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Fermilab Interface Control Document
INTERFACES FOR THE PIP-II LB650 CRYOMODULE
ED0007561, Rev. -

Rev.	Date	Description	Originated By	Checked By	Approved By
-	03/21/2018	Initial Release	*V. Roger*		

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A note to reviewers and approvers of Rev-

As of the revision date of this document, not enough design information is known about LB650 cryomodule and its interfacing systems to write a complete, comprehensive interface control document. As such, this revision documents what we know today, and highlights areas of uncertainty or where more design is required. The expectation is that this document will be revised when the design has progressed far enough that all interfaces may be completely specified.

1. Purpose - LB650 Cryomodule

The purpose of this document is to map out the external interfaces of the LB650 cryomodule, i.e. how it interfaces with the connected systems of PIP-II and the PIP-II Injector Test (formerly known as PXIE). This document endeavors to cover all connections to the LB650 cryomodule that will be made in the PIP-II Injector Test cave or PIP-II Tunnel.

The LB650 itself is documented in model/drawing …

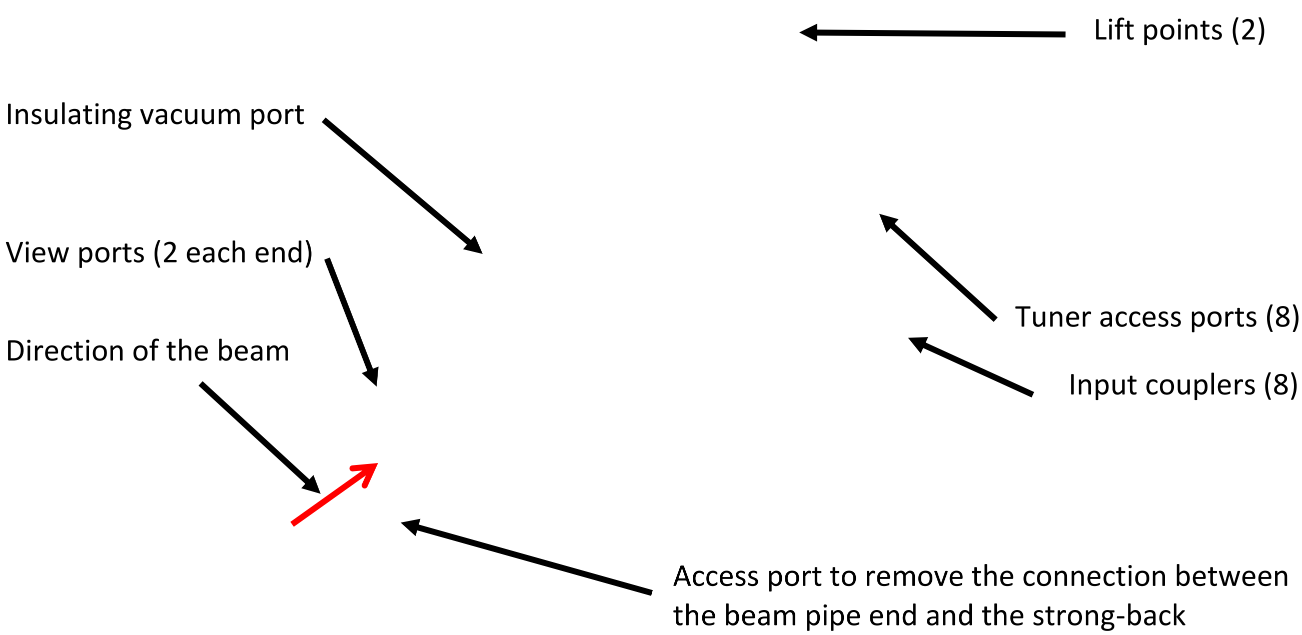


Figure 1.1: LB650 cryomodule external features

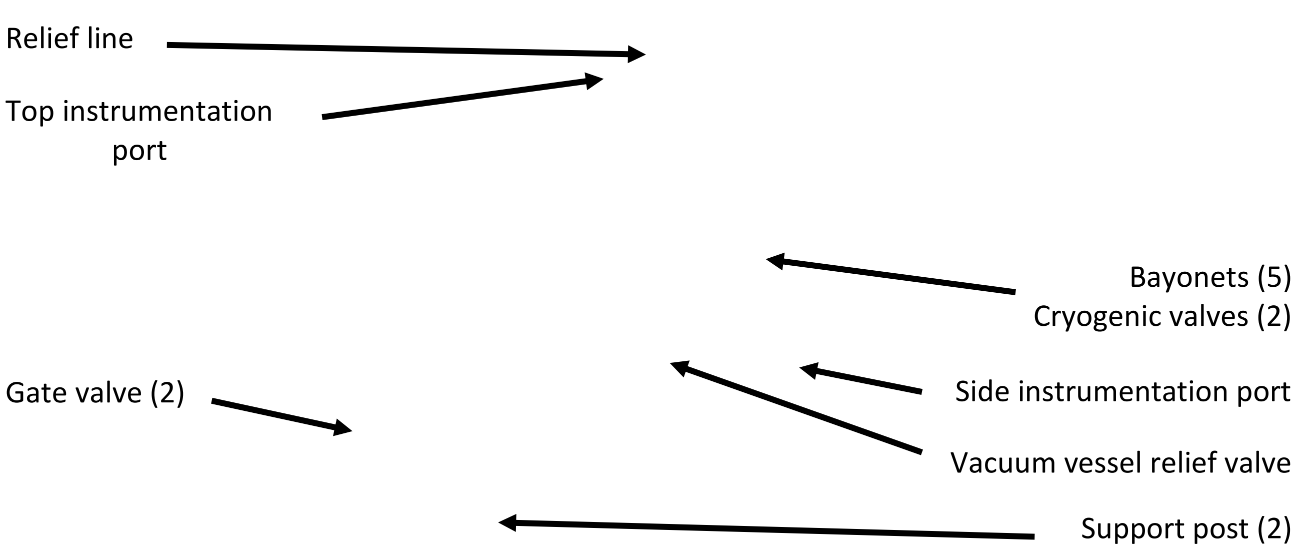


Figure 1.2: LB650 cryomodule external features - As seen from cryo interface side

2. Beam Line Connections

The LB650 provides gate valves at each end of the beamline. These valves are the only connection between adjacent cryomodules or other beamline components. Unlike systems with continuous insulating vacuums and cryogenic piping systems, (e.g. XFEL, LCLS-II), cryomodule connections in PIP-II are made to the linac infrastructure at each cryomodule.

Figure 2.1 shows the connection to the beamline. This connection is the same on each side of the cryomodule. The gate valve is a pneumatically-actuated all metal gate valve. All beamline connections are via …" Conflat flanges.

Figure 2. 1: Gate valve beam line interface - Arrangement does not match current design.

