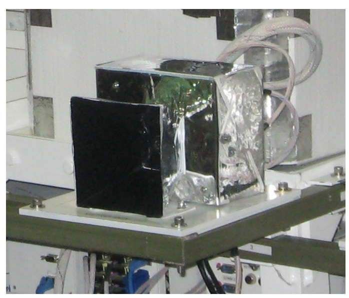
SALISH KOOTENAI COLLEGE
COMPUTER ENGINEERING

SKC Wide Field Camera

Final Report



SKC HASP Team

December 2011

Table of Contents

SKC WFC HASP

Team Members

SALISH KOOTENAI COLLEGE

COMPUTER ENGINEERING

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1. Introduction

Salish Kootenai College's (SKC) Wide Field Camera (WFC) is a student and faculty designed, built, tested, and operated prototype general purpose astronomical visible light camera for the 2010 High Altitude Student Platform (HASP) flight. The electronic design includes a CMOS image detector, FPGA control of image acquisition and storage, and Flash memory storage of images for post-flight retrieval and analysis. The optical design is a fixed focus camera with a Sunex DSL 115 optic: 4.5 mm focal length, f/2.0, 68 deg field of view. The camera has a fixed mount that points the optical axis towards Earth's horizon, with balloon rotation providing passive pointing.

The primary goal of this project was to provide SKC computer engineering students with systems engineering experience for scientific payloads carried on balloon or spacecraft platforms, with a secondary goal of testing the system design in near space conditions to enable refinement of the design for possible future flight opportunities.

2. Design

Hardware Description

The SKC WFC consists of a custom designed control board and a Micron MT9M131 CMOS image sensor demo board mounted to a custom designed aluminum housing. This assembly is affixed to a mounting plate supplied by the HASP project. The SKC WFC control board is made of 6 subsystems (refer to the SKC WFC block diagram in the appendix): an Altera Nios II processor based microcontroller, an SKC designed Frame Grabber, Frame Buffer SRAM memory, an SD card socket, power converting and regulation circuitry, thermal monitoring circuitry, and an RS 232 voltage level converter.

The Nios II processor based microcontroller and the Frame Grabber are instantiated on an Altera Cyclone III FPGA (refer to the SKC WFC FPGA/SRAM/CAM block diagram in the appendix). The Nios II processor based microcontroller includes 40 kB of on chip memory for code and data storage, an interface to the off FPGA Frame Buffer memory, an SD card component, a serial UART, a JTAG UART, an EPCS device controller, an Analog to Digital converter interface, and several parallel I/O ports. The Nios II processor based microcontroller and the Frame Grabber work in tandem to control and acquire images from the Micron MT9M131 CMOS image sensor Demo board.

The Frame Grabber is necessary because the Nios II processor isn't fast enough to keep up with the CMOS image sensor's minimum frame rate. The frame grabbing operation is started by a control bit from the Nios II processor. Once started the frame grabber monitors status lines (Frame Valid, Line Valid, and Pixel Clock) from the CMOS image sensor to control pixel data writes to the Frame Buffer memory (a Cypress 4 MB SRAM). The Nios II processor reads the Frame Buffer memory to process, store, and transmit the image.

Raw images and telemetry are stored on an SD card for post flight retrieval. The Nios II serial UART and Maxim 3232 True RS232 transceiver are used to transmit downlink records to the HASP flight system for transmission to the ground.

The HASP flight system provides up to 0.5 amps at 33 – 29 VDC through an EDAC 516 connector to the SKC WFC. This voltage is initially converted to 5 V by a Recom Power RP15-2405SAW 15 W 5 V DC to DC converter. The 5 V from the DC to DC converter is connected to the Micron CMOS image sensor demo headboard which has its own regulator. Linear regulators provide 3.3 V, 2.5 V and 1.2 V to the SKC WFC control board. Current draw by the SKC WFC from the EDAC 516 connector was .110 A at 30 V. This yields 3.3 W which is well under the 15 W maximum draw specified in the HASP interface manual.

