TIMING SYSTEM FOR MEDAUSTRON
BASED ON OFF-THE-SHELF MRF TRANSPORT LAYER

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Abstract

MedAustron is a new particle accelerator-based ion beam research and therapy centre under construction in Wiener Neustadt, Austria. The timing system for its synchrotron-based accelerator is being developed in close collaboration with Cosylab.

We have used Micro Research Finland (MRF) transfer layer and designed and implemented a generic, reusable high-level logic above transport layer inside the generator and receiver FPGA to fulfill machine specific requirements which exceed MRF's original high-level logic capabilities. The new timing system is suitable for small to mid-size accelerators. Its functionalities include support for virtual accelerators and a rich selection of event response mechanisms. The timing system uses a combination of a real-time link for downstream events and a non-real-time link for upstream messaging and non time-critical communication.

This article explains the benefits of building a timing system on a proven, stable timing transport layer and describes the high-level services provided by MedAustron timing system.

ABOUT MEDAUSTRON

MedAustron [1, 2] is intended for research and clinical therapy applications. Its synchrotron-based accelerator will have 3-5 ion sources (protons, carbon ions and possibly other light ions) and 5 beamlines, one of which is a rotating gantry. It will provide ion beams with energies up to 800MeV to several irradiation stations used for different purposes. Development follows defined processes and quality management standards. Among the development goals is to use commercially available components where possible to minimize the technological and economical risks. The machine will serve as a blueprint for further applications. Accelerator layout is shown in Figure 1.

TECHNOLOGY CHOICE FOR MEDAUSTRON TIMING SYSTEM HW

No out-of-the box timing system solution exists yet for MedAustron's type of accelerators. The key requirements for the timing system are a deterministic network protocol for real-time operation, reliable event/data distribution and fast response times from the timing system master to all (about 300) controlled devices. It must provide 1µs real-time control loop resolution, 100 ns timestamp resolution and support for 250.000 different accelerator cycles.

When approaching timing system design, we examined the possibilities of reusing existing technology and Micro Research Finland (MRF) [3] proved the most suitable. MRF is designed for more demanding light-source accelerators and satisfies MedAustron synchronization requirements well. What it lacks is the required higher-level logic and a generic accelerator timing system application. We therefore decided to keep MRF's widely used and proven timing transport layer and build the high level logic application on top in its FPGA firmware. As MedAustron Control System (MACS) software will run on National Instruments' PXIe controllers, we will develop MRF cards in PXIe form factor.

An important part of the timing system is the software support which is fully integrated into MedAustron Control System (MACS). The software provides flexible mechanisms for configuration, control and supervision of the timing system. It is implemented within MedAustron's Front End Control System (FECOS) software framework, developed in LabVIEW, also in close collaboration between MedAustron and Cosylab.

Reusing the MRF timing transport layer for timing system design proved to be the right approach, as it enabled us to deal with machine specifics and focus more on integration aspects of the design, which is often an underestimated and overlooked part of timing system development.

TIMING SYSTEM OVERVIEW

MedAustron Timing System, called the Real-time Event Distribution Network (REDNET) comprises a real-time and a non-real-time link. The real-time link is based on MRF transport layer and custom logic in FPGA, whereas the non-real-time link is based on Gigabit Ethernet.

The real-time network topology is the same as original MRF: one Event Generator (EVG) and multiple Event Receivers (EVR), connected in tree topology with multiple fanout layers. Each card is located in a PXI crate with the PXI controller running support software. The combination of an EVG (or EVR) card with its support software is called the Main Timing Generator (MTG); or Main Timing Receiver (MTR), respectively. The timing system will control about 300 devices, but EVR's sophisticated I/O mechanisms lower the number of required EVRs. Support software provides access to configuration and control to the supervisory control system and triggers transmission of traffic over both the real-time and the non-real-time interface.

