LLRF CONTROL FOR SPX @ APS DEMONSTRATION EXPERIMENT*

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Abstract

The SPX experiment at APS is part of the APS upgrade project, using deflecting cavities to chirp the electron pulse and then generate short pulse X-ray (SPX). To minimize the influence to other users on the storage ring, the phase synchronization of the two deflecting cavities is required to be better then 77 millidegree. A LLRF4[1] board based system is designed to demonstrate the capability of meeting this requirement. This paper discuss the hardware and firmware design of the demonstration experiment including the cavity emulator, LO and reference reference generation, receiver chassis, and LLRF control algorithm.

INTRODUCTION

The Short Pulse X-ray project is part of a larger APS upgrade. The scheme uses a deflecting cavity to chirp the beam, and then use the chirped beam to generate X-rays. After a long drift, the X-ray pulse can be shortened by passing through a slit.[2] In order to minimize the impact on other sections of the APS ring caused by the deflecting cavity, a same deflecting cavity is used downstream to un-chirp the beam. The amplitude and phase difference between the two deflecting cavity field will determine the cancellation accuracy.

Beam dynamic analysis shows that the common amplitude and phase variation should be limited below 7% and 10° to generate high quality X-rays, and the differential amplitude and phase variation between the upstream and the downstream cavities should be controlled below 1% and 0.077°. The distance between the two cavities is about 50 meters. The differential phase variation is critical for the success of the LLRF system.

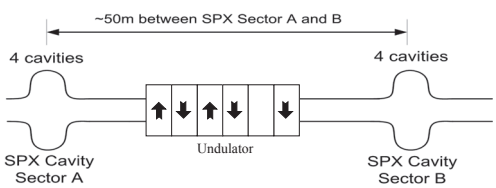

Figure 1: Two deflecting cavities for SPX.

To accomplish the high accuracy amplitude and phase control of the two deflecting cavity, an integration of fiber based RF reference distribution system and the RF cavity low level control system is designed under the collaboration between ANL and LBNL.

In the initial phase (PHASE 1) of this collaboration, we designed the system and assembled the required chassis. A two system test has demonstrated that the LLRF control system can control the cavity with high accuracy and low added noise.

CHASSIS DESIGN

There are 3 kinds of chassis are developed: the LO and reference generation chassis, the receiver chassis, and the cavity emulator chassis.

LO and Reference Generation Chassis

The LO and reference generation chassis generate the reference RF and local oscillator for each receiver from an external or internal 351.9 MHz reference.

$$f_{\mathrm{ref}} = 351.9 \cdot 8 = 2815\,\mathrm{MHz}$$

$$f_{\mathrm{LO}} = f_{\mathrm{ref}} - 351.9/6 = 2756\,\mathrm{MHz}$$

A picture of the LO and reference generation chassis is shown in figure 2.a.

Receiver Chassis

The receiver chassis contains analog front end circuits and digital signal process boards. A picture of the receiver chassis is shown in figure 2.b.

Part of LO is frequency divided by two to be used as clock for the LLRF4 board. The remaining LO power is amplified and used in every up and down converter. These converters were designed by Ron Akre for the LCLS timing and synchronization system.[3] Each chassis can handle up to 6 down converter channels and 2 up converter channels.

A LLRF4 board is used to accomplish the digital signal processing. Its firmware will be explained later.

Space is reserved for a future upgrade to integrate with the fiber based reference transmission system, incorporating the optical beat receiver part, the AOM driving circuits, and the photodiode bias controller.

Cavity Emulator Chassis

To demonstrate the behavior of the receiver chassis before testing on a real superconducting cavity, we assembled two chassis using a crystal and mixers to emulate the real cavity. The picture of the cavity emulator is show in Figure 2.c. The down- and up-conversion mixers and a laboratory synthesizer translate the crystal resonance from

