

# **REMOTE IMAGING SYSTEM ACQUISITION (RISA) SPACE ENVIRONMENT MULTISPECTRAL IMAGER**

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## **ABSTRACT**

The RISA imaging team is tasked to research, develop, implement, and test a multispectral imaging system capable of supporting multiple NASA exploration objectives. This year's NASA team is responsible for characterizing the newly implemented liquid lens, implementing a charging circuit complete with rechargeable batteries and a solar panel array, and redesigning the already developed wireless data transmission system. The charging circuit will be fully designed by our electrical engineering team using Gallium Arsenide solar panels provided by AZUR SPACE Solar Power. The implementation of this solar panel array will enable the final system to be completely independent of any power consumption from the spacecraft. The wireless data transmission system will be redesigned to utilize a compression technique as opposed to entire-image compression, as the previous system had implemented. This edit, in conjunction with an interfacing bypass through hardwiring of the image sensor to the Gumstix COM, will drastically increase the data transmission rate. These modifications will therefore increase the rate at which NASA can send and receive data and/or the communication of rate of the camera commands through the designed GUI.

As a result of new mission objectives and requirements associated with new age space vehicles, little physical capacity is available, especially compared to past NASA Space Shuttles. Employing a multi-purpose imaging system alleviates the need of manifesting multiple individual imagers by incorporating the numerous desired functions into one system. The final version of the imager, which is expected to be completed in follow-up work, is intended to be flight ready and will be used in the crew cabin, on the exterior of NASA vehicles, and on Lunar and other planetary surfaces.

For this year's imager, the preliminary design review was broken down into four sections: the battery, the solar panel, the charging circuit, and wireless hardware. In each of these sections, multiple designs were considered, but the charging circuit and wireless system were decided to be custom designed by the team.

## **BATTERY DESIGN RESULTS**

In the battery design review, five batteries were reviewed; Lithium Polymer, Silver Zinc, Lithium Titanate, Zinc Bromide, and Zinc-Air. Following obstacles during the implementation

cycle, another battery was reviewed and ultimately used in the final design; Nickel Metal Hydride.

After assigning values and doing a trade-off analysis for all of the batteries, the Silver Zinc battery was decided to be the best fit for the system. This is due to its extremely high energy density, power, efficiency and self-discharge rate. However, the battery does not have as high of a voltage compared to the second and third best battery. This can be easily dealt with by designing the power circuit around the inclusion of two batteries rather than one.

Due to an update in the charging circuit and the solar array (which will be reviewed later), the Silver Zinc battery and the Lithium Polymer batteries were decided to be ineffective due to problems with compatibility as well as an issue with the seller. Considering this, the Nickel Metal Hydride battery was determined to be the best fit for the overall system power requirements. The main reasoning for this choice is due to its nominal cell voltage and energy density. Two of the main power design requirements stated that that the battery must fit inside the current enclosure and that it must be compatible with the Gumstix Overo Fire COM. Nickel Metal Hydride C cells have a nominal voltage of 1.2 Volts, which when put in series inside of a battery pack can have an overall voltage of 6 Volts. The Gumstix Overo Fire COM is a module that runs on 5 Volts and has an internal regulator that works more efficiently the closer the input voltage is to 5 Volts. Aside from this benefit, one area that this battery does not perform well in compared to the others is the overall efficiency of the battery. However, due to the lower voltage difference between the battery and the Gumstix COM, it was determined to be a better fit for the system.

## **SOLAR PANEL ASSEMBLY DESIGN RESULTS**

In the solar panel design review, four different solar panel types were considered; Indium Gallium Phosphide, Thin Film, Crystalline Silicon, and Gallium Arsenide.

After the trade-off analysis for the solar cell types, Gallium Arsenide cells were decided to be the best fit, despite their high cost. There were numerous benefits of the Gallium Arsenide cells compared to the cost. Due to the team's large budget, this factor was easily overlooked.

Once Gallium Arsenide cells were selected, many companies were contacted to place an order for the proposed 2 cell design. We soon realized that purchasing such a small amount of cells was very uncommon, and that every company required a minimum purchasing limit. After months of failed purchasing attempts, AZUR Space Solar in Germany agreed to send the team three triple junction GaAs solar cells free of charge to help us move forward with the final design.

## **CHARGING CIRCUIT RESULTS**

In our preliminary design, a suitable commercial off the shelf charging circuit was not found that met the specifications of the system. Mostly, charging circuits are designed for much larger systems with much larger voltages. Because of this, a general solution was devised to create a custom charging circuit for the system. The new implementation plan is to use a maximum power point tracker (MPPT) along with a much smaller custom circuit for use in the system.

