

Beam Instrumentation Department (LOBI)	Document Type:	Document Name: F-DS-BD-13e_ElecProfile_SEM_T	Date: 22.06.2017
	Detailed Specification of SEM-Grid for HEBT	EDMS Number: 1179710	Page1 of 32

Document Title:	Detailed Specification for 'Secondary Electron Emission Grid (SEM-Grid)' for HEBT F-DS-BD-13e_ElecProfile_SEM_T
Description:	This document contains the Detailed Specification of the beam diagnostic component 'Secondary Electron Emission Grid (SEM-Grid)' for the High Energy Beam Transport (HEBT) lines. This document covers all items of psp-code 2.3.6.5.1.
Division/ Organization:	LINAC & Operations Beam Instrumentation (LOBI)
Field of application:	Project FAIR@GSI

Document History:

Version	Prepared by:	Checked, Date	Released, Date	Comment
V 0.1	M. Witthaus	2010-12-03		Draft version
V 1.0	S. Löchner, J. Frühauf, B. Walasek-Höhne	2013-04-15		New electronics included
V 1.1	C. Andre	2015-11-20		Spec for HEBT only
V1.2	C. Dorn, M. Witthaus, S. Löchner, B. Walasek-Höhne	2015-11-30		Ready for 1 st Approval
V2.0	M. Witthaus, T. Hoffmann, B. Walasek-Höhne	2016-03-03		2 nd Approval
V2.1	C. Andre	2017-06-22		3 rd Approval Changes by A. Reiter

Table of Contents

1.	Purpose.....	4
2.	Scope.....	4
3.	Responsibilities	5
4.	General Functionalities.....	6
4.1.	Overview	6
4.1.1.	Measurand / Quantity to be measured	6
4.1.2.	Physical Measurement Principle	6
4.1.3.	Measurement Challenges	6
4.2.	Foreseen Component Setup	7
4.2.1.	System Schematic	7
4.2.2.	Constituents of the BD Component	7
4.3.	Basic Component Parameters.....	8
4.4.	Installation Locations and Special Requirements	8
5.	Mechanical Setup.....	9
5.1.	Overview	9
5.1.1.	Mechanic Constituents of the BD Component.....	10
5.2.	Vacuum Parts.....	12
5.3.	Mechanical Drive/ Feed-through.....	12
5.4.	Exemplary Realisation at GSI.....	13
6.	Electronics and Data Acquisition	15
6.1.	Overview	15
6.1.1.	Electronic Constituents of the BD Component.....	19
6.2.	Beam Line Electronics.....	21
6.3.	Components in Electronic Rooms	21
6.4.	Cabling.....	22
6.5.	Exemplary Realisation at GSI.....	22
7.	Timing Requirements	23
8.	Data Acquisition Software	24
8.1.	General Requirements	24
8.2.	General Functionality	25
8.3.	Operational Modes	25
8.4.	Required I/O settings.....	25
8.5.	Required Beam Information.....	26
8.6.	Online Display and Control.....	26
8.7.	Data for Logging and Offline Analysis and Archiving	26
8.8.	Special Issues and Boundary Conditions	26
9.	Related Subsystems	27
9.1.	Pneumatic Drive.....	27
9.2.	Cleaning-Voltage Supply	27
10.	Quality Assurance, Tests, and Acceptance	27
11.	Scope of Work and Delivery	27
11.1.	Scope of Work.....	27
11.2.	Scope of Delivery	28
12.	Technical Parameter List.....	29
13.	Open Issues / Questions	30
I.	Attached Documents.....	31
II.	Related Documentation.....	31
III.	Abbreviations	32

List of Tables

Table 1: Basic System Parameters for HEBT	8
Table 2: Basic electronic parameters (POLAND, status Q2/2013).....	19
Table 3: Minimum measurement duration (t) to monitor a current (I) in the most sensitive range of the CFC (range of 10 μ A is equal Q_{min} of 250 fC per pulse).....	21
Table 4: Time resolution dependency on cable length.....	21
Table 5: Basic timing requirements.....	23
Table 6: Technical parameter list for HEBT	29

List of Figures

Figure 1: Functional schema of SEM-Grids.	7
Figure 2: Prototype of vacuum chamber and mechanics for HEBT SEM-Grid.....	9
Figure 3: Prototype of HEBT SEM-Grid mechanical setup.	10
Figure 4: Prototype of pneumatic actuator for HEBT SEM-Grid.....	11
Figure 5: Prototype of SEM-Grid Detector. Front view (left) and back view (right).	12
Figure 6: SEM-Grid mounted on linear actuator.....	13
Figure 7: SEM-Grid with cable feed-throughs for signals from the detector.....	13
Figure 8: The 19" POLAND unit. On the left side 4 analogue frontend boards with 8 analogue channels are located. In the middle part the logic unit is placed. A motherboard connects all cards.	15
Figure 9: Basic schematics of SEM-Grid electronics. The distance between SEM-Grid and CFC-input should be as short as possible.....	16
Figure 10: Measured SEM-Grid profile of 300 MeV/u kinetic energy Ni beam at GSI High Energy Beam Transport Lines (HEST), scaled to 10^8 incident particles.	17
Figure 11: Picture of a single APFEL ASIC. Up to 16 (24) ASICs are used for the APFEL add-on system, mounted on a common motherboard.	17
Figure 12: Signal path schematic of the combined POLAND and APFEL add-on system. The signals from a SEM-Grid are splitted in front of the APFEL. In case of low current and fast signals readout the sensitive path via APFEL is used, for medium and high current as well as long beam pulses the POLAND readout system is used. Both data are received via the same PC system.....	18
Figure 13: Beam profile measurements of a 5.9 MeV/u Au ion beam at UNILAC; beam current was 240 nA and pulse length 200 μ s.....	18
Figure 14: Basic scheme of existing GSI realisation.	23

1. Purpose

The purpose of this document is to specify the technical requirements of the Beam Diagnostic (BD) component Secondary Electron eMission Grid (SEM-Grid) for High Energy Beam Transfer lines (HEBT) [2] of FAIR [1]. It is the most detailed document in the hierarchy of beam diagnostic documentation to specify all rules and information for the planned technical realization of this system.

The Detailed Specification serves as an entry point for third parties to get an overview of the required functionalities of a beam diagnostic component, to evaluate the scope of the instrument and to learn about the achievements reached with existing realisations at GSI.

Whenever regulations and requirements are specified in the General Specifications [3], Technical Guidelines or Common Specifications for Beam Diagnostics [4], they are only referenced in the present document. The related documents are listed in Appendix II.

No legal or contractual conditions are treated in this document. All related information is given in the General Specifications for FAIR [3].

Appendix III contains a list of abbreviations used in this document.

2. Scope

The Secondary Electron eMission Grid (SEM-Grid) system for profile measurement described here is intended for usage in the High Energy Beam Transport (HEBT) beam of FAIR.

Throughout the FAIR project individual technical components are unambiguously identified by their unique PSP code (Project Structure Plan). Moreover the sub-structure of beam diagnostic equipment is also reflected by detailed PSP codes for BI sub-components.

The present document covers the following PSP codes:

PSP	BD Component	FAIR Section
2.3.6.5.1	Secondary Electron Emission Grid	HEBT
2.3.6.5.1.1	Detector	HEBT
2.3.6.5.1.2	Vacuum Chamber	HEBT
2.3.6.5.1.3.0	Mechanics others	HEBT
2.3.6.5.1.3.1	Pressurized air drive	HEBT
2.3.6.5.1.4	Long Cables	HEBT
2.3.6.5.1.5.2	Pressurized air control	HEBT
2.3.6.5.1.6	Data Acquisition (per channel)	HEBT

Civil construction and building issues are specifically **not** covered in the present document.

3. Responsibilities

The responsibilities with respect to changes and modifications of the present document are entirely in the hands of the Beam Instrumentation Department (LOBI) of the GSI Helmholtz Center for Heavy Ion Research GmbH (GSI) Darmstadt.

4. General Functionalities

4.1. Overview

For fast extracted beams in the High Energy Beam Transfer (HEBT) lines, the transverse beam profile will be measured using well established Secondary Electron eMission Grids (SEM-Grids).

4.1.1. Measurand / Quantity to be measured

The primary measurand is the transverse beam profile measured by the instrument during the passage of the entire beam or of a fraction thereof.

The beam parameters related to the measurement system are:

- transversal beam position
- transversal beam profile

4.1.2. Physical Measurement Principle

A SEM-Grid detector consists of wire arrays in the horizontal (x) and vertical (y) planes. For the typical GSI realisations the distance between the x-plane and y-plane is 1 – 2 mm and the pitch of the wires is usually 1 to 1.5 mm, depending on the desired spatial resolution and expected beam size.

