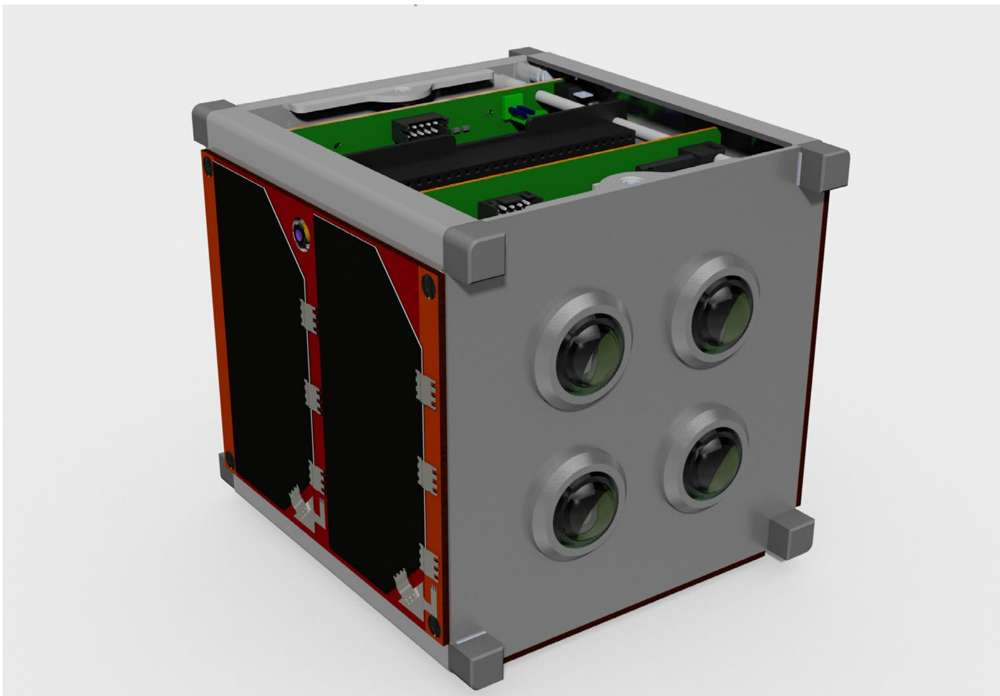
In Response To:
Cubesat Launch Initiative - NNH19ZCQ001O



Prepared By:

Matthew Travis
President, Aerospace Research & Engineering Systems Institute, Inc.
Matthew.Travis@aresinstitute.org
(321) 289-0872

Sponsor Organization:
Aerospace Research & Engineering Systems Institute, Inc. (DUNS040408605)

Calypso – Fully Optical Spacecraft-to-Ground Communications

Aerospace Research & Engineering Systems Institute, Inc.

Information contained in this proposal is not restricted or proprietary. It is the mission of the Aerospace Research & Engineering Systems Institute to advance technology development for space-related applications and to promote STEM education worldwide. As part of that mission, we disseminate technical information to the greatest extent possible. Information in this proposal may be freely distributed without restriction.

.

Mission Parameters Table

CubeSat Mission Parameters								
Mission Name	Mass	Cube Size		Desired Orbit	Acceptable Orbit Range	400 km @ 51.6 degree incl. Acceptable – Yes or No	Ready for Dispenser Integration Date	Desired Mission Life
Calypso	1.3 kg		Altitude	400 km	250-650 km	Yes	10/01/2020	90 days (min)
			Inclination	51.6	28.5 - 90			

Project Details Table

CubeSat Project Details						
Focus Area(s) (e.g., science, technology,education)	Student Involvement Yes or No	NASA funding		Sponsoring Organization(s)	Collaborating Organization(s)	
Technology Development & Education	Yes	Yes or No No	Organization	Aerospace Research & Engineering Systems Institute, Inc.	Vogue Aerospace & Defense, Inc. Phoenix Launch Systems, Inc.	Intl – Yes or N No

Points of Contact:

Matthew Travis, Principal Investigator
105 Bowler Springs St.
Las Vegas, NV 89148

Matthew.Travis@aresinstitute.org
(321) 289-0872

It is desired that all communications be directed solely to the individual listed above. Mr. Travis is the primary Point-of-Contact for all matters relating to Calypso.

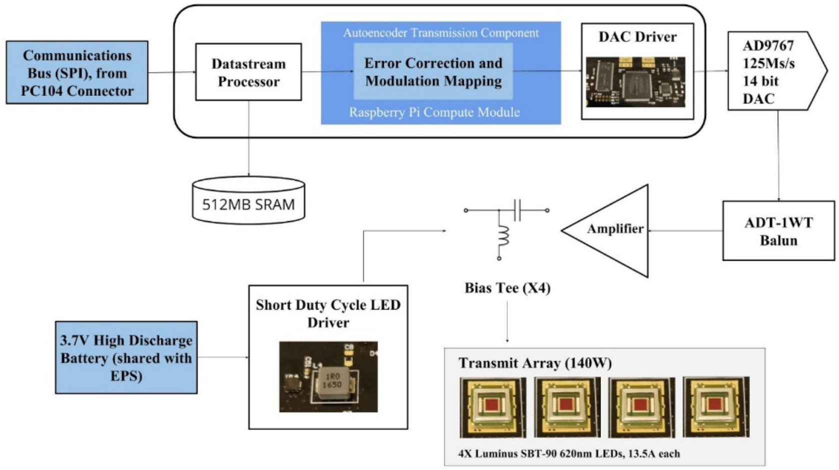
Proposal Abstract - Overview and Objectives

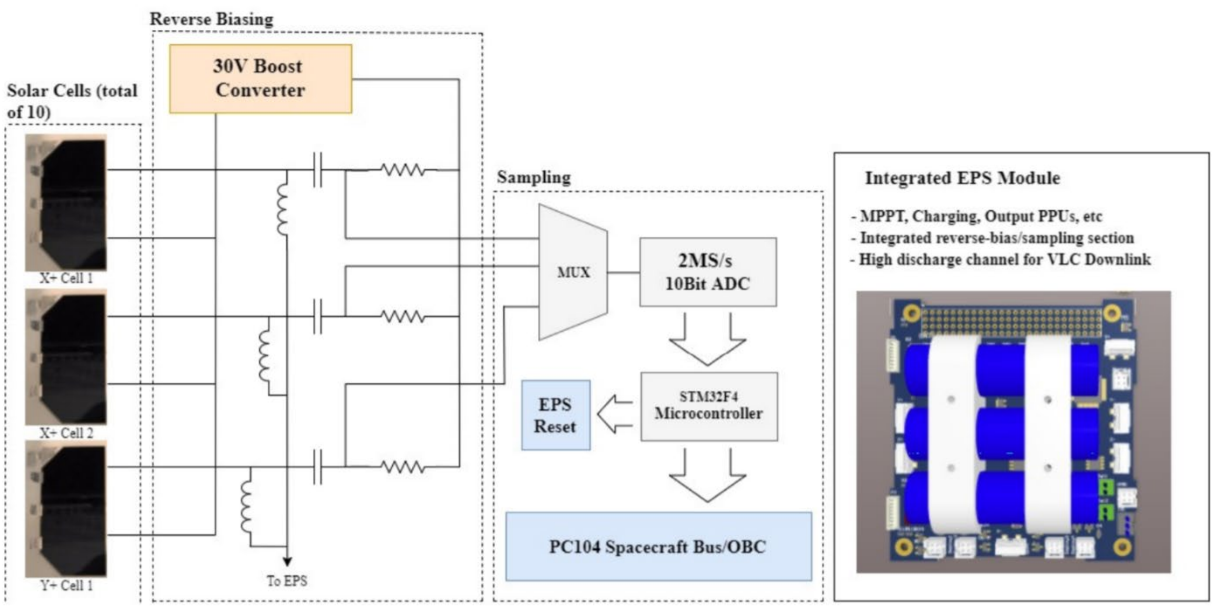
The primary objective for the Calypso Cubesat is to collect atmospheric data to allow the use of deep learning on optical communication systems. Free space optical communication techniques have been the subject of numerous investigations in recent years, with multiple missions expected to fly in the near future. Existing methods require high pointing accuracies, dramatically driving up overall system cost. Recent developments in LED-based visible light communication (VLC) and past in-orbit experiments have convinced us that the technology has reached a critical level of maturity. On these premises designed a new optical communication system utilizing a VLC downlink and a high throughput, omnidirectional photovoltaic cell receiver system. By performing error-correction via deep learning methods and by utilizing phase-delay interference, the system is able to deliver data rates that match those of traditional laser-based solutions. Calypso will allow us to mature the technology and to provide an opportunity for the full scale development of optical communication techniques on small spacecraft as a backup telemetry beacon or as a high throughput link. At the same time, we recognized that such a system provides an excellent platform for STEM outreach. With an apparent visible magnitude of 2.5, the transmitter complements a Raspberry Pi payload to enable real-time student interaction with the satellite and user applications to be uploaded to the payload computer.

