LIBERA

LIBERA BOOK

2023

SOLUTIONS FOR **PARTICLE** ACCELERATORS

INSTRUMENTATION TECHNOLOGIES

SOLUTIONS FOR **PARTICLE ACCELERATORS**

“The Libera folks,” that’s how the accelerator community knows us, and we’ve made quite an impression since we began our story back in 2003. Over the last two decades we have supplied nine out of ten synchrotron light sources around the world with our **Libera beam position monitoring** and **stabilization systems**. We believe Libera is much more than just the sum of its parts. It offers the best possible performance for the price, with pro-active engineering, reliability and **long-term support.** But for us, it is the relationships with our customers that Libera has enabled us to develop over the years that we cherish the most.

Today, Libera addresses a wider range of particle accelerator applications, including **Beam Loss Monitoring, Digital Low-Level RF Controls** and **RF Generation** and **Distribution,** offered for both circular and linear machines. This means more tools for our users and also the possibility to enter exciting new application areas, such as **Particle Therapy** and **Isotope Production.**

In the last few years we have also started to offer our domain knowledge and technical expertise to users that have chosen different HW platforms, and this has resulted in the first projects using the standard **MTCA.4 boards,** and in the first **industrialization of prototypes** developed by our customers.

Going forward, we believe that combining our expertise and the building blocks developed thus far with a flexible, proactive approach and long-term support will enable us to partner with the most challenging projects, and to find **innovative** ways to meet the requirements for the machines of the **future.**

Elvis Janežič

CEO of Instrumentation Technologies

Libera references

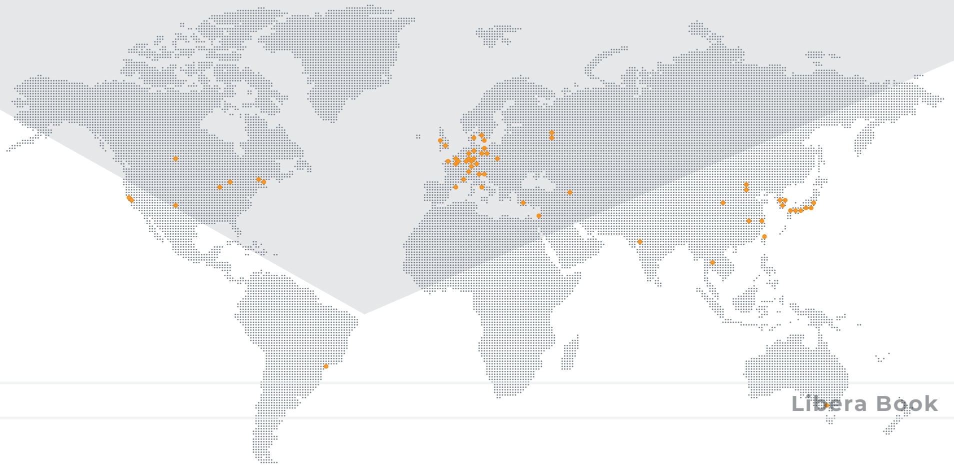
Asia
BARC
HIRFL—CSR
HiSOR
HUST
IBS—RISP
IHEP-CAS—BEPC II, ADS, CSNS, HEPS
IMP-CAS—C-ADS, LEAF, SSC-LINAC,
IMS—UVSOR
Inter University Accelerator Centre
ISSP
KAERI—KOMAC
KEK—PF, PF-AR, LINAC, SUPER B,
J-PARC, cERL
Nagoya University—Aichi Synchrotron
NewRT Medical Systems
NSRRC—TLS, TPS
PAL—PLS II, XFEL ITF, EUV,
PIEAS
RRCAT—INDUS, INDUS II
SACLA—Spring-8
SAGA
SINAP—SSRF, SXFEL
SJTU
SLRI—SPS
Tsinghua University
USTC—NSRL

Australia
ANSTO—Australian Synchrotron

Europe
AVO-ADAM—LIGHT
BINP—SKIF
CELLS—ALBA
CERN
CNAO
DESY—PETRA III, FLASH, DESY XFEL,
DORIS III
Diamond Light Source
ELI—BEAMS
ESRF—ESRF-EBS
Forschungszentrum Jülich—COSY
Fritz Haber Institute
GSI—FAIR
HZB—BESSY II
HZDR—ELBE
INFN-LNF—Daphne, ELI-NP, SPARC, LATINO,
SABINA, CLEAN, STAR
INFN-LNS
INFN-LNL—SPES
Jagiellonian University—SOLARIS
JINR—NICA
KIT—KARA
LAL—THOM-X
Lund University—MAX III, MAX IV
MedAustron
Physics Institute of the University of Bonn
Politecnico di Milano
PSI—SLS, SwissFEL
Research Instruments
RRC Kurchatov Institute—SIBERIA II
ScandiNova
SCK-CEN—MYRTE, MINERVA
SESAME
Sincrotrone Trieste—Elettra, Elettra 2.0, FERMI
Synchrotron SOLEIL
STFC ASTeC—EMMA, CLARA

North America
ANL—APS, APS-U
Best Medical International
BNL—ERL, NSLS II, X-RAY ring
Bridge 12
Canadian Light Source
Cornell University—CHESS, CESR
Fermilab
Idaho National Laboratory
LBNL—ALS
NUSANO
Oak Ridge National Laboratory
RadiaBeam
SLAC—LCLS, SPEAR 3

South America
ABTLuS—LNLS



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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)

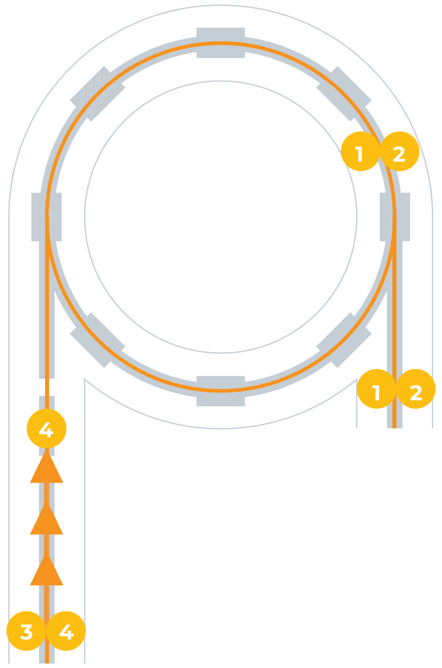
HADRON	ELECTRON	PHOTON
-	-	-
Libera Hadron	Libera Brilliance+	Libera Photon
Libera Single Pass H	Libera Single Pass E	
Libera Spark	Libera Spark	
	Libera CavityBPM	

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 BPMs 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 /< 45 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 μm/°C	2 μm/°C	0.3 μm/°C	0.5 μm/°C
Position RMS at bunch-by-bunch data rate	10 μm **	6 μm **	/	/
Position RMS at fast 10 kHz data rate	/	< 1 μm **	/	/
Position RMS at slow 10 Hz data rate	/	< 1 μm **	/	/
Position RMS at 1 MHz data rate	/	/	< 1 μm	< 3 μm, < 0.03°

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

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

Hadron BPMs 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 output	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 channels and Analog output	Optional**	No	Optional**	No
Closed Orbit Feedback Application	No	Yes, see page 38 or 40	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)

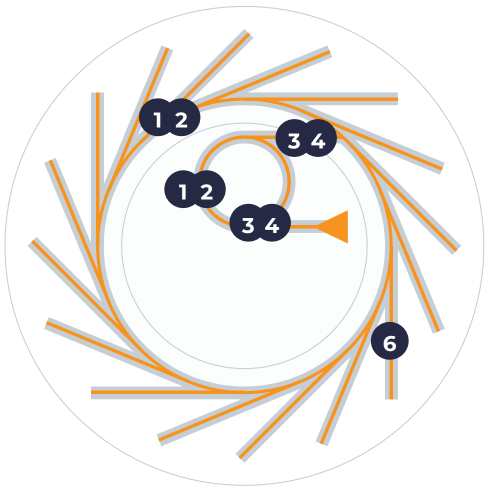
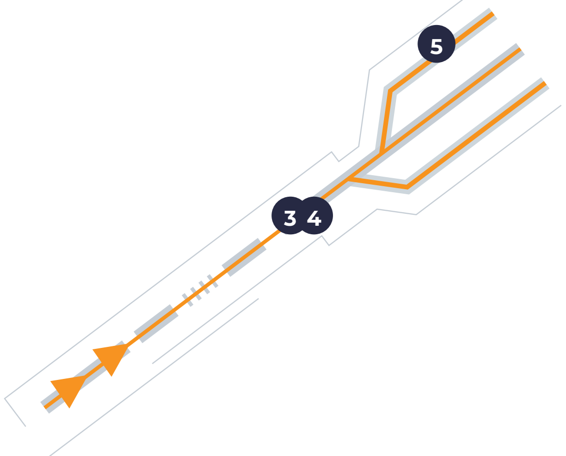


Figure 3: Example of a 4th generation light source (FEL / ERL)



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 Libera Pilot Tone FE.

3 Libera Single Pass E

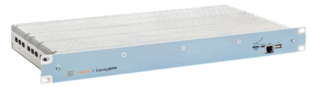
- Used in electron LINACs
- Event announcing of beam patterns
- Flexible DSP can process various filling patterns from single bunch to CW
- Accessories: Libera DWC
- Extensions: real-time data streaming, feedback application, serial I/O interface

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 a few Hz
- Compatible with diamond and blade detectors
- Extensions: real-time data streaming

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 BPMs Capabilities and Performance	for CIRCULAR machines			for LINEAR machines		
	Libera Spark ERXR	Libera Spark ERPT	Libera Brilliance+	Libera Spark EL	Libera Single Pass E	Libera CavityBPM
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)/ Optical	Electrical (up to 3)*	Electrical (4)/Optical	Electrical (up to 3)*
Calibration	Manual	Pilot tone****	Crossbar switch DSC Libera XBS FE	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 Libera Pilot Tone FE - see page 41

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

Electron BPMs 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 option	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	Reference clock with PLL	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 output	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 from 38 to 40	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 BPM 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, ±0.2 µA, ±2 µA, ±20 µA, ±200 µA, ±2 mA
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 BPM Functionalities	Libera Photon
Short pulse detection	Used for pulsed currents with signal dynamics within the measurement bandwidth (< 80 kHz). Pulse repetition up to 2 Hz is supported.
DC signal monitoring	Typically used for monitoring the currents from blade detectors or other current-type detectors 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 equation. 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 important 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 channels.

