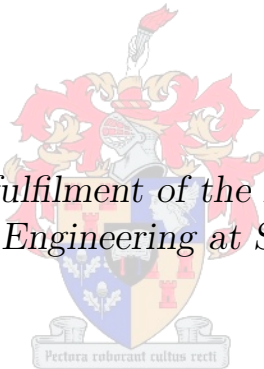


Tracking collar and infrastructure for leopard research

BY

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

Keywords: Leopard, Collar, Tracking, Conservation.

This project targeted the development of a new tracking collar, trap telemetry system and supporting infrastructure, to aid researchers from the Cape Leopard Trust. Previously used collar products had all proven insufficient in some capacity and remote monitoring of trap sites was also required. Tracking collars are used to identify the movement patterns of the leopards and through the resulting research, assist in protecting this threatened species. In the development of the tracking collar and trap telemetry system, a high level system design was first formulated, identifying major components that would be required. Alternative methods for implementation were then considered and the most optimal chosen. Two different modes of communication with the collar were envisioned and designed for. These would be used to transmit logged coordinates obtained from a GPS receiver back to researchers. A VHF terrestrial radio link was investigated, but an Iridium Satellite based solution was ultimately selected. An Iridium Satellite communications system was also used for transfer of trap state data. Ultimately, a working trap telemetry system was delivered for use by researchers. The tracking collar system had progressed to a working prototype, requiring miniaturisation and packaging before deployment. A possible packaging solution was also identified. The trap telemetry system, although displaying certain deficiencies, provided a capability previously unavailable to researchers. With further development, there is potential for the tracking collar to provide accurate satellite tracking and communications in a mass and price combination not previously available.

Opsomming

Sleutelwoorde: Luiperd, Halsband, Volg, Bewaring.

Hierdie projek het as doel die ontwikkeling van 'n nuwe opsporingshalsband, 'n lokval telemetriese stelsel en die nodige ondersteunende infrastruktuur daarvoor. As hulpmiddels vir navorsers van Cape Leopard Trust. Geen van die halsband produkte wat tot nou toe gebruik is, het voldoen aan al die nodige behoeftes nie, en dit was ook nodig om die lokvalterreine van 'n afstand te kan monitor. Die opsporingshalsbande word gebruik om die bewegingspatrone van luiperds vas te stel en die navorsing wat daarop volg, help dat 'n bedreigde spesie bewaar word. Die ontwikkeling van die opsporingshalsband en lokval telemetriese stelsel het begin met die formulering van 'n hoëvlak stelselontwerp waarin die hoofkomponente wat benodig sou wees geïdentifiseer is. Alternatiewe metodes van bewerkstelling is daarna oorweeg en die optimale hiervan is gekies. Twee verskillende metodes van kommunikasie met die halsband is voorgestel en ontwerp. Hierdie sou gebruik word om die vasgelegte koördinate wat van 'n GPS ontvanger verkry is, na navorsers terug te versend. 'n Terrestriale radioverbinding is ondersoek, maar 'n Iridium Satelliet-baseerde oplossing is uiteindelik verkies. 'n Iridium Satelliet kommunikasie stelsel is ook gebruik vir die oordrag van data aangaande die lokvaltoestand. Uiteindelik is 'n werkende lokval telemetriese stelsel gelewer vir die gebruik van navorsers. Die opsporingshalsband stelsel was nou 'n werkende prototipe, wat slegs verklein en toepaslik verpak moes word voor dit in gebruik geneem kon word. 'n Moontlike oplossing tot die verpakkingsprobleem is ook identifiseer. Die lokval telemetriese stelsel, hoewel dit steeds tekorte toon, voorsien die navorsers van voorheen onbekombare inligting. Met verder ontwikkeling is daar potensiaal vir die opsporingshalsband om akkurate satellietopsporing en kommunikasie te voorsien in 'n kombinasie van laer massa, sowel as prys, soos nog nooit voorheen beskikbaar nie.

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Nomenclature

Acronyms

BPS	Bits Per Second
CLT	Cape Leopard Trust
COTS	Commercial Off The Shelf
CSV	Comma Separated Value
DC	Direct Current
DIP	Dual In-line Package
DNA	Deoxyribonucleic Acid
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FSK	Frequency Shift Keying
GCBC	Greater Cederberg Biodiversity Corridor
GDP	Gross Domestic Product
GIS	Geographic Information System
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Position System
GSM	Global System for Mobile Communications
IC	Integrated Circuit
I2C	Inter-Integrated Circuit
I/O	Input/Output
ISM	Industrial, Scientific and Medical
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
LDO	Low-dropout Regulator
LED	Light-emitting Diode
LEO	Low Earth Orbit
LIC	Lithium-ion Capacitor
LSB	Least Significant Bit

MOSFET	Metal Oxide Semiconductor Field-effect Transistor
MPPT	Maximum Power Point Tracking
MSB	Most Significant Bit
PCB	Printed Circuit Board
PSRR	Power Supply Rejection Ratio
RFID	Radio-frequency Identification
RSSI	Received Signal Strength Indicator
SBD	Short Burst Data
SLA	Sealed Lead-acid
SPI	Serial Peripheral Interface Bus
TVS	Transient Voltage Suppression
UART	Universal Asynchronous Receiver/Transmitter
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
UHMWPE	Ultra-high-molecular-weight Polyethylene
UTC	Coordinated Universal Time
VHF	Very High Frequency
ZAR	South African Rand

Variables

symbol	description
R_{\max}	Maximum resistor value for Hall Effect switch biasing.
$V_{\text{BATTERY MIN}}$	Minimum supply voltage at which the system will remain active.
$V_{\text{ENABLE HIGH}}$	Minimum voltage which is accepted as a high level input.
$I_{\text{ENABLE MAX}}$	Maximum current the regulator enable pin is capable of pulling.
I_{loss}	Current leaked by system through Hall Effect switch biasing resistor.
$V_{\text{BATTERY MAX}}$	Maximum supply voltage the system is likely to experience.
$R_{\text{HALL SWITCH}}$	Hall Effect switch biasing resistor value.
E_{daily}	Daily power usage of the component.
$V_{\text{operating}}$	The operating voltage of the component.
I_{average}	The average current drawn by the component during the time it is active.
T_{duration}	The time that the component is activate during each use.
T_{period}	The time between activations of the component.
η_{supply}	Efficiency of the power supply that is supplying the component.
$l_{\text{degree max}}$	Maximum length on the earth's surface of a longitudinal degree.
c_{earth}	Circumference of the earth.
$\phi_{\text{min GCBC}}$	Lowest latitude forming part of the GCBC.

symbol	description
a	Transverse radius of earth.
b	Conjugate radius of earth.
$l_{\text{degree min GCBC}}$	Minimum length of a longitudinal degree in the GCBC.
$l_{\text{error max}}$	Maximum loss of position accuracy.
$l_{\text{range GCBC}}$	Minimum geographic range addressable in the GCBC.
C_{transfer}	Average battery charge required for Iridium data transfer in mAh
C_{success}	Average battery charge used for a successful Iridium transmission in mAh.
C_{fail}	Average battery charge used for a failed Iridium transmission in mAh.
P_{fail}	Probability of an Iridium transmission attempt failing.

Chapter 1

Introduction

1.1 Animal Tracking

With the looming extinction of numerous plant and animal species on earth, great effort is required to protect those that are endangered. Together with this, the booming world human population is placing continued strain on food resources.

Through their research, education and conservation efforts, the Cape Leopard Trust (CLT) works to protect predator species in the Greater Cederberg Biodiversity Corridor (GCBC) and other areas of South Africa. Much of their research efforts rely on mapping the movement patterns (by use of data collection collars fitted to the animals) of leopards in the GCBC and capturing them (in steel cages set in remote locations) for biological data collection.

The majority of commercial collars previously used by the CLT proved too weak for the abrasive terrain of the GCBC and stresses that the leopards placed on them. Those that did survive, were plagued by other problems. The system most widely deployed relied on researchers first locating the animal by driving around and periodically checking for a beacon signal transmitted by the collar. After locating such a signal, a directional antenna is used to estimate the direction, from them, to the leopard. In the event that these first two steps were successful (as they were often not), the researchers would need to get into close proximity and activate a handheld terminal to download logged coordinate data from the collar (which also failed regularly). Combined with such ease of use difficulties, these collars were also known to fail prematurely and placed much financial strain on the CLT through their high cost.

At the onset of this study, the method of catching leopards for collaring and biological data collection relied on steel cages set in spots that the animals were expected to move through. The cages, providing an easy through-way in densely vegetated areas, had steel doors closing both ends when a pressure plate in middle was triggered. The challenge presented, is that these cages need to be checked at least once daily, to see if they have been triggered. This necessitates extensive hiking and driving through the mountainous terrain

and severely limited the number of cages that could be concurrently set.

Through cooperation with the CLT, this study aimed to assist in the protection of the Cape Mountain Leopard by providing technological solutions, aiding researchers in their activities. The development of two major systems was identified for this purpose. The first is a telemetry system used to monitor remote sites where leopards are caught in traps to collect biological data and fit tracking collars. The second being a new tracking collar, improving on deficiencies (mainly reliability, lifetime and cost) experienced with other commercially manufactured collars in use.

Alternative concepts to satisfy the requirements of such systems were explored and some implemented in hardware and software. Different modes of communication were investigated for these systems. An initial design relying on a very high frequency (VHF) terrestrial radio link was ultimately replaced by an Iridium satellite based solution. A potential design for collar packaging was also suggested.

Ultimately a working trap telemetry system was delivered to researchers. Though certain further deficiencies were identified, it proved operationally usable. As for the tracking collar, a working prototype was manufactured, but was however not yet suited for packaging. A number of potential avenues for future research were also explored.

1.2 Objectives

The overarching objective of this project was to develop technological solutions to aid members of the CLT in conserving and managing the leopard population in the GCBC. This was attempted by creating a tracking collar and supporting infrastructure as an alternative to the previously used commercial models.

The primary data that researchers are interested in, is the movement patterns (where they roam and how they use the terrain) of the animals. Secondary to this, they wanted to identify spots where predation took place, so that the diet of these animals could be established by visiting these localities.

Functionality integrated in this system includes location logging (coordinate data of animal movement) that might be triggered, either at set time intervals or, by sudden acceleration (as experienced during hunting). A method by which to upload this location data to the researchers via a wireless link, forms the other primary aim of this research.

The primary design constraints were size, weight and survivability. The collar ideally weighs 200g, is shaped in such a manner as not to disturb the animal and can be subjected to years of extreme abuse without failure. Ideally this collar should also cost less than R10 000, be operational for a two year period and streamline the process of data collection.

Even though the primary requirements for this collar are set to the needs of the CLT and their leopard research, other applications do exist. The design should be easily transferable to other animal research projects requiring tracking, where the animals are similar or larger

in size than leopards. If the collar packaging were to be removed, the electronics could also easily be utilised for asset tracking purposes.

Secondary to this, the process of collaring animals also required optimisation. To this end, a telemetry system was required for the traps used to catch the animals.

1.3 Process Followed

The nature of this project does not lend itself to extensive literary study. In the initial stages, interviews were held with the key role players of the CLT and field trips undertaken to see the challenges faced first-hand. Existing attempts at solutions were then identified and evaluated. These all proved to be deficient in some or other capacity.

At this stage it was clear that a new tracking system needed to be developed. Key components required by the system were identified. Alternative implementations for these components were then identified and the most suitable selected.

1.4 Summary and Contributions to Technical Solutions

In this thesis:

- Problems with current tracking collars and requirements for future models are detailed.
- Potential modes of radio communication in the GCBC are compared.
- A trap telemetry system design is presented and tested.
- A pre-production model of collar electronics and software is evaluated.

1.5 Contents of Thesis

- Chapter 2: Background to Development

At the outset of the research into developing solutions for leopard tracking, the reasons behind tracking are discussed. The principles of conservation biology and the need for food security are motivated. The current state of research activities in the GCBC is listed, along with the technological deficiencies of current equipment used.

- Chapter 3: Existing Solutions

This chapter describes the methods used to capture and collar leopards. It then continues in listing the current types of commercially available tracking collars. Brief mention is also made of previous academic projects.

- Chapter 4: Trap Telemetry System
Here the development of a telemetry system used to monitor the leopard capturing cages and traps is reviewed. The features required of such a system are identified and then translated into a model of system functionality. The model is implemented with details provided on the electronics, packaging and software design. Lastly, the system is evaluated through field testing and usage by researchers from the CLT.
- Chapter 5: Collar System Concept
The concept behind a tracking collar is analysed in this section. The features required and practical limitations on a collar are first considered. A number of alternative systems are then examined, most notably based on different methods of downloading logged coordinate data from collars. This model of collar operation is then divided into subsystems and the components for each envisioned. Finally a list of system concepts previously evaluated, but abandoned, are listed.
- Chapter 6: Communications
In this chapter we examine the considerations regarding communications systems for downloading logged coordinate data. In the initial model, where terrestrial radio links would be utilised, an operating frequency is selected by taking regulatory influences and expected link range into account. The modes in which data would be downloaded from the collar are then discussed, together with a description of an ad-hoc radio network developed for forming communication channels with collars. Lastly, the selection of the Iridium satellite network is motivated for use with both collars and field terminals.
- Chapter 7: Collar Electronics Design
The collar electronics design is organised into the major subsystems as identified in Subsection 5.4.3. Detail is provided to motivate individual component selections and, where appropriate, how they were implemented. Where necessary, simulations are also employed to verify correct design.
- Chapter 8: Collar Packaging
Packaging forms a critical part in the reliability deficiencies of previously used commercial collar products. The requirements for the collar's physical construction are first identified. These are then taken into consideration in selecting an appropriate material from which to manufacture the collar. A possible design is also suggested.
- Chapter 9: Collar Software Design
The collar software design chapter starts by describing the overall operation of the collar firmware. Mention is then made of strategies employed to minimise power consumption. A method of compressing logged coordinate data is evaluated. The reasoning behind the default configuration of the scheduling system is provided. A

description of the PC software to be used by researchers to download collar data is also presented.

- Chapter 10: Collar Results

The results chapter aims to evaluate and quantify the success of the designs produced as part of this thesis. A list is provided of all circuit boards constructed, their intended purpose, issues encountered and whether they achieved success. Measurements of key system parameters are provided. Unresolved errors in system operation are catalogued and potential solutions suggested. Finally the collar developed as part of this thesis is compared to commercially available collar products.

- Chapter 11: Conclusion and Future Work

In this final chapter a summary of the work accomplished is presented. Recommendations are also made as to possible further avenues of research.

- Appendices

In addition to the information provided in this thesis, a number of supporting documents are attached in appendices. These include circuit diagrams, printed circuit board (PCB) layouts and design drawings. Also provided are examples of SPICE models and impedance matching network designs. Lastly, a list of materials on the accompanying DVD is supplied along with detailed results gained from testing.

Chapter 2

Background to Development

2.1 Introduction

In this chapter we discuss the reason for undertaking the development of a new collar system and supporting infrastructure. The ecological base for research is covered by a description of conservation biology and the need for food security. The umbrella species method is identified as that being used by the CLT and the current state of their research is explained. Finally, shortcomings of the current tracking solutions as experienced by the CLT are discussed.

2.2 Ecology

2.2.1 Conservation Biology

One of the primary motivators for this project is from the conservation biology perspective. Conservation biology addresses the biology of species, communities and ecosystems that are perturbed by human activities or other agents and provides principles and tools to preserve biological diversity[11].

The aim of the CLT is not only to conserve the leopard population, but to protect and improve the health of the GCBC as a whole.

The identification of animals' home ranges forms a central part of their conservation strategy. Through the mapping of each animal's territory much can be learnt with regard to their population numbers, diet and habits. This is, of course, not limited to leopards, but they have been chosen because of their role as apex predator.

2.2.2 Food Security

The primary cause for decline in leopard population in the Cederberg area has historically been the conflict between commercial livestock farmers and the predators. Farmers set out on organised campaigns to trap and shoot leopards during the last couple of centuries. Large

areas of wilderness have also been reclaimed for farming purposes, reducing the available habitat and isolating populations.

This organised extermination has now voluntarily ended through the work of the CLT and their conservation programs.

The problem of stock losses is still of importance as this constitutes a financial loss to commercial farmers and could even result in a destruction of livelihood for sustenance farmers.

A large part of the workforce in the South African economy is reliant on the agricultural sector and these losses pose a direct threat to the financial security of the workers. In South Africa agriculture contributes less than 4% to gross domestic product (GDP) but accounts for 10% of total reported employment[9].

2.3 Umbrella Species Research

At the time of this study, a popular method for determining the required size of a conservation area was the umbrella species method [10]. This method relies on the identification of a species that is central to an ecosystem and likely to traverse most parts of it. The range of this species is then identified and used to determine the area required for a conservation zone which is to be established.

The Cape mountain leopard acts as the main umbrella species for the GCBC. Caracal were identified as another umbrella species and were being tracked.

2.3.1 Current State of Research

Research in the GCBC consists of determining the behaviour, diet and territory of the leopards, as well as identifying populations of other species endemic to the region.

The leopard acts as a flagship species, as well as an umbrella species. The charismatic nature of the animal it is advantageous for fund raising initiatives and other public relations activities.

2.3.2 Technological Shortfalls

A number of commercial products for animal tracking already exist and new designs are continually being released onto the market. During interviews with key role players from the CLT the need for new collar solutions was expressed as previous models had exhibited a number of deficiencies.

The collars being used at the onset of this study were manufactured by Vectronic Aerospace GmbH. They consisted of a Global Positioning System (GPS) receiver, VHF transmitter, ultra high frequency (UHF) transceiver and lithium primary cell battery (most likely based on lithium-thionyl chloride chemistry).

These collars are the only products currently used by the CLT, as all others tend to fail mechanically. The abuse the animals put the collars through in the harsh terrain routinely leads to breakage.

Other manufacturers' collars evaluated include: Lotek Wireless Inc., Followit AB, Sirtrack, Telemetry Solutions, AWE, Collar Clinic, Africa Wildlife Tracking CC, Televilt Sweden, BlueSky Telemetry, Telonics, Wildlife Track Inc., Advanced Telemetry Systems, North Star and Tracking Management Systems.

2.3.2.1 Range

Whilst the VHF 'ping' component of the collar has good range (up to 10km) it is very difficult to pinpoint the animal's current position using this. Multiple readings need to be taken in different locations to estimate the distance and direction of the animal from the points visited. This is further complicated by reflections of the radio waves off the mountainous terrain and the low directionality of the antenna used.

Downloading stored GPS coordinate data requires use of a collar manufacturer supplied UHF transceiver device. This transceiver has a very short range and is unreliable. It has happened on a number of occasions that although the researcher can see the animal, the terminal will not communicate with the collar. It is likely that the UHF transceiver located in the collar, is switched on only periodically, to conserve power.

Ideally, downloads should be possible at a range of several kilometers or via satellite. Alternatively, unattended downloads should be possible.

2.3.2.2 Lifetime

Capturing a leopard in a cage or snare is time consuming, expensive, undesirable and has a low probability of success. Collar lifetime should therefore be as long as possible. Batteries used in current collars do not last more than 6 months.

Researchers from CLT identified 2 years as being the lifetime they would want from a collar.

2.3.2.3 Reliability

As noted in subsection 2.3.2.2, it is extremely time consuming, expensive and stressful to the animals as well as to CLT personnel to fit new tracking collars to the leopards. It is therefore crucial that the collars stay operational for the entire length of their designed lifetime.

Current collars routinely fail within months or even weeks of being fitted. The exact reason for these failures is unknown.

Common mechanical failure includes the breakage of the collar material. With the previous Vektronic Aerospace collar it is routinely found that the mild steel bolts used to

secure the plastic housing containing the control electronics and battery to the collar band are ground down. This is due to the abrasive nature of the animal's habitat, coupled with the tendency of the animal to rub against objects.

The electronics and software package also needs to function reliably for the duration of the collar's life. This entails having a power supply and electronic components that will not fail and software that does not become trapped in an undefined state.

2.3.2.4 Cost

Depending on the South African Rand - United States Dollar exchange rate at the time of purchase, the CLT paid in the area of R30 000 to R45 000 per collar. This puts tremendous economic strain on the organisation, as it relies on donor capital to operate.

A replacement collar costing less than R10 000 would allow the programme to track more animals and expand to new areas.

2.3.2.5 Functionality

The operating procedure for downloading coordinate data is complex and unwieldy. Locating the animal via the VHF 'ping' mechanism is difficult and prone to failure. The UHF transceiver will for unknown reasons at times not communicate with the collar, though we suspect this is due both to the animal moving behind an obstruction and the periodic activation of the UHF receiver.

The ability to perform downloads from the collar without intervention from the researcher is also sought. Current systems being used (developed by Vectronic Aerospace GmbH) do not support this and require the researcher to track the animal and manually initiate a communications link via UHF radio modem. Previous attempts to obtain the protocol specification being used from Vectronic Aerospace GmbH were not met with cooperation. An attempt was also made to reverse engineer the communications protocol used over the USB connection of the hand-held terminal with limited results[4].

2.4 Conclusion

In this chapter we identified the reasoning behind researching and conserving the cape mountain leopard. The limitations of current commercial products in terms of range, lifetime, reliability, cost and functionality were also explained.

Chapter 3

Existing Solutions

3.1 Introduction

In this chapter the methodology of capturing and collaring leopards is described. Further, the existing types of tracking collar are listed and discussed.

3.2 Trapping and Tagging

A primary method of gaining detailed information on animals in an area is through trapping in snares or cages. This provides a researcher the opportunity to collect physical data (mass, size, age and health etc.), collect tissue samples for deoxyribonucleic acid (DNA) extraction and allow for the fitting of tracking devices.

Cages and snares are set up without any bait and work by being placed in positions where the surrounding terrain acts as a funnel. Animals will take the route of least resistance, attempt to pass through the cage or snare and be trapped. Cages are currently triggered by a pressure plate in the middle of the cage, which release two heavy steel doors at either end. Snares are triggered by a pressure plate buried beneath the ground. This releases a spring loaded mechanism that tightens a steel cable noose around the animal's paw.

Monitoring of cages and snares is difficult as they are, by necessity, located in remote areas and often inaccessible by vehicle. Traps need to be checked twice daily, requiring a significant investment in man hours, fuel and vehicles. A satellite communications based monitoring system, was developed, as part of two final year projects[3][12], at the Electrical and Electronic Engineering Department at Stellenbosch University to improve this.

The reliability of this telemetry system was, however, not sufficient for it to be used in the field. It was therefore decided to redesign the entire system for improved reliability. This system would share many common hardware components and software with the collar system, and make use of the Iridium satellite network.

If a leopard has been caught, a veterinarian and other support staff are called in. The animal is sedated, measurements and samples taken and a tracking collar fitted.

3.3 Commercial Collars

At the onset of this study a number of commercial products existed for the use in animal tracking; in addition, a number of new devices appeared on the market during the course of this study. Manufacturers of these devices, all of which had proved to be deficient in some form for the task at hand, are listed in Subsection 2.3.2.

3.3.1 Use of GPS in Collars

In all but the most basic ‘ping’ type collars and Argos based systems, all current products on the market make use of the GPS system for satellite based positioning. This system does not provide a communications infrastructure, but is a global navigation satellite system (GNSS) system, thus providing only positional data, which then has to be transferred from the collar via another channel.

3.3.2 Ping Collars

The earliest forms of tracking collars consisted of dumb VHF transmitters. These would periodically (typically every second) send out a signal (‘ping’) and the researcher would then attempt to locate the animal by using a directional antenna to determine its direction.

These systems rarely remained in use at the time of this study.

3.3.3 Argos system Collars

Collars available at the onset of this study which make use of this system possessed an Argos transmitter, which transmits only an identification number. Collar location is then determined by the satellite measuring the Doppler shift in transmission frequency as it orbits over the area. This provides an accuracy of up to 150 meters.

The next generation of Argos transmitters was being deployed during the course of this study. They afforded the ability to upload arbitrary data to the Argos satellite network. This afforded the possibility of using a GPS for location logging and Argos to upload the tracking data. Early indications were, however, that the terminals were much larger and heavier than those of the previous generation.

In November 2011 it was also learnt via interviews with members of the CLT that they find the the cost of data transmission on the Argos network prohibitively expensive.

3.3.4 GSM Collars

A large number of manufacturers supply Global System for Mobile Communications (GSM) connected collar products. These all typically possess a GPS receiver, which logs positioning data, which is then uploaded via a GSM connection.

These are, however, rarely usable in wilderness areas due to the lack of cellular network coverage.

3.3.5 Satellite Communication Based Collars

Various satellite networks exist which can be used to transfer data between ground stations. There are networks relying on low earth orbit (LEO) satellites which decrease the transmit power required for a terminal to establish communications with the satellite. This is a critical requirement, as the transmitters typically used to communicate with satellites in higher orbits are too large and heavy to be integrated into a collar.

A number of collars relying on the Globalstar, Orbcomm and Argos satellite constellations (as discussed in Subsection 3.3.3) were available on the market. These were, however, all excessively large and heavy, thus not suited for use by the CLT.

At the time this study was commenced, the only LEO satellite constellation with good coverage of South Africa was the Iridium satellite constellation. During the initial phases of research, the Iridium transceivers available on the market were too large and heavy for use in a collar, but it was thought that they could be placed in larger static ground terminals that would communicate with the collars via another channel.

In mid 2009 rumour had spread of a new generation Iridium terminal that would be much smaller and lighter than the previous generation, but all efforts to gain additional information from Iridium Communication Inc. were met with stiff resistance. The next generation Iridium terminal was launched in June 2010 and it was decided that this antiquated previous collar designs. At the time this research was concluded, other manufacturers had also released Iridium based collars. The excessive mass of these commercial collar did, however, preclude them from use by the CLT.

3.4 Academic Projects

Though previous academic projects to produce animal tracking collars have been attempted[2][13], neither of these provided the required low power usage and lifetime.

3.5 Conclusion

In this section we have described the process by which research is conducted on the leopards. The current types of commercial collars available on the market were briefly discussed (their problems are outlined in Subsection 2.3.2) and previous academic projects in the field are mentioned.

Chapter 4

Trap Telemetry System

4.1 Introduction

In order to fit a tracking collar to a leopard, it must first be captured. This is done by means of cages or soft-catch snares. These traps, however, need to be monitored regularly in order to minimise suffering or any detrimental effects to the captured animal's health. This is a time consuming and expensive task to undertake in the mountainous terrain of the GCBC.

A cage telemetry system would enable the researchers to remotely monitor trap sites. This would result in a reduction in the operating cost of research, free up time for other research activities and allow for more traps to be set simultaneously. This system would, ideally, be required to stay operational for years (the lifetime would be dependent on the battery used) without requiring any maintenance other than cleaning of the solar panels.

In this chapter the requirements for such a telemetry system are defined and a conceptual and detailed design formulated.

4.2 System Requirements

A system to monitor cage and trap sites would include the following functionality:

- Sensor to detect whether the trap has been triggered.
- Sensor to verify that an animal has been trapped in the cage or snare and identify it.
- Communications system for transferring sensor data to researcher.
- The system would be capable of running unsupported in wilderness areas without any supporting infrastructure.
- A user interface (UI) for the monitoring should be provided to the researcher.
- The entire system should be easily transportable by researcher travelling by foot through the mountainous terrain of the GCBC.

- The system should be able to report its battery health.

These high level system requirements lead to the identification of the system components required, namely:

- A switch to monitor whether the trap has been triggered.
- A camera to take photos of the area in which the trapped animal would be expected to be, as well as a lighting system for taking photographs in low light conditions.
- A satellite radio terminal via which the trap state and photos would be transmitted to the researcher.
- A controller unit to manage all the peripheral components.
- Batteries, solar panels and a solar charge regulator to power the system indefinitely would be required. Containers would also be needed, to house the system and protect it sufficiently for outdoor use.
- Application software to be run on the researcher's computer to display the trap state and photos.

4.3 System Concept

A cage telemetry system would be fitted to the existing steel cages used to capture leopards. This system would relay the state of the cage door, as well as images of the inside of the cage to the researcher's base station via the Iridium satellite network and the internet, as illustrated in Figure 4.1.

Weeks prior to the deployment of the system it was, however, learnt that cages were no longer being used to capture the animals. A soft-catch snare had replaced the cages, as it did not have the by-catch (animals that are caught in the traps, other than the intended targets, namely leopards) problems associated with using cages and also resulted in less injury and trauma to the leopards. This did, however, not constitute any major design changes to the system, as only the triggering mechanism required alteration.

The proposed cage telemetry system removed features previously offered by those systems developed as final year projects. The inclusion of relays to drive a motor to open the cage was unnecessary as no such cage had been built. An infrared (IR) motion sensor was also removed, as it would not be needed to trigger the cage door to shut. The micro switch used to check the cage door status was replaced by a reed switch in the snare version of the system.

The complete field system consists of a controller box, solar panel, gate switch (replaced by a reed switch in the snare version), Iridium antenna, camera and lighting units. A sealed

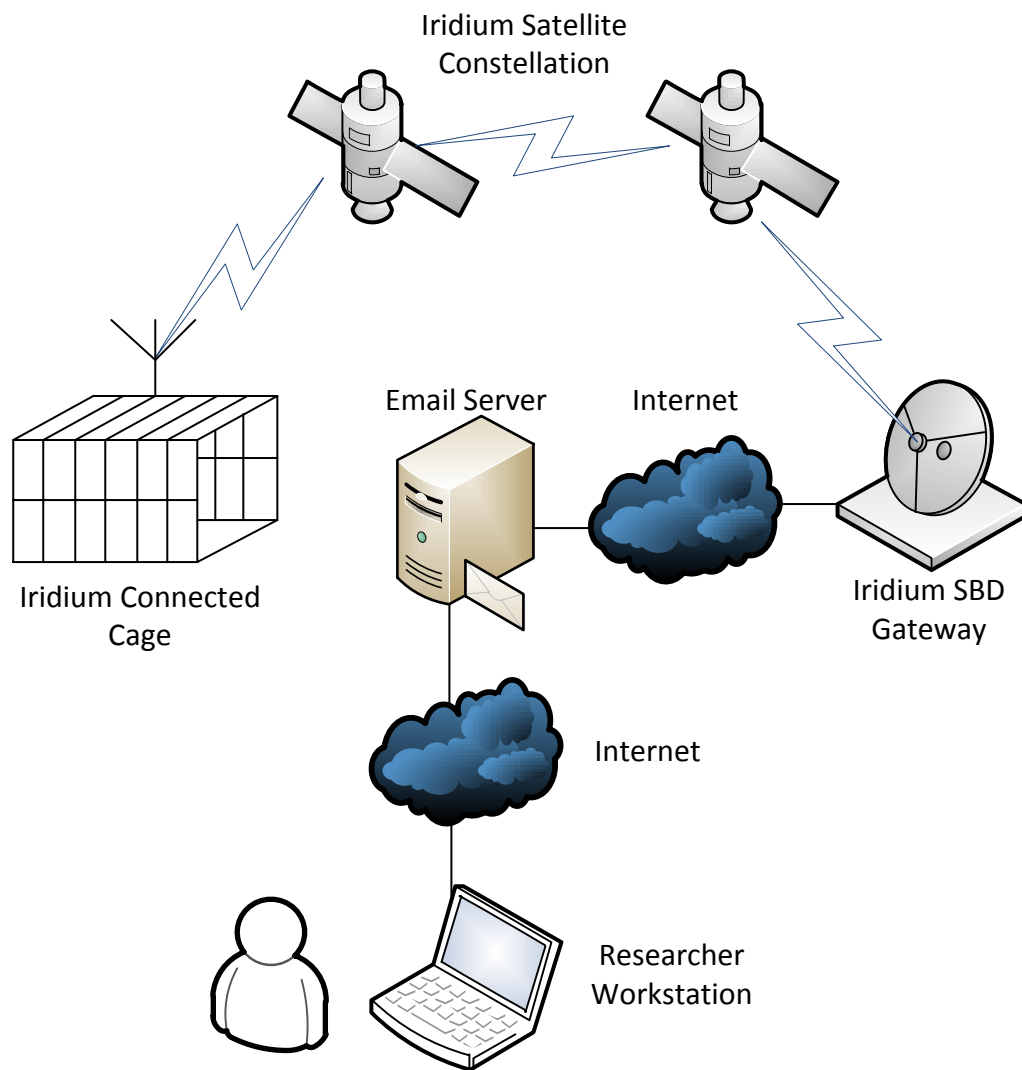


Figure 4.1: *Cage telemetry system diagram.*

lead-acid (SLA) battery, solar battery charge regulator, Iridium transceiver and control printed circuit board (PCB) are housed in the controller box.

A software package is installed on the researcher's computer that connects to an email account where messages from the Iridium transceiver are delivered. The program continually monitors this email account and alerts the researcher to any events. It also allows the researcher to send commands to the field unit.

The control system periodically synchronises its internal time with that of the Iridium network and uses this to send status updates (cage door, or snare trigger status and battery charge) at predetermined times. This allows for detection of a system malfunction should a status update not be received during the allocated time window. In the event of the cage being triggered, a photo is taken of the inside of the cage and transmitted to the researcher.

During all stages of the redesign of this system, reliability was taken into account. Whilst the system would still be liable to failure, it was attempted to have failures occur in such a manner as not to endanger the health and safety of the captured animal.

4.4 Hardware Design

4.4.1 Components

The trap telemetry system control board was designed to be simple and reliable. Readily available components were used as far as possible. An overview of the hardware layout is given in Figure 4.2, with the complete system schematics and board layouts being provided in Appendix A.

