SWAMPSAT ANTENNA SYSTEM

By

DANTE AUGUSTUS BUCKLEY

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2009

To my wife who inspires me everyday; to my colleagues and friends who believe in me; and to my girls (Koda, Kenai, & Roxy) who always love me

ACKNOWLEDGMENTS

First, I must thank the Lord for giving me the strength to accomplishment my thesis and my graduate studies. I must thank my parents Daniel and Mary Ann Buckley, for their sacrifices in order for me to become the man I am and to give me the opportunity to pursue higher education. I must thank the Rivera family, especially Basilio and Yamile Rivera, not only for entrusting me with their greatest treasure, my wife Taryn, but also for believing in my aspirations.

With deepest gratitude and respect, I sincerely thank Professor Norman Fitz-Coy for his everlasting patience with me and his guidance as my academic advisor and mentor in life. For his support and faith in me, I am honored. There are numerous undergraduate and graduate classmates, but I owe many thanks to the Space Systems Group, my graduate team within the Department of Mechanical and Aerospace Engineering. Thanks to my colleagues Shawn Allgeier, Sharan Asundi, Katie Cason, Takashi Hirmatsui, Sushant Kadmidivan, Frederick Leve, Tzu Yu (Jimmy) Lin, Matthew Mahin, Vivek Nagabhushan, Kunal Patankar, Salvador Torre, and Andrew Waldrum.

I must thank those that created, participated, and believed in the goals established by the student-led Small Satellite Design Club, SSDC. I'd like to thank the Gator Amateur Radio Club, GARC especially the faculty advisor, Dr. Jay Garlitz, AA4FL and station manager, Jeff Capehart, W4UFL. I must thank Mario de Aranzeta and Barbara Beck for allowing access to their facilities for me to conduct my research. I must thank Mr. Larry Bradford for his continual support. I'd like to thank the Florida Space Grant Consortium and Space Florida in particular, Dr. Jaydeep Mukherjee, for supporting the Florida University Satellite Design Competition in which I acquired valuable experience. I would also like to thank the small satellite community in particular the CubeSat Community for their support and cooperation.

I would also like to thank Dr. Janise McNair for her time reviewing my masters research. I would like to extend my gratitude to Dr. Carol Chesney for her assistance in completing my masters research.

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Requirements for the Degree of Master of Science

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By

Dante Augustus Buckley

August 2009

Chair: Norman Fitz-Coy
Major: Aerospace Engineering

SwampSat is the first University of Florida CubeSat mission and is an on-orbit technology demonstrator of a compact three-axis attitude control system for rapid retargeting and precision pointing (R2P2) capabilities. The focus of this thesis is the SwampSat antenna system. Various antenna configurations, antenna materials, packaging and deployment techniques feasible for CubeSat operation and P-POD integration were surveyed.

The SwampSat antenna system design must integrate to the structural and electrical design in a non-intrusive manner. The antenna system modules are developed to support an assembly process which can be performed independently and then interfaced to the SwampSat mechanical frame and electrical components. A deployment mechanism is developed and tested for the transmit and receive antennas. Successive prototypes of the antenna system have been fabricated and tested and the final flight design is presented. The antenna system will undergo further field and deployment testing to mitigate failure modes.

Dipole antennas were selected for the SwampSat mission based on requirements and specifications of the mission and the outcome of the survey, a dipole antenna design was adopted for SwampSat.

CHAPTER 1
INTRODUCTION

> "The art of engineering is to take a bright idea and with money, personnel, materials, and the proper regard for the environment produce something the public wants at a price it can afford to pay"

1.1 Research Motivation

Leading nations within Europe and Asia have focused on education highlighting science and technology and as a direct result have enhanced their performance and capabilities in space. [8] The current United States administration has defined science education and training as the target areas for the next generation. [3] At the state level, the Governor's Commission in the Future for Space and Aeronautics in Florida stated, "Florida's residents from Key West to Pensacola must embrace the statewide importance of the aerospace industry, as it benefits more than just the communities along the Space Coast. Beyond our borders, the nation and the world must learn to see Florida as more than just a launch site but also a home for manufacturing and assembly of rockets, satellites, and aircraft and for the research and innovation that underpins all of these industries" [8].

Since traditional satellites are costly and designed to accommodate sophisticated and redundant systems for operation, they are not appropriate for educational purposes. The emerging CubeSat program offers students educational opportunities through access to space with acceptable risks and affordable costs. The standard 1U CubeSat form factor, a 10 centimeter cube, poses a challenge to innovate technology and utilize commercially available parts to obtain rapid results. The CubeSat program provides a knowledge-based platform for students and collaborators to assemble and to venture into the space frontier.

The CubeSat concept was authored jointly by California Polytechnic State University (Cal Poly - San Luis Obispo) and Stanford University, and is quickly becoming a standard for small satellites in the pico- and nano-satellite classifications [15]. Small satellites are classified as pico-, nano-, micro-, and mini-satellites based on nominal mass and dimension. [2].

Due to their limited size, computational resources, and power generation capabilities, CubeSats offer the unique ability to provide technology research and development as well as educational opportunities. In addition to universities, government agencies, and commercial industries within the CubeSat community have the chance to interact with one another. [17].

The CubeSat concept embraces the idea that small satellites complement traditional satellites and offer the community improvements in cost and schedule which cannot be achieved by the traditional satellites. The 3U Poly Pico-satellite Orbital Deployer (P-POD) is a certified container which holds up to three 1U CubeSats. P-PODs can be integrated to various launch vehicles worldwide as secondary payloads thus offering additional access to space. CubeSats are currently scalable in 1/2 U increments up to 3U however several multi-pod configurations are under development which could support multiple units. [20]

The scope of this thesis is limited to the antenna system selection, integration, and deployment mechanism for the University of Florida CubeSat known as SwampSat.

1.2 Thesis Outline

This thesis is organized as follows. Chapter 1 provides an introduction to how the CubeSat program plays a pivotal role in education and developing science and technology previously unaffordable and available in satellite operations. Acknowledgements of the successes of the vibrant CubeSat community by government and commercial industries illustrate a prime example of motivating pico- and nano- satellite flights. The SwampSat mission is demonstrating enabling technology to add utility to these class of satellites through the demonstration of a novel attitude control system.

Chapter 2 explores common antenna configurations and materials for CubeSats and the design tradeoffs for the antenna selected. Antenna systems on existing CubeSats were surveyed.

Chapter 3 describes the successive design improvements in the SwampSat antenna systems. The SwampSat antenna system module is presented. Antenna packaging techniques and a deployment mechanism are detailed.

Chapter 4 details the testing of the antenna deployment and supporting communication hardware for verifying the effectiveness of the antenna system design.

In Chapter 5, a supplemental communications section is provided to elaborate on the preparation for SwampSat tracking and operation.

Chapter 6 presents conclusions and future work.

1.3 CubeSat Background & Heritage

CubeSats have become a growing trend in university pico- and nano- satellite research programs worldwide. The initial focus behind the CubeSat program was to allow universities to engage and train students by providing affordable access to space. Commercial-Off-The-Shelf (COTS) components and miniaturization of satellite technology have enabled the CubeSat missions to be successful. An emerging market opportunity has become evident as the space industry embraces the concept of CubeSats. Entities such as the National Science Foundation (NSF) [10], the National Reconnaissance Office (NRO) [9], and National Aeronautics and Space Administration (NASA) have invested in supporting the development of CubeSat technologies. NSF's space-weather and atmospheric research department sponsored two university affiliated 3U CubeSat missions in 2008. NSF plans to continue this program as experimental results become available. NSF is also supporting the Advanced Space Technologies Research and Engineering Center (ASTREC), which is a Industry/University Collaborative Research Center (I/UCRC) hosted by the University of Florida and North Carolina State University aiming to enhance the utility of small satellites through focused technology and research [7]. The

NRO's Innovative Experiment Initiative (IEI) Broad Agency Announcement (BAA) acknowledged the need for advances in several critical small satellite subsystems. As a result, the NRO established a CubeSat office called Q_bX to monitor and develop pico-and nano-satellite technologies for improved satellite systems.

CubeSats provide universities a means to train students for the workforce and allow academia to solve innovative problems through project management skills and space systems engineering techniques. The CubeSat program has been elevated from an educational status quo to space business opportunities. Traditional satellites take years to be developed and tested before their flight is outdated. [6] The evolution of the CubeSat must be contributed to the emphasis on standards and will continue to expand as the infrastructure (ie. secondary payloads, multi-pod configurations, and flexible launch opportunities) develop. CubeSats have relatively rapid development cycles and quick turnaround on investment versus traditional satellites. The proliferation of small satellites do circumvent for an affordable yet effective orbital debris mitigation device once a mission has been achieved. The orbital lifetime versus operational lifetime causes challenges for the CubeSat missions. However, the University of Tokyo's XI-IV pronounced SAI-four launched in 2003 is still operational. CubeSat mission life cycles were originally proposed to last a few months or years. The team of XI-IV verified a CubeSat's bus can be comprised of COTS components. XI-IV has been operating for over six years since its launch in June of 2003.

1.4 SwampSat

SwampSat is a technology demonstrator being developed at the University of Florida. SwampSat is in the 1U CubeSat form factor and weighs 1.2 kilograms.

SwampSat performed a P-POD fit check conducted at Cal Poly's clean room facility (Fig. 1-1).

SwampSat's primary objective is to demonstrate a compact three-axis attitude control system (comprised of a pyramidal cluster of single gimbaled control moment gyroscopes)

Figure 1-1. SwampSat fit check unit

for rapid retargeting and precision pointing (known as R2P2) for pico-and-nano satellite applications [18]. SwampSat is contains an entire satellite bus which must carry out its functions and tasks for SwampSat to perform. A list of operational concepts which will be demonstrated on-orbit include:

- Establishing communications in both directions
- Validating supporting subsystems:
  - ADS: Inertial measurement unit, sun sensor, magnetometer
  - CDH: Software and analog/digital converters, flight computer board
  - EPS: Batteries, solar cells, power supply board
- Downlinking pre-maneuver attitude data
- Performing attitude maneuvers
  - Sun pointing
  - Retargeting
- Downlinking of post-maneuver results

SwampSat is the inaugural University of Florida CubeSat mission which received a first place award for its design at the 4th Annual FUNSAT, the Florida University Satellite design competition sponsored by Space Florida and the Florida Space Grant Consortium.

SwampSat has provided team members and collaborators valuable hands-on experience relating to space systems engineering and critical team managing decision-making skills. The SwampSat project demonstrates the roles and capabilities necessary within a multi-disciplinary group to carry out the engineering of a successful small satellite mission. Subsequent missions will incorporate the engineering practices developed by the SwampSat team.

1.5 CubeSat Communications

The communication subsystem provides the critical link between the satellite and the users on the ground. CubeSats currently use radio-communication systems in the Very High Frequency (VHF), Ultra High Frequency (UHF), S and X amateur radio bands respectively. The ability of the CubeSat community to utilize the existing amateur radio community has expanded the mission operations profile for university CubeSats. Radio frequency (RF) techniques are commonly implemented in CubeSat missions due to their omnidirectional, frequency selection, and worldwide tracking capabilities.

Omnidirectionality is an important feature for CubeSats because they currently lack the attitude sensors and actuators to precisely point instrumentation such as high gain antennas. A directional antenna could improve the antenna gains for CubeSats so a higher data rate can be achieved but also needs to maintain the attitude for pointing requirements.

A compilation of the CubeSat transceivers with their specifications and results determine which CubeSat communication designs were functional. Transmit frequencies, modulations, antenna types, power outputs, and data downloaded are compiled for known operational CubeSats. [13] Monopoles and dipoles dominate the CubeSat antenna configurations while few patch antennas have been implemented.

As developments in attitude sensors and actuators mature, CubeSat communications will benefit. An increase in pointing capabilities which can directly benefit gain and increasing the gain is a major challenge in CubeSat communications. Directional antennas could maximize the throughput for CubeSat operations reducing the limited memory stored for telemetry analysis. One such methodology to increase CubeSat communications by implementing a small satellite sensor network which could distribute various processes across several CubeSats in a constellation [16]. The satellite link to link concept still would require the common radio frequency antenna systems to command and track from the ground.

