Technical Report--Study of LPSD Electronics in Vacuum

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Subject: We present the results of vacuum testing on a prototype detector module for the ARCS instrument. The vacuum testing took place over a period of two months.

Introduction: Reducing the background scattering characteristics of the final flight path is of interest in the design of neutron scattering instruments. One method of reducing background scattering is by the introduction of a vacuum between the sample and detector. Operation of the detector electronics in vacuum would allow for greater flexibility in design and could eliminate a number of design tradeoffs and greatly reduce the number of vacuum feed-throughs needed to place detectors in the vacuum. Because of the difficulties involved with vacuum operation of electronics, this is something that has not been considered to be an option. With the availability of low power electronics, and the requirement by many SNS instruments for vacuum in the final flight path we felt that the possibility of vacuum operation of detector electronics should be revisited.

In order to corroborate earlier test results that indicated vacuum operation was possible[1], a custom vacuum tank was created for the testing of ARCS linear position sensitive detector (LPSD) modules. The size of the custom chamber allowed testing of the entire detector module, including preamplifier and analog to digital conversion electronics, in vacuum. Two parameters were of critical interest during the vacuum testing. First we wanted to verify that the operational temperature of the electronic components was well below the rated operational limit of 70 C. Second, we wanted to verify that there were no unexpected changes in baseline voltages that might indicate unexpected component value changes or deposition of out gassed residues on the circuit board.

Below, we present the results of almost two months of continuous vacuum operation. We find that the current SNS electronics design can be operated in vacuum and find no evidence of overheating or board contamination.

Experimental Summary: Over a two month period we tested in vacuum a prototype detector module consisting of eight linear position sensitive tubes and associated electronics. The electronics consisted of preamplifiers and an A/D converter time stamp board or ROC board. All electronic enclosures were painted black to maximize the emissisivity of the radiative surfaces. The entire assembly including cables was placed in a custom vacuum chamber made for the purpose of testing the equipment. No B_4C was placed in the vacuum.

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[1] Measurements in Oct. 2001 of the SNS preamplifier electronics showed a 3-5 degree temperature rise in operational temperature when placed in vacuum.

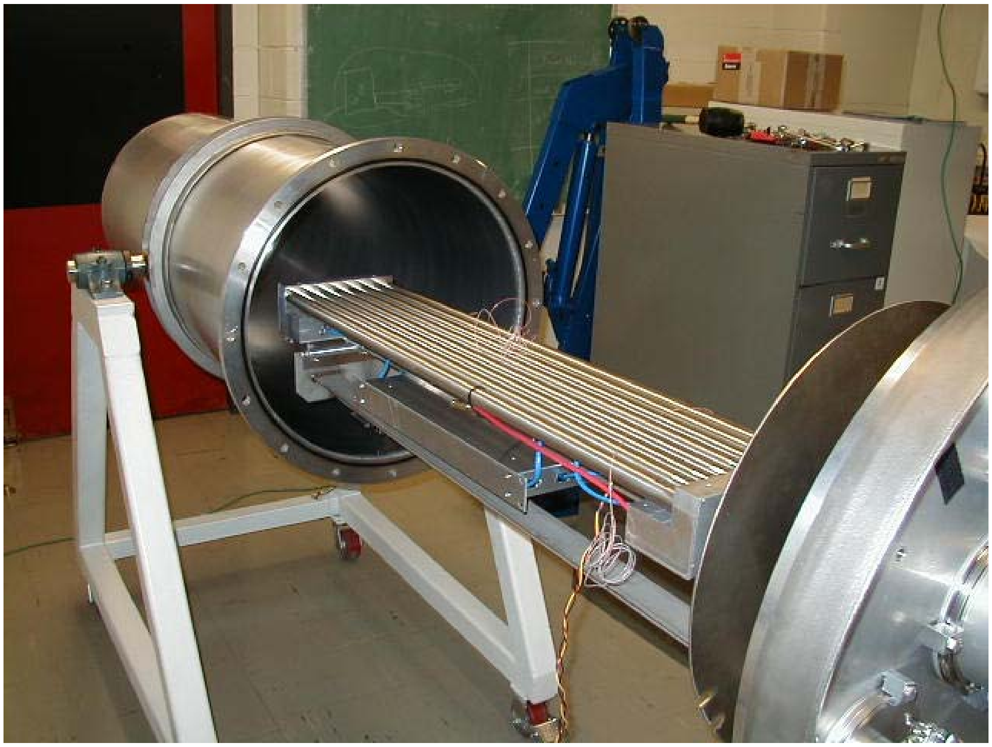

Figure One: Showing the vacuum test chamber and a complete eight tube detector module. In this picture the electronics enclosures have not be blackened.

