



LIBERA

# LIBERA BOOK

2021

SOLUTIONS  
FOR  
**PARTICLE**  
ACCELERATORS



INSTRUMENTATION  
TECHNOLOGIES

# SOLUTIONS FOR PARTICLE ACCELERATORS

The accelerator community knows us as the Libera folks. It looks like we've left an impression since our story began back in 2003. Since then, nine out of ten synchrotron light sources around the world have been equipped with our Libera beam position stabilization systems. But Libera is much more than just the sum of its products. It means the best possible performance for the price. It means innovation, quality, and reliability. It means long-term support. It is the relationships we have nurtured over the years with our customers that we cherish most.

Libera products seamlessly combine hardware and software into powerful instruments that measure a variety of beam parameters. Those measurements are then used in feedback loops to optimize the performance of a particle accelerator. Different accelerators have different needs. However, through the re-configurability and modularity of Libera instruments we can accommodate a variety of end-user requirements.

Libera instruments are developed and manufactured by the Instrumentation Technologies Company. Established in 1998, the business has grown from a garage-based start-up to an established company known for its Libera and Red Pitaya products, and for launching the Center of Excellence for Biosensors, Instrumentation and Process Control (COBIK).

- Rok Uršič

Founder of Instrumentation Technologies



## LIBERA REFERENCES

### Asia

Bhabha Atomic Research Center  
Chinan Biomedical Technology  
HiSOR  
HUST  
IBS—RISP  
IHEP—BEPC II, ADS, CSNS  
IMP-CAS—C-ADS, LEAF, SSC-LINAC, CSR,  
HIRFL  
IMS—UVSOR  
Inter University Accelerator Centre  
ISSP  
KEK—PF, PF-AR, LINAC, SUPER B,  
J-PARC, cERL  
Nagoya University—Aichi Synchrotron  
NewRT Medical Systems  
NSRRC—TLS, TPS  
PAL—PLS II, XFEL ITF  
Peking University  
RRCAT—INDUS, INDUS II  
SACLA—SPring-8  
SINAP—SSRF  
SJTU  
SLRI  
Tokamak Energy  
Tsinghua University  
USTC, NSRL—HLS, HLSII

### Australia

Australian Synchrotron

### Europe

AVO-ADAM—LIGHT  
CANDLE  
CEA  
CELLS—ALBA  
CERN  
DELTA  
DESY—PETRA III, FLASH, DESY XFEL,  
DORIS III  
Diamond Light Source  
ELI - Extreme Light Infrastructure  
ESRF—ESRF-EBS  
Forschungszentrum Jülich—COSY  
Fritz Haber Institute of the MPS  
GANIL

### GSF—FAIR

Helmholtz-Zentrum Berlin BESSY II  
Helmholtz-Zentrum Dresden-Rossendorf  
—ELBE  
IBPT—KARA  
IJS  
INFN—Daphne, ELI-NP, SPARC  
IPNO  
ISA—ASTRID II  
Jagiellonian University—SOLARIS  
JINR—NICA  
LAL—THOM-X  
Lund University—MAX III, MAX IV  
MedAustron  
Physics Institute of the University of Bonn  
PSI—SLS, SwissFEL  
Research Instruments  
RRC Kurchatov Institute—SIBERIA II  
ScandiNova  
SCK-CEN  
SDU—TARLA  
SESAME  
Sincrotrone Trieste—Elettra, FERMI  
SOLEIL Synchrotron  
STFC ASTeC—EMMA, CLARA  
University of Twente

### North America

ANL—APS, APS-U  
Best Medical International  
BNL—ERL, NSLS II, X-RAY ring  
Canadian Light Source, CLS  
Cornell University—CHESS, CESR  
Idaho National Laboratory  
LANL—LANSCE  
LBNL—ALS  
Michigan State University—FRIB  
Northwestern University  
NUSANO

Oak Ridge National Laboratory  
RadiaBeam  
SLAC—LCLS, SPEAR

### South America

ABTLuS—LNLS



# Table of Contents

|                                   |           |                                               |           |
|-----------------------------------|-----------|-----------------------------------------------|-----------|
| <b>BPM Electronics</b>            | <b>05</b> | <b>Clock Transfer System</b>                  | <b>29</b> |
| Hadron BPM Electronics            | 06        | Capabilities                                  | 31        |
| Electron & Photon BPM Electronics | 08        | Performance Specifications                    | 31        |
| Architecture & Platforms          | 12        |                                               |           |
| <b>Beam Loss Monitor</b>          | <b>14</b> | <b>Reference Master Oscillator</b>            | <b>32</b> |
| Signal Processing                 | 14        | <b>Wide Dynamic Range Low Noise Amplifier</b> | <b>34</b> |
| Capabilities                      | 16        |                                               |           |
| Functionalities                   | 16        | <b>Control System Integration</b>             | <b>35</b> |
| <b>Digitizers</b>                 | <b>17</b> | <b>GUI</b>                                    | <b>36</b> |
| Libera Digit 125                  | 17        |                                               |           |
| Libera Digit 500                  | 19        | <b>Extensions</b>                             | <b>37</b> |
| <b>Current Meter</b>              | <b>21</b> | DAI Module                                    | 37        |
| Interfaces & Signal Processing    | 21        | Orbit Feedback Solutions                      | 38        |
| Capabilities                      | 23        | SER Module                                    | 39        |
| Signal Data Path                  | 23        | SER 2 Module                                  | 39        |
| <b>Digital LLRF</b>               | <b>24</b> | GDX Module                                    | 40        |
| Interfaces & Signal Processing    | 25        | Libera DWC                                    | 40        |
| Capabilities                      | 27        | Elettra Pilot-Tone Front-End prototype        | 41        |
| Functionalities                   | 27        | <b>Services &amp; Support</b>                 | <b>43</b> |
| Performance Specifications        | 28        |                                               |           |
| Interface Extensions              | 28        | <b>Contact</b>                                | <b>44</b> |

# BPM ELECTRONICS

Libera Beam Position Monitor (BPM) electronics feature a high-resolution position measurement of the beam (electrons, protons, ions, photons, etc.). Their flexible digital signal processing calculates the beam position with different bandwidths and techniques, enabling measurements in different beam modes and regimes:

- pulsed, single bunch
- pulsed, micro/macro pulse
- bunch-by-bunch
- turn-by-turn
- first-turn measurement
- closed loop (fast, slow)

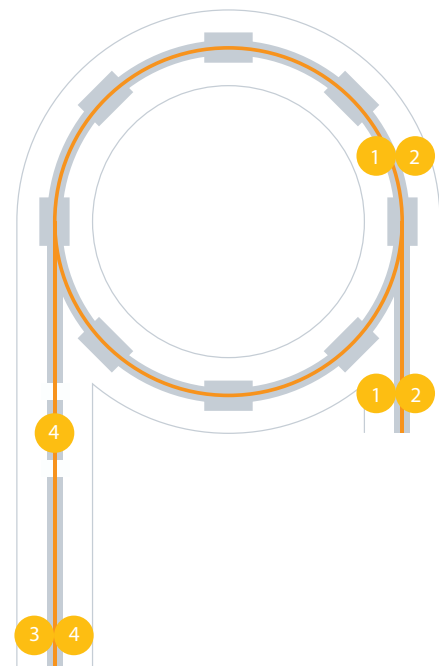
| HADRON               | ELECTRON             | PHOTON        |
|----------------------|----------------------|---------------|
| -                    | -                    | -             |
| Libera Hadron        | Libera Brilliance+   | Libera Photon |
| Libera Single Pass H | Libera Single Pass E |               |
| Libera Spark         | Libera Spark         |               |
|                      | Libera CavityBPM     |               |

# Hadron

## Hadron BPM Electronics

Instruments intended for use in Hadron machines are shown in Figure 1. Several versions are available, based on different technology and form-factors. They provide various levels of measurement performance and functionalities. The BPM pickup types supported are button and shoebox pickups.

Figure 1: Example of hadron machine: LINAC injector, transfer line, synchrotron, and extraction line



### 1 Libera Hadron

- Used in proton/hadron synchrotrons
- Bunch-by-bunch position calculation
- Large buffers for ADC and position data storage
- Tune measurement, FFT processing, slow monitoring, etc.
- Accessories: Libera Amplifier 110
- Extensions: real-time data streaming, feedback application, serial I/O interface



### 2 Libera Spark HR

- Used in proton/hadron synchrotrons and ring-to-target beam transfers
- Bunch-by-bunch data processing
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O



### 3 Libera Single Pass H

- Used in proton/hadron linear accelerators
- Beam position and phase measurements calculated for two signal harmonics
- Extensions: real-time data streaming, feedback application, serial I/O interface







### 4 Libera Spark HL

- Used in proton/hadron linear accelerators and transfer lines
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O



The capabilities, performance, and functionalities of the hadron BPM electronics depend on the specific instrument and application are presented in Tables 1 and 2.

| Hadron<br>BPMs<br>Capabilities and Performance | for CIRCULAR machines                                                                               |                                                                                                   | for LINEAR machines                                                                                 |                                                                                                          |
|------------------------------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
|                                                |  Libera Spark HR |  Libera Hadron |  Libera Spark HL |  Libera Single Pass H |
| General Product code                           | LSHR                                                                                                | LHAD                                                                                              | LSHL                                                                                                | LSPH                                                                                                     |
| BPM slots                                      | 1                                                                                                   | 1 - 4                                                                                             | 1                                                                                                   | 1 - 4                                                                                                    |
| Supported input frequency range                | < 35 MHz                                                                                            | < 55 MHz                                                                                          | < 750 MHz                                                                                           | < 700 MHz                                                                                                |
| A/D conversion                                 | 125 MHz/14 bit                                                                                      | 250 MHz/16 bit                                                                                    | 125 MHz/14 bit                                                                                      | 130 MHz/16 bit                                                                                           |
| Cooling                                        | Passive                                                                                             | Active (fans)                                                                                     | Passive                                                                                             | Active (fans)                                                                                            |
| Power supply                                   | PoE                                                                                                 | 110/220 V, 250 W                                                                                  | PoE                                                                                                 | 110/220 V, 250 W                                                                                         |
| Timing signals                                 | Electrical (up to 3)*                                                                               | Electrical (4)/Optical                                                                            | Electrical (up to 3)*                                                                               | Electrical (4)/Optical                                                                                   |
| Fast data links                                | RJ-45                                                                                               | RJ-45 & SFP                                                                                       | RJ-45                                                                                               | RJ-45 & SFP                                                                                              |
| Maximum input signal *                         | < 1.2 V peak pulse voltage*                                                                         | < 2 V peak pulse voltage*                                                                         | < +10 dBm*                                                                                          | +10 dBm                                                                                                  |
| Input gain/attenuation                         | Fixed                                                                                               | Fixed                                                                                             | Programmable, 31 dB                                                                                 | Fixed                                                                                                    |
| Temperature drift, typical                     | 2 $\mu\text{m}/^{\circ}\text{C}$                                                                    | 2 $\mu\text{m}/^{\circ}\text{C}$                                                                  | 0.3 $\mu\text{m}/^{\circ}\text{C}$                                                                  | 0.5 $\mu\text{m}/^{\circ}\text{C}$                                                                       |
| Position RMS at bunch-by-bunch data rate       | 10 $\mu\text{m}$ **                                                                                 | 6 $\mu\text{m}$ **                                                                                | /                                                                                                   | /                                                                                                        |
| Position RMS at fast 10 kHz data rate          | /                                                                                                   | < 1 $\mu\text{m}$ **                                                                              | /                                                                                                   | /                                                                                                        |
| Position RMS at slow 10 Hz data rate           | /                                                                                                   | < 1 $\mu\text{m}$ **                                                                              | /                                                                                                   | /                                                                                                        |
| Position RMS at 1 MHz data rate                | /                                                                                                   | /                                                                                                 | < 1 $\mu\text{m}$                                                                                   | < 2 $\mu\text{m}$ , < 0.01°                                                                              |

\* Can be extended/customized depending on user requirements // \*\* measured with K=10mm

Table 1: Hardware capabilities and performance of hadron beam position monitors





| Hadron<br>BPMs<br>Functionalities                  | for CIRCULAR machines                                                                                 |                                                                                                     | for LINEAR machines                                                                                   |                                                                                                            |
|----------------------------------------------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
|                                                    |  Libera Spark HR |  Libera Hadron |  Libera Spark HL |  Libera Single Pass H |
| Bunch-by-bunch processing                          | Yes                                                                                                   | Yes                                                                                                 | No                                                                                                    | No                                                                                                         |
| Real-time data streaming                           | Optional*                                                                                             | Optional*                                                                                           | Optional*                                                                                             | Optional*                                                                                                  |
| Slow data                                          | No                                                                                                    | Yes                                                                                                 | No                                                                                                    | No                                                                                                         |
| Gain control                                       | No                                                                                                    | Libera Amplifier 110, external variable gain amplifier                                              | Yes                                                                                                   | No                                                                                                         |
| Selectable processing window                       | Yes                                                                                                   | Yes                                                                                                 | Yes                                                                                                   | Yes                                                                                                        |
| Processing delay                                   | Yes                                                                                                   | Yes                                                                                                 | Yes                                                                                                   | Yes                                                                                                        |
| Multi-chassis synchronization                      | Trigger-based                                                                                         | Reference clock with PLL                                                                            | Trigger-based                                                                                         | Trigger-based                                                                                              |
| Data time stamping                                 | Trigger-counter                                                                                       | Based on external RF clock                                                                          | Trigger-counter                                                                                       | Trigger-counter                                                                                            |
| Interlock detection and out-put                    | Optional**                                                                                            | No                                                                                                  | Optional**                                                                                            | Yes                                                                                                        |
| Postmortem capability                              | No                                                                                                    | Yes                                                                                                 | No                                                                                                    | Yes                                                                                                        |
| FFT/FFT peak                                       | No                                                                                                    | Yes                                                                                                 | No                                                                                                    | No                                                                                                         |
| Single-pass measurement                            | Yes                                                                                                   | Yes                                                                                                 | Yes                                                                                                   | Yes                                                                                                        |
| Additional Digital I/O chan-nels and Analog output | Optional**                                                                                            | No                                                                                                  | Optional**                                                                                            | No                                                                                                         |
| Closed Orbit Feedback Applica-tion                 | No                                                                                                    | Yes, see page 36 or 38                                                                              | No                                                                                                    | No                                                                                                         |
| *Requires additional module                        | GbE interface                                                                                         | GDX module                                                                                          | GbE interface                                                                                         | GDX module                                                                                                 |
| ** Requires additional module                      | DAI module                                                                                            |                                                                                                     | DAI module                                                                                            |                                                                                                            |

Table 2: List of functionalities of hadron beam position monitors



# Electron

## Electron & Photon BPM Electronics

Instruments intended for use in linear and circular electron machines are shown in Figure 2 and Figure 3. Several versions are available, based on different technology and form-factors. They provide different levels of measurement performance and functionalities. The BPM pickup types supported are button, stripline, and cavity-type pickups.

Figure 2: Example of a 3rd generation light source (synchrotron)

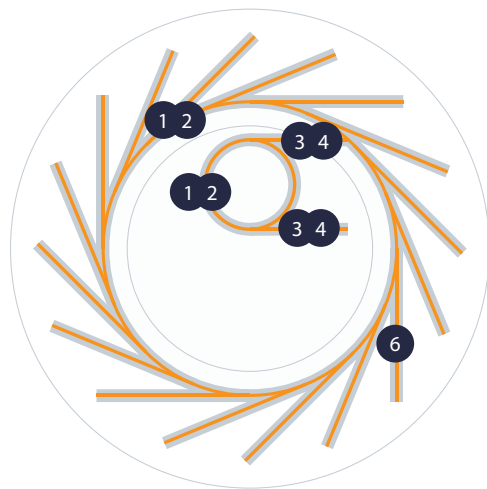
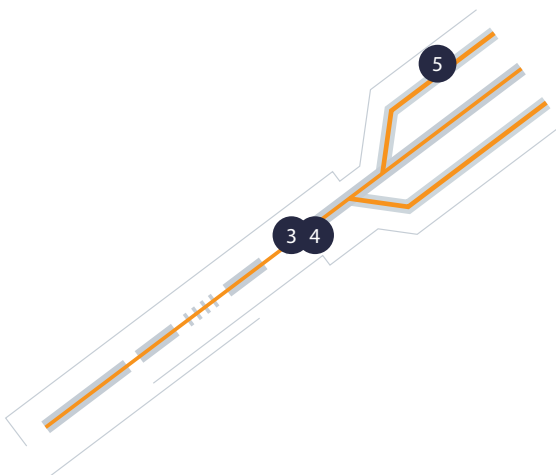


Figure 3: Example of a 4th generation light source (FEL / ERL)



### 1 Libera Brilliance+

- Used in electron synchrotrons
- Data bandwidth from 15 MHz to 5 Hz
- Sub-micron long-term stability
- Built-in orbit feedback and timing system interfaces
- Extensions: Fast Orbit Feedback application, serial I/O interface



### 2 Libera Spark ERXR/ERPT

- Used in electron synchrotrons
- Data bandwidth from 15 MHz to 5 Hz
- Fast data link towards orbit feedback
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O
- For Spark ERPT only: Calibration with the pilot tone provided by the Elettra Pilot-Tone Front-End.



