UNIVERSIDAD CARLOS III DE MADRID

BACHELOR THESIS

GPS system implementation using software defined radio platform

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"Fall seven times, stand up eight."

– Stephen Bush

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Abstract

Escuela Politécnica Superior Leganés
Signal Theory and Communications Department

Bachelor's Degree in Telecommunication Technologies Engineering

GPS system implementation using software defined radio platform

by IRENE PINTOR SOUSA

Every day new technologies are being developed and introduced to the market, shaping people's daily life. The principal aim of our society is making up an ecosystem that provides anything, anytime, anywhere. For this purpose, more powerful and efficient devices, improved devices are being designed as the key ingredients.

In this report it is shown the study and the implementation of a Global Positioning Service device, a technology that is used by more than four thousand millions of users. The present work explores the Global Positioning System development using a Software Radio Defined Platform.

The implementation of this development is divided into four main parts: GPS signal acquisition and treatment carried out by the receptor, GPS received signal demodulation using Binary Phase Shift Keying, decoding through Direct Sequence Spread Spectrum of the previous demodulated signal, and finally, once the necessary data from the message was obtained, the position estimation.

In order to perform all the process it was used as working tool a device known as Universal Software Radio Peripheral. This device allows for analysing from a visual point of view more accurate the four different phases explained previously. These phases represent the basis to be able to achieve the necessary knowledge about proper operation ot the Global Positioning System. The whole application was developd using LabVIEW software, a dataflow visual programming language and environment designed by National Instruments.

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Resumen

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GPS system implementation using software defined radio platform

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Cada día nuevas tecnologías son desarrolladas e introducidas en el mercado, modelando así la vida diaria de la sociedad. El principal objetivo de nuestra sociedad es conseguir crear un ecosistema que proporcione lo que sea necesario, en cualquier momento y en cualquier lugar. Para ello, equipos más potentes, eficientes y mejorados son diseñados como los ingredientes claves de este nuevo ecosistema.

En este trabajo se presenta el estudio y la implementación de un receptor de señales GPS, tecnología que hoy en día es utilizada por más de cuatro mil millones de usuarios. Para ello se lleva a cabo el desarrollo del Sistema de Posicionamiento Global (GPS) mediante la utilización de una plataforma de radio definida por software.

La implementación del desarrollo se divide en cuatro procesos principales: adquisición y el tratamiento de la señal GPS por parte del receptor, demodulación por desplazamiento de fase binaria (BPSK) de la señal GPS recibida, decodificación en espectro ensanchado por secuencia directa (DSSS) de la señal demodulada y por último, una vez obtenidos los datos necesarios del mensaje, la estimación de la posición.

Para la realización de todo el proceso se utilizó como herramienta de trabajo un dispositivo conocido como Universal Software Radio Peripheral (USRP). Este aparato permite analizar desde un punto de vista visual más preciso las cuatro fases indicadas anteriormente. Estas fases suponen la base para lograr adquirir el conocimiento necesario sobre el funcionamiento del Sistema de Posicionamiento Global (GPS). El desarrollo completo de la aplicación fue implementado utilizando LabVIEW, un entorno de desarrollo integrado diseñado por la conocida compañía National Instruments.

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ACRONYMS

ADC	**A**nalog to **D**igital **C**onverter
BER	**B**it **E**rror **R**ate
BMCS	**B**ackup **M**aster **C**ontrol **S**tation
BPSK	**B**inary **P**hase **S**hift **K**eying
CNAV	**C**ivilian **NAV**igation
CRC	**C**yclic **R**edundancy **C**heck
DAC	**D**igital to **A**analog **C**onverter
DoD	**D**epartment **O**f **D**efense
DSSS	**D**irect **S**equence **S**pread **S**pectrum
EM	**E**lectro **M**agnetic
ECEF	**E**arth **C**entered **E**arth **F**ixed
ECSS	**E**uropean **C**ooperation for **S**pace **S**tandards
ESAC	**E**uropean **S**pace **A**stronomy **C**entre
FEC	**F**oward **E**rror **C**orrection
FOC	**F**inal **O**peration **C**apability
FPGA	**F**ield **P**rogrammable **G**ate **A**rray
GA	**G**round **A**ntenna
GIOVE	**G**alileo **I**n-**O**rbit **V**alidation **E**lement
GIS	**G**eographic **I**nformation **S**ystem
GLONASS	**GL**obal **O**rbiting **N**avigation **S**atellite **S**ystem
GNSS	**G**lobal **N**avigation **S**atellite **S**ystem
GPS	**G**lobal **P**ositioning **S**ystem
HOW	**H**and**O**ver **W**ord
IODC	**I**ssue **O**f **D**ata **C**lock
IODE	**I**ssue **O**f **D**ata **E**phemeris
IOV	**I**n-**O**rbit **V**alidation
LabVIEW	**Lab**oratory **V**irtual **I**nstrumentation **W**orkbench
LFSR	**L**inear **F**eedback **S**hift **R**egister
LNAV	**L**egacy **NAV**igation
LORAN	**LO**ng **RA**nge **N**avigation
LSB	**L**east **S**ignificant **B**it
MCS	**M**aster **C**ontrol **S**tation
MEO	**M**edium **E**arth **O**rbit
MIMO	**M**ultiple **I**nput **M**ultiple **O**utput
MNAV	**M**ilitary **NAV**igation
MS	**M**onitor **S**tation
MSB	**M**ost **S**ignificant **B**it
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NAVSTAR	**NAV**igation **S**ystems for **T**ime **A**nd **R**anging
NI	**N**ational **I**nstruments
OCS	**O**perational **C**ontrol **S**ystem
PN	**P**seudo **N**oise
OECD	**O**rganisation for **E**conomic **C**o-operation and **D**evelopment
PSK	**P**hase **S**hift **K**eying
RF	**R**adio **F**requency

SA	**S**elective **A**vailability
SDR	**S**oftware **D**efined **R**adio
SPS	**S**tandard **P**ositioning **S**ervice
TOW	**T**ime **O**f **W**eek
TLM	**T**e**L**e**M**etry Word
US	**U**nited **S**tates
USA	**U**nited **S**tates of **A**merica
USRP	**U**niversal **S**oftware **R**adio **P**eripheral
USSR	**U**nion of **S**oviet **S**ocialist **R**epublics
UTC	**C**oordinated **U**niversal **T**ime
VI	**V**irtual **I**nstruments
WAAS	**W**ide **A**rea **A**ugmentation **S**ystem
WGS	**W**orld **G**eodetic **S**ystem

1 INTRODUCTION AND GOALS

In this section of the report a general description about the main topic is going to be described. It will be explained the possible impacts and improvements that this development can cause on the society. In order to value this fact, it will be introduced into the socio-economic context. It will be explained the diverse regulations Global Positioning System deals with. Finally, it will be mentioned the report organization.

1.1 Introduction

Navigation is defined as the science of getting a craft or person from one place to another. GPS is the abbreviation of Global Positioning System and it uses the NAVSTAR constellation, whose acronym is Navigation Systems for Time and Ranging.

Its methodology consists on determining the position of points on the earth's surface, relying on the radioelectric information emitted by the satellites.

It is a system based on artificial active satellites, forming a constellation of at least 24 of them. It allows different precision ranges depending on the used receptor type and the applied technique.

In 1957, during the celebration of the Toronto's Congress, the idea of launching

some artificial satellites with geodesic purposes took place. With this innovation they expected to solve the existing inter visibility on the classic geodesy. The main idea was determining the absolute position of a point using similar methods as the ones implemented on the satellites photography or the ones designed for the star observations.

GPS System has been designed by the Department of Defense of the United States. Its initial objective was improving the navigation army satellite system, known as TRANSIT. The first satellite was made in 1978 and in 1994 the whole system was operational.

The reference system associated to it is known as World Geodetic System (WGS). Its first global reference ellipsoid was established on 1960 and it was improved in later occasions until it reached its current version denominated WGS84 (defined on 1984). Over this reference system it can obtained the cartesian coordinates or polar coordinates of the point from where the observation was made. To calculate the position of a point using GPS positioning methods it is necessary to take into account all the previously mentioned information.

In the early 70's the GPS project was proposed in order to satisfy the military requirements of the United States' Government. They were interested on developing a system capable of determining the exact terrestrial position without paying special attention to the meteorological conditions and under an unified coverage system. Once this system was consolidated, its applications were implemented with commercial uses, spreading this technology among the scientific community. Nowadays, this technology can be found in navigation, topography and geodesy applications, covering from the administration of a fleet of ships to the automation

of construction machines.

To face the control exerted by the United States' Government, the European Union is developing its own satellite constellation so now it will have its own navigation system. This new system is named as Galileo and the number of satellites will be between 24 and 35. Moreover, there exists a similar systems, named GLONASS, of russian origin.

1.2 Goals and motivations

The main goal of this project is to study GPS Receptor system and to analyze their usage for localization purposes by developing and testing a visual proof of concept application. The leading reason for conducting it is to face a challenging project whose topic is a expanding technology of huge potential market.

To create a proof of this concept, it will be explained the progress that has to be followed in order to develop a new Global Positioning Service receiver using an Universal Software Radio Peripheral, known as URSP. This equipment gives us the possibility of carrying out a new GPS device so it can be learnt how a mechanism like this one works from the inside. It will be shown how the signals are transmitted and what is the process for demodulating and decoding these received signals. As a result, it could be used with some teaching purposes.

Particular Objectives:

- Investigating the whole process of how a GPS signal is received and treated.

- Investigating in more detail how the signal is demodulated and decoded so the necessary data is obtained.

- Implementing the necessary computations with the data obtained from the transmitted signal in order to get the geostationary position.

- Implementing the previously objectives mentioned using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) as design software.

All the previously mentioned objectives lead to the most significant motivation of this work. This project was chosen so in a future it can be used with teaching purposes. In such way, it will help putting this knowledge into practice and create a proof of concept about Global Positioning System on a visual way.

1.3 Project stages

This section describes the different sequential stages involved in the project. They provide an overall idea of the implemented work.

1.3.1 1st Stage: GPS protocols research

Once the project was chosen and the goals were established, extensive research about GPS system was carried out to gain a deep understanding about this technology. A solid base of knowledge was necessary to get full capabilities on the treated topic. Therefore, this task was decisive for the project success. This stage culminated with the acquisition of an Universal Software Radio Peripheral, known as USRP. This tool was used to receive GPS signal, so its demodulation and decoding could be carried out later.

1.3.2 2nd Stage: GPS Signal detection

The goal for the next stage was detecting GPS signals using the previously mentioned peripheral. This involve studying how GPS signals are transmitted and how these signals can be treated using the developed application, as well as carrying out a basic study on LabVIEW software. Once the research was done, it was time to code a basic application to put this knowledge into practice. For that, it was used all the previously acquired practical knowledge about the software.

