COMPACT BEAM POSITION MONITOR FOR ELECTRON AND PROTON MACHINES

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Abstract

Monitoring and subsequent optimization of the linacs, transfer lines, energy recovery linacs and synchrotrons, requires specific instrumentation optimized for beam position and charge measurements. Libera Spark is the newly developed instrument intended for position and charge monitoring in electron and proton machines. The motivation, processing principles and first results at laboratories are presented.

INTRODUCTION

In this paper we introduce a compact platform that aims to host a wide range of applications like various BPMs, Digitizers, Beam Loss Monitors etc. This paper focuses on a new family of BPMs called Libera Spark.

LIBERA SPARK

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 analog signal processing
- Digitalization
- Internal communication buses
- Power supply unit
- Cooling system
- Control system integration layer

In this new development, we take advantage of the latest advances in System on Chip technology to introduce a compact platform (see Fig. 1) that combines a high level of hardware and software integration with our knowledge regarding reconfigurable analog signal processing [2].

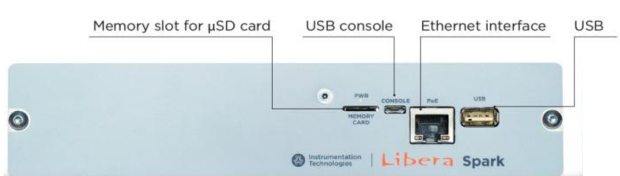

Figure 1: Libera Libera Spark front panel.

HW and SW Integration

Hardware and software are designed taking in account the balance between generality and optimization. This makes possible to add specific features and gives more space for customization, opening at the same time the way for developing different applications, as shown in Fig. 2.

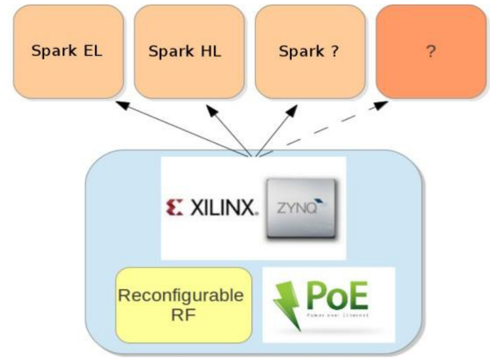

Figure 2: Platform concept based on SoC.

The core part is the SoC Xilinx 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.

Basic building blocks are presented in the Fig. 3. Pulses from the pickup electrodes are passed through the analog processing chains. Depending on the beam type, the chain includes a combination of filters, several attenuation and amplification elements etc. By combining hardware components and specific DSP, various applications can reside on a single platform. The following Libera Spark instruments are currently available [3]:

- Libera Spark EL (Linear electron machines, Energy Recovery Linacs)
- Libera Spark HL (Linear proton machines)
- Libera Spark ER (Electron rings)
- Libera Spark HR (Proton rings, proton beam transfers)

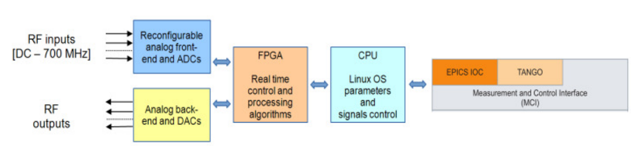

Figure 3: Building blocks.

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.). EPICS interface is part of the standard software package.

ISBN 978-3-95450-169-4

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. The main advantages of such system 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, the system can be powered over Ethernet according to the PoE standard IEEE802.3af.

Easy SW Maintenance

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 Libera Spark both FPGA and Linux code are loaded from the same image when the unit is turned on. Two different boot options are supported:

- Memory card boot: if a memory card is inserted in the device socket (see Fig. 1), then the Linux OS will boot from the image contained in the memory
- File Transfer Protocol (TFTP) boot: if no memory card 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.

DATA PROCESSING

For linear accelerators and energy recovery LINACs, the digital signal processing outputs data for any beam flavour: single bunch, train of bunches (macro pulse) or it can provide the continuous data stream with chosen averaging factor for continuous beam. Stored beam is processed on a bunch-to-bunch or turn-by-turn basis (wide-band data). The turn-by-turn processing is done in frequency or in time domain. Several processing options are specified by the digital signal processing that is specific to instrument version.

INSTRUMENTS, USE CASES AND PERFORMANCES

Measurement performance mostly depends on the Libera Spark version of the instrument and front-end configuration. Its parameters are set in accordance with accelerator type and its main parameters. Furthermore the drivers for the RF front end configuration are type of sensor (stripline, capacitive, shoe-box) and beam flavor (single bunch, macro-pulse, stored beam, etc.).

Electron Linac (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 rms is close to 3 µm (kx = ky = 10 mm) for a single-bunch beam structure (see Fig. 4).

