2012
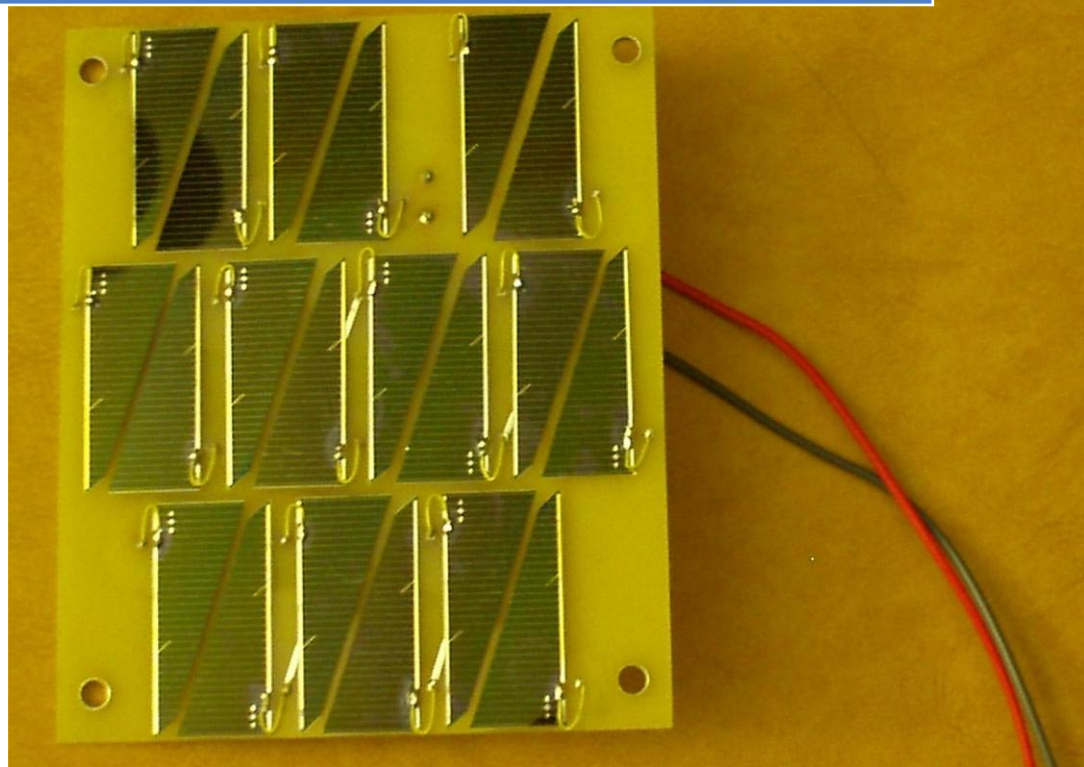
Solar Panel Design Decision and General Information Sheet

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iSAT Group

1/1/2012

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Revisions Sheet

Date	Editor	New Sheets/ Additions
Jan 2012	Alex Carrere	Document Created

Introduction

This paper is meant to be a guide and a reference to new and old members alike who wish to know about, understand, and improve on the decisions made and processes implemented to build the current solar panels (as of January 2012). The following paragraphs in the introduction will lay out background information on solar panels and cube satellites. This entire document was written with the idea that the reader will be able to follow the decisions made to construct the solar panels and then with this knowledge find areas of the project for improvement.

Solar Panels

In space, the most powerful source of energy is the sun. When in day, the sun provides $1367 \frac{W}{m^2}$ of energy to the satellite [SMAD]. The trick, of course, is to harness this energy in a usable way. For about 60 years, humans have used solar cells (or photovoltaics) in order to convert this wealth of energy in the suns rays (photons) into usable energy in the form of current (electrons). This process uses semiconductors which when excited by the photons, release a free electron that is then lose to flow as current. The principles of this conversion are not as important to understand as the fact that with all forms of energy conversion, this process has an efficiency. Manufacturing processes and material choices have improved over the years so that high grade cheaper terrestrial solar cells made from silicon can reach efficiencies of around 18% and more expensive space grade solar cells made from triple junction gallium arsenide can reach about 32% efficiency in production models [SMAD]. Some cells still in the R&D phases have been known to go up to 40% efficiency. The terrestrial models are cheaper and have less efficiency because they do not need to be as space efficient as space cells where the projects usually have extreme surface area requirements. Solar cells can be manufactured in all shapes and sizes depending on the manufacturer and the production material. Solar cells are electrically connected and mounted together to form solar arrays, also known as solar panels.

In order to obtain energy from other sources, those supplies must be carried up with the satellite on launch which is both inefficient in terms of space and costly so those options such as batteries or nuclear reactors will not be discussed here.

