Recent advances and results of MWL FS and MWL GT verification and tests

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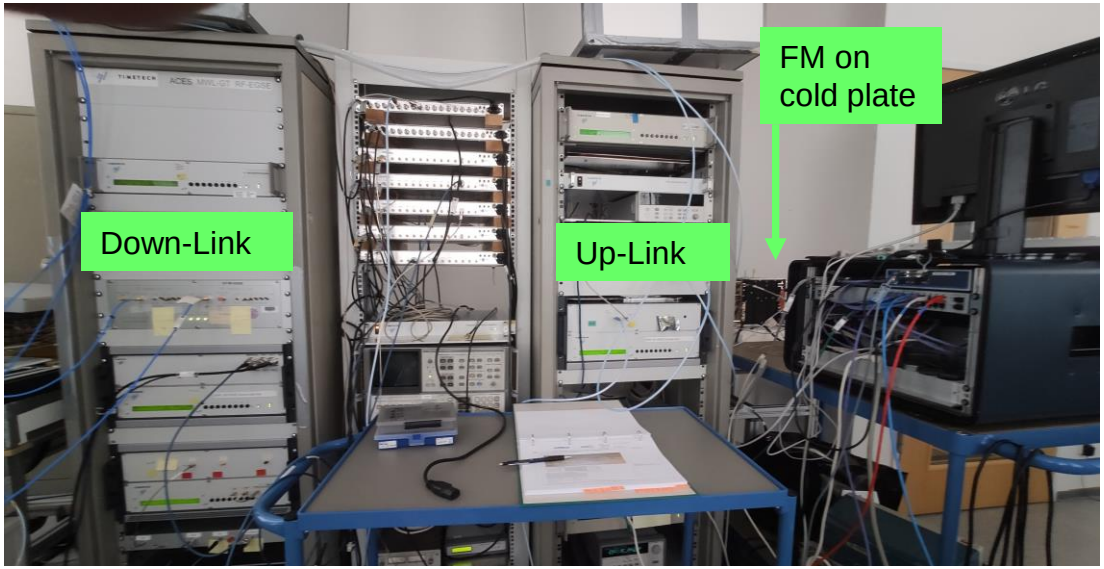
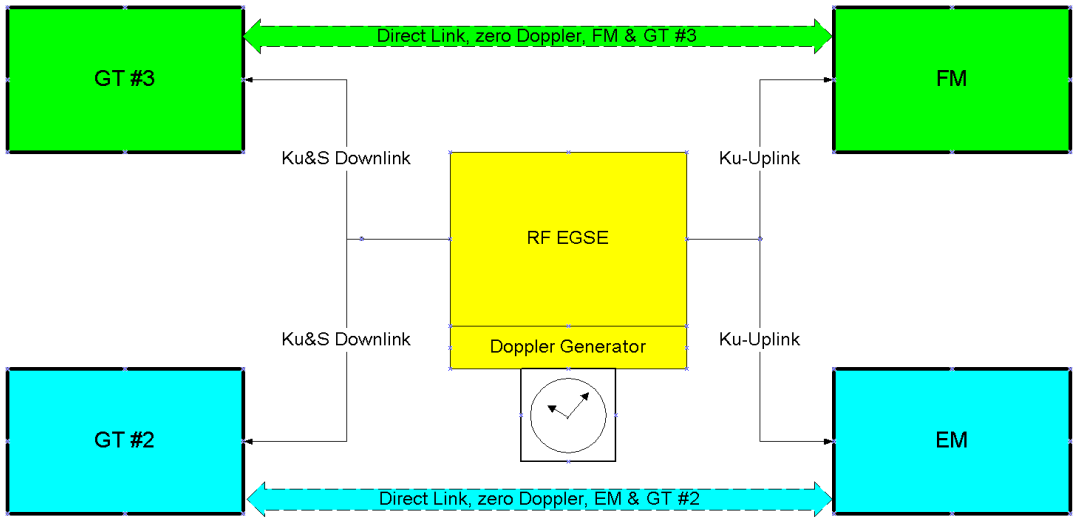
Outline

- Activities with RF EGSE
  - Updates, connections, calibrations…
- GT Activities and Tests
  - TWO GT assembled, connections, tests, some selected results
- FS Verification and Tests
  - AM / PM calibrations
  - Dynamic PLL response & Bump calibration
  - RF Sensitivity (tests ongoing)
  - RF Interference Test (tests ongoing)
  - Dynamic Doppler verification, to come

RF EGSE Activities





Simultaneous Multiple connections

1. Pair FM <-> GT #3
2. Pair EM <-> GT #2

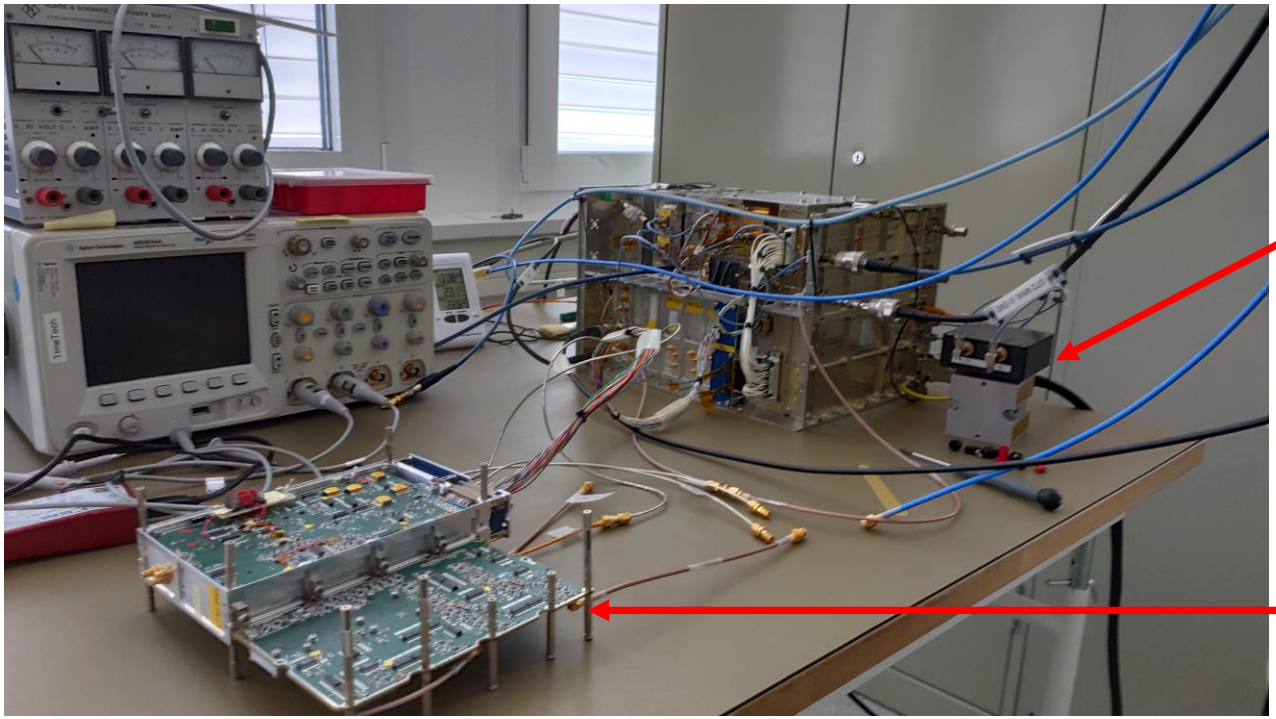
Cables firmly installed
Well-defined interfaces at boxes

