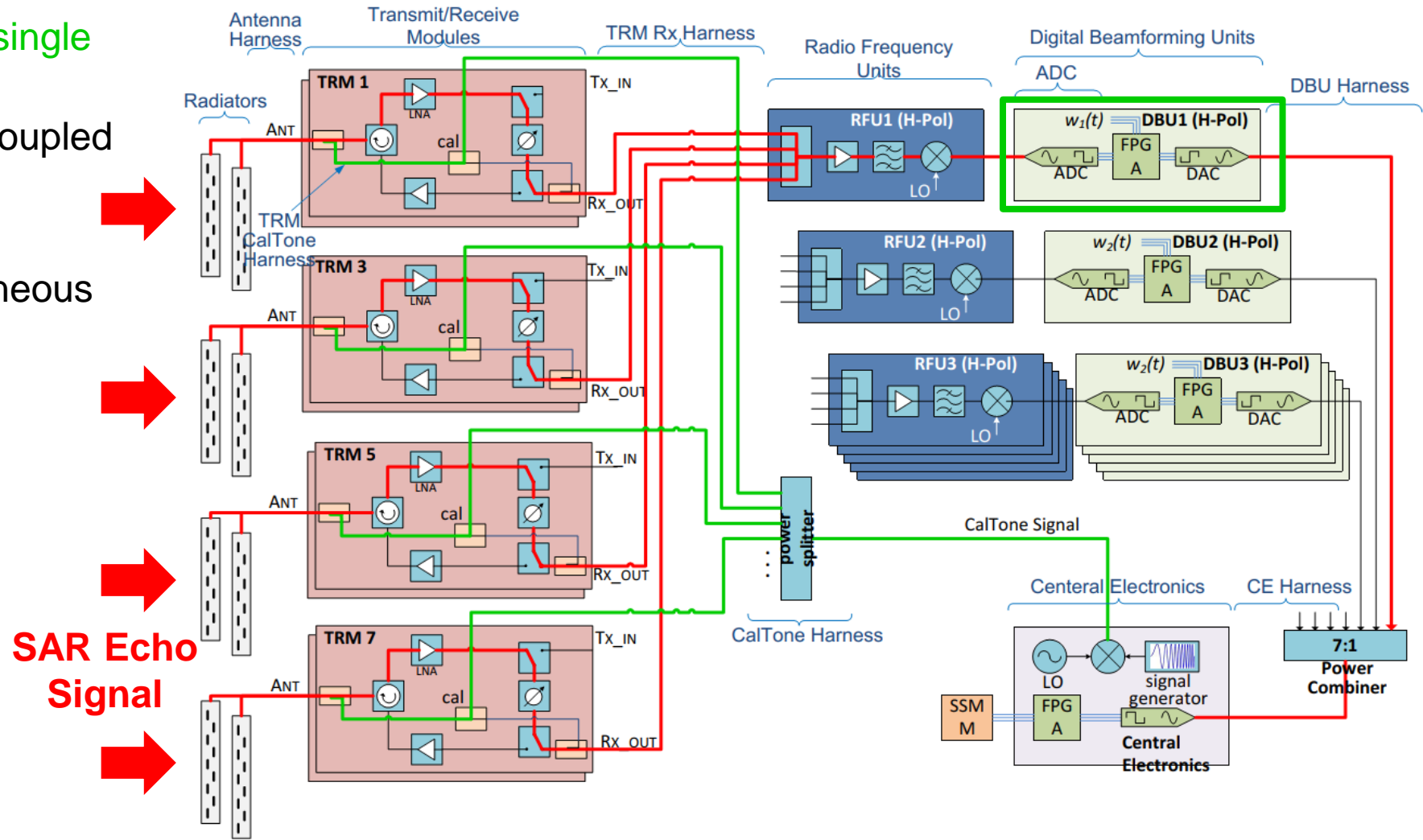


DBU output phase drift



CalTone Calibration Concept

- Calibration signal (single tone signal)
- Calibration signal coupled to TRM
- Evaluation at DBU
- Calibration simultaneous to SAR operation



