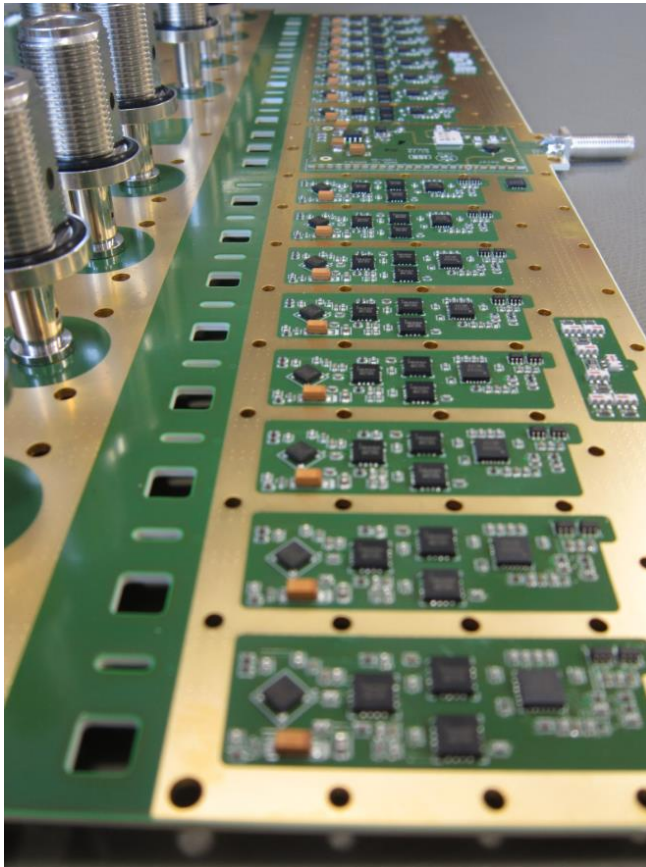
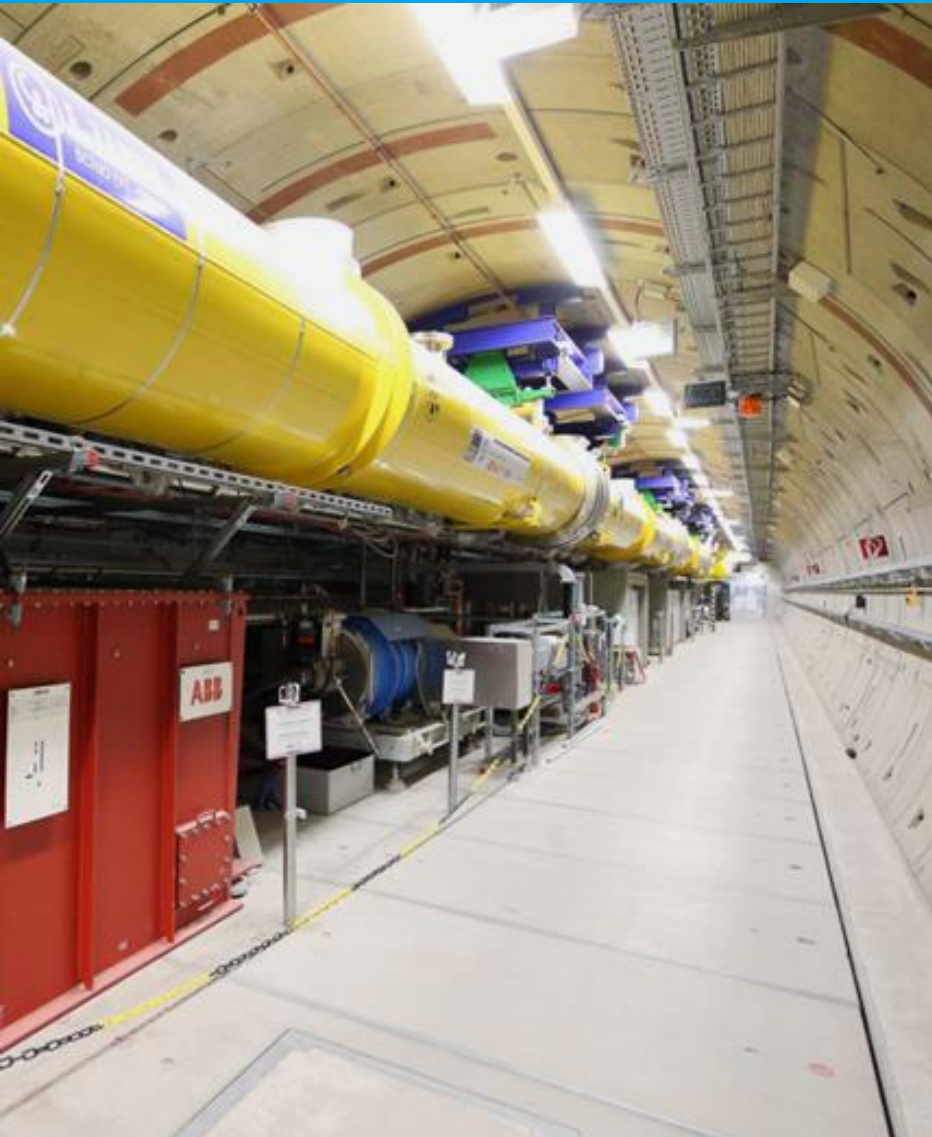


LLRF Workshop 2017



Drift calibration for the European XFEL

Frank Ludwig, (DESY)
Uros Mavric, (DESY)
Jan Piekarski, (WUT)
Christian Schmidt, (DESY)
Lukasz Butkowski, (DESY)
Matthias Hoffmann, (DESY)
Guenter Möller, (DESY)
Krzysztof Czuba, (WUT)
Holger Schlarb (DESY)
for the LLRF-Team
Barcelona, 18.10.2017



Content

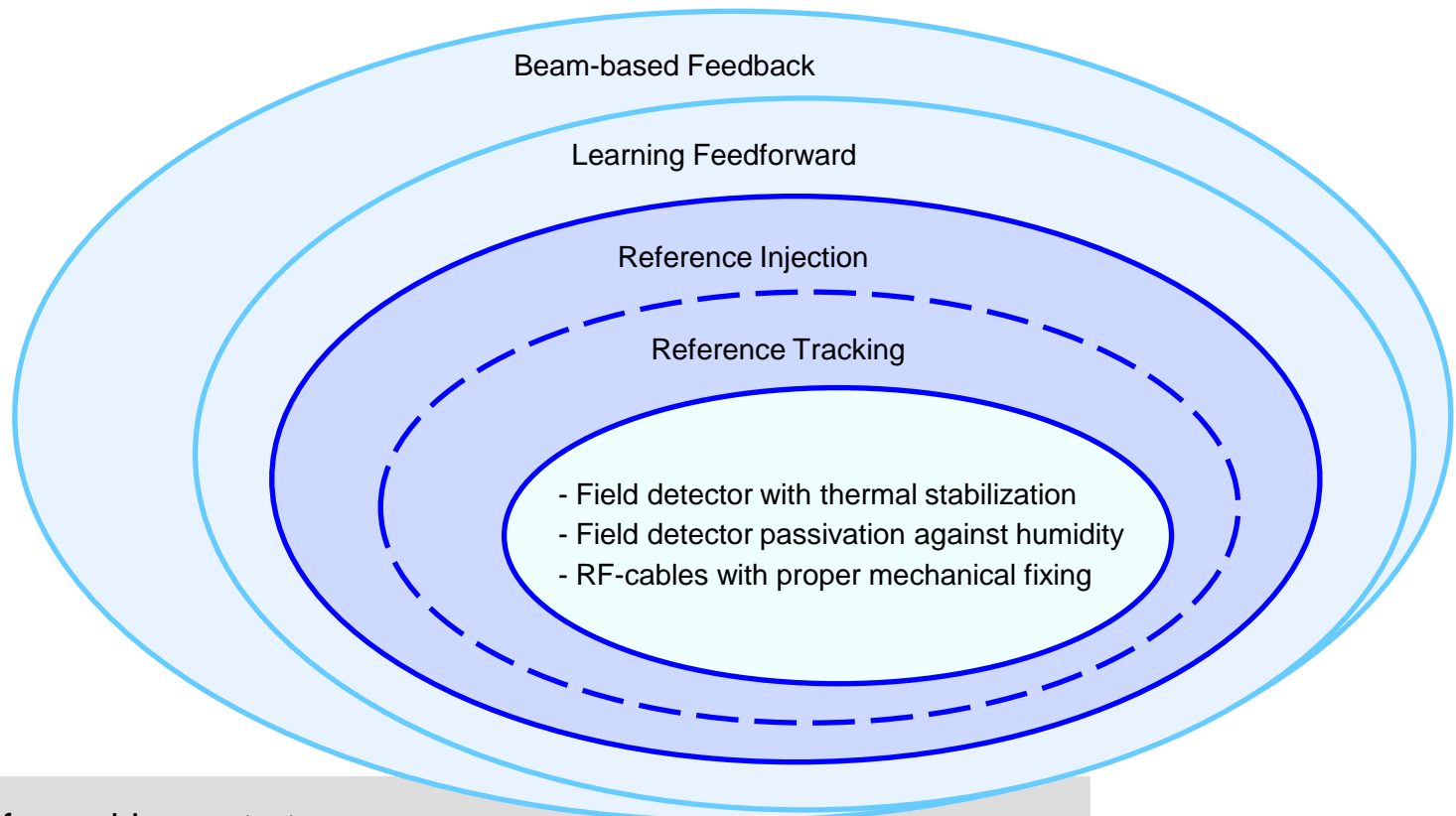
- 1 Motivation
- 2 Concepts
- 3 Drift-Calibration-Module
 - Hardware,
 - Software,
 - Production,
 - Tests
- 4 Long-term Performance
- 5 Summary and Outlook

