ZEUS-2 Housekeeping

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1 ZEUS-2 Cycle Box

- ZEUS-2 Cycle Box BOM — *Cycle Box BOM ZEUS-2.xlsx*
- Calibration files — *ZEUS-2 Test Data Calibration.xlsx*
- Signal requirements — *Cycle Box Signal Requirements.docx*
- Back panel design modifications — *Back Panel*

ZEUS-2 is the second-edition High-Redshift (Z) and Early Universe Spectrometer. The instrument is composed of temperature stages ranging from 50K to 100mK (when cool). Thermistors (sensors whose resistances change based on their temperatures) are located throughout these stages. The cycle box retrieves signals from these sensors, forwarding them to a computer for monitoring. Originally designed for ZEUS, the cycle box included circuits for controlling heaters within the dewar — both the heaters and corresponding circuit were eliminated in the new model. The circuits within the cycle box were redesigned for ZEUS-2, enabling more precise temperature measurements.

To reach the low temperatures required for the bolometric detector arrays, a dual-stage ADR (adiabatic demagnetization refrigerator) was employed. The superconducting magnet in the ADR produces a strong magnetic field; when active, the molecules within two salt pills are polarized. As the magnet's magnetic field is slowly reduced (proportional to the magnet's current), the molecules' orientations randomize again — the energy required for this re-randomization is extracted from the surrounding region, reducing the temperature of the system. An external power supply and programmer are used to control the current through the ADR. For ZEUS-2, the cycle box cards provide excitation currents for the thermistors, amplify the sensors' voltage responses, and interface with the magnet power supply programmer.

The cycle box consists of six individual circuit cards, four of which are designed to monitor different types of sensors. The GRT 0-3 and GRT 4-7 cards are designed for the GRT sensors; each card is capable of monitoring up to four sensors. The 4-Wire card provides current for up to four four-lead sensors (diodes, etc.), while the 2-Wire card is capable of monitoring up to eight two-lead sensors (resistors, etc.). A four-lead sensor can be connected to the 2-Wire card by tying the positive and negative leads together — however, this will result in a less precise temperature reading. A fifth card in the cycle box distributes/collects the signals to/from the cycle box from/to the exterior connectors (to either the dewar or the computer). The sixth card is a pass-through for signals to/from the magnet power supply programmer.

Each sensor is assigned a channel, which is selected via two push-buttons on the front panels of the cycle box cards — the one on the left of the digital LED display decreases the channel number

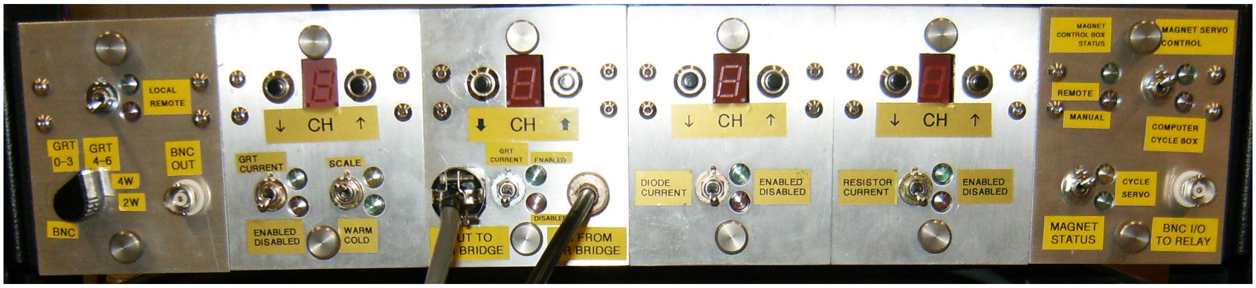

Figure 1: The front of the the cycle box for ZEUS-2. From left to right, the front panels are of the back plane, GRT 0-3, GRT 4-7, 4-Wire, 2-Wire, and magnet servo cards. The push buttons on four of the panels change the current channel selected, which is displayed in the corresponding digital LED display. To complete a circuit with the selected sensor, the enable/disable switch must be set to enable (up). For computer control, the local/remote switch on the front panel of the back plane should be set to remote. To read the voltages straight from the cycle box (instead of through a computer program), a voltmeter can be connected to the BNC connector on the back plane's front panel. The card selection for the BNC is controlled with the adjacent 5-throw double-pole switch. For increased resolution at lower temperatures, the temperature scale switch on the GRT 0-3 front panel should be set to cold. The **Magnet Servo Control** switch on the magnet servo front panel controls what determines the current set point and ramp rate of the magnet controller — this should be set to Computer until a hardware PID loop is installed on the card. The **Magnet Status** switch controls the resolution of the magnet's power supply. When on Servo, the ADR is in parallel with a 1Ω resistor, increasing the current resolution.

by one, while the one on the right increases the channel. The channel numbers wrap from highest to lowest (or vice versa) when a limit is reached. The red digital LED display in the top center of the front panels displays which channel is currently selected for monitoring. To send a current to the identified sensor (to receive a voltage), the current enable/disable toggle switch on the front panel must be set in the up (enable) position. The red and greed LEDs indicate whether a card's current is enabled or disabled (green = enabled, red = disabled). The GRT 0-3 card has one additional switch over the other cards: Temperature Scale. This switch places different resistors in the amplification circuit, increasing the voltage reading resolution for low temperatures.

The circuits within the cycle box do not always behave as expected. When there are no cables attached to the rear connectors, the voltage output of each card is not close to the expected 5V (it varies between -6V and +4V). However, once a cable is attached to the back connectors, all voltage outputs hover around +5V, even though there may not be a sensor attached to any leads. As the cycle box is designed to operate with cables attached to the back panel, this issue was not resolved.

There are four connectors exiting through the back of the cycle box. The 20-41 and 22-55 Amphenol Miniature Cylindrical connectors connect to the Dewar. The 20-41 carries all 4-wire and 2-wire signals, while the 22-55 has all GRT lines. The USB-B female connector on the back of the cycle box connects the computer to the LabJack device. These three connectors are located in an interchangeable plate on the back right side of the back panel. This plate can be removed from the cycle box and replaced with an earlier design that houses a 37-pin D-Sub connector (used with the ZEUS cycle box to connect to the DAQLAB) instead of the USB-B. The fourth connector on the ZEUS-2 cycle box is a 25-pin D-Sub, permitting communication with the AMI 412 Magnet

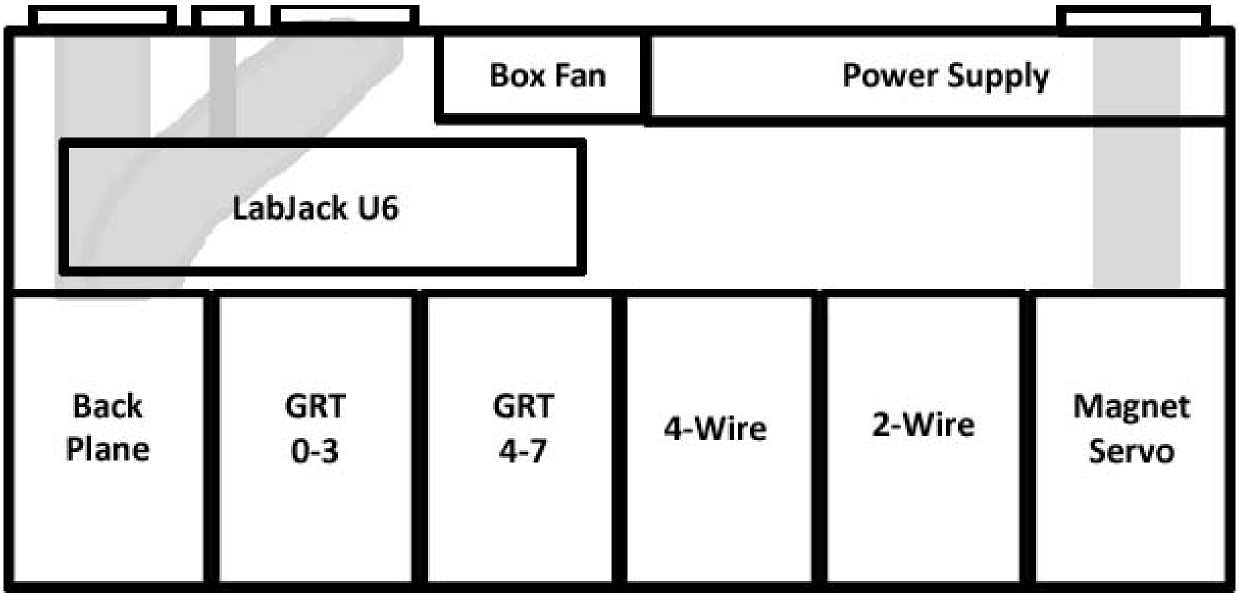

Figure 2: (Not to scale.) Schematic of the inside of the cycle box, as seen from the top (the front of the box, with all the controls, is located at the bottom of the image). The LabJack U6 is also connected to the back plane via two D-Sub connectors. Each of the cards has a ribbon cable running between itself and the back plane.

Power Supply Programmer. It is located on the right-hand side of the back panel, below the power switch.

The cycle box is housed in a much larger rack-mount box than the original. To switch to the smaller box, the side, top, and bottom panels can be replaced with those from the original box.

It is possible to convert to the original ZEUS cycle box, if necessary. All but the GRT 0-3 card need to be changed back to their original cards. The front plates for the old Resistor and Diode cards are the current 2-wire and 4-wire front plates, respectively. The digital LED displays can be removed from the ZEUS-2 cards as needed. The interchangeable back plate needs to be replaced so the D-Sub connector to the DAQLAB can be connected to the cycle box. In addition, the GND line on the 20-41 Dewar connector must be reconnected to the cycle box's power supply — the box fan will need to be removed to access the power terminals.

All analog outputs from the ZEUS-2 cycle box are differential. To be controlled remotely, it requires four digital inputs, fifteen digital outputs, six analog inputs, and two analog outputs from a data acquisition device.

1.1 Back Plane

- Protel PCB Project — *back plane*
- Netlist — *Back Plane Netlist.xlsx*
- Front panel design — *Panel, Hub2*

The back plane card of the cycle box routes all signals from the Dewar to the cycle box cards and from the cards to the computer. It houses the Local/Remote switch, which determines whether channel selection is performed by the front panels of the cycle box or by the computer. The differential analog signals from each of the four cards can be measured with a voltmeter via the BNC connection on the front panel of the back plane — the connected card is determined by a 5-pole double-throw switch, also on the front panel of the back plane. Four of the five spots on this switch are currently occupied.

Ribbon cables from the back plane card to the both GRT cards, the 4-wire card, and the 2-wire card are all identically wired. See the wiring diagram for details on these and other connections on the card.

1.2 GRT 0-3

	Range	Open	Shorted
Warm	$< 250\Omega$	4.978 V	0.0099 V
Cold	$< 2k\Omega$	4.978 V	0.0101 V

- Protel PCB Project — *4ch GRT reader*
- Netlist — *GRT netlist.xls*
- Front panel design — *Panel, GRT*

The GRT 0-3 card is the one card used in both the ZEUS and ZEUS-2 cycle boxes. The only change made to the card from the original design was to create a differential output analog signal. Consistent with the other cards in the ZEUS-2 cycle box, pin 19 on the back connector of the card is the high signal, while pin 20 is the low signal. Minor alterations have been made to the original back plane of the ZEUS cycle box to accommodate this change, allowing the card to be compatible with both models of the cycle box. The Protel files for the ZEUS GRT circuit were modified to reflect these changes When there is nothing connected to the back connector of the cycle box, the voltage output of the GRT 0-3 card is not constant and differs depending on which channel is selected; it floats between 1 and 3 V — this is unrelated to the settling time required for the electronics when changing channels on the card.

1.3 GRT 4-7 Multiplexer

Range	Open	Shorted
$1k\Omega - 20k\Omega$[1]	2.507 V	0.231 V

- Protel PCB Project — *4ch GRT 4-7 multiplexer*
- Netlist — *GRT 4-7 Switch Netlist.xlsx*
- Front panel design — *Panel, GRT Switch*

[1] This depends on the setting of the AC bridge. For the range of the GRT sensors used through 08/2011, a setting of $20k\Omega$ is appropriate.

The GRT 4-7 multiplexer card serves as a pass-through card for four additional GRT sensors. The measurement is made with the LR-400 Four-Wire AC Resistance Bridge (explained in detail in Sec. 2). The current and voltage lines are switched via two multiplexers on the card, connecting the different sensors to the back of the AC Bridge through the 5-pin MHex connector on the front panel of the card. The measured resistance can be recorded via a voltage signal passing through the BNC connector on the front panel, which then runs to the back plane. When there is nothing connected to the rear of the cycle box and the AC Bridge is disconnected from this card, the voltage output of the card is less than 0.5 V.

1.4 4-Wire

Range	Open	Shorted
$10k\Omega - 1M\Omega$	4.226 V	0.00002 V

- Protel PCB Project — *4ch current source*
- Netlist — *4W netlist.xlsx*
- Front panel design — *Panel, Diode*

Containing four channels, the 4-Wire card generates a 10 μA current with which to measure the resistance of the sensors. This current is tuned with the resistor R43 and diode DZ1. The card has two separate op-amps for the voltage measurement — one for the positive signal and one for the negative signal. The card is based on the design for the Diode/Resistor cards of the ZEUS cycle box. The front panel for this card is the same as that for the Diode card of the original cycle box. When there is nothing connected to the back dewar connectors of the cycle box, this card outputs -5.9 V.

1.5 2-Wire

Range	Open	Shorted
$10k\Omega - 1M\Omega$	4.231 V	0.00094 V

- Protel PCB Project — *8ch current source*
- Netlist — *2W netlist.xlsx*
- Front panel design — *Panel, Diode*

As it only requires two leads per sensor, the 2-Wire card can cycle through up to eight sensors. This is the only card that does not have a true differential signal — for every channel, the outputted voltage is in reference to the card's GND. The circuit produces an excitation current of $10\mu A$, sent to the selected sensor. This current can be tuned with the resistor R43 and diode DZ1. As with the 4-wire card, this card is modeled after the Diode/Resistor cards of the ZEUS cycle box. Its front panel is the same as the Resistor card from the original cycle box. When the back connectors of the cycle box are disconnected, this card outputs a voltage of 4.25 V.

1.6 Magnet Servo

- Protel PCB Project — *magnet servo*
- Netlist — *Magnet Servo Netlist.xlsx*
- Front panel design — *Panel, Magnet Servo*

This card has two relatively independent tasks to complete. Its primary occupation is the main communication line between the computer and the AMI 412 Magnet Power Supply Programmer (hereafter known as the magnet controller). All outputs from the magnet controller pass through this card, and the magnet current limit and ramp rate signals are sent through this card back to the magnet controller. For stabilizing the temperature of the magnet while servoing, the card has the ability to switch between an on-board, hardware PID loop and a computer PID loop (used to determine a new current limit and ramp rate). At the moment, the hardware PID loop does not exist, so this switch ***(Magnet Servo Control) should remain on Computer***.

The second task of this card is to optionally increase the resolution of the power supply to the magnet. When servoing the magnet, only a trickle current (<100 mA) is needed. The analog signals used to set the ramp rate and current limit of the magnet controller are controlled with two 12-bit DACs from the LabJack, within a range of 0–5 V. This provides a resolution of $5\text{V}/(2^{12}) = 1.2\text{mV}$. On a power supply capable of a range of 0–100 A, this becomes a resolution of $(100\text{A}/5\text{V}) * 1.2\text{mV} = 30\text{mA}$. This should be fine enough to successfully control the magnet. If more resolution is required, switching the front Magnet Status switch (on the front panel of the Magnet Servo card) to Servo will turn on a relay, sending current through a second, external relay (not currently assembled). This relay places a 1Ω resistor in parallel with the ADR, reducing the maximum current from 100 A to 10 A across the ADR and increasing the resolution to 3 mA. The connection between the small relay on the Magnet Servo card and the larger external relay is the BNC connection on the front panel of the Magnet Servo card (this provides the current for the external relay, when necessary).

