

**AC 2007-1108: ACCURATE CRYOCHAMBER FOR A SMALL LABORATORY  
WITH SMALL BUDGET**

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# ACCURATE CRYOCHAMBER FOR A SMALL LABORATORY WITH SMALL BUDGET

## Abstract

Development of electronic devices for cryogenic temperatures requires specialized environmental chambers. The Microelectronics Research and Communications Institute required a low-cost alternative to the readily available environmental chambers. The solution was a simple aluminum cylinder cooled by pulsing liquid nitrogen into the cylinder to control the temperature of the electronics under test. National Instruments LabVIEW, GPIB communications, and simple bench top instruments control the temperature inside the chamber. This low-cost alternative will reach and sustain any set point temperature between room temperature and  $-190^{\circ}\text{C}$  with an accuracy of  $\pm 5^{\circ}\text{C}$ .

## Why Reinvent the Chamber?

For NASA missions to the outer planets in the next two decades, reduced energy consumption means reduced payload. The development of electronics that operate at extremely cold temperatures ensure that they require less energy to keep the electronics warm enough to operate reliably. This technique reduces requirements for weight and volume of both the on-board power source and the insulation that encloses the experiments. It also helps the designers by placing the electronics closer to the sensors. In developing such low-temperature electronics, the University of Idaho's Microelectronics and Communications Institute (MRCI) recognized a need for a low-cost, low-temperature test chamber. Such chambers can be quite costly, even for a temperature range that permits cooling with liquid nitrogen.

The MRCI has not previously performed cryogenic testing for developing electronics. Cryogenic testing requires special procedures and equipment, as liquid nitrogen is hazardous and requires special handling precautions. The industry standard for cryogenic testing uses large and costly environmental chambers to perform electronics testing. The cost to implement a full environmental chamber can be in excess of \$40,000 for a new liquid nitrogen cooled unit. In addition to the purchase cost of the unit, liquid nitrogen must be stored and transferred with special vacuum-insulated bottles and lines. The MRCI required a cheaper alternative to the commercial environmental chambers currently available.

## Requirements

For environmental testing at cryogenic temperatures, the MRCI needs an environmental testing chamber equivalent to liquid nitrogen chambers that are available from commercial vendors. Any temperature between room temperature and  $-180^{\circ}\text{C}$  is possible in many of the commercial liquid nitrogen cooled chambers on the market. The accuracy of the temperature inside the chamber must be within  $\pm 5^{\circ}\text{C}$  of the set point temperature. The MRCI cold temperature chamber must also be flexible to change with the MRCI for their future needs, and it must do so at a very low cost. The requirements for the MRCI cold temperature environmental chamber

must meet the following criteria:

1. Portable: One person can move the chamber
2. Efficient: It must use less than one standard transfer cylinder of liquid nitrogen for one 8 hour test
3. Capable of any temperature below room temperature to  $-180^{\circ}\text{C}$
4. Safe
5. Automated real-time temperature monitoring
6. Easy to use for MRCI personnel with minimal training
7. Adaptable to any type of package pin configuration
8. Low cost: less than \$5,000

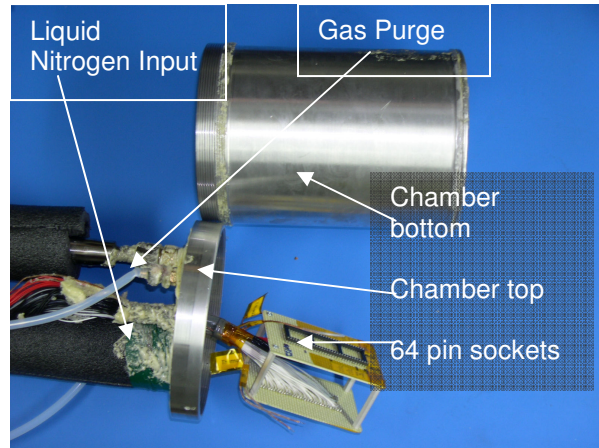


Figure 1 The Low Cost Environmental Chamber

### Low Cost Chamber

The environmental chamber is a relatively simple design. The chamber is an aluminum cylinder, 23 cm diameter by 25.5 cm tall, with a removable top. Two 64-pin sockets, wired to four external D-Subminiature connectors, provide electrical access to the device under test. The 64-pin socket connection inside would accommodate any type of electronic packaging with the help of adapters. Figure 1 shows the environmental chamber.

