INSTRUMENTATION
TECHNOLOGIES

LIBERA

Precise Generation and Distribution System of RF Reference Signal for SKIF Accelerator Complex

M.Cargnelutti, D.Tinta, B.Baričević, L.Bogataj, B.Repič, S.Zorzut, M.Šajn, M.Jug
(Instrumentation Technologies, Solkan, www.i-tech.si)

Sergey Evgenyevich Karnaev, Alexey Levichev, Sergey Sinyatkin
(BINP SB RAS, Novosibirsk, www.inp.nsk.su)

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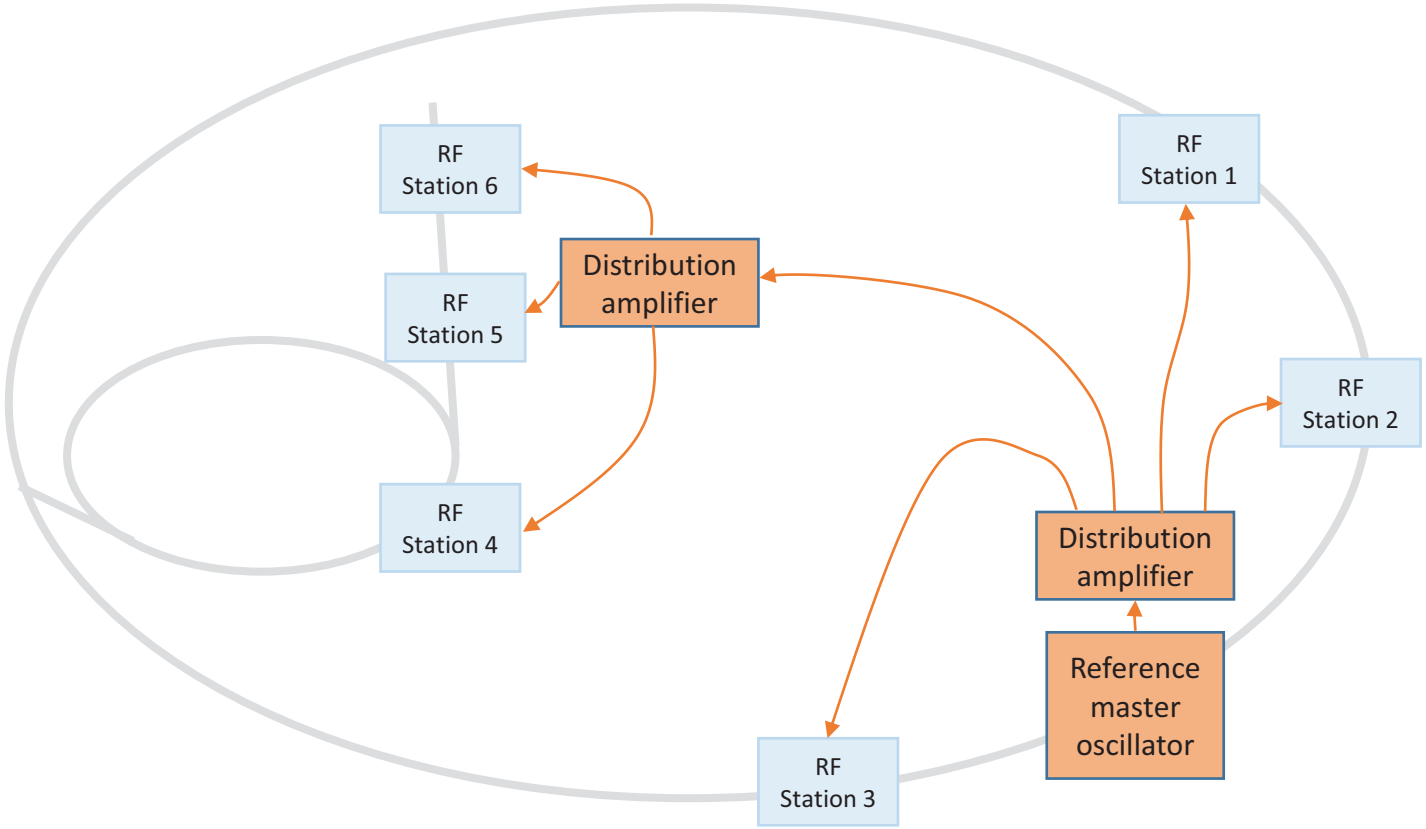
Outline

- Purpose of the RF generation and distribution system
- Project background and motivation
- The SKIF project requirements
- Design & development status and results
    - Reference Master Oscillator
    - Distribution Amplifier
    - Optical RF signal transfer system
- Conclusions

Purpose of the RF generation and distribution system

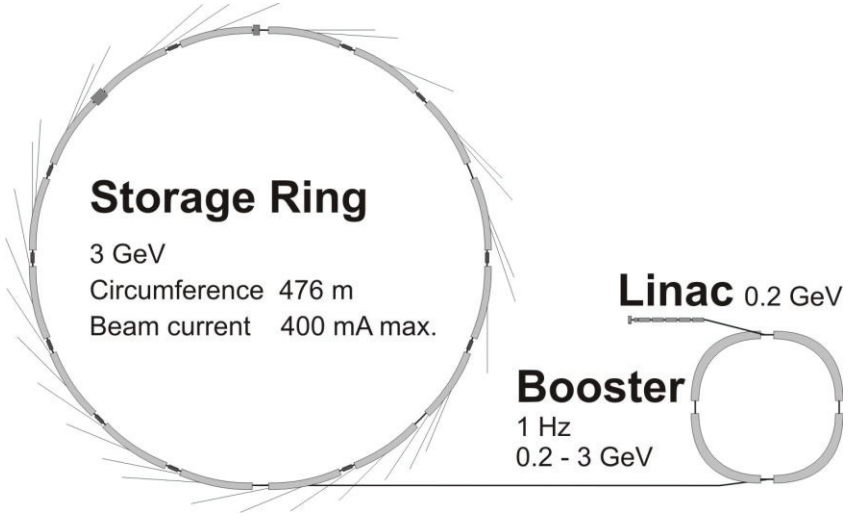
- Ensuring synchronization between different accelerator subsystems (e.g. accelerating structures, diagnostics, etc..)
- **Challanges**:
  - Strict RF jitter requirements
  - Strict long-term stability requirements
  - Big distances between different RF stations
  - Different frequencies to be generated
  - Environmental conditions fluctuations



Project background and motivation

- **BINP** has experience in development, production, study and maintenance of large accelerator facilities

- A new 4th generation synchrotron light source i.e. SKIF accelerator complex is being built in Novosibirsk



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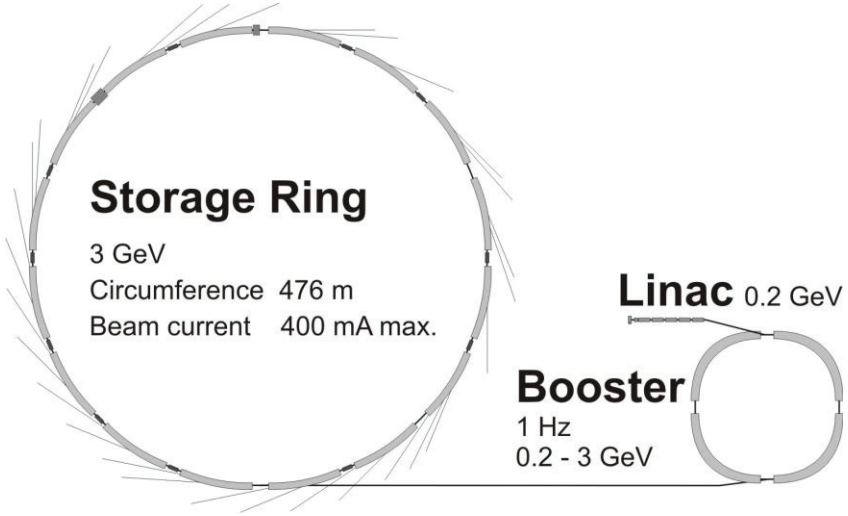