The vacuum test system, which can be seen in figure one consisted of a cylindrical vacuum chamber approximately 60cm in diameter and 1.5 meters in length. Inside the chamber a painted black sheet of aluminum was placed against the inside vacuum wall to improve the radiative characteristics of the interior. The vacuum system consisted of a turbo pump directly mounted to the chamber, backed by a dry roughing pump through 2 meters of tubing. Vacuum feedthroughs consisted of a mix of standard and custom designed feedthroughs. Power and thermocouple connections were made through commercially available feedthroughs, while a custom designed feedthough was used to connect Cat5 ethernet cables which were required for communications with the detector electronics. Thermocouples were placed on four different integrated circuits. It was determined with earlier vacuum studies that the temperature rise on the preamp board was of the order of 3-5 degrees above ambient temperature, therefore we decided to measure only components on the A/D converter or ROC board. On the ROC board a mix of analog and digital components were monitored including field programmable gate arrays (FPGA)s, A/D converters and input buffers.

The maximum temperatures were seen on the channel FPGAs (53 C) and on the input buffer, (50 C). Both these temperatures are well below the operational maximum of 70 C. Except for a period in which the room containing the apparatus was covered with plastic and the air conditioning turned off because of removal of asbestos insulation, temperature fluxuations of the order of ± 0.5 C . (During the asbestos removal temperature fluxuations were of the order of ±2 C.)

Electrical measurements indicated that the integrator input offset voltage remained constant (except for initial changes due to temperature rise) throughout the period of testing. The integrator input offset voltage was measured because changes in its value affect the accuracy of the position measurement. In the current design, changes in the offset voltage can be corrected for[2] so these changes would no cause position errors. However, significant changes in its value could be indicative of leakage currents due to contamination deposited on the circuit board while in vacuum. Additional tests with the high voltage applied to the LPSD indicated that no measurable adverse effects from dielectric breakdown occurred.

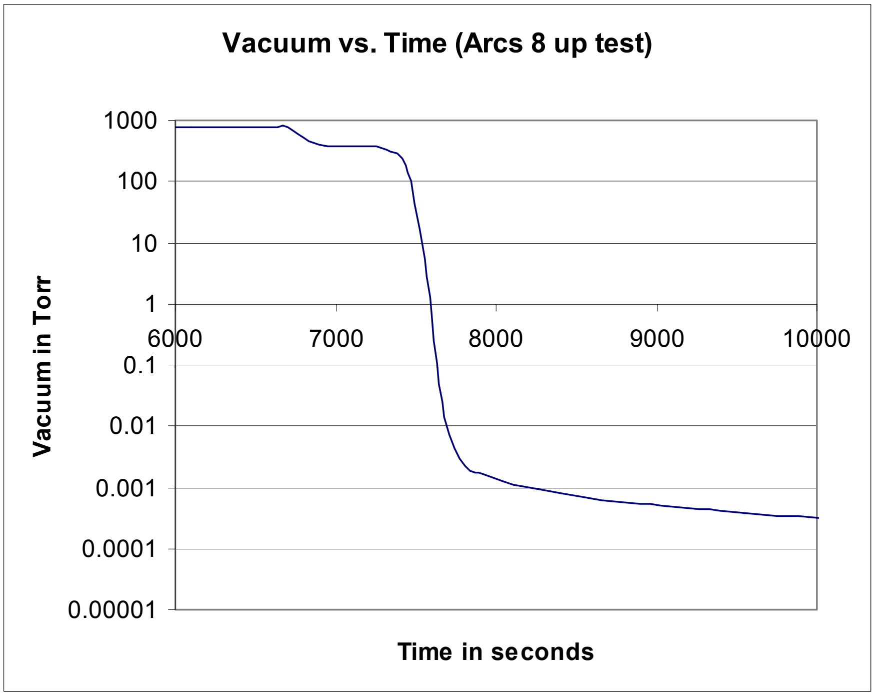

Figure two: Showing the behavior of the vacuum versus time for the first hours of pumping.

Vacuum Characteristics: Figure two shows the vacuum versus time for the first few hours of data logging. The main vacuum value was opened at a time of about 6800 seconds. The pressure begins to drop significantly after 15minutes and continues to drop more slowly after that. High voltage can be applied whenever the vacuum falls below 1milliTorr. Figure three shows vacuum versus time on a longer time scale showing that pressure does not stabilize but continues to slowly drop. This is probably due to out gassing of the plastic wire insulation and other components in the vacuum.

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[2] This technique does not lead to a reduction in the speed of the electronics.

