FEL AND LIBERA BOTH PUSH PERFORMANCE INTO NEW FRONTIERS

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Abstract

Free Electron Lasers and Libera electron beam position processor share a common vocation – they both push performance into new frontiers. Advances in electron accelerator technology that enabled FELs to fulfill their earliest days promises have also been due to the recent developments in the beam instrumentation. Libera that has till now been successfully employed in the light sources projects promises to become an indispensable tool also in the FEL field. The three main advantages of Libera are: all-in-one, customization and connectivity. All-in-one is the concept of unification of various building blocks and thus various functionalities in one product. The customization is enabled by the product's reconfigurability that allows it to grow and support new requirements and application without changing hardware. The consequence of the two is the capacity of the single instrument to perform a variety of tasks that before were split among different devices. Connectivity improves the communication between controls and beam diagnostics, brings out-of-the-crate-freedom and opens unforeseen possibilities for feedback building, inter-accelerator cooperation and remote technical support.

INTRODUCTION

FELs are often called the fourth generation light sources. Even if they are quite different from storage rings there is one goal they certainly have in common: a high quality beam. For FELs the quality of the electron beam is measured by the brightness, where is it not only necessary to create a bright electron beam but it is also necessary to preserve the brightness as the electron is accelerated and transported to the laser. From the earliest days of FELs, it was clear that they were capable to overcome the limitations of the previous generations light sources in the field of very high average power and very short wavelengths. But it is only the recent developments in electron accelerator technology that enabled FELs to start to fulfill their earliest day promises.

With a practical example of Libera we would like to show that the revolutionary design of this beam position processor could with success be employed to improve the quality of beam. We start with the description of the first member of the Libera product family, the electron beam position processor, which is an all-in-one, customizable product with rich connectivity options. It is intended for demanding beam position monitoring and local and global feedback applications on the light sources.

However, a Libera common, reconfigurable hardware platform allows expanding the number of family members. Developing a new Libera member, which would cover the specific needs of pulsed machines like free electron lasers is certainly an option, which we demonstrate with some preliminary measurements in the final paragraph. Each user can customize various attributes of the system to its needs, yet at the same time benefit from the portability of the core all-in-one encapsulated software. Flexible software architecture allows rapid adaptation to multiple applications. By leveraging "commodity" technologies, this flexibility is actually achieved at reduced cost. The use of "open standards" for intra- and inter-system communication simplifies integration within the lab, feedback building, and enables a broader view of integration between research facilities

LIBERA ADVANTAGES

Libera electron beam position processor is the first member of the Libera family. Its advantages are as follows:

All-in-One

All-in-one is the concept of unification of various building blocks and thus various functionalities in one product. Libera is an all-in-one solution that enables accurate beam position monitoring, trouble-free commissioning, and local and global feedback building. The timing and housekeeping functions do not span across multiple boards in different racks, but are all contained in a single module.

Customization

Customization is a capability that allows adaptation of functionality of the device to specific requirements without changing hardware. For the purpose of this paper we identify three types of customization:

The parametric customization allows adjustment of performance by simply changing parameters, without affecting architecture of the programmable hardware. Examples are analog board gain control and FIR filter bandwidth by changing tap settings.

The architectural customization involves changes of logic configuration (FPGA firmware, DSP code and other software) to optimize performance for a particular purpose. It allows building specific logical and signal processing blocks, data-flow paths and algorithm implementations.

The customization of communication interfaces involves communication interfaces that can facilitate implementation of different communication standards without changing hardware.

Connectivity

Fast serial interconnect technologies provide a brand new perspective on the process of developing high-availability and next-generation accelerator control and feedback systems.

In general, individual modules may have their own processors, operating systems and memory and can communicate independently with other modules. Because nodes are operating-system agnostic, integration is no longer required at the driver/backplane level but ascends to the network and transport layers, using standard protocols, which means significant time savings and simpler design models.

LIBERA BUILDING BLOCKS

In the following part of the paper we discuss details about the Libera electron beam position processor. A 1U 19” enclosure with a power supply accommodates analog and digital boards, which are supported by software that is easily adjustable to customer needs.