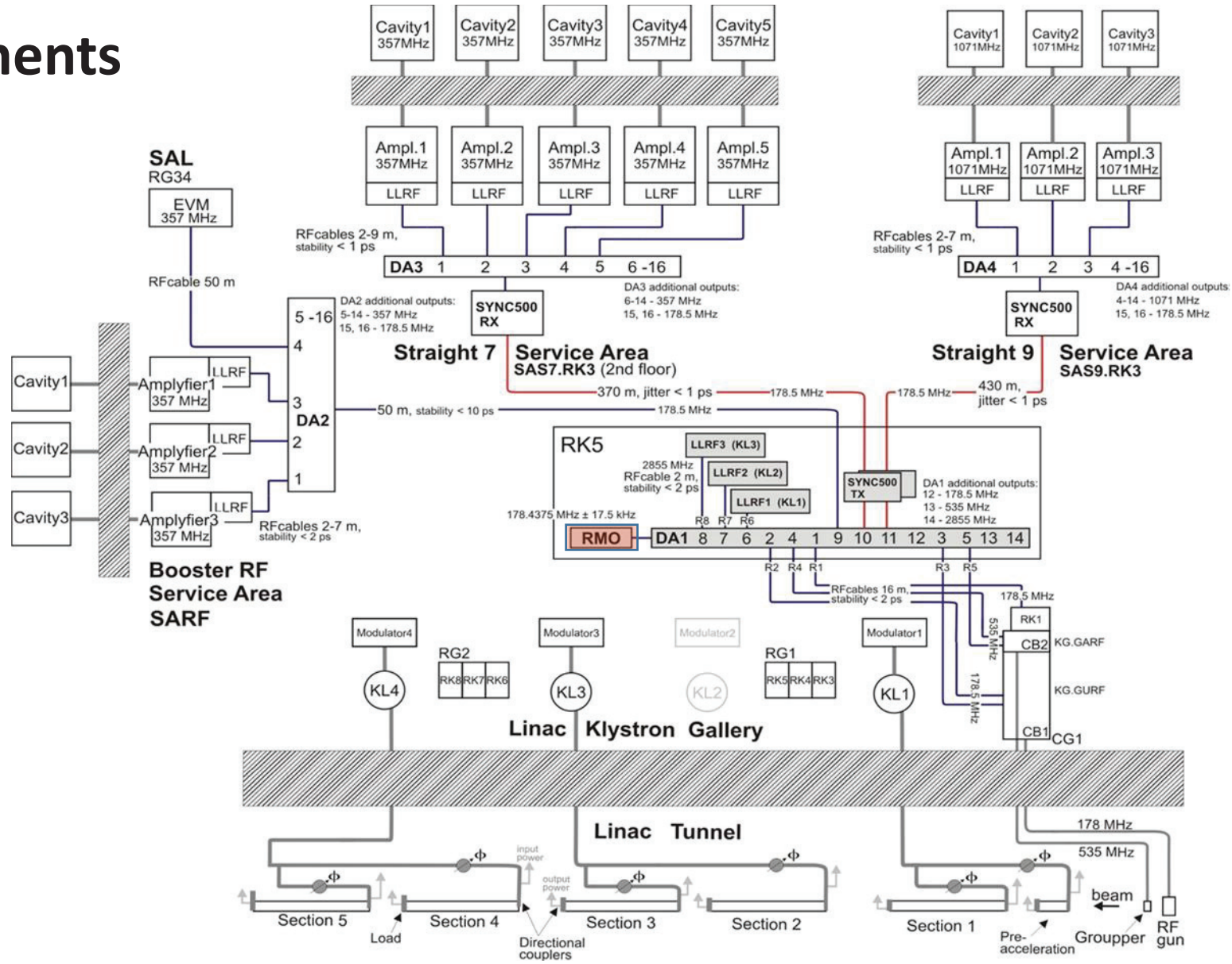
- **I-Tech** has experience in design, development and production of electronic devices for the accelerator machines:
  - BPM electronics and BLM systems
  - Digital LLRF systems
  - RF and Current Digitizers
  - Reference master oscillators
  - Distribution amplifiers for RF signals
  - RF reference transfer systems, etc.
- **Product example**: Libera SYNC is an optical reference transfer system developed for the SwissFEL, in collaboration with PSI

Goal: Design and develop a system for the RF generation and distribution that meets the SKIF project requirements

The SKIF project requirements

The main components of the system:

- **Reference Master Oscillator** (RMO) at 178.5 MHz
- **Distribution Amplifiers** (DA), supporting also generation of higher harmonics of the RF signal
- Low drift and jitter **optical RF signal transfer systems** (Libera SYNC)
- Low drift RF cables



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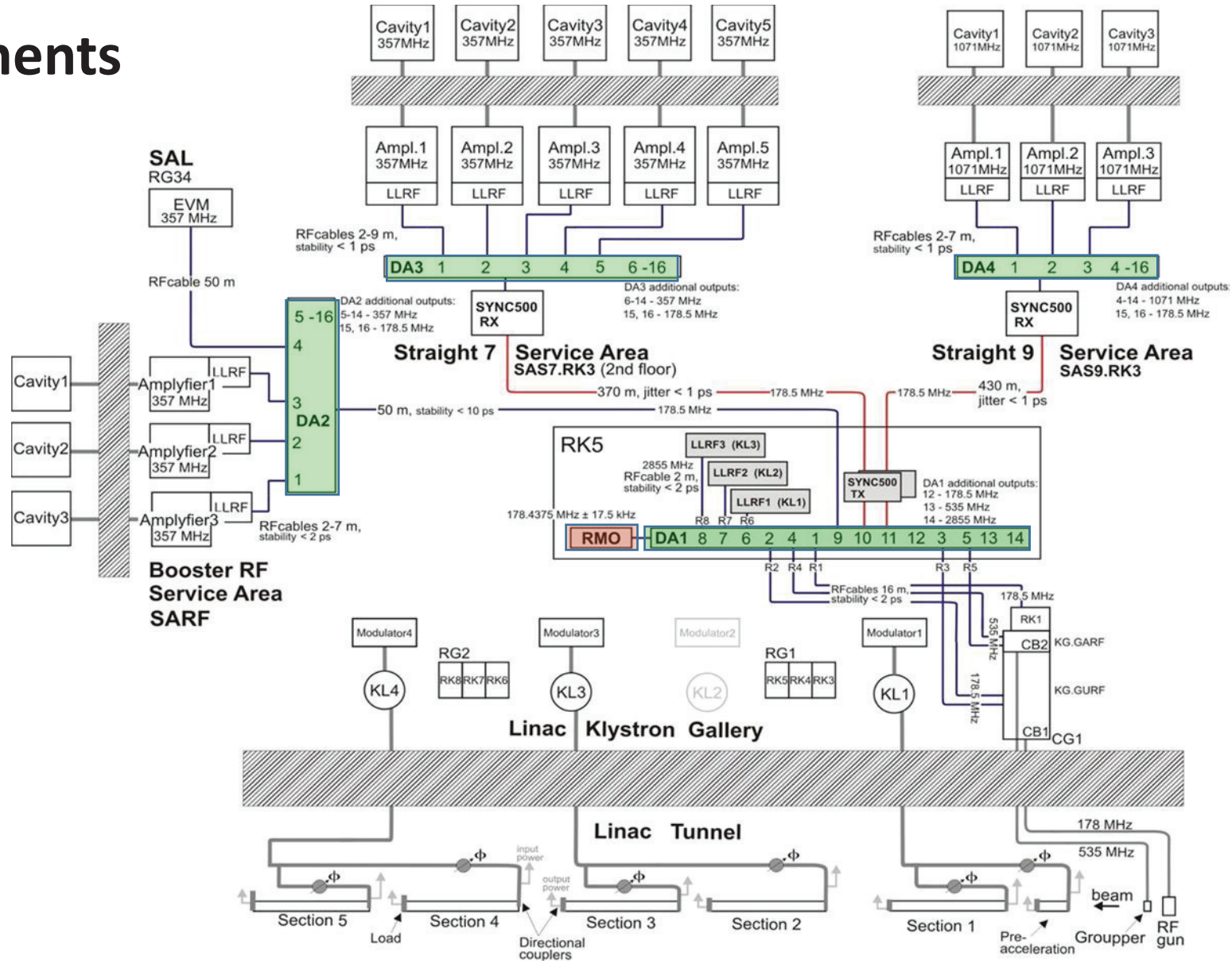

