COMPACT SINGLE PASS BPM

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Abstract

Monitoring and subsequent optimization of linacs and beam transfers requires specific instrumentation for beam position data acquisition and processing. Spark single pass BPM is the newly developed prototype intended for position and charge monitoring in classical single-multi bunch operation linacs and transfer lines. Flexibility of the instrument enables the installation on electron and proton single pass machines. The motivation, processing principles and first results are presented.

INTRODUCTION

In this paper we introduce a compact platform that aims to host a wide range of applications. First instruments built on this platform will be Spark EL and Spark HL (see Fig. 1). The instruments will be designed for processing of electron beams (Spark EL) and proton beams (Spark HL) in linear accelerators and beam transfers.

Figure 1: Libera Spark front/back panel.

A NEW PLATFORM

Looking at the beam instrumentation used to monitor and stabilize an accelerator, every device suits a specific role, but it is possible to identify some key components that are always present:

- RF front-end and analogue signal processing chains
- Internal communication buses
- Power supply unit
- Cooling system

In this new development, we take advantage of the latest advances in SoC technology to introduce a compact platform that combines a high level of hardware integration with our knowledge regarding reconfigurable analogue signal processing.

HW and SW Integration

Hardware and software are designed taking in account the balance between generality and optimization. It will be always possible to add specific features to customize it, opening at the same time the way for developing different applications, as shown in Fig. 2.
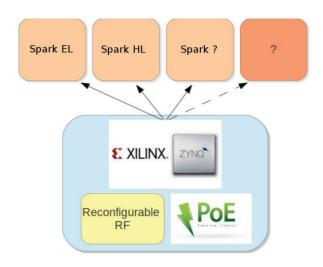

Figure 2: Platform concept based on SoC.

The core part is the SoC Xilinix Zynq 7020 [1] which combines the high-speed processing of the FPGA together with the flexibility of a CPU, all within the same chip. The inner communication between the two entities and the chance to share the same memory removes at the same time two of the biggest bottle-necks that still characterize separate-chip solutions:

- No communication protocols needed
- No data copy between FPGA and CPU.

The specifics of the analogue front-end will cover the user requirements. Integrations with specific band-pass filters, phase-locked-loop (PLL) and variable attenuators are possible if the application requires them. Fig. 2 shows an example of the HW architecture of a BPM application.

Low Power Instrument

SoC requires less power than a multiple-board solution. Furthermore proper selection of the RF components (amplifiers, analog-to-digital converters, etc.) reduces the amount of heat that the cooling system has to treat. This enables the way towards passive cooling with the integration of the heat sink in the crate. Consequently fans are no longer needed, and from the system point of view, the main advantages are:

- No moving parts means no maintenance required
- Fans-induced noise is no longer present on the signals
- Less space and less power required from the system.

With the low power requirement, precisely less than 15 Watt, the system can be powered over Ethernet according to the PoE standard IEEE802.3af. In the case of accelerator applications, if the unit is powered over Ethernet, it is possible to put it closer to the machine (e.g.

5m), reducing at the same time the cost of cables and noise on the signal.

Easy SW Maintenance

The unit software can be basically divided in the design that configures the FPGA, application and other interfaces supported by the operating system on the CPU side. The operating system running on Xilinx Zynq SoC is Linux OS.

In the presented platform, the software packages will not be installed in the device memory, but both FPGA and Linux code will be loaded from the same image when the unit is turned on. In more details two different boot procedures will be supported:

- Memory card boot: if a memory card is inserted in the device socket (see Fig. 2), then the Linux OS will boot from the image contained in the memory
- File Transfer Protocol (TFTP) boot: if no memory is inserted, the boot procedure will start from the FLASH memory, and the software image will be downloaded from a configured TFTP server

In both cases a software update can easily be realized replacing the software image in each unit, with no need to deal with packages and configuration files in the operating system. In particular for a complete set of units configured to use TFTP, only one image should be modified.

CONTROL SYSTEM INTEGRATION

On the top layer, Libera Spark provides the MCI with a development package and Command Line utilities for open interaction in different control systems. On top of the MCI, various adaptors to different control systems can be implemented (EPICS, Tango, etc.). The EPICS interface is part of the standard software package.

DATA PROCESSING

Both instruments, Spark EL and Spark HL, share same data processing which is initiated by the external event signal. The short signal from the detector is first shaped by the analog front-end filtering, designed in relation to the accelerator parameters and than sampled with 14 bit ADC converters. The maximal sampling frequency can be set to 125 MHz.