4.4.1.1 MCU

The microcontroller (MCU) selected was the same as that used on the collar (as discussed in Subsection 7.2.1), this would facilitate hardware design and software reuse.

Switches and light-emitting diodes (LEDs) were incorporated for debugging control and system status indication. The board included 2 RS232 interfaces (via a Texas Instruments MAX3232EID), one for communication with the Iridium transceiver module and another for debugging purposes. A relay and metal oxide semiconductor field-effect transistor (MOSFET) were used to control, respectively power to the Iridium and to the camera modules.

4.4.1.2 Power

Switching and linear regulators were used to step down voltage from the 12V lead-acid battery to the 3.3V and 5V rails used on the board, camera and LED flash modules.

A Traco Power TSR 1-2433 switching regulator was selected to supply the 3.3V rail. This was done because of its high reliability (5350000h MTBF), minimal component count,

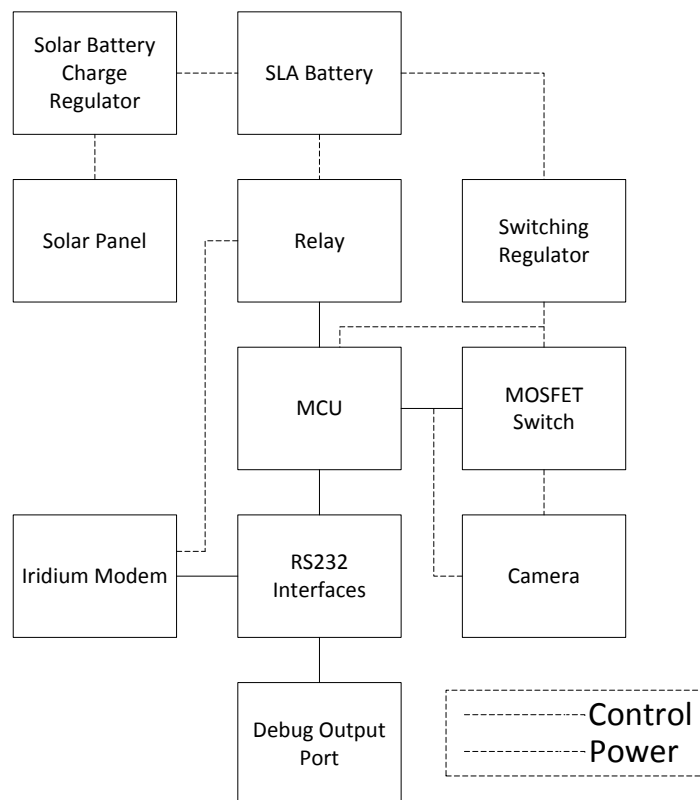


Figure 4.2: *Trap telemetry system hardware design block diagram.*

availability and high efficiency.

The Rohm BA05ST linear regulator was selected to drive the LED flash circuit because of its ability to be switched on and off by the 3.3V logic from the MCU and the ease of sourcing it.

4.4.1.3 Camera

The COMedia Ltd. C328R camera module was selected for use as the image sensor. This module provides a 3.3V transistor-transistor logic (TTL) universal asynchronous receiver/transmitter (UART) interface to the system over which commands are sent and photos transferred in JPEG format. The module was chosen for the simplicity with which it could be integrated into the system (primarily because it provided JPEG compression functionality) and the ease with which it could be sourced locally. The operation of this module at 3.3V resulted in 3.3V being selected as the operating voltage for the MCU as well. By doing this, an additional level of translation circuitry was eliminated.

A high powered LED was used as a camera flash. Current to the LED was regulated by a linear regulator coupled with a series resistor. The flash was controlled by switching the enable pin on and off directly from the MCU.

4.4.1.4 Iridium Modem

In order to make the system board compatible with both the older generation Iridium 9601 modems (of which 2 had already been purchased) and the newer 9602 modems (for future copies of the system) it was decided to make use of a RS232 interface board from Intricode Solutions. This board provided a RS232 interface to the modem, as well as power regulation, status LEDs and a power switch. The integrated power regulation allowed for the Iridium modem to be powered directly from the 12V SLA battery used.

A relay is also provided to control power supply to the Iridium module. This functions to remove power when the module is not in use, lowering overall power usage and to power cycle it in case of a fault condition. The relay that was selected is the Omron G6J2FSY3DC. It was selected as it was easily available at a relatively low cost, a 3V coil voltage and was packaged as a surface mount component.

4.4.1.5 Protection

Transient voltage suppression (TVS) diodes were placed on all externally connected data and control lines to and from the MCU, in order to protect it. The diode selected was the Vishay MSP3V3-M3/89A, chosen for its 4.1V breakdown voltage and ease of sourcing locally.

4.4.1.6 Solar

A readily available Iridium antenna and a 20W solar panel were, respectively, selected to fulfil the required roles. The Microcare MPPT8A solar battery charge regulator was selected for its maximum power point tracking (MPPT) capability. This capability results in increased efficiency of the charging circuit, as it alters the impedance, as seen by the solar panel, to provide maximum power transfer.

4.4.1.7 Battery

To power the system, a 12V 12Ah SLA battery was selected. This could supply the large peak current demanded by the Iridium modem without damaging the cells. The choice for this specific cell was motivated by ease of maintenance. Should the cell reach its end of life, the researcher should easily be able to replace it without assistance from professional sources, as it has the same form factor as batteries commonly used in motorcycles.

4.4.2 Power Budget

A 1.8W load was measured to be drawn by the controller board (this is a peak figure with the relay and LEDs all activated). Assuming this figure is used to calculate daily power usage, the controller board can be expected to contribute 43.2Wh.

Although the camera and flash modules together contribute 3W to the system load, their activation for less than 1 minute and likely activation of less than once per day leads to them having no significant impact on the total power usage.

Assume that the Iridium modem transmits a photo once per day and status messages every hour. It draws 1.5W on average over a period of 5 minutes for a status message and 15 minutes (a significant percentage of the transmit time is taken up by waiting for a satellite to pass overhead) for a photo upload. The total usage per day is then 3.4Wh.

It can thus safely be assumed that in a worst case scenario the power consumption is still less than 50Wh per day. With a 20W solar panel, sunshine will only be needed for 3 hours per day (assume some battery charging inefficiency) to sustain charge levels. Should the solar panel fail, the system could still be operational for 2 days, under worst case conditions, using the 12V, 12Ah (144Wh) battery specified.

4.5 Packaging

An IP66 rated enclosure (dust tight and protected from powerful water jets) was used to package the controller board, iridium modem, solar charge regulator and battery. Cable glands were used to seal the spaces where holes had been drilled into the container for wiring. The assembled system is shown in Figure 4.3.

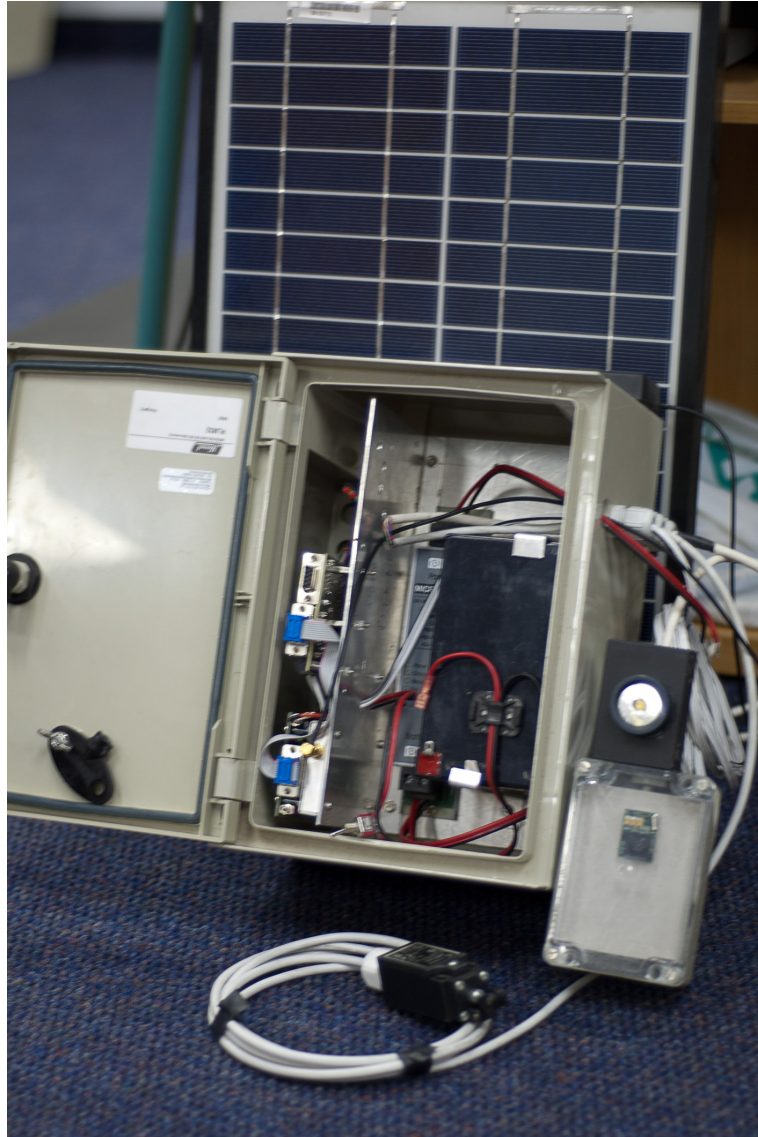


Figure 4.3: *Trap telemetry system before being deployed.*

4.6 Software Design

4.6.1 Field Unit

Due to the remote physical location of the various sites, the primary goal with the programming of the cage telemetry system was reliability. This relied on the correct identification of fault conditions and the correction thereof.

First a watchdog timer was employed to reset the controller system to a known state in the event that it was no longer responsive. Along with this, timeouts were implemented for communication with the camera and the Iridium modules. The camera and Iridium modules are powered down when not in use, or power cycled when a fault condition is detected.

Dynamic memory allocation was avoided and the choice made to rely solely on static allocation at compile time, to guarantee that no memory leaks would occur. Further, the system was segregated into logical software modules (often correlated to a specific hardware component) and an effort was made to keep their implementation and operation opaque from each other.

The operation of the firmware is illustrated in Figure 4.4.

4.6.1.1 Camera Operation

In order to take photographs, a protocol is specified by the manufacturer. Various ‘acknowledgment of receipt’ commands are also required for correct operation of the camera, but are excluded from this discussion for the sake of brevity. A number of undocumented timing constraints are also not discussed, but are listed as commentary in the program source code.

First, after the camera has been powered on, a sequence of bytes must be continually sent to the camera until an acknowledgment of receipt is received. This is to synchronise the baud rate at which that the camera transmits data with that of the microcontroller (the camera performs automatic baud rate detection). If no acknowledgment is received, the camera is assumed to be in an undefined state and it is power cycled.

It is then possible to send a number of configuration commands. These are used to set parameters such as the image resolution, compression, colour depth, size of transfer packets etc.

Instruction is sent for the camera to take a photo. At the same time this command is executed, the microcontroller also switches on the LED flash.

Finally, the camera is requested to transfer the photograph. This is done in the form of packets of predetermined size. Each packet contains a sequence number, checksum and part of the photo data. Once a packet has been received, the checksum of its photo data is calculated and compared to the checksum included in the packet. If the checksums match, the data is put in a temporary buffer, otherwise the packet is again requested.

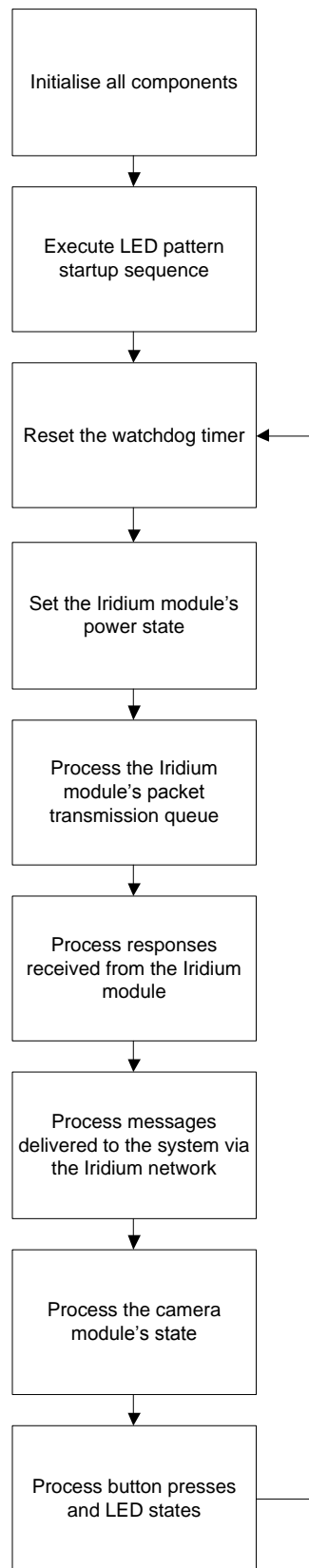


Figure 4.4: *Cage telemetry system software operation block diagram.*

The majority of the source code used to interact with the camera was gained from a third party library; it was, however, extensively modified to support operation in conjunction with a watchdog timer and support reset in the event of undefined behaviour.

4.6.1.2 Iridium Operation

The Iridium SBD modules make use of an AT command set for interaction. A protocol stack was thus implemented to interface with them.

As the size of Iridium SBD packets are limited to 340 bytes, it was necessary to split image uploads into smaller packets. Two types of packet were also supported, namely status packets and photo packets. In order to reliably transmit different kinds of packet it was decided to implement a queue system. This queue system is agnostic as regards the type of packet being transmitted.

Photo packets contain, in the first packet, sequence numbering, the size of the photo (2 bytes are used for this) and the first block of photo data. Thereafter packets contain only sequence numbering and photo data. The addition of a checksum for the photo data was excluded, as the Iridium SBD system has integrated checksum functionality to ensure the validity of SBD packets. All packets would total 340 bytes (338 bytes photo data and 2 bytes sequence numbering), except possibly the last packet, which contains the remainder of the photo not yet transmitted (this will be 338 bytes or less in size).

First packet:

0	1	2	3	4	...	339
Pkt nmbr	Ttl pkts	Image size		Photo data		

Remaining packets:

0	1	2	...	339
Pkt nmbr	Ttl pkts	Photo data		

Last packet:

0	1	2	...	bytes remaining + 1
Pkt nmbr	Ttl pkts	Photo data		

Status packets are 10 bytes in size, as this is the smallest amount of transmission data payable (it costs the same to transmit 1 byte as it does to transmit 10 bytes). The packet consists of 4 bytes of header and footer data, 1 byte containing the state of the cage door and other possible future peripherals, 2 bytes containing the battery voltage and 3 bytes containing the time at which the packet was created.

0	1	2	3	4	5	6	7	8	9
0xAA	0xAA	Status	Hours	Minutes	Seconds	Battery voltage	0xAA	0xAA	0xAA

Commands to the unit may also be received. Command packets consist of 8 identical bytes. The value of the byte determines the command to be executed. All 8 bytes are checked to verify that they are the same. This forms a rudimentary error checking mechanism. This mechanism is included as a safety mechanism (protection against erroneous command execution) and as the minimum payable message size on the Iridium network is 10 bytes (no extra cost is incurred by padding with the duplicate bytes).

4.6.2 PC Software

In order to enable researchers to monitor the trap, application software was supplied for their computers. This software provided the following functionality:

- Retrieval and display of trap status report messages and photos.
- Alert popup messages for traps that have missed their scheduled status reports.
- Audible alerts for events requiring researcher intervention.
- Saving of configuration data and reports received.
- Sending commands to the field unit (request a photo and deactivation of the telemetry unit).

A screenshot of the software is provided in Figure 4.5. The Java programming language was used to program the software. A Microsoft Windows based installer was also developed to install the required Java Runtime Environment, third party software libraries, program software as well as creating shortcuts and an uninstaller for the program.

4.7 Field Testing

During November 2011 the trap telemetry system was deployed in the GCBC, by the author, in conjunction with a researcher from the CLT. The entire system was easily transportable, along with the tools needed for installation, in a single backpack as shown in Figure 4.6.

A number of inadequacies were exposed during deployment of the system. First the camera, flash unit and wiring were too visible, because of their light colouring. This was remedied by applying black electrical insulation tape to all offending surfaces. To camouflage the controller box, it was partially buried as can be seen in Figure 4.7 (the controller box is visible in the bottom right hand corner of the image).

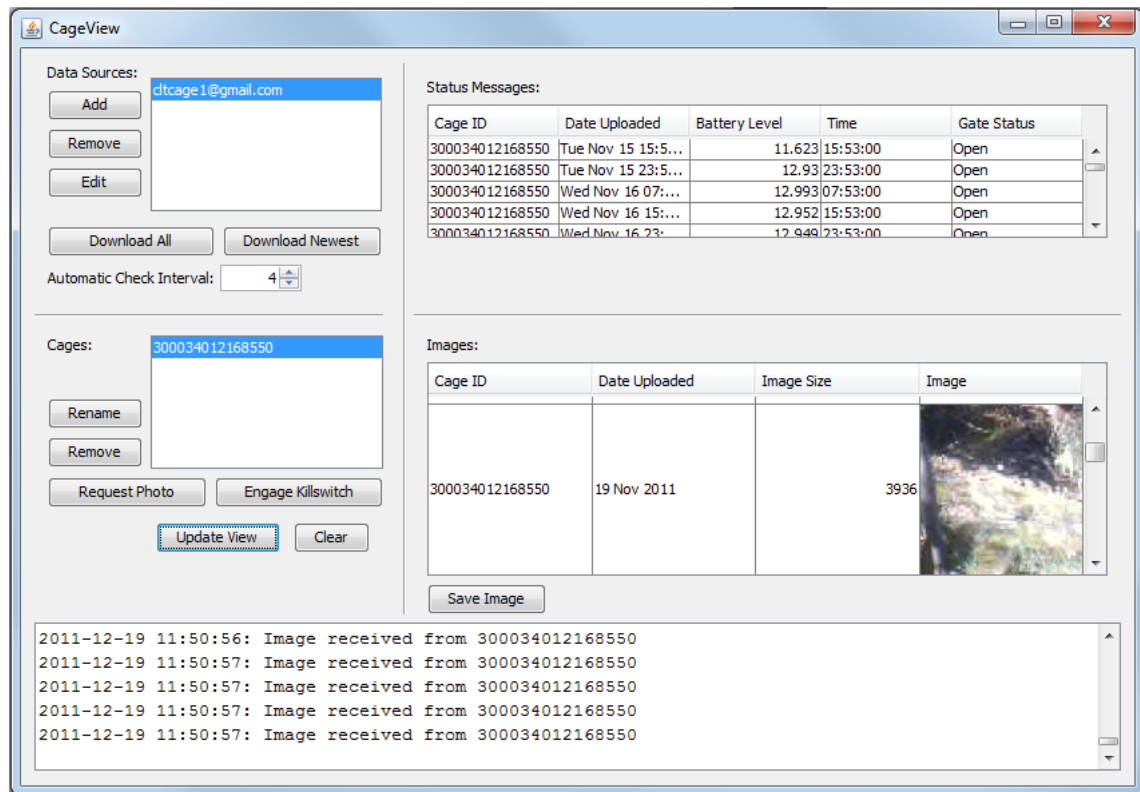


Figure 4.5: *Cage telemetry system application software screenshot.*

As the system had originally been intended for use in the close confines of a cage, the camera resolution proved inadequate to accurately discern the area around the trap (this is due to the camera unit being located further away from the trap than had been expected).

Downloading of status reports occurred more slowly than expected, as previous testing had made use of a much higher bandwidth internet connection, than that available to the researchers at their home.

The system performed as expected until it was deactivated three weeks later, when trapping in the area was stopped temporarily.

4.8 Conclusion

Due to the late stage of development of the collar system, when this additional project was added, the difficulty thereof was greatly decreased. This is due to the high degree of software and hardware reuse between the projects and the lessons learned from familiarity with the production process.

In this chapter we thus discussed the the need for particular requirements and the design of the trap telemetry system, and also discussed its performance. In the following chapter the system concept of the tracking collar is discussed.



Figure 4.6: *Trap telemetry system packaged in a backpack, ready to be deployed.*



Figure 4.7: *Trap telemetry system as deployed with snare in path.*

Chapter 5

Collar System Concept

5.1 Introduction

In this chapter the concept of how a proposed collar system could function is proposed. The required features of such a system are identified, as well as the constraints imposed thereon. Systems based on a terrestrial radio network or a satellite communications constellation are identified and the required subsystems listed. Other alternatives considered, but rejected, are also discussed.

5.2 Required Features

As the primary function of the system was to track the animals and identify kill sites, the system would need to provide location data. In order to identify hunting sites the system needs to sense sudden acceleration. For the recorded data to be retrieved a wireless link is needed.

The required feature set was then functionally identified as:

- Determination of geographic location by the use of a GPS module.
- Detection of sudden acceleration by means of an accelerometer.
- Wireless data transfer capability via a radio modem.

5.3 Design Limitations

Other than the limitations imposed by identification of current deficiencies in commercial collars, as listed in Subsection 2.3.2, the primary design constraint is collar mass.

Limitations for the mass of the collar were gained from interviews with role players from the CLT. At the time of this study, in academic and nature conservation circles, the current best practice for collar mass, to avoid negatively affecting the animal, is 2 - 4% of their body mass. It was therefore decided to design for 2% or less of the leopard's body mass.

Using these figures, the following collar masses are obtained:

- Male Leopard: 350g
- Female Leopard: 280g
- Male Caracal: 180g
- Female Caracal: 100g

The width of banding material used was indicated nominally to be 3cm on the side of the animal's neck. As larger widths are acceptable on top of the neck and below it, 5cm was chosen for these. A nominal collar diameter of 44cm for males and 34cm for females was indicated. The packaging for electronics and other components should also not protrude more than necessary from the collar. If possible, bulges at the top of the collar should be avoided, as this area is exposed to excessive mechanical wear.

Due to the great expense in time and money associated with capturing a leopard and collaring it, 2 years was indicated as an desirable lifetime.

5.4 Proposed System

Coordinate logging was common to all systems considered. This would be accomplished by making use of a satellite based positioning service. A GPS receiver would be switched on at predetermined intervals or when sudden acceleration was detected. Coordinate data would then be stored in non-volatile memory onboard the collar. Along with logging, stored coordinate data would also periodically be uploaded from the collar to a remote device via a wireless communications interface. This system operation is illustrated in Figure 5.1.

5.4.1 VHF Based Designs

A number of options for downloading data from the collar was considered. The first group relied on deployable field terminals with VHF data radios. Three variants of these were considered and designed. Data communication with the collars was accomplished via VHF radio links. The field terminal would continually transmit a beacon signal to notify any collars in the area that it was available to download data. Collars would only power their VHF receiver periodically (for instance every 5 minutes for 2 seconds) to listen for field terminals in the vicinity. If the collar detected a field terminal, it would enable its VHF transmitter and transmit a message to the field terminal to announce its presence. Data would then be downloaded from the collar to the field terminal. This method was chosen as it minimises the time that the collar based VHF transceiver is powered, thus saving battery power and extending its lifetime.

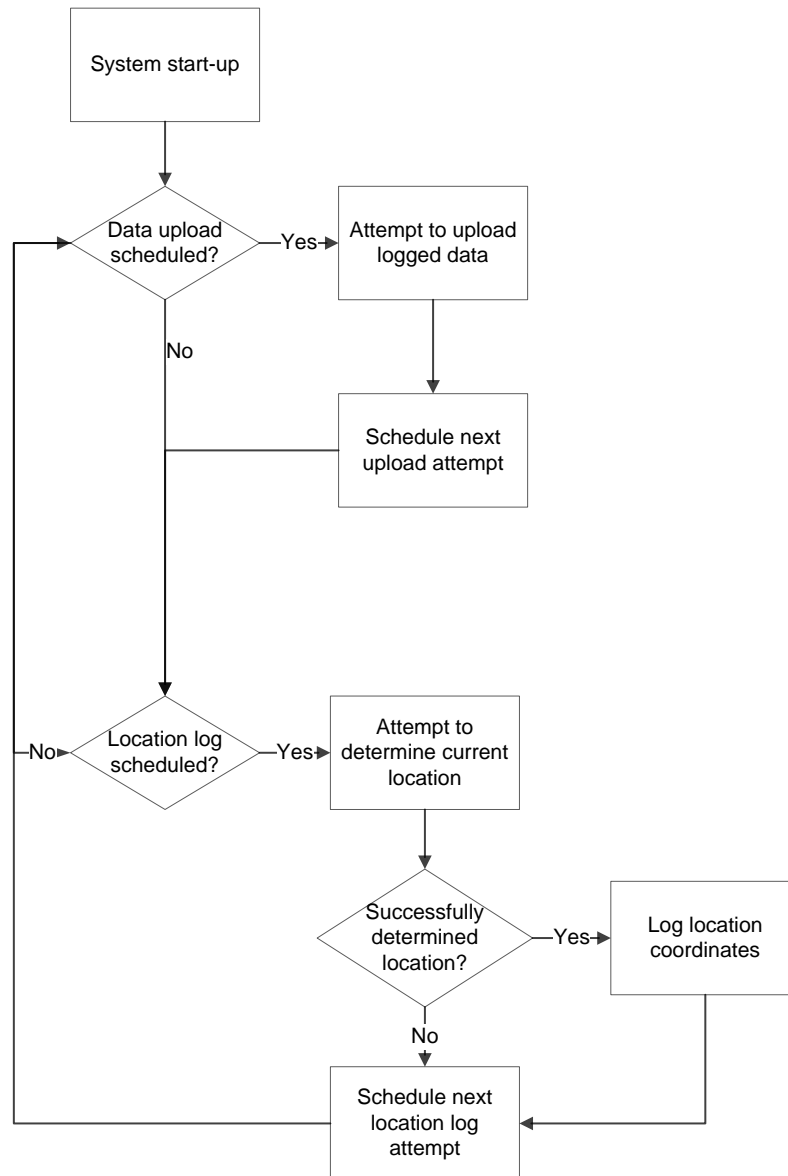


Figure 5.1: Collar system operation.

5.4.1.1 Removable Flash Memory

The first variant of field terminal would simply store data downloaded from collars on a removable flash memory card. This card could then periodically be retrieved from the terminal and coordinate data extracted from it. This arrangement is illustrated in Figure 5.2.

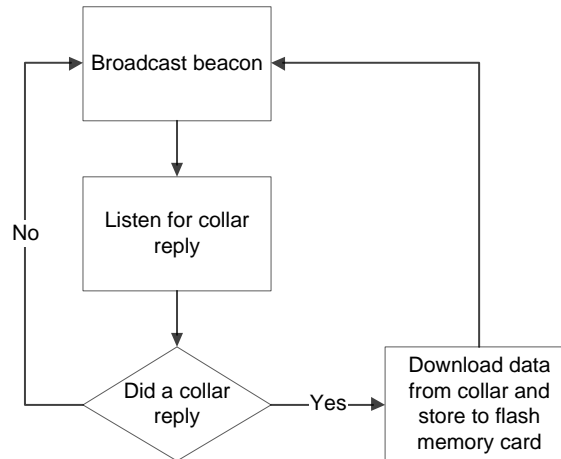


Figure 5.2: *Removable flash memory field station mode of operation.*

5.4.1.2 Ad-hoc Network

In this arrangement use is made of a VHF ad-hoc network of field terminals. This system was developed in parallel with the development of a collar[1]. Once data had been downloaded from the collar, it would be passed on between terminals and delivered to the base station where the researcher resides. This arrangement is illustrated in Figure 5.3, with the collar mode of operation illustrated in Figure 5.4.

5.4.1.3 Iridium Satellite Connection

The final option made use of Iridium 9601 satellite radio modems. After data had been downloaded from a collar, it would be transmitted via the Iridium satellite network and delivered via email (one of the delivery options provided by Iridium Satellite LLC via the internet) to the researcher. This arrangement is illustrated in Figure 5.5.

5.4.2 Iridium Based Collar Design

Whilst the initial collar designs relied on VHF radio communications for downloading tracking data, this method was deemed to be antiquated with the release of the Iridium

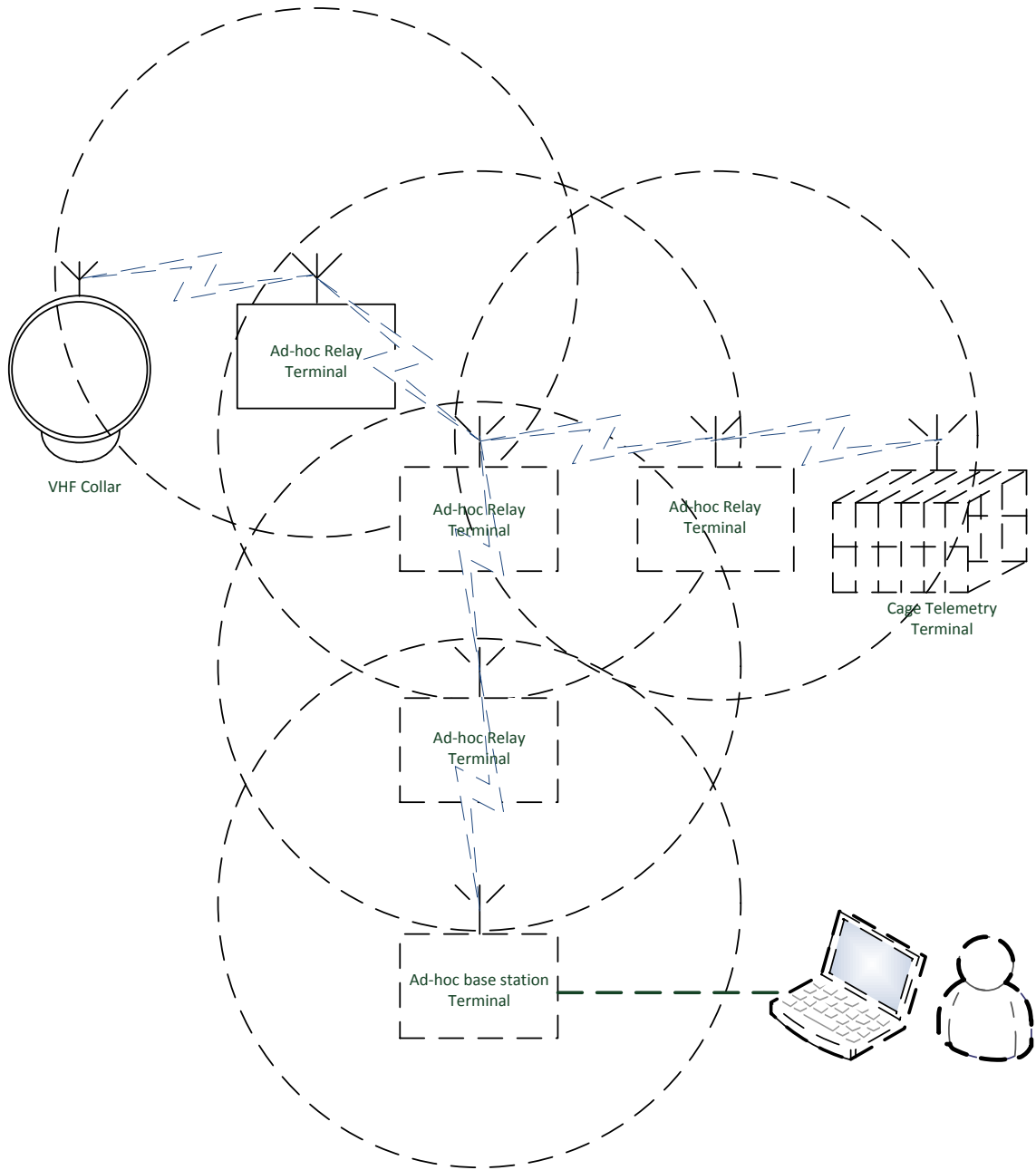


Figure 5.3: *Ad-hoc network usage diagram.*

9602 module. With integration of the Iridium 9602 module, uploads to the network can be done at arbitrary times when a satellite is available (ideally a satellite is always within view, but due to the mountainous terrain in the GCBC, this is unlikely to be the case). Assuming a coordinate logging rate of once every 15 minutes, a Iridium SBD message will be transmitted approximately once per day. Once the data has been delivered to a preset email inbox, software provided to the researcher will download it to their computer and present the coordinates in a meaningful way. This system arrangement is illustrated in

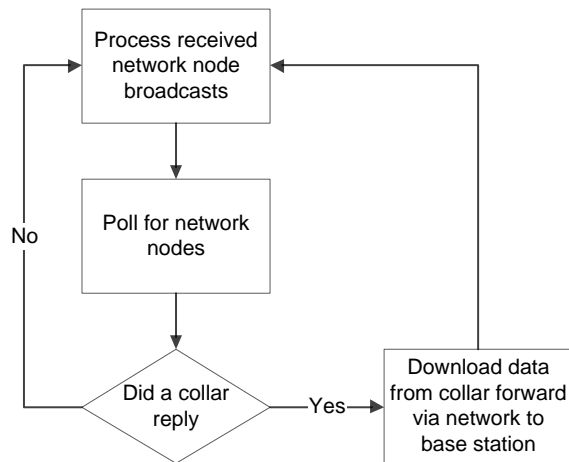


Figure 5.4: *Ad-hoc network connected field station mode of operation.*

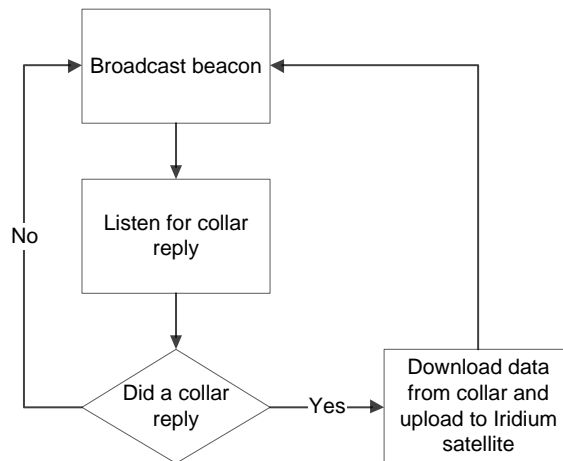


Figure 5.5: *Iridium satellite connected field station mode of operation.*

Figure 5.6, with the collar mode of operation illustrated in Figure 5.7.

