# STATUS OF THE SPALLATION NEUTRON SOURCE RADIO FREQUENCY SYSTEMS*

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*Abstract*

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory has been operational and delivering beam to the target for 3 years. During this time SNS has increased the beam power delivered to the target to more than 800 kW, greater than 50% of the design goal. The Radio Frequency (RF) Group has acquired a fair amount of experience in the operation and maintenance of SNS RF systems during the power ramp-up process. This paper reviews the design and layout of the various SNS RF systems, documents the present state and performance of the systems; and broadly covers system improvements, issues raised during operation and future RF system requirements.

## SNS RADIO FREQUENCY SYSTEMS [1]

Figure 1 gives the layout of the SNS linear accelerator radio frequency (RF) systems. A 2 MHz 80 kW gridded-tube amplifier, not included on Figure 1, is actually part of the ion source equipment and is used to ionize the ion source hydrogen gas. Also not included on Figure 1 is a set of four Medium Energy Beam Transport (MEBT) rebuncher cavities along with gridded-tube, 402.5 MHz, 20 kW amplifiers that maintain the longitudinal distribution of the beam as it is transported from the Radio Frequency Quadrupole (RFQ) to the first Drift Tube LINAC (DTL) tank. The LINAC RF consists of a single 2.5 MW, 402.5 MHz klystron to drive the RFQ; six 402.5 MHz, 2.5 MW klystrons for the DTL section; four 805 MHz, 5 MW klystrons for the Coupled Cavity LINAC (CCL) section and eighty one 805 MHz, 550 kW klystrons for the Superconducting Cavity LINAC (SCL) section.

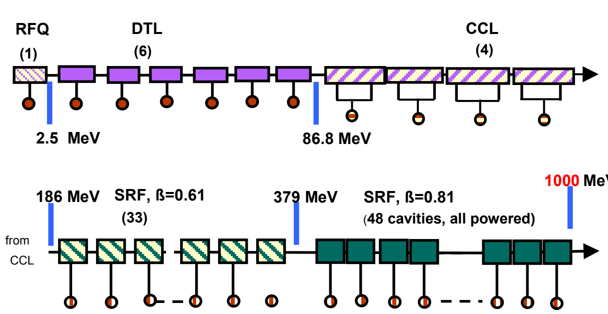


Figure 1: Layout of LINAC RF modules.

Figure 2 displays the accumulator ring RF system distribution. The Accumulator Ring RF system is comprised of four ferrite-loaded, dual-gap cavities powered by gridded-tube power amplifiers. Three cavities operate at the revolution frequency of 1.05 MHz supplying 14 kV of bunching voltage per cavity. A single dual gap cavity, identical to the fundamental cavities except for the resonating capacity, operates at the second harmonic of the revolution frequency 2.1 MHz and provides 20 kV of bunching voltage.

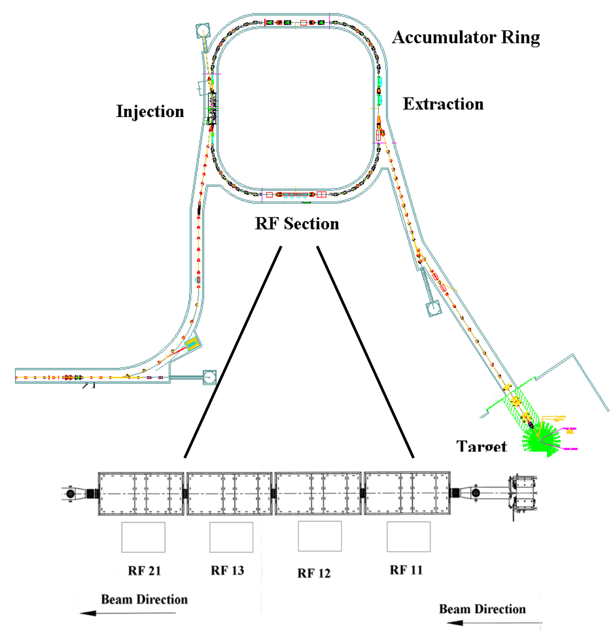


Figure 2: Layout of ring RF components.