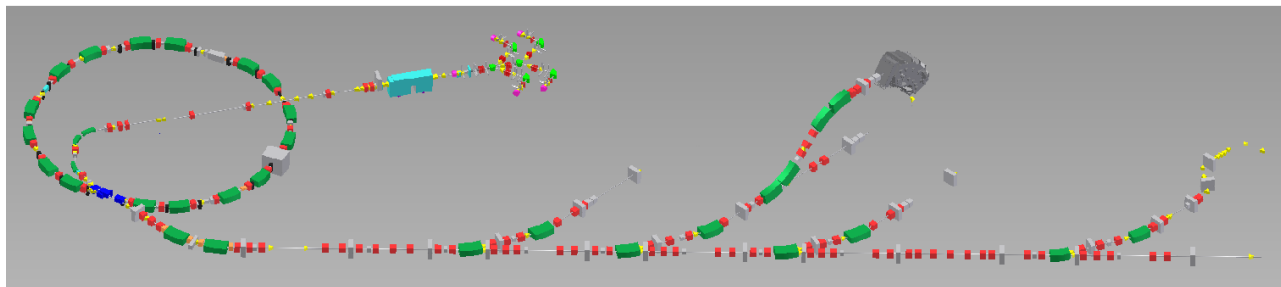**07 Accelerator Technology**

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Figure 1: MedAustron accelerator layout0

The configuration of MTG and MTRs is done by the supervisory control system via a non real-time supervisory interface.

TIMING SYSTEM HIGH LEVEL SERVICES

The following subsections describe the timing system's main services. Richness of logic in communication and event response mechanisms also illustrates specific requirements of MedAustron accelerator class.

Event Response Mechanisms

The timing receiver offers multiple possibilities of controlling its neighbouring cards via numerous hardware connections and via software IRQs. Through LabVIEW API, the user can easily configure the Event Receiver to:

- trigger external devices (via TTL, fibre optic, etc.)
- trigger PXI/PXIe neighbouring cards (via star trigger bus)
- provide neighbouring cards with real-time data (via trigger bus)
- provide SW applications with IRQs and real-time data
- provide delayed, inverted or otherwise "post-shaped" response to timing events (e.g. for fine tuning of synchrotron injection synchronization down to 5 ns resolution)

All types of subscriptions to different events can be used by the same application.

Virtual Accelerator (VAcc) Support

Timing events are scheduled in 5 separate, concurrently usable execution slots (ES), providing concurrently running virtual accelerator functionality. The concept enables users to program individual accelerators as if they were separate, each of them having its own execution configuration. However, timing events of all VAccs are piped through the same serial link (fibre optic), where prioritization takes place in case events are scheduled for emission at the very same moment. Receivers can be linked to any combination of these VAccs and event responses for different ES can be configured separately.

This feature will enable commissioning of different parts of accelerator (e.g. ion sources) at the same time independently, reducing commissioning time immensely. During machine use, it will provide a safe, controllable way of experimenting with new accelerator settings.

Commands

Commands are an extended concept of timing events, also providing data payload, which makes them very useful for distributing near-real-time information. They are implemented using the concept of pipes, additionally abstracting the communication channel to make it even easier to use. Commands have the lowest priority. Figure 2 illustrates command segmentation in the presence of higher-priority traffic.

Heartbeat Event and Time Service

Along with emission of timing events defined in a sequence, the MTG also provides a unique heartbeat event emitted independently of any other traffic. Its emission range is configurable, ranging from 0.5Hz to 50Hz. Generation and emission of the event is done autonomously in EVG hardware, the software only enables and disables the heartbeat and sets the emission rate. Receiver response to the heartbeat event is fully configurable. This functionality is used to operate the injector in temperature stabilized mode.

The time service mechanism provides a transparent way of distributing current time to all receivers.

Asynchronous User Event

Asynchronous, software-triggered user timing events can be emitted by the EVG along with other higher priority traffic. This is useful for testing purposes and data acquisition.