Cube Satellite Standard

As I am sure everyone knows by now, cube satellites are governed by a standard created by Stanford and Cal Poly about 13 year ago in order to help universities obtain cheap launches for nanosatellites. They accomplish this by imposing extreme size, weight, and operational restrictions on the cubesat. The entire standard will not be discussed here (please visit the Cubesat group Dropbox for more information) but the restrictions related to the solar panels will be briefly reviewed. As can be seen in Appendix A, a cubesat is a 10 cm cube. But due to the P-Pod rails which are present so the cubesat can slide into the P-Pod housing, the four vertical sides have a 8.3 cm x 10 cm space available for the solar panels. The top and bottom horizontal surfaces are also constrained with the tips of the rails protruding from the satellite. The P-Pod is the housing which holds the cubesat during launch. The requirements also restrict any material from protruding from the surface of the cube to 5 mm which makes deployable solar panel arrays a much more difficult option. For more information about cube satellites or previous cube satellite projects visit http://en.wikipedia.org/wiki/CubeSat or http://www.cubesat.org/.

Basic Power Analysis

This power analysis will go through the basic steps used to calculate the theoretical amount of power generated by any solar panel on the cube satellite. This analysis is implemented to determine if an arrangement of solar cells is adequate to generate the necessary power to run the electronics of the satellite. I have placed these calculations before the design process because they are instrumental to the development of the panels and deserve a more prominent space.

The following analysis uses numbers which are representative but not exactly the same as those used in the actual satellite so refer to the Power Budget for the actual calculations and numbers. To calculate the power necessary we must make some assumptions. The first is that we will have five solar panels on the satellite (one side will house the flashbulb and antenna). Next we will assume

- Intensity of the Sun = 1367 W/m^2
- Solar cell efficiency = 28%
- Surface area of One Side = 83 cm^2
- Solar Panels = 5
- Packing Factor = 60%
- Factor to account for Free Rotation = ¼ [SMAD 416]
- Degradation of GaAs Cells per year = 2.75% [SMAD 417]

The intensity of the sun is the solar constant. The factor to account for free rotation and the degradation of cells per year were both found in SMAD. They take into account the random rotation of the satellite and the per year degradation of GaAs solar cells. The surface area is chosen by the size constraint of the cube satellite requirement. The solar cell efficiency is the efficiency of the purchased solar cells. The following equation is then used to calculate the power produced by the satellite while in the sun at the beginning of life (which does not take into account cell degradation).

$$BOLPower\ [W]$$
$$= sun\ intensity\left[\frac{W}{m^2}\right] * solar\ cell\ efficiency$$
$$* surface\ area\ of\ 5\ sides\ of\ iSAT[m^2] * packing\ efficiency * Rotation\ Factor$$

To calculate the End of Life (EOL) Power, just multiply it by one minus the degradation factor as follows

$$EOL\ Power[W] = BOL\ Powers[W] * (1 - Degradration\ Factor)$$

It is important to use the EOL Power for all calculations so that the satellite can operate at full planned capacity for the entire life of the mission. This EOL Power is in the units of Watts. In order to calculate how much energy the satellite can harness during eclipse (no sun), we must find out how long the cubesat will be in the sun to collect energy. Since all electronics will be off while in the sun, all energy converted can then be used during eclipse. For our satellite's planned orbit of 300 km, the satellite will orbit the Earth 15.86 times a day [SMAD]. This means each orbit is 90.5 minutes long. The maximum

eclipse (no sun) time is 40% of the orbit (worse case scenario) which is 36.24 minutes or 2174 seconds long (SMAD). This leaves the time in the sun as 54.26 minutes or 3255 seconds. To calculate the amount of power available per sun-eclipse cycle

$$EOL\ Energy\ per\ cycle\ [J] = EOL\ Power[W] * Sun\ Time[s]$$

The cubesat is only using energy in eclipse though so the amount of energy will remain the same, but the time to use the energy will be shorter so the power will be different. Calculating this new Eclipse Power gives

$$EOL\ Eclipse\ Power\ [W] = \frac{EOL\ Energy\ per\ cycle[J]}{Eclipse\ Time[s]}$$

This finally gives us the amount of power available each eclipse to run all the electronics of the satellite which in our case will include the radio, antenna, and most importantly flashbulb. This calculation is still quite theoretical and does not take into account any inefficiency in the energy storage or transfer process. Those issues can be taken into account in the above equation by percentage loss factors. A more accurate gauge of actual energy storage will need to be determined later most likely through a combination of experiment and theory. But, for now this theoretical treatment will be accurate enough for the design purposes.

Design Process

This section is meant as a step-by-step walkthrough of the design process which took place during the Fall 2011 semester to construct the solar panels. Each decision will be discussed to the best of the author's abilities so that the reasons and facts necessary for each decision are documented and commented on. This process will follow a chronological order to best describe the choices that were made with the given information.