5.4.3 System Components

The system can be separated into a number of main components. These include control, communications, sensing and power subsystems, as illustrated in Figure 5.8.

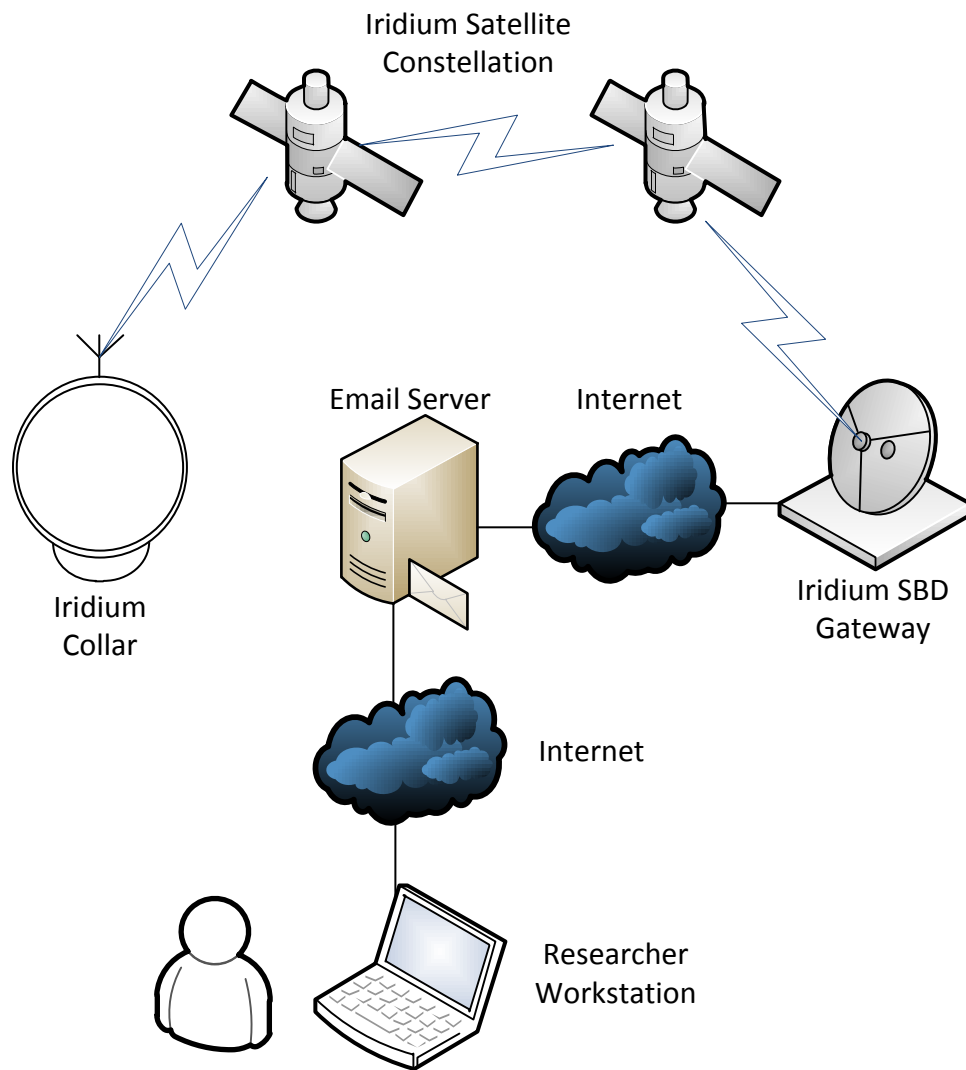


Figure 5.6: *Iridium satellite connected collar network diagram.*

5.4.3.1 Control

In order to control all the peripheral devices and facilitate storage of data, a microcontroller unit (MCU) is included in the device. The MCU is responsible for defining the logical operation of the device. It communicates with peripheral devices according to preset protocols and issues commands to them.

5.4.3.2 Communications

In order to download collected data and issue commands to the collar a radio based communications interface is provided. This may take the form of a terrestrial radio transceiver or a satellite modem.

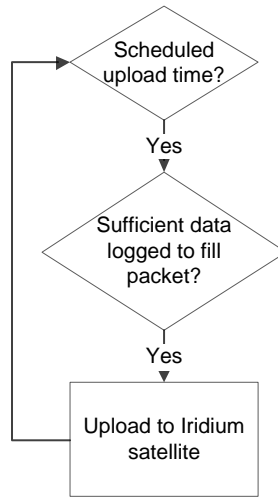


Figure 5.7: *Iridium satellite connected collar mode of operation.*

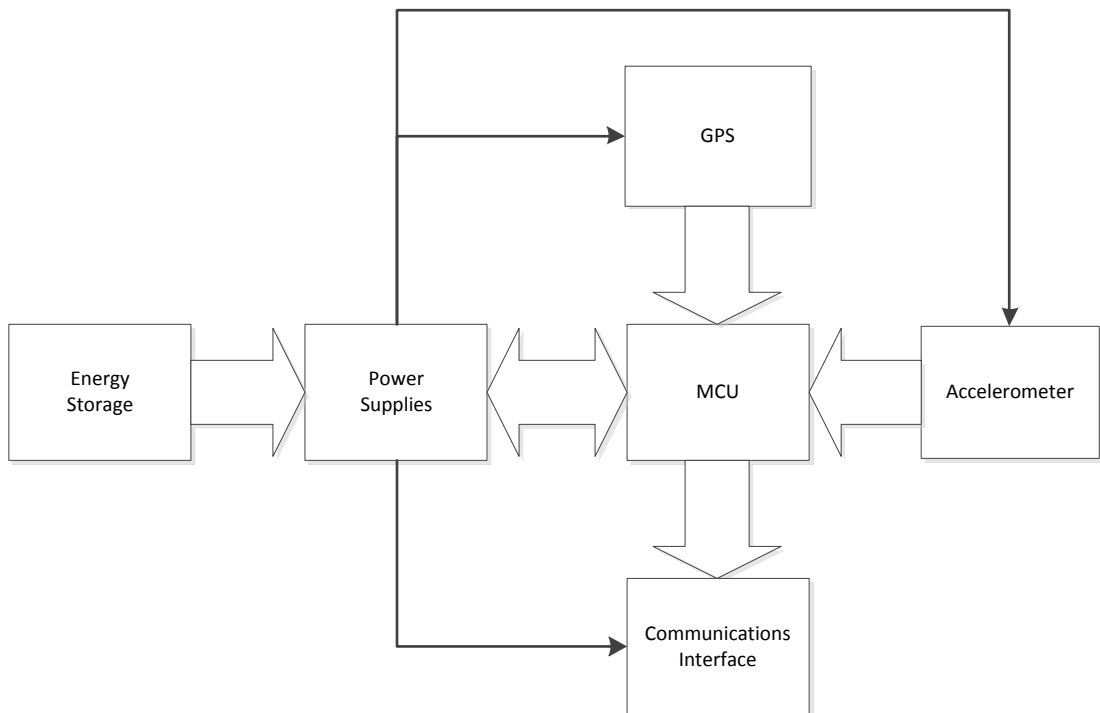


Figure 5.8: *Block diagram of collar system.*

5.4.3.3 Sensing

Two primary sensor systems are required for the operation of the collar.

The first is the system responsible for determining the geographic location of the collar. A satellite based position service is most suited to this task, available options at time of publishing being Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and Global Positioning System (GPS).

Secondly the detection of hunting behaviour is required. This is accomplished by use of an accelerometer to detect the sudden acceleration of the leopard attempting to catch its prey.

5.4.3.4 Power

Multiple power supplies are required for powering the different components. Circuitry should also exist to power down these supplies in order to minimise power usage. Supply design is optimised for efficiency.

A primary cell battery is the only source of energy for the system components. The primary cell is also buffered by another energy storage device in order to provide high peak currents.

5.5 Abandoned System Concepts

In the initial phases of this project, alternate solutions were explored. These attempted to find novel approaches to the problems faced.

5.5.1 Optical Tracking

Optical tracking was suggested as a viable method by researchers from the Rensselaer Polytechnic Institute (RPI). The system would consist of camera platforms dotted about the area with a camera mounted on pan and tilt mechanisms. Image recognition software would then identify a leopard entering the area and following it as it moved through the viewable range of the platform.

This approach was deemed to be unrealistic, as it would require an immense number of platforms to cover any significant area in the GCBC because of the mountainous terrain. Such a large number of manmade objects could also spoil the natural beauty of the area for many tourists.

5.5.2 Strobe Lights

Collars or small adhesive packages equipped with IR strobe LEDs were also suggested by researchers from RPI. The flashes from these units would be observed by a constellation of

earth orbiting satellites. Location data of the observed flashes would then be transmitted back to earth.

Ignoring other technical limitation, the prohibitive cost of developing, launching and operating a satellite network with these capabilities alone makes this approach unfeasible.

5.5.3 Passive Radio Tags

It was initially thought that leopards preying on sheep located in small fenced camps at night were a major problem. To this end a system was envisioned where leopards would have radio-frequency identification (RFID) tags attached. Sensors would encircle the camp and detect a leopard if it tried to enter. This would then sound an alarm or deploy other countermeasures in order to chase the leopard away.

Most of the farms in the area do not however, make use of small fenced camps. The use of Anatolian Shepherd Dogs for protection is also a proven method for protecting tightly grouped flocks. The importance of this problem was thus seen to have been overestimated and further investigation halted.

5.5.4 Airborne Radio Terminals

In a case where a terrestrial radio network is used to communicate with collars, a significant number of ground stations would be required in order to attain a high coverage area. An alternative to this is an unmanned aerial vehicle (UAV) or tethered balloon containing an antenna and radio transponder. Such a system would have a very large coverage area relative to a static ground station. This would negate many of the problems involved with obtaining permission to erect ground stations on property controlled by Cape Nature.

Regulatory limitations for objects that could cause collisions with aircraft and the abandoning of the idea of a terrestrial radio network resulted in this approach not being further investigated.

5.5.5 Energy Harvesting

Relying on primary cell batteries to supply power to the device places significant strain on the lifetime, due to the mass and size constraints of the battery. In order to increase lifetime, energy harvesting from external sources can be incorporated.

Solar power provides a reliable source of external energy during daylight hours. This was, however, abandoned during the design of the collar packaging, as it was learnt from the CLT that other collar designs incorporating solar panels make the collar highly visible. Light reflected from the solar panels effectively destroys the leopards' camouflage and could interfere with their hunting patterns.

A kinetic energy harvesting device design was attempted in a number of final year projects. None of these have, however, delivered a useable solution and have thus not been incorporated into the collar design.

5.5.6 Delayed Batch Coordinate Processing

A new feature that was introduced with the UBX 6 series GPS chips from u-blox AG is "Capture & Process". This technology allows for the raw data received from the analogue-to-digital converter (ADC) to be stored. This data can then at a later stage be downloaded, processed and the coordinates extracted. In this way the time taken to log a coordinate is kept under 200 milliseconds and, correspondingly, the power usage is extremely low.

Unfortunately the minimum order quantity (MOQ) for these chips is 300 000. The local distributors were also uncooperative about supplying any technical details regarding the system.

5.6 Conclusion

In this section proposed collar systems based on a VHF terrestrial network utilising different field terminals were discussed as well as the design for a possible satellite communications based collar. Both of these collar concepts are investigated in the following chapters. The VHF based solution being initially selected for development, is later abandoned in favour of a satellite based system with the release of the Iridium 9602 module. The required collar subsystems were identified and expanded upon. Lastly, abandoned avenues of research were listed and motivated.

Chapter 6

Communications

6.1 Introduction

In this chapter the frequency selected for a terrestrial radio network is motivated by examining regulatory influences as well as the coverage provided for a given frequency. A system for the functioning of communications on such a network is discussed. Details on the ad-hoc network protocol developed as part of another project for use with VHF based collars is provided. Finally, the selection of a satellite network is investigated.

6.2 Frequency Selection

The radio frequency chosen for a collar relying on a radio data modem for communication is critical to the design. The frequency has major influences on the expected usable range, the construction of the collar (geometry of the antenna is defining) and the licenses required. Frequencies in the range of 100-1000MHz were identified as being ideal, as frequencies below this would necessitate too large an antenna and above this would cause free space losses that were too high.

6.2.1 Regulatory Influences

In order to minimise bureaucratic overhead the frequency would need to be in either an industrial, scientific and medical (ISM) band frequency or in one already allocated to wildlife telemetry. For South Africa the possible frequencies were identified as 433.05-434.79 MHz (ISM) or 148-152 MHz (wildlife telemetry inside national game parks).

6.2.2 Propagation Plots

The possible frequencies for use were simulated for different power output levels to determine a rough estimate of the expected communications range. Elevation data from the GCBC was used in conjunction with possible base station locations. 151.3Mhz was

used as one simulation frequency, because of module selection considerations described in Subsection 7.3.1.

As can be seen in Figure 6.1, there is a drastic difference in the required output power to obtain similar ranges for the 2 frequencies. A similar coverage pattern is achieved by the 151.3Mhz system (Figure 6.1a) to the 433Mhz system (Figure 6.1b), which has 17dB more transmit power.

It was therefore decided that 151.3Mhz would be used for the tracking collar and other supporting infrastructure.

Further simulation was then done to ascertain the added benefit of increased output power. It was initially believed that the topography of the region would limit range more quickly than free space losses. It can, however, be seen in Figure 6.2 that free space loss was still the primary range limit up to 500mW output power.

6.3 Communication Model

6.3.1 Opportunistic Downloads

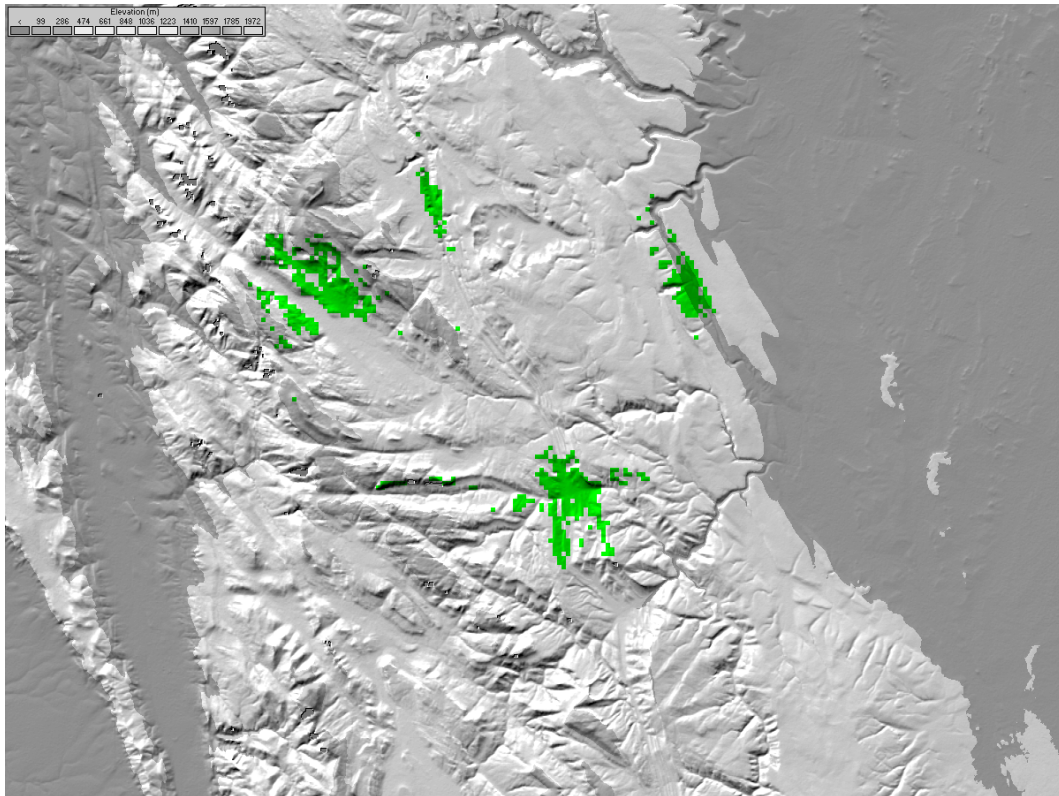
In order to minimise power usage and user effort, an opportunistic model for downloading coordinate data from collars is used. Rather than continually transmitting a signal to be tracked, the receiver on the collar is powered on only periodically. It is thus left to unattended field terminals or mobile terminals to continually transmit a beacon signal. If this beacon signal is received by the collar during the timeframe that its receiver is powered on, it may then power on its transmitter and communicate with the field terminal.

By making the reasonable assumption that once a collar has come into range of a field terminal, it is likely that it will stay within range for a timeframe in the order of multiple minutes, we may thus set the receiver on-time period to be in the order of minutes. This on-time is then determined by the length of beacon pulses and the stabilisation time of the receiver.

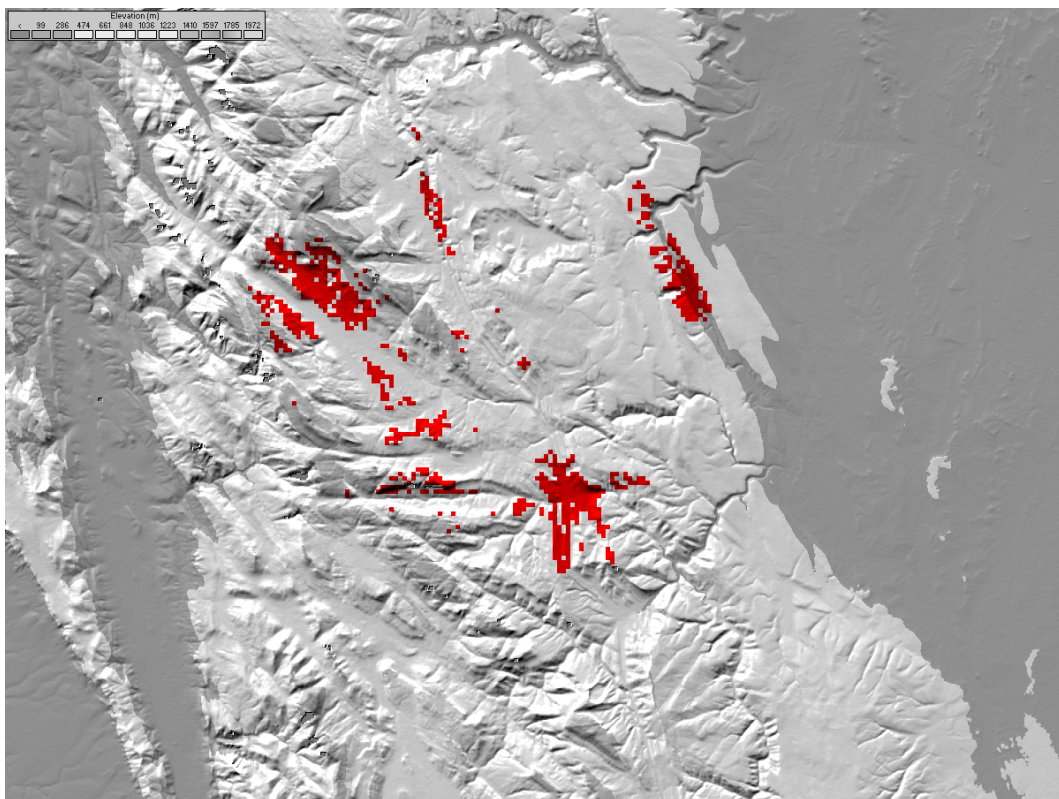
6.3.2 Hot Pursuit Mode

In the scenario where the researchers wish to track the animal in real time, provision is made for a "hot pursuit" mode.

In this mode the time between activations of the VHF receiver is drastically reduced. A field terminal may then request continuous GPS tracking, with updated coordinates transmitted every second.



(a) 10mw at 151.3MHz



(b) 500mW at 433MHz

Figure 6.1: *Comparison of communication ranges by radio frequency*

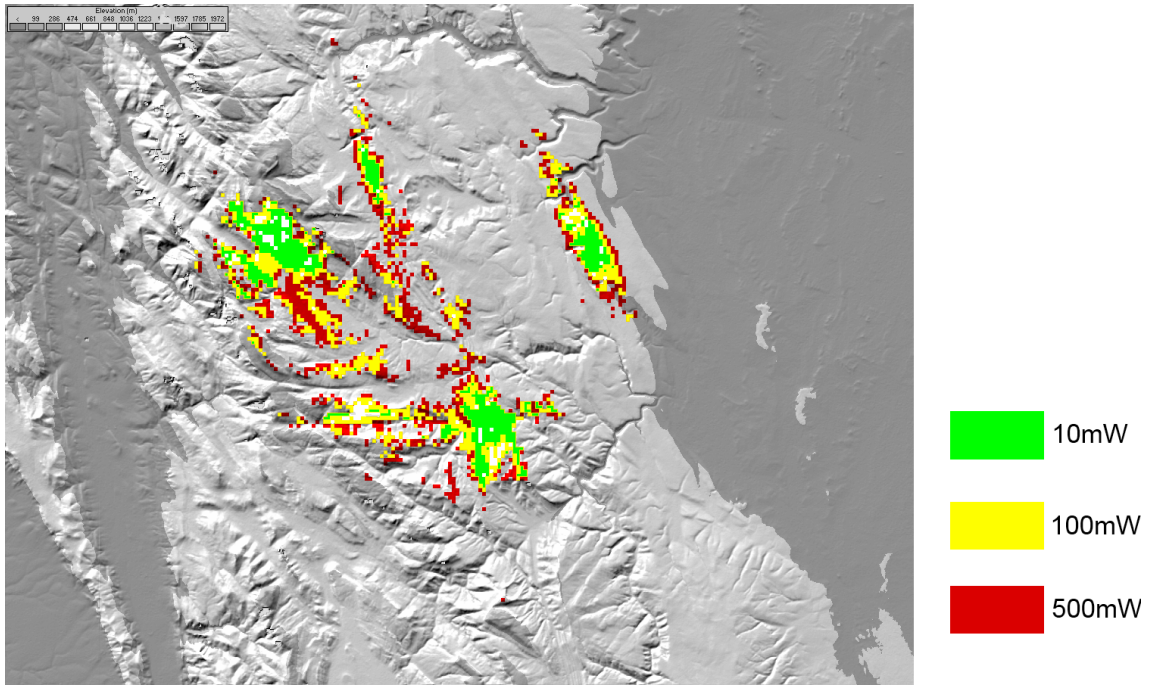


Figure 6.2: *Comparison of communication ranges by power output.*

6.4 VHF Ad-Hoc Network Protocol

The VHF based collar concept makes use of ad-hoc network infrastructure designed and manufactured as part of another master's thesis[1]. Whilst the collar did not function as a node through which data could be routed, it does conform to the same MAC protocol definitions. Special provision is made in the ad-hoc router nodes for communication with collar nodes.

A baud rate of 4800 bits per second (bps) was chosen for VHF communications. This was selected after testing the resulting bit error rates for different baud rates[1] and finding no reduction in error rate for lower transfer speeds down to 1200 bps (the unit is advertised as capable of 10 000 bps maximum).

Due to a direct current (DC) bias accumulating in the capacitor of the slicing circuit, resulting in bias towards a high or low logic state, it is recommended by the manufacturer to implement Manchester coding.

Further, the data slicer in the VHF modem requires a preamble to set the correct slicing point (0x55 is recommended). A synchronisation bit (0xFF) is included to aid the UART in detecting the start bit, thus reducing framing errors. 0x017F was selected as the byte sequence used to indicate the start of data transmission.

Forward error correction and error detection is included in the form of Reed-Solomon coding and a cyclic redundancy check (CRC-16 polynomial).

Packets were laid out as follows:

Preamble						
Data slicer settling bytes			Receive UART lock bytes		Message start indicator	
0x55	0x55	0x55	0x00	0xFF	0x01	0x7F
Control				CRC	Data	FEC
Broadcast ID	Leopard ID	Message Number	Hop Count	CRC-16	DATA	Reed-Solomon
1 byte	1 byte	1 byte	1 byte	2 bytes	216 bytes	26 byte

The development of higher level routing and data transmission control protocols allow for VHF communication with the collar to form part of a larger, multipurpose network to be deployed in the research area. Whilst the bandwidth provided makes this technology unsuitable for more exotic applications such as real-time video streaming, it would be sufficient to deliver photos from camera trap sites.

6.5 Satellite Network Selection

A study was made to identify all possible methods of obtaining a satellite communications channel. From initial findings, it was observed that all networks that did not make use of satellites in LEO required large, expensive terminal equipment that places great demands on their power supply.

This left a number of individual satellites and satellite constellations.

The Argos system, specifically designed for worldwide tracking and environmental monitoring, was already being used in a number of animal tracking collars. The first generation of these did not, however, not provide the required positional accuracy. The second generation of Argos system satellites that was in the process of being deployed at the time of this study provided arbitrary data upload capability. The transceivers for the second generation were, however, also much larger and not suitable for use in a collar.

Only one other satellite system could be found that satisfied the project requirements for integration into a collar. Four large satellite constellations, for primary use in satellite telephony, provided data services as well. The Iridium, Globalstar, Thuraya and Orbcomm networks all comprise multiple satellites providing near constant coverage of their usage areas. Through investigation of published coverage areas and correspondence with Quake Global Inc. (an engineering firm specialising in satellite communications products) it was determined that only the Iridium network would provide continued, reliable coverage of the GCBC.

The Iridium network also provided a data service tailored to small uploads and downloads (data uploads of arbitrary length, with a maximum of 340 bytes) known as Short Burst Data (SBD). There were also Iridium terminals available that provide only SBD functionality. This allowed for smaller, lower power satellite terminals to be used.

In the end, the Iridium option provided the only practical choice. This was due to it being the only network available with coverage of the GCBC, ground terminals small enough to be integrated into a collar and with pricing within the budgetary constraints of the CLT.

6.6 Conclusion

In this section the 148-152MHz band was identified for use with a terrestrial radio network based collar design. The proposed modes of operation such a system would possess were discussed, and the ad-hoc network protocol to be used detailed. The selection of the Iridium satellite constellation for use with a satellite communications based collar design was motivated.

Chapter 7

Collar Electronics Design

7.1 Introduction

This chapter is divided according to the main collar subsystems as discussed in Section 5.4. An overview of the hardware layout is given in Figure 7.1, with the complete system schematics and board layouts provided in Appendix B. Therefore, the selection of individual components is motivated through calculation, simulation or comparative analysis. Predictions are also made as to the expected lifetime of the system.

7.2 Control

7.2.1 MCU

MCU selection provided a very large number of possible devices, but only a few models satisfied all the initially identified requirements.

Of all the requirements, very low power consumption was the primary factor in selecting a MCU. As the device would be required to work for years on a single battery charge, minimizing power usage in every possible location was desired.

Closely correlated to power consumption is the supply voltage for the MCU. 1.8V microcontrollers were at the time of this study the lowest commonly available logic level MCUs, with many low power peripherals designed for use in cell phones and other mobile devices also operating at 1.8V. A MCU that could tolerate slight drops in supply voltage (below 1.8V) was also deemed positive, as aid in providing improved system stability and reliability.

As the number of collars that would be built was very small and taking into account the cost of current collar solutions, price was not considered as a factor in the selection of an MCU.

In the initial system design, a number of necessary integrated peripherals were identified. The system would need an integrated brown-out detector and watchdog timer to ensure

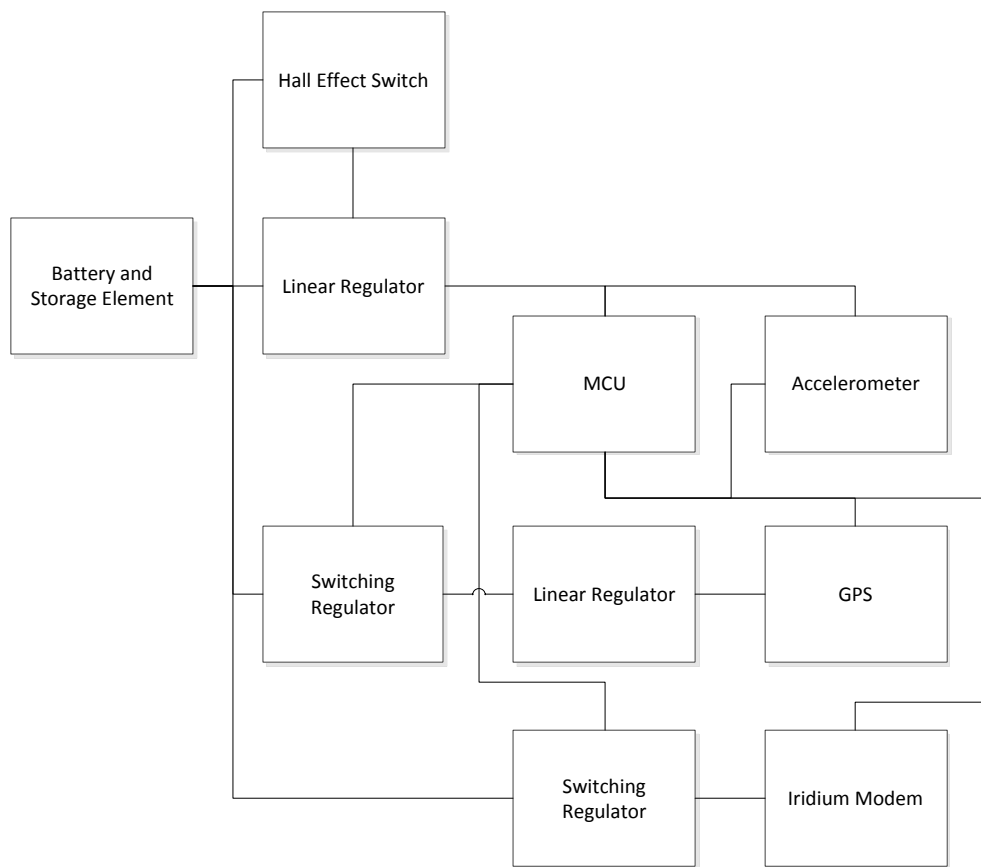


Figure 7.1: *Block diagram of collar electronic systems.*

reliability and stability. Initial designs had identified 5 external peripherals requiring serial communication (GPS, VHF modem, accelerometer, flash memory and debug interface). This number was later reduced, but only after the device selection had been made.

As the MCU would not need to address much memory or do intensive processing and the lowest power microcontrollers were all 8 or 16-bit architectures, these were selected.

A large active user community was deemed to be desirable, as this would provide large numbers of examples of implementations and an avenue for support, should the manufacturer be unable to provide it.

As this project allowed for state of the art components to be used, a modern MCU architecture was deemed to be desirable.

A large number of MCUs were investigated, but most were not considered for further evaluation for various reasons (primarily high power consumption or lack of required integrated peripherals). These included, but were not limited to, those offered by Freescale Semiconductor, Fujitsu, Infineon, NXP Semiconductor and STMicroelectronics.

Manufacturer	Range	Voltage Range	Serial Interfaces	Community	Flash / RAM (KB)
Atmel	ATXMEGA	1.6V-3.6V	16	Active, mature	384 / 32
Microchip	PIC24F	1.8V-3.6V	6	Active, mature	32 / 2
Renesas	RL78/G1X	1.6V-5.5V	21	Inactive, new	512 / 32
Texas Instruments	MSP430	1.8V-3.6V	16	Active, new	128 / 16

Table 7.1: *Comparison of primary MCU candidates.*

In Table 7.1 the candidates for MCU are listed (values in table depict only the best available figures in range, not specific MCU models). The MCUs manufactured by Atmel and Renesas are the only ones to exceed all the requirements, as they are the only models that are able to function reliably under 1.8V. The RL78/G1X series, which may have been suitable, was, however, still under development at the time MCU selection was made. The Atmel ATXMEGA range of MCUs was therefore selected.

7.2.2 Level Translation

7.2.2.1 Level Translators

For translation between voltage logic levels in serial interface circuits, where a voltage rail was available for both the logic levels involved, dedicated level translator integrated circuits

(ICs) were used. This provided the most convenient solution, as it minimised the component count (a single IC per translation interface).

The TXS (for I2C interfaces where an open-drain driver is connected on the bidirectional data I/O) and TXB (all other monodirectional I/O) ranges of level translators manufactured by Texas Instruments were selected, because of their low power usage, ease in sourcing (sample components are readily available and there is fast delivery) and performance far exceeding the requirements.

The specific ICs in the TXS and TXB ranges were selected according to the required number of translators per logic level.

7.2.2.2 Discrete Transistor Circuits

In cases where both voltage logic level rails were not available, or where only switching was required, translation was accomplished via discrete transistor circuits. Digital transistors (NPN transistors with integrated bias and feedback resistors) were used to minimise the component count.

