Aerospace Systems Laboratory Student Satellite Program: Dock Support Board and Bandit Electronics Revisions

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Summary

The Student Satellite Program, run through Washington University's Aerospace Systems Laboratory (ASL), is a group of interdisciplinary student engineers who are currently working on the newest versions of the Akoya and Bandit satellites for the Air Force Research Laboratory's (AFRL) upcoming University Nanosat-5 competition. The competition features close to a dozen universities that submit spacecraft for review, with the winning University receiving support from the AFRL for a secondary launch of their satellite.

Significant work this semester has gone into the updating of the Akoya/Bandit electronics: specifically, the Dock Support Board (which sits on the Akoya satellite and performs functions necessary for communication and docking with Bandit) has been re-designed with greater processing power and more sophisticated image capture and processing capabilities. Extra analog-to-digital conversion circuitry was added to the Dock Support Board to eliminate the previous need for a separate "Frame Capture Board." These changes mirror updates in the Bandit electronics, which now use a 32-bit Atmel processor in conjunction with a 3-megapixel Micron camera for image-based navigational computations. Additionally, the previous design calling for two separate radios to handle communications and image download from Bandit has been abandoned; a 2.4gHz Meshnetics Zigbit module, which operates under the Zigbee radio protocol, now handles all radio communications from Bandit.

This report is divided into five sections, which gave an overview of the Akoya/Bandit satellite as well as an in-depth look at the Bandit electronics and their current revisions. Additional sections detail my contributions this semester to the project.

Section I - Introduction

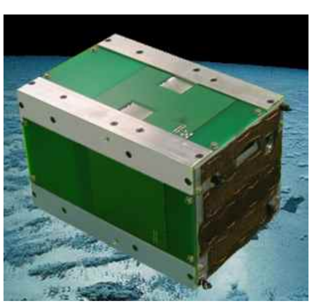

Figure 1 - Bandit

Bandit and Akoya are actually two separate satellites: the 34-kilogram Akoya serves as the parent satellite to the 3-kilogram Bandit and is responsible for its deployment through a proprietary docking system developed by ASL engineers. Bandit's primary goal is the demonstration of independent operation of a lightweight "service vehicle," with an emphasis on its docking and image capture, and navigation

Figure 2 - Akoya

capabilities. Another focus of the Bandit/Akoya satellite team is to demonstrate the benefits of rapid integration and testing (RIT) of hardware, a collaborative goal with Santa Clara University in California. This goal was successfully demonstrated at the 2006 Conference on Small Satellites with the exchange of “black box” functional units that rely on a common data exchange protocol.

The problem the electronics team faced this semester was the need for upgrading to a third revision of the Bandit and Dock Support Board electronics, which will be described in depth in Section II. In Section III I describe my design process for an NTSC video decoder circuit, a key component to the Revision 3 electronics upgrade. In Section IV, I describe the padstack and component footprint design processes, another of my major tasks this semester and an important step in beginning circuit board layout. In Section V, I conclude my work and offer a look at the future of the project.

Section II - The Electronics Overview

Development of a third revision of the Bandit Satellite (referred to as Bandit-C) was ongoing before the start of my research this semester. Akoya-B, the second major revision of the host satellite, will remain mostly unchanged for the upcoming Nanosat-5 competition. The team’s goal for the upcoming Nanosat-5 Final Competition Review is full integration of the Akoya-B and Bandit-C satellites and the successful demonstration of Bandit’s new capabilities. With this, we hope to win the Nanosat-5 competition.

My work this semester has involved assisting fellow ASL engineers Lane Haury and Forrest Rogers-Marcovitz with the electronics re-design. Changes in the electronics can most easily be described by first discussing the Dock Support Board, which actually sits on the Akoya satellite but is generally considered part of the Bandit Electronics.

2.1 - Dock Support Board (DSB) Overview

The Dock Support Board sits near the Akoya docks and handles all communications with the Bandit satellite. It also provides communications between Bandit and ground, since Bandit does not have a radio downlink to ground. The figure on the next page shows a block diagram of Revision 2 of the Dock Support Board:

