**PIP-II AccU-BSTR -Dampers-CHG0 Interface Specification Document (ISD)**

Document number: ED00xxxxx

Document Approval

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Revision History

|  |  |  |
| --- | --- | --- |
| Revision | Date of Release | Description of Change |
| - | 05-01-2022 | Initial Release. |
|  |  |  |
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Table of Contents

[1. Purpose 5](#_Toc102026886)

[2. Scope 5](#_Toc102026887)

[3. Acronyms 6](#_Toc102026888)

[4. Reference Documents 7](#_Toc102026889)

[5. Interface Description Summary 8](#_Toc102026890)

[6. Beam Line Interfaces 9](#_Toc102026891)

[6.1. Mechanical Requirements 9](#_Toc102026892)

[6.1.1. Location 9](#_Toc102026893)

[6.1.2. Toroidal Cores 11](#_Toc102026894)

[6.1.3. Magnetic Shielding 11](#_Toc102026895)

[6.1.4. Ceramic Break 11](#_Toc102026896)

[6.2. Vacuum Requirements 11](#_Toc102026897)

[6.3. Cleaning Requirements 11](#_Toc102026898)

[6.4. Mounting Requirements 11](#_Toc102026899)

[6.5. Enclosure Environmental Requirements 13](#_Toc102026900)

[6.5.1. Thermal Requirements 13](#_Toc102026901)

[6.5.2. Radiation Requirements 13](#_Toc102026902)

[7. Infrastructure Interfaces 13](#_Toc102026903)

[7.1. Cable Requirements 13](#_Toc102026904)

[7.1.1. Interconnect Cable Requirements 13](#_Toc102026905)

[7.1.2. Signal-Passing Cable Requirements 13](#_Toc102026906)

[7.1.3. Common mode chokes 13](#_Toc102026907)

[7.2. Cable Penetration Requirements 14](#_Toc102026908)

[7.3. Conventional Facilities Requirements 14](#_Toc102026909)

[7.3.1. Relay Rack Requirements 14](#_Toc102026910)

[7.3.2. Power Requirements 14](#_Toc102026911)

[7.3.3. Grounding Requirements 14](#_Toc102026912)

[7.4. Gallery Environmental Requirements 14](#_Toc102026913)

[7.4.1. Radiation 14](#_Toc102026914)

[7.4.2. Thermal 14](#_Toc102026915)

[7.4.3. Humidity 14](#_Toc102026916)

[8. Signal Interfaces 15](#_Toc102026917)

[8.1. Overview 15](#_Toc102026918)

[8.2. Commercial Cassette Interface Requirements 16](#_Toc102026919)

[8.2.1. Booster DCCT Electronics 16](#_Toc102026920)

[8.2.2. Booster Distribution Box Interface Requirements 16](#_Toc102026921)

[8.3. LLRF System Interface Requirements 16](#_Toc102026922)

[8.4. Clock/Timing System Interface Requirements 16](#_Toc102026923)

[8.5. Controls Interface Requirements 17](#_Toc102026924)

[9. Appendix I 18](#_Toc102026925)

[10. Appendix II 19](#_Toc102026926)

# Purpose

This document describes the details of the firmware and software specifications for the new Booster BCM system of the PIP-II AccU-BSTR -Dampers-CHG0 Task, 121.05.04.04.03 PIP-II Project.

Key cost, schedule, technical and programmatic assumptions are provided in PIP-II Project Assumptions [1]. Interface specifications are upwards traceable to the associated Global Requirements Documents (GRDs)[2], Physics Requirements Documents (PRDs)[3][5], Functional Requirement Specifications(FRSs)[6], and Technical Requirement Specifications(TRSs)[7] where applicable. All specifications shall abide by requirements outlined in Fermilab Engineering Manual (FEM), Fermilab ES&H Manual (FESHM), and Fermilab Radiological Control Manual (FRCM), as appropriate.

# Scope

This Interface Specification Document (ISD) contain the information necessary to define all of the external interfaces along the new Booster BCM signal path. All interfaces for this activity are external to the PIP-II project except for the Level2 Accelerator Upgrade Project and the Level3 manager for Booster Upgrades. Since the interfaces for this activity are external to the PIP-II project Level3 Tasks, they aren’t included in the PIP-II MICD[4].

