Mars Settlement Exhibit Project

Interactive Qualifying Project Report completed in partial fulfillment

of the Bachelor of Science degree at

Worcester Polytechnic Institute, Worcester, MA

Submitted to:

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Abstract

This report, prepared for the Mars Foundation, lays out a plan for developing a museum exhibit pertaining to the settlement of Mars called the ”Phobos First Scenario”. Plans for the production of a model Mars rover with accompanying software and game objects are contained herein. Supporting research was done documenting the reaction to the plan and the likely efficacy of such an exhibit. Corollary exhibit materials are also presented. Using the recommendations and materials in this report, it should be possible to build a full museum exhibit fit for children of middle-school age given appropriate funding.

Contents

1 Introduction

The next frontier for human settlement rather than exploration or simple resource extraction is probably Mars. The case for a moon base is grounded in economics, but Mars settlement would open a new era for humanity. The Mars Foundation is concerned with promoting the habitation of Mars through manned settlement missions that are by definition one way trips. This goal is an important landmark in technological development and human expansion. It represents the foundation of a new age of human expansion and a safety net for humanity as a species.

In trying to achieve this goal, the Mars Foundation coordinates a number of projects focused on both building public support for Mars settlement and the gathering of planning resources and research assessing alternative approaches to a successful mission that would launch this settlement project. This project falls under the former category, attempting to improve the long-run public perception of Mars missions. In short we are to convince the next generation that such a mission is possible and that the risks are acceptably low for the first wave of colonists to arrive. They will not have the ability to return to Earth immediately so if they fail they will die. This possibility is a major impediment to political and economic support for the attempt. The Phobos scenario is an effort to reduce both the actual risks faced by the first construction teams and massively impact the perceived safety of the mission. Our job is to figure out how the next generation will learn about his exciting possibility in an engaging way that is educational as well as informative so that at least the planning process can begin in the next decade.

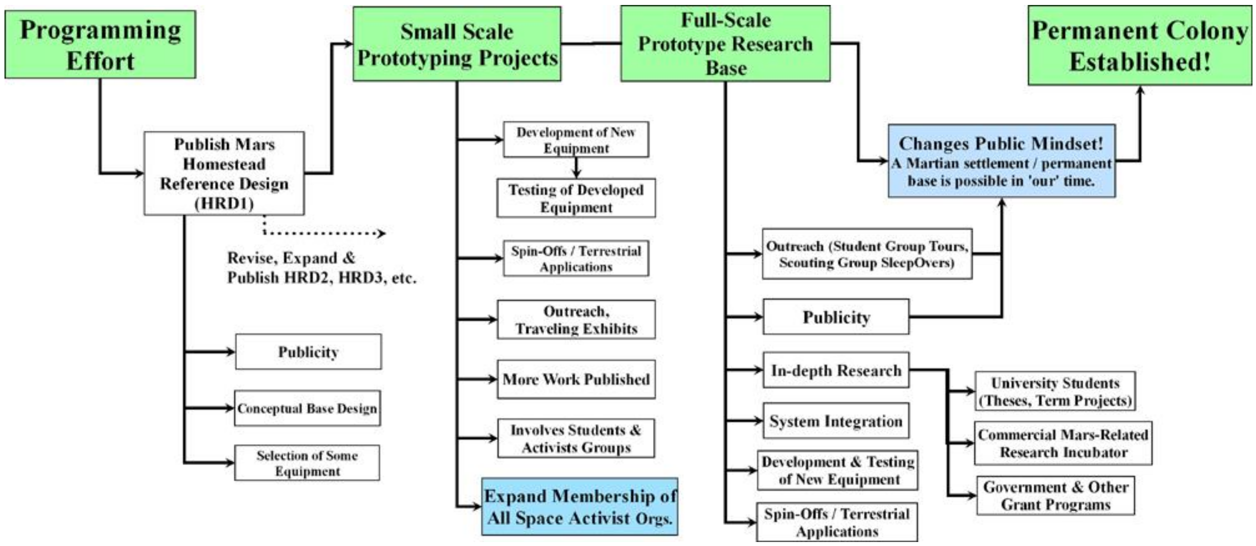

Figure 1: Mars Foundation Goals

In general, the public is wary of any efforts to develop a manned mission to Mars. Most people doubt the feasibility of such a mission. As long as human settlement of Mars remains as a figment of science fiction in the public eye, the lack of necessary funding and support will ensure it remains just that. To make this vision a reality, steps must be taken to educate the public on the enabling technologies, both in development and already existent that make a mission to Mars in the next decade possible.

As it stands, it is impossible to change the minds of the average US voter on Mars policy. In general, adults tend to have formed their opinions on this topic already and are not easy to sway even with compelling evidence. The best alternative is to work on educating the next generation of society’s decision makers. Looking at a younger demographic allows for evidence to be presented and judged by more open minds. By providing unbiased information on enabling technologies and building interest in space development, the goal is to make the importance and possibility of Mars development self-evident without delivering the message as directly.

The Mars Foundation already puts on or sponsors infrequent educational events for school children, but hasn't looked yet at a way of standardizing and distributing a program for Mars education. Ideas for a large facility, a cross between a museum and theme park already exist. The approach of a smaller exhibit that could be reproduced or moved around to attain greater coverage had yet to be examined, and doing so became our mission.

This project team will examine the idea of a smaller more versatile exhibit for promoting Mars settlement. By creating an experience specifically tailored for a younger demographic, this research should present the Mars Foundation with a more effective, time and cost efficient method of proliferating information on Martian settlement technologies and plans. Much of the research involves the creation of prototypes for an interactive experience designed to more fully engage the viewer. Some of the research conducted was done with local school children. Existing museum exhibits are examined and analyzed for efficacy in communicating information and the amount of interest they are capable of generating. Feedback was also sought in a professional setting at the Young Professional, Student, and Educator (YPSE) 2013 conference oft held by Region 1 of the AIAA at Johns Hopkins' APL, in Laurel Maryland.

By gathering data from these sources and using the knowledge and experience of Mars Foundation founder and liaison for this project, Bruce Mackenzie, a way of providing an engaging educational experience was developed. The final outcome of the project is the development of a set of plans for creating an exhibit based around the core idea of a Mars base construction simulation. These plans are flexible in that they have provisions for both highly funded and limited to non-funded approaches to obtaining an exhibit. Additionally, a prototype model rover was also delivered along with interface software. This is the basis around which the exhibit plans revolve. Alternate uses for this rover and software as an educational and promotional aid for Mars settlement have also been explored and are detailed herein. It may be of general utility for other science exhibits designed for this age group as well.

3 Literary Review

Since Spirit and Opportunity landed on Mars, something like human presence has been on Mars via robotic rovers over the last ten years. Because of the exploration done in these ten years, now Mars is not quite as strange and unimaginable for both the public and the scientific community. In the meantime, plenty of major discoveries on this planet has been exhibited to the public in this last decade. For our exhibit, we took note of several different kind of projects and space exhibitions developed in the past ten years. We even sent team members to see how this is handled at the National Air and Space Museum in Washington DC.

Mars Homestead Project

First and foremost, Mars foundation's Mars Homestead Project is one of the first to declare that. "The mission of the Mars Homestead Project is to design, fund, build and operate the first permanent settlement on Mars".

The initial goal for the Mars Homestead Project is to identify the core technologies needed for an economical, expandable Mars Base built primarily with local materials. Efforts will then be focused on prototype projects of increasing sophistication. These could include the selection of existing equipment which could be used on Mars, or the construction of prototypes of new equipment. These steps will lead the Mars Foundation to the establishment of an entire simulated Mars settlement at a location here on Earth, which will serve as a research and outreach center.

The initial programming feasibility study has been conducted by a small Program Team, whose members have professional or academic experience in applicable engineering areas. Areas of expertise include: Materials, Structures, Mechanical Systems, Architecture, Agriculture, Nutrition, Process/PSSS, Electrical Systems, I&C, Data/Telecom, EHS, IE, Mars Geology/Topography, Space Transportation, Spacesuits, Systems Integration, and many others.

The Mars Foundation has also established a small board of technical advisors who provide expertise in specific areas, and created a general "brainstorming" discussion group which is open to the interested public, regardless of their level of technical experience.

Some locally derived materials have been examined for initial settlement construction. These materials include locally produced fiberglass - wound on site, metals, masonry - either for un-pressurized shelter or covered with regolith to hold the pressure, polyethylene & other polymers made from ethylene from the CO2 atmosphere, and any plant products - especially if a byproduct of food growth. The MHP team continues to evaluate these options as well as a number of potential alternatives.” - marsfoundation.org

Figure 2: Hillside Settlement Proposed Design

10 Years on Mars Exhibition

On the night of Jan 3rd, 2004, the rover Spirit landed on the Mars. It was followed by its twin, Opportunity, three weeks later. At first, these two robots were expected to explore this strange planet for about three months. One of their most important goals was find the evidence of past water activity on the Mars. Startlingly, both rovers have found a lot of evidence along these lines, which far exceeded the expectations of their creators. . In 2010, Spirit got stuck in a sand trap and after dragging one inoperable wheel for a while it was declared completely dead in 2011. However, Opportunity still operates now and has showed no signs that it will soon slow down.

"Opportunity is still in excellent health for a vehicle of its age," mission project manager John Callas, of NASA's Jet Propulsion Laboratory in Pasadena, Calif., said in a statement. "The biggest science may still be ahead of us, even after 10 years of exploration."

This Museum exhibition highlighted the accomplishments of these two rovers by a set of photos which were taken by the cameras on these rovers.

"This set of spectacular images captures the beauty of Mars while telling the amazing stories of Spirit and Opportunity as they explored water-related deposits," John Grant, supervisory geologist in the museum’s Center for Earth and Planetary Studies and chair of the rover mission's science operations working group, said in a statement.

Figure 3: Model of Opportunity

Figure 4: The photo exhibition of 10 years on Mars

ATK-NASA Exhibition

In this exhibition, WTK teamed up with NASA to exhibit and educate people about what the next step of deep space exploration of Mars looks like. Which has some common with our exhibition.

Figure 5: ATK-NASA

Figure 6: ATK-NASA

In this exhibition, lots of space science and NASA's future plan of deep space exploration had been presented more to teach children and teenagers deep space exploration is within their reach than to convey any particular facts to them... "I learned that the rocket can't keep on burning unless the booster is attached," Leger said, noting the most interesting thing he learned at the exhibit.

Mars One

Mars one is another project could not be ignored despite an amateurish technical base. It is a Dutch company that announced plans last year to establish the first human settlement on the Mars in 10 years. Thousands of people volunteered to go as part of the first wave of settlers

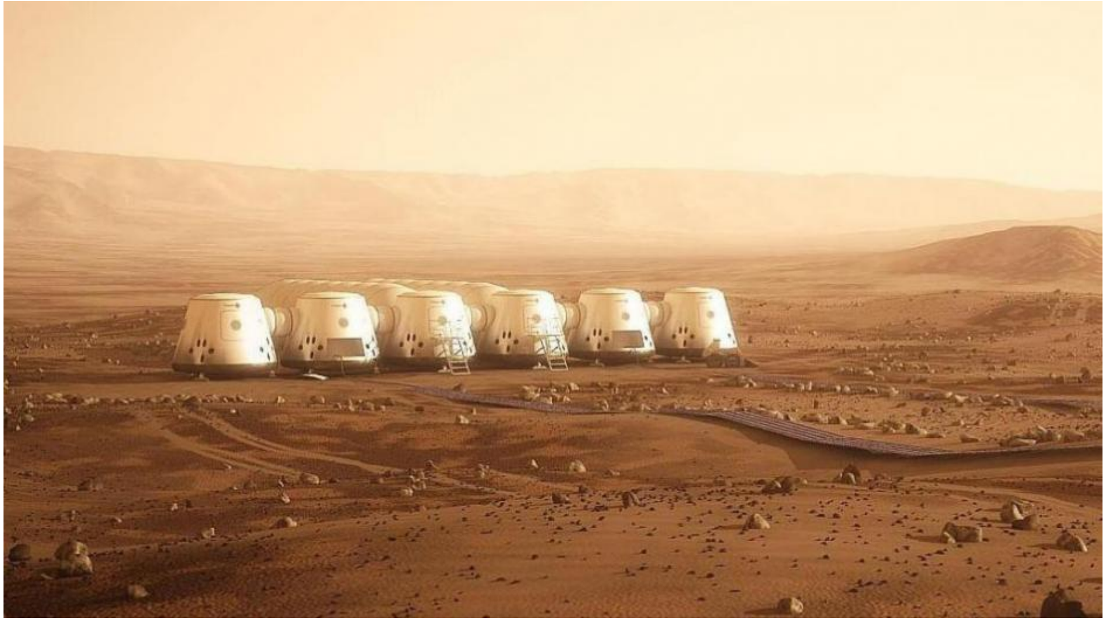

Figure 7: Mars One Settlement

In this project, Mars One wanted pick travelers to involve in a full-time training program which included a one-way ticket to Mars. Mars One founders Bas Landsorp and Arno Wielders, both of them previously employed in technology and space industries, declared that Mars One planned to send probes and robotic rover in early 2016 to set the stage for habitation of the red planet.