Generation of Viming Uequences Nocally on the Receiver

A mechanism is provided to generate event sequences on the receiver directly from software. The sequence generation is non-real-time; this feature is useful for testing and integration purposes, when a fully functional timing system setup with an event generator is unavailable.
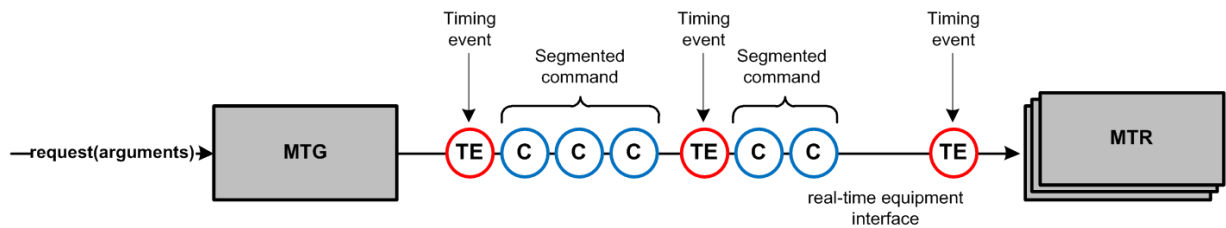
Figure 2: Command segmentation in the presence of higher-priority traffic0

Real-Vime Vraffic Rrioritization Ucheme

Figure 3 explains the prioritization of different real-time traffic and offers an insight into the mechanisms implemented inside EVG FPGA firmware. All emission mechanisms are conveniently configurable through LabVIEW API.

The figure shows that among the 5 ES, one has top priority over all other traffic. Next is the heartbeat event, then the other 4 ES, followed by asynchronous user events and commands.
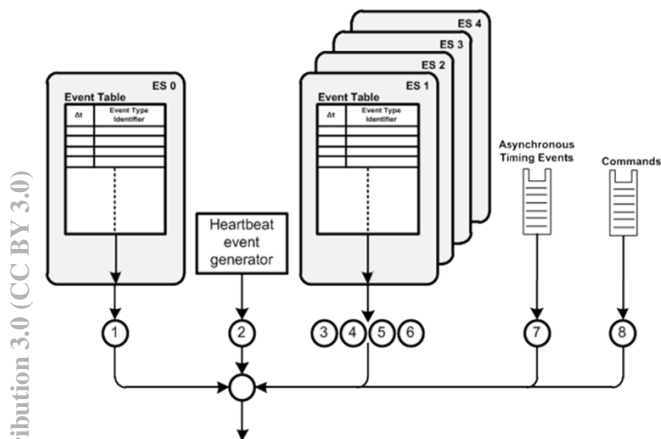

Figure 3: Message prioritization scheme0

Synchronization Parameters

Table 1 shows the timing characteristics of the event emission mechanism.

Timing events can be scheduled with the granularity of 1μs. This means that every μs, events from all 5 execution slots and the heartbeat event can be scheduled for emission. In such case, fixed prioritization occurs, as shown in Figure 3. At reception, events are time-stamped with 100 ns resolution. These timing characteristics satisfy MedAustron timing system requirements, which strongly guided the system design. The underlying MRF transport layer greatly exceeds this synchronization performance.

Table 1: Timing Uystem Uynchronization Rarameters

Event Emission Granularity "	1 μs
Timestamp Resolution	100 ns

CONCLUSION

By using the off-the-shelf product from MRF, which offers an already widely used, well proven and stable transmission layer, and building the machine specific real-time application on top of it, the overall design time can be greatly reduced. With this approach the effort of designing a timing system can be strongly focused on specifics of the machine itself and not on the timing distribution layer, which has already been successfully addressed multiple times before. The total time from requirements to the working system was less than 2 years. This design approach is the way to achieve precise, but versatile solutions able to cope with complex use cases. The resulting reusable timing system design is suitable for small to mid-size accelerators.

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