

Automated Trace Gas Trapping System (ATGTS)

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Executive Summary

Modern agricultural practices contribute significantly to global greenhouse gas emissions, and two critical gases released by these agricultural processes are carbon dioxide (CO_2) and nitrous oxide (N_2O). The release rates of these gases are poorly understood on local scales. In order to mitigate the release of them through new agricultural practices, a method of monitoring the release of these gases on a local scale is needed. Team 7 designed an automated device capable of trapping these gases as they are released over a one month time period without supervision. The trapping of these gases is facilitated by the use of two molecular sieve traps, which physically trap the CO_2 and N_2O molecules in the sieve. To successfully trap these gases, a desiccant trap is included to remove water molecules from the air. A chemical CO_2 trap is also implemented to remove CO_2 from the N_2O sample. Control of the gas flow through the system is facilitated by a pump and solenoid valves regulated by a microcontroller. Power for the system is provided by a battery, capable of providing 25 aH of power. The physical structure and other components of the ATGTS are designed to keep the device at ambient conditions to correctly model the release of these gases on a global scale.

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1 Introduction

Many scientists regard climate change as the most critical contemporary issue threatening the earth's ecosystem. In response, international agreements have been drafted to monitor and control the emissions of greenhouse gases, such as the Kyoto Protocol. One major component of these protocols is the development of emissions trading schemes such as carbon crediting. Carbon crediting refers to purchasable credits which allow a company to emit a certain amount of greenhouse gases. An integral part of this drive is to both reduce greenhouse gas emissions and research new methods to quantify these emissions. In order to facilitate future carbon crediting programs, it is of great interest to develop a method by which to measure trace amounts of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions from soil to the atmosphere.

As part of the global drive to control greenhouse gas emissions, efforts are underway to understand the emission of greenhouse gases from agricultural practices. N_2O and CO_2 produced by the microbes within soil are released when it is tilled or otherwise disturbed. These gases are produced by the microbes within the soil. As a result, deforestation and the creation of farmland are leading contributors to the release of greenhouse gases into the atmosphere. Typically, levels of CO_2 in the atmosphere are modeled using techniques from meteorology, but measurements of a much finer resolution must be developed if carbon crediting programs are to be implemented effectively.

The amount of N_2O that is released into the atmosphere by agricultural soils is by comparison not well understood (Hengeveld, 1995). More accurate measurements regarding N_2O emissions in particular are crucial to the understanding and control of greenhouse gases. While N_2O is much less prevalent than CO_2 in the atmosphere, it is one thousand times more capable of retaining heat, rendering it an even greater contributor to heat retention in the atmosphere.

To measure the flux of these gases from the soil over time, a remote trapping system must be designed. This trapping can occur using molecular sieve, aka. molsiv, which traps gases based on their molecular volume. The trapped gases will then be removed and isotropically analyzed in order to determine their origin. This device will facilitate future carbon crediting systems by providing a method of measuring local emissions of greenhouse gases, as well as tools for analyzing the origins of these gases to improve land management.

The key to this new approach is the use of molecular sieve (molsiv) for trapping gases. Molsiv physically filters out molecules of a given size from air passing through it. The trapped molecules can later be removed from the molsiv without significant isotopic fractioning. Because of this, existing techniques in isotopic analysis can be applied to determine the microbial origins of these gases.

The ATGTS will trap a sample of each gas on molsiv. These sampling events will occur in succession,

each lasting approximately five minutes. Undesired gases will be sequentially removed by a desiccant and chemical CO_2 trap before reaching the molsiv. After both sampling events occur, six hours elapse before the next sampling events. This trend will continue for a one month period called the test span. The pump should operate sufficiently slowly during each sampling event to allow scrubbing of N_2O and CO_2 from the respective chambers. At the end of the test span, all four traps in the system should be replaced with new empty traps, and the filled traps will be sent back to the lab for analysis. Furthermore, the six hour period separating sampling events should incorporate any rainfall and changes in ambient temperature to the sampling chamber. Lastly, the device must also measure and record the air temperature and humidity inside and outside of the device.

For the readers convenience, all figures and tables in this document are referenced by section and then order of appearance. For example, Figure 4.1 is the first figure of Section 4. While some figures are included in the body of the text, many are included in the appendix, Section 6. If so desired, the reader should feel free to detach this section from the rest of the document to provide a quick reference. The appendix begins on page 22 and will be referenced throughout the body of the report.

2 Design of the ATGTS

2.1 Identification and Translation of Customer Requirements

The first step in our design process was to identify our customer requirements and use these to establish the required subsystems of our device. In their proposal, the sponsor provided a list of nine requirements for the ATGTS.

1. Provide continuous measurement of CO_2 and N_2O over a period of weeks to months regardless of weather events.
2. Allow sequential trapping of H_2O and CO_2 which compete with N_2O for exchange sites on molecular sieve.
3. Sufficient flow rate for relatively rapid headspace purging/scrubbing in order to reduce power requirements, but slow enough to foster complete adsorption of N_2O on the molecular sieve.
4. Compact and easily deployable, yet with sufficient chamber area to encompass spatial variability.

5. Although solar power is desirable to minimize battery size and power requirement, the system should have sufficient power to operate for one complete cycle (e.g. 1 month) and function in low light environments (e.g. under forest canopy).
6. After CO₂ and N₂O are trapped from the system, the chamber should be equilibrated with the atmosphere.
7. Internal chamber temperature and moisture conditions should approximate ambient conditions.
8. Gas recovery from the molecular sieve after trapping must be close to 100% with no significant isotopic fractionation.
9. The system is developed to be deployed over bare soil (e.g. agricultural soils) or where the vegetation has been removed and the below ground biomass left intact.

To further understand these requirements, the House of Quality technique was utilized. This is shown in Figure 2.1. The first step in forming the House of Quality was to identify customer wants. Team 7 came up with a listing of ten customer wants from the nine requirements listed above. Next, the importance of these wants was discussed. Continuous measurement, removal of undesired gases from sample volumes, and automation were regarded as the most important.

		Interaction Matrix							
		Strong Negative Relationship: ⊗ Negative Relationship: x Positive Relationship: + Strong Positive Relationship: ⊕							
Primary Want	Secondary Want	Power	System flow rate	Frequency of samples	Number of samples	Trap size	Sub-Chamber sealing	Sample size	Outer door sealing
Sampling system	Continuous measurement of trace gases	3	9	3	3				5
	Trap H ₂ O and CO ₂ sequentially	1	3						5
	Sufficient flow rate	1	9				3		3
	Sufficient power for one month	9	1	9	9				4
Functioning flux chamber	Flux chamber must equilibrate	1		1					9
	Sufficient flux chamber size							9	1
	Approximate ambient conditions	1		3			1	1	3
Physical usage	Deployable over bare soil								9
	Compact and easily deployable	3				9		3	
	Fully automated	9					1		1
How important		118	96	72	56	18	18	28	82
Target		24 kWh	4 to 8 mL/s	4 to 6 /day	120 to 180	40 mL	Air tight	170mL	Air tight

Figure 2.1: House of Quality for the ATGTS

Team 7 then created a list of eight measures by which these wants could be quantified. Correlations between these measures were then established. Finally, weights were assigned to each want and measure

pair. By multiplying these weights with the relative importance of that particular want, the importance of each measure was established. This yielded the most important measure to be the minimization of power, which confirmed our expectations. In talking with project sponsors, preliminary target numbers for each specification were drafted.

Following the House of Quality, a FAST diagram was used to identify the structure of the device. This diagram is shown in Figure 2.2. Using the FAST diagram, requirements were drafted for the needed subsystems. Team 7 identified the main function of the ATGTS as measuring soil flux for data extrapolation and analysis. To do this, the ATGTS need to be able to obtain samples of gases and replicate environmental conditions. Two separate gas samples are needed, meaning that two traps are required, and thus two sampling events. Molecular sieve traps will be used to hold the gases, and so the sample volumes must be passed through the traps. This is done by controlling the air flow through the system, which is accomplished by a combination of solenoid valves and a pump. These components are governed by the microcontroller.

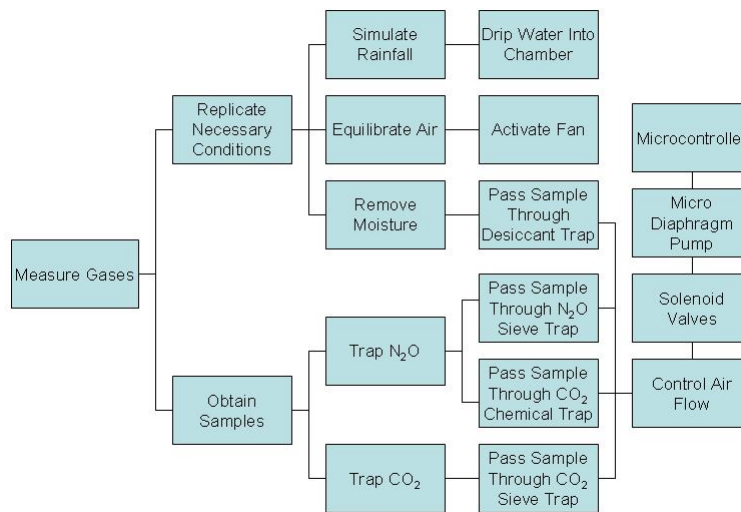


Figure 2.2: FAST diagram for the ATGTS

To replicate environmental conditions, three key factors are required. First, rainfall must be simulated, necessitating a method to collect rainfall and deliver it to the soil flux chamber. Second, the air in the soil flux chamber must be equilibrated with the outside atmosphere at the conclusion of each sampling event. A fan and door with access to the outside atmosphere will be included for this purpose. Finally, moisture must be removed from the sample volumes so that the molecular sieve traps can function properly. Thus, a desiccant trap is needed to keep the traps from clogging.

Design requirements of the ATGTS will now be broken down. First, mechanical requirements on the size and organization of the traps will be discussed. Next, methods for controlling the mechanical portions of the project will be developed. Finally, the electrical controls and electromechanical devices required to facilitate the ATGTS's operation are discussed.

2.2 Mechanical Requirements

The system must be designed to completely trap trace gases using molecular sieve. The main chamber will serve as a collection facility for gases released by the soil. Then, CO_2 and N_2O must be collected from this chamber. There are many constraints on the system based upon the properties of the molecular sieve. The molecular sieve can not be exposed to any water vapor as the pores in the molecular sieve will clog with water instead of the desired trace gas. This provides the need for a desiccant trap to remove water vapor from the air before it reaches the molecular sieve.

To maintain a closed system during trapping, a system of sub-chambers is used. It is important to realize that the sampling of gases must be in a closed system to control sample volume. Therefore, if a sub-chamber is to be used, it must be isolated from the soil flux chamber during the sampling process. Also, CO_2 and N_2O must be trapped in various stages. The molecular sieve filters these gases based on their molecular volume, and remain in the trap until they are removed in an offsite process. The molecule volume of CO_2 and N_2O is very similar, and N_2O is thousands of times less abundant in the atmosphere than CO_2 (Halpert, 1996). If both gases were to collect on the same trap, it would be impossible to measure the percentage of N_2O . It is because of this that the system must be designed to strip CO_2 from the sample prior to trapping the N_2O on the molecular sieve. The best way to strip the CO_2 from the gas without affecting the concentration of the N_2O is to use a chemical CO_2 trap.

Sub-chambers are required to provide different sample sizes for both gas trapping systems. CO_2 is much more prevalent in the atmosphere, and will require a smaller sub chamber than N_2O to operate within the constraints of the molecular sieve. Two sub-chambers are needed to have the device function in the same manner as the ATGTS proof of concept test.

Air flow is created by a pump and redirected by valves opening and closing. These control details are discussed further in the next section. Due to the effect of soil moisture on microbial processes, the mechanical design must also accommodate rain water collection. This system will distribute the rain water into the main chamber to provide regular atmospheric moisture conditions. Following the sample cycle, the main chamber and sub-chambers are equilibrated with atmospheric conditions.

2.3 Mechanical Control

Figure 6.6 shows the flow of gas through the system. The control of the gas flow is critical to accurate sampling. This flow will be controlled by a pump and a series of solenoid controlled valves. During the rest cycle, the system is off, and gases will accumulate within the soil flux chamber. During sampling, the pump will switch on and begin to pull the sample from the sealed sub-chamber through the system, with the N_2O trapping occurring first. A pair of 2-way solenoid valves will regulate airflow into and out of the N_2O sub chamber. This air will be pulled through the first 3-way solenoid valve into the H_2O desiccant trap. A second 3-way valve will redirect the air flow through a chemical CO_2 trap followed by a N_2O molecular sieve trap. This air will then flow through the pump and back into the N_2O sub chamber, maintaining a closed system.

