

The Design and Implementation of Various Subsystems for Pico-Satellites

by

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Contributions to this Paper

KUBESat Power Board:

- Testing
- Problem analysis
- Redesign

KUBESat Interface Board:

- Design inception
- Component selection
- Schematic design
- Layout design
- Layout of software functions

KUTESat Power Board:

- Testing
- Problem analysis
- Redesign
- Sectional failure analysis
- Theoretical DC-converter efficiency analysis
- Contributing directive in software functionality

KUTESat Payload Board:

- Problem analysis
- Complete redesign of Image Capturing subsection
- First order component analysis & selection
- Board stack layout design
- Design of functional software operation

KUTESat-2 Power Board

- Design conception
- Component analysis – efficiency studies
- Component selection

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Chapter 1: Project Overview

1.1 Introduction

The University of Kansas has united its efforts with other universities and several facets of the aerospace community to develop satellites less than 2 kg, often referred to as pico-satellites and less than 30kg (nano-satellites), that can demonstrate and test technologies necessary to accomplish the study of various areas of interest for the Department of Defense and NASA. The unofficial program is entitled “CubeSat” and is a world-wide higher education initiative. The University of Kansas currently endorses its own adaptation of this program called the Kansas Universities Technology Evaluation Satellite (KUTESat), which is built around the CubeSat program but also incorporates additional objectives. The Balloon Satellite (BalloonSat) mission, which is a weather balloon based satellite, was developed to provide a viable test environment in support of the KUTESat program. Figure 1.1 summarizes an outline of the pico and nano - satellite development effort at the University of Kansas.

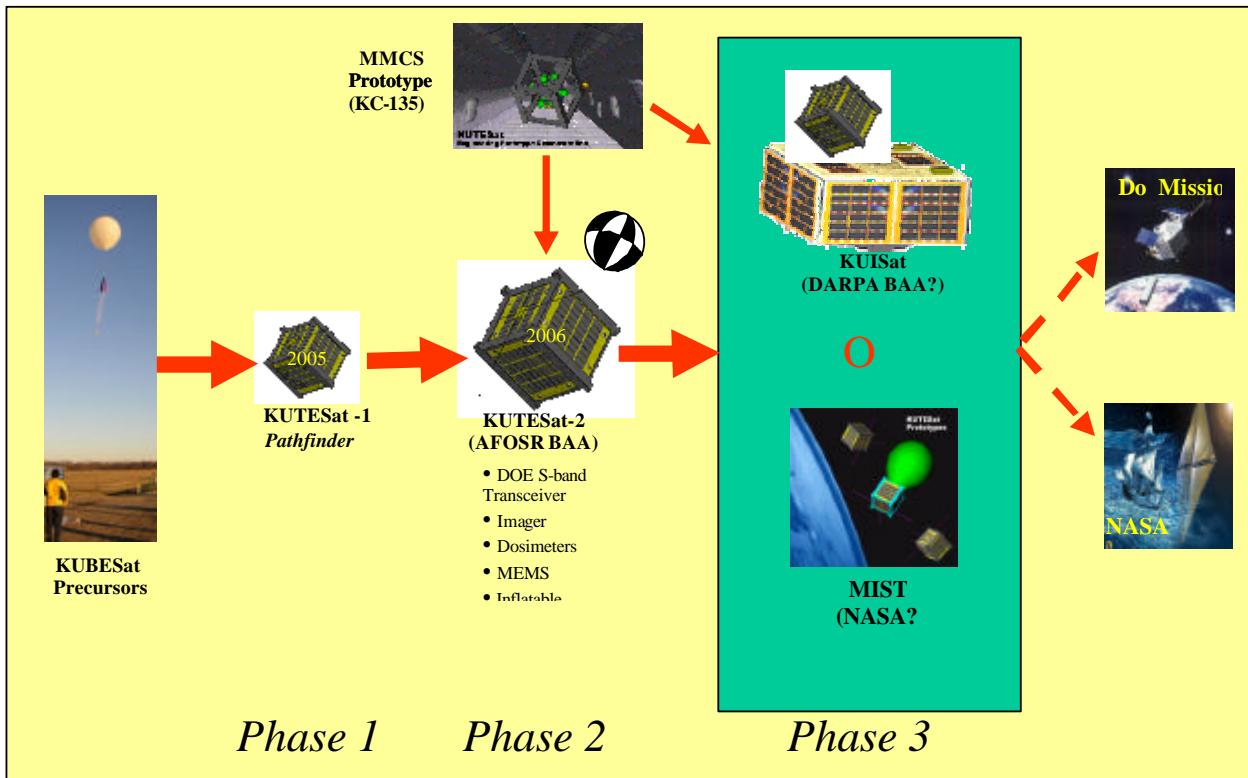


Figure 1.1, University of Kansas Pico-Satellite Program Overview

1.2 Description of CubeSat

The initial concept of a standardized pico-satellite was conceived by Professor Robert Twiggs of Stanford University in association with the Space Systems Development Laboratory. His goal was to develop a standardized set of design parameters which would provide a universal platform for all designs to be based upon. The program Professor Twiggs developed was CubeSat which specifies the weight, overall dimensions, and launch vehicle interface a satellite unit must adhere to in order to exploit the following: reduced satellite development time and leveraged launch opportunities via the standardized launch deployment system, Poly Picosat Orbital Deployer, P-POD. In the past, satellite development efforts at the university level

spanned a number of years from inception to formation often extending past the time frame of a college student's career. Additionally, upon completion, the satellites usually had to wait for several years before finding a suitable launch opportunity. The CubeSat program overcomes these hindrances by providing a common launch platform which launches several pico-satellites at once, and by narrowing the design scope. Furthermore, the wide spread participation of approximately 50 universities world-wide allows for free flow of information and innovation to be readily shared among participants.

1.3 Introduction of KUTESat

Under Professor Sorenson, the CubeSat initiative has evolved into the Kansas Universities Technology Evaluation Satellite (KUTESat). KUTESat aims to promote interest in space activities among partner universities (e.g. Emporia State University, Haskell Indian Nations University, Kansas State University, Pittsburg State University, and Wichita State University) and elementary and secondary schools within the state. The KUTESat project is currently composed of three phases: Phase 1, will facilitate experience in the designing, building, testing, and operating of a pico-satellite, KUTESat-1: Pathfinder Mission, in low Earth orbit (LEO). Pathfinder, being the initial stepping stone, will be the sole initiative of the University of Kansas. Phase 2, the development of an engineering prototype to evaluate a miniature maneuvering control system (MMCS) in a weightless environment will take place concurrently and be incorporated into the design of the pico-satellites of Phase 3. This phase will be developed in conjunction with Wichita State University. The third phase, MIST, will ultimately simultaneously coordinate the flight of three pico-satellites (KUTESat-3, KUTESat-4, and

KUTESat-5) working in conjunction in LEO. KUTESat-2 will be launched prior to KUTESat-3 and KUTESat-4 to verify the new implementations functionalities.

1.4 Overview of BalloonSat

In order to provide a fairly similar testing environment, Professor Sorenson developed a balloon satellite (BalloonSat) to design, build, test, and operate a satellite-like vehicle which could be used to observe and verify newly designed KUTESat components and subsystems. The BalloonSat consists of two fundamental modules: High Altitude Balloon System (HABS) and Kansas University Balloon Experiment Satellite (KUBESat). HABS provides the overall system governance and a primary communication link with the base station. It is primarily charged with the task of controlling the maximum ascension altitude and relaying its position according to on board Global Position System (GPS) approximately once every two seconds. This module although undergoing technology and design augmentations will remain constant while the payload of the KUBESat will alter. KUBESat, although in communication with the primary control module, independently conducts preprogrammed measurements and experiments which are reported via a secondary communication system to the base station. The system configuration is illustrated below in Figure 1.2.

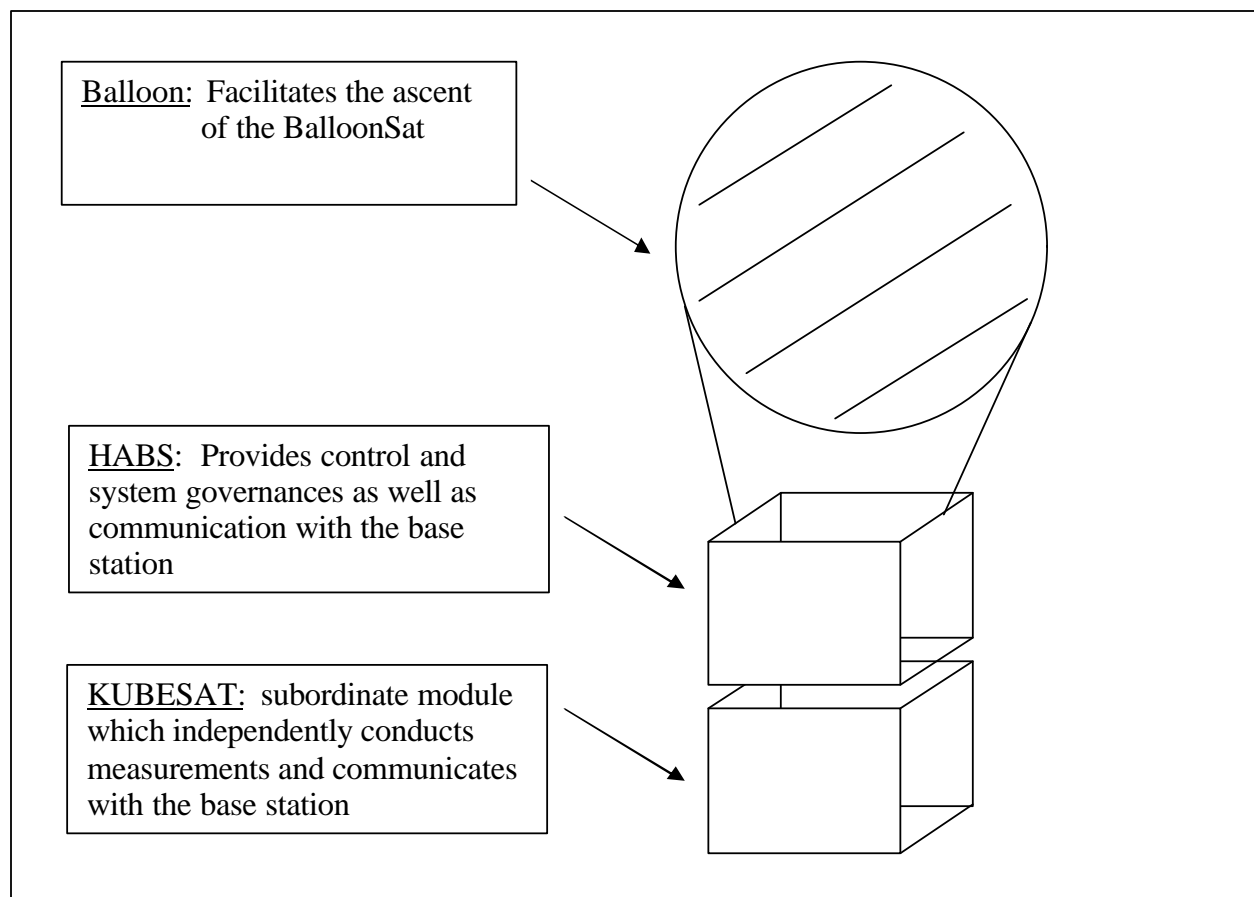


Figure 1.2, BalloonSat System configuration

1.5 Overview

The remainder of this paper will focus on my involvement in: the HABS subsystem; Phase 1, KUTESat-1; and Phase 3 KUTESat-2. Chapter 2 is a detailed introduction of the HABS system explaining the functional operations of the components that make up the module. An account of the HABS power system in terms of testing, analysis, and redesign work is described in Chapter 3. Chapter 4 outlines the necessity for the HABS interface board, design, layout, and defining programming function operations. A presentation of modular functionalities for the

KUTESat-1 system is specified in Chapter 5. Chapter 6 summarizes the key operations of the Power system including a synopsis of the software. The KUTESat-1 Payload design, analysis, schematic, and software outline are discussed in Chapter 7. The next generation power board for the KUTESat-2 mission is presented in Chapter 8. Chapter 9 is the summary of the work accomplished as well as suggestions for future work and improvements.