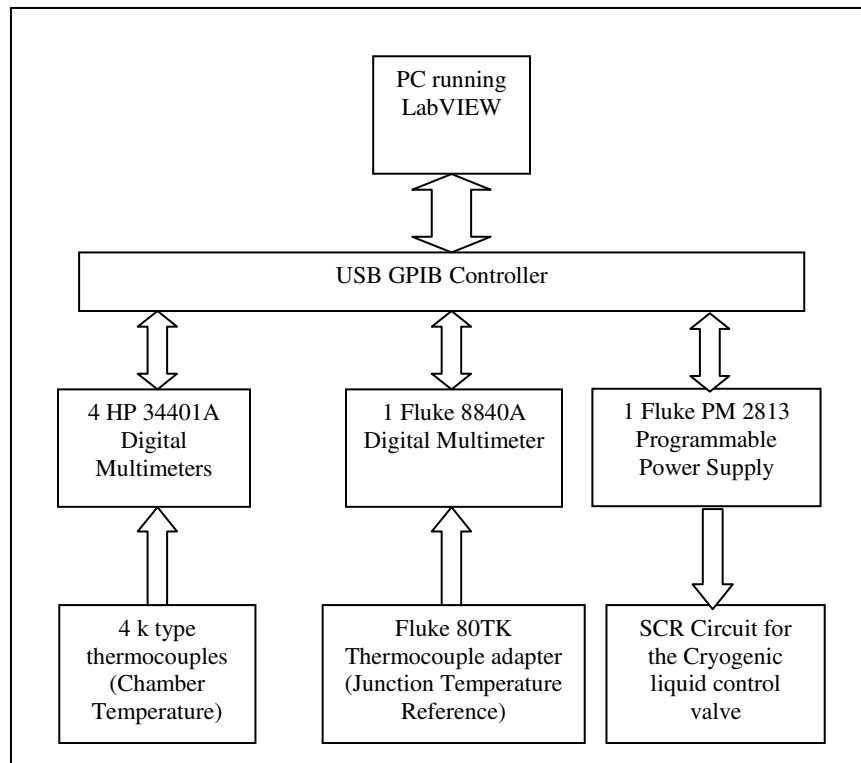


Figure 2 Control System Communications

For the control of the chamber temperature, a National Instruments LabVIEW Virtual Instrument program, running on a PC, reads four thermocouples inside the chamber and compares the temperature with the chosen set point. The program then pulses liquid nitrogen into the chamber to adjust the temperature to match the set point. The LabVIEW program running on the PC uses a USB GPIB controller for the instrument communications. The GPIB controller communicates with several bench top instruments; four HP 34401A digital multimeters, one Fluke 8840A digital multimeter with a Fluke 80TK thermocouple adapter, and one Fluke PM 2813 programmable power supply connected to an SCR circuit for the cryogenic liquid solenoid valve. Figure 2 shows the control system communications.

To measure the temperature in the chamber, the four HP 34401 digital multimeters read the voltage of each of four K-type thermocouples. The voltage read by the multimeters is the galvanic response of the thermocouple created by the temperature difference between the reference junction and the sensing junction. In the case of the chamber, the sensing junction is inside the chamber and the reference junction is outside of the chamber, at the four D-Subminiature connectors. The Fluke 8840A digital multimeter with a Fluke 80TK thermocouple adapter reads the reference junction temperature.

Using the National Institute of Standards and Technology (NIST)<sup>1</sup> equations and coefficients for the voltage of a K-type thermocouple, the reference temperature voltage compensates the voltages of the thermocouples. In the case of compensating the junction voltage at room temperature, (1) is used to find the voltage of a known temperature.

$$E = \sum_{i=0}^n C_i (t_{90})^i + a_0 e^{a_1 (t_{90} - a_2)^2} \quad (1)$$

$$E_{comp} = E_{measured} + E_{junction} \quad (2)$$

Adding the reference voltage to the chamber thermocouple voltages creates the compensated voltage (2). Using the NIST inverse temperature equation and coefficients and the compensated voltage, the temperature is calculated using (3).

