High Intensity Neutrino Source Test Facility at Meson Non-Ionizing Radiation Safety System

1 Version Info

Refer to this section to view changes made between different versions of this document. Major version number changes will involve changes in the design of the RF power distribution.

2 Introduction

The purpose of the High Intensity Neutrino Source (HINS) program is to demonstrate the feasibility of a new design for a high energy, high intensity H- accelerator. The projected final design of the accelerator will have H- beam accelerated to 8 GeV, stripped, and injected into the Main Injector for acceleration into the neutrino target. There are two major aspects of this accelerator that make it different from any existing linear accelerator: multiple cavities are driven from a single high power source, and the transition from normal conducting to superconducting cavities occurs at a low particle velocity ($\beta = 0.145$). The first aspect implies that fine control of the phase and amplitude at individual cavities must be performed at high power levels. The second aspect implies that low velocity, superconducting cavity structures that have never been used to accelerate beam are necessary.

The test facility at Meson for the HINS program will consist of a linear accelerator up to 90 MeV of beam energy. The beam-line components for the facility will include an H- ion source, an RFQ, a section of room temperature cavities and superconducting solenoids, and up to three cryomodules with superconducting cavities and solenoids. The facility will also include all of the RF power and distribution, power supplies, and controls necessary to accelerate the beam.

In the first phase of the program, it will be necessary to test many of the individual high level RF components to insure that they meet the specifications needed for accelerating beam. These components include cavities, couplers, phase shifters, and tuners. Each time a different component is tested, it will take full control of the RF power source. However, because of the different hazards involved with testing components, different test will be performed in different physical locations of the facility.

As the program continues, a beam line will be commissioned. This beam line will require RF power for room temperature accelerating cavities, superconducting accelerating cavities, bunching cavities, and an RFQ. A network of power hybrids and directional couplers will be created to distribute the power at the proper levels to the proper components.

Cavity and RF component testing will continue while the beam line is commissioned. As many as three different areas of the facility may require RF power from the klystron at any given time. This implies an RF distribution with a series of switches to direct the flow of RF power.

2.1 Block Diagram of System

The high power RF system is centered around the 2.5 MW klystron and its support equipment. The pulsed bias of the klystron is provided by a charging supply, modulator, and pulse transformer combination capable of 100 kV pulses. Other power supplies control the filaments and solenoids of the klystron. A remote controlled signal generator acts as the source of the RF signal. The signal goes through a gate switch to control rep-rate and act as an interlock control. The signal then goes through a variable attenuator to control amplitude and enters an 800W power amplifier followed by a 12dB attenuator, before going to the klystron. The output of the klystron enters WR-2300 waveguide which is connected to a circulator. The reverse output of the circulator is terminated with a water cooled, 45 kW (ave.) load, and the forward output is connected to an RF waveguide switch. The switch directs the RF power to either a waveguide termination or waveguide to the test areas.