Because Altera Cyclone III FPGAs are a volatile device the configuration and program memory must be reloaded each time power is cycled. The SKC WFC has two methods for reloading configuration and program memory. A JTAG UART is used during development work. An EPCS16 serial configuration device is used to reload the configuration and program memory during flight and testing when the JTAG UART interface isn’t available.

Thermal performance is monitored with an Analog to Digital Converter and a set of 8 thermistors.

Software Description

The two SKC WFC payloads run the same control software with the only difference being in the format of the uplink commands. The control software consists of two files, the main control software and the interrupt service routine. The main control software was written in C and compiled with the Altera Monitor Program by SKC computer engineering students and faculty. The interrupt service routine was provided by the Altera University Program.

The SKC WFC control software acquires and transmits images and telemetry data four ways: at power up or reset, after a GPS string is received from the HASP flight system, by serial uplink command, or after a five minute period of no serial activity. In normal operation GPS strings are received once every four minutes. This results in images and telemetry data being acquired and transmitted on four minute increments. The serial transmission rate was set to 4800 baud.

The SKC WFC control software can be divided into three main processes, an initialization process, an operations process, and an acquisition process. The initialization process is run once at power on or reset and it initializes the WFC system and runs the acquisition process once. The operations process consists of a simple loop that waits for serial transmission and processes the serial transmission. The acquisition process acquires an image and telemetry data, processes the image, creates the downlink record, and transmits the downlink record on the serial channel. Before transmission of the downlink records starts serial receive interrupts are enabled to allow uplink commands to be received. Uplink command bytes received via the interrupt routine are buffered for later processing.

The operations process consists of a wait loop (refer to the flowcharts in the Appendix) that monitors the serial line. There are two ways to exit the wait loop. The first way, a time out, occurs if no serial input is received within 5 minutes of the serial wait loop. The time out sets the stored GPS string values to hex AA to indicate a non-valid GPS string,runs the acquisition process, and control is returned to the beginning of the operations process.. The second way to exit the wait loop is when a serial byte is received. In this event the operations process waits for the second serial byte to be received. The second serial byte determines if the serial string is a command or a GPS string. In the case of a command (second serial byte equals hex 02) the command is processed and control is returned to the beginning of the operations process. In the case of a GPS string (second serial byte equals hex 30) the software checks to see if exposure sweep flag is set, runs the acquisition process, and control is returned to the beginning of the operations process. If the exposure sweep is set the exposure is changed to the next value and a check is run to see if the exposure sweep has finished. If the sweep is finished the exposure sweep flag is cleared.

The image processing that takes place on board the WFC consisted of creating a 50kB grayscale JPEG image from each full color image. The JPEG algorithm implemented on the WFC FPGA in C code, written from scratch by the SKC team, follows the JPEG standard (ITU-T Recommendation T.81 | ISO/IEC 10918-1) and the JPEG File Exchange Format (http://www.ecma-international.org/publications/files/ECMA-TR/TR-098.pdf). In order to fit the final configuration within the capacity of the FPGA we had selected, our C code could not contain floating point calculations, so our JPEG code was written with only integer calculations.

The SKC WFC software has two record types, an SD card record and a downlink record. The main difference between these two records is that the image stored in the SD card record is a raw unprocessed color image and the image transmitted in the downlink record is a black and white JPEG compressed image.

3. Design/Development Issues Encountered

Flight Software Issues

Issue 1:

Any time that an exposure command was issued to the WFC system, the first two images of every sweep appeared to be very dark or highly washed out and never at the correct exposure. Though the first two images of every exposure command was incorrect, the images after the first two were at the correct exposure setting.

When the camera head board was connected to the Aptina Imaging development kit for testing, the images at the different exposure settings worked as expected. When reconnecting the camera head board to the WFC system, the first two images of any exposure command that was issued was taken at incorrect exposure settings.