### 3 Libera Single Pass E

- Used in electron LINACs
- Event announcing of beam patterns
- Flexible DSP can process various filling patterns from single bunch to CW
- Accessories: Libera DWC
- Extensions: real-time data streaming, feedback application, serial I/O interface



### 4 Libera Spark EL

- Used in electron LINACs and transfer lines
- Flexible DSP can process various filling patterns from single bunch to CW
- Accessories: Libera DWC
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O



### 5 Libera CavityBPM

- Used in FEL undulator sections and interaction points
- Supporting S-band and C-band cavities, High-Q and Low-Q
- Bunch-by-bunch data processing down to 16 ns bunch spacing
- 3 GHz and 6 GHz versions
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O



### 6 Libera Photon

- Used in synchrotron and FEL beamlines
- Data bandwidth from 80 kHz to just a few Hz
- Compatible with diamond and blade detectors
- Extensions: Interlock output, real-time data streaming, analog output, digital (serial) I/O









The hardware capabilities, performance, and functionalities of the electron beam position monitors are summarized in Tables 3 and 4. The instruments are generally built on three platforms, each of them offering specific advantages.

| Electron<br>BPMs<br>Capabilities and<br>Performance | for CIRCULAR machines                                                             |                                                                                   |                                                                                   |                                                                                    | for LINEAR machines                                                                 |                                                                                     |
|-----------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|                                                     |  |  |  |  |  |  |
| General product code                                | LSXR                                                                              | LSPT                                                                              | LBRP                                                                              | LSEL                                                                               | LSPE                                                                                | LCAV                                                                                |
| BPM slots                                           | 1                                                                                 | 1                                                                                 | 1 - 4                                                                             | 1                                                                                  | 1 - 4                                                                               | 1                                                                                   |
| Supported input frequency range                     | < 750 MHz                                                                         | < 750 MHz                                                                         | < 700 MHz                                                                         | < 750 MHz                                                                          | < 700 MHz                                                                           | < 6 GHz                                                                             |
| A/D conversion                                      | 125 MHz/14 bit                                                                    | 125 MHz/14 bit                                                                    | 130 MHz/16 bit                                                                    | 125 MHz/14 bit                                                                     | 160 MHz/16 bit                                                                      | 500 MHz/14 bit                                                                      |
| Cooling                                             | Passive                                                                           | Passive                                                                           | Active (fans)                                                                     | Passive                                                                            | Active (fans)                                                                       | Passive                                                                             |
| Power supply                                        | PoE                                                                               | PoE                                                                               | 110/220 V                                                                         | PoE                                                                                | 110/220 V                                                                           | 110/220 V                                                                           |
| Timing signals                                      | Electrical (3)*                                                                   | Electrical (3)*                                                                   | Electrical (4)/                                                                   | Electrical (up to 3)*                                                              | Electrical (4)/Optical                                                              | Electrical (up to 3)*                                                               |
| Calibration                                         | Manual                                                                            | Pilot tone****                                                                    | Crossbar switch DSC                                                               | Manual/Static                                                                      | Manual/Static                                                                       | Manual/Static                                                                       |
| Fast data link                                      | RJ-45                                                                             | RJ-45                                                                             | RJ-45 & SFP                                                                       | RJ-45                                                                              | RJ-45 & SFP                                                                         | /                                                                                   |
| Maximum input signal*                               | < -10 dBm continuous                                                              | < -10 dBm continuous                                                              | < +4 dBm continuous                                                               | < 5 V peak pulse voltage                                                           | < 7 V peak pulse voltage                                                            | 16 dBm                                                                              |
| Input gain/attenuation                              | Programmable, 31 dB                                                               | Programmable, 31 dB                                                               | Programmable, 31 dB, automatic mode                                               | Programmable, 31 dB                                                                | Programmable, 31 dB                                                                 | Programmable, 31 dB                                                                 |
| Temperature drift, typical                          | 2 µm/°C                                                                           | <1 µm/°C ***                                                                      | 0.2 µm/°C                                                                         | 0.3 µm/°C                                                                          | 0.3 µm/°C                                                                           | 0.3 µm/°C                                                                           |
| Position RMS at turn-by-turn data rate              | 0.3 µm**                                                                          | 1 µm***                                                                           | 0.5 µm**                                                                          | /                                                                                  | /                                                                                   | /                                                                                   |
| Position RMS at fast 10 kHz data rate               | 0.04 µm**                                                                         | 0.1 µm***                                                                         | 0.07 µm**                                                                         | /                                                                                  | /                                                                                   | /                                                                                   |
| Position RMS at slow 10 Hz data rate                | 0.02 µm**                                                                         | 0.05 µm***                                                                        | 0.02 µm**                                                                         | /                                                                                  | /                                                                                   | /                                                                                   |
| Position RMS at single bunch                        | < 10 µm**                                                                         | /                                                                                 | /                                                                                 | 4 µm**                                                                             | 1 µm**                                                                              | < 1 µm                                                                              |
| Position RMS at macro pulse/ continuous wave        | /                                                                                 | /                                                                                 | /                                                                                 | < 4 µm                                                                             | < 1 µm                                                                              | < 1 µm                                                                              |

\* Can be customized // \*\* Measured with K=10 mm // \*\*\* depends on setup configuration //\*\*\*\* requires Elettra Pilot-Tone Front-End – see page XYZ

Table 3: Hardware capabilities and performance of electron beam position monitors

| Electron<br>BPMs<br>Functionalities               | for CIRCULAR machines                                                               |                                                                                     |                                                                                     |                                                                                      | for LINEAR machines                                                                   |                                                                                       |
|---------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|                                                   |  |  |  |  |  |  |
|                                                   | Libera Spark ERXR                                                                   | Libera Spark ERPT                                                                   | Libera Brilliance+                                                                  | Libera Spark EL                                                                      | Libera Single Pass E                                                                  | Libera CavityBPM                                                                      |
| Bunch-by-bunch processing                         | No (only single bunch/single turn)                                                  |                                                                                     |                                                                                     | Yes                                                                                  | Yes                                                                                   | Yes                                                                                   |
| Turn-by-turn processing                           | Yes                                                                                 | Yes                                                                                 | Yes, multi-bunch op-tion                                                            | No                                                                                   | No                                                                                    | No                                                                                    |
| Real-time data streaming                          | Optional *                                                                          | Yes                                                                                 | Optional *                                                                          | Optional *                                                                           | Optional *                                                                            | No                                                                                    |
| Slow data                                         | Yes                                                                                 | Yes                                                                                 | Yes                                                                                 | No                                                                                   | No                                                                                    | No                                                                                    |
| Gain control                                      | Yes                                                                                 | Yes                                                                                 | Yes (automatic)                                                                     | Yes                                                                                  | Yes                                                                                   | Yes                                                                                   |
| Multi-chassis synchronization                     | Reference clock with PLL                                                            |                                                                                     |                                                                                     | Trigger-based                                                                        | Trigger-based                                                                         | Trigger-based                                                                         |
| Data time stamping                                | Yes                                                                                 | Yes                                                                                 | Yes                                                                                 | Trigger-counter                                                                      | Trigger-counter                                                                       | Trigger-counter                                                                       |
| Interlock detection and out-put                   | Optional**                                                                          | Optional**                                                                          | Yes                                                                                 | Optional**                                                                           | Yes                                                                                   | Optional**                                                                            |
| Postmortem capability                             | No                                                                                  | No                                                                                  | Yes                                                                                 | No                                                                                   | No                                                                                    | No                                                                                    |
| Single-pass measurement                           | No                                                                                  | No                                                                                  | Yes                                                                                 | Yes                                                                                  | Yes                                                                                   | Yes                                                                                   |
| Frequency down-conversion                         | Direct (with ADCs)                                                                  | Direct (with ADCs)                                                                  | Direct (with ADCs)                                                                  | Optional***                                                                          | Optional***                                                                           | Internal (with mixer)                                                                 |
| Additional Digital I/O channels and analog output | Optional**                                                                          | Optional**                                                                          | No                                                                                  | Optional**                                                                           | No                                                                                    | Optional**                                                                            |
| Fast Orbit Feedback Application                   | No                                                                                  | No                                                                                  | Yes, see page 36 or 38                                                              | No                                                                                   | No                                                                                    | No                                                                                    |

|                                |               |            |               |            |            |  |
|--------------------------------|---------------|------------|---------------|------------|------------|--|
| * Requires additional modules  | GbE interface | GDX module | GbE interface | GDX module |            |  |
| ** Requires additional module  | DAI module    |            | DAI module    |            | DAI module |  |
| *** Requires additional module |               |            |               | Libera DWC | Libera DWC |  |

Table 4: List of functionalities of electron beam position monitors

## Photon BPM Electronics

The hardware capabilities, performance, and functionalities of the photon beam position monitor are presented in Tables 5 and 6.


| Photon<br>BPM<br>Capabilities & Performance |  |
|---------------------------------------------|-------------------------------------------------------------------------------------|
|                                             | Libera Photon                                                                       |
| General product code                        | LPHO                                                                                |
| Input channels                              | 4                                                                                   |
| Input frequency range                       | < 80 kHz                                                                            |
| A/D conversion                              | 2.5 MHz/18 bit                                                                      |
| Cooling                                     | Passive                                                                             |
| Power supply                                | PoE                                                                                 |
| Timing signals                              | Electrical (3)                                                                      |
| Calibration                                 | Manual                                                                              |
| Fast data link                              | RJ-45                                                                               |
| Maximum input signal                        | < 2 mA                                                                              |
| Current ranges                              | ±60 nA, ±0.2µA, ±2µA, ±20µA, ±200µA, ±2mA                                           |
| Temperature drift, typical                  | 0.01 µm/°C                                                                          |
| 8-hour stability (23°C, 200 µA)             | 0.02 µm                                                                             |
| RMS uncertainty @ 180 µA (10 kHz data rate) | < 0.02 µm                                                                           |
| RMS uncertainty @ 180 µA (10 Hz data rate)  | < 0.01 µm                                                                           |

Table 5: Hardware capabilities and performance of the photon beam position monitor


| Photon<br>BPM<br>Functionalities                  |                                                                                                                                                                                |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                   | Libera Photon                                                                                                                                                                                                                                                       |
| Short pulse detection                             | Used for pulsed currents with signal dynamics within the measurement bandwidth ( < 80 kHz). Pulse repetition up to 10 Hz is supported.                                                                                                                              |
| DC signal monitoring                              | Typically used for monitoring the currents from blade detectors or other current-type detec-tors in the beamlines.                                                                                                                                                  |
| Configurable processing bandwidth                 | Parallel processing provides data buffers at configurable data rates and bandwidths. Users can change filtering blocks’ coefficients to adjust filters’ response.                                                                                                   |
| Current measurement                               | Amplitude in each channel can be transformed into current with a simple calculation equa-tion. Current value requires manual calibration and has limited accuracy.                                                                                                  |
| Postmortem data storage                           | Dedicated memory buffer is intended for storing the data just before a Postmortem trigger event. Complete functionality provides configurable buffer size, write offset and reports im-portant information about the absolute time of the Postmortem trigger event. |
| External BIAS support                             | External BIAS source can be connected directly to the instrument to apply a BIAS to all 4 chan-nels.                                                                                                                                                                |
| Additional Digital I/O channels and analog output | Analog and/or digital outputs can be used to control auxiliary components or convert current values to analog voltage. DAI extension module is required.                                                                                                            |

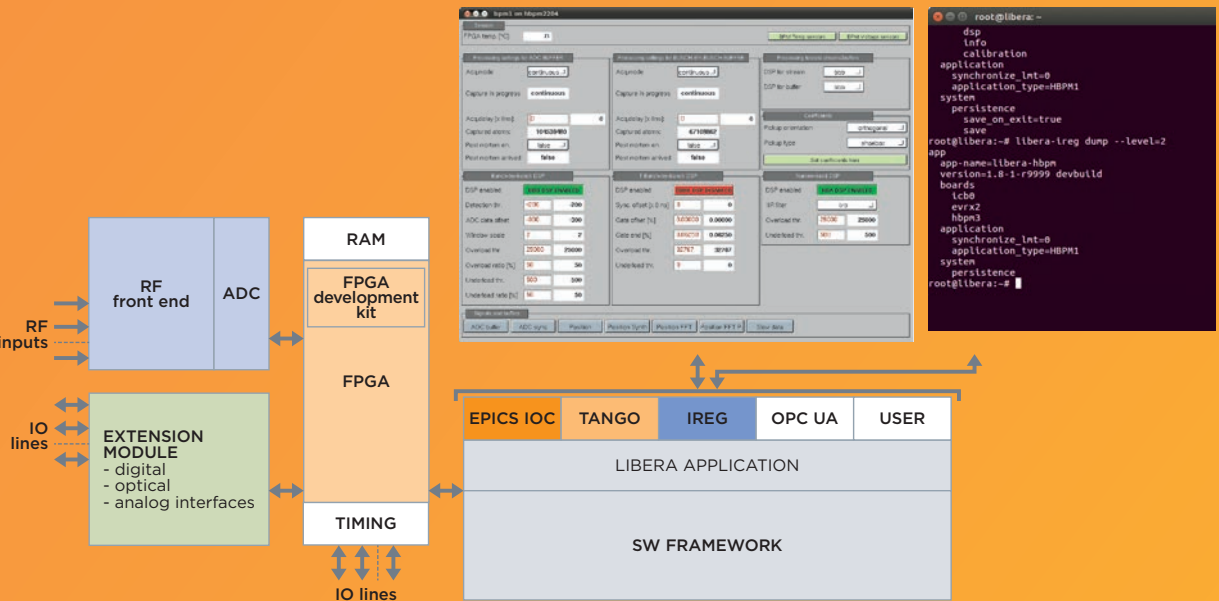
Table 6: List of functionalities of the photon beam position monitor

# Architecture & Platforms

The general architecture of Libera BPM electronics is presented in the block diagram in Figure 4. At the heart of every instrument is a digitizer consisting of ADCs and an FPGA processor running all of the real-time DSP algorithms and filling data into the memory. RF signals from the BPM pickups are processed by the analog RF front-end, which filters, amplifies, attenuates, and down-converts them, if necessary. The signals are later digitized by the ADCs. The ADC data is processed inside of the FPGA and calculated information such as position, phase, intensity, and so on, is stored in the memory. All the information is available to the user through the instrument software interfaces and control system adapters.

The default instrument configuration already provides all I/O lines required for normal operation, however the instrument functionalities can be further expanded with extensions requiring different HW modules, depending on the instrument platform—see the section on Extensions (page 37).

Figure 4: Generalized block diagram of Libera BPM electronics



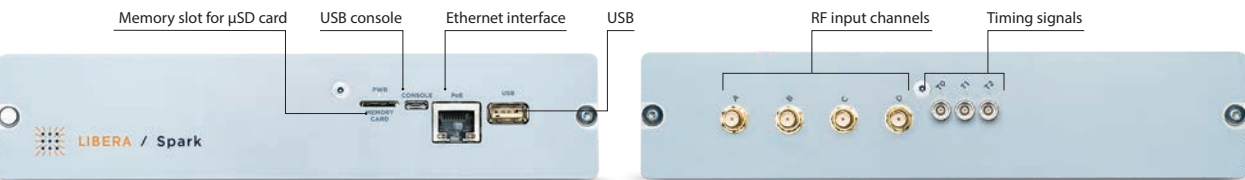
BPM electronics are available in different technology platforms that have different form factors. The BPM modular platform is based on the MTCA.0 modular technology and hosts up to four BPM modules in a 2U 19" chassis. Several extensions are available for the orbit feedback and timing system—see the section on Extensions.

