FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO



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Development of an ARGOS beacon for the VORSat CubeSat

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Resumo

Cada vez mais os satélites tem uma maior importância na recolha de dados, na transmissão de informação e nas comunicações a nível mundial. É cada vez mais frequente o envio de satélites para a atmosfera de modo a que estes possam recolher dados para experiências ou mesmo para o ser humano entender melhor o meio ambiente que o rodeia.

Esta dissertação nasce de um problema criado pela reentrada dos satélites na atmosfera e na necessidade de desenvolver um sistema fiável que possibilite a localização do satélite mesmo depois da reentrada.

O satélite a ser lançado para a atmosfera é um CubeSat. Um CubeSat é um satélite de pequenas dimensões, normalmente de 10*10*10 cm, que tem como vantagem ser um satélite de baixo custo e de fácil produção. Estes satélites são extremamente versateis e são usados por universitários, pelo mundo fora, para explorar o espaço. Devido a sua constituição este satélite é extremamente complicado de recuperar após a sua reentrada.

Com esta necessidade como fundo, esta dissertação tem como objectivo o desenvolvimento de um beacon ARGOS que será incorporado no VORSat (VHF Omni Directional Radio Range Satellite). O VORSat consiste num programa que visa o desenvolvimento de um pequeno satélite. Este programa esta a ser desenvolvidos por alunos na Faculdade de Engenharia da Universidade do Porto (FEUP). Este projecto diz pretende enviar um satélite para a LEO (Low Earth Orbit) e recuperar a ERC (Earth Reentry Capsule) após a sua reentrada na atmosfera terrestre. Pretende-se que este beacon tenha um baixo consumo de modo a maximizar a vida útil das baterias que irão a bordo do satélite.

Numa primeira fase foi feito um estudo a cerca dos beacons já existentes, bem como, um estudo sobre o sistema ARGOS/GPS que será o sistema de comunicação utilizado.

Numa segunda fase será construída uma PCB (Printed Circuit Board) de teste que conterá um oscilador local a frequência de 401.65MHz, um modelador I/Q, um amplificador de potencia RF, uma antena e um microcontrolador. Todo o dimensionamento deste sistema tem em conta os consumos e optimização dos mesmos tentado reduzi-los ao máximo. Esta placa servirá para testar a solução adoptada.

Numa segunda fase será projectada uma versão, da primeira PCB, miniaturizada de modo a que esta possa ser integrada no satélite.

Desta forma o produto final desta dissertação será um beacon que irá emitir a localização do nosso satélite após a reentrada do mesmo na atmosfera terrestre de modo a que este possa ser localizado e posteriormente recolhido.

Abstract

Nowadays, satellites have a very relevant role in data collection, transmission of information and worldwide communications. It is becoming more and more common to send satellites into the atmosphere so that they can collect data for experiments or even to better understand the environment that surrounds the Earth.

This dissertation is born to solve a problem created by the reentry of satellites in the atmosphere and the need to develop a credible system that allows the location of the satellite even after its reentry.

The satellite that will be launched into the atmosphere is a CubeSat. A CubeSat is a small satellite, with the typical dimensions of 10*10*10 cm, which has the advantage of being a low cost and easy production satellite. These satellites are extremely versatile and are used by university students around the world, to space exploration. Because of its constitution, this satellite is extremely difficult to recover after its reentry.

With this need as background, this dissertation aims to develop an ARGOS beacon that will be incorporated into the VORSat. The VORSat is a small satellite program that was being developed by students at Faculty of Engineering of the University of Porto. This project regards send a satellite to the LEO and to recover the Earth Reentry Capsule (ERC) after its reentry. It is intended that this beacon has a low consumption to maximize the battery life time.

In a first phase a study was made about the existing beacons, as well as a study about the ARGOS/GPS system that is used in communication.

In a second phase, a PCB was built. This PCB contains a local oscillator with the frequency of 401.65MHz, a I/Q modulator, a RF power amplifier and a microcontroller. The whole design of this system takes its optimization and the reduction of its power consumptions into account. This board serves to test the adopted solution.

In a third phase, the projected version of the first PCB was miniaturized so that it can be integrated into the satellite.

Thus, the final result of this dissertation is a beacon that will broadcast the location of our satellite after its reentry into Earth's atmosphere, so that it can be located and subsequently retrieved.

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I also want to extend my thanks to Nuno Sousa and Rui Fernandes for the willingness shown to provide me access to the laboratories and in everything I needed. I also want to thank João Soares Silva for the productive discussions we had.

Before concluding, it is necessary to equally thank Ricardo Rodrigues for all of his patience and friendship during these seven years. I have always been able to count on him, especially when the nerves took control of me.

Finally, I thank my parents for believing, from the very beginning, that I would be able to complete my degree and for all the sacrifices they made for me to reach this goal. Thanks especially for the patience and affection that they had with me in the hardest moments.

Nuno Filipe Sousa Cardoso

"À minha avó paterna Aurora Abreu.
Aos ausentes sempre presentes."

Nuno Cardoso

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Acronyms and Abbreviations

BJT	Bipolar Junction Transistor
BPSK	Binary Phase-Shift Keying
CLS	Collect Localisation Satellites
CNES	French Space Agency
CoCom	Coordinating Committee for Multilateral Export Controls
DAC	Digital to Analogue Converter
DBCP	Data Buoy Cooperation Panel
DMMC	Downlink Messaging Management Center
ERC	Earth Reentry Capsule
FEUP	Faculdade de Engenharia da Universidade do Porto
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HDOP	Horizontal Dilution of Position
IOC	International Ocean Commission
ISRO	Indian Space Research Organization
JAXA	Japan Aerospace Exploration Agency
LEO	Low Earth Orbit
MosFet	Metal Oxide Semiconductor Field Effect Transistor
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
OBHD	On-Board Data Handling
PCB	Printed circuit board
PLL	Phase Locked Loop
PMT	Platforms Messaging Transceivers
POES	Polar Orbiting Environmental Satellites
PSK	Phase Shift Keying
PTT	Platform Terminal Transmitters
PVT	Position, Velocity and time
RPU	Receiver Processor Unit
SMD	Surface Mount Devices
SOOP	Ship of Opportunity Program
SVs	Space Vehicles
TXU	Transmitter Unit
UNESCO	United Nations Educational, Scientific and Cultural Organization
UTC	Coordinated Universal Time

VDOP	Vertical Dilution of Position
VORSat	VHF Omni Directional Radio Range Satellite

Chapter 1

Introduction

With the increase of technology, it is more and more usual to send satellites to space in order to fulfill all kinds of tasks, ranging from collecting data on the atmosphere for research and weather forecasts to worldwide communications.

It is increasingly necessary to have means of communication and location for the satellites that are sent into space. This is particularly obvious in those satellites that are sent into space and, when they reenter the Earth atmosphere there is not an efficient way to locate them.

A CubeSat, for example the QB50 [12], is a small satellite (10x10x10 cm, weighing 1 kg) which offers all the standard functions of a normal satellite. This functions can go from attitude determination to uplink and downlink communications. The CubeSats are a low cost satellites and it takes about two years to develop a CubeSat from the provision of funding until launch. A single CubeSat is simply too small to also carry sensors need for significant scientific research. For that reason the universities develop this kind of satellites with an educational objective. However, nowadays multiple CubeSats were launched into the atmosphere and with similar sensors make possible to answer questions which are inaccessible otherwise.

The reentry of satellites into earth atmosphere is a critical phase of its mission. This is due to the fact that this is low cost satellites and do not have great means to survive the reentry on earth atmosphere. So on the CubeSat goes a capsule that will survive reentry and where is the collected data. Normally difficulties were experienced in recover this capsule due to the tracking system failure.

To fulfill that assumption, a study was made about the existing location systems, in order to design and implement a prototype of a beacon that will allow a correct and easier location of the satellite after its reentry into the Earth atmosphere.

1.1 Context/Scope

This project appears under the general scope of the VORSat project. Its main objective is to launch a satellite to LEO (Low Earth Orbit), in order to make measurements and studies. While considering how to develop my project, the need to develop a communication module arose, in order to ensure that the satellite can communicate with other satellites and provide data about its position. Consequently it has been proposed to develop an ARGOS beacon to establish the communication.

The design of this beacon must keep in mind that it must be optimized in terms of power consumption, since only then we will be able to reduce the size of batteries that will be necessary as well as the size and weight of the satellite itself. It is also important to take aspects of size into account.

Therefore, the satellite will have two types of power supply: a short time power supply and another one that will give the satellite, through time, the energy it needs. The short time power supply consists of batteries that will be on board the capsule. They will be used until the release of the capsule containing the beacon falls into the ocean. On the other hand, the long term power supply will be designed to allow the beacon to have enough energy to transmit its location, every now and then when drifting on water, so it can be retrieved. This power supply can be made with sacrificial anodes that will be placed on the outside of the capsule. This way the beacon will obtain energy of the chemical reaction between the sea water and the sacrificial anodes. The planned landing zone will be the Portuguese coastal oceanic area.

1.1.1 The VORSat Project

The VORSat project arises from a partnership between FEUP (Faculdade de Engenharia da Universidade do Porto) and ESA (European Space Agency), with the objective of creating a CubeSat that will be launched into a LEO in order to collect data and track its reentry into the atmosphere.

This project is being developed by students. The VORSat project is divided on multiple stages, having as main objectives:

- The development of a attitude determination system based on the phase analysis of transmitted waves;
- Prediction and adjustment system for the re-entry trajectory OBHD (on-board data handling), for a nano-satellite;
- The integration of cork composites on the heat shield of a nano-satellite;
- The implementation of an ARGOS transmitter in the capsule in order to obtain its position after the reentry through Earth atmosphere;
- The landing/ditching and the recovery of the ERC (Earth Reentry Capsule). An model of this ERC can be seen in figure 1.1.



Figure 1.1: An example of an ERC. The radius of the capsule is approximately 5cm. [1]

The landing point is an essential part of the mission, as it can determine the success or failure of the recovery operation. Two main options are currently under analysis: splashing down in the ocean or landing in a desert, figure 1.2. This happens to be so due to the low population and building density, reducing the possibilities of collateral damages. The capsule is being designed to withstand the impact on water or sand without the need of a parachute.

Desert	Ocean
Easier recovery	Harder recovery
High thermal amplitudes	Larger landing area
Smaller area ⇒ higher accuracy on the reentry process	Larger area ⇒ less accuracy required on the reentry process
Possibility of recovery by others	Reduced visibility in bad weather
Flotation not required	Flotation required
Fewer requirements for corrosion	Corrosion must be accounted for
Less stringent requirements: more space available	**Demanding requirements: less space available**

Figure 1.2: Comparative analysis between two different landing sites [2]

After the analysing the characteristics of the two solutions, it was decided that the landing zone would be the ocean, as mentioned in the section 1.1

1.2 Motivations and Objectives

The main motivation of this thesis is the retrieval of the satellite after its reentry through Earth's atmosphere. It should be noted again that the VORSat project, which this dissertation is a part of, is a project that is being developed by students.

However it should be stated that being this a beacon module to be embedded in the ERC, it is subject to limitations in terms of power consumption for batteries that will not hold for long periods of time with high power consumption.

Nevertheless, complications concerning energy consumption are known and will be faced throughout this thesis by lowering the peak and average consumption from the power supply.

To reduce the power consumption of the Argos beacon, we have the following objectives:

- Mount switches on the circuit, in a way that allows to turn on the components only when necessary;
- Use a microcontroller to control these switches;
- Develop software for optimizing the consumption of the microcontroller;
- Create a system for energy storage, with capacitors, in order to remove the load peaks of the batteries and to increase the their life time.

At an academic level, it is fair to admit that with the development of this project it will be possible to validate the utility of the ARGOS system to make the location of the satellite after its reentry. Therefore, the central objectives of this dissertation are:

- The design of an ARGOS beacon using components such as an 401.65MHz PLL(Phase Locked Loop) based frequency generator, an RF power amplifier, an I/Q modulator, an antenna and a microcontroller;
- The development of a PCB for testing purposes. The circuit that will be tested is the one that was designed (hardware);
- The development of a C language code that will be processed by the microcontroller to produce the desired waveforms (software);
- The development of a miniature version of the beacon. It is intended to build a PCB with 4cm*4cm. The corner of this PCB will be cut off so it can be embedded in the ERC.

By taking all of these facts into consideration, it is possible to create an effective way of localization after the reentry of the satellite in the Earth atmosphere. So it is with great motivation that I look forward to the development of this beacon for VORSat.

1.3 Document Structure

After this introduction, this document contains five more chapters:

- In chapter 2, the state of the art regarding this dissertation is described. Initially, there is an ARGOS system exposure, followed by an introduction about the evolution that this system has suffered over the years. Furthermore, the ARGOS - 2 is described with detail and presentation of its features and the operating modes of the communication of this system is also included. The different types of location technologies, along with their respective advantages and disadvantages are also referred and it is also shown which technology will be used in the proposed objectives.

- In chapter 3, the design of the ARGOS beacon is described. All the constituents components of our system are also explained, with the various available alternatives and choices that were made, taking into account the initial premises.

- In chapter 4, the implementation of the module is reviewed in order to show the result of assembly process; the implemented hardware is also presented. There is also a presentation of the software architecture, to explain the operation mode of the beacon at the routine level. Flowcharts are included to illustrate the operation mode.

- In chapter 5, the collected results during the system testing period are listed, in order to be able to evaluate its performance. There are still non-functional requirements to be considered.

- In chapter 6, an overview of the steps taken throughout this dissertation is made, as well as an analysis of the completed work. Also and because, this project is part of a bigger one (VORSat) and, in order to increase and add value to the module developed, especially its usefulness and versatility, several different approach routes for future work were included.

Chapter 2

State of the Art

2.1 Argos

Since the main purpose of this dissertation is the development of an Argos beacon for the localization of a reentry capsule of a satellite, first it is necessary to define clearly what the ARGOS system is, the developments that it has suffered over the years and how we can use this system to solve our problem.

2.1.1 Introduction

The ARGOS system allows the localization and data gathering around the world, and is typically used in the study and protection of the environment and its species. This system uses a set of satellites called POES (Polar Orbiting Environmental Satellites) that enable the coverage of the system on a global scale.

Since the beginning of its creation the main objective of the ARGOS system was to answer the needs of both scientific and industrial world. This system is an important tool for the scientists, because it allows them to study environment of our planet, therefore improving the understanding about the environment around us.

In the industry, this system is a fundamental help in the length of the regulations for the environmental protection.

Some applications of the ARGOS system are:

- Location of any object equipped with an ARGOS transmitter;
- The collection of environmental data;
- Allows the observation of the oceans by measuring the temperature and salinity. Can also observe the sea currents;
- Monitorization the fishing areas;

- Animal monitorization;
- Reinforces the maritime safety.

Nowadays, more than 16.000 ARGOS transmitters are active each month worldwide.

2.1.2 History

Around the year of 1978, the ARGOS system has been created by of a Franc-American collaboration that included CNES (French Space Agency), NASA (National Aeronautics and Space Administration) and NOAA (National Oceanic and Atmospheric Administration). The intent of these organizations was to create a system that would allow the collection of meteorological as well as oceanic data across the world.

Some years later, by the year of 1986, the CLS (Collect Localization Satellites) was created by the CNES with the intent of operating the ARGOS system so that it can be marketed.

Nowadays, the development of this system counts with the participation of some more agencies like NASDA (National Space Development Agency) and the Eumesat (European Organization of the Exploitation of Meteorological Satellites). These agencies have been handing over an important contribution in the development of the system and adapting it to the needs of the world.

In the sphere of international cooperation, agreements have been made with the ISRO (India Space Research Organization) to incorporate an ARGOS transmitter on the next platform to be launched to space.

As a result of this cooperation between organizations, the ARGOS system has become widely used by international programs such as:

- DBCP (Data Buoy Cooperation Panel);
- SOOP (Ship of Opportunity Program);
- Argos profiling float project.

These programs were implemented under the guidance of the IOC (International Ocean Commission) of UNESCO (United Nations Educational, Scientific and Cultural Organization).

There was also an evolution in data transfer that is due to the development of the used technologies and the adjustment of the system to the needs of today. The system initially started with the ARGOS - 1 and after numerous improvements ARGOS - 3 being the version that is currently used. The main differences between the systems from ARGOS - 1 up to ARGOS - 3 can be observed in the figure 2.1.

2.1.3 Developments in the System

The ARGOS system, since its beginning, has been subject of improvements to meet the requirements of the users. The final advance was the ARGOS - 3 that brought improvements on the level of system performance.

Center Frequency: 401.65 MHz	Argos-1	Argos-2	Argos-3
Bandwidth range	24 kHz	80 kHz	110 kHz
Processing units	4	8	9 low data rate + 3 high data rate
Uplink data rate	400 bps	400 bps	400 bps (low) + 4800 bps (high)
Downlink	NO	NO	YES
Downlink data rate	—	—	400 bps (nominal) or 200 bps
Satellites	< NOAA K	NOAA K,L,M,N	MetOp A, B, C, NOAA N'
Data transmitted per satellite pass	500 bits	500 bits	Up to 30 kbits

Figure 2.1: Evolution of the data transmission system [3]

One of these improvements was the evolution of communication platforms. This leads to the ability of PMTs (Platform Messaging Transceivers) to succeed in bidirectional communication, that is, the ability to uplink and downlink. The DMMC (Downlink Messaging Management Center) makes all the downlink communication management of the CLS and the CNES.

Another major improvement, from the point of view of the users, was the increase in the capacity of the data transmission. This development allows a data transfer about ten times higher than the ARGOS - 2. The maximum data transfer rate of the ARGOS - 3 system is about 4.8Kbit/s.

Due to the fact that the capacity of data transfer was increased, the efficiency of data transfer was also improved. Eliminating the need of resending messages that will be transmitted to the satellites. That way the satellites do not receive messages with errors. This is possible due to the implementation of a field in the messages that is the acknowledgment field. This field causes the satellite to respond with acknowledge for a PMT and it stops sending the message since it has been received successfully.

PMTs have a software that allows gathering information from satellites when they are in range for data transmission. This information is obtained from the downlink communication. This kind of communication increases the life time of the PMTs because it reduces the data transmission time and saving energy as well as increasing the life time of the batteries.

The evolution towards the ARGOS - 3 system also allows the PMTs to be controlled remotely, that is, the user can turn on and off the transmitter or change the sampling time of the sensor that is being operated. This new capability is possible by sending short messages to the PMTs through the DMMC (Downlink Messaging Management Center) that can go up to 128 bits. This allows a greater control over the platforms and a better response to the same tasks for which they were

assigned. This advantage brought by the ARGOS - 3 will not be used during the development of this beacon, since the only objective is to send and not to receive messages.

These improvements are compatible with the existing transmitters ensuring the continuity and the compatibility of the system.

2.2 Argos - 2

In this section an approach will be made to the ARGOS - 2 system. There will be a survey of characteristics and the necessary equipment. Finally, an approach of its mode of operation regarding the communications will be made. In this thesis ARGOS - 2 system specifications will be used because it is only necessary to send data to the satellite, and there is no need for bidirectional communication capabilities.

2.2.1 Characteristics

The ARGOS - 2 has brought several innovations relative to its predecessor, making the system better and with greater ability to respond to the needs of the users.

The characteristics of the ARGOS - 2, as seen in figure 2.1, results in the following set of advantages over the ARGOS - 1:

- Better quality of transmission due to a greater sensitivity of the Argos receiver;
- Larger receiver bandwidth;
- Less competition between messages arriving at the antenna;
- Many more messages are received with better quality.

As we can verify, the increase of bandwidth, that the ARGOS - 2 brought us, allows a better distribution of frequencies that are received by the PTT (Platform Transmitter Terminal). This improvement allows the messages received by the PTT to be much less prone to errors, which causes the rate of correct received messages to increase. This increase in the bandwidth, allows also a greater flexibility in periods of repetition of the messages by the ARGOS transmitter.

As it can be seen in figure 2.1, this evolution of the ARGOS system keeps the same data rate transmission for each satellite pass. This feature makes possible to transmit, at most, up to 500 bits of data per pass.

Finally, it is important to note that another major advantage is that this development has brought improvement in the percentage of reception of the data transmitted by the satellite. This evolution is shown in figure 2.2, where you can see the percentage of messages successfully received by the ARGOS satellites 1 and 2 in the y-axis depending on the number of PTT in the x-axis.

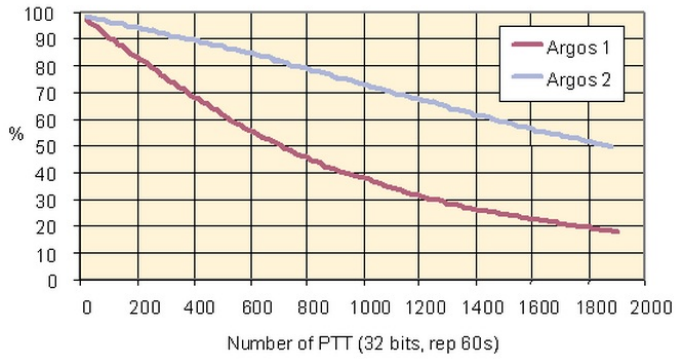


Figure 2.2: Probability of reception by Argos-1 and 2 satellites vs. platform density [4]

2.2.2 Transmitters and PMTs

Although the system uses ARGOS - 2, most of the satellites that will receive our messages already support ARGOS-3, as ARGOS - 3 was designed in a way that ensures compatibility with all transmitters that already exist. However it should be noted that these transmitters are not prepared to take full advantage of the ARGOS - 3 potential, such as the high data transfer rate or the uplink communication. To get the maximum output of the system a PMT to communicate with the satellite to send and receive messages should be used. This is all possible due to the fact that the ARGOS - 3 system takes advantage of the new communication system, providing downlink and uplink data transfer.

