HIGH POWER RF DISTRIBUTION AND CONTROL FOR MULTI-CAVITY CRYOMODULE TESTING *

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Abstract

Qualification of the superconducting radio-frequency (SRF) cavities in the cryomodules for accelerating performance needs to be done through high power processing. A four-way waveguide power distribution system with independent control of power outputs has been developed for testing the multi-cavity cryomodules for the SNS linac. SNS is employing two types of cryomodules: one type with three medium beta six-cell cavities and the other with four high beta six-cell cavities. The cryomodule that is being manufactured as a spare and the new cryomodules for the future SNS power upgrade project (PUP) will be high beta types. Four-way power distribution with independently controlled power outputs was considered useful for powering all cavities at the same time with a klystron amplifier since the SNS test facility was configured for single klystron operation. Since certain interaction between the cavities under severe field emission was suspected in existing cryomodules, this type of high power test can be valuable for characterization of SRF cavities. By implementing a vector modulator at each arm of the splitting system, the amplitudes and the phases of RF outputs can be controlled independently. This paper discusses the present status of the development.

INTRODUCTION

Tests of the cavities in cryomodules at full RF power levels were done during the last several years at SNS after repairing some of the superconducting RF cavities that developed problems during commissioning and beam production. Removing higher-order mode (HOM) couplers and disabling piezo tuners required warm up of the SRF cavities and high power processing before replacing them in the linac tunnel. The cavities in a cryomodule were tested one by one to ensure restored performance after the repairs. The tests verified that the cavities were repaired successfully and the operational capability was restored.

Some of the cavities have shown strong field emissions at voltages lower than the design levels [1]. Field emission was one of the major limitations preventing the cavities working at design field gradients. That problem exhibited possible interactions between the cavities. This unknown problem prompted the necessity of investigation of the cavity field emission interaction within a cryomodule. Since the RF test stand at SNS was designed and constructed to use only one klystron at a time, three or four cavities in a cryomodule could not be tested simultaneously.

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DEVELOPMENT

Operation of high power RF vector modulators has been an interesting topic for reducing the cost of high power RF accelerators. The approach required fast RF phase shifters for accelerating the beam in cavities. However, for high power processing and characterization of SRF cavities in the SNS test facility with no beam, fast RF vector control is not necessary. Table 1 shows the high power test specification for the SNS cryomodules.

Table 1: SNS Cryomodule RF Test Parameters

Frequency	805 MHz
Power	0 - 550 kW / each output 4 x 550 kW total (4 x 750 kW max for PUP)
Duty cycle	8% (1.3 msec, 60 Hz pulsed)
Phase	0 – 180° max / each output

Figure 1 illustrates the layout of the four-way waveguide power splitting system with a four-cavity cryomodule. Three magic-T hybrids are used at the top of the system to provide four outputs with equal amplitudes and phases. Figure 2 shows the system block diagram of the RF processing system accommodating the four-way power splitting waveguide circuit. The goal is to have four high power RF outputs with independent control of the amplitudes and phases using the vector modulators.

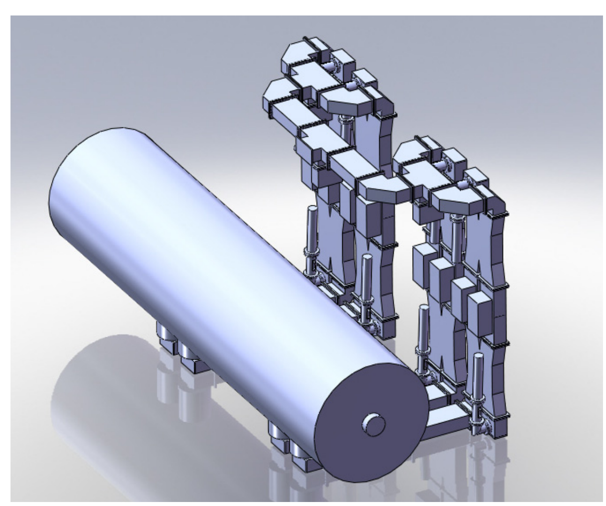


Figure 1: Layout of four-way waveguide power splitting system for a four-cavity cryomodule test.