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

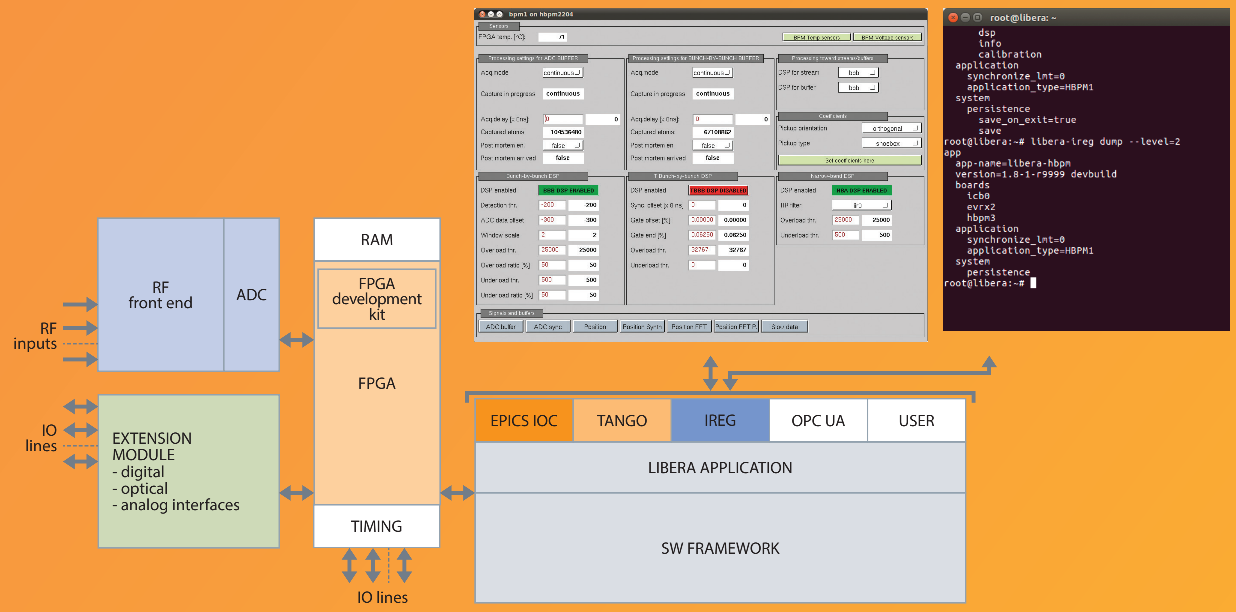
Photon

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.

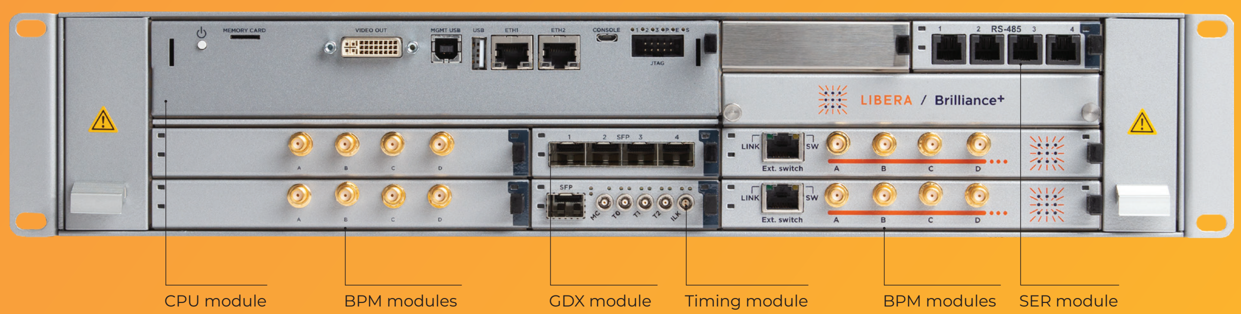
The default instrument configuration already provides all I/O lines required for normal operation, however the instrument's functionalities can be further expanded with extensions requiring different HW modules, depending on the instrument platform—see the section on Extensions (page 37).

Figure 4: Generalized block diagram of Libera Instruments



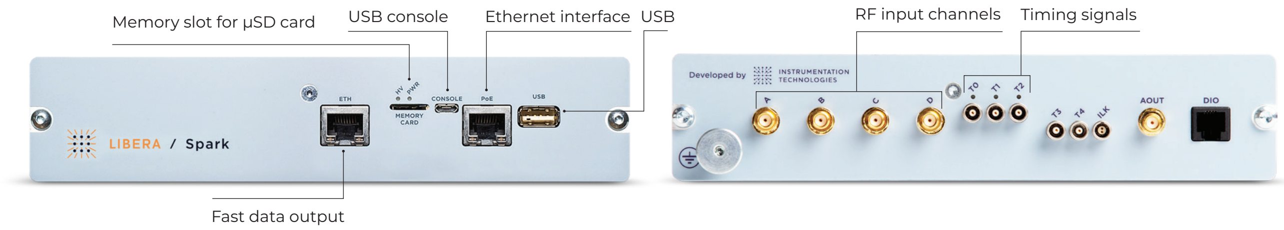
BPM electronics are available in different technology platforms that have different form factors. The BPM modular platform is based on the MTCA.0 technology and hosts up to four BPM modules in a 2U 19" chassis (Figure 5). Several extensions are available for the orbit feedback and timing system—see the section on Extensions.

Figure 5: BPM electronics based on our modular platform



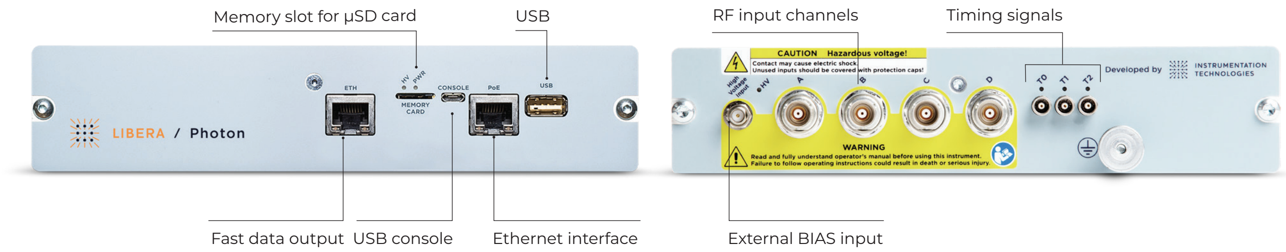
Our integrated platform is based on system-on-chip technology. Due to its low power consumption, the instrument is powered over Ethernet with PoE standard, and is passively cooled. Given the small dimension (BPM electronics is contained in a 1U 9.5" chassis), it can be installed in the tunnel close to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

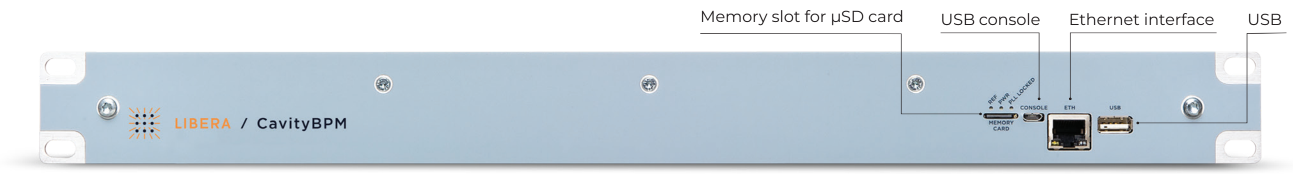


Figure 9: CavityBPM electronics based on Libera integrated platform, back panel

BEAM LOSS MONITOR

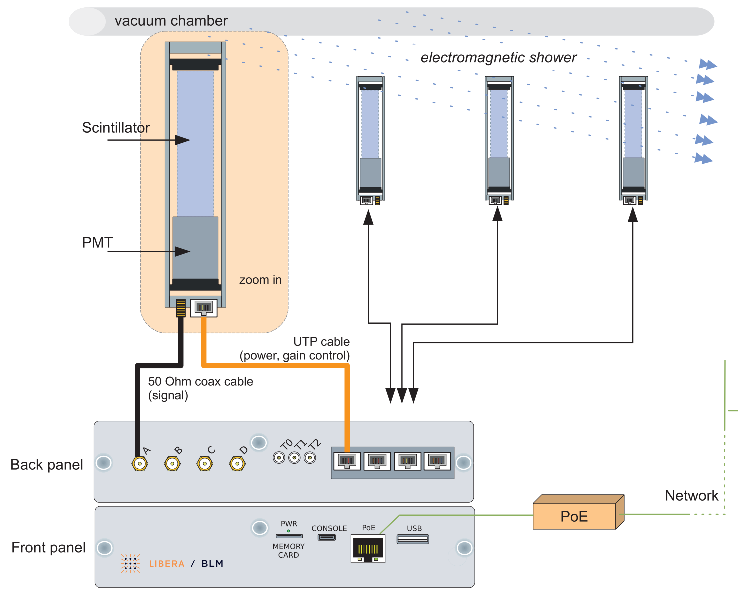
The Libera BLM handles all types of losses and measures them with a high level of detectability and high time resolution. Compared with other BLM systems, the beam loss monitor from the Libera family detects the losses ranging from a single electron to the huge losses that usually occur during injection.

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.

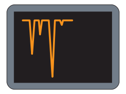
The beam loss monitor is available in two configurations:

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

Figure 10: Beam loss monitor system configuration



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 both power supply and gain control (Figure 10).

Signal Processing

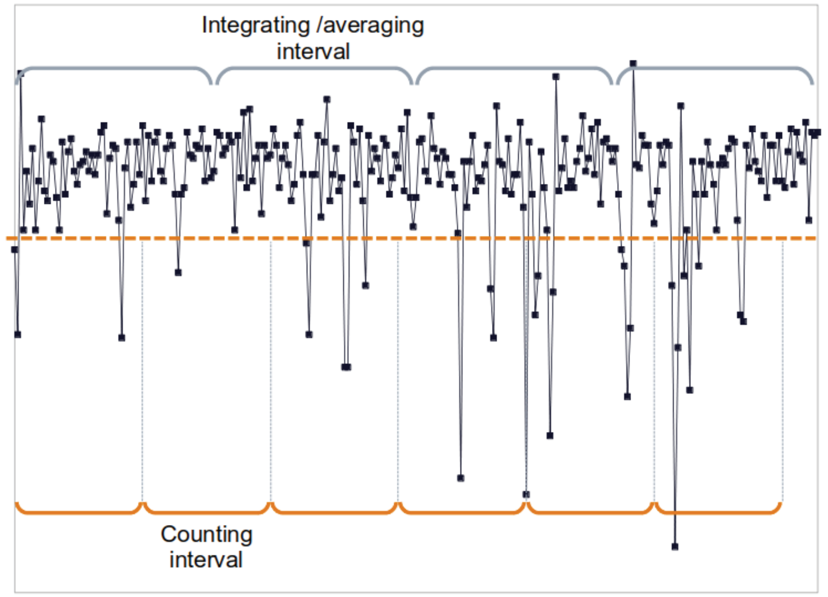
The signal from the beam loss detector (usually a photo-multiplier tube) is typically a unipolar pulse or train of pulses with negative polarity. It is possible to detect huge losses and very small losses thanks to the switchable front-end input impedance. The input signal is sampled by a PLL-controlled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

The raw sampled data is stored in a buffer upon a trigger event. Generally, there are two processing chains: integrating/averaging and counting.