If ions interact with the wire material, secondary electrons are emitted from the wire surface. It results in an electric current flow back onto the wire. The wire currents are simultaneously measured and together represent the beam profile.

4.1.3. Measurement Challenges

SEM-Grid is an intercepting method to observe the transversal beam position and profile. SEM-Grid allows online monitoring of fast extracted ion beams.

For low energy beams like at UNILAC, thermal heating or thermal electron emission can lead to profile distortions and even wire destruction. One solution to prevent this is to limit either the beam current or pulse length.

The usage of low noise components is crucial for the electronics circuitry. The cables between amplifier stages and the amplifier circuits have to be characterised by high quality and low noise.

The amplifiers have to have a low offset and low temperature drift. A constant behaviour of the different input channels (for each wire of the SEM-Grid) is required.

4.2. Foreseen Component Setup

The diagnostic component as specified in the present document is the product of on-going R&D work within GSI Beam Instrumentation (LOBI) and Experiment Electronics (RBEE) departments. It is important to note that minor changes of the parameters given here might become necessary during the course of project realisation. Any contributor shall account for the fact that limited alterations of the technical realisation as described here will be communicated by GSI Beam Instrumentation department (see section 3) as soon as the modification is approved and agreed upon by the responsible persons at GSI and FAIR.

The intent of the present specification is to give a coherent overview of the present planning for the BD component. Technical aspects and parameters, e.g. in sections 4.3 and 12, which are still under discussion are clearly marked as being preliminary throughout the document and the reader is requested to pay special attention to the list of open issues (see section 13).

4.2.1. System Schematic

For beam profile measurements, the well-established Secondary Electron eMission Grids (SEM-Grids) will be used. The principle of operation is shown in Figure 1. SEM-Grid detectors, mechanics, electronics and DAQ are in-house development in cooperation between GSI LOBI and RBEE Departments and are frequently used at GSI. More information about the detector mechanics can be found in section 5. Details about the currently used electronics are described in section 6.5.

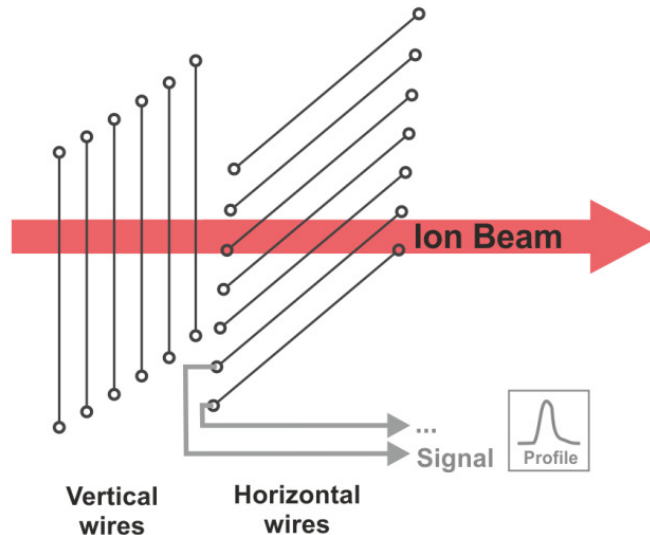


Figure 1: Functional schema of SEM-Grids.

4.2.2. Constituents of the BD Component

The BD component SEM-Grid consists of the following parts:

- vacuum chamber with flange to be consider separately
- mechanical feed-through for pneumatic drive

- pneumatic drive with control unit
- detector with 2×64 wires or ribbons with 1 – 1.5 mm pitch
- holder for detector with bellow
- POLAND electronics and extended electronics for low intensity beams
- pulse stretcher for fast extracted beams
- data acquisition system
- device controller with digital I/O
- internal cabling between SEM-Grid and vacuum signal feed-through, and connection to clearing electrodes
- cable feed-throughs for wire signals and eventually clearing electrodes
- power supply
- power supply for clearing electrode
- short cables
- long cables

4.3. Basic Component Parameters

Table 1: Basic System Parameters for HEBT

Number of elements	Module 0 – 6: 74 Module 0 – 3: 51	
Detection width (standard)	mm	64 – 96
Number of wires/ribbons		2×64
Wire/ribbon pitch	mm	1 – 1.5
Typical number of particles		$10^5 - 10^{11}$
Min./typical beam pulse length	ns	50/ 100
Voltage for cleaning electrode*	V	50
Repetition rate	Hz	5
Simultaneous display of measured profiles		Min. 5

* for SEM-Grid equipped with cleaning electrodes

4.4. Installation Locations and Special Requirements

The present document covers the parameters for the BD component SEM-Grid foreseen for installations in the FAIR HEBT lines.

The technical parameters for the given locations differ in:

- special solution due to beam line bake out required at following positions: T1S4, T1X1
- special solution due to high radiation (e.g. shielding) is required at the following positions: T8DU, T1D1 (beam dumps);

The number of foreseen components as well as special requirements can change due to modifications in HEBT topology.

5. Mechanical Setup

5.1. Overview

SEM-Grid is a direct, but intercepting, method to observe transverse beam profiles. One typical realisation of the system is schematically shown in Figure 2.

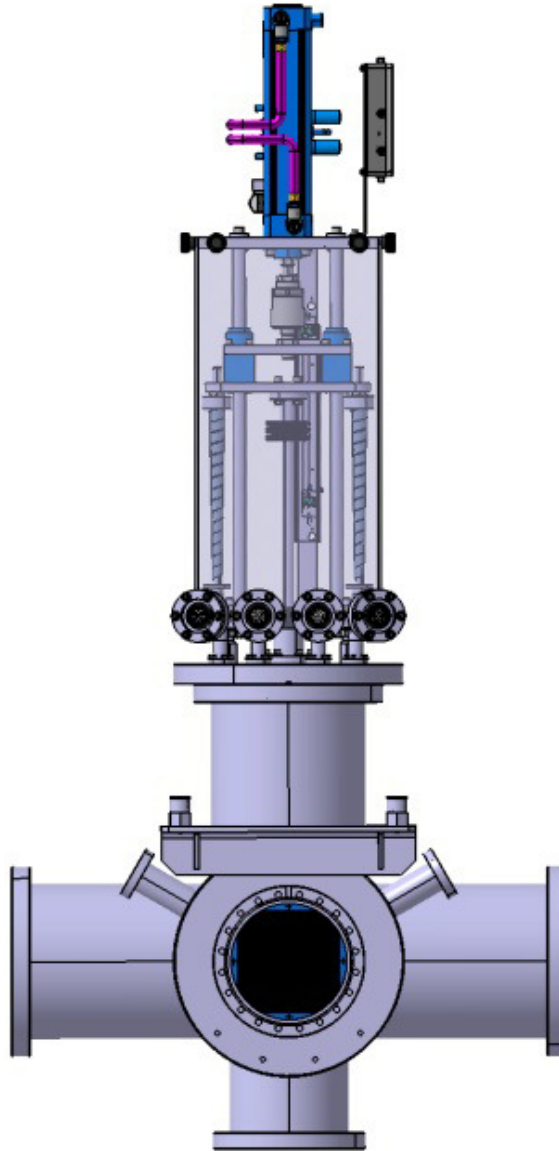


Figure 2: Prototype of vacuum chamber and mechanics for HEBT SEM-Grid.

The SEM-Grid detector consists of an isolating frame made of glass-ceramics, in which the detector wires or ribbons are fixed. Each wire/ ribbon can expanded with a spring or other solution is possible to have sufficient mechanical tension. HEBT SEM-Grids for both planes include 64 horizontal and 64 vertical wires or ribbons, spaced by 1 – 1.5 mm. The diameter of wires is typically 0.1 mm. For the HEBT, a different solution with ribbons is considered and will finally be defined later.

Document Title: Detailed Specification of Secondary Electron Emission Grid

For the HEBT lines, where ribbon arrays will be utilised, clearing electrodes must be foreseen to avoid excessive cross talk.

The detector is mounted on a pneumatic driven linear actuator to move the device in and out of the beam. Only two positions are possible to obtain correct measurements of the beam profile by device: inner and outer end position. Intermediate stop positions are not foreseen.

A SEM-Grid can only be installed in the horizontal (top flange of diagnostic chamber) or vertical plane (right/ left flange).