Calibration & Verification

- RF signal amplitudes
- Frequency and range settings
- AM/PM characterisation

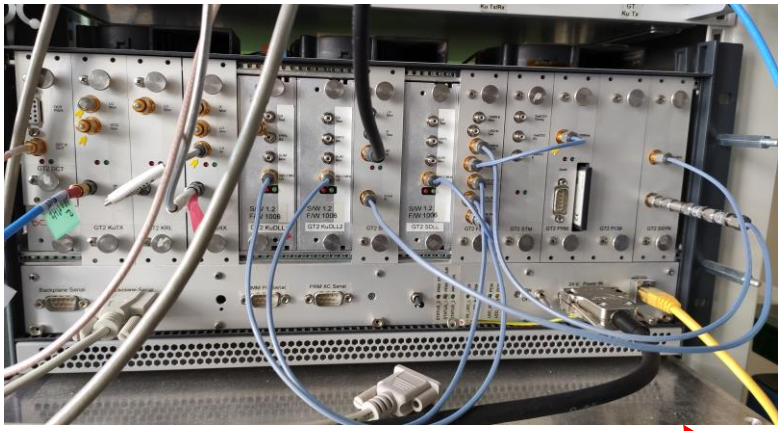
Reproducible and long-term stable signals

EM set-up and connections, ELT mockup



- EM serves as representative test-bed, for any HW, SW and FW tests and verifications
- Various break-out boxes and extenders for simplified module access
- It is paired with the GT development and test stand, for GT design and verification.
- Connected to RF-EGSE for non-zero Doppler tests

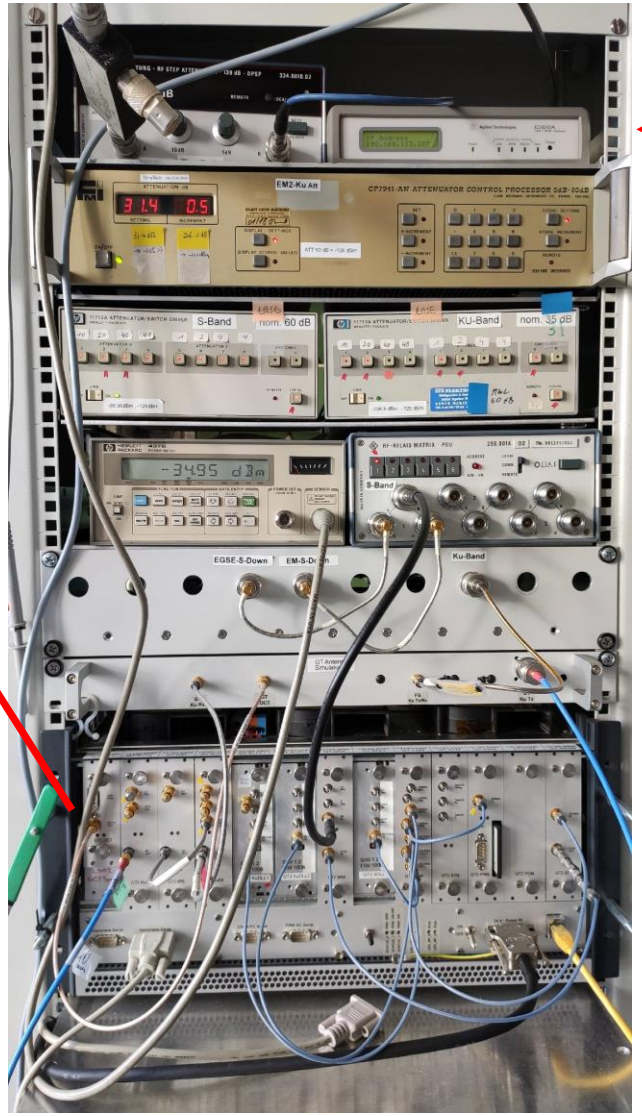
GT Manufacturing & Verification



GT #2 in test environment

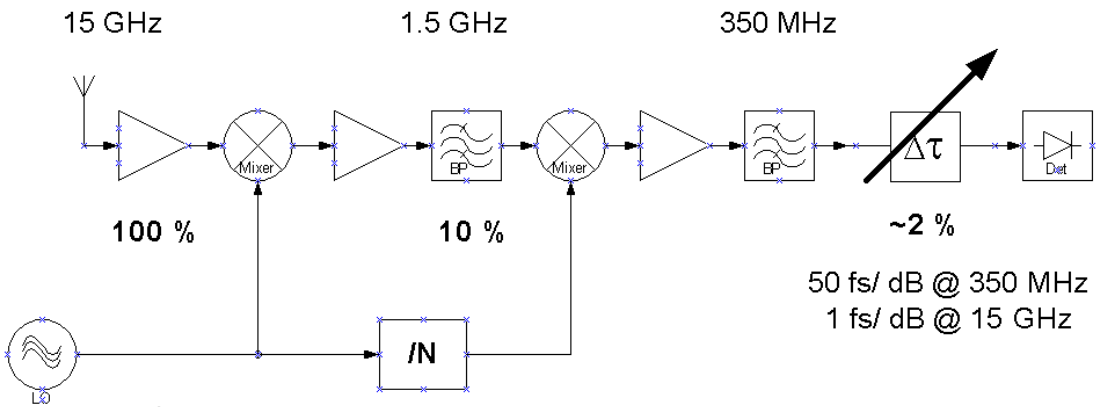
- One Ku-Transmitter
- Two Ku-Receiver Channels
- One S-Receiver Channel
- S-Band delay monitor (loop)

- Ku-Loop is closed externally at the antenna



Calibrate for AM/PM
"NO" AM/PM in receivers

- Earlier attempts poor, severely limited by instrumentation
- New: Use AM/PM-free attenuators
  - Ku-Band (TESAT): Rotary-Vane WG attenuator (used for TWT AM/PM tests)
  - S-Band: Evanescent-mode attenuator
- Observation: „Receivers exhibit virtually NO AM/PM" for carrier phase (why? see block diagramme below…)
- Calibrate RF-EGSE for AM/PM using MWL receivers together with these attenuators
- Result:
  RF-EGSE is calibrated wrt AM/PM, for code and carrier



Ku-Band: rotary vane attenuator (Mfg Flann)

