A Picosecond Sampling Electronics “KAPTURE” for Terahertz Synchrotron Radiation

*International Beam Instrumentation Conference, 14-18 September 2014, Monterey, USA*

Outline

- Motivation & Introduction: What did we develop KAPTURE for?
  - Coherent Synchrotron Radiation (CSR) in the THz Range
  - Ultra-Fast Terahertz Detectors
- The KAPTURE System
- CSR Studies with KAPTURE
- Summary
Bursting CSR Emission During Low-$\alpha_c$-Mode

- ANKA - storage ring
- 0.5 - 2.5 GeV electron energy
- 184 RF Buckets
- 2 ns bunch spacing
- bunch lengths down to 1-2 ps

CSR bursts occur at varying frequencies. Frequencies are dependent on bunch current and machine settings (e.g., beam optics, RF voltage).

Peak signal for a single bunch recorded at each revolution.

Bursting CSR Emission During Low-$\alpha_c$-Mode

Peak CSR Power / a.u.

Time / ms

0 2 4 6 8 10 12 14

1.10 mA

0.33 mA

0.25 mA

0.12 mA

Peak signal for a single bunch recorded at each revolution.
Ultra-Fast THz Detectors

Hot-Electron-Bolometer (NbN)

- Response time < 165 ps
- LHe cooling
- Developed at DLR


YBCO-Detector

- Response time < 15 ps
- LN2 cooling
- Developed at KIT-IMS


Quasi-Optical Broadband Detector (Schottky diodes)

- Response time < 200 ps
- No cooling required
- Commercially available (ACST, VDI)

Study of the Bursting Behavior in Multi-Bunch

Idea: Monitor the THz-radiation from every bunch for every revolution. Continuously!
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- Fast THz Detectors
  - Quasi-optical broadband detector at room temperature
    - Response time < 200 ps
    - Frequency range: 50 GHz up to 1 THz
    - Based on Schottky diode
  - Hot Electron Bolometer (NbN)
    - Cryogenic (LHe)
    - Response time < 165 ps
    - Frequency range: 200 GHz up to 4 THz
    - High sensitivity
  - YBCO detector
    - Cryogenic (LN2)
    - Response time < 15 ps
    - Frequency range: 30 GHz up to 2.5 THz

- Resolve intensity of each bunch (minimal bunch spacing 2 ns)

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- M. Brosi (miriam.brosi@kit.edu) – Online Burst Analysis of Coherent THz Radiation at ANKA
  - March 31th, 2014

- Synchrotron light is emitted when a beam of electrons travels, at very high speed, in curved paths. The radiation is emitted in the forward direction.

- The synchrotron radiation leaves the storage ring through tangential ports. These ports allow the radiation to pass onto the experimental stations located outside the storage ring.
Study of the Bursting Behavior in Multi-Bunch

- Idea: Monitor the THz-radiation from every bunch for every revolution. Continuously!

- Oscilloscope with enormous memory & fast readout?

- Hot Electron Bolometer (NbN)
  - Cryogenic (LHe)
  - Response time <165ps
  - 200 GHz up to 4 THz
  - High sensitivity

- YBCO detector
  - Cryogenic (LN2)
  - Response time <15ps
  - 30 GHz up to 2.5 THz

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Solution

KAPTURE SYSTEM
Karlsruhe Pulse Taking Ultra-Fast Readout Electronics
Picosecond pulse sampling requirements

**Requirements:**

1. **measuring amplitude and peaking time of each pulse,** pulse width of 20 – 100 ps

2. **Pulse repetition rate of 500 MHz**

3. **Continuous acquisition for long observation time:** seconds, minutes...

4. **Wideband circuitries,** bandwidth DC-60GHz

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Coherent THz radiation

Wideband Low Noise Amplifier

YBCO Det.

LNA

Terahertz synchrotron radiation

Pulse measured with a real-time oscilloscope (bandwidth 60GHz)
1. **Sampling**: each pulse sampled with 4 samples by the **KAPTURE** system, minimum sampling time of 3 ps.
Picosecond pulse sampling system for CSR

Coherent THz radiation

Terahertz synchrotron radiation

1. Sampling: each pulse sampled with 4 samples by KAPTURE system, minimum sampling time of 3 ps.

2. Data transfer: digital samples transferred to high-end GPU (Graphics Processing Units) by a PCIe-DMA architecture

GPU-DAQ

Continuous data streaming

Pulse with repetition rate 500 MHz
Picosecond pulse sampling system for CSR

1. **Sampling**: each pulse sampled with 4 samples by KAPTURE system, minimum sampling time of 3 ps.