## **WIRELESS SYSTEM RESULTS**

While performing the initial design of the system, it was recommended that we implement a custom wireless design which modified the data access of an 8-bit bus located on the SC2M8 (image sensor). Prior to this school year, NASA determined that there was a data bottleneck in the system at this data connection. After multiple sources of consultation during the design process, it was decided that the data would be accessed using a parallel connection as opposed to a USB serial connection. This was the only option that would completely eliminate the bottleneck, so there wasn't a need for a trade-off analysis (the only other option was to leave the data connection as it was).

Due to incomplete documentation from last year's team, we were awestruck when we discovered a detrimental error with the camera. The camera does not always connect to the router, and when it does connect, it loses its connection if bumped by any slight disturbance. Since none of the software on the camera had any correlation to bumps, it was easily determined that the issue was purely hardware related. Also, its action of occasionally connecting without any modification to the code further solidifies that the issue is hardware related. After carefully examining the solder connections and shielding of each of the electronics stack layers, no source of the issue was found. The only possible errors that we determined were plausible were: a noisy rectifier (when the camera is powered via wall socket), or antenna effects of the wire coming from the rectifier in combination with the camera's power wire. Of these two sources of error, the more likely cause is the antenna effect. We determined that this might be the case because the only physical object that moves during a test is the long wire supplying the camera with power. A slight change in the movement of the antenna might introduce frequencies to the system that knock the camera out of its connection to the router. To avoid this issue, we recommend adding a simple low-pass filter at the input of the power cord so that all of these high frequencies will be ignored. With the addition of the charging circuit, there is no need for a long power cable, so this might eliminate the antenna effects as well.

## **FINAL CONCEPT DESIGN**

The RISA imager currently has 3 main subsystems. These systems include the optical system, the electrical/software system, and the mechanical system that houses it all. For this year's modifications to this imager, the team will be mainly be modifying the electrical/computer subsystem. The optical students on the team are currently in the process of testing the functionality of last year's final product and will not be redesigning the lens system. For this reason, the majority of the designs will focus on the electrical and computer system. However, the additions to the electrical system require some hardware additions. The main hardware addition is the solar assembly, which has been added to ensure prolonged use without relying on outside sources of power. The high level design concept for this year's additions is on figure 1.

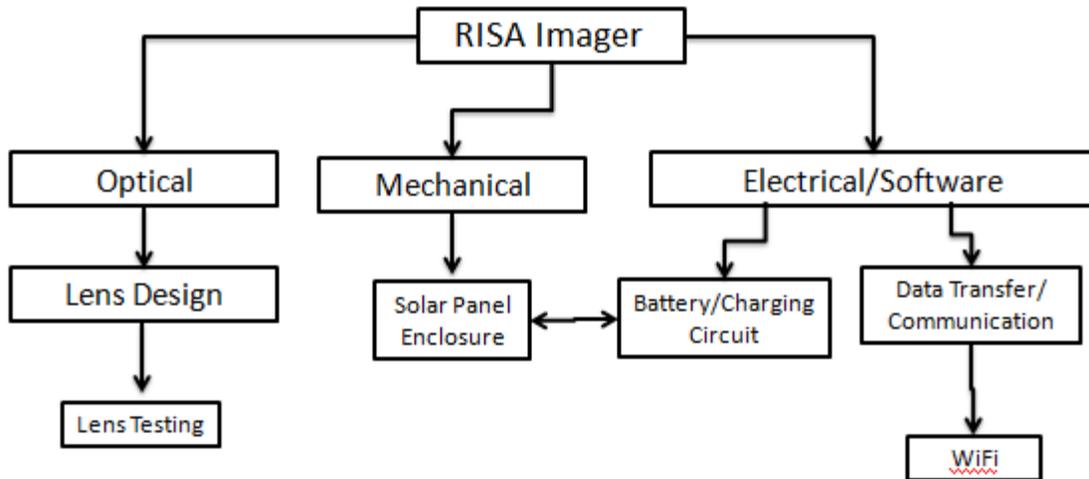


Figure 1. *This year's changes to the current system*

## OPTICAL ANALYSIS

The original plan for the 2012 – 2013 optical team was to characterize the lens both in Zemax and in the lab by using a variety of tests. The parameters to be tested were; Focal Length, BFD, location of cardinal points, Modulation Transfer Function, Distortion, and 3<sup>rd</sup> Order Aberration Content.

