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ISRC and LEBT Controls - Detailed Systems Design Document

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1. SCOPE

The document contains the Control System Design Description of the Ion Source (ISRC) and the Low Energy Beam Transport (LEBT), the first two components of the of the ESS linear accelerator.

This is the "as-built" design document describing the current architecture and implementation. This document is therefore the reference for maintenance, adaptations and new implementation activities.

2. ISSUING ORGANISATION

This document is issued by the European Spallation Source (ESS) ERIC, Integrated Control System (ICS) Division, Hardware and Integration Group.

3. CONTEXT

ESS is an accelerator driven neutron spallation source. The linear accelerator, or LINAC, is thus a critical component.

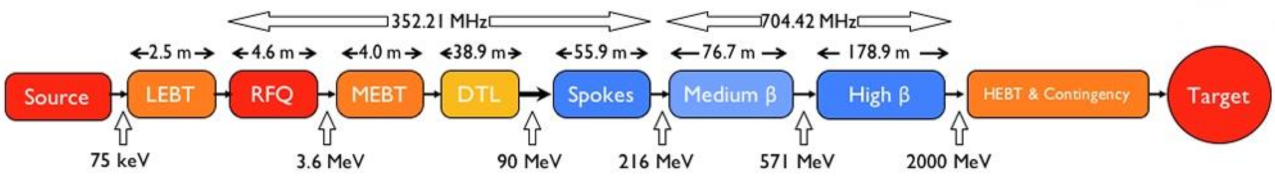


Figure 1 - Schematic picture of the different parts of the ESS machine.

On Figure 1, from left to right: The Source (= ion source = ISRC) and the LEBT. The actual accelerator (LINAC) starts with the RFQ and ends just before the Target. The Target. The Instruments are not shown in this picture.

The ESS machine consists of four major parts:

- Ion Source and LEBT ("the Injection unit")
- Accelerator
- Target
- Instruments

The ion source is of the type Electron Cyclotron Resonance (ECR), and its task is to produce a plasma, i.e. ions in a vacuum chamber. The ions produced in the ESS machine are H^+, which is the same as protons (p^+). The protons are repelled from the ion source unit, as pulses shorter than 6 ms, into the Low Energy Beam Transport (LEBT) unit. In the LEBT the proton pulses get more focused and are chopped to less than 2.86 ms. The pulsed proton beam is then repelled from the LEBT and injected into the next unit; the Radio Frequency Quadrupole (RFQ) which is the start of the actual accelerator. In the accelerator the proton beam is steered towards the target station. When the protons hit the target, they will emit neutrons that are collected by the neutron instruments to perform different scientific experiments.

Figure 2 shows a general side view of the ISRC and LEBT unit.

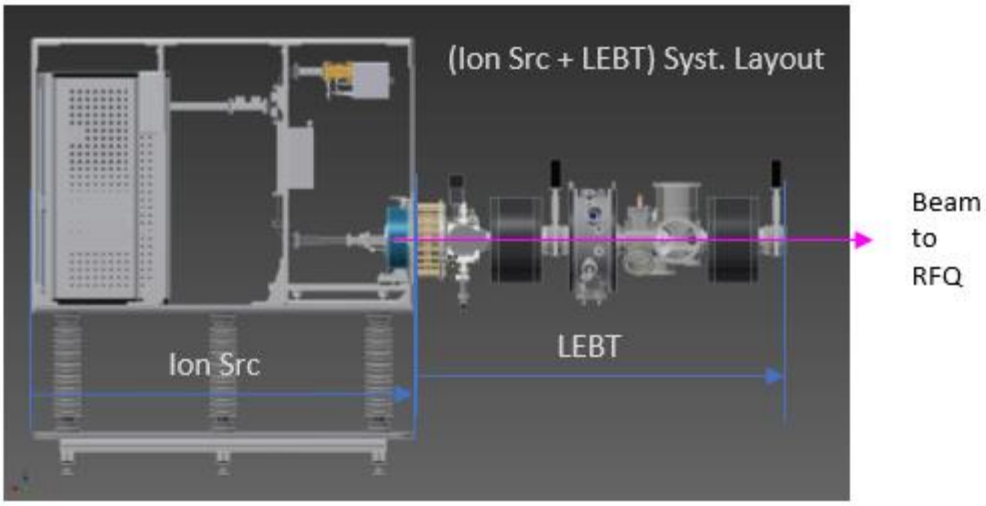


Figure 2 - CAD picture of the ISRC and LEBT unit.

Figure 3 is a schematic picture over the ISRC and LEBT. The white squares represent sub-systems that ICS will integrate into the ESS EPICS Environment, and the numbers in each square link to the sub-system name mentioned in the picture text.

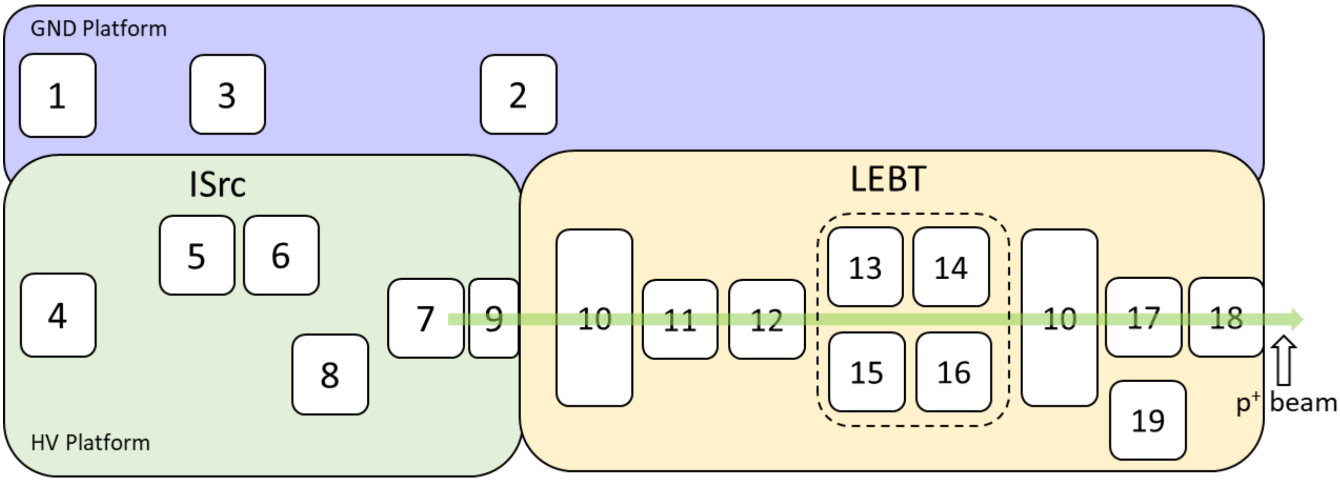


Figure 3 - A schematic picture of sub-systems that ICS will integrate into EPICS.

From Figure 3:

- <u>GND Platform:</u> 1) Insulating Transformer, 2) ISRC_LEBT Controls, 3) Power Supply,
- <u>ISrc (and HV Platform):</u> 4) ISRC Controls, 5) Magnetron, 6) Automatic Tuning Unit, 7) Plasma Chamber, 8) Gas Injection System, 9) Beam Extraction System
- <u>LEBT:</u> 10) Solenoid and Steerer [2 pcs], 11) Iris, 12) Chopper, 13) Faraday Cup, 14) EMU, 15) NPM, 16) DSM, 17) BCM, 18) Collimator, 19) Gas Injection System. Systems 13 – 16 are gathered in the "diagnostic box", dotted line. Note that some

systems, like the Vacuum System and the Water Cooling System are handled outside this detailed design document.

4. DESIGN CONSTRAINT AND ASSUMPTION

The design of the Control System of the Source and LEBT is aligned with the ICS Handbook [1], with the following exceptions:

- VME architecture is used instead of the µTCA;
- EPICS 3.14 instead of EPICS v4;
- Motion controls for the LEBT based on Delta Tau Geobrick solution instead EtherCAT;
- A dedicated Timing system (Annex A) has been designed to allow the machine to operate. It remains intended that this is not the final setup that will be deployed in ESS site.

These choices are motivated by stability/availability reason at the time of design.

The Control System is built based on EPICS (Experimental Physics and Industrial Control System) software toolkit and Control System Studio (CSS) is the standard tool for the OPI screens.

Even if the ISRC and LEBT can be seen as two different systems they are often considered as one unique system (i.e. the “injection system” so far). This is reflected even in the design where they share many components. This design choice is motivated by a general optimization of the resources re-using the HW and SW components where applicable. This can also be considered an advantage in terms of space, power consumption and costs.

5. ISRC DESIGN DESCRIPTION

The following section provide the architecture of the ISRC Control System in terms of:

1. General architecture (5.1).
2. Equipment description (5.2).
3. Control System software (5.3).

5.1. Control System General Architecture

The general architecture of the ISRC Control System is shown in Figure 4.

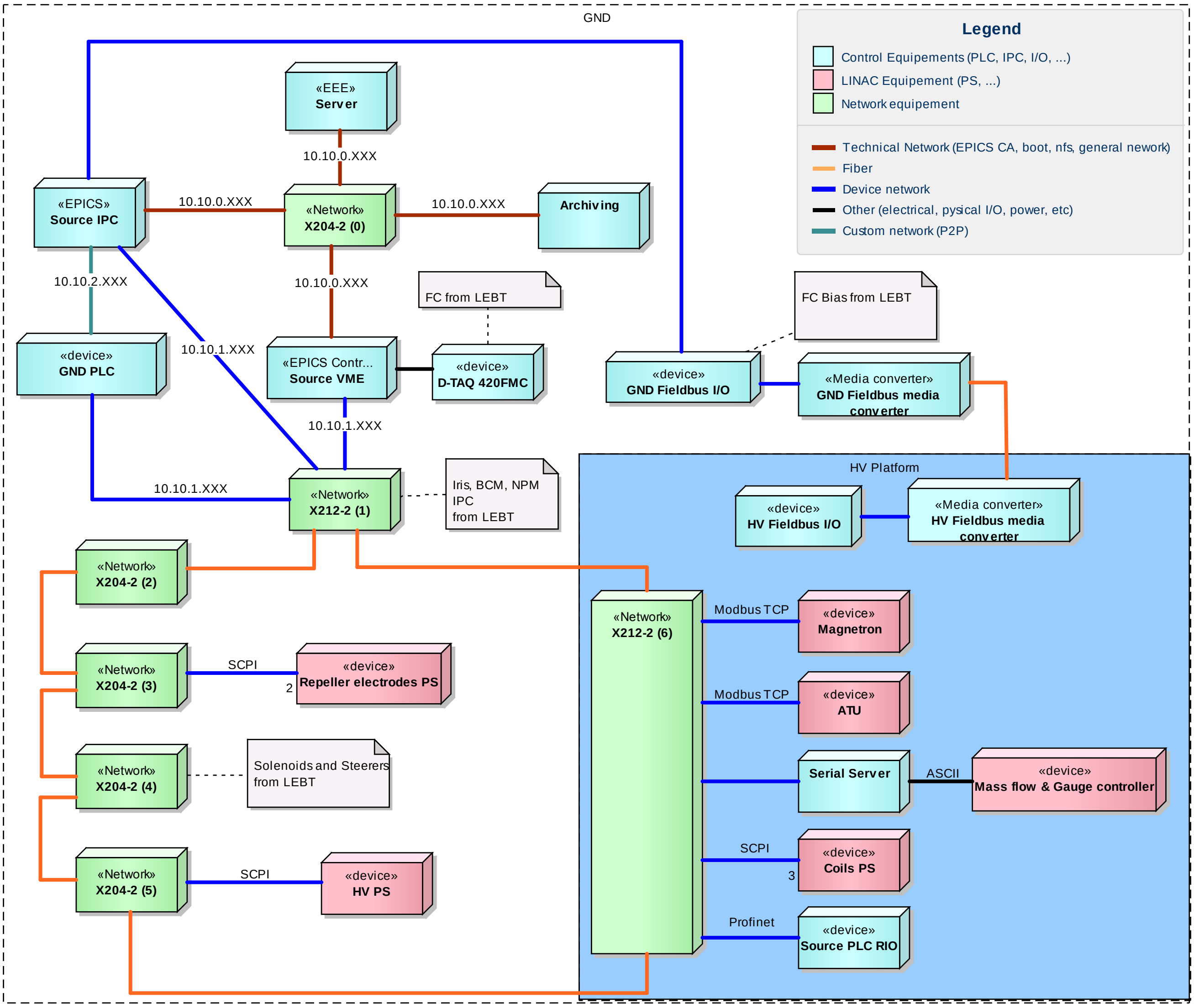


Figure 4 - ISRC Control System architecture

The Control System is physically displaced in two locations:

- The High Voltage platform (HV)
- The Ground platform (GND)

The devices on the HV platform (i.e. located at the potential to which it is raised) are those one needed to control the plasma generation. The device on ground potential are instead intended for data acquisition and SW control systems. Different networks are used to connect all devices:

- Technical network for the EPICS Channel Access (CA), boot, NFS and other general communication network.
- The device network is dedicated for the field bus communication (like Profinet, Modbus etc…).

- The custom network is a P2P network connection between the “Source IPC” and the “Source PLC”.
- A fiber optic link is used to create a ring that connects device on HV with device on GND. A direct fiber optic link is also used to connect the EtherCAT module on GND with that one on HV. The use of these optic link ensures a proper isolation between the GND and the HV platform.

The following section will describe the different equipment that compose the ISRC. Note that some enabling systems for the ISRC, like the Vacuum Control System and the Water Cooling Control System, are described outside this document.

5.2. ISRC Equipment

As shown in Figure 4, the ISRC consists of different devices that can be divided in three main categories:

1. Control Equipment (e.g. PLCs, IPC, Crates, data acquisition board)
2. Linac Equipment (e.g. Power Supplies, Coils)
3. Network Equipment (e.g. network switches)

Devices on HV platform are listed in Table 1, those one on GND level in Table 2.