S-Band: Evanescent-mode attenuator, Mfg Spinner

Impressive:
Delay does not change, despite physical length is changing

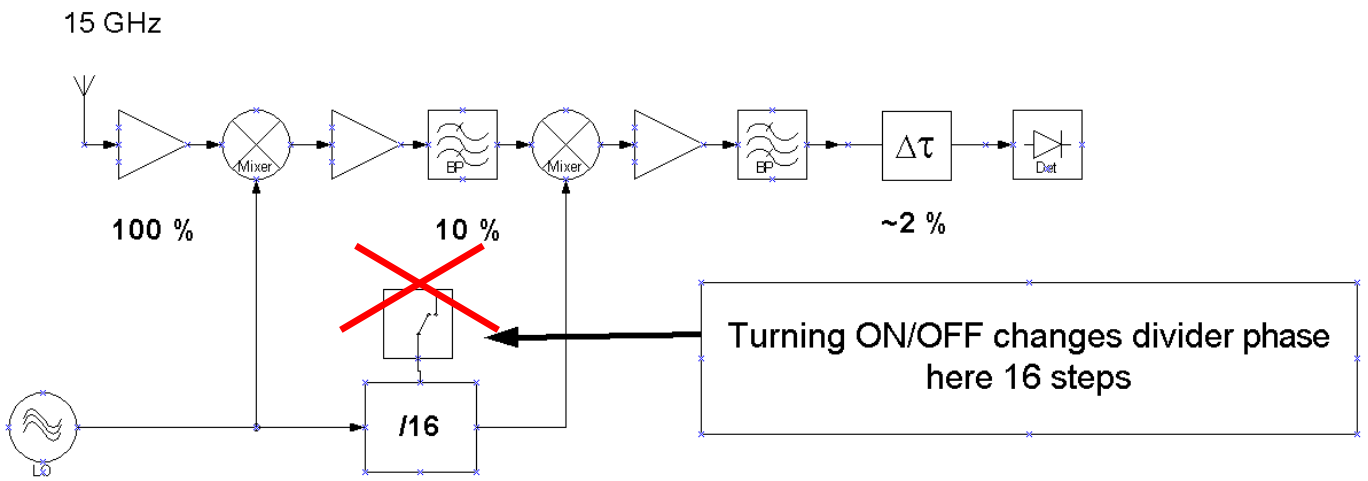
cation and test.

“Divider problem”, phase continuity solved

- A „Divider problem“ has been identified during last end-to-end test (E-2-E)
- DLL ON/OFF was necessary to recover from possible SEU effects
- Problem solved using DLL-FPGA reload without module switching (requiring a small SW & FW change)

As result:

- NO module-switching required any more during nominal operations
- All RF synthesisers & dividers run continuously, incl Test-loop carrier oscillator
- Full phase continuity is ensured, for code and carrier, during a full operation period



Ongoing Tests:
Example: RF Intereference Test

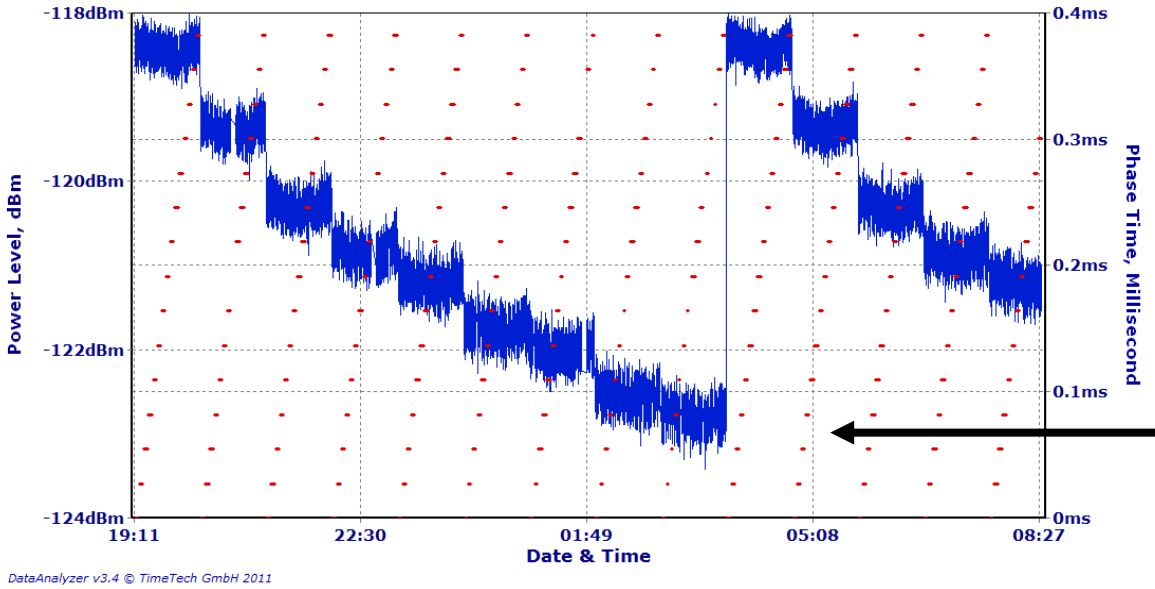
FM on cold plate

- On-Going verification tests, example: CDMA interference test
- Script-based
- Automatic data recording, semi automated test evaluation, ongoing

Ongoing Tests:
RF Sensitivity & Intereference

- RF test levels have changed since last E-2-E test to better account for unfavorable locations (i.e. Tokyo) and rain
  - Requirement
  - Acquisition: starting at 5° up to 10°
  - Tracking above 10° (no carrier cycle slips)
- Rx receiver lock-in sensitivity has been increased by 8 dB since E2E, which does not change noise levels!
- Lock-in algorithm and lock detector performance required changes to FW and SW, FPGAs
- New tests ongoing to adapt to the new situation
- Preliminary results promising
- Caution:
  - published results are taken under different configurations
  - new set of data being acquired

FM RF Sensitivity
very preliminary ongoing



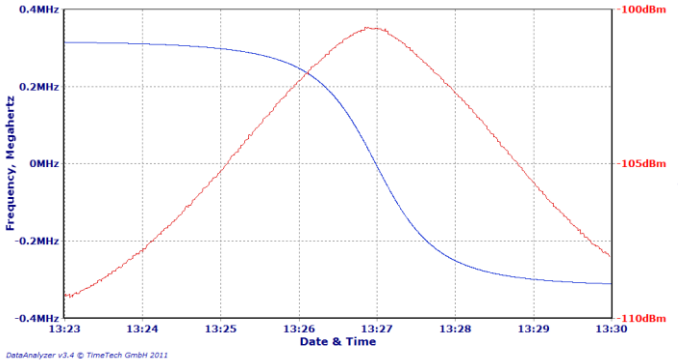
Phase vs. Time Phase vs. Time	
2019/08/15 19:12 - 08/16 08:29	
Data Source A:	FS-CO1.Abs
Data Source B:	FS-ST1.Par1
No Averaging	
Averaged Samples:	None
Min Value:	0.025us
Max Value:	382.540us
Average:	187.799us
Std.Dev:	117.641us
Data Length[s]:	47844
Peak-To-Peak:	382.514us
2-Sigma:	235.283us
Scale:	100us/div