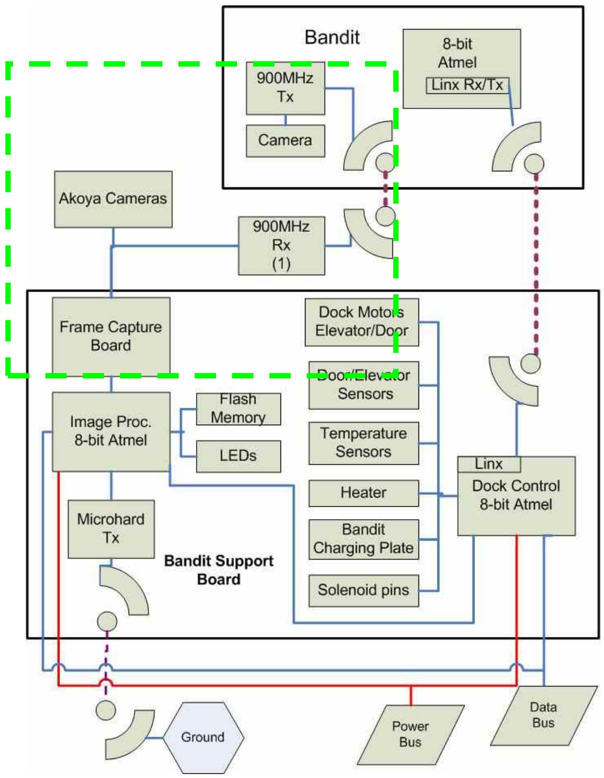

Figure 3 - Rev. 2 Dock Support Design

In a Dock Support Board "trade study" (see Reference 3) published by ASL engineers, the following configuration for the Dock Support Board was suggested. This design provided the basis for Revision 3 changes that we have made this semester:

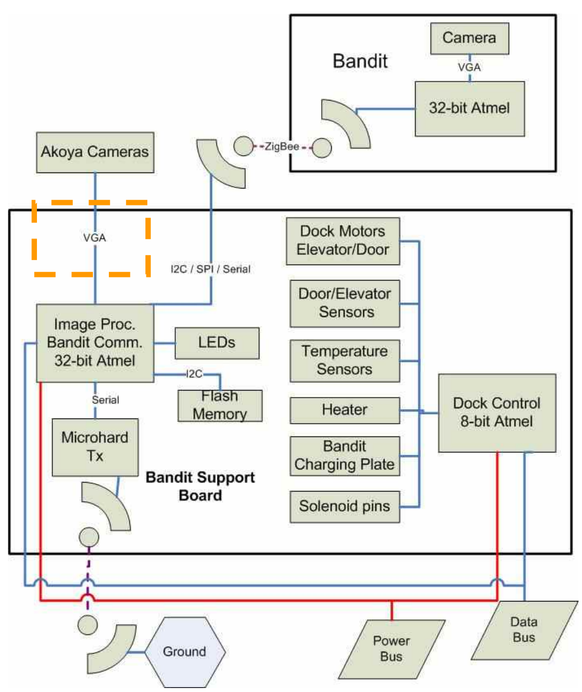

Figure 4 - Suggested Revision 3 Dock Support Board Block Diagram

2.2 - Rev. 3 Dock Support Board Changes

The following list describes the problems with the original design, and details the improvements that are being made to the newest revision.

1) **Original design does not give Bandit the capability to do its own image processing and navigation**. Referring to the green outline on the DSB, The original design requires Bandit to transfer its images using a 900Mhz analog radio to a "Frame Capture Board" on the DSB. This Frame Capture Board performed the analog to digital conversion of the images, which were then processed using an 8-bit Atmel microprocessor. This made image-based navigational updates very slow (as long as twenty seconds for a single image). Therefore, the new design eliminates the frame capture board and places a 32-bit Atmel processor on Bandit, which handles on-board image processing from a new CMOS imager. In this configuration, we expect image updates as frequently as once per second. Not shown in the block diagram is a circuit I designed using a Texas Instruments video decoder chip (part no. TVP5150AM1), which decodes the NTSC video signal from the dock camera into a digital VGA signal (see orange outline). These changes give a more intuitive signal path: images from the two cameras are kept separate, and the decoding/processing done on those images stays on-board.
2) **Using separate analog and digital radios to communicate between Bandit and the Dock Support Board is expensive and inefficient.** The Revision 2 design used two radios to handle image downlink and commands separately. This was problematic for power and RF reasons. We will now be using a single low power, 2.4Ghz Zigbit radio module that operates under the Zigbee radio protocol. More will be said about this in the Bandit section.
3) **Original design needed additional current sensing capabilities and brownout protection.** Based on suggestions from Ed Richter and others who have reviewed our designs over the semester, we have added some additional current sensors for the dock motors as well as a voltage supervisor chip (part no. STM6718) which regulates our 3.3V and 1.8V power supplies on the DSB.