5.1.1. Mechanic Constituents of the BD Component

Mechanic constituents of the SEM-Grid are:

- diagnostic vacuum chamber with the flange typically CF200, for details see [23].
- pneumatic driven linear actuator
- detector
- cable feed-throughs

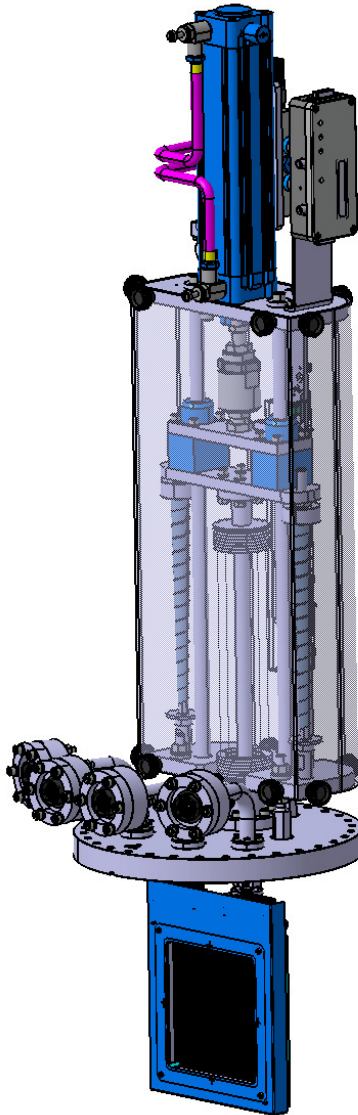


Figure 3: Prototype of HEBT SEM-Grid mechanical setup.

Diagnostic chamber

The vacuum chamber in-between two flanges will be the commonly used solution. In one vacuum chamber more than one beam diagnostics component can be installed, but the beam path must be free in the extended state. The vacuum chambers have to have a flange for the detector on a linear actuator. The size of this flange strongly depends on the detector's sensitive area. In common cases the flange will be a DN200CF. Further details can be found in the Detailed Specification of Vacuum Chambers [23].

Pneumatic Driven Linear Actuator

The linear actuator (see Figure 4) moves the detector into the beam center and out of the beam, see [22].

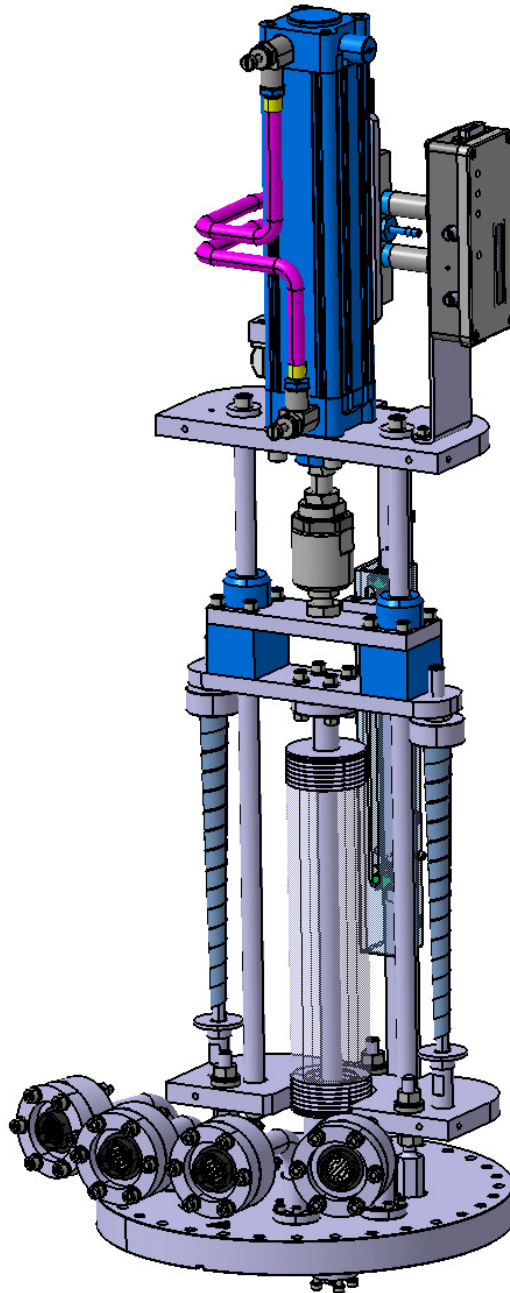


Figure 4: Prototype of pneumatic actuator for HEBT SEM-Grid.

Detector

The SEM-Grid detector consists of an isolating frame made of glass-ceramics, in which the detector wires or ribbons are fixed as presented in Figure 5.

- numbers of wires/ ribbons: 2×64
- detection width: 64 – 96 mm
- wire/ ribbon thickness: to be defined later
- wire/ ribbon pitch: 1 – 1.5 mm
- wire/ ribbon material: to be defined later, typically carbon or tungsten-rhenium alloy W(Re)

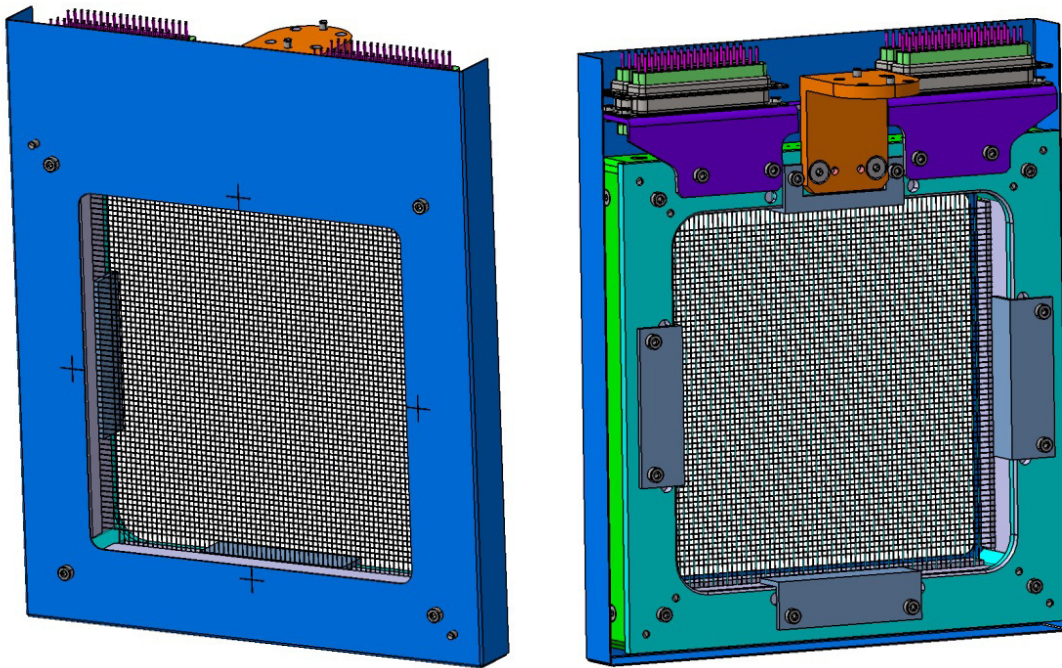


Figure 5: Prototype of SEM-Grid Detector. Front view (left) and back view (right).

5.2. Vacuum Parts

For manufacturing and factory acceptance tests of vacuum parts, the requirements included in the Common Specification for FAIR Beam Diagnostics [4] have to be fulfilled.

All vacuum components e.g. detector have to fulfil Vacuum Technical Guidelines [100], [101], [102], [103], [104], [105], [106], [107], [108], [109] and [110].

5.3. Mechanical Drive/ Feed-through

Vacuum feed-throughs for SEM-Grid detectors on linear actuators are needed, for details see [21], [22] and [24].

For dust protection, the pneumatic actuator must be enclosed in a protective box; a transparent material is preferred.

Four multi-pin (with 32 pins each, MIL-C-26482) signal cable feed-troughs are needed. Detailed design of cabling in the vacuum will be clarified later within GSI BI department.

5.4. Exemplary Realisation at GSI

SEM-Grids are used to measure the transverse beam profiles. They are very helpful for beam alignment and optimisation. Since the planar coverage for each detector is $< 10\%$ (per plane), even at low beam energies more than 80% of the beam passes through the SEM-Grid undisturbed, and simultaneous profile measurements at several successive locations are possible. At high energies one can pass the beam through many SEM-Grids at the same time for measurements.