The CO_2 trapping event is very similar to the N_2O trapping event. However, there are two major differences between the two flow paths. First, the CO_2 sub-chamber is much smaller than the N_2O sub-chamber. Second, after the second 3-way solenoid valve, the air will be redirected through a single CO_2 molecular sieve trap.

Moisture conditions within the flux chamber must be equilibrated with the atmosphere to ensure relevant trace gas producing conditions. This means that rainfall must be collected in a reservoir atop the device and dropped into the chamber using a rainfall dispersal grate.

2.4 Electrical Devices & Control

The electrical system will provide direction and power to the mechanical control while taking simple measurements. The CY3214-PSOCEval USB microcontroller is the backbone of this control system. Two removable humidity/temperature sensors are also provided for measuring these quantities inside and outside the soil flux chamber. Gas expansion and microbial activity both depend heavily on temperature, thus, accurate readings are important to BERI's soil research. The data gathered from these sensors will be stored electronically. This unit will provide a downloadable file at the end of the month cycle that details temperature cycles over the course of the month.

The microcontroller will also control the flow cycle and air equilibration process of the entire system. This entails regulating the air pump, solenoid valves, and electronic actuators to provide the gas flow as described in the mechanical control section. A state machine is simulated to control the device as it operates.

The microcontroller will provide logic signals for these actions. However, power for device operation is provided by a battery system via reed relays. This battery must power the closed system for the duration of

one month. This battery system will also require a fault LED. This fault LED will display to the user that the battery is low. The electrical control of this system must be robust enough to operate uninterrupted for the duration of one month.

2.5 Conceptual Designs

The design of this system has to provide a deployable self contained unit that is robust enough to operate for the duration of one month. This provides a triage in the design of the system that defines some parameters as more immediately important. For this reason, the exhaust fan, pump, and traps are designed first. The desiccant, chemical CO₂, N₂O, and CO₂ traps are designed with quick connect fittings at each end of the trap so they can be easily taken off and replaced at the end of the one month test span.

The design of the sub-chamber is the most critical issue facing Team 7. There are several designs for the two sub-chambers. One design entails two separate sub-chambers and a door on the soil flux chamber that opens to let gas circulate inside each of the sub-chambers. The door would be opened and closed by a servo motor. Each sub-chamber will have two valves; one of the valves will open to the trap system and the other will open to the pump. For the purging process, the trap valve will close and the pump valve will open allowing fresh air to circulate through the sub-chambers.

Another design includes the two sub-chambers in a single housing with a wall dividing the two chambers. The sub-chamber housing design consists of a cylinder inside of another cylinder. Holes will be machined along the side of each cylinder as shown in appendix Figure 6.9. A servo motor will rotate the outside sub-chamber allowing the holes to line up, allowing air to circulate inside the two sub-chambers. A valve between the two sub-chambers will be mounted on the dividing wall. It will open when the purging process begins, allowing the air to circulate from both sub-chambers through the pump valve, while the trap valves will be closed. There are five valves (two valves lead to the traps, two valves lead to the pump and one valve is on the wall) in this design.

The last design is a plastic cube sub-chamber housing. This design still incorporates a wall dividing the two sides, but it does not utilize a valve. There will be four valves that connect to the housing, two that lead to the traps and two that lead to the pump. Due to the segregation of the two samples, this sub-chamber design allows for the elimination of the purging procedure. A Figure of this sub-chamber is included in appendix Figure 6.10.

The feasibility of the described prospective designs is ranked in Table 2.3. Point values for each component denote the importance of each component. The more important the component is, the higher point value

	Design 1	Design 2	Design 3	Point values for each component
Quick connects	8	8	8	1
3-way valves	3	3	4	2
4-way valve	1	1	0	3
Fans	1	1	1	2
Pump	1	1	1	3
Sub-Chamber casing	2	1	1	4
2-way valves	4	5	4	1
Servo motors	3	2	2	2
Point totals	40	35	33	

Figure 2.3: Rankings of conceptual designs for the sub-chamber.

it is assigned. The design with the lowest point value total is the most feasible. Using this table, the third design was chosen for use in the sub-chamber. This sub-chamber is discussed in more detail later.

2.6 Design Process: Budgeting & Planning

After these requirements and basic designs were reached, we began to plan out our design process. First, we decided on how our project would be budgeted. In addition to the \$1500 from the combined ECE and ME budgets, we received \$4000 from our sponsors for prototyping the ATGTS, yielding a combined budget of \$5500. The bulk of this funding went to the mechanical team, who were budgeted \$3500 for their items. Most of this \$3500 was marked for fittings, solenoids, and actuators. For example, a single solenoid of the kind used in the ATGTS cost \$120, and ten solenoids were used in the design. These three sets of items were given a combined budget of \$2500. The remaining \$1000 was set aside for building materials for the traps and sub-chamber, along with other small parts. The electrical team was budgeted \$1000, \$500 of which was reserved for the purchase of a battery. The remaining money was budgeted other IC's and components required for the design. The remaining \$1000 of the original allotment was left as a reserve if another area went over budget.

Our Gantt chart is included in Figures 6.1, 6.2, & 6.3. Our design process was broken up into a construction phase and a testing phase. We planned to be done one week ahead of design day, however delays in part orders pushed this back. For example, an order for 3-way solenoid valves put in on October 4th was not received until November 25th.

3 Technical description of work

This section details the work done by Team 7 to fit the design criteria established in Section 2. First, the physical design and layout of the ATGTS are explained. Next, the implementation of this hardware is included. This section includes many details about why and how certain hardware choices were made. Following this, the new software designed for the ATGTS is brought up, followed by guidelines for how the microcontroller implements this software.

3.1 Hardware Design

The design of the ATGTS consists of a 300mm diameter PVC cylinder outer casing, which will be separated into four separate levels. The outer casing is oriented vertically and the levels are divided by 6.35mm thick PVC sheet. The first level consists of the soil flux chamber, volume sampling sub-chamber, rainfall dispersal grate, and a fan with access to ambient air to equilibrate the flux chamber. The second level contains all four chemical or sieve traps and an access door for trap removal/replacement. The third level houses the pumps, 3-way valves, power supply, and microcontroller, while the fourth level serves as the rainfall reservoir.

3.1.1 First Level

The first level, or the soil flux chamber, is approximately 250mm in height, and is the support for the device. This level sits directly above the soil surface being sampled. The assembled chamber is seen in Figure 6.8. 50mm of this chamber height extends into the soil to aid in stability of the ATGTS. Contained within this soil flux chamber is the sub-chamber housing. Two sub-chambers are formed out of 6.35mm thick PVC rectangular housing, and serve as the gas sampling volumes. The N_2O and CO_2 sub-chambers will be 150ml and 20ml volumes respectively and divided are by a 6.35mm thick PVC wall.

The sub-chamber housing design chosen makes use of a split chamber design coupled with a 6.35mm thick Aluminum sliding door controlled by an electric linear actuator. The design is illustrated in Figure 6.10. Both the N_2O and smaller CO_2 sub-chambers are visible in this Figure. This design eliminates problems seen by a conventional swinging door design in reference to sealing the chambers. Using the sliding door design with ball bearings mounted in tracks allows for a sandwiching of the door by sealant material, providing an airtight seal. The sealing material chosen was Viton. Viton is relatively easy to work with, and is also chemically inert, an important consideration in the ATGTS. A notch is made into the far left side of the

sub-chamber for the aluminum door to slide into and provide a tight seal.

Initially, this sub chamber design possessed a large dead volume in the back of N_2O chamber. This resulted in insufficient flow through the sub chamber, which could corrupt results. To correct this, Team 7 incorporated a rear vent on one end of the sub chamber. This vent is seen on the far right side of Figure 6.10. This smaller door allows air in the flux chamber excited by the fan to move throughout the N_2O chamber, eliminating the concern of a dead volume occurring in the chamber. The sliding aluminum door is lengthened so that when the sub-chamber is open, the rear vent is pushed open by the sliding door. This is shown by the red sliding door pushing the rear vent open in Figure 6.10. The addition of a small spring and Viton on this door ensures a seal when the sub-chamber is closed. The major structure of the sub-chamber is made of PVC.

Located 50mm below the sub-chamber is the rainfall dispersal grate. When rain is released from the fourth level rainfall reservoir, it must be evenly distributed over the sample soil. This is achieved with a sloping perforated circular disc made out of .25mm thick aluminum sheet, which may be viewed in Figure 6.11.

The last item contained within the soil flux chamber is the equilibrate fan. This fan is 60mm in diameter and mounted on the outer case wall between the end of the sub-chamber housing and the equilibrate door. This door is actuated by a second linear motor. The door and fan will serve to equilibrate the soil flux chamber with the ambient air, and their operation will be discussed later in the device operation section.

3.1.2 Second Level

The second level of the ATGTS is approximately 240mm in height and contains all four chemical and sieve traps; the desiccant trap, chemical CO_2 trap, and two molsiv traps for the N_2O and CO_2 . The desiccant trap removes moisture from the air before the sample air reaches the other traps. The trap consists of Nafion tubing wrapped inside a desiccant filled PVC pipe with end caps. The Nafion tubing allows moisture to be extracted out by the desiccant while not affecting the air content of the tube. The chemical CO_2 trap consists of a stainless steel tube filled with Carbosorb, and will extract CO_2 from the sample air prior to its arrival in the N_2O trap. The two molsiv traps for N_2O and CO_2 collection will also be made of stainless steel tubes, but filled with molecular sieve 5Å. To prevent sample contamination during trap transport, two manual shutoff valves are included at both ends of the traps. In addition, these traps will also have quick connects on each end for easy removal.

The molsiv traps are curved into a horseshoe shape, allowing them to be of necessary length while still

fitting in the second level. All traps are designed to be removed after one month by opening an access door. The PVC door is 248mm in height and spans half the outer case's circumference. The door is mounted with small galvanized metal hinges and locked with two load rated draw latches. To prevent moisture from entering the level, the door will be sealed with basic home weather-stripping.

3.1.3 Third Level

The third level is approximately 133mm in height and its contents are supported by two 6.35mm thick PVC sheets. Controlling and powering the system is a Cypress PSoC microcontroller and a 14.8V lithium battery. The microcontroller controls the fan and linear actuators located in level one, as well as the solenoid valves and the pump located in level three. The specifics of the microcontroller timing to run all electro-mechanical components will be discussed in section 3.3. Since packaging is a concern in this level, micro inert solenoid valves were chosen for both 2-way and 3-way applications because they are relatively small, 33mm in length and 9mm in diameter. In addition, a micro diaphragm gas sampling pump was chosen due its low power consumption, small size, and high flow rate of .3L/min. All plumbing connections in the device use 1.59mm outer diameter PEEK tubing. PEEK tubing was chosen due to its excellent tensile strength, 90MPa, and because it is chemically inert.

3.1.4 Fourth Level

The fourth level contains the rainfall reservoir. This level consists of a funnel which spans the diameter of the device to collect and drain rainwater onto the soil, thereby simulating the ambient environment. Linking the rainfall reservoir and dispersal grate found in level one is a 6.35mm outer diameter Tygon tubing regulated by a one way solenoid valve. This valve is open only at certain times in the device cycle, during the equilibrate stage. Covering the rainfall reservoir is a cone shaped plastic screen which stops debris from plugging the ambient environment rainfall simulator.

3.2 Hardware Implementation

Sub-chamber housing

Construction of the sub-chamber housing required a great deal of patience and care. The first step was to assemble the inner N₂O and CO₂ sub-chambers. Due to an extensively long drying time for the glue to attach the Viton seal to the PVC, assembly took longer than planned. This portion can be seen in the far right of Figure 6.14. Next, the other components of Figure 6.14 were cut to size. The sliding aluminum

door and rear vent were joined onto the existing portion. Finally, the outer door seals the space in the bearing track from outer air. This seal is the green rectangle in the left side of 6.10. Figure 6.12 shows the inner chamber seals of the completed sub-chamber. Figure 6.13 shows the completed rear vent, with spring attached. During testing of this seal, it was found that the size of the aluminum sliding door was insufficient to provide a strong seal. This test will be further discussed in Section 4. To correct this, a small aluminum plate was added to the existing door.

Traps and Flow Path

The trap manifold was made out of 6.35mm thick PVC with two 2mm thick aluminum plates on each side. A 250mm by 200mm piece of PVC was cut with a band-saw to make the trap manifold. Two 1 inch holes were cut out of the PVC for the chemical CO₂ trap, and four 12.7mm holes were cut of the PVC with a push press for the NO₂ and CO₂ traps. The holes then were sanded down with a hand sander to make a shape that resembles the flat nut on the quick connect stem. The stems for each of the traps were then placed into their respective holes. Then, two 22.23mm holes and four 9.53mm holes were cut out of the two aluminum plates. The aluminum plates were then place on both sides of the PVC plate. This was done to hold the quick connect stems in their places.

