LLRF CHARACTERISATION OF THE DARESBURY INTERNATIONAL CRYOMODULE

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Abstract

The 2-cavity Superconducting RF (SRF) Linac cryomodule of the Accelerators and Lasers in Combined Experiments (ALICE) machine located at Daresbury Laboratory will be replaced by a new International Energy Recovery Linac (ERL) Cryomodule in early 2013. This has been developed in collaboration with Stanford and Cornell Universities, LBNL and FZD Rossendorf. The improved 7-cell, 1.3 GHz SRF cavities will be characterised and compared with the original 9-cell cavities. A digital Low Level RF (LLRF) system using the LLRF4 board developed by Larry Doolittle has been developed at Daresbury Laboratory and has been installed on the upgraded cryomodule. An initial RF test has been performed in April 2013 with the digital system being configured in a self-excited loop so that microphonic sensitivity and Lorentz force detuning can be analysed. This paper sets out to discuss the qualification process, testing and results of the upgraded cryomodule installation.

INTRODUCTION

The Daresbury International Cryomodule has been tested with a new digital LLRF system developed at Daresbury Laboratory [1]. As the first RF test of this new cryomodule, the cavities have been driven with low power to measure microphonic detuning. The digital LLRF system, which adopts the LLRF4 board (designed by Larry Doolittle at LBNL) is capable of fast feedback /feed forward control and phase regulation using a slow DAC output. To perform these tests, the digital system was configured in self-excited loop mode to allow for high Q_L measurement.

Daresbury LLRF System

The digital LLRF system is based around the LLRF4 evaluation board, shown in Figure 1.

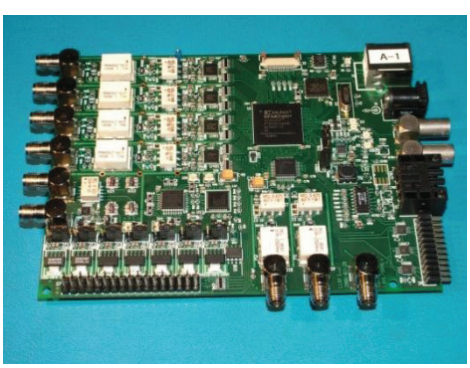

Figure 1: LLRF4 board.

The LLRF4 consists of a low cost Xilinx Spartan 3 Field Programmable Gate Array (FPGA), four high speed 14 bit ADC channels and two 14 bit high speed DAC channels. The board includes a USB controller, which allows a host computer to configure the FPGA and implement a high speed communications channel between the user FPGA code, and the host computer.

The LLRF4 has been integrated into a robust industrial 19” rack enclosure containing stable filtered power supplies, and a temperature controlled plate, onto which the analogue front end components are secured.

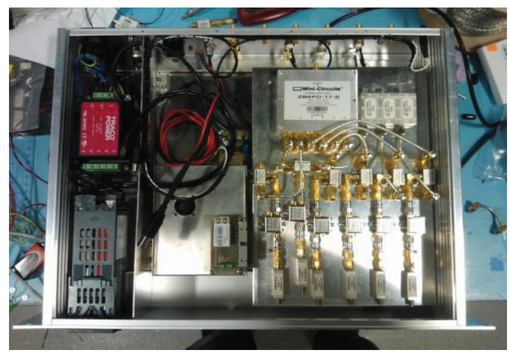

Figure 2: 19” enclosure, housing LLRF4 board and analogue components.

Several versions of FPGA firmware have been developed for different purposes. These include a feedback / Feed-forward based system for use on long pulse (several ms) machines, a feed-forward / cable calibration system for short pulses (1 - 4 µs) and a phase locked loop system for cavity conditioning purposes.

A host computer running scientific linux 6.3 provides a graphical user interface to the FPGA firmware, and acts as a bridge to the machine EPICS control system. This has been coded using python script.

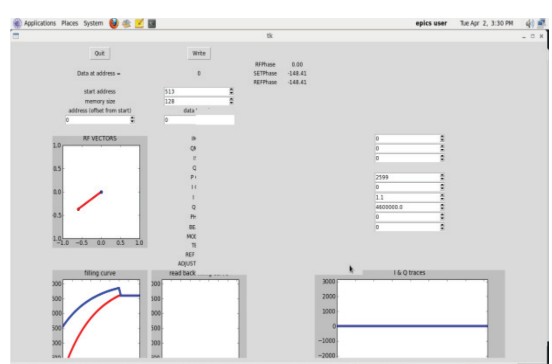

Figure 3: Python GUI.

