Low Phase Noise Local Oscillator and Clock Generation for Cavity Field Detection

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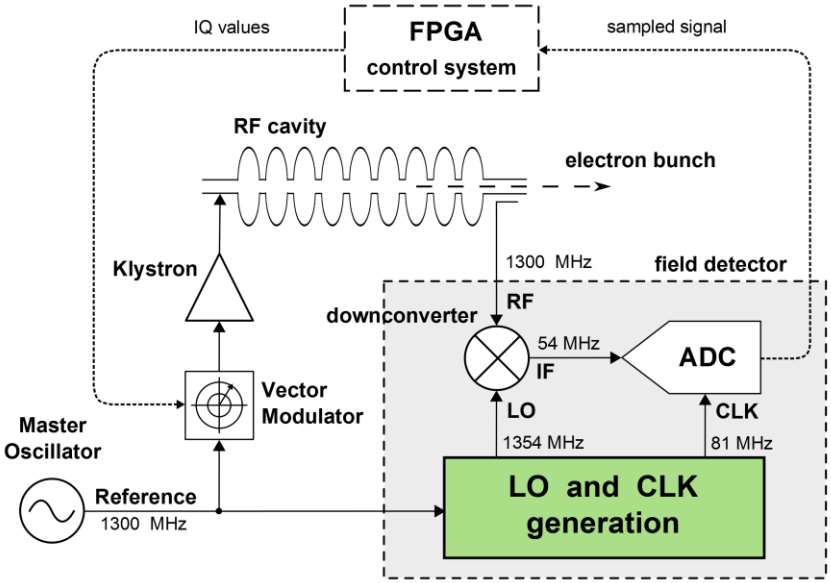
Outline

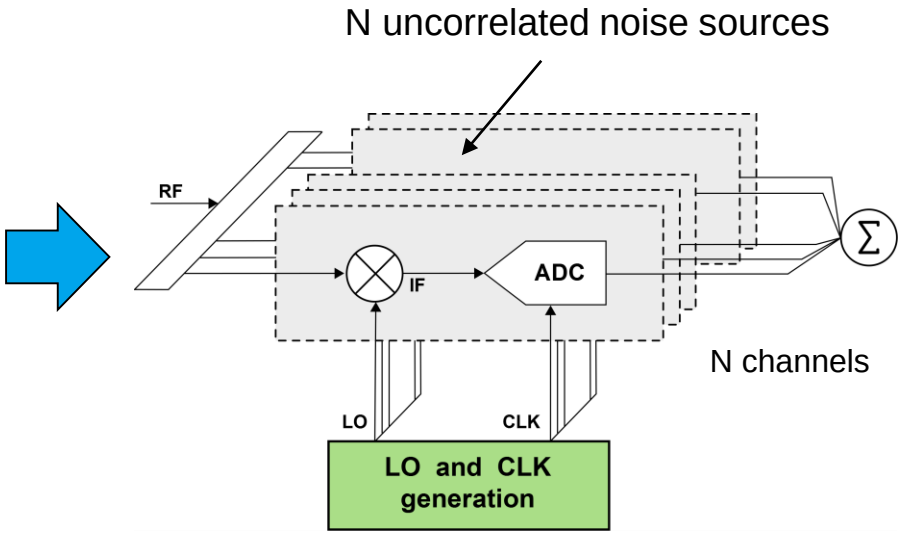
- Introduction
- Frequency synthesis concepts
- Mixing technique
- Analysis
- Prototyping
- Final design
- Results
- Summary

Introduction

- RF cavity field control system



LO Generation Module - LOGM



1 correlated noise sources !!!

- Local Oscillator (LO) signal is a crucial contributor to the receiver phase noise
- Ultra-low phase noise LO is a must
  - < 3 fs RMS time jitter [10 Hz ÷ 1 MHz]
  - < -160 dBc/Hz noise floor

spec for the European XFEL

- Low phase noise Clock (CLK) is needed

Introduction

> LOGM requirements

- Input signal:
  - 1x REF 1300 MHz +21 dBm
- Output signals:
  - 3x REF 1300 MHz +11 dBm (uVM, HOM, KLM)
  - 2x REF 1300 MHz +3 dBm (uDWC)
  - 9x LO 1354 MHz +14 dBm
  - 9x CLK 81 MHz 1.2 Vpp square
- Synchronization RESET functionality for 81 MHz CLK signal
- LO power adjustment [+12 … +17 dBm]
- LO performance:
  - RMS additive jitter < 3 fsec (10Hz - 1MHz)
  - Phase noise floor < -160 dBc/Hz
  - Spurious-free range > 80 dBc
- Diagnostics:
  - RF signals monitor outputs
  - Power level detectors, temperature sensors
  - Power supply menagement
- Packaging:
  - standard 19” crate, low-profile (1U high)

XFEL system frequency configuration:

- REF 1300 MHz
- LO 1354 MHz
- IF 54.16 MHz (1300 / 24)
- CLK 81.25 MHz (1300 / 16)

Frequency synthesis concepts

> Phase-lock loop technique

Advantages

- shaping phase noise characteristic
- superior performance possible

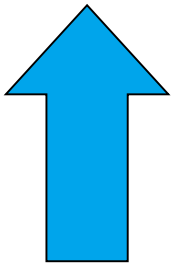
Disadvantages

- lack of small PCB-mount oscillators with sufficiently good performance

> Mixing technique

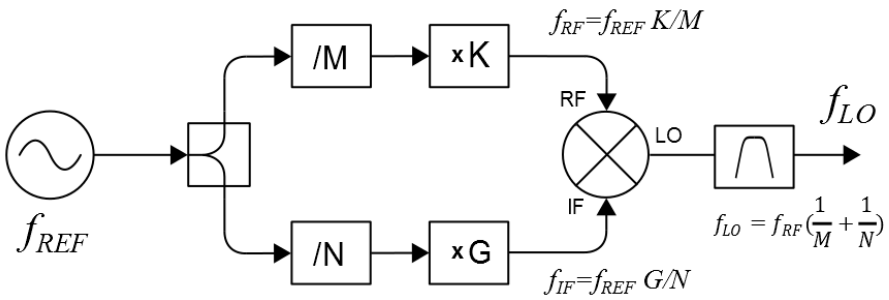
Advantages

- low phase noise
- sufficient performance possible
- components easily available
- easy to integrate on PCB



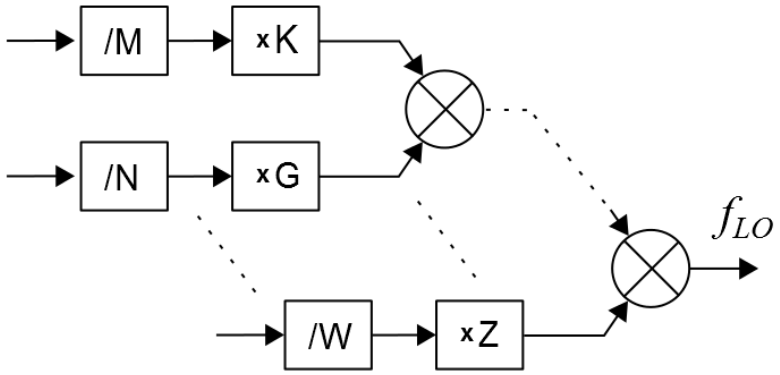
Mixing Technique

> Single-stage mixing



$$f_{LO} = f_{RF} \pm f_{IF}$$

> Multi-stage mixing



RF and LO are close each other !!