1.3.3 3rd Stage: GPS Signal demodulation and decoding

Once detection was achieved it was necessary to know how GPS signal will be demodulated and decoded. In order to accomplish these processes was parsed to read and research the fields corresponding to BPSK modulation and DSSS codification. The key concept at this stage was the fact that these methods gave an estimation so it was needed to deal with several fluctuations. Nevertheless, the overall performance in terms of accuracy was good enough to move on to the following stage.

1.3.4 4th Stage: Positioning analysis

After the previously steps, it was time to compute the real GPS receptor distance with respect to the satellites. For that, it was necessary the research of some mathematical methods in order to obtain these results.

Unfortunately the results were an approximation of the real ones due to the already mentioned fluctuations.

1.3.5 5th Stage: Proof of concept application development

All the knowledge and expertise gained through the previous stages was then used to develop a proof of concept. The goal was to test the acquisition, treatment and computation of the corresponding GPS receptor position.

This phase was an enriching challenge because it involves coding in a different kind of programming from the usual ones, learning about GPS signals and how to manipulate them.

1.3.6 6th Stage: Testing and outcomes analysis

Once the previous stages were already completed, the application was tested in order to analyze its performance taking into account that positioning accuracy has a special importance. The analysis involved determining that some design parameters should be modified according to the specific scenario to ensure proper functioning.

1.3.7 7th Stage: Documentation

The last - but not least - phase to finish the project was to gather, organize and document all the knowledge acquired as well as the job implemented throughout the project. This stage represents all the concepts acquired during the process so it can provide a reference for people interested in how a GPS receptor works from inside.

1.4 Resources

This section briefly explains the resources used for the accomplishment of the project.

1.4.1 Hardware

- Samsung 300E5A laptop (Intel Core i5-2450M CPU @ 2.50GHz, 6GB RAM)

- NI USRP-2920. Tunable center frequency from 50 MHz to 2.2 GHz covering FM radio, GPS, GSM, radar, and ISM bands. Windows 10 compatibility.

- Cable Assembly SMA to SMA, 1M.

- 824-960 MHz, 1710-1990 MHz Dual-band Vertical Antenna.

- 144 MHz, 400 MHz, 1200 MHz , Tri Band Vertical Antenna.

- USRP MIMO Sync and Data Cable, 0.5M

- International power supply

- 3 m Ethernet cable

1.4.2 Software

- National Instruments LabVIEW 2015 System Design Software. Version 15.0. Student edition.

- Matlab software environment. Version 7.12.0 (R2011a).

- LaTeX. High/quality typesetting system designed for the production of the technical documentation, which was used to build this document.

1.5 Regulatory Compliance

There exists one organization which has a direct effect on the suggested scenario in this document: ECSS (European Cooperation for Space Standardization).

1.5.1 European Cooperation for Space Standardization

European Cooperation for Space Standardization (ECSS) is an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities. It can be seen that the standard [1] will be applied on the project. It is needed to satisfy it since the project represents a similar situation than the one explained on the standard. From it, it is obtained the basis for the different messages that will be exchanged between the GPS receptor and the satellites. Moreover, there exists the possibility of adding new messages which will be needed during the development [2].

1.6 Socio-Economic Context

During the last year, the population of Spain has suffered a slow decrease on its number, as it was doing since 2011. In addition to the last statement, in Figure 1.1 is shown the exact number for the beginning of this year, 2016.

Resident population in Spain	Population at 01/01/2015	Population at 01/01/2016	Variation %
Total population	46.449.565	46.438.422	-0,02
Men	22.826.546	22.805.060	-0,09
Women	23.623.019	23.633.362	0,04
Spaniards	41.995.211	42.019.525	0,06
Foreign Nationals	4.454.353	4.418.898	-0,80

Figure 1.1: Spanish resident population in 2016. *(Source: Instituto Nacional de Estadística -INE-)*

As it can observed, the natural population growth is suffering a significant decrease. The responsible of it is a reduction on the vegetative growth whose prediction for future years reflects a similar situation. The graphic shown below in Figure 1.2 represents the evolution and future prediction for the natality, mortality

and vegetative growth.
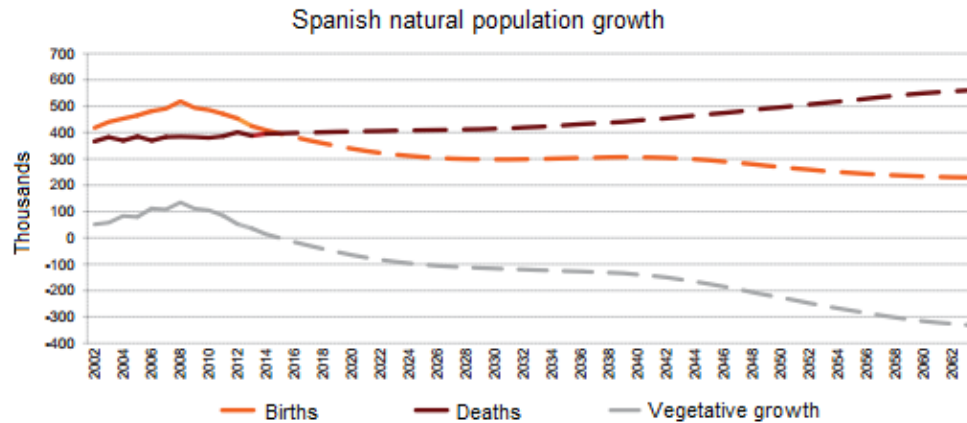
Figure 1.2: Spanish natural population growth. *(Source: Instituto Nacional de Estadística -INE-)*

Over the last years, the spanish economy has suffered the effects as a consequence of a real important economic crisis. In fact, this crisis has had a global effect on all the core nations. It has had influence on all sectors producing a huge decrease on the global home economy.

In the next Figure 1.3 it is shown the Unemployment rate of the last documented period:

Figure 1.3: Economically active population survey. *(Source: Instituto Nacional de Estadística -INE-)*

This high unemployment level has produced a purchasing power decrease not just for the spanish territory but also it has had a worldwide effect. The spanish families dedicate less amount of money to consumption. Nevertheless, it can be appreciated that there is a unemployment rate decrease, -2.37. an encouraging data

which means the spanish economy is slowly coming back.

Moreover, another important indicator about the spanish economy is the Gross Domestic Product (GDP) index. As it can be see in the Figure 1.4, its growth was decreasing over the last years. However, in 2015 it started to slowly increase recovering the values of previous years to the crisis.
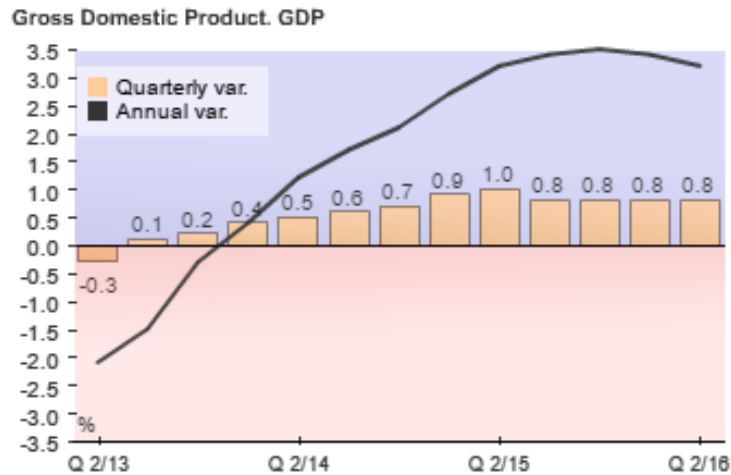
Figure 1.4: Spanish gross domestic product. *(Source: Instituto Nacional de Estadística -INE-)*

This economic crisis has produced an effect on the companies and states so they have reduced their investments over the last years. The first reduction was over the projects related to research and new technologies, same projects as the one it is been carried out in this document. Fortunately, this crisis is subsiding and this fact is visible for all the economic sectors.

Throughout the ages it can be seen that it is necessary the existence of a constant research over the new technologies sector. Nowadays, it is a fundamental sector over the rest and it is constantly developing new projects. Only in this way, all the needs of these market would be satisfied.

1.7 Document Structure

The thesis consists of eight chapters and three appendices. A brief summary about the contents of each of them is presented below to help with the document reading.

1.7.1 Chapter 1: Introduction

This first chapter is meant to introduce the project to reader by providing with in-depth knowledge to understand Global Positioning System, as well as stating the regulatory compliance it has to follow, its socio-economic context and pointing out the document structure.

1.7.2 Chapter 2: State of the art

This chapter will provide with a basic introduction on a GPS Receptor in addition to an outline of its market forecast.

1.7.3 Chapter 3: Work Environment Description

In this chapter it will be introduced the implemented software, LabVIEW, as well as the SDR used technique, USRP.

1.7.4 Chapter 4: GPS Signal

This chapter will detail the theory about the steps that were required to transmit, receive and treat GPS signals. It includes its demodulation and decoding, in addition to the corresponding process which is carried out so the final positioning is obtained.

1.7.5 Chapter 5: Tool Development

This chapter will explain how the GPS receptor was designed using the previously detailed software. Information about the different interfaces that were used is also provided.

1.7.6 Chapter 6: Testing and results

This chapter will describe the results that were obtained when testing the program.

1.7.7 Chapter 7: Problems encountered and further development

This chapter will describe the problems and obstacles found throughout the development of the project, along with their solution or the possible workarounds that would be implemented on a future. This leads to future tasks that would be carried out in forward editions.

1.7.8 Chapter 8: Planning and budgeting

This chapter will cover how the project was broken down into simpler tasks, the followed timing plan and associated costs description.

1.7.9 Chapter 9: Conclusions

This last chapter summarizes the most important insights during these months, along with a personal opinion about the experience of completing my bachelor thesis.

1.7.10 Appendix A: Extended abstract

This appendix summaizes the most important information about this document. It includes a brief introduction, a general vision about the project objectives. Finally, it inlcudes also descriptionf of its final resuts and conclusions.

1.7.11 Appendix B: Matlab Codes

This appendix provides the Matlab codes to perform on one side the C/A Code sequence generation for each satellite and on the other side, the development of the Ranging equation so the final user location can be obtained.

1.7.12 Appendix C: User's Manual

This appendix provides an user manual so the developed project can be reproduced.

2 STATE OF THE ART

The main topic of this project will be introduced, its structure will be described and finalliy the relationship betweem the implemented device and the ones that already exists on the market will be given.

2.1 Global Navigation Satellite System

Global Navigation Satellite System (GNSS) is known as a satellite system that is used to pinpoint the geographic location of a user's receiver anywhere in the world [3].

