ARRO INTERIM REPORT

April 7, 2006

REV A1

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1 Early Enclosure Concepts

The early stages of the project focused on defining the project and deciding which design goals were most important in terms of the end use of the observatory. Various options were considered that relate to the various configurations and operational characteristics of ARRO, as well as material properties, available components, etc.

The most fundamental question that needed to be addressed has to do with the configuration of ARRO and the main issue centered around whether the basic structure should be capable of accommodating an interior workspace. The concerns are that,

> 1) if the enclosure is exposed to the environment during the annual service visit, the temperature specifications will be violated
> 2) if the weather is less than ideal during the annual visit, access to the interior of the enclosure (by a team member standing outside) may not be practical, resulting in the need to set up a shelter and making a quick site visit impossible.

After much discussion of the pros and cons of various possible designs, the decision, driven by the results of a numerical model, was to design an enclosure that was minimal in interior volume such that accomodation of personnel was a secondary priority. For the most part, this decision was driven by the need to maximize the scientific data output of ARRO. Compromising the number of days of autonomy for the convenience of a comfortable work space does not justify a significant loss of autonomy.

In the end, the final design does provide an interior workspace, albeit very small. This is somewhat of a compromise based on the recognition that a small, simple space can, in fact, be accomodated with very little impact on autonomy.

1.1 Design Guidelines

In order to make ARRO backward compatible with AGOs as much as reasonable, the decision was made to set the minimum operating temperature at 32 F. This decision was based on a survey of the users of AGOs, specifically asking what the minimum temperature is that their instrument can tolerate. Likewise, the maximum operating temperature was set to 95 F, again based on the tolerance of the existing instruments. Note that a high maximum operating temperature helps the system autonomy because it stores thermal energy, which the models show to be significant.

The following initial design guidelines were identified:

1) Ambient temperature range will be -94 F to +23 F peak.
2) The equipment operating range will be 32 F to 95 F.
3) Wind Power will be supplied from a 3 kW HR3 windturbine with 3-phase bridge rectifier panel.
4) Solar power will be supplied by a 750 W PV array with Trace C-40 charge controller.
5) A battery bank will be incorporated to provide 11 days of autonomy.
6) A System Controller Unit (including DC power distribution and environment control) will provide central control of the ARRO (provided by Dartmouth College).
7) A Data Acquisition Unit will handle the data acquisition, as well as provide an interface to the Iridium modems, allowing bi-directional communications to and from the System Controller Unit (Data Acquisition Unit provided by University of Maryland).
8) A Burst Mode Acquisition Unit (to be supplied by Stanford University) will handle high data rates. Interface to Iridium TBD.

1.2 Initial Design Concepts

Based on the above information, a number of preliminary designs were developed and discussed at a review in June, 2003. The very first idea (which preceded some of the numerical modeling) was to develop a 'pop-top' structure. This structure, when closed, would have enough space for the interior equipment but not much more. When a service team arrived on site, the team would literally raise the roof, expanding the interior workspace significantly and, potentially, provide a heated interior workspace. While this design has the advantage of accomodating team members without the need for additional support, its complexity was thought to be excessive. Specifically, sealing the enclosure would be difficult and the mechanism raising the roof would need to accomodate the optical penetrations and might be difficult to design. The “pop-top” design is shown below in Figure 1.

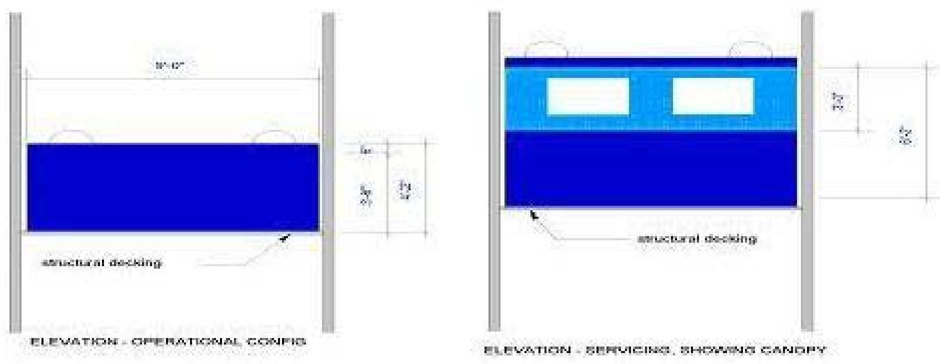


Figure 1

"Pop Top" Enclosure Concept

The second design was much simpler. Shown below in Figure 2, this design was based on a commercially available freezer enclosure (a so-called Bally Box). The design was proposed by Northern Power and has the advantage of using commercially available components, but also had significant limitations with regard to available sizes, etc. Its most significant disadvantage is that the thickest wall panels are only 6 inches, reducing the number of days of autonomous
operation from the goal of 11 to less than 4. This was considered far from adequate for our needs. An attempt was made to supplement the panels with vacuum insulated panels, which appeared to provide adequate insulation. However, the concern that 'vacu-panels' had never been tested in extremely cold regions and the risk (and repair costs) associated with their failure was seen as insurmountable and the vacu-panel solution was no longer considered.

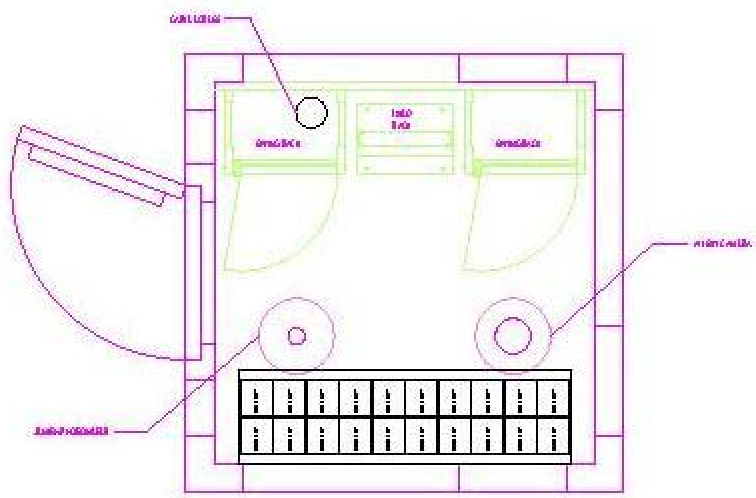


Figure 2

Original Bally Box Concept

The third design was also proposed by Northern Power and is shown in Figure 3

This design and its variations was still based on a Bally box, whose insulation was supplemented with foam, although only in certain compartments. The figure shows one example with the batteries kept in a subcompartment. Note that the enclosure has four access panels. Ultimately, it was determined that the multiple access panels allowed excessive infiltration. Also, in all of the cases presented, only rough estimates of the expected autonomy were available and none were more than a few days. For this reason, the concept was abandoned and it was decided to build the most compact structure possible to maximize the autonomy.

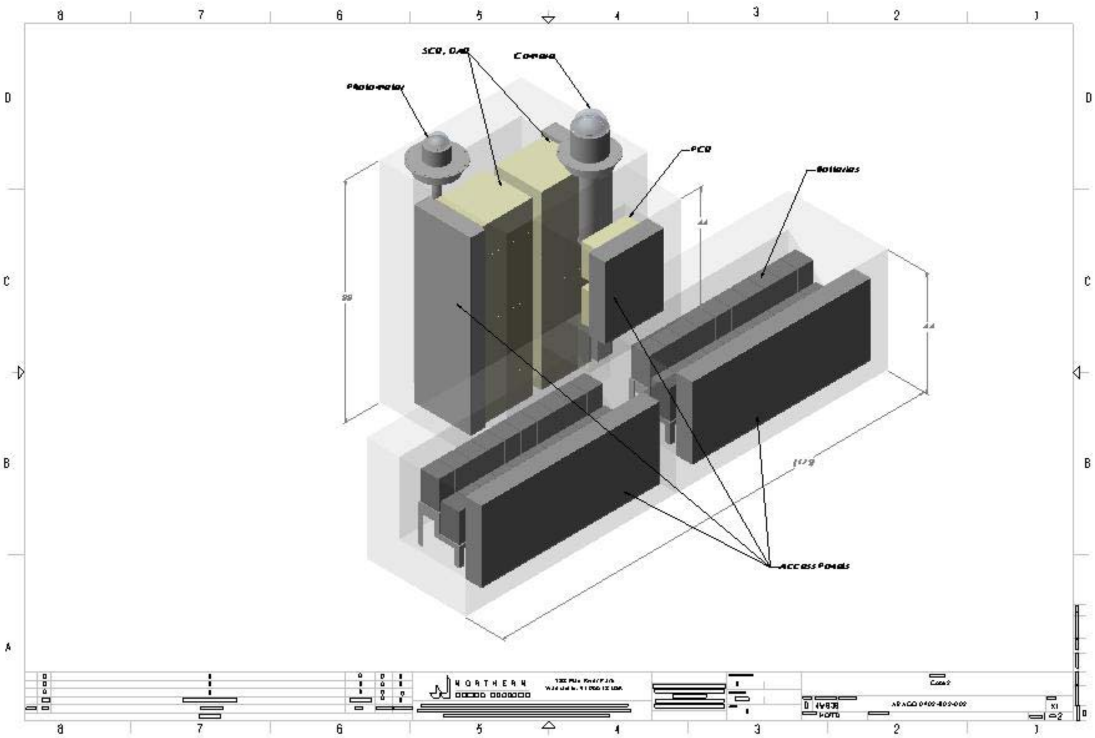


Figure 3

Bally Box Design With Supplemental Foam

After these (and other) unsuccessful attempts, the task of designing the enclosure was handed over to personnel at CRREL. Gary Phetteplace began the development of a dynamic model (described below) while Jim Buska began work on the enclosure design itself. After a few meetings where results of the model were discussed, it became clear that the best enclosure design would be a simple cubic box. It was also noted that providing a small interior workspace would not have a significant effect on the autonomy. Stated somewhat differently, it was noted that the facilities for accomodating optical instruments would be the most significant heat sink and that the ultimate size of the enclosure had only a small relative effect. The initial design of the
enclosure is shown below in Figure 4. Additional drawings are included in appendix J.

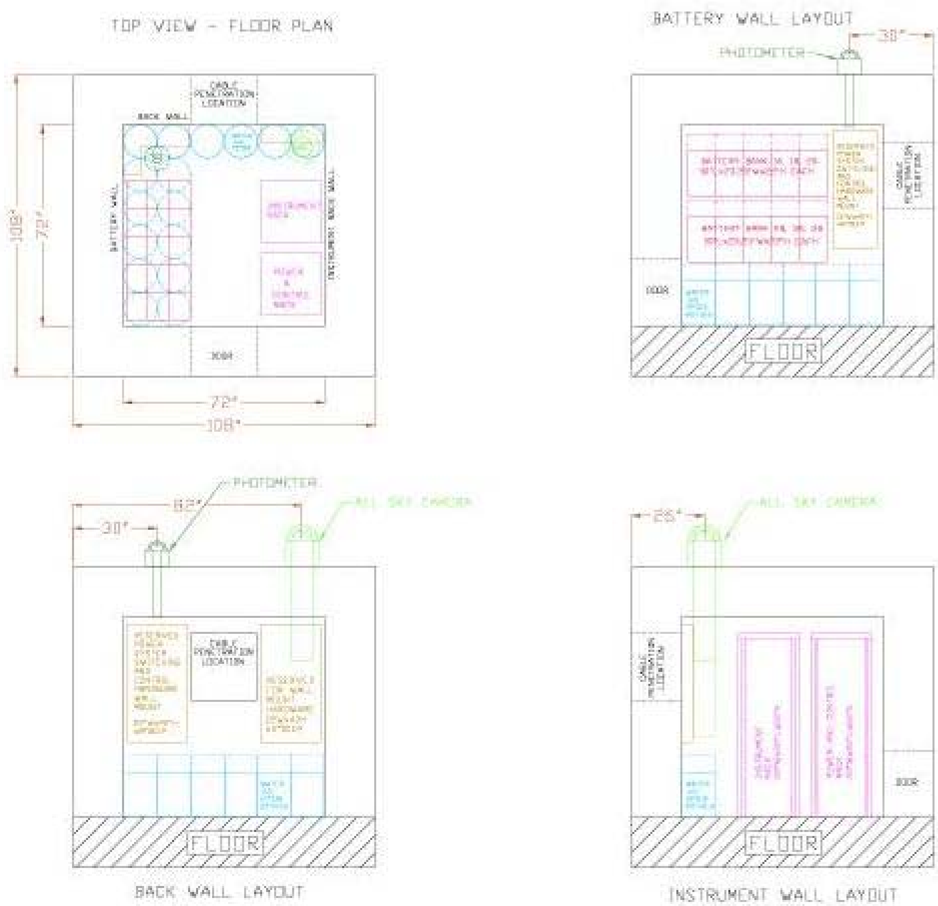


Figure 4

Final ARRO Implementation

In order to comply with a requirement that ARRO be deployable with a Twin Otter, the enclosure was designed in a modular fashion such that each component would fit inside the fuselage (Twin Otter fuselage drawings were provided by Ken Borek). The enclosure consists of an extremely tight wall section consisting of 18-inches of polyurethane foam sandwiched by oriented strand board (OSB) panels. The box has three types of penetrations;

1) Two double-paned acrylic domes in the roof for a photometer and an all-sky camera,
2) Cable entry ports at the back of the structure
3) a door at the front of the box. More specific information regarding the enclosure and associated testing is provided below.

Finally, in every respect, the modeling and design of the system is intended to be as scalable as possible. It is our intention to not only develop an enclosure that can function reliably in extreme cold temperatures, but to advance our knowledge of this type of system so that the technology can be used in systems deployed to different regions with different weather conditions.

2. British Antarctic Survey Personnel Input

Many discussions were held with engineers from the British Antarctic Survey about the successes and failure of their system. The three most significant points that they passed on to us were that

1) thermal energy storage could substantially improve autonomy
2) their experience with wind power generation was not very promising
3) the biggest problem that persisted in their observatories resulted from the poor performance of the cable penetrations.

Each topic is addressed below, where we first explain that numerical modeling demonstrates the effectiveness and practicality of thermal energy storage, which is incorporated into the ARRO design. As far as the wind power and penetration problems are concerned, we believe that we have them solved.

2.1 Numerical Efforts: Electrical Versus Thermal Energy Storage

The experience of BAS, though somewhat anecdotal, emphasized the possible advantanges of combining electrical and thermal energy storage. To further explore the potential advantages of this, a dynamic model was developed by Gary Phetteplace at CRREL. The model considers the following heat and electrical energy flows.

1) Heat transfer through the walls
2) Heat transfer through the optical domes
3) Heat transfer through the instrumentation cable access
4) Infiltration through joints in the walls, doorway, and instrument cable access
5) Heat flow to/from the thermal storage media (water jugs)
6) Heat flow to/from the batteries
7) Electrical load from instruments and controls
8) Wind generator output.
9) Electrical energy to/from the batteries.
10) Electrical energy to heaters.

The most significant heat loss from the shelter is the heat transfer through walls. This has been treated as one dimension heat conduction with the cross sectional area equal to that which exists at the midpoint in the wall thickness. The model uses a 7 layer, explicit finite difference model with inside and outside convection resistances. The heat loss through the cable access bulkhead is calculated as linear heat conduction through a prescribed connector bulkhead cross sectional area with an effective thermal resistance equal to one half of that of the remainder of the wall.

The shelter has two optical domes used for a photometer and an all-sky camera. The original concept design called for these to be single layer acrylic domes. We quickly realized that as such they represented a major heat loss from the shelter. Hence, double layer acrylic domes were fabricated and tested. Heat transfer through the optical domes is modeled as linear heat conduction with inside and outside convective resistances added. For the double layer dome the airspace has still air film resistance added as well. The cross sectional area for heat transfer is taken as the average surface area of the two domes. Infiltration is another very significant component of the heat loss. Infiltration was treated with standard ASHRAE correlations (ASHRAE 2001) extrapolated to a half-story structure for both the wind and stack coefficients. The effective crack area was taken as 0.02 cm2/lmc, a value that is equivalent to a very tight window sash (ASHRAE 2001).

Thermal storage has been included in the design in order to allow the shelter to maintain a suitable environment for the instrumentation during periods of no recoverable wind power. The model assumes that the thermal storage medium is contained in cylindrical containers. The containers are modeled as infinite circular cylinders with a convective boundary condition on their exteriors (Carslaw and Jaeger, 1959). Heat input to cylindrical containers is accomplished by immersion heaters located at their centerline. The heat transfer between the heater and the thermal storage medium is not modeled, i.e. heat input to the thermal storage medium is assumed to be instantaneous and without thermal resistance. This is felt to be a reasonable assumption since the heater temperature will be significantly higher than the surrounding storage medium and convective mixing will result in favorable heat transfer conditions.

The batteries within the shelter will be a significant mass and hence they have a significant sensible heat effect on the shelter energy balance. Heat transfer to/from the batteries is modeled by assuming they form an infinite slab with convection on both sides (Carslaw and Jaeger, 1959). The material properties of the batteries are taken as mass-weighted composite of nickel, cadmium, polyethylene, steel, and water with the proportions extablished by the manufacturer's data for the specified batteries. The wind turbine output is modeled as one or more simple linear functions of wind speed with specified cut-in and cut-out limits. The possibility that multiple wind turbines with different characteristics could be used in a combination has been included in the model.

2.2 Wind power generation

Again, BAS engineers provided important but minimal information regarding the failure of their wind power generators. Similar stories were obtained from other groups (Steve Musko of Michigan, Rick Sterling of Berkeley and others). Typically, the various generators appeared to have self-destructed, likely due either to a problem with bearings or with brushes. The spotty evidence for the failure of small wind generators led to a suggestion by Dr. Jack Doolittle that a small wind farm be established at the South Pole in order to determine precisely how the failures occurred and to compare the robustness of various wind generators side-by-side. While we were not able to carry out this task, we did acquire several generators of various sizes in order to compare their performance side-by-side.

As explained in the original proposal, mountains along the coast in East Antarctica form a barricade in the shape of a bowl that contains the Polar Plateau, a gently sloping region that exists at an altitude of approximately 2,900 meters and encompasses a significant fraction of the continent, including the South Pole. This topography leads to an unusually stable weather pattern, with temperature inversions driving steady winds away from the highest elevations of the plateau toward the coast. These steady winds, which typically average 3-6 m/s during winter months and exceed 15 m/s only rarely, contrast dramatically with winds reaching nearly 90 m/s that occur along the Antarctic coast.

Data recorded by Northern Power Inc., using their HR-3 wind generator located at the South Pole in 1997, show that the wind power available ranged from 182 kWh in February to 703 kWh in May. For a 31--day month, the total energy required for ARRO operation (based on a 50 W instrument budget plus 50 W in supporting electronics) is 74.4 kWh. Clearly, a large safety margin exists as long as enough energy can be stored to adequately bridge gaps in wind speed. However, at certain locations near the very top of the plateau, for example near Dome C, lower average wind speeds may make it harder to achieve 100% duty cycle with the wind generator alone.

For these reasons, the Northern Power HR-3 generator was thought to be the best choice, initially. On the other hand, our numerical studies have been showing that the cut-in speed of the wind generator (i.e., the lowest speed where the generator starts to produce any power) is critical in the sense that the duty cycle of ARRO depends strongly on the cut-in speed. Not being able to verify the test data from Northern Power, we were not able to accurately determine the performance of the generator in the vicinity of the cut-in speed. This fact, compounded by the significant cost of the HR-3, as well as its large size, led us to consider other (smaller) alternatives.

Six small generators were acquired in order to conduct side-by-side tests. Initially, all six were installed in a field near Dartmouth College and monitored. The following table lists relevant information.

Ampair Pacific 100
Used on polar plateau by both ANUBIS project and AGO project
Cut-in speed: ~3 m/s
Produces up to 100 W/hr
Weighs 13 kg
Recommended by Rick Sterling (Berkeley) and Hugh Piggot (Scoraig Wind)

Bergey XL.1
No known Antarctic usage
Cut-in speed: 2.5 m/s
Weighs 34 kg
Produces up to 1 kW/hr
Bergey products in general recommended by Paul Gipe (author)

LVM Aero6gen-F
Claims use in Antarctica, but no proof
Cut-in speed: ~2.6 m/s
Weighs ~13 kg
Produces approximately 100 W/hr
Recommended in Chelsea Green article

Marlec Rutland 910-3F
Used on polar plateau by ANUBIS project
Cut-in speed: 3 m/s
Weighs 17 kg
Produces approximately 100 W/hr
Recommended by Chelsea Green article

Southwest Windpower Whisper H40
Previous model (Air 403) used by Mt. Erebus and ANUBIS projects
Cut-in speed: 3.4 m/s
Weighs 21 kg
Produces approximately 900 W/hr
Former models recommended on Chelsea Green article

Windside WS 0,30A
U of Michigan plans to use one on polar plateau, one supposedly in use at McMurdo
Cut-in speed: 3 m/s
Weighs 80 kg
Produces approximately 108 W/hr
Interest expressed by several Antarctic scientists

By simply observing the generators over the course of a few months, a few points quickly became clear.

1. The cut-in speeds provided by the manufacturers are not accurate. In fact, the Ampair and Aerogen units were consistently the last ones to begin turning as the wind increased, in spite of their claims.

2. The Rutland generator was the most 'eager', the one that turned the most freely (and actually produced low levels of power).

3. The Bergey and Whisper both started up well in low winds. The Whisper generator, in particular, appears to have a cut-in speed slightly higher than the Rutland.

4. The Windside proved to be very awkward to install and has poor performance in low winds. In addition, it requires constant lubrication (consumes electrical power) in cold-weather applications.

Finally, this work was being carried out just as the African Wind Power unit was becoming available. The AWP 3.6 generator is rated at 1 kW. The most significant advantage it has over all of the above choices, though, is a very large rotor diameter, enabling a cut-in speed of 2.5 m/s. This generator is currently being used with the existing AGOs and appears to be performing very well.

2.2.1 Bearing tests

A simple experiment was carried out to test the effect of extreme cold temperatures on bearing performance. Bearing tolerances are specified by their ABEC number (Annular Bearing Engineers' Committee), such that higher numbers refer to closer tolerance bearings, so an ABEC-7 bearing is tighter (and smoother) than an ABEC-5, for example. For our test, we acquired a set of three bearings that were identical in size, but conformed to ABEC-3, -5 and -7 specifications. All three bearings were placed in a freezer at CRREL, set to a temperature of -50C. In a matter of minutes, it was not possible to turn the ABEC-7 bearing by hand. Although this result may not seem surprising, it is still not clear whether the seizing is due to the decrease in some gap size or whether the rolling friction changes dramatically at extreme temperatures. In any case, the clear conclusion is that bearing tolerances need to be considered in wind generators for extremely cold regions; likewise, it is likely this effect that caused the self-destruction of the generators described above.

2.3 Cable penetrations

In discussions related to the best method for feeding cables through the enclosure wall, we found that the BAS group saw this as the weakest point in their system. Reducing heat loss through penetrations was difficult to keep at a minimum while at the same time providing capability to remove and replace cables.

In an effort to keep this loss at a minimum, and keeping in mind that the numbers and exact diameters of the cables/wires and their associated connectors were not necessarily fixed prior to transfer of equipment to the ARRO a design was developed which accommodates those unknowns without the use of specialty products. This design also allows for the installation of cables/wires with existing connectors attached, negating the task of removing the connector in order to feed the wire through a penetration, and then performing bench type work on the cable/wire in the field to reattach the connector.

The ARRO penetrations are made up of six 2-inch ID openings, and fourteen 1.5-inch ID openings. The two sizes and quantities of conduits were determined by estimated instrument and support hardware cabling requirements. The layout of the penetration for the ARRO enclosure is shown in a figure provided below. Of the available 72 inch by 18 inch surface area of the available back wall panel, an area of approximately 28 inches by 18 inches can be used due to instrumentation racks on either side of the back wall and location of panel joints. The design utilizes Schedule 80 PVC pipe with Slip x Female adapters on each end, the same diameter as the pipe. The pipe extends through the panel with the end of the female adapter flush with the outside of the OSB skin. These pipes are installed prior to foaming the panel. The adapters then have PVC plugs screwed into them to seal the penetration.

It has been realized that polyethylene backer rod and tube insulation snuggly fit within the PVC pipe. The backer rod is used for blank penetrations and small diameter wire (< ¼”), and the tube insulation is used to wrap large diameter cable or wire that is to be placed in the pipe. There are varying sizes of tube insulation available to accommodate the various sizes of cable/wire and pipe size. This foam is very robust down to -70°C as tested in one of the CRREL cold rooms.

To assemble, the intact plugs are removed from a penetration and the backer rod insulation is removed. The cable/wire with connector is fed through the penetration to the appropriate length. Tube insulation is installed on the cable, which is performed easily due to a manufactured slit along the length of the insulation. A split lace wire mesh cable puller is then placed on the insulation to allow the pulling of the slightly oversized insulation through the pipe. The insulation is trimmed to length just short of the end of the female adapters.

A PVC plug will then have a hole drilled through the end axially, slightly larger than the diameter of the cable/wire (see figures below). The plug is then cut in half which will allow installation on the wire already in the penetration, and screwed into the adapter to a snug. This prevents the foam and wire from being pulled out of the installation. The cable/wire strain relief is provided by the snug fit of the tube insulation, also the plug pushing in on the end of the tube insulation deforms the foam and creates a tighter fit around the cable/wire.

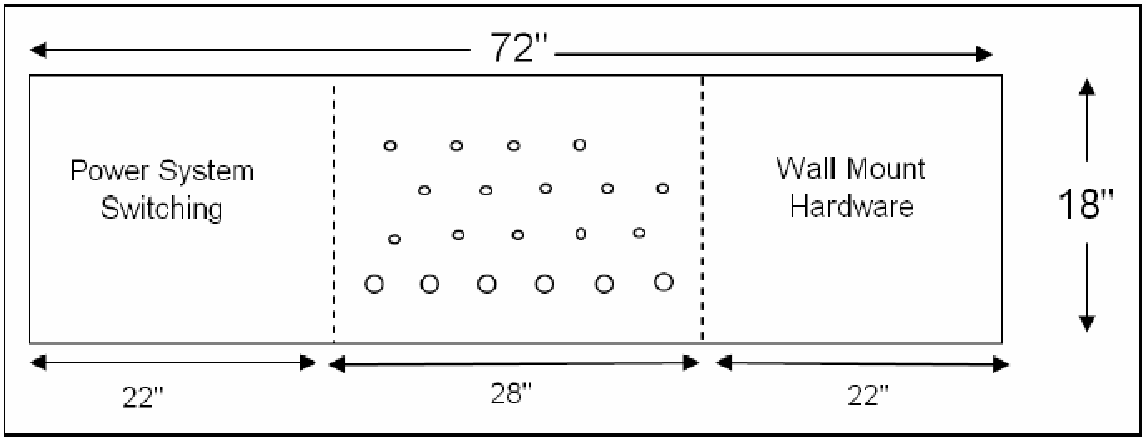


Figure 5

ARRO PENETRATION LAYOUT

Figure 6

ARRO PENETRATION BACKEROD AND PVC PLUG

3 ARRO SUBSYSTEMS

The following sections detail the various subsystems designed and implemented for the ARRO System

3.1 System Controller Unit and Support Hardware

The ARRO System Controller Unit (SCU) was developed at UNH to provide control and status information for all functionality of the ARRO system (outside of instrument data acquisition). The functionality of the SCU has been tested successfully through a series of bench tests as well as an extended overall system test (with wind generator source and solar panels connected) which is detailed in Appendix E. The functionality of the SCU that has been tested successfully is detailed below.

1) **Temperature Control**: Monitors a series of temperature sensors and controls a set of resistive heaters to keep the enclosure at a constant set temperature. The SCU algorithm uses information such as the state of charge of the battery bank as well as charging status from the wind generator/solar panel controller to determine when and for how long heaters are enabled
2) **Analog monitoring**: In addition to the monitoring of the temperature sensors, the SCU has the capability of monitoring various housekeeping voltages as well as future user supplied voltages. A total of 71 single ended analog inputs can be digitized at a 12 bit resolution.
3) **Power Distribution:** The SCU provides a controlled 24V to as many as 16 instruments in the ARRO system. The SCU algorithm has the capability to enable/disable instrument power based on battery state of charge and average instrument current use. Each power source is controlled via an isolated solid state relay
4) **Serial and Discrete I/O:** The SCU provides multiple standard RS232 serial ports as well as discrete isolated I/O which can be interfaced be used for user defined functions.
5) **Conrolled Shutdown/Powerup:** Provides the functionality to provide a controlled powerdown into a cold soak, as well as a controlled powerup from a cold soak.

3.1.1 System Controller Hardware Summary

The SCU consists of 2 main boards. The processor board contains all circuitry needed to provide the SCU algorithm functionality. It consists of 3 PLDs, a series of analog multiplexers, 8 16550 based UARTS and opto-isolated discrete I/O circuitry. It also houses the Rabbit 3000 based embedded processor board via board stacking connectors. A picture of the ARRO processor board is provided below. Currently there are two ARRO Processor Boards that have been assembled and tested successfully.

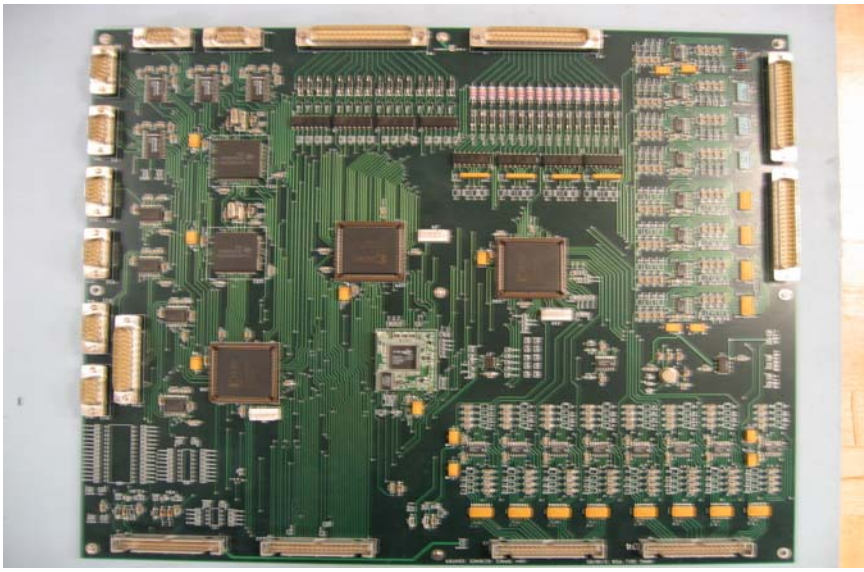


Figure 7

ARRO Processor Board

The Power Distribution Board provides all the means of switching power to 16 ARRO instruments. It also provides the capability of turning on/off up to sixteen. It consists of a total of 32 isolated solid state relays as well as 2 DC to DC converters that provide power to the ARRO Processor Board. Currently two ARRO Power Distribution boards have been assembled and tested successfully.

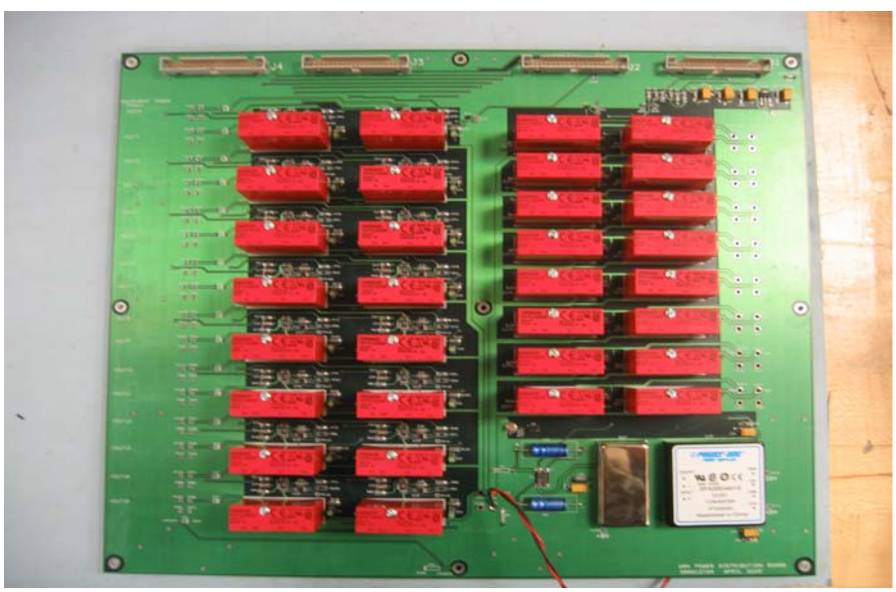


Figure 8

ARRO Power Distribution Board

3.1.2 Water and Ambient Heaters

The Solid State Relays on the Power Distribution Board that control power to heaters are grouped into eight relays to drive ambient heaters as well as heaters that are immersed in water. Each of the eight ambient heaters consume approximately 5 watts each while each of the water heaters consume 100 watts. In order to support the higher power consumption of the water heaters an external relay board was developed which included solid state relays which supported up to 10 amps of thru-current. A picture of the ARRO water heaters as well as the associated ARRO Relay Board is provided below.

Figure 9

ARRO Water Heaters

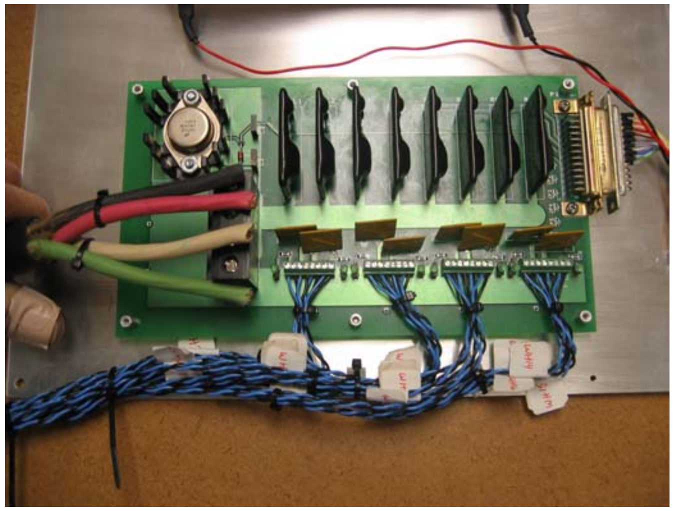


Figure 10

ARRO Power Relay Board

3.1.3 Items Remaining to be tested

1) SCU/DAU Interface

A fairly simple protocol between the SCU and DAU has been developed but needs to be tested using the full end to end Iridium link.

2)Back up Temperature Switches

The SCU was tested down to -50 degrees C and cold soaked for a period of three days. The controlled powerdown and powerup proved to be successful during this test even though electronics being used were rated down to -40 degrees C only. As an additional safety precaution we plan on integrating a bimetallic temperature switches to ensure power is applied after the -40 degree C threshold. This has proved successful in the AGO implementation.

We have selected a temperature switch but further testing needs to be implemented before integrating it into the system.

3.2 Data Acquisition System

The ARRO Data Acquisition System provides all the functionality associated with acquiring data from ARRO instrumentation, and interfacing the Iridium Satellite

Link in order to provide a real time feed of data back to the user. The system was developed by the University of Maryland.

This system is based on the original AGO data acquisition system and incorporates all the hardware and software features of the AGO Data Acquisition Unit . In addition it provides several enhancements. These include:

1) Iridium modem communication, for data acquisition and instrument control;

2) Standardized on-site data storage (IDE, FAT32), with compact-flash recording medium (no moving parts, no altitude pressurization);

3) Lower power consumption (reduced by 26%);

4) 16-bit instrument ADC resolution (instead of 12-bit AGO DAU capability).

Since the full-time communications link (Iridium) is bi-directional (full-duplex), this capability allows 'intelligent' control of data acquisition parameters, by command via the CONUS data acquisition computer. This feature is implemented in the AGO DAU, but will be enhanced in the ARRO DAS by the addition of burst-mode instrument sampling (see section 3.3).

The ARRO Data Acquisition Unit (DAU) provides the signal interface with scientific experiments, and maintains accurate time. Thirty-one data channels are provided for use by scientific projects, and one additional data channel monitors 32 separate housekeeping functions. The status of each of the data channels, including the states of programmable parameters, is under the control of the DAU. The parameters which can be programmed individually for each data channel include the on/off status, the sampling rate, data resolution, and the signal type, which can be either analog or serial; the command structure is robust, with synchronization bytes and checksum bytes, in order to avoid misinterpretation of messages. The DAU operates autonomously, after instrument channel parameters have been programmed via RS-232 port; the programming needs to be performed only once, and is preserved during power interruption by means of storage in nonvolatile memory. Data and time can be retrieved from the DAU on demand, via the same RS-232 port.

The DAU supports 24 differential analog signals, in the range ±10v, and 12 serial (RS-232 or RS-422) channels. Any of the 31 instrument (experiment) channels can be programmed to use any one of the analog or serial ports. The instrument data can be sampled at 8-bit, 12-bit, or 16-bit resolution, and the sampling interval for any channel can be one of 0.1, 0.2, 0.5, 1, 2, 5, 10, or 60 seconds. Any of the instrument channels using a serial channel can operate in synoptic mode, so that data can be transferred to the DAU at high rate so long as the serial channel's hardware handshaking lines are monitored to regulate the data transfer. In addition to the instrument channels, one housekeeping channel monitors the status of 32 signals from the station environment; all 32 housekeeping channels enter the chassis via a single connector, and are processed using a separate analog board. The instrument serial ports are full-duplex, so an experiment can use a single serial port for two-way communication; the instrument receives timing information and command messages from the DAU, and the same port can be used to return data to the DAU. Each data physical record is identified with the instrument channel, sampling rate, data resolution, and UTC date/time with 0.1 second resolution and millisecond accuracy; for the instrument channels, a logical record is one signal sample, while the housekeeping logical record is a sampling of all 32 channels.

Time is maintained by the DAU software, using a crystal-controlled 10-Hz interrupt. The timing accuracy is kept to within one millisecond, using synchronization with a GPS-based Coordinated Universal Time (UTC) clock. Every 0.1 second, a synchronized ASCII time string is sent to each of the instrument serial ports, containing the date and time to 0.1 second resolution; the time digits are sent with the more rapidly changing numbers appearing earlier in the string, for the benefit of the experiment software.

Although the original AGO DAU has had extensive operating experience in the field, much of the original hardware has become obsolete over the 10-year lifetime of the system, including the STD bus, the 8-MHz single-board-computer, and the Magellan GPS/UTC clock. Some of the components are no longer produced/supported by the original manufacturers, and continued support for others is indefinite. Consequently, the University of Maryland developed a replacement Data Acquisition System (DAS) using modern components.

The DAS incorporates data recording capability using a DOS operating system, IDE hard drive support, and flash RAM recording medium or other non-mechanical mass storage, which can be exchanged quickly, and using a standard IDE interface; the data will be organized in standard FAT32 file structure. In addition, remote data access and instrument communication capability will be implemented using Iridium modems. The DAS can be configured for 24 differential analog channels, and 12 serial channels; the experiment analog boards has 16-bit ADC resolution.

At the time of writing this document, a full Data Acquisition Unit has been developed, interfaced to the Iridium Link and fully tested on the bench. Further testing will be implemented to incorporate the DAU in a full end to end system test with the System Controller Unit.

3.3 ARRO Burst Mode Module

The ARRO Burst Mode Module (BMM) was developed by Stanford University to provide a means to interface instruments with periodic high sampling requirements to the small bandwidth data link available over the Iridium modems.

The Burst Mode Module acquires 16 bit data at high sampling rates, process, buffer, and transmit the data to the DAU over a serial port. Sampling speed is variable on command, but was set at 100ksps for the current version (future software revisions will allow changing software filters on the fly). Due to time constraints, the first unit (Alpha) was sent out to test with the bare minimum features for testing with the whole ARRO system.

3.3.1 System Description

The BMM was designed to sample at high data rates, up to 100khz per channel, store the data locally (on flash memory), process the data into jpeg spectrograms, and transmit the jpegs to the DAU. Sampling at 100khz results in 200k bytes per second per channel, or equivalent to 1.6 megabits per second per channel. This transmitted over (9600 baud) serial to the DAU is around 3 minutes, and over IRIDIUM (2400 baud) amounts to 11 minutes. By processing the data into jpeg spectrograms, a whole minute’s worth of data can be compressed into a 100k byte file. When the PI of a project looks at the spectrograms and finds data that is worth downloading, he/she can specify which portion of data to download.

Furthermore, many other features were to be included. The BMM was designed with a low power state, so that unused components can be put to sleep when not used. This allows the BMM to draw minimal power in the sleep mode. The original specifications of the BMM also called for the ability to track the input, so that data acquisition can be triggered by events defined by the PI. Thus, the BMM would have a terminal mode, where the user can communicate through the DAU and issue commands to the BMM.

3.3.2 Alpha System Implementation

The alpha model of the Burst Mode Module was sent out for testing purposes, and due to major time constraints, most of the wanted features were not implemented. The parts that were implemented were the sampling system and the power control system. The most important part of the new BMM was the design of the buffered sampling system. This system has an 18bit wide by 512 deep FIFO (first in first out) buffer on each channel to buffer data so that at a certain threshold, the DSP is notified of the availability of the data and fetches what is in the buffer. All the logic was provided by a CPLD running at 12.8Mhz. The DSP stores this data in it’s local RAM, and sends out the data to the DAU immediately after sampling is done. Since the alpha unit was sent out, various other systems have been completed and tested. The CF system is now done. The compact flash interface boards have been designed to allow the stacking of multiple cards, with the limit on available power. Each compact flash card is treated as a separate drive, so on failure of a card or file system, the system should be able to recover with the remaining cards intact. The file system is also finished and tested. It is a custom file format that removes all the complexities of a normal file system (FAT, NTFS, etc) by determining file sizes beforehand. There are a few systems that have not been completed yet. The digital trigger is going to be done on the CPLD. Changing sampling rates and FIR filtering on the fly through serial commands has not been implemented. This requires the addition of filter tap files that needs to be uploaded to the DSP file system and read at runtime. The digital input is set up to be either I2C, SPI, or regular asynchronous serial. This feature still needs some work, as it's a bit harder to control. The interface to respond to commands passed on by the DAU was not implemented since the server software is not capable of such a feature. This version of the BMM is currently capable of reading the time off the DAU serial port, wait for the right time to start sampling, acquire data for 1 second, and transmit 1000 words of data per channel (so not to take up the entire bandwidth). After all is finished, the BMM will go into sleep mode. Unfortunately, its not yet achieved the real low power sleep mode yet. When everything is running, the full system run around 5 watts (200mA @ 24V). In the current sleep mode, the system only drops down to 2.4 watts (100mA @ 24V). There can be greater improvements to the power control system, but that will have to wait for the next version. Schematics of the Burst Mode Hardware are detailed in Appendix I.

3.3.3 Enclosure Description

The BMM is currently enclosed in a 19" rack mountable unit. On the front panel, from left to right, is Channel 1, Channel 2, activity LED, and the reset pushbutton. On the back panel, there are three connectors. The black plug on the left is the power plug; pin 1 is 24V (yellow/brown on cable sent), Pin 2 is case ground (blue), and Pin 3 is system ground (brown). The top serial connector (DB9) is for a Null Modem cable. This is the DSP programming port. The DB25 is the straight serial port for hookup with the DAU. In the near future, another BNC will be added for the Digital Trigger, another set of diagnostic LED will sit next to the blue LED, the digital inputs header will be brought out, and a power switch (with fuse) will be installed on the front panel. If there is room, there are provisions for a small LCD screen and keypad for manual selection of modes. The next version of the BMM will be constructed in a smaller chassis. The circuit boards for the system have been dramatically reduced in size. This will allow a large (perhaps 5U) 19" rack to hold several burst mode modules.

3.4 Dartmouth High Frequency Instrument Implementation

ARRO development has included some instrument development specific to the ARRO, required for testing purposes. Initial ARRO test deployment at either a

New England location or in Antarctica would include such a subset of test instruments in order to fully test functionality of the system.

To this end, Dartmouth has put a modest effort into preparing a low-power HF receiver for inclusion in test ARRO units. Engineer Mike Trimpi and graduate student Chris Colpitts at Dartmouth College have participated in this development. This project has also brought Mike Trimpi and his extensive (over 40 years) of Antarctic experience as a consultant to the ARRO development.

For ARRO operation, Dartmouth has modified the design of a 17-antenna phased array operated at Sondrestrom during 1999-2003. The antenna number has been reduced to five and reduced the required experiment power to under 5 Watts. The design modification is complete and a prototype, intended for inclusion in ARRO, is under construction.

Figure 11 shows a block diagram of the ARRO HF receiver. The sensor elements consist of five magnetic loop antennas deployed in an "L" pattern at distances up to 0.5 km from the observatory. The receiver uses three of these antennas at a time, alternating between using the wide separation (approximately 500 m) and using the narrow separation (approximately 50 m), in order to get well-resolved directions of both low-frequency (LF) and high-frequency (HF) waves, respectively. All antennas require active preamplifiers; single coaxial cables provide power to the preamplifiers and return signals to the receiver, thus saving significant cable weight for deployment.

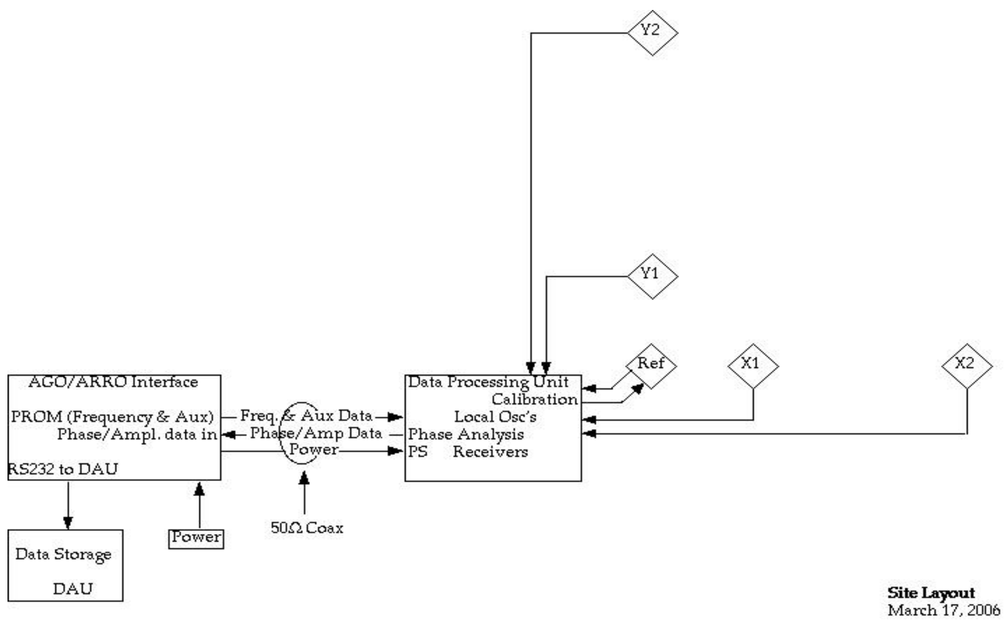


Figure 11

Dartmouth HF Instrument Layout

The main receiver/analyzer electronics, labeled "Data Processing Unit" (DPU) in Figure 11, resides in an unheated vault near the central or "reference" antenna. Analog electronics in the DPU extracts the desired bandwidth of the received signals and determines amplitude and the phase difference between signals received from each pair of antennas. By rapid stepping of the frequency, amplitude and phases are determined as a function of frequency over any desired frequency range from 100-5000 kHz. Frequency resolution is approximately 1 kHz. The amplitude and phases are digitized, formatted into RS-232, and transmitted at 115 kB rate over coaxial cable to the "ARRO interface" electronics which resides inside the ARRO. As in the case of the cables to the antennas, this single coaxial cable provides power to the DPU and transmits the RS-232 signal back to the ARRO.

The final component of the ARRO HF receiver is the interface electronics. This unit accepts the RS-232 data at 115 kB from the DPU and re-formats it to fit the baud rate specified by the ARRO DAU being provided by University of Maryland. This final data rate is completely flexible and depends on the space allocated to the HF data in the ARRO archive. The HF receiver collects data at a uniform high rate and averages the data as required to meet ARRO DAU specifications. Data compression is employed to maximize the scientific output per unit of data storage. The interface electronics also contains the central control of the ARRO HF receiver, which is an EPROM containing a schedule of frequency and bandwidth selections. This EPROM can be readily replaced during summer servicing missions to change experiments. The ARRO interface electronics also include a variety of features to allow on-site diagnosis of instrument function, such as a digital serial port which can be directly connected to a laptop computer to monitor all data at the highest rate, independent of the ARRO DAU, as well as analog data ports.

3.5 Optical Domes

Early on in the design process of the ARRO it was determined that the optical domes required for the imaging instruments would provide a significant portion of the heat loss associated with the enclosure. As a result it was determined that heat loss testing of a “double domed” (a smaller dome nested within a larger) concept was essential.

The plot on the next page summarizes the results of the CRREL cold box tests on the double dome assembled at Dartmouth College in July of 2004. The agreement between the heat loss as modeled (based on handbook data and assumptions) and the measured heat loss is reasonably good. The delta T for both cases is based on surface temperatures rather than the inner and outer air temperatures in an effort to remove the effect of the assumptions made in the model regarding inner and outer skin coefficients. The measured heat loss data are extremely good in terms of fitting a linear trend with delta T.

According to the thermal model developed for ARRO, the double layer dome will lose about 50% less heat than a single 7 inch dome. Even using the double layer domes, the two domes will represent a significant fraction of the heat loss from the shelter. Two of these double domes would generate about 25% of the heat loss of the walls for the larger shelter now being modeled.

Based on calculated values, it was determined that an improvement of 10-15% in dome performance might be realized if the interstitial space between the domes was filled with argon gas, and just a bit more if filled with krypton gas.   Although not implemented for the original design, the gas filled dome option is still an option for future design implementations.

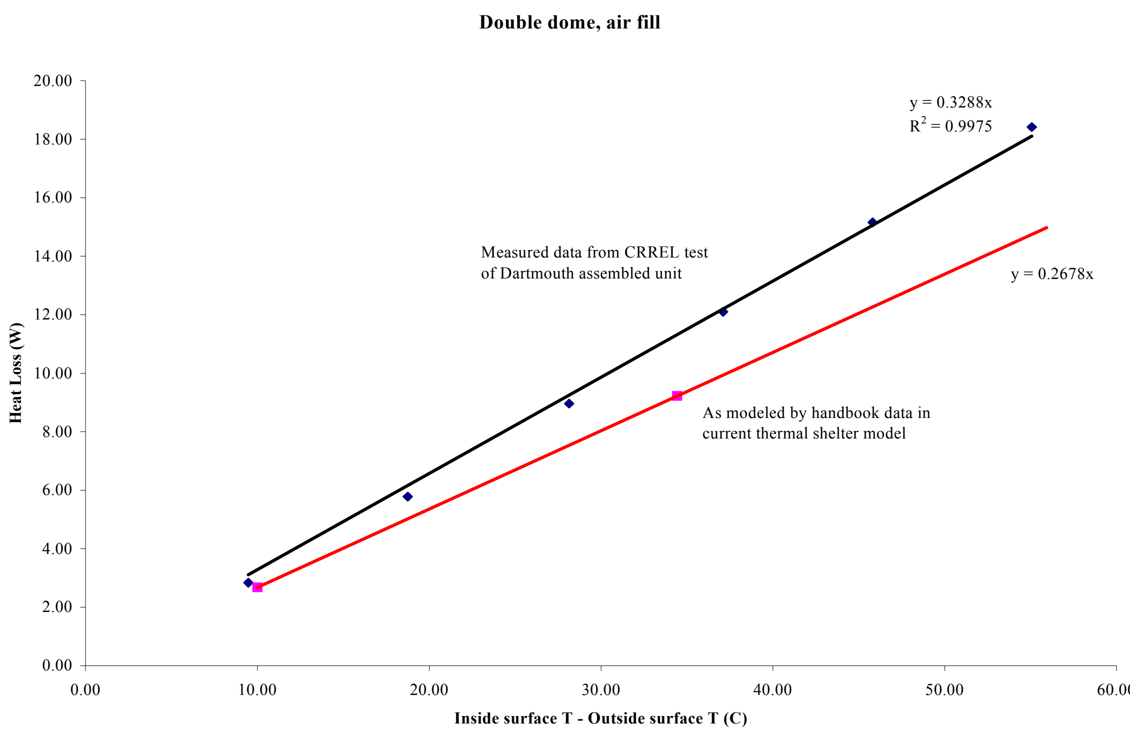


Figure 12

Optical Dome Heat Loss Testing Results

3.6 Battery Selection

With a variety of battery storage devices available to be integrated into the ARRO unit, there was a requirement for an initial analysis to select a battery type for the ARRO system. We were striving for a battery that would maintain its ampacity at low temperatures, maintain freeze tolerance at even lower temperatures, provide a minimal amount of maintenance and a long overall lifetime.

The two most attractive options included a standard Nicad and a gel/lead acid battery. We decided to move forward with the Nicad battery due to its potential freeze tolerance at temperatures below -50 deg C, and more importantly its capability to maintain ampacity at low temperatures. Choosing the manufacturer for the Nicad battery was the next step and many options existed for this decision as well. We settled on the Saft/Sunica Plus series for the following reasons.

1) The manufacturer's capability to produce a modified "arctic" electrolyte that would bring freeze tolerance below -50 deg C. Please note this was an option that was not unique to the Saft series, but at the same time was not available from all selected manufacturers as well.
2) The lines significant field experience. Including a previous successful installation in Antarctica which required batteries to be cold soaked during winter months.
3) The manufacturer's willingness to work with us to prove their specifications at low temperatures.

There were also some potential drawbacks with the Nicad batteries which also needed to be looked at closely before finalizing the decision.

1) Outgassing characteristics: We were designing for an extremely well insulated enclosure that would not allow significant venting. Outgassing rates within the enclosure proved to be a significant concern.
2) Reliability of manufacturers specifications. Even with the previous field installations noted we still needed additional assurance through testing that the battery enclosures would remain intact well below -50 degrees C.
3) AGO experience with Nicads. The AGO team was very helpful with providing information regarding issues with Nicad batteries that they experienced in the recent past. Important issues included
    a. Cold temperature ampacity which was much below manufacturers specifications
    b. Outgassing rates high with "top-off" durations much shorter than required one year increments.

With these issues in mind we began testing the batteries. We used the CRREL small cold chamber to cold soak the battery to prove the mechanical robustness of the battery enclosure at extremely low temperatures. The full test procedure along with digital photos of the test are included in Appendix E of this document.

In addition we were able to obtain specific outgassing rates (based on charge rate and static voltage) for the Saft Sunica batteries directly from the manufacturer. We in turn plugged this data into our simulated model of the enclosure and realized that based on our worst case charge rate of our battery bank, we would be well within ranges of providing proper venting of outgassing.

As an extra precaution we added the capability to charge our battery bank at a voltage slightly lower then the nominal charging voltage associated with 100 percent of possible charging efficiency. Although a slight decrease in charging voltage produces a slight decrease in overall system efficiency, it has a great effect on reducing outgassing rates from the battery bank.

4. ARRO Enclosure Design

4.1 Enclosure design comments and drawings

The final enclosure design was designed and implemented through a the Army Cold Regions Laboratories in Hanover New Hampshire. The enclosure provided a 6'X6'X6' interior working space with 18" polyurethane foam insulated wall panels configured in an overlapping/jigsaw type implementation. This implementation was intended to provide a longer heat path for filtration through panel seams as well as provide increased structurable stability. Details and drawings of the enclosure are provided in Appendix

4.2 Enclosure Testing Procedure

In order to provide a full end to end test of the ARRO design and validate the operational model, a system test was performed in CRREL's Materiel Engineering Facility (MEF) which supports cold tests of large structures and vehicles to -50 °C. The test plan was aggressive due to time constraints on the facility, thus it was determined the best use of the cold room time was to achieve a steady-state condition at a -50 °C exterior temperature and measure the energy load required to maintain an interior temperature of +10 °C. Initially, the interior and exterior of the ARRO were 'cold-soaked' to -50 °C. Three full water jugs (thermal storage) were placed in the shelter and frozen as well. A key component of model validation was comparing the amount of time it took the interior of the shelter and the water to warm to +10 °C.

The ARRO Enclosure was constructed in the MEF at room temperature. Once construction of the structure was complete, two sets of air leakage tests were conducted to measure infiltration losses; one prior to sealing the seams with tape, and a second after all of the joints on the exterior of the structure were sealed with tape to replicate the field-condition of batten-seam strips placed over all of the exterior joints. The goal of measuring infiltration losses was to isolate the amount of 'leakage' due to the panel joints. In order to minimize the impact of infiltration from other potential sources the door joints were taped, the cable penetrations plugged . Results of the “untaped-seam” tests indicated the structure experienced infiltration on the order of that achieved with the best commercial construction practices. Subsequent to taping the panel joints, the instruments were not sensitive enough to capture the magnitude of the losses which translated to the structure being at least an order of magnitude “tighter” than the most efficient commercial structures. The contractor indicated this was the most efficient structure he had ever tested. Note that these results were achieved despite the inability to tape the exterior joints of the bottom panels because they rested on a platform.

Following the infiltration tests a total of 18 thermocouples were placed on the interior walls, exterior walls, within the walls, on water jugs, inside water jugs and on the battery surfaces. It was important to monitor the temperature of all these components to help determine both when all of the elements were ‘cold-soaked’ and when they had achieved steady-state following the warm-up phase. All of the thermocouples were routed through the ARRO’s cable entry ports and then through an instrument passage in the MEF to a data logger located in a warm office space adjacent to the test facility. The thermocouples placed on the interior and exterior wall surfaces and within the ARRO walls allowed us to develop a temperature profile through the wall during testing that we could later compare with our computer model. After instrumentation was installed, the ARRO door was opened and the optical dome plugs were removed from the ceiling in order to promote faster cool-down of the entire structure. A graphical representation of the average MEF temperature, average ARRO air temperature, water jug temperatures and internal wall temperatures of the ARRO during the entire cold-room test is illustrated below

Cooling of the test chamber was initiated at approximately 1200 hrs on 2 September 2005 and following a few shut-downs for maintenance, all of the components reached -50 °C at approximately 1400 hrs on 7 September 2005. At that point the dome plugs were inserted, the door was closed and internal resistive heaters turned-on that ran off the NiCad batteries. The resistive heaters were run for a period of approximately 24 hours as a test to measure the operating performance of both the batteries and the ARRO’s system controllers following a shut-down due to extreme cold. This was the first ‘cold’ test of the system software and controllers and everything performed as expected. Since the heat-generating capacity of the resistive heaters was fairly small, and it was not possible to recharge the batteries (they were disconnected from solar panels and the wind generator for this test), we shut-down the resistive heaters and installed a 3-kW electric fan heater with a control unit to rapidly warm the structure to +10 °C. In the field, the ARRO’s main heat source will be immersion heaters placed in the water jugs. However, due to time constraints for this test, we elected to fill only 3 water jugs and heat the shelter with a fan-type unit rather than the immersion heaters.

As illustrated in Figure 11, the average air temperature inside the ARRO rapidly warmed to approximately +8 °C within 8 hours of switching-on the 3-kW fan heater. By monitoring the thermocouples and energy consumption of the heater, it was noted the shelter achieved a relative steady-state condition at 1200 hrs on 11 September 2005. However, despite exposure to warm air for 4.5-days, the water jugs did not thaw completely during this phase of testing – this further emphasizes the importance of the submersible heating units specified for the shelter when it is deployed in the field. At the culmination of initial warming with the fan heater, the shelter was consuming approximately 430 W of power. It was recognized that the latent heat of ice-water transition was consuming a certain amount of energy, but a visual observation of the jugs indicated only the centers of the jugs were not thawed and the limited available test facility time predicated advancing to the next phase of testing. Prior to this, an infrared camera was used to determine the relative heat losses at the panel joints, door and cable entry ports and determine where efforts to reduce heat losses should be focused.