a. Scientific Objectives

The primary objective of the Calypso optical payload is to demonstrate the viability of a fully optical spacecraft complete with an uplink and downlink on the VLC downlink and the PV-cell uplink. A number of exciting technologies have presented themselves through the adoption of VLC technology. The mission has the following goals:

• To measure atmospheric attenuation over time in various atmospheric conditions through power monitoring on the pre-calibrated transmitter
• To train and evaluate a deep learning system for optical communication error correction on a earth-to-LEO link
• To evaluate the feasibility of differential phase delay correction using two or more ground stations and a wide-beam VLC transmitter





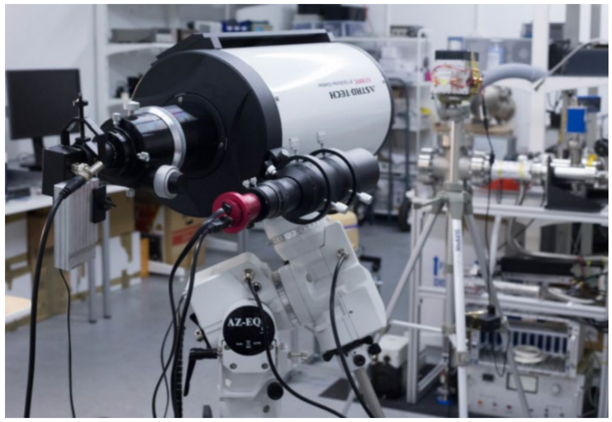
Free space optical communication systems need to compensate for channel impairments such as atmospheric distortion and the frequency response of hardware components (i.e. transmitter LEDs). In order to account for such problems through an economical and lightweight method, an innovative method using deep learning was devised. Utilizing the research of O'Shea and Hoydis, we modeled the downlink as an autoencoder, an unsupervised learning device used to map high dimensional data to lower dimensions, acting similar to a compression algorithm. This allows us to maximize the channel bandwidth. Communications systems generally require mathematically tractable models. However, in the interest of lowering costs of development and deployment in production environments, it is more economically feasible to eschew traditional multiple stage communication systems in the favor of a single end-to-end deep learning system optimized for the specific hardware and channels, lowering development time and cost. As certain types of deep learning systems (specifically, recurrent neural networks) are known to be Turing complete and universal function approximators, we are able to combine the various parts of classical communication architecture into a single block and have the neural network model it in its entirety.

The cost of deep learning systems have been falling rapidly and as efficiency of GPU systems improve, it is possible to embed such a system into a Cubesat. There are current research efforts in creation of specialized ASICs (Application Specific Integrated Circuits) optimized for neural network systems, including Google's Tensor Processing Units. In future iterations, it is possible to integrate such chips into Cubesats instead of off-the-shelf graphical processing units designed for embedded systems (in this case the Raspberry Pi on-board GPU) that will be flown on Calypso, allowing higher power efficiency and better optimization.

The autoencoder system will implemented with a one-hot input vector of the maximum size the Calypso's embedded Raspberry Pi module is capable of efficiently running in flight conditions (which will be determined later empirically). Assuming an input vector of size n where n = 16, each packet of data fed into the encoder would be log2n and in this case 4 bits of data. The goal of the neural network is to minimize the difference between the theoretically achievable SNR and the actual SNR. The theoretical transmission we are modeling upon utilizes a QAM-16 transmission system with Hamming(7,4) error correction. It has already been demonstrated by O'Shea and Hoydis that such machine learning based signal processing systems are capable of performing just as well if not exceeding the efficiency of a traditional encoding and/or modulation system that operate in discrete stages. On this premise, we have decided to train the neural network on Calypso while it is in flight instead of doing so on the ground with theoretical atmospheric loss models so as to achieve the highest efficiency in practice. The training data will be sent up via the main RF uplink and it will be used to train the optical communication system. The system proposed by O'Shea and Hoydis is implemented with the final layer of the encoder being 7 neurons, due to the choice of error correction. The output of the encoder is passed through a I-Q modulator via the Altera before being pushed into DAC. Similarly, the ADC on the downlink also has its output passed through a I-Q modulator before being fed into the decoder system. The use of machine learning as a replacement for a traditional signal processing stack offers great flexibility as the communication system can now be updated in-flight. The self-optimizing nature also means that it would attempt to attain the best performance possible with minimum human intervention.

It has been suggested that provided a large enough separation between the transmitters (in the order of multiple kilometers), the interference between the two beams can effectively correct for atmospheric scintillation. However, the differential phase delay is too small for use in atmospheric fluctuation correction on most spacecraft due to physical restraints preventing the two transmitters from being positioned a substantial distance apart. However, the use of visible light communication techniques opens up the possibility of multiple synchronized receivers due to the wide beam coverage. The Calypso payload will evaluate the use of this technique using two identical Rubidium time-synchronized receivers placed 20KM apart to record the differential delay between the two received signals. The data is then interfered and corrected digitally to recover the transmission.

Each ground station is composed of a 30cm aperture Ritchey-Chretien telescope mounted on a commercial German Equatorial mount. Tracking is achieved via a coaxial 5cm refractor and a control computer. Both of the stations will be equipped with a YAG-pumped uplink laser modulated by a DAC/FPGA setup, which also allows the interference-based correction technique to be used on the PV-cell uplink. We expect the cost of each ground station in its final configuration to be under $9000, a figure crucial for duplicability and widespread adoption to allow the construction of a ground station network. At the same time, the same hardware could be shared among multiple bands, together with laser downlink users, to spread deployment cost. A prototype is shown in the figure below:



Reverse biasing photodiodes is a common technique for improving bandwidth by increasing the number of photocarriers and improving drift velocity. The use of self-biasing on solar cells has been investigated in the VLC industry. This technique has been demonstrated to improve the -3dB bandwidth of a PV cell by up to 60% utilizing a 30V bias provided by a lightweight upconverter. Moreover, it was determined that minimal energy losses were incurred as biasing recovers significant energy expenditure through increasing PV cell efficiency.

The use of the uplink as the primary communication system requires that the receiver is powered on at all times. Thus we employed a low power wake-up scheme utilizing an envelope detector and a 2MS/s COTS ADC which polls all faces for a period of 100mS each at a reduced sampling rate. This scanning process can be implemented to consume minimal standby power as demonstrated by similar implementations in commercial wake-up receivers. The ground station broadcasts a link start signal for 5 seconds. When a clock signal is recovered, the ADC selects the face with the best SNR and processes telemetry data. One of the primary goals of this payload is to investigate the feasibility of such a system as an emergency communication and reset channel. The implementation of the receiver circuitry in the EPS allows it to power cycle the spacecraft via dedicated control. At the same time, the received telemetry can be delivered to the OBC to overrides radio link data.

b. Educational Objectives

Numerous opportunities for Science, Technology, Engineering and Math (STEM) collaboration will accompany this proposal before and after the spacecraft is on orbit. Currently, we are in discussions with schools for collaboration on a student designed and managed secondary payload as well as participation in the final development, testing and launch of the demonstration mission. We are awaiting a memorandum of understanding to be finalized in support of this collaboration.

Additionally, we will encourage and promote third-party participation in various activities once Calypso has been delivered to orbit.

The Calypso project will feature a website that will provide educational material relating to optical communications system, space-to-ground communications - history, technologies and utilization - including fact sheets, sample lesson plans and activities for the classroom. Additionally, the website will have a dashboard where the public will be able to view the status of the spacecraft and its systems in real-time, including uplink and downlink messages.

From the dashboard, people will be encouraged to enter and transmit their own message (with appropriate delay for safety). These messages will appear in the downlink data as well as being detectable upon transmission from Calypso. This will provide schools a unique interactive platform for educating students and the public in a variety of scientific disciplines, including but not limited to:

- Atmospheric studies (induced distortion - i.e. "twinkle", Doppler effect, changes in perceived color due to atmospheric variation)
- Airborne pollution
- Physics of light propagation
- Climate of the upper atmosphere
- Communications system technology and operation

As part of the Calypso project, designs for a receiving station and tutorial on its operation will be made available to schools and the public so that anyone will have the information on how to build their own ground station. Individuals will be able to submit messages for transmission and reception by the various ground stations all over the world. This will open up the field of amateur/public long distance over-air communications without requiring the kind of extensive, time-consuming and sometimes costly training, certification and licensing that hampers adoption of amateur (HAM) radio.

c. Relevance to NASA Strategic Goals

The proposed technology answers the high cost, low reliability, and low scalability inherent in current systems, possibly allowing a transformational change in Cubesat and SmallSat communications. Through increasing the affordability of a high-throughput downlink the technology will open up new possibilities for NASA, OGAs, and commercial customers while offsetting demand for existing radio telecommunication infrastructure. The technology is currently at TRL 4.