This external relay is a Magnecraft 701 Series "Ice Cube" Relay (part 781XAXM4L-12D). Its coil is rated at 0.7W and 12V, resulting in a required current of about 50mA. As the cycle box power supply has 5V and 15V, a resistor is needed in the circuit on the magnet servo card to drop the supply voltage to 12V. It is not yet installed in the card — ***the resistor should have resistance of*** 51.4Ω ***with a minimum power rating of 0.175W (this is different than what is specified in the PCB project — use these specifications instead).***

1.7 *Cycle Box* LabVIEW VI

The Cycle Box VI monitors the temperature sensors throughout ZEUS-2. On the front panel, there are four graphs displaying the temperature readings for the sensors, one graph for each cold stage. To monitor a channel, the corresponding check-box on the far left must be selected. The voltage reading and corresponding temperature are displayed in the Voltage and Temperature columns, respectively. The user has control over to which graph each sensor belongs — this is controlled in the Graph column. For the first four GRT channels, a selection of either the warm or cold scale is also available; this control is located in the last column on the right.

An error box towards the bottom of the screen will display any LabJack errors that develop while the program runs (it will not show an error if one of the subVIs has a problem). The Empty Scan List red LED, located below the error cluster, will light if the cycle box is on remote control

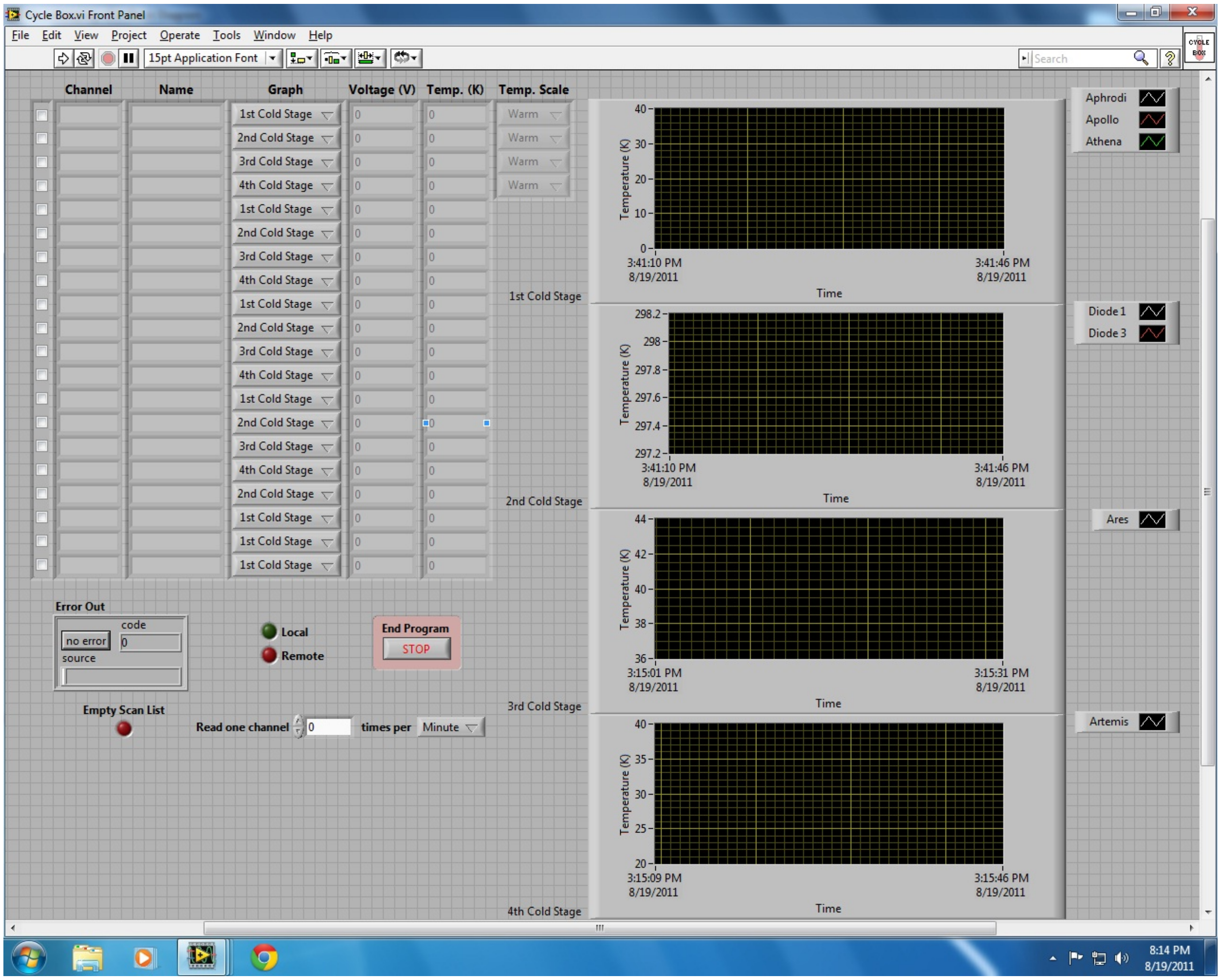

Figure 3: The front panel of the independent Cycle Box VI. To scan channels, select the appropriate check-boxes on the left side of the screen. The channel numbers and names (as written in *Sensor_ID.txt*) are displayed in the corresponding columns. Select on which graph to display each of the scanned channels via the drop-down menus in the **Graph** column. The last measured voltage and calculated temperature will be displayed in the corresponding columns, and the temperatures will also be graphed on the graphs on the right of the screen. For the first four GRT channels, the temperature scale is set via the drop-down menus in the **Temp. Scale** column. Any errors encountered will be displayed in the **Error Out** box in the lower right. If no channels are selected to scan (and the cycle box is set to Remote), the **Empty Scan List** LED light will illuminate. The control status of the cycle box (as determined by a switch on the front panel of the Back Plane card) is indicated via the **Local** or **Remote** LEDs on the screen. The settling time of the LabJack U6 is set via the inputs in the sentence **Read one channel** ___ **times per** ___. To end the program at any time, press the End Program button.

but there are no channels selected to scan. This is only a warning signal — the program will not crash if this scenario occurs. The Local and Remote LEDs are indicators to show the status of the Local/Remote line of the cycle box. If the cycle box is on Local, the program waits until it is switched to remote. (Unfortunately, it cannot read out the channel voltages manually selected on the cycle box front panel, since there is no feedback from the box to determine to which channels the signals refer — the only thing it knows is from which card the signal is coming.)

The blanks within the sentence "Read one channel ___ times per ___" are user-inputs. These values determine the settling time of the program (how many seconds between when the program switches the cycle box to particular channels and streams in voltage values), based on these inputted values and the maximum number of channels selected on any of the four sensor cards. The minimum settling time is five seconds — this value overrides any inputted value when necessary.

To end the program, click on the End Program button labeled STOP. Depending on when in the code this is selected determines how fast it will stop — it could produce up to two more data points. Every time the program is stopped, the file *Initialization.txt* is overwritten. This file sets the initial values of the front panel at the start of the program (monitoring status, graph, temperature scale, and the rate at which the channels are scanned). A version of this file must always reside in the same folder as the Cycle Box VI.

All identifying information about the sensors is controlled with the *Sensor_ID.txt* file. This file must also be kept in the same folder as the Cycle Box VI. The Channel name, sensor Name (both displayed on the front panel of the program), conversion file name, and whether the conversion file is a relationship between resistance (R) and temperature or voltage (V) and temperature are columns within the text file.

1.7.1 General summary

After uploading all necessary text files, including calibration and conversion tables, the cycle box VI enters a while-loop that ends only when the End Program button is pressed. Within each iteration of the while-loop, the LabJack first reads the Local/Remote line — if it is low (local), the program skips to the end of the while-loop. If this signal is high (remote), the program proceeds to the next step.

After determining which channels are selected to be monitored, the program adds requests to enable the appropriate cards on the cycle box (via *currentED.vi*). It then selects which channel to next scan, based on the selected channels on each card and the last channel scanned (via *cbChannelSelect.vi*). The LabJack then sets all the digital signals accordingly. After waiting the given settling time (no less than five seconds), the predetermined channels are streamed, gathering 100 data points over a one-second period. The average value of each channel's voltage readings are returned (occurring within *cbScan.vi*) and converted to temperatures (within *tempConvert.vi*). Both the voltage and temperature readings are displayed on the front panel (*updateCT.vi*), and the temperature values are graphed on their respective XY plots (*graphTemp.vi*). The data is then written to a text file (one for each channel), along with the date and time of acquisition (within *writeFile.vi*). This process repeats until either the End Program button is depressed or the cycle box is switched to local mode.

Upon ending the program, the last values inputted by the user on the front panel are saved in the initialization file (*writeInitializationFile.vi*), and all cards are disabled.

1.7.2 Nitty-gritty details

Reading initial text files

The *sensor_ID.txt* file must be in the same folder as *Cycle Box.vi.* This file includes the Channel and Name for each of the sensors within ZEUS-2. It also has a column referencing the type of conversion required to translate the voltage reading to a temperature — either resistance or voltage. The last column in the file consists of the file name for the conversion table for each of the sensors. *Cycle Box.vi* imports this ID file and separates the data into individual arrays to be displayed and/or referenced later in the program.

With the imported list of conversion table names, *Cycle Box.vi* uploads each of the required tables, storing them in a 2D cluster of arrays. All conversion table files must be stored in the same folder as *Cycle Box.vi.* Within a for-loop (iterating through the twenty calibration table file names), the program checks to see if a required calibration file has already been uploaded. If so, then it moves on to the next file name. If not, then it uploads that table. The first line in these calibration table text files should label the sensor type. It should then skip a line, having the headings for the columns in the third line: temperature followed by either resistance or voltage. Following this should be the numerical data. While these tables are uploaded, a twenty-element array is built, storing a number $0-n$, n being one less than the number of conversion tables uploaded. This array will allow the program to later identify which table to use when analyzing a particular channel.

Cycle Box.vi also uploads the calibration files for the cycle box cards. These file names are hard-coded — to change them requires an alteration in the main block diagram. The calibration files are to be stored in the same folder as *Cycle Box.vi.* It removes the first three rows of the file (the header lines) and stores the remaining data in an array of a cluster of points. The program combines all these arrays into a 2D array of clusters. These calibration files are needed when the conversion table for a sensor is temperature v. resistance — the measured voltage needs to be converted to a resistance before it can be turned into a temperature.

The final file to be referenced before entering the while-loop within *Cycle Box.vi* is *Initialization.txt.* This stores numeric values equal to the last entered values of the Monitor, Graph, and Temp. Scale columns as well as the settling time components (from the last program run). This file is overwritten when the program ends (after the End Program button is pressed). A version of it must be included in the same folder as *Cycle Box.vi.*

CurrentED.vi

- Inputs
  - Device handle
  - Error cluster
  - Four-element boolean array
- Outputs
  - Device handle
  - Error cluster

The boolean array represents whether a card is enabled (true) or disabled (false). For each of the cards, the enable/disable digital line is set to either high or low (a list of requests is made — the task has not yet been sent to the LabJack).

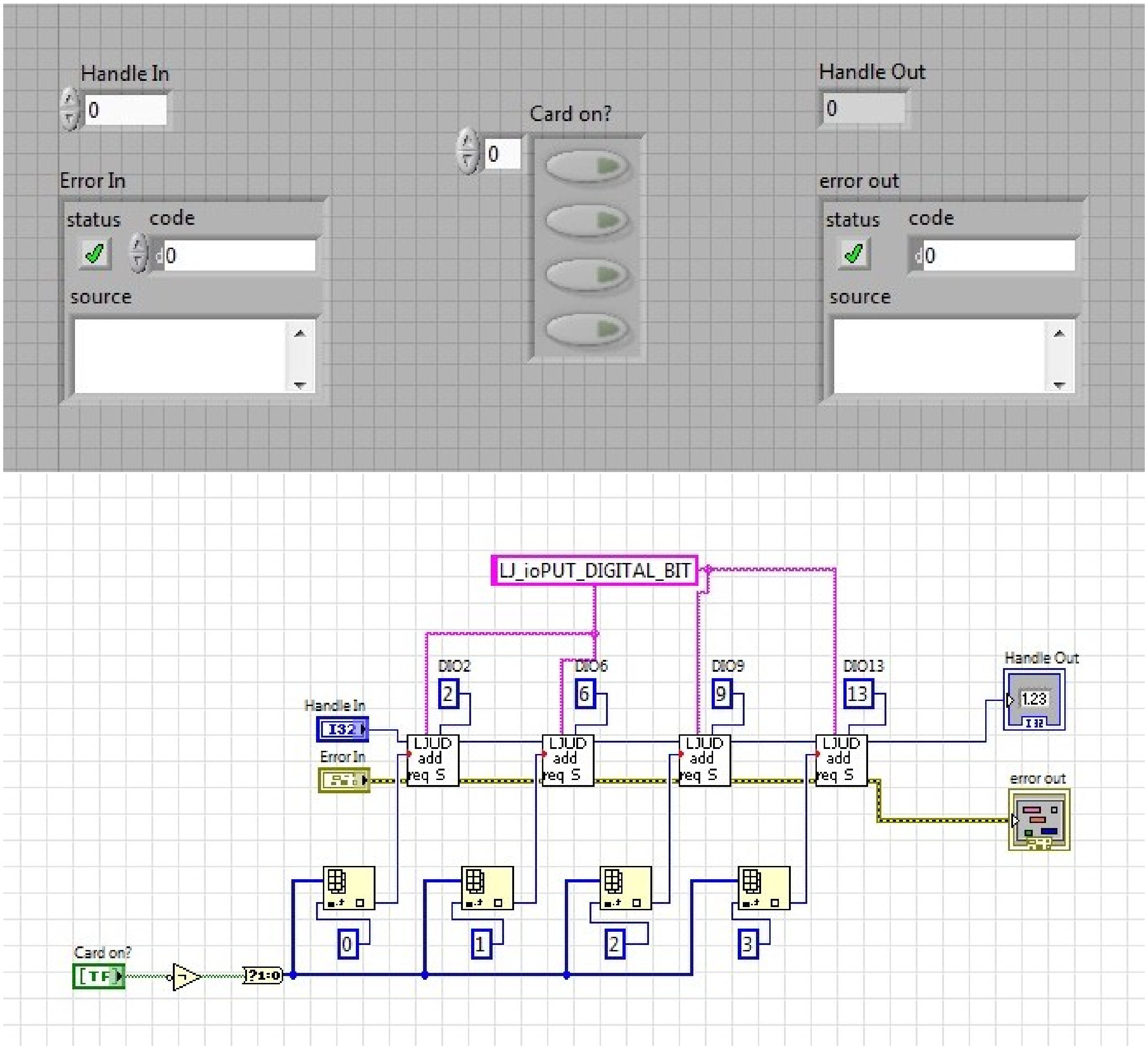

Figure 4: The front panel and block diagram of *CurrentED.vi*, or Current Enable/Disable. This subVI constructs a list of requests to set the current enable/disable signal for each of the four cycle box cards.

cbChannelSelect.vi

- Inputs
  - Device handle
  - Error cluster
  - Monitor cluster
  - Four-element boolean array
  - Temp. Scale array
  - Selected Channels array
- Outputs
  - Device handle
  - Error cluster
  - Temperature scale (integer)
  - Relative channels array