CHAPTER 2
SURVEY FOR SWAMPSAT ANTENNA SYSTEM DESIGN PARAMETERS

2.1 Survey of Antenna Configurations

Miniaturization of antennas for electronic devices and computers have become a growing interest in antenna designs. [4] A large emphasis of the current antenna manufacturers is to focus on small antennas which could ultimately be embedded into a surface on a printed circuit board. However fundamental mechanical limitations hinder the free-space wavelength to which an antenna element must couple. The SwampSat antenna configuration was selected keeping in mind these mechanical and electrical factors:

- Packaging
- Rigidity
- Acceptable Gain
- Sufficient Bandwidth

A brief description of available antenna concepts is detailed below to motivate the selection process.

2.1.1 Parabolic Reflectors

A parabolic reflector is a reflective device to collect or project radio waves. The parabolic reflectors transforms an incoming plane wave traveling along the axis into a spherical wave converging toward a focus. A spherical wave generated by a point source placed in the focus is transformed into a plane wave propagating as a collimated beam along the axis.

The construction of a parabolic reflector is not feasible for SwampSat due to volume constraints.

2.1.2 Dipole

A dipole antenna consists of a center-fed point which splits into two elements for transmitting or receiving radio frequency energy. The current amplitude on a dipole antenna decreases uniformly from maximum at the center-fed point to minimum of zero at the element ends. Packaging a dipole with respect to the center-fed point is commonly implement in CubeSats due to their packaging and deployment characteristics. The length of the dipole antenna is directly related to the operational frequencies so the antenna lengths can be determined based on the desired frequency.

The dipole antenna configuration is an appropriate choice for SwampSat.

2.1.3 Monopole

A monopole antenna is a type of radio antenna formed by replacing one half of a dipole antenna with a ground plane normal to the remaining half. If the ground plane is large enough, the monopole behaves exactly like a dipole, as if its reflection in the ground plane formed the missing half of the dipole. However, a monopole will have a directive gain of 3 dBi, and a lower input resistance, resulting in overall lower antenna efficiency.

The monopole antenna is appropriate but is not selected for SwampSat due to lower gain as compared to a dipole.

2.1.4 Helical

A helical antenna is an antenna consisting of a conducting wire wound in the form of a helix. In most cases, helical antennas are mounted over a ground plane. Helical antennas can operate in one of two principal modes: normal (broadside) mode or axial (or end-fire) mode. In the normal mode, the dimensions of the helix are small compared with the wavelength. The far field radiation pattern is similar to an electrically short dipole or monopole. Helical antennas can be used in two modes, transverse and longitude. When operating in transverse mode the helix behaves as a group of ring antennas. The radiation is directed perpendicular on the axis of the helix, and adjusting the diameter of each ring and the turn space between of each helical coil allows for circular polarization. Helical antennas have a predictable pattern, gain, and impedance over a wide frequency range. The directionality depends on the quantity of helical coil windings. As the length of the antenna increases so does the gain.

The helical antenna is not feasible for SwampSat due to volume constraints.

2.1.5 Microstrip and Patch

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. CubeSats have not utilized many microstrip patch antenna designs due to the challenges of miniaturization and parameter specifications. [11]

The microstrip and patch antenna is not feasible for the selected SwampSat frequencies.

2.1.6 Horn

The horn dimensions and shape, placement of the reflector, and reflector's dimension and shape alter the beam pattern. Horn antennas are typically implemented as feed elements for large radio astronomy, satellite tracking, and communication dishes. Horn antenna is a common element of phased arrays and serves as a universal standard for calibration and gain measurements of high-gain antennas. [4]

The horn antenna is not feasible for SwampSat due to volume constraints.

2.2 Antenna Configuration Selection

Selecting the horn, helical, and parabolic reflector for a SwampSat antenna system are not feasible as the packaging difficulties cannot be accommodated on the structural design in Fig 3-1. Patch antennas were eliminated from the design because of the frequency selected. A higher frequency would decrease the dimensions of the patch antenna which could be embedded within the SwampSat structure. However, the frequencies allocated for the SwampSat mission especially the 2 meter band ensures the patch antenna design is not applicable. Monopole and dipole dominate the antenna configurations in CubeSats. [13] Additionally, the only antenna systems commercially available to the CubeSat community are monopole and dipole configurations. Innovative Solutions in Space (ISIS) Inc. has partnered with Clyde Space is offer COTS antenna system design for tape springs [1].

The antenna configurations defined in the previous section are compared in Table 2-1. As a result, the dipole antenna is selected.

Table 2-1. Pros and cons on antenna configurations survey for SwampSat

Antenna Type	Pros	Cons
Parabolic Reflector	high gain	packaging, deployment alignment, highly directional
Dipole	omnidirectionality frequency dependent, packaging	low gain, no radiating at the antenna tip
Monopole	omnidirectionality, frequency dependent	low gain, no radiating at the antenna tip
Helical	high gain, circular polarization, simple in structure	packaging and deployment deployable volume
Microstrip/Patch	narrowband, small size, no deployment, frequency dependent	low gain
Horn	high gain, simple construction	packaging difficulties, construction joints, highly directional

2.3 Dipole Antenna Design Tradeoffs

The antenna length is directly related to the operating frequency, η, where $\frac{\lambda}{4}$ is the length of a single element of a half-wave dipole, and c is the speed of light. As the length of the antenna decreases, the frequency increases. For the selected SwampSat frequencies, the single elements of the transmit antenna are 34.3 cm and those of the receive antenna are 101 cm by applying Eq. 2–1.

$$\frac{\lambda}{4} = \frac{c}{4\eta} \tag{2–1}$$

2.4 Survey for SwampSat Antenna Material

Several characteristics were analyzed to select the material for the SwampSat antenna dipole elements. Since a dipole antenna was selected, the material needed to be elastic in order to fit inside the CubeSat constraints. Fabrication and the ability to solder factored into the selection of the final flight antenna material.

The following factors for antenna selection are:

- Elasticity
- Conductivity
- Low friction
- Considerable change in parameters in extreme temperature conditions
- Ability to solder
- Fabrication

2.4.1 Nitinol

Nitinol is a nickel titanium alloy which is known for its shape memory characteristics. Nitinol wires have flown on several CubeSats [13]. However, an increased bandwidth is desired for SwampSat and nitinol strips would have a higher bandwidth due to their increased width. Care must be taken to fabricate nitinol elements and solder connections to nitinol.

The difficulty of packaging nitinol due to its stiffness characteristics validated not selecting nitinol for SwampSat antenna material.

2.4.2 Tape Spring Steel

Tape spring steel is a common antenna material utilized on several CubeSat missions due to its ability to be packaged in a confined volume. Additionally , spring steel fabrication is a straight-forward process that can be easily accomplished in the lab. Solderable connections require that the coating be removed from the tape measure. Any necessary holes for mounting and deployment in the antenna elements can fabricated in-house.

The factors of the tape spring steel mentioned validated the selection of tape spring steel for the SwampSat antenna material.

CHAPTER 3
SWAMPSAT ANTENNA SYSTEM DESIGN

The SwampSat antenna system is designed for integration to the flight hardware to accomplish successful antenna storage, deployment and operation. The subsystems and components are interdependent. The antenna system is mechanically integrated into the SwampSat structure and electrically interfaces to the SwampSat communication board and flight computer board. The structural and electrical impact of the SwampSat antenna system is addressed in the design. The antenna system is split into two modules; transmit and receive antenna system modules. This chapter addresses the design of both these modules. The antenna system modules also address the assembly process. The SwampSat layout with the deployed antennas is shown in Fig. 3-1 and the components involved in determining the layout of the antenna system are in Table 3-1. Overall, the antenna system design goals are:

- Modular design
- Ease of integration with SwampSat system
- Minimal mass

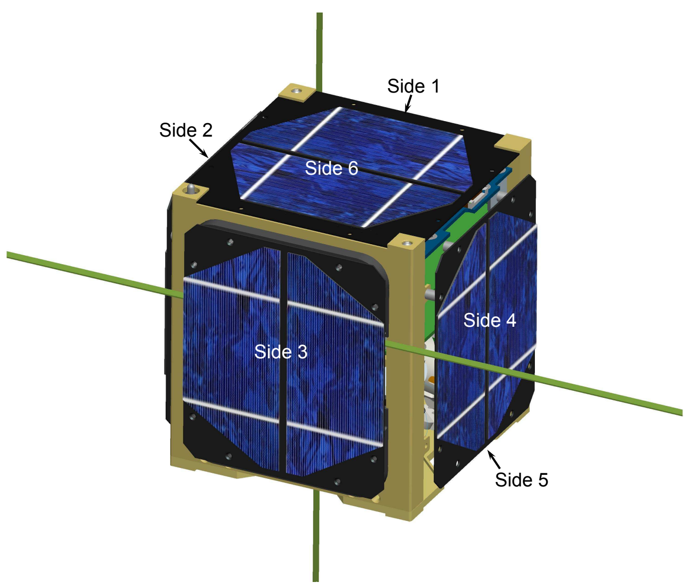


Figure 3-1. SwampSat layout with crossed dipole antennas

Table 3-1. Components involved in antenna system layout

Side	Component
1	Transmit Antenna
	Magnet Coil
	USB Connector
	Remove-Before-Flight Pin
2	Magnet Coil
3	Receive Antenna
4	J-Tag Connector
5	Base Plate
6	Magnet Coil

The SwampSat aluminum frame depicted in Fig. 3-2 shows the holes for mounting the composite panels.

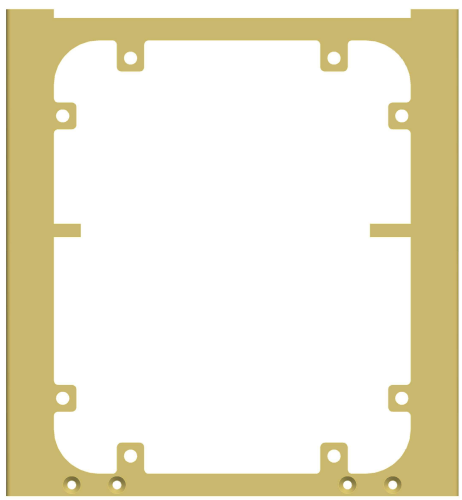


Figure 3-2. Aluminum frame for mounting the composite panels

Each antenna system module is sandwiched between the aluminum frame and the composite panel. The antenna system consists of two different delrin plate designs for the transmit and receive dipole antenna elements. The modules are mounted on opposite sides to avoid a collision of the antenna elements during simultaneous deployment in Fig. 3-1. The transmit antenna system design is detailed first and the receive antenna system design and reason is next.

3.0.3 Transmit Antenna System

The transmit antenna system is sandwiched between a composite panel as shown in Fig. 3-3 which corresponds to Fig. 3-1. The transmit antenna system design must accommodate for the thickness of the magnet coil.

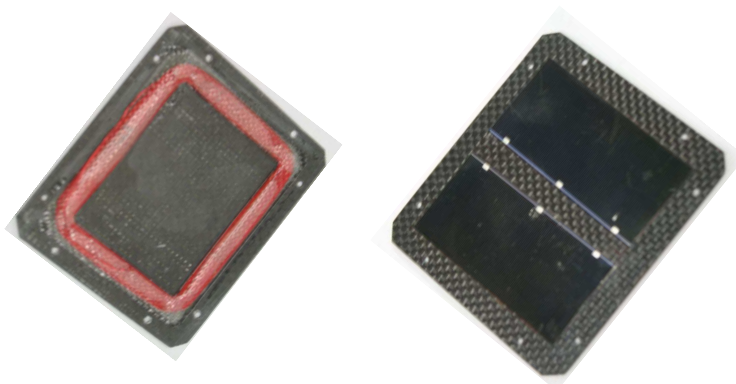


Figure 3-3. Composite panel (front and back view)

In addition to the magnet coil as Table 3-1 shows, a USB connector and Remove-Before-Flight (RBF) pin must be addressed in the transmit antenna system design.