Next, the chemical and molsiv traps were constructed. Calculations for the sizes of these traps can be found in Tables 6.2 and 6.3. Both traps were made from 7.7mm inner diameter, 9.5 mm outer diameter, 304 stainless steel tubing. At the ends of each trap were manual valves, quick connects, and reducers purchased from Swagelok. The quick connect body connects to the valve, and the stem connects to the tubing that transfers the gas from the sub chamber. The body of the quick connect had a 6.35mm inch male connection end and the stem end of the quick connect had a 6.35mm inch tube fitting end. The reducers fit into the tube fitting end of the quick connect, which consists of a ferrule and a nut that are tightened to make an air tight seal between the two parts. The reducers then connect to the PEEK tubing and are tightened with a nut and ferrule. On the other side of the manual valves are unions with tub fittings and male ends on them. The male end is inserted in the manual valve and the stainless steel tubing is placed into the tube fitting to complete the traps. The CO₂ molsiv trap was built in the exact same way as the N₂O molsiv trap. The complete trap manifold can be seen in Figure 6.19.

Finally, the desiccant trap was built. Calculations on its size can be found in Table 6.4. The base of this trap is a 19.05mm circular pvp pipe. A 304.8mm section of Nafion tubing is curled up inside this pipe. The remainder of the trap is filled with desiccant material.

Main Body

The final assembly step is the construction of the main body. The top segment of the ATGTS, which includes a rain catcher, is connected over top of the main body. The top of the rain catcher is shown in Figure 6.16. The rain is held here until a solenoid on the other side is opened. Covering this rain catcher is a screen, shown in Figure 6.17. This screen prevents debris from entering the system and causing damage or corruption of results.

Solenoid Control & Actuation

Upon reception of the solenoid valves, testing revealed that they took a large amount of power when kept open. Over the course of a month, the solenoids would use 10 amp-hours of power. To reduce this, Team 7 decided on a pulse width modulation scheme using the microcontroller and a transistor switch as shown in Figure 6.4. The microcontroller sends a PWM signal to the input of a transistor, which causes the average voltage across the solenoid to be reduced. After contacting the solenoid manufacturer, it was discovered that only five volts were needed to keep the solenoids open, as opposed to the 12 volts they took during opening. Because the supply voltage from the battery is higher than 12 volts, signals to the transistor switch are first modulated with a duty cycle of 82%. After a second, this duty cycle is switched to 38%. This reduced the power consumption of the solenoid valves by 60%, to 4 amp-hours.

Power Supply

After all components were finalized, a battery was selected to complete the power system. An initial design for the ATGTS given to Team 7 by the sponsors had a 55 amp-hour budget. Reducing the power draw was the major electrical challenge encountered by Team 7. Two primary battery options were discussed; lithium ion and deep cycle lead-acid. Deep cycle batteries are cheaper, but are extremely heavy and bulky, which would hamper the mobility of the ATGTS. In addition, they are complicated to charge. Instead lithium ion was chosen due to its superior power density. In order for the lithium ion battery to be affordable and provide a sufficient safety margin, the ATGTS would need to draw no more than 20 Amp hours.

With most components on our device running at 12 volts, we chose a 14.4 volt Lithium battery to use in our design. In order to power the microcontroller and fan, which run at five volts, we purchased a buck converter. To conserve component life, all devices that needed to run at 12 volts were also pulse width modulated in the same way as the solenoids. The power requirements of the system are listed in Table 3.1. This table is based on a six hour cycle. For each cycle, only certain components run for given time periods.

A timer was also included which shuts off the microcontroller and other devices when the machine is resting. Both of these topics are discussed in more detail in Section 3.3. Power for the ATGTS is provided by a 25 amp-hour lithium ion battery. This provides a large safety margin against battery capacity decay and design error. 20A fuses are added at the terminals of the battery as a safety precaution.

Element	Current	Quantity	Run Time/ cycle	Run Time	Total AH
Fan	80mA	1	1min	3Hr/month	240mAHr
2-way Solenoid	50mA	2	7min	21Hr/month	2.1AHr
Water Solenoid	1550mA	1	10sec	.5Hr/month	775mAHr
3-way Solenoid	60mA	4	7min	21Hr/month	5.4AHr
Microcontroller	30mA	1	10min	30Hr/month	900mAHr
Pump	100mA	1	7min	21Hr/month	2.1AHr
Linear Actuators		2	.25min		150mAHr
Timer	50mA	1	10min	30Hr/month	1.5AHr
					Estimated total
					13.165 aH

Table 3.1: Listing of power requirements of the ATGTS

To get power to the various components, a number of cables were built out of 12 gage solid core copper wire soldered to connectors. These gave a great deal of flexibility in where components were located, which was important for prototyping. These wires were run from pins on the circuit board to the various components throughout the ATGTS. The wire pairs were also twisted to help reduce the effect of noise on our system.

3.3 Software and Interface Design

In order to control the ATGTS, a custom program had to be developed. The CY3214-PSOCEval USB microcontroller was chosen at the sponsor's request due to ease of programming and Dr. Ostrom's previous experiences with this platform. As previously discussed, this design is based around a simulated state machine. This concept is detailed by Figure 3.1, and will be discussed in the coming pages. The implemented states are Rest, Mix, N_2O , CO_2 , and Equilibrate. The exact structure of this state machine in coding will be discussed in section 3.4.

Rest State

In the rest state, the microcontroller is shut off by an external timer. This timer was originally designed for periodic feeding of fish. Electrically, it is in series with microcontroller following the buck converter. It

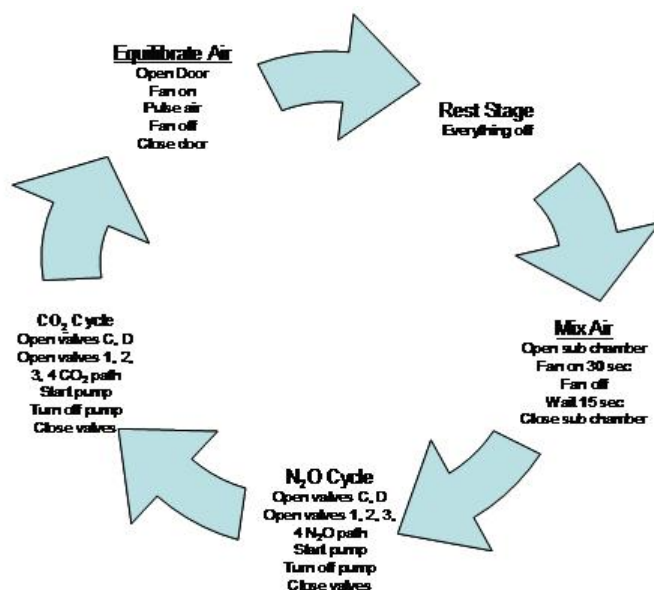


Figure 3.1: State machine simulated in microcontroller

is accurate, efficient, and can power the microcontroller when it switched on via the timer's internal relay. After six hours, the relay closes and the microcontroller activates.

Mix Cycle

After activation, the microcontroller activates the soil flux chamber fan. This fan runs for 30 seconds, and stirs the air to ensure an equal sampling in the next state. After this stir, there is a 15 second period before the sub-chamber door is closed, sealing the sample. The purpose of this wait is to allow for the air to cease moving.

N₂O Cycle

With the sub-chamber sealed, the N₂O sample is run through the trap system. The microcontroller opens valves C and D in Figure 6.6. In addition, the three-way valves 1,2, and 3 are opened for the N₂O path as indicated in Figure 6.6. The signals to the valves are pulse width modulated, with a duty cycle of 38% and frequency of 100 KHz, as discussed in Section 3.2. Next, the microcontroller activates the pump via a transistor switch. The pump is run for five minutes to circulate the sample volume through the trapping system. At the end of this time period, the pump is turned off by the microcontroller, and all valves are closed.

CO₂ Cycle

The CO₂ cycle is very similar to the N₂O cycle. This time, valves A and B are opened in Figure 6.6, and the three-way valves open for the CO₂ path. Due to the smaller sample size of the CO₂ chamber, the pump is only run for 2 minutes. After this time, the valves and pump are deactivated.

Equilibrate Cycle

The final state of the device equilibrates the soil flux chamber and sub-chamber with the outer atmosphere. The microcontroller opens the outer door and sub-chamber with linear motors. The soil flux chamber fan is then pulsed on and off in 10 second cycles with a 5 second lag period for 5 minutes. This pulsing will match the inner air with outer air. A pressure sensor is provided to ensure that the air is properly exchanged. If the pressure measured by the sensor is outside constraints for operation, the microcontroller can make a log entry and cease operation to preserve the validity of the existing sample. An LED attached to the exterior of the ATGTS is also lit to alert the user. After the air is equilibrated, the microcontroller is deactivated by the timer and enters the rest state.

In addition to the microcontroller, a USB data logger is also provided. This device monitors temperature, humidity, and dew point every 5 minutes over the entire month long sampling period. This data is important to researchers trying to determine the source and flux of the trace gas samples collected by the ATGTS. This device is mounted on the interior of the soil flux chamber near the soil, and the data from these devices is read each month and then returned. The IP67 waterproof rating ensures field robustness.

3.4 Software Implementation

The microcontroller was previously run using a direct state machine design which had five states. Components were turned on during a particular state and off when the state was over. Extra counters were needed because some components need to be on for 30 seconds which is one half the state duration of 1 minute. However, due to the limited number of counter blocks available, this path was abandoned. A new programming strategy was developed to simulate a state machine. This new method utilizes a real time clock that starts at zero every time the microcontroller is powered on. Figure 3.2 shows a graphical version of this program. All of the system control variables are linked to this clock, making function of the ATGTS very intuitive. For example, the first thing the ATGTS does when activated is turn on the fan to mix the air in the sub chamber, the fan control uses a conditional if statement to activate the fan at 00:00:05 time and then deactivate it at 00:00:35 time. This type of logic allows for a single timer to be used for the system.

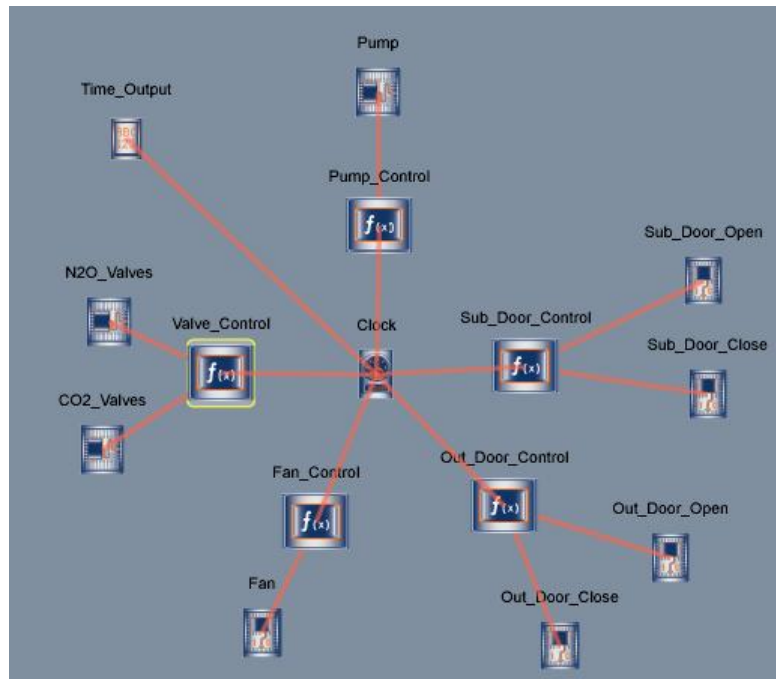


Figure 3.2: View from the PSOC programming environment of the simulated state machine.

The linear actuators are each controlled by two logic level output signals from the microcontroller. One of these signals is used to extend the linear actuator and the other retracts it. The motor driver integrated circuit supplies a positive or negative 12V depending on the state needed to run the linear actuators.

The solenoid valves and pump are run by pulse width modulation (PWM) signals to reduce their overall power consumption. The solenoids need to be activated initially by 12V and then can be held open at 5V. More specifically, the microcontroller outputs a 78% duty cycle PWM at 100 kHz to activate the solenoid for 1 sec. After this 1 sec interval the PWM is reduce to a 38% duty cycle at 100 kHz to supply 5V and keep the solenoids open. Another component which uses PWM is the pump which is activated using a 42% duty cycle to supply the 6V needed for the pump to operate.