– 123 dBm

FM Code sensitivity approaching **– 123 dBm**

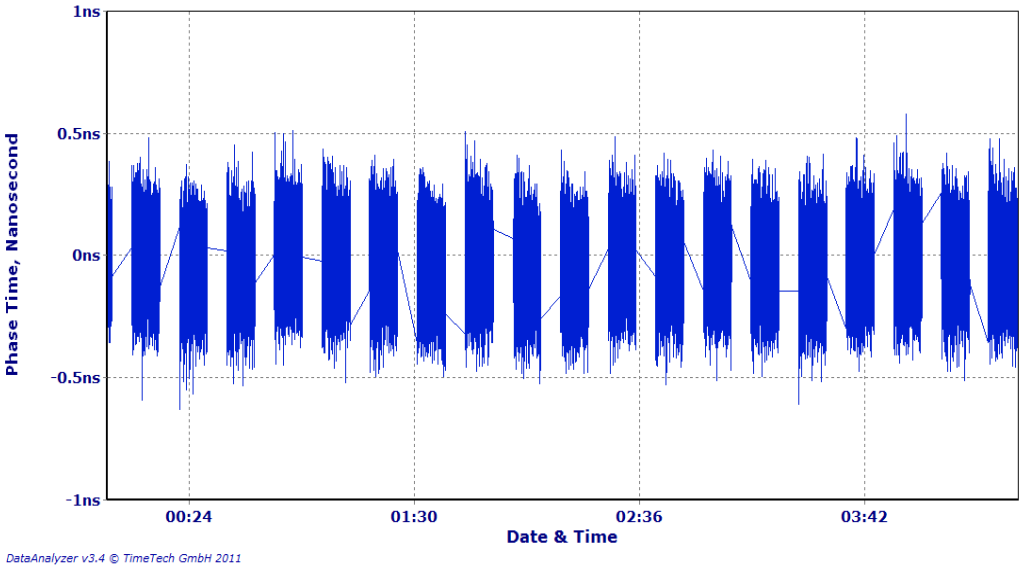
Test:
15 acquisitions at each RF signal level
Then change range and amplitude

FM Phase continuity vs RF EGSE under realistic Doppler conditions January 2019



Frequency vs. Time	
Frequency vs. Time	
2016/08/12 13:23 - 08/12 13:29	
Data Source:	FS-CA3.Dop
No Averaging	
Averaged Samples:	None
Min Value:	-310.740kHz
Max Value:	313.939kHz
Average:	43.066kHz
Std.Dev:	263.466kHz
Data Length[s]:	419
Peak-To-Peak:	624.679kHz
2-Sigma:	526.931kHz
Scale:	0.005kHz/div

Blue: Doppler
Red: Amplitude

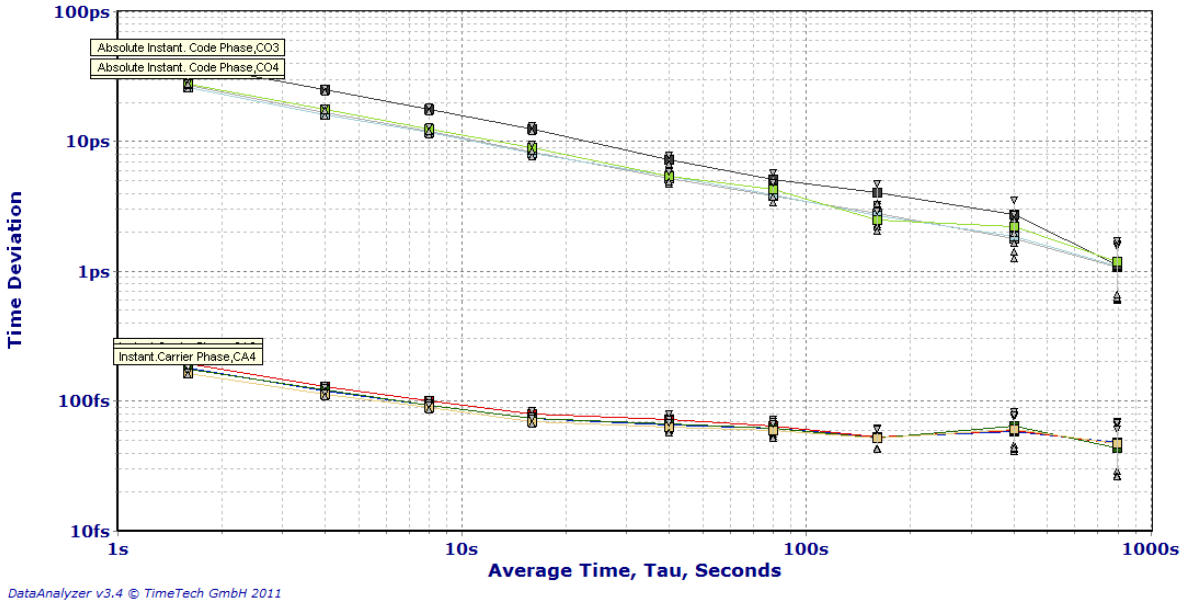


Phase vs. Time	
2019/01/20 00:00 - 01/20 04:26	
Data Source A:	FS-CO2.Abs
Data Source B:	FS-OB2.Par1
Data Source C:	FS-ST2.Par1
Data Source D:	FS-CA2.Ins
No Averaging	
Averaged Samples:	None
Min Value:	-629.302ps
Max Value:	578.338ps
Average:	-34.159ps
Std.Dev:	125.669ps
Data Length[s]:	15998
Peak-To-Peak:	1207.640ps
2-Sigma:	251.338ps
Scale:	500ps/div

FM Code – minus - Carrier, reproducible between lockins

FM to RF EGSE stability
signal -105 dBm, max amplitude

TDEV: Code Phase
10E-12 @ 10 s

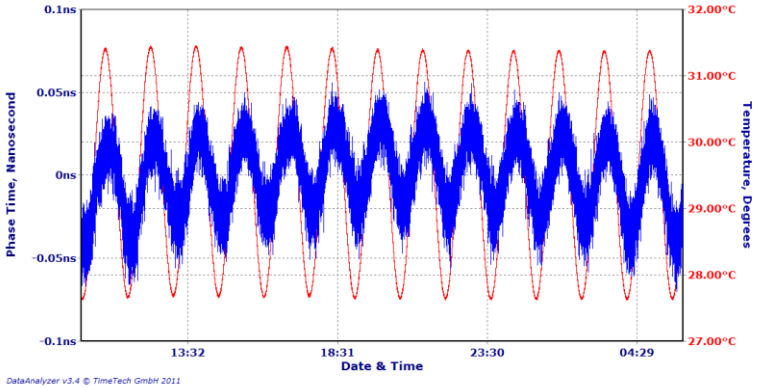


Time Deviation vs. Tau	
2018/12/03 16:00 - 12/03 17:29	
Data Source: FS-CO3.Abs	
No Averaging	
Noise:	Flicker PM
2s	3.94E-11
4s	2.48E-11
8s	1.76E-11
16s	1.25E-11
40s	7.24E-12
80s	5.12E-12
160s	4.02E-12
400s	2.75E-12
800s	1.11E-12