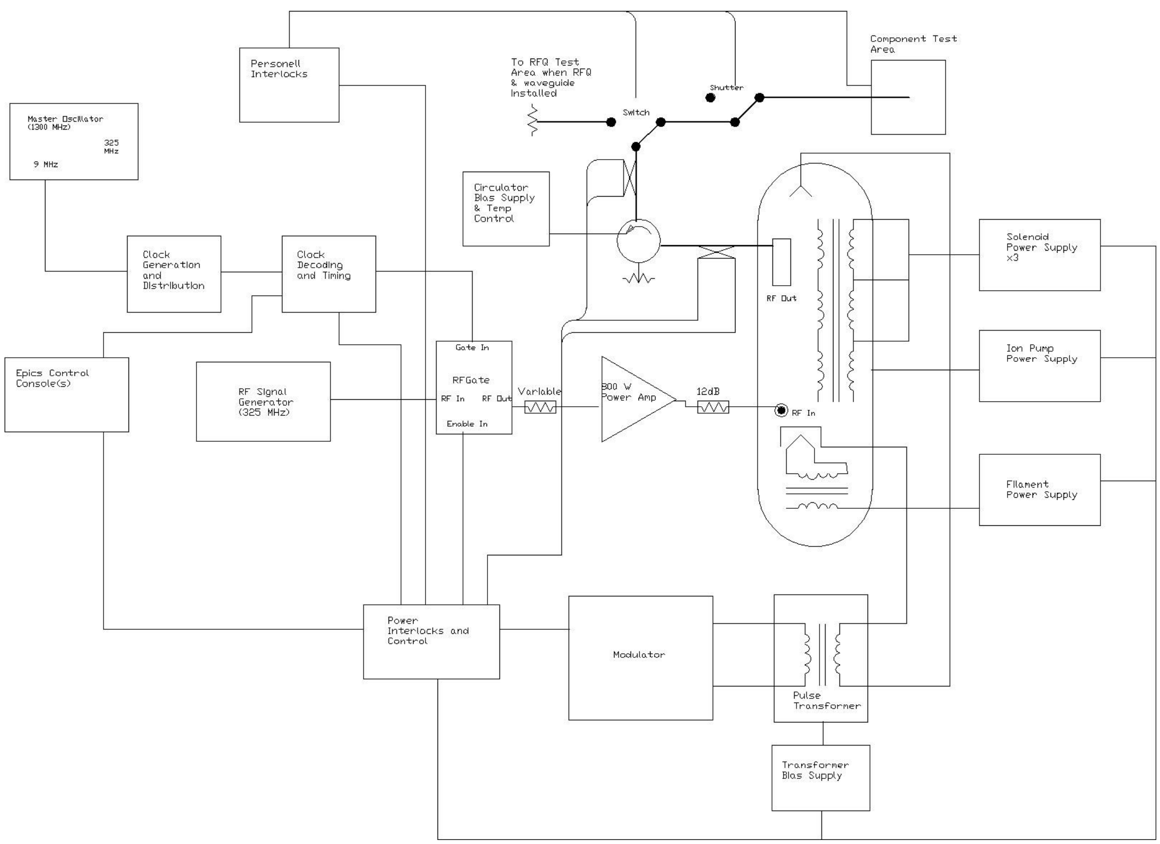

Figure 1: Block diagram of HINS Meson RF distribution components. Bold lines represent waveguides.

2.1.1 Test Areas

After the RF enters the test area waveguide, it encounters a 10 dB directional coupler. The through port of the coupler is connected to another series of waveguides followed by a waveguide shutter. This shutter is capable of reflecting all incident RF power back toward the klystron when it is shut. A waveguide to coax transition follows the shutter, and this coax line enters the component test area. The component test area is a 10’ x 10’ RF screened enclosure. All component tests are performed within the sealed screen enclosure and all power and signal monitor cables enter through a bulkhead in the screen. The coupled port of the 10 dB coupler comes out as a coax line and enters a coaxial switch. The switch can route the RF power to a fixed load, or the rest of the coaxial line. After the switch, there is another 10 dB coupler. Both the through port and the coupled port outputs continue into the test cryostat cave. There, the coaxial lines act as cavity power sources with one line set to the klystron power/10 and the other set to the klystron power/100. Each line extends into the cryostat test cave.

2.2 Physical Layout of System

The test facility is located in the southeast corner of the Meson building, just east of the Meson beam line. The modulator components and the klystron all form a line just east of the testcryostat enclosure (see figure 2). Interlock, control, and power supply racks are located across from the pulse transformer. The waveguide and waveguide components around the klystron are located 12’ off the ground. The test area waveguide altitude drops to 1’, just before the bend to the component test area. The area around the waveguide to coax transition at the component test area is surrounded by a 10’ x 10’ interlocked cage. The other end of the waveguide switch is terminated.