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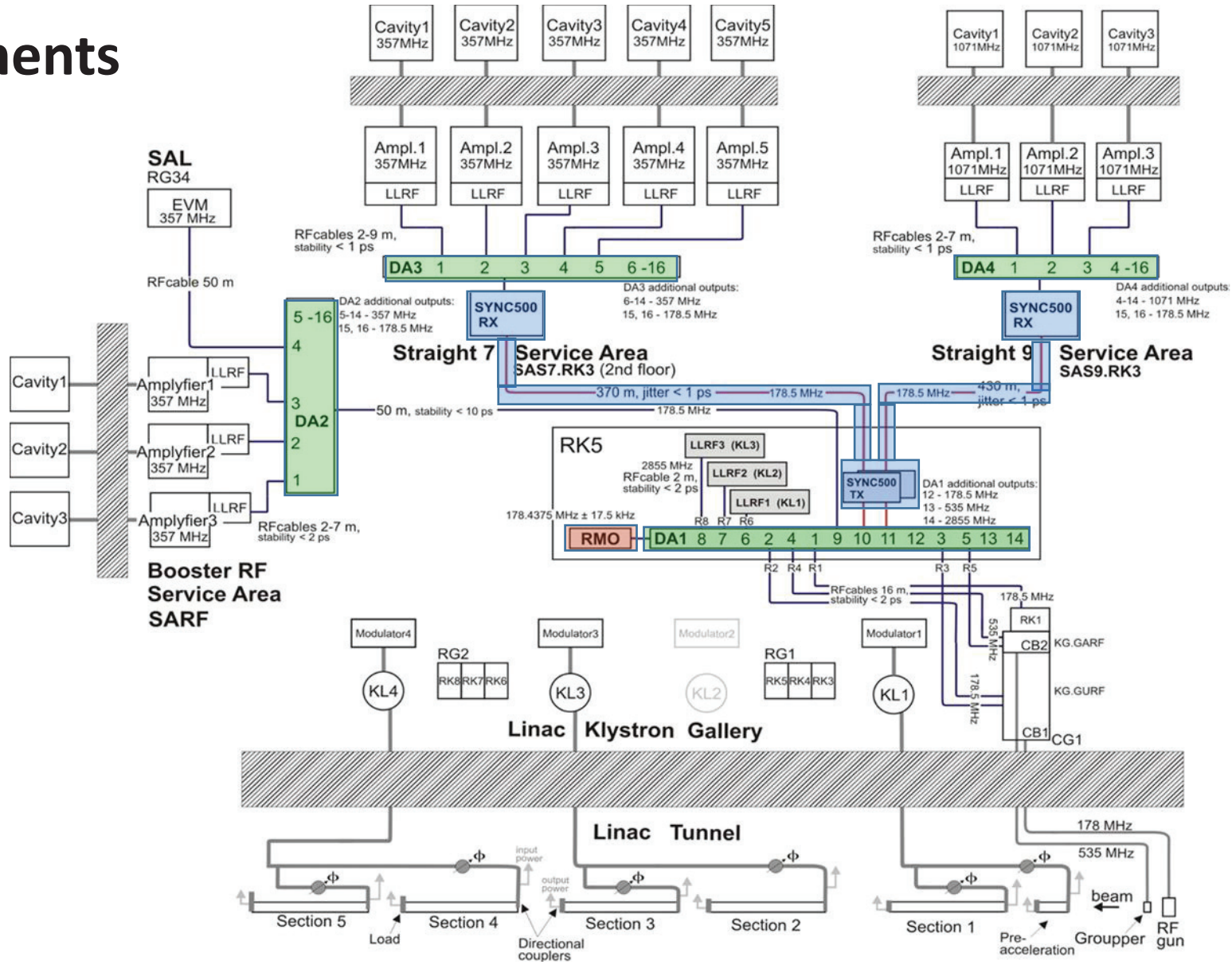

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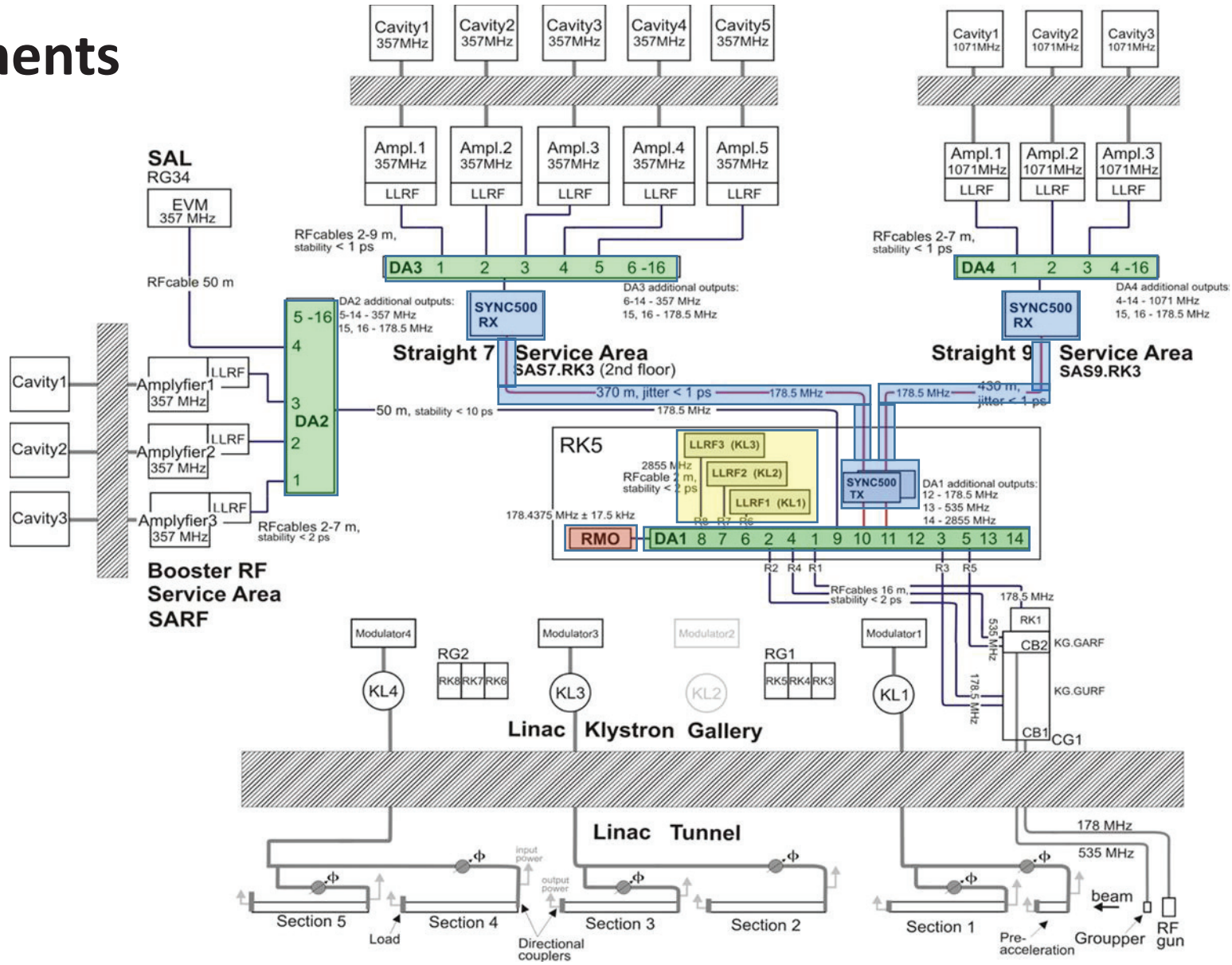
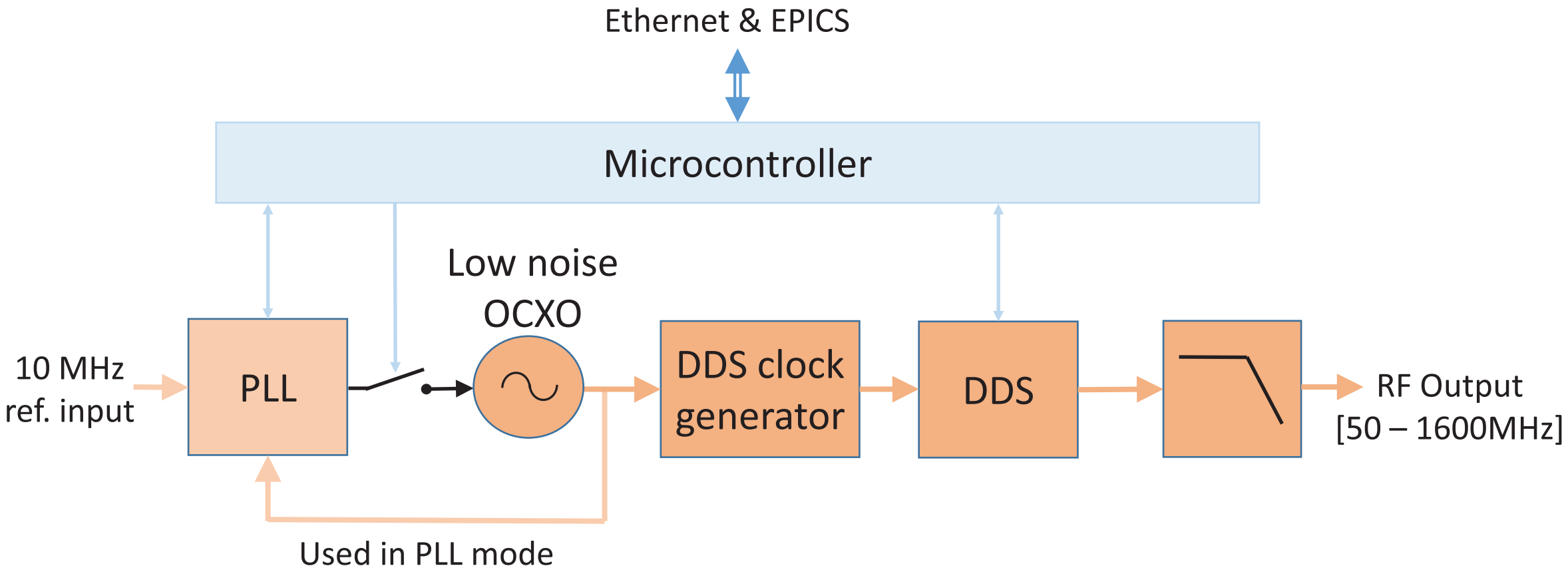


