Design and development of common applications for different particle accelerators*

M.Cargnelutti, D.Škvarč, D.Tinta, R.Hrovatin, Instrumentation Technologies, Solkan, Slovenia

Abstract

The instrumentation used in particle accelerators for machine operation, and even more so for machine physics, demands performance and functionalities which cannot be achieved by using generic instruments from the commercial market. Often the only alternative is to develop specialized and optimized instruments in-house. These unique solutions are not directly usable in other institutes; however, for some particular applications, common solutions do exist which can be designed in a more generally usable way. The goal of this project is to develop generic functionalities and applications that will be useful over a wide set of target environments, solving challenges in the areas of beam position monitoring, single-pass beam measurement, radiation spectroscopy, fast orbit feedback and low level RF control instruments.

Introducing reconfigurable instruments

The basic concept in the development of solutions that will be able to address the issues for a broader range of particle accelerators is *reconfigurability*. This has to be the general way of approaching a problem: first think about how to solve it generally, then think about how to make it possible to adapt the solution to address other similar problems. The technologies nowadays available for hardware, radio frequency and software make it possible: examples are FPGAs, PLD and FPRF.
A reconfigurable design leads to the construction of a system that can match different accelerators, scaling with their requirements with no need to change the hardware components. Furthermore, it makes standardization of the manufacturing process possible, reducing costs while opening the way to user-specific software customizations.

Libera Instruments

The instruments produced by *Instrumentation Technologies* under the *Libera* brand are the target devices of this project. These reconfigurable instruments are the result of a simple principle: identify the common functionalities and building blocks that characterize a broad spectrum of different applications, then join them together to form an HW/SW platform from which all the specific instruments can be developed.

An instrument that addresses a realistic need in a particle accelerator covers the whole structure, from the physical connection of some detectors to the analogue RF front-end, signal sampling and digital processing in FPGA and/or software. The final layer in this vertical is integration within the control system.
As shown in Figure 1, the generic system is typically organized in one or more FPGA-based AMC modules and an embedded computer:

1. The AMC modules are used for real-time input signal processing (analog signal conditioning, A/D conversion, filtering, data storage, etc.) and for the timing synchronization of the instrument with the accelerator control system.
2. The embedded computer hosts the software framework and the application-specific logic. All the data acquired from the AMC modules can be further processed and provided to the user with several standard interfaces (EPICS, Tango, WEB, etc.).

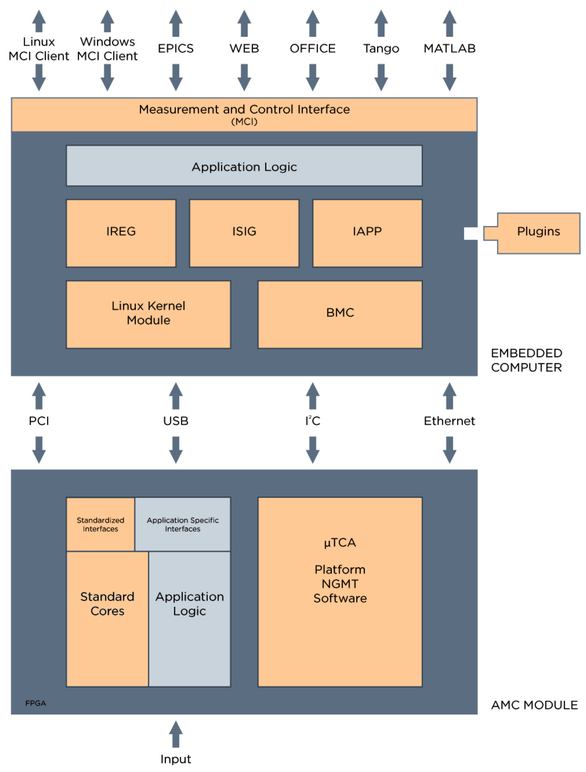

Figure 1: Hardware, Software and communication interfaces of a Libera instrument.

An HW/SW architecture of this type is the ideal basis on which to develop different applications: only the grey blocks in the figure are application-specific and need to be changed during the development of a new product. The result can then be adapted to fit the needs of accelerators characterized by different working conditions, and upgraded by using plugins. A list of the instruments that will be addressed in the project is provided below:

- *Libera Brilliance+* electron beam position processor;
- *Libera Single-Pass E* electron beam position processor for single-pass machines;
- *Libera Single-Pass H* hadron beam phase & position processor for single-pass machines;
- *Libera LLRF* digital RF stabilization system;
- *Libera Spectra* digital pulse processor for spectroscopy experiments.