Device	Manufacturer / Model	Function	Interface
Magnetron (microwave generator)	Sairem GMP20K IP 56T400FXX3IR	Provides microwaves for plasma generation	Modbus TCP
Magnetron Fast Shut-down unit	Sairem	Provides fast switch-off of the magnetron. This device is part of MPS and it is not discussed further in this document.	-
Automatic Tuning Unit (ATU)	SAIREM AI 4S A	Optimizes the coupling between the microwave generator and the plasma chamber of the source	Modbus TCP
Coils power supply	TDK-LAMBDA GEN 10-500-LAN-3P400	Coils around the plasma chamber provide magnetic field for plasma containment. There are three coils in total	SCPI

Device	Manufacturer / Model	Function	Interface
		(External, Medium and Injection), each one is controlled separately by a dedicated PS.	
Serial Devices Server	Moxa NPort 5150	Provides TCP/IP interface to serial devices (RS-232/422/485). It is used here for the Vacuum System Controller.	N.A.
Mass flow & Gauge controller (Vacuum system)	MKS 946	Provides regulation of gas flow into the plasma chamber and vacuum measurement	ASCII RS232/485
Source PLC RIO	Siemens S7-1500 PLC	Source Interlocks Control. This is a Remote I/O Module connected to the Source PLC on ground (5.2.2)	Profinet
Network switch / Media converter	Siemens Scalance X212-2	A network switch Copper/Fiber media converter, Provides Ethernet connection between HV and GND racks, and High Voltage Power Supply	N.A.
GND Fieldbus Media Converter	Beckhoff CU1561	Connects fieldbus I/O nodes on GND and HV levels	N.A.
HV Fieldbus I/O module	Beckhoff	Temperature monitoring of coils, plasma chamber and matching transformer	EtherCAT

Table 1 - Equipment on HV platform

Device	Manufacturer / Model	Function	Interface
High Voltage power supply	FUG HCH 15000-100000	Provides the 75kV voltage to the HV platform required to extract the beam	Ethernet, SCPI
Repeller Electrodes Power Supply	FUG HCP 35-3500	Provide voltage for extraction system	Ethernet, SCPI
Source IPC	Nexcom NISE 3600E	EPICS I/O Controller for PS PLC and EtherCAT modules	Ethernet, TCP/IP
Source VME	-	EPICS I/O Controller for Timing generation. Refers to 5.2.1 for more details about configuration	Ethernet, TCP/IP
Source PLC	Siemens S7-1500 PLC	Source Interlocks Control (5.2.2). This is the central node connected to the RIO module on the HV platform.	Ethernet, Profinet, S7
GND Fieldbus I/O	Beckhoff	Cooling System I/O Node. See 5.2.4 for more details	EtherCAT
HV Fieldbus Media Converter	Beckhoff CU1561	Connects fieldbus I/O nodes on GND and HV levels.	EtherCAT.
Network switch with Copper/Fiber Converter	Siemens Scalance X212-2, X204-2	Provide Ethernet connection through a ring network between HV, GND and High Voltage Power Supply	Ethernet, TCP/IP
EPICS Main Server	Desktop PC	Local EEE server synchronized with the main ESS one,	Ethernet, TCP/IP

Device	Manufacturer / Model	Function	Interface
		provides EPICS modules, network boot scripts etc.	
EPICS Operator PC	Desktop PC	Provides EPICS Control GUI	Ethernet, TCP/IP
Archiving System	Desktop PC	Archiving server for EPICS PV	Ethernet, TCP/IP

Table 2 - Equipment on GND

The ISRC and LEBT are controlled by some shared units; they share the same physical VME I/O Controller, PLC, Industrial PC (IPC) and EtherCAT I/O, see box number 2 in Figure 3. For example, the ISRC_LEBT Controls control different power supplies, both on HV and on GND. In chapters 5.2.1 to 5.2.4 these shared control units are described.

Some functions of the ISRC_LEBT Controls are, mainly dedicated to the ISRC (thus called "ISRC Controls"), see box number 4 in Figure 3.

5.2.1. VME I/O Controller

The VME I/O Controller consists of a 4U VME crate (ELMA Type 39) with the VME modules detailed in Table 3.

Device	Manufacturer / Model	Function	Interface
CPU	IOxOS IFC 1210	Required to run IOCs	VME
Data acquisition	D-Tacq ACQ420FMC-4-2000-16, with Breakout board (DIN rail) and prefabricated cable.	This is a FMC module installed on the CPU. It used to acquire signals from BCM and FC on the LEBT.	FMC
EVR Board	MRFI PMC-EVR-230	Event receiver for synchronous data acquisition	PMC
EVG board	MRFI VME-EVG-230	Event generator used for timing. Provides the 14 Hz pulse required to operate the machine and for synchronous data acquisition.	VME

Device	Manufacturer / Model	Function	Interface
Event Fan-Out Board	MRFI VME-FOUT-12	This is a fan-out board required to distribute the trigger to other components of the ISRC and the LEBT.	VME
EVR Board	VME-EVR-230RF + UNIV-HFBR-1528	Event receiver required to send the trigger to the Magnetron on the HV platform (optical link)	VME

Table 3 - VME I/O Controller devices

5.2.2. Industrial PC (IPC)

The IPC I/O controller is used to control slow equipment on the ISrc (i.e. PLC and EtherCAT I/O modules) and the devices that belongs to the LEBT (i.e. Solenoids, Steerers, Iris and Chopper, see 6.2)

5.2.3. PLC

One PLC is used for (slow) Interlocks Control of the ISRC and the LEBT. In some documentation this PLC is called “Source PLC”.

Initially this PLC was intended only for Local Protection System (LPS) and Personnel Safety Systems (PSS) needed for operation in Catania.

For Test Stand operation in Lund, the LPS will be kept (on this PLC) and the PSS from Catania will be removed. In addition to this, the Personal Safety System (PSS0) will have some connections to this PLC.

In the future (when ESS is in “normal conducting LINAC operation”) the LPS will still be present on this PLC, the Machine Protection System (MPS) will also have connections with it, but it is not yet clear if the PSS will have any interface with this PLC or if the PSS will have a direct hardwired connection with the ISRC and LEBT.

The PLC consists of two units; a CPU with additional analogue and digital modules on the GND Platform and a Remote I/O unit on the HV Platform. The two units are connected through a ring network using fiber optic link to grant a proper isolation as shown in Figure 5.

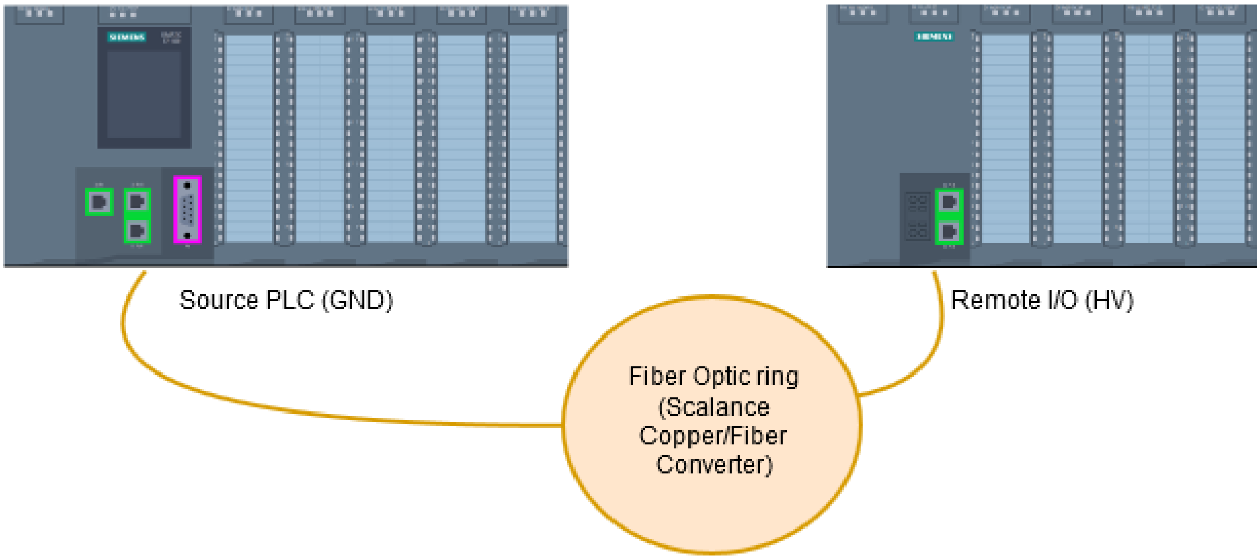


Figure 5 - PLC Architecture

The PLC on GND is mainly dedicated for the LEBT and it consists of the modules described in Table 4. Siemens S7-1500 family was selected.

Name	Quantity	Part number
Load power supply PM 70W, 120/230 V AC, 24 VDC, 3 A	1	6EP1332-4BA00
CPU 1516-3 PN/DP	1	6ES7516-3AN01-0AB0
Digital input, DI 16x24VDC HF	1	6ES7521-1BH00-0AB0
Analog input, AI 8xU/I/RTD/TC ST	2	6ES7531-7KF00-0AB0
Digital output, DQ 16x24VDC/0.5A ST	2	6ES7522-1BH00-0AB0
Memory card, 12 MB	1	6ES7954-8LE02-0AA0
Front connector, screw-type terminal for 35mm modules, 40-pin	5	6ES7592-1AM00-0XB0

Table 4 - PLC on GND specification

The PLC (the Remote I/O module) on the HV platform is instead dedicated for interlock control of the Source equipment. It doesn’t have the CPU (this is why it is only a Remote I/O module) and it consists of the modules described in Table 5.

Name	Quantity	Part number
Load power supply PM 70W, 120/230 V AC, 24 VDC, 3 A	1	6EP1332-4BA00
Interface Module, IM 155-5 PN ST	1	6ES7155-5AA00-0AB0
Digital input, DI 16x24VDC HF	2	6ES7521-1BH00-0AB0
Analog input, AI 8xU/I/RTD/TC ST	1	6ES7531-7KF00-0AB0
Digital output, DQ 16x24VDC/0.5A ST	1	6ES7522-1BH00-0AB0
Front connector, screw-type terminal for 35mm modules, 40-pin	4	6ES7592-1AM00-0XB0

Table 5 - PLC RIO module specification

A simplified I/O list is attached to this design document in Annex B. A more detailed list of I/O signals managed by the source PLC is contained in [3], which has to be considered as the always most updated one.

5.2.4. EtherCAT (Fieldbus) I/O

The EtherCAT technology is adopted for “low level” data acquisition on the field when data sampling is modest (up to 100 kHz or less) and when there is no need to implement interlock functions (a PLC is more appropriate for this). Beckhoff’s EtherCAT solution has been selected in this case.

Like the PLC, the EtherCAT modules are split between the GND and the HV platform. Counter to the PLC they are not connected through a ring network but with a direct fiber optic link achieved by a couple of Copper/Fiber media converter modules. The optic link is used to allow a proper isolation.

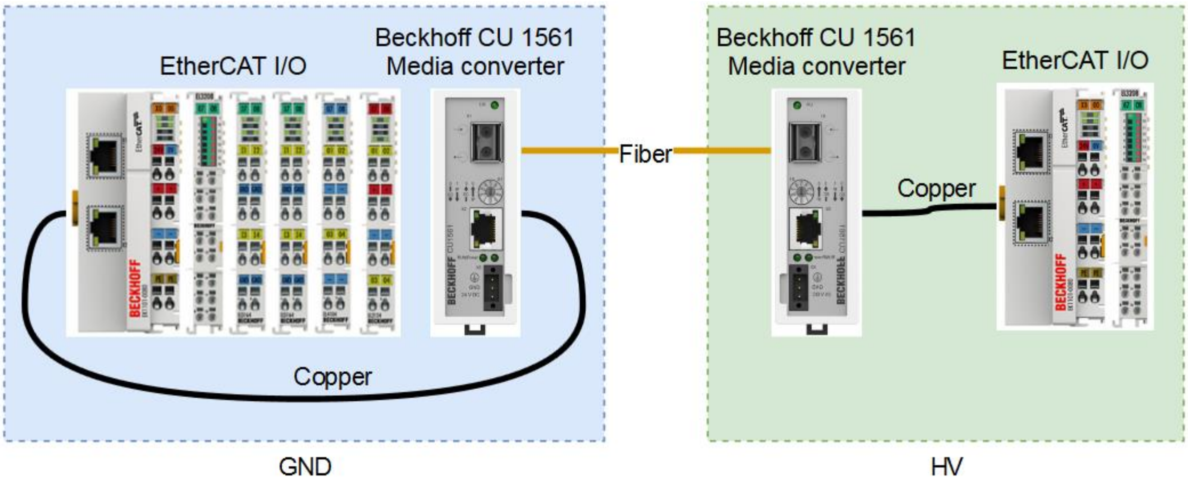


Figure 6 – EtherCAT (Fieldbus) I/O architecture

The I/O modules on GND are composed by different modules as specified in Table 6.

Module Name	Quantity	Part number
Bus Coupler	1	Beckhoff EK1101
AI module, 8 channels (RTD)	1	Beckhoff ES3208
AI module, 4 channels (0…10 V)	2	Beckhoff ES3164
AO module, 4 channels (0…10 V)	1	Beckhoff ES4104
DO module, 4 channels (5V)	1	Beckhoff ES2124
Copper/Fiber Converter	1	Beckhoff CU1561

Table 6 - EtherCAT I/O modules on GND, specifications

The main purpose of the EtherCAT modules on GND are to measure:

- Ambient humidity and temperature on GND.
- Set and read back the voltage and the current of the LEBT Faraday Cup Bias Power Supply
- Set the output voltage of the LEBT Chopper.

It is worth mentioning that this will probably not be the final configuration. In fact, the second module in the list (i.e. the AI RTD, ES3208) it is not currently used and it is possible that it will be removed later.

While modules on GND are used only for the LEBT, the I/O modules on the HV are instead intended for the ISRC. They are intended for monitoring the temperature of:

- The Coils that envelop the plasma chamber;
- The Plasma chamber it-self;
- The matching transformer (= the Automatic Tuning Unit);

Module Name	Quantity	Part number
Bus Coupler	1	Beckhoff EK1101
AI module, 8 channels (RTD)	1	Beckhoff ES3208
Copper/Fiber Converter	1	Beckhoff CU1561

Table 7 - EtherCAT I/O on HV platform

5.3. ISRC Control System Software Architecture

The control system software for the source (i.e. m-epics-source, [4]) is based on Experimental Physics and Industrial Control System (EPICS) framework and it consists of the following main components (see Figure 7):

- VME
- IPC
- Source OPI

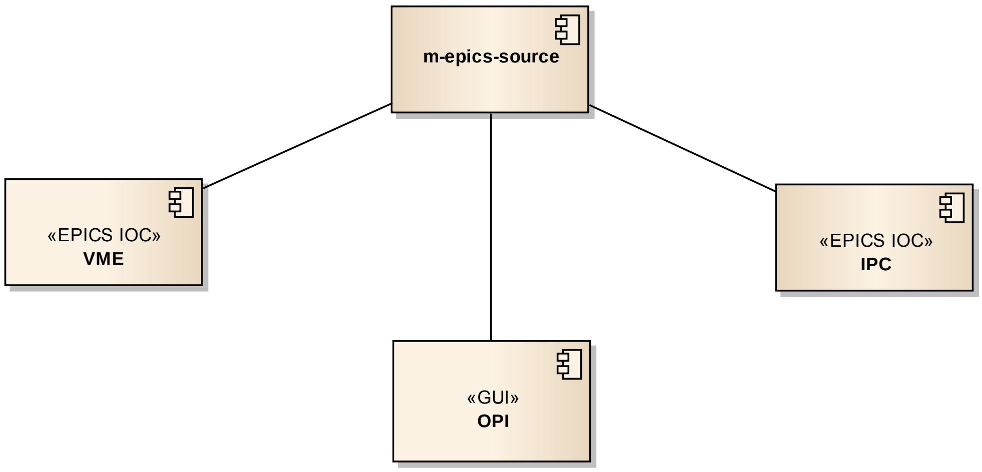


Figure 7 - ISRC Software Architecture

The EPICS start-up scripts (i.e. source-vme and source-ipc) depends on different EPICS modules that are specific for each device controlled (see Figure 8 and Figure 10). The VME and IPC components are then responsible to configure the modules required and to instantiate the proper database templates. The OPI component represents the Graphical User Interface containing the screens required to operate the source.