A delrin plate for the transmit antenna elements is shown on the left in Fig. 3-4 while the the transmit antenna system module is shown on the right in Fig. 3-4. The delrin plate illustrates the indentation for accessing the USB connector and the RBF pin, the groove for the packaging of each transmit dipole antenna element, the deployment mechanism, and the antenna feed points.

The transmit dipole antenna elements are mounted on the delrin plate as labeled on Fig. 3-5. The antenna is wrapped inside the groove created by the composite panel and the lip on the delrin plate. A nylon fiber (in blue) routes between the hole at each tip of the transmit antenna elements. The nylon fiber applies a tension to restrain the transmit antenna elements from deploying. A recess in the delrin transmit plate is designed to accommodate the insertion of the nylon fiber and to allow for sufficient room for the

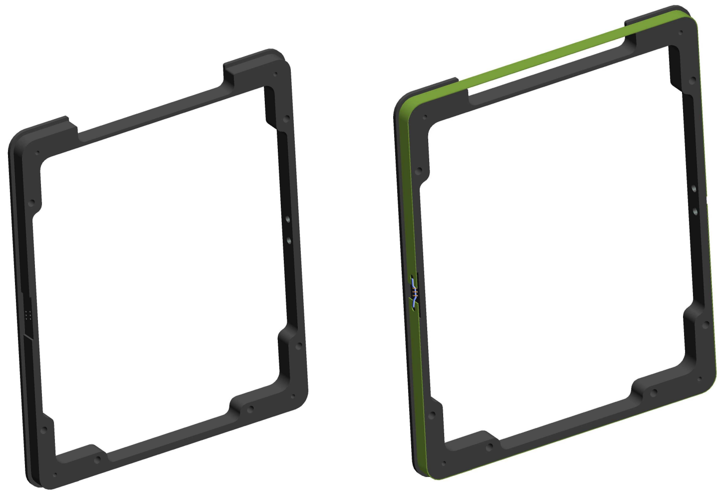


Figure 3-4. Transmit antenna module

deployment mechanism. The tension applied by the nylon fiber. The transmit antenna deployment mechanism resides on the middle of rail 2 on side 3 as indicated in Fig. 3-1. The nylon fiber is designed to route through the nichrome burn-wire (in orange) located on the recess on the delrin plate. To reiterate, the nichrome burn-wire is activated by a switch which severs the nylon fiber which rotates the flaps ultimately deploying each dipole receive element simultaneously into their flight configuration for operation.

3.0.4 Receive Antenna System

The receive antenna system is sandwiched between a composite panel and aluminum frame just as the transmit antenna system however however the magnet coil is on the back side in Fig. 3-6 which corresponds to side 3 of Fig. 3-1.

A delrin plate is designed for the receive antenna is on the left in Fig 3-7 while the receive antenna system module on the right in Fig. 3-7 illustrates the accommodations of

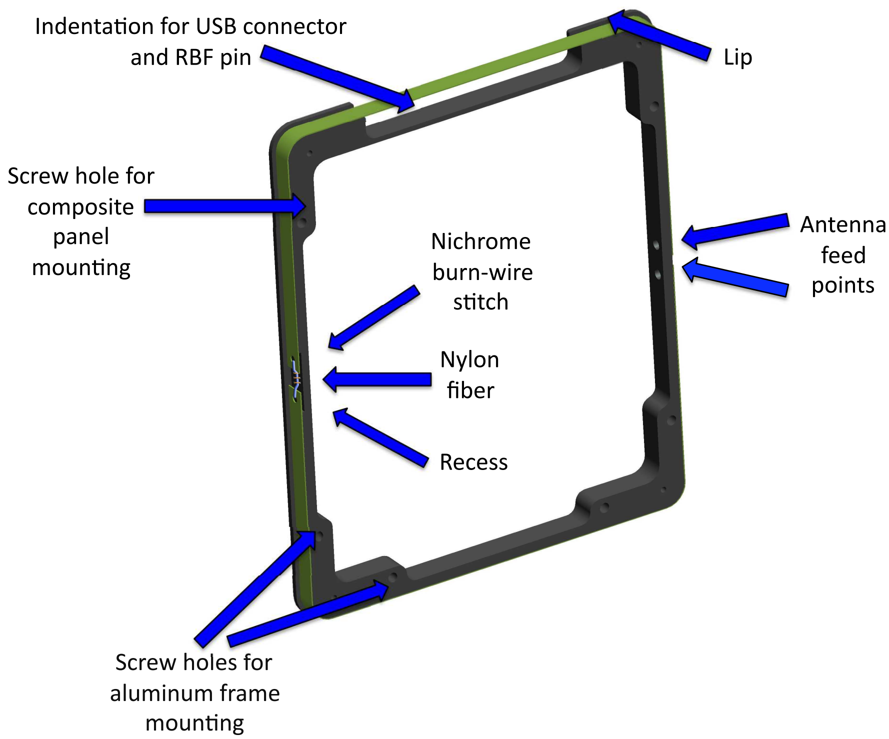


Figure 3-5. Labeled transmit antenna system module

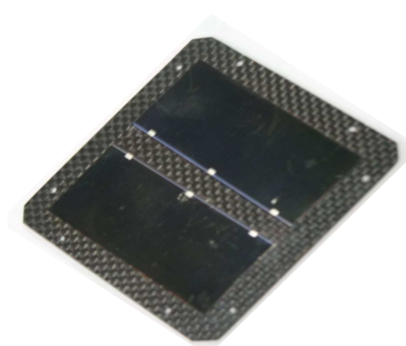


Figure 3-6. Composite panel

two cavities for packaging the receive dipole antenna elements, the deployment mechanism design and the antenna feed points.

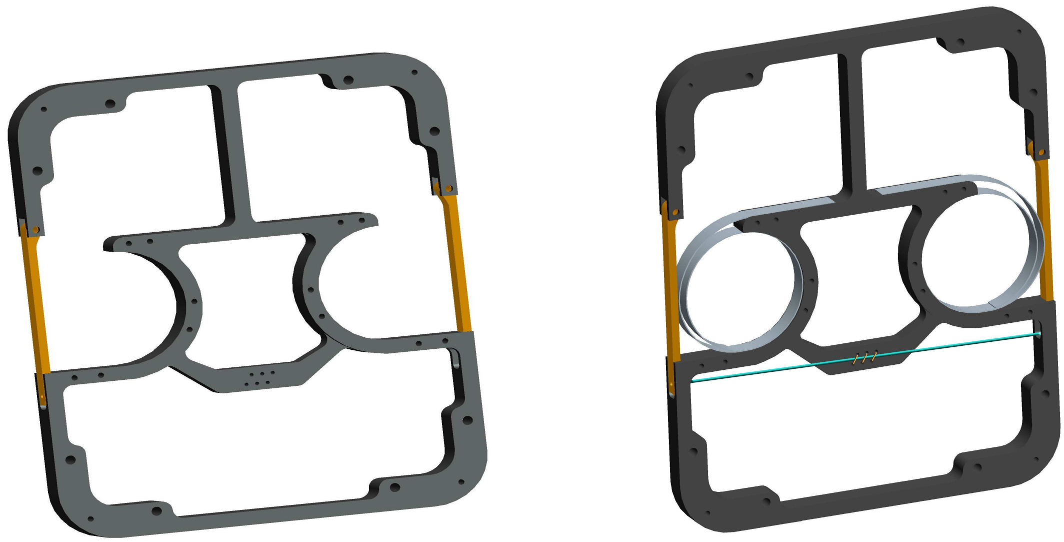


Figure 3-7. Receive antenna module

The receive antenna system module has no magnet coil on the composite panel so the inner extremities of the module design in Fig. 3-7 do not interfere. However, the width of the magnet coil on side of the transmit antenna system module physically interferes and so a separate design is motivated to ensure proper integration and assembly.

The receive dipole antenna elements are mounted on the delrin plate as indicated by Fig. 3-8. The antenna is coiled and stored inside the cavity. A nylon fiber (in blue) routes from the flap restraint (in yellow) on one edge of the delrin receive module and routes directly across to the flap restraint on the opposite edge. The flap restraints are free to rotate about the pivot point about a pin slotted in the hole. The other end of the flap is where the nylon fiber which is fed across is routed. A recess in the delrin receive module is designed to accommodate the insertion of the flap restraint end and to allow sufficient room to route the nylon fiber placed in tension and ultimately deployed. The tension created by the nylon fiber across the flap restraints will ensure the storage of the receive antennas until the deployment mechanism is activated. The receive antenna deployment mechanism resides on the delrin plate in the middle as indicated in Fig. 3-8. The nylon fiber is designed to route to the surface of the delrin plate where the nichrome burn-wire is located. The nichrome design to the the deployment mechanism region of the delrin plate which contains a nichrome burn-wire (in orange) is stitched at this location so that the nylon fiber is routed underneath the stitches on the ends and over the center stitch. This technique was tested and ensures a proper contact between the nylon wire and nichrome burn-wire so upon heating the nichrome burn-wire, the nylon fiber is severed. The same stitch and deployment technique is implemented on the transmit. The connection for the deployment mechanism is discussed in a following section in this chapter.

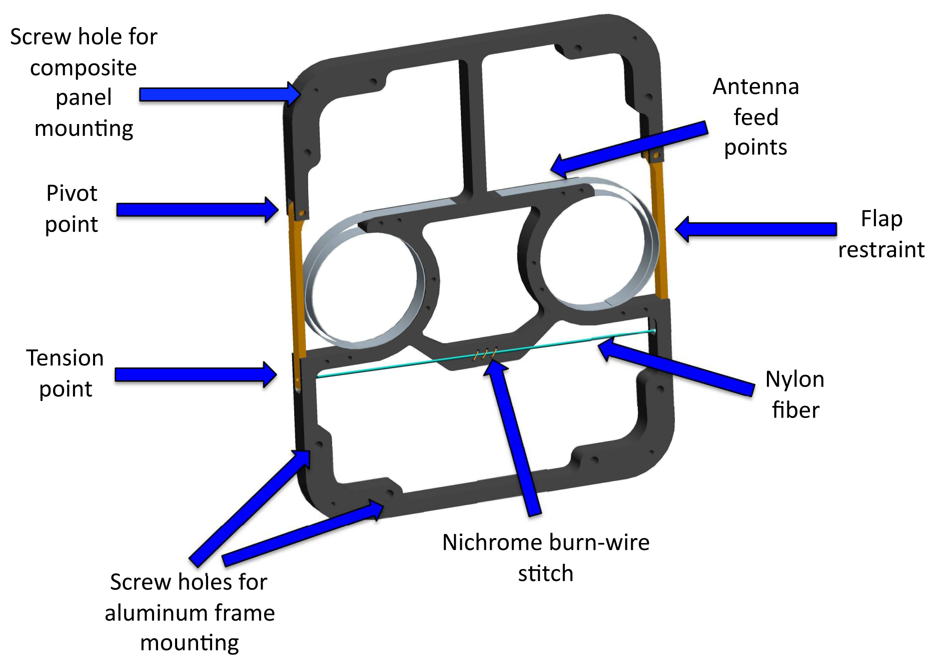


Figure 3-8. Labeled receive antenna system module

3.0.5 Antenna System Integration

The antenna system is integrated to the sides of the aluminum frame in Fig. 3-9. However the assembly process for the antenna system is designed to The dipole antenna configuration shall be stowed on opposite faces. The dipole antennas will be packaged on opposite faces and will be deployed in a normal configuration to each other as indicated in Fig. 3-1.

