Small Wearable Antenna for Animal Tracking

Undergraduate Students: Jared R Fowler, Jon M Austin, Kathy T Estrada, Martin Velazquez, Robyn Mohr, and Ruben Sanchez
Faculty Advisors: Kathleen Melde and Michael Marcellin

Department of Electrical Engineering, The University of Arizona, Tucson, AZ, USA

Abstract

Many tracking devices exist in today's world. There are car tracking devices, hunting dog tracking devices, and even cell phone tracking devices. The use of Global Positioning Systems (GPS) has increased the ability to track various subjects throughout all parts of the world. However, there is no reliable tracking device for small mammals that allows researchers to maintain an unobtrusive distance from the animals. The goal of this project was to begin the process for designing a tracking system for small mammals. The overall system design utilizes a Garmin Astro 320 GPS tracking unit in order to focus on effectively reducing the size of the external antenna. Through the use of current technology and the knowledge of several engineering disciplines, an antenna was designed and embedded into a collar which connects with the Astro unit. This new antenna is compact and more suitable for tracking the Golden Lion Tamarin, a small monkey living in the Brazilian rain forest.

I. Introduction

Currently the Golden Lion Tamarin (*Leontopithecus rosalia)*, of the Brazilian Rainforest, is on the endangered species list with a population of less than 1,500 [1]. Researchers in Brazil have been studying these mammals hoping their research will provide substantial information to help the species. Unfortunately, due to the small stature of the tamarin and rough secluded jungle environment, tracking them has proved to be difficult. In order to propagate location data through the dense foliage Multi Use Radio Service (MURS) frequencies in the VHF band are utilized. The use of these frequencies in the VHF band requires a quarter-wave monopole antenna of 49.3 cm in length. The average adult size of the Golden Lion Tamarin ranges from 19 to 22 cm (7.5 to 8.75 inches) with a neck circumference of about 11 cm (4.33 inches). Due to this size difference current tracking systems based on this antenna are inconvenient and pose safety risks to the animal. These issues drive the need for an innovative device to use for tracking small mammals. This project designs a wearable antenna functional in the MURS frequency range with a footprint small enough to safely be worn by the Golden Lion Tamarin.

Ansys High Frequency Structure Simulator (HFSS) was used to simulate prototypes. These prototypes were then hand constructed and profiled with an HP8510c Vector Network Analyzer and then tested for maximum communicable distance while attached to a transmitter system.

II. Top-level Design of Final Design Concept

The system used is the Garmin Astro 320 GPS tracker and DC-40 collar turnkey system (Fig. 2.1). A government owned, public use GPS satellite network will transmit location data to the DC-40 tracking collar using L1 and L2 GPS frequencies. The collar device will then broadcast its own signal to the handheld receiver, the Astro 320, via an unlicensed frequency band in the VHF range known as the Multi-Use Radio Service (MURS) band. These frequencies lie between 151.82 MHz and 154.60 MHz [3]. The antenna for this system was modified to create a smaller footprint to prevent interference with the tamarins' natural behavior. The antenna was integrated into the collar itself utilizing a zigzag design as shown in Fig. 3.1. The handheld receiver was not modified during the course of this project. The Astro 320 handheld was chosen due to the mapping capabilities, frequency range and user friendliness of the device [2]. The DC-40 collar has the GPS system designed into the transceiver box instead of into the collar as some of the other commercially available devices did. This facilitated our ability to change out the collar to something smaller and integrate it with the new antenna design.

Figure. 2.1. Astro 320 Handheld & System Overview

III. Antenna Design

The wearable portion of the top-level design can be broken down into two subsystems: the antenna and the transmitter box. The DC-40 transceiver package houses the GPS receiver and terrestrial VHF broadcast transmitter radios. The UHF GPS antenna is housed internally within this enclosure. A microcontroller is used for interpreting GPS positional data received and protocols to broadcast the positional data through the VHF transmitter. This enclosure also houses a battery pack for power which requires the majority of the size of the box. The contents of this transmission box will be unaltered for the scope of this project; however, the dimensions of the box itself are important as it is to be mounted to a wearable animal collar as well as serving as an end point for the antenna subsystem.

The radiating element of the antenna subsystem will be a modified monopole antenna design. Simulations were used to determine the size and layout of the antenna. The final design consisted of four branches of a regular ‘zigzag’ pattern which was then folded over making two layers and imbedded into a collar.