5.3.1. VME component

The VME component is designed to control different Power Supplies used to produce and extract the beam, “fast” equipment and synchronized data acquisition. It controls then the Event Generator of the timing system to provide the 14 HZ main pulse and the trigger for the LEBT Chopper.

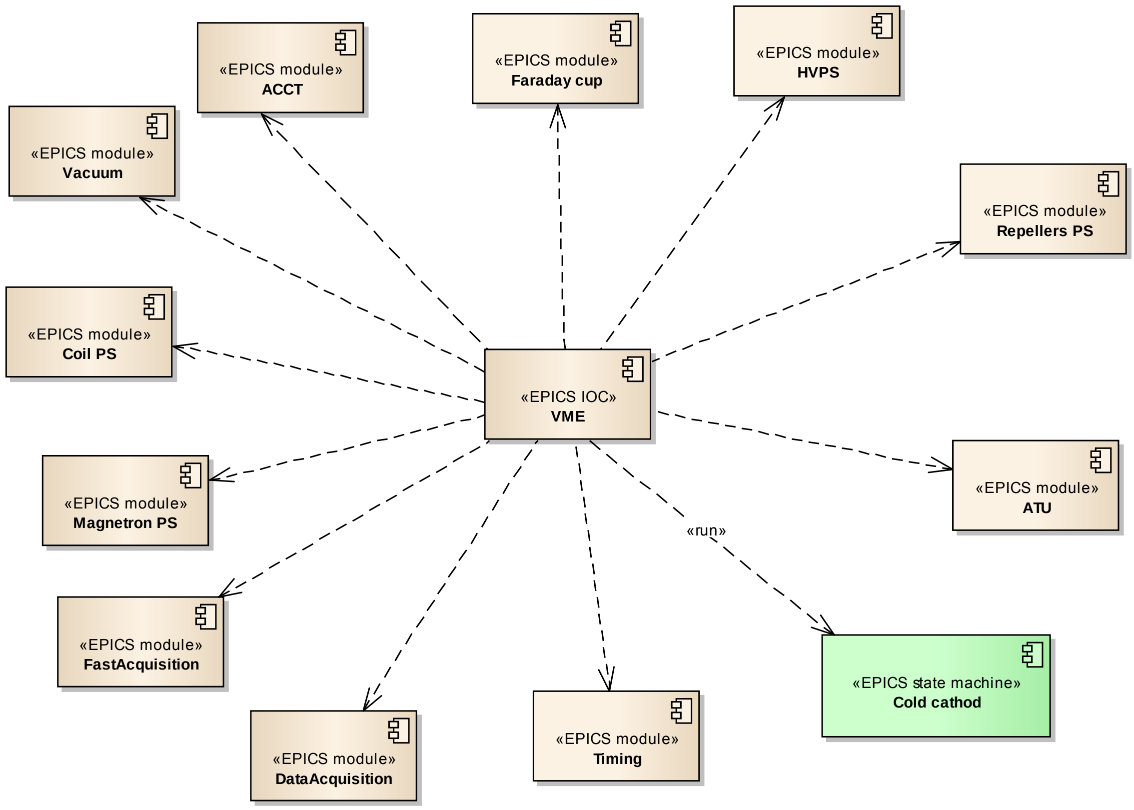


Figure 8 - Source VME component architecture

The application running on VME controls the following equipment:

Device	Required Module(s)
Magnetron PS	sairemgmp20ked
ATU	sairemai4s
MFC (Vaccum)	vac_ctrl_mks946 vac_mfc_mks_gv50a vac_gauge_mks_vgd
Coils Power supply	tdkgen10500
HV Power supply	fug
Repeller PS	fug
Faraday Cup	faradaycup
FastAcquisistion	fastacquisition
DataAcquisition	dataacquisition

ACCT	acct
Timing	mrfioc2

Table 8 - Source VME modules dependency

As a design choice the VME source application is used to control even devices that are part of the LEBT:

- Faraday Cup (Data acquisition and bias PS)
- ACCT on the collimator (see 6.2.4)
- Chopper (TTL trigger only)

This design choice is motivated by costs and space containment. A data acquisition board was needed for the first BCM at the exit of the Source (i.e. one channel of the D-Tacq board, see Table 3). Since this board has in total four channels, it has been decided to use the other channels for the LEBT Faraday Cup and the second BCM before the collimator. It remains intended that this is not the final setup and that these components (FC, ACCT on the collimator and the Chopper) will be separated and migrated to µTCA platform.

Regarding the Chopper, the VME source application is used to provide the TTL trigger synchronized with the main pulse generated by the EVG. This design choice is motivated by the fact that the source is already equipped with an EVR board required to perform synchronized data acquisition and it is possible to use one output channel of this EVR to send the trigger to the Chopper. This avoid the use of a different EVR only for this (again costs and space containment)

The VME component is also responsible to control the state machine that controls the cold cathode (Figure 9). This state machine is used to put the cold cathode at the ground only when the vacuum given by the Pirani gauge is under 1.10e-4 mBar.

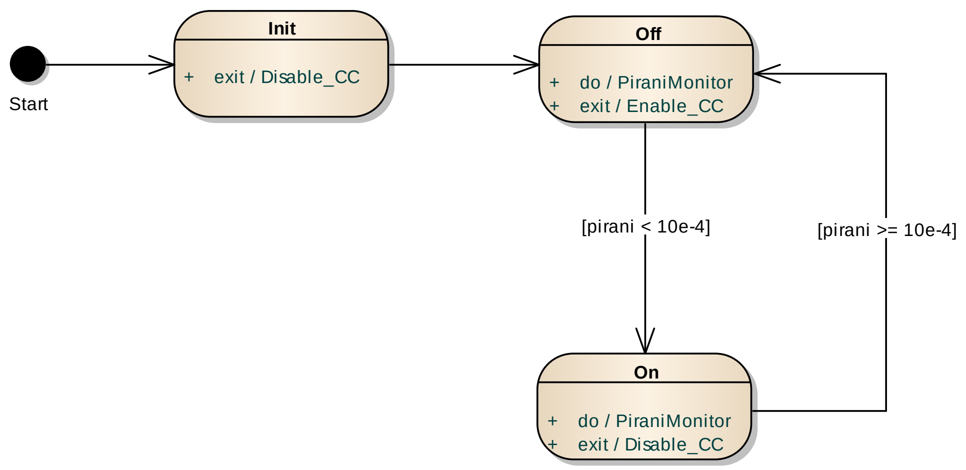


Figure 9 - Cold Cathode State Machine

The VME application requires the generic autosave EPICS tool module to be able to save the value of the EPICS PVs configured and restore them when the application is restarted.

5.3.2. IPC component

The IPC EPICS component is intended to control field bus data acquisition devices (i.e. the EtherCAT modules, see 5.2.4) and the "slow" interlock PLC (5.2.2). The architecture of the IPC application is shown in Figure 10.

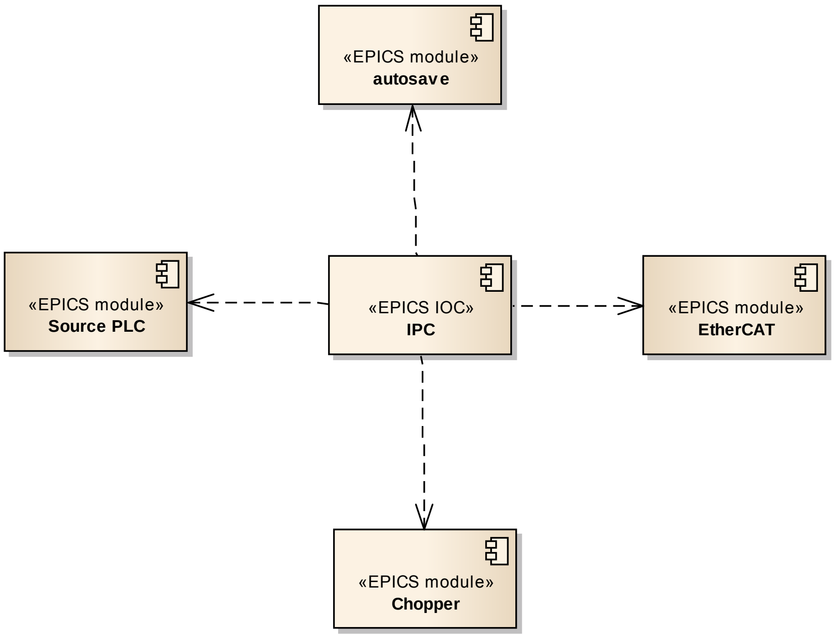


Figure 10 - IPC SW architecture

The devices controlled by the IPC application are listed in Table 9.

Device	Required Module(s)
Chopper	chopper
PLC	plc-source, s7plc
EtherCAT	ecat2db
Autosave	autosave

Table 9 - IPC modules

As a design choice the Source IPC component controls both PLC and EtherCAT modules. The IPC is shared between the ISRC and the LEBT elements. This design choice is motivated by the need to share the resource available reducing the need to have different HW/SW to control the Ion Source and LEBT separately. Again, this is not the final design and they can be separated later in ESS site installation.

The IPC application controls the power supply of the LEBT chopper connected to the EtherCAT modules on ground (6.2.3). The TTL trigger of the chopper is instead controlled by the VME component. This design choice is motivated by the fact that the IPC application is running on a system without any EVR installed and it is not then able to generate the proper trigger synchronized with the main pulse provided by the EVG.

Like the VME application, the IPC requires the generic autosave EPICS tool module to be able to save the value of the EPICS PVs configured and restore them when the application is restarted.

5.3.3. OPI component

The last main component of the Control System Software is the OPI. This component contains the set of screens of the operator interface allowing to operate with the Source. It is specifically designed to provide both a general overview and detailed view for each system / subsystem. It contains also a dedicated page to identify the different origins of interlocks, giving the possibility to resolve / reset them when required.

Control System Studio (CSS) has been selected as standard to design the Graphical User Interface.

6. LEBT DESIGN DESCRIPTION

The following section provide the architecture of the LEBT Control System in terms of:

1. General architecture (6.1).
2. Equipment description (6.2 and 6.3).
3. Control System software (6.4).

6.1. Control System General Architecture

The general architecture of the LEBT Control System is shown in Figure 11.

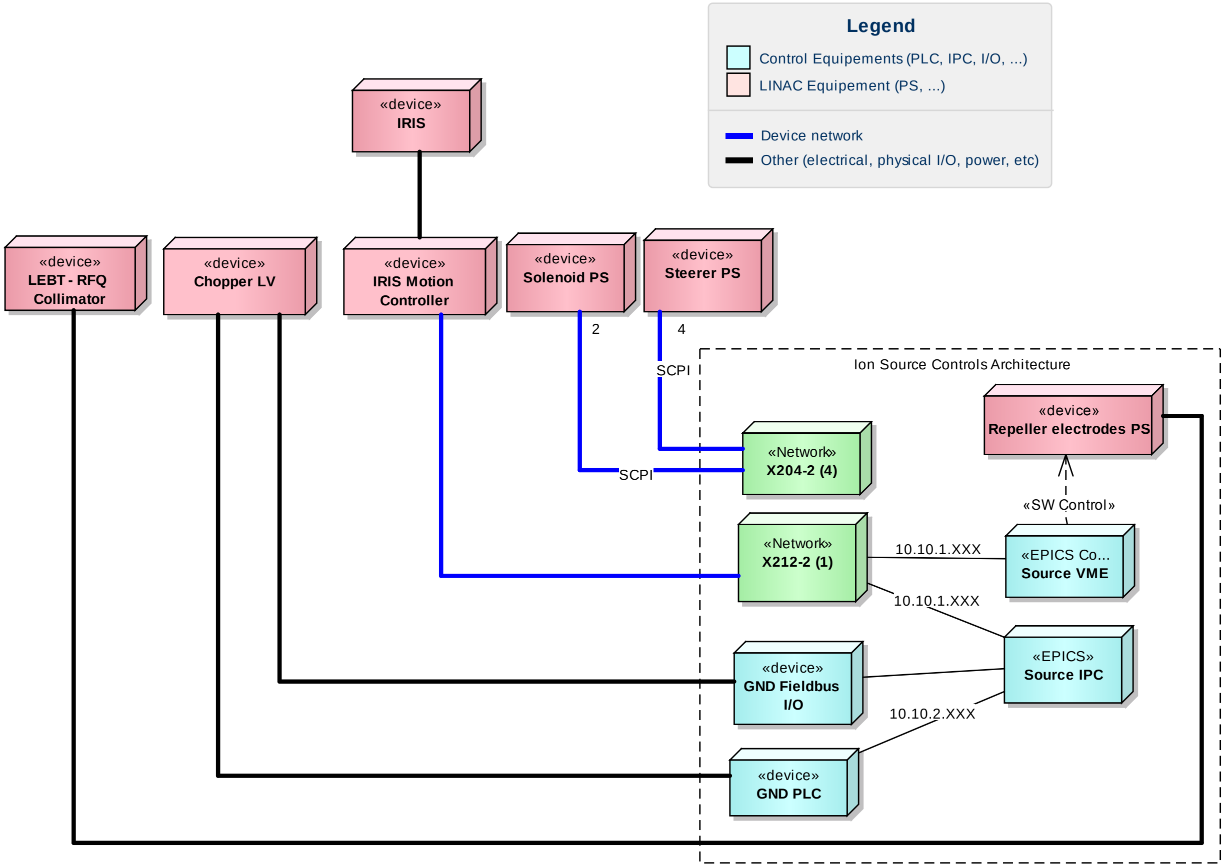


Figure 11 - LEBT Control System Overview

The LEBT consists of the following elements:

- Solenoids;
- Steerers;
- Iris
- LEBT - RFQ Collimator;
- Chopper;

As design choice, the controls of these devices (i.e. Source VME, Source IPC, GND PLC and GND Fieldbus I/O) are the same used for the ISrc (see 5.2). Considering that many signals are shared between the ISrc and the LEBT this choice is motivated by the need to optimize HW and SW resource re-using the same components where applicable.