1 Motivation – Robust machine operation - Options

FIL

XFEL desired long-term requirements [forever]:

Amplitude stability $<0.01\%$, Phase stability $<0.01\text{deg}$ @1.3GHz



- Simplify machine restart
- Minimize LLRF system recalibrations for vector sum

2 Concepts – long-term stable Cavity Field Detection

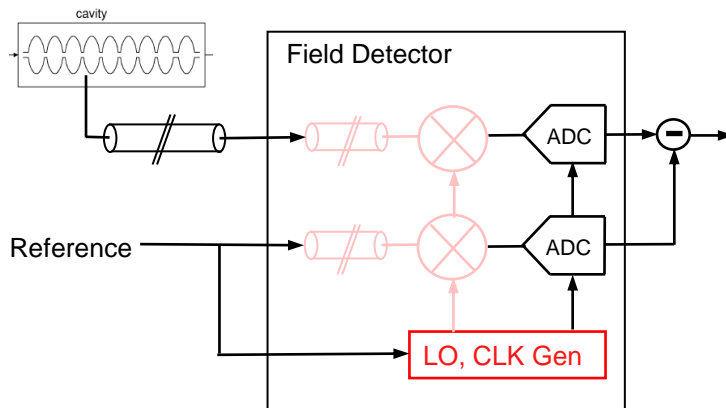
■ No stabilization :

+/- Fully rely on beam-based feedbacks

■ Passive stabilization :

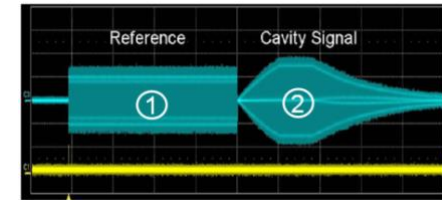
- + Simple method
- Requires rack stabilization <0.2deg_pp
- Requires metal rf-package with sealing

■ Reference tracking :

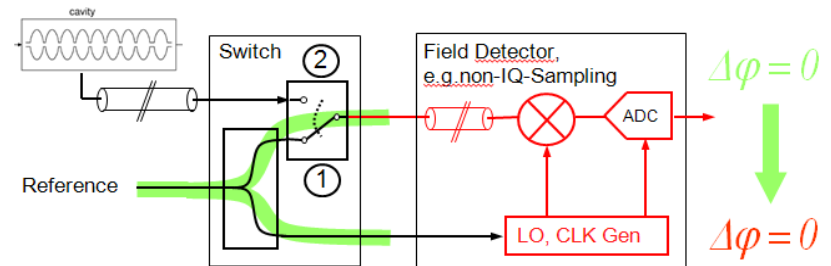


- Suppress only correlated noise, not mixer 1/f-noise
- +/- Efficient only for symmetric receivers (Demonstrated, e.g. with direct sampling)
- +/- Depends on packaging and rf-cable properties

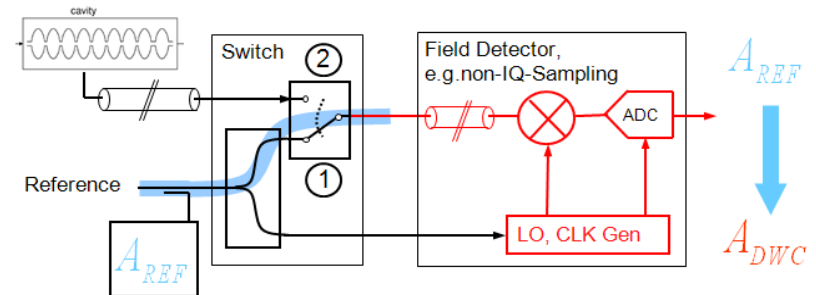
■ Reference injection : (only for pulsed machines)



Relative Phase Calibration :



Absolute Amplitude Calibration :

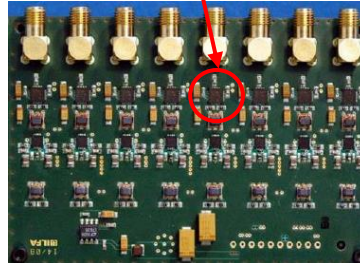
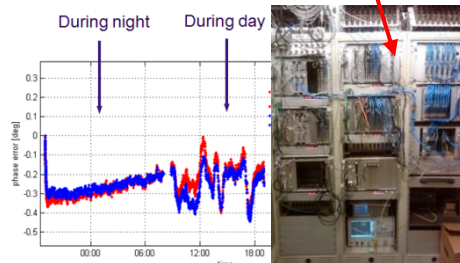
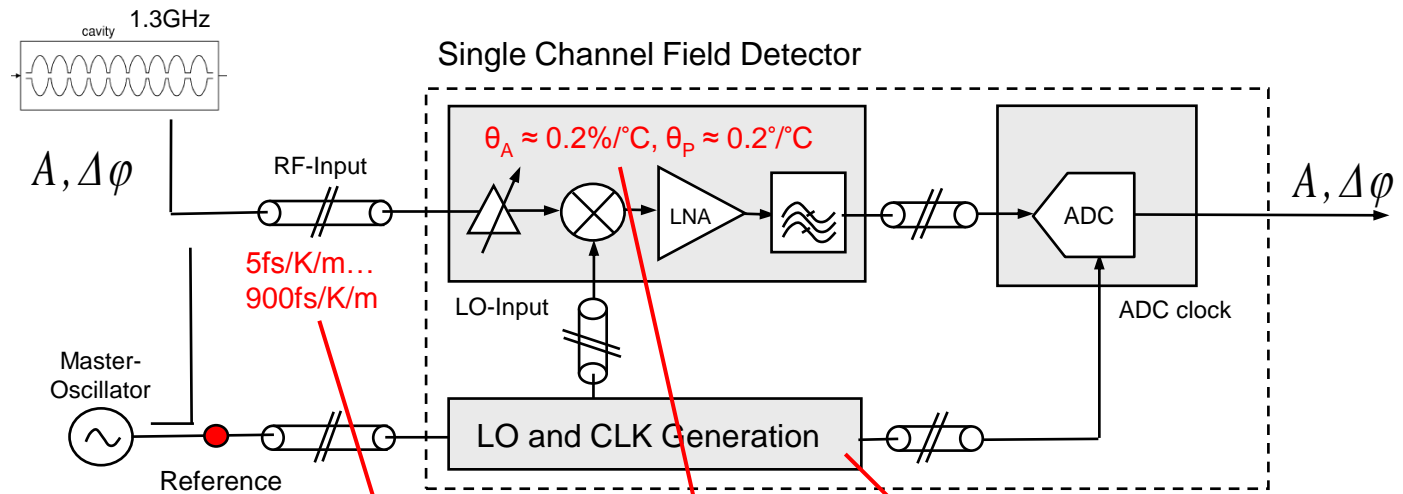


■ Reference injection (2nd-tone) :

■ Reflection at the cavity :

1 Motivation – Examples of long-term Instabilities

- Distributed down converters using the non-IQ-sampling scheme



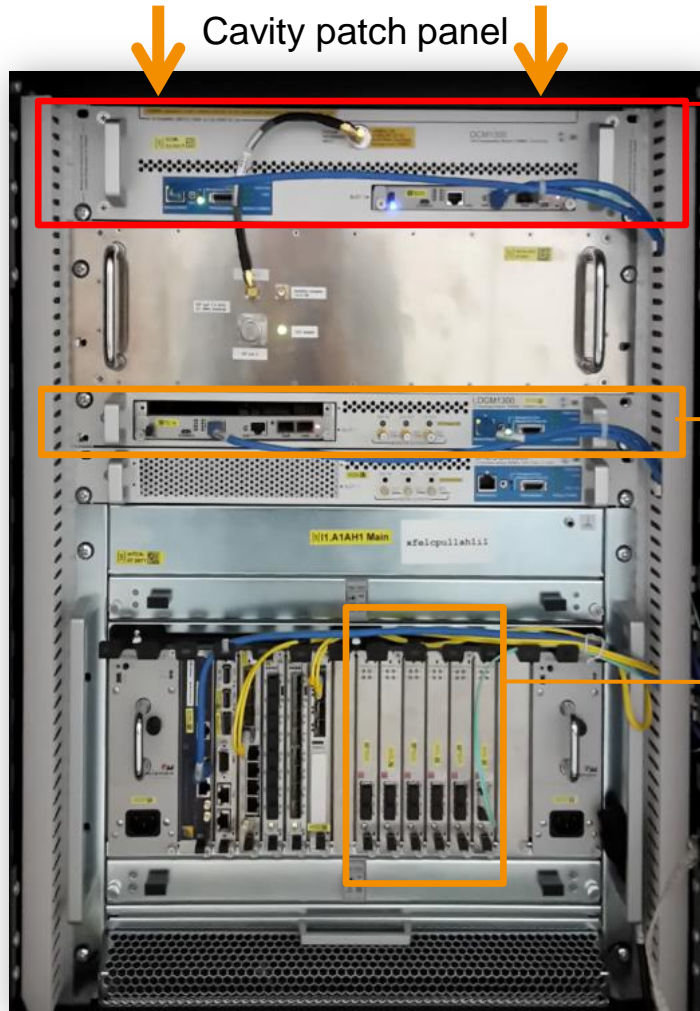
cables,
dividers,
amplifiers,
filters...