The beacon that will be developed will only take advantage of the uplink communication to minimize size and power consumption.

The PMTs began to be developed in order to be implemented on the satellite ADEOSII. This satellite was part of a cooperation with the Japanese JAXA (Japan Aerospace Exploration) and was released in 2002 [13].

After the launch of this satellite the PMTs evolved so much that the size has been reduced and their ability to send data has been increased.

2.2.3 Devices

As we will use satellites that support ARGOS - 3 to communicate, we will make a survey of the equipment that this new development of the ARGOS system brought.

The receivers are the RPUs (Receiver Processor Unit) and the transmitters are the TXUs (Transmitter Unit). These units are important because they bring improvements to the level of data processing and data transmission.

The RPUS are responsible for receiving and processing the uplink signals that arrive with the frequency of 401.65MHz. This unit receives the data and then puts a time tag in order to be possible to identify the time when the data was received. Furthermore, they add a measurement of the carrier frequency Doppler shift, that can be used, together with subsequent measurements to

estimate the transmitter location on Earth. The RPU has the ability to act as an interface between the satellite and the TXU during the downlink communication. In a completely digital perspective, the RPU stores the messages that receives and then forwards them, in real time, to the nearest station.

The TXUs are responsible for sending the messages for the platforms, equipped with PMTs, with a frequency of 466MHz. The acknowledge signal allows data transmission without errors. Users can set the address of the PMT for the TXU they are transmitting to, since that it can communicate with several stations at the same time. This type of configuration is done through the downlink communication.

It is still possible, through downlink communication, to set up the TXU to send messages at a global level and define the time of broadcasting.

2.2.4 Operating Modes of Communications

The transmitters that are used nowadays can be programmed to send messages on periodic intervals for the satellites only when they are in range. This feature allows us to save energy and with it an increase in batteries lifetime.

The communication between the beacon and the satellite has to satisfy a set of rules for the communication among them to be successful . The rules to follow are:

- The transmission frequency must be stable at 401.650MHz$\pm$30KHz so that errors do not appear;
- The time interval between two consecutive messages must be between a minimum of 90 and a maximum of 200 seconds;
- Use of a unique platform identification number;
- The transmission duration of each message must be less than one seconds complying to the ARGOS data protocol.

The ARGOS devices are equipped in satellites that placed in polar orbits. These satellites have the designation of POES and they draw a synchronous trajectory at 850 Km of altitude in order to capture all signals from the transmitters. After that, the satellite stores the messages and forwards them in real time to the land station.

Each satellite is periodically in range for each beacon, every day at same place and at same time. The satellites have a reception area for the signal of about 5000 km of diameter. This makes it possible for all transmitters in this area to communicate with the satellite, as you can see in figure 2.3.

The satellite covers the earth surface while describing its orbit. Due to this factor, when a satellite equipped with a device detects an ARGOS transmitter, it receives the messages that it sends and each satellite can get about 1000 simultaneous connections.



Figure 2.3: Reception area of a signal for a satellite [5]

The satellites transmit in real time to the control centers on earth. This communication is ensured by an L-band network of about 60 antennas, which are distributed in order to obtain a global coverage.

There are two control centers on a global level. One center is located in Toulouse, France and the other is located in Washington DC, in the United States of America. Once the data is received by these research centers, they process it, calculate the location and automatically provide the information to the users. It is also possible to the user to choose the way to receive the data, which can be from a e-mail to online display.

It is given, to the users, the possibility to send messages through a web interface for the DMMC and this sends the message to all the main transmitters that are located in Toulouse, Fairbanks and Svalbard. These transmitters are able to communicate with the satellites to send then the messages from the users.

2.3 Location Technologies

In this section a survey of the existing tracking technologies in the market is presented, as well as their advantages and disadvantages.

2.3.1 Argos

Since the beginning of its development, the ARGOS system was intended to locate animals that travel long distances, such as whales, or who habitats in inaccessible places, regardless of

living in terrestrial or marine environments. In the ARGOS system, the location is performed based on the principle of the Doppler effect. This principle of location is based on each time the ARGOS equipment, embedded on the satellite, receives a message from a transmitter it will measure the frequency of the signal and add a label with the arrival time as shown in figure 2.4.

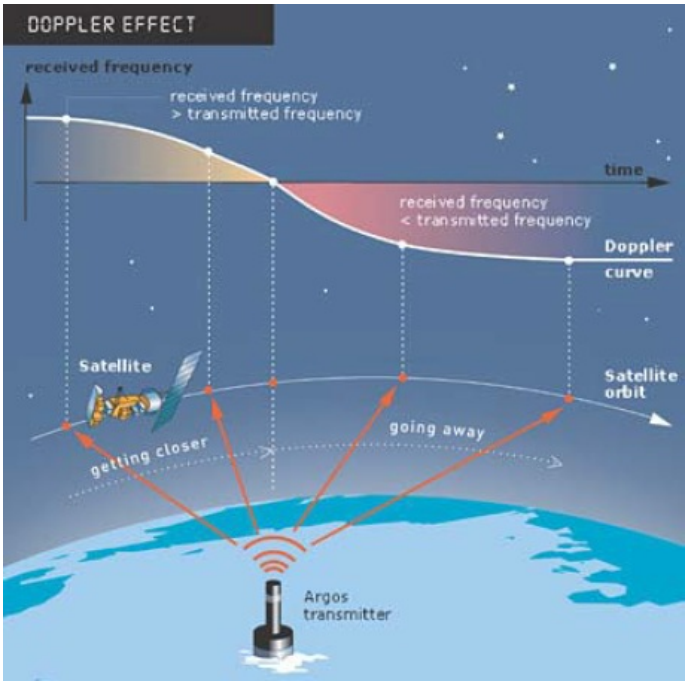


Figure 2.4: Principle of location by the Doppler effect [5]

One of the problems of the localization by the Doppler effect is that there are always two possible positions for the location of the transmitter. One to the left and the other to the right of the satellite footprint. These locations are the nominal ("true") location and the mirror ("virtual") location. This two locations are symmetrical and for that cause, in a first instance it is not possible to distinguish them.

To compare the location, an analysis is made by using the least squares method based on the relative Doppler shift of ideally four transmitted. To calculate an estimated position of the transmitter it is used the first and the last message received by a satellite pass. This process is done by creating a cone whose vertex coincides with the position where the satellite was when it received the first message.

The cone makes an angle with the trajectory of the satellite and this angle can be calculated as the difference between the frequency that is received by the satellite and the frequency that the sender is transmitting. This process is made for the first and the last message resulting two cones of the process.

The intersection of these two cones causes two possible locations for the transmitter. A good understanding of this process can be seen in the figure 2.5.

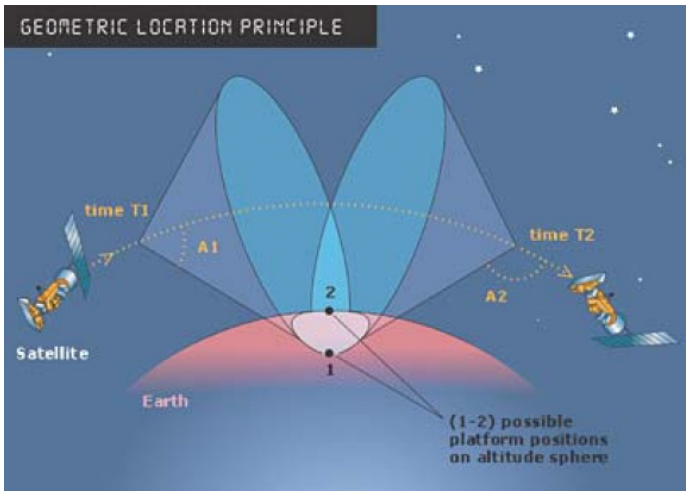


Figure 2.5: The positioning based on Least squares analysis [5]

After having the two positions the selection of position of the transmitter is chosen and tested about their plausibility. Four tests are made in order to validate the location:

- Minimal residual error;
- Transmission frequency continuity;
- Minimum displacement (shortest distance covered since the most recent location);
- Plausibility of velocity between locations.

For the selected location to be valid and made available to users at least two tested parameters must be valid.

The main question that arises concerning the ARGOS location system through the Doppler effect is the low accuracy of the found locations. This low accuracy is easily detected in marine animal that spend much time underwater. The system attempts to combat this problem by providing a global coverage.

2.3.2 GPS - (Global Positioning System)

The GPS (Global Position System), is a system that allows the location of objects that are equipped with a GPS receiver. This system uses a network of 24 Navstar satellites that are orbiting Earth at 11,000 miles.

One of the advantages of this system is the fact of being a free resource and can be used for a variety of applications. This system is used for:

- Air, land and sea navigation;
- Vehicle and vessel tracking;

- Natural resource management;
- Survey and mapping.

The satellites that are used in the GPS system transmit signals at frequency of 1575.42MHz and that signal can be detected by the receivers on the ground. The GPS satellites transmit two low power radio signals and the civilian GPS uses the L1 frequency of 1575.42MHz in the UHF band.

However, the GPS is limited by physical conditions that restrict its operation. These conditions are normally referred to as COCOM (Coordinating Committee for Multilateral Export Controls) limits. These conditions are:

- Disable tracking when moving faster than 1,000 knots (approximately 1,151 mph or 1,852 km/h);
- Disable tracking at an altitude higher than 60,000 ft (approximately 18,000 m)

When both conditions are triggered the GPS receiver cannot acquire the coordinates of the location.

The GPS receiver communication is defined within the NMEA (National Marine Electronics Association)[6] that provides the real time position according to the NMEA format.

The NMEA data format is widely used and provides the user with PVT (Position, Velocity, time) information in real time. This format of data has many sentences that can be applicable to GPS. For example the GGA data, figure 2.6 or the RMC data figure 2.7.

GGA - essential fix data which provide 3D location and accuracy data.

```
 $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47

Where:
     GGA          Global Positioning System Fix Data
     123519       Fix taken at 12:35:19 UTC
     4807.038,N   Latitude 48 deg 07.038' N
     01131.000,E  Longitude 11 deg 31.000' E
     1            Fix quality: 0 = invalid
                               1 = GPS fix (SPS)
                               2 = DGPS fix
                               3 = PPS fix
                               4 = Real Time Kinematic
                               5 = Float RTK
                               6 = estimated (dead reckoning) (2.3 feature)
                               7 = Manual input mode
                               8 = Simulation mode
     08           Number of satellites being tracked
     0.9          Horizontal dilution of position
     545.4,M      Altitude, Meters, above mean sea level
     46.9,M       Height of geoid (mean sea level) above WGS84
                      ellipsoid
     (empty field) time in seconds since last DGPS update
     (empty field) DGPS station ID number
     *47          the checksum data, always begins with *
```

Figure 2.6: The GGA message [6]

As you can see these messages have well-defined fields containing the necessary information for the device location. It is also worth noting that all these messages contain a checksum field, which allows to have a control over the data. This field lets you know if the received data is valid or not, making it a good tool for error control.

More examples of messages supported by this system can be seen in the reference [6].

RMC - NMEA has its own version of essential gps pvt (position, velocity, time) data. It is called RMC, The Recommended Minimum, which will look similar to:

```
$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230394,003.1,W*6A

Where:
     RMC          Recommended Minimum sentence C
     123519       Fix taken at 12:35:19 UTC
     A            Status A=active or V=Void.
     4807.038,N   Latitude 48 deg 07.038' N
     01131.000,E  Longitude 11 deg 31.000' E
     022.4        Speed over the ground in knots
     084.4        Track angle in degrees True
     230394       Date - 23rd of March 1994
     003.1,W      Magnetic Variation
     *6A          The checksum data, always begins with *
```

Figure 2.7: The RMC message [6]

2.3.3 Argos/GPS

A GPS receiver can be added to an ARGOS beacon to achieve higher location accuracy. The main goal of this new system is to create a tracking system that has the great accuracy of GPS and the great transmission capability of the ARGOS system. At the hardware level, this new system ARGOS-GPS, contains a ARGOS PMT connected to a GPS receiver that receives the data using the ARGOS system and after that sends it to an ARGOS processing center. This system is illustrated in the figure 2.8.

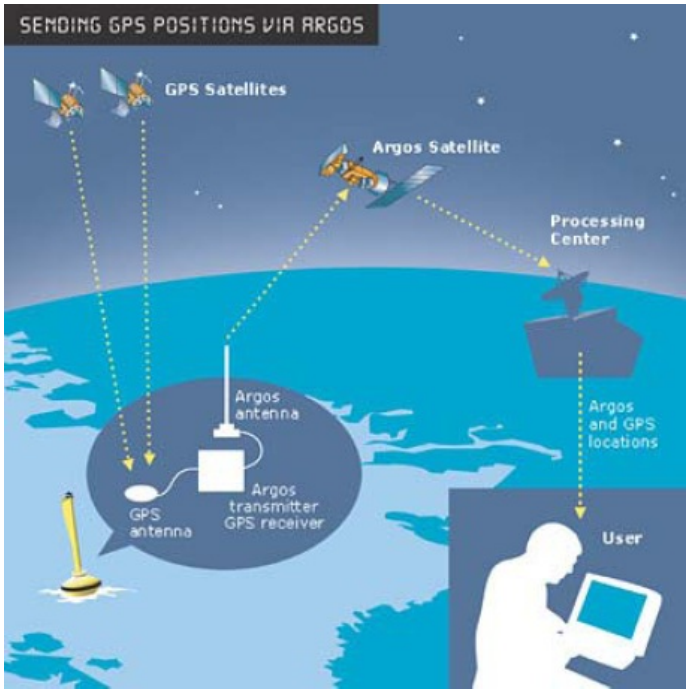


Figure 2.8: The Argos/GPS system architecture [5]

The signal can be corrected and these corrections can be stored in ARGOS messages. The treatment of corrections, made to the data received by the GPS, can be done the same way that the localization of the ARGOS system is made. This makes it possible to use localization by the Doppler effect in the case of the GPS signal is not received.

The use of GPS along with localization using the Doppler effect brings great advantages such as higher accuracy, better collection of positions during the day and the end of the dependence that the system has from the quality of the transmitter.

The GPS signal can be affected due to various factors such as weather conditions, the positioning of the antenna or even due to vegetation. This is a problem, because once the GPS signal is affected the message that will be sent by the ARGOS system will also be affected. This kind of issues may be more serious when we refer to marine animals because the GPS signal takes about 30 seconds to acquire the satellite signal and then send the data.

These problems can be explained due to the fact that these animals spend little time on the sea surface. Other causes to this problems can also be the waves or the inappropriate submersion of the antenna. These difficulties affect the connection and create difficulties to keep the connection with the satellite.

In response to these issues, solutions have been developed. The Fastlock system was created by the Wildtrack Telemetry System Ltd [14] and the Tracktag by the NAVSYS Lda. This equipment was designed to fix all the gaps that the traditional GPS system has and in this way make the system more robust. These receptors have the ability to keep the signals from the GPS satellites with an accuracy of milliseconds. The received data is stored on the device and after that the messages are transmitted in the form of an ARGOS message.

The Fastloc - GPS technology is more adequate to locate animals that live in regions that are little known and where there is a low probability of recovering the transmitter.

As all of these locations are estimated values, this implies that they are subject to an error that can be calculated. Examples of typical errors are shown in figure 2.9.

This type of error is considered isotropic and thus can be characterized by the so-called *radius of error*, that is, the error estimation of the location that is also used to determine the class of the error as shown in figure 2.9. The error may not be only isotropic, so it is best to approach the error by an ellipse than by a circle and the users can still use data provided by CLS to better define the ellipse.

A good example of an ARGOS - GPS application is documented in the work of David W. Sims et al (2009) [15]. In this experience, three Mola Mola fishes were captured on the coast of Portugal and a Fastlock-GPS device and a platform with an ARGOS transmitter were attached to each one in order to determine, measure and analyze the movements of these animals. The ARGOS-GPS system was encapsulated in order to prevent damage to the equipment.

These species usually swim at a depth of 472 meters and continues under water for long periods of time. Because of this factor a saltwater switch was placed nearby the ARGOS antenna to conserve the battery during in which periods that the animal is under water. When the fish emerge from the water the Fastlock receiver acquires the GPS signal and through the ARGOS system the messages are sent with GPS data that has been collected.

This work supports the idea that messages in the ARGOS-GPS format have more precision than the localization through the Doppler effect. Two sets of samples were collected and after

Class	Type	Estimated error*	Number of messages received per satellite pass
G	GPS	< 100m	1 message or more
3	Argos	< 250m	4 messages or more
2	Argos	250m < < 500m	4 messages or more
1	Argos	500m < < 1500m	4 messages or more
0*	Argos	> 1500m	4 messages or more
A	Argos	No accuracy estimation	3 messages
B	Argos	No accuracy estimation	2 messages
Z	Argos	Invalid location (available only for Service Plus/Auxiliary Location Processing)	

Figure 2.9: Errors in calculations of approximations [5]

comparing those that corresponded to Fastlock-GPS a better result was achieved than those that used the Doppler effect.

The results obtained for the accuracy of localization using the Doppler effect are of 150m to Class 3 and of 1000m for class 0, while the test carried out on the ground provided the following results 482m +/- 153m for class 3 and 5179m +/- 3677m for class 0.

The second set of tests that was calculated from the data collected by a GPS and received through the ARGOS communication and using 8 satellites returned the following results: 26m +/- 19.2m. In the case of 5 satellites the results are 64m +/-79.4m.

Comparing the two methods it is possible to conclude that the Argos-GPS location provides better results.

2.3.4 GPS phone tag

An alternative to the usual tracking systems is the GPS phone tag [16]. This technology combines the quality of the GPS system localization with the efficiency of data transfer via GSM (Global System for Mobile Communications) used in mobile phones. An example of a GPS phone tag device can be seen in figure 2.10.

The main characteristics of this system are:

- GPS quality locations at an user-controlled rate;

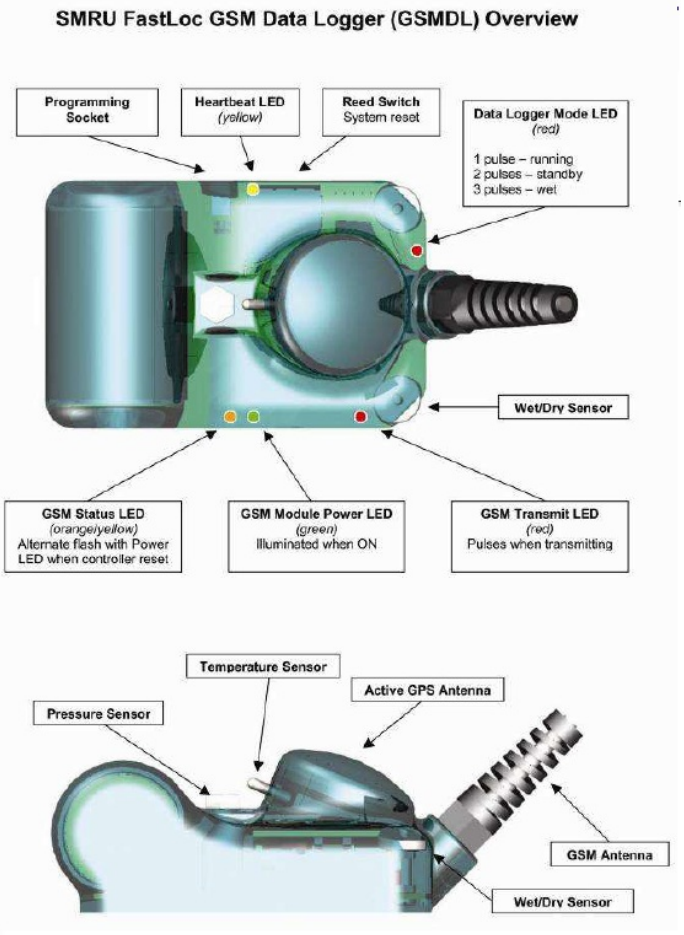


Figure 2.10: Example of a GPS phone tag device [7]

- Complete and detailed individual dive and haulout records;
- Low cost;
- International roaming capability;
- High energy efficiency;
- The normal size of a GPS phone tag is about 100*70*40 mm, still being a considerable size.
- High bandwidth.

It is possible to use the Fastloc-GPS receiver [17] to get, more quickly, the required information to determine the location of the transmitter. However, the main goal of this technology is that the data is sent over a quad-band GSM module that emits whenever there is network coverage. This allows for an intelligent power management and to obtain a high bandwidth.