LLRF Test System

For the experiments described in this paper, the LLRF system was operated using the Phase locked loop mode FPGA firmware. Figure 4 shows the layout of the cryomodule RF test system. The test system is configured as a digital self-excited loop, with the cavity probe signal being down converted to near 50 MHz and fed into one of the fast ADC channels of the LLRF4 board; the probe signal is then demodulated inside the FPGA, its phase calculated through a CORDIC and output to the slow DAC channel. The phase signal drives the external FM modulation channel of the Hewlett Packard 8657B signal generator, which is used as a Voltage Controlled Oscillator (VCO) to give the master clock for the LLRF4 board. The local oscillator signal required by the mixer is generated by a Wenzel frequency multiplier, which multiplies the VCO frequency by 6 times. Table 1 lists the operating frequencies of the DLLRF system for testing. One of the RF output channels of the LLRF4 board connects to a power amplifier to provide a maximum of 0dBm forward power to the cavity. A four port directional coupler is connected between the output power amplifier and the SRF cavity to be tested. Forward and reflected powers are measured with a Boonton RF pulse power meter. The amplitude and phase set points are controlled through a host computer via the USB controller of the LLRF4 board. The advantage of this set up is that the LLRF system can track the cavity frequency change due to microphonics and Lorentz force detuning, which is especially convenient whilst the cavity is near critical coupling. There is therefore no requirement for operation of the mechanical tuner whilst performing these characterisation measurements.

Table 1: RF Frequencies Generation of the DLLRF System

RF(MHz)	VCO(MHz)	LO(MHz)	IF(MHz)
1300.0000	208.7591	1252.5547	47.4453

The digital LLRF system was initially connected to the cavity and operated in CW open loop mode (no control). Figure 5 shows the resultant cavity probe and reflected power traces. It can be seen that significant deviations from the ideal flat top pulse are observed. These deviations are due to microphonic detuning of the cavity from vibrational sources, coupling to the cavity.

The digital phase locked loop was subsequently switched on, and Figure 6 shows the closed loop cavity response. It can be seen that the forward and reflected traces are much smoother with improved flat top performance.

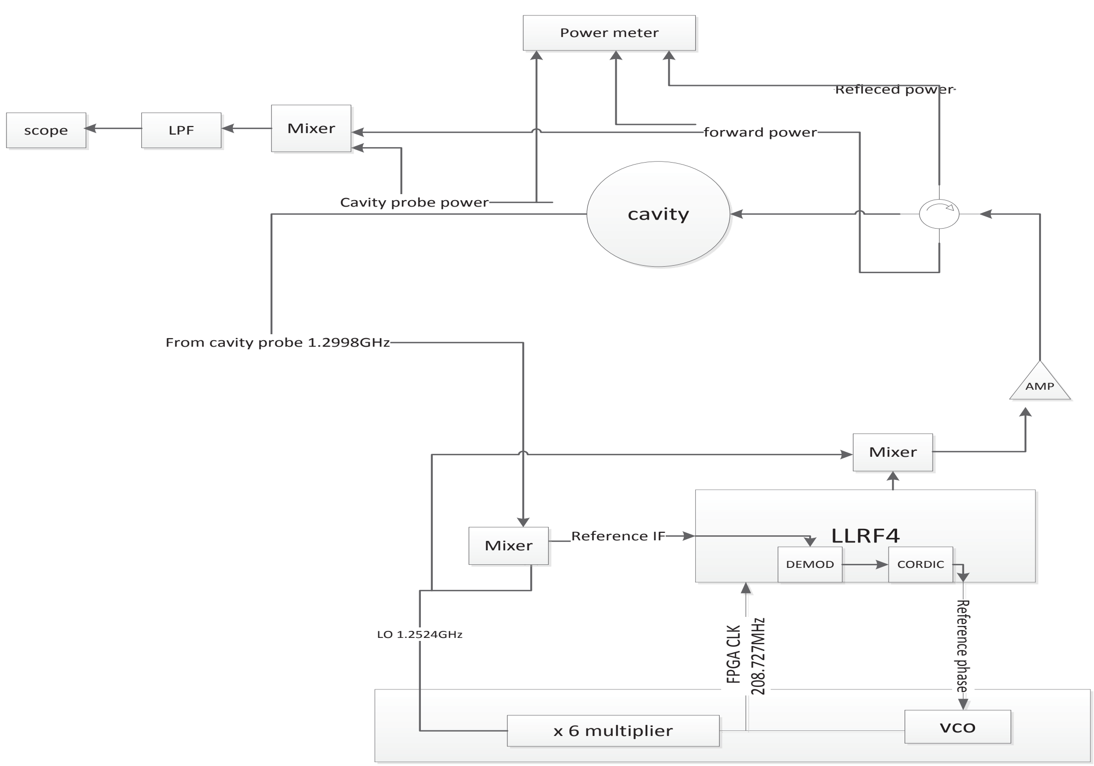

Figure 4: Digital VCO_PLL system. LLRF4 board performs as a digital phase detector to regulate the VCO frequency.