Aside these elements there are (also on GND) other equipment that are used for beam diagnostic purposes:

- Faraday cup (FC);
- Emittance Measurement Unit (EMU);
- Beam Current Monitor (BCM);
- Non-Invasive Profile Monitor (NPM);
- Doppler Shift Measurement (DPL or DSM);

Note:
Some systems, like the Vacuum Control System and the Water Cooling Control System are described outside this document. According to figure 3, the LEBT also has a Gas Injection System. However, the controls for the Gas Injection System will be covered by the Vacuum System's controls, and thus not described in this document.

6.2. LEBT Devices and Control Equipment

6.2.1. Solenoids and Steerers

Solenoids and steerers are assembled together and they can be considered as a unique entity.

Solenoids have the aim to confine the beam keeping the protons as close as possible applying a magnetic field. Steerers, as the name says, have the aim to steer the beam of protons in order to make it pass through the LEBT collimator (see chapter 6.2.4).

There are two solenoids. Each one has two steerers, one for the vertical axis and one for the horizontal axis (there are two solenoids and four steerers in total then).

These devices are controlled by the following Power Supplies by means of the LEBT IOC (6.4.1).

Device	Manufacturer / Model	Function	Interface
Power Supply (x2)	Sorensen SGA 30X501D-2GAA	Provides power to solenoids	Ethernet / ASCII
Power Supply (x4)	Sorensen XG 12.5-120 MEB MIA-3.14-KP-CE	Provides power to Horizontal and Vertical steerers	Ethernet / ASCII

Table 10 - Control Equipment of LEBT Solenoids and Steerers

Each solenoid also has two polarity switches that are controlled by Source PLC to invert the polarity of the steerers.

6.2.2. Iris

The LEBT has two "Beam Intercepting Devices": the iris (or diaphragm) and the collimator. The function of the iris is to define the diameter of the beam. The iris adjusts light intensity of the beam. It's the same principle as in a camera. We can also compare the main purpose of the iris with a resistor: the resistor, in function of its value (geometric shape), adjusts the current which goes through it.

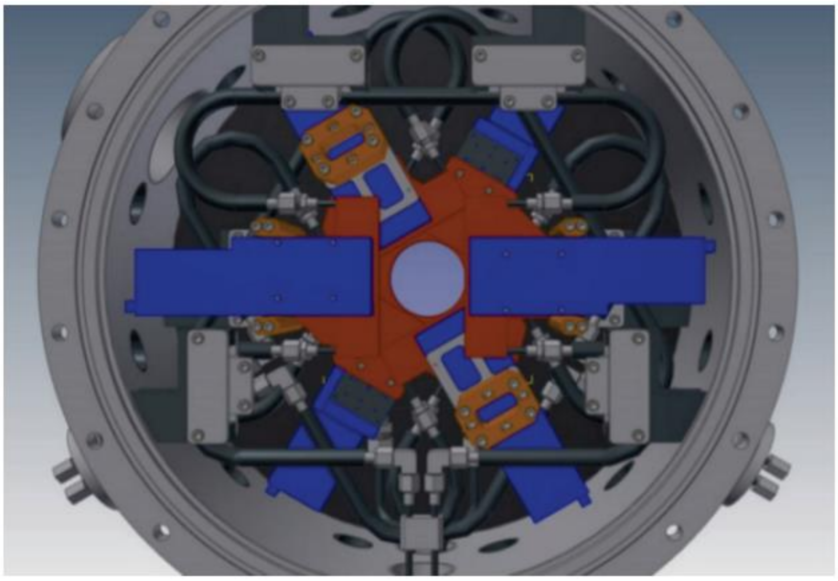


Figure 12 – The LEBT's iris

The iris consists of six different blades (the "orange" ones in Figure 12) to give the proper shape to the beam. Each blade is moved independently from the others by six axes (the "blue" ones in Figure 12) controlled by the control motion equipment listed in Table 11 by means of the LEBT IOC (6.4.1).

The blades are flat, so the shape of the iris is hexagonal with an aperture between 1 and 80 mm. However, to get the iris shape as circular as possible, there is another kind of blade which is not flat but triangular. This implicates that the iris shape is a dodecagon, closer to the circular shape. Because of the geometry of these triangular blades, the aperture range is smaller: from 5mmto 70mm.

Device	Manufacturer / Model	Function	Interface
Motion control unit	Geo Brick LV IMS II 9BD8F34470008E100DL	Provides control of iris motors	Ethernet / ASCII
Power Supply	-	Provides the required power to the motion control unit	-

Table 11 - Control Equipment of LEBT iris

6.2.3. Chopper

The chopper is a device with a twofold purpose:

1. It crops the beam pulse generated by the source (about 6-10 ms long) into a pulse with well-defined and sharp flanks (about 2.86 ms long).

2. It has also an important role in the scope of MPS since it is able to stop the beam within approximately 300 ns. This overcomes the slow response of switching off the magnetron (which takes about 100 µs).

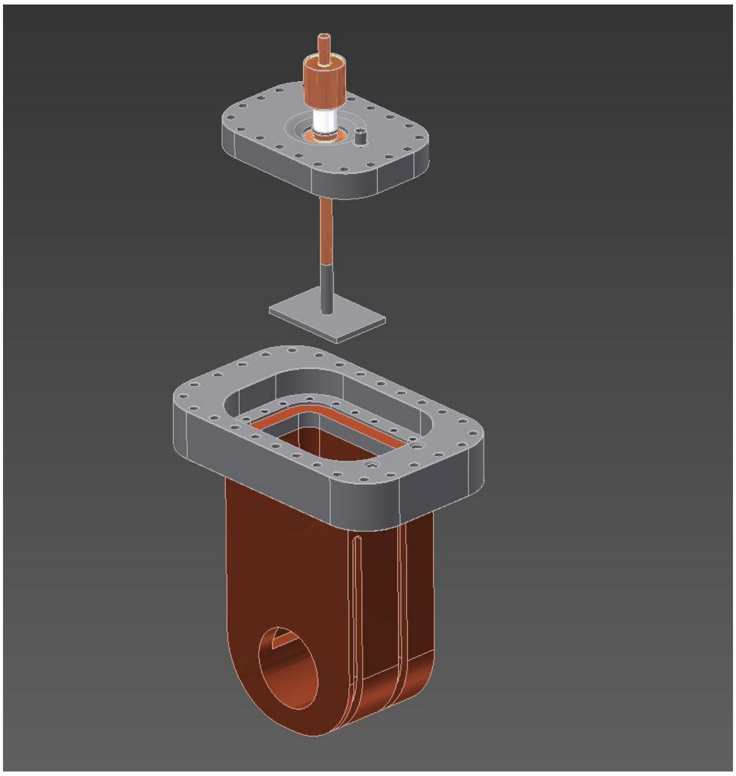


Figure 13 – Mechanical view of the LEBT chopper beam line section.

The LEBT chopper consists of three components:

1. High Voltage module.
2. Low Voltage module.
3. The section of beam line (vacuum chamber) with the deflecting electrodes and the feedthrough.

As shown in Figure 14, the chopper is interfaced with the following subsystems:

- Timing System (Triggering)
- Integrated Control System (Control & Monitoring)
- Beam Interlock System (Machine Protection)

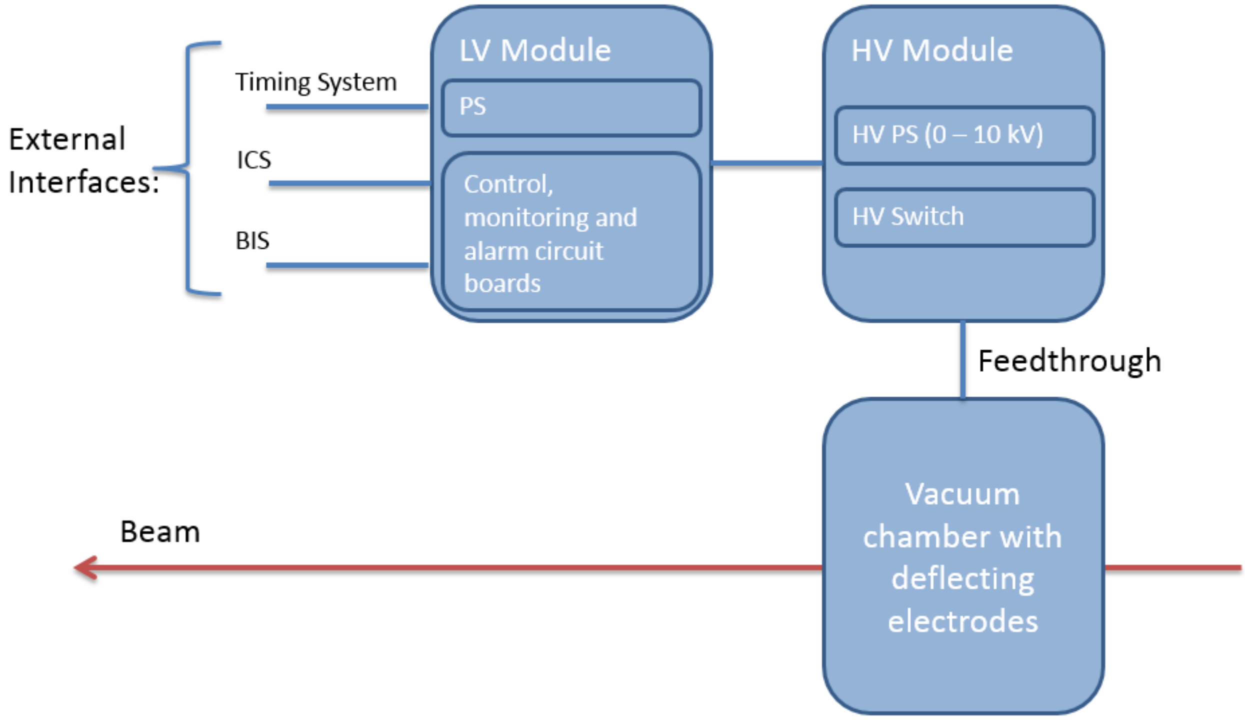


Figure 14 – General architecture of the LEBT Chopper

The chopper is controlled by the ISrc PLC and the EtherCAT equipment (see 5.2.2 and 5.2.4). The timing signal for the chopper is provided by the ISrc VME IOC (see 5.3.1) while the PLC and EtherCAT is controlled by the ISrc IPC IOC (see 5.3.2).

6.2.4. LEBT - RFQ Collimator

The LEBT – RFQ Collimator represents the interface between the LEBT and the RFQ sections of the ESS Accelerator. Its main role is to actuate a vacuum break between the relative high pressure of the LEBT and the low pressure of the RFQ.

The LEBT – RFQ Collimator has also the function of a beam dump. The LEBT Chopper can, in fact, deflect the beam so it doesn't pass through the collimator aperture, thus avoiding the beam to be "forwarded" to the next sections of the Accelerator.

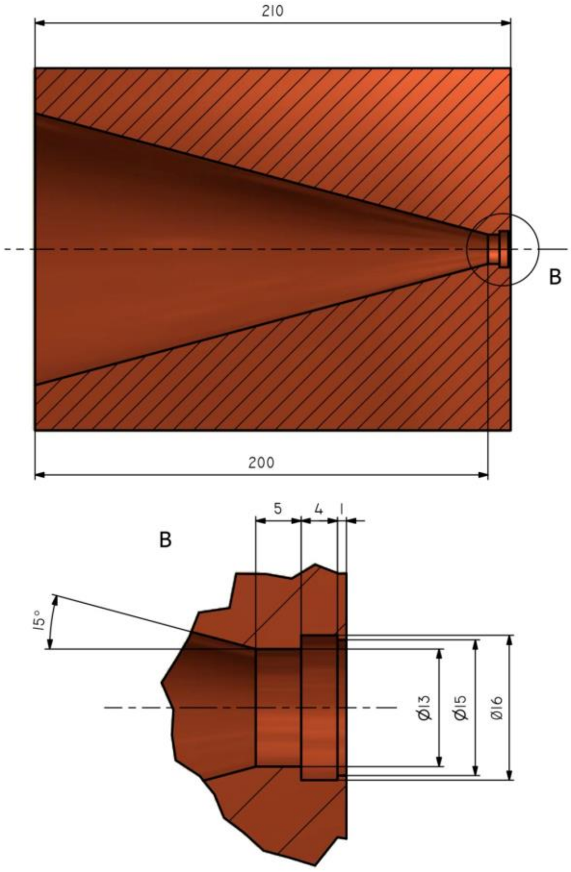


Figure 15 - LEBT – RFQ Collimator

The conical shape is where the beam will be dump. The first 5 mm of cylindrical shape are used to decrease the vacuum conductance. The following 4 mm are used to house a repelling electrode. The last millimetre is at ground potential to shield the RFQ from the electric field of the repeller. The voltage and current applied to the repeller is controlled by one of the Repeller Power Supply listed in Table 12.

Device	Manufacturer / Model	Function	Interface
Repeller Electrodes Power Supply	FUG HCP 35-3500	Provide voltage to the repeller electrode of the Collimator.	Ethernet, SCPI

Table 12 – Control equipment for the LEBT - RFQ Collimator

6.3. LEBT Diagnostic

6.3.1. Faraday Cup

The Faraday Cup (FC) is a diagnostic device that allow to measure the length of the pulse and the total current of the beam. When inserted into the beam line, the Faraday Cup acts as beam stopper not allowing the beam do pass through it.

The original design of the control system for the FC is shown in Figure 16.

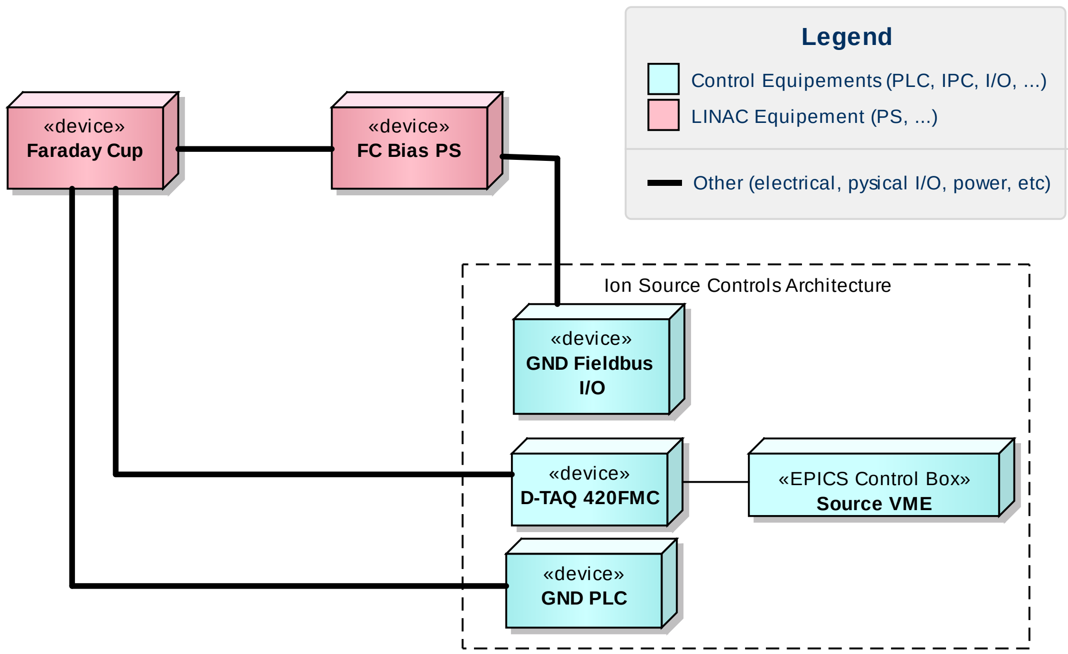


Figure 16 - Control system architecture of LEBT FC (original design)

In this original design, the Faraday Cup is controlled by the EtherCAT and PLC module on GND (see Table 13). It requires the Bias Power supply that is controlled by the Source (ISRC) IOC.