The technology allows for infusion with Cubesat technology for applications that have hit the data rate ceiling in terms of traditional radio communications such as remote sensing and data relay.
In the short term, we also see significant STEM outreach potential due to its ability to provide visual feedback to the ground user. A predicted maximum visual magnitude of 2.5 allows real-time interaction with the spacecraft and can be easily adapted for multiple STEM education missions such as orbital tracking.

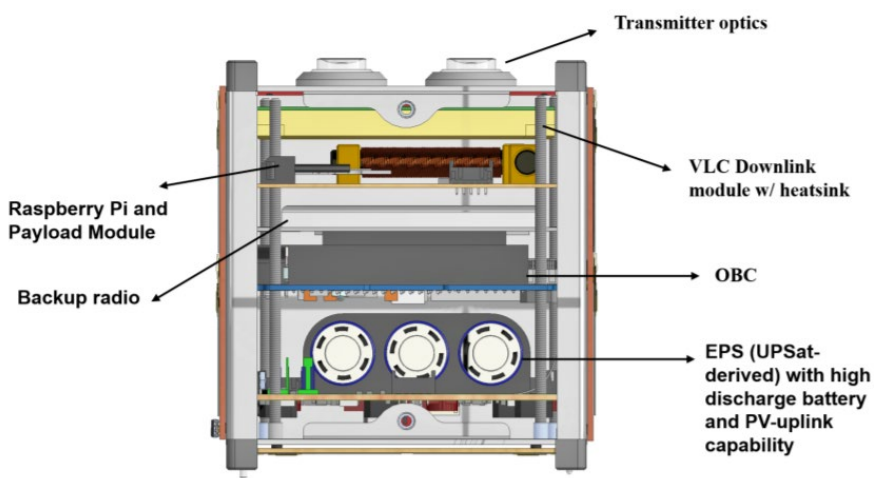
d. Commercialization Potential

The rising demand for high bandwidth communications on Cubesat-class spacecraft which accompanies the increasing utilization of small spacecraft for commercial and high-data rate applications is well recognized. As the amount of data generated increases, there has been a shift towards S-band and X-band radio which utilizes large, cost prohibitive (>5m) ground stations to achieve higher bandwidths. Laser communication is out of the budget of most Cubesat missions, often costing more than the entire project lifecycle while requiring a complete redesign. The proposed technology is positioned to fill in the gap between traditional and laser communication in terms of bandwidth and cost, offering a drop-in replacement or complement to existing radio systems. The major predicted use cases are listed below.

1. To provide low cost, 10Mb/s to 50Mb/s downlink with user-deployable, small scale ground stations for high bandwidth applications
2. To allow for full optical communications with Cubesats and unburdened by FCC radio licensing and regulations while providing higher performance as a drop-in replacement for traditional UHF/VHF radio
3. To provide academic institutes with a powerful STEM education platform through visual feedback

We plan to develop a network of ground stations compatible with non-coherent links to allow quick adoption of this technology. We estimate the potential market for this technology at approximately 50 Cubesats and microsatellites per year.

2. Mission Implementation



All subsystems for Calyspo, except the student-led payload, have been built and tested or have been budgeted and will be purchased commercially. The structure, the solar panels, the special EPS system required for the optical experiment, the OBC, the optical communications payload, and the thermal imager were designed and built over the period from 2016-2017 with engineering assistance and testing infrastructure provided by Aphelion Orbitals, Inc. at their facility in Union City, NJ.

A long distance ground test has already been carried out successfully on the optical communication payload. An orbital test is required to establish atmospheric characteristics and test the viability of the differential phase correction system.

(Pictured above: We currently are in possession of a Pumpkin, Inc. 1U Cubesat Kit that is the base for the Calypso project)

a. Command and Data Handling

In order to reduce mission risk, we have decided to utilize a reliable COTS Cubesat Kit and flight module for CD&H acquired from Pumpkin, Inc. The core of this system contains a Texas Instrument MSP430 microcontroller running the flight-proven Pumpkin Salvo RTOS. The module communicates with the rest of the Cubesat via USART, SPI, and I2C through the bus connector and interfaces directly with the telemetry system. In addition, it buffers data collected by onboard sensors, the optical communications system, and the thermal imager on a 2GB SD card until transmission. The flight software has already been completed with exception to the handling of the optical training data downlink and video compression.

Two other software processors interface with the CubeSat Kit flight module, both of which run Perihelion OS from Aphelion Orbitals, Inc. Perihelion OS has been developed on top of a customized Linux kernel and NASA's Core Flight System (cFS). The Raspberry Pi Compute module (ver. 3) contains a BCM2837 quad-core 1.2GHz processor, 1GB of RAM, and 4GB of eMMC flash storage. This will be used to house and run student-led experiments, which are isolated from the rest of the Cubesat to mitigate mission risks, and to train and execute the TensorFlow based neural network for the optical communications experiment. The EPS has the ability to disable this processor in case of unexpected behavior or excessive power draw. The second processor is a STM32F427 ARM Cortex M4 microcontroller located on the electrical power system board, which manages and processes incoming data from the PV-cell receivers. Both of these processors are designed to be programmable in-orbit. The continued operation of either processor is not mission critical and will only affect their respective mission objectives.

b. Electrical Power System

Calypso will utilize a custom EPS solution to accommodate the reverse-biasing and ADC required for the PV-cell uplink experiment. Based on an existing EPS products, it uses five independent maximum power point tracking (MPPT) solar channels and high-efficiency converters to provide 3.3V, 5V, and 12V rails with seven solid-state switches to various satellite subsystems. The EPS can provide a maximum output power of 15W on the 5V rail and 13.2W on the 3.3V rail, at nearly twice the peak power of the 8W (5V rail) and 3W (3.3V rail) expected for the Calypso Cubesat. Two high-capacity Panasonic 18650 3400mAH cells and one high-discharge 2800mAH cell make up the battery pack. The cells are heated and temperature regulated. A reliable battery charging and protection circuit is built into the EPS board. This battery pack has been successfully tested in Aphelion's thermal vacuum chamber. The single high-discharge battery is wired directly to the optical communications downlink board to provide safe, pulsed 35A, 3V to 4.1V unregulated power. A thermal control system acts as a safety shut-off.

The 5 solar panels on the Calypso Cubesat (covering the X+, X-, Y+, Y-, and Z- faces) were supplied by Aphelion Orbitals. Each panel contains 2 30.5% efficiency, space-rated, triple junction cells with integrated cover glass, sun sensor, and temperature sensor. These provide an orbital average power of 1.91W, which allow 2 minutes of full optical communications operation per orbit. Reverse-biasing of the solar panels, which is required by the experiment, has been tested with no impact on overall power generation as the technique increases the efficiency of the PV cells in compensation to the energy expended.

c. Attitude Determination and Control

The optical communications downlink, with a beam divergence of 20 degrees, requires an active ADCS system. We have selected the CubeSpace CubeTorquer and CubeCoil actuators with ultra-low remnance cores for 3-axis control to provide a maximum actuation of 5%. These units have flight heritage from QB50 precursor missions. The pointing accuracy requirement of the Calypso Cubesat is 10 degrees and attitude determination is 15 degrees, as the optical ground station enables closed-loop control of spacecraft attitude. The attitude determination system, which consists of the solar-mounted sun sensors, MEMS accelerometers gyroscopes, and the Raspberry Pi/CMOS camera based sun/nadir sensor provides knowledge down to 0.1 degrees (3-sigma). With only the sun sensors functional, the system still retains 10 degree knowledge, allowing all scientific and educational objectives to be met.

d. Communications

The Microhard MHX420 has been flown multiple times with the Pumpkin Cubesat Kit on missions such as ITUpSat1 and was selected for Calypso due to its reliability and flight heritage. The AO-produced UHF tape measure antenna utilizes a proven construction and deployment technique.

The optical communications system is also capable of transmitting and receiving data. These have a higher risk than the UHF radio, but will act as a backup system. The PV-cell uplink is capable of power cycling the Cubesat upon receiving at least 3 reset signals within a 2 minute period from the ground station laser, preventing accidental resets.

e. Thermal and Structural Design

Calypso employs the commercial, flight proven Pumpkin solid-walled Cubesat chassis. Certain modifications were performed on the structure, including milling of cable routing ports and the removal of the Z+ panel, replacing it with the LED transmitter.

Due to the high discharge employed by the transmitter, an LM76 temperature sensor has been designed into the transmit module to force a shutdown in case of overheating. Two additional sensors under the batteries allow constant monitoring.