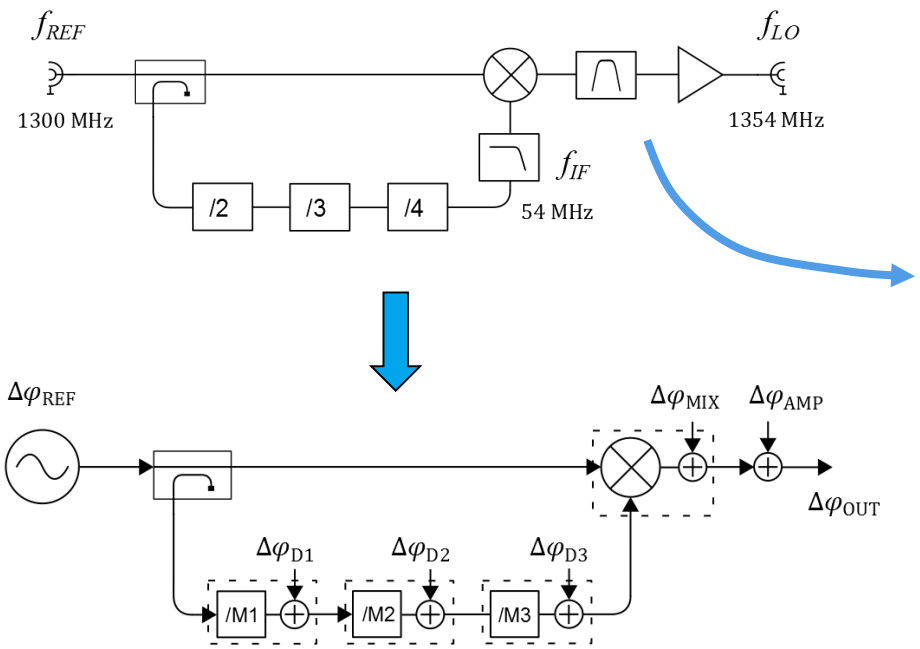
➡ it is hard to select the LO out of the mixer spectrum (filtration)

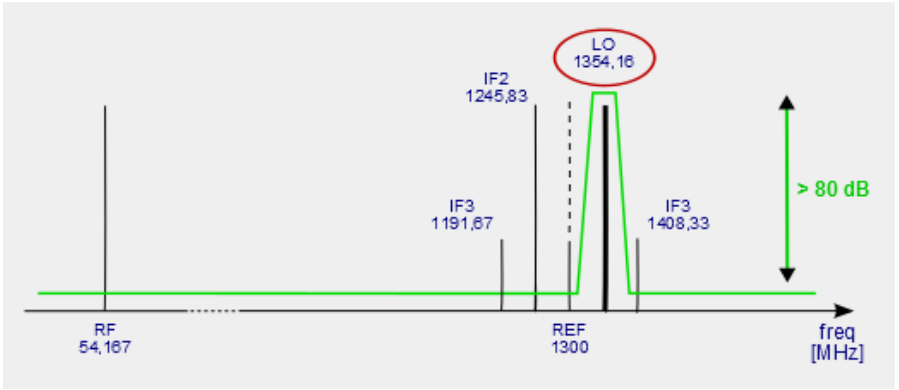
- Simple design
- Minimum number of components
- **High spec for LO filter**

- Complex design
- High number of components
- **Relaxed spec for LO filters**

Analysis

- Single-stage mixing



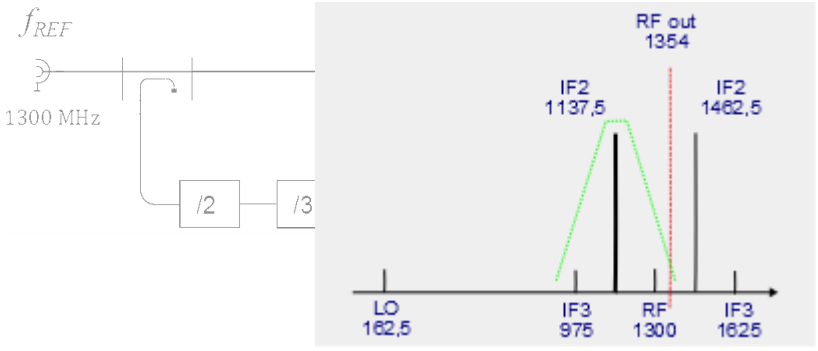


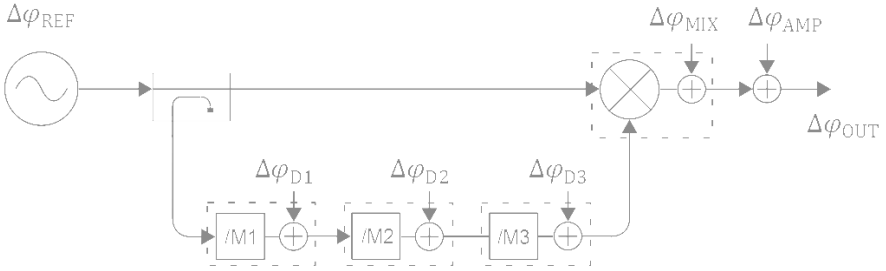
phase noise propagation model

$$|\Delta\varphi_{out}|^2 = \left[\left[\frac{|\Delta\varphi_{REF}|^2}{{M_1}^2} + |\Delta\varphi_{D1}|^2\right]\cdot\frac{1}{{M_2}^2} + |\Delta\varphi_{D2}|^2\right]\cdot\frac{1}{{M_3}^2} + |\Delta\varphi_{D3}|^2 + |\Delta\varphi_{MIX}|^2 + |\Delta\varphi_{AMP}|^2$$

Analysis

> Single-stage mixing





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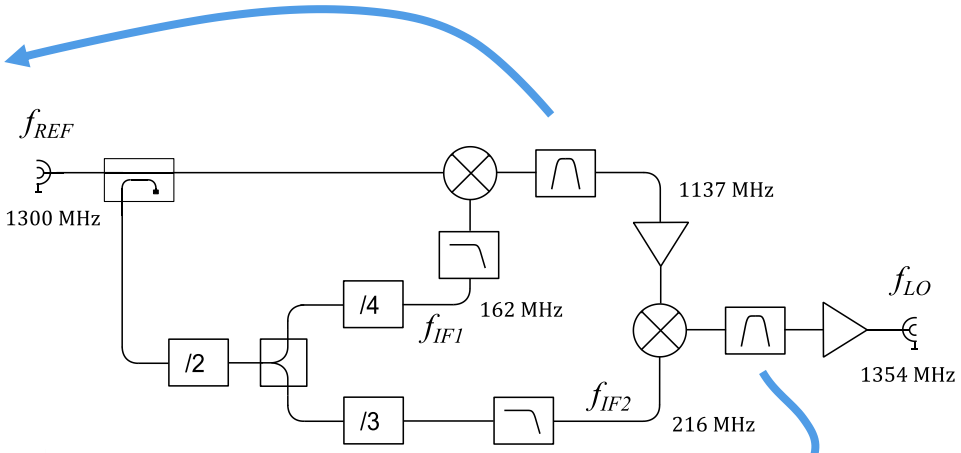
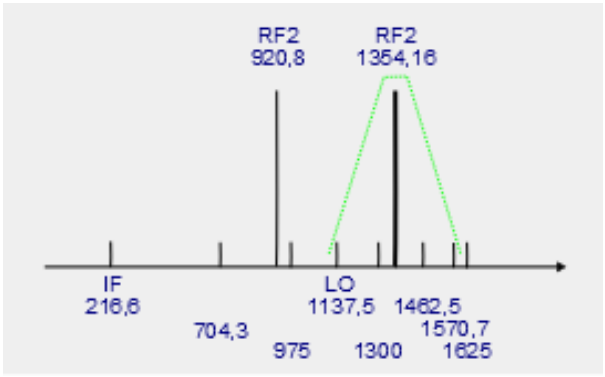
> Double-stage mixing