Unfortunately, the camera's electrical systems experienced some failures connecting the camera to the router, which prevented the team from having full control of the liquid lens and thus the focal length of the entire system. Although there was some initial test data taken, it is not of the nature required for serious characterization as it was mostly taken for purposes of refining the testing procedures. Despite its limited use it is provided for reference of future teams.

In order to find the basic lens parameters we used a basic nodal slide setup. This test was performed with only the lens barrel. Therefore no voltage was applied to the liquid lens. According to the VariOptic datasheet for the liquid lens, when 0 volts are applied the radius of the liquid lens should be 10.91 mm. When the liquid lens is in this configuration, the lens system should have an effective focal length of 38.73167 mm and a BFD of 19.39824 mm.

This type of setup is not completely accurate. The main reason for this is collimation of the source. Collimation is achieved by using a mirror to back reflect light through a large copier lens to form a point on the surface of the source. Extremely accurate collimation is not possible because of imperfections in the observation capabilities of the testers. However, this test can give a good approximation of the first order parameters, which gives us a reasonable confidence about whether or not the system was constructed well.

In order to make sure the results were more accurate and gave a good picture, two different nodal slide setups were used. In the first setup the effective focal length is 43 mm +/- 2 mm and the back focal distance is 25 mm +/- 1 mm. In the second setup the effective focal length is 40.7 mm +/- 2 mm and the back focal distance is 23.5 +/- 1 mm. In summary, we can trust the optical system is behaving according to the predictions of the previous team.

## **OPTICAL TESTING**

For the field of view test, no filter was used. The camera was set-up to take an image of the ruler from about 1086mm away so that the image of the ruler is a distance of 194mm in the horizontal direction. This produced a full-field of view of  $10.208^\circ$  without the filter. During FY12, the team previously tested this field of view. With the micron sensor the FFOV was measured to be  $9.8^\circ$ , which provides a 4.16% error.

In testing for the modulation transfer function of the system; the original plan was to use the electrically tunable filter to go in 10 nm steps from 400 – 720 nm. At each wavelength the team planned to snap a picture of the slanted edge portion of the ISO 12233 target and then run this image through a program called Imatest in order to determine the modulation transfer function of the system at that wavelength. We would then later use NIR filters to determine the modulation transfer function of the system using NIR light.

Unfortunately during testing the camera system failed to connect to the wireless router as well as incurring a number of other issues. The team determined that there was most likely some sort of hardware failure because a slight bump to the camera would cause the system to lose connection. Because of this the team was not able to utilize the focus control of the liquid lens. In addition, the USB interface was also not functioning correctly which made taking images with the camera impossible.

The test subject for our astigmatism testing is a spoke pattern without any filter. Since the resultant lines were not noticeably blurred in the horizontal or vertical directions, there should be low astigmatism within the optical system. These images are not ideal and the team would have preferred to take more and run them through computer analysis to find astigmatism values, but issues with the camera prevented it.

When the filter was applied, the image darkened. This means that with proper illumination and the filter applied to the correct wavelength band for the source, and then a clean image was seen. With the filter tuned to 500nm, now some lines from the spoke pattern are visible.

For these images, the target chart was placed a farther distance away at about 107.5 inches or 273.05 centimeters away. This test image is captured without the filter because it was too far away and the source illumination was too low for any light to be reflected back and visibly seen by the camera. Solutions for this include brighter or stronger sources or moving the chart closer. For next time, a broadband source such as an incandescent light should be used so that the chart can be seen throughout different wavelength bands.

## **ELECTRICAL ANALYSIS**

In order to test the power design a series of steps must be completed. A simulation must be ran inside of a spice program to test for the correct voltages and currents at each node. Different

inputs and defective parts must also be tested to ensure the circuit shows the correct and desired behavior. Next the parts were ordered and tested in the lab. Since the LT3652 is a SMT component and adapter must be used to test the components on a solder-less breadboard. The same tests from the simulation must be conducted in lab and the results compared. If these results are fairly similar a printed circuit board design can then be created in a PCB design program. Once the PCB was received the final circuit was constructed and must again run the same tests to ensure that the results as comparable and it is ready to become part of the prototype. Hardware modifications must be made at the simulation stage of testing.