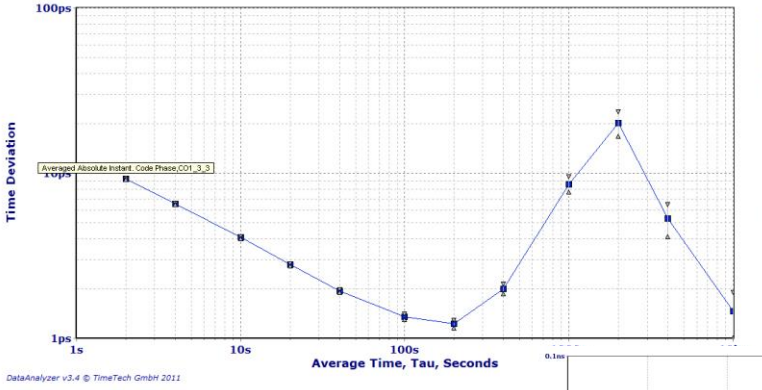
Achieve carrier cycle identification within 10..20 s, at high amplitude

TDEV: Carrier Phase
9E-14 @ 10 s

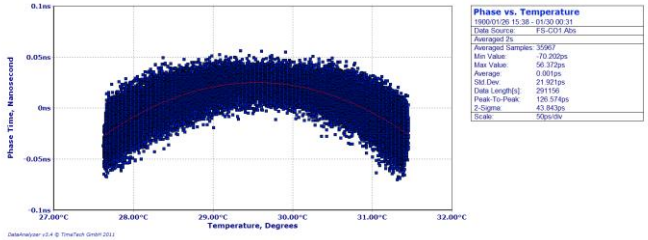
Thermal stability, code phase



Phase vs. Time	
Phase vs. Time	
2018/12/01 10:00 - 12/02 05:59	
Data Source:	FS-CO1.Abs
Averaged 2s	
Averaged Samples:	35997
Min Value:	-70.124ps
Max Value:	56.400ps
Average:	0.001ps
Std.Dev:	21.925ps
Data Length[s]:	71992
Peak-To-Peak:	126.524ps
2-Sigma:	43.849ps
Scale:	50ps/div



Time Deviation vs. Tau	
2018/12/01 10:00 - 12/02 05:59	
Data Source: FS-CO1.Abs	
Averaged 2s	
Noise:	White PM
2s	9.22E-12
4s	6.53E-12
10s	4.08E-12
20s	2.79E-12
40s	1.94E-12
100s	1.35E-12
200s	1.22E-12
400s	2.00E-12
1000s	8.60E-12
2000s	2.02E-11
4000s	5.30E-12
10000s	1.46E-12



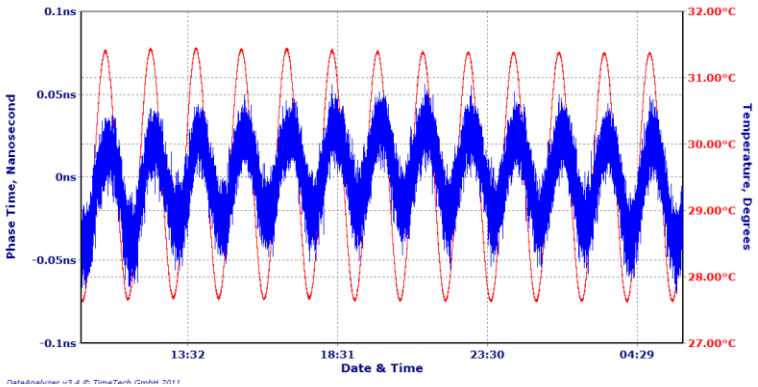
Phase vs. Temperature	
1980/01/26 15:38 - 01/30 00:31	
Data Source:	FS-CO1.Abs
Averaged 2s	
Averaged Samples:	35967
Min Value:	-70.202ps
Max Value:	56.372ps
Average:	0.001ps
Std.Dev:	21.921ps
Data Length[s]:	291156
Peak-To-Peak:	126.574ps
2-Sigma:	43.843ps
Scale:	50ps/div

Code Phase Temperature: 3 Kpp

Long-term stability degraded

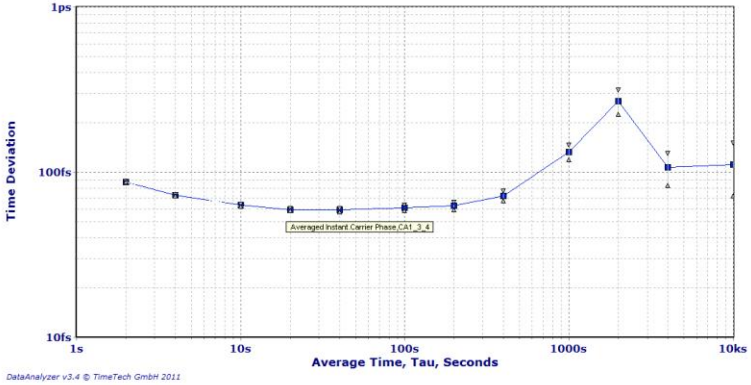
Derive corrective parameters

Thermal stability, carrier phase



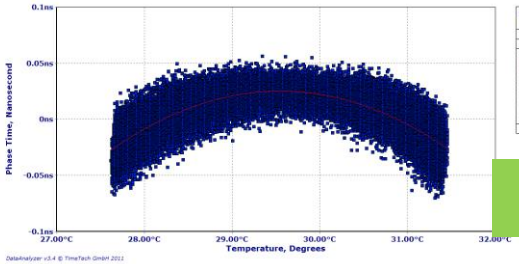
Phase vs. Time Phase vs. Time	
2018/12/01 10:00 - 12/02 05:59	
Data Source:	FS-CA1.Ins
Averaged 2s	
Averaged Samples:	35997
Min Value:	-1.285ps
Max Value:	1.072ps
Average:	0.000ps
Std.Dev:	0.327ps
Data Length[s]:	71992
Peak-To-Peak:	2.357ps
2-Sigma:	0.654ps
Scale:	50ps/div