It has its precedent on the terrestrial systems known as LORAN (Long range Navigation) and Omega, which used radio terrestrial transmitters of low frequency (100 kHz) instead of satellite transmitters. These systems diffused a radio pulse from a master localization, followed by duplicated pulses emitted from a serie of slaves stations. The delay between the reception and the signal delivery in the auxiliary stations was controlled, allowing the receptors to be able to compare between the reception delay and the controlled delay. Through this method it is possible to know the exact distance to each of the auxiliary stations.

The first Navigation Satellite System was the system known as Transit, a system deployed by the United States Army in 1960. Transit was based on the Doppler

(a) LORAN system

(b) Omega system

Figure 2.1: Precedent GPS systems

Effect. The satellites travel on known trajectories and diffuse their signals on a known frequency. The received frequency differs slightly from the diffused signal due to the satellite movement with respect to the receptor. Motorizing this frequency shift in short intervals, the receptor is able to determine in which side is respect to the satellite. The combination of several measures connected to the exact satellite orbit knowledge can determine a concrete position.

Satellite-based navigation systems use trilateration to locate the user, through calculations involving information from a number of satellites. Trilateration is a mathematical method that uses the geometry of triangles analogously to triangulation. Each satellite transmits coded signals at precise intervals. The receiver converts signal information into position, velocity, and time estimates. Using this information, any receiver on or near the earth's surface can calculate the exact transmitting satellite position and the distance (from the transmission time delay) between it and the receiver. Coordinating current signal data from four or more satellites enables the receiver to determine its position.

Two GNSS systems are currently in operation: the United States Global

Figure 2.2: Transit system

Positioning System (GPS) and the Russian Federation's Global Orbiting Navigation Satellite System (GLONASS). A third, Europe's Galileo, is slated to reach full operational capacity in 2008. Each of the GNSS systems employs a constellation of orbiting satellites working in conjunction with a network of ground stations.

2.2 Global Positioning System

The Global Positioning System (GPS) is a satellite network that orbit the earth at fixed points above the planet and beam down signals to anyone on earth with a GPS receiver. These signals carry a time code and geographical data point that allows the user to pinpoint their exact position, speed and time anywhere on the planet [4].

The Global Positioning Systems consists on a constellation made by 24 operational satellites and 3 backup satellites. This constellation started running
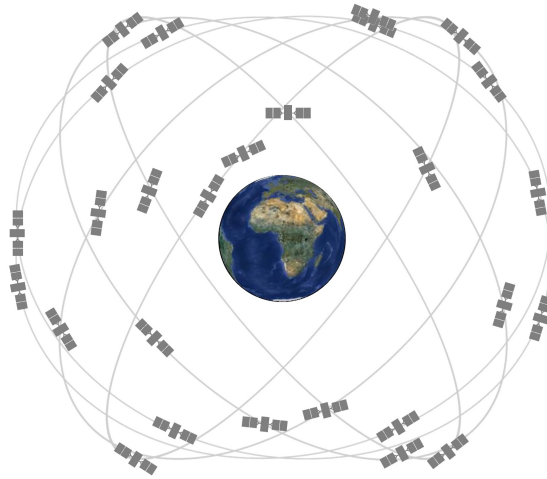
Figure 2.3: GPS constellation. *(Source: GPS.gov)*

around 1990 and it became fully operational in 1993. In order to carry out the continuous global coverage, the satellites from GPS system are grouped together in orbits of 4 satellites, adding up to a total of 6 orbits, as it is shown in Figure 2.3. With this geometric constellation, from 4 to 10 satellites are visible from any part of the world, but just 4 satellites are needed in order to determine the information from the localization.

With a view to obtain the position, the used receptor automatically locates at least three satellites from the net and from these three satellites it receives signals. These GPS signals bring the corresponding position and the internal clock of each of the satellites that have transmitted the signal. With these signals as basis, the receptor synchronises its own clock and compute the delay of each signal, that is the distance to each satellite. Once the four different distances to each of the satellites has been obtained, using trilateration it determines the relative receptor position. To get the complete position, it extracts from the signals previously received the coordinates of each corresponding satellite and in such way it computes the absolute GPS receptor position.

2.2.1 GPS History

Originally designed for military and intelligence applications at the height of the Cold War in the 1960s, with inspiration coming from the Soviet spacecraft Sputnik launch in 1957. With this new device scientists were able to track the satellite with shifts in its radio signal known as the "Doppler Effect".

The United States Navy conducted satellite navigation experiments in the mid 1960's. Transit was the first satellite system launched by the USA and tested by the US Navy in 1960. It was designed so the United States Navy was able to track US submarines carrying nuclear missiles. With six satellites orbiting the poles, submarines were able to observe the satellite changes in Doppler and pinpoint the submarine's location within a matter of minutes.

In the early 1970's, the Department of Defense (DoD) wanted to ensure a robust, stable satellite navigation system would be available. Embracing previous ideas from Navy scientists, the DoD decided to use satellites to support their proposed navigation system. Transit was succeeded by the Timation satellite, which demonstrated that highly accurate atomic clocks could be operated in space. GPS developed quickly for military purposes thereafter with a total of 11 "Block" satellites being launched between 1978 and 1985 [5].

However, it was not until the Union of Soviet Socialist Republics (USSR) shot down a Korean passenger jet - flight 007 - in 1983 that the Reagan Administration in the US had the incentive to open up GPS for civilian applications so that aircraft, shipping, and transport the world over could fix their positions and avoid straying into restricted foreign territory.

Upgrading GPS system was delayed by NASA space shuttle SS Challenger disaster in 1986 and it was not until 1989 that the first Block II satellites were launched. By the summer of 1993, the US launched their 24th Navstar satellite into orbit, which completed the modern GPS constellation of satellites - a network of 24 - familiar now as the Global Positioning System, or GPS. 21 of the constellation of satellites were active at any one time; the other 3 satellites were spares; in 1995 it was declared fully operational. Today's GPS network has around 30 active satellites in the GPS constellation.

Today, GPS is a multi-use, space-based radionavigation system owned by the US Government and operated by the United States Air Force to meet national defense, homeland security, civil, commercial, and scientific needs [6].
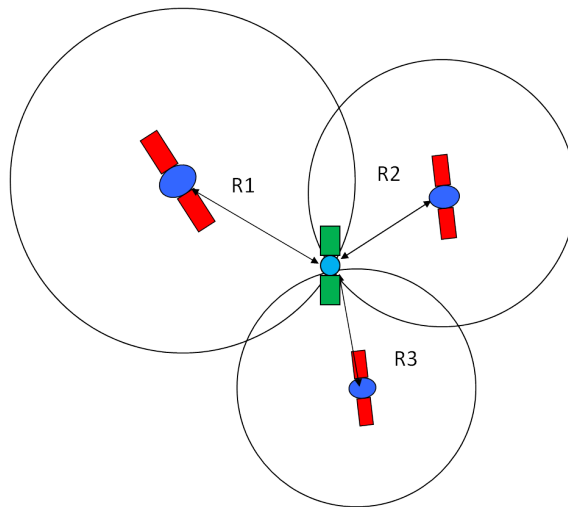
Figure 2.4: GPS system. *(Source: NASA.gov)*

2.2.2 GPS Standard Positioning Service

The GPS Standard Positioning Service (SPS) is defined as follows:

The SPS is a positioning and timing service provided by way of ranging signals broadcast at the GPS L1 frequency. The L1 frequency, transmitted by all satellites,

contains a coarse/acquisition (C/A) code ranging signal, with a navigation data

message, that is available for peaceful civil, commercial, and scientific use [7].

In this section it will be explained the three different segments that form the GPS Standard Positioning Service. Now a brief overview will be given and later they will be explained in detail.

- **Space Segment**: a constellation of 24 satellites distributed in six orbital planes inclined 55 degrees from the equator in a Medium Earth Orbit (MEO) at about 20,200 kilometers and circling the Earth every 12 hours.

- **Control Segment**: stations on Earth monitoring and maintaining GPS satellites.

- **User Segment**: receivers that process the navigation signals from GPS satellites and calculate position and time [8].

GPS Space Segment

In the Space Segment 24 satellites are found. These satellites have synchronized trajectories in order to cover all the Earth surface. To be more concrete, they are distributed in six different orbital planes of 4 satellites each. The electric energy needed for its correct functioning is acquired from two panels composed by solar cells located on its sides.

In the table below, the most important aspects about the satellites are shown.

Altitude	20,200 km
Orbital Period	11 h 56 min (12 sideral hours)
Inclination	55 degrees (with respect to Earth equator)
Design line	7.5 years
Solar panels and batteries	Made of Ni-cad

Table 2.1: Satellite characteristics

In Figure 2.5 it is presented an overview of the generation and transmission process for a Block IIA satellite.
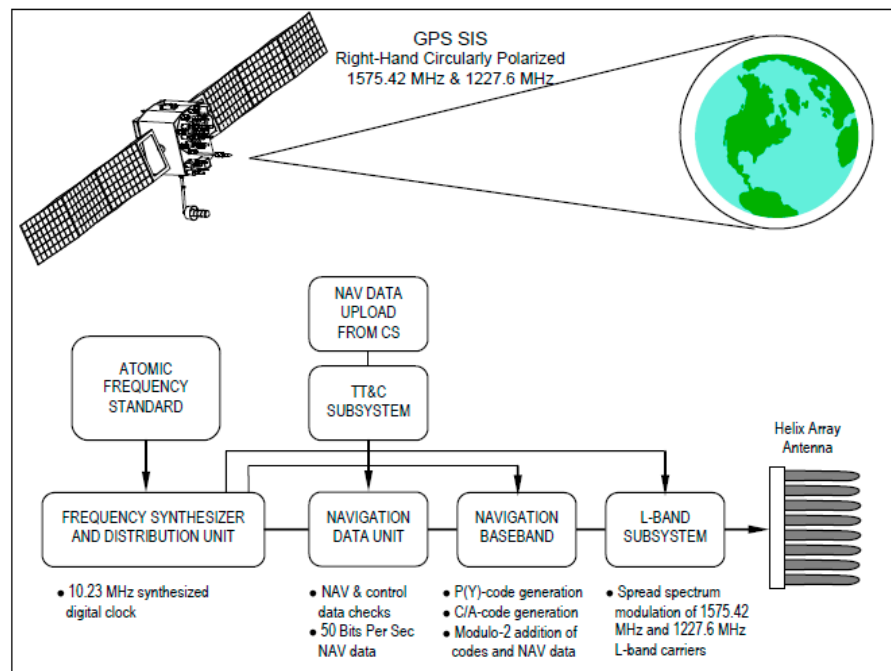
Figure 2.5: Space segment. *(Source: GPS.gov)*