The result of the Prototype stage produces the following outputs:

Vin	Vbat	Vout
3V	0.5V	0.4V
4V	0.9V	0.9V
5V	1.6V	1.5V
6V	3.4V	3.4V
7V	4.5V	4.4V
8V	6V	5.9V
9V	6V	5.9V

Table 1: Power Output Test Results

Vout	Vbat	Iout	Ibat
6.5V	0.1A	1.5V	0.38A

Table 2: C-Si Module 7V/379mA Test Results

Vout	Vbat	Iout	Ibat
1.6V	0.1A	8.9V	.48A

Table 3: C-Si Module at 9V/500mA Test Results

Battery Voltage	Charge time at 100mA	Charging time at 250ma	Charging time at 500ma
6.03V	31.88 hours	12.75 hours	6.38 hours

Table 4: Charge Time at Various Amperages

## ELECTRICAL SUBSYSTEM ACCEPTANCE TESTING

In the electrical requirements and acceptance test planning, there were two major components that our team focused on; wireless data transmission rate and the solar assembly. Testing of the wireless data transmission subsystem is largely incomplete due to the fact that the system unexpectedly stopped working during optical testing, disabling the programming team from making changes to the software or hardware and also testing of the data transmission subsystem. The solar assembly, however, was able to be tested, and all requirements related to this system were theoretically completed. Again, due to the system failure, we were unable to practically complete testing, but the calculations showed that the requirements were met. The system can

theoretically be run for more than 12 hours on a single charge, and the system does have a solar based rechargeable battery.

## **MECHANICAL SUBSYSTEM**

This year's team did not modify last year's imager enclosure, but the addition of a solar panel array required additional mechanical designs to be implemented. NASA anticipates that next year's team will make more headway on the mechanical enclosure that encapsulates the electronics stack and SC2M8. Until then, a generic solar array enclosure was designed separate from the electronics enclosure. The purpose of this enclosure is to protect the solar cells from the roughness of basic transport; the cells are extremely fragile and can crack at the slightest impact. Being as there were no Mechanical Engineers on this year's team, the mechanical design needed to be as simple as possible. Due to a last minute change from NASA, the solar cell enclosure had to be redesigned since the CDR. The dark areas within the center are supposed to represent each solar cell, and they are also supposed to account for the metal connector tabs above and below each cell. Notice that there are two metal pieces that make up the outer parts of the assembly.

This assembly is modeled as anodized aluminum in order to preserve the electrical characteristics of the solar cells. The glass that covers the solar cells is Fused Silica type, and is made by Esco Optics. The glass is specially designed to transmit in the spectral range that the solar cells operate, and is also radiation hardened. Lastly, this glass is protected against outgassing, which is the process of a solid breaking up into a gas that could potentially corrode other components.

The glass fits in to the aluminum casing with sufficient space for the solar cells and interconnecting wires, and is held in place by the metal lid that is the top piece of figure 5.15. This lid is held in place by 8 screws that screw directly into the bottom base plate. If this base plate is desired to be attached to the rest of the camera, the lid is required to be taken off first due to the access of four screw holes. The solar cells rest on top of a vibration dampening material called Sorbothane, as suggested by NASA.

Due to the sticky nature of the Sorbothane, the cells did not need to be adhered using double-sided tape (which was the original thought). The wires that attach these cells in series were chosen so that they would be able to handle the maximum currents being outputted from the cells. These 22 gauge wires are rated to handle up to 9A of instantaneous current. To feed these wires into the rest of the camera, holes were drilled through the bottom of the enclosure so the wires can connect to the custom charging circuit

## **CONCLUSION**

The main purpose of this document is to lay out each requirement and show if our final system fulfilled each requirement, and how exactly it achieved it. These systems include solar assembly (which includes solar panel array, charging circuit, and battery), data transmission system and optical testing and analysis. Upon completion of the year, some of our subsystems came out as

well as expected, but some did not. Notable successes include; the solar assembly and the optical testing. The solar assembly subassembly theoretically successfully fulfilled all requirements. Of the optical testing that was completed, the results were positive and the testing results in this document shows that. The shortcoming of this project was the data transmission system, which was unable to be implemented due to a system failure caused by the previous team's design, and is currently unable to be fixed by the current team. Due to the system failure, some of the optical system tests were unable to be completed. The system was successful in the fact that the budget was not an issue whatsoever, and we were able to complete the project with money to spare. With more time, the first thing accomplished would be to get the system working again. It is a huge detriment to have a non-working system, especially when changes in coding need to happen. After the system is working, optical testing and field testing of the solar assembly needs to be completed, followed by changes to coding to account for the new parallel connection to the SC2M8. Once all of that is completed, code optimization is recommended as well as possibly redesigning the mechanical enclosure, as it is currently not very ergonomically useful.

## **REFERENCES**

NASA Remote Imaging System Acquisition (RISA) Camera Project – Final Report. Martin, Mayer, Owan, Stevens, Suring. 2012. University of Arizona