The integrating/averaging processing chain processes the data with multiple operations, such as static offset removal, absolute function, threshold triggering and multiple decimation factors (integrating interval) that reduce the raw data rate to turn-by-turn or slower data rates.

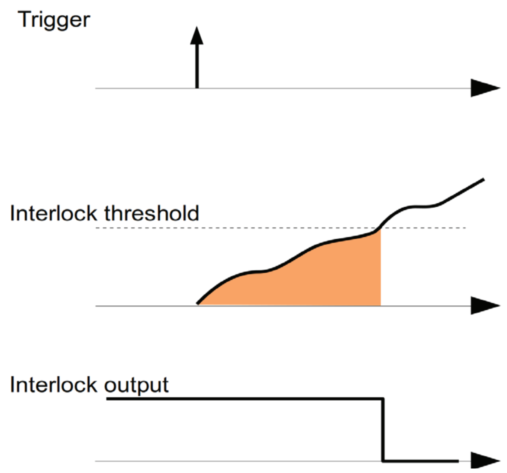
These buffered data flavors provide the user with quantitative view of the loss shape at different sampling rates. The counting processing chain monitors the raw data (sample by sample). There are multiple counting modes which are configurable for static and dynamic loss thresholds. The loss counter values are provided for counting interval observation window (0.1 – 1 second). With sampling clock being locked to an external reference, it is possible to adjust up to two configurable detection windows that monitor selected part of the fill pattern.

Figure 11: Beam loss signal processing parameters



Counting is done for each of the four detectors individually. The coincidence counting algorithm can detect the coincidence loss events on selectable detectors (2, 3 or 4) in a configurable time window.

Figure 12: Interlock detection



The Postmortem and Interlock features are optionally available to integrate the Libera BLM into the Machine Protection System. The Interlock function compares the continuously integrated loss with a threshold limit. As soon as the limit is exceeded, the hardware output changes its state (Figure 12). Detection works with an 8 ns period.

Beam loss detectors are provided with a scintillating material sensitive to gamma rays, X-rays or neutrons. A special version of the beam loss detector can be provided with no scintillator, but with an FC or SMA connector for connecting the optical fiber that acts as a scintillating material.

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	LBLD1.000.001	LBLD1.000.002 LBLD1.000.003	LBLD1.000.001
Input channels	4	Scintillator material	EJ-200	Optical fiber	EJ-410
Input frequency range	~35 MHz large signal bandwidth ~50 MHz small signal bandwidth	Sensitivity to particles	Gamma, X-ray		Neutron
Matching impedance	50 Ω/1MΩ, selectable	Peak wavelength of the scintillator	425 nm		450 nm
A/D conversion	125 MHz/14 bit	Photo multiplier tube (PMT)	Hamamatsu 10721-110		
Cooling	Passive	Peak wavelength of the PMT	400 nm		
Power supply	PoE	Rise time of the PMT	0.57 ns		
Timing signals	Electrical (3)	Supply voltage	5 V		
		Gain control voltage	0 to 1 V		
Maximum input signal	±1.25 V @ 1 MΩ ±5 V @ 50 Ω				
Output channels	4x power supply (up to ±15 V) 4x gain control (up to +12 V)				

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 (attenuation, 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 voltage to up to 4 independent channels.
Interlock detection and output	Monitor the accumulated loss value and trigger an output signal for the machine protection system.

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

DIGITIZERS

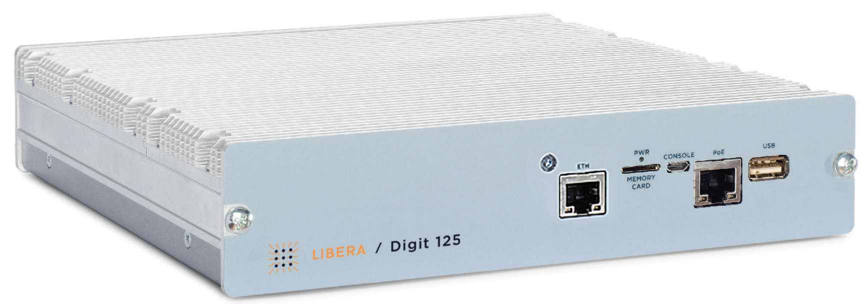
Libera digitizers provide users with a base from which to develop their own application. The instruments provide all the building blocks from the gain-controlled RF input signals to the ADC data storage, from the offset removal to the exposure of processing parameters through the control system interface.

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 (Figure 13) 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



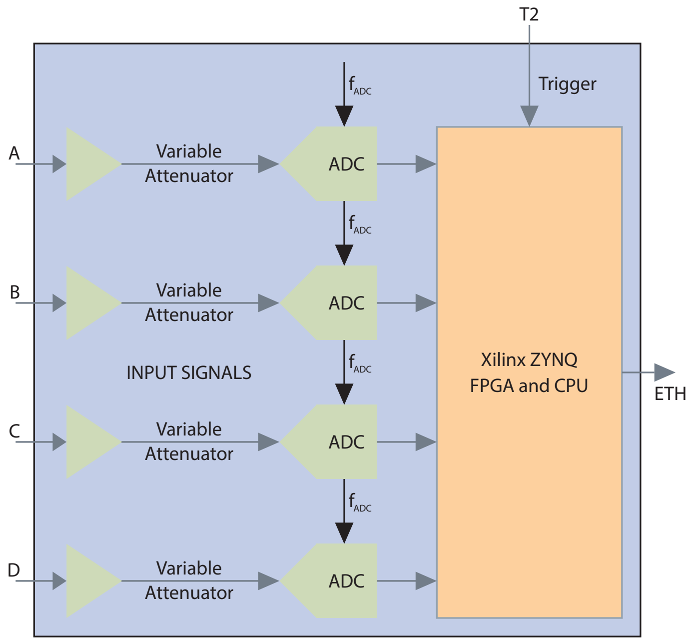
AC and DC coupled versions

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 application.

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 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 DC-coupled: 40 MHz
Input impedance	AC-coupled: 50 Ω DC-coupled: selectable 50 Ω / 1 MΩ
Maximum input signal level	AC-coupled: ± 1 V @ 50 Ω DC-coupled: ± 5 V @ 50 Ω 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 user)	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 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 MSps, phase-locked to an external reference signal. The data are stored in a 2 GB configurable segmented buffer with different acquisition modes and trigger rates of up to 500 Hz (Figure 15).

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) in the 300-500 MHz range. The dynamic range of the system is over 90 dB.

AC and DC-coupled versions

The DC-coupled version has a front end with a 250 MHz bandwidth, suitable for the 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 bandwidth 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 are stored. One trigger input is used to trigger the data acquisition in a large ADC buffer with a total size of 2 GB. The buffer can be segmented in chunks of a minimum of 32,768 samples, and can be acquired in different modes of trigger frequencies.

Pulse processing and phase-shifting on individual channels

The pulse processing SW module allows discriminating 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 four channels independently, to compensate for the cable length.

SFP module and WebGUI

Four Small Form-factor Pluggable (SFP) modules allow fast data exchange using UDP packages. The web-based GUI allows quick access to the instrument by just typing the IP address into a web browser (Figure 16).

Figure 16: Libera Digit Web GUI accessible from web browser

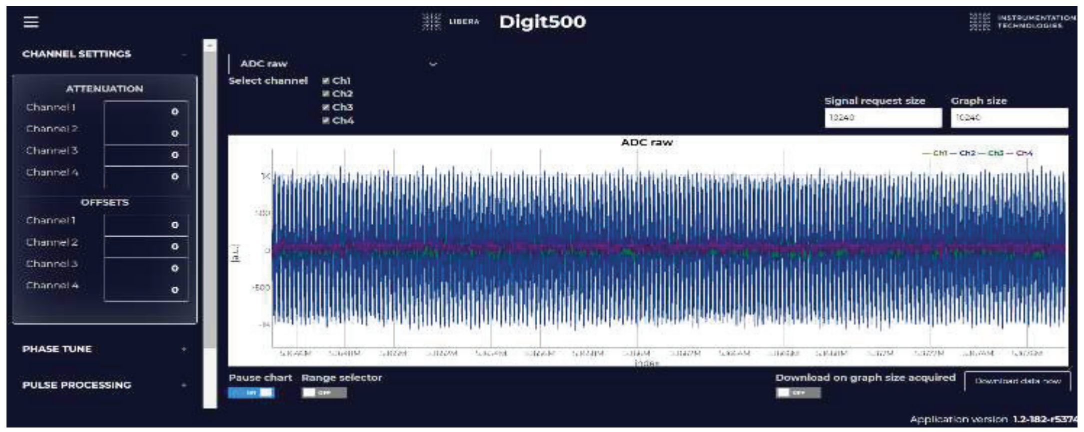
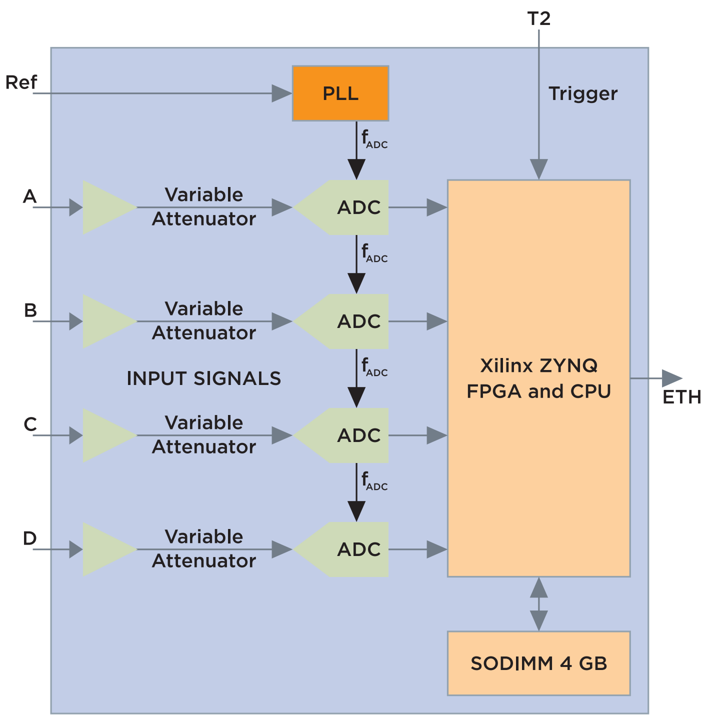


Figure 17: Block diagram of Libera Digit 500



Libera Digit 500 Technical Specifications	
General product code	L500
Input channels and connector	4, SMA connector
ADC conversion	From 300 MSps to 500 MSps (default) with 14 bit resolution
Sampling clock	Can be locked to an external reference via PLL in the 300 MHz – 500 MHz range
Input signal bandwidth	DC-coupled: DC - 250 MHz AC-coupled: 1 MHz - 2 GHz
Input impedance	50 Ω
Maximum input signal level	DC-coupled: ± 1 V AC-coupled: 10 dBm
Input gain / attenuation	SW programmable 0-31 dB channel independent
Dynamic range	90 dB
PLL reference signal level and connector	- 2 dBm – 4 dBm, SMA
Trigger signal level and connector	3.3 V TTL, LEMO connector
Maximum trigger rate	500 Hz: it can be extended to 1000 Hz with SW modification
Memory	2 GB RAM: it can be extended to 4 GB with SW modification
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)	SFP outputs (4x)
	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 10: Technical specifications of Libera Digit 500