In addition, all hardware and software development shall abide by the PIPII Beam Instrumentation (BI) Quality Control (QC) Plan [10] and the overarching Accelerator Systems Quality Assurance (QA) Plan [9]. If inconsistencies between these documents are discovered, Accelerator Systems QA Plan has precedence.

# Acronyms

|  |  |
| --- | --- |
| ACNET | Accelerator Control NETwork |
| AD | Accelerator Division |
| BCM | Beam Current Monitor |
| BI | Beam Instrumentation |
| DAQ | Data Acquisition |
| DCCT | DC Current Transformer |
| DDCP | Distributed Data Communication Protocol |
| DSP | Digital Signal Processing |
| EMI | Electromagnetic Interference |
| EPICS | Experimental Physics and Industrial Control System |
| FEM | Fermilab Engineering Manual |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FRS | Functional Requirements Specification |
| GRD | Global Requirements Document |
| ISD | Interface Specification Document |
| IOC | Input/Output Controller |
| LLRF | Low Level Radio Frequency |
| MFTU | Multi-Function Timing Unit |
| MICD | Master Interface Control Document |
| PRD | Physics Requirement Document |
| QA | Quality Assurance |
| QC | Quality Control |
| REDIS | REmote DIctionary Server |
| RF | Radio Frequency |
| RFI | Radio Frequency Interference |
| TRS | Technical Requirements Specification |

# Reference Documents

|  |  |  |
| --- | --- | --- |
| # | Reference | Document # |
| 1.
 | PIP-II Project Assumptions | PIP-II docDB 144 |
| 1.
 | PIP-II Global Requirements Document (GRD) | ED0001222 |
| 1.
 | PIP-II Parameters Physics Requirements Document (PRD) | ED0010216 |
| 1.
 | PIP-II Master Interface Control Document | ED0010433 |
| 1.
 | PIP-II Booster BCM Physics Requirements Document (PRD) | ED000xxxx |
| 1.
 | PIP-II Booster BCM Functional Requirements Specification (FRS) | ED00xxxxx |
| 1.
 | PIP-II Booster BCM Technical Specification Document (TRS) | ED00xxxxx |
| 1.
 | PIP-II Booster BCM DAQ Network | ED00xxxxx |
| 1.
 | PIP-II 121.03 Accelerator Systems Quality Assurance (QA) Plan  | PIP-II docDB 4805 |
| 1.
 | PIP-II Beam Instrumentation Quality Control Plan | PIP-II docDB 5520 |
| 1.
 | Multi-Function Timing Unit | docDB 6741 |

# Interface Description Summary

At a high level, various interface types can be grouped by how the Booster BCM System is interconnected with other accelerator and PIPII subsystems. For this document, these interface types and group categories are shown in Figure 5‑1 as well as defined in the following list:

* + 1. Beam Line – interfaces related to installation of pickup components in the enclosure
			- Mechanical (Vacuum, Bolted beam line connections, Girder Mounting)
			- Environmental (Thermal, Radiation)
		2. Infrastructure – interfaces related to utilities and structures, provided as part beneficial occupancy requirements of the Booster gallery, Booster enclosure, and conduits in between
			- Electrical (Cable trays, Penetrations, AC Power, Grounding)
			- Building (Relay Racks, Conventional Facilities)
			- Environmental (Thermal, Radiation)
		3. Control System – related to data-passing interfaces between the Booster BCM system and the Control System
		4. Clock/Timing System – related to signal pathways between Booster BCM system and the Clock/Timing System
		5. LLRF System – related to signal pathways between Booster BCM system and the Booster LLRF System



Figure 5‑1. High Level Interface Block Diagram

# Beam Line Interfaces

## Mechanical Requirements

The pickup for the Booster BCM system is a commerical inflange unit from Bergoz Electronics, shown in Appendix I. It is DC current transformer (DCCT), whose core(s) are embedded in a pair of Conflat flanges with a shape and bolt pattern compatible with the Booster Long10 section. The pickup bolts must be tightened at the industry-standard recommended torque according to the flange type, but not beyond.

Also, the pickup’s inner diameter shall be 96mm and a flange to flange length of 120mm.

In addition, the pickup should be constructed from AISI316LN to prevent corrosion.

Vendor shall supply pickup with uniquely identifiable serial number.

Component fiducialization and alignment specifications shall be documented and transmitted from the L5AM to PS Alignment.

### Location

As depicted in Figure 6‑1, Figure 6‑2,and Figure 6‑3, the pickup shall be installed in the Booster Long10 section, upstream the existing B:CHG0 pickup. The pickup should be installed as far as possible from magnetic stray field sources and RF ducts.