* Work supported by U.S. Department of Energy under contracts DE-AC02-05CH11231 and DE-AC02-06CH11357.
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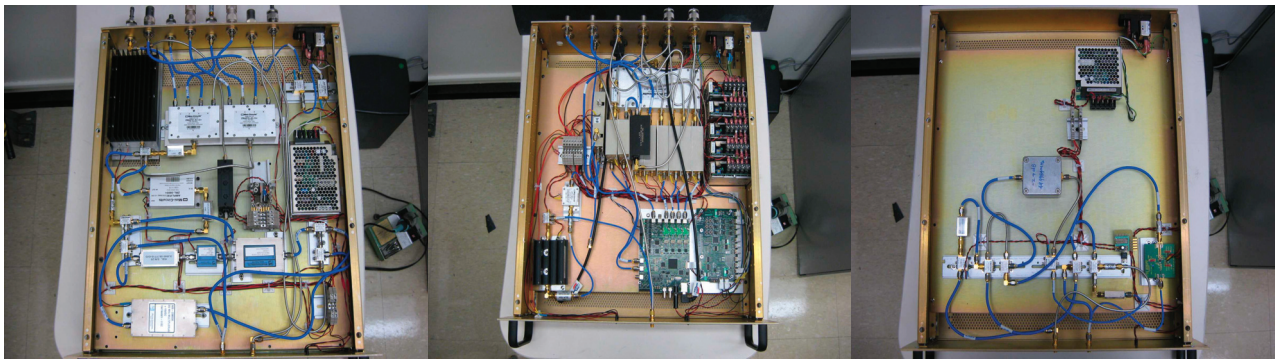
ISBN 978-3-95450-115-1



a b c

Figure 2: SPX LLRF chassis: a-LO and reference generation; b-Receiver; c-Cavity emulator.

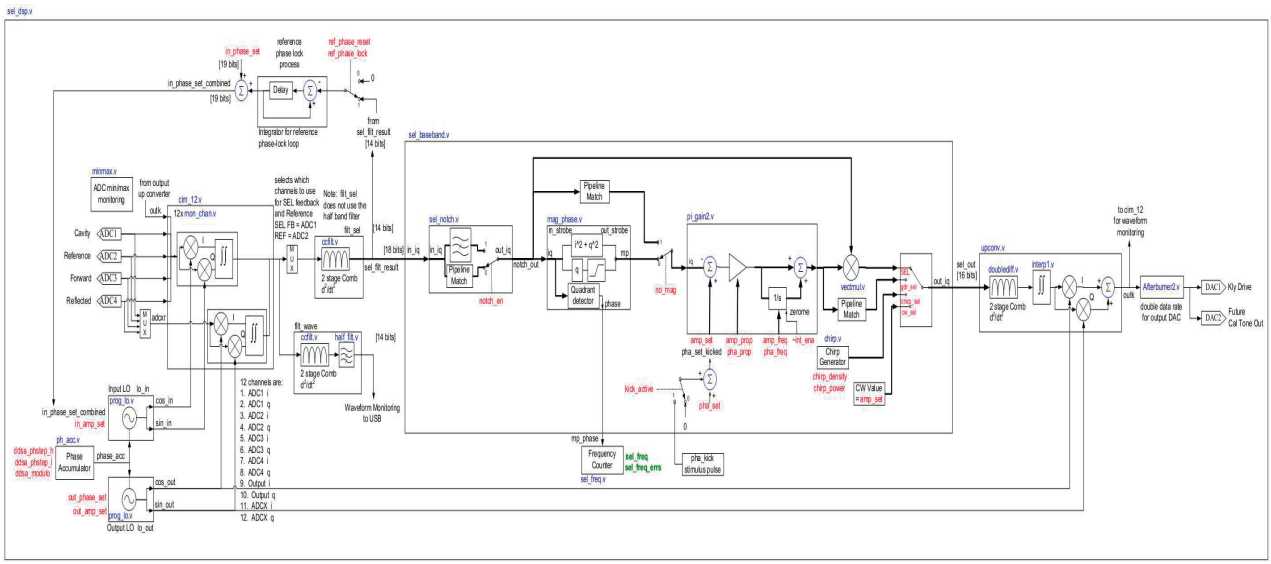


Figure 3: SPX LLRF firmware block diagram.

50 MHz to 2815 MHz. The crystal filter has a bandwidth of about 1 kHz, with spurious modes 300 kHz away.

FIRMWARE AND SOFTWARE DESIGN

The software and firmware is developed based on the LLRF4 software and firmware development platform [4]. The platform provides the chip drivers for the LLRF4 board and implements communication with a host computer running Linux. It also provides a development GUI.

The IF inputs from the down converter are band pass filtered by the LLRF4 on board filters and digitized at f_{clk} before send to the FPGA to process.

The block diagram of the DSP algorithm is illustrated in figure 3. The digitized signals are further mixed down with a direct digital synthesizer (DDS), and filtered by a two stage CIC filter to get accurate baseband I and Q signals.

The frequency relationship between f_{clk}, f_{LO} and f_{IF} is

$$f_{\mathrm{clk}} = f_{\mathrm{LO}}/2/18 = 76.57\,\mathrm{MHz}$$

$$f_{\mathrm{IF}} = 351.9\,\mathrm{MHz}/6 = 58.65\,\mathrm{MHz} = f_{\mathrm{clk}} \cdot \frac{36}{47}$$

The reference phase is combined with the phase set point to make the cavity follow the reference. At baseband, both self excited loop (SEL) and generator driven resonator (GDR) modes of cavity control are implemented.