The optical communication module contains a 89g heat sink produced from 7075 aluminum that is in direct thermal interface with the LED transmitters. This prevents overheating of the module during pulsed operation. The heat sink was tested with the full transmit cycle in a thermal vacuum chamber to have a maximum temperature rise of 24 degrees Celsius when not facing the sun (the only condition under which the transmitter will power on).

3. Merit Review

Since project conception in 2016, Calypso has undergone multiple merit reviews involving both internal personnel and external subject matter experts. The reviews assessed the merits of the project to meet objectives in NASA's Strategic Plans from 2017 through 2019.

It has been determined that Calypso adequately addresses goals in NASA's Strategic Plan relating to technology development for future LEO and deep space communications communications using visible light. Calypso also address NASA's educational goals with the inclusion of a student-built payload and the participation of academia and the public during on-orbit operations.

There are no outstanding issues currently identified that would adversely impact the mission's merit

Review Team membership (partial) – Sihao Huang, Haowen Lin, David Nagy, Connor Givans, Matthew Travis, Michael Ressa

4. Feasibility Review

Since project conception in 2016, Calypso has undergone multiple feasibility reviews involving both internal personnel and external subject matter experts. The maturity of the project has adequately demonstrated its feasibility.

First, most hardware and software is currently on-hand and has been tested in the laboratory environment. The optical component has been thoroughly tested on the ground and proven to be feasible. The theory behind the communications experiment has been demonstrated during our rigorous testing.

One requirement that is still being addressed is building out the complete management and technical team with the appropriate experience and expertise. The reviewers recognize that many positions cannot be filled until certain technical and programmatic milestones are met. As we reach those milestones, we are continuing to build out our management and operational team and anticipate that process to continue through on-orbit deployment.

The only uncertainty remaining relates to fully executing the mission. These risks include funding, potential hardware failure and inability to manifest a launch. However, these are risks that every cubesat mission faces and are not directly related to the feasibility of the mission itself.

Review Team membership (partial) – Sihao Huang, Haowen Lin, David Nagy, Connor Givans, Matthew Travis, Michael Ressa

APPENDIX A: Management and Planning

a. Organizational Structure

The Calypso project mission will be guided by four complementary and overlapping teams under the corresponding individual authority:

1. Project Planning
2. Mission Design and Operations
3. Science Operations
4. STEM and Outreach

Mr. Matthew Travis is the Principal Investigator for the Calypso project.

The Project Planning team will be responsible for ensuring successful execution of the overall project, including regulatory compliance, launch provider integration, launch, NASA interface, External and Public Relations and finance.

The Mission Design and Operations segment will be responsible for spacecraft final assembly, testing and qualification, flight software development and qualification, payload integration in the spacecraft, ensuring compliance with all applicable criteria as directed by the launch provider and NASA, preflight testing and verification, on-orbit commissioning, interface and coordination with the STEM and Outreach team.

We are utilizing the NASA Operational Simulator for Small Satellites (NOS3) and Open Mission Control Technologies (OpenMCT) as key tools for mission design, development, simulation and operations.

Science Operations will interface with the Mission Design and Operations team to ensure the payload is successfully integrated and prepared for launch and to complete on-orbit checkout after launch. Science Operations will be responsible for the operation of the payload once the spacecraft has been declared operational and all activities relating to the payload will flow through Science Operations, including STEM activities. Science Operations will interface with the Mission Design and Operations and STEM teams to ensure successful operation of the science payload and execution of all planned activities.

The STEM and Outreach team will coordinate all educational activities and be the Point Of Contact for educational institutions participating in the Calypso mission and associated STEM activities. This team will also be the primary interface with the public and media and will create and direct all activities related to public outreach and media relations. The STEM and Outreach team will operate under the direct supervision of the Project Planning team.

b. Hardware and Software Status

At the time of this proposal, most of the hardware for the Calypso spacecraft has been procured and is on hand at the organization's facility. A list of the major components and status is as follows:

Subsystem	Mass (g)	Average Power Consumption (W)	Peak Power Consumption (W)	Hardware/Testing Status
Optical Communications Downlink		0.9	145	Two prototypes have been ground tested. Thermal vacuum testing complete, flight hardware being built.
Structural Components		-	-	Purchased from Pumpkin, on hand
AO Solar Panels		0.02	0.02	Full flight set provided by Aphelion.
AO EPS and Batteries		0.		Flight hardware thoroughly tested, batteries and engineering assistance provided by Aphelion.
Raspberry Pi Compute		0.3	1.1	Purchased COTS, on-hand
CMOS Camera				Purchased COTS, on-hand
FLIR Lepton Thermal Imager				Purchased COTS, on-hand
Student-designed RPi Host/Payload Board and experiment		0.1	0.5	Not yet designed. Led by Stuyvesant High School; design intervention if necessary to ensure timeline security and reliability.
CubeSat Kit Flight Module		0.2	0.2	Purchased from Pumpkin.
Microhard Telemetry Module		0.3		Available COTS.
Antenna		-	-	
Total				
Margin				

Software specific to the payload and ground systems is currently in development and targeted for completion in the first quarter of 2020. Our open source software, utilizing the NASA Core Flight System derived Perihelion OS from Aphelion Orbitals, Inc. is complete and ready for utilization.

As a backup, there are currently several software packages that we would be able to utilize and successfully execute the scientific and engineering objectives of the Calyspo mission. Obviously, it is desirable in the long term to have our own software utilized but it is prudent to maintain alternatives in order to protect the viability of the overall spacecraft mission.

c. Mission Budget

The majority of the spacecraft hardware components have already been purchased or manufactured. Three components that we still need to acquire are:

CubeSat Kit Flight Module

Telemetry Module

Antenna

All software is either on hand or in the late stage of development. This includes the software that will run on the spacecraft, ground systems software and programs used during design, assembly and testing. We anticipate no future monetary costs related to project software.

Labor costs for paid employees has already been factored into our budget planning as a sunk cost and will not add to the project cost total in the future. Nearly all work is performed by volunteers. Mission operations, scientific and engineering investigations as well as outreach activities will be conducted solely utilizing volunteer labor. As such, we do not anticipate a significant labor cost, if any, to result from this proposal.

All prelaunch testing and qualification will take place at our facility prior to delivery to the launch provider or payload integrator.

Execution of the Calypso mission will take place at ARES Institute's. The facilities are being made available at no cost to the project.

Ancillary costs, e.g. internet access, electrical, water, are being assumed by ARES Institute, Inc. as a component of their normal operational budget and have not been nor will be charged to the Calypso project.

In summary, we anticipate no substantial forthcoming expenses directly related to Calypso or this proposal except for the above-mentioned hardware components. The mature state of project development gives us confidence that future costs will be minimized successfully.

APPENDIX B: Funding Commitment

Aerospace Research & Engineering Systems Institute, Inc.
Matthew Travis
105 Bowler Springs St
Las Vegas, NV 89148

November 1, 2019

To Whom It May Concern,

As the sponsoring organization for the Calypso cubesat, the Aerospace Research & Engineering Systems Institute, Inc. remains fully committed to the project's success. The organization affirms its ability to fully support the technical and financial obligations required to complete development of the cubesat through on-orbit deployment. We will be able to meet the project's needs using capital and resources that we currently have on-hand and our expected organizational budget through the year 2023.

Sincerely,

Matthew Travis
President, Aerospace Research & Engineering Systems Institute, Inc.
matthew.travis@aresinstitute.org
(321) 289-0872

Phoenix Launch Systems, Inc.
http://www.phoenixlaunchsystems.com
matthew.travis@phoenixlaunchsystems.com ~ 321.289.0872

November 1, 2019

To Whom It May Concern,

As a collaborating and supporting organization for the Calypso cubesat, Phoenix Launch Systems is committed to the project's success. We affirm our ability to support the technical and financial obligations required to complete development of the cubesat through on-orbit deployment. We will be able to support the project's needs through the year 2023.

Sincerely,
Matthew Travis
President, Phoenix Launch Systems, Inc.
matthew.travis@phoenixlaunchsystems.com
(321) 289-0872

APPENDIX C: Resumes

Name: Matthew Travis (Principal Investigator)

President, Aerospace Research & Engineering Systems Institute, Inc., 2003 – Present: ● Coordinate the technical development and implementation of programs as proposed by the Executive Committee. ● Lead authority for all Cubesat-related projects and outside collaborations. ● Manage member services and act as primary authority for creation of grant proposals and execution of awards. ● Contribute material to those productions as an accredited news journalist at the organization's Kennedy Space Center bureau.

President, Phoenix Launch Systems, Inc. (2019-Present)

President, COO & Chief Engineer, Vogue Aerospace & Defense, Inc.
Education: University of Illinois, Urbana-Champaign, IL. 1988-1997, Aeronautical/Astronautical Engineering and Computer Science.

