A LLRF Hardware Testbench for LCLS-II

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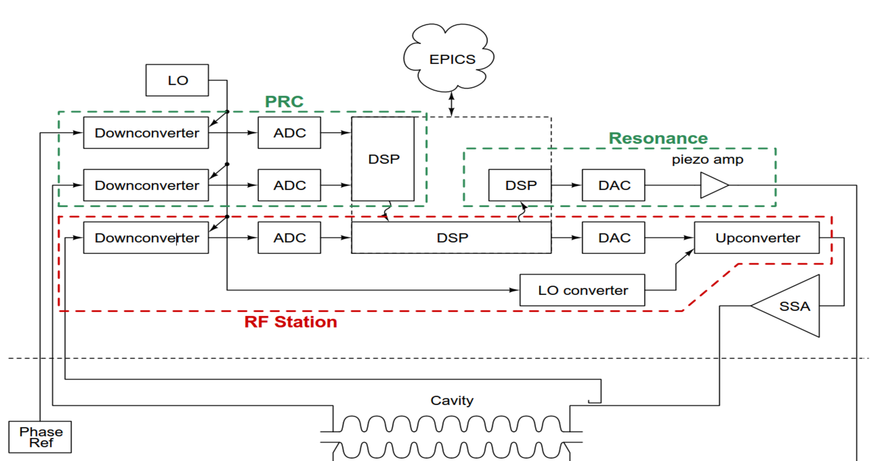
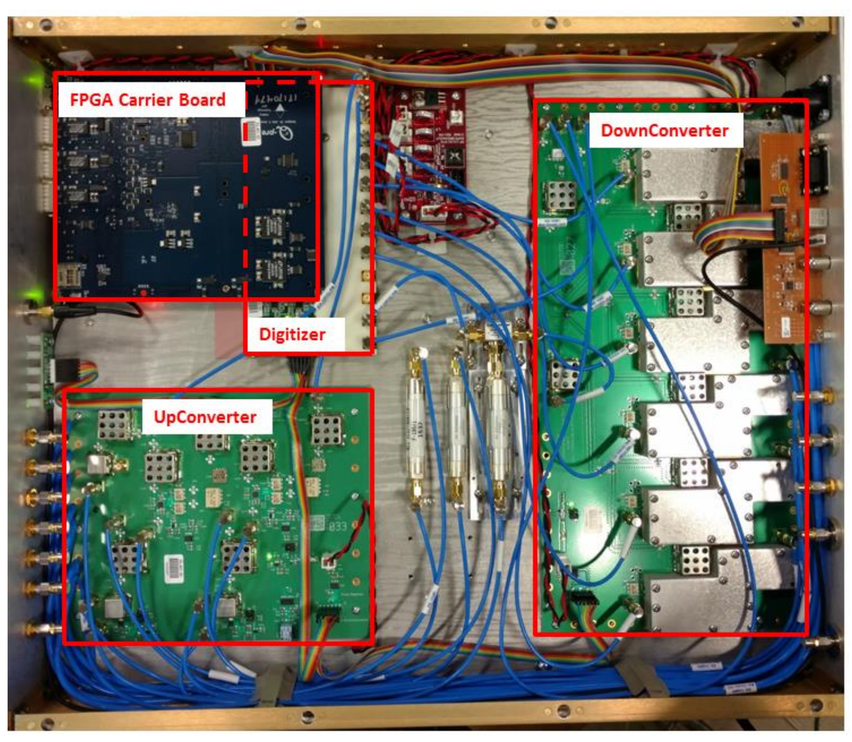
Abstract

The LLRF system designed for the LCLS-II at SLAC uses a Single Source Single Cavity (SSSC) architecture to meet the RF stability requirements: 0.01˚ in phase and 0.01% in amplitude. Key components of the system include the Precision Receiver Chassis (PRC), which acquires signals from four cavities and the RF Station (RFS) which controls two cavities and drives two SSAs. A system made of one PRC with two RFSs has been tested and the ability to meet RF field stability requirements has been demonstrated. Heading into the production phase of LCLS-II, we developed a LLRF hardware testbench to characterize a large quantity of these key components. In absence of a superconducting cavity and cryomodule, a narrow bandwidth, high Q dual cavity emulator was developed and is being used to test the LLRF system, allowing the SLAC team to obtain realistic measurements without the burden of an actual cryomodule. These results were validated by comparing with those obtained in cold testing of actual LCLS-II cavities at FNAL and with the CMOC modeling system. In this work we present the testbench design along with phase noise measurements and a demonstration of cavity RF field control.