When the system is in GSM coverage all the data stored in the internal memory of the device is sent. However the data can be stored for 6 months and when the equipment is moved from

its location, the data can be downloaded from the device. Since transmission at recent location estimates is the requirement for VORSat, the use of GSM is not usable.

2.4 Summary

In this chapter, an introduction to the ARGOS system was made, since it is the main communication system of our beacon. A short summary of its evolution over time as well as its features and applications was also made. Then, the current tracking systems on the market were mentioned as well as their advantages and disadvantages taking into account our problem.

We can also conclude that because of its potential the ARGOS-GPS system will be used for the beacon. This system brings together the features of the ARGOS and the GPS systems attempting to reduce its flaws. In the GPS we will adopt the GGA and RMC messages because they provide all the necessary data to pinpoint the beacon location, latitude, longitude, velocity, altitude, HDOP (Horizontal Dilution of Position) and VDOP(Vertical Dilution of Position). This data will be treated and sent in the ARGOS communication.

The GPS phone tag system could also be a good choice but because of its size is not viable for the project since the beacon will be embedded in a satellite of reduced dimensions.

In the next chapter an approach to the beacon that will be used as a starting point to solving the problem of this dissertation is made, as well as, the design of the beacon as a starting point of the project.

Chapter 3

Dimensioning of the Beacon

Before starting to implement the beacon it is necessary to make a careful analysis about the adopted topology to approach the problem, as well as the components that will be part of it. The design phase of the circuit is therefore an important phase of this dissertation. This chapter will present all the conditions, theoretical calculations and variables that have been taken into account during the design of the beacon. The calculations made during the design of the beacon are detailed in appendix A.

3.1 Adopted Topology

As mentioned in section 1.2, our beacon, in its most simplified form, will consist of a microcontroller that will command the rest of the circuit and process the data sent by a GPS through a serial port. There will also be an frequency generator that will provide a constant frequency of 401.65MHz to an I/Q modulator. The signal that will be returned by the modulator will go through an RF power amplifier that will amplify the signal to get an expected output power of 2 Watt during transmission. Finally, the circuit will have an antenna to radiate the signal.

This layout can be seen in a simplified form in figure 3.1.

It is also necessary to note that the final circuit is more complex than the one shown in figure 3.1, as can be seen in figure 3.12, due to the fact that the circuit has to fulfill the needs of the chosen components.

This topology has been adopted to address the problem because this solution better implement the objective of the beacon. Being the level of energy consumption a critical aspect, it is possible to verify that it would not make much sense to have a microcontroller with a built-in I/Q modulator, since the microcontroller will be used for longer periods than the modulator (there would be an unnecessary power consumption). Therefore this topology enables us to shut down most of the devices when they are not being used, in order to save energy.

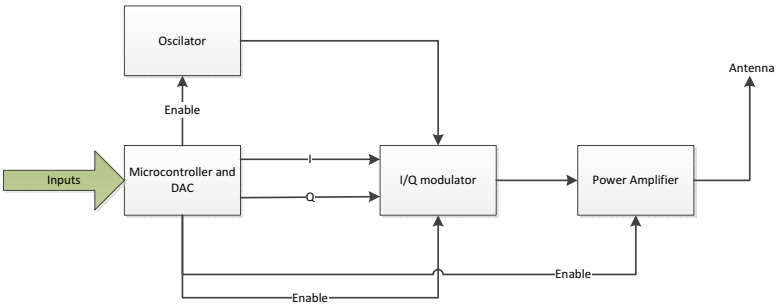


Figure 3.1: Simplified architecture of the proposed solution

Moreover, we want to send data over short periods of time, reinforcing the idea previously presented.

Another reason why this topology has been adopted is the fact that all components that constitute the beacon are SMD (Surface Mount Devices) which facilitates their integration into a small size PCB. Finally, these components are relative well know, having already been used before.

3.2 Choice of the Components

At this point we will start by choosing the microcontroller, taking the needs of the beacon into account. Since it is necessary to generate two distinct analog signals to drive to enter the I/Q modulator it is necessary that the microcontroller has at least two DACs (Digital to Analog Converter). The DAC's should have a good resolution, so 12 bits resolution was chosen.

Another important aspect that must be taken into account, is energy consumption. It should be as small as possible, therefore it is better to use a microcontroller with a low supply voltage.

Finally, the circuit will be in standby mode during certain periods of time to conserve battery power. Due to this, factor it is necessary that the microcontroller has a small wake-up time in order to allow it to react within the desired time.

Table 3.1: Microcontrollers characteristics

Parameters	Atxmega16A4 [18]	ADuC7026 [19]	MSP430F123 [20]
Vcc	3.3V to 3.6V	3.6V	1.8 V to 3.6 V
Icc per I/O	20mA	45mA	200 μA at 1 MHz at 2.2 V
Wake-up time	0.17 μs	3 μs	6 μs
DAC's resolution	12 bit	12-bit	N/A
SRAM	3.3KB	8kB	8KB

As can be seen in table 3.1 the MSP430F123 has no internal DAC, which taking into account the presented solutions makes it no longer a valid option for the microcontroller. The Atxmega 16A4 has a lower power consumption than ADuC7026 which indicates that it will be a better option for our circuit. We can also verify that the first microcontroller has a much lower wake-up time than the second.

It is worth noting that the two DAC have the same resolution and the only advantage provided by the ADuC7026 relatively to Atxmega 16A4 is a larger SRAM size. For our case the ATxemga SRAM memory is enough. So taking into account all the factors discussed above we can choose the Atxmega.

Another of the components to be chosen is the local oscillator whose frequency has a fixed value of 401.65MHz. The frequency has to be stable, as discussed in section 2.2.4. Because of this, the most viable solution was an oscillator that could be controlled by voltage.

Therefore have been found two oscillators that met our constraints. One is the CVCO33Cl [21] and the other is the CVCO55BE [22]. What differs between the two oscillators is the frequency range that each one provides. The CVCO33CL has a frequency of 400 to 440MHz and the CVCO55BE has a frequency range of [400 to 800MHZ], as observed in table 3.2. We can verify that the CVCO55BE has a bigger power consumption than the CVCO33CL.

Table 3.2: Characteristics of the oscillators

Parameters	CVC033CL [21]	CVC055BE [22]
Vcc	3.3V	5V
Icc	16mA	17mA
Load Impedance	50 Ω	50 Ω
Frequency Range	400-440MHz	400-800MHz

Given the fact that the frequency is located at 401.65MHz, the two selected oscillators meet this requirement. Therefore the fact that the CVCO33Cl has a lower power consumption than CVCO55BE, elects it to be part of the beacon.

To obtain a stable frequency at the oscillator output, a control system has been designed with a PLL (Phase Locked Loop). The design of this control system will be presented later ahead in section 3.3.2.

In order to reduce the power consumption of the beacon, this oscillator only has to be active during the transmission of messages to the ARGOS satellite. Consequently, a switch made with a MOSFET (Metal Oxide Semiconductor Field Effect Transistor) will be placed in his power supply in order to turn it on when necessary. The design of this switch will be presented in section 3.3.1.

As indicated in figure 3.1, the I/Q modulator is the third component of the circuit. This component picks up the waves I and Q, which are given by the microcontroller DAC and, use them to modulate te 401.65MHz signal from the oscillator. This microcontroller has only one DAC but since it has the possibility to sample and hold it can produce two outputs with a DAC, loosing a bit of the sampling frequency. This waveform is already in the Manchester PSK +/- 60 degrees coding. So the next step is the choice of the I/Q modulator.

This component should have a power supply of 3.3V and should have a range of frequencies that allows it to operate at the frequency of 401.65MHz. After a search by several manufacturers, two devices were found at Analog Devices as can be seen in figure 3.2.

As can be seen from figure 3.2, both the AD8345 [23] and the AD8346 [24] have the same power supply operating at 3.3V. Although one of the central concerns is to reduce the circuit

Part# Results: 14	Min RF Frequency (MHz)	Max RF Frequency (MHz)	RF Freq (MHz)	IQ Freq (MHz)	Carrier Suppress (dBm)	Sideband Suppress (dBc)	Noise Floor (dBm/Hz)	Output P1dB (dBm)	IIP3 (+dBm)	Voltage Supply (V)	Supply Current	Package
AD8345	140MHz	1GHz	140 to 1000	80MHz	42	42dBc	155	2.5	-	2.7 to 5.5	65mA	16-Lead Tssop
AD8346	800MHz	2.5GHz	800 to 2500	70MHz	42	36dBc	147	3	-	2.7 to 5.5	45mA	16-Lead Tssop

Figure 3.2: Characteristics of the modulators

consumption, as we can verify the AD8346 minimum RF frequency is well above the intended for the beacon. Although the AD8346 has a lower power consumption, the chosen modulator will be the AD8345.

This modulator provides an output signal with 1mW which be important to define our RF power amplifier because we need an output power of 2W. This automatically implies that our amplifier should have a gain of 2000, approximately 33dB.

Subsequently, and taking into account the facts set before, we proceed to the choice of the RF power amplifier.

In the choice of the amplifier, our main condition is that it needs top provide a gain of 33dB. So the surveys of possible solutions has been oriented to the desired gain. It was found an amplifier that meets the range of frequencies where it has to work and has a gain of 32.5 dB which is quite close to the intended. In table 3.3, we can see the amplifier electrical characteristics. From here we see that the amplifier needs to be supplied with a minimum voltage of 6.2V.

Table 3.3: Characteristics of the power amplifier

Parameters	MSA-0886-BLKG [8]
Vcc	6.2V to 9.4V
Id	65mA
Load Impedance	50 Ω
Frequency Range	0.1 to 3GHz
Gain	32.5 dB

Being the beacon powered at a voltage of 3.3V and since the amplifiers require a power supply between 6.2V to 9.4V a problem arises. To solve this situation, the adopted solution was to use a DC/DC converter to increase the voltage from 3.3V to the desired value. In this case that voltage will be 12V, since the amplifier requires at least 10V in order to have an operating voltage of 7.8V as shown in figure 3.3.

Looking at figure 3.3, and using the data of table 3.3, we can easily conclude the value of that Rbias resistance. The value is calculated as follows:

$$Rbias = \frac{Vcc - Vd}{Id} \Longleftrightarrow Rbias = \frac{10V - 7.8V}{65mA} = 33.8\Omega \tag{3.1}$$

Since it is difficult to find a resistor of 33.8 Ω a 40 Ω resistor was chosen, which means that the Vd value will be 7.4V, still within the operating voltages.

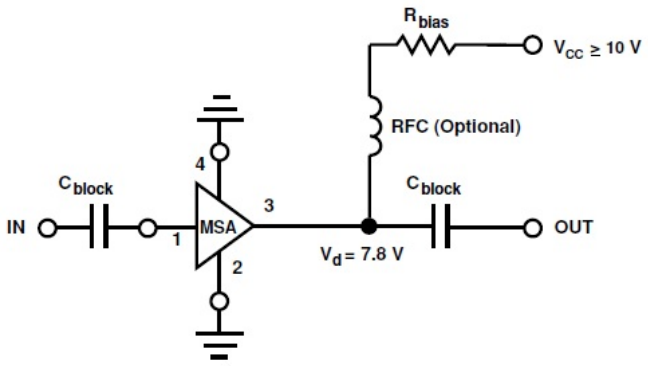


Figure 3.3: Power amplifier - typical configuration[8]

So, to provide these 10V of power supply to the amplifier an IE0312S-H [25] was chosen rising the voltage from 3.3V to 12V.

After choosing all the components for the adopted topology, the antenna was selected. This antenna must have an operating frequency that allows the operation on 401.65MHz and an input impedance of 50 Ω. Since it will be embedded in the PCB the antenna dimensions should be as small as possible. Two options were found as shown in the table 3.4.

Table 3.4: Characteristics of the Antennas

Parameters	CAN4311129200431K [26]	CAN4313121200431B [27]
Working Frequency	400MHz to 500MHz	400MHz to 500MHz
Bandwidth	20MHz	20MHz
Impedance	50 Ω	50 Ω
Dimensions	12mm * 4mm	37mm * 7mm
Gain	0.5dBi	0.5dBi

As can be seen by the data presented in the table, the two antennas have the same characteristics but the CAN4311129200431K is considerably smaller so it was chosen.

3.3 Choice and sizing of the remaining components

After starting the choice procedure of components that will integrate the beacon it is necessary to understand that alone they would not work. It is necessary to design the control system as well as the interfaces between them. So, below the entire design of the components and the control system for the circuit is presented.

3.3.1 Switches

As mentioned earlier, the component choice took the reduction of power consumption into consideration. Please note that, from all the components that were chosen, only four do not have a

chip enable signal. This signal allows to activate and deactivate specific components. One of this components is the opamp. This component has a current in the order of pico Ampere, so it will be discarded because its power consumption is very low.

Still, the VCO, the DC/DC converter and the power amplifier operational state need to be controlled. A way to control the operation of these components is to introduce a switch in their power supply and allowing switching on and off the components.

For this propose a PNP MOSFET will be used. As the DC/DC converter is used to supply the power amplifier it is obvious that controlling the operation of the converter we can also control the operation of the power amplifier. This allows a reduction in the number of MosFets used.

In this section the switch for the VCO will be dimensioned and the other for the CC/CC converter will be dimensioned in section 3.3.5. However, the MosFet chosen for this switch is the same for the switch to control the converter.

Since this MosFet will lead the voltage from the source to the drain, a survey was made looking for one that had the smallest voltage drop when in triode state, that is the lower Vds.

Taking into account this restriction and after performing a survey the NTR2101P MOSFET [9] was chosen, which has a Vds lower than 300mV. By analysis of figure 3.4, is possible to see that for a Vgs of 3.3V and a 500mA Idmax, the Vds drop is less than 300mV.

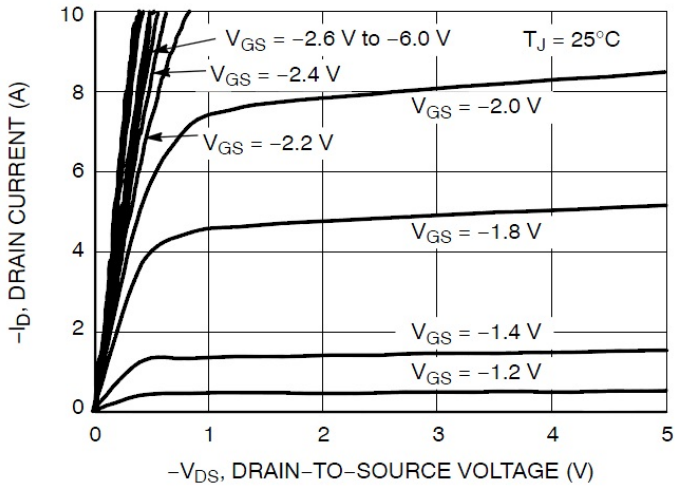


Figure 3.4: Id vs Vds [9]

The topology adopted for this switch can be seen in figure 3.5.

Next, the values of R1 and R2 resistors will be determined in order to make the MosFet behave like a switch. It should be noted that its gate is connected to the microcontroller.

The R1 resistance will have a value of 100Ω. This resistance limits the current peak in the gate, so that by varying the gate voltage, the current that goes through the gate capacitor does not tend to infinity. Normally these gate resistances are small. The resistance R2 will have a value of 1KΩ. This is a normal pull-up resistor.

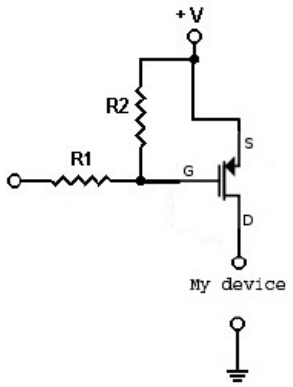


Figure 3.5: MosFet as a Switch

3.3.2 Oscilator Control

Since the VCO is a voltage controlled oscillator it is necessary to introduce a specified voltage to obtain a specified frequency. As in this case the frequency should be as stable as possible, a solution that could dynamically adjust the control voltage of the VCO was chosen in order to stabilize as possible the frequency generated.

In order to achieve this frequency stability a PLL was introduced in the beacon. A search was made for PLLs that support the frequency of 401.65MHz and have an operating voltage of 3.3V. The TRF3750 [10] PLL was chosen.

The PLL is a device that compares the phase of an input frequency divided by a R factor with the phase of the output frequency of the VCO in order to generate a charge pump voltage. This voltage is the VCO control voltage. The operation of the PLL can be easily understood through the analysis of its functional block diagram, that can be observed in figure 3.6.

As we can see from the figure, the signal from the input oscillator is divided by a R value that is defined in the PLL programming phase as well as the prescaler, the A and B registers. The output signal of the VCO passes through the prescaler register where its frequency is divided by the value of this registry. This frequency should not exceed 200MHz which is the operation limit of the PLL.

Finally, the signals are injected into this Phase Frequency Detector (PFD) which as the name suggests, compares the two signals in terms of frequency and phase and by adjusting the voltage of the charge pump making this coincide and leading to the desired frequency.

The basic configuration of the PLL that is available in its datasheet and which is in figure 3.7 was adopted. The capacitors and resistors values available into that example were used. Additionally 1KΩ resistors were placed, on the programming pin of the PLL for pull-up to ensure that it has the correct voltage to read a logical one.

To complete the PLL circuits it should be noted that this device has a charge pump voltage (VCP), that needs to be at least 1V greater than the power supply. Since Vcc is 3.3V this means that the VCP is at least 4.3V.

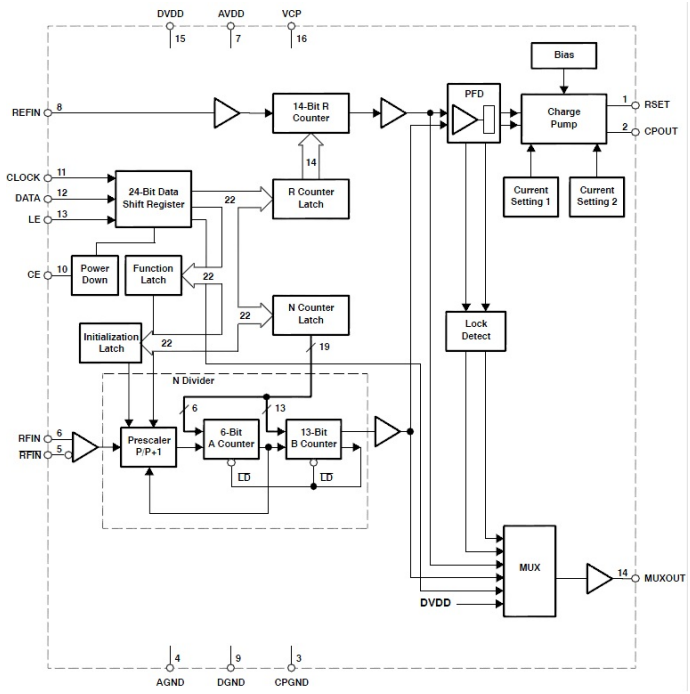


Figure 3.6: Functional block diagram [10]

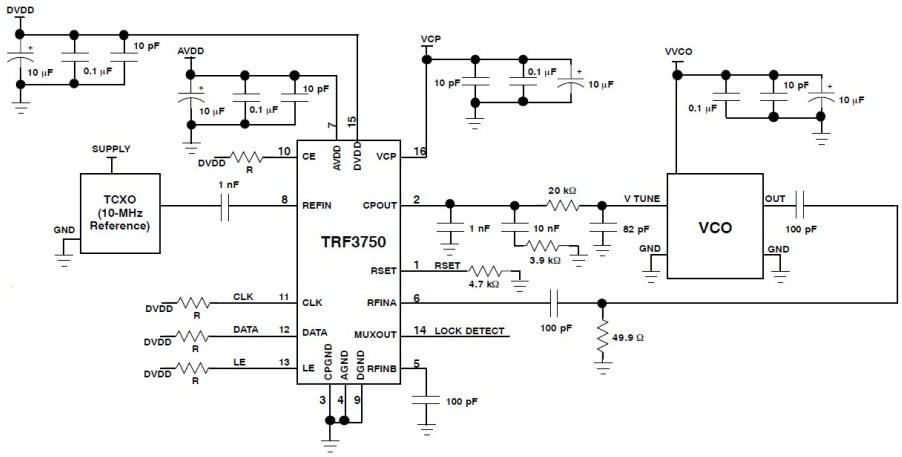


Figure 3.7: Tipical PLL configuration [10]

In the case of our beacon this voltage can only be provided by the DC/DC converter. It was decided that the VCP voltage would be 5V and this way the circuit shown in figure 3.8 has been adopted, to ensure that voltage.

The zener diode was placed in the circuit for providing the function of voltage regulator to obtain a voltage as close as possible to 5V. The chosen zener diode was the BZX55C5V1 [28], having a maximum voltage of 5.1V and a Izk 1mA.

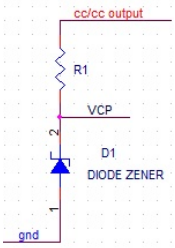


Figure 3.8: VCP power Supply

A preliminary test to the DC / DC converter was made in order to verify that it provides 10V when under load, after which an appropriated value for the resistance R1 was calculated as follows:

- Ir = 7.5mA + izk
- Vcc = 10V
- VCP = 5V

Using the following equation:

$$R1 = \frac{Vcc - VCP}{Ir} = \frac{10V - 5V}{7.5mA + 1mA} = 588\Omega \tag{3.2}$$

We obtain the value of the resistance R1 that is 588Ω. The value will be approximated to the standard value of 660Ω.