Chapter 2: HABS & KUBESat

2.1 Back Ground / Overview

As described in the introduction, the BalloonSat provides a testing platform for the space-distended satellite subsystems. The BalloonSat was initially designed by the AE & EECS senior design classes in the Spring Semester of 2003. Although, it has flown, the BalloonSat is still partially under development and optimization. The BalloonSat consists of two primary modules: the High Altitude Balloon System (HABS), and the KU Balloon Experiment Satellite (KUBESat) modules, Figure 1.3. The HABS system provides the balloon's governance and flight strategic interaction with the ground station. The KUBESat module provides a generic interface for all testing payloads. It is designed to operate completely independently in terms of power generation and distribution. It also possesses the means to communicate with the HABS modules via a direct wired interface port. HABS is the c^2 and is the interface between the KUBESat and the ground station.

Sections 2.1.1 and 2.1.2 provide a brief subsystem level overview. Section 2.2 and 2.3 address design considerations and implementations for existing problems for both the HABS and the KUTESat modules respectively.

2.1.1 HABS Subsystem

The HABS system is comprised of the following subsystems: Power, KUBESat Interface, Front Panel, Cut Down Timer System (CDTS), Microprocessor, External Devices, Mechanical System, Communications, and Recovery System. Figure 2.1 summarizes the HABS systems.

2.1.2 KUBESat Subsystem

The KUBESat system is comprised of the following subsystems: HABS Interface, Power, Payload, Microprocessor, and Communication System, Figure 2.2.

2.2 HABS Interface Board: Problem Operating via Connected Mode

The Kenwood TH-DA(G) Amateur Radio is used to establish the communication link between the ground station and the HABS module of the BalloonSat. The Kenwood Radio provides both the actual communication radio and a terminal node controller (TNC). The terminal node controller is used to create the broadcast packets as well as provide link-layer
Kljladfj

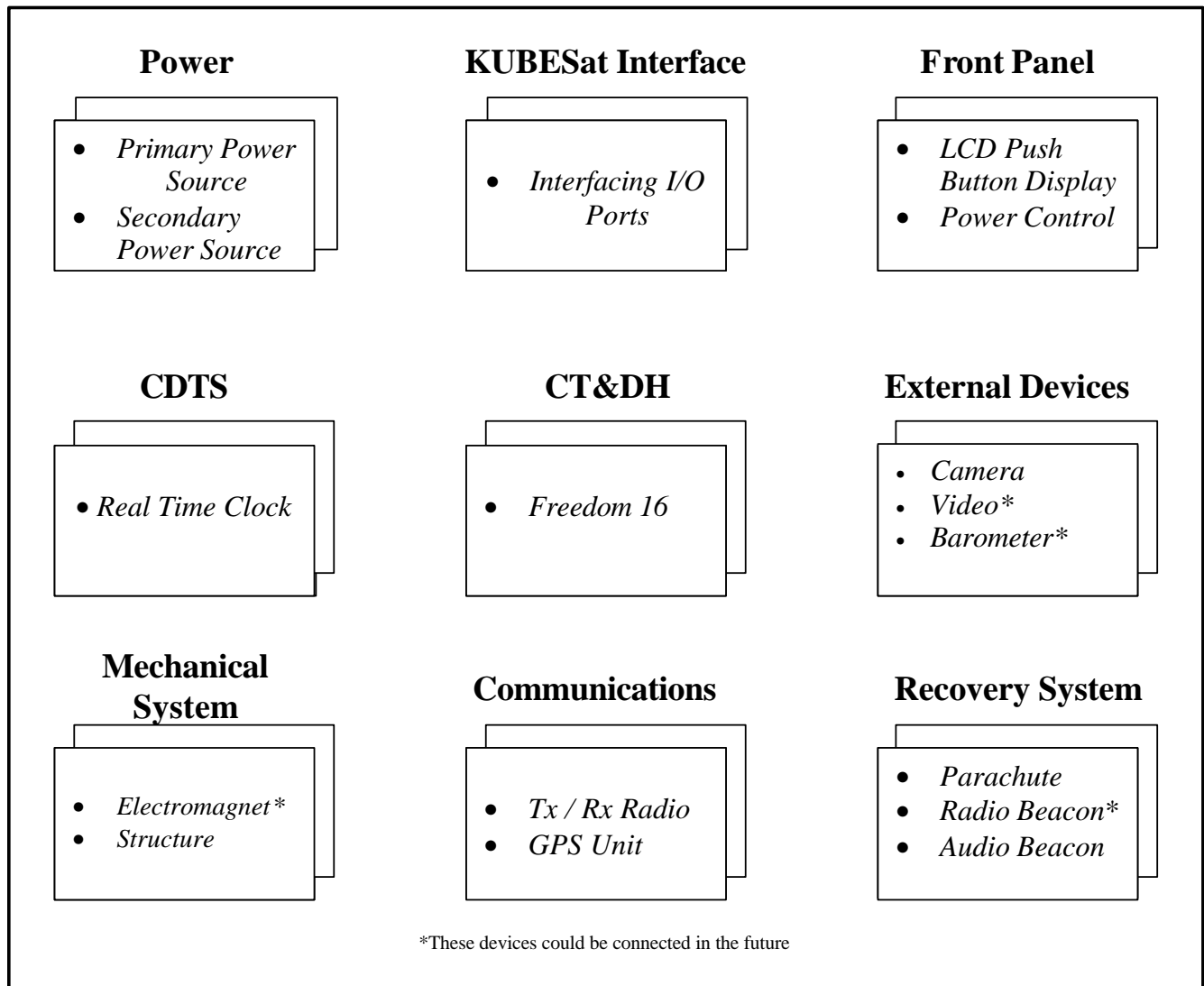


Figure 2. 1, HABS subsystem summary

intelligence for the communication channel which can include retransmission of lost packets.

For the purpose of the BalloonSat project, the radio can operate in two modes: broadcast mode and connected mode. The broadcast mode, as the name suggests, only uses carrier sense multiple access (CSMA) as defined by the amateur X.25 (AX.25) communication protocol to arbitrarily introduce packets to the airways without any assurance of arrival of the information at

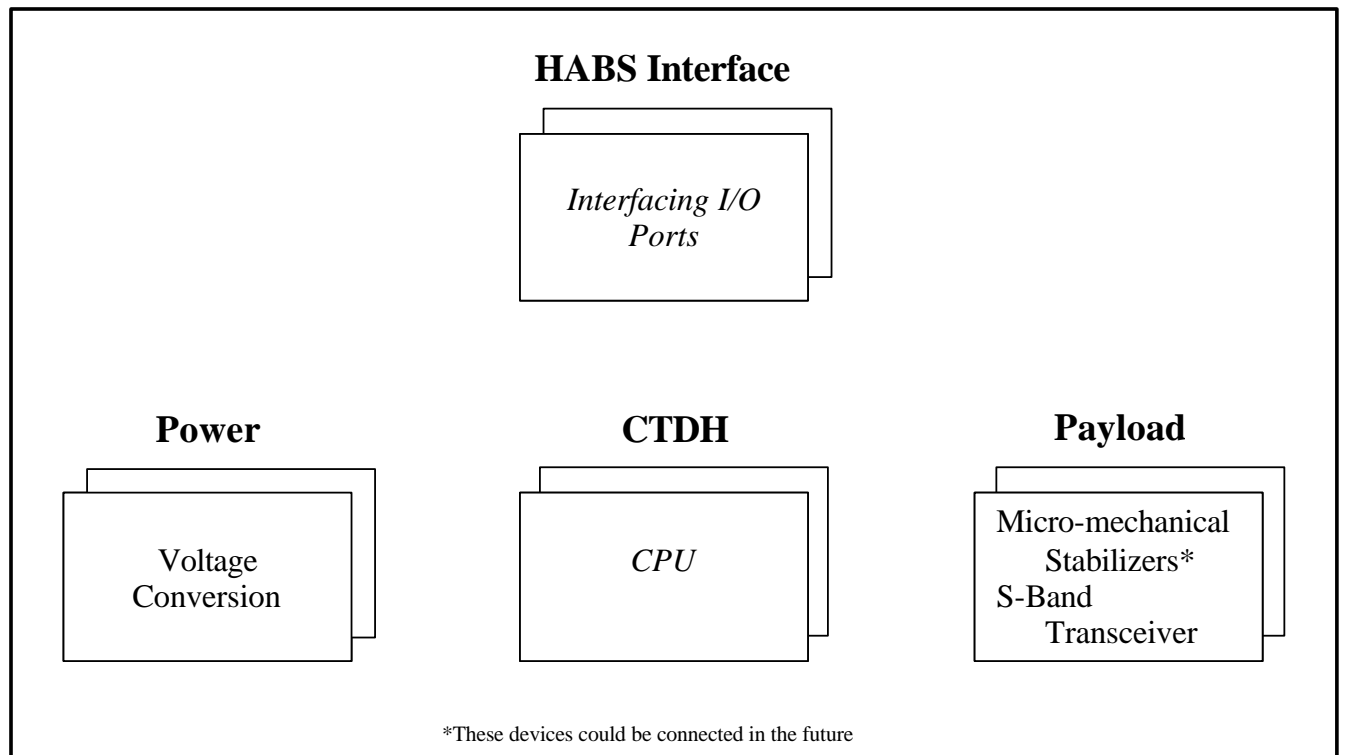


Figure 2. 2, KUBESat subsystem summary

the desired destination. CSMA monitors the communication channel in order to ensure that multiple hosts are not communicating at the same time. Connected mode establishes a verifiable communication link between the source and the destination. Although, as in broadcast mode, the information can be intercepted by any listening party, the destination sends an acknowledgement every time a valid packet is received. The connected mode is, for multiple reasons, the preferred method of communication.

The integrated TNC has two RS232 ports, but can only support one RS232 port input while operating in connected mode. Currently the microprocessor, the Freedom 16, and the global positioning system (GPS), both possessing an RS232 interface, connect to the Kenwood Radio allowing only for broadcast mode communication. In addition to controlling the

communication-layer control, the TNC programs the GPS to communicate using a predefined positioning format, GPGGA, which upon request from the micro-processor, is parsed and sent to it. The micro-processor uses the altitude measurement from the GPS to determine when it should start its descent.

Communicating via the RS232 port provides the universal asynchronous receiver-transmitter (UART) interface protocol between connected devices. UART ensures correct packet formatting, communication verification, logic level compliance ...etc. The Freedom 16 only possesses one RS232 port which is in constant utilization broadcasting status information and responding to any commands originating from the ground station.

There are several possible approaches to provide for a viable solution. The key design parameter to consider is that the GPS data is needed for both the microprocessor's onboard governance and the ground station tracking system.