4 Methodology

4.1 Formulation of Goals

The initial goals for this project were somewhat removed from the final results. Significant time was taken in deciding the ultimate goal of this project. Deliberations on this front happened as a collaboration of the team, the advisor, and the sponsor. The final goals and deliverables for the project are a product of an ideal and the time constraints and resource limitations under which the project needed to operate.

4.2 Exhibit Design

4.2.1 Control Stations

The control station was envisioned to replicate that of a small control booth. Each station would have room for two occupants, “Controllers”, to control a single rover at a time; one person would act as the “Driver”, while another would act as an “Operator”. A broad control panel, approximately 5 feet long by one to one and a half feet deep, would house the majority of the available controls. A large touchscreen, surrounded by two joysticks for both Controllers, would serve as the primary control inputs.

This method of input was decided upon as the broad majority of the population in the United States has had exposure to both joysticks of some sort (including arcade style ones), and even more importantly, touch screens, such as those found on common smartphones.

A minimum of two widescreen monitors would be used for a display output from each control station PC, one located in front of each Controller. The software running on the PC would automatically fill the monitors with relevant information about the faux base, the construction rover and base status, and display camera feeds, both real and virtual, from the rovers, base and satellites.

4.3 Concept Rover

As part of the exhibit development portion, a rover concept design was created. The overall goal of the rover design is to create an interactive component of the exhibit. This was decided as to increase the entertainment value, and thus the impact-ability and memorability, of the exhibit to all museum-goers. This design concept includes several items, including the electronic control system, mechanical construction and interactions, and the mission control station for users to interact with.

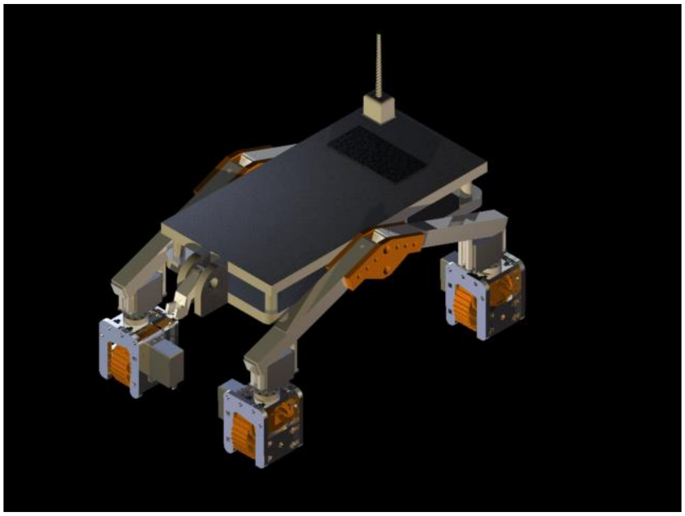

Figure 8: Rover Concept Design

Several suggestions and items that could be modified to more aptly suit a given museum/environment setting were devised and considered during the development of the concept design, and will be mentioned to allow for future examination and modification.

The conceptualized rover design is that of a utility vehicle for a Mars Settlement under-construction and partially operational. The direct role it plays in the exhibit is explained in more detail in section X (exhibit).

4.1.1 Design Requirements

One key requirement that was decided early in the project was that the ability of young members of the public to interact in a meaningful way with the exhibit was essential. The purpose of this was so that, one, it would better help achieve the primary purpose of the exhibit – that is, to help convince the younger public that it is possible to live and settle on Mars within a generation. The exhibit would do this by being something that they would be able to manipulate and have an interactive experience with, and thus remain interested in for a long period of time while at the exhibit's location. It also had to be meaningful to watch someone else operate on the exhibit, while waiting for his or her turn, due to natural limits with how many people can use the exhibit at once.

This leads to the second reason: by creating an interactive exhibit that can capture the public's attention span for a longer period of time than a typical display, there is time to deliver and more complete and complex message than a sound bite. One is trying to give people an impression of a feasible Mars settlement with more than superficial and glossy pictures. The goal is a demonstration that provokes more thought about the topic, leaving one with some answers and more questions to engage the curiosity and creative problem solving of the 10% of the population that is more informed opinion leaders with substantial influence on public perceptions and opinion.

As a result, the primary task of the project could be stated and a list of requirements created to guide the design process that would shape the exhibit rover concept. Requirements ranged from being mandatory, to very important, to being a nice addition if possible (See Table 1). A guiding force that had to be followed was the mandate of our sponsor, the Mars Foundation, and their goal to promote interest in the younger generation to create a permanent settlement on Mars. Items that might detract from the experience of promoting this interest were ruled out as unwise. Foremost among these were things that might stretch credibility and raise questions about the near term feasibility of what was depicted. For example, the technical design IQP team had envisioned using a space tether to drop the Phobos base into place. Although this is an intriguing design as an engineer, and experts would likely agree that it could be done within the next ten to twenty years, it would be difficult to depict that in an exhibit. Also, our audience was the general public. It could seem far-fetched to them, a scenario we are aiming to avoid.

Requirement	Priority Level	Comments
Ease of use	Very High	Basic functionality mastered within a minute of use
Realistic	High	Approximate the aesthetics and utility of actual NASA designs as much as possible to prevent a "Sci-Fi" feel.
Control Flexibility	Medium	The system needs to be able to adapter to the approximate skill levels and learning speeds of those using the exhibit very quickly

Table 1: Exhibit Development Priority List

4.1.2 Mechanical

A central component of the exhibit is the miniature, yet functional Mars rover. It was determined early in the design phase that the rover would be between 8 and 16 inches long, due to cost constraints and the size limitations of the overall exhibit. The design process was guided by two main priorities; these are scaled functionality, and a technically realistic physical appearance.

Mechanical Design

Several different mechanical layouts were considered, however most of them were deemed unacceptable for reasons including a lack of robustness, difficulty to manufacture, and a layout that caused the rover to be difficult to drive for younger children. The rover's mechanical design can be broken down into five main sub-components. These are the steering mechanism, the wheels, the suspension, the chassis, and the arm.

Steering

The first choice for a steering arrangement was a holonomic platform, where each of the four powered drive wheels (mounted to the chassis in a rectangular profile) were connected to a separate motorized swivel mount. This is very similar to the wheel layout for real-world rovers, such as NASA's Spirit and Opportunity, so realism in terms of current technology is preserved. On Mars where there is an atmosphere flying robots and windmills would be possible, but the public would consider that fanciful. Something like a current Mars rover is believable and appropriate to the modest construction and assembly job to be depicted. One wants to keep it interesting and deliver some surprises so the task is not too mundane, but credibility is of the greatest importance, as this is not a video game.

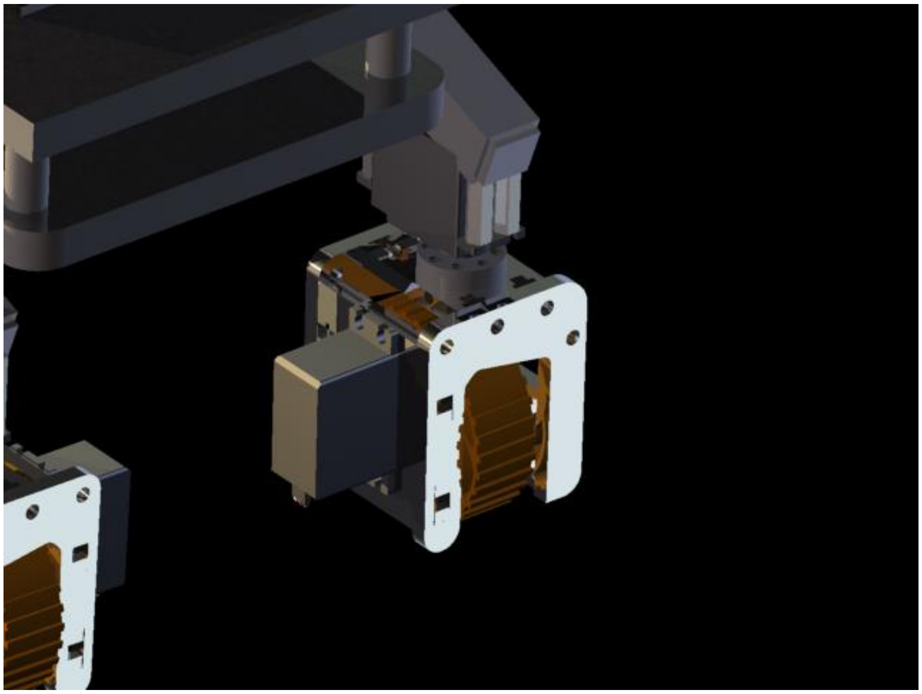

Figure 9: Rover Steering Design

Using a computer algorithm, steering can be simplified to take only forwards, backwards, right, and left as control inputs. This makes control and movement of the rover easy to learn for even very inexperienced drivers, while satisfying the mechanical interest and curiosity of more sophisticated (older) drivers. It will also avoid problems for those with less hand-eye coordination and abilities.

Wheels

The wheels were designed to appear reminiscent of the wheels found on current real Mars rovers, with spokes forming the inner geometry, and an angled, treaded external circumference. Since the steering mechanism would twist the wheels about an axis perpendicular to the ground, the wheels were designed to be narrower proportionately than real rover wheels, so as to avoid too much skid-friction.

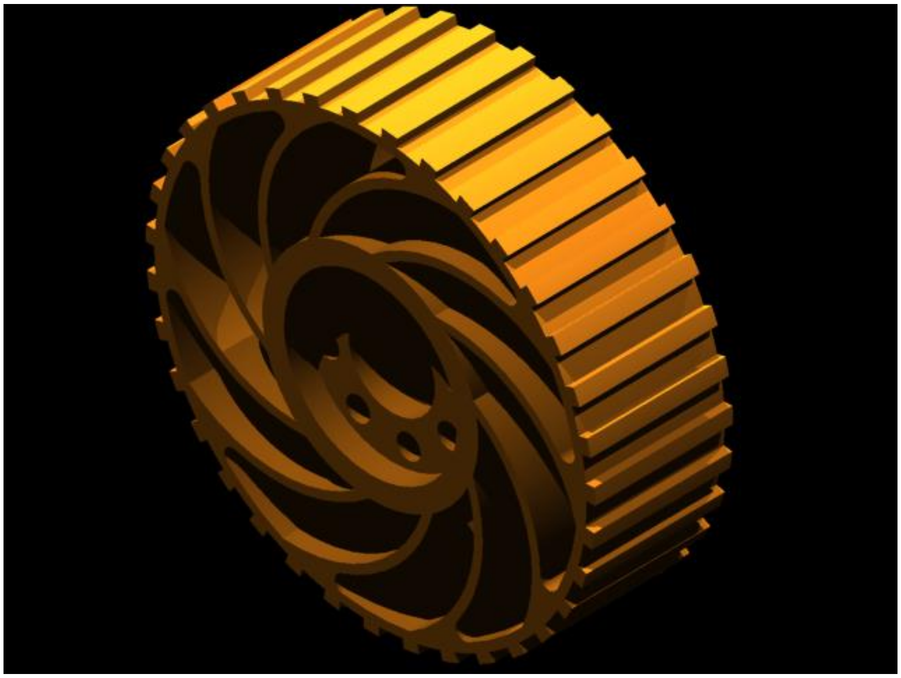

Figure 10: Rover Wheel Design

Chassis and Suspension

To handle the “harsh terrain” within the exhibit, the rover was designed with a “rocker-bogie” linkage in the suspension, allowing the rover to flex and move over rocks and “craters”. The chassis of the rover is kept level relative to the ground plane through the use of four extension springs. On rovers such as NASA’s Spirit, there are multiple pairs of rocker-bogie suspensions, but for the reason of scalability, the exhibit rover was designed with one pair [3].

However, this is not unrealistic, as a rover used in a Mars settlement would be more reminiscent of a utility truck, and the site would be selected to be relatively free of obstacles and then further smoothed before assembly was undertaken.