Constraints

The project began with a set of constraints. First, the panels had to produce the maximum amount of power. Following the goals of the satellite to provide an optical beacon in space, the satellite needs to flash as many times as possible overhead to increase the probability of being viewed from Earth. Since the satellite will not have a G&C (Guidance and Control) System, this frequency had to be high enough so that given random rotation, the satellite will still flash sufficiently toward earth to be seen when overhead. Secondly, the panels had to be cost-efficient. This constraint is enforced partially due to the prohibitive cost of buying premade solar panels because as discussed later, they cost around $2500 and partially because this project is about engineering students making engineering decisions. Granted, buying panels is a smart engineering decision because it saves time and increases reliability, but similarly, it means the team would have to spend more time fund-raising than making actual engineering choices. Thirdly, the panels must fit on the outside of the cube satellite. In space, surface area is extremely limited and on the cubesat with its size constraint, this is doubly true. To summarize, the three major constraints which the panels were designed for are optimal power, low-cost, and size.

Of these three constraints, size was the most important because if the panels do not fit within the cubesat architecture then the satellite will not even be able to launch.

Size

Knowing the cube satellite size constraint limits the surface area available for the solar panels of the cubesat. Since the project mandates optimal power, the maximum amount of space available should be used so that the maximum quantity of cells can be arranged on the panel. The panels for the four vertical surfaces of the cubesat each have a side of 8.3cm x 10cm (Appendix A). Every side of the cubesat is 10cm x 10cm but the vertical surfaces have the P-Pod posts which allow the satellite to slide into the P-Pod. These posts measure .85cm each. The top and bottom faces of the cubesat are not discussed here though panels will be designed for those sides later.

Solar Cells

The single most important decision in this process was the choosing of the solar cells. As was mentioned earlier in the introduction, two major manufactured materials exist for solar cells. The first is silicon. Silicon was the material of the first solar cells and nowadays is mostly used in terrestrial settings due to its low production cost and low efficiency. Terrestrial applications generally value cost over surface area consumed so silicon is a great fit. These cells generally range from 12%-18% efficient and come in two crystal types, monocrystalline and polycrystalline. Monocystalline cells are usually more efficient due to the presence of just a single crystal but are a bit more expensive while polycrystalline are less expensive but generally less efficient. The second most common material used is Gallium Arsenide Solar Cells. These cells use gallium arsenide wafers instead of silicon. They are semiconductors just like silicon, but are much more efficient. The efficiency for these solar cells is about 25%-30% for production models, but some R&D cells have been known to reach 40%. Due to the extreme surface area constraint of our satellite and the desire for the most power possible, the Gallium Arsenide cells were chosen for the satellite. These cells are more expensive, but as will be shown later can still be found for reasonable prices. Also as shown above, a basic power analysis performed using the calculations covered in the Basic Power Analysis section reveals that these cells should at the very least produce enough power for adequate function of the satellite.

Since the satellite needs gallium arsenide cells, the challenge was finding ones that were cheap enough to meet the mission goals. First, already constructed cubesat solar panels were investigated. This option was quickly discarded due to its high price. One of the major players in the cubesat industry, Clyde Space, sells high quality cube satellite panels, but each one costs over $2000. These panels can be found at http://www.clyde-space.com/. After contacting the owner of the company our project was offered a set of six panels for a discounted price of $2000 each, but this cost is prohibitively expensive and does not meet the project goals. The next option was to construct self-made panels from individual solar cells. The two main companies which manufacture these gallium arsenide cells are Spectrolab and Emcore. One option which arose was to purchase triple junction gallium arsenide cells in the 20-40 cm^2 range. These cells are priced between $600-$1000 per cell. These prices are expensive, but more importantly, the weird sizes would not allow for a sufficient packing factor. After significant contact between the two companies and the author, cheap gallium arsenide cells were found at a third party

vendor called SensorMetrix. The cells cannot be purchased from either company because of their rules against dealing with small order sizes.

