PERFORMANCE OF DIGITAL LLRF SYSTEM FOR STF IN KEK

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Abstract

RF operations were carried out at the STF (Superconducting RF Test Facility) in KEK. The digital feedback system was installed in order to satisfy the strict rf-field requirements. The rf field stabilities under various feedback parameters are presented in this report. Cavity detuning measurements (microphonics, quench detection, etc.) were among the various studies that were conducted. Results of these studies are also summarized.

INTRODUCTION

The STF is a test facility for pulsed superconducting cavities aiming for ILC (International Linear Collider). An amplitude of 0.07% and a 0.24° phase are required for rf stability in the ILC in order to satisfy the collision luminosity [1]. In order to satisfy these requirements, a digital llrf (low-level radio frequency) system has been developed.

The STF started its operation in July 2007 [2], and several llrf studies have been carried out. Some of the topics studied are as follows:

(1) Study of cavity field stability

(2) IF mixture method: This method enables us to reduce the number of ADCs by combining intermediate frequency (IF) signals. This method has been validated by using electrical cavity simulators. This is the first time a study has been conducted using a real super-conducting cavity [3].

(3) Instability evaluation: An evaluation of the feedback performance under all fundamental modes such as the 8/9π mode was performed. This evaluation was carried out by eliminating the analog low-pass filter that was inserted between the IQ modulator and the DACs [4].

(4) Direct rf detection using a fast 14-bit ADC: In order to develop next-generation future rf detection systems, we examine a 14–bit fast ADC with a bandwidth of more than 1.3 GHz. This method allows the detection of the rf signal without the use of a downconverter [5].

(5) Analysis of the rf monitor: llrf monitors are used for the evaluation of cavity characteristics such as microphonics and for quench detection.

In this report, we summarize the results of the above studies.

DIGITAL LLRF SYSTEM

The digital llrf system comprises an rf signal generator (RF & CLK), downconverters, and a DSP/FPGA board having ten 16-bit ADCs and two 14-bit DACs. The

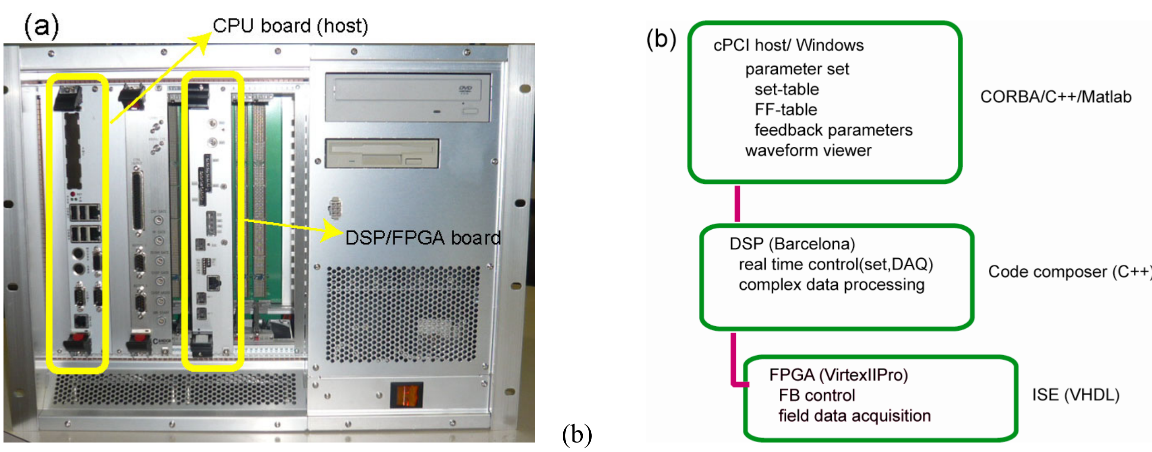

Figure 1: Photograph of cPCI system (a), and system layers inside cPCI (b).

