**PIP-II IT Test Facility 650 MHz RF Distribution System Technical Requirement Specification**

**1. Purpose**

The PIP2IT test facility 650 MHz RF distribution system transports output power from power amplifiers to input couplers of 650 MHz superconducting cavities in both LB650 and HB650 cryomodules for testing those cavities up to 110% of their specified maximum E field along beam line.

This document specifies technical requirements which enables this distribution system meet its functional requirements defined in document “The PIP2IT test facility 650 MHz RF distribution system functional requirement specification”,

 Document No. TBD

**2. Scope**

The PIP II test facility 650 MHz RF distribution system consists of six separate distribution lines. Each distribution line connects the output port of an RF power amplifier on one end and the input port of the input coupler of a cavity on the other end; and transports RF power from the amplifier to input coupler of the cavity (Figure 1). Each distribution line consists of standard coaxial and waveguide transmission line components, a circulator and a dual directional coupler (Figure 2). The technical specification defined in this document applies to all six distribution lines.



Figure 1. Scope of PIP2IT Test Facility 650 MHz RF Distribution System.



Figure 2. Schematic of the distribution line design plan.

**3. Acronyms**

OSHA: Occupational Safety and Health Administration

FCC: Federal Communications Commission

PA: Power Amplifier

SSA: Solid State Amplifier

CW: continues wave

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**4. Reference**

1. PIP-II L3 FRS, ED0008023, Rev. –

2. PIP-II LB650, 650 MHz RF Amplifier Functional Requirement Specification ED0003413, Rev. B

3. PIP2IT Test Facility 650 MHz RF Distribution System Functional Requirement Specification, ED0000000

4. FCC OET Bulletin 65, Edition 97-01

5. Fermilab Engineering Manual, <https://directorate-docdb.fnal.gov/cgi-bin/ShowDocument?docid=34>

6. ESH DocDB Document 4112-v1, FESHM 5100 - Structural Safety FINAL, <http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=4112>

7. LLRF FRS TBD

Other….

**5. Operating Condition**

The following operation conditions apply to all technical specifications defined in this document.

The high power test of all cryomodules may be performed with output power up to 40 kW from each power amplifier and with partially or fully reflected RF power at any phase when each cavity is operated in either pulsed or CW mode.

At the end of each pulse or the end of operation the stored energy in a cavity will be released and generate up to 90 kW (peak) of backward RF power which decays exponentially to zero in ~5 milliseconds.

**6. Technical Specification**

6.1 Power capability: each assembled distribution line should be capable of transporting 40 kW output power of a power amplifier (PA) to the input port of a cavity in a HB650 cryomodule.

6.2 Total attenuation of each distribution line: less than 0.4 db.

6.3 Dual directional coupler

Power: 40 kW CW, with up to full reflection @ any phase

Center Frequency: 650 MHz

Bandwidth: 10 MHz (650 MHz +/- 5 MHz)

Coupling: -50 +/- 0.5 dB (forward & reverse, with factory calibrations labeled)

Coupling Flatness: 0.1 db in the 650 MHz +/- 1 MHz frequency region and 0.3 db over bandwidth

Directivity: ≥ 40 dB across bandwidth

Mainline VSWR: < 1.02:1

Insertion loss: < 0.01 dB

Coupling ports: dual broadwall (same side) loop couplers, external termination

Coupling port: VSWR ≤ 1.2:1 Typical

Coupling Port Connectors: Type N, female (non-teflon material), 50 ohm impedance

Material: Aluminum 6061, corrosion resistant

Flanges: standard WR1150, CPRF

FINISH: RoHS COMPLIANT CHEMICAL CONVERSION COATING

6.4 Circulator

Port configuration: 3 Ports, Port 1 (input port) and Port 2 (output port) are in-line, Port 3 is terminated by a water cooled 50 Ohm termination (load).

Flanges of all ports: 6 1/8”, 50 Ohm, EIA

Center Frequency: 650 MHz

Bandwidth (BW): +/- 6 MHz

Insertion loss at center frequency: ≤ 0.18 db at center frequency, ≤ 0.3 db in BW

VSWR at all ports: ≤ 1.10:1 at center frequency, ≤1.20:1 in BW

Isolation: ≥ 26 db at center frequency, ≥ 20 db in BW

Power handling capability: the circulator should function normally (above listed specifications should not deteriorate, no sparking and overheating should occur) under the operating conditions listed in section 5.

Cooling system: De-ionized water

Coolant connector: 1/2” NPT male connector, stainless steel

Maximum coolant flow rate: 10 gpm

Maximum coolant pressure drop: 20% of inlet pressure

 Maximum coolant inlet pressure: 145 PSI

Active magnetic adjustment for temperature compensation: to be specified by vendors

6.5 RF termination (Load, connected to Port 3 of circulator)

Frequency 650 MHz

Impedance: 50 ohms

Power: 80 kW, CW

Flange: 6 1/8”, 50 Ohm, EIA

VSWR: ≤1.15:1

Coolant: LCW water

Coolant connector: 3/4″ (garden hose) or 1/2” NPT male connector, stainless steel

Coolant flow rate: 10 gpm

Max. Inlet Water Pressure: 100 PSI

Max. Outlet Water Temp.: 90°C

Water Connectors: 3/4″ (garden hose) or 1/2″ NPT

Finish: Conversion Coating & Bright Nickel

**7. RF Leakage**

7.1 RF leakage at any joint of the distribution system should be less than 0.4 mW/cm^2 measured at the closest distance from the joint. (FCC OET Bulletin 65, Edition 97-01)

**8. Quality Assurance**

8.1 Each dual directional couplers should be measured with a Network Analyzer before being used in the distribution system. The parameters to be measured include return loss at all 4 ports, insertion loss, coupling ratio and directivity.

8.2 Each circulator should go through two step examination before being used in a distribution line.

First, it should be measured with a Network Analyzer. The parameters to be measured include return loss at all ports, insertion loss and isolation between each pair of ports.

Second, after Network Analyzer measurement each circulator should be high power tested up to 40 kW. During the high power test, the return loss at input port and insertion loss between input port and output port should be measured and compared with the results measured by Network Analyzer. The test should be repeated under the condition of: output port is terminated with 50 Ohm load and is shorted with various length of extension (0, 1/8, 1/4, 1/2 wavelength of TEM wave at 650 MHz). The heat compensation function should be monitored during the high power test.

8.3 All mechanical support structures should comply with the standard described in documents of Fermilab Engineering Manual and ESH DocDB Document 4112-v1, FESHM 5100 - Structural Safety FINAL.