2.2.1 HABS Interface Board: Solution

Via the use of a relatively inexpensive UART to serial peripheral interface (SPI) conversion integrated circuit (IC), the hardware aspect of the problem becomes virtually a one chip solution. SPI provides a full-duplex synchronous serial interface that is easily implemented on any microprocessor. The only limitation to using SPI is that the microprocessor has four available input/output ports: Data In, Data Out, Clock, and Chip Select. As will be described in the next section, Hardware Design, all other components serve merely to provide voltage conditioning or timing synchronization.

The majority of this solution lies in the imbedded code for the Freedom 16 microprocessor which will be in control of this interface. Further details of the code will be described in the Software Design section.

2.2.2 HABS Interface Board: Hardware

The MAX3100 is a readily available and industry wide communication protocol translation IC. It only requires an external clock source, which is used for baud-rate compliance; and a voltage translation circuit, in order to adapt the logic levels to the appropriate voltage standards. The board schematic is provided below in Figure 2.4, HABS Interface Board Schematic.

Additionally, a 10 column by 2 row header, JP1 in Figure 2.4 and Figure 2.5, is placed on the opposite side of the board from the interfacing connector. This secondary connector makes no electrical connections between the boards and serves in a purely structural capacity. A copy of the board layout is displayed in Figure 2.5, HABS Interface Board Layout.

The layout observes the '10 10 rules' (specifies the space between traces and the minimum trace width) in order to ensure a high probability of successful fabrication of the printed circuit board (PCB). All passive components use the most common industry standard footprint to ease the population of the board. The dual ground planes provide some isolation to electro magnetic interference (EMI), but mainly aid in the design of the layout itself. EMI is of very little concern for this board due to its relatively slow logic level transition speeds.

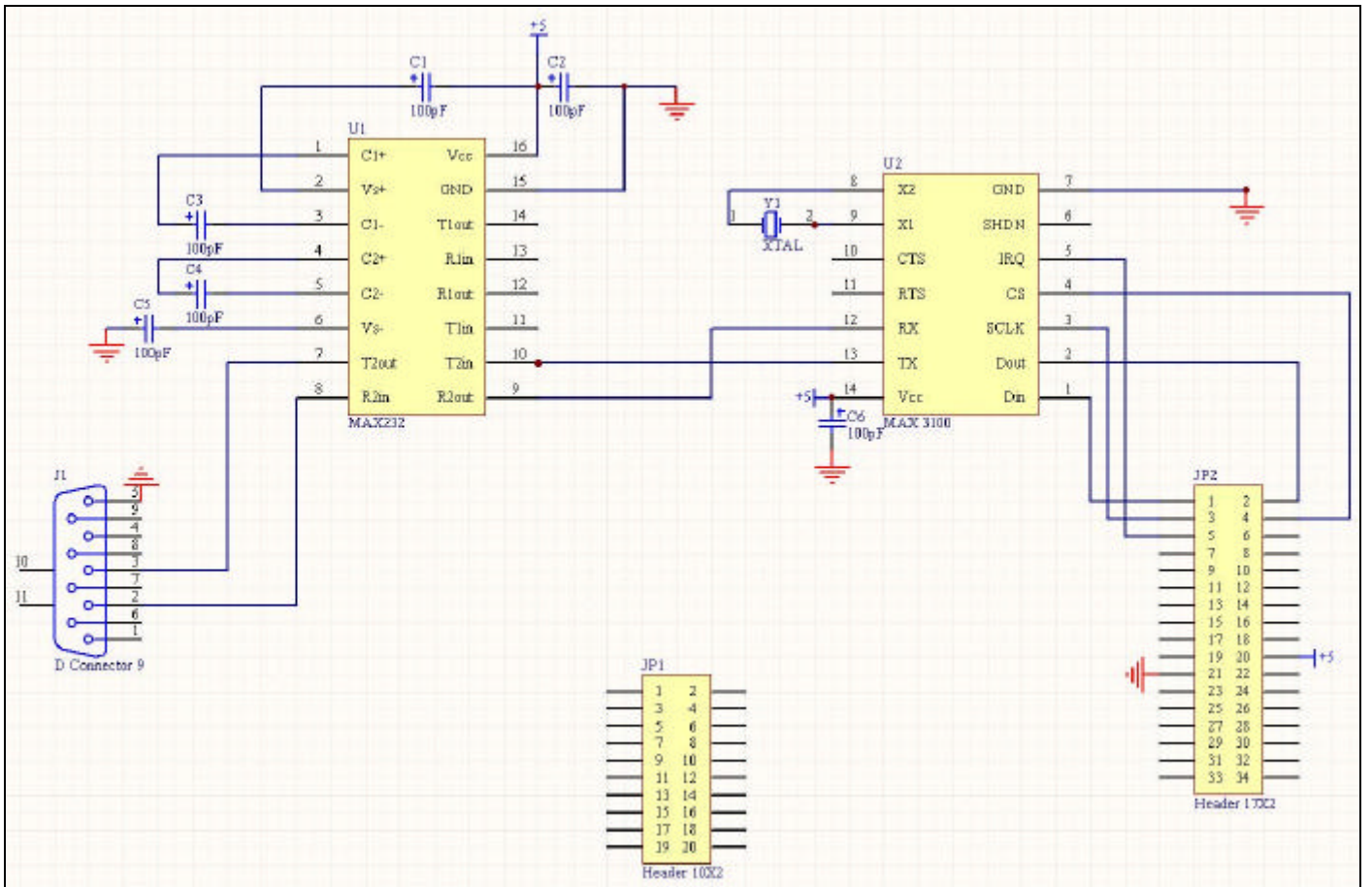


Figure 2.4, HABS Interface Board Schematic

2.2.3 HABS Interface Board: Software

The freedom 16 microprocessor will control the operations of the GPS via the interface of this board. The interfacing software can be decomposed into two main tasks. The first task will be the initialization of the GPS to communicate using the GPGGA format. The process of enabling this mode including proper packet formation is described in full by the Garmin GPS 25 LP manual included in Appendix A.

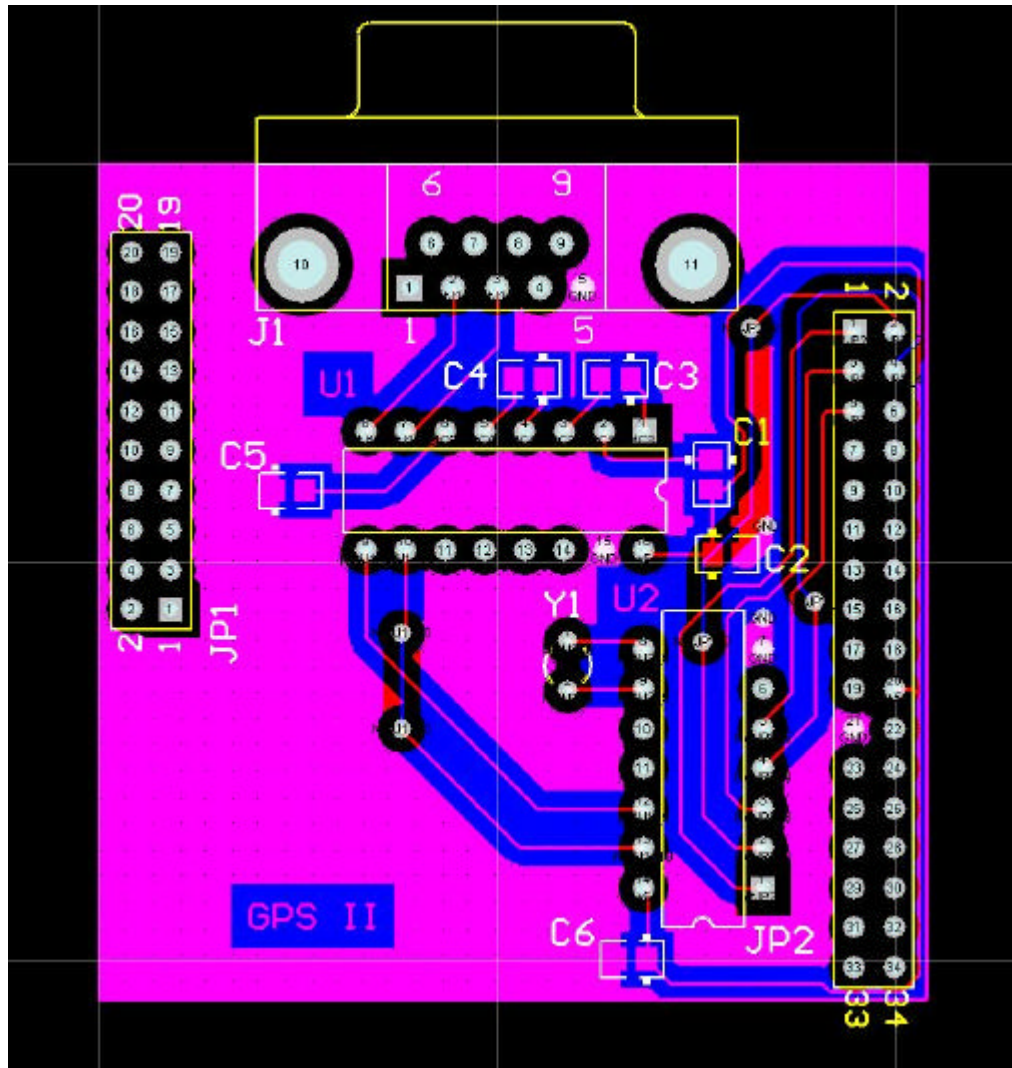


Figure 2.5, HABS Interface Board Layout

The second task will capture the GPS data and either parse the incoming data to resolve the altitude information, which will determine when the BalloonSat should start its decent, or pass all incoming packets via the TNC and radio to the ground station. All data will be processed in real-time meaning no buffering will take place and the micro-processor will only

accept information arriving on the GPS data port prior to processing, otherwise ignoring any incoming packets.

2.3 KUBESat Power Board: Operation Problems

The KUBESat module, the HABS module, and the KUTESat-1 have, until now, never had a complete working power conversion board. The HABS module, for example, employs a prefabricated 5 volt DC-DC converter to provide the system with the necessary power. All three power subsystems share the same inherent design which is adapted as needed to the individual requirements for each subsystem: MAX1709, 5v DC converter; MAX1620, 3.3v DC converter, and Max1771, 12v DC converter. The other commonalities shared by all three designs, is that they were all produced in-house with a milling machine, and that the 5-volt DC conversion stage did not work once a load was applied. This is not to say that it was only that 5-volt section which did not work, but that this problem was universal to all boards.

The KUBESat power board provides both 5 and 3.3 volts via the fore mentioned MAX1709 and the MAX1620, Appendix C and D respectively. The 3.3 volt DC-DC conversion section functioned as expected, but the 5v portion exhibited the characteristic voltage drop under load conditions. Figure 2.6 depicts the board composition in a schematic format.

The fundamental design is taken from the application suggestions from the manufacture's data sheet. The only differences are a slight alteration of the components' values and the quality of the components that the manufacture used to create the documentation.