SAR Echo Signal

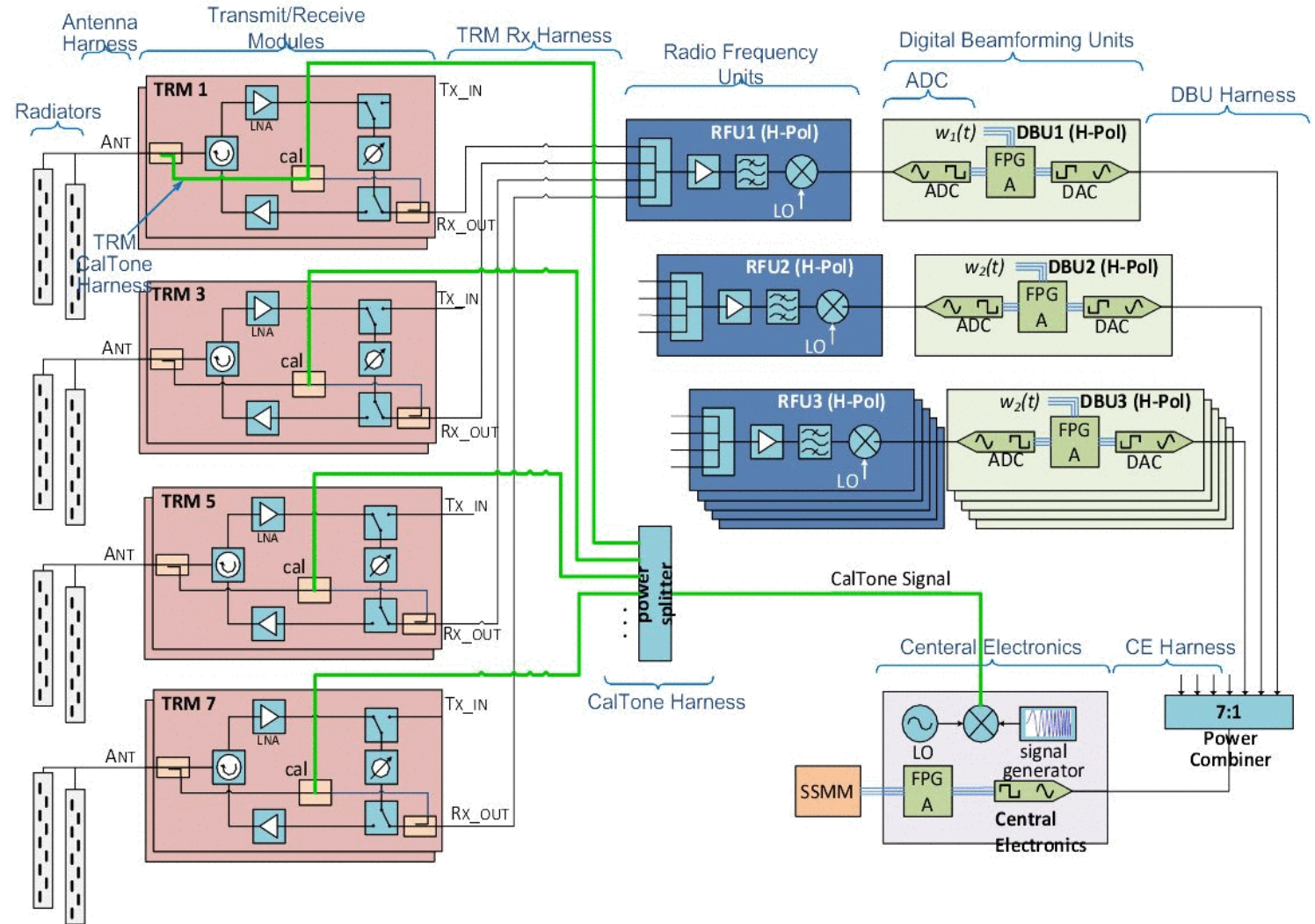
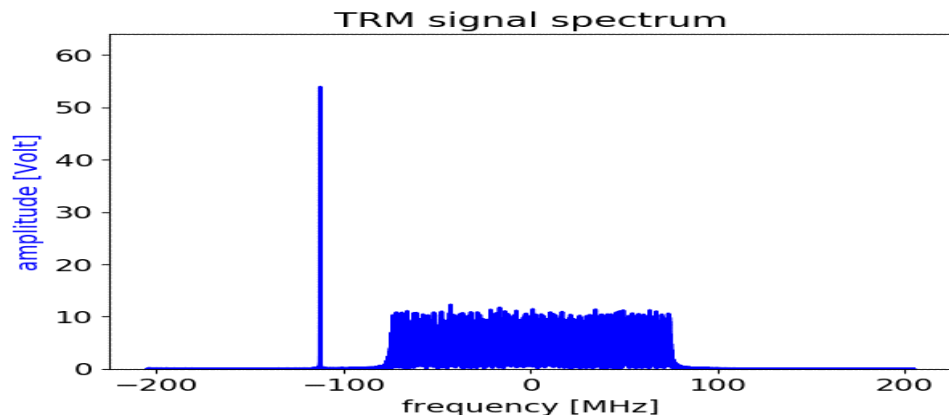
Calibration signal sequence