Figure 5: BPM electronics based on our modular platform



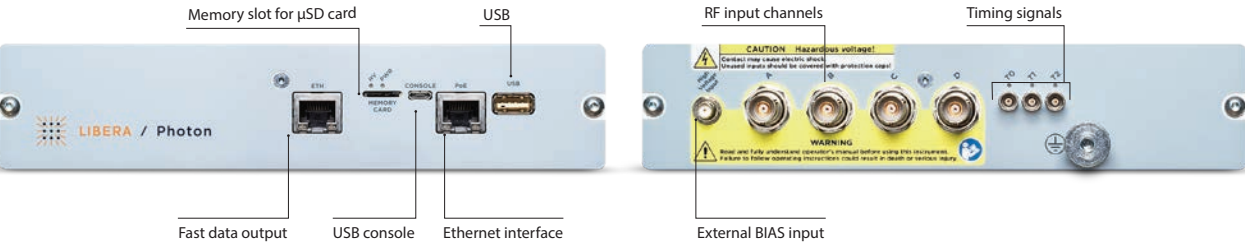
Our integrated platform is based on system-on-chip technology. Due to its low power consumption, the instrument is powered over Ethernet with PoE standard, and is passively cooled. Given the small dimension (BPM electronics is contained in a 1U 9.5" chassis), it can be installed in the tunnel close to the BPM pickup in an appropriate radiation protected location (see Figure 6).

Figure 6: BPM electronics based on our integrated platform



Photon BPM electronics is still based on the integrated platform and provides a second RJ-45 interface that is used to output the Fast data stream and a USB port. TRIAX connectors are used for input channels (Figure 7).

Figure 7: Photon BPM electronics based on our integrated platform



The BPM electronics for the cavity-type BPM pickups are also based on Libera integrated platform, which in this case is enlarged to a 1U 19" chassis due to the higher amount of heat that needs to be passively dissipated. The instrument can be expanded to four RF inputs and SFP connectors for fast data exchange.

Figure 8: CavityBPM electronics based on Libera integrated platform, front panel



Figure 9: CavityBPM electronics based on Libera integrated platform, back panel





# BEAM LOSS MONITOR

The Libera BLM handles all types of losses and measures them with a high level of detectability and high time resolution. In contrast to other BLM systems, the beam loss monitor from the Libera family detects the losses ranging from a single electron to the huge losses that usually occur during injection.

Thanks to its high time-resolution (8 ns), it provides detailed insight into sub-turn and intra-pulse losses. This effectively makes it possible to detect and select only those losses that come from a part of the beam-fill pattern.

The beam loss monitor is available in two configurations:

- Beam loss monitor electronics
- Beam loss monitor system (electronics + detector)

## Signal Processing

The signal from the beam loss detector (usually a photo-multiplier tube) is typically a unipolar pulse or train of pulses with negative polarity. It is possible to detect huge losses and very small losses thanks to the switchable front-end input impedance. The input signal is sampled by a PLL-controlled sampling clock.

The raw sampled data is stored in a buffer upon a trigger event. Further down the processing chain, the data is processed in order to remove the static offset and apply averaging and integration factors (Figure 10). The buffered data provides a quantitative view of the loss shape.

Figure 10: Beam loss signal processing parameters

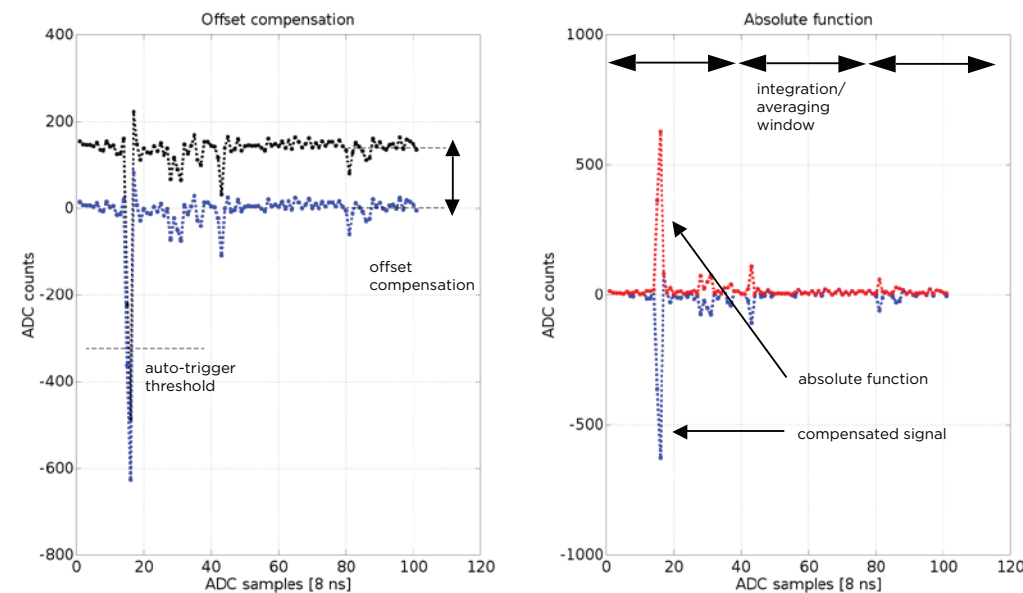
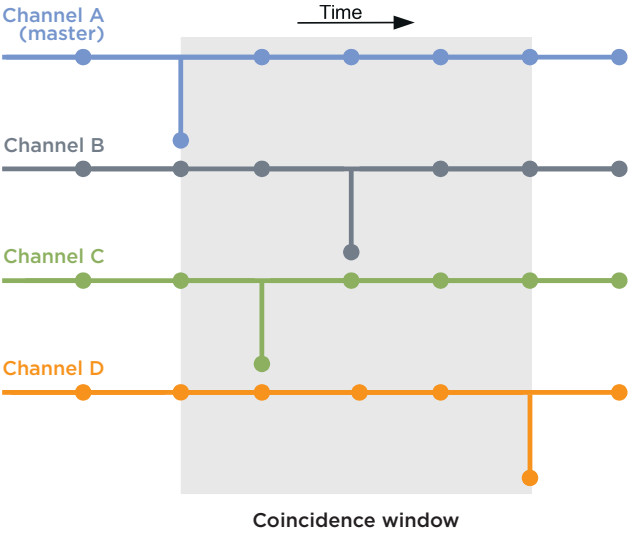


Figure 11: Coincidence loss monitoring

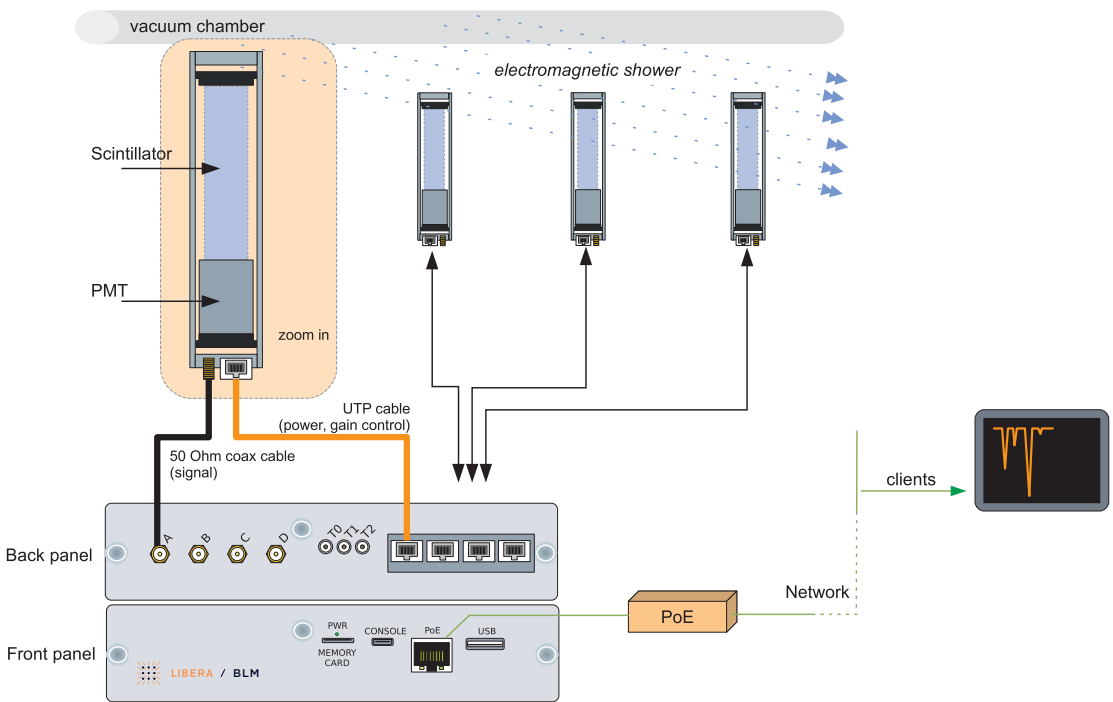


In parallel, losses are continuously monitored and counted at a rate of 8 ns. Counting modes are fully configurable for static and dynamic loss thresholds. Being locked to a sampling clock and an external clock, it is possible to adjust up to two configurable detection windows that monitor only a selected part of the fill pattern.

With up to four beam loss detectors connected to the same instrument, an algorithm can automatically detect if the loss was detected in all detectors at the same time (coincidence counting mode). Coincidence is monitored in a configurable time window as shown in Figure 11.

The beam loss monitor system consists of the beam loss detector and readout electronics. The electronics are provided in a standard 1U 9.5" housing and are powered through a PoE compliant Ethernet interface. For each of the four possible beam loss detectors, the electronics provide PMTs with power supply and gain control (Figure 12).

Figure 12: Beam loss monitor system configuration





## Capabilities

The hardware capabilities of Libera BLM are summarized in Table 7.



| Libera BLM Capabilities |  | Libera Beam Loss Detector |                                                                                                                                                                                                                                                                                                             |
|-------------------------|-----------------------------------------------------------------------------------|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General product code    | LBLM                                                                              | General product code      | LBLD                                                                                                                                                                                                                                                                                                                                                                                           |
| Input channels          | 4                                                                                 | Input channels            | Scintillator Rod for γ-ray detection EJ-200 from Scionix)                                                                                                                                                                                                                                                                                                                                      |
| Input frequency range   | ~35 MHz large signal bandwidth<br>~50 MHz small signal bandwidth                  | Input frequency range     | Typical dimensions: <ul style="list-style-type: none"><li>• Length: 100 mm</li><li>• Diameter: ~22 mm</li></ul>                                                                                                                                                                                                                                                                                |
| Matching impedance      | 50 Ω/1 MΩ, selectable                                                             | Matching impedance        | Aluminum housing, ~2 mm Lead shielding                                                                                                                                                                                                                                                                                                                                                         |
| A/D conversion          | 125 MHz/14 bit                                                                    | A/D conversion            |                                                                                                                                                                                                                                                                                                                                                                                                |
| Cooling                 | Passive                                                                           | Cooling                   | Photosensor (Hamamatsu 10721-110) <ul style="list-style-type: none"><li>• Input voltage: (5±0.5) V</li><li>• Input current: 2.7 mA maximum</li><li>• Gain control voltage: 1.1 V maximum (at 1 MΩ)</li><li>• Rise time: 0.57 ns</li><li>• Dark current: 1 nA (typical)</li><li>• Peak sensitivity wavelength: 400 nm</li><li>• Dimensions (H × W × D) mm: approximately 50 × 22 × 22</li></ul> |
| Power supply            | PoE                                                                               | Power supply              |                                                                                                                                                                                                                                                                                                                                                                                                |
| Timing signals          | Electrical (3)                                                                    | Timing signals            | Beam loss detector <ul style="list-style-type: none"><li>• Dimensions (H × W × D) mm: approximately 220 × 25 × 25 (without the fitting holder)</li><li>• Weight: approximately 150 g (without the lead cover)</li><li>• Operating temperature: +10°C to +40°C</li></ul>                                                                                                                        |
| Maximum input signal    | ±1.25 V @ 1 MΩ<br>±5 V @ 50 Ω                                                     | Maximum input signal      |                                                                                                                                                                                                                                                                                                                                                                                                |
| Output channels         | 4x power supply (up to ±15 V)<br>4x gain control (up to +12 V)                    | Output channels           |                                                                                                                                                                                                                                                                                                                                                                                                |

Table 7: Hardware capabilities of Libera BLM and the photo-multiplier tube

## Functionalities

The functionalities of the beam loss monitor are summarized in Table 8.


| Libera BLM Functionalities         |                                            |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
| Low loss detection                 | Detecting volumes as low as a single electron loss using high input impedance and high gain.                                   |
| Strong and fast loss detection     | Detecting strong losses during injection (typically).                                                                          |
| Automatic loss detection           | Adjustable threshold for automatic buffer storage.                                                                             |
| Configurable processing parameters | ADC offset compensation, integration and averaging window lengths, loss detection windows and individual channel delays.       |
| Counting modes                     | Select between static and dynamic thresholds for loss counts. Apply a custom recovery time and threshold.                      |
| Coincidence loss detection         | Compare up to 4 channels for simultaneous loss events.                                                                         |
| Loss value calibration             | Compensate the raw loss value with current gain settings (attenu-ation, photosensor dynamic gain and photosensor static gain). |
| Postmortem data storage            | Dedicated memory buffer is intended for storing the data just before a postmortem trigger event.                               |
| Photosensor control                | Provide power supply and adjust gain control volt-age to up to 4 independent channels.                                         |
| Interlock detection and output     | Monitor the accumulated loss value and trigger an output signal for machine protection system.                                 |

Table 8: Hardware functionalities of Libera BLM and the photo-multiplier tube

## DIGITIZERS

Libera digitizers provide users with a base from which to develop their own application. The instruments provide all the building blocks from the gain-controlled RF input signals to the ADC data storage, from the offset removal to the exposure of processing parameters through the control system interface.

The available software and firmware infrastructures provide an already working template, with the possibility to extend its functionalities, focusing only on its core part: the signal processing algorithms. The instruments are network-attached devices, with standard interfaces that facilitate integration into the control system (EPICS, Tango, TCP-IP socket, etc.).

### Libera Digit 125

The Libera Digit 125 is a 4-channel digitizer with dual 14-bit ADCs and a sampling frequency of 125 MHz. The data is stored in a configurable buffer with a maximum of 8 M data samples stored per channel.

Figure 13: Libera Digit 125



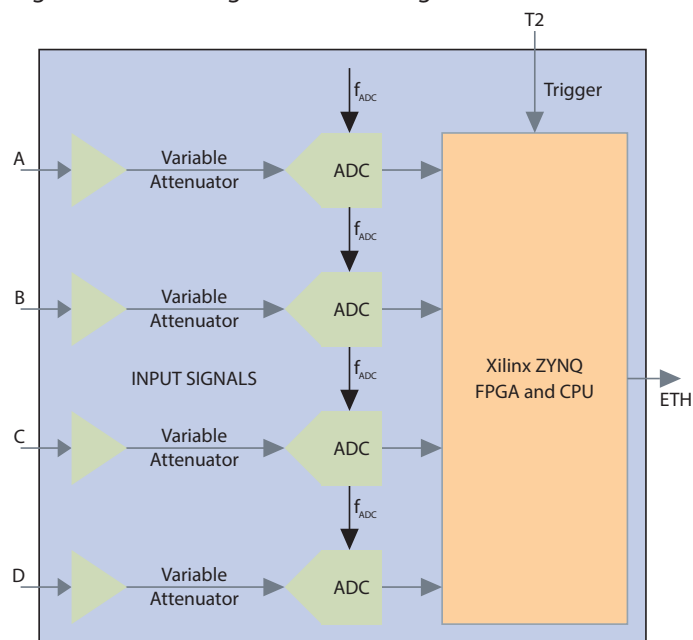
#### AC and DC coupled versions

The DC-coupled version has a front end with a 40 MHz bandwidth, suitable for time-domain processing of signals coming from different types of sensors. The AC-coupled front end has a bandwidth ranging from 10 MHz to 700 MHz and is suitable for narrow-band signals and digital down-conversion applications.

#### Flexible data buffering

A single trigger input is used to trigger the data acquisition in a large ADC buffer with total size of 8 MS per channel. The data buffer size can be reduced in order to support higher acquisition trigger frequencies.

