Deep Cryogenic Low Power 24 Bits Analog to Digital Converter with Active Reverse Cryostat

Marcos Turqueti, Soren Prestemon, Robert Albright
Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

Abstract

LBNL is developing an innovative data acquisition module for superconductive magnets, where the front-end electronics and digitizer reside inside the cryostat. This novel system allows conventional electronic technologies, such as enhanced metal–oxide–semiconductors, to work inside cryostats at temperatures as low as 4.2K. This is achieved by careful management of heat inside the module, thereby keeping the electronics enveloped at approximately 85K. This approach avoids all the difficulties that arise from changes in carrier mobility in semiconductors at deep cryogenic temperatures.

There are several advantages to utilizing this approach. A significant reduction in electrical noise occurs due to the low temperature environment in which the electronics are immersed, reducing the thermal noise for signals captured inside the cryostat. Also, the shorter distance that signals will be transmitted before digitalization reduces pickup and cross-talk between channels.

Introduction

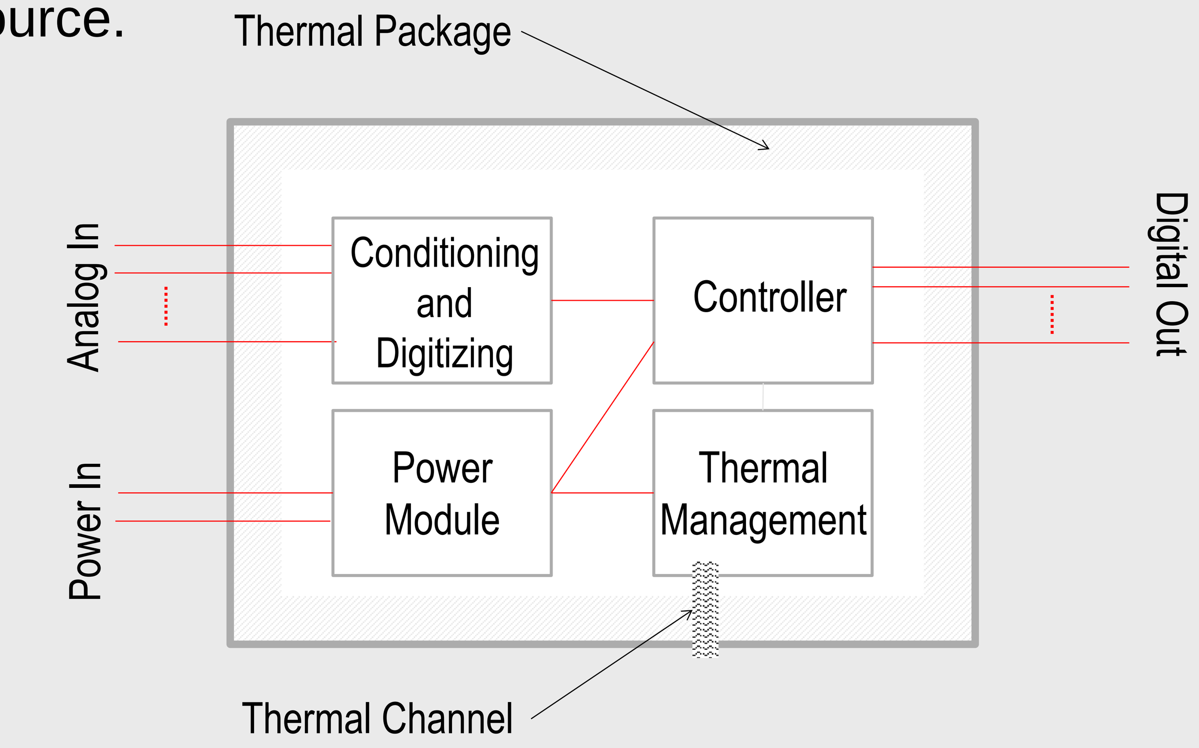
The demand for more sensors to instrument superconductive magnets is increasing as new advanced superconducting magnet prototypes are commissioned. Table 1 shows the typical number of sensing wires in superconductive magnets recently tested at LBNL. Presently, the number of wires coming out of the cryostat is directly proportional to the number of sensing elements inside the cryostat. This is not an ideal solution in that it adds further complexity to the feed-through interface, increasing the probability of failure in cabling, heat losses, cross talk, and short-circuits between adjacent wires. LBNL's innovative new system allows the user to increase the number of sensors while keeping a constant number of wires.