$$t_{90} = \sum_{i=0}^n d_i E_{comp}^i \quad (3)$$

This process results in an accurate

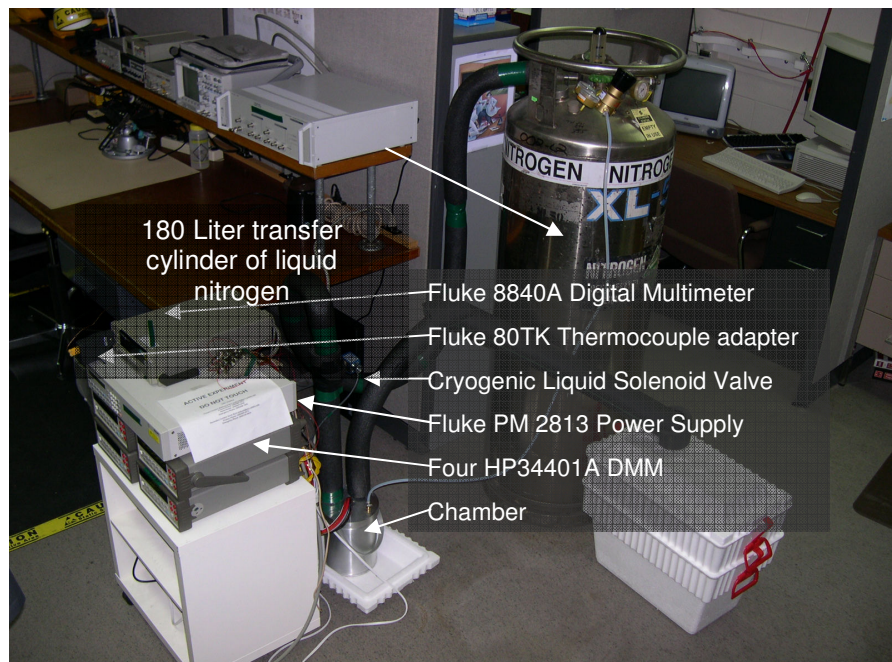


Figure 3 The Chamber and Control System Setup in the Laboratory

temperature measurement, as read on the multimeter, of the inside of the chamber to within  $\pm 0.1^\circ\text{C}$ . A copy of the NIST coefficients used for the equations is in Appendix A.

To control the temperature inside the chamber, liquid nitrogen is pulsed into the chamber in a controlled fashion. Liquid nitrogen flows from a standard 180-Liter transfer cylinder to the chamber, through a line in the top of the chamber. A cryogenic solenoid valve controls the flow of liquid nitrogen to create the required pulses. Insulated tubing provides appropriate uniformity of the pulse amplitudes. Exhaust of the evaporated liquid nitrogen gas is through a second additional line to an evaporation cooler.

A hysteresis regulator controls the chamber's internal temperature by regulating pulse length and frequency. The temperature of the electronics under test inside the chamber is within  $\pm 5^\circ\text{C}$  of a set point over a range between room temperature and  $-190^\circ\text{C}$ . The LabVIEW program reads in the temperature of the chamber and compares the temperature to the set point temperature. The program then pulses the valve to maintain the temperature in the chamber to be within  $\pm 5^\circ\text{C}$  of the set point temperature. The Fluke PM 2813 power supply remotely switches an SCR circuit, thereby controlling the cryogenic valve.

The chamber has another line attached to the top for a gaseous nitrogen purge for water abatement. The gaseous nitrogen purge also helps to create an even distribution of temperature throughout the volume of the chamber during off-valve periods. Figure 3 shows the entire system setup in the laboratory.

The LabVIEW program is easy to use with only minimal knowledge of LabVIEW front panel operations. The front panel has three tabs for file setup, control setup, and readings. The file setup tab includes the directory settings and the header information entries.

