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TECHNICAL SPECIFICATION
for the
HSR 49.2 MHz RF System Circulators

Quality Classification: A-3

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REVISION HISTORY

Revision #	Effective Date	Summary of Change
00	3/05/2026	Initial Release
01	6/29/2026	Revisions from FDR feedback.

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LIST OF ACRONYMS

AC	Alternating Current
ASME	American Society of Mechanical Engineers
BNL	Brookhaven National Laboratory
BSA	Brookhaven Science Associates
EIA	American Electronic Industries Alliance
EIC	Electron-Ion Collider
ESH	Environment, Safety and Health
FAT	Factory Acceptance Testing
FPC	Fundamental power coupler
HPRF	High-Power Radiofrequency
HSR	Hadron Storage Ring
IEC	International Electrotechnical Commission
NCRF	Normal Conducting Radiofrequency
NPT	National Pipe Thread
NRTL	Nationally Recognized Testing Laboratory
RF	Radiofrequency
SAT	Site Acceptance Testing
VAC	Volts Alternating Current
VNA	Vector network analyzer

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Technical Specification for the HSR 49.2 MHz RF System Circulators

1 SCOPE

This document defines the technical specifications for the Hadron Storage Ring (HSR) 49.2 MHz Radiofrequency (RF) System Circulators to be used at the Electron-Ion Collider (EIC) at Brookhaven National Laboratory (BNL) managed by Brookhaven Science Associates (BSA).

1.1 Background

The EIC Project will design, build, and install the accelerator hardware for a new electron storage ring, an electron injector, and modifications to the hadron ring required to produce an electron-ion collider and infrastructure. It will include one interaction region, with an allowance for a second, and one detector. The facility is designed to meet requirements to ensure high reliability and availability for the user program.

The High-Power RF (HPRF) System for the HSR 49.2 MHz RF System will be used to provide power to the 49.2 MHz Normal Conducting RF (NCRF) Cavities. These cavities will be used for the bunch splitting of hadron beams in the HSR of the EIC. During operations of the cavity, the full RF can be reflected towards the RF system requiring a circulator to protect components.

2 APPLICABLE DOCUMENTS

The following specifications, standards and drawings form a part of this specification to the extent specified herein. Unless otherwise specified, the applicable revision level of these documents shall be that in effect on the date of the solicitation or contract. Exceptions must be approved in writing by BSA.

In the event of a conflict between the applicable documents and this specification, the Contractor shall immediately notify the BSA Contractual Representative who shall in each instance determine which document takes precedence and advise the Contractor accordingly. Failure to notify BSA of a document conflict shall not relieve the Contractor's responsibility to ensure full compliance to all requirements.

Document Number	Document Title
EIC-RFS-SOW-015	Statement of Work for the HSR 49.2 MHz RF System Circulators
ASME BTH-1-2023	Design of Below-the-Hook Lifting Devices

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3 SPECIFICATIONS

3.1 Technical/Performance Characteristics

The Circulators shall meet the interface specifications presented in Table 1. Circulator environment specifications are in Table 2, and RF performance specifications may be found in

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Table 3.

Table 1: Circulator interface specifications.

Parameter	Min.	Nominal	Max.	Unit
Coaxial line standard		EIA 6 1/8″		N/A
Coolant connectors (inlet and outlet)		1″ NPT male connector		N/A
Arc detector viewport connector		2x FSMA		N/A

Table 2: Circulator environment specifications.

Parameter	Min.	Nominal	Max.	Unit
Magnetic stray field[1]			5	Gauss
Cooling system coolant		Tap or demineralized water		N/A
Tolerable coolant input temperature	20	25	35	ºC
Tolerable ambient temperature	15		40	ºC
Tolerable relative air humidity			65%	N/A
Tolerable coolant input pressure			10	bar
Tolerable barometric pressure	29.50			inHg

[1] Measured at 1 meter distance from the device in any direction.

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Table 3: Circulator RF specifications.

Parameter	Min.	Nominal	Max.	Unit
Operating Frequency	44.2	49.2	54.2	MHz
Reference impedance		50		ohms
Steady-state forward power[2]	120			kW
Steady-state reverse power at any phase[2]	120			kW
Insertion loss at nominal frequency[3]			0.1	dB
Insertion loss at min. and max. frequency[3]			0.2	dB
Return loss at nominal frequency[3]	26			dB
Return loss at min. and max. frequency[3]	20			dB
Isolation at nominal frequency[3]	26			dB
Isolation at min. and max. frequency[3]	20			dB
Phase over dynamic range[2]			10	º

Table 4: Circulator pulsed RF specifications.