System Description

Table 1 Number of sensing wires for superconductive magnets tested at LBNL

Magnet Name	VTap wires	SG wires	RTD wires	Others wires	Total # of wires
TQS03b	56	96	16	4	172
HD03b	60	80	16	8	164
HQ02b	92	80	16	8	196

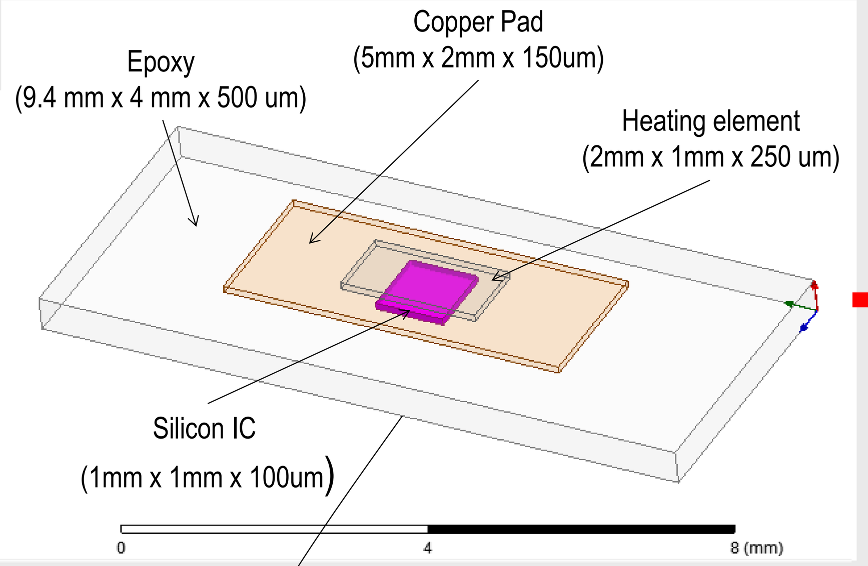
To illustrate the capabilities of this system, we can use the table above as a reference. While for TQS03b it took 96 wires to read 24 strain gauges, if we were to use this prototype to read the same amount of strain gauges, we would need only 7 wires when utilizing the internal current source.

