A TIMING SYSTEM FOR CYCLE BASED ACCELERATORS

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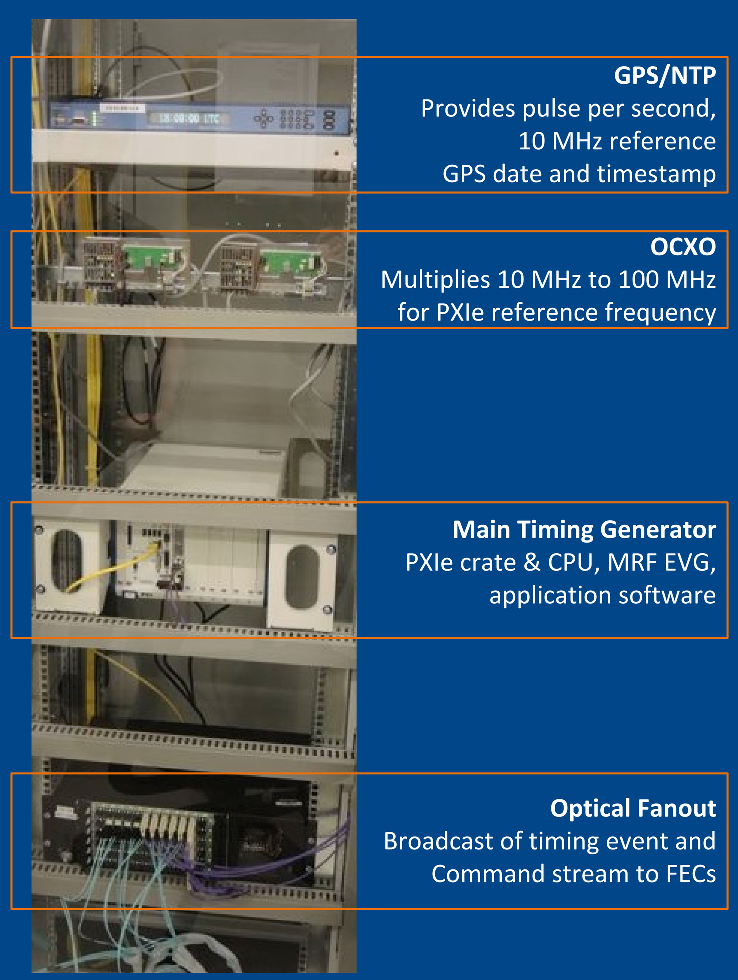
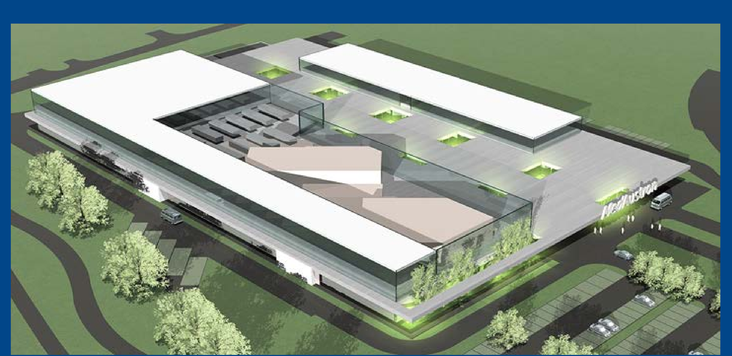
ABSTRACT

Synchrotron accelerators with multiple ion sources and beam lines require a high degree of flexibility to define beam cycle timing sequences. We have therefore designed a ready-to-use accelerator timing system appliance based on off-the-shelf hardware and software that can fit mid-size accelerators and that is easy to adapt to specific user needs. This Real Time Event Distribution Network (REDNet) has been developed under the guidance of CERN within the MedAustron-CERN collaboration. The system is based on the MRF transport layer and has been implemented by Cosylab. While we have used the NI PXIe platform, it is straightforward to obtain receivers for other platforms such as VME. The following characteristics are key to its readiness for use: (1) turn-key system comprising hardware, transport layer, application software and open integration interfaces, (2) performance suitable for a range of accelerators, (3) multiple virtual timing systems in one physical box, (4) documentation developed according to V-model.