Carrier Phase Temperature: 3 Kpp



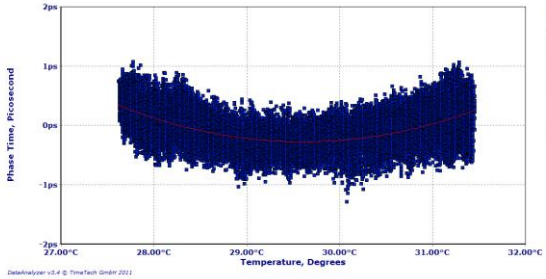
Time Deviation vs. Tau	
2018/12/01 10:00 - 12/02 05:59	
Data Source: FS-CA1.Ins	
Averaged 2s	
Noise:	Flicker PM
2s	8.75E-14
4s	7.26E-14
10s	6.31E-14
20s	5.93E-14
40s	5.90E-14
100s	6.09E-14
200s	6.26E-14
400s	7.19E-14
1000s	1.33E-13
2000s	2.69E-13
4000s	1.07E-13
10000s	1.11E-13

TDEV: Carrier Phase degraded



Phase vs. Temperature	
1900/01/26 15:38 - 01/30 00:31	
Data Source:	FS-CO1.Abs
Averaged 2s	
Averaged Samples:	35967
Min Value:	-70.202ps
Max Value:	56.372ps
Average:	0.001ps
Std.Dev:	21.921ps
Data Length[s]:	291156
Peak-To-Peak:	126.574ps
2-Sigma:	43.843ps
Scale:	50ps/div

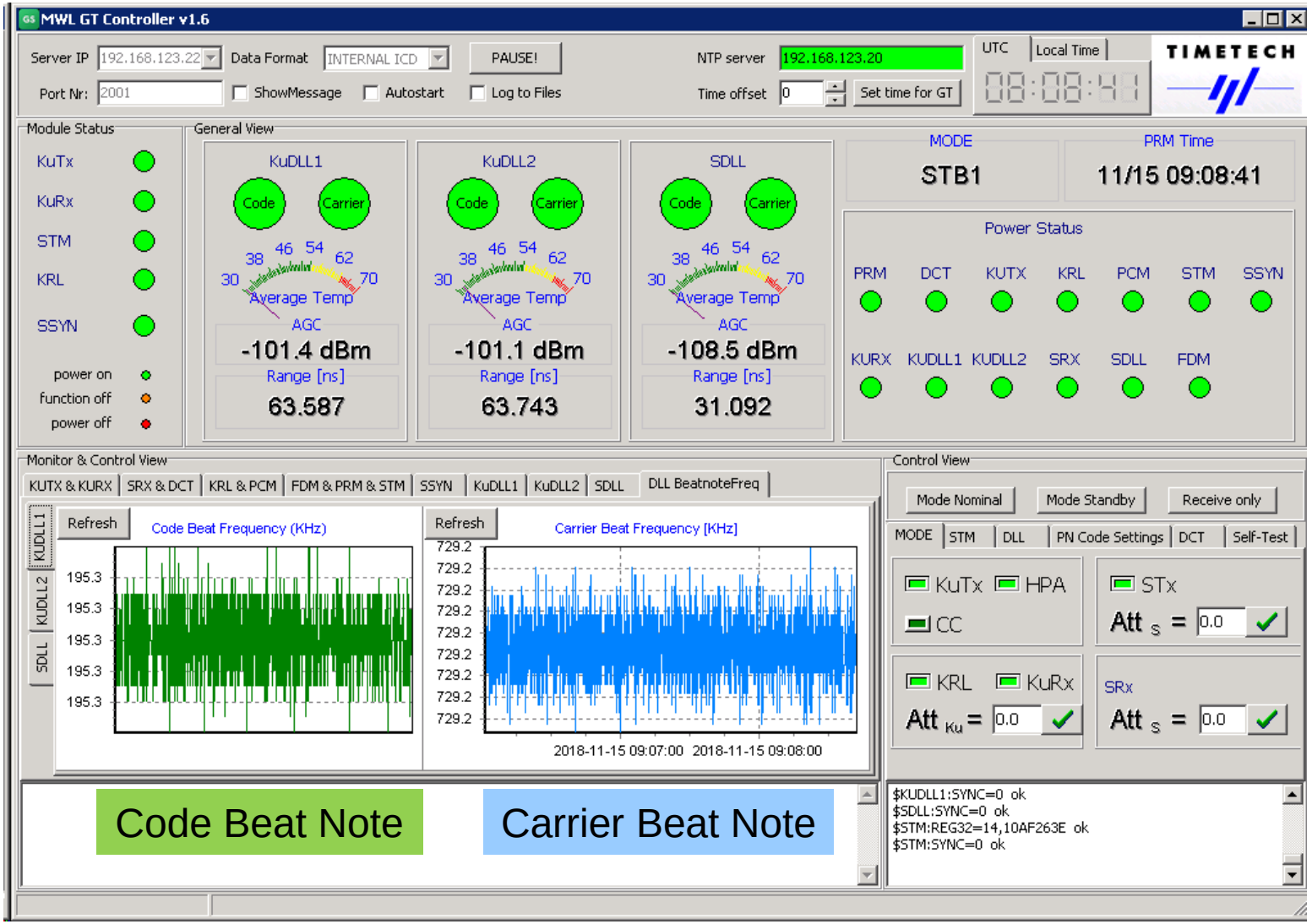
Code



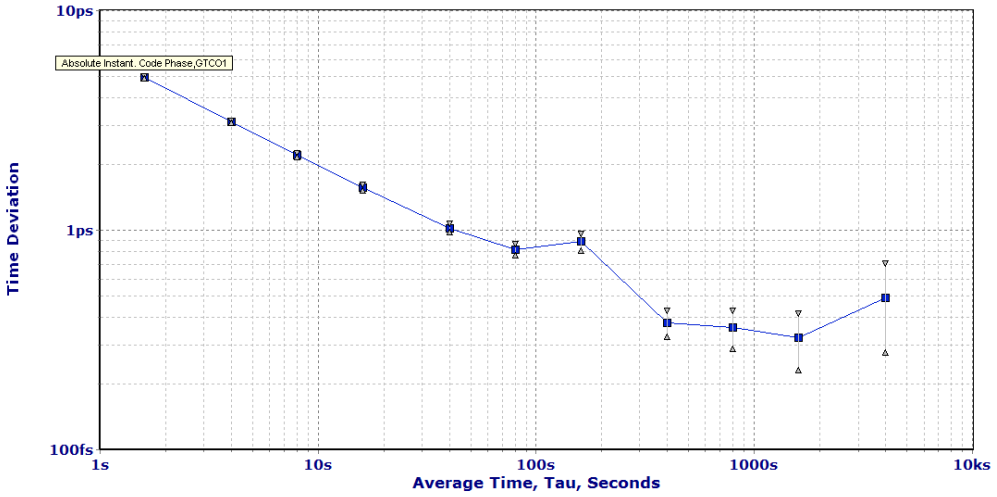
Phase vs. Temperature	
1900/01/26 15:38 - 01/30 00:31	
Data Source:	FS-CA1.Ins
Averaged 2s	
Averaged Samples:	35967
Min Value:	-1.286ps
Max Value:	1.072ps
Average:	0.000ps
Std.Dev:	0.327ps
Data Length[s]:	291156
Peak-To-Peak:	2.357ps
2-Sigma:	0.654ps
Scale:	1ps/div