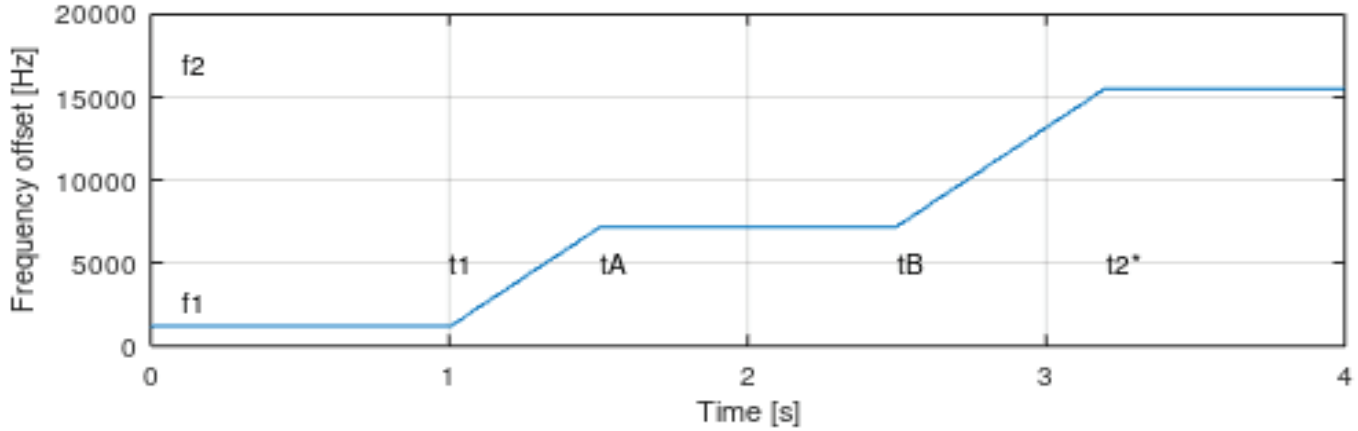
RMO performance parameters and features

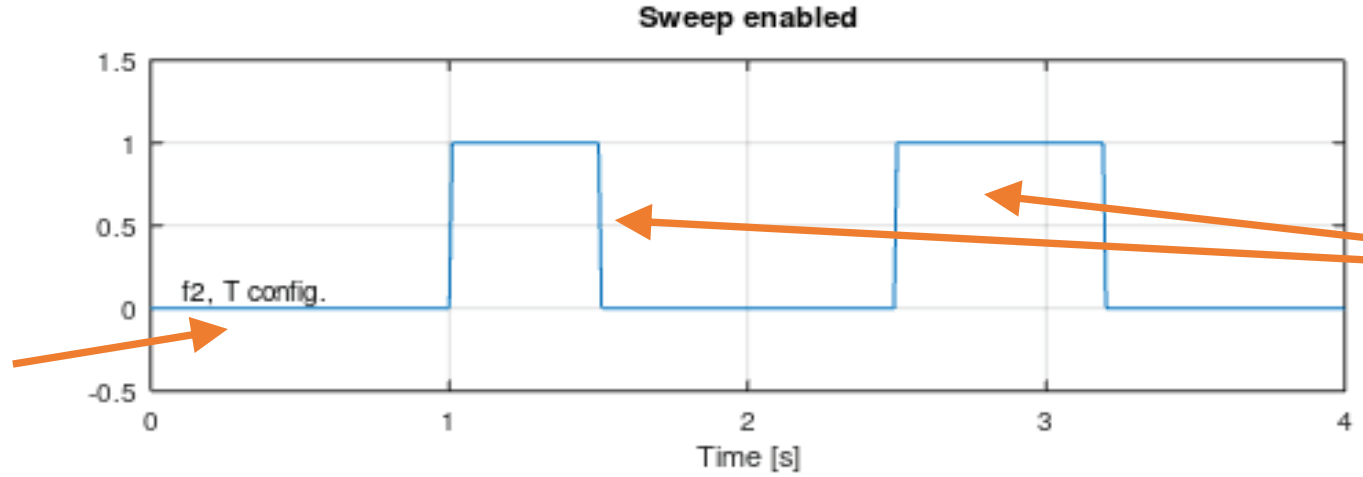
- RF output:
  - **178.5±1 MHz** will be used in the SKIF case
    from ~50 MHz to 1600 MHz (optionally up to 3200 MHz), remotely configurable
  - 15 dBm, 50 Ω
  - integrated phase noise (jitter) from 10 Hz to 10 MHz: **<90 fs RMS**
- Based on DDS concept (Digital Direct Synthesis)
- PLL (external reference locking) and free running mode
- Reference input: 10 MHz, 0-10 dBm, 50 Ω
- Frequency sweep functionality
- Ethernet (Telnet) interface, EPICS IOC available

