INSTRUMENTATION
TECHNOLOGIES

LIBERA

Development of a X-band LLRF prototype for the EuPRAXIA@SPARC_LAB LINAC

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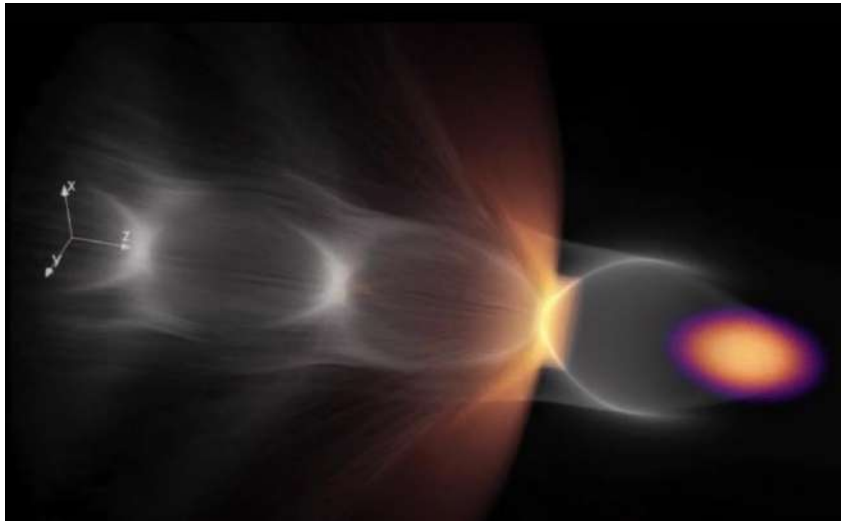
Outline:

- EuPRAXIA project
- Introduction to Low Level Radio Frequency
- LIBERA LLRF
- X-Band and it’s challenges
- Preliminary Requirements of EuPRAXIA X-Band LLRF
- Overview of Research Activities
- Preliminary Results
- Outlook & Conclusions

EuPRAXIA project

- EuPRAXIA → European Plasma Research Accelerator with eXcellence In Applications.
- Innovative electron accelerator using laser- and electron-beam–driven plasma wakefield acceleration.
- High Performance, Compact size, Cost Efficient
- Applications → Medical therapy, High-Energy Physics Research, Industrial applications



Credit: Alberto Martinez de la Ossa / DESY

EuPRAXIA Doctoral Network

- MSCA Doctoral Network with a budget of 3.2M €
- 12 high-level Fellowships (10 Fellows will be funded by the EU, another two by the UKRI guarantee funds)
- Interdisciplinary and cross-sector plasma accelerator research and training program carried out between universities, research centres and industry
- Recognized importance of plasma accelerator R&D at European level!