These solar cells are called TASC (Triangular Advanced Solar Cells) and are produced by Spectrolab. The Data Sheet, Dimensions, and Orientations for the cells can be found in Appendix B. These cells are cut from the corners of the larger Spectrolab solar cells and are basically scraps (to them). They are of similar quality to the expensive Spectrolab cells, but just do not carry the same performance guarantees. The three most important characteristics of the cells are that they are inexpensive, high efficiency, and small. The cells are sold in denominations of 50 cells at a chosen orientation (-1 or -2) for $125 plus shipping. This price fits perfectly into the inexpensive goals of the project. Also the cells have a nominal efficiency of 27% which is a high efficiency gallium arsenide production cell. Added to that, the cells are very small so they can fit very easily into the size constraint mandated by the cube satellite and have a high packing factor. A picture is provided below of two TASC cells place in a rectangle configuration.
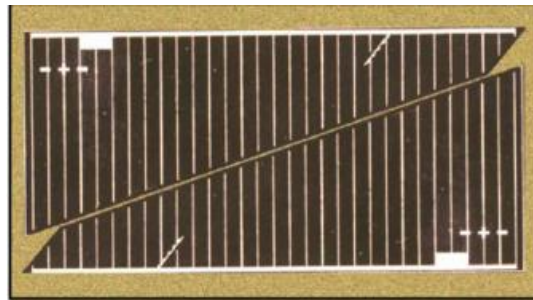

Figure 1: Two TASC Solar Cells

A few problems do exist with these cells though. Firstly, they are just cells. This means that the panels must be constructed to fit the cells. The cells are a little sensitive to heat so they may crack when soldering. Finally, the positive electrical connection point is on the top of the cell while the ground plane is the entire underside. Care must be taken not to electrically connect the two. Eventually the larger cells from Spectrolab may be investigated again in combination with the TASC cells since new money may be available for purchase of these cells. This new combination may produce a higher packing factor.

Printed Circuit Board (PCB)

After the solar cells were chosen, the problem arose of how to arrange the cells and connect them securely to the chassis. After looking at other cube satellite's solar panels such as those produced by Clyde Space and Swiss Cube (http://swisscube.epfl.ch/), the answer was to design a printed circuit board (PCB). These boards have numerous advantages, the first of which is that they not only become the physical connection between the solar cells and the chassis but they also provide the electrical connection between cells which cut down on excess wiring that would be very difficult for novices. The boards can also be produced in quantity for cheap prices and high precision using online vendors.

Throughout this entire process, Ken Ramsley was consulted frequently because of his expertise in printed circuit boards. After talking with him, a decision was made to design the printed circuit

boards using ExpressPCB's (http://www.expresspcb.com/) free design software. This decision was made due to the ease of use of their design software and their cheap prototype board pricing. Once designed, the boards could be ordered directly through ExpressPCB's online ordering system.

Before I venture into the design process some circuit board vocabulary will be covered (REF)

- Mil or Thou = .001 inches
- Trace = Segment of conductor route
- Via = Plated through hole used to route a trace from one layer to another
- Hole = Soldering points for wires
- Pad = The portion of the conductive pattern on printed circuits designated for the mounting or attachment of components.

To design the board, ExpressPCB's design software was downloaded. Then a rectangular board measuring 8.3cm x 10cm was created. This size is the surface area available on one vertical side of the cube satellite. The maximum space was used to allow for optimal surface area usage for the panel. Next, using the cells dimensions found in Appendix B, a custom "component" which was the same size as the solar cell (orientation -2) was constructed. Since each cell will be paired with another "flipped" cell to create a rectangle, another custom component was created which used two of the previously built components to make a rectangle pair with a 50 mil separation between the two cells.
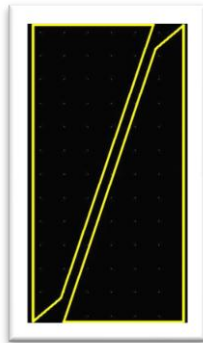

Figure 2: Two TASC Cell outlines created in ExpressPCB

This separation was chosen to attempt to ensure that when the cells were assembled together they would not physically or electrically touch. This could easily occur if not enough separation was present due to the imprecise, by-hand assembly process and possible excess conductive epoxy (see section on Epoxy).

When placing and arranging these cell rectangles around the PCB multiple considerations were taken into account. The maximum packing factor was desire to covert the maximum energy possible. The cells had to be far enough away from one another to have holes were wires could be soldered from the positive terminal of the cells to the PCB. Mounting holes had to be place on each of the corners to secure the PCB to the chassis, and a common positive and negative wire had to leave the panel.

Since the nominal voltage produced by each cell is $V_{oc} = 2.52\ V$ the cells had to be connected in such as way to add their voltages so that they could charge the nominal 7.5V battery pack used on the

satellite. Ken Ramsley recommended that the cells be connected so that the voltage of each cell grouping was 25% higher than the nominal battery voltage. To achieve this, five cells were connected together to attain a group nominal voltage of approximately 12.5V.