Long-term stability depends on temperature and humidity

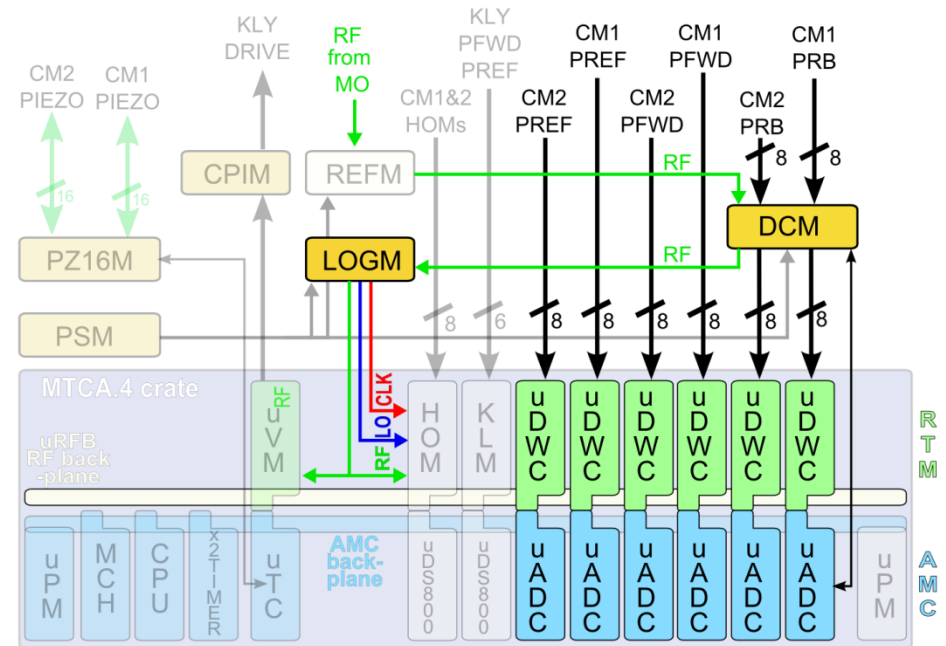
2 Overview – XFEL LLRF System

■ XFEL 48-channel LLRF station:



■ Sub-components and signal-flow: (standard non-iq sampling scheme)

- Drift Compensation DCM 2U 19" Module
- LO-Generation LOGM 1U 19" Module
- Down-Converter DWC RTM MicroTCA.4
- Low-noise Digitizer ADC AMC MicroTCA.4



3 DCM – Hardware

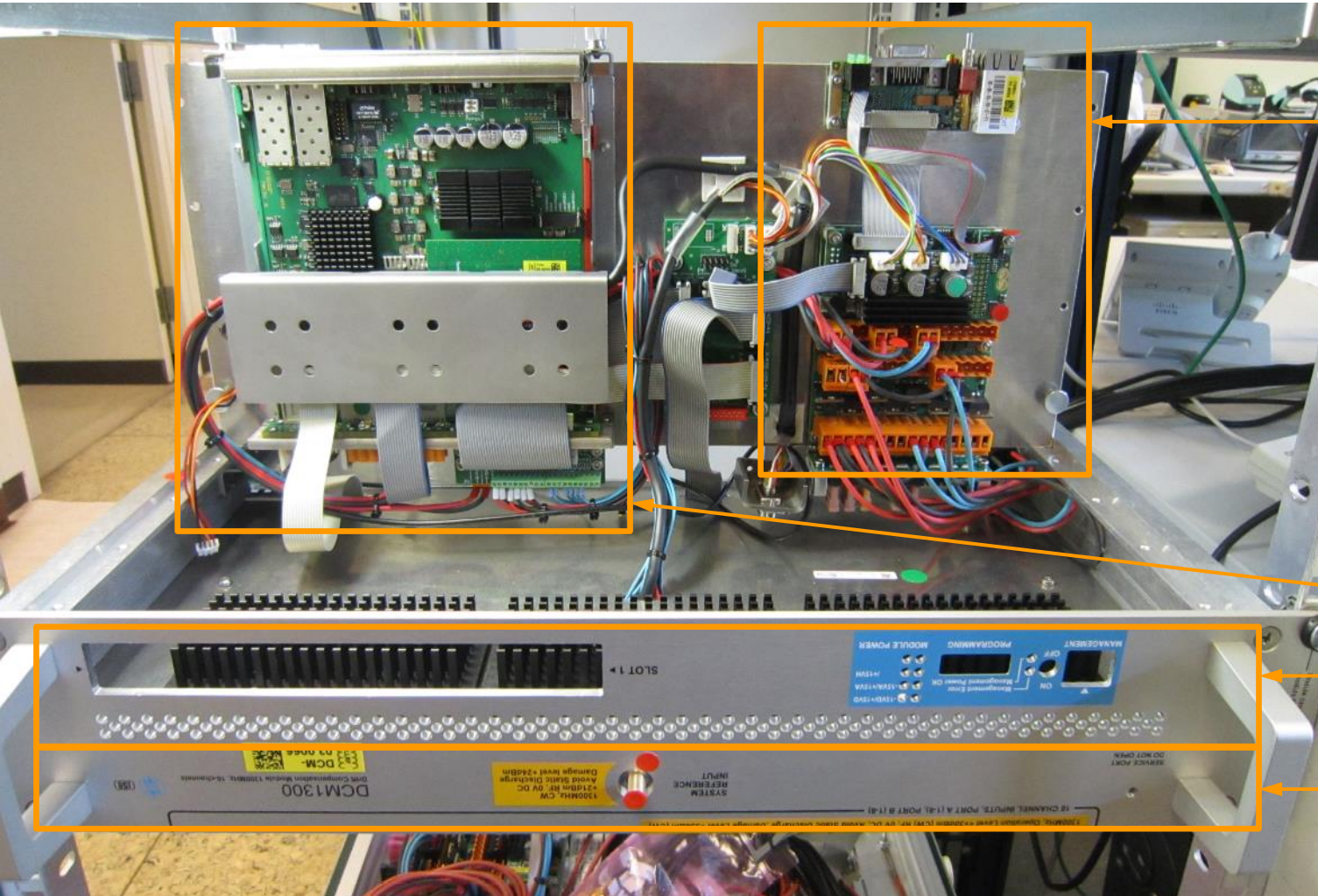
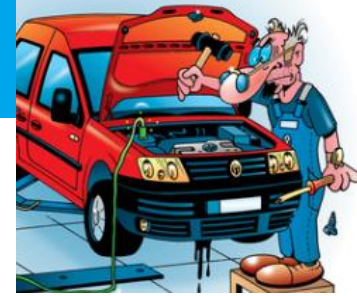
Front view



Rear view



3 DCM – Hardware – Service Plate



Power-Management:

- Control 8 voltages. max 10A
- Voltage/current tracking
- 3xfan support
- Fuse support

TMCB-Diagnostic/Control:

- 3x peltier temperature control via FMC-board
- rf-switch control
- rf-attenuator control
- rf-amplitude readout (24-bit)
- 2xSFP connection

Unsealed section:

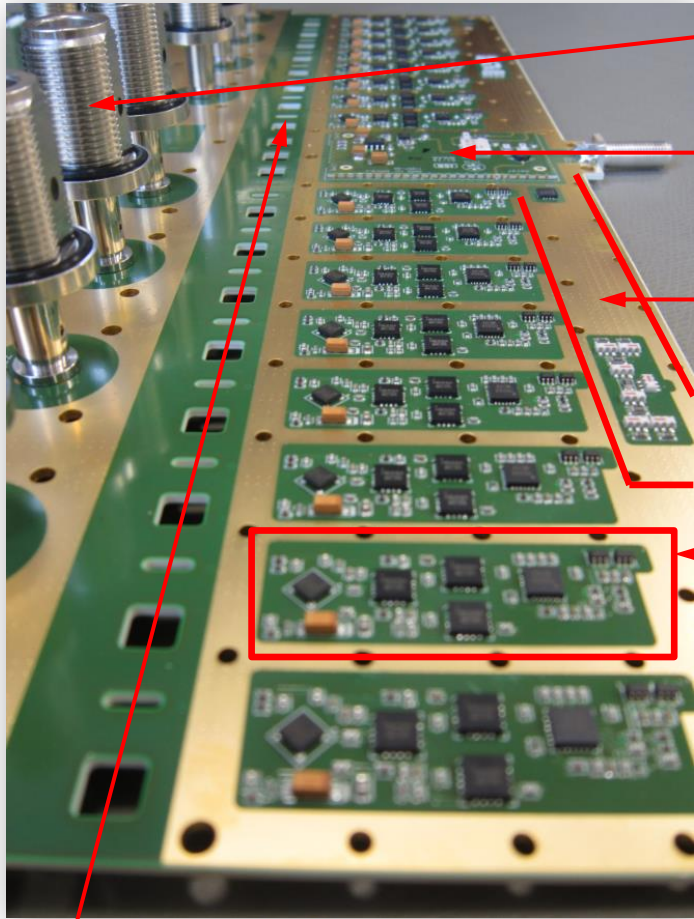
- Transport of heat dissipation

Sealed section:

- Houses rf-components
- Sensors

3 DCM – RF-Compensation

16-channel rf-switches:



Course attenuation:
- 10dB integrated

Reference injection:
- rf-amplitude detection

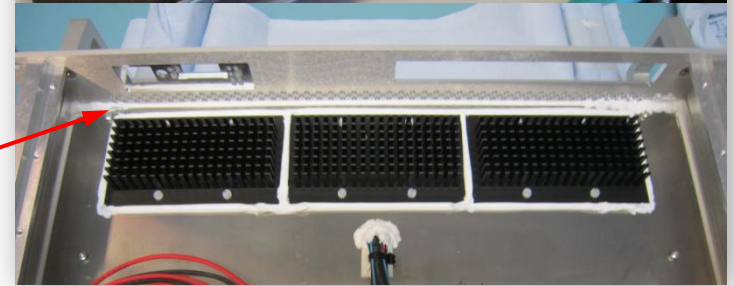
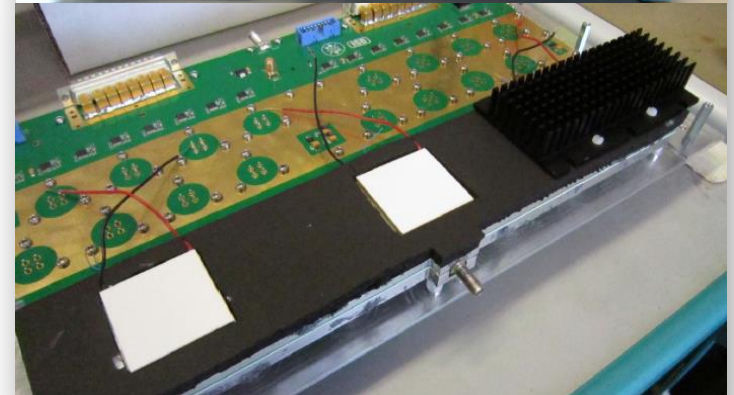
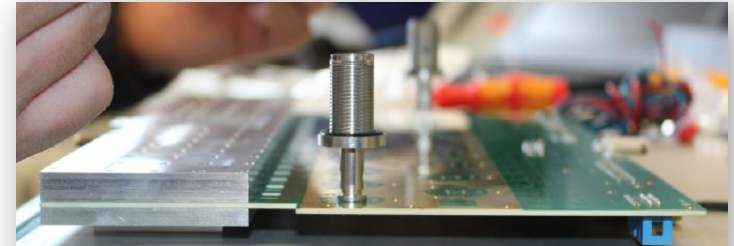
Reference distribution:
- passive

Switch-cell:
- Triplet rf-switches
- Cavity front-attenuation

Sealing with silicone

Thermal bridge to rack temperature

Thermal stabilization / Sealing



3 DCM – Software

Man control panel in DOOCS:

1.72247 Reference amplitude
1024 Reference average count (debug)
LLRF Trigger: DAQ Trigger
Trigger 4: Backplane Trigger (if extra BP line)
Trigger setup:
1625000 In ms
81250 LLRF (if used as forward)
1219050 Reference on
406500 Reference off
568750 Amplitude detection on DCM
7.00 Amplitude detection on ADC board
Average 2^n (IQ sampling ...): 6

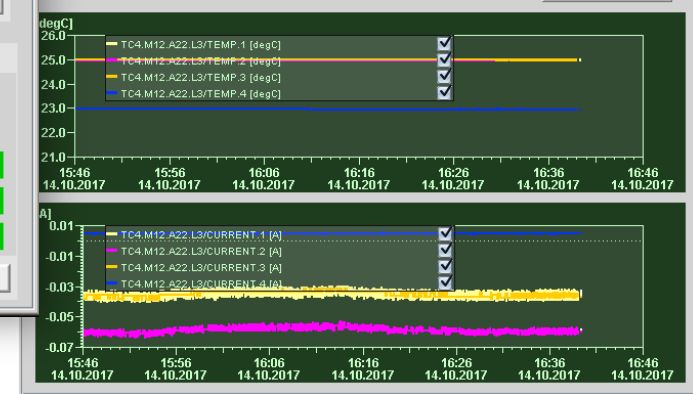
Attenuator settings
CTRL.M1.A22.L3
Cavity Value
1 0.0
2 0.0
3 0.0
4 0.0
5 0.0
6 0.0
7 0.0
8 0.0

DCM Sensor overview
Box Temp 26.68 degC
Hum 40.03 % RH
TC4 PCB 33.54 degC
28.24 % RH
sealed area 26.30 degC 37.05 % RH
TEC1 24.99 degC
TEC2 24.97 degC
TEC3 24.99 degC
ool 24.90 degC 24.80 degC 24.84 degC 25.44 degC