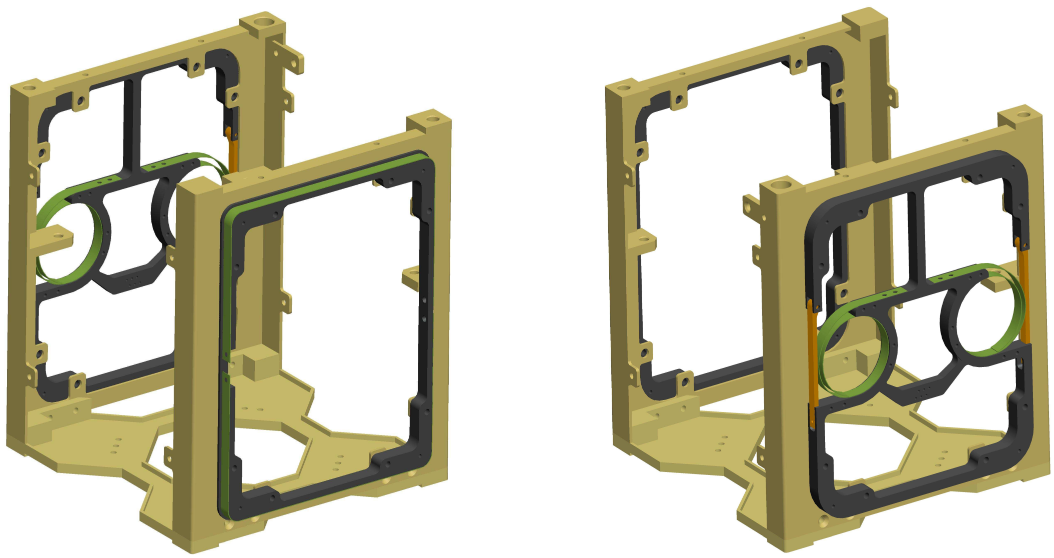


Figure 3-9. Views of transmit and receive antenna system modules

The next section details the antenna design and fabrication.

3.0.6 Dipole Antenna Design and Fabrication

The transmit and receive antenna lengths and corresponding frequencies are compiled in Table 3-2. The frequency directly corresponds to Eqs. 2–1 to determine the antenna lengths. The antenna fabrication process document is in the appendix.

Table 3-2. Theoretical dipole lengths with respect to operating frequencies

	Total Length	Frequency
Transmit Antenna	34.3 cm	437.385 MHz
Receive Antenna	103 cm	145.980 MHz

The next section details the electrical components and interfaces for the antenna system.

3.0.7 Electrical Components and Interfaces

The electrical components and interfaces for the antenna system integrate to the Stensat transceiver board and the SwampSat Flight Computer (SFC430) board.

3.0.7.1 Stensat Transceiver Board and Antenna Connector Assembly

A COTS communications board was purchased for SwampSat from Stensat Inc. The Stensat transceiver board has flight heritage and has flown on several CubeSat missions. [13] Table 3-3 includes the transceivers specifications.

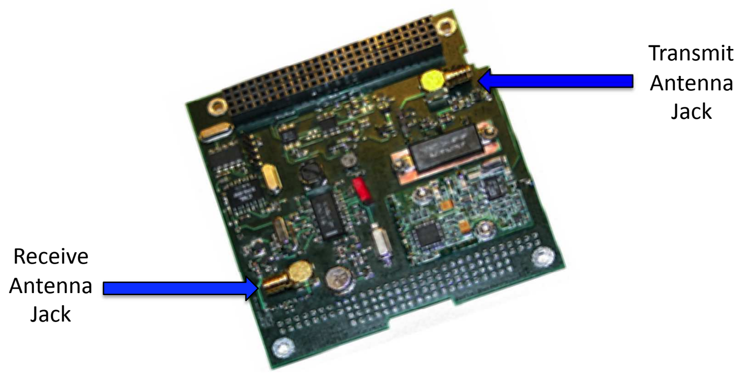


Figure 3-10. Stensat transceiver with antenna jacks

Table 3-3. Stensat transceiver specifications

Specification	Parameter
Bandwidth	30 kHz
Nominal Power	1 watt
Transmit Frequency	437.385 MHz
Transmit Baud Rate + Modulation	1200 baud + AFSK
Transmit Baud Rate + Modulation	9600 baud + FSK
Receive Frequency	145.980 Mhz
Receive Baud Rate + Modulation	1200 baud + AFSK
Packet Protocol	AX.25

The nominal impedance of a dipole antenna is 73Ω while the Stensat transceiver is 50Ω. A SubMiniature version A (SMA) connector is utilized for the Stensat transceiver transmit and receive antenna jacks seen in Fig. 3-10. A coaxial cable with a SMA plug fits into the Stensat transceiver's antenna jacks for a connection to the antenna feed points.

The antenna feed point end of the coaxial cable is pig-tailed 3-11 and is routed to the transmit antenna feed points where the antenna connector assembly in Fig. 3-12.

Figure 3-11. Pig-tailed coaxial cable for testing

The transmit and receive antenna system modules have the same antenna connector assembly. However, the length of the cable is different between the transmit and receive antenna as indicated by the locations of the antenna jacks on the Stensat transceiver and the antenna connector assemblies on the transmit and receive antenna system modules respectively.

The coaxial cable for flight shall be pig-tailed by the cable supplier with the appropriate lengths for the flight assembly process.

3.0.7.2 SwampSat Flight Computer Board and Antenna Deployment Switch

The SwampSat Flight Computer (SFC430) board contains the main flight processor, but for the scope of this thesis only relevant items pertaining to the antenna system design are included. The circuitry necessary to activate the deployment mechanism is onboard the SFC430 board. To activate the nichrome burn-wire, a the load switch is implemented. The load switch is located as close as possible to the antenna deployment region for reduced wire routing of the transmit and receive antenna deployment regions. The antenna deployment test process document in the appendix includes a setup of the load switches and details the necessary circuitry for melting the nylon fiber with the nichrome burn-wire to deploy the dipole elements.

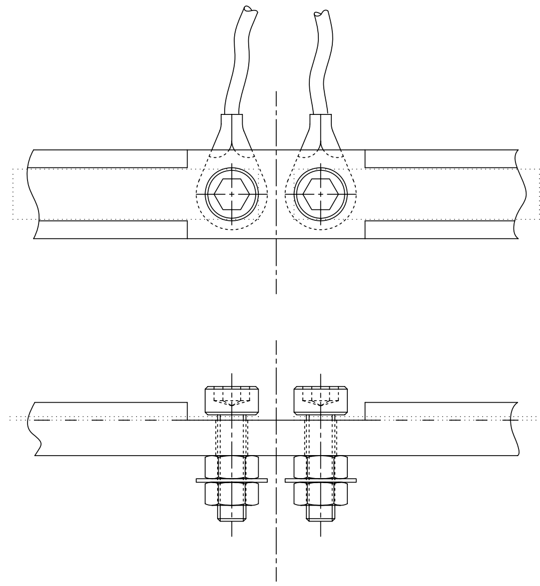


Figure 3-12. Antenna connector assembly

3.0.8 Antenna System Mass Budget

According to the density of delrin selected, the delrin transmit antenna system module's mass is 8 grams and the receive antenna system module's mass is 13 grams. The overall mass of the antenna system module including fasteners and connectors is estimated to be less than 25 grams.

3.0.9 Short Circuit Protection

Short circuits happen when current travels along a different path from the one it originally intends. Typically fuses, circuit breakers, and overload protection devices are utilized to mitigate a short circuit. However, the physical design of an antenna must take into consideration the conductive materials in which it might encounter during operation. Components such as a radio module may sustain permanent damage rendering a CubeSat's communications system useless. Techniques available for protecting the antenna were considered. A coating of non-conductive powder on the antenna surface could be applied. Since outgassing is a concern, the powder option is not feasible. However, kapton has the potential to suffice as to mitigate an antenna short circuit.

3.0.9.1 Sleeved Kapton Antenna

Kapton is a common material that has served in several applications. Familiarity of the material's characteristics from previous research on an application for a de-orbiting device for CubeSats assisted in techniques for handling kapton for space applications [5]. Fig. 3-13 illustrates a technique to encapsulate an antenna.

Kapton is a thin-film that has several space gossamer applications. [14]

Figure 3-13. International Space Station experiment of sleeved antenna kapton concept

Various types of kapton films are under investigation for the best material to encapsulate the antenna materials. A mold shall be constructed and placed under particular temperature and pressure variations to self-bond the kapton films to produce a seal. The mold material must allow for the cured kapton to be removed from the mold without bonding to the mold.

3.1 Antenna Packaging Techniques

The antennas packaging techniques implemented utilized the nylon fiber to apply tension. Several nylon fibers (various gauges of fishing line) were tested under various tension loads.

A creep test was performed on different gauge nylon fibers to determine if there is any significant creep of the nylon fiber under tension. The tension required to package the antennas is sufficient for the minimal load nylon fiber of eight pounds.

3.1.1 Assembly Process

For flight assembly of the nylon fiber and nichrome burn-wire, care shall be taken to reduce all moisture that might cause slippage in the nylon fiber's knot. The packaging shall be completed inside a clean room. Considering gloves need to be worn at all times inside the clean room when handling the flight hardware, tying knots and burn wire stitching shall be difficult. Fly fishing tying tools practices shall be utilized inside the clean room to perform these intricate tasks.

Recalling, a goal is to support an assembly process which can be performed independently and then interfaced to the SwampSat mechanical frame and electrical components. The composite panel and delrin antenna module can be independently assembled and then mounted to SwampSat's aluminum frame.

Further details of the assembly process will be determined as flight hardware becomes available.

CHAPTER 4
ANTENNA SYSTEM TESTING

The antenna system testing is comprised of several tests to mitigate the failure modes for operation. An antenna deployment experiment representing hardware similar to flight is detailed. A high speed video captured the dipole antennas post-deployment. Both the transmit and receive antennas must be impedance matched with the StenSat transceiver and the antennas tuned to the allocated operating frequency. A field test plan is also outlined. The StenSat transceiver also tested the transmission and reception of the various operational modes, a beacon string, and example telemetry strings.

4.1 Antenna Deployment Experiment

A antenna deployment test experiment requires circuitry to actuate the nichrome burn-wire mechanism. Two devices were considered to provide the necessary specifications to deploy the antennas. A discrete field effect transistor (FET) and load switch were considered. A FET is a type of transistor that relies on an electric field to control a conductive channel. A load switch is utilized with a low-voltage operation, low-current consumption, fast timing responses, small footprint, and ease of use. The load switch has a slew rate control which when the device is turned on, the current fed to the load is gradually supplied to prevent a sudden surge of electricity that may damage various SwampSat components. The load switch is chosen for the antenna deployment experiments. An antenna deployment test document is in Appendix detailing the setup for the tests conducted.

A high speed camera was utilized to capture the deployment process.

4.2 Impedance Matching and Antenna Tuning

Dipole antennas in free space behave differently than dipole antennas near conductive elements. The SwampSat aluminum frame has an impact on the actual operating frequency prescribed by the dipole lengths. Impedance matching between the antennas and the StenSat transceiver are also detailed. The antenna impedance, Z_L has to matched with the transmission line, Z_0. Maximum power transfer between the source and load occurs when a system impedances are appropriately matched. The signal-to-noise-ratio for the system is also improved and reduces the phase errors and amplitude. Equation 4–1 refers to the reflection coefficient which is used to assist in matching the impedances.

$$\eta(f) = \frac{Z_L(f) - Z_0}{Z_L(f) + Z0} \tag{4–1}$$

The voltage standing wave ratio (VSRW) relation in Equation 4–2 corresponds to the ratio of the amplitude of a partial standing wave at an antinode (maximum) to the amplitude at an adjacent node (minimum), in an electrical transmission line.

$$VSWR(f) = \frac{1 + |\eta(f)|}{1 - |\eta(f)|} \tag{4–2}$$

The process to perform the impedance matching and tuning is outlined in the appendix.

4.3 Antenna System Field Testing

The Stensat transceiver was first tested with a rubber duck antenna on the CubeSat Kit development board. The Stensat Bandwidth Test Document in the appendix illustrates the setup and tests performed at Timco Engineering. Timco Engineering is a local company who provides FCC certification for communication devices. Figure 4.3 shows an anaerobic chamber which is utilized to analyze frequency disturbances under various exposure. A rate table rotates the device of interest to sample data points for analysis.