3. Alignment and Stand Interface

The cryomodule will be aligned both internally and externally. There will be no need or ability to adjust the internal cavities and solenoids relative to each other after assembly. The external fiducials will be referenced to internal alignment. For internal alignment verification, two viewports will be on each external end of the vacuum chamber. Through these viewports, internal open wire targets attached to each cavity and solenoid will be visible to measure transverse shifts due to cool down.

External fiducial blocks shall be mounted on the outside of vacuum chamber of the cryomodule. These fiducial blocks will hold 1.5” SMR nests. Figure 3.1 shows the requirements and approximate locations for external fiducials on the LB650 cryostat.

The LB650 and PPD/Alignment teams shall provide all fiducials and referencing from external fiducials to internal cavity positions at 2 K. Internal fiducials on cavities and solenoids are required to accomplish this. However, since these fiducials are not accessible in PIP-II, details of this fiducialization and alignment scheme are outside the scope of this document.

The PPD/Alignment team shall align LB650 as a rigid body in the PIP-II Injector Test and PIP-II such that cavities and solenoids are aligned with the nominal beamline axis when the LB650 is at 2K.
The predicted 300 K → 2 K shift of cavity string relative to cryostat vessel in the alignment group CSYS is

X: -0.1 mm (+X is from the beamline towards the coupler side of the cryomodule)

Z: -1.2 mm (+Z is from the beamline vertically upwards)

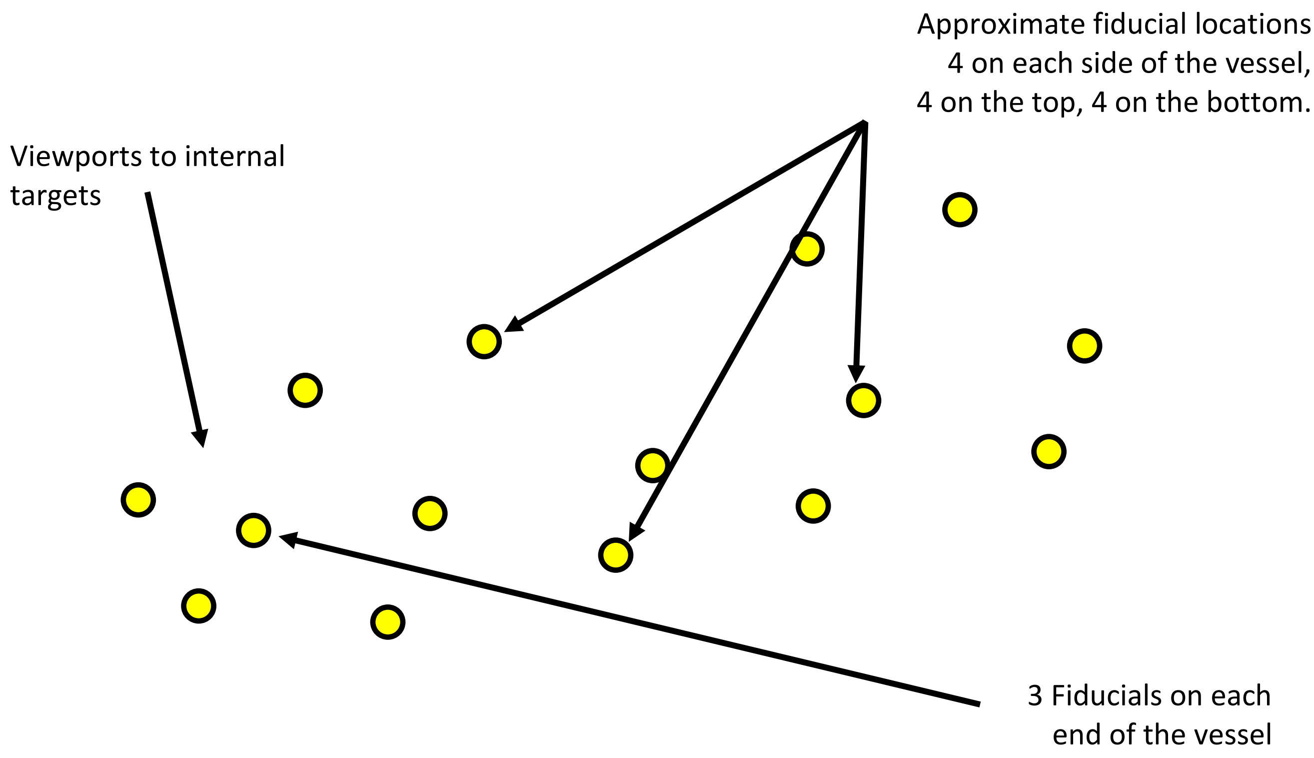


Figure 3.1: Approximate external fiducial locations. All fiducials will be tack welded to the vacuum vessel.

The alignment of LB650 cryomodule is provided with:

- 4 vertical screw adjustors (36 mm in diameter)
- 2 transverse (left-right) adjustment turnbuckles
- 2 longitudinal adjustment screws

All of these adjusters interface to bearing pads or attachment locations on an I-beam section. The LB650 team will provide the adjusters and I-beam section (everything shown in figure 3.2). The bottom of the I-beam section will be rigidly supported by structure provided by the AD/Mech Systems team (see section 4).

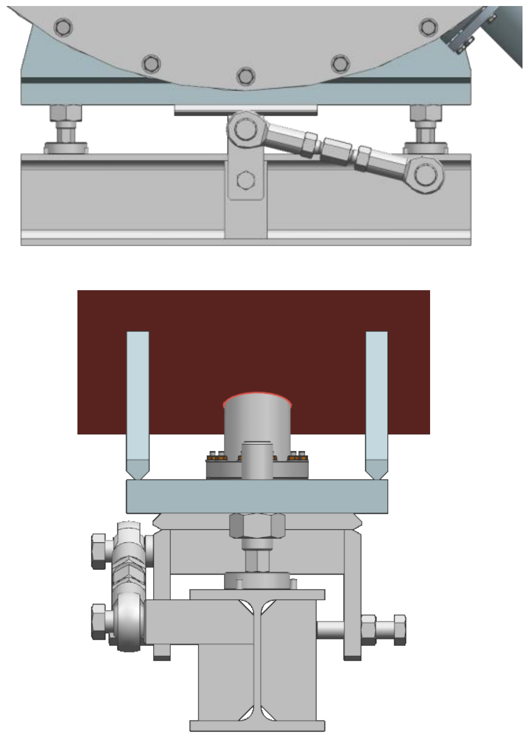


Figure 3. 2: Interface between the vacuum vessel and the supports.

4. Handling, Transportation, Structural Interface to Facility

The AD/Mech Systems team shall provide a support girder or surface to accommodate the structural beam of the cryomodule adjustment stage. The location of this interface plane is indicated in figure 4.1 below. The interface shall be a bolt pattern of metric bolts to be specified as part of adjustment stage design.