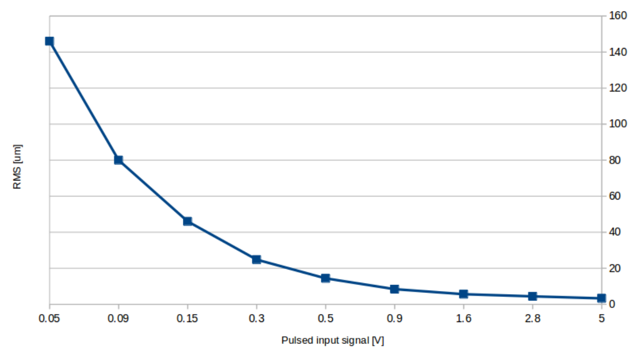

Figure 4: Single bunch measurement performance versus input signal level (0 dBFS = 5 V peak).

First beam tests were performed at ELBE (Electron Linac for beams with high Brilliance and low Emittance) facility in Germany. Tests were performed on 25 kHz repetition rate beam with 60 pC bunch charge (1.5 µA average current only). The position rms was around 10 µm (see Fig. 5); User reported that all noise was mainly real beam position deviations.

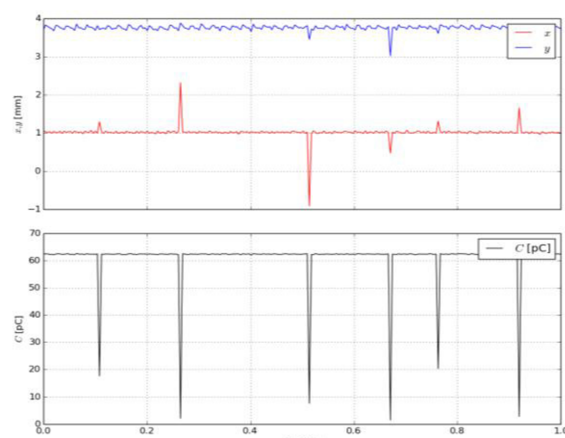

Figure 5: Position and charge measured on 60 pC beam. Spikes in the data are caused by a not synchronized trigger signal and beam injection (250 Hz free running).

Energy Recovery Linac (Spark EL + DWC)

First Libera Spark beam tests at ERL were performed at KEK Compact ERL in Japan. The machine works with 1 µs long beam bursts (see Fig. 6). Post circulation beam signals superimpose on pre circulation beam signals with a constant delay of 0.3 µs. The focus was on the head and tail part of the signal containing only pre and post circulation beam signals [4].

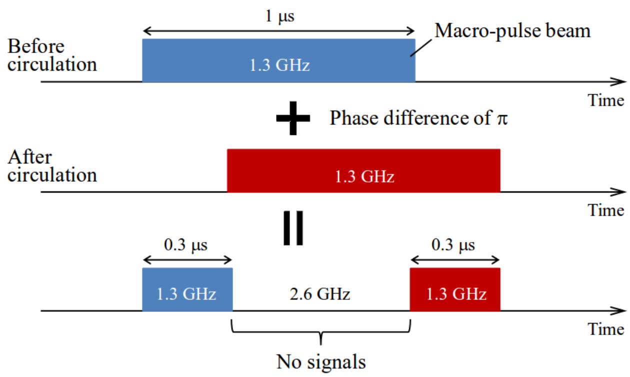

Figure 6: KEK Compact ERL beam pattern.

Bunch repetition frequency in KEK Compact ERL is 1.3 GHz. The signal from the pickup was connected to the Libera DWC (down-converter from 1.3 GHz to 500 MHz) and then to the Libera Spark front end. By proper settings of Libera Spark DSP parameters the useful part of the signal was isolated from the rest. In such way the unit calculated four positions per macro-pulse: head position, two invalid positions and tail position. Expected beam position results were achieved. On the Fig 7, head and tail beam position of five consecutive injections is presented.

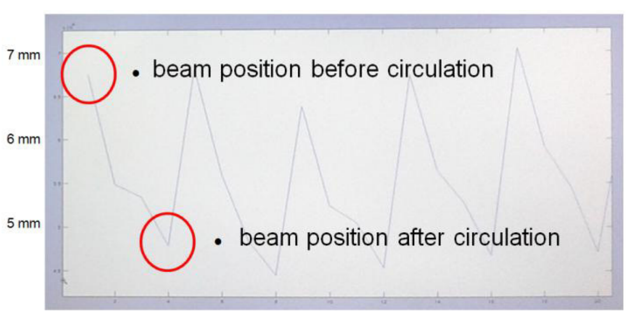

Figure 7: Head and tail beam positions of five consecutive injections.