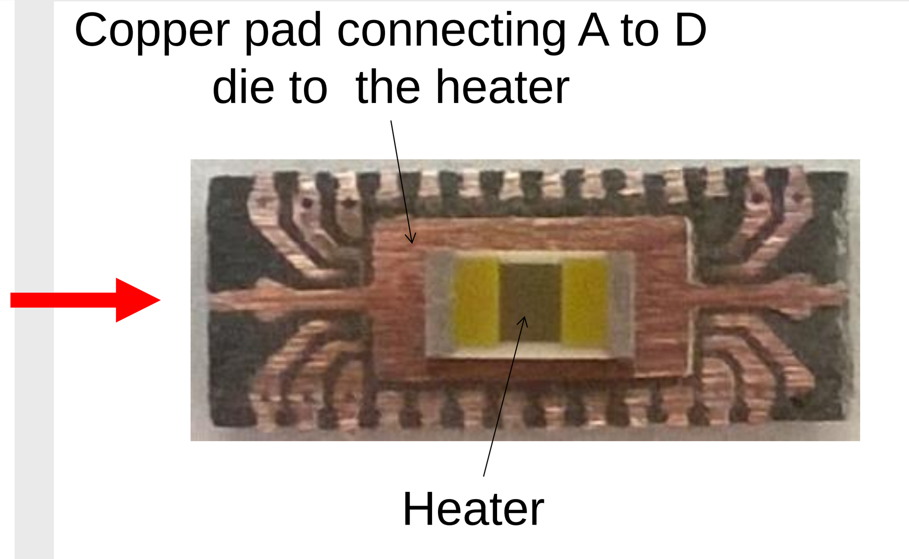


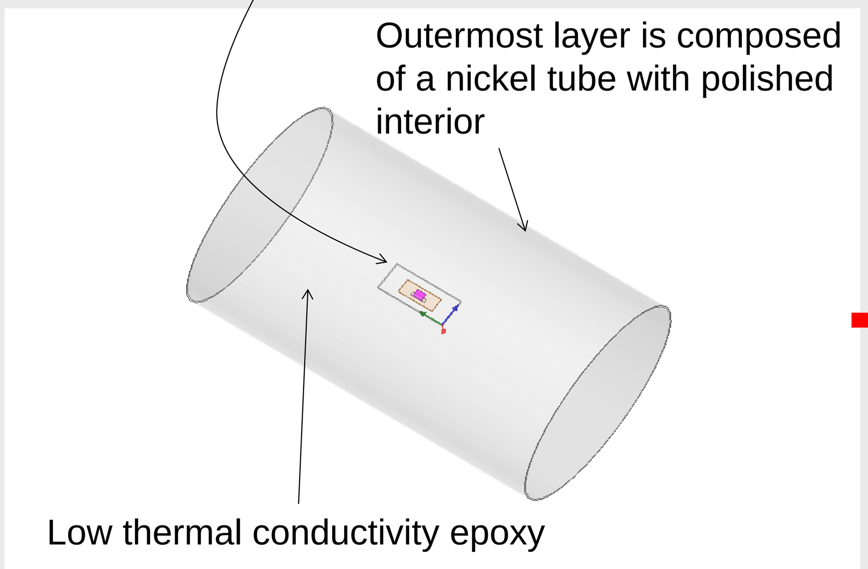
The basis of this cryogenic data acquisition system is a reverse cryostat that creates a small thermal bubble inside the cryogenic vessel. In the case of this prototype a volume of approximately 1mm^3 is keep at 85K±1. This volume is contained by a thermal envelope that actively manages heat inside the package, maintaining a constant temperature around the A to D converter. It does this with the help of a thin film heater, and a resistance temperature detector (RTD). The RTD feeds temperature information to a proportional-integral-derivative (PID) controller that, in the case of this prototype, is located remotely outside the cryogenic vessel. Future versions will have the PID encapsulated with the A to D.

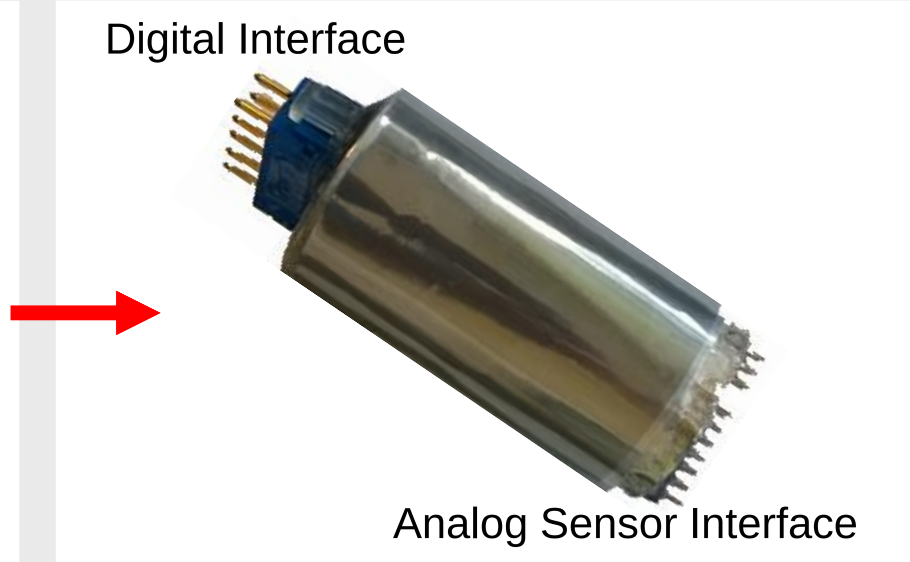
This prototype has, at its heart, a 16 channel, 24 bit A to D converter, capable of a sampling at up to 20kSPS. Channel zero of the A to D is reserved for the RTD, making 15 channels available for collecting sensor information. This system requires a total of 7 wires to work.

The system can be divided into five basic elements, as illustrated by the figure on the left; the Thermal Package, Conditioning and Digitizing Electronics, Controller, Power Module, and Thermal Management.