Analog Board

The analog board consists of a quasi-crossbar switch, four identical RF channels, four analog-to-digital converters, and an interface to the digital board.

The innovative patent-pending quasi-crossbar switch matrix unites the benefits of both the multi-channel and the multiplexed system, and at the same time compensates for the disadvantages of the two. We achieve reproducibility and good “beam vs. current” dependence, which are multiplexed system characteristics and – using a multi-channel approach – we ensure a broader band of operation facilitating position measurements on a turn-by-turn basis. Specifically, the switch facilitates redirection of any of the four input signals to any of the four RF channels.

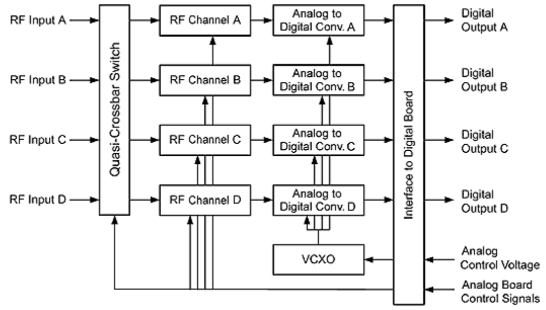

Figure 1: Analog board block diagram.

Digital Board

Core building blocks of the Digital Board are the FPGA (Free Programmable Gate Array), SBC (Single Board Computer) and Memory. The board has also a very rich set of interfaces.

The Virtex II Pro **FPGA** with two IBM PowerPC™ 405 processors from Xilinx is the core of the digital board. It is a system-on-chip (SoC) solution, which facilitates the following functionalities: digital signal processing, communication, formatting, timing, and housekeeping. This architecture allows replacement of some hard-wired DSP functionality with more flexible procedural description of algorithms. Another powerful feature of the Virtex-II Pro FPGA is integrated up to 3.125 Gbps Rocket IO transceivers. The transceivers address all existing connectivity requirements as well as emerging high-speed interface standards.

The **SBC** (Single Board Computer) built around a StrongArm-based Intel Xscale PXA255A processor, is a mezzanine board. It provides application software, bootstrap for the configurable FPGA logic, configuration, diagnostics and maintenance of Libera. Programming of the FPGA via SBC is extremely efficient and it takes approximately 1 second. The SBC downloads the FPGA code via LAN, facilitating easy configuration of a BPM system consisting of many Liberas. The embedded Linux operating system with networking capabilities simplifies integration into an accelerator control system. Fast Ethernet is a native networking solution.

High capacity **Memory** enables the storage of a large amount of data. The basic Libera electron beam position processor configuration allows storing 32 Mbytes of data or 1 million turn-by-turn samples.

The **SFP** (Small Form Pluggable) widely supported open standard enables hot swap of various types of fiber optic and copper-based transceivers into host equipment. This provides the user with the flexibility to choose between different protocols. Applications include: Gigabit Ethernet, Fibre Channel, and Infiniband.

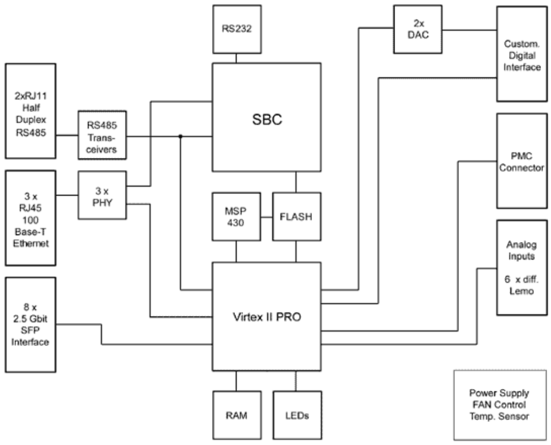

Figure 2: Digital board block diagram.