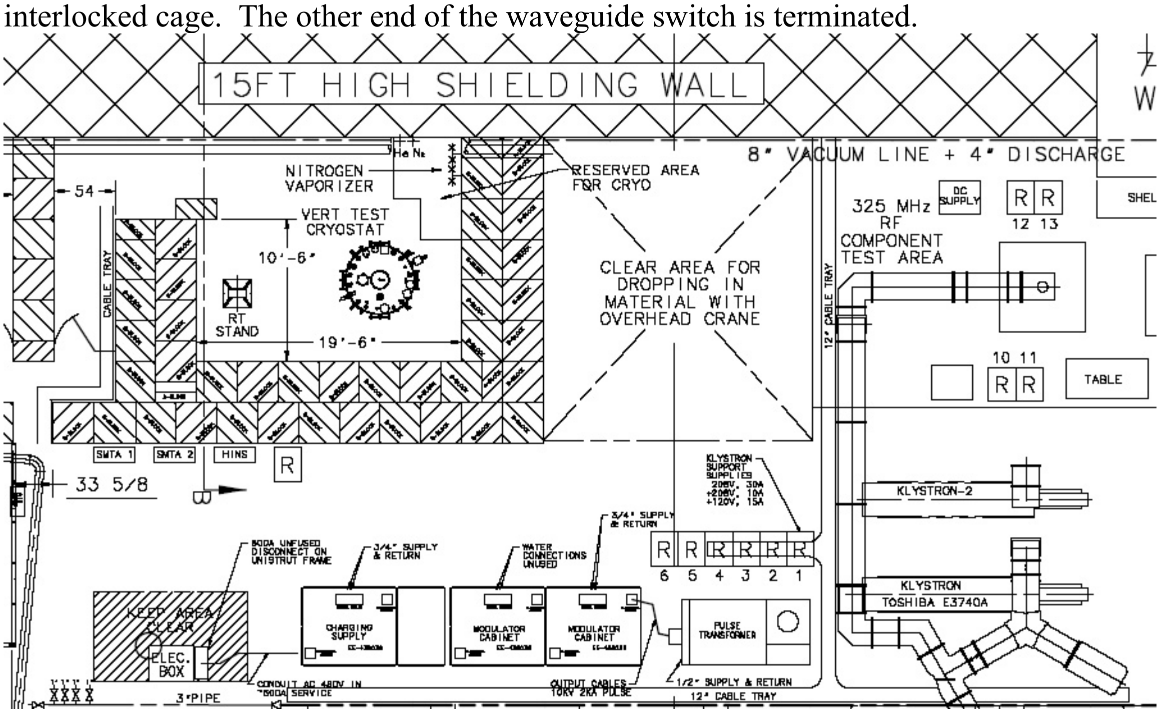

Figure 2: Pysical layout of Meson HINS facility.

2.3 Operation Specifications

	Max
Operating Frequency	325 MHz
Klystron Peak Power	2.5 MW
Klystron Average Power	78 kW

RF Driver Amp	800 W

Table 1: Absolute maximum ratings for key operational specifications.

2.4 Modes of Operation

The HINS facility at Meson currently has two mutually exclusive modes of operation: component test and klystron commissioning. The first mode is used for testing power RF components in air. The waveguide switch routes RF power to the component test area. The second mode will exist during the early commissioning of the RF power devices. The klystron will need to be commissioned before the beam line enclosure and RF distribution exist. During this time, the end of the waveguide switch that normally would go to the beam line enclosure will be terminated in a matched load. This will allow klystron power testing while beam line RF distribution is constructed.

3 Hazard Analysis

The purpose of this document is to explain the mitigation of hazards associated with non-ionizing radiation. The purpose of this section is to describe possible conditions where personnel could be exposed to unsafe levels of RF radiation.

3.1 Waveguide Leak

If any parts of the waveguide or its components are not sealed properly, RF radiation could leak out of the waveguide. One possible reason for a leaky waveguide is an improper connection during the construction of the waveguide system. This can be caused by improper installation or a material defect in an end of the waveguide. Another possible reason for a waveguide leak could be some mechanical trauma after construction is completed and verified.