RMO functional block scheme



RMO frequency sweep

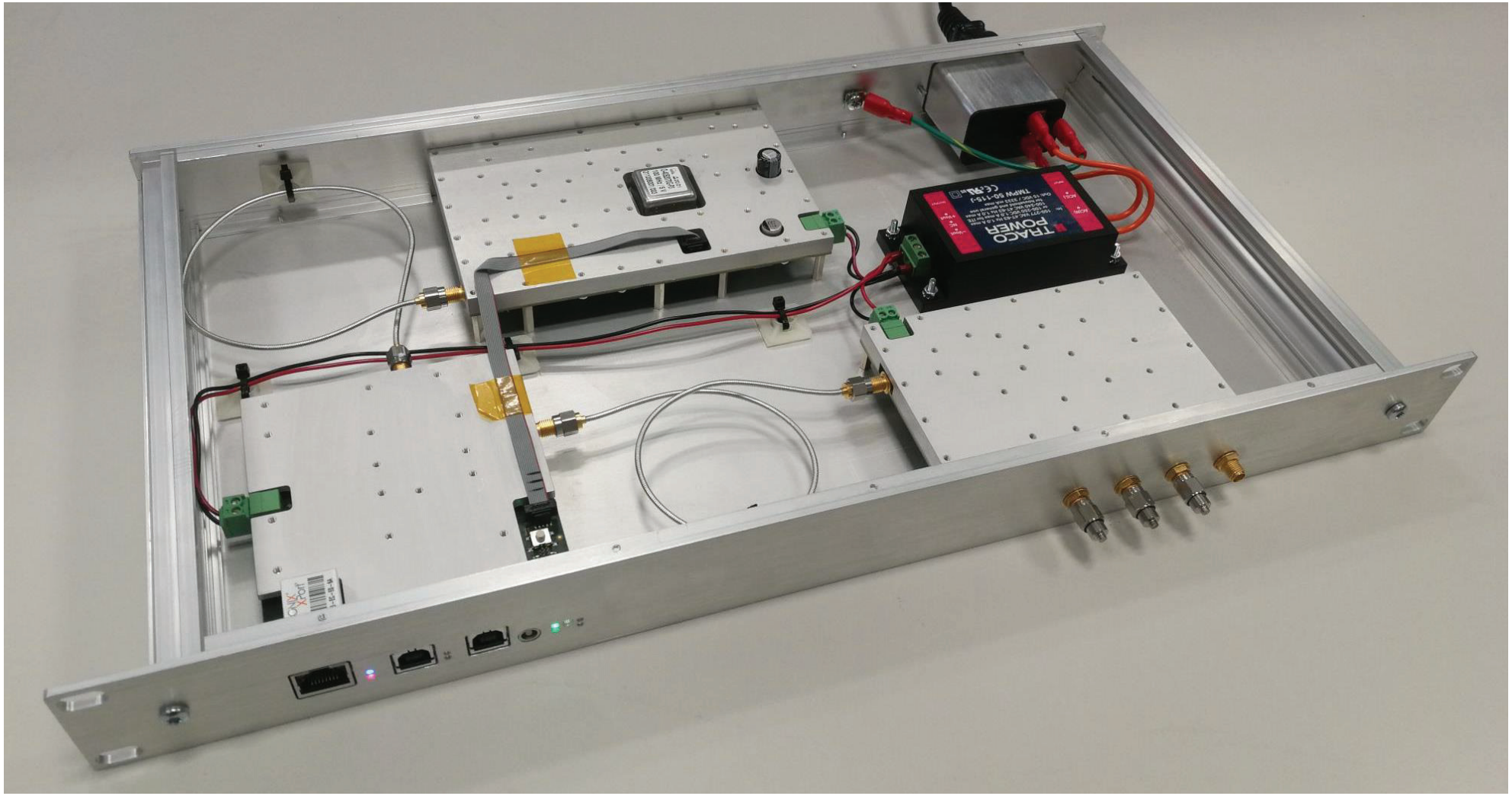




Desired frequency and sweep time

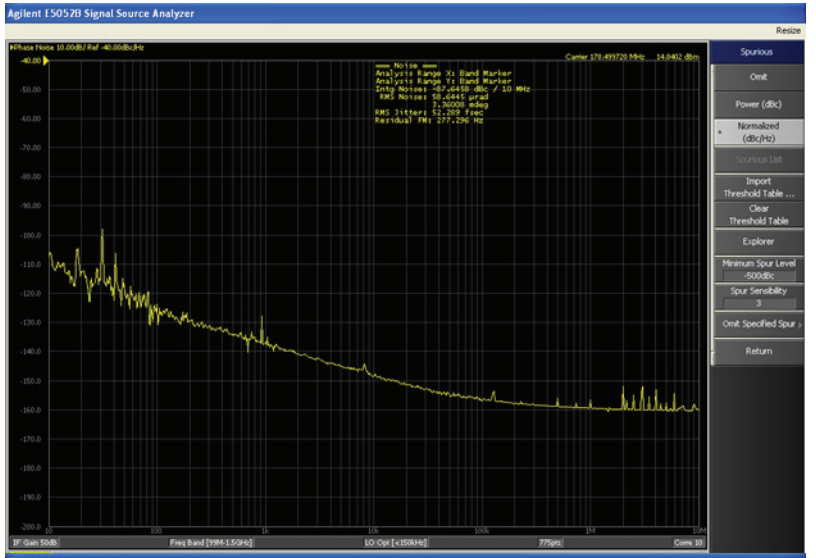
SW enabler for frequency sweep

RMO prototype under test



RMO prototype test results @178.5±1 MHz

Frequency [MHz]	Jitter with spurs [fs]	Jitter without spurs [fs]
177.5	73.99	51.85
177.7	96.92	48.26
177.9	86.89	60.72
178.1	62.39	48.17
178.3	62.54	50.96
178.5	52.29	47.15
178.7	51.28	48.55
178.9	53.16	49.31
179.1	53.43	49.56
179.3	55.43	48.77
179.5	50.11	48.21



Spectrum for 178.5 MHz signal

Spectrum for 177.7 MHz signal

Spurs coming from DDS

RMO prototype test results @100-3200 MHz

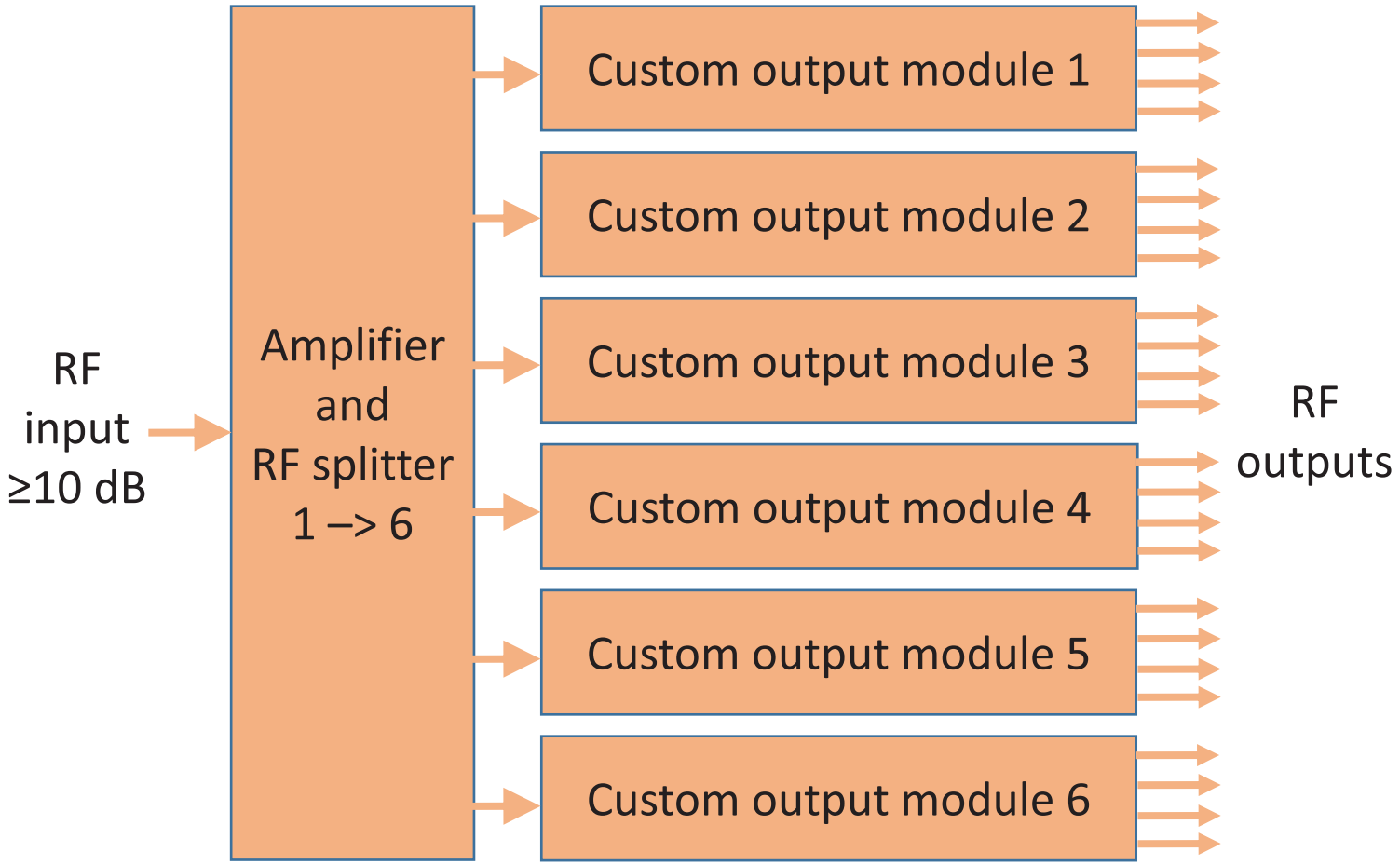
Frequency [MHz]	Jitter with spurs [fs]	Jitter without spurs [fs]
100	71	63
200	49	44
400	45	39
500	46	40
600	45	39
800	42	36
1000	45	40
1200	45	39
1400	45	39
1600	41	35

Frequency [MHz]	Jitter with spurs [fs]
1800	41
2000	39
2200	41
2400	41
2600	43
2800	42
3000	45
3200	39

Distribution Amplifier parameters and features

- RF input:
  - 178.5 MHz
  - 15 dBm or 10 dBm
  - 50 Ω
- RF outputs:
  - Modular arhitecture supports up to 24 RF outputs at different harmonics of the input frequency:
    x1 => 178.5 MHz, **x2** => 357 MHz, **x3** => 535 MHz, **x6** => 1071 MHz, **x16** => 2856 MHz
    Other multiplication and/or division factors are also possible.
  - 15-18 dBm
  - 50 Ω
- Integrated added jitted from 10 Hz to 10 MHz: <5 fs RMS
- Temperature stabilized device
- Form factor: 2U, 19“