LLRF Architecture





2 RFSs, 1 PRC and 1 Resonance Control Chassis per LLRF rack to drive 4 superconductive cavities (half cryomodule).

Precision Receiver Chassis, PRC (LBNL): Processes 4 cavity signals and the phase reference line. Processed amplitude and phase information are sent to the RFS via fiber optic links at 2.5Gbaud.

RF Station, RFS (LBNL): Processes forward, reflected and driver loop back signals. I/Q signal from PRC is used by the feedback algorithm to drive 2 cavities through 2 SSAs.

Cavity signals are down converted and digitized in the PRC. The processed signals are then sent to the RFS over a digital optical-fiber link. The RFS closes the feedback algorithm and drives the cavities. Cavity signals and forward and reflected signals are processed in separate chassis to minimize crosstalk.

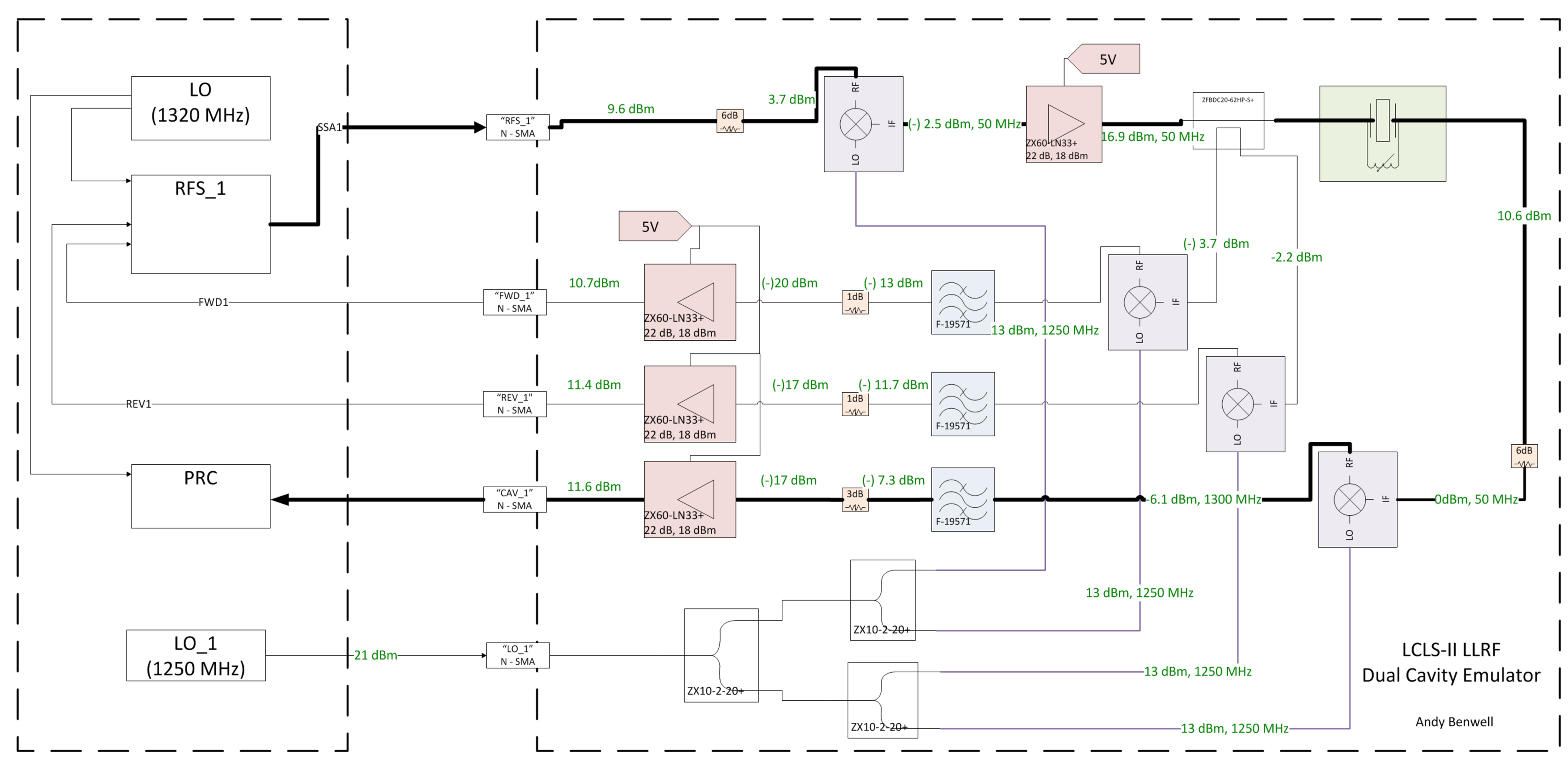
DownConverter, UpConverter and FPGS Carrier Boards are common for RFS and PRC