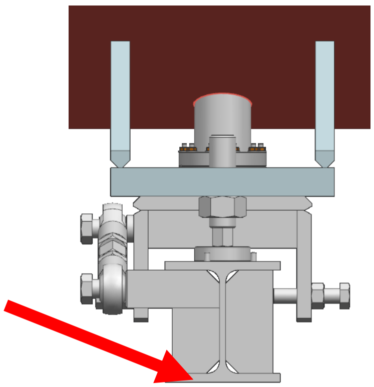


Figure 4.1: Interface plane between LB650-provided adjustment stage and Facility-provided girder shown with red arrow

Figure 4.2: hard points for hoisting interface

In order for cryomodules to be installed in the PIP-II tunnel, the cryomodules must reside within a specified transverse volume envelope, both while in position and during transportation down the service aisle. As such, the LB650 cryomodule shall reside within the transverse envelope and meet all requirements defined in drawing F10051442 [2]. Note that this drawing also defines the height of the interface between the adjustment stage and the girder.

The LB650 team shall provide the tooling and fixturing required, if any, to transport the LB650 cryomodule by truck to CMTF or the PIP-II facility.

The LB650 team shall provide rigging interfaces and instructions to allow the LB650 cryomodule to be manipulated by crane. If a below-the-hook lifting fixture is required, the LB650 team shall provide the fixture. Hard points for the hoisting interface are shown in figure 4.2 above.

The CMTF facility provides a loading area with truck access and 24’ hook height. In order to clear PIP-II Injector Test cave walls during installation, the LB650 rigging scheme shall be designed to provide a minimum of 8.5’ clearance below the LB650 during a lift. A clearance of 11.5’ would be more desirable, in that the top layer of wall blocks would not need to be removed. A clearance of 16’ would be optimal, in that only roof blocks over the LB650 location would need to be removed.

The PIP-II conventional facility shall provide a loading area with truck access and hook height $\geq$ 20’

The AD/Mech Systems team (TBR) shall provide a cryomodule transportation fixture for installation of LB650 and other cryomodules in the PIP-II tunnel. This fixture may use the hoisting and/or adjustment interfaces on the cryomodule. This fixture will not be designed or used in the PIP-II Injector Test installation.

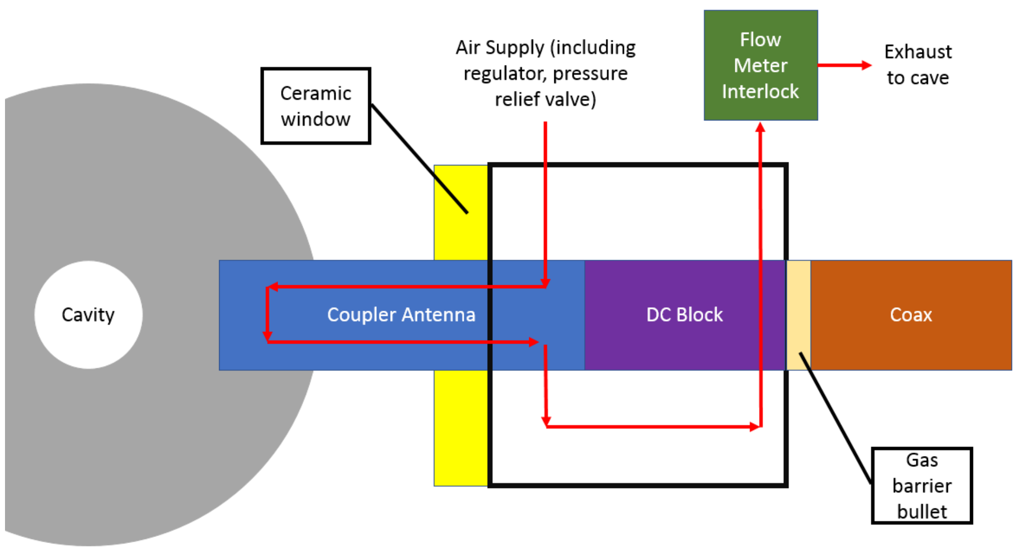
5. Facility Utilities

The LB650 requires a source of clean, dry nitrogen for cryostat backfill. The AD/Fluids team shall provide nitrogen in the PIP-II Injector Test cave for this purpose. (Note: this nitrogen is NOT used for beamline vacuum backfill).

The LB650 requires compressed air for valve operation (intermittent use). The AD/Fluids group shall provide this air, with the following parameters:

- 5 valves on LB650 CM (2 beamline vacuum gate valves, 1 insulating vacuum gate valve, 2 cryo valves)
- “Instrument quality” air - conditioned, dry, low-oil
- System MAWP 100 psig
- System supply pressure at interface to LB650 $\geq$ 80 psig
- Fitting on LB650: INSERT - Location TBD

The LB650 also requires compressed air for the coupler window and DC block (continuous use). See block diagram below for the general configuration.



The AD/Fluids group shall provide this air, with the following parameters:

- One supply line to each coupler/DC block assembly. The 8 couplers are supplied in parallel
- Each coupler/DC block assembly are supplied with a single air flow, which flows through the antenna first and then the DC block
- Conditioned air
  - Particles $\geq$ 5µm filtered
  - Moisture removed, dew point $\leq$ -10°C
  - Oil removed
- System MAWP 50 psig
- System protected with relief valve, setting = 40psig at initial installation
  - Setting may be increased up to MAWP later if more flow is required

- System supply pressure at interface to LB650 regulated
    - Adjustable 15-50 psig, nominal 30 psig
    - One regulator for all 8 window connections
- Flow rate requirements
    - Absolute minimum permissible flow: >1g/s (>1.7 SCFM) per coupler/DC block
    - Intial setting of interlock: >2 SCFM per coupler/DC block
    - Target nominal flow rate: >2.5 SCFM per coupler/DC bock
    - Total target nominal flow delivered to LB650 = 2.5 X 8 = 20 SCFM minimum
    - Total target nominal flow rate available for future SSR2 = 25 SCFM minimum
        - Note - SSR2 is expected to have approximately 2X the required flow rate, but has 5 cavities as compared to LB650's 8. SSR2 cryomodules will be tested in the PIP2IT cave, so the system should be designed with enough capacity for this future upgrade
- Instrumentation of return air flow from each coupler/DC block required (8 return flow measurements total). LB650 team to provide air-tight coupler and DC block. AD/RF to provide air-tight bullet at RF connection to DC block. AD/Fluids team to provide flow measurement.
- Inlet Fitting on LB650: INSERT
- Outlet Fitting on LB650: INSERT

The LB650 does not require water cooling for any system. (Note – RF circulators and loads provided by AD/HLRF and located below the cryomodule will require cooling. Specification of this is not within the scope of this document).

The LB650 does not require AC power in the cave. (Note - Insulating vacuum systems will, but these are provided by AD/vacuum engineering, and specification is not within the scope of this document).

Note that the LB650 will be sensitive to vibration induced by fluids systems. Please see microphonics requirements in section 12.