For each of the cards, the next channel to be scanned is determined within a while-loop, and the corresponding digital lines corresponding to the signal number on the cycle box cards are assigned values of high or low. The temperature scale digital signal is also set to the correct value. The relative-channels-selected-to-be-scanned output is an array of values 0-7 — the channel number within a given card; the first element corresponds to the selected channel on the GRT 0-3 card, and the last element is the channel number on the 2-Wire card.

cbScan.vi

- Inputs
  - Device handle
  - Error cluster
  - Relative Channel array
  - Four-element boolean array
  - Voltage array
- Outputs
  - Device handle
  - Error cluster
  - Empty scan list boolean value
  - Absolute channel array
  - Time stamp
  - Updated voltage array

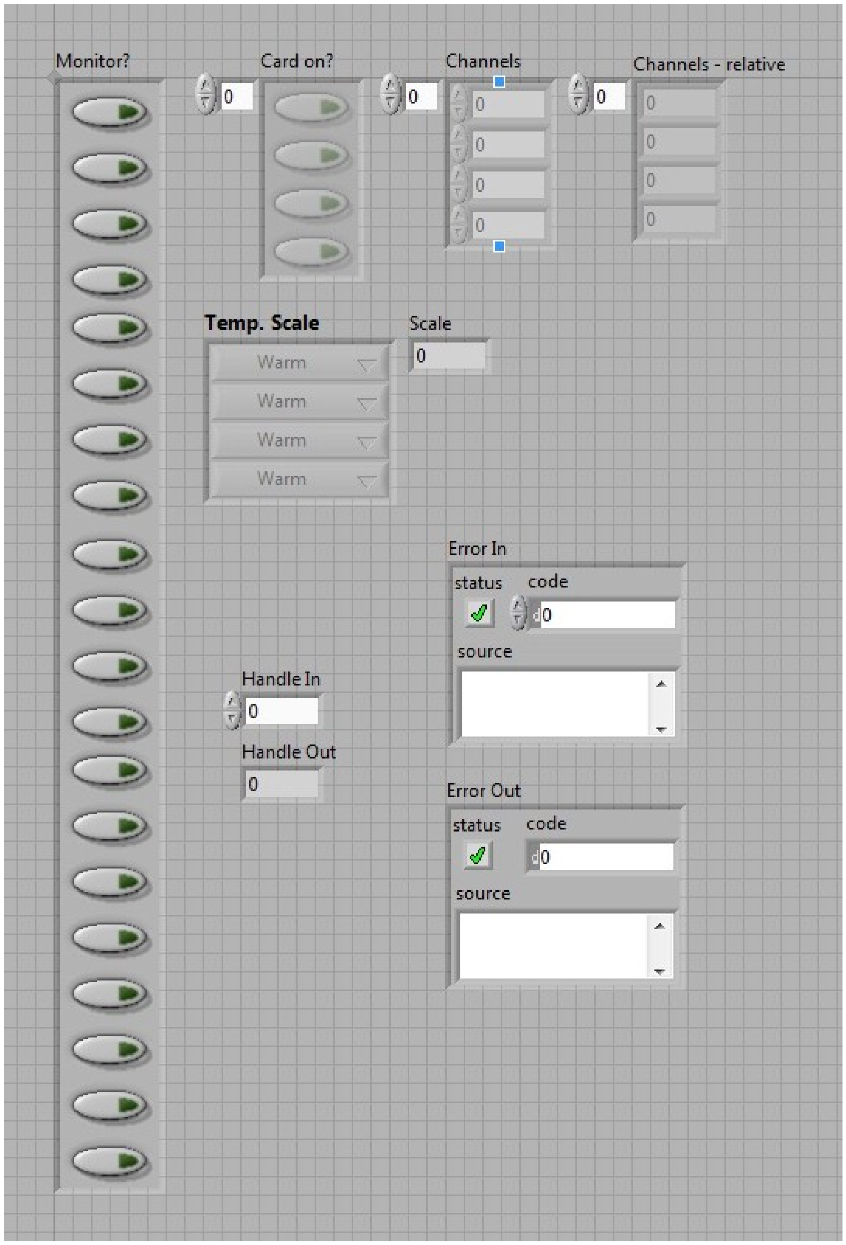

Figure 5: The front panel of the *cbChannelSelect.vi* subVI, or DIO Select. This subVI determines the next channel to scan on each cycle box card.

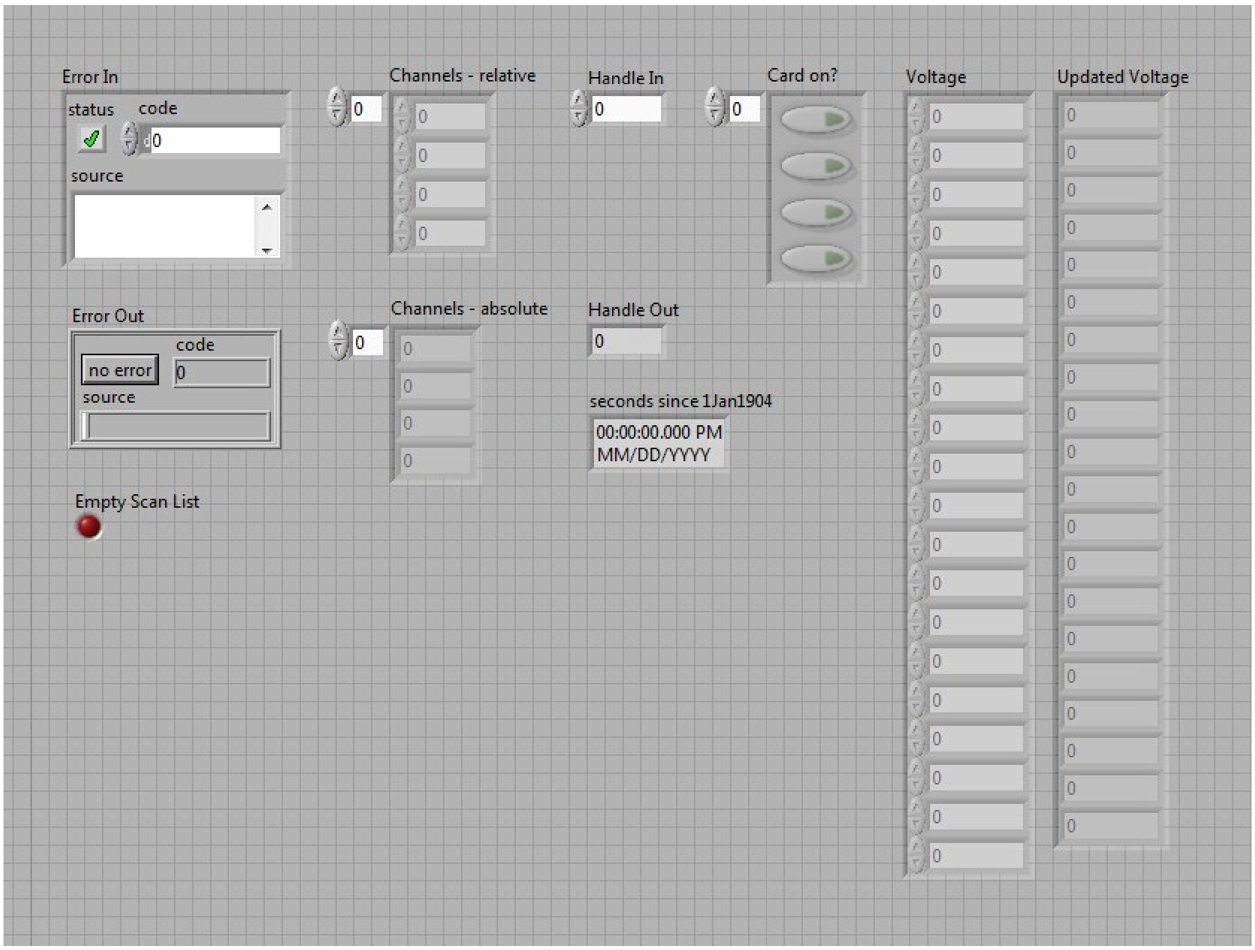

Figure 6: Front panel of the subVI *cbScan.vi*, or Stream Analog Scan. It is responsible for compiling the list of channels to scan, streaming the data from the LabJack for the selected channels, and updating the Voltage array with the new average values.

Based on the boolean array passed into the subVI (identifying which cards are active), the channels to be scanned are added to an array. If this list of channels is not empty and the cycle box is on the remote setting, the list of channel numbers is passed into *streamAverage.vi* along with a hard-coded scan rate and total scans per channel value. This subVI returns the average voltage reading for each of the channels scanned. *cbScan.vi* updates the displayed voltage array with the new average voltage values of the maximum four scanned channels.

If the scan list is empty, a signal is set to alert the user that the scan list is empty (useful if the cycle box is on remote but nothing is selected to be scanned — this does not cause the program to crash). The time when the *streamAverage.vi* is called is stored for future graphing and data storage.

streamAverage.vi

- Inputs
  - Device handle
  - Error cluster
  - Scan List (+)
  - Scan List (–)
  - Range constants
  - Advanced cluster
  - Total scans
  - Scan rate (Hz)
- Outputs
  - Device handle
  - Error cluster
  - Average voltage

This subVI streams data from the LabJack at the inputed rate (100 Hz, set in *cbScan.vi*). The stream function for the LabJack is called N times within a for-loop, N equaling the total number of scans divided by the scan rate in Hz (so each iteration should run for about one second). Within each iteration, all the data points within each channel are summed together. After all scans are complete, the average voltage for each channel is found. These values are then returned in an Average Voltage array.

tempConvert.vi

- Inputs
  - Conversion tables
  - Calibration array
  - GRT 0-3 temperature scale

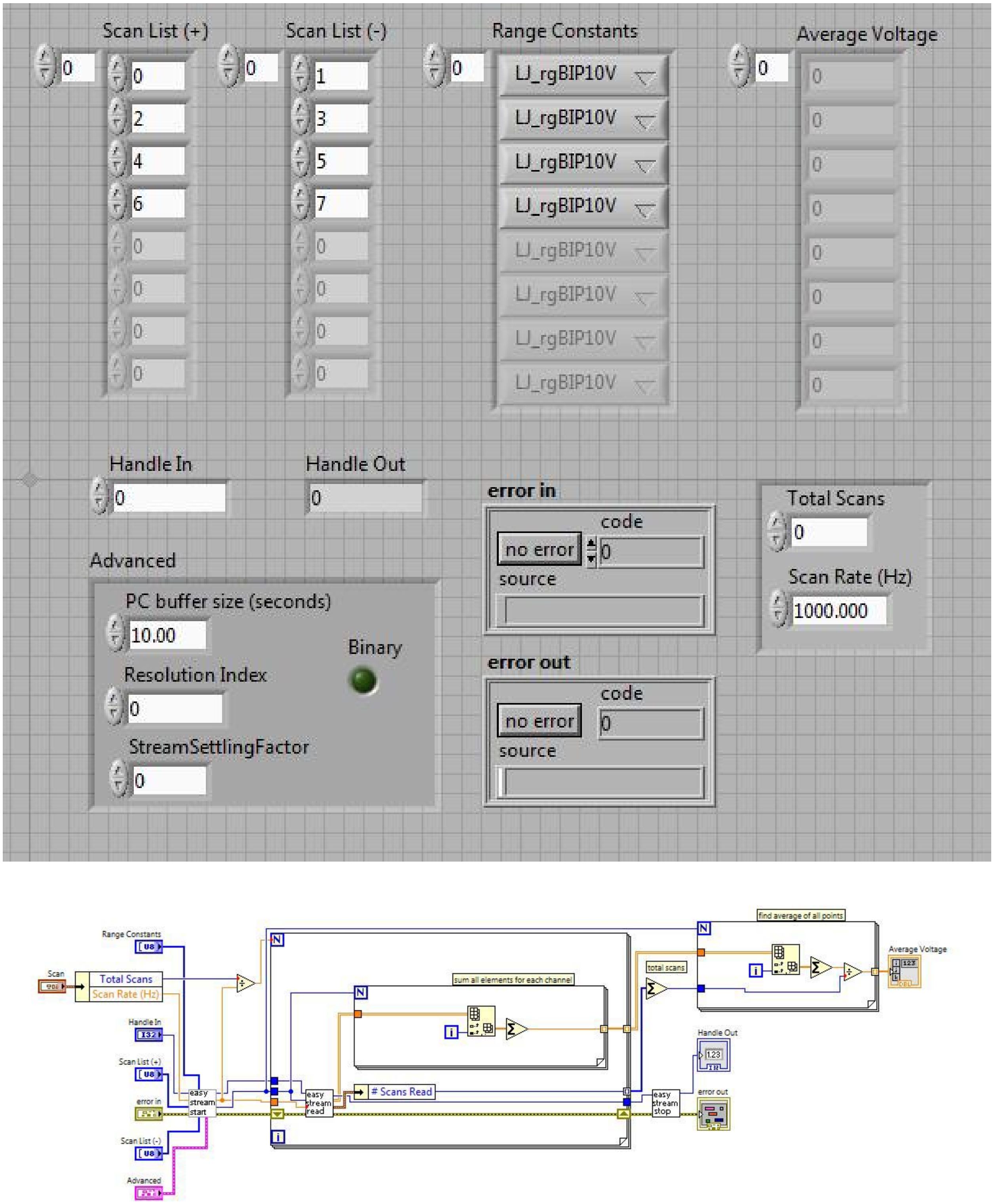

Figure 7: Front panel and block diagram of *streamAverage.vi*, or Average Stream. It is responsible for streaming values from the LabJack for the selected channels and computing the average voltage value for each channel.

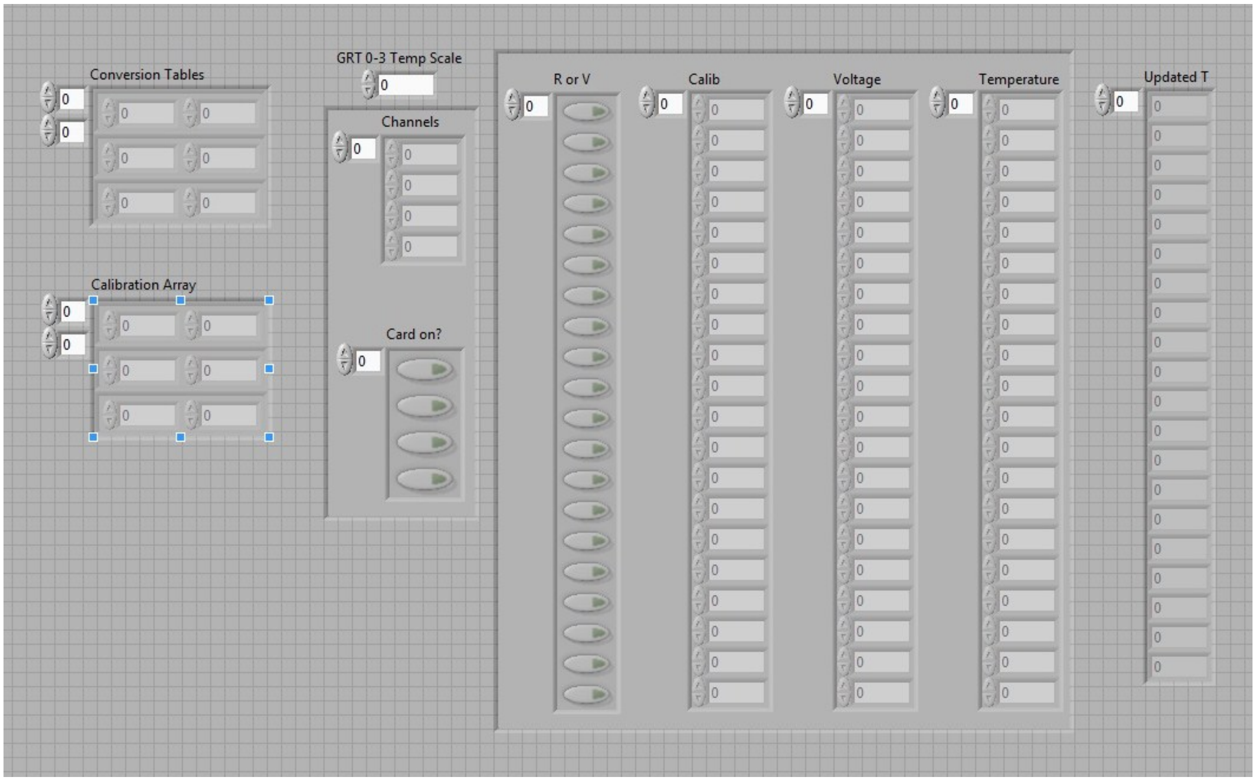

Figure 8: The front panel of subVI *tempConvert.vi*, or Temp Conv. It converts the average voltage reading to a temperature for each of the most recently scanned channels.

