# Status of DLLRF System Development for Soleil-II Project

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## ABSTRACT

In the framework of the SOLEIL upgrade project towards SOLEIL II, a compact digital Low Level Radio Frequency (LLRF) system, based on the MicroTCA plateform, is being developed, which will provide better flexibility and easier maintenance than the present analog one. Derived from a 1.3 GHz system for the LUCRECE project, its sampling with a 10 MHz intermediate frequency (IF) makes it easily adaptable to any other RF system.

## SOLEIL-II : RF R&D program

SOLEIL Synchrotron is a French research facility dedicated to explore inert or living matter thanks to synchrotron light source. Started in 2006, it has now entered a new major upgrade phase with the SOLEIL-II project which aims at designing and operating a machine whose main organ will be a new Storage Ring (SR) based on a Multi-Bend Achromat lattice to achieve much higher average spectral brilliance, coherent and nano-focused flux while maintaining the broad spectrum of photons ranging from the far infrared to hard X-rays.

SOLEIL-II SR will essentially rely on two RF systems:

- a fundamental one at 352 MHz, which will provide the RF voltage and power necessary for an adequate electron beam energy acceptance and compensation of its energy loss per turn;
- a harmonic one, at 3 or 4 times 352 MHz, aimed at lengthening the bunches up to about 100 ps FWHM in order to preserve the low emittance and insure a suitable beam lifetime.

For the fundamental RF system, four HOM-damped cavities of the ESRF-EBS type will be used, each powered with a 200 kW solid sate amplifier (SSA). A digital LLRF based on the microTCA with the DAMC_FMC2ZUP board will control each RF plant.

## Hardwares

**Tested**

- ZC706 Zynq evaluation board
- Vadatech crate VT812: (8 AMCs + 4 RTMs + 2 MCHs + JSM + Telco Alarm)
- UTC002 (Vadatech MCH)
- AMC580 (Vadatech) => Zynq Ultrascale+ (ZU+) + 2 HPC FMCs
- FMC224 (Vadatech) => 4 CH DAC AC coupled (JESD204)
- FMC-4CH-125 (Techway)