6. Coupler Port (CP) & RF Connections

The LB650 cryomodule has eight Coupler ports located along the length of the Cryomodule. The coupler ports include the RF connection and associated instrumentation. Figure 6.1 shows the locations of the coupler ports. The LB650 provides an RF input connection: 3 1/8” EIA standard 50 Ohm Coax.

AD/RF team provides RF distribution to this point, including any directional couplers, local circulators, and circulator loads.

Each port accommodates multiple connections in addition to the RF input. A list of the connectors, sensor type and other information of the coupler ports instrumentation can be seen in table 6.3 below.

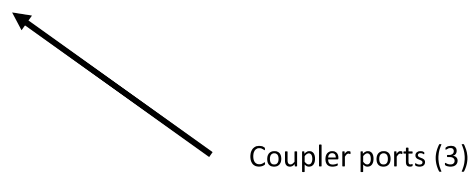


Figure 6.1: Locations of Coupler Ports

A prototype of the coupler is shown under test in figure 6.2. The operating voltage is between XX and XX kV. Couplers for LB650 at PIP-II Injector Test will be rated and tested to XXX kW [3].

In addition to the RF input, each coupler port accommodates other instrumentation and interface points:

- One RF field probe (i.e. the E-pickup)
- Thermometry for various points in the coupler
- Connections for field emission probe, which looks for emitting electrons
- Two air inlets (see section 5)
    - 1 air inlet (A) uses dry room temperature air to keep the ceramic window warm
    - 1 air inlet (B) to keep the inlet RF power chamber cool
- A connection for high voltage bias
- A power supply connection for the Photo multiplier tube (PMT) which is looks at the ceramic window.
- A connection for the PMT signal

The connections and pinouts of these interfaces are tabulated in Table 6.3

Figure 6.2: First is the front view of coupler port in testing. Second is side view to show connection on back side.

Table 6.3: RF coupler connections. Typical at each *coupler port*

7. Tuners and Tuner Access Ports (TAP)

The LB650 Cryomodule will have a tuner on each cavity. The tuners attach to each cavity shown in figure 7.1.

Figure 7.1: LB650 tuner configuration

These tuners consist of a stepper motor, piezos, 2 limit switches and a temperature probe. The tuners are accessed via the tuner access ports (TAPS) which are located on the side of the cryomodule shown in figure 7.2. The entire actuation group is assembled on a removable cartridge in order to increase its reliability allowing the removal from the cryomodule via the tuner access port in the case of failure of one of the components. Please see ED000XXXX [4] for more detailed information on the cavity tuner.

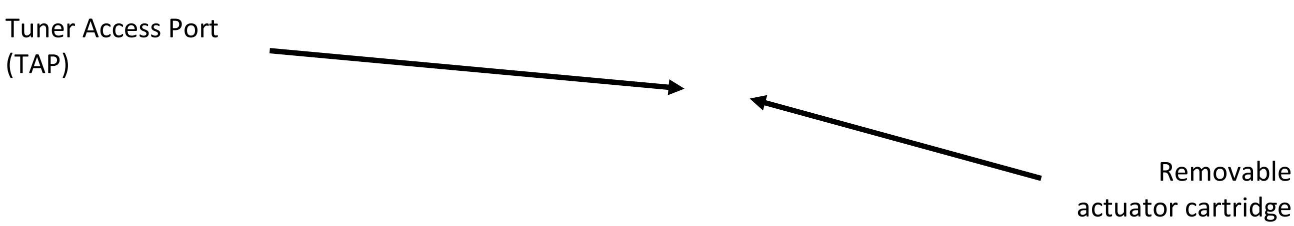


Figure 7.2: Access ports to the removable cartridge

Nomenclature and numbering

The Tuner Access Ports are identified by their associated cavity (e.g. TAP1 through TAP3, TAP1 services cavity 1). Each TAP accommodates several multi-pin electrical connectors. To each connector is assigned an identifying number. For example, TAP1-C3 refers to connector #3 on the 1st Tuner Access Port.

The connections hosted on the TAPs cover not only tuner-associated hardware, but also miscellaneous instrumentation (liquid level, etc.).

Connections present on every TAP (e.g. motion control for the tuner) are shown in Table 7.3 Connections present only on some TAPs (e.g. helium level probe interfaces are all on TAP1) are shown in Table 7.4

In the following tables the instrumentation for each tuner access port has been defined. Some changes are expected before the final review of the cryomodule. Please to refer to F100XXXX to get the last version of the Piping and Instrumentation diagram [5].

Figure 7.3: Tuner Access ports - Connectors #

Table 7.4: 1st Tuner Access Port

Table 7.5: 2nd Tuner Access Port

Table 7.6: 3rd Tuner Access Port

8. Top instrumentation Port (TP)

In addition to the two pressure transducers a 19-pins connector is used for measuring the temperature of the thermal shield.

Table 8.1: Top instrumentation port

Connector 1: Swagelok 6LV-8-VCR-3-8TB3 (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	X	PE-G1	0-100 Torr, VCR 8 female MKS 230EA–00100BB	Top flange	TP-C1

Connector 2: Swagelok 6LV-8-VCR-3-8TB3 (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	X	PE-G2	0-100 psia, VCR 8 female MKS 750C12PCE4GD	Top flange	TP-C2

Conflat flange for the relief line, 10" CF F10075540

Connector 3: DT02H-14-19PN (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	I+	TE-SH	Cernox CX-1030-CU-HT	Thermal shield	TP-C3-P1
2	I-				TP-C3-P2
3	V+				TP-C3-P3
4	V-				TP-C3-P4
5	I+	TE-SH	Cernox CX-1030-CU-HT	Thermal shield	TP-C3-P5
6	I-				TP-C3-P6
7	V+				TP-C3-P7
8	V-				TP-C3-P8
9	I+	TE-SH	Cernox CX-1030-CU-HT	Thermal intercept relief line	TP-C3-P9
10	I-				TP-C3-P10
11	V+				TP-C3-P11
12	V-				TP-C3-P12
13					
14					
15					
16					
17					
18					
19					

9. Cryogenic Connections

Cryogenic Circuits

The schematic of the cryomodule cryogenic piping is shown in Figure 9.1 and 9.2

The LB650 Cryomodule will have three sections held at different temperatures:

- The outer shield is held at 35-50 K with gaseous Helium
- The inner shield is held at 5 K with liquid helium
- The cavities and solenoids are held at 2 K with superfluid liquid helium

Interfaces of each circuits are as follows:

- The 35-50 K and 5 K helium connections are through Fermilab Bayonets (F10085260)
- The sub atmospheric pumping line holding the 2 K circuit at low pressure is the large bayonet of JLAB design (F10008295).

Location of the interface points and dimensional information are shown in figures 9.3 and 9.4.

The LB650 includes two WEKA DN15 cryo valves, serving as a JT valve and a cooldown control valve. The data sheet for the cryo valves can be viewed in the appendix.

