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VIRTUAL SIGNAL SPECTRUM ANALYZER DEVELOPMENT BASED ON REDPITAYA AND EPICS FOR TUNE MEASUREMENT IN BEPC-II

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Abstract

An independent tune measurement system was developed in BEPCII using Direct Diode Detect (3D) technique. The system includes two diagonal electrode signals of a set of BPMs, a self-designed board based on Direct Diode Detect (3D) technique, and a commercial spectrum analyzer. For replacement of the commercial spectrum analyzer and integrated to the central EPICS system, an EPICS device driver is developed based on the EPICS base and ASYN module support, using an open source digital electronics Red Pitaya and its software "Spectrum". According to the application requirements of tune measurement in BEPCII, the device driver finds the frequency point and power value corresponding to the X&Y tune between 631 to 874 kHz. The spectral resolution is 119 Hz. An EPICS IOC is built and run on Red Pitaya for accessing the device driver. A CSS-based user interface shows the signal's power spectra and the tune frequency directly.

INTRODUCTION

The betatron tune is one of the most important parameters of the storage ring, especially for colliders. It plays a crucial role in brightness optimization. At present, the tune measurement system in BEPCII [1] can only be monitored when the beam betatron oscillation amplitude is large enough due to its sensitivity problem. In order to solve the defect, a high-sensitivity tune measurement system based on a diode peak hold circuit is under development and being teseted, which is refered to as Direct Diode Detection (3D) tune measurement system. An original 3D tune measurment system was developed by Marek Gasior originally in CERN according to the work of predecessors [2, 3].

The 3D tune measurement system requires a spectrum analyzer to perform spectrum observation. And its results are expected to be integrated to the central control system EPICS and database system of BEPCII. The commercial spectrum analyzers are usually expensive, and the integration with the central control system cannot be achieved easily for non-open-source.

This paper presents development of a virtual spectrum analyzer for the 3D tune measurement system in BEPCII. It is based on a digital electronics platform named Red Pitaya [4] with an embedded linux operating system on it. An API for BEPCII 3D tune measurement is developed firstly based on the open source code "Spectrum" of Red Pitaya, allowing users to survey frequencies corresponding to the X&Y tunes of the collider. Then, an EPICS driver support for spectrum analyzer is written, based on ASYN [5], redpitaya-epics [6] and the API source code. An EPICS IOC for 3D tune measurement system is built and tested with a CSS-BOY interface.

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HARDWARE ARCHITECTURE

The hardware architecture of 3D tune measurement system is demonstrated in Fig. 1. Signals from the two BPM diagonal pickups, with main frequency range 499.8±1.262MHz, are processed by the 3D tune measurement electronics, and then transferred to an EPICS virtual spectrum analyzer running on the Red Pitaya board. The graphical user interface was developed using CSS (Control System Studio) which executes on a remote PC，which located in the same LAN (Local Area Network) with the Red Pitaya board.

Red Pitaya is built around a Xilinx Zynq-7010 SoC processor combined with an FPGA. The board has two 14 bits ADCs with sampling rates up to 125MHz and a SD-Card slot for holding a Linux operating system. Spectrum Analyzer turns Red Pitaya into a 2-channel DFT Analyzer, with frequency span from DC up to 62.5MHz.

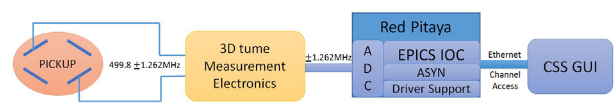

Figure 1: The hardware architecture of the 3D tune measurement system for BEPCII.

SPECTRUM ANALYZE API FOR BEPCII 3D TUNE MEASUREMENT

All Red Pitaya applications are web-based and do not require any software configurations on the remote PC. Users can access APIs via a web browser (such as Firefox). Red Pitaya is known for its open source, but the spectrum analyzer API that is currently in use is spectrumPro. The original open source code of spectrum analyzer API we use is outdated and written in the C language and is independent of the present header files like rp.h which are responsible for data interaction with the DDR3 memory.

To solve "Application Not Loaded" problem when access the spectrum Analyzer API, lots of debug statements are added to the C source code. Then according to error or warning messages in the debug.log file, the API can be accessed remotely via a web browser after many "nignx [7]: worker process: symbol lookup error" errors are excluded.

Data sampled and initially processed by Red Pitaya is located in the internal storage area of Zynq, and its storage depth is limited to 16×1024×14 bits. However, considering the problems of network traffic and data refresh rates on the web browser, the spectrum analyzer extracts

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data at a ratio of 4:1 after the DFT algorithm, which increases the spectral resolution by 4 times.

In the tune measurement system, the amplitude of the signal input to Red Pitaya is less than 1V, and the signal frequency is less than 1.262 MHz. Since the tune of the collider is semi-integer symmetrical, the most effective frequency is distributed between DC and 631kHz or between 631 and 1262kHz. Due to lots of noise signals locate in the frequency range 0~631kHz, the spectrum components between 631 and 1262kHz are more interesting. Therefore, the sampling frequency 1.97 MHz is selected to detect the effective spectral component of the tune measurement system. Then the effective spectrum range is 0~976kHz with a corresponding spectral resolution 477Hz.