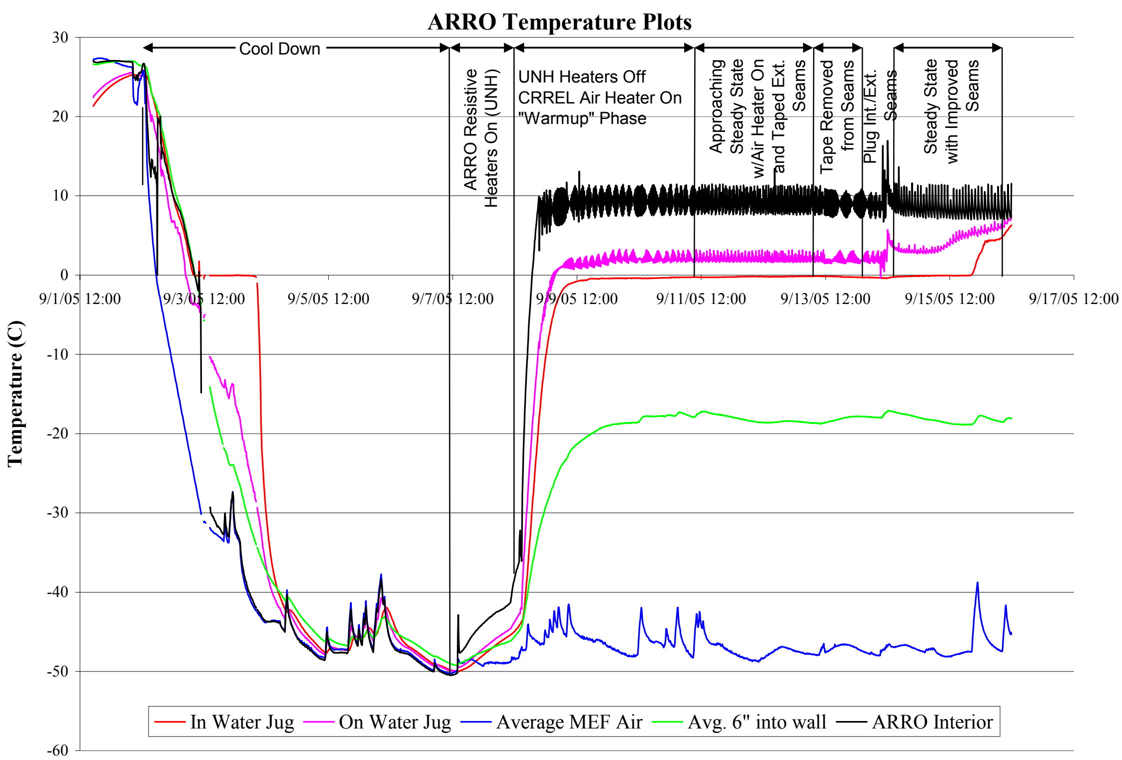


Figure 13

ARRO Full Scale Temperature Test Results

Despite impressive results obtained during the infiltration loss tests, it was clear from the IR camera survey that infiltration at the panel joints was the major source of heat loss for the shelter. Additionally, the thermocouples reported

intense temperature stratification inside the ARRO as there were below-freezing temperatures at the floor (where we were unable to tape the exterior seams) and temperatures in excess of +15 °C at the ceiling. To simultaneously reduce infiltration and limit internal temperature stratification we removed the tape over the exterior panel joints and ‘chinked’ all of the seams with fiberglass insulation. On the interior, we caulked and taped all panel joints we could access. There were a few locations behind the instrument and battery racks that were not accessible on the interior, and we were unable to fill the bottom panel joints with insulation on the exterior for the same reason we could not tape them during the blower door tests.
Upon completion of the mitigation measures we closed the ARRO door and let the shelter operate from 1600 on 14 September 2005 to 1100 on 16 September 2005. Referencing Figure 3 we see that the heater cycled significantly fewer times than during the previous tests, the water jugs completely melted and all interior temperatures were approaching +9 °C. Most importantly, the shelter was consuming slightly less than 200-W of power. Thus, the relatively simple panel joint improvements cut the energy requirements by more than half which brought it close to the average heat loss of approximately 160 W that our model predicted for the 1992 calendar year when the average ambient was -50.6 °C.

4.3 ARRO Testing Conclusions

Our experience evaluating remote instrument shelter design alternatives with our thermal model was proven to be extremely useful. The characteristics of the wind turbine, particularly at low wind speed, have been shown to be of paramount importance. Use of water as a thermal storage material, particularly latent heat, was shown to be very beneficial.

Full scale tests of the ARRO in a refrigerated cold room at approximately -50 °C illustrated the importance of reducing infiltration losses while simultaneously validating many design features of the ARRO, such as the door and instrumentation cable access ports. The use of infrared thermography was instrumental in guiding our efforts to reduce heat loss. The ultimate v heat loss values obtained during the test exceeded our model prediction by approximately 25%; an amount we are very comfortable with given the remaining infiltration issues we were unable to address in the test, and the dissimilarities between the tested and modeled condition. Thus, the testing provided an approximate validation of our thermal model, and proved to have significant economical advantages over full-scale testing while allowing for custom design of ARRO’s to any location with sufficient historical environmental data.

4.4 The Need for Testing at Wais Divide

While the freezer tests described above have provided important information, more realistic tests, of course, are needed. Testing at the Wais Divide provides a location where the enclosure will be situated in a severe environment, although the temperatures will not be as cold as desired for testing, nor will the winds be as moderate as those higher on the plateau. Given the logistical situation with the South Pole, however, tests at the Wais Divide will have to suffice.

An additional and very important reason for testing at the Wais Divide is that it feeds directly into the upcoming PENGUIn proposal. At a recent PENGUIn team meeting, the team agreed that targeting magnetospheric substorms would be a key component of the proposed research. To a large degree, this is intended to coincide with the upcoming launch of the Themis satellite with this objective.

The very special opportunity provided by the Wais Divide location is that, by pure chance, it is located within ~200 kms of the magnetic footprint of the eastern GOES satellite, a geosynchronous satellite routinely used to monitor aspects of substorms. In addition, the footprint of this sattelite in the northern hemispheres maps precisely to Post de la Baleine (PBQ) in Canada. Here, Natural Resources Canada (NRCan) has a fluxgate magnetometer already in place and, in addition, a group of Canadian scientists have agreed to provide additional instrumentation in support of the PENGUIn project (details will be provided in the PENGUIn proposal). For the first time ever, similar instruments will be at opposite ends of the same magnetic field line, backed up with a geosynchronous satellite to provide in-situ data. This situation has never been achieved before. When one considers that the Themis satellite will also be in orbit (over this region) to study substorms, it becomes clear that the science potential for this configuration is incredibly unique.

It is for these reasons that deploying an ARRO to the Wais Divide is highly desirable.

5. ARRO Deployment

5.1 Deployment Options

The original proposal emphasized the importance of being able to deploy the ARROs with a Twin Otter. This was in response to a situation where the LC-130 aircraft were not able to fully support the annual logistical needs for OPP, noting that the BAS AGOs had been successfully deployed using Twin Otters.

The final ARRO design complies with this constraint for all subsystems and components needed for an installation. The enclosure design has been particularly challenging but is modular such that each section is small enough to fit on the aircraft, based on drawings and other information provided by Ken Borek Ltd.

On the other hand, the disadvantage of using a Twin Otter for deployment is that several flights are likely required. Installation of the BAS AGOs required between 7 and 11 flights, depending on the site location. We expect that the ARROs would require similar resources, based on our estimates of possible payload arrangements.

At the same time, it has become clear that the best possible design is one that accomodates deployments using any combination of Twin Otters, LC-130, land traverse and/or partial air drop. Unfortunately, the first ARRO enclosure was designed with only Twin Otter deployments in mind and is slightly too large to fit on an LC-130 as an assembled enclosure (the original design is 9x9x9 ft). However, future enclosures will be sized (8x8x8 ft) so that they will fit on an LC-130 fully assembled. This approach means that an enclosure can be fully assembled at McMurdo, reducing the time required in the field significantly. The same is true if the enclosures can be delivered using a traverse, of course. Another possibility is that sections of the enclosure may be air dropped to remote sites, reducing the number of Twin Otter flights, although this idea needs some discussion to make sure the enclosure sections would not be damaged. Every effort is being made to minimize the impact on OPP logisitics with regard to the deployment of ARRO enclosures.

5.2 Expected Deployment Procedure

The initial installation procedure for the ARRO system was developed with the assumption that a four person team would be available for deployment. In developing the procedure an emphasis was made on performing as many parallel tasks as possible to maximize efficiency and minimize the amount of time needed on the ice.

The procedure included tasks such as melting snow on site for filling water jugs, implementation of a full end to end test on site along with proper analysis of data, and full erection of the HR3 wind generator (with minimal powered machinery requirements beyond a snowmobile for transportion of parts on site). A full schedule and description of the installation procedure is provided in Appendix A of this document. Specific installation procedures are detailed in

6. ARRO Wind Turbine Deicing

6.1 ARRO Wind Turbine Deicing Concept

In environments that are wet as well as cold-such as certain areas of Antarctica-ice can build up on outdoor structures including antennas, communication equipment, and wind turbines. A turbine in an iced environment can expect a power loss of as much as thirty percent when compared to a turbine in ideal conditions (Tammelin et al., 2001). Based on the same study, ice can also affect wind resource estimates due to icing on anemometers. Besides Antarctica, icing has also been shown to be problematic in coastal and northern areas of Canada, as well as in the northern United States. Testing done with a small horizontal axis turbine in coastal Newfoundland shows that icing can cause up to an 80 % blade volume increase, significantly altering the aerodynamic performance of the turbine and seriously degrading the operational efficiency (Bose et al., 1992).

Some deicing techniques that have been considered for wind turbine use are pneumatic boots or flaps, freezing point depressant systems, electro-magnetic impulse deicing methods, and electrothermal systems. Due to various reasons such as efficiency, practicality, cost, and safety concerns, none of these technologies are considered viable options for wind turbine deicing. A wind turbine deicing prototype has been created based on the patented pulse electro-thermal deicing (PETD) process developed by Professor Victor Petrenko's group. The PETD process, if designed properly, does not impair the aerodynamics of the turbine or add additional stresses to the mechanical components. Neither does it create negative environmental impact nor use great amounts of energy.

The pulse electro-thermal deicing process relies, as its name suggests, on both electrical and thermal properties of the materials in the system. An electrically conductive layer is applied uniformly to a surface. When needed, a short, high-power pulse of electricity creates enough heat to melt a very thin layer of interfacial ice. This layer of melt-water allows the ice to slide off of the surface. Because the pulse is so short, and because the system is normally operated only when icing has occurred, the PETD method uses far less power than the other kind of electrothermal heating (i.e., resistive heating). Additionally, because the pulse is very quick, no energy is wasted heating either the air or the bulk of the ice and snow; the short pulse creates a melt layer before the heat can dissipate to the surroundings and only the interfacial ice is melted. The pulse electro-thermal deicing process has been patented by Professor Victor Petrenko and his research group at Dartmouth College.

The prototype turbine PETD system was designed and tested using the Rutland Windcharger. The Windcharger is very small wind unit of the type commonly referred to as a micro turbine. Brian Lawson of the University of Alaska Fairbanks has used Rutland wind turbines in isolated and frozen areas of central Alaska, and was able to describe how the unit reacts to icing. Additionally, he has expressed interest in further testing of the deicing prototype at repeater sites in central Alaska.

The three main systems of the PETD wind turbine deicer are the deicing surface on the blades (the blade radio controls that determine which blade pair is deiced as well as the length of the pulse. The blade heaters are made of double-sided flexible printed circuit material, with a trace etched into the copper on the inner surface (against the blade) to provide the desired resistance, and solid copper on the outer surface (exposed to the air and ice) to allow the ice to slip off easily.

Power transfer is accomplished by inductive coupling, with the energy stored in a bank of ultracapacitors mounted on the face of the rotor.

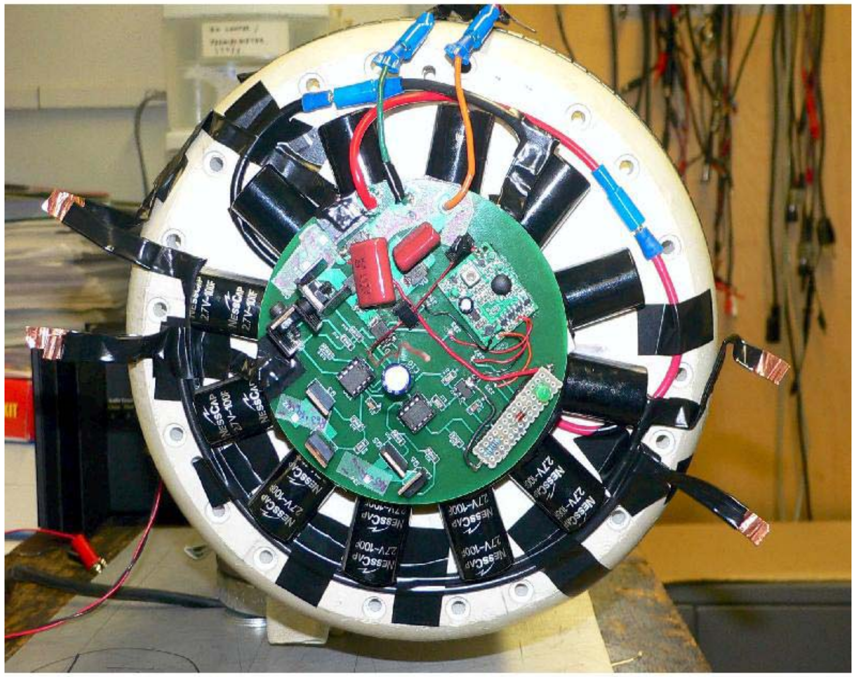


Figure 14

ARRO Deicing System: Front View

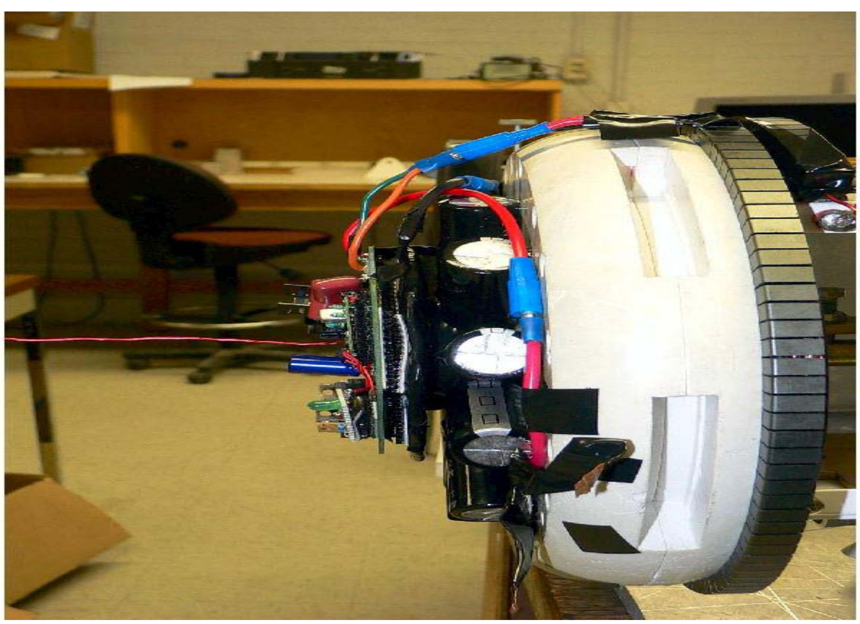


Figure 11

ARRO Deicing System: Side View

6.1 Testing Results.

The prototype development of a pulse electro-thermal wind turbine deicer has been successful. Although the system does not work perfectly (the current system does not provide enough power to deice both blades in a pair), the concept has been adequately demonstrated. The use of inductive coupling for contactless power transfer has been shown to be highly effective. The chosen deicing surface provides both an even distribution of heat and an accurate resistance, and the use of radio signals to control the pulse makes the deicer easy to operate. The wind turbine deicer works with both simple ice and heavy rime ice accumulation, and the smooth deicing surfaces make it easy for the ice to slip off of the blades.

The PETD technology is well-suited to wind turbine deicing, and could work well both for use in the ARRO project, in Brian Lawson's Alaskan project and, with more extensive development, for utility-grade turbines through out the cold climates. The system as currently designed would need more energy storage capability on the rotor before it would be fully functional in Alaska or at an ARRO site in Antarctica-especially if it were to work at temperatures lower than -6 C. The prototype deicer lends itself well to this type of after-market use, and with a few modifications could be adapted for easy installation on the Rutland units already in operation.

7. Presentations and publications

Phetteplace, G., and J. Weale, "Thermal Design of an Autonomous Instrument Shelter for Remote Antarctica", submitted to the International Conference on Cold Climate HVAC in Moscow, Russia, 21-24 May 2006.

Weale, J. C. and G. E. Phetteplace, "Design, Construction and testing of an Autonomous Instrument Shelter for Remote Antarctica", submitted to ASCE International Conference on Cold Regions Engineering, 23-26 July 2006, Orono, ME.

Plagge, A. M., "Pulse Electro-thermal Deicing of Wind Turbine Blades", MS Thesis, 2005, Thayer School of Engineering at Dartmouth College.

Lessard, M. R., P. Riley, D. Rau, H. Kim, J. LaBelle, A. Plagge, M. Trimpi, T. Rosenberg, D. Detrick, U. Inan, J. Chang, J. Weale, G. Phetteplace, J. Buska, K. Bjella, and K. Rancourt, "The Autonomous Real-time Remote Observatory (ARRO)", presented at International Association of Geomagnetism and Aeronomy, Toulouse, France, 2005.

Plagge, A., M. R. Lessard, J. W. LaBelle, T. Rosenberg, U. Inan, G. Blaisdell, and K. Rancourt, "The Autonomous Real-time Remote Observatory (ARRO)", presented at the 2003 Fall AGU meeting.

APPENDIX A

SYSTEM SPECIFICATIONS AND SCHEDULE OVERVIEW

The following appendix contains the following documentation:

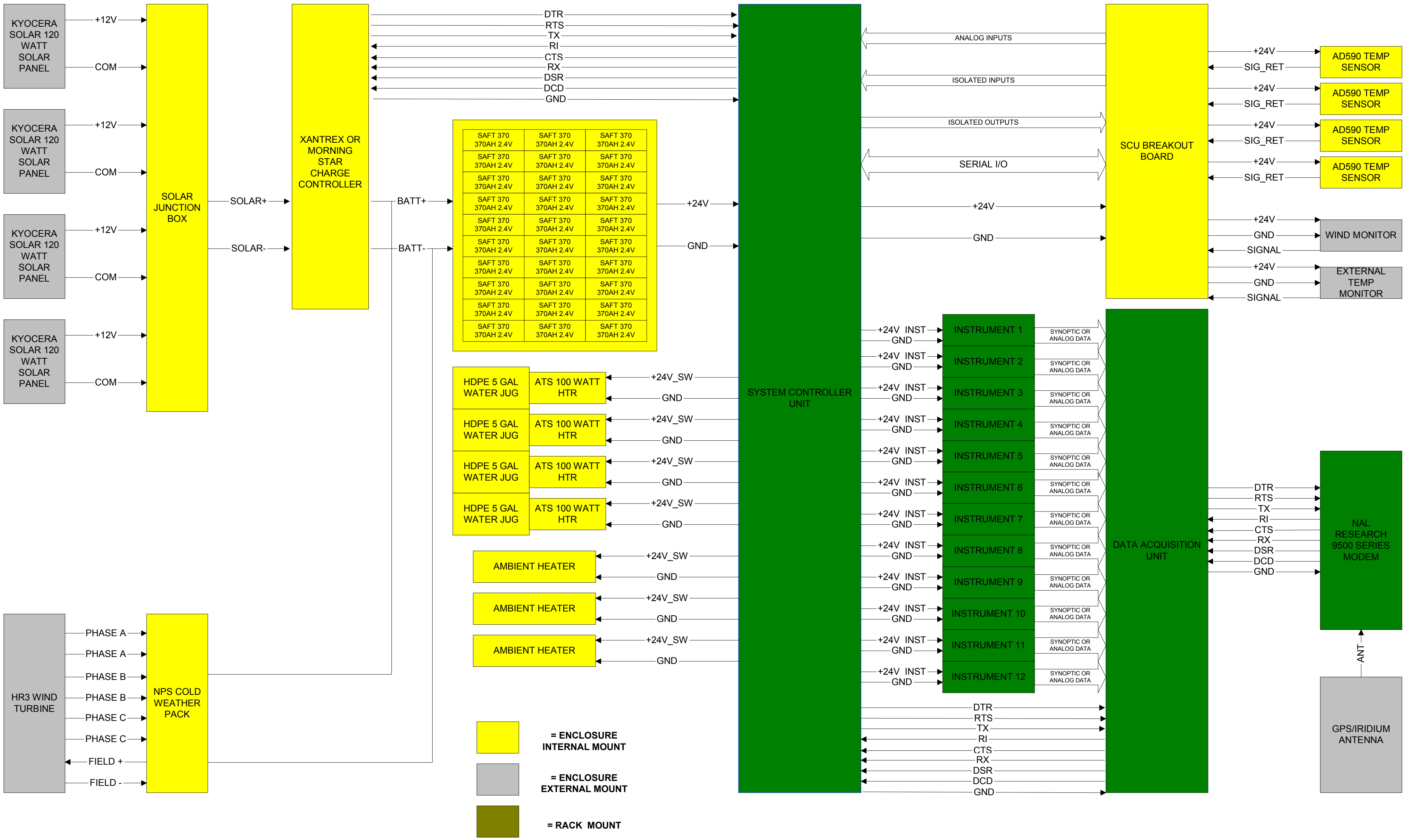
1) An overall block diagram of the internal hardware for the ARRO System

2) The original Functional Specification written for the ARRO System

3) The proposed schedule and task list for the ARRO deployment for South Pole 2005/2006

4) The modified schedule for WAIS Divide deployment in 2006/2007

ARRO ENCLOSURE WIRING DIAGRAM REV 01



ARRO FUNCTIONAL SPECIFICATION

DARTMOUTH COLLEGE

May 26, 2003

REVISION 02

ARRO Functional Specification
Rev 02

1. Overview

The Autunomous Real-time Remote Observatory (ARRO) will be designed to support the housing and data acquisition of several independent instruments that will share a total of 50 Watts of dedicated power for instrumentation and acquisition/control electronics. The ARRO will be designed to be installed on the Antarctic Plateau where temperatures can range from -94 degrees Farenheit in the winter to up to 23 degrees Farenheit in the summer. Additional considerations will be made to support installations in Arctic locations.

The ARRO system will be transported to its site using Twin Otters planes only. Special design considerations should be made to minimize the amount of transport trips required. The system must be able to accommodate snow drifting of 12 inches of snow per year or more. This will most likely drive the enclosure to be built on stilts with the capability of lifting the enclosure during servicing periods.

The ARRO will incorporate a power system that will supply the 50 watt power as well as any additional power needed to heat the observatories enclosure to a minimum of 32 degrees F and a maximum of 94 degrees F. The power system will incorporate the use of both a wind turbine as well as multiple solar panels at determined locations on the side of the enclosure. The power system should be able support continuous operation through a minimum of 11 days without solar or wind power.

The ARRO system will be designed to support a total of 31 configurable data channels dedicated to instrument data acquisition. An example of the type of instrumentation currently implemented is shown in the table below. This table details the instrumentation, channel allocation and sampling rates associated with AGO Site 1.

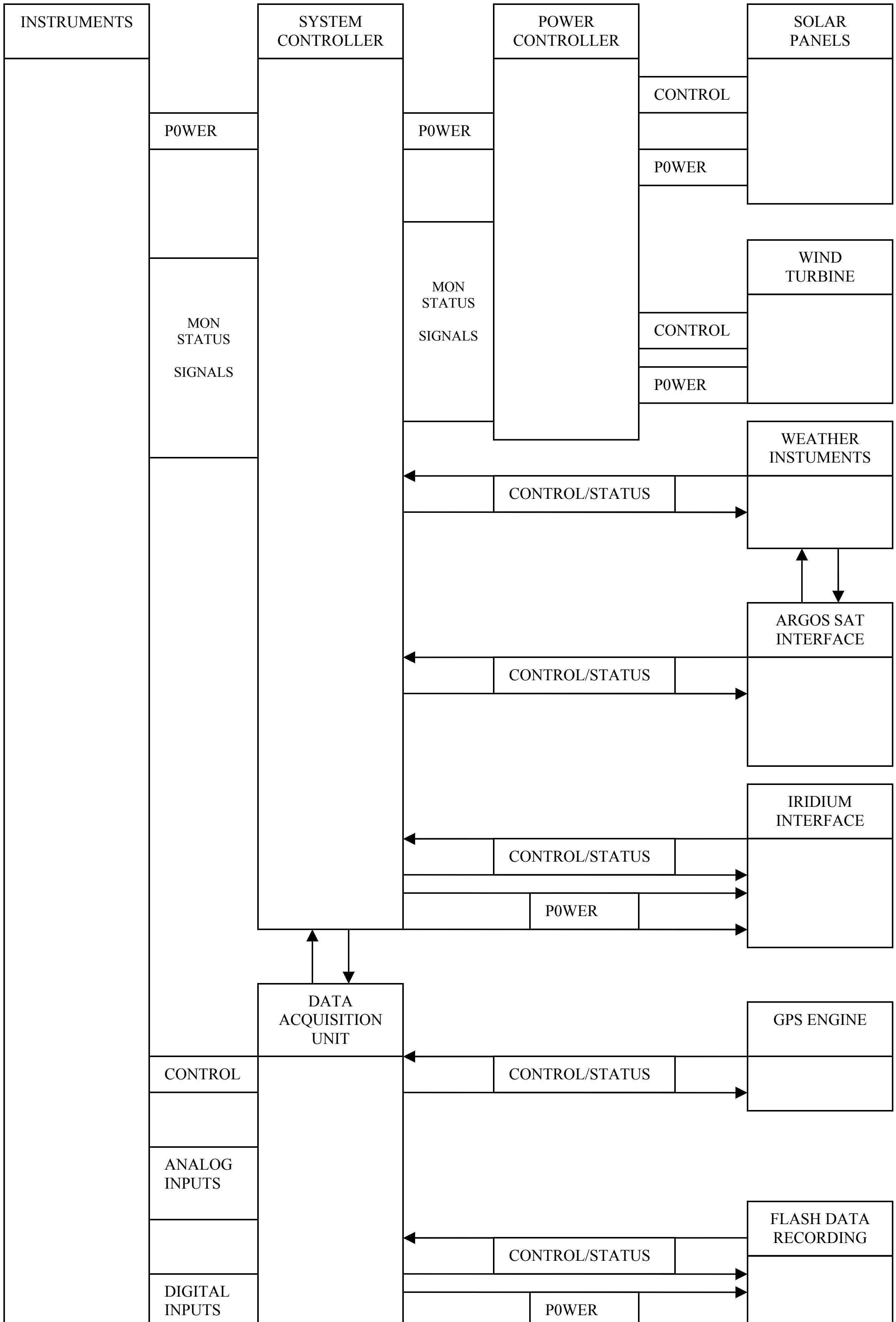
AGO Site 1: Science Instrumentation

Instrument	Owner	Channel	Sampling Rate
Housekeeping	N/A	Single Channel	1 min
Imaging Riometer	University of Maryland	Single Channel	Synoptic
Searchcoil Magnetometer	Tohoku University	X Direction	0.1 sec
Searchcoil Magnetometer	Tohoku University	Y Direction	0.1 sec
Searchcoil Magnetometer	Tohoku University	Z Direction	0.1 sec
Fluxgate Magnetometer	Bell Labs	Fluxgate H	1 sec
Fluxgate Magnetometer	Bell Labs	Fluxgate D	1 sec
Fluxgate Magnetometer	Bell Labs	Fluxgate Z	1 sec

VLF Radiowave Receiver	Stanford U	.5-1KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	1-2KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	2-4KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	4-8KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	8-16KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	16-32KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	30-40KHZ	0.5 sec
VLF Radiowave Receiver	Stanford U	SNAPSHOT	Synoptic
VLF Radiowave Receiver	Stanford U	BEACON1	0.5 sec
VLF Radiowave Receiver	Stanford U	BEACON2	0.5 sec
VLF Radiowave Receiver	Stanford U	2-4KHZ E-W	0.5 sec
VLF Radiowave Receiver	Stanford U	NAA 24KHZ	0.5 sec
All-sky Camera	University of California	Single Channel	Synoptic
LF/HF Receiver	Dartmouth	Single Channel	Synoptic

1.1 ARRO Controller Units

There will be separate controller subsystems within the ARRO acquisition/control system. All subsystems will be installed in separate chassis contained within a standard 19 inch rack. A block diagram is provided in below and the sections to follow detail the components of the each subsystem


INSTRUMENTS
SYSTEM CONTROLLER
POWER CONTROLLER
SOLAR PANELS
CONTROL
P0WER
P0WER
P0WER
WIND TURBINE
MON STATUS
SIGNALS
MON STATUS
SIGNALS
CONTROL
P0WER
WEATHER INSTUMENTS
CONTROL/STATUS
ARGOS SAT INTERFACE
CONTROL/STATUS
IRIDIUM INTERFACE
CONTROL/STATUS
P0WER
DATA ACQUISITION UNIT
GPS ENGINE
CONTROL
CONTROL/STATUS
ANALOG INPUTS
FLASH DATA RECORDING
CONTROL/STATUS
DIGITAL INPUTS
P0WER

1.2 Data Acquisition Unit

1.2.1 Instumentation Channels

The ARRO Data Acquisition Unit (DAU) will support acquisition and digitization of all instrumentation analog input signals, as well as providing a digital interface for instrument serial inputs .

A total of 36 Data Channels will be supported. 12 of these channels will be dedicated Serial I/O channels while 24 are dedicated Analog Data Channels.

Serial Data Channels: The Serial Data Channels will implement a standard UART type interface using 8 bit data , 1 stop bit, no parity. Full modem handshaking will be supporting. Each port will be capable of being configured to either RS232 or RS422 signalling. The baud rate of each port will be set at 9600 baud. Each serial input will be brought into the box using a standard DB9 female DCE configuration allowing a straight connection to a PC or laptop. The serial ports will provide the means to allow either the System Controller Unit or the DAU to send status/control messages to the instrumentation. In addition all serial/synoptic data from the instruments shall be transmitted over these channels

Analog Data Channels: Each Analog Data Channel will be accepted differential at a +/-10V range. The sampling range will be configurable from 1Khz?? to 1 sample per 60 seconds. The ADC resolution of each input will be 12 bits. Each analog input will be brought in on a (connector and pinout TBD)

1.2.2 Burst Mode Capability

There will be dedicated hardware in the system to support a time dependent “Burst Mode” capability. Considerations should be made to develop the design in a modular fashion such that Burst Mode hardware will lie in series between a single instrumentation output and a single synoptic channel on the DAU. As a result up to 12 Burst Mode “cards” will be supported by the ARRO system. A single Burst Mode card will provide a single analog input, a single serial output, and an external trigger option. The analog input should provide a high impedance +/-10V input similar to the DAU analog inputs. The Burst Mode Card will also provide the capability of triggering its high sample rate off of a programmed threshold associated with the instrument input. In addition provisions to provide specified “burst” intervals should be configurable. The following trigger options should be capable of being programmed over the serial port.

1) External rising edge trigger
2) External falling edge trigger
3) External toggle of state
4) Instrument input integrated threshold
5) Instrument input peak level threshold
6) Time interval/counter

The Burst Mode card's sampling rate (both in burst mode and non-burst mode states) shall also be capable of being programmed over the serial interface.

The DAU serial port should treat a Burst Mode card connection as if it were any other synoptic type instrument channel. As a result the Burst Mode card will provide support for all digitization and serialization needed to interface to the serial port at 9600 baud. The port on the card will support the modem handshaking interface to the DAU serial port.

In addition to the digitization and serialization, the Burst Mode card will have to provide all necessary data buffering to support the limited bandwidth of the Iridium satellite link. Special care should be taken to develop a memory sizing based on a "worst case scenario" where each DAU serial port is connected to a Burst Mode Card operating at its maximum sampling rate. To ease the total of amount of memory installed for a particular configuration (and reduce cost), the design should allow memory upgrade/downgrade capability by placing the buffer memory in sockets (ie DIMMS).

1.2.3 Non Volatile Data Storage

The DAU will support a specified amount of Non-Volatile data storage dedicated to instrumentation data storage. This will be accomplished using a compact flash recording medium. A standardized data recording interface (IDE) will interface the compact flash device to the DAU's processor. Current technology allows for up to 21GB of storage which will accommodate approximately 3 years of satellite data transmissions.

1.2.4 Timing outputs:

All DAU acquisition timing will be synchronized to an onboard GPS receiver. Acquisition clocks will be created using associated frequency dividers locked to the accurate 1PPS (one pulse per second) clock originating from the receiver. A subset of these divided clocks will be brought out to connectors on the DAU chassis to make available to instruments/future implementations. Included in this subset will be the 1PPS signal itself, a 1Khz clock and a 1Mhz clock. In addition to the sync clock outputs, each serial port will also send a timing string out each of the serial ports that will contain time/date information.

1.2.5 Iridium Satellite Interface

The DAU will provide the interface to the Iridium modem used for satellite data transmissions. It will also provide satellite health information from the modem to the SCU. The Iridium interface signals will be sent to the SCU where a "clear pass" through configurable logic will be implemented prior to being output to a DB9 connector. The pass through the configurable logic at the SCU will provide the means to buffer and route to multiple Iridium modem interfaces in future implementations.

1.3 System Controller Unit

The System Controller Unit (SCU) will be responsible for monitoring and control of the system as a whole. This includes functionality such as monitoring system voltages, providing a pass through interface to the Iridium satellite modem, and controlling internal environmental conditions. The following sections detail the functionality of the SCU.

1.3.1 System Monitor Voltages

There will be a large effort to incorporate a large amount of housekeeping monitoring in the hopes of being able provide as much system information as possible over the satellite link. A list of general housekeeping monitors, along with monitors specific to each instrument is presented below.

General Housekeeping Monitors

SIGNAL	SOURCE	DESTINATION	TYPE	DESCRIPTION
Bat_Temp1	Battery String Location 1	SCU Input Connector	Analog	Battery temperature monitor 1
Bat_Temp2	Battery String Location 2	SCU Input Connector	Analog	Battery temperature monitor 2
Bat_Temp3	Battery String Location 3	SCU Input Connector	Analog	Battery temperature monitor 3
Bat_Temp4	Battery String Location 4	SCU Input Connector	Analog	Battery temperature monitor 4
Bat_Voltage	SCU	SCU (Internal)	Analog	Battery Voltage
Overall Charge Current	PCU	PCU to SCU via serial port	Serial	Overall current used to charge battery bank
Solar Panel Current	PCU	PCU to SCU via serial port	Serial	Solar Current measurement via small resistive shunt
Wind Turbine Current	PCU	PCU to SCU via serial port	Serial	Wind Turbine measurement via small resistive shunt

Solar Voltage	Solar Panel	PCU to SCU via serial port	Serial	Post-regulated solar panel voltage
Wind_Voltage	Wind Turbine	PCU to SCU via serial port	Serial	Post-regulated wind turbine voltage
Wind Turbine Rotations	Wind Turbine	PCU to SCU via serial port	Serial	Measure of the total number or rotations the blades on the wind turbine
Humitity_Int	Enclosure Interior	SCU Input Connector	Analog	Interior humidity measurement
Sys_Temp1	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp2	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp3	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp4	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp5	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp6	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp7	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Sys_Temp8	Enclosure Interior	SCU Input Connector	Analog	Internal Temperature Monitor
Snow Height	Exterior	SCU Input Connector	Analog	Measurement of snow depth looking down from bottom of enclosure
Wind Speed	Exterior	SCU Input Connector	Analog	Outside Wind Speed
Wind Direction	Exterior	SCU Input Connector	Analog	Outside Wind direction
Air Temperature	Exterior	SCU Input Connector	Analog	Outside Air Temperature
Bar_Pressure	Exterior	SCU Input Connector	Analog	Outside Barometric Pressure
Humidity	Exterior	SCU Input Connector	Analog	Outside Relative Humidity
Satellite Carrier	Sat_Modem	Satellite Modem to SCU via serial port	Discrete	Bit indicating if modems receiver is locked and has carrier
VSWR	Sat_Modem	Satellite Modem to SCU via serial port	Analog	Analog VSWR indicating reflected transmit strength. Used to indicate short/open antenna or proper termination.
Receive_SNR	Sat_Modem	Satellite Modem to SCU	Analog	Analog signal indicating signal to noise ratio of received signal
VCC_SAT	Sat_Modem	SCU	Analog	Supply Voltage at Satellite Modem
VCC_ANT	Sat_Modem	SCU	Analog	Supply Voltage Output to Antenna (assuming active)

Instrument Monitoring

The following monitor signals are associated with each of the 16 possible installed instruments.

SIGNAL	MEASURED	DESTINATION	TYPE	DESCRIPTION
Peak Current	SCU	SCU	Analog	Instrument Peak Current Monitor. Reset after each read
Integrated Current	SCU	SCU	Analog	Integrated current used for power consumption estimates
Current Limit	SCU	SCU	Analog	Controller registered value for instruments current limit
ON/OFF State	SCU	SCU	Discrete	Controller registered value for ON/OFF state
Over Current	SCU	SCU	Discrete	Instruments overcurrent monitor
Voltage_CB	SCU	SCU	Analog	Voltage applied to instrument after circuit breaker/fuse
Voltage	SCU	SCU	Analog	Voltage applied to instrument prior to circuit breaker/fuse

Each monitor input will be resistor divided to a 0 to 5V range and digitized to a 12 bit resolution. Each input will be received differential and low pass filtered at the SCU. The frequency of status reports of the general monitor signals will be configurable.

1.3.2 Temperature Control

The SCU will monitor the up to 12 temperature sensors placed throughout the enclosure. Through the monitoring of these signals, the SCU will provide a set amount of temperature control of associated resistive heating elements. The SCU will inform the PCU via its shared serial port to divert current to specific heaters. The PCU will then divert access current to the heaters if it is available.

The nominal system wide temperature will be 32 degrees Farenheit. Due to the fact that there will be independent control of multiple resistive heat elements, the potential exists to produce defined temperature gradients within the enclosure. For example it may be advantageous to control heaters closer to instrumentation at a higher temperature than the batteries.

Nominal temperature values associated with each heating element will be software configurable. There will be a significant amount of attention paid to detecting faulty temperature monitors and adjusting accordingly, to avoid over/under heating.

1.3.3 Power Distribution and Control

Each instrument will be provided 28VDC. The 28VDC will be controlled and current limited through the System Controller. In the event an instrument exceeds its specified current limit for a specified period, the instrument will have power switched off and a notification message will be sent over the satellite link.

All instrument power will be isolated from the main power bus using DC to DC converters. All instrument and electronics box chassis will be referenced to Surface Ground (ie electrically connected to stilts on the ARRO box which are driven into the ice).

1.3.4 Power Control

Power for the ARRO system will be supplied by a combination of Solar Panels and a Wind Turbine source. During "dark" months with limited or no sunlight, the Wind Turbine will provide the majority of power for the system. During "light" months with little or no darkness, the Solar Panels will provide the majority of power.

The power system will be designed to provide a continuous 50 watts of power. If for some reason the power system is unable to source the required instrumentation power, the system controller will introduce a succession of low power modes to compensate for the reduced supply. These modes will also have the potential to be activated if the interior ever passed a particular temperature threshold associated with overheating. The following details the levels of power control options

1) Level 1: Sleep Mode

Place sleep capable instruments into sleep/wakeup mode.
This mode reduces power by removing power from it between sample periods.

The System Controller will contain a non-volatile register for each instrumentation channel that corresponds to the time period needed for that particular instrument to power up and stabilize. Through synchronization with the DAU, the System Controller will wake up the unit at a specified time prior to sampling (corresponding to the powerup/stabilize register). The DAU will then sample the data and immediately put the instrument back to sleep to conserve power. This process repeats every sampling period

2) Level 2: Satellite Link Power Down

Powerdown RF Iridium modem. Data will be continue to be logged in Flash memory yet the real time satellite link will be disabled. Satellite modem could be powered up at specified intervals to transmit status.

3) Level 3: Data Drop

Sampling period of instrumentation is reduced in increments. Priority algorithm associated with which instruments reduces first and by how much will be configurable. Sample rates will continue to drop until a specified rate.

4) Level 4: Instrument Power Down

Begin powering down instruments for specified intervals. Length of interval increases until power stabilizes or if a particular interval is reached where each instrument is permanently shut down until power is restored.

1.3.5 Cold Soak condition

The SCU and DAU shall be able to recover gracefully when power is removed from the system and should also be able to sustain an extended shutdown period when temperatures dip well below operating temperature.

Once power has been removed from the period for a specified period of time and the above Level 4 Instrument Power Down state has been reached where all instruments are powered down, the SCU will divert all its unused power to the resistive heaters. The SCU will then monitor the temperature sensors. If the temperature continues to drop beyond a specified threshold, it will send a command to the DAU to indicate that it will need to power its supply down..

Once this command is sent, the DAU will begin a controlled shutdown. As part of this controlled shutdown process, any queued data stored for transmission over the Iridium Link will be written to compact flash. Once the DAU finishes its controlled powerdown it will send a message back to the SCU to indicate it is OK to remove power.

Once power is removed from the DAU the SCU will continue to monitor the temperature sensors. If a second, lower threshold is reached (one that approaches the minimum operating temperature of the SCU electronics), the SCU will send a message to the Power Control Unit over a shared serial port indicating its interface will shortly be unreliable. The SCU will then go through a controlled shutdown process.

The SCU's power will only be supplied again via an indication from the Power Control Unit that it can supply power to the SCU and DAU.

1.4 Power Control Unit

1.4.1 Solar/Wind Control

The Power Control Unit (PCU) will be responsible for all control of the power interface between the Wind Turbine and the Solar Panels. It will incorporate all regulation and filtering associated with providing the SCU with a clean 28 Volt rail capable of supplying a continuous 50 Watts.

1.4.2 Battery Control

The PCU will also provide all necessary control associated with charging the battery bank. Careful attention will be made to prevent overcharging of the batteries as well as charging the batteries at a rate to help maximize their lifetime.

1.4.3 System Controller Interface

The PCU will provide an interface to the SCU via a standard UART connection. The following status information monitored by the SCU shall be transferred over this link.

1) Integrated Wind Turbine Current produced
2) Integrated Solar Panel Current produced
3) Post regulated Wind Turbine Voltage
4) Post regulated Solar Panel Voltage
5) Overall Battery Charging current
6) Total Wind Turbine Blade Rotations

In addition to providing status information, the PCU shall be able to decode a series of defined messages from the SCU to be determined later.

2 Iridium Satellite Link

The ARRO system will be designed to communicate full duplex over the Iridium satellite link. The unit will initially operate with a single unit but provisions will be made to allow up to six Iridium Modems to operate in parallel.

The units will be designed to communicate point to point (Iridium modem to Iridium modem) with data received by a matching Iridium modem located at a central location (location TBD). Data will be recorded to a central database allowing flexible access to both health and instrumentation data.

The modem will communicate at rate of 2400 Baud.

2.1 Iridium Modem

The modem used to provide an interface to the Satellite link will be the NAL research model A3LA-I (six channel version TBD). The unit operates off of 5 volts and is rated down to -30 degrees Celsius. The unit is designed to accept standard AT commands for its Host interface and offers a standard DB9 DTE serial port connector. The serial port will communicate at satellites 2400 Baud Rate but can be configured to communicate at a higher rate. The RF interface presents standard a standard TNC connector for its output

2.1.1 Antenna

The Motorola SAF5350 will be used for the systems Antenna. The antenna accepts a TNC input and has a base diameter of approximately 3.25” and a height of 5”

2.1.2 Antenna Cable

The connection between the modem and the antenna will be to TNC, 50 ohm?, Teflon?, coaxial cable assembly.

3 Wind Turbine

The ARRO power system will incorporate the use of the Northern Power HR3 wind turbine.

3.1 Mechanical Specifications

3.2 Output Specifications

3.3 Efficiency

4 Solar Panels

(Solar panel specs needed)

4.1 Mechanical Specifications

4.2 Output Specificatons

4.3 Efficiency

5 Enclosure

The ARRO enclosure will be designed to supply 50 watts of instrumentation power at a minimum internal temperature of 32 degrees and a maximum of 94 degrees Farenheit for as long as 11 days without solar or wind power.

5.1 Enclosure Dimensions

TBD

5.2 Thermal Characteristics

The interior of the enclosure will be heated to a minimum of 32 degrees Farenheit by internal resistive heaters yet there should be attention to control the nominal temperature above 32 degrees to maximize autonomy characteristics.

5.2 Racks

Instruments and associated control circuitry will be housed in standard 19” wide by 20” deep racks. The amount of racks, as well as the height of each rack will be driven by the enclosure sizing. Accomodations should be made to support up to 12 feet of total rack space for both instrumentation and control circuitry. It is important to note that this number can be reduced if the enclosures sizing (that is driven by the autonomy requirements) cannot support it.

Careful attention should be paid to servicability of the instrument and control racks. Ample space should be designed to allow servicing from both the front and back of the racks and providing the capability of moving the racks (ie rollers) should be strongly considered.

5.3 Batteries

Batteries will be housed within the enclosure and will be sized to store power for instrumentation, control circuitry, as well as power needed to keep the internal temperature at or above 32 degrees Farenheit at all times. Special consideration will be made to make the batteries as accessible as possible for servicing.

5.4 Optical Domes

There will be two optical domes to support imaging instrumentation. The mechanical envelope for the domes and associated imaging instrumentation is displayed below. Considerations will be made to provide space below each instrument to allow servicing inside of the enclosure. It is important to note that if the enclosure dimensions make internal servicing difficult, external servicing of the imaging instruments will be considered.

A-362: ARRO INSTALLATION SCHEDULE 1/25/05 to 2/2/05
REV 01

JANUARY 25

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
1	ARRIVE , ACCLIMATE, UNPACK	1				
2	MEET WITH BAKER, SULLIVAN, CORBIN, RESEARCH ASSOCIATE VERIFY SITE AND GO OVER TRENCH REQUIREMENTS	1 (PM)				

JANUARY 26

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
3	TRANSPORT ENCLOSURE FOOTINGS, ENCLOSURE GUYS TOWER FOOTINGS, TOWER PIECES, CABLE BOXES, JBOX AND GINPOLE AND ENCLOSURE PLATFORM WITH SNOWMOBILE ASSISTANCE	2 (AM)				
4	MARK TRENCH LOCATIONS (WITH RESPECT TO DOWNWIND DIRECTION)	2 (AM)				
5	DIG AND PLACE ENCLOSURE FOOTING TRENCHES	2 (PM)				
6	DIG AND PLACE ENCLOSURE GUYS/VERIFY WITH LEVEL	2 (PM)				

JANUARY 27

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
7	TRENCH FOR TOWER DUG	3 (AM)				
8	ENCLOSURE PLATFORM PLACED AND MOUNTED	3 (AM)				
9	ATTACH GIN POLE AND PLACE BLOCK FOR LIFTING ENCLOSURE PIECES	3 (AM)				
10	ATTACH WINCH TO ENCLOSURE FOOTING	3 (PM)				
11	BLOCK AND ASSEMBLE TOWER PIECES IN TRENCH	3 (PM)				
12	ASSEMBLE FLOOR PANELS AND LAYERS 1 AND 2 OF WALL PANELS	3(AM/PM)				

JANUARY 28

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
13	INSTALL DOOR AND TOP WALL PANELS OF ENCLOSURE	4 (AM)				
14	INSTALL JBOX AND CABLE BUNDLE TO TOWER	4 (AM)				
15	ATTACH BLOCK AND TAGLINES AND PREPARE FOR LIFT					
16	LIFT ROOF PIECES AND INSTALL DOOR HARDWARE	4 (AM)				
17	INSTALL HEATER IN ENCLOSURE	4 (AM)				
18	DIG GUY TRENCHES FOR TOWER GUYS	4 (AM)				

19	TRANSPORT BATTERIES, BATTERY RACK, WATER JUGS, HARDWARE CASES AND ELECTRONICS CASES, ALTERNATOR, BLADES, TAIL ASSEMBLY AND SADDLE TO SITE (SNOWMOBILE SUPPORT)					
20	LIFT TOWER ASSEMBLY AND GUY ANCHORS	4 (PM)				
21	BACKFILL ANCHOR TRENCHES	4 (PM)				

JANUARY 29

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
22	BACKFILL MAIN TOWER TRENCH	5 (AM)				
23	REMOVE GIN POLE AND BLOCK FROM ENCLOSURE FOOTING	5 (AM)				
24	ATTACH SECOND LARGE WINCH TO TOWER	5 (AM)				
25	PLACE BLOCK AT TOP OF TOWER AND LIFT GIN POLE TO APPX 10FT CLEARANCE FROM TOP ENCLOSURE PIECES FLANGES	5 (AM)				
26	INSTALL INTERIOR INSULATION (FOAM OR SPRAY)	5(AM/PM)				
27	APPLY BATTEN SEAMING	5(AM/PM)				
28	FILL JUGS WITH SNOW AND ALLOW TO MELT	5(PM)				

JANUARY 30

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
29	ATTACH TAIL ASSEMBLY TO SADDLE	6(AM)				
29	RAISE AND INSTALL SADDLE WITH TAIL ASSEMBLY (TEAM SWITCH)	6(AM)				
30	INSTALL BATTERY RACK AND BATTERIES	6(AM)				
31	INSTALL NPS REGULATOR	6(AM)				
32	INSTALL RACKS, DAU, SCU AND BURST MODE	6(AM)				
33	INSTALL HEATERS AND TEMPERATURE SENSORS	6(AM)				
34	INSTALL SOLAR PANEL MOUNTS	6(PM)				
35	WIRE AND INSTALL SOLAR PANELS	6(PM)				
36	RAISE ALTERNATOR	6(PM)				
37	ATTACH AIR DAMPER	6(PM)				
38	WIRE SADDLE TO JBOX	6(PM)				
39	WIRE ALTERNATOR TO SADDLE	6(PM)				

JANUARY 31

TASK #	TASK DESCRIPTION	DAY	PAUL	MARC	AMANDA	X
40	WIRE HR3 REGULATOR THROUGH ENCLOSURE	7(AM)				
41	RAISE AND ATTACH BLADES	7(AM)				
42	WIRE AND ATTACH GPS/IRIDIUM	7(AM)				
43	GROUND TOWER	7(AM)				
44	REMOVE HEATER	7(AM)				
45	START SYSTEM TEST	7(AM)				
46	START LOGGING SYSTEM	7(PM)				
47	PACK	7(PM)				

FEBRUARY 1

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
48	VIEW LOG DATA	8(AM/PM)				
49	MEET WITH RESEARCH ASSOCIATE FOR WINTER SUPPORT, REVIEW TEST	8(AM/PM)				

FEBRUARY 2

TASK #	TASK DESCRIPTION	DAY/TIME	PAUL	MARC	AMANDA	X
50	STOP TEST FINAL VIEWING OF DATA	8(AM)				
51	DEPART	8(AM)				

ARRO WAIS DIVIDE TOP LEVEL SCHEDULE: JAN 06

PROJECT	MARCH 2005	APRIL 2005	MAY 2006	JUNE 2006	JULY 2006	AUGUST 2006
MODEL	Finalize changes to model Obtain wind data for WAIS Divide and run integration routine					
ENCLOSURE DESIGN	Finalize Design of new generation Enclosure DESIGN REVIEW	Finalize Shop designs and begin fabrication	Fabricate Panels	Complete Fabrication and ship Installation team to carry out test assembly	Additional cold testing needed Begin packing	Finish Packing and ship
STILT DESIGN	Finalize Stilt Design. Implement modifications based on new enclosure design.	Fabricate Stilts	Complete Fabrication	Test assembly of stilts	Pack	Ship
SYSTEM HARDWARE DESIGN	Order additional hardware needed	Set up Conus station at UNH and Iridium connections	Assemble any additional hardware needed	Install into newly assembled enclosure	Final modifications and packing	Ship

APPENDIX B

THERMAL MODELING AND ENERGY STORAGE ANALYSIS

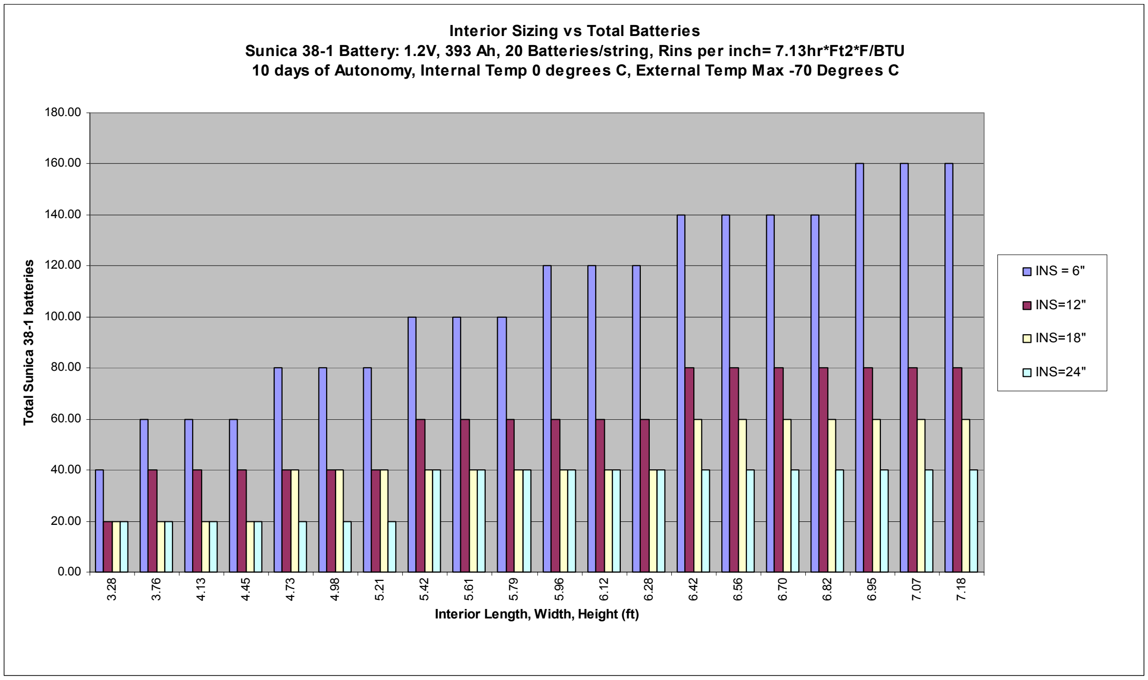
The following appendix contains the following documentation:

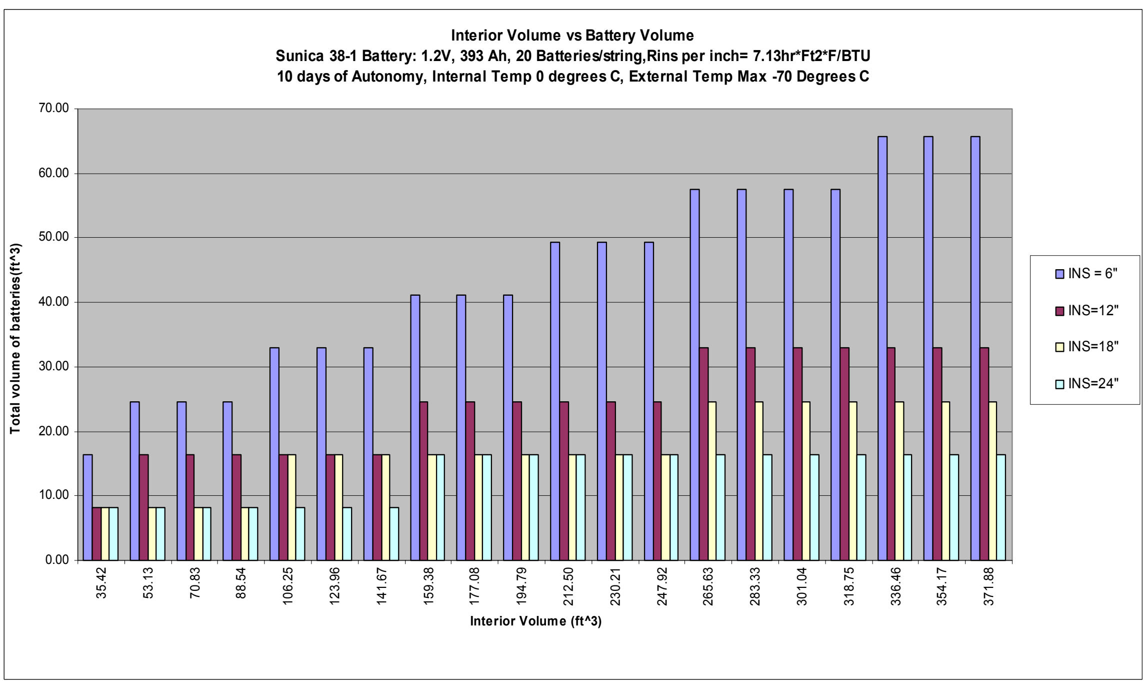
1) The output of the static thermal model which was used to determine initial battery sizing

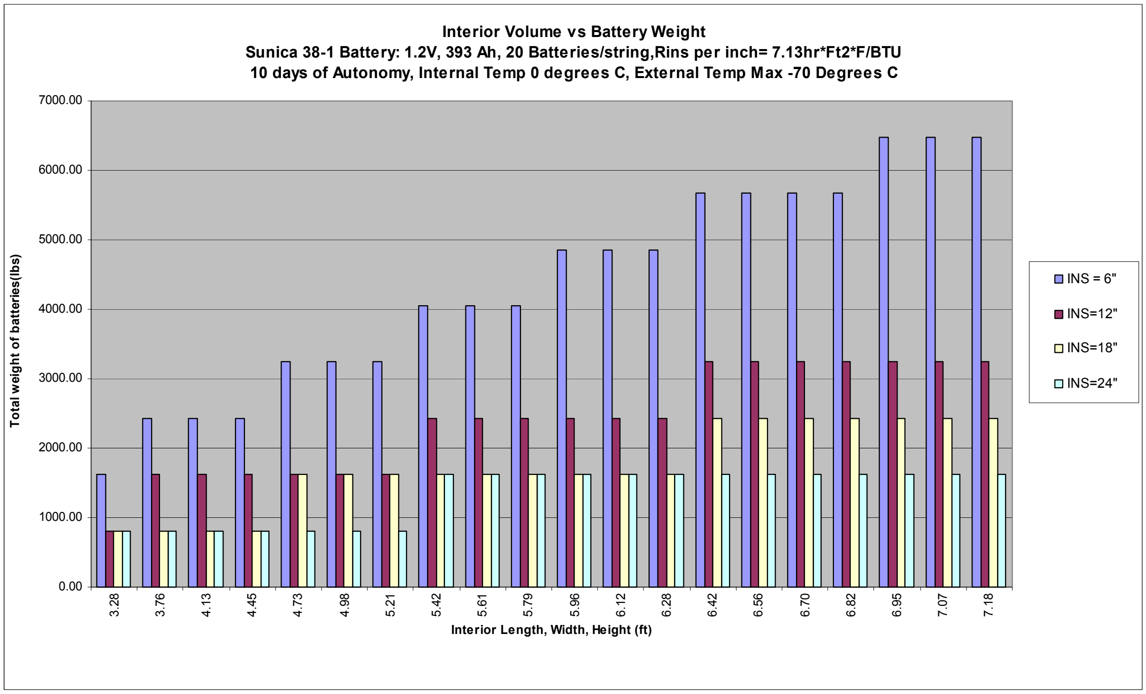
2) Static thermal model source

3) The output of the dynamic thermal model (integration routine) which was also used in battery sizing analysis as well as initial autonomy estimation

APPENDIX XX:
BATTERY SIZING ANALYSIS







Interior Volume vs Battery Weight
Sunica 38-1 Battery: 1.2V, 393 Ah, 20 Batteries/string,Rins per inch= 7.13hr*Ft2*F/BTU
10 days of Autonomy, Internal Temp 0 degrees C, External Temp Max -70 Degrees C
Total weight of batteries(lbs)
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
3.28
3.76
4.13
4.45
4.73
4.98
5.21
5.42
5.61
5.79
5.96
6.12
6.28
6.42
6.56
6.70
6.82
6.95
7.07
7.18
Interior Length, Width, Height (ft)
INS = 6"
INS=12"
INS=18"
INS=24"

			ARRO STATIC THERMAL MODEL						REV08	
TEMPERATURE CONDITIONS					TEMPERATURE CONDITIONS					
			C	F					C	F
		TOUT MIN	-70	-94			TOUT MIN		-70	-94
		TOUT MAX	-5	23			TOUT MAX		-5	23
		TIN MIN	0	32			TIN MIN		0	32
		TIN MAX	35	95			TIN MAX		35	95
INSULATION CHARACTERISTICS					INSULATION CHARACTERISTICS					
		RVALUE	7.568	43			RVALUE		18.48	105
		RVALUE SKYLIGHTS	18.48	0.16			RVALUE SKYLIGHTS		18.48	105
		INSULATION THICKNESS	0.165	0.541667			INSULATION THICKNESS		0.381	1.25
BUILDING DIMENSIONS					BUILDING DIMENSIONS					
		WALL HEIGHT	1.32	4			WALL HEIGHT		2.081784	6.83
		WALL WIDTH	1.32	4			WALL WIDTH		2.3622	7.75
		ROOF/FLOOR HEIGHT	1.32	4			ROOF/FLOOR HEIGHT		2.3622	7.75
		ROOF/FLOOR WIDTH	1.32	4			ROOF/FLOOR WIDTH		2.3622	7.75
		TOTAL SKYLIGHT SURFACE AREA(2)	0.032	0.363			TOTAL SKYLIGHT SURFACE AREA(2		0.032	0.363
		EXTERIOR WALL1	1.7424	16			EXTERIOR WALL1		4.91759	52.9325
		EXTERIOR WALL2	1.7424	16			EXTERIOR WALL2		4.91759	52.9325
		EXTERIOR WALL3	1.7424	16			EXTERIOR WALL3		4.91759	52.9325
		EXTERIOR WALL4	1.7424	16			EXTERIOR WALL4		4.91759	52.9325
		INTERIOR WALL1	1.3068	11.66667			INTERIOR WALL1		3.331271	35.8575
		INTERIOR WALL2	1.3068	11.66667			INTERIOR WALL2		3.331271	35.8575
		INTERIOR WALL3	1.3068	11.66667			INTERIOR WALL3		3.331271	35.8575
		INTERIOR WALL4	1.3068	11.66667			INTERIOR WALL4		3.331271	35.8575
		EXTERIOR ROOF	1.7424	16			EXTERIOR ROOF		5.579989	60.0625
		INTERIOR ROOF	0.9801	8.506944			INTERIOR ROOF		2.56064	27.5625
		INTERIOR ROOF MINUS SKYLIGHT	0.9481	8.143944			INTERIOR ROOF MINUS SKYLIGHT		2.52864	27.1995
		EXTERIOR FLOOR	1.7424	16			EXTERIOR FLOOR		5.579989	60.0625
		INTERIOR FLOOR	0.9801	8.506944			INTERIOR FLOOR		2.56064	27.5625
BUILDING U VALUES					BUILDING U VALUES					
		WALLS	0.132135	0.023256			WALLS		0.054113	0.009524
		FLOOR	0.132135	0.023256			FLOOR		0.054113	0.009524
		ROOF	0.132135	0.023256			ROOF		0.054113	0.009524
		SKYLIGHT	0.054113	6.25			SKYLIGHT		0.054113	0.009524
HEATING LOAD					HEATING LOAD					
		WALL1	12.08721	34.18605			WALL1		12.61845	43.029
		WALL2	12.08721	34.18605			WALL2		12.61845	43.029
		WALL3	12.08721	34.18605			WALL3		12.61845	43.029
		WALL4	12.08721	34.18605			WALL4		12.61845	43.029
		ROOF MINUS SKYLIGHT	8.769424	23.86365			ROOF MINUS SKYLIGHT		9.578182	32.6394
		SKYLIGHT	0.121212	285.8625			SKYLIGHT		0.121212	0.4356
		FLOOR	9.065407	24.92733			FLOOR		9.699394	33.075
		TOTAL HEATING LOAD	66.30488	471.3977			TOTAL HEATING LOAD		69.87259	238.266

