Design of a small satellite UHF identification and TT&C radio beacon

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Well written abstract to be added here

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# Nomenclature

*Variables:*

*c* = speed of light [299,792,45 m/s]

*d* = path distance [m]

*f*= radio frequency [Hz]

= Receive antenna gain [dB]

= Transmit antenna gain [dB]

*Terms, Abbreviations and Acronyms:*

APM = Arduino pro mini

CMOS = Complementary metal-oxide semiconductor

c-Si= Crystalline Silicon

EEPROM = Electrically erasable programmable read-only memory

FPGA = Field-programmable gate array

FSPL = Free-space path loss

GaAs = Gallium-Arsenide

IDE = Integrated development environment

ISM = Industrial, scientific and medical

LDO = Low dropout

LED= Light emitting diode

LEO = Low earth orbit

LPWAN = Low-power wide area network

LTE = Long-term evolution

NASA = National Aeronautics and Space Administration

P2P = Point-to-Point

PCB = Printed circuit boards

RF= Radio frequency

RX = Receive

SSA = Space situational awareness

TASC = Triangular advanced solar cells

TX = Transmit

TT&C = Telemetry, tracking and control

USB = Universal serial bus

# Introduction

The reduction in economic and resource costs of designing, manufacturing and launching a small satellite has led to an increased number of small satellites being launched and operated in the Low Earth Orbit (LEO) space environment[[2]](#endnote-2). A greater number of objects in the LEO environment has resulted in a decrease in space situational awareness (SSA) and an increase in the number of space debris, which leads to a larger reliance on resource expensive ground station monitoring equipment to maintain situational awareness in the LEO environment.

The reduced cost of launching a small satellite into the LEO environment is due to multiple small satellites being released from a single launch platform, this is commonly known as ride sharing. Ride sharing has resulted in upwards of 100 small satellites being released from the same launch vehicle in a small-time frame[[3]](#endnote-3). This has led to a reduction in SSA immediately after the satellites launch and throughout its operational life cycle due to difficulties in identifying individual satellites. Identifying a larger number of small satellites in the LEO space environment results in a greater demand on the limited ground-based optical and Radar monitoring resources to maintain a reduced SSA capability.

The standardisation of small satellite manufacture has reduced the cost of production allowing government, educational and commercial organisations will little to no space mission experience to create and produce small satellite designs to meet their organisations requirements. The unique development and design process to meet these organisations requirements for each satellite has resulted in a 55% failure rate for academic institutions and a 23% failure rate for commercial industry[[4]](#endnote-4). The causes of small satellite failures are difficult to determine as the failure can reduce the amount of satellite telemetry data available which results in the reason of satellite failure being contributed to a number (5-10) of possible causes. The ride sharing launch also produces difficulties in identifying an individual satellite immediately after release by the ground monitoring stations which can result in greater failure rates due to difficulties in creating the initial communication link with the individual satellite[[5]](#endnote-5). A satellite failure can cause that satellite to be uncontrollable and/or difficult to trace causing it to become a space debris object. Increased numbers of space debris in the LEO environment diminishes SSA which leads to an increased risk of a collision for all users of the LEO space environment. ~~A collision between two objects in a space environment results in a larger number of smaller space debris objects leading to an exponential risk of further collisions between objects, which is known as the Kessler Syndrome[[6]](#endnote-6).~~

A solution needs to be investigated that will provide better methods of obtaining satellite telemetry data and provide a cost-effective method of tracking small satellites and space debris ~~(due to satellite failure~~) in the LEO space environment.

The purpose of this project will be to design a self-sufficient, independent satellite radio beacon system that can transmit satellite identification and telemetry data using a UHF radio signal that can be tracked using multiple geographically dispersed, cost-effective ground receiving stations.

