SPALLATION NEUTRON SOURCE LLRF TEMPERATURE DEPENDENCE AND SOLUTION *

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Abstract

The Spallation Neutron Source (SNS) has been operating since the first neutrons were produced on April 29, 2006. During the last several years the beam energy has been methodically ramped-up and outlying issues solved to improve system reliability. During the beam studies a temperature dependency has been discovered with the Low-Level Radio Frequency (LLRF) systems. The effect is small but readily observable as increased beam losses. The temperature dependence has been studied both in the accelerator and in the laboratory and the sensitive components identified. A prototype solution that replaces the temperature dependant components of the LLRF System has been designed and is in initial testing. Preliminary results of the laboratory tests have been encouraging. Accelerator tests are planned after installation during the December 2010 maintenance cycle.

INTRODUCTION

The Spallation Neutron Source (SNS) has been operating since the first neutrons were produced on April 29, 2006. During the last several years the beam energy has been methodically ramped-up and outlying issues solved to improve system reliability. During beam studies, a temperature dependency has been discovered with the Low-Level Radio Frequency (LLRF) systems. The overall effect is small but readily observable as increased beam loss. Studies show a strong correlation between beam loss, Field Control Module (FCM) phase reference, and the klystron gallery temperature. The current LLRF system consists of a field control module (FCM), high-power protection module (HPM), and a temperature controlled down-converter [1]. The system utilizes radio frequency (RF) reference signals that are distributed via a temperature controlled drive line that is located in the tunnel and is both temperature and pressure regulated. With the use of temperature regulation in the down-converter portion of the LLRF system and phase-matching reference and field probe cables we had not expected to experience temperature dependencies.

LINAC TESTING

The temperature dependence of the LLRF was initially noticed when the building temperature of the klystron gallery failed to regulate due to an issue with the air handlers. Closer inspection showed that the dependence had been present at least for the last several run cycles but is less pronounced when the air handlers are operating properly.

Systematic tests of the RF systems have been performed in an attempt to isolate the cause of the temperature drift with the RF reference system initially suspected. The RF reference system was proven to be stable with average drifts between the 402.5 MHz and 805 MHz reference sections to be approximately +/-1 pS. The local oscillator (LO) distribution was also eliminated as a source of drift due to it being shared by both up and down conversion channels [2]. This limited the possibilities to drifts within the LLRF system racks or associated RF cabling.

Rack Temperature Compensation

Two LLRF racks were selected to have a prototype temperature compensation system installed in them, one was a standard LLRF system rack located in the DTL6 section of the Linac and the second was the Master Oscillator/Amplifier rack. These racks were chosen due to their close physical location to each other. The temperature compensation system consisted of an Omega I-series PID temperature controller, resistive thermal devices (RTD) placed in the rack, and a heater. The heater was constructed utilizing constant-wattage heating cable rated at 8 watts per foot. Thirty-four feet of cable was coiled up near the bottom of each rack and the system set to regulate approximately 5 degrees Celsius above ambient rack temperature.

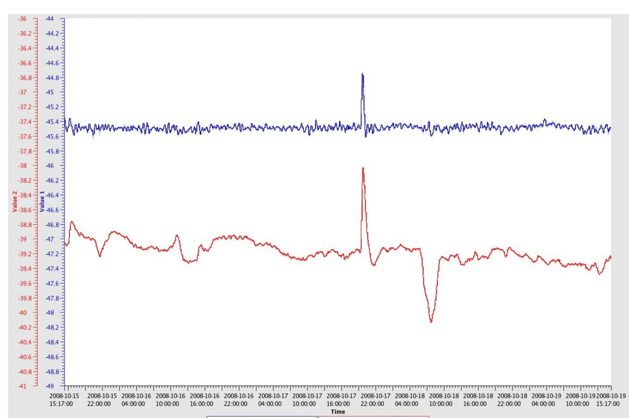

Figure 1: FCM Phase Measured for DTL5 & DTL6

The results of the rack temperature tests are promising, with the rack temperatures regulating nicely at +/-0.1 degree Celsius around the setpoint. Figure 1 shows the results of the temperature regulation in the DTL6 LLRF

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

rack. The blue trace is the reference signal for DTL6 and the red trace is the reference signal for DTL5 (DTL5 is unregulated).