EuPRAXIA Doctoral Network

EuPRAXIA Doctoral Network

UK Research and Innovation

cividec Instrumentation

Consiglio Nazionale delle Ricerche

INFN Istituto Nazionale di Fisica Nucleare

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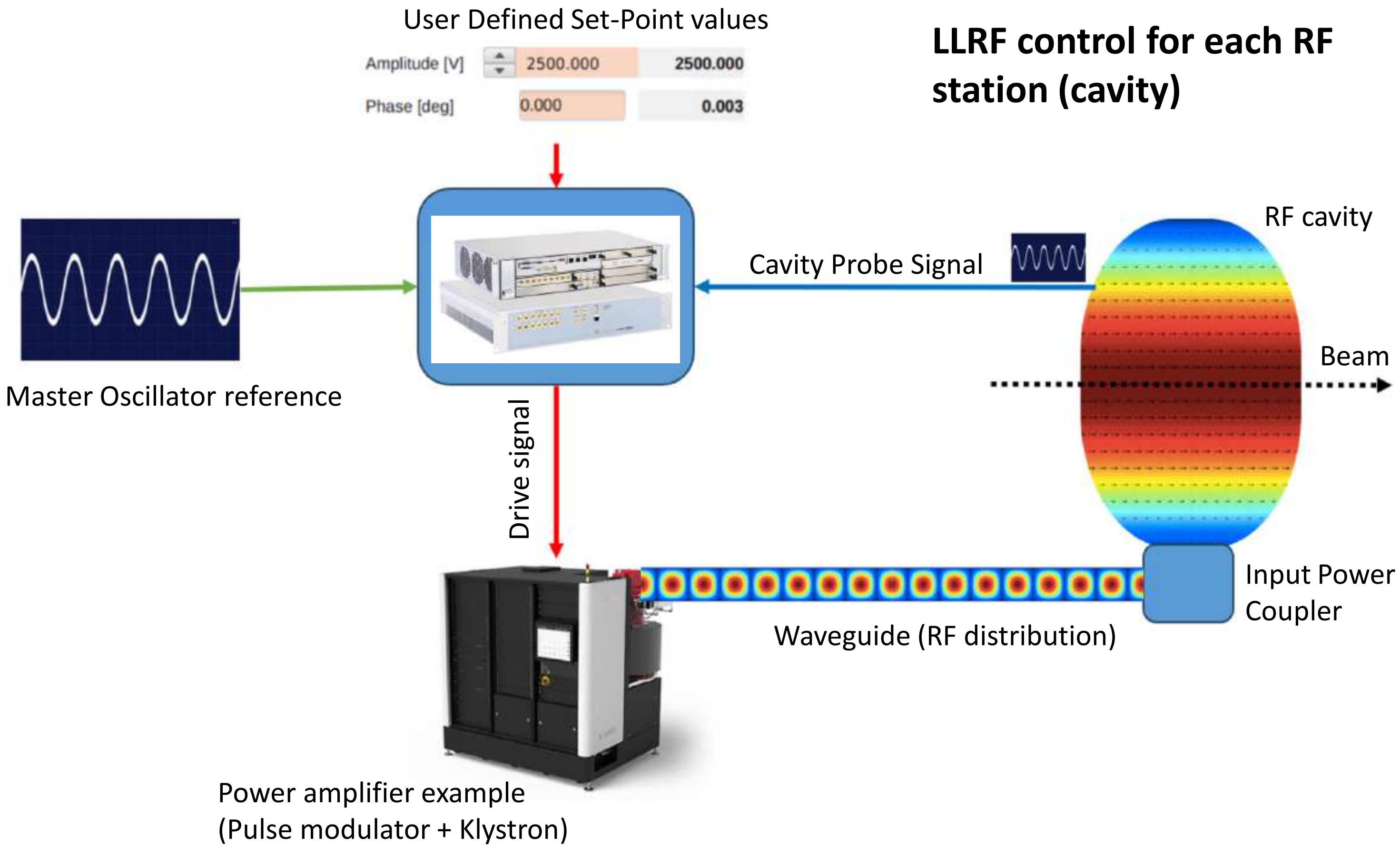
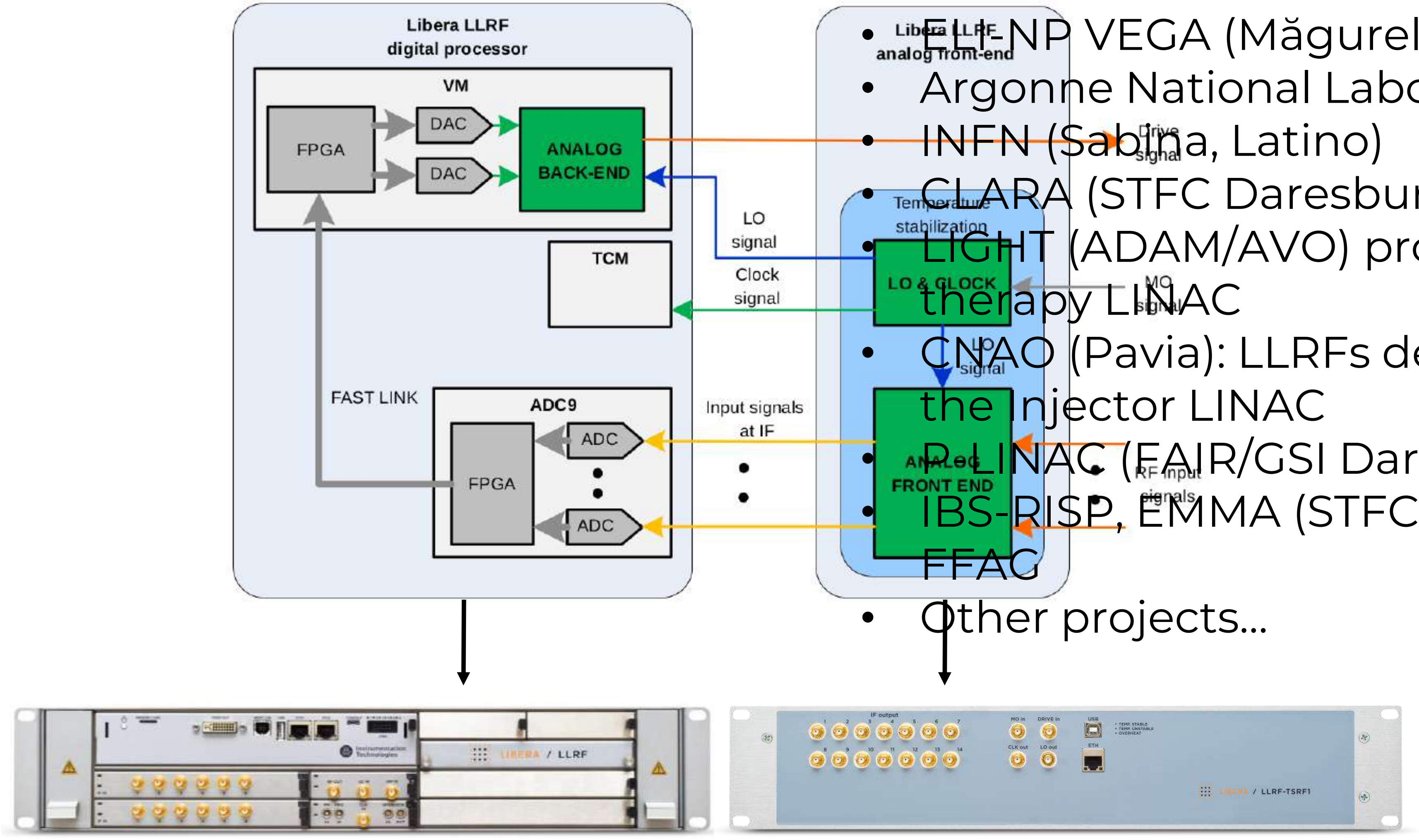
Introduction to Low Level Radio Frequency



- Subsystem of Radio Frequency (RF) system.
- Maintain the stability and control of frequency, phase and amplitude.
- Deviation between the measured signal and the reference activates feedback control system.

LIBERA-Low Level Radio Frequency



Some references:

- ELI-NP VEGA (Măgurele)
- Argonne National Laboratory (APS)
- INFN (Sabina, Latino)
- CLARA (STFC Daresbury UK)
- LIGHT (ADAM/AVO) proton cancer therapy LINAC
- CNAO (Pavia): LLRFs delivered for the Injector LINAC
- P-LINAC (FAIR/GSI Darmstadt)
- IBS-RISP, EMMA (STFC Daresbury) FFAG
- Other projects...