Figure 14: Block diagram of Libera Digit 125



| Libera Digit 125<br>Technical Specifications             |                                                                                         |
|----------------------------------------------------------|-----------------------------------------------------------------------------------------|
| General product code                                     | L125                                                                                    |
| Input channels and connector                             | 4, SMA connector                                                                        |
| ADC conversion                                           | 125 MSps, 14 bit                                                                        |
| Input signal bandwidth                                   | AC-coupled: 10 MHz – 700 MHz<br>DC-coupled: 40 MHz                                      |
| Input impedance                                          | AC-coupled: 50 Ω<br>DC-coupled: selectable 50 Ω / 1 MΩ                                  |
| Maximum input signal level                               | AC-coupled: ± 1 V @ 50 Ω<br>DC-coupled: ± 5 V @ 50 Ω<br>1.25 V @ 1 MΩ                   |
| Input gain / attenuation                                 | SW programmable 0-31 dB channel independent                                             |
| Trigger signal level and connector                       | 3.3 V TTL, LEMO connector                                                               |
| FPGA / CPU                                               | Zynq-7020 / ARM Cortex-A9                                                               |
| Booting                                                  | Micro-SD, TFTP server                                                                   |
| Power                                                    | PoE                                                                                     |
| Cooling                                                  | Passive                                                                                 |
| Available extensions (SW needs to be developed by us-er) | LEMO single (2x): Single-ended LEMO, Input/Output config-urable                         |
|                                                          | LEMO differential (1x): Differential LEMO, Interlock output (requires external circuit) |
|                                                          | SMA (1x): 16-bit 100 kSps DAC output, 1 V at 50 Ohm                                     |
|                                                          | RJ-14 (1x): up to 20 Mbps, half-duplex                                                  |

Table 9: Technical specifications of Libera Digit 125

## Libera Digit 500

The Libera Digit 500 is a 4-channel digitizer with 14-bit ADCs and a sampling frequency of 500 MHz, phase locked to an external reference signal. The data is stored in a 4 GB configurable, segmented buffer, with different acquisition modes and trigger rates up to 500 Hz.

Figure 15: Libera Digit 500



### Digitizer with Phase-locked sampling frequency

Each of the four inputs is adjusted in amplitude with a 31 dB software-controlled variable attenuator and later sampled by the ADC converter with sampling controlled by an external reference signal locked through a phase locked-loop (PLL). The dynamic range of the system is over 90 dB.

### AC and DC coupled versions

The DC-coupled version has a front end with 250 MHz bandwidth, suitable for time-domain processing of signals coming from different types of sensors. The AC-coupled front end has a bandwidth ranging from 1 MHz to 2 GHz and is suitable for narrow-band signals and digital down-conversion applications. The front end can also be customized to include different types of analog filtering.

### Digital offset removal and flexible data buffering

The ADC data offset can be removed in the FPGA before the data is stored. One trigger input is used to trigger the data acquisition in a large ADC buffer with a total size of 4 GB. The buffer can be segmented in chunks of a minimum of 32,768 samples and can be acquired in different modes trigger frequencies. Pulse processing and phase shifting on individual channel

The pulse processing allows to discriminate pulses based on a threshold value. Different quantities are calculated in the FPGA (root square sum, peak, average and, sum). The phase shifting allows the user to set the phase for each of the 4 channels independently to compensate cable length.

### SFP module and WebGUI

Four Small Form Pluggable (SFP) module allows fast data exchange using UDP packages. WebGUI allows quick access to the instrument by just typing the instrument IP address in the Web browser.

Figure 16: Libera Digit Web GUI accessible from web browser

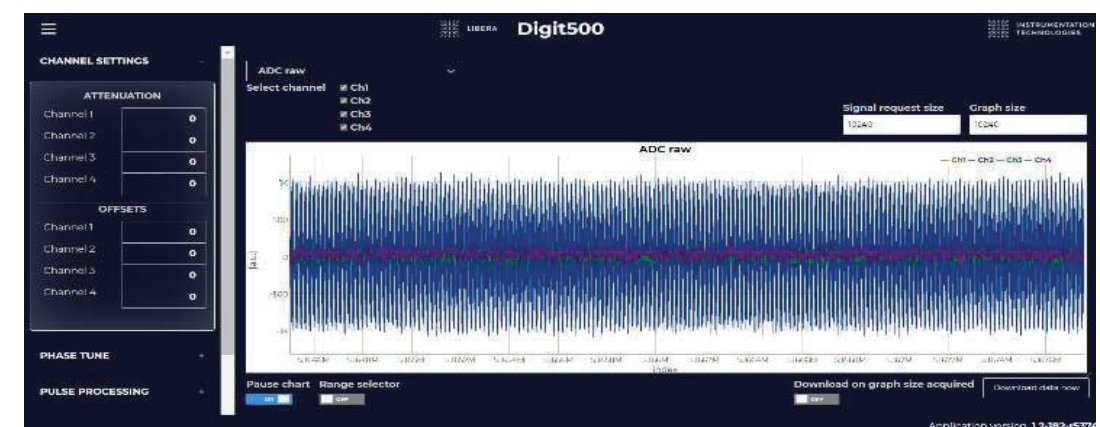
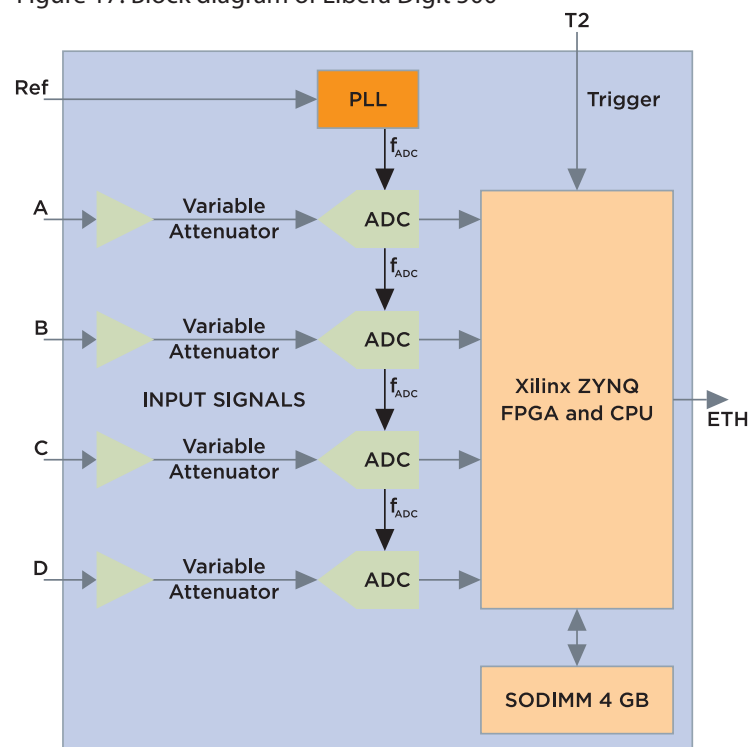


Figure 17: Block diagram of Libera Digit 500



| Libera Digit 500<br>Technical Specifications            |                                                                                          |
|---------------------------------------------------------|------------------------------------------------------------------------------------------|
| General product code                                    | L500                                                                                     |
| Input channels and connector                            | 4, SMA connector                                                                         |
| ADC conversion                                          | 500 MSps, 14 bit                                                                         |
| Input signal bandwidth                                  | DC-coupled / AC-coupled: DC - 250 MHz / 50 kHz - 2 GHz                                   |
| Input impedance                                         | 50 $\Omega$                                                                              |
| Maximum input signal level                              | DC-coupled / AC-coupled: $\pm 1$ V / 10 dBm                                              |
| Input gain / attenuation                                | SW programmable 0-31 dB channel independent                                              |
| Dynamic range                                           | 90 dB                                                                                    |
| Reference signal level and connector                    | - 2 dBm – 4 dBm, SMA                                                                     |
| Trigger signal level and connector                      | 3.3 V TTL, LEMO connector                                                                |
| Sampling clock                                          | Locked to external reference via PLL (300 MHz – 500 MHz)                                 |
| Memory                                                  | 4 GB RAM / 1.07 seconds of data per input channel                                        |
| Memory organization                                     | Segmented buffer / min. chunk size 32768 samples per channel                             |
| FPGA / CPU                                              | Zynq-7035 / ARM Cortex-A9                                                                |
| Booting                                                 | Micro-SD, TFTP server                                                                    |
| Power                                                   | 220 V                                                                                    |
| Cooling                                                 | Passive                                                                                  |
| Available extensions (SW needs to be developed by user) | LEMO single (2x): Single-ended LEMO, Input/Output configurable                           |
|                                                         | LEMO differential (1x): Differential LEMO, Interlock output (re-quires external circuit) |
|                                                         | SMA (1x): 16-bit 100 kSps DAC output, 1 V at 50 Ohm                                      |
|                                                         | RJ-14 (1x): up to 20 Mbps, half-duplex                                                   |

Table 10: Technical specifications of Libera Digit 500

## CURRENT METER

The Libera Current Meter is a general-purpose current measuring device with 4 input channels, compatible with high impedance current sources and capable of measurements from  $\pm 60$  nA to  $\pm 2$  mA. The instrument features six current ranges that can be switched manually or automatically, and each channel is factory-calibrated against a known current source.

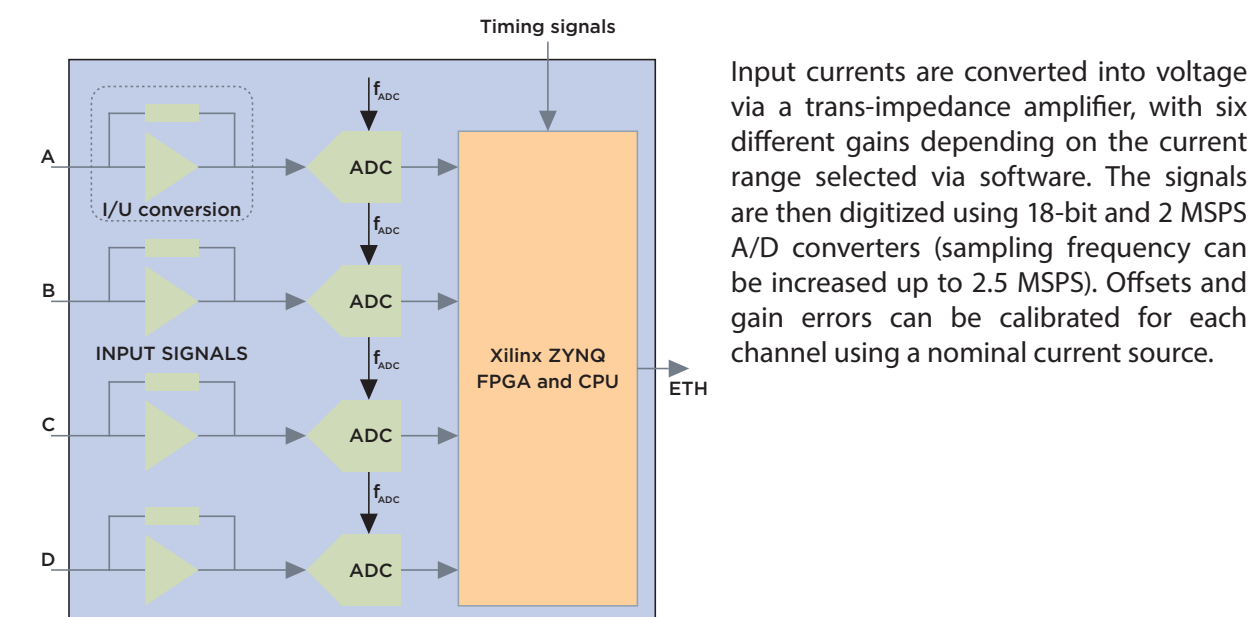
The Libera Current Meter is typically used to measure currents from Faraday cups, wire scanners and grids, and loss detectors with current outputs. It can be used in research reactors to measure current from miniature fission chambers (MFC) and self-powered neutron detectors (SPND) during pulse measurements and steady state mode.

## Interfaces & Signal Processing

Figure 18: Libera Current Meter



Figure 19: Block diagram of Libera Current Meter



Input currents are converted into voltage via a trans-impedance amplifier, with six different gains depending on the current range selected via software. The signals are then digitized using 18-bit and 2 MSPS A/D converters (sampling frequency can be increased up to 2.5 MSPS). Offsets and gain errors can be calibrated for each channel using a nominal current source.



WebGUI direct and simple access

The instrument is accessible, with a WebGUI interface by simply typing the instrument IP address into the web browser. In addition to the WebGUI interface, the instrument can also be connected via a TCP-IP socket, enabling connections with Python, LabView, Matlab and other clients. The operating system is based on Linux and loaded using a Micro-SD card or via a TFTP server.

Figure 20: Libera Current Meter Web GUI accessible from web browser



Capabilities



| Libera<br>Current Meter<br>Capabilities  |  |  |
|------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| General product code                     | LCMB                                                                                | LCMT                                                                                |
| Input signals and connectors             | BNC (without high voltage BIAS)                                                     | TRIAx (with high voltage BIAS up to 150 V)                                          |
| Input channels                           | 4                                                                                   |                                                                                     |
| Input frequency range                    | From 15 kHz at lowest current range up to 80 kHz at highest current range           |                                                                                     |
| A/D conversion                           | 2 MHz by default (max 2.5 MHz) / 18 bit                                             |                                                                                     |
| Cooling                                  | Passive                                                                             |                                                                                     |
| Power supply                             | PoE                                                                                 |                                                                                     |
| Timing signals                           | External / Internal trigger                                                         |                                                                                     |
| Calibration                              | Factory calibrated                                                                  |                                                                                     |
| Maximum input signal                     | < 2 mA                                                                              |                                                                                     |
| Current ranges                           | ±60 nA, ±0.2µA, ±2µA, ±20µA, ±200µA, ±2mA                                           |                                                                                     |
| Temperature drift, typical               | < 1% / °C                                                                           |                                                                                     |
| 8-hour stability (1 °C) (23°C, 1 µA)     | 30 nA peak-to-peak                                                                  |                                                                                     |
| RMS uncertainty @ 1 µA (slow 10 Hz data) | < 50 pA                                                                             |                                                                                     |

Table 11: Libera Current Meter capabilities

BNC and TRIAX versions

The instrument is available with BNC input connectors (without high voltage BIAS) or with TRIAX connectors (with high voltage BIAS up to 150V).



BNC version, back panel



TRIAx version, back panel

Flexible data acquisition

A trigger input is used to trigger fast data acquisition in a large buffer with a total size of 1 million samples per channel. Different data acquisition modes are available. ADC data buffer acquisition with 2 MHz sampling output is used for short and triggerable pulses acquisition. These data is then filtered and decimated to provide lower rate data streams. Fast and intermediate data streams with 100 kHz and 1 kHz data rates are available for longer events when higher sampling resolution is needed. DC current measurement is available with a 10 Hz data rate.

Signal Data Path

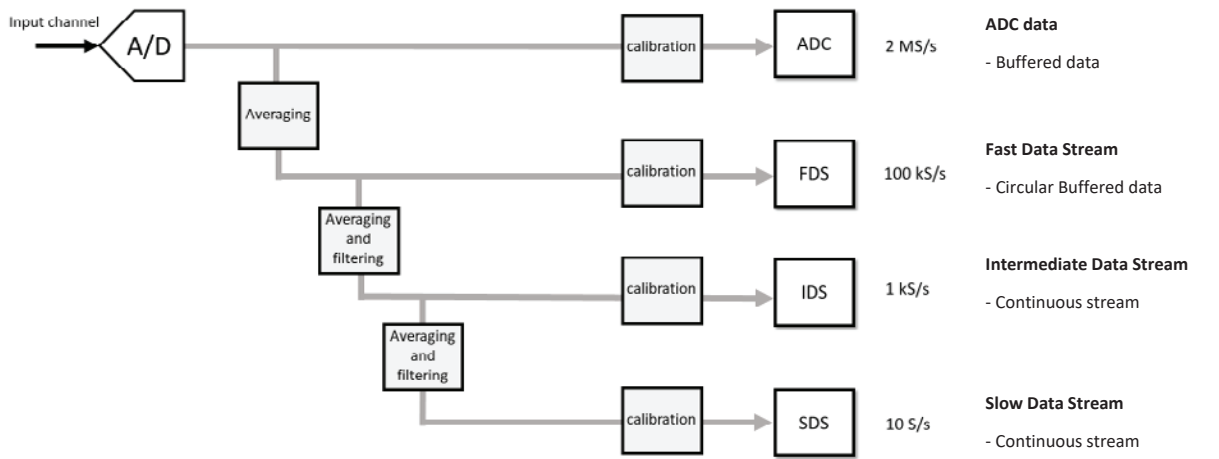


Table 12: Libera Current Meter signal data path

# DIGITAL LLRF

The Libera LLRF is a digital processing and feedback system that monitors and stabilizes the quality of the beam acceleration by controlling the phase and amplitude of the RF field injected into the machine accelerating structures. Being designed to be modular and reconfigurable, the system can fit the exact requirements of any kind of accelerator, providing three core functions:

## STABILIZATION OF THE CAVITIES' RF FIELDS

The cavity field is stabilized based on the RF signals acquired from the accelerating structures and the set-point specified by the user. The fast feedback loop controls the properties of the RF signal, by applying a drive signal to the high power amplifiers (e.g. Klystrons).