- Channels
- Card on?
- R or V
- Calibration code
- Voltage
- Temperature

- Output
  - Updated temperature

Separating which calibration array and conversion table are necessary for each channel read, the subVI calls *calcTemp.vi* to convert the average voltage reading to a temperature. The updated temperature array is returned.

calcTemp.vi

- Inputs
  - Conversion tables

- Calibration array
- R or V
- Calibration code
- Voltage
- Temperature
- Channel

- Output
  - Updated temperatures

Using the average voltage and other inputs, this subVI calculates the corresponding temperature of the sensor. If the channel's conversion table is R v. T, then the voltage reading is converted to a resistance via the calibration array for that particular card. The resistance is then used in the conversion table to find a temperature reading. If the conversion table is V v. T, no calibration array is needed — the average voltage is converted directly to a temperature. In either case, when looking up a value in a table to find the corresponding resistance/temperature, a linear fit is used when the exact look-up value does not exist in the table. The new calculated temperature is placed in the Temperature array, which is then returned.

updateCT.vi

- Inputs
  - Channel temperatures — before
  - Channel times — before
  - Temperature
  - Channels
  - Chard on?
  - Time stamp
- Outputs
  - Channel temperatures — after
  - Channel times — after

For each of the four cards within the cycle box, if a card is on, the new calculated temperature is added to the correct channel array within the channel temperatures cluster. The time stamp is also added to that channel's time array within the channel times cluster. The updated clusters are returned.

graphTemp.vi

- Inputs

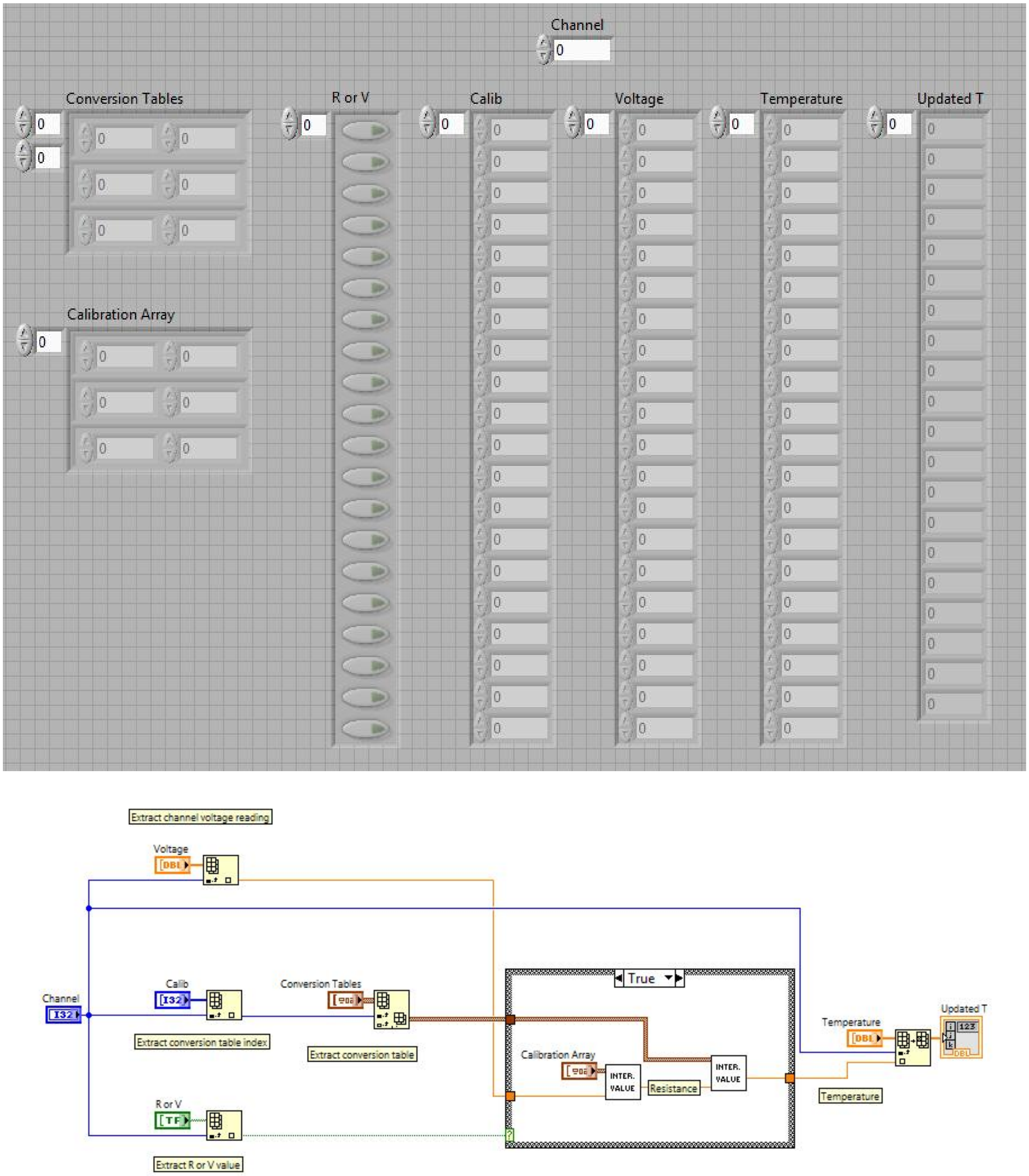

Figure 9: The front panel and block diagram for subVI *calcTemp.vi* or Calc Temp. It converts an averaged voltage reading for a particular channel into a temperature.

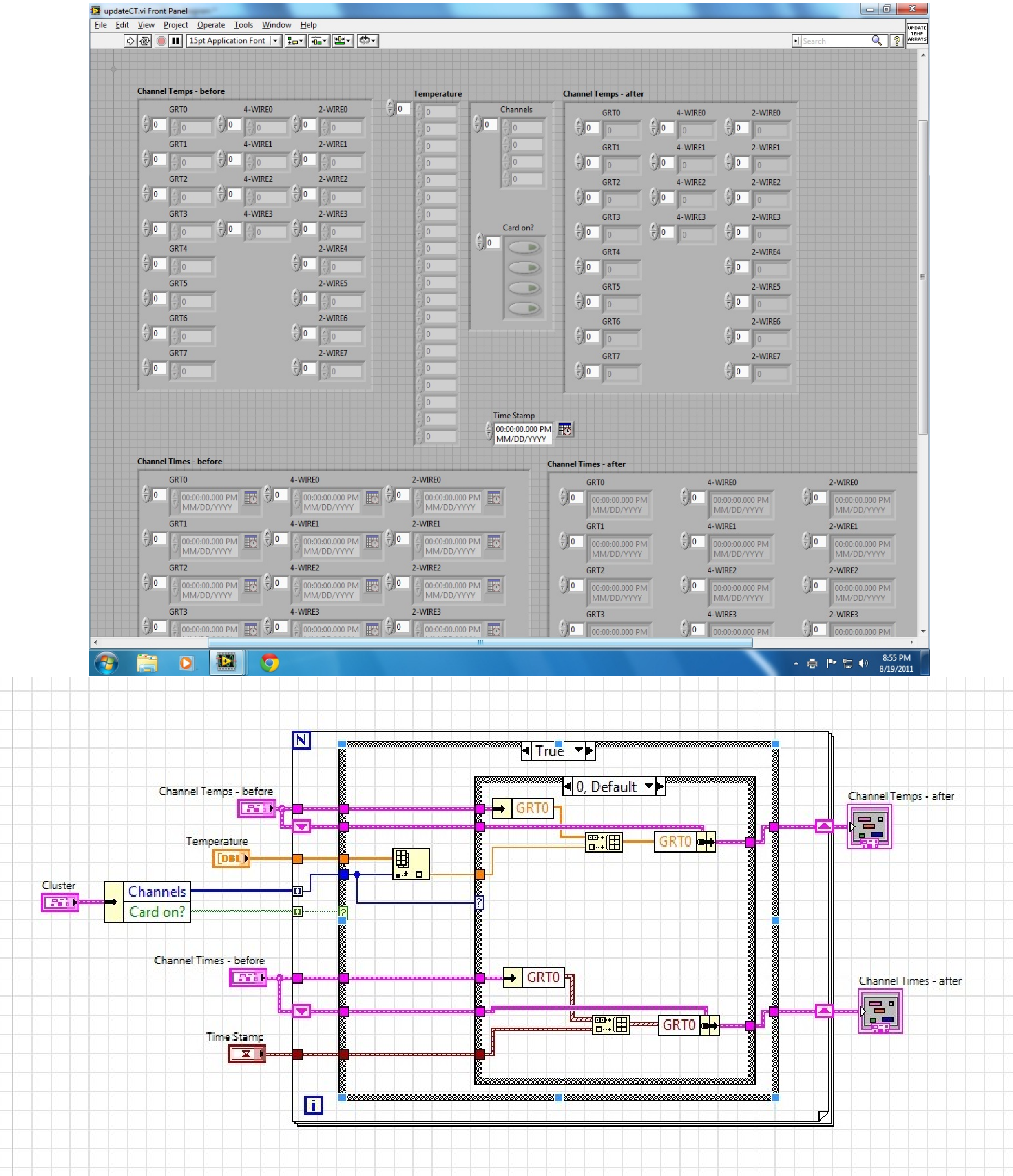

Figure 10: The front panel and block diagram for the subVI *updateCT.vi* or Update Temp Arrays. The new temperatures are added to their corresponding channels' arrays, and the time stamp from when the data was streamed is concatenated to the channels' time arrays. These arrays are used for the displayed graphs and final text files containing all recorded data from the session.

- Channel times
- Monitor
- Names
- Graph key
- Channel temperatures
- Graph minimum values

- Outputs
  - 1st cold stage graph
  - 2nd cold stage graph
  - 3rd cold stage graph
  - 4th cold stage graph
  - Legend formatting (names, number of plots)

This subVI cycles through each of the twenty available channels. If a channel is selected to be monitored, then its temperature array and time stamp array are added to the array corresponding to the graph on which it has been selected to be displayed. The graph arrays are returned, along with the names for each channel and the number of plots on each graph (used to format the graph legends).

writeFile.vi

- Inputs
  - Sensor IDs
  - Voltage array
  - Temperature array
  - Channel number
  - Time stamp
  - Calibration file name

This subVI records the voltage and temperature data for each of the channels to individual text files. If a file for a channel does not already exist, one will be created. The file name includes the date and name of the sensor. The first line of each file contains the same information, along with the channel number. The titles for each column are Date, Time, Voltage (V), and Temperature (K). Data is formatted in columns following the order of the heading. A new file will be created for each new day, since the date is part of the file name.

writeInitializationFile.vi

- Inputs
  - Monitor?

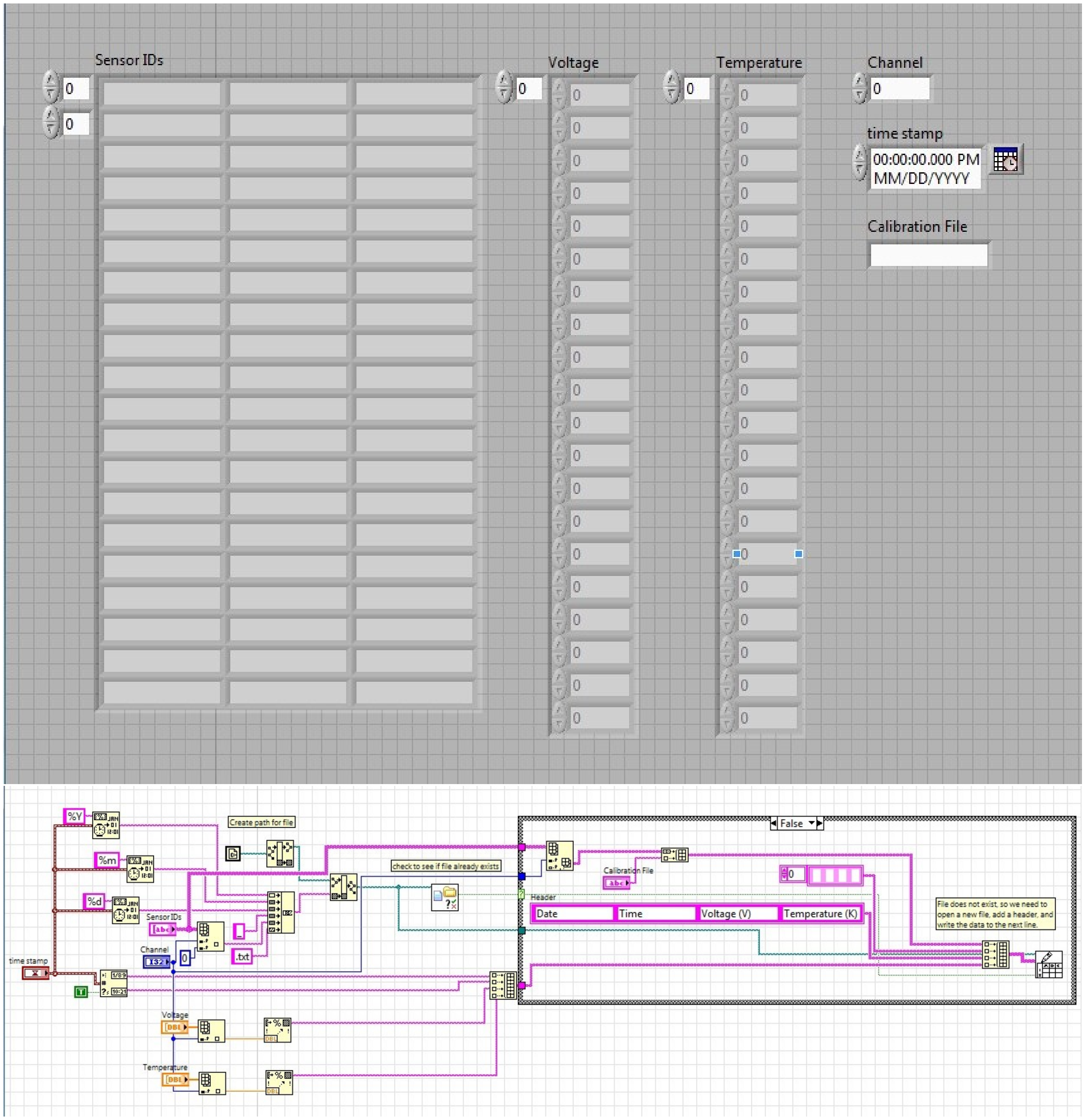

Figure 11: The front panel and block diagram for the subVI *writeFile.vi* or Write Data to File. It writes the voltage and temperature data to a channel's text file. Each channel has its own file, and new files are created for every day data is recorded.