3.3.3 Dimensioning of the opamp as an inverter

This part of the circuit is responsible for inverting the signal that is generated by the DAC from the microcontroller. Since the I/Q modulator requires a differential for best operation, this circuit is needed.

A typical inverting configuration with an unitary gain was adopted, as shown in figure 3.9.

A search was performed for a single component that had two opamps and that worked at 3.3V. The AD8502ARJZ [29], fulfills such requirements.

The resistors R5, R6, R7 and R8 are part of the negative feedback loop that sets the gain. The gain is given by the expression:

$$Gain = -\frac{Rf}{R} \tag{3.3}$$

As the resistances are equal, we have secured an unity inverted gain.

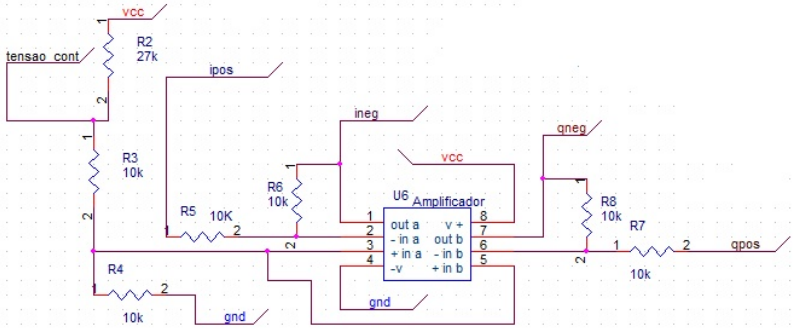


Figure 3.9: Opamp - inverting configuration

The *tensao cont* voltage presented in the circuit provides a reference voltage to the microcontroller DAC to optimize its functionality because it requires a reference voltage to work properly.

Being the desired voltage at this point of 1.4V obtained from 3.3V by a voltage divider composed by 20K(10K+10K) in series with R2, the latter is given by:

$$tensaocont = \frac{20k}{20k + R2} * Vcc \tag{3.4}$$

This expression gives a value of 27KΩ for R2. The detailed calculation is presented in appendix A, section A.1.

Finally, the modulator requires that the waves have a DC component of 0.7V. Due to this fact the non inverting input will have a voltage of 0.7V to give that offset to the wave, to be obtained from tensaocont = 1.4V by the 10K+10K resistor divider.

3.3.4 I/Q modulator

One of the main components of the circuit is the I/Q modulator. It should receive a special attention because it makes the modulation of the signal to be sent.

According to the component datasheet it is possible to see that the modulator requires an average voltage of 0.7V at his differential inputs and a differential voltage of 200mVpp. The configuration used for this device can be observed in figure 3.10.

Notice that there is a balun between the VCO output and the modulator input. This component is not anything more than a RF transformer with a ratio of 1:1. A search for a similar balun to the one that appears in the figure 3.10 specified by the device datasheet led to the choice of the CX2156NL [30] balun.

3.3.5 Control system for the DC / DC converter

A significant part of the circuit, at the power level, is the DC/DC converter. This converter supplies the RF power amplifier and the PLL charge pump and for that reason it only needs to

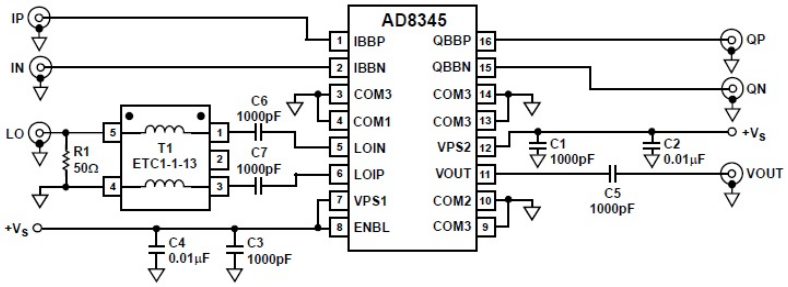


Figure 3.10: I/Q modulator - basic configuration

be enabled during data transmission. Taking this factor into account a control circuit has been designed. It can be seen in figure 3.11.

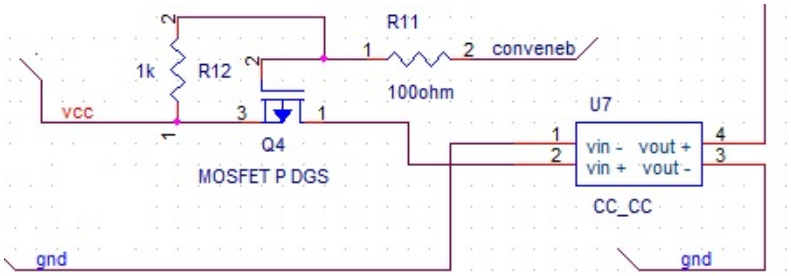


Figure 3.11: Supply circuit for the DC/DC converter

Next, the values of R1 and R2 resistors will be determined in order to set the MosFet to behave like a switch. It should be noted that its gate is connected to the microcontroller.

The R1 resistor will have a value of 100Ω. This resistor serves to limit the current peak in the gate, so that by varying the gate voltage, the current that passes through the gate capacitor does not tend to infinity (normally these gate resistors are small). The resistor R2 will have a value of 1KΩ, is a normal value for a pull-up resistor.

The complete circuit schematic can be observed in the figure 3.12.

3.3.6 Calculation of the transmission line

After looking at the antenna and the power amplifier datasheets it is clear that they are designed to operate with an impedance of 50Ω. This implies the need for a transmission line with that impedance.

To calculate this impedance we use the following equations A.3 and A.4 that relate the impedance with the width of tracks and the substract of the PCB.

$$Z = \frac{Z0}{2\pi * \sqrt{2*(1+\varepsilon r)}} * ln(1 + \frac{4h}{\omega eff} * (\frac{14+\frac{8}{\varepsilon r}}{11} * \frac{4h}{\omega eff} + \sqrt{(\frac{14+\frac{8}{\varepsilon r}}{11} * \frac{4h}{\omega eff})^2 + \pi^2 * \frac{1+\frac{1}{\varepsilon r}}{2}})) \quad (3.5)$$

$$\omega eff = \omega + t * \frac{1+\frac{1}{\varepsilon r}}{2\pi} * ln(\frac{4e}{\sqrt{(\frac{t}{h})^2 + (\frac{1}{\pi} * \frac{1}{\frac{\omega}{t}+\frac{11}{10}})^2}}) \tag{3.6}$$

The symbols shown in the equations have the following meanings:

- Z0 = impedance of free space;
- ε r = dielectric constant of substrate;
- ωeff = effective width;
- w = width of strip;
- h = thickness ('height') of substrate;
- t = thickness of strip metallization.

The material used to manufacture the PCB is FR4 and has the characteristics listed in table 3.5.

Table 3.5: Characteristics of the FR4

Parameters	FR4
εr	4.8
h	1.5mm
t	1mm

In addiction we have that Z=50Ω and the Zo= 119.917π.

After having all the parameters we can solve the equation A.3 in order to obtain an effective width of the track (ωeff).

We obtain an effective width of 2.7388mm after the solving the equation A.3. After this we will use this value to solve the equation A.4 in order to obtain the real width of the track that the PCB should have.

So, having the ωeff=2.7388mm we get a ω=2.22mm as the ideal width for the 50Ω impedance transmission line.

The detailed calculations are presented in appendix A, section A.2.

3.3.7 Control of the microcontroller

The microcontroller is the main circuit of the beacon. It controls the other components and processes the data to be sent. Therefore it is the device that will operate for larger periods.

However, if you turn off this component when not needed we would save energy. In the following order of ideas the most efficient way of doing this is putting in the beacon a Real Time

Clock that will only ensure that the microcontroller is waken from stand-by made early when it is needed. The chosen Real Time Clock was the M41ST87W[31], since it can be powered by 3.3V and has a low current consumption (0.75μA).

3.3.8 Dimensioning of the system for energy storage

The objective with this system is to protect the power supply from the current peaks. To achieve this objective was placed a capacitor in parallel with the 10V power supply, as implemented using the DC/DC converter. This capacitor will provide the initial current that the circuit needs and then the power supply provides the remaining.

The circuit requirements are:

- I = 300mA;
- ΔV=0.5V;
- time=1s.

Using the equation 3.7, and solving them in order to C.

$$I_c = C * \frac{dVc}{dt} \Longleftrightarrow 0.3 = C * \frac{0.5}{1} \tag{3.7}$$

We obtain a capacitor of 600mF.

3.4 Summary

In this chapter, a presentation of the adopted topology to attack the problem as well as the reasons why choose this solution was made.

Several solutions for the components that integrate the beacon were presented, as having been chosen based on the presented criteria.

Finally the rest of the circuit was presented divided in modules, together with the dimensioning of the components need for its operation.

The final circuit of the beacon is represented in figure 3.12, being more complex than the one adopted at the starting point.

In the next chapter the implementation of the proposed solution will be explained. The procedure for manufacturing of the hardware and software will be exposed. Also the PCB layouts will be presented and the software algorithms will be explained using flowcharts.

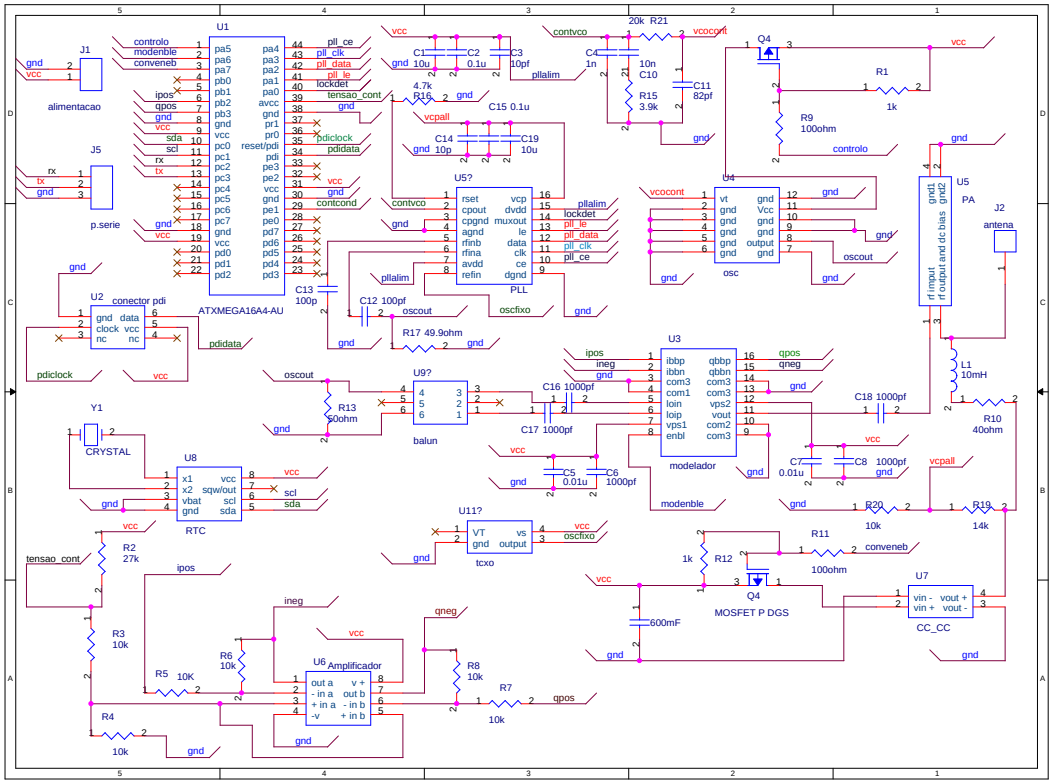


Figure 3.12: Architecture of the proposed solution

Chapter 4

Implementation

After detailing the component choice and the circuit design, it is now possible to present the details regarding the implementation of hardware and firmware.

4.1 Hardware Implementation

After the design of the circuit, its physical implementation. Start with the design of the PCB.

During the design of the PCB the considerations listed in the appendix B have been taken into account. We tried to reduce the problems that could be created by a poor distribution of the components, by the noise and still try to control the impedances of the lines.

Figures 4.1 and 4.2 show, respectively, the top and bottom footprints of the PCB to be produced. Their detailed versions are in the appendix D.

This PCB has 8cm*8cm and was designed this way because this is a PCB for test the prototyped circuit. It was necessary to have some room to correct some mistakes made during its production, or even during the design of the circuit itself.

After soldering the components to the PCB, we obtained the result shown in figure 4.3.

It is easy to understand after analyzing the figure that a button to reset the microcontroller, a capacitor of 10μF to the power supply to filter some noise and the pull-ups from the PLL were added after the drawing.

It should be noted that the PCB layout is mirrored when compared with the board that was made.

A critical evaluation of the performance of the board will be made in chapter 5 when the presentation of the results from the tests is done.

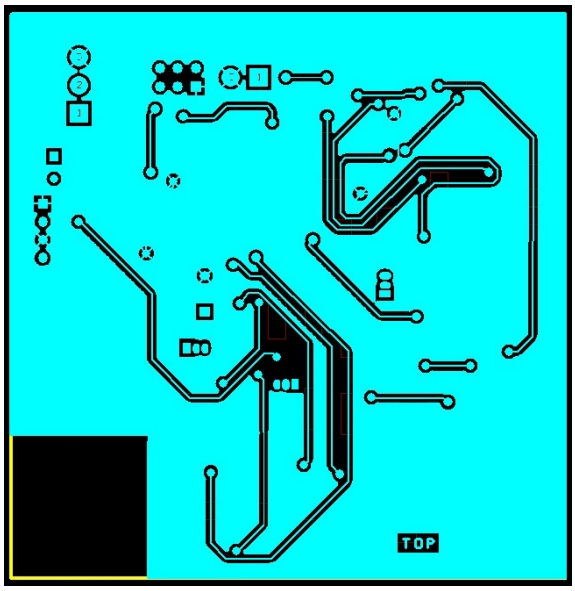


Figure 4.1: Top PCB footprint

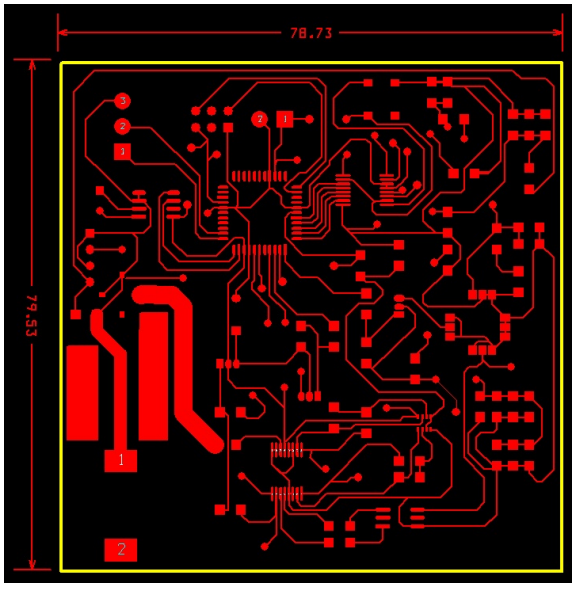


Figure 4.2: Botton PCB footprint

4.2 Software Implementation

After producing the circuit it is necessary to write the microcontroller firmware, which enables it to perform the intended functions that we intend for the beacon.

The microcontroller was programmed following a philosophy of state machines. These state machines can be separated into three major parts: the main state machine, the serial port interrupt and the timer interrupt state machine.

The main state machine is represented in the figure 4.4.

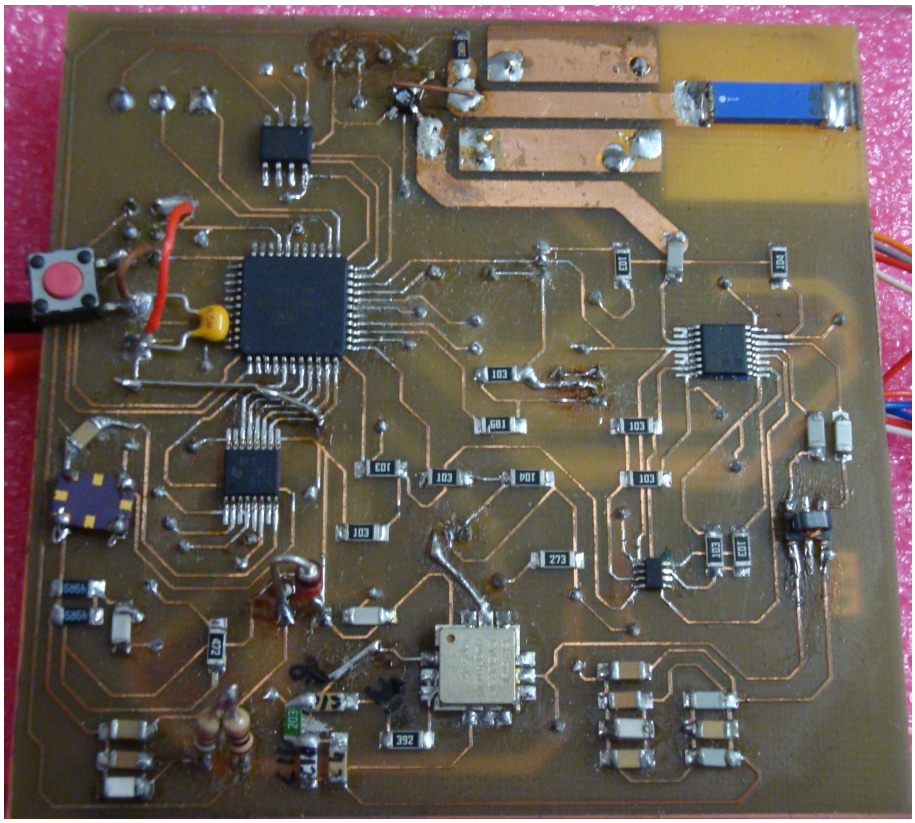


Figure 4.3: Prototyped Beacon - bottom view

As we can see in the flowchart from the main routine of our program, the microcontroller stays in state zero, waiting that the timer overflows or that something is received from the serial port. These are the only two possibilities that make the program leave this state. This state is represented in the state machine by the state zero (do nothing). In the flowchart the letter "N" corresponds to the word "NO" and the letter "Y" to the word "YES".

It should be noted that the sending of data will be periodical. Consequently the program, even being in the zero state, will be waiting for a timer that determines whether it is time to send data or not. If it is not the time to send data, the program will wait from new data to be received from the serial port. In this case the microcontroller will treat and store the data conveniently and then return to the state zero waiting for the time to send a message.

After receiving the data from the serial port the state machine jumps to state one where it will calculate the checksum from the received data. Once finished this operation the state machine moves forward in its implementation and will determine, in state three, the expected value of the checksum and then compare with the one obtained. This operation serves to detect errors in data transmission.

After this calculation the microcontroller will check if the received checksum is correct. If it is not, an internal flag is activated and is when the time to send a periodic message is reached, the beacon sent's a standard message to enable the location of the beacon through the Doppler effect.

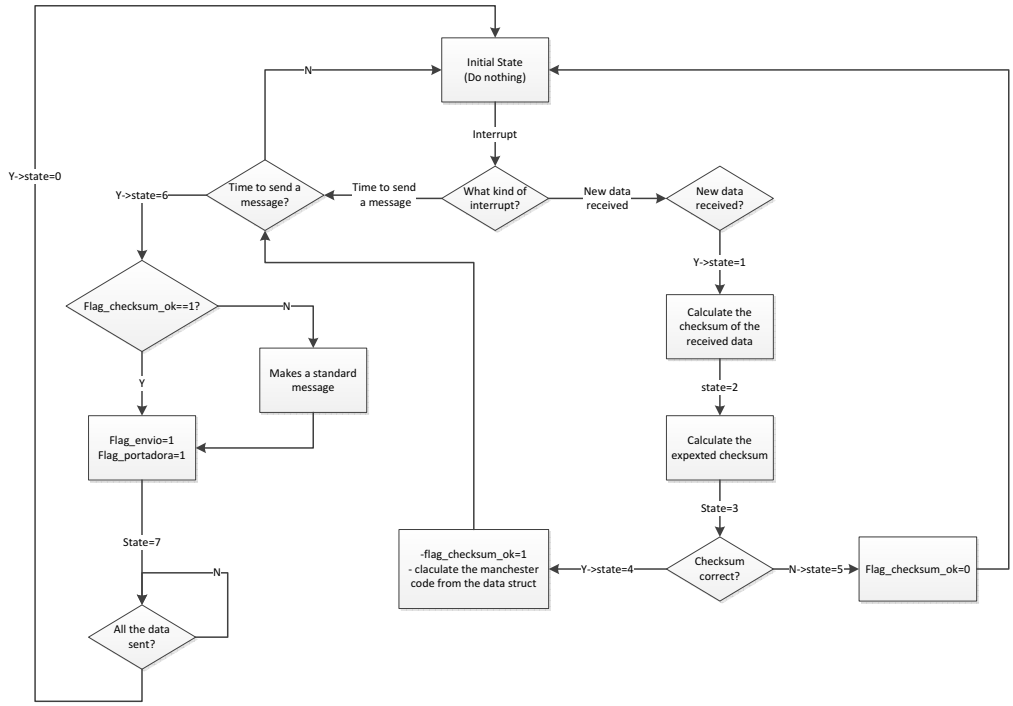


Figure 4.4: Flowchart from the program main

After this the microcontroller returns to the zero state.