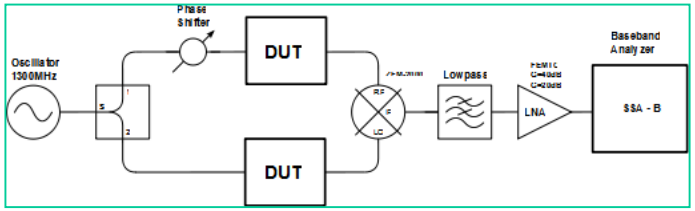


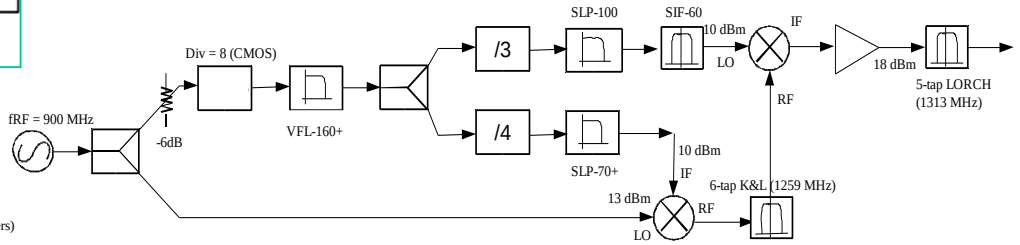


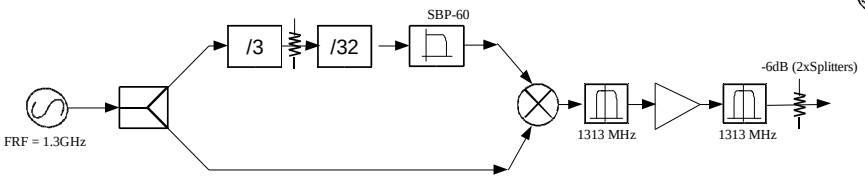
Prototyping

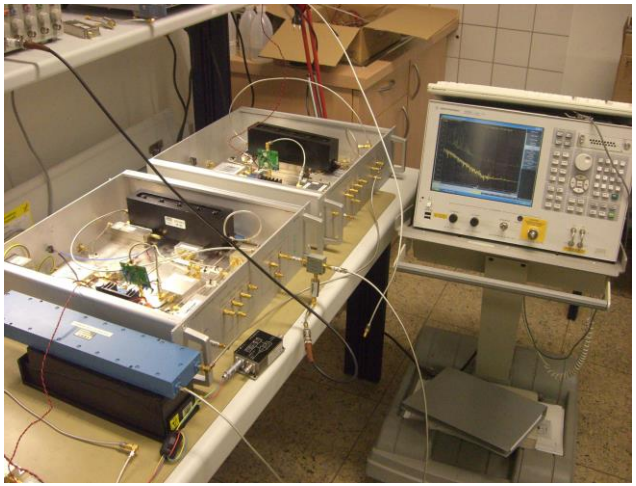
- Single-stage mixing
- Double-stage mixing

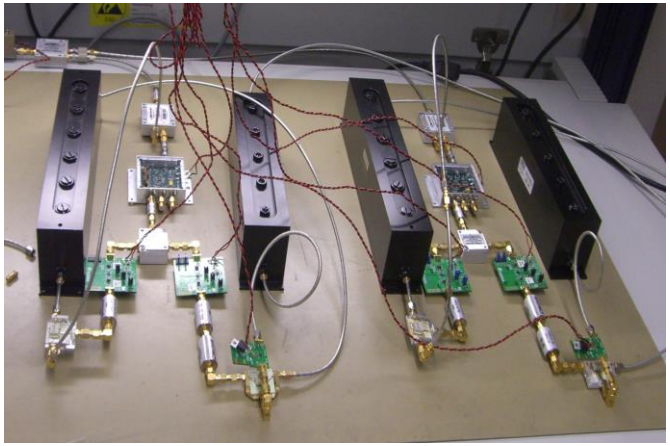
Residual phase noise measurements (2DUT phase detector method)