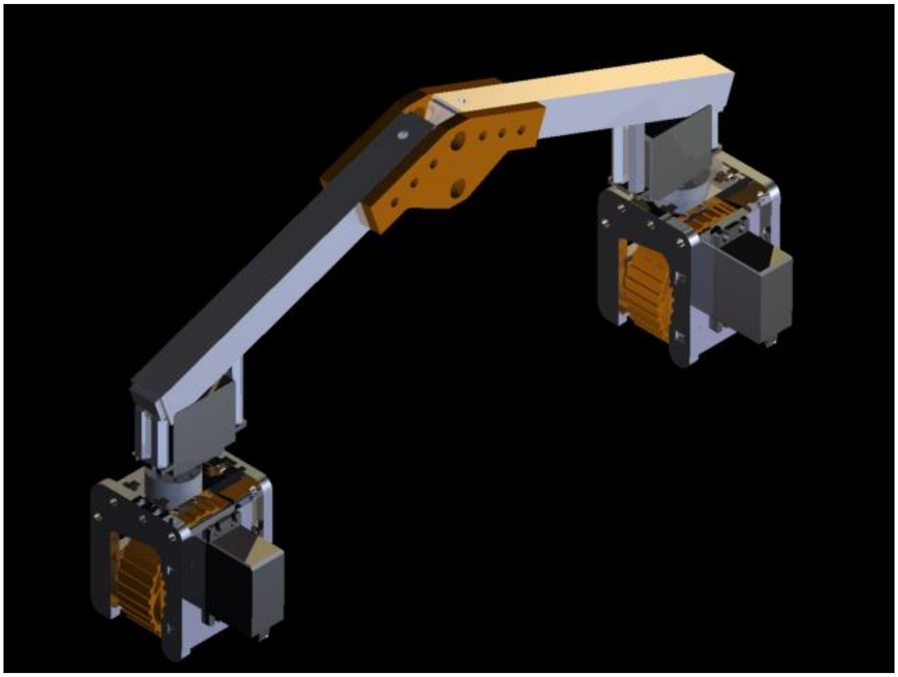

Figure 11: Rover Concept Design

It was decided that the rover should be modular and thus able to accommodate a variety of appendages and sensing equipment. Hence, the chassis was designed to be slightly larger than required, and was outfitted with multiple redundant mounting points to promote future expansion and flexibility. The battery holder towards the rear of the chassis was designed to hold both 7.2 Volt and 9.6 Volt batteries, so that new components requiring additional power beyond our needs could be accommodated. Because the exact size and layout of the electronic control system was not known at the time this design decision was made, an undercarriage was designed that could hold a microcontroller up to 4.5” by 7”.

Arm

For the rover to be effective in assembly applications and generally useful, it must be able to manipulate its environment in some way. Manipulation and arrangement of the model “habitation pods”, was going to be the first activity depicted. It had to do this well, but not be limited to this activity. We decided on a small, servo-actuated fork-lift which was implemented using an acrylic bar and a return-spring. This was placed directly on the front-center of the rover, and is capable of lifting one end of a pod and dragging it to its target location.

4.1.3 Electronics

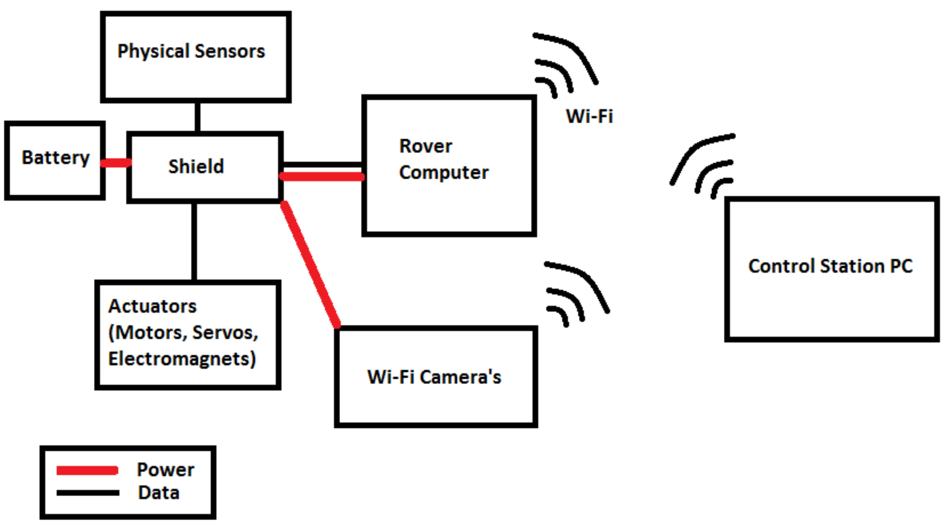

Figure 12: Rover Electronics Functional Diagram

The concept rover will have an onboard computer. It is imagined that this will be a semi-custom solution in a finished exhibit. The computer would consist of one of the many microcomputers available today for embedded DIY projects, such as the Raspberry Pi, Gumstix or BeagleBone (picture) –Choosing one of these for the computer would greatly cut down design costs. It is an immense advantage if no effort has to be expended on hardware design for a microprocessor and other related components. A “Shield” would be added to help the computer interface with the rest of the rover electronics on-board, including batteries, actuators and sensors. This shield could be either custom-designed, or one of the many commercially available models that can easily be adapted. The rover computer would have software written for it to interface with and control all on-board actuators and sensors. The use of a full “computer” with an operating system (OS) simplifies the work to be done connecting the networking control with the control station. It also provides ample processing power for all features that may be added to the robot on top of what is described in this report. Then the developer of the exhibit can completely abstract away (hide) all complex operations of the rover from the exhibit patrons that view, operate and interact in other ways with the rover.

The computer will connect via IEEE 802.11 (commonly known as Wi-Fi) to a local access point and router. The connection would provide a means of having the control station for the rover communicate back and forth, enabling control of the rover, as well as transmission of sensor data to the station. This information may be displayed to people viewing the exhibit, after being put in a viewable format by the control station. All of this capability would be added via the software run on the computer, making it infinitely modifiable. While the use of another wireless standard is certainly feasible, if the rover computer can handle wireless networking easily with the help of the OS involved (such as Linux), it would save development time to stick with Wi-Fi.

In order to preserve realism given that on Phobos one would actually see what was going on primarily through the “eye” of the rover, at least one remotely-viewable camera should be included, possibly two or more if there is adequate funding for the design and purchase of the equipment. The camera would provide a viewpoint from the rover directly, similar to current exploratory rovers such as Curiosity and Opportunity used by NASA currently. However, this is a construction vehicle, and ideally one would like to be able to monitor the rover in action from a nearby, separate vantage point while building the Mars base. While this could be done by another rover in the same vicinity, it would be better to have the rover deploy or pass by a camera in a viewing position on a tripod that can pan by swiveling but has a fairly limited movement capability. If the rover can move this stand around it the camera mount does not need to be more capable or flexible than the one commonly seen in department stores concerned about shoplifting. .

Numerous physical and virtual sensor ideas, in addition to actuators, have been considered possible add-ons, intended to add a level of complexity and realism to the exhibit rovers. The physical sensors can be added onto the rover construction, and used to provide some feedback about the rover’s operation and the environment to the human controllers at the control station. The actual information supplied can be modified based on the written control station software, and tailored to specific venues or audiences (e.g. a reduction in complexity if it is being transported to a fifth-grade school demo, while trending towards a more realistic view when deployed in a museum that serves college students and other adults). Virtual sensors would exist solely in the control station software, and emulate things like atmospheric conditions on the surface of Mars, which cannot be modeled based on real data from a rover in an exhibit.

Physical Sensors

IR/Laser Distance sensors	Can be used to generate a virtual map of the rover surroundings to augment the camera and provide sight at angles the camera cannot reach – this can be displayed on the control station for those interested
Wheel torque and speed feedback (motor current and wheel encoders)	Can be used to provide closed-loop feedback for motion, enabling movements to accurately follow the desires of the controller. Also may be used to indicate heavy-load conditions while pulling or on slopes.
Accelerometer, Gyroscope and Magnetometer in an Inertial Measurement Unit (IMU)	Can be used to display a consistent heading of the rover to the controller, similar to an airplanes attitude indicator. Note that the magnetometer would have to be "modified" to work on Mars.
Ambient Light Conditions (including visible, infrared and ultraviolet)	Indicates the current lighting and radiation conditions on the surface,

	including non-visible spectra. This can also be made into a purely virtual sensor.

Table 2: Rover Physical Sensor Proposal List

Virtual sensors

Sediment Tester	"Tests" the soil at the rover for potentially resourceful minerals and elements, such as iron content.
Atmosphere Tester	Reports the current atmospheric conditions on Mars to the control station, including temperature, pressure and gas content.

Table 3: Rover Virtual Sensor Proposal List

5 Progress Report

A summary description of what this project produced as a deliverable to the sponsor reveals that it consists primarily of a vision backed by a set of plans for creating an interactive exhibit. The elements of the plan s include contingency plans that are appropriate to a low, high and ideal funding level. Since we do not envision there being only one version of this exhibit nationwide all three may be implemented somewhere. After hearing of our concept and the YPSE meeting, a member of the audience on the board of a discovery center offered an invitation to communicate further with the staff of a Maryland based science education organization. The Mars Foundation already has a list of New England institutions that might be an appropriate venues. These are said to differ substantially in terms of available funding and ability to fund raise. . In any situation the exhibit plans revolve around three main and two peripheral components: the central activity revolving around controlling a simulated Martian base building robot; corollary exhibit displays; basic educational materials connecting the exhibit to educational goals of interest to teachers running a 5th or 8th grade class field trip and promotional materials, i.e. posters and signage.

5.1 Rover Physical Prototype

The exhibit utility rover is the element of the display that we took beyond paper plan to a working prototype, when put to the test in practice, it met nearly all of the design requirements outlined in Section 4.2.2. The most important design parameter adhered to was the maintenance of current conceptions of realism while exhibiting practical functionality (i.e. it does not look overly futuristic). Early in the project, a decision was made to attempt to implement a portion of the exhibit as a prototype, in order to get some feedback data during a demonstration of the prototype from a suitable audience of teachers, students or discovery center staff on the appeal and effectiveness of our designs. Candidly we were concerned that the activity could be too mundane, that audiences would see it as little more than a remote controlled vehicle connecting tubes in a mock landscape. Unless the imagination necessary to make this activity serve as a proper depiction of a monumental and unprecedented moment in human history could be evoked, it would not hold their interest. It was projected that the imaginations of the 10-15 year old children would enable a suspension of reality that put them in a faraway place at another point in time, if we gave them just a bit of help in maintaining the illusion. However, due to the high potential cost of a full exhibit, we felt the need to test that notion in some way, so as to avoid producing a boring activity at the cost of considerable time and effort.

Due to resource and time constraints, only a portion of the complete design could be constructed, and you can guess what part a group of robotics majors would consider the most interesting part. However, to do otherwise would have wasted our expertise doing things liberal arts major might do as well or better. So it was the rover that was constructed and taken to the point of a 3rd generation prototype since several modifications were made after the original attempt and then practical changes were made to reduce complexity and construction costs. It also had to be feasible to construct within the time, budget and tooling available to us. As such, the constructed prototype could be described as bare-bones – it has only a few of the planned features available on it, but it still does provide a good indicator of how the design concept will work in a finished setting and helps sponsors, potential funders and users to envision the possibilities. Since other examples of the rest of the elements exist, it also helps make the case that this can be done at a reasonable cost by removing one of the larger uncertainties requiring a relatively rare and expensive skill set.

5.1.1 Implementation Modifications

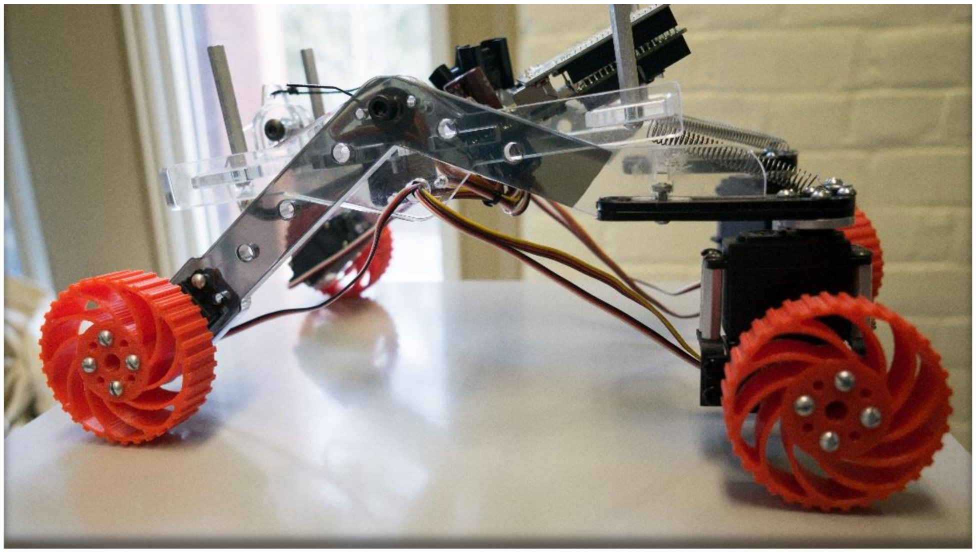

Figure 13: Current Rover Prototype

One of the many modifications that had to be made was the reduction in the number of available sensors and actuators that could be operated with during a demonstration of the prototype. The front wheel servos that enable the swivel of the wheel were removed due to a lack of available high-torque TowerPro MG995 servos [2]. A consequence is that the holonomic capability (near omnidirectional motion) was removed. However, with the rear wheels maintaining a swivel capability, the ability to turn was not impacted in a significant way.