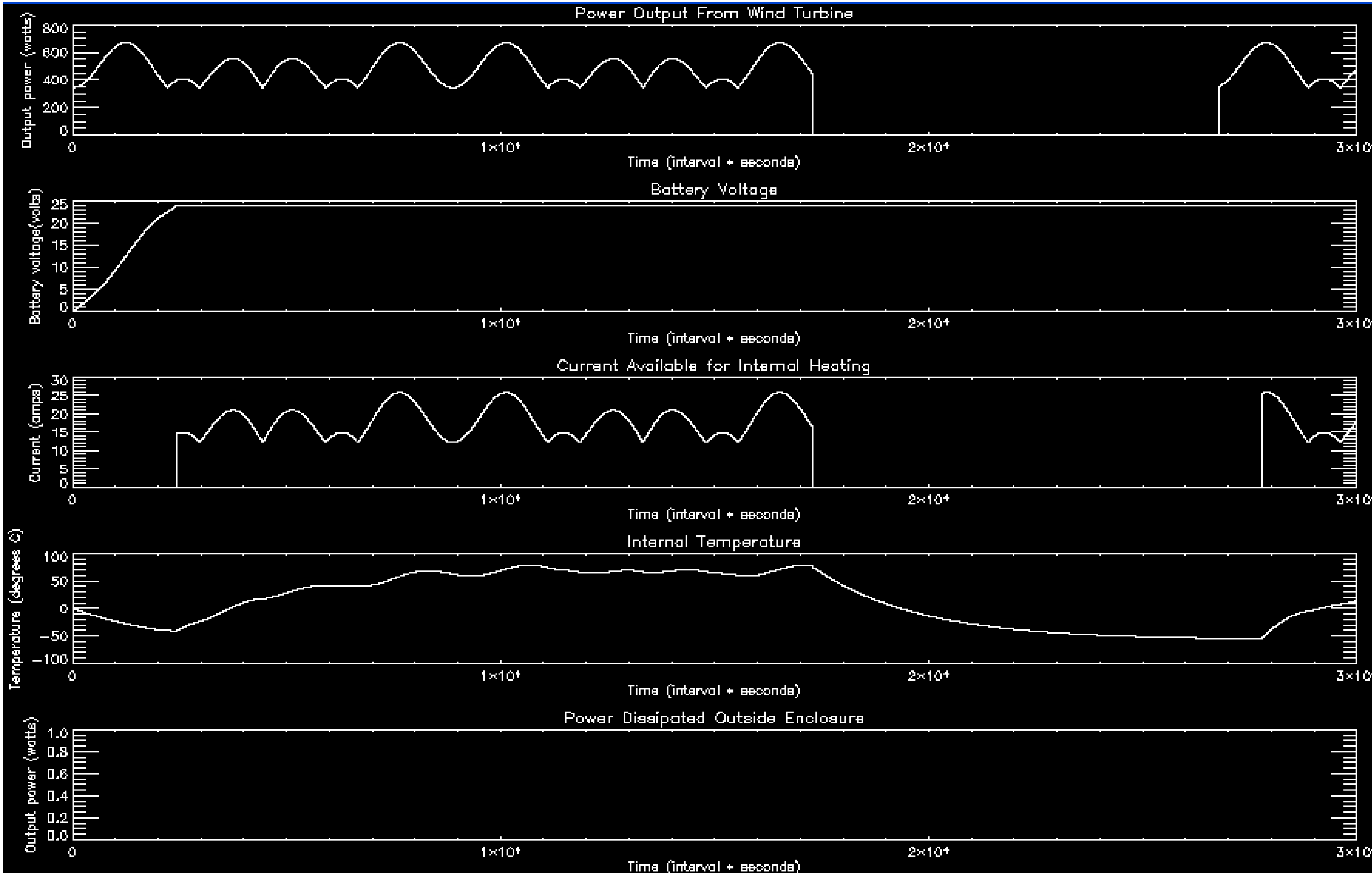
	Battery Amp Hours	393												
	Battery Volume(m3),(ft3)	0.0116	0.4111				Max Temp Differential	74						
	Battery Cell Voltage	1.2					Autonomy Req	10						
	Battery Output Voltage	24												
	Battery Mass(lbs)	40.5												
Interior Volume(m3)	Interior Volume(ft3)	Ins thickness (m	Ins thickness (in	Insulation Rf	Wall L,W,H(m	Wall L,W,H (ft)	Tot Wall Surf Area	Heat Load (W)	Energy Load(Ah)	Tot Batt	Batt Vol (m3)	Batt Vol (ft3)	Batt weight(lbs	Net Int Vol
1	35.4168103	0.1524	5.999988	7.13994	1	3.281	6	62.18539652	621.8539652	40	0.464	16.444	1620	0.536
1.5	53.12521546	0.1524	5.999988	7.13994	1.144714243	3.75580743	7.862224183	81.48592138	814.8592138	60	0.696	24.666	2430	0.804
2	70.83362061	0.1524	5.999988	7.13994	1.25992105	4.133800965	9.524406312	98.71316385	987.1316385	60	0.696	24.666	2430	1.304
2.5	88.54202576	0.1524	5.999988	7.13994	1.357208808	4.4530021	11.0520945	114.5464798	1145.464798	60	0.696	24.666	2430	1.804
3	106.2504309	0.1524	5.999988	7.13994	1.44224957	4.73202084	12.48050294	129.3508373	1293.508373	80	0.928	32.888	3240	2.072
3.5	123.9588361	0.1524	5.999988	7.13994	1.518294486	4.981524208	13.83130888	143.3509045	1433.509045	80	0.928	32.888	3240	2.572
4	141.6672412	0.1524	5.999988	7.13994	1.587401052	5.208262852	15.1190526	156.6973801	1566.973801	80	0.928	32.888	3240	3.072
4.5	159.3756464	0.1524	5.999988	7.13994	1.650963624	5.416811652	16.35408534	169.4975469	1694.975469	100	1.16	41.11	4050	3.34
5	177.0840515	0.1524	5.999988	7.13994	1.709975947	5.610431081	17.54410643	181.8312025	1818.312025	100	1.16	41.11	4050	3.84
5.5	194.7924567	0.1524	5.999988	7.13994	1.765174168	5.791536444	18.69503905	193.7597361	1937.597361	100	1.16	41.11	4050	4.34
6	212.5008618	0.1524	5.999988	7.13994	1.817120593	5.961972665	19.81156349	205.3316552	2053.316552	120	1.392	49.332	4860	4.608
6.5	230.209267	0.1524	5.999988	7.13994	1.866255578	6.123184553	20.8974593	216.5861322	2165.861322	120	1.392	49.332	4860	5.108
7	247.9176721	0.1524	5.999988	7.13994	1.912931183	6.276327211	21.95583426	227.5553766	2275.553766	120	1.392	49.332	4860	5.608
7.5	265.6260773	0.1524	5.999988	7.13994	1.957433821	6.422340365	22.98928297	238.2662795	2382.662795	140	1.624	57.554	5670	5.876
8	283.3344824	0.1524	5.999988	7.13994	2	6.562	24	248.7415861	2487.415861	140	1.624	57.554	5670	6.376
8.5	301.0428876	0.1524	5.999988	7.13994	2.040827551	6.695955195	24.98986256	259.000752	2590.00752	140	1.624	57.554	5670	6.876
9	318.7512927	0.1524	5.999988	7.13994	2.080083823	6.824755023	25.96049227	269.0605842	2690.605842	140	1.624	57.554	5670	7.376
9.5	336.4596979	0.1524	5.999988	7.13994	2.117911792	6.94886859	26.91330216	278.9357277	2789.357277	160	1.856	65.776	6480	7.644
10	354.168103	0.1524	5.999988	7.13994	2.15443469	7.068700218	27.849533	288.6390421	2886.390421	160	1.856	65.776	6480	8.144
10.5	371.8765082	0.1524	5.999988	7.13994	2.18975957	7.184601149	28.77028184	298.1818974	2981.818974	160	1.856	65.776	6480	8.644

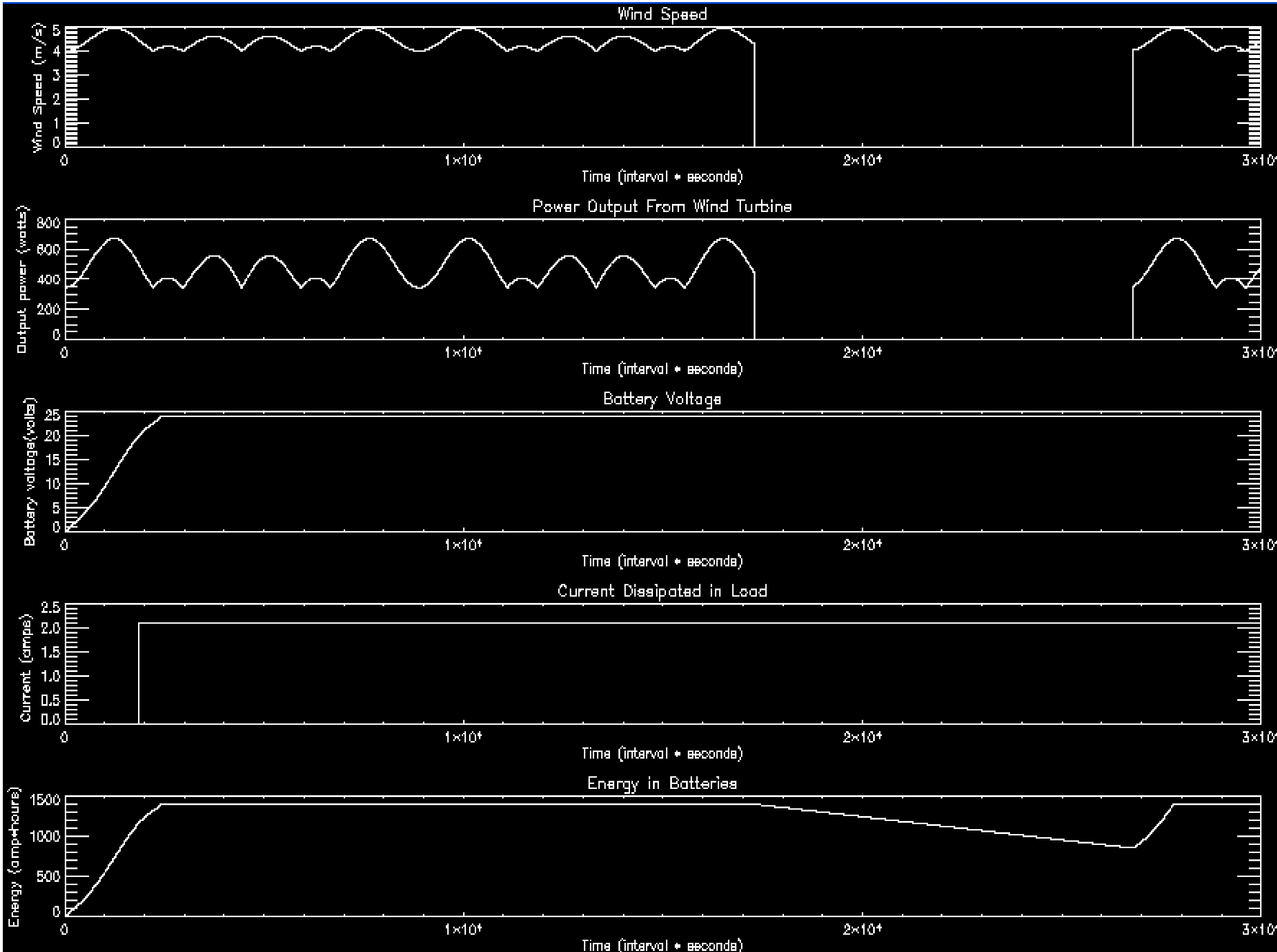
	Battery Amp Hours	393												
	Battery Volume(m3)	0.0116	0.4111				Max Temp Differential	74						
	Battery Cell Voltage	1.2					Autonomy Req	10						
	Battery Output Voltage	24												
	Battery Mass(lbs)	40.5												
Interior Volume(m3)	Interior Volume(ft3)	Ins thickness	Ins thickness (in	Insulation Rf	Wall L,W,H	Wall L,W,H (ft)	Tot Wall Surf Area	Heat Load (W)	Energy Load(Ah)	Tot Batt	Battery Vol	Batt Vol (ft3)	Batt weight(lbs	Net Int Vol
1	35.4168103	0.2286	8.999982	10.70991	1	3.281	6	41.45693101	414.5693101	40	0.464	16.444	1620	0.536
1.5	53.12521546	0.2286	8.999982	10.70991	1.144714243	3.75580743	7.862224183	54.32394759	543.2394759	40	0.464	16.444	1620	1.036
2	70.83362061	0.2286	8.999982	10.70991	1.25992105	4.133800965	9.524406312	65.8087759	658.087759	40	0.464	16.444	1620	1.536
2.5	88.54202576	0.2286	8.999982	10.70991	1.357208808	4.4530021	11.0520945	76.36431984	763.6431984	40	0.464	16.444	1620	2.036
3	106.2504309	0.2286	8.999982	10.70991	1.44224957	4.73202084	12.48050294	86.23389155	862.3389155	60	0.696	24.666	2430	2.304
3.5	123.9588361	0.2286	8.999982	10.70991	1.518294486	4.981524208	13.83130888	95.56726964	955.6726964	60	0.696	24.666	2430	2.804
4	141.6672412	0.2286	8.999982	10.70991	1.587401052	5.208262852	15.1190526	104.4649201	1044.649201	60	0.696	24.666	2430	3.304
4.5	159.3756464	0.2286	8.999982	10.70991	1.650963624	5.416811652	16.35408534	112.9983646	1129.983646	60	0.696	24.666	2430	3.804
5	177.0840515	0.2286	8.999982	10.70991	1.709975947	5.610431081	17.54410643	121.2208016	1212.208016	80	0.928	32.888	3240	4.072
5.5	194.7924567	0.2286	8.999982	10.70991	1.765174168	5.791536444	18.69503905	129.1731574	1291.731574	80	0.928	32.888	3240	4.572
6	212.5008618	0.2286	8.999982	10.70991	1.817120593	5.961972665	19.81156349	136.8877702	1368.877702	80	0.928	32.888	3240	5.072
6.5	230.209267	0.2286	8.999982	10.70991	1.866255578	6.123184553	20.8974593	144.3907548	1443.907548	80	0.928	32.888	3240	5.572
7	247.9176721	0.2286	8.999982	10.70991	1.912931183	6.276327211	21.95583426	151.7035844	1517.035844	80	0.928	32.888	3240	6.072
7.5	265.6260773	0.2286	8.999982	10.70991	1.957433821	6.422340365	22.98928297	158.8441864	1588.441864	100	1.16	41.11	4050	6.34
8	283.3344824	0.2286	8.999982	10.70991	2	6.562	24	165.827724	1658.27724	100	1.16	41.11	4050	6.84
8.5	301.0428876	0.2286	8.999982	10.70991	2.040827551	6.695955195	24.98986256	172.667168	1726.67168	100	1.16	41.11	4050	7.34
9	318.7512927	0.2286	8.999982	10.70991	2.080083823	6.824755023	25.96049227	179.3737228	1793.737228	100	1.16	41.11	4050	7.84
9.5	336.4596979	0.2286	8.999982	10.70991	2.117911792	6.94886859	26.91330216	185.9571518	1859.571518	100	1.16	41.11	4050	8.34
10	354.168103	0.2286	8.999982	10.70991	2.15443469	7.068700218	27.849533	192.4260281	1924.260281	100	1.16	41.11	4050	8.84
10.5	371.8765082	0.2286	8.999982	10.70991	2.18975957	7.184601149	28.77028184	198.7879316	1987.879316	120	1.392	49.332	4860	9.108

	Battery Amp Hours	393												
	Battery Volume(m3)	0.0116	0.4111				Max Temp Differential	74						
	Battery Cell Voltage	1.2					Autonomy Req	10						
	Battery Output Voltage	24												
	Battery Mass(lbs)	40.5												
Interior Volume(m3)	Interior Volume(ft3)	Ins thickness	Ins thickness (in	Insulation Rf	Wall L,W,H	Wall L,W,H (ft)	Tot Wall Surf Area	Heat Load (W)	Energy Load(Ah)	Tot Batt	Battery Vol	Batt Vol (ft3)	Batt weight(lbs	Net Int Vol
1	35.4168103	0.3048	11.999976	14.27988	1	3.281	6	31.09269826	310.9269826	20	0.232	8.222	810	0.768
1.5	53.12521546	0.3048	11.999976	14.27988	1.144714243	3.75580743	7.862224183	40.74296069	407.4296069	40	0.464	16.444	1620	1.036
2	70.83362061	0.3048	11.999976	14.27988	1.25992105	4.133800965	9.524406312	49.35658192	493.5658192	40	0.464	16.444	1620	1.536
2.5	88.54202576	0.3048	11.999976	14.27988	1.357208808	4.4530021	11.0520945	57.27323988	572.7323988	40	0.464	16.444	1620	2.036
3	106.2504309	0.3048	11.999976	14.27988	1.44224957	4.73202084	12.48050294	64.67541866	646.7541866	40	0.464	16.444	1620	2.536
3.5	123.9588361	0.3048	11.999976	14.27988	1.518294486	4.981524208	13.83130888	71.67545223	716.7545223	40	0.464	16.444	1620	3.036
4	141.6672412	0.3048	11.999976	14.27988	1.587401052	5.208262852	15.1190526	78.34869007	783.4869007	40	0.464	16.444	1620	3.536
4.5	159.3756464	0.3048	11.999976	14.27988	1.650963624	5.416811652	16.35408534	84.74877344	847.4877344	60	0.696	24.666	2430	3.804
5	177.0840515	0.3048	11.999976	14.27988	1.709975947	5.610431081	17.54410643	90.91560124	909.1560124	60	0.696	24.666	2430	4.304
5.5	194.7924567	0.3048	11.999976	14.27988	1.765174168	5.791536444	18.69503905	96.87986803	968.7986803	60	0.696	24.666	2430	4.804
6	212.5008618	0.3048	11.999976	14.27988	1.817120593	5.961972665	19.81156349	102.6658276	1026.658276	60	0.696	24.666	2430	5.304
6.5	230.209267	0.3048	11.999976	14.27988	1.866255578	6.123184553	20.8974593	108.2930661	1082.930661	60	0.696	24.666	2430	5.804
7	247.9176721	0.3048	11.999976	14.27988	1.912931183	6.276327211	21.95583426	113.7776883	1137.776883	60	0.696	24.666	2430	6.304
7.5	265.6260773	0.3048	11.999976	14.27988	1.957433821	6.422340365	22.98928297	119.1331398	1191.331398	80	0.928	32.888	3240	6.572
8	283.3344824	0.3048	11.999976	14.27988	2	6.562	24	124.370793	1243.70793	80	0.928	32.888	3240	7.072
8.5	301.0428876	0.3048	11.999976	14.27988	2.040827551	6.695955195	24.98986256	129.500376	1295.00376	80	0.928	32.888	3240	7.572
9	318.7512927	0.3048	11.999976	14.27988	2.080083823	6.824755023	25.96049227	134.5302921	1345.302921	80	0.928	32.888	3240	8.072
9.5	336.4596979	0.3048	11.999976	14.27988	2.117911792	6.94886859	26.91330216	139.4678638	1394.678638	80	0.928	32.888	3240	8.572
10	354.168103	0.3048	11.999976	14.27988	2.15443469	7.068700218	27.849533	144.319521	1443.19521	80	0.928	32.888	3240	9.072
10.5	371.8765082	0.3048	11.999976	14.27988	2.18975957	7.184601149	28.77028184	149.0909487	1490.909487	80	0.928	32.888	3240	9.572

	Battery Amp Hours	393												
	Battery Volume(m3)	0.0116	0.4111				Max Temp Differential	74						
	Battery Cell Voltage	1.2					Autonomy Req	10						
	Battery Output Voltage	24												
	Battery Mass(lbs)	40.5												
Interior Volume(m3)	Interior Volume(ft3)	Ins thickness	Ins thickness (in	Insulation Rf	Wall L,W,H	Wall L,W,H (ft)	Tot Wall Surf Area	Heat Load (W)	Energy Load(Ah)	Tot Batt	Battery Vol	Batt Vol (ft3)	Batt weight(lbs	Net Int Vol
1	35.4168103	0.381	14.99997	17.84985	1	3.281	6	24.87415861	248.7415861	20	0.232	8.222	810	0.768
1.5	53.12521546	0.381	14.99997	17.84985	1.144714243	3.75580743	7.862224183	32.59436855	325.9436855	20	0.232	8.222	810	1.268
2	70.83362061	0.381	14.99997	17.84985	1.25992105	4.133800965	9.524406312	39.48526554	394.8526554	40	0.464	16.444	1620	1.536
2.5	88.54202576	0.381	14.99997	17.84985	1.357208808	4.4530021	11.0520945	45.8185919	458.185919	40	0.464	16.444	1620	2.036
3	106.2504309	0.381	14.99997	17.84985	1.44224957	4.73202084	12.48050294	51.74033493	517.4033493	40	0.464	16.444	1620	2.536
3.5	123.9588361	0.381	14.99997	17.84985	1.518294486	4.981524208	13.83130888	57.34036179	573.4036179	40	0.464	16.444	1620	3.036
4	141.6672412	0.381	14.99997	17.84985	1.587401052	5.208262852	15.1190526	62.67895205	626.7895205	40	0.464	16.444	1620	3.536
4.5	159.3756464	0.381	14.99997	17.84985	1.650963624	5.416811652	16.35408534	67.79901875	677.9901875	40	0.464	16.444	1620	4.036
5	177.0840515	0.381	14.99997	17.84985	1.709975947	5.610431081	17.54410643	72.73248099	727.3248099	40	0.464	16.444	1620	4.536
5.5	194.7924567	0.381	14.99997	17.84985	1.765174168	5.791536444	18.69503905	77.50389443	775.0389443	40	0.464	16.444	1620	5.036
6	212.5008618	0.381	14.99997	17.84985	1.817120593	5.961972665	19.81156349	82.1326621	821.326621	60	0.696	24.666	2430	5.304
6.5	230.209267	0.381	14.99997	17.84985	1.866255578	6.123184553	20.8974593	86.63445286	866.3445286	60	0.696	24.666	2430	5.804
7	247.9176721	0.381	14.99997	17.84985	1.912931183	6.276327211	21.95583426	91.02215062	910.2215062	60	0.696	24.666	2430	6.304
7.5	265.6260773	0.381	14.99997	17.84985	1.957433821	6.422340365	22.98928297	95.30651181	953.0651181	60	0.696	24.666	2430	6.804
8	283.3344824	0.381	14.99997	17.84985	2	6.562	24	99.49663443	994.9663443	60	0.696	24.666	2430	7.304
8.5	301.0428876	0.381	14.99997	17.84985	2.040827551	6.695955195	24.98986256	103.6003008	1036.003008	60	0.696	24.666	2430	7.804
9	318.7512927	0.381	14.99997	17.84985	2.080083823	6.824755023	25.96049227	107.6242337	1076.242337	60	0.696	24.666	2430	8.304
9.5	336.4596979	0.381	14.99997	17.84985	2.117911792	6.94886859	26.91330216	111.5742911	1115.742911	60	0.696	24.666	2430	8.804
10	354.168103	0.381	14.99997	17.84985	2.15443469	7.068700218	27.849533	115.4556168	1154.556168	60	0.696	24.666	2430	9.304
10.5	371.8765082	0.381	14.99997	17.84985	2.18975957	7.184601149	28.77028184	119.272759	1192.72759	80	0.928	32.888	3240	9.572

The following plots are direct outputs from our initial integration simulation routine. Note the wind input in this case was simulated with a varying input along followed by a full 10 days of autonomous operation with no wind or solar input. The outputs of this model, in conjunction with our static model were used to determine our battery sizing requirements




Wind Speed
Wind Speed (m/s)
Time (interval * seconds)
Power Output From Wind Turbine
Output power (watts)
Time (interval * seconds)
Battery Voltage
Battery voltage(volts)
Time (interval * seconds)
Current Dissipated in Load
Current (amps)
Time (interval * seconds)
Energy in Batteries
Energy (amp*hours)
Time (interval * seconds)

APPENDIX C

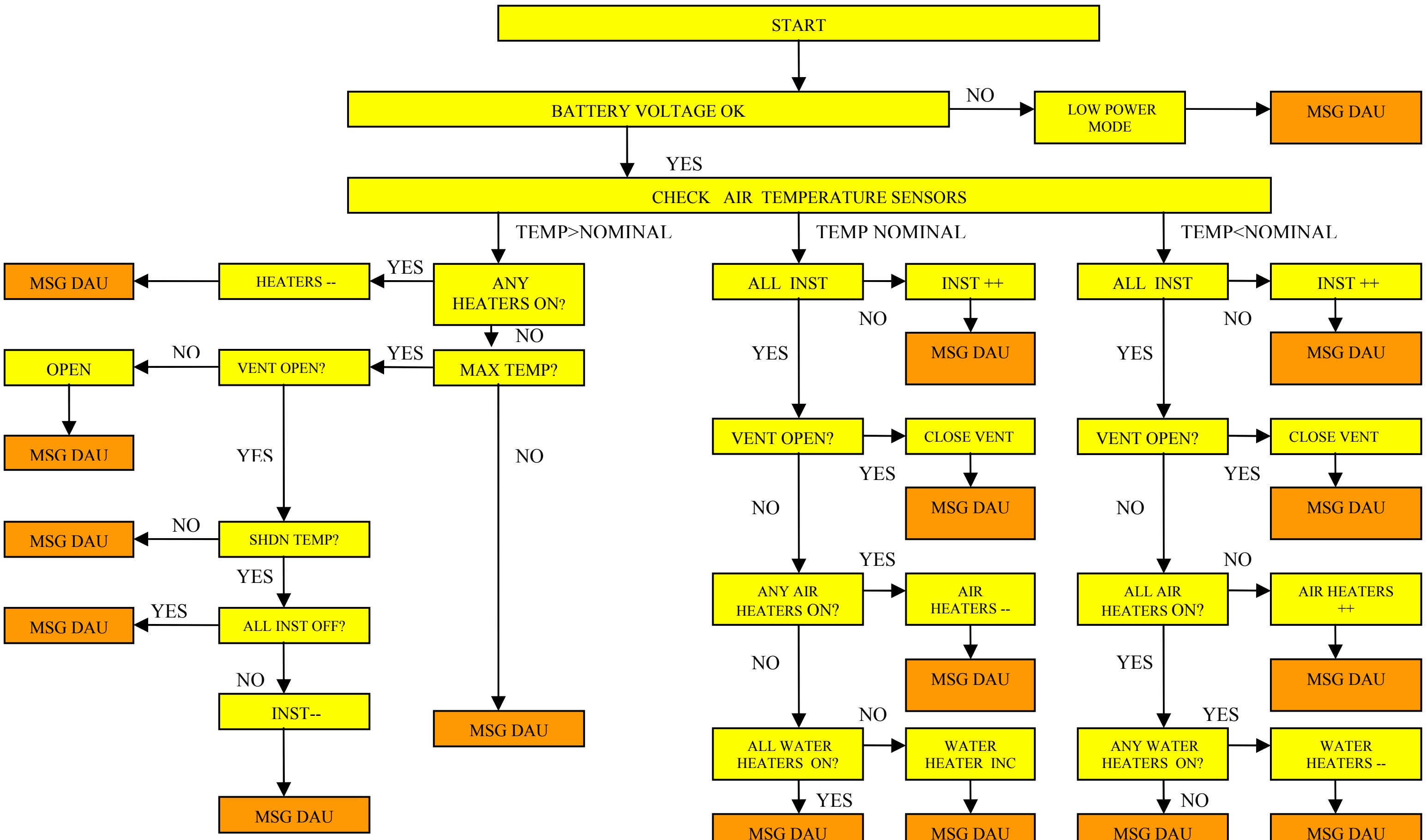
SYSTEM CONTROLLER UNIT ALGORITHM DEVELOPMENT

The following appendix contains the following system documentation:

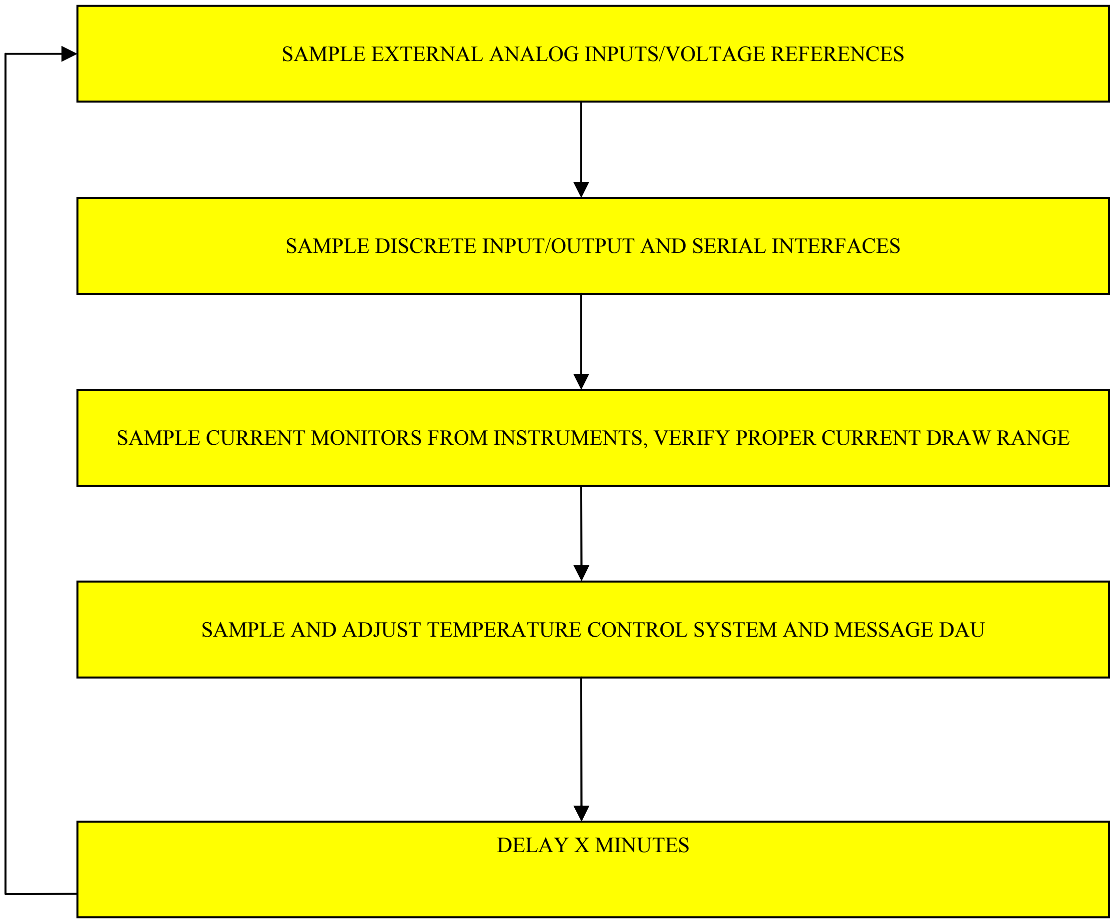
1) Flow diagrams of the software algorithm implemented in the System Controller Unit

2) System Controller Unit Command Summary

ARRO SYSTEM CONTROLLER TEMPERATURE CONTROL FLOW DIAGRAM



ARRO SYSTEM CONTROLLER TOP LEVEL FLOW DIAGRAM



COMMAND DESCRIPTIONS

OPEN VENT	Open the venting system associated with the ARRO Enclosure
CLOSE VENT	Close the venting system associated with the ARRO Enclosure
INST--	Remove power from an additional instrument. This only occurs if the Shutdown temperature has been reached. If power has been removed from all of the instruments, no action is taken
INST++	Apply power to an additional instrument. If all instruments are powered no action is taken.
WATER HEATER INC ENABLE	Enable an increase in power applied to the water heaters. Note this command will be gated with a maximum allowable water temperature readback from the water temperature sensors. It is important to note that water heating is only enabled when the air temperature is nominal and the air heaters are not powered
HEATERS--	Remove power from one of the heaters. Note that for removal of power from heaters, air heaters will be removed first followed by water heaters. If all heaters are turned off, no action is taken
AIR HEATERS--	Remove power from one of the air heaters. If all air heaters are powered off, no action takes place.
AIR HEATERS++	Apply power to an additional air heater. If all air heaters are powered off, no action takes place.
LOW POWER MODE	Mode entered when voltage on battery has started to drop significantly. In this mode, all power to air heaters and water heaters are instantly removed.

STATUS CHECK DESCRIPTIONS

SHDN TEMP?	Has the cumulative air temperature reading increased to the point where we want to start shedding power from the instruments. Most likely this temperature will be approximately 70 - 80 degrees C
ALL INST OFF?	Have all of the science instruments had power removed from them. This will be a readback of the register controlling the solid state relays providing power to the science instruments
ALL INST ON	Are all of the science instruments powered? This will be a readback of the register controlling the solid state relays providing power to the science instruments.
ANY HEATERS ON?	Do any of the heaters (both water and air) have power applied to them?
ANY AIR HEATERS ON?	Do any of the air heaters have power applied to them?
ALL AIR HEATERS ON?	Do all of the air heaters have power applied to them?
ANY WATER HEATERS ON?	Do any of the water heaters have power applied to them?
ALL WATER HEATERS ON?	Do all of the water heaters have power applied to them?
MAX TEMP?	Has the cumulative air temperature reading increased to the point where we want to open the enclosure vent? Most likely this temperature will reside in the range of 40 – 60 degrees C
BATTERY VOLTAGE OK?	Readout of battery sample voltage to verify it within proper tolerances of the nominal battery bank voltage. If a droop on the battery bank is detected the system immediately goes into Low Power Mode.

INSTRUMENTATION NOTES

1) All temperature readings will be the result of averaging of multiple temperature sensors within the enclosure. Pre determined faulty monitors will be eliminated from the calculation.
2) Programmable hysteresis will be implemented for the below nominal, at nominal, and above nominal thresholds.
3) There will be multiple air and water heaters installed within the enclosure. These are installed both to provide redundancy as well as provide a means of progressively adding uniform heat to the enclosure. Therefore states in the above diagram such as AIR_HEATER++ or AIR_HEATER-- refer to the powering or removal of power of one of multiple units.

APPENDIX D

ARRO TESTING SUMMARY

The following appendix contains the following system documentation:

1) Testing summary for the end to end system cold room test performed in August and September of 2005

2) Photographs of the internal hardware taken prior to testing

2) The cold chamber test performed on the Sunica Plus Nicad batteries in 2004

ARRO INSTALLATION AND TEST SUMMARY
September 15, 2005

The following document details the testing performed on the initial ARRO system at the Cold Regions Research Environmental Labs (CRREL) from August 7 through September 12.

The ARRO system is intended to be an autonomous system used to power up to 16 scientific instruments at a power dissipation of up to 50 watts. In consists of a hybrid power system including the 3 kilowatt HR3 wind turbine from Northern Power Systems as well as 8, 120 watt solar panels mounted. The power control system is a custom design developed at the University of New Hampshire. The Data Acquisition system, developed at the University of Maryland provides acquisition and transmission of both analog and digital instrument data. The transmission is accomplished via a bi-directional Iridium satellite connection interfaced directly to the Data Acquisition unit.

The system tested at CRREL was a slightly scaled down version of what will actually be installed at the South Pole this upcoming January. The setup for the test system is detailed below

SYSTEM SETUP

1) **HR3 Wind Turbine:** The HR3 wind turbine was mounted directly on a 40 foot Rohn RG45 tower. The tower was guyed at 32 feet to concrete slabs place on the ground. A detailed description of the HR3 wind turbine is detailed in the sections to follow.
2) **Kyocera Solar Panels:** 2, Kyocera 120 watt, 12 volt panels were wired in series to produce a 24 watt input. The charge controller used is a Xantrex/Trace C-40 controller
3) **ARRO enclosure:** The ARRO enclosure consists of 18 panelized pieces, each with 18" of foam sandwiched between pieces of OSB. The panelized pieces fit together in an overlapping formatting to help ensure the longest possible thermal path at each junction point
4) **Battery Bank.** The Saft Sunica Plus 370 amp-hour Nicad battery was used for energy storage. The CRREL test unit used a single string of batteries, consisting of ten cells which produced a 370 amp-hour bank at 24V. The actual installation will have the three banks placed in parallel.
5) **Water Jugs**: 4, 50 gallon water jugs were placed in the unit to provide additional thermal mass inside of the enclosure. Each were filled approximately 90% full with some space to allow for expansion during freezing. The actual installation at South Pole will have a total of 16, 50 gallon jugs installed.

HR3 INSTALLATION

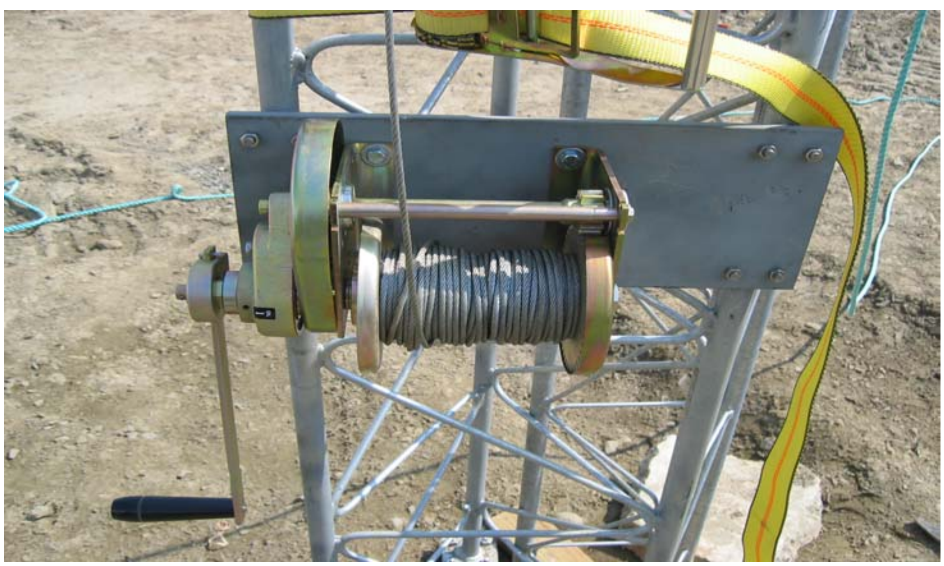
The following steps detail the installation of the HR3 wind turbine.

1) The footings were set in concrete with approximately 3 inches from the ground to the flanges. At the South Pole the concrete will be replaced by a backfilled hole approximately 3 feet deep. EITHER WAY IT IS EXTREMELY IMPORTANT TO KEEP MAKE SURE THE FLANGES ARE SET LEVEL WHEN COMPLETE
Tools needed (South Pole): Shovel and level

2) The first tower section is placed on the wooden footer placed in the ice. Note there are four separate tower pieces: one intended to be installed last for the guys (this is a thicker piece) and three similar pieces which are mounted first. Out of the three similar pieces it is a good idea to pick the worst in terms of bent flanges since it easier to deal with this on the ground. A picture of the footer (concrete placed) and with the first tower piece installed is shown below. Install 12 bolts and nuts and finish by installing PAL nuts. Note: To line up holes on flanges, use an awl and rubber mallet

Tools needed: Allan wrench, level, Awl, rubber mallet/hammer

3) Install main winch by using supplied flat washers, bolts and nuts to mount to winch plate. Use provided UBOLTs to install winch plate on to tower. Install plate between the second and third lattice set on the first tower section.



Tools needed, Allan wrench

4) Attach two sections of gin pole together using provided nuts and bolts. Install gin pole swing arm in insert (Note this should sit freely). Place provided wood block flush with one of the far edges of the tower with respect to the winch. Place the

foot of the gin pole against this wood block and attach the sheve to the top of the first tower section using a carabiner. Attach the winch line which passes through the sheve on the end of the gin pole. Attach tag line to gin pole. With one person steadying the gin pole, one person on the winch and one person guiding the tag line, use the winch to raise ginpole flush to tower. Strap gin pole to tower section as shown below.

tools needed: one strap two carabiners, rope for tag line

5) Align gin pole swing arm such that sheeve will feed winch cable directly over the first tower section. Attach sheeve to the top of gin pole swing arm and attach winch cable to second tower section. Ensure the gin pole is attached such that there is enough headroom to swing the second tower section directly above the first. Once lifted, lower the second section onto the first and align flanges. Install flange bolts and tighten. Install pal nuts.

6) Remove sheeve from top of gin pole and place on top of second tower section. Place second ratchet strap and secure gin pole to tower at the top of the second tower section (in a position to allow sliding of the gin pole). Attach winch carabiner to gin pole. Make sure connection is low enough on the gin pole to allow a proper amount of rise to account for the raise of the next 1 ft tower section. Raise gin pole with winch allowing it to slide along the straps (keeping the gin pole from swinging away).

7) Reattach ratchet straps to allow gin pole to take a load. Strap attachment is shown below. Both straps should be installed as below

8) Remove winch attachment from gin pole and move sheeve from top of second tower section to gin pole swing arm.

9) Repeat for third section

10) Attach guy wires to fourth tower section and let them hang. Attach fourth tower to winch and lift as detailed in step 5.
11) Install guy wires to anchors. Guy installation at CRREL is shown below. Holes in the ice will have to be dug prior at South Pole. PROPER GUYS FOOTINGS NEEDS TO BE DETERMINED.

12) Repeat raise of gin pole as detailed above. Make sure that gin pole is raised high enough to allow installation of both saddle and alternator. This should be at least 10 feet.
13) Assemble saddle and tail arm assembly on the ground.
14) Place sheeve at top of swing arm. Strap saddle and tail arm with supplied straps and connect to end of winch (note, the balance point for the saddle tail arm assembly is offset from the center of the saddle and this prevents the saddle from easily being lowered into the top of the tower section. It is advised to attach the winch line directly over the saddle and then connect a small ratchet strap from the tail arm to that point over the saddle to achieve a horizontal lift of the entire assembly). Connect tag line to saddle. Raise saddle with winch with tag line being held to clear tower properly. Line up saddle flange holes up with third tower section. Install bolts, tighten and top with PAL Nuts.
15) Remove main Saddle bolt and caps and bolts to allow alternator to sit flush in insert.
16) Strap alternator on ground using three provided straps. Alternator must be angled at 30 degrees to allow proper installation into saddle. A picture of the alternator strapping is provided below.

ALTERNATOR STRAPPING

17) Attach winch end to strap end and raise alternator into Saddle. Reinsert main bolt to secure alternator and intall caps and bolts.
18) Use supplied bolts to attach furl winch to bottom of tower assembly (on tower lattice next to main winch). Feed winch end up through tower and attach to chain fed from alternator/saddle
19) Attach dampner to alternator using supplied hardware
20) Using supplied tubes and hardware, bolt tail fin to tubes (see HR3 installation manual)
21) Attach tail assembly to main winch end and raise.
22) Feed tail tubes through inserts on Saddle (see HR3 installation manual) and secure using provided hardware.
23) Furl alternator up completely using furl winch
24) Using main winch (or tag line with a person to guide up the tower), raise the blades one by one. Attach blades to rotor using supplied hardware with CURVED EDGE TOWARDS THE WIND.
25) Attach JBox to tower approximately 3 feet below saddle (using supplied Ubolts).
26) Attach 10AWG wires coming from saddle to terminal blocks in JBOX (see HR3 installation manual).
27) Feed 6 cables (Phase A, Phase, B, Phase C, Field +, Field – , and chassis gnd) in a bundle up the tower. Attach Chinese finger and cable feedthrough to end of cable bundle and feed into JBox.
28) Use an additional strap to tie cable bundle to tower to provide additional/emergency strain relief.

29) Attach cable ends to appropriate terminal blocks in JBOX
30) Use cable ties to secure cable down length of tower.
31) Attach cable ends to appropriate terminal blocks on HR3 regulator on within the HR3 unit.
32) Defurl unit.

FULLY ASSEMBLED HR3

HR3 FURLED WITH GINPOLE ATTACHED

Installation Summary

The total installation time for the unit ended up being over 200 man-hours with 2 to 3 people working on it the majority of the time.

Initially a good deal of time was used in discussion and analysis of the best way instal particular components since we had a very vague installation manual to go by which did not detail specifics to our installation. Several calls had to be made to the manufacturer to clarify and detail specifics of the installation.

What also really drove the time of installation up was the provided raising procedure using the gin pole. For each section of the tower and wind turbine assembly inserted, the gin pole would have to be raised using the winch and strapped properly to the tower. Then the sheeve would have to be returned to the gin pole and the appropriate piece would be raised. This turned out to be extremely time consuming and increased safety risk since we had to spend a good deal of time on the tower. For future installations, a "Tipup" tower assembly should be considered giving the capability to put together the bulk of the assembly on the ground.

We believe we can cut a good deal of our learning curve time at the Pole, but also realize that this installation will be a lot more difficult with full cold weather gear at lower temperatures. We also expect a good deal of time digging both for the tower footing as well as the guy wire attachments. As a result we may see the installation time decrease somewhat but most likely not dramatically.

ARRO BOX INSTALLATION

Refer to Foamtech installation manual for detailed installation instruction

Installation Summary

A team of four was used to put together the ARRO box assembly. The team was able to fully assemble the unit (minus all batten seaming and joint insulation) within 8 hours of work for a total of 32 man hours. The interior was assembled in 1 day by two people for a total of 18 man hours. The initial unit was assembled inside the CRREL MEF cold room with a simple 2X4 constructed support. 10 ft clamps, a step ladder and scaffolding were used to assist in putting the box together. A cordless drill and screws were used to secure the panels together.

Pictures of both the individual panels as well as the assembled enclosure are provided below.

Testing Summary

Note the following is a brief summary of the testing done to the ARRO unit. For more detailed data, please see the ARRO data results summary.

A two week testing at -50 degrees celcius inside of the MEF was allocated for the ARRO unit. Approximately 14 temperature sensors are placed within the ARRO enclosure for real time temperature status. In addition more than 20 thermocouples were added to various areas in the enclosure to provide additional thermal data during the test.

The unit was initially brought down to -50 degrees C with the door open to help accelerate the cool down. During this period, power was switched off from both the wind turbine as well as the solar panels.

The unit was cold soaked until both the inside of the walls and the center of the water jugs (which were the last to reach steady state) reached -50 degrees C. Once the unit reached steady state the door was sealed and bus power was enabled to the power system

The ARRO System Controller Unit was configured to enable all air heaters which would provide a total of approximately 600 watts to heat up the inside of the enclosure. When bus power was switched on the System Controller Unit came up and enabled power to the heaters properly. It was quickly noted that the 600 watts from the air heaters provided only a slight rise in temperature over time. Initially the rise was approximately 1 degree every 2 hours.

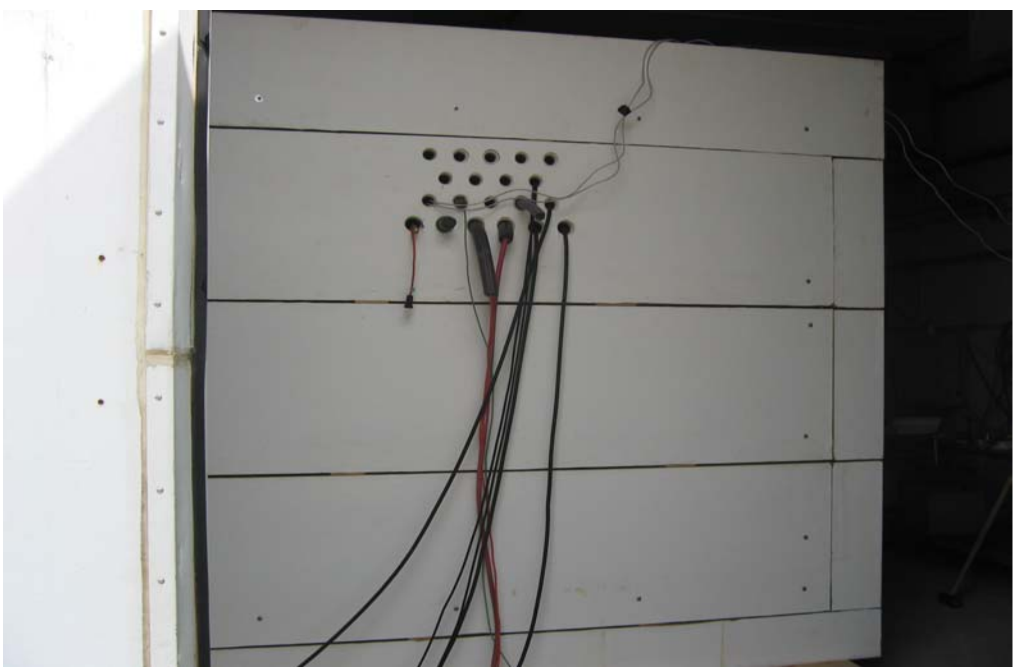
In order to accelerate the temperature rise, a 3 kilowatt heater was inserted inside of the enclosure and was ran over a three day period. The ARRO System Controller Unit was disabled. The control on the heater was set to approximately 10 degrees C with a 10 degree deadband. Once the enclosure reached steady state at approximately 10 degrees C (with all water jugs thawed), measurements were made to determine the steady state heat load. The resulting value came out to be approximately 1 kilowatt (see Phitteplace data).

Thermal imagers were then brought into the enclosure and it was noted that a significant portion of the heat loss was due to air infiltration through the joints of the panels (see thermal imaging pictures). The joints were then filled with fiberglass insulation to help combat the infiltration.

The steady state heat load was once again measured after the fiberglass data and the steady state load dropped to 200 watts with the heater. The 3 kilowatt heater was then removed and the System Controller Unit was enabled once again. The air heaters were able to control the temperature to a steady state value of 10 degrees and verified the approximate 200 watt heat load (see Riley data).

Pictures below:

Assembled Enclosure: Front



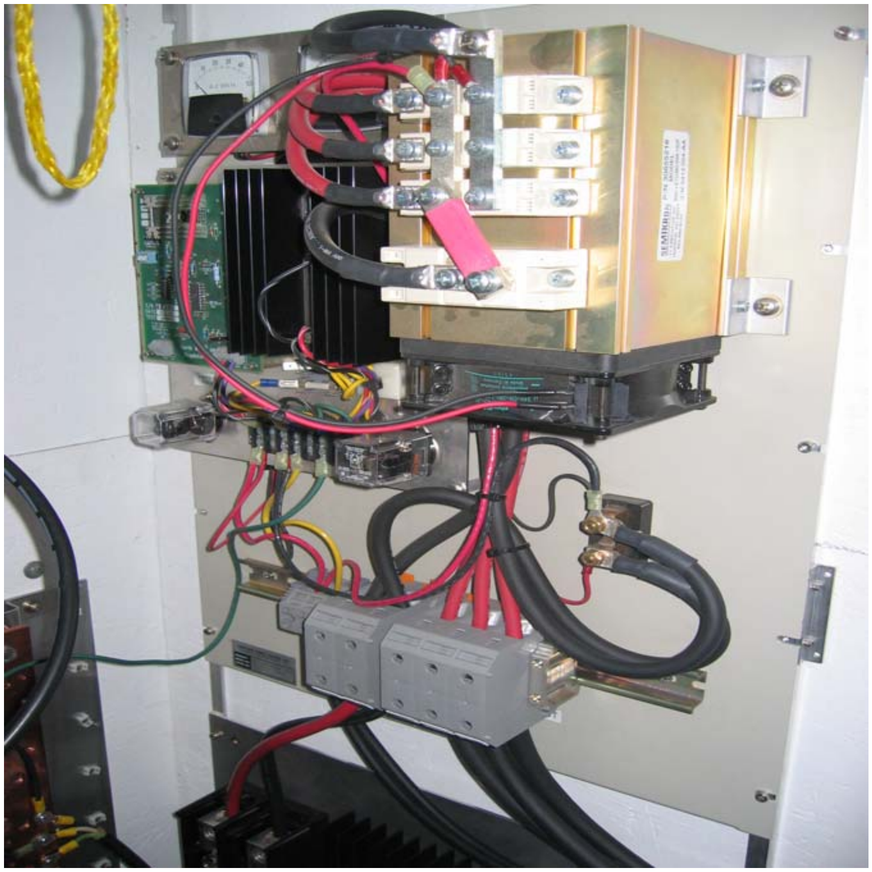
Assembled Enclosure: Back

Individual Wall Panels

Conclusions

Proper insulation of the wall panel joints is VITAL for proper operation of the system. It is noted that batten seaming will be added for the actual installation but additional insulation will be needed. Blown foam insulation and backerod insulation will be considered.