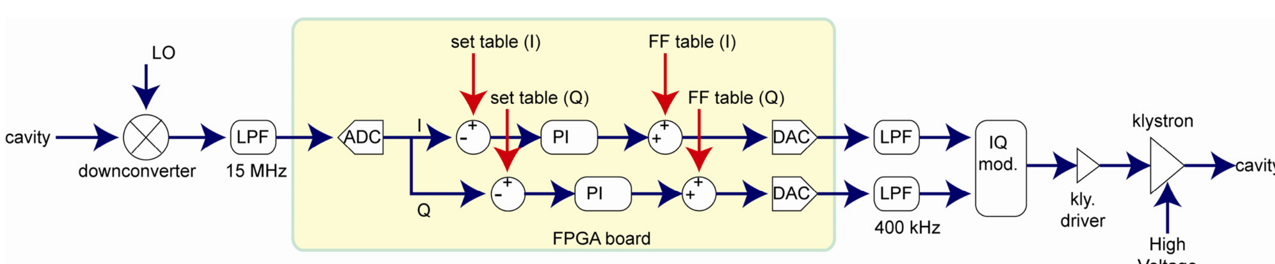

Figure 2: Block diagram of digital llrf system in case of a single cavity operation.

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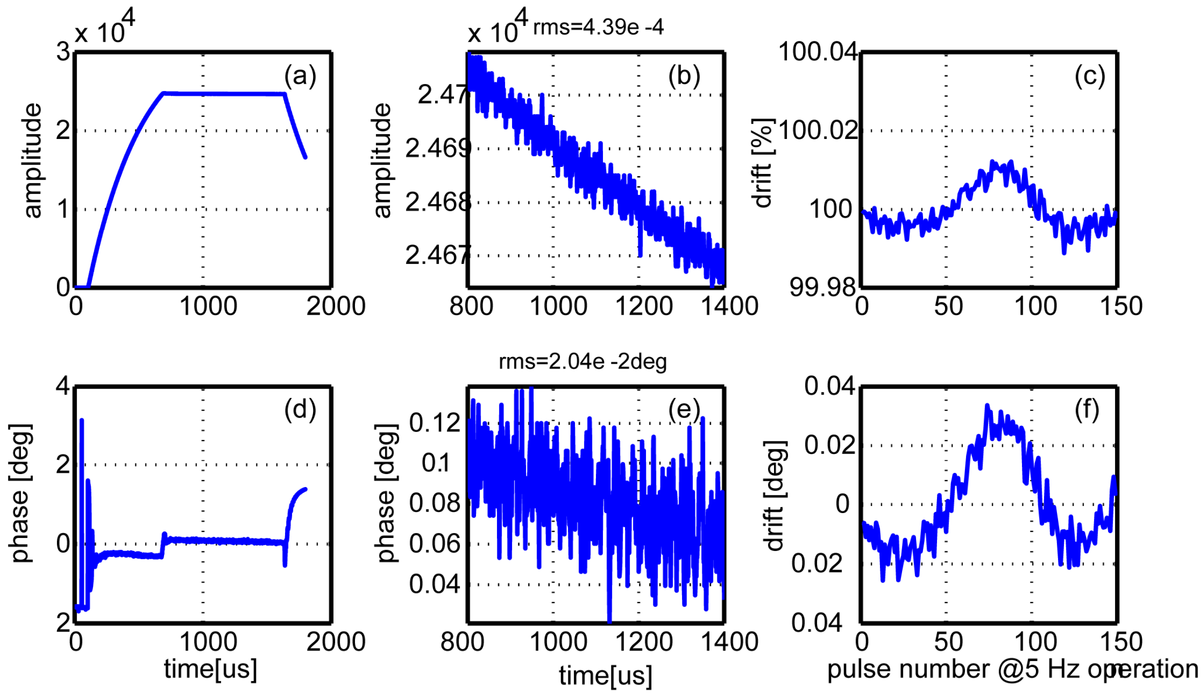

Figure 3: Performance of the llrf field regulation. Amplitude (a) and (b), drift of the amplitude during 30 seconds (150 pulses) (c), phase stability (d) and (e), drift of the phase during successive 150 pulses.