To start laying out the PCB, first the amount of cells that can fit must be determined. In an ideal situation 24 cells (12 rectangle pairs) can fit on the board, but this would not leave any space for the mounting holes, or wire connections. Also the cells must be arranged in groups of 5 cells so the number of cells on each panel must be divisible by 5. Therefore, 20 cells were chosen to be place on the board. These 10 rectangle pairs were arranged on the PCB so that enough space was left for the mounting holes, the positive/negative out wire holes, and separation between the rectangle pairs.
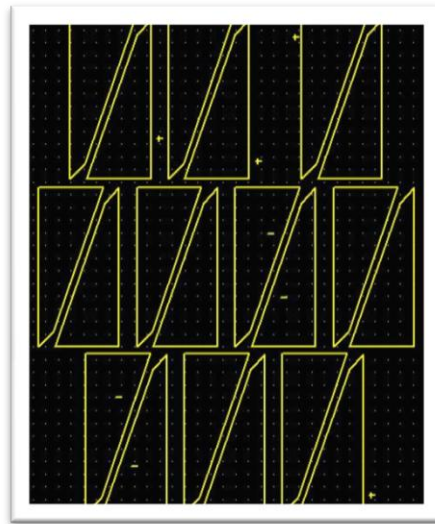

Figure 3: Arranged TASC Cells in ExpressPCB

The mounting holes (shown below) were chosen so that they fit #6-32 screws. After speaking with Ken Ramsley, this size screw was determined to be strong enough to secure the panels during launch. As of now, no stringent mechanical analysis has been performed. Long rectangular pads with one via inside were placed beneath every cell. These pads allowed the connection medium, solder or epoxy, to physically and electrically secure the cell to the PCB. The via allows the electrical connection to be made to the other side of the PCB (if needed), but also acts as an anchor to physically secure the cell onto the PCB. Holes with pads were then added to the sides of each cell so that wires could be soldered from the positive terminal of each cell into the circuit board. Traces were then used to connect the cells in series into groups of 5. These groups were then all connected in parallel to the in/out terminal at the top middle-right of the board. The finished design is shown below.
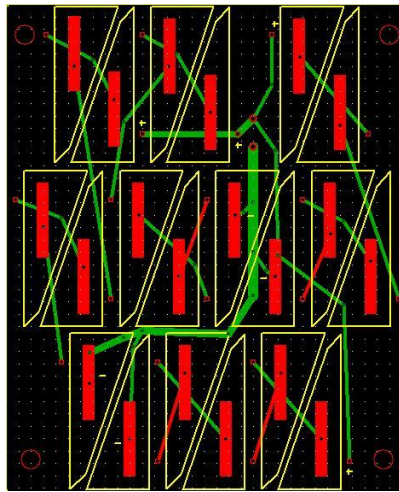
Figure 4: Completed PCB Design in ExpressPCB

In the picture above red denotes components on the top layer, green denotes components on the bottom layer, and yellow denotes the silk screen. The silk screen is just for visual reference and is not conductive. The traces used are between 30 thou and 100 thou. The 30 thou traces are used between cells and the 100 thou ones are used when connecting the five cell groupings together in parallel. The width of the trace determines how much current it can carry safely without fear of failure. These traces are over-speced for their job, but space was available so a large safety factor was included. The holes for the positive terminal wires are small because the wire necessary to transfer the current is not large. Smaller wires also occupy less space on the board.

Solder versus Conductive Epoxy

Two easy to use mediums exist to electrically and physically connect the solar cells to the PCB, solder paste and conductive epoxy. Solder paste consists of flux with microscale solder beads suspended inside and is primarily used for surface component mounting. The paste is placed between two metal surfaces, such as between a solar cell and a PCB pad and then passed through a solder oven. The oven melts the solder with a process called reflow soldering. The two components are then physically and electrically attached. Conductive epoxy on the other hand is an adhesive which usually contains silver. Epoxy comes in two tubes, resin and hardener, and when combined it begins to cure and eventually solidifies. Solder is a metal and therefore rigid with a very low volume resistivity (around $1.5e^{-5}\Omega * cm$). On the other hand, epoxy is a resin and therefore more forgiving, but it has a higher volume resistivity (around $6e^{-4}\Omega * cm$). Since the thickness of the conduction medium is negligible, the difference in conductivity should not play an important factor. However, the extra "give" in the epoxy should help to dampen vibrations during launch. The most important advantage of the epoxy though is that it can cure at room temperature. As mentioned earlier, the solar cells are sensitive to high temperature so reflow soldering process may crack the cells. Added to this, configuring a reflow soldering process is complicated and time consuming. Therefore, using epoxy is the safer and more time efficient approach. One problem that the epoxy introduces though is outgassing. In space since the pressure is very small, any air pockets in a material can rise to the surface and cause outgassing. This material then floats off into space and may condense on any satellites. Outgassing is highly regulated by NASA so in order to prevent it, expensive conductive epoxy must be purchased that is non-

outgassing and NASA approved. This small disadvantage is not enough to change the outcome that conductive epoxy is the best attachment medium for this PCB. The epoxy found to suit these purposes is Epoxy Technology's EPO-TEK H20E Electrically Conductive Silver Epoxy.

