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PIP-II LB650, 650 MHz RF Amplifier

Functional Requirements Specification

**IIFC Approvals**

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Revision History

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| --- | --- | --- |
| Revision | Date of Release | Description of Change |
| - | 17 JUL 2010 | Initial Draft – Docdb |
| - | 16 SEP 2015 | Initial Release – Uploaded into Teamcenter (ED0003679) |
| - | 10 NOV 2015 | Updated for RRCAT review |
| A | 28 DEC 2015 | Changes in line with RDR requirements (ED0003413) |
| B | 23 APR 2020 | Updated format; Included new requirements for construction phase |
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# Purpose

An FRS describes the project needs and/or requested behavior of a system or component. The document typically outlines what is needed by the end user as well as the requirements and requested properties of inputs and outputs. The FRS specifies the functions that a system or component must perform and establishes consensus among stakeholders on what the system is expected to provide.

# Scope

The scope of the 650MHz LB650 RF amplifier function consists of all RF power amplifiers used to power LB650 cavities in the PIP-II linear accelerator. Each LB650 cavity in the accelerator will have a dedicated RF amplifier for its power source. Each amplifier will receive a dedicated signal from a 650MHz LLRF control system as an input. The output of the amplifier drives an RF distribution system that is connected to the input coupler of the cavity.

# Acronyms

|  |  |
| --- | --- |
| FEM | Fermilab Engineering Manual |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FRS | Functional Requirements Specification |
| HPRF | High Power Radio Frequency |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| LLRF | Low Level Radio Frequency |
| MPS | Machine Protection System |
| PIP-II | Proton Improvement Plan II Project  |
| RF | Radio Frequency |
| SRF | Superconducting Radio Frequency |
| TC | Teamcenter |
| WBS | Work Breakdown Structure |

# Reference

|  |  |  |
| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | RF Power Systems EPDM | ED0002850 |
|  | PIP-II Linac RF Systems PRD | ED0010220 |
|  | PIP-II RF Power System L3 FRS | ED0008023 |
| 2 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) (FEM) | - |
| 3 | [Fermilab Environmental Safety and Health Manual](http://eshq.fnal.gov/manuals/feshm/) (FESHM) | - |
| 4 | Fermilab Radiological Control Manual (FRCM) | - |

# Key Assumptions

These requirements for the amplifier assume that the necessary cooling media is provided to the power equipment (i.e. water and forced air) and that the cooling infrastructure can remove the heat generated.

# Functional Requirements

## Primary Requirements

These requirements define the primary purpose of the HLRF system within the project scope.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-A001 | The amplifier shall have sufficient and stable gain to maintain the closed loop bandwidth for cavity field regulation as specified in PRD. |
| F-ED0003413-A002 | The amplifier shall be capable of providing sufficient power to accelerate a continuous stream of beam current in the LB650 cavities with amplitude specified in GRD. |
| F-ED0003413-A003 | The amplifier shall respond to changes in drive amplitude and phase quickly enough to maintain closed loop stability as specified in PRD. |
| F-ED0003413-A004 | The amplifier shall respond to changes in drive amplitude and phase with sufficient precision to compensate for beam loading in the cavity as specified in PRD. |
| F-ED0003413-A005 | The amplifier shall be able to provide for pulsed operation for purposes of conditioning SRF cavities and input couplers. |
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## Personnel Safety Requirements

These requirements define system features that are necessary to protect beam enclosure and HPRF maintenance personnel.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-B001 | The amplifier shall accommodate a signal input that disables the amplifier output in a verifiable and fail-safe manner. |
|  F-ED0003413-B002 | The amplifier shall have a visible, removable plug into a power receptacle or be equipped with a fail-safe, external means of verifying that its main power source has been disconnected. |
|  F-ED0003413-B003 | The amplifier shall have a visible, removable plug into a power receptacle or be equipped with an internal means of measuring the AC mains voltage with standard probes from a volt-meter. |
|  F-ED0003413-B004 | The amplifier shall have a ground stick accessible point for discharging any hazardous stored electrical energy after the main power source is disconnected. |
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## Self-Preservation Requirements

These requirements specify the necessary isolators and protection interlocks for the power amplifiers.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-C001 | The amplifier shall withstand any backward power wave that can be reflected from the RF distribution circulator. |
|  F-ED0003413-C002 | The amplifiers shall disable their output if their input drive power exceeds the drive necessary for the maximum specified output power. |
| F-ED0003413-C003 | The amplifier shall protect itself from input overdrive.  |
|  F-ED0003413-C004 | The amplifiers shall disable their output if the reflected power into the output exceeds the amplifier specification. |
|  F-ED0003413-C005 | The amplifiers shall disable their output and bias if the cooling system fails. |
|  F-ED0003413-C006 | The amplifiers shall disable their output and bias if critical internal temperatures are exceeded. |
|  F-ED0003413-C007 | The amplifiers shall disable their output and bias if coolant water inlet temperatures significantly exceed specified values. |
| F-ED0003413-C008 | The amplifiers shall disable their output and bias if the ambient temperature significantly exceeds specified values. |
| F-ED0003413-C009 | The amplifiers shall not re-enable the output after being disabled by a trip until the trip is RESET. |
| F-ED0003413-C010 | The amplifier should be able to withstand sudden loss of line power without damage and return to a safe state when power is restored. |