CURRENT METER

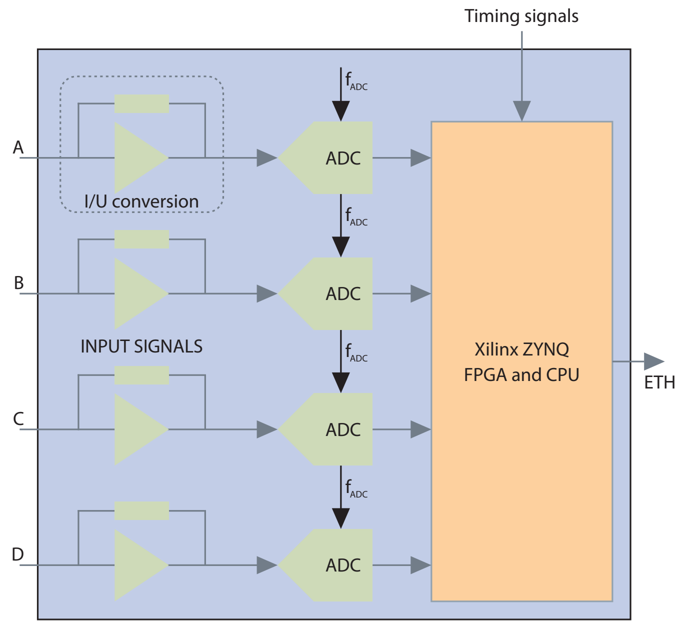
The Libera Current Meter is a general-purpose current measuring device with 4 input channels, compatible with high impedance current sources and capable of measurements from ± 60 nA to ± 2 mA. The instrument features six current ranges that can be switched manually or automatically, and each channel is factory-calibrated against a known current source (Figure 18).

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.

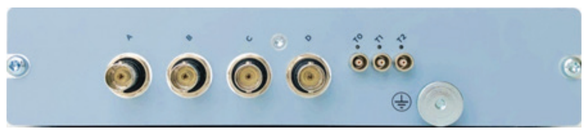
WebGUI direct and simple access

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

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 a higher sampling resolution is needed. DC current measurement is available with a 10 Hz data rate.

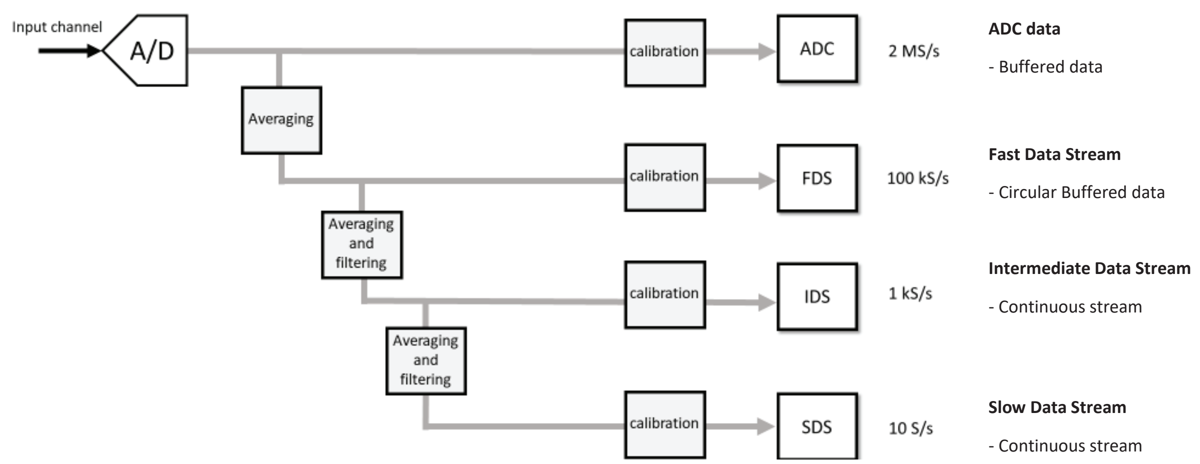
Capabilities

Libera Current Meter 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, ±0.2 μA, ±2 μA, ±20 μA, ±200 μA, ±2 mA	
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

Signal Data Path

Figure 21: 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

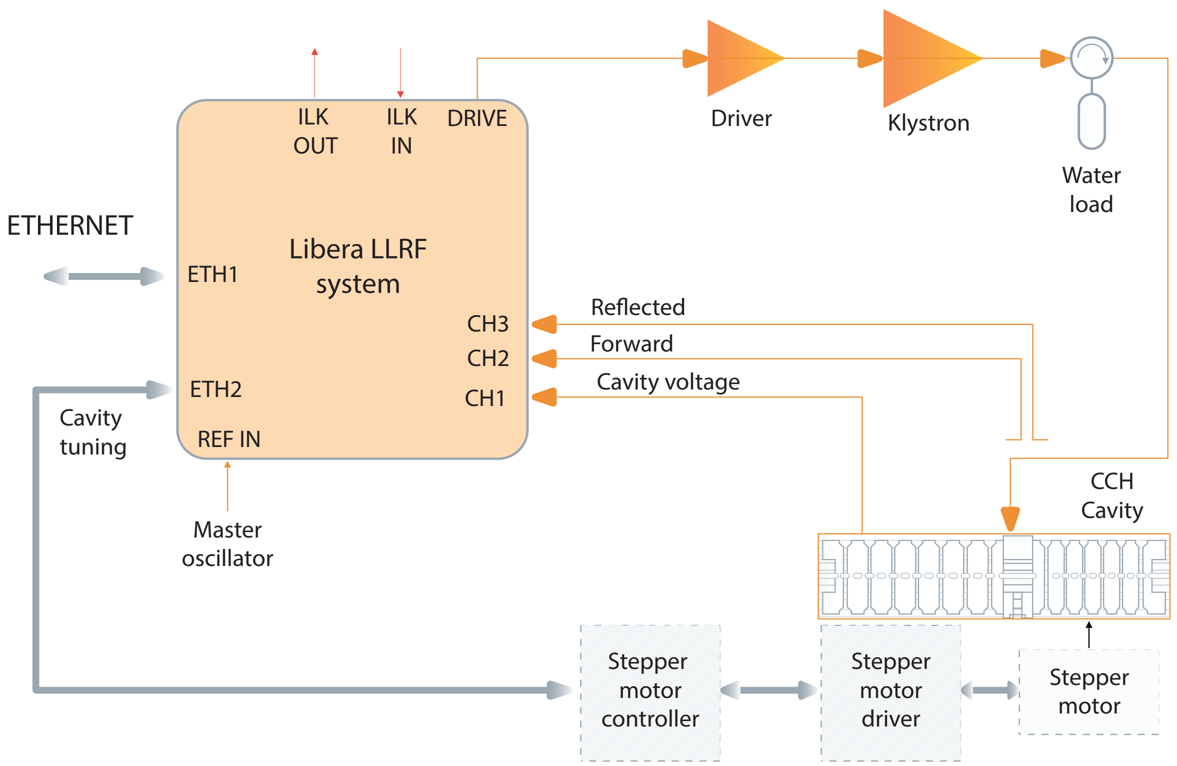
The LLRF system keeps the RF cavities at resonance by monitoring the forward and reflected signals from the RF cavities, the system can be interfaced to control slow and fast tuners (e.g., stepper motors and piezo controllers) which modify the cavity mechanical properties.

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 22 presents a possible configuration of Libera LLRF in the accelerator environment:

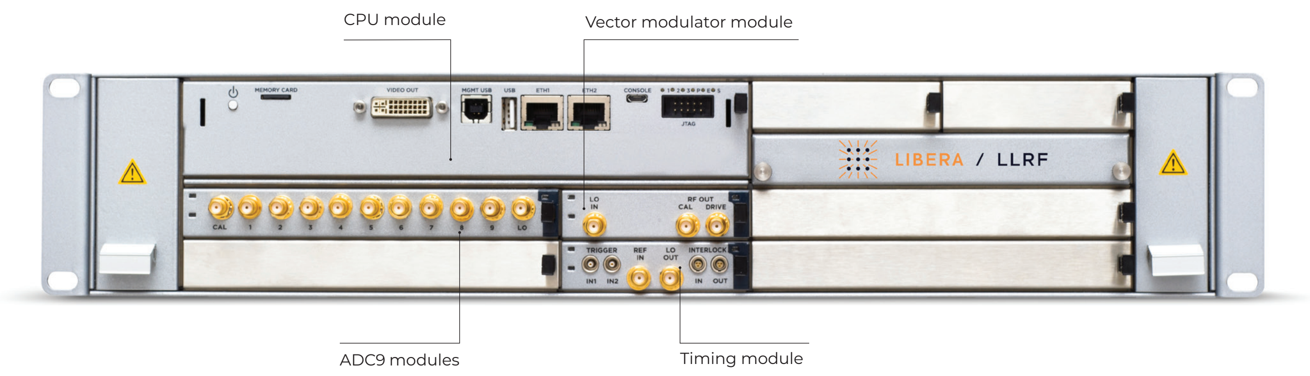
Figure 22: Possible configuration of Libera LLRF in the accelerator environment



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 23).

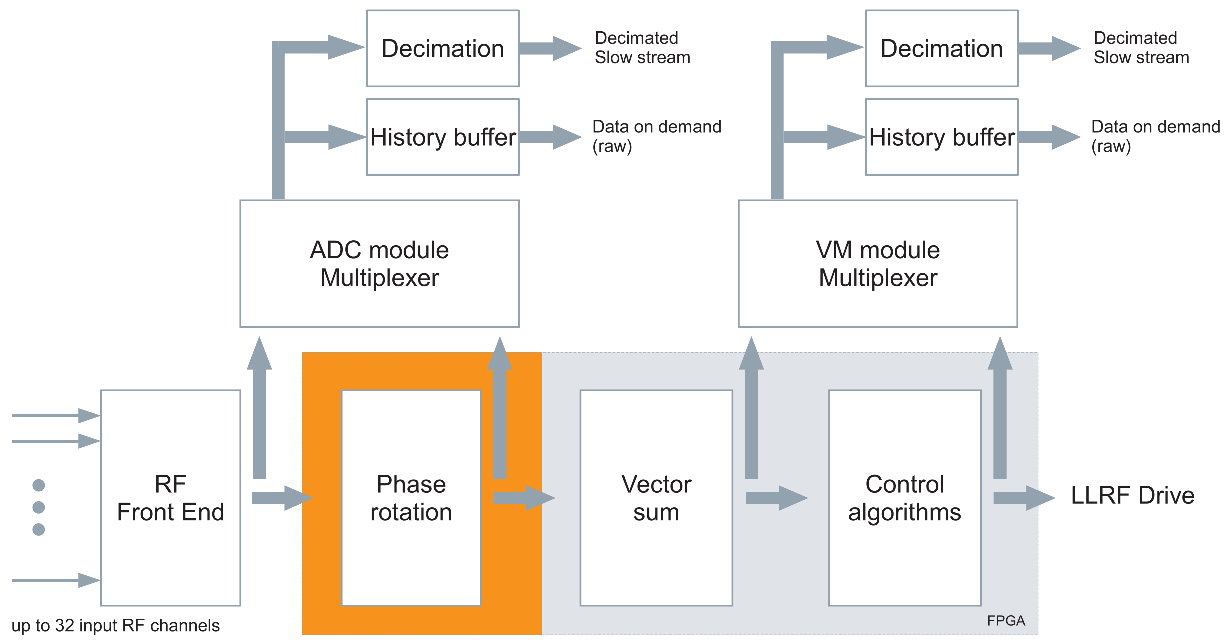
Figure 23: Libera LLRF



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 24).