2.3 - Bandit Boards Overview

The core of Bandit's electronics reside in a main stack of three 4x4" multi-layer printed circuit boards, called the Command Board, Power Board, and Sensor/Actuation Board. Connections between these boards are made using pin-to-pin headers, which minimizes space. Other electronics are contained on additional smaller PCB's, but the main stack carries out the major operations. The functions of these boards are detailed below:

1) **Power Board:** The Power Board is the simplest of the three, and serves two major functions. First, it contains the charging circuitry that is needed when Bandit is docked and charging. Since Bandit has no solar cells of its own and a battery life of about 30 minutes, it must charge between "sorties" during which it is deployed from the dock and carries out its missions. Second, the Power Board takes the 12 volts supplied by ten 1.2 volt NiCad AA batteries and converts it to 5V and 24V. These regulated voltage supplies

are sent through connectors to the other boards. The 5V is further stepped down to both 3V and 1.8V, used as supplies to digital circuits. The valves are fired using the 24V supply.

2) **Sensor Board:** The Sensor Board contains important "health" sensors that give readings of current, voltage, and temperature, as well as our navigations sensors including roll rate gyros and accelerometers. "Latchup protection," a type of power regulation that protects against the effects of free ionized particles in space, is also implemented here. 10 and 12-bit analog-to-digital converters (part nos. TLC1543I and TLC2543I, respectively) are used to digitize sensor values for use by the processor.

3) **Command Board:** The Command Board is the most complex of the three. It contains the Atmel 32-bit microprocessor (AT32AP7000) and all supporting hardware, including 20MB of external RAM (both SRAM and DRAM) and a flash ROM chip which stores Bandit's code. More on the Atmel processor will follow—note changes to the design in the "Current Progress and Changes" section. The Command Board also contains step-down voltage converters to supply 1.8 volts and 3.3 volts to the digital chips, as well as a brownout detection circuit as described in the Dock Support Board section. The Command Board also contains a Micron 3-megapixel camera and the Meshnetics Zigbit radio module, both mounted directly on the PCB. Antenna design for the Zigbit is ongoing, but we are expecting to use a basic dipole whip antenna mounted on the Bandit frame and connected to the Command Board through an SMA connector.

2.4 - Rev. 3 Bandit Board Changes

The block diagram below shows the most significant changes made to the Bandit boards:

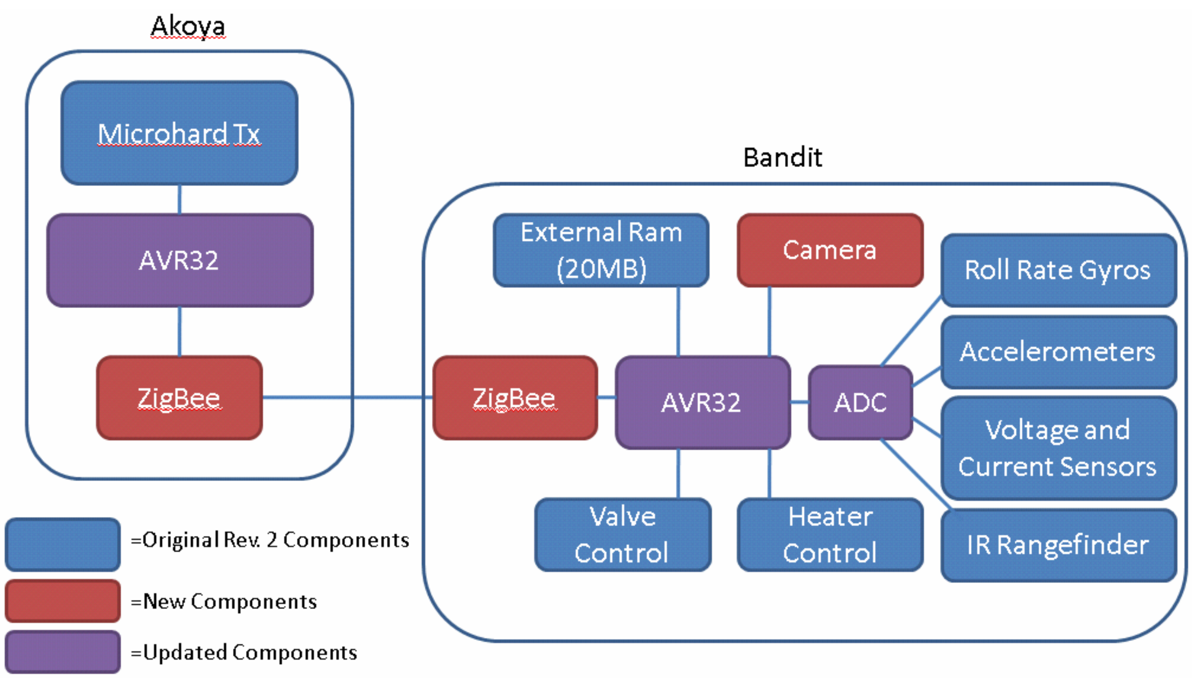

Figure 5 – Changes to Bandit Electronics

The following lists describe the improvements being made to the new design:

New Components (shown in red above):

1) The old analog camera has been replaced by the **Micron MT9001 3-megapixel CMOS camera** that is mounted directly onto the Command Board. The camera has on-board 10-bit analog-to-digital conversion that outputs a VGA signal (10 data lines, HSYNC, VSYNC) directly to the processor.
2) The **Zigbit radio modules**, which operate under the Zigbee radio protocol, have replaced the two previous radios. Zigbee is a low-power, low data rate, and high-sensitivity wireless networking protocol (frequently compared to Bluetooth) that was designed for noisy and cluttered environments. Zigbee has a history of use on satellites. It transmits at 2.4GHz and is capable of data rates as high as 250kbits/sec. The following chart gives a comparative look at power consumption differences between the old and new electronics designs:

	Max. Power Consumption (Watts) for Different Operational Modes					
Component	**Quantity**	**Volts**	**Launch**	**Dock/Standby**	**Heaters On**	**Heaters Off**
Atmel	1	5	0	0.14	0.14	0.14
Valves (10 valves total)--unreg	6	24	0	0	4.5	4.5
Camera and Transmitter	1	9	0	0	1.26	1.26
Heaters--unreg	2	12	0	0	6	0
Sensor (Accelerometer)	1	3.3	0	<.01	<.01	<.01
Sensor (roll rate gyros)	3	5	0	0.09	0.09	0.09
Sensor (Temperature)	10	5	0	<.01	<.01	<.01
Surface LEDs	24	5	0	0	3.6	3.6
Power System (20 % of Capacity)	1	12	0	0.84	0.84	0.84
		Total Consumption (Watts):	0	1.07	16.43	10.43

	Max. Power Consumption (Watts) for Different Operational Modes					
Component	**Quantity**	**Volts**	**Launch**	**Dock/Standby**	**Heaters On**	**Heaters Off**
Atmel	1	5	0	0.2475	0.2475	0.2475
Valves (10 valves total)--unreg	6	24	0	0	4.5	4.5
Camera	1	3	0	0	0.24	0.24
Zigbee	1	3	0	0	0.057	0.057
Heaters--unreg	2	12	0	0	6	0
Sensor (Accelerometer)	1	3.3	0	<.01	<.01	<.01
Sensor (roll rate gyros)	3	5	0	0.09	0.09	0.09
Sensor (Temperature)	10	5	0	<.01	<.01	<.01
Surface LEDs	24	5	0	0	3.6	3.6
Power System (20 % of Capacity)	1	12	0	0.84	0.84	0.84
		Total Consumption (Watts):	0	1.1775	15.5745	9.5745

Figure 6 – Bandit Power Chart

The top chart gives peak power consumption for the old design, while the bottom chart gives the peak power consumption for Revision 3. Notice in red the power efficiency of the Zigbee and CMOS camera: I calculated their peak consumption to be around .25 watts. Compare this to the 1.25 watts of peak consumption from the old camera and 900Mhz transmitter, and the power savings of the Zigbit are clear.

Updated Components (shown in purple in **Figure 5** above):

1) As mentioned, the **32-bit Atmel processor**, released recently, is now handling all of Bandit's processing needs. The increased processing power of the AVR32 coupled with the increased availability of images (from camera changes and elimination of Frame Capture Board) will allow Bandit's image-based navigation algorithms to run more quickly. Whereas image-based navigational updates were previously available sometimes as little as once every 20 seconds, the new design could provide these updates as quickly as every second, or even faster. The image-based navigation is used in conjunction with the roll rate gyros and accelerometers to provide data to a control algorithm in Bandit software, which determines the firing of thrusters and keeps Bandit navigating correctly.
2) Also mentioned above, some of the ADC chips have been upgraded to 12 bits converters, which should give better data from the gyros and accelerometers and strengthen the on-board navigation capabilities of Bandit.