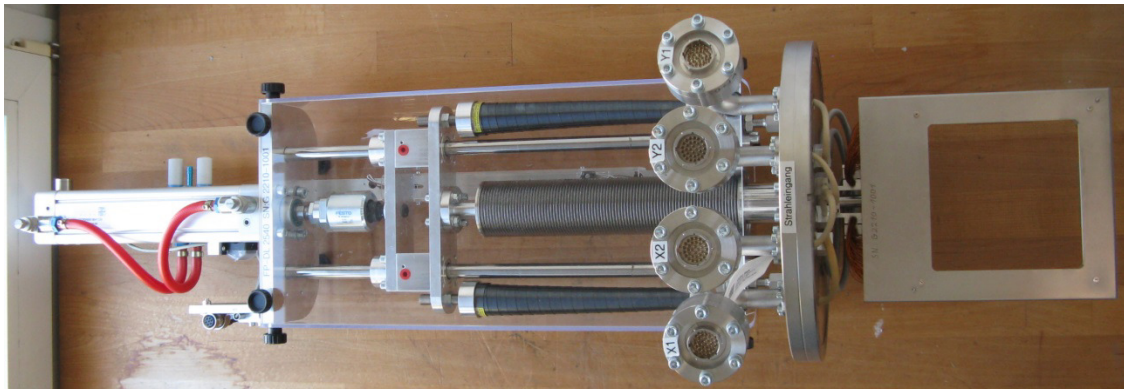


Figure 6: SEM-Grid mounted on linear actuator.

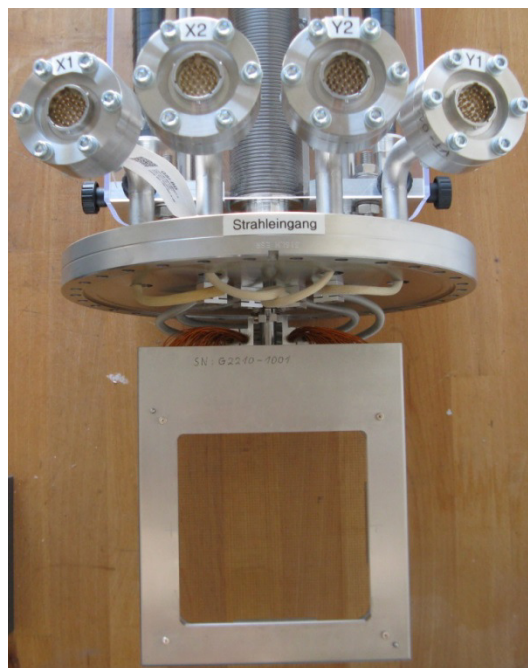


Figure 7: SEM-Grid with cable feed-throughs for signals from the detector.

Physical parameters

- permissible thermal power < 0.1 W/mm (wire thickness: 0.1 mm for W-Re alloy)

Detector

The detector consists of a frame with the detector wires, where each wire is pre-stressed by a spring, and fixed in an electrically isolated retainer. Important parameters are:

- active area: approximately $80 \times 80 \text{ mm}^2$
- wire thickness 0.1 mm
- wire center pitch 1 – 2 mm
- wire material e.g. W-Re alloy
- mechanical connection to linear actuator
- as vacuum signal feed-throughs, four connectors (37 pin) are used

Mechanics

The detector is mounted on a linear drive. Extension and retraction to the beam path is possible. The detectors move completely in or out of the beam, intermediate positions are not needed. The parameters are:

- distance from outer flange surface to beam center axis: 240 mm
- stroke: 150 mm
- limit switches are provided to monitor the position at the end positions

To drive the detector position, a pneumatic cylinder (type: Festo DNC-50-150-PPV-SA SA-205 449) is used. The mounting flange is a CF Flange DN150 or larger. Depending on the type of detector, suitable cable feed-through implementation is provided. For 64×64 wires 4 round connectors with 32 sockets (type: Amphenol - Aerospace PTIH - 20-41PN) are used.

All respective parts are designed for a vacuum pressure of 10^{-9} mbar.

6. Electronics and Data Acquisition

6.1. Overview

In this chapter, the development of a new data electronics system for SEM-Grid data acquisition is presented.

The SEM-Grid electronic measures the beam current from the SEM-Grid wires and the resulting profiles are presented in a Graphical User Interface (GUI). Each individual measurement channel is based on a charge-to-frequency converter (CFC) followed by a pulse counter.

A 32 channel readout system called POLAND (**PrOfiLe AcquisitionN Digitiser**) has been developed in collaboration with GSI Experiment Electronics Department (RBEE). POLAND as shown in Figure 8 combines all different PCBs (analogue frontend electronics unit, protection unit, pulse counters and digital communication unit) in a 19 inch 1 U industrial chassis.

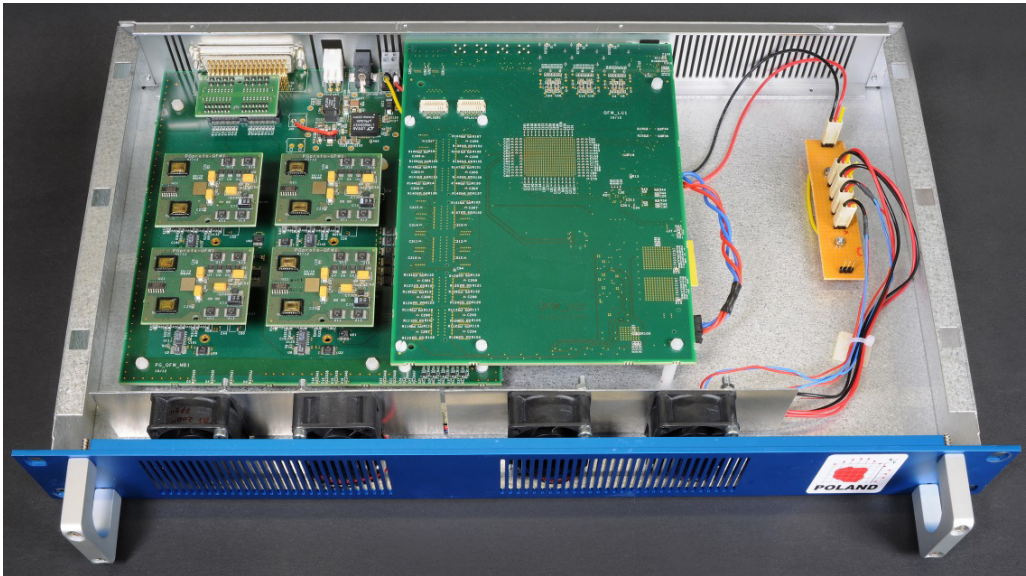


Figure 8: The 19" POLAND unit. On the left side 4 analogue frontend boards with 8 analogue channels are located. In the middle part the logic unit is placed. A motherboard connects all cards.

Its design is easy to maintain and therefore a cost-efficient solution. The POLAND system has been developed in such a way that it can be easily extended to readout larger channel numbers by combining different POLAND units. Data readout is done via fibre-optic cables to a standard PC with a FESA compatible network interface card (see Figure 9).

One of the main and critical components is the analogue frontend unit. An application-specific integrated circuit (ASIC) chip based on charge-to-frequency

Document Title: Detailed Specification of Secondary Electron Emission Grid

converter circuit named "QFW" [A 1] has been developed by the ASIC group of the GSI Experiment Electronics Department.

POLAND will be installed in accelerator tunnels with high radiation level, thus has to be at least radiation tolerant. Critical components have been already tested for their radiation performances (e.g. total ionising dose tests of the CFC ASIC were performed up to 11 kGy (SiO₂) with X-rays [A 2]). Currently Single Event Effects (SEE) studies are ongoing concerning their impact to the digital logic (FPGA) of the POLAND unit.