Figure 6‑1 – Map of Booster Long10 Location



Figure 6‑2 – Picture of Booster Long10 Location



Figure 6‑3 – Placement of the new commerical pickup (left) with respect to B:CHG0 (right) ; Bellows on the US/DS transition spool pieces (1&2) attached to the face of the NPCT are circled in yellow.

### Toroidal Cores

Toroid cores of the commerical pickup are made out of high permeability amorphous alloy thin ribbons, using a special manufacturing process to improve its magnetic characteristic stability. In addition, these cores require a very careful packaging and a sophisticated annealing treatment, both thermal and magnetic, using a longitudinal field and a transverse field.

An arrow printed on the sensor shows the direction of positive current for positive output voltage.

### Magnetic Shielding

The pickup shall also incorporate a multilayer magnetic shielding using amorphous alloys, which provide a good shielding factor from external magnetic fields. This further minimizes errors induced by nearby unavoidable beamline components.

### Ceramic Break

The wall current break (“gap”) of the pickup is a ceramic ring (Al2O3 99.7%) brazed onto two Kovar transition sleeves.

## Vacuum Requirements

The pickup assembly is designed to be UHV compatible and to maintain the vacuum of < 1e-7 Torr. Usual procedures pertinent to the vacuum pressure objective must be applied.

## Cleaning Requirements

Soap or alcohol cleaning is recommended; to reach pressure down to 1e-11 mbar, adequate pumping and cleaning, e.g. plasma, are required.

## Mounting Requirements

Load-bearing support structures shall be provided to mechanically support and electrically isolate the Booster BCM pickup from the vacuum beam pipe. In addition, DB15 sensor connector dimensions must be taken into consideration. Feedthroughs for BCM cable connections shall remain accessible in the installed configuration.

Table 6‑1 and Table 6‑2 lists the drawings for the stands and mounting fixtures.

Table 6‑1. Drawings of Stand/Mounting Fixtures for new pickup (B:DCCT)

|  |  |  |
| --- | --- | --- |
| # | Drawing # | Drawing Title |
| 1 | F10156059 | Bergoz NPCT Stand and Adjuster Assembly |
| 2 | F10158593 | Bergoz-Toroid Booster Installation Assembly |

Table 6‑2. Modifications to Stand/Mounting Fixtures of downstream B:CHG0

|  |  |  |
| --- | --- | --- |
| # | Drawing # | Drawing Title |
| 1 | F10156452 | Beam Line Magnet Stands Standard Toroid Frame Assembly |
| 2 | F10156396 | Toroid Stand 3.25” BeamTube Top Clamp |
| 3 | F10156407 | Toroid Stand 3.25”: BeamTube Bottom Clamp |
| 4 | F10156414 | Toroid Stand 3.25” Beam Clamp Assembly |
| 5 | F10156432 | Toroid Stand Top Support Plate |
| 6 | F10156455 | 8” x 8” x 0.5” Aluminum Bar |
| 7 | F10156456 | 8” x 7” x 0.5” Aluminum Bar |
| 8 | F10156457 | 1/8” Aluminum Gusset |
| 9 | F10156481 | Toroid Stand Toroid Support Weldment |
| 10 | F10156529 | Pearson Current Monitor Model 3100 |
| 11 | F10156553 | B-Line B22A 40.125 LG Back to Back Strut Channel |

## Enclosure Environmental Requirements

### Thermal Requirements

100°C (212°F) should never be exceeded at any time during bake out or operation. Above this temperature the sensor alloy annealing is lost and cannot be recovered.

No in-situ baking is planned, but special baking temperature limits requirements shall be agreed on and approved by both the Stakeholders and Vacuum Systems. For instance, if the vacuum chamber requires bake out, it is recommended that a thermal shield be installed between the vacuum chamber (or the heating sleeves) and the pickup. The thermal shield can be a simple copper cylinder cooled by water circulating in a copper tube brazed onto the cylinder. The water circuit must not pass thru the pickup aperture. Instead, it must enter and go out on the same side of the pickup, otherwise it makes a shorting loop around the toroidal cores.

### Radiation Requirements

The pickup shall be a "Rad-tolerant" sensors, which is constructed from radiation-resistant materials to withstand the radiation levels at the enclosure location. The pickup is equipped with a DB15 male connector affixed to the outer side of the sensor head. The connector dielectric is rad-tolerant glass-fiber-reinforced PBT. The connector points axially, its base flush with the sensor outer surface.