2.5 - Current Progress and Changes

Work on the Bandit boards and DSB is still in progress. We have mostly completed the design phase of the boards and are completing their layouts. Currently, I am working with sales representatives from Advanced Circuits, who will be fabricating our boards and placing some of the components.

Some significant changes to the boards have been made and are of note:

1) A "daughter board" for the Atmel processor and memory chips has been developed and will be included in the board orders. The AVR32 processor is a 256-ball Ball Grid Array component, and requires a six-layer board. Additionally, the BGA placement cannot be done on-site in the ASL labs, so we have asked Advanced Circuits to place this IC and accompanying components (including RAM chips and some resistors/caps). By creating a daughter board, we are able to reduce the DSB and Command Boards (which previously contained the AVR32's) to fewer layers, resulting in significant cost savings.
2) The Power Board is being re-designed to use more standard components—we ran into some issues with legacy components that are no longer readily available from distributors.

Section III – NTSC Decoder Design

As mentioned above, an important change to the Revision 3 electronics was the elimination of the Frame Capture Board. However, since we kept the analog dock camera, we still needed a way to digitize data from that camera. I was responsible for developing a circuit around the Texas Instruments TVP5150AM1 decoder chip, which takes in the NTSC analog video signal from the dock camera and outputs a digital VGA signal to the processor. This schematic design was done in our licensed version of Orcad Capture, version 15.7. The schematic is shown below.