2. **Data transfer**: digital samples transferred to high-end GPU (Graphics Processing Units) by a PCIe-DMA architecture.

3. **Real-time GPU data elaboration**: pulses reconstruct, amplitude and peaking time respectively with “mV” “picosecond” accuracy are evaluated.

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**Diagram**

- Coherent THz radiation
- YBCO Det.
- Wideband Low Noise Amplifier
- LNA
- Pulse sampling
- FPGA
- DMA/PCIe
- PCIe
- KAPTURE system
- GPU-DAQ
- High throughput readout electronics
- DDR3

**Graph**

- Pulse with repetition rate 500 MHz
- Sampling points: S₁, S₂, S₃, S₄
- Detector response (mV) vs. Time (ns)
KAPTURE Box

- Pulse input
- LNA
- Wideband power divider
- DC-DC power supply
- KAPTURE board
- High throughput readout board
- PCIe link
KAPTURE Board

- KAPTURE sampling board
  - High throughput readout Board
  - Sampling channel

Sampling stage

- Fast ADC
- RF filters
- Shielding
- Analog RF input
- Picosecond delay chip
- Track & hold

Wideband CPW trans. line with via fences

- Minimum sampling time: 3 ps (min. equiv. sampling time 300GS/s)
- RMS time jitter noise < 1.7 ps
- RMS noise (ADC) < 1 mV
- Dynamic range: ± 800 mV per channel
- Max pulse rate up to 550 MHz

100 GHz

**KAPTURE  sampling board**

**✓** Minimum sampling time: 3 ps (min. equiv. sampling time 300GS/s)
**✓** RMS time jitter noise < 1.7 ps
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**✓** Dynamic range: ± 800 mV per channel
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Beam Test Setup at IR2 Beamline at ANKA in May 2014

Terahertz beam

YBCO detector

Cryogenic & detector control

Wideband power splitter

LNA

KAPTURE board and readout

KAPTURE Graphic User Interface
Beam test with YBCO detector and KAPTURE system

Real-time pulse sampling

Possible filling scheme at ANKA

184 bunches
revoltion time 368ns

Train 1 and 2

2 ns

Real-time sampling pulses (zoom)

Dataset with more than 200 million sampled pulses

Sampled points

GPU pulse reconstruction

Peak height, time and pulse width can be retrieved!

$\Delta t_{S2} - \Delta t_{S1} = 15 \text{ ps}$

$\Delta t_{S3} - \Delta t_{S2} = 9 \text{ ps}$

$\Delta t_{S4} - \Delta t_{S3} = 15 \text{ ps}$
CSR Studies with KAPTURE

Can record > 10^6 turns
CSR Studies with KAPTURE

Do all bunches show a similar behavior for same bunch currents?

Ongoing investigation of bunch-bunch effects.
Simultaneous Acquisition with 2 “identical” detectors (e.g. for balanced detection)

1 Sample point per detector.

Possible to connect up to 4 detectors!

ADC0

Bunch Current 0.653 mA

ADC1

Bunch Current 0.653 mA
Summary - KAPTURE Features

- Dynamic range of ± 800 mV (per channel) with RMS noise < 1 mV
- Very low time jitter (RMS < 1.7 ps) → sampling time accuracy of 3 ps
- High data throughput readout board based on PCIe-DMA (32Gb/s)
- Real-time data elaboration based on high-end Graphics Processing Units (GPUs)
- Under final commissioning at ANKA
- Flexible measurement opportunities
  (e.g. 4 sample points for 1 detector or up to 4 detectors with 1 sample point each)
- Can be adapted for other scientific applications and/or synchrotron facilities
Thank you for your attention!

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(will happily answer all your technical questions)

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(PhD student, also here at IBIC’14 ➔ TUPD10)
Backup slides
KArlsruhe Pulse Taking Ultra-fast Readout Electronic

12 bit @ 500 MHz

Sampling channel

ADC

Wideband power splitter 1:4

Analog signal

PLL

RF clock

Clean jitter PLL (RMS = 400 fs)

Low RMS jitter Fanout buffer

Picosecond delay chip

Set by FPGA

24Gb/s Streaming (12 bit * 4 samples * 500 MHz)

FPGA

DMA

PCle - DAQ

GPU - DAQ