The liquid crystal display (LCD) is used to present useful system information. In the top left corner of the LCD the current cycle of the system is shown. In the top right the timer of the system is shown. The bottom line of the LCD displays the fan RPM and the system valve pressure. The LCD displays the state by saving six predefined states; Mix Air, N2O, CO2, Equilibrate, and Stop. The LCD will change its state at a predefined time interval ranging from approximately 30seconds to 5 minutes. The fan and pressure sensor, speed and pressure values respectively, are displayed by connecting to the microcontroller and using analog-to-digital converters to send the information to the LCD. These valves are updated every clock cycle.

The timer is as 0000 where the first two zeros display the minutes and last two zeros display the seconds. The formula used was $(\text{Clock Min} \times 100) + \text{Clock Sec}$.

Error checking of the system involves integrating a pressure sensor and fan RPM feedback into the microcontroller. Originally, it was planned to monitor the position of the linear actuators, this could not be accomplished because the supplier was not able to supply the proper specifications. The pressure sensor normally reads 95kPa under normal atmospheric pressure. Threshold pressures of 90kPa to 100kPa were chosen, that when exceeded a warning LED will signal an error has occurred. To make sure a proper air sample is being equilibrated with the ambient environment, a warning LED will signal if the fan drops below 500RPM. When an error occurs the system microcontroller will send a signal to a power shut off relay. This will turn off all system function except the warning LED signal which will notify a passerby of needed maintenance. Also, incorporating this fail safe into the design will make use of whatever data has been collected so far prior to ATGTS shut off.

4 Testing

A number of tests on the function of the ATGTS components were done over the semester. In order to establish the time required for the trapping cycles, the flow rate of the pump was tested. This was performed in the ECE laboratory. Figure 6.18 shows the basic apparatus used to test the flow rate. There were three different test setups for the pump; the first test consisted of the pump connected to a 355.6mm tygon tube. The second test consisted of the pump connect to 1/16 inch PEEK tubing with a length of 3 feet. The last test added a solenoid valve to the previous setup between the pump and the PEEK. The last test setup is very similar to the setup the device will have in its operation. The result of the pump flow rate test is shown in Table 4.1.

Setup	Pump w/ Load (mA)	Valve (mA)	Time (s)	Volume (mL)	Flow Rate (mL/s)
Tygon tubing	90	NA	14.5	100	413.79
3' PEEK, 1/16"	100	NA	23.6	100	254.24
3' PEEK, valve	100	110	24	100	250.00

Table 4.1: Testing of pump flowrate connected to various components.

As shown in Table 4.1, the minimum flow rate was 250 mL/min. This results surpasses the requirement of a 150 mL/min flow rate. With this flow rate, the total time for the sampling intervals was reduced from 10 to 7 minutes. This also conserved power and battery size by not operating the pump for an additional 3 minutes.

Testing the sub-chamber's seals was preformed in the Mechanical Engineering Shop. After the sub-chamber was built, the sealing for between the door and Viton foam was tested. The two inner chambers were filled with water, then the door was slid into place where it would seal off the inner chambers. The first attempt to seal the sub-chamber failed because there was not enough pressure on the Viton to achieve sealing. A second test was run with additional metal sheets on the door, which caused more pressure on the Viton. This test was successful in sealing the sub-chamber. After re-running the test several times to validate the results, wearing of the Viton was seen. This is shown in Figure 6.20. This problem will lead to a new design of the bearing track for the sub chamber, which will be talked about in Section 5.1.

Testing also took place on the combined flow system. When the power draw of this system was analyzed, it was discovered that the solenoids drew a great deal more power than expected. Table 4.2 shows the expected power draw for the solenoids and pump over a month long cycle. Each of the six solenoid valves draws 110 mA of current when open. Initially it was believed that the solenoids would require power to open, but would lock in place once moved and not require any power to hold open. This testing also revealed that even if the power budget was adjusted to accommodate this, the solenoids would become dangerously hot over the sampling period. Thus, a way of reducing the power required by the solenoids valves was developed.

	Pump in Amps	# of valves	Valves in Amps	Mins	A-H/day
N ₂ O cycle	0.1	6	0.11	2	0.101
CO ₂ cycle	0.1	6	0.11	5	0.253
	N ₂ O cycle	3.04			
	CO ₂ cycle	7.6			
	Total	10.64			

Table 4.2: Calculated monthly power budget for the flow system, including solenoid valves and pump.

This led to the implementation of the PWM scheme as previously discussed. Table 4.3 shows the results of testing after this scheme's implementation. The required current to hold the valves dropped to about 40mA, a 60% reduction. The solenoids still heat up when active, but they are no longer dangerous. This testing also takes into account the extra circuitry required for controlling the PWM scheme.

	Pump in Amps	# of valves	Valves in Amps	Mins	A-H/day
N ₂ O cycle	0.1	6	0.04	2	0.040
CO ₂ cycle	0.1	6	0.04	5	0.099
	N ₂ O cycle	1.192			
	CO ₂ cycle	2.98			
	Total	4.172			

Table 4.3: Calculated monthly power budget for the flow system after PWM scheme for valves

5 Conclusion

5.1 Future Work

There are a number of future improvements that could be made to this first generation prototype. First, the present sub-chamber design is not robust enough for long term actuation. The sliding door wears down the Viton seal on the chamber door. This wear can be seen in Figure 6.20. If left uncorrected, the seal could go bad and all data regarding the flux rate of the trace gases would be compromised. As a result, in the weeks to come a new sub-chamber housing will be designed, incorporating a sliding linear actuator that indexes into the seal. In effect, the door will squeeze onto the Viton, as opposed to sliding across the Viton. This will be accomplished by changing the shape of the sub-chamber bearing tracks.

A second improvement is in the solenoid valves. The existing valves do not lock in position when moved, and take a great deal of power to keep open. Team 7 addressed this issue by using pulse width modulated signals to reduce the power required by the solenoids. If locking solenoids could be found for a similar price and size, many pieces of hardware could be removed, reducing the manufacturing cost of the device.

Another future improvement could be replacing the homemade electrical cables with a standard cable. For large scale manufacturing, using homemade cables is not very economic. There are a variety of cables that could be used instead. These would provide a higher degree of robustness. A final suggested improvement is the inclusion of new sensors throughout the device. Adding flow sensors into the system could allow for easier maintenance in the event of an error. It would also confirm that the device is always running as expected.

One failure of the group is that only limited testing has been done on the complete device. Given that this device is designed to operate over a month long period, a full scale test would have been impossible. Also, extracting data on the trapping of gases on the molsiv traps was also unfeasible for our time period. Removing and analyzing the traps is an energy intensive process which takes a great deal of time. Testing of the ATGTS is the most pressing piece of coming work that must be completed before the design can be implemented in the field.

5.2 Closing Remarks

Team 7 has successfully designed a prototype device capable of providing continuous measurement of N_2O and CO_2 over a month without outside interaction. This project was completed on time and within budget, as shown in the bill of materials, Table 6.1. The ATGTS maintains a very small ecological footprint on its surroundings. Replication of ambient atmosphere conditions ensures that the data collected matches

with what occurs in nature. The ATGTS is the first step toward implementing carbon credit systems as well as understanding the release of N_2O into the atmosphere. Both are important to the global effort to control global warming and climate change. Existing micro meteorological techniques possess insufficient resolution for use in carbon crediting systems, and no such techniques exist for N_2O .

The ATGTS is also unique in that it is the only device currently available that is capable of long term monitoring of CO_2 and N_2O emissions without isotopic fractioning. This is due to the use of molecular sieve, which physically traps the CO_2 and N_2O molecules, and the implementation of sub-chambers to reduce the volume of gas sampled. Stable isotope techniques can then be applied to the samples to determine the respiratory sources of CO_2 as well as the microbial pathways of N_2O . Understanding respiratory microbiological pathways provides researchers with the ability to redefine the impact of farming on the environment.

6 Appendix

6.1 Technical Roles

Each member of Team 7 has provided a description of their technical work on the project.

Adam Grisdale



My main portion of the project was designing and building the trap manifold. The purpose of a trap manifold is that our sponsors wanted all the traps to be together on one housing, so the traps, are easy to get to and exchange with new traps. I first started by asking our sponsors Dr. Ostrom and Dr. Smemo about trap sizes and the sizing of the tubing that will be used to transfer the trace gas. With that information they also gave me constraints on the flow rate, materials, and need for quick replacement. With my constraints and part supplier lists I started calling companies and asking if they had parts that would satisfy my objective. After talking with a few companies, I found a company called Swagelok that could supply all the parts that I would need. With the data sheets from the parts I selected, I then started to draw all the parts in UN 6 (CAD program) so I could design the actual trap manifold. With the CADmodels, I could also show our sponsors a visual representation of my idea for the trap manifold and make sure that they like the idea before I actually built the manifold. After they approved the model, I then started on building the trap manifold.

The components for the trap manifold came about four days after ordering them. After I received all of my parts, I started building the manifold itself. The manifold is basically a rectangular PVC box that has six holes in it. The six holes are for the stem part of the quick connects that is to be place in the manifold. Two steel plates will go on either side so they can hold and support the quick connects that are in the manifold. After the trap manifold was built, I tested the quick connect to make sure they properly work and also made sure that they are easy to replace them too.

I worked with the other Mechanical Engineers in designing every component in the device. I helped with the designing of the sub chamber. This component required the most design time because the sub chamber is the most important part of our device. The most critical part of the sub chamber is its air tight seal. If the seal was poorly designed, the sub chamber would not work correctly and the device would be a failure. The sub chamber has many different design changes to, mainly for packaging reasons. We initially had a cylinder shaped sub chamber but then later changed it to a rectangular box. Then our sponsor wanted us to add another door on the sub chamber so there would be no dead volume (non-circulating air) in the sub

chamber.

Alex Kerstein



My role in Team 7 was to provide document preparation services, and specialize in high level design and purchasing. This previous statement is a reasonable summarization of my contribution to the ATGTS, save for extensive prototype construction and minor testing conducted throughout the semester. I contributed to most mechanical portions of the ATGTS with the other two M.E. team members. I was more responsible for some components of the ATGTS than others. The major component I focused on was the sub-chamber housing.

The first step in the design process is to identify constraints of the design from the customer. Through a series of group meetings with Dr. Ostrom, I was able to extract the specifics of the design challenge. Using this, I and the other M.E. team members created the mechanical design criteria for the device. Once design criteria for the entire device and more specifically the sub-chamber housing was agreed upon, the team set out to create a conceptual design. Several conceptual designs were brainstormed as a group.

Once a conceptual design was chosen the design procedure began. I chose a sub-chamber shape by doing several dimension and volume calculations which took into regard physical constraints and customer input. Early on, a rotating servo door for the sub-chamber housing was chosen. After attempting to actually model this design into Unigraphics, I decided it would be far to complicated to seal effectively and so design iteration developed which used a linear actuated door. This door was originally to be constructed of PVC, but later was changed to aluminum to increase door fatigue life. After having modeled this entire sub-chamber in Unigraphics, Dr. Ostrom remarked upon the likely hood of a dead volume being present in the N₂O chamber. In response to this, I designed a different sliding door shape which catered to a newly adopted second door system which utilized a spring to apply force and close the second door to ensure sealing. I then modeled this design iteration in Unigraphics. This design is the final design utilized in the ATGTS prototype.

It is important to note, although I modeled all the design iterations of the sub-chamber housing, this is not the only modeling I conducted of components for the ATGTS. I also modeled the entire equilibrate door sub assembly and various other purchased components. Furthermore, I assembled all components modeled by M.E. team members using Unigraphics to create a complete computer model of the ATGTS.

Following creation of a completed model of the finalized design of the entire ATGTS and more specifically the sub-chamber housing, creation of the prototype began. Simultaneously, component ordering and retrieval was conducted by contacting suppliers. This job was done as a group with the assistance of Dr. Ostrom's

office personal. The entire device, save for the circuitry, was built in the machine shop by the M.E. team members over a period of approximately five weeks. I have aided in the construction of every component of the device in some way using both hand tools and power tools. In reference to the sub-chamber housing and outer door I cut several sections of PVC and Viton sealing material. In addition, I end-milled bearing tracks for the sliding doors in both devices.

Following completion of certain components throughout the construction of the ATGTS prototype, various testing was conducted. Static testing included filling the sub-chamber with water to check sealing condition and pumping water through a valve via a 900mm length of PEEK tubing to check the flow rate was high enough.

Josh Kowalski



As a group, the ME's were responsible for developing the system flow chart, designing the physical structure, identifying and ordering mechanical components, material selection, and finally manufacturing a prototype. All of the above tasks were accomplished with a collaborative effort, specifically design work. Some specific items that I was responsible for include material selection, budget tracking, gas trap volume calculations, and prototype manufacture.