DSP/FPGA board is installed in the cPCI, which is the same as the J-PARC linac system [6]. Figure 1 (a) shows an image of the cPCI.

RF & CLK are used to deliver the local oscillator (LO; 1.31 GHz) signal and the clock (40 MHz) signal generated by the clock distribution chips (AD9510) and IQ modulators (AD8346) [3].

The FPGA board is a mezzanine card made up of a commercially available DSP board (Barcelona by Spectrum Inc.), and it facilitates fast feedback; DSP board is used for running complicated algorithms such as those for detuning and loaded-Q calculations. System developments are carried out using electric cavity simulators, which are installed in commercial FPGA boards and are capable of deferring beam loading and microphonics and Lorentz force detuning [7].

Figure 1 (b) shows the system configuration of the cPCI. The waveforms generated by each ADC are stored in a block RAM (2048 deep) in the FPGA board. The stored data in the block RAM is expandable like a digital oscilloscope (max. 40 MHz) and it can be accessed via the cPCI host. Windows operating system is installed in the CPU board of the cPCI (Host), and the Matlab library helps the online analysis of the llrf performance. The host records the waveforms generated in the last 30 seconds, which are highly useful for the evaluation of phenomena such as microphonics and cavity quench.

Fig. 2 shows the sequence of the digital feedback system. The rf pickup signal is downconverted to an intermediate frequency (IF) signal of 10 MHz (additional IFs were introduced in the case of IF-mixing [3]). Active mixers (AD8343) are used for downconversion. In order to eliminate the higher-order modes of the mixers, the output of the downconverters is filtered using low-pass filters with a 15-MHz bandwidth. The 16-bit ADCs (40 MHz clock) sample the IF signal directly, and proportional-integral (PI) control is performed. Two 14-bit DACs drive the IQ modulator (AD8349) via low pass

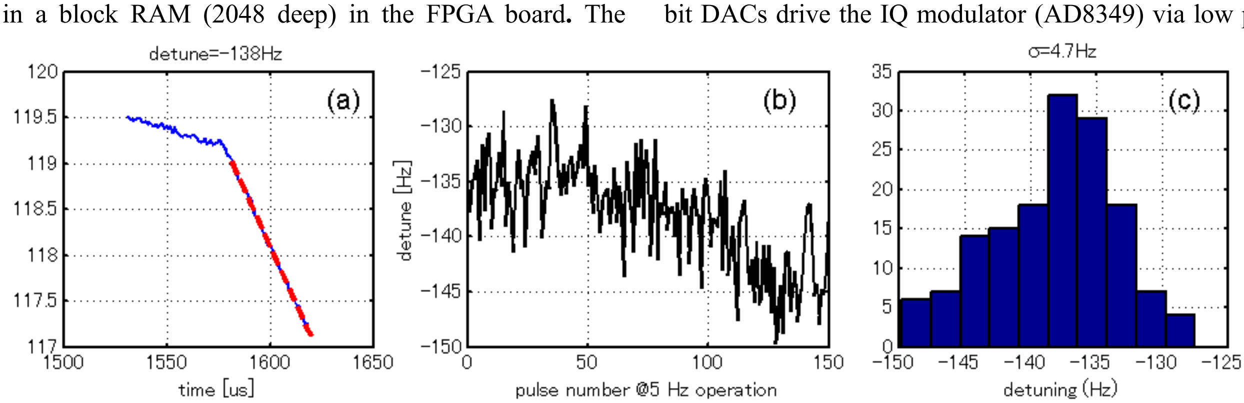

Figure 4: Phase change during the decay time (a), detuning change (b) and histogram of the detuning (c).