GPS Control Segment

The Operational Control System (OCS) is comprised of four major subsystems: a Master Control Station (MCS), a Backup Master Control Station (BMCS), a network of four ground antennas (GAs), and a network of globally-distributed monitor stations (MSs). An overview of the OCS is provided in Figure 2.6.
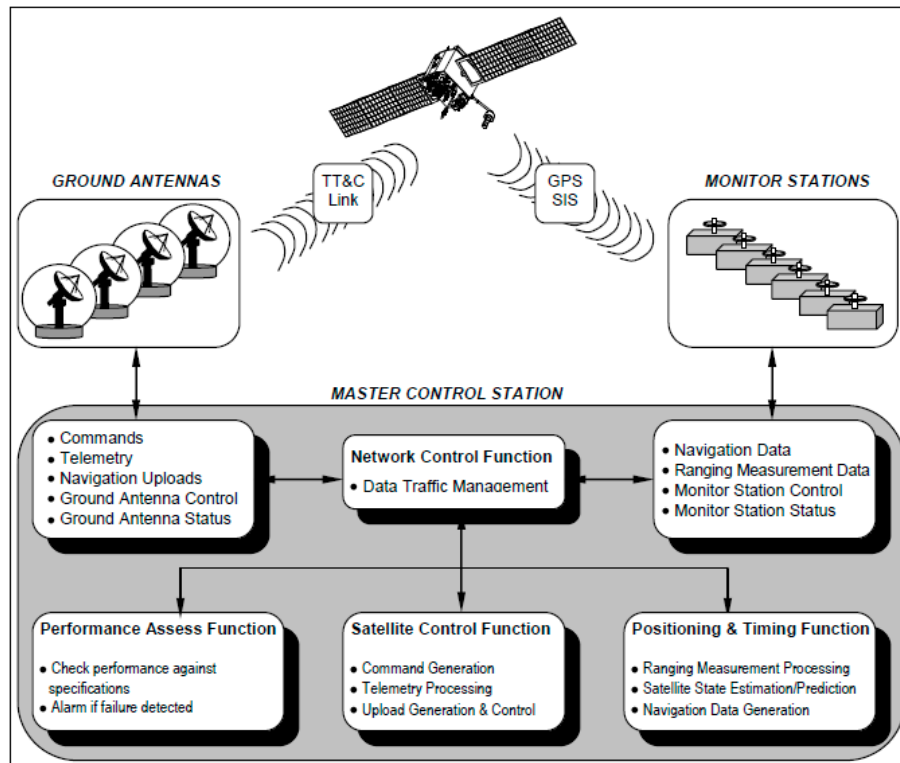
Figure 2.6: Control segment. *(Source: GPS.gov)*

The global navigation satellite systems composed by the control segment consists on a serie of ground stations. These stations transmit control information to the satellites so they can control the orbits and realize the necessary maintenance service of the whole constellation. It can be said that they are automatic tracking stations globally distributed. As well, they motorize the orbits jointly the signals of each satellite sending corrections when they are needed. They control the satellite activations and deactivations according to the maintenance needs.

GPS User Segment

This GPS segment varies depending on the application it is developing. It is formed by all the devices used for the reception of the signals emitted by the satellites. Also inside of this segment it can be found the necessary software for the communication established between the computer and the receptor as well as the information post-

process in order to obtain the results.

It is necessary to take into account that GPS Systems was designed by the United States' DoD with exclusive military purposes. For that reason the principal aim of GPS System was centered on the vehicle's positioning and military troops localization everywhere. Years later, some applications on the navigation field started to be developed. These applications correspond to the present GPS receptor, which will be explained in more detail in Section 2.3.

2.2.3 GPS Future

Nowadays GPS navigation devices besides being high-technology products, they represent an important application in our daily life.

This phenomenon started when in 2000, the President Bill Clinton gave the green light to stop intentionally scrambling satellite signals[9]. For the first time, civilians were able to enjoy GPS signals with the same accuracy as the one the military had long used.

Despite of GPS technology has been quickly developed, it has not taken advantage of all its potential yet as it was pointed out by Johannes Angenvoort, the executive vice president of NAVIGON's Development. According to the study made by the European Commission, the Global Navigation Satellite market will reach a turnover of 236.000 millions of euros by 2025. A significant growth taking into account that in 2005 the turnover was about 69.000 millions of euros [9].

In order to perform this growth, there is a GPS modernization program, that is an ongoing, multibillion-dollar effort to upgrade GPS space and control segments with new features to improve GPS performance. It is introducing modern technologies

throughout the space and control segments that will enhance overall performance, in addition to new civilian and military signals.

- **GPS III**

  The GPS modernization program involves a series of consecutive satellite acquisitions, as it is the case of GPS III. This new system is a robust version of the actual one, with a bigger availability and a significant reduction on the complexity introduced by the new incorporations [10].

  Some of the improvements of this new system are described below:

  - The incorporation of two additional civil signals for certain civilian applications:

    * A second civil signal at GPS L2 frequency at 1227.60 MHz to meet the needs of high-precision science uses.

    * A third civil signal, designated as L5 at 1176.45 MHz to meet the needs of critical safety-of-life applications such as civil aviation.

  - A fourth civil signal, designated as L1C, will be common with other Global Navigation Satellite Systems (GNSS) systems, such as the European Galileo helping the interoperability between each other.

  - A network-centric architecture is replacing legacy computers and communications, allowing more frequent and precise satellite commands that will improve accuracy.

  - A better designed structure for GPS signals.

  - An increment on the signal power. Now the L5 frequency will count with a power level of -154 $d\beta$.

  - The number of motorized stations will be doubled, reaching 12 stations.

By the time all the improvements are already implemented, GPS III will be the primary federally provided radionavigation system for the foreseeable future and will be augmented and improved to satisfy future military and civil requirements for accuracy, coverage, availability, continuity, and integrity [11].

- **Galileo**

During the last years of the XX century, a small group of countries belonging to the European Union started to show some rejection and insecurity about GPS system (of US origin) and GLONASS (of Russian origin). They were afraid of, in case of an international armed conflict, as much United States as Russia could restrict or make more difficult the access limiting the military and civil activity of the region. But also the precision and the effectivity from GPS and GLONASS systems, were two characteristics of being aware of in a future.

To face this situation, the European Union jointly with the European Space Astronomy Centre (ESAC) defined a plan in which they will be able to eliminate these fears and give the opportunity to Europe of positioning itself at the forefront of GPS market. So, in 2003 Galileo was promoted, a geolocation system entirely developed and managed by European organizations, guaranteeing the independence of the region and improving the positioning services (even 70 centimeters of accuracy).

This system, formed by thirty satellites and several management centers, have been developed, unlike GPS and GLONASS systems, with a civil purpose. This is why they declared that the system control will be carried out by civil authorities, once it is functional. Nevertheless, it can be used for military purposes if a conflict takes place on the European Union.

The satellites which form Galileo are situated in a lower orbit than the geostationary one, but in a higher with respect to GPS and GLONASS orbit. Specifically, the thirty satellites are distributed in three different planes with a radius of 23,222 km each. The estimated life of each satellite is greater than twelve years.

Its process is divided in three phases. During the period between 2005 and 2008, the GALILEO system successfully completed the phase GIOVE (Galileo In-Orbit Validation Element). In this phase, two satellites were placed into orbit in order to perform various checks. The signal analysis subsequently confirmed the success of the first phase. Both satellites were removed in 2012.

Between 2011 and 2012, IOV (In-Orbit Validation) phase was completed. In this new phase, four new satellites were deployed in order to perform more checks on the system operation. As an explanation, any electronic device requires a minimum of four satellites to properly perform a geo-positioning [12].

On the last stage, known as FOC (Final Operation Capability), the remaining 26 satellites will be launched into orbit, allowing full system operation and the start of services. The first of the satellites belonging to this phase was placed in orbit in 2014, while the most recent was sent into space at the end of 2015.

Currently more than ten satellites are still placed in orbit. According to the planning defined by the European Union and ESA, six of these will be launched over 2016. The remaining satellites will be sent into space in the incoming years, setting as a deadline 2020, almost a decade later than it was expected initially [13].

The initial project cost was 1,000 million of euros. Right now, the European

Union estimates a total cost of 7,000 million of euros.

Figure 2.7: Galileo system

2.3   GPS Receptor basics

This topic will start with a classification of the different types of GPS receptors. Depending on the used observer for determining the receptor position there exist two types of GPS receptors. Pseudorange measurement receivers (code) which are the navigators, and pseudorange and phase measurement receivers which correspond to the topographic and geodesic receptors.

They can be also classified on receptors capable of registering L1 frequencies (C/A codes) or receptors capable of jointly registering L1 and L2 frequencies (dual frequency receptors).

The following schemes represent these previous classifications.
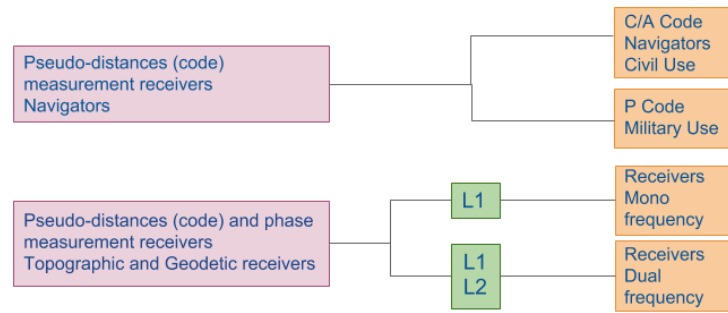
Figure 2.8: Receiver classification

In addition to this classification, it will be explained a brief description of these devices. The one used on topographic and geodesic applications are made up of the following elements:

- GPS Antenna. It receives and amplifies the emitted signal.

- GPS Computer. It is responsible of the signal decoding and it registers the observations too.

- Terminal. It is an user interface that allows the control on the reception state, the calculation process and it also carries out the edition on the receptor data.

The positioning is always refer to the antenna. It is connected to the receptor through a preamplifier either directly or using a cable. Its function consists on converting the electric received current into electromagnetic energy.

GPS receptor is formed by a series of elements whose responsibility resides on the radio frequencies reception. these radio frequencies are emitted by the satellites. Besides, they usually have different channels in order to simultaneously follow some satellites, an intern processor with its corresponding logic support, a memory unit for the information storage, control keyboard, communications screen with the user,

different connections for different functions and finally an intern or extern power source.

Finally, tripods, special cables, meteorological control equipments and other auxiliary material are implemented too.

