

Satellite Health Sensors and  
Power Control Network

Junior Design – Spring 2006

Team Members:  
Nathan Greenfield  
Josh Miller  
David Meyn

Faculty Advisor:  
Dr. Rob Maher

## Table of Contents

<b>Project Description</b>	
Description	3
Specifications	3
<b>Proposed Design</b>	
Proposed Solution	5
Foreseeable Challenges	7
<b>Project Management</b>	
Team Organization	7
Tasks to be Accomplished	8
Time Table	8
Parts and Materials Budget	9
<b>Project Deliverables</b>	10
<b>Associated Impacts of Design</b>	10
<b>Appendices</b>	
Appendix A – Schematics	12
Appendix B – Software Flow Chart	15
Appendix C – Power and Temperature	
Ratings for Monitored System Components	18
Appendix D – Gantt Chart of Design Project	20
Appendix E – Relevant Data Sheets	22

## **Project Description and Specifications**

### **Description:**

The purpose of this design project is to provide a system to monitor and control the power being delivered to various key components aboard the Space Science and Engineering Lab's BarnacleSat class satellite, Electra. In the event of a power problem, the sensor network must be able to detect the event, determine the severity of the problem, and disconnect the malfunctioning component from the satellite's power bus.

A satellite is confronted with different conditions while operating in orbit compared to functioning on a laboratory bench. One such concern is the flash memory module onboard the satellite receiving a charged particle strike while in orbit. This charged particle can cause the flash memory to latch-up which would result in a dangerous increase in current draw. Left unchecked, this current draw can destroy the flash memory, resulting in complete mission failure.

### **Electra Background:**

The mission of Electra will be to test the deorbiting capability of an electrodynamic tether to aid in slowing the accumulation of "space junk" in orbit around the Earth. The electrodynamic tether will drag through the Earth's magnetic field and decrease an orbiting objects total kinetic energy to bring it out of orbit more rapidly than if left alone. CubeSat class satellites are especially troublesome as they can remain in orbit for more than 25 years when placed in high orbits. Electra will be deployed from a Delta II booster and remain connected to the booster by a tether. High resolution GPS data will be collected to monitor the deployment of the tether and this data will be stored in the flash memory module to be transmitted to the ground for analysis. Protection of this data is vital to the success of the mission, which is the driving consideration for the sensor network.

### **Specifications:**

The entire design calls for at least twelve sensors to measure currents, voltages and temperatures throughout the satellite. These sensors must be 3.3 V compatible parts to run from the satellite's existing power system. Four current sensors will monitor the current draw from the radio, GPS receiver, RF amplifier and the flash memory. Four more current sensors will be monitoring current output from the four solar panels powering the satellite. The onboard battery will require three separate sensors for monitoring voltage, current and temperature. Four temperature sensors will be mounted throughout the satellite for structural thermal analysis. Appendix B contains a spreadsheet listing the range of values each sensor will be required to monitor, including temperature, voltage and current, depending on the specific component it will be connected to.

An I<sup>2</sup>C communication bus will be used to relay the data from the sensors to the flight computer for logging and fault management. Once the data has been received by the flight computer, the measured values will be used to determine if a given component is operating within specifications. An example would be whether or not the battery is within a given temperature range to permit safe charging while the satellite is exposed to the sun. The I<sup>2</sup>C drivers used to communicate with the sensors must be compatible with the Freescale MC9S12XDP512 flight computer.