Manufacturing Process

With all the material chosen for the solar panel, the only steps left was to assemble it all into one working solar panel. Some special equipment was purchased or constructed to make this job easier and more repeatable. Since most likely six or more of these would be produced, it was important to have the same quality and low chance of failure panels on each side.

Assembly Equipment

Solder Mask

The most daunting task in the assembly is to ensure that the cells in the rectangle pairs do not touch one another. With this in mind, a solder mask was produced to help with the repeatable placement of the cells. The solder mask is a piece of aluminum which was cut using the highly precise EDM (Electrical Discharge Machine). The mask is a cutout of the outer limits of each rectangle cell pair on the PCB. This means that during assembly, a solar cell can be placed in the cutout rectangle and pressed against the wall to ensure correct placement. The plans for the EDM were made by creating a SolidWorks of the mask using measurements taken from the PCB design software. The SolidWorks was then converted to a drawing which was given to Brian Corkum along with the aluminum piece to cut on the EDM. The mask is aligned with the PCB by sliding a screw through the mounting holes in the PCB which have matching holes on the top solder mask and a corresponding thick solid piece of aluminum. The alignment holes were precisely cut on the mask and corresponding bottom piece by the author using a mill.
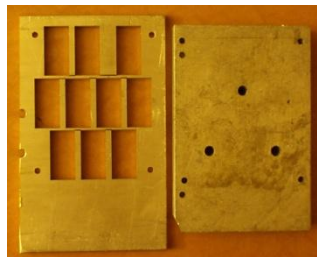

Figure 5: Solder Mask (Left) and corresponding Bottom Piece (Right)

Handi-Vac

The cells are very fragile so grapping them with a finger, placing them down into the solder mask, and adjusting them into position can cause cracks or full breaks to occur in the cell. This mishandling leads to unreliability or failure in the panel. To fix this problem, the Handi-Vac Dissipative Kit was purchased from Edmund Optics. This item is a suction cup with a bulb at the end which is used to pick up and place electronic equipment. In this case, the purchase is a perfect way to lift the cells and place them vertically down into the solder mask without cracking them. The item also decreases finger prints on the cells.

Syringe

One of the most difficult aspects of the assembly is placing enough epoxy to adhere the cell to the PCB while not allowing the epoxy to seep out and electrically connect two cells together. This problem usually arises between the two cells in the rectangle pair due to their close proximity. Using a very small syringe helps to alleviate this problem by only allowing a small amount of epoxy out at a continuous rate. A .5 mL, 12.7mm long syringe was used for this purpose though a slightly larger syringe is recommended. Still even with the syringe, practice must be completed to ensure that too much epoxy is not dispensed.

Assembly Steps

1. Set up Assembly Equipment: Epoxy, Solar Cells, Solder Mask, new PCB, Epoxy, Syringe, and Alignment Screws.
2. Place clean, empty PCB in the Solder Mask
3. Mix Epoxy Resin and Hardener with appropriate amounts given on package directions
4. Place mixed Epoxy in Syringe
5. Dispense Epoxy onto PCB surface on the long rectangular pad
6. Pick up one Solar Cell with the Handi-Vac and carefully place into position using the Solder Mask as a guide.
7. Repeat Step 5&6 until all the cells are arranged
8. Allow sit five minutes then remove Solder Mask
9. Allow Epoxy to cure for 24 hours
10. Cut and strip top of 30 AWG Wire
11. Solder Wire into holes on back side of PCB, cut to length and strip top
12. Carefully bend Wire using tweezers and solder onto positive terminal of Solar Cell.
13. Repeat Step 13 until all positive terminals have been electrically connected to PCB.

