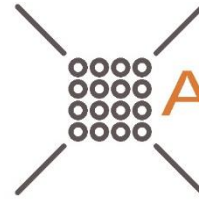


ASTRON



APERTIF

APERture Tile In Focus

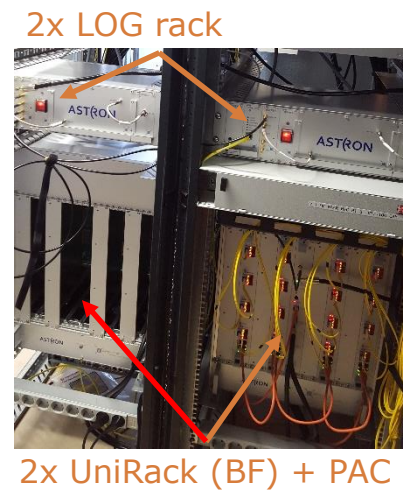
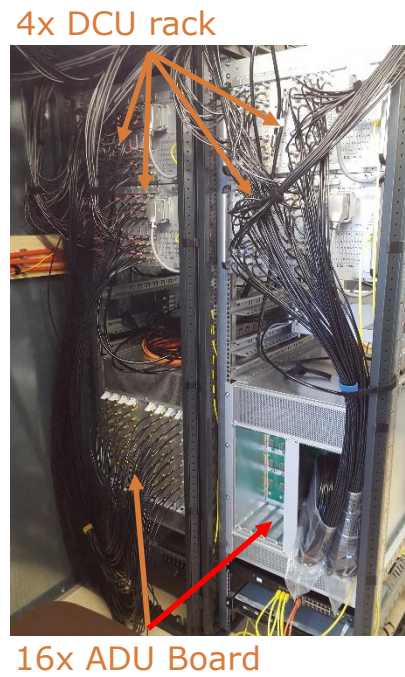
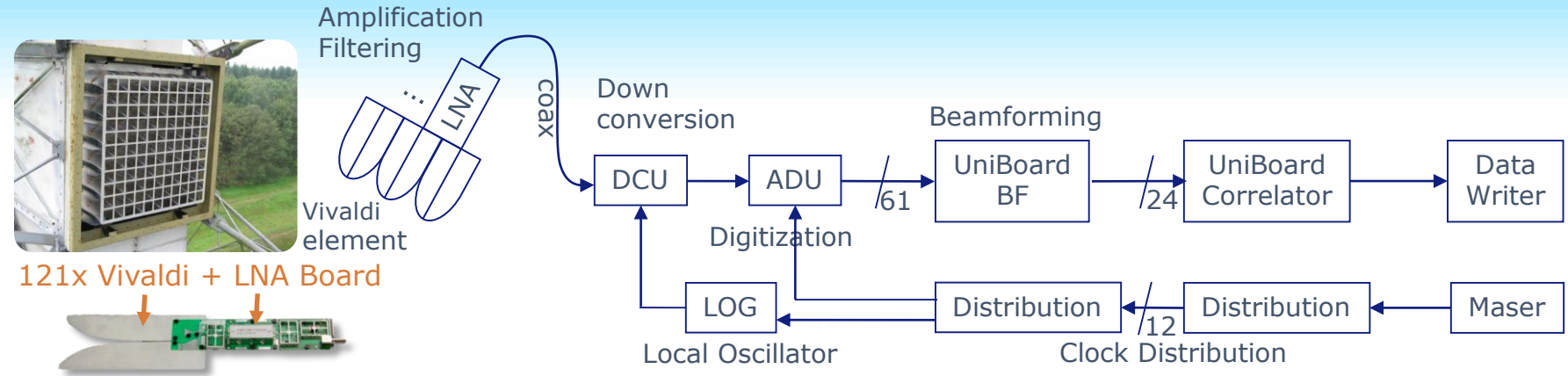
Online Calibration of the *WSRT Phased Array Feed system*

Boudewijn Hut

- Phased Array Technology

- Why calibration?
- How to calibrate?
 - Calibration with or without reference signal
- Online calibration scheme for APERTIF
 - Two designs
- Future plans

PAF Technology: many receiver chains



Why Calibration?