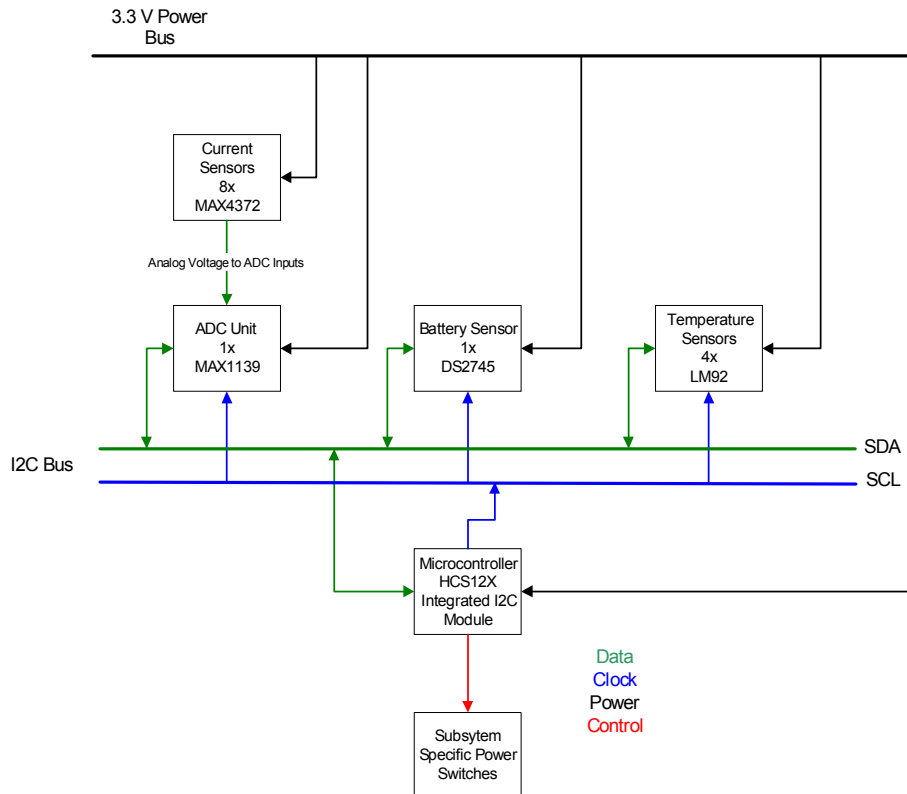
The network must be functional on a development/prototype board to be integrated into the satellite for bench testing. Printed circuit boards are not required as the system will share board space with multiple subsystems upon completion of the satellite.

A summary of the required specifications for confirmation of the final design is included below:

- 3.3 V Compatible Parts
- I<sup>2</sup>C Communication between sensors and flight computer
- Minimum of twelve (12) sensors
- Selected components must be able to operate within the temperature range expected for the satellite in space. (-10°C - 20°C)
- Low power consumption
- Power regulation system to control power to components in case of system error, especially flash memory power errors
- Software compatible with Freescale MC9S12XDP512

## Proposed Design

The solution for the sensor network employs the use of sensors with both digital and analog outputs to monitor the required systems. All of the proposed components meet the 3.3 V specification, the operating temperature requirement and can be connected to an I<sup>2</sup>C bus for communication. Summaries for each selected component begin below. The schematics for the proposed solution can be found in appendix A and relevant data sheet excerpts containing operating specification and example application circuits can be found in appendix C. The following block diagram summarizes the sensor network.



### Current Sensors:

The selected current sensors are Maxim MAX4372 high side current sensors. Low power consumption and a wide range of high side input voltage makes this sensor ideal. With only 30  $\mu$ A of supply current needed for operation, the MAX4372 will have little effect on the current power budget for the satellite. The high side voltage input can range from 0 to 28 V and is also independent of the supply voltage. This is an advantage for measuring the solar cell output current as the high side voltage can exceed the supply voltage by nearly 600 mV. The sensor will output a voltage directly proportional to the current measured through the sense resistor. External sense resistors will be used to customize the full scale current limits depending on the component to be measured. The sense resistors to be used in the design will be 1% resistors to provide the most accurate sensor data due to the small currents that will be measured. There is a 20 V/V gain between the voltage output and the voltage across the sense resistor. The 20 V/V gain was selected to match the input to the analog to digital converter which will be used to transmit the sensor data to the flight computer. Each sensor output will have to be

calibrated for the most accurate telemetry as the output gain for each sensor varies to a small degree. The characterization of each sensor is a trivial task which will not require substantial time to complete. The ADC will be discussed in detail in the next section.