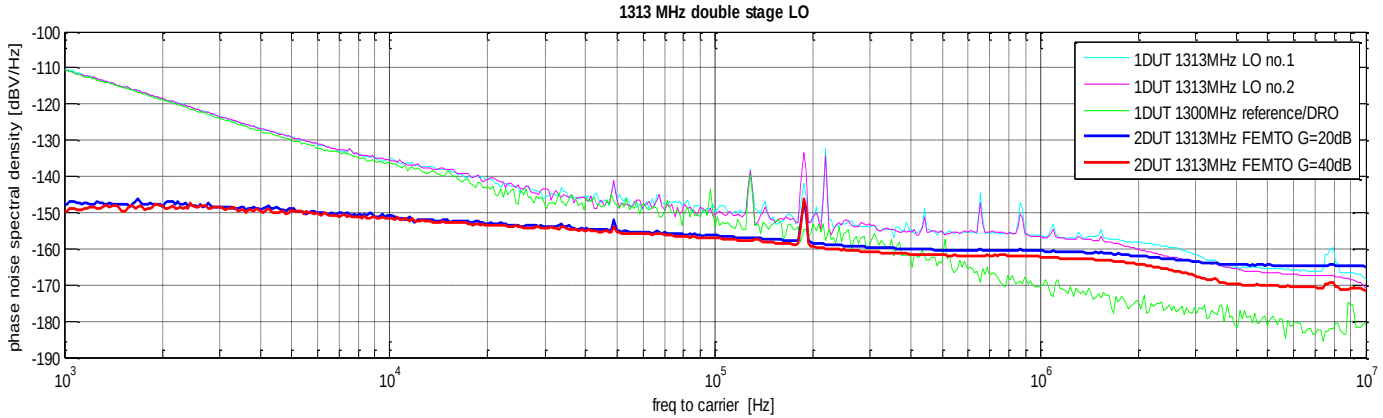






Prototyping

- LO residual RMS phase noise measurements and jitter calculations



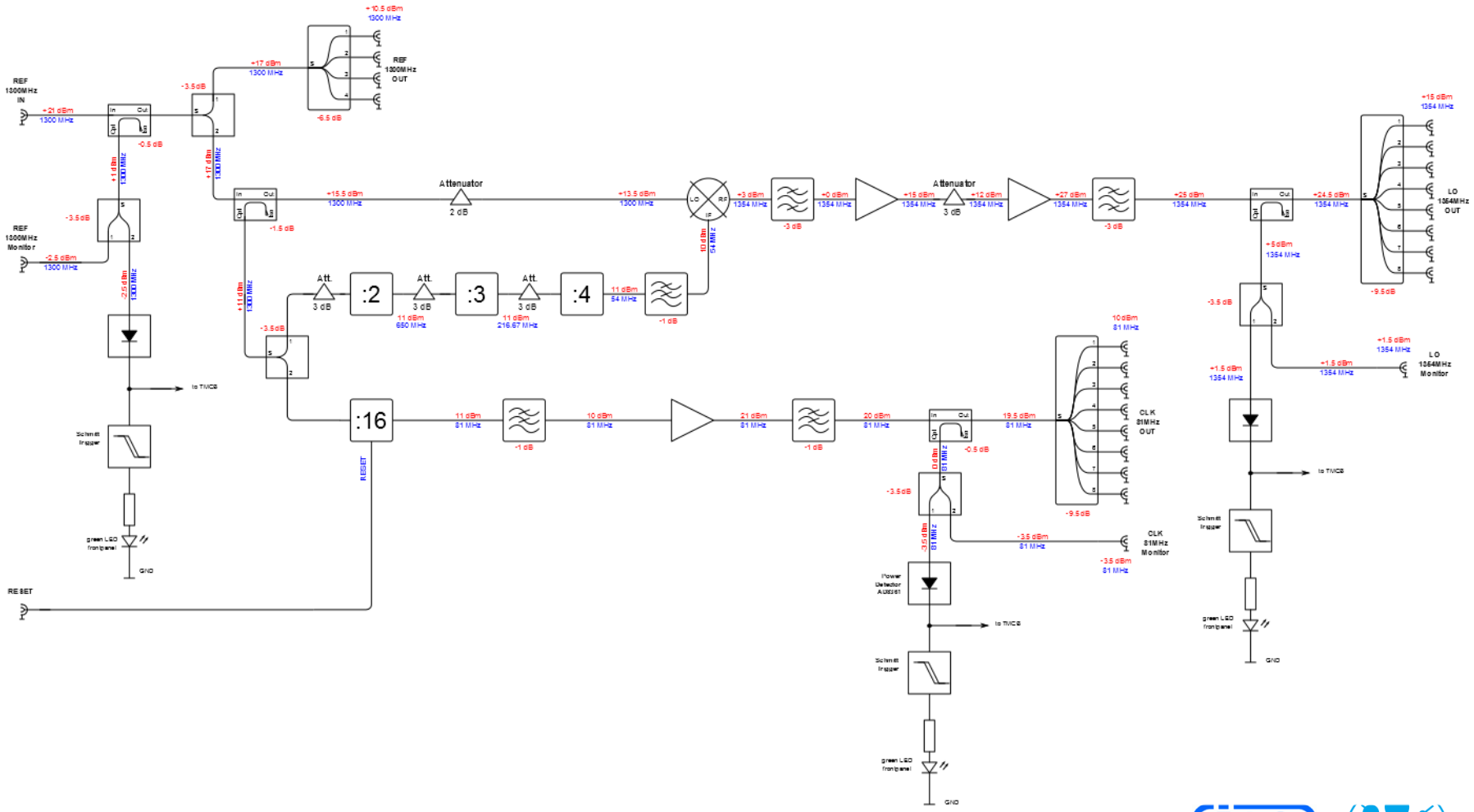
LO 1313 MHz	single-stage	double-stage
jitter **10 Hz – 1 MHz**	2.6 fs (1.2 mdeg)	3.4 fs (1.6 mdeg)
Cross-check meas. jitter **1 kHz – 10 MHz**	2.6 fs (1.2 mdeg)	2.8 fs (1.3 mdeg)

- Compact high-quality ceramic filters available !