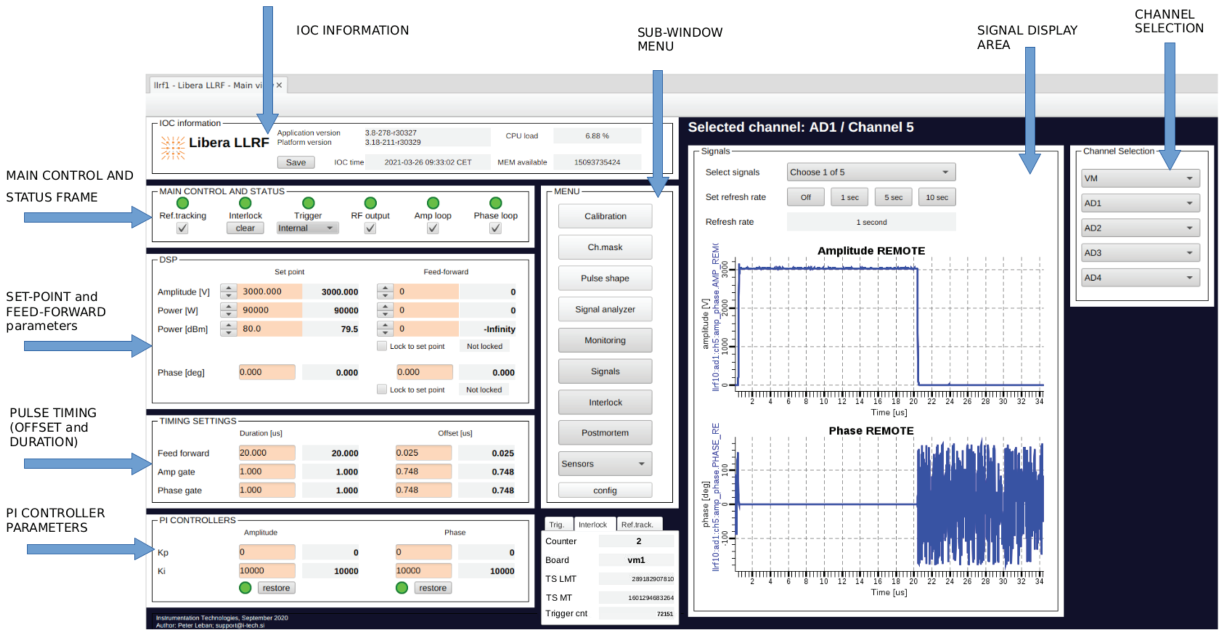
Figure 24: Signal processing in the Libera LLRF system



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 25.

Figure 25: Graphical User Interface (GUI) for the Libera LLRF



Capabilities

The capabilities of the Libera LLRF system are summarized in Table 12.

Libera LLRF Capabilities	
General product code	LLRF
RF input channels	Up to 32 (8 per ADC9 module, 6 channels per KADC 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
RF output channels	2 (1 RF drive, 1 calibration output)
Maximum RF output power	> 10 dBm
Cooling	Active
Power supply	110/220 V

Table 12: Capabilities of the Libera LLRF system

Functionalities

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

Libera LLRF Functionalities	
Machine Operation mode	· Continuous Wave (CW) · Pulsed · Combined
Fast-feedback loop	· Generator Driven Resonator (GDR) and Self-Excited Loop (SEL) · Intra-Pulse and Pulse-to-Pulse feedback · Feedback loop (Amplitude and Phase, I & Q) · Beam Loading compensation · Compensation for Klystron non-linear response · Compatible with variable RF frequency machines · Extensible to multiple inputs from cavities driven by the same klystron
Cavity tuning	· Based on the cavity detune measurement algorithms: based on forward and reflected signals for CW machines, based on cavity voltage decay on pulsed machines · Slow tuning with PID controller and stepper motor driver interface · Fast tuning loop with piezo controller
Signal monitoring and Diagnostics	· Input signals and internal feedback signals · Visualize raw or demodulated signals on the graphical user interface · Direct measurement of amplitude and phase · Derived measurement of signal power and cavity resonant frequency
Machine Protection	· Low latency interlock interface (Input and Output) with active low failsafe logic
Temperature Compensation	· Temperature-stabilized RF front-end within separated chassis (Figure 26) · Calibration output usable for RF cables and RF front-end electronics calibration

Table 13: Functionalities of the Libera LLRF system

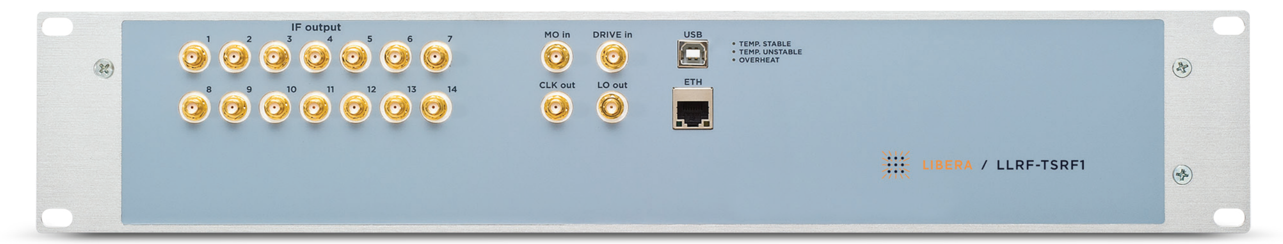
Performance Specifications

The main performance specifications of the Libera LLRF system are summarized in Table 14.

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 14: Performance specifications of the Libera LLRF system

Figure 26: Libera LLRF temperature stabilized RF front-end

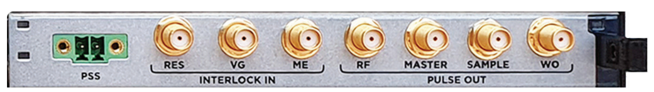


Interface Extensions

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.
- Libera LLRF Digital input and output interfaces (such as interlocks and triggers) can be extended through extension modules.

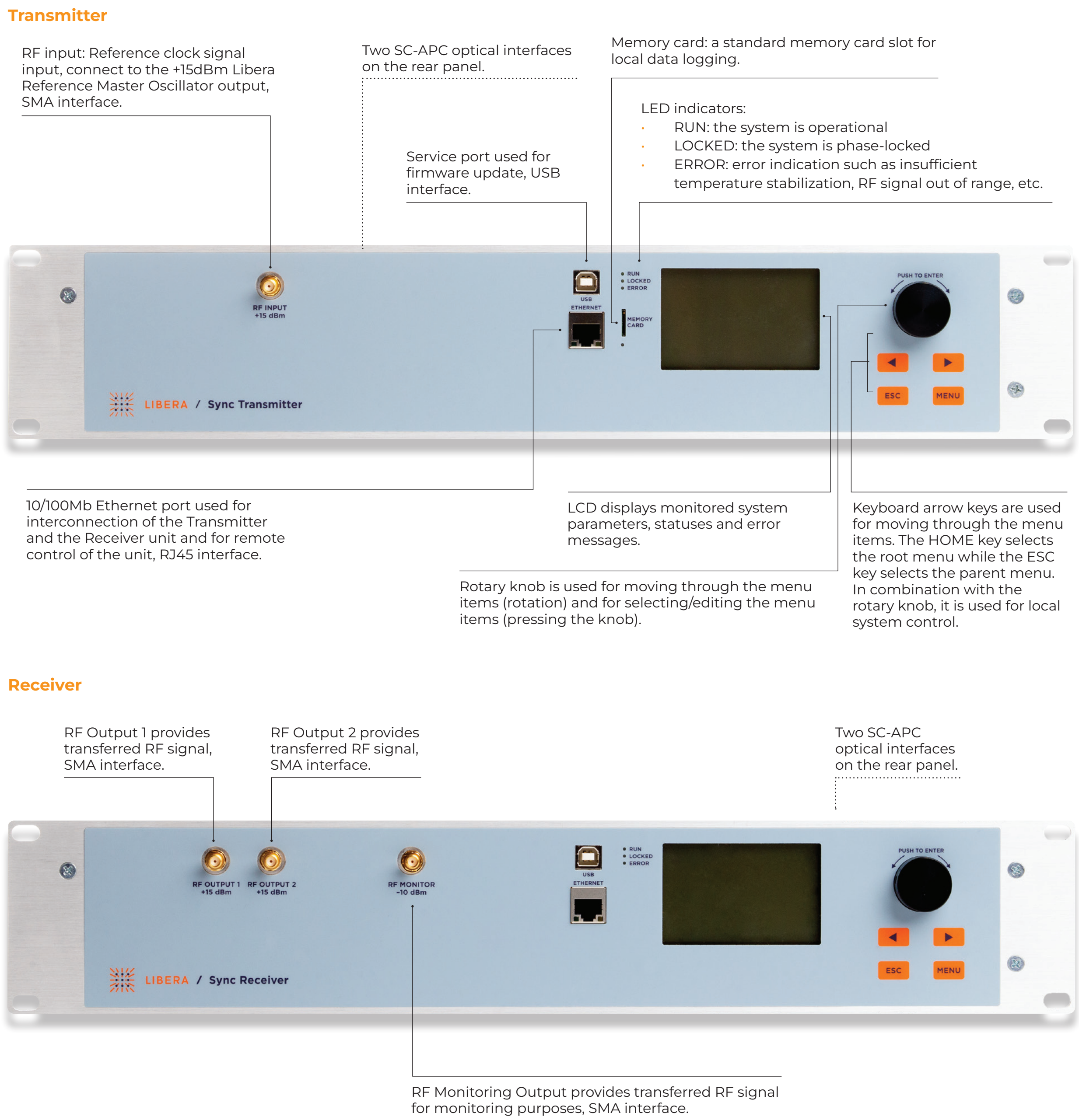
Figure 27: The Libera LLRF interfaces can be extended through Digital I/O modules



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 28).

