Digital LLRF system for TRIUMF ISIS buncher

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LOW LEVEL RADIO FREQUENCY WORKSHOP 2023

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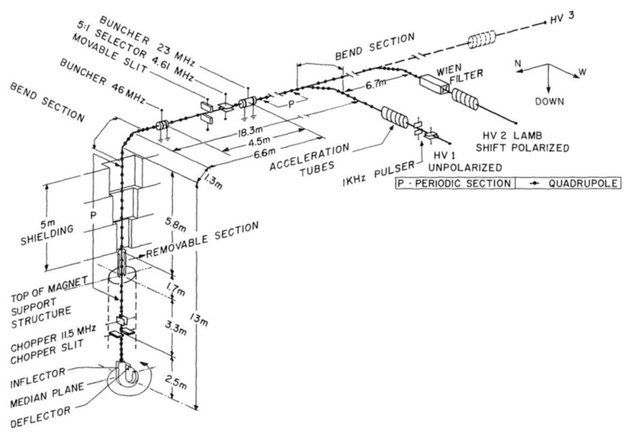
Abstract

The ISIS buncher system at TRIUMF operates at frequencies of 23MHz, 46MHz, and 4.6MHz. The 23MHz and 46MHz signals drive two buncher cavities, while the 4.6MHz signal drives the 5:1 selector. The reference signal for the LLRF system is obtained from the pickup signal of the cyclotron's cavity, ensuring that all frequencies are synchronized with it. In the event of a spark occurring in the cyclotron's cavity, the LLRF system may lose its reference signal. To address this, a phase-locked loop with a track and hold function is designed to maintain the frequency when the reference signal is absent. The 4.6MHz frequency is derived by dividing the 23MHz reference signal frequency by 5. Designing the divide-by-5 circuitry posed specific challenges in a binary system.



Injection beam line

SYSTEM DESIGN

- **Hardware based on TRIUMF digital LLRF**

System

ZYNQ 7030 FPGA

Maximum 4 channels of RF inputs and outputs.

250MSPS ADC and DAC

- Re-designed firmware for ISIS buncher system.

The 1/5 frequency divider is designed

Width of the PLL is increased to 38 bits.

The reference track and hold module is designed.

- Based on Linux operating system.