In order to simplify development of the software and the shield, an Arduino was used in place of the micro-computer. A consequence is that the prototype software also will not be easily upgradeable in the future without a complete redesign, but it did enable the team to complete a rover and deliver it to the Mars Foundation for demonstrations that be scheduled immediately.

5.1.2 Mechanical

The rover's final mechanical layout was a carefully chosen compromise between expense, robustness, realism, and practicality. Some unforeseen problems were encountered during the manufacturing and assembly process, but did not greatly slow down the process due to the ready availability of laser-cutting and 3D-printing resources at WPI.

Steering

The final choice was a pseudo-holonomic platform, where the two real wheels were connected to a separate motorized swivel mount, and the front two powered wheels were mounted rigidly on their respective rocker-bogie arms. This was done due to initial problems getting the front swivels to maintain structural integrity when encountering obstacles in the rover's path. This does not remove the ability to turn nearly on-point however, as the rear swivels are capable of orienting the driving wheels such that when powered they cause the entire rover to rotate in place. This feature maintained the original desired simple control system while reducing the number of anticipated mechanical failure modes.

Wheels

The final rover wheels were 3D printed for three reasons:

1) Creating the desired wheel geometry using a material such as aluminum or brass would have required access to a 5-axis CNC mill, a resource that was not available at the time.

2) It is a good demonstration to students of the usability of 3D-printed objects in real-world applications. We were claiming that we were going to have robots and 3D printers make more robots and 3D printers, and we wanted to be able to reconfigure the robots. One likely change would be to replace the wheels as the rover is sent different places to do different things.

3) It increases the independent ability to replicate the rover, allowing it to be reproduced and used by organizations and individuals elsewhere.

The wheel hubs were designed to that they could be easily mounted to a readily available off-the-shelf RC servo aluminum mounting hub using 8/32 bolts. Although the wheels exhibit low friction when used on surfaces such as table-tops and wood floors, they function similarly to their full-size counterparts when used on granular and textured surfaces (e.g. sand, carpet, etc.). It is possible to affix rubber treads to the wheels so that optimal operation is possible on all surfaces.

Chassis and Suspension

The rocker-bogie suspension was laser cut from ¼" black acrylic and worked exactly as planned. Each side consisted of two "arms" that were connected to a central pivot point with an underside angle between them of 140 degrees. The pivot point was created using a ⅜" threaded rod. The main chassis of the rover was kept level with respect to the arms through the use of four extension springs placed at each corner of its rectangular base. This enabled the rover to move and pivot to accommodate the obstacles it encountered in a manner visually identical to that of the real-world rovers. The base of each arm was affixed with a perpendicular acetal plastic plate to which the swivel and drive servos could be attached. Initially, problems with arm misalignment were encountered, but were rectified by using a pair of brass bushings at the arm pivots to reduce friction.

The chassis was laser cut from ⅜" clear acrylic, and was designed as a trussed structure to minimize weight. Because it was known that the addition of a wireless camera may be possible in the future, the width was increased by 1" and the length by 2". The battery bay was placed on the underside because the rover's center of gravity would be too high with the placement of a pan-and-tilt wireless camera. Three-dimensional geometry for the chassis was achieved by placing the planar acrylic components at right-angles to each other by a system of square slots and steel hex standoffs. The mounting location for the control electronics was placed on the underside of the “solar panel” (which also functions as a protective cover for the rover’s inner workings) to save room and to give the electronics an air gap to prevent overheating.

Arm

The arm of the rover was created using aluminum angle stock and ⅜” acrylic, and was placed in the location as originally designed. However, it was realized that the actuator servo would interfere with the placement of the camera, so it was moved towards the back of the chassis, and transmitted torque to the arm using a cable and spring return. Additionally, a spring was placed in series with the cable so that in the case of the arm attempting to lift something too large or becoming stuck, the spring would extend and prevent the stalling and overheating of the servo.

5.1.3 Electronics

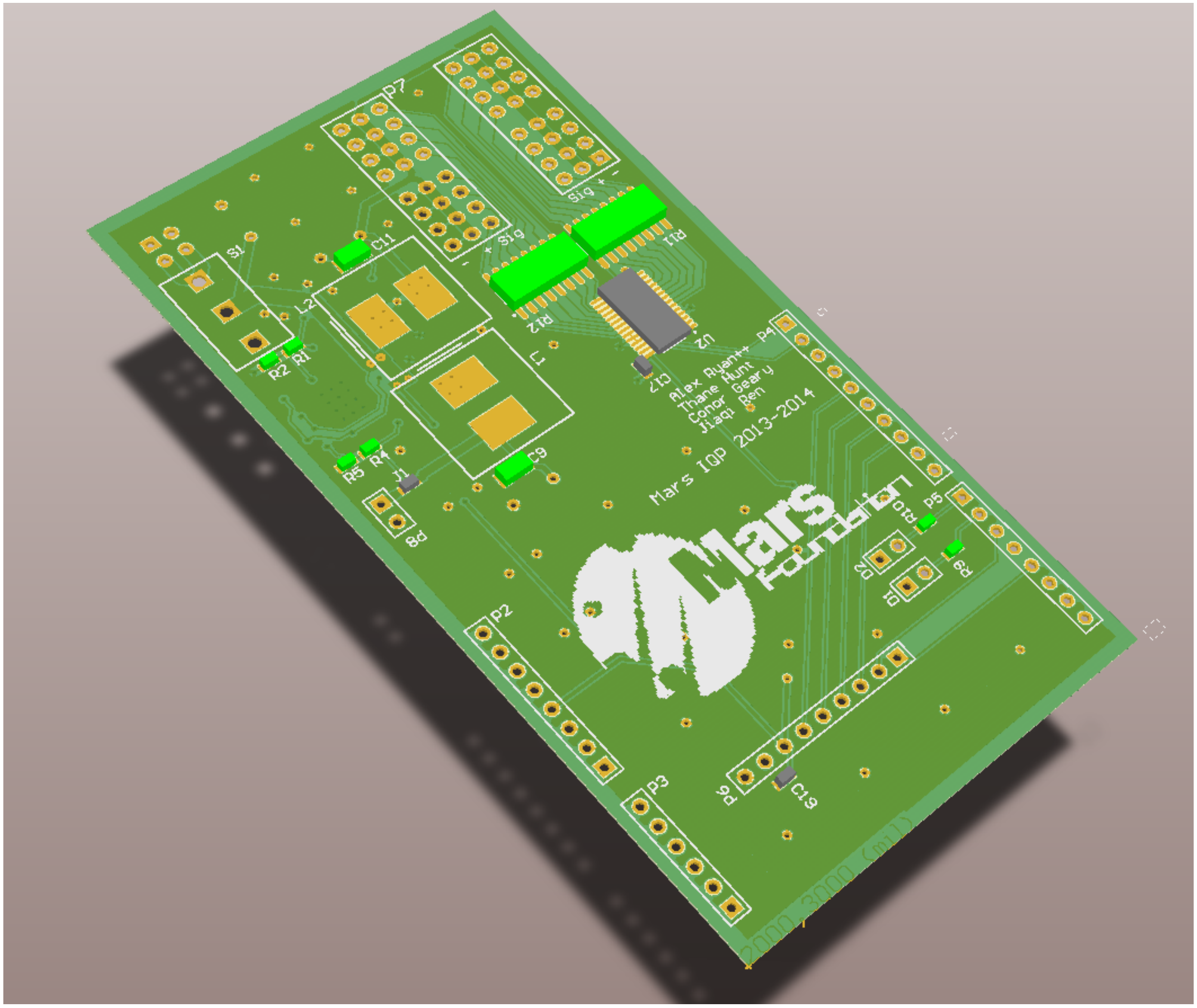

Figure 9: Prototype Rover Custom Shield Render

A custom Arduino shield was developed that incorporated several of the planned capabilities from the concept rover, including power management, servo control, and wireless communication.

A PCA9685 IC was added to perform servo control functionality. It communicated via the I2C bus standard with the Arduino, and automatically handled providing control signals to up to 16 connected servos (only 7 channels were used on the prototype). Overload and reverse polarity protection were added in case wires were connected improperly in future use, to prevent most damage to the electronics.

As the Arduino does not have any built-in networking capability (and thus unable to natively communicate wirelessly to the control station), an Adafruit CC3000 Wi-fi module was purchased and installed. Combined with a software library for the Arduino, it provided an easy link to the prototype control station by connecting to a Wi-Fi router and transceiving UDP packets for control commands and status updates.

(Insert CC3000 Wifi module breakout picture from Adafruit)

Additionally, power regulation circuitry was added in the form of a Linear Technology buck-converter IC. It provides power regulation to all components on the board, except for the Arduino, which has its own regulator circuitry. This enables nearly any common hobby RC battery, such as 2, 3 or 4-cell lithium-ion or lithium polymer (Li-Ion or Li-Po) batteries to be used to power the rover.

For testing purposes, a cheap Wi-Fi webcam was purchased. It is the Easy-N M136 model, running on a 5V power supply provided directly from the rover shield power supply. After configuration, it will connect to the same access point that the CC3000 Wi-Fi module will connect to, providing a connection straight to the computer station.

The appendix contains a full set of reference schematics.

5.1.4 Control Software

The prototype rover control software was written in the Processing Language, a version of Java. This was chosen due to its natural abundance of libraries for the networking, graphics and joystick applications. Due to time constraints with the project, it was created with the intent in mind of being easily modifiable by another programming party, while lacking nearly all aesthetic additions that would make the Mars Utility Rover Control Station concept more like a finished piece of software.

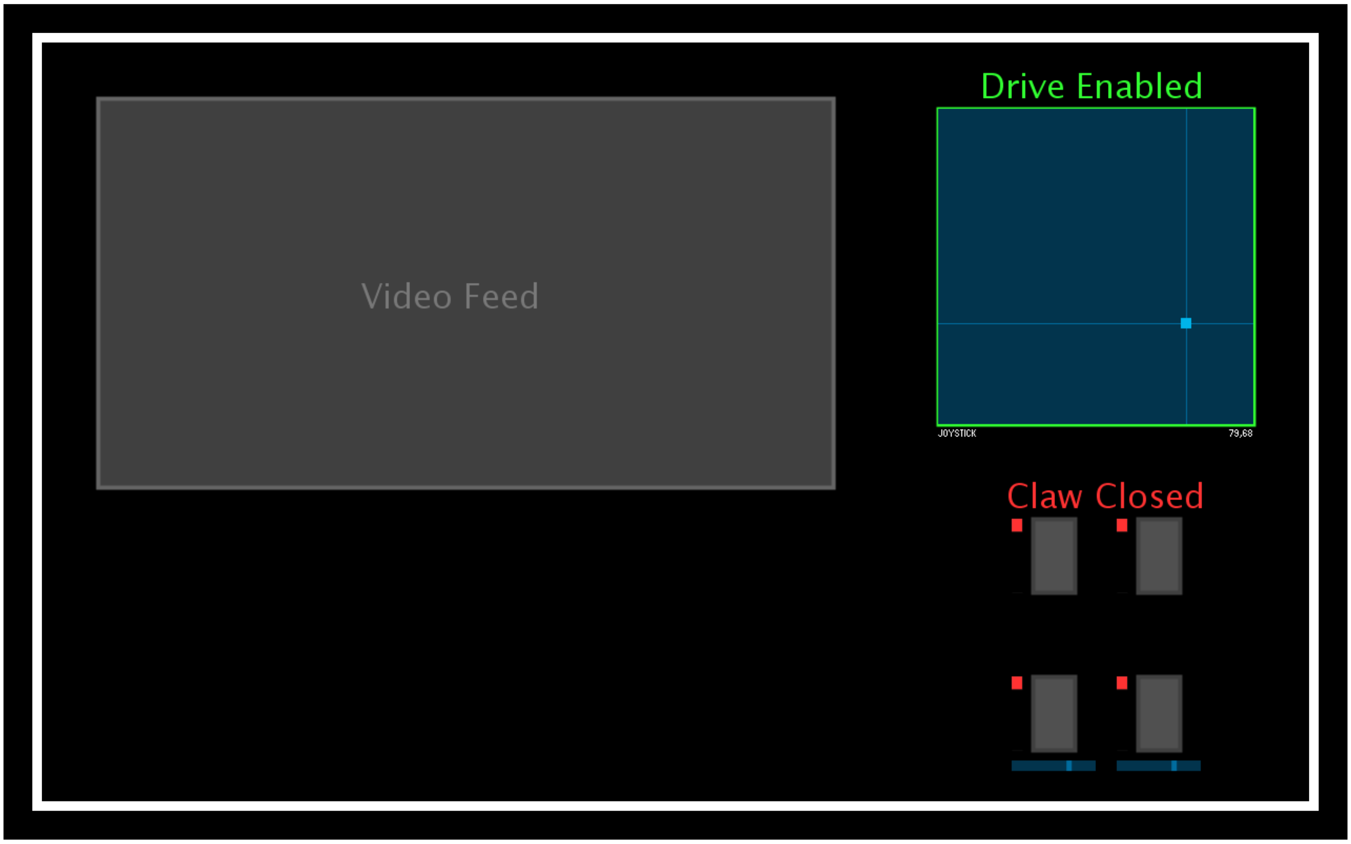

Figure 10: Prototype Rover Control Program GUI

The prototype rover program works by connecting to a common wireless access point (Wireless AP), such as a router, which is shared with the rover. It starts sending broadcast UDP messages, a common IP communication method, to the rover, checking whether it is connected yet or not. Once both endpoints are connected, the rover consistently sends feedback data packets with the rover's status, indicating to the program that it is alive. Additionally, the program sends short UDP packets extremely fast to the rover containing commands to update its actuator systems for driving and pod management.