Electron Synchrotron (Spark ER)

The ER version of the Libera Spark is typically used in booster or storage ring. The instruments differ from others in the main data processing concept (frequency domain) and additional input for the reference clock (for sampling clock PLL).

ESRF (European Synchrotron Radiation Facility) in France, is one of the first users of Libera Spark ER. 75 units are installed in the ESRF booster ring (RF = 352.202 MHz). Submicron position rms measurement was reached during laboratory test at ~ 1 MHz Turn-by-Turn data rate (see Fig. 8).

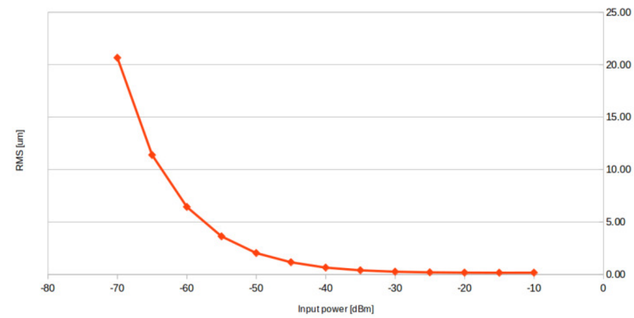

Figure 8: Libera Spark ER position measurement performances.

All the units at ESRF are installed directly in the tunnel close to the BPM sensors, at the location where low radiation doses are present (see Fig. 9).

Figure 9: Spark ER installed at ESRF.

Proton Linac (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 unit measurements were performed with 62.5 MHz pulsed input signal. Under 1 µm position rms measurement was reached (kx = ky = 10 mm) at 1 MHz output data rate (see Fig. 10)

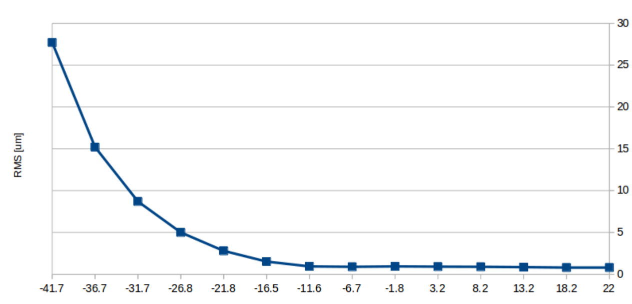

Figure 10: Macro-pulse measurement performance versus input signal level (0 dBFS = 22 dBm).

Compactness, passive cooling with powering over Ethernet makes this instrument perfect candidate for beam monitoring on proton therapy machines. One of the first users who successfully tested and adopted Libera Spark

ISBN 978-3-95450-169-4

HL is ADAM (Applications of Detectors and Accelerators to Medicine) project in Switzerland.

Proton Beam Transfer (Spark HR)

The main purpose of the Libera Spark HR is to provide position information and data for post processing on the circular hadron machines. Specifics of hadron synchrotrons are variable frequency, bunch length and sometimes also signal intensity. Carefully designed low pass filter assures good RF front end linearity within 35 MHz bandwidth. Only linear frequency response of the RF front-end can assure good performances in such variable conditions.

Since the beam in the hadron synchrotron to target transport line equals to the one in the ring before extraction, Libera Spark HR can successfully monitor also the beam during transport. Beam pattern monitored with Libera Spark at CSNS (China Spallation Neutron Source) beam to target transport line is presented on the Fig. 11.

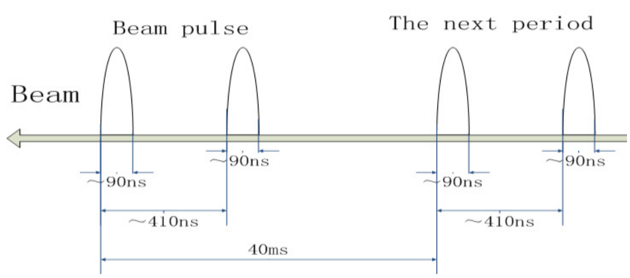

Figure 11: Beam pattern at CSNS ring to target transport line.

CONCLUSION

New family of BPMs for electron and proton 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.

Positive users' feedback proves that Libera Sparks' are promising instruments 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", PAC 2013, Pasadena, CA USA, September 13, THPAC04.

[2] Instrumentation Technologies, "Libera Spark EL HL User Manual and Specifications v1.00", Solkan, November 2015.

[3] Instrumentation Technologies, "New line of Libera products", Libera Workshop 2016, Solkan, Slovenia, July 2016.

[4] R. Takai *et al.*, Design and Initial Commissioning of Beam Diagnostics for the KEK Compact ERL, IBIC2014, Monterey, September 14 - 18.