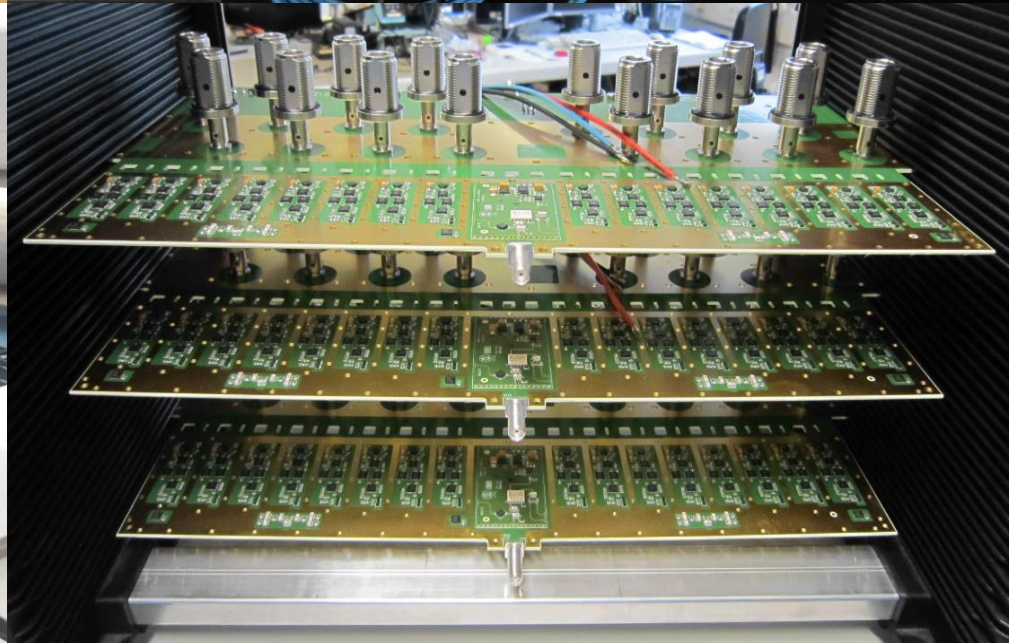
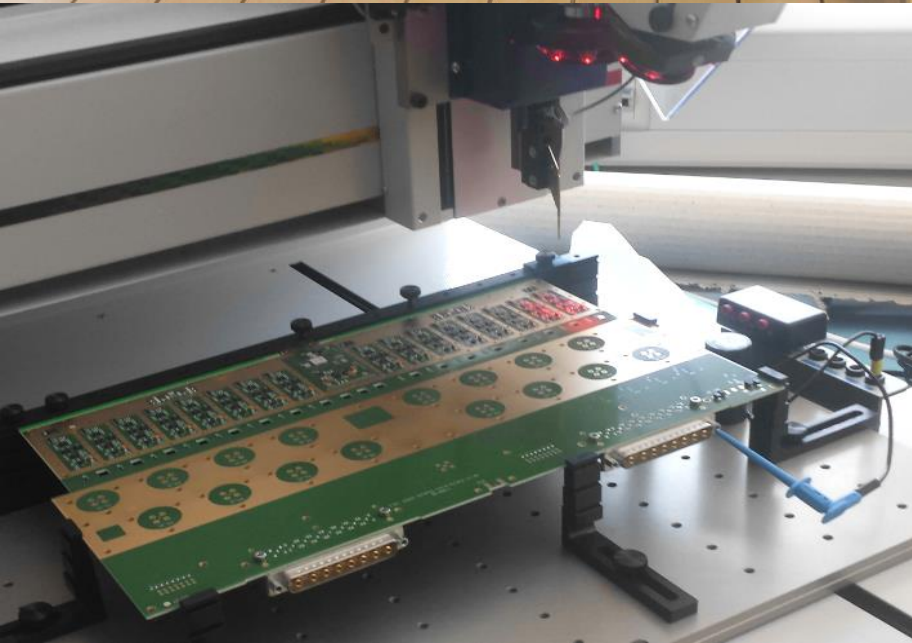
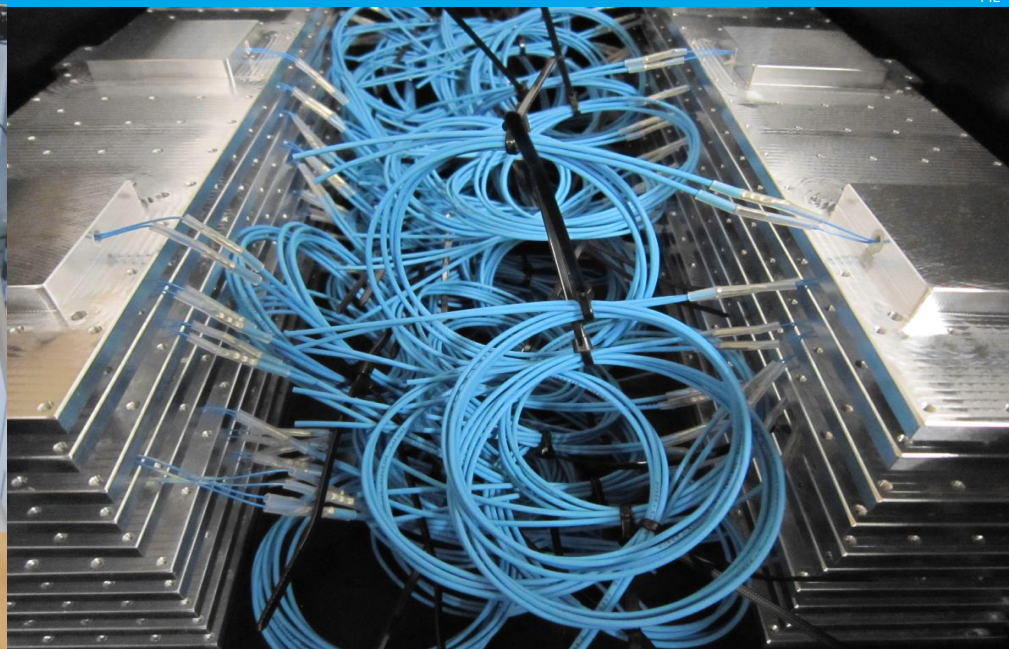
Sw Mode Sw Pos Ena
Ch1
Ch8

DCM Main control panel
Box Status: Reset Enabled, MISC, A det ena Enabled, FRED
Ambient: sealed 26.3 degC, unsealed 26.7 degC, ratio 1.08
Module 1: DCM active, Attenuator CTRL Disable all, Corrections applied, AmpI below limit, Switch in Cav Pos, Phase below limit, Switch in auto Mode, Trigger CNT Status
Module 2: DCM active, Attenuator CTRL Disable all, Corrections applied, AmpI below limit, Switch in Cav Pos, Phase below limit, Switch in auto Mode, Trigger CNT Status
Buttons: C1 C2 C3 C4 C5 C6 C7 C8 Overview

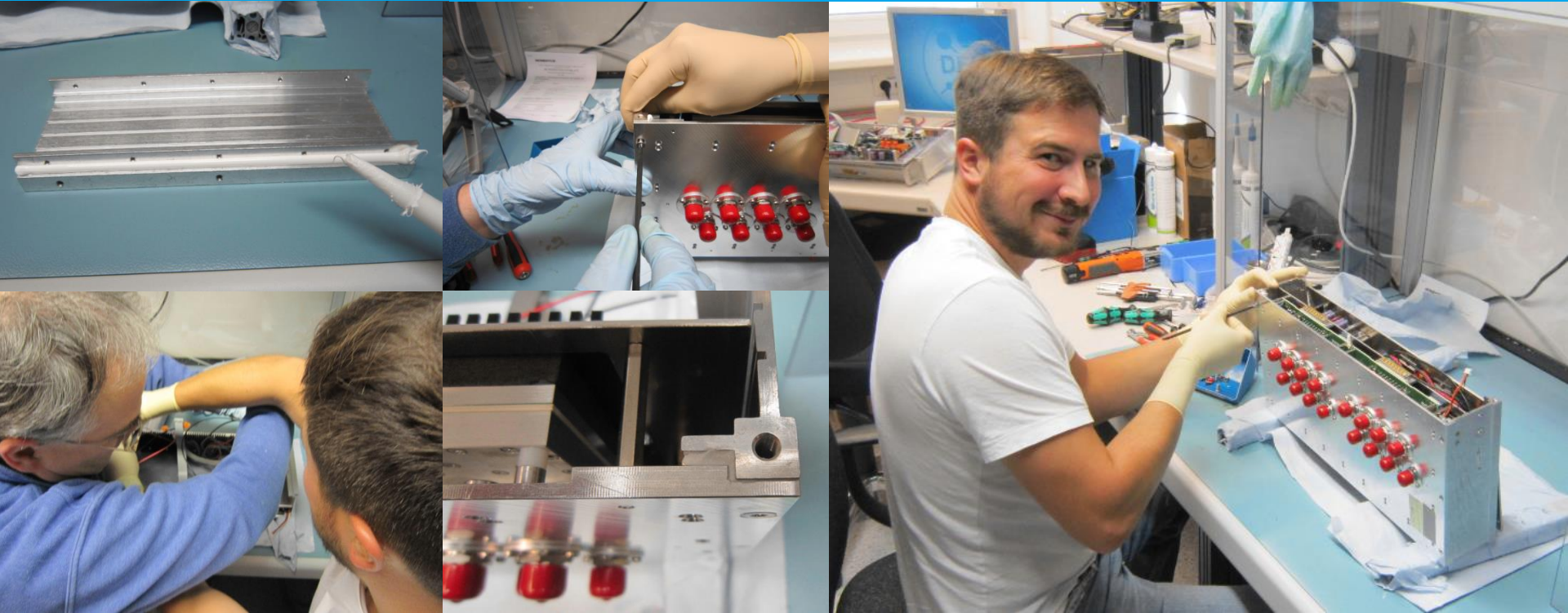
TC4 - 4 Channel Temperature Controller
Board Status:
Temperature (in loop) Setpoint [degC] Ctrl Enabled Undertemp Overtemp Current
Chan 1: 24.99 degC 25.00 -0.04 A
Chan 2: 24.96 degC 25.00 -0.06 A
Chan 3: 24.99 degC 25.00 -0.04 A
Chan 4 disabled
On Board Temperature: 33.53 degC 3.3 V connected
On Board Humidity: 28.24 % RH 5 V initialised
Reinit HW



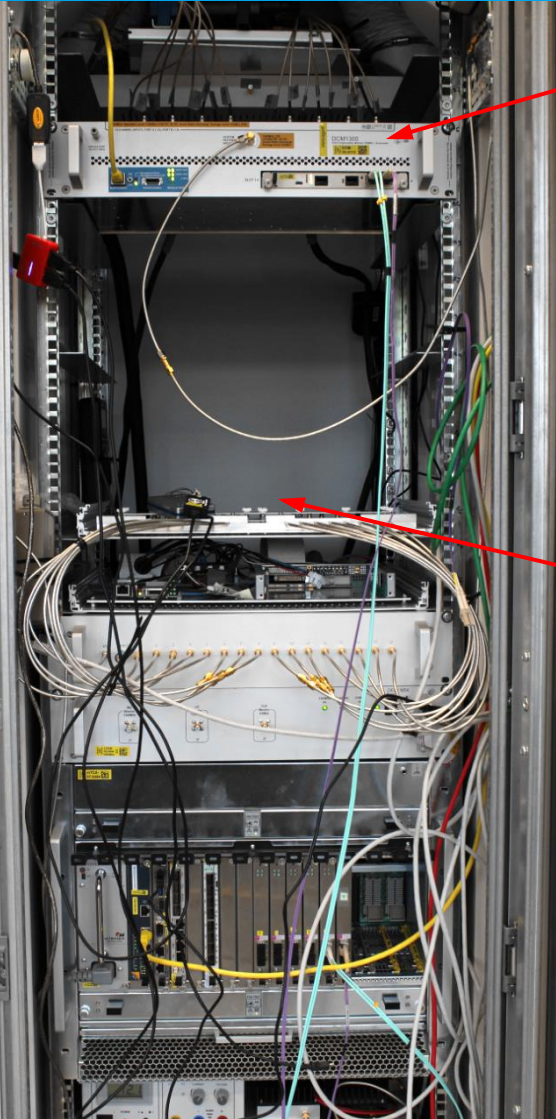
3 DCM – Production – Sub-Components – 60 Modules