Theoretically, the power required for the transmission of the RF signal is calculated in Equation 4–3 and the parameters listed in Table 4-1.

$$\frac{P_r}{P_t} = G_t Gr(\frac{\lambda}{4\pi d}) \tag{4–3}$$

Figure 4-1. Timco Engineering test facility

Table 4-1. Transmission power constant for SwampSat analysis

Constant	Description
P_r	receiver power
P_t	transmitter power
G_t	transmitter gain
G_r	receiver gain
d	distance between receiver and transmitter

In order to simulate the range and attitude of the antenna system for operation, an experiment has been coordinated with the Florida Department of Wildlife and Forestry. A map of the radio towers and forest towers in Alachua county and surrounding counties were analyzed to pinpoint optimal trajectories based upon estimated altitudes for the SwampSat mission. The test requires a certified FCC technician to operate the Gator Nation Earth Station (GNES) equipment inside the Mission Control Room. The GNES technician shall point the UHF and VHF antennas in the direction of particular tower of interest. AX.25 packets shall be transmitted and received back and forth from GNES to the the particular tower which houses SwampSat. A test plan has been devised to orient SwampSat in several different orientations as to characterize how the antenna system will behave with the Mission Control Room. The data collected from this experiment will be compared to the flight information. This is a static scenario and unfortunately a dynamic scenario is not available at this time. However if an opportunity arises where SwampSat can be flown in an aircraft, further data can be collected and analyzed.

4.4 Stensat Transceiver Testing

The Stensat transceiver utilizes the AX.25 protocol for packet transmission and reception. The transceiver implements a I^2C protocol. The Stensat Bandwidth Test Document in the appendix elaborates the test conducted to analyze the bandwidths and emissions of the transceiver through the use of a spectrum analyzer.

CHAPTER 5
SUPPLEMENTAL COMMUNICATIONS

5.1 Frequency Allocation and Coordination

The International Amateur Radio Union (IARU) assigns a satellite advisor to review the application for an amateur radio space station. The University of Florida received their frequency coordination in Decemeber 2006 for developing and testing their communications hardware. Figure 5-1 contains the information submitted for a University of Florida CubeSat mission. The callsign, WG4SAT, has been assigned to the University of Florida CubeSat. The primary ground station is W4DFU which is an affiliated student organization known as the Gator Amateur Radio Club (GARC). The faculty advisor and trustee of the radio station and is the responsible operator for the University of Florida CubeSat mission.

Gatorsat	Updated: 27/12/2006	Responsible Operator	Jay Garlitz AA4FL
Supporting Organisation	Gator Amateur Radio Club @ the Univ of Florida		
Contact Person	jgarlitz@ufl.edu.nospam		
Headline Details: A 100mm cubesat project designed to demonstrate a non-intrusive space debris abatement device for pico-satellites. Possible launch date of Feb 2008 from Baikanour into a 98 deg inclination sun syncronous orbit. 1k2 AX25 packet downlink on 437.385MHz with 2 watts of RF is planned. More info from www.gatorradio.org and www.ufsmallsat.com			
Applications Date:	23/12/2006	Freq coordination completed on	27/12/2006

Figure 5-1. University of Florida CubeSat Frequency Allocation

5.2 SwampSat Link Budget

The SwampSat link budget was analyzed using spreadsheet adopted by the the Amateur Radio Satellite Corporation (AMSAT) and the IARU. [12]. The version 2.4.1 link budget is a downloadable user-friendly input-output spreadsheet of eighteen integrated worksheets to calculate the parameters necessary for the link budget analyses. The following items are included in the spreadsheet are in Table 5-1

Table 5-1. IARU link budget paramters

Integrated worksheet headings for link budget analysis	
Title Page and Instructions for Use, References, and Revisions	
Orbit and Frequency and Transmitters	
Receivers and Antenna Gain	
Antenna Pointing Losses and Antenna Polarization Loss	
Atmospheric and Ionospheric Losses and Modulation/Demodulation Method	
Uplink Command Budget and Downlink Telemetry Budget	
System Performance Summary and Antenna Patterns	
Design a Dish - Beam Roll-Off and Plots	Transmission Line Loss T
Voltage Standing Wave Ratio (VWRS) Loss Tool	Orbit Shape Data

Further communication link budgets will be reviewed. A Satellite Tool Kit from Analytical Graphics Inc. (AGI) scenario will be created when the orbit insertion data is known. A preliminary link budget

5.3 Mission Control Room

The mission control room for SwampSat is located inside the radio station owned by the Gator Amateur Radio Club (W4DFU - EL89 - Lat 29 38 39 N, Lon 82 21 3 W) from the 11th oor of the dental sciences building. A 2 meter VHF uplink and 70 centimeter UHF downlink is achieved via two right handed circularly polarized Yagi antennas. The antennas perform satellite tracking through azimuth and elevation rotors. Uplink commands and telemetry downlinking is accomplished through the digital communications software. The satellite equipment is known as the Gator Nation Earth Station (GNES). The GNES workstation is depicted in Fig. 5-2. The GNES tower is shown in Fig. 5-3. The GNES equipment is listed as the following hardware and software in Table 5-2.

5.4 Mission Operations Center

The Mission Operations Center (MOC) (see Fig. 5-4) is utilized for coordinating satellite contacts and analyzing telemetry. The facility uses tracking software which is identical to the mission control room. The purpose of the MOC is to make mission decisions based on computer simulations and telemetry analysis. The MOC also involves

Figure 5-2. GNES workstation inside the Mission Control Room

Figure 5-3. GNES UHF and VHF Antennas on the rooftop

Table 5-2. GNES hardware and software components

Hardware	
	iCOM 910H dual band transceiver
	Kantronics KPC-9612 TNC
	Yaesu G-5500 Rotor controller
	GS-232B rotor control interface
	Mirage KP-2 downlink preamplier
	Hy-Gain UB-7030SAT UHF Yagi antenna
	Hy-Gain 216S VHF Yagi antenna
Sotftware	
	SatPC32
	Orbitron
	WinAOS
	WinListen
	WiSPDDE
	Satellite ToolKit

team members and collaborators without a certified technician's license to participate in SwampSat's operation. Only licensed technicians are capable of commanding and operating the GNES equipment. The MOC plans to be upgraded by providing an autonomous operation of the GNES through the MOC.[21]

5.5 GENSO

GENSO stands for the Global Educational Network for Satellite Operations. GENSO is an initiative by the European Space Agency's Educational Department initiated in 2006 that interconnects a worldwide network of ground station via internet enabled software. The main focus is to provide educational missions an increased coverage for tracking educational satellites. The focus of GENSO is to support Low Earth Orbit (LEO) missions, since several universities are operating there. However, LEO satellites have increased orbital speeds and decreased swath coverage and therefore have a limited communications window. GENSO coordinates a distributed number of amateur radio teams worldwide. A GENSO-compliant spacecraft has a set priority and other restrictions as to which ground station shall operate at a given time. The University of Florida's

Figure 5-4. Mission Operations Center (MOC) display of CP6 ground track

GNES has submitted a request to join and has been contacted to join the limited software release in the fourth quarter of 2009. [19]

GENSO plans to develop a software standard which allows ground stations to communicate with non-local spacecraft, virtually sharing the data among spacecraft ground operators via the internet. Scheduling algorithms and streaming mission data via the internet would increase the reliability of the telemetry.

5.5.1 Uplink and Downlink Specifications

The uplink and downlink use the AX.25 amateur radio protocol for packet data transmission. The AX.25 protocol allows up to 200 characters per packet. Only text, punctuation, and numerical ASCII characters are permitted. The uplink (ground to satellite) will operate in the Very High Frequency (VHF) band at a carrier frequency of 145.980 MHz. The Audio Frequency-Shift Keying (AFSK) modulation scheme is utilized, allowing for a 1200 baud receive data rate. The downlink (satellite to ground) will operate in the Ultra High Frequency (UHF) at a carrier frequency of 437.385 MHz. The transmitter can operate in two modes: 1200 baud AFSK and 9600 baud Frequency-Shift Keying (FSK). The transmitter consumes 1 Watt of power while active. The frequencies used for telemetry were granted by the International Amateur Radio Union on January 14, 2007. The satellite has been granted the call sign WG4SAT. Our space station licensee is submitting notification and updates to the Federal Communications Committee (FCC) to satisfy Rules and Regulations sub part C, special operations, (Part 97.207 sub paragraph g) as adopted on May 31, 1989.

5.5.1.1 Telemetry

The SwampSat telemetry is still under review as the EDU is being completed. However, the following nomenclature in 5.5.1.1 has been devised and shall be the expanded where necessary.

The transmitter can accommodate up to 200 bytes per transmission. These numbers reflect an ASCII conversion: 1 nibble (4 bits) gets converted to 1 byte (8 bits). This must be done for the transceiver. An initial estimate of 720 bits was calculated for the initial telemetry string however the data needs to be converted to ASCII so the telemetry length must doubled. So a more accurate estimate is 180 bytes (1440 bits). A data budget is being compiled

The following expression indicates a header and divider telemetry string sample. All the dividers have three bytes. The headers depend on the particular data string of interest.

$$< SUBSYSTEMHEADER >:< DATA > \_\_ < DATA > \_\_ < DATA > \_\_ < . >$$

$$EXAMPLE : SS : 0F2\_\_243\_\_F21\_\_B23\_\_987\_\_111.MM : 032\_\_214\_\_217$$

Table 5-3. Telemetry nomenclature

Subsystem component	Acronym
Sun Sensors	SS
Power Supply (EPS)	PS
IMu	IM
Motor Controller board (MIC)	MC
MagnetoMeter	MM
Transceiver (tX and rX)	XX

CHAPTER 6
CONCLUSION AND FUTURE WORK

6.1 Conclusion

The SwampSat antenna system is a requirement that must meet several operational and engineering standards. Several design iterations were presented but only one SwampSat antenna system will be flown in orbit. Careful consideration was taken to ensure the proper antenna configuration and material were surveyed to incorporate the best practical method for SwampSat operation. The ideal antenna system design is under development and will soon be tested with the flight hardware.

6.2 Future Work

SwampSat is in the midst of its build phase with a goal of launching early 2010. Subsystem integration and testing phase has been underway. A EMI (electric magnetic interference) compliance test shall be performed on the SwampSat electronics to determine any spurious transmission. Full up system testing shall be completed following the results of the subsystem integration and testing. A mission readiness review shall be conducted to determine the processes necessary to complete testing and and evaluation as to approve the engineering for SwampSat.

The SwampSat telemetry decoding software program will soon be created to analyze the downlink data. This program shall be distributed to interested amateur radio operators worldwide. Every licensed amateur radio ground operator will be categorized by their callsign and grid square (ie. KI4LDJ and EL89). The ground operator shall have the ability to downlink and retrieve telemetry for our mission. The Small Satellite Design Club website will host a mission operations link with all the pertinent information of the operational mode SwampSat is in.

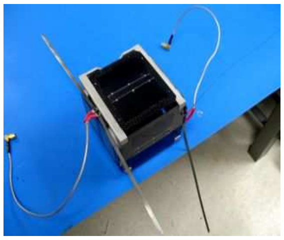
APPENDIX: SWAMPSAT ANTENNA SYSTEM DOCUMENTATION

Subsystem: Comms		Document Number: 09A1TD0302	Part No.
Begin: 6/29/09	**End:** 7/7/09	**Tested By:** Dante @ Brain Institute, AMRIS RF Lab, Rm LG 100	**Test No.:** N/A

Objective

To use the network analyzer to find out the resonant frequency of the receive and transmit antennas.