X-Band Low Level Radio Frequency

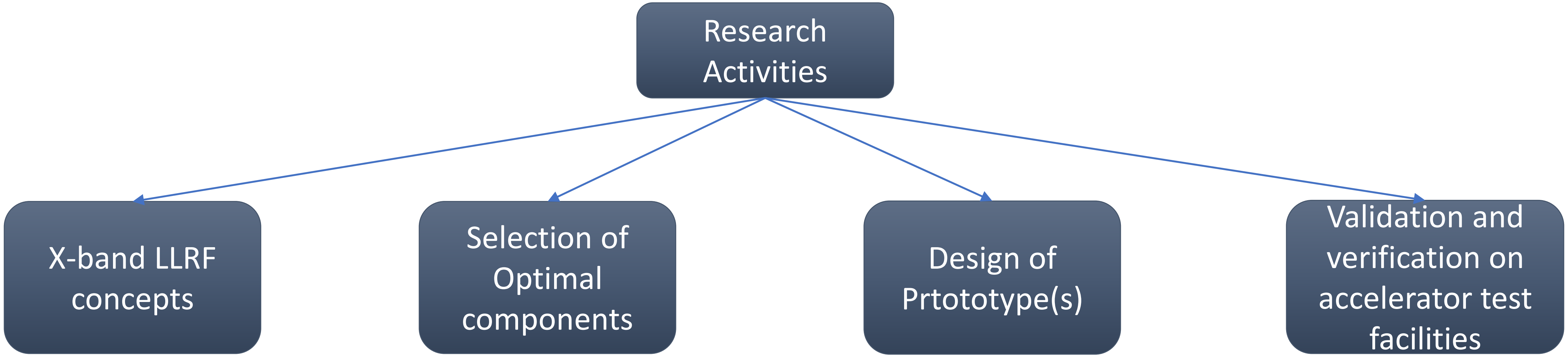
- Development of accelerator technology at higher frequencies up to X-Band allows high accelerating gradients [MV/m] and shorter accelerating structures (compact machines).
- Challenge of controlling RF parameters (amplitude and phase) at high frequencies and for very short pulses (100ns).
- LLRF system stability influenced by temperature drifts at higher RF frequencies.
- There is no commercial LLRF system working in X-band that meets the requirements of the EuPRAXIA@SPARC_LAB LINAC.

Preliminary Requirements of EuPRAXIA X-Band LLRF

Parameter	Desired value
Mode of operation	Pulsed
Carrier frequency	11.994 GHz
Back-end BW	> 80 MHz
Back-end output level	> 10 dBm
Front-end BW	> 25 MHz
Front-end max. input level	20 dBm
Sampling rate	≥ 250 MS/s
Time window	≥ 3 us
RF pulse max. repetition rate	≥ 400 Hz
Minimum pulse-to-pulse detectable amplitude jitter (front end)	< 0.05% rms
Minimum pulse-to-pulse detectable phase jitter (front end)	< 0.015 deg rms (@ 11.994 GHz)
Vector Modulator pulse-to-pulse added amplitude jitter	< 0.05% rms
Vector Modulator pulse-to-pulse added phase jitter	< 0.015 deg rms (@ 11.994 GHz)
n. RF input ch. for LLRF prototype	≥ 2
n. RF output ch.	1
Pulse shaping (amplitude & phase) of vector modulator output	Arbitrary (from spreadsheet)

Overview of Research Activities

- Development of a prototype for an X-band LLRF system, tailored to the EuPRAXIA@SPARC_LAB LINAC requirements.

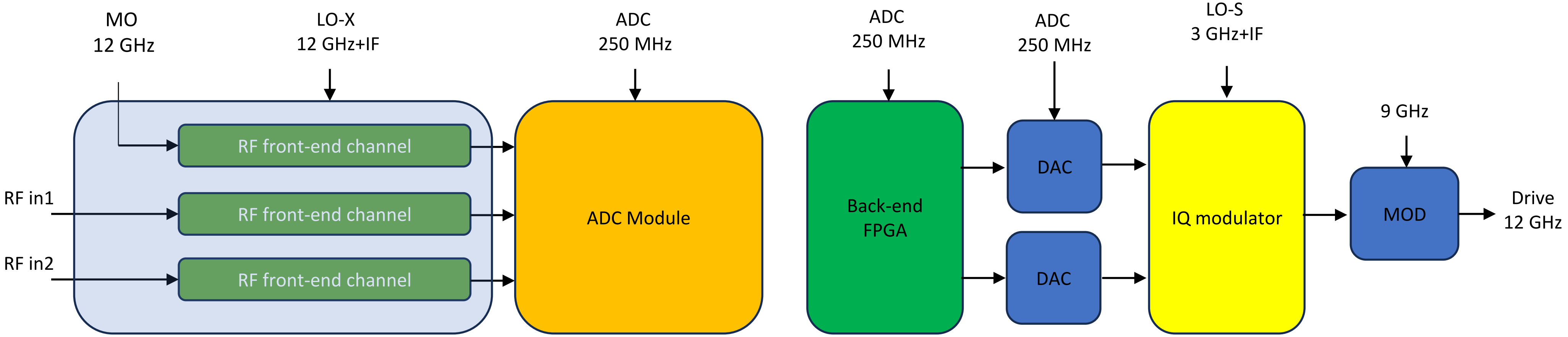


- Once confirmed on a testbench, the prototype will be industrialized into a commercial instrument.

Conceptual Block Diagram

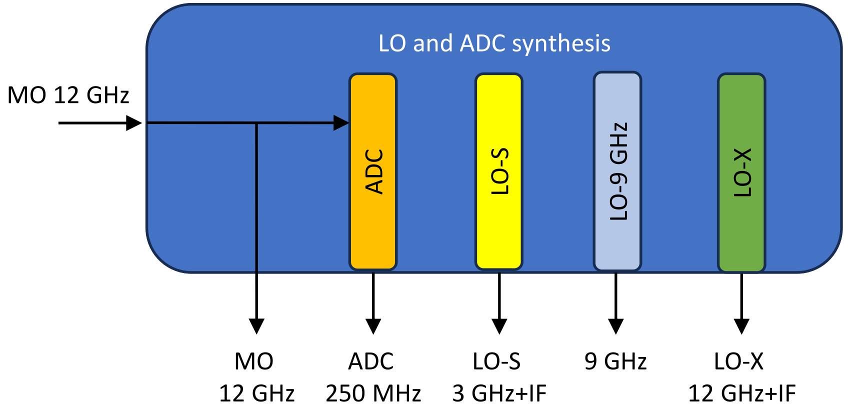
- Designed approach of the X-Band LLRF prototype.