- Difference in gain and phase of individual elements
 - Sun radiates on some cables directly



- Drift between receiver chains affects beamshape
 - Requirement on beamshape
 - Requirement on beamformer weights
 - 0.3 dB in amp; 2 degree in phase

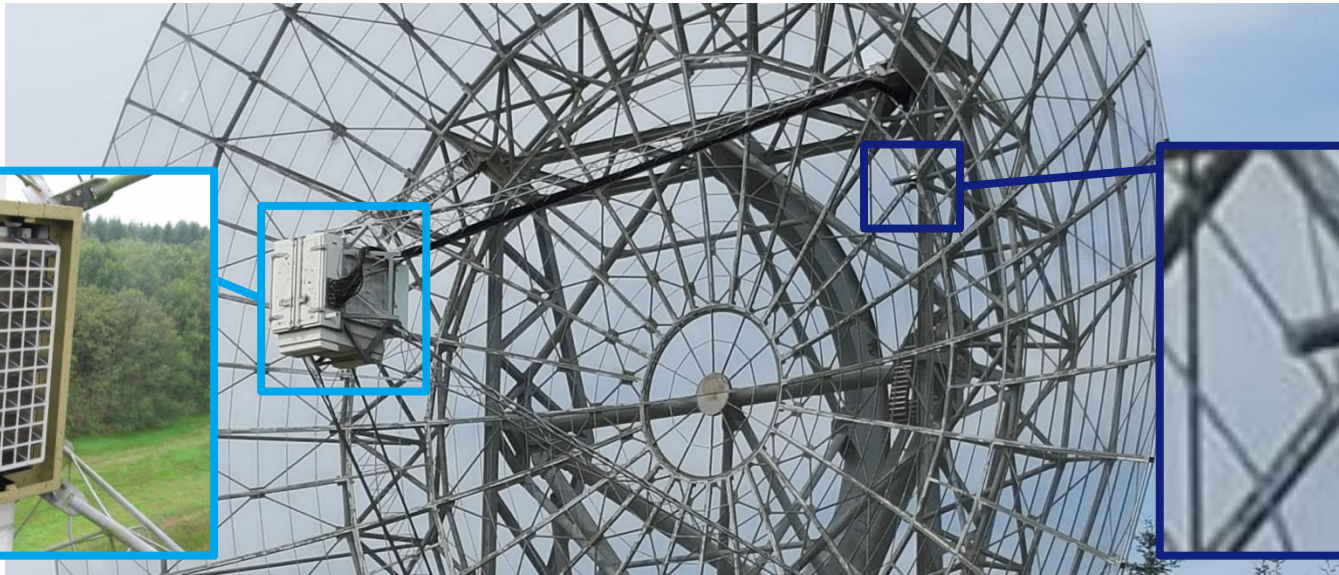
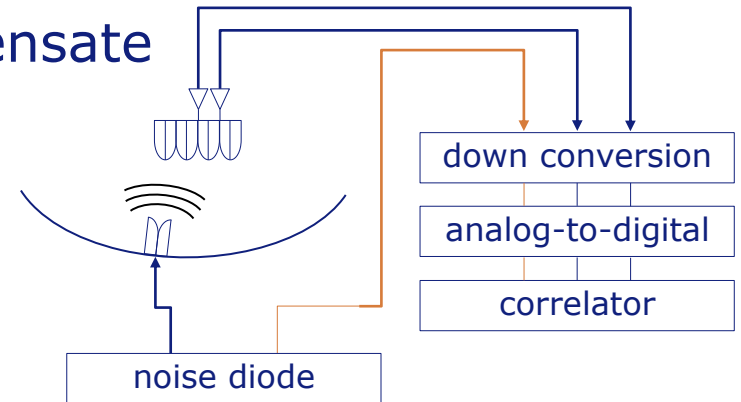
How to Calibrate?