#### Analog to Digital Converter:

An analog to digital converter will be used to convert the analog voltage output from the current sensors to a digital value that can be sent to the flight computer. The Maxim MAX1139 provides not only A/D conversion but also an I<sup>2</sup>C interface to transmit the digital values. Following with the low power consumption specification, the MAX1139 automatically goes into standby mode when not in use and only requires full power when called upon to convert analog signals. Twelve input channels are available for conversion of either current sensor data or voltage bus levels. One of the twelve input channels will be used to supply a 3.3 V reference voltage for the conversion. The input voltage can vary from -0.3 V to  $V_{DD} + 0.3$  V which led to the above mentioned decision to use the 20 V/V current sensors. With the typical full scale sense voltage of 150 mV, a gain of 20 V/V puts the maximum current sensor output at 3 V. This gives a buffer for the converter input voltage of 0.6 V. Each conversion channel can be accessed separately or in sequence from the I<sup>2</sup>C bus.

#### Temperature Sensors:

National Semiconductor LM92 temperature sensors will be used to measure the satellite's structural temperature at various points of interest. These sensors were chosen based on recommendations from members of other SSEL projects and due to the fact that they are already I<sup>2</sup>C compatible and simple to implement. The stable and measurable temperature range for the sensors is -25°C to +125°C. The expected temperature range for the satellite and structure is -10°C to 20°C.

#### Battery Sensor:

Instead of using individual sensors to measure the voltage, current and temperature of the battery, a single chip solution will be used. Maxim's DS2745 battery monitor provides measurement of all three values and is I<sup>2</sup>C compatible. The temperature is measured through direct physical contact with the battery and the value is converted with a built-in ADC. Voltage measurements are taken directly from the high side of the battery with the sensor connected in parallel with the battery. The ADC used by the temperature sensor is multiplexed to also handle voltage conversion. An external current sense resistor is connected in series with the battery's ground path to measure the current flow. A separate ADC is used to convert the sense voltage to a digital value. Each measured value is stored in a separate data register that can be accessed through the I<sup>2</sup>C interface. The DS2745 is also designed specifically for monitoring Li-Ion batteries which the satellite will use for energy storage.

#### Power Control:

Once the data from individual sensors is transmitted to the flight computer, subsystems will be checked for possible fault conditions. An example of a fault condition is high current draw from the flash, indicating the flash has latched up. If this occurs the power to the flash must be cycled to prevent damage to the flash. A P-type enhancement

MOSFET device will be connected in series to the input voltage pin of each monitored component to control the power. The gate of each MOSFET will be connected to an output pin on the flight computer to control the current flow through the MOSFET. A P-type enhancement device was selected due to the fact that current will flow while the gate is grounded. This means that the output pin controlling the gate must only be set high to disconnect the power.

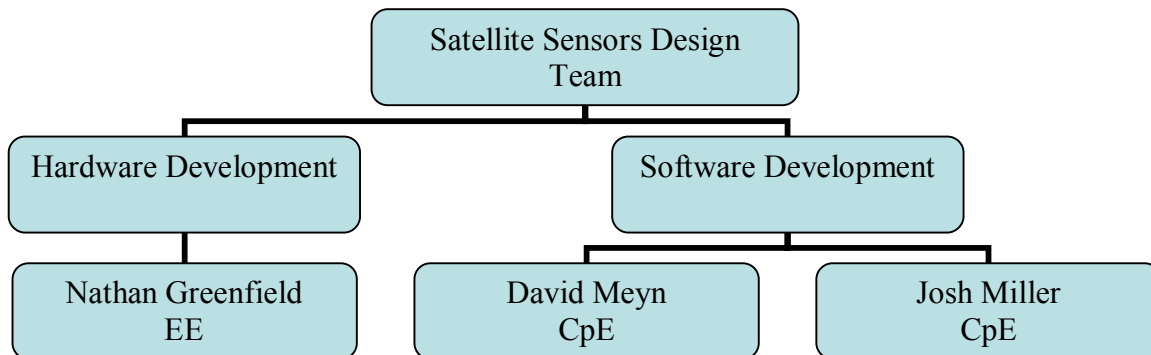
Foreseeable Challenges:

With the majority of the hardware selected, software development will require a large majority of the design time. The software will also be required to test the hardware that requires I<sup>2</sup>C communication to extract sensor data. By the end of spring semester, basic I<sup>2</sup>C drivers will be completed for the subsystem demo. These drivers will read temperature data from an LM92 sensor and display the results using a bank of LEDs or an LCD screen. Once the drivers are completed, additional software will be written during the fall semester to actually analyze the incoming sensor data and take the proper action depending on the related subsystem.