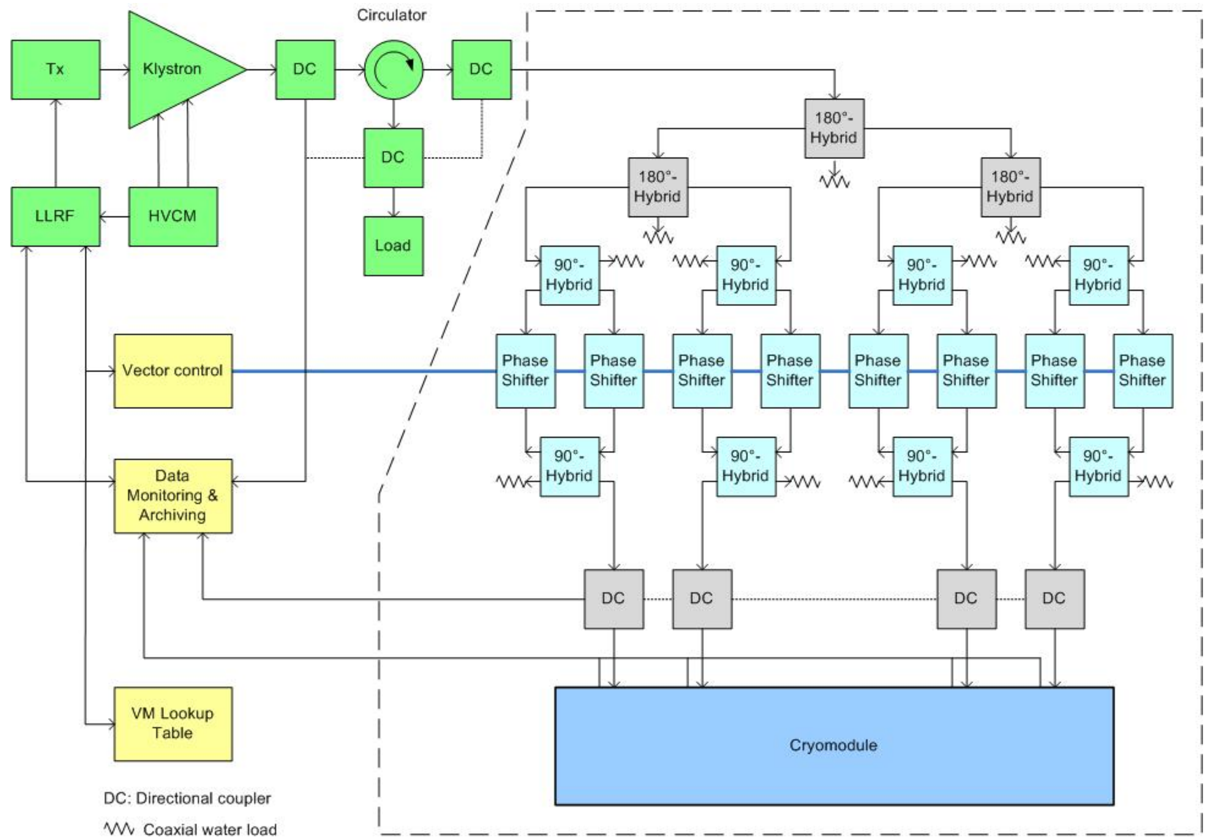


Figure 2: High power RF distribution system using waveguide vector modulators being implemented for testing up to four cavities in a cryomodule simultaneously.

Phase shifter and Vector Modulator

At each magic-T output port, a vector modulator consisting of two quadrature hybrids and two motorized phase shifters is placed in line. Each isolation port is terminated with a coaxial matched load. Each cavity and water load input has a dual directional coupler for monitoring the forward and reflected powers. Each waveguide phase shifter is a motorized mechanical phase shifter that is controlled by a stepper motor controller with a precision position feedback potentiometer that has 6” stroke and 0.1% readback accuracy. The maximum speed of the motor control is estimated to deliver 20°/sec in phase shift.

Low Level RF System (LLRF)

The LLRF control system for the SNS RF test facility has been updated and used for various high power RF processing tasks such as SRF cavity processing and coupler/window conditioning [2]. The equipment setup was done using the EPICS platform and is virtually identical to the RF control of the SNS linac [3]. The system is flexible to support operation at either one of the two different SNS linac frequencies (402.5 & 805 MHz). The High Power Protection Module (HPM) is completely configured for monitoring the RF load operation and the machine protection. The RFTF control room is also updated with solid state and TWT amplifiers for further testing and processing of superconducting cavities.

Phase Shifter Actuation and Control

Each phase shifter is operated with a stepper motor and controller for adjusting the position of the phase shifting element in the phase shifter. Each controller can supply up to 4 Amperes of stepping motor current. The phase shifters are to be adjusted with feed-forward control using a lookup table that contains the transfer characteristics of the amplitude and the phase vs. the positions of the phase shifters in the vector modulators.