two options

- Emit stable broadband noise
- Track changes of this signal to compensate

1: Without reference signal (NxN)

2: With reference signal (Nx1)

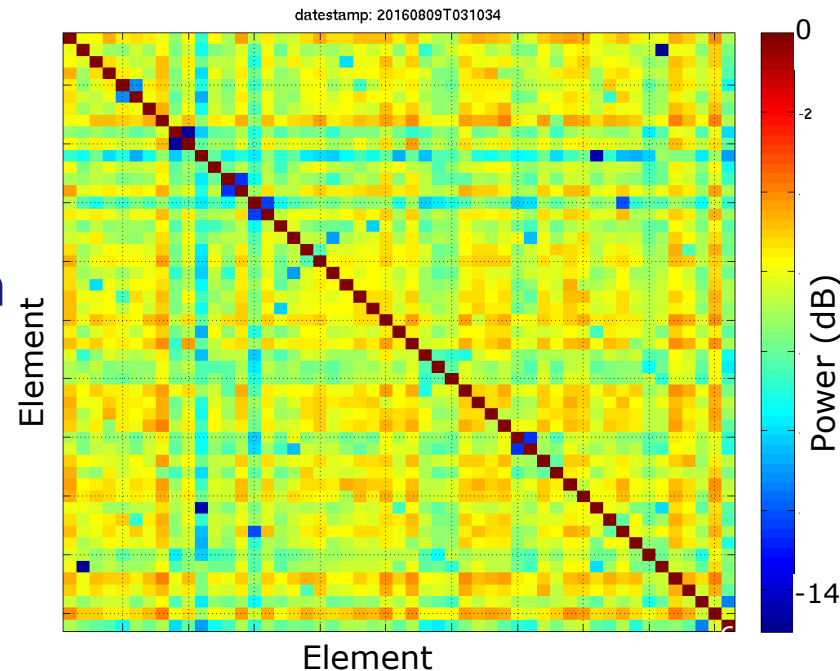
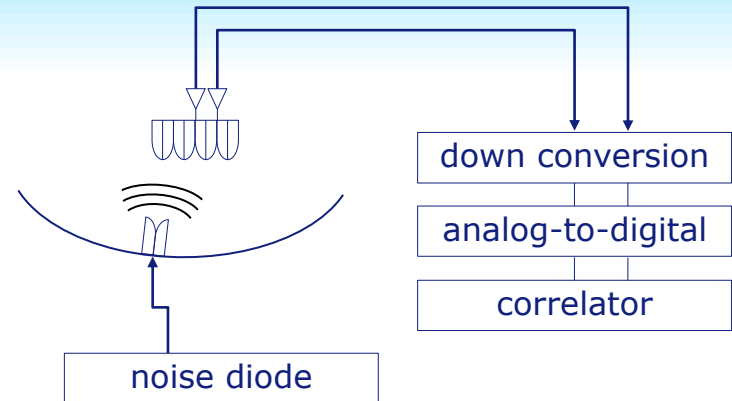


How to Calibrate?

option 1: without reference

- Record $N \times N$ correlation matrix R_t
 - At start ($t = t_0$)
 - Every x seconds thereafter