2.3.1 Commercial GPS Receptor

There exist four different commercial GPS receptors. They can be distinguished between each other depending on the reached accuracy. Taking into account this fact they are classified as following:

- Navigator

  They just receive data about the C/A code through the L! carrier. These devices match the code and determine the pseudo distance present between the satellite and the receptor, giving tridimensional coordinates as the final result of the geographic position.

  They are simple GPS receptors of low price. They work automatically obtaining an accuracy below 10 meters (without Selective Availability SA)

- Submetric GPS receptor

  They are GPS devices of similar characteristics as the ones mentioned before. The reference equipment works separately from the mobile one, which can be working either on cinematic mode or static mode. Opposite to the navigators, they use corrections.

  The obtained accuracy are below 1 meter, although they depend on the receptor type and the mathematical algorithms. Its applications belong to the cartography and Geographic Information System (GIS) fields.

- Mono-frequency code and phase GPS receptor

  These receptors take data from the L1 carrier either on its modality C/A code or phase. They work on differential mode in real time but also in pre-recorded time. The accuracy increments considerably with respect to the two previously mentioned, they can reach until 1cm + 2ppm of precision. This high precision allows to use them on topographic applications. Another important advantages of them is its low prices.

- Dual-frequency GPS receptor

  More precision devices, they are used on topographic and geodesic applications. They take data emitted by the satellites through both carriers, making C/A code and P(Y) code measurements on the L1 carrier, measurements of P(Y) code and L2C on the L2 carrier and phase measurements in both carriers.

  They work on real and pre-recorded time reaching an accuracy of the 5mm + 1ppm order and decreasing the observation time. In addition to its geodesic and topographic applications, they are used for deformation control and photogrammetric control networks too. Its observations times are shorter than the previous ones and its distances longer than 20 km.

The table below summarizes the previous concepts [14]:

METHOD	FREQUENCY	OBSERVABLES	PRECISION	APPLICATIONS
Absolute	L1	C/A code	±10 m	Navigation
Differential	L1	C/A code	1 m	Cartography/GIS
Differential	L1	C/A and Phase	1 cm + 2 ppm	Topography
Differential	L1 and L2	C/A and Phase	5 mm + 1 ppm	Topography/Geography

Table 2.2: GPS receivers

2.3.2 Educational GPS Receptor

After doing some research into this topic, it was found the surprising result that there are not such a device as the one implemented.

GPS technology belongs to the new technologies field, an actual field in which nowadays, there are a lot of investments.

It is true that there already exist some educational applications for it but these applications just explain its theory from a more visual way. In the following link, some of these applications can be found.

http://recursostic.educacion.es/observatorio/web/en/equipamiento-tecnologico/
didactica-de-la-tecnologia/71-aplicaciones-didacticas-del-gps-i

There exists another kind of application which uses GPS technology with a different educational purpose. In this case, the use the technology but not for explaining it, in opposite they use GPS to get information about educations. Education GPS is the OECD (Organisation for Economic Co-operation and Development)source for internationally comparable data and analysis on education policies and practices, opportunities and outcomes. Accessible any time, in real time, the Education GPS provides you with the latest information on how countries are working to develop high-quality and equitable education systems [15].
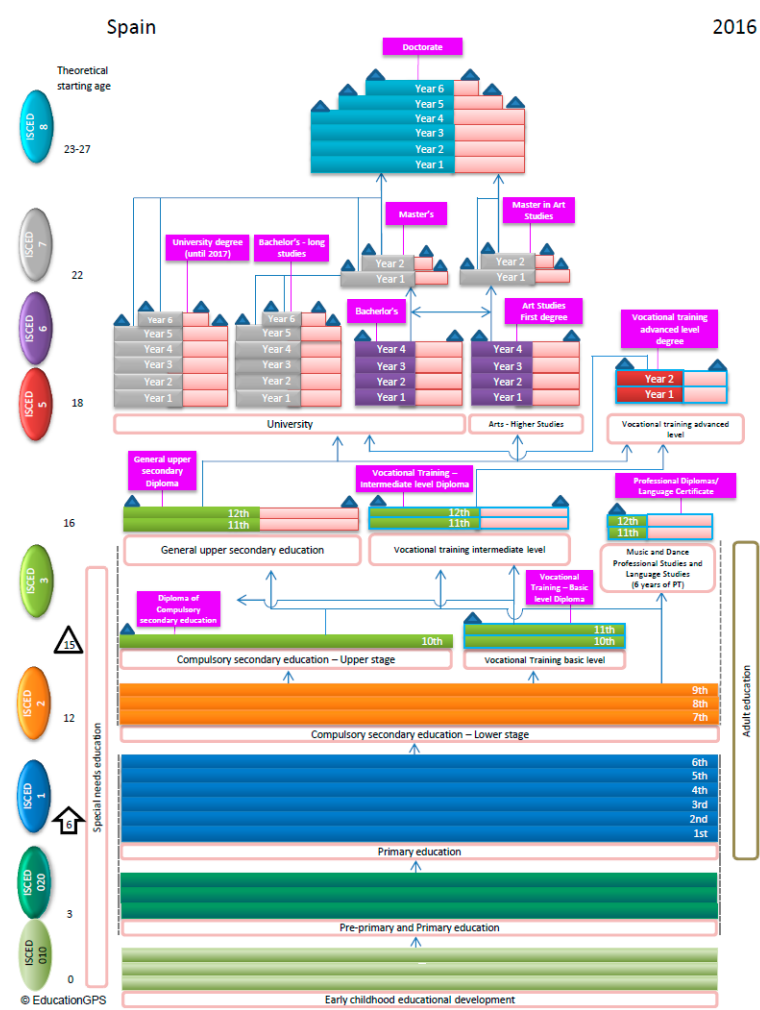
Figure 2.9: Education GPS application. *Source(OECD)*

Therefore, it can be said that the developed device in this document is an innovating device, being the first one that will make easier the teaching on this field.

2.3.3 Comparison

In this section, a brief comparison between the implemented device in this document and the previous ones will be exposed.

Nowadays GPS technology is present on almost every new designed technologies

as it was exposed in previous sections. Its presence is gradually increasing not just in the navigation fields. It is hard to think about any application which does not have this technology included on its body. It was surprising to realize that this kind of technology has not been designed previously with educational purposes. In fact, a lot of academic programs include it on their programs but they just contemplate it from a theoretical point of view.

On one hand, It can be said that this design was a good idea from the educational point of view. It will allow the demonstration of this technology not just theoretical but also the practical one. It also has some improvements over the present commercial GPS receptors. It is the case of its possibility of being modified in future editions, adding new improved features which will make this receptor a better option.

On the other hand, it is necessary to stand out also its main disadvantages with the respect the others. The most important one is a economic disadvantage, as it will show in Section 8.2. As it can be seen on the markets, the commercial price of a GPS receptor is around 114.00€ [16] (the cheapest one). Another important disadvantage of the implemented GPS is its lower accuracy in comparison with the present commercial devices. It has to be mentioned that this fact could be improved in future works.

3 WORK ENVIRONMENT DESCRIPTION

This chapter will introduce the main components of the project to the reader, explain how they work and reveal their capabilities to provide context awareness. The different available specifications will also be described, along with a brief introduction to the lastest developed radiocommunication systems, SDR. Finally, information about USRP peripheral will be provided. The user manual for this peripheral is given in Appendix C.

3.1 LabVIEW Software

LabVIEW is a highly productive development environment for creating custom applications that interact with real-world data or signals in fields such as science and engineering. The net result of using a tool such as LabVIEW is that higher quality projects can be completed in less time with fewer people involved.

LabVIEW itself is a software development environment that contains numerous components, several of which are required for any type of test, measurement, or control application.

The G programming language is central to LabVIEW; so much so that it is often called "LabVIEW programming". Using it, you can quickly tie together

data acquisition, analysis, and logical operations and understand how data is being modified. From a technical standpoint, G is a graphical dataflow language in which nodes (operations or functions) operate on data as soon as it becomes available, rather than in the sequential line-by-line manner that most programming languages employ. You lay out the "flow" of data through the application graphically with wires connecting the output of one node to the input of another.

Its main benefits are given below:

- Intuitive, flowchart-like dataflow programming model.

- Shorter learning curve than traditional text-based programming.

- Naturally represents data-driven applications with timing and parallelism
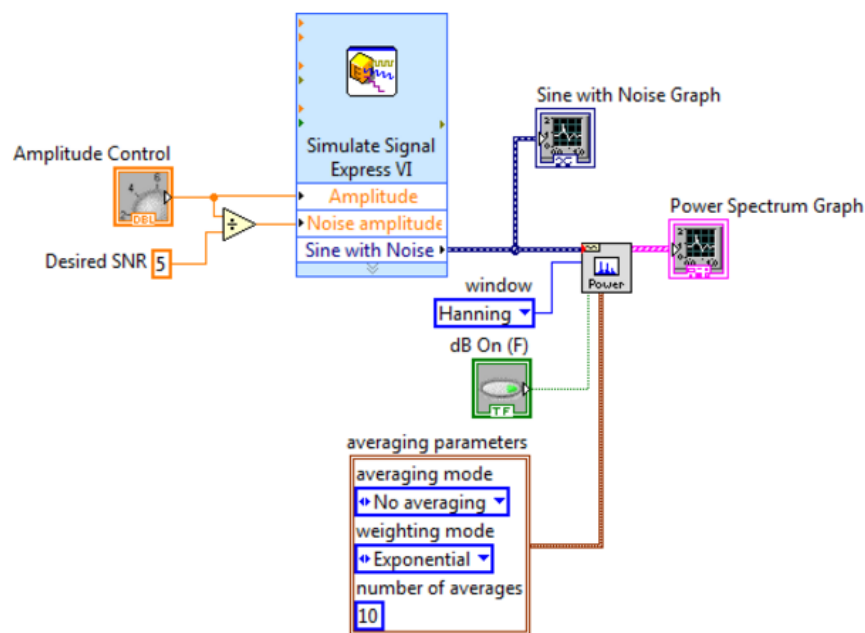
Figure 3.1: LabVIEW G Code block diagram. *(Source: LabVIEW)*

LabVIEW contains a powerful optimizing compiler that examines your block diagram and directly generates efficient machine code, avoiding the performance

penalty associated with interpreted or cross-compiled languages. The compiler can also identify segments of code with no data dependencies (that is, no wires connecting them) and automatically split your application into multiple threads that can run in parallel on multicore processors, yielding significantly faster analysis and more responsive control compared to a single-threaded, sequential application.

With the debugging tools in LabVIEW, you can slow down execution and see the data flow through your diagram, or you can use common tools such as breakpoints and data probes to step through your program node-by-node. The combination of working with higher-level building blocks and improved visibility into your application's execution results in far less time spent tracking down bugs in your code [17].