Full-scale system deployed at facility site in data center. Power converters are remotely controlled via optical fibers at distances from 25 to 120 meters.

The MedAustron accelerator, featuring four ion sources, IH-based Linac, synchrotron, three horizontal, one vertical beam line and one proton gantry. Energy ranges from 60 to 800 MeV/u, up to 250 MeV/u proton equivalent for ion therapy [2].



From the “green-field” to start of commissioning in two years from 03/2011 to 03/2013.

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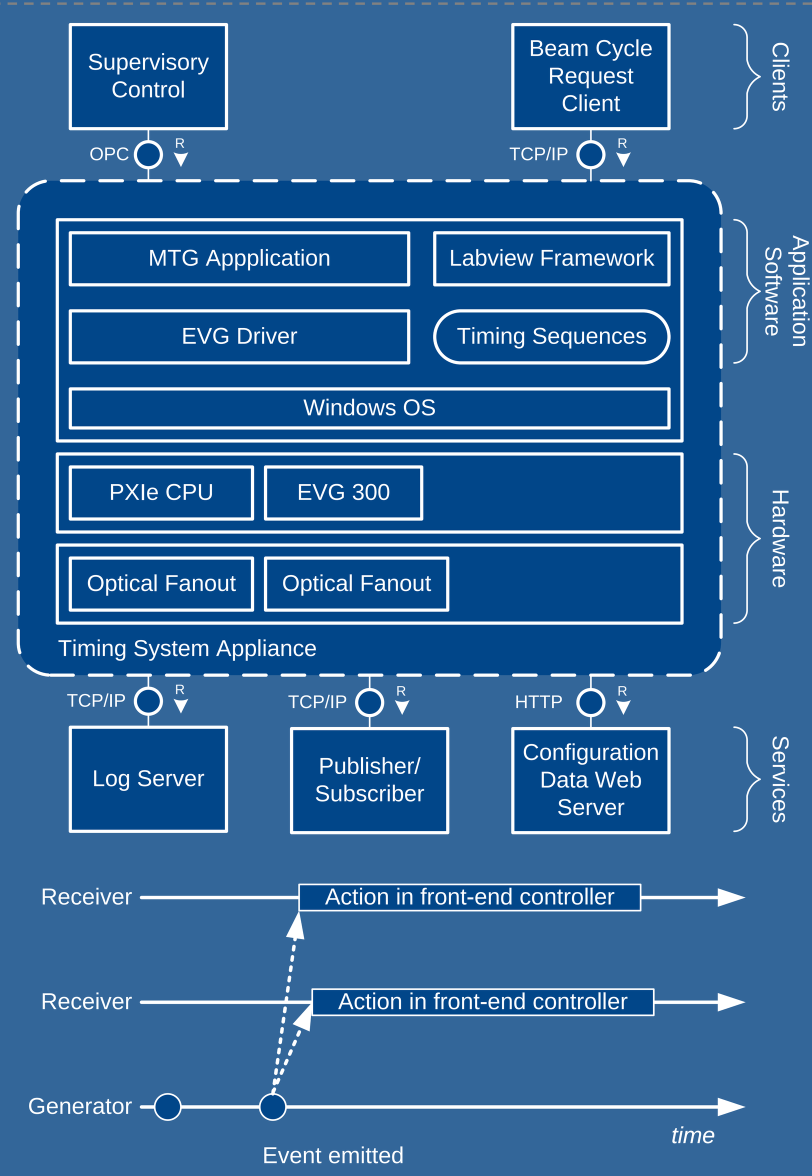
ARCHITECTURE AND DESIGN