The reasoning behind this design is to reduce the footprint of the antenna, while maintaining a proper resonating frequency to facilitate broadcasts by the 153 MHz VHF terrestrial transmitter within the DC-40 transmission box. This ensures proper functionality of the antenna, while not impeding the natural behavior of the small mammal. To accomplish this design the radiating element of the antenna was constructed of 26 gauge solid core insulated copper wire. This gauge of wire was chosen for the ability to manipulate the wire, while maintaining the desired shape once constructed. The insulation acts as a protective barrier to avoid any unwanted shorts in the antenna, which would change the operational frequency of the antenna. The bends of the antenna lower the resonant frequency, while at the same time reducing the total length of the antenna. This causes a decrease in efficiency which is seen in the field range testing. However, this trade-off makes it possible to reduce the total size of the antenna to a suitable length.

The curved zigzag of the radiating element itself was attached to a nylon material and made to the desired length. The nylon material was chosen to ensure that the collar does not interfere electrically with the antenna, and also remains light and comfortable on the neck of the animal. A coating of epoxy was placed on the final prototype antenna to minimize shifting and help to maximize the performance.

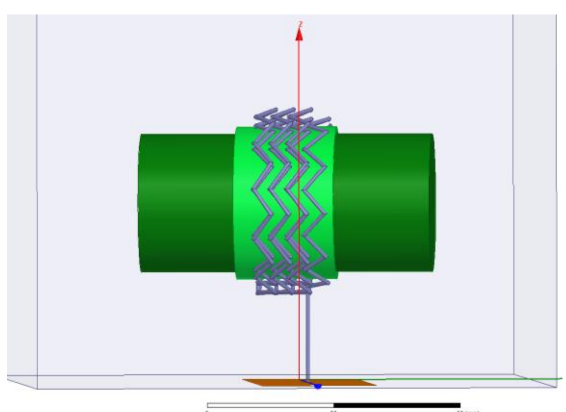

Figure. 3.1: Antenna Apparatus Attached To Collar

IV. Analysis

The analysis started with a 49.3 cm straight quarter-wave monopole antenna, this length was obtained from first finding the wavelength of our operational frequency by

$$\lambda = \frac{c}{f} \quad , \tag{1}$$

with *c* being the speed of light in free space and *f* being 152MHz, the center of the MURS band. Then adding zigzags and curving it into a collar shape modified the monopole antenna to a smaller wearable size. HFSS was used iteratively to bring the resonant frequency of the proposed antenna into the desired range required for transmission.

In the initial design, the antenna was bent around a cylinder, which was given parameters to represent a body. A hollow cylinder was placed around the 'body' and a material was selected to represent the collar. The antenna was then drawn around the collar and the model simulated. The original design resulted in a return loss of 300 MHz, which was twice as high as the desired frequency of 152 MHz. The width and angles of the zigzags were lengthened and decreased to try to obtain a lower frequency. A lower frequency can be achieved by increasing the length of wire on the antenna. Adding more wire decreased the frequency, but this effect was canceled out by decreasing the angles of the zigzags, which increases the frequency. 285 MHz became the smallest frequency that was possible from using this technique, so other options were explored.

Since the angles became an issue with the previous attempts, they were kept constant and a different technique was implemented. The base and height of the zigzags were kept constant at 1 cm height by 0.5 cm width. The zigzags do not go all the way around the collar; instead, they stop at 10.5 cm then return to make another path around the collar, this spacing is set at 0.4 cm. The analysis of this design resulted in a resonant frequency of 223.2 MHz.

This design brought down the resonant frequency compared to the original, however it needed further decreasing. To achieve the 152 MHz a second layer of wire was added to the design and resulted in the final design shown in Fig. 4.1. The final design has a height of 10.5 cm and width of 1.7 cm with a spacing of 0.2 cm between layers. The final results obtained from HFSS are shown in Fig. 4.2. The antenna resonates at 152 MHz with a return loss magnitude of -5.0024 dB and has an input impedance of 23.5 + j 9.82 ohms as shown in Fig. 4.2.