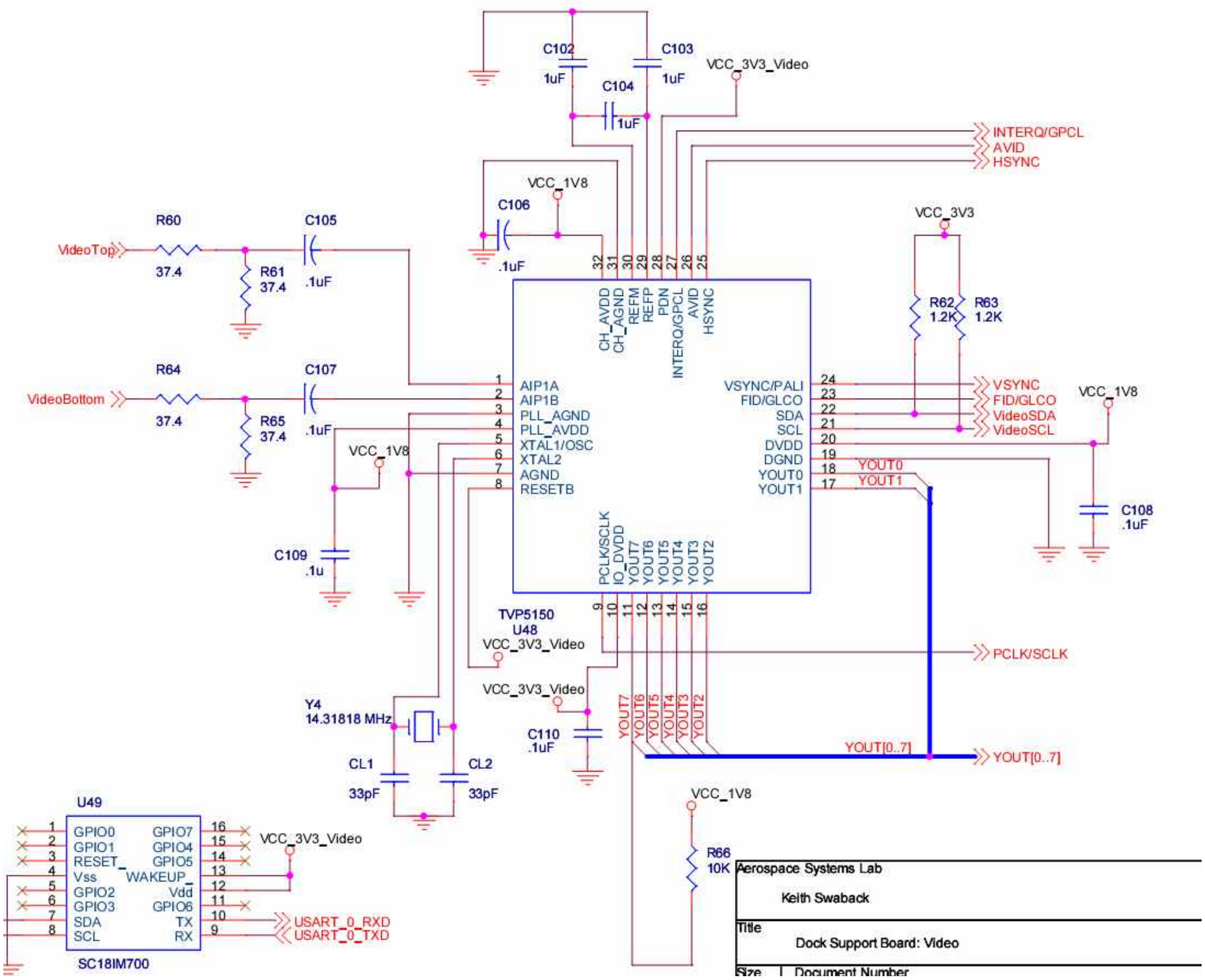

Figure 7 – NTSC Decoder Circuit

I designed this circuit based on suggestions made in the product datasheet. I will comment on the most important input/output signals that are shown above. VideoTop is the input video feed from the dock camera, in composite (NTSC) video format. A-D conversion is done on-chip, and several signals are output. The YOUT[7:0] are the video data lines and contain all of the image information. The VSYNC and HSYNC lines are horizontal sync and vertical sync signals, respectively. The VideoSDA signal and VideoSCL are the I2C ("I squared C") data and clock lines. I2C is a popular serial interface used to connect peripherals, and is the data bus used to communicate between different Atmel processors on Akoya/Bandit. The decoder chip is clocked by a 14.31818MHz crystal oscillator, with load capacitors of 33pF.

Section IV – Padstack/Footprint Design

Padstack and footprint design are necessary first steps in board layout. The licensed version of Orcad 15.7 that ASL owns does not include the Component Information System (CIS), which is a database that contains component footprint information, padstack information, and more. Thus, for any new parts that we have not used previously and for which we don't have footprints drawn up, we must create new padstacks and footprints.

The first step involved is creating an appropriate "padstack" for the component, based on "landing patterns" or pin information given in the datasheets. Padstacks are basically the copper shapes that appear on printed circuit boards to which components are soldered. The Pad Designer tool is included with the Orcad suite, and this is what I used to create many of the padstacks.

A screenshot of the first window is shown below:

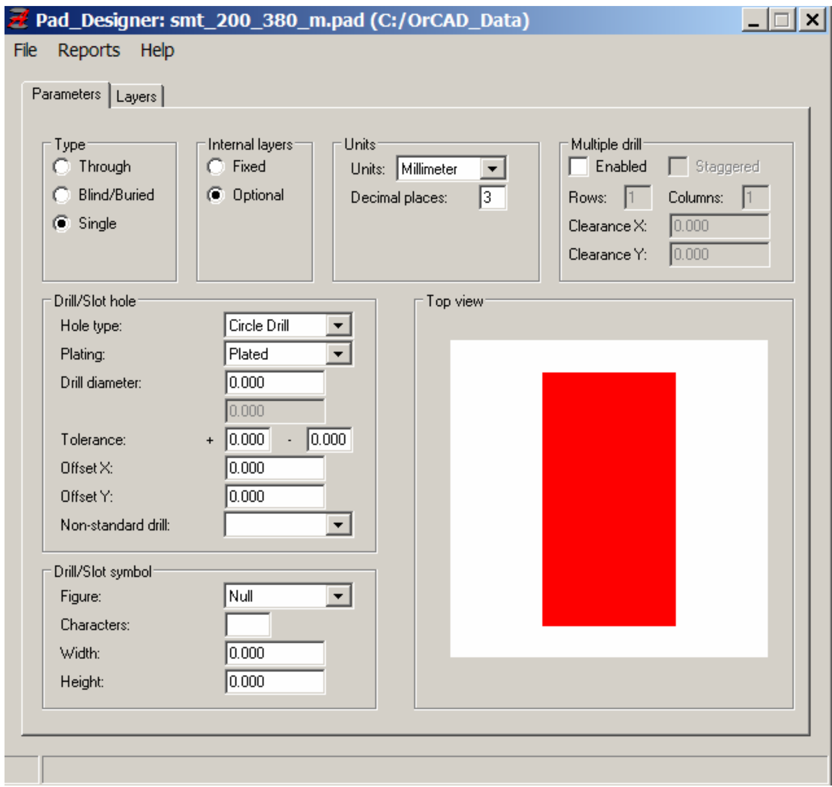

Figure 8 – Pad Designer, first window

Typically, the only important adjustments here involve choice of units. Dimensions on datasheets are frequently given in both millimeters and mils—I design padstacks in both. Also, the "type" category is important. Our surface mount pads are single layer; we don't use blind or buried padstacks. The "through" option should be selected if designed a pad for a thru-hole component.