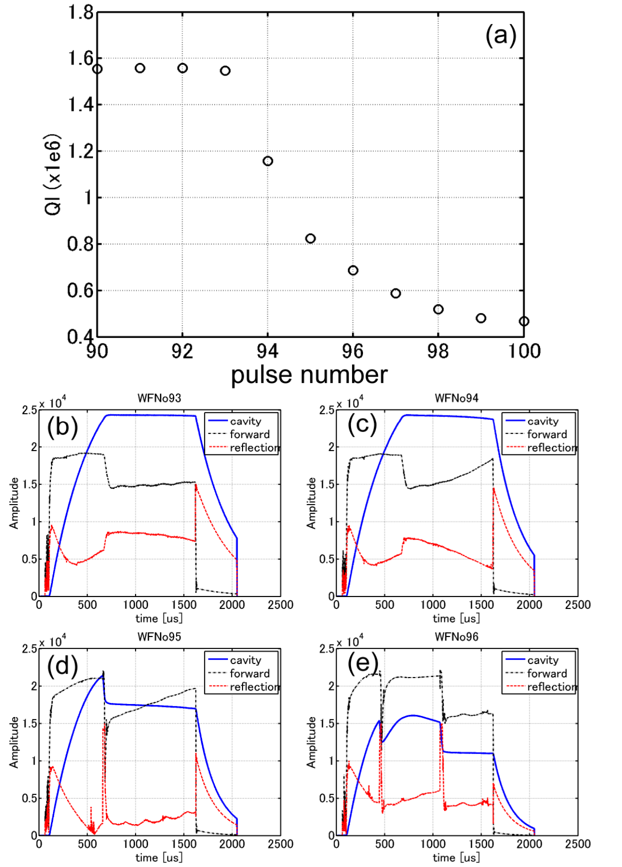

Figure 5: Decrease in loaded Q values (Ql) at quench (a) and waveforms just before and after quench (b)~(e). Blue: cavity field, black: drive power, red: reflection power.

filters that have a bandwidth of 400 kHz. The rf signal is amplified by a klystron driver (max. 500 W) and a klystron (TH2104A, 1.5 ms, max 5 MW, 5 pps).

PERFORMANCE OF THE LLRF SYSTEM

The rf waveforms produced during the feedback operation are shown in Fig. 3. The amplitude of the rf field is an arbitrary value (corresponding to the output of the 16-bit ADC). Only proportional feedback control was applied (without feed-forward) with a feedback gain of 80. The amplitude and phase stabilities are 0.04% rms and 0.02°, respectively. In general, the performance depends on perturbations such as pulse-to-pulse fluctuation of the klystron's high voltage, gain of the klystron driver, and cavity detuning induced by microphonics or Lorentz force detuning. The observed decrease in the amplitude can be attributed to the non-linear characteristics of the klystron driver. The drifts in 150 successive pulses are +/–0.01% and +/–0.02°. Although these results were obtained without using a beam, They satisfy the ILC requirements.

The rf waveforms can be used for online/offline analysis of the cavities. The microphonics of the cavities were evaluated by using cavity detunings, which were calculated from the phase changes when the rf field decayed (Fig. 4 (a)). Figure 4 (b) shows detuning changes during the application of 150 successive pulses. The histogram of detuning (Fig. 4 (c)) indicates that the microphonic values are approximately 4.7 Hz rms, which is similar to those of FLASH (4 Hz) [8].

Another example of llrf off-line analysis is the observation of waveforms when quench occurs. Figure 5 (a) shows the loaded Q values, which were calculated from the time constants of field decay, along with the waveforms. Figure 5 (b)~(e) show the waveforms before and after quench took place. When quench occurs (pulse #94), the cavity field decreases, despite an increase in the klystron drive power. The loaded Q values of successive pulses (#95, #96, etc.) decrease rapidly. Since the quench spreads fast (in one rf pulse), the rf power should be cut off immediately in order to minimize the heat load of the cryogenic system during quench (or decrease in loaded Q). New software is being developed to facilitate quench detection and the instant stopping of the rf if quench occurs.

SUMMARY

The measured rf stabilities of the digital llrf system at the STF were 0.04% in amplitude and 0.02°. in phase. The rf waveforms obtained using the digital llrf system are utilized for the evaluation of cavity parameters such as microphonics and for determining Lorentz force detuning. The operation of 4 superconducting cavities is scheduled for November 2008 and methods such as vector sum control method will be examined.

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