## ION SOURCE RF [2]

A tuned gridded-tube amplifier is presently utilized to provide up to 80 kW of 2 MHz RF power for ionizing the hydrogen gas. The Ion Source is operated at a Direct Current (DC) potential of -65 kV as is the ionizing antenna. A matching transformer and resonant matching network transform the low ionizing antenna impedance to the 50 ohm output impedance of the power amplifier. The amplifier floats at the Ion Source DC potential of -65 kV leaving little access to the RF equipment during Ion

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source operation. The particular amplifier utilized, while adequate for initial SNS start up and Ion Source development phases, proves to be less than desirable for the high reliability ultimately desired of SNS. In addition, the multiple tuned circuits presently in use all interact making reliable Ion Source performance difficult to achieve. A semi-broad-band solid-state amplifier is on order to replace the gridded-tube unit, and a high voltage transmission-line isolation transformer which would allow the amplifier to operate at ground potential is under development.

The original antenna matching network utilizes a ferrite step-down transformer along with a resonating inductor and capacitor network with the antenna forming a portion of the resonating inductance. While this is an effective matching scheme, it does include losses, must be water cooled, and can overheat damaging the components. A capacitive matching network design is in progress to be incorporated in the near future.

## RFQ RF SYSTEM

The original RFQ drive scheme incorporated eight coupling loops. Adjustment of these coupling loops to achieve uniform power transfer across all loops was difficult. A factor of two in drive power between various couplers has been observed which, at full power, would stress some of the couplers beyond their design limits. Drawing on experience with the SCL couplers, which can handle considerably greater power, a design was generated and incorporated utilizing only two coupling loops.

The SNS RFQ is held in resonance by a pair of chillers that regulate at fixed temperature. One chiller cools the vanes while a second cools the RFQ body. Heat added by RF drive is offset by these chillers. The system has operated well at the shorter than design pulse lengths SNS has been operating with, but cooling issues are becoming apparent as the pulse length is increased. While the RFQ tuning is able to be maintained with the present hardware it has become increasingly more difficult to achieve the desired stability over extended running periods. An upgrade of the cooling system is presently in the planning stage and work is underway to determine the overall system requirements.

## MEDIUM ENERGY BEAM TRANSPORT REBUNCHER SYSTEM [3]

The amplifiers utilized for this system comprise only a small fraction of the overall SNS RF systems but have proven to be a major source of trouble. The amplifiers tend to arc internally resulting in large AC line currents that open system circuit breakers often damaging them in the process. Attempts to limit the fault currents or to identify the actual cause of arcing have not been successful. A candidate replacement solid-state amplifier is being evaluated.

## SUPERCONDUCTING LINAC

An extra converter-modulator has recently been added to the SCL section and the distribution of klystrons per modulator reconfigured. The first 11 medium-Beta section klystrons are now powered by a single modulator with the remaining SCL klystrons configured with 10 klystrons per modulator. The original configuration powered 11 or 12 klystrons per modulator depending on location. To enhance modulator reliability the system has typically been operated with reduced cathode voltage limiting the available klystron power below the level needed to operate at full design intensity. With the new configuration, SNS now operates with all but the first 11 SCL klystrons at the 75 kV design level.

The SCL has had on going trouble with cold cathode vacuum gauges failing to operate. This can leave cavities without protection. In an attempt to restore a measure of protection Pico-ammeters that monitor electron probes in each cavity have been added and have, in some cavities, been incorporated into the LLRF interlock chain. Software has also been added to detect the onset of a quench and turn off the RF drive before a cavity actually quenches.

With the ability to operate the SCL klystrons at the design voltage of 75 kV stability issues been observed on several klystrons. These klystrons are all of the same design and will be replaced as time permits.

## KLYSTRON ISSUES

The SNS klystrons have been operating for approximately half of their design life of 50,000 hours. The warm LINAC klystrons have the most hours accumulated ranging from 25,000 hours to 33,000 hours. These tubes were the first to be installed and were operated while completing the superconducting section of the LINAC. The SCL klystrons range from 25,000 hours to 28,000 hours. It is difficult to deduce expected lifetime of the SNS klystron plant at this point in SNS operation. Although the klystron voltage and current is monitored there is considerable droop on the cathode voltage and the cathode pulse length has been adjusted throughout the operating period to reduce unnecessary stress on the cathode power supply. Perveance data obtained from archived voltage and current readings exhibit unrealistic jumps resulting from the way the archived data have been processed. Sufficient data needed to observe trends in the klystron perveance is just beginning to be acquired.