3.2 Open Waveguide Exposure

If any part of the RF distribution system is left open or disconnected, the open connection could act as a powerful RF transmitter into the open air. This situation could develop because of the transient nature of component connections to the waveguide and coax. For example, someone could leave the RF connection to a test cavity open while performing maintenance on the cavity. Someone could leave the coax output in the component test cave open while configuring a new measurement setup. Someone could leave the RFQ RF connection disconnected while performing maintenance. The waveguide distribution could be left in an incomplete state, but still have RF power sent down the line.

3.3 Component Failure

There is a possibility that RF components connected to the RF distribution system could fail in a way that will cause stray RF to propagate in open air. A large spark or excessive temperatures could affect a device's capability to propagate and contain RF power. Many RF devices will run in vacuum, so that an RF failure must coincide with a vacuum failure that is easier to detect. There are some components that are at atmospheric pressure that are not sealed. These devices have the potential to fail in a hazardous way.

4 Waveguide Certification

In order to guard against waveguide leaks, a waveguide certification process is necessary. Whenever any changes are made to the permanent RF structure, it must be inspected at low power for any RF leakage. Low RF power signals can be input into the coax line, and the different interfaces between waveguide pieces and components are monitored for low level RF signals.

5 Critical Devices

There are a number of devices that are critical to personnel protection from harmful RF power levels. The devices fall into two categories: controls to disable RF output and monitors.

5.1 Klystron Modulator

The klystron modulator provides the high voltage pulse power necessary to accelerate the electron beam in the klystron. Without this high voltage pulse, the klystron cannot amplify RF into the waveguide. Most of the personnel and equipment protection interlocks disable the modulator when they are tripped. The modulator provides a fast and reliable way to disable the RF power.

5.2 Waveguide Switch

The waveguide switch is used to route RF either to the termination or the test area. The opposing function of the switch is to isolate RF power users from the klystron when they do not require power, such as new test set-ups and maintenance. The position of the switch is monitored and used in the interlock logic.

5.3 Waveguide Shutter

The waveguide shutter is the first and primary means of protecting test component area users from hazardous levels of RF radiated power. The shutter sits upstream of the component test area. When closed, it reflects incident power back to the source (klystron circulator). The shutter can be physically padlocked into position to provide a means for LOTO protection when working in the component test area. The position of the shutter is also monitored by the interlock system to insure that the klystron output is not sending power to the shutter when it is open with personnel in the test area.

5.4 RF Leak Detectors

As a backup to the switches and shutters, there are a number of RF power detectors located around test areas and waveguide junctions. These detectors are set to trip when average power levels at the detector exceed $1 mW/cm^2$. These detectors are monitored by the interlock system.

6 Interlocks

The personnel interlock system for the klystron RF distribution has control over the klystron modulator. Any bad combinations of critical device read-backs or trips will disable the modulator and inhibit RF production from the klystron. The other inputs to the personnel safety system are from the beam line and test enclosure interlocks.

6.1 Enclosures

It is only within these areas that components can be connected and disconnected from the power RF distribution waveguide without using the waveguide certification process. All of the enclosures have interlocked gates as entrances.

6.1.1 Component Test Area

The component test area contains the greatest potential hazard for non-ionizing radiation. It receives the full power of the klystron, has components connected and disconnected from the power source without certification, and it has no concrete shielding. There are no other significant hazards associated with the area. To remedy the potential of large stray RF fields in the open, the component test area is enclosed within a 10' x 10' conducting cage. The cage attenuates the signal from inside by a minimum of 40 dB before radiating outside. The entrance to the cage is an interlocked gate, and no RF power is permitted in the cage without the cage clear and the gate locked. As an extra precaution, there are RF leak detectors located inside and just outside the cage.