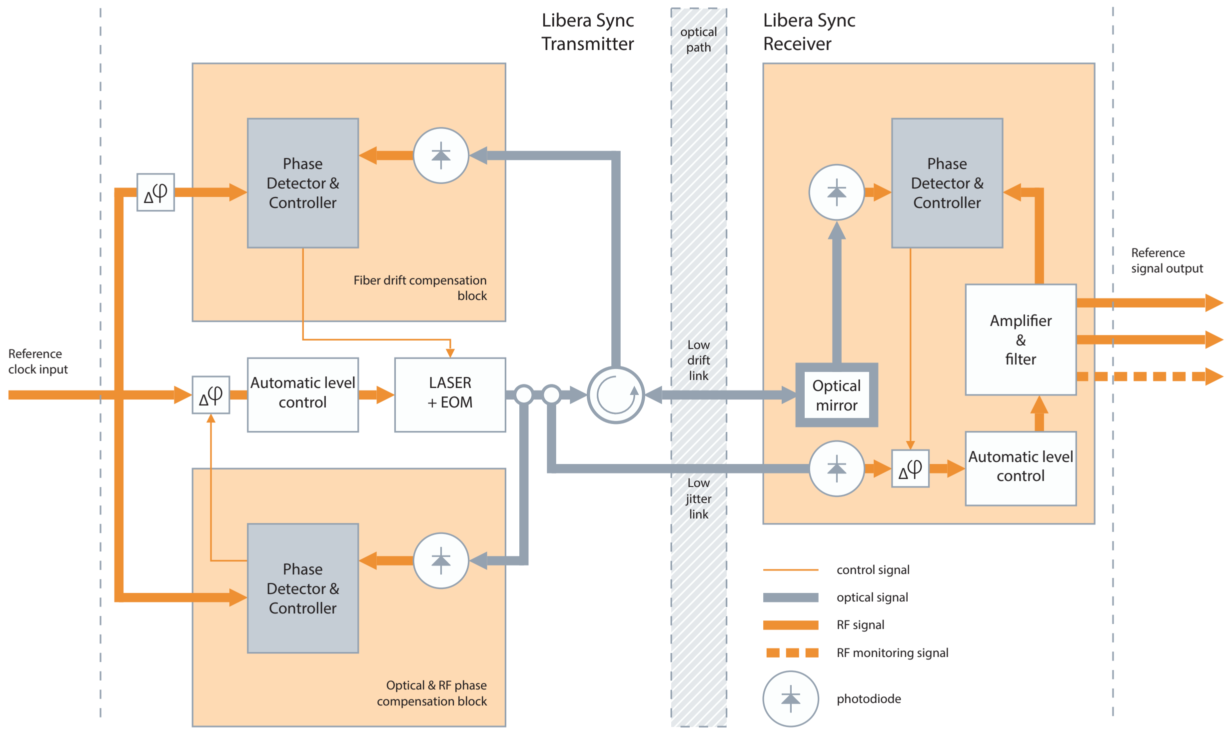
Figure 28: Clock transfer system Libera Sync



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 29). 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 29: 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.

Capabilities

The Libera Sync covers S-band frequencies. Its capabilities are summarized in Table 15.

Libera Sync Capabilities	
General product code	LSYN
Carrier frequency	2.6 GHz, 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 15: Performance specifications of the Libera Sync system

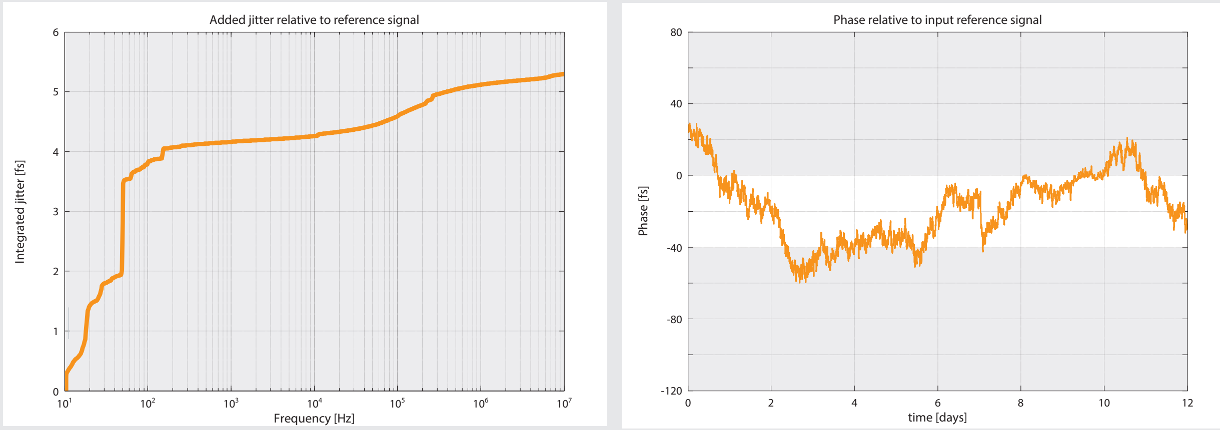
Performance Specifications

The performance specifications of the RF clock transfer system are summarized in Table 16, while Figure 30 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 phase drift	< 40 fs peak-to-peak typ. < 100 fs peak-to-peak max.

Table 16: Performance specifications of the Libera Sync

Figure 30: Libera Sync added jitter and long-term phase stability measured



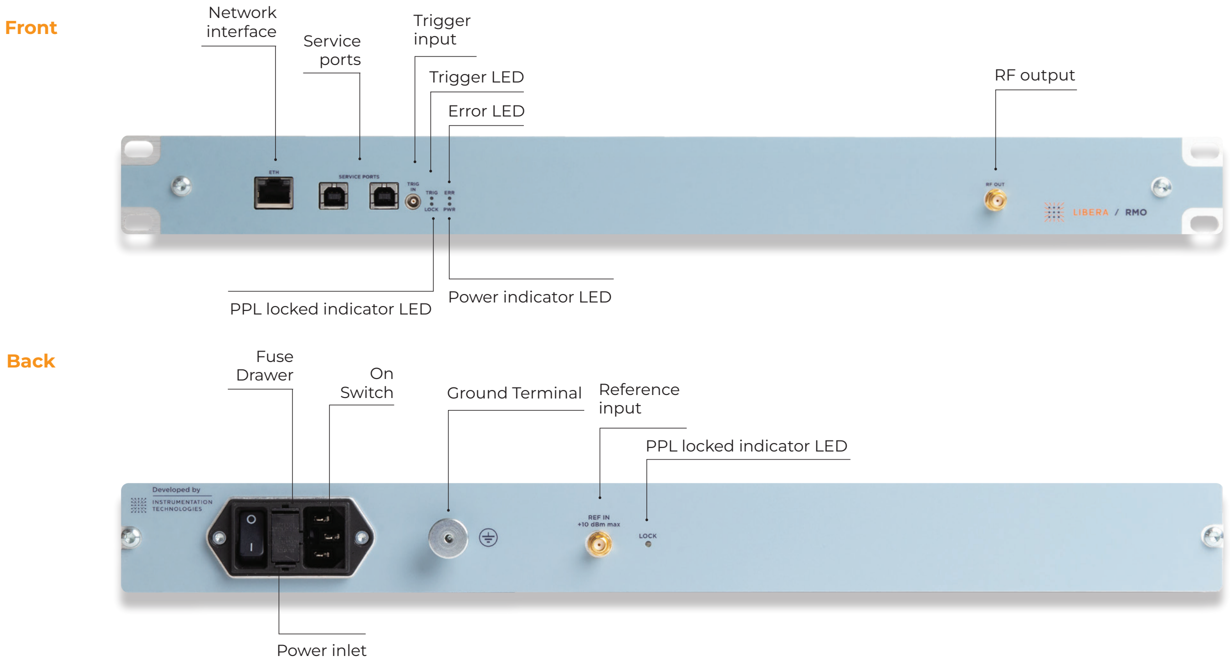
REFERENCE MASTER OSCILLATOR

The Libera Reference Master Oscillator generates an RF signal with low phase noise at the nominal output power of +15 dBm. 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 (+/−50 ppb in range of temperature from -20 to +70 °C) combined with extremely low phase noise, below 100 fs in a range between 10 Hz and 10 MHz. The front and back panels of the instrument are shown in Figure 31.

A Direct Digital Synthesizer (DDS) is implemented to extend the Libera RMO frequency range (Figure 32)

Figure 31: Libera Reference Master Oscillator, front & back panel

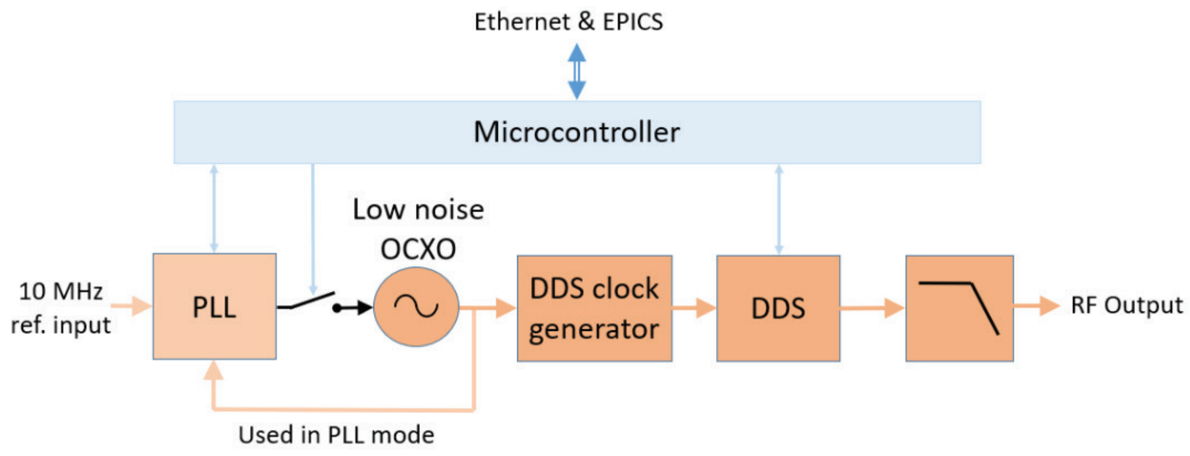


The RF specifications of the Libera Reference Master Oscillator are presented in Table 17.

Libera Reference Master Oscillator	
General product code	LRMO
Supported frequency range	50 Hz – 3 GHz
Nominal output power	+15 dBm
Output power stability	0.02 dB/°C (within 20 to 25 °C)
Return loss	-15 dB
Frequency stability	5*10^-11 (Allan Deviation in free running mode)
Integrated phase noise (max)	< 90 fs (10 Hz – 10 MHz) (typically in the order of 50-60 fs)
Harmonic suppression	< 50 dBc up to 5th harmonic
PLL lock time	< 30 s

Table 17: RF specifications

Figure 32: The Libera RMO block scheme with a PLL locked OCXO, the DDS and the output stage providing a high-quality Master Oscillator reference.



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 24 RF outputs (Figure 33).

Figure 33: Libera RMO Distribution Amplifier, front panel

Thanks to the modular design of the Libera RMO Distribution Amplifier, it 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 (Figure 34).