Device	Manufacturer / Model	Function	Interface
Bias Power Supply	ISEG THQ 2CH 2HE 60W T2300006_2HE	Provide Bias power supply to the FC	RS-232 / ASCII
EtherCAT FC I/O (Fieldbus)	See 5.2.4		
PLC	See 5.2.3		

Table 13 - Control equipment for the LEBT FC (original design)

The FC is then connected to the DAQ acquisition board (D-TAQ is its manufacturer), on the Source VME crate (see 5.3.1), that acquires the value of the current and shows it on the operator GUI. The data acquisition needs to be synchronized with the main ESS 14 Hz pulse (see Annex A). This is achieved with an EVR connected to the timing system. In the current set up, this is still achieved by the EVR installed in the Source VME that provide the trigger to the DAQ board.

The architecture described so far refers to the original design, as delivered from the ESS in-kind partner CEA. At the moment the Faraday Cup (FC) Bias Power Supply (PS) is not, due to a damage, controlled by the EtherCAT modules on GND, but instead controlled by one of the repellers' PS. It should also be considered that the controls for the FC will, later on, be completely moved out from the Source Controls, so a general redesign of the present architecture is needed in the future.

The actual implementation deviates from the original design as follow:

1. EtherCAT modules are not used.
2. The repeller power supply (FUG HCP 35-3500) listed in Table 2 on row 2 is used instead of the Bias Power Supply listed in Table 2 on row 1 It is controlled directly by the Source VME application with an Ethernet/SCPI interface.

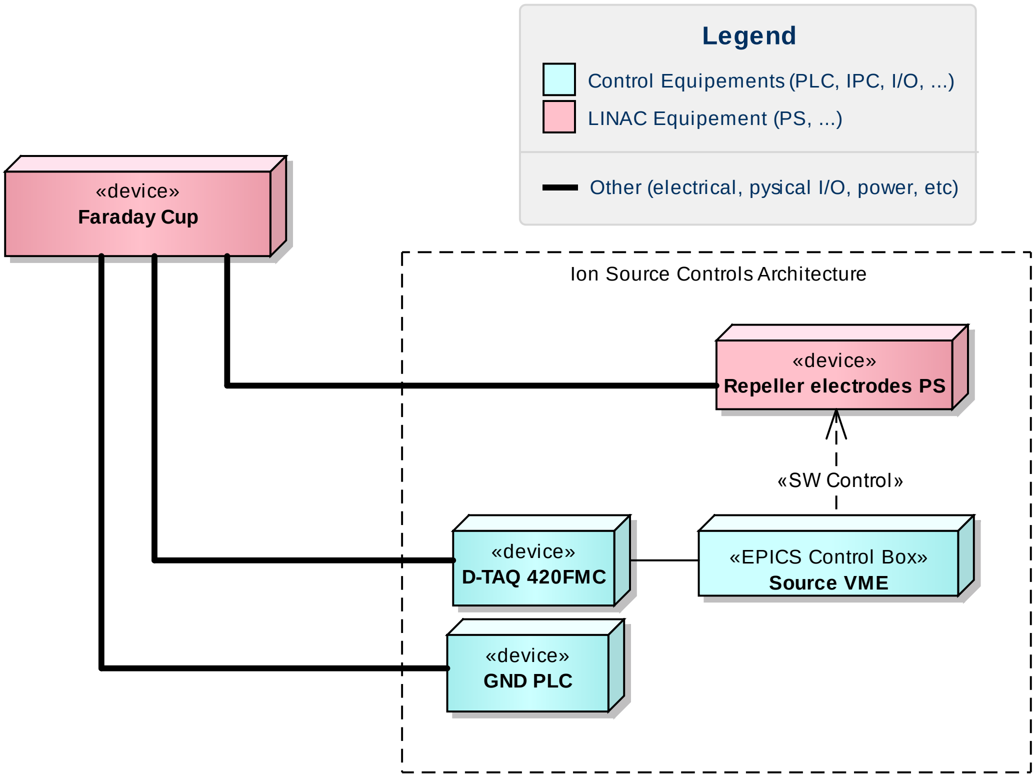


Figure 17 - Control system architecture of LEBT FC (as <u>temporarily</u> built in Lund)

Note that the architecture in figure 16 is also temporary since, in the future, the Faraday Cup will be a completely independent system under the control of the ESS Beam Diagnostic group (a group within the Accelerator division).

6.3.2. Beam Current Monitor

The Beam Current Monitor (BCM) is another diagnostic device that is able to measure the current of the beam that flows through it. It can be compared to the FC described in chapter 6.3.1, with the significant difference that it doesn't stop the beam like the FC does.

The BCM consists of two main components:

- The ACCT (AC Current Transformer) is the sensor that measures the current that flows through it.
- The ACCT-E-RM interface is the electronics device that transform the raw signal read by the ACCT in a proper voltage / current level.

The Beam Current Monitor doesn't require any additional control equipment (e.g. PS, PLC, and so on). It is connected to the DAQ board of Source VME crate that read the value of the measured current.

The architecture of the BCM control system is shown in Figure 18.

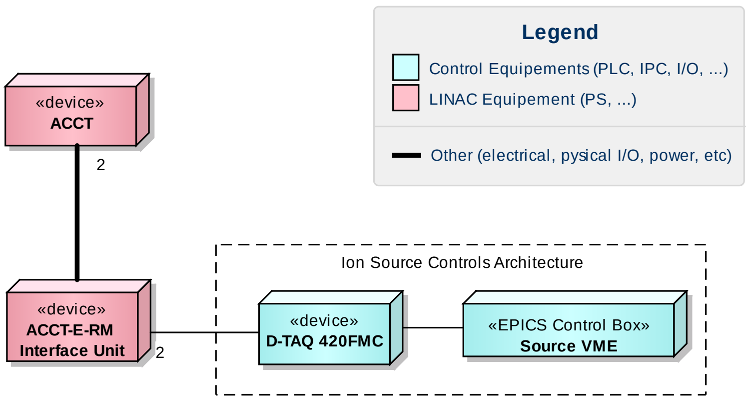


Figure 18 - Control system architecture of LEBT BCM

There are actually two BCMs. One is installed at the beginning of the LEBT to measure the current of the beam produced by the source, the other one is installed at the end to measure the value of the current (and the length of the pulse) that the LEBT transports to the next section (i.e. the RFQ). The two signals are then connected to the DAQ of the source VME and they are shown in the operator GUI.

As for the FC, a connection with the ESS timing system is required to perform synchronized data acquisition with the main 14 Hz pulse (see Annex A), and with the same considerations as made for the FC (see 6.3.1).

As for the FC, this is only a temporary set up. In the future, also the BCM will be a totally independent system on the Ion Source Controls, but under control of the ESS Beam Diagnostic group.

6.3.3. Emittance Measurement Unit

The Emittance Measurement Unit (EMU) is a diagnostic device used to measure the emittance value of the beam, providing a quantity and quality measure of the beam itself.

The EMU is a completely independent system. Its general architecture is shown in Figure 19, control equipment is listed in Table 14

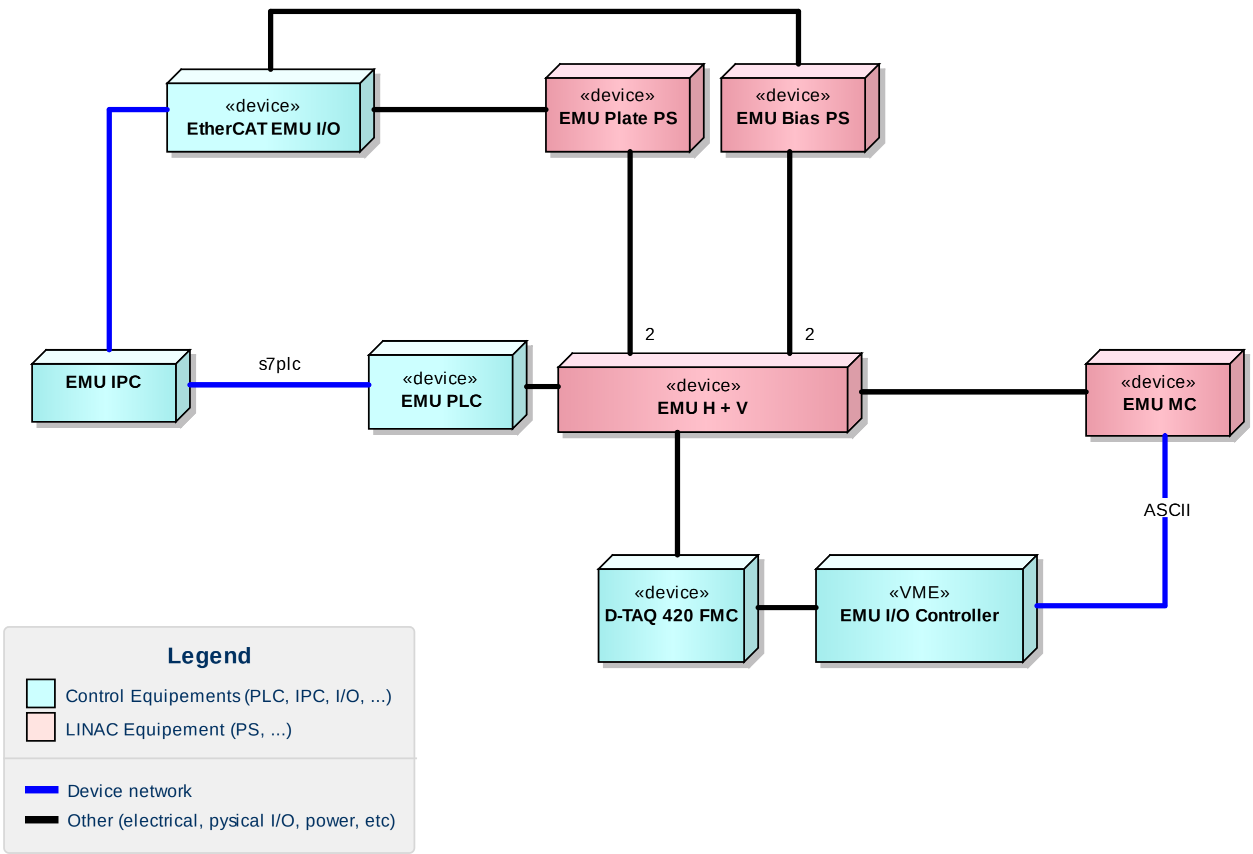


Figure 19 - EMU Control System Architecture

Device	Manufacturer / Model	Function	Interface
EMU IPC	Nexcom NISE 3600E	EPICS I/O Controller for PS PLC and EtherCAT modules	Ethernet, TCP/IP
VME EMU I/O Controller	-	EPICS I/O Controller. Refers to Table 15 for	Ethernet, TCP/IP

Device	Manufacturer / Model	Function	Interface
		more details about configuration	
EMU PLC	Siemens S7-1500 PLC	EMU Interlocks Control (Table 16).	Ethernet, Profinet, S7
EtherCAT EMU I/O (Fieldbus)	Beckhoff	Cooling System I/O Node. See Table 17 for more details	EtherCAT
Plates Power Supply (x2)	Trek 609E-6	Power supply for EMU plates	Electrical
Motion Control Unit	Geo Brick LV IMS II 9BD8F34470008E100DL	Provides control of EMU motors	Ethernet / ASCII
Bias Power Supply	ISEG THQ 2CH 2HE 60W T2300006_2HE	Provide Bias power supply to the FC (inside the EMU)	RS-232 / ASCII

Table 14 - Control equipment of the LEBT EMU

The VME I/O controller crate of the EMU is used to perform *fast* data acquisition and measurement of the emittance. It consists of a 4U VME crate (ELMA Type 39) with the VME modules detailed in Table 15. The IPC I/O controller is used to control *slow* equipment (i.e. PLC and motion control unit).

Device	Manufacturer / Model	Function	Interface
CPU	IOxOS IFC 1210	Required to run IOCs	VME
Data acquisition board (DAQ)	D-TAQ ACQ420FMC-4-2000-16, with Breakout board (DIN rail) and prefabricated cable.	This is a FMC module installed on the CPU. It used to read emittance values from the EMU heads.	FMC
EVR Board	MRFI PMC-EVR-230	Event receiver for synchronous data acquisition	PMC

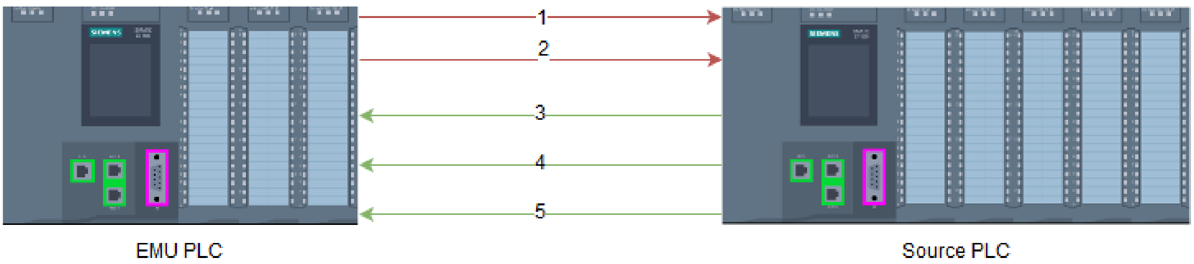
Table 15 – Control equipment of the EMU VME I/O controller

One PLC is used for (slow) Interlocks Control of the EMU. It consists of a Siemens S7-1500 family CPU with additional analogue and digital modules as detailed in Table 16.

Name	Quantity	Part number
Load current supply PM 70W, 120/230 V AC, 24 VDC, 3A	1	6EP1332-4BA00
CPU 1516-3 PN/DP	1	6ES7516-3AN01-0AB0
Digital input, DI 16x24VDC HF	2	6ES7521-1BH00-0AB0
Analog input, AI 8xU/I/RTD/TC ST	1	6ES7531-7KF00-0AB0
Digital output, DQ 16x24VDC/0.5A ST	1	6ES7522-1BH00-0AB0
Memory card, 12 MB	1	6ES7954-8LE02-0AA0
Front connector, screw-type terminal for 35mm modules, 40-pin	3	6ES7592-1AM00-0XB0

Table 16 - EMU PLC specification

By design, and as delivered from the ESS in-kind partner CEA, the EMU's PLC has some connections with the Source's PLC as shown in in Figure 20. (Note that the EMU PLC architecture for ESS Lund is still under discussion).