Chief Operating Officer, Aphelion Orbitals, Inc., 2016 – 2019: ● Coordinate the development and implementation of programs as proposed by the Board of Director; ● Manage day to day business operations; ● Lead compliance officer; ● Chief Designer, launch vehicles; ● Lead software engineer.

Staff Programmer, University of Illinois, 06/1997 – 11/1998: ● Developed web-based educational applications for the College of Agricultural, Consumer and Environmental Sciences.● Served in a lead role in the development of JavaBeans components for online applications. ● Engineered application development using Perl, SQL and Java.● Developed applications for staff to manage curricula, testing and student records. Responsible for design and implementation of MySQL, MS Access and MS SQL Server databases.

Programmer, National Center for Supercomputing Applications, 08/1995 – 1/1996: ● Developed applications in C++ and Java. ● Created shared libraries in C/C++ that were callable from Java, in support of the Habanero object-sharing and collaboration project. ● Performed debugging and Q.A for the NCSA Mosaic web browser development team.

Name: Michael Ressa

Founder, CEO/CTO, Vogue Aerospace & Defense, Inc., 2017- Present
Education: ● Electrotechnics, Electromechanics & Industrial Electronics, State Institute for Industry & Crafts, "IPSIA L. SANTARELLA", Bari (Apulia, Italy), 1985-1991. ● Aerospace Engineering/Physics, San Jose State University and Solano College (Partial Credits), 1998-2002. ● Continuous Self Thought studies in several-desired specific Engineering & Physics disciplines. CEO: he leads the Company into a "New School of Thought" comprised of a new thinking and startegy for a modern XXI Century Industrial Direction, that will allow for the lowest possible launch costs, New Space technology cost-effective solutions and a new generation of future weapons. All specifically-continuously thought for the US Space & Defense Programs of new demanded specific and several requirements.

CTO: On-demand Problem Solver and Inventor, New Conceptual Design/Groundwork related

Theoretical Studies of Innovative Space & Tactical Missile Mechanics/Propulsion, Non-Conventional Space Propulsion (Clean Sheet Design), Missile Defense & Next Generation Weapon Systems.

Extended & Ongoing Work: ● *"The Limit of Application in Liquid Propellant Launch Vehicles"* (CLVs & LALV), (1994-2017); ● *"Dimensional Reject and Mass Ratio-Geometry Equivalency"* (1994-1998); ●*"Grilled Solid Rockets & Hybrid Coupling"* (2007-2014); CASTO™ - *"Coaxial-Authophage-Stage-To-Orbit"* ● PCT WO2014/022836 A2: *"Universal Elliptical-Sliced Solid Grain Geometry and Coupled Grill-Feedththrough Featured Assembly for Solid Rocket Motor and Hybrid Rocket Design"* (2007-Present); ●*"3D-Printed Light-Weight Featured Continuous-Thread for General Industrial Applications, Spacecraft Deorbit and High Performance Compact Launch Vehicles"* (2016-2019); ● US 62/484,567 (04/2017): *"Skin-Staging Methods and Optional Reusable Essential Vehicle or Variable Volume Launch Vehicle Coupling Features for Limit of Application of Eco-Friendly Monopropellants"* (2014-Present); ● US 29/604,468: *"Spherical-Coaxial Assembly Featured Stage-To-Orbit Launch Vehicle"* (*"Sphere Rocket"* - Vogue-RLV/RLE™, 1994-Present). Ongoing Classified Work: ● Pioneering 1st Gen. Vogue-RLV/RLE™; ● RESSA™ - *"Rocket Engine for Solar System Applications"* (1st prototype, Q2 2020); ● LIWAPROS™ - *"Lunar/In-Space Water-Based Propulsion System*"; ● RETMA™ - *"Rocket Engine for Tactical Missile Applications"*; ● HITEP™; ● ATAL™-*"Any-Take-Off/Any-Landing"* (Space-Defense); ● NGW™ - *"Next Generation Warhead"*; ● SAW™ ● KOAB™ (New Generation Aerial Bomb, Defense); ● ARPO™ (Long-range Artillery Shell).

APPENDIX D: Research Paper

(Included with permission)

Fully Optical Spacecraft Communications: Implementing an Omnidirectional PV-Cell Receiver and 5Mb/s LED Visible Light Downlink with Deep Learning Error Correction

Sihao Huang and Haowen Lin

Aphelion Orbitals, Inc.

3433 Joe Murell Dr, Titusville FL 32780

Free space optical communication techniques have been the subject of numerous investigations in recent years, with multiple missions expected to fly in the near future. Existing methods require high pointing accuracies, drastically driving up overall system cost. Recent developments in LED-based visible light communication (VLC) and past in-orbit experiments has convinced us that the technology has reached a critical level of maturity. On these premises, we propose a new optical communication system utilizing a VLC downlink and a high throughput, omnidirectional photovoltaic cell receiver system. By performing error-correction via deep learning methods and employing atmospheric correction, the system is able to produce data rates that match those of traditional laser-based solutions. A prototype of the proposed system has been constructed, demonstrating the scheme to be a feasible alternative to laser-based methods, opening up the path for the implementation of optical communication techniques on small spacecraft as either backup telemetry beacons or high throughput links.

I. Introduction

The large surface area of the PV cells on a spacecraft provides a significant sensor area which can be utilized as an omnidirectional receiver on many solar panel layouts. Previous researchers have proposed the use of this unique asset as a backup communication system,[6] realizing that a low cost, low power consumption uplink could be created by using the photovoltaics as a laser receiver. Such proposed systems have low data rates of around 10Kb/s, allowing them to serve as effective emergency alternative-band communication systems, but not as an operational uplink.

PV cells are intrinsically difficult to work with as high-bandwidth components due to their high parasitic capacitance, and high photocarrier drift and diffusion times. Building on the work of Won-ho Shin et al.,[9] who demonstrated 17.05 Mbps discrete multitone transmission on a solar panel receiver, we propose an implementation of overcoming these limitations through reverse biasing with little impact on the overall efficiency of the power system.

One of the most significant advantages of the use of a PV-cell receiver is the low mass and power penalty to a small spacecraft. This becomes more apparent on Cubesats and even femtosatellites, negating the need for an uplink receiver or antenna, providing mass, cost, and power budget savings in a design environment when all three are critical to mission success.

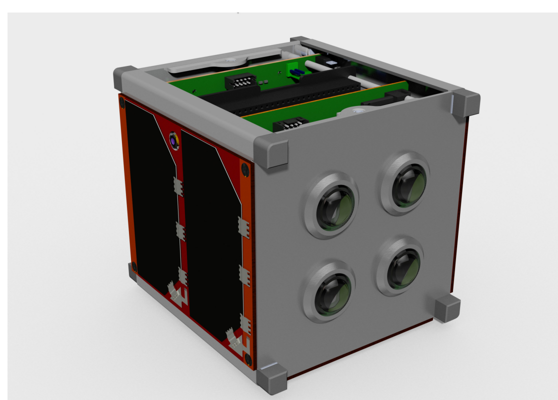


Figure 1. Implementation of proposed VLC transmitter and PV-cell receiver on the Calypso Spacecraft

Successful commercial implementation of a fully optical communication system depends on high reliability and low pointing accuracy requirement. The second part of the link utilizes a non-coherent, LED-based transmitter which enables a stable downlink without an operational, high accuracy attitude determination and control system (ADCS). The use of LED beacons is not new; the idea has been trialed on FITSAT-1, which successfully recovered a 5kHz modulation on the signal.[11] ShindaiSat[2] flown in 2014 utilized an array of 36 LEDs on its high gain array, with a total output of 86.4W. This allowed for a data rate of 9.6Kb/s while utilizing basic FSK modulation and white light, which negated the possibility of spectrum filtering. Moreover Li-Fi and similar technologies have matured the field of visible light communication considerably and the characteristics of LEDs are well known.[5]

Despite lower directionality, the significant efficiency improvement of LED transmitters (state-of-the-art at around 70% for LEDs, 30% for laser diodes) enables a power-per-bit value that was much lower than expected. The data rate ceiling for a transmitter bound by the power and pointing limits of a 3U Cubesat is predicted to be around 50Mb/s. This, too, sparked significant internal interest for further research as it indicates a large potential in nanosatellite applications to fill the gap in communication bandwidth. Future advancements such as larger ground stations, improved focusing systems, and optimized modulation/recovery techniques will enable the envelope to be pushed even further.