ISBN 978-3-95450-122-9

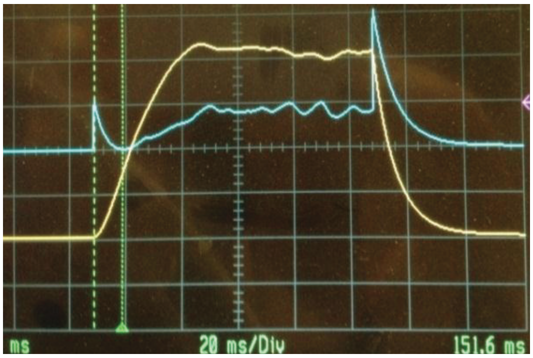

Figure 5: Cavity 1 open loop test, cavity driven by a rectangular pulse.

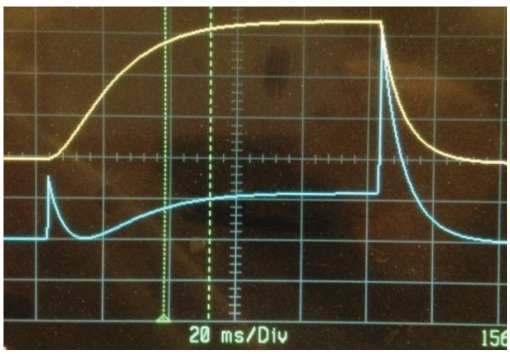

Figure 6: Cavity 1 closed loop test. Cavity controlled by digital self-excited loop. Signal noises are largely suppressed by the phase lock loop.

Microphonics Measurements

To study the microphonics effects on the cryomodule, the SRF cavities were driven with a CW signal from the digital LLRF system. The cavity probe signal was then mixed with the forward RF signal and filtered by a low pass filter [2]. An FFT was then used to show detuning peaks caused by the microphonics. Again, the cavities have been set up in self excited loop and open loop operation. Figure 7 shows the cavity 1 microphonics spectrum. In open loop measurement, strong detuning peaks are shown at 1 Hz, 7 Hz, 24 Hz, 35 Hz, 38 Hz, 47 Hz, 78 Hz, etc. Once the loop is closed, the overall noise floor is up to 30dB lower at f < 200Hz, and many detuning peaks removed. However, the 50 Hz resonance and its harmonics remain on the spectrum, this is from the UK mains electricity supply, which is common in the background environment. There is a low frequency resonance at 0.24 Hz.

The test data was sampled over 5 seconds. Further tests with long duration are planned for very low frequency microphonics measurement. For cavity 2, in open loop operation, strong resonances have been observed at 1 Hz, 7 Hz , 21.5 Hz, 23.5 Hz, 35 Hz, 48 Hz, 68 Hz, 71 Hz, 78 Hz, 82 Hz, 98 Hz,etc. When the loop is closed, resonances remain at 1 Hz, 37.5 Hz, 50 Hz and its side bands, shown in Figure 8.

Common resonances for both cavities are at 7 Hz, 24 Hz, 35 Hz, 47 Hz, 78 Hz and 50 Hz and its sidebands. Apart from the 50 Hz mains signal, sources of these resonances are yet to be identified.

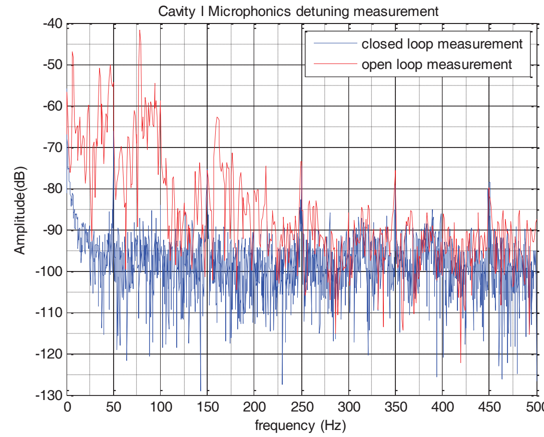

Figure 7: Cavity I microphonics test.

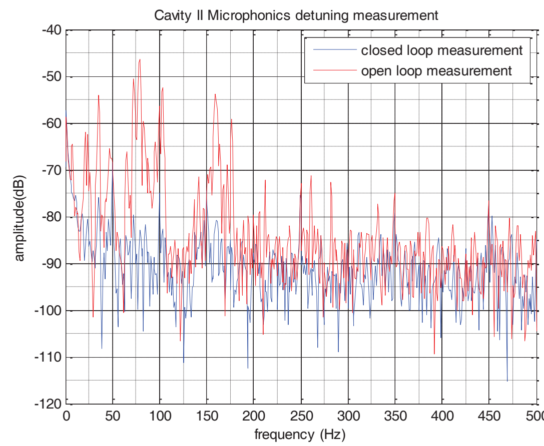

Figure 8: Cavity 2 microphonics test.

SUMMARY

An initial test of the DICC module and its LLRF control system has been successfully carried out. This has involved the commissioning of a new digital LLRF system. Various low frequency (mechanical) detuning peaks have been measured and the LLRF system has been demonstrated to overcome these disturbances. These were adequately damped by use of a digital phase locked loop. Future experiments will include the measurement of Q_0 [3,4] from helium mass flow and full implementation of Piezo tuners for overcoming Lorenz force detuning,

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