– Graph key
– Temperature scale
– Times (number of times to scan each channel)
– Length (length of time over which to spread the channel readings)

This subVI writes all user input data of the main VI to a text file. It is called at the very end of the Cycle Box VI, after all data has been recorded. At the beginning of the VI, this file is referenced, so the last selected settings for the program are the initial settings the next time run. There are four columns in this file, one for each of the inputs (times and length are put in the same column).

2 LR-400 Four-Wire AC Resistance Bridge

The current and voltage leads of the AC bridge are located on a connector in the back of the device. Pins 1 and 2 carry the current, while pins 4 and 5 carry the voltage. It displays the measured resistance on the front panel, and a corresponding voltage signal is expelled from the front BNC connector. This device is capable of measuring three different values — the resistance, the difference between the detected resistance and a set value on the front panel, and ten times this difference. The Cycle Box VI assumes it is reading resistance.

The AC Bridge can be remotely controlled. All front panel settings are available via the D-Sub connector on the rear panel, except for the set resistance and the span trim. The set resistance can be programmed via the front BNC connector. This reference resistance is the sum of the inputted value in the front BNC connector and the dials on the front panel. We opted to leave it on manual because we do not have to change any of the settings while cycling or servoing the dewar. There is enough resolution in the resistance setting without having to measure the difference between a set resistance and the sensor.

There is an additional BNC connector on the rear panel. It always outputs ten times the resistance difference, no matter what the front panel setting. This is on a $\pm$ 10 V scale.

Pin-outs of the rear panel connector can be found on page 300-6 – 300-7 in the LR400 resistance-bridge manual. A diagram of the five-pin back connector (for remote sensing) can be found on page 100-12 of the manual.

3 AMI 412 Magnet Power Supply Programmer

- Protel PCB Project — *Main PC Board*

An extremely thorough, intense investigation was conducted of the magnet controller, in order to determine how it can be controlled remotely. When testing the magnet controller, it can be connected to the power supply — be sure to disconnect the power supply lines from the ADR and short them, so as not to ruin the magnet.

3.1 Front Panel

The front panel of the magnet controller contains both controls and indicators. There are LEDs to alert that the controller is on, the magnet has quenched (it has gone above 4.9K and is no longer

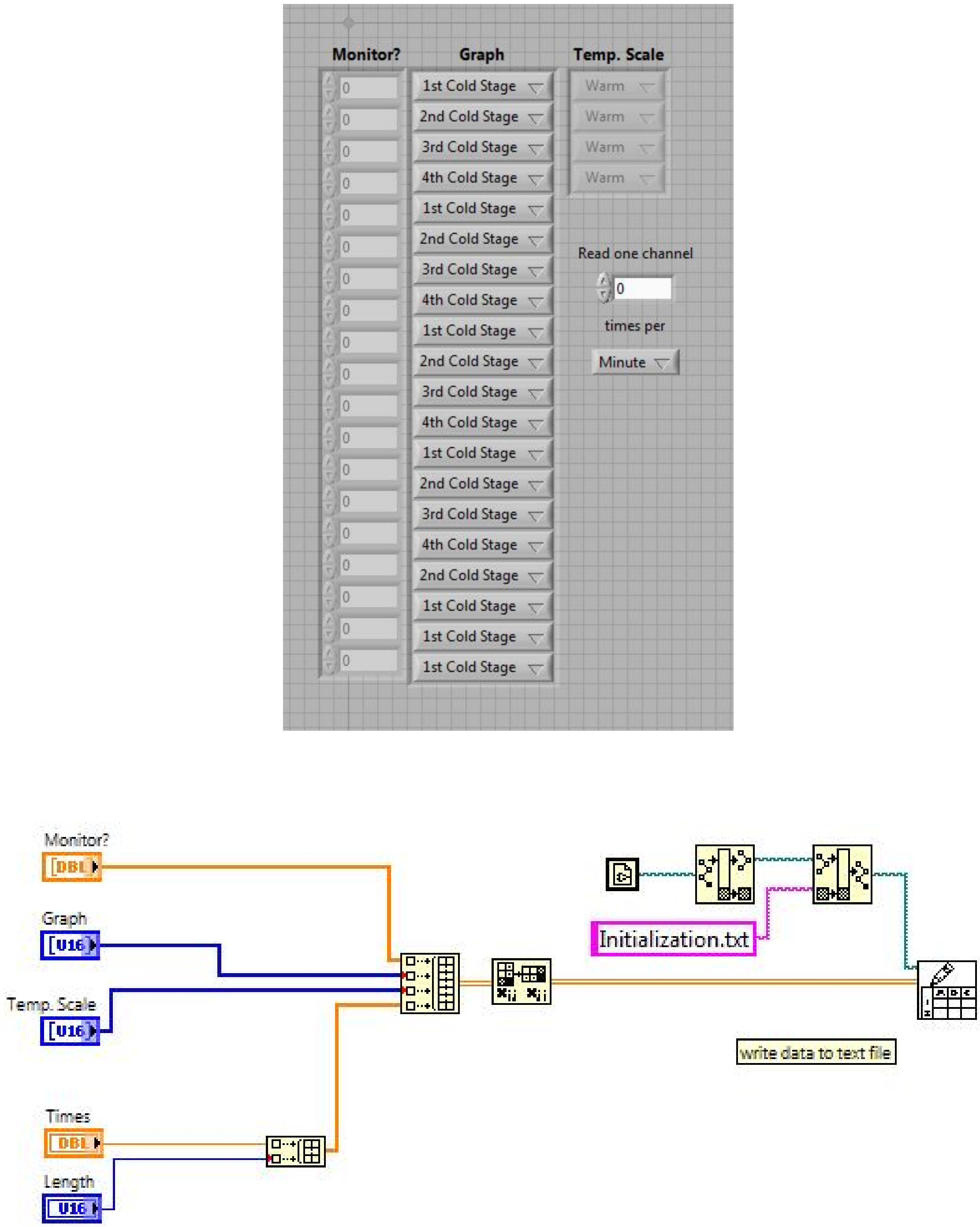

Figure 12: The front panel and block diagram for *writeInitializationFile.vi* or Write Initial. File. This subVI creates a text file to reference at the start of the program, to set all user inputs to those values last set the last time the program was run.

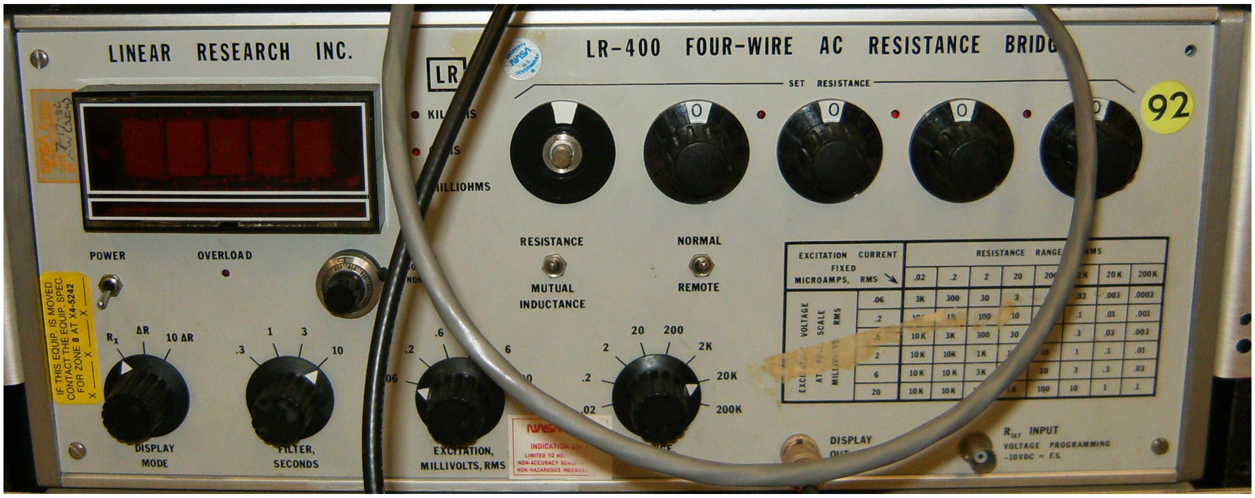

Figure 13: The front of the AC Bridge. The measured resistance is shown in the five-panel digital LED display on the left. The five black knobs on the top-right are used to set the reference resistance, required when the lower left-most knob is set to either ΔR or $10\Delta R$ (labeled **Display Mode**). The second knob in from the left on the bottom, labeled **Filter, Seconds**, sets the time length for the filter; it should set to 10, the highest possible setting. The third knob in from the left is the **Excitation, Millivolts, RMS** selection, determines the excitation voltage across the connected sensor; it is set to 0.06 mV, the lowest setting. The right-hand-most knob on the bottom determines resistance scale; for ZEUS-2, this should be set to $20K\Omega$. The power switch is located on the far left. The AC Bridge is also capable of measuring inductance — the switch to change between these two quantities is located in the center of the front panel. Unnecessary for ZEUS-2, the AC Bridge can be controlled remotely — the switch for this setting is also located on the front panel. The left-hand BNC connector on the bottom outputs a voltage signal corresponding to the measured resistance — this should be connected to the BNC connector on the front panel of the Cycle Box's GRT 4-7 card. The second BNC connector on the front panel shown here is an analog input for the reference resistance (manually set by the five black knobs at the top of the front panel).

Figure 14: Picture of the front panel of the magnet controller. The magnet's voltage is displayed on the needle gage, and the current is shown in the digital LED display labeled **Magnet Current**. The power switch is a toggle switch in the center of the panel — a green LED light beside it indicates if the controller is on or off. The mode knob is to the right of the power switch. The red **Quench** Detection LED light is next to the Quench **Off/Reset** switch. The controls for the Ramp Rate are located in the upper right corner of the front panel, while the Current and Voltage Limit potentiometers and LED indicators are in the lower right corner of the panel.

superconducting), the voltage limit has been reached, the current limit has been reached, and that there is power and/or current flowing to the persistent switch heater (not used in ZEUS-2). ***The red Current Limit LED light will fade on and off if the controller is set to Computer mode but there is no voltage input to the current limit and ramp rate pins on the back connector.*** The magnet's voltage is shown on a voltmeter built into the front of the controller, and the magnet's current is displayed on a digital LED display.

There is a switch that determines if the magnet controller is in manual mode (settings are determined by the front panel controls) or computer mode (settings are determined by signals from the back panel 25-pin D-Sub connector). In either mode, ***the Ramp Rate range is set by the knob on the front panel*** — there are options of 0.1, 1, or 10 Amps/second. For example, if 1 Amp/second were selected, the Variable knob to the right has a resolution of 0.002 Amps/second, up to a maximum Ramp Rate of 1 Amp/second. When in Manual mode, all inputs from the back connector are ignored. However, the analog outputs are still active, so the computer can always record the magnet's current and voltage.

There is a switch which determines whether to ramp up or down to the set current limit, or pause in the middle of changing the current. This switch is disabled when in Computer mode — the current will automatically increase or decrease to match the given set point. The two additional knobs on the front panel of the magnet controller determine the maximum voltage limit and the maximum current limit of the magnet. The magnet controller will not allow any additional current to enter the magnet if one of these limits is reached. The Voltage Limit potentiometer should always be set to 10V.

3.2 Remote Control

After extensive study of the inside of the magnet controller, it was determined that ***the pin-out provided in the magnet controller manual is INCORRECT***. The actual pins are a mirror-image of what is depicted in the manual (the correct pin-out is shown in Fig. 3.2).

When controlled remotely, the magnet controller requires two analog signal inputs — a ramp rate and a current limit. Both with a range of 0–5 V, the ramp rate determines how fast (amps/second) the current changes. A signal of 5V corresponds to either 0.1, 1, or 10 amps/second, depending on the setting of the Ramp Rate Range knob on the front panel. The analog current limit determines the current to which the magnet controller will ramp up or down. A 5V signal corresponds to the maximum current of which the power supply is capable (in the case of ZEUS-2, this is equal to 100A). The Janis two-stage ADR in ZEUS-2 has a maximum current rating of only 10A.

Inputs from the magnet controller to the computer (via the cycle box) include the magnet's current and voltage (both analog), and the digital signals: opto-isolator signal (a.k.a. current set point indicator — communicates if the magnet has reached the set current limit), computer/manual mode (communicates in which mode is the magnet controller), quench status, and the persistent switch status. The digital signals within the magnet controller are switches — they have no voltage or current flowing. In order to obtain a usable signal, one of the two pins of each signal was grounded, and the other was connected through a resistor to a +5V source (on the Magnet Servo card of the Cycle Box). Therefore, when the measured signal is high, the switch is off, and when the signal is low, the switch is on. Not used with ZEUS-2, the shunt output of the magnet controller is an analog signal — it is a second measurement of the current across the shunt bar in the energy absorber.

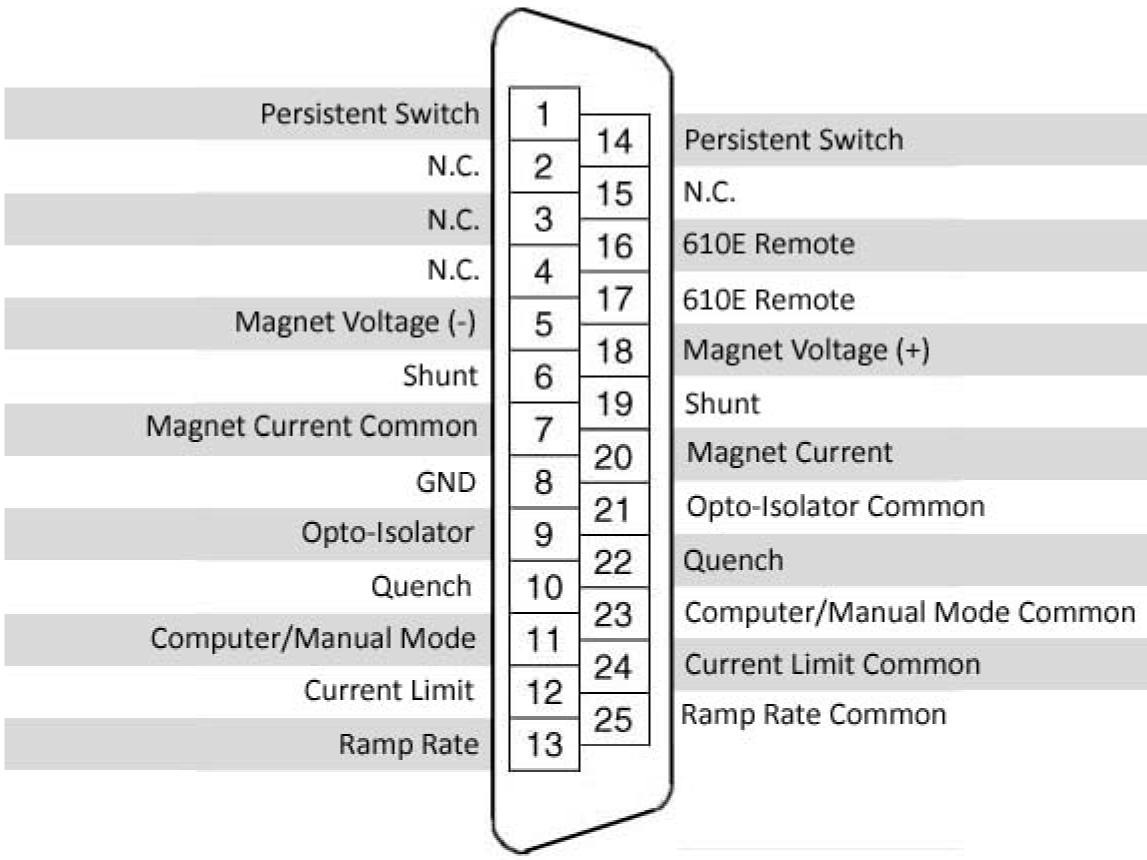

Figure 15: Pin-out of the 25-pin D-Sub connector on the back of the magnet controller and the cycle box. This is different than that shown in the magnet controller's user manual.