This exposure issue that occurs appears to be a transition period of image exposures resulting from any exposure command that is executed to the WFC system. The transition period in any case lasts for a period of two images, and is then corrected. As a team, we were unable to debug or resolve this issue prior to flight. However, we were able to get great images by keeping the WFC in auto exposure mode.

Issue 2:

Altera Monitor Program (AMP) and Altera Quartus II were used to upload the WFC system flight software and configuration to the FPGA on the system. The AMP was used to upload flight software configuration via the JTAG interface on the WFC system. Quartus II was used to load the flight software configuration onto the WFC system's EPCS device to store the flight software and configuration. Because the FPGA is a volatile device the EPCS device is necessary to reload the software and configuration when the system is powered off.

When testing in a lab setting, the flight software and configuration loaded via AMP and the JTAG interface worked fine for taking images with the WFC system. When loading the flight software and configuration via the EPCS device the WFC system did not work correctly.

This issue has been unresolved.

Issue 3:

Another problem that we encountered was with the SD card interface controller. Team members were able to conclude that the SD card component, which was instantiated onto the Nios II processor system, only worked with Quartus II version 9.1 (The Quartus II software installed in the engineering lab was version 10). Once we reverted back to version 9.1, we were able to resolve the issue.

4. Flight Summary

On Wednesday, August 15, 2011 at 7:28 a.m. MDT the LSU HASP balloon was launched time from NASA Columbia Scientific Balloon Facility in Ft. Sumner, NM. It remained in flight until Wednesday, August 15, 2011 at 5:39 p.m. MDT when flight was terminated. The balloon's impact was at approximately 6:30 p.m. MDT. This resulted in a total flight time of about 7 hours and 55 minutes.

Upon power up both cameras started operating as expected. Initial images and telemetry looked good (see the first images in the appendix). After two hours of flight the Earth portion of the image seemed to be over exposed on Payload #4. When this continued to happen for several images it was decided that powering down the camera and resetting the system would be the best option. After letting Payload #4 sit for several minutes the camera was turned back on to see if there was any change in picture quality. After letting Payload #4 take several images the Earth portion of the image still seemed to be overexposed. It was decided to run a manual exposure sweep to see if the auto-exposure was working incorrectly. The images received were completely washed out so the exposure sweep was ended. The next image showed that the problem was still present. After letting Payload #4 run for a while a few images showed up with the Earth portion of the image at least partially exposed correctly (see the third set of images).

This change only occurred briefly and the images went back to an overexposed Earth portion (see the fourth set of images) until the descent was underway. During the descent stage and for the rest of the flight the images looked correct.

Another issue encountered with Payload #4 during flight was a loss of several images.

The images taken from Payload #6 were clear and the system operated as we expected for the entire flight. Because it showed no problems Payload #6 was left alone to run without any uplink commands.

Both cameras were still powered on during impact and we received several images from both payloads on the ground. The images taken at this time were both very clear (see the fifth set of images) and the go ahead was given to power off and wait for the cameras to be sent back here in Montana for more testing and data retrieval.

5. Results and Analysis

Images from SKC WFC #6 were as expected throughout the entire flight. The camera continued to function and record images even after impact.

Images from SKC WFC #4 showed an Earth portion of the image that appeared to be over exposed for much of the float portion of the flight. This was attributed to high temperatures in SKC WFC #4

During Flight, the SKC flight team had noted the temperature readings from the DC converter seemed unrealistically high- especially at higher temperatures. This was confirmed in post-flight testing and analysis. Figure 1 illustrates the problem by comparing two SKC WFC #4 thermal monitoring channels (solid lines) against three control readings (dotted lines); two from a Vernier Labquest digital temperature sensor, in addition to readings from an analog Hg glass thermometer.