Notes

- Depending on the cure time of the Epoxy it may be necessary to only mix enough for a portion of the panel's cells so that the Epoxy does not harden before positioning the Solar Cells
- DO NOT allow the Epoxy to harden outside the projection of the bottom of the Solar Cells. This will lead to electrical shorting between Solar Cells.
- Care must be taken to avoid creating a solder bridge between the positive and negative sides of the Cell while soldering the wire into place. This could short the two sides.
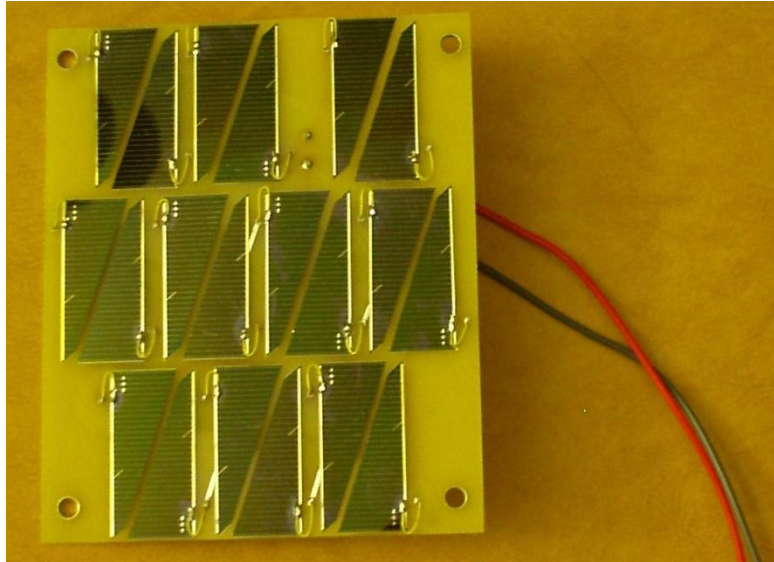
Completed Solar Panel

**Figure 7: Completed Solar Panel with Bare Leads**

Conclusion

This entire document has systematically laid out the design ideas and process followed in creating the vertical solar panels for Brown's Cube Satellite. Though not perfect, the author's hope is that with this knowledge, an uninitiated person can look at this document, understand how to make the panels and improve on the design or process. The current solar panels are by no means the optimal panels. Many improvements can and should be made. Some thoughts on avenues for improvement include combining Spectrolab's larger solar cells with the TASC cells to create a higher packing factor or using a Boost (voltage converter) instead of combining the cells in groups. In the future, many tests need to be run to show the experimentally determined power output of these cells and to test if the panels are working.

References

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- http://www.4pcb.com/index.php?load=content&page=index&page_id=18#L
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- www.ExpressPCB.com
- Wertz, James Richard., and Wiley J. Larson. *Space Mission Analysis and Design [SMAD]*. Torrance, CA: Microcosm, 1999. Print.