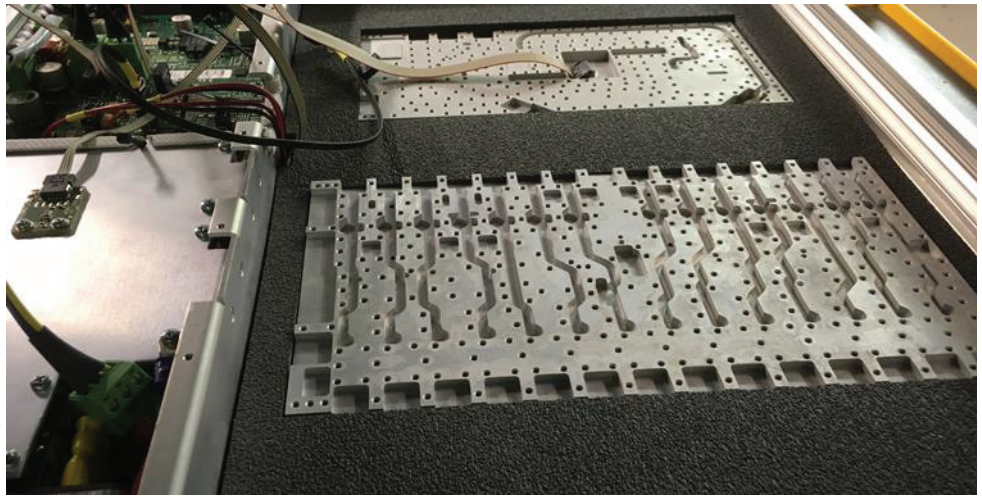
Distribution Amplifier modular arhitecture



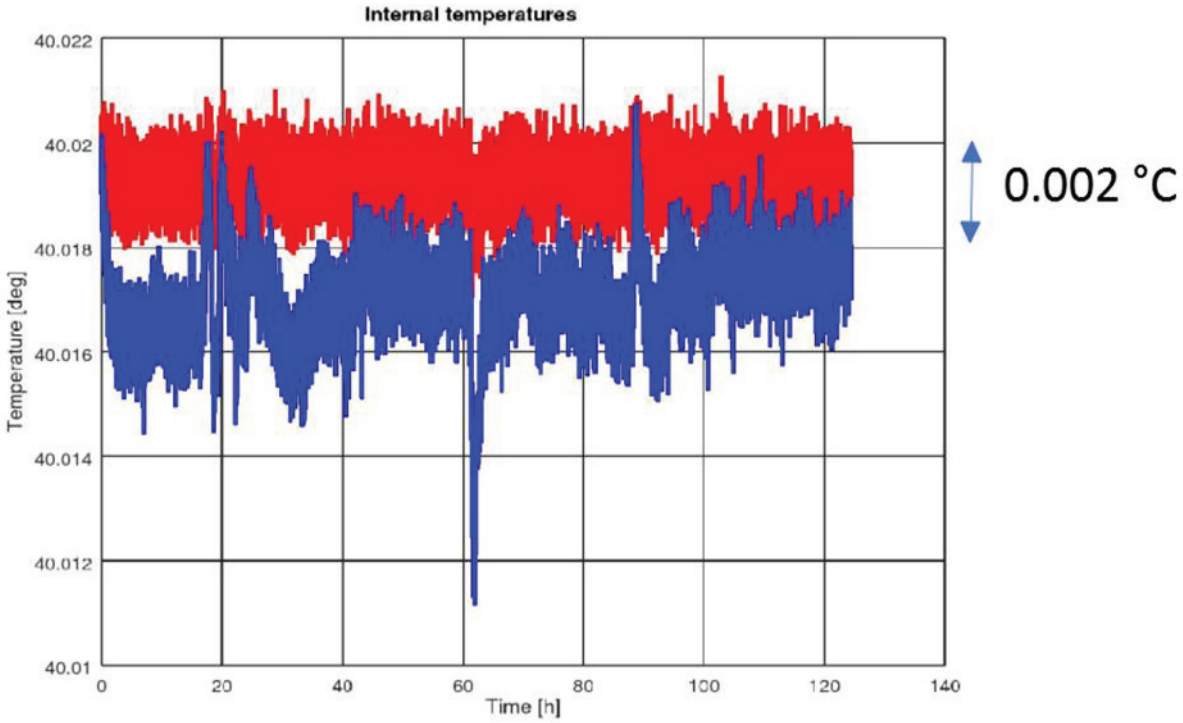
Custom output modules:

- Amplifiers
- Multipliers for gen. of higher harmonics
- Dividers for gen. of sub-harmonics

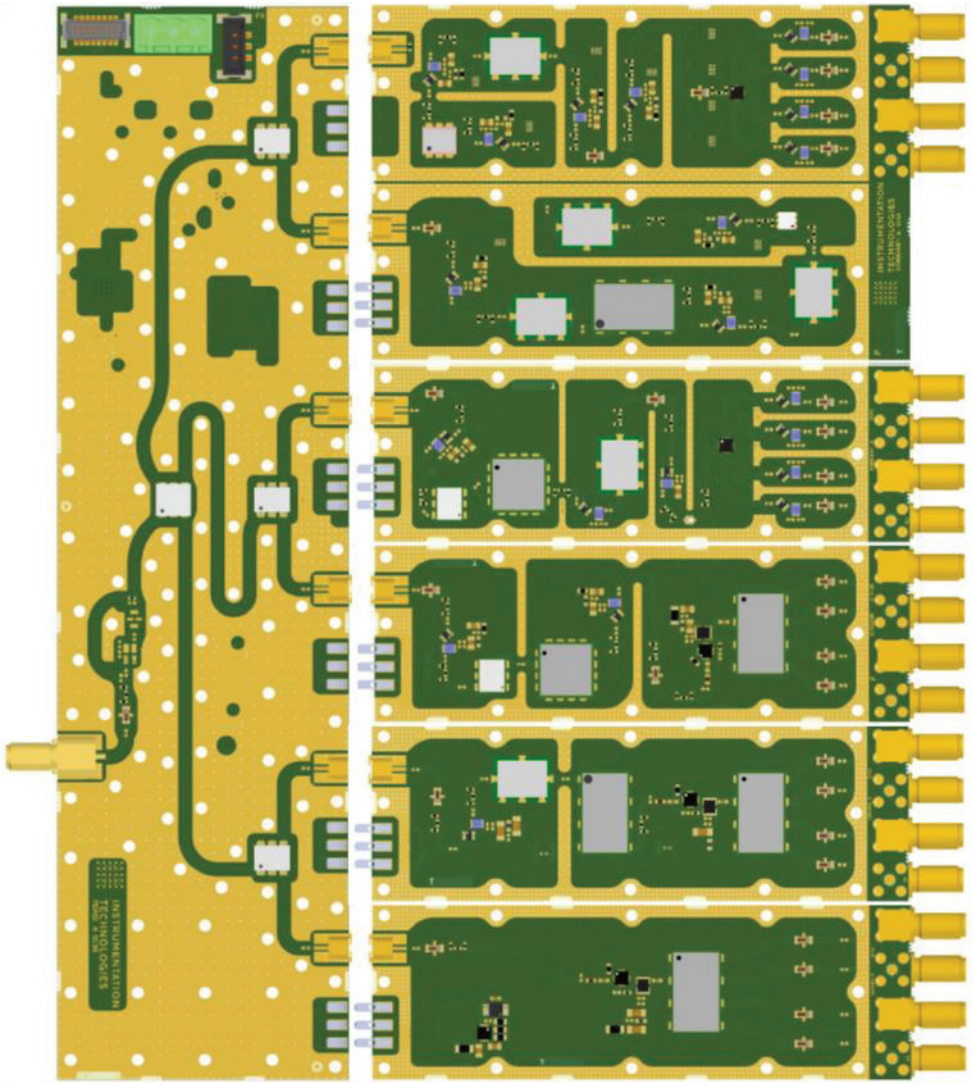
Distribution Amplifier temperature stabilization



- Temperature sensors & controllers
- TEC elements
- Shields & heat sinks
- Insulation