A joystick connected to the computer is monitored for use as an input device, controlling the actions of the rover. The program interprets the joysticks current angle of tilt as the desired direction the controller wants the rover to go, maps the direction into servo commands for the rover's wheels, and sends the commands over the wireless interface described immediately before. A series of button presses is interpreted for controlling the claw that grabs and releases base pods.

5.2 Exhibit

The central focus of exhibit based off of these plans is a group activity putting a student into the role of an astronaut building a base on Mars. Using the Phobos Scenario guidelines as inspiration, the premise of this activity is this: "You are an astronaut on a mission to Phobos. From this base on Phobos, you are tasked with assembling a base on the Martian surface using a remotely operated vehicle to place habitation and infrastructure modules into an appropriate configuration." In this activity, the "construction vehicle" consists of a custom built miniature remote controlled rover. Detailed plans for the construction of this rover are provided as a part of this report. A "module" refers to a small model of a Martian habitation pod used as a game object in this activity. The actual activity has students operating the RC vehicle or vehicles using a laptop with connected controls.

5.2.1 Game Designs

This "game" is a simulation primarily designed to hook student's interest in the exhibit overall by providing an exciting experience. Secondarily, it gives a presents a rough idea of the requirements of a real Martian base and acts as the basis for several design activities that could be included as part of the exhibit.

Basic Rules

The game supports a number of players proportional to the number of rovers and amount of field space constructed. In a situation with a small playing field and only one rover, only 8 students could be occupied at a single time with activities surrounding the game.

The primary participants in this activity are the "pilots" at the controls of the rover. It is recommended that two students operate each rover together, one controlling the rover drive and another the camera view and manipulator arm. Another group of two students can supervise the field as mission controllers, advising the pilots on the location of modules and other possible problems. Additionally a group of 2 – 4 students could observe the activity and be tasked with improving the design of the rover manipulator or wheels.

The actual objective of the game is the assembly of a functioning Mars base (in simulation). This task requires the inclusion of certain modules. The exact requirements need to be scaled to the final location and nature of the exhibit, but can be parameterized somewhat. Approximately half the modules should be standard habitation modules, one quarter should be dedicated to food production, and the remaining quarter should be some mix of life support, workshops, manufactories, or other supplementary modules. The nature of each module will be clearly marked, but the actual construction will vary by budget. Details regarding the modules are discussed in a subsequent section of the report.

Modules are queued at a production facility. Ideally this would be a large structure representing a facility for producing modules. In a lower budget situation, the modules could merely be stacked or laid out in rows at predetermined spot on the playing field. Modules will have to be placed starting at another prop representing a power station or landing capsule. The end condition of the game can be either determined by the completion of a base meeting the already discussed criteria or with a time limit, presented as a fuel limitation of the rover.

This describes the most basic premise for the activity which can be done with limited funding or setup. There are however, a number of other ideas that are dependent on further funding or a permanent location these are described in the next section along with their requisite conditions.

Extended Game Elements

1. Advanced Modules

The design of the modules with greater funding available would likely include more complex elements. Modules can be designed to light up when attached and also provide indication at the monitor from which the students control the rover that the module is online. This way, the activity can be more easily controlled or automated; the computer can keep track of the number and type of placed modules and indicate when a minimum base has been established. This is esp. important in a museum setting as it allows the activity to run on its own with less of a staffing requirement.

2. Improved Playing Field

Currently, the team has not developed a comprehensive plan for constructing a playing field or tested playing surfaces. The game as it is assumes a simple flat playing surface without ornamentation or significant terrain features. However, a better playing surface might consist of a mockup Martian environment. Creating a plaster or concrete field with terrain elevation features, sand pits, and valleys creates allows for creating a more interesting base and for a greater focus on rover design. Presenting uninhabitable or non-traversable areas creates restrictions that make the game more difficult and more enjoyable.

3. Rover Reconfiguration

With the prerequisite of an improved playing field, redesign or reconfiguration of the current rover design presents an opportunity for another activity. In small groups of two to six, students would be given the opportunity to analyze the performance of components of the model rover being used by the base building activity. Specifically, the wheels, the manipulator arm, and the steering control scheme could be presented as flawed systems and students would be expected to brainstorm improvements. Taking this activity further would present this team of students the opportunity to swap out the rover's wheels, choosing from an array of prefabricated wheels, the set that most closely resembles their desired improvements. The same could be done for the manipulator arm. The ultimate version of this activity would allow the students to work with a staff member to actually use 3D design software to make custom alterations and print a new set of wheels or manipulator for the rover.

A simpler approach to actual alteration of the rover is allowing the students to choose a new steering control scheme from a pre-produced set. This is functionality is implemented already in the prototype version of the rover, and only needs an interface option to control it.

4. Additional Cameras

If funding and a permanent space were available, a number of camera angles could be added to the standard rover camera included on the current design. An overhead camera view of the field from above represents a satellite view or a view from the Phobos base and allows students better vision of what they're doing on the field. With even more funding this camera could be used to provide a graphics overlay of the playing field with objectives marked out; this would be necessary for adding other sub-objectives like mining or rescue missions to the base-building game. Using image recognition with QR codes or other markers, the position of rovers and modules can also be determined with this overhead camera, even allowing automated field cleanup and making optional objectives more immersive.

A camera placed along the rover's manipulator arm would also be ideal, letting the students move modules around with better accuracy and providing increased realism. These improvements are advantageous as they give the impression of technology being at appoint where even a museum exhibit can simulate in miniature the actual functionality of a Mars mission.

5.2.2 Phobos Mission Control Center

The control station was envisioned to replicate that of a small control booth. Each station would have room for two occupants, "Controllers", to control a single rover at a time; one person would act as the "Driver", while another would act as an "Operator". A broad control panel, approximately 5 feet long by one to one and a half feet deep, would house the majority of the available controls. A large touchscreen, surrounded by two joysticks for both Controllers, would serve as the primary control inputs.

This method of input was decided upon as the broad majority of the population in the United States has had exposure to both joysticks of some sort (including arcade style ones), and even more importantly, touch screens, such as those found on common smartphones.

5.2.3 Proposed Exhibit Layout

Any exhibit following the recommended guidelines should consist of three main components: an interactive hook/activity that draws attention and builds interest in the viewer; a set of less engaging, more informative semi-interactive displays that keep interest through hands-on or highly visual learning/representation of knowledge; lastly, for viewers that have been fully hooked by the previous displays, purely informational, but visually interesting displays (i.e. posters) that provide denser, more serious information about Martian settlement and the Phobos scenario. The final component is more targeted towards adult viewers than students, but is meant for viewing by both. This section describes one potential layout in detail following these guidelines.

The majority of the exhibit is dominated by the already discussed base building simulation. This is the centerpiece of any possible exhibit layout, around which more educational materials and displays revolve.

The playing field abuts the center of one wall, the background displaying a Martian panorama. On one side lies a Phobos control station, where students pilot rovers or oversee the "mission". Against the other side of the playing field is a table workspace with laptops or other materials for redesigning parts of the rover. The forward side of the playing field is empty for viewing or access purposes. The overall shape of the field allows access by museum staff to any part of it while standing beside it. Likely, the field would be surrounded by Plexiglas shields to prevent tampering with the rover or modules.

Against the side walls of the exhibit there would be tables displaying supplementary material. These provide a more educational but less interactive way of communicating information and demonstrating enabling technologies. A concise list of possible table sub-exhibits:

1. <u>3D Printing Display</u>

   A real 3D printer set to constantly but slowly produce pertinent materials, i.e. rover parts, modules, actual parts that could be used on Mars in a habitation module, etc. The cost of the filament to produce these parts constantly could potentially be negated by sale of the produced parts as souvenirs at a marked up rate. This is a cheaply produced and visually appealing display, ideal for any budget range, but better suited to a semi-permanent location.

2. <u>Chemical Synthesis</u>

   Another option for a display table is a methane generation setup, showing one of the many chemical manufacturing processes that would be used on base.

3. <u>Orbital Mechanics and Gravity</u>

   A display demonstration both the nature of orbits around Mars and the difference in

Martian gravity is another viable display. A simple setup could demonstrate the relationship between linear velocity and other orbital parameters. To demonstrate Mars gravity simply, several backpacks could be weighted differently inside for an equivalent mass on the Earth, Moon, and Mars.

The final piece of the exhibit consists of a few poster designs that communicate a number of points about Martian settlement. These poster designs can be found in the Appendix.

6 Summary and Recommendations

In conclusion, the team has designed the basic framework for creating an exhibit around a particular interactive game. The work completed centers around designs and prototypes for a remotely controlled rover, representing what a robotic construction vehicle on Mars might look like. Software for the rover and the computer interface have been developed and will be delivered to the sponsor independently of this report. The basic rules of a game using this rover and mockup Martian base modules has also been detailed, with possibilities for extension and improvement outlined. Options for both high cost and low cost options in exhibit construction were presented, with the understanding that is would be best to use a low cost implementation for testing this game concept. Finally, a cursory review and description of other exhibit elements provides the sponsor with ideas but not fully fledged designs for the other components necessary for a fully implemented exhibit in a museum or similar venue.

The results of this project as the team leaves it consist of an incomplete proof of concept with a very promising future. Beyond the scope of this report, limited work will be performed to finish the groundwork for a proof of concept exhibit, including the final rover prototype, software, and limited educational materials. The final work will consist of a completed and revised physical prototype and a small number of game modules. In continuation of this project it is recommended that, after seeking additional funding, the remaining necessary components for staging a game be purchased or fabricated and a specific set of rules finalized. With these additional preparations, a trial run should be conducted at a museum or school to gauge the actual efficacy of the exhibit format and determine whether this project is worth continuing. If the project is continued, this report can serve as a guide for adding further complexity and features to the exhibit and the base building game.

Lastly, it is recommended that subsequent work on this project should involve personnel with more background in education or in marketing. The results of this project have proved to be very technical in nature, perhaps to a fault and further work should consist of making the material and prototypes developed better suited towards a museum audience.