The LabVIEW program controls the temperature in the chamber according to how the user has set the system. In addition, the program is able to choose which thermocouple (or thermocouple average) controls the temperature of the chamber. The

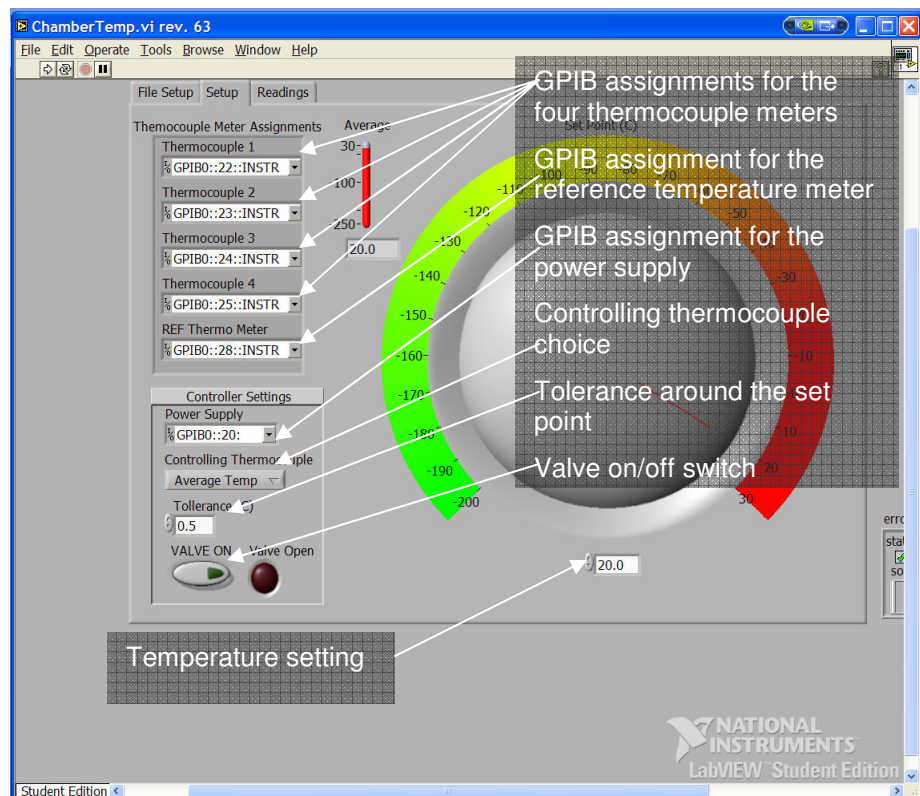


Figure 4 Control Setup Tab



control setup tab has seven settings for the chamber control system:

1. The GPIB assignments for the four-thermocouple meters
2. The GPIB assignment for the reference temperature meter
3. The GPIB assignment for the power supply
4. The controlling thermocouple(s) choice
5. Valve on/off switch
6. The chamber temperature
7. The temperature tolerance around the set point

Figure 4 shows the Control Setup tab.

The GPIB assignments are made by choosing the correct GPIB address from the drop-down menus for each of the thermocouple multimeters, the reference temperature multimeter, and the power supply. A drop down list of choices is available for the controlling thermocouple. They are single thermocouples, the average of any combination of pairs of thermocouples, or the