#	EMU PLC	Source PLC	Signal
1	DO4, CH0	DI2, CH0	MPS Status
2	DO4, CH2	DI2, CH8	EMU insrted
3	DI1, CH2	DO7, CH13	FC Inserted
4	DI1, CH1	DO7, CH14	Vacuum status
5	DI1, CH9	DO7, CH15	Vertical EMU water flow status

Figure 20 - Connection between EMU PLC and Source PLC.

The most important links are those one that allow to exchange information about the status of the EMU and the Faraday Cup (i.e. links 2, 3 in Figure 20). The FC and the EMU can share the same diagnostic tank. As consequence, it shall not be possible to operate with the EMU when the Faraday Cup is inserted into the proton beam and vice-versa.

Finally, the field bus (the EtherCAT VME I/O in figure 19), consists of the EtherCAT modules from Beckhoff listed in Table 17. These modules are intended to control the bias power supplies for the EMU plates and the embedded Faraday Cup.

Module Name	Quantity	Part number
Coupler	1	Beckhoff EK1101
AI module, 4 channels (0...10 V)	1	Beckhoff ES3164
AO module, 4 channels (0...10 V)	2	Beckhoff ES4104

Table 17 - EMU EtherCAT VME I/O (Fieldbus) specifications

6.3.4. Non-Invasive Profile Monitor

The NPM in the LEBT measures the position and the size of the beam. It is designed to be mainly a beam position system (i.e. it measures the beam centroid position in order to steer the beam) although information on beam profile and beam size is also received. Basically, the NPM consists of two cameras to measure the beam profile in horizontal and vertical axis.

It uses the residual gas luminescence monitor principle: the proton beam can excite residual gas particles, which then emit light when de-exciting. This light is imaged via an optical system to a detector with a spatial resolution. One advantage of this method is that no components have to be installed inside the vacuum system. The beam profile can be reconstructed with standard CCD/CMOS camera and commercial lenses.

The general architecture is shown in Figure 21, while the control equipment is listed in Table 18.

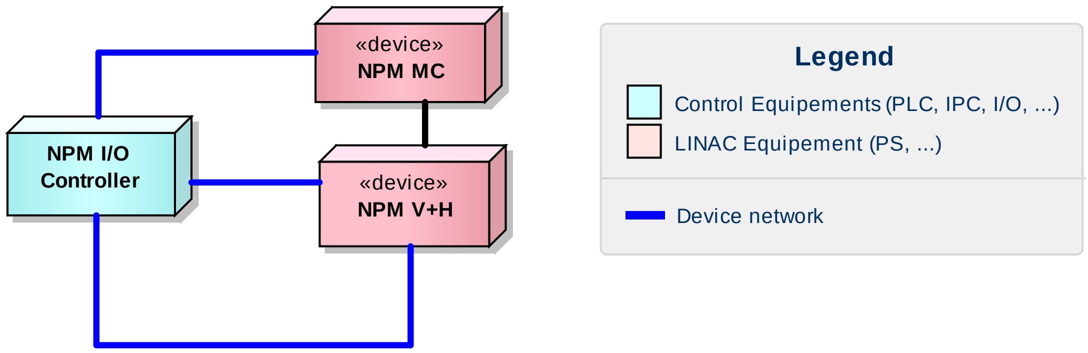


Figure 21 - NPM Control System Architecture

Device	Manufacturer / Model	Function	Interface
NPM IPC	Kontron KISS 2U Short KTQ87	EPICS I/O Controller for NPM control (cameras data readout and motion control)	Ethernet TCP/IP
Motion Control Unit	Geo Brick LV IMS II 9BD8F34470008E100DL + Plus Power Supply	Provides control of camera lenses focus distance	Ethernet ASCII
EVR Board	MRFI PCIe-EVR-300	Event receiver for synchronous data acquisition	PCIe
TTL Fanout with connecting cable	MRFI IFB-300 + 2 UNIV TTL OUT	Distribute TTL Trigger from EVR to the cameras	-
Detector (x2)	Prosilica GT 3300	Acquisition camera	TCP/IP

Table 18 - NPM Control Equipment

The original control system design consists of only <u>one</u> NPM. The final set up (in Lund) will consist of <u>two</u> identical NPMs with the same equipment as listed in table 18.

6.3.5. Doppler Shift Measurement

The Doppler Shift Measurement (DPL or DSM) is designed to measure the fraction species produced by the source, namely H+, H2+, and H3+ ions. It is based on spectral measurement of the luminescence of the residual gas excited by the particles produced by the ion source. The proportion of the different ions can be reconstructed by measuring the doppler shift with a monochromator.

The general architecture is shown in figure 22 while the control equipment is listed in table 19.

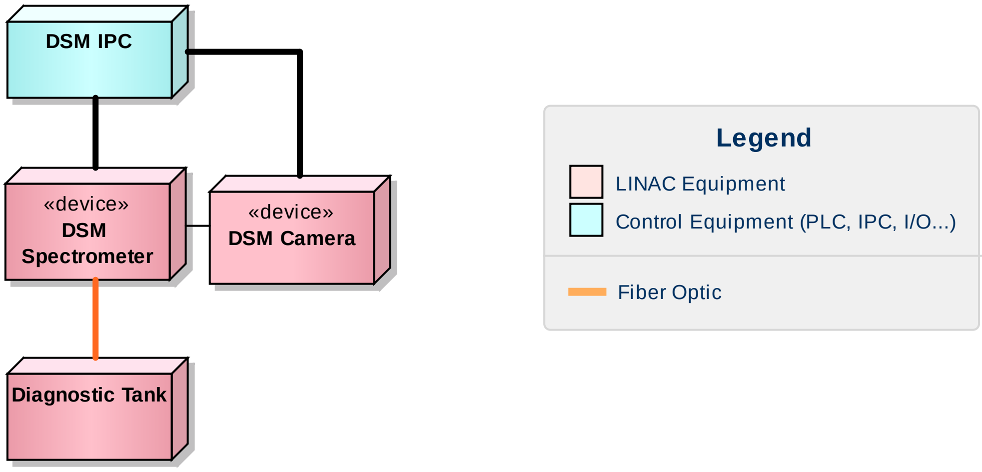


Figure 22 - DSM Control System Architecture

The DSM spectrometer (and the connected camera) is the device that actually measures the fraction spaces produced by the source using a fiber optic cable directly connected to the diagnostic tank on the beam line.

Device	Manufacturer / Model	Function	Interface
DSM IPC	Dell R330	EPICS I/O Controller for Doppler (cameras data readout and motion control)	Ethernet TCP/IP
EVR Board	MRFI PCIe-EVR-300	Event receiver for synchronous data acquisition	PCIe
TTL Fanout with connecting cable	MRFI IFB-300 + 1 UNIV TTL OUT	Distribute TTL Trigger from the EVR to spectrometer.	-
Spectrometer	Andor Shamrock 500i + Andor Newton Camera	DSM Measurement	USB

Table 19 - DSM Control Equipment

As with the FC, this DSM setup is not the final one. The final design for the DSM includes a mirror inside the beam line that needs to be controlled by a motion control unit. The setup in Catania-didn’t contain any beam line element and no motion control unit was designed for it.

6.4. LEBT Control System Software Architecture

6.4.1. LEBT SW Architecture

The control system software for the LEBT (i.e. m-epics-lebt, [4]) is based on the Experimental Physics and Industrial Control System (EPICS) framework and it consists of the following main components:

- LEBT IOC
- LEBT OPI

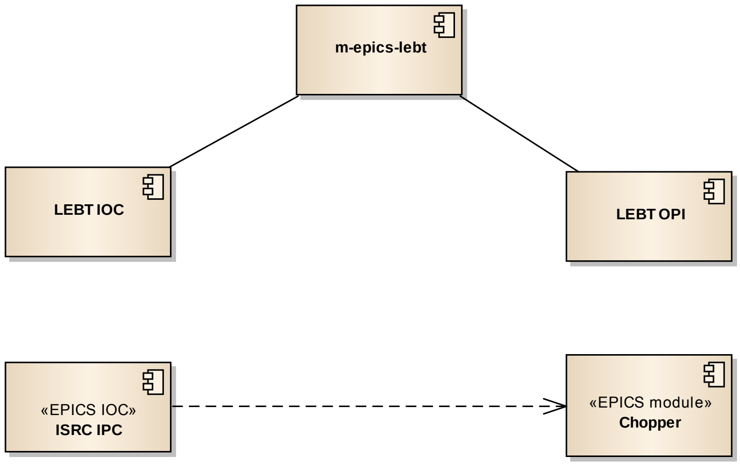


Figure 23 - LEBT Software Architecture

The LEBT IOC is a collections of different specific EPICS modules to control the solenoids, the steerers and the iris, while the chopper is controlled by the Source IPC (see 5.3.2). This is represented by the “require” relationship (see Figure 24 - LEBT component architecture). The LEBT IOC is then responsible to configure the modules required and to instantiate the proper database templates. The LEBT OPI component represents the Graphical User Interface containing the screens required to operate the source.

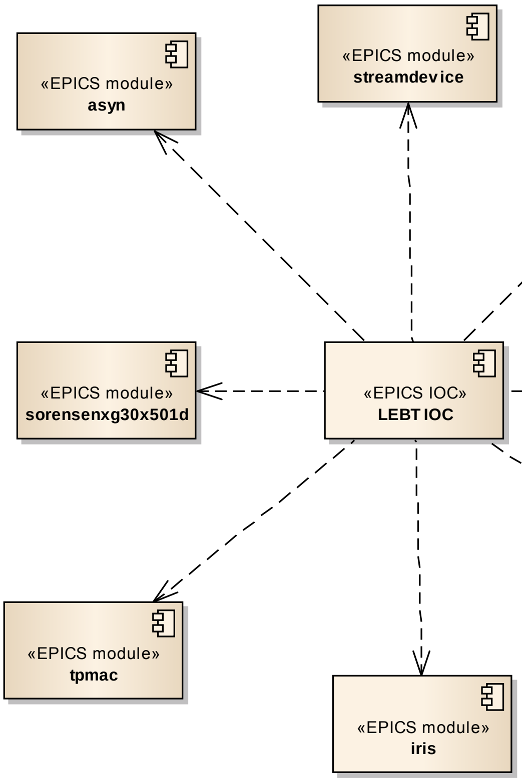


Figure 24 - LEBT component architecture

The LEBT IOC controls the following equipment:

Device	Required Module(s)
Steerer PS	sorensenxg125120
Solenoid PS	sorensensga30x501d
Iris	iris motor tpmac
Tools	asyn streamdevice autosave

Table 20 – LEBT IOC modules dependency

The asyn, streamdevice and autosave modules are general purpose EPICS modules, not specific for the LEBT and they are not further detailed.

6.4.2. LEBT Diagnostic SW

The beam diagnostic SW component devices are separated from the LEBT one and are used to control the following:

- EMU
- NPM
- DSM (Doppler)

The control SW for the FC and the BMC are instead embedded into the control SW of the ion source (see 5.3.1).

6.4.2.1. EMU SW

The EMU application (i.e. m-epics-emu) consists of two different IOCs (Figure 25). One is running on the VME crate with the aim to perform fast data acquisition and high-performance data processing (Figure 26). The other is running on the IPC (Figure 27) and it is intended for slow operations (basically for PLC and motion control).

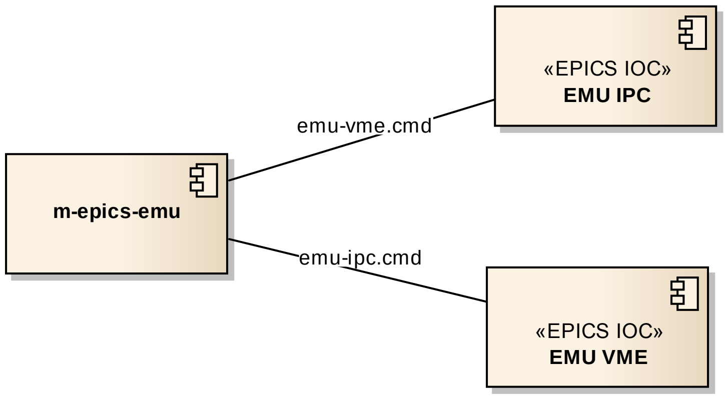


Figure 25 - EMU IOC Software Architecture

It should be considered that the motion control modules are required by both IOCs, since the VME application needs to retrieve some information about the status of the motor to control the data acquisition properly.

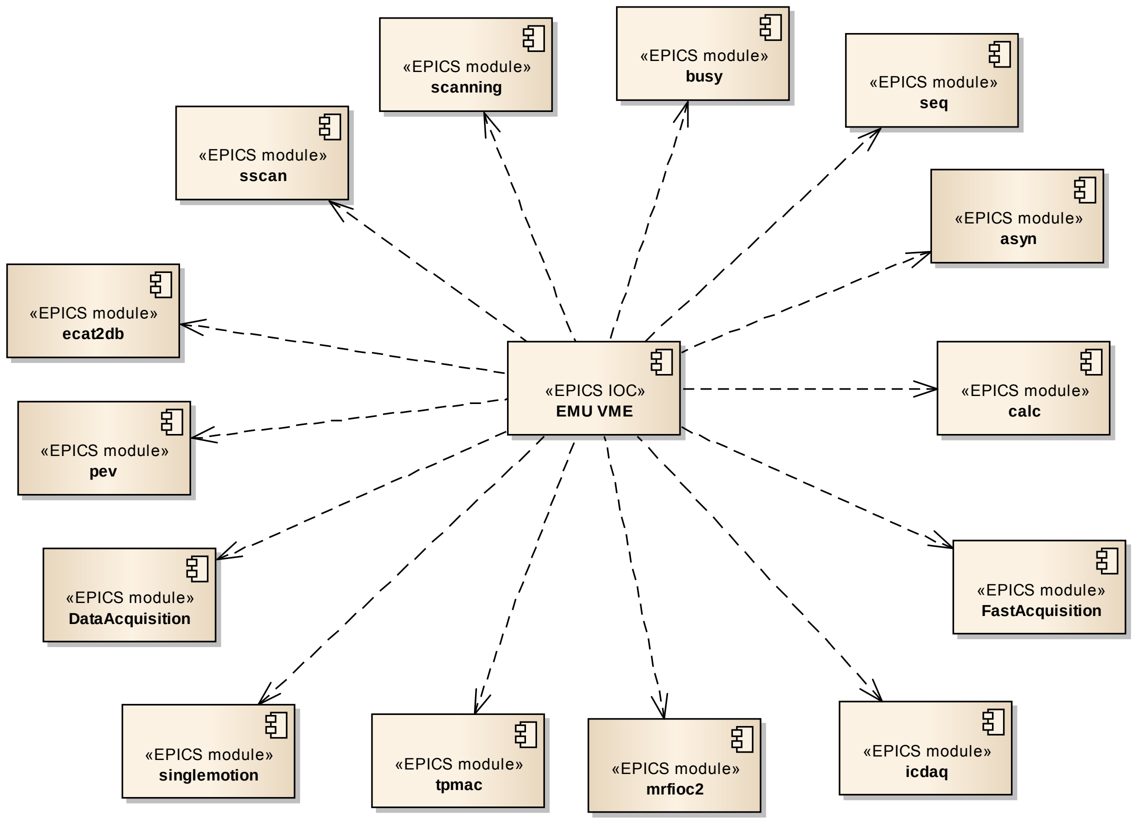


Figure 26 - EMU VME Software architecture

This EMU VME is one of the most complex IOC in the ESS accelerator. It relies on many different EPICS modules listed in Table 21.