7 Bibliography

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8 Appendix

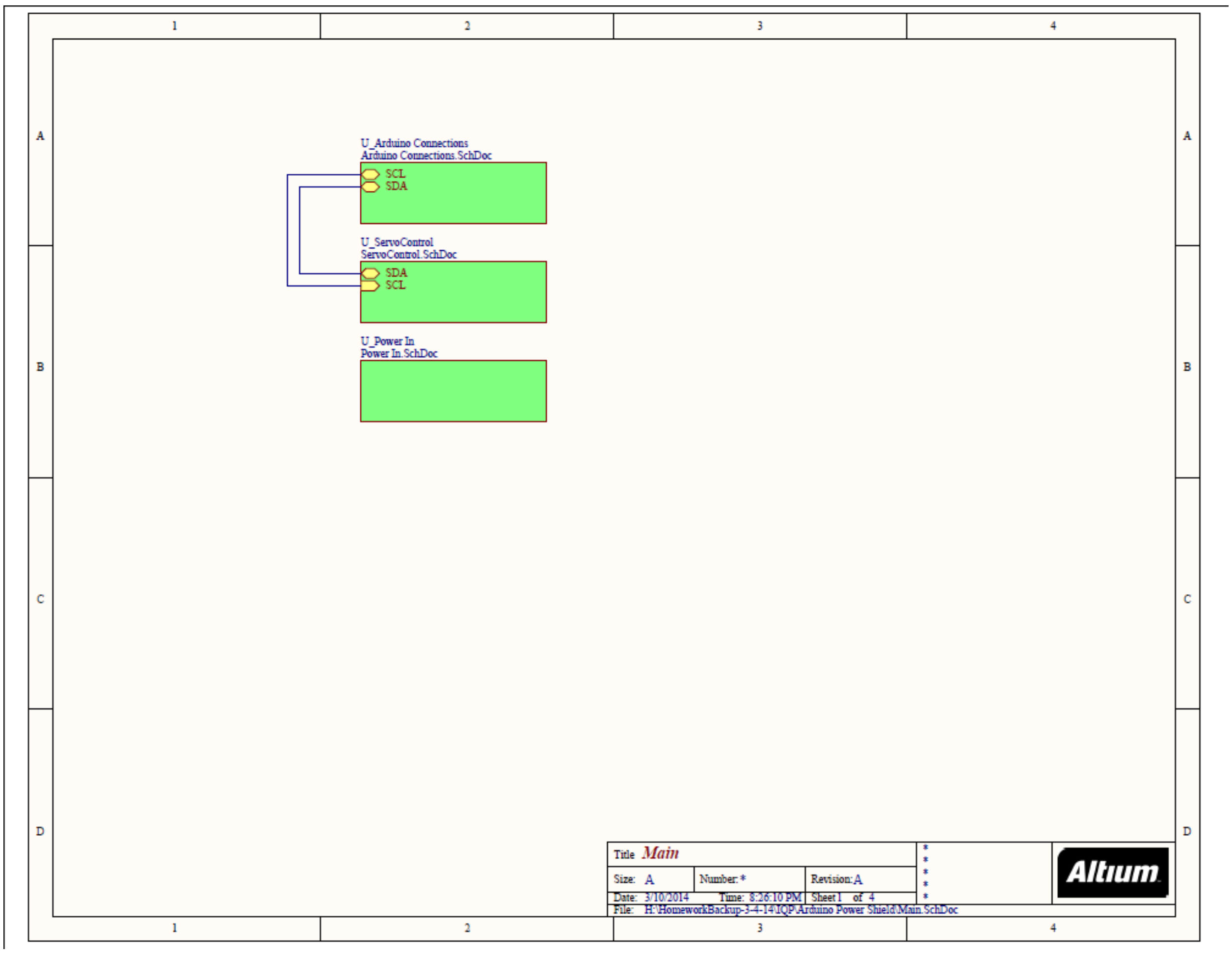

Figure 11: Prototype Rover Shield PCB - Schematic 1

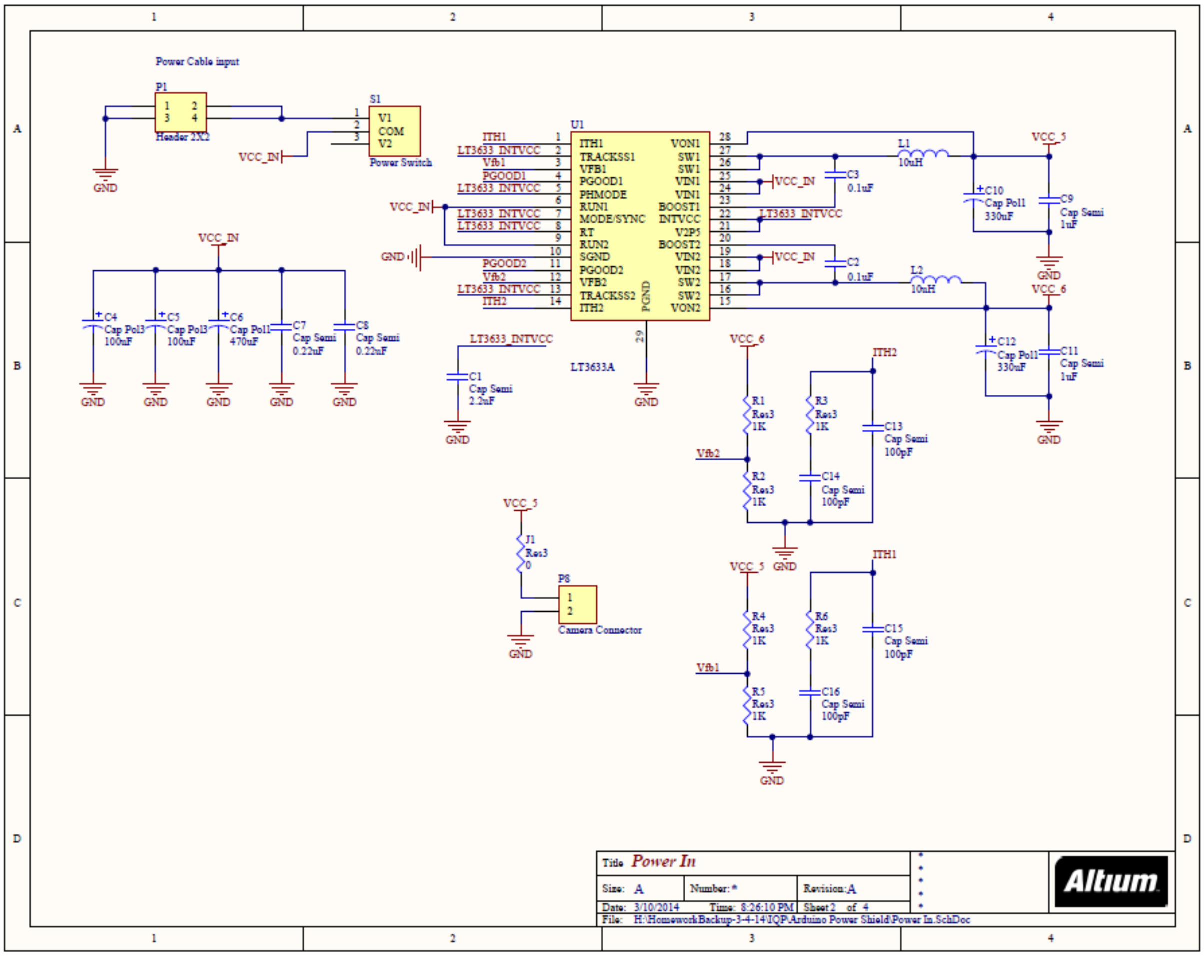

Figure 12: Prototype Rover Shield PCB - Schematic 2

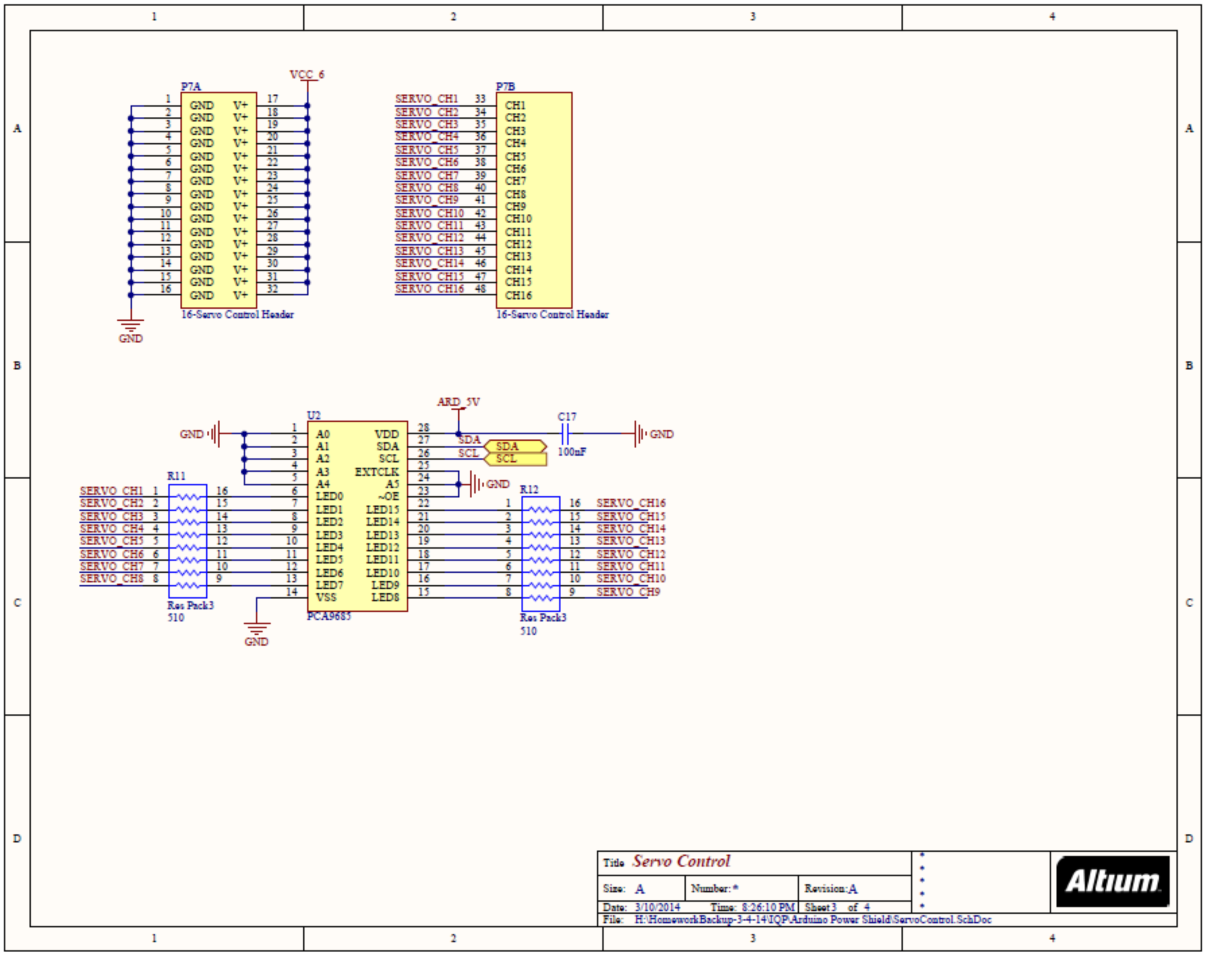

Figure 13: Prototype Rover Shield PCB - Schematic 3

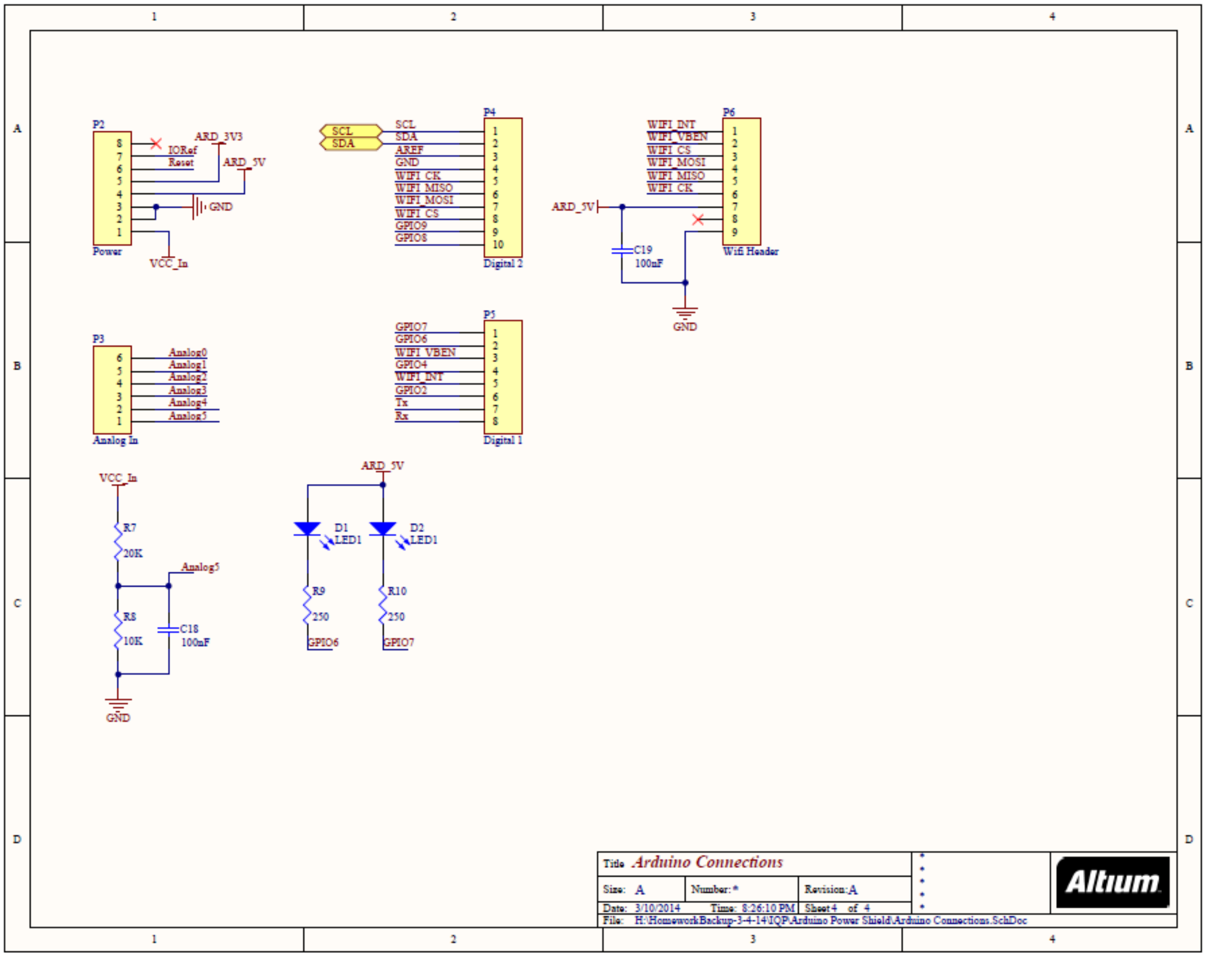

Figure 14: Prototype Rover Shield PCB - Schematic 4

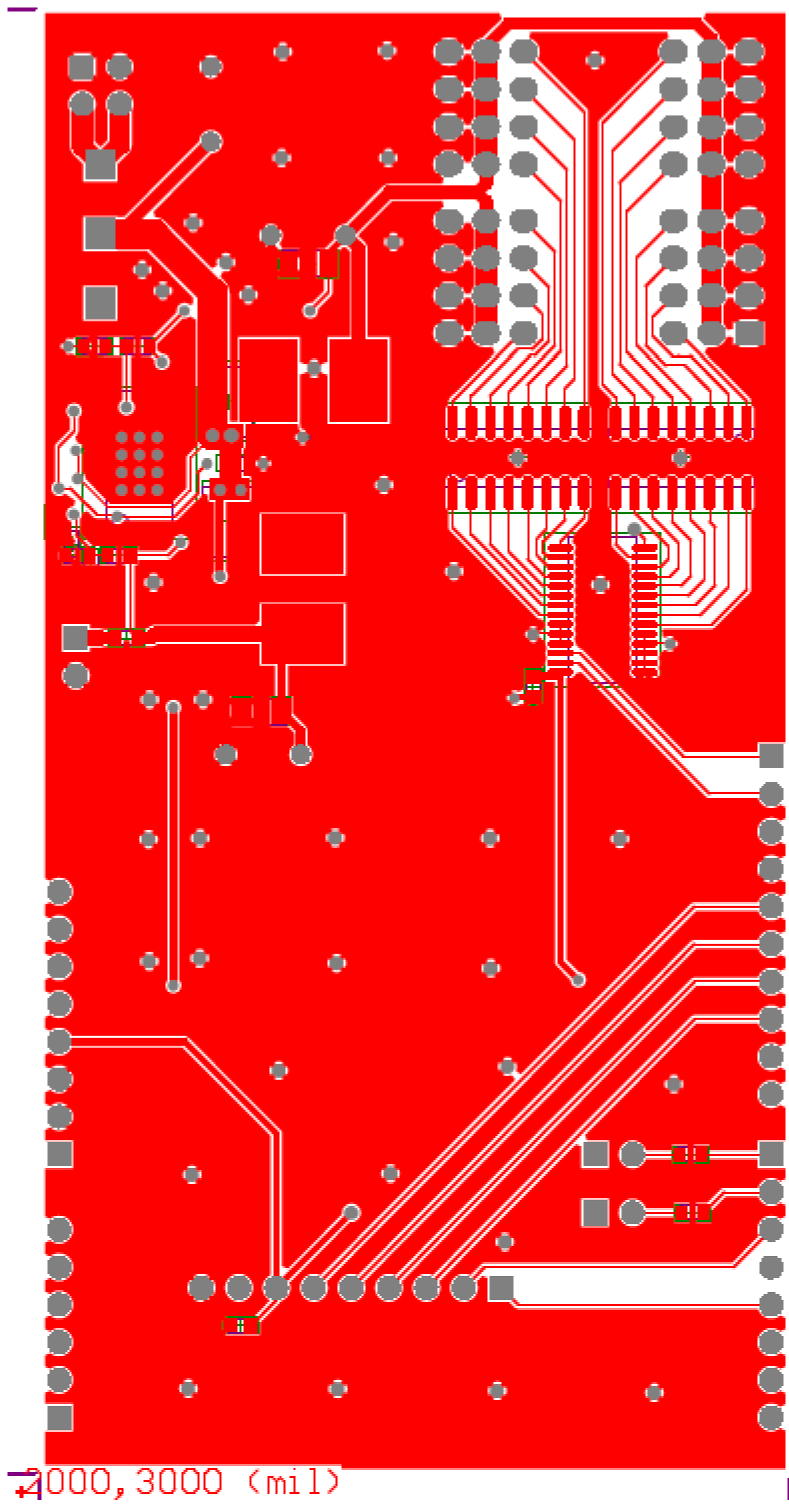

Figure 15: Prototype Rover Shield PCB - Top Copper Layout

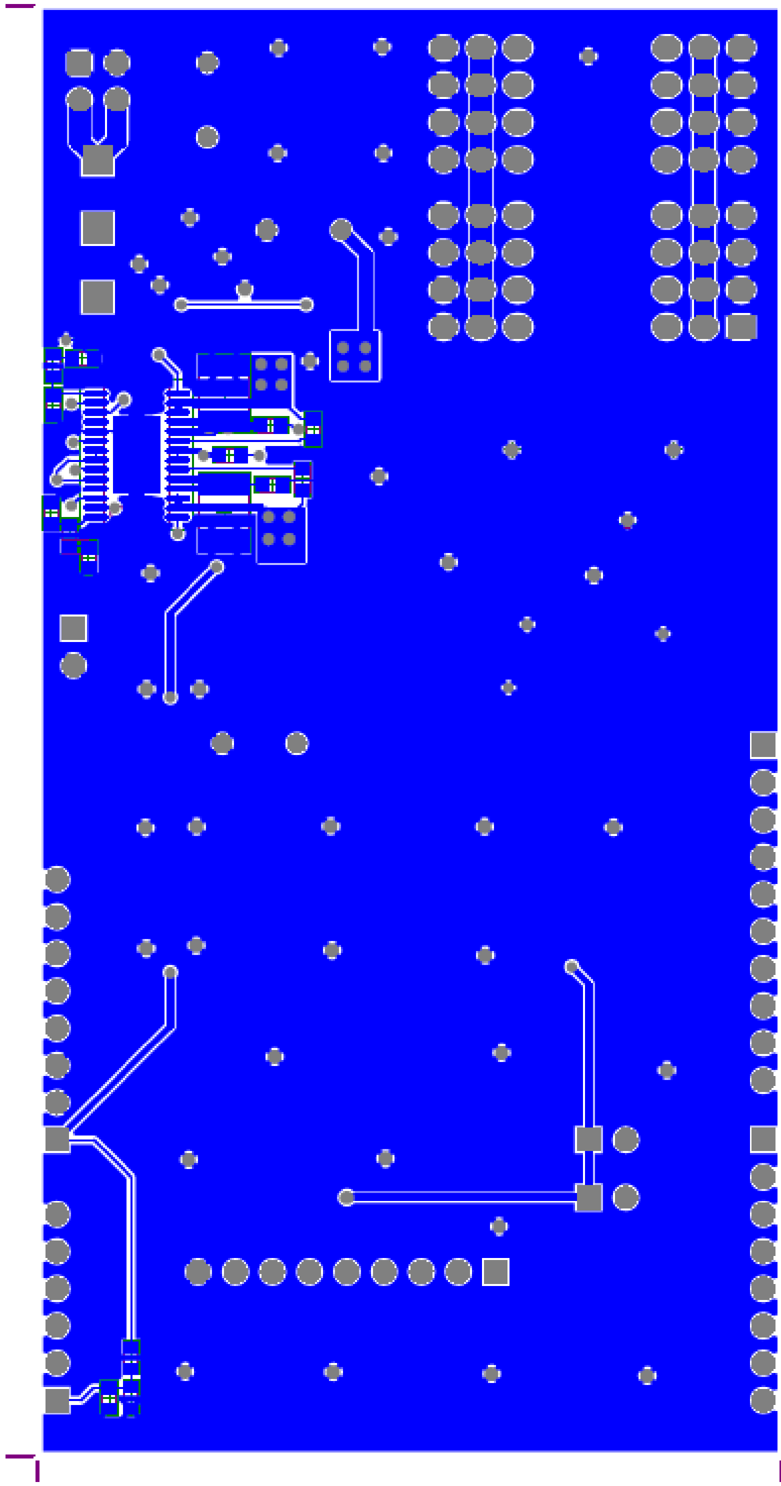

Figure 16: Prototype Rover Shield PCB - Bottom Copper Layout

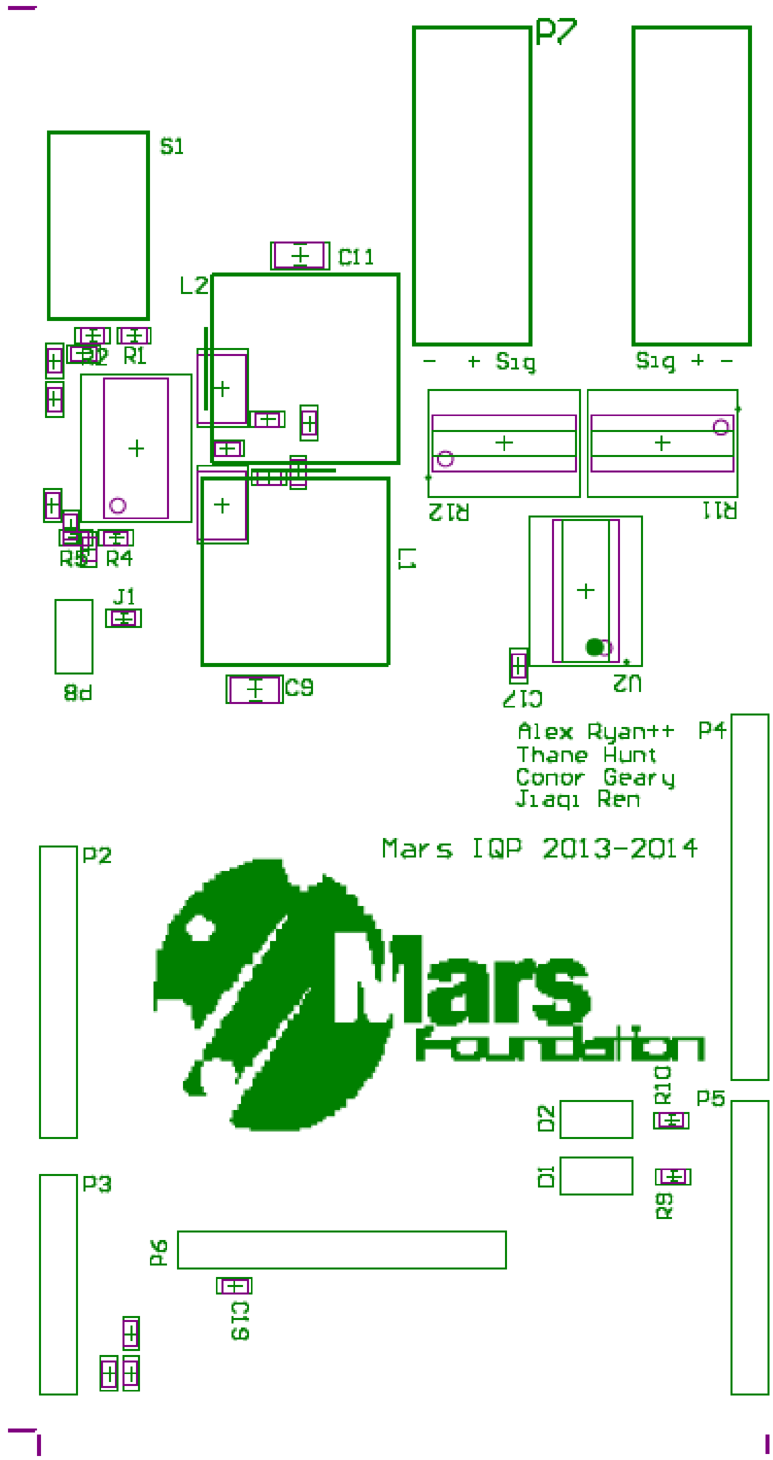

Figure 17: Prototype Rover Shield PCB - Top Silk Screen

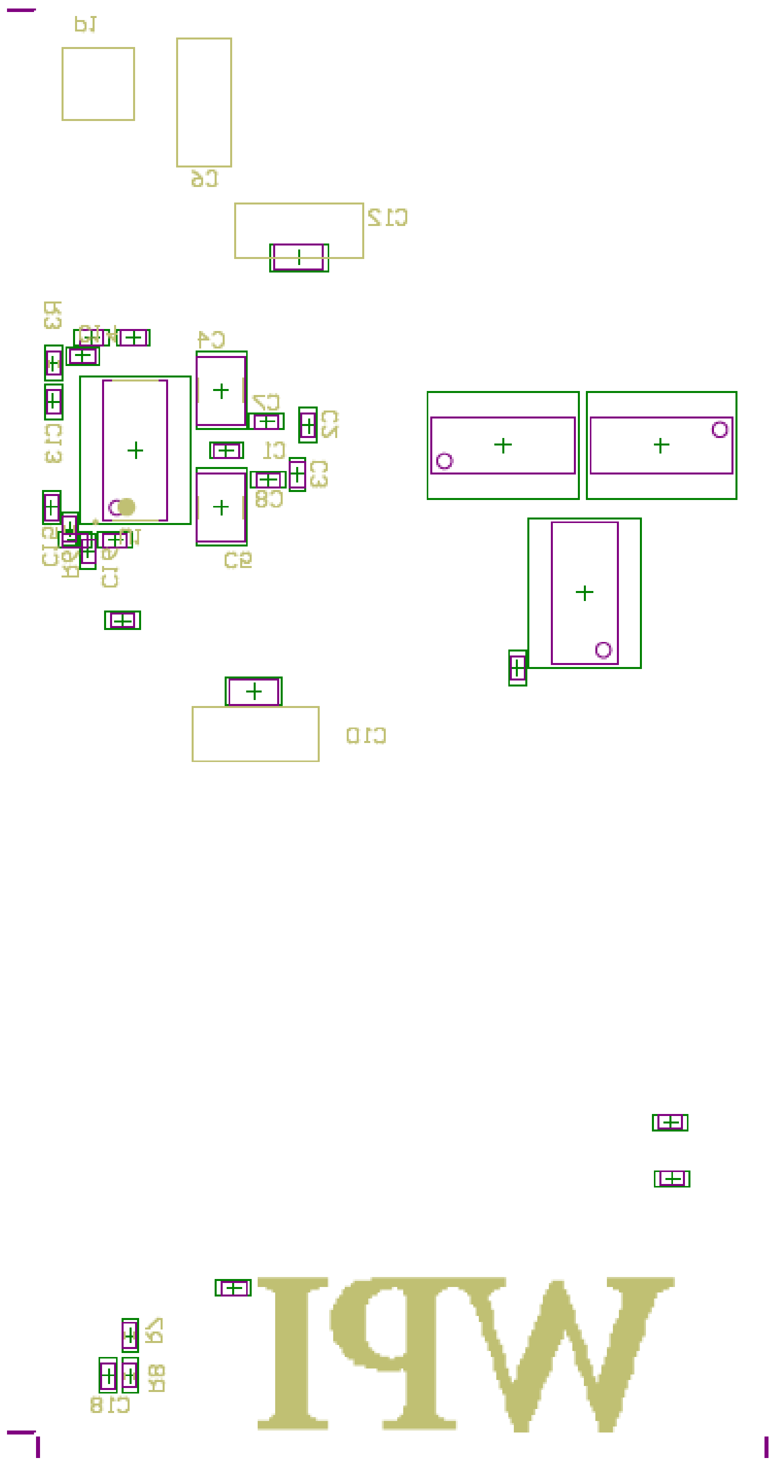