While the results of the rack temperature compensation tests are good, there is some concern with the difficulties in implementing this solution. Some of the major concerns is operating the electronics at an elevated temperature could shorten component life, retrofitting the equipment racks with insulation is difficult, and the possibility of needing additional electrical power to support the heaters is expensive.

LABORATORY TESTING

With the success of the rack temperature compensation, a concerted effort was given to isolate the temperature dependant components in the LLRF system. As expected, the major contributors to the drifts were the filters, mixers and amplifiers associated with the Analog Front End (AFE) board and the RF Output (RFO) board's frequency conversion circuits.

The laboratory tests were conducted utilizing a 27 cubic foot Test Equity 1000 series temperature chamber that is capable of holding a full-sized 9U VXI crate and down converter chassis. A LabView application was developed to control the temperature chamber, Agilent Technologies E5071C network analyzer, and Rohde & Schwarz SML01 signal generator to gather the data required to support the investigation.

Analog Front End

The Analog Front End (AFE) was originally a commercially designed board with four analog channels utilized to route in the cavity forward, reflected, and field probe signals. The fourth channel is used to provide the reference signal from the master oscillator. The forward and reflected channels are down-converted on board while the field probe and reference signals are down-converted in the down-converter chassis. All signals must be converted from the RF frequencies of 402.5 or 805 MHz to the 50 MHz IF frequencies prior to digitizing and processing. This board was redesigned in 2007 when additional FCM modules where purchased to eliminate an expensive proprietary design from the system. The redesigned AFE has been modified to remove all frequency conversion channels and make all channels common 50 MHz IF channels. This change has improved the temperature stability of the board and has had the added benefit of transforming the FCM into a generic single frequency field/amplitude controller.

Table 1 provides data on the average temperature drifts measured in the commercial, SNS designed, and new 50 MHz only boards. Channel A & B are down-converted channels for the first two boards and shows the greatest improvement in temperature drift. The original IF channels show some improvement between the commercial board and the SNS design due to tighter tolerance components being used.

Table 1: AFE Amplitude Drift

Average Amplitude Drift dB/deg C			
Channel	Commercial	SNS	50 MHz
A	0.2848	0.0451	0.0031
B	0.3452	0.0269	0.0031
C	0.0157	0.0038	0.0029
D	0.0112	0.0077	0.0023

RF Output

The RF Output (RFO) board generates the 50 MHz IF output signal via a Texas Instruments 14 Bit Digital to Analog Converter (DAC). This signal is locally up-converted to either 402.5 or 805 MHz RF, filtered and amplified prior to exiting the RFO board. The frequency conversion components and amplifiers were found to have similar drifts as the ones experienced on the AFE. To remove the temperature dependence, the RFO was redesigned with these components removed from the RFO and moved to the frequency conversion RF chassis. The new RFO showed similar improvement in temperature stability with the original average drift measuring 0.0339 dB/degree C and the new board measuring 0.0033 dB/degree C.

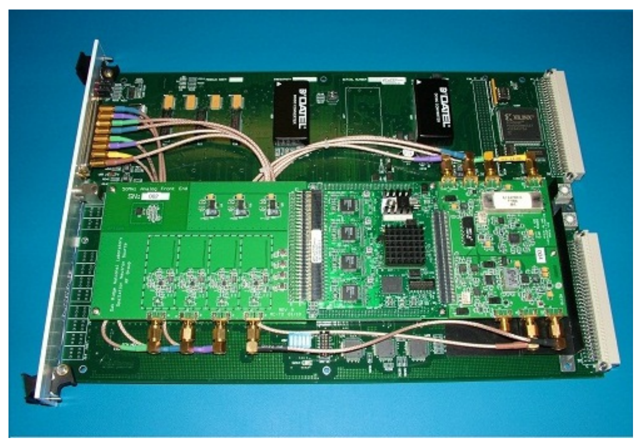

Figure 2: 50 MHz FCM Module

With the movement of the frequency conversion components off of the FCM, additional connections are required between the controller and the frequency conversion RF chassis. These connections were able to be accommodated by utilizing the two spare connector locations and reutilizing some of the functions of the old connections. This allows the current FCM hardware to be reused without having to have any mechanical modifications made. A picture of the new FCM and daughter cards is shown in figure 2 for reference.

