STATUS OF THE SPALLATION NEUTRON SOURCE PROTOTYPE ACCUMULATOR RING LOW LEVEL RADIO FREQUENCY CONTROL SYSTEM*

Mark Crofford, Tom Hardek, Kay-Uwe Kasemir, and Maurice Piller, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

Abstract

The Spallation Neutron Source has recently installed a prototype low level radio frequency (LLRF) control system for initial testing. This system is designed to replace the original fixed frequency, two harmonic Accumulator Ring LLRF system used to maintain a gap in the proton beam for extraction to the target. This prototype system is based on the hardware for the Linac LLRF system that has been modified to operate at the low frequencies required for the ring. The goal of the final system is to leverage the mature hardware and software of the Linac systems with the added flexibility needed to support the heavy beam loading requirements of the Accumulator Ring.

INTRODUCTION

The Spallation Neutron Source has recently installed a prototype low level radio frequency (LLRF) control system for initial testing in the Accumulator Ring. This system is designed as a possible replacement for the current fixed frequency, two harmonic Accumulator Ring LLRF system used to maintain a 250 nS gap in the proton beam for extraction to target. The prototype system is based on the Linac LLRF system with modifications to operate at the 1.05 MHz ring revolution frequency. By utilizing similar technology as the Linac system we can standardize on a single hardware platform limiting the types of spare systems we need to maintain. For the initial tests, only open and closed loop operations have been explored without the opportunity to look at beam loading issues.

SYSTEM OVERVIEW

The SNS Accumulator Ring utilizes first and second harmonic cavities to maintain the necessary 250 nS gap in the beam for extraction to the target. The three first harmonic cavities operate at 1.05 MHz and the second harmonic cavity operates at 2.10 MHz. The second harmonic cavity is used to reduce the peak current of the accumulated beam [2]. The current LLRF system provides for fast amplitude and phase feedback control for the cavities. It also provides a slow dynamic tuning control scheme for detuning the cavity to allow for the heavy beam loading experienced in the ring.

The prototype control system is shown in Figure 1 and consists of a modified Field Control Module (FCM), High-power Protection Module (HPM), V124 Timing module, V108 Utility Module, and a Motorola MVME2100 Input/Output Controller (IOC). The FCM/HPM pair is similar to the systems utilized for the Linac except that the operating frequency has been modified to support the ring frequencies. The modifications required the design of a new Analog Front End (AFE) and RF Output (RFO) daughter boards for the FCM module and recalibration of the RF detectors in the HPM module. In addition, an analog chassis for frequency conversion and a master oscillator have been developed.

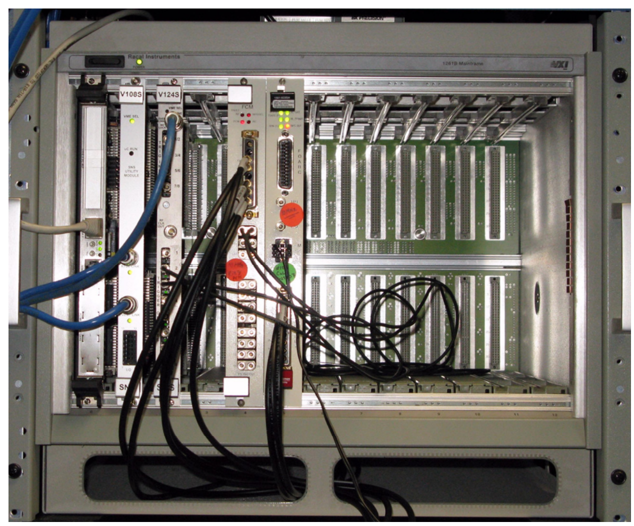

Figure 1: Prototype Ring LLRF System

The initial prototype system operates at 10 MHz due to some frequency dependencies of the FCM and HPM modules. The analog chassis is used to convert the 10 MHz signal down to 1 MHz and provide amplification of the LLRF drive signal up to 29 dBm to provide adequate power to drive the IPA. The master oscillator chassis supports both the first and second harmonic cavities and provides a 40 MHz reference for the FCM module, 8 and 9 MHz local oscillator frequencies, along with 1, 2, and 10 MHz signals [1]. All frequencies generated by the master oscillator are locked to the 32 MHz revolution frequency. A patch panel has been installed on the prototype system to simplify the connections between the operational LLRF system and the prototype system.

* ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

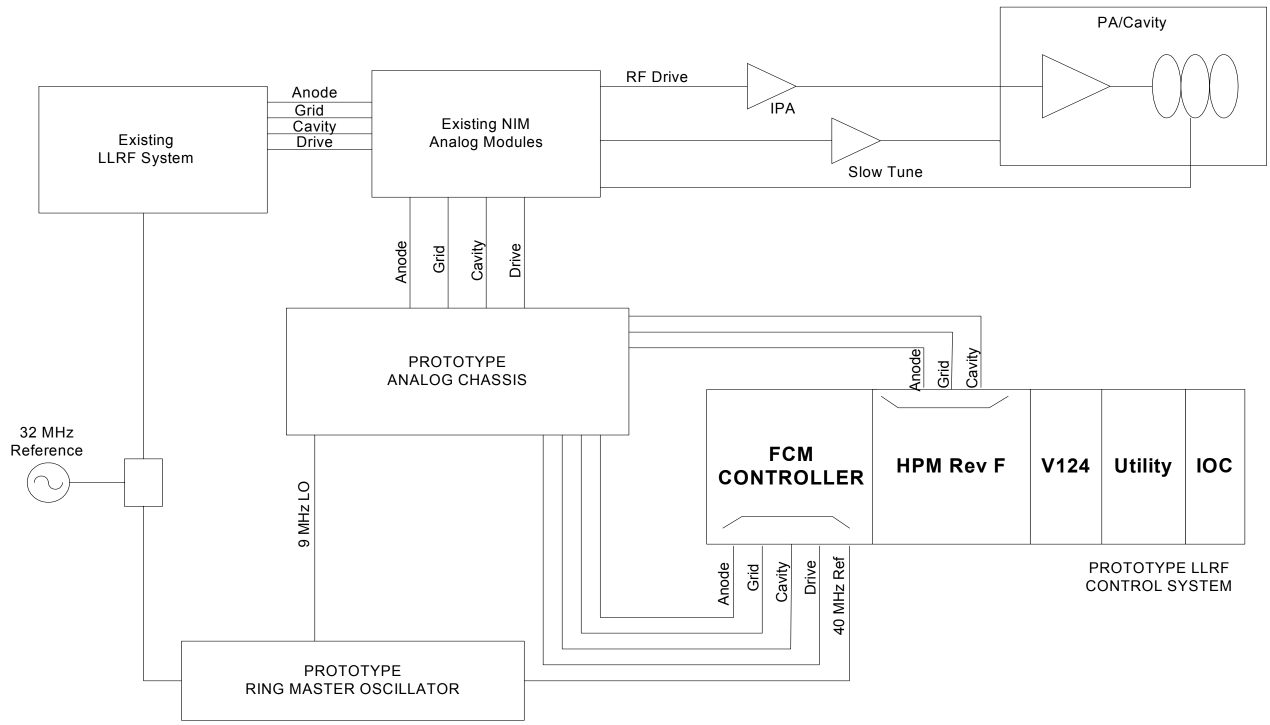

Figure 2: Test setup for prototype LLRF

TEST SETUP

The prototype system is installed in the ring service building adjacent to the current LLRF control system. This allows easy switching between the prototype and any of the operating systems. Figure 2 provides a block diagram of the test setup that is being used for initial testing. The idea was to be able to couple off the Anode, Grid, and Cavity signals without having to disturb the operational system. This allows for monitoring the test with the original system giving a calibrated reference point for the cavity parameters. This is helpful for the prototype system because calibration of the system was not required or performed. The existing analog modules were retained for the test to provide the coupled signals needed along with protection in case of any issues with the prototype. The 32 MHz reference signal utilized for the current LLRF systems is used for the input to the prototype master oscillator to maintain coherency between all systems.