- Single-mixer LO synthesis for final implementation

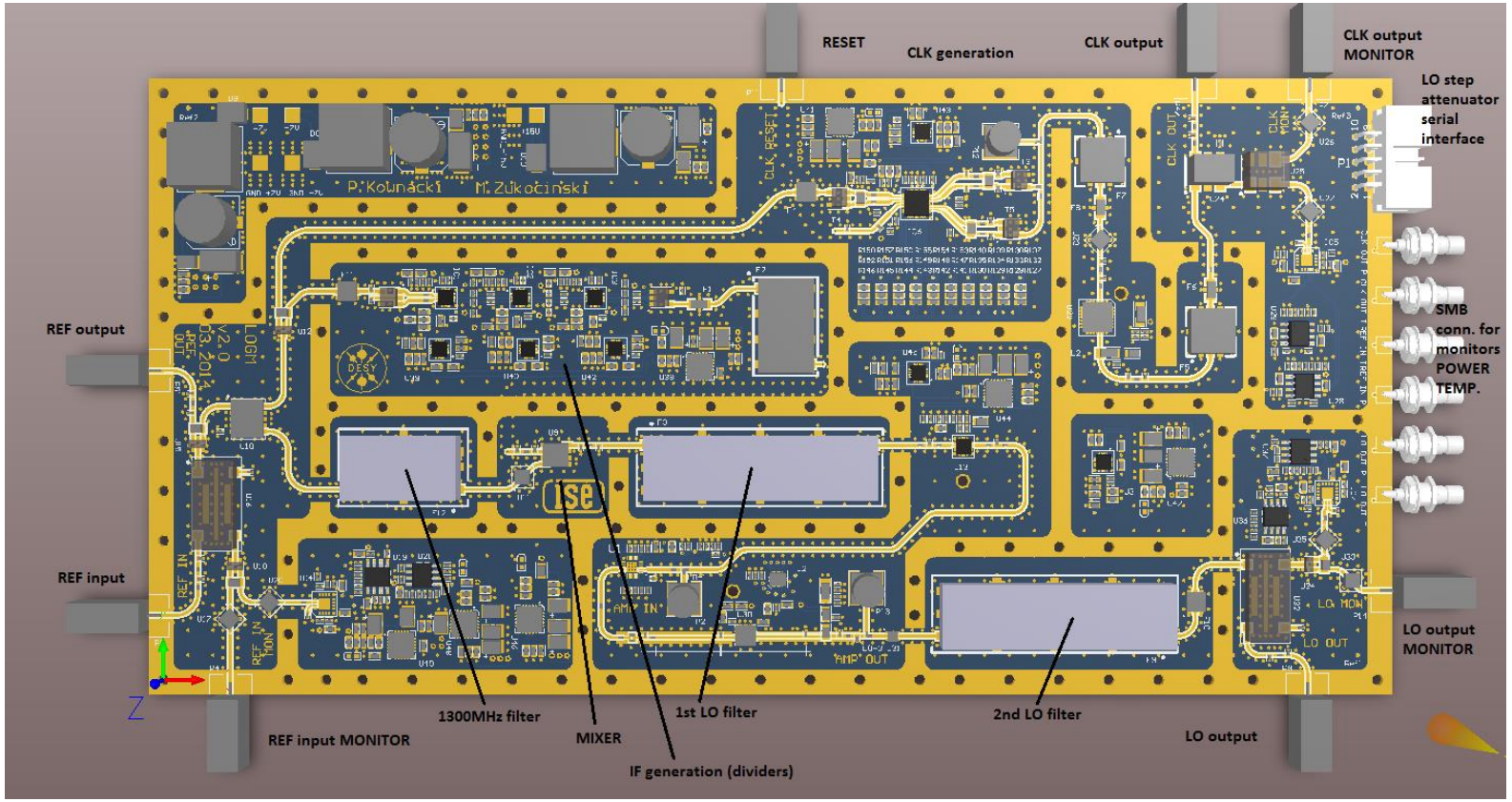
Final design

- Block diagram of the LOGM module



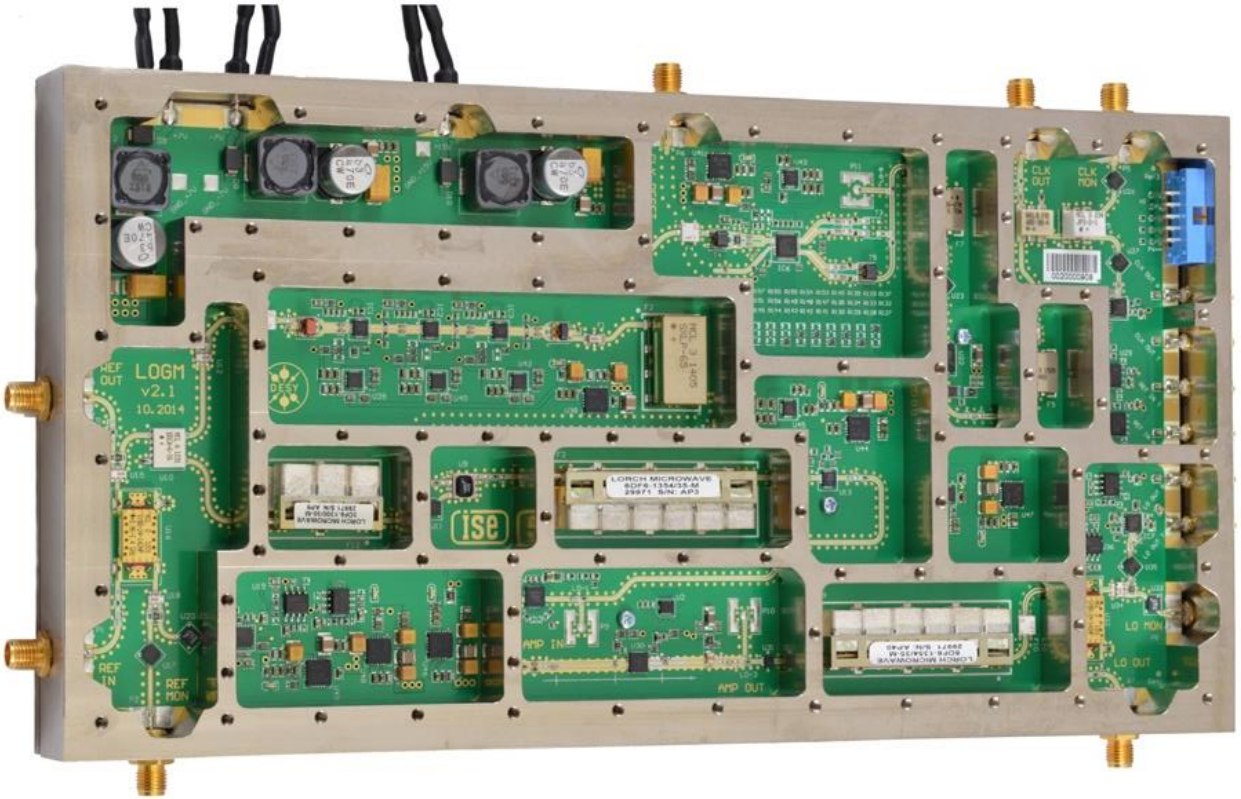
Final design

- PCB layout of LOGM



Final design

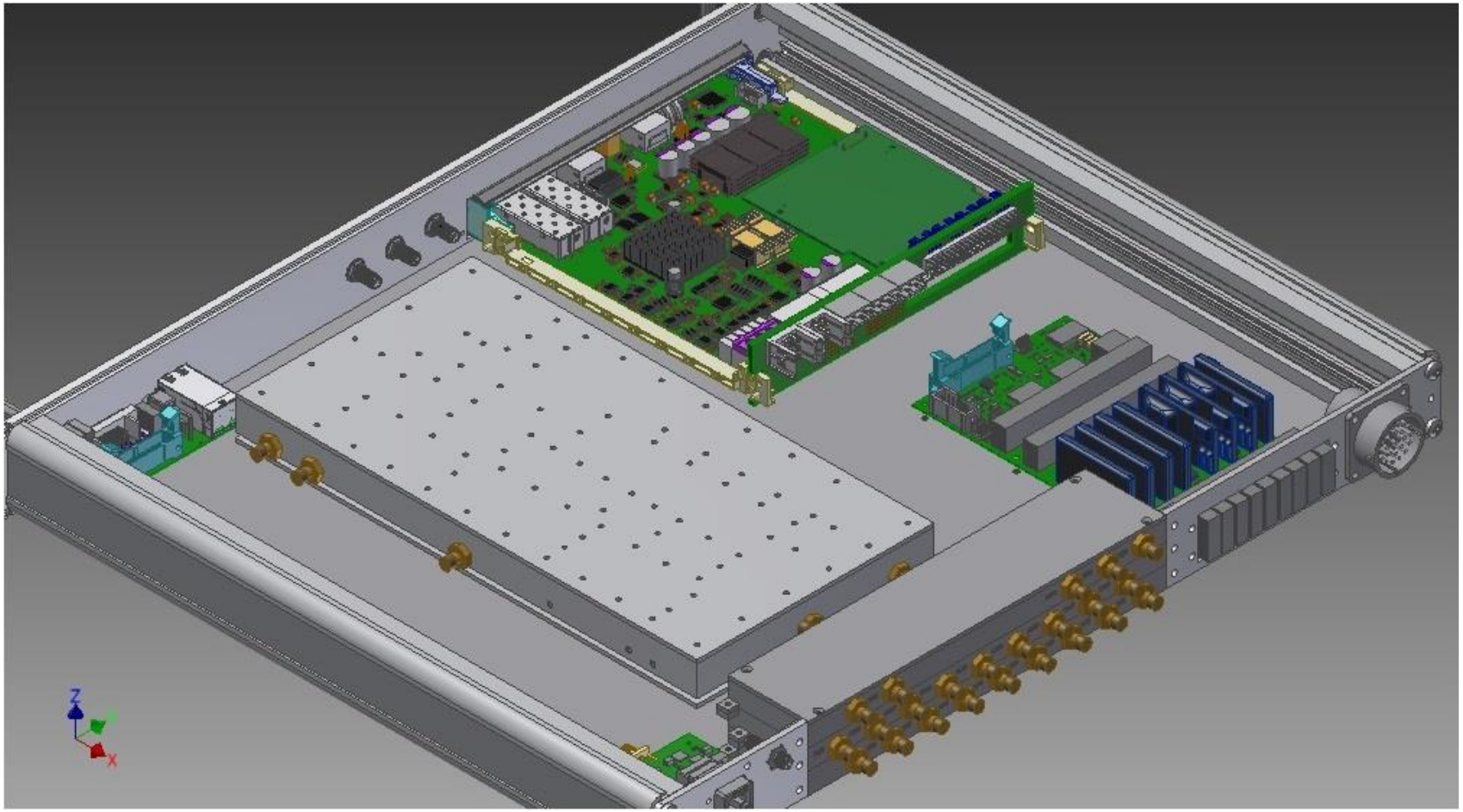
- LOGM module (PCB + metal case)



- Metal casing for improved EMI/EMC
- Reduced conductive crosstalk and radiative couplings (SFR >80 dBc)
- Efficient heat dissipation