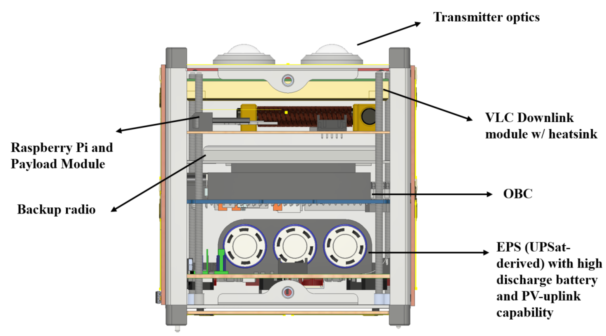


Figure 2. Internal layout of the Calypso 1U Cubesat

Amongst the biggest challenges in implementing a commercial VLC system are:

- The hardware implementation and miniaturization of a high power, high bandwidth system
- The difficulties presented by atmospheric distortion and, and the compensation techniques necessary to counteract these impedances
- The relatively poor signal to noise ratio of non-coherent carriers compared to laser-based systems

In this paper we address all three issues respectively.

II. Link Design

Signal to noise ratio is a prime concern on the spacecraft downlink due to the low monochromaticity of single-color LEDs (most COTS components have a spectral spread of around 15nm). At the same time, the design is restricted by a wider beam. Nevertheless LEDs allow for a far high power in a small footprint compared to laser-based systems. To this we have chosen a peak electrical power of 140W and average operational power of 15W, with an electro-optical efficiency of 70%, well within the feasible limits of a 1U Cubesat.

The gain of the transmitter and receiver are given by the following:[1]

$$G(tx) = \frac{16d^2}{\lambda^2}$$

$$G(rx) = (\frac{\pi d}{\lambda})^2$$

A 400 KM circular orbit is used with a maximum angle from zenith of 40, a beam divergence of 20, and a homogeneous power distribution. Note that as a result of the relatively large beam width, we approximate the aiming loss to 1dB resulting from receiver tracking inaccuracies. A 30cm (12 inch) commercially available telescope is used as the receiver and 700 photons/bit is assumed.

Transmit Power	19.9 dBW
Transmitter Gain	12 dBi
Path Length	522 km
Free Space Path Loss	260.5 dB
Atmospheric Loss	2 dB
Pointing Loss	1 dB
Receiving Aperture	30 cm
Receiver Gain	123.6 dBi
Received Power	-107.3 dBW
Bit Rate (700 $photons/bit$)	$8.85 \cdot 10^4 bits/s$

This is comparable to most high-performance S-band systems available on the market today and offers similar bit rate to laser communication systems on the same scale. Overall the system offers a very attractive alternative to either solution due to its low cost and reduced ADCS requirements. It is also worth noting that with a radiant flux of $8.16 \cdot 10^{-9} W/m^2$, the satellite will have a predicted visual magnitude of around 1, making it visible under good seeing conditions.

The uplink laser will utilize a 150W YAG-pumped 1064 nm laser mounted coaxially to the downlink receiver and tracking setup via a 0.3m transmitter. The ground station cost is of a lower concern as such systems do not need to be made available to every spacecraft operator. The implementation of a pixel array-based tracking system allows for a tracking error of less than 1.2 arcsecond (3σ) without a fine steering mirror, and for spacecraft identification in emergencies where the exact orbit may not be known. A simple radiometric link budget gives the received power of the link.

Transmit Power	21.76 dBW
Transmitter Gain	121.0 dBi
Path Length	522 km
Free Space Path Loss	255.8 dB
Atmospheric Loss	2 dB
Pointing Loss	1 dB
Receiving Area	$70cm^2$
Receiver Gain	108.9 dBi
Received Power	-8.12 dBW

At a irradiance of $1000W/m^2$, with a 8.12 dbW, or 0.154W, of received power, it is predicted that the peak-to-peak voltage of the signal is 0.45V. This allows for relatively easy detection using the electrical power system or a dedicated channel. The data ceiling of the system is thus bound mostly by the effective bandwidth of the solar cells.

III. Implementation

The proposed communication architecture, composed of a VLC downlink and PV-cell uplink, will be flown on Calypso, a 1U Cubesat developed jointly between Aphelion Orbitals and the Aerospace Research & Engineering Systems Institute. The two functions are contained in a dedicated VLC downlink module and a custom EPS-integrated uplink driver. This mission serves to both demonstrate the low volume and ADCS requirements of the system by implementing it in the given form factor and power budget.

III.A. Cell Based Uplink

Reverse biasing photodiodes is a common technique for improving bandwidth by increasing the number of photocarriers and improving drift velocity. The use of self-biasing on solar cells has been investigated in the VLC industry.[9] This technique has been demonstrated to improve the -3dB bandwidth of a PV cell by up to 60% with a 30V bias achieved by a lightweight upconverter. Moreover, it was determined that very low energy losses are incurred as biasing recovers significant energy expenditure through increasing PV cell efficiency.

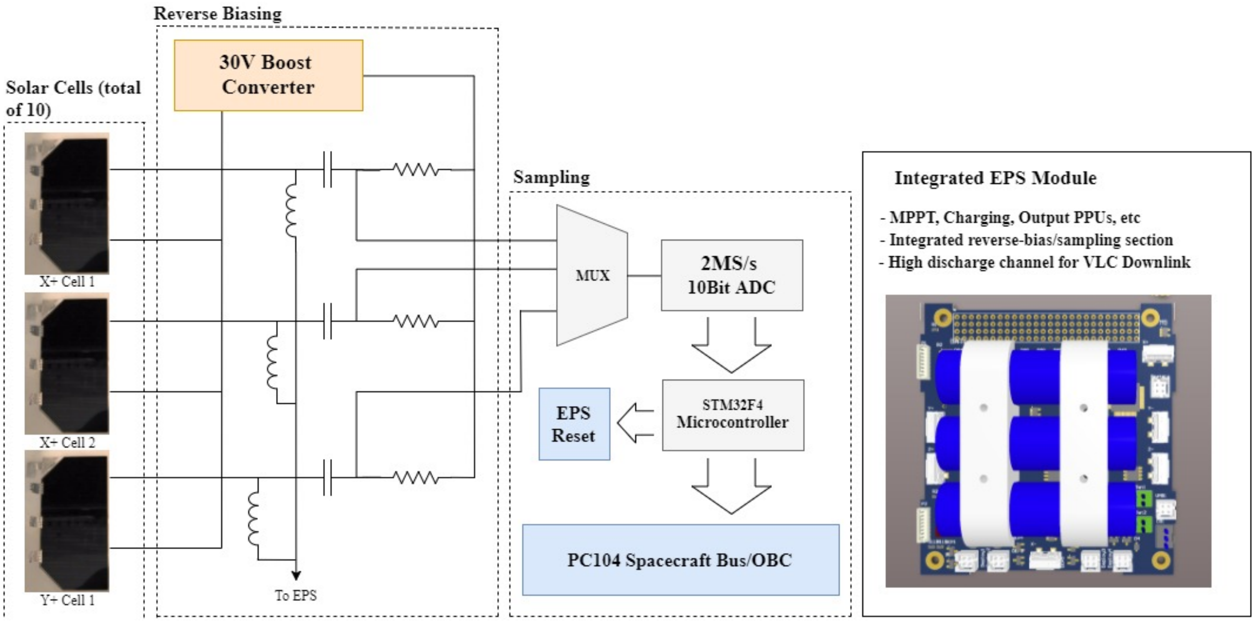


Figure 3. Topology of the PV-cell uplink with internal reverse-biasing. The spacecraft EPS board performs all functions in an integrated module. Note that only 3 cells out of 10 are depicted.

The use of the uplink as the primary communication system requires that the receiver is powered on at all times. Thus employed a low power wake-up scheme utilizing an envelope detector and a 2MS/s commercial-off-the-shelf ADC which polls all faces for a period of 100mS each at a reduced sampling rate. This scanning process can be implemented to consume minimal standby power as demonstrated by similar implementations in commercial wake-up receivers.[4] The ground station broadcasts a link start signal for 5 seconds. When a clock signal is recovered, the ADC selects the face with the best SNR and processes telemetry data.

One of the primary goals of this payload is to investigate the feasibility of such a system as an emergency communication and reset channel. The implementation of the receiver circuitry in the EPS allows it to power cycle the spacecraft via dedicated control. At the same time, the received telemetry can be delivered to the OBC to overrides radio link data.

III.B. Visible Light Downlink

A survey of COTS LEDs has revealed that, though limited, there exists a number of options available that provide built-in lensing at a 20-degree beam width. However, to open up the possibility for more efficient, monolithically packaged, high power diodes, additively manufactured, low profile lenses can be used without major thermal concern due to the low duty-cycle of the transmitter. The implementation on Calypso utilizes four high efficiency, high power, 620 nm Luminus SBT-90 LEDs capable of 1600 lumens at 13.5A peak power each.