Carrier

GT #3 Stability using TLT
System Overview, telemetry

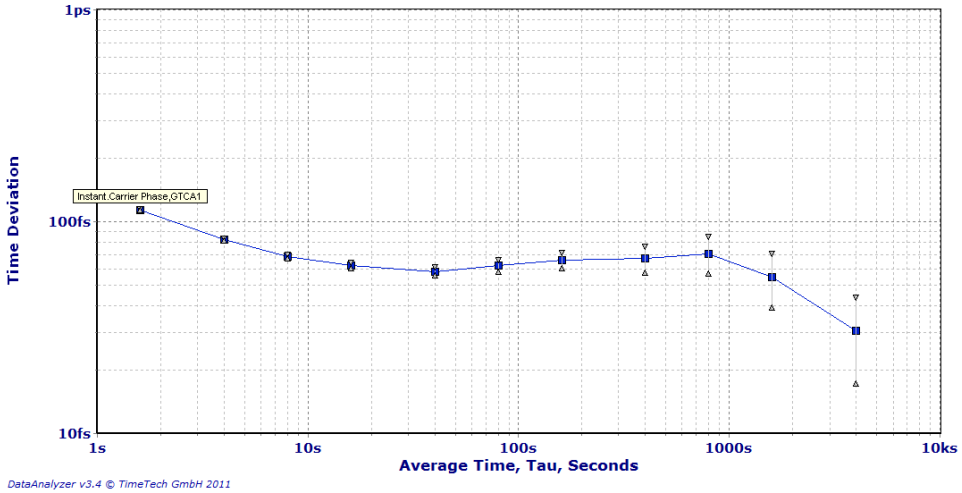


GT #3 Stability using TLT Code and Carrier Phase, high amplitude, -101 dBm



Time Deviation vs. Tau	
2018/11/15 00:00 - 11/15 05:59	
Data Source: GT-GTCO1.Abs	
No Averaging	
Noise:	White PM
2s	4.97E-12
4s	3.11E-12
8s	2.20E-12
16s	1.56E-12
40s	1.02E-12
80s	8.17E-13
160s	8.86E-13
400s	3.78E-13
800s	3.60E-13
1600s	3.23E-13
4000s	4.91E-13

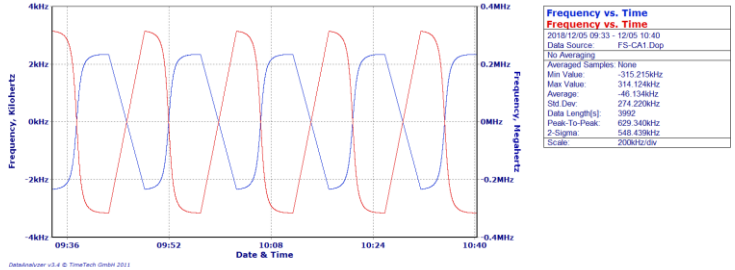
TDEV: Code Phase 1E12 @ 100 s



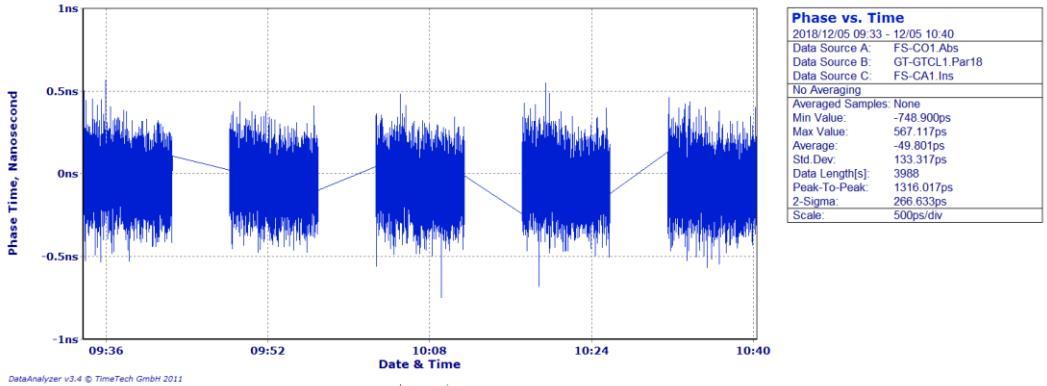
Time Deviation vs. Tau	
2018/11/15 00:00 - 11/15 05:59	
Data Source: GT-GTCA1.Ins	
No Averaging	
Noise:	White PM
2s	1.14E-13
4s	8.23E-14
8s	6.87E-14
16s	6.21E-14
40s	5.82E-14
80s	6.21E-14
160s	6.58E-14
400s	6.69E-14
800s	7.08E-14
1600s	5.50E-14
4000s	3.06E-14

TDEV: Carrier Phase 6.5E-14 @ 160 s

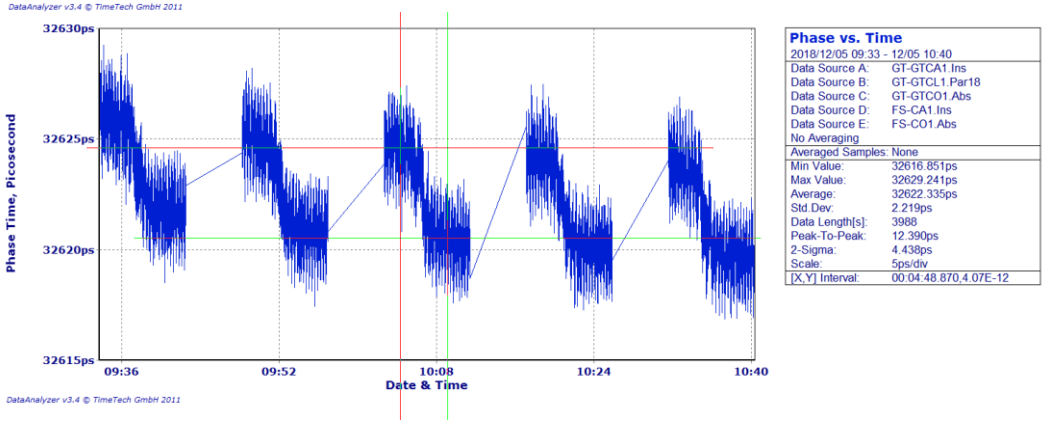
FM to GT2 Doppler Test
"long cables" 150 ns el. Length de-synchronisation



