

DEVELOPMENT OF A TEMPERATURE MAPPING SYSTEM FOR 1.3-GHz 9-CELL SRF CAVITIES*

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Abstract

The mapping of outer wall temperature during the vertical test of a superconducting radio-frequency (SRF) cavity has been one of the most useful tools to detect bad spots of the cavity. However, few systems except a rotating-arm type one have been developed so far for 9-cell cavities. Since it will be an essential tool to identify the failure of the cavities, we started to develop a fixed-board-type temperature mapping system that will enable us to map the temperature of 9-cell cavities in a much shorter time than rotating-arm type. This paper describes the design, status of the development and preliminary tests of the design.

INTRODUCTION

A temperature mapping (T-mapping) system has shown to be a very useful tool to identify and understand the failing mechanisms that occur while operating SRF cavities. Basically two types of T-mapping systems exist, i.e., fixed-board [1-4] and rotating-arm [5-7] types. In the framework of our collaboration with the International Linear Collider (ILC) program led by FNAL, we are developing a full 9-cell fixed T-mapping system. To the best of our knowledge, no such system has ever been developed for a multi-cell cavity so far. It is believed that a fast T-mapping system is necessary to diagnose the problems of failed cavities. This paper describes such a system with 5508 sensors with only 720 cables coming out from the cryostat.

SYSTEM DESCRIPTION

For the full system, we consider 612 sensors per cell and 5508 sensors in total for the 9-cell cavity. Azimuthally, each board is separated by 10 degrees. Since placing over 5508 cables through connectors at the top cryostat flange is prohibitive, how to reduce the number of cables is a challenge. We decided to develop a multiplexing scheme inside the cryostat. The multiplexing scheme groups the sensors into 9 groups of 612 sensors, i.e., with one scan it multiplexes the sensors covering the cavity in the range of 40 degrees azimuthally. Therefore, we only need to provide power to those 12 boards while keeping the others off. In order to do this we make use of common diodes and resistors which have been successfully tested at temperatures as low as ~1.4 K. Figure 1 shows a solid model of a TESLA-type 9-cell cavity with 6 sensor boards. We decided to have 3 sensor boards per one azimuth that covers 3 cells each. This decision was made with the compromise between ease of

installation and sensor adjustment tolerance, i.e., if we have only one board that covers 9 cells, it will be very sensitive to the overall cavity length which can be changed during the cavity tuning. By performing the multiplexing inside the cryostat, the complexity of the interface is similar to that of a single-cell fixed system, with the addition of 9 power lines sequentially switched from the outside.

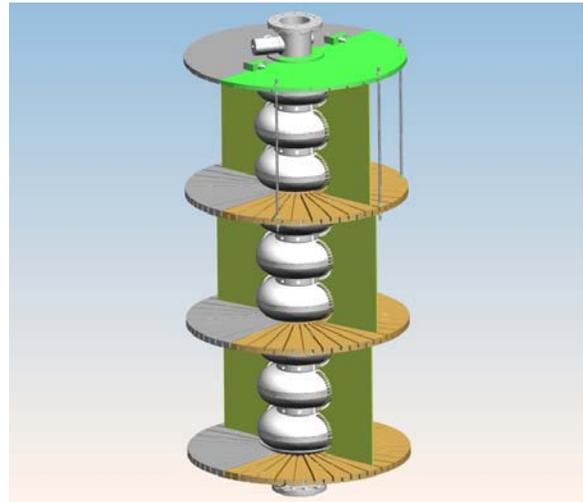


Figure 1: Solid model of a 9-cell cavity with 6 sensor boards attached.

Finally the data will be scanned and acquired by 4 National Instruments SCXI-1130 (256-channel multiplexer, 900 channels/s) and 4 National Instruments PXI-4070 DMM.

TEMPERATURE SENSOR

The sensors to be used are Allen-Bradley 100Ω resistors, which changes its resistance rapidly at the measurement temperature of ~2 K. Figure 2 shows the data for 4 resistors from 1.62 K to 4.13 K. The sensors will be assembled on the boards in a similar way as shown by G. Ciovati [8].

Self Heating Test

An important parameter to be determined in order to optimize the operation of the sensors is the maximum allowed current through the sensor such that there is little self heating. We have tested at superfluid helium temperature the power multiplexing concept, the self heating current and tested the diodes. We designed a PCB board including the circuits shown in Figure 3.