3 DCM – Production – Assembly – 60 Modules



3 DCM – Functional Tests



Final Module Test

Power [dBm]	Output	[dB] Converter Loss	Power [dBm]	Output	[dB] Converter Loss
Reference	-6.4359403	12.56406	Reference	-6.2893	12.7107
12.50	-17.800919	-20.300919	12.50	-17.81257	-20.31257
2.50	-18.32277	-20.32277	2.50	-18.335142	-20.335142
Conv. loss target [dBm]	-18.786211	-20.286211	Conv. loss target [dBm]	-18.799263	-20.299263
13.00	-19.765356	-20.265356	13.00	-19.787281	-20.287281
Cavity	-21.74013	-20.24013	Cavity	-21.758472	-20.258472
Reference	-25.698805	-20.198805	Reference	-25.698805	-20.198805
13.00	-33.599987	-20.099987	13.00	-33.599987	-20.099987
Cavity	-48.01131	-19.81131	Cavity	-49.235096	-20.235096



PCB Inspection

Running Mode: TMCB is set to run mode ?

Ampl. Detect. : Amplitude detection on ?

Step 2: Check all DWC att and callb setting are ok

DWC setup and ADC calibration

1. Settings for the DWC att. and the signal...

Channel	DWC Attenuator [dBm]	Calibration Factor
1	0.0	0.7078
2	0.0	0.6910
3	0.0	0.6329
4	0.0	0.6191
5	0.0	0.6081
6	0.0	0.6178
7	0.0	0.6454
8	0.0	0.6296

Module	DCM Att. [dBm]	Ampl [mV]	Power [dBm]
Module 1	31.5	0.889	-88.407
Module 1	31.5	0.888	-88.407
Module 1	31.5	0.792	-89.021
Module 1	31.5	0.811	-88.811
Module 1	31.5	0.772	-89.235
Module 1	31.5	0.849	-88.407
Module 1	31.5	0.811	-88.811
Module 2	31.5	0.849	-88.407
Module 2	31.5	0.830	-88.607
Module 2	31.5	0.811	-88.811
Module 2	31.5	0.830	-88.607
Module 2	31.5	0.753	-89.455
Module 2	31.5	0.830	-88.607
Module 2	31.5	0.772	-89.455

Reference Ampl. [mV] h. l. m. l. low

Module 1 1.1904

Module 2 1.1904

Step 4: Check Temperature and humidity readout

Running: Push to Reset, TMC Ena

In-loop Temperature	Setpoint	Ena	Current	Humidity sensor
1 24.99 degC	32767		-0.03 A	Humidity 21.0 % RH
2 24.88 degC	32767		-0.07 A	Tempera... 32.2 degC
3 24.90 degC	32767		-0.06 A	

1 maximum, 2 middle, 3 minimum

Temperature over, Temperature under, Current Overto, SW, SW

Out of loop Temperature	Humidity (unsealed)	Humidity (sealed)
1 24.86 degC	32.6 % RH	42.9 % RH
2 24.93 degC	26.5 degC	25.0 degC
3 24.84 degC		Humidity Ratio

External Temp. sensor 24.79 degC, 0.76121

Power [dBm]	Output	[dB] Converter Loss	Power [dBm]	Output	[dB] Converter Loss
Reference	-6.7027283	12.297272	Reference	-6.4186516	12.581348
12.50	-17.777662	-20.277662	12.50	-17.882807	-20.382807
2.50	-18.304241	-20.304241	2.50	-18.397272	-20.397272
Conv. loss target [dBm]	-18.747173	-20.247173	Conv. loss target [dBm]	-18.864817	-20.364817
13.00	-19.75077	-20.25077	13.00	-19.860705	-20.360705
Cavity	-21.721823	-20.221823	Cavity	-21.795277	-20.295277
Reference	-25.698805	-20.198805	Reference	-25.698805	-20.198805
13.00	-33.56417	-20.099987	13.00	-33.56417	-20.06417
Cavity	-48.40724	-19.40724	Cavity	-49.235096	-20.235096

Precision: 2.70

Start test

Test finished!

Documentation & Teststand:

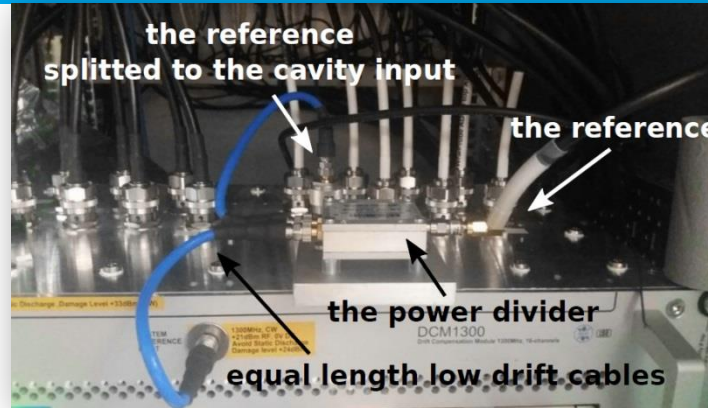
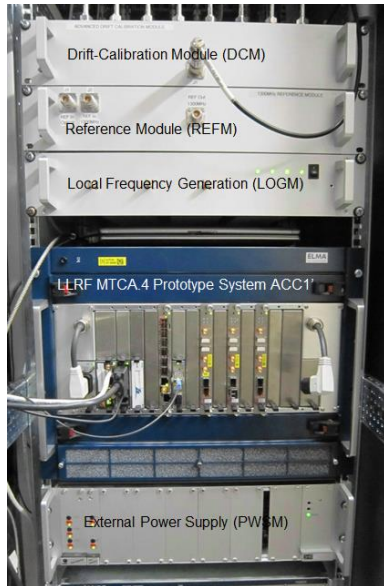
- Production Instruction
 - Assembly Instruction
 - Test Procedure Definition
 - Teststand Software
 - Failure Reports
 - Bug fixing
- ... a lot of work ...



4 Long-term performance (Laboratory) – Constant Temperature

FIL

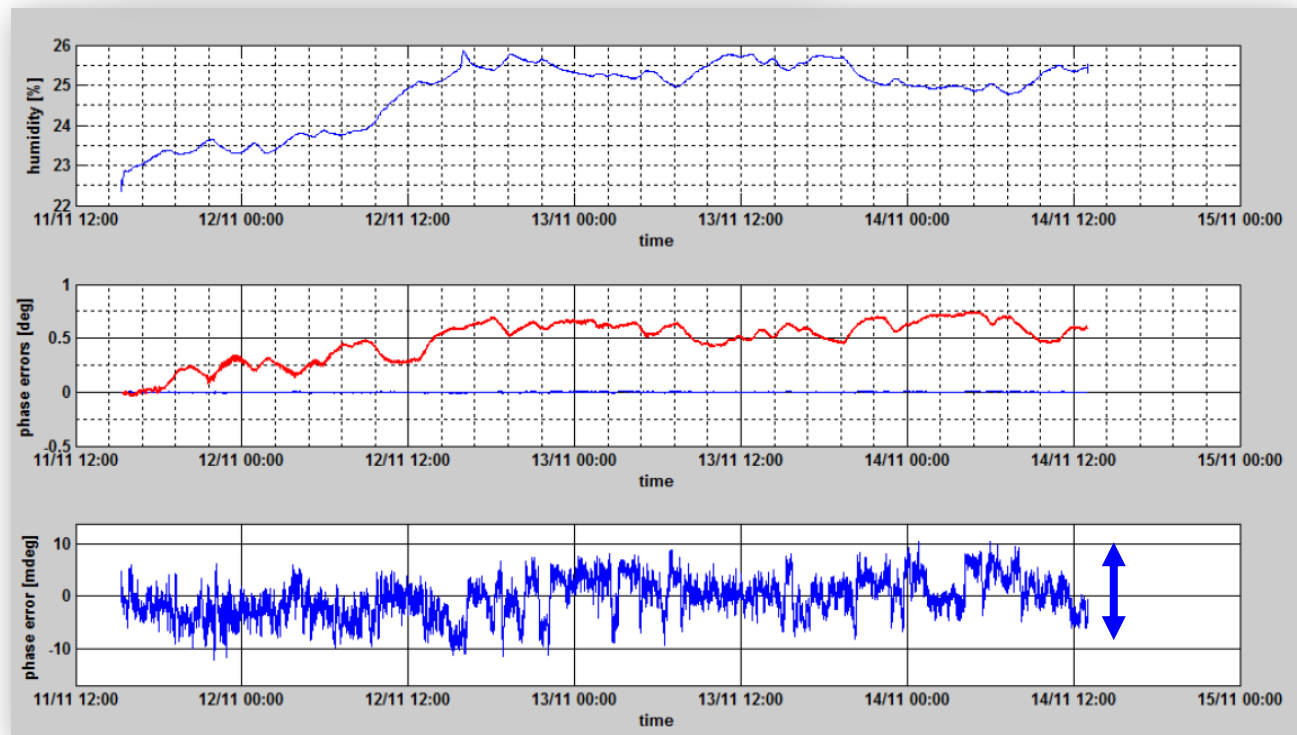
- FLASH injector hutch :
(stability <math><0.2\text{degC}_{pp}</math>)