## Cavity Protection Requirements

These requirements specify how the amplifier will protect its cavity and cavity components from damage due to RF and beam.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-D001 | The amplifiers shall accommodate an input signal that will disable the output of the amplifier in a fail-safe manner. |
|  F-ED0003413-D002 | The amplifiers shall provide an output signal that represents the output disabled state of the amplifier (for MPS). |

## Control & Diagnostics Requirements

These requirements define the necessary remote and local controls for power amplifier operation. These requirements also define the necessary available diagnostics for operation and maintenance.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-E001 | The amplifiers shall include a signal input for turning the amplifier output ON, a signal input for turning the amplifier output OFF, and a signal input for RESETting the amplifier after the output is disabled. |
|  F-ED0003413-E002 | The amplifiers shall include a local switch that disables the remote signal inputs. |
|  F-ED0003413-E003 | The amplifiers shall include a local means, on the amplifier, for turning the amplifier output ON, a local means for turning the amplifier output OFF and a local means of RESETting the amplifier after the output is disabled. |
|  F-ED0003413-E004 | The amplifiers shall provide signal outputs that represent the output enabled and the different output disabled states of the system such as cooling interruption, overtemperature, or high reflected power. |
|  F-ED0003413-E005 | The amplifiers shall provide a standard network connection for access to internal parameters for advanced diagnostics. |
| F-ED0003413-E006 | The amplifiers shall provide a trigger input for synchronous sampling of RF power output and advanced diagnostics parameters.  |
|  F-ED0003413-E007 | The amplifiers shall provide a time-stamped buffer of data generated by the synchronous trigger for later retrieval through the network connection. |
|  F-ED0003413-E008 | The amplifier shall provide a signal that represents its RF power output. |
|  F-ED0003413-E009 | The amplifier shall provide a warning when the coolant inlet temperature is out of specified range. |
| F-ED0003413-E010 | The amplifier shall provide a warning when the ambient temperature is out of specified range. |
| F-ED0003413-E011 | The amplifier shall have an independent mains sources for amplifier control and diagnostics system to allow verification of readings during maintenance and repair. |

## Installation and Integration Requirements

These requirements define the specifications that will ensure that the HPRF components can be successfully installed and connected between the beam line and gallery.

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-F001 | The space occupied by the HPRF amplifiers shall fit inside the PIP-II gallery building.  |
|  F-ED0003413-F002 | Each pre-assembled amplifier component shall fit on a standard fork lift pallet or have sufficient clearance and stability for standard forks to lift the component directly. |
|  F-ED0003413-F003 | Each pre-assembled amplifier component shall fit inside a standard size trailer for transport. |
| F-ED0003413-F004 | The pre-assembled amplifier shall be crated to survive shipping by truck, airplane, or ship without requiring component repairs on arrival at destination. |
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## Maintainability Requirements

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| **Requirement #** | **Requirement Statement** |
|  F-ED0003413-G001 | The amplifier components shall have a small enough MTBF and MTTR to maintain availability specified in  |
| F-ED0003413-G002 | The amplifier shall have a means of draining its coolant for maintenance, transport, and long term storage. |
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# Safety Requirements

The system shall abide by all Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements including but not limited to:

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| --- |
| Electrical Safety |
| * FESHM Chapter 9110 Electrical Utilization Equipment Safety
 |
| * FESHM Chapter 9160 Low Voltage, High Current Power Distribution Systems
 |
| * FESHM Chapter 9190 Grounding Requirements for Electrical Distribution and Utilization Equipment
 |
| General Safety |
| * FESHM Chapter 2000 Planning for Safe Operations
 |

Any changes in the applicability or adherence to these standards and requirements require the approval and authorization of the PIP-II Technical Director or designee.

In addition, the following codes and standards in their latest edition shall be applied to the engineering, design, fabrication, assembly and tests of the given system:

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| --- |
| NFPA 70 – National Electrical Code |
| IEC Standards for Electrical Components |
| * IEC 61010-1 Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use
 |
| * IEC 61204 Low-Voltage Power Supply Devices, D.C. Output – Performance Characteristics
 |
| * IEC 60068 Environmental Testing of Electronic Equipment
 |

In cases where International Codes and Standards are used the system shall follow FESHM Chapter 2110 Ensuring Equivalent Safety Performance when Using International Codes and Standards and requires the approval and authorization of the PIP-II Technical Director or designee.

Additional Safety Requirements that are not listed in the general list above shall be included in the Requirements table in the Functional Requirements section.