Cryogenic controls

The LB650 itself does not include any controls, only the instrumentation and pneumatic valves as described herein. The AD/Cryo team is responsible for implementing controls to achieve and maintain the requisite operation parameters of the LB650.

Figure 9.1: LB650 Cryo Piping Block Diagram

Figure 9.2: LB650 Cryo Interface P&ID [5]

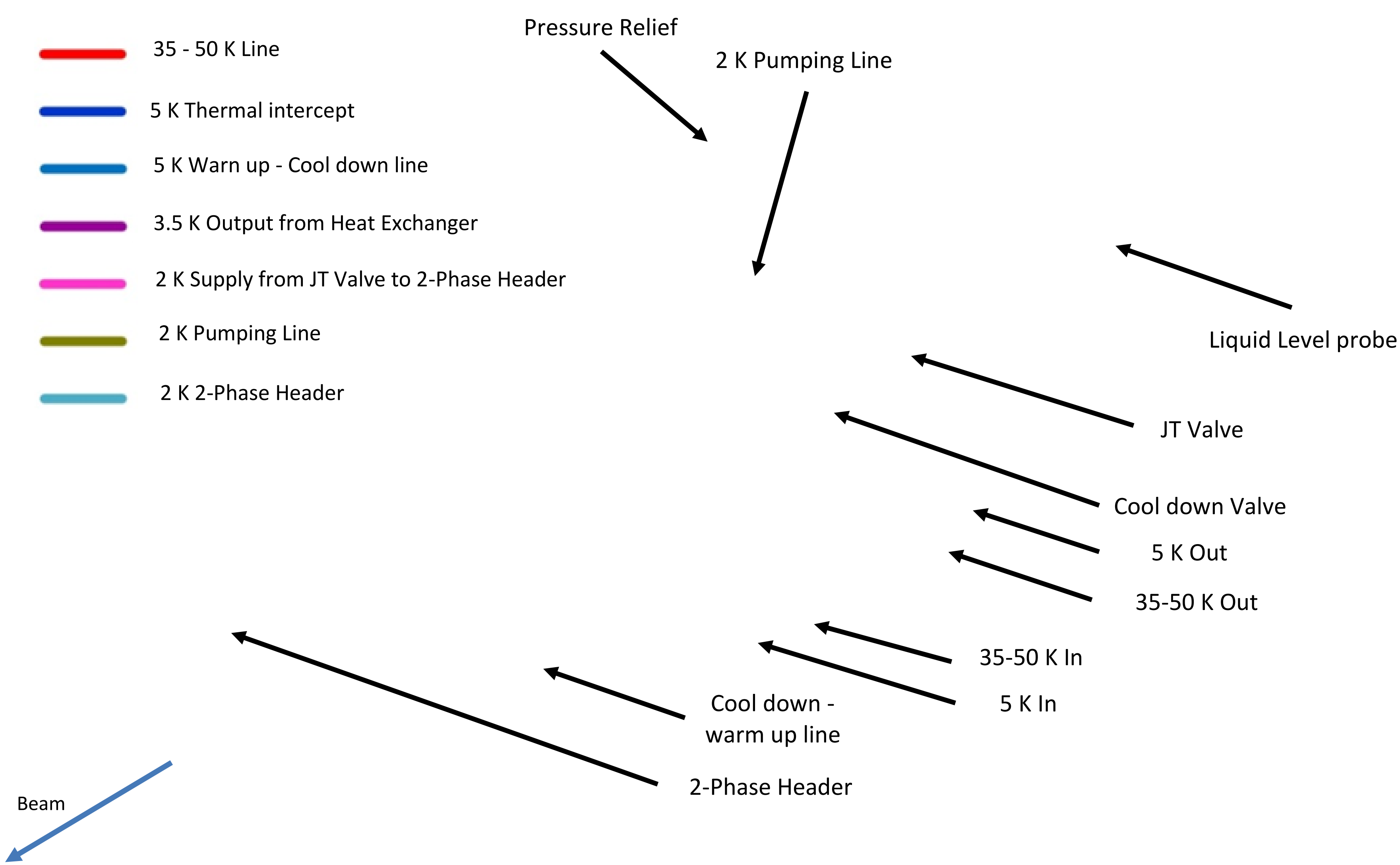


Figure 9.3: LB650 Cryogenic circuits

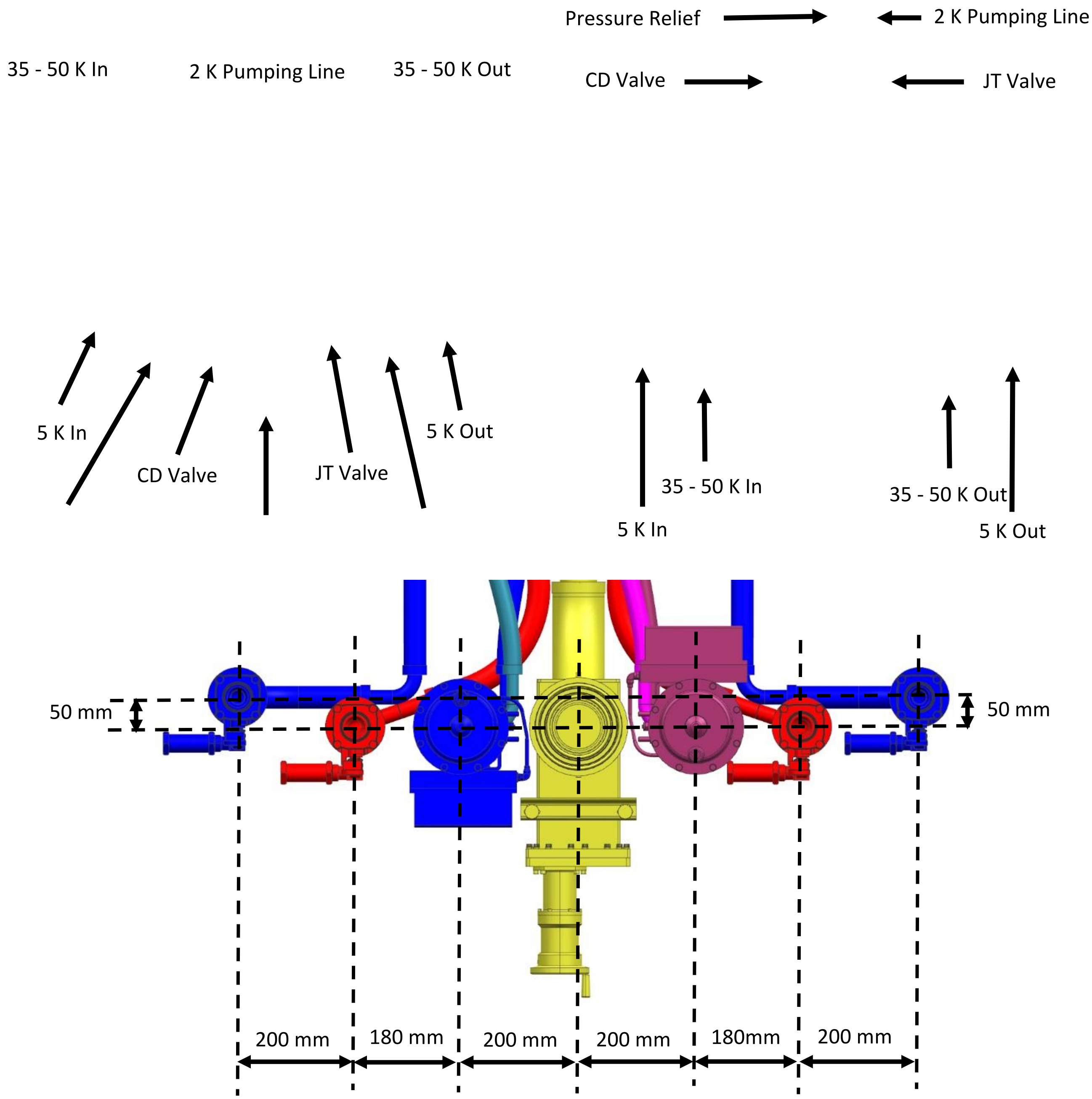


Figure 9.4: LB650 Cryogenic connections

Coldmass Mass

In order to design the PIP-II Injector Test Cryo Distribution System (CDS), it is necessary to define the thermal cold mass in each temperature regime. The LB650 shall have cold masses as specified in the table below:

Temperature	Mass	Comments
Mass at 35-50 K	kg +/- 5%	No mass for bayonets and JT with connecting lines, no mass for thermal straps
Mass at 5 K	kg +/- 10%	No mass for bayonets and JT with connecting lines, no mass for thermal straps
Mass at 2 K	kg +/- 5%	No mass for bayonets and JT with connecting lines, no Power couplers and thermal straps

Pressure Relief

The LB650 includes a port for pressure relief of the 2 K circuit, as shown in Figure 9.5. The port is a 10" Conflat flange. The LB650 cryomodule does not include a relief valve on this line.

The LB650 does provide pressure relief of the 35-50 K and 5 K circuits thanks to a relief valve located on the bayonet.

The LB650 does provide an integral parallel-plate pressure relief for the cryostat.

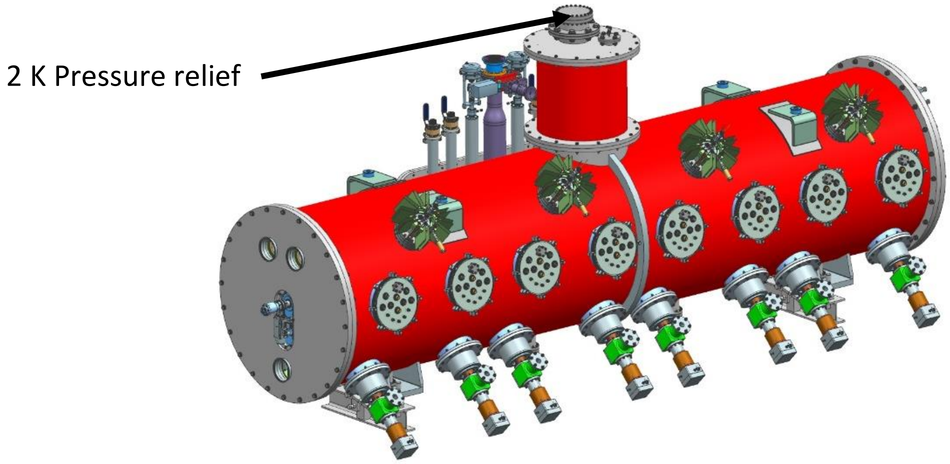


Figure 9.5: 2K Pressure Relief Port

Note that the LB650 will be sensitive to vibration induced by this system. Please see microphonics requirements in section 12.