The ATGTS is a gas trapping device, this makes proper material selection critical. Through communication with our project sponsor, I was able to obtain information concerning materials and their interaction with gases. Through additional research, it was decided to manufacture all structural components out of white PVC sheet. White PVC is chemically inert, and its properties allow the team to most accurately mimic environmental conditions. Consulting with my fellow ME's, a proper thickness was identified and ordered. I was also responsible for ordering miscellaneous hardware such as threaded inserts, screws, fittings, and hinges through McMaster-Carr for assembly. To track the team's budget, I created a budget spreadsheet that listed each component along with specifications, manufacturer, part number, price, and quantity.

To connect the various mechanical plumbing components of the system, extensive research was conducted by the ME team. I contacted various laboratory vendors with our design specifications and worked with their technical staff. After developing a list of potential options, I constructed a pricing spreadsheet, and placed an order for PEEK tubing through VICI. An issue arose concerning our pump. The flange connections on the pump were unable to join to the PEEK tubing. I contacted VICI, and working with their technical staff we developed a soft tubing adapter to connect the pump to the rest of the system.

The gas traps of the ATGTS are used to remove CO₂ and N₂O from the air for measurement. The extraction of these gases is done at a temperature of 350 C. Moreover, the carbosorb material used to trap the gases is a strong base. Very few materials can handle these conditions, and it was decided to utilize stainless steel. Through online research, I found a number of potential vendors. Through data provided by our project sponsor and independent research, I obtained information to determine the volume of molecular sieve needed to contain the amounts of gases that we anticipated over a one month time period. I then developed a spreadsheet to calculate the volumes of our gas traps. From CAD drawings, I was able to obtain the size restrictions of the housing compartment of the device, and match available sizes to our design criteria. By modifying the spreadsheet, I was able to minimize trap size while still maintaining a safety factor of 10.

Upon receiving the building materials, the ME group began manufacture in the engineering machine shop. Each team member aided in the measurement, cutting, and shaping of each component. From CAD drawings, I measured component dimensions from the raw PVC sheet material, and cut out these shapes using the bandsaw. The sub-chamber and outer door of the ATGTS feature sliding door closure systems comprised of aluminum doors. I milled the shape of the doors to be dimensionally accurate. To attach the bearings that allow the doors to slide, I first created bearing axles using hardened steel compression pins. I lathed the pins down to the appropriate outer diameter, and beveled the edges to start to fit the bearings. Using a piece of scrap wood and a rubber mallet, I placed the bearings on top of the lathed pins, and tapped the bearings into place. Finally, using a mill, I drilled into the sides of the doors to create the axle housings and inserted the bearing assembly.

Dan Cashen



My portion of the overall project was to design and build the solid state circuitry. I designed and built a circuit board that modifies the output of the microcontroller to provide the proper driving voltage and current for the various devices. Then, I revised this system to reduce current draw by 80% solenoid hold on voltage. The board uses the 14.4V lithium ion battery to power 5 MOSFET control circuit, a dual H-Bridge and the microcontroller through a voltage regulator. The control circuits use a MOSFET to eliminate the ground path and use a diode to insure discharge path for stored inductor current in an inductive device. This circuit is an industry standard and is discussed further in the electrical section. Two of the control circuits control all of the solenoids. These use a PWM signal to produce varying voltage. The voltage starts at 12V to

open the solenoid and then drops to 3V to hold the solenoid open. This substantially reduced the power consumption of the ATGTS system. The three other control circuits provide power to the fan, pump and water solenoid as discussed in the electrical section. The microcontroller is driven from a standard voltage regulator that is also located on this board. The H-bridge is used to reverse the polarity of the signal to the linier actuators as well as provide enough current to power the linier actuators. I designed, tested and built the solid state circuitry in this project and it works flawlessly.

I was the manager of the team and this lead me to spend ample time facilitating the completion of the project. I spent quite some time acquiring missing parts, turning in assignments and scheduling meetings. I have provided comments suggestions and assistance to virtually every part of this project to insure its success.

Chris Gliniecki



I made the original power consumption estimates and calculations, repeating them as necessary as various improvements were made to the design to conserve energy. This involved determining the current draw from each component, multiplying by its time in operation over the course of the month-long running time of the overall system, and summing the results for each part, thus finding the overall power requirements of the ATGTS. These calculations were used to set current targets for some parts as well as the ultimate requirements of the battery.

I also went over and lowered down the options for part selection and engaged in some device testing. In terms of the construction of the demo device, I assembled the cabling used to connect components together.

Much of my technical contribution to the team revolved around fitting the part selections to the design constraints, particularly power. This involved determining each function that needed to be fulfilled and how, then browsing for suppliers of the requisite parts using the internet. In my case, more time was focused on the latter, as battery selection became a central issue for the project as the team waited for the other parts to be fabricated and shipped. I focused on determining how much energy each of the components used in the design would need, so that we could decide on a battery before they arrived, something that we needed to accomplish in order to have the battery ready for implementation in a timely manner. This number was greatly reduced as I worked with the rest of the team to find ways to make the device more efficient, allowing us to find a safer and more attainable power source.

I described the requirements of the system's month-long operation cycle and our solutions to them in the proposal presentation, wrote a brief application note intending to instruct new engineers in a method

of estimating the energy requirements of any proposed system similar to the ATGTS, and detailed our own efforts to reduce power consumption in the design issues paper. It should be noted that each of the other team members had a hand in all of this, and I occasionally helped others out with the technical components on which they were focused; this was truly a team effort.

Thomas Hancasky



My portion of the overall project stated in the proposal was the microcontroller selection and integration. However, over the course of the semester this role was expanded to include things overlooked or miscalculated. Such things included researching components, making power calculations, making part selections, and proto-boarding circuits.

The microcontroller was picked for its ease of programmability and ability to take a design and program any PSoC with similar resources without redesigning a program. I have exclusively done all the programming of the microcontroller. I researched Cypress forums and watched online tutorials to gain the knowledge needed to program the PSoC. The program of the microcontroller consists of a state machine of five states, which includes Mix-Air, CO₂ cycle, N₂O Cycle, Equilibrate Cycle, and the Rest Cycle. During each state specific components have been programmed to cycle on and off along with some error detection features. These features include a pressure sensor, fan RPM speed, and linear actuator position. If one of these sensors indicates an error has occurred, an LED will flash to indicate to the operator that an error has occurred.

Due to the fact things were over looked or miscalculated my technical role was expanded to include power calculations and battery selection. My power calculations concluded that a suitable battery of 1.8kg 25.2AH can be used as opposed to the 34kg 100AH deep-cycle battery previously proposed. Another contribution was to research the external timer needed for the project. I provided three usable solutions and e-mailed them to the group for review and we ended up selecting a 12V fish feeder timer I had researched.

Another technical contribution to the group was the researching and proto-boarding of the MOSFET relay circuits used in the system to control the solenoid valves, fan, and linear actuators. These circuits are a modified version from a past design team who used the same LeeCo valves and from research online other components were added. Our design uses more readily available MOSFETs and incorporates a voltage canceling diode. Also by using pulse width modulation from the microcontroller the power consumption of the valves was decreased by roughly 50 percent.

A robust fan was needed for this project in order to operate in the harsh environmental conditions that

the ATGTS would be placed in. I researched a water proof fan with an IP 55 rating and interfaced it with the microcontroller to monitor its rotational speed to determine if a good sample would be taken. If the fan RPMs drop, the microcontroller will turn on an LED to notify that an error with the fan has occurred. This speed is also displayed on the LCD screen along with other relevant information.

Alex Esbrook



My work was primarily focused on bridging the gap between the mechanical and electrical components of the project. Team 7's project was unique from others in that from an electrical standpoint, it was relatively simple. Transistor drive circuits were used to power and control nearly all portions of the project. However, there was a lot of mechanical work that needed to be done, from the construction of the sub-chamber to laying out the tubing for air to flow through. I focused on translating electrical constraints to mechanical ones, and vice versa.

One prime area where this came up was with our solenoids. The mechanical team selected solenoids that worked, but took a great deal of power to operate. I worked with the mechanical team as well as the other members to develop a solution for the problem. I also directed our mechanical team members on the use of a linear motor. Originally, the mechanical design used a rotating door, perfect for a servo. However, we switched this to a sliding door, which would work well with a linear motor. My prime contribution to this was in developing our plan for controlling the position of the motor. I also worked on selecting the battery and choosing our dc/dc converter. I also contributed to the development of the state machine concept for the microcontroller, as well as the flow diagram of the overall system.

6.2 Gantt Chart

The Gantt Chart is included in the following pages.

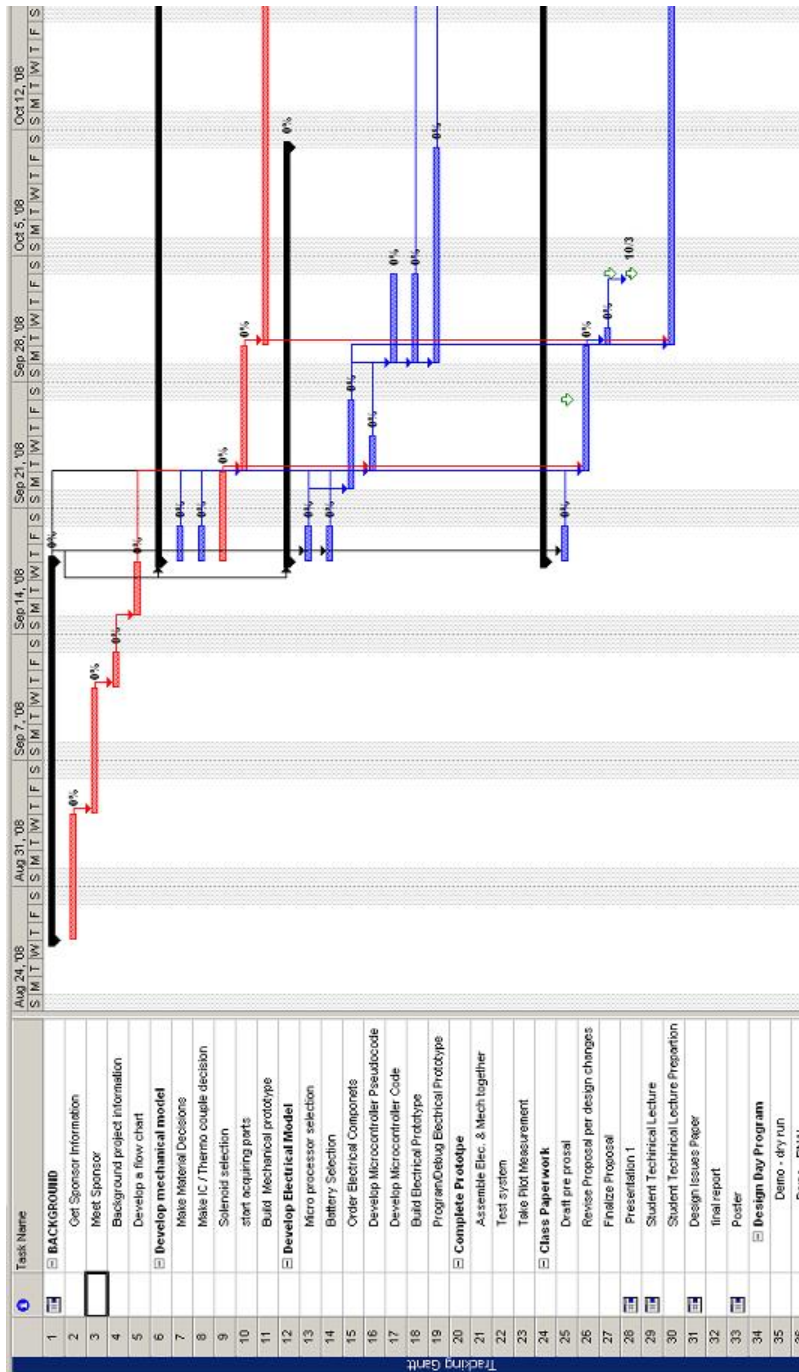


Figure 6.1: Page 1 of the Gantt Chart.