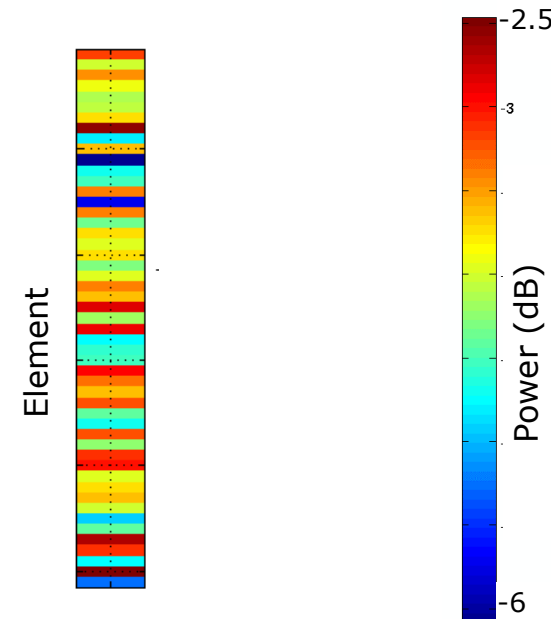
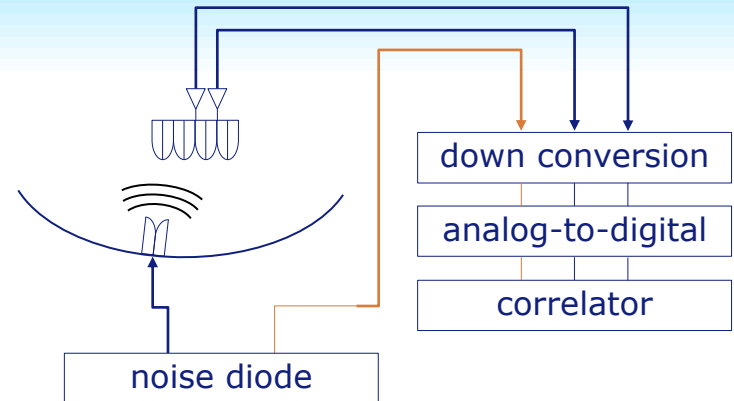
- Correction $w_{corr,t} = e_t \oslash e_{t_0}$
 e_t is the eigenvector, corresponding to the largest eigenvalue of R_t
 \oslash denotes the element-wise division



How to Calibrate?

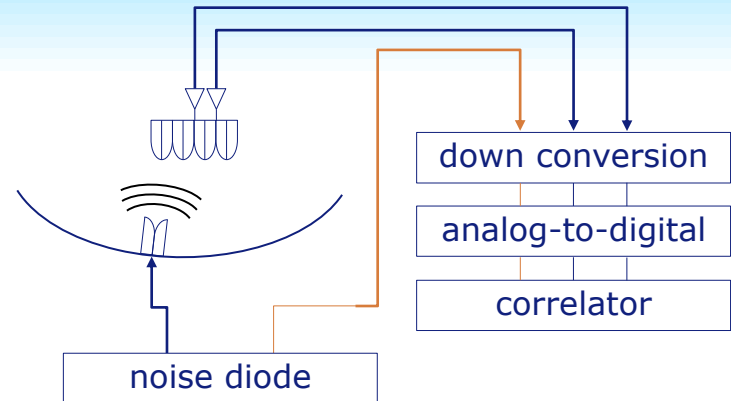
option 2: with reference

- Correlating PAF elements against noise diode
- Record $N \times 1$ correlation vector \mathbf{r}_t
- Correction $\mathbf{w}_{corr,t} = \mathbf{r}_t \oslash \mathbf{r}_{t_0}$
- Fewer correlation values can be traded for frequency bins
- Reduces time spending on online-calibration

