PIP-II High Power Radio Frequency

Functional Requirements Specification

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**Document Approval**

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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 HPRF WBS entry covers design, procurement, fabrication, and testing of the Linac RF power amplifiers and transmission hardware. It includes development of systems at 162.5 MHz, 325 MHz, and 650 MHz, for both test infrastructure and Linac systems. Each RF cavity in the accelerator will have a dedicated RF amplifier for its power source (the RFQ will have two amplifiers, one for each input coupler). The scope of the HPRF function lies between the RF signal source (LLRF) and the input coupler of the various accelerator cavities as shown in red in Figure 1. The key components of the system will consist of a RF power amplifier and the connection between the amplifier and input coupler of the cavity.

Figure 1: Simple block diagram of RF system for PIP-II cavities.



# Acronyms

|  |  |
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| 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

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| **#** | **Reference** | **Document #** |
| 1 | RF Power Systems EPDM | ED0002850 |
| 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 HPRF systems 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-121.03.03-A001 | The HPRF system shall provide a linearly magnified replica of its input signal within the specified bandwidth of its operation. |
| F-121.03.03-A002 | The HPRF system shall transport RF power signals from the output of the power source to the cavity input coupler without RF leakage. |
| F-121.03.03-A003 | The HPRF system amplifiers shall accommodate external interlock input signals to protect against potential damage to the amplifiers, load including cavity, and harm to personnel. |

## 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-121.03.03-B001 | All HPRF systems that drive SRF cavities shall accommodate a signal input that disables the amplifier output in a verifiable and fail-safe manner. |
| F-121.03.03-B002 | Each HPRF 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-121.03.03-B003 | Each HPRF 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-121.03.03-B004 | Each HPRF amplifier shall have a ground stick accessible point for discharging hazardous stored electrical energy after the main power source is disconnected. |

## Self-Preservation Requirements

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

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| **Requirement #** | **Requirement Statement** |
| F-121.03.03-C001 | The HPRF system shall withstand any backward power wave that can be reflected or generated from the cavity during operation without damage. |
| F-121.03.03-C002 | The HPRF system amplifiers shall disable their output if their input drive power exceeds the drive necessary for the maximum specified output power. |
| F-121.03.03-C003 | The HPRF system amplifiers shall disable their output if the reflected power into the output exceeds the amplifier specification. |
| F-121.03.03-C004 | The HPRF system amplifiers shall disable their output if the cooling system fails. |
| F-121.03.03-C005 | The HPRF system amplifiers shall disable their output if critical internal temperatures are exceeded. |
| F-121.03.03-C006 | The HPRF system amplifiers shall not re-enable the output after being disabled by a trip until the trip is RESET. |

## Cavity Protection Requirements

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

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| **Requirement #** | **Requirement Statement** |
| F-121.03.03-D001 | The HPRF system amplifiers shall accommodate an input signal that will disable the output of the amplifier in a fail-safe manner. |
| F-121.03.03-D002 | The HPRF system 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-121.03.03-E001 | The HPRF system 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-121.03.03-E002 | The HPRF system amplifiers shall include a local switch that disables the remote signal inputs. |
| F-121.03.03-E003 | The HPRF system 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-121.03.03-E004 | The HPRF system 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-121.03.03-E005 | The HPRF system shall provide a linear sample of the forward and reflected RF power at the cavity input coupler. |
| F-121.03.03-E006 | The HPRF system amplifier shall provide a signal that represents its RF power output. |

## 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-121.03.03-F001 | The space occupied by the HPRF amplifiers shall fit inside the PIP-II gallery building. |
| F-121.03.03-F002 | Each pre-assembled HPRF system component shall fit on a standard fork lift pallet or have sufficient clearance and stability for standard forks to lift the component directly. |
| F-121.03.03-F003 | Each pre-assembled HPRF system component shall fit inside a standard size trailer for transport. |
| F-121.03.03-F004 | The HPRF system distribution for each cavity shall fit inside a gallery to beam line penetration and capable of being assembled from outside the penetrations. |
| F-121.03.03-F005 | The HPRF distribution system route shall not interfere with the route of other distribution systems nor interfere with cryomodule transport through the tunnel or accelerator enclosure. |

# 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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| Pressure and Cryogenic Safety |
| * FESHM Chapter 5031 Pressure Vessels |
| * FESHM Chapter 5031.1 Piping Systems |
| * FESHM Chapter 5031.5 Low Pressure Vessels and Fluid Containment |
| * FESHM Chapter 5031.6 Dressed Niobium SRF Cavity Pressure Safety |
| * FESHM Chapter 5032 Cryogenic System Review |
| * FESHM Chapter 5033 Vacuum Vessel Safety |
| 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 |
| Radiation Safety ANSI ASC A14.3  -2000  Safety Requirements for Fixed Ladders |
| * FRCM Chapter 8 ALARA Management of Accelerator Radiation Shielding |
| * FRCM Chapter 10 Radiation Safety Interlock Systems |
| * FRCM Chapter 11 Environmental Radiation Monitoring and Control |
| 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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| ASME B31.3 Process Piping ANSI ASC A14.3  -2000  Safety Requirements for Fixed Ladders |
| ASME Boiler and Pressure Vessel Code (BPVC) |
| CGA S-1.3 Pressure Relief Standards |
| NFPA 70 – National Electrical Code |
| IEC Standards for Electrical Components |

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.