Up and Down converters designed at FNAL

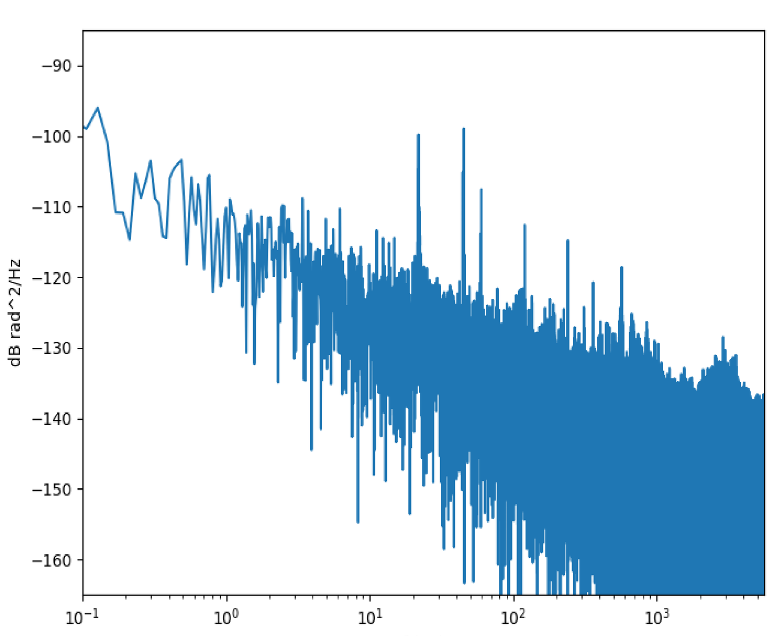
Digitizer and FPGA Carrier boards designed at LBNL