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Plugin development within Libera Brilliance+

The instrument features high precision position measurement of the electron beam in the storage ring and in the booster. It provides several data paths at different sampling rates, each with own bandwidth and resolution.

Figure 2.a: Libera Brilliance+.

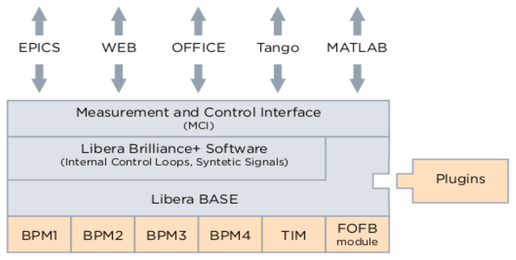

Figure 2.b: Libera Briliance+ HW/SW structure.

During the first months of the project, the work has been focused on the development of three new plugins for the Brilliance+ electron beam position monitor [1], shown in Figure 2.

Plugins are a smart and quick way of extending the functionality of an application, without the need to upgrade the software binaries of the application. The *LiberaBASE* software framework provides an interface that handles the installed plugins, thus upgrading the application functionalities and extending the user experience. Three new plugins have been developed in response to customer requirements and feedback:

1. The ***Statistics plugin*** provides statistical information on the beam position. The average value and standard deviation of the X and Y beam coordinates are available for the *Slow Acquisition (SA)* stream and the *Turn-by-Turn (TbT)* signal. The user can set the number of data samples to use for the calculation and the update mode (*on trigger and periodic*).

2. The ***FFT plugin*** is an efficient implementation of the *Fast Fourier Transform* algorithm, applied on the X and Y coordinates of the TbT signal. The frequency resolution is user configurable and can be set by the number of required output samples, from 1 to 2^{16}. The calculation is based on a mixed-radix algorithm, which enables access to the signal on trigger up to rates of 10Hz.

3. The ***Single-Pass plugin*** introduces a functionality that makes Libera Brilliance+ able to perform single-bunch position measurements (e.g. in transfer lines or injector) [2]. The position of the bunch is computed through time-domain processing of the ADC raw data, so the system needs to be synchronized with the bunch arrival.
   The window that defines the useful samples on which the calculation is performed is defined by three user-settable parameters: the threshold level used to detect the bunch pulse, the number of pre-trigger samples and the number of post-trigger samples. Figure 3a shows the typical ADC signal acquired by the instrument while Figure 3b plots the position resolution over the bunch charge. Good results are achievable for bunches with a charge above 10 nC.

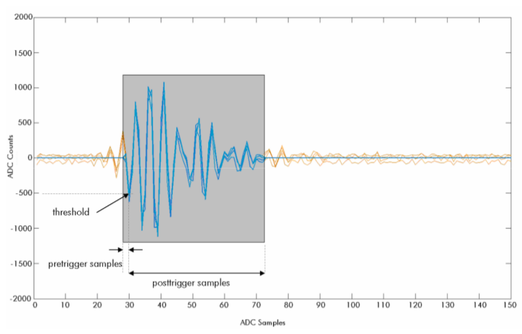

Figure 3.a: acquired ADC data and parameters for single-pass bunch position calculation.

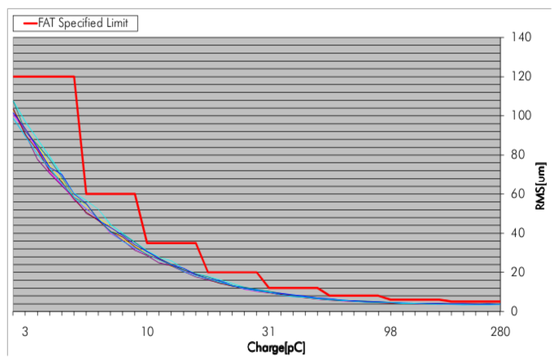

Figure 3.b: resolution in the bunch position calculation over the bunch total charge.

Conclusion and future work

General knowledge of accelerators and their applications has been acquired during the first months of the project. Three software plugins for the Libera Brilliance+ Beam Position Monitor have been developed, giving users a way of upgrading their instruments with new features without the need for software updates. Future directions include further software development for existing devices as well as an analysis of emerging accelerator technologies in order to find requirements and potentials for new instrument developments.

References

[1] Libera Brilliance+ user manual.
[2] Libera Brilliance Single Pass position measurements, A. Kosicek, M. Znidarcic, PAC09.

Instrumentation Technologies, d. d., Velika pot 22, SI-5250 Solkan, Slovenia
P: +386 5 335 26 00, **F**: +386 5 335 26 01, **E**: info@i-tech.si, **W**: http://www.i-tech.si

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