Materials Required



SwampSat EDU with Deployed Antennas

Network Analyzer

Transmit and Receive Dipole Antenna Elements

SMA-to-BNC Connectors

50 Ω termination

Short Closed Circuit Cap

Test Personnel

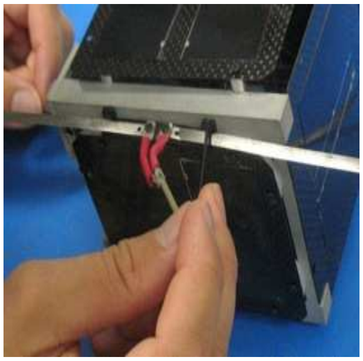
Permission granted by:
Barbara Beck
Dante Buckley
Sushant Kadimdivan
Tim Bowen

Subsystem: Comms		Document Number: 09A1TD0302	Part No.
Begin: 6/29/09	**End:** 7/7/09	**Tested By:** Dante @ Brain Institute, AMRIS RF Lab, Rm LG 100	**Test No.:** N/A

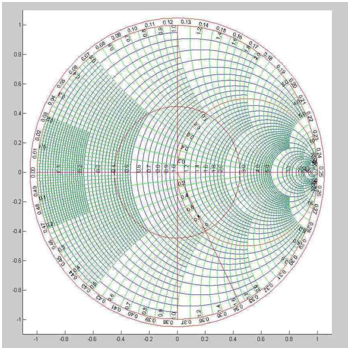
Special Instructions

A HT Radio antenna can be carried along. These antennae are already tuned for 2m or 70cm band and can be verified on the network analyzer. Several radios are available for check out with the Gator Amateur Radio Club.

With the current configuration of the cubesat, the receive dipole antenna comes into contact with the screw that is used attach delrin ledge to the cubesat chassis. Hence, during this testing, the screws holding the delrin ledge to the SwampSat EDU are removed.



Removing the screws



Smith Chart

Familiarity with smith chart is helpful when performing this antenna test. The Smith Chart is used by electrical and electronics engineers specializing in radio frequency (RF) engineering to assist in solving problems with transmission lines and matching circuits.

The Smith Chart can be used to represent many parameters including impedances, admittances, reflection coefficients, scattering parameters, noise figure circles, constant gain contours and regions for unconditional stability.

Theory:

The frequency of operation of an antenna is set by the length of the antenna elements.
For a half wave dipole the total antenna length is equal to the half wavelength of the desired operating frequency. The dipole is said to be resonant at that frequency. In other words the antenna impedance does not have any imaginary part at the frequency of resonance. This document illustrates the procedure to find out the resonant frequency of the antennas.

Procedure

Subsystem: Comms		Document Number: 09A1TD0302	Part No.
Begin: 6/29/09	**End:** 7/7/09	**Tested By:** Dante @ Brain Institute, AMRIS RF Lab, Rm LG 100	**Test No.:** N/A

Procedure

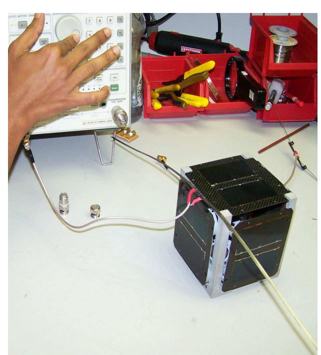
At first, appropriate connectors should be selected to connect the antenna to the network analyzer. The network analyzer sports a female BNC connector at the reflection-test port. The connector used on the cable connected to the antenna is a SMA plug (male). Hence an appropriate converter from a male SMA to a female BNC should be used. The figure shows the configuration that was used for this test set up. Also it is recommended that an extension cable be used to connect the antenna to the network analyzer. This is to make sure that the antenna is kept sufficiently away from the network analyzer metal chassis, so that there is little interaction between them.

Every time the network analyzer is booted up or when the operating frequency spectrum is changed, it has to be calibrated. The steps to be followed for the same have been illustrated below. A perfect short and a perfect load (50 ohms) termination are needed to perform the calibration.

Calibration of the network Analyzer-

a. Start the network analyzer and set the centre frequency and span of the frequency spectrum to be analyzed. This can be done by hitting the “centre” button on the network analyzer front panel (stimulus subsection) followed by keying in the desired frequency from the keypad. The same should be performed for setting the span with the “span” key.
b. Next, press “CAL” button.
c. Press “Calibrate Menu”.
d. Press “Reflection Port 1”.
e. Keep the Reflection Port unconnected.
f. Press “Open Female”.
g. Press “Done”.
h. Repeat the steps (e through g) for the short and 50 ohms, but with perfect short and perfect load terminations at the reflection-test port respectively. The gender of the termination is “male” for the short and perfect load terminations.

50 Ω termination

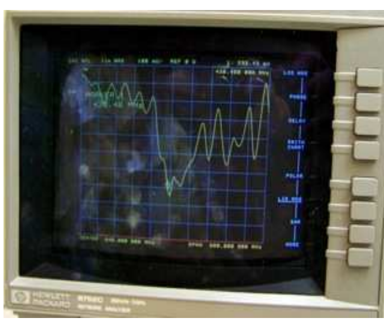


Rx Antenna Impedance Testing

Subsystem: Comms		**Document Number:** 09A1TD0302	**Part No.**
Begin: 6/29/09	**End:** 7/7/09	**Tested By:** Dante @ Brain Institute, AMRIS RF Lab, Rm LG 100	**Test No.:** N/A

Testing the Resonant Frequency

1. Calibrate the network analyzer for the transmit antenna with a center frequency of 440 MHz and a total span of 800MHz. This effectively gives us a range where both transmit and receive antennas can be analyzed with the same calibration. The effective spectrum displayed on the network analyzer screen is 40MHz to 840MHz. This range can be reduced to increase the resolution and focus at either 2m band or the 70 cm band.
2. Press the "Format" key on the display sub-section of the network analyzer. From the options displayed on the right side of the display, select "linear display"."Smith Chart" can be selected from the format menu if desired.
3. Connect the antenna, if not already connected. The plot of the reflected power at different frequencies will be seen on the display. The frequency which has the least power reflected has the least impedance mismatch and is the resonant frequency. The antenna might have resonance at multiple harmonics. The fundamental will usually show the lowest dip on the plot.



Transmit Dip

Smith Chart – Transmit Antenna

Both receive and transmit antennas were tested for their resonant frequencies and the results are shown in the table below. Since the Cubesat chassis is made of metal, it modifies the near-field distribution of the antenna. Hence, two readings were taken down, one with the antenna mounted on top of the chassis and the other sufficiently away from the metal chassis.

Observations:

Antenna in free-space (away from CubeSat)-

	Length (cm)	Observed Resonant Freq. (MHz)	Calculated Resonant Freq.* (MHz)
Receive	25.4	270	295
Transmit	16.4	393	457

*Velocity propagation factor for steel has not been considered while calculating theoretical frequency of resonance.

Subsystem: Comms		**Document Number:** 09A1TD0302	**Part No.**
Begin: 6/29/09	**End:** 7/7/09	**Tested By:** Dante @ Brain Institute, AMRIS RF Lab, Rm LG 100	**Test No.:** N/A

Antenna mounted on the CubeSat -

	Length (cm)	Observed Resonant Freq. (MHz)	Calculated Resonant Freq.* (MHz)
Receive	25.4	297	295
Transmit	16.4	439	457

*Velocity propagation factor for steel has not been considered while calculating theoretical frequency of resonance.

RESULTS:

The results show that placing the antenna near to the CubeSat structure tends to increase the resonant frequency. Hence, all further tuning for the antenna should be done with the antenna placed in the final flight configuration so as to include the parasitic effects due to the metal CubeSat structure. Also it is seen that when placed on the CubeSat, the transmit antenna is tuned near 439MHz, which is the desired resonant frequency. Hence it is sufficiently tuned. The receive antenna on the other hand has to be tuned to the 2m band (~145 MHz).

One of the other important observations made was that the bandwidth of the antennas increased when placed close to the CubeSat structure. This will allow us to reduce the width of the tape antenna, while still maintaining sufficient bandwidth. Also, one more important observation is that when placed near the CubeSat, the measured frequency of resonance corresponds more closely to the ideally calculated frequency, i.e. neglecting the velocity propagation factor of the antenna material. This provides us with an empirical formula for calculating the frequency of resonance when mounted on the CubeSat.

Empirical formula: Length of Dipole = c / (2*f)

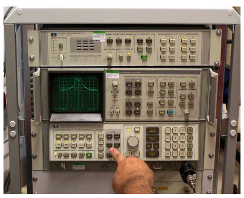
Where c = speed of light
f = operating frequency

Subsystem: Communications		**Document No.:** 09/A1/TD/05/01	**Part No.**
Begin: 03/27/09	**End:** 03/27/09	**Tested By:** Dante Buckley, Victor Robles, Shawn Allgeier	**Test No.: 1**

Objective

To measure the transmission bandwidth of the Stensat transceiver for the SwampSat communications subsystem.

Material Required:



Spectrum Analyzer

CubeSat Development Board with Stensat Transceiver

Kenwood HT

Special Instructions

The transceiver should always be operated with a load attached (e.g. an antenna, dummy load, or measuring device). Operating the transmitter without a load produces unnecessary wear.

Procedure

The Stensat transceiver characterization was performed at Timco Engineering, a local company in New berry, FL which performs FCC qualification certifications for RF devices.

1. Setup the Stensat Transceiver and CubeSat Development board for operation. Use the Kenwood HT to confirm that the transmitter is operating. The HT can be connected to a computer with terminal software (e.g. Hyperterminal) to verify that the data is successfully modulate / demodulated, and that the signal is therefore representative of the transmitter's intended output.

2. Connect the Stensat transceiver terminals (SMA connector) into the spectrum analyzer (Figure 1) using a SMA connector.

3. When setup is complete utilize the spectrum analyzer to sweep the frequency spectrum and measure the spectral density, spurious emission levels, and emitted power.

Subsystem: Communications		Document No.: 09/A1/TD/05/01	Part No.
Begin: 03/27/09	**End:** 03/27/09	**Tested By:** Dante Buckley, Victor Robles, Shawn Allgeier	**Test No.: 1**

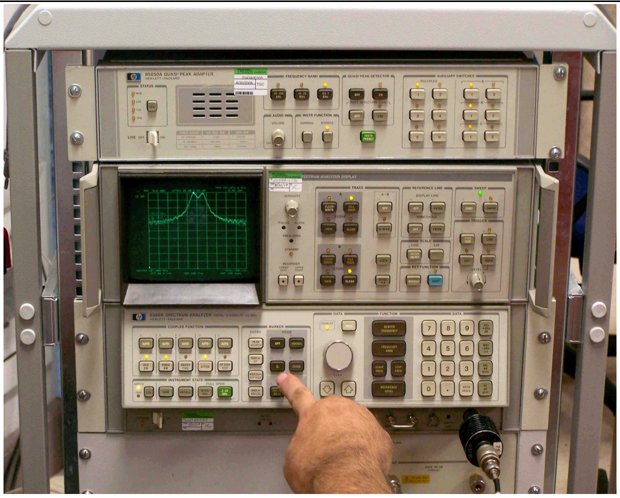


Figure 1: Spectrum Analyzer

Test Data

The bandwidth of the emitted signal was measured for levels of -3 dB, -20 dB, -60 dB at a signal rate of 1200 baud, with the carrier (437.385 MHz) referenced as 0 dB. Plots of the measured bandwidths are shown in (Figure 2, Figure 3, Figure 4). The measure values for bandwidth are listed in Table 1. Note that -60 dB lies within the noise level of the measurement equipment. The measurement values for spurious harmonic emission are listed in Table 2.