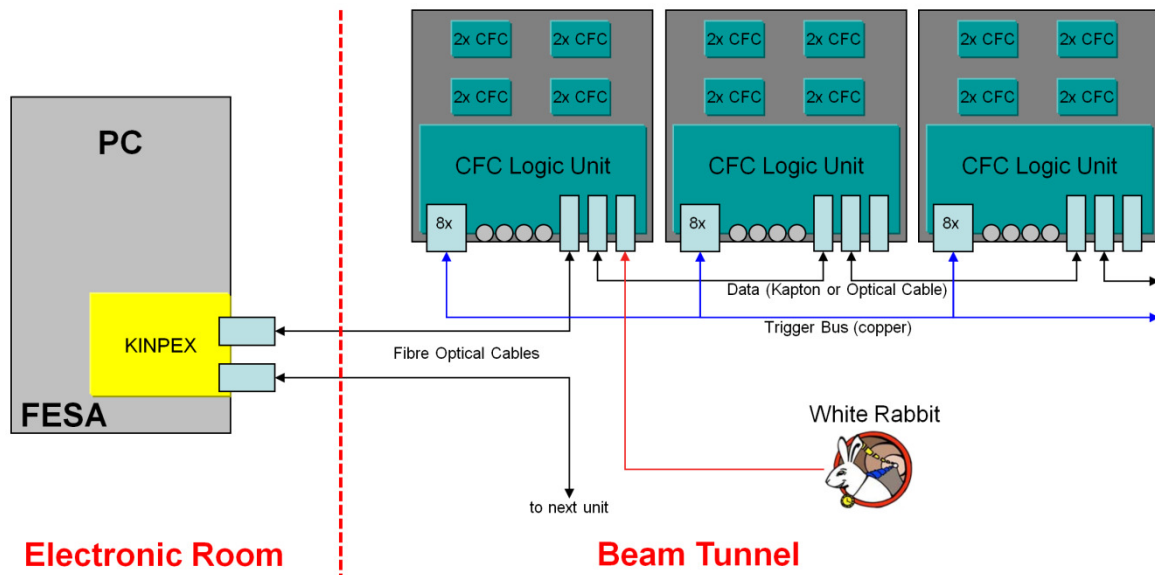


Figure 9: Basic schematics of SEM-Grid electronics. The distance between SEM-Grid and CFC-input should be as short as possible.

For the fast extracted beams pulse stretcher circuits are necessary to transform the pulse length into a region of e.g. several hundred microseconds. The stretching factor may depend on the application and, hence different stretcher circuits may be necessary.

Typical beam profile measurements with POLAND system during GSI experiment at with high energy ion beams are presented in Figure 10.

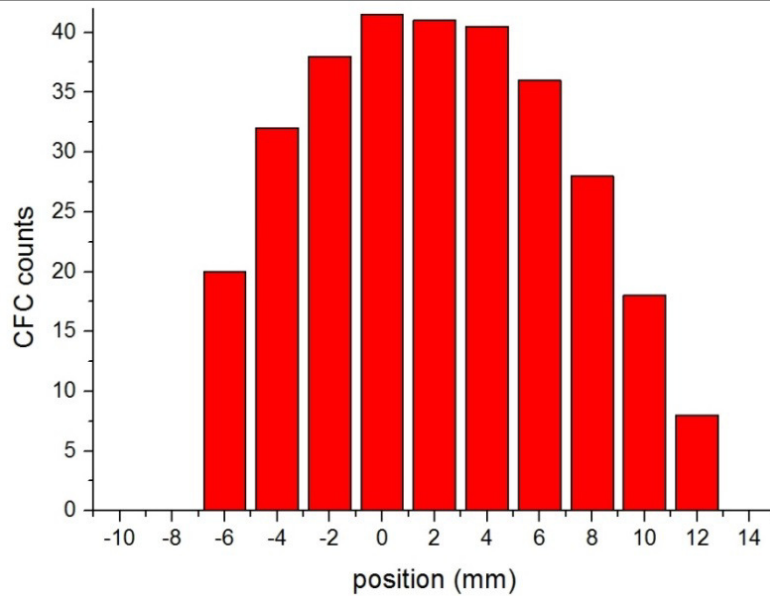


Figure 10: Measured SEM-Grid profile of 300 MeV/u kinetic energy Ni beam at GSI High Energy Beam Transport Lines (HEST), scaled to 10^8 incident particles.

For special applications where very short beam pulses and very low beam currents are expected, an additional electronic system based on the APFEL (ASIC for Panda Front-end Electronics) [A 3] readout chip (Figure 11), is foreseen. APFEL can be installed into the signal path between the SEM-Grid and the POLAND system. Where the POLAND system counts quantities of charges, the APFEL front-end of the ASIC is based on a charge sensitive amplifier (CSA).

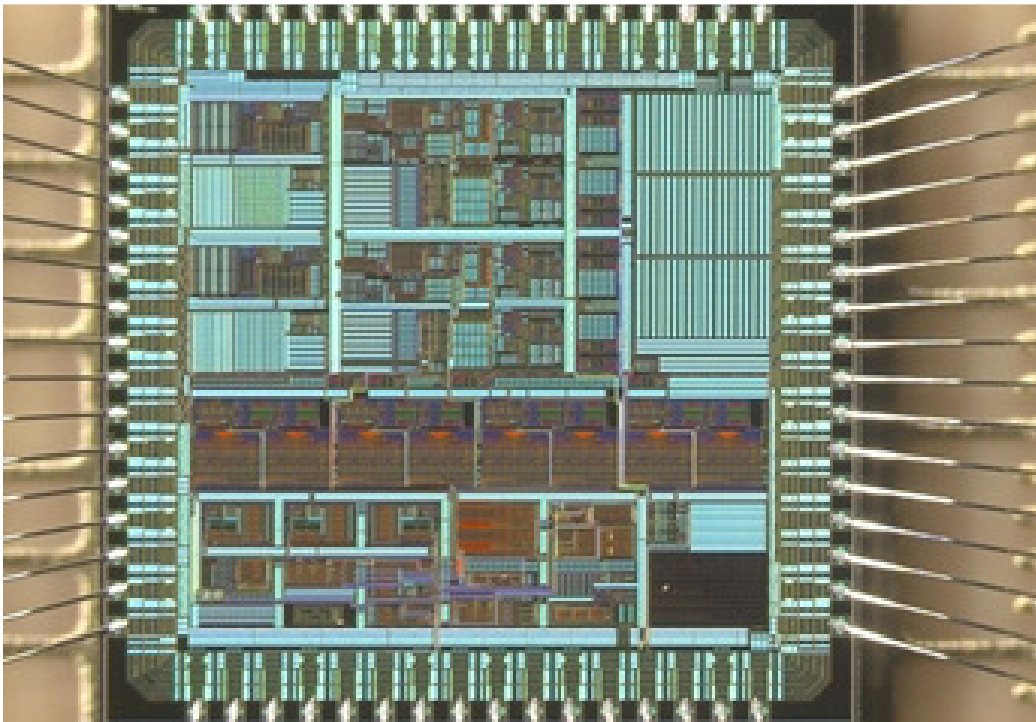


Figure 11: Picture of a single APFEL ASIC. Up to 16 (24) ASICs are used for the APFEL add-on system, mounted on a common motherboard.

Document Title: Detailed Specification of Secondary Electron Emission Grid

This additional system improves the measuring range by about 3 orders of magnitude to smaller charges and fast single pulse signals. To achieve this resolution the distance between SEM-Grid and APFEL input should be as short as possible – less than 3 meters. Figure 12 gives an overview about the signal path between SEM-grid via APFEL resp. POLAND readout electronic to the FESA access point.

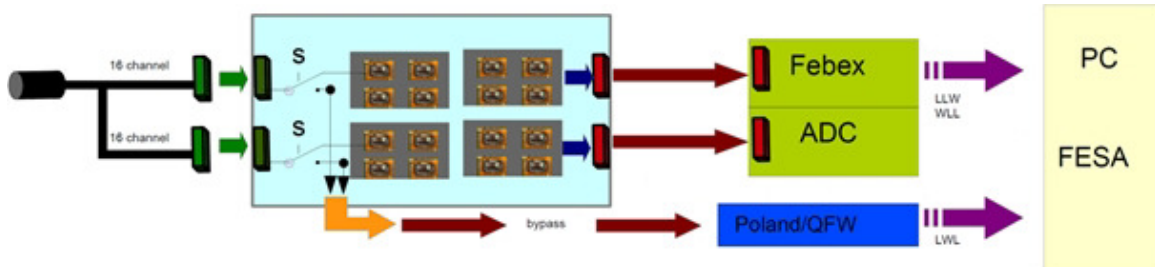


Figure 12: Signal path schematic of the combined POLAND and APFEL add-on system. The signals from a SEM-Grid are splitted in front of the APFEL. In case of low current and fast signals readout the sensitive path via APFEL is used, for medium and high current as well as long beam pulses the POLAND readout system is used. Both data are received via the same PC system.

Typical beam profile measurements with APFEL system with low energetic ion beams are presented in Figure 13.