Distribution Amplifier PCBs for SKIF



RF input
178.5 MHz

x16 = 2856 MHz
18 dBm

x6 => 1071 MHz
15 dBm

x3 => 535 MHz
15 dBm

x2 => 357 MHz
15 dBm

x1 => 178.5 MHz
15 dBm

RF
outputs

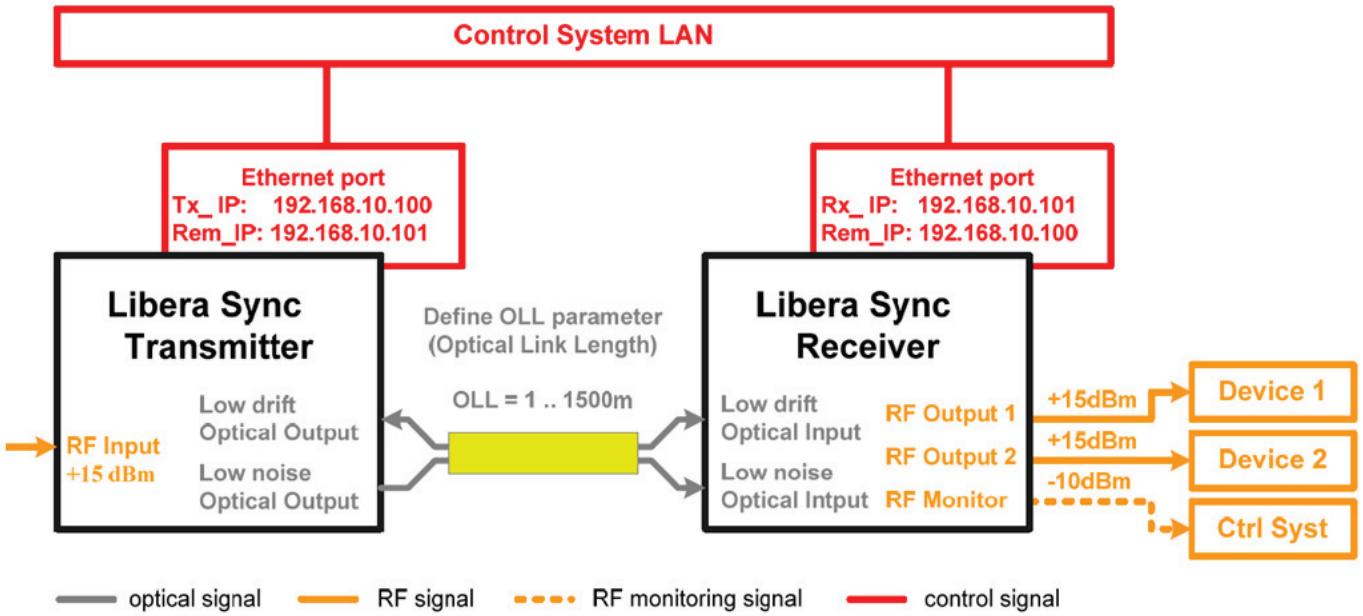
RF signal transfer system performance parameters and features

RF input	178.5±0.02 MHz, 15±1 dBm, 50 Ω
RF outputs	15±1 dBm, monitor output -10±3 dBm, 50 Ω
Integrated added jitted from 10 Hz to 10 MHz	<300 fs RMS
Long-term phase stability in 24 hours	<700 fs peak-to-peak
Phase drift compensation capability	500 ps
Maximal optical link length	1500 m
Calibration and tuning mode	Automatic
Form factor of transmitter and receiver	2U, 19“

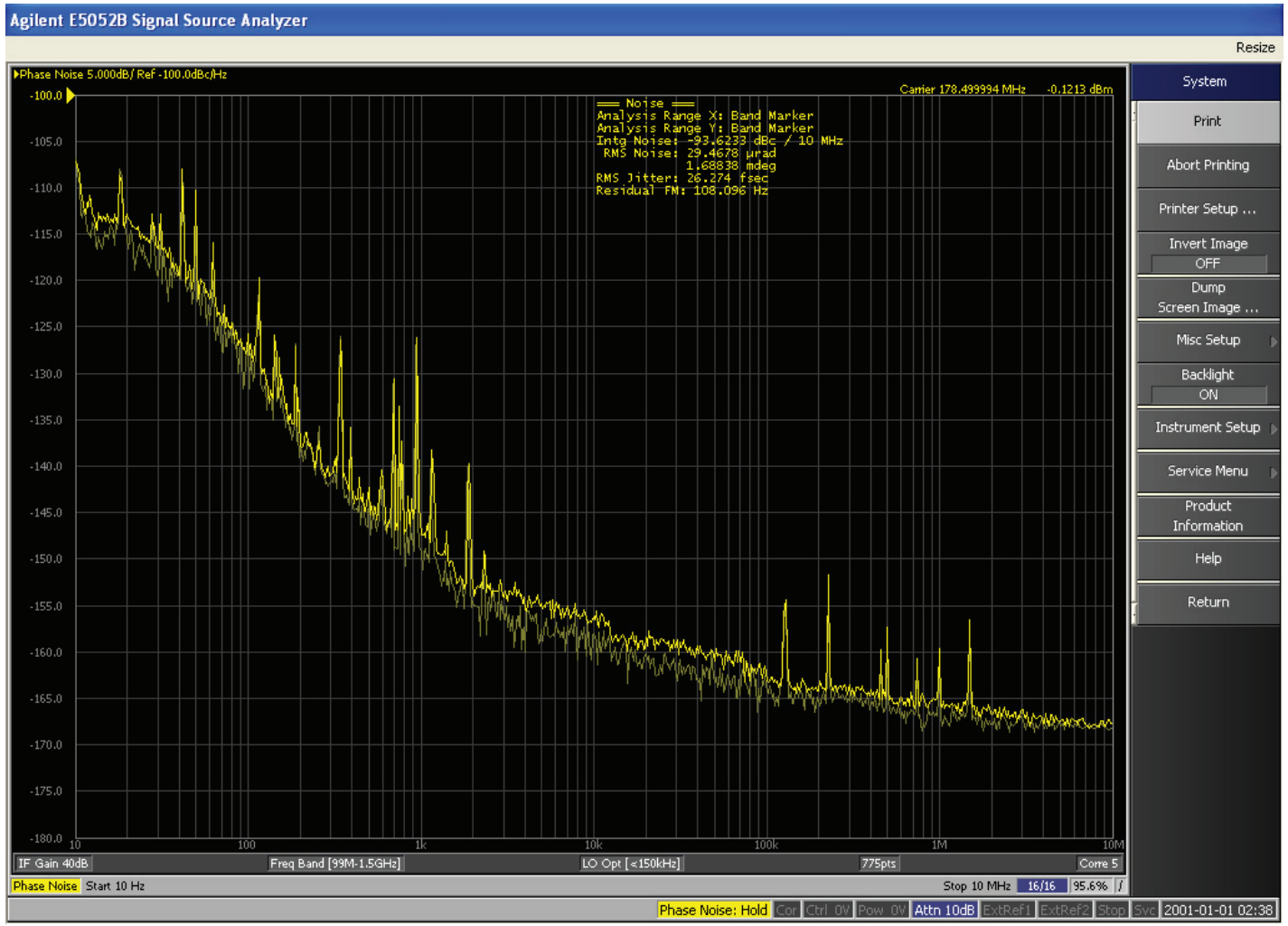
Optical RF signal transfer system Libera Sync