Function	Required Module(s)
Timing synchronization	mrfioc2
Data acquisition	scanning DataAcquisition FastAcquisition ifcdaq
Motion control unit	singlemotion tpmac
General purpose	ecat2db asyn pev busy seq calc sscan

Table 21 – EMU VME modules dependency

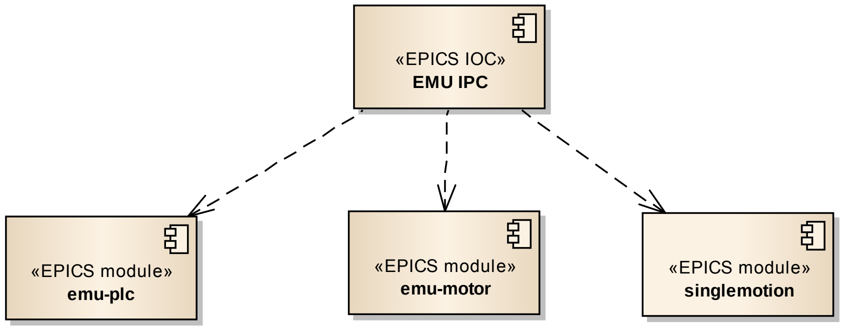


Figure 27 - EMU IPC Software architecture

The IPC control application relies on the EPICS module listed in Table 22

Function	Required Module(s)
PLC	emu-plc
Motion control	singlemotion emu-motor

Table 22 - EMU IPC modules dependency

6.4.2.2. NPM SW

The SW architecture of the NPM is shown in Figure 28.

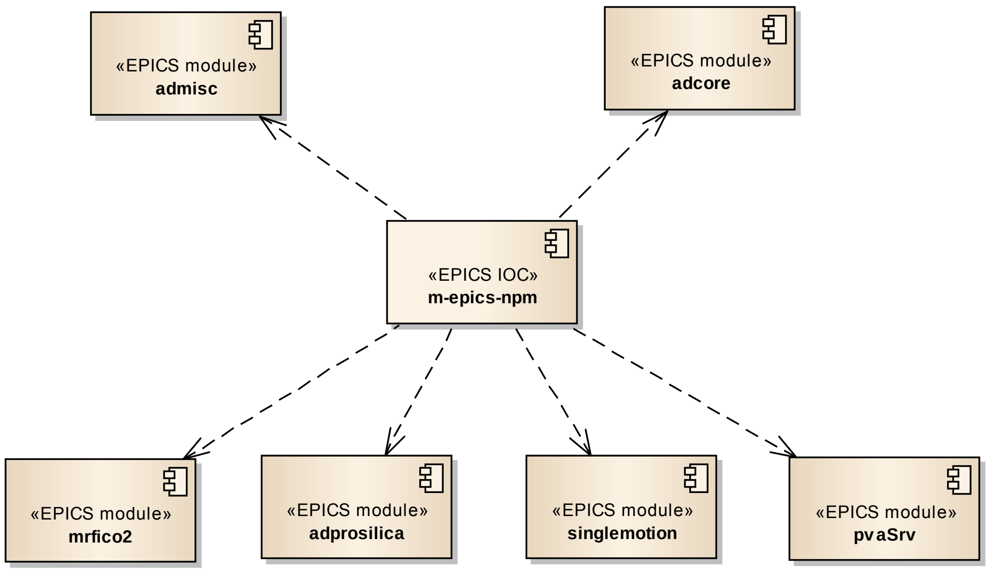


Figure 28 - NPM Software Architecture

The NPM IOC has a dependency on the Area Detector Core module (i.e. adcore) and on the Area Detector Miscellaneous (i.e. admisc). It relies on the EPICS modules listed in Table 23 to control the NPM

Device	Required Module(s)
EVR	mrfioc2
Acquisition camera	adprosilica
Motion control unit	singlemotion
Area Detector	adcore admisc
Tools	pvaSrv

Table 23 - NPM EPICS modules dependency

6.4.2.3. DSM SW

The SW architecture for the DSM is shown in Figure 29.

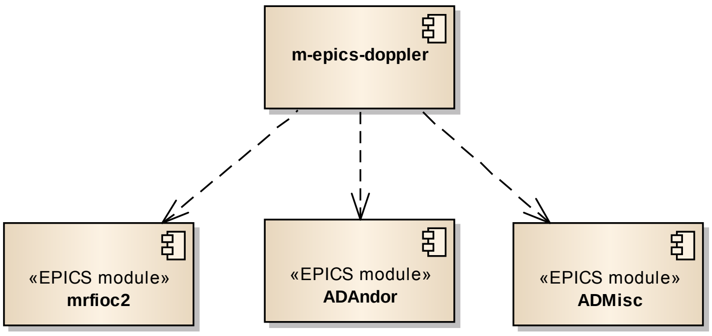


Figure 29 - DSM Software Architecture

The DSM IOC has a dependency on the timing module (i.e. mrfioc2) and on the Area Detector Andor plug-in (i.e. ADAndor providing support for the camera and the spectrometer). It also relies on the Area Detector Miscellaneous (i.e. ADMisc) for miscellaneous Area Detector functionalities.

Device	Required Module(s)
EVR	mrfioc2
Spectrometer	adandor
Area Detector	admisc

Table 24 - DSM EPICS modules dependency

6.4.3. LEBT OPI component

The last main component of the LEBT Software architecture is the operator interface (OPI). This component contains the set of screens for the operator interface, allowing to operate with the LEBT. It is specifically designed to provide both a general overview and a detailed view for each system / subsystem. It contains also a dedicated page to identify the different origins of interlocks, giving the possibility to resolve / reset them when required.

Control System Studio (CSS) has been selected as standard to design the Graphical User Interface.

7. GLOSSARY

Term	Definition
AI	Analogue Input
AO	Analogue Output
ATU	Automatic Tuning Unit
BCM	Beam Current Monitor
CAD	Computer Aided Design
CS	Control System
CA	Channel Access
CSS	Control System Studio
D-TAQ	A manufacturer of data acquisition boards
DAQ	Data AcQuisition board
DI	Digital Input
DO	Digital Output
DSM	Doppler Shift Measurement
EMU	Emittance Measuring Unit
EPICS	Experimental Physics and Industrial Control System
EVG	EVent Generator
EVR	EVent Receiver
FC	Faraday Cup
FMC	FPGA Mezzanine Card
FPGA	Field-Programmable Gate Array
GUI	Graphical User Interface
HW	Hardware
I/O	Input / Output
ICS	Integrated Control System
IOC	Input Output Controller
IPC	Industrial PC

Term	Definition
ISRC	Ion Source
LINAC	LINear ACcelerator
LEBT	Low Energy Beam Transport
MC	Motion Control
MFC	Mass Flow Controller
MPS	Machine Protection System
NFS	Network File System
NPM	Non-invasive beam Profiler Measurement
OPI	OPerator Interface
P2P	Point to point
PCI	Peripheral Component Interconnect
PCIe	PCI Express
PMC	PCI Mezzanine Card
PS	Power Supply
PSS	Personnel Safety System
PV	Process Variable
RF	Radio Frequency
RIO	Remote I/O
RTD	Resistance Temperature Detector
S7	The name of a Siemens product
SCPI	Standard Commands for Programmable Instruments
SW	Software
TCP	Transport Control Protocol
TTL	Transistor-Transistor Logic

8. REFERENCES

[1] ICS Handbook (ESS-0067637)
[2] ISRC & LEBT User Manual (ESS-0123103)
[3] Source PLC I/O List (ESS-0131500)
[4] Source EPICS module (m-epics-source)
[5] LEBT EPICS module (m-epics-lebt)
[6] EMU EPICS module (m-epics-emu)
[7] Doppler EPICS module (m-epics-doppler)
[8] NPM EPICS module (m-epics-npm)

[9] I/O List EMU (ESS-0131502)

ANNEX A TIMING

For latest version and a detailed description of the Timing System architecture, see the ICS Handbook [1].

The ESS facility operates with a 14 Hz cycle. In normal operation (up to) 2.86 milliseconds long proton beam pulses are generated, accelerated and steered to the target station at a frequency of 14 Hz. Many of the facility components (and thus accelerator, target and neutron instrument) have to work synchronously with this operating cycle. The ESS thus has a timing system designed to broadcast precise timestamps, synchronous triggers and data (e.g. beam modes) to a large number of receivers with a deterministic latency.

More specifically, the timing system provides the following services:

- Trigger signals to subsystems in the facility, (e.g. the RF systems appropriately for beam acceleration).
- Clock signals that are synchronous and in phase over the whole facility.
- Synchronous transmission of beam-related parameters to all relevant controllers in the facility. These parameters can include things like the beam destination, expected beam mode (beam current, pulse length, repetition rate) and also information from measurements of the past pulse.
- Timestamps (“wall clock time”) that are synchronised all over the facility and can be attached to the data collected by the EPICS software.
- Repeated distribution of sequences of events that happen in one beam cycle.

The current timing system implemented for the ISRC and LEBT is not the final one that will be deployed for the ESS site. It is a “test stand” implementation required to operate the machine and doesn’t deliver all the final beam modes. It is thus intended that this will not the final configuration and that its design is going to be reviewed. The architecture of this custom timing infrastructure is shown in Figure 30.

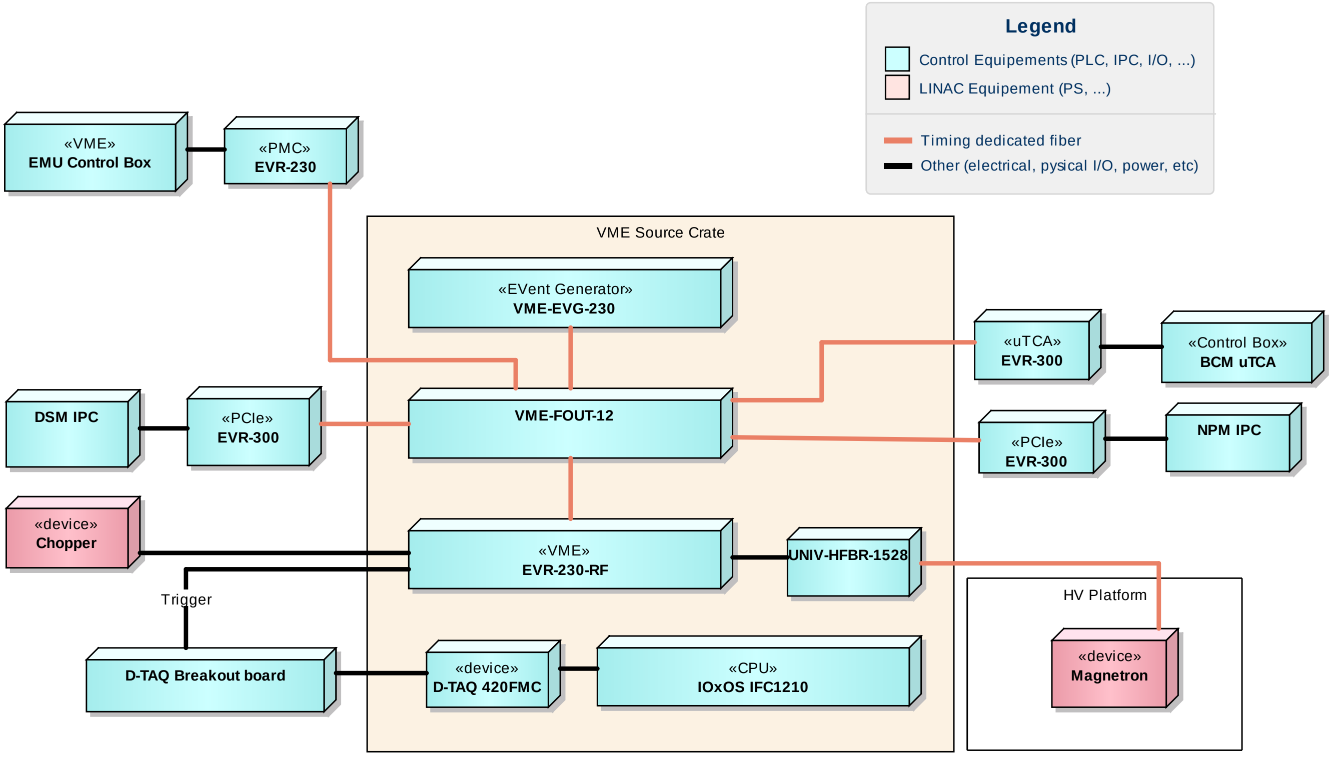


Figure 30 - ISRC and LEBT Timing System

At the root of the timing system is the Event Generator (EVG) that converts timing events and signals to an optical signal. This signal is distributed to different Event Receivers (EVRs) through an optical fan-out units The EVRs decode the optical signal and produce hardware and software output signals based on the timing events.

The configuration of the timing system components is done using EPICS. With EPICS, the EVG is programmed to deliver a pulse of a certain width at a given rate (e.g. 14 Hz) and the EVR can be programmed to respond to event codes in several ways (trigger outputs, software actions) and to handle the data that is distributed through the timing system.

The EVG used for the ISRC and LEBT is based on the VME architecture (i.e. VME-EVG-230) and it is controlled by the Source VME IOC component (5.3.1). Each system that need to receive timing events and to perform synchronous operations with the main pulse are then equipped with and EVR. Three types of EVR are used:

- a PCIe board (i.e. EVR-300 DC) used for Industrial PCs (i.e. Doppler and NPM);
- a VME PMC card for VME based systems (i.e. EVR-230-RF for the source and the LEBT EMU);
- a µTCA compatible device (i.e. EVR-300) for µTCA.4 based system (i.e. the BCM).

To be considered that this still is a temporary “test stand” setup since, in the final one, only µTCA and PCIe board will be used.