Doppler shape, code and carrier

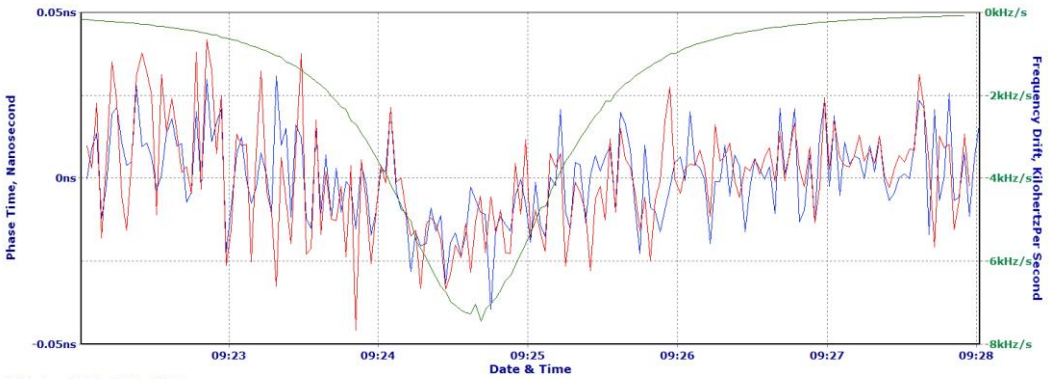


Code minus carrier after code ambiguity removal and carrier cycle identification
Shall be straight line

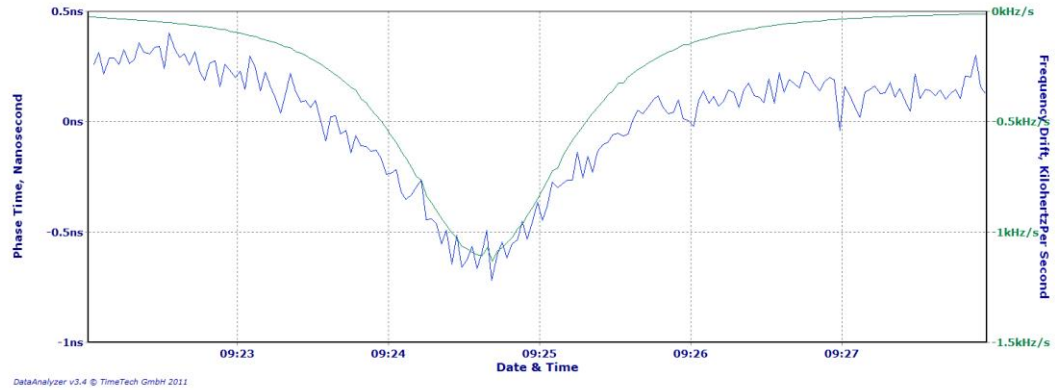


2-way carrier phase:
De-Synchronisation
due to
- Short cables to FM
- Long cables to GT2

FM to GT2 2-way Test
TestDLL Bump due to relative acceleration



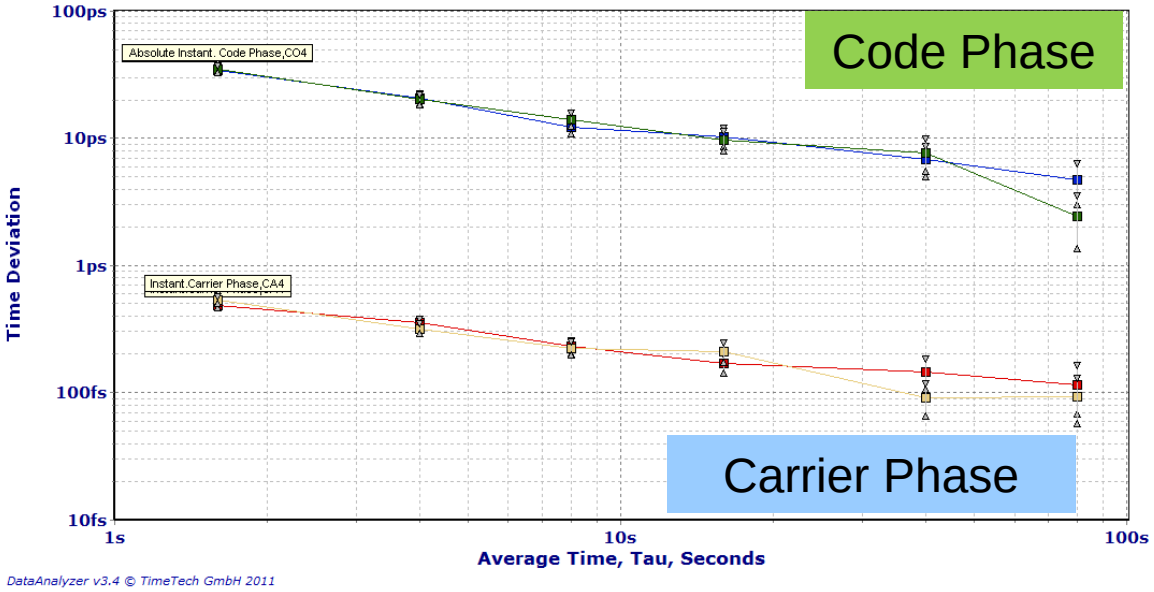
Code phase vs Doppler Rate
Ku-Band



Code phase vs Doppler Rate
S-Band

Solution:
Calibrate for bump in non-dispersive conditions, i.e. on ground
Using code minus carrier, see slide 11

CDMA and Interference Test using EM (new link budget)



Time Deviation vs. Tau	
2019/05/20 14:30 - 05/20 14:40	
Data Source: FS-CO4.Abs	
No Averaging	
Noise:	White PM
2s	3.44E-11
4s	2.04E-11
8s	1.21E-11
16s	1.02E-11
40s	6.74E-12
80s	4.68E-12

Wanted signal: low, -119 dBm
Interfering signal: high, -97 dBm
Difference: 22 dB

Minor interference effect only for long tau within measurement uncertainty

Summary & Conclusions

1. Phase Continuity — OK, full ops period
2. AM/PM — OK, negligible
3. Code Dynamics (PLL bump) — OK, to be calibrated
4. Signal delay, carrier — understood
5. Signal delay, code — understood
6. RF sensitivity — ongoing (OK prelim)
7. CDMA interference — ongoing (OK prelim)
8. Internal EMC/EMV — ongoing (OK prelim)
9. GT shows matching performance

Further Tests related to performance excerpt

1. Realistic GS Szenario (FS with RF EGSE), formerly E-2-E test
   - „Full set“ of GS active, GS handover test
   - Full Doppler & Range simulation
   - Verify scaling (equal phase-time on all measurements)
     - Essential to determine ionosphere
   - Doppler stress test (15% higher than expected maximum)
2. Two-Clock Test (FS vs GT)
   - Realistic clock drifts, absolute scaling
   - unambiguous time transfer after interruptions
3. ELT-Operations
4. Signal delays (see Luigi‘s talk)
   - Very much reduced effort, based on instrument‘s own measurements
   - More accurate, because signal detectors are always the ones used in operations.