Through the configuration of various software parameters, Libera Spark offers processing of various beam types (flavors). After the hardware triggers signal which announces the arrival of the bunch, the search of bunch signal is started. The bunch signal is detected in comparison with the threshold parameter, then a useful part of the signal is defined with the pre-trigger and post-trigger parameters. The sum of the pre-trigger and post-trigger defines the processing window. The signal energy is calculated from the signal as defined by the processing window. After calculating the four signal amplitudes – Va, Vb, Vc and Vd – the beam position is calculated

using formulas for X and Y. Four options can be used for position calculation:

- Diagonal pickup orientation – Linear formula
- Diagonal pickup orientation – Polynomial formula (3rd order)
- Orthogonal pickup orientation – Linear formula
- Orthogonal pickup orientation – Polynomial formula (3rd order):

$$X = X_{OFFSET} + \sum_{ij=0}^{3} K_{Xij} \left(\frac{(V'_A - V'_C)}{(V'_A + V'_C)} \right)^i * \left(\frac{(V'_B - V'_D)}{(V'_B + V'_D)} \right)^j$$

$$Y - Y_{OFFSET} + \sum_{ij=0}^{3} K_{Yij} \left(\frac{(V'_A - V'_C)}{(V'_A + V'_C)} \right)^i * \left(\frac{(V'_B - V'_D)}{(V'_B + V'_D)} \right)^j$$

In the case of longer beam structures, similar data processing is used, based on the appropriate signal windowing [2]. The data calculation is initiated by the external trigger event and is automatically stopped after the bunch structure is over (see Fig. 3). The decimated batch of data is available for transmission to the control system. In the case of continuous wave operation, the unit continuously processes and outputs the stream of decimated beam position data.
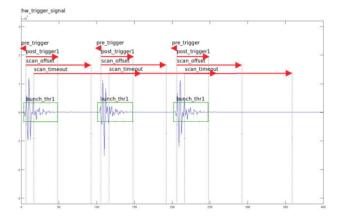

Figure 3: Macro-pulse mode.

POSITION MEASURING PERFORMANCE

Measurement performance mostly depends on the Spark front-end configuration [2]. Its parameters are set in accordance with main accelerator parameters. The driver for the RF front end configuration is type of sensor (stripline, capacitive, shoe-box) and beam flavor (single bunch, macro-pulse, etc.).

Spark EL

The standard type of Libera Spark EL implements 500 MHz SAW filters with 10 MHz bandwidth. Relatively narrow filter serves to lengthen the short, few picoseconds long signal, to a longer structure (nanoseconds). At operational beam charges, the position measurement resolution is close to 3 µm (kx = ky = 10 mm) for a single-bunch beam structure (see Fig. 4). Input signal is presented on Fig. 5.
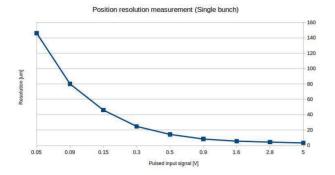
Figure 4: Single bunch measurement performance versus input signal level (0 dBFS = 5 V peak).
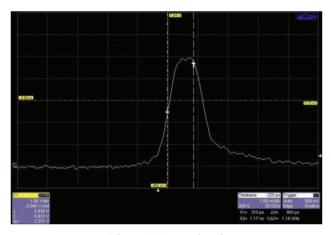

Figure 6: Macro-pulse measurement performance versus input signal level (0 dBFS = 22 dBm).

CONCLUSION

The development of new BPM prototypes for linear machines based on the SoC technology has been presented in this article. The introduced platform combines knowledge about reconfigurable RF front-ends with the advantages of a compact and passively cooled instrument that can be powered over Ethernet and booted from a server using SW image.

As a first development, the linear BPM prototypes are promising applications that show very good performances, simple and straightforward architecture and an excellent price-to-performance ratio.

REFERENCES

[1] M. Cargnelutti, "Beam position electronics based on system on chip platform", THPAC04, Proc. of NA-PAC2013, Pasadena, California, USA (2013), http://www.JACoW.org

[2] Instrumentation Technologies, "Libera Single Pass E User Manual v1.00", Solkan (September 2011).

Figure 5: Input signal.

Default operational full-scale of the instrument is 5V, but can be configured in accordance to the accelerator beam dynamic range.

Spark HL

The nature of proton beams requires different filtering and RF front-end configuration in compression to the electron ones. Here the pulses are longer and structured in macro-pulses with bunch frequencies typically from 50 MHz to 400 MHz. In this case usually LC filters are used to shape the pulse. The prototype measurements were performed with 62.5 MHz pulsed input signal. Under 1 μm position resolution measurement was reached (kx = ky =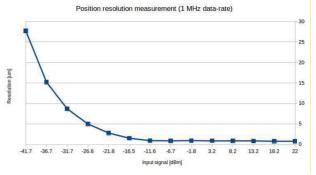 10 mm) at 1 MHz output data rate (see Fig. 6).