After the the received data is processed a timer is activated, which activates an interrupt service routine where, the message will be sent. This transmission is represented in the timer interrupt flowchart that is shown in figure 4.6 and that will be explained later in this document. After sending the message the state machine returns to its initial state (zero state), waiting for more data or for a timeout to sent another message.

Taking into account that the microcontroller stays a lot of time waiting for data that is received by the serial port, it is necessary to explain that the state machine that runs in the interrupt service routine is generated by the serial port.

It should be noted that there are two ways to read what is received through the serial port. We have the polling method that locks the microcontroller causing it to not perform any other functions while waiting for data. The other method is by interrupts, releasing the microcontroller to perform other functions. In this case, the second method will be used.

As seen in the flowchart represented in the figure 4.5, which represents the routine for the serial port interruption, it receives one char at a time and always tests if the char received is a '$'. This is done because this is a start character of a NMEA message and it is never repeated in the middle of the data, so if we receive another '$' in the middle of the message that means that the message has an error and then we begin storing the data again from that point. The values received are being stored in the two buffers until the fourth value. At this point we test if we received a 'G' or a 'R' that distinguish the two types of messages that we can receive. If it is one or the other it

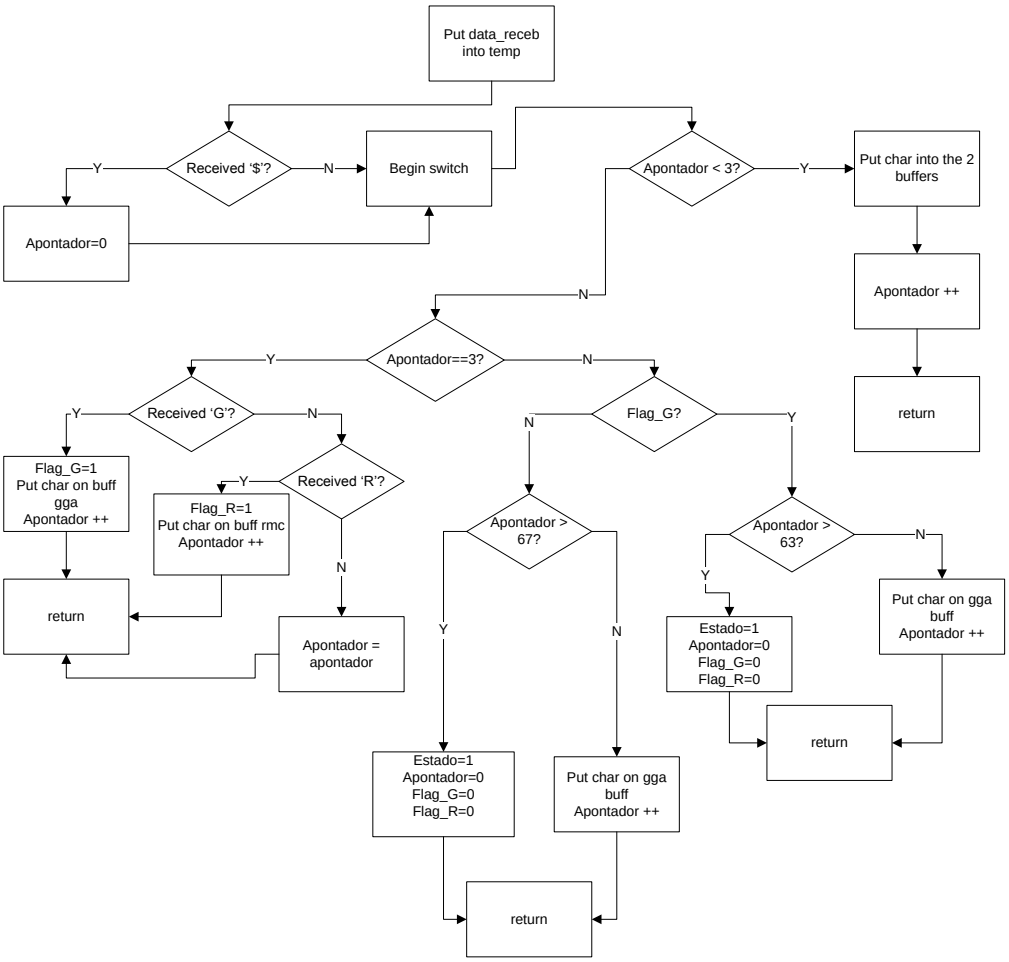


Figure 4.5: Flowchart from the USART interrupt

activates the corresponding flag and will also fill the corresponding buffer. When the end of the data is reached we reset the flags and the variable "apontador". Finally we put the state of the main state machine into one and the program returns from the interrupt.

The last flowchart to be presented in figure 4.6, is the interruption due to the overflow from the timer. This routine is responsible for sending data in Manchester encoding to the DAC to generate the waveforms for the I/Q modulator. Some considerations about the Manchester encoding can be found in appendix C.

Table 4.1: Format and structure of the Argos message.

Pure Carrier	Preamble	Size of the message	Platform ID	Data
160 ms	24 bits (FFFE2F)	4 bits	20 bits	N*32 Bits (1<N<8)

The constitution of the Argos message can be seen in table 4.1. It is possible to note that this message is preceded by a pure carrier with a specific duration of 160ms. Sending of the carrier plays a specific role in the Argos message: it serves for the receiver to determine the frequency

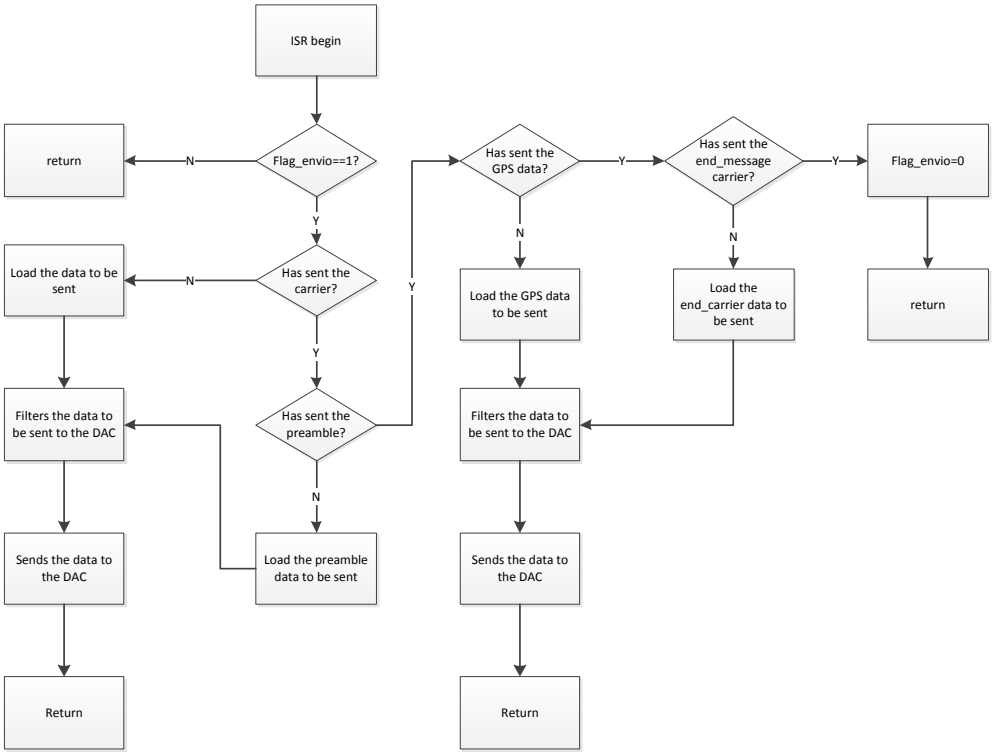


Figure 4.6: Flowchart from the Timer interrupt

at which the signal is being received. After sending the carrier, the next data to be sent are: the preamble, the size of the message being sent and the ID of the platform that is sending. The preamble is a block that is sent to be enable detecting the received signal easily. Finally the data blocks are sent, containing data from the GPS. These blocks can go from 32bits to 8*32bits. Finally and in our implementation, after sending all the Argos message a little more of pure carrier is sent to prevent errors in the decoding of the signal.

It is possible to see in the flowchart represented in figure 4.6 that there is another step, during the timer interrupt, before sending the data to the DAC. The data to be sent, first goes to an FIR filter in order to smooth the phase transitions. This process presents spreading. The spectrum, avoiding errors during the decoding phase of the signal. This filter also provides a better spread spectrum of the signal in order to end the signal replication on other frequencies without being other than the desired. The design and calculations of this filter are covered in the section 4.2.1.

After filtering these values, the routine sends them to the DAC in order for it to generate the waveforms that are sent to the I/Q modulator. After the routine disables the timer and returns.

4.2.1 Filter Design

The need to implement a filter arises due to the possibility of improving the data transmission. Since the signal that is being modulated is BPSK (Binary Phase-Shift Keying), this type of modulation makes the output voltage transitions of the DAC more sudden and that creates a square

wave over time. The transitions of the square wave cause in the modulated signal, the appearance of side skirts that are not desirable. This phenomenon has an effect that can be observed with greater detail in figure 4.7.

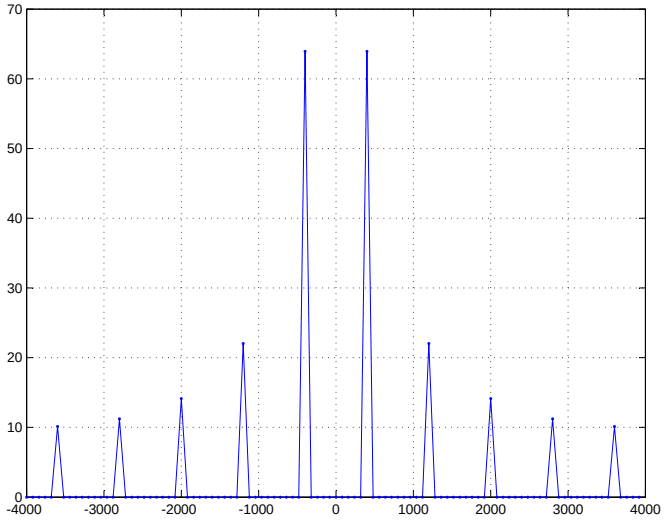


Figure 4.7: Example of a spectrum signal with side skirts

The design of the implemented filter has been made in Matlab. For this purpose it was used the code shown in figure 4.8, in order to generate the filter coefficients. After observing the used code, it is possible to verify that the filter to be implemented will be of order 9.

```
K>> Z = -ones(20,5);
K>> Z(11:20,:) = 1;
K>> Z = Z(:);
K>> f = tukeywin(9,2); f = f/sum(f); plot((1:length(Z))', Z, (1:length(Z))'-4, filter(f,1,Z), '.-');
```

Figure 4.8: Matlab code for the FIR filter generation

After simulation, the coefficients that determined for the filter are:

F = [0,1,2,3,4,3,2,1,0];

As can be seen there are two coefficients which are zero and for that reason can be eliminated. This reduction means that the filter implemented is in fact a filter of order 7. So the filter coefficients are :

F = [1,2,3,4,3,2,1];

These coefficients have been, after scaling, rounded to integer values, to enable its implementation using integer calculations. After the filter designed, its frequency response and the effect the filter will have on the output waveform of the DAC were simulated. The frequency response of the filter is shown in figure 4.9. On the other hand the effect that the filter will have on the DAC

output can be seen in figure 4.10. This result shows that the wave that will be produced is closer to the sinusoidal making the transitions smoother.

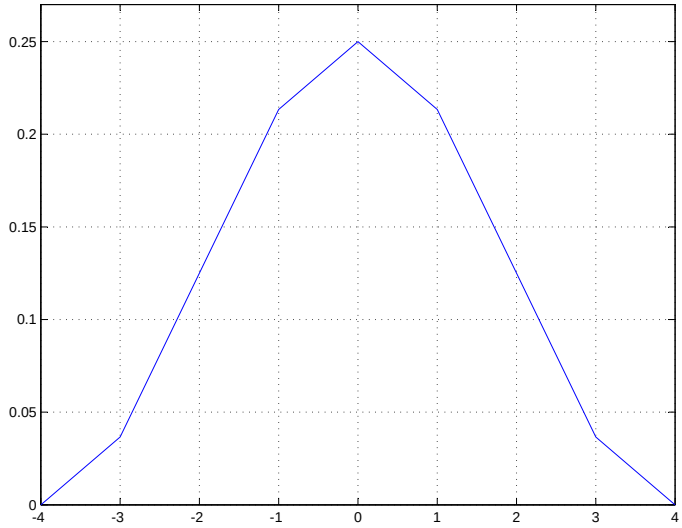


Figure 4.9: Impulse response of the filter

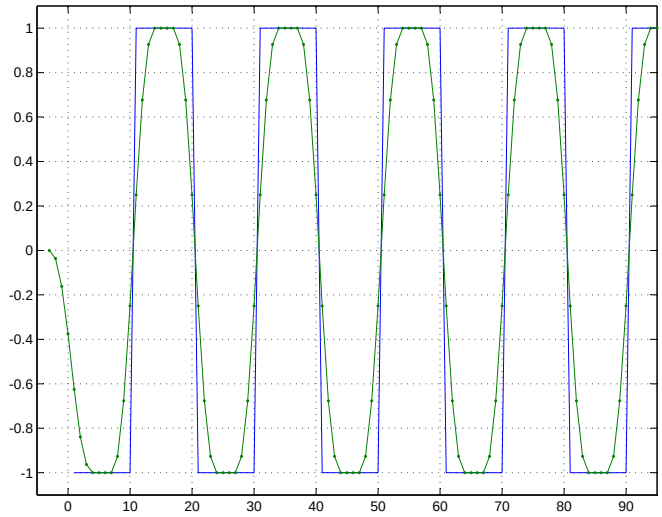


Figure 4.10: Example of the effect of the filter in the DAC output waveform

The change in the DAC output waveform will make changes in the modeled signal. These changes can be observed in figure 4.11. Through the analysis of figure 4.11 it is possible to verify that the side skirts problem has been mitigated. It is even possible to verify that the signal spread spectrum is better defined benefitting their decryption.

After the analysis of the effect that the filter will produce, it is possible to say that its implementation will bring benefits to the system.

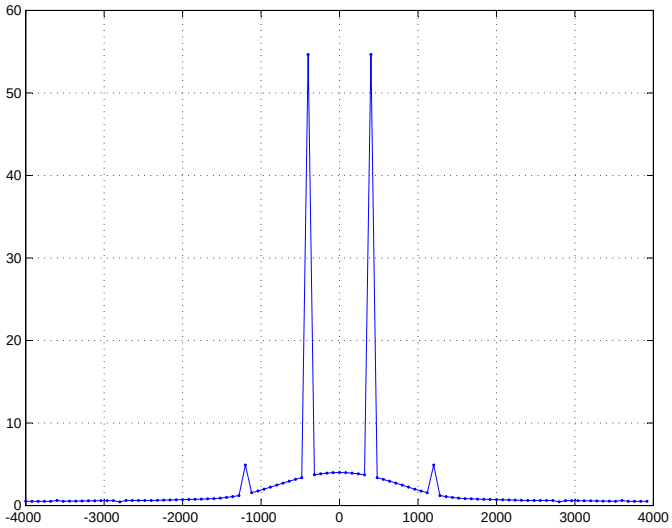


Figure 4.11: Example of the filtered signal

4.2.2 Treatment of the data coming from the GPS

The data received from the GPS will be processed and then stored in a structure. In this subsection the way how the data will be treated is approached. The data chosen to be sent are shown in table 4.2.

Table 4.2: Data to be sent

Type of variable	Data name	What contains the variable
unsigned long int	flag_time	Contains the time at which the message was received
unsigned long int	latitude	contains the latitude at which the beacon is located
unsigned long int	longitude	contains the longitude at which the beacon is located
unsigned long int	altitude	contains the altitude, relative to sea level
unsigned short int	velocidade	contains the speed over the ground of the beacon
unsigned short int	track_angle	contains the track angle of the beacon

Those data were selected from among those that GPS can provide, since they are necessary to make a good location of the beacon. The manner chosen to encode the data received through the GPS turned them into integers, so the variables are of type unsigned long int or unsigned short int depending on the required resolution and extreme possible values of each one.

The time given by the GPS comes in the format hh: mm: ss (hour:minute:second). The time will be encoded in an integer, thus making the two most significant numbers of that integer are the

hours, the two intermediates are the minutes and the less significant are the seconds. For example encoding the time 12h:35m:19s will lead to the number 123519 and this number will be stored in the variable flag_time.

For latitude representation it was chosen a resolution of one thousandth of a minute, so the integer number that will be created corresponds to the conversion of data received in a thousandth of a minute. It is worth noting that the latitude is given with an orientation, and that orientation can be North (N) or South (S). If the latitude orientation is north, the previously generated number will stay the same. On the other hand if it is south the number will be multiplied by -1. For example, the following latitude 48 deg 07.038' S will be converted into:

latitude = (4*600000+8*60000+0*10000+7*1000+0*100+3*10+8)*(-1) = -2887038

For longitude representation it was chosen a resolution of one thousandth of a minute, so the integer number that will be created corresponds to the conversion of data received in a thousandth of a minute. It is worth noting that the latitude is given with an orientation, and that orientation can be East (E) or West (O). If the latitude orientation is east, the previously generated number will stay the same. On the other hand if it is west the number will be multiplied by -1. For example, the following longitude 11 deg 31.000' E will be converted into:

longitude = (0*6000000+1*600000+1*100000+3*10000+1*1000+0*100+0*10+0) = 731000

Attitude is represented in decimetres. For example, encoding the altitude 545.4 meters will lead to the number 5454 decimetres and this number will be stored in the variable altitude.

For velocity representation it was chosen a resolution meters per second, so the integer number that will be created corresponds to the conversion of data received in meters per second. It is worth noting that the velocity is given in knots and 1 knot is 0.54 m/s. For example, the following velocity 022.4 will be converted into:

velocidade = 0*1000*0.514+2*100*0.514+2*10*0.514+4*0.514 = 115.136

Finally, the track_angle comes in degrees, and for that reason the representation chosen was a tenth of a degree. For example, the following track angle 084.4 deg will be converted into:

track_angle = 0*1000+8*100+4*10+4 = 844

After being treated and stored in the corresponding variables of the structure, the data will be encoded in Manchester BPSK. This type of encoding consists basically in doubling the number of bits according to the rules of Manchester encoding BPSK. These rules can be found in appendix C. The manchester encoding that will be used to encode the data can be seen in figure 4.12.

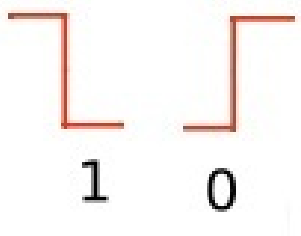


Figure 4.12: Manchester encoding

So, for example, the data 1100 will be encoded into 10100101. After having made this encoding the data will be stored in a vector and then will be ready to be transmitted. This process is similarly done for the preamble, the size of the message and for the ID of the platform. This data is stored in a different vector.

4.3 Summary

In this chapter, a presentation of the implemented hardware was made together with the concerns that we have during the process. A presentation of the software implementation was also made, with the details of the main routines implemented in the microcontroller, and the encoding of the data obtained for the GPS receiver. The need to implement a filter was also explained, with its design and the expected results should have.

In the next chapter the tests and the results obtained will be presented. Critical evaluations of the beacon will be made.

Chapter 5

Tests and results

After describing the process used in implementing the design, it is now essential to present the preformed tests, along with their results, in order to determine the compliance with the requirements of the project.

5.1 Tests performed

Since this dissertation required the development of hardware and firmware, the testing and subsequent results were separated into two parts.

5.1.1 Hardware Tests

5.1.1.1 PLL and VCO Tests

The first part of the circuit to be tested was the PLL. The PLL was programmed with a value of 200 in the R register. This implies that the 10MHz reference signal will be divided by 200. The PLL was also programmed to place the waveform obtained after dividing the reference signal by the R value on the MuxOut output.

The waveform obtained on the muxout output is represented in figure 5.1.

Since the frequency of the input signal is 10MHz and is being divided by 200 the output signal should have a frequency of 50KHz. This is the obtained value for the frequency, as shown in figure 5.1.

After ensuring the PLL is properly programmed, it must be insured that the VCO is generating the desired frequency. For checking the proper functioning of the VCO with the PLL, a spectrum analyser was used that allowing us to analyse signals with a frequency of 401.65MHz. This test is represented in figure 5.2.