The SKC WFC #4 "case" channel read from a thermistor secured between the aluminum case and the insulation lining the case interior. This positioning isolated the sensor from temperatures experienced within the interior of the camera case, which were subjected to excess heat generated by the DC Converter. For this reason, the "case" channel was selected as the best indicator of the other non-problematic channels of the thermal monitoring array (ambient, case, 3.3V regulator, and FPGA).

On this basis, the performance of the SKC WFC #4 thermal monitoring subsystem exhibited satisfactory results. In general, the "case" trend correlated quite well with the control readings. Although there was a max difference between the "case" channel and the Hg analog readings of ~12° at 4:00pm, the convergence of these readings near the end of the test is reassuring. It could be expected that the case thermistor should react more slowly to the heating of the chamber since its position kept it insulated from the convective flow within the chamber. This assumption is supported near the end of the test. At ~5:00 the chamber door was opened to allow for cooling. The presence of the sudden spikes in the control references are a result of an influx in convective flow. Notice that the three readings from the interior of the case exhibit a minimal effect.

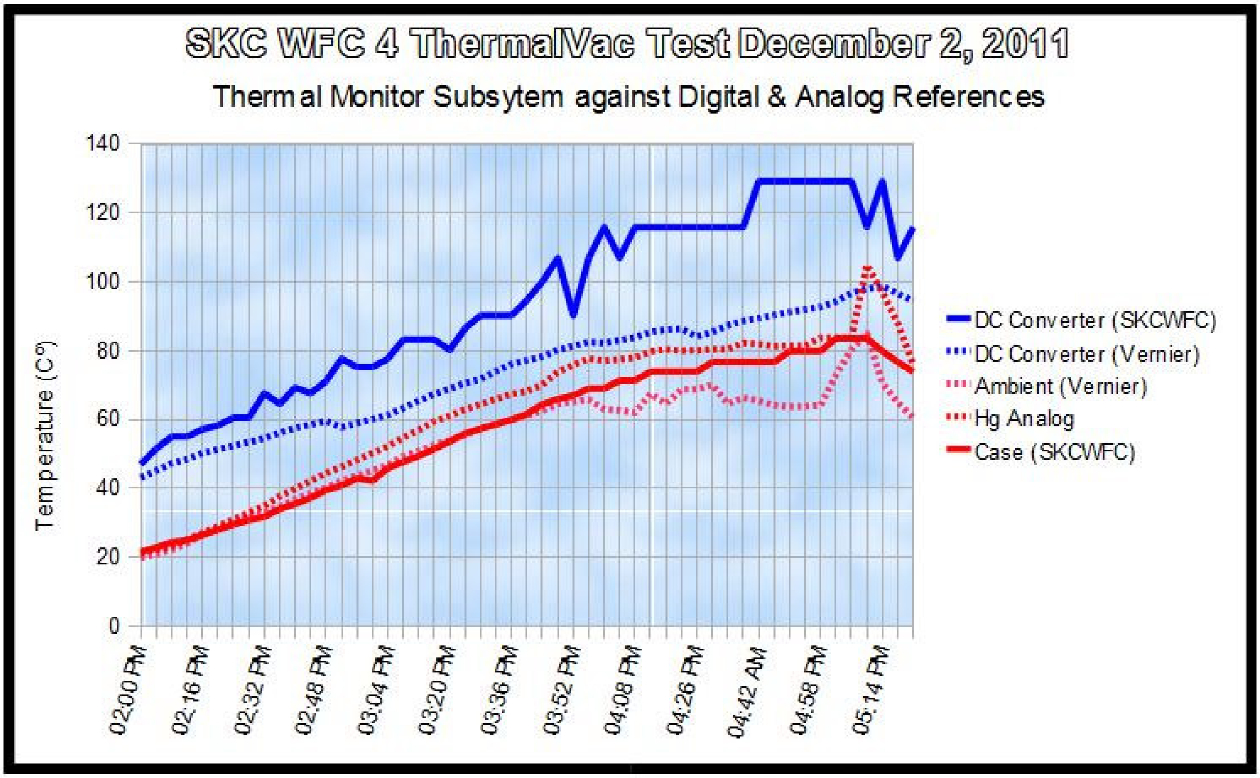


Figure 1: Results of thermal vac test investigating the integrity of the SKC WFC #4 thermal monitoring system