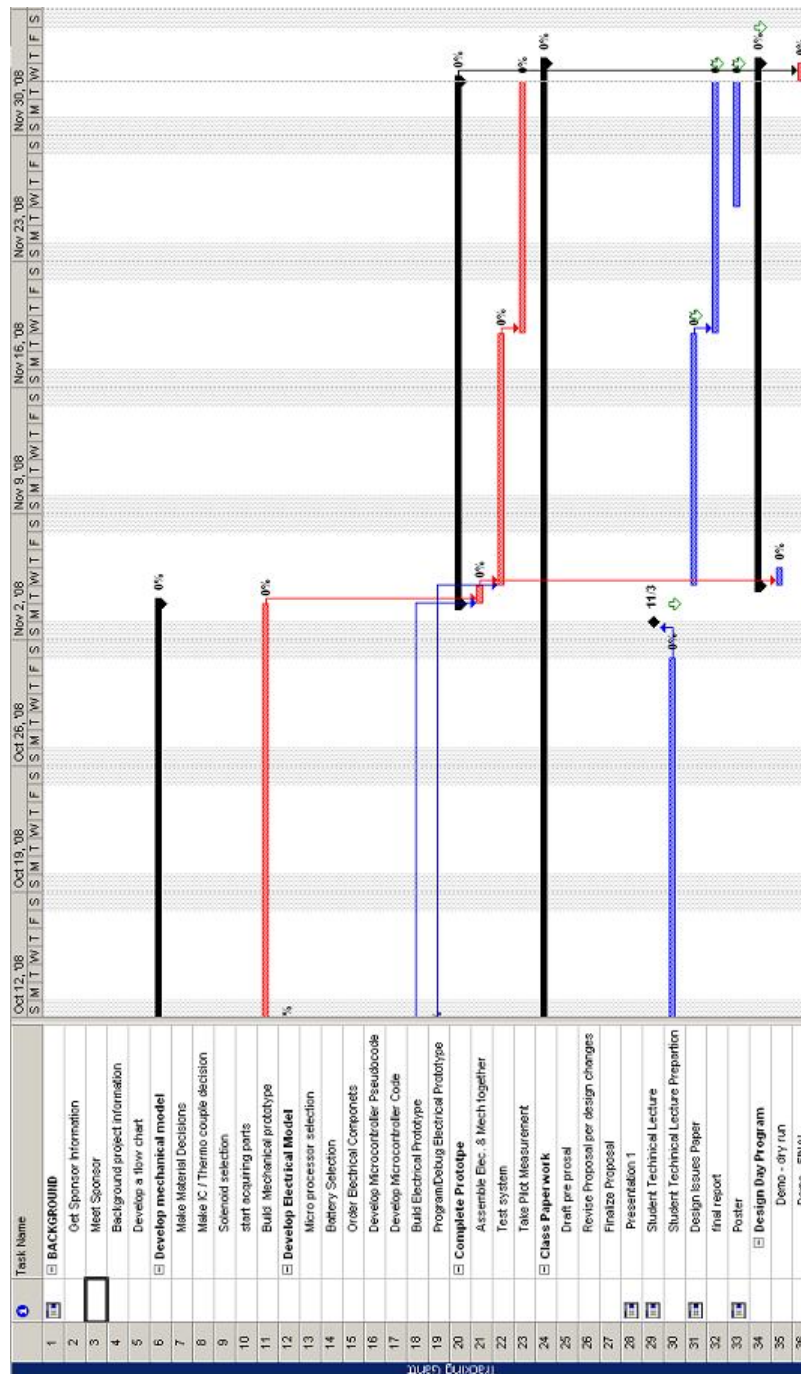


Figure 6.2: Page 2 of the Gantt Chart.

Task Name	Duration	Start	Finish	Predecessors
BACKGROUND	15 days	Thu 8/28/08	Wed 9/17/08	
Get Sponsor Information	5 days	Thu 8/28/08	Wed 9/3/08	
Meet Sponsor	5 days	Thu 9/4/08	Wed 9/10/08	2
Background project information	2 days	Thu 9/11/08	Fri 9/12/08	3
Develop a flow chart	3 days	Mon 9/15/08	Wed 9/17/08	4
Develop mechanical model	33 days	Thu 9/18/08	Mon 11/3/08	1
Make Material Decisions	2 days	Thu 9/18/08	Fri 9/19/08	
Make IC / Thermo couple decision	2 days	Thu 9/18/08	Fri 9/19/08	
Solenoid selection	3 days	Thu 9/18/08	Mon 9/22/08	
start acquiring parts	5 days	Tue 9/23/08	Mon 9/29/08	9,7,8
Build Mechanical prototype	25 days	Tue 9/30/08	Mon 11/3/08	10
Develop Electrical Model	17 days	Thu 9/18/08	Fri 10/10/08	1
Micro processor selection	2 days	Thu 9/18/08	Fri 9/19/08	1
Battery Selection	2 days	Thu 9/18/08	Fri 9/19/08	1
Order Electrical Components	5 days	Mon 9/22/08	Fri 9/26/08	13,14
Develop Microcontroller Pseudocode	2 days	Tue 9/23/08	Wed 9/24/08	5,7,8,9
Develop Microcontroller Code	5 days	Mon 9/29/08	Fri 10/3/08	16,15
Build Electrical Prototype	5 days	Mon 9/29/08	Fri 10/3/08	15
Program/Debug Electrical Prototype	10 days	Mon 9/29/08	Fri 10/10/08	15
Complete Prototype	21 days	Tue 11/4/08	Tue 12/2/08	
Assemble Elec. & Mech together	1 day	Tue 11/4/08	Tue 11/4/08	11,18
Test system	10 days	Wed 11/5/08	Tue 11/18/08	21,19
Take Pilot Measurement	10 days	Wed 11/19/08	Tue 12/2/08	22
Class Paperwork	55 days?	Thu 9/18/08	Wed 12/3/08	
Draft pre proposal	2 days	Thu 9/18/08	Fri 9/19/08	1
Revise Proposal per design changes	5 days	Tue 9/23/08	Mon 9/29/08	7,13,14,1,8,9,25
Finalize Proposal	1 day?	Tue 9/30/08	Tue 9/30/08	26
Presentation 1	0 days	Fri 10/3/08	Fri 10/3/08	27
Student Technical Lecture	0 days	Mon 11/3/08	Mon 11/3/08	30
Student Technical Lecture Preparation	24 days	Tue 9/30/08	Fri 10/31/08	10,15
Design Issues Paper	10 days	Wed 11/5/08	Tue 11/18/08	
final report	10 days	Wed 11/19/08	Tue 12/2/08	31
Poster	5 days	Wed 11/26/08	Tue 12/2/08	
Design Day Program	21 days	Wed 11/5/08	Wed 12/3/08	
Demo - dry run	1 day	Wed 11/5/08	Wed 11/5/08	21
Demo - FINAL	1 day	Wed 12/3/08	Wed 12/3/08	20

Figure 6.3: Enlarged view of the Gantt Chart labels.

6.3 Bill of Materials

	Component Details	Company	Part Number	#	Price	Total
1	Li-Ion Battery Pack: 14.8V 25.2Ah	BatterySpace	PL-8570170-4S2P-CAR	1	\$334.50	\$334.50
2	Smart Charger (6.0A)	BatterySpace	CH-Z-USC-14.8V-6.0	1	\$74.95	\$74.95
3	Pressure Sensor	Digi-Key	MPX4250AP-ND	1	\$12.45	\$12.45
4	60mm Fan Screen	Digi-Key	CR373-ND	1	\$2.77	\$2.77
5	Motor Driver H-Bridge IC	Digi-Key	497-2936-5-ND	1	\$6.24	\$6.24
6	Waterproof Axial Fan 60mm	Newark	96M1774	1	\$48.78	\$48.78
7	Programmable Timer	Super-Feed Enterprise	dt01	1	\$66.95	\$66.95
8	DC/DC Converter, 60W	Newark	06P9791	1	\$9.78	\$9.78
9	Data Logger, IP67	Thermoworks	TW-USB-2	1	\$82.00	\$82.00
10	Connector,Wire/Cable	Grainger	3BY21	3	\$6.86	\$20.58
11	3/8 in. Tube OD x 1/4 in. Male NPT	Swagelok	SS-600-1-4	4	\$9.50	\$38.00
12	Reducer, 1/8 to 1/16	Swagelok	SS-100-R-2	2	\$12.90	\$25.80
13	Reducer, 1/4 in. x 3/8 in. Tube OD	Swagelok	SS-400-R-6	4	\$9.00	\$36.00
14	Reducer, 1/4 to 1/16	Swagelok	SS-100-R-4	6	\$15.80	\$94.80
15	Aluminum, for 1/8" ID tubing	Swagelok	SS-400-R-8	2	\$10.40	\$20.80
16	Quick-Connect 1.0 Cv, 3/8 in.	Swagelok	SS-QC6-S-600	4	\$24.40	\$97.60
17	Quick-Connect Body	Swagelok	SS-QC6-B-4PM	4	\$36.30	\$145.20
18	Quick-Connect Stem 2.4 Cv, 1/2 in.	Swagelok	SS-QC8-S-810	2	\$31.50	\$63.00
19	Quick-Connect Body	Swagelok	SS-QC8-B-8PM	2	\$59.50	\$119.00
20	Bellows-Sealed Valve, Welded, 1/4 in.	Swagelok	SS-4H4	4	\$139.40	\$557.60
21	5 m, 1/16" OD, 0.055" ID	VICI	TPK155-5M	1	\$95.00	\$95.00
22	1/16" OD to 1/16"-3/32" ID Peristaltic	Upchurch Scientific	P-797	2	\$12.55	\$25.10
23	PEEK, 1/16" OD, 0.01" ID	Upchurch Scientific	M-657	28	\$13.11	\$367.08
24	5', 1/4" OD, 1/8" ID	McMaster-Carr	5046K11	1	\$8.05	\$8.05
25	12" x 12", 1/8" thick	McMaster-Carr	3156T13	1	\$92.02	\$92.02
26	12v, 2 Way Normally closed	Lee Company	LFVA1210420H	5	\$139.79	\$698.95
27	12v, 3 Way, Normally closed	Lee Company	LFRX0501900B	5	\$145.15	\$725.75
28	60mm x 25mm frame, 12v	ADDA	AQ0612LB-A70GL-LF	1	\$11.50	\$11.50
29	Microcontroller	Cypress	CY3214-PS0CEvalUSB	1	N/A	\$0.00
30	Linear Actuator, 60mm stroke, 12v	Fergelli Automations	-	2	\$80.00	\$160.00
31	NC, 1/4" port size, 12v, Viton seal	STC Valve	2S040	1	\$48.00	\$48.00
32	8mm OD, Shields on both sides	Motion Industries Inc.	693ZZ	8	\$11.68	\$93.44
33	300mm diameter				N/A	\$0.00
34	1', 0.5" OD, 0.46" ID, seamless	onlinemetals.com		3	\$6.85	\$20.55
35	7.7mm ID, 9.5 mm OD				N/A	\$0.00
36				2		\$0.00
37	Draw latch	McMaster-Carr	6082A12	5	\$4.20	\$21.00
38	Brass, 100 count, 5/32", 2-56	McMaster-Carr	92395A111	1	\$11.00	\$11.00
39	Steel, 100 piece, 2-56, 5/8"	McMaster-Carr	91802A074	1	\$5.86	\$5.86
40	Brass, press fit, 50 count, 1/4", 6-32	McMaster-Carr	92395A113	1	\$12.00	\$12.00
41	Aluminum, for 1/8" ID tubing	McMaster-Carr	5058K551	2	\$4.00	\$8.00
42	2ft by 2 ft, 1/4"	McMaster-Carr	8747K148	1	\$29.43	\$29.43
43	Crimp Style pin, Male	Tyco	102107-3	20	\$0.25	\$4.92
44	Crimp Style pin, Female	Tyco	87750-3	20	\$0.35	\$6.94
45	Crimp Style pin, Housing	Tyco	87499-3	20	\$1.23	\$24.60
46	Brass barbed fitting	Watts	A-740	2	\$1.65	\$3.30
47	Brass Pipe Nipple	Watts	A-741	1	\$2.35	\$2.35
48	Gloss Clear	Rust-Oleum	1901830	1	\$3.49	\$3.49
49	Plastic White Paint	Rust-Oleum	211339	1	\$4.99	\$4.99
50	Lacquer Thinner, 1qt	Sunnyside	45732	1	\$6.29	\$6.29
51	15ft Braided wire	Anchorwire	121127	1	\$2.91	\$2.91
52	Corner Brace, 1"	Ultra	16400	2	\$3.49	\$6.98

Total: \$4,356.30

Table 6.1: Bill of Materials

6.4 Literature and website references

1. Braswell, B.H., D.S. Schimel, E. Linder and B. Moore, 1987: The response of global terrestrial ecosystems to interannual temperature variability. *Science*, 278, 870-872.
2. K. A. Smemo, N. Ostrom, and G. P. Robertson 2008 unpublished
3. Halpert, M.S. and G.D. Bell, 1997: Climate assessment for 1996. *Bull. Amer. Meteor. Soc.*, 78, 1-49.
4. Hengeveld, H. and P. Kertland 1995. An assessment of new developments relevant to the science of climate change. *Climate Change Newsletter* (Australian Bureau of Resource Sciences, Canberra), 7, August, 24p

6.5 Electrical Schematics

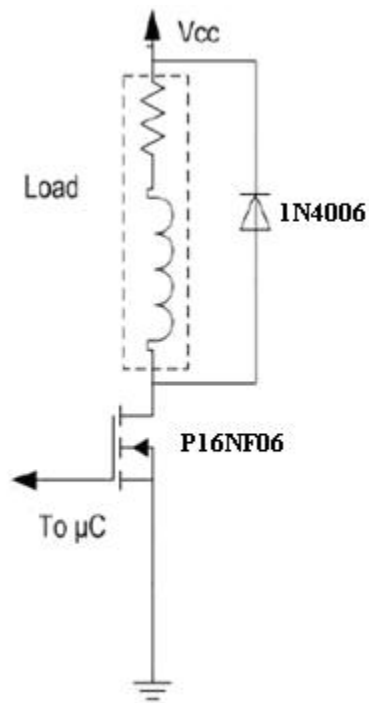


Figure 6.4: Drive circuit used for solenoids and pump.