10. Cryomodule Vacuum Systems

Beamline Vacuum

The connection to beamline vacuum is via the gate valves detailed in Section 2.

The LB650 itself does not provide any pumping of beamline vacuum (except for natural cryo pumping). The AD/Vacuum team shall provide pumping at each end of the LB650 to achieve requisite vacuum levels before and after cooldown, as shown in Table 10.2.

All vacuum work on the LB650 beamline vacuum and adjacent vacuum systems shall follow low-particulate UHV vacuum practices as defined in the PIP-II Injector Test Vacuum FRS [6].

The CMTF/Facilities team shall provide a cleanroom and mass-flow-control pumping station for use with the LB650.

Insulating Vacuum

The LB650 deliverable does not include any pumping of insulating vacuum (except for natural cryo pumping).

The LB650 does provide a 6” Conflat port for insulating vacuum pumping hardware, the location is shown in Figure 10.1

The AD/Vacuum team shall provide insulating vacuum hardware to achieve requisite vacuum levels before and after cooldown, as shown in Table 10.2

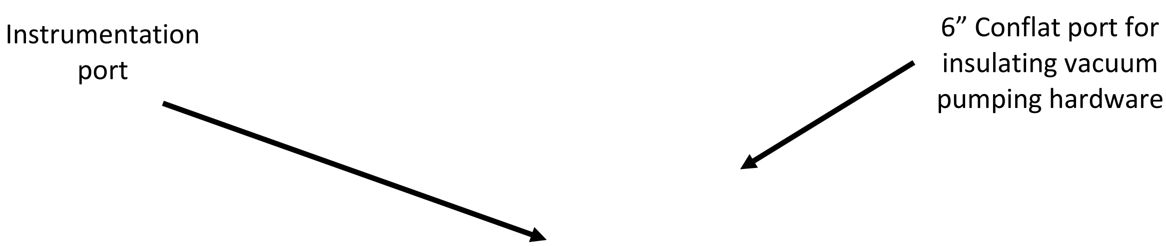


Figure 10 1: Insulating Vacuum Pumping Port - Arrangement does not match current design.

Coupler Vacuum – none

There is no separate coupler vacuum on LB650 cryomodule.

Target Vacuum Levels

Maximum H_2 flux from the HEBT to the LB650 shall be INSERT. AD/Vacuum is responsible for oversight of HEBT/Dump design to ensure this requirement is met.

Note – HWR cryo-pumping is assumed to effectively isolate LB650 from MEBT-generated H_2. As such, no LB650-based requirement is levied on the MEBT.