Of greater concern is the performance of the SKC WFC #4 “DC Converter” channel. The Vernier thermal sensor was fastened directly to the component beside the thermistor of the thermal monitoring subsystem, providing identical test conditions. The results exhibit what was suspected during flight- the “DC Converter” was reading far too high.

The chart clearly shows significant degradations in both accuracy and precision as temperature increases. Regarding accuracy, the gradual divergence between the DC Converter readings are likely resultant of a critical increase in resistivity of the sensor material. Revisiting the datasheet, the EPCOS B57861 thermistors implemented in the design have an operational temperature rating of just 25°C. Failure to have recognized this in the design process was a mere oversight that could have been easily rectified in the ADC processing algorithm. Unfortunately, the consequence of this inaccuracy propagated by compounding the degradation of the channel's precision. However, the primary cause of the degrading precision is a combined result of underestimating the actual temperatures experienced in flight, and overestimating the ability of the component to dissipate heat. Figure 2 exhibits the Matlab model used to determine the Rvalues on the ADC channels. The vertical variations between the plots are an indication of the level of resolution as a function of temperature. The blue highlights mark the design choice implemented, while the purple highlights indicate a solution to the failure. Noting the blue model in the left column, beyond ~50°C, the voltage resolution is greatly diminished and consistent with the behavior of the channel during flight and post-flight testing.