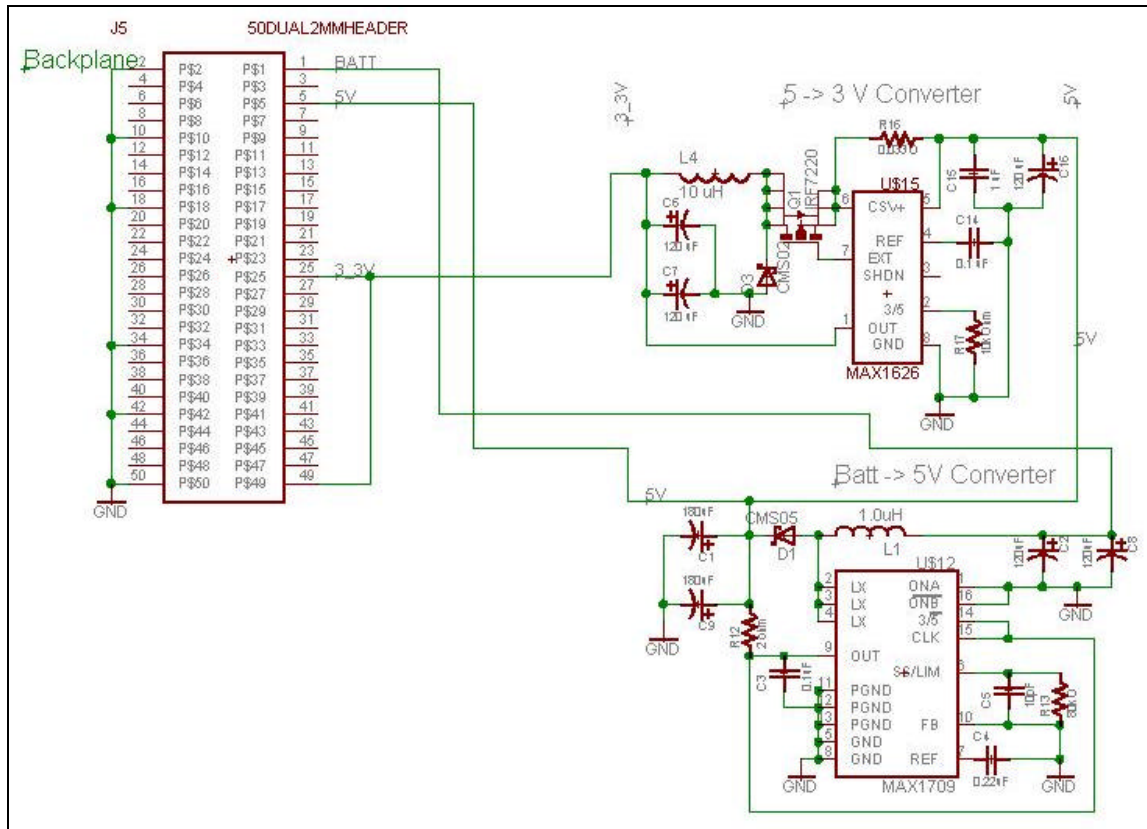


Figure 2.6, KUBESat Power Board Schematic

2.3.1 KUBESat Power Board: Solution

The KUBESat power board was subjected to standard debugging procedures: double checking component placing, verifying connections, inspecting proper component values, etc. A new board identical to the board being test was tested with only the 5v conversion section being populated. The problem persisted even after employing standard debugging practices to identify the problem. Figure 2.7 presents the layout of the original power board that was tested.

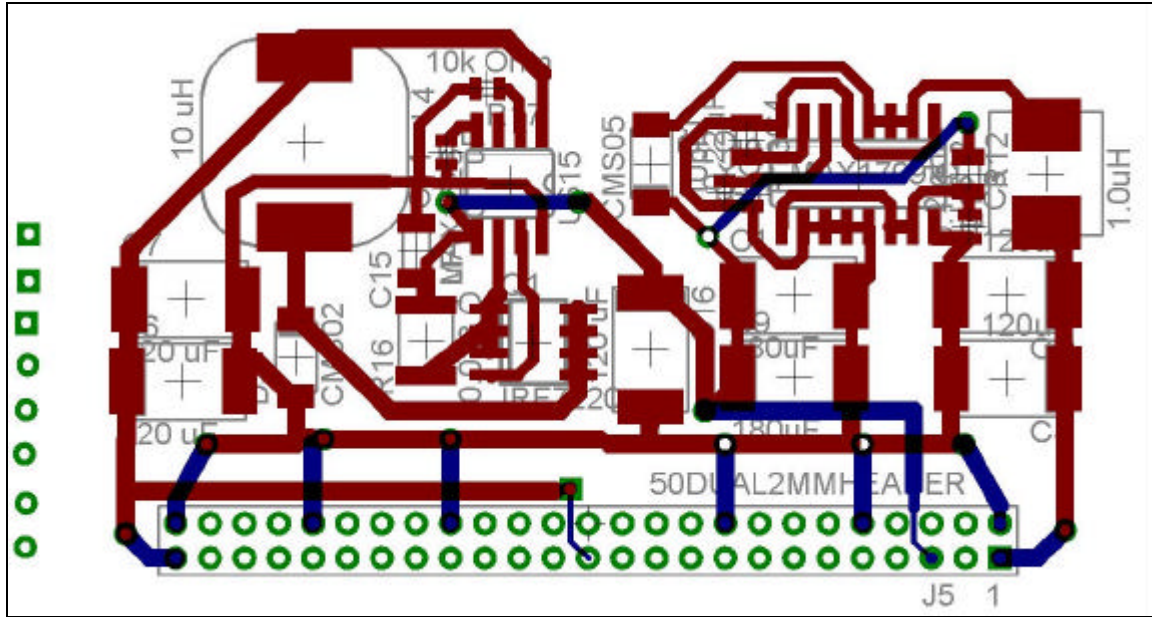


Figure 2.7, KUBESat Power Board Layout

Adding to frustration, the exact replica of this circuit was implemented and working on the new KUTESat-1 power board. The only difference in the new KUTESat-1 board and this, the KUBESat board, was that the KUTESat-1 board was fabricated by a professional PCB manufacturer.

Finally, a closer comparison between the two circuits revealed that although the specified trace widths were not the same for both circuits, the in-house manufactured boards has a much smaller power trace width. Additionally, the inherent nature of the milling process reduces the specified trace width by 10 to 30%. The depth of the copper is deeper than the mill bit causing the mill bit, which is virtually a cone shape tool, to grind away more than the desired portion of the copper. Figure 2.8 graphically demonstrates this phenomenon.

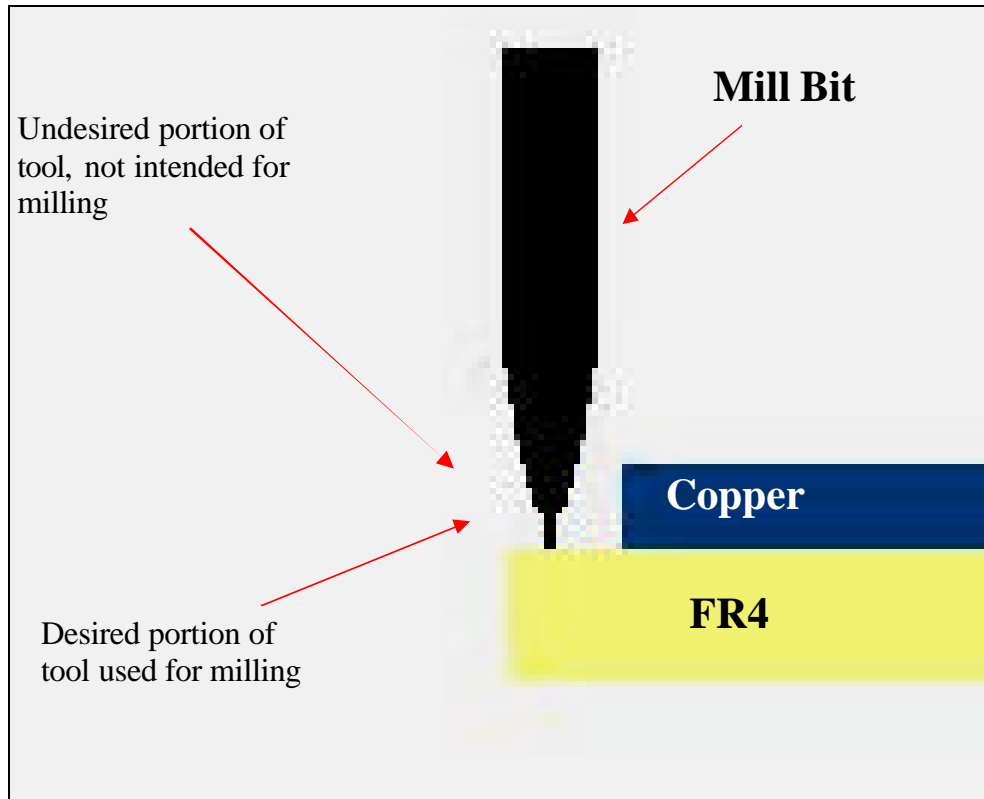


Figure 2.8, Milling Phenomena

Moreover, performing some basic first order trace width calculations using a standard PCB trace width calculator for the approximate current load reveals that even under the best case conditions, the system was bound to fail. The initial design specified 6 mil power-trace widths which under maximum current loads of 4 Amps could cause a 500°C temperature rise of the copper traces. This is not including any effects of the IC or the passive components. This explains why the IC and the passive components would overheat and start smoking.

The redesign of the KUBESat power board allots a maximum temperature rise of 20 °C (being conservative). Using standard trace width calculation procedures, calculating trace area in terms of current, and the trace width in terms of area and copper weight, Brad Suppanz's PCB

Trace Width Calculator specifies a microstrip trace width of approximately 49 mils. The new board's trace widths are 50 mils.

2.3.2 KUBESat Power Board: Testing

In order to verify the design changes yielded a working power board, power resistors were used to simulate loads and current consumptions. Table 2.1 summarizes the tested parameters and corresponding results.

Table 2.1, Test Parameters and Results for KUBESat Power Subsystem

<i>Section</i>	<i>Input Voltage (V)</i>	<i>Output Voltage (V)</i>	<i>Load (Ohms)</i>	<i>Output Current (A)</i>	<i>Input Current (A)</i>	<i>Efficiency (%)</i>
5v DC	3.6	5	0	0	0	0.00
5v DC	3.6	5	150	0.034	0.06	78.70
5v DC	3.6	5	68	0.074	0.12	85.65
5v DC	3.5	5	33	0.15	0.26	82.42
5v DC	3.5	5	15	0.34	0.6	80.95
5v DC	3.6	5	9.2	n/a	n/a	n/a
3.3v DC	5	3.6	0	0	0	0.00
3.3v DC	5	3.25	150	0.0218	0.03	47.23
3.3v DC	5	3.25	68	0.0476	0.07	44.20
3.3v DC	5	3.26	33	0.0958	0.13	48.05
3.3v DC	5	3.27	15	0.1977	0.28	46.18
3.3v DC	5	3.26	9.2	0.44	0.61	47.03

The efficiency coefficient, although not appearing optimal, is within expected and acceptable operating ranges. The components, as well as the trace widths, were not optimized for their respective applications. Furthermore, remembering that the 5v DC converter powers the 3v converter, the efficiency of the 3.3v DC converter is a function of the efficiency of the 5v DC converter and therefore must be significantly lower than otherwise expected.

Chapter 3: KUTESat-1

3.1 KUTESat-1: System Overview

The Kansas Universities Technology Evaluation Satellite-1, (KUTESat-1), system is very similar in functionality to the HABS module. The distinguishing difference is that the individual subsystems are all locally controlled using microprocessors which in turn communicate with the governing system's central control microprocessor. Providing modularized intelligence on a subsystem level allows for overall system sophistication and prompt response time to any developing system changes. A modularized function diagram of the complete KUTESat-1 Pathfinder Mission including the monitoring ground station is depicted in Figure 3.1.