The satellites radio beacon will primarily allow for the identification of an individual satellite during launch and its operational life cycle providing greater SSA and leading to a lower the risk of collisions in the LEO environment. Multiple graphically dispersed ground mounting stations constructed using low-cost, commercially available components will be utilised to track the satellites beacons radio signal allowing the existing resource intensive ground-based monitoring systems to focus on other LEO space objects. The beacon will have a secondary function that can provide telemetry data for satellite on-orbit fault finding to facilitate the determination of causes of failure. Determining the actual cause of failure as opposed to having several possible causes of failure will contribute to reducing the number of failures in future launches and operations. This system can be extended to include an alternative communications pathway that can be used to provide limited control of the other satellite sub-systems to offer a redundant system to correct on-orbit failures. Correcting an on-orbit failure can result in the regain control of the small satellite reducing the number of space debris objects in the LEO environment.

# Aim

The aim of this project is to design and produce a ground-tested satellite UHF radio beacon prototype and a cost-effective ground monitoring station prototype that can sustain a communications link over the distances to a satellite in the LEO environment. In order to achieve this overall aim, three aspects will be investigated, firstly The satellite radio beacon will be a self-sustained UHF communication system that can operate independently of all other satellite sub-systems for the duration of the satellites operation mission (until deorbit). Secondly The UHF communications link will be able to support the reliable transfer of satellite identification and telemetry data over a 1000kms to support operations and monitoring of satellites in the LEO space environment. Finally The ground monitoring station will be capable of capturing the satellites identification and telemetry data and recording the precise time of arrival of the radio signal. The ground station will be constructed using low-cost, commercially available components and operated using low resource software.

# Background/Literature Review

review of existing research and systems of the same or similar functions and why an integrate identification and TT&C system is desirable/beneficial.

1. **Requirement for an independent Identification and TT&C system**

The standardisation of small satellite design, construction and launch has reduced the cost of manufacturing and launching a small satellite into a low earth orbit which has led to the number of small satellite missions increasing from 20 missions in 2011 to 322 in 2018 with the number estimated to increase to 300 missions in 2019 and between 2000 to 2800 missions to be launched in the next 5 years[[7]](#endnote-7). A small minority of these planed missions will be delivered to LEO using dedicated launch vessels but most of the satellite are expected to utilize the current rideshare or piggyback launch vessels[[8]](#endnote-8). The Indian Space Research Organisation released 104 small satellites into LEO during a 12-minute cluster release from a single launch vessel on the 15th of February 2017[[9]](#endnote-9), which provided a demonstration of the ability for a cluster launch but also presented the problem of identifying a singular satellite within the launch cluster. Early identification and communication with the satellite and the ability to provide multiple pathways to correct system error or faults provides a good determination of mission success[[10]](#endnote-10). include imagine a system did X which resulted in Y.

The 55% and 23% failure rate of the previous small satellite missions can be contributed to some common faults such as communications systems failure, power system failure, Bus system or payload interface failures, deployable component failure, failure of components (due to quality, inadequate documentation, limited testing) or system failures due to delays in launch (system degradation). When the satellite fails on launch or in orbit then the exact determination of the cause of failure is difficult to ascertain as the communication link with the ground station is often non-functional preventing satellite telemetry data from being received. The provision of a system that provides telemetry and satellite state data to the ground station irrespective of a failure of any satellite sub-system provides information that can be used to either determine the cause of failure or help reduce the number of possible causes of failure. When the cause of failure is identified or the number of possible causes of failure is reduced then this information can be used to reduce the incidents of full or partial failure in future small satellite missions reducing the failure rate of small satellites.

If the cause of failure is diagnosed whilst the satellite in on mission from the provided telemetry data, then there remains the possibility that an on-orbit rectification could be carried out and the mission can be completed or partially completed. The on-orbit rectification will require some sort of communication path to the satellite to be able to carry out any command to bring the affected system back to a serviceable state. If an emergency communication system has not been provided with the satellite system, then this radio beacon could be utilized to provide minor control of the satellite systems via an alternative communications link.