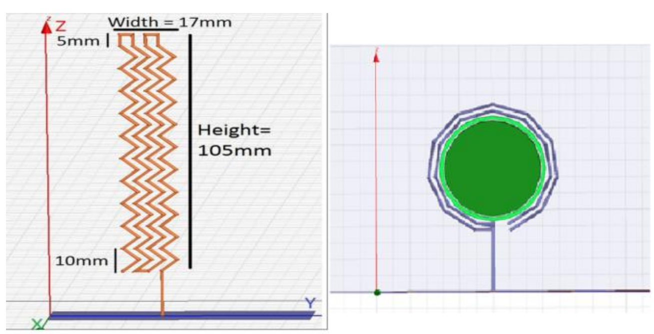

Figure. 4.1: Upright dimensions of the antenna, and side view of the curved antenna illustrating two layers

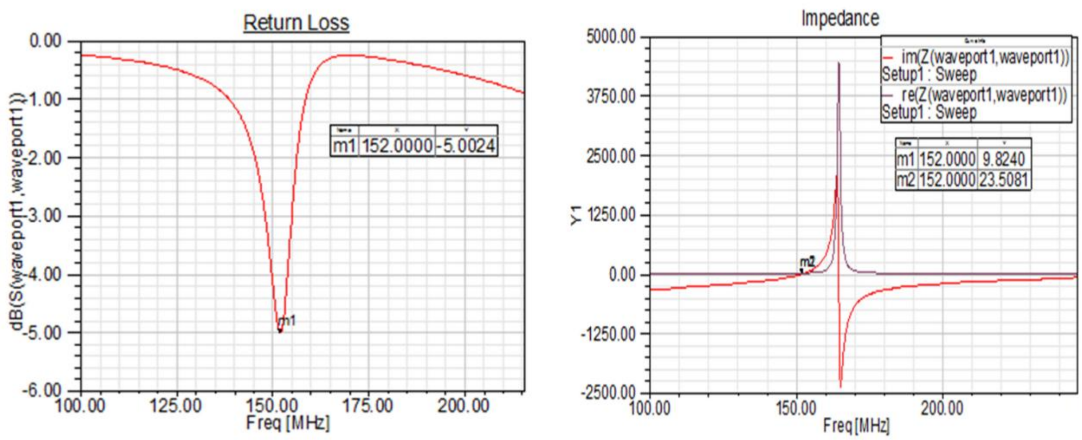

Figure. 4.2: The return loss and impedance of the final design

V. Development Plan and Implementation

The development of the antenna consisted of three phases which were simulation, building and testing. The first phase was the simulation utilizing HFSS to create an antenna with the desired characteristics. Once a design was successful during simulation it was taken into the building phase. 26 gauge insulated wire was used for the antenna, since it could be easily manipulated into the shape needed. In order to build the antenna, cloth was first laid on top of a cork board, and then a grid was placed on top of the cloth. Pins were placed at the correct intervals and the wire was bent through the pins until the shape was achieved. The wire was sewn to the cloth during the building process in order to keep the desired shape. Initially, three prototypes were produced for testing. These three prototypes had the same basic design, with minor differences produced from hand building the designs. Each prototype was named after the color and material used for the design. The prototypes were named: black nylon, blue canvas and blue nylon. The wire on the black collar was secured down with epoxy to keep its shape. The collar wire was completely encased into the collar material shown in Fig. 5.1.

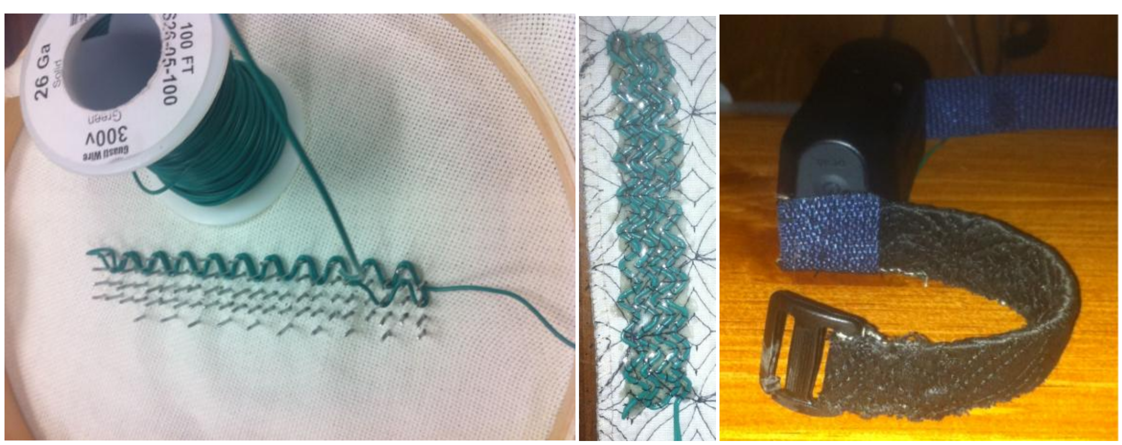

Figure. 5.1: Construction and Final Prototype Antenna (Black Collar)