## CAVITY TUNING

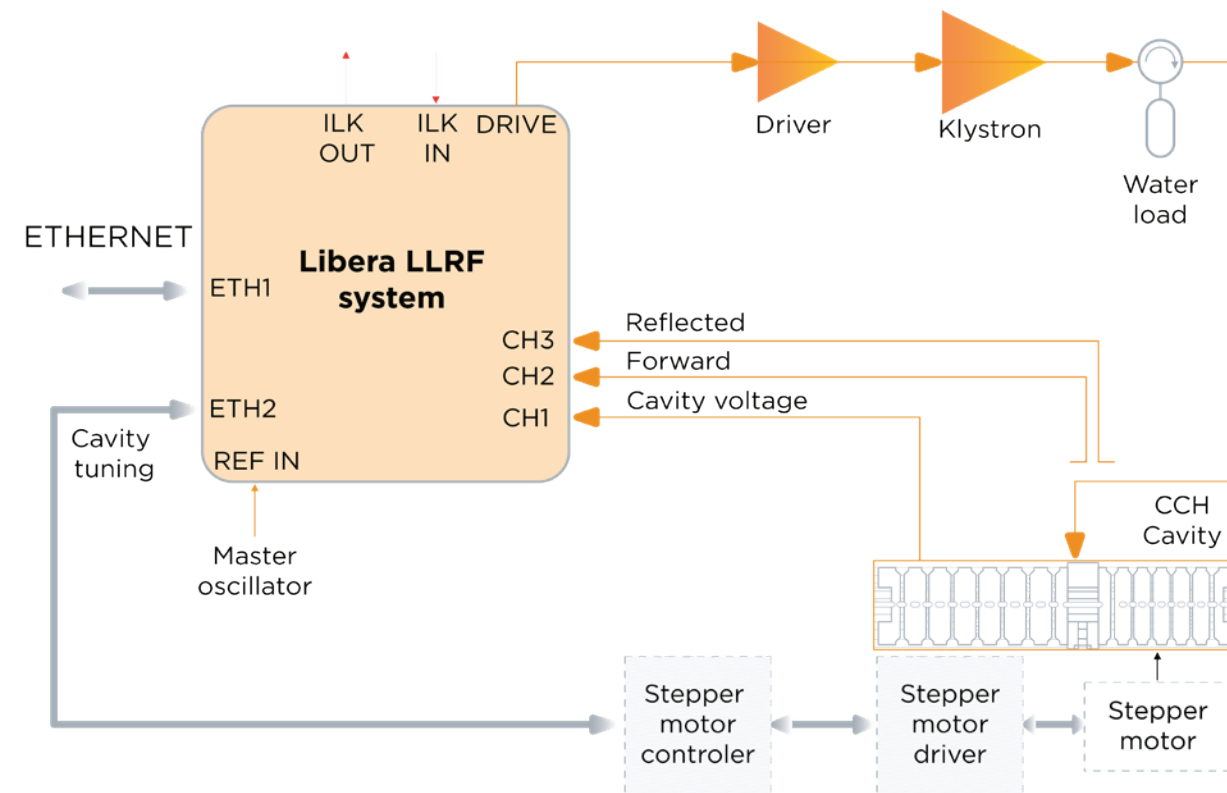
The LLRF system keeps the RF cavities at resonance by monitoring the forward and reflected signals from the RF cavities, the system can be interfaced to control slow and fast tuners (e.g., stepper motors and piezo controllers) which modify the cavity mechanical properties.

## MACHINE DIAGNOSTICS

The user is able to analyze all the signals digitized by the system, as well as the status of the feedback loop. Several signals can also be monitored by the system and Interlock events are triggered if something unexpected happens.

The block diagram presented in Figure 21 presents a possible configuration of Libera LLRF in the accelerator environment:

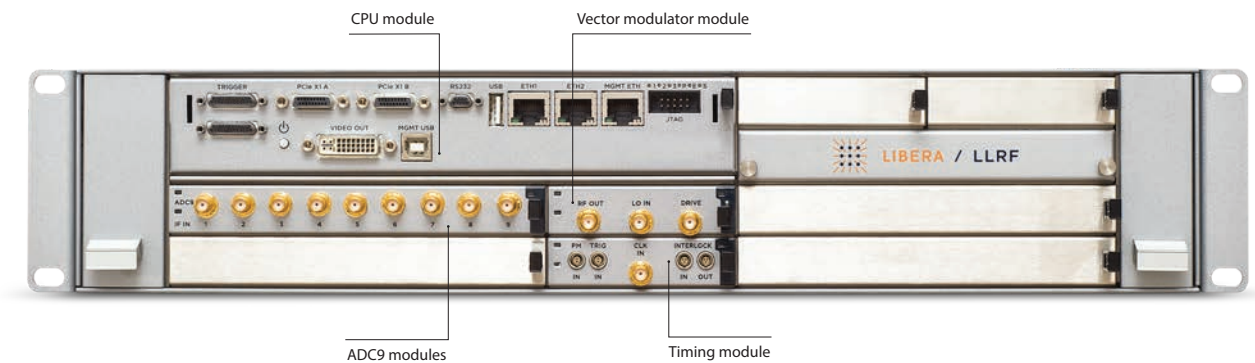
Figure 21: Possible configuration of Libera LLRF in the accelerator environment



# Interfaces & Signal Processing

The Libera LLRF system is based on the MCTA.0 standard with several AMC boards connected to the chassis front panel (Figure 22).

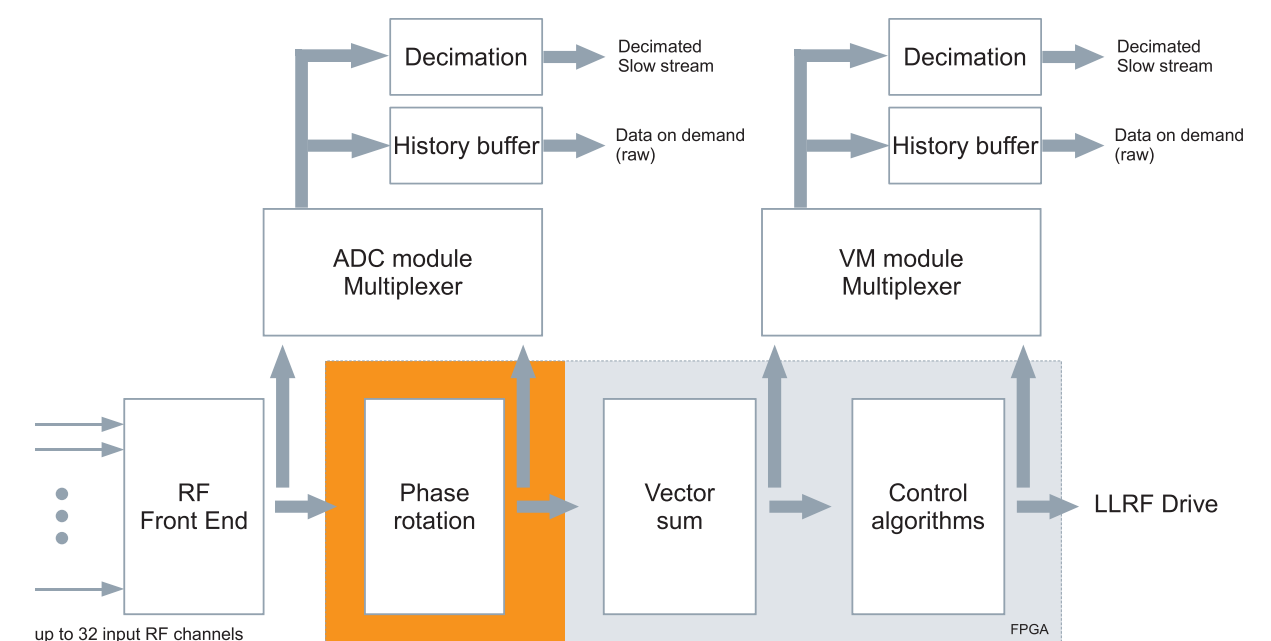
Figure 22: Libera LLRF



Up to four processing modules (ADC9) can be connected to the system in order to acquire up to 32 RF signals from the cavities; if less signals need to be acquired, the number of ADC9 modules can be reduced.

The ADC9 modules are responsible for the analog signal processing of the input signals and their digitization with 130 MS/16 bit A/D converters: this data is stored in the device memory and is available to the user. The digitized signals are later transferred to the Vector Modulator board, where the feedback logic is actually implemented (Figure 23).

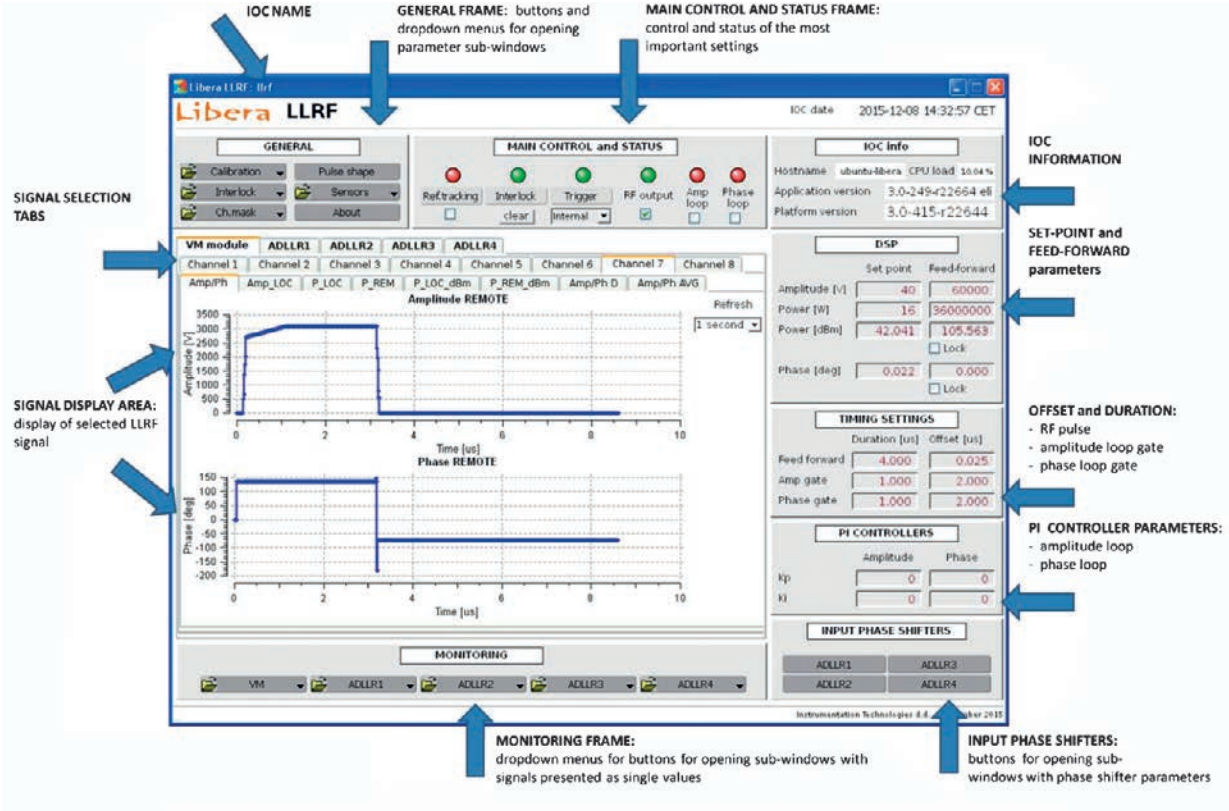
Figure 23: Signal processing in the Libera LLRF system



The phase rotation block is used to calibrate each different input signal in phase and amplitude; this is so that differences in RF cabling and delays resulting from the beam time of flight don't influence the LLRF control. The vector sum then combines all the acquired signals into one equivalent signal, which is used as the input for the control algorithm

In addition to the data digitized through the A/D converters, the user can also analyze the signals inside the feedback loop, either at the original rate or at decimated rate. One of the possible ways to monitor all this information is through the system Graphical User Interface (GUI), as presented in Figure 24.

Figure 24: Graphical User Interface (GUI) for the Libera LLRF



# Capabilities

The capabilities of the Libera LLRF system are summarized in Table 13.


| Libera LLRF Capabilities |  |
|--------------------------|-------------------------------------------------------------------------------------|
| General product code     | LLRF                                                                                |
| RF input channels        | Up to 32 (8 per ADC9 module)                                                        |
| RF input frequency       | Up to 12 GHz                                                                        |
| Maximum RF input power   | 20 dBm                                                                              |
| A/D conversion           | 130 MHz/16 bits                                                                     |
| FPGA processing          | Xilinx Kintex Ultrascale + and Virtex 5 (depending on the version)                  |
| RF output channels       | 2 (1 RF drive, 1 calibration output)                                                |
| Maximum RF output power  | > 10 dBm                                                                            |
| Cooling                  | Active                                                                              |
| Power supply             | 110/220 V                                                                           |

Table 13: Capabilities of the Libera LLRF system

# Functionalities

The functionalities of the Libera LLRF system are summarized in Table 14.


| Libera LLRF Functionalities       |                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Machine Operation mode            | <ul style="list-style-type: none"><li>Continuous Wave (CW)</li><li>Pulsed</li><li>Combined</li></ul>                                                                                                                                                                                                                                                                                                                                                      |
| Fast-feedback loop                | <ul style="list-style-type: none"><li>Gain Driven Resonator (GDR) and Self-Excited Loop (SEL)</li><li>Intra-Pulse and Pulse-to-Pulse feedback</li><li>Separate or combined loop (Amplitude and Phase, I &amp; Q)</li><li>Beam Loading compensation</li><li>Compensation for Klystron non-linear response</li><li>Compatible with variable RF frequency machines</li><li>Extensible to multiple inputs from cavities driven by the same klystron</li></ul> |
| Cavity tuning                     | <ul style="list-style-type: none"><li>Based on the cavity detune measurement algorithms: based on forward and reflected signals for CW machines, based on cavity voltage decay on pulsed machines.</li><li>Slow tuning with PID controller and stepper motor driver interface.</li><li>Fast tuning loop with piezo controller</li></ul>                                                                                                                   |
| Signal monitoring and Diagnostics | <ul style="list-style-type: none"><li>Input signals and internal feedback signals</li><li>Visualize raw or demodulated signals on the graphical user interface</li><li>Direct measurement of amplitude and phase</li><li>Derived measurement of signal power and cavity resonant frequency</li></ul>                                                                                                                                                      |
| Machine Protection                | <ul style="list-style-type: none"><li>Low latency interlock interface (Input and Output) with active low logic</li></ul>                                                                                                                                                                                                                                                                                                                                  |
| Temperature Compensation          | <ul style="list-style-type: none"><li>Temperature-stabilized RF front-end within separated chassis (Figure 25)</li><li>Calibration output usable for RF cables and RF front-end electronics calibration</li></ul>                                                                                                                                                                                                                                         |

Table 14: Functionalities of the Libera LLRF system



# Performance Specifications

The main performance specifications of the Libera LLRF system are summarized in Table 15. The results were obtained at the DESY FLASH and Daresbury Laboratory EMMA at a 1 MHz BW pulsed mode of operation.

| Libera LLRF Performance Specifications                                   |                        |
|--------------------------------------------------------------------------|------------------------|
| Amplitude stability                                                      | < 0.01% RMS            |
| Phase stability                                                          | < 0.01° RMS            |
| Latency (Input → Drive output)                                           | Down to 250ns          |
| Long-term temperature stability with temperature stabilized RF front-end | < 100fs RMS / 72 hours |