Results:

dB	Bandwidth
-3	12.4 KHz
-20	23.6 KHz
-60	800 KHz

Table 1: Bandwidth Measurements

Subsystem: Communications		**Document No.:** 09/A1/TD/05/01	**Part No.**
Begin: 03/27/09	**End:** 03/27/09	**Tested By:** Dante Buckley, Victor Robles, Shawn Allgeier	**Test No.: 1**

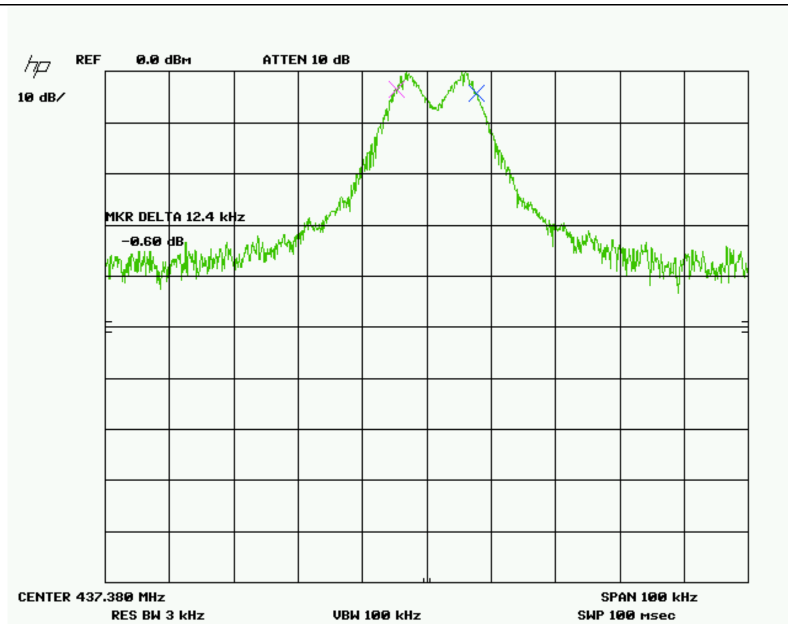


Figure 2: -3 dB Bandwidth Measurement

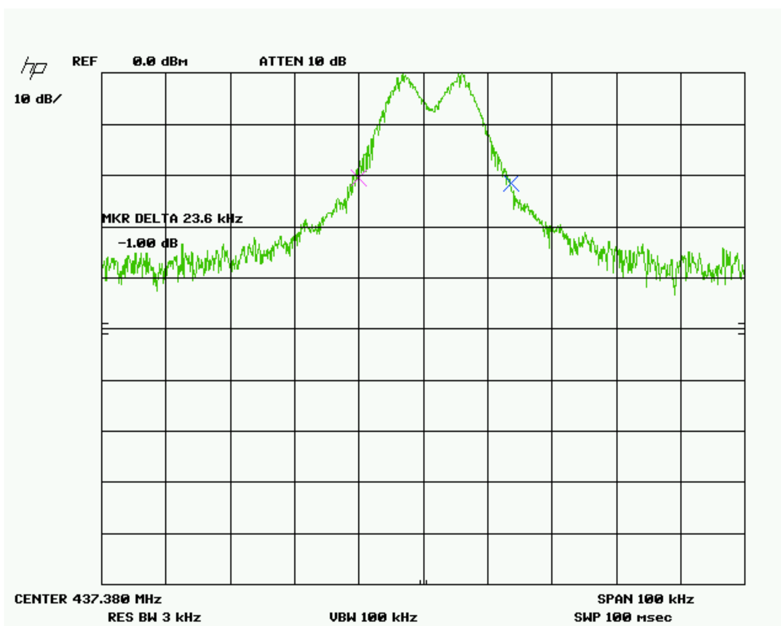


Figure 3: -20 dB Bandwidth Measurement

Subsystem: Communications		**Document No.:** 09/A1/TD/05/01	**Part No.**
Begin: 03/27/09	**End:** 03/27/09	**Tested By:** Dante Buckley, Victor Robles, Shawn Allgeier	**Test No.: 1**

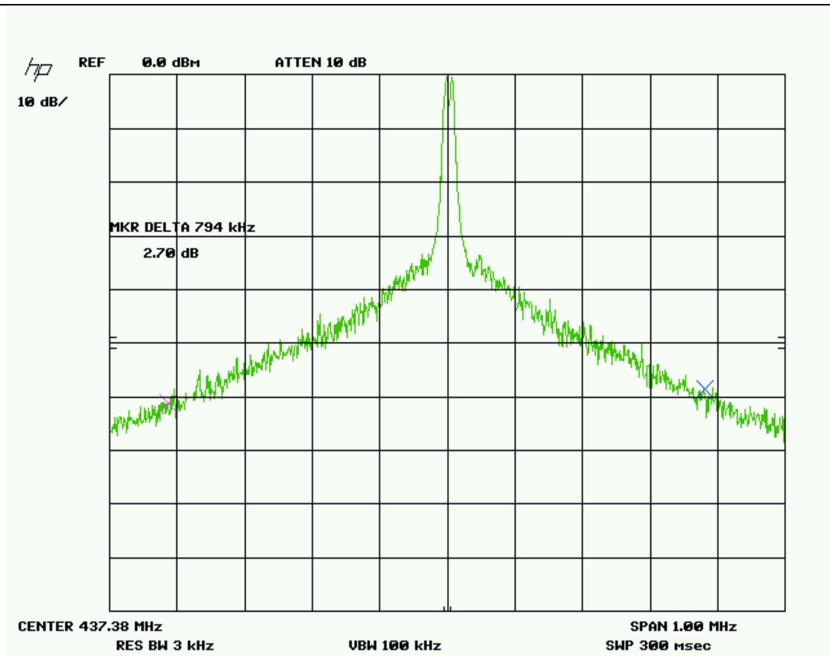


Figure 4: -60 dB Bandwidth Measurement

Harmonic	DBc
1st (437 MHz)	0
2nd (874 MHz)	- 55
3rd (1,312 MHz)	- 63
4th (1,749 MHz)	> -86
5th (2,186 MHz)	> -86

Table 2: Harmonic Levels

The measured power delivered to the antenna terminals of the Stensat transmitter is 1.047 W (+30.2 dBm).

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Begin: 05/20/09	**End:** 07/01/09	**Tested By:** Dante Buckley, Sushant Kadimdivan, and Kunal Patankar	**Test No.: 1**

Objective

Establish the technique for the nichrome burn wire mechanism and determine specifications for the antenna deployments.

Material Required:

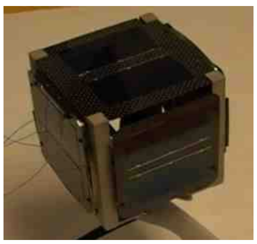


Figure 1: CubeSat Frame

Figure 2: Antenna Deployment Switch

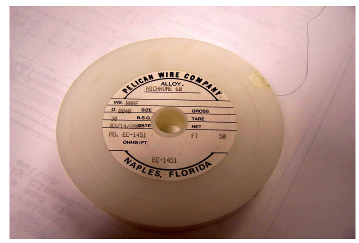


Figure 3: Nichrome Burn-Wire

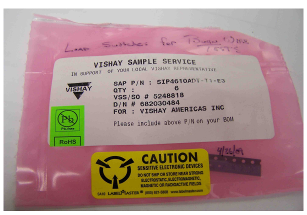


Figure 4: Load Switches

Figure 5: Nylon Fishing Line

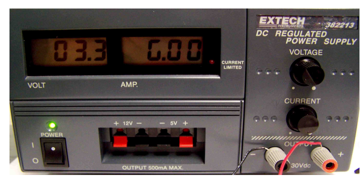


Figure 6: Power Supply

Figure 7: PVC Quarter-Round Guides

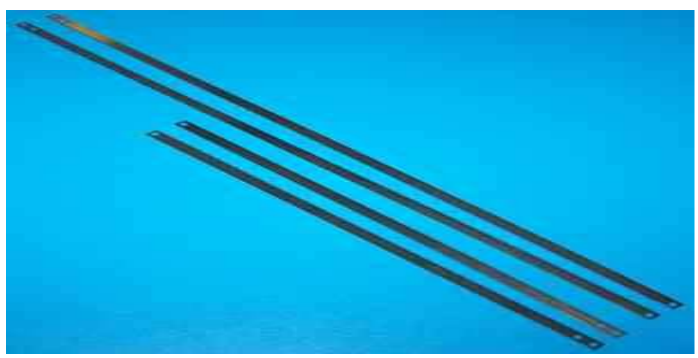
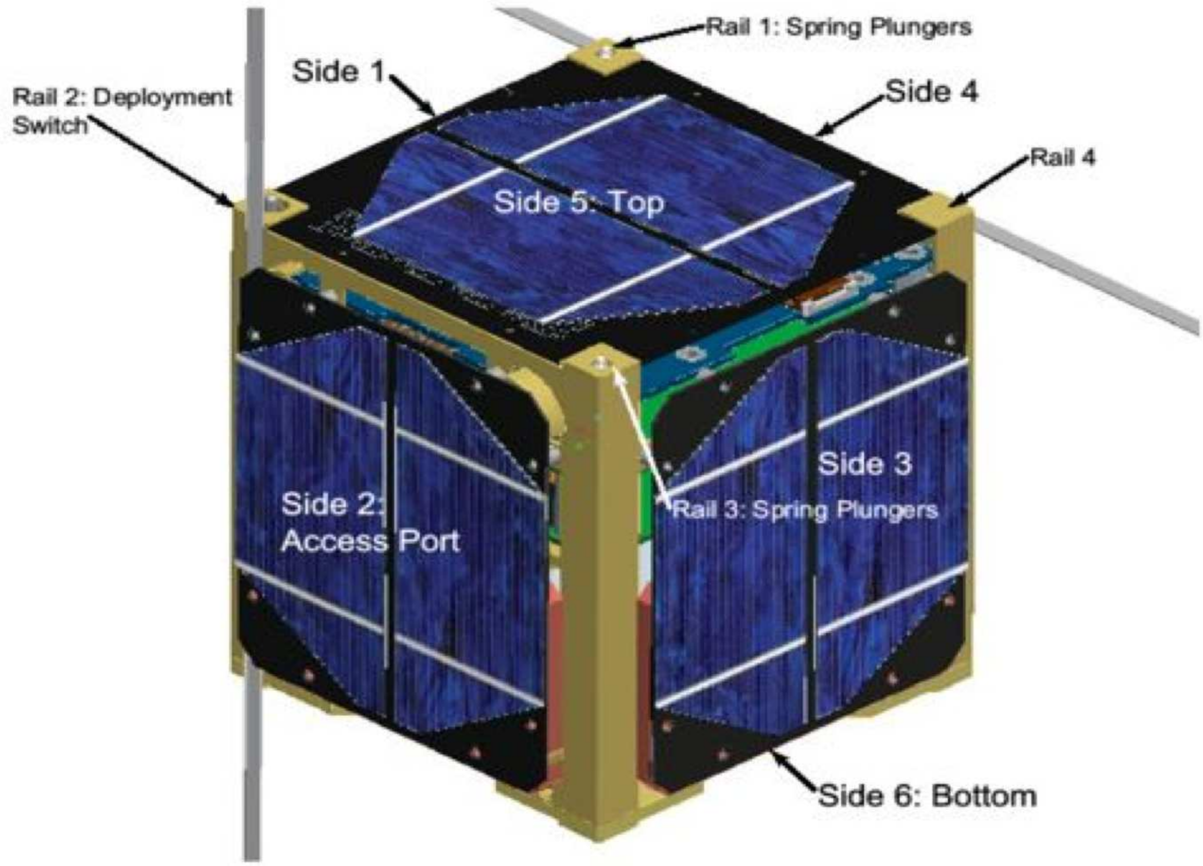


Figure 8: Transmit and Receive Dipole Antenna Elements

Subsystem: Communications		Document No 09/A1/TD/05/01	Part No
Begin: 05/20/09	**End:** 07/01/09	**Tested By:** Dante Buckley , Sushant Kadimdivan,	**Test No**

Special Instructions

The dipole configuration is illustrated in the following SwampSat orientation figure:



SwampSat Orientation (Side 2: Tx Antenna & Side 4: Rx Antenna)

The load switch needs 3.3 V to operate and since the test is manually driven, a switch is applied.