In this project it was used the version 2015. This version was the only compatible version with the Windows 10 software. In Section 4, there will be explained the different components implemented on the design. As well as, the controls and interfaces with their functions involved on the process.

3.2   Software Defined Radio

Software Defined Radio (SDR) is a radiocommunication system where components that have been typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system. Although the concept of SDR is not new, the recent evolution of digital electronics has made possible the possibility of carrying out some process that previously were unachievable from a practical point of view.

A basic SDR is usually formed by a personal computer equipped with a sound car, or other analog-to-digital converter, preceded by some form of radio frequency (RF) front end. Instead of using special-purpose hardware for signal processing, with this system signal processing is handed over to the general-purpose processor. Such as design has a configuration which allows widely different radio protocols changes based solely on the software used.

The main utility of these radio systems resides on military and cell phone services, both of them should serve a wide variety of changing radio protocols in real time.

In the long term, software defined radios are expected to become the dominant technology in radio communications, since SDRa along with software defined antennas are the enables of the cognitive radio. In addition, this technology can be flexible enough to avoid the limited spectrum assumptions, as some designers of the previous kinds of radios estimated. It is the case of the improvements introduced by spread spectrum, ultra wideband and cognitive radio techniques, software defined antennas, dynamic transmitter power adjustment and wireless mesh network.
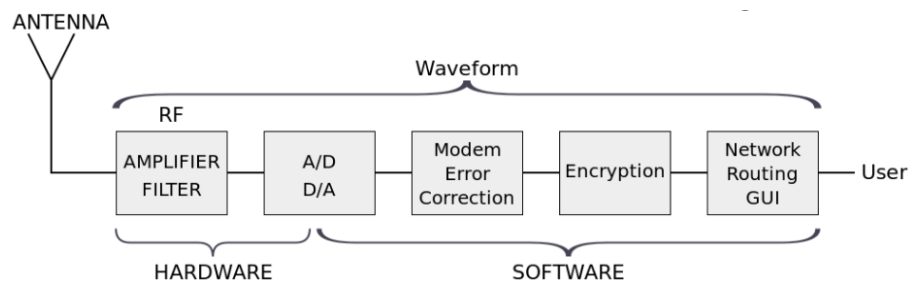
Figure 3.2: Software Defined Radio Structure

- **Technological Factors**

  In this small subsection it is going to be exposed the different facilities that graphic tools such as LabVIEW have.

  To begin with, it is necessary to take into account the simplicity of learning

these kind of tools. This fact is produced by the facility of finding free manuals and tutorials about them, but also there exist some communities where other developers or users can help in the resolution of doubts and problems as well as sharing information about them. The significant technological grade of evolution does not imply a higher complexity on the learning of these techniques.

Moreover, it has been mentioned the use of programmable boards, known as FPGA, since they allow the creation of reconfigurable peripherals. Even this kind of circuits is not so fast as the others in the sector, its capacity of reconfiguration makes them stand out. Another important factor is the present competition and cooperation between the companies, which makes easier the development of new software and hardware.

- **Advantages**

  SDR technology motivates the creation of wireless interoperable devices with a lot of advantages, among them [18]:

  - Multiple operational modes.

  - Reconfiguration.

  - Over-The-Air actualizations.

  - Lower development costs.

3.3 Universal Software Radio Peripheral

Universal Software Radio Peripheral (USRP) is a flexible and affordable transceiver that turns a standard PC into a powerful wireless prototyping system. Paired with LabVIEW Communications System Design Software, USRP

transceivers help you prototype a wide range of single-channel and MIMO wireless communications systems [19].

The USRP product family includes a variety of models that use a similar architecture. It counts with a motherboard which provides clock generation and synchronization, FPGA, ADCs, DACs, host processor interface, and power regulation subsystems. These subsystems are the basic components that are required for baseband processing of signals. A modular front-end, called a daughterboard, is used for analog operations such as up/down-conversion, filtering, and other signal conditioning. This modularity permits the USRP to serve applications that operate between DC and 6 GHz.

The USRP and LabVIEW Communications System Design Suite offer a powerful solution for prototyping RF and communications systems. Build a complete wireless communications system using the intuitive LabVIEW programming environment that supports multirate DSP for physical layer communications and helps you integrate .m file scripts and C language algorithms.

- **USRP 2920**

  In order to develop the GPS receiver, NI USRP 2920 was chosen. Its main characteristics and components are given in the following description.

  NI USRP-292x transceivers provide relevant, hands-on laboratory learning in RF and communications as part of an affordable teaching solution. National Instruments leverages the power of NI LabVIEW software and Ettus Research hardware to deliver these affordable software-defined radio (SDR) transceivers for accessible communications experimentation in multiple frequency bands.

  A LabVIEW development system delivers an ideal way to interface with NI

USRP SDR hardware and develop and explore communications algorithms for processing received signals and synthesizing signals for transmission. The NI-USRP software driver features functions (LabVIEW VIs) for control of one or more connected USRP devices.   At a high level, the driver provides LabVIEW VIs for opening sessions, configuring hardware, performing read/write operations, and closing sessions.

NI USRP-292x Kit Contents are given below [20]:

  – NI USRP-2920 device.

  – International power supply.

  – 3 m Ethernet cable.

  – 0.3 m SMA-SMA Loop Back cable.

  – 30 dB SMA inline attenuator.

  – NI-USRP software driver.

  – LabVIEW Modulation Toolkit.

  – LabVIEW MathScript RT Module.

  – LabVIEW Digital Filter Design Toolkit.

Figure 3.3: 2920 NI USRP. *(Source: LabVIEW)*

4 GPS SIGNAL

In this section it will be introduced a brief description of GPS signal structure as well as the process to be followed in order to demodulate and decode this signal. In addition, it will be given an introduction of the navigation message. Then, along Chapter 5, these processes will be illustrated with the developed LabVIEW interfaces, which will show the final result of this document.

4.1 GPS Signal Structure

GPS signals are transmitted in two radio frequencies of the UHF band, known as the L band by the IEEE. These two frequencies are called as L1 and L2, both of them are derived from the common frequency f_0:

$$f_0 = 10.23MHz$$
$$f_{L1} = 154f_0 = 1,575.42MHz \hspace{2cm} (4.1)$$
$$f_{L2} = 120f_0 = 1,227.60MHz$$

The signals are formed by three components:

- **Carrier**. There GPS signal consists on three carriers on the L band, L1, L2 and L5. However, in this document only L1 and L2 will be treated.

- **Navigation data**. It contains the satellite orbits information. This

information is sent to all satellites by the ground GPS stations. The data bit rate has a value of 50 bps as it will be shown in Section 4.2.

- **Sequence spread spectrum**. Technique implemented on mobile communications in order to spread the signal spectrum to be transmitted. Depending on the obtained information it uses a determined code or sequence to implement the process. One characteristic of this code is its pseudo noise form as it will be illustrated on Subsection 4.3.1. This code modulates the carrier in such a way that it increase or decrease the transmission or reieption bandwidth, and decrements the spectral power (power level in any given frequency). The spectrum of the resulting signal has a similar aspect as the pseudo noise so it will be seem as noise for all the satellites except the one whose own code is equal as the one transmitted. This technique is known as Direct-Sequence Spread Spectrum and is explained in Subection 4.3.3.

After this brief summary about GPS signals, it is time to explain in detail GPS signals generation. Figure 4.1 represents a block diagram in which GPS signal (containing only L1 and L2 carriers) generation process is illustrated. The clock signal has a frequency value of 10.23 MHz. More exactly, the frequency is equal to 10.22666666543 MHz since it depends on Einstein's relativity. On one side, this special relativity compares accelerations and gravitational forces and on the other side, it anticipates that following fact: the time pass for clock A, which is situated in a place with lower gravitational force than other place where clock B is, is observed faster than that the same time pass in the second clock. Therefore, due the fact GPS satellites are subject to lower gravitational force, the transmitters' clock seems faster than the ones over the earth's surface and as a result the frequency value is then decreased to 10.23 MHz.
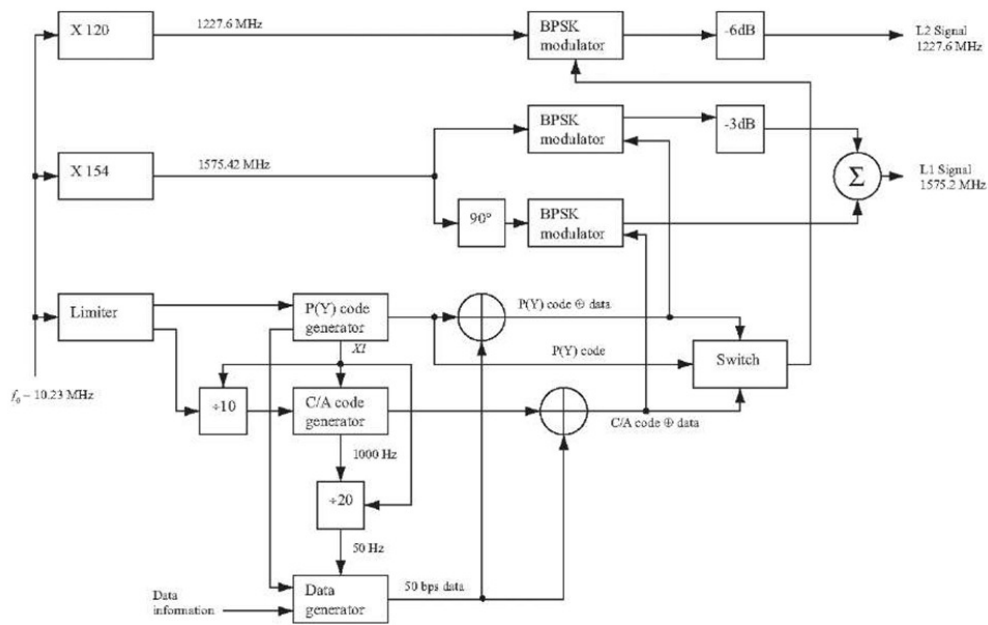
Figure 4.1: Signal generation in a GPS satellite

This frequency is multiplied in two different occasions, firstly by 154 so it is obtained the value for L1, secondly by 120 originating the L2 value. In the bottom of the figure is described how C/A and P(Y) Codes are generated, following the previously indicated chip rates, and the navigation message, which is twenty times slower than the repetition C/A Code frequency. The P(Y) Code generator is responsible, through signal denoted as X_1 in the diagram, of getting a perfect synchronization between the spread spectrum rates and the navigation message. The codes are combined following the addition rule of module two.

The XOR (exclusive OR) operation is used over binary sequences represented by 0's and 1's, whose properties are shown in Table 4.1a. If the binary sequence was represented by the polar non-zero return representation, i.e.: 1's and -1's, the ordinary multiplication can be applied.