Table 15: Performance specifications of the Libera LLRF system

Figure 25: Libera LLRF temperature stabilized RF front-end



# Interface Extensions

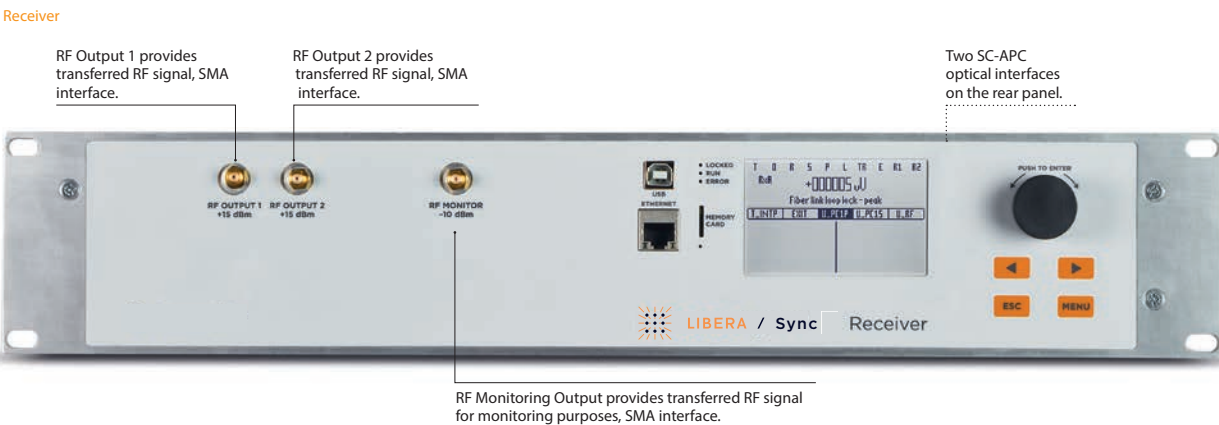
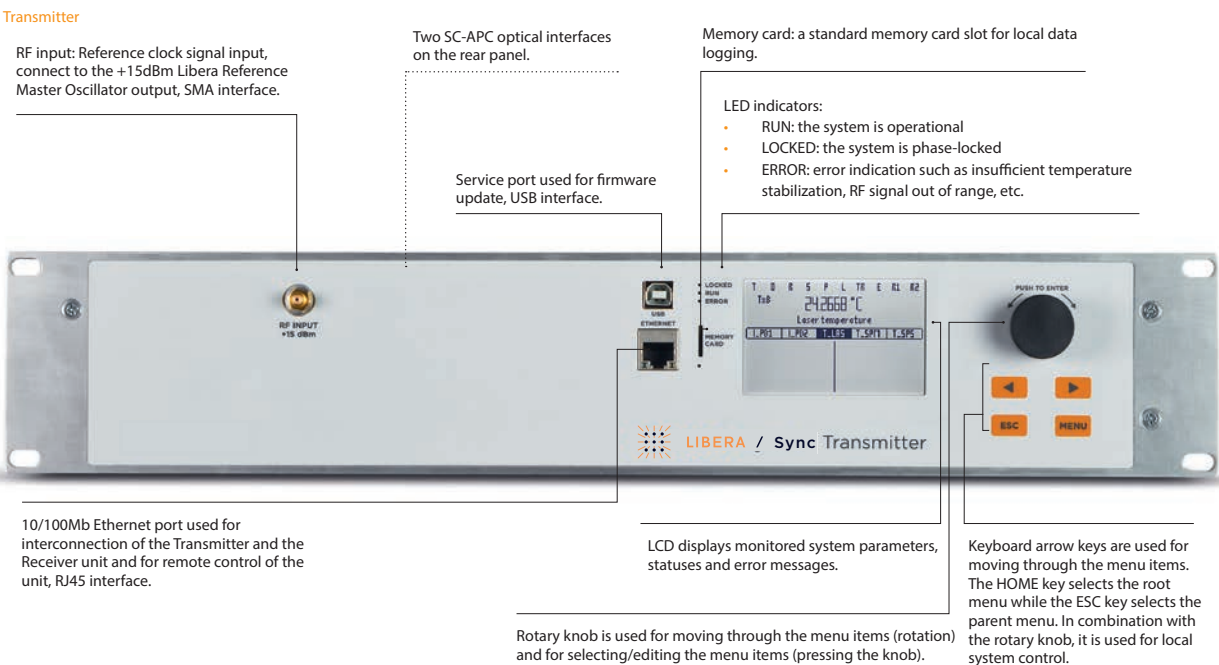
Libera LLRF interfaces can be upgraded through software modules or physical interface upgrade modules:

- A secondary Ethernet port can be used for data streaming through protocols like UDP or similar in order to transfer LLRF data to remote servers.
- A USB port can be used to interface LLRF to cavity tuning systems.

# CLOCK TRANSFER SYSTEM

The Libera Sync is used to transmit high-quality clock signals from a source, usually a Libera Reference Master Oscillator, to numerous systems that need to be synchronized along the machine (e.g., LLRF stations). It consists of a transmitter and a receiver connected with a pair of single-mode optical fibers (Figure 26).

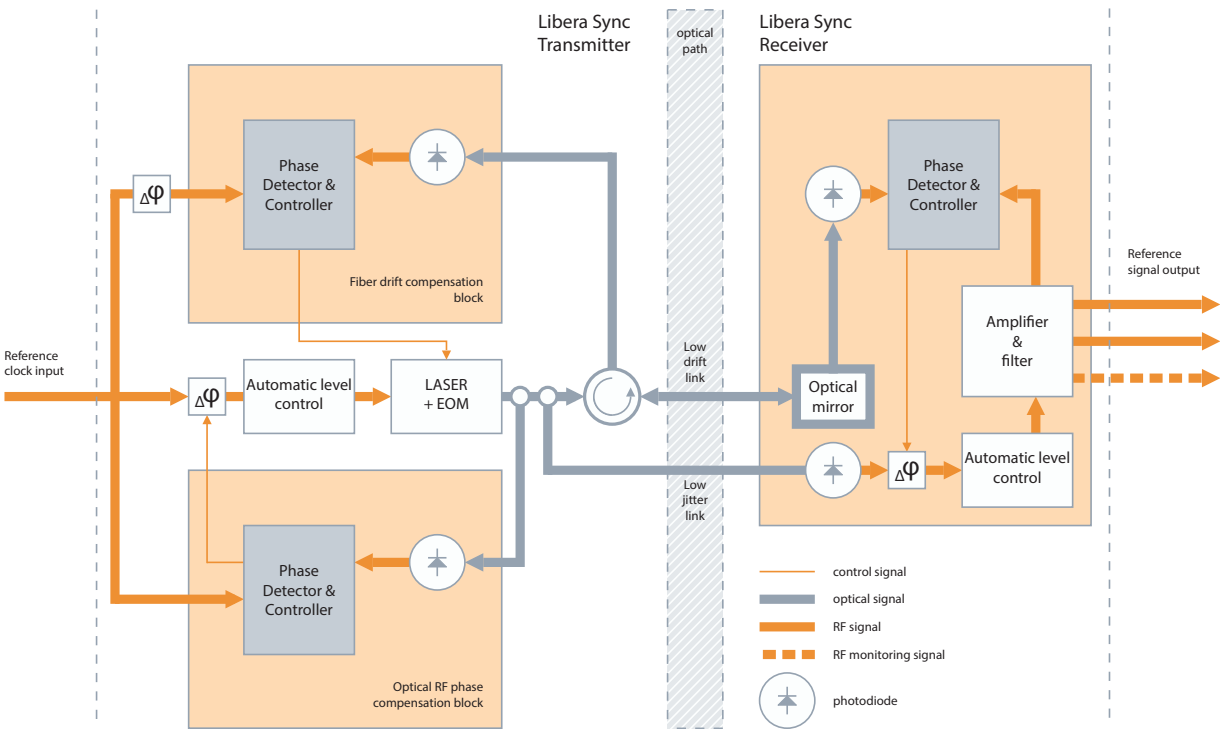
Figure 26: Clock transfer system (Libera Sync)



The transmitter input signal is a continuous wave RF reference signal that modulates an optical carrier through an electro-optical modulator. The modulated signal is split into two parts and fed into the two optical links: a low-drift link and a low-jitter link (see the block scheme in Figure 27). The low-drift signal is partially reflected at the receiver and is used to perform phase drift compensations in the transmitter.

At the receiver, the optical signals from both links are demodulated into the RF domain. The low-jitter signal is amplified, filtered, and stabilized in amplitude and phase, using the low-drift signal. This signal is used to provide two RF outputs and one monitoring output.

Figure 27: Libera Sync block scheme



To achieve the required performance and stability over the long term, both transmitter and receiver units must be installed in an environment controlled for both temperature and humidity. The system start-up and tune procedures are done automatically. Once tuned, the system requires very low maintenance.

## Capabilities

The Libera Sync covers S-band frequencies: its capabilities are summarized in Table 16.

| Libera Sync Capabilities               |                                     |
|----------------------------------------|-------------------------------------|
| General product code                   | LSYN                                |
| Carrier frequency                      | 2.856 GHz, 2.9985 GHz, 2.9988 GHz * |
| RF inputs                              | 1                                   |
| RF input level                         | (15 ± 1) dBm                        |
| RF outputs                             | 2                                   |
| RF output level                        | (15 ± 0.5) dBm                      |
| Optical link length (maximum)          | 1500 m                              |
| Optical fiber drift compensation range | 500 ps                              |
| Dimensions                             | 2U 19" standard                     |
| Calibration and tuning mode            | Automatic                           |
| Operating temperature range            | 20 – 30 °C                          |
| Operating relative humidity range      | 0 – 80 %                            |
| * Custom frequencies are available     |                                     |

Table 16: Performance specifications of the Libera Sync system

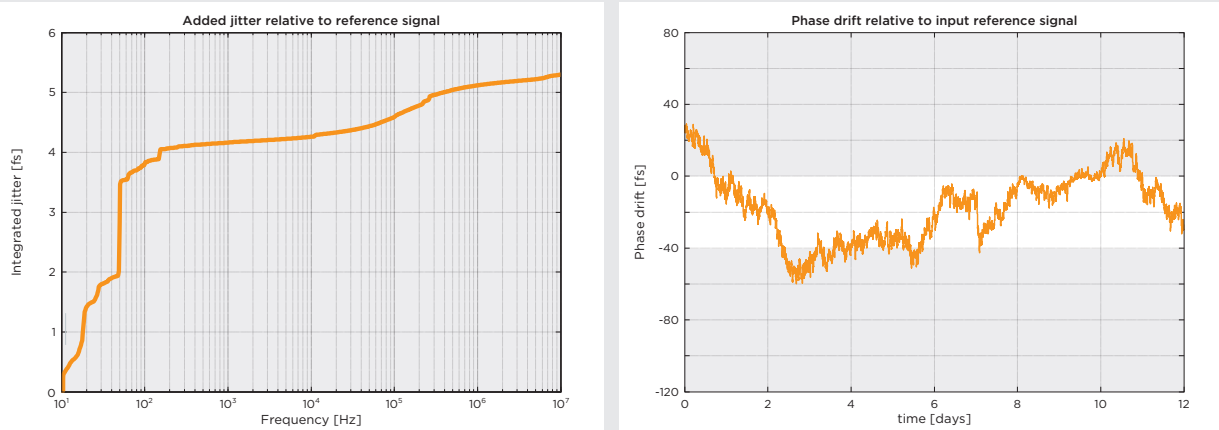
## Performance Specifications

The performance specifications of the RF clock transfer system are summarized in Table 17, while Figure 28 presents the added jitter measurement and long-term stability for the Libera Sync.

| Libera Sync Performance Specifications         |                                                         |
|------------------------------------------------|---------------------------------------------------------|
| Added jitter (integrated from 10 Hz to 10 MHz) | < 10 fs RMS                                             |
| 24-hour drift                                  | < 40 fs peak-to-peak typ.<br>< 100 fs peak-to-peak max. |

Table 17: Performance specifications of the Libera Sync

Figure 28: Added jitter and long-term phase stability measured with Libera Sync

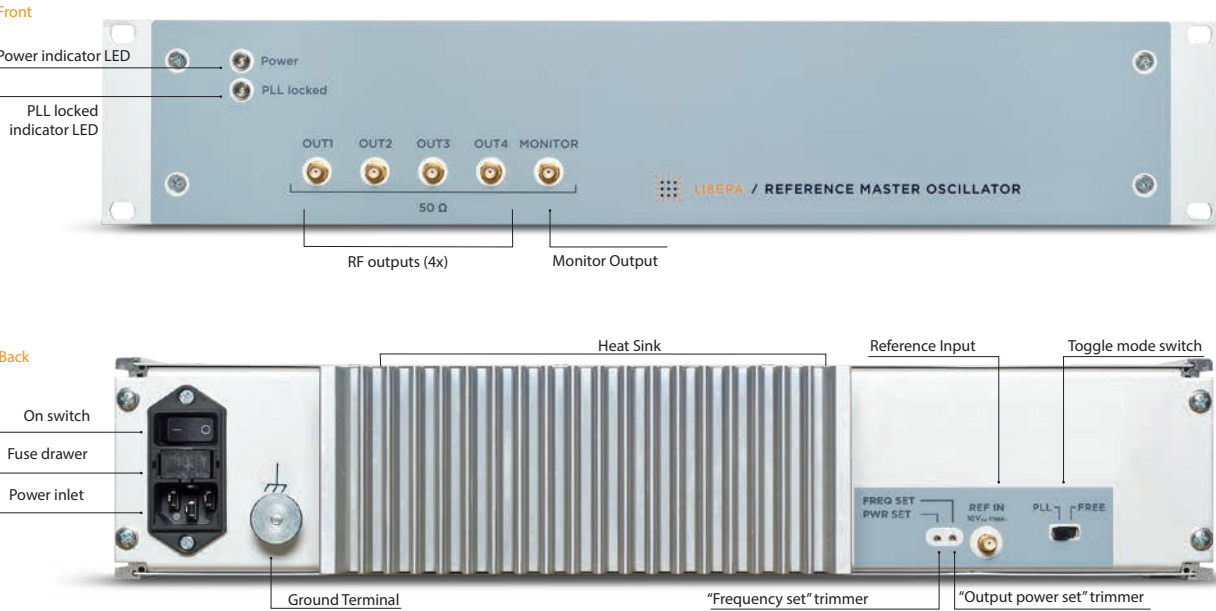


# REFERENCE MASTER OSCILLATOR

The Libera Reference Master Oscillator provides a sine wave signal with low phase noise to four outputs with a maximum power of +18 dBm per output. The device free-runs on an internal OCXO which can additionally be locked to an external 10 MHz reference signal.

The oscillator has very good frequency stability when free-running on OCXO ( $\pm 0.3$  ppm in range of temperature from 20 to 40 °C) combined with extremely low phase noise, below 30 fs in a range between 10 Hz and 10 MHz. The front and back panels of the instrument are shown in Figure 29.

Figure 29: Libera Reference Master Oscillator, front & back panel



The RF specifications of the Libera Reference Master Oscillator are presented in Table 18.


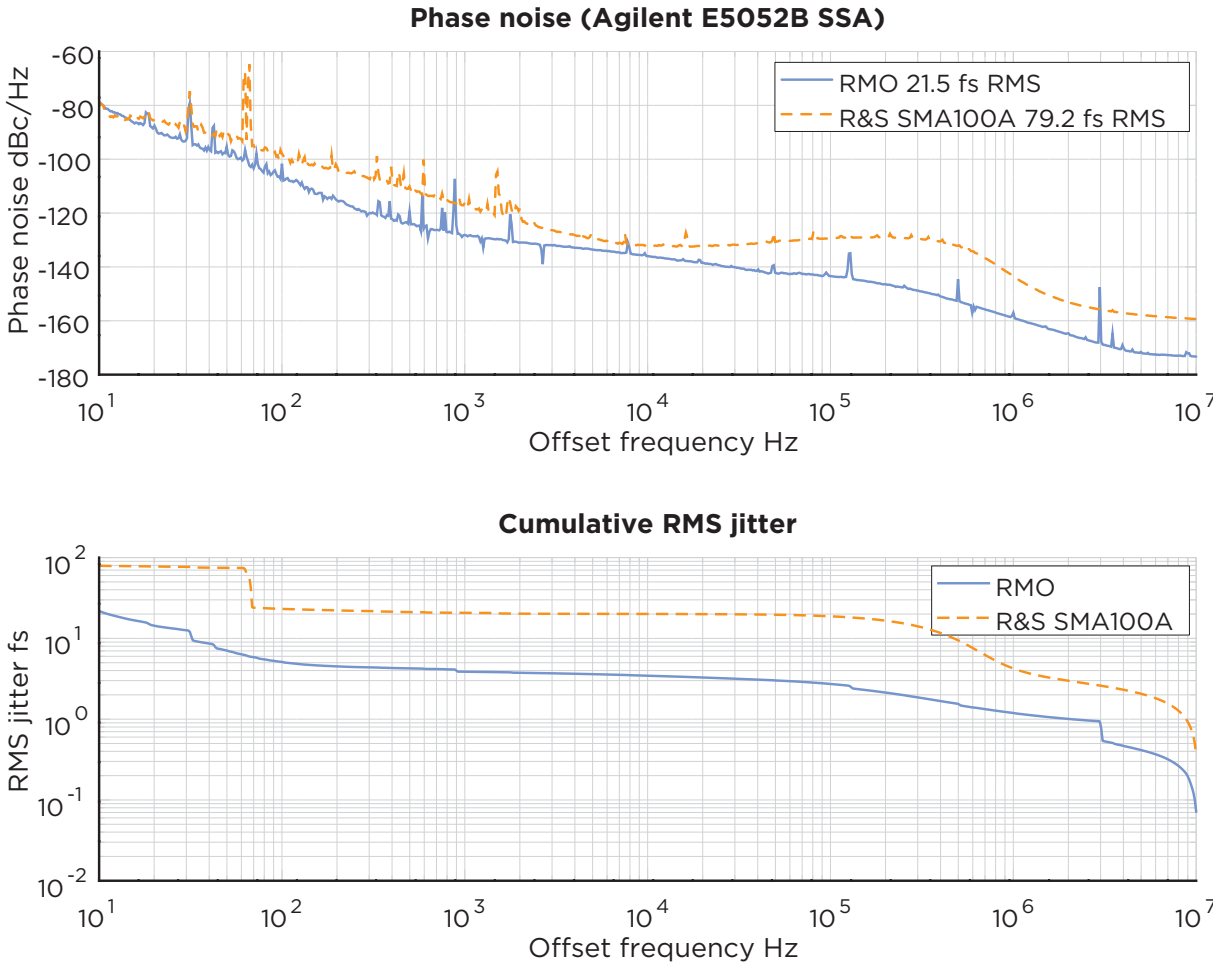
| Libera Reference Master Oscillator            |  |
|-----------------------------------------------|--------------------------------------------------------------------------------------|
| General product code                          | LRMO                                                                                 |
| Minimum settable power per output             | +13 dBm                                                                              |
| Maximum settable power per output             | +18 dBm                                                                              |
| Monitor output power (referenced to outputs)  | -20 dB                                                                               |
| Output power stability                        | 0.08 dB/°C                                                                           |
| Amplitude balance between any two outputs     | < 0.3 dB                                                                             |
| Return loss                                   | -20 dB                                                                               |
| Frequency stability                           | 5*10 <sup>-11</sup> (Allan Deviation in free running mode)                           |
| Integrated phase noise (max)                  | < 30 fs (10 Hz – 10 MHz)                                                             |
| Phase drift between any two outputs (typical) | < 0.1 deg/°C                                                                         |
| Harmonic suppression                          | < 55 dBc up to 5th harmonic                                                          |
| PLL lock time                                 | < 60 s                                                                               |

Table 18: RF specifications

Figure 30: Typical Libera Reference Master Oscillator phase noise performance compared with a Rohde & Schwarz SMA100A RF generator



The number of RF outputs can be further increased by means of an optional temperature stabilized Libera RMO Distribution Amplifier unit connected to the Libera Reference Master Oscillator unit. The Libera RMO Distribution Amplifier supports up to 12 RF outputs (Figure 31).