# Appendix A: Cubesat Size Constraints
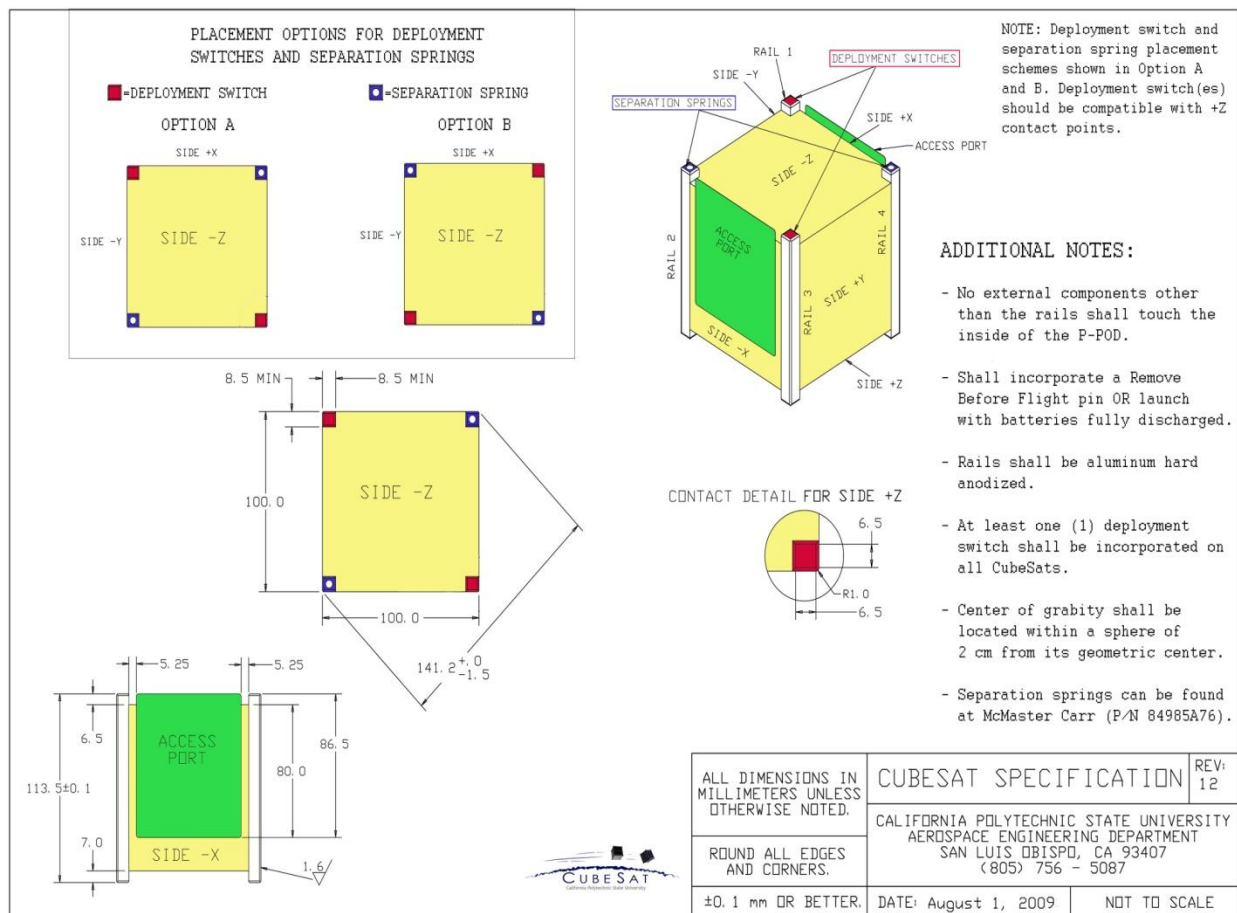
Appendix B: TASC Solar Cells

TASC Solar Cell Data Sheet

Spectrolab

Photovoltaic Products — www.spectrolab.com

Triangular Advanced Solar Cells (TASC)

Product Description & Applications

- Designed for high power terrestrial applications, where space is at a premium.
- Two solar cells can be arranged within an approximate rectangular area of 0.611 x 1.254 inches (1.55 x 3.18 cm) with a cell gap of 0.018 inches (0.46 mm). See picture.
- Each solar cell is ideally matched to charge a single 1.2 V battery cell (eg. Ni-MH, NiCad, etc.). Cells can be wired in parallel for increased current. Two solar cells in series can charge one 3.6V Li-ion battery cell.
- A major advantage using these solar cells compared to silicon cells is that they deliver greater than 4 times higher voltage. Therefore, only one of Spectrolab's multi-junction solar cells is required to generate the same voltage as 5 Si solar cells connected in series
- Compared to typical silicon cells, these solar cells are *over twice as efficient* and thus will deliver more than twice the power for the same area.
- Uses and applications: A variety of power-consuming electronic equipment can benefit from these cells, especially if the area available is small or the time required for charging is limited. For example, these cells help power devices used during business trips, emergency situations or for the outdoor activities.
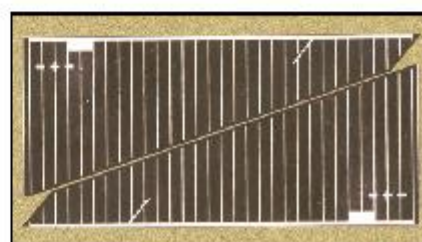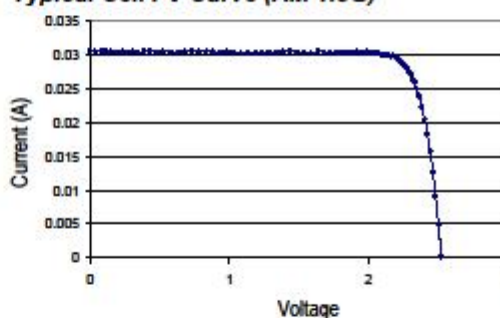

Not Actual Size

Typical Cell Electrical Parameters
1 Sun, AM1.5G (100.0 mW/cm²) 25°C

I_{sc}= 31 mA	I_{mp}= 28 mA
V_{oc}= 2.52 V	V_{mp}= 2.19 V
P_{mp}= 0.027 W/cm²	Cff= 80 %
Efficiency= 27 ± 3% Absolute	Temp. Coeff. V_{mp} = -6.2 mV/°C

Product Description

Cell Type	Improved triple-junction gallium arsenide
Method of Cell Growth	Metal Organic Vapor Phase Epitaxy
Polarity	n/p
Thickness	190 μm (0.0075 in.)
Area	2.277 cm² (0.353 sq. in.)
Mass	0.234 g
Assembly Methods	Soldering, welding, metallized epoxy
Device Design	Monolithic, two terminal triple junction. n/p GaInP₂, GaAs, and Ge solar cells interconnected with two tunnel junctions.
Antireflective Coating	Multi-layer providing low reflectance over wavelength range 0.3 to 1.8μm.

Typical Cell I-V Curve (AM 1.5G)

ISO9001:2000 REGISTERED

SPECTROLAB

A BOEING COMPANY

The information contained on this sheet is for reference only. Actual specifications for delivered products may vary. 4/10/02

Spectrolab Inc. 12500 Gladstone Avenue, Sylmar, California 91342 USA • Phone: 818.365.4611 • Fax: 818.361.5102

TASC Solar Cell Dimensions

TASC Solar Cell Orientation

-1   -2