7.3 Communications

7.3.1 VHF Modem

Very few commercial off the shelf (COTS) VHF radio modules were found to be available in the 148-152MHz frequency range, as selected in Subsection 6.2.2. Almost all were too large and heavy for use in collars. Only one module with sufficient power output to cover a substantial range and compliant with the other requirements was available.

The Radiometrix BiM1H module provides a 500mW, 151.3MHz transceiver in a 33 x 23 x 12mm DIP package. This module provides integrated FSK modulation and power amplification, to facilitate a direct UART to VHF radio interface, requiring only level translation and a power supply in addition.

7.3.2 Iridium Terminals

With Iridium Communications Inc. being the sole manufacturer of data terminals, very little variety existed. Alternate manufacturers simply resold Iridium Communications Inc. devices, at times with external circuitry to add functionality.

As only data transfer would be used (no voice) and a continuous network connection would not be required, it was decided to make use of the Iridium SBD data service (as discussed in Section 6.5).

In the initial design phase, where the Iridium modems would only have been used in standalone field terminals, a local supplier of prebuilt Iridium 9601 modems, with a RS232

serial port and power regulation was identified. The Intricode 9601 Powertray simplified interfacing with the device and removed complexity from integration. The arrival of the Iridium 9602 modem, provided a marked improvement in device mass. This was to date the first option for a satellite radio modem that would be small and light enough to fit inside a collar.

The low powered design required to maximise battery life of the collar, led to the decision to make use of the standard 9602 module, as an effort could then be made to optimise its power supply for maximum efficiency.

7.3.3 Antennas

7.3.3.1 VHF

To serve as a qualitative assessment for a VHF antenna radiation pattern, a basic antenna was designed and simulated in FEKO, an electromagnetic simulation software package.

The basic dipole form of antennas was used, simulated as a series of wire elements to calculate the far-field gain. The geometry was, however, changed in bending the dipole to form a loop around the animal's neck. The animal was approximated as a cylinder of water and placed above an infinitely large ground plane with dielectric constant of 3 (the dielectric constant of dry sandy soil). This model is illustrated in Figure 7.2.

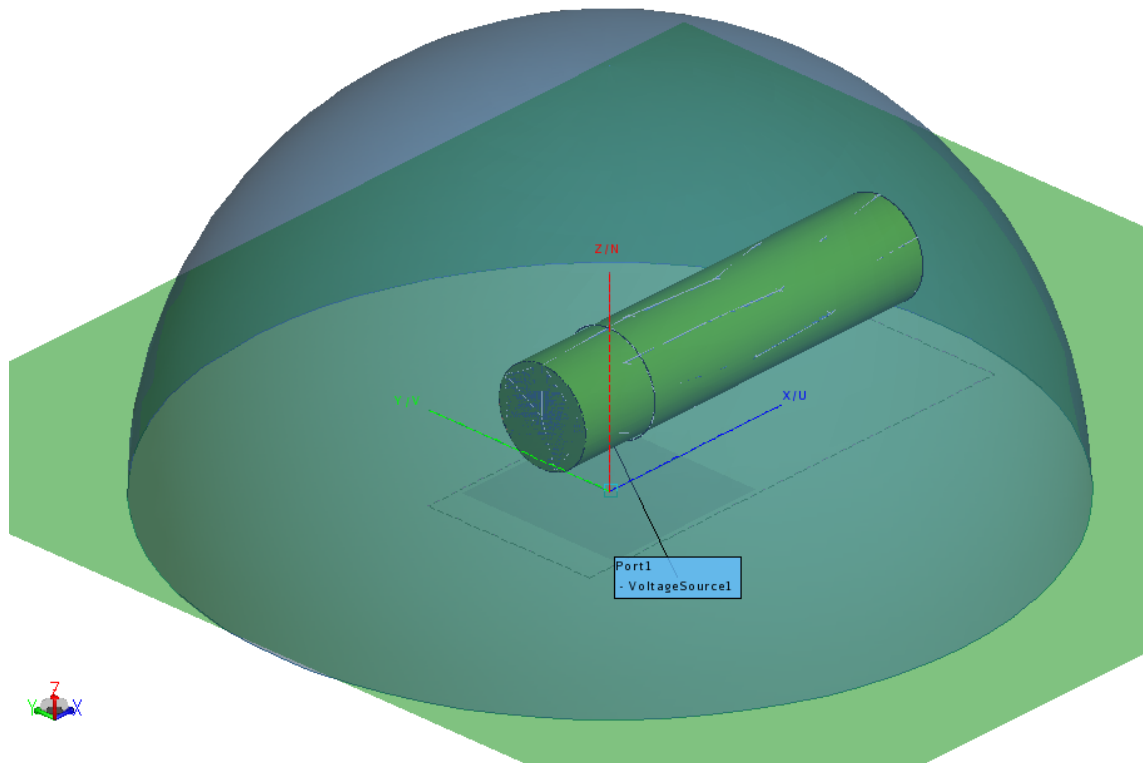


Figure 7.2: *Electromagnetic model of leopard with VHF antenna.*

It was, however, observed through experimentation that major changes in the geometry of the antenna and other simulation parameters had little effect on the observed radiation pattern (observed pattern illustrated in Figure 7.3). This led to the assumption that the close proximity of the antenna to the ground was dominating all other factors. It was also considered that the simulation parameters were not set correctly to give a realistic result. The modeling of the antenna on a leopard is a complex problem and a simple answer is unlikely. The effort described here, can, however, be viewed as a first iteration.

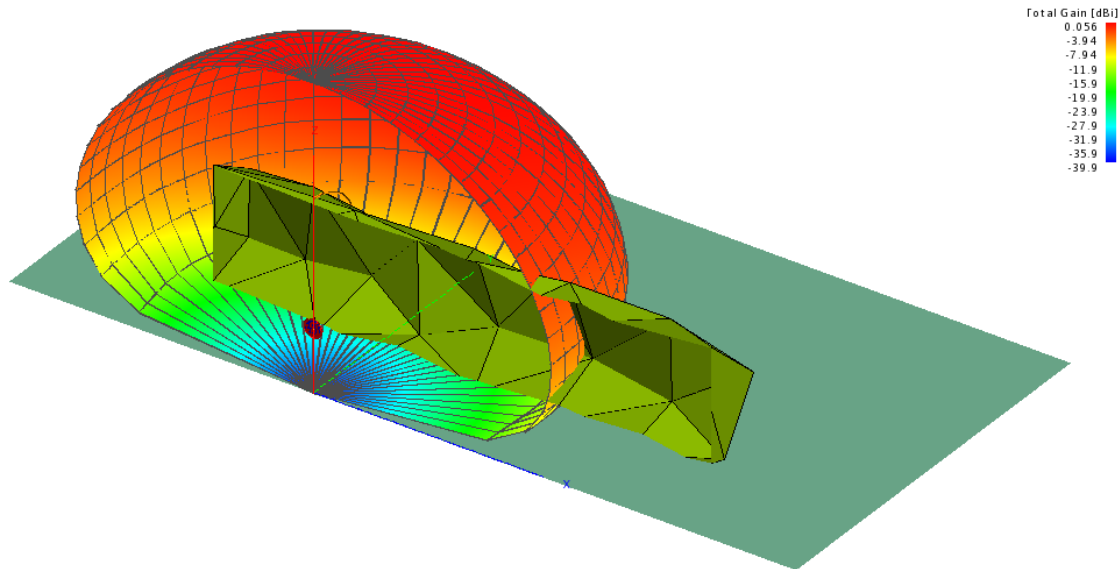


Figure 7.3: *Antenna simulation of VHF antenna around leopard's neck.*

The design of a VHF antenna for the collar was therefore deemed to be a specialist task and assigned to a final year student. This was further supported by known best practices for minimum antenna height above ground for antennas operating in this band. A final antenna would be the result of an extended specialised design effort.

7.3.3.2 Iridium

The antenna selected for the Iridium system is the Sarantel SL3101. It is the only COTS Iridium antenna available (as of December 2011) that fits the space and mass requirements imposed by the collar. It is also particularly suited to use in the collar as its decafililar helix design provides resistance to detuning from surrounding dielectrics.

7.3.3.3 GPS

The choice of GPS antenna is directly linked to the decisions made in the collar geometry as discussed in Section 8.4. In order to avoid a unit at the back of the animal's head, the GPS antenna is to be placed in the bottom unit. This excluded the use of a patch antenna. An antenna similar to that used for the Iridium system was thus selected, in order to minimise

system complexity and simplify testing. The Sarantel SL1203 was selected as it provided the same connectorised interface as the Sarantel SL3101 (Iridium antenna). This simplified the construction of the collar design and provided an easier way to test the antenna orientation when used with a prototype PCB. The quadrifilar helix design also provides resistance to detuning from surrounding dielectrics.

7.3.4 Impedance Matching Networks

For a number of previous iterations of the system, microstrip transmission line networks were designed to provide impedance matching. These were modelled and simulated by making use of AWR Microwave Office 2009TM, a software package tailored to microwave engineering problems.

The design process for these networks was as follows:

1. Identify required impedance (50Ω for all examples) of network input and output at the required frequency band.
2. Leave space for the matching network in the PCB layout.
3. Select a network geometry that is expected to fit in to the space provided.
4. Model the network geometry in AWR Microwave Office.
5. Optimise the specific dimensions of the geometry to provide suitable performance (S_{11} smaller than 0.1 and S_{21} greater than 0.9).
6. Revise the choice of geometry or PCB layout if no suitable solution is found.

Examples of designs are included in Appendix E.

7.4 Sensing

7.4.1 Accelerometer

A number of 3-axis microelectromechanical systems (MEMS) accelerometers tailored for use in cellular telephones and other low power battery operated devices had been released onto the market or were in development during this study (accelerometer selection was made in July 2010). These provided a number of advanced features that would make them ideally suited for sudden acceleration detection in a collar.

Digital interfaces were provided in the form of serial peripheral interface bus (SPI) or inter-integrated circuit (I2C), removing the need for an analogue to digital converter. A supply voltage of 1.8V was compatible with all, allowing them to interface directly with the MCU with minimal supporting circuitry. All had configurable integrated filtering capability

and could be set to trigger an interrupt if preset conditions were met. Power consumption for these devices was also very low, enabling them to be permanently activated. Table 7.2 contains details of the three devices that were considered.

The Freescale Semiconductor MMA8450Q was selected as it complied with all the requirements and could easily be sourced.

Manufacturer	Model	Power Consumption	Digital Interface	Package	Availability
Freescale Semiconductor	MMA8450Q	31uA @ 50Hz 42uA @ 100Hz	I ² C	QFN	In production
Analog Devices	ADXL346	27uA @ 50Hz 40uA @ 100Hz	I ² C, SPI	LGA	Under development
VTI Technologies	CMA3000-D01	11uA @ 40Hz 50uA @ 100Hz	I ² C, SPI	BGA	In production

Table 7.2: *Comparison of accelerometer candidates.*

7.4.2 GPS Receiver

In order to determine the geographic location of the collar, a GPS receiver was required. An integrated GPS module was sought above a GPS chipset to minimise component count. An operating voltage of 1.8V was required, in most instances, by the low power versions of these modules.

A subset of the modules evaluated is listed in Table 7.3. The u-blox NEO-6G was selected, as it proved to be technologically on par or superior to competing products and was also easily procurable from local suppliers.

Manufacturer	Model	Coldstart Sensitivity	Supply Voltage	Acquisition Current	Time-To-First-Fix	Module Availability
u-blox AG	NEO-6G	-148 dBm	1.8 V	47 mA	< 26 s	Locally
Fastrax	IT430	-147 dBm	1.8 V	47 mA	< 35 s	Import
Trimble	C1216	-156 dBm	3.3 V	37 mA	< 38 s	Import

Table 7.3: *Comparison of GPS Module candidates.*

7.5 Power

7.5.1 Hall Effect Switch

A Hall Effect switch was identified as a practical way to control the activation state of the device without compromising the hermetic seal of the collar electronics. The use of these switches was also standard practice in other collar products in the commercial market.

The Melexis MLX90248 Hall effect switch selected was a bi-polar, had high sensitivity (6mT maximum) and extremely low power consumption (5uA at 3V). It was also selected for its ease of sourcing from local suppliers in small quantities. It functioned by internally short circuiting the output pin to ground when a magnetic field falling within the required parameters was present. This switch would drive the enable pin (active high) of the regulator connected to the MCU. All other regulators would be in the off state until switched on by the MCU.

As the output of the devices acts as a switch, short circuiting the output pin to ground, a pull-up resistor is placed between the input voltage supply and output pin. This then has the effect of pulling the enable pin of the regulator high when a magnet is not attached to the device. 100pF and 10nF capacitors are also placed at the output and input respectively, according to the manufacturer's recommendation. The layout is illustrated in Figure 7.4.

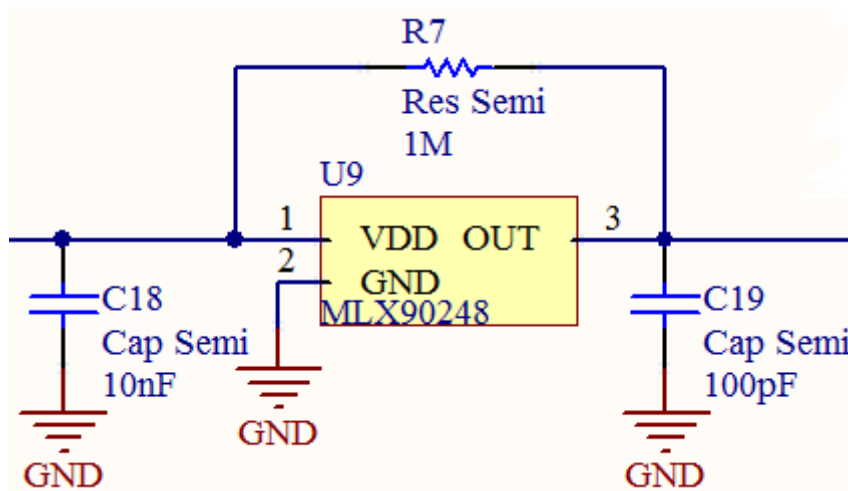


Figure 7.4: Layout of Hall effect switch circuit.

The required size of the resistor is determined by the input current draw of the regulator enable pin. It must allow for the voltage at the enable pin not to drop below 0.9V with the lowest battery voltage at which the MCU is still expected to function (1.8V). It should, however, still be large enough not to cause undue energy losses when the system is powered down by a magnet, as it would typically be for long periods of time before being fitted to an animal. As seen in Equation 7.1 the maximum resistance is $1.8M\Omega$. A $1M\Omega$ resistor

was therefore selected, as it would easily be able to deliver the required current, was readily available and would not allow any significant current to drain from the battery whilst the collar is switched off (as seen in Equation 7.2).

$$R_{\max} = \frac{V_{\text{BATTERY MIN}} - V_{\text{ENABLE HIGH}}}{I_{\text{ENABLE MAX}}} = \frac{1.8V - 0.9V}{500nA} = 1.8M\Omega \quad (7.1)$$

$$I_{\text{loss}} = \frac{V_{\text{BATTERY MAX}}}{R_{\text{HALL SWITCH}}} = \frac{3.6V}{1M\Omega} = 3.6\mu A \quad (7.2)$$

7.5.2 Power Supplies

For designing power supplies, the capacitor and inductor values selected were either according to the manufacturer's reference implementation, or according to the formulas provided in the datasheets. When the option existed for different values, a value resulting in lower noise was selected (whilst still falling within the range recommended by the manufacturer).

7.5.2.1 MCU and Peripherals

In the case of the collar, the MCU power supply would be enabled permanently during the use of the device. To minimise losses a low-dropout regulator (LDO) with low quiescent current was selected. Although the conversion efficiency of LDOs is low for large voltage differentials (typically 3.4V to 1.8V in this case, resulting in 53% efficiency), due to the low average current draw of the MCU and accelerometer, the quiescent current dominates. Whilst various switching regulator topologies offer much better conversion efficiency, their quiescent current is also much higher.

The Texas Instruments TPS72718 provided an extremely low quiescent current of only 7.9 μ A, an active high enable and stability when used with small ceramic capacitors. Although this device is much more expensive than other suitable alternatives and provided higher performance than was required, cost was a not a factor in this design.

7.5.2.2 GPS Receiver

The GPS module would contribute a significant percentage of the power drain from the battery, but would also require a very low noise on its power supply. A two stage design was selected to maximise efficiency whilst still keeping noise figures low. A switching power supply would first step down the voltage, so improving the conversion efficiency of the LDO. The LDO would then further step down the voltage to the required 1.8V, delivering a very low noise power supply to the GPS module. The difference between the input and output voltage of the LDO needs to be minimised to maximise efficiency, however, the smaller this

differential, the less the LDO's ability to reject noise on its input. In order to maximise efficiency, a LDO with very large PSRR and low drop out voltage was thus required.

The Texas Instruments TPS62240 programmable output voltage, switching, step-down regulator was selected. The TPS62240 was designed with portable battery powered applications in mind and featured very high efficiency. A shielded inductor was used in the layout of the power supply to minimise electromagnetic interference with the GPS module.

A Texas Instruments TPS73118 LDO was selected for its very low (30mV) dropout voltage and very low output noise, even with small, low ESR output capacitors ($30\mu V_{RMS}$ with $0.1\mu F C_{NR}$).

7.5.2.3 VHF Modem

The VHF modem constituted the largest power user in the VHF collar design. It would therefore require a very efficient power supply in order to maximise battery life. Due to the stresses on battery life, it was decided not to use a two stage design, as was used with the GPS module, but rather a passive filtering circuit with very large output capacitor. This had the added advantage of being able to better supply peak currents without inducing a voltage drop.

A Texas Instruments TPS61026 high efficiency, switching boost converter was selected for this purpose. It provided high efficiency across a wide range of load currents. This is important as the VHF modem draws only 8mA when in receive mode (as opposed to the 290mA during transmit mode) and would be active in this mode for much longer periods of time than in the transmit mode.

7.5.3 Iridium Modem

As the Iridium module would constitute a major percentage of the device's power usage, the best effort was made to optimise for efficiency. The Iridium module also posed significant challenges because of its high current requirements (1.5A pulses at 5V) as well as tight restrictions on the amount of power supply noise allowed.

Power requirements:

- Supply voltage of 5.0V DC +/-0.5V with a voltage ripple of less than $40 mV_{pp}$.
- The supply voltage droop over an 8.3ms burst of 1.5A current should not be more than 0.2 volts.
- $100 mV_{pp}$ noise voltage from 0 to 50 kHz
- $5 mV_{pp}$ noise voltage at 1 MHz measured in 50 kHz bandwidth
- $10 mV_{pp}$ noise voltage at 1 MHz measured in 1MHz bandwidth

- $5 mV_{pp}$ noise voltage above 5 MHz measured in 1 MHz bandwidth.

As the battery voltage would be 3.6V or lower and high efficiency is desired, a step-up switching power supply was required. A large number of switching power supplies were evaluated, high efficiency across the current load range as well as relatively low noise (more noise than most linear regulators, but much lower than most switching supplies) were the primary selection criteria.

After an extensive search of many manufacturers' devices (including, but not limited to, Texas Instruments, Traco Power, National Semiconductor, Maxim, ON Semiconductor and STMicroelectronics), the Linear Technologies LTC3428 was selected.

This device provided a novel architecture making use of a 2-phase, current boost converter. This allowed the device to switch at 1 MHz, but with the apparent switching frequency being 2 MHz, maximising efficiency, whilst minimising noise. A 4-phase model, the LTC3425 was also evaluated, but rejected due to its excessive component count. The implementation of the module was kept as close as possible to the manufacturers reference design, with similar components selected when those specified by the manufacturer were not available (inductors, Schottky diodes and capacitors). Shielded inductors were also employed in an attempt to minimise electromagnetic interference (EMI) due to switching noise.

As the module did not provide load isolation when disabled (via enable pin), a transistor switch was included to eliminate any power usage by the Iridium modem in this state. The circuit was simulated in SPICE before construction to verify correct operation (the Spice model is included in Appendix D).

7.5.4 Batteries

In the case of rechargeable cells, lithium iron phosphate ($LiFePO_4$) or lithium-ion polymer ($LiPo$) were identified as being suitable for different circumstances. $LiPo$ cells had the advantage of being available in geometries other than cylindrical cells (almost all other chemistries make use of cylindrical cells). This could provide more flexibility in the design of the collar packaging. They also provide excellent energy density per unit of mass and volume. Shelf life is, however, not as long as that provided by $LiFePO_4$. The loss of capacity would, over a period of approximately two years, put the energy densities of $LiPo$ and $LiFePO_4$ on the same level, with $LiFePO_4$ excelling for longer periods of time. $LiFePO_4$ also has the capacity to provide high currents.

Recharge capability would be integrated into the design in the event that a practical kinetic or solar charging solution was found.

Lithium-thionyl chloride ($Li-SOCl_2$) was selected as the primary cell chemistry. It provided low self discharge (less than 1% per year) and the highest energy density for sealed cells, commercially available. Peak current delivery was, however, very limited and a large current buffer would be required to drive the Iridium and GPS modules.

Release of 40F, 100F and 200F lithium-ion capacitors (LIC) by Taiyo Yuden Corporation during 2011 provided an attract alternative to electric double-layer capacitor banks as current buffers.

If mechanically possible, the use of a C sized cell was desired above that of for instance 2 AA cells. This is due to the fact that the C cell provides higher energy density to mass ratio (0.17Ah/g for a C cell as opposed to 0.12Ah/g for AA cells).

Ultimately the Tadiran SL-2770 8.5Ah C cell battery and a 100F LIC were selected to power the system.

7.5.5 Solar Power

The possibility of including solar cells in the collar design would afford a potentially much improved collar lifetime. A solar cell with reasonable efficiency, low weight and suitable size was sought. The PowerFilm, Inc. MP3-25 was identified. It provides 25mA, 3V power source in a 114mm x 25mm package, weighing only 0.8g. The inclusion of this into the collar design would rely heavily on the collar construction and ability to camouflage it (previous attempts in commercial collars to add solar cells resulted in the animal being highly visible due to reflected light).

7.5.6 Alternate Power Supplies

On the final collar prototype PCB, 2 alternative power supplies were also integrated. These provided possible alternatives to be investigated.

The first relies on a LiPo cell to act as current buffer, charged by 2 *Li-SOCl₂* cells via a charge regulator IC. The LiPo cell selected for this was the Turnigy nano-tech 160mAh. It provided a nominal voltage of 3.7V with 25-40C (thus capable of supplying 4-6.4A) discharge capability, far exceeding the system's high current draw requirements. The charger IC chosen was the Analogic Tech AAT3681. This linear charge regulator was selected because of its very low programmable charge current. In order not to discharge the *Li-SOCl₂* batteries at too high a current (dramatically shortening their lifetime), the AAT3681 may be programmed by use of a 105k Ω resistor to limit charge current to 8mA.

The other alternative supply provides the capability to easily integrate an energy harvesting device into the system at a later stage. It relies on an IC developed by Texas Instruments, the BQ25504, released near the end of this study. Novel capability provided by this is a highly efficient boost converter/charger requiring only microwatts of power to begin operating. This device allows for various threshold and hysteresis settings as well as MPPT capability, enabling a robust battery charging solution. For the test implementation a 40F LIC was selected as energy storage device, with charge being delivered by a solar panel as described in Subsection 7.5.5.

7.5.7 Power Budget

During component selection best efforts were made to design for minimal power consumption in order to maximise the system's battery life. In order to specify the required battery capacity we did, however, need to calculate a power budget. The figures obtained in Table 7.4 were calculated as described in Equation 7.3.

$$E_{daily} = \frac{V_{operating}[V] \times I_{average}[A] \times T_{duration}[h] \times T_{period}[h]}{\eta_{supply} \times 24[h]} = x[Wh] \quad (7.3)$$

E_{daily} = Daily power usage of the component in Wh.

$V_{operating}$ = The operating voltage of the component in volts.

$I_{average}$ = The average current drawn by the component during the time it is active, in ampere.

$T_{duration}$ = The time that the component is activated during each use, in hours.

T_{period} = The time between activations of the component in hours.

η_{supply} = Efficiency of the power supply that is supplying the component.

1. For components powered directly from the battery η equals 1.
2. Linear regulators provide an efficiency in the form $\eta = \frac{V_{output}}{V_{input}}$.
3. Switching regulators' efficiencies are gained from their respective datasheets. The value is read off a curve between the regulator input voltage (3.6V, *Li-SOCl₂* cell voltage) and the expected current draw. It is noted that this is not the average current draw, but a inference of the instantaneous loads expected.
4. Where two regulators are used to power a component, the resulting efficiency is the product of the two regulators' efficiencies.
5. Regulators with very low quiescent currents relative to those of their load current were selected. The influence of quiescent current is thus negligible in most cases. For the MCU's regulator, the quiescent current is included in the current usage.

Component	Voltage	Current	Efficiency	Duration	Period	Energy
MCU and misc.	1.8 V	100 μ A ¹	50%	24 h	1 day	9 mWh
Hall Effect Sensor	3.6 V	10 μ A	100%	24 h	1 day	1 mWh
Accelerometer	1.8 V	30 μ A	50%	24 h	1 day	3 mWh
GPS	1.8 V	47 mA	70%	1 min ²	30 min	97 mWh
Iridium Modem ³	5 V	170 mA	90%	100 s	1 day	26 mWh
Total:						136 mWh

Table 7.4: *Projected collar power usage per day.*

7.5.8 Expected Lifetime

As seen in Table 7.4, the expected power usage per day is 136mWh. Coupled with the 8.5Ah C cell *Li-SOCl₂* battery discussed in Subsection 7.5.4, this equates to a lifetime of approximately 225 days. This is, however, in all probability a highly optimistic prediction. Accurate figures can only be attained by extensive field testing and even then a large variance is expected due to the differences in the terrain of individual animal's territory.

7.6 Conclusion

In this section we detailed the selection and implementation of the various subsystems identified in Section 5.4 as hardware components. Expectations as to the expected lifetime of the system were also made.

¹Regulator quiescent current is included in this figure.

²This figure was determined by taking 10 coordinate readings and cycling the GPS module's power between each. The average time for a GPS lock to be achieved was 1 min. It is, however, noted that the backup supply of the GPS module was active, thus the SRAM contents were retained between power cycles. This significantly increases the speed of GPS locks, as the GPS ephemeris and almanac data does not need to be redownloaded. In a real world scenario, the time between GPS locks will necessitate periodic reupload of the ephemeris and almanac data.

³Measurements were performed to determine the average current draw and transmission duration under strong signal conditions.

Chapter 8

Collar Packaging

8.1 Introduction

The physical construction of the collar band forms a critical part of the requirements of the system (current commercial collars routinely fail mechanically). In this chapter the requirements for the collar's mechanical performance are identified. Material selection is then detailed, followed by a potential design.

8.2 Requirements

The primary mode of failure for almost all the collars that have been tested by the CLT is mechanical breakdown. Almost all, with the exception of the Vectronic Aerospace GmbH manufactured collar, were deemed completely unfit for use because of this. Even this exception did, however, suffer significant damage. It was a common occurrence for the heads of mild steel bolts, used to assemble the collars, to be completely worn down.

The sandstone formations found in abundance inside the GCBC are highly abrasive and it is believed that the act of animals rubbing against these rocks is the main cause of mechanical wear. A material with very high abrasion resistance was thus sought. Since antennas would be integrated into the collar material, the use of metal in the collar banding was ruled out as this would interfere with the antenna's radiating pattern.

8.3 Material Selection

In order to minimise the collar mass, different plastics were investigated as possible materials for use. In previous projects polyurethane was identified as a suitable material and attempts were made to cast a collar. The results from this project were, however, not satisfactory[5].

In this study ultra-high-molecular-weight polyethylene (UHMWPE) was identified as a more suitable material.

Advantages afforded by UHMWPE include:

- Abrasion resistance higher than that of steel and only exceeded by polytetrafluoroethylene (commonly known under the trade name Teflon).
- Very high impact resistance (UHMWPE fibres are used in ballistic body armour).
- It is odourless, tasteless and non-toxic.
- UHMWPE sheets and rods can easily be machined.

8.4 Physical Design and Manufacture

In the design of the collar packaging an attempt was made to minimise the number of pieces that needed to be milled. A prototype was envisioned comprising two pieces of milled UHMWPE held together by 10 nuts and bolts. A representation of this design is illustrated in Figure 8.1 and detailed design drawings provided in Appendix C.

Assuming a density of $0.940g/cm^3$ for UHMWPE, the mass of the bottom unit is $156g$ and the plug $37g$, totalling $193g$.

Due to unwillingness of manufacturers and material suppliers to provide their services for a project of this scale, a prototype was never produced. Through meetings with these parties it was, however, established that the complex shapes of the collar band could be formed by standard milling techniques from a block of UHMWPE.

8.5 Conclusion

In this section, after the stringent requirements relating to strength, mass and abrasion resistance had been identified, UHMWPE was identified as a suitable material from which to manufacture the collar. A potential design for the collar was then modelled using CAD software. Actual manufacture will have to take place during the next phase, as this is a relatively expensive and time consuming process.

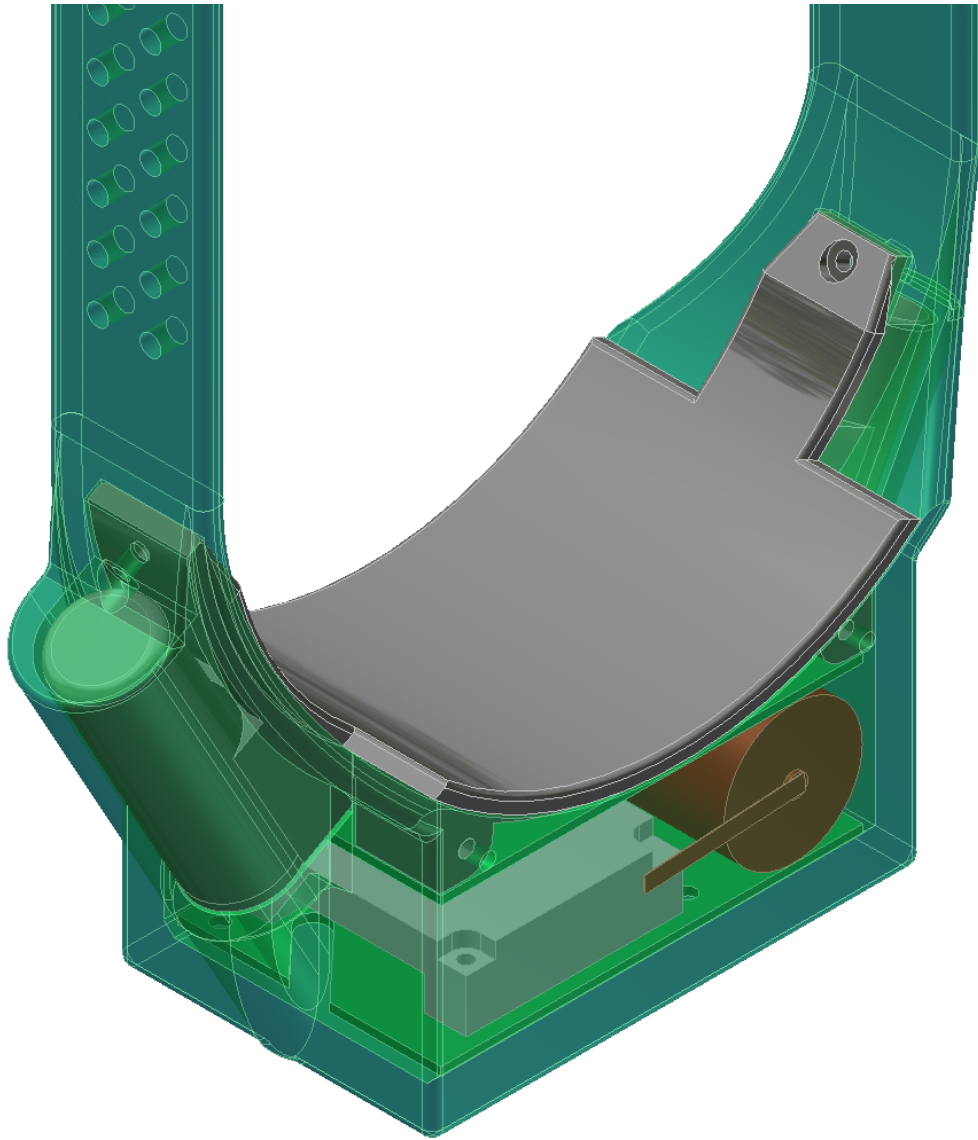


Figure 8.1: *3D Representation of collar.*

Chapter 9

Collar Software Design

9.1 Introduction

In this chapter an overview of the collar firmware is given. The general operational process of the collar is illustrated and strategies for power saving are outlined. A method for logged GPS coordinate compression is described and motivated. The software to be used on the researcher's computer is also detailed.

9.2 System Operation

The collar system software operation is based on a linear series of processes as illustrated in Figure 9.1.

A scheduling system making use of per minute addressing of a 24 hour period is used. This scheduling system is responsible for requesting GPS logs and Iridium data log uploads. A simple implementation allowing for the permitted daily window a task may run in, the period at which the task should be executed and the time to wait before retrying a task in the event that it has failed, is provided. The internal clock may be synchronised with Coordinated Universal Time (UTC) via functionality provided by the GPS module.

As the electronics had not been incorporated into a final collar packaging at the time the final prototype system was undergoing testing, the accelerometer was configured to trigger on detection of a tap, rather than sudden acceleration (of the type that would be expected to coincide with hunting behaviour).

The method of Iridium modem packet transmission is similar to that described in subsection 4.6.1.2. Compression of the GPS coordinate data is described in Section 9.4.