In the BEPCII 3D tune measurement system, it is required to have at least multiple power points in the range of 1.262kHz to detect the peak power frequency accurately. To improve the spectral resolution 477Hz, an offset is brought into the frequency output calculation system instead of data extraction without changing the output point number 2×1024. Then the spectrum API ranges from 631kHz to 874kHz with a spectral resolution 119Hz. Since the tune frequencies of BEPCII is very close to half-integer which equals to the frequency 631kHz, 874kHz is larger enough to show all the interesting frequency components.

Figure 2: Tests for spectrum API: The upper one is tests in Laboratory with signal at 667kHz & 220mV; The bottom one is tests in the BEPCII IP Station, in which the peak frequency 624 & 638kHz both correspond to the X tune in BEPCII.

The focus of the tune measurement system is to detect the X&Y tune frequency points automatically. In view of the fact that there is no overlap between the X and Y tune frequency band in BEPCII, the 631 to 874kHz frequency band is divided into two sections respectively corresponding to the frequency range of the X&Y tunes. Methods for finding the tunes are:

1. Calculates the power of the data after the DFT algorithm is executed;
2. Finds the peak power points separately in the two sections, and record their power and frequency value;
3. Calculates the X&Y tune values with their frequency divided by 1.262MHz respectively.

After the modification and compilation of the API is completed, tests are carried out in laboratory and the BEPCII IP (Instrumentation Position) station. The results are shown in Fig. 2. Tests in the laboratory demon-strates that the smaller the input amplitude, the better the signal-to-noise ratio on the spectrum charts; Tests in the IP station shows that the virtual spectrum analyzer API is fully capable of meeting the needs of BEPCII 3D tune measurement system.

SPECTRUM ANALYZER BASED ON EPICS

EPICS is a set of Open Source software tools, libraries and applications developed collaboratively and used worldwide to create distributed soft real-time control systems for scientific instruments such as a particle accelerators, telescopes and other large scientific experiments [8]. Asyn is a general purpose facility for interfacing device specific code to low level communication drivers, and its primary target is for EPICS IOC device support [5]. Andraz Pozar from Australian Synchrotron developed an EPICS device driver support for Red Pitaya based on asyn, named redpitaya-epics, which supports for fast data acquisition and analogue and digital in/outs [9]. This paper aims to contribute a virtual spectrum analyzer based on EPICS for the BEPCII 3D tune measurement. Works for spectrum analyzer development is based on both the spectrum API and the redpitaya-epics source code. There are some problems to be solved for Spectrum Analyzer realization:

1. Redpityaya-epics calls for the header file rp.h to access the memory areas. While the file fpga.h in the spec-trum API accesses the memory data independently, which conflicts with functions in the file rp.h.
2. Redpitaya-epics is based on C++ while the sepctrum API is based C language. This makes many functions in the Spectrum API not recognized by redpitaya-epics.
3. The default equalization filter parameters and the default sampling frequency setting in Red Pitaya library file librp.a or librp.so, are very different from parameters in Sepctrum API source code.

The EPICS driver support is developed for ai and wave-form record support. And an EPICS IOC is created based on the driver support and runs on the Red Pitaya Linux operating system. The CSS GUI on a remote PC access the EPICS PVs and presents users the results of

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power spectral and the auto-detected peak power points, which is shown in Fig. 3. This EPICS virtual spectrum analyz-er has been tested in laboratory and its noise is main-tained in the range of -110~120dBm.

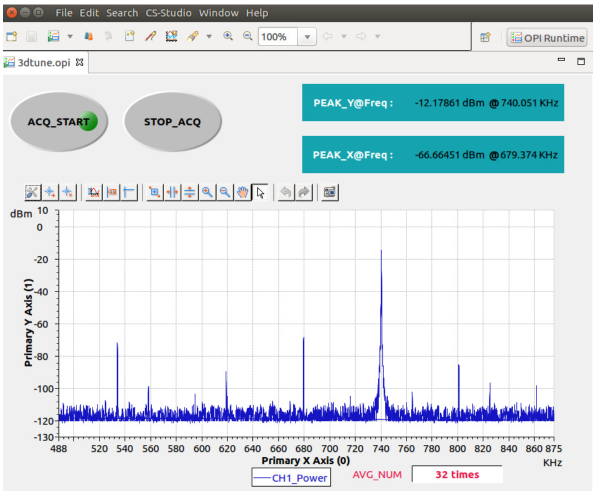

Figure 3: Tests for the EPICS IOC as a Spectrum Analyz-er.

CONCLUSION

A virtual spectrum analyzer is integrated into EPICS and meeting the requirements of BEPCII 3D tune measurement system. An EPICS IOC based on spectrum analyzer driver support is created and tested in laboratory. Tests will go on in the IP Station in future when BEPCII runs in Collision mode. More importantly, the development of the Red-Pitaya-based EPCIS IOC provides a choice for device selections in future data acquisition systems.

ACKNOWLEDGEMENTS

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