**Project Management**

Team Organization:

The design team has been divided into two groups, hardware and software development. The organization of the design team is shown below.



Weekly design meetings have been established with both the customer and faculty advisor. These meetings allow all those involved with the project to remain apprised of new developments on all aspects of the project. The meetings are also forums for new ideas or problem solving techniques that may not have been thought of by individual members.

By using the team organization shown above, the following tasks have been assigned to each group and a corresponding team member. This task list is limited to tasks that pertain to the design, construction and testing of the system. A complete task

list including requirements for EE 391/492 is included in the time table in the following section.

Hardware Development	Software Development
1) Selection of hardware components Nathan Greenfield	1) Software Flowchart Dave Meyn, Josh Miller
2) Hardware Schematics Nathan Greenfield	2) I <sup>2</sup> C A/D Interface – MAX1139 Dave Meyn
3) Customization of components to specific subsystems – i.e. current sense resistors Nathan Greenfield	3) LM92 Interface Josh Miller
4) Mounting of sensors to surface mount boards for bench testing integration Nathan Greenfield	4) I <sup>2</sup> C General Purpose Drivers Dave Meyn, Josh Miller
5) Sensor calibration Nathan Greenfield	5) Integration with existing flight software Dave Meyn, Josh Miller
6) Hardware Debugging Nathan Greenfield	6) Software Troubleshooting and Debugging Dave Meyn, Josh Miller
7) Final construction and integration of system Nathan Greenfield, Dave Meyn, Josh Miller	

Upon completion of the above listed tasks, the sensor network will be ready for delivery to the SSEL as a complete subsystem.

#### Time Table:

The following timeline lists the milestones of the project, their due dates and the required steps that will need to be completed to be considered successful. Appendix D contains a Gantt chart listing each of the below requirements with specific time spans for the listed subtasks.

#### **Spring Semester - 2006**

- *Design Presentation* – 2/16/06
- *Preliminary Design Review* – 3/30/06
  - Hardware Selection
  - Hardware Testing w/o I<sup>2</sup>C
  - Initial Schematics
- *Design Proposal* – 4/20/06
  - Team Tasks/Management Assigned
  - Parts Budget
  - Finalize Goals/Deliverables
- *Poster* – 4/24/06
- *Subsystem Demo* – 4/27/06
  - I<sup>2</sup>C Driver Development
  - Software Demo Development



**Fall Semester – 2006** (dates subject to change - dependent on class schedule)

- *Hardware Development and Construction* – 9/8/06  
     Ordering All Parts and Materials  
     Surfboard Construction
- *Hardware and Software Testing* – 11/24/06  
     Software Development (Full System)  
     Subsystem Testing  
     Full System Debugging  
     Confirmation of system functionality  
     Design Revisions (if required)
- *Integration/Documentation* – 12/4/06  
     Software Documentation  
     Project Binder
- *Final Design Review* – 12/8/06  
     Final Report  
     Final Project Demonstration  
     Final Presentation
- *Design Fair* – 12/7/06
- *Final Delivery Of Sensor Network*– 12/8/06

Weekly design meetings with the faculty advisor and customer will also be scheduled for the fall semester.

Budget:

The majority of the components to be used for the sensor network will be provided by the SSEL. These components are listed with an actual cost of \$0.00. Small scale components such as 5% resistors and capacitors are not included in the following budget due to relatively low cost. The 1% sense resistors are included due to the higher price per resistor compared to typical 5% resistors.