Figure 18: Prototype Rover Shield PCB - Bottom Silk Screen

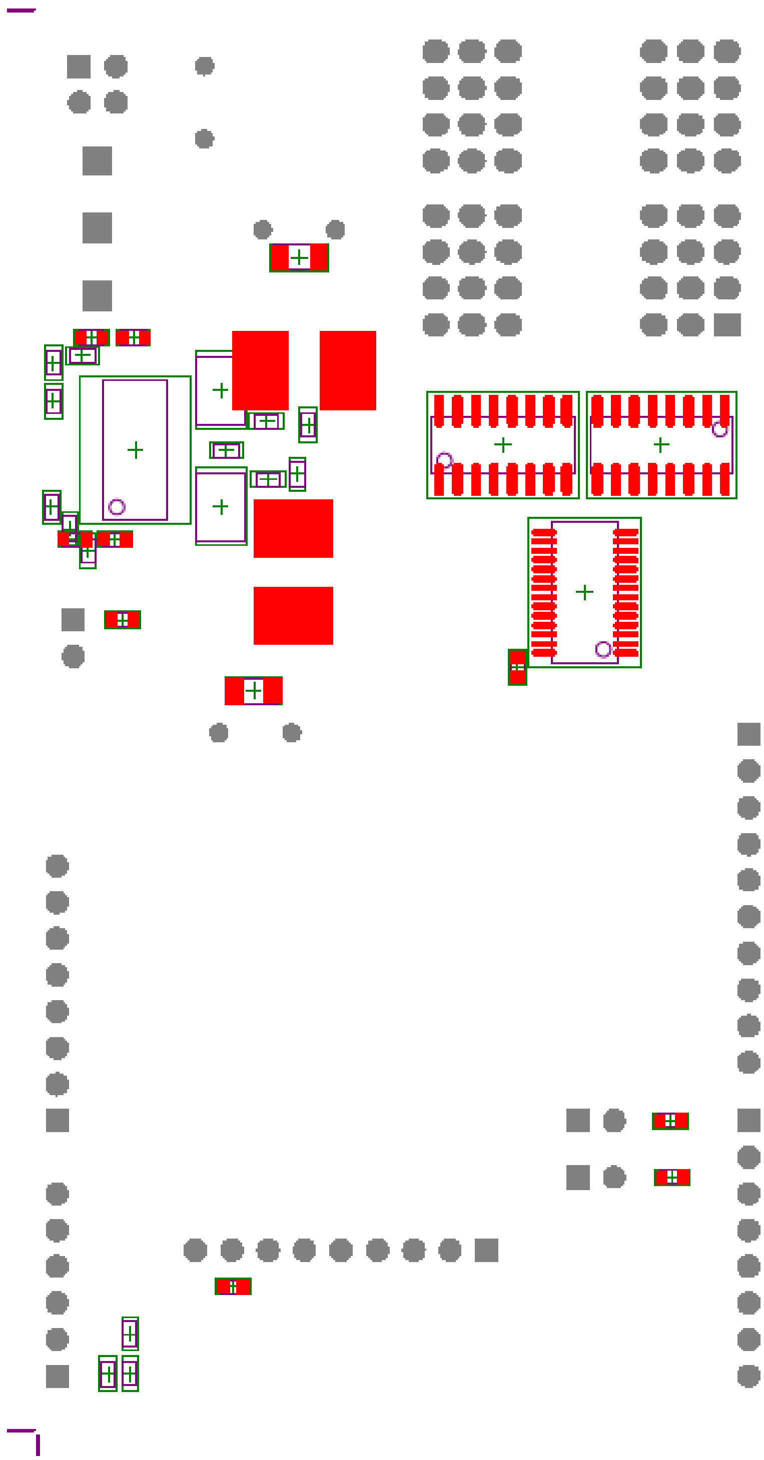

Figure 19: Prototype Rover Shield PCB - Top Pad Master

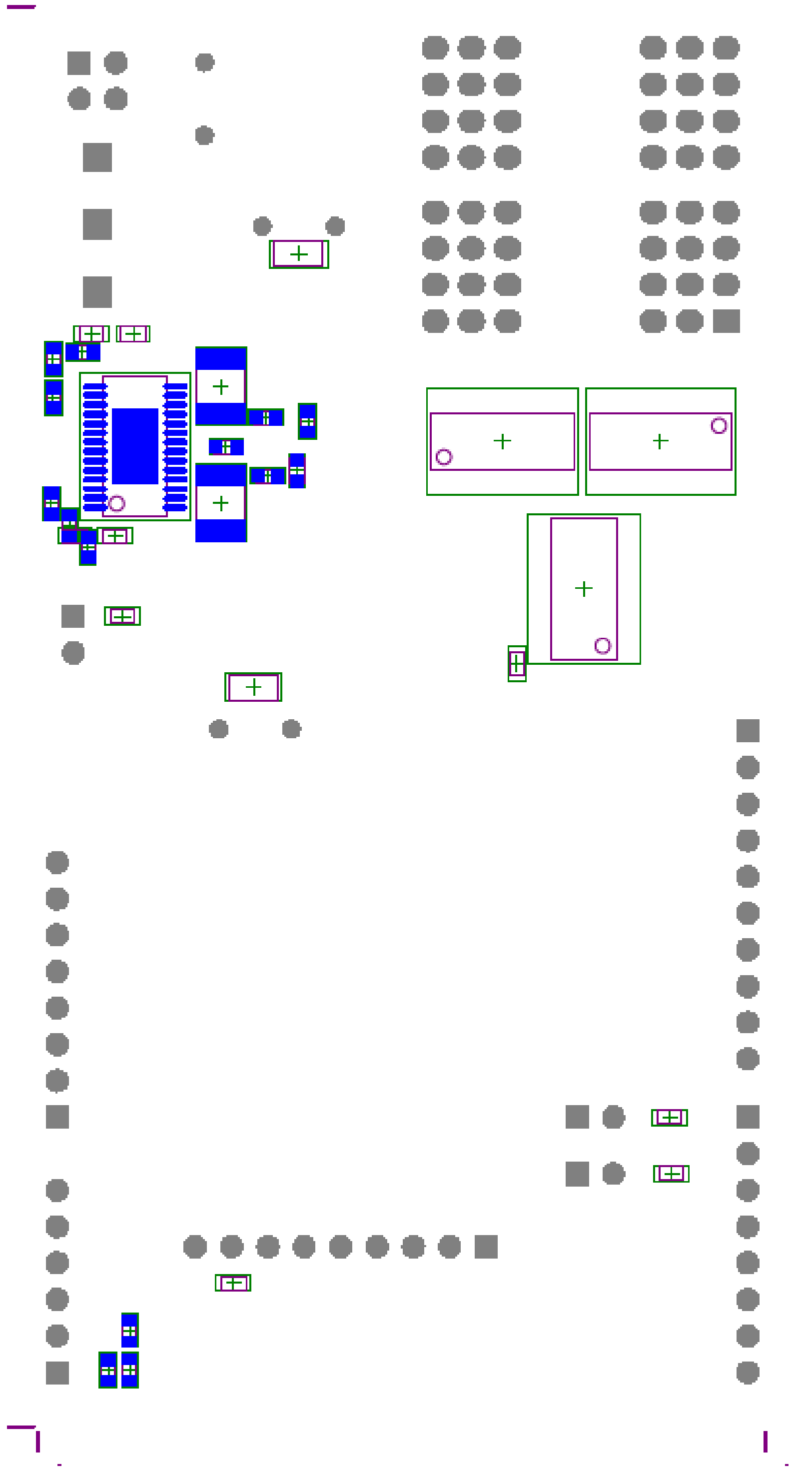

Figure 20: Prototype Rover Shield PCB - Bottom Pad Master

Bill of Materials

Main

Source Data From:	Arduino Power Shield.PrjPCB
Project:	Arduino Power Shield.PrjPCB
Variant:	None
Creation Date: 3/10/2014	8:26:16 PM
Print Date: 41708	41708.85166

Footprint	Comment	LibRef	Designator	Description	Quantity
1608[0603]	Cap Semi	Cap Semi	C1, C2, C3, C7, C8, C13, C14, C15, C16, C17, C18, C19	Capacitor (Semiconductor SIM Model)	12
1812	Cap Pol3	Cap Pol3	C4, C5	Polarized Capacitor (Surface Mount)	2
RAD-0.2	Cap Pol1	Cap Pol1	C6, C10, C12	Polarized Capacitor (Radial)	3
C1206	Cap Semi	Cap Semi	C9, C11	Capacitor (Semiconductor SIM Model)	2