Sequence modes:

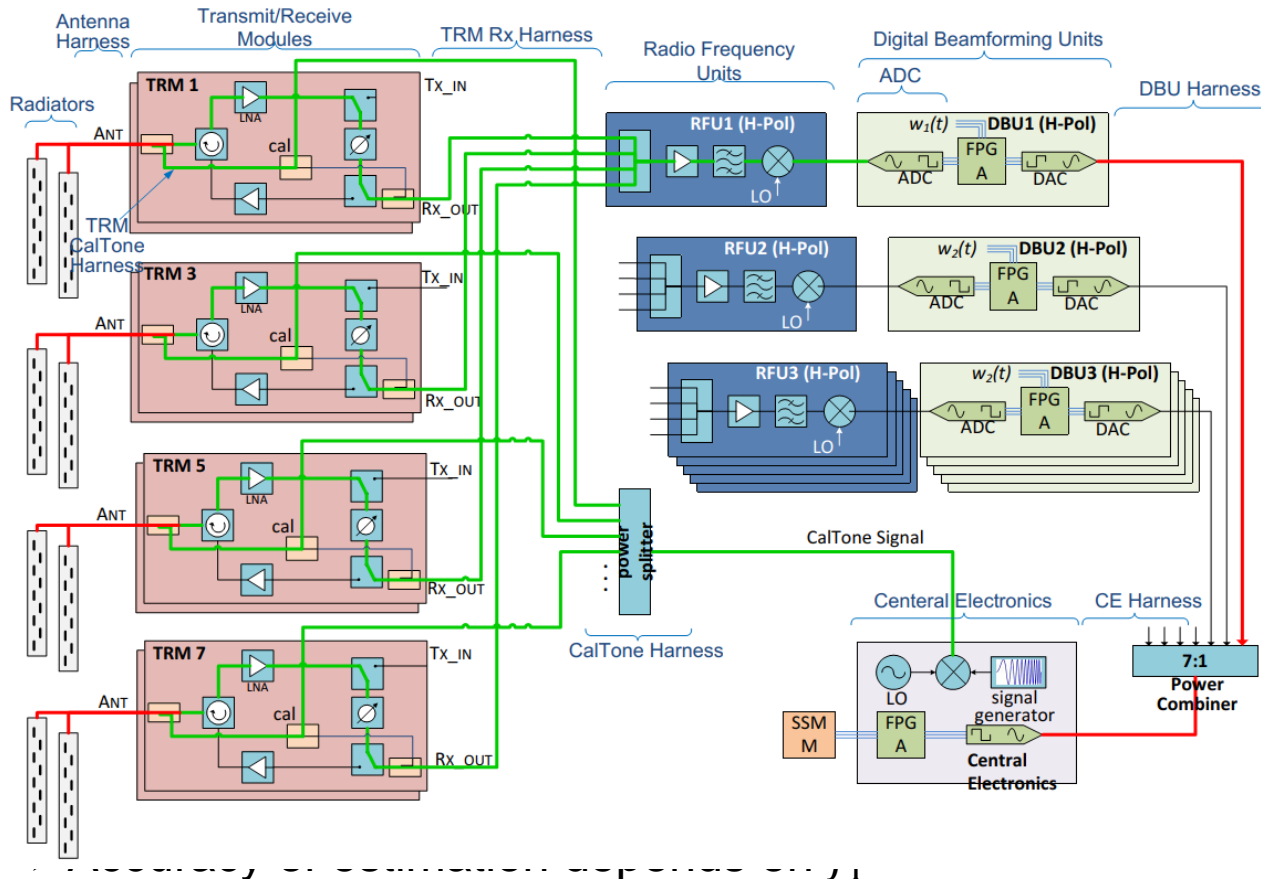
- 1 of N: calibration signal sequentially coupled to one element

Calibration signal frequency:

- Fixed frequency
- Frequency stepping

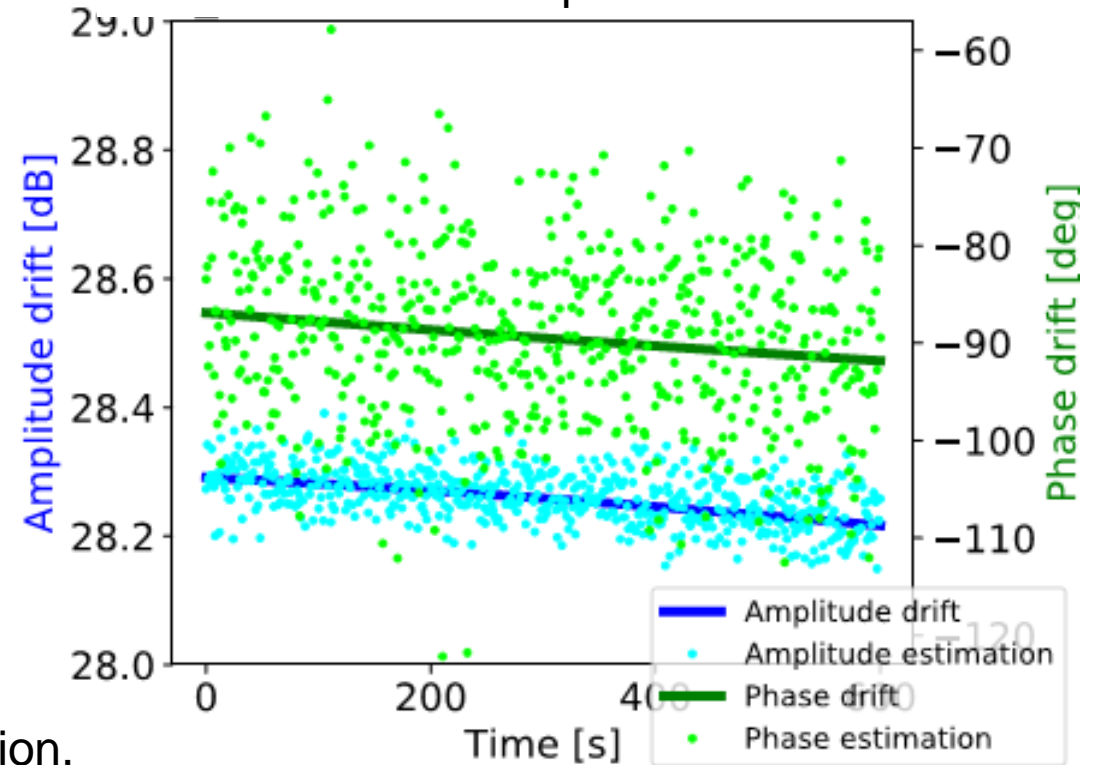


Estimation Of The Drift

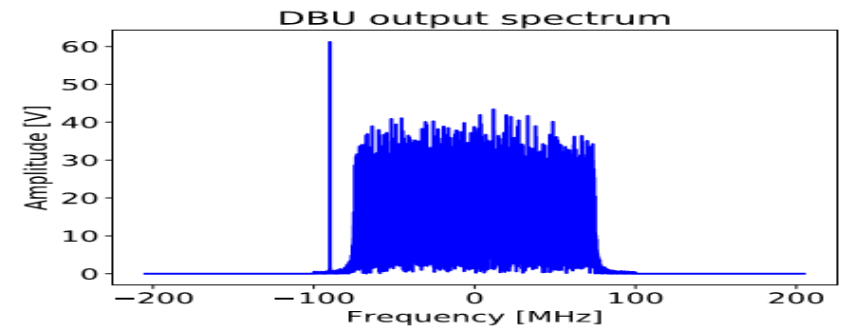


➤ Estimate drift in elements passed by calibration signal

DBU output drift



action,

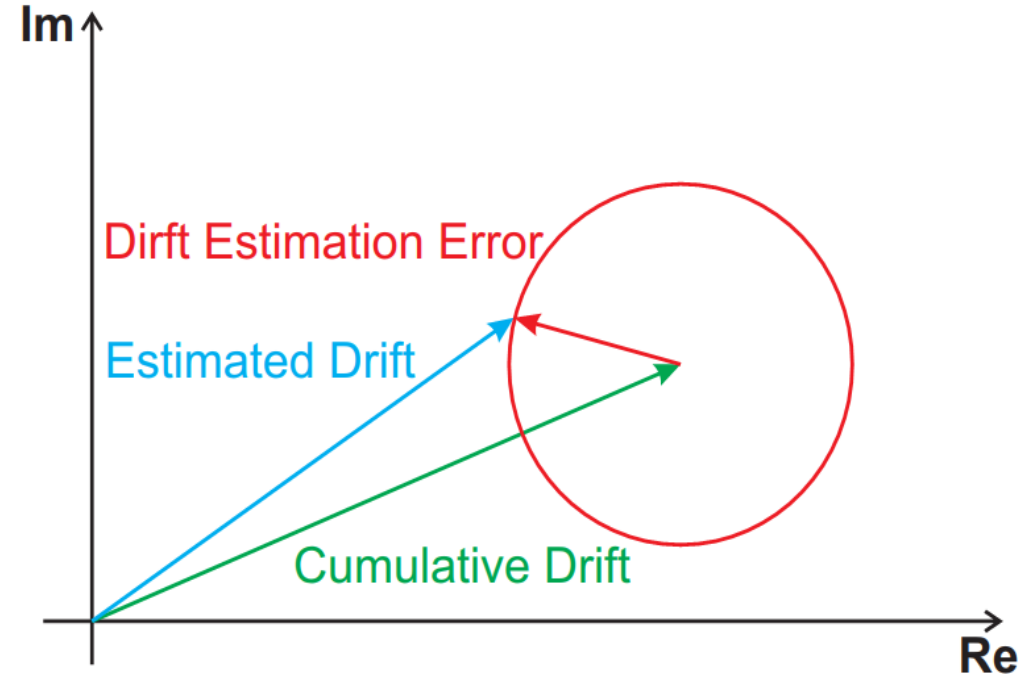


RX Drift Estimation Error

➤ Measured drift:

$$\begin{aligned}
 D_{DBU}(t_{slow}, f_1) &= \frac{S_{DBU}(t_{slow}, f_1) S_{ct}^*(f|f_1)}{|S_{ct}(f|f_1)|^2} \\
 &= \frac{H[S_{RX}(t_{slow}, f_1) + S_{ct}(f|f_1)] S_{ct}^*(f|f_1)}{|S_{ct}(f|f_1)|^2} + N \\
 &= H + \frac{H S_{RX}(t_{slow}, f_1)}{S_{ct}(f|f_1)} + N
 \end{aligned}$$

SAR echo signal (points to S_{RX})
Noise (points to N)
Wanted (points to H)
Error (points to the fraction term)



- SAR echo signal is zero mean signal
- Drift estimation is uniformly distributed around true drift
- Improve drift estimation using multiple previous values