Installation of the wind turbine was much more time consuming then expected. Must consider additional assistance (possibly crane help?) or increase time at South Pole Station

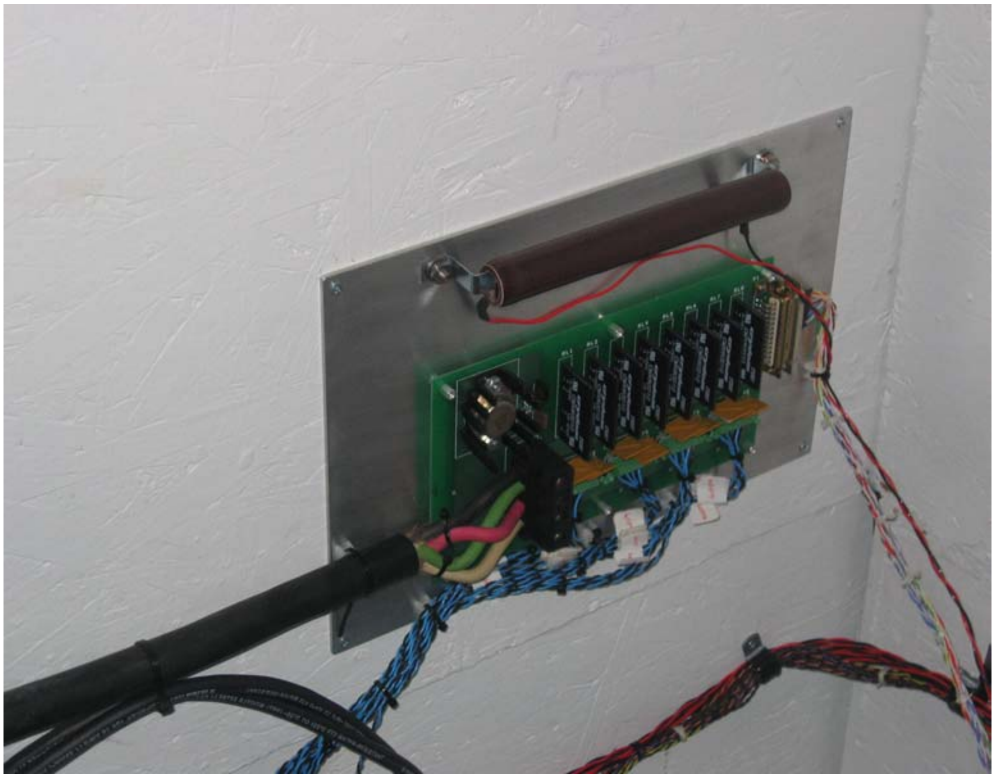


HR3 WIND TURBINE REGULATOR

XANTREX COLAR CHARGE CONTROLLER AND TEMPERATURE SENSOR/HEATER BREAKOUT PANEL

HR3 WIND GENERATOR

HR3 WIND GENERATOR

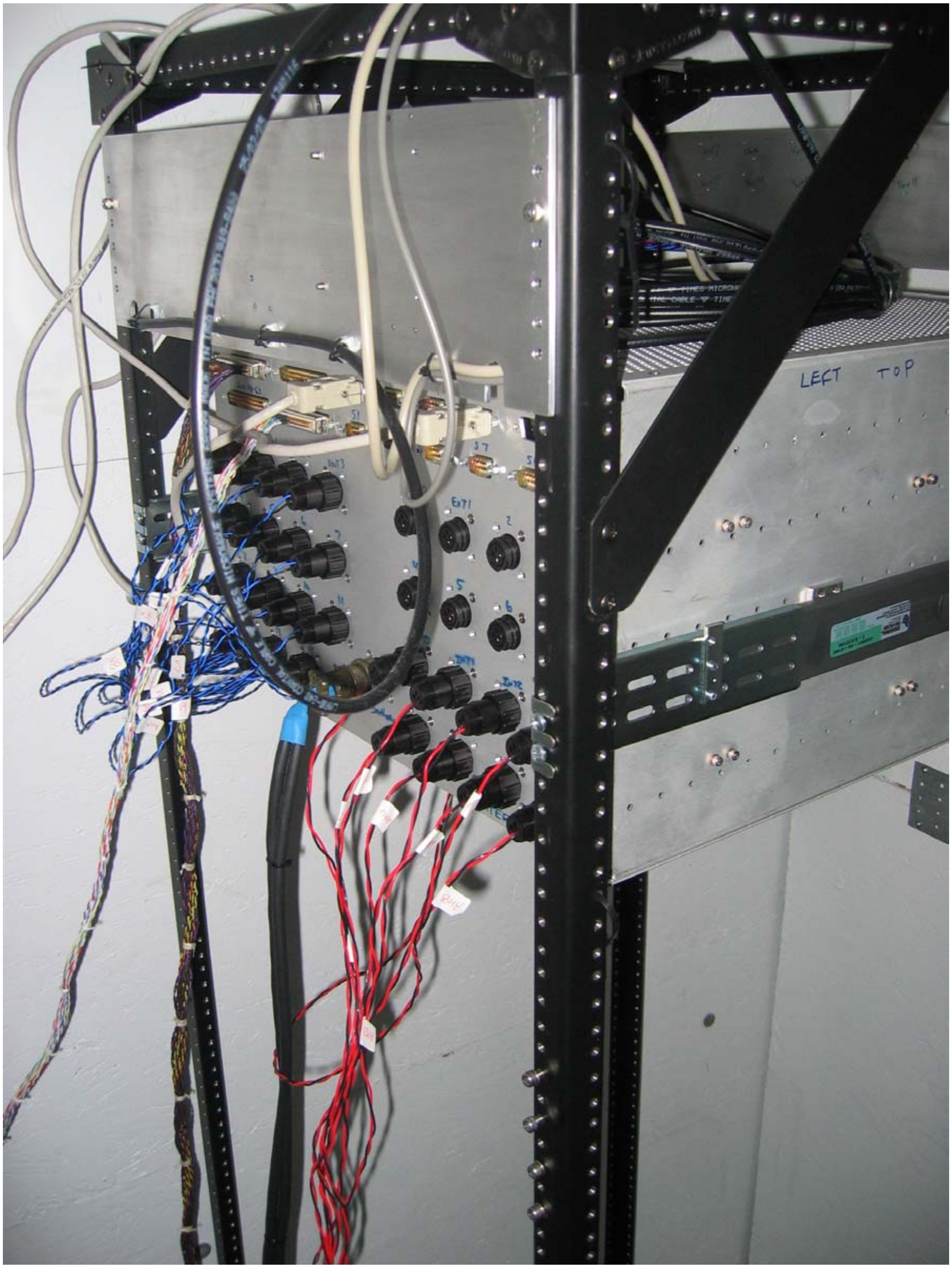


ARRO RELAY BOARD AND AMBIENT RESISTIVE HEATER

ARRO TEST DUMMY LOAD (TO SIMULATE 16 INSTRUMENTS DISSIPATING A TOTAL OF 50 WATTS)

ARRO BATTERY RACK AND SUNICA PLUS NICAD BATTERIES

5 GALLON POLYETHYLENE WATER JUGS



CONTROL RACK WITH SCU AND IRIDIUM MODEM INSTALLED

SUNICA PLUS BATTERIES: POST COLD SOAK TESTING

SUNICA BATTERIES IN COLD CHAMBER DURING COLD SOAK

APPENDIX E

ARRO PARTS LIST

The following appendix contains the following system documentation:

1) A complete parts list for all internal hardware for the ARRO system (excluding DAU and Burst mode assemblies)

SYSTEM CONTROL BOARD

PART REF	PART DESCRIPTION (PART NUMBER/DISTRIBUTOR)	PACKAGE	TEMP RANGE	#/PCB	UNIT COST
PCB	SCU PCB (PCPRO #ARRO128DR)			1	$271.91
Y1-Y2	1.8432MHz CRYSTAL (DIGI 535-9009-ND)	HC49U	-20, +70	2	$1.20
Y1-Y2	HC49U CRYSTAL INSULATOR (DIGI 492-1039-ND)	2-HOLE	-20, +70	2	$0.07
U1,U4-U19	ADG509A ANALOG MUX (DIGIKEY ADG509AKR-ND)	16-SOIC NARROW	-40, +85	17	$4.86
U2	INA114 INSTRUMENTATION AMP (DIGIKEY INA114BP-ND)	8-DIP	-40, +85	1	$9.50
U3	LF412 JFET OP AMP (DIGI LF412MH-ND)	T0-5	-55, +125	1	$9.07
U20-U27	PS2501L4 PHOTOCOUPLER (DIGI PS2501-4-ND)	16-DIP	-55, +100	8	$1.22
U28-U30	XC95108 PROG. LOGIC DEVICE (XILINX XC95108-20PC84I)	84PLCC	-40, +85	3	$12.65
U31, U32	TL16C554 ASYNCHRONOUS COMMUNICATIONS (ARROW TL16C554IFN)	68PLCC	-40, +85	2	$11.14
U33-U36	MAX3244 RS232 TRANSCEIVERS (MAXIM MAX3244EWI)	28 SOIC	-40, +85	4	$7.38
U37-U40	MAX 222 LINE DRIVERS (DIGI MAX222EWN-ND)	18 SOIC	-40, +85	4	$5.83
SOCKET	SOCKET FOR XC95108 (DIGI AE7345-ND)	84PLCC		3	$1.21
SOCKET	SOCKET FOR TL16C554 (DIGI AE7344-ND)	68PLCC		2	$1.04
ALL Q's	4401 SWITCHING TRANSISTOR (DIGI MMBT4401LT1OSCT-ND)	SOT-23	-55, +150	17	$0.06
D200+	IN4001 DIODES (DIGI 1N4001RLOSCT-ND)			32	$0.03
D1-D4	GREEN LED's (DIGI 160-1142-ND)			4	$0.12
SOCKET	LED SOCKETS (DIGI A460-ND) included on PDB PCB				
J1-J4	40 PIN HEADER (DIGI MHB40K-ND)			4	$2.20
J5,J6	34 PIN 0.05"HEADER (Z-WORLD 416-0011)	2x27 .05	-55, +105	2	$1.50
J7	10 PIN 0.05" HEADER (Z-WORLD 406-0026)	2x5 .05	-55, +105	1	$1.45
J8-J10	6 PIN MOLEX HEADER (DIGI WM4204-ND	6 .1"	-40, +105	3	$0.53
SOCKET	6 SOCKET CONNECTOR (DIGI WM2004-ND)	6 .1"		3	$0.42
CONTACTS	CONTACTS FOR 6 SOCKET CONNECTOR TIN (WM2200-ND)			18	$0.07
P1-P4	37PIN PCB MOUNT D-SUB (DIGI 1537MN-ND)		-55, +105	4	$4.96
P6-P13	9PIN PCB MOUNT D-SUB (DIGI 509M-ND)		-55, +105	8	$1.73
P14	25 PIN PCB MOUNT D-SUB (DIGI 525M-ND)		-55, +105	1	$3.07
RES (SEE SCH)	1.0kOHM RESISTOR (DIGI 311-1.0KACT-ND)	SM R0805	-55, +125	22	$0.08
R4	3.9kOHM RESISTOR (DIGI 311-3.9KACT-ND)	SM R0805	-55, +125	1	$0.08
RES (SEE SCH)	1/8W 10kOHM RESISTOR (DIGI 10KEBK-ND)	THRU RES18		8	$0.06
R18	1/8W 51kOHM RESISTOR (DIGI 51KEBK-ND)	THRU RES18		1	$0.06
RES (SEE SCH)	10.0kOHM RESISTOR NETWORK (DIGI 4816P-1-103-ND)	SM	-55, +125	16	$0.83
RES (SEE SCH)	4.3kOHM 1W 5% METAL OXIDE RESISTOR (DIGI P4.3KW-1BK-ND)	THRU	-55, +125	16	$0.01
RES (SEE SCH)	1kOHM SIP RESISTOR (DIGI 4306R-1-102-ND)	THRU	-55, +125	4	$0.42
R311, R321	1MOHM 1/8W RESISTOR (DIGI 1.0MEBK-ND)	THRU	-55, +125	2	$0.06
R312, R322	1.5kOHM 1/8W RESISTOR (DIGI 1.5KEBK-ND)	THRU	-55, +125	2	$0.06
CAP(SEE SCH)	22uF KEMET TANTALUM CHIP CAPACITOR (DIGI 399-1657-1-ND)	SM-X		14	
CAP(SEE SCH)	0.1uF PANASONIC X7R 50V CAPACITOR (DIGI PCC2239CT-ND)	C1206	-55, +125	224	$0.23
CAP(SEE SCH)	0.01uF PANASONIC X7R 50V CAPACITOR (DIGI PCC1784CT-ND)	C0603	-55, +125	16	$0.05
C325, C315	22pF CAPACITOR (DIGI PCC220ACVCT-ND)	C0603	-55, +125	2	$0.05

C326,C316	56pF CAPACITOR (DIGI PCC560ACVCT-ND)	C0603	-55, +125	2	$0.06
CAP(SEE SCH)	0.68uF CAPACITOR (DIGI PCC1892CT-ND)	C1206	-55, +125	12	$0.30

POWER DISTRIBUTION BOARD

PCB	PDB PCB (PCPRO #ARRO127DR)			1	$271.91
CAP(SEE SCH)	0.1uF PANASONIC X7R 50V CAPACITOR (DIGI PCC2239CT-ND)	C1206	-55, +125	41	$0.23
CAP(SEE SCH)	22uF KEMET TANTALUM CHIP CAPACITOR (DIGI 399-1657-1-ND)	SM-X		7	$0.16
C41, C42	47uF ELECTROLYTIC CAPACITOR	THRU	-55, +125	2	$4.49
D1-D33	GREEN LED's (DIGI 160-1142-ND)			32	$0.12
SOCKET	LED SOCKETS (DIGI A460-ND)			36	$0.12
J1-J4	40 PIN HEADER (DIGI MHB40K-ND)			4	$2.20
Q1-Q16, Q18-Q33	G3TC TRIAC DRIVERS (DIGI Z2031-ND)	THRU	-30, +80 **	32	$14.18
Q17, Q34	4401 SWITCHING TRANSISTOR (DIGI MMBT4401LT1OSCT-ND)	SOT-23	-55, +150	2	$0.06
RES(SEE SCH)	69.8kOHM 1/8W 1% RESISTOR (DIGI P69.8KFCT-ND)	R1206	-55, +125	18	$0.06
RES(SEE SCH)	10.0kOHM 1/8W 1% RESISTOR (DIGI P10.0KFCT-ND)	R1206	-55, +125	50	$0.06
R21, R119	1.0kOHM 1/8W 1% RESISTOR (DIGI P1.00KFCT-ND)	R1206	-55, +125	2	$0.06
RES(SEE SCH)	24.9kOHM 1/8W 1% RESISTOR (DIGI P24.9KFCT-ND)	R1206	-55, +125	16	$0.06
RES(SEE SCH)	0.3OHM 1W 1% RESISTOR (DIGI PT.30YCT-ND)	R2512		16	$0.68
T1	40OHMS 4A COMMON MODE CHOKE (DIGI 240-1101-1-ND)	SMT		1	$0.91
U1-U16	INA140 BI-DIRECTIONAL SHUNT MONITOR (DIGI INA170EA/2K5CT-ND)	MSOP-8	-40, +85	16	$2.25
U18	3.3V DC-DC CONVERTER (LINEAR TECHNOLOGY LT1117IST-3.3)	SOT223	-40, +125	1	$2.52
U17	5V 15W POWER-ONE LES015 DC-DC CONVERTER (DIGI 179-2124-ND)	THRU	-40, +100	1	$66.00
U19	+/-15V 20W POWER-ONE DFA20E24D15 DC-DC CONVERTER (DIGI 179-1049-ND)	THRU	-40, +90	1	$105.50
R120	10.0K 1/16W 0.1% 0603 RESISTOR	R0603		1	$0.58
U20	AD590 TEMP TRANDUCER TO-52 2 TERMINAL	THRU		1	$7.10
FUSE	HEATER LOAD RESETTABLE 2.5A HOLDING FUSES (DIGI MF-RX250-ND)	THRU		16	$0.61
FUSE	INSTRUMENT RESETTABLE 0.5A HOLDING FUSES (DIGI MF-R050-ND)	THRU		16	$0.50
CONNECTOR	2-PIN CONNECTOR HEADER (DIGI WM4200-ND)	THRU		1	$0.27
CONNECTOR	2-PIN HOUSING W/RAMP/RIB (DIGI WM2000-ND)	THRU		1	$0.21
CONNECTOR	FEMALE CONTACTS FOR 2-PIN CONNECTOR 22-30AWG (DIGI WM2200-ND)			2	$0.06
***	HUMIDITY RANGE ON G3TC (45-85%)				

HEATER POWER SYSTEM

PCB	HEATER RELAY BOARD			1	$76.41
RELAYS	10AMP DC SSR RELAYS (DIGI CC1125-ND)			8	$28.32
REGULATOR	28V IN 5V OUT VOLTAGE REGULATOR LM140 (DIGI LM140K-5.0-ND)			1	$7.29
REGULATOR	HEATSINK FOR LM140 (DIGI HS140-ND)			1	$1.50
C1	0.22uF CAPACITOR (DIGI 399-2094-ND)			1	$0.68
C2	0.1uF CAPACITOR (DIGI 399-2074-ND)			1	$0.25

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R1-R8	10K SM RESISTOR (DIGI P10.0KFCT-ND)			8	$0.07
D1	1N4001 DIODE (DIGI 1N4001RLOSCT-ND)			1	$0.13
LED2-9	3MM GREEN DIFFUSED LED (DIGI 160-1142-ND)			8	$0.11
T-BLOCK	TERMINAL BLOCK 2.54MM 8 POSITION HTR OUTPUT (DIG 277-1279-ND)			4	$4.61
T-BLOCK	TERMINAL BLOCK 10.16M 4 POSITION 60AMP POWER INPUT (DIGI WM5966-ND)			1	$7.99
FUSES	RESETTABLE 5AMP HOLDING FUSES (DID MF-R500-ND)			8	$0.72
CONNECTOR	DB25S RIGHT ANGLE CONNECTOR (STOCK)			1	
CONNECTOR	DB25P SOLDER CUP CONNECTOR (DIGI 125M-ND)			1	$3.28
CABLE	8AWG 4 CONDUCTOR SOOW CABLE (MSC 31739790)			10'	$1.80
CABLE	20AWG TWISTED PAIR TEFLON CABLE (STOCK)			162'	
CONNECTOR	FEMALE QUICK-DISCONNECTS FOR WATER JUG HEATERS (MCM 7243K112)			32	$0.25
CONNECTOR	MALE QUICK-DISCONNECTS FOR WATER JUG HEATERS (MCM 7243K118)			32	$0.26
JUGS	5 GALLON POLYETHLENE STORAGE PAIL (MCM 4135T132)			16	$21.16
TEMP SENSOR	AD590 TEMP TRANSDUCERS FLAT PACK 2-TERMINAL (DIGI AD590JF-ND)			14	$14.38
CONNECTOR	AMBIENT HEATER/DUMMY LOADS CONNECTORS (DIGI A1357-ND)			20	$2.08
CONNECTOR	MALE CONTACTS 20-24AWG CRIMP (DIGI A1357-ND)			50	$0.38
CONNECTOR	CONNECTOR STRAIN RELIEF (DIGI A1330-ND)			2	$2.76
HEATERS	IMMERSIBLE 100W 24V HEATERS (ATLANTIC THERMAL EM75-12.62/01)			16	
HEATERS	HUNTINGTON ELECTRIC AMBIENT HEATERS (DIGI FVT100-10-ND)			8	$6.33
SCU/PDB E-BOX PARTS					
HOUSING	TECHMAR ENCLOSURES (BK-10H-18D-WHR-2PC-BAH)			1	$186.00
HOUSING SLIDE	TECHMAR ENCLOSURES SOLID BEARING SLIDE (QDLS-SB-16/22)			1	$61.00
CONNECTOR	BATTERY POWER INPUT CABLE CONNECTOR (DIGI 97-3106A-14S-2S-ND)			1	$14.63
CONNECTOR	BATTERY POWER CABLE CONNECTOR CLAMP (DIGI 97-3057-1007-ND)			1	$6.16
CONNECTOR	BATTERY POWER INPUT CONNECTOR (DIGI 97-3100A-14S-2P-ND)	PANEL MOUNT		1	$15.15
CONNECTOR	INSTRUMENT OUTPUT POWER CONNECTOR (DIGI A1360-ND)	PANEL MOUNT		16	$1.72
CONNECTOR	HEATER OUTPUT POWER CONNECTORS (DIGI A1360-ND)	PANEL MOUNT		16	$1.72
CONTACTS	CONNECTOR CONTACT SOCKETS 20-24AWG (DIGI A1343-ND)	PANEL MOUNT		128	$0.47
CONNECTOR	JACK SOCKETS FOR D-SUBS SHORT (DIGI MDVS44-ND)			15	$1.77
CONNECTOR	INSTRUMENT POWER CABLE CONNECTOR (DIGI A1357-ND)			2 FOR TESTING	$2.07
INST	INSTRUMENT POWER CONNECTOR PINS (DIGI A1648-ND)			8	$0.49
CABLE	16AWG 2 CONDUCTOR SJEOOW POWER CABLE (MSC 60540168)			50'	$0.37
IRIDIUM MODEM HARDWARE					
MODEM	NAL RESEARCH IRIDIUM MODEMS A3LA-D			2	$1,050.00
POWER	DC-DC CONVERTER SYN-DC-936			1	$170.00
POWER	AC-DC CONVERTER LA-2098			1	$150.00
CABLE	30' ANTENNAE CABLE LMR240-30			2	$60.00
ANTENNAE	MAST MOUNT ANTENNAE SAF5350B			2	$200.00

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INSTRUMENT RACKS					
RACKS	19" RACK HARDWARE (Star Case #RFMPA)			2	$119.95
RACKS	19" RACK DEPTH RAILS (Star Case #RFC08RU)			2	$24.95
RACKS	19" RACK HEIGHT RAILS (Star Case #RFC35RU)			2	$84.95
RACKS	19" RACK BRACES (Star Case #RFBRACES)			4	$29.95
SOLAR POWER SYSTEM					
SOLAR	SOLAR PANELS KYOCERA KC120 (WHOLESALE SOLAR 1101200)			6	$502.00
CONTROLLER	XANTREX TRACE C40 CHARGE CONTROLLER (WHOLESALE SOLAR)			1	$130.00
TEMP SENSOR	XANTREX TRACE BATTERY TEMP SENSOR BTS-15 (WHOLESALE SOLAR)			1	$25.00
CABLE	PANEL TO PANEL CABLE 12/2 SJEOOW 300 VOLT (MSC 60540267)			100'	$0.63
CABLE	COMBINER TO INSIDE CABLE 6/3 SOOW (MSC 31739808)			30'	$1.90
CONNECTOR	RING TERMINAL CONNECTOR 12 AWG (MSC 54040209)			50	$0.14
SWITCH	SOLAR DISCONNECT SWITCH (AFFORDABLE SOLAR #226)			1	$50.86
COMBINER	COMBINER BOX XANTREX TCB-6 (ALTERNATIVE ENERGY STORE XANTCB6)			1	$180.20
CABLE	CABLE GRIPS FOR KC120 PANELS (DIGI 288-1179-ND)			12	$1.49
CABLE	CABLE GRIPS FOR COMBINER/SWITCH/CONTROLLER (DIGI 288-1183-ND)			5	$3.63
CHASSIS	GROUNDING BAR (MCMASTER 71375K71)			1	$70.20
CHASSIS CABLE	ARCTIC ULTRAFLEX 14AWG GREEN (POLAR WIRE PRODUCTS)			100'	$0.16
D-BLOCK	1 LINE 6 LOADS SINGLE POLE DISTRIBUTION BLOCK (MSC 54014907)			2	$29.30
T-BLOCK	16-POLE TERMINAL STRIPS 3/8"C/C (MCM 7527K55)			3	$3.80
T-BLOCK	TERMINAL BLOCK JUMPERS (MCM 7527K59)			32	$0.08
CONNECTOR	RING TERMINAL 14-16AWG 1/4"STUD SOLAR PANEL CHASSIS (MCM 7113K456)			50	$0.19
CONNECTOR	RING TERMINAL 6AWG #10STUD INTERNAL CHASSIS (MCM 7113K365)			50	$0.19
WIND POWER SYSTEM					
TURBINE	NORTHERN POWER HR3 WIND TURBINE			1	
TOWER	NORTHERN POWER HR3 TOWER			1	
REGULATOR	NORTHERN POWER HR3 COLD WEATHER REGULATOR			1	
BATTERY STORAGE COMPONENTS					
BATTERIES	SAFT NI-CAD SUNICA PLUS 370-2			30	
CONNECTORS	BATTERY TERMINAL CONNECTOR LUGS 4AWG (MCM 7106K53)			13	$0.73
CABLE	BATTERY CABLE 4AWG BLACK (MCM 6948K22)			10'	$1.26
CABLE	BATTERY CABLE 4AWG RED (MCM 6948K62)			20'	$1.26
CABLE	BATTERY CABLE 2AWG RED (MCM 6948K714)			10'	$1.83
CABLE	BATTERY CABLE 2AWG BLACK (MCM 6948K713)			10'	$1.83
CRIMPER	TERMINAL JUG CRIMPER (MCM 7061K12)			1	$28.91

D-BLOCK	2-POLE DISTRIBUTION BLOCK 1 LINE - 4 LOADS (MCM 7626K42)			1	$20.26
UNH MANUFACTURED PARTS					
SOLAR/WIND	ALUMINUM ANGLE STOCK FOR WALL MOUNTING HARDWARE (MCM 88805K42)			4	$7.71
BATTERY	ALUMINUM PLATE STOCK FOR BATTERY RACKS (YARDE 6061-T651-PL)			2	$333.00
BATTERY	ALUMINUM TUBE STOCK FOR BATTERY RACKS (YARDE 6061-T6-RT)			3	$58.00
MISCELLANEOUS PARTS					
CABLE TIES	SMALL BLACK NYLON CABLE TIES (DIGI PLT.7M-M0)			1000	$0.04
CABLE TIES	4" LONG BLACK NYLON CABLE TIES (MCM 7130K52)			100	$0.16
CABLE TIES	5.5" LONG BLACK NYLON CABLE TIES (MCM 7130K53)			100	$0.35
DUMMY LOADS	150 OHM 1% 5W ALUM HOUSED RESISTOR (DIGI RHA-150-ND)			16	$4.43
CLAMPS	CABLE CLAMPS 1"DIA (DIGI 8134K-ND)			10	$0.42
CLAMPS	CABLE CLAMPS 3/4"DIA (DIGI 8130K-ND)			10	$0.38
CLAMPS	CABLE CLAMPS 1/2"DIA (DIGI 8126K-ND)			10	$0.34
LIGHTS	3 LED COMET 24VDC LIGHT (THE LED LIGHT .COM #H COMET 3)			2	$32.65
SCREWS	#6 3/4"LONG WOOD SCREWS (MCM 93360A110)			100	$0.08

APPENDIX F

ARRO ELECTRICAL DOCUMENTATION

The following appendix contains the following system documentation:

1) Schematics of System Controller Unit Processor Board

2) Schematics of System Controller Unit Power Distribution Board

SCU CONTROLLER BOARD

SYS_CTRL

SCHEMATIC B

UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER		
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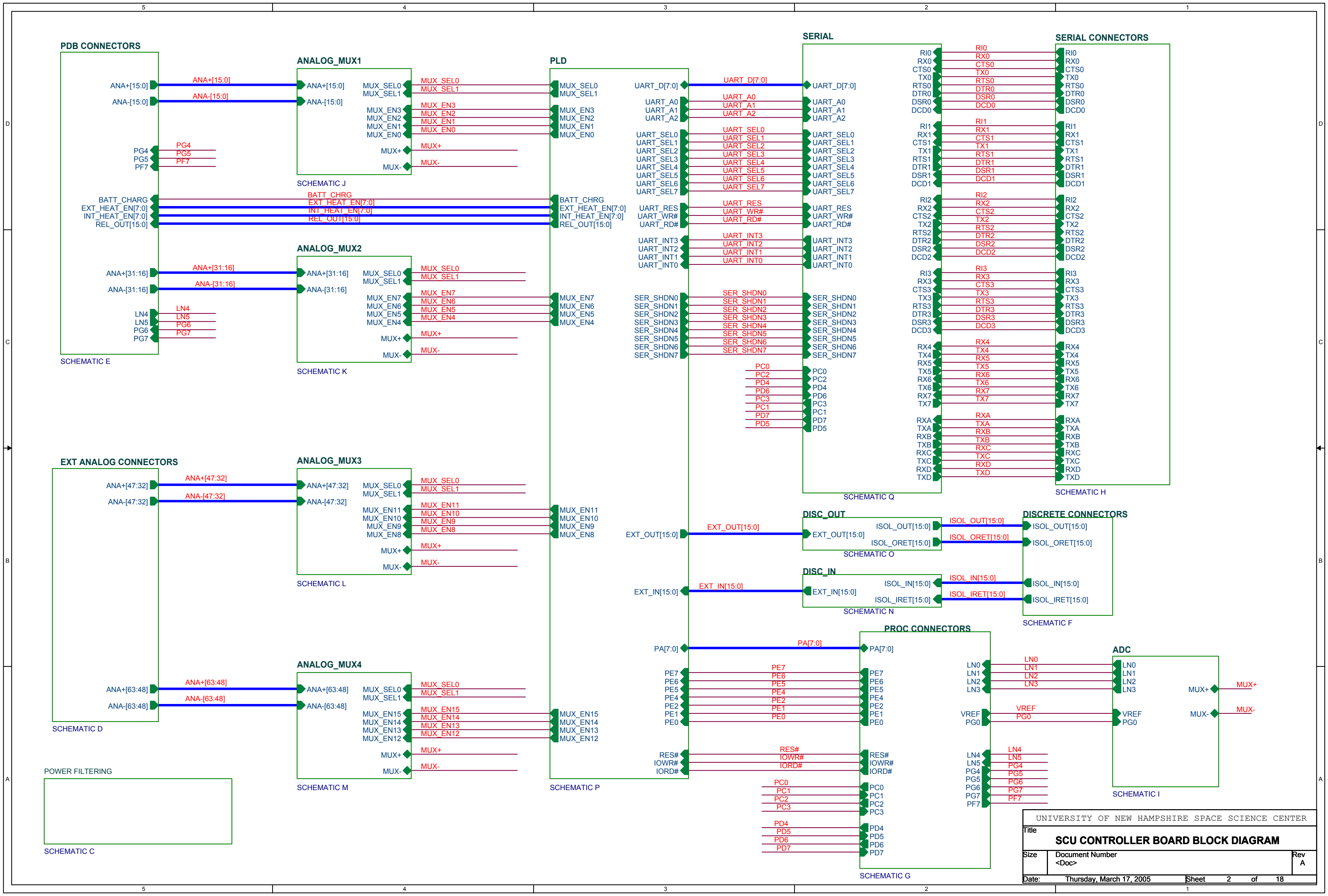
Size B	Document Number <Doc>	Rev A
Date: Thursday, January 27, 2005	Sheet 1 of 18	

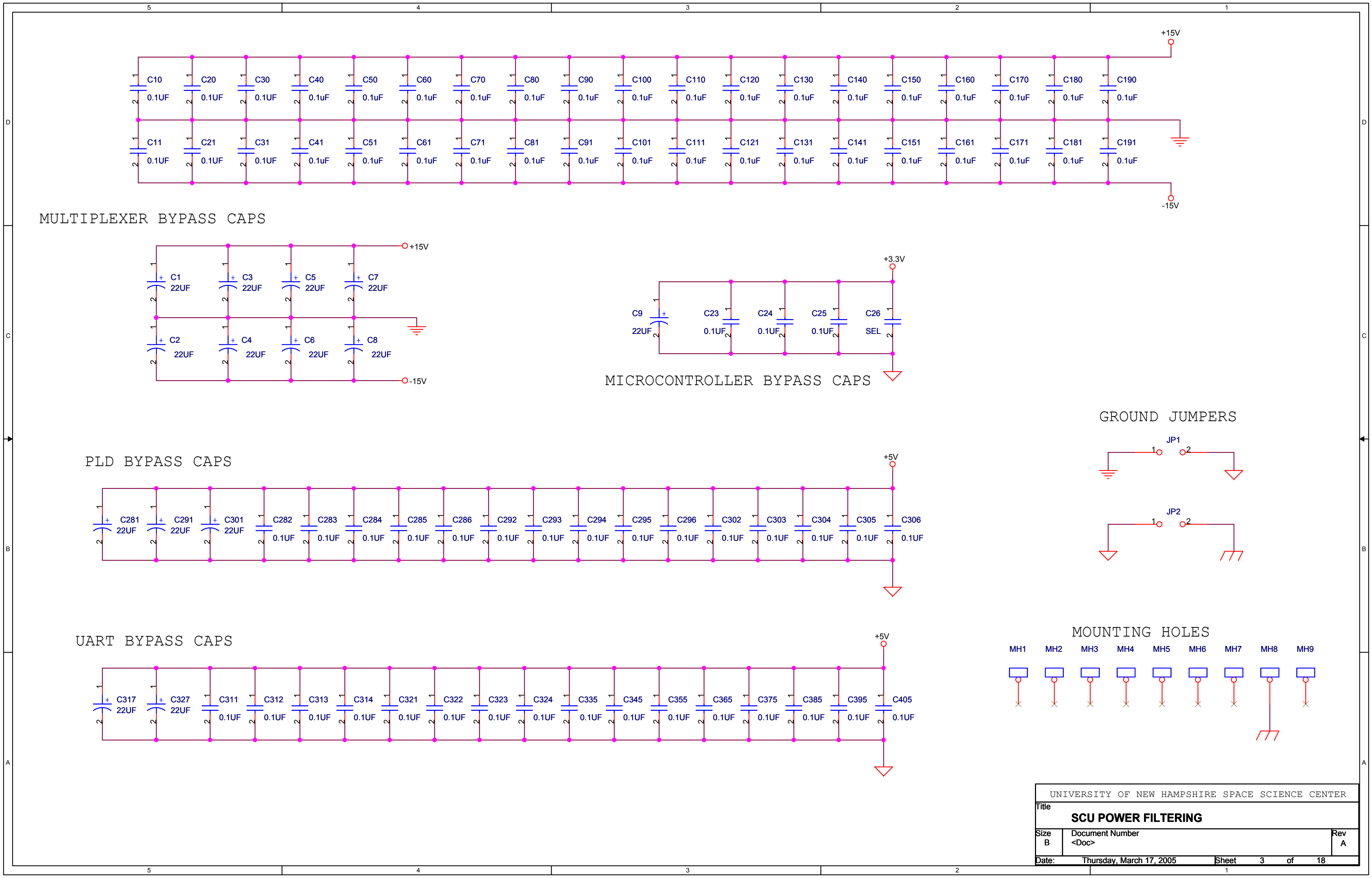


UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title: SCU CONTROLLER BOARD BLOCK DIAGRAM

Size | Document Number <Doc> | Rev A

Date: Thursday, March 17, 2005 | Sheet 2 of 18



+15V
C10 0.1UF
C20 0.1UF
C30 0.1UF
C40 0.1uF
C50 0.1uF
C60 0.1uF
C70 0.1uF
C80 0.1uF
C90 0.1uF
C100 0.1uF
C110 0.1uF
C120 0.1uF
C130 0.1uF
C140 0.1uF
C150 0.1uF
C160 0.1uF
C170 0.1uF
C180 0.1uF
C190 0.1uF
C11 0.1UF
C21 0.1UF
C31 0.1UF
C41 0.1UF
C51 0.1UF
C61 0.1UF
C71 0.1uF
C81 0.1uF
C91 0.1uF
C101 0.1uF
C111 0.1uF
C121 0.1uF
C131 0.1uF
C141 0.1uF
C151 0.1uF
C161 0.1uF
C171 0.1uF
C181 0.1uF
C191 0.1uF
-15V
MULTIPLEXER BYPASS CAPS
+15V
C1 22UF
C3 22UF
C5 22UF
C7 22UF
C2 22UF
C4 22UF
C6 22UF
C8 22UF
-15V
+3.3V
C9 22UF
C23 0.1UF
C24 0.1UF
C25 0.1UF
C26 SEL
MICROCONTROLLER BYPASS CAPS
GROUND JUMPERS
JP1
JP2
PLD BYPASS CAPS
+5V
C281 22UF
C291 22UF
C301 22UF
C282 0.1UF
C283 0.1UF
C284 0.1UF
C285 0.1UF
C286 0.1UF
C292 0.1UF
C293 0.1UF
C294 0.1UF
C295 0.1UF
C296 0.1UF
C302 0.1UF
C303 0.1UF
C304 0.1UF
C305 0.1UF
C306 0.1UF
UART BYPASS CAPS
+5V
C317 22UF
C327 22UF
C311 0.1UF
C312 0.1UF
C313 0.1UF
C314 0.1UF
C321 0.1UF
C322 0.1UF
C323 0.1UF
C324 0.1UF
C335 0.1UF
C345 0.1UF
C355 0.1UF
C365 0.1UF
C375 0.1UF
C385 0.1UF
C395 0.1UF
C405 0.1UF
MOUNTING HOLES
MH1 MH2 MH3 MH4 MH5 MH6 MH7 MH8 MH9
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
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SCU POWER FILTERING
Size B
Document Number <Doc>
Rev A
Date: Thursday, March 17, 2005
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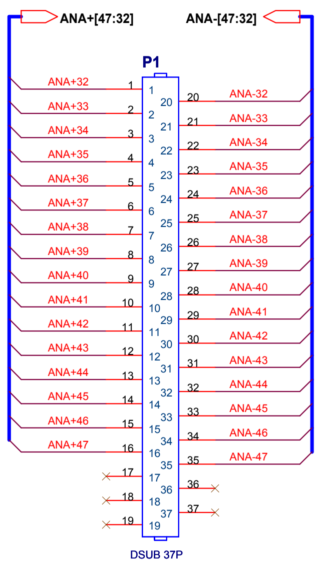
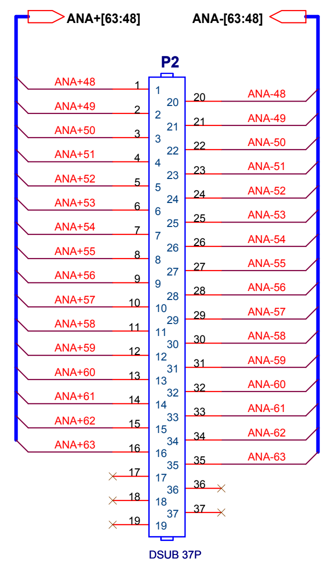
SYSTEM HOUSKEEPING ANALOG INPUTS





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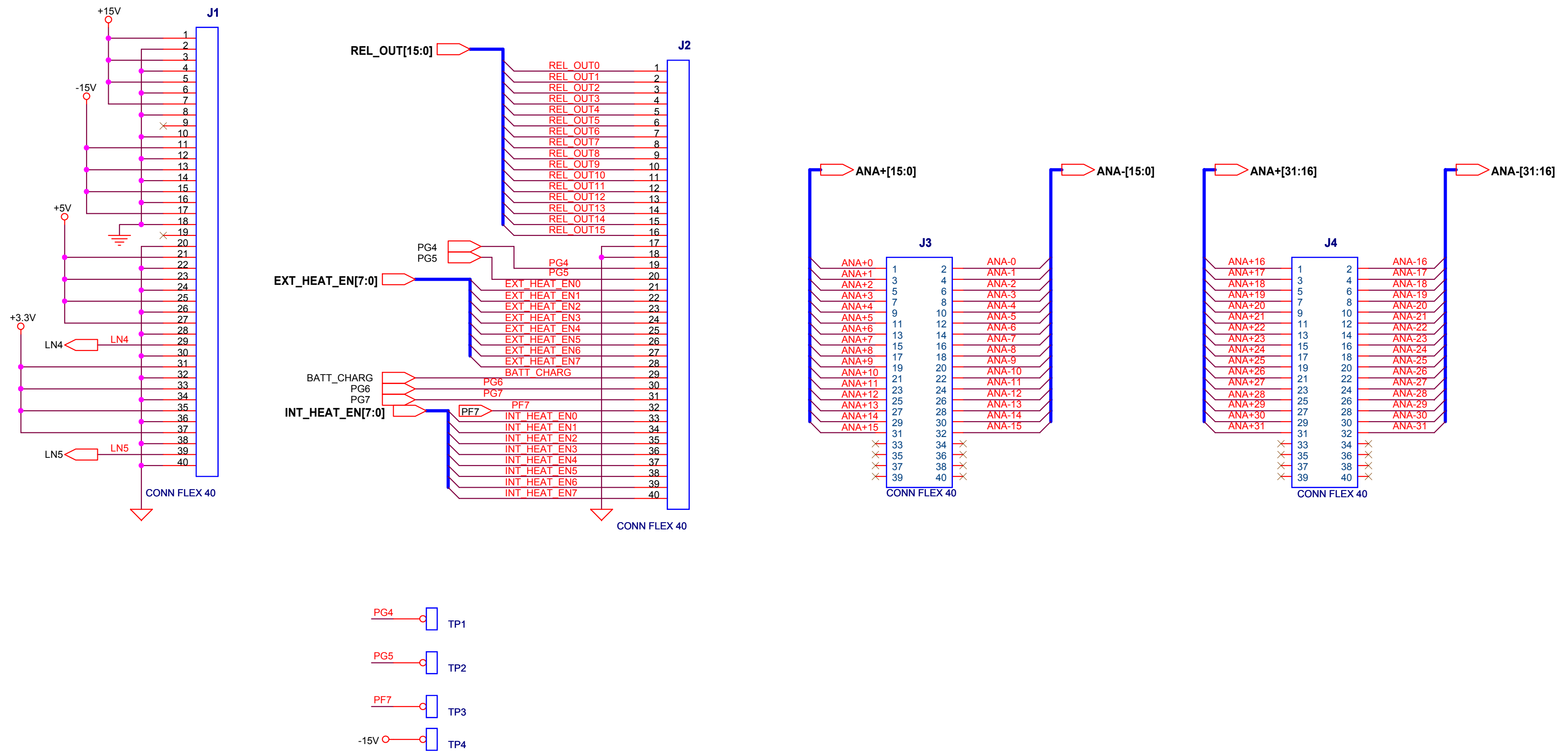

UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title
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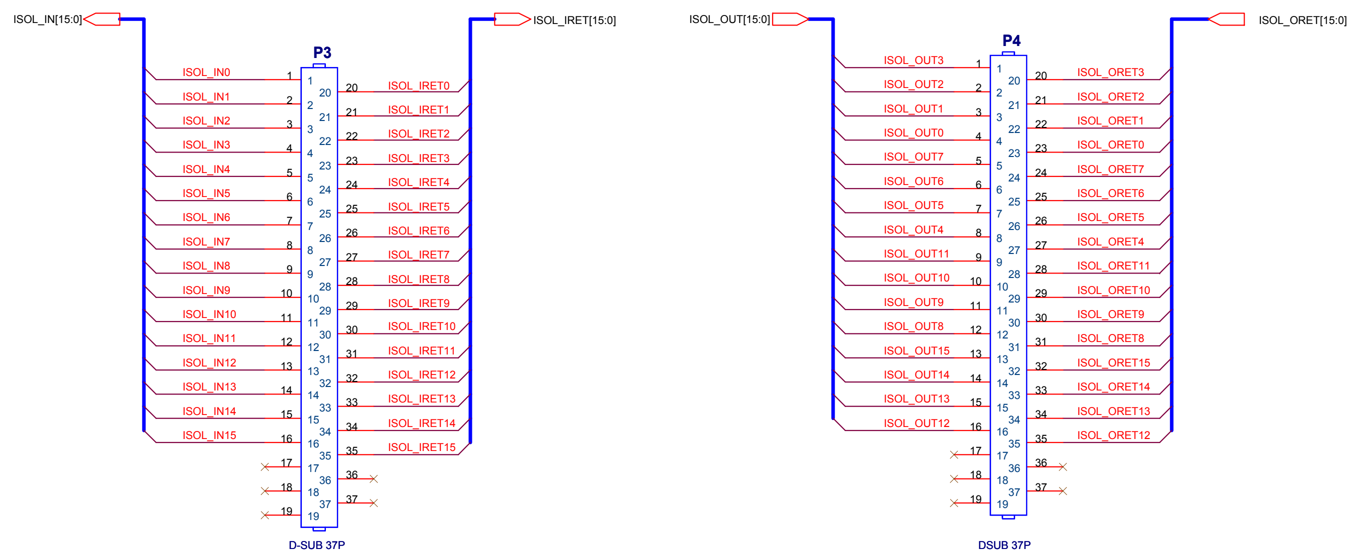
Size	Document Number	Rev
B	<Doc>	A

Date: Thursday, March 17, 2005 Sheet 5 of 18



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER			
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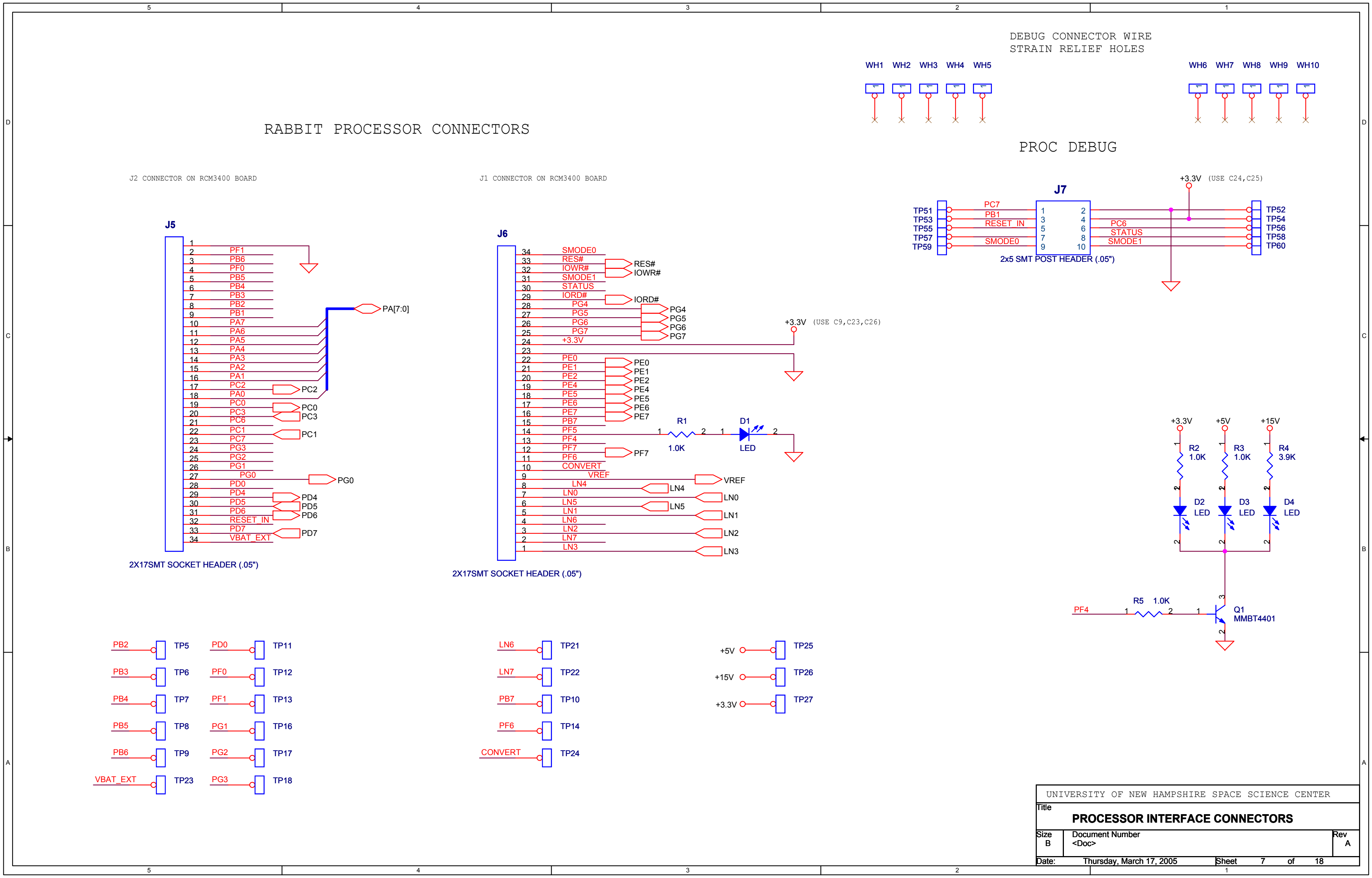
DEBUG CONNECTOR WIRE
STRAIN RELIEF HOLES
WH1 WH2 WH3 WH4 WH5
WH6 WH7 WH8 WH9 WH10
RABBIT PROCESSOR CONNECTORS
PROC DEBUG
J2 CONNECTOR ON RCM3400 BOARD
J1 CONNECTOR ON RCM3400 BOARD
J5
PF1 PB6 PF0 PB5 PB4 PB3 PB2 PB1 PA7 PA6 PA5 PA4 PA3 PA2 PA1 PC2 PA0 PC0 PC3 PC6 PC1 PC7 PG3 PG2 PG1 PG0 PD0 PD4 PD5 PD6 RESET_IN PD7 VBAT_EXT
PA[7:0]
2X17SMT SOCKET HEADER (.05")
J6
SMODE0 RES# IOWR# SMODE1 STATUS IORD# PG4 PG5 PG6 PG7 +3.3V PE0 PE1 PE2 PE4 PE5 PE6 PE7 PB7 PF5 PF4 PF7 PF6 CONVERT VREF LN4 LN0 LN5 LN1 LN6 LN2 LN7 LN3
2X17SMT SOCKET HEADER (.05")
+3.3V (USE C9,C23,C26)
R1 1.0K
D1 LED
J7
TP51 TP53 TP55 TP57 TP59
TP52 TP54 TP56 TP58 TP60
PC7 PB1 RESET_IN SMODE0 PC6 STATUS SMODE1
2x5 SMT POST HEADER (.05")
+3.3V (USE C24,C25)
+3.3V +5V +15V
R2 1.0K
R3 1.0K
R4 3.9K
D2 LED
D3 LED
D4 LED
PF4
R5 1.0K
Q1 MMBT4401
PB2 TP5
PB3 TP6
PB4 TP7
PB5 TP8
PB6 TP9
VBAT_EXT TP23
PD0 TP11
PF0 TP12
PF1 TP13
PG1 TP16
PG2 TP17
PG3 TP18
LN6 TP21
LN7 TP22
PB7 TP10
PF6 TP14
CONVERT TP24
+5V TP25
+15V TP26
+3.3V TP27
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
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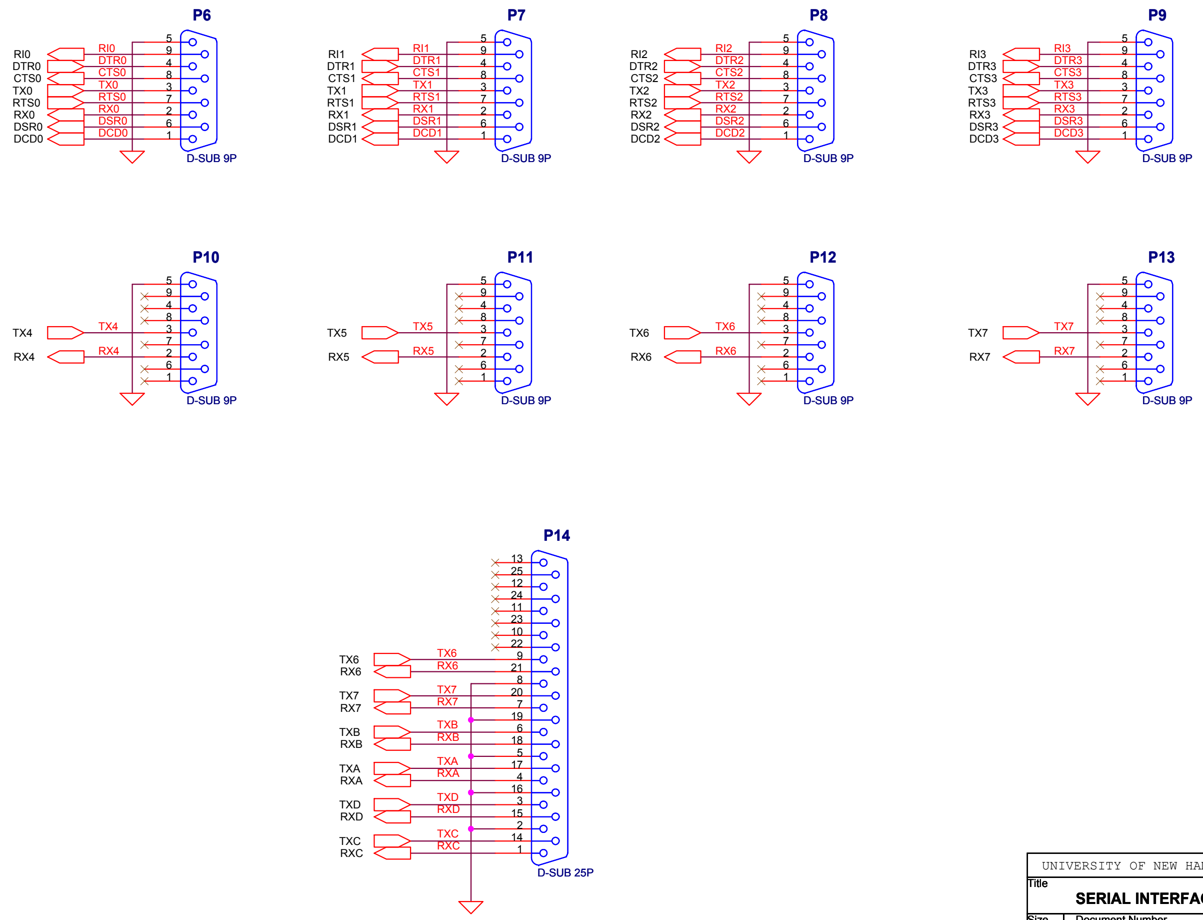
Size B
Document Number <Doc>
Rev A
Date: Thursday, March 17, 2005
Sheet 7 of 18



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

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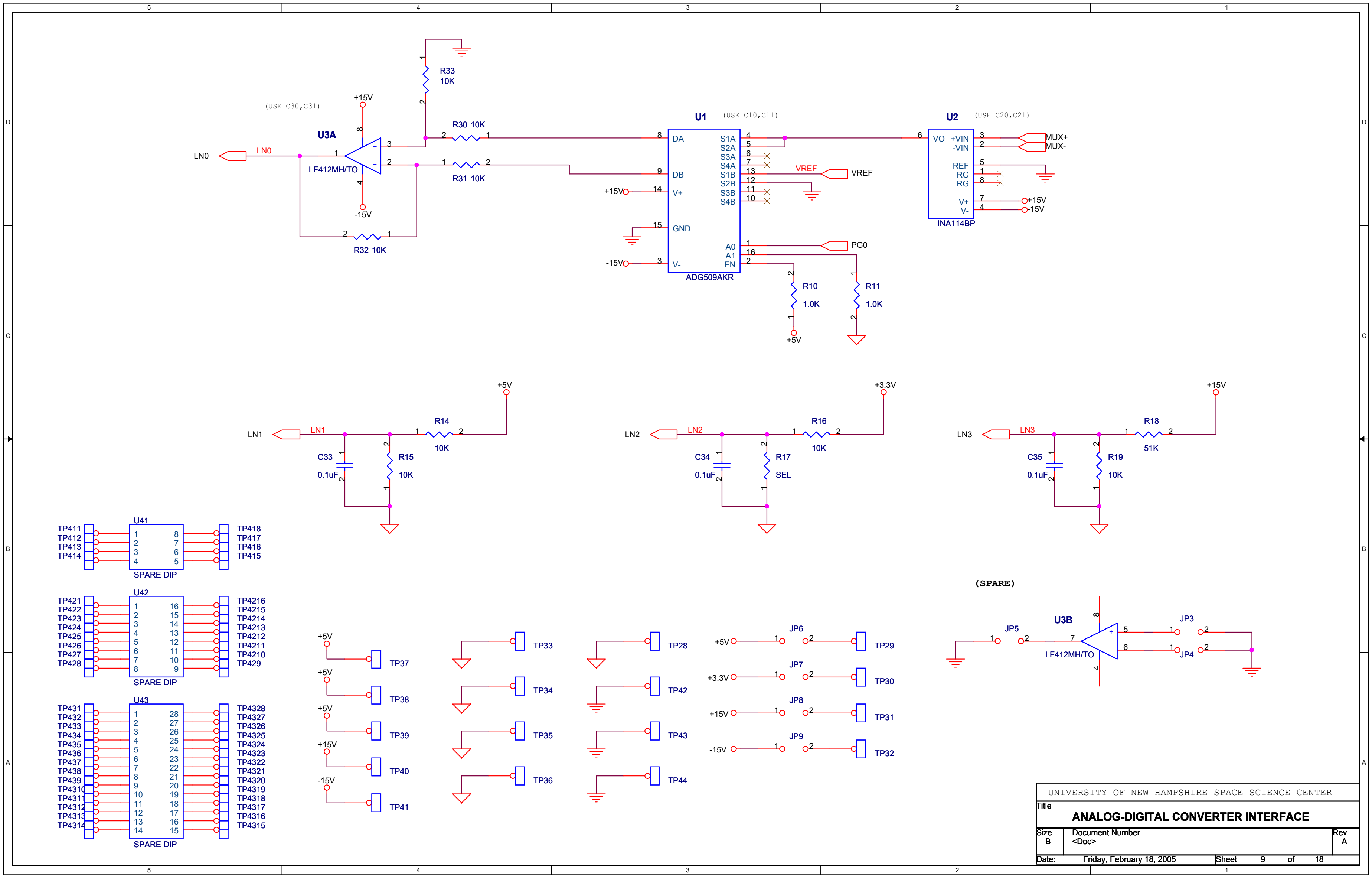


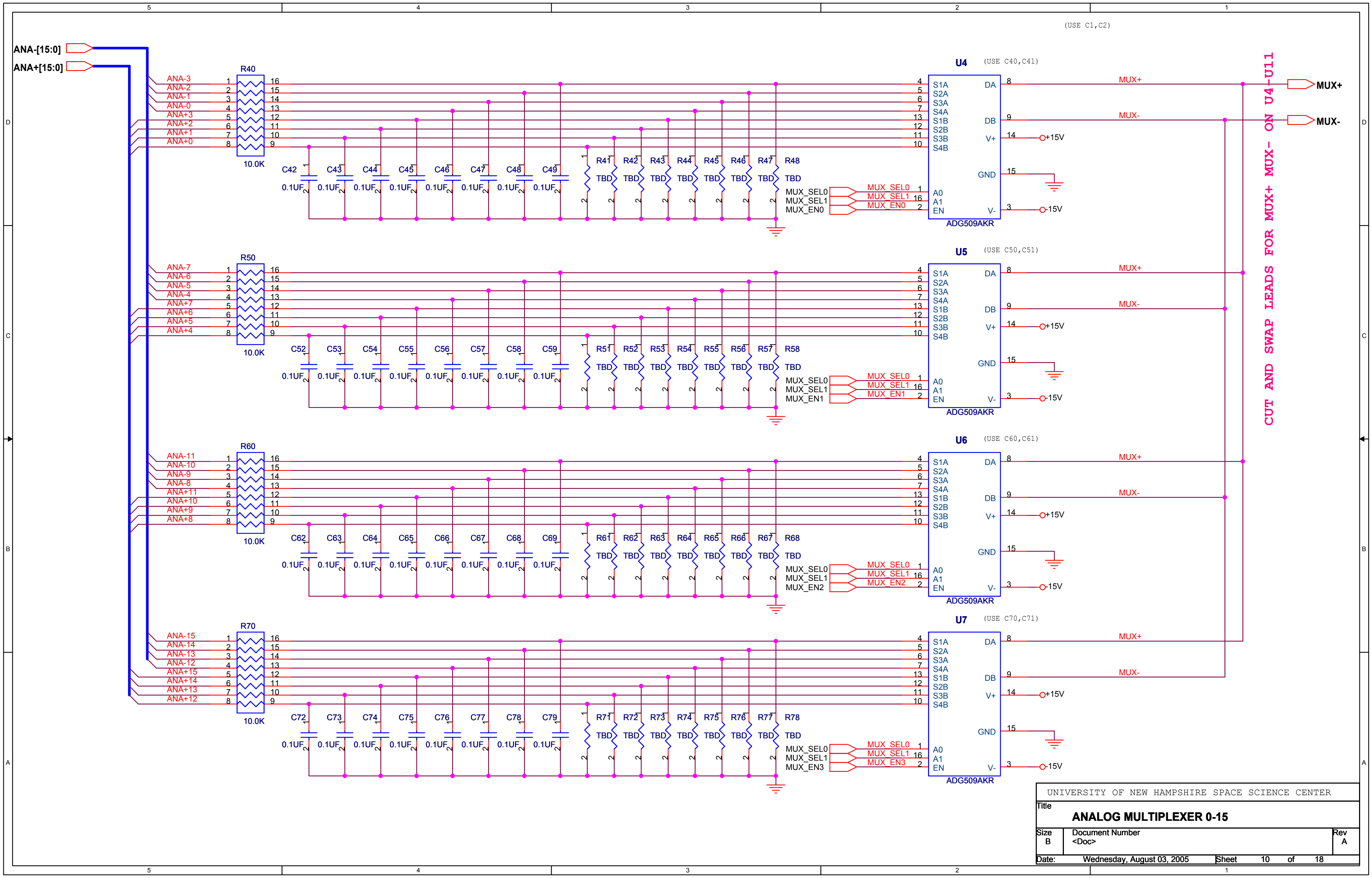
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title

ANALOG-DIGITAL CONVERTER INTERFACE

Size	Document Number	Rev
B	<Doc>	A

Date: Friday, February 18, 2005 Sheet 9 of 18



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

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Size	Document Number	Rev
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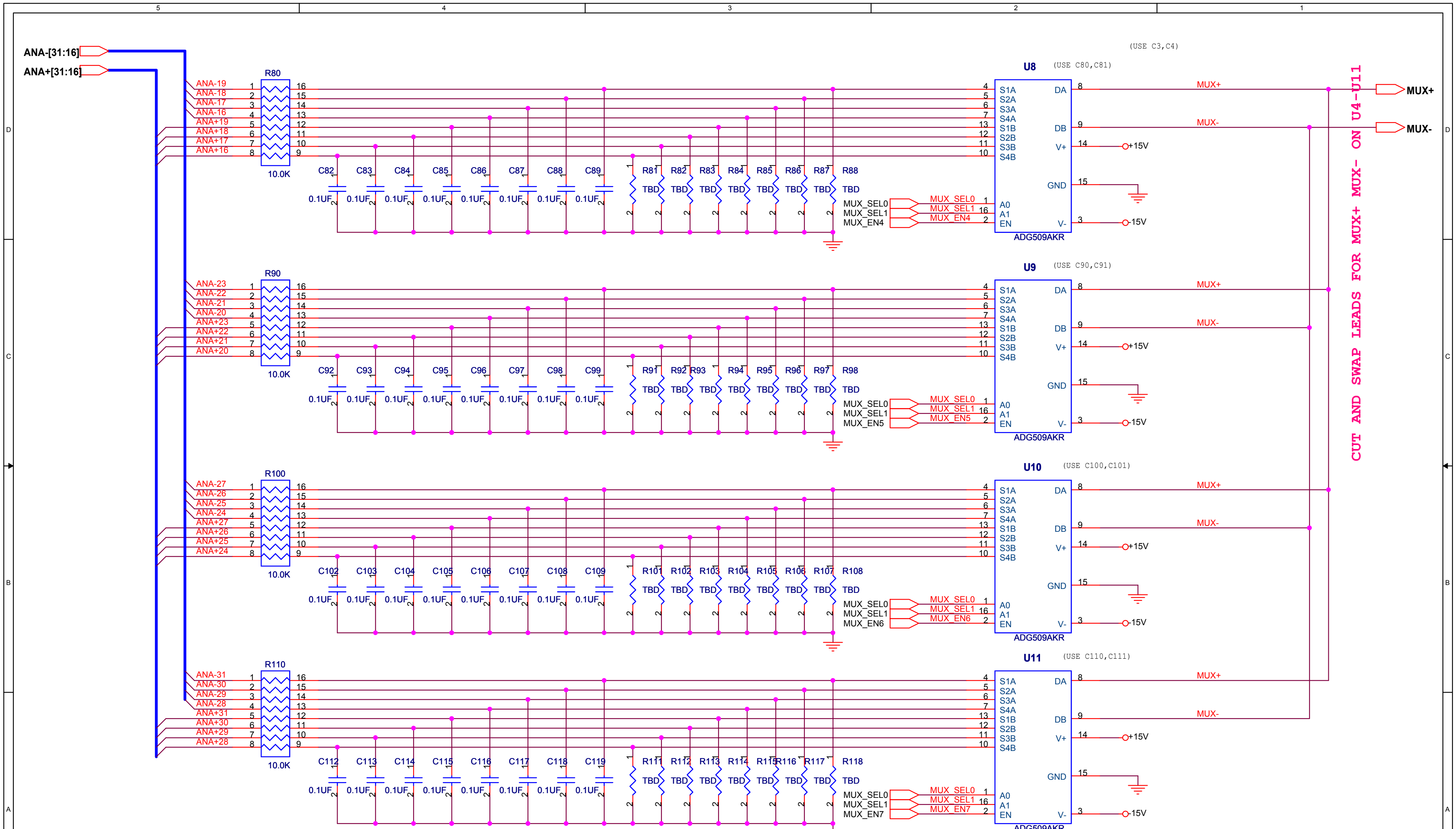
Date: Wednesday, August 03, 2005 | Sheet 10 of 18



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

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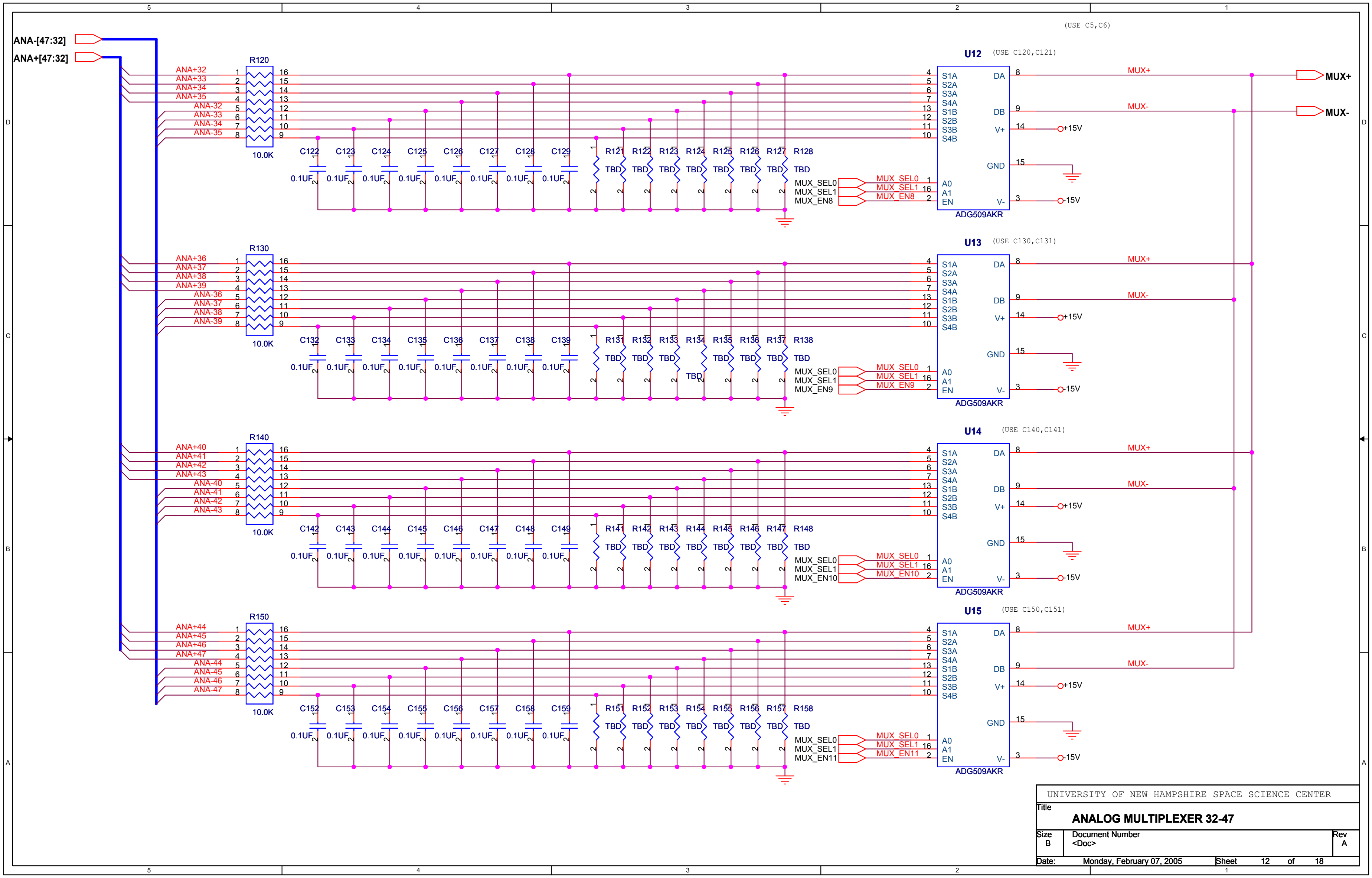