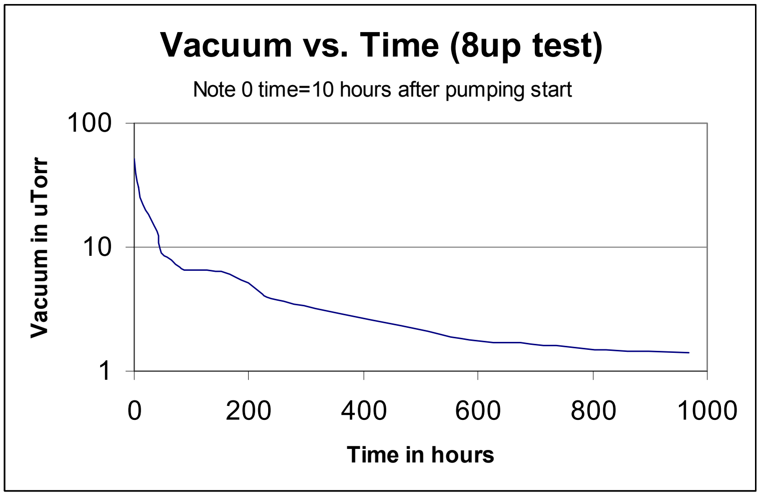

Figure three: Showing the vacuum pressure over a long period of time. Note that the pressure does not plateau even after 800 hours of pumping.

Component temperature rise:

Figure four shows the temperatures of two components with the highest operation temperatures. The temperature stabilized approximately 10 hours after pumping began. Data for more than one month is presented in figure five. The rise in temperature at 100 hours (figure five) coincided with asbestos removal in the room.

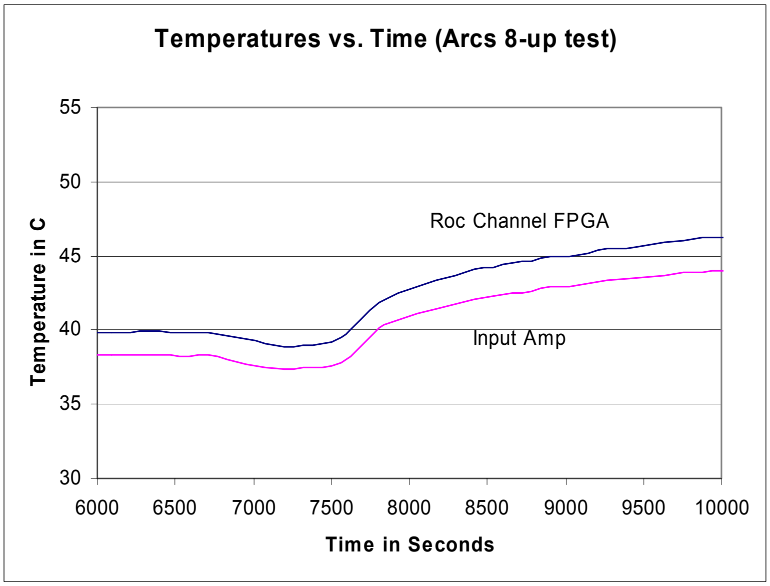

Figure four: Show the temperature of two components as a function of time just before and after pumping started in the vacuum chamber.

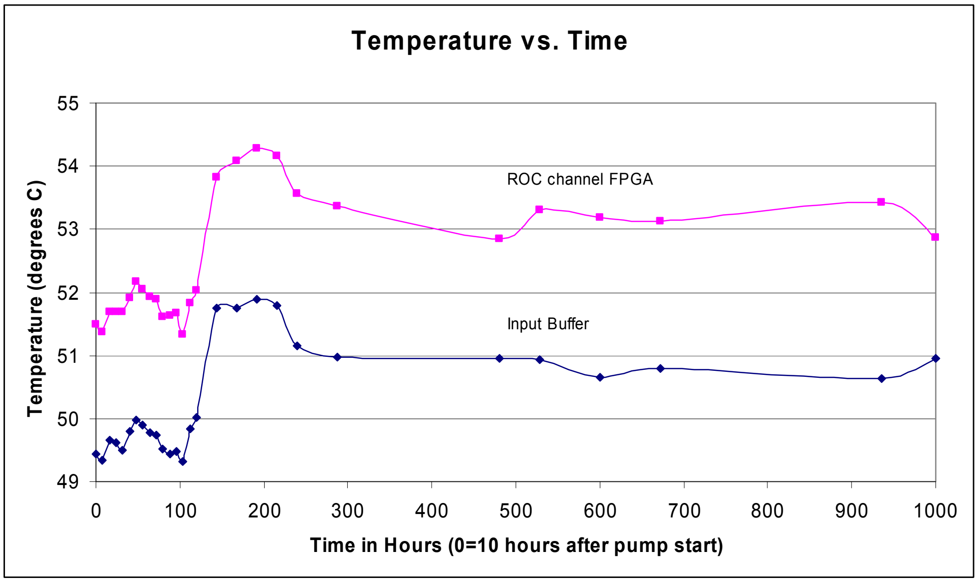

Figure five: Showing the temperature of two components over a period of 1000 hours. Components are in vacuum.