Input	Input	Output
0	0	0
0	1	1
1	0	1
1	1	0

(a) Exclusive OR operation

Input	Input	Output
-1	-1	1
-1	1	-1
1	-1	-1
1	1	1

(b) Ordinary multiplication

The properties of the multiplication of two binary non-zero return sequences are shown in Table 4.1b. The C/A Code $\oplus$ data and P(Y) Code $\oplus$ data signals shown in Figure 4.2 are given to both L1 frequency modulators. There, the signals are modulated with the carrier signal using Binary Phase Shift Keying (BPSK) modulation. It has to be taken into account that both codes are modulated on phase and in quadrature between each other in the L1 frequency band. This is, there is a 90 degrees shift between both codes, as it can be observed in Figure 4.3. After, the signals corresponding to P(Y) Code, are attenuated by a factor of $3d\beta$ and then added so they form the resulting L1 signal. SPS just uses the C/A code signals.
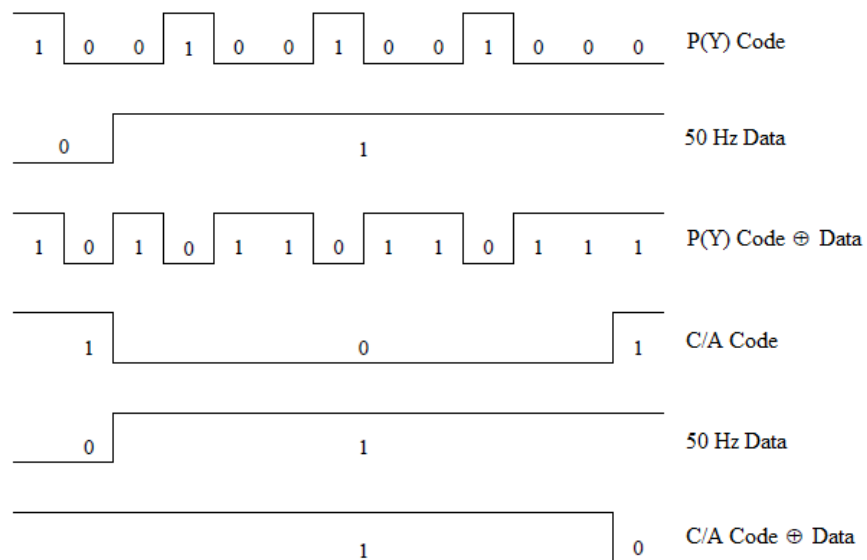
Figure 4.2: GPS code combined with data

Therefore, the transmitted signal by the k satellite can be described as:

$$s^k(t) = \sqrt{2P_C}\left(C^k(t) \oplus D^k(t)\right)cos(2\pi f_{L1}t) +$$

$$\sqrt{2P_{PL1}}\left(P^k(t) \oplus D^k(t)\right)sin(2\pi f_{L1}t) +$$

$$\sqrt{2P_{PL2}}\left(P^k(t) \oplus D^k(t)\right)sin(2\pi f_{L2}t) \quad (4.2)$$

where P_C, P_{PL1}, P_{PL2} are the values for the power of C/A or P(Y) code signals, C^k is the C/A code sequence corresponding to the k satellite. P^k is the P(Y) code sequence assigned to the k satellite, D^k is the navigation data sequence, f_{L1} and f_{L2} are the carrier frequencies for L1 and L2, respectively.
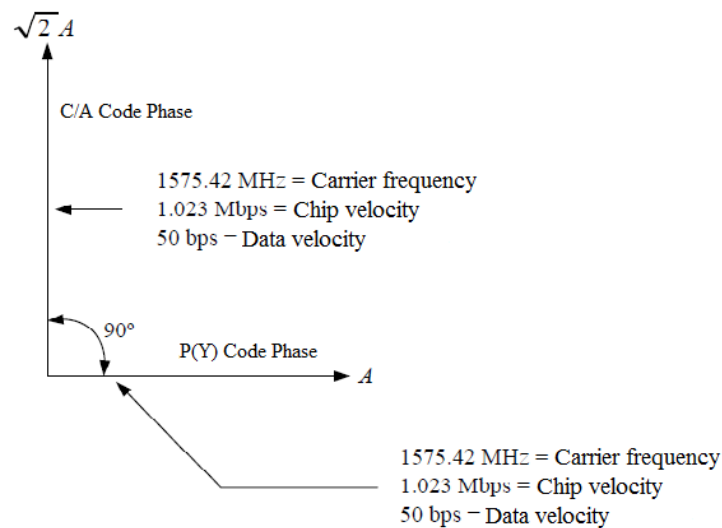
Figure 4.3: GPS signal structure for L1

Figure 4.4 shows the three different parts that form the L1 frequency signal. C/A Code is repeated automatically every ms, and a single navigation bit takes 20 ms. This difference makes that for every navigation bit, the signal contains 20 complete C/A Codes. $D(t)$ is the discrete bits flow for the navigation data.

Figure 4.5 illustrates Gold Code C, navigation data D, the added signal for module number two $C \oplus D$, and the carrier. The final signal is created through

BPSK modulation where the carrier instantly performs a 180 degrees phase shift at the moment the chip changes. When a navigation data bit transition happens, the final signal is shifted 180 degrees. GPS C/A spectrum is represented in Figure 4.6.
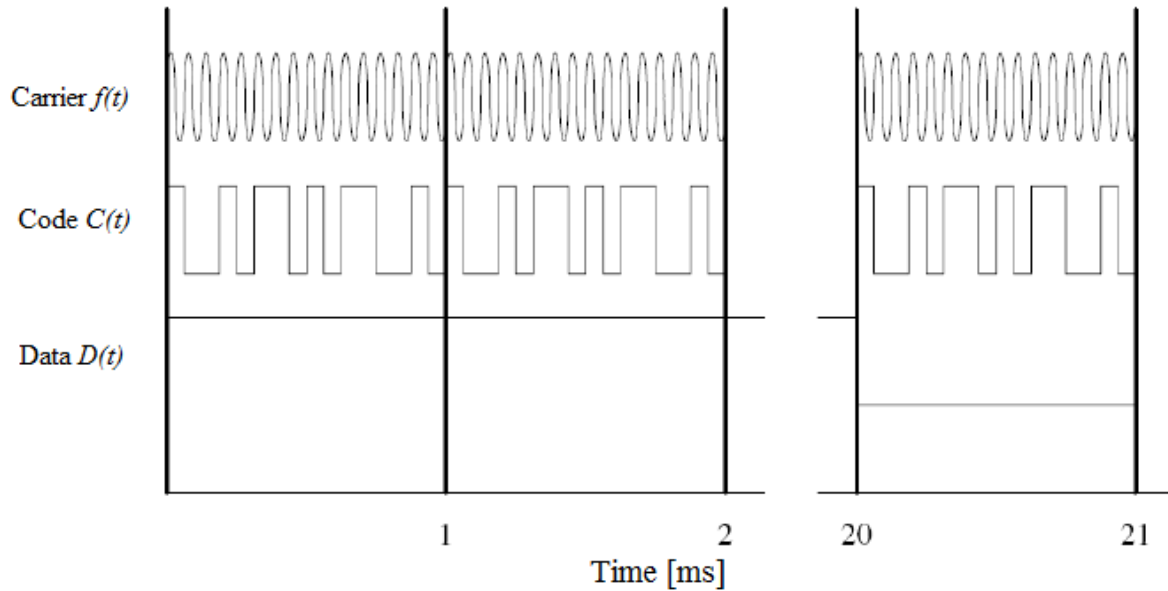
Figure 4.4: General GPS signal structure

As a summary: In GPS technology, code length is equal to 1023 chips, it has a chip rate of 1,023 MHz (time period of a 1 ms), chip data of 50 Hz (20 code periods for a data bit), equivalent to the 90% of signal power inside 2 MHz bandwidth.
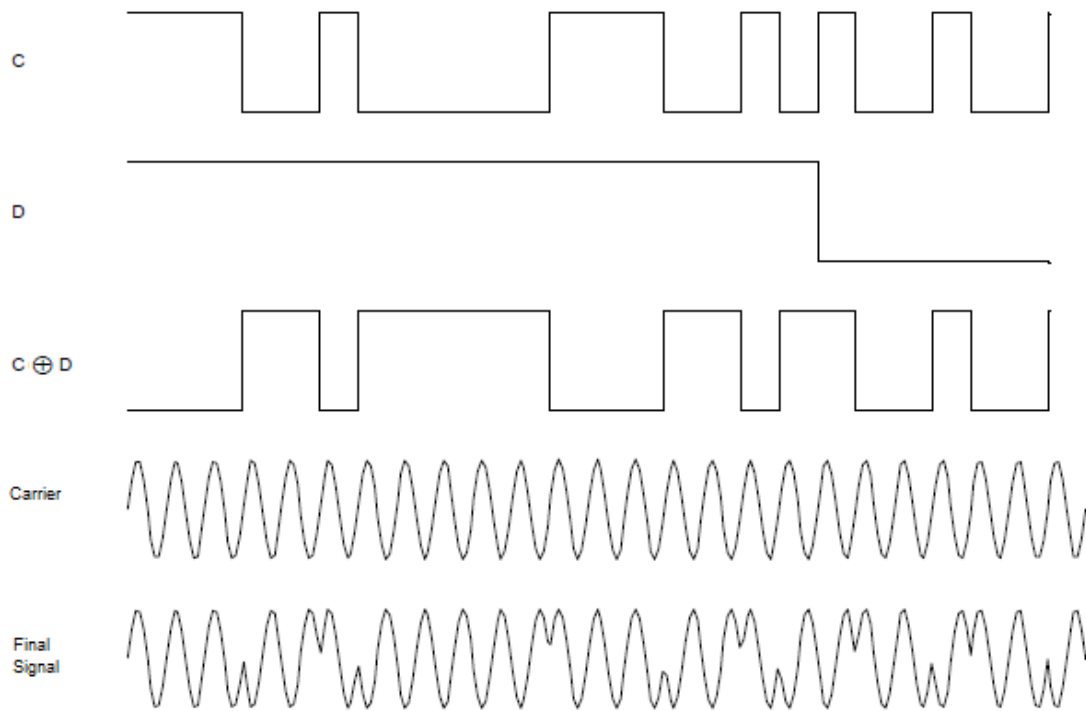
Figure 4.5: BPSK modulation effect over L1 signal (C/A code and navigation data mix)
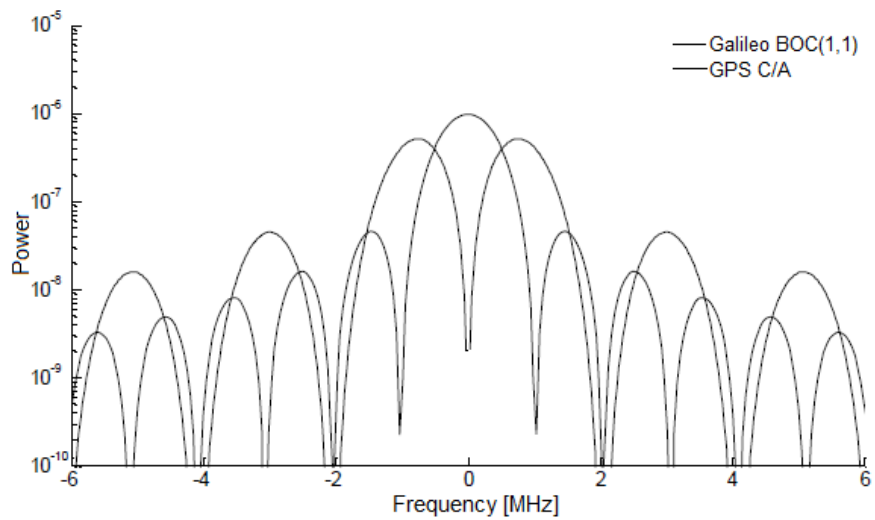
Figure 4.6: GPS C/A L1 spectrum. Central frequency 1575.42 MHz