Debian 11 operating system

Linux HID gadget

- USB HID device

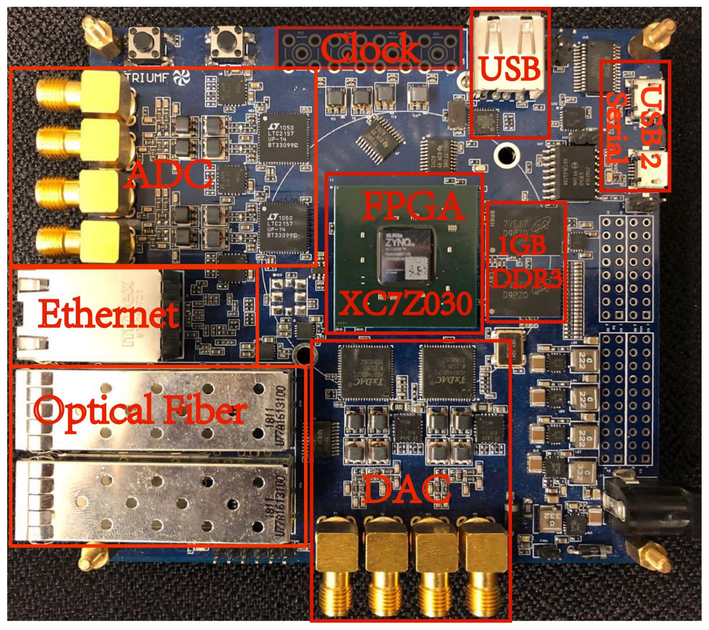
48 bytes customized USB HID commands

No drivers needed on windows OS

- All programmable parameters

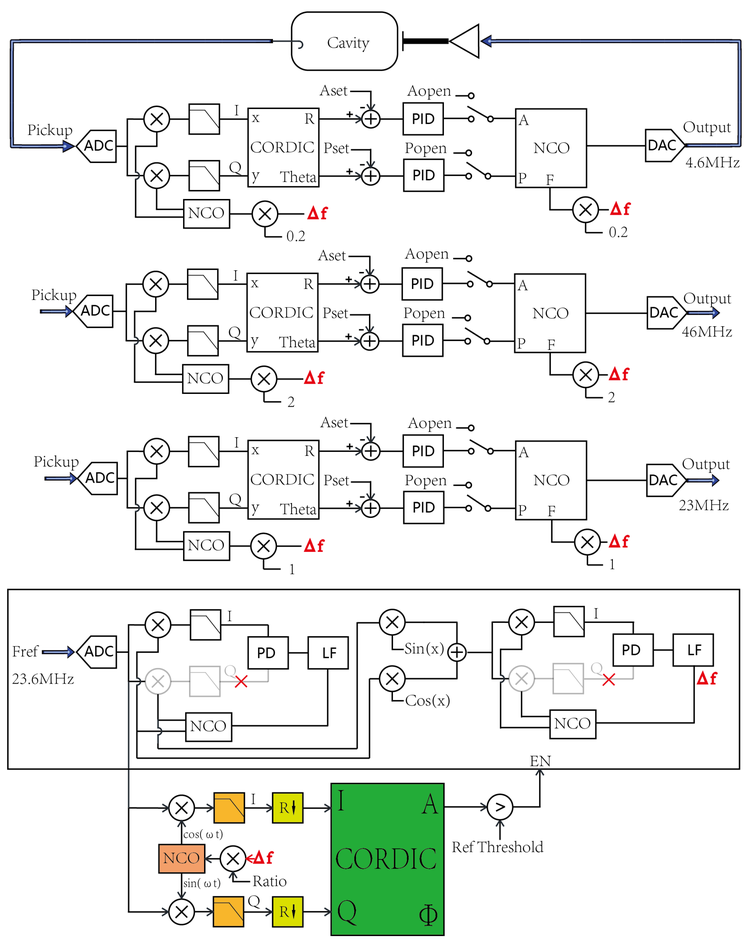
Reference signal frequency, threshold, output frequency, amplitude and phase parameters are all run-time programmable.

Hardware



TRIUMF digital LLRF system

Firmware



Track and hold PLL

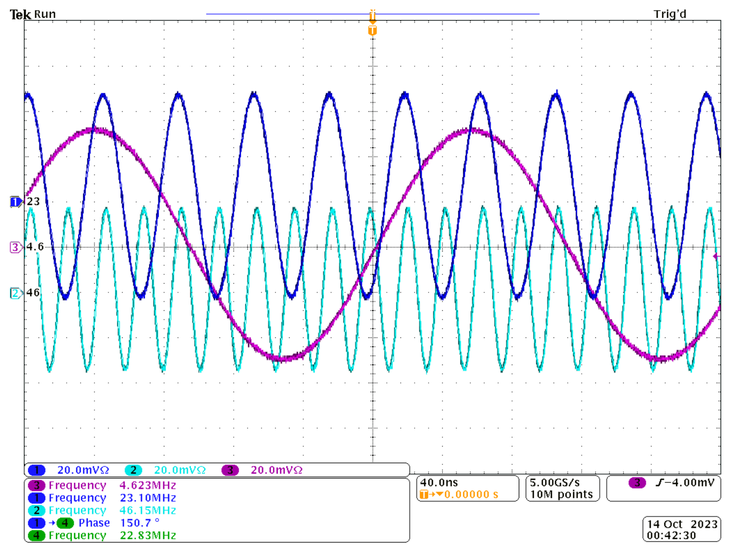
- **Track mode: Phase-lock to the reference signal**
- Hold mode: stop at the current frequency when the reference signal is gone
- Reference threshold value controls the PLL mode
- 1/5 reference frequency

It is very challenging to get the 1/5 reference frequency in FPGA. A python threat is used to switching the frequency ratio periodically.

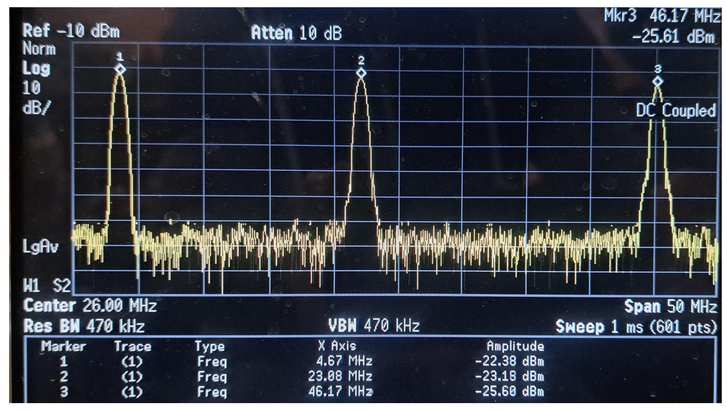
- Phase detector

The phase detector is re-designed to insure there is only one working point In [0,359].

Test results



Waveform of the LLRF system outputs



Spectrum of the LLRF system outputs

Conclusion

A digital LLRF system has been build for ISIS buncher. The new LLRF system is built based on the Linux Operating system and serves as an all-programmable platform. During the 2023 winter shutdown, the LLRF group successfully installed the digital LLRF control systems to the ISIS buncher system.

The initial test results for the system with beam have been positive, indicating the improved performance and functionality of the LLRF system. The digital LLRF system for ISIS buncher demonstrated greater abilities, flexibility, and ease of use, providing a significant advancement for the LLRF group and facilitating the control of RF systems at TRIUMF.

Discovery, accelerated