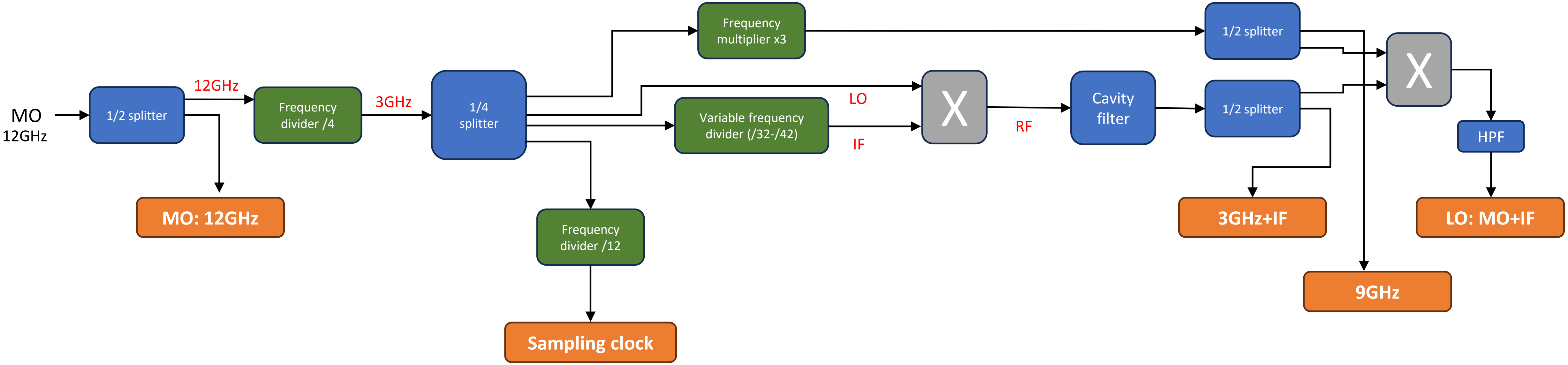
- Single-stage Down conversion
- Double-stage Up conversion



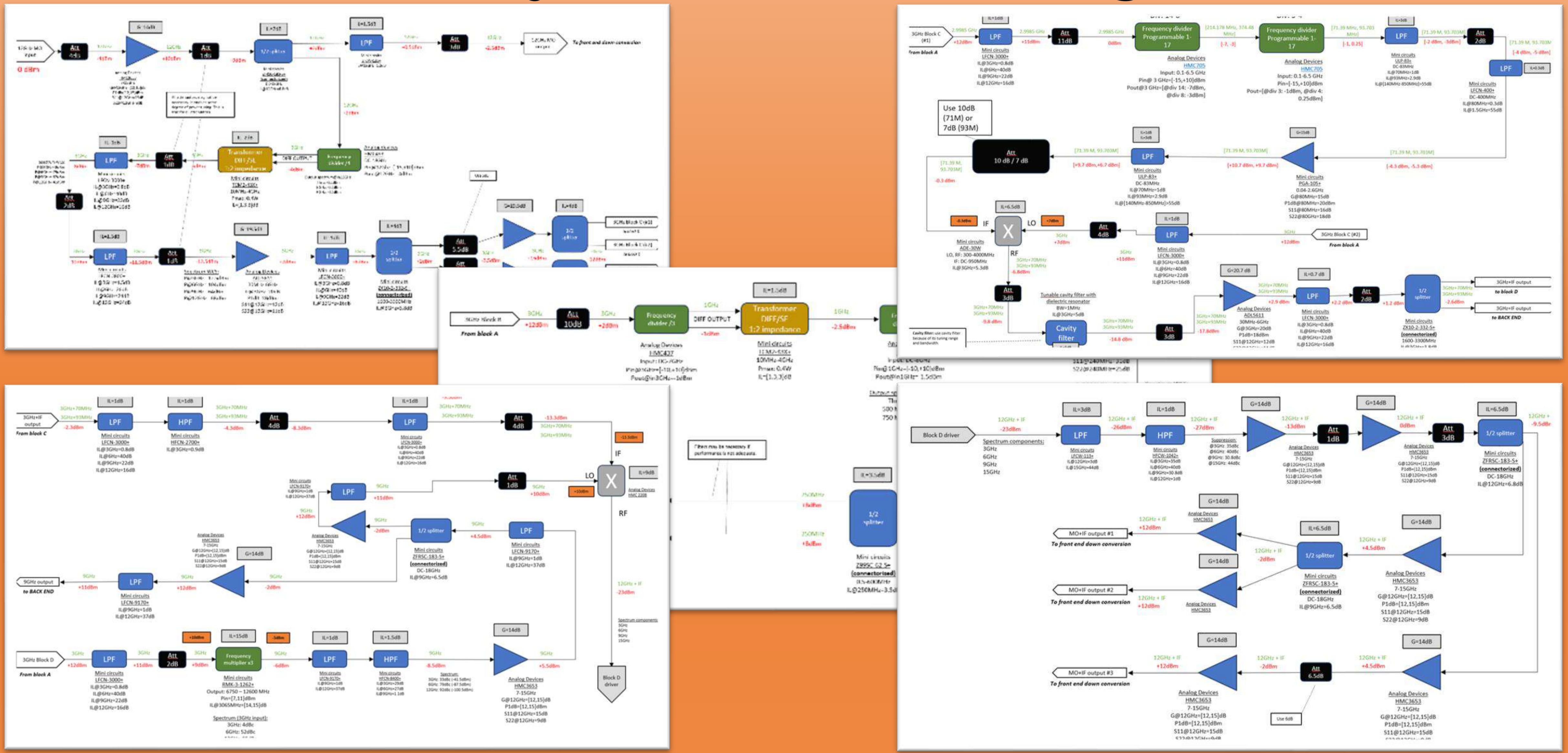
LO and ADC Synthesis Block Diagram

- Architecture of LO and ADC synthesis block.