To ensure reliable operation, timeouts are implemented for operation with the GPS and Iridium modules. In the event that a timeout is triggered, the corresponding task is rescheduled via the scheduler system.

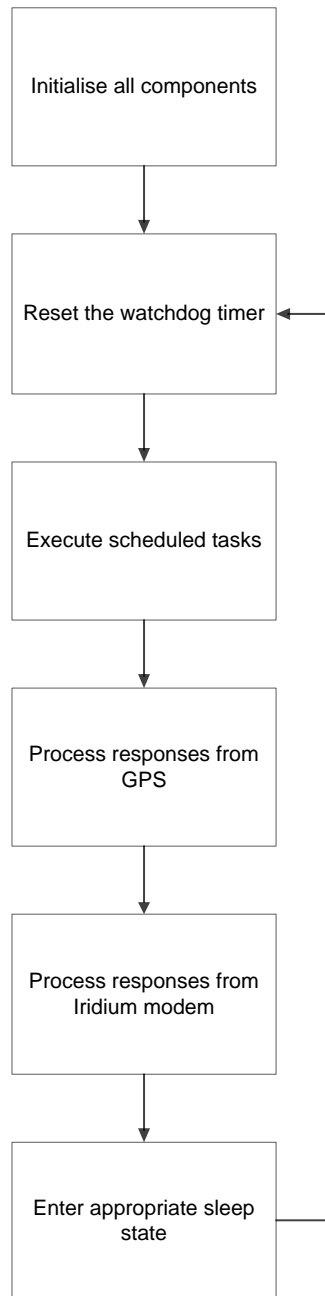


Figure 9.1: *Collar main loop operation.*

9.3 Power Saving

An effort was made to make moderate use of the advanced power saving techniques enabled by using the Atmel XMEGA range of microcontrollers.

The following measures were implemented in attempts to minimise power usage:

Only the lowest functional power state (sleep mode) was used at any given time. This was realised by integration of a sleep manager (framework for sleep manager provided by Atmel). The sleep manager facilitated for program modules to initiate locks on the lowest allowable sleep level for the microcontroller to enter (in which they would still function correctly). At the end of every main loop execution, the sleep manager would enter the deepest allowable sleep level (specific by lock bits).

Peripheral components of the MCU would be powered down when not in use. This is enabled by setting power reduction registers on the MCU.

In order to further minimise power consumption by the MCU, the operating frequency was selected as 8MHz. This provided a 20% safety margin from the maximum clock frequency of 10MHz at 1.8V. Whilst further reducing the frequency would result in a minor change in current draw, the added time that operations would take negates this effect.

9.4 Coordinate Log Storage

In an effort to minimise the use of onboard storage and reduce the amount of data to be transmitted via the Iridium modem, coordinate data is compressed.

Coordinate data is received from the GPS as two 32-bit signed integers representing latitude and longitude (derivation of base shown in Equation 9.1 and Equation 9.2, although these values are not precisely accurate, they are sufficient for this purpose). As the 8 least significant bits (LSB) of each number represent accuracy above that which the GPS module is capable of (as demonstrated in Equation 9.3), they are discarded. The 8 most significant bits (MSB) represent large geographic areas (as demonstrated in Equation 9.4) and it can be expected that a leopard will remain in a area no greater than 1000 km². Coordinate data is thus compressed down to 32 bits. These 32 bit logs are packaged into packets of 8 logs as they are stored in electrically erasable programmable read-only memory (EEPROM) or flash memory pages (8 logs per 32 byte page). Every 64th log, however, is not compressed so that the absolute position may be determined to set the correct 8 MSB of the other logs (These packets thus contain only 7 logs).

$$l_{\text{degree max}} = \frac{c_{\text{earth}}}{360^\circ} = \frac{40075[\text{km}]}{360^\circ} = 111319.9[\text{m}] \quad (9.1)$$

With $\phi_{\min \text{ GCBC}} = -33^\circ$, $a = 6378137.0[\text{m}]$, $b = 6356752.3142[\text{m}]$

$$l_{\text{degree min GCBC}} = \frac{\pi a \cos \phi_{\min \text{ GCBC}}}{180 \sqrt{1 - \left(\frac{a^2 - b^2}{a^2}\right) \sin^2 \phi_{\min \text{ GCBC}}}} = 93453[\text{m}] \quad (9.2)$$

18.8661925° is encoded as `0x46D98AA5` by the GPS module. The omission of the least significant 8 bits thus renders a loss of accuracy that is at maximum `0x000000F`, or 0.0000015° . Loss of the most significant 8 bits equates to a length of `0xFFFFFFFF` or 26.8435455° .

Thus we find:

$$l_{\text{error max}} = l_{\text{degree max}} \times 0.0000015 = 0.167[\text{m}] \quad (9.3)$$

$$l_{\text{range GCBC}} = l_{\text{degree min GCBC}} \times 26.8435455 = 2509[\text{km}] \quad (9.4)$$

This position error is smaller than the accuracy desired and what can be expected of the GPS receiver. Further more the range provided is sufficiently large to ensure that a leopard crossing over multiple ranges in a single log block is highly unlikely (this is, however, possible in the event that a leopard is located at the corner of a range block).

9.5 Scheduling System Configuration

As a default configuration of the scheduling of tasks on the collar, the following values were selected (changeable upon request of the researcher). Researchers may already have a model of the sleeping patterns of an animal, based on the time it has moved through camera traps and by analysis of its scat (sleeping patterns correlate strongly with the type of prey the animal prefers).

As leopards are primarily nocturnal[6] (this may vary greatly, depending on the preferred prey of the leopard), use of the GPS and Iridium modules are scheduled to occur at times that the animal is likely to be moving about and not sleeping in a sheltered location (shelter could interfere with satellite visibility). GPS locks and Iridium uploads are thus scheduled to be performed between 16:00 and 08:00. A retry period is also implemented for each task in the event that it should fail.

Iridium uploads are performed (in the event of a full EEPROM page) once a day, with a retry period of 6 hours, normally scheduled to be performed at 22:15. The GPS module is scheduled to be activated once every 30 minutes with a retry period of 30 minutes (this is to allow the LIC to fully recharge and not overlap with a Iridium upload operation).

9.6 Iridium Operation

The Iridium subsystem is activated by the scheduler subsystem. Once activation has occurred, stored coordinate data is loaded from the EEPROM storage and copied to a RAM buffer in the MCU and then to the Iridium module's internal buffer. If a strong signal from an Iridium satellite is present, transmission is attempted.

As part of an attempt to minimise power supply noise and improve efficiency, the Iridium modem is powered down and uploading rescheduled in the event that a weak signal level is detected after power-on. This is an attempt to minimise the time that the Iridium modem is powered on (saving energy) and decrease the number of failed transmissions. By limiting the amount of time for which the module is powered on, a reduction in the charge depletion of the energy buffering storage capacitors is achieved. This greatly reduces or eliminates dips in the supply voltage during times of high current draw.

Refer to Appendix F for full system source code.

9.7 PC Software

In order for researchers to monitor the collar, application software is supplied for their computers. This software provides the following functionality:

- Retrieval and display of logged coordinates and battery level.
- Saving of configuration data and logs received in JSON (JavaScript Object Notation) structures.
- Exporting logs in either CSV (Comma Separated Value) or KML (Keyhole Markup Language) formats.
- Opening logs in Google Earth or other GIS (Geographic Information System) software.

A screenshot of the software is provided in Figure 9.2. The Java programming language was used to write the software.

Refer to Appendix F for PC software source code.

9.8 Conclusion

In this section we discussed the mode of operation of the collar system, detailing the power saving strategies employed. Further, a lossy method of coordinate data compression was described and motivated. Finally, motivation was given for the default configuration parameters of the scheduling system and a description of the PC software used by researchers to download collar data was provided.

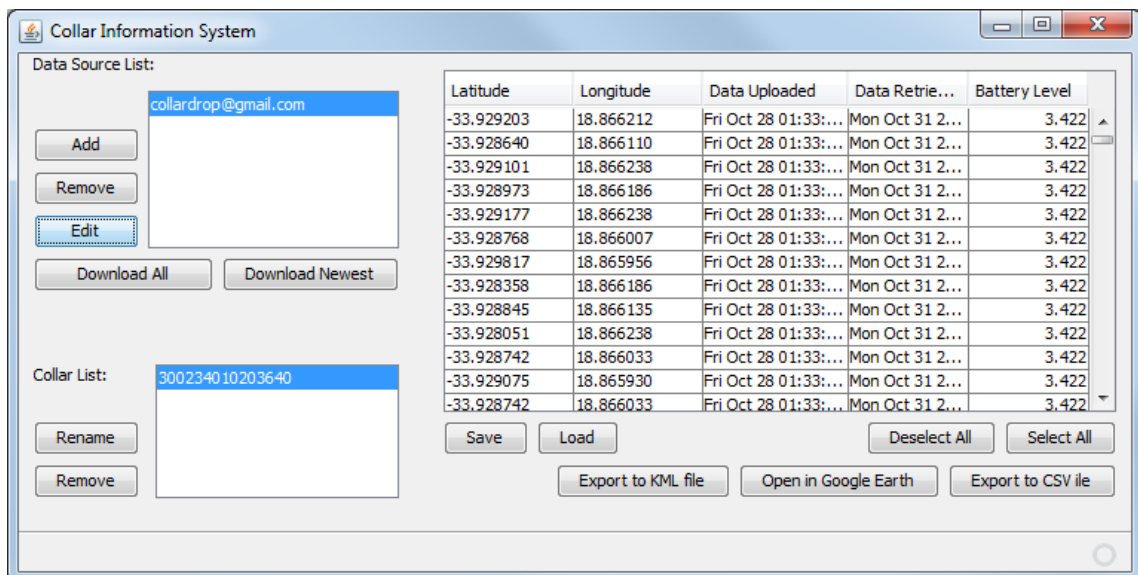


Figure 9.2: Collar application software screenshot.

Chapter 10

Collar Results

10.1 Introduction

In this chapter the success of various circuits that were constructed will be evaluated. Measurements relating to the final prototype are provided. Comparisons are made between the system developed and existing commercial products.

10.2 Units Constructed

Detailed schematics and PCB layouts for the units discussed are provided in Appendix H, included on the accompanying DVD.

10.2.1 VHF Based Collar

10.2.1.1 Goal

To construct a fully functional and miniaturised PCB for use in the bottom unit (as illustrated in Figure 10.1) of a VHF connected collar. The bottom unit would include power storage, MCU, accelerometer and VHF transceiver. The GPS would be located on a separate PCB to be located at the top of the collar, but with its switching power supply component located in the bottom.

10.2.1.2 Success

The correct layout and programming of the MCU was verified. Regulators used for the MCU and VHF module functioned as expected and it was possible to interface with the VHF module (integrity of VHF communications was, however, not verified).

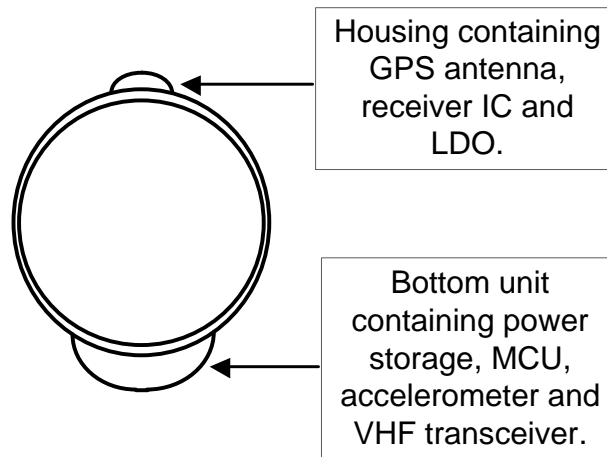


Figure 10.1: *Split collar electronics housing diagram.*

10.2.1.3 Problems

A constant and unexplained current draw of 70mA by the PCB was measured. This proved to be very difficult to debug as all power was routed through internal layers (4-layer PCB), small surface mount components were used and no test-points provided. The source of this load has not been identified. Incorrect footprints were used for the 5V switching regulator, the accelerometer and the hall-effect switch.

10.2.1.4 Workarounds

The incorrect footprint for the Hall effect sensor was remedied by flipping it over and rotating it before soldering. Small PCBs were manufactured, on which the 5V regulator and accelerometer were mounted and then connected to the main PCB via wires.

10.2.1.5 Lessons

An additional review of component footprints is required before a PCB is identified as being ready for manufacture. The inclusion of test points at which to connect measurement probes contributes greatly to ease of debugging.

10.2.2 UART-RS232 Interface

10.2.2.1 Goal

Construct a PCB for use as a debug interface for collar prototype boards. The PCB would allow interfacing of an arbitrary logic level (between 1.65V and 5.5V) UART to RS232.

10.2.2.2 Success

The system operated as desired.

10.2.2.3 Problems

A malfunction leading to the system being inoperable was traced to top and bottom ground planes not being connected.

10.2.2.4 Lessons

Care should be taken when having boards manufactured without through hole plating to ensure that components can be connected to the appropriate tracks.

10.2.3 VHF Module

10.2.3.1 Goal

To create a module providing a UART to the VHF transceiver interface and supporting a power supply to be used in a modular collar electronics prototype.

10.2.3.2 Success

The switching regulator successfully regulated the 3.6V input voltage and delivered 5V on the output.

10.2.3.3 Problems

The switching regulator used to power the VHF transceiver failed and stopped regulating the output voltage (input voltage passed directly to the output). As no switching noise was observed on the output, and after consultation with engineers from Lanner Inc, it is believed that static electricity might have damaged the output stage MOSFETs of the regulator.

10.2.3.4 Lessons

Switching regulator integrated circuits are sensitive and prone to failure if improperly handled. Future designs making use of the Texas Instruments TPS61026 should limit exposure of sensitive tracks to accidental touch or include additional electrostatic discharge (ESD) protection.

10.2.4 GPS Module Interface

10.2.4.1 Goal

To provide a level translation interface to allow connection of the VHF Based Collar board to a u-blox LEA-4P GPS evaluation module. This allowed the software design associated with operating a GPS module to be tested before manufacturing the required hardware.

10.2.4.2 Success

The voltage regulator and level translation components both operated as expected. The system successfully interfaced UARTs operating at 1.8V and 3.3V.

10.2.5 MCU Module

10.2.5.1 Goal

Manufacture of a simple PCB containing only the MCU and interface electronics to connect peripheral boards containing the other modules required for a collar. Test points were also placed at all supply pins to allow for precise measurement of component power usage.

10.2.5.2 Success

Ultimately the board helped identify the errors associated with programming MCUs on this and other boards.

10.2.5.3 Problems

Problems with programming of the MCUs were traced to a faulty cable and bug in the programming software.

10.2.5.4 Lessons

Identified problems with programming procedure that allowed for corrections to be made on other boards.

10.2.6 Iridium Based Collar Board 1

10.2.6.1 Goal

Construction of a board aimed at being a testbed for components to be used in an Iridium based collar. These include the integration of a GPS module with active antenna supply, Iridium module, impedance matching networks and MCU.

10.2.6.2 Success

The MCU and its RS232 debugging interface functioned as expected after errors identified by testing of the MCU module PCB were removed.

10.2.6.3 Problems

The 5V regulator used to power the Iridium module was not operational. This problem was traced to incorrect connection of the module. As this regulator was only intended to be used for testing purposes and was not suitable for use in a collar, further development of this PCB ceased.

10.2.7 Switching Supply Test

10.2.7.1 Goal

Knowledge of the feasibility of using a switching power supply to provide a low noise power output at high efficiency to the Iridium 9602 module was required. A PCB was thus manufactured to test the performance of a Linear Technology LTC3428 dual phase switching power supply.

10.2.7.2 Success

The power supply successfully provided high current, 5V output from the 3.6V input voltage. Switching noise was, however, above the specified maximum noise levels for the Iridium 9602 module.

10.2.7.3 Lessons

Additional filtering of the output noise would be required if the LTC3428 were to be used in powering the Iridium 9602 module.

10.2.8 Iridium Based Collar Board 2

10.2.8.1 Goal

As with the first Iridium based collar board, this board would enable the testing of components for use in an Iridium based collar. The correct functioning of the MCU, 5V switching supply, GPS and Iridium module were to be evaluated. To simplify the design, the MCU was operated at 3.3V for ease of integration with the GPS and Iridium modules.

10.2.8.2 Success

The MCU functioned as expected and communications with the Iridium and GPS modules was possible.

10.2.8.3 Problems

External power was required to operate the GPS module's regulator as the input voltage supplied to it was too small to result in a large power supply rejection ratio (PSRR). The lock times and repeated signal loss of the GPS module was traced to a design fault. The GPS antenna pass-through on the Iridium module, although requiring an active GPS antenna supply, did not pass this antenna supply current through to the antenna. This led to high losses in the antenna cable and poor signal to noise ratio at the GPS antenna input.

The Iridium module also exhibited less than ideal performance. Most attempts at transmission failed and the detected received signal strength indicator (RSSI) showed continued low levels. This was attributed to excessive noise on the module's power supply or poor performance of the impedance matching network.

10.2.8.4 Lessons

The GPS signal pass-through capability of the Iridium module blocks DC current used to power an active GPS antenna. Additional filtering is possibly required on the Iridium module's power supply. The impedance matching networks were possibly not functioning as intended.

10.2.9 Iridium Based Collar Board 3

10.2.9.1 Goal

As with the previous 2 Iridium collar test boards, this board would enable the testing of components for use in an Iridium based collar. This board would test the correct functioning of the MCU (operating at 1.8V), accelerometer, Hall-Effect switch, the 5V Iridium supply with accompanying filter network and the Iridium 9602 module. A new GPS module would also be used. The module would be powered by a two stage, high efficiency power supply and a GPS antenna integrated onto the board.

10.2.9.2 Success

The MCU, accelerometer, Hall-Effect switch and GPS system all functioned to satisfaction. The Iridium module, however, still showed poor performance, as previously experienced.

10.2.9.3 Lessons

A better understanding of the nature of power draw by the Iridium modem and duration of a typical transmission were gained. Figures were obtained on the typical duration of a GPS lock. This information could then be used in the design of energy storage requirements.

10.2.10 LiPo and EDLC Test Board

10.2.10.1 Goal

The use of a LDO to power the Iridium module would greatly reduce the noise levels on its power supply. A large energy storage element capable of supplying high peak currents would also lead to the primary cell battery achieving a higher capacity (particularly for *Li-SOCl₂* cells). To this end, a system making use of a LiPo cell and an EDLC to act as current buffer for the Iridium and GPS power supplies was envisioned. The board constructed would evaluate this concept, through integration of an EDLC, LDO, LiPo cell with accompanying charge controller and MOSFET switches to control current flow.

10.2.10.2 Success

Although all parts functioned as designed, the system concept proved lacking. The LiPo charge circuit successfully charged the LiPo cell, MOSFET switches controlled charging and discharging of the EDLC and LDO successfully provided a low noise 5V output for use with the Iridium module.

10.2.10.3 Problems

The capacity of the EDLC required to power the Iridium module for the duration of its transmission was, however, greatly underestimated. With the capacity of the EDLC required to successfully accomplish this being excessively large, this system concept was abandoned.

10.2.10.4 Lessons

The total power usage for a packet transmission with the Iridium modem was significantly higher than what has been expected after interpreting the figures supplied in the Iridium modem's datasheet.

10.2.11 Iridium Based Collar Board 4

10.2.11.1 Goal

This collar prototype board was to evaluate a complete collar electronics package. Included are the MCU, accelerometer, Hall-Effect switch and level translation circuitry. The GPS and Iridium modules with their respective power supplies and antenna solutions are integrated

as they would be in a production model collar. Finally, three energy storage systems were evaluated. The first would rely on a *Li-SOCl₂* cell to charge a 100F LIC. A second design relied on a LiPo cell to act as temporary energy storage, to be charged from two *Li-SOCl₂* cells. An energy harvesting based design is also provided, making use of a 40F LIC as storage element, though no viable method of energy harvesting existed at the end of this study.

10.2.11.2 Success

The board proved to be functionally operational when used with the 100F LIC buffered power supply. The system could successfully capture coordinate data and transmit it via the Iridium network as controlled by the MCU's scheduling system. The energy harvesting circuit successfully charged the 40F LIC when connected to a PowerFilm MP3-25 solar panel.

10.2.11.3 Problems

The Iridium power supply still showed noise figures above the maximum levels specified by the Iridium transceiver manufacturer. The LiPo charge circuit overcharged the LiPo cell, causing it to rupture.

Due to supply chain problems the system making use of the 100F LIC could never be tested with the specified 8.5Ah *Li-SOCl₂* cell.

10.2.11.4 Lessons

The suggested collar concept is indeed a workable solution.

10.3 Testing and Measurement

10.3.1 Supply Measurements

Measurements were performed using Fluke 175 (current) and Major Tech MT23 (voltage) digital multimeters and an Agilent Technologies MSO-X 3014A mixed signal oscilloscope. Due to the internal noise floor of the oscilloscope, measurements smaller than 10mV cannot be reliably made. The prevalent ambient temperature during testing was 18°C.

As can be seen in Table 10.1 the MCU and GPS power supplies provide extremely low noise. Though the MCU supply does not require such low noise performance, the apparent energy lost to quiescent currents appears to be encouragingly low. As for the GPS, the very low noise present on its 1.8V supply is conducive to faster lock times. Additional efficiency gained by using a step-down switching regulator between the battery supply and LDO also appears to have been a good design decision.

Noise on the Iridium supply during the 1.5A bursts found during transmission does, however, continue to be a problem (as shown in Figure 10.2). These large bursts result in

1.8V MCU Supply	
Output voltage	1.801V
Supply current (normal mode)	1.35mA
Supply current (sleep mode)	460µA
Supply current (average)	460µA
Supply current (accelerometer triggered)	560µA
Output voltage noise	< 10mV _{pp}
5V Iridium Supply	
Input voltage	3.575V
Output voltage	5.149V
Peak supply current for transmission	500mA
Average current from battery for transmission (5/5 signal strength)	25mA
Output voltage noise (idle)	< 10mV _{pp}
Output voltage noise (active)	40mV _{pp}
Output voltage noise (transmit)	315mV _{pp}
GPS Switching Supply	
Input voltage	3.574V
Output voltage	2.304V
Maximum supply current	38mA
Minimum supply current	25mA
Average supply current	32mA
Output voltage noise	50mV _{pp}
1.8V GPS Supply	
Output voltage	1.803V _{pp}
Output voltage noise	< 10mV _{pp}

Table 10.1: *Power supply characteristics.*

noise with an amplitude of 340mV_{pp} . During the receive cycle, noise with an amplitude of 40mV_{pp} is also observed. Whilst these figures place the noise levels well outside the requirements as stipulated by the manufacturer, communications are still successful.

Due to losses induced by the multimeter probes, exact measurements of the Iridium module's peak currents were not possible. Peak currents as sourced from the LIC did, however, appear to be in the 500mA range.

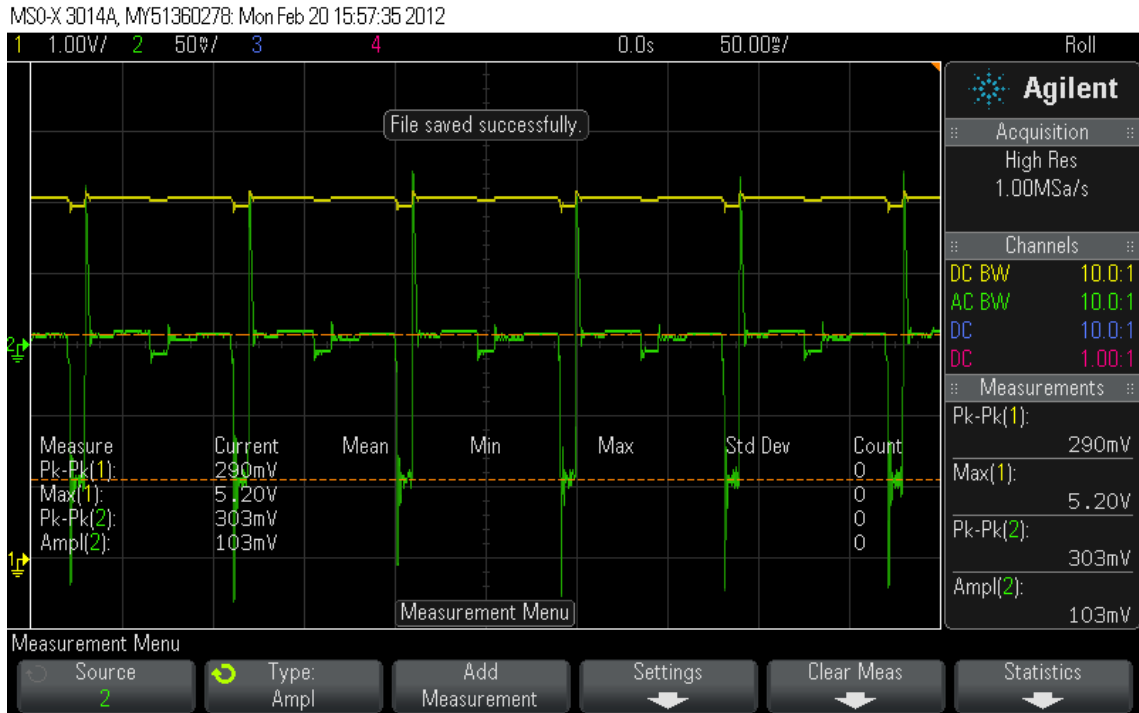


Figure 10.2: Noise on 5V Iridium supply (yellow DC 1V/div, green AC 50mV/div).

10.3.2 GPS Performance

10.3.2.1 Power Usage

In order to gauge the power consumption of the GPS module a test was executed over a 24 hour period. Logs were attempted every 30 minutes and the current supplied from the battery input was continually monitored. These results are shown in Table 10.2.

Current of MCU and GPS over 24h period	
Minimum supply current	450uA
Maximum supply current	19.46mA
Average supply current	2.46mA

Table 10.2: GPS power usage measurements.

10.3.2.2 Position Accuracy

In order to evaluate the position accuracy of the GPS module, 20 positions locks were taken and the deviation from the true position calculated. As from Equation 9.2, the length of a degree for the test setup was calculated. For testing purposes, the distance from the absolute position to the logged point was taken as if located on a flat plane. Only a partial sky view was available for testing, as the system was located inside a building. This less than optimal sky view likely contributed to the lack of accuracy and linear error pattern as observed in Figure 10.3.

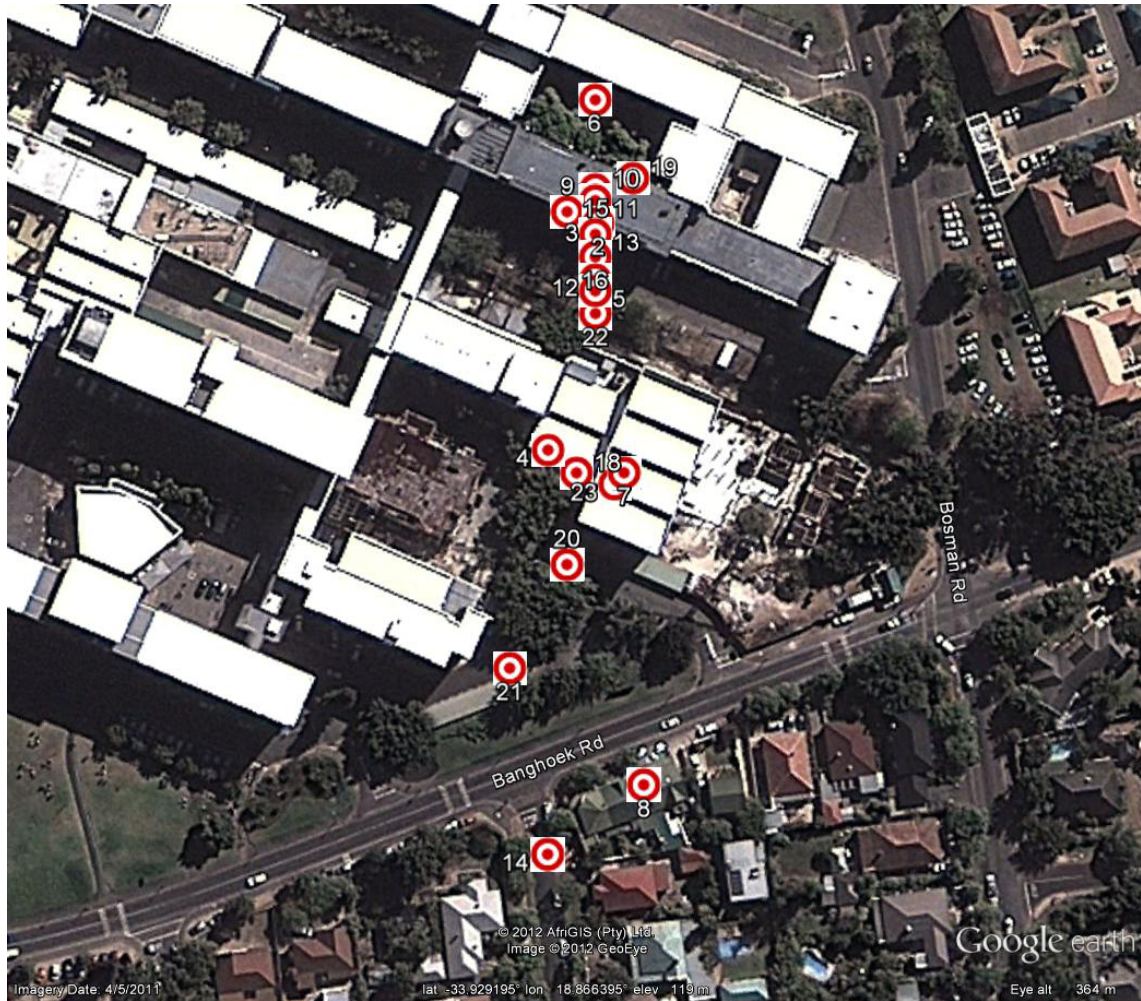


Figure 10.3: Aerial view of logged coordinate data.

For the 20 test cases, the average deviation was 41m, with a minimum error of 0.4m and a maximum of 156m. This error is much larger than the 20m accuracy parameter specified for accepting a position as valid. The limited sky view is likely responsible for this, but not an unrealistic scenario in the field either. Due to the fact that researchers typically use multiple position logs to locate kill sites [8] this does not constitute a major problem. The 41m average deviation is still more than adequate to identify a cluster of logs and calculate a relative mean position which one would then expect to contain the kill site.

In order to further verify the accuracy of position logs for non-static logging, the system was temporarily packaged and transported by motor vehicle (along roadways), on foot (in a mountainous ravine) and statically placed (with limited sky view). These logs showed a very high degree of accuracy, with only a single major deviation for the non-static period during the vehicle borne segment of the trip. A partial view of the logged coordinates in the Bain's Kloof region is provided in Appendix G.

10.3.2.3 Speed of Position Acquisition

Average duration of position acquisition was determined by logging every 30 minutes, until 30 such logs had been collected (noting the time each took).

The average duration in testing was 111s (individual times listed in Appendix G). As can be seen in Figure 10.4, the majority of acquisitions were in the order of 60s. This was, however, greatly offset by 5 failed acquisitions, leading to the 5 minute timeout period taking effect.

Battery life could possibly be further extended by shortening the timeout period. This would be done by examining a large set of acquisition attempts to determine the upper duration bound, beyond which the acquisition time greatly increases.

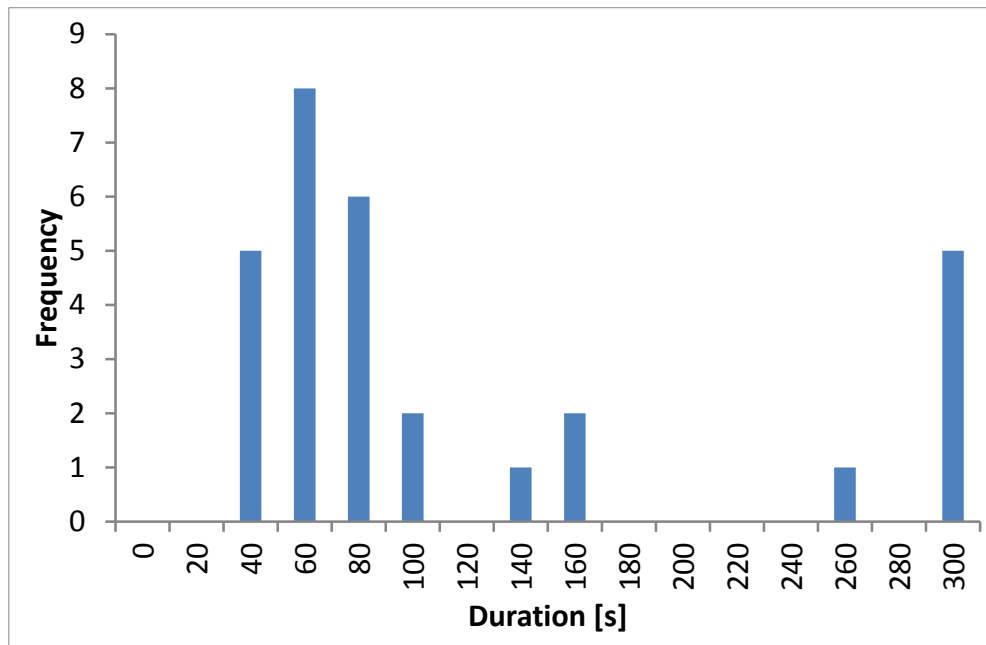


Figure 10.4: Histogram of GPS acquisition times.