VI. Requirements Review

There were a few requirements required by the sponsor for our system. The system is required to operate at a frequency band unlicensed by the Federal Communications Commission (FCC). This was met through the tuning of the antenna in the software design phase. The antenna was designed in the HFSS simulation software to a frequency of 152 MHz, which gives some bandwidth tolerance. The Astro 320 GPS system already operates in the correct GPS range and was not to be altered for this project.

Another constraint was the ability for the system to operate in the environment of the tamarin. The typical environment of the tamarin is the Brazilian rain forest. Such an environment is very wet, and is covered in dense foliage; this type of environment requires a relatively low frequency signal to broadcast data efficiently and weatherproof enclosures to ensure the safety of the electronics. The system chosen was designed for use during hunting, which typically involves some form of precipitation, as well as, brush and forested regions. So the system itself meets this requirement. The antenna was the only part of the system being modified, and once the desired characteristics were met, the antenna was enclosed in an epoxy substrate for protection.

The main concern for the project was the tamarins safety and convenience. Due to this concern the antenna design should be able to do its job, while fitting around the neck of the tamarin in a manner as to not inhibit the natural behavior of the monkey. By incorporating the antenna into the collar device, it reduces the chance of the antenna to wrap around the monkey's appendages as the current system is doing.

The broadcasting range of the system was another important aspect of the design. This is necessary to allow researchers the ability to track without interfering with the natural desire of the tamarins to avoid humans. A minimum of a 1 mile line of sight broadcasting range was required to prevent the need for human/animal contact. The design, tuning, and final build of the antenna were key factors in ensuring the range requirement was met.

VII. Acceptance Test Plan

The acceptance test plan was divided into two phases; experimental lab testing and field testing. The lab testing was done using the HP 8510c Vector Network Analyzer (VNA). The VNA was calibrated before each test with open circuit, short circuit, and 50 Ohm load circuit stubs to ensure accurate antenna response for the frequency range of 100 MHz to 300 MHz.

The network analyzer was also used to determine how well the built antennas matched the resonant frequency and impedance obtained from the HFSS simulations. The HFSS simulation has a return loss of -5.0024 dB at 152 MHz and an impedance of 23.5 + j9.82 ohms. Failure to resonate at the 151.82-154.6 MHz range was to dictate a failed design.

The Institutional Animal Care and Use Committee determine projects that are allowed to perform live animal testing. Our team did not have permission for this style of testing, so a different method for testing the effects of a body in close proximity to the antenna was used. The method chosen was the use of saline solution in a plastic bottle. Bodies consist 90% of saline water, therefore, the sponsor and the team deemed this a valid substitute for a live tamarin or animal for testing. Furthermore, all testing was done with no direct human contact with the prototypes, while the testing was in progress. The antennas were tested with a 'body' created with a plastic travel bottle filled with a saline solution. The body effect has a minor effect on the resonance frequency of the antenna and as such was accounted for in simulation.

Once the initial set of network analyzer results were done, field testing commenced. Field testing fell into two singular tests. The first of which was to ensure each transmitter device with prototype antenna connected with the Astro 320 handheld device. A passing result places confidence in the VNA testing and allows the antennas to be tested for range. The second test was a line of sight range test to satisfy the one mile line of sight range requirement.

The location of the range testing was done alongside a road east of Davis-Monthan Air Force Base in Tucson, Arizona. This site was chosen for its long flat desert area that runs along the road. The purpose of these tests was to determine the maximum distance the antennas were able to broadcast. Also, to ensure meaningful positional data was able to be received. Failure of this test is determined by not meeting the one mile distance and was to result in further tuning of the antenna to a more pronounced return loss resonance. The final distance of the antenna was declared after a connectivity loss of the antenna occurred and a countdown of five minutes elapsed.

Figure. 7.1: The Field Testing Packaging

To satisfy the "no human and animal testing" constraint they were placed in plastic zip bags with saline solution bodies (Fig.7.1). These packages were then carried on foot away from a declared start point of where the Astro 320 was located until contact was lost with the Astro 320.