# Infrastructure Interfaces

## Cable Requirements

### Interconnect Cable Requirements

One 8-pair radiation-tolerant multiconductor interconnect cable, described in Appendix II, shall connect the pickup in the enclosure to the electronics in the gallery. The maximum length of the interconnect cable is 130m.

Both ends of the interconnect cable shall be terminated with DB15 connectors. Male DB15 connector shall be used at pickup end; female DB15 at rear panel of electronics chassis.

### Signal-Passing Cable Requirements

Other digital and analog signal cables connecting to other subsystems shall use standard cables, connectors, and adaptors, as needed (Refer to 8).

### Common mode chokes

EMI coupling into electric circuits by way of ground loops can be reduced by using common-mode filters on both end of all cable segments. A cable segment is any cable between two points where the shield is grounded. For example, a cable between an oscilloscope and a grounded patch panel is a segment. An AC power cord between an instrument and an AC socket is a segment.

Simple common-mode filters can be made by passing the signal cable (twisted pair or coaxial) through a ferrite core. Passing the signal cable several times through the ferrite core increases the magnetic coupling -hence the common-mode noise rejection- by the square of the number of turns... until the capacitive coupling defeats the rejection. In practice, about 7 turns are optimum. The magnetic characteristics of the ferrite cores must correspond to the frequency spectrum of the noise to be rejected.

Ferrite cores can be complemented advantageously by cores of amorphous cobalt alloy or nanocrystalline iron alloy cores next to the ferrite cores. MnZn tubes over the cables are effective against high frequencies >500 MHz. At low frequency down to 50Hz, iron-based nanocrystalline cores are effective. Cores with “soft” B-H loop ( e.g., Hitachi Metals Finemet FT-3KL core annealing, Vacuumschmelze 500F field-annealed core) are preferred.

## Cable Penetration Requirements

Cable runs should via the penetrations nearest the pickup and should not share conduits with magnet power supply cables. If the cable path is through a high RFI environment, cables should pass through metallic electrical conduits; aluminum conduits are appropriate to reject RFI.

## Conventional Facilities Requirements

Electronics and equipment, which require standard Conventional Facilities interfaces, shall comply with general occupancy, cable tray, power and ground requirements.

### Relay Rack Requirements

Electronic components shall be installed in the gallery and bolted into standard relay racks based on EIA-310. The chassis shall be 3U (DIN norms) tall, 19” wide, and 300mm deep, excluding protruding connectors.

### Power Requirements

The power supplies for all electronic components require 120 V AC, 1.5Amax, 50/60 Hz power.

The pickup shall be commented to the cassette module before before connecting the chassis to the mains.

### Grounding Requirements

Electronic components are grounded to the AC mains ground by way of the power cord and outlet or rebar network. Additional filtering shall be used to remove line harmonics at the rack power supplies, as needed.

## Gallery Environmental Requirements

### Radiation

Electronic components must not be exposed to ionizing radiations. Doses as small as 102 Gy may damage the MOS components used. Consequently, electronic components shall not be installed in the enclosure.

### Thermal

Components installed in the Booster gallery, shall withstand operating temperatures between -40ºC and 100ºC.

### Humidity

Electronic components shall operate in non-condensing environments of the Booster gallery.

# Signal Interfaces

## Summary of System Architecture

To accompany the commerical pickup, the vendor shall provide an 3U tall, 19” wide electronic chassis, 2 power supply modules, and 2 cassette modules. Both cassettes are matched to their associated sensor and cable's length. When a cassette is used with another unmatched sensor, its output shall most likely be unstable and noisy. However, connecting another sensor does not damage the electronics.

The active cassette module shall provide two output signals. An output signal from the active cassette module shall be given to the Booster Signal Distribution box. Another signal from the active cassette module shall be connected to the Booster DCCT Electronics. As shown in Figure 8‑1, the Booster DCCT Electronics shall receive signals from the Booster LLRF as well as Control MFTU.



Figure 8‑1 – External Interfaces to components within the Booster BCM system (blue) architecture

In addition, the Booster DCCT electronics shall host analog signal conditioning circuitry, firmware for digitization and buffering, DSP for normalized current measurements, and software for data acquisition for the Booster DCCT Front End Server. The server shall maintain the all external interfaces onto the AD Controls Network. More detailed specifications are captured in the Booster BCM DAQ Network[8].