REDNet Appliance

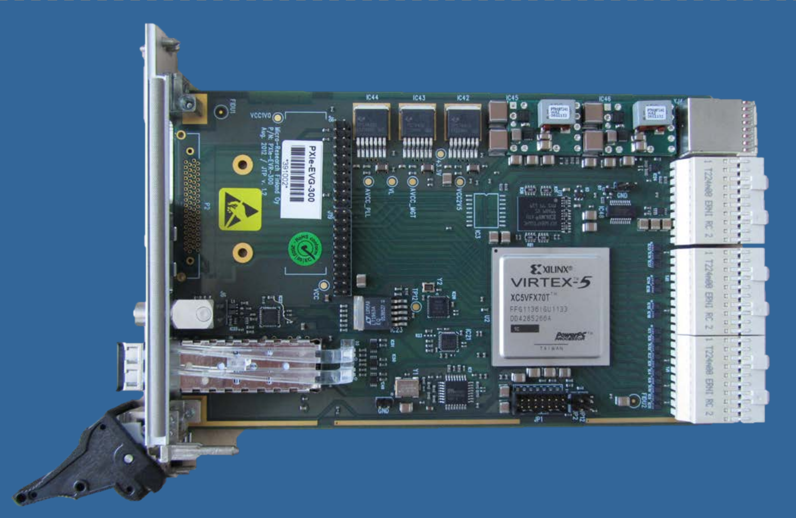
Task is to ***distribute events in real-time*** *to front end controllers of beam-line elements, where they trigger actions, which are associated to particular events.*

- Includes hardware, software, drivers, libraries
- Integrates with SCADA systems via OPC
- Operation principle is broadcast of events
- Receivers react on events in a timing slot:
  - software interrupt
  - configurable pulses on optical or electrical auxiliary outputs on event receiver card
  - triggers and information on backplane, e.g. PXI Start Trigger Bus and Star Trigger Lines
- Up to 5 timing slots can be concurrently used
- Each timing slot can be used to emit a sequence of timing events
- On a single crate, different applications and hardware cards can subscribe to different events in different timing system slots

```
<TimingSequence id="ExampleCycle"
version="1.0.0" UUID="..." status="in work"
author="..."
creation="2011-02-09T09:22:30.835593Z" ..>
    <EventTypeIdentifier id="StartCycle"
    time="0" spec_time="0" isDynamic="false"
    rt="true" nonrt="true" acknowledge="false"
    index="0" absolute_time="0"
    is_primary="true" />
    ...
    <EventTypeIdentifier id="StartAcceleration"
    time="305000" spec_time="310000"
    related_event="10" isDynamic="false"
    rt="true" nonrt="true" acknowledge="false"
    index="12" absolute_time="577242"
    is_primary="true" />
    ...
    <EventTypeIdentifier id="EndCycle"
    time="479000" spec_time="479000"
    related_event="26" isDynamic="false"
    rt="true" nonrt="true" acknowledge="false"
    index="27" absolute_time="3000744"
    is_primary="true" />
</TimingSequence>
```

Functions

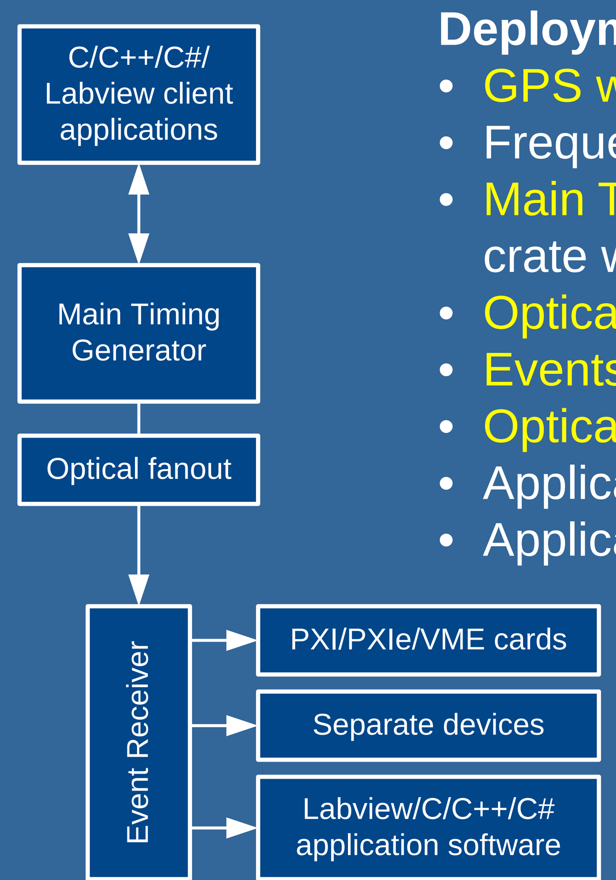
- Specification of timing event sequence in XML
- Accelerator cycle is a sequence of events
- Run is a set of cycle sequences
- Event time specifications in μsec
- Events with broadcast parameters:
  - real-time event over optical link,
  - non real-time over TCP/IP publisher
  - acknowledgement required before continue
- Sequences are stored on Web server
- Timing specifications can be overridden at run-time for machine development purposes
- Sequence picked for specific beam cycle based on cycle identifier mask and filter