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ANA+[47:32]
R120
R130
R140
R150
10.0K
ANA+32
ANA+33
ANA+34
ANA+35
ANA-32
ANA-33
ANA-34
ANA-35
ANA+36
ANA+37
ANA+38
ANA+39
ANA-36
ANA-37
ANA-38
ANA-39
ANA+40
ANA+41
ANA+42
ANA+43
ANA-40
ANA-41
ANA-42
ANA-43
ANA+44
ANA+45
ANA+46
ANA+47
ANA-44
ANA-45
ANA-46
ANA-47
C122 C123 C124 C125 C126 C127 C128 C129
C132 C133 C134 C135 C136 C137 C138 C139
C142 C143 C144 C145 C146 C147 C148 C149
C152 C153 C154 C155 C156 C157 C158 C159
0.1UF
R121 R122 R123 R124 R125 R126 R127 R128
R131 R132 R133 R134 R135 R136 R137 R138
R141 R142 R143 R144 R145 R146 R147 R148
R151 R152 R153 R154 R155 R156 R157 R158
TBD
U12 (USE C120,C121)
U13 (USE C130,C131)
U14 (USE C140,C141)
U15 (USE C150,C151)
(USE C5,C6)
S1A S2A S3A S4A S1B S2B S3B S4B
DA DB V+ GND V-
A0 A1 EN
ADG509AKR
MUX_SEL0
MUX_SEL1
MUX_EN8
MUX_EN9
MUX_EN10
MUX_EN11
+15V
-15V
MUX+
MUX-
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
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Size B
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Rev A
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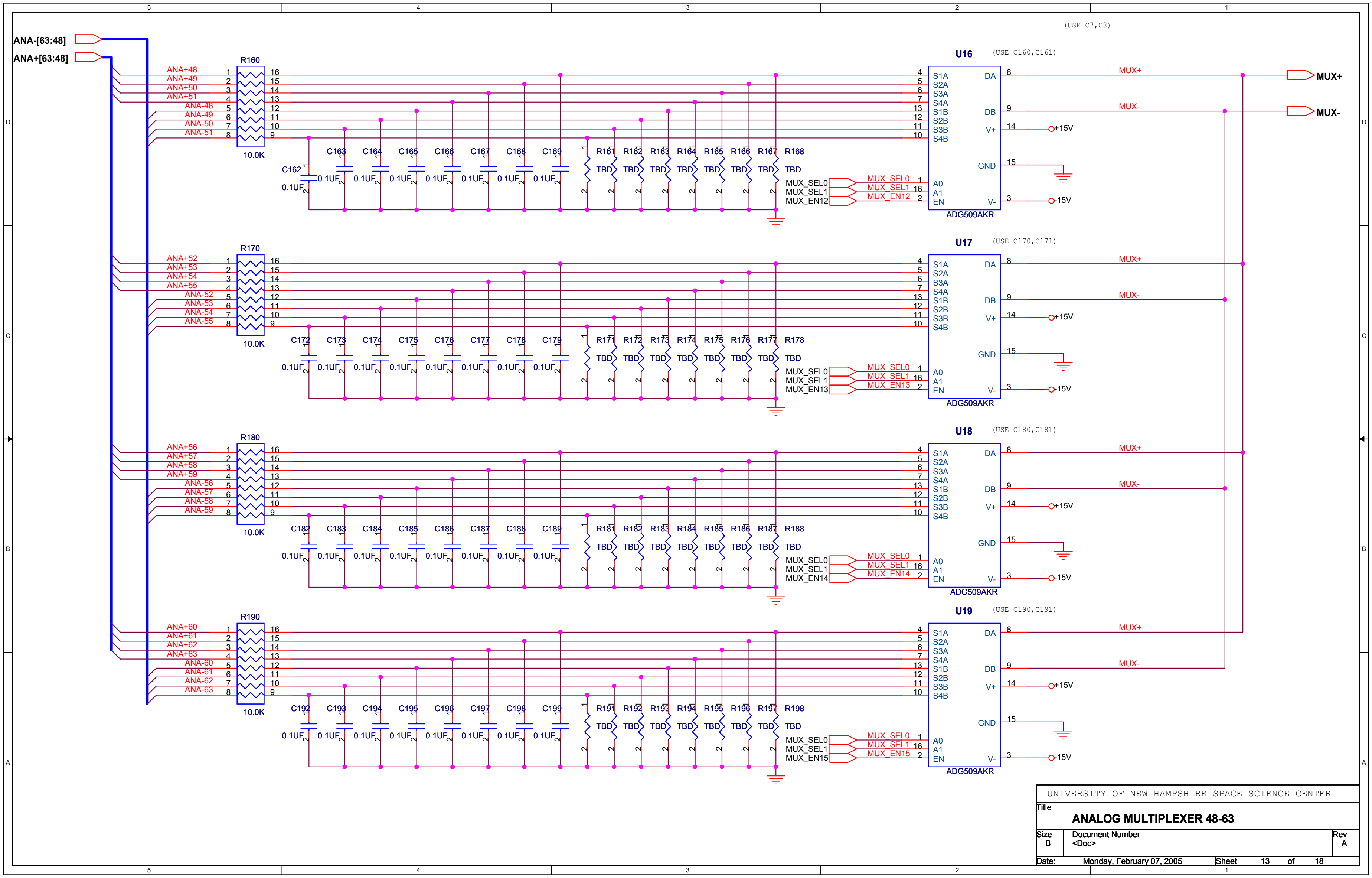
Sheet 12 of 18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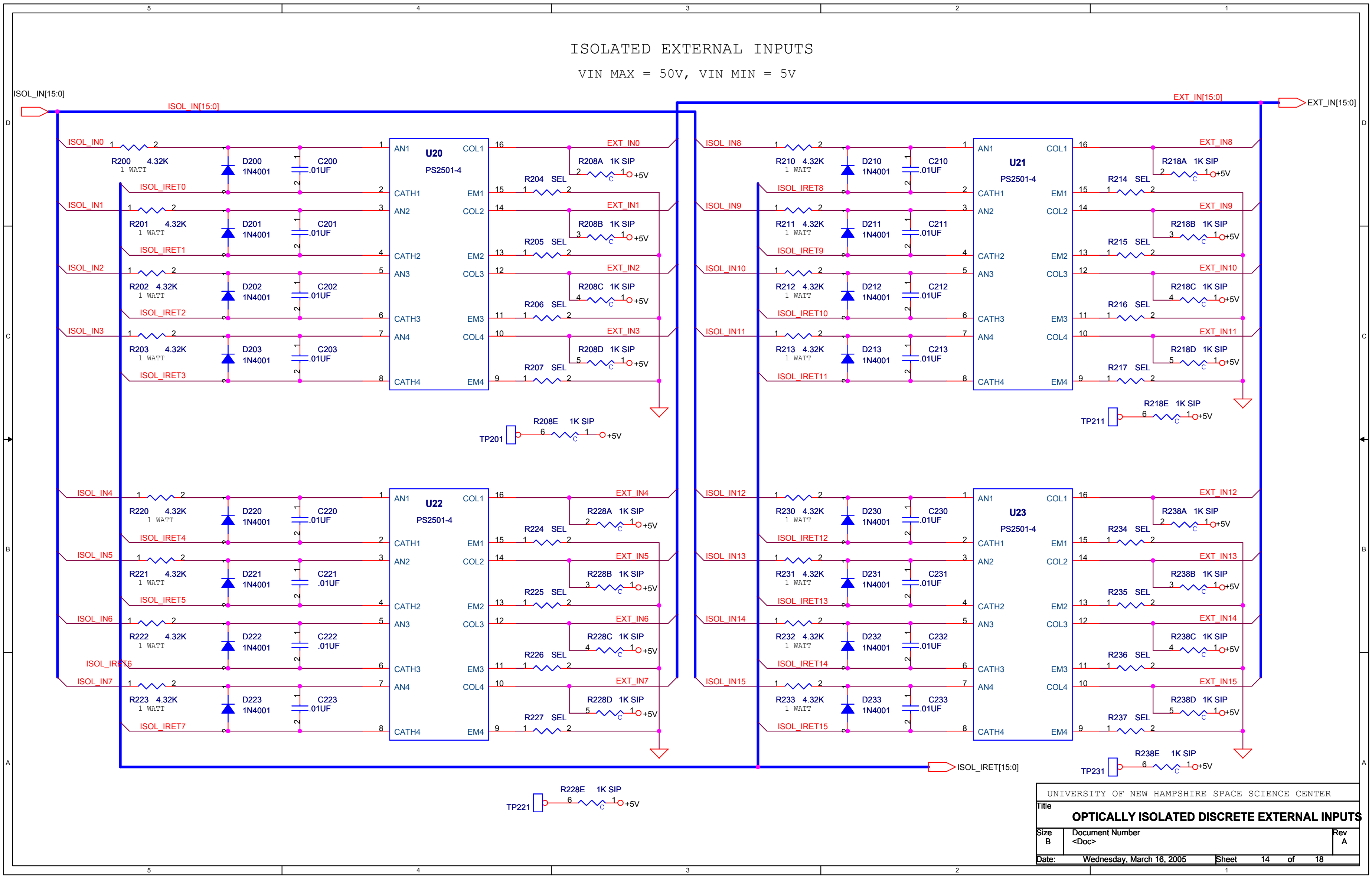
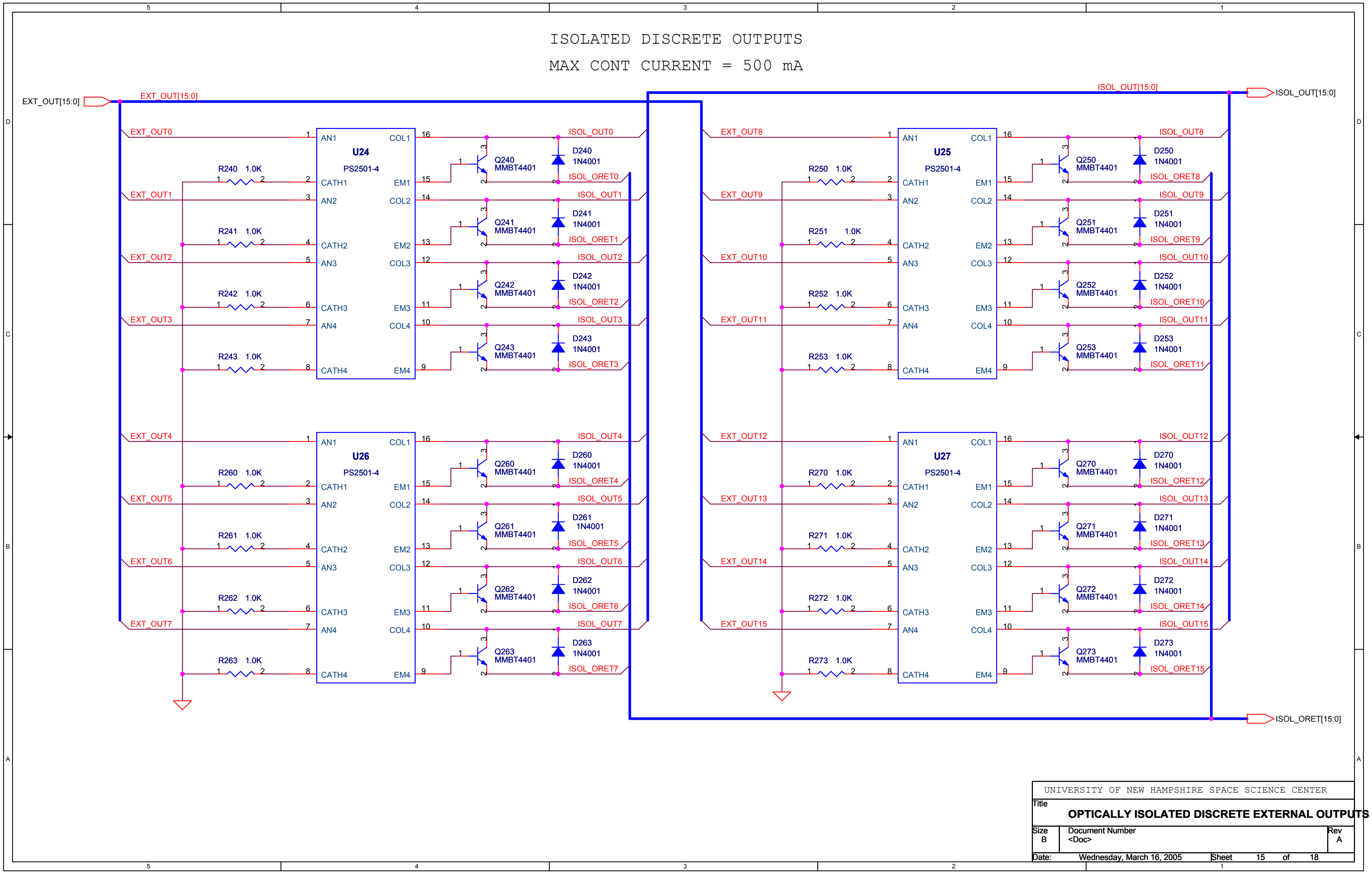
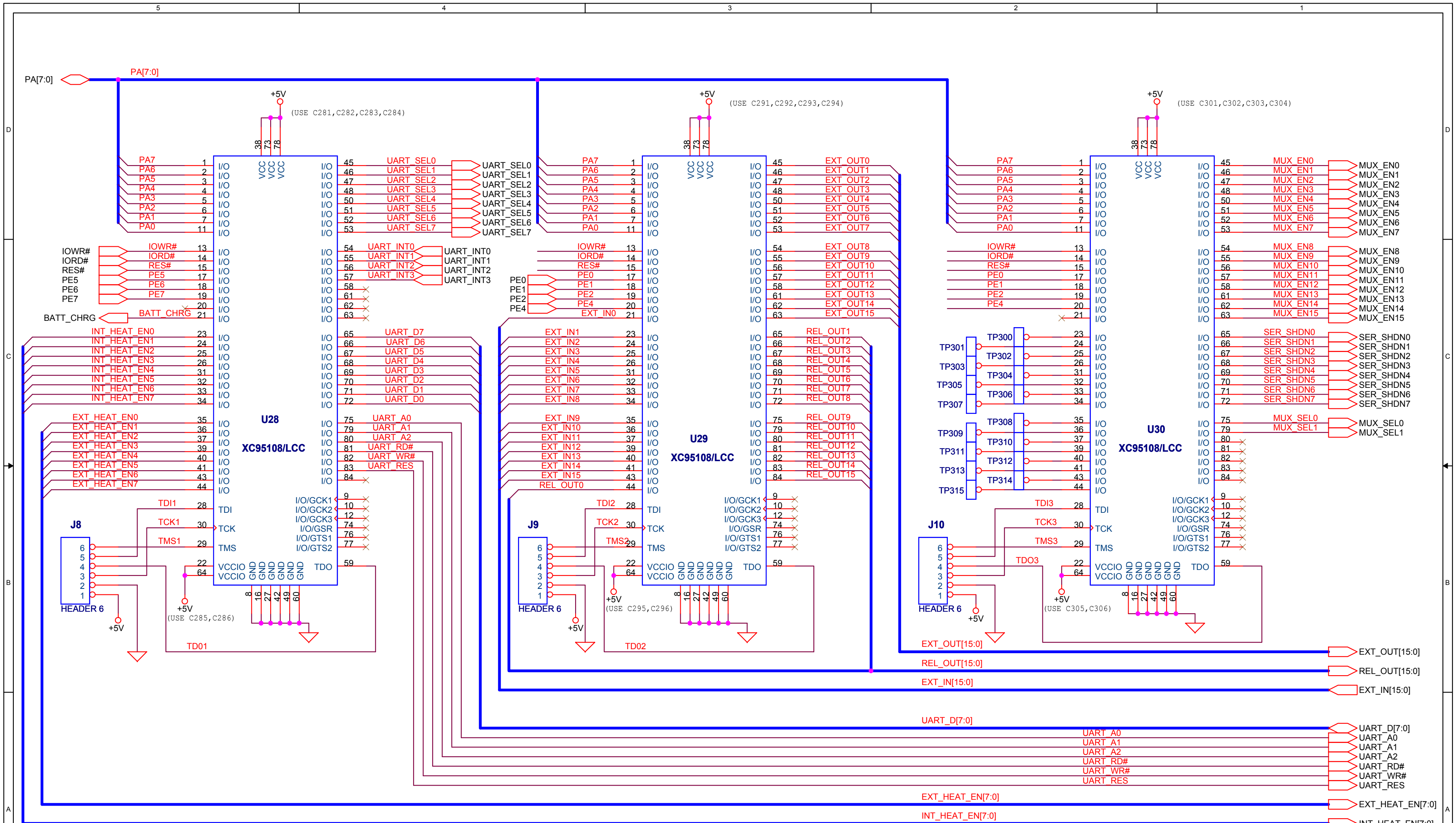
R160
R170
R180
R190
10.0K
U16
U17
U18
U19
(USE C7,C8)
(USE C160,C161)
(USE C170,C171)
(USE C180,C181)
(USE C190,C191)
ADG509AKR
S1A S2A S3A S4A S1B S2B S3B S4B
DA DB V+ GND A0 A1 EN V-
MUX+
MUX-
+15V
-15V
MUX_SEL0
MUX_SEL1
MUX_EN12
MUX_EN13
MUX_EN14
MUX_EN15
0.1UF
TBD
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
ANALOG MULTIPLEXER 48-63
Size B
Document Number <Doc>
Rev A
Date: Monday, February 07, 2005
Sheet 13 of 18


ISOLATED EXTERNAL INPUTS
VIN MAX = 50V, VIN MIN = 5V
ISOL_IN[15:0]
EXT_IN[15:0]
ISOL_IRET[15:0]
U20 PS2501-4
U21 PS2501-4
U22 PS2501-4
U23 PS2501-4
TP201
TP211
TP221
TP231
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
OPTICALLY ISOLATED DISCRETE EXTERNAL INPUTS
Size B
Document Number
<Doc>
Rev A
Date: Wednesday, March 16, 2005
Sheet 14 of 18


ISOLATED DISCRETE OUTPUTS
MAX CONT CURRENT = 500 mA
EXT_OUT[15:0]
ISOL_OUT[15:0]
ISOL_ORET[15:0]
U24 PS2501-4
U25 PS2501-4
U26 PS2501-4
U27 PS2501-4
AN1 AN2 AN3 AN4 CATH1 CATH2 CATH3 CATH4 COL1 COL2 COL3 COL4 EM1 EM2 EM3 EM4
R240 1.0K
R241 1.0K
R242 1.0K
R243 1.0K
R250 1.0K
R251 1.0K
R252 1.0K
R253 1.0K
R260 1.0K
R261 1.0K
R262 1.0K
R263 1.0K
R270 1.0K
R271 1.0K
R272 1.0K
R273 1.0K
Q240 MMBT4401
Q241 MMBT4401
Q242 MMBT4401
Q243 MMBT4401
Q250 MMBT4401
Q251 MMBT4401
Q252 MMBT4401
Q253 MMBT4401
Q260 MMBT4401
Q261 MMBT4401
Q262 MMBT4401
Q263 MMBT4401
Q270 MMBT4401
Q271 MMBT4401
Q272 MMBT4401
Q273 MMBT4401
D240 1N4001
D241 1N4001
D242 1N4001
D243 1N4001
D250 1N4001
D251 1N4001
D252 1N4001
D253 1N4001
D260 1N4001
D261 1N4001
D262 1N4001
D263 1N4001
D270 1N4001
D271 1N4001
D272 1N4001
D273 1N4001
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
OPTICALLY ISOLATED DISCRETE EXTERNAL OUTPUTS
Size B
Document Number <Doc>
Rev A
Date: Wednesday, March 16, 2005
Sheet 15 of 18

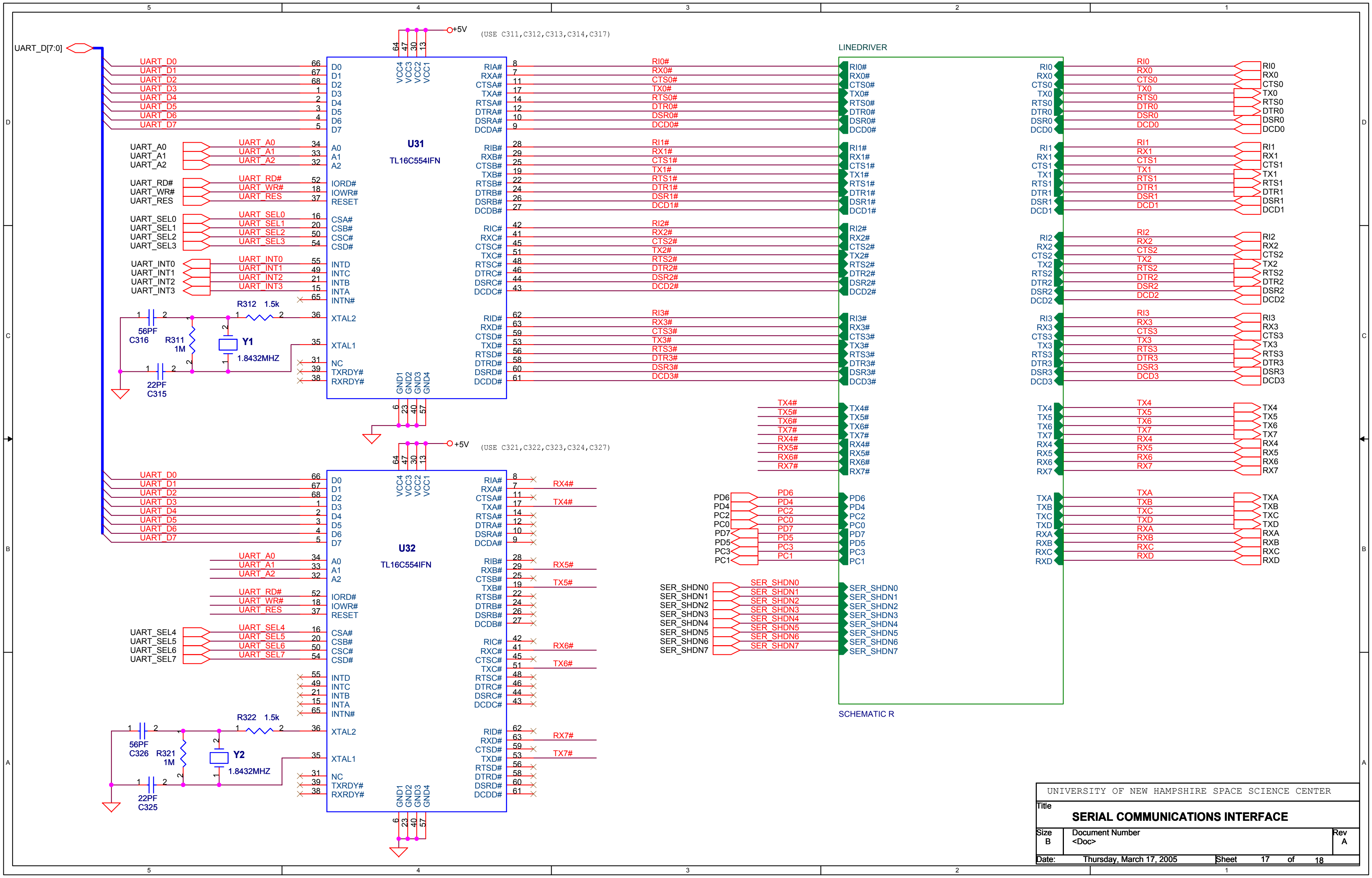


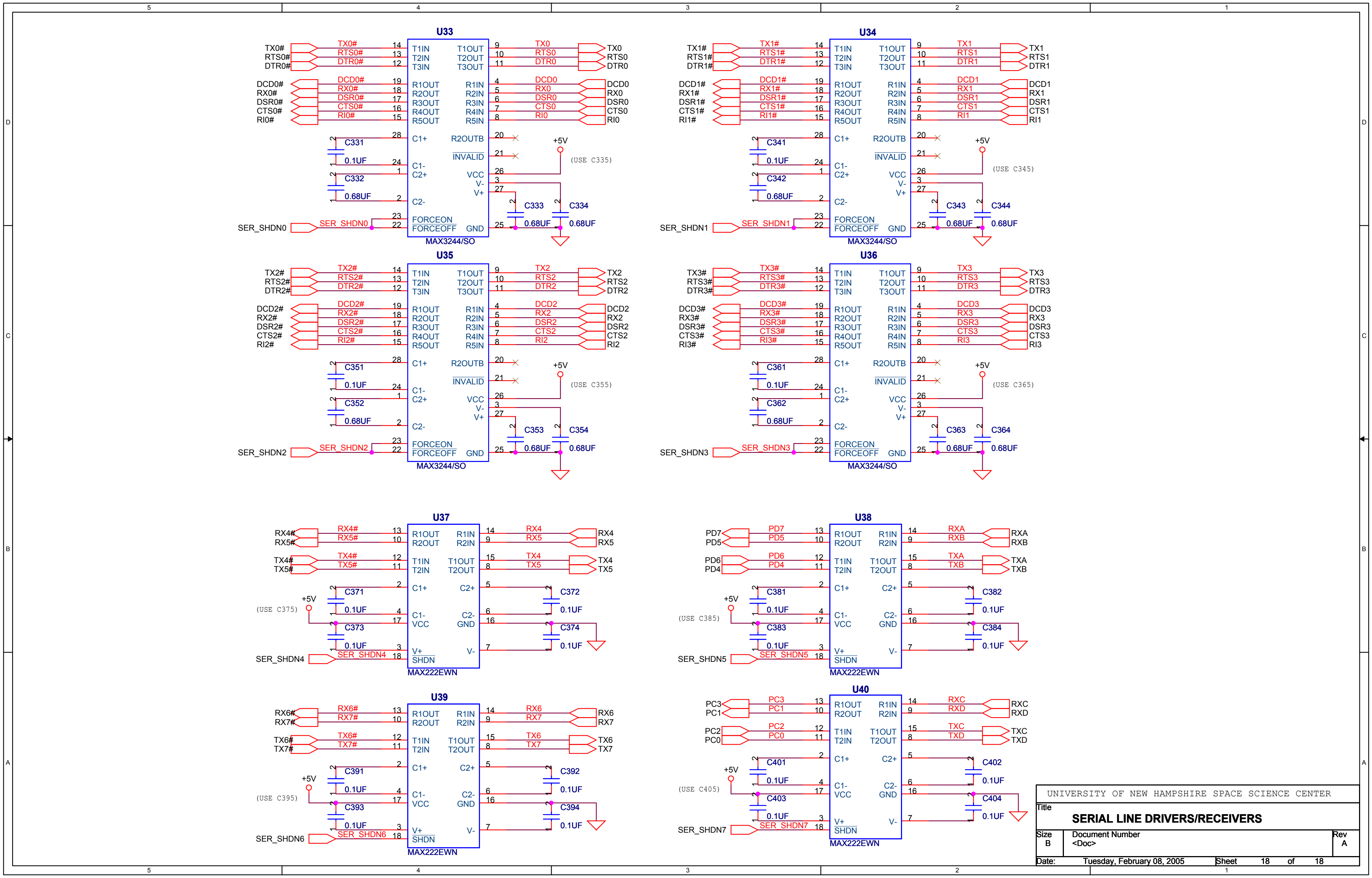
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title: PROGRAMMABLE LOGIC DEVICES (PLD)

Size	Document Number	Rev
B	<Doc>	A

Date: Thursday, February 10, 2005 — Sheet 16 of 18


UART_D[7:0]
(USE C311,C312,C313,C314,C317)
(USE C321,C322,C323,C324,C327)
+5V
U31
TL16C554IFN
U32
TL16C554IFN
R312 1.5k
R311 1M
C316 56PF
C315 22PF
Y1 1.8432MHZ
R322 1.5k
R321 1M
C326 56PF
C325 22PF
Y2 1.8432MHZ
LINEDRIVER
SCHEMATIC R
UART_A0
UART_A1
UART_A2
UART_RD#
UART_WR#
UART_RES
UART_SEL0
UART_SEL1
UART_SEL2
UART_SEL3
UART_SEL4
UART_SEL5
UART_SEL6
UART_SEL7
UART_INT0
UART_INT1
UART_INT2
UART_INT3
SER_SHDN0
SER_SHDN1
SER_SHDN2
SER_SHDN3
SER_SHDN4
SER_SHDN5
SER_SHDN6
SER_SHDN7
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
SERIAL COMMUNICATIONS INTERFACE
Size B
Document Number <Doc>
Rev A
Date: Thursday, March 17, 2005
Sheet 17 of 18

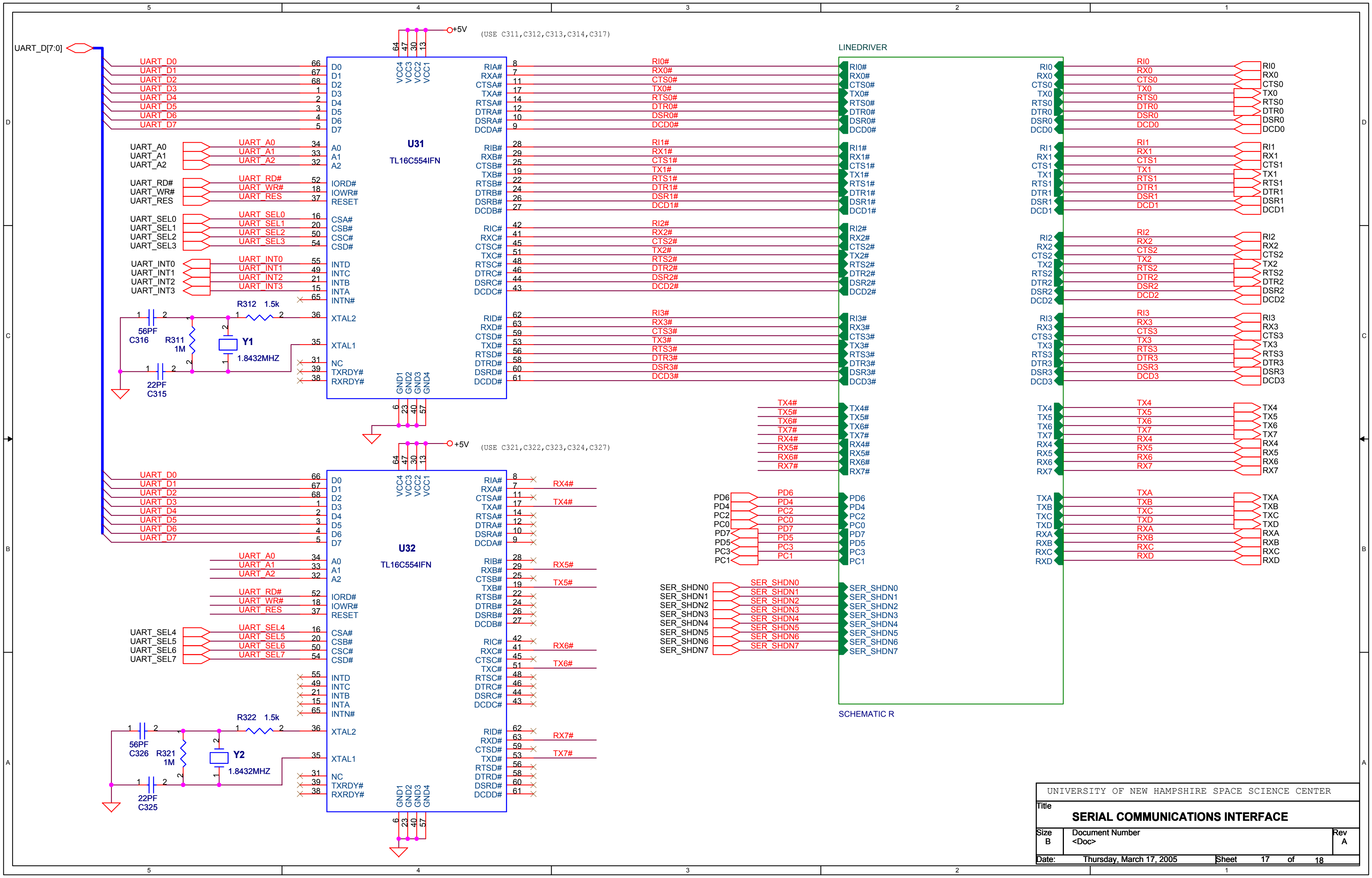


UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

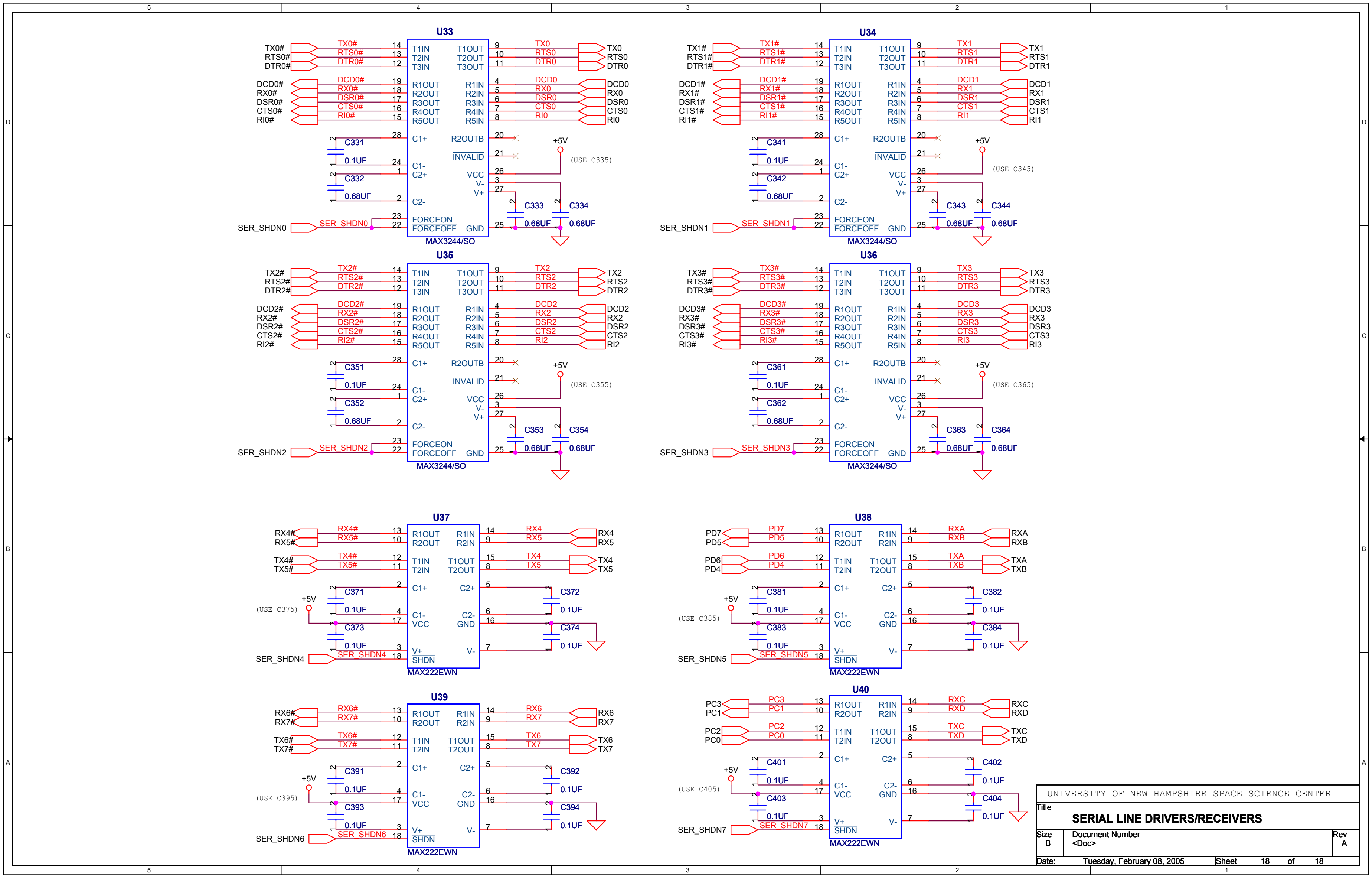
Title
SERIAL LINE DRIVERS/RECEIVERS

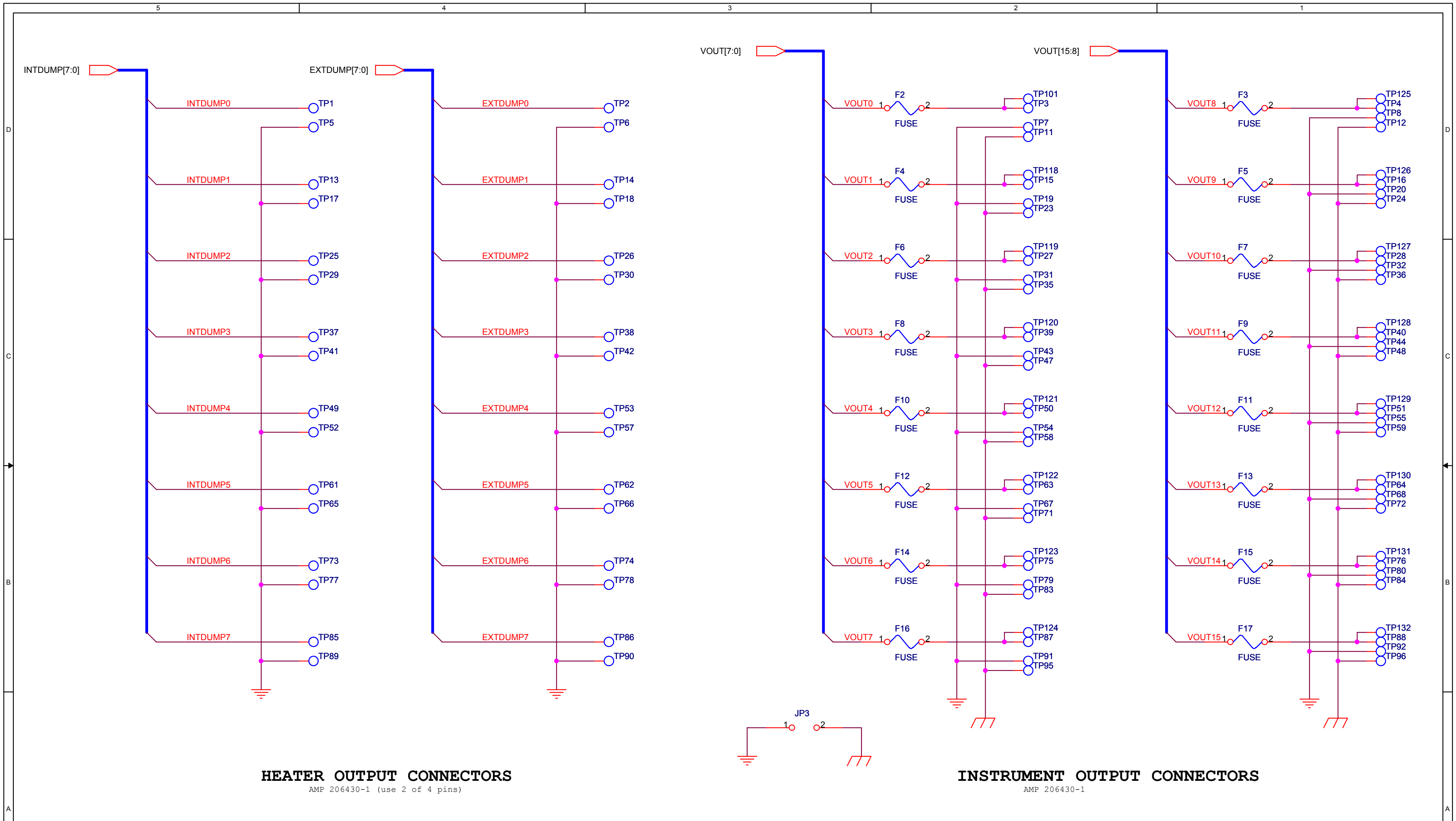
Size	Document Number	Rev
B	<Doc>	A

Date: Tuesday, February 08, 2005 Sheet 18 of 18

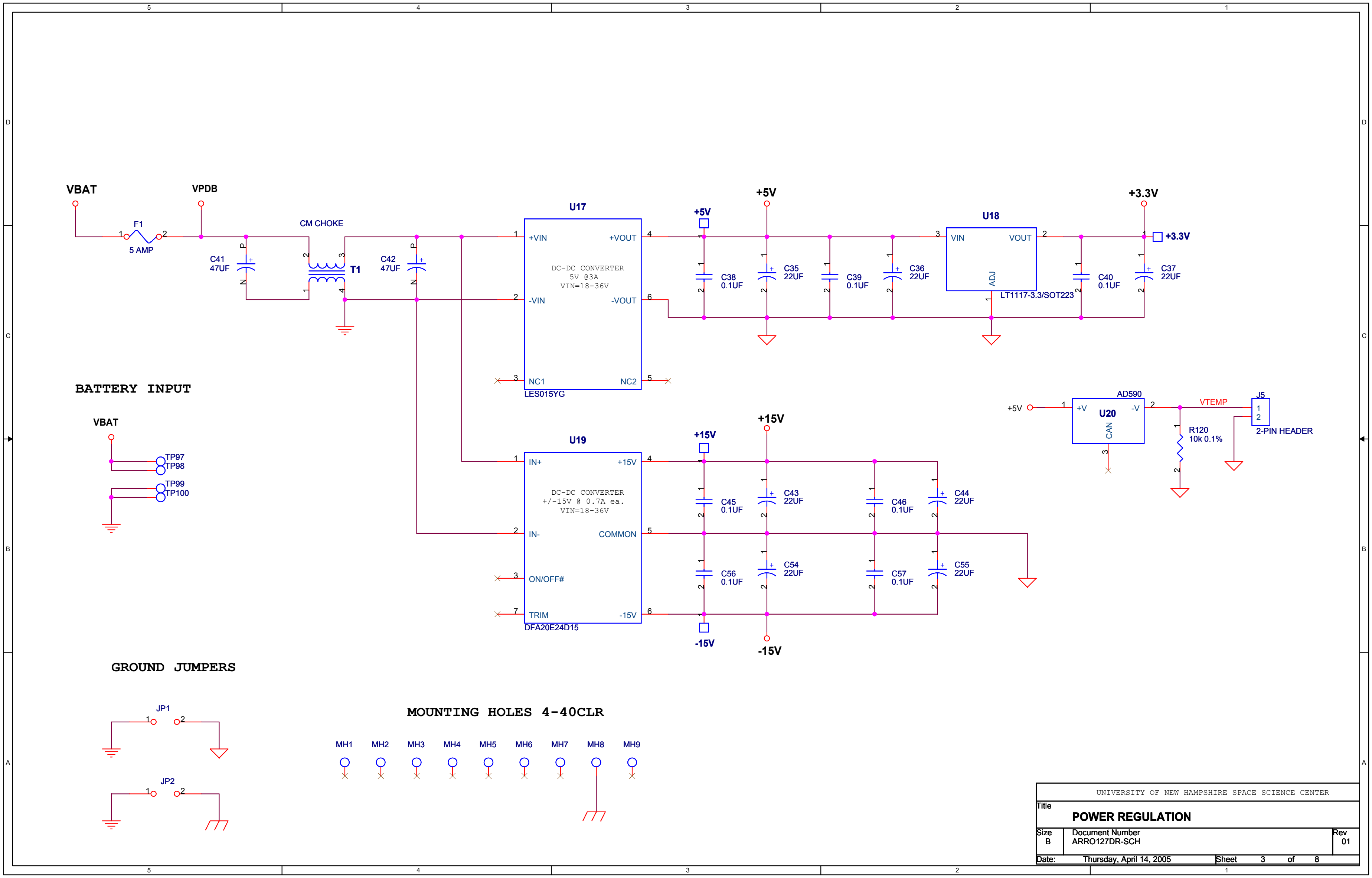


UART_D[7:0]
+5V
(USE C311,C312,C313,C314,C317)
U31
TL16C554IFN
R312 1.5k
56PF C316
R311 1M
Y1
1.8432MHZ
22PF C315
LINEDRIVER
SCHEMATIC R
+5V
(USE C321,C322,C323,C324,C327)
U32
TL16C554IFN
R322 1.5k
56PF C326
R321 1M
Y2
1.8432MHZ
22PF C325
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
SERIAL COMMUNICATIONS INTERFACE
Size B
Document Number <Doc>
Rev A
Date: Thursday, March 17, 2005
Sheet 17 of 18


U33
U34
U35
U36
MAX3244/SO
U37
U38
U39
U40
MAX222EWN
SER_SHDN0
SER_SHDN1
SER_SHDN2
SER_SHDN3
SER_SHDN4
SER_SHDN5
SER_SHDN6
SER_SHDN7
+5V
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
SERIAL LINE DRIVERS/RECEIVERS
Size B
Document Number <Doc>
Rev A
Date: Tuesday, February 08, 2005
Sheet 18 of 18



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER		
Title: HEATER AND INSTRUMENT CONNECTORS		
Size: B	Document Number: ARRO127DR-SCH	Rev: 01
Date: Tuesday, April 12, 2005	Sheet 2 of 8	


VBAT
VPDB
F1
5 AMP
C41
47UF
CM CHOKE
T1
C42
47UF
U17
+VIN
+VOUT
DC-DC CONVERTER
5V @3A
VIN=18-36V
-VIN
-VOUT
NC1
NC2
LES015YG
+5V
+5V
C38
0.1UF
C35
22UF
C39
0.1UF
C36
22UF
U18
VIN
VOUT
ADJ
LT1117-3.3/SOT223
+3.3V
+3.3V
C40
0.1UF
C37
22UF
BATTERY INPUT
VBAT
TP97
TP98
TP99
TP100
U19
IN+
+15V
DC-DC CONVERTER
+/-15V @ 0.7A ea.
VIN=18-36V
IN-
COMMON
ON/OFF#
TRIM
-15V
DFA20E24D15
+15V
+15V
C45
0.1UF
C43
22UF
C46
0.1UF
C44
22UF
C56
0.1UF
C54
22UF
C57
0.1UF
C55
22UF
-15V
-15V
AD590
+5V
+V
U20
-V
CAN
VTEMP
J5
2-PIN HEADER
R120
10k 0.1%
GROUND JUMPERS
JP1
JP2
MOUNTING HOLES 4-40CLR
MH1
MH2
MH3
MH4
MH5
MH6
MH7
MH8
MH9
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
POWER REGULATION
Size
B
Document Number
ARRO127DR-SCH
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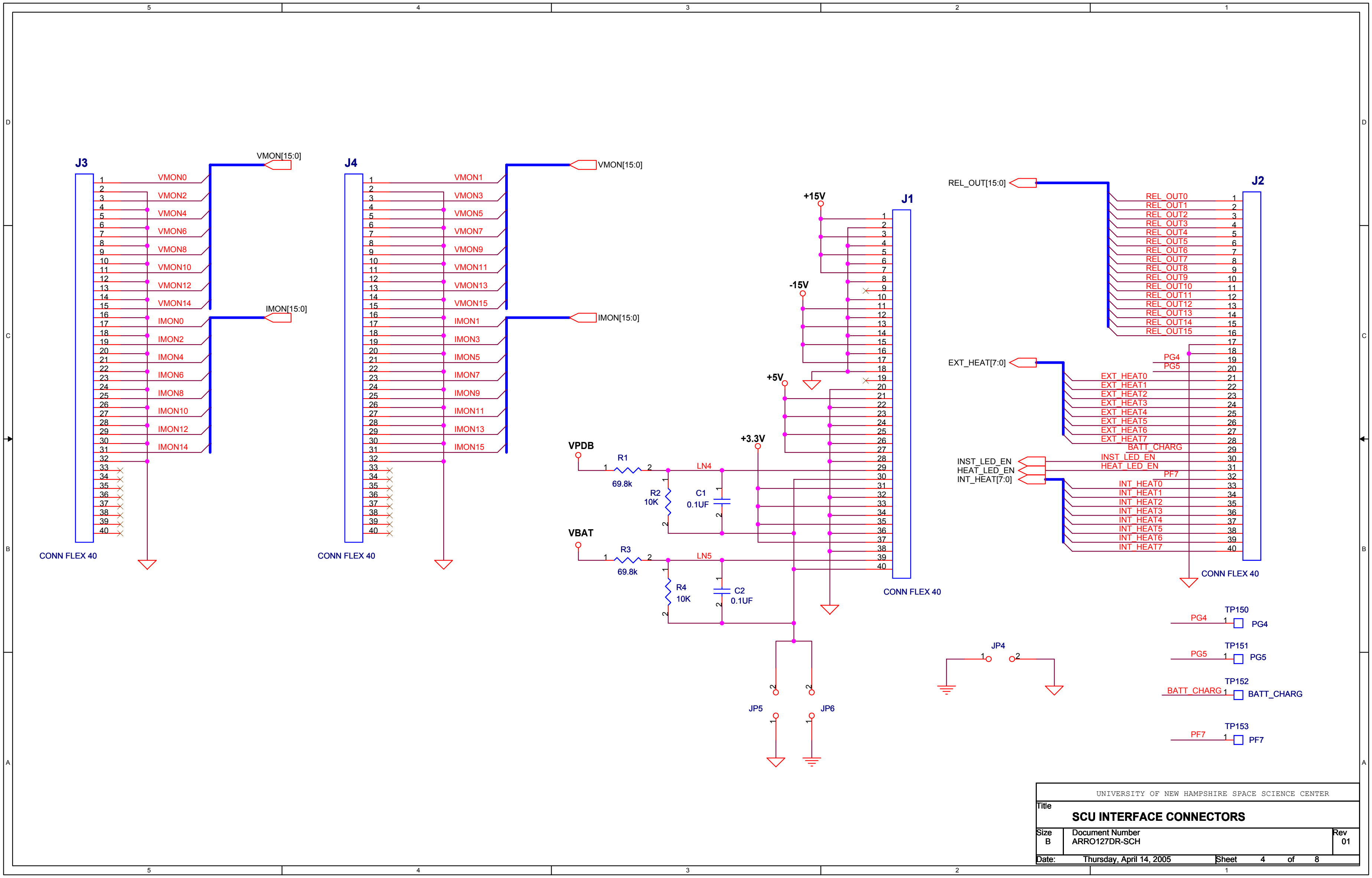
01
Date: Thursday, April 14, 2005
Sheet 3 of 8

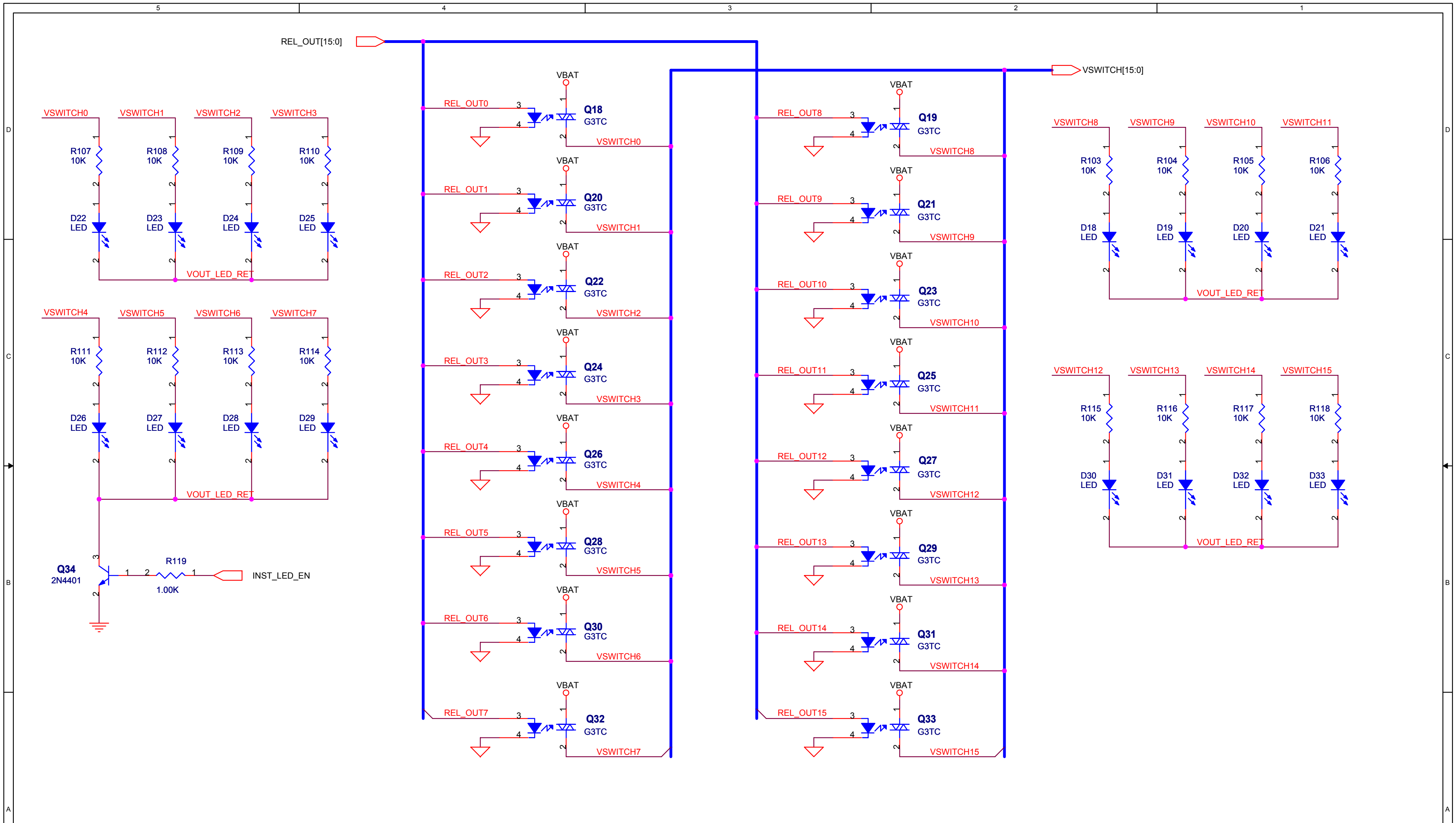


UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title: **SCU INTERFACE CONNECTORS**

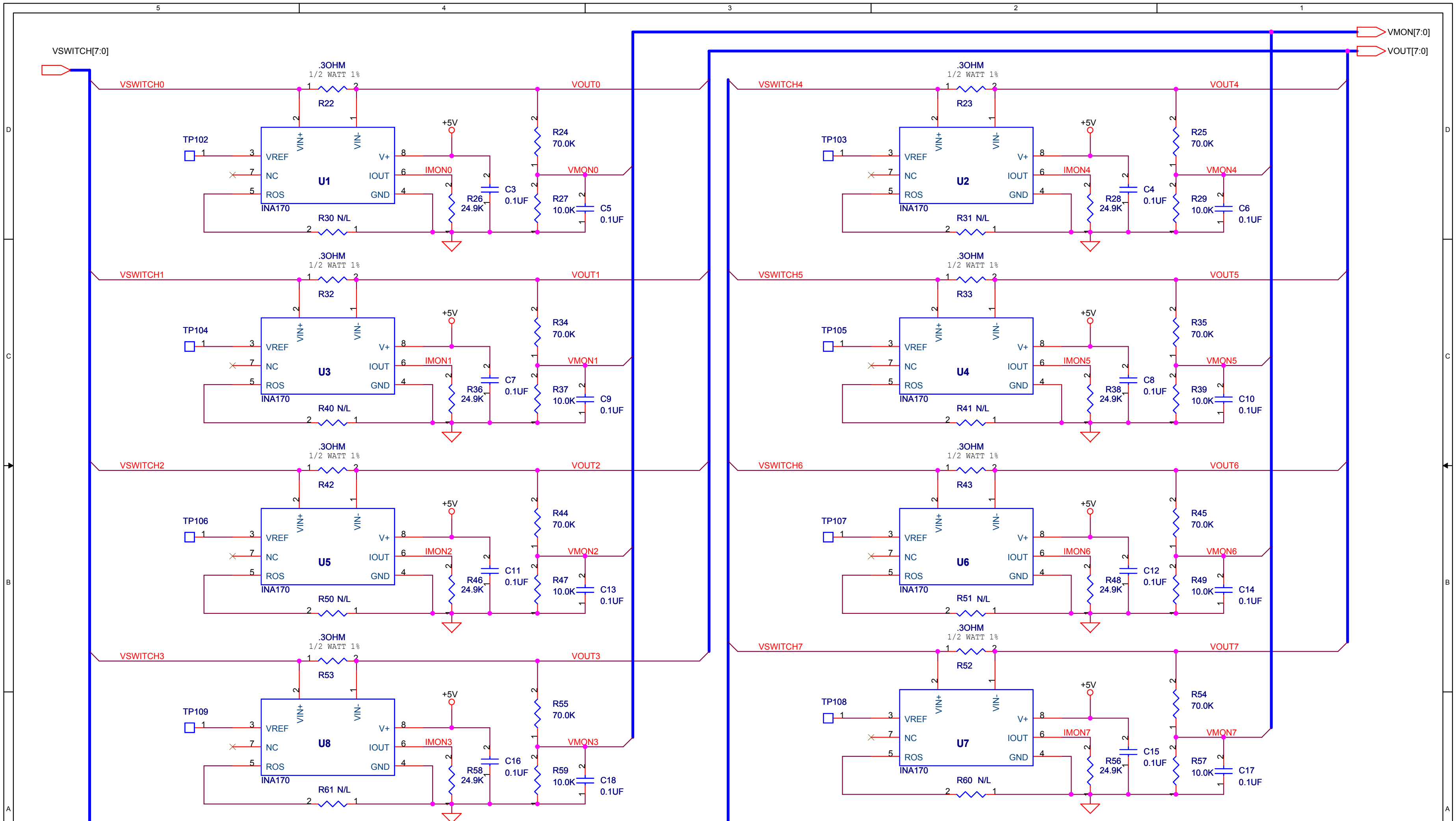
Size	Document Number	Rev
B	ARRO127DR-SCH	01

Date: Thursday, April 14, 2005 | Sheet 4 of 8



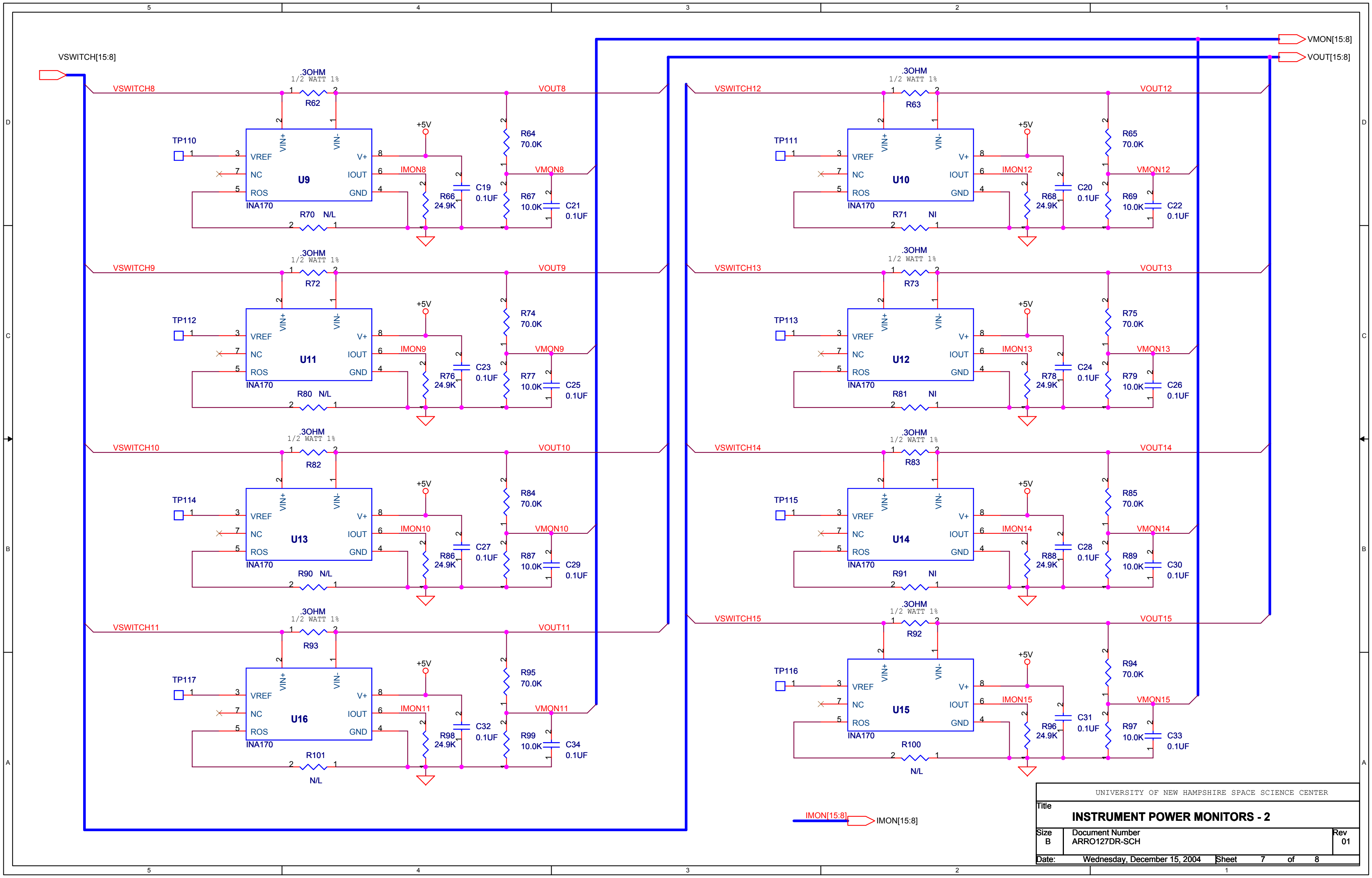
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