Figure 31: Libera RMO Distribution Amplifier, front panel



The Libera RMO Distribution Amplifier can be customized in terms of number of RF outputs. The frequency of the outputs can be divided or multiplied from the provided input frequency for applications where coherent subharmonics are required.



# WIDE DYNAMIC RANGE LOW NOISE AMPLIFIER

The Libera Amplifier 110 is a four-channel, low noise, non-inverting measurement amplifier. Its gain can be set in increments of 10 dB from –50 dB to 60 dB via an SPI control interface.

The Libera Amplifier 110 is intended to reduce wide dynamic ranges in order to enable further signal processing and acquisition. An example of application is pickup signals in beam position monitoring in accelerators, where the Libera Amplifier 110 can be used in combination with, for example, the Libera Hadron.

Figure 32: Libera Amplifier 110



The main features of the Libera Amplifier 110 are shown in Table 19.


| Libera Amplifier 110        |  |
|-----------------------------|--------------------------------------------------------------------------------------|
| General product code        | LAMP                                                                                 |
| Dynamic range               | from -50 dB to 60 dB                                                                 |
| Input voltage               | max. 230 V peak (max. average input power 1.5 W per channel)                         |
| Output voltage              | ±2 V peak                                                                            |
| Bandwidth                   | from 40 kHz to 55 MHz                                                                |
| Gain error between channels | max. ±0.1 dB                                                                         |
| Output referred added noise | < 15 mVrms, for gain 60 dB<br>< 5 mVrms, for gains <60 dB                            |
| Input and output impedance  | 50 Ω                                                                                 |

Table 19: Libera Amplifier 110 specifications

# CONTROL SYSTEM INTEGRATION

Firmware and FPGA code run in hardware modules. The hardware modules are integrated to higher-level software through the libera-kernel layer. The custom-written kernel is integrated within the Libera BASE software framework which provides hardware abstraction and simplifies development of custom applications and integration to various control systems. Libera BASE also contains platform management and health monitoring functionalities.

The instrument-specific application is integrated within the Libera BASE framework that provides access to the application’s configuration parameters and data buffers and streams.

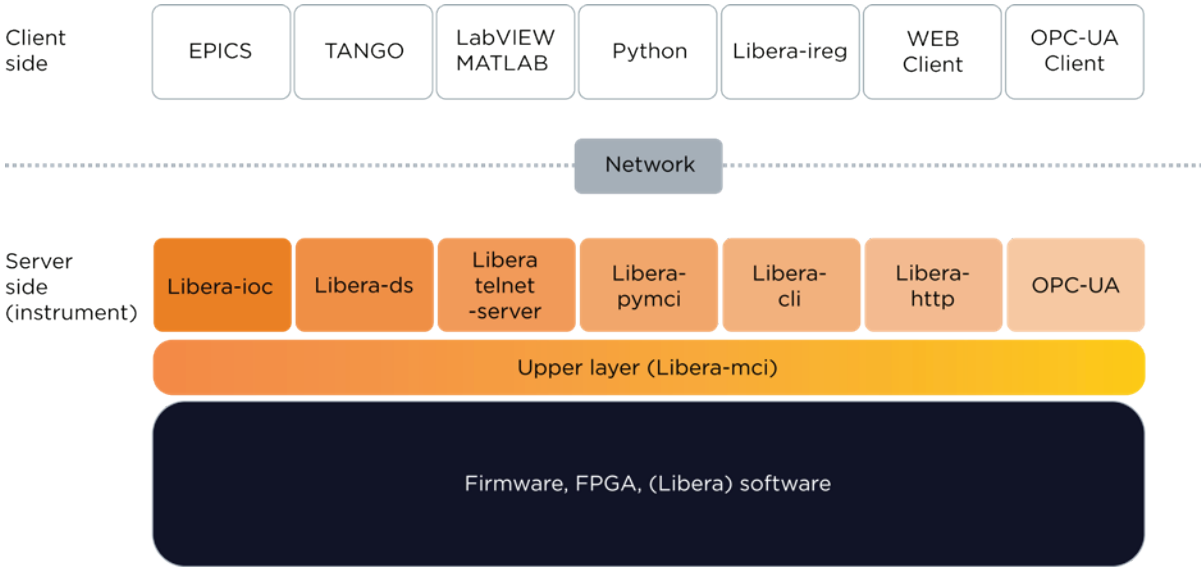
The Measurement and Control Interface (MCI) layer transfers parameters and data between the Libera application and various servers. Servers, such as EPICS, TANGO and FESA, run in the instrument. Some servers (e.g. EPICS) can run on external machines and connect to the MCI layer via the network.

Servers that run in Libera instruments (platform dependent) support the following clients:

- EPICS
- TANGO
- LabVIEW/MATLAB
- HTTP (WEB browsers)
- Python
- OPC-UA
- Custom-written C++ clients such as libera-ireg

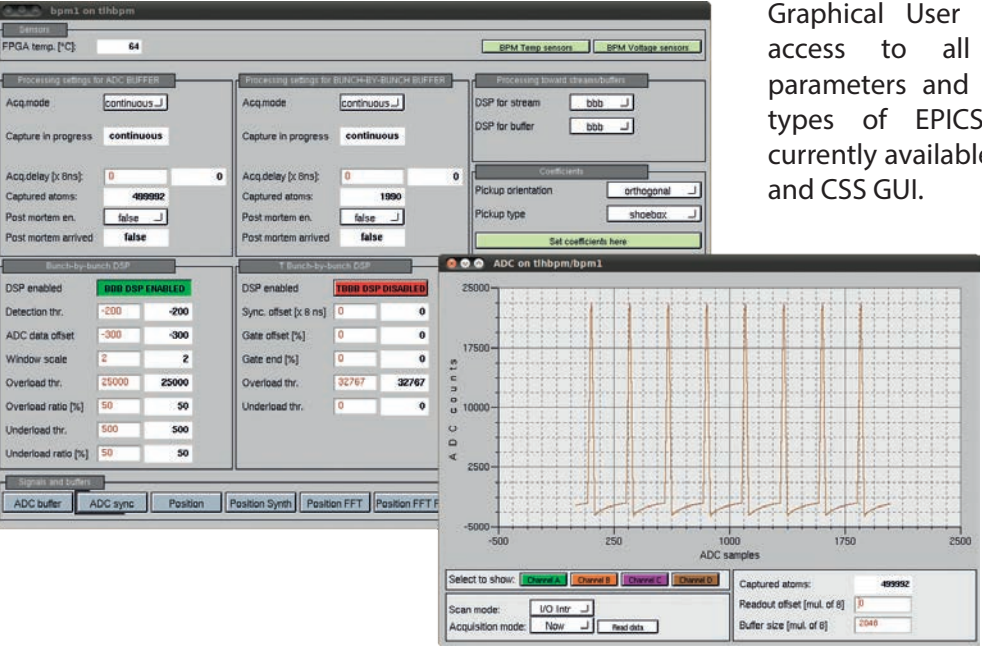
Libera software is compiled for standard Linux distributions (Ubuntu, CentOS, Zynq). Source code for servers such as EPICS and TANGO is available to users.

Figure 33: Software interfaces and building blocks within Libera instruments



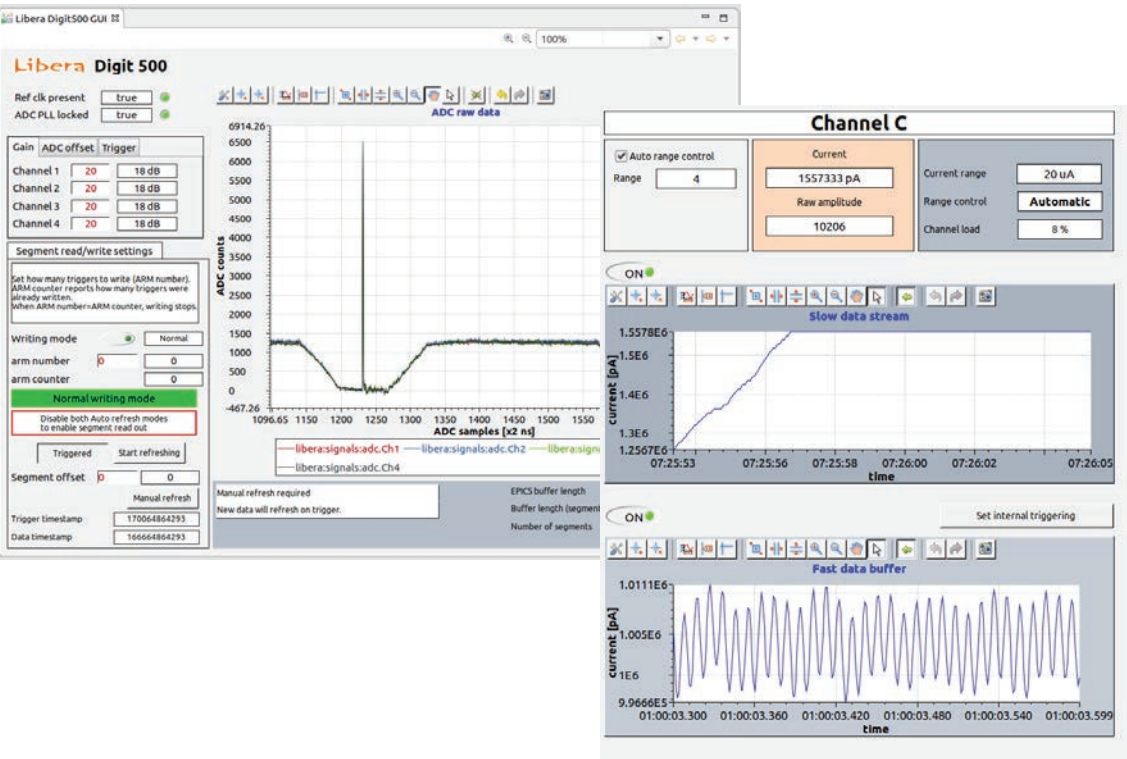
# GUI - GRAPHICAL USER INTERFACE

Figure 34: Example of EDM-based GUI



Graphical User Interfaces provide access to all the instrument parameters and signal data. Three types of EPICS-based GUIs are currently available: EDM GUI, Qt GUI, and CSS GUI.

Figure 35: Example of CSS-based GUI



# EXTENSIONS

Libera instruments can be integrated with other accelerators' subsystems by extending their functionalities using specific modules and custom-developed applications (Table 20).

| Extension                       | Description / example                                                                                                                                                        | Works with                                                                                                                            | Required module                                                                                                                            |
|---------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| Fast Orbit feedback solution    | • Complete solution for electron machines that use Libera Brilliance+ instruments (Figure 37).                                                                               | • Libera Brilliance+                                                                                                                  | • GDX module<br>• SER module<br>• Orbit feedback application software<br>• Dedicated optical network<br>• Magnet correction data receiver* |
|                                 | • Complete solution for hadron machines that use Libera Hadron instruments (Figure 37).                                                                                      | • Libera Hadron                                                                                                                       | • GDX module<br>• SER 2 module<br>• COFB application software<br>• Dedicated optical network<br>• Magnet correction data receiver**        |
| Real-time data streaming        | • Real time data streaming directly from the FPGA through a dedicated instrument interface                                                                                   | • Libera Brilliance+<br>• Libera Single Pass E<br>• Libera Hadron<br>• Libera Single Pass H<br>• Libera Spark<br>• Libera Digit 500** | • GDX module or GbE interface (depending on the instrument)                                                                                |
| Interlock detection and output  | • Interlock detection and hardware interface towards Machine Protection System.<br>• Compatible with Libera Platform C instruments.                                          | • Libera Spark<br>• Libera Cavity BPM<br>• Libera BLM                                                                                 | • DAI module<br>• Interlock detection software                                                                                             |
| Additional Digital I/O channels | • Add 2 extra digital I/O interfaces (LEMO) for communication and/or control of auxiliary components.                                                                        | • Libera Spark<br>• Libera Digit 125<br>• Libera Digit 500                                                                            | • DAI module<br>• I/O control software**                                                                                                   |
| Analog outputs                  | • Add an analog output to control an auxiliary component or transform a selected digital value (e.g. SUM, position, etc.) into a 16-bit analog value.                        | • Libera Spark<br>• Libera Digit 125<br>• Libera Digit 500                                                                            | • DAC control software**<br>• DAI module                                                                                                   |
| Serial interface                | • Add a RS-485 interface for half-duplex communication with auxiliary components.<br>• Add multiple RS-485 interfaces for real-time data streaming towards magnet receivers. | • Libera Spark<br>• Libera Digit 125<br>• Libera Digit 500                                                                            | • DAI module RS-485 control software**                                                                                                     |
| Frequency down conversion       | • Convert a higher-frequency signal to match the input capabilities of a Libera instrument.                                                                                  | • Libera Spark EL<br>• Libera Single Pass E                                                                                           | • Libera DWC                                                                                                                               |

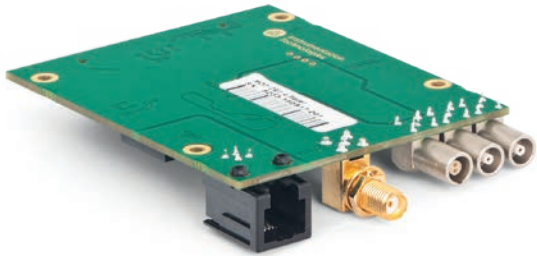
\* Not provided by Instrumentation Technologies  
\*\* Basic control included only. Can be customized by users using source code.

Table 20: Extension options for Libera instruments

## DAI Module

The DAI module extends the inter connection capabilities of Libera Platform C instruments as shown in Table 21 (Libera Spark, Libera Photon, Libera Digit).

Figure 36: DAI module



| Interface              | Description                                                     |
|------------------------|-----------------------------------------------------------------|
| LEMO single (2x)       | Single-ended LEMO, Input/Output configurable                    |
| LEMO differential (1x) | Differential LEMO, Interlock output (requires external circuit) |
| SMA (1x)               | 16-bit 100 kSps DAC output, 1 V at 50 Ohm                       |
| RJ-14 (1x)             | up to 20 Mbps, half-duplex                                      |

Table 21: Technical specifications of the DAI module

# Orbit Feedback Solutions

A complete orbit feedback solution consists of several Libera instruments like Libera Brilliance+ or Libera Hadron based on a modular platform, all equipped with the GDX module, which enables them to exchange the orbit beam position data via a dedicated network. Inside of every GDX module, specific data processing calculates the corrections to apply to the magnet controllers (via the optional SER or SER II modules). The correction can be made locally or globally. A general schematic is shown in Figure 37.