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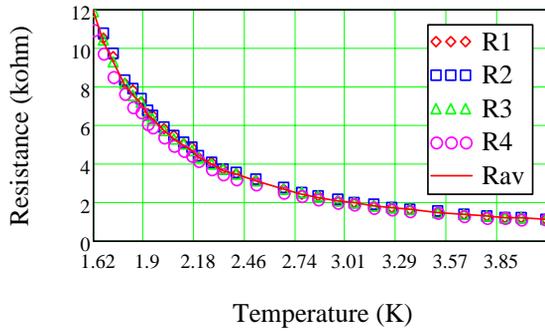


Figure 2: Temperature dependence of 4 Allen-Bradley resistors and its average value.

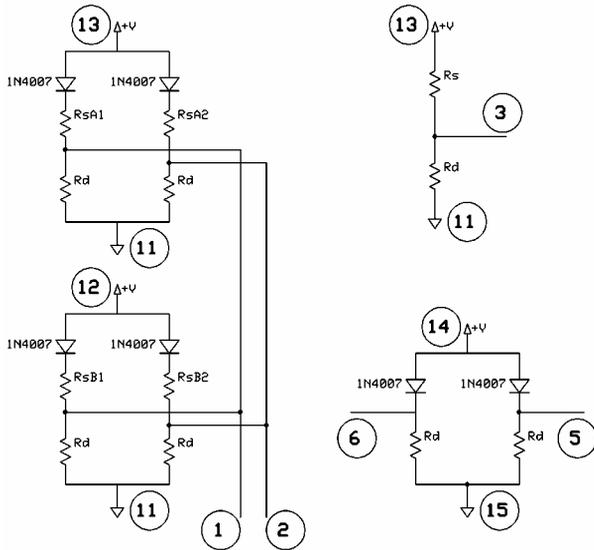


Figure 3: Prototype board. Left: power switching concept; upper right: self heating test; lower right: diodes operation test. RsA2 and RsB1 are Allen-Bradley resistors.

For the self heating test, we just implemented a voltage divider circuit with a fixed valued resistor of 33.18 kΩ. Figure 4 shows the measured data compared with the expected values.

The voltage reading becomes nonlinear around an applied current of 25 μA. Therefore, this value is the driver of the overall design, making sure that the current through the sensors always remains below such value.

SWITCHING TEST

The circuit on the left in Figure 3 simulates the multiplexing of 2 channels by powering either one of them. The diodes are conventional 1N4007 and the value of the resistance Rd is ~100 kΩ. In order to prove the multiplexing concept, we used for RsA1 and RsB2 fixed resistors of about 1 kΩ. Therefore, the expected voltage from sensor 1 in this experiment is given by

$$V_1 = \frac{V_s - V_d}{RsA1 + \left(\frac{2}{Rd}\right)^{-1}} \cdot \left(\frac{2}{Rd}\right)^{-1}$$

where V_s is the applied voltage and V_d is the voltage drop across the diode.

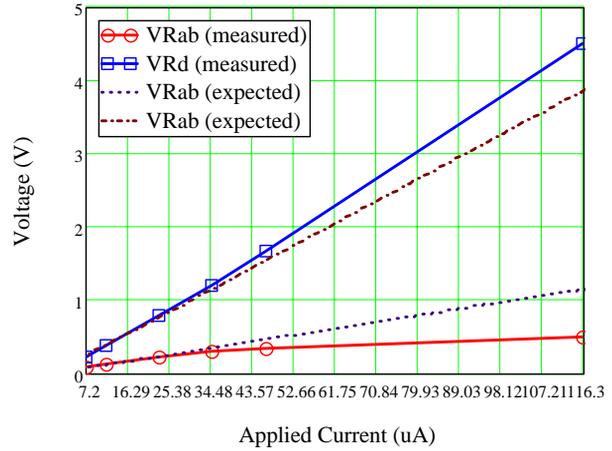


Figure 4: Measured and expected voltage from the self heating test (upper left circuit in Figure 3).

Using the data for the sensors given in Figure 1, and $R_d=100$ kΩ, we get the expected voltage as a function of the temperature given in Figure 5. The sensitivity at 2 K is approximately $dV/dT = .186$ mV/mK.

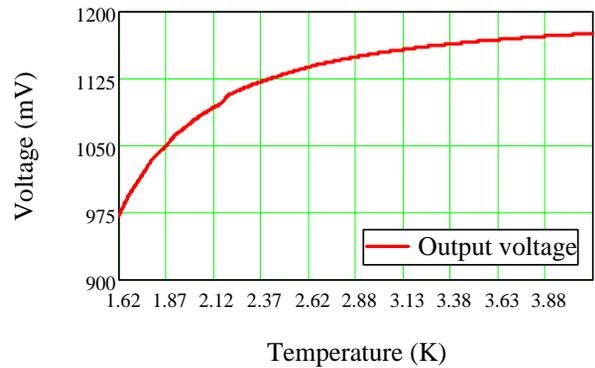


Figure 5: Expected output voltage from a sensor channel after multiplexing.