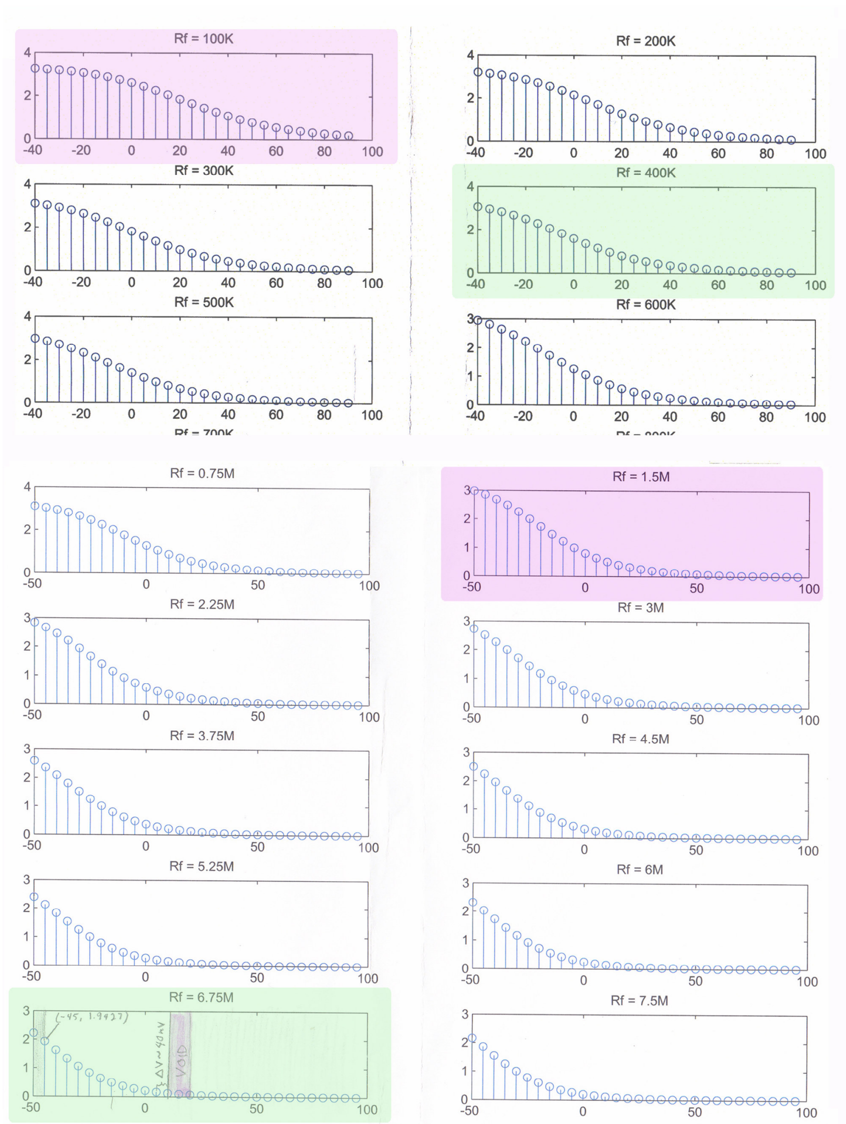


Figure 2: The original Matlab model used to choose R18 and R19, the high and low biased ADC channels devoted to the DC converter. The blue highlights indicate the implemented design choice. The violet hi lights a combination that would have produced better functionality.

6. Conclusion

The SKC WFC provided valuable systems engineering experience to the students and faculty of SKC. Project management, scheduling, and planning a complex real-world project of this nature is invaluable to students and allows them to apply what they learn in the class room on a project with very specific goals and timelines. Chief lessons learned were in the thermal management of near space operations of systems, integration and testing areas, and the management and planning areas.

Thermal, especially high temperatures, issues are difficult to deal with. Our results and analysis point to high temperatures causing the image degradation on SKC's WFC Payload 4. During our initial design we were concerned with low temperatures. However, after the first thermal vacuum chamber tests the low temperatures weren't as big an issue as the high temperatures. During that first thermal vacuum chamber test and even while running on a lab bench the DC to DC converter ran hot and it was felt that this would provide plenty of heat for the system. During flight and in post flight analysis it seems we didn't do as good a job of managing the high temperatures as we expected. This was one of the chief areas the students and faculty gained. Even though space seems like it is a cold environment electronics can easily run hot.

The integration – testing – modification cycle can be at least as long as the initial design cycle. Plan accordingly.

Flight plan – have a well thought out and practiced flight plan. A twelve hour flight might seem like you'll have a lot of time but our experience was that when decisions have to be made they have to made quickly and having preplanned contingencies can be a big help

Management – Create as detailed a schedule as you can during the initial phase of your project. Regularly update and monitor that schedule to ensure your project will be completed as planned. Testing and integration is a complex, iterative and time consuming process; allow plenty of time for this phase of your project.

Appendices

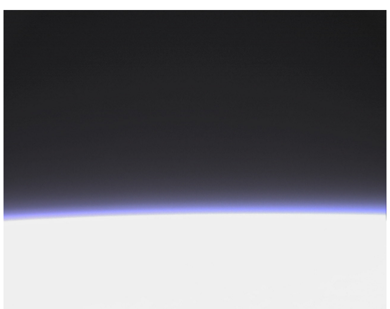
1. **Flight Images**
2. **Subsystem Block Diagram**
3. **Software Flowcharts**

HASP Wide Field Camera Payload 4 Flight Images

7:02:13am MDT, 31 August 2011
latitude = North 34 deg 29.4612 min
longitude= West 104 deg 13.0629 min
altitude = 1266 meters above sea level = 4154 ft

HASP Wide Field Camera Payload 6 Flight Images

7:02:13am MDT, 31 August 2011
latitude = North 34 deg 29.4612 min
longitude= West 104 deg 13.0629 min
altitude = 1266 meters above sea level = 4154 ft