## Commercial Cassette Interface Requirements

The commerical cassette provide 2 analog outputs. The specification both are as follows: 100Ω high-impedance bipolar signal of +/-10Vpk. Also, both are referenced to the cassette ground and is isolated from the chassis.

Coaxial RG58 cables shall be used with BNC connectors. A common mode choke filter should be used to reject common mode noise (Refer to Section 7.1.3).

### Booster DCCT Electronics

The active commerical cassette shall provide analog signal to the Booster DCCT Electronics, as the primary input to the final measurements. In addition, post-process normalized waveforms shall be available to the Control System over Ethernet (Section 8.6).

A differential input (i.e. with floating inputs) should be used when the commerical cassette and the transition board grounds are not the same. In addition, to reject differential mode noise, a 100nF ceramic capacitor should be installed between signal wire and ground at the transition board input.

### Booster Distribution Box Interface Requirements

The active commerical cassette shall provide analog signal to the Booster Distribution Box, for diagnostic purposes and scope displays. This signal reflects the raw NPCT response to beam, and it shall not be normalized to the LLRF.

## LLRF System Interface Requirements

­­­­­­­­­­­­­­­­­­­­The Booster LLRF system supplies reference RF curves of the proper frequency and phase, which must follow the change in velocity in the protons during acceleration. The frequency at injection is roughly 37.86 MHz and increases to 52.81 MHz at extraction time. These curves produce the low-level signals from waveform generators.

The Booster LLRF analog signal shall be distributed to the Booster DCCT electronics. The nearest available port of an existing fanout box should be used.

The specification for analog signals is as follows: 50Ω bipolar signal of +/-0.5Vpk. Coaxial RG58 cables shall be used with BNC connectors. A common mode choke filter should be used to reject common mode noise (Refer to Section 7.1.3). More detailed requirements and specifications for the Booster LLRF signal are not within the scope of this document.

## Clock/Timing System Interface Requirements

Booster BCM electronics shall receive timing signals from a MFTU unit [11], provided by Controls.

The MTFU shall decode to receive and decode global clock signals as well as receive Booster timing signals. The MFTU shall provide 16 delayable TCLK event-based TTL triggers, and another 16 TTL triggers, referenced to the Booster timing. Control shall provide accompanying ACNET devices for all the triggers to set and monitor the trigger’s parameters. These signals shall trigger the logic to align both firmware and software modules with accelerator operations. This is critical for proper signal digitization, signal processing, and data acquisition.

The MFTU should be installed in the same or adjacent rack to the Booster Electronics chassis. Coaxial RG58 cables shall be used with BNC connectors.

## Controls Interface Requirements

Booster BCM electronics shall connect to a dedicated, centrally managed switch with at least 10/100 Ethernet port connectivity. This switch shall be capable of up-linking to 10Gbps to a rackmount front end Linux-based server. Together, these form a private DAQ network. All network hardware, required for the Ethernet connection, must be supported by Accelerator Division / Controls Department networking staff. Future expansion in a climate-controlled environment suitable for commodity network and computer equipment should be considered.

The server shall have a 1U form factor, with a multi-core processor running at least 2.4GHz, redundant power supplies and multiple hot-swappable hard drive bays. In addition, the server shall have a minimum of 8GB of RAM, 1TB hard drive, and 4 Ethernet 1Gbps ports.

The server shall be responsible for concentrating data from the data acquisition modules in the Booster BCM Electronics, using a subscriber communication protocol. Also, this protocol shall be used to exchange initialization settings and modifiable system parameters to the Booster BCM electronics. More details are captured in the Booster DAQ Network[8].

In addition, the server shall manage servicing all data requests from client applications, including delivering data to the Controls System through the EPICS Input/Output Controller (IOC) applications. The requirements for the IOCs are:

* Must be capable of data logging all process variables (PVs) per Booster cycle at 20Hz.
* Must be capable of delivering and displaying BI waveforms up to 2048 points per Booster cycle at 20Hz.

Decimation at the IOCs shall relax network requirements between the Booster BCMS and the Controls System. Higher network bandwidths should be provided between the Booster DCCT Electronics and the Front End Server.

# Appendix I



Figure 9‑1 – Schematic, provided by vendor, of inflange pickup

# Appendix II



Figure 10‑1 – NPCT radiation-tolerant cable 5719/A