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 Libera Hadron, for example.

Figure 34: Libera Amplifier 110

The main features of the Libera Amplifier 110 are shown in Table 18.

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 < 5 mVrms, for gains <60 dB
Input and output impedance	50 Ω

Table 18: 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.

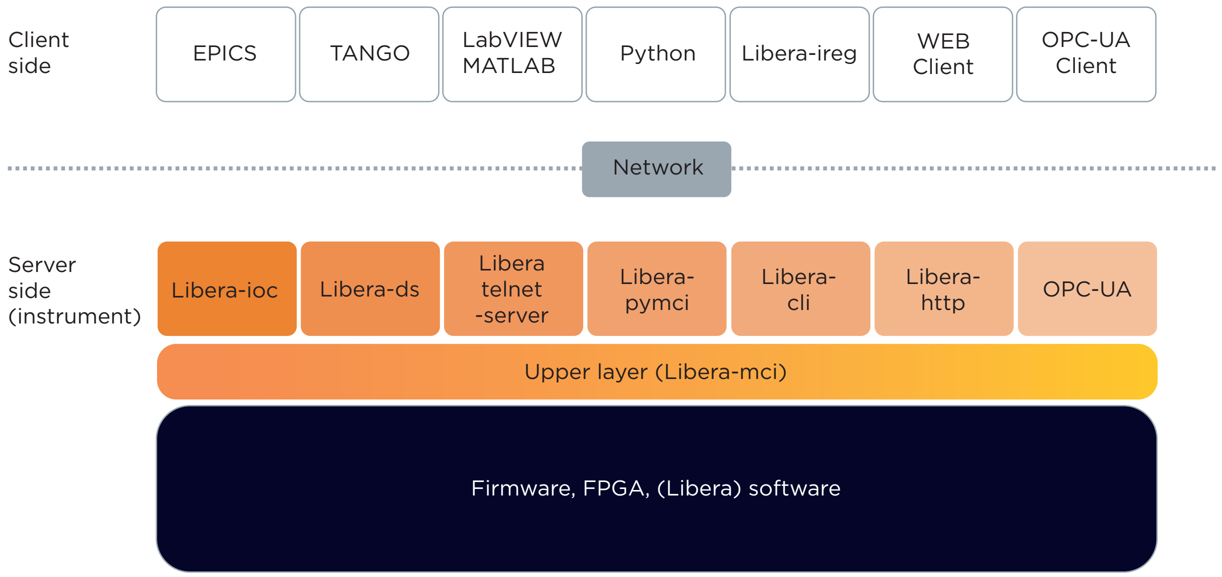
The Measurement and Control Interface (MCI) layer transfers parameters and data between the Libera application and various servers. Servers, such as EPICS, TANGO and FESA, run in the instrument. Some servers (e.g. EPICS) can run on external machines and connect to the MCI layer via the network (Figure 35).

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

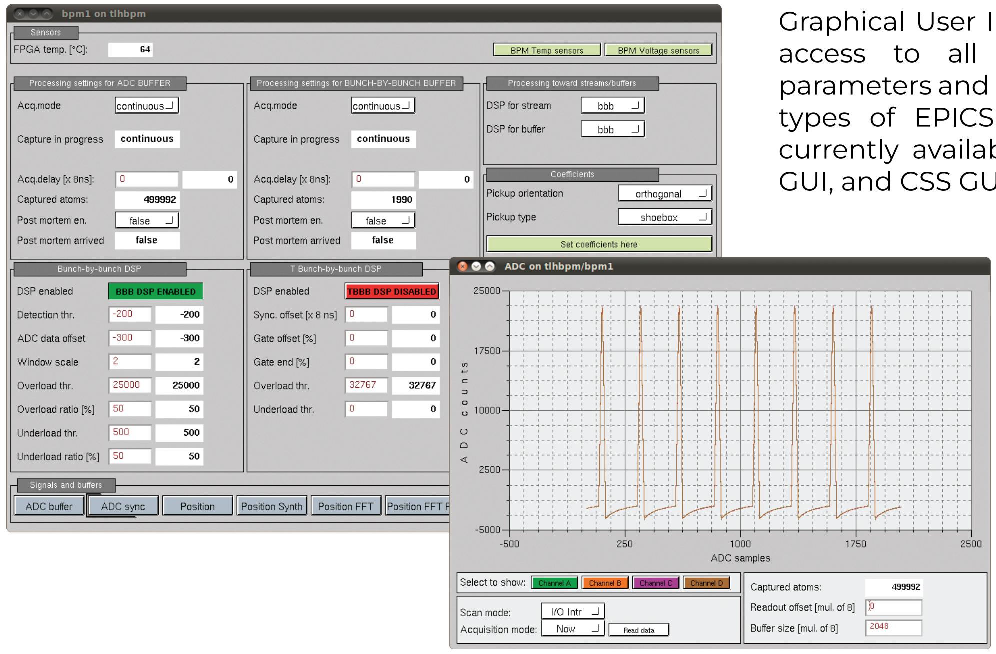
Libera software is compiled for standard Linux distributions (Ubuntu, CentOS, Zynq). Source code for servers such as EPICS and TANGO is available to users.

Figure 35: Software interfaces and building blocks within Libera instruments



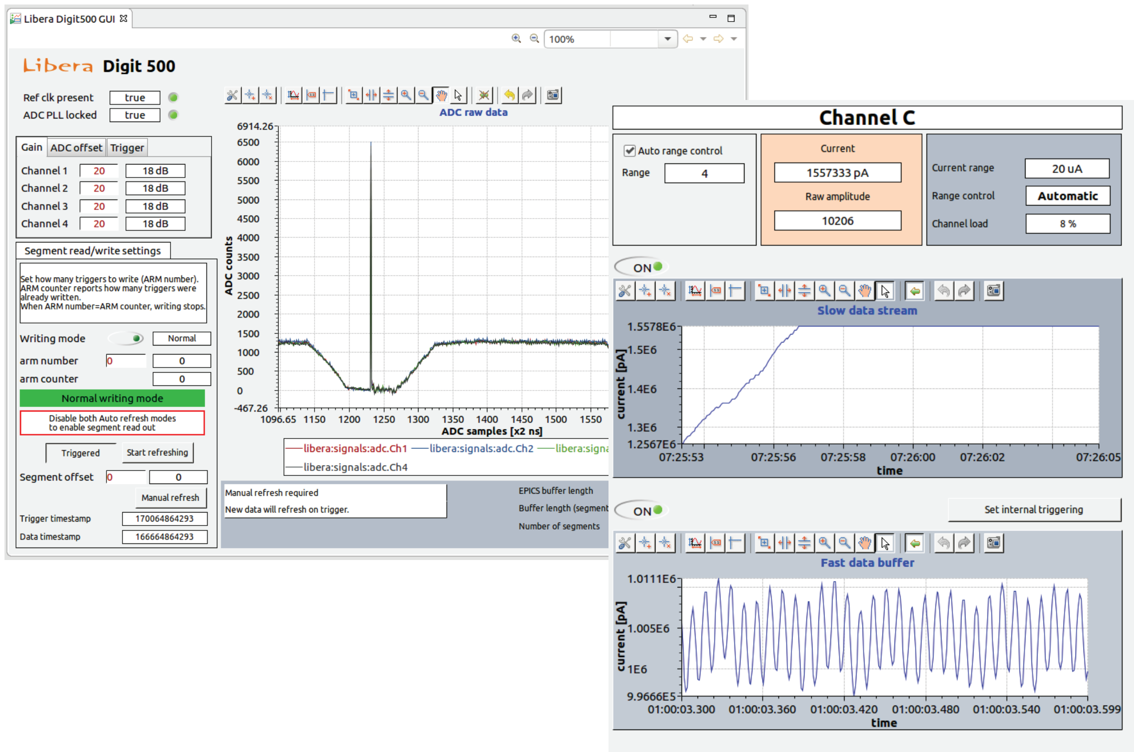
GUI - GRAPHICAL USER INTERFACE

Figure 36: 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 37: 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 19).

Extension	Description / example	Works with	Required module
Fast Orbit feedback solution	· Complete solution for electron machines that use Libera Brilliance+ instruments (Figure 39).	· Libera Brilliance+	· GDX module · SER module · Orbit feedback application software · Dedicated optical network · Magnet correction data receiver*
	· Complete solution for hadron machines that use Libera Hadron instruments (Figure 39).	· Libera Hadron	· GDX module · SER 2 module · COFB application software · Dedicated optical network · Magnet correction data receiver**
Real-time data streaming	· Real time data streaming directly from the FPGA through a dedicated instrument interface	· Libera Brilliance+ · Libera Single Pass E · Libera Hadron · Libera Single Pass H · Libera Spark · 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. · Compatible with Libera Platform C instruments.	· Libera Spark · Libera Cavity BPM · Libera BLM	· DAI module · 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 · Libera Digit 125 · Libera Digit 500	· DAI module · 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 · Libera Digit 125 · Libera Digit 500	· DAC control software** · DAI module
Serial interface	· Add a RS-485 interface for half-duplex communication with auxiliary components. · Add multiple RS-485 interfaces for real-time data streaming towards magnet receivers.	· Libera Spark · Libera Digit 125 · 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 · Libera Single Pass E	· Libera DWC

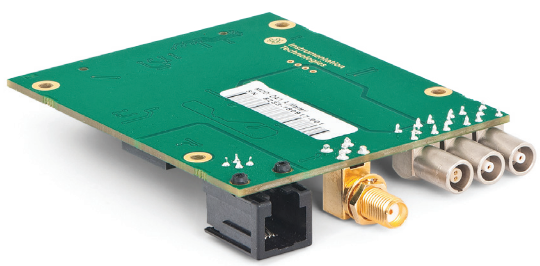
* Not provided by Instrumentation Technologies
** Basic control included only. Can be customized by users using source code.

Table 19: Extension options for Libera instruments

DAI Module

The DAI module extends the interconnection capabilities of Libera Platform C instruments as shown in Table 20 (Libera Spark, Libera Digit).

Figure 38: 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 20: 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 39.

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 40.