In SEL mode, we use the baseband cavity signal I and Q to calculate the signal amplitude. The amplitude and Q are interleaved and compared with the amplitude and phase set point. The difference are used as the error signal of a two channel proportional integral (PI) control loop. The PI calculation result is vector multiplied with the same cavity I and Q signal with appropriate delay.

For GDR mode, the same PI controller is used, but the two signals used as error are I and Q compared to the set point.

To help bring up the cavity, the DSP can provide an open-loop constant or chirped drive signal.

The baseband outputs are interpolated by another CIC filter and up converted to the IF by mixing with another

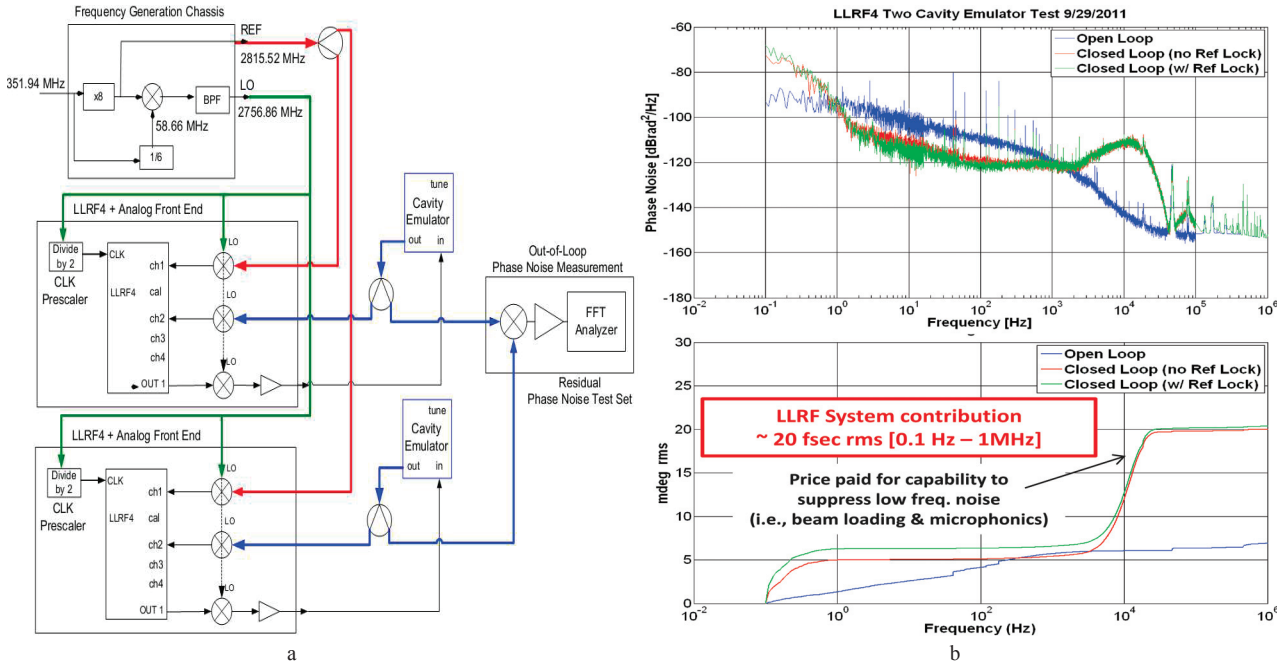


Figure 4: SPX LLRF two system test.

direct digital synthesizer. The up and down converter DDS amplitude and phase can be adjusted independently.

TWO SYSTEM EXPERIMENT

To measure the performance of the system, a two system experiment is setup as shown in figure 4.a. This experiment uses two receiver chassis to control two cavity emulators. The common reference for both chassis and LO are coming from the LO and reference generation chassis. The out of loop phase error is measured by a Wenzel residual phase test set and the result is analyzed by a FFT analyzer.

Some experimental results are shown in figure 4.b. The phase noise within the control bandwidth is suppressed by the control system. The overall LLRF system contribution is about 20 fs in the band of 0.1 Hz to 1 MHz.

SUMMARY

A low level RF control system for SPX is designed to accomplish the small differential phase variation between two deflecting superconducting cavities. The control chassis are designed and partially fabricated. Two system test used two receiver chassis to control two cavity emulators, and the out of loop phase variation measurement shows the LLRF part of the system is quiet enough.

In the coming several months, we are will integrate the LLRF control system with the fiber based reference delivery system, and include a full calibration tone algorithm in the firmware.

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ISBN 978-3-95450-115-1