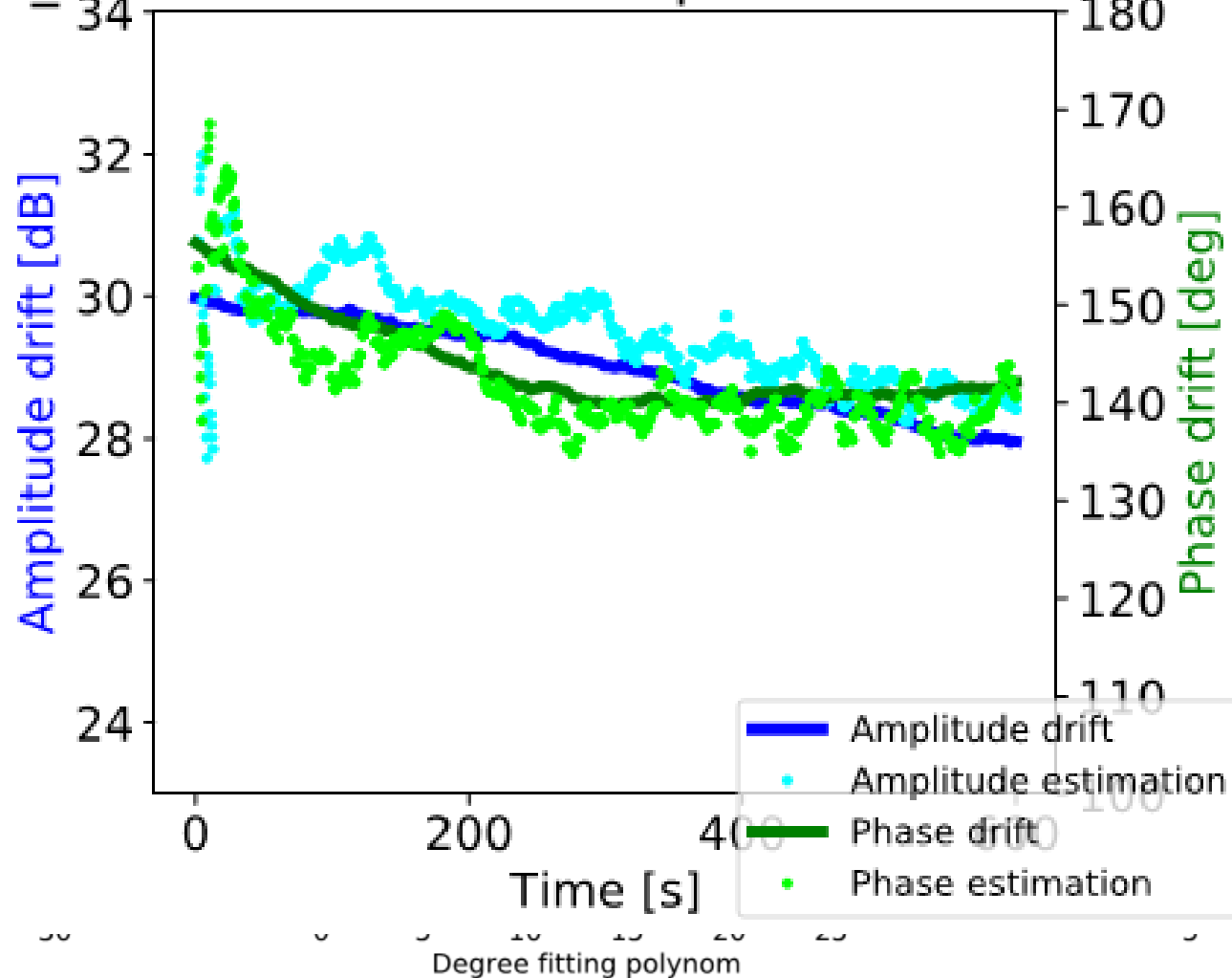
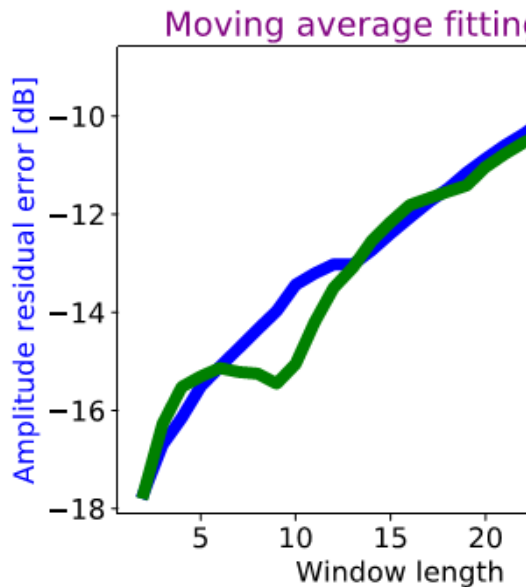


Comparison Of Improved Estimation Methods

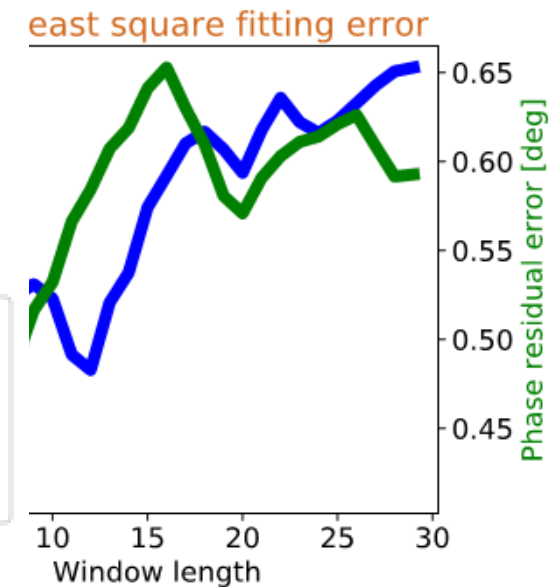
Estimation methods: DBU_ADC calculated vs. improved estimated drift

➤ Moving average

- Performance dependent on variation/sample
- Low computational complexity
- No real prediction



linear fit
computational complexity
limited prediction capabilities (linear)



Summary

- Mathematical model developed
- Simulation tool implemented
 - Aid system design
 - Adaptable to any multi-channel instrument
 - Different calibration methods
 - Determine the errors and residual errors
 - Performance analysis
- Single tone calibration analysis
- Investigated drift estimation methods