As mentioned in chapter 2, until recently there were no fully functioning power systems in any of the ongoing satellite projects. Sections 3.2 provides a detailed description of the analysis, redesign, and testing of the Power Distribution subsystem. Section 3.3 outlines the design for the next generation Payload module which correctly interfaces with the high speed digital camera.

3.2 KUTESat-1: Power Distribution Subsystem

The power distribution subsystem consists of a multitude of functions including: generation of 3.3v, 5v, and 12v; primary, secondary, and payload current monitoring and control administration; analyzing satellite positioning via solar cell power generation; and governing power supply source, solar vs. battery. Figure 3.2 the schematic of the KUTESat-1 power board.

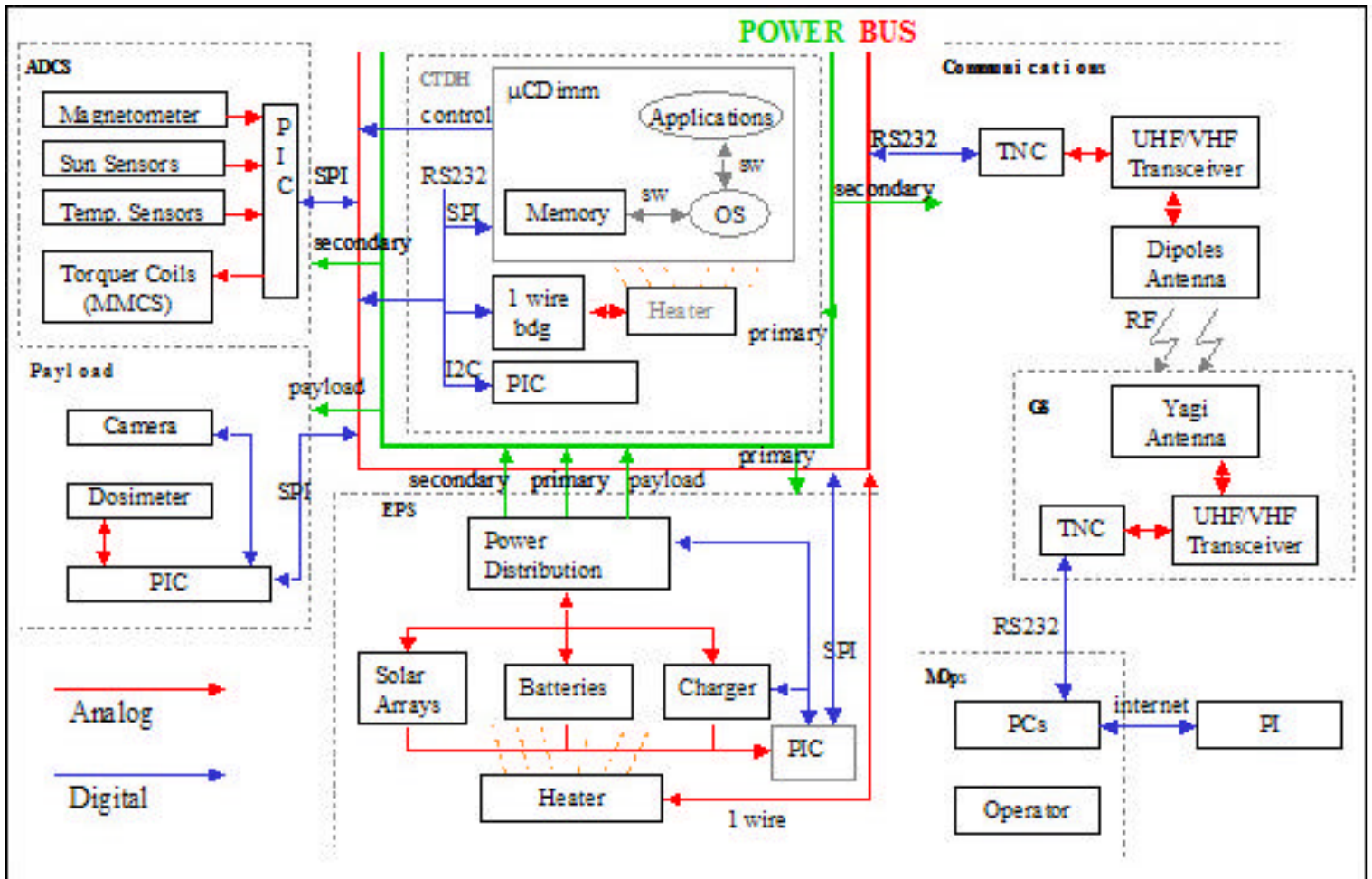
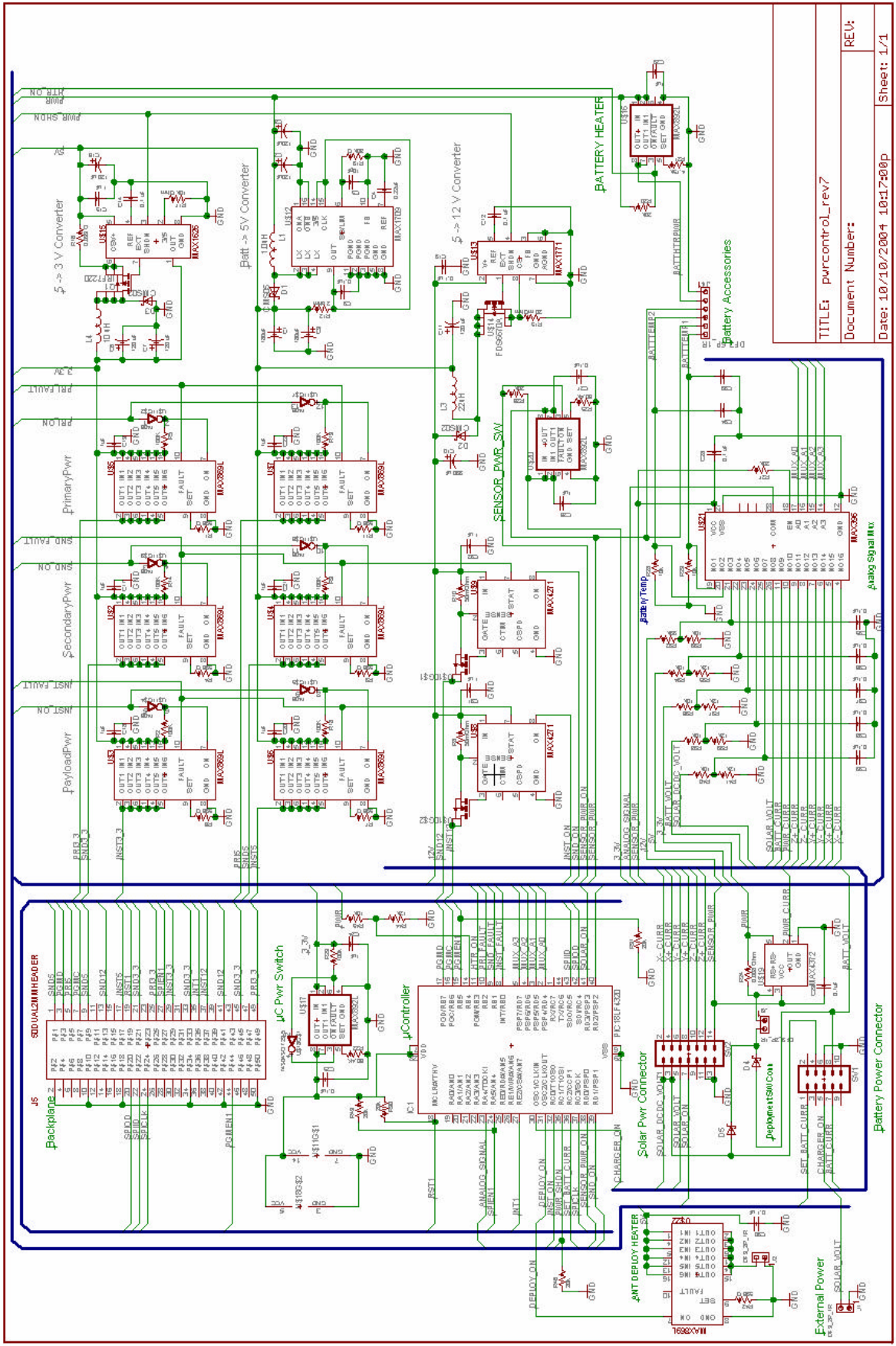


Figure 3.1, Pathfinder Mission Functional Module Diagram

All the fore-mentioned functions are monitored and controlled by the subsystem microprocessor. The microprocessor communicates to the KUTESat central processor via a backplane which connects all auxiliary boards. The backplane also serves as the power bus for the entire KUTESat-1 system.



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Figure 3.2, KUTESat-1 Power Board

3.2.1 KUTESat-1: Design Implementation Problems

The initial board was manufactured using the in-house mill. Although trace width of the power traces were a concern, they were not as narrow as the widths of the KUBESat Power Board. Furthermore, not only did the 5v DC converter not operate properly, the 12v DC converter was only providing around 8 volts. Figure 3.3 is a picture of the initially fabricated and populated power board.

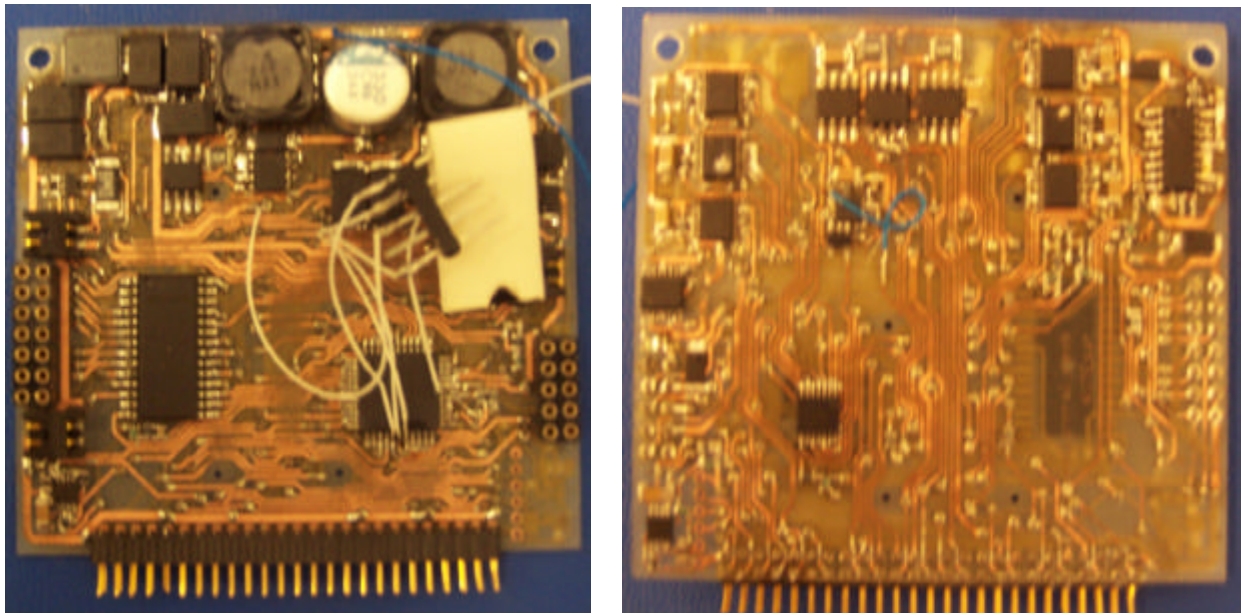


Figure 3.3, Original KUTESat-1 Power Board: top and bottom

As can be seen, this board's physical presence already presents a perplexed electrical platform. After countless hours, a short circuit was discovered impeding the output of the 5v DC converter and a diode that had been soldered was opposing the intended direction of current. The 12v section did not exhibit any visual imperfection or any improper component values. It was

eventually discovered that the wrong transistor was populated. The 'rogue' transistor could not supply the necessary power.