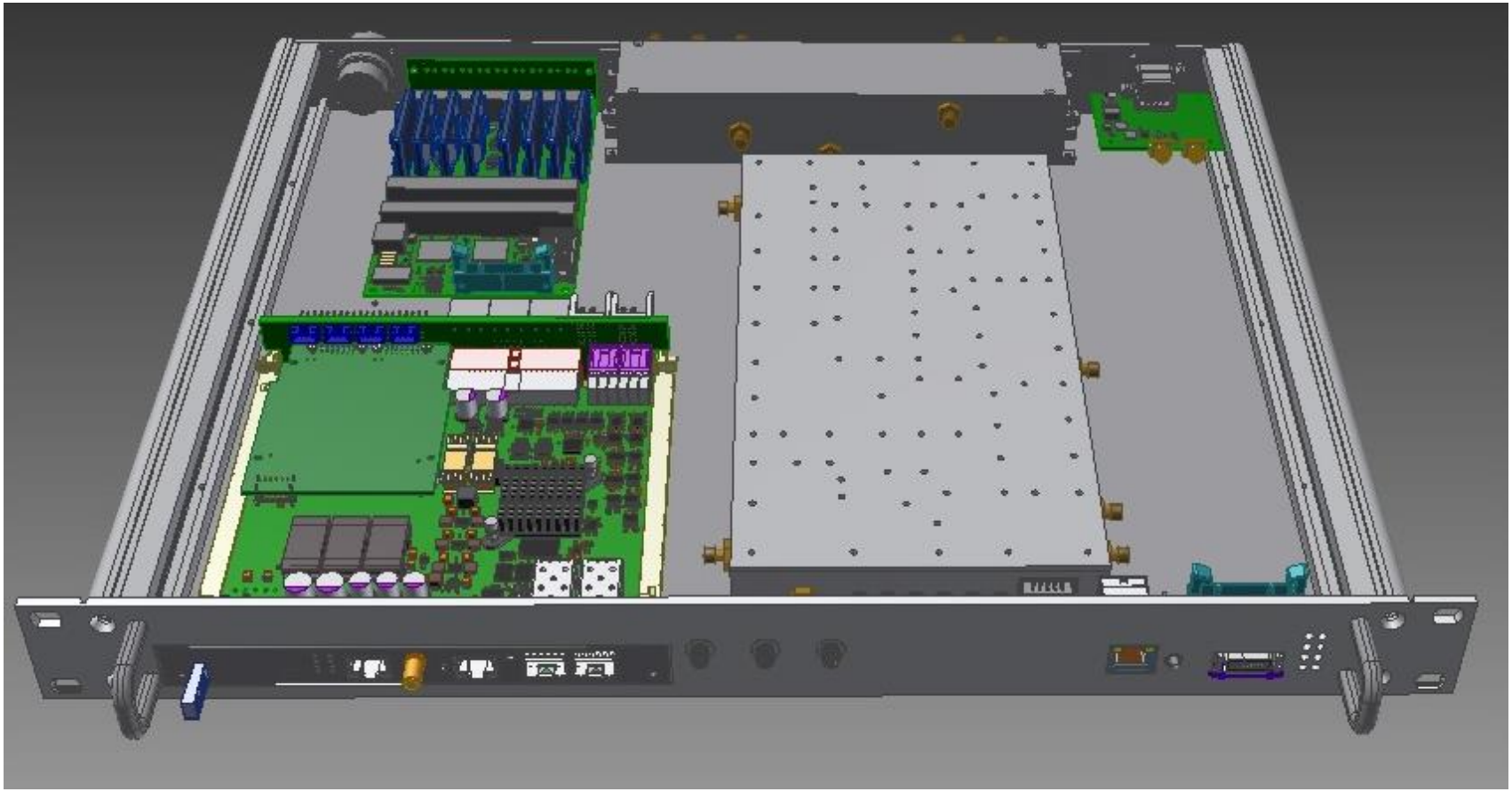
Final design

- LOGM 19” crate – 3D mechanical modeling (crate integration)



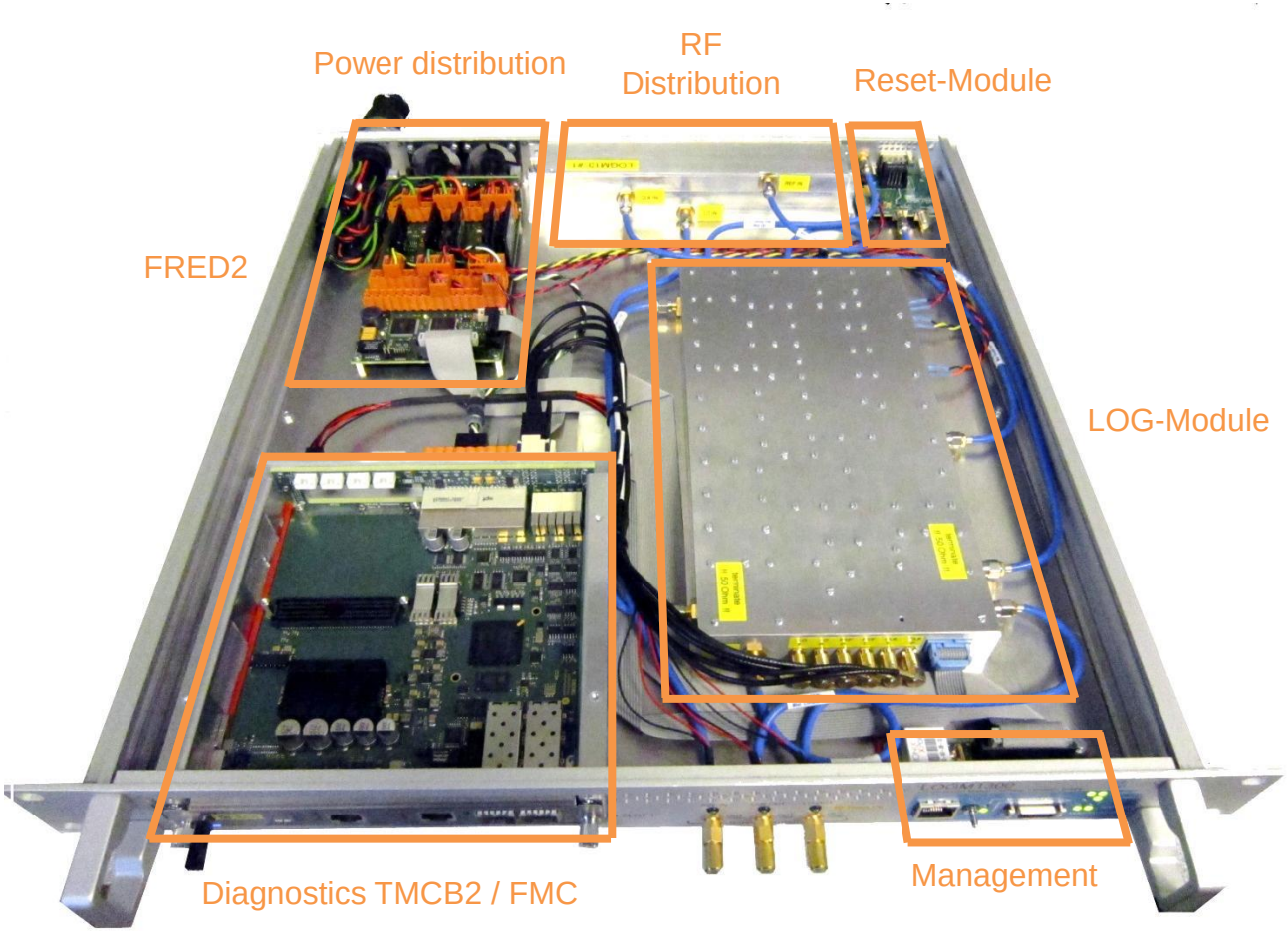
Final design

- LOGM 19” crate – 3D mechanical modeling (crate integration)



Final design

- LOGM 19” crate – internal arrangement



Final design

- LOGM 19” crate

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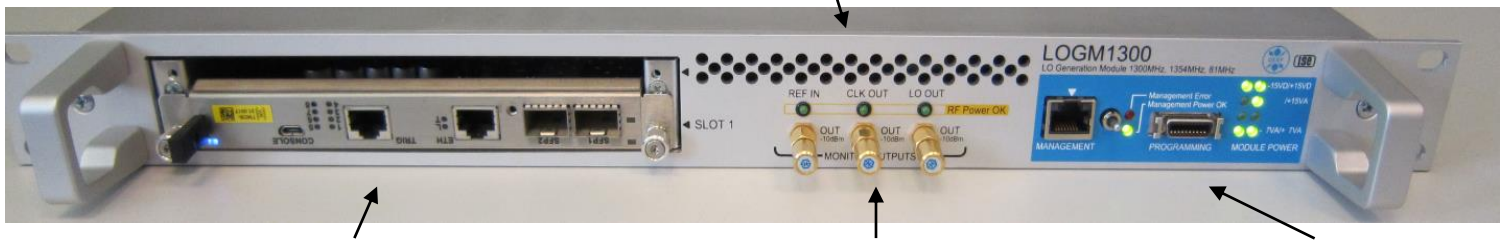
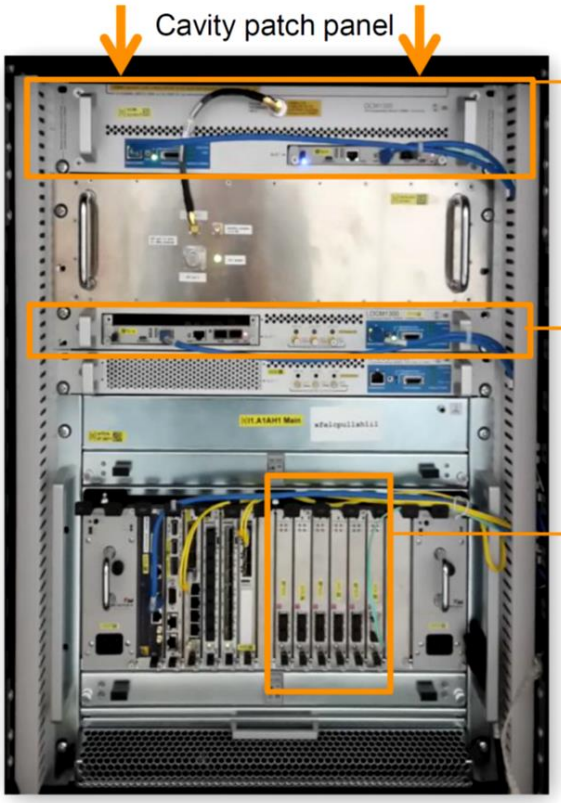