It is possible to observe that the frequency given by the VCO is stable at 401.648MHz and it has a peak in -1.52dBm. These results show us that the frequency has a small deviation from the

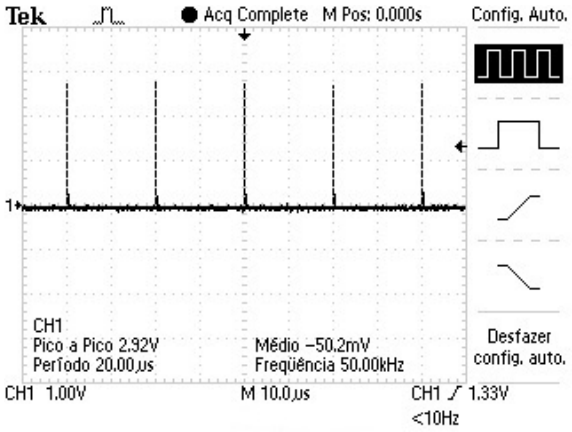


Figure 5.1: PLL muxout waveform

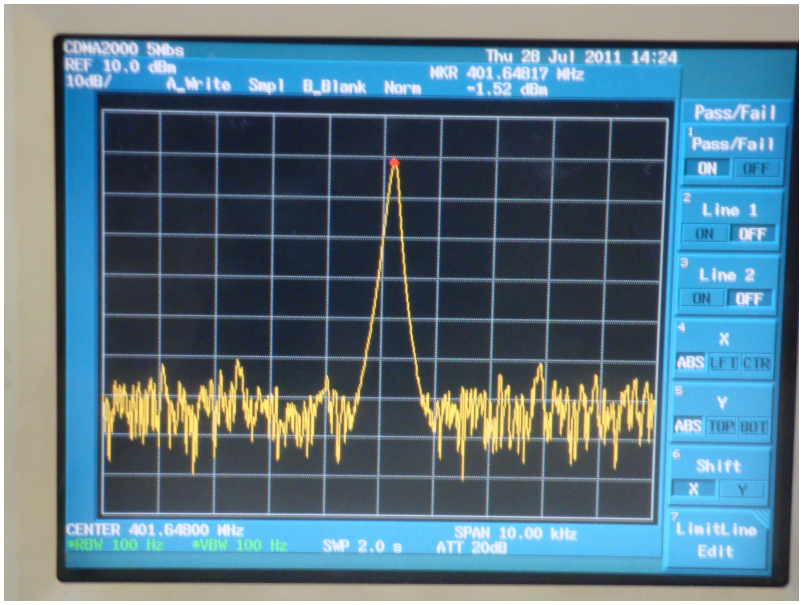


Figure 5.2: VCO output

desired value. This difference is due to a frequency reference mismatch between the generator and the spectrum analyser.

5.1.1.2 DAC and Opamp Tests

After testing the PLL and the VCO, the DAC and the Opamp correct operation must be tested. To test the DAC's an 8 sample 1KHz sine wave will be generated. In order to generate the sinusoidal wave it is essential to know how to switch the output voltage on the DAC. The output voltage from a DAC channel is given as:

$$V_{DAC} = \frac{ChData}{0xFFF} * Vref \ [18] \tag{5.1}$$

The samples values are in table 5.1, and the extended version of the calculations can be found in appendix A.3.

Table 5.1: Sine wave values

Parameters	Value	DAC output voltage
v[0]	3552.5	0.867
v[1]	3627.75	0.885
v[2]	3660	0.893
v[3]	3627.75	0.885
v[4]	3552.5	0.867
v[5]	3477.25	0.849
v[6]	3445	0.842
v[7]	3477.25	0.849

This variation of the DAC output voltage is necessary because the I/Q modulator uses this type of voltage variations in its signals inputs. A timer from the microcontroller will be used to generate an interrupt at 8KHz. With this it is possible to test and confirm the correct operation of the timer. The wave form of the DAC is shown in figure 5.3. It is visible that this wave is a bit deformed, due to the fact that a small number of samples were used. If the number of samples increased, the resolution of the wave would be significantly better.

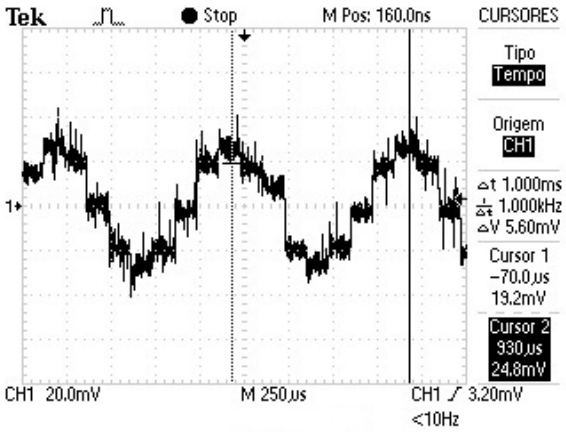


Figure 5.3: DAC output waveform

After analysing figure 5.3, we can conclude that both the DAC and the timer are working properly. Each point of the wave is being generated at a frequency of 8KHz, so the frequency of the generated wave is 1KHz as can be seen in the figure 5.3.

After insuring the proper functioning of the DAC and the timer, the opamp must be tested. The 8 sample sine wave generated by the DAC was fed into the opamp input and its output is represented in figure 5.4.

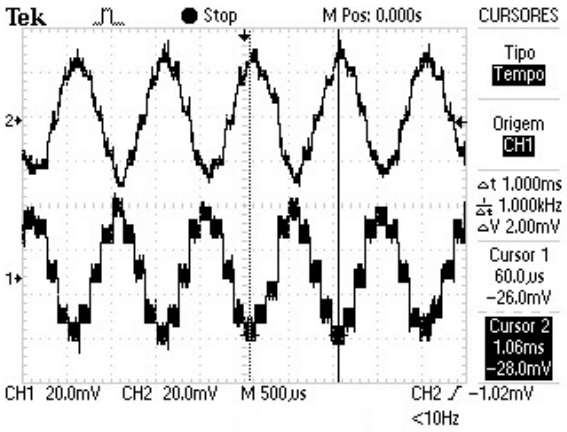


Figure 5.4: Opamp output to an 8 sample sine wave input

Figure 5.4 confirms to say that the opamp is operating correctly.

5.1.1.3 I/Q Modulator Tests

A test to the I/Q modulator was also performed with this wave. After feeding into one of the inputs the sine wave generated by the DAC, and a DC level into the other (along with the reversed waves), the data collected from the modulator output, with a spectrum analyser, can be seen in figure 5.5.

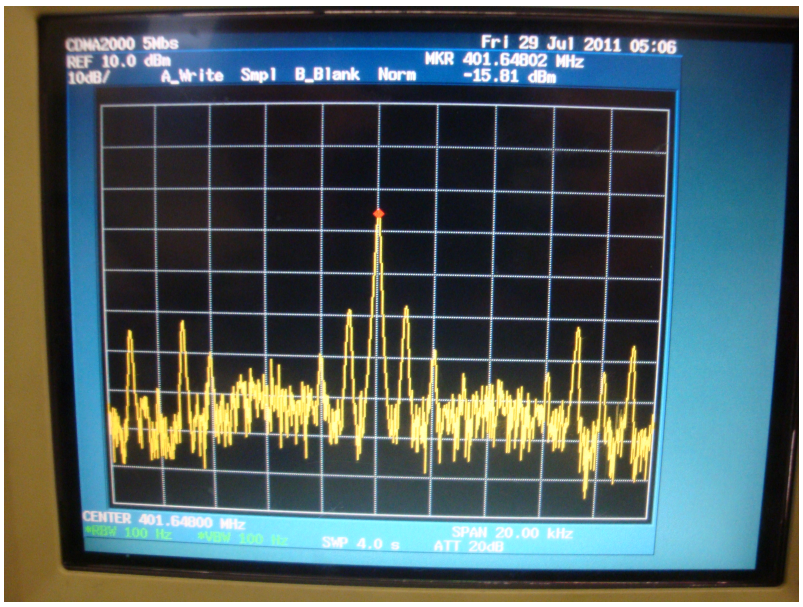


Figure 5.5: I/Q modulator output wave, with a 1KHz sin wave as an input

It is possible to see that the received signal has a well-defined carrier at the frequency of 401.648Mhz, that the other two peaks are from the modulated sinusoidal wave and that they are separated by 1KHz. This peaks occurs because the wave that is being modulated has a frequency of 1KHz. To complement this analysis, another test was made with a radio. The radio was tuned at a 401.65MHz frequency making possible for us to listen to the sound of the 1KHz modulated wave. The received signal was recorded using matlab and the received waves can be observed in figure 5.6. In detail, the signal were demodulated using upper side band demodulation, being the radio tuned to a frequency roughly 2KHz below 401.65MHz.

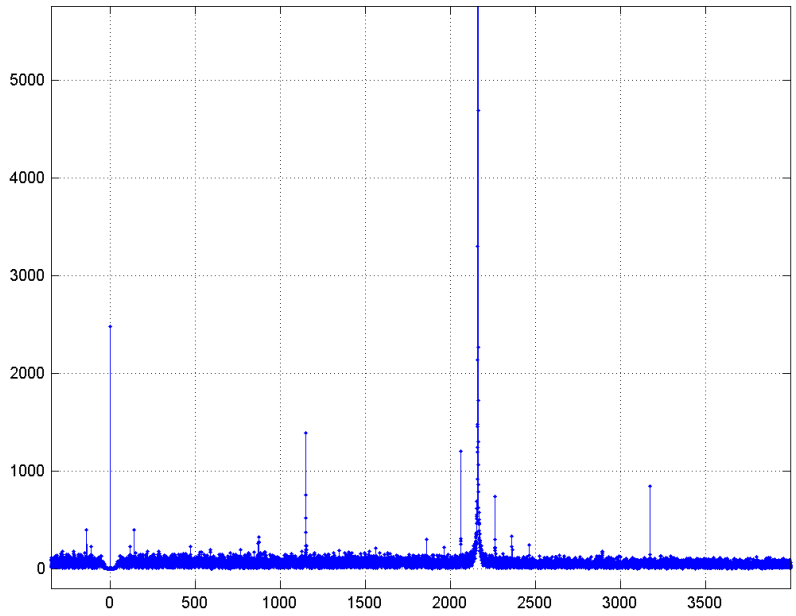


Figure 5.6: Sin wave with 1KHz of frequency recorded with matlab

With these results we can say that the I/Q modulator is working properly.

5.1.1.4 Power Amplifier Tests

The last stage of testing was to verify the signal at the RF power amplifier output. This signal was tested in order to prove its correct functioning.

The data obtained after measuring the signal at the RF power amplifier output, is represented in figure 5.7.

By comparing figures 5.7 and 5.5, we can verify that the carrier stays in the same frequency and still has the waves at 1KHz on each side. We can also see that there is an increase in power on the signal. This proves that the amplifier is working as expected.

5.1.1.5 Power Consumption Tests

During the previous these tests the values for the voltage and current consumption were recorded. After establishing an average, the current consumption for 3.3V values are shown in

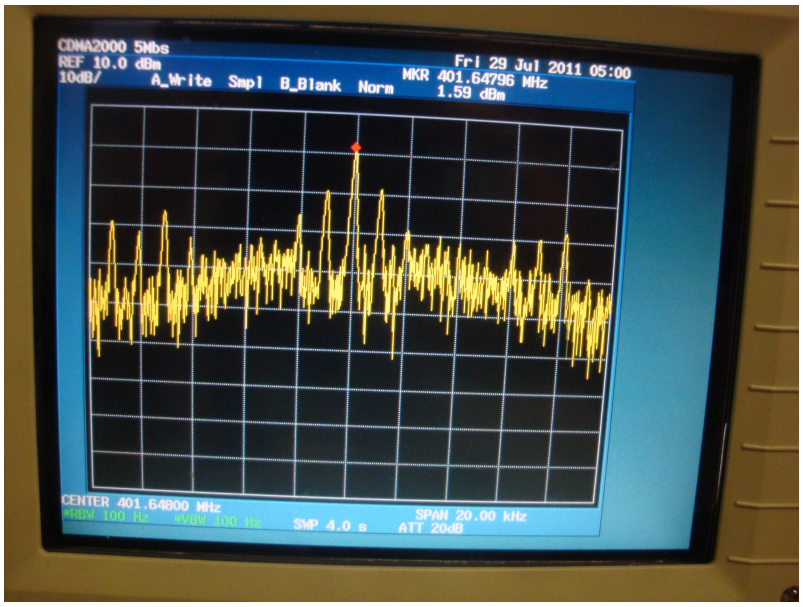


Figure 5.7: RF power amplifier output, with modulated a 1KHz sin wave as an input

table 5.2. There are three distinct operation modes:

- Sleep mode - In this mode all of the beacon components are disabled, with the exception of the microcontroller USART;
- Processing mode - In this mode the microcontroller processes the data sent by the GPS while the other devices are disabled;
- Transmission mode - All the devices are enable and the beacon is transmitting data.

Table 5.2: Circuit power consumption

Power modes	Current consumption (mA)
Sleep	15
ID	25
Transmission	350

A study was made concerning the battery lifetime for a 1000mA/h battery. This study was made assuming that the GPS sends data four times per hour. These results are shown in figure 5.8.

It is possible to see that the battery lifetime has a maximum of 66 hours with one transmission per hour. More studies are available in appendix E. These studies were made under the same conditions. The only variable was the current consumption in sleep mode.

A chart of the battery lifetime, for a current consumption in sleep mode of 1mA was made, for a comparative study. The result can be observed in figure 5.9.

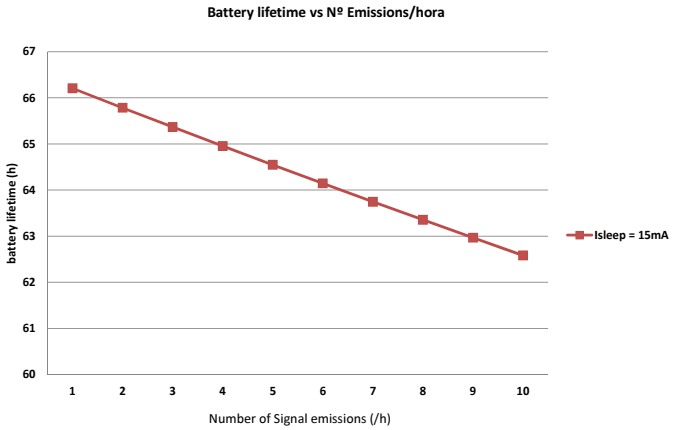


Figure 5.8: Battery lifetime with a Isleep of 15mA

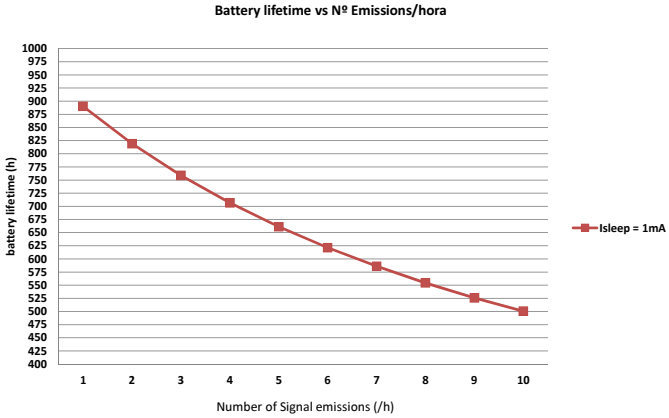


Figure 5.9: Battery lifetime with a Isleep of 1mA

After comparing figures 5.8 and 5.9, it is possible to verify that the battery lifetime increases significantly with the reduction of the current consumption in sleep mode. This confirms that current consumption in sleep mode it what has the most influence in the battery lifetime.

In order to minimize the current, the sleep modes of the microcontroller were used. Currently a minimum current of 4.5mA in sleep mode, which leads to a battery lifetime of 216 hours. It should be possible to reduce the current consumption for 1mA.

Finally, with the use of the microcontroller sleep mode we can wake up the microcontroller with its internal real time counter and thus eliminating the need for an external RTC. This is an improvement because reduces, not only the overall power consumption but the space occupied on the PCB as well.

5.1.2 Firmware Tests

After validating the circuit proper functioning the firmware must be tested. The firmware is responsible for data processing and transmitting. The operation of the FIR filter will also be tested,

to prove that it has the desired effect.

A radio receiver and a Matlab routine was used to test whether the signal is being well transmitted, modulated and if the data is being well encoded. The signal is received by the radio and stored in Matlab. To analyse the received signal a Matlab program, developed as part of a master thesis "Development of an Argos Beacon for the VorSat" by Eduardo Magalhães [32] was used. The objective of the master thesis referenced is to develop an Argos decoder and an Argos generator in Matlab.

5.1.2.1 I and Q phase contributions

Before starting to encode and transmit data it must be ensured that both the I and Q signals have the correct phases. This is achieved by adjusting an offset that is then added to the voltage value given at the DAC output.

In order to do this test, two wave forms were generated using the DAC, corresponding to the I and Q modulator inputs. These wave forms can be observed in figure 5.10.

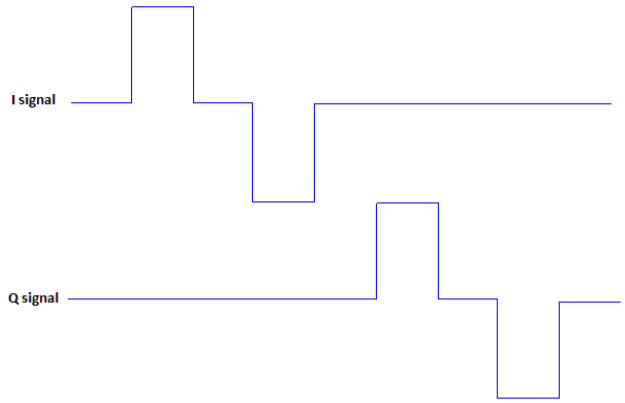


Figure 5.10: DAC wave

It is possible to observe in figure 5.11, that the I and Q signals have the correct phase. There is a high concentration at the (0,0) point and other points are scrolled with the time which gives this, the appearance of a circumference.

If the phase of the I and Q signals is not correct, errors will occur when decoding data. One of the most common errors that occur is to alter the zero logical value to one logical value, for example the preamble will be 0001D0 instead of FFFE2F.

5.1.2.2 Tests to validate the received signal and its decoding

At this stage, the signal transmission will be tested. A set of data will be transmitted (table 5.3). A matlab program will be used to decode the signal. This program developed in another master thesis as referred before in section 5.1.2.

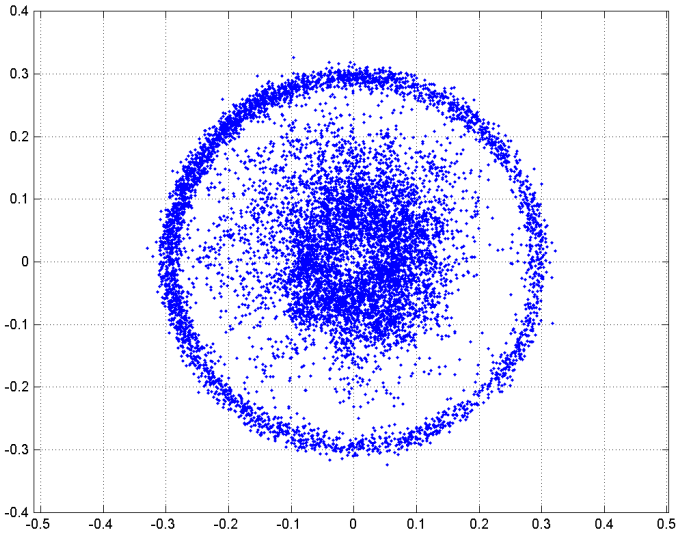


Figure 5.11: I/Q Constellation

Table 5.3: Data to be transmitted

Parameters	Data	outgoing data
Preamble	-	FFFE2F
ID	6560	-
flag_time	123519	1E27F
latitude	4807.038,N	2C0D7E
longitude	01131.000,E	0B2778
altitude	545.4	00154E
velocidade	15	0F
track_angle	255	FF

After the data transmission, matlab was used to store the transmitted data. Figure 5.12, shows received signal and makes it possible to verify that there are three distinct parts, all well defined.

The first part is the pure carrier, the second part is the data and the last part is again pure the carrier. Again it is possible to verify that the signal phase is within the required +/- 60 degrees. The next step was to zoom on the signal in order to verify that the received signal did not contain errors, as shown in figure 5.13.

Figure 5.13 also represents the preamble message and by observing it, it is possible to verify that the transmitted preamble was FFFE2F, as expected. In this test the phase is compared with the phase of half a symbol before, and this causes the 120 degrees transitions in the signal phase.

The Argos signal requires a phase of +/- 60 degrees. In figure 5.14 is made an analysis of the signal phase.

It is possible to see that this phase is centred and the variations between the highest and the lowest point is of about 120 degrees. This means that the phase is varying between + 60 and -60 degrees thereby meeting the Argos system requirements.