A standalone orbit feedback solution is another possible topology where the feedback calculations are not performed inside of each BPM processor, but a data concentrator (Orbit Feedback platform) is used. Each BPM processor streams out the beam position to one or two Libera instruments on our modular platform equipped with the GDX module (optionally also with the SER/SER 2 module). The Orbit Feedback platform concentrates on the GDX module the BPM positions coming from each BPM electronics (global orbit data). The orbit feedback application inside the module applies custom-written algorithms and data processing before being sent to the magnet controllers (locally or globally). A general scheme is shown in Figure 38.

For circular machines, the closed loop operation can be further expanded with dedicated modules that extend the instrument capabilities enabling global orbit feedback. These modules fit inside the instruments and provide fast serial communication links that can be used with optical or copper cables, GbE, and RS-485 interfaces. These interfaces can be used to control the corrector magnets and/or pre-amplifiers.

Figure 37: Complete orbit feedback solution for electron/hadron machines

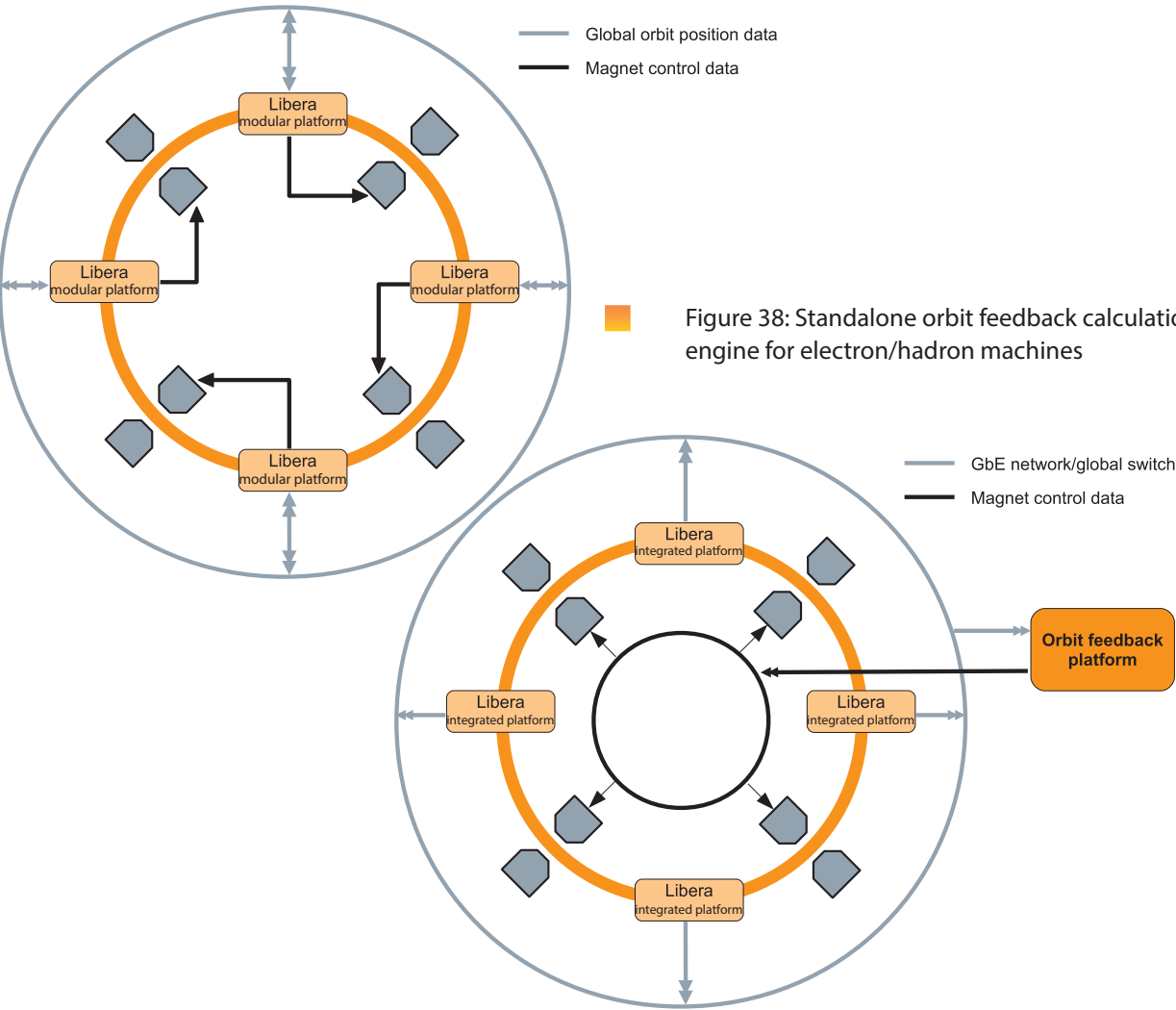


Figure 38: Standalone orbit feedback calculation engine for electron/hadron machines

# SER Module

The SER module features four RS-485 interfaces directly controlled from the GDX module. The protocol and the baud rate are specified by the application in the GDX module (Table 22).

Figure 39: SER Module



| SER Module     |                                              |
|----------------|----------------------------------------------|
| I/O interfaces | RJ-25, LVDS links to GDX module              |
| Baud rate*     | Up to 2.5 Mbit/s                             |
| Protocol*      | Asynchronous protocol EIA 485, byte per byte |

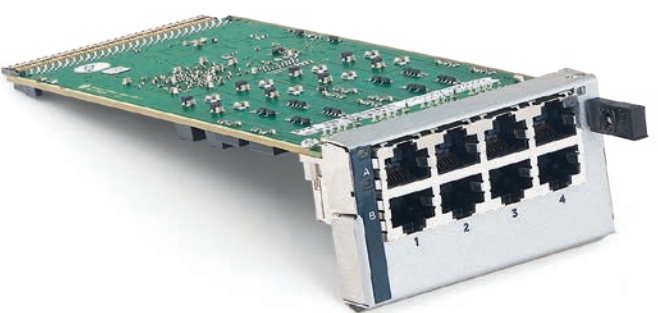
\* Specified by application in the GDX module

Table 22: Capabilities of SER module

# SER 2 Module

The SER 2 module features eight RS-485, RJ-45 interfaces controlled via the PCI express link (Table 23).

Figure 40: SER 2 Module



| SER 2 Module   |                                          |
|----------------|------------------------------------------|
| I/O interfaces | RJ-45, PCI express link to AMC connector |
| Electrical     | EIA 485                                  |
| Protocol       | High speed USI protocol                  |

Table 23: Capabilities of SER 2 module



# GDX Module

The GDX module extends the interconnection capabilities of the BPM electronics. Four protocol independent small form pluggable (SFP) slots can be used to build a closed loop of all the instruments in the accelerator. It features a Virtex6 FPGA, which is completely open to user-developed applications. It can process the internal (within the chassis) and external position data at various data rates (Table 24).

| GDX Module                                                            |                                                                                     |
|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| FPGA chip                                                             | XC6VLX240T-2FF784C                                                                  |
| Memory                                                                | 2 GB DDR3                                                                           |
| I/O interfaces                                                        | 4x SFP+ compliant, compliant multiprotocol operations, LVDS links to AMC connectors |
| SFP protocol                                                          | AURORA, GbE, others on request; independent to each SFP                             |
| PClexpress x4 bus interface to instrument's backplane                 |                                                                                     |
| On-board clock synthesizer and programmable VCXO for clock generation |                                                                                     |
| Board management is already established                               |                                                                                     |

Table 24: Capabilities of GDX module

# Libera DWC

The DWC-SP circuit is a four-port RF downconverter that can be used to down-convert the RF input signals from S-band to an intermediate frequency (Table 25).

| Libera DWC          | 1.3 GHz    | 3 GHz      |
|---------------------|------------|------------|
| Supply voltage      | 6 V DC     | 6 V DC     |
| RF Input connector  | SMA        | SMA        |
| RF Input frequency  | 1300 MHz   | 2856 MHz   |
| RF Input power      | Max 15 dBm | Max 15 dBm |
| LO Input connector  | SMA        | SMA        |
| LO Input frequency  | 800 MHz    | 2356 MHz   |
| LO Input power      | 5 dBm      | 5 dBm      |
| RF Output connector | SMA        | SMA        |
| RF Output frequency | 500 MHz    | 500 MHz    |

Table 25: Technical specifications of the Libera DWC

Figure 41: GDX module



Figure 42: Libera DWC



# Elettra Pilot-Tone Front-End prototype

Instrumentation Technologies and Elettra Sincrotrone Trieste are presently working on a project for the industrialization of the Pilot-Tone Front-End prototype described in this chapter. An industrial version is expected in mid-2022.

Beam current dependency, thermal drifts of electronics and variations of the cables frequency response (due to changes in temperature or humidity) exert a strong influence on the accuracy of the BPM system. They trigger inter-channel gain differences, which introduce uncontrolled fluctuations in the calculated positions.

The Elettra Pilot-Tone Front-End helps to compensate for all these factors simultaneously. A low phase-noise pilot-tone signal is added to the RF BPM signals, right after the BPM pickup, at a slight different frequency. In this way both signals (BPM signal and Pilot-Tone signal) propagate through the RF cables and the electronics front-end and every change in the signal path affects them in the same manner. The FPGA processing of the digital electronics, in this case **Libera Spark ERPT**, is able to reconstruct both signals independently and uses the pilot-tone signal information to correct the BPM RF signal.

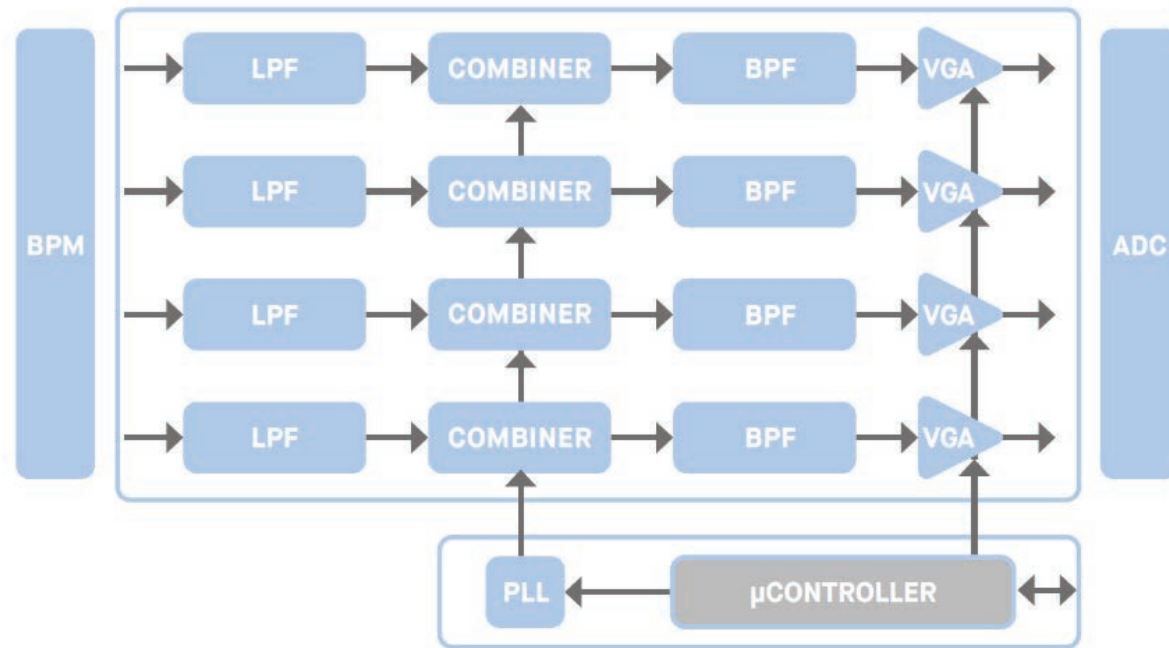
| Pilot-Tone Front-End  |                                                                                                                                                               |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Input channels        | 4 (SMA connectors)                                                                                                                                            |
| Output channels       | 4 (SMA connectors)                                                                                                                                            |
| Input impedance       | 50 Ohm                                                                                                                                                        |
| Noise Figure          | 7 dB (depends on the setting of the first variable attenuator)                                                                                                |
| Gain                  | from -28 dB to +35 dB                                                                                                                                         |
| Crosstalk             | Better than -55 dB                                                                                                                                            |
| Bandwidth             | Different versions available: <ul style="list-style-type: none"><li>• 342.5 MHz – 357.5 MHz</li><li>• 398 MHz – 410 MHz</li><li>• 495 MHz – 505 MHz</li></ul> |
| Input return loss     | -29 dB at 500 MHz                                                                                                                                             |
| 1dB compression point | +2 dBm at 500 MHz                                                                                                                                             |
| Reference input       | Two versions available: <ul style="list-style-type: none"><li>• Internal programmable PLL</li><li>• External reference input</li></ul>                        |
| Communication         | TCP-IP over Ethernet                                                                                                                                          |
| Supply voltage        | External, +12V                                                                                                                                                |
| Supply current        | 500mA                                                                                                                                                         |
| Dimensions            | 170x170x55mm                                                                                                                                                  |
| Weight                | 500g                                                                                                                                                          |

Table 26: Technical specifications of the Elettra Pilot-Tone Front-End prototype

Figure 43: Elettra Pilot-Tone Front-End prototype



Figure 44: Block Diagram



## SERVICES & SUPPORT

### Commissioning assistance

Assistance in installation, commissioning, and integration into the control system.

### On-site and remote support

Get in touch with our skilled engineers, who have a full knowledge of the system. We will help you with hardware, software, or system integration issues throughout the product's lifecycle.

### On-site demonstration and testing

Try the instruments on your machine. One of our experts can visit you and assist you with testing.

### Training

Hands-on training sessions on the use of Libera instruments are organized either on-site or at Instrumentation Technologies premises.

### Instrument customization

Our flexible hardware and software architecture provides different options for extending functionalities.

### Warranty extension

Extend the standard warranty period for the instruments and fix the cost of potential malfunctions in advance.

# Libera

## Get in touch with us:

### HQ

Instrumentation  
Technologies d.o.o.

Address  
Velika pot 22,  
SI-5250 Solkan  
Slovenia

Web  
[www.i-tech.si](http://www.i-tech.si)

Contacts  
P: +386 5 33 52 600  
F: +386 5 33 52 601  
E: [info@i-tech.si](mailto:info@i-tech.si)

Customer support  
E: [support@i-tech.si](mailto:support@i-tech.si)

Sales/Marketing  
E: [sales@i-tech.si](mailto:sales@i-tech.si)

### CHINA

Parlitec (Beijing)  
technology co. Ltd.

Address  
A903,  
Chaoyang north road 13,  
Chaoyang district,  
Beijing, China

Contacts  
P: +8601059396219  
F: +8613811181795  
E: [info@parlitec.com](mailto:info@parlitec.com)

### JAPAN

Positive ONE  
Systems Corporation

Address  
Shibuya Mark City, 1-12-1,  
Dougenzaka,  
Shibuya-ku  
Tokyo, Japan

Web  
[www.positive-one.biz](http://www.positive-one.biz)

Contact person  
Mr. Masaharu Umeda  
P: +81-3-3256-3933  
E: [masaharu.umeda@positive-one.com](mailto:masaharu.umeda@positive-one.com)

### INDIA

Geebee International

Address  
12 - A, Lane W - 16,  
Sainik Farms,  
New Delhi  
India

Web  
[www.geebeginternational.com](http://www.geebeginternational.com)

Contact person  
Sahil Pershad  
P: +91 98107 54666  
F: +91 (11) 2 955 3209  
E: [sahil@geebeginternational.com](mailto:sahil@geebeginternational.com)

# Get in touch

#### MORE AT WWW.I-TECH.SI

Visit our website to read more about Libera products, download conference papers on the use of Libera in different accelerators around the world, and learn about the next gathering of the community at a Libera Workshop.

#### TECHNICAL SUPPORT

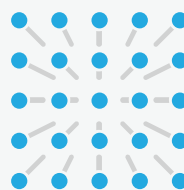
Prompt and reliable. You can request on-site support or we can assist you remotely. You are also welcome to join us at the Libera Workshop training sessions to get the most out of the support offered.



WHERE IDEAS MEET TECHNOLOGY



**LIBERA**



**INSTRUMENTATION  
TECHNOLOGIES**

**HEADQUARTERS**

Instrumentation Technologies, d.o.o.,  
Velika pot 22, SI-5250 Solkan,  
Slovenia, EU

**PHONE**

+386 5 335 26 00

**EMAIL & WEBSITE**

info@i-tech.si  
sales@i-tech.si  
www.i-tech.si