HDR1X2	LED1	LED1	D1, D2	Typical RED GaAs LED	2
J1-0603	Res3	Res3	J1, R1, R2, R3, R4, R5, R6, R7, R8, R9, R10	Resistor	11
PCBComponent_1	Inductor	Inductor	L1, L2	Inductor	2
HDR2X2	Header 2X2	Header 2X2	P1	Header, 2-Pin, Dual row	1
HDR1X8	Power	Header 8	P2	Header, 8-Pin	1
HDR1X6	Analog In	Header 6	P3	Header, 6-Pin	1
HDR1X10	Digital 2	Header 10	P4	Header, 10-Pin	1
HDR1X8	Digital 1	Header 8	P5	Header, 8-Pin	1
HDR1X9	Wifi Header	Header 9	P6	Header, 9-Pin	1
4x3x4 Header	16-Servo Control Header	16-Servo Control Header	P7		1
HDR1X2	Camera Connector	Header 2	P8	Header, 2-Pin	1
SO-16_N	Res Pack3	Res Pack3	R11, R12	Isolated Resistor Network	2
3-Pos SPST Slide Switch	Power Switch	Power Switch	S1		1
LT3633-A	LT3633A	LT3633A	U1		1
PCA9685	PCA9685	PCA9685	U2		1
					47

Approved	Notes

Figure 21: Prototype Rover Shield PCB - Bill of Materials