VIII. Results and Performance

The frequency profile results from the network analyzer of the prototype antennas shown in Fig 8.1. All of the test subjects showed resonances at the 152 MHz point. The black nylon collar gave a resonance of -6.586 dB at 152 MHz, the blue canvas collar exhibited a resonance of -4.149 dB at 152 MHz, and the blue nylon had a resonance at -5.152 dB. These results are consistent with only minor deviation from the simulated results.

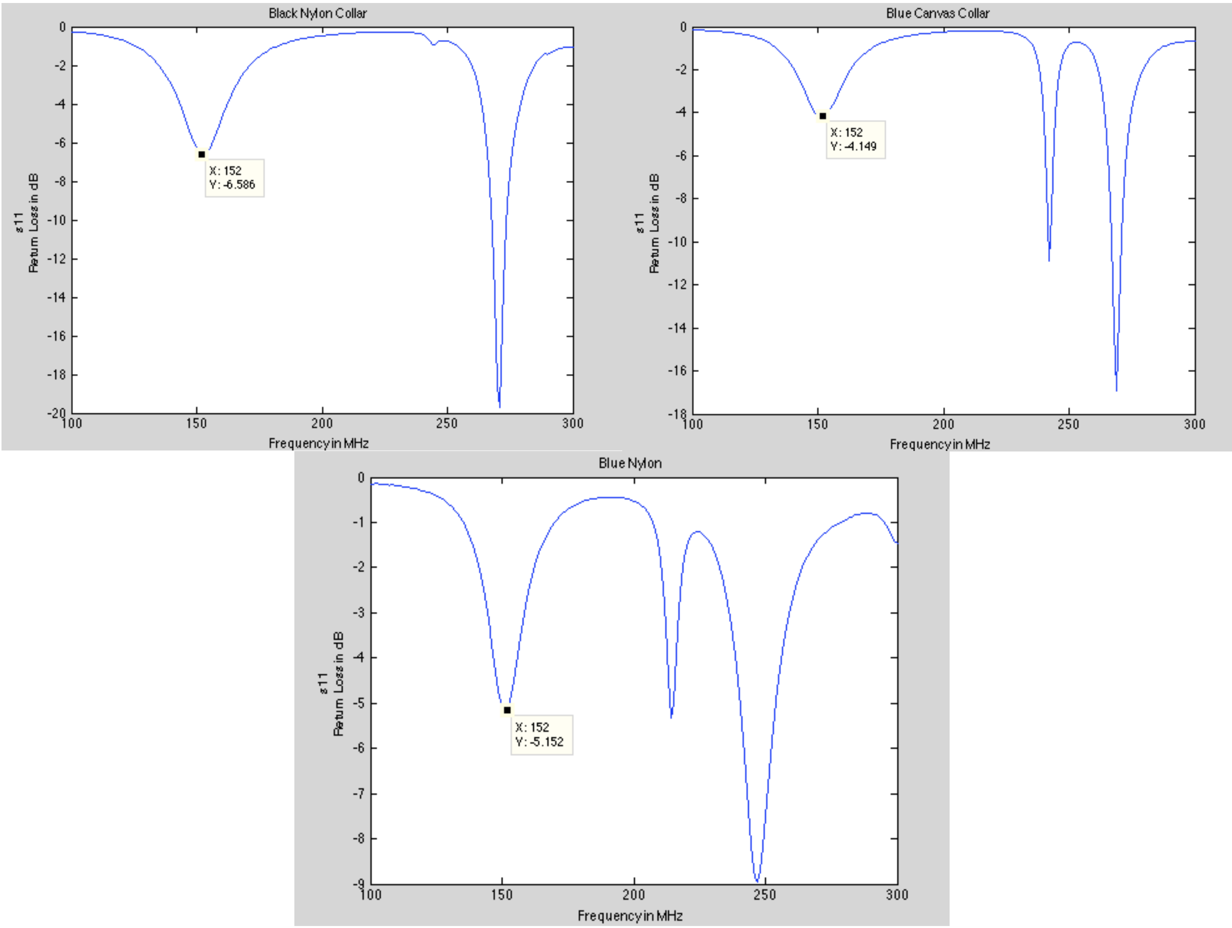

Figure. 8.1: Frequency Response of the Prototypes

The results from the network analyzer testing with the transmitter attached indicate all the antennas should be able to communicate with the Astro 320 receiver. The extra resonance frequencies at the higher frequency ranges, while undesired, should not inhibit proper functioning and are a result from the zigzag design. It is worth noting the black nylon antenna was the only of the test subjects to have its shape held stationary with the use of epoxy. It is proposed keeping the antenna in place and ensuring minimal shifting of the structure helps in reducing extraneous resonances and yields a smaller reflection coefficient.