10.3.3 Iridium Performance

Measurements of the Iridium transceiver power usage were performed in a number of ways.

Firstly, 20 transmissions of a standard packet were performed. For each of these transmissions, the total duration of time for which the module is powered on, the average, minimum and maximum currents supplied by the primary cell battery and the success of the transmission were recorded. A brief summary of these measurements is provided in Table 10.3, with individual measurements provided in Appendix G.

Average power usage for Iridium transceiver	
Successful transmissions	13/20
Average minimum current	10mA
Maximum current	47.0mA
Average current	16.3mA
Average duration	23.6s

Table 10.3: *Iridium power usage measurements.*

Before each transmission was initiated, the system was powered down and current from the primary cell battery to the LIC was less than 500uA. As the specified primary cell could not be sourced by the time testing commenced, a bench power supply was used to emulate it. For test purposes, the debug interface was also enabled, further contributing to the total power usage. The antenna was located inside a building, pointing out of a window, which thus resulted in only a partial sky view.

It is important to note that the current from the primary cell battery only gradually declines after the Iridium module has been powered down. This is due to the buffering effect of the LIC. In order to calculate the total power used for an Iridium transmission one thus needs to measure the average current from the start of transmission until the primary cell current returns to the value it had before transmission was attempted.

To this end, 10 trial runs were performed (detailed results in Appendix G), measuring the average current and time till the LIC has been recharged (supply from battery below 500uA). It was found that the average energy usage associated with a successful data transmission is in the order of 1.49mAh (for the 3.6V a *Li-SOCl₂* cells used) as calculated in Equation 10.1.

$$\begin{aligned}
 C_{\text{transfer}} &= C_{\text{success}} + C_{\text{fail}} \cdot P_{\text{fail}} + C_{\text{fail}} \cdot P_{\text{fail}}^2 + C_{\text{fail}} \cdot P_{\text{fail}}^3 + \dots & (10.1) \\
 &= 1.245 + 0.457 \times 0.35 + 0.457 \times 0.35^2 + 0.457 \times 0.35^3 + \dots \\
 &= 1.491[\text{mAh}]
 \end{aligned}$$

10.4 Projected Lifetime

From these figures we may extrapolate a rough estimate of the collar's expected lifetime. As the GPS constitutes the largest load (as can be seen in Table 7.4), let us first examine its

effect on battery life.

The GPS constitutes an average current of 2.46mA, as seen in Table 10.2. Assuming that the GPS is activated for 16 hours per day and attempts a log every 30 minutes (as specified in Section 9.5), the total consumption is then 43.04mAh (39.36mAh whilst GPS is activated and 3.68mAh in sleep mode). In this scheme 32 logs would thus be generated every day (assuming each attempt is successful; Iridium subsystem power usage would decrease with failure in GPS log acquisitions).

With the Iridium data payload of 256 bytes and 32 bytes typically representing 8 logs (7 logs for every 64th log), an Iridium upload would thus be required approximately every second day. From the average power usage of 1.49mAh, as shown in Subsection 10.3.3, the contribution of the Iridium module would then be 0.75mAh per day.

This results in a total daily drain from the primary cell battery of 43.79mAh. In the best case scenario, such a collar would then last 194 days (8.5Ah cell capacity).

The capacity of the SI-2770 cell is however dependent on the current it is supplying. If one were to consider the situation where only the MCU is powered in sleep mode, the expected capacity of this cell falls from 8.5Ah to 8Ah (as depicted in the component's datasheet for the associated load current). In the case where the system continually provides 30mA, a capacity in the order of 5.8Ah would be expected. Whilst maximum currents even larger than this are sometimes present during Iridium transmission, the contribution of the Iridium subsystem to the total power usage is relatively minimal. We may thus use the current characteristics of the GPS subsystem to achieve a more realistic expectation.

As seen in Table 10.1, the average supply current to the GPS's power supply is 32mA. An expected primary cell capacity in the order of 5.8Ah is thus realistic. This results in a total expected collar lifetime of 132 days.

These calculations, however, do not take into account a voltage drop from the *Li-SOCl₂* cell. Whilst the voltage decay due to cell capacity depleting is minimal for *Li-SOCl₂* cells, high current draws do result in substantial voltage drops. The effect of this is, however, very difficult to predict due to the buffering effect of the LIC and the unknown long term performance of the LIC. Only extensive long term field testing would provide an accurate lifetime figure.

10.5 System Mass

The mass of a completed collar product is critical to the success thereof. Although a complete system had not been realised by the end of this study, an evaluation can be made of the design in relation to it.

As can be seen in Table 10.4 the total collar mass will likely be in the region of 346g. This makes the collar unsuited to most of the leopards in the GCBC, except for the larger adult males

Component	Mass [g]
Collar packaging	193
Tadiran SL-2770 battery	53
Taiyo Yuden 100F LIC	12
Sarantel SL3105SP Iridium antenna	29
Sarantel SL1203 GPS antenna	14
Iridium 9602 transceiver	30
Other electronics	15
Total	346

Table 10.4: *Collar system mass calculation.*

Further development of a lighter packaging solution could place the proposed design within the mass requirements for smaller leopards (280g for female). The mass of such a packaging solution would, however, need to be in the order of 30g (electronics being 150g) to be used on a male caracal (maximum 180g collar, as discussed in Section 5.3). This is likely to place the Iridium collar concept out of reach for the smaller animals.

10.6 Unresolved Issues

10.6.1 LiPo Charge Circuit

The success of the LiPo cell based buffer design was limited. The system did charge the LiPo cell and limited the current drawn from the primary battery. However, it did not correctly shut down the charging cycle and proceeded to overcharge the LiPo cell, rupturing it.

During testing of the charge circuit, it was observed that the cell had reached a voltage of 4.3V (above the charge cut-off voltage of 4.2V). The charge circuit did thus not stop charging when it should have. The exact cause of this failure is unknown. Because of the extreme fire hazard posed by overcharging LiPo cells, this problem was not further investigated.

10.6.2 Sleep Mode Induced UART Problems

It was found that using the manufacturer supplied drivers for sleep mode operation together with the driver for UART operation caused corruption and delays in transmitting data on the UART. This problem was avoided by implementing a simpler driver for the UART, but the exact cause of the malfunction is still unknown.

10.7 Comparison

Although a complete field deployable system was not realised, a number of the advantages a miniaturised and packaged system would possess are evident from the test performed.

10.7.1 Mass

Relative to other Iridium satellite based collars entering the market during the course of this study, this collar provides the lowest mass (when packaged as suggested in Chapter 8). Products available from Lotek (785g minimum), Sirtrack (660g minimum), Vectronic Aerospace (700g) and Advanced Telemetry Systems (825g) all fall above the maximum possible collar mass for leopards in the GCBC. A possible miniaturised and packaged version of the design suggested here should be in the order of 350g (as indicated in Table 10.4), providing a novel capability to the CLT.

The proposed system does not, however, compete with the VHF/UHF terrestrial collars supplied by Vectronic Aerospace. The reduced mass of these make them usable on the smaller female leopards.

10.7.2 Functionality

Relative to the current collars provided to the CLT by Vectronic Aerospace, the proposed system provides a number of functional advantages.

The addition of sudden acceleration triggered coordinate logging provides a novel capability for identifying hunting sites.

Leopards may be tracked from any location where an internet connection is available. This provides a major improvement on the difficulty tracking of leopards via the ‘ping’ VHF component of their collars and the subsequent downloading of data (often unreliable) via short range UHF link.

The system provides functionality similar to that of commercially available Iridium based collar products in terms of communications.

10.7.3 Cost

One of the initial goals of this project was to provide a more cost effective way for researchers to conduct their studies. The purchasing price and operational costs of a collar are thus of great importance. Although such a comparison does not take into development and other incidental costs, it does reflect this project as an option to the CLT relative to other commercial products.

The operational cost of using the Iridium satellite network is approximately (depending of service provider) US\$35 per month. This will be the similar to using an Iridium based solution from another manufacturer. The existing terrestrial radio links used to download

data from collars do not entail any monthly cost, but the terminals used for this also need to be purchased. As for the cost of the collar itself, a projected cost in the region of R15700 is calculated in Table 10.5. This is a factor 2-3 times cheaper (depending on exchange rates) than those supplied by Vectronic Aerospace making use of VHF/UHF communications. With the collar packaging constituting two thirds of the total system cost, an alternative design for this would result in a much more affordable collar product.

Component	Cost [ZAR]
Iridium 9602 transceiver	3200
PCB	250
Sarantel SL1203 GPS antenna	380
Sarantel SL3105SP Iridum antenna	520
Taiyo Yuden 100F LIC	380
Packaging	10000
u-blox NEO-6G GPS module	300
Tadiran SI-2770 battery	170
Other electronic components	500
Total	15700

Table 10.5: *Tracking collar cost breakdown.*

10.7.4 Durability

No moving parts are present in the collar electronics design, it is thus believed that this would not pose a problem to the durability of the collar.

As no functional prototype of the collar packaging was ever constructed, proper evaluation of this requirement is not possible. Due to the extremely high strength and abrasion resistance of the materials specified it is, however, expected that the design would be sufficiently effective.

10.7.5 Lifetime

A lifetime of 132 days as calculated in Section 10.4, with GPS scheduling as specified in Section 9.5, will result in a total of 4256 GPS log attempts. This projected lifetime is similar to those of the current Vectronic Aerospace VHF communication based collars (excluding those that fail prematurely and with allowance for variance in the order of a month). Though a lifetime of 6 months is not expected with the current configuration, it should be possible to decrease the GPS log frequency to provide this.

Relative to other Iridium based satellite collars, the lifetime is much more restricted (Lotek IridiumTrackM 2D, 785g, 1 year with a GPS log every 45 minutes and Vectronic

Aerospace GPS Plus 2D, 800g, 11500 GPS logs). The mass of these systems, however, places them well outside the scope of use by the CLT.

10.8 Conclusion

In this section we listed all the units developed during the course of this study, together with their individual successes and failures. Whilst all designs up to the development of the fourth Iridium based collar lacked critical functionality, the final prototype requires only miniaturisation. Evaluation of the power supplies, GPS and Iridium performance were provided. Whilst the Iridium power supply still exhibits excessive noise, the system is operational and results from the other power supplies look promising. The accuracy of the GPS subsystem is somewhat worse than expected, but within reasonable limits. Performance of Iridium transmissions makes it suitable for the required task. A projected collar lifetime of 132 days was calculated, falling below the desired lifetime. This lifetime does, however, still compare favourably with that of commercially available collars. The system mass is also above the desired figure, making it suitable for male leopards only. A collar with these capabilities, mass and size, is a novel addition to the market. Whilst a couple of unresolved issues still remain, these were bypassed or mitigated in the final product design. Finally it was found that the proposed system compares favourably to existing commercial products.

Chapter 11

Conclusion and Future Work

11.1 Discussion of Results and Summary

11.1.1 Trap Telemetry System

A telemetry system to monitor remote trap sites was required by researchers. This would free up time spent manually checking traps and resources (fuel and vehicle maintenance), allowing simultaneous monitoring of more trap sites in a wider geographical area.

The envisioned system would, in the event of a trap being triggered, notify the researcher and also provide a photo of the trap site so as to identify the cause of the trigger.

This was realised in the form of a controller unit, a solar panel with accompanying charge regulator, a camera unit with flash, an Iridium module and battery. A reed switch provided reliable sensing of the trap state. Care was taken to design the electronics for reliability. This was implemented through extensive use of TVS diodes and controller unit initiated power cycling of all peripheral components. The unit was also packaged in a waterproof casing.

Reliable operation of the controller unit was further assured through the use of a watchdog timer and timeouts for peripheral component operations. Software to be used on the researcher's personal computer further aided reliability. The system would raise an alert if the field unit had not transmitted its state information (which it does at a regular interval) within the expected timeframe. This software also allows for viewing of transmitted photos in the event that the trap is triggered.

With the deployment of the cage telemetry system during November 2011 and March 2012, it was tested under real world conditions, in its intended deployment mode. Whilst some deficiencies were identified in the system design, notably insufficient photo resolution and high visibility, it reliably provided the critical functionality required. The deployment of this system provides a capability not previously afforded to researchers and use thereof should continue for a number of years.

11.1.2 Collar System

Development of a new collar system was necessitated by the shortcomings of commercial systems available to the CLT. The VHF/UHF radio communications based products they had previously been using often proved unreliable and lacked needed functionality (such as unattended data downloading). To this end, alternate tracking concepts were explored.

The first of these concepts relied on terrestrial radio links to communicate with collars fitted to the leopards. A number of operating concepts around such a system were investigated. Such a system would make use of the GPS satellite constellation to determine location. A wireless communications interface would also be provided to retrieve logged coordinate data from the collar. Field terminals that performed opportunistic downloads from passing collars were envisioned, with three alternate methods of data backhaul (flash memory cards, ad-hoc radio network and Iridium satellite).

An initial study was made identifying a suitable frequency band and the requisite hardware to implement a terrestrial radio communications link. 151.3 MHz was selected after taking into account propagation simulations, regulatory influences and readily available radio modems.

Use of the Iridium satellite constellation to facilitate direct data uploads from the collar became a reality with the release of new, compact transceiver modules during 2010. From this point the initial VHF based designs were abandoned and all focus shifted to a collar incorporating the Iridium 9602 module.

In order to realise a hardware design for the collar system, it was divided into a number of logical subsystems. For each, available methods of implementation were explored and the apparent best chosen. These designs were then refined, taking into account the interaction between systems.

Another component of the collar design was the physical packaging. Mechanical wear on existing commercial collars has in the past often led to their premature failure. To this end UHMWPE was selected as the collar material for its extreme abrasion resistance and lightweight strength. A design consisting of 2 pieces of milled UHMWPE was modelled and awaits manufacture.

Embedded firmware development for the collar centred on minimising power usage and ensuring reliable operation. Various strategies were employed to minimise power consumption, including the use of low power sleep modes for the microprocessor and disabling of any circuitry not actively being used. A compression scheme for logged coordinate data was also implemented in order to minimise both storage usage and the amount of data that would need to be transmitted via the Iridium network. Reliable operation was strengthened by use of a watchdog timer and timeouts for communications with peripheral components. Software was also developed for use by researchers on their personal computers. This software allows management of multiple collar data sources, the export of the data in CSV and KML formats as well as facilitating viewing in GIS packages such as Google Earth.

In testing the performance of the final, pre-miniaturisation collar prototype produced was promising. Through measurement and extrapolation it is believed that the collar would remain operational for 132 days. In the default configuration, coordinate logging would be attempted every 30 minutes during a 16 hour daily window. The calculated mass of a complete collar solution did place it above the requirement for smaller leopards and it would only be usable on larger specimens. Ultimately, whilst the system did not reach all the objectives initially identified, it would provide novel capability not previously afforded to researchers of the CLT, in production format.

11.2 Summary of Technological Extensions

A number of contributions to the field of animal tracking have been made by this project, namely:

- Development of globally deployable telemetry reporting system with imaging capabilities.
- Design of a high efficiency, low noise power supply, capable of supplying large burst currents whilst minimising average current drawn from the battery supplying it.
- Construction of a collar electronics prototype providing VHF radio communications to a ad-hoc wireless network.
- Construction and testing of a Iridium satellite connected collar prototype.
- Design of a collar packaging solution with high resilience to physical abuse.
- Proposal for a manufacturable collar system providing capabilities outside of solutions commercially available, for use on smaller animals (smaller mass than commercial alternatives).

11.3 Future Work

11.3.1 Collar Packaging

At the time this report was submitted, the physical collar design had not been manufactured.

The expected cost of machining a block of UHMWPE into the collar form is expected to cost in the order of R10 000 (by the Rapid Product Development Institute of the industrial engineering faculty at Stellenbosch University), with material costs in the order of R1000 (supplied by Gartech Equipment CC). This puts the costs associated with producing a collar outside the budgetary possibilities for the project.

An alternative collar construction making use of rubber coated nylon belting material (used in industrial conveyor belt systems) should be investigated. Production techniques other than CNC milling could also be used.

11.3.2 Collar Power Supply

With the lifetime of the collar greatly influenced by the efficiency of its power supply components, further improvement in this area is warranted.

The development of a switch-mode only power supply for the GPS module could constitute a major reduction in GPS power usage.

Continued advances in the fields of electric double-layer capacitors, lithium-ion capacitors, battery capacity and energy harvesting solutions merit constant improvements on the design offered in this report.

11.3.3 Revert to Terrestrial Communications Infrastructure

Whilst Iridium satellite connected collars and trap telemetry systems provide a convenient communications platform, it does however have its shortcomings. The high power usage and costs associated with operating them justifies the continued development of the VHF ad-hoc network platform.

The use of UHF data radios for transfer of logged data from collars may also be feasible. The decreased range could be offset by placing terminals near paths known to be frequented by leopards. This could result in a reduction in power usage and thus an increase in collar lifetime.

11.3.4 Expansion to Other Species

Expansion of the tracking collar project to support other species is very feasible and sought after. Interest has been shown in a tracking collar for use on caracal and jackal to support current research collaborators. The need for lower cost collars for use in national game parks has also been identified via communication with parties involved.

11.3.5 Diversification of Feature Sets

Whilst the Iridium connected collar does provide a number of unique features, its mass makes it usable only on very large male leopards.

Conversely, a VHF based collar limits the area in which it can be used to the range of the ad-hoc wireless network.

The development of a range of collaring solutions is thus required to address the problems faced. These would include both VHF and Iridium connected collars, as well as perhaps collars with no external communications interface, for use on caracal and jackal.

11.3.6 Additional Collar Features

Whilst this project focused on the core functionality required for research purposes, a number of additional features have been envisioned. These include:

- Activity monitoring via the accelerometer.
- Temperature monitoring.
- Strobe lighting to aid in locating the animal.
- Audible alarm to aid behavioural training.

11.3.7 Delayed Batch Coordinate Processing Reverse Engineering

As discussed in Subsection 5.5.6, the use of delayed batch coordinate processing was abandoned due to an inability to source the required hardware. An evaluation module (u-blox EVK-CK) is, however, available at a cost of US\$ 199. It would perhaps be possible to reverse engineer such a evaluation module and reuse some of its components in a very low powered collar.

11.3.8 Coordinate Compression

Whilst the scheme for coordinate compression, described in Section 9.4 works, a more efficient system would reduce the amount of data required for transmission via the Iridium network.

Possible areas of further study include:

- Use of the zlib compression library (making use of the DEFLATE compression algorithm), as it is suited to this task because of its low resource usage (little RAM and weak CPU available on the collar).
- Rather than storing absolute coordinates, a scheme where difference (delta) between the last known location and current location is stored.

11.3.9 Trap Telemetry System

After deployment of the trap telemetry system, a number of possible improvements were identified.

With the majority of by-catch problems eliminated by the switch from cages to soft-catch snares, the necessity for photos of the captured animal is questionable. A future system could exclude this capability and perhaps have instead a mechanism to detect continued strain on the trap mechanism.

Alternatively, the problems associated with insufficient resolution of photos may also be eliminated by using the ad-hoc network discussed in Chapter 6 and illustrated in Figure 5.3

to transfer images. With the prohibitive cost of sending large volumes of data over the Iridium satellite network removed, file sizes may be increased and also the image resolution.

The system packaging could be coated in camouflage material prior to deployment.

In the event that the VHF ad-hoc network were to be deployed, a VHF connected version of the system could be developed in order to save on the subscription and airtime costs currently associated with the Iridium system.

11.3.10 Error Check Polynomial for Ad-hoc Wireless Network

The CRC-16 polynomial selected for use selected[1] is shown to not be optimal[7] for the block size used in the VHF ad-hoc network. The implementation used is, however, very fast, consuming little of the CPU resources.

A polynomial of 0xAC9A could possibly be a better choice[7]. The fastest known implementation of this polynomial, however, is by making use of a lookup table. If memory requirements allow, the use of the 0xAC9A polynomial implemented via the use of a lookup table could replace the CRC-16 polynomial currently in use.

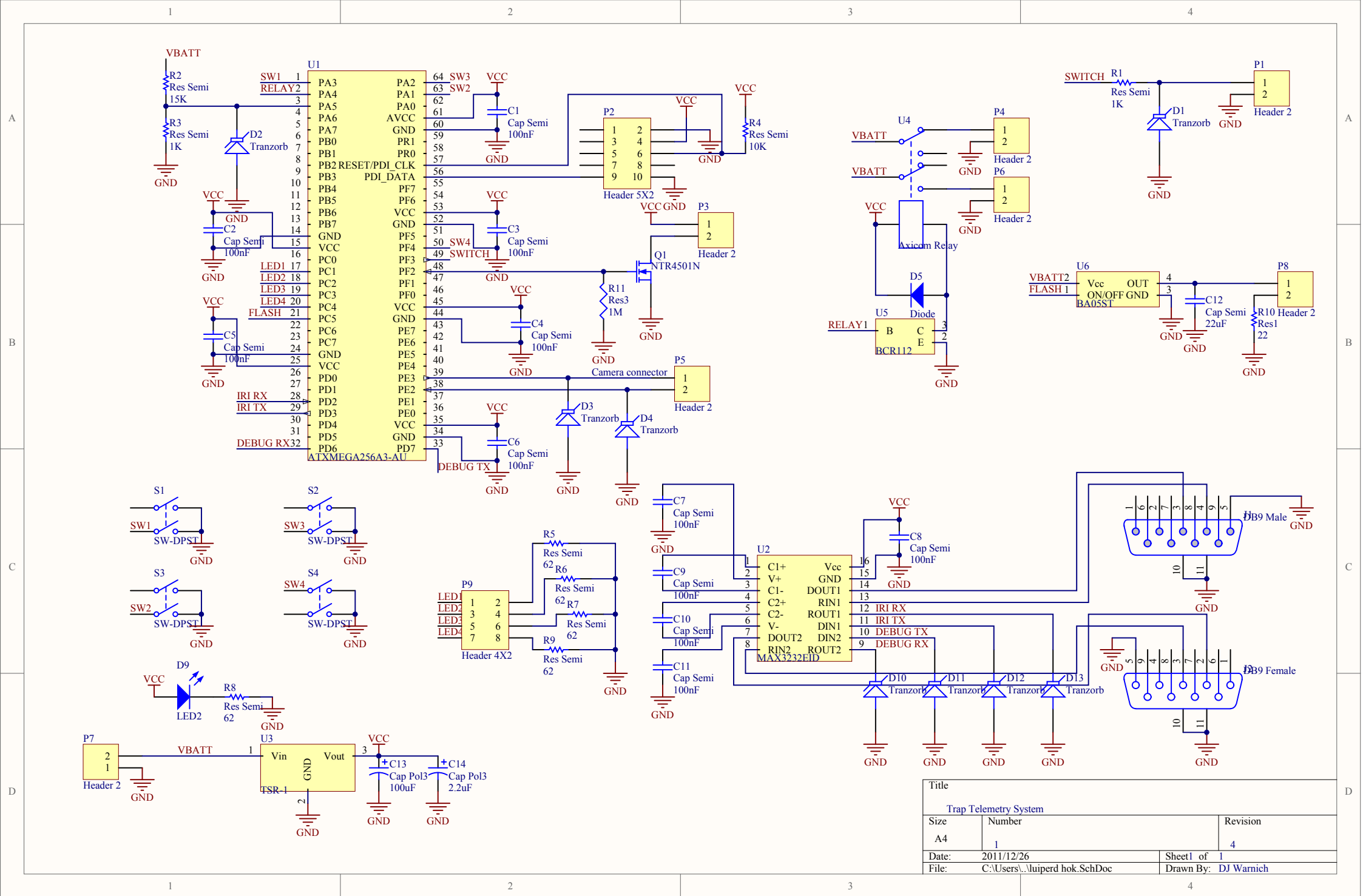
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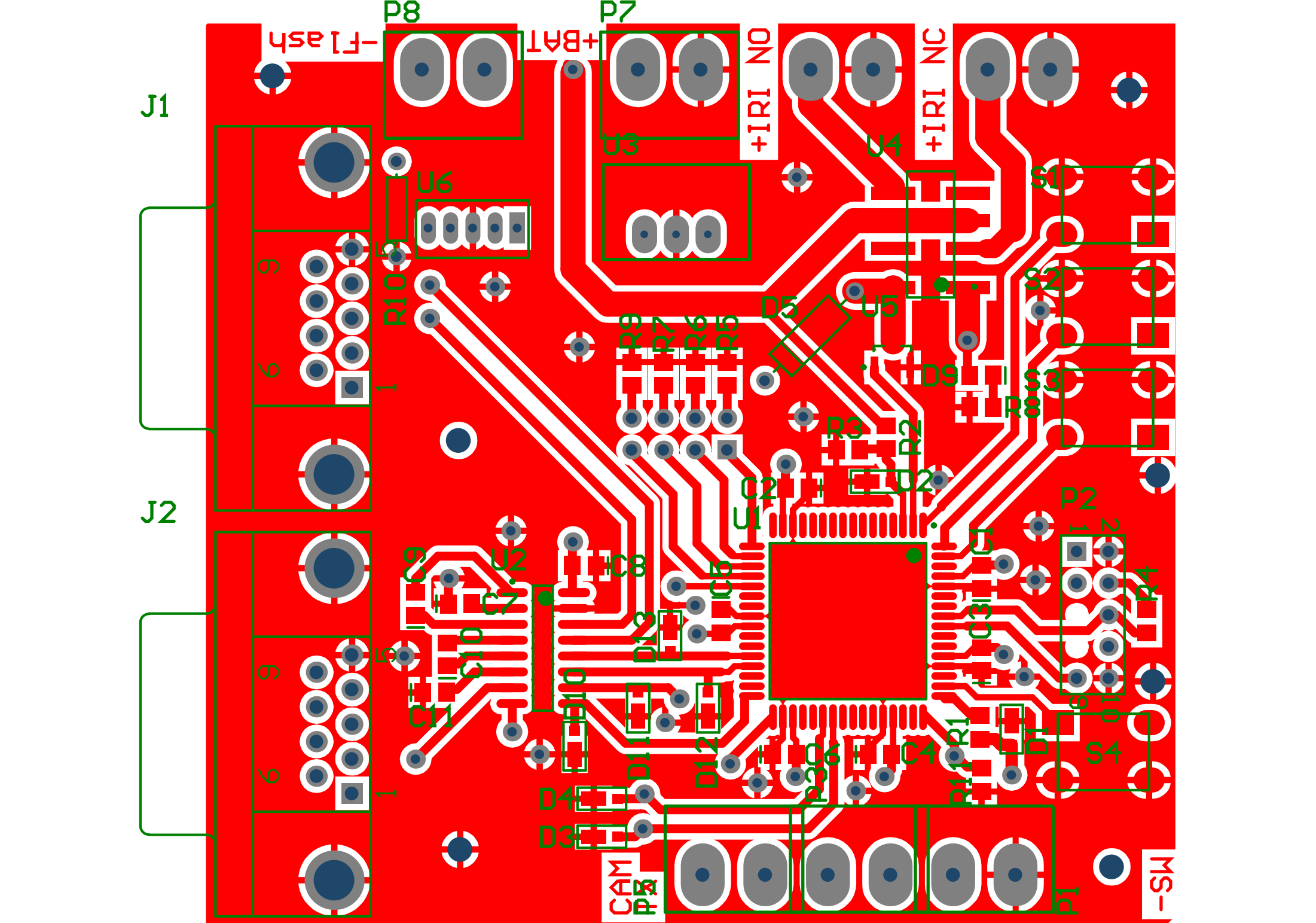
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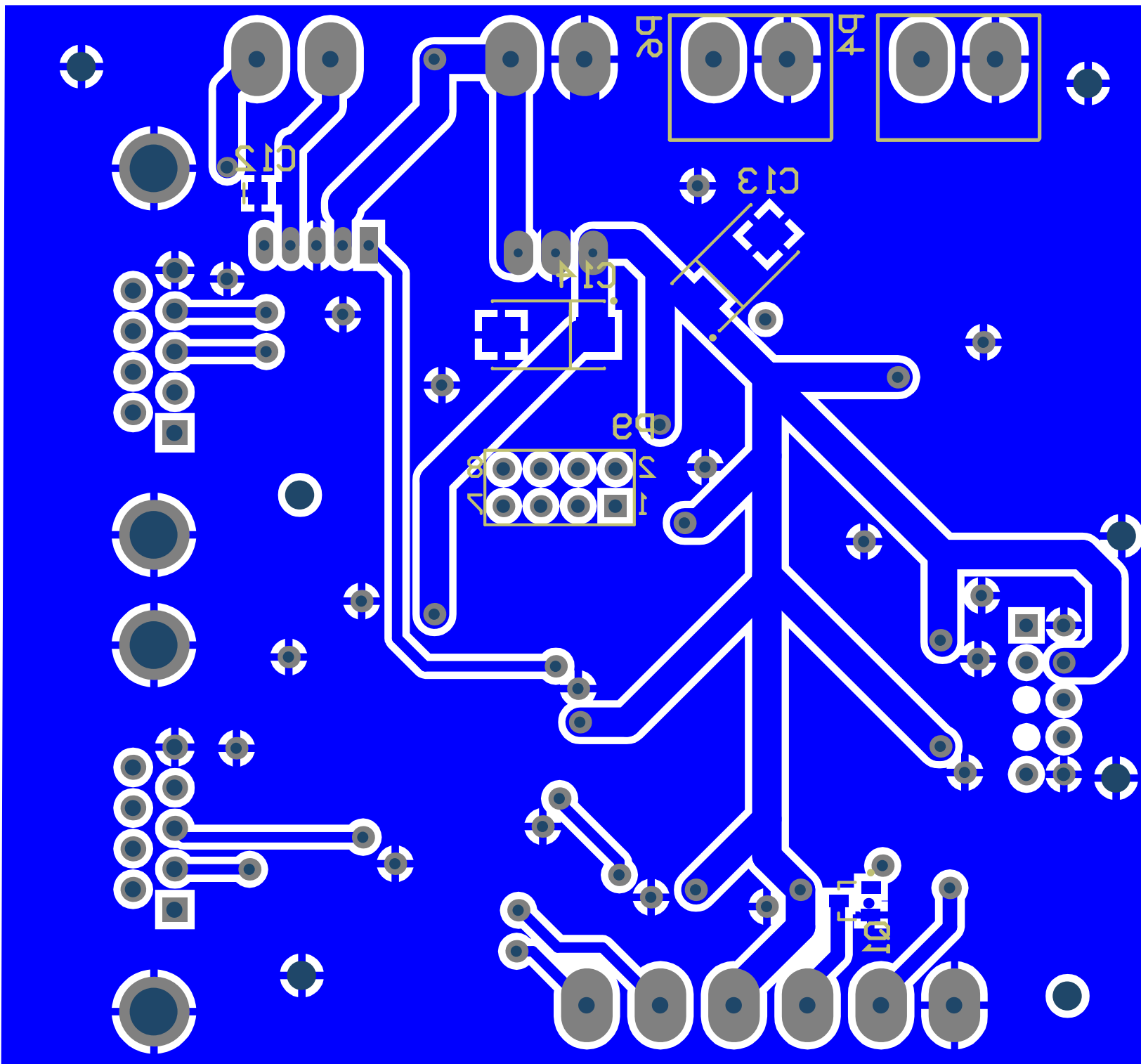
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Appendix A: Trap Telemetry System Circuit Schematic and Board Layout