Existing Libera Sync at 3 GHz is being adapted to the RF of 178.5 MHz

Libera Sync block scheme

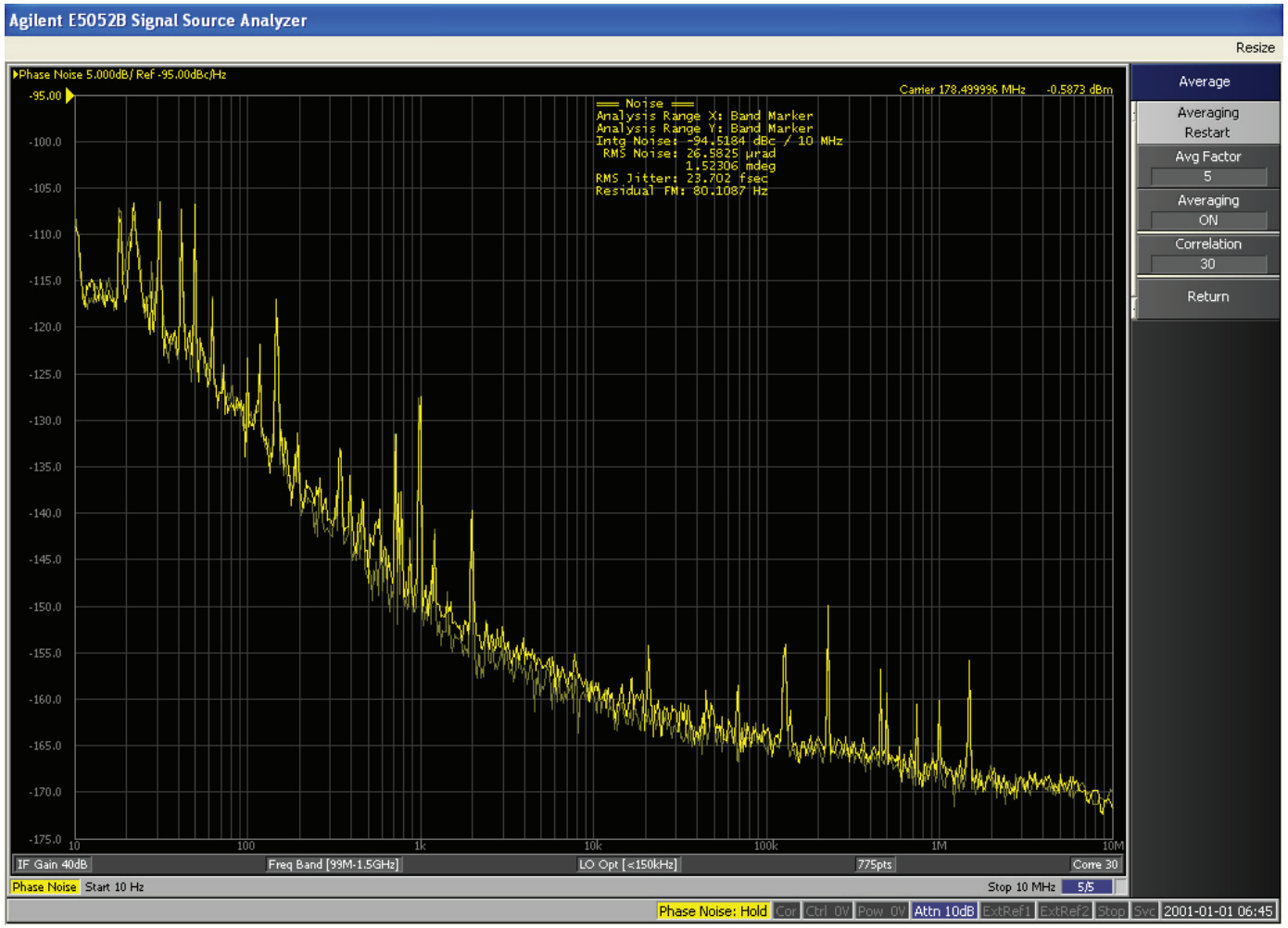


Adaptation to 178.5 MHz – Testing of phase shifters



Generator jitter: 23.39 fs RMS
Gen. & DUT jitter: 26.27 fs RMS
DUT added jitter: **<u>11.95 fs RMS</u>**

Adaptation to 178.5 MHz – Testing of variable attenuators

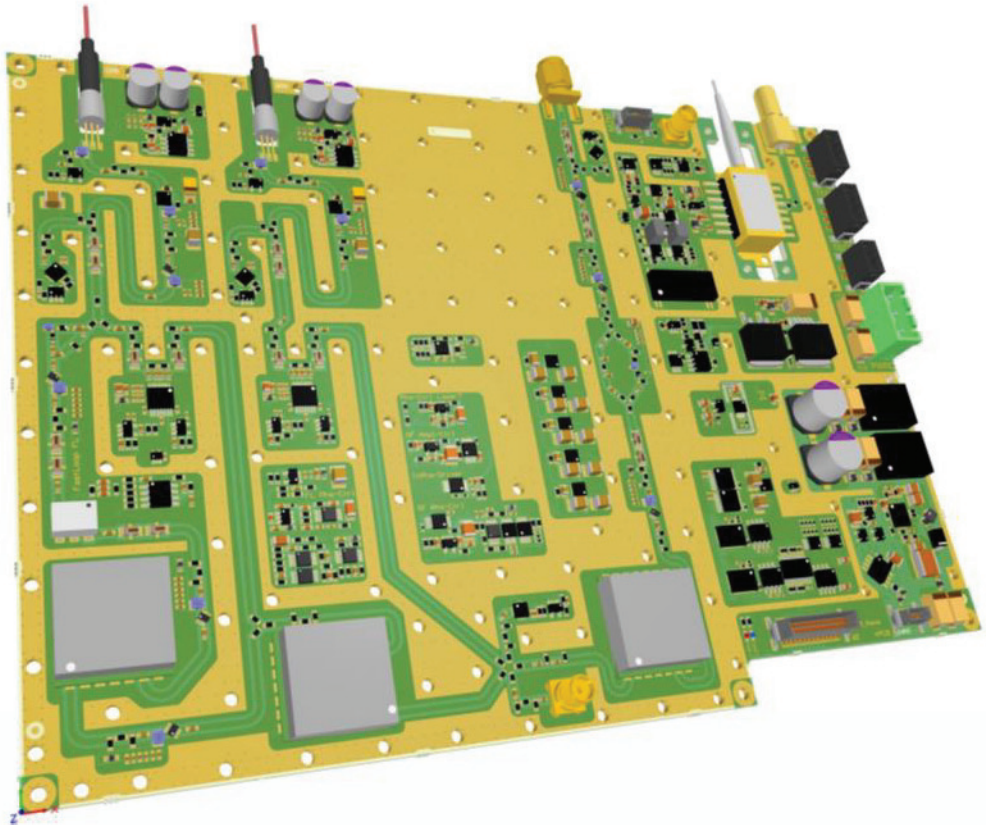


Generator jitter: 22.76 fs RMS
Gen. & DUT jitter: 23.7 fs RMS
DUT addded jitter: <u>6.62 fs RMS</u>

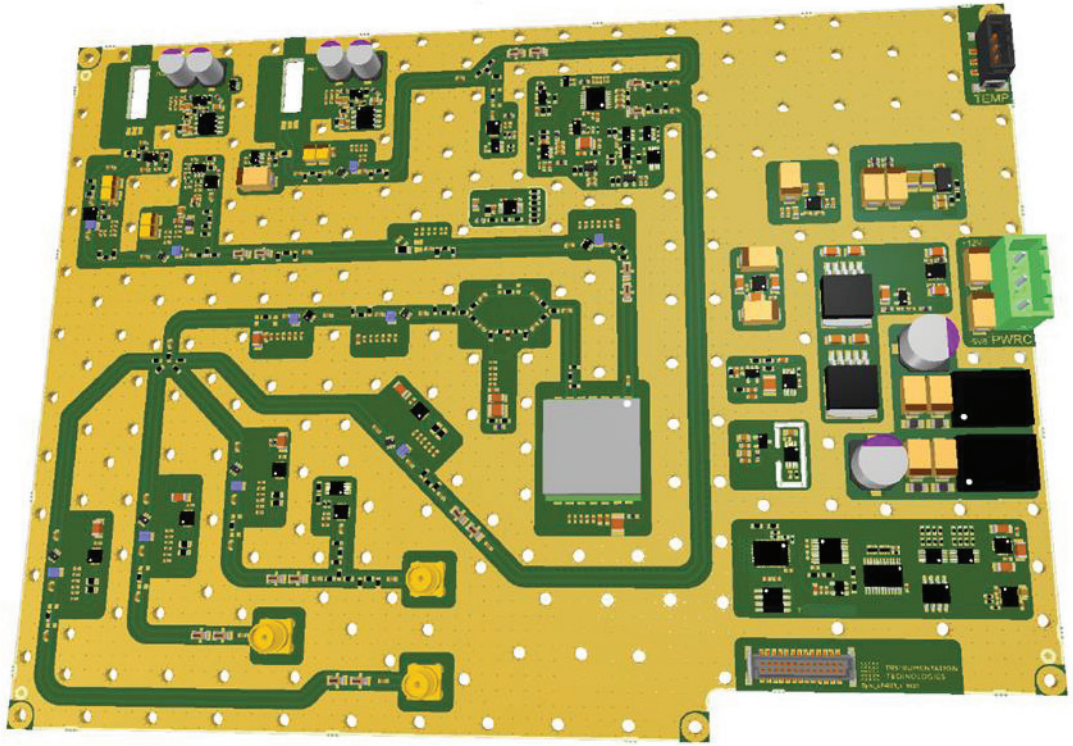
The main two components that could deteriorate the jitter performance were tested OK!

The PCBs have been adapted and are in production

Transmitter



Receiver



Conclusions

- The SKIF RF distribution system consists of RMO, several DA and Libera SYNC, defined over several online meetings in the second part of year 2020.
- The development started in April 2021, with first deliveries in January 2022
- The Libera RMO, DA and Libera SYNC are being developed in parallel
- We have regular project meetings with BINP to communicate the progress, preliminary results and taking decisions
- Overall, we are in line with the project timeline and happy on the collaborative approach from both teams!

Thank you for
your attention!