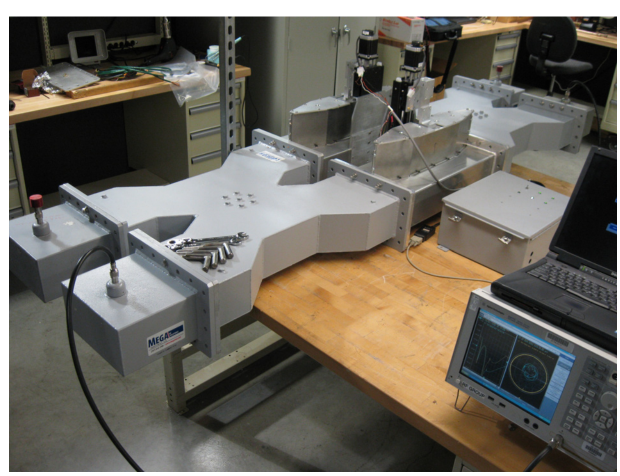
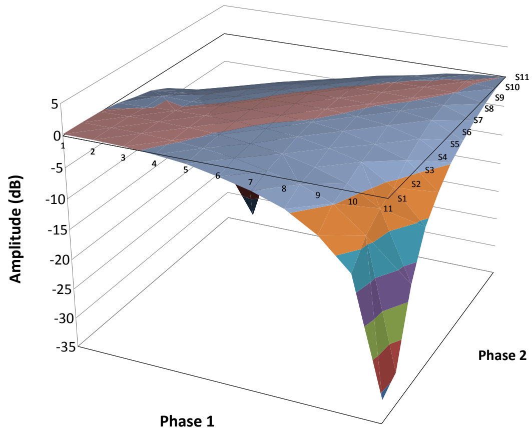
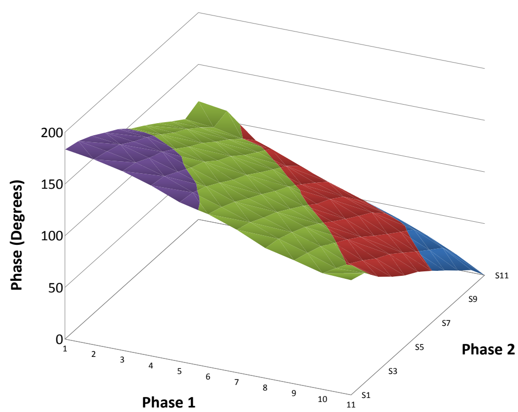


Figure 3: Low power bench measurement of a vector modulator setup.



(a)



(b)

Figure 4: Low power bench measurement of a vector modulator setup. (a) Amplitude, (b) Phase.

Vector Modulator Test

Figure 3 shows the vector modulator unit under bench test that will be used as a high power RF controller of each of the four outputs in the four-way system. The measurement setup used waveguide to coaxial transitions at the waveguide ports. A 4-port vector network analyzer was utilized for accuracy and ease of measurements. Figures 4(a) and 4(b) show the measured amplitude and phase characteristics of the unit vector modulator. Each phase shifter can change the phase up to 185° individually which is sufficient to vary the output power 0 – 100% in amplitude and 0 – 180° in phase of the input wave. This measurement data will be used as the initial lookup table for the control system to move the phase shifters to the desired positions for a specified power level and phase at an output of the power splitting system. The insertion loss in a single phase shifter was estimated to be 160 W of maximum power dissipation while operating at 550 kW, 7% duty cycle.

EPICS Control

The control system for the SNS RF test facility has been setup in an EPICS environment that is virtually identical to the control system for the SNS linac. The system has been used to test the repaired cryomodules and to perform high power RF processing of cavity couplers and windows.

Data Acquisition and Logging

The data generated during the test and operation will be archived in the EPICS data archiver and viewed afterward using the Control System Studio (CSS). The archiver and the CSS data viewers are also identical to the applications used in the SNS linac operations. Other Labview based programs for data acquisition and control are prepared to aid certain SRF tests and processing in the test facility. For other measurements and test such as plasma processing and vertical dewar tests with solid-state amplifier control, the acquired data can also be stored and analyzed in the Labview software.

Power Generation

The RF Test Facility is equipped with two klystron sockets that can accommodate two high power klystrons at two different frequencies: one for 2.5 MW at 402.5 MHz and the other for 550 kW (or 5 MW) at 805 MHz. An 11 MW peak power high voltage converter modulator (HVCM) operates at 8% duty cycle to power the klystron amplifiers. The HVCM is designed to supply up to 135 kV to the collectors of the klystrons.

TEST PLAN

A high beta cryomodule being manufactured as a spare for the SNS linac will be completed by the end of 2011. The plan is to test the cryomodule which will be placed in the RFTF test cave with the four-way waveguide power splitter system in early 2012. The vector modulators will be high power tested this summer and the entire power control system will be ready. The system is considered useful for complete cryomodule testing of the upcoming PUP project of SNS.

ACKNOWLEDGEMENT

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