Frequency Conversion RF Chassis

The original down converter chassis has had the most modifications made to it to support the added functions moved from the FCM. The original down converter chassis utilized coaxial-style RF components to speed the design process when the SNS LLRF was initially designed. The new frequency conversion RF chassis that replaces it is a surface mount design that supports both up and down conversion functions for the LLRF. The chassis is designed to support both single and dual LLRF systems by using either one or two Frequency Conversion RF (FCRF) boards per chassis. Tests of the new board are encouraging with it meeting all of the original specifications for the down converter chassis. Channel to channel isolation is good and has been measured to be greater than -75 dBc. The RF output level has been increased from +10 dBm to greater than +15 dBm to support the additional LLRF drive requirements for some of the systems. Figure 3 provides a picture of the new board, up and down conversion functions are separated on the left and right sides of the board.

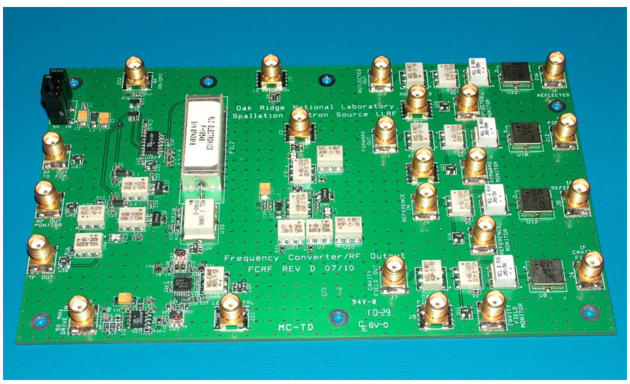

Figure 3: Frequency Conversion RF Board

While the components that are used for the frequency conversion still exhibit temperature dependencies, the problem is addressed by temperature controlling the chassis. The FCRF boards are mounted on a 0.25 inch thick temperature regulated aluminum plate that is maintained at 110 +/- 0.1 degrees Fahrenheit. Regulation is provided by an Omega I-series PID controller with insulation surrounding the circuit boards and RF cables. Monitor ports have been added to allow troubleshooting of all RF signals including the LLRF drive signal that was unmonitored in the old design. Care has been taken to ensure critical signals have the same path length and that connectors are minimized to limit failure points.

WORK STATUS/IMPROVEMENTS

The temperature measurements have been completed for all daughter cards and subassemblies. The integrated 50 MHz FCM has been tested but full system tests are still uncompleted. Final assembly of a dual frequency conversion RF chassis is currently in progress. An additional temperature chamber test of the complete LLRF system including the Frequency Conversion RF chassis is still needed. With SNS currently in a neutron production cycle, the system cannot be installed until the next maintenance outage scheduled for December 2010.

SUMMARY

Minor beam movement can be observed during neutron production cycles and has been correlated to the klystron gallery building temperature and the LLRF system. An investigation of the movement appears to point to a temperature dependency with the FCM module. Initial attempts to temperature stabilize the LLRF equipment racks show that it is possible to minimize the effect of the klystron gallery temperature on the LLRF systems but is not necessarily the most cost effective solution.

The SNS field control module's AFE and RFO daughter cards have been shown to have the majority of the systems temperature drift associated to them. Both of these daughter cards have been redesigned to eliminate the temperature sensitive components. A prototype frequency conversion chassis has been developed to address these issues by temperature controlling all of the sensitive components. Laboratory temperature testing shows promising results for the new system. Additional tests with a dual LLRF system installed in the klystron gallery are scheduled during the upcoming maintenance shutdown.

REFERENCES

[1] M. Champion, et al, "Overview of the Spallation Neutron Source Linac Low-Level RF Control System", PAC05, May 2005

[2] M. Piller et al, "The Spallation Neutron Source RF Reference System," PAC05, May 2005