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 39: Complete orbit feedback solution for electron/hadron machines

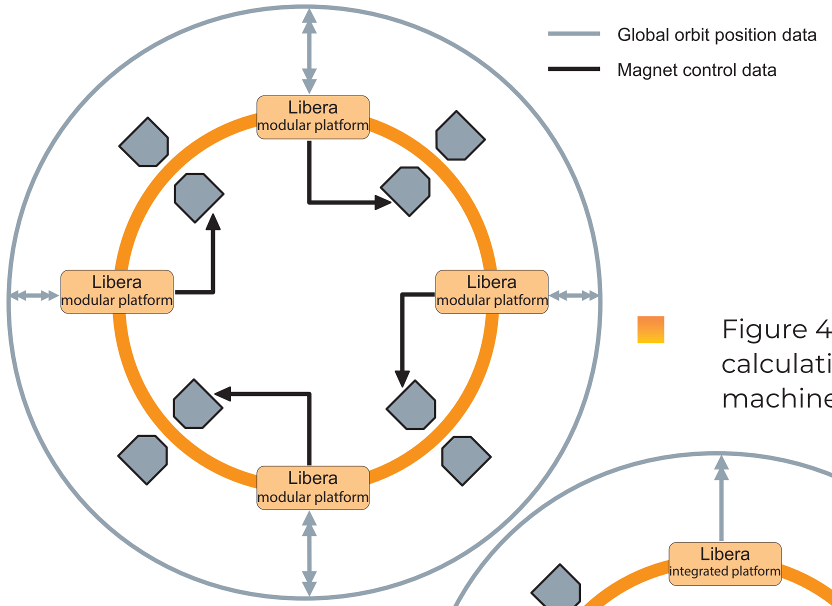
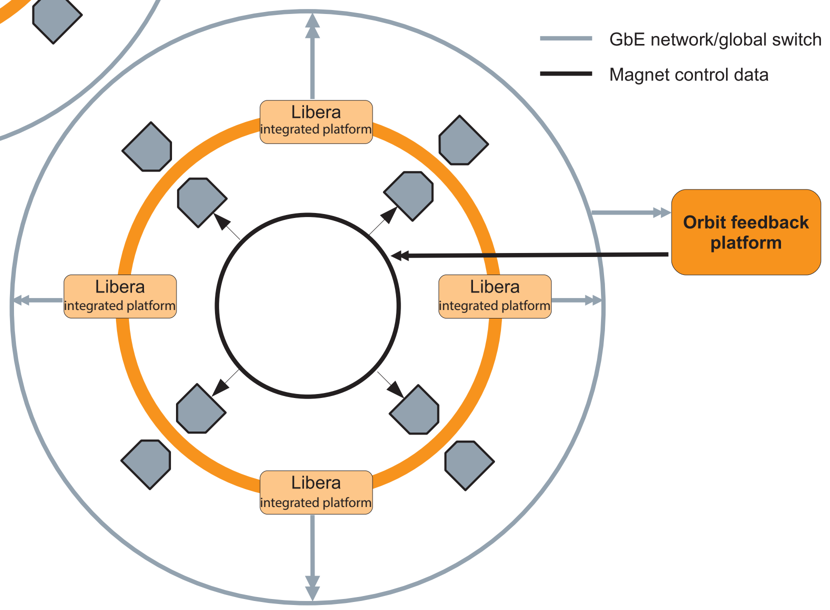


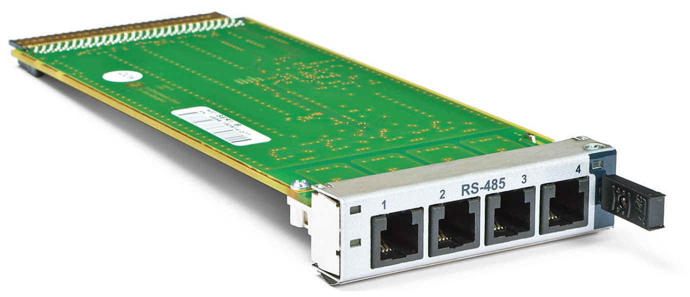
Figure 40: Standalone orbit feedback calculation engine for electron/hadron machines



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 21).

Figure 41: 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

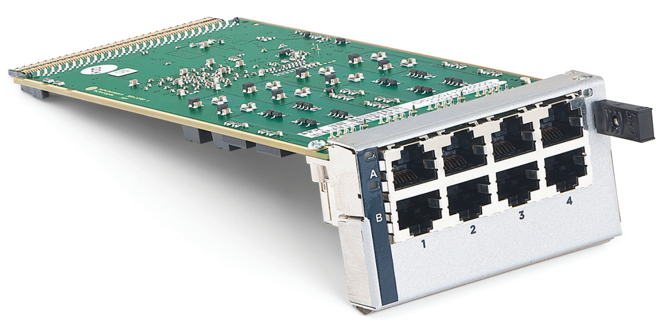
* Specified by application in the GDX module

Table 21: 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 22).

Figure 42: 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 22: 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 23).

GDX Module	
FPGA chip	Xilinx Virtex 6
Memory	2 GB DDR3
I/O interfaces	4x SFP+ compliant, multiprotocol operations, LVDS links to AMC connector
SFP protocol	AURORA, GbE, others on request; independent to each SFP
PCI express x4 bus interface to AMC connector	
On-board clock synthesizer and programmable VCXO for clock generation	
Board management is already established	

Table 23: Capabilities of GDX module

Figure 43: 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 24).

Libera DWC	1.3 GHz	3 GHz
General product code	LDWC1.000.002	LDWC1.000.003
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

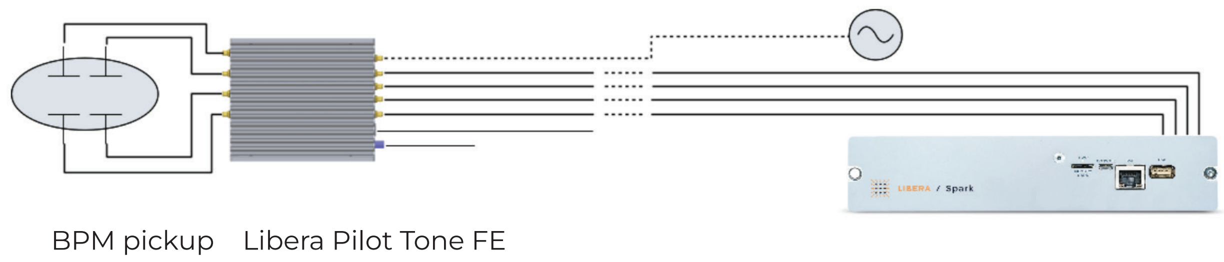
Table 24: Technical specifications of the Libera DWC

Figure 44: Libera DWC

Libera Pilot Tone FE

Beam current dependency, thermal drifts of the electronics and variations in cables caused by changes in temperature and humidity affect the accuracy of the BPM system. The Libera Pilot Tone FE is installed in the tunnel and connected between the BPM pickup and BPM electronics. It combines the RF BPM signals with a pilot tone signal that is slightly offset to the RF. Both signals pass through the RF cables to the BPM electronics and are exposed to the same disturbances.The BPM electronics (e.g. Libera Spark ERPT) process both signals independently in the frequency domain. A digital algorithm compensates the RF BPM signal based on information from the pilot tone in real time.

Figure 45: Example setup of the Libera Pilot Tone FE in combination with Libera Spark ERPT.



Most common RF frequencies are supported: 352 MHz, 408 MHz and 500 MHz. The Libera Pilot Tone FE is powered and controlled through PoE RJ-45 interface via TCP-IP. Important settings are confirmed through an optical interface.

Such BPM system ensures stable position readout with long-term stability < 1 µm.

Libera Pilot Tone FE	
General product code	LPTFE
Frequency versions	500 MHz 408 MHz 352 MHz
Input / Output channels	4 / 4 (SMA-F connectors)
Input impedance	50 Ohm
Programmable attenuation	0 to 90 dB
1 dB compression point	+16 dBm
Crosstalk	Better than -60 dB
Pilot tone generation	Internal or external (SMA-F input)
Control interface	TCP-IP over Ethernet
Power supply	PoE or 9-12 V, 1 A
Dimensions	175x151x40mm
Weight	1,2 kg
Temperature dependence	Frequency dependence: approximately -250 Hz/°C Amplitude dependence: approximately -0.03 dB/°C

Table 25: Technical specifications of the Libera Pilot Tone FE

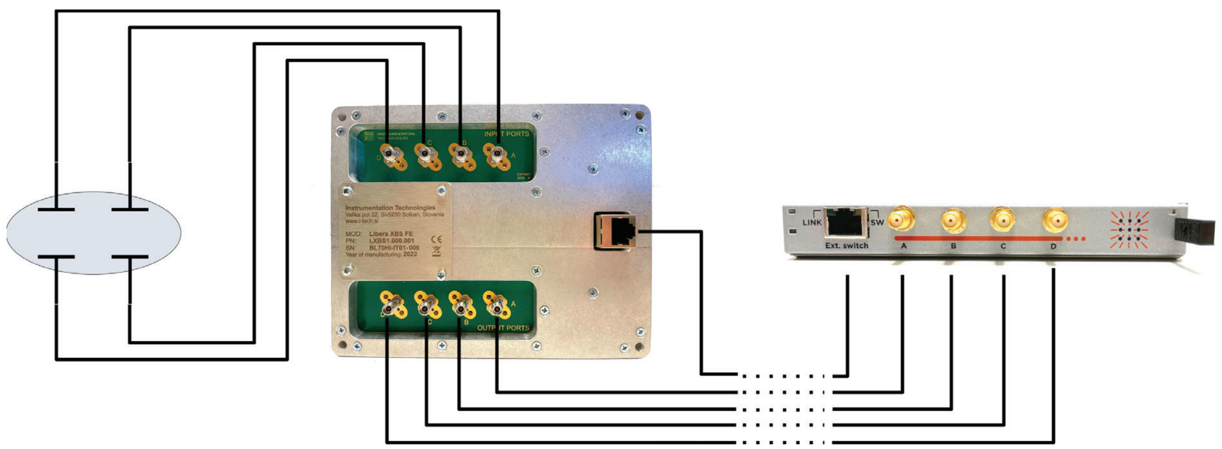
Figure 46: Libera Pilot Tone FE

Libera XBS FE

Libera XBS FE is a supplementary analog front-end for the Libera Brilliance+ BPM electronics, to be used in combination with the 3rd generation BPM module. The Libera XBS-FE contains a cross-bar switch matrix, similar to the one used in the standard Libera Brilliance+ BPM modules, and is intended to be installed in the tunnel, as close as possible to the BPM pickup.

The advantage of switching the RF signals already in the tunnel, is the possibility to also compensate the long-term drifts that are induced on the long RF cables, in addition to the ones in the electronics.

Figure 47: Connection scheme of Libera XBS FE and the 3rd generation BPM module in Libera Brilliance+



The Libera XBS FE supports all standard synchrotron RF frequencies. It is powered and controlled by the 3rd generation BPM module through a standard Cat.7 cable and RJ-45 interface. The switching frequency is configurable by the digital control in the Libera Brilliance+ and is fully synchronized with the Digital Signal Conditioning that calculates the calibration coefficients.

The system of Libera XBS FE and Libera Brilliance+ ensures a stable position readout with RF cables as long as 200 meters.

Libera XBS FE	
General product code	LXBS1.000.001
Frequency range	350 MHz to 510 MHz
Input / Output channels	4 / 4 (SMA-F connectors)
Maximum input signal range	+4 dBm CW
Maximum distance to the BPM module	200 meters (tested)
Power supply and control cable	Cat.7 S/FTP
Temperature dependence	< 200 nm / K
Dimensions	173 x 129 x 19 mm
Weight	~0.8 kg

Table 26: Technical specifications of the Libera XBS FE

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.

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WHERE IDEAS MEET TECHNOLOGY

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