Final design

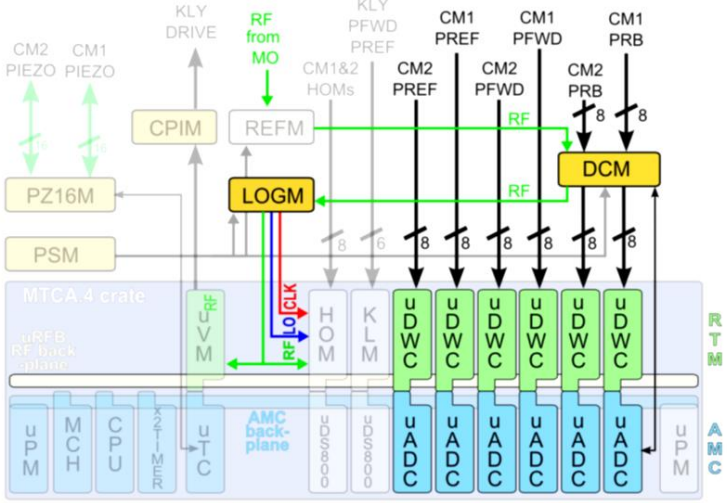
> LOGM 19” crate in the XFEL LLRF system

- XFEL 48-channel LLRF station:



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

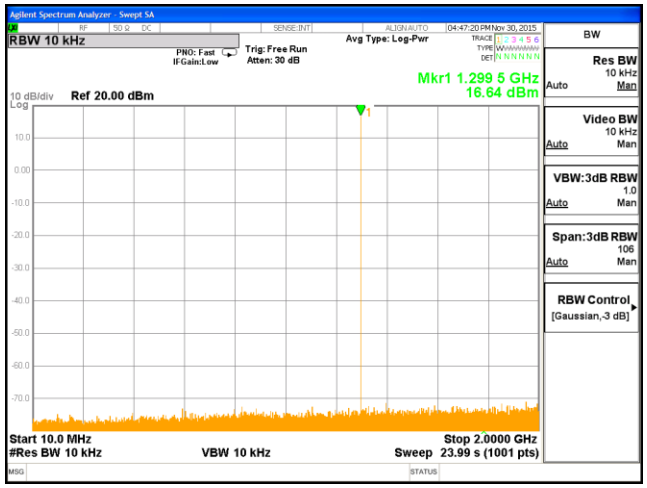
Drift Compensation	DCM	2U 19” Module
LO-Generation	LOGM	1U 19” Module
Down-Converter	DWC	RTM MicroTCA.4
Low-noise Digitizer	ADC	AMC MicroTCA.4



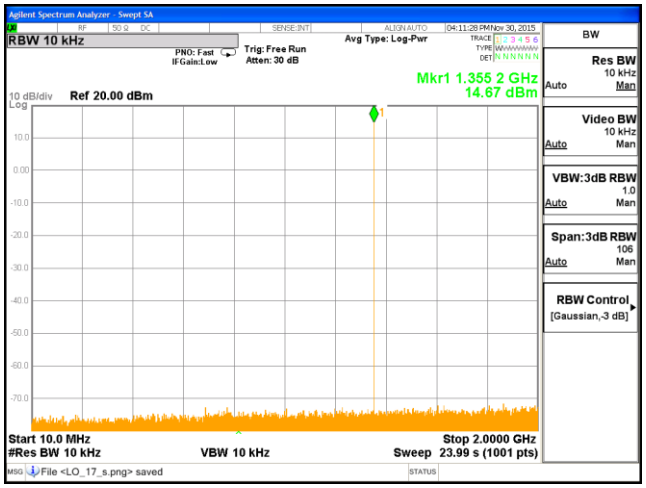
courtesy of Frank Ludwig, LLRF Workshop 2015, Shanghai

Results

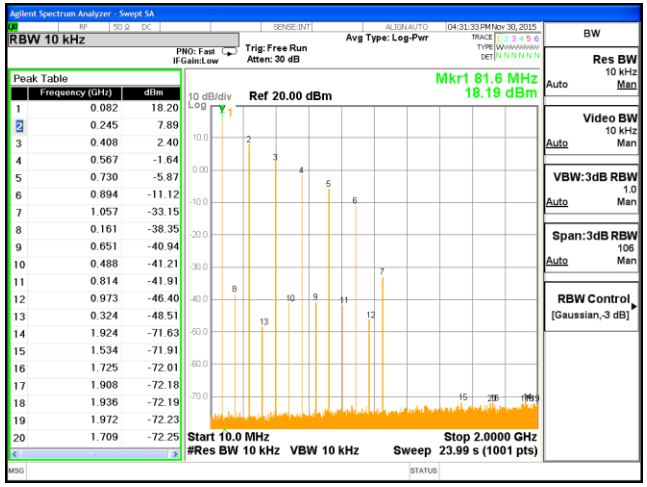
REF spectrum



LO spectrum



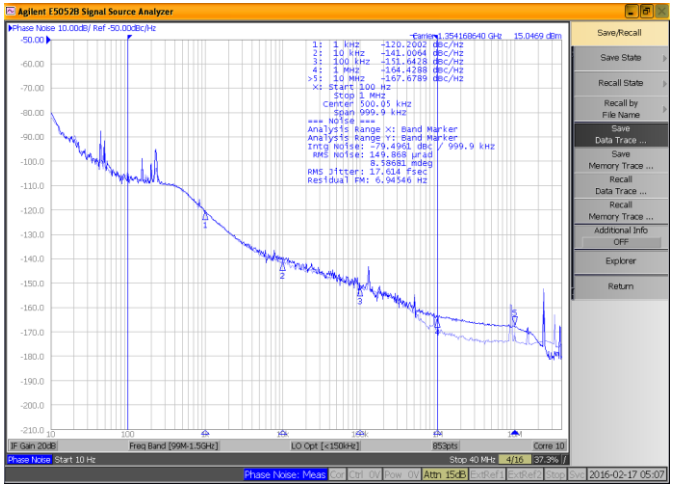
CLK spectrum



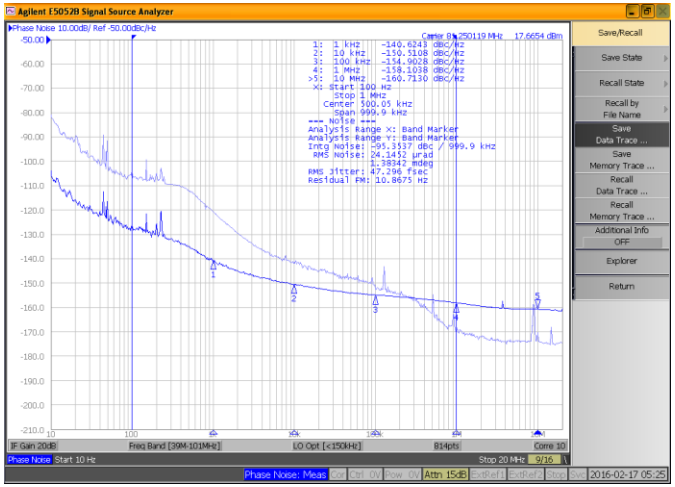
- Clean spectrum
- Spurious-free-range >80 dBc
- CLK bandwidth up to 1 GHz