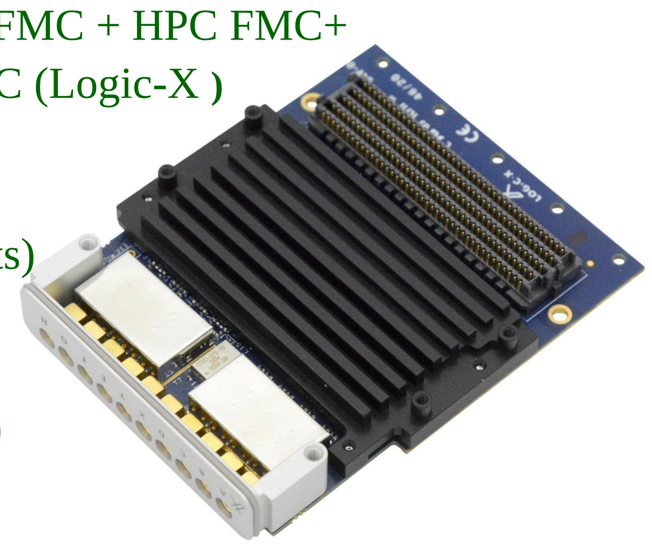
## Final choice

**Digital systems**

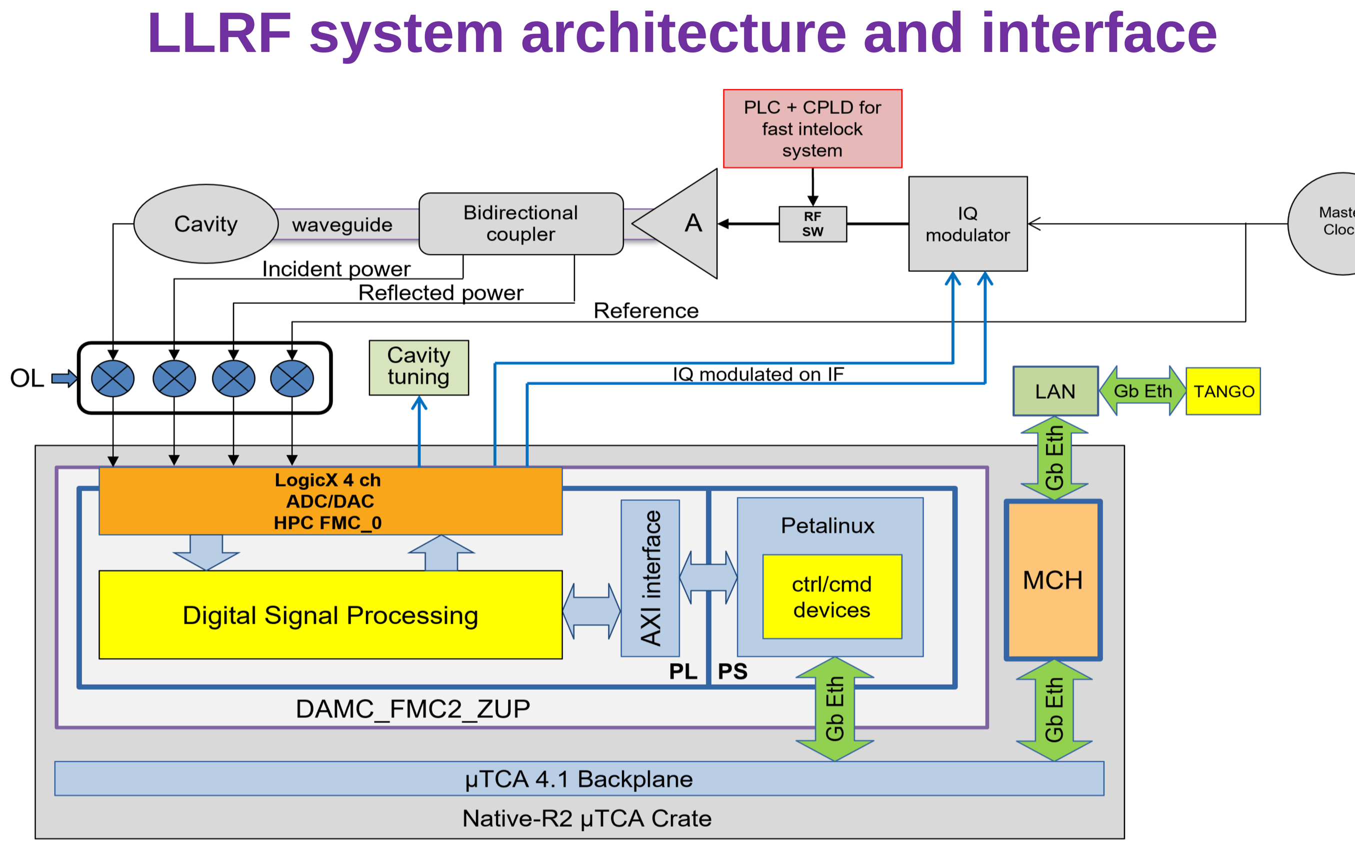
- Native-R2 µTCA platform, MCH-PHYS80 (Nat Europe)
- DAMC-FMC2ZUP (CAENels) => ZU+ + HPC FMC + HPC FMC+
- FMC LXD31K4-DC 4 channel 16-bit ADC/DAC (Logic-X )

**RF analog components**

- Mixer ADL5801 (Analog Devices)
- Amplifier GVA-93+, ZHL-1-2W-S (Mini-Circuits)
- PLL LTC6951 (implemented in the LXD31K4)
- IQ modulator LTC5598 (Analog Devices)
- Master clock synthetizer MXG5181B (Keysight)
- SRS Rubidium FS725 10 MHz Clock source