The PIP-II Injector Test vacuum system shall be designed to achieve vacuum levels in the LB650 as specified in Table 1.2. The AD/Vacuum team is responsible for design and oversight to ensure these requirements are met:

Table 10.2 – Vacuum requirements

Requirements and devices of the cryomodule vacuum subsystems

		Beamline vacuum	**Insulating vacuum**
Description		In contrast to storage ring type light sources, here the beam particles pass the straight linac only once. Therefore, the beamline vacuum pressure requirement with respect to losses due to scattering on the residual gas are relaxed. Effects like emittance growth, fast ion instabilities or dynamic pressure increase due to synchrotron radiation are negligible. However, particles can act as field emitters and thus limit the performance of the cavities.	The insulating vacuum serves to minimize convective heat transfer to the cavity helium vessel and heat conduction through residual gas the MLIs. For this purpose, a pressure of less than 1.0×10^{-4} Torr is required for the insulating vacuum space.
Pressure(Torr)	**At cold**	$\leq 1 \times 10^{-10}$	$\leq 1 \times 10^{-6}$
	prior to cool-down	$\leq 1 \times 10^{-8}$	$\leq 1 \times 10^{-4}$
Characteristics		Particle free pump-down/venting	Pressure dominated by water in MLI, permeation through many O-rings
Pumps	**Roughing**	Turbo, w/ particle free setup	Roots Blower, then Turbo
	In operation	Ion pump from ends of cryomodule	Turbo
Gauges	**Cold cathode gauge**	Inverted magnetron, BNC/SHV connectors, 2.75" CFF, MKS #104220008	
	Convection gauge	2.75" CFF, MKS #103170024SH	
All-metal right angle valve		DN-40 CF-R, manual actuator, hexagon head, VAT #54132-GE02	

Instrumentation on the cryogenic side port

Connector 1: DT02H-14-19PN (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	I+	TX-730H	Cernox CX-1030-CU-HT	5K line inlet	SP-C1-P1
2	I-				SP-C1-P2
3	V+				SP-C1-P3
4	V-				SP-C1-P4
5	I+	TX-730H	Cernox CX-1030-CU-HT	5K line inlet	SP-C1-P5
6	I-				SP-C1-P6
7	V+				SP-C1-P7
8	V-				SP-C1-P8
9	I+	TX-731H	Cernox CX-1030-CU-HT	After coold down valve	SP-C1-P9
10	I-				SP-C1-P10
11	V+				SP-C1-P11
12	V-				SP-C1-P12
13	I+	TX-731H	Cernox CX-1030-CU-HT	After coold down valve	SP-C1-P13
14	I-				SP-C1-P14
15	V+				SP-C1-P15
16	V-				SP-C1-P16
17					
18					
19					

Connector 2: DT02H-14-19PN (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	I+	TX-732H	Cernox CX-1030-CU-HT	2K line before the JT valve	SP-C2-P1
2	I-				SP-C2-P2
3	V+				SP-C2-P3
4	V-				SP-C2-P4
5	I+	TX-732H	Cernox CX-1030-CU-HT	2K line before the JT valve	SP-C2-P5
6	I-				SP-C2-P6
7	V+				SP-C2-P7
8	V-				SP-C2-P8
9	I+	TX-733H	Cernox CX-1030-CU-HT	2K line after the JT valve	SP-C2-P9
10	I-				SP-C2-P10
11	V+				SP-C2-P11
12	V-				SP-C2-P12
13	I+	TX-733H	Cernox CX-1030-CU-HT	2K line after the JT valve	SP-C2-P13
14	I-				SP-C2-P14
15	V+				SP-C2-P15
16	V-				SP-C2-P16
17					
18					
19					

Connector 3: DT02H-14-19PN (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	I+	TX-734H	Cernox CX-1030-CU-HT	Pumping line before the heat exchanger	SP-C3-P1
2	I-				SP-C3-P2
3	V+				SP-C3-P3
4	V-				SP-C3-P4
5	I+	TX-734H	Cernox CX-1030-CU-HT	Pumping line before the heat exchanger	SP-C3-P5
6	I-				SP-C3-P6
7	V+				SP-C3-P7
8	V-				SP-C3-P8
9	I+	TX-735H	Cernox CX-1030-CU-HT	Pumping line after the heat exchanger	SP-C3-P9
10	I-				SP-C3-P10
11	V+				SP-C3-P11
12	V-				SP-C3-P12
13	I+	TX-735H	Cernox CX-1030-CU-HT	Pumping line after the heat exchanger	SP-C3-P13
14	I-				SP-C3-P14
15	V+				SP-C3-P15
16	V-				SP-C3-P16
17					
18					
19					

Connector 4: DT02H-14-19PN (COLOR)					
#	Wire	Tag #	Instrumentation	Location	Connector ID
1	I+	TE-SH	Cernox CX-1030-CU-HT	Thermal shield top	SP-C4-P1
2	I-				SP-C4-P2
3	V+				SP-C4-P3
4	V-				SP-C4-P4
5	I+	TE-SH	Cernox CX-1030-CU-HT	Thermal shield bottom	SP-C4-P5
6	I-				SP-C4-P6
7	V+				SP-C4-P7
8	V-				SP-C4-P8
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Figure 10.3: Instrumentation on the cryogenic side port

11. RF Interlocks

The AD/RF and AD/interlocks team shall implement RF interlocks. RF interlocks shall be in place during conditioning and operation of the LB650 cavities.

The RF interlock system monitors signals form the following sources in the LB650:

1. Monitor the multipacting arc activity in the Coupler using a PMT at the warm region.
2. Three field emission probes located at the warm region of the coupler, the 35-50 Kelvin region of the coupler, and the cold cavity side of the coupler (5 Kelvin region). These probes monitor the coupler and cavity for plasma inception.
3. The coupler ceramic window temperature on the warm region is monitored using an IR sensor head and a separate PT1000 platinum RTD.
4. Air flow through RF couplers
5. Cavity vacuum soft and hard limits from the cold cathode gauges and the vacuum pumps. The hard limits are programmed into the CC gauge and the vacuum pump. The soft trip limits are programmed into the PLC which digitizes the analog signals from each of these devices. A TTL bit is used to interface these devices to the interlock system when the vacuum level transitions beyond the trip limit.

The main task of the interlock system is to control the fast GaAs switch which enables low level RF (325 MHz signal) to the amplifier. This switch is enabled when all RF interlocks are made up and controlled by a TTL high sourced at the System Control board in the interlock system. In the event of any trip detected, the RF switch is opened in approximately 120 nanoseconds for all type of trips except the Field emission probes where the switch opening is delayed based on the amount of energy deposition required to condition the source away < 1.0 Joule (RF energy times TF pulse duration).