<b>Component</b>	<b>Manuf</b>	<b>Part No.</b>	<b>No. Req'd</b>	<b>Price</b>	<b>Typical Cost</b>	<b>Actual Cost</b>
Microcontroller	Freescale	MC9S12XDT512	1	\$15.01	<b>\$15.01</b>	<b>\$0.00</b>
Temperature Sensors	National Semi.	LM92	4	\$1.88	<b>\$7.52</b>	<b>\$0.00</b>
Current Sensors	Maxim	MAX4372	8	\$1.34	<b>\$10.72</b>	<b>\$0.00</b>
A/D I2C Module	Maxim	MAX1139	1	\$6.69	<b>\$6.69</b>	<b>\$0.00</b>
Battery Sensor	Maxim	DS2745	1	\$1.84	<b>\$1.84</b>	<b>\$1.84</b>
Sense Resistors (1%)	Ohmite		9	\$1.54	<b>\$13.86</b>	<b>\$13.86</b>
<b>Totals</b>			24		<b>\$55.64</b>	<b>\$15.70</b>

## **Project Deliverables:**

Upon completion of the project in December of 2006, the SSEL will receive the following:

- 1) Fully functioning sensor network ready for bench testing integration
- 2) Software I<sup>2</sup>C Drivers for data and sensor communication
- 3) Project Binder
  - a. Hardware datasheets
  - b. Software documentation
  - c. Final schematics with subsystem specific component values
  - d. Final budget

The above listed items will be made available in both standard and electronic form for addition to the SSEL documentation library and data server.

## **Engineering Impacts:**

- *Economic*
  - Due to the high costs of launching a satellite, construction costs should be kept as small as reasonably possible for a university funded project. Keeping the sensor network cost low leaves more funds available for more advanced equipment to carry out important science mission objectives.
- *Environmental*
  - The space environment that the sensor network will ultimately be operating in required special consideration in designing the system. The temperature range will be much larger than typical room temperature environments. The parts selected for the design are all capable of operating between -40°C and 85°C. Radiation hardened parts would be the most suitable components for the system, but due to high cost, low availability and the relatively low orbit of the satellite, they have been excluded.
- *Sustainability*
  - The sensor network being designed must be able to function for a minimum of three months. In this three month period the network must reliably detect power faults and react correctly to prevent damage to key components. Regular maintenance will not be possible. Full reliability testing will not be possible due to time constraints and the lack of resources to fully simulate a space environment. Again radiation hardened parts would be preferred for the entire system, but the cost and availability of these items make them prohibitive.
- *Manufacturability*
  - Future part availability for construction of the sensor network would be a concern if the system was being designed for large scale distribution. But, the system will only be implemented for Electra and final part purchasing will be made as soon as the system is shown to fully comply with the required specifications.
- *Ethical*
  - N/A
- *Health and Safety*

- N/A
- *Social*
  - N/A
- *Political*
  - Due to the possibility of launching Electra through a Russian based agency, export laws have to be considered in selecting parts. The companies manufacturing the components for the sensor network only require following applicable United States trade and export laws. These include not exporting components to embargoed nations such and Cuba and Syria. Proper US channels will be followed to export the satellite as a whole if and when a foreign agency is used for launch.

# **Appendix A**

## **Design Schematics**

**Page 13 – Current Sensor Layout**

**Page 14 – Temperature Sensor, ADC and  
Battery Sensor Layout**





# **Appendix B**

## **Software Flowchart**

**Page 16 – Data Collection/Error  
Detection/Fault Conditions**

**Page 17 – Error Resolution**







# **Appendix C**

## **Power and Temperature Ratings for Measured Components**

### **Page 19 – Min/Max Operating Ranges for Monitored Components**



# **Appendix D**

## **Gantt Chart for Project**

**Page 21 – Spring 2006 and Fall 2006  
Design Project Tasks**



# **Appendix E**

## **Relevant Data Sheets**

**Page 23 – National Semiconductor LM92  
Temperature Sensor**

**Page 24 – Maxim IC MAX4372  
Current Sensor**

**Page 25 – Maxim IC MAX1139  
ADC Unit**

**Page 27 – Maxim IC DS2745  
Battery Sensor**