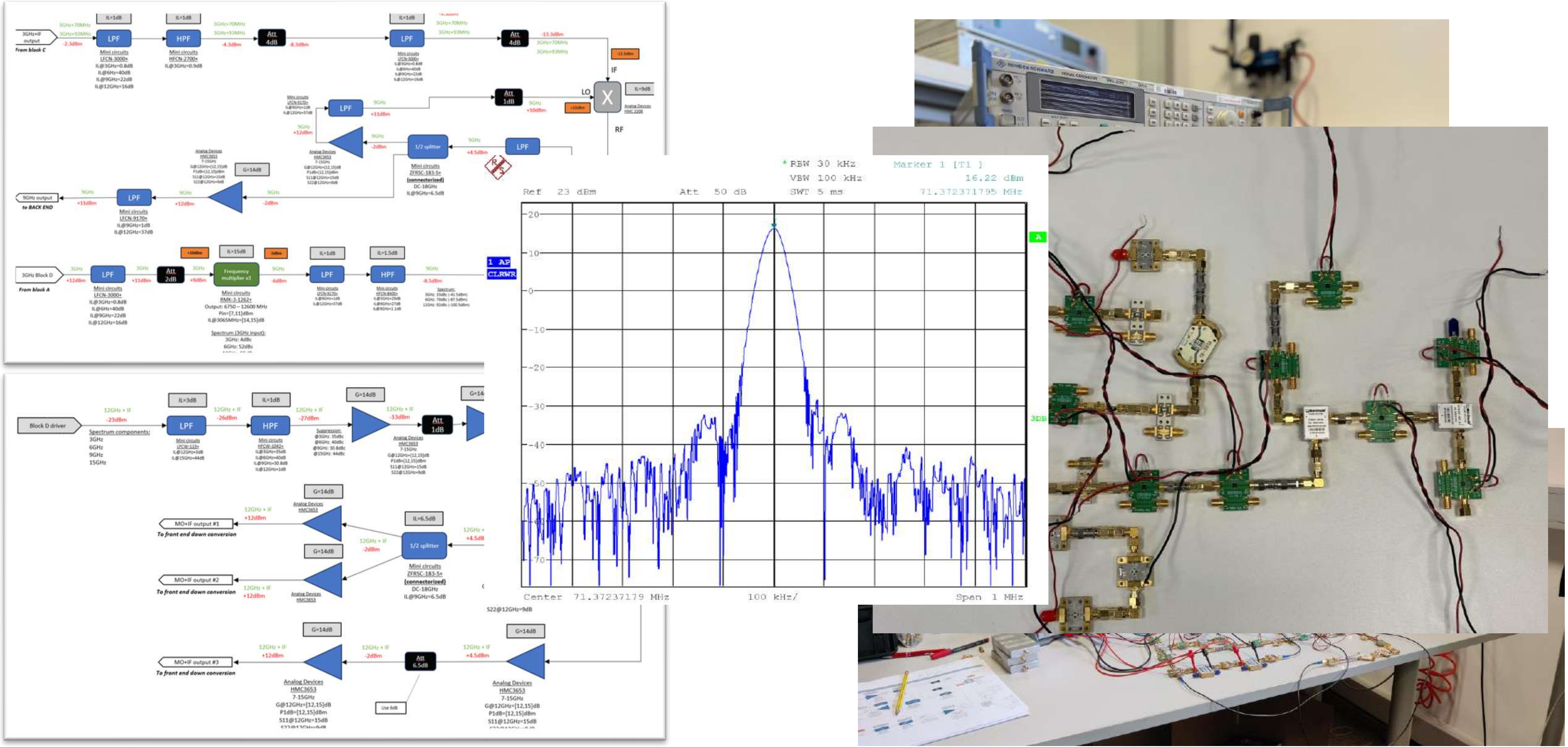
LO and ADC Synthesis Block Diagram



Components Testing

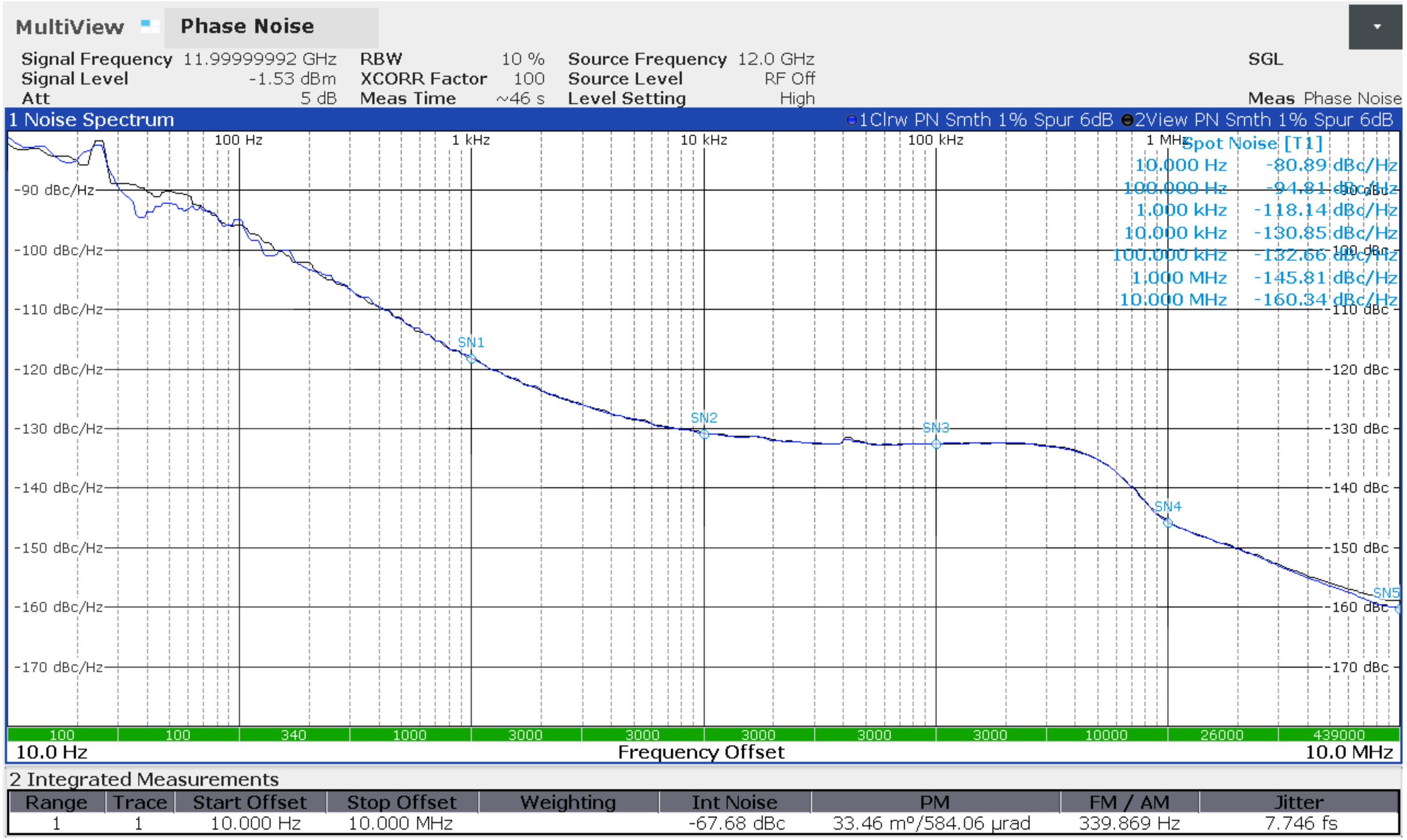
S.No	Component	Description	Gain / Loss	Output power level	Power sweep (input power sensitivity)	P1db: 1dB compression point	Harmonics and Spurious	Phase noise (input and output)	S11	S22	Frequency response S21 vs. Frequency
1	Amplifier	12 GHz	✓	✓	✓	✓	✓	--	✓	✓	✓
2	Low Pass Filter	12 GHz, 9 GHz	✓						✓	✓	✓
3	High Pass Filter	12 GHz, 9 GHz	✓						✓	✓	✓
4	Mixers	12 GHz, 3 GHz	✓	✓	✓ (LO)	✓	✓				
5	Low Pass Filter	3GHz, 400MHz, 250MHz, 80MHz	✓						✓	✓	✓
6	Power Splitter	12 GHz, 3 GHz, 250MHz	✓	✓					✓	✓	✓
7	Amplifier	3 GHz, 250 MHz	✓	✓	✓	✓	✓	✓	✓	✓	✓
8	FrequencyDivider	12 GHz		✓	✓		✓	✓	✓	✓	
9	FrequencyDivider	3 GHz, 1 GHz		✓	✓		✓	✓	✓	✓	
10	FrequencyDivider	Progrmmable		✓	✓		✓	✓	✓	✓	
11	Cavity Filter	IF Frequencies	✓						✓	✓	✓