Software controls were able to be quickly deployed due to the similarities with the Linac systems. Existing EPICS screens required minor changes to update location information for the prototype. All needed timing signals were available locally and only required the addition of jumpers.

PRELIMINARY RESULTS

System testing has been very limited due to development time restraints and some hardware failures. Initial problems were discovered with the master oscillator chassis appearing to not maintain lock between the prototype system and the current LLRF systems. This issue was corrected but unfortunately shortened the time available for system testing. Initial tests were performed to demonstrate open loop operation with the existing high power RF systems and cavities. No unexpected issues were noted with these tests and the system easily produced the RF power required to generate a 10 kV gap voltage in the cavity. Figure 3 below is a screen shot displaying open loop operation, the red trace is the cavity field, blue trace beam power, and the green trace is grid power.

Figure 3: Open loop cavity 1.1

Closed loop operation was tested and worked as expected. Figure 4 is a screen shot of the system operating in closed loop at 10 kV gap voltage. Gain settings and rotation angle were determined experimentally for stable operation. Additional study time is needed to further characterize the system to optimize loop parameters. All tests have been conducted using expert level control settings and no tests have been conducted with beam loading.

Figure 4: Closed loop cavity 1.1

FUTURE DEVELOPMENT

The prototype system has been bench tested and initial field tests have been performed. Beam loading studies are planned in the near future. Much development work still remains on the system before it is usable for normal operations. The current prototype is a narrowband system using an intermediate frequency of 10 MHz so that the original I/Q algorithms can be used [4]. This requires the signals to be up or down converted back to 1 MHz to drive the RF PA. The final system is planned to operate at the ring frequencies to eliminate the need for up/down conversion but this will require extensive changes to the firmware. A wideband channel is to be added to support beam based direct feed forward control to allow for beam harmonic correction. The current prototype is limited to a pulse width of 1300 uS and this is acceptable for normal operations. Having the ability to operate over a longer pulse (~5000 uS) would be beneficial to support ring experiments.

For the initial tests, the cavity pre-detuning was accomplished with the current LLRF system, this functionality needs to be implemented in the prototype system prior to release. Grid-boost features are currently not supported by the prototype and must be added. Calibrations and power readouts still need to be completed to make the system usable by the Operations staff.

The High-power Protection Module will require some modifications to operate at the ring frequencies without up conversion. The current detectors will not operate at 1 MHz and will need to be replaced with a lower frequency version [1]. This will require the board to have the RF front-end redesigned.

SUMMARY

The initial bench and field tests of the prototype Accumulator Ring LLRF control system have been completed. Open and closed loop operation into a ring cavity has provided promising results but much additional testing is required before the next generation prototype can be implemented. Considerable design work is required before this system can replace the current system. Plans are in place for additional testing of the system to explore the beam loading characteristics of the system. The goal of this first prototype is to gain the needed experience to develop the next generation LLRF ring control system.

ACKNOWLEDGEMENT

The authors would like to thank the members and management of the SNS RF, Physics, and Operations Group for their support and H. Ma of Brookhaven National Laboratory for his contributions to this project.

REFERENCES

[1] M. Crofford, et al, "Proposed Upgrade of the Spallation Neutron Source Accumulator Ring LLRF Control System", LLRF07, Knoxville, TN, October 2007.
[2] T. Hardek, et al, "The Spallation Neutron Source Accumulator Ring RF System", PAC'07, Albuquerque, NM, June 2007.
[3] J. M Brennen et al, BNL, New York, "RF System for the SNS Accumulator Ring," PAC 2001, Chicago.
[4] H. Ma, et al, "Digital RF Control for Spallation Neutron Source Accumulator Ring" PAC'07, Albuquerque, NM, June 2007.
[5] M. Blaskiewicz and K. Smith, "Self-adaptive Feed Forward Scheme for the SNS Ring RF System", Proceedings from EPAC 2004.
[6] K. Smith, et al, "Progress on the SNS Ring LLRF Control System", proceedings of PAC 2003.