The next set of problems involved the PIC18F4320 microprocessor which could not be programmed correctly. Again, employing good engineering debugging procedures, the correct implementation could be found. The problem was two fold: 1), the microprocessor in-circuit programmer was found to be faulty. It should be mentioned that there are a multitude of in-circuit programmers available all utilizing slightly different methodologies. 2), by using another manufacture's in-circuit programmer which did not supply its own power, it was discovered that the microprocessor's active current supervisory subsystem was not providing the correct voltage.

Overcoming these impediments brought about yet another problem; the PIC could be programmed but would not execute any of its functions. Reevaluating all of the microprocessor's interfacing hardware, it was concluded that the software must be at fault. This is quite a unique circumstance, for the microprocessor confirmed it had been programmed correctly which can usually only be done if a working program is loaded. The code revealed that the incorrect microprocessor-inherent-function library had been used to compile the program yielding to the explanation that it must have been vary similar to the expected code.

The new and completely working board is presented below in Figure 3.4.

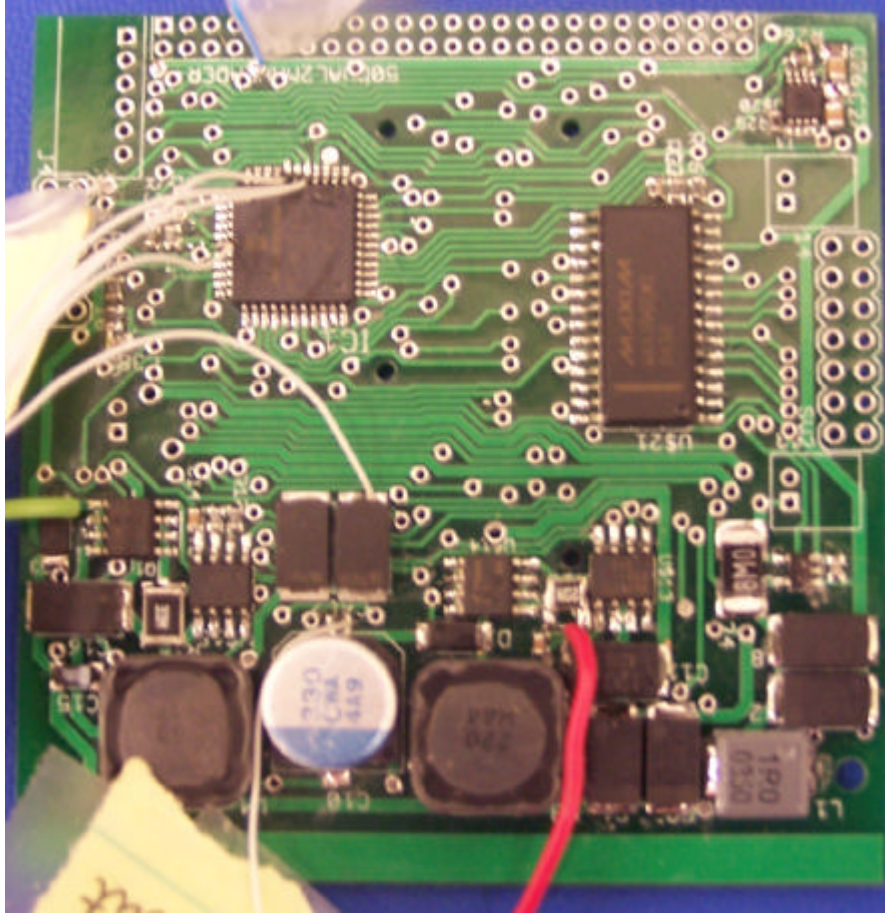


Figure 3.4, New KUTESat-1 Power Board

3.2.2 KUTESat-1: Testing

In order to verify the design changes yielded a working power board, power resistors were used to simulate loads and current consumptions. Table 3.1 summarizes the tested parameters and corresponding results. The yellow highlighted rows are tests conducted outside of the power rating of the test resistors, they represent conditions which forced the resistors to fail, and therefore are not to be taken into account.

Table 3.1, Test Parameters and results for the KUTESat-1 Power Subsystem

		<i>Input Voltage (V)</i>	<i>Output Voltage (V)</i>	<i>Load (Ohms)</i>	<i>Output Current (A)</i>	<i>Input Current (A)</i>	<i>Efficiency (%)</i>
	5v DC	3.6	5.3	0	0	0.03	0.00
	5v DC	3.6	5.07	150	0.034	0.075	63.84
	5v DC	3.6	5.07	68	0.075	0.16	66.02
	5v DC	3.5	4.98	33	0.15	0.28	76.22
	5v DC	3.6	4.76	9.2	0.52	2.3	29.89
5v Direct	3.3v DC	5	3.5	0	0	0.01	0.00
	3.3v DC	5	3.18	150	0.022	0.03	46.64
	3.3v DC	5	3.18	68	0.048	0.05	61.06
	3.3v DC	5	3.2	33	0.096	0.09	68.27
	3.3v DC	5	3.2	9.2	0.36	0.34	67.76
	12v DC	5	12.2	0	0	0.01	0.00
	12v DC	5	12.23	150	0.08	0.23	85.08
	12v DC	5	12.23	68	0.17	0.5	83.16
	12v DC	5	12.2	33	0.35	0.98	87.14
	12v DC	5	9.8	9.2	1.04	2.23	91.41
3.6 via the 5v DC	3.3v DC	3.6	3.6	0	0	0.02	0.00
	3.3v DC	3.6	3.3	150	0.022	0.05	40.33
	3.3v DC	3.6	3.3	68	0.048	0.085	51.76
	3.3v DC	3.6	3.29	33	0.096	0.15	58.49
	3.3v DC	3.6	3.31	9.2	0.458	0.86	48.97
	12v DC	3.6	12.45	0	0	0.02	0.00
	12v DC	3.6	12.5	150	0.085	0.5	59.03
	12v DC	3.6	12.48	68	0.18	1.05	59.43
	12v DC	3.6	12.2	33	0.36	2	61.00
	12v DC	3.6	n/a	9.2	n/a	n/a	n/a

The efficiency coefficient, although not appearing optimal, is within expected and acceptable operating ranges. The components, as well as the trace widths, were not optimized for their respective applications. Furthermore, remembering that the 5v DC converter powers the 3v and the 12v converter as tested in the cases in the “3.6 via the 5v DC” column, the efficiency of the secondary DC converters is a function of the efficiency of the 5v DC converter and

therefore must be lower than if it were powered directly as corroborated by the “5v Direct” column.

3.3 KUTESat-1: Next Generation Payload Module

The originally designed payload module did not account for the minimum data transfer rate of the Agilent ADCM Camera Module. The camera can only vary its transfer rate from 40 to 4 MHz even though an external clock must be provided. The data was being interfaced directly with the payload microprocessor. The PIC family microprocessors have a top operating speed of 1 MHz, but their performance becomes questionable. A schematic of the original board is shown in Figure 3.5.

In addition to capturing the image data, the payload board also has to provide the capability of storing the variable length data. Joint Photographic Experts Group (JPEG) does not have a standard file size, and sends small data packets to ground station via the system’s central processor and communication link. The communication link will be fairly slow due to the transmission delay and having to operate only while maintaining line-of-sight.

3.3.1 KUTESat-1: Solution

The use of IDT’s 72V298L10PFI FIFO provides the ideal solution. For one, all components selected for the satellite mission must be able to operate from -40°C to 85°C, usually referred to the industrial temperature range. Secondly, this component operates using two clocks: a read cycle clock, and a write cycle clock. This allows the least amount of

interfacing circuitry between the high-speed image data and the low-speed board governing microprocessor. Additionally, the 298 series FIFO is a 64Kbyte component which allows for approximately two pictures to be stored before having to clear the memory. At present the flight operations manuscript prescribes the complete processing - from capturing the image to receiving the image by the ground station - of one image at a time. The system's central processor will receive the image data packets and forward them to the communication subsystem at the lowest priority. Since the performance characteristics of the communication link can vary and the wait time being indeterminate, it could take up to several orbits before the complete image data is received and assembled.

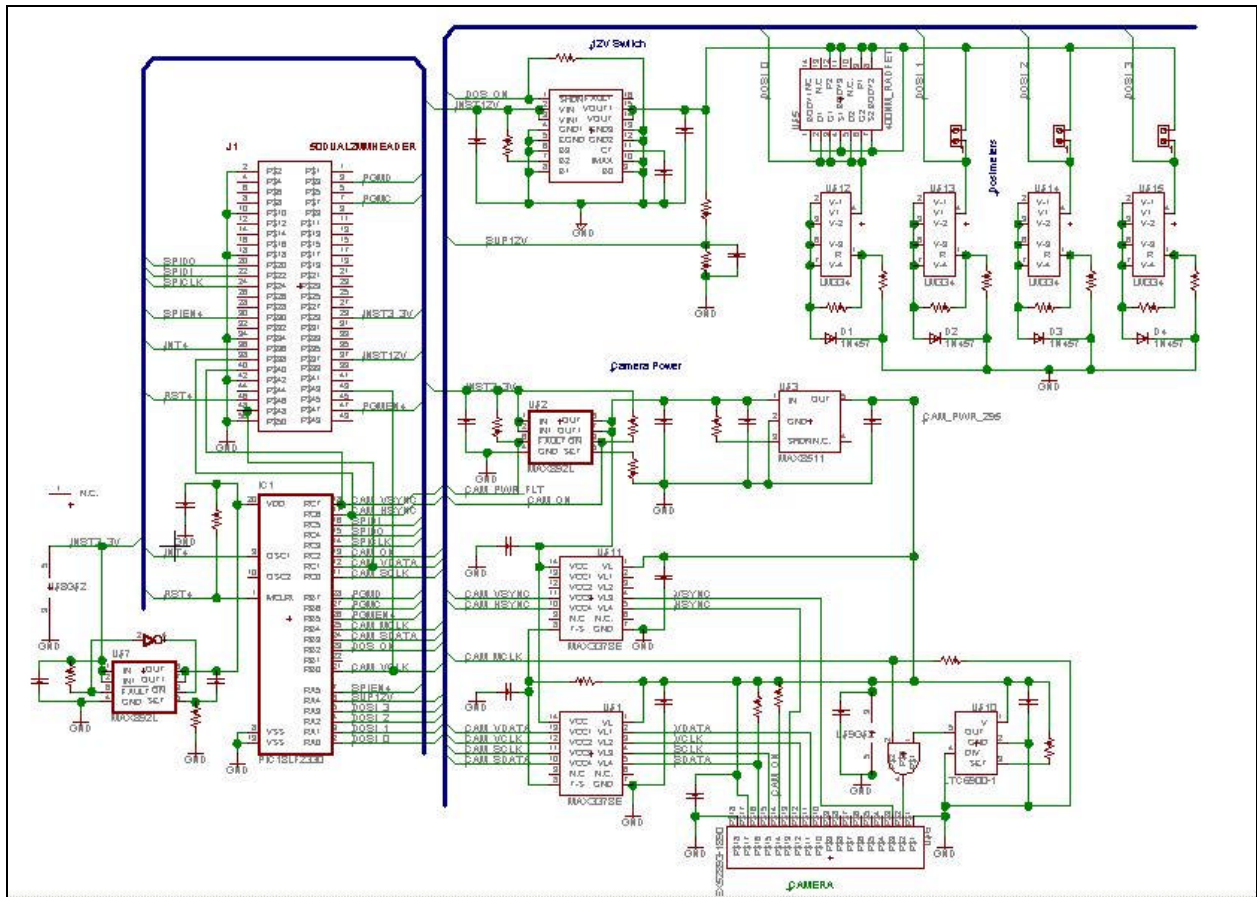


Figure 3.5, Original Payload Board Schematic

3.3.2 KUTESat-1: Implementation

In order to minimize the number of new components, the onboard clock, LTC6900, will remain the write clock source at its preprogrammed frequency of approximately 5.128 MHz. The microcontroller will control the transmission of the clock pulse to the camera via an OR Gate, U\$9 in Figure 3.5. The actual clock frequency is of little relevance since the same clock source drives the camera and the FIFO. The microcontroller provides the clock for the FIFO during data-reading cycles.