Measurement Setup



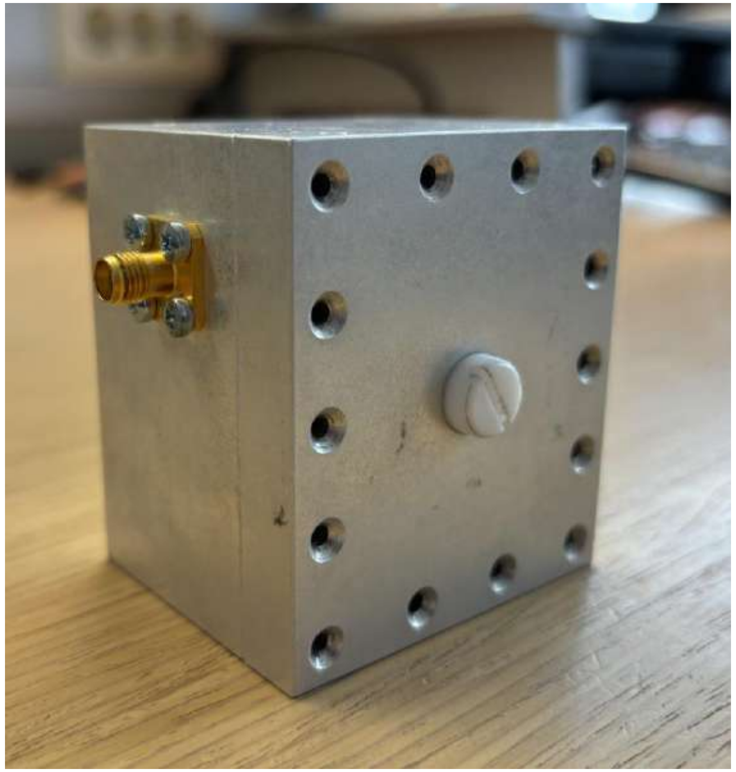
Input vs Output Phase noise (Amplifier)