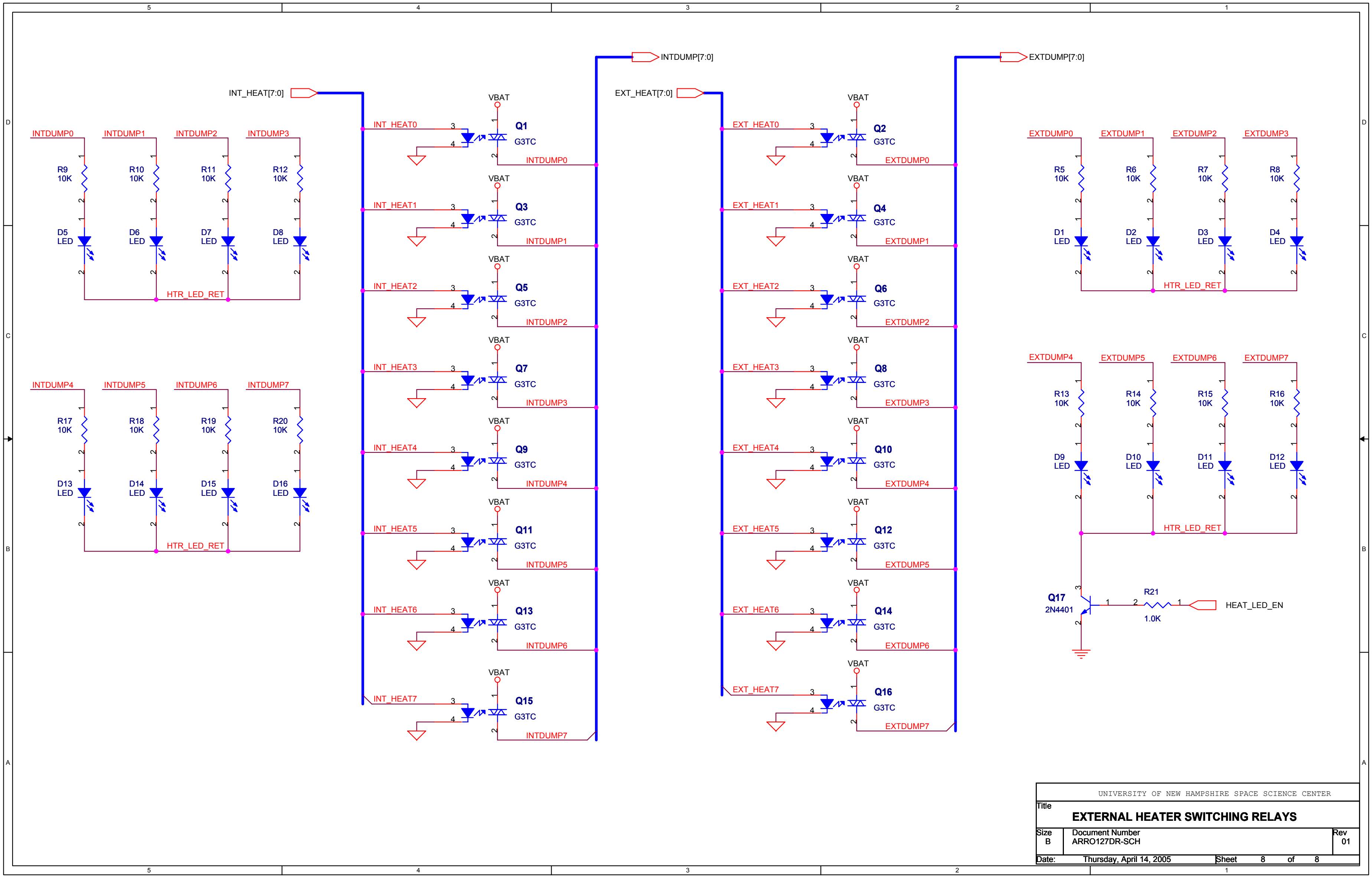
Title		
INSTRUMENT POWER SWITCHING RELAYS		
Size B	Document Number ARRO127DR-SCH	Rev 01
Date: Thursday, April 14, 2005	Sheet 5 of 8	



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title	INSTRUMENT POWER MONITORS - 1	
Size B	Document Number ARRO127DR-SCH	Rev 01
Date: Tuesday, December 21, 2004	Sheet 6 of 8	


VSWITCH[15:8]
VMON[15:8]
VOUT[15:8]
IMON[15:8]
VSWITCH8
VSWITCH9
VSWITCH10
VSWITCH11
VSWITCH12
VSWITCH13
VSWITCH14
VSWITCH15
VOUT8
VOUT9
VOUT10
VOUT11
VOUT12
VOUT13
VOUT14
VOUT15
VMON8
VMON9
VMON10
VMON11
VMON12
VMON13
VMON14
VMON15
IMON8
IMON9
IMON10
IMON11
IMON12
IMON13
IMON14
IMON15
.3OHM
1/2 WATT 1%
R62
R63
R72
R73
R82
R83
R93
R92
TP110
TP111
TP112
TP113
TP114
TP115
TP116
TP117
VIN+
VIN-
VREF
NC
ROS
V+
IOUT
GND
U9
U10
U11
U12
U13
U14
U15
U16
INA170
+5V
R64 70.0K
R65 70.0K
R74 70.0K
R75 70.0K
R84 70.0K
R85 70.0K
R95 70.0K
R94 70.0K
R66 24.9K
R68 24.9K
R76 24.9K
R78 24.9K
R86 24.9K
R88 24.9K
R98 24.9K
R96 24.9K
R67 10.0K
R69 10.0K
R77 10.0K
R79 10.0K
R87 10.0K
R89 10.0K
R99 10.0K
R97 10.0K
C19 0.1UF
C20 0.1UF
C21 0.1UF
C22 0.1UF
C23 0.1UF
C24 0.1UF
C25 0.1UF
C26 0.1UF
C27 0.1UF
C28 0.1UF
C29 0.1UF
C30 0.1UF
C32 0.1UF
C31 0.1UF
C34 0.1UF
C33 0.1UF
R70 N/L
R71 NI
R80 N/L
R81 NI
R90 N/L
R91 NI
R101 N/L
R100 N/L
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
INSTRUMENT POWER MONITORS - 2
Size B
Document Number ARRO127DR-SCH
Rev 01
Date: Wednesday, December 15, 2004
Sheet 7 of 8


INT_HEAT[7:0]
INTDUMP[7:0]
EXT_HEAT[7:0]
EXTDUMP[7:0]
VBAT
Q1 G3TC
Q2 G3TC
Q3 G3TC
Q4 G3TC
Q5 G3TC
Q6 G3TC
Q7 G3TC
Q8 G3TC
Q9 G3TC
Q10 G3TC
Q11 G3TC
Q12 G3TC
Q13 G3TC
Q14 G3TC
Q15 G3TC
Q16 G3TC
INT_HEAT0
INT_HEAT1
INT_HEAT2
INT_HEAT3
INT_HEAT4
INT_HEAT5
INT_HEAT6
INT_HEAT7
EXT_HEAT0
EXT_HEAT1
EXT_HEAT2
EXT_HEAT3
EXT_HEAT4
EXT_HEAT5
EXT_HEAT6
EXT_HEAT7
INTDUMP0
INTDUMP1
INTDUMP2
INTDUMP3
INTDUMP4
INTDUMP5
INTDUMP6
INTDUMP7
EXTDUMP0
EXTDUMP1
EXTDUMP2
EXTDUMP3
EXTDUMP4
EXTDUMP5
EXTDUMP6
EXTDUMP7
R9 10K
R10 10K
R11 10K
R12 10K
R17 10K
R18 10K
R19 10K
R20 10K
R5 10K
R6 10K
R7 10K
R8 10K
R13 10K
R14 10K
R15 10K
R16 10K
D5 LED
D6 LED
D7 LED
D8 LED
D13 LED
D14 LED
D15 LED
D16 LED
D1 LED
D2 LED
D3 LED
D4 LED
D9 LED
D10 LED
D11 LED
D12 LED
HTR_LED_RET
Q17 2N4401
R21 1.0K
HEAT_LED_EN
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
EXTERNAL HEATER SWITCHING RELAYS
Size B
Document Number ARRO127DR-SCH
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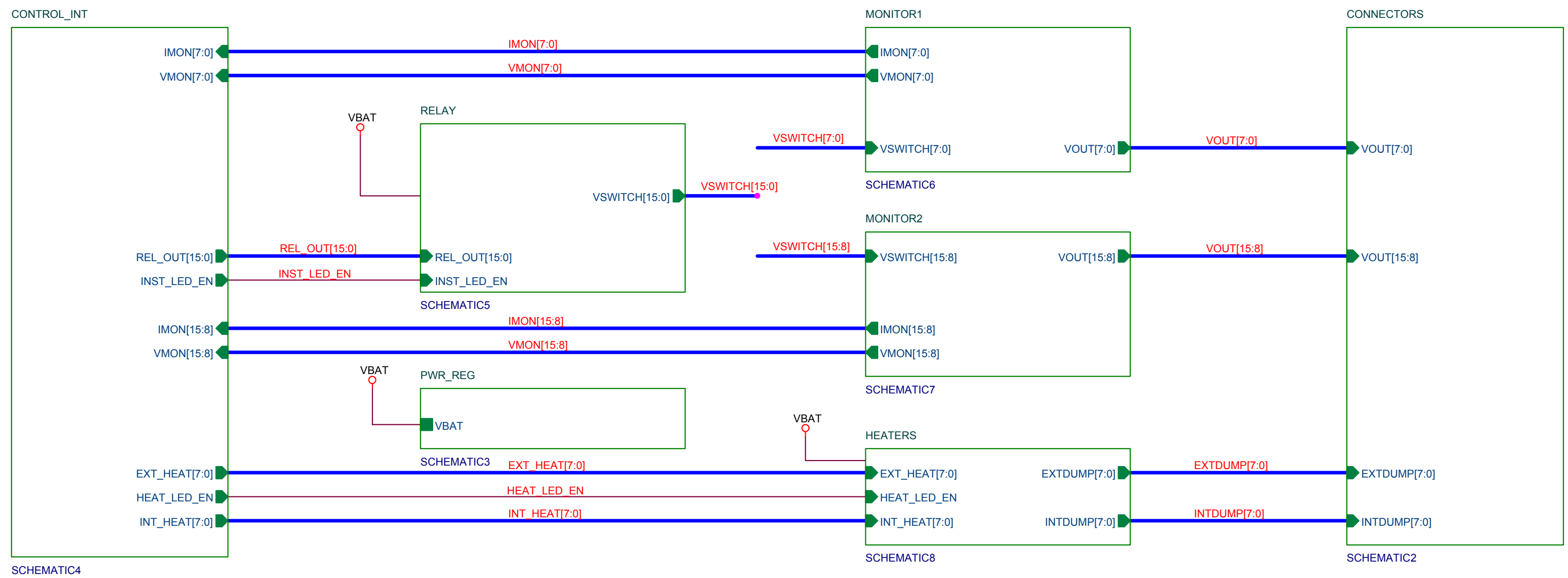
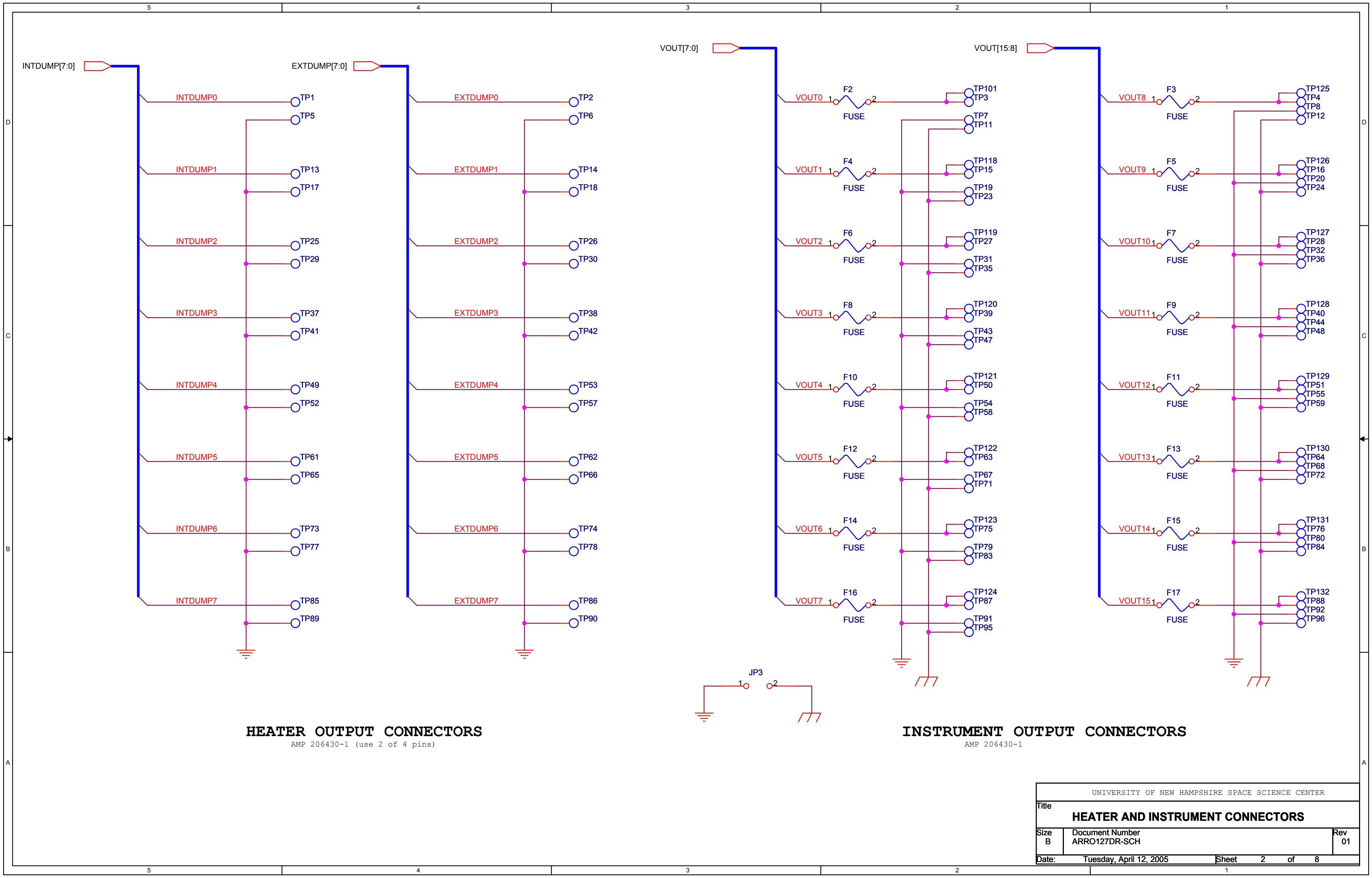
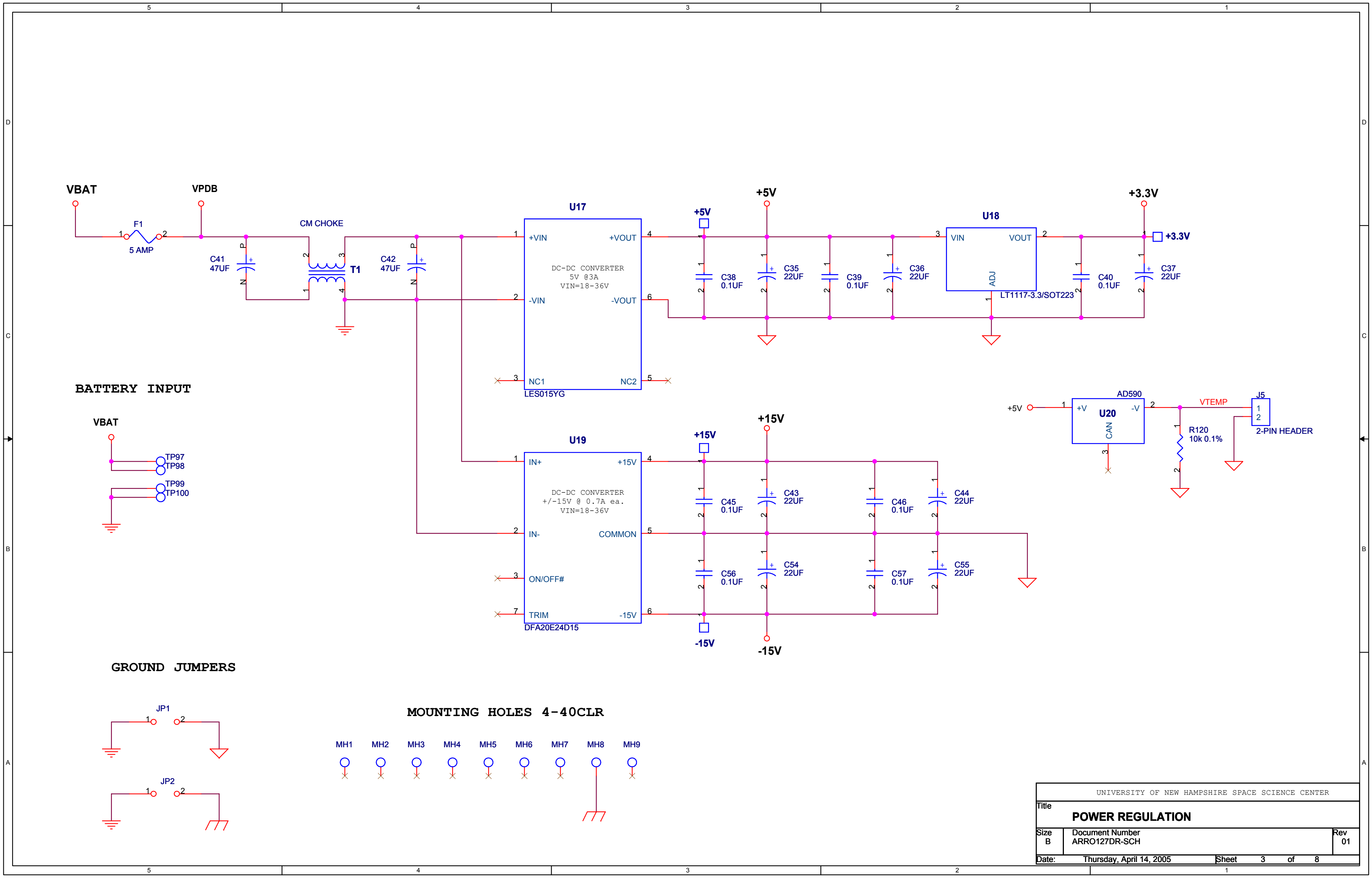
Date: Thursday, April 14, 2005
Sheet 8 of 8

SCU POWER DISTRIBUTION BOARD



UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER			
Title: SCU POWER DISTRIBUTION BOARD (PDB)			
Size B	Document Number ARRO127DR-SCH		Rev 01
Date: Thursday, April 14, 2005	Sheet 1 of 8		


INTDUMP[7:0]
EXTDUMP[7:0]
VOUT[7:0]
VOUT[15:8]
INTDUMP0
INTDUMP1
INTDUMP2
INTDUMP3
INTDUMP4
INTDUMP5
INTDUMP6
INTDUMP7
EXTDUMP0
EXTDUMP1
EXTDUMP2
EXTDUMP3
EXTDUMP4
EXTDUMP5
EXTDUMP6
EXTDUMP7
VOUT0
VOUT1
VOUT2
VOUT3
VOUT4
VOUT5
VOUT6
VOUT7
VOUT8
VOUT9
VOUT10
VOUT11
VOUT12
VOUT13
VOUT14
VOUT15
F2 FUSE
F4 FUSE
F6 FUSE
F8 FUSE
F10 FUSE
F12 FUSE
F14 FUSE
F16 FUSE
F3 FUSE
F5 FUSE
F7 FUSE
F9 FUSE
F11 FUSE
F13 FUSE
F15 FUSE
F17 FUSE
JP3
HEATER OUTPUT CONNECTORS
AMP 206430-1 (use 2 of 4 pins)
INSTRUMENT OUTPUT CONNECTORS
AMP 206430-1
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
HEATER AND INSTRUMENT CONNECTORS
Size B
Document Number ARRO127DR-SCH
Rev 01
Date: Tuesday, April 12, 2005
Sheet 2 of 8



VBAT
VPDB
F1
5 AMP
C41
47UF
CM CHOKE
T1
C42
47UF
U17
+VIN
+VOUT
DC-DC CONVERTER
5V @3A
VIN=18-36V
-VIN
-VOUT
NC1
NC2
LES015YG
+5V
C38
0.1UF
C35
22UF
C39
0.1UF
C36
22UF
U18
VIN
VOUT
ADJ
LT1117-3.3/SOT223
+3.3V
C40
0.1UF
C37
22UF
BATTERY INPUT
VBAT
TP97
TP98
TP99
TP100
U19
IN+
+15V
DC-DC CONVERTER
+/-15V @ 0.7A ea.
VIN=18-36V
IN-
COMMON
ON/OFF#
TRIM
-15V
DFA20E24D15
+15V
C45
0.1UF
C43
22UF
C46
0.1UF
C44
22UF
C56
0.1UF
C54
22UF
C57
0.1UF
C55
22UF
-15V
AD590
+5V
+V
U20
-V
CAN
VTEMP
J5
2-PIN HEADER
R120
10k 0.1%
GROUND JUMPERS
JP1
JP2
MOUNTING HOLES 4-40CLR
MH1
MH2
MH3
MH4
MH5
MH6
MH7
MH8
MH9
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
POWER REGULATION
Size
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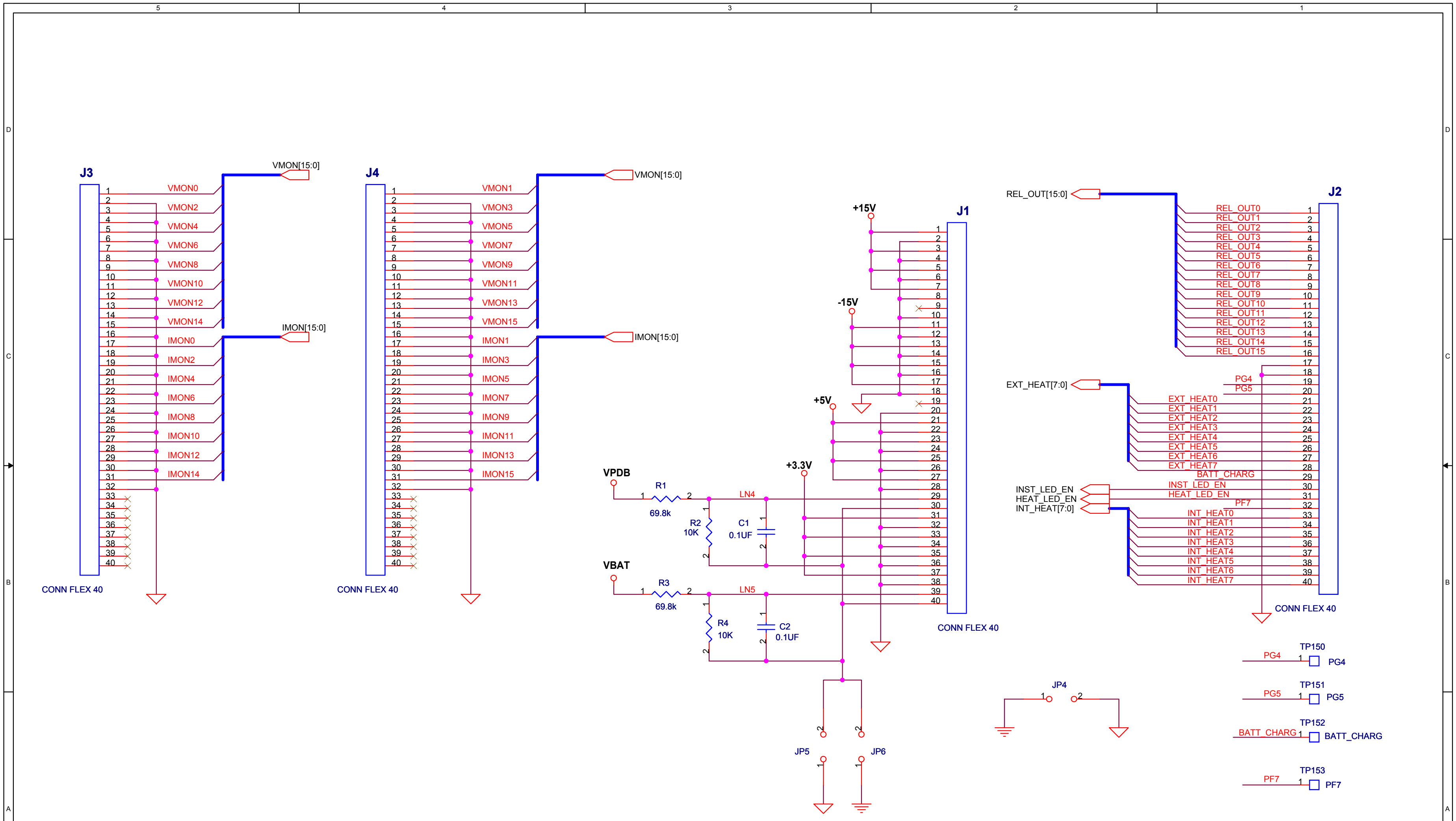
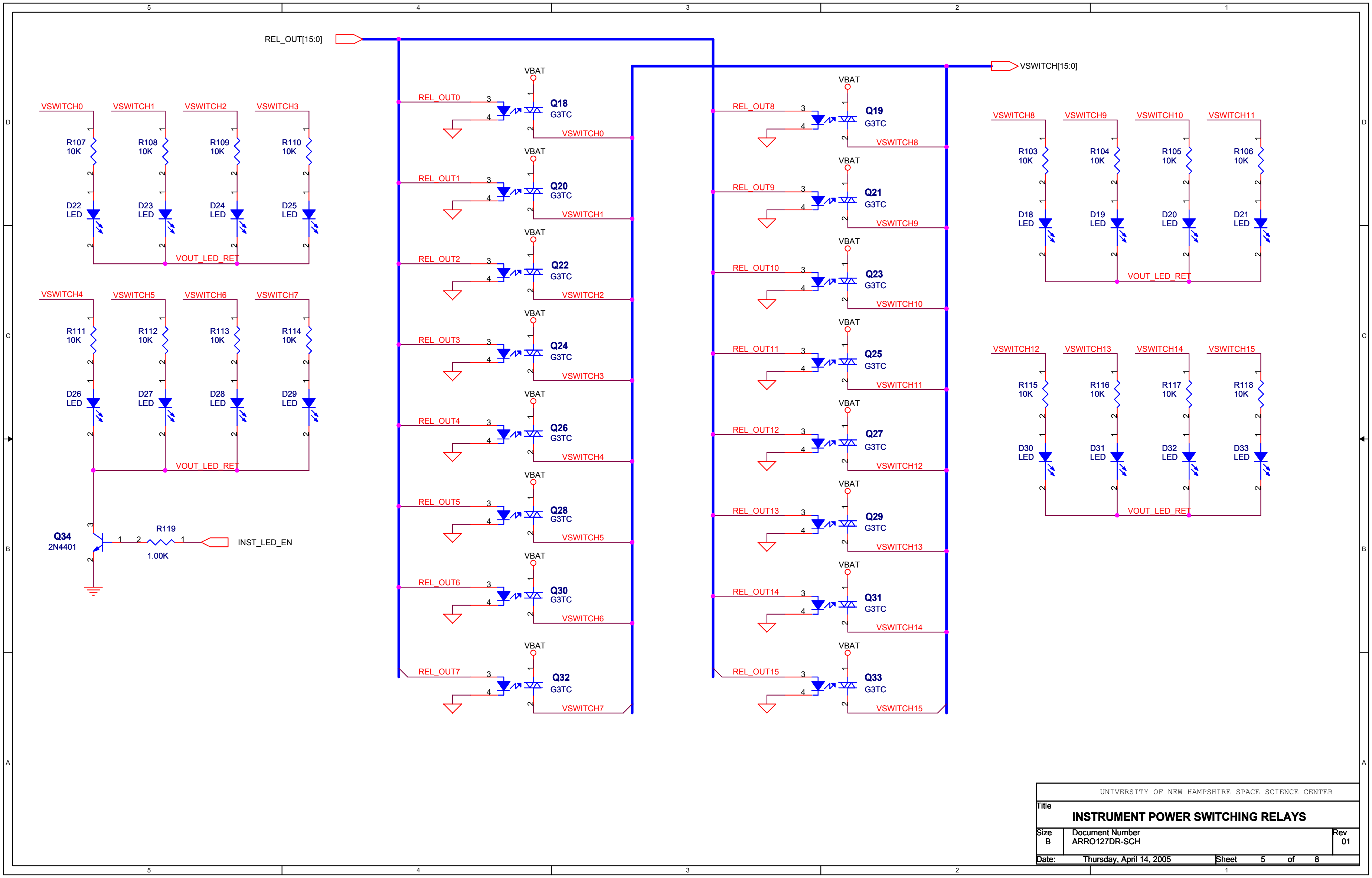
Date: Thursday, April 14, 2005
Sheet 3 of 8

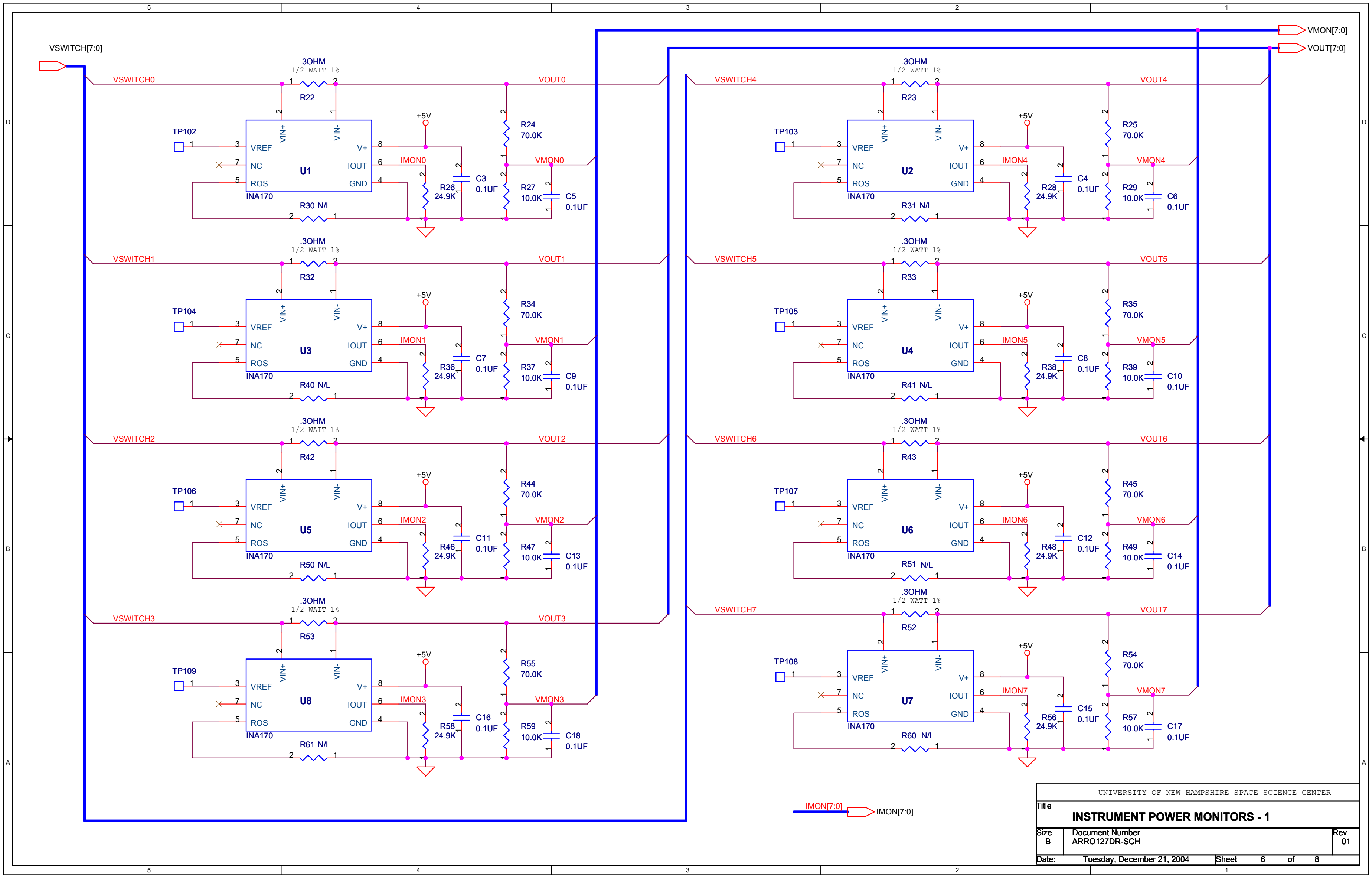


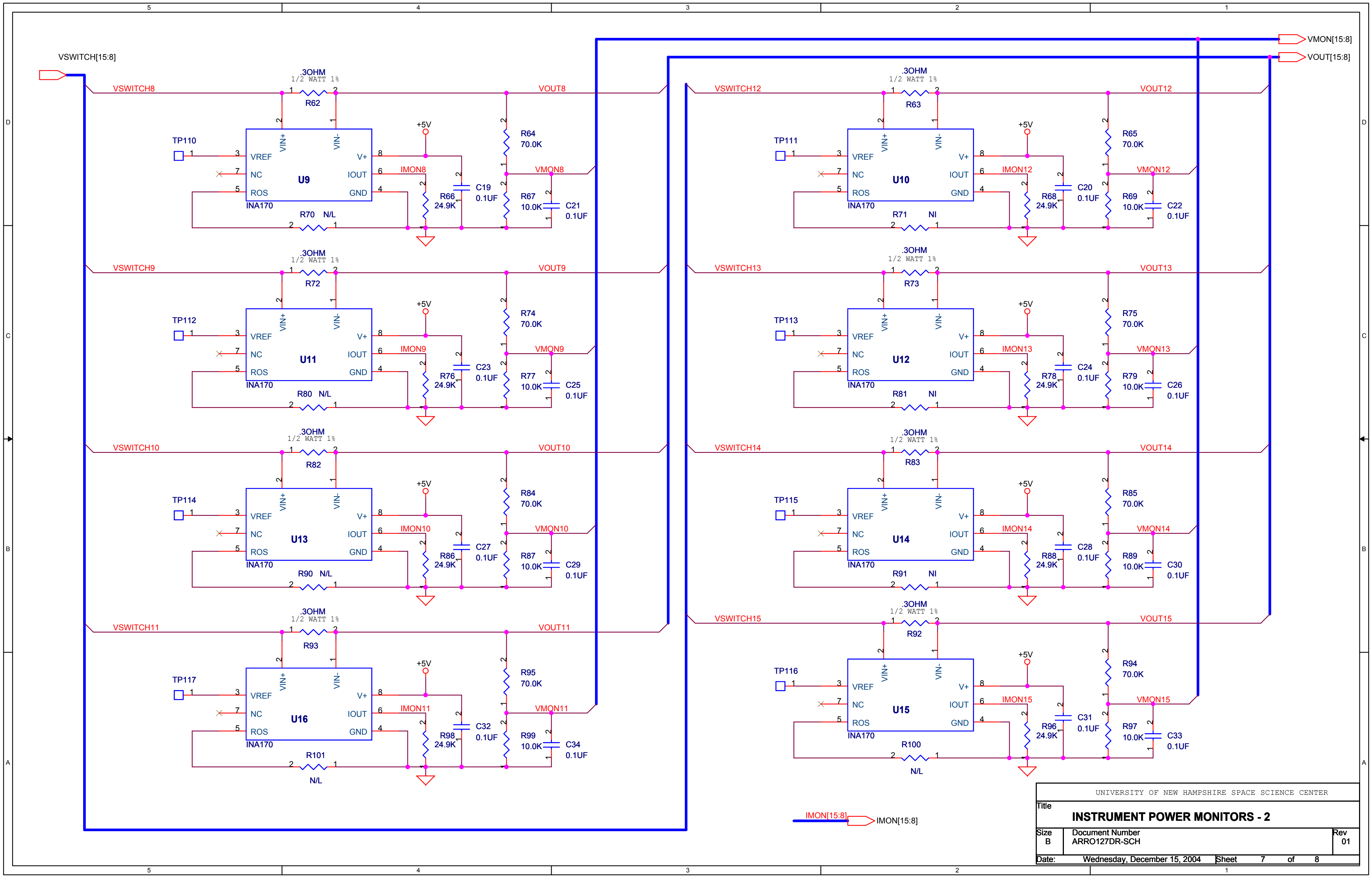
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER			
Title: SCU INTERFACE CONNECTORS			
Size: B	Document Number: ARRO127DR-SCH		Rev: 01
Date: Thursday, April 14, 2005		Sheet 4 of 8	

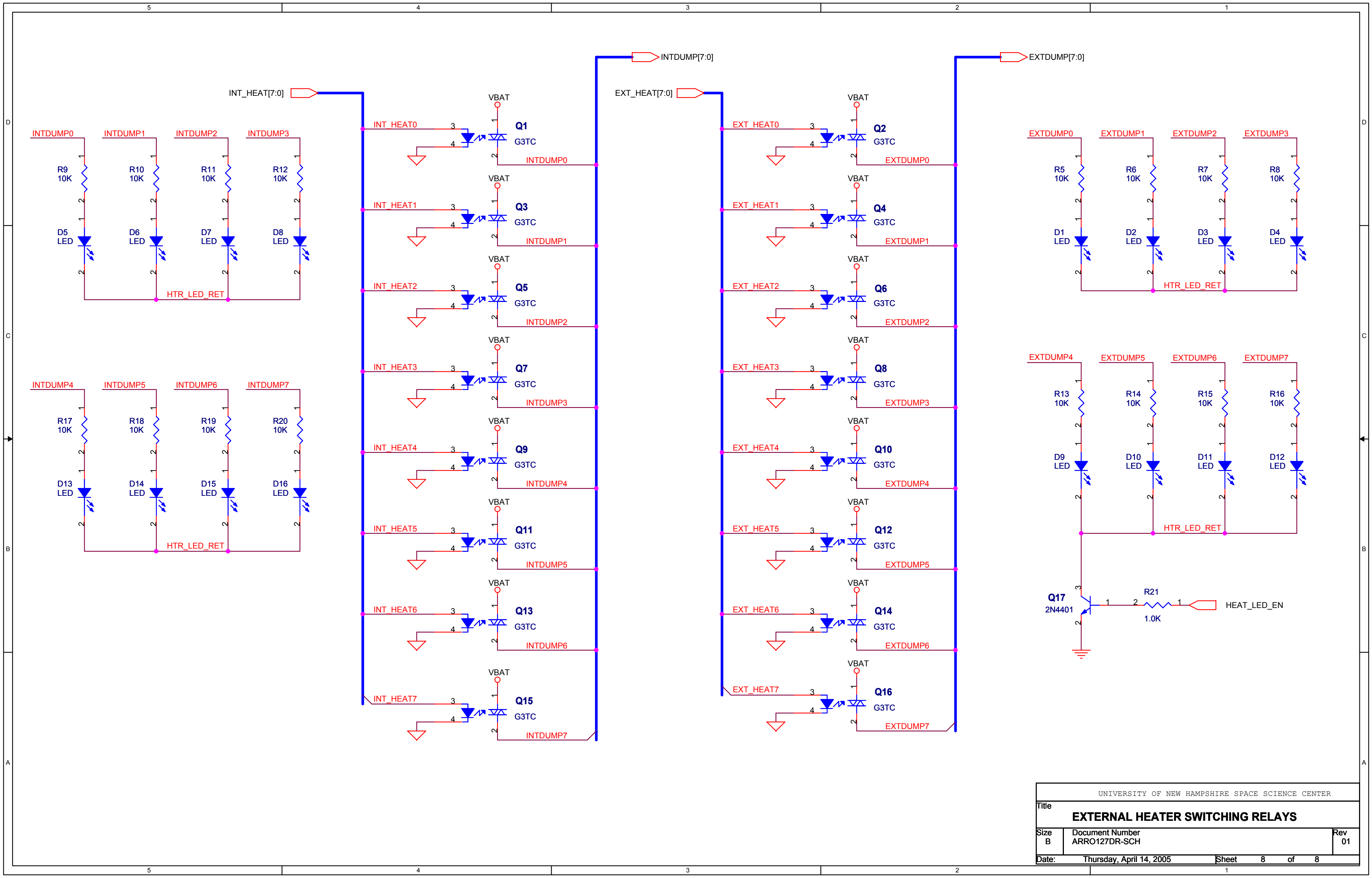


UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER

Title	INSTRUMENT POWER SWITCHING RELAYS	
Size B	Document Number ARRO127DR-SCH	Rev 01
Date: Thursday, April 14, 2005	Sheet 5 of 8	


VSWITCH[7:0]
VMON[7:0]
VOUT[7:0]
IMON[7:0]
VSWITCH0
VSWITCH1
VSWITCH2
VSWITCH3
VSWITCH4
VSWITCH5
VSWITCH6
VSWITCH7
VOUT0
VOUT1
VOUT2
VOUT3
VOUT4
VOUT5
VOUT6
VOUT7
VMON0
VMON1
VMON2
VMON3
VMON4
VMON5
VMON6
VMON7
IMON0
IMON1
IMON2
IMON3
IMON4
IMON5
IMON6
IMON7
.3OHM
1/2 WATT 1%
R22
R23
R32
R33
R42
R43
R53
R52
U1
U2
U3
U4
U5
U6
U8
U7
INA170
VREF
NC
ROS
VIN+
VIN-
V+
IOUT
GND
TP102
TP103
TP104
TP105
TP106
TP107
TP109
TP108
+5V
R24 70.0K
R25 70.0K
R34 70.0K
R35 70.0K
R44 70.0K
R45 70.0K
R55 70.0K
R54 70.0K
R26 24.9K
R28 24.9K
R36 24.9K
R38 24.9K
R46 24.9K
R48 24.9K
R58 24.9K
R56 24.9K
R27 10.0K
R29 10.0K
R37 10.0K
R39 10.0K
R47 10.0K
R49 10.0K
R59 10.0K
R57 10.0K
C3 0.1UF
C4 0.1UF
C5 0.1UF
C6 0.1UF
C7 0.1UF
C8 0.1UF
C9 0.1UF
C10 0.1UF
C11 0.1UF
C12 0.1UF
C13 0.1UF
C14 0.1UF
C16 0.1UF
C15 0.1UF
C18 0.1UF
C17 0.1UF
R30 N/L
R31 N/L
R40 N/L
R41 N/L
R50 N/L
R51 N/L
R61 N/L
R60 N/L
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
INSTRUMENT POWER MONITORS - 1
Size B
Document Number ARRO127DR-SCH
Rev 01
Date: Tuesday, December 21, 2004
Sheet 6 of 8


VSWITCH[15:8]
VMON[15:8]
VOUT[15:8]
IMON[15:8]
VSWITCH8
VOUT8
VMON8
IMON8
VSWITCH9
VOUT9
VMON9
IMON9
VSWITCH10
VOUT10
VMON10
IMON10
VSWITCH11
VOUT11
VMON11
IMON11
VSWITCH12
VOUT12
VMON12
IMON12
VSWITCH13
VOUT13
VMON13
IMON13
VSWITCH14
VOUT14
VMON14
IMON14
VSWITCH15
VOUT15
VMON15
IMON15
.3OHM
1/2 WATT 1%
R62
R63
R72
R73
R82
R83
R93
R92
U9
U10
U11
U12
U13
U14
U16
U15
INA170
VREF
NC
ROS
VIN+
VIN-
V+
IOUT
GND
TP110
TP111
TP112
TP113
TP114
TP115
TP117
TP116
+5V
R64 70.0K
R65 70.0K
R74 70.0K
R75 70.0K
R84 70.0K
R85 70.0K
R95 70.0K
R94 70.0K
R66 24.9K
R68 24.9K
R76 24.9K
R78 24.9K
R86 24.9K
R88 24.9K
R98 24.9K
R96 24.9K
R67 10.0K
R69 10.0K
R77 10.0K
R79 10.0K
R87 10.0K
R89 10.0K
R99 10.0K
R97 10.0K
C19 0.1UF
C20 0.1UF
C21 0.1UF
C22 0.1UF
C23 0.1UF
C24 0.1UF
C25 0.1UF
C26 0.1UF
C27 0.1UF
C28 0.1UF
C29 0.1UF
C30 0.1UF
C32 0.1UF
C31 0.1UF
C34 0.1UF
C33 0.1UF
R70 N/L
R71 NI
R80 N/L
R81 NI
R90 N/L
R91 NI
R101 N/L
R100 N/L
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
INSTRUMENT POWER MONITORS - 2
Size B
Document Number ARRO127DR-SCH
Rev 01
Date: Wednesday, December 15, 2004
Sheet 7 of 8



INT_HEAT[7:0]
INTDUMP[7:0]
EXT_HEAT[7:0]
EXTDUMP[7:0]
VBAT
Q1 G3TC
Q2 G3TC
Q3 G3TC
Q4 G3TC
Q5 G3TC
Q6 G3TC
Q7 G3TC
Q8 G3TC
Q9 G3TC
Q10 G3TC
Q11 G3TC
Q12 G3TC
Q13 G3TC
Q14 G3TC
Q15 G3TC
Q16 G3TC
INT_HEAT0
INT_HEAT1
INT_HEAT2
INT_HEAT3
INT_HEAT4
INT_HEAT5
INT_HEAT6
INT_HEAT7
EXT_HEAT0
EXT_HEAT1
EXT_HEAT2
EXT_HEAT3
EXT_HEAT4
EXT_HEAT5
EXT_HEAT6
EXT_HEAT7
INTDUMP0
INTDUMP1
INTDUMP2
INTDUMP3
INTDUMP4
INTDUMP5
INTDUMP6
INTDUMP7
EXTDUMP0
EXTDUMP1
EXTDUMP2
EXTDUMP3
EXTDUMP4
EXTDUMP5
EXTDUMP6
EXTDUMP7
R9 10K
R10 10K
R11 10K
R12 10K
R17 10K
R18 10K
R19 10K
R20 10K
R5 10K
R6 10K
R7 10K
R8 10K
R13 10K
R14 10K
R15 10K
R16 10K
D5 LED
D6 LED
D7 LED
D8 LED
D13 LED
D14 LED
D15 LED
D16 LED
D1 LED
D2 LED
D3 LED
D4 LED
D9 LED
D10 LED
D11 LED
D12 LED
HTR_LED_RET
Q17 2N4401
R21 1.0K
HEAT_LED_EN
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
Title
EXTERNAL HEATER SWITCHING RELAYS
Size B
Document Number ARRO127DR-SCH
Rev 01
Date: Thursday, April 14, 2005
Sheet 8 of 8

APPENDIX G

ARRO MECHANICAL DOCUMENTATION

The following appendix contains the following system documentation:

1) Layout diagrams of internal heaters, waterjugs, battery jugs, etc

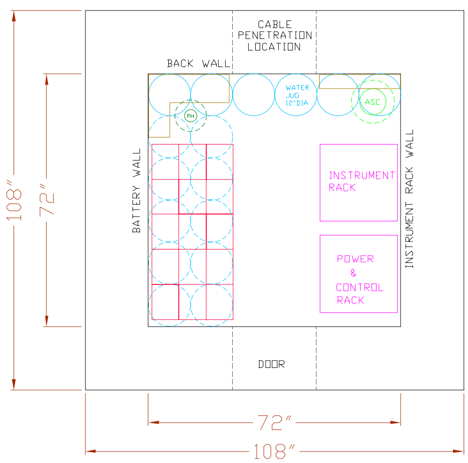
2) Mechanical Drawings for all machined components in the ARRO enclosure

ARRO INTERNAL ENCLOSURE LAYOUT

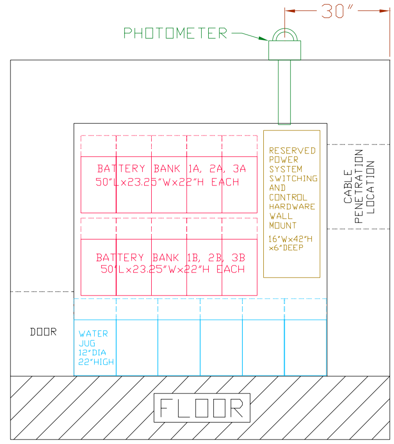
#1887 FLRPLN18.DWG
FLRPLN18.PDF

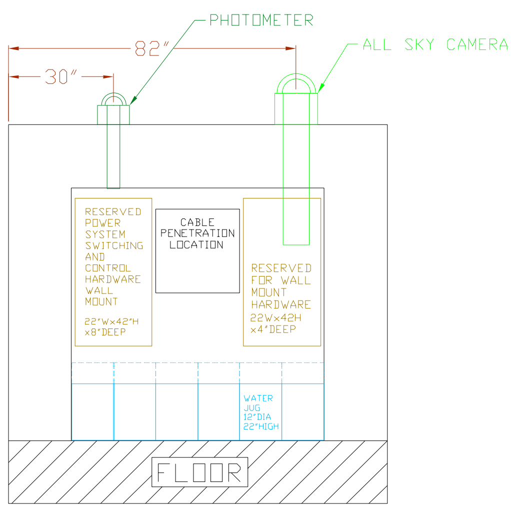
5/10/05

TOP VIEW - FLOOR PLAN

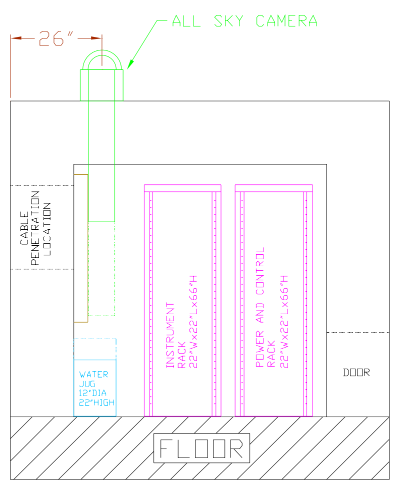


BATTERY WALL LAYOUT





BACK WALL LAYOUT

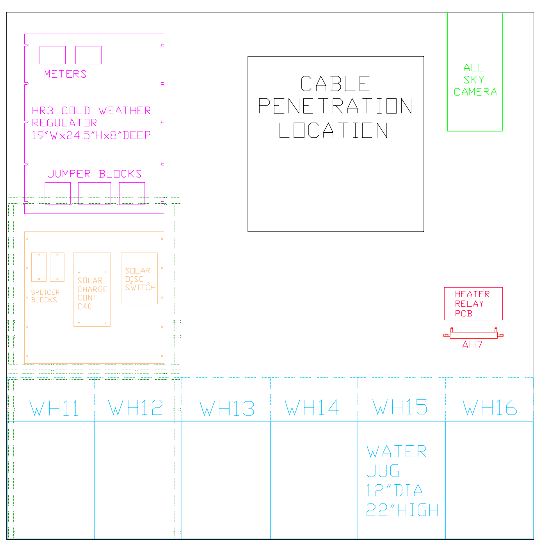


INSTRUMENT WALL LAYOUT

- INSIDE ENCLOSED AREA IS 6'x6'x6'. WALL THICKNESSES ARE SHOWN 18"THICK.
- PRELIMINARY PLACEMENT: PENETRATIONS NEED TO CONSIDER PANEL JOINTS. PHOTOMETER AND ALL SKY CAMERA LOCATIONS ARE FLEXIBLE BUT SHOULD STAY IN THE GENERAL LOCATION SHOWN ABOVE.
- CABLE PENETRATION LOCATIONS ARE SHOWN AS 24"Wx24"HIGH AND STARTING 6" FROM THE ENCLOSURE CEILING. THEY SHOULD BE LOCATED IN THE CENTER OF THE BACK WALL AND NEAR THE TOP OF THE ENCLOSURE. EXACT LOCATION CAN BE DETERMINED BY CRREL IN CONSULTATION WITH THE MANUFACTURER AND UNH.
- SIXTEEN WATER JUGS 11.75"DIAx16"H EACH ARE SHOWN AS 12"DIAx22"H WITH 6"HEIGHT CLEARANCE.
- BATTERIES ARE SHOWN 7.75"Wx10"Lx22"H INCLUDING 6" HEIGHT CLEARANCE.
- INSTRUMENT RACKS ARE 22"WIDEx22"DEEPx66"HIGH TO ALLOW THEM TO FIT THROUGH THE DOOR AND BE STOOD UP.

ARRO BACK WALL DETAIL LAYOUT

#1888 BACKWALL.DWG
8/8/05
DRAU

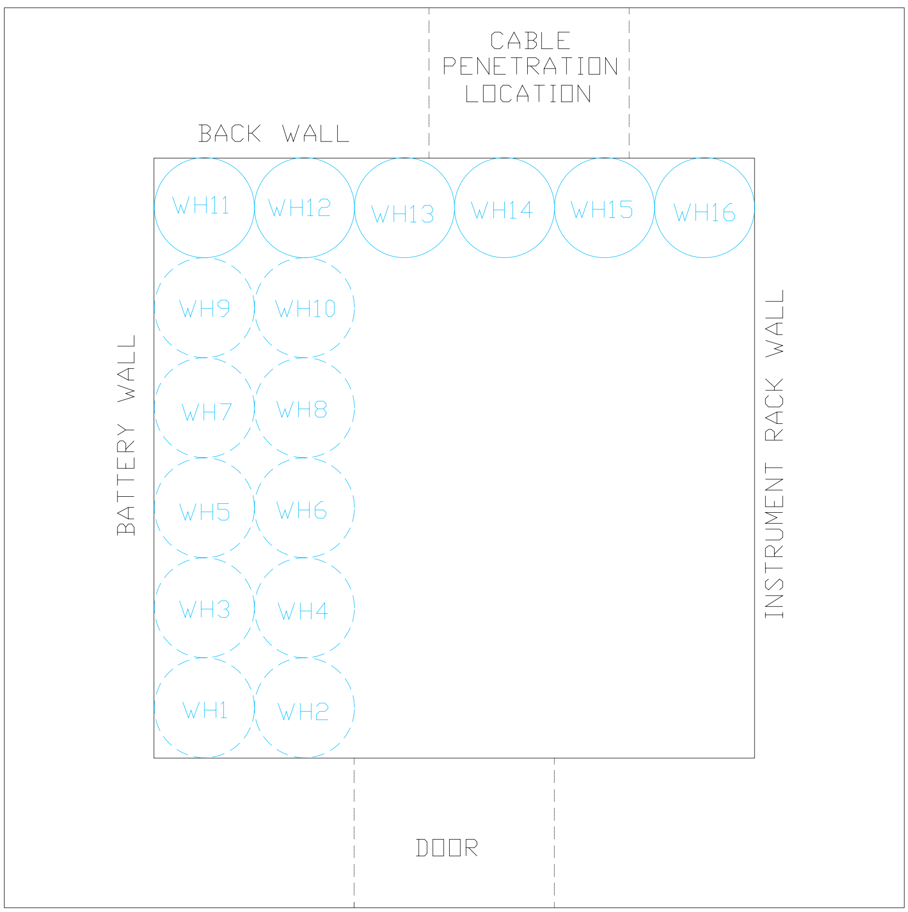


WATER JUG HEATER LAYOUT

TOP VIEW

WATERJG.DWG
JULY26, 2005
#1926

ALL HEATER WIRES ARE LIGHT BLUE TWISTED WITH BLACK 20 AWG

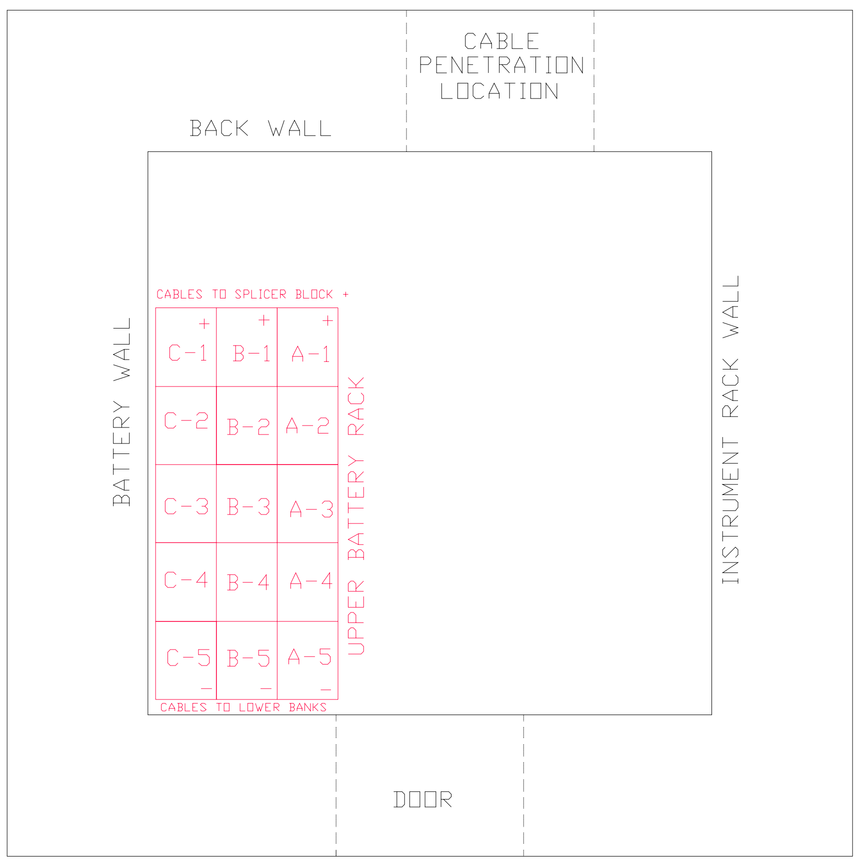


SIGNALTO HEATER TO TEMP SENSOR CORRELATION

ISOL_OUT0 - HTRCNTRL0 - WATER HEATERS 1/2 (WH1/WH2) - TS7
ISOL_OUT1 - HTRCNTRL1 - WH3/WH4 - TS8
ISOL_OUT2 - HTRCNTRL2 - WH5/WH6 - TS9
ISOL_OUT3 - HTRCNTRL3 - WH7/WH8 - TS10
ISOL_OUT4 - HTRCNTRL4 - WH9/WH10 - TS11
ISOL_OUT5 - HTRCNTRL5 - WH11/WH12 - TS12
ISOL_OUT6 - HTRCNTRL6 - WH13/WH14 - TS13
ISOL_OUT7 - HTRCNTRL7 - WH15/WH16 - TS14

TOP BATTERY BANK LAYOUT

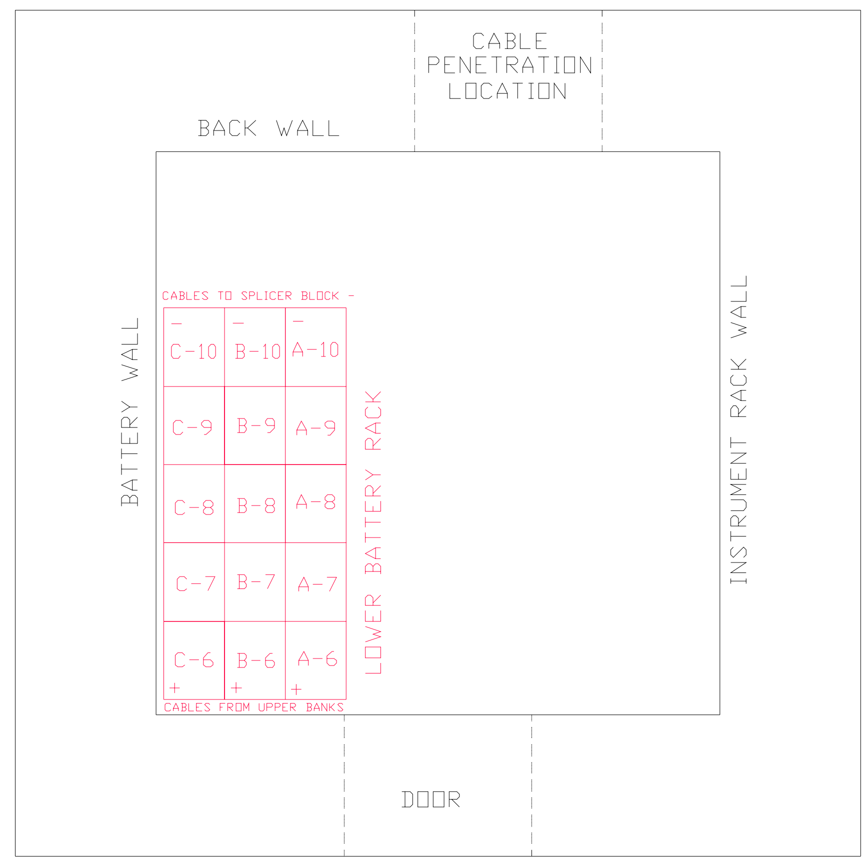
TOP VIEW



BOTTOM BATTERY BANK LAYOUT

TOP VIEW

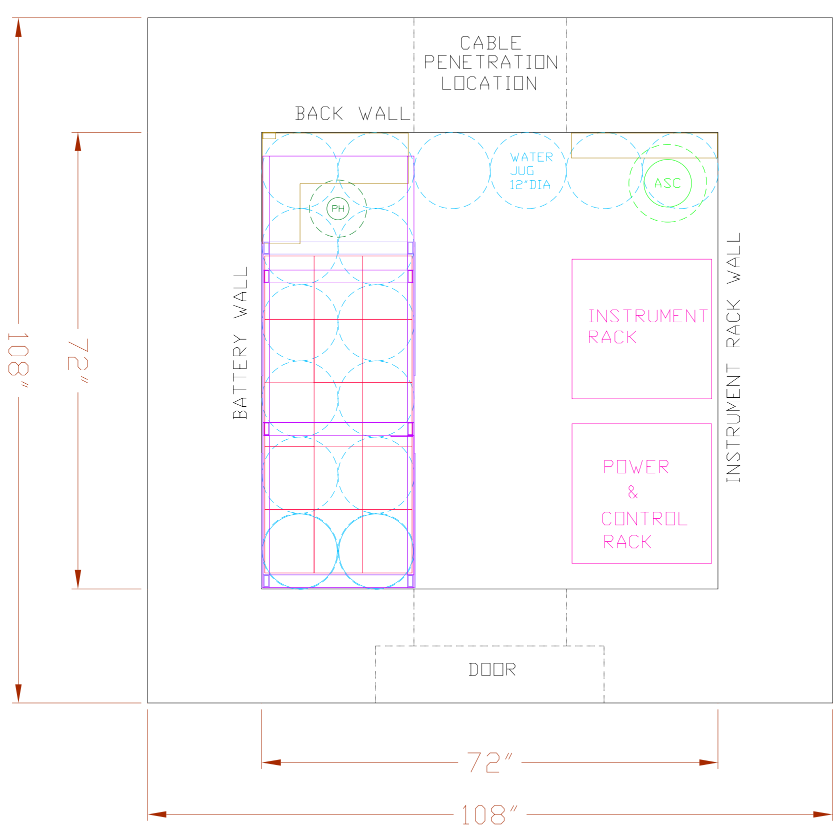
BATTBANK.DWG
#1928
JULY 27 2005



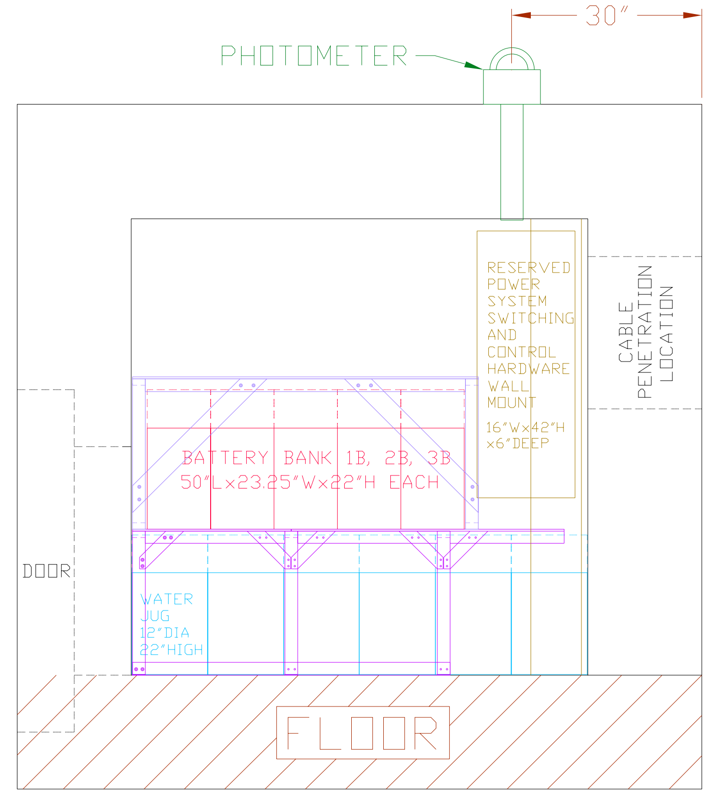
ARRO INTERNAL BATTERY WALL LAYOUT

#1889 BATTWALL.DWG

TOP VIEW - FLOOR PLAN



BATTERY WALL LAYOUT

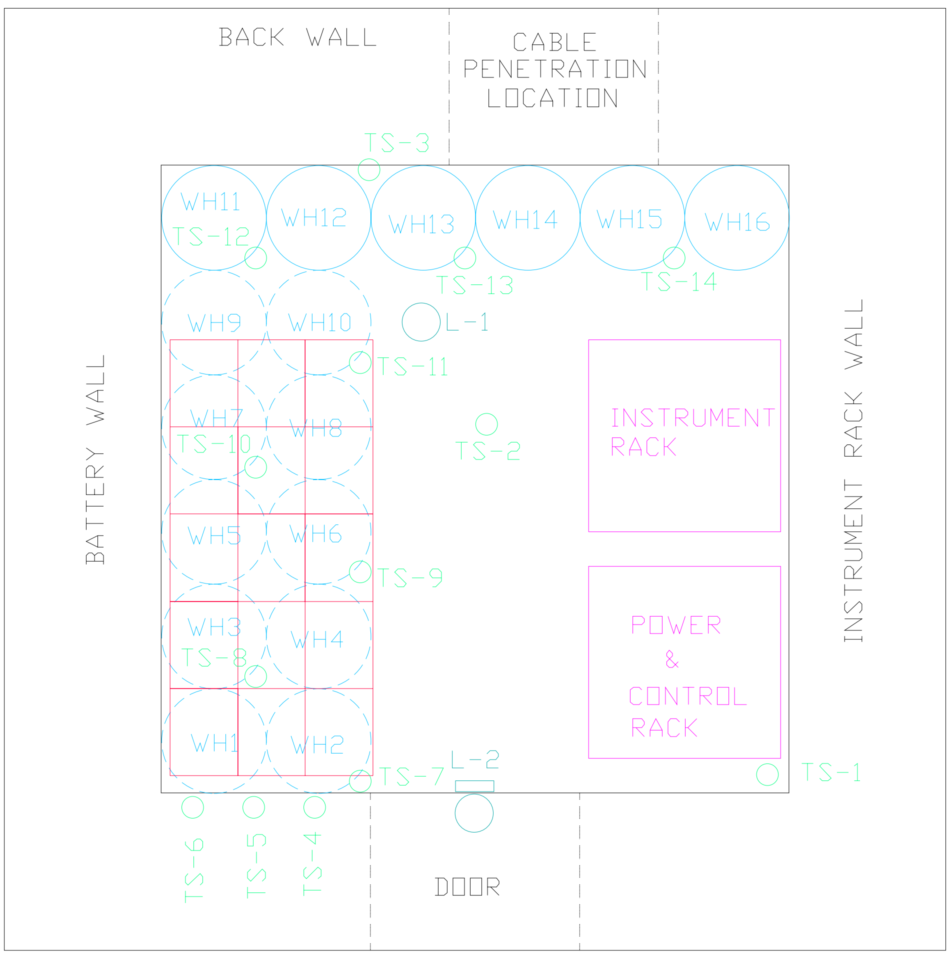


TEMPERATURE SENSOR AND LIGHT LAYOUT

TOP VIEW

TSENSORL.DWG
JULY 29, 2005
#1930

ALL SENSOR WIRES GET CONNECTED TO TERMINAL STRIPS NEAR CHASSIS BAR.