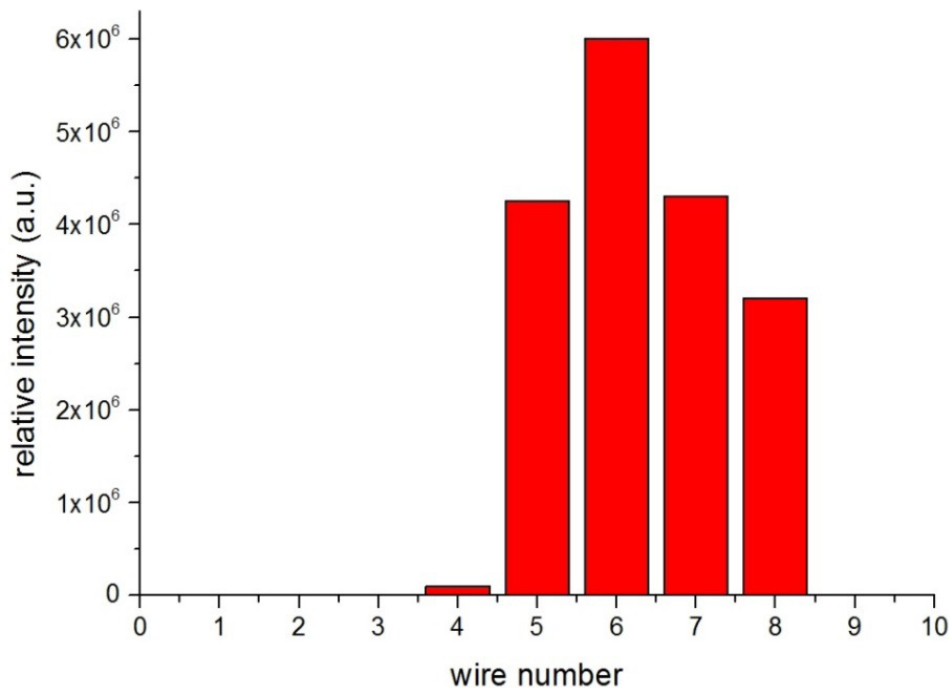


Figure 13: Beam profile measurements of a 5.9 MeV/u Au ion beam at UNILAC; beam current was 240 nA and pulse length 200 μ s.

6.1.1. Electronic Constituents of the BD Component

The electronics for the SEM-Grid consists of the following parts:

- Pulse stretcher circuit(s) with Electro-Static Discharge (ESD) diodes
- CFC electronics for each wire
- Electro-Static Discharge (ESD) diodes to prevent CFC damages due to high voltages
- APFEL electronics
- Control unit
- Interface, compatible to FESA
- Power supply
- Calibration / test generator (internal circuit)
- Cables / Optical fibres
- Pneumatic actuator with control unit
- High voltage power supply for cleaning electrode

Table 2: Basic electronic parameters (POLAND, status Q2/2013).

System Parameter	Unit/Level/Comment
Module	1U
Number of Input Channels	32
Ranges (max. tolerable input current)	10 ⁽¹⁾ /100 ⁽¹⁾ /1000 ⁽²⁾ /10000 ⁽²⁾ μ A; programmable
Current Polarity	pos. / neg.; programmable
Offset-Correction	switchable, global for all channels
Offset-Level	adjustable for each channel
Dynamic Range	120 dB
Gain Accuracy	< $\pm 1\%$
Min. Measureable Current	see comment ⁽³⁾ and Table 5
Start-Trigger	external / internal; programmable
Stop-Trigger (measurement pulse)	internal; programmable
Measurement Duration	up to 17200 s ^(8, 9)
Time Resolution	μ s ... s; see comment ^(3, 6) and Table 5
Time Slice Duration (Readout Interval)	20 ns to 86 s; programmable ^(8, 9)
Number of Time Slices	actual 200 ^(8, 9) (more possible)
Data Taking	dead time less
Repetition Rate	mHz to kHz (depending on total measurement time)
Max. Cable Length (detector to device input)	see comment in ⁽⁶⁾
Hardware	
Min. Charge Pulse(CFC ASIC)	250 fC (in range 10 μ A)
Resolution Limit	± 150 fC (1 σ) ⁽⁴⁾
Max. Output Frequency (CFC internal)	40 MHz at 10/100/1000/10000 μ A
Typ. Pulse Length (CFC internal)	app. 8 ns
In-/Output-Level (CFC internal)	LVTTL

Document Title: Detailed Specification of Secondary Electron Emission Grid

Jitter (error distribution of each channel output)	$\leq 0.1 \%^{(5)}$
Temperature Drift of Conversion Factor (0-50°C)	$\leq 0.7 \%$ (in relation of 20°C reference) (5)
Frequency Deviation between 4 Channels of one CFC ASIC	$< 1 \%^5$
Test Current	programmable (individual or different patterns possible)
Control Unit	FPGA
Pulse Counter in Control Unit	32 bit, programmable
Cable Connection	Fibre Optic Cable
FESA Integration	foreseen; Linux PC for controlling of modules (up to 256 devices with fibre optic cable daisy-chain)
White Rabbit Timing	used for trigger
Radiation Tolerance	tested up to 11 kGy (SiO ₂) ¹⁰
Scalability	multiple units can be combined to a larger local group (daisy-chained); up to 256 units are possible
Maintenance	the FPGA can be remotely reconfigured via the optical data communication protocol. For safety reasons a fall-back version is permanently stored at POLAND
Power Consumption	up to 30 W
Input Voltage	12 V DC

¹ Internal, realised inside of CFC ASIC² External, realised as current divider³ In the most sensitive range currents are measured with 0.25 pC/pulse. The smallest possible current to be measured depends strongly on the duration for the measurement: $I = Q/t$ ⁴ In relation to measurements with first prototype⁵ Values dependent on beam intensity, pulse length and/or cable length. Note also ⁷⁶ In relation to measurements with first prototype – modifiable by software⁷ The cable length defines the time resolution of the electronics. The capacitance of the cable (~100 pF/m) and the input resistance of the CFC channel (20 kΩ) determine the time constant T of the equivalent RC circuit. The cable between detector and input channels should be short.⁸ Determined for the first prototype, measured under real conditions with beam⁹ Measurements of all channels from one single CFC ASIC¹⁰ All ASICs stayed functional after radiation; increased offset-current (<1 nA, typical); immediate self-annealing after X-ray radiation switch-off. After several weeks of relaxation the CFC ASIC showed up identical parameters as before irradiation (test described in [A 2])

Document Title: Detailed Specification of Secondary Electron Emission GridTable 3: Minimum measurement duration (t) to monitor a current (I) in the most sensitive range of the CFC (range of 10 μ A is equal $Q_{\min}$ of 250 fC per pulse).

Current (I)	Minimum Measurement duration (t) for one CFC count	Output frequency
25 nA	10 μ s	100 kHz
2.5 nA	100 μ s	10 kHz
500 pA	500 μ s	2 kHz
250 pA	1000 μ s	1 kHz

Table 4: Time resolution dependency on cable length

Cable length	τ (R·C)
1 m	2 μ s
5 m	10 μ s
10 m	20 μ s
25 m	50 μ s

R = Input Resistance, 20 k Ω , internal

C = Capacitance of cable (e.g. bedea Messkabel 32x0,45L/1,4 (F) - FRNC, 100 pC/m)

The time resolution per single time slice is given by $t_{\text{time slice}} \geq 3.3 \tau$. Therefore the cable length has to be kept as short as possible.

6.2. Beam Line Electronics

The design of the beam line electronics must take the expected radiation levels along the beam line into account. It is foreseen to install the POLAND as well as APFEL measurement units close to the beam line. In order to readout a larger number of SEM-Grids channels, multiple POLAND units can be joined together to form a local readout group (see Figure 9). The maximum number of POLAND units in a daisy chain is limited to 256 units or 8192 channels. A start trigger via TTL or the White Rabbit timing protocol is necessary for a proper operation. In case of multiple units in daisy chain operation the trigger signal must be applied only to the first POLAND unit. The start trigger to the other units is then distributed via the common trigger bus signal cable.

6.3. Components in Electronic Rooms

A standard industrial PC is foreseen as a “combiner” PC (see Figure 9). It is equipped with at least one optical trans-receiver PCI card called KINPEX. This card has been also developed by the GSI Experiment Electronics Department and has 4 optical fibre ports. This device can be operated via the FESA protocol.

6.4. Cabling

Cabling details depend on the used solution for the front-end electronics. A low noise cable with small capacitance is required to reduce the capacitive load on the electronics input e.g. bedea Messkabel 32×0,45L/1,4 (F) - FRNC. Due to the low pass filter effect (see Table 4), the cable length should be kept below 25 m.

Data readout from CFC modules to a "combiner" PC is done via optical cables. For triggering a start TTL signal is distributed to the POLAND systems. More CFC modules (for example from one SEM-Grid) are combined to local groups. Every group has only one start trigger receiver (= Master unit). The received trigger signal is then distributed via a multi-wire ribbon cable between these local modules (= Clients). The number of modules per serial chain will be limited to 4 devices. Each "combiner" PC can handle up to four different readout chains. The "combiner" PCs are used for data transmission and programming of the CFC modules. Additionally, these PCs comprise an Ethernet connection to communicate with the FESA control system.