Previously all the data was transferred via a SPI bus. In order to simplify the transfer process, all of the data will be transmitted in parallel to the FIFO. Table 3.2 is taken directly from the Agilent camera manual and specifies all of the input/output (I/O) pins of the connector.

As can be seen from Table 3.2, pins 4 through 11 serve as the data byte and pin 3 and pin 13 are JPEG specific data formatting information bits. It is not yet known if these signaling bits will be necessary to reassemble the image. In order to design the most dynamic and forgiving data capture system, all output data will be captured for post processing on Earth. Currently all 8 data bits will be in one byte and the two signaling bits, with 6 conditioning bits set to zero, will comprise the second byte. If it is discovered at a later time that the additional two bits are not needed, it will be very easy to update the system to only read the first byte.

Table 3.2, Agilent ADCM-1650 Camera Manual page 8

Pinout				
Location	Signal Name	Type	Description	Notes
1	GND	Common	System Ground	
2	MCLK	Input	Module Clock	
3	VSYNC	Output	Vertical Synchronization	[End_of_Frame]
4	DATA0	Output	Parallel Data 0	
5	DATA1	Output	Parallel Data 1	
6	DATA2	Output	Parallel Data 2	
7	DATA3	Output	Parallel Data 3	
8	DATA4	Output	Parallel Data 4	
9	DATA5	Output	Parallel Data 5	
10	DATA6	Output	Parallel Data 6	
11	DATA7	Output	Parallel Data 7	
12	VCLK	Output	Video Clock	[Data_Ready]
13	HSYNC	Output	Horizontal Synchronization	[End_of_Line]
14	ON/OFF	Input	Voltage Regulator Control	
15	SCLK	Input	Serial Interface Control Clock	
16	SDATA	Input/Output	Serial Interface Control Data	
17	V _{CC}	Input	Voltage Input	
18	GND	Common	System Ground	

It may also be noted that Table 3.2 has 12 outputs. Pin 16's data is only relevant if the communication is implemented via a SPI bus. Pin 12 is the data ready line which indicates that the data buffer on the camera is full and ready to transfer. All outputs from the camera are voltage level translated. The camera operates at 1.8v and the microcontroller and the FIFO operate at 3.3v.

The original PIC microcontroller, 18LF2330, only provides 17 I/O ports, which is not enough. The 18F4520 provides 35 I/O ports which will be needed for both the parallel data capture and for the controlling logic of the FIFO.

The existing dosimeters subsection will remain untouched except for an additional voltage supply translation circuit. The complete payload board, from a subsystems level, will be composed of four main sections: Dosimeters, Camera, Microprocessor, and Power Translation, Figure 3.6.

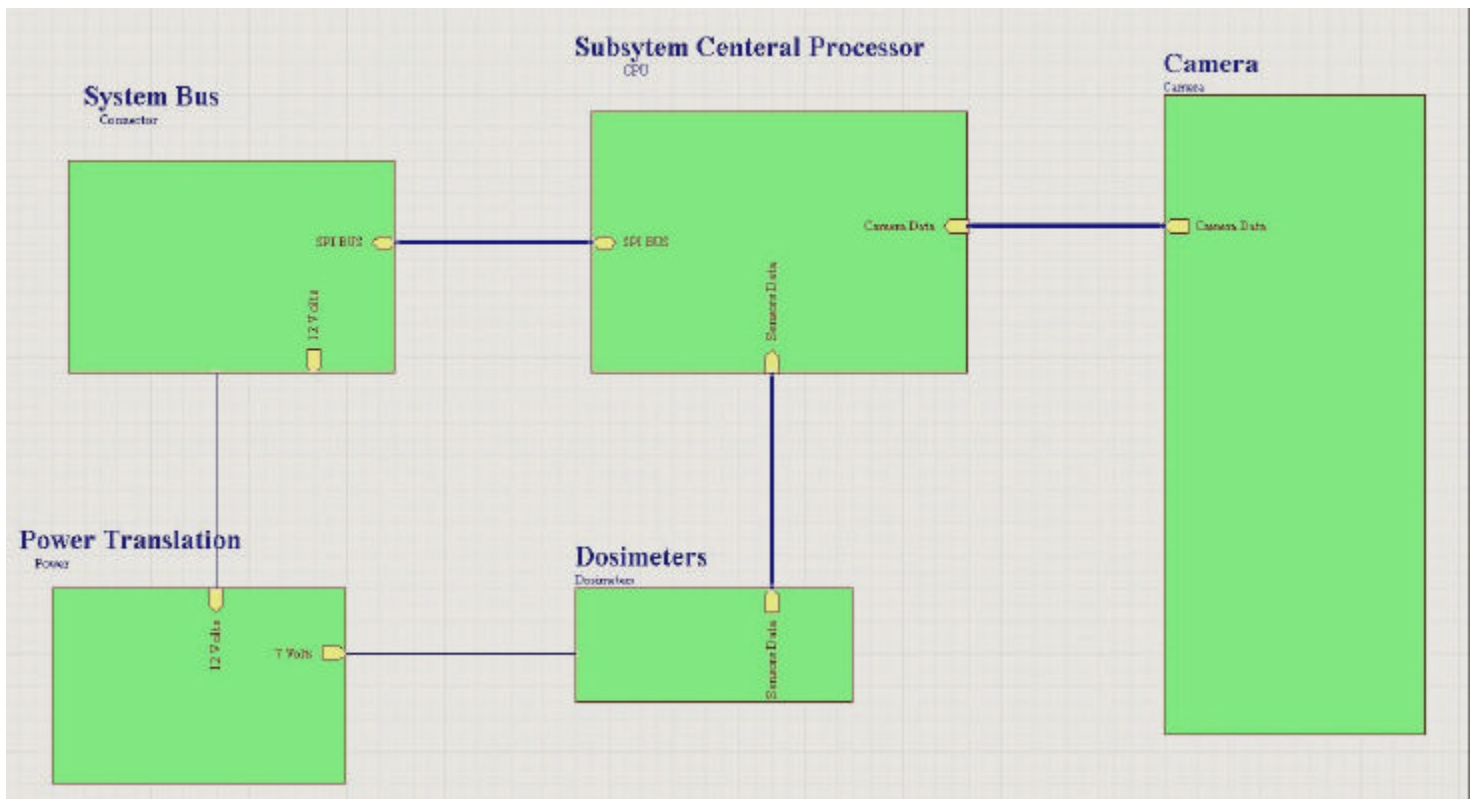


Figure 3.6, Payload Subsystem Overview

Chapter 4: KUTESat-2

4.1 KUTESat-2: Motivation for New Power Subsystem Design

Efforts have already been underway to start the design process for the forthcoming second pico-satellite. In addition to the new functionalities that will be incorporated, the existing subsystems from KUTESat-1 will undergo modifications and redesign work if necessary.

The power subsystem must be redesigned for several reasons. One, an improvement to the efficiency of each voltage converter will enhance the entire system performance. Currently, an algorithm is in place that monitors the battery level. Once it reaches 50% capacity, all system functions, including communications, are suspended allowing virtually all of the power generated from the solar cells to recharge the battery. The duration of this process is yet to be determined; the only certainty is that it could take up to several orbits before the system could again assume its tasks.

Secondly, the heat dissipation from each conversion circuit has a two fold effect. First it creates heat which is a major issue in space, a vacuum, for it is very hard to redirect. This is not usually a major issue for terrestrial applications, for the ambient air can function to exchange the heat. Secondly, the lingering heat produced by these circuits will cause the components themselves to fail more readily.

Third, the battery only has a limited life cycle. Reducing the number of times it has to be charged and discharged will prolong the satellite's lifetime.

4.2 KUTESat-2: Design And Characterization Of New Components

The initial augmentation to the original design will be the implementation of next generation solar cells. KUTESat-1 is currently using dual junction solar cells which exhibit approximately 21.5% nominal efficiency. Triple junction solar cells, the next generation of solar cells, provides approximately 26.5% nominal efficiency. The increased power conversion efficiency will prolong the battery life by addressing more of the satellite system's power needs. The triple junction solar cells are available from Spectrolab, a Boeing subsidiary. Spectrolab is also the provider of the current solar cells used in the KUTESat-1 mission.

The KUTESat-2 will be using the Honeywell S-Band Transceiver which has a power requirement of 28 volts nominal (26 – 30v) and 2 amps. McDowell Research Corporation manufactures a rechargeable lithium ion battery, MRC-2590, that can source 28.8 volts at 6 amps. This is a great match for the overall system. The requirements are as follows: 3.3v at 250mA, 5.0v at 300mA, 12v at 100mA, and 28v at 2A. The MRC-2590 would be able to provide more than double the system's required power consumption. Furthermore the McDowell battery specifies that it is capable of more than 500 charge cycles.

In order to address the DC converter efficiency, each voltage level will be derived directly from the main battery source. Although initially this may seem like a greater financial burden than the previous solution, the monetary difference is nominal. The price of the supplemental components that are needed to yield a better efficiency would cost roughly the same if not more. Furthermore, implementing a 'one box' solution guarantees quality of service. On the other hand, even if premium components are used, the layout and the characteristics of the printed circuit board itself can attribute to the overall performance. Table 4.1 presents a series of 'one step solutions' DC to DC converters for all of the voltage-level requirements.

Table 4.1, DC to DC Converter Operation and Performance Parameters

<u>LES SERIES - 15 WATT</u>							
MODELS - (See the last page of section for options.)							
MODEL	INPUT VOLTAGE (VOLTS)	INPUT VOLTAGE RANGE (VOLTS)	MAXIMUM INPUT CURRENT (AMPS)*	OUTPUT VOLTAGE (VOLTS)	RATED OUTPUT CURRENT (AMPS)	RIPPLE & NOISE pk-pk (mV)	TYPICAL EFFICIENCY**
LES008YD	24	18-36	0.6	2.5	3.00	75	77%
LES010YE	24	18-36	0.8	3.3	3.00	100	81%
LES015YG	24	18-36	1.1	5	3.00	100	84%
LES015YH	24	18-36	1.3	12	1.25	120	85%
LES015YJ	24	18-36	1.3	15	1.00	150	86%
LES008ZD	48	36-75	0.35	2.5	3.00	75	77%
LES010ZE	48	36-75	0.4	3.3	3.00	100	81%
LES015ZG	48	36-75	0.6	5	3.00	100	83%
LES020ZG-3N	48	40-60	0.63	5	4.00	100	84%
LES015ZH	48	36-75	0.65	12	1.25	120	86%
LES015ZJ	48	36-75	0.65	15	1.00	150	86%

NOTES: * Maximum input current at minimum input voltage, maximum rated output power.
 ** At nominal V_{OUT} , rated output.