TS-1 AIR NEAR SCU/PDB RACK
TS-2 AIR MOUNTED ON CEILING NEAR LIGHT
TS-3 AIR MOUNTED NEAR SOLAR DISCONNECT SWITCH
TS-4 BATTERY MOUNTED ON (A) BANK ON SIDE OF A-5
TS-5 BATTERY MOUNTED ON (B) BANK ON SIDE OF B-5
TS-6 BATTERY MOUNTED ON (C) BANK ON SIDE OF C-5
TS-7 WATER MOUNTED ON JUG 2 FOR WH1/WH2
TS-8 WATER MOUNTED ON JUG 3 FOR WH3/WH4
TS-9 WATER MOUNTED ON JUG 6 FOR WH5/WH6
TS-10 WATER MOUNTED ON JUG 7 FOR WH7/WH8
TS-11 WATER MOUNTED ON JUG 10 FOR WH9/WH10
TS-12 WATER MOUNTED ON JUG 11 FOR WH11/WH12
TS-13 WATER MOUNTED ON JUG 13 FOR WH13/WH14
TS-14 WATER MOUNTED ON JUG 15 FOR WH15/WH16

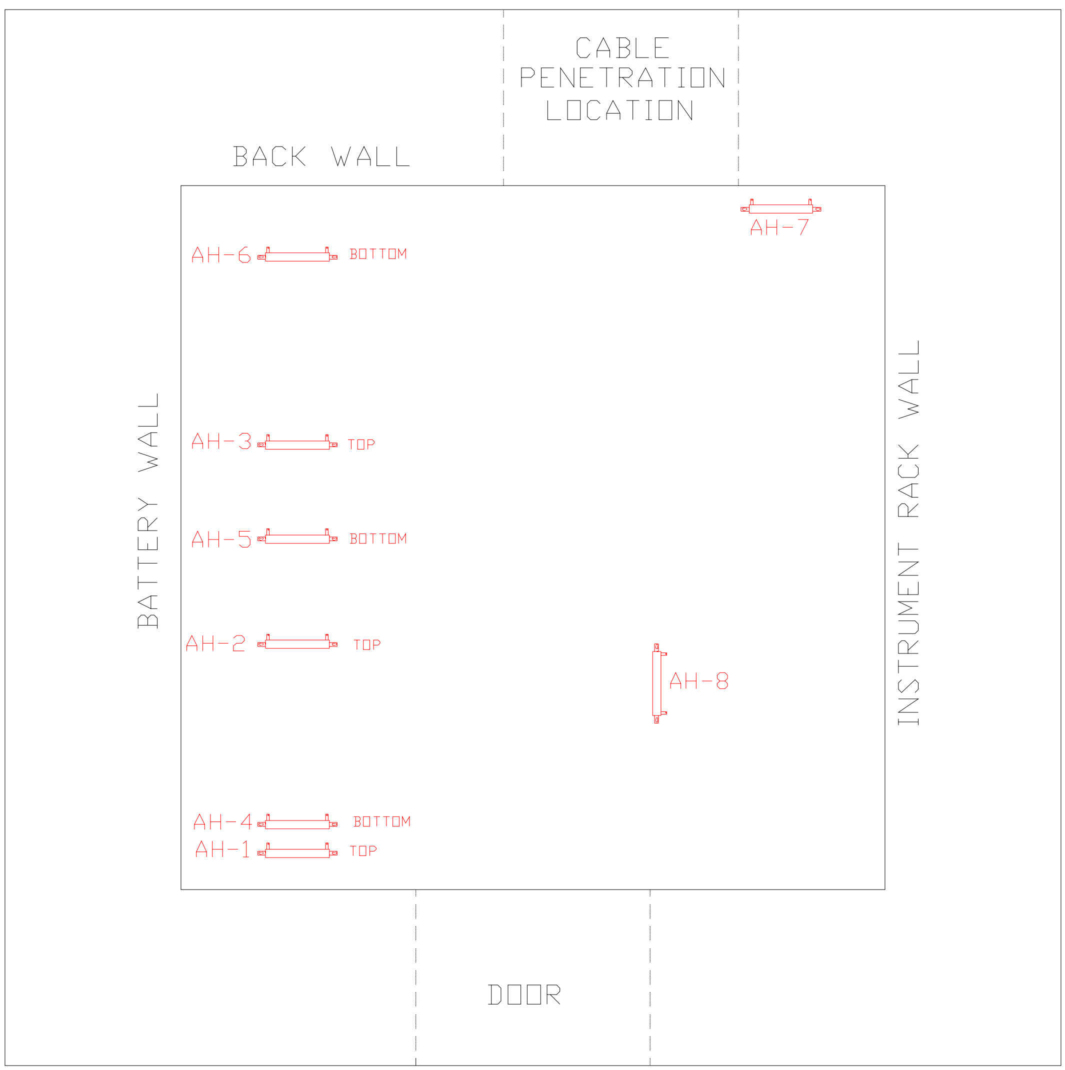
AIR SENSORS HAVE YELLOW/BLACK WIRE
BATTERY SENSORS HAVE ORANGE/BLACK WIRE
WATER JUG SENSORS HAVE BROWN/BLACK WIRE

L-1 IS LIGHT #1 AND IS MOUNTED ON CEILING
L-2 IS LIGHT #2 AND IS MOUNTED TO THE WALL ABOVE THE ENTRANCE DOOR.
LIGHTS HAVE GREEN AND BLACK WIRE.

AMBIENT HEATER LAYOUT

TOP VIEW

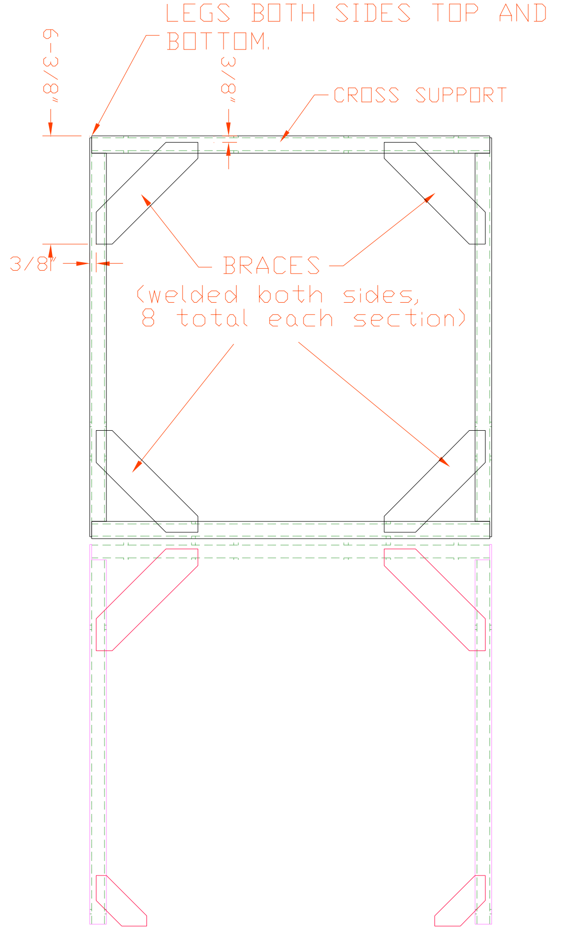
AMBHTR.DWG
#1927
JULY 27 2005



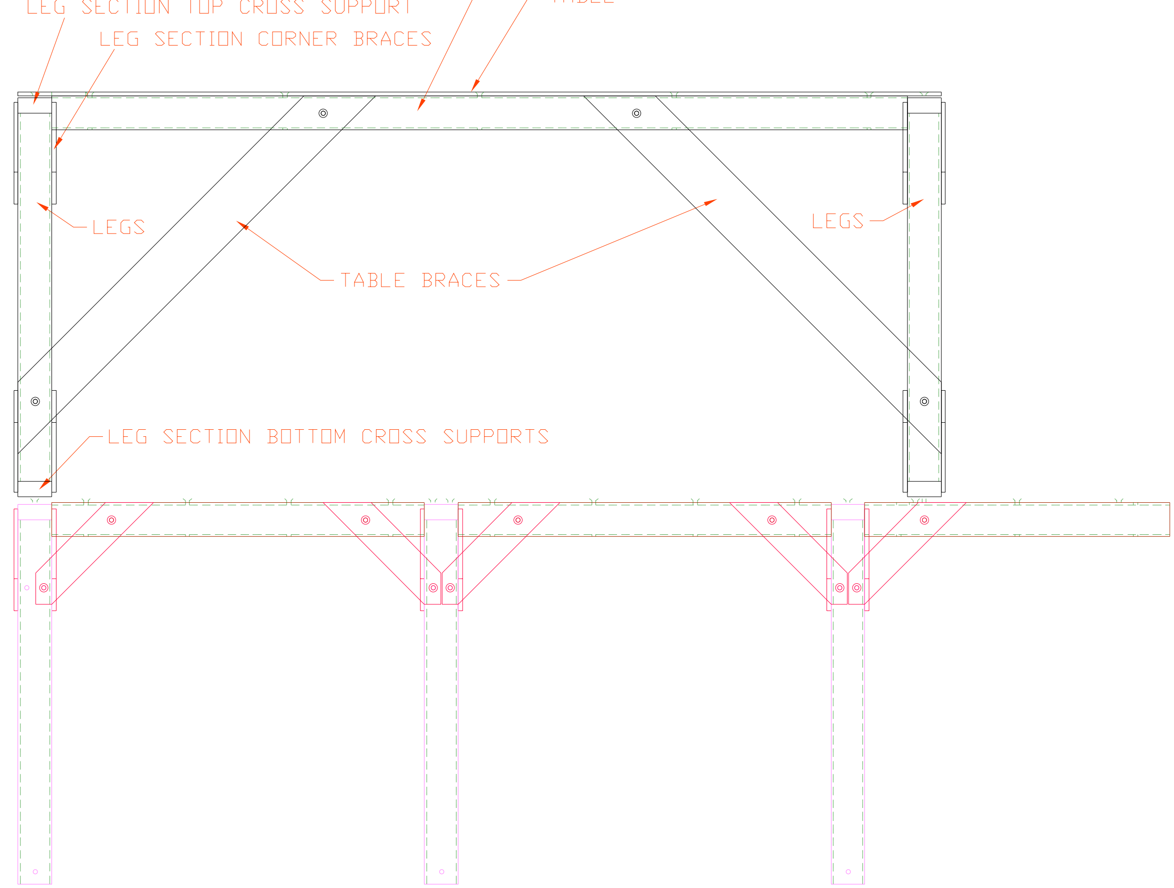
SIGNAL TO AMBIENT HEATER CORRELATION

INTDUMP0 - AMBIENT HEATER 1 (AH1)
INTDUMP1 - AH2
INTDUMP2 - AH3
INTDUMP3 - AH4
INTDUMP4 - AH5
INTDUMP5 - AH6
INTDUMP6 - AH7
INTDUMP7 - AH8

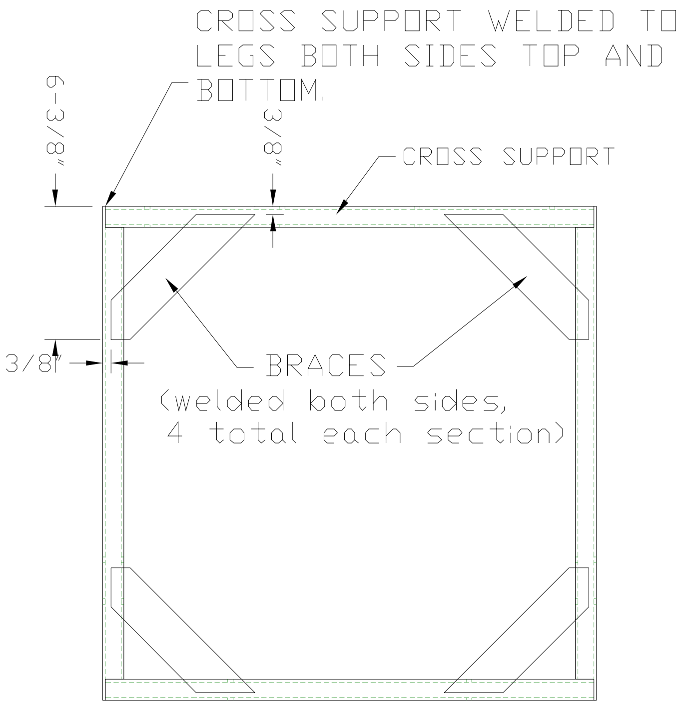
UBR LEG SECTION

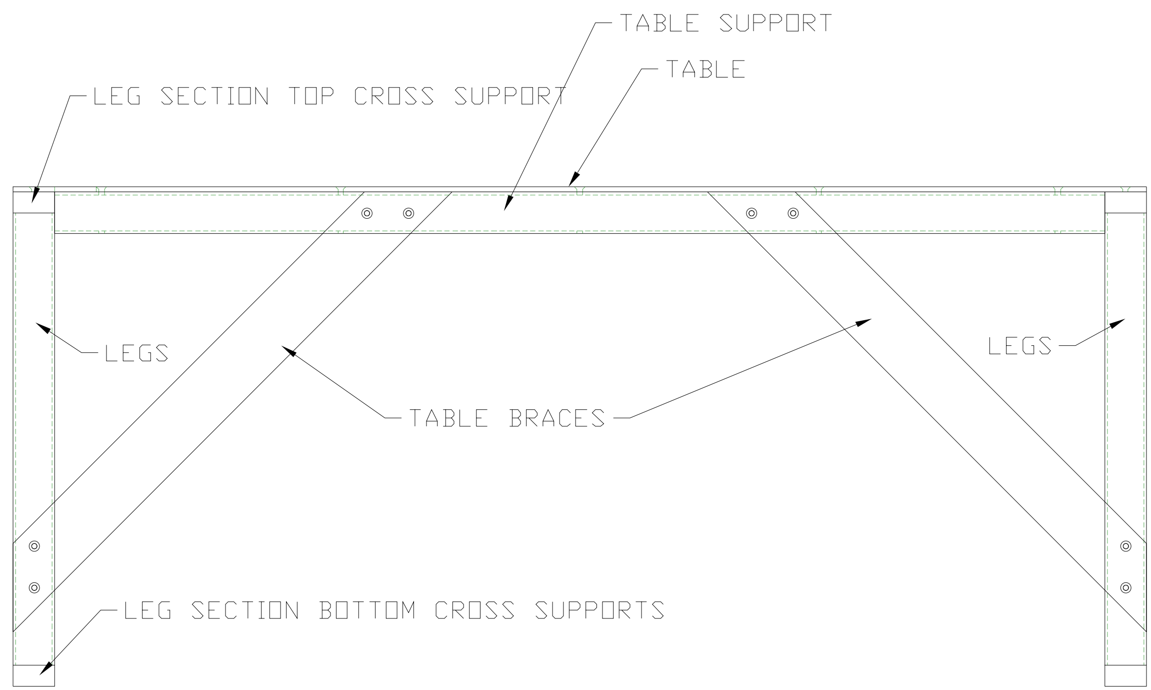


UPPER BATTERY RACK (UBR)

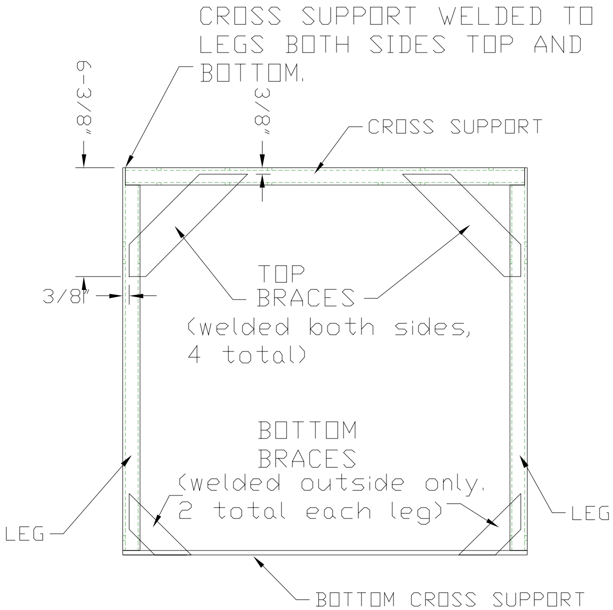


UPPER BATTERY RACK (UBR)
#1911 UBR.DWG

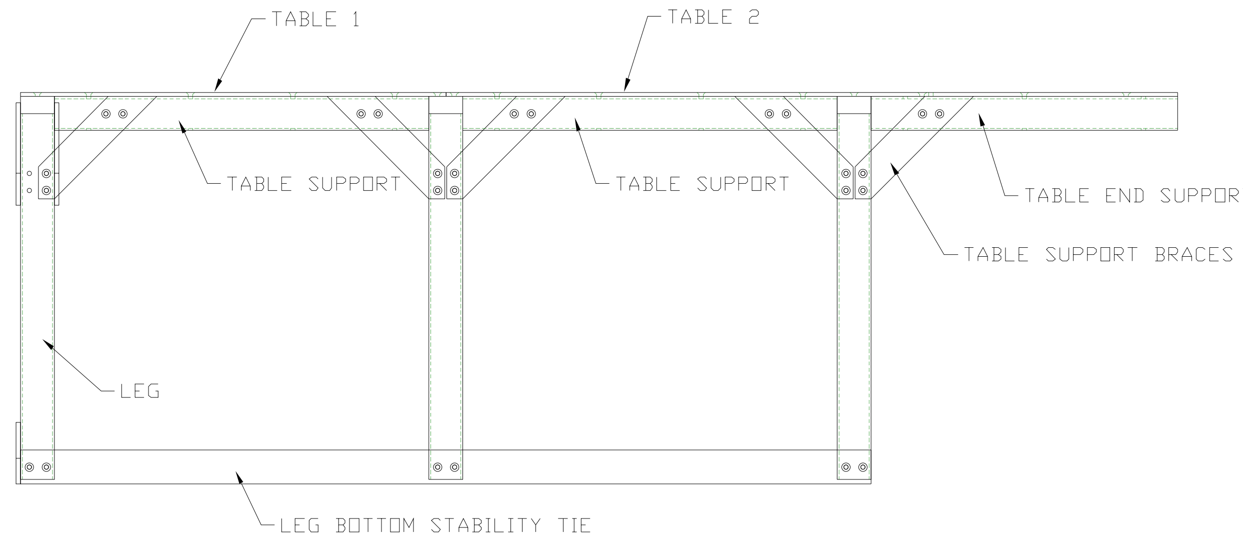


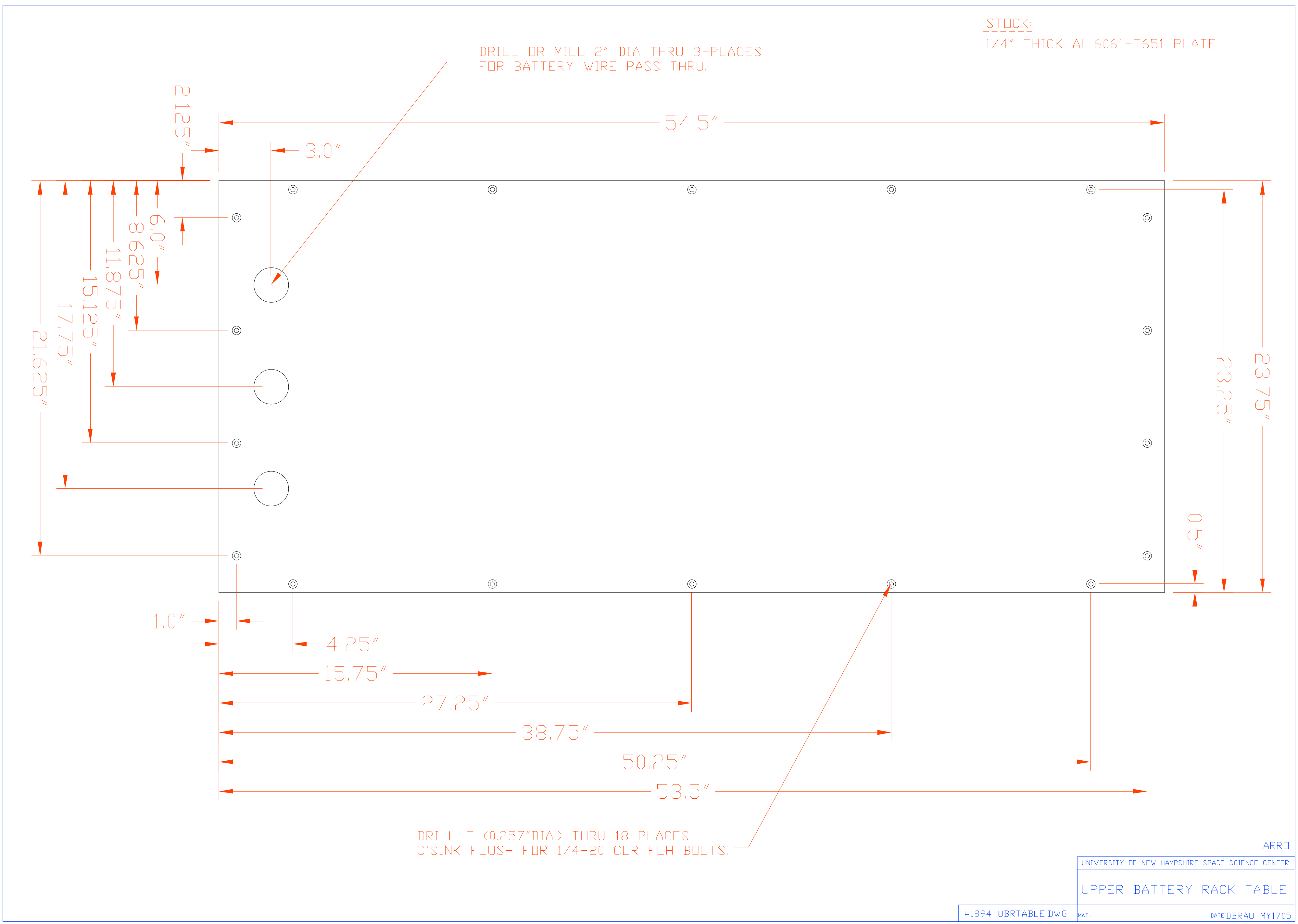


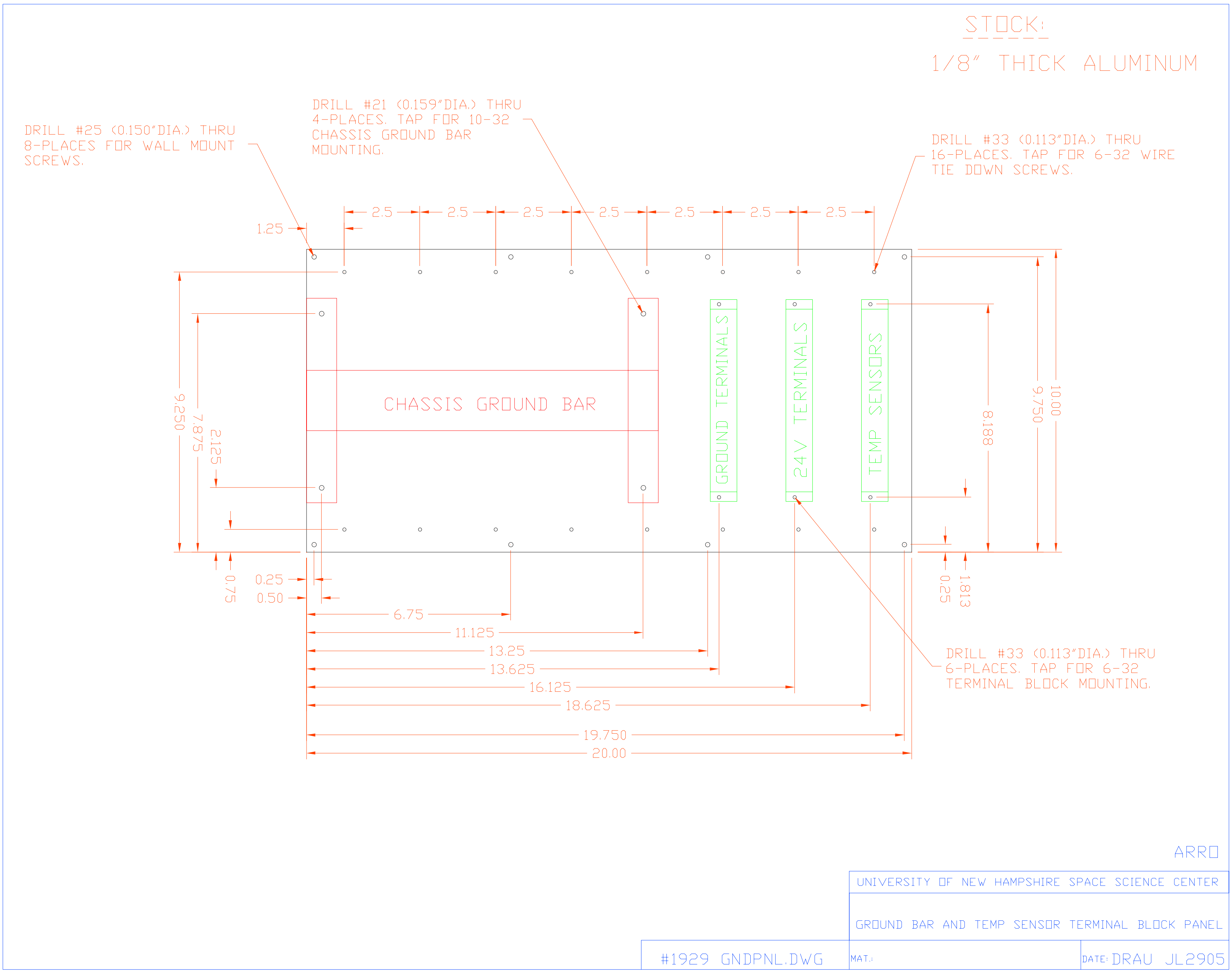
LOWER BATTERY RACK (LBR)
#1910 LBR.DWG

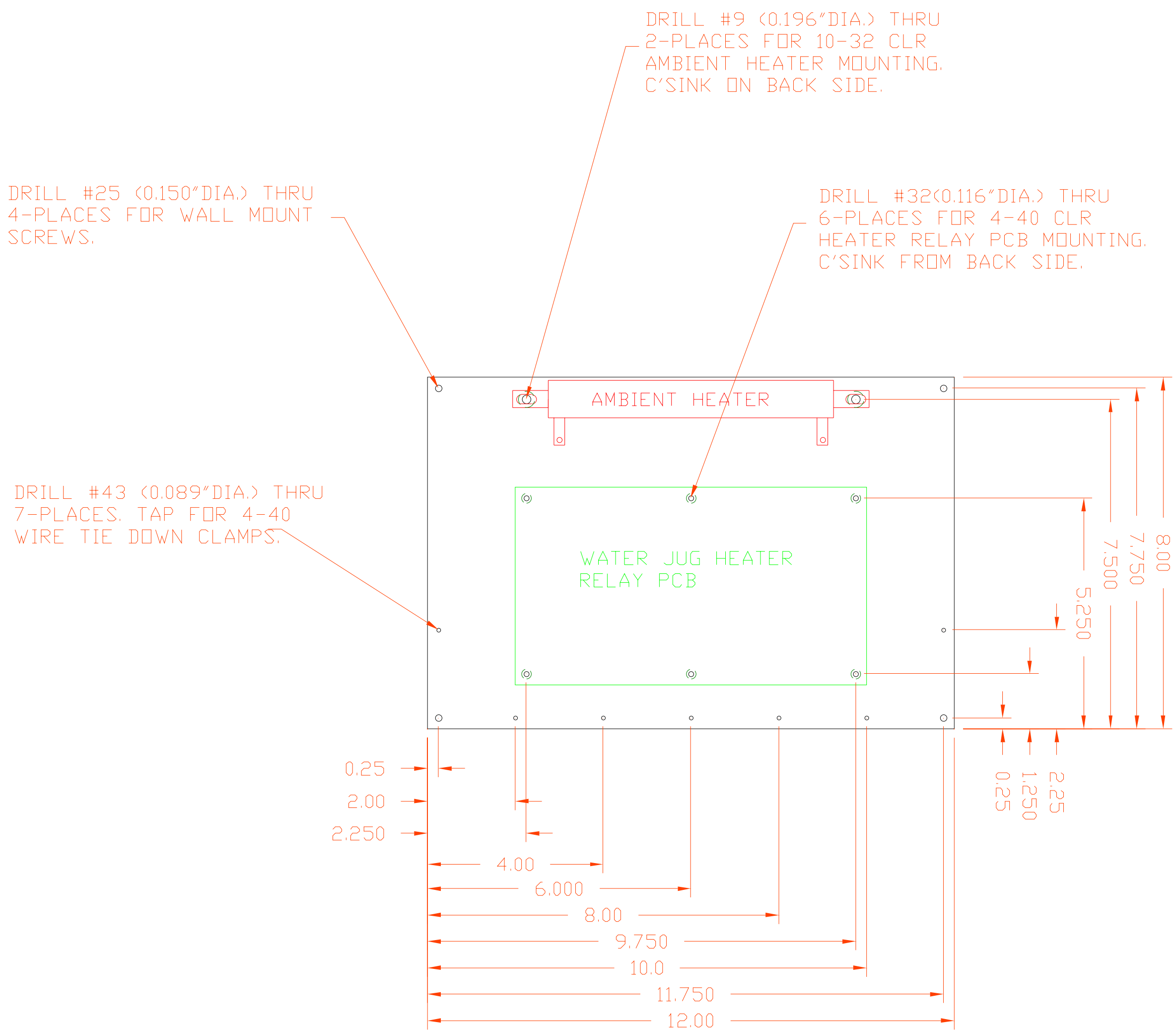


LBR LEG SECTION




STOCK:
1/4" THICK Al 6061-T651 PLATE
DRILL OR MILL 2" DIA THRU 3-PLACES
FOR BATTERY WIRE PASS THRU.
54.5"
3.0"
2.125"
6.0"
8.625"
11.875"
15.125"
17.75"
21.625"
23.25"
23.75"
0.5"
1.0"
4.25"
15.75"
27.25"
38.75"
50.25"
53.5"
DRILL F (0.257"DIA.) THRU 18-PLACES.
C'SINK FLUSH FOR 1/4-20 CLR FLH BOLTS.
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
UPPER BATTERY RACK TABLE
#1894 UBRTABLE.DWG
MAT.
DATE DBRAU MY1705

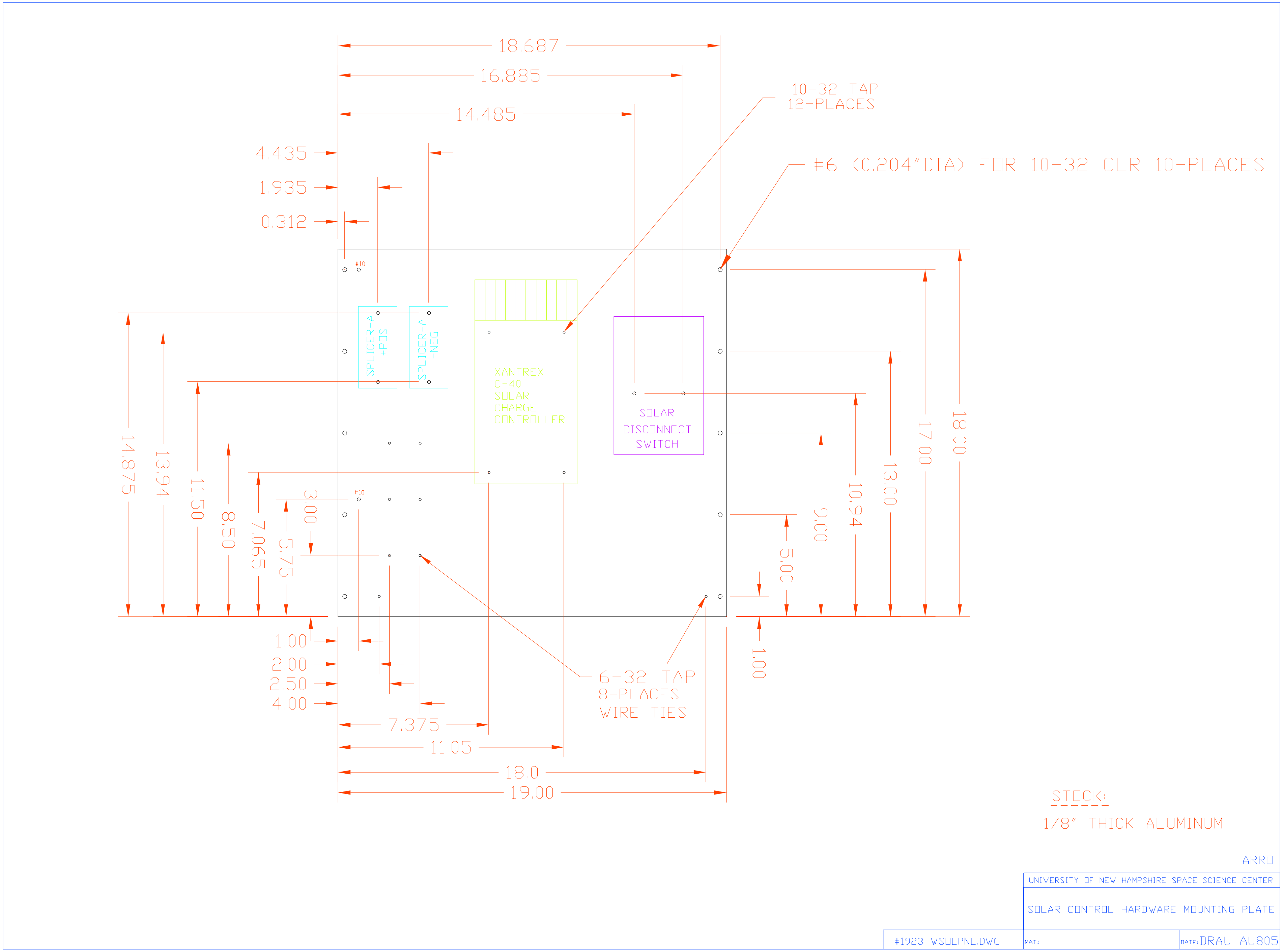

STOCK:
1/8" THICK ALUMINUM
DRILL #25 (0.150"DIA.) THRU 8-PLACES FOR WALL MOUNT SCREWS.
DRILL #21 (0.159"DIA.) THRU 4-PLACES. TAP FOR 10-32 CHASSIS GROUND BAR MOUNTING.
DRILL #33 (0.113"DIA.) THRU 16-PLACES. TAP FOR 6-32 WIRE TIE DOWN SCREWS.
DRILL #33 (0.113"DIA.) THRU 6-PLACES. TAP FOR 6-32 TERMINAL BLOCK MOUNTING.
CHASSIS GROUND BAR
GROUND TERMINALS
24V TERMINALS
TEMP SENSORS
1.25
2.5
9.250
7.875
2.125
0.75
0.25
0.50
6.75
11.125
13.25
13.625
16.125
18.625
19.750
20.00
10.00
9.750
8.188
1.813
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
GROUND BAR AND TEMP SENSOR TERMINAL BLOCK PANEL
#1929 GNDPNL.DWG
MAT.:
DATE: DRAU JL2905

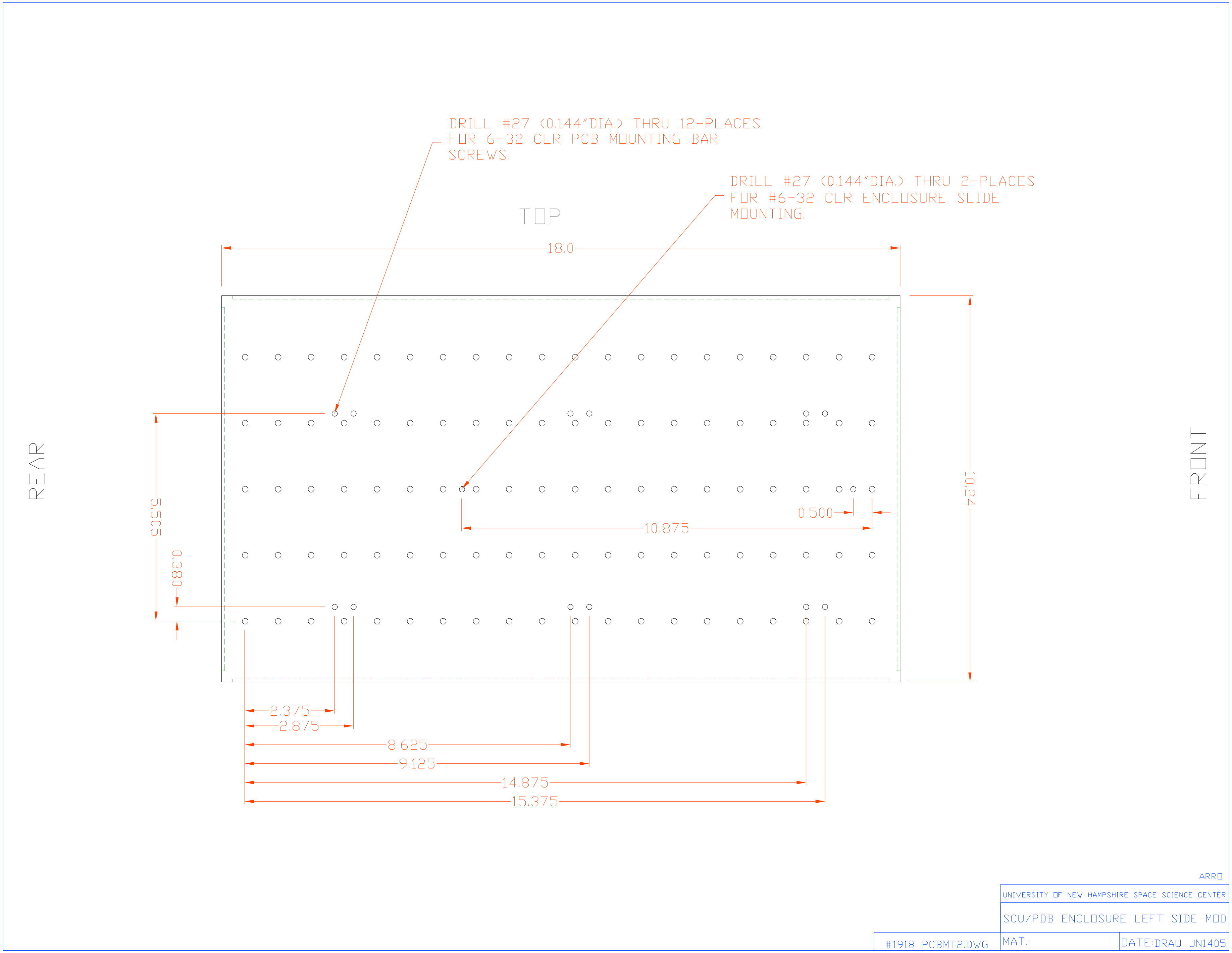


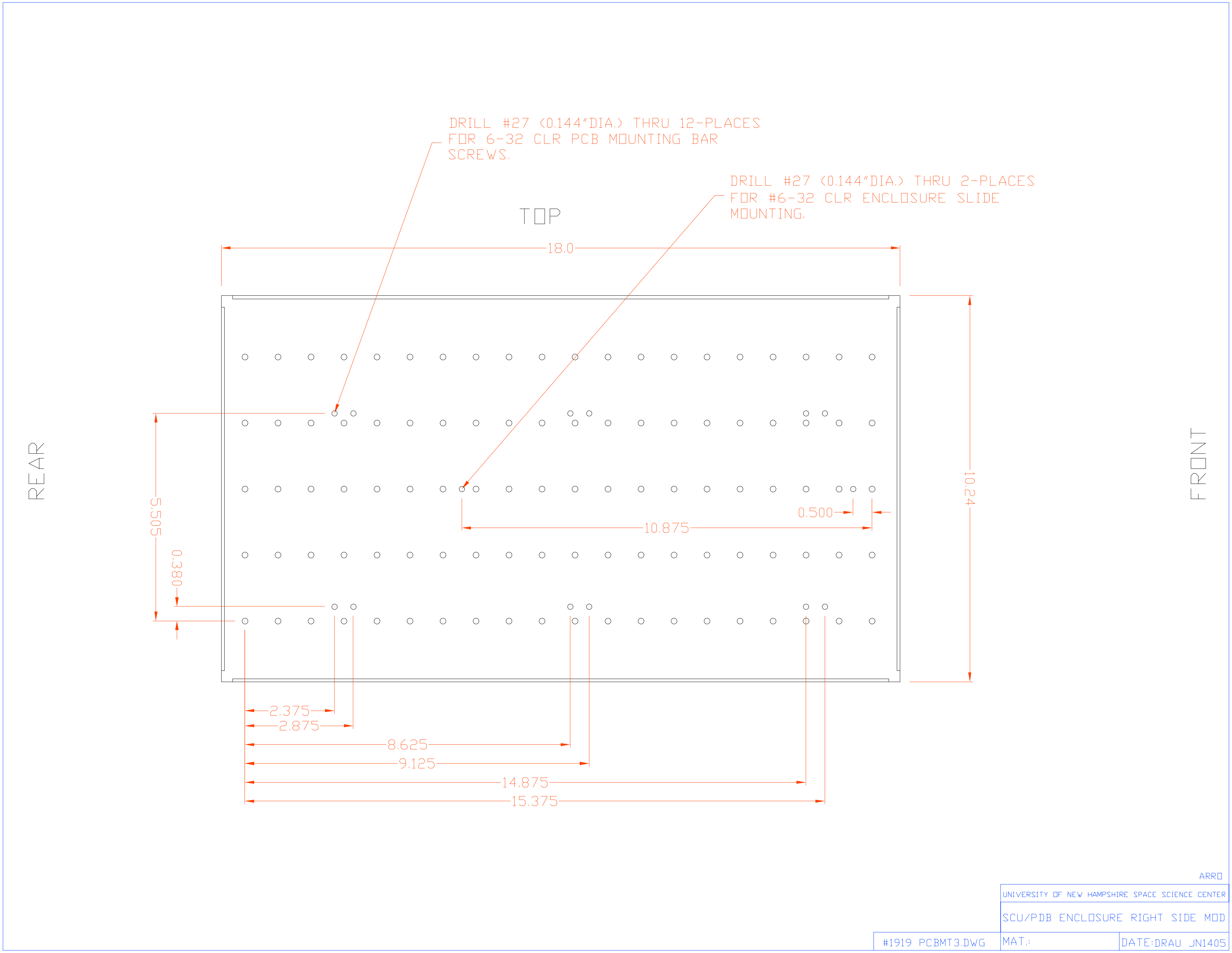
STOCK:
1/8" THICK ALUMINUM

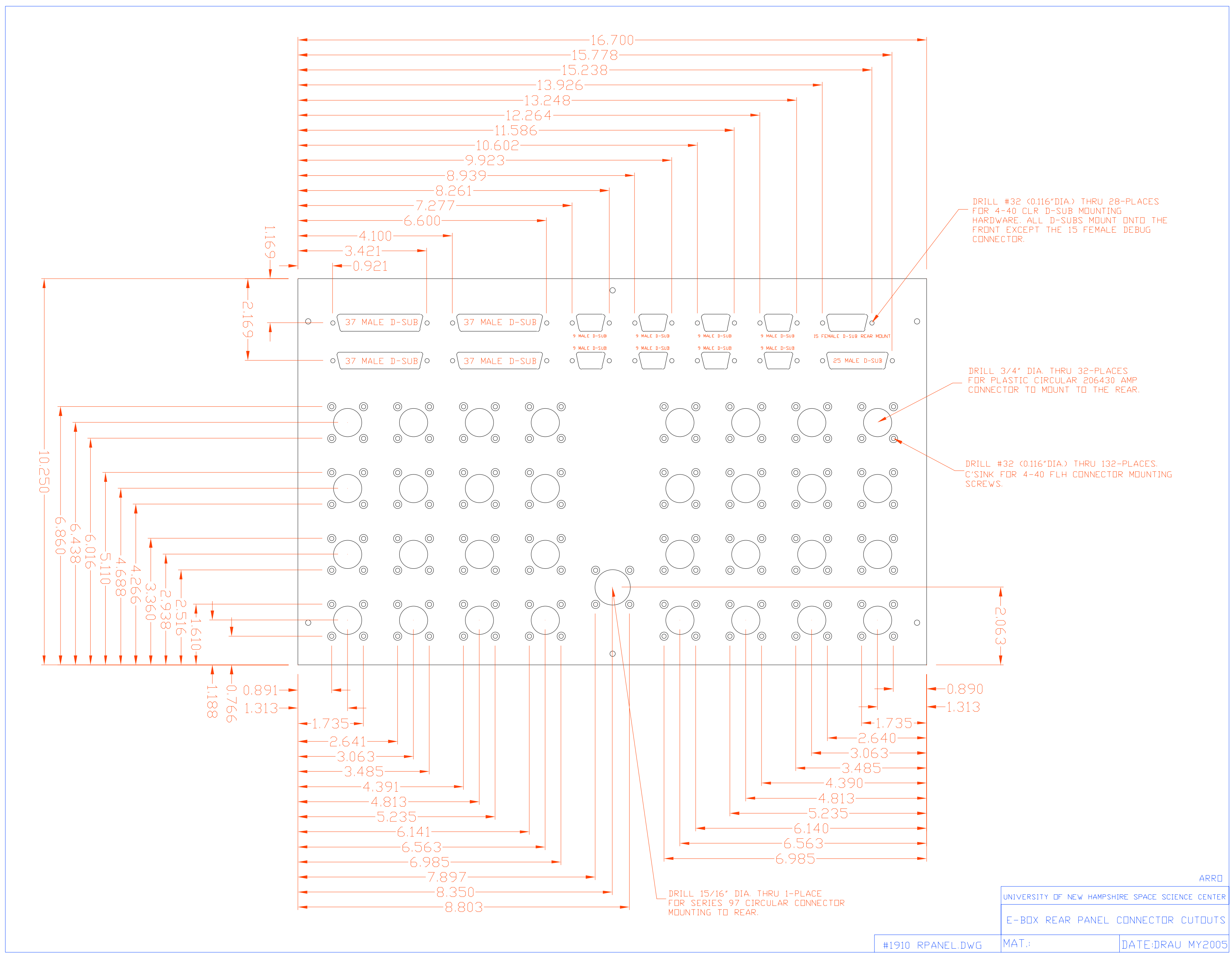
ARRO

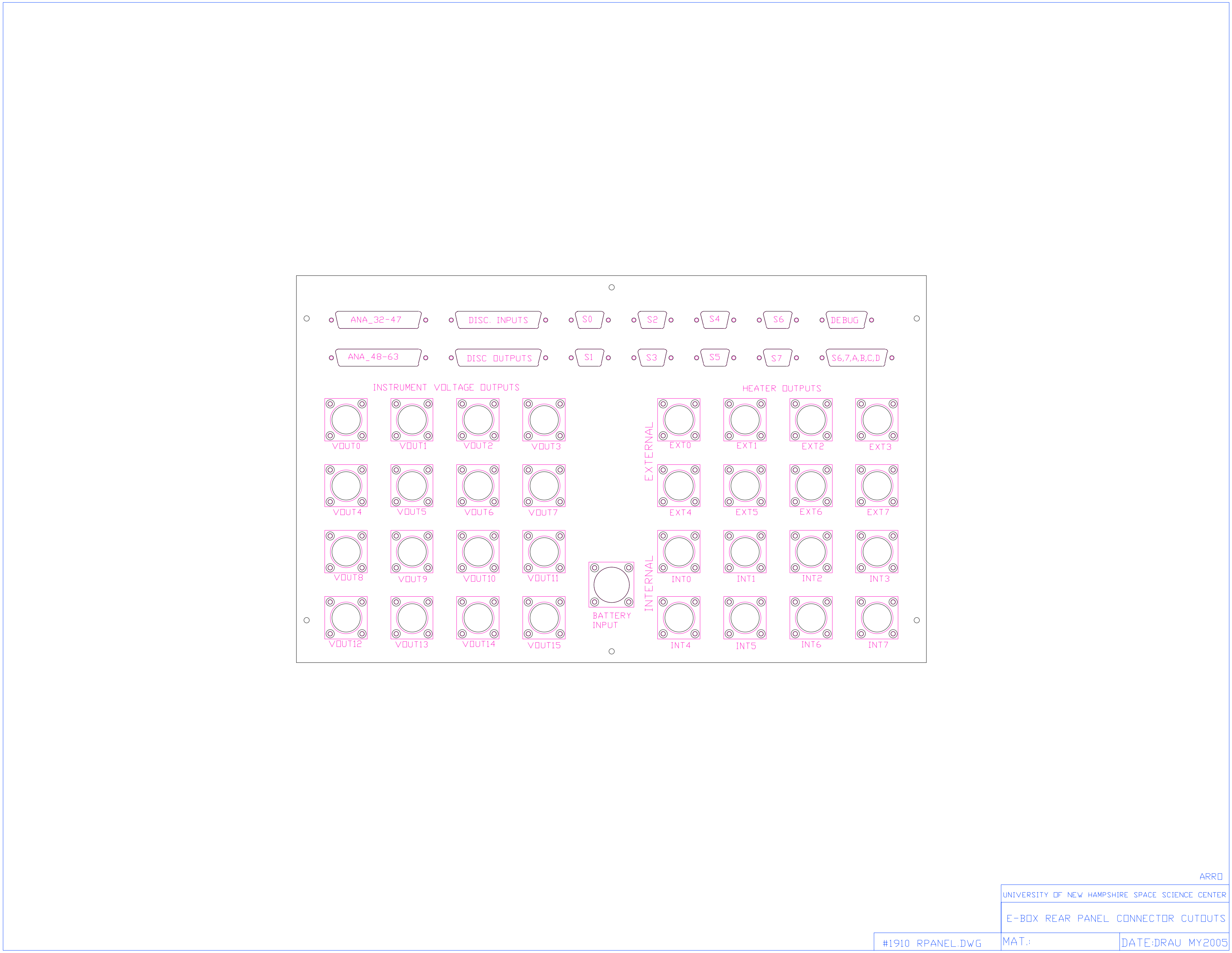
	UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER	
	HEATER RELAY PCB & AMBIENT HEATER MOUNTING PANEL	
#1925 HTRPNL.DWG	MAT.:	DATE: DRAU JL1805


18.687
16.885
14.485
10-32 TAP
12-PLACES
#6 (0.204"DIA) FOR 10-32 CLR 10-PLACES
4.435
1.935
0.312
#10
SPLICER-A
+POS
SPLICER-A
-NEG
XANTREX
C-40
SOLAR
CHARGE
CONTROLLER
SOLAR
DISCONNECT
SWITCH
18.00
17.00
13.00
10.94
9.00
5.00
1.00
14.875
13.94
11.50
8.50
7.065
5.75
3.00
1.00
2.00
2.50
4.00
6-32 TAP
8-PLACES
WIRE TIES
7.375
11.05
18.0
19.00
STOCK:
1/8" THICK ALUMINUM
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
SOLAR CONTROL HARDWARE MOUNTING PLATE
#1923 WSOLPNL.DWG
MAT.:
DATE: DRAU AU805


DRILL #27 (0.144"DIA.) THRU 12-PLACES
FOR 6-32 CLR PCB MOUNTING BAR
SCREWS.
DRILL #27 (0.144"DIA.) THRU 2-PLACES
FOR #6-32 CLR ENCLOSURE SLIDE
MOUNTING.
TOP
18.0
REAR
FRONT
10.24
5.505
0.380
0.500
10.875
2.375
2.875
8.625
9.125
14.875
15.375
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
SCU/PDB ENCLOSURE LEFT SIDE MOD
MAT.:
DATE:DRAU JN1405
#1918 PCBMT2.DWG


DRILL #27 (0.144"DIA.) THRU 12-PLACES
FOR 6-32 CLR PCB MOUNTING BAR
SCREWS.
DRILL #27 (0.144"DIA.) THRU 2-PLACES
FOR #6-32 CLR ENCLOSURE SLIDE
MOUNTING.
TOP
18.0
REAR
FRONT
5.505
0.380
10.24
0.500
10.875
2.375
2.875
8.625
9.125
14.875
15.375
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
SCU/PDB ENCLOSURE RIGHT SIDE MOD
#1919 PCBMT3.DWG
MAT.:
DATE:DRAU JN1405


DRILL #32 (0.116"DIA.) THRU 28-PLACES FOR 4-40 CLR D-SUB MOUNTING HARDWARE. ALL D-SUBS MOUNT ONTO THE FRONT EXCEPT THE 15 FEMALE DEBUG CONNECTOR.
DRILL 3/4" DIA. THRU 32-PLACES FOR PLASTIC CIRCULAR 206430 AMP CONNECTOR TO MOUNT TO THE REAR.
DRILL #32 (0.116"DIA.) THRU 132-PLACES. C'SINK FOR 4-40 FLH CONNECTOR MOUNTING SCREWS.
DRILL 15/16" DIA. THRU 1-PLACE FOR SERIES 97 CIRCULAR CONNECTOR MOUNTING TO REAR.
37 MALE D-SUB
9 MALE D-SUB
15 FEMALE D-SUB REAR MOUNT
25 MALE D-SUB
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
E-BOX REAR PANEL CONNECTOR CUTOUTS
MAT.:
DATE:DRAU MY2005
#1910 RPANEL.DWG

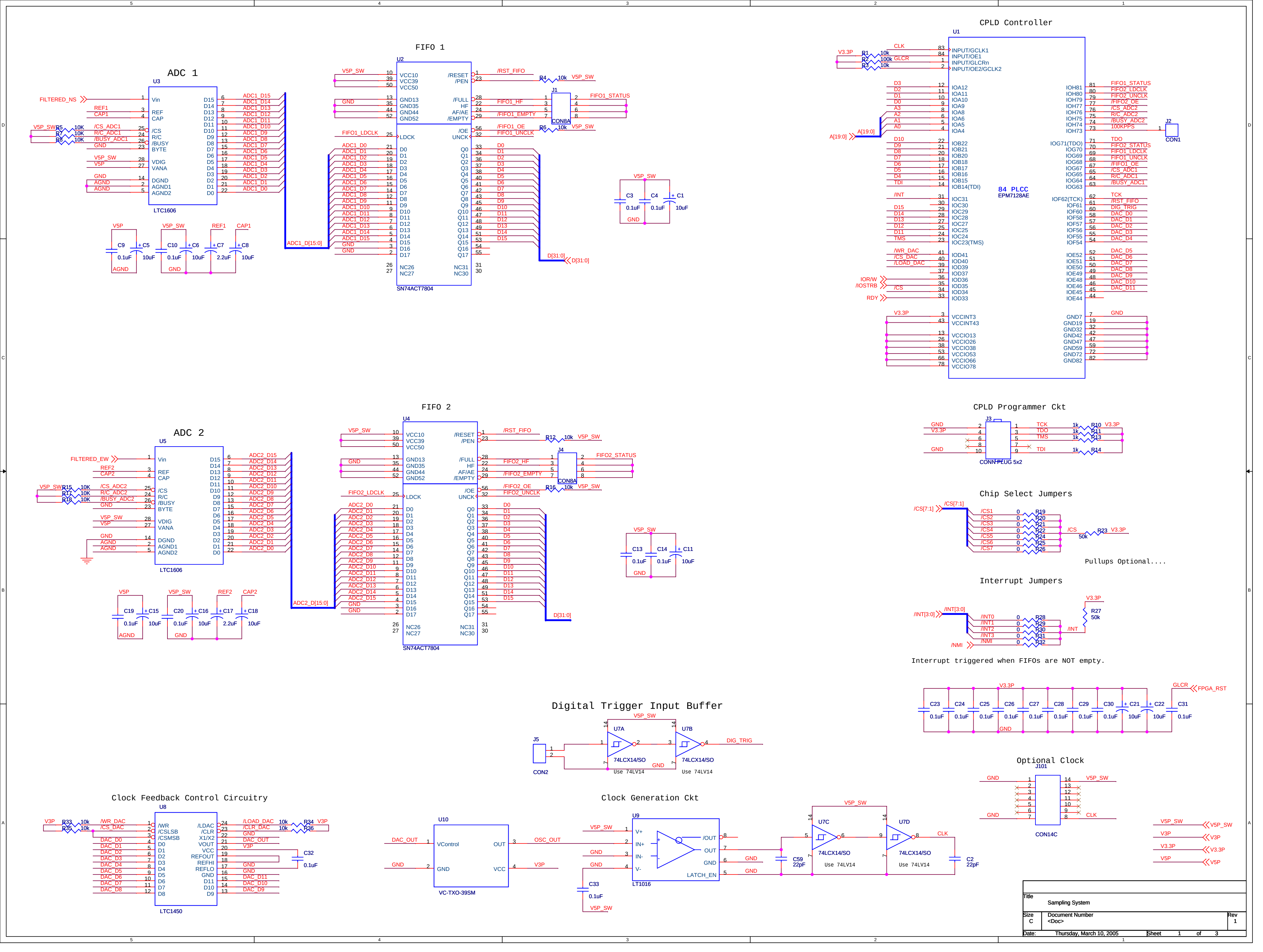

ANA_32-47
DISC. INPUTS
S0
S2
S4
S6
DEBUG
ANA_48-63
DISC OUTPUTS
S1
S3
S5
S7
S6,7,A,B,C,D
INSTRUMENT VOLTAGE OUTPUTS
HEATER OUTPUTS
EXTERNAL
INTERNAL
VOUT0
VOUT1
VOUT2
VOUT3
VOUT4
VOUT5
VOUT6
VOUT7
VOUT8
VOUT9
VOUT10
VOUT11
VOUT12
VOUT13
VOUT14
VOUT15
BATTERY
INPUT
EXT0
EXT1
EXT2
EXT3
EXT4
EXT5
EXT6
EXT7
INT0
INT1
INT2
INT3
INT4
INT5
INT6
INT7
ARRO
UNIVERSITY OF NEW HAMPSHIRE SPACE SCIENCE CENTER
E-BOX REAR PANEL CONNECTOR CUTOUTS
#1910 RPANEL.DWG
MAT.:
DATE:DRAU MY2005