HASP Wide Field Camera Payload 4 Flight Images

5:38:13pm MDT, 31 August 2011
latitude = North 34 deg 49.6350 min
longitude= West 110 deg 31.3083 min
altitude = 38,232 meters above sea level = 125,440 ft

HASP Wide Field Camera Payload 6 Flight Images

5:38:13pm MDT, 31 August 2011
latitude = North 34 deg 49.6350 min
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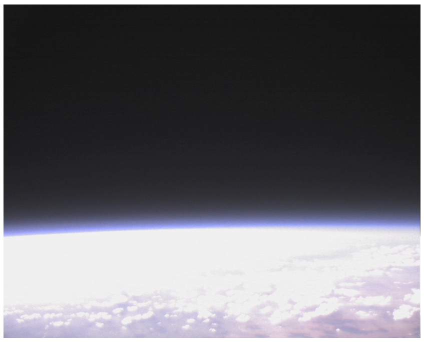	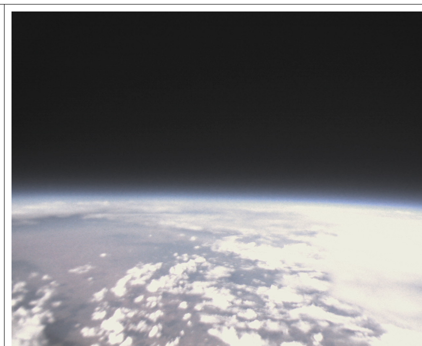