Additionally, the typical efficiency is on average 30% better than previously achieved by the power subsystem designed for KUTESat-1. Furthermore, all of these components meet the industrial temperature rating and are readily available from Digikey.

Chapter 5: Conclusions & Future Work

5.1 Conclusions

The designs and proposed ideas for new designs presented in this work attempt to provide a realistic and fundamentally sound approach to solving the many different pico-satellite application needs. In order to ensure the highest level of standard and the university's role as a leader among the CubeSat community, a continual effort must be exerted to constantly analyzed, redesigned, and test the existing satellites.

The power boards for both the KUBESat module and the KUTESat-1 mission have been tested in a controlled environment and have proven to be flight worthy. The KUBESat is ready to fly this upcoming weekend, but may be delayed until next semester due to the availability of students. And the KUTESat-1 mission is to be launched into outer space sometime during the month of March 2005. The Payload board is nearing completion, as well, and should be ready for delivery to the launch integrator in January. The next generation power system for the KUTESat-2 will not become an active endeavor until after the successful launch of the KUTESat-1 mission. As for the HABS interface board, it too will be pursued after KUTESat-1 is underway, at which time the BallonSat will become an integral part in testing next generation subsystems.

5.2 Future Work

5.2.1 HABS

The next generation HABS module should limit the needed interaction with the internal modules. Currently the preflight test consists of reopening the HABS module completely and testing each subsystem manually. The Freedom 16 microprocessor's manufacturer can provide an external LCD display with an interactive keypad, which could be used to interface with the module's central processor to conduct all of the onboard tests externally. Figure 5.1 is a picture of Steroidmicros' LCD Arrow-pad Mounting Kit which would be necessary to fully integrate the external display with the governing microprocessor. Additionally, Steroidmicros already provides the core program functions to interface with the arrow-keypad greatly reducing development time and effort.

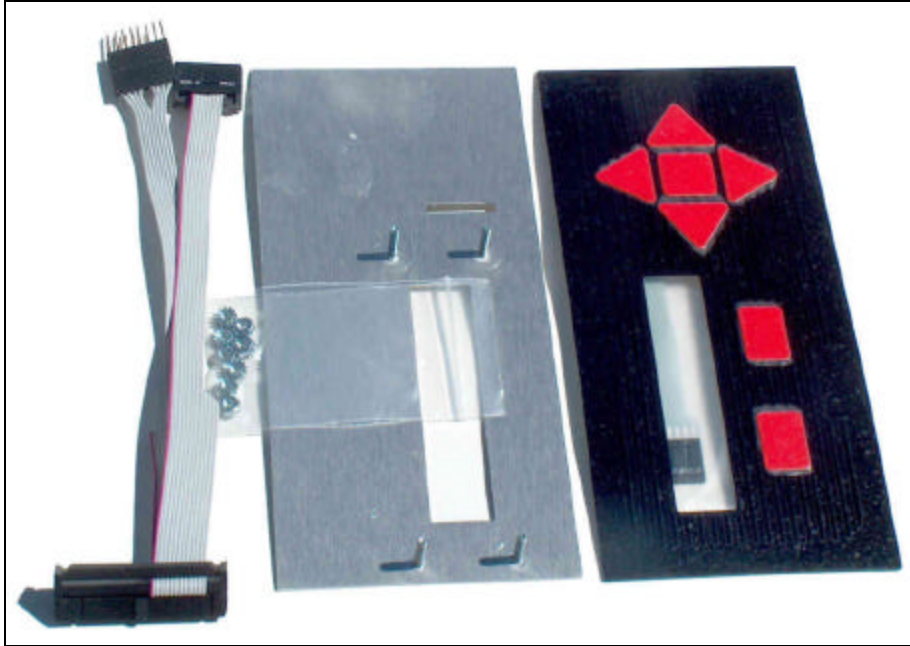


Figure 5.1, LCD Arrow-Pad Mounting Kit

The new front panel would consist of a recessed cavity which will house the LCD & Arrowpad interface and the power input for the recharging. Prior to launch, a protective lid will seal the cavity shielding both the LCD and the power input from moisture, as shown in Figure 5.2.

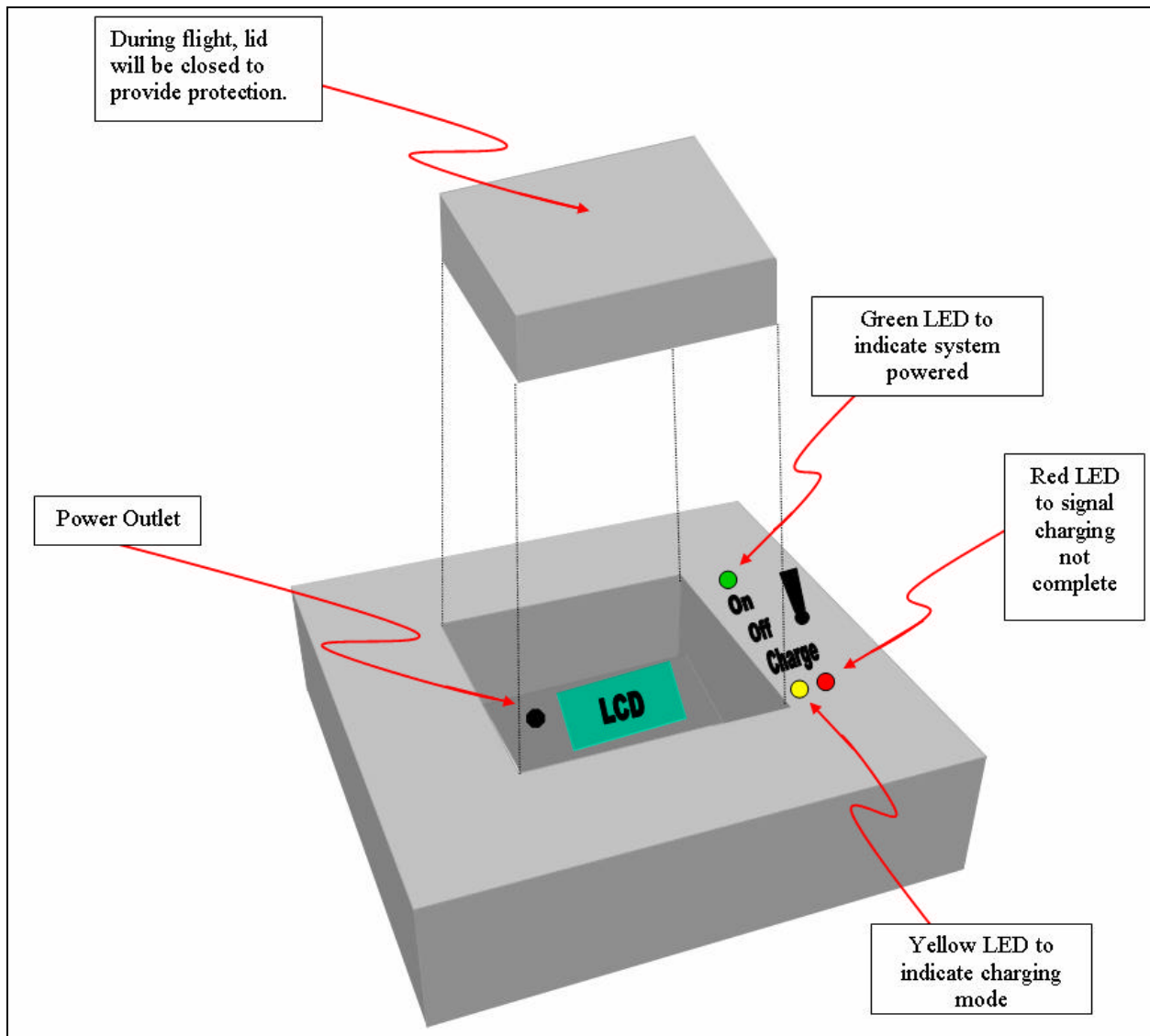


Figure 5.2, Next Generation HABS Front Panel

The power control will be located on the front panel via a three position switch, as depicted in Figure 5.2: on, off, charging. Status indication lights will confirm that the proper selection is active as describe in Table 5.1. When the switch is in the on position the green LED will be illuminated. Placing the switch in the charging position will illuminate both the yellow

and the red LED. The red status LED will be turned off after the charging cycle has been completed.

Table 5.1, LED Operation Mode Indication Table

	Status LEDs		
	Green	Yellow	Red
<i>Power Off</i>			
<i>Power On</i>	<i>Active</i>		
<i>Charging</i>		<i>Active</i>	<i>Active</i>
<i>Charging completed</i>		<i>Active</i>	

It is notable to mention that the input connector for the 12 volt recharging unit will be located next to the LCD display on the front panel. When the system is placed in recharging mode, the Kenwood transceiver battery will simultaneously be recharging as well. A layout of the Front Panel is depicted in Figure 5.

5.2.2 KUTESat-2

All of the future modifications to be done for the KUTESat-1 will be incorporated into the new work undertaken for the KUTESat-2 satellite. In addition to the components specified for the power board, a simple charging circuit and a transfer circuit collecting the power generated from the solar cells have to be designed. These tasks should be fairly trivial since both functions already exist and operate for the KUTESat-1 system.

References:

Kenwood Corporation, Kenwood TH-D7AG:

<http://www.kenwood.net/indexKenwood.cfm?do=ProductDetails&ProdID=5018&Group=5>

Last Updated: March 2003

Garmin Ltd, Garmin GPS-35-HVS: <http://www.garmin.com/products/gps35/>

Last Updated: September 2003

INTEC Automation Inc., Freedom-16, ss16V2: <http://www.steroidmicros.com/ss16.html>

Last Updated: October 2000

Spectrolab Inc., Solar cells: <http://www.spectrolab.com/com/com.htm>

Last Updated: May, 2002

McDowell Research Corporation, MRC-2590:

<http://www.mcdowellresearch.com/pdf%20files/Batteries/MRC-2590%20Data%20Sheet.pdf>

Last Updated: January, 2002

Power-One Inc., DC converters:

<http://rocky.digikey.com/WebLib/Power%20One%20Web%20Data/LES%20Series%20-%2015%20Watt.pdf>

Last Updated: March, 2001

Jupitermedia Corporation, CSMA: http://www.webopedia.com/TERM/C/CSMA_CD.html

Jupitermedia Corporation, UART: <http://www.webopedia.com/TERM/U/UART.html>

Jupitermedia Corporation, SPI: <http://www.webopedia.com/TERM/S/SPI.html>

Author: Brad Suppanz; *Trace width calculator:*

<http://www.geocities.com/CapeCanaveral/Lab/9643/TraceWidth.htm>, 6/12/98

Last Updated: July, 2004

Web Info Power Designers, DC converters:

http://www.powerdesigners.com/InfoWeb/design_center/articles/DC-DC/converter.shtm

Last Updated: January, 1998

Author: Isaac Nason, Jordi Puig-Suari, Robert Twiggs; *Development of a Family of Picosatellite Deployers Based on the CubeSat Standard:*

http://cubesat.calpoly.edu/_new/references/ppod_paper.pdf, January, 2002 IEEE: 0-7803-7231-X/01

Author: Dr. Trevor C. Sorensen; “*Conceptual Description of the Kansas Universities, Technology Evaluation Satellite 2 (KUTESat-2)*”;

Author: Dr. Trevor C. Sorensen, Marco Villa; 2004 EPSCoR Proposal, “*Kansas Universities’ Technology Evaluation Satellite – The Mist Mission*”; 2004