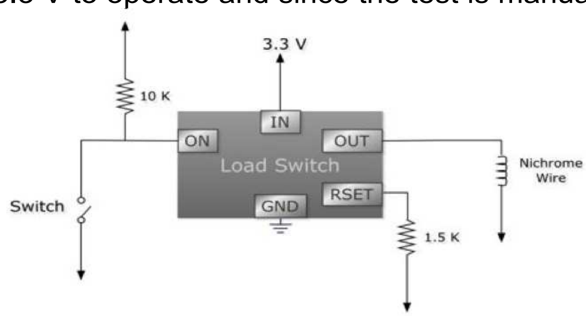
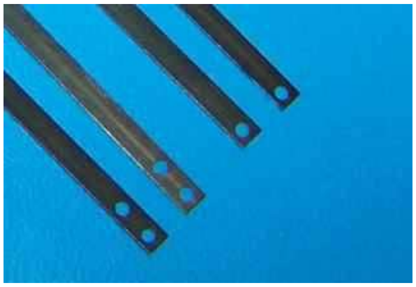


Figure 9 Antenna Deployment Test Circuit Diagram

Su Communications		Document 09/A1/TD/05/01	Part
Begin: 05/20/0	**End:** 0	**Tested** Dante Buc Kadimdivan, and Kunal Patankar	**Test**

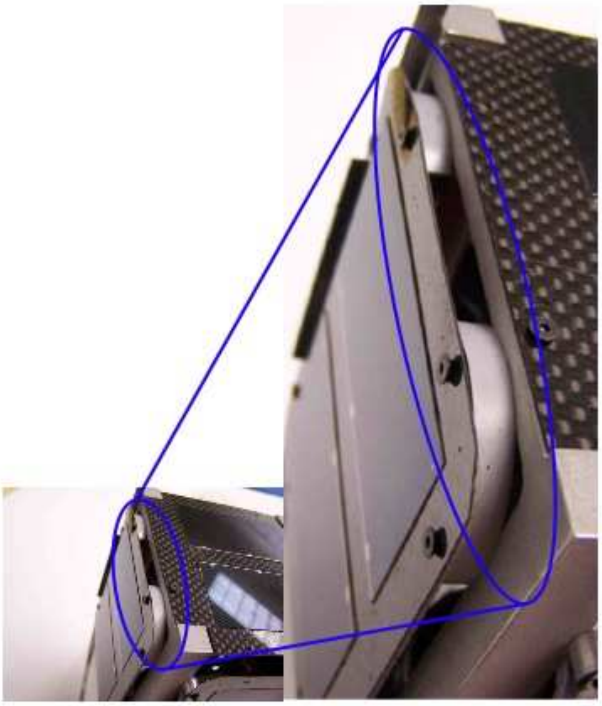
Procedure

This procedure applies to both transmit and receive dipole antennas. The antennas are mounted with the two holes to the CubeSat frame and the single hole to package the antenna elements.



Two holes for mounting and one for packaging

Step 1) Wind the antenna around the groove between the composite panel and edge of the satellite's chassis.



Antenna Groove featuring quarter-round guides

Subsystem: Communications		Document No.: 09/A1/TD/05/02	Part No.
Begin: 0	**End:** 07/01/09	**Tested By:** Dante Buckley , Sushant Kadimdivan,	**Test No.: 1**

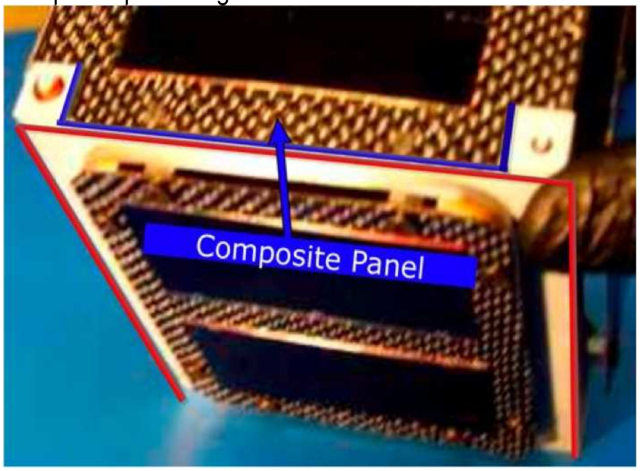
Step 2) Apply tension with your fingers when wrapping around the quarter-round guides to ensure the antenna is flush. No part of the antenna should protrude out beyond the composite face as illustrated in the following figures.

Antenna in tension

Flush from the top view

Flush from the side view

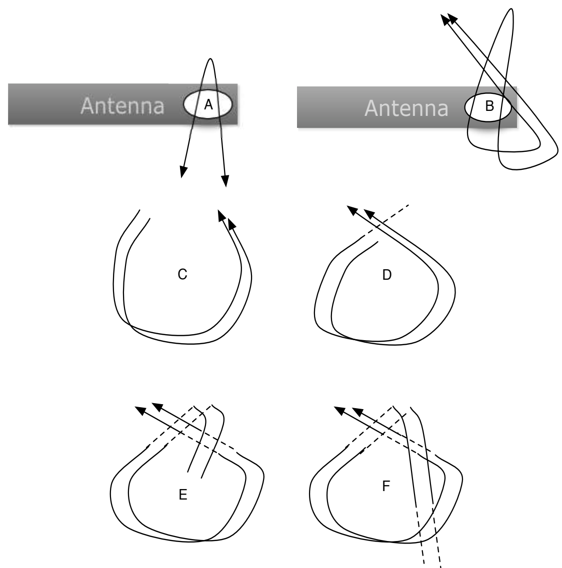
Step 3) The composite panel edge (shown in the figure with the blue line) must be flush with the edge of the Cube frame (shown in red) to ensure the antenna deploys and does not collide with a protrusion of the composite panel edge.



Flush Edge

Step 4) Follow the knot diagram from steps A-F in the following figures. In Step F, use the clippers to cut the nylon fiber after the knot created in step F. Only one fiber will remain to apply the tension necessary for packaging.

Subsystem: Communications		Document No.: 09/A1/TD/05/02	Part No.
Begin: 0	**End:** 07/01/09	**Tested By:** Dante Buckley , Sushant Kadimdivan,	**Test No.: 1**



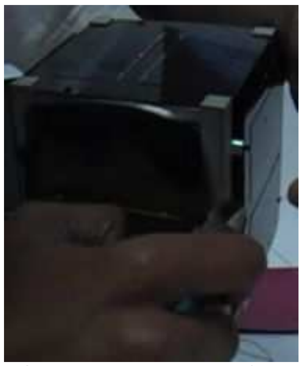
Diagram

Securing the lines (C-D)

Tying the lines (E-F)

Now the antennas are secured in place with the nylon fibers. The job becomes easier if the knot at one of the ends is tied before it is folded in position.

Subsystem: Communications		**Document No.: 09/A1/TD/05/02**	**Part No.**
Begin: 05/20/0	**End:** 07/01/0	**Tested By:** Kadimdi	**Test No.: 1**



` **Cutting excess nylon fibers** **Overlapping Antenna**

If it doesn't overlap then the ends can be joined directly with a small nylon fishing line, or going around the perimeter of the CubeSat panel boundary. The short connection constrains the nichrome burn wire to be wound to the fishing line. The perimeter technique is preferred if the nylon has a clear path to be wound-on. In other words, the nylon should not get tangled in anything around the perimeter which could cause any obstacle.

Antennas restrained by the nylon and load switches connected to burn wire

<u>Step 5)</u> Now the nichrome has to be wound around the nylon for around 3-4 close turns. Use the plastic tongs if necessary.

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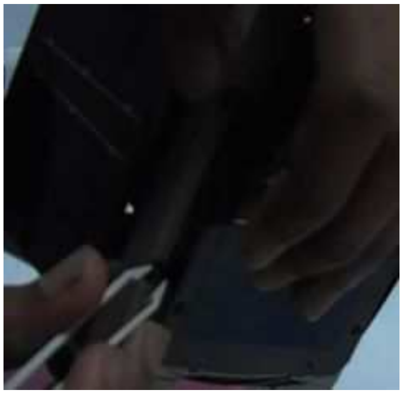
Begin: 05/20/0	**End:** 07/01/0	**Tested By:** Kadimdi	**Test No.: 1**

Plastic tongs to squeeze nichrome wire



Plastic tongs to grip nylon

This has to be done for both the antennas. Short circuit prevention must be taken such into consideration (ie. the aluminum chassis of the CubeSat does not short the nichrome coils). A short circuit could damage other circuitry, or possibly render the nichrome coil in-effective.

The total length of the nichrome wire <u>must be kept as short as possible</u> to keep the resistance low. Standard gauge wires can be used to extend the nichrome burn wires to connect to the circuitry. This is required to generate sufficient current at a voltage of 3.3 volts.

<u>Step 6)</u> The coils on both the antennas have been connected to the load switch in parallel because the load switch has the capability to supply sufficient current for both the coils.

Antenna Deployment Switch Ready

<u>Step7)</u> When all the preparation is complete, push the yellow button on the deployment box can activate the load switch. Stay clear of the antennas deploying to prevent any injuries. When the load switch is activated, the nichrome will heat to melt the nylon fibers to ultimately deploy the antennas into their dipole configurations.

Subsystem: Communications		**Document No.: 09/A1/T /05/02**	**Part No.**
Begin: 05/20/09	**End:** 07/01/09	**Tested By:** Kadimdi	**Test No.: 1**

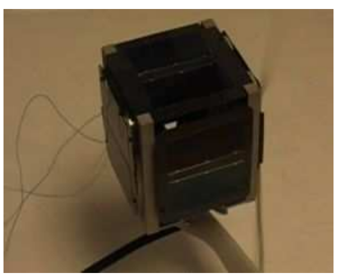
Test

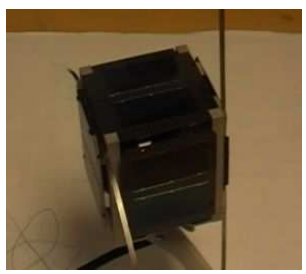
Setup was completed and tests were carried out multiple times. A current of 500 mA was sufficient burn through the nylon fibers to deploy the antennas. This is a safe estimate with 300 mA enough to barely melt the nylon fibers. Thus it turns out to be around 1 A for both nichrome burn wire. The switch has to be activated for around 4- 5 seconds to make sure the nylon is melted. The nichrome burn wire has a distinctively red glow when initiated.

Results

Satisfactory results were obtained with respect to the electronics set up. The current limiting resistor required was around 6.8 kΩ (limited to 1 A) in the deployment circuitry. The switch/ON pin has 10 kΩ pull-up resistor since there is no internal pull up. The pin is active low.

The following freeze frames show a successful deployment:


Transmit Antennas Deploy


Receive Antennas Deploy


Successful Deployment

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BIOGRAPHICAL SKETCH

Dante Augustus Buckley was born in December of 1982 in Cincinnati, Ohio. He grew up in Cincinnati until 1991 where his family of moved around from Montgomery, Alabama to Charleston, South Carolina to Omaha, Nebraska and has resided in the state of Florida since 1998. Growing up, he was an active athlete playing baseball, basketball, football, and his favorite sport soccer. Dante is a high school graduate from Bishop Moore High School in Orlando, FL in 2001 and member of the 2000 State Championship soccer team. Dante met his wife-to-be at Bishop Moore. Dante became a United States Soccer Federation (USSF) referee in 1997 and is currently an aspiring State 5 USSF referee, a high school official, and also a National Collegiate Athletic Association (NCAA) soccer official.

Dante was accepted into the University of Florida's College of Engineering in 2001. During his late undergraduate studies, he is credited for co-founding the University of Florida's Small Satellite Design Club (SSDC) in 2005 after being selected to compete in world-wide student competition at the 19th Annual USU/AIAA Small Satellite Conference in Logan, Utah. The paper, a Gossamer Technology Demonstrator for De-orbiting Pico-satellites, proposed a non-intrusive compact aerobraking technique to induce drag to mitigate the orbital lifetime. SSDC's primary goal was to establish a permanent small satellite program on campus. SSDC focused its efforts to winning the Annual Florida University Satellite Design competition sponsored by the Florida Space Grant Consortium & Space Florida in pursuit to build the first student built CubeSat at the University of Florida. Dante received his Bachelors in Science (B.S.) in Aerospace Engineering in 2006 and continued his satellite research with the Space Systems Group, the research group advised by Professor Norman Fitz-Coy. The Space System Group technically supports the CubeSat mission known as SwampSat. In November 2008, ASTREC, the Advanced Space Technologies Research & Engineering Center was established focusing on a paradigm to transform pico- and nano-satellite technologies for increased utility in on-orbit capabilities. Dante received his Masters of Science (M.S.) from the University of Florida in the summer of 2009. Dante plans to continue his studies at the University of Florida in pursuit of a career in the emerging small satellite sector.

Dante married his better half, Taryn Rivera, on June 28, 2008 at St. James Cathedral in Orlando, FL. Dante and Taryn reside in their home in Gainesville.