In a similar manner, the current going through the sensor is given in Figure 6.

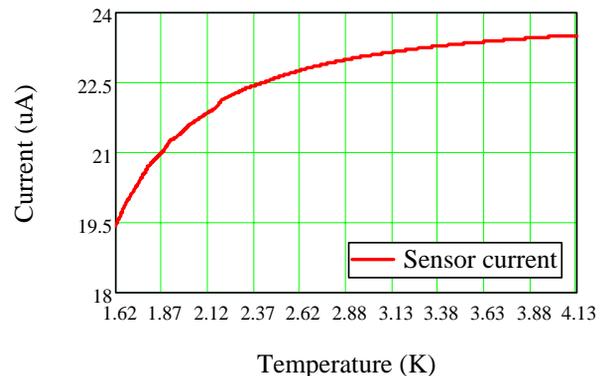


Figure 6: Expected current through the sensors.

In order to achieve these plots, we need to impose a voltage of ~ 1.2 V after the diode in order to prevent self heating. The dynamic range between 1.62 K and 4.13 K is ~ 0.206 V. The $R_d = 100$ k Ω value was not randomly chosen for the test. The real system is designed to use $R_d = 450$ k Ω , which multiplexed among 9 lines, gives a term $R_d/9 = 50$ k Ω , which is exactly the same as in the test when $R_d = 100$ k Ω and multiplexing two lines.

The test performed at superfluid helium temperature showed great agreement with the expected results, and the small differences are caused by the non-exact value of all the resistors and also the non-exact values of the voltage drop across the diodes. However, when operating the system, a zero calibration will be performed initially where only increments of the output voltage are meaningful. The voltage drop across the diode at liquid helium temperature becomes significantly large compared to room temperature, i.e., ~ 3 V compared to 0.7 V for an inexpensive diode (1N4007). However, it varies only slightly between ~ 2 K and ~ 4 K, although it cannot be ignored. This is overcome by two factors: first, the position of the diodes on the board are such that their temperature should be that of the liquid helium at the testing pressure, and second, since the temperature of the liquid helium may change throughout the test, we implemented in each three cell board a testing circuit where we will monitor the voltage drop from a diode and then apply the appropriate corrections.

BOARD DESIGN

The final board layout is shown in Figure 7 with the sensor locations and Figure 8 shows a picture of a manufactured board ready to have the sensors attached.

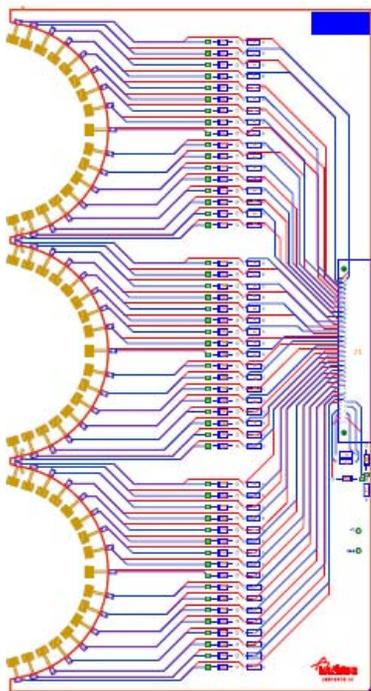


Figure 7: 3-cell section board layout.

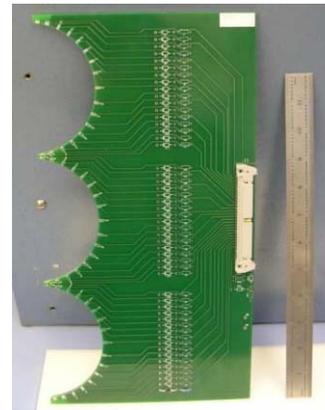


Figure 8: Fabricated 3-cell section board.

CONCLUSIONS

We have demonstrated an innovative system to reduce the complexity of the cabling for a 9-cell T-mapping system by performing a power multiplexing scheme within the cryostat. If this scheme works, we need only about 720 cables coming out of the cryostat for about 5508 temperature sensors. The system is under fabrication and final assembly and experimental data will be available within a few months.

ACKNOWLEDGEMENT

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