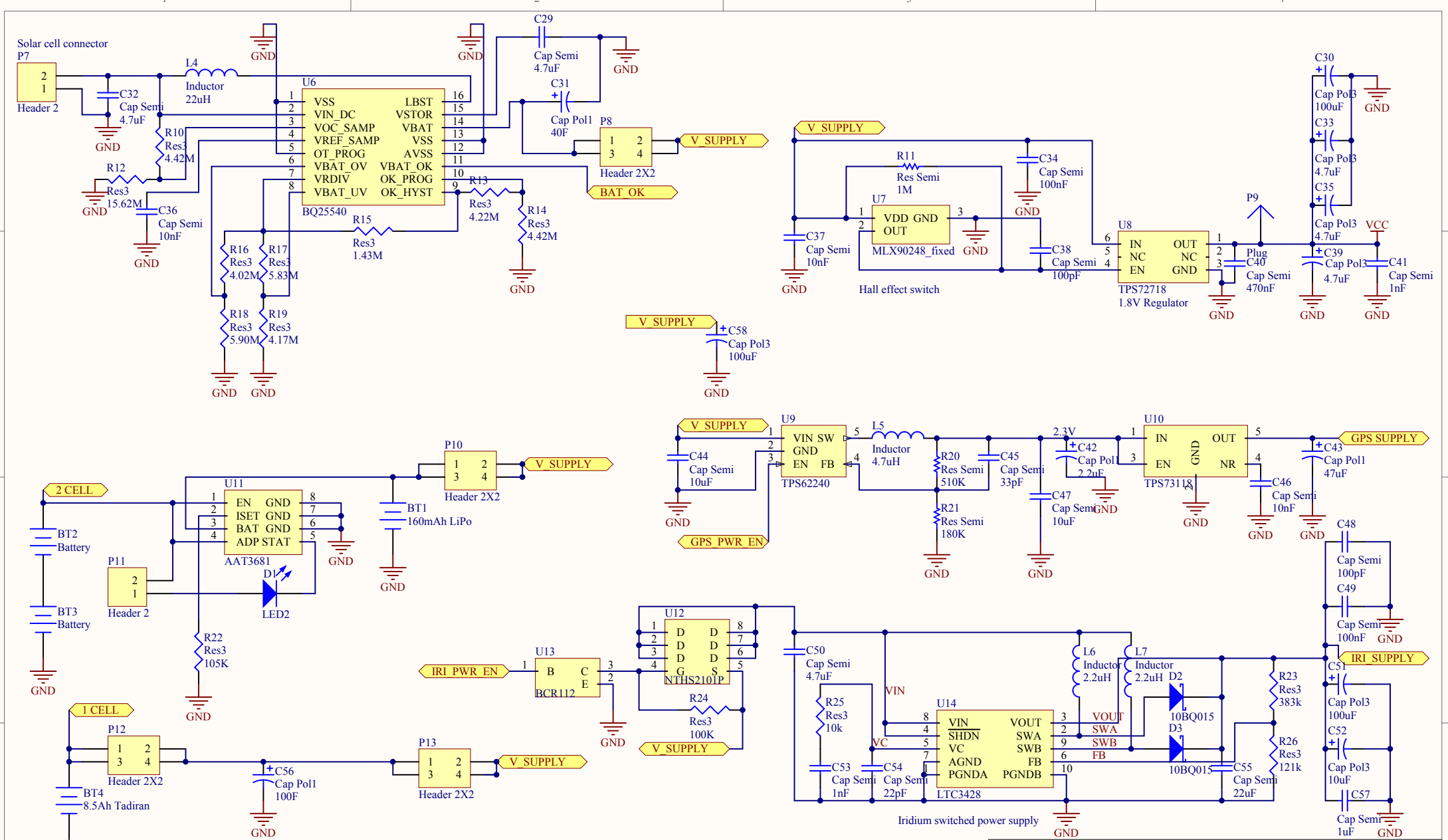


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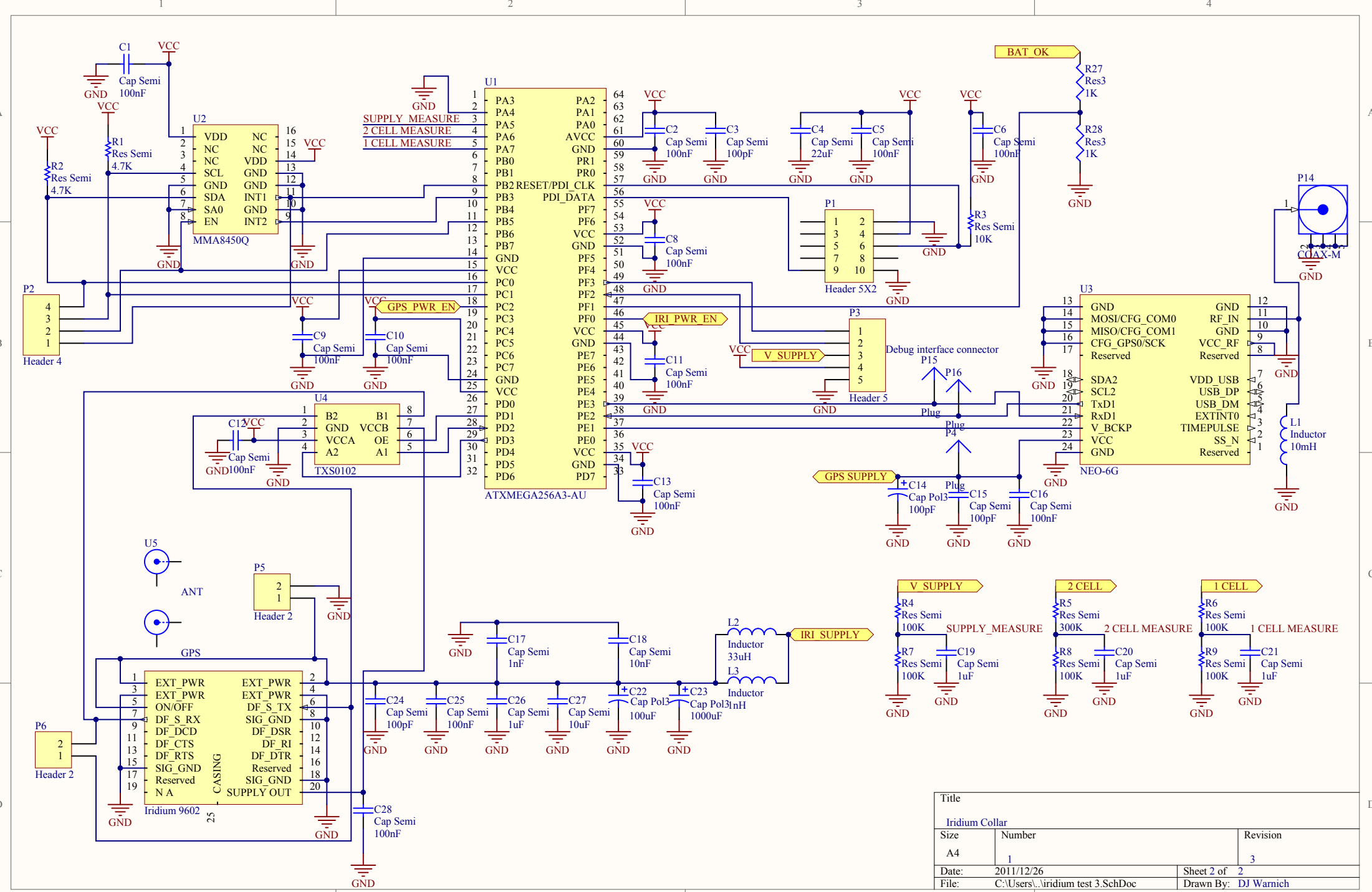




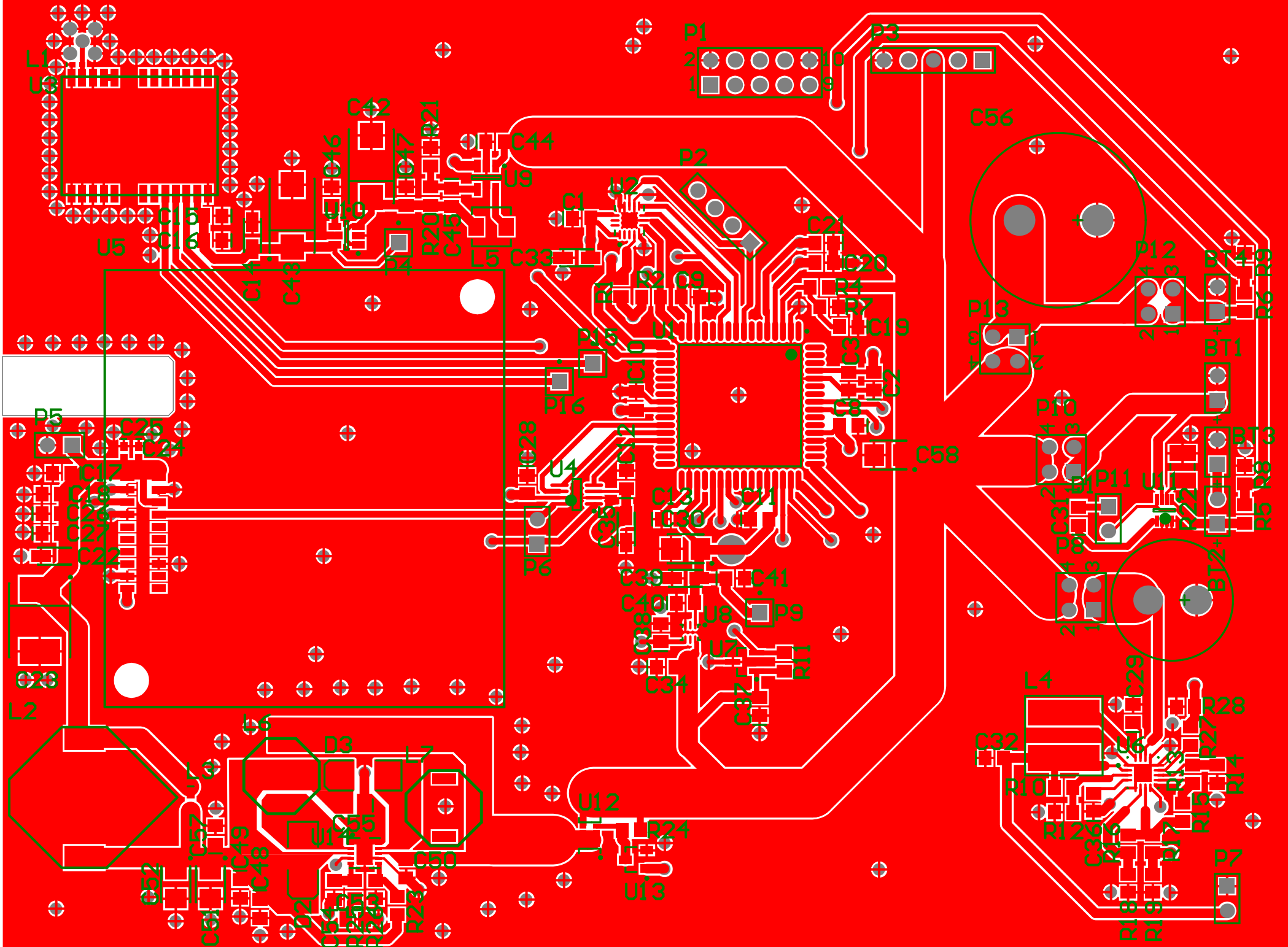
Appendix B: Collar Circuit Schematic and a Prototype Board Layout

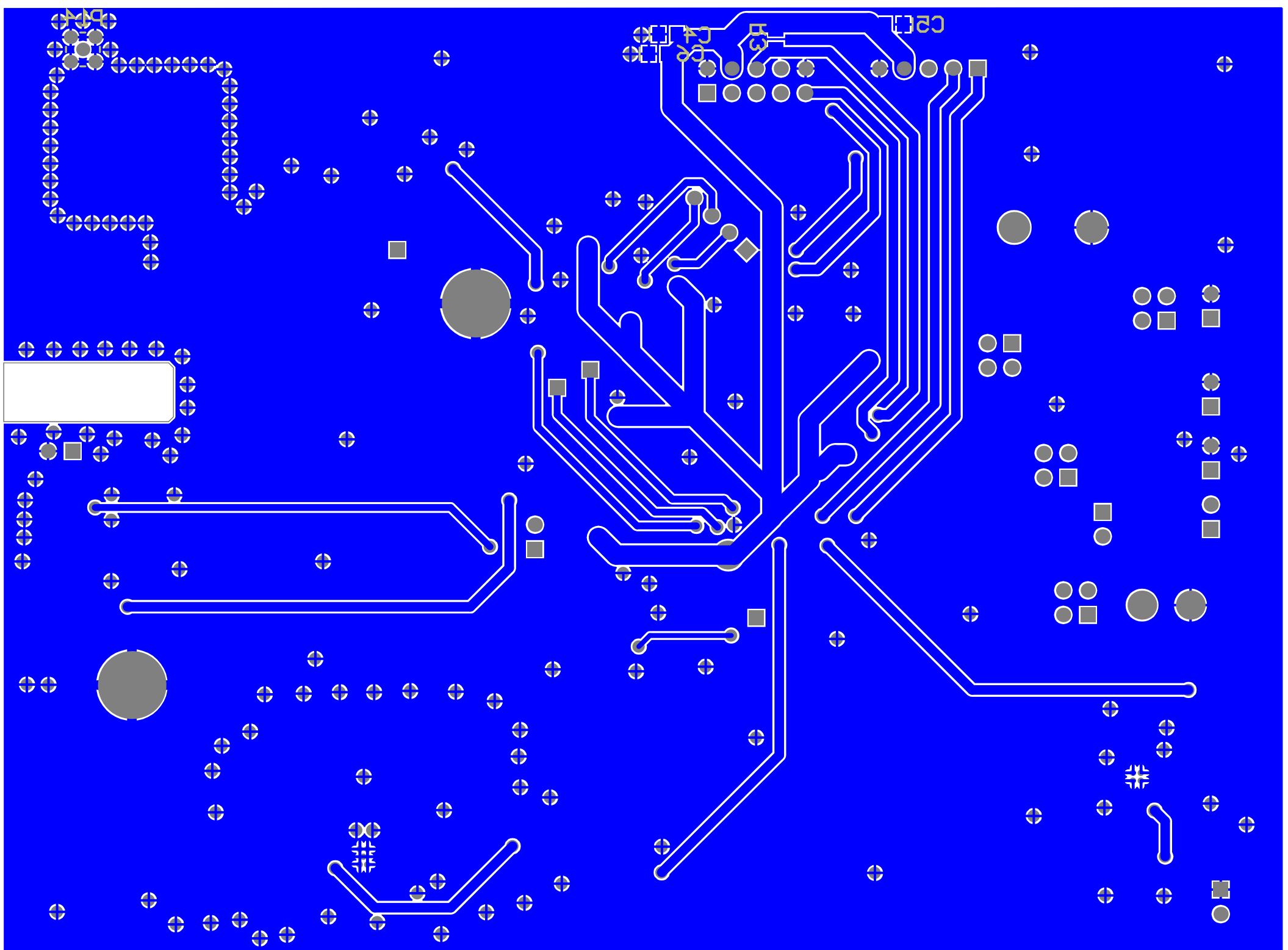


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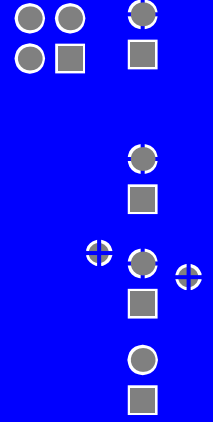
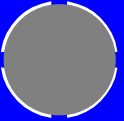
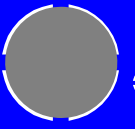


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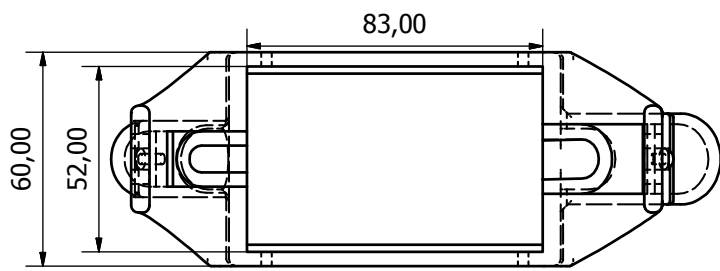
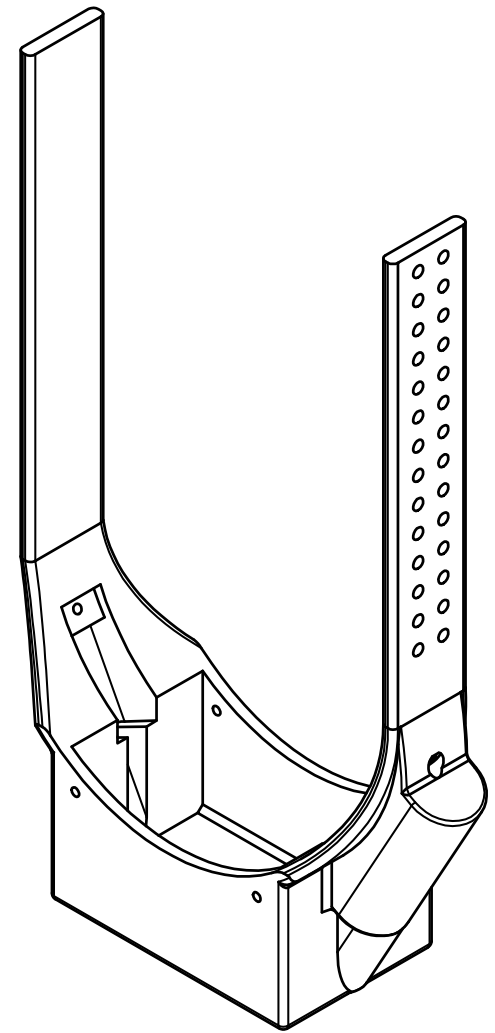
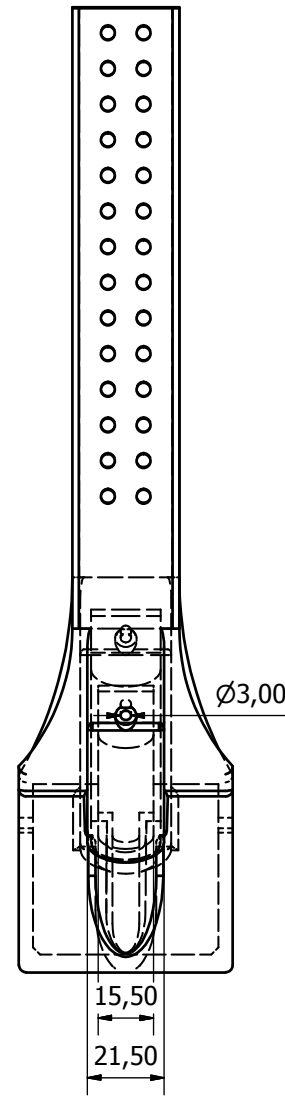
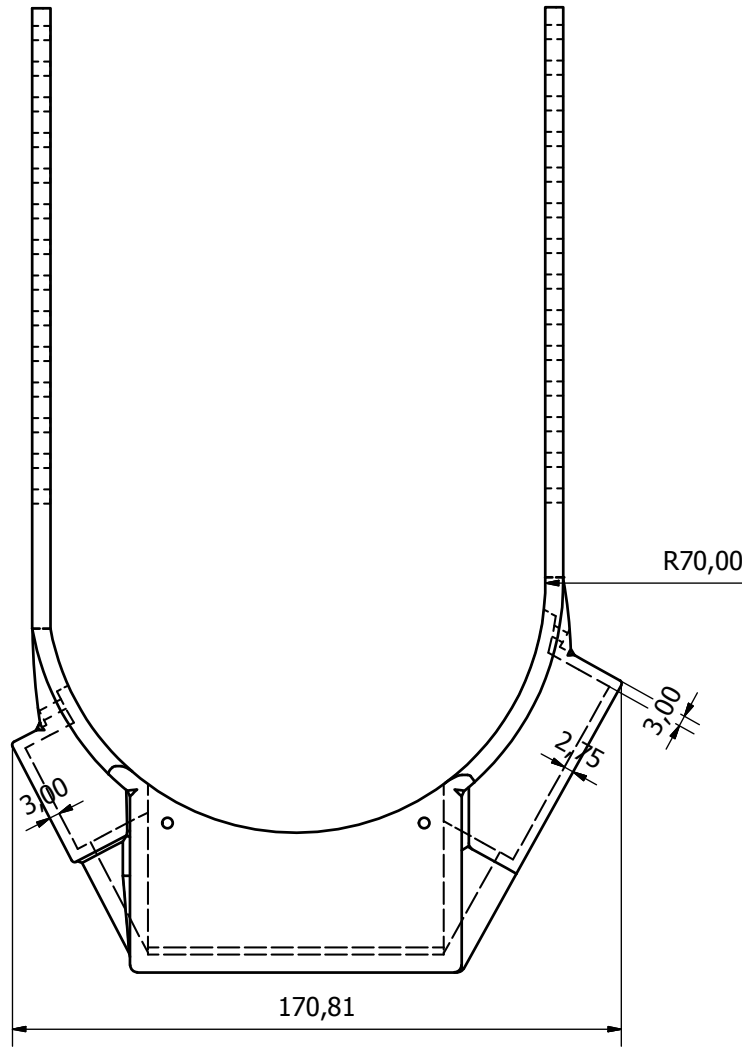
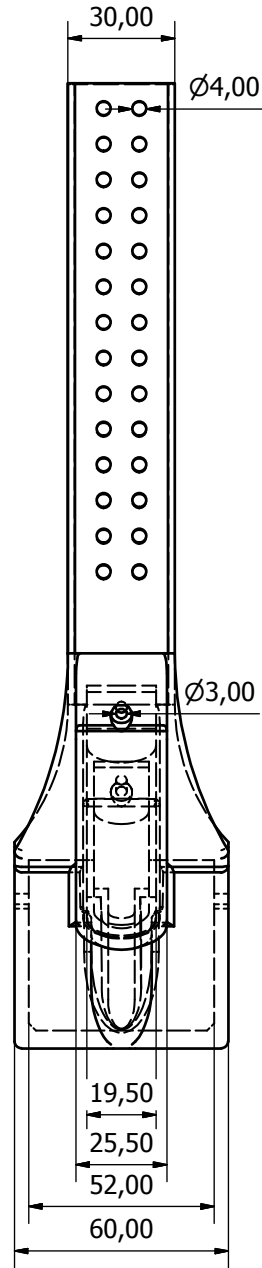
C2
F3
F4
F5



Appendix C: Collar Physical Design Drawings

6 5 4 3 2 1

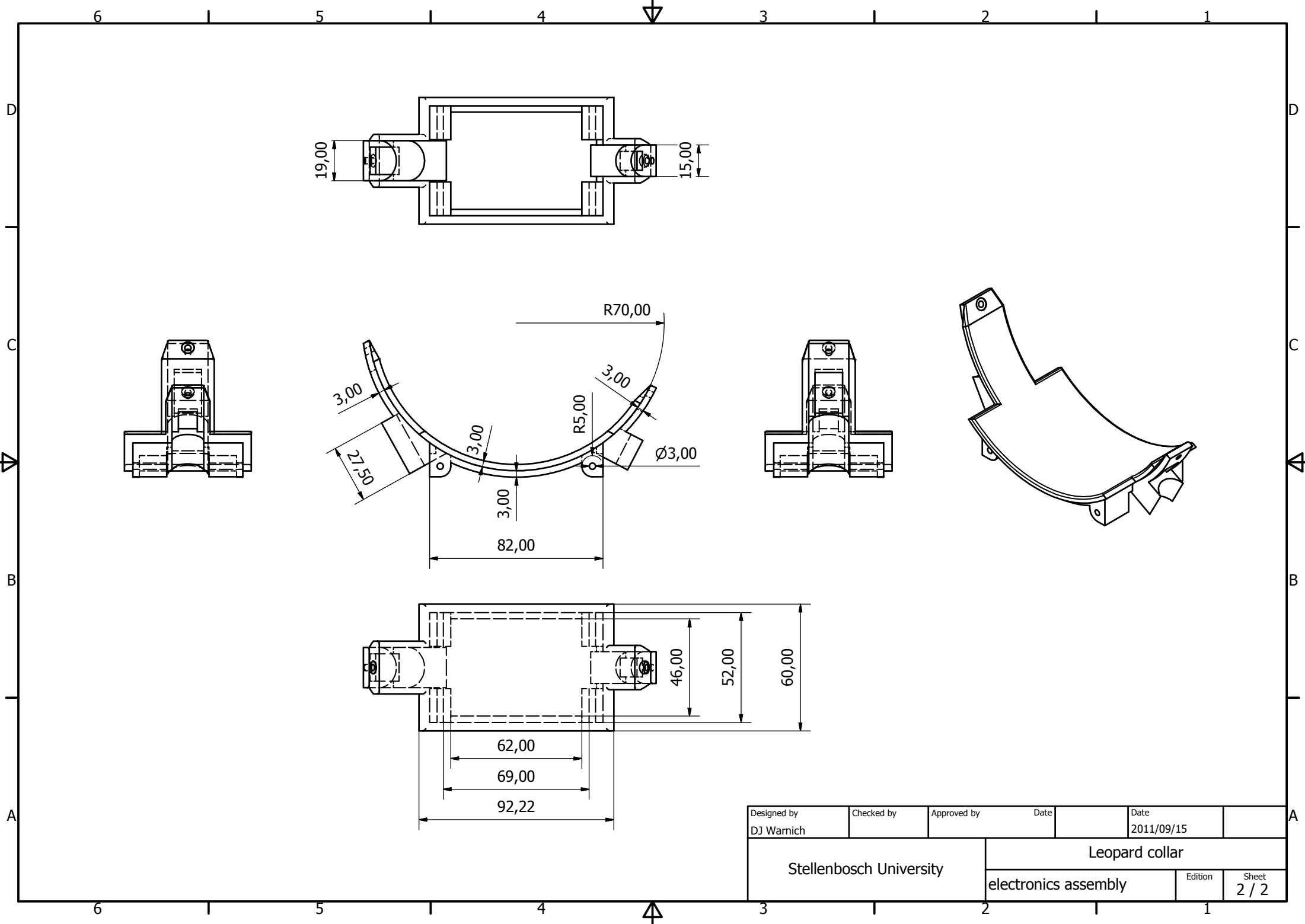
D
C
B
A



Designed by DJ Warnich	Checked by	Approved by	Date	Date 2011/09/15	
Stellenbosch University			Leopard collar		
			electronics assembly		Edition

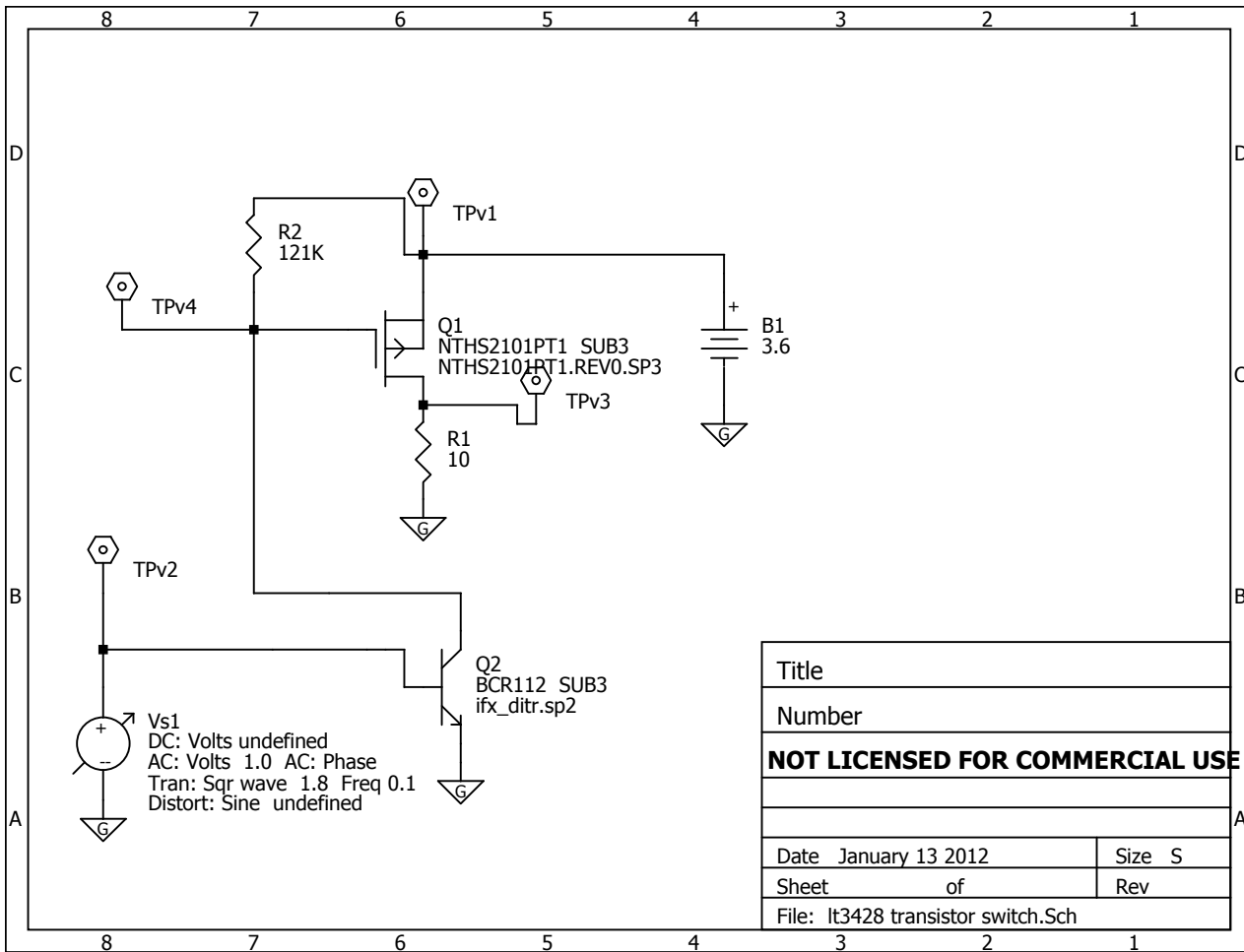
6 5 4 3 2 1

D
C
B
A



Designed by DJ Warnich	Checked by	Approved by	Date	Date 2011/09/15	
Stellenbosch University			Leopard collar		
			electronics assembly	Edition	Sheet 2 / 2

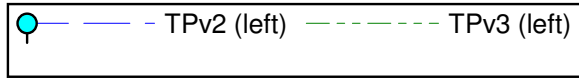
Appendix D: Spice Models



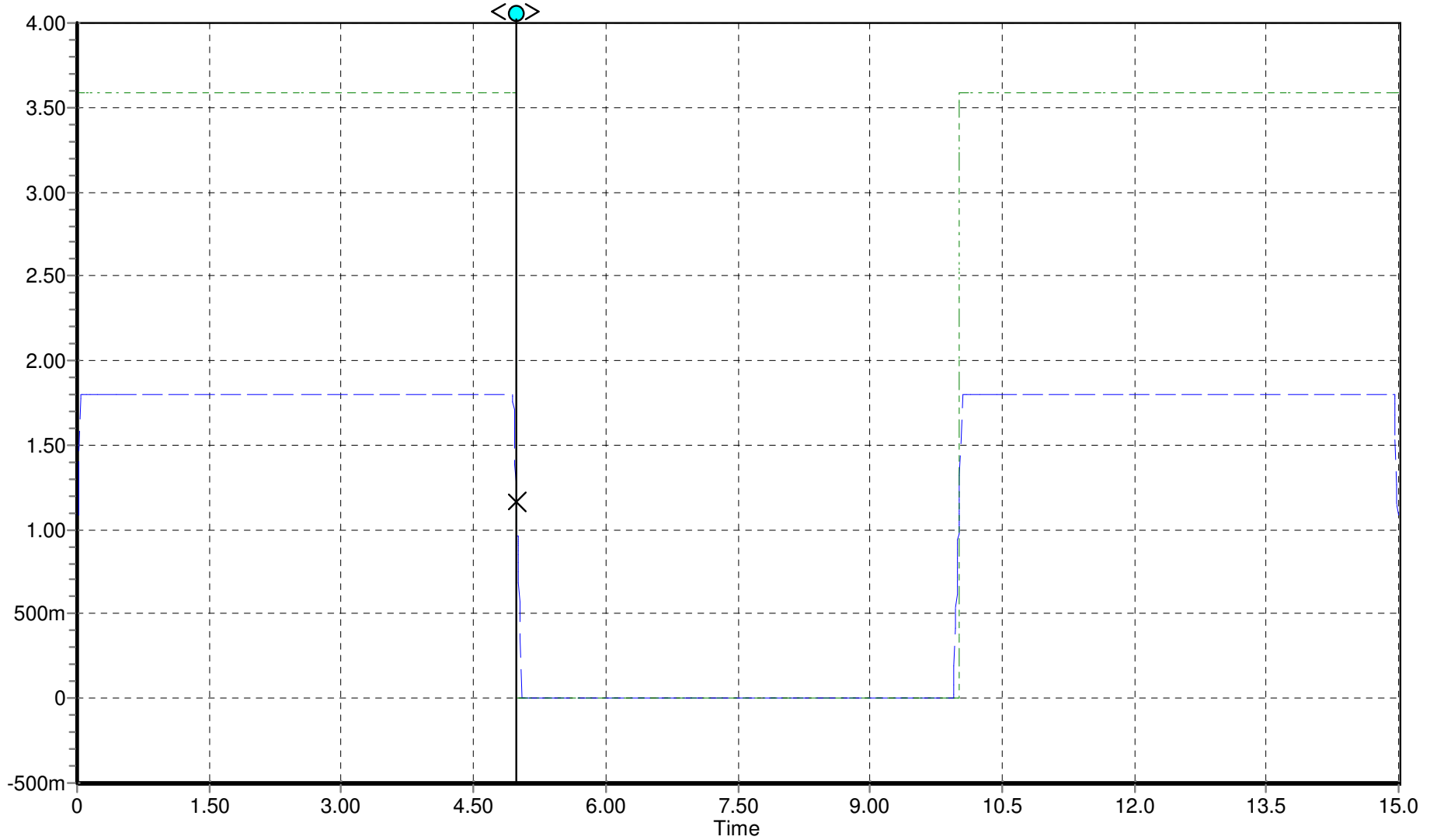
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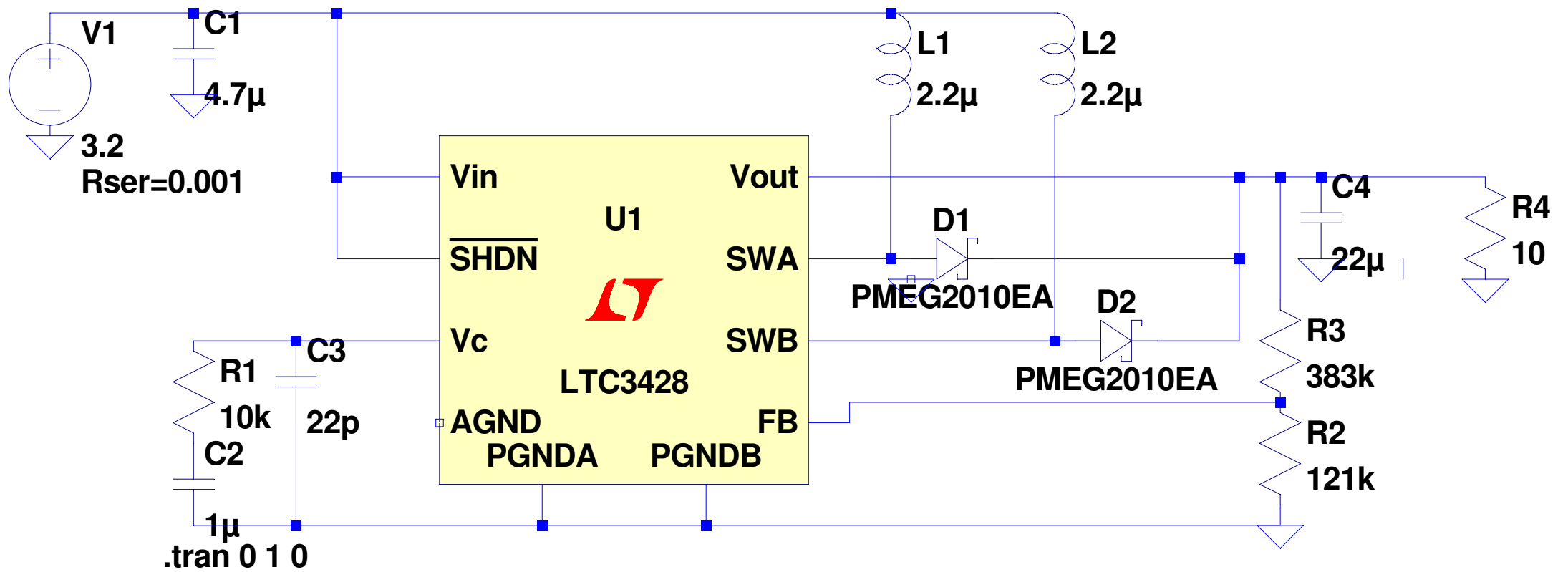
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Transient - New, It3428 transistor switch.Sch + It3428 transistor switch.Anl, 06 February 2012