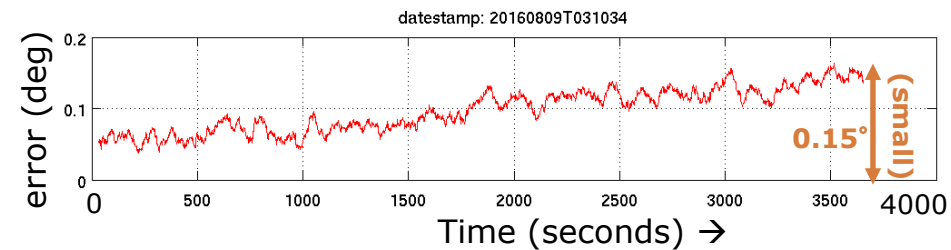
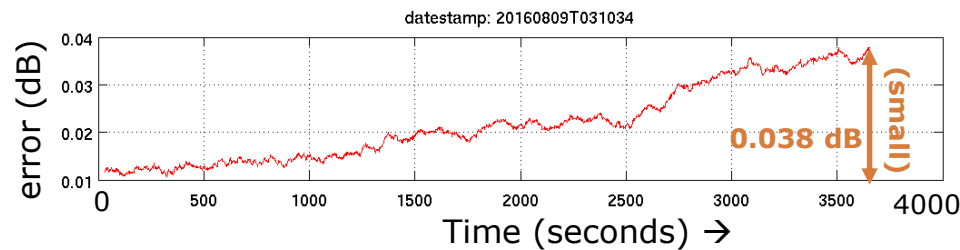
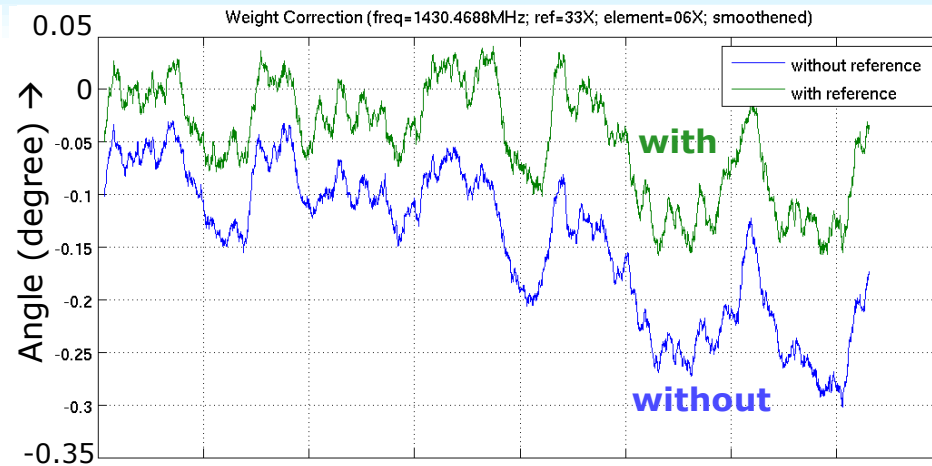
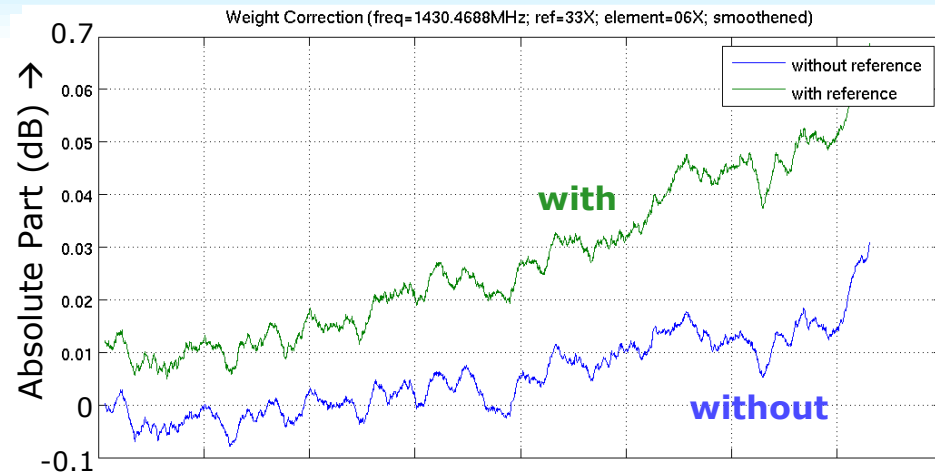


Comparison Measurement

- Measure full correlation matrix every second, for 1 hour
- Without reference, select correlation matrix of PAF elements
- With reference, select correlation vector with calsrc
- Determine $w_{corr, t}$ for every second with and without reference
- Compare correction factor for a single PAF element
- Measurement during night time