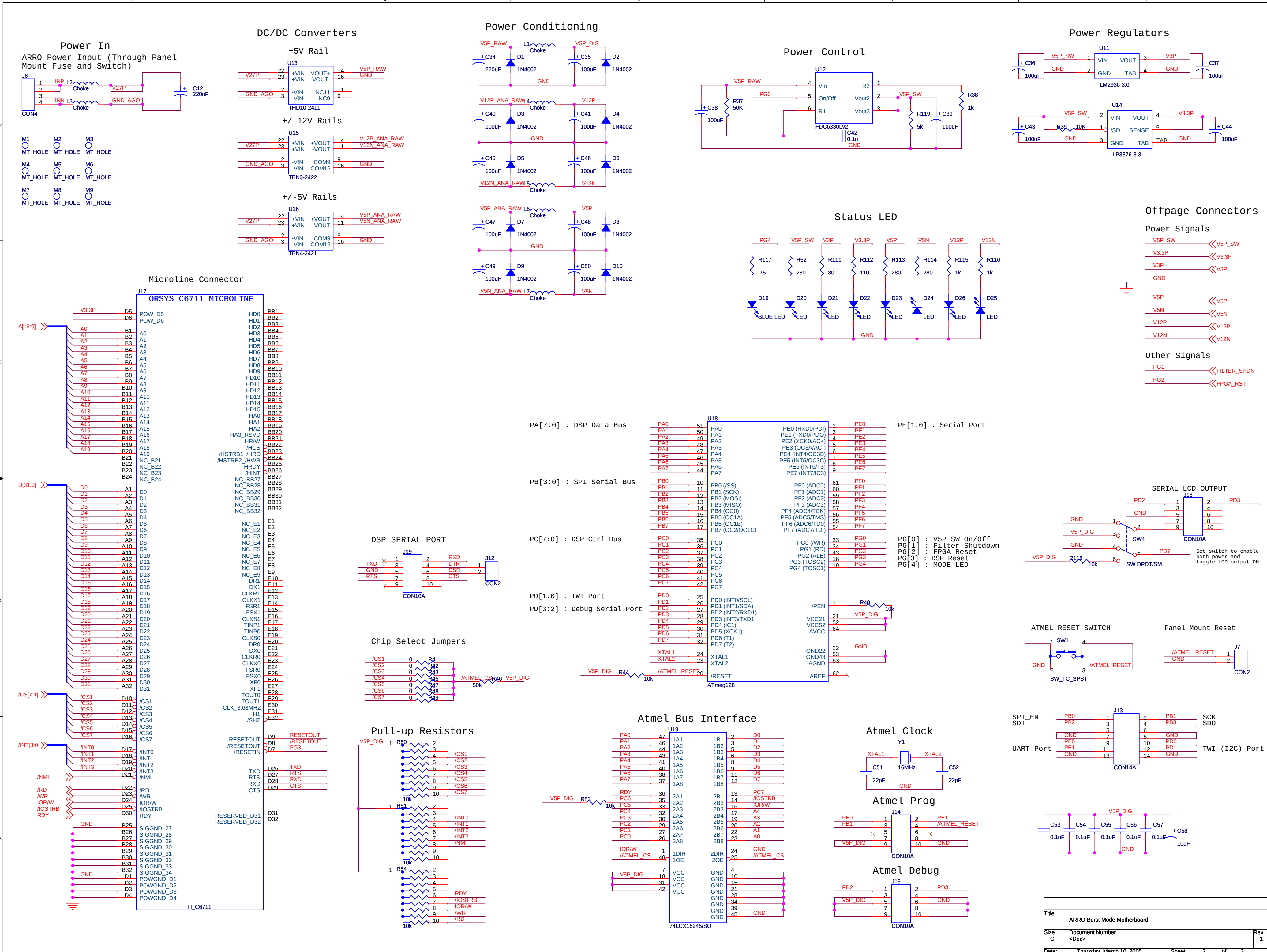
APPENDIX I

ARRO BURST MODE UNIT DOCUMENTATION

The following appendix contains the following documentation:

1) Photographs of the Burst Mode Module
2) Alpha Version Burst Mode Schematic


ADC 1
FIFO 1
CPLD Controller
84 PLCC
EPM7128AE
ADC 2
FIFO 2
CPLD Programmer Ckt
Chip Select Jumpers
Pullups Optional....
Interrupt Jumpers
Interrupt triggered when FIFOs are NOT empty.
Digital Trigger Input Buffer
Optional Clock
Clock Feedback Control Circuitry
Clock Generation Ckt
Title
Sampling System
Size
C
Document Number
<Doc>
Rev
1
Date: Thursday, March 10, 2005
Sheet 1 of 3

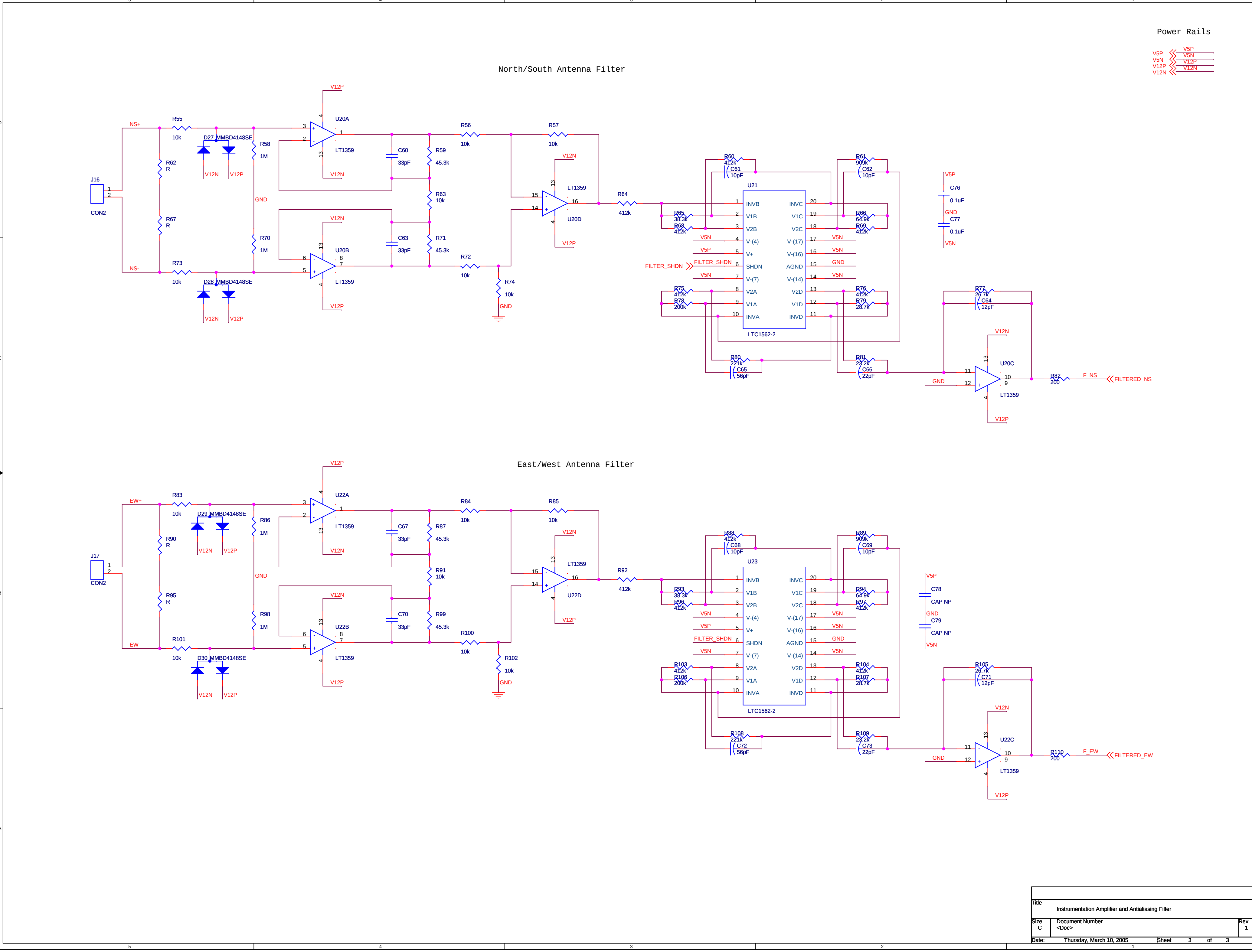


Power In
ARRO Power Input (Through Panel Mount Fuse and Switch)
DC/DC Converters
+5V Rail
+/-12V Rails
+/-5V Rails
Power Conditioning
Power Control
Power Regulators
Status LED
Offpage Connectors
Power Signals
Other Signals
Microline Connector
ORSYS C6711 MICROLINE
PA[7:0] : DSP Data Bus
PB[3:0] : SPI Serial Bus
PC[7:0] : DSP Ctrl Bus
PD[1:0] : TWI Port
PD[3:2] : Debug Serial Port
PE[1:0] : Serial Port
PG[0] : V5P_SW On/Off
PG[1] : Filter Shutdown
PG[2] : FPGA Reset
PG[3] : DSP Reset
PG[4] : MODE LED
DSP SERIAL PORT
Chip Select Jumpers
Pull-up Resistors
Atmel Bus Interface
Atmel Clock
Atmel Prog
Atmel Debug
SERIAL LCD OUTPUT
Set switch to enable both power and toggle LCD output ON
ATMEL RESET SWITCH
Panel Mount Reset
SPI_EN
SDI
SCK
SDO
UART Port
TWI (I2C) Port
Title
ARRO Burst Mode Motherboard
Size
C
Document Number
<Doc>
Rev
1
Date: Thursday, March 10, 2005
Sheet 2 of 3

Power Rails

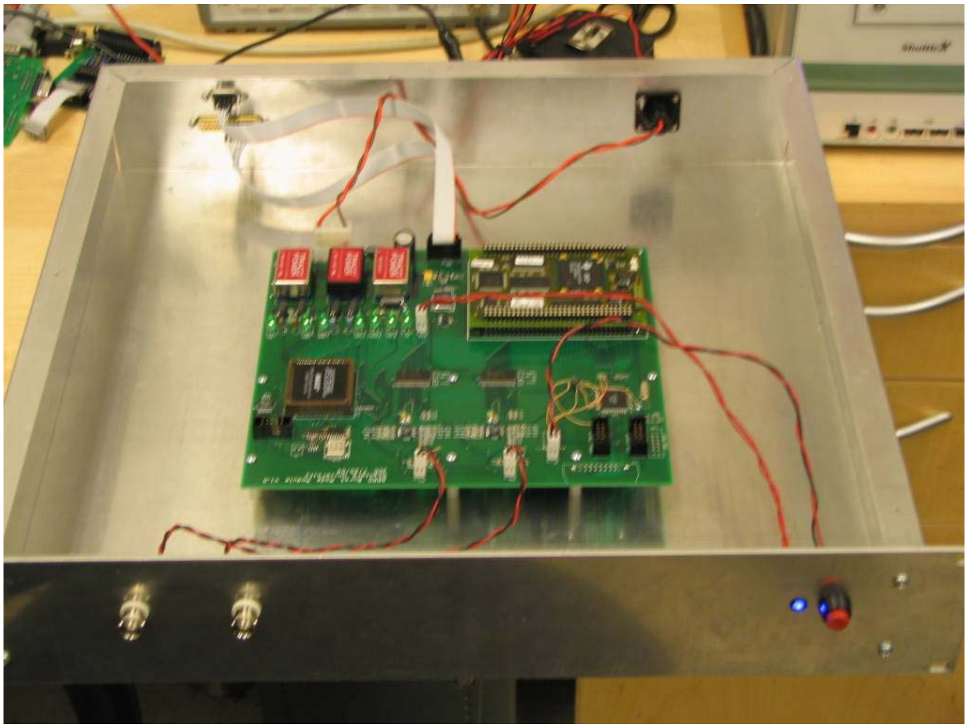
North/South Antenna Filter

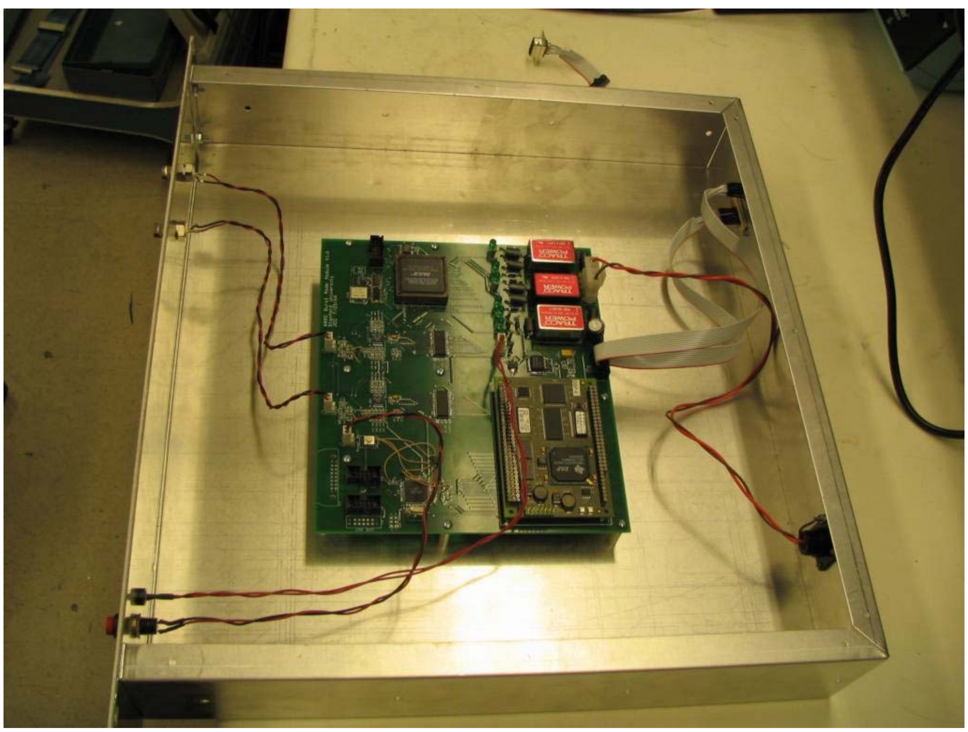
East/West Antenna Filter

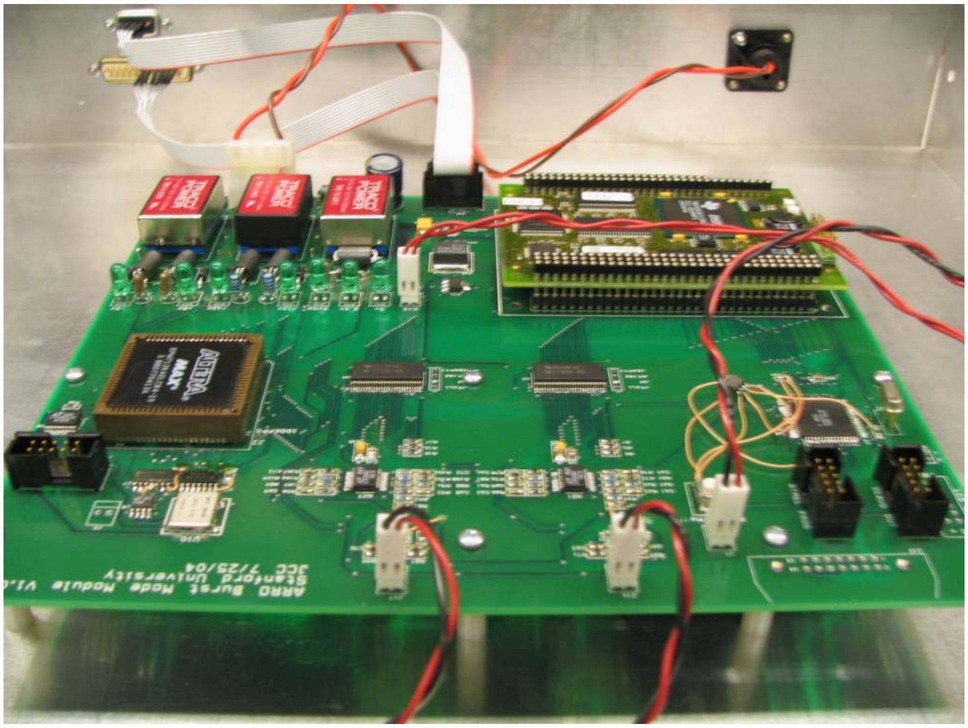


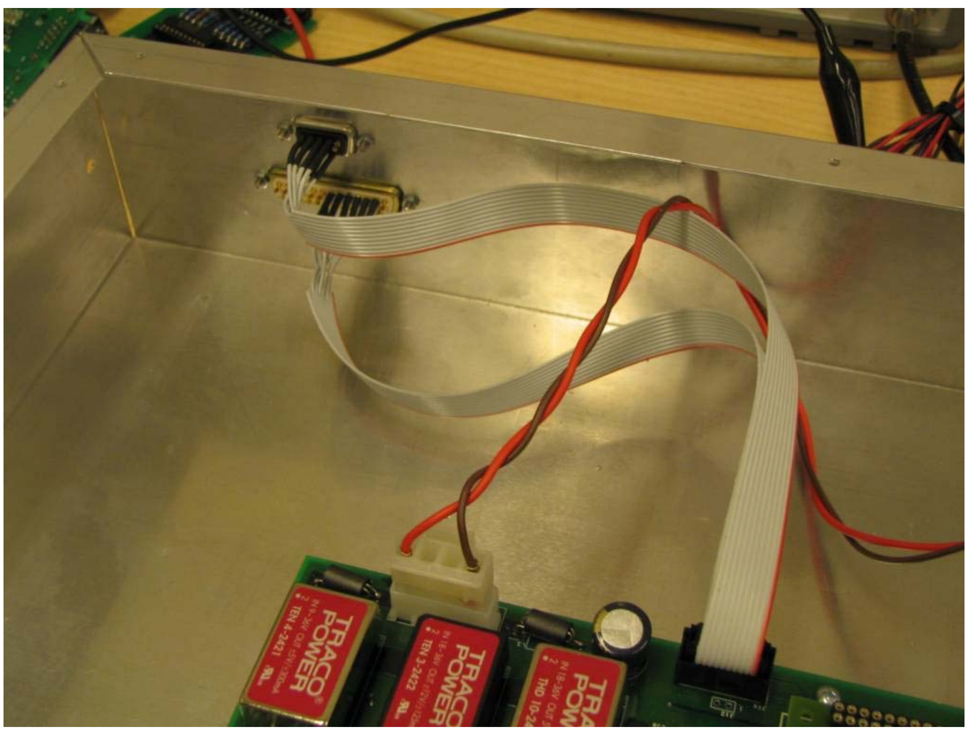
Title	Instrumentation Amplifier and Antialiasing Filter	
Size C	Document Number <Doc>	Rev 1
Date: Thursday, March 10, 2005	Sheet 3 of 3	

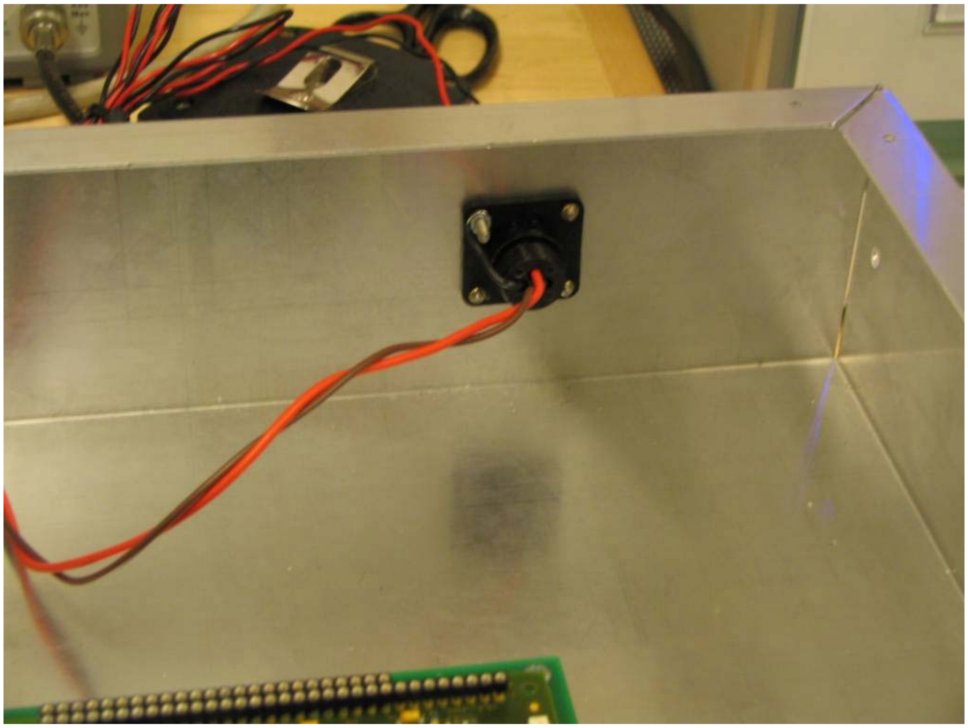
BMM Photos:

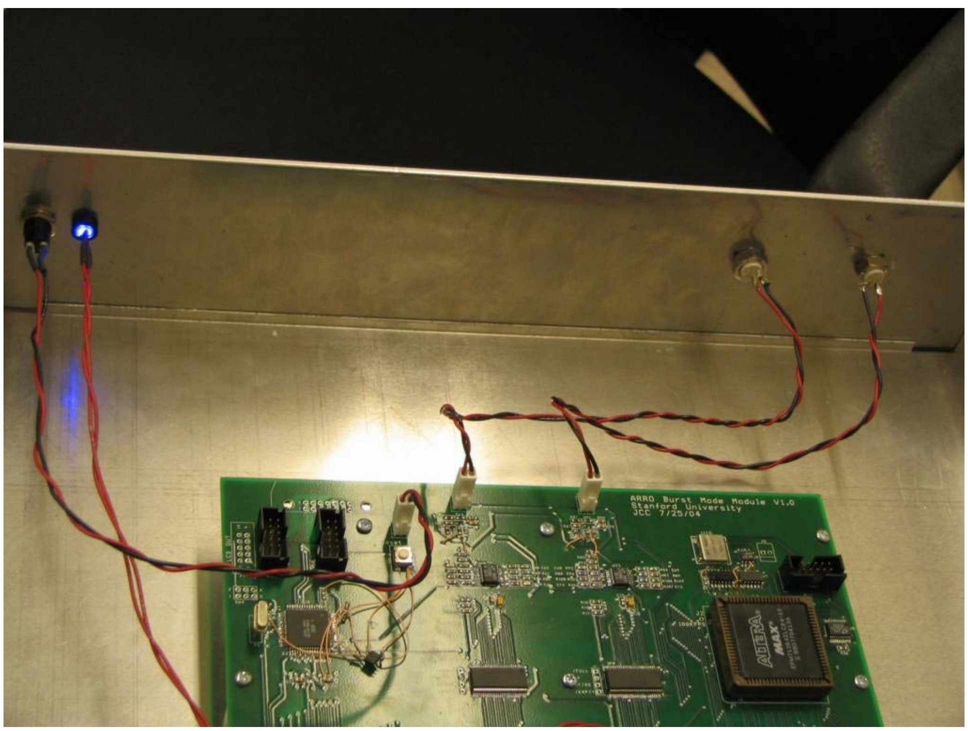





ARRO Burst Mode Module V1.
Stanford University
JCC 7/25/04


TRACO POWER
TRACO POWER
TRACO POWER




ARRO Burst Mode Module V1.0
Stanford University
JCC 7/25/04
MAX

APPENDIX H

ARRO DATA ACQUISITION UNIT DOCUMENTATION

The following appendix contains the following system documentation:

1) Details on the setup and implementation of the Data Acquisition Unit (DAU)

Setting Up the ARRO DAU/DAW/Iridium Data System

The ARRO data acquisition system comprises several components, including:

1) data acquisition unit (DAU);
2) data acquisition watchdog chassis, with Iridium modem/SIM;
3) Wintel data acquisition computer, with Iridium modem/SIM.

In addition to these components, a separate PC (*e.g.*, notebook) can be used to record the DAU's output data stream, in parallel with the transmission of the data via the Iridium telecommunications link; this permits on-site recording of data for quick-look analysis of the data quality.

The software components include:

1) ARRODAU.exe, residing inside the DAU chassis;
2) ARROMON.exe, operating on an external PC, used to program the DAU in the field;
3) Iridium.exe, residing on the data acquisition computer;
4) IridMON.exe, residing on the data-logging PC.

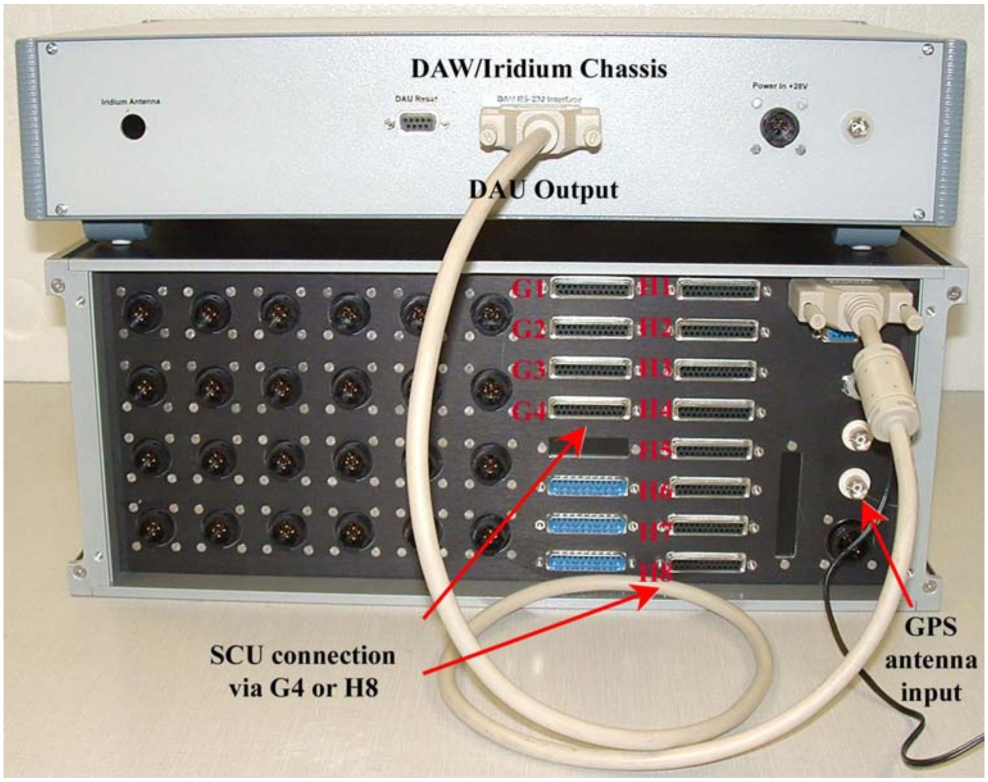
DAU Field Programming

The setting of the instrument channel parameters of the DAU can be performed in two ways: 1) by editing the startup parameter file, ARRO_DAU.par, which resides on the hard disk inside the DAU; and 2) by using an external PC to examine and/or change the parameters. An example parameter file is provided at the end of this document, and this file was included with the DAU on initial delivery to UNH.

The data output from the DAU is managed through COM1 of its internal SBC (single-board-computer). The COM1 DTE signal is accessible on the front panel of the DAU, and the converted DCE signal is made available on both the front and rear panels, via both 9-pin and 25-pin D-sub jacks. The figure shows the DAU chassis connected to the programming PC via the 25-pin D-sub jack on the front panel; this connection must not be made while the Iridium chassis is connected to the DAU. The PC is shown running the ARROMON.exe program.

DAU Rear Panel Connections

The data output from the DAU is managed through COM1 of its internal SBC (single-board-computer). The COM1 DTE signal is accessible on the front panel of the DAU, and the converted DCE signal is made available on both the front and rear panels, via both 9-pin and 25-pin D-sub jacks. The figure shows the DAW/Iridium chassis connected to the DAU via the 25-pin D-sub jack on the rear panel.



The twelve serial I/O ports from the DAU are configured for 9600 baud, 8 data bits, 1 stop bit, no parity, and are labeled G1-G4 and H1-H8; these designations are recognized by ARRODAU.exe as serial I/O ports. ARRODAU.exe sends an ASCII timing string to all serial I/O ports, EXCEPT ports G4 and H8, so that these two ports can be used with external equipment that cannot handle the timing string (*e.g.,* the ARRO SCU).

The GPS antenna connection to the DAU is made at the lower BNC jack on the rear panel.

On-site Data Recording

The front-panel 9-pin D-sub connector on the DAW/Iridium chassis can be used to record the DAU's output data stream, which is simultaneously routed to the DAW/Iridium chassis; this connection can be used while the Iridium connection is operating, since pin 3 of the D-sub jack is not connected, so the DTE/Tx signal assertion of the external recording PC cannot interfere with the Iridium operation.

DAU Software Development/Programming

The front panel of the DAU has jacks for the onboard SBC, including COM1, COM2, video, and keyboard. With the top panel removed, an external floppy disk drive can be connected via a standard cable to the jack accessible at the top of the SBC board in the PC/104 stack. In the figure, the video monitor shows the output of the ARRODAU.exe program during normal operation.

The configuration used during development of the software is shown in the following figure. During development, another PC was used in place of the notebook PC shown, and the notebook was used to simulate a synoptic data stream for testing the serial I/O ports.

<u>**Setup Steps**</u>

The individual steps involved in setting up the complete operating data system include:

1) install the SIM cards into the Iridium modems, noting the MSISDN number of the SIM in the DAW/Iridium chassis, and modify the Iridium.par file, if necessary;
2) install the modem into the DAW/Iridium chassis;
3) connect the DAW/Iridium chassis with the DAU, using a serial I/O cable (provided);
4) connect the power cords to the DAW/Iridium and DAU chassis (provided);
5) install the Iridium.exe software onto an external data acquisition PC;
6) connect the serial port of the data acquisition PC to the second Iridium modem;
7) connect the GPS antenna to the rear panel of the DAU;
8) power up all components; the ARROMON.exe program that operates the DAU will begin execution autonomously, however there is a 10-second hiatus before the keyboard operation is disabled, during which the program can be exited by hitting any key on a connected keyboard;
9) start the Iridium.exe program on the data acquisition computer.

If it is necessary/desired to modify the DAU's parameters, the default parameter file (D:\ARRO_DAU.par) can be edited, using any ASCII text editor, or the ARROMON.exe program can be executed on an external PC connected to the DAU's output channel (COM1), but note that the Iridium connection should be disabled during this procedure.

An example parameter file is shown below:

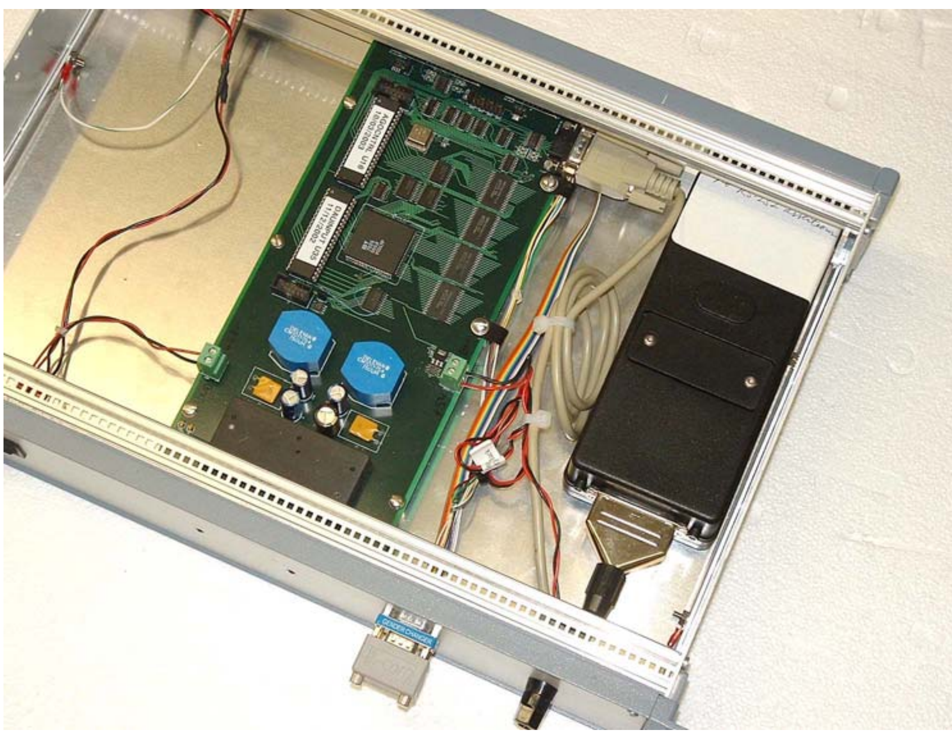
```
.___________________________________________________________________________
.
.                  United States National Science Foundation
.
.                                  ARRO
.                  Autonomous Relocatable Remote Observatory
.
.                     Station AR1/Location: S90 00 E000 00
.___________________________________________________________________________
.
.   Allowed sampling rate mnemonics:  50Hz => 50-Hz sampling rate
.                                     20Hz => 20-Hz sampling rate
.                                     10Hz => 10-Hz sampling rate
.                                      5Hz =>  5-Hz sampling rate
.                                      2Hz =>  2-Hz sampling rate
.                                       1s =>  1-second sampling interval
.                                       2s =>  2-second sampling interval
.                                       5s =>  5-second sampling interval
.                                      10s => 10-second sampling interval
.                                       1m =>  1-minute sampling interval
.                                      Syn =>  Synoptic sampling mode
.___________________________________________________________________________
.
Delimiter |
.
00 | SCU                                |  ON | G4 |  8 |  Syn | MC |
01 | Burst mode                         | OFF | G1 |  8 |  Syn | MC |
02 | Broadbeam Riometer, 38.2 MHz       | OFF | A1 | 16 |   1s | MC |
03 | Photometer, 427.8nm                | OFF | A2 | 12 | 50Hz | MC |
04 | Fluxgate H-axis                    | OFF | B1 | 16 |   1s | MC |
05 | Fluxgate D-axis                    | OFF | B2 | 16 |   1s | MC |
06 | Fluxgate Z-axis                    | OFF | B3 | 16 |   1s | MC |
07 | Searchcoil X-axis                  | OFF | C1 | 12 | 10Hz | MC |
08 | Searchcoil Y-axis                  | OFF | C2 | 12 | 10Hz | MC |
09 | Searchcoil Z-axis                  | OFF | C3 | 12 | 10Hz | MC |
10 | Unassigned                         | OFF | NC |  8 |   1s | MC |
11 | Unassigned                         | OFF | NC |  8 |   1s | MC |
12 | Unassigned                         | OFF | NC |  8 |   1s | MC |
13 | Unassigned                         | OFF | NC |  8 |   1s | MC |
14 | Unassigned                         | OFF | NC |  8 |   1s | MC |
15 | Unassigned                         | OFF | NC |  8 |   1s | MC |
16 | Unassigned                         | OFF | NC |  8 |   1s | MC |
17 | Unassigned                         | OFF | NC |  8 |   1s | MC |
18 | Unassigned                         | OFF | NC |  8 |   1s | MC |
19 | Unassigned                         | OFF | NC |  8 |   1s | MC |
20 | Unassigned                         | OFF | NC |  8 |   1s | MC |
21 | Unassigned                         | OFF | NC |  8 |   1s | MC |
22 | Unassigned                         | OFF | NC |  8 |   1s | MC |
23 | Unassigned                         | OFF | NC |  8 |   1s | MC |
24 | Unassigned                         | OFF | NC |  8 |   1s | MC |
25 | Unassigned                         | OFF | NC |  8 |   1s | MC |
26 | Unassigned                         | OFF | NC |  8 |   1s | MC |
27 | Unassigned                         | OFF | NC |  8 |   1s | MC |
28 | Unassigned                         | OFF | NC |  8 |   1s | MC |
29 | Unassigned                         | OFF | NC |  8 |   1s | MC |
30 | Unassigned                         | OFF | NC |  8 |   1s | MC |
31 | Unassigned                         | OFF | NC |  8 |   1s | MC |
```

Connecting the Iridium Modem

Install the SIM card into the modem, by removing the small plate on one side, and inserting the SIM chip into the memory socket under the plate; note the MSISDN number of this SIM, which must be entered into the Iridium.par parameter file in order to access the modem.

The Iridium modem installed inside the DAU/Iridium chassis must be connected to the 9-pin D-sub jack on the DAW board, and to the +5V power terminals on the DAW board, as shown in the following figure. In order to align the modem's RF jack with the hole in the rear panel of the chassis, the modem must be spaced ¼ inch from the bottom panel of the chassis. Standoffs have been provided in the delivered chassis (6-32 thread), which can be used to mount the modem if existing holes in the modem are tapped appropriately. However, it is recommended that stainless steel standoffs be used in the final configuration, because the aluminum standoffs provided are not suitable for permanent use (but they're all I had).

The DAU mirroring jack on the front panel needs a gender changer (9-pin/F-F, provided) to connect it to an external PC for on-site data recording; the port is configured for DCE operation, so a null modem is not needed to connect it with the PC's COM1 port (DTE configuration).



APPENDIX J

<u>ARRO ENCLOSURE DOCUMENTATION</u>

The following appendix contains the following documentation:

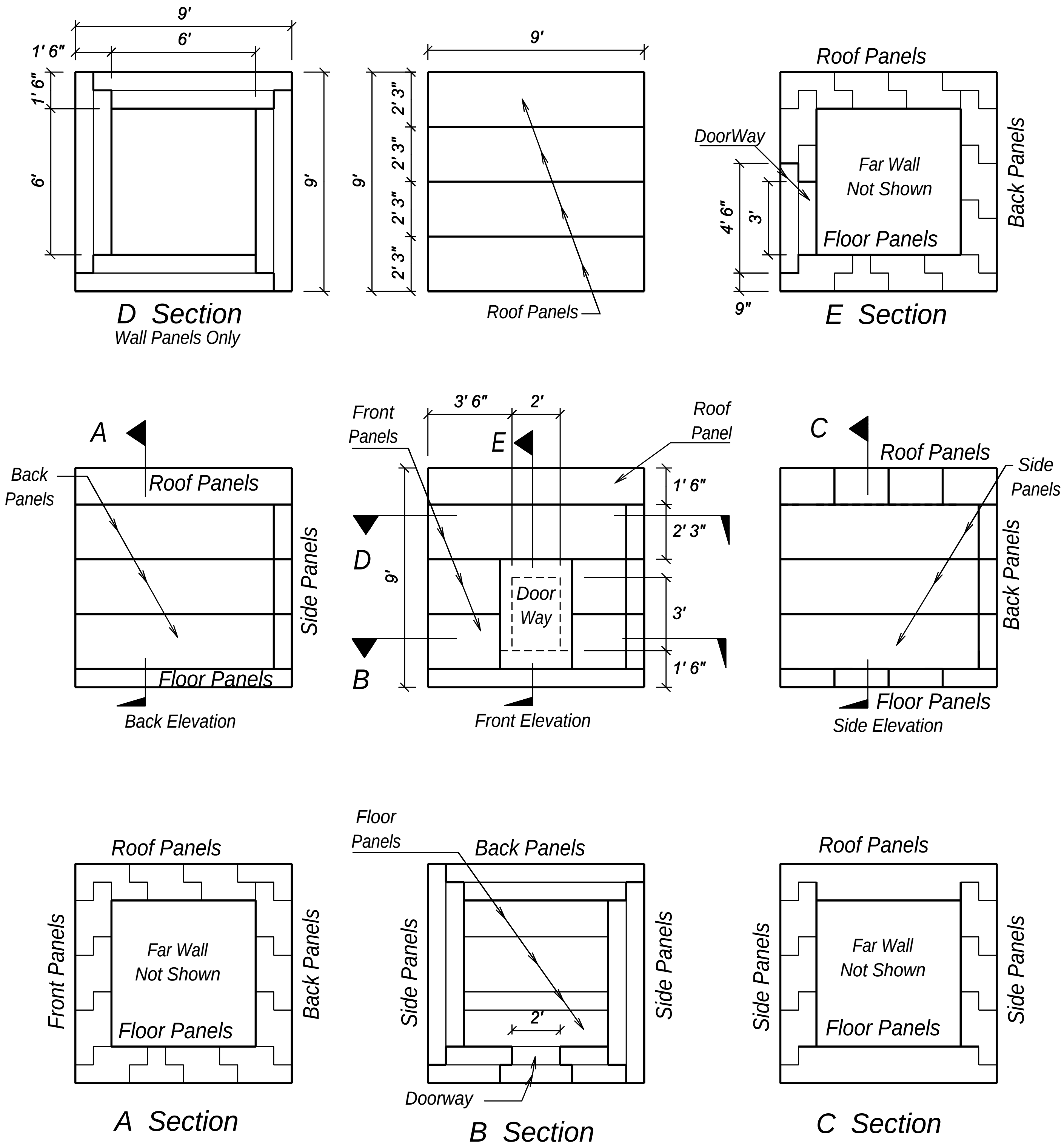
1) Enclosure concept drawing
2) Enclosure machine drawings

Panel Drawings Index

July 6, 2005

Dwg I.D.	Description	Latest Rev.
PL1	Overall panel layout	May 11
PL2	Panel layout w/panel I.D.	July 5
PL3	Typical floor & wall panels	May 13
PL4	Typical roof panels	May 13
PL5	Typical door & front panels	May 17
PL6	Typical panel connections	July 5
SK-1	Panel Fit, Wall to Floor	July 5
SK-2	Panel Fit, Roof-to-Wall-to Floor	July 5
SK-2A	Panel Fit, Enlarged Roof-to-Wall	July 5
SK-3	Panel Fit, Wall-to-Wall	July 5
SK-4	Back Wall Penetrations	July 5
SK-5	Door Fit	June 28
FP-1	Floor Panel 1	July 5
FP-1A	Floor Panel 1 OSB cut sheet	July 5
FP-2	Floor Panel 2	June 29
FP-2A	Floor Panel 2 OSB cut sheet	June 11
FP-3	Floor Panel 3	June 29
FP-3A	Floor Panel 3 OSB cut sheet	July 5
WP-4	Wall Panel 4	June 8
WP-4A	Wall Panel 4 OSB cut sheet	July 5
WP-5	Wall Panel 5	June 8
WP-5A	Wall Panel 5 OSB cut sheet	July 5
WP-6	Wall Panel 6	June 9
WP-6A	Wall Panel 6 OSB cut sheet	July 5
WP-7	Wall Panel 7	June 9
WP-7A	Wall Panel 7 OSB cut sheet	June 11

Dwg I.D.	Description	Latest Rev.
WP-8	Wall Panel 8	June 9
WP-8A	Wall Panel 8 OSB cut sheet	July 5
WP-9	Wall Panel 9	June 9
WP-9A	Wall Panel 9 OSB cut sheet	July 5
WP-10	Wall Panel 10	June 21
WP-1OA	Wall Panel 10 OSB cut sheet	June 20
WP-11	Wall Panel 11	June 29
WP-11A	Wall Panel 11 OSB cut sheet	June 29
WP-12	Wall Panel 12	June 22
WP-12A	Wall Panel 12 OSB cut sheet	July 5
WP-13	Wall Panel 13	July 5
WP-13A	Wall Panel 13 OSB cut sheet	July 5
WP-14	Wall Panel 14	June 9
WP-14A	Wall Panel 14 OSB cut sheet	July 5
WP-15	Wall Panel 15	June 21
WP-15A	Wall Panel 15 OSB cut sheet	June 21
RP-16	Roof Panel 16	June 29
RP-16A	Roof Panel 16 OSB cut sheet	June 23
RP-17	Roof Panel 17	June 23
RP-17A	Roof Panel 17 OSB cut sheet	June 23
RP-18	Roof Panel 18	June 24
RP-18A	Roof Panel 18 OSB cut sheet	June 24
DR-19	Door (19)	June 26
DR-19A	Door (19) OSB cut sheet	June 26



PL1

Cold Regions ARRO Project

Overall Panel Layout

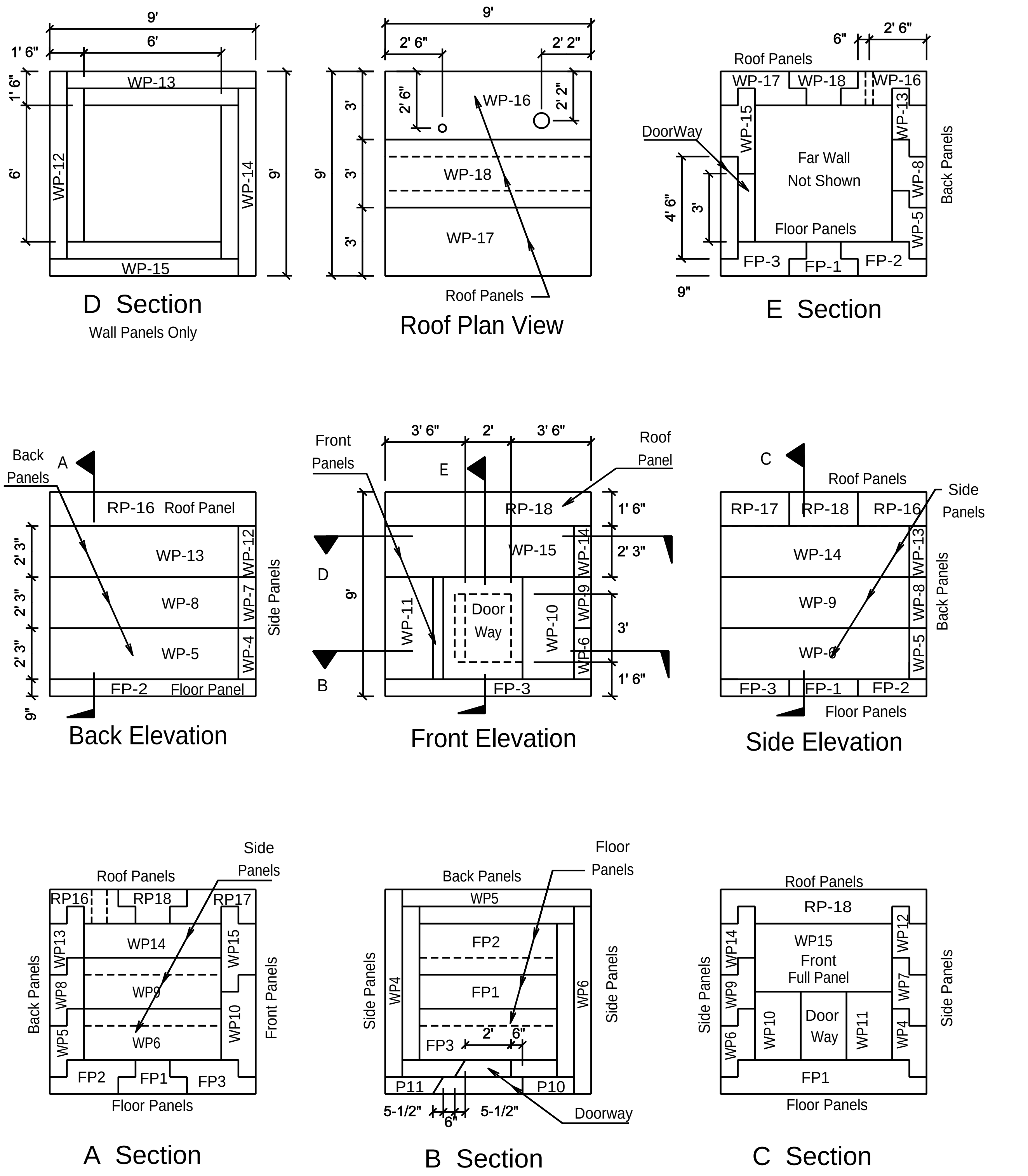
DATE: May 11,2005

SCALE: 1/8" = 1' 0"

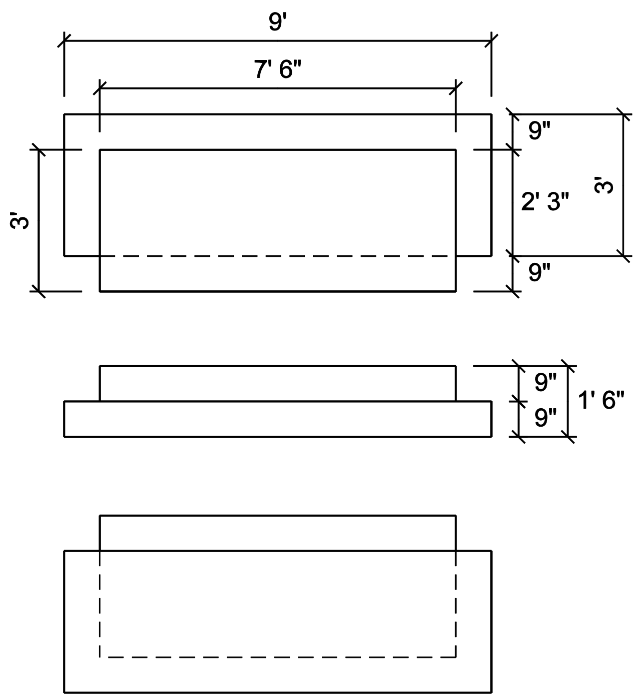
FOAM-TECH

NORTH THETFORD, VT 05054

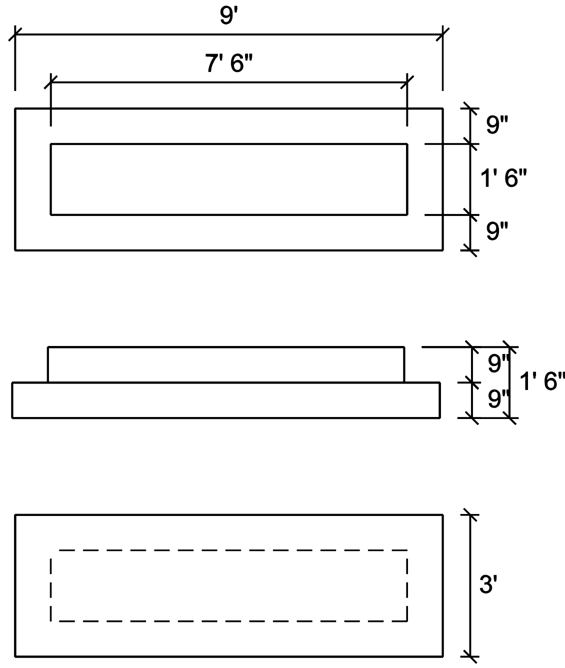
Drawn By: DWO



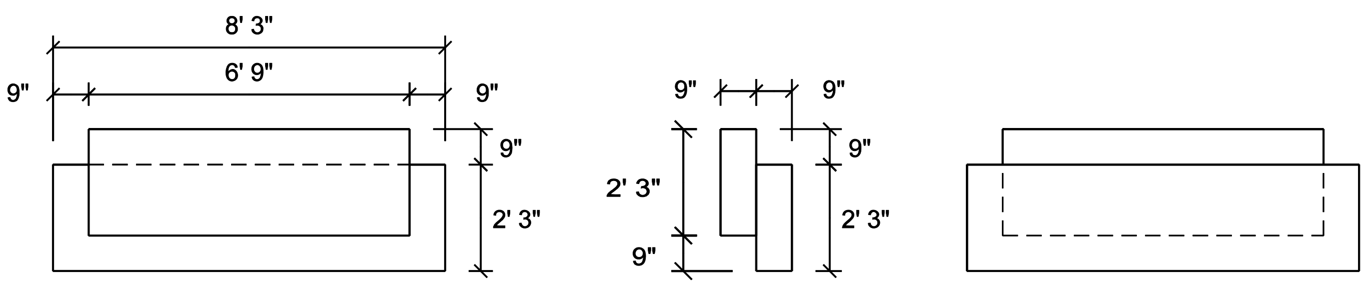
PL2	Cold Regions ARRO Project Panel Location DATE: July 5, 2005 SCALE: 5/32" = 1' 0"	FOAM-TECH NORTH THETFORD, VT 05054 Drawn By: DWO



P-1 & P-3



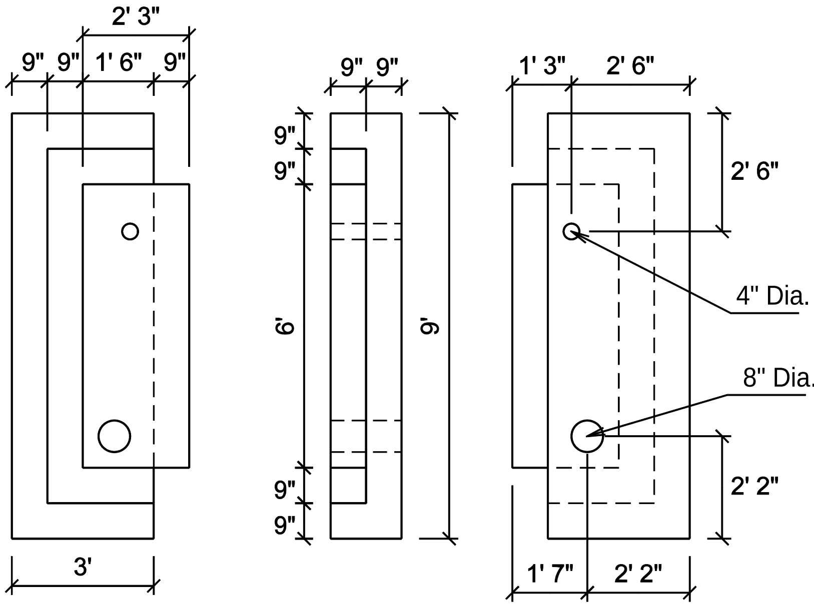
P-2



WALL PANELS

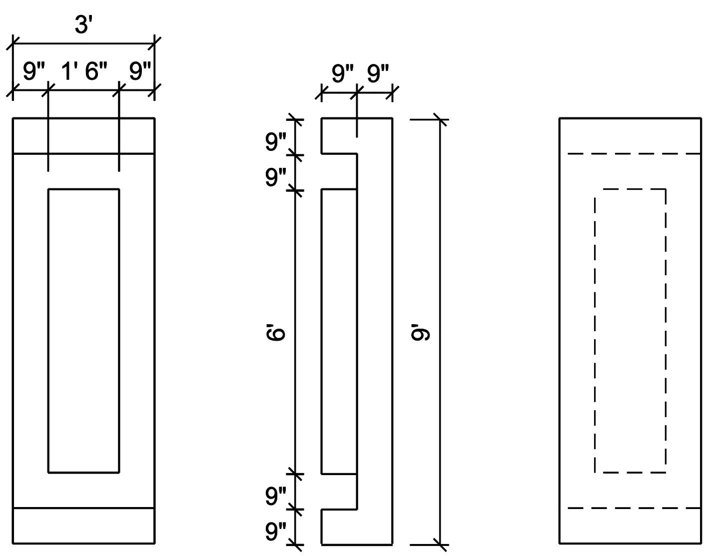
P-4, 5, 6, 7, 8, 9, 12, 13 & 14

PL3	Cold Regions ARRO Project Floor & Wall Panels DATE: May 13, 2005 SCALE: 1/4" = 1' 0"	FOAM-TECH NORTH THETFORD, VT 05054 Drawn By: DWO



P-16 As Shown

P-18 w/o Holes



P-17

PL4

Cold Regions ARRO Project

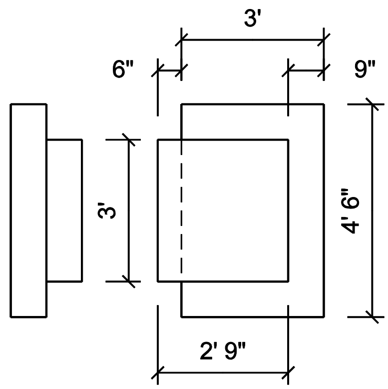
Roof Panels

DATE: May 13, 2005 SCALE: 1/4" = 1' 0"

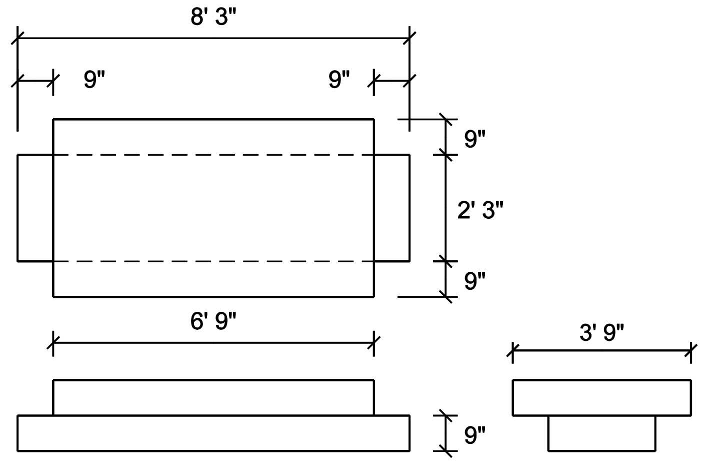
FOAM-TECH

NORTH THETFORD, VT 05054

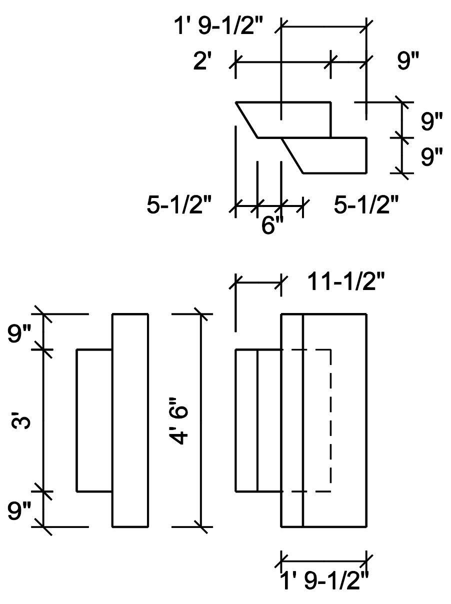
Drawn By: DWO



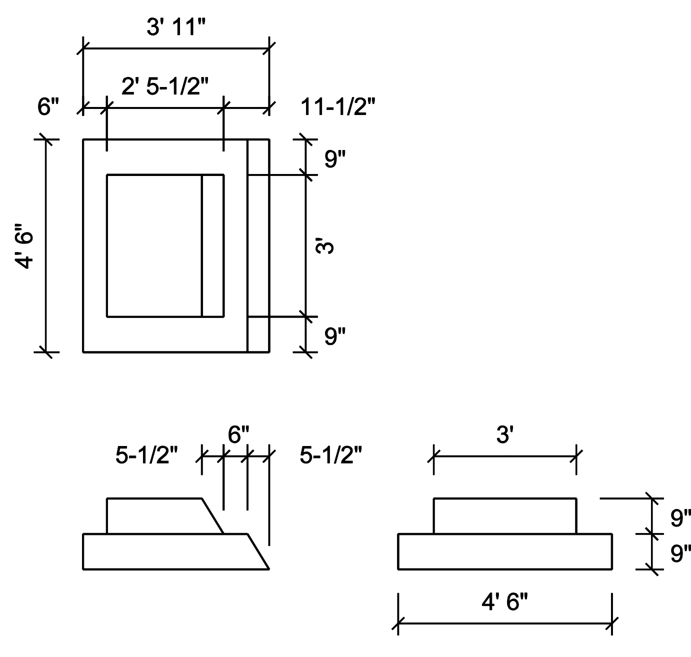
P-11



P-15



P-10



DOOR

PL5

Cold Regions ARRO Project
Door & Front Panels

DATE: May 17, 2005 SCALE: 1/4" = 1' 0"

FOAM-TECH
NORTH THETFORD, VT 05054
Drawn By: DWO