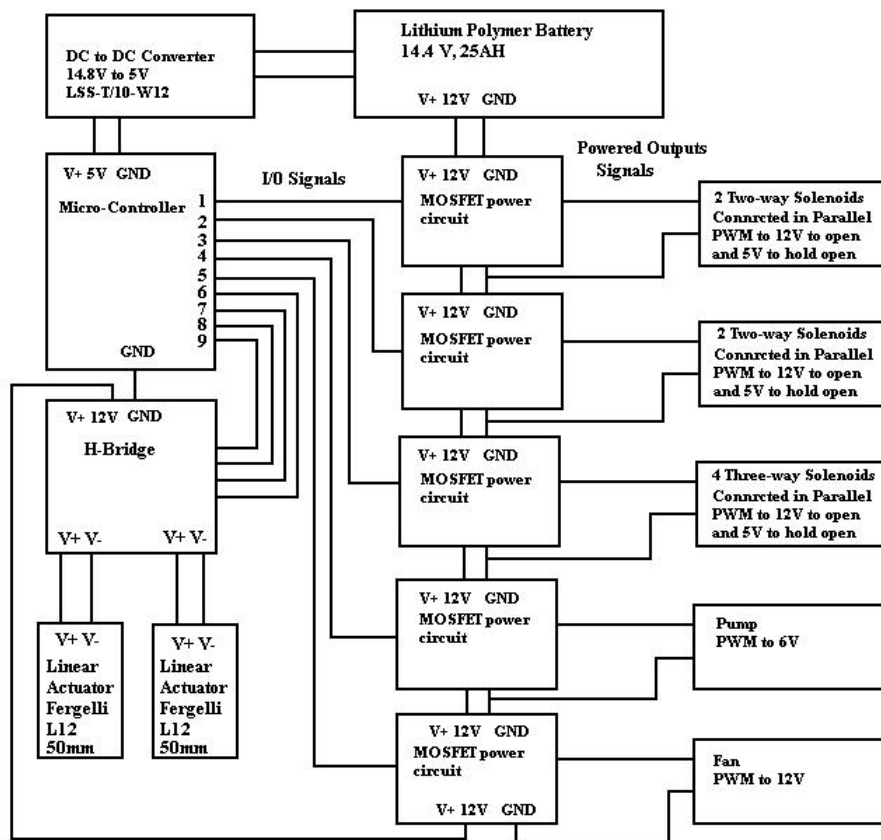


Figure 6.5: Block Diagram for electrical system.

6.6 Mechanical Calculations

CO ₂ Chemical Trap Volume Calculation		
CO ₂ concentration in air (L of CO ₂ / L of air)	0.01	
N ₂ O sub chamber volume (L)	0.15	Inputs
Hours between cycle (hrs)	4	
Cycles per month	186	
Volume of CO ₂ in sub chamber (L)	0.0015	
CO ₂ density (g/L)	1.799	
Mass of CO ₂ in sub chamber (g)	0.0027	
Mass of all CO ₂ extracted over 1 month period (g)	0.5019	
Mass of CO ₂ removed from 1g of Carbosorb (g)	0.4	
Mass of Carbosorb needed for Chemical CO ₂ trap (g)	1.2548	
Mass of Carbosorb w/ safety factor of 2 (g)	2.5096	
Volume of Carbosorb in 1g (L)	0.0015	
Volume of Carbosorb needed for chemical CO ₂ trap (L)	0.0038	

Table 6.2: Calculation for the size of the CO₂ chemical trap.

N ₂ O Molecular Sieve Trap Volume Calculation		
N ₂ O concentration in air (L of CO ₂ / L of air)	0.00002	
N ₂ O sub chamber volume (L)	0.15	Inputs
Hours between cycle (hrs)	4	
Cycles per month	186	
Volume of N ₂ O in sub chamber (L)	0.000003	
N ₂ O density (g/L)	1.799	
Mass of N ₂ O in sub chamber (g)	0.00001	
Mass of all N ₂ O extracted over 1 month period (g)	0.001004	
Mass of N ₂ O removed from 1g of Sieve 5A (g)	0.4	
Mass of Sieve 5A needed for Chemical N ₂ O trap (g)	0.00251	
Mass of Sieve 5A w/ safety factor of 2 (g)	0.005019	
Volume of Sieve 5A in 1g (L)	0.0015	
Volume of Sieve 5A needed for chemical CO ₂ trap (L)	7.53E-06	Output

Table 6.3: Calculation for the size of the Molecular Sieve trap

Volume of water collected in one month		
For 100% RH, 20°C, Mass of water in 1 liter of air per cycle (mg)	8.6	
Mass of water in a 3 liter volume (mg)	25.8	Input
Density of water at 20°C (g/L)	1000	
Time between each cycle (hours)	4	
Number of cycles per month	186	
Mass of water in a 3 liter volume after one month of cycles (g)	4.7988	
Volume of water collected in one month (mL)	4.7988	
Volume of water collected in one month considering a factor of safety of 2 (mL)	9.5976	Output

Table 6.4: Calculation for the size of the Desiccant trap

6.7 Mechanical Figures

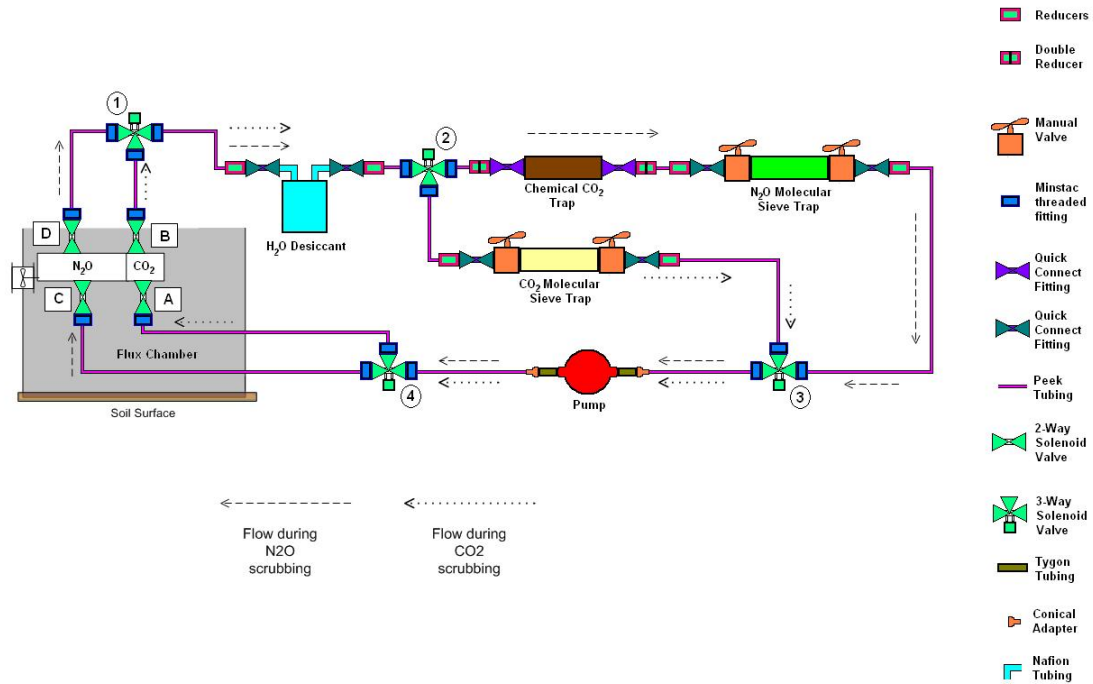


Figure 6.6: Flow Chart of gas flow in ATGTS.

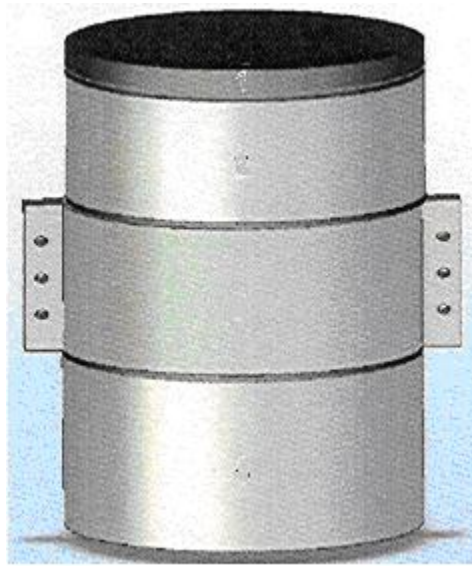


Figure 6.7: Outer case concept photo of the ATGTS

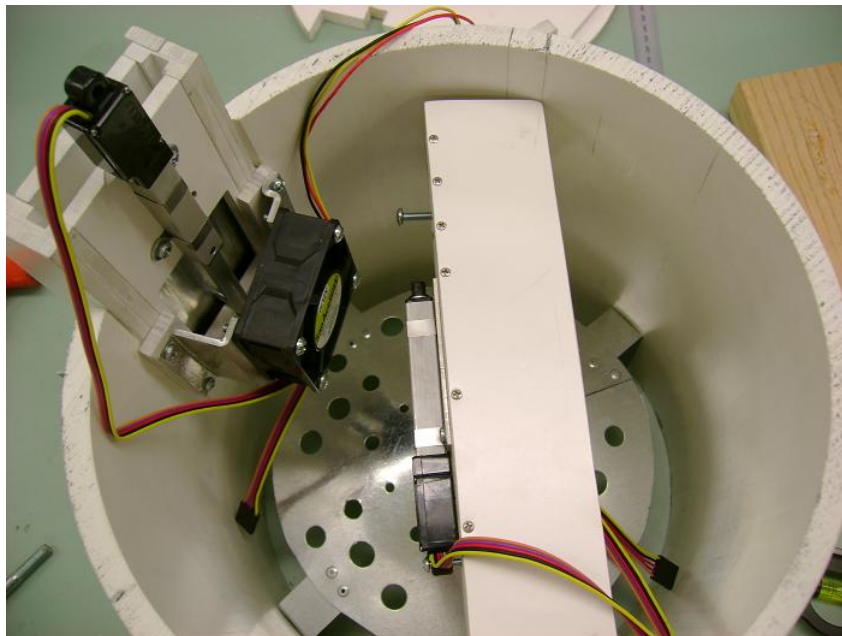


Figure 6.8: View of the soil flux chamber. The equilibrate door is seen in the top left. The rainfall grate is seen in the bottom center of the picture, underneath the sub-chamber.



Figure 6.9: Conceptual design of a rotating sub-chamber.