Result

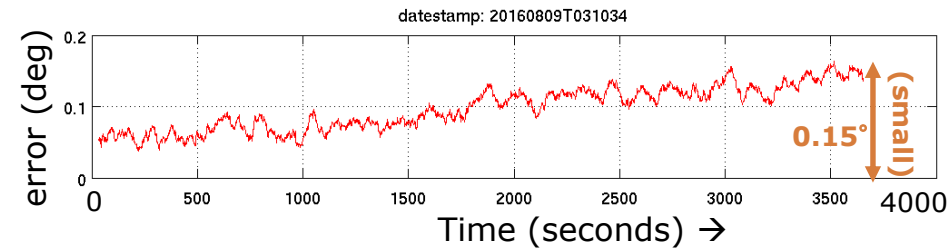
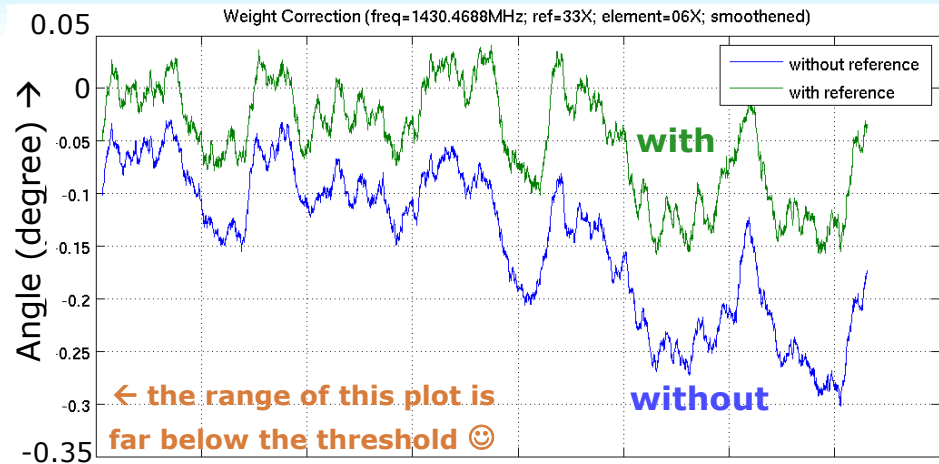


- Adding reference gives similar result
 - Sky signal may cause variations

Result

- Threshold for new calibration:
 - 0.3 deg amp; 2 deg phase
 - Threshold not reached within 1 hour!
- During night time, online calibration interval longer than 1 hour
- Adding reference gives same result