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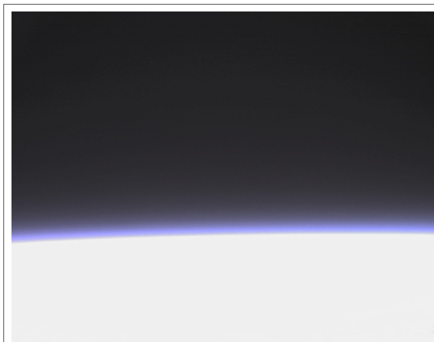	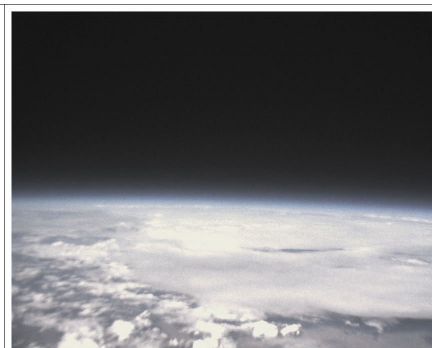
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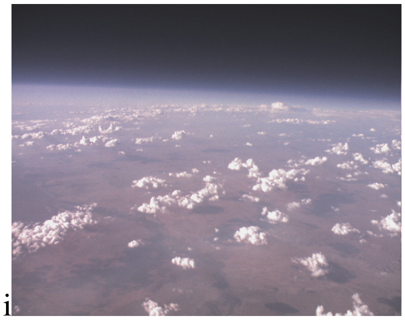
i	
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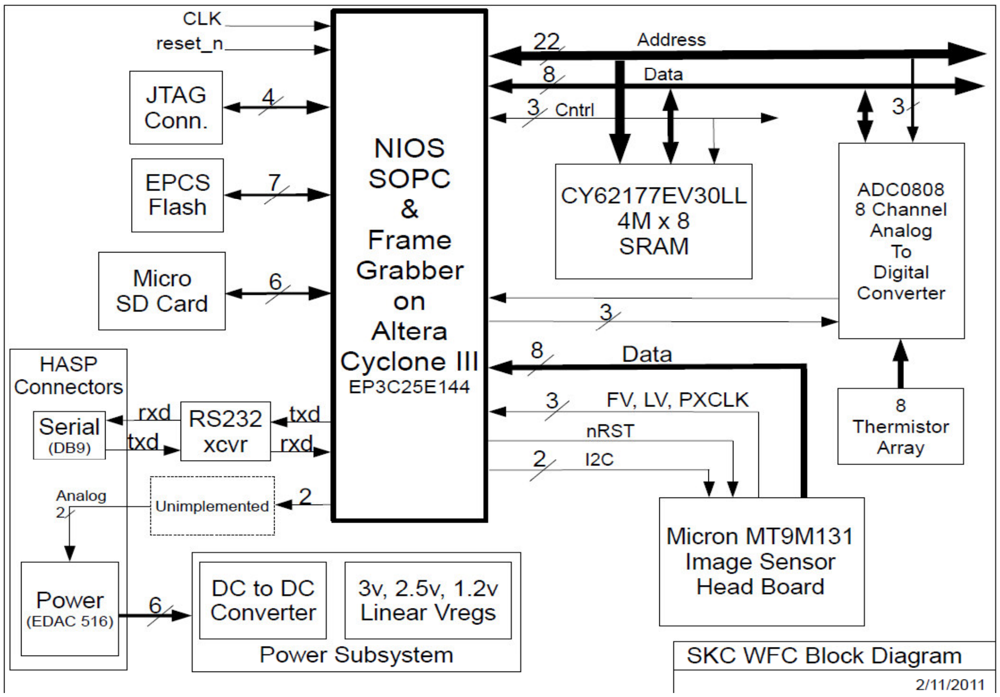
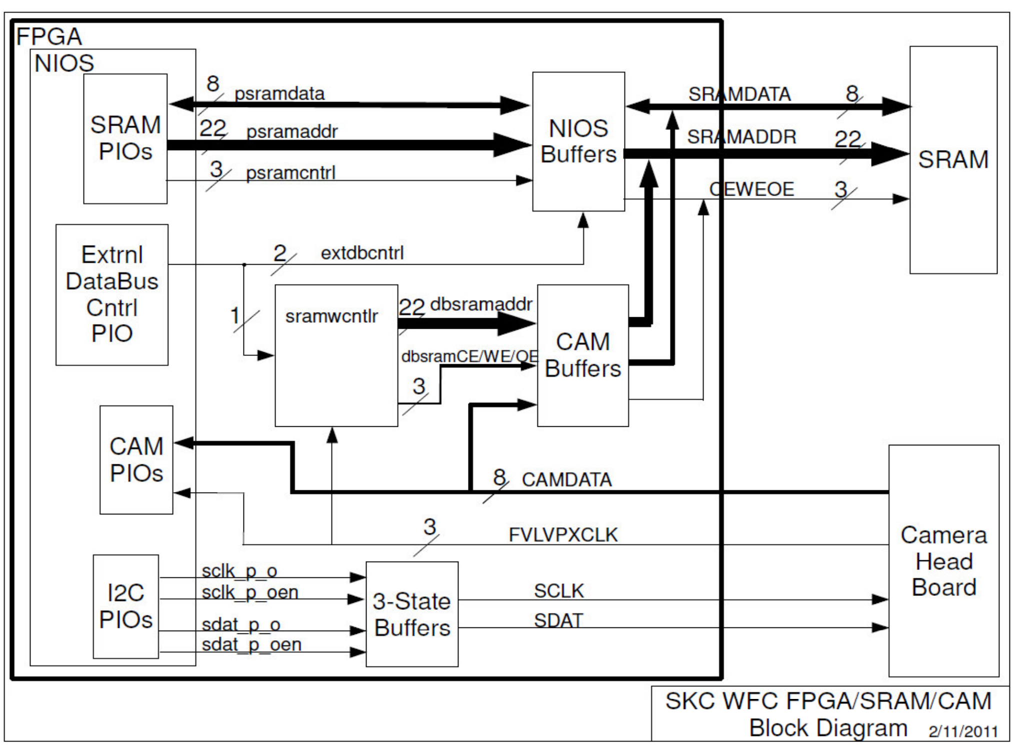
Subsystem Block Diagram





Software Diagrams