[Courtesy of J. Piekarski]

FLASH injector hutch ACC1' operation

<math><40\text{fspp}</math> over 3 days (1.3GHz)
<math><50\text{mK}</math> internal temp stability

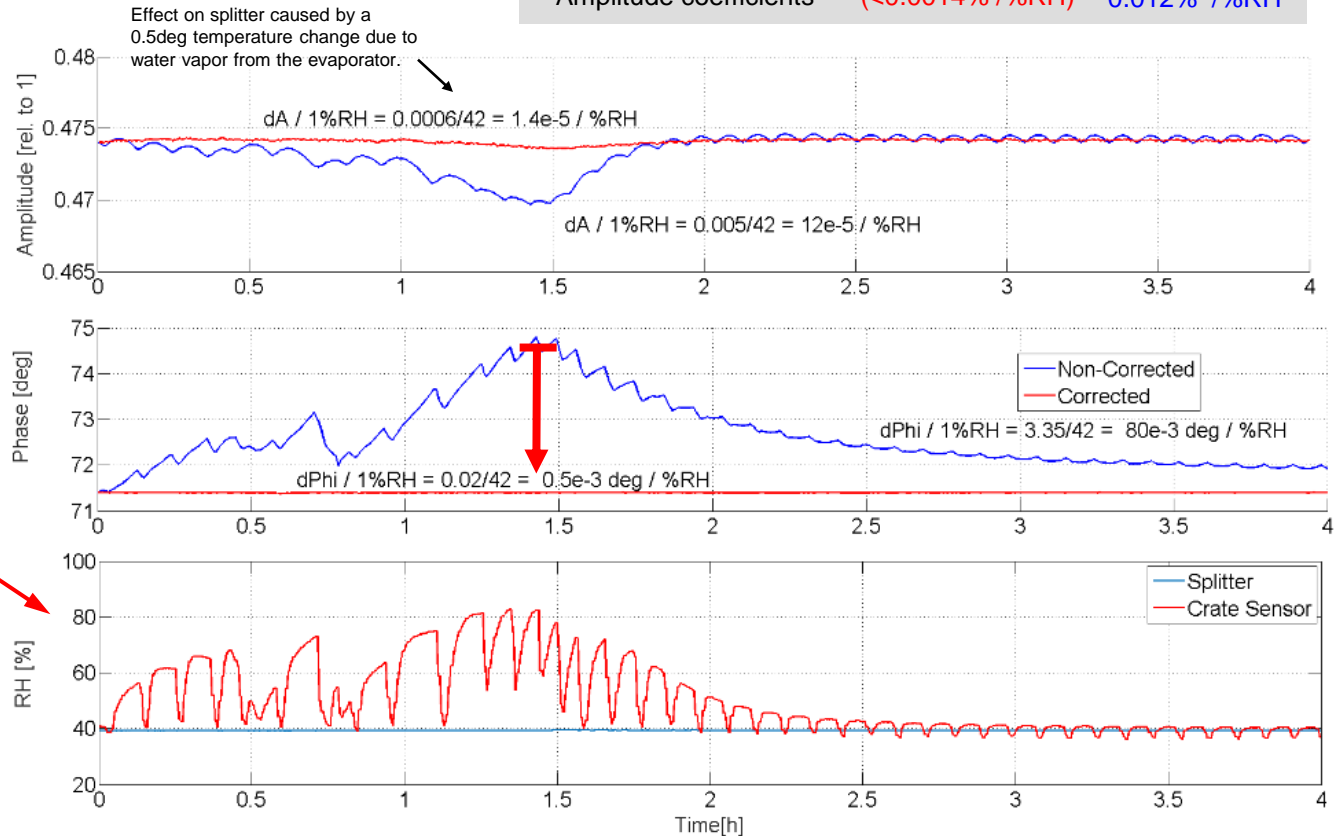
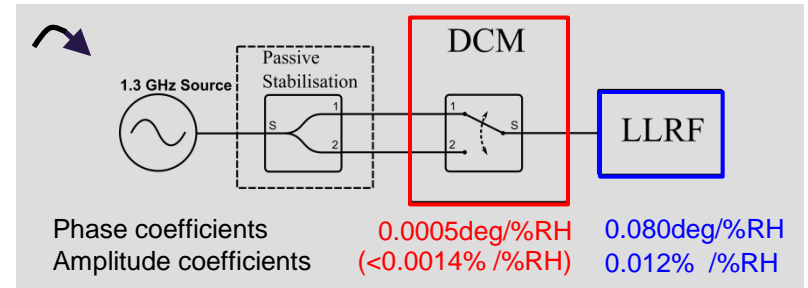


4 Long-term performance (Laboratory, 22h) – rough environment

■ Humidity step response :



3.3deg_pp -> 0.02deg_pp
1/160 reduction (1.3GHz)

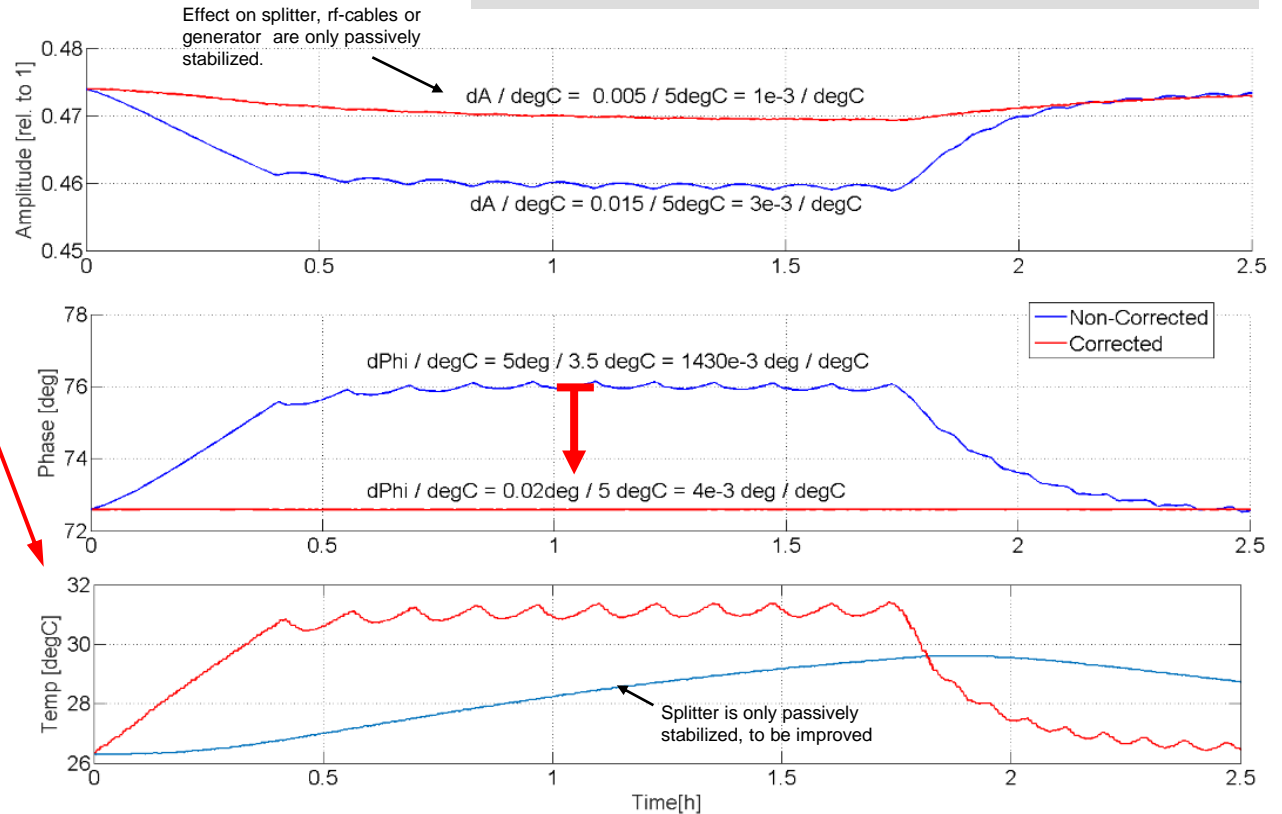
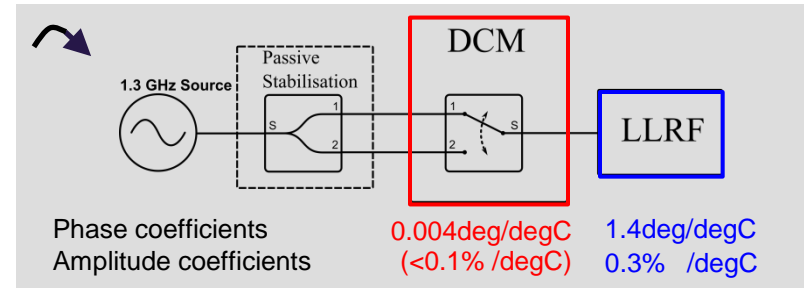