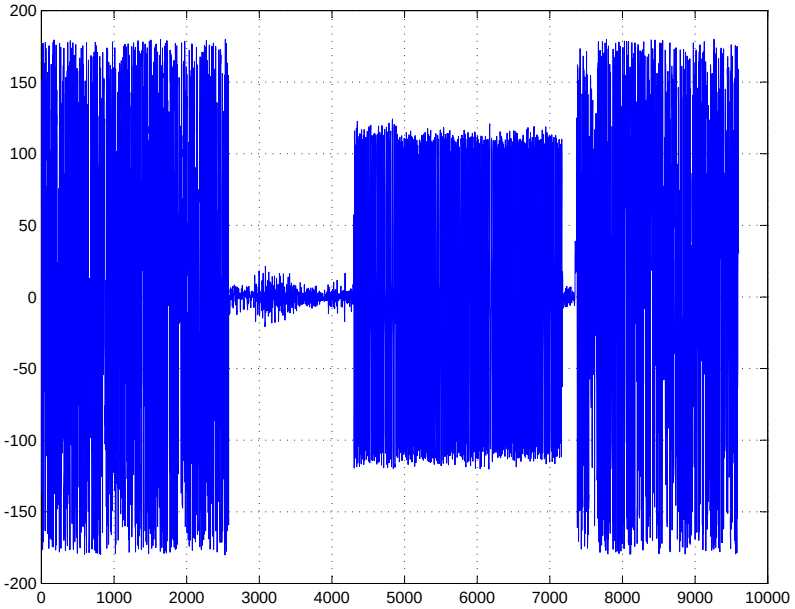


Figure 5.12: Differential of the angle function of the received signal

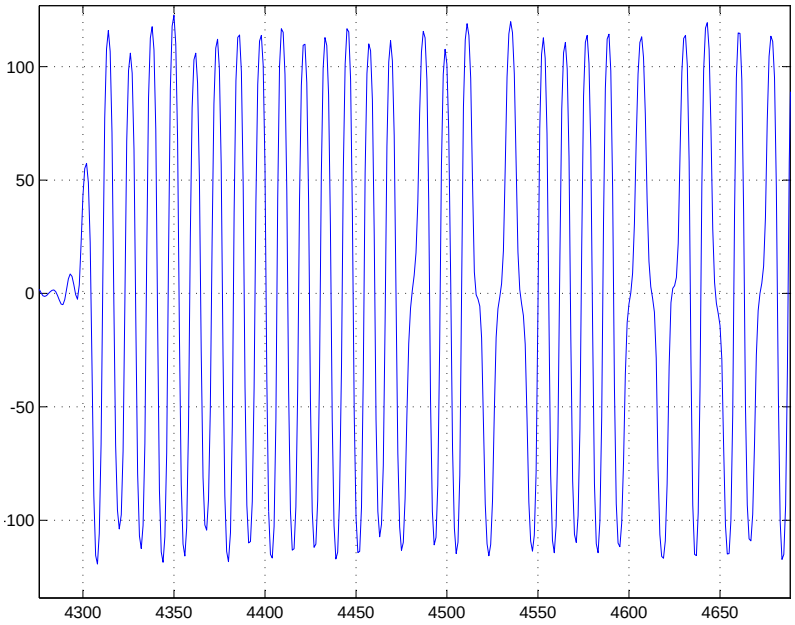


Figure 5.13: Received Signal zoomed

The contribution of the I and Q phases to the modeled signal are also evaluated. These contributions are shown in figure 5.15.

It is possible to verify that the I component has a null contribution for the phase and that the Q signal varies between + 60 and - 60 degrees. This distribution contributes to the balancing the contribution of the two components in the modulated signal and causes the phase variation found

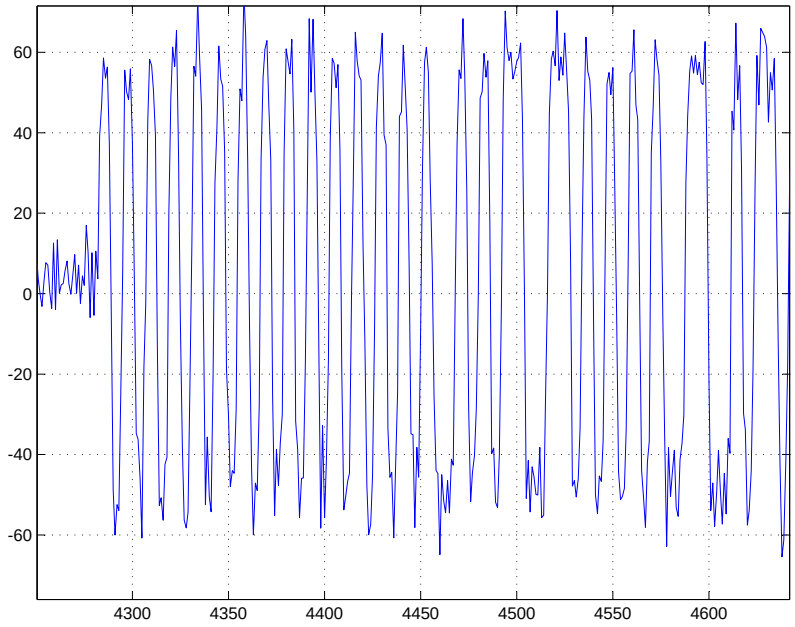


Figure 5.14: Received signal phase

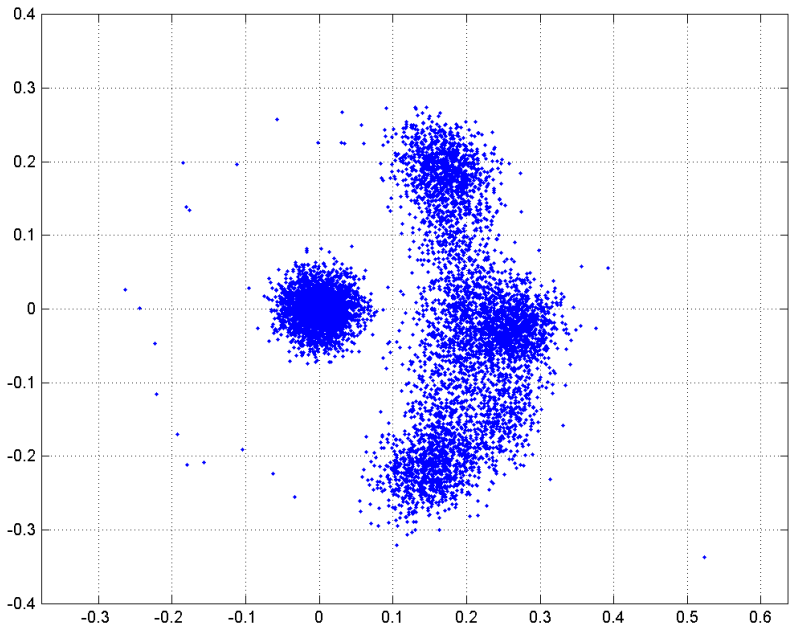


Figure 5.15: I/Q constellation

in figure 5.14. If the contribution of each of the components was different, I/Q constellation would have a different layout and the phase variation would be higher or lower.

The last step in this analysis is to verify that the decoded data matches the data that was modulated and sent. Running the matlab program, gave the results shown in figure 5.16.

All of the decoded data will be compared to the initial set as is shown in table 5.3.

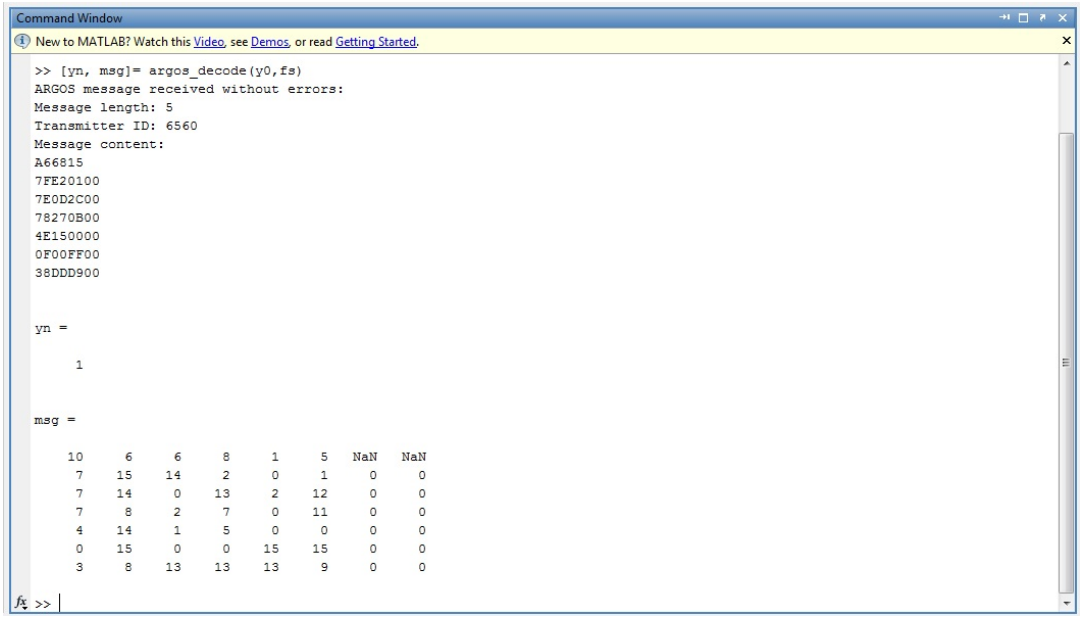


Figure 5.16: Matlab Result

The matlab program initially provides the size of the sent message, (in this case it is 5). This corresponds to the number of 32 bits words that have been sent. These are exactly the same 5 words of 32 bits sent, since neither the preamble or the ID contribute to this value.

The next data given by the program, is the platform ID with the value 6560. It is also possible to verify that this value matches the initial value.

The following data corresponds to data transmitted in the order that appear in table 5.3. The data is decoded byte by byte, from the least significant byte to the most significant byte.For example, the flag_time was decoded as 00012E7F value instead of 7FE20100. The same is valid for the rest of the data, so it is possible to say that the received data matches the sent data, thus confirming a successful transmission.

The velocity and the track_angle are two short int variables, allowing them to be represented in the same 32 bit word. The fifth word is the one where this data is represented.

Finally, the last data with 32 bits word is represented, carrying the checksum. The checksum was implemented to prevent transmission errors and matches the one generated by the computer.

Taking into account all data previously presented, it is possible to say that the beacon has modulated and transmitted data correctly. It has successfully sent a Argos message.

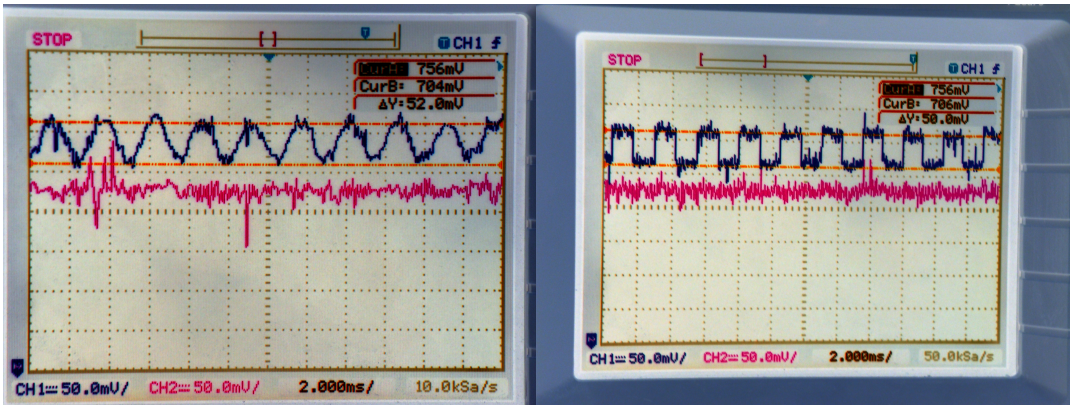
5.1.2.3 Filter Tests

After implementing the filter, a series of tests were made in order to validate its proper operating mode. These tests also helped to observe the improvements the filter added to the beacon.

Initially, the waveform of the DAC output was analysed in order to see what has changed. The voltage variation in figure 5.17 is of 50mVpp, which does not exceed the maximum of 200mVpp

imposed by the modulator. It should be noted that the blue color signal corresponds to the Q signal and the other to I signal.

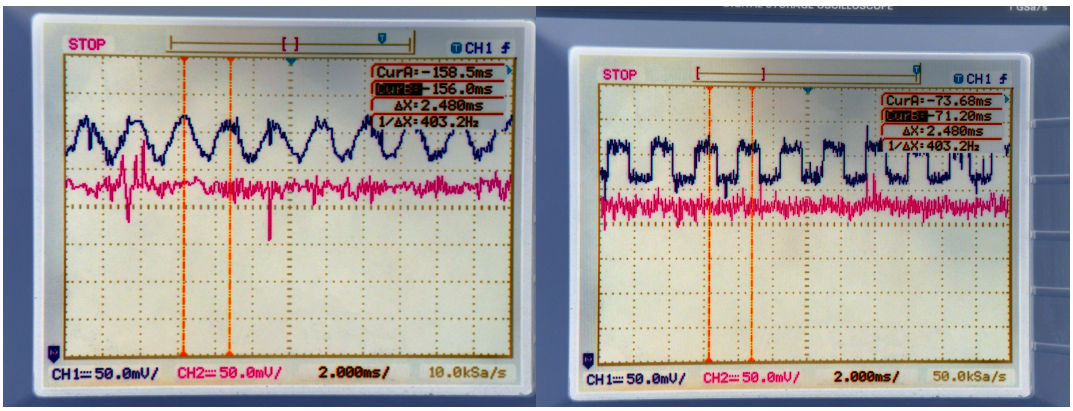
One of the benefits of the filter is visible in the waveform. So in figure 5.17b, the wave form is more square wave like while in figure 5.17a, where the signal is already filtered, is smoother.



(a) Filtered DAC Signal (b) DAC signal without filter

Figure 5.17: DAC Signals - wave amplitude

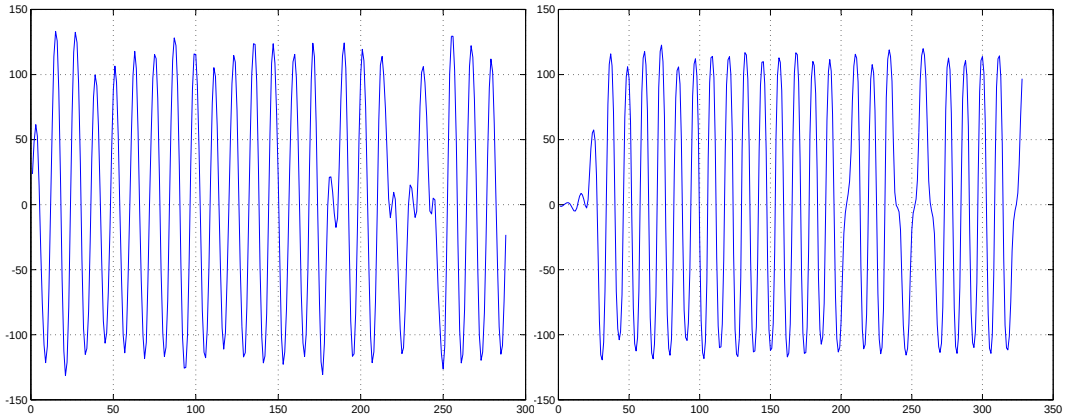
Yet another feature, as can be observed on figure 5.18, is that the filtering of the signal does not affect the rate at which each symbol is sent. So we can see that each symbol continues to be sent at a rate of 400Hz. This allows the Argos message to continue to have its maximum duration of 1 second, as intended.



(a) Filtered DAC Signal (b) DAC signal without filter

Figure 5.18: Time between symbols

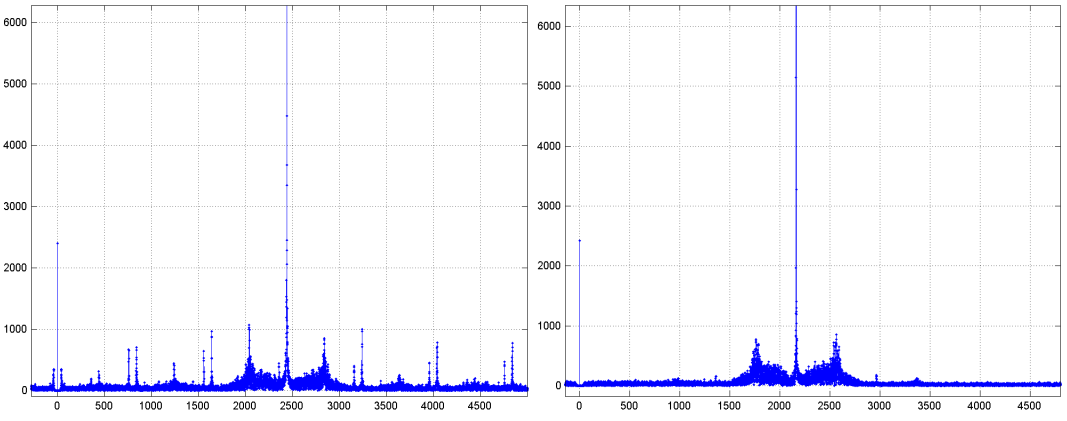
The same signal, with the same content, is received with or without the filter. The obtained result can be seen in figure 5.19. The two samples correspond to the signal preamble. It is possible to observe a great improvement in terms of signal transitions. The smoother transitions caused by the filter causes less errors in the transmission and in the decoding of the signal.



(a) Preamble of Received signal without filter (b) Preamble of Received signal with filter

Figure 5.19: Preambles of Received Signals

Another benefit of the filter is that improves the spectral spreading of the signal. It was done a Fourier analysis was made, in matlab, of the transmitted signal with and without filter. As can be seen in figure 5.20, there is a visible improvement of the spread spectrum. This is partially because of the disappearance of the side skirts. In figure 5.20a, the Fourier transform of the signal without the filter is shown. There are several side skirts and the spectrum is very widespread. On the other hand, on figure 5.20b, the Fourier transform of the filtered signal is shown and it is possible to verify that the side skirts no longer exist and the spread spectrum is much more concentrated in the area around the carrier.



(a) Fourier transform of the received without filter (b) Fourier transform of the received with filter

Figure 5.20: Fourier transform of the received signal

With all the facts presented above it is possible to verify that the filter is not only working properly but that it enhances the system performance.

5.2 Miniature Version of the PCB

After performing all the tests, another PCB was designed, but now with the dimensions restrictions to make it use in VORSat. Basicly a miniaturization of the first board was made. To be used in VORSat the board should have the maximum dimensions of 4cm * 4cm.

Figures 5.21 and 5.22 show the top and the bottom of the produced PCB. It is possible to check that the PCB has the necessary 4cm * 4cm.

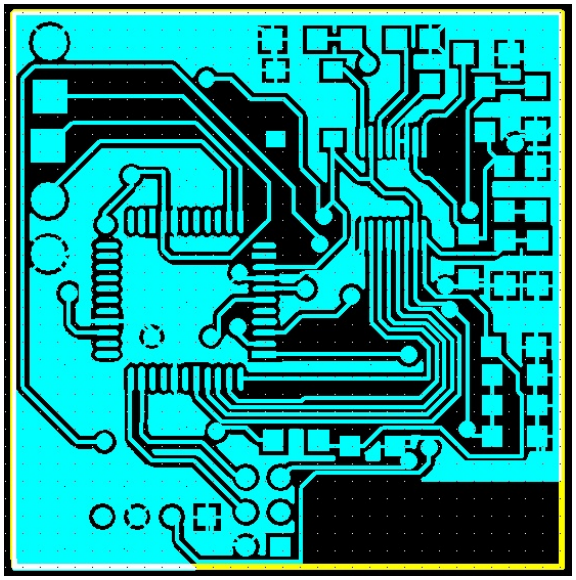


Figure 5.21: Top footprint from the 4cm PCB

During the design of the PCB, several aspects were taken into account such as separating the analogic part from the digital part. The digital part of the beacon was placed in the top layer and the analogic part in the bottom layer of the PCB.

It was also taken into account the placement of the VCO, to insure that no signal would leak into the antenna. Taking this factor into account, the VCO was placed at the other end of the bottom layer, as can be seen in figure 5.22.

As a last step, a ground plane was created in order minimize interference.

It is possible to decrease the size of the PCB even more. This could be achieved by reducing the size of the resistors and capacitors. The advantage of reducing the size of the board is the fact that facilitates its integration into many different scenarios.

5.3 Summary

In this chapter the results obtained after performing a sequence of comparative tests were presented.

It was possible to demonstrate the beacon compliance with the objectives defined in the beginning of this dissertation.