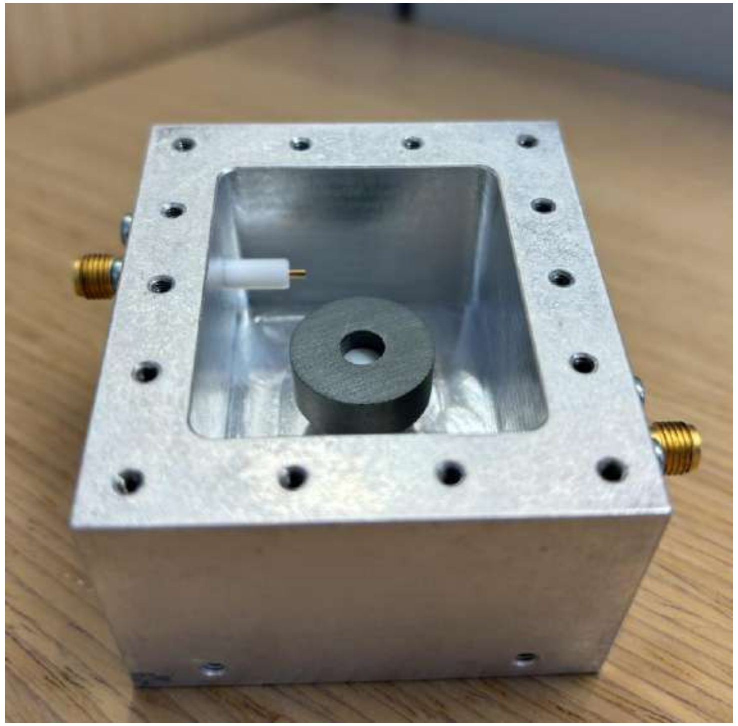
Phase Noise Measurements

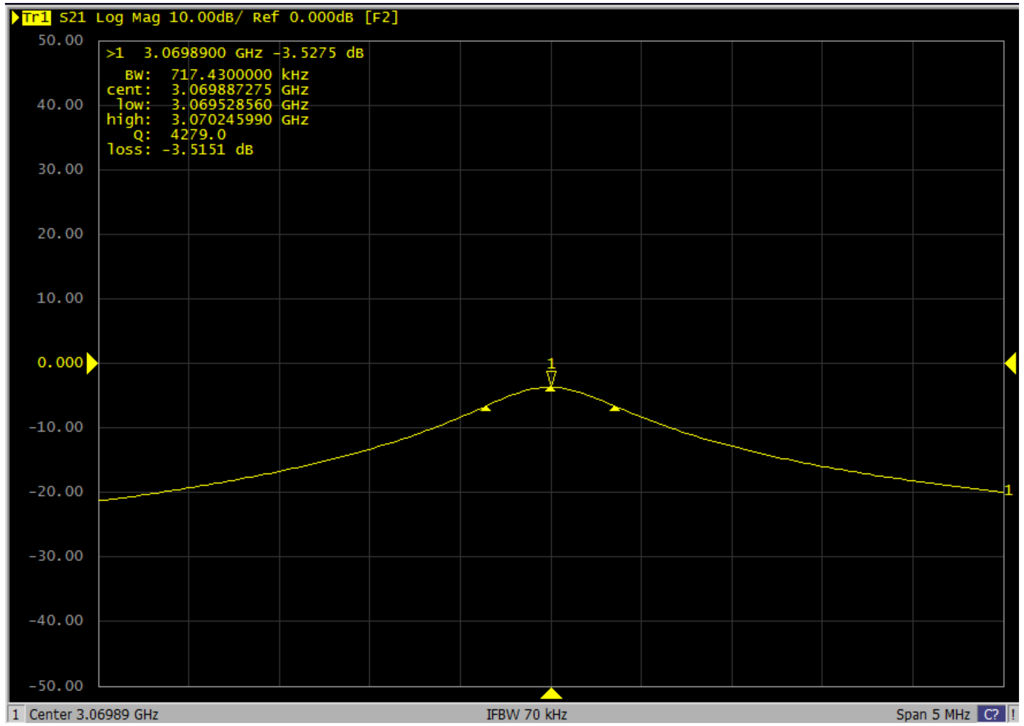


Cavity Filter Analysis

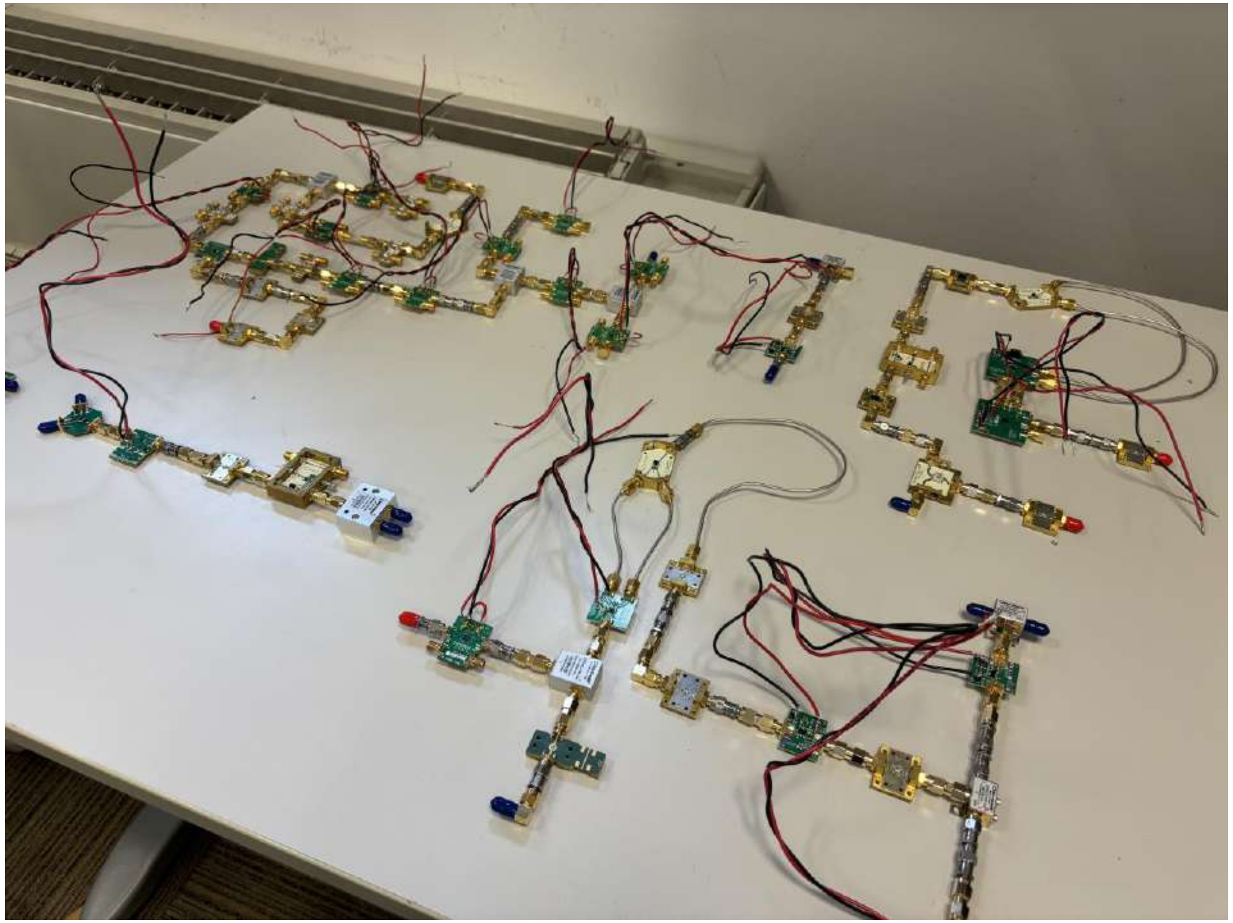
- 3 GHz Cavity filter with a ceramic resonator.
- Tunable range and Frequency depends on size of the resonator.
- Small Insertion loss F_{LO+IF}, moderate Rejection at F_{LO} & F_{LO-IF}