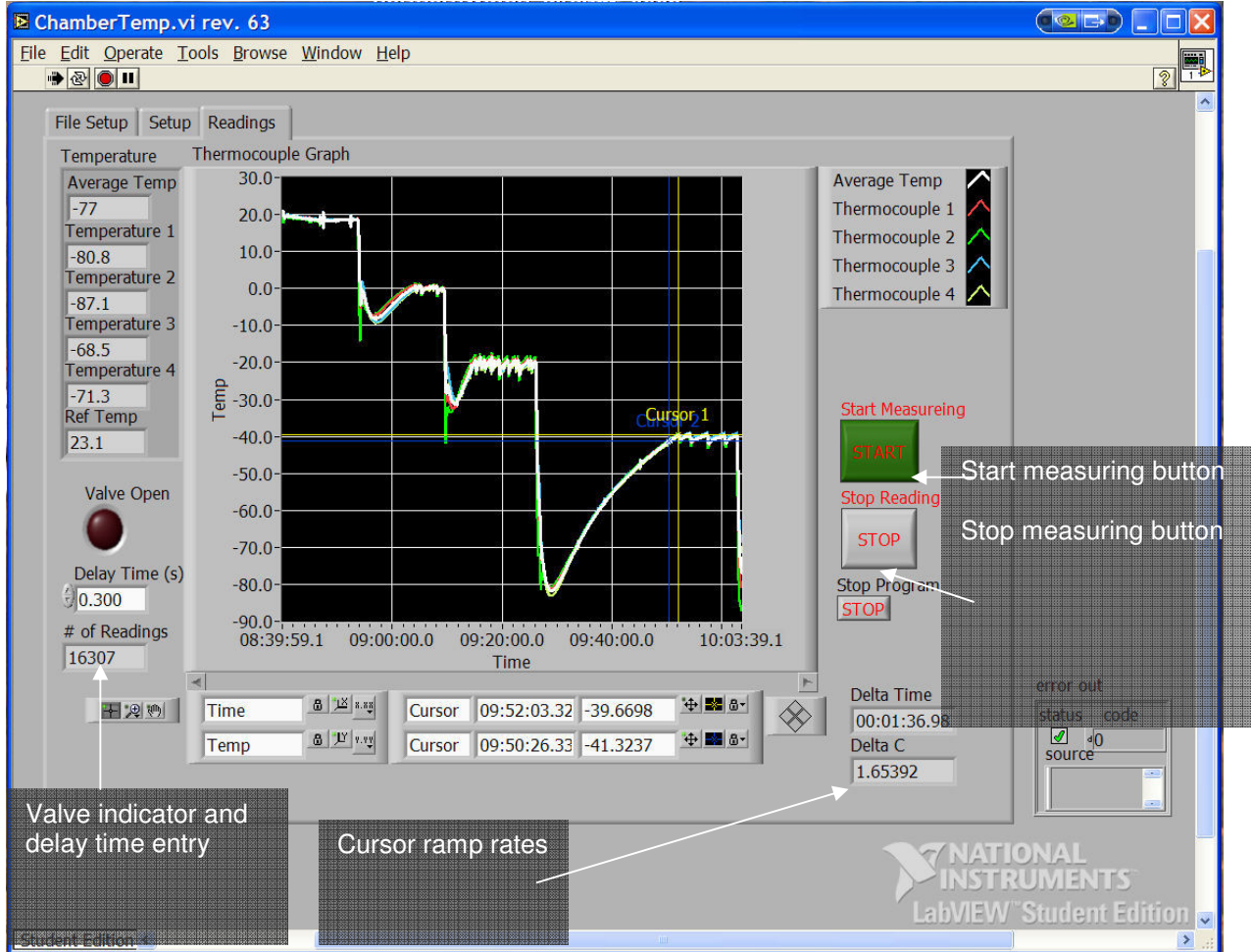


Figure 5 Readings Tab

average of all four. These options allow the user to run the test if a thermocouple fails without the delay to replace the failed thermocouple. The tolerance around the set point can be set between 0.5°C and 2.0°C.

The Readings tab shows the temperature both digitally and graphically (see figure 5).

On the Readings tab, an indicator shows when the valve open command is on. In addition, the user can increase the valve delay time on the Readings tab. The Start-Reading button starts the control sequence, and the Stop-Reading button stops the control sequence. The Readings tab also has a graph to show the trend of the chamber temperature against the time. Using the cursors in the graph, the user can determine the ramp rate of the chamber. The user adjusts the temperature ramp rates by slowly raising and lowering the set point temperature.

### Initial Testing

The initial testing shows an excellent temperature profile of the chamber to each chosen set point. It is now possible to set any temperature from room temperature to -190°C, and the steady state temperature is accurate to  $\pm 5^\circ\text{C}$  of that set point. The two tests of the chamber show how the chamber reacted to the air temperature as the controlling temperature for the chamber and to the package temperature controlling the chamber temperature.

The first test had electronics inside the chamber to ensure measurement of the electronics at low temperature was possible. The four thermocouples were taped, in pairs, to the two 64 pin packages inserted in the sockets. Taping all the thermocouples to the packages gave poor performance and large temperature overshoot. LabVIEW monitors the temperature of the thermocouples and adjusts the temperature to match the set point temperature. Unfortunately, the temperature of the package takes more time to decrease than the air temperature of the chamber.

Using the package temperature as the controlling temperature caused large amounts of overshoot. The LabVIEW program caused the overshoot by pulsing the valve longer than required at each set point. The result was that the chamber cooled below the set point. After the package cooled to the temperature of the chamber, it took a long time to warm back up to the set point temperature. Figure 6 shows this behavior.