To maximize transmit antenna gain, we have evaluated a number of commercial TIR lens and parabolic reflector attachments. As no suitable lightweight component was found for the large aperture of the Luminus LEDs, a set of additively manufactured lenses based on an SLA process will be produced and subsequently processed for a suitable surface finish.

The Calypso payload implements a downlink LED driver with 140W peak power and a 40Mb/s bandwidth limit. Scaling down a transmitter of this power represented a sizable technical obstacle due to thermal dissipation.

This was mitigated through the low specified duty cycle which restricts the transmitter to a 2 minute on-time per orbit. An Altera Cyclone IV handles the stream processing and interfacing with the OBC. The FPGA, together with a Raspberry Pi compute module, implements an end-to-end

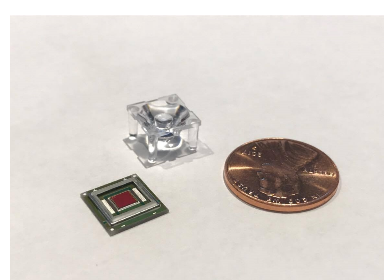


Figure 4. A Luminus SBT-90 LED with an evaluated COTS TIR lens

deep learning-based signal processing system that drives a 125Ms/s, 14 bit DAC. This produces a QAM-16 modulated signal that is fed into four different high-powered bias-tees after amplification. A dedicated high discharge battery in the EPS feeds the synchronized pulsed MOSFET LED driver.

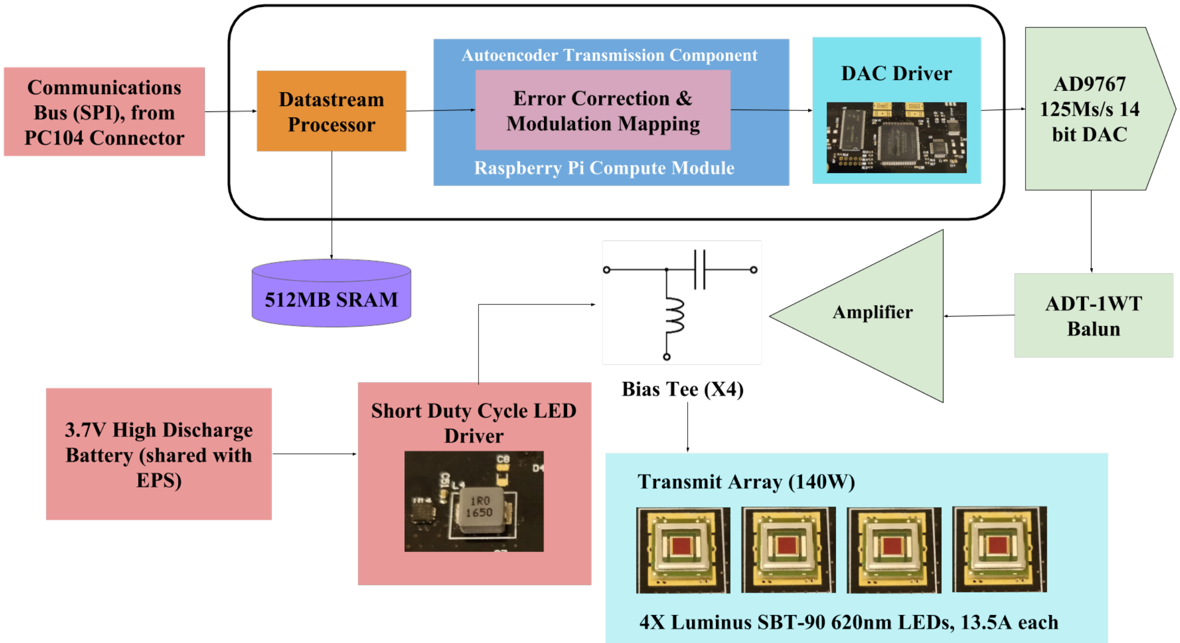


Figure 5. High level block diagram of the VLC downlink transmitter

The module is contained within a single PC104 form-factor PCB mounted on the Z+ face of the Cubesat, weighing 150g. An integrated, 7075 aluminum housing on the back of the unit is directly coupled to the LEDs and switching circuitry to act both as an EMI shield and a heat sink. Prototypes of the driver circuitry have been constructed, as shown in Figure 5.

The units have been tested rigorously in Aphelions facilities for power characteristics, modulation response, and thermal dissipation under vacuum conditions. A second revision will be made in accordance with the testing, which called for a higher powered preamplifier.

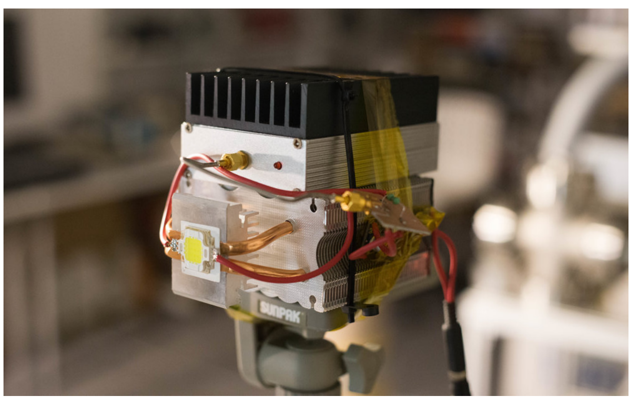


Figure 6. Prototype VLC transmitter with amplifier and bias-t

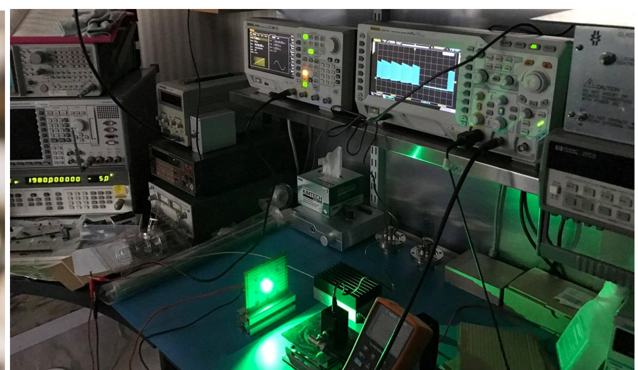


Figure 7. Early transmitter test showing an FM sweep. A DC-biased QPSK link was demonstrated using the same hardware.

IV. Ground Station/Compensation

Free space optical communication systems need to compensate fpr channel impairments such as atmospheric distortion and the frequency response of hardware components (i.e. transmitter LEDs). In order to account for such problems through an economical and lightweight method, an innovative method using deep learning was devised. Utilizing the research of O'Shea and Hoydis, we modeled the downlink as an autoencoder,[8] an unsupervised learning device used to map high dimensional data to lower dimensions, acting similar to a compression algorithm. This allows us to maximize the channel bandwidth. Communications systems generally require mathematically tractable models.[8] However, in the interest of lowering costs of development and deployment in production environments, it is more economically feasible to eschew traditional multiple stage communication systems in the favor of a single end-to-end deep learning system optimized for the specific hardware and channels, lowering development time and cost.

As certain types of deep learning systems (specifically, recurrent neural networks) are known to be Turing-complete[10] and universal function approximators,[7] we are able to combine the various parts of classical communication architecture into a single block and have the neural network model it in its entirety. The cost of deep learning systems have been falling rapidly and as efficiency of GPU systems improve, it is possible to embed such a system into a Cubesat. There are current research efforts in creation of specialized ASICs (Application Specific Integrated Circuits) optimized for neural network systems, including Googles Tensor Processing Units. In future iterations, it is possible to integrate such chips into Cubesats instead of off-the-shelf graphical processing units designed for embedded systems (in this case the Raspberry Pi on-board GPU) that will be flown on Calypso, allowing higher power efficiency and better optimization.