- Sky signal may cause variations

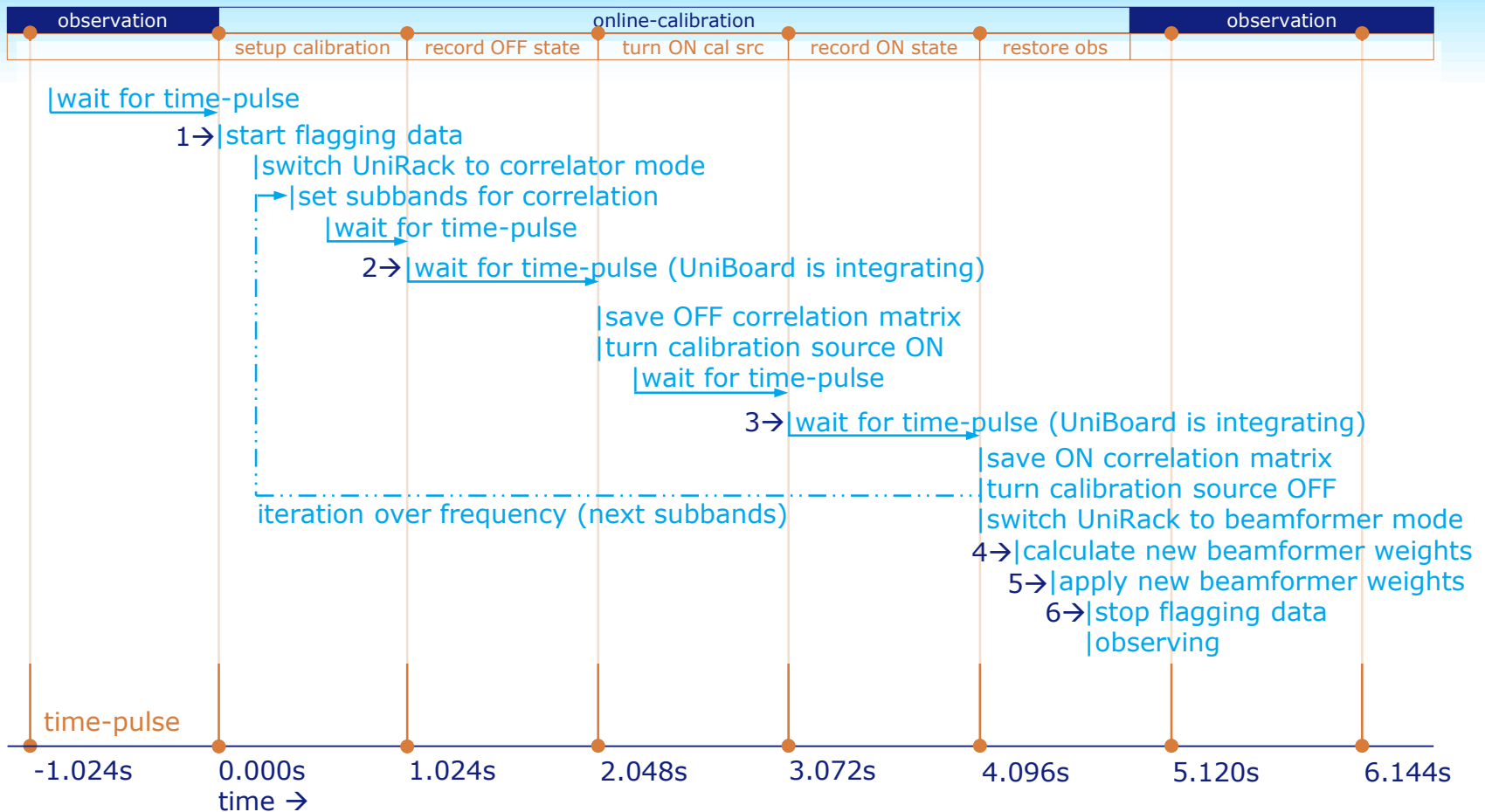


Online Calibration: 6 Steps

1. Flag data
2. Record R_{off}
3. Record R_{on} (or r_{on})
4. Calculate new weights: $R_{on,t}$ & $R_{on,t_0} \rightarrow$ bf weights
5. Apply new beamformer weights
6. Unflag data

R_{off} is included to track relative system temperature

Online Calibration: 6 Steps



■ total measurement time = $(n_iterations * 4 + 1) * 1.024 \text{ sec}$

Online Calibration: two options

- A single loop records
 - **64x64** complex correlation matrix for **6** subbands, **or**
 - **1x64** complex correlation vector for **252** subbands

Option	Percentage of bandwidth per iteration	Percentage of bandwidth (total)	Number of iterations required	Time required for calibration measurement
64x64x6 <i>(without reference)</i>	1.5%	33%	22	91.136 s
		66%	44	181.248 s
		100%	67	275.456 s
1x64x252 <i>(with reference)</i>	66%	33%	1	5.12 s (17.8x faster)
		66%	1	5.12 s (35.4x faster)
		100%	2	9.216 s (29.9x faster)

- If it works, time improvement of factor > 17.8

Summary

- Two options for PAF calibration
- Adding a reference
 - Gives same correction factor
 - Reduces the time required for online calibration
 - by factor ~ 30
- Online calibration interval > 1 hour (system stable)
 - During night time
- Future
 - Test that variation between options is due to sky signal
 - Perform longer tests (including sunrise & sunset)