Parameter	Min.	Nominal	Max.	Unit
RF pulse width	0.001		100	ms
RF duty cycle	1		50	%

[2] Refer to Section 4.3.1.1 for additional information.
[3] CW & Pulsed

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3.2 Mechanical Specifications

The Circulator must have at least 3 mounting holes prepared for crane lifting with crane eye bolts, and it must comply with ASME BTH-1-2023 standard. Also, it must be structurally designed to allow lifting with a forklift. Instructions for crane and forklifting must be provided by the Contractor. Information about the engineering process such as, but not limited to, load stability, shear and compressive stresses, center of mass annotations, etc., must be provided. No plastic deformation of any parts shall occur during the displacement or lifting of any devices.

The body material of the Circulator must be in aluminum and/or stainless steel. Internal pipes for the water-cooling system of the Circulator must be made of either copper or stainless steel. Hoses, if used, must be made of radiation-tolerant material. Teflon-based materials must not be used anywhere in the design.

The Circulator design must allow for vertical mounting on a surface. The Circulator mounting surface may not house any one of its three main RF network connections. The Contractor must provide information regarding how much weight can be loaded and sustained by the RF connector located facing up, across the Circulator body and opposite to the mounting surface. The remaining three sides of the Circulator that are not used for mounting must each house one of the three main RF network connections.

3.3 Active Compensation Unit

If the Contractor proposes any type of electronic mechanism to act on a parameter of the Circulator (i.e. magnetic field) in order to comply with any specifications, this electronic mechanism must be enclosed in a 19″ rack-standard crate, and it must use a 1 Phase, 120 VAC supply with an IEC 600320 standard C14 (male) connector. It shall operate at a 60 Hz electric grid. It must also provide critical operational data via a RJ45 connector interface for data-logging purposes. A manual that describes the principles of operation and specifications of the compensation unit must be provided by the Contractor.

3.4 Environment, Safety and Health (ESH)

Identification of hazards, and their mitigation, shall occur during all stages of the life of the Equipment including; installation, commissioning, operation, maintenance, and repair. Identification of means to eliminate or manage each hazard shall be provided based on the following hierarchy:

- Eliminate the hazard, or manage the hazards in the following hierarchy;
- Substitute with something less hazardous, or
- Engineer – mitigate the severity of the hazard, or
- User Personal Protective Equipment (least desirable).

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4 VERIFICATION

Appropriate inspection/tests shall be performed to ensure equipment conforms to all specifications in Section 3 of this document.

4.1 Classification of Inspections

Circulators and all accompanying equipment shall be subjected to the following inspections and testing to determine compliance with all applicable specifications:

- Factory Acceptance Testing (FAT).
- Incoming Inspection at BNL.
- Site Acceptance Testing (SAT) at BNL.

4.2 Factory Acceptance Testing

4.2.1 Low-power RF test

The Circulators shall be submitted to low-power (i.e. less than a watt entering any of its ports) RF tests. Conventional RF equipment, such as – but not limited to – a vector network analyzer (VNA), must be used. The VNA must be set up in the linear sweep frequency mode and the following setup data must be provided:

- Center frequency and frequency span;
- Output power;
- Intermediate frequency bandwidth;
- Number of data points;
- Average;

Measurements taken with the VNA in the frequency bandwidth stipulated on the requirement tables must have frequency steps not greater than 1 kHz. The calibration standard must be provided along with information about the calibration kit used. Data on the scattering parameters must be provided in the Touchstone (.sNp) file format using the magnitude [dB]/phase [º] data format.

The low-power tests must validate the following parameters of

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Table 3:

- Insertion loss at center frequency;
- Insertion loss in bandwidth;
- Return loss at center frequency;
- Return loss in bandwidth;
- Isolation at center frequency;
- Isolation in bandwidth;

The low-power tests must be performed at the Contractor's site, or at a Contractor's subcontractor's site.

4.3 Site Acceptance Testing at BNL

4.3.1 High-power RF test

The Circulator shall be submitted to high-power (i.e. up to 120 kW at the device interface ports) RF tests. The high-power tests will be performed at BSA's site. A test plan with the proposed setup for the high-power test will be formulated by BSA.

4.3.1.1 Phase over dynamic range

The phase over dynamic range specification defined in

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Table 3 refers to how much the forward transmission phase is allowed to vary over input power.

4.3.1.2 Steady-state condition

The steady-state condition mentioned in the circulator requirement table is defined as follows: the device has been excited with a continuous-wave 120 kW RF signal and has reached thermal equilibrium. The point of thermal equilibrium will be determined by analyzing the readings from thermocouples positioned at different points of the circulator. The high-power test shall be performed in such a way as to ensure that the circulator can reliably operate in the steady-state condition.

4.3.1.3 Phase specifications of reverse power

The circulator shall be tested into an Open, Short, and Load with discrete 45° phase rotations at nominal frequency from 0° to 135°.

4.3.1.4 Pulsed RF

The Circulator will be tested at full rated power over the pulse specifications in Table 4, verifying compliance to specifications in Table 3.