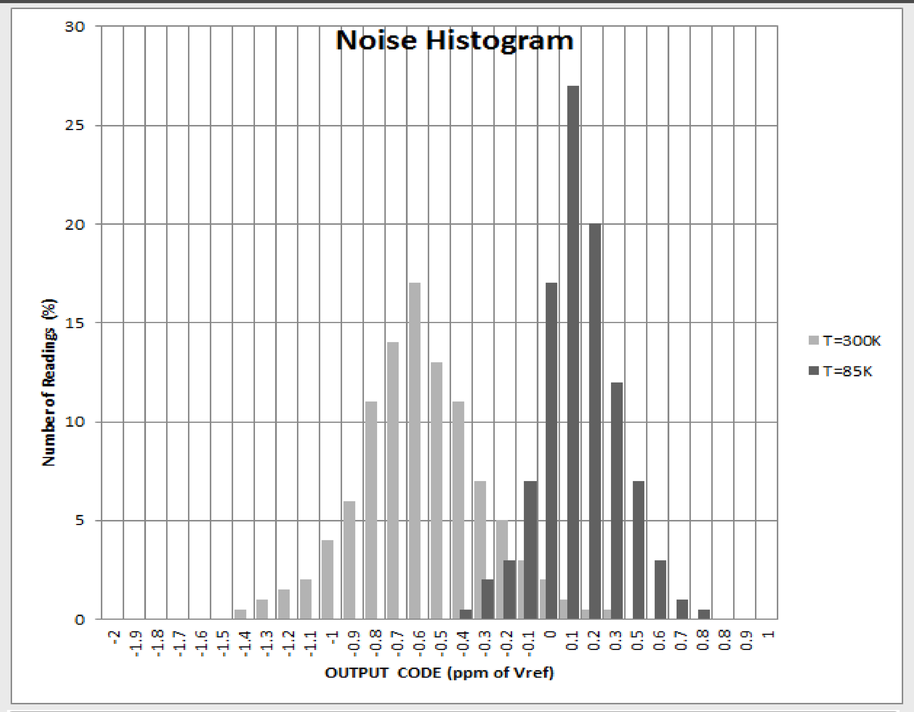


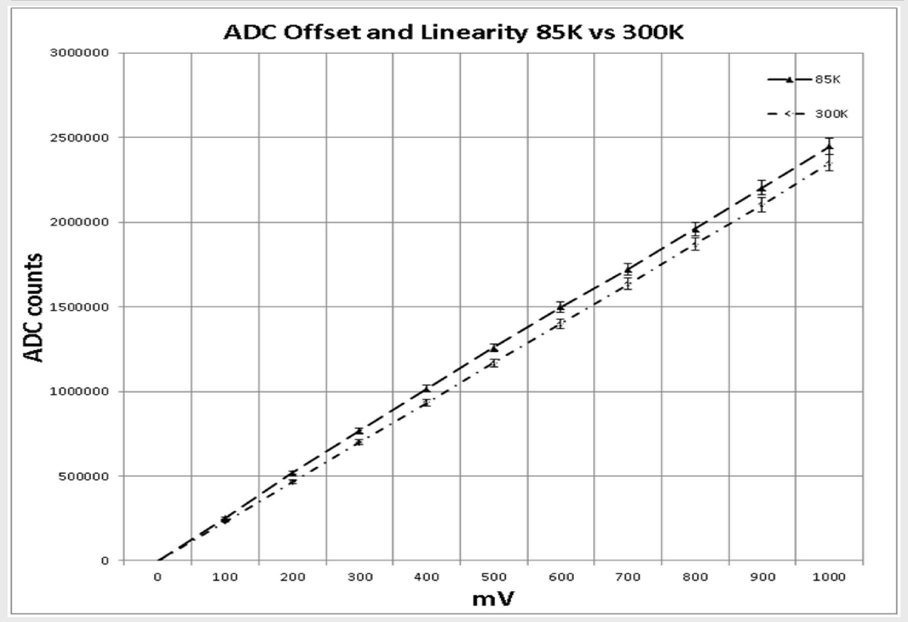




The set of pictures on the left illustrates the thermal package assembly. The A to D converter ASIC die is located on the other side of the copper pad. The A to D consumes only 400uW, while the heater used to maintain the A to D operating temperature consumes 40mW for the current prototype. This will be dramatically improved in the next version, when a much lower thermal conductivity insulator will be utilized for the outer layer of the package.

Results





The graphs above shows noise performance and linearity for 85K and 300K.

Conclusion

This work shows that it is possible to operate a compact, low power superconductive magnet data acquisition system inside the magnet's cryostat. This offers a new paradigm for data acquisition at liquid helium temperatures wherein the information collected from sensors at the magnet can now come already digitized to the cryostat head. There are several advantages to this approach including increased robustness of the cabling system, reduced thermal noise on the A to D, a decreased number of wires going out of the cryostat, and the utilization of low voltage digital signals.

Many improvements will be implemented on future versions of the system, such as optically isolating the power supply, adding an internal current source for the strain gauges, completely embedding the thermal management system, and improving the cryogenic insulation.