The distance testing was conducted as described in Section VII. Table 8.2 exhibits the maximum distance results obtained in all collars. Results are consistent with the s11 return loss magnitudes for each collar.

Test Subject	Maximum Distance		Return Loss at 152 MHz	
Blue Nylon	0.79	miles	-5.152	dB
Black Nylon	1.45	miles	-6.586	dB
Blue Canvas	0.69	miles	-4.149	dB

Table 8.1. Distance Results of the Test Subjects

A final table is compiled showing which system requirements were met based on these test results.

Requirements	Application	Requirements Met	Comments
Transmitter operations at frequency range of 151-154.6 MHz	Astro 320 hand held unit operates at this given range. Antenna created will be tuned to this frequency	Yes	The protoype antennas yielded resonant frequencies at 152 MHz and -5 dB with the body effect
Antenna shall be incorporated in the collar	Zigzag antenna will be attached to a break away collar to curve around the neck.	Yes	The prototype antennas were stitched into nylon collars and measured 10.5 cm
Operate in mammal's environment	Astro 320 packaging currently designed for non ideal conditions. Insulated wire will be used to allow for any type of weather condition	Yes	The transmission packaging of the Garmin DC-40 was unmodified and remains weatherproof
Will fit around tamarins neck (11cm)	Tuning in the final stage will accomplish this requirment	Yes	The prototype antennas measured to be 10.5 cm
Should broadcast within 1 mile	Astro 320 has 95% accuracy for 7 mile line of site range	Yes	A broadcast range of 1.45 miles was achieved.
Will not inhibit natural behavior or movement of tamarine	Incorporating the antenna into the collar device removes the need for the oversized antenna	Yes	The antennas are incorporated into a collar desing as to not inhibit the natural behavior of the tamarine

Table 8.2. Satisfied Requirements

IX. Closure

The major accomplishment of this project was the engineering of a small wearable antenna. Simulating the antenna with HFSS and testing it with the network analyzer confirmed its operation within the desired frequency range of 151.82 MHz to 154.60 MHz; this is known as the MURS frequency band. MURS frequency was crucial in operation not only as the Astro 320 system frequency, but it propagates through a dense forest more efficiently than a higher frequency such as those in the gigahertz range. By integrating the zigzag antenna into the Astro 320 system collar, a 77% reduction in size was obtained. The zigzag antenna operated with the DC-40 transmitter box and was mapped out on the Astro 320 handheld unit. This proved to be successful by surpassing the one mile range requirement and giving a total distance of 1.45 miles.

The main challenge of the project was the size of the original antenna, which was about the same length as the Golden Lion Tamarin. This length was very inconvenient to the monkey; it tangled around the monkey's arms and other parts of its body. Incorporating a new antenna into the collar design small enough to fit around the monkey's neck was also a challenge. The zigzag design proved to be the best solution to meet these requirements set by the sponsor. The final prototype of the antenna was epoxied and covered completely, so the wires of the antenna were not showing. The advantage of doing this provided little movement for the zigzagged wires, and helped improve the overall range of the collar.

The completion of this project opens the doors for continuing the project in the future, such as reducing the original Astro 320 collar transmitter box, improving battery life while reducing the size of the actual battery, and possible changes to the circuit board of the transmitter box. All this was done in an effort to improve the technology to track the Golden Lion Tamarin, as well as help other small mammals be removed from the endangered species list.

X. Acknowledgment

Partial support for this project was obtained from the National Institutes of Health grant number R25EB012973-01, from the National Science Foundation Grant ECCS-1027703, and from the International Foundation for Telemetering.

XI. References

1. "Golden Lion Tamarin Leontopithecus Rosalia". NationalGeographic.com. n.d. Web. 10 Sept. 2011.
2. Garmin Corporation, Garmin (Europe) Ltd., Garmin International, Inc. Astro™ owner's manual. Olathe, Kansas: US, Garmin Ltd, 2009. Print.
3. FCC. Federal Communications Commission. n. d. Web. 15 Oct 2011
4. IACUC.ORG. Institutional Animal Care and Use Committee. 2011. Web. 9 Nov. 2011.
5. Save the Golden Lion Tamarin. Save the Golden Lion Tamarin. n.d. Web. 7 Sept. 2011.