Cost effective can also make the systems available to general public and contribute to the important task of SSA

1. **Existing systems and research**

The existing available systems include the CUBIT system from SRI international[[11]](#endnote-11), the SOARS system developed by TIGER innovations, a passive RF tag being developed by Stellar Exploration inc[[12]](#endnote-12), the HyELT system proposed by M42 technologies, a radio beacon designed for the IRASAT1 cube satellite[[13]](#endnote-13) and a safety radio beacon developed by University of West Bohemia[[14]](#endnote-14).

The CUBIT, SOARS and passive RF tag deliver a similar capability in which an RF signal is used to deliver an identification to a ground-station to uniquely identify a satellite but are unable to provide any telemetry data or any control of the satellite.

The safety radio beacon developed by the University of West Bohemia is an on-board capability to provide satellite telemetry in normal and emergency (satellite failure) situations in the 433MHz range. This system provides only telemetry information whilst neglecting satellite identification, tracking and control and operates in an RF band that is subjected to congestion and RF signal detection degradation.

The HyELT system proposed by M42 technologies is similar in concept to this project in which it provides a transponder for uniquely identifying a satellite as well provide satellite health and state data. This project will provide a better solution as it allows for an alternative control pathway for the satellite as well as provide a system by which all satellites may be tracked from a series of ground stations.

The radio beacon designed for the IRASAT1 cube satellite provides similar capabilities to the HyELT system and this project but the radio utilizes the congested VHF radio band using a licensed band of frequencies resulting in this project providing a more robust and easily implemented solution.

There exist a few systems that identify a satellite using optical based systems such as the ELROI system being developed by Los Alamos national laboratory[[15]](#endnote-15) and the LEDSAT system developed by the University of Rome[[16]](#endnote-16) with the ELROI undertaking on orbit trials in 2018 with no success of positive detection of an optical identification tag[[17]](#endnote-17). The optical based systems can provide satellite identification but are unable to provide TT&C data making a beacon with an RF signal a better solution.

All the current systems in development either provide identification or satellite telemetry data via a signal that can be tracked but none of them provide a system that can include all these capabilities in one self-sustained system. This project will provide a radio beacon that can provide all of these capabilities as well provide scope to be further developed to include customizable telemetry data from the satellite systems as well as provide scope to be extended to include a control capability for on-orbit rectification of system failures.

# The present study

Will discuss the breakdown of the project into its three components and each subsystem…

* Satellite radio beacon
  + Power generation
  + Power storage and regulation
  + Computer processing
  + Radio transmitter
  + System software
* Communications Link
* Ground receiving station
  + Computer processing
  + Radio transmitter
  + GPS module
  + System software
  + Position calculations using DTOA

## Satellite Radio Beacon

### **Methods**

### **Results**

### **Discussion**

## Communications Link

### **Methods**

### **Results**

### **Discussion**

## Ground Receiving Station

### **Methods**

### **Results**

### **Discussion**

# Conclusions

The initial research has that a feasible system can be developed integrating existing technologies and systems that will provide an identification and TT&C radio beacon for a small satellite in LEO. The results of the power consumption checks of each individual sub-system demonstrates that a system operating an Arduino based processor and a HopeRF RFM95 LoRa radio module on regulated power generated from a solar source is a feasible design for the radio beacon. The communications link requires further investigation and testing to demonstrate that it can operate over the expected distances, a design for a solar panel array that is capable of operating in a space, a more efficient power regulation system design and a possible energy storage system design are required to be investigated before the initial PCB design and prototype of a UHF identification and TT&C radio beacon can commence.

# Recommendations

It is recommended that the project continues as per the planned methodology using the timeframes detailed in the GANTT chart (appendix A). The project should be extended to include the first 4 extension items detailed in the future work section as additional deliverables as these items are very closely aligned to the development of the space segment of the radio beacon. Developing these 4 extensions with this project will require much less resources to integrate, then if these system extensions were developed in a separate project as there will be much less cost in terms of materials and human resources. The fifth and sixth extension item should be considered as an additional optional deliverable on this project (time permitting) as the system can leverage existing research that has been completed by this organisation allowing quicker integration of the research technology whilst using a smaller amount of resources.

# Acknowledgements

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