Data readout from APFEL modules to a "combiner" PC is done via optical cables. For triggering a start TTL signal is distributed to the APFEL systems.

6.5. Exemplary Realisation at GSI

Currently used at GSI, the digital module of the SEM-Grid electronics is outdated and not foreseen for operation in the FAIR facilities. Also the analogue unit cannot be manufactured anymore, because many electronic components are obsolete and not available anymore. The circuit schematic in this section is given just for reference. A new design based on CFC was necessary and fulfil all requirements for FAIR.

The electronic measuring system consists of analogue I/U-converter modules with short cable connections (< 25 m) to dedicated control electronics.

For the I/U-converter the following parameters are applied:

- Integration time: (500 µs/5 ms)
- Current range: 20 nA – 1 mA f. s.
- Number of channels: 16 – 96

For control and digitisation the following modules are required for each SEM-Grid:

- ADC module (12 bit resolution) differential input, ≥ 1 MSa/s with input for the control unit (Convert Command, TTL)
- Digital I/O, TTL, 8 bit input, 8 bit output

The wire current signals are fed into I/U-converters and are individually amplified using switchable preamplifiers, comprising a large dynamic range of 120 dB. The measurement signals are multiplexed and sequentially digitised using a slow

Document Title: Detailed Specification of Secondary Electron Emission Grid

(1 MSa/s) ADC-board. A control- and info-card switches the different amplifier stages and provides a non-volatile memory for details/info-data of the connected SEM-Grid hardware. The measured data of the wire currents are transmitted via a MIL Bus-card. This serial/differential field bus (MIL-STD-1553B) was specially modified for GSI data transfer and communication.

The MIL-Bus cable connects the MIL-bus interface with a VME control unit. This controller reads and sets all properties of the SEM-Grid electronics, by timing-event driven software modules. Located on top, a group-controller unit manages up to 9 device controllers and provides network connection.

The results of the profile measurements are displayed in the main control room on PC-screens by dedicated graphical user programs.

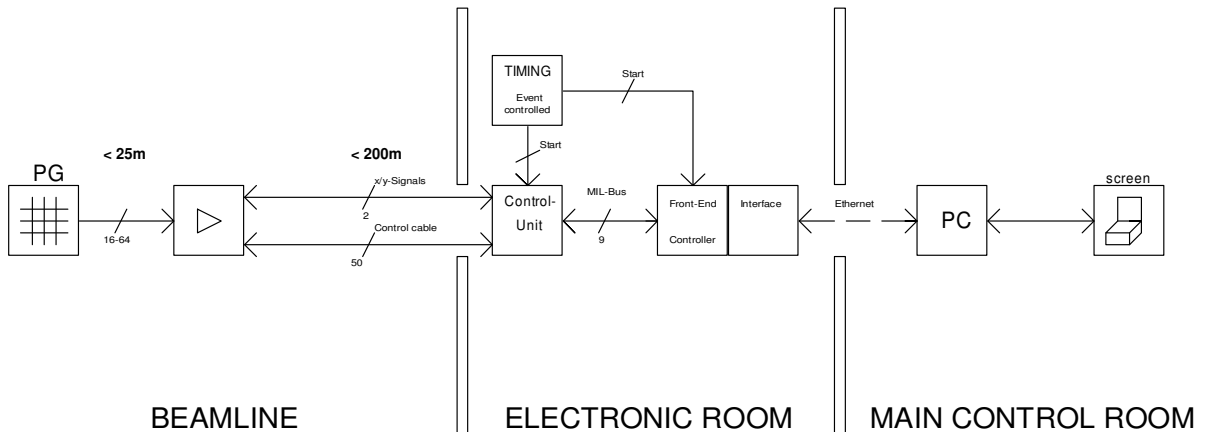


Figure 14: Basic scheme of existing GSI realisation.

7. Timing Requirements

All DAQ systems requiring machine timing or related triggers and gate functionalities must use the FAIR timing system based on the White Rabbit protocol [26]. Timing receiver hardware [27] will be available in the following form factors:

- AMC (e.g. μ TCA)
- PCIe
- VME
- PMC
- Stand-alone system

The trigger functionality of the SEM-Grid electronics must be able to cope with fast extracted beams of 50 ns or slow extracted beam of several seconds duration. The timing jitter must be below 1 μ s.

Table 5: Basic timing requirements.

Start Trigger	external acquisition start + delay
Stop Trigger	external acquisition stop
Other	selectable trigger, FESA controlled

8. Data Acquisition Software

8.1. General Requirements

Beam diagnostic data acquisition software must be based on the CERN-built FESA system including the GSI-specific extensions. The FESA version to be used must be the latest actual version released at GSI. For details of the FESA system see Detailed Specification for Data Acquisition [20].

So-called FESA classes interact directly with the hardware, handle hardware settings and publish acquired data to remote clients (i.e. graphical user interfaces) via a defined interface. The interface must comply with the 'Guideline for designing FESA equipment software at the GSI and the FAIR facility' [111] and the 'Guideline for Connecting new Equipment to the Accelerator Control System' [112]. This guideline details the naming conventions and interface parts (like Status, Setting and Acquisition properties) which are mandatory for FESA software to be used in the accelerator control system. Furthermore GSI FESA template classes have to be used as base for the class development. They are provided to ensure seamless integration of the FESA class into the control system.

The concepts for FESA based DAQ systems shall be discussed and agreed on with GSI experts before the main programming work has started. In addition a code review before final integration into the ACS is foreseen. An iterative development style based on frequent feedback and demonstration of the present status of work is mandatory.

The following list gives a broad but not necessarily exhaustive overview over the general requirements of a FESA class (the final version 'Guideline for designing FESA equipment software at the GSI and the FAIR facility' which specifies the binding requirements).

- Property data should be as far as possible self-contained, which means it should contain all information needed to use the data for different purposes including
 - Displaying
 - Archiving
 - Correlationwithout access to other data-sources e.g. databases, FESA classes, etc.
- Property data should represent values in SI units if applicable (i.e. Ampere, Volt, Particles/sec, etc.). The physical unit should be sent with the data.
- Acquisition data must contain information on the timing context (cycle stamp (timestamp of cycle start), cycle name, acquisition time) at which it was acquired.
- Measurement values should have information about their quality. An alarm when leaving a tolerance band must be raised.
- Supervision of the device status must be supported

- FESA classes must provide all functionality to integrate with other parts of the control system like
 - Alarm system
 - Post-mortem system
 - Data archiving and logging

If applicable, FESA classes for beam diagnostics must also provide functionality for

- Equipment self-test and calibration
- Logging and archiving for offline analysis of all data (in general to disk) on demand either manual or triggered by ACS independent on the above mentioned archiving and logging system of the ACS

8.2. General Functionality

The main purpose of the SEM-Grid system is the measurement of transverse beam distributions and their statistical moments.

8.3. Operational Modes

Different trigger modes have to be implemented in the software to allow for commissioning and maintenance, as well as standard operation:

- Manual trigger mode: acquisition is started/stopped by software command
- ACS trigger mode: acquisition is started/stopped by the timing system

The data acquisition software shall provide the following acquisition modes:

- Single shot (one start, possibly one stop trigger)
- Cyclic mode (repetitive start with start/stop trigger)
- Free-running mode

The following operational modes are required:

- Online data (horizontal and vertical profiles)
- Trending (position and statistical moments vs. time)
- Alarm/Interlock (alarm generation when crossing tolerance band)

8.4. Required I/O settings

To control the measurement setup the following I/O-channels have to be provided:

- Set all hardware parameters, gain, offset, etc.
- Set to self-test or calibration

8.5. Required Beam Information

In order to provide the required functionality the following beam parameters have to be supplied to the DAQ system via timing system, LSA or databases (not on front-end level):

- Ion charge state
- Ion species, defined by atomic number Z and atomic mass A
- Ion energy in units of MeV/u
- Nominal particle number
- Beam spot size

8.6. Online Display and Control

In general the software shall supply the complete set of information about the measurement device to the client application:

The basic requirements for the online display and control are:

- Plot of actual beam positions, profiles and width at min. 5 Hz repetition rate
- Display of the complete device status
- Display of alarm condition when leaving tolerance band
- Setting of self-test / calibration mode
- Setting of values for tolerance band
- Switching of operational modes

8.7. Data for Logging and Offline Analysis and Archiving

For logging and offline analysis the following functions are required:

- Generation of data files on demand (manual/automated by ACS)
- Further definition of file format and header contents
- Generation of log-files (controlled by ACS)
- Post-mortem functionality (set and triggered by ACS)

8.8. Special Issues and Boundary Conditions

Some additional features have to be implemented in the data acquisition software:

- The ACS has to supply the predicted beam intensity and spot size (for automated gain settings).