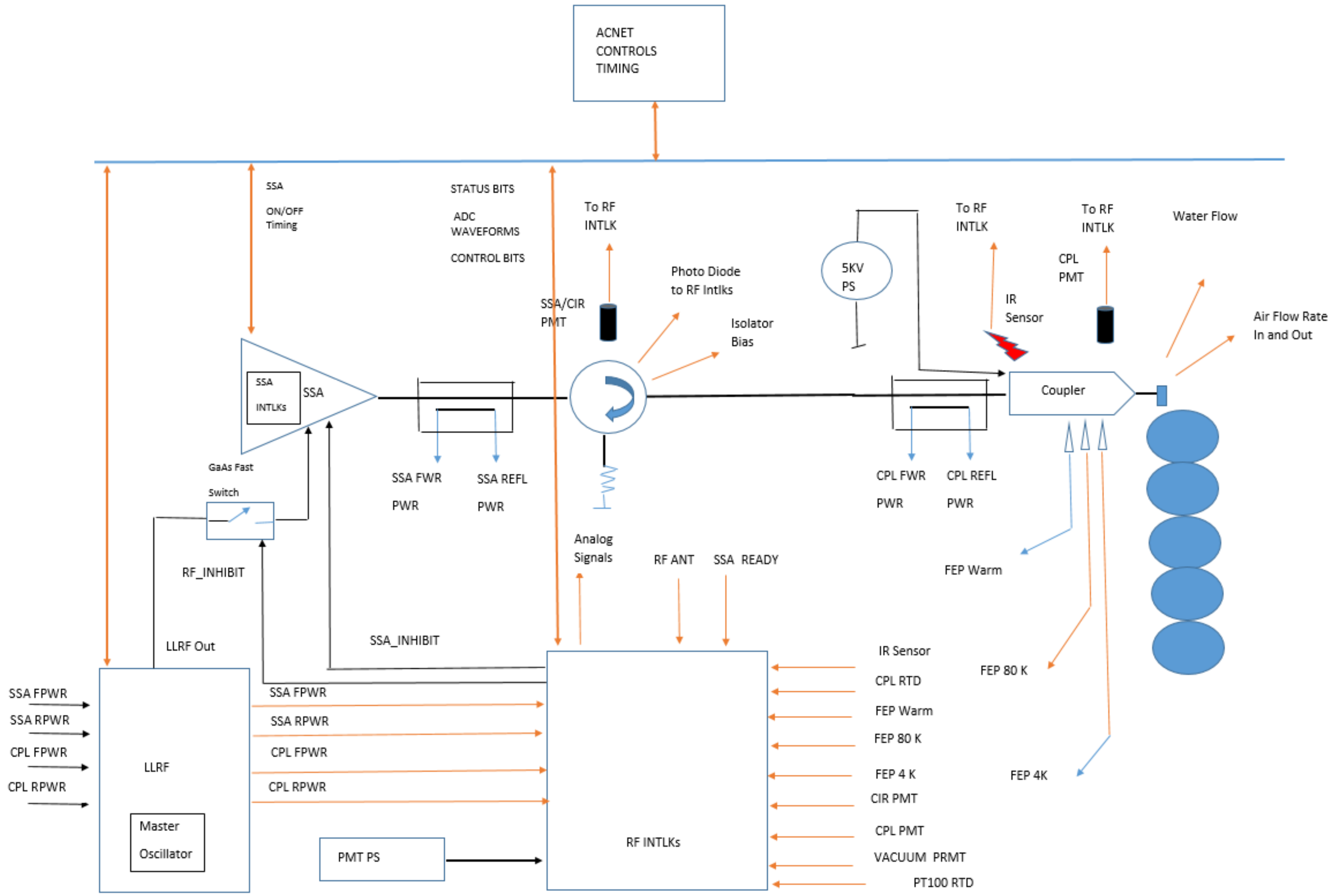

Figure 14.1: Overview Schematic of the LB650 interlocks

12. Microphonics

Isolation and damping of external sources of vibration from the LB650 cryomodule is critical to achieve the tight resonance control specifications for PIP-II.

In PIP-II Injector Test, no active vibration control is planned. As such, passive measures are needed to ensure that the vibration environment is workable.

All hardware connecting to LB650, and all hardware within 3 m of the cryomodule shall conform to the vibration control best-practices documented in [7]. This specifies minimum qualitative requirements for system design. Further design and analysis may reveal that more stringent and quantitative requirements are needed for some systems. Specific considerations for some critical interfacing systems are listed below.

Cryogenics
Cryogenic lines should all include bellows/vibration breaks close to the cryomodule, with no hard mountings in between. This should isolate external mechanical vibrations from transmission into the module. Additionally, sharp transitions/restriction of helium flow should be avoided, reducing flow noise. These cryo lines should also be properly constrained and have their movement damped.

Fluids
RF drive lines will have water cooling, and similar best practices can be applied here as to cryo lines: no hard mountings connected to the cryomodule, avoid flow restrictions/transitions/throttling to reduce flow noise. These are less complicated because soft lines can be used, not in a vacuum jacket. These lines should also be properly constrained and have their movement damped.

Gas lines will be used to cool the cavity couplers. Given their proximity to the cavity, it will be important to avoid any flow noise in these lines. Experience with the RFQ air lines indicates that noise should not be an issue as the lines are sized. Additionally, they should be vented far from the cryomodule. Use of soft lines for supply and exhaust reduces danger of vibration transmission.

Cryomodule Footing
The cryomodule will be hard mounted to a girder. That is, it will essentially be rigid to the facility floor. As such, it is important to minimize vibration sources in nearby equipment that can couple into floor.

Beamline Connections
Bellows should be incorporated along the beamline to minimize vibration transmissions. These bellows should be in a free state during operations.

RF Connections
The coax line to the cavities (provided by AD-RF) should incorporate flexibility at the interface to the coupler. This should be implemented with a flexible section of coax near the cryomodule. Damping should be incorporated to further minimize transmission of vibration. Air flow in the RF couplers should not excite microphonics at dangerous level.

Signal Connections
Mostly signal wires and small RF cables, these should be all either soft or flexible lines. Some strain relief will likely be built into these wires, and they are not considered a dangerous source of vibration.

External sources and measurement devices

The PIP-II Injector Test/CMTF facility was designed with consideration for vibration isolation. For example, the cryoplant is built on a separate foundation. Hardware near the cryomodule should be designed and installed per the best practices document [7]. However, given that PIP-II Injector Test is a shared facility and a test facility, there is currently no intention to impose broad vibration-control requirements or operations constraints within the facility. Experience with PIP-II Injector Test will guide further thinking in this matter.

The PIP-II Injector Test/Facilities team shall provide environment monitoring devices close to LB650 so that environmental vibrations can be monitored. In the case of unacceptable microphonics, this system may be used to identify and mitigate driving sources.

Internal Monitoring Devices

There are no requirements or plans to incorporate vibrating measuring devices in the cryomodule.

References

[1] Drawing XXXX: Assembly, Cryomodule LB650 MHz.
[2] Drawing F10051422: ENVELOPE, TRANSVERSE, PIP-II CRYOMODULES.
[3] ED000XXXX: FRS, 650 MHz Coupler.
[4] ED000XXXX: Specification for the LB650 tuner.
[5] Drawing F10042546: P&ID, PIP2IT Cryogenic Distribtion System.
[6] ED0004444: FRS, PXIE Vacuum Systems.
[7] ED0002931: Vibration control best-practices for PXIE.

Appendix

VAT

WEKA CRYO VALVE