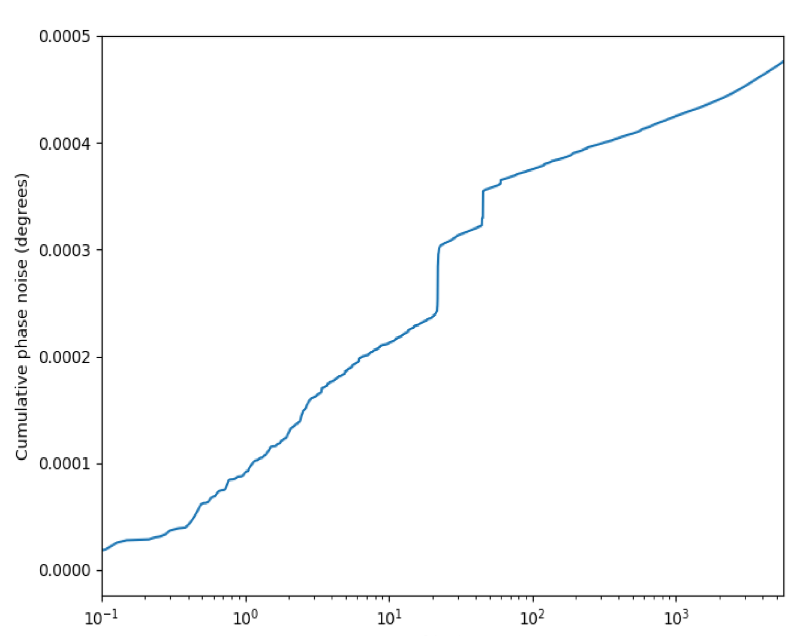
Dual Cavity Emulator

Key component of the test environment. In absence of a real cavity and cryomodule, the dual cavity emulator has allowed SLAC to test and integrate the different components of the LLRF system. The 1.3GHz drive signal from the RFS is down mixed with a LO 1250MHz to obtain 50MHz, the resonate frequency of the emulator. Forward, reflected and cavity signals are mixed with the LO 1250MHz to obtain 1.3GHz signals going to the PRC and RFS. The narrow bandwidth of the crystal allows tuning and cavity field control tests.



Phase Noise Measurements





Considerations to achieve Low Noise:

- Acquisition of signal in a separated chassis (PRC)
- Digitizer and downconverter boards are mounted on a aluminum plate to maintain stable temperature of the components.
- Low noise LDO voltage regulators used to filter out voltage reference frequencies.

Procedure:

- 1.3GHz signal split into two input channels. About 1M points collected per channel over a period of 93.95 seconds. Frequency resolution of ~0.01Hz
- 1Hz high pass filter can be applied to the data due to the beam based feedback
- Differential phase noise measurement data available for analysis.

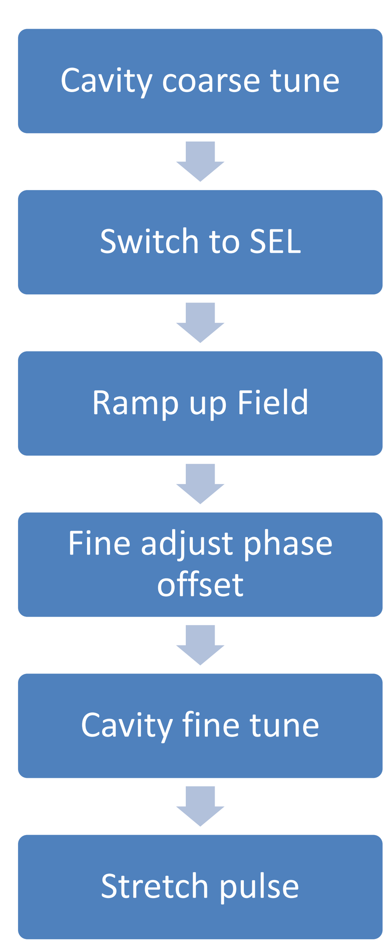
Results:

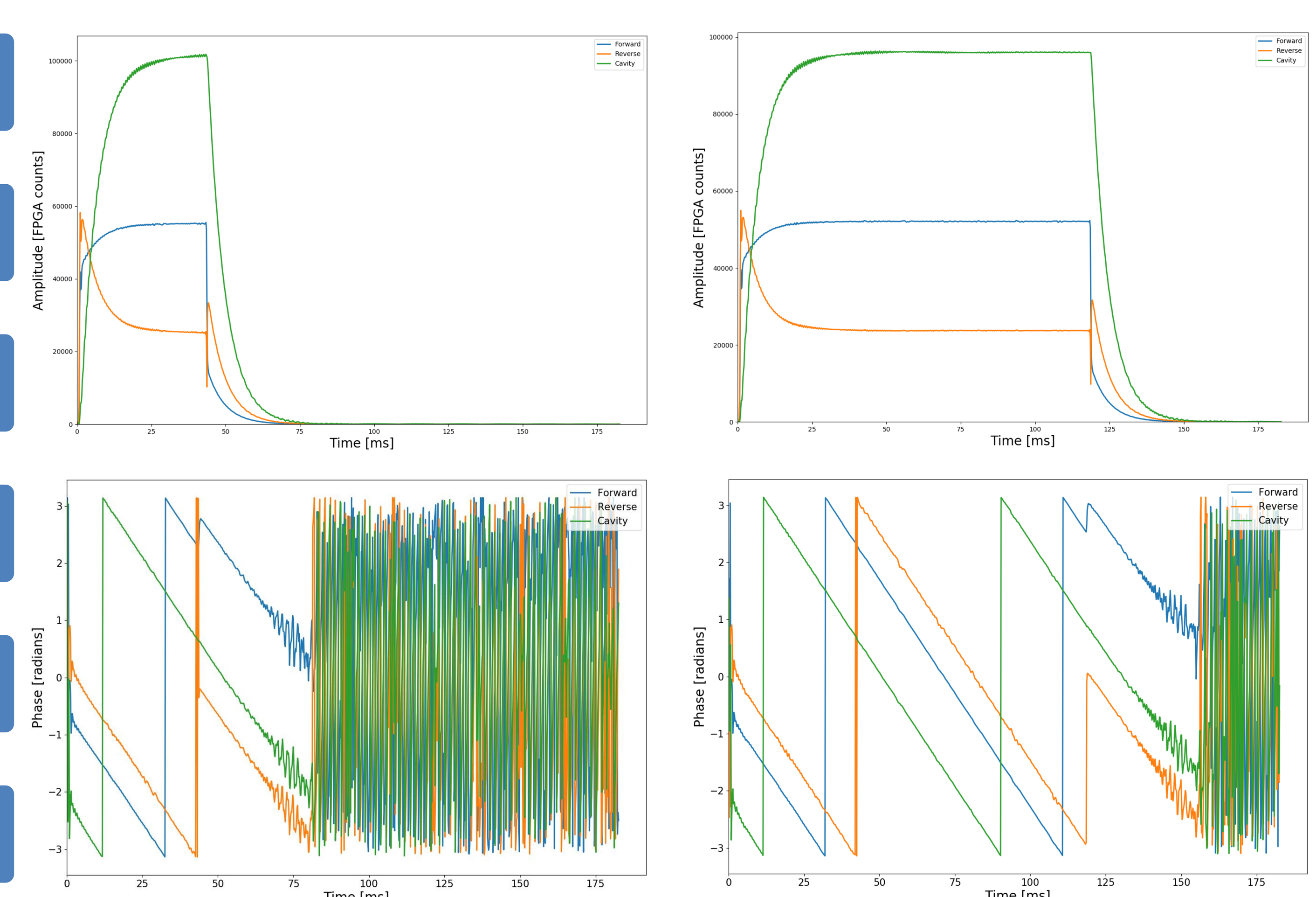
- Differential phase noise power spectral density plot below -90dB.
- Cumulative differential phase noise below 0.0005 degrees for frequencies from DC to 5.4 KHz.
- Data gathered at different fan speeds. Observable noise at high speeds.

Cavity Field Control

Cavity field control has been demonstrated using the dual cavity emulator. Ramping up of the field amplitude, adjustment of the field phase and pulse stretching has been tested in SEL mode. Results have been validated by comparing with FNAL results, obtained with actual LCLS-II cavities and cryomodule.

- Forward, reverse and cavity signals behave as expected.
- Coupling between forward and reverse signals due to Bi-Directional coupler used in the cavity emulator
- 180 degree jump at reverse phase when the pulse ends





Future Work

- During the last few months the boards, chassis, rack and heat exchanger have been modified to achieve final production versions. A production rack is being set up at SLAC with final versions of all the components. Characterization of the new equipment has to be done in terms of noise and temperature stability.
- SSAs should be integrated to the tests, as well as a second RFS and the and Resonance Control Chassis, to reach a complete characterization of the LLRF rack.
- Fully automated qualification scripts are expected to test large amounts of equipment. Integration with EPICS will allow visualization of data acquisition in real time.

Acknowledgements & References

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