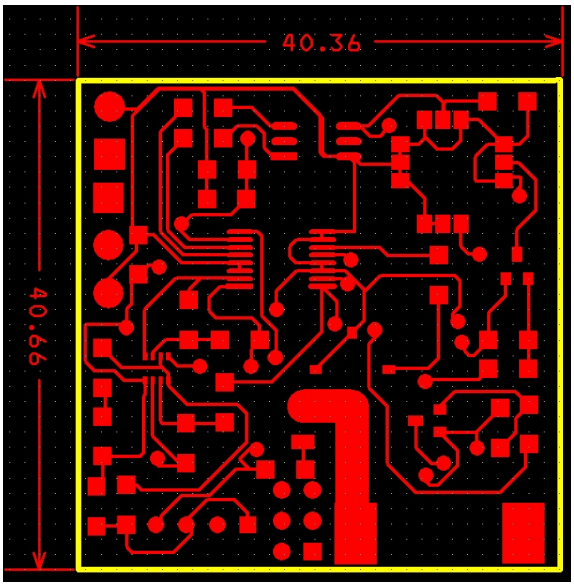


Figure 5.22: Bot footprint from the 4cm PCB

A miniature version of the PCB was also presented, allowing its integration in the VORSat. Next will be presented the conclusions of the dissertation.

Chapter 6

Conclusions and Future Work

This chapter, is an overview of the final status of the project. It also outlines some topics for future work.

6.1 Summary of the performed work

The core objective of this dissertation is to create a beacon capable of transmitting the messages generated by the GPS as an ARGOS message. This beacon was implemented on a PCB that should be used as a starting point for the development of a solution that can be integrated in the VORSat.

In order to achieve this, the following steps were taken:

- A study about the ARGOS system, as well as the tracking technologies currently in use. This insight, allowed the choice for the best solution. Several conclusions drawn from this study, lead to the solutions used in the system, taking into account its specifications;
- Then, the topology for the beacon was selected. In this process the different type of components that integrate the circuit and their features. Ways to minimize the power consumption of the beacon were defined by taking into account the part of each component plays;
- The circuit was designed and the values for the resistors and capacitors calculated. At this stage all the components that are a part of the beacon were set in the PCB and their connections drawn;
- Once the circuit design was finished, the process of designing the PCB (CAD) for testing the prototyped solution began. After this, the PCB was produced;
- A set of tests were made, in order to validate the proper functioning of the different parts of the circuit. These tests were made during the construction of the beacon (hardware), and during the development of the firmware for the microcontroller;

- At this point several attempts were made in order to lower even more the power consumption of the beacon. The biggest effort to reduce the power consumption of the microcontroller when it is not processing data;
- Finally, a miniaturized version of the first PCB was produced in order to integrate it in the VORSat.

6.2 Concluded Objectives

By comparing the original objectives of the project with the analysis of the results gathered during the testing stage, we can conclude that the core objectives of this thesis were achieved.

As for the objectives relating the power consumption of the beacon, it is possible to state that they were also achieved, with the exception of the proposed system for energy storage using capacitors. This system was designed in chapter 3, section 3.3.8, and implemented on the PCB but not tested.

Even so the prototype offers all of the required features by VORSat.

6.3 Future work

Despite the fact that the functional prototype meets all requirements, it is still possible make some improvements to the beacon.

Two different groups for future implementations can be identified - those that correspond to the Hardware and the other that correspond to the Firmware.

Hardware:

- Test the designed energy storage system, in order to remove the load peaks of the batteries and to increase their life time;
- Embedding a high-brightness LED in the circuit in order to enable a signaling feature for the beacon.

Firmware:

- Code optimization - reduce the execution time, further reducing the power consumption;
- Using an Analogue to Digital Converter, to dynamically adjust the contributions of the I and Q signals for the modulated signal phase.

The final topic for future work would be to test the beacon outside the laboratory. This test should consist into communicating with an ARGOS satellite, and tuning a radio in the ARGOS downlink frequency in order to receive the acknowledge that confirms a successfully data transmission.

Appendix A

Expressions, Calculations and Results

In this appendix all the expressions and calculations of the whole design of the beacon are available.

A.1 Sizing of the opamp as an inverter

$$tensaocont = \frac{20}{20+R2} * Vcc \Longleftrightarrow \frac{20}{20+R2} = \frac{tensaocont}{Vcc} \tag{A.1}$$

$$R2 = \frac{20*(Vcc-tensaocont)}{tensaocont} = \frac{20*(3.3-1.4)}{1.4} = 27K\Omega \tag{A.2}$$

A.2 Calculation of the transmission line

In this section all calculations that have been made in order to obtain the line width in order to connect the antenna are presented.

Because of the complexity of the equation A.3, the method adopted to find ωeff which leads to an impedance of 50Ω was to change the values of ωeff until finding an acceptable value for Z.

$$Z = \frac{Z0}{2\pi*\sqrt{2*(1+\varepsilon r)}} * ln(1+\frac{4h}{\omega eff} * (\frac{14+\frac{8}{\varepsilon r}}{11} * \frac{4h}{\omega eff} + \sqrt{(\frac{14+\frac{8}{\varepsilon r}}{11} * \frac{4h}{\omega eff})^2 + \pi^2 * \frac{1+\frac{1}{\varepsilon r}}{2}})) \tag{A.3}$$

The results have been obtained using Matlab and are shown in table A.1.

After observing table A.1, it is possible to conclude that the optimal value for the ωeff is 2.7388mm.

The same method was adopted to solve equation A.4.

Table A.1: Results of solving the equation A.3

ωeff (mm)	Z (Ω)
2.0000	59.4340
2.5000	52.6607
2.6000	51.5087
2.7000	50.4120
2.7300	50.0932
2.7350	50.0405
2.7388	50.0005
2.7400	49.9879

$$\omega eff = \omega + t * \frac{1+\frac{1}{\varepsilon r}}{2\pi} * ln(\frac{4e}{\sqrt{(\frac{t}{h})^2 + (\frac{1}{\pi} * \frac{1}{\frac{\omega}{t}+\frac{11}{10}})^2}}) \tag{A.4}$$

The results have been obtained using Matlab and are shown in table A.2.

Table A.2: Results of solving the equation A.4

ω (mm)	ωeff(mm)
2.2500	2.7684
2.2320	2.7504
2.2700	2.7453
2.2200	2.7383

After observing the table A.2, it is possible to conclude that the optimal value for the ω is 2.2200mm.

A.3 Calculation of the values for sinusoidal wave

In this section all calculations that have been made in order to obtain the values for the sinusoidal wave 1KHz are presented.

The sine wave will have a DC component of 0.865V and a variation of 50mVpp.

$$v_{chdata}[0] = 3230 + 0.75 * 430 = 3552.5 \tag{A.5}$$

$$v_{DAC}[0] = \frac{Chdata}{0xFFF} * Vref = \frac{3552.5}{4095} * 1 = 0.867V \tag{A.6}$$

$$v_{chdata}[1] = 0.7 * 0.25 * 430 + 3230 + 0.75 * 430 = 3627.75 \tag{A.7}$$

$$v_{DAC}[1] = \frac{Chdata}{0xFFF} * Vref = \frac{3627.75}{4095} * 1 = 0.885V \tag{A.8}$$

$$v_{chdata}[2] = 0.25 * 430 + 3230 + 0.75 * 430 = 3660 \tag{A.9}$$

$$v_{DAC}[2] = \frac{Chdata}{0xFFF} * Vref = \frac{3660}{4095} * 1 = 0.893V \tag{A.10}$$

$$v_{chdata}[3] = 0.7 * 0.25 * 430 + 3230 + 0.75 * 430 = 3627.75 \tag{A.11}$$

$$v_{DAC}[3] = \frac{Chdata}{0xFFF} * Vref = \frac{3627.75}{4095} * 1 = 0.885V \tag{A.12}$$

$$v_{chdata}[4] = 3230 + 0.75 * 430 = 3552.5 \tag{A.13}$$

$$v_{DAC}[4] = \frac{Chdata}{0xFFF} * Vref = \frac{3552.5}{4095} * 1 = 0.867V \tag{A.14}$$

$$v_{chdata}[5] = (-0.7) * 0.25 * 430 + 3230 + 0.75 * 430 = 3477.25 \tag{A.15}$$

$$v_{DAC}[5] = \frac{Chdata}{0xFFF} * Vref = \frac{3477.25}{4095} * 1 = 0.849V \tag{A.16}$$

$$v_{chdata}[6] = (-1) * 0.25 * 430 + 3230 + 0.75 * 430 = 3445 \tag{A.17}$$

$$v_{DAC}[6] = \frac{Chdata}{0xFFF} * Vref = \frac{3445}{4095} * 1 = 0.842V \tag{A.18}$$

$$v_{chdata}[7] = (-0.7) * 0.25 * 430 + 3230 + 0.75 * 430 = 3477.25 \tag{A.19}$$

$$v_{DAC}[7] = \frac{Chdata}{0xFFF} * Vref = \frac{3477.25}{4095} * 1 = 0.849V \tag{A.20}$$

Appendix B

Design of a PCB

The development of a PCB layout for manufacturing the board is a process that needs special care when we have designed the circuit with an analogic and a digital part. There are several steps that must be taken into account in order to minimize interference that the board creates in the circuit. Therefore, first it is necessary to define the problems that can occur and ways to minimize or even supress them. All these considerations about the design of a PCB that contains an analogic and a digital circuit can be found in reference [33].

B.1 Problems

The most common problems that arise from the design of PCB are related to noise issues. This noise is often called the transient noise and is caused by electromagnetic interference. Noise is a concern if it interferes with the input signal of an analogic amplifier, because that will not only amplify the signal but also the noise and this can lead to errors and less desirable situations.

Another type of electromagnetic interference is the crosstalk noise. This type of noise can induce a current in adjacent lanes and can change the behavior of other components. This can be detrimental to the performance of the our circuit for example.

As we will see later in this document, the impedance control of certain lines is a major factor for the reliability of high frequency circuits.

B.2 Noise reduction

A primary consideration for the reduction of any type of noise is to create links as shorter as possible so that is less likely to create noise along the line. The tracks corresponding to the input and output must be separated one from the other so that the signal from the amplifier output will not create feedback in the inputs adjacent to this output.

With this type of concerns we can prevent and even eliminate certain noise loops of signal that would turn lanes into antennas.

B.3 Distribution of Components in the PCB

The layout of components on a PCB is very important because if we want to reduce the noise by creating links as short as possible, as mentioned in section . The SMDs are devices that are best suited for analog circuits because they allow a better packing of the components which reduces the connections sizes.

We could say that we should place the components in order to reduce the distance between them to reduce noise on the links and we also should group the components by power supply, getting the digital part on one side and the analog on the other in order to prevent logical transitions on the digital circuits create noise in the analog part.

B.4 Impedance Control Techniques

The impedance control of a line is essential during the drawing of a PCB. This is because some components have a specific impedance of input and output, for example, antennas or RF power amplifiers among others. The impedance control can be done by calculating the width of the connection. It is usually added additional protection to reduce the electromagnetic interference.

One of the ways to protect the connections of these interferences is to create ground lanes around and below the line in order to shield the line with ground planes. These plans serve as a shield that protects the connection and provides return paths for the signals and so no interferences are created.

Appendix C

Encoding the Base band signals

There are several ways to transmit digital signals at baseband nowadays. In this case, the beacon that we will produce will transmit a Manchester encoding, BPSK and for that reason a study about this type of coding is given here.

C.1 Manchester encoding

The Manchester encoding can be of two types: differential or non-differential. The coding that is used in ARGOS is the non-differential encoding.

It should be noted that the Manchester encoding has the following characteristics:

- Ensures the existence of a transition for every bit transmitted
- For each bit transmitted, can be up to 2 transitions.

Considering the characteristics outlined above we can conclude that for each bit "0" or "1" that we want to encode we will have a different encoding. In this type of encoding when are wants to encode a zero this represents a logical transition from the logical level "1" to the logical level "0". Already on the other side when are wants a logic one it will represent a transmission from the logical level zero to the logical level.

This type of coding bits can be seen in figure C.1.



Figure C.1: Bits encode [11]

An example of a Manchester encoding for the 010001101110 data can be observed in figure C.2. As you can see every positive transition must occur between positive transitions of the clock. With this we can conclude that the rate of bits per second is twice of the baud rate.

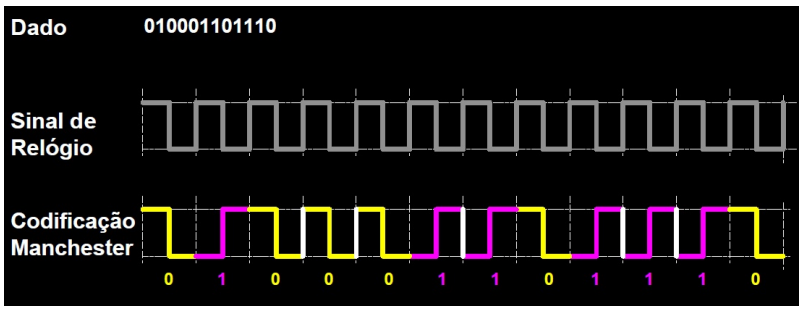


Figure C.2: Example as a mancheste code

Appendix D

PCB Footprints

In this appendix are provided the footprints from the test PCB and the miniaturized one. It is possible to see the bottom and the top view.

D.1 PCB Test Version

D.1.1 Bottom View

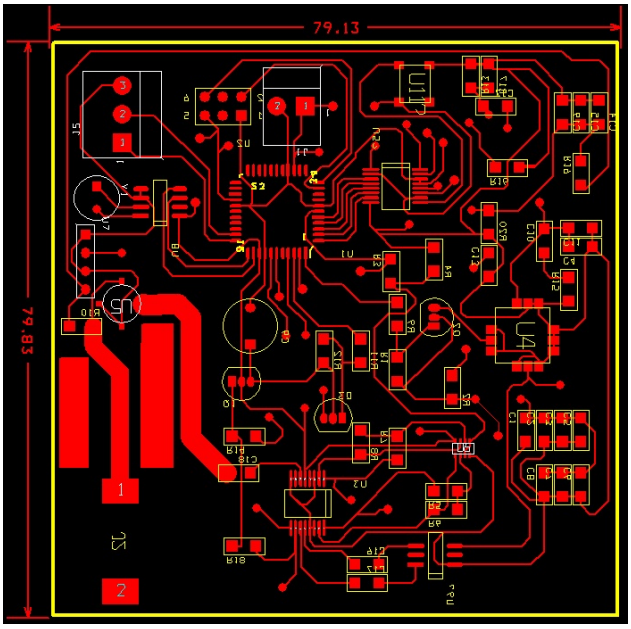


Figure D.1: PCB - Bottom View

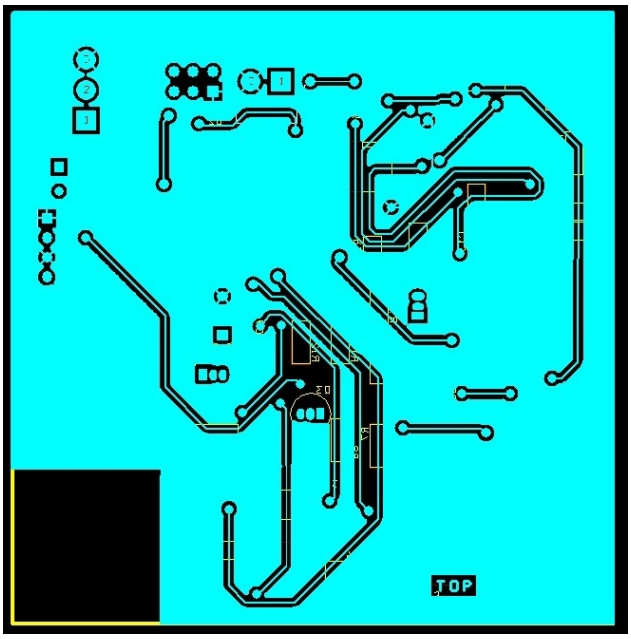


Figure D.2: PCB - Top View

D.1.2 Top View

D.2 PCB - Miniaturized Version

D.2.1 Bottom View

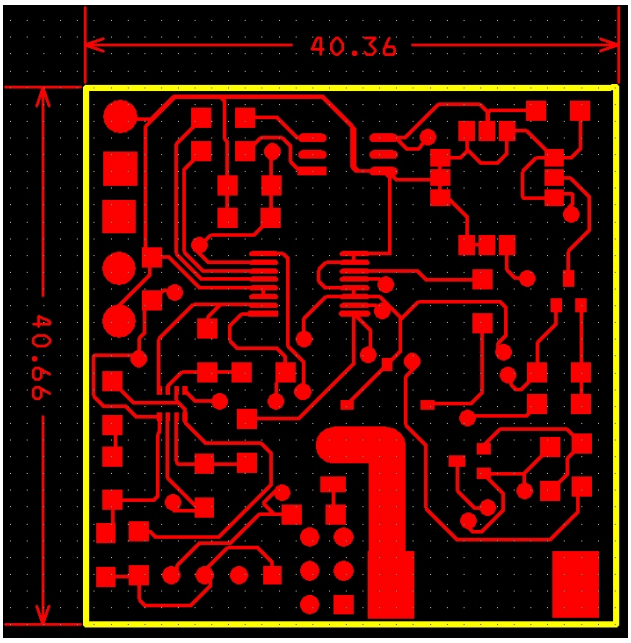


Figure D.3: Miniaturized PCB - Bottom View

D.2.2 Top View

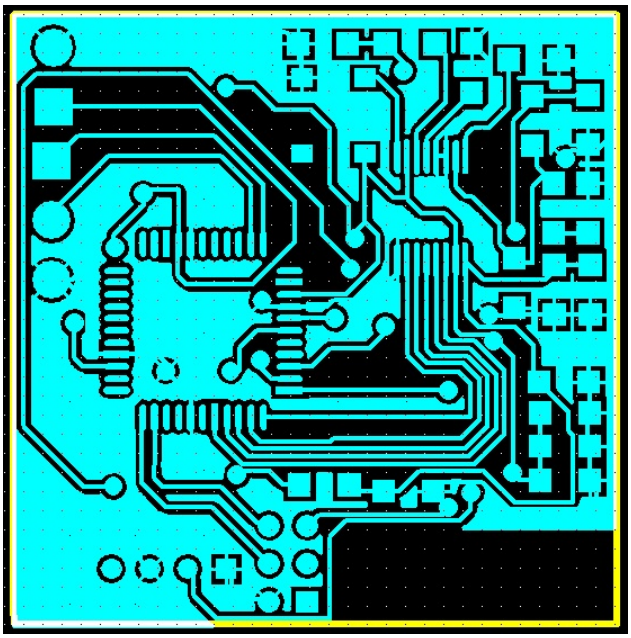


Figure D.4: Miniaturized PCB - Top View

Appendix E

Power Consumption Graphics

In this appendix contains the battery lifetime studies that were made. For this studies we assume that the GPS sends data four times per hour and we change the sleep current consumption.

It is possible, by comparing the figures E.1, E.2 and E.3, to see that the battery lifetime decreases with the growth of the sleep mode current.

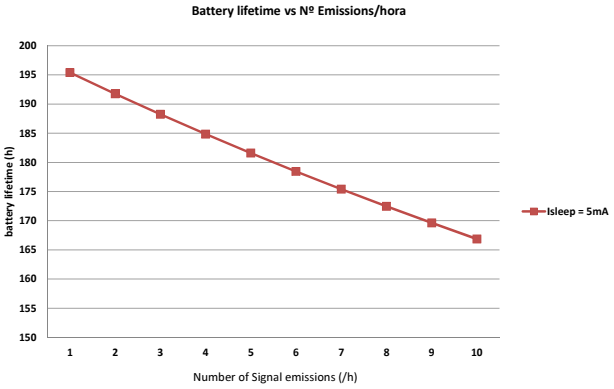


Figure E.1: Battery lifetime with a Isleep of 5mA

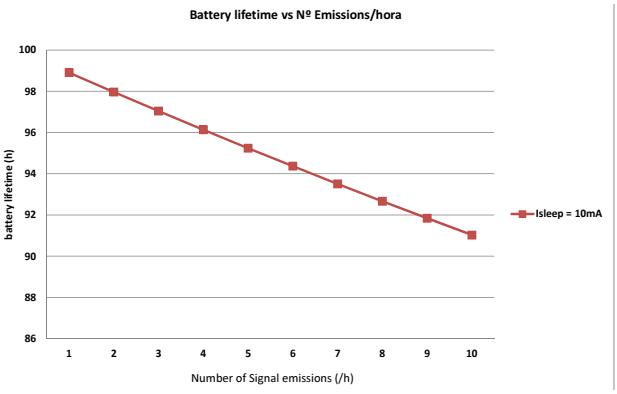


Figure E.2: Battery lifetime with a Isleep of 10mA

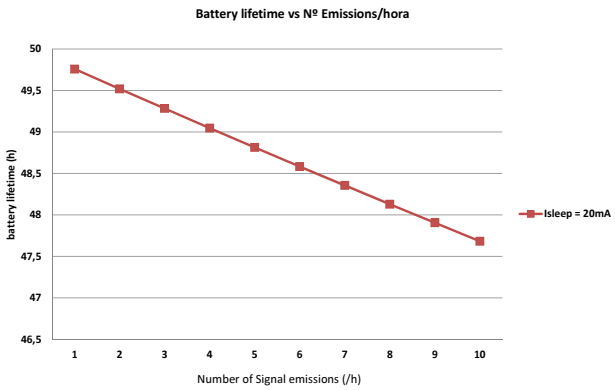


Figure E.3: Battery lifetime with a Isleep of 20mA

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