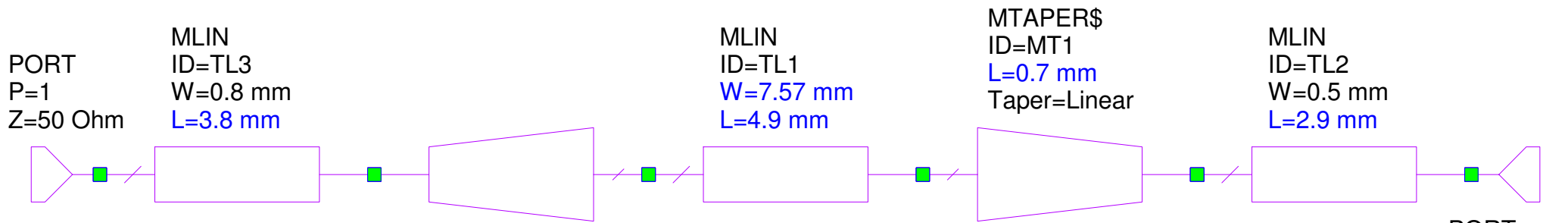


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x	4.98586E+0

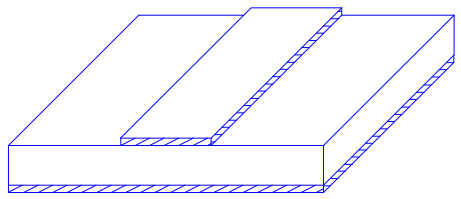


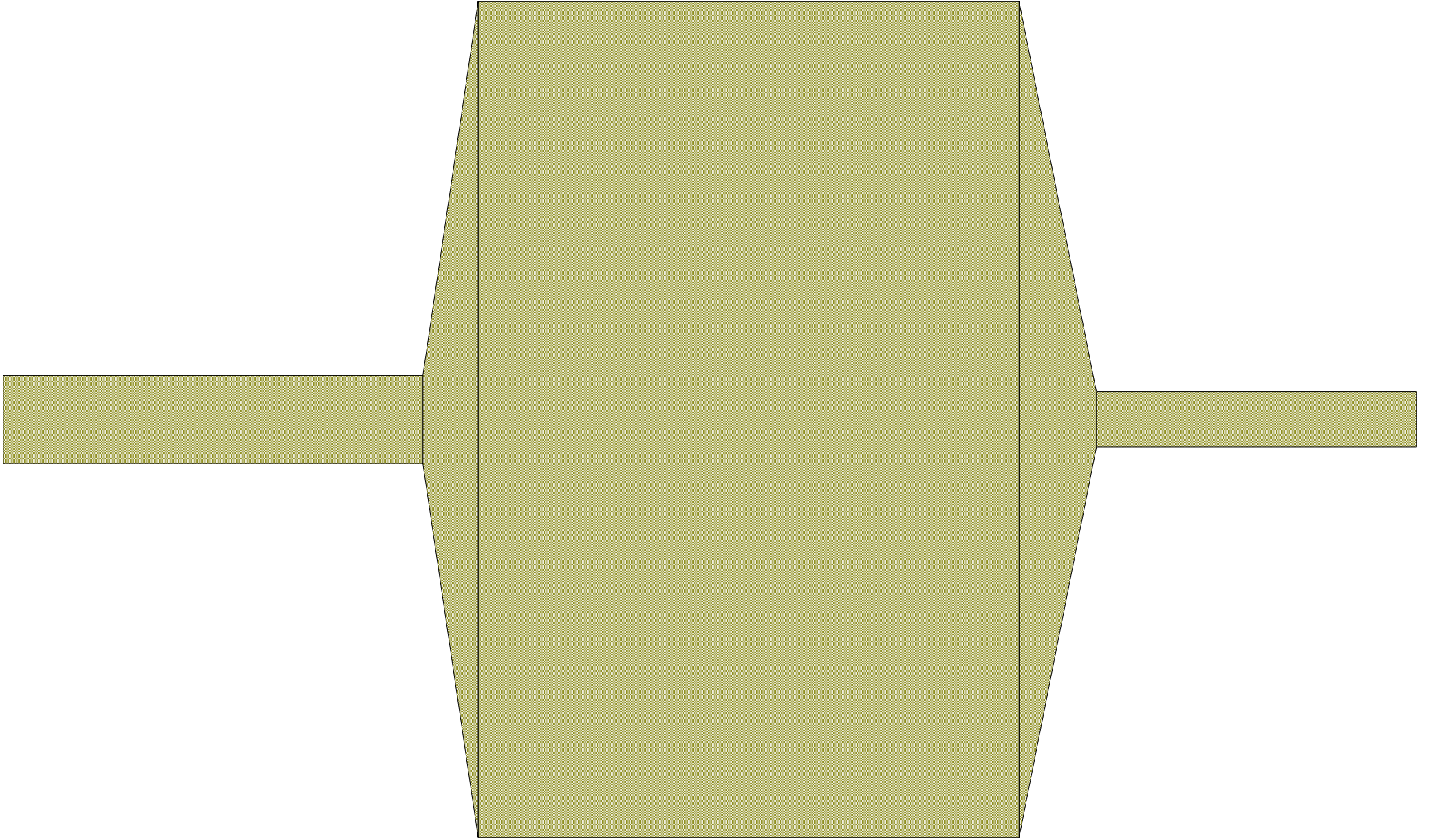


Appendix E: Impedance Matching Networks

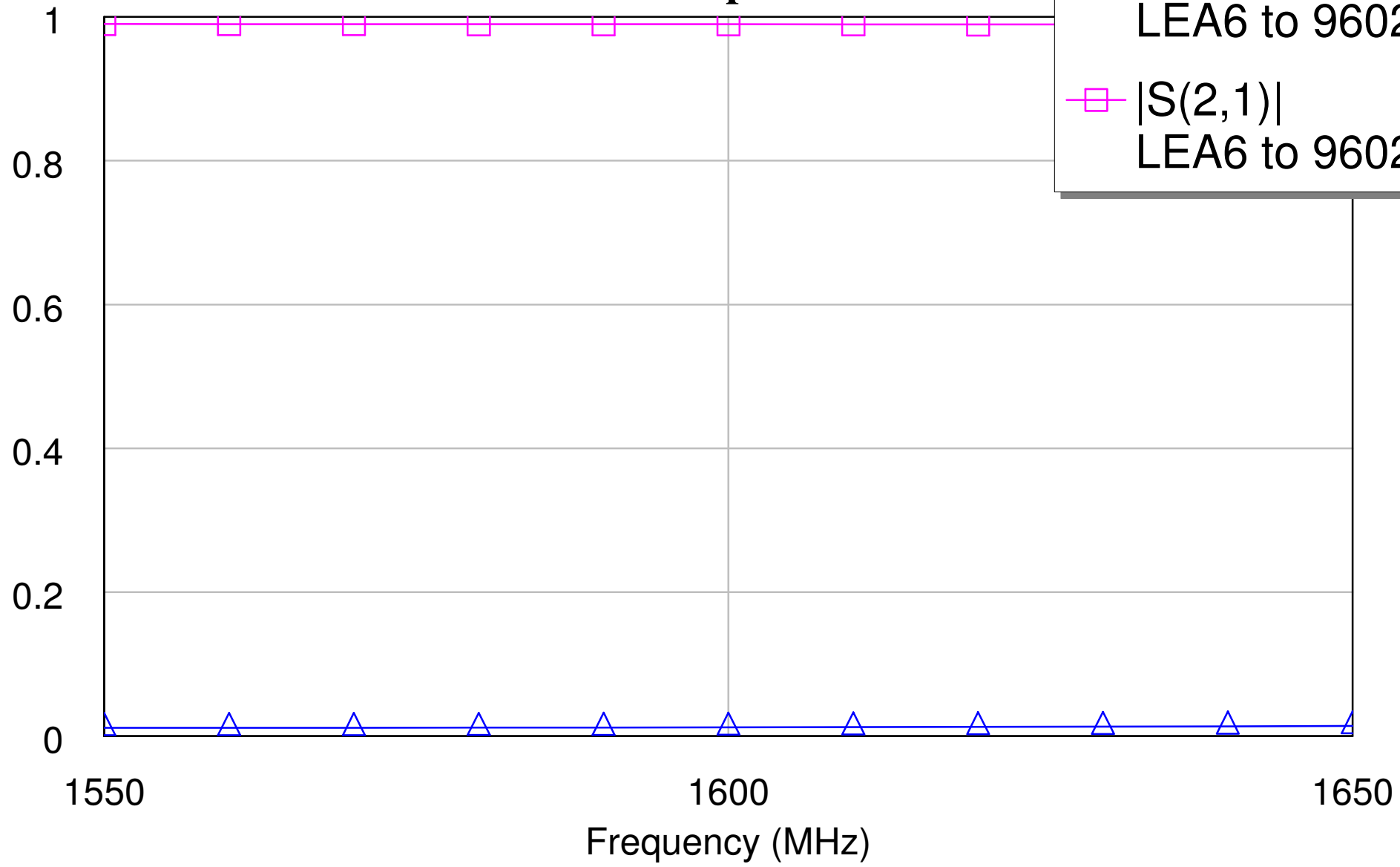
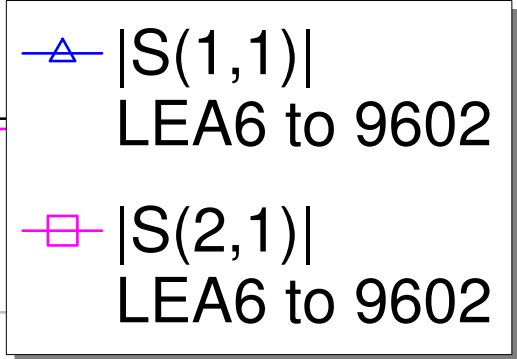


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 H=1.6 mm
 T=0.035 mm
 Rho=1
 Tand=0.02
 ErNom=3.38
 Name=SUB1

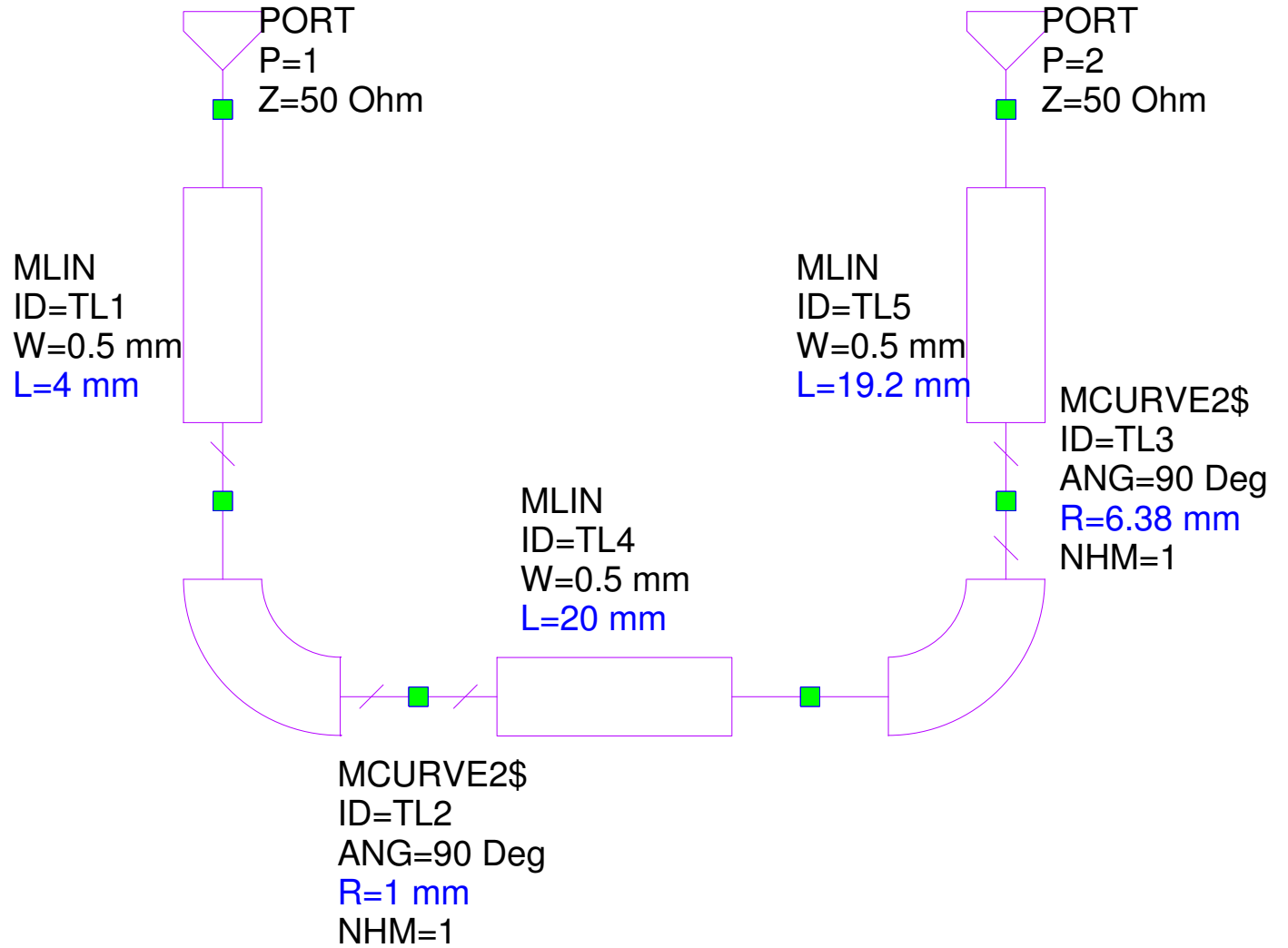
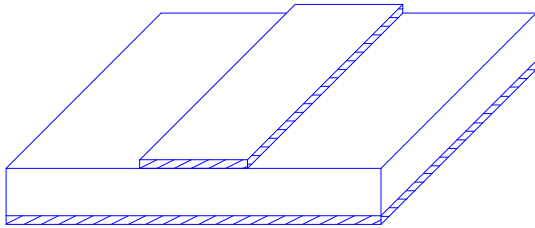




Graph 1



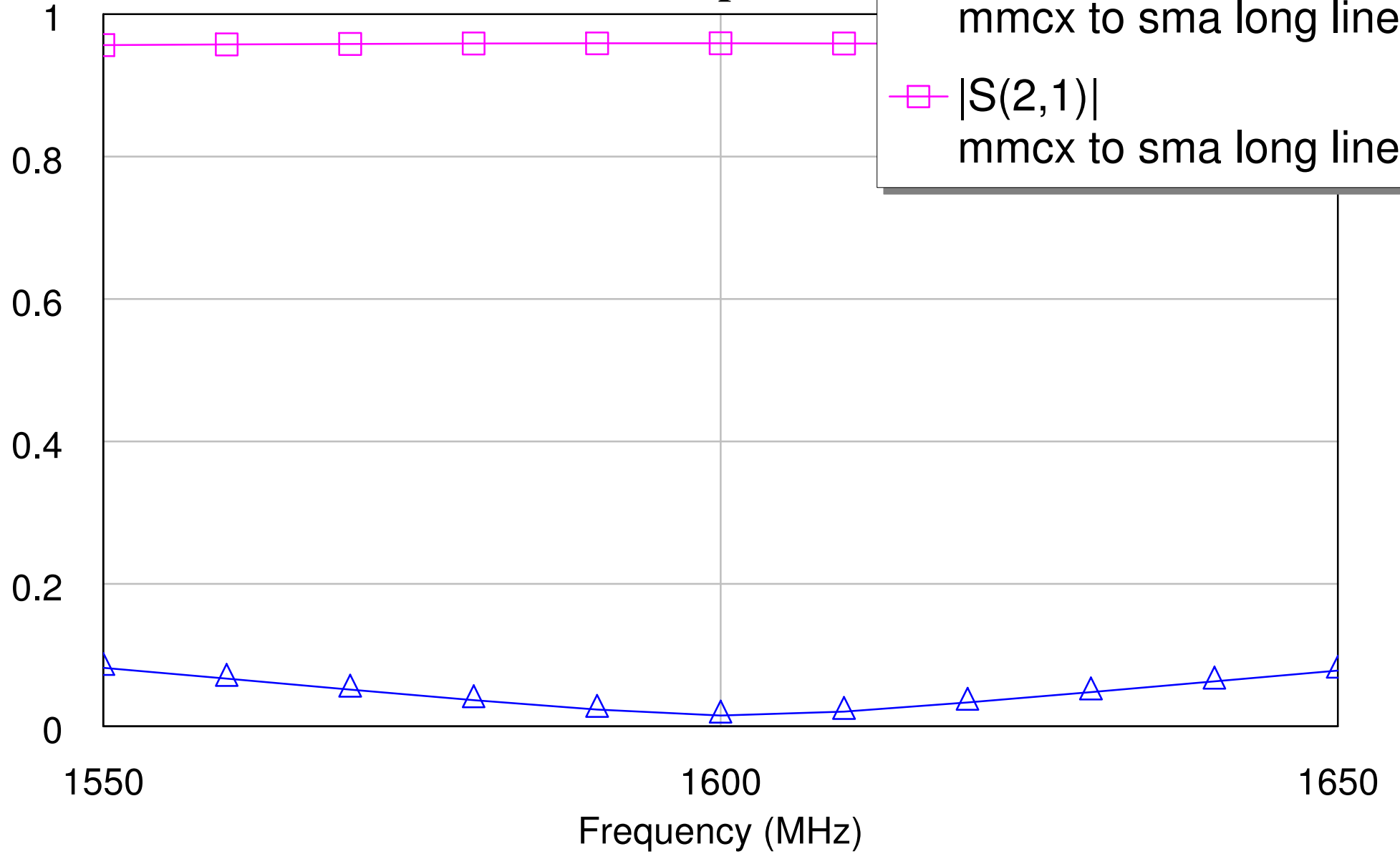
MSUB
Er=4.5
H=1.6 mm
T=0.035 mm
Rho=1
Tand=0.02
ErNom=3.38
Name=SUB1





Graph 1

- △— $|S(1,1)|$
mmcx to sma long line
- $|S(2,1)|$
mmcx to sma long line



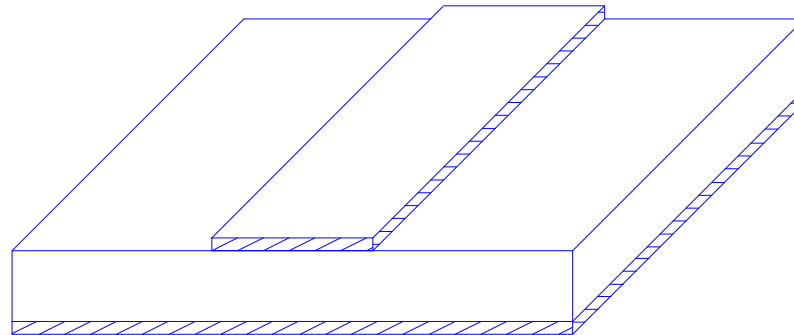
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P=1
Z=50 Ohm

MLIN
ID=TL1
W=2.99 mm
L=17.6 mm

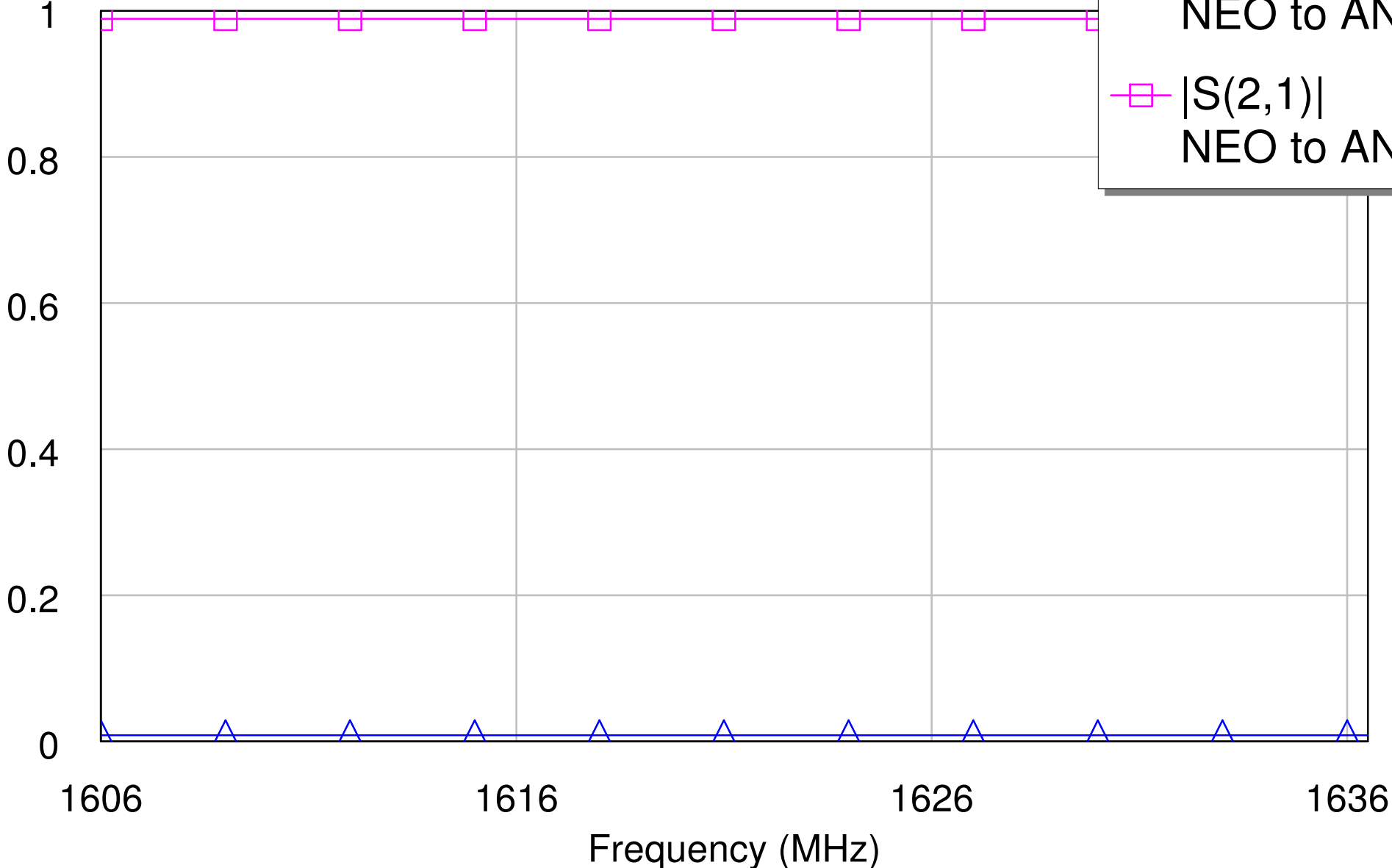
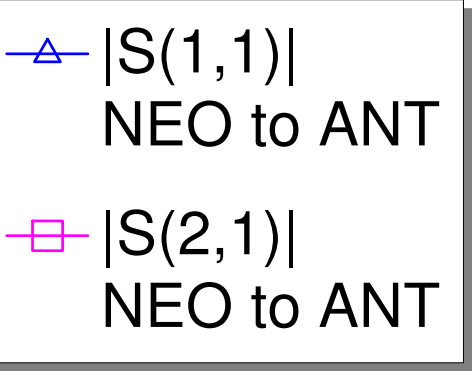


MSUB
Er=4.5
H=1.6 mm
T=0.035 mm
Rho=1
Tand=0.02
ErNom=3.38
Name=SUB1

PORT
P=2
Z=50 Ohm



Graph 2



Appendix F: List of Materials Included on DVD

- PCB design projects.
- Source code.
- Collar mechanical design files.
- Electronic copy of thesis.
- RF simulations.

Appendix G: Test Result Data

Trial Num	Duration [s]	Avg current [mA]	Min current [mA]	Max current [mA]	Success
1	25.8	18.18	9.69	31.85	Success
2	20.1	14.3	9.67	27.42	Success
3	15.27	18.02	9.95	31.74	Success
4	13.3	16.04	10	27.21	Success
5	26.5	15.9	9.87	32.35	Success
6	7.4	13.03	7.63	18.59	Aborted
7	19.82	15.74	10.67	30.03	Success
8	13.23	13.7	10.11	19.62	Aborted
9	6.56	12.69	7.57	16.91	Aborted
10	19.93	14.92	9.83	29.32	Success
11	20.01	14.73	9.72	27.97	Success
12	19.93	14.73	9.86	30.47	Success
13	19.87	15.78	10.51	29.51	Success
14	59.62	24.06	12.28	46.99	Success
15	26.59	17.4	10.43	34.37	Success
16	24.26	17.98	9.78	30.24	Failed
17	33.33	19.22	12.26	31.84	Aborted
18	20	14.1	9.48	28.01	Success
19	66.27	23.66	11.88	42.85	Timed out
20	13.55	12.74	9.99	18.68	Aborted
Average	23.567	16.346	10.059	29.2985	

Table 1: *Iridium transceiver transmission power usage and success test results.*

Longitude [°]	Latitude [°]	Delta long [°]	Delta lat [°]	Dist long [m]	Dist lat [m]	Delta dist [m]
18.86645	-33.9286	-4E-06	-2.5E-06	-0.36988	-0.2775	0.462407
18.86644	-33.9286	4.3E-06	2.29E-05	0.397625	2.5419	2.572812
18.86632	-33.9291	0.00013	0.000509	12.23391	56.5323	57.8409
18.86644	-33.9287	4.3E-06	0.000151	0.397625	16.7499	16.75462
18.86644	-33.9283	4.3E-06	-0.00028	0.397625	-31.5573	31.5598
18.86652	-33.9291	-7.3E-05	0.00056	-6.70415	62.2155	62.57567
18.86657	-33.9298	-0.00012	0.001252	-11.4387	138.9387	139.4088
18.86637	-33.9285	8.1E-05	-2.8E-05	7.499398	-3.1413	8.130728
18.86644	-33.9285	4.3E-06	-8E-05	0.397625	-8.8245	8.833454
18.86644	-33.9285	4.3E-06	-5.4E-05	0.397625	-5.9829	5.996099
18.86644	-33.9287	4.3E-06	0.000125	0.397625	13.9083	13.91398
18.86644	-33.9286	4.3E-06	2.29E-05	0.397625	2.5419	2.572812
18.86632	-33.93	0.00013	0.001405	12.23391	155.9883	156.4673
18.86644	-33.9286	4.3E-06	2.29E-05	0.397625	2.5419	2.572812
18.86644	-33.9286	4.3E-06	7.41E-05	0.397625	8.2251	8.234706
18.86642	-33.9285	3E-05	-2.8E-05	2.764883	-3.1413	4.184775
18.86639	-33.9291	5.5E-05	0.00056	5.13214	62.2155	62.42682
18.86655	-33.9285	-9.8E-05	-0.00011	-9.07141	-11.6661	14.77797
18.86637	-33.9293	8.1E-05	0.000765	7.499398	84.9483	85.27869
18.86621	-33.9296	0.00023	0.000996	21.70294	110.5227	112.6334
18.86644	-33.9288	4.3E-06	0.000202	0.397625	22.4331	22.43662

Table 2: GPS accuracy test results.

On Time [s]	Recharge Time [s]	Average Current [mA]	Energy [mAh]	Transmission
9	1140	1.5	0.475	Failed
21	1140	3.28	1.039	Success
35	1370	3.36	1.279	Success
12	1080	2.33	0.699	Success
21	1080	3.07	0.921	Success
66	1587	5.4	2.381	Success
28	1218	3.47	1.174	Success
27	1006	4.38	1.224	Success
6	623	1.87	0.324	Failed
35	442	4.65	0.571	Failed
Average energy for successful transmission:				1.245 mAh
Average energy for failed transmission:				0.457 mAh

Table 3: Iridium transmission energy usage test results.

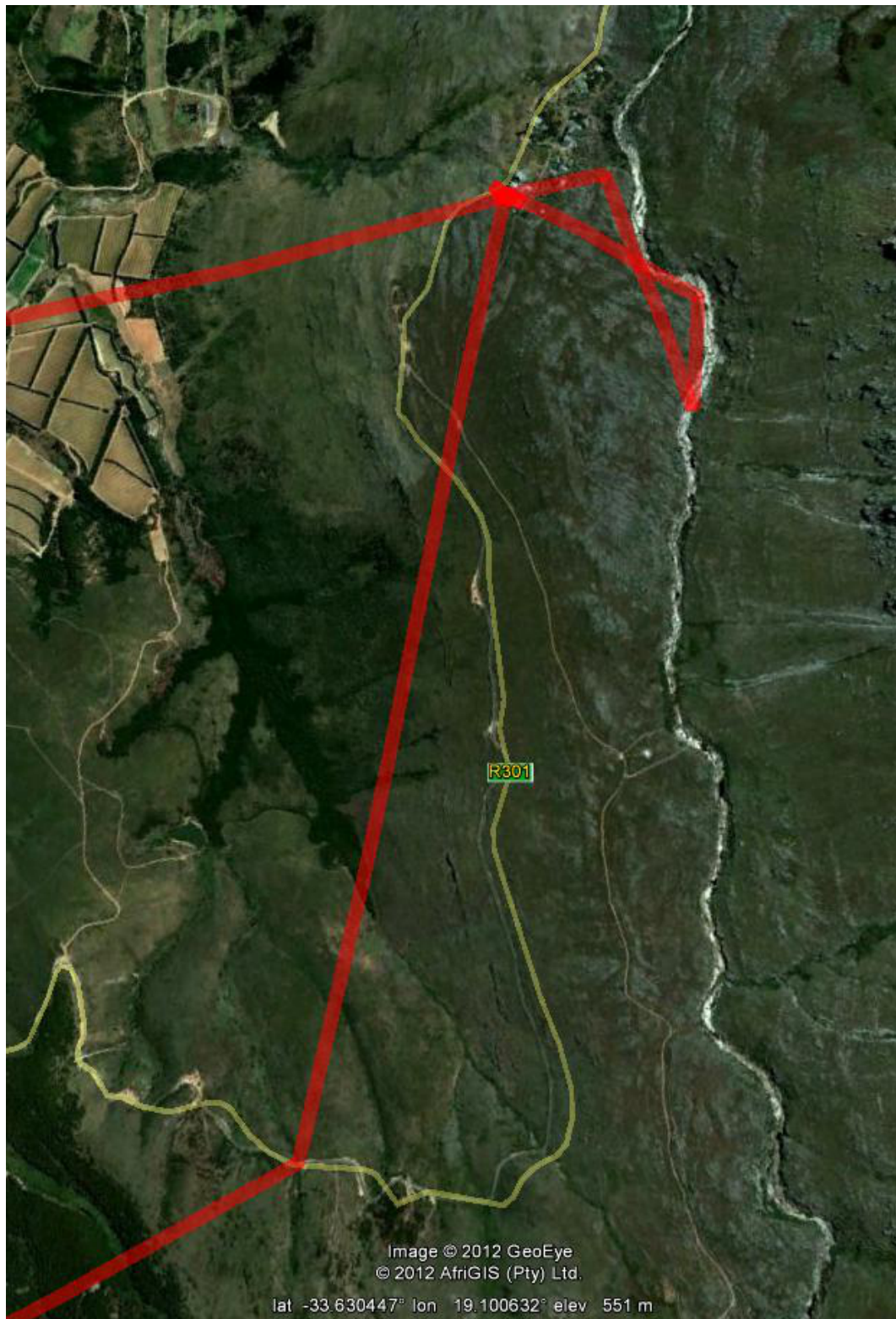


Figure 1: *Logged coordinate path overlay on satellite imagery from Bain's Kloof region test.*