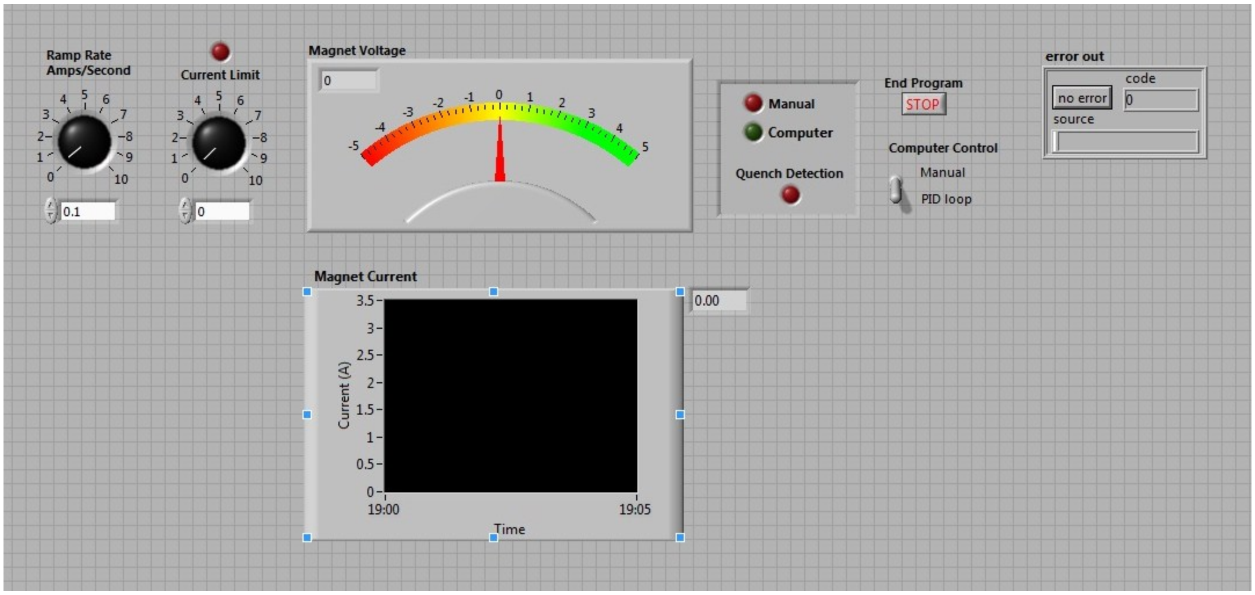

Figure 16: Front panel of the Magnet Controller VI. The ramp rate and current limit values are manually set via the black knobs on the left. When the current limit is reached, the red LED above the current limit knob lights. The magnet's voltage is displayed on the needle gauge, and its current is shown on the labeled graph. The manual and computer LEDs light accordingly — when the controller is set on manual, the computer only records the voltage and current of the magnet. If the magnet quenches, the quench detection LED will light. To stop the VI at any time, press the End Program button. Any LabJack errors will show in the Error Out cluster.

3.3 *Magnet Control* LabVIEW VI

This VI provides interface to the magnet controller. It includes a digital front panel, so the ramp rate and current limit signals can be set "manually." For the computer to automatically control these inputs based on temperature measurements, Michelle Silverstein wrote a VI based on a PID loop during the Fall 2010 — this option can be selected in the Magnet Control VI as well (as of August 2011 this option was not yet enabled).

3.3.1 General Summary

After starting the VI, the status of the computer/manual switch, quench status, and current limit indicator are retrieved from the LabJack. At the same time, the magnet's current and voltage are read in from the LabJack. These signals and values are displayed on the front panel of the VI.

The values inputed by the user for the ramp rate and current limit are then sent to the LabJack. As a stand-alone VI, this program cannot communicate with a PID loop, as there is no reference value (i.e. temperature) for it to use.

3.3.2 Nitty-gritty details

addDIO.vi

- Inputs

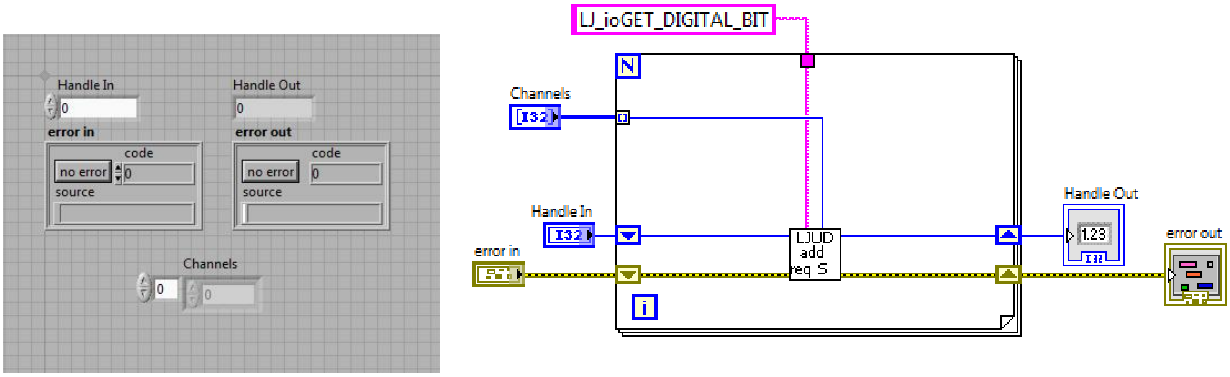

Figure 17: Front panel and block diagram for the subVI *addDIO.vi* or Add DIO. It adds a request to read in a digital channel (from the inputted list) from the LabJack.

  - Device handle
  - Error cluster
  - Channels array

- Outputs
  - Device handle
  - Error cluster

This subVI loops through the channels listed in the input Channels array, adding them to a list to send to the LabJack from which to read. This function is for any number of digital channels.

addAIN.vi

- Inputs
  - Device handle
  - Error cluster
  - Channels (+) array
  - Channels (-) array
- Outputs
  - Device handle
  - Error cluster

Looping through each of the positive channels, the subVI adds requests for each set of positive and negative channels to read their differential value the next time the LabJack is called. This subVI is intended for differential analog signal requests only.

getDIO.vi

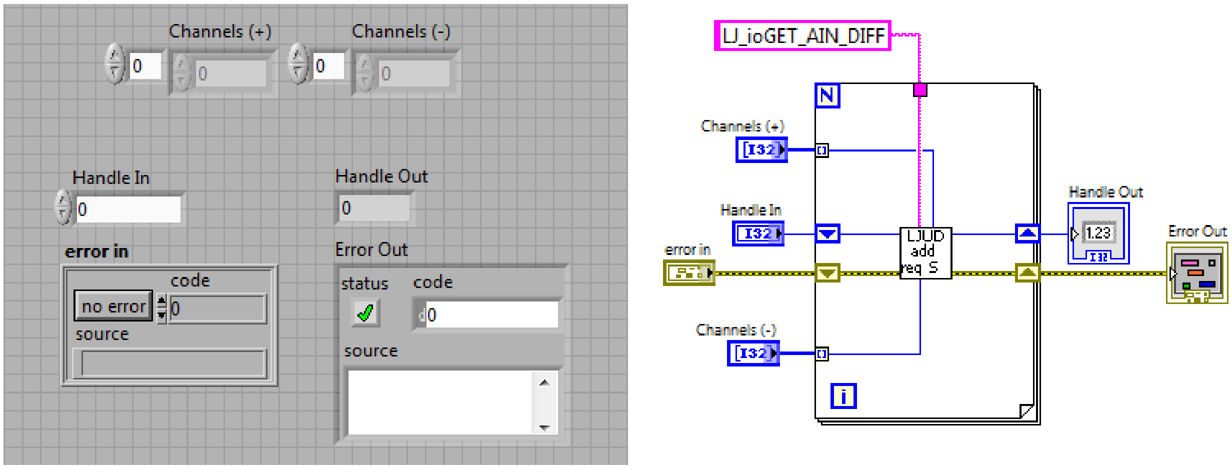

Figure 18: Front panel and block diagram of *addAIN.vi* or Add AIN Diff. This subVI adds a request to read in the differential analog channels (from the inputted list) from the LabJack.

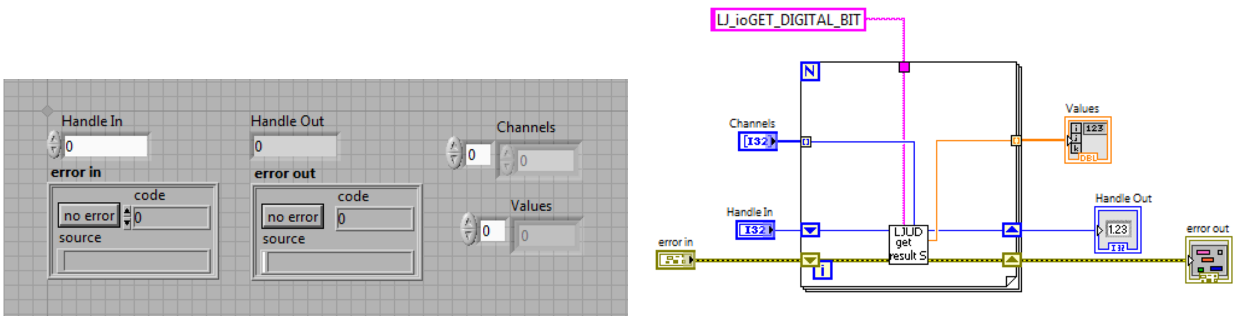

Figure 19: Front panel and block diagram of the subVI *getDIO.vi* or Get DIO. It stores the values in an array that were read from the LabJack, according to the specified digital channels.

- Inputs
  - Device handle
  - Error cluster
  - Channels array
- Outputs
  - Device handle
  - Error cluster
  - Values array

This subVI loops through the listed channels and recalls the LabJack's read values, storing them in an array. This VI is for digital channels only.

getAIN.vi

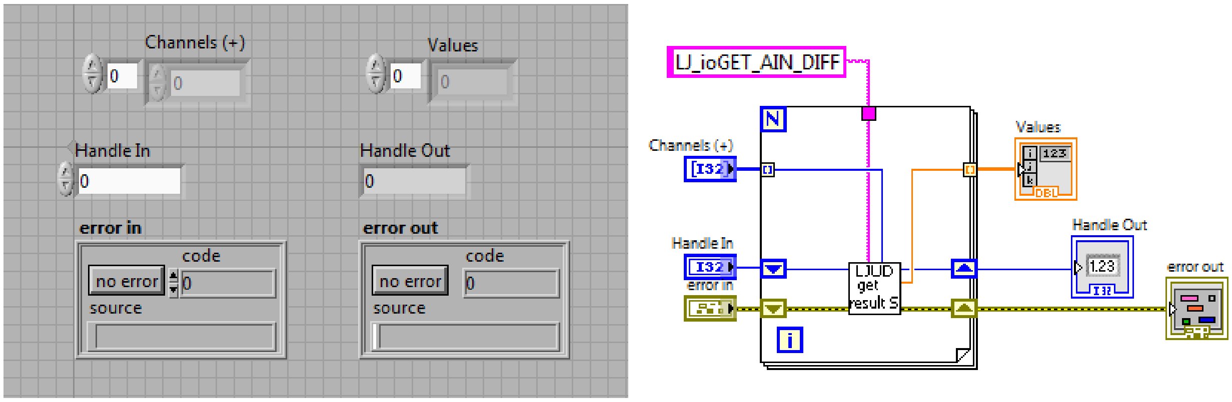

Figure 20: Front panel and block diagram of the subVI *getAIN.vi* or Get AIN Diff. It stores the values in an array that were read from the LabJack, according to the specified positive differential analog signals.

- Inputs
  - Device handle
  - Error cluster
  - Channels (+) array
- Outputs
  - Device handle
  - Error cluster
  - Values array

The subVI loops through the listed channels and recalls the LabJack's read differential values, storing them in an array. This VI is for differential analog channels only.

putDAC.vi

- Inputs
  - Device handle
  - Error cluster
  - Channels array
  - Values array
- Outputs
  - Device handle
  - Error cluster

This subVI loops through the listed channels and adds a request to set the analog outputs at the given value, to be sent to the LabJack. This VI is intended for analog outputs only.

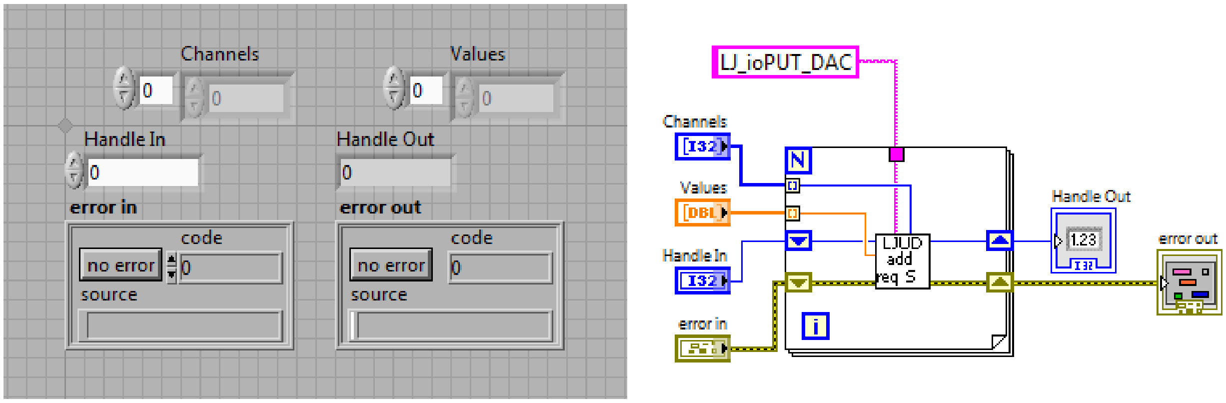

Figure 21: Front panel and block diagram for the subVI *putDAC.vi* or Assign DAC Values. It assigns analog output channels of the LabJack to the specified values.

Figure 22: Picture of the front panel of the magnet power supply. The power switch is the large rocker switch on the far left. The magnet voltage is shown in the left digital LED display. When in manual mode (not used for ZEUS-2), the **Voltage** knob controls the voltage output of the power supply, while that labeled **Current** controls the current output of the supply. When remotely controlled by a variable voltage, the LED light above the voltage knob should be lit. The digital LED display on the right shows the current output of the power supply. The supply needs to be calibrated — this current display reads 0.5 A less than the actual output current.

4 800W/1kW EMS II Power Supply

When testing the power supply, short the external lines together — it will respond as if a superconducting magnet were attached to the leads.

The power supply can be controlled locally (by turning the voltage and/or current dials on the front panel) or remotely (using a variable external voltage, current, or resistance). There are different arrangements of the connections between the screw terminals on the back of the power supply for the different control settings. Diagrams of the different arrangements can be found in the user's manual.

4.1 Remote control

The power supply is capable of producing 100A at 10V. It is currently configured to alter the voltage output to the magnet, based on a variable voltage supply. (A controlled voltage is applied between screw terminals 4 and 6 on the back panel; this 0-5V potential difference linearly controls the 0-10V voltage output of the power supply.) From the input parameters of the magnet controller, the power supply receives a voltage signal from the control box, within the range 0–5V. This signal determines the voltage output of the power supply (0V = 0, 5V = 10V).