## LLRF system architecture and interface



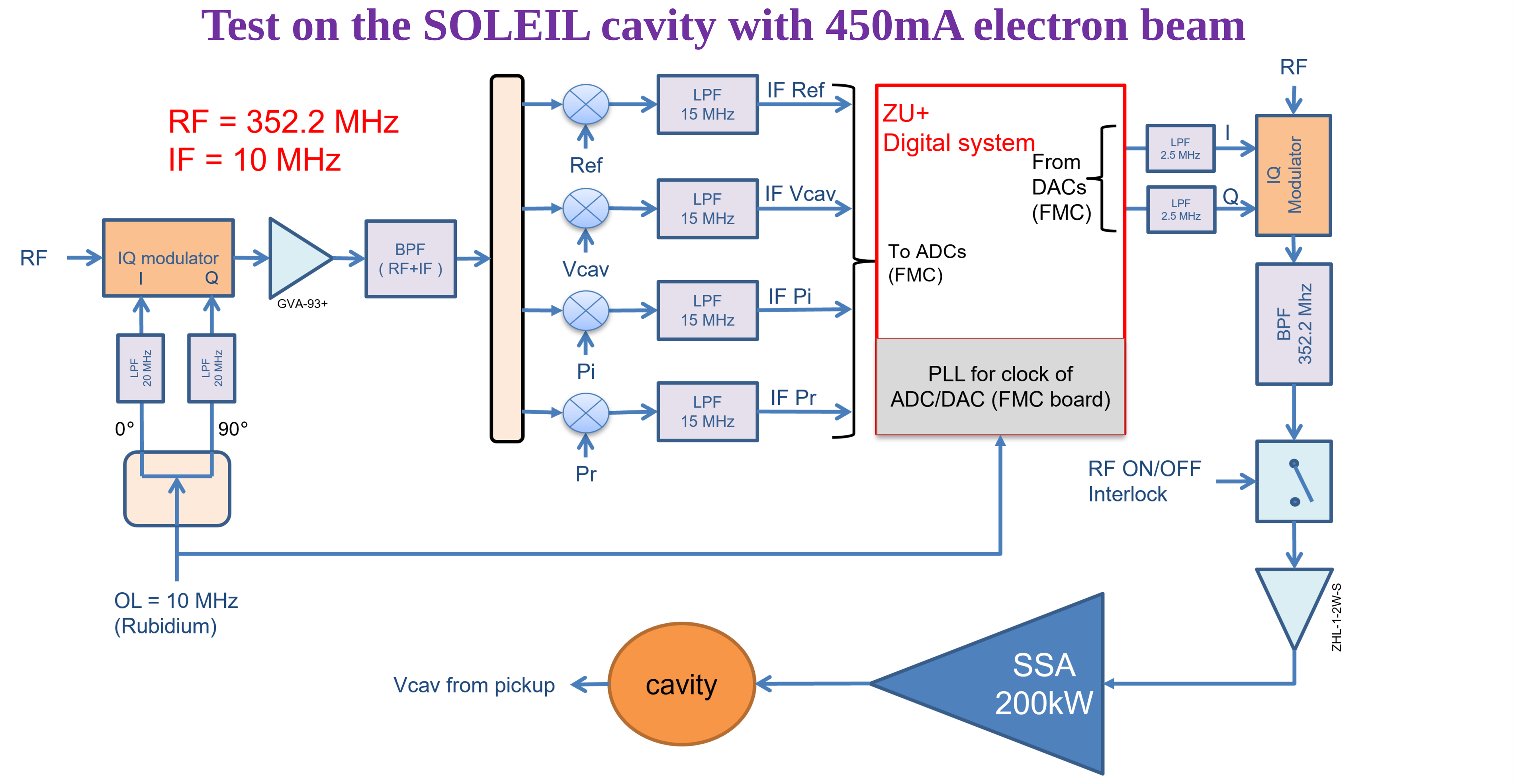

## Jitter and amplitude/phase accuracy measurements on IF signals

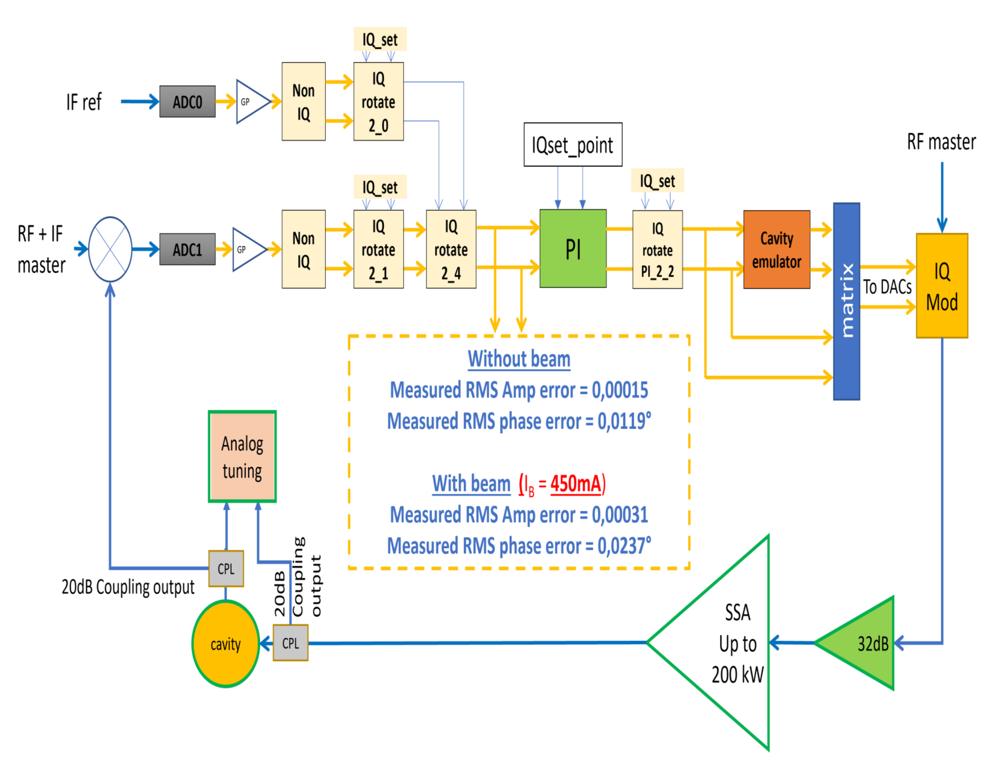
This versatile LLRF design will be used for SOLEIL-II and LUCRECE which requirements are very tight in terms of amplitude/phase accuracy: **$10^{-4}$/0.01° rms**. All RF analog components are carefully chosen and are used in the best setup condition to reduce the phase noise. The measured jitter of Rubidium FS725 10 MHz Clock source is around **0.3 ps** (0.01° ⇔ 2.8 ps). The MXG5181B master clock (352 MHz) synthesizer jitter is **0.033 ps** (0.01° ⇔ 0.079 ps).

The digitalized cavity voltage is compared with a RF reference signal to suppress all common phase noise due to the ADC sampling clock.