Several klystrons have been changed out during the short SNS operating period. Table 1 gives the history of these failures. Two klystrons, one from the SCL section and one from the CCL showed repeated cathode arcing and have been replaced. In the case of the SCL klystron, fault currents were observed on the particular klystron with no fault current present on the two adjacent klystrons sharing the oil tank and power supply. Only the failing klystron was replaced and the arcing did not return. This klystron has not yet been operated on the test stand to verify that it really has problems and no attempt at high voltage conditioning has yet been undertaken. The CCL 5 MW klystron appears to be in good shape although the combination has not yet been operated at full power. The arcing continued after the klystron and oil tank were replaced

The CCL 5 MW klystrons have experienced issues with corrosion of the Ion Pump high-voltage connectors. This issue is exacerbated by the fact that the Ion Pump power supplies do not latch off after an over-current fault. The corrosion combined with occasional high humidity result in repeated high-voltage connector arcing that severely stresses the connector. The corrosion issue has not been observed with the connectors used on the other klystron types.

Table 1: Klystron Failure

| | | | |
|---|---|---|---|
| DTL | E2V | Body Water Leak | Repaired and in service |
| DTL | E2V | Body Water Leak | Replaced - not tested |
| DTL | E2V | Focus Magnet short to ground | Repaired - waiting for testing |
| DTL | Thales | Focus Magnet short to ground | Repaired - waiting for testing |
| CCL | Thales | Cathode Arcing | Replaced and evaluating |
| SCL | CPI | Magnet Water Leak | Not yet repaired |
| SCL | CPI | Cathode Arcing | Replaced - waiting for testing |

## TRANSMITTER ISSUES

Repeated Filament supply failures occurred early in SNS operation. These are high tech power supplies that generate 0 to 120 VAC that can be ramped slowly under control of a microprocessor controller. The problem was traced to a failing integrated circuit controller internal to the supplies. The controller chips were replaced and there has been minimal trouble from these supplies since.

Klystron Ion pump power supplies include dual over current alarm circuitry that is used to remove high voltage and filament current under poor vacuum conditions. The pump supplies automatically restore high voltage after a fault. If the fault is generated by an arc at the connector, the supplies will restart and repeatedly arc, severely stressing the ion pump high voltage connector. A latching feature has been added to these supplies for use with klystrons in storage and is being considered as a modification to the operational supplies.

## ACCUMULATOR RING RF SYSTEM

The accumulator ring High Power RF System has operated with little trouble since installation. There has been some trouble with the solid-state driver stages and a replacement amplifier is being evaluated.

The Low Level RF System that drives the high power ring equipment is radically different from the remainder of the LLRF system in hardware and software. While the system operates sufficiently well with high beam loading, it is difficult for Operations Staff to communicate with [4]. In addition the software does not interface nicely with the SNS EPICS control system. A program is underway to develop a replacement system that would utilize much of the existing LINAC LLRF hardware and software [5].

## LOW LEVEL RF ISSUES

Connectors and cables present the majority of issues for the LLRF Systems. Even though the connectors selected for this system are of high quality, changes in loss in the 0.5 db range are experienced that result in significant operational difficulties. There is not yet a viable solution to this problem.

As the beam intensity is increased losses must be monitored increasingly more carefully. Losses varying as a function of the klystron gallery ambient temperature have been observed. These losses were traced to small phase and amplitude excursions in the Low Level RF field control modules. The LLRF system currently regulates to better than 1 percent in field and 1 degree in phase, but small temperature effects still exist. A developmental temperature regulation scheme has been installed within one LLRF rack that greatly improves the temperature stability of the equipment within that rack and work is in progress to develop a more refined system to be added to all LLRF racks.

## FUTURE REQUIREMENTS

SNS has just embarked on a power upgrade project that will add 36 more SCL cavities, 36 additional klystrons with their associated circulators, loads, and waveguides and 6 more SCL style transmitters. In addition, SNS will require more power from many of the SCL klystrons. SNS has already purchased 700 kW klystrons as replacement spares with the additional power requirement in mind.

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