Results

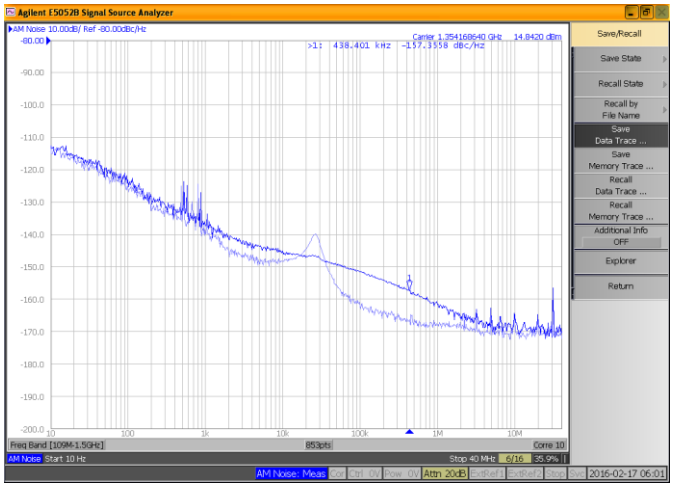
LO absolute phase noise spectrum



CLK absolute phase noise spectrum



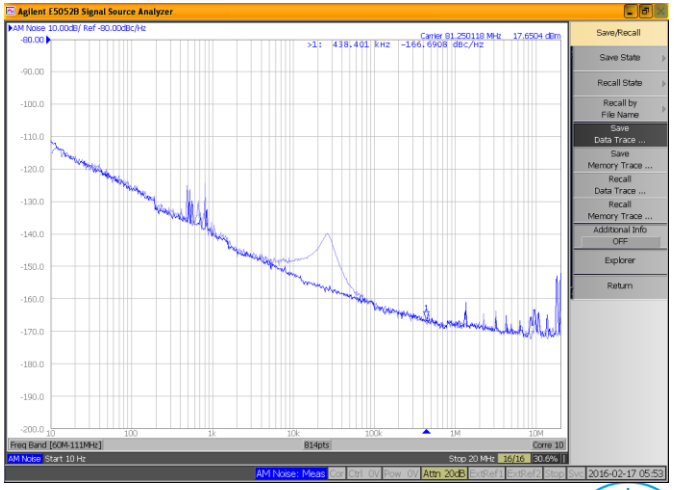
LO amplitude noise spectrum



> Noise floor

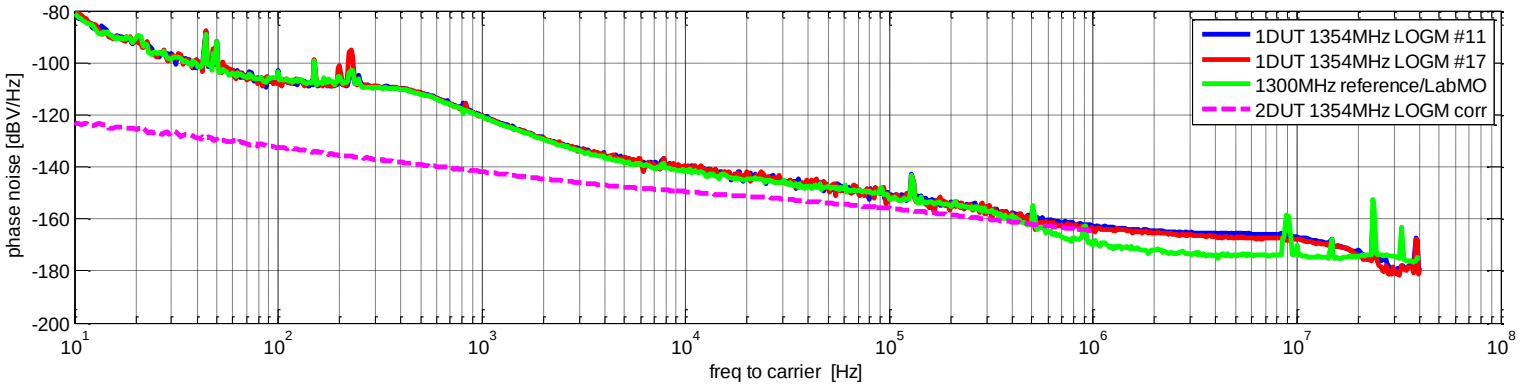
< -160 dBc/Hz

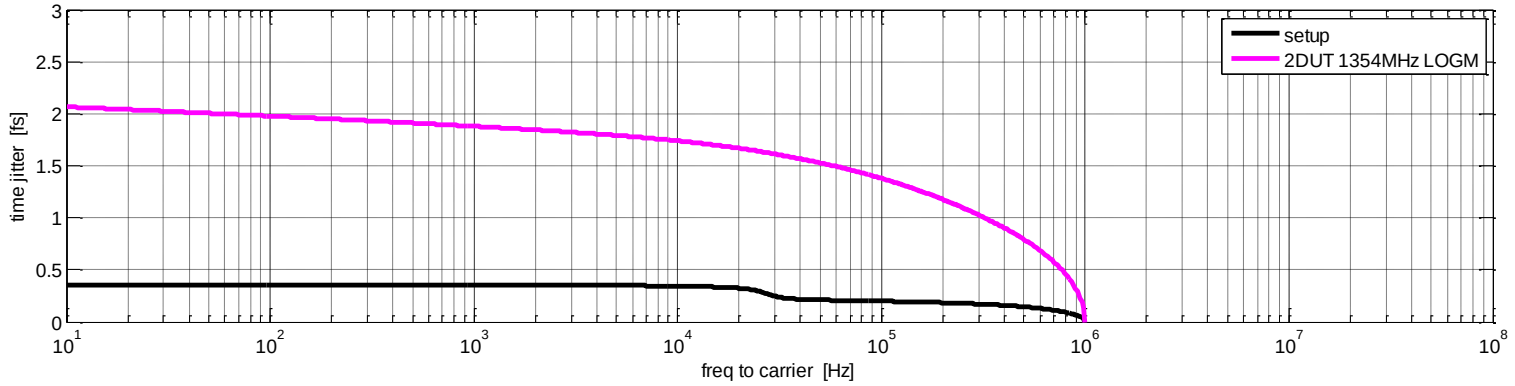
CLK amplitude noise spectrum



Results

- Residual phase noise and jitter



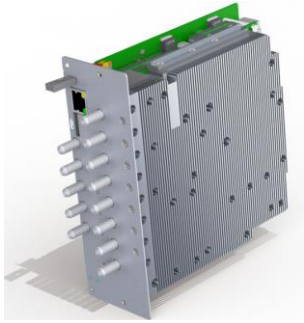


- RMS time jitter ~2 fs [10 Hz – 1 MHz]

Summary

- Mixing technique useful for ultra-low phase noise LO generation
- High performance LO and CLK generation module for European XFEL was developed
  - LO: ~2 fs of RMS time jitter [10 Hz - 1 MHz]
  - LO: <-160 dBc/Hz noise floor
  - spurious-free-range > 80 dBc
- Motivation for spin-off projects:
  - DRTM-LOG1300 highly compact RTM module for MTCA.4

    (poster on Tuesday by Tony Rohlev)



  - Universal LO&CLK generation module for LO [300 MHz – 6 GHz]

    (poster on Wednesday by M. Żukociński)

Thank you for your attention !