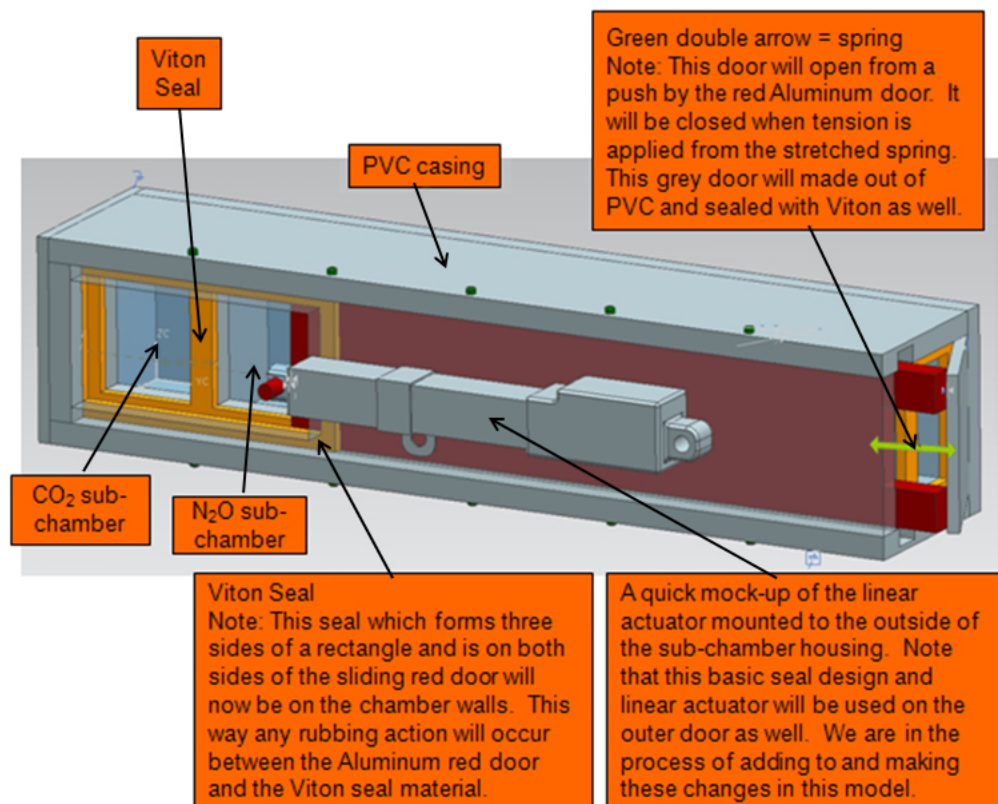


Figure 6.10: Conceptual design of the cube sub-chamber.

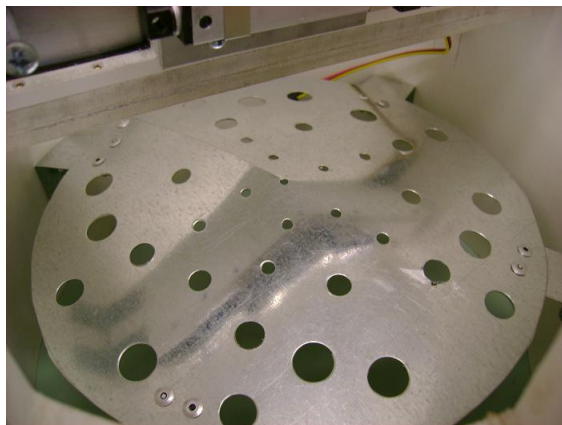


Figure 6.11: Rainfall dispersion grate in the soil flux chamber.

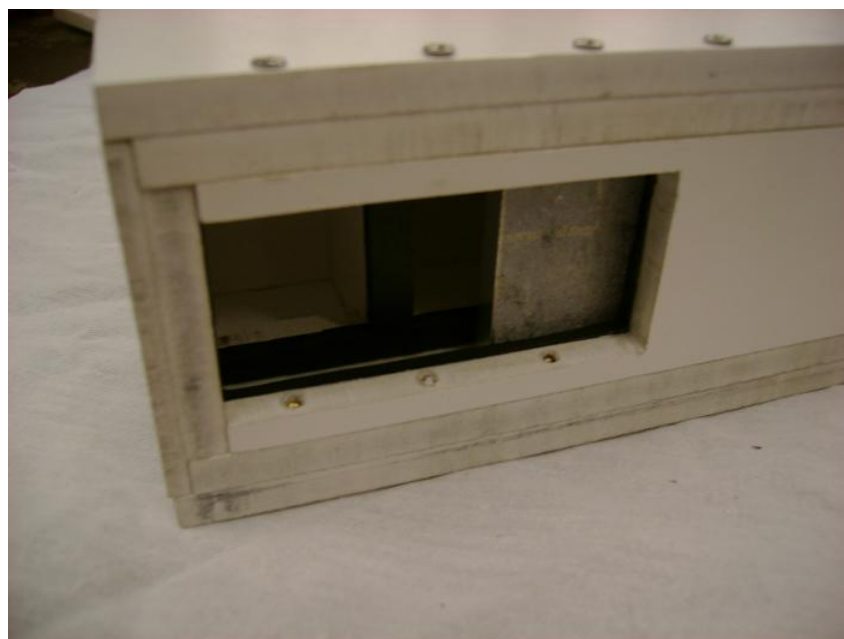


Figure 6.12: View of assembled sub-chamber, looking into inner N_2O and CO_2 chambers.

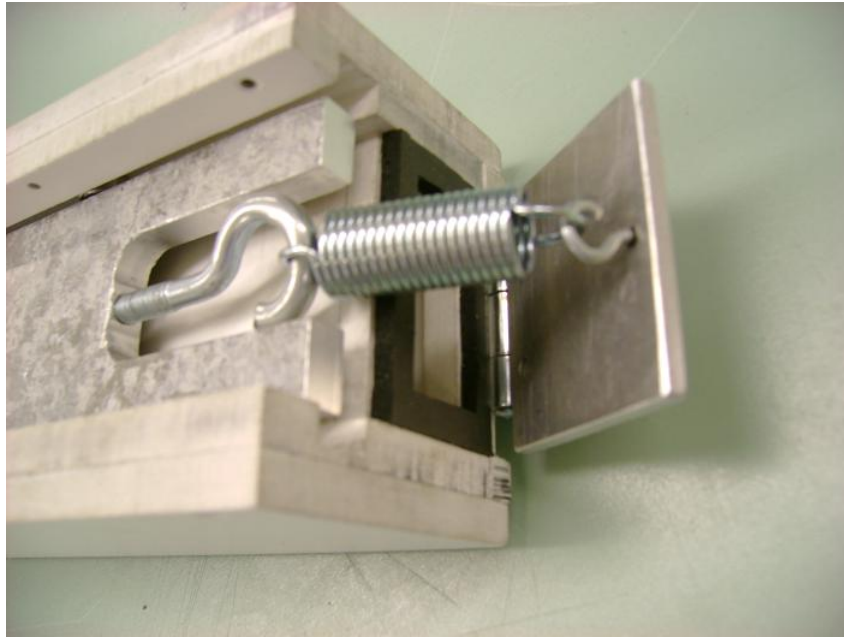


Figure 6.13: View of spring door, assembled sub-chamber.

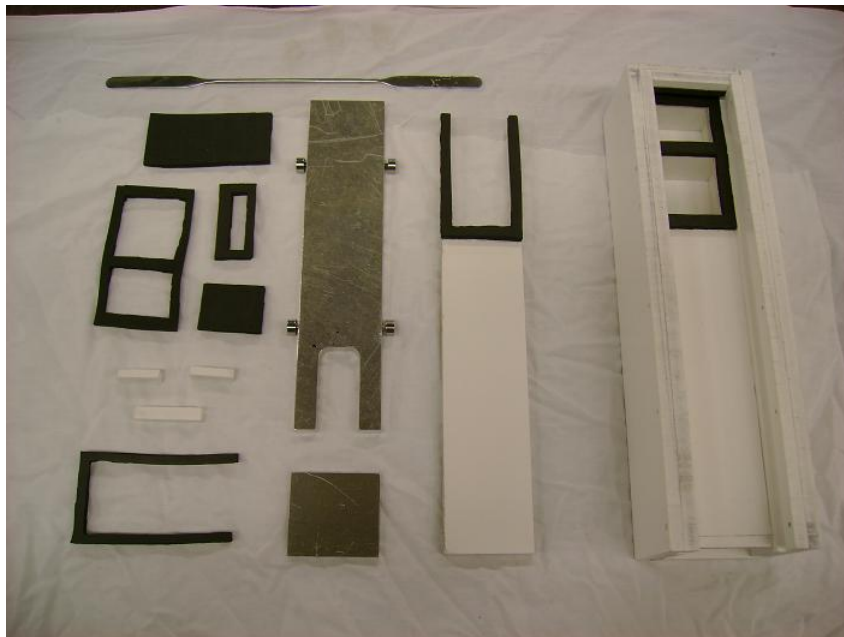


Figure 6.14: Exploded view of sub-chamber and Inner sub-chamber.



Figure 6.15: Soil flux chamber outer body.

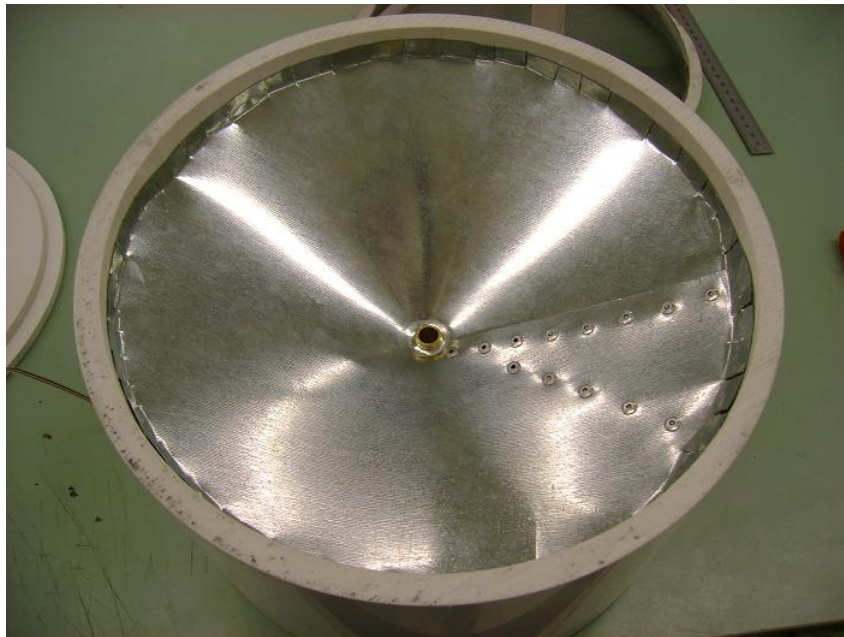


Figure 6.16: Top view, looking down, of rain catcher.



Figure 6.17: Assembled rain catcher, on top of the main body.

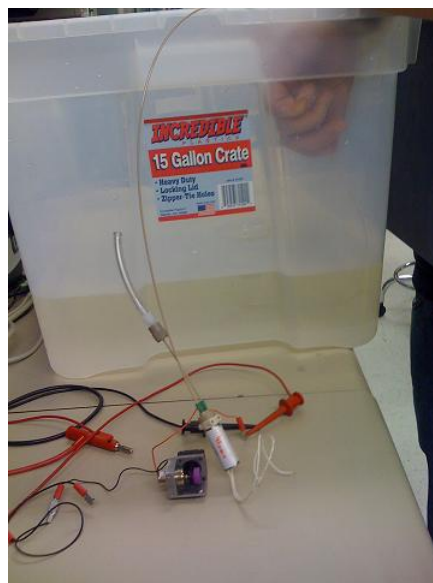


Figure 6.18: Assembly used to test flow rate of pump.

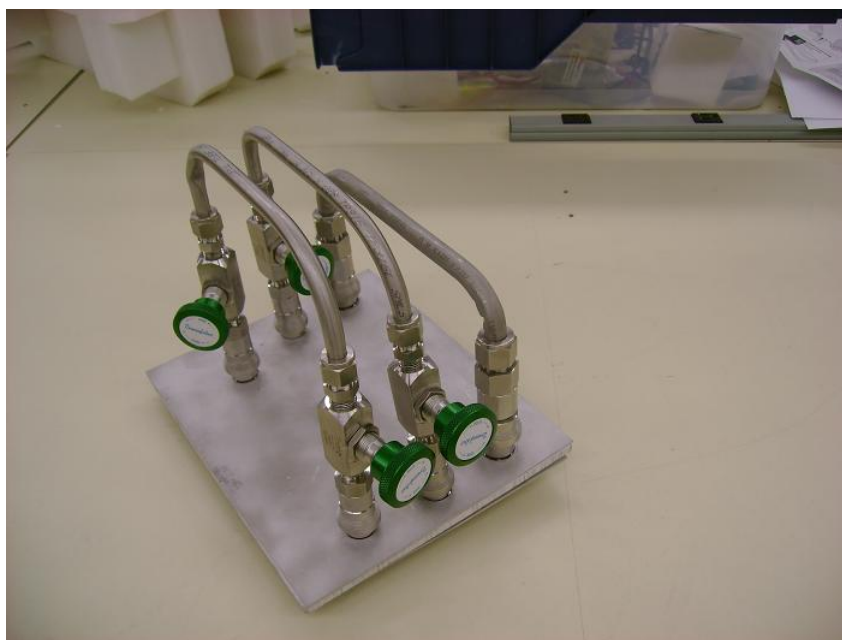


Figure 6.19: Trap manifold, containing the chemical trap and pair of molsiv traps.



Figure 6.20: Viton seal of inner sub-chambers. Note the fraying of the center piece of Viton.