**High Power Test Plan of Fermilab PIP-II 650 MHz 40 kW Circulator**

This document describes the test procedures for each 650 MHz waveguide junction circulator after being received. ”. These circulators shall be used for PIP-II IT 650 MHz rf distribution system. The “specification” in this document refers to the document “Specification of 650 MHz 40 kW CW Waveguide Ferrite Junction Circulator.”

**Vendor**

1. Low power test (Network Analyzer measurement: return loss, insertion loss, isolation).

2. Cooling Water test (Pressure, flow rate, leakage).

3. Arc detector test.

**Fermilab**

**1 General check.**

1.1. Physical damage, if any, especially flanges.

1.2. Verify magnetic stray field.

1.3. Connect cooling water and install water flow meter, pressure gauge, and Temperature sensors for measuring both inlet and outlet water parameters (flow rate, water pressure, and water temperature). Install a temperature sensor on circulator body for measuring body temperature. Check water leakage, if any, under conditions defined in vendor’s specification. Check and make sure water temperature, flow rate, and pressure meet vendor’s requirement. (This step 1.3 should be performed after Low power Network Analyzer Measurement).

1.4. Verify arc detector and arc detector reaction time. (Need to communicate with vendors on the verification method.)

**2. Low power test (Network Analyzer measurement)**

2.1. Measure S parameters (set frequency span cover full bandwidth) with a Network Analyzer to verify: return loss at each port, insertion loss between each pair of ports while the third port is terminated with a fixed LOAD, and isolation between each pair of ports while the third port is terminated with a fixed LOAD. Record changes (drift) of S parameter with ambient temperature change. Repeat the above measurements with third port is terminated with a SHORT.

2.2. Terminate output port with an adjustable LOAD and measure full two port S parameters at and between input port and 3rd port while LOAD is moved away from initial position by15 steps (~1 inch movement per step). The measurement should be made at each step. If adjustable LOAD is not available use WG 1150 insertions (straight sections) to adjust the position of the LOAD by 4 steps (~3.7 inch movement per step). Repeat this measurement using each port of the circulator as input port and follow rotation of the circulator to choose output port and third port.

2.3. Terminate output port with an adjustable SHORT and measure full two port S parameters at and between input port and 3rd port while SHORT is moved away from initial position by 15 steps (~1 inch movement per step). The measurement should be made at each step. If adjustable SHORT is not available use WG 1150 insertion to adjust the position of the SHORT. Repeat this measurement using each port of the circulator as input port and follow rotation of the circulator to choose output port and third port.

2.4. (Optional) During measurements in step 2.1, may change magnet coil adjustment settings and watch how much the curve would move. (this step is optional and should have vendor’s permission).

**3. High Power Test**

During high power test, stop test should arc occur three times in any one of test steps and communicate with the manufacturer.

The power rating for all water cooled LOADs in all high power test steps should be ≥ 80 kW.

3.1 Connecting cooling water and verify water parameters described in step 1.3. All water parameters should meet vendor’s requirement, be data-logged and outlet water flow rate should be one of interlock input signals.

3.2 (optional) Repeat S parameter measurement performed in step 2.1.with a Network Analyzer. Compare them with the results of measurement in step 2.1.to check how the S parameters change with temperature.

 3.3. Install a WR1150 dual directional coupler at each port of the circulator. Connect a power meter (dual channel) to each coupling port of a directional coupler (total 6 coupling ports). Calibrate power meters. All signals read by power meters should be data-logged. Connect a power amplifier (PA) to the input port of the directional coupler at Port 1 of the circulator. Connect a water cooled WR1150 LOAD to the directional coupler at each Port 2 and 3 of the circulator (see Figure 1.) May replace WR1150 water cooled load with a 6 -1/8” 50 Ohm coaxial water cooled load joined with a WR1150 to 6-1/8” coax transition if WR1150 water cooled load is not available.

3.4 Increase RF power (650 MHz) in step of 1 kW to 40 kW. Dwell at each power level for 10 minutes. Stay at 40 kW for 24 hours. Record (data-log) forward and reflected power at all three ports all time and use them to calculate insertion loss, return loss and isolation. Check the function of the temperature compensation unit (TCU) during the entire test time and adjust it if necessary. Observe and record fluctuation of return loss, insertion loss and isolation at (or between) all ports, and settle time (if any) of these parameters after power level is changed. Change inlet water temperature by a few degree F (if possible) and check the capability of TCU to compensate the temperature change without need of operator’s adjustment. The TCU should function automatically after some adjustment made.

3.5 At 40 kW power level, sweep frequency by the amount allowable by power amplifier to verify bandwidth of the circulator at high power level.

3.6 (Optional) Calorimetric measurement --- use water temperature difference between inlet and outlet water and flow rate of the water cooled LOAD to verify insertion loss with measurement results of directional coupler, if necessary. (May use thermal insulation outside the LOAD temporarily, for this step only.)

3.7 Connect a water cooled adjustable SHORT to output port of the directional coupler at output port of the circulator. Connect a water cooled fixed LOAD to the output port of the directional coupler at the 3rd port of the circulator. Repeat test step 3.4 – 3.6.

3.8 Turn off power. Adjust SHORT position by moving SHORT away from initial position by 1 inch. Turn on RF power and increase power to 40 kW immediately. Stay at 40 kW for 1 hour. Check the function of the temperature compensation unit (TCU) during the entire test time and adjust it if necessary. Observe and record fluctuation of return loss, insertion loss and isolation at (or between) all three ports and settle time of these parameters, if any. Repeat the above procedure 15 times (move SHORT 1 inch away from previous position). If adjustable SHORT is not available use WG 1150 insertion to adjust the position of the SHORT by 15 steps, (1 inch movement per step).

3.9 During tests of 3.8, make sure (by fine adjustment of the SHORT position) one of the 15 positions of the SHORT will create maximum E filed at center of the ferrite inside the circulator and one of the 15 positions of the SHORT will create maximum H filed at center of the ferrite inside the circulator. Dwell time at these positions as well as adjacent 4 positions should be 24 hours at 40 kW at each position.

3.10 Repeat test 3.7 – 3.9 using each port of the circulator as input port and follow rotation of the circulator to choose output port and third port.

3.11 Analyze data and compare the performance to the Network Analyzer measurement and specification.

**4. Low power test (Network Analyzer measurement)**

4.1 Repeat measurement in step 2.1 to check the change (if any) of S parameters of the circulator after all high power tests.

Figure 1. Schematic of High Power Test Setup