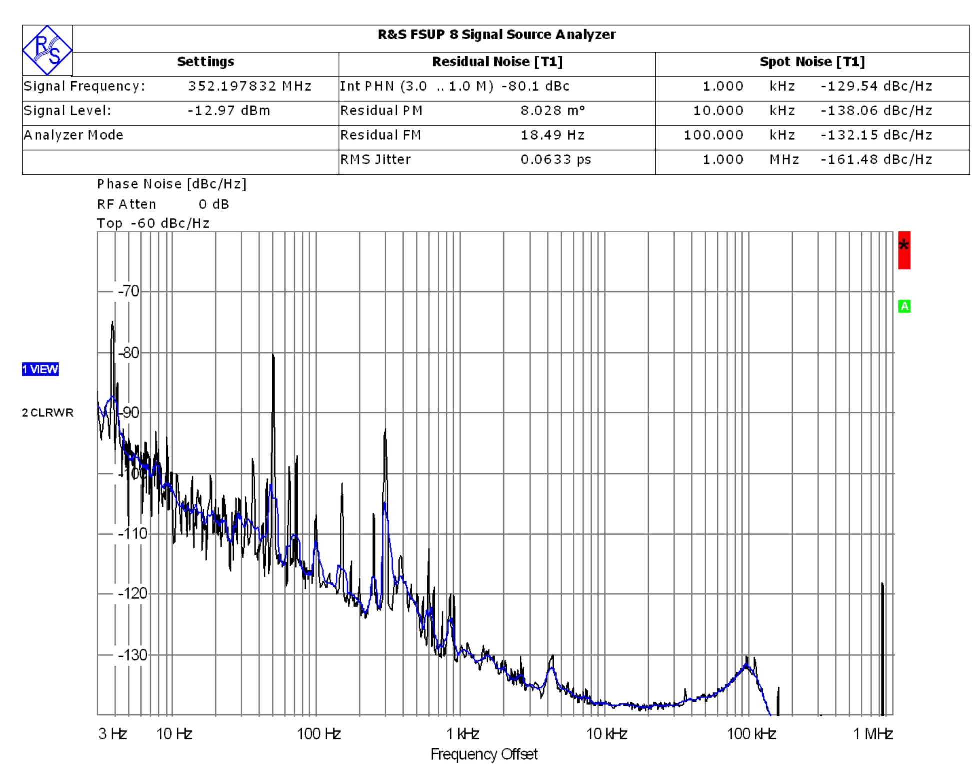
The RF analog front-end and back-end are optimized with favorable signal levels in every intermediate mixer stage. The phase jitter on the 10 MHz IF signals, measured with R&S FSUP+B60 option, is **1.67 ps**. The amplitude/phase accuracy for the reference and cavity signals as measured by the digital system are respectively **$10^{-4}/0.95\times10^{-2}$° rms** and **$2\times10^{-4}/1.2\times10^{-2}$° rms**. The former is limited by ADC SNR, probably by the ADC clock jitter also and certainly by additive phase noise on the analog components whereas the slight degradation on the latter is due to some rounding errors in the digital signal processing. Improvements are possible in the future implementation.

### Test on the SOLEIL cavity with 450mA electron beam




*Digital LLRF system tested on the SOLEIL cavity with 450 mA stored beam current*




*Phase noise measurement on the cavity pickup (closed loop, Gain = 18) with 450 mA stored beam current*

This first test on the SOLEIL cavity with stored beam is a full success: the closed loop accuracy is **$3\times10^{-4}/2.4\times10^{-2}$° rms** with a loop gain of 18. The phase noise of the cavity pickup signal is measured directly by the R&S FSUP+B60 option analyzer. It corresponds to **0.06 ps**, which is comparable to the present analog system.

The control application is relying on a Python server application which is running on the Processing System (PS) of the ZU+ and on a host computer with a Python client application which reads/writes registers and collects data. Its ergonomics and reactivity have to be improved.

The SOLEIL II jitter requirements are largely met. The RF analog down/up converter is very well optimized for 352.2 MHz. A new system, based on the same design, will be improved for the LUCRECE project which requires an accuracy of 0.01° rms at the frequency of 1.3 GHz.

## SOLEIL-II and LUCRECE DLLRF status and perspectives

The Zynq technology is selected for the LLRF digital processing system of the SOLEIL II and LUCRECE projects. The presence of an ARM processor and a classical FPGA on the same chip make the communication very easy. The FPGA works with IQ processes and the ARM converts IQ into amplitude and phase. Preliminary tests were performed using ZC706 Zynq board, interfaced with a four channel ADC FMC board from Techway. All basic signal processing modules relying on non-IQ demodulation technique were successfully implemented and tested.

In a second stage, all the IQ digital processes were migrated on the ZU+ based DAMC_FMC2ZUP board which is integrated in a NAT µTCA platform. The LXD31K4-DC 4 channel ADC/DAC FMC board from Logic-X is successfully interfaced. This FMC board is currently under development for some improvements. The SOLEIL Tango control system will be embedded on the ZU+ P S. It is expected that thanks to the above-mentioned efforts, the very tight precision (0.01° rms) required for LUCRECE will be met.