4.2 Resolution

The resolution of the power supply is based on the resolution of the control signal. As covered in Sec. 1.6, the resolution of the power supply is 30 mA. With an additional resistor of 1 Ω parallel to the ADR, this resolution can be increased to 3 mA.

5 LabJack U6

The LabJack U6 is a data acquisition (DAQ) device used to send and retrieve signals from the cards within the Cycle Box and the computer. It has two external connectors to link to the cycle box's back plane card and an USB port to connect to the computer.

5.1 Software details

There are separate drivers for Windows and Mac/Linux. For Windows' LabVIEW, LabJack provides a complete set of VIs for controlling the LabJack. Nothing as extensive is provided for the Mac/Linux user, though the drivers are provided. There exists a LJ Control Panel, useful for easily testing the device and installing any necessary software updates.

Communication with the LabJack U6 is relatively simple. After opening the LabJack, a list of requests is compiled. This list identifies which digital ports are inputs and which are outputs, and configures the analog input ports to be single-ended or differential along with their range. It also sets the values for any analog outputs. The list is then sent to the LabJack, and any values to be read are retrieved afterwards. A second call to one of the AddRequest functions resets the request list. See *LabJack pseudo-code.txt* for more details. All output signals are kept at their last given value until they are set to a new value. There is no need to close the device at the end of data acquisition.

5.2 Hardware details

The LabJack U6 is capable of fourteen single-ended analog input signals (or seven differential), twenty digital I/O lines, two analog outputs, two counters, and four timers. It also includes two current sources (200 uA and 10 uA), a ± 12 V power source, and two 5V voltage sources (for reference for multiplexers, etc.). As mentioned in Sec. 1, the cycle box is currently occupying six differential analog inputs, nineteen digital I/O, and two analog outputs. The LabJack U6 has a number of screw terminals also available, for quick connections. The signals available include four analog inputs (AIN0–3), both analog outputs (DAC0–1), and four digital I/O (FIO0–3). These are organized in groups of four, each including a GND and 5V voltage source. The LabJack U6 receives its power from the USB connection with the computer.

5.3 *Housekeeping* LabVIEW VI

This VI combines the Cycle Box VI and the Magnet Control VI. It includes the front panels from both VIs and calls on them as subVIs. The cycle box VI has been split into two separate subVIs: *subCycleBoxSend.vi* and *subCycleBoxRetrieve.vi*. The settling time was removed from the cycle box subVIs and placed in the main while-loop of the housekeeping VI. This is to allow the cycle box subVIs to only be called when data is to be read from the cycle box (allowing for a long settling

Figure 23: The LabJack U6. Visible are the external screw terminals and the USB connection. On the back-side are located the two D-Sub connectors. The LabJack is the DAC (Data Acquisition) device used with the ZEUS-2 cycle box to interact with a computer. It monitors temperature sensors and controls the current and voltage of the Janis two-stage ADR.

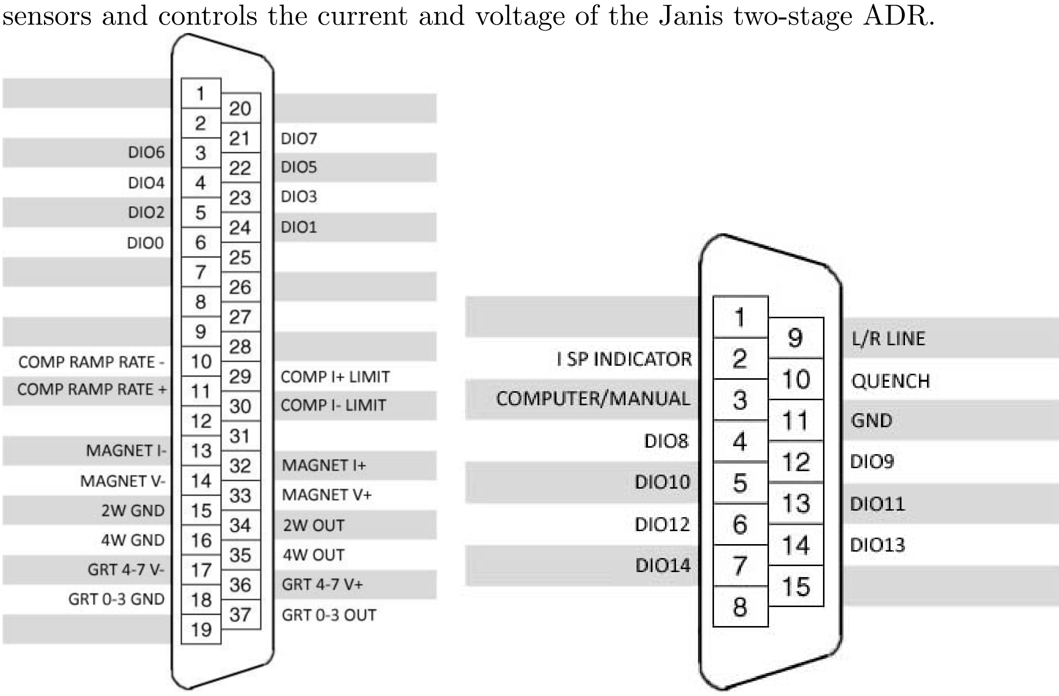

Figure 24: Pin-outs for the two connectors on the LabJack U6, as used with the ZEUS-2 Cycle Box. More details can be found in the Computer tab of the file *Inter-plate Pin Connections.xlsx*.

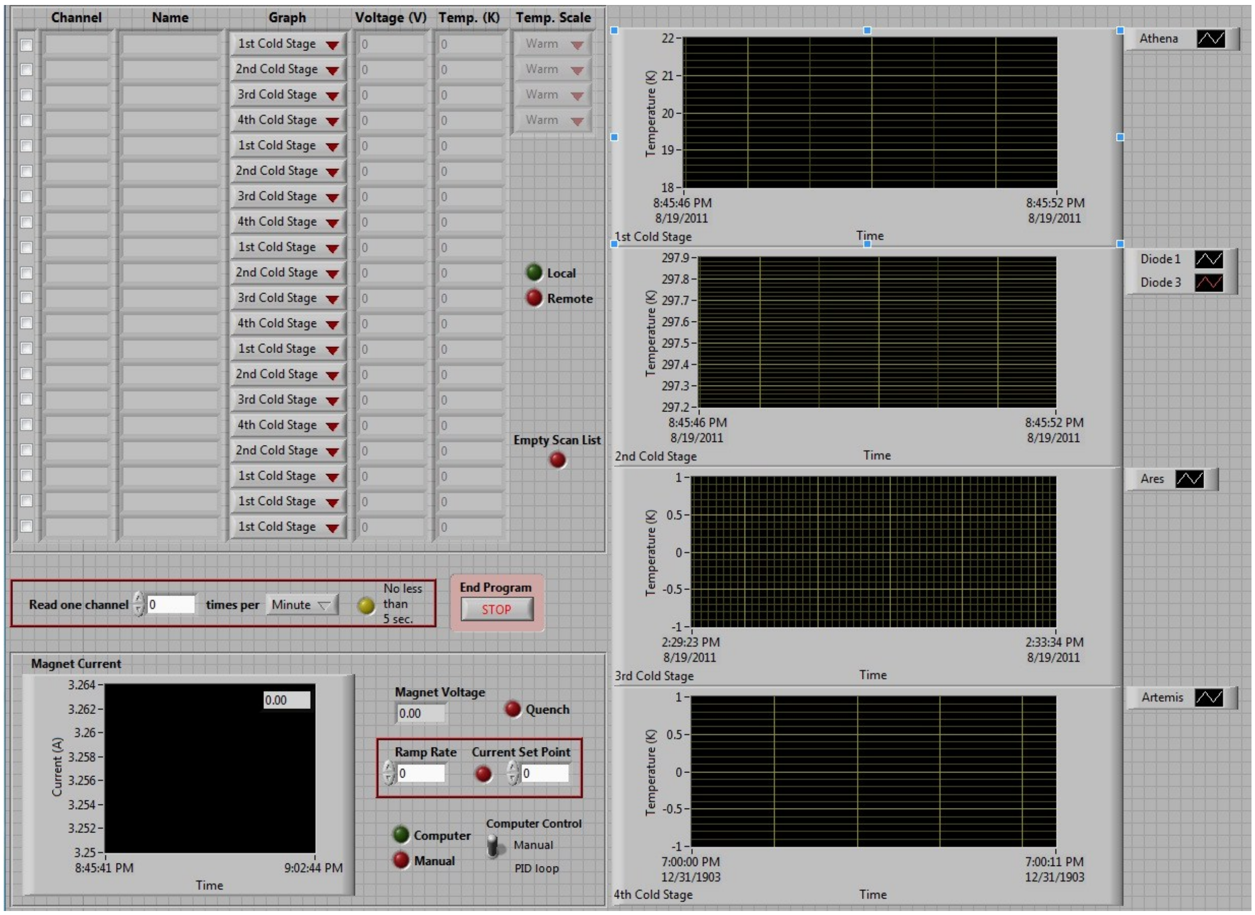

Figure 25: Front panel of *Housekeeping_v2.vi*. This is the main program to run during observations, as it calls both the cycle box and the magnet controller VIs as subVIs.

time), whereas the magnet control subVI will be run in every iteration. Constructing the program this way allows it to run much faster and be more responsive to user input.

5.3.1 *subCycleBoxSend.vi*

- Inputs
  - Device handle
  - Error cluster
  - Front panel inputs
- Outputs
  - Device handle
  - Error cluster
  - Channels — relative
  - Scale
  - LEDs

This subVI is the first half of the original cycle box VI. It retrieves the local/remote channel and sets the digital signals for which channel to monitor, the temperature scale, and the channel lines. It will only be called on the first iteration of the main while loop, or when data has just been obtained from the LabJack.

5.3.2 *subCycleBoxRetrieve.vi*

- Inputs
  - Device handle
  - Error cluster
  - Front panel inputs cluster
  - While-loop variables cluster
- Outputs
  - Device handle
  - Error cluster
  - While-loop outputs cluster
  - Cold stage graph data and formatting cluster
  - Digital displays cluster
  - Empty scan list boolean

Also known as Cycle Box Get, *subCycleBoxRetrieve.vi* is the second half of the original cycle box VI. It converts the most recent voltage readings to temperatures, updating both the digital displays and the cold stage sensor temperature graphs. This subVI is also responsible for updating the text files for each sensor read. It will only be called if the minimum settling time has passed, as calculated in the housekeeping VI (based on user input). If the amount of time requested has not passed, this subVI is skipped.

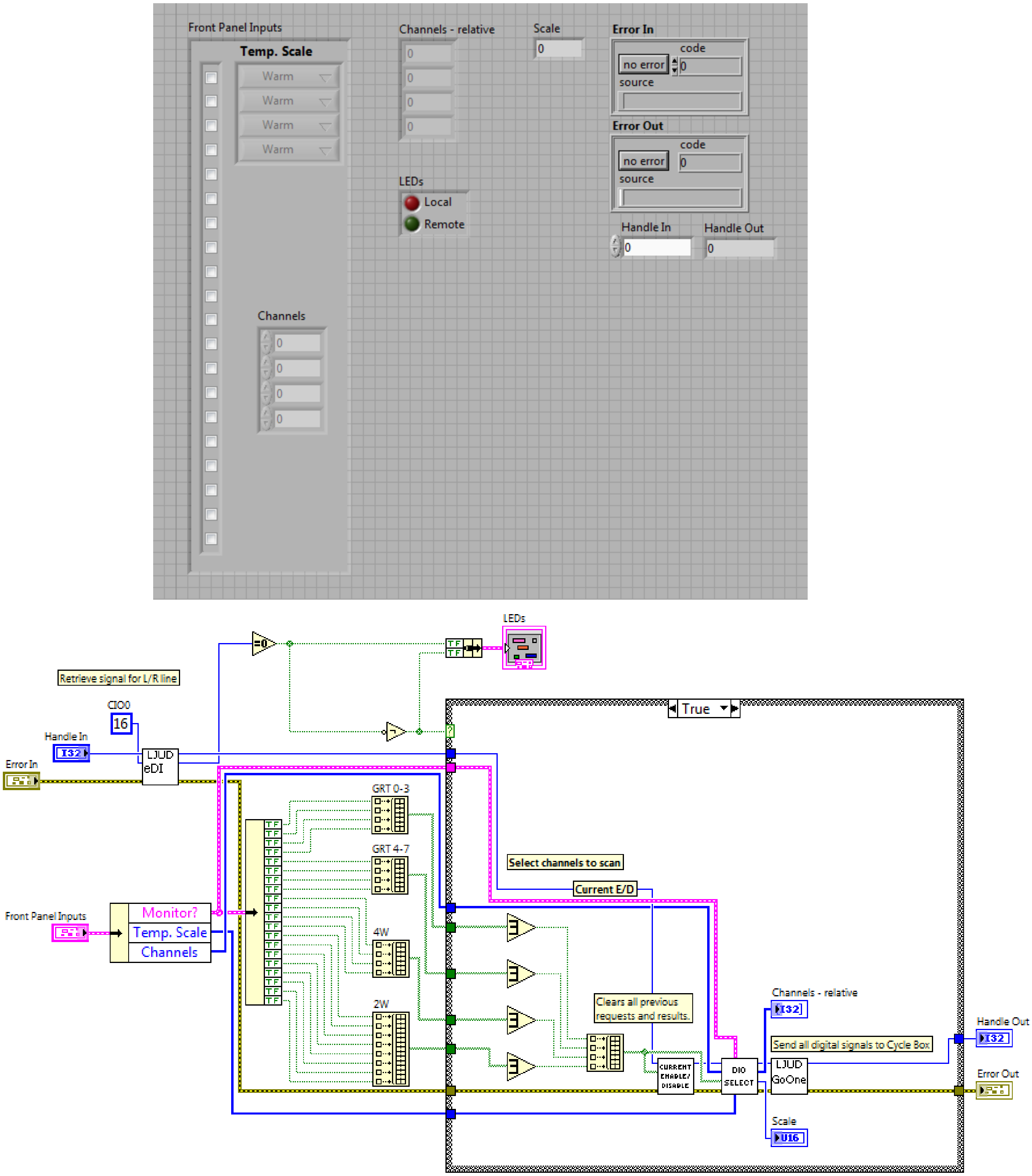

Figure 26: Front panel and block diagram of *subCycleBoxSend.vi* or Cycle Box Send. It retrieves the local/remote signal and sets the digital channels of the LabJack accordingly.

5.3.3 *subMagnetController.vi*

- Inputs
  - Device handle
  - Error cluster
  - Magnet control boolean
  - Ramp rate
  - Current set point
- Outputs
  - Device handle
  - Error cluster
  - LED boolean cluster
  - Magnet voltage
  - Magnet current
  - Current limit boolean

This subVI is identical to a single iteration of the original magnet controller VI. It is called with every iteration of the while loop within *Housekeeping_v2.vi*, regardless of if either cycle box subVI was called. Thus, updates to the magnet's current and voltage readings occur frequently.

6 Dewar additions

6.1 Break-out boards

- Protel PCB Project — *50K Board*
- Protel PCB Project — *4K Board*
- Pin connections — *Inter-plate Pin Connections.xlsx*

The first cold stage break-out board has a total of five MDM connectors — 25-pin, 37-pin, and three 51-pin. The first three listed connect the board with the external circular connectors, while the two remaining 51-pin connectors link this board with the second cold stage board. There are traces on both sides of the board. Two additional pins on the first cold stage provide a pass-through for the ADR voltage sensing lines.