6.2 Personnel Safety Logic

In order to insure that RF power is not delivered to areas that are not prepared to accept it and safeguard personnel, the interlock system monitors the switch positions, shutter position, and RF leak detectors. There is a manual permit key that is capable of disabling the monitor, and if any leak detectors trip, the interlock system disables the modulator immediately. If the waveguide switch is routing RF power to the test area, then either the shutter is closed or the cage safety system is reset for modulator operational permit.

Permit Key	F	X	T	T	T	T
Leak Detector	X	T	F	F	F	F
Waveguide Switch	X	X	L	W	W	W
Waveguide Shutter	X	X	X	C	O	O
Test Cage Interlock	X	X	X	X	F	T
RF Permit	F	F	T	T	F	T

Table 2: Personnel safety logic table. Character key - Permit Key(T=on,F=off), Leak Detector(T=leak detected,F=no leak), Waveguide Switch(L=to load,W=to waveguide), Waveguide Shutter(C=closed,O=open), Test Cage Interlock(T=cage secure,F=cage not secure), RF Permit(T=permit granted,F=no permit), X=don't care

6.3 Other Interlocks

There are other interlocks on the system that are not as much meant for personnel protection as for equipment protection. These interlocks monitor temperatures of components and water, cooling water pressure and flow, output and reflected power levels, vacuum, etc. There are also some extra personnel interlocks on access doors to high voltage equipment and enclosures with hazardous x-ray levels.

7 LOTO

Part of the personnel safety procedures involves controlling critical devices while maintenance is performed on equipment. The first level of protection is the interlock system. The second level is LOTO of the critical devices themselves. Each critical device has its own LOTO document that describes the detailed procedure used to lock out the device and the list of people qualified to lock the device off. This section summarizes some of these documents.

7.1 Klystron/Modulator

There will be instances where we will want to lock out the klystron. For example, there will be times when new waveguide infrastructure is added to the system, and the interlocks may not be enough to safeguard the work. In order to do this, the modulator and other power supplies (solenoids, cathode, transformer bias, etc.) need to disabled and locked out. There are two modes for locking out the power to the charging supply for the modulator. One mode is for maintenance on the modulator and charging supply itself. LOTO certification for this mode is limited to power supply experts. The other mode is just to insure that no power gets to the klystron. LOTO certification for this mode will be broader and involve personnel familiar with the operation of only the klystron as well.

7.2 Waveguide Shutter

The waveguide shutter is equipped with a locking mechanism. The shutter can be locked into a particular position, disabling remote control by the interlock system. This locking mechanism can be used as an extra safeguard to maintenance and setup in the component test area.

8 Klystron Output Power Control

Another way to protect personnel from overexposure to RF broadcasts is to limit the output power of the klystron to levels that are necessary for operation and testing. The output power of the klystron is controlled two ways: adjusting the modulator output voltage and controlling the level of the RF input into the klystron. Because the modulator output voltage is a remotely adjustable parameter, the main output power control protection will come from the RF input.

The first level of protection from overdriving the klystron comes from a high power 12dB attenuator that drops the signal of the 800W amplifier to a maximum of 50W. This is preceded by a manual, switchable, variable attenuator. This attenuator is set to insure that the peak output power of the klystron is limited below its capability and what is necessary for the operation.

9 Component Testing Procedures

Each component test experiment involves different configurations of the klystron settings and connections to the waveguide in the test area. To insure proper communication between the component test area users and the klystron operator, a test procedure document must be created for the experiment. This document should include the following information:

1. Name(s) of the component test area experimenters.
2. Description of the experiment.
3. Diagram and description of the waveguide connection.
4. Description of all other signals required to enter/exit the enclosure.
5. Name(s) of klystron operators.
6. Required RF power level(s).
7. Estimated amount of time to complete experiment.
8. If testing to failure, description of expected failure mode.

All component test area experimenters must be qualified to access the component test area and secure it. They also must be qualified to perform LOTO on the waveguide shutter. The klystron operators must be qualified for all of the above plus be qualified to operate the klystron and lock it out.