9. Related Subsystems

Related subsystems of the SEM-Grid consist of:

- Pneumatic actuator
- Cleaning voltage supply (to be defined later)

9.1. Pneumatic Drive

For standard scintillating screens as discussed in Chapter 6.3, the linear actuator with two positions (In/Out) can be realized in a reliable design, using a pneumatic drive which is specified as a subsystem [22], [24].

9.2. Cleaning-Voltage Supply

Applicability has to be defined.

10. Quality Assurance, Tests, and Acceptance

All the information concerning Quality Assurance aspects as well as FAT and SAT tests are included in [4].

11. Scope of Work and Delivery

Manufacturing and testing of SEM-Grids has to be performed as described in the documents delivered by GSI/FAIR.

11.1. Scope of Work

Definition of the final setup in agreement with the GSI LOBI department, regarding all requirements described in the detailed specification.

- Final definition of the system details, according to mechanics, electronics, data acquisition and subsystems, in agreement with GSI BI department.
- Manufacture and tests of mechanical parts and supports, as described in chapter 5 and 10.
- Delivery of all purchase components
- Development and production of special electronics
- Development of software for control & readout, timing, subsystems and GUI, as described in chapters 7, 8 and 9.
- Assembly of pre-series and tests, according to chapter 10.
- Assembly of the complete setups and tests, according to chapter 10.
- Commissioning of the setups with software in the FAIR facility.

11.2. Scope of Delivery

The scope of delivery is the complete SEM-Grid setup, consisting of all components described in the detailed specification, concerning

- Detector functional unit
- Mechanics
- Hardware components
- Electronics & Data Acquisition
- Software

The components have to be delivered to GSI. The SEM-Grid setups have to be assembled, tested and integrated into the FAIR HEBT beam line, as well as commissioned with the software.

Each SEM-Grid setup has to be labelled with component ID (CID) codes provided by GSI, see [113].

12. Technical Parameter List

The technical parameter list is a draft version until now and has to be modified and completed substantially, as soon as the relevant calculations are performed.

Table 6: Technical parameter list for HEBT

Note that these parameters are under evaluation!

Number of elements	Module 0 – 6: 74 Module 0 – 3: 51 HEBT A: 24 HEBT B: 15 HEBT C: 12	
Overall length of diagnostic chamber	mm	460 – 790*
Horizontal aperture	mm	150 – 400
Vertical aperture	mm	150 – 400
Detection width	mm	64 – 96
Number of wires		2 × 64
Wire/ribbons pitch	mm	1 – 1.5
Max. peak current		depend on location
Min. number of particles (pilot beam)		$10^5 – 10^{11}$
Typical beam pulse length	ns	50/100
Dynamic range	dB	120
Gain Accuracy		$\leq \pm 1\%$ f. s.
Test/Calibration		calibration possible only in 10/100 μ A-range
Repetition rate	Hz	5
Number of measurement devices per beam pulse (parallel measurements)		5

* Length of chamber depends on number of SD components installed at defined position

13. Open Issues / Questions

Currently following questions are not cleared, or have to be defined:

- Radiation hardness of electronics
- Detector mechanics: equipped with cleaning electrodes
- Detector mechanics: wire/ribbon thickness and material
- APFEL development

I. Attached Documents

No documents attached.

II. Related Documentation

The first paragraph contains all design reports and the General and Common Specifications of FAIR and the Beam Instrumentation Department. The second paragraph is devoted to the Detailed Specifications of the Beam Diagnostics work package, whereas the third paragraph lists all relevant Technical Guidelines. Paragraph four contains documents that are specific for the present Detailed Specification.

General Documents [1..19]

- [1] FAIR Baseline Technical Report
- [2] EDMS 1332223 Technical Design Report HEBT
- [3] EDMS 1365092 F-GS-F-01e General Specification of the FAIR Accelerator Facility Project
- [4] EDMS 1174185 F-CS-BD-01e Common Specifications Beam Diagnostics for FAIR

Detailed Specifications Beam Diagnostics [20..99]

- [20] EDMS 1179740 F-DS-BD-40e DAQ
- [21] EDMS 1179741 F-DS-BD-41e SubSys+StepperMotor
- [22] EDMS 1179743 F-DS-BD-43e Mech+MechanicalDrives
- [23] EDMS 1179744 F-DS-BD-44e Mech+VacuumChambers HEBT
- [24] EDMS 1179747 F-DS-BD-47e SubSys+PneumaticDrive
- [25] EDMS 1176027 F-DS-C-03e Settings-Management-System
- [26] EDMS 1176029 F-DS-C-05e General-Machine-Timing-System
- [27] EDMS 1176030 F-DS-C-06e Timing-Receivers

Accelerator Technical Guidelines Vacuum [100..199]

- [100] EDMS 1172876 F-TG-V-2.24e Materials in UHV
- [101] EDMS 1172873 F-TG-V-2.7e Ceramics for Vacuum Applications
- [102] EDMS 1172887 F-TG-V-3.11e Bolts for Use in Vacuum
- [103] EDMS 1172904 F-TG-V-6.10e Cleaning Assemblies and Sub-Assemblies in Vacuum
- [104] EDMS 1172894 F-TG-V-6.1e Cleaning of UHV Components Stainless Steel
- [105] EDMS 1172895 F-TG-V-6.2e Cleaning of Vacuum Components
- [106] EDMS 1172897 F-TG-V-6.4e Cleaning of Ceramics for Use in UHV
- [107] EDMS 1172898 F-TG-V-6.5e Cleaning of Aluminium Components
- [108] EDMS 1172905 F-TG-V-7.1e Mechanical Acceptance Test for UHV Components
- [109] EDMS 1172906 F-TG-V-7.2e Vacuum Properties Acceptance Test without Bakeout
- [110] EDMS 1172907 F-TG-V-7.3e Vacuum Properties Acceptance Test with Bakeout
- [111] EDMS 1235310 F-DG-C-01e FESA development guideline
- [112] EDMS 1235721 F-DG-C-04e Equipment Integration Guideline
- [113] EDMS 1229368 F-TG-B-0.5e CID and Barcode

Special Documents and Technical Notes [A 1.. A10]

- [A 1] H. Flemming and E. Badura, "A high dynamic charge to frequency converter ASIC", GSI Scientific Report 2004, www.gsi.de
- [A 2] S. Löchner et al., "Total Ionising Dose Studies of the QFW ASIC", GSI Scientific Report 2009, www.gsi.de
- [A 3] H. Flemming, P. Wiczorek, "Low Noise Preamplifier ASIC for the PANDA Experiment"
- [A 4] P. Wiczorek, H. Flemming, "First Beam time Results for PANDA EMC Barrel Prototype Proto 120"

III. Abbreviations

μTCA	Micro Telecom Computing Architecture
ACS	Accelerator Control System
ADC	Analog-to-Digital Converter
AMC	Advanced Mezzanine Card
ASIC	Application-Specific Integrated Circuit
BD	Beam Diagnostic
CERN	Conseil Européen pour la Recherche Nucléaire (European Organisation for Nuclear Research)
CF-Flange	ConFlat-flanges
CFC	Charge-to-frequency Converter
DAQ	Data Acquisition
DIN	Deutsche IndustryNorm
DS	Detailed Specification
ESD	Electro-Static Discharge
FAIR	Facility for Antiproton and Ion Research
FESA	Front-End Software Architecture
FPGA	Field Programmable Gate Array
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH
GUI	Graphical User Interface
HEBT	High Energy Beam Transport
HV	High Voltage
I/O	Input/Output
LOBI	GSI Beam Instrumentation Department
LSA	LHC Software Architecture
NIM	Nuclear Instrumentation Module
pBar Separator	Antiproton Target and Separator
PC	Personal Computer
PCB	Printed Circuit Board
pLinac	Proton Linac
PMC	PCI Mezzanine Card
QA	Quality Assurance
RBEE	GSI Experimental Electronics Department
R&D	Research and Development
RIB	Rare Isotope Beam
SEM-Grid	Secondary Electron Emission Grid
TCP/IP	Transmission Control Protocol/Internet Protocol
TG	Technical Guideline
TP	Twisted Pair
TTL	Transistor-Transistor Logic
VME	Versa Module Eurocard
WR	White Rabbit