The correction for the overshoot is simply to use two of the four thermocouples to measure an average air temperature. The LabVIEW program now can

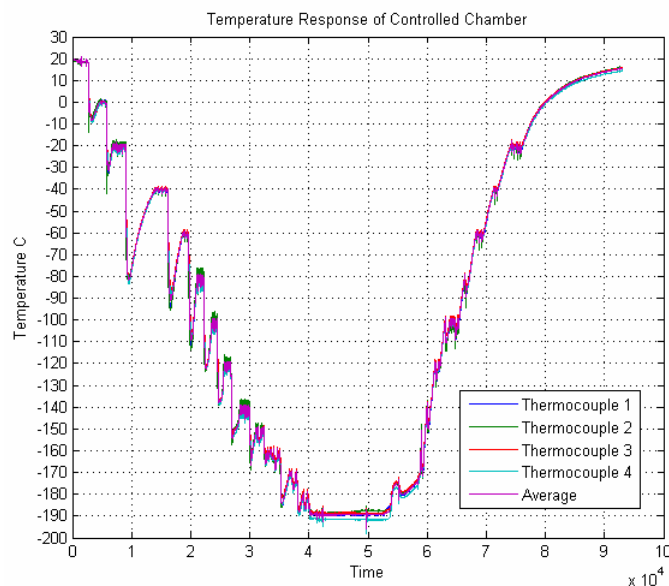


Figure 6 the Chamber Response with the Package Temperature Controlled

choose any combination of the four thermocouples to measure the air temperature. The two other thermocouples are attached to the two packages to monitor the temperature of the packages. When the package temperature converges to the set point temperature, the test at that set point temperature can begin.

The second test of the chamber was with the air temperature as the controlling temperature. The graph in Figure 7 shows the tight control of the air temperature around each temperature set point. The plot of the thermocouples shows a step down of the temperature in increments to control the ramp rate to be 1°C per minute. The step down sequence was in 10°C changes with each set point held for 10 minutes. The rising temperature set points were in 20°C increments held for 10 minutes.

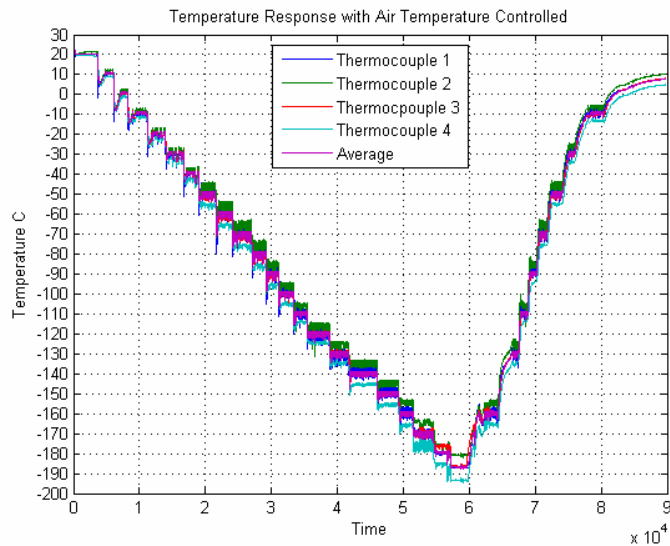


Figure 7 Improved Temperature Response with the Air Temperature as the Controlling Temperature

### Does the Chamber Meet All the Requirements?

This design meets all the requirements for the MRCI cold temperature chamber. The chamber is very portable, even with the added lines on the top of the chamber. One person can easily move the 7 kg chamber. The chamber reached a minimum temperature of -190°C during the initial testing. This temperature is 10°C below the requirement. The efficiency of the chamber is much greater than a commercial chamber due to the injection of the liquid nitrogen into the small chamber in controlled amounts. In addition, the line from the transfer cylinder to the chamber, and the chamber, has foam insulation to decrease the amount of liquid nitrogen used to cool the chamber. One 180-liter transfer cylinder of liquid nitrogen supplies enough liquid nitrogen for two full day tests.

The LabVIEW program successfully controlled the temperature in the chamber to within 5°C of any set point temperature from room temperature to -190°C. The chamber is safe for personnel. The injection of the liquid nitrogen into the chamber keeps the liquid nitrogen isolated from the personnel. The only danger is from excessive amounts of gaseous nitrogen (evaporated liquid nitrogen) replacing the normal air in the room. A personal gas meter was purchased to monitor the level of oxygen in the air during the test to alert the user when the oxygen in the air is low. Also, the system fails safe with the control valve moving to the closed position to stop the flow of liquid nitrogen into the chamber.