The second cold stage break-out board has two 51-pin MDM connectors, with all signals coming from the first cold stage break-out board. The 9-pin MDM connector is the link to the third cold stage, while the 21-pin MDM connector connects to the fourth cold stage. The traces are only on one side of this board. Both boards were fabricated by Sunstone Circuits (*www.sunstone.com*) using the ValueProto method.

All GRT signals are carried from the 22-55 connector through the 51 pin connector on the first break-out board to one of the two 51-pin connectors on the second board. From there they are dispersed between the second, third, and fourth cold stages — the 9-pin connector carries two GRTs

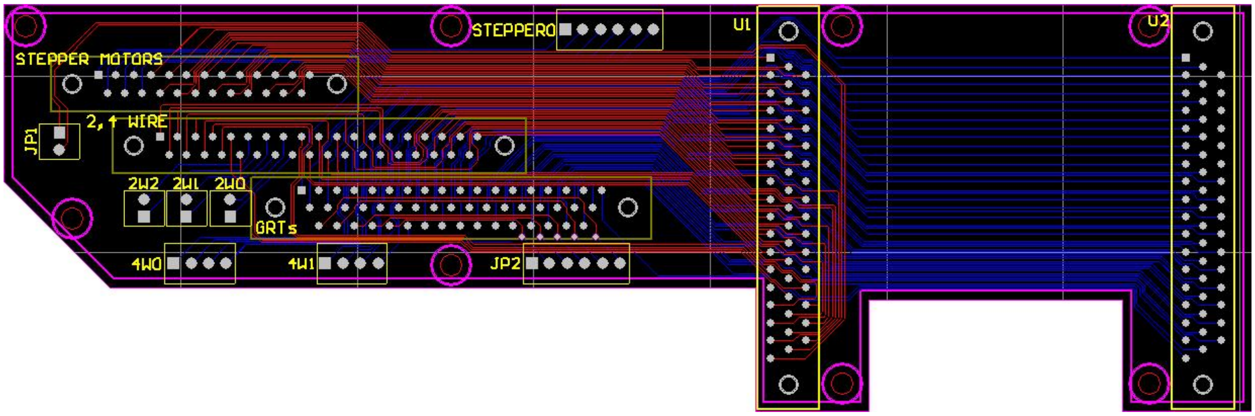

Figure 27: Protel image of the first cold stage break-out board (not to scale). Red lines represent traces on the top surface, while blue lines are traces on the bottom surface of the PCB. Traces are 0.007" thick. The minimum distance between any two traces is 0.007". These dimensions were the minimum permitted by Sunstone's ValueProto manufacturing. All GRT signals connect to the second cold stage via U2, while the stepper motor limit switch, 2-, and 4-wire signals are carried through U1 to the second cold stage.

(GRTs 1 and 2) to the third cold stage, while the 21-pin connector links five GRT sensors (GRTs 3-7) to the fourth cold stage. GRT0 remains on the second cold stage. The 4-wire and 2-wire signals flow from the 20-41 connector to the 37-pin connector on the first cold stage. 4W0-1 and 2W0-2 remain on the first cold stage. Two 4-wire (4W2-3) and five 2-wire (2W3-7) signals continue to the second cold stage on the other 51-pin connector, where they are dispersed to sensors. The stepper motor limit switch lines are carried in the 16-26 connector to the first cold stage in the 25-pin connector. Three of the four (LS 1-3) continue to the second cold stage on the same 51-pin connector as the 2- and 4-wire sensors, where they are dispersed. LS 0 is on the first cold stage.

As designed, each of the two break-out boards connect as many pins as possible, regardless of whether or not there are currently signals assigned to them. See *Inter-plate Pin Connections.xlsx* for details on the signal paths.

6.2 Cables

- On-board connectors — *Thermometry connectors.docx*

The cables from the cycle box to the dewar both contain twisted pairs. The one with the 20-41 connectors has 40 24-AWG conductors, and that connecting the two 22-55 connectors has 50 28-AWG conductors.

Between cold stages, the connectors are attached with LakeShore's 36-AWG dual twist phosphor bronze cryogenic wire with Polyimide insulation(product number WDT-36-100). Connecting sensors to the break-out boards is 34-AWG twisted copper wire with Teflon insulation (product number WCT-YB-34-25 and WCT-RB-34-100). A list of the sensor connectors can be found in the on-board connectors file listed at the beginning of this section.

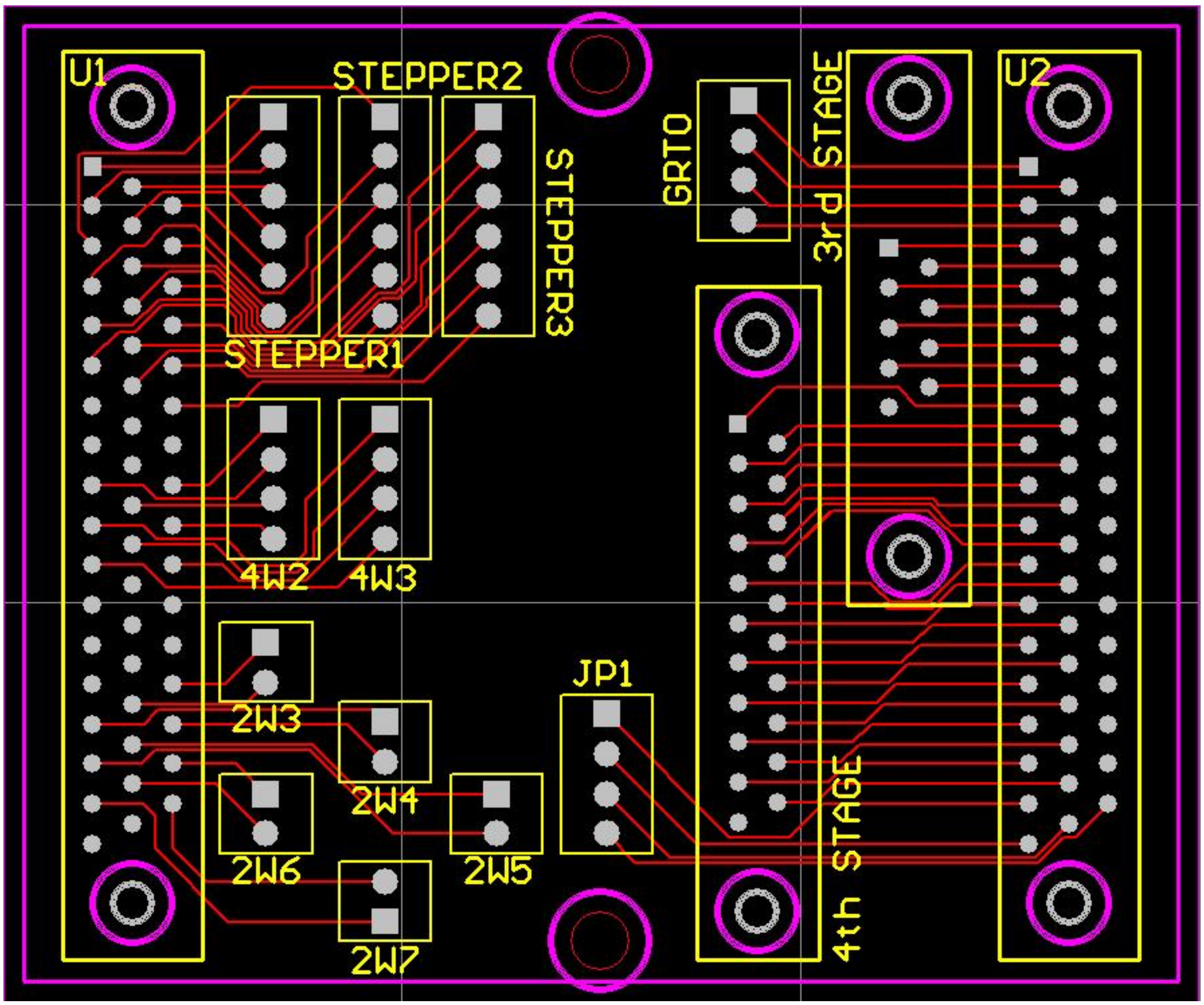

Figure 28: Protel image of the second cold stage break-out board (not to scale). All traces are located on the top surface. Traces are 0.007" thick. The minimum distance between any two traces is 0.007". These dimensions were the minimum permitted by Sunstone's ValueProto manufacturing process. Connectors U1 and U2 correspond to those by the same name on the first cold stage break-out board.

6.3 Copper strips

17 piles of 90 strips of 0.001" x 0.5" copper, 2.6" long, 90 strips 4.1" long, and 90 strips 4.5" long, were cut from a roll of length 476 ft. To simplify the process, two right-angles were C-clamped to the corner of a table. A wooden dowel was inserted into some of the holes towards the top of the angles. The roll of copper was hung on this dowel. To keep it from wobbling left and right, wide circular pieces of scrap aluminum were also placed on the dowel, on either side of the roll, to provide extra support. The copper was cut on the table surface using a rotary cutter. While cutting on cardboard or poster-board is possible, the cut edge tends to fold into the cutting surface, not keeping the desired flat edge. Using a thin piece of Teflon was the best surface upon which to cut.

6.4 G10 stand-offs

The G10 supports were assembled for between the baseplate and first cold stage and the first and second cold stage. Those between the baseplate and first cold stage are composed of a rectangular-shaped piece of G10 and two aluminum rectangular slugs. An aluminum piece was cemented to each short end of the G10, one on the top and the other on the bottom (forming an S-shape). All epoxied surfaces were first lightly scuffed with fine grit sand paper and cleaned with acetone. The adhesive was applied to both surfaces with a taffy stick. Before placing the two sides together, a 0.001" spacer was placed around each screw hole on top of the adhesive, so the resulting layers were aluminum – adhesive – spacer – adhesive – G10. The entire stand-off was held together in a custom-made jig, held under compression. Each piece was set to cure at room temperature for approximately twenty-four hours.

The same general process was followed for the cylindrical supports for the second cold stage. The inside ends of the G10 cylinders were scuffed with fine grit sand paper. To simplify the process, a small piece of the sand paper was wrapped around the end of a wooden dowel with a diameter slightly less than that of the G10. It was then much easier to apply even pressure to the G10 when using the sand paper. A cotton-tipped applicator was used to apply epoxy to the inside of the G10 cylinders. These were also held in a custom-made jig for approximately twenty-four hours at room temperature to cure.

6.5 Super-insulation

Eleven layers of super insulation for the first cold stage were cut out and taped together, forming concentric cylinders. The circular top had a minimum diameter of 19.25". The height of the cylinder was 21". The first layer is 0.25" larger than the shield, as the insulation should not be tight against the heat shield. 0.75" was added to the height of the insulation to allow it to hang over the base-plate.

6.6 Helicoils

Helicoils were inserted into the base plate of the Dewar, along with other copper and aluminum parts within the instrument.

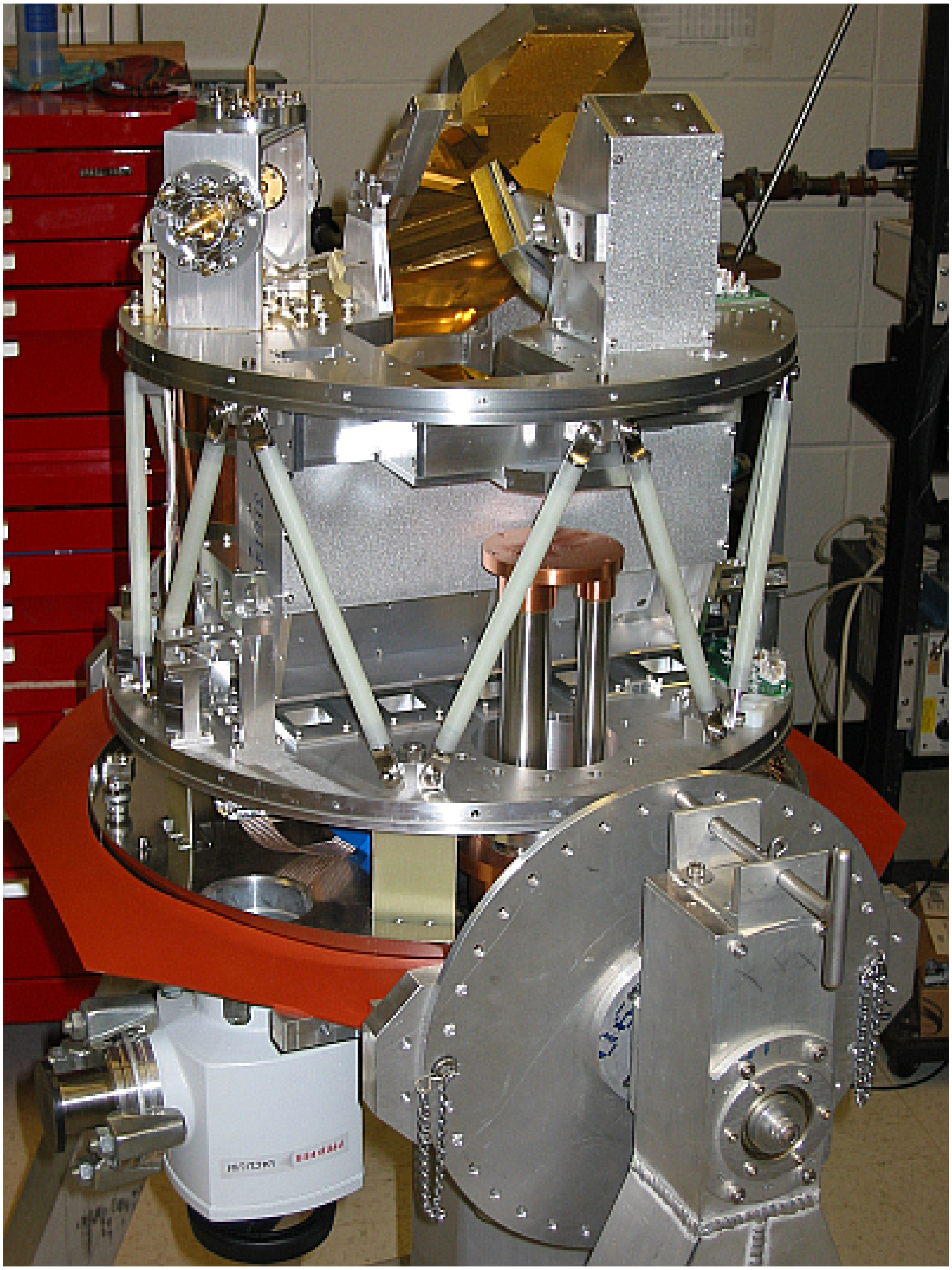

Figure 29: First two stages of ZEUS-2. The rectangular G10 stand-offs can be seen between the baseplate and the first cold stage. The cylindrical G10 supports form a triangular pattern to support the second cold stage.

Figure 30: Branson Ultrasonic Cleaner, Model 1510. This cleaner was used to clean most small aluminum parts within the dewar. It uses a diluted cleaner with ultrasonic technology to loosen dirt particles and oils from surfaces. DO NOT use the general cleaner with copper - the copper will react with the cleaner.

7 Bransen Ultrasonic Cleaner, Model 1510

- Cleaning instructions — *Ultrasonic cleaner instructions.docx*

The mixing and rinsing directions included in the listed operating instructions are for the SF1 Solvent Free Degreaser concentrate.

If the cleaner must be cleaned (solution has evaporated inside), use a nonabrasive cloth and water only.

When cleaning copper parts, the SF1 Solvent Free Degreaser cannot be used — a chemical reaction occurs with the copper. Instead, use a salt and vinegar mixture developed by Eve Vavagiakis (although this seems to still allow the copper to oxidize... though it can be wiped off without too much hassle).