A screenshot of the second window is shown below:

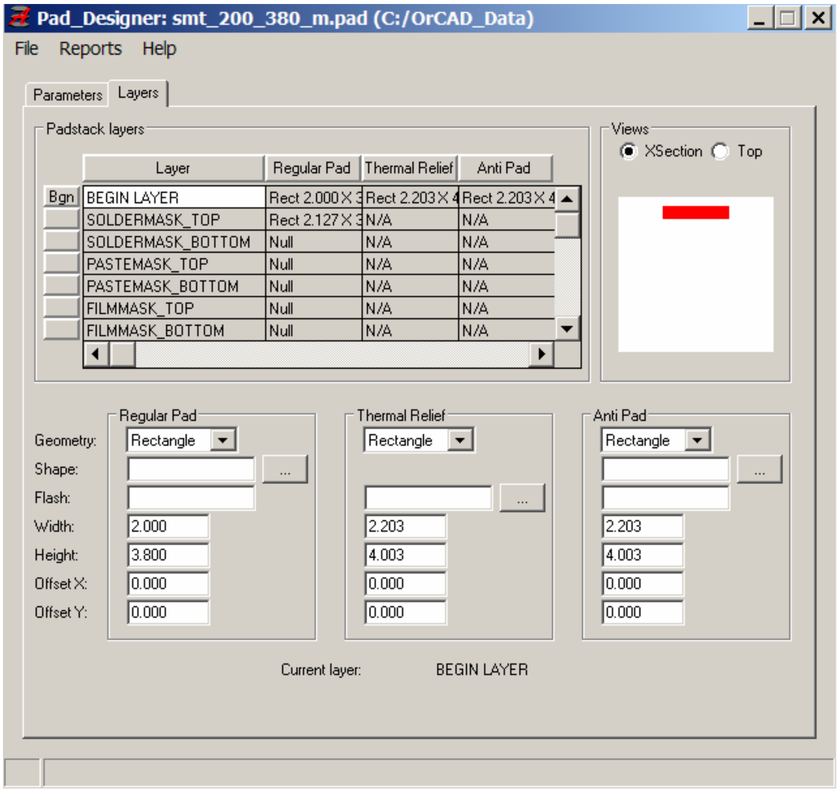

Figure 9 – Pad Designer, second window

This window allows changes to a variety of options, specifications, and dimensions in the padstack. The pad size and shape is designated under the “Regular Pad” section. Then, 5 mils of were added to both the width and height dimensions of the “Thermal Relief” section and “Anti Pad” section. The “thermal relief” assists in the soldering process by helping focus heat on the pad that is being soldered. The “Anti Pad” section is an extra space of copper that is etched from other layers when the pad is not supposed to contact that layer. Finally, 8 mils around each pad are added to the Soldermask_Top layer. A solder mask is a coating around the pad that helps to prevent solder from bridging between adjacent pads. Completed footprints are saved with a .pad file extension.

The second step that must be completed before laying out a PCB is the creation of package “footprints.” A footprint is basically a designation of how much space the component will take up on the PCB, and shows the package outline as well as the configuration of the pads to which the pins/terminals of the component will be soldered. The Orcad suite features an application called PCB Editor that handles both footprint creation and board layout. A screenshot of the program is shown below:

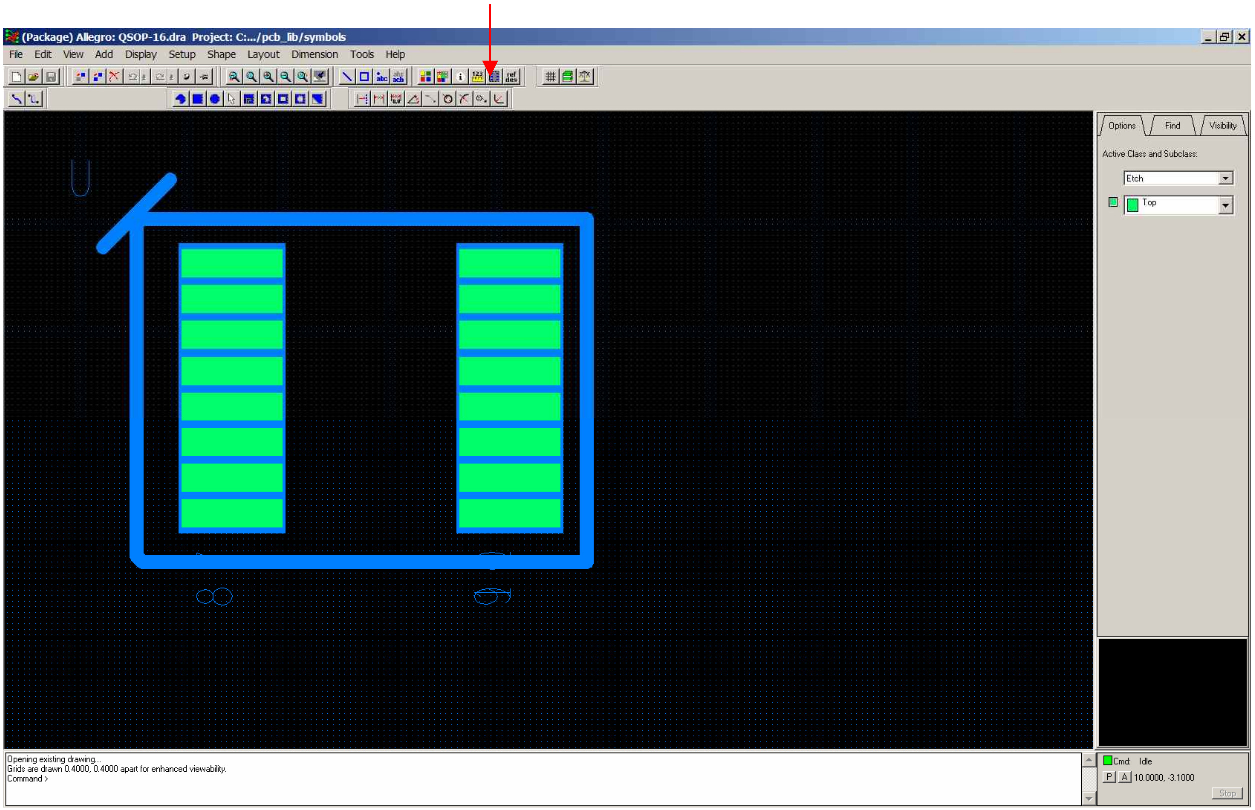

Figure 10 – PCB Editor window

This image shows a recent component footprint I have created. The basic process involves using the dimensions in the datasheets to first place pads in the appropriate configuration. These pads are automatically numbered when the pad placement tool, shown with a red arrow above, is selected. Once the pads are laid out correctly, a reference designator should be selected. This is basically just a letter that designates what type of component the part is—for example, this is some type of integrated circuit, and thus its reference designator is a U.

The last step of this process is drawing a silkscreen around the outline of the package. When looking at a PCB, the silkscreen is the white outline drawn directly onto the PCB, and serves as a visual tool showing in what orientation the component should be placed. Above, the silkscreen is the blue outline around the pads. Note that the line in the upper-left corner of the above component indicates the location of pin 1.

Section V – Conclusion

Updating the Bandit and Dock Support Board is an ongoing process. Currently, boards and parts are being ordered, and in the next few weeks testing will begin. The ultimate goal is to have fully integrated the Revision 3 electronics into the Akoya-B and Bandit-C satellites in time for Final Competition Review (FCR), which occurs next January and decides the winner of the Nanosat-5 program.

This project has given me many hands-on opportunities to work with a team of engineers with a common goal. Besides the contributions I have described in depth above, I have had opportunities to present my work in front of a group of design reviewers from the Air Force

Research Laboratories, coordinate the purchasing of boards and components, and get real-world experience with professional CAD software and multi-layer PCB layout.

Section VI – Relevant References

The following is a list of websites and internal documents that were useful for my project.

1) Aerospace Systems Laboratory Homepage. <http://asl.wustl.edu>.

2) Orcad Flow Tutorial. <http://www.cadence.com/downloads/orcad/files/OrCAD15-7DemoTutorial.pdf>.

3) Rogers-Marcovitz, Forrest. “Dock Support Board Trade Study.” ASL Internal Document. Published 3 Dec 2007.

4) University Nanosatellite Program Homepage. <http://www.vs.afrl.mil/UNP/About.html>.

5) Washington University Nanosat Homepage. <http://nanosat.wustl.edu>.