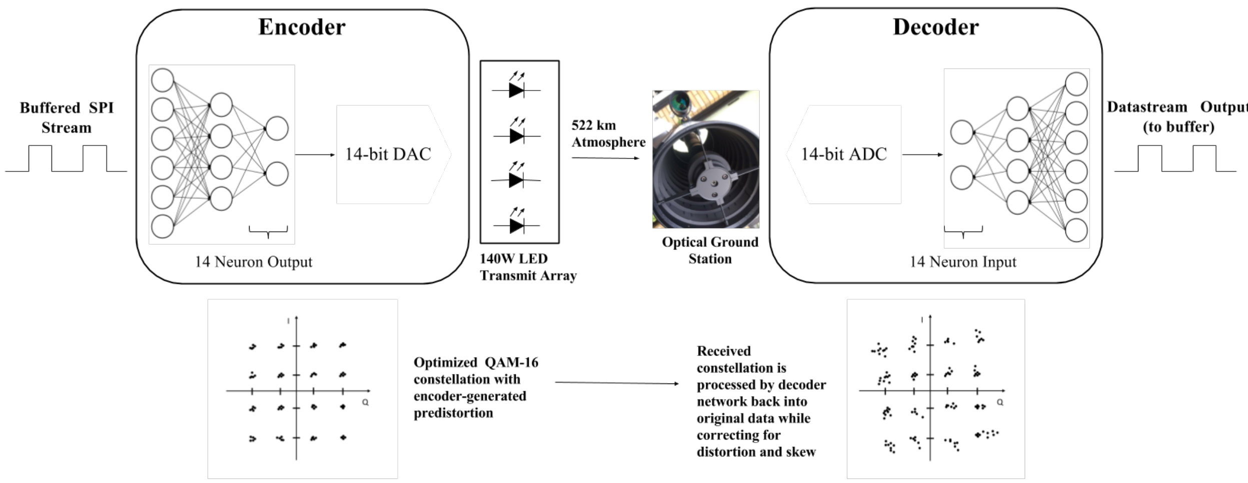


Figure 8. Prototype VLC transmitter with amplifier and bias-t

The autoencoder system will implemented with a one-hot input vector of the maximum size the Calypso's embedded Raspberry Pi module is capable of efficiently running in flight conditions (which will be determined later empirically). The goal of the neural network is to minimize the difference between the theoretically achievable SNR and the actual SNR. The theoretical transmission we are modeling upon utilizes a QAM-16 transmission system with Reed-Solomon error correction. It has already been demonstrated by O'Shea and Hoydis that such machine learning based signal processing systems are capable of performing just as well if not exceeding the efficiency of a traditional encoding and/or modulation system that operate in discrete stages. On this premise, we have decided to train the neural network on Calypso while it is in flight instead of doing so on the ground with theoretical atmospheric loss models so as to achieve the highest efficiency in practice. The training data will be sent up via the RF uplink and it will be used to train the optical communication system.

The system proposed by O'Shea and Hoydis is implemented with the final feed-forward layer of the encoder being 14 neurons, driving the 14-bit DAC. The ADC on the downlink has a 14-output which will be fed into the decoder system.

At the same time, we recognize that VLC offers an exciting opportunity in atmospheric correction technology. When multiple transmitters are used on a single link, a differential phase delay can be observed, given by the following equations:[3]

$$\phi_1 = k \int_0^H [n_0 - n_1(z)]dz$$

$$\phi_2 = k \int_0^H [n_0 - n_1'(z)]dz$$

Where n_0 is the average diffraction index, n_1 represents the fluctuation of that value, and k is the wavenumber of the transmitting beam. Hence,

$$\sigma_\phi^2(H,\theta) = \langle(\phi_1 - \phi_2)^2\rangle = 2.914k^2(\frac{d}{H})^{\frac{5}{3}} sec\,\psi \int_0^4 C_n^2(z) z^{\frac{5}{3}} dz$$

C_3^5, the atmospheric structure constant, is a function of height z and is given by $C_h^2(h) = 0.0059(\frac{v}{27})^2(10^{-5h})^{10}e^{-\frac{h}{1000}} + C_0 e^{-\frac{h}{100}}$, C_0 is approximately $1.7 \cdot 10^{-14}$.

It has been suggested that provided a large enough separation between the transmitters (in the order of multiple kilometers), the interference between the two beams can effectively correct for atmospheric scintillation. However, the differential phase delay is too small for use in atmospheric fluctuation correction on most spacecraft due to physical restraints preventing the two transmitters from being positioned a substantial distance apart.

However, the use of visible light communication techniques opens up the possibility of multiple synchronized receivers due to the wide beam coverage. The Calypso payload will evaluate the use of this technique using two identical Rubidium time-synchronized receivers placed 20KM apart to record the differential delay between the two received signals. The data is then interfered and corrected digitally to recover the transmission.

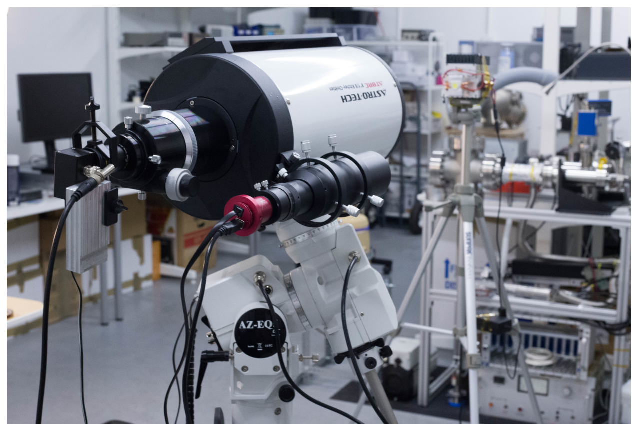


Figure 9. Ground station prototype based on a Ritchey-Chretien telescope with coaxial tracking system and commercial mount

Each ground station is composed of a 30cm aperture Ritchey-Chretien telescope mounted on a commercial German Equatorial mount. Tracking is achieved via a coaxial 5cm refractor and a control computer. Both of the stations will be equipped with a YAG-pumped uplink laser modulated by a DAC/FPGA setup, which also allows the interference-based correction technique to be used on the PV-cell uplink. We expect the cost of each ground station in its final configuration to be approximately \$8000, a figure crucial for replicability and widespread adoption to allow the construction of a ground station network. At the same time, the same hardware could be shared among multiple bands, together with laser downlink users, to spread deployment cost.

V. Mission Goals

The primary goal of the Calypso optical payload is to demonstrate the commercial viability of a fully optical spacecraft complete with an uplink and downlink. At the same time, a number of exciting technologies have presented themselves through the adoption of VLC. The mission also has the following goals.

- To measure atmospheric attenuation through a pre-calibrated transmitter and power monitoring
- To train and evaluate a deep learning system for optical communication error correction
- To evaluate the feasibility of differential phase delay correction using two ground stations

VI. Conclusion

Building on a number of past missions directed at exploring the use of VLC on satellites, we have described a highly economical and space efficient bidirectional communication system designed for use on small satellites and as an emergency beacon. Utilizing state-of-the-art deep learning technology, we are able to implement a system in for use in optical communications that is capable of optimizing itself. This system is shown to have a number of unique advantages and can be easily commercialized based on present levels of maturity. Currently the flight version of the optical communication payload is under development and is expected to be integrated into the Cubesat by the end of 2017.

References

[1] Jennifer C. Ricklin (auth.) Arun K. Majumdar. *Free-Space Laser Communications: Principles and Advances.* Optical and Fiber Communications Reports 2. Springer-Verlag New York, 1 edition, 2008.

[2] Nakajima Atsushi, Sako Nobutada, Kamemura Masato, Wakayama Yuuki, Fukuzawa Arata, Sugiyama Hironori, and Okada Naoki. Shindaisat : A visible light communication experimental micro-satellite.

[3] Si Yuan Yu (auth.). *Wei Xing Guang Tong Xun Miao Zhun Bu Huo Gen Zong Ji Shu.* Shi Er Wu Guo Jia Zhong Dian Tu Shu Chu Ban Gui Hua Xiang Mu Guang Xue Yu Guang Zi Xue Cong Shu. China Science Publishing & Media Ltd., 1 edition, 2016.

[4] C. Carrascal, I. Demirkol, and J. Paradells. A novel wake-up communication system using solar panel and visible light communication. In *2014 IEEE Global Communications Conference*, pages 461–467, Dec 2014.

[5] Svilen Dimitrov and Harald Haas. *Principles of LED Light Communications: Towards Networked Li-Fi.* 03 2015.

[6] X. Guo and J. Thangavelautham. Novel Use of Photovoltaics for Backup Spacecraft Laser Communication System. *ArXiv e-prints*, February 2017.

[7] K. Hornik, M. Stinchcombe, and H. White. Multilayer feedforward networks are universal approximators. *Neural Netw.*, 2(5):359–366, July 1989.

[8] Timothy J. O'Shea and Jakob Hoydis. An introduction to machine learning communications systems. *CoRR*, abs/1702.00832, 2017.

[9] Won-Ho Shin, Se-Hoon Yang, Do-Hoon Kwon, and Sang-Kook Han. Self-reverse-biased solar panel optical receiver for simultaneous visible light communication and energy harvesting. *Opt. Express*, 24(22):A1300–A1305, Oct 2016.

[10] Hava T. Siegelmann and Eduardo D. Sontag. On the computational power of neural nets. In *Proceedings of the Fifth Annual Workshop on Computational Learning Theory*, COLT '92, pages 440–449, New York, NY, USA, 1992. ACM.

[11] T. Tanaka, Y. Kawamura, and T. Tanaka. Overview and operations of cubesat fitsat-1 (niwaka). In *2013 6th International Conference on Recent Advances in Space Technologies (RAST)*, pages 887–892, June 2013.