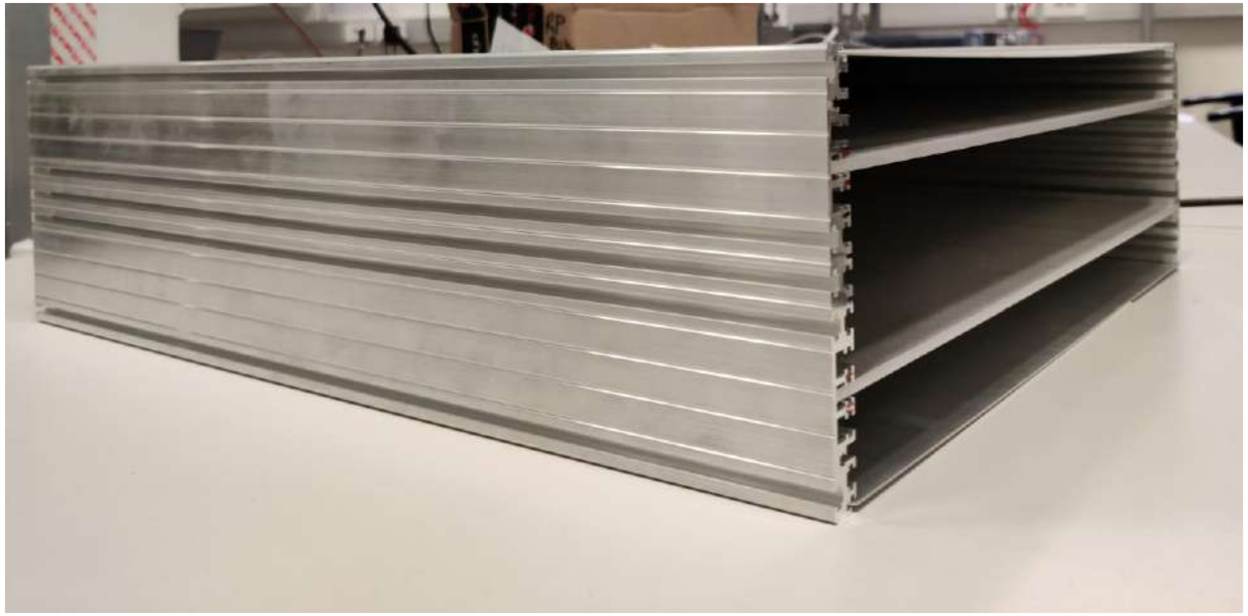






Outlook & Conclusions





Outlook & Conclusions

- Assembly of Components chain in a 19“ chassis → April,2024.
- Performance tests on the Front-End & Evaluation of Back-End → end of summer 2024.
- Prototype Finalization → Dec,2024.
- Laboratory tests at INFN-LNF (TEX facility) → Early 2025.

Thanks for taking part and have a nice Libera workshop 2024!

Back-Up Slides

Introduction to Low Level Radio Frequency

- Subsystem of Radio Frequency (RF) system, handles the control and stabilization of the RF signal at a low level of power.

- Maintain the stability and control of the RF signal parameters such as frequency, phase and amplitude.

- LLRF starts by measuring the characteristics of the RF signal. The amplitude and phase of the signal is detected from the cavity.

- The measured signal is then compared to a reference signal.

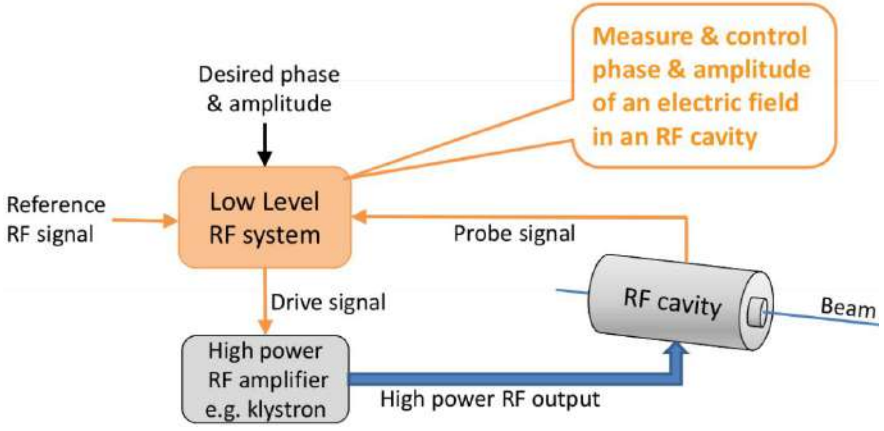


Figure: LLRF control for each RF cavity
Reference Borut

Introduction to Low Level Radio Frequency

- Deviation between the measured signal and the reference activates feedback control system.
- This system brings the signal back into alignment with the reference.
- This feedback loop is continuous and rapid, to ensure the RF signal stays within the desired parameters.
- Operates in real time with sub-microsecond response times.

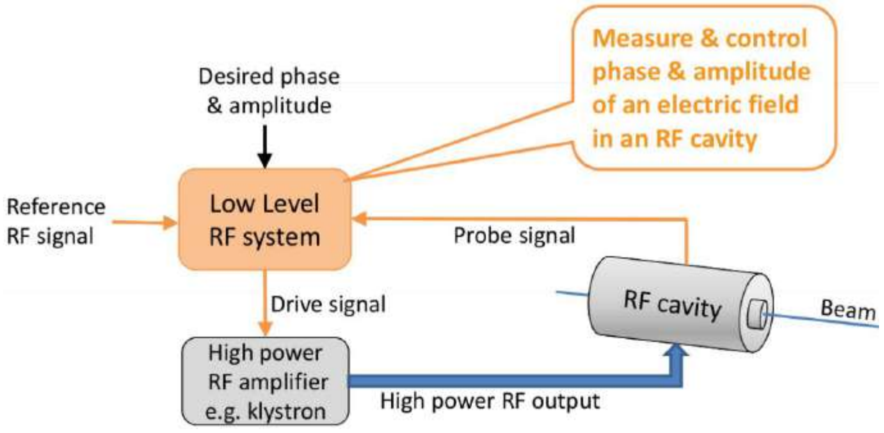


Figure: LLRF control for each RF cavity
Reference Borut