Only minimal training is required to run the chamber. Training in cryogenic liquid safety and LabVIEW front panel operations is all that is necessary. The chambers sockets are adaptable to



any type of electronic packaging with simple resizing adapters. It will hold 64 pin and smaller electronic packages.

The chamber is a low-cost implementation for a cold temperature environmental chamber with a final cost of \$2,200 for construction and materials. Table shows 1 a detailed cost list for the chamber.

Item		Cost
Materials for Chamber		\$250.00
Plumbing supplies		\$1,700.00
Cryogenic valve		\$200.00
Insulation		\$50.00
	Total	\$2,200.00

Table 1 Cost List for the Cryogenic Test Chamber

## Conclusion

The MRCI now has improved testing capabilities for cold temperature testing at cryogenic temperatures. The chamber is a cryogenic temperature chamber with temperatures as low as -190°C. The chamber is safe with no direct exposure to the liquid nitrogen, and it is portable due to the compact size of the chamber. It is efficient, as only \$30 of liquid nitrogen is required to run an eight-hour test. The temperature in the chamber can be set to any temperature from room temperature to -190°C, giving a large range of temperatures to choose for measurements of electronics. It will hold the set point temperature to within 5°C until the depletion of the liquid nitrogen in the transfer cylinder. It is adaptable to any size of package, including 40 and 64 pin packages, which are the two sizes of packages the MRCI uses regularly. Very little training is required to use the chamber and run the LabVIEW program. Verifying the temperatures of the electronics is easy due to the spreadsheet file saved by the LabVIEW program. The MRCI is now equipped to perform extreme environment testing for cold temperature electronics.

## References

<sup>1</sup>National Institute of Standards and Technology (1990), *K-type thermocouple equations, t90 standard*, available at [http://srdata.nist.gov/its90/download/type\\_k.tab](http://srdata.nist.gov/its90/download/type_k.tab), (3 February 2005)

## Appendix A

### NIST Temperature to Voltage Coefficients (Equation 1)

name: reference function on ITS-90

type: K

temperature units: °C

emf units: mV

range: -270.000-0.000 °C	
Coefficient	Value
C0	0.000000000000E+00
C1	0.394501280250E-01
C2	0.236223735980E-04
C3	-0.328589067840E-06
C4	-0.499048287770E-08
C5	-0.675090591730E-10
C6	-0.574103274280E-12
C7	-0.310888728940E-14
C8	-0.104516093650E-16
C9	-0.198892668780E-19
C10	-0.163226974860E-22

range: 0.000-1372 °C	
Coefficient	Value
C0	-0.176004136860E-01
C1	0.389212049750E-01
C2	0.185587700320E-04
C3	-0.994575928740E-07
C4	0.318409457190E-09
C5	-0.560728448890E-12
C6	0.560750590590E-15
C7	-0.320207200030E-18
C8	0.971511471520E-22
C9	-0.121047212750E-25
Exponential for 0.000-1372 °C	
A0	0.118597600000E+00
A1	-0.118343200000E-03
A2	0.126968600000E+03

### NIST Voltage to Temperature Coefficients (Equation 3)

Inverse coefficients for type K:

Temperature (°C)	-200-0.00	0.000-500	500-1372
Voltage Range (mV)	-5.891-0.000	0.000-20.644	20.644-54.866
D0	0.0000000E+00	0.0000000E+00	-1.318058E+02
D1	2.5173462E+01	2.508355E+01	4.830222E+01
D2	-1.1662878E+00	7.860106E-02	-1.646031E+00
D3	-1.0833638E+00	-2.503131E-01	5.464731E-02
D4	-8.9773540E-01	8.315270E-02	-9.650715E-04
D5	-3.7342377E-01	-1.228034E-02	8.802193E-06
D6	-8.6632643E-02	9.804036E-04	-3.110810E-08
D7	-1.0450598E-02	-4.413030E-05	0.000000E+00
D8	-5.1920577E-04	1.057734E-06	0.000000E+00
D9	0.0000000E+00	-1.052755E-08	0.000000E+00
Error Range	-0.02-0.04	-0.05-0.04	-0.05-0.06