4 Long-term performance (Laboratory, 22h) – rough environment

Temperature step response :

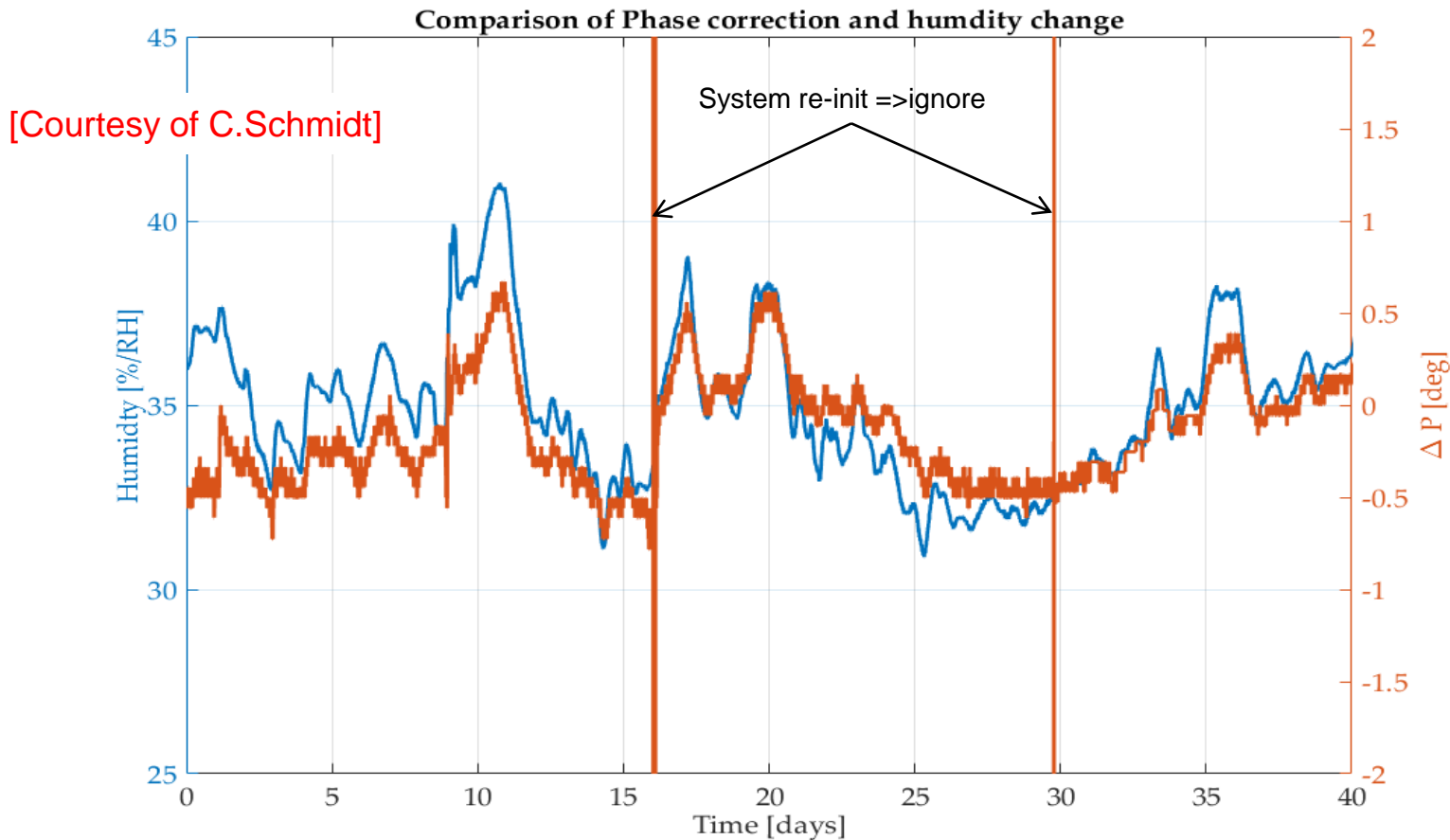


5deg_pp->0.02deg_pp
1/250 reduction (1.3GHz)



4 Long-term performance (FLASH) – DCM in Action

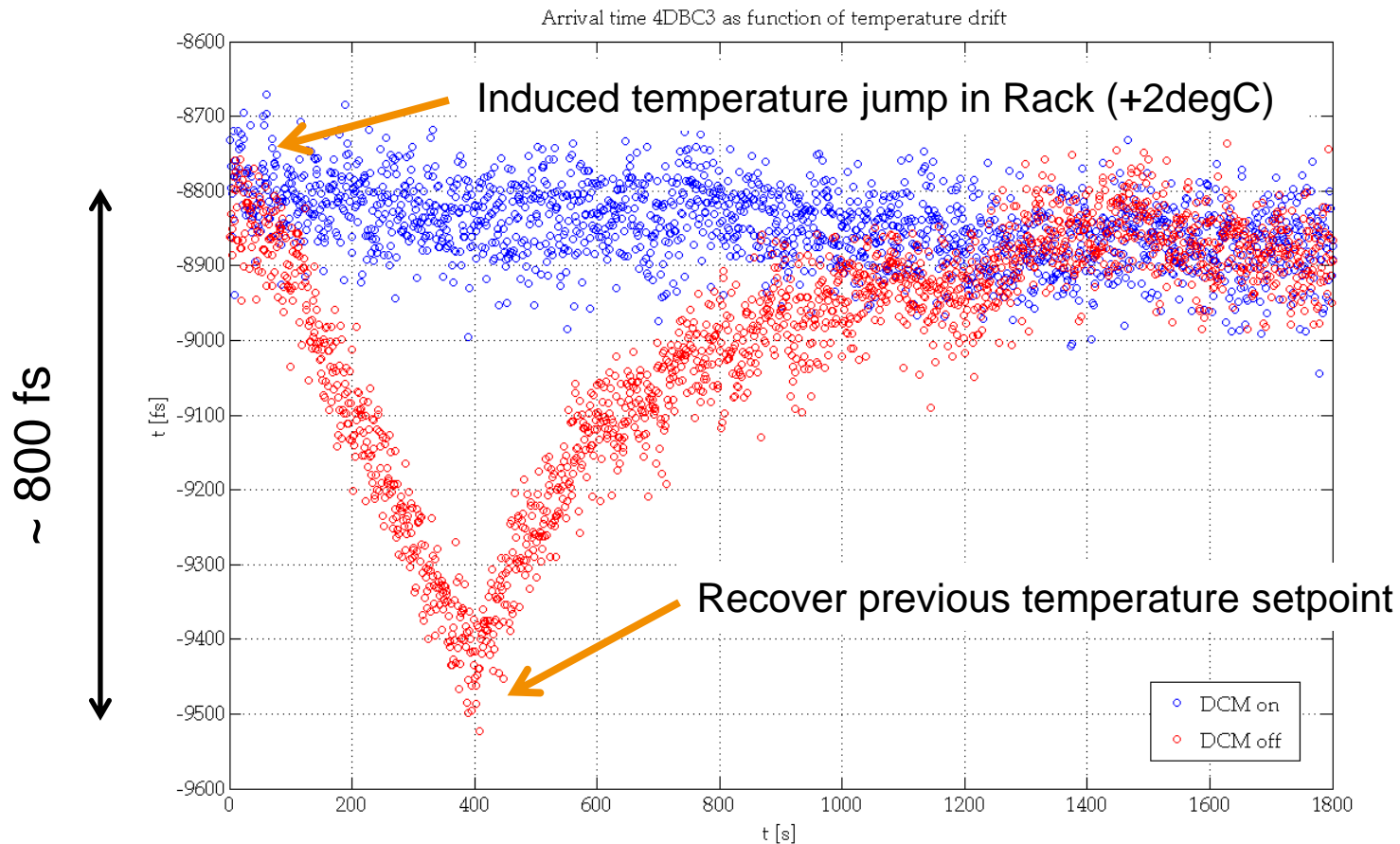
FIL



- ↪ - Humidity induced phase drifts dominates and compensated using the DCM
- Rule of thumb => **1% Humidity change ~ 0,1deg Phase change**

4 Long-term performance (FLASH) – Arrival time

- Arrival time at 4DBC3 with ACC23 DCM on/off :
[Courtesy of C.Schmidt]



5 Summary and Outlook

FIL

- The Drift-Calibration Module stabilizes LLRF-systems down to 0.02deg_pp and 0.02%_pp at 1.3GHz for pulsed machines.
- A module for CW-operation is under construction.



Thanks for your attention!