PXIe EVR 300I event receiver card. Two versions exist: one with auxiliary outputs on front panel and one with flat cable connector to interface to an electrical signal output box as shown below for Lemo and scope output.

Additional Features

- User events can be asynchronously enqueued
- Absolute timestamp of events (100 nsec UTC)
- Various configurable reference clocks synchronized to GPS wall clock generated in event receiver cards, e.g.:
  - 100 MHz, 10 Hz for Linac, 200 kHz for DSPs
  - 2 kHz reference for power converter
- Precision triggering of multiple elements in range of nsec
- Start of cycle offset with respect to some reference frequency
- 20 auxiliary outputs via interface box
- Events on RS-232 to interface controllers
- Generation of sequences and test pulses locally on event receiver cards without need for a connected main timing event generator



Deployment

- GPS wall clock Symmetrikom SyncServer S350
- Frequency multiplier from 10 MHz to 100 MHz OCXO
- Main Timing Generator as National Instruments 3U 8 slot PXIe crate with PXIe CPU and MRF EVG 300 card
- Optical fanout as 6U cPCI crate and MRF optical fanout cards
- Events transmitted over standard OM3 Gigabit Ethernet fibers
- Optical triggers from receiver cards via OM1 fibers
- Application software running on MS Windows 7 64 bit
- Application software programmed in Labview
  - Client libraries for C, C++, Labview and C# to
  - Events via TCP/IP based publisher/subscriber
  - Logging via log4j compatible protocol
  - System auto configures from Web server via HTTP
  - OPC enabled, integrated with SIEMENS WinCC OA

Availability

- Appliance made available from CERN via partner Cosylab
- Generator, fan-out and receiver cards via Micro Research Finland
- Alternative platforms such as PXI, cPCI, PCIe and VME and drivers for different operating systems possible on demand

KEY REQUIREMENTS

Adaptable to many different use cases

- Sequences of events, phase aligned reference clocks, triggers, timestamps
- Interface to software, to cards in same chassis, external devices without intelligence

Concurrent control and reconfiguration

- Medical irradiation = sequence of different cycles = different settings
- Reconfigure for different event sequence in less than 250 msec

Simple system management

- Self-contained appliance
- Easy integration of SCADA systems
- Easy integration with different front-ends

High performance & reliability

- Real-time synchronization at 1 μsec
- Synchronization of few elements with10 nsec precision
- Safe operation for clinical mode

PERFORMANCE

- **250 different** user-defined **events**
- Up to 512 events per timing sequence
- Up to 1024 minutes per sequence (extensible)
- **Scalable** to a few thousand receivers
- Signal propagation compensation over fiber if required
- **Reference clocks** up to **100 MHz**
- **Timestamp precision 100 nsec**
- Trigger synchronization < 10 nsec
- Event synchronization at 1 μsec
- Uninterrupted operation > 1 week

SUMMARY

Based on the PIMMS design, an accelerator main timing system for a mid-size class of synchrotron accelerators requiring large amounts of different beam cycles, no dead-times between cycles and a high flexibility without a need to intervene at hardware or firmware level for adaptation has been devised. Test operation has shown good performance and robustness. We have therefore decided to make the CERN IP and design available through an integration partner, Cosylab (Ljubljana, Slowenia). The system is based on the MRF timing system transport layer. Current implementations by Cosylab are available for PXI and PXIe systems with Labview software support for front-end controller applications. The design is, however, flexible and timing receiver cards for other platforms such as VME exist such that accommodating different hardware and operating system platforms are a mere implementation task.

REFERENCES

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[5] R. Stefanic et al., “Timing System Solution for MedAustron; Real-Time Event and Data Distribution Network”, in proceedings of ICALEPCS 2011, WEPMN015