The rise of 10-20 degrees could be anticipated by analyzing the power draw by the ROC board, and calculating the power dissipated by a 10 degree rise in temperature. If we assume an emittance of one, we obtain $P = \sigma(T^4{}_2 - T^4{}_1) \approx$ 6mW/cm^2. The ROC board is about 700cm^2 and could therefore radiate about 8 watts. The ROC board consumes about 11 watts of power so that conductive heat loss and additional slight temperature rise can account for the other 3 watts of power. Table 1 below lists the temperature in air and in vacuum at the end of 1000 hours for all measured components.

Thermocouple	In Air Temperature (Celsius)	Vacuum temp. @1000 hours
ROC main FPGA	38.6	49.9
ROC channel FPGA	40.2	53.2
2.5V regulator	37.5	48.5
A/D converter	30.7	41.5
Input Buffer	38.5	50.8

Table 1: Showing the temperature of components in air and in vacuum.

Electrical performance:
One parameter that is important to measure is the offset voltage at the integrator. A one millivolt error in the baseline value can produce an error of about .3% in the position measurement. This offset is affected by the entire preamp, ROC analog chain and therefore we consider it an important measure of component stability and also an indicator of gross contamination of the board. A second measure of contamination would be an excessive number of measured background events when high voltage is applied to the preamps. To obtain a good statistical average of the baseline voltage the high voltage must be low enough so no neutron events are registered in the tube. For the first 1000 hours the high voltage was set to 50volts to allow baseline measurements to be done. Afterwards the high voltage was set to 2000V to allow background events to be counted.

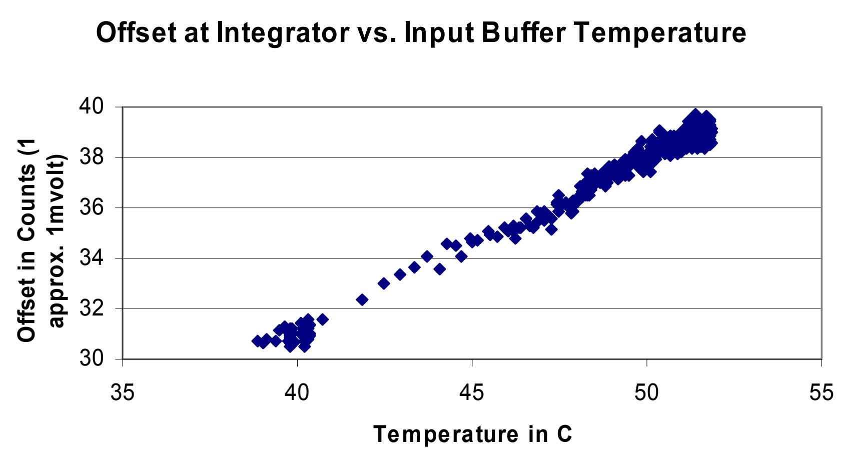

Figure six: Showing offset voltage vs. temperature.

Figure six shows the results of the offset voltage for tube 1. Similar results were obtained for the other channels. We see that for approximately every 1.5 degrees, the offset changes by 1 millivolt. This indicates that during initial vacuum pump down, if operation is desired, then the changes in the offset voltage caused by the continuing rising in the component temperature must be compensated for. Such a mechanism is in place in the present design and measurements on the effects of short-term temperature changes on position accuracy will take place once the vacuum chamber is relocated near a neutron source. During the 1000 hour measurement period the measured offset varied between 37.4 and 39.9 millivolts. This indicates that there was no gross contamination of the circuit board or significant component value changes during the measurement period.

High Voltage was applied to the LPSDs after about 1200 hours in vacuum. The background event rate was measured to be 20 counts for six active tubes in 10 minutes time. (Counts seen in each tube were statistically similar.) The measured rate is similar to the background rate measured at ISIS[3] of 2-3 counts per tube in a 10 minute period. We conclude that the 1200 hours of vacuum exposure had no observable detrimental effects on the dielectric breakdown strength of the electronics (circuit board or high voltage capacitors). A second measurement of the background was done about two months after the first measurement. A rate of 30 counts/10 minutes was measured which is statistically similar to the 1200-hour value of 20 counts/10 minutes.

Conclusion:

Measurements in vacuum of the linear position tube electronics indicates that the operational temperatures of electric components are well with operational limits, typically rising 10 to 12 degrees Celsius. With additional planned changes in layout techniques and newer versions of the FPGAs measured vacuum temperatures should be even lower. Monitoring of the offset voltages and baseline neutron event rate indicated that there are no short-term effects on dielectric breakdown voltages. No indication of vacuum deposition of contamination on the circuit boards was seen. We conclude that vacuum operation is feasible with the current SNS electronics design.

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[3] "New Horizons in Position Sensitive 3He Detectors", ICANS 1998, C.D. Frost et. Al.