The EVR installed on the source VME is used to distribute timing trigger to other devices as follow (see Figure 31):

- One TTL output is used to trigger synchronous data acquisition with the D-Tacq FMC board (used for the FC and the BMC) connected to a breakout board.
- A second TTL output is used for sent the trigger to the LEBT Chopper.
- A third output is the trigger for the Magnetron on the HV platform. Differently from the previous, this is sent through an optical fiber link using the additional output module installed on board of the EVR (i.e. the UNIV-HFBR-1528);

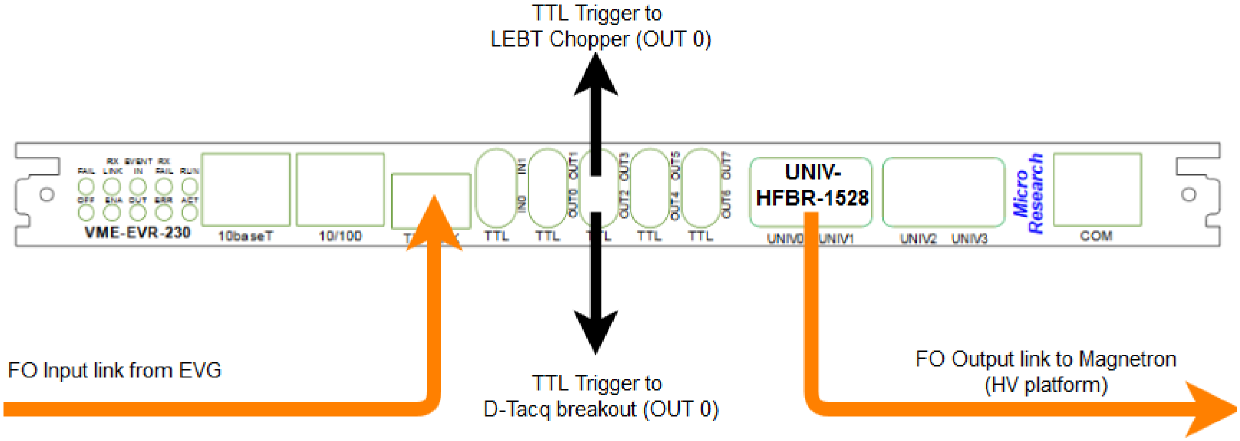


Figure 31 - Source EVR Trigger distribution

ANNEX B I/O LIST

This Annex contains a simplified version of the I/O signal list for the ISRC & LEBT. . For more details refers to [3] and [9] that contain always the most updated information.

B.1 GND PLC

I/O Type	Electrical Type	Slot	Channel	Section	Comment
DI	24V	2	0	ISRC	Machine Protection System Status
DI	24V		1	ISRC	LNS Safety System Status
DI	24V		2	ISRC	Access Status key
DI	24V		3	LEBT	Faraday Cup In
DI	24V		4	LEBT	Faraday Cup Out
DI	24V		5	LEBT	Faraday Cup Cooling Water Flow Status
DI	24V		6	ISRC	Chopper Power System Status
DI	24V		7	ISRC	Chopper Chopping Voltage Alarm
DI	24V		8	LEBT	EMU Inserted Status
DI	24V		9	LEBT	Solenoid 1 Temperature Status
DI	24V		10	LEBT	Solenoid 2 Temperature Status
DI	24V		11	LEBT	Solenoid 1 Cooling Water Flow Status
DI	24V		12	LEBT	Solenoid 2 Cooling Water Flow Status
DI	24V		13	LEBT	Beam Stop Cooling Water Flow Status
DI	24V		14	LEBT	Collimator Cooling Water Flow Status
DI	24V		15	ISRC	Electrodes Cooling Water Flow Status
DI	24V	3	0	ISRC	Chopper Cooling Water Flow Status
DI	24V		1	LEBT	IRIS Cooling Water Flow Status
DI	24V		2	LEBT	EMU Horizontal Plane Cooling Water Flow Status
DI	24V		3	LEBT	EMU Vertical Plane Cooling Water Flow Status
DI	24V		4	LEBT	Vacuum Status
DI	24V		5	LEBT	Horizontal Steerer 1 Power Supply Polarity
DI	24V		6	LEBT	Horizontal Steerer 2 Power Supply Polarity
DI	24V		7	LEBT	Vertical Steerer 1 Power Supply Polarity
DI	24V		8	LEBT	Vertical Steerer 2 Power Supply Polarity
DI	24V		9		DI Spare
DI	24V		10		DI Spare
DI	24V		11		DI Spare
DI	24V		12		DI Spare
DI	24V		13		DI Spare
DI	24V		14		DI Spare
DI	24V		15		DI Spare
AI	4-20 mA	4	0	ISRC	GND Cooling Water Inlet Pressure
AI	4-20 mA		1	ISRC	GND Cooling Water Outlet Pressure
AI	4-20 mA		2	ISRC	GND Cooling Water Inlet Temperature

AI	0-10V		3	LEBT	Horizontal Steerer 1 Current
AI	0-10V		4	LEBT	Horizontal Steerer 2 Current
AI	0-10V		5	LEBT	Vertical Steerer 1 Current
AI	0-10V		6	LEBT	Vertical Steerer 2 Current
AI	0-10V		7	LEBT	Solenoid 1 Current
AI	0-10V	5	0	LEBT	Solenoid 2 Current
AI	4-20 mA/0-10V?		1		AI Spare
AI	4-20 mA/0-10V?		2		AI Spare
AI	4-20 mA/0-10V?		3		AI Spare
AI	4-20 mA/0-10V?		4		AI Spare
AI	4-20 mA/0-10V?		5		AI Spare
AI	4-20 mA/0-10V?		6		AI Spare
AI	4-20 mA/0-10V?		7		AI Spare
DO	24V	6	0	ISRC	Source Status to Machine Protection System
DO	24V		1		DO Spare
DO	24V		2	ISRC	High Voltage Power Supply Interlock Command
DO	24V		3	LEBT	Solenoid 1 Power Supply Enable Command
DO	24V		4	LEBT	Solenoid 2 Power Supply Enable Command
DO	24V		5	LEBT	Horizontal Steerer 1 Power Supply Interlock Command
DO	24V		6	LEBT	Horizontal Steerer 2 Power Supply Interlock Command
DO	24V		7	LEBT	Vertical Steerer 1 Power Supply Interlock Command
DO	24V		8	LEBT	Vertical Steerer 2 Power Supply Interlock Command
DO	24V		9	LEBT	Faraday Cup Insert Command
DO	24V		10	ISRC	Chopper High Voltage Enable Command
DO	24V		11		DO Spare
DO	24V		12	ISRC	Faraday Cup NOT Inserted Status
DO	24V		13	ISRC	Source Status to LNS Safety System
DO	24V		14		DO Spare
DO	24V		15		DO Spare
DO	24V	7	0	LEBT	Horizontal Steerer 1 Power Supply Positive Polarity Command
DO	24V		1	LEBT	Horizontal Steerer 2 Power Supply Positive Polarity Command
DO	24V		2	LEBT	Vertical Steerer 1 Power Supply Positive Polarity Command

DO	24V		3	LEBT	Vertical Steerer 2 Power Supply Positive Polarity Command
DO	24V		4	LEBT	Horizontal Steerer 1 Power Supply Negative Polarity Command
DO	24V		5	LEBT	Horizontal Steerer 2 Power Supply Negative Polarity Command
DO	24V		6	LEBT	Vertical Steerer 1 Power Supply Negative Polarity Command
DO	24V		7	LEBT	Vertical Steerer 2 Power Supply Negative Polarity Command
DO	24V		8		DO Spare
DO	24V		9		DO Spare
DO	24V		10		DO Spare
DO	24V		11		DO Spare
DO	24V		12		DO Spare
DO	24V		13	LNS	Copy of source status (FC inserted) to EMU
DO	24V		14	LNS	Copy of vacuum status to EMU
DO	24V		15	LEBT	Vertical EMU water flow switch copy

Table 25 - GND PLC I/O list

B.2 HV PLC (Remote I/O)

I/O Type	Electrical Type	Slot	Channel	Section	Comment
DI	24V	2	0	ISRC	Magnetron MW Power Status
DI	24V		1	ISRC	Coil 1 Cooling Water Flow Status
DI	24V		2	ISRC	Coil 2 Cooling Water Flow Status
DI	24V		3	ISRC	Coil 3 Cooling Water Flow Status
DI	24V		4	ISRC	Matching Transformer Cooling Water Flow Status
DI	24V		5	ISRC	Plasma Chamber Cooling Water Flow Status
DI	24V		6	ISRC	Vacuum Status (H2 Injection)
DI	24V		7	ISRC	H2 Isolation Valve Open Feedback
DI	24V		8	ISRC	H2 Isolation Valve Closed Feedback
DI	24V		9	ISRC	Coil 1 Power Supply Status
DI	24V		10	ISRC	Coil 2 Power Supply Status
DI	24V		11	ISRC	Coil 3 Power Supply Status
DI	24V		12	ISRC	Coil 1 Temperature Status
DI	24V		13	ISRC	Coil 2 Temperature Status
DI	24V		14	ISRC	Coil 3 Temperature Status
DI	24V		15	ISRC	Access Status doors
DI	24V	3	0	ISRC	Neutral To Ground Resistor Switch Status
DI	24V		1		DI Spare
DI	24V		2		DI Spare
DI	24V		3		DI Spare
DI	24V		4		DI Spare
DI	24V		5		DI Spare
DI	24V		6		DI Spare
DI	24V		7		DI Spare

DI	24V		8		DI Spare
DI	24V		9		DI Spare
DI	24V		10		DI Spare
DI	24V		11		DI Spare
DI	24V		12		DI Spare
DI	24V		13		DI Spare
DI	24V		14		DI Spare
DI	24V		15		DI Spare
AI	0-10V	4	0	ISRC	Vacuum Level (H2 Injection)
AI	4-20 mA		1	ISRC	HV Cooling Water Inlet Pressure
AI	4-20 mA		2	ISRC	HV Cooling Water Outlet Pressure
AI	4-20 mA		3	ISRC	HV Cooling Water Inlet Temperature
AI	4-20 mA		4	ISRC	HV Cooling Water Outlet Temperature
AI	4-20 mA/0-10V?		5		AI Spare
AI	4-20 mA/0-10V?		6		AI Spare
AI	4-20 mA/0-10V?		7		AI Spare
DO	24V	5	0	ISRC	Magnetron Enable Command
DO	24V		1	ISRC	Coil 1 Power Supply Enable Command
DO	24V		2	ISRC	Coil 2 Power Supply Enable Command
DO	24V		3	ISRC	Coil 3 Power Supply Enable Command
DO	24V		4	ISRC	H2 Isolation Valve Open Command
DO	24V		5		DO Spare
DO	24V		6		DO Spare
DO	24V		7		DO Spare
DO	24V		8		DO Spare
DO	24V		9		DO Spare
DO	24V		10		DO Spare
DO	24V		11		DO Spare
DO	24V		12		DO Spare
DO	24V		13		DO Spare
DO	24V		14		DO Spare
DO	24V		15		DO Spare

Table 26 - HV Remote I/O list

B.3 EMU PLC

I/O Type	Electrical Type	Card number	Channel number	Section	Comment
DI	24V	1	0	INFN	Machine Protection System Status
DI	24V		1	INFN	Vaccum status
DI	24V		2	INFN	Source status, faraday cup inserted
DI	24V		3	INFN	Horizontal emittance-meter, high end of run
DI	24V		4	INFN	Horizontal emittance-meter, low end of run
DI	24V		5	INFN	Vertical emittance-meter, high end of run
DI	24V		6	INFN	Vertical emittance-meter, low end of run
DI	24V		7	INFN	Horizontal emittance-meter, water flow detection sensor n°1
DI	24V		8	INFN	Horizontal emittance-meter, water flow detection sensor n°2
DI	24V		9	INFN	Vertical emittance-meter, water flow detection sensor n°1
DI	24V		10	INFN	Vertical emittance-meter, water flow detection sensor n°2
DI	24V		11	INFN	Seesaw (bascule), power status (0 si EMU H et 1 si EMU V)
DI	24V		12	INFN	Water flow switch n°1
DI	24V		13	INFN	Water flow switch n°2
DI	24V		14	INFN	Horizontal beam stop temperature interlock
DI	24V		15	INFN	Horizontal slit temperature interlock
DI	24V	2	0	INFN	Vertical beam stop temperature interlock
DI	24V		1	INFN	Vertical slit temperature interlock
DI	24V		2	INFN	Horizontal emittance-meter, parking position
DI	24V		3	INFN	Vertical emittance-meter, parking position
DI	24V		4	INFN	DI Spare
DI	24V		5	INFN	DI Spare
DI	24V		6	INFN	DI Spare
DI	24V		7	INFN	DI Spare
DI	24V		8	INFN	DI Spare
DI	24V		9	INFN	DI Spare
DI	24V		10	INFN	DI Spare
DI	24V		11	INFN	DI Spare
DI	24V		12	INFN	DI Spare
DI	24V		13	INFN	DI Spare
DI	24V		14	INFN	DI Spare
DI	24V		15	INFN	DI Spare
AI	4-20 mA	3	0 1	INFN	Horizontal Beam Stop, temperature transmitter
AI	4-20 mA		2 3	INFN	Horizontal Slit, temperature transmitter
AI	4-20 mA		4 5	INFN	Vertical Beam Stop, temperature transmitter
AI	4-20 mA		6	INFN	Vertical Slit, temperature transmitter

			7		
AI	0-10V/4-20mA		8 9	INFN	AI Spare
AI	0-10V/4-20mA		10 11	INFN	AI Spare
AI	0-10V/4-20mA		12 13	INFN	AI Spare
AI	0-10V/4-20mA		14 15	INFN	AI Spare
DO	24V	4	0	INFN	Machine Protection System Command
DO	24V		1	INFN	External system interlock, EMU status
DO	24V		2	INFN	EMU Status to source, head inserted
DO	24V		3	INFN	Geobrick interlock, moving autorization
DO	24V		4	INFN	Amplifier n°1 interlock, working autorization
DO	24V		5	INFN	Amplifier n°2 interlock, working autorization
DO	24V		6	INFN	Seesaw (bascule) command. 0 = Vertical, 1 = Horizontal
DO	24V		7	INFN	Bias power supply n°1 interlock, working autorization
DO	24V		8	INFN	Bias power supply n°2 interlock, working autorization
DO	24V		9	INFN	Horizontal emittance-meter, brake command
DO	24V		10	INFN	Vertical emittance-meter, brake command
DO	24V		11	INFN	DO Spare
DO	24V		12	INFN	DO Spare
DO	24V		13	INFN	DO Spare
DO	24V		14	INFN	DO Spare
DO	24V		15	INFN	DO Spare

Table 27 - EMU I/O list

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	William Ledda	18/12/2017
2	New version including design of LEBT	William Ledda	09/05/2018