Software

The software is composed of system software and application software. The application software is limited to the SBC. System software, on the other hand, spans FPGA with embedded PowerPC processors, in addition to the SBC

The **System Software** can be roughly divided into the operating system component, covering GNU/Linux and the embedded, digital signal processing (DSP) component on the FPGA. The key elements of the latter are various filtering and decimation algorithms. These can be tuned to the end-user’s requirements so that BPM data is available on a precise time scale, with desired bandwidth and accuracy. Additionally, fast feedback can be implemented upon the end user's request. The GNU/Linux operating system on the SBC provides a flexible and capable platform for such tasks as networking, maintenance and customization.

The **Application Software** enables seamless integration of Libera into various accelerator control systems. It allows users to interface Libera across a network, deploy custom applications on Libera and use Libera in fields or for tasks previously not envisioned, yet in a way that is consistent and well defined. The Control System Programming Interface (CSPI) is a high-level programming interface that allows separating control system-dependent knowledge from logic and details related to Libera. The CSPI is effectively shielding applications from intricacies and changes in the underlying system software and hardware. Implemented as a library, the CSPI facilitates accessing full Libera functionality in a consistent and documented way.

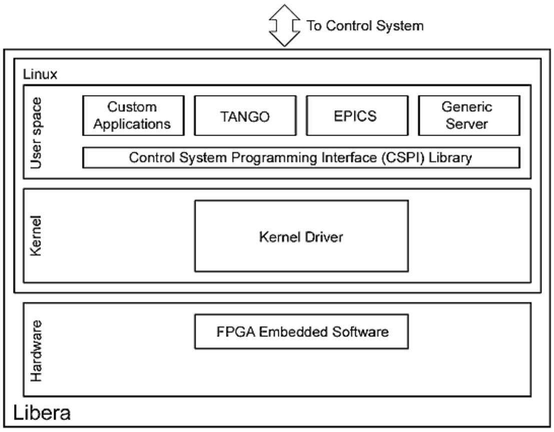

Figure 3: Software block diagram.

COVERING THE NEEDS OF THE PULSED MACHINES

The performance of the first Libera family member was optimized for the 3rd generation light sources, which are based on storage rings and where signals originating from the pickups are periodic in nature. However, we also encouraged our users to put Liberas in their Linacs and transfer lines. The motivation for that is very practical: to have a uniform BPM system installed on the whole accelerator facility. This approach simplifies system integration, commissioning and maintenance, which in turn significantly lowers system life-cycle cost.

One of the most challenging aspects of measuring beam position on FELs is pulse to pulse position measurement fluctuation, which limits measurement resolution. In order to evaluate how well Libera covers the needs of FELs, we performed laboratory measurements of Libera electron beam position processor. Individual pulses were generated using a step recovery diode. Figure 4 shows measurement resolution as a function of bunch charge. To estimate bunch charge we took sensitivity of a typical storage ring button pickup and assumed that current sensitivity of a typical stripline is ten times higher.

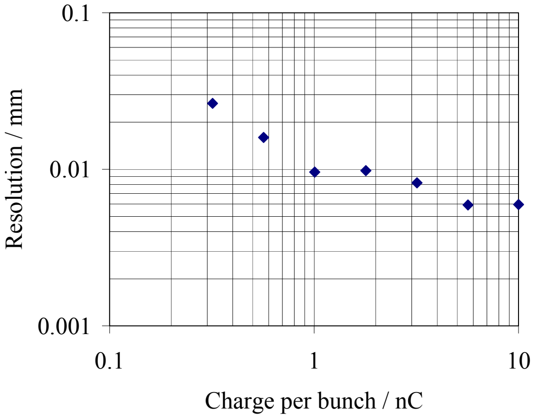

Figure 4: Laboratory measurement of pulsed to pulse position fluctuation for a typical stripline pickup with position sensitivity of 0.1 mm^{-1}.

CONCLUSIONS

Libera is a product family, which open architecture provides solid foundation for building different family members, each optimized to satisfy specific beam instrumentation needs. In this article we have explained all-in-one, customization and connectivity advantages of Libera family. We have also demonstrated that already the first member of the Libera family, the electron beam position processor, is showing excellent performance. Despite being optimized for storage rings, it may satisfy also the FEL beam position monitoring needs. Developing a new Libera member especially for the FEL machines, we are confident to be able to significantly improve the performances.

ACKNOWLEDGEMENTS

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