4.2   Navigation Data Structure

Navigation data is defined as the detailed information about each satellite's position and the network which is modulated on top of both the C/A and P(Y) ranging codes at 50 bps, needed by GPS receiver. The navigation message format considered on this document is called LNAV data (for Legacy NAVigation).

This information is sent over L1 frequency with a velocity of 50 bps. In Figure 4.7 is represented the global structure of a complete data message, where each subframe contains 300 bits of 6 seconds duration. Subframes 1, 2 and 3 are repeated every 30 seconds while subframes 4 and 5 have 25 versions before being repeated. That is, the whole navigation message is repeated every 12,5 minutes.

The basic format of the navigation data is a frame whose length is equal to 1500 bits, containing 5 subframes, of 300 bits length each. A subframe contains 10 words, each word has a length of 30 bits. The subframes 1, 2 and 3 are repeated every frame. The 25 versions of the last frames 4 and 5 (same structure but different data) are called as 1 to 25 pages.

With a bit rate of 50 bps, subframe transmission lasts 6 seconds, frame transmission 30 seconds and complete data message 12,5 minutes.
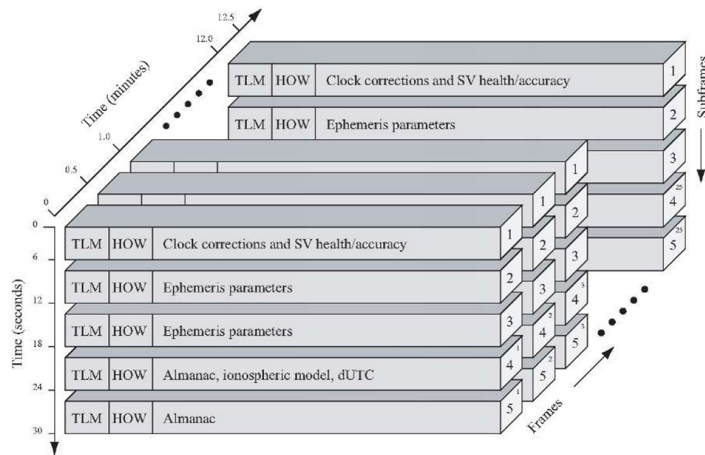
Figure 4.7: GPS navigation data structure

The navigation message information can be classified in three different broad areas:

- GPS date and time, in addition to the satellite's status and health indication.

- Ephemeris data. Orbital information which allows the receiver to calculate the position of the satellite. Each satellite transmits its own ephemeris.

- Almanac data, containing information and status concerning all the satellites. Each of them transmits almanac data for several satellites, depending on which PRN numbers are in use.

The duration of these parts of informations varies, whereas ephemeris information is highly detailed and considered valid for no more than four hours, almanac information is more general and is considered valid for up to 180 days. In order to determine which is the satellite transmitting, GPS receiver is assisted by almanac data. Once the receiver obtain the corresponding signal from the satellite, it downloads the ephemeris data directly from it. It repeats this process for the rest of satellites. To perform the position calculation is necessary that an accurate and

complete copy of the satellite's ephemeris data is obtained by the receiver. If the signal from a satellite is lost while its ephemeris data is being acquired, the receiver must discard that data and start the process again.

A receiver must process 25 whole frames worth of data to retrieve the entire 15,000 bit almanac message. Therefore, it is obtained the previously mentioned value of 12.5 minutes that are required to receive the entire almanac data from a single satellite. Frames begin and end at the start/end of week plus an integer multiple of 30 seconds. At start/end of week the cycling between pages is reset to page 1.

There exist two types of navigation message: LNAV-L, which is used by satellites with PRN numbers 1 to 32 (called lower PRN numbers), and LNAV-U used by satellites with PRN numbers 33 to 63 (called upper PRN numbers). Both of them use similar formats: subframes 1 to 3 implement the same format, while subframes 4 and 5 uses almost the same.

4.2.1 Telemetry message: health of satellite and handover word

The 10 words subframes always start with these two special words

TLM is the first word of each subframe and it is repeated every 6 seconds. It has a preamble of 8 bits and it is followed by 16 reserved and parity bits.

The handover word, named as HOW, contains a truncated Time of Week (TOW) version of 17 bits , followed by two flags which give security information to the user, among others. The next 3 bits show the subframe identificator (ID). This ID corresponds to the subframe number where the word HOW is located for each frame [21].
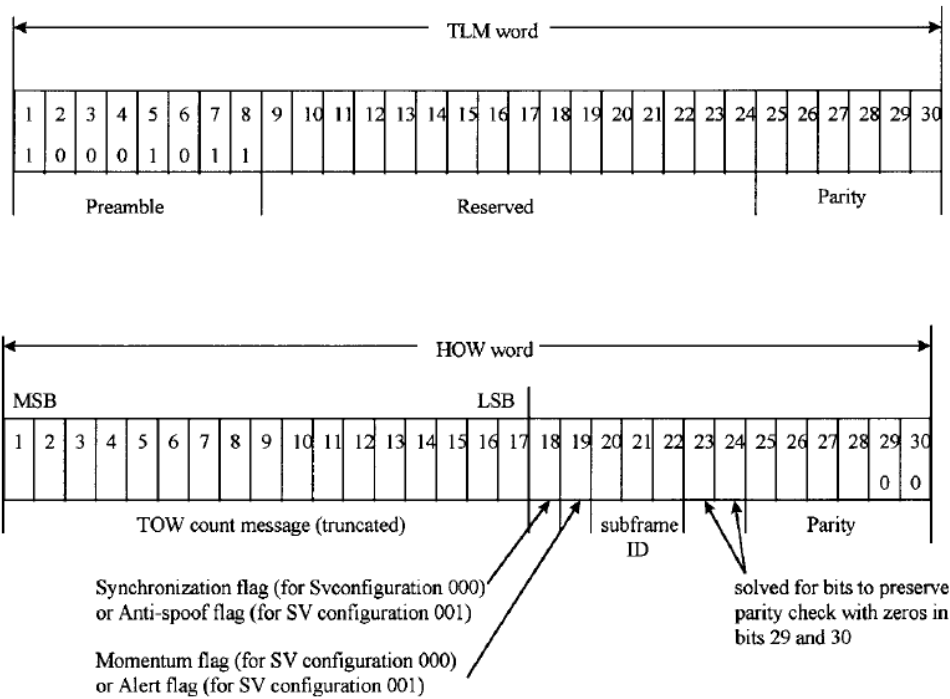
Figure 4.8: TLM and HOW words

4.2.2 Data in the Navigation message

- **Subframe 1** - Clock and satellite's health state data. The first subframe contains firstly the clock information. This information is necessary to compute in which moment the navigation message is transmitted by the satellite.

  Moreover, subframe 1 includes data about the satellite's health indicating if the navigation data are reliable or not.

- **Subframe 2 and 3** - Ephemeris satellite data. These subframes contains the ephemeris data. It makes reference to the satellite orbit and it is needed to compute the satellite position.

- **Subframe 4 and 5** - Data support. As it was discussed before, the last two subframes are repeated every 12.5 minutes, making a 50 subframes total.

Subframes 4 and 5 contains almanac data. This is, ephemeris and reduced clock data. It is necessary to take into account that each satellite transmits almanac data of every GPS satellite but just its own ephemeris data. The rest of subframes 4 and 5 corresponds to UTC parameters, health flags and ionosphere data.

In Section 5.3 detailed information about acquisition and structure of the navigation data is given.

4.2.3 Time

GPS time is expressed with a resolution of 1.5 seconds. It is composed by a week number and a week time count (TOW). Its zero point (week 0, TOW 0) is defined to be 1980-01-06T00:00Z.

In each subframe, each handover word contains the 17 most significant bits of the TOW count. These correspond to the start of the next following subframe. Note that the 2 least significant bits can be safely omitted since in the navigation message, one HOW occurs every 6 seconds. This is equal to the truncated TOW count resolution. Equivalently, the truncated TOW count is the time duration from the last GPS week start/end to the beginning of the next frame what is counted in units of 6 seconds.

Each frame from subframe 1 contains the 10 least significant bits of the corresponding GPS week number. Note that each frame is entirely within one GPS week because GPS frames do not cross GPS week boundaries. Since rollover occurs every 1,024 GPS weeks (approximately every 19.6 years; 1,024 is 2^{10}), a receiver that computes current calendar dates needs to deduce the upper week number bits

or obtain them from a different source. One possible method is saving its current date in memory when shut down, and when powered on, assume that the newly decoded truncated week number corresponds to the period of 1,024 weeks that starts at the last saved date. This method correctly deduces the full week number if the receiver is never allowed to remain shut down (or without a time and position fix) for more than 1,024 weeks ($\sim$19.6 years).

4.2.4 Almanac data

The almanac data is formed by coarse orbit and status information for each satellite, an ionospheric model, and information to relate GPS derived time to Coordinated Universal Time (UTC).

In subframes 4 and 5, a part of this almanac data is contained on each frame. The complete almanac data is transmitted by each satellite in a total of 25 frames, requiring the aforementioned 12.5 minutes. The purposes developed by this data are shown below:

- During the satellites acquisition, it assists to GPS receiver so it can generate a list of visible satellites based on stored position and time. At the same time, position fixes can be developed using ephemeris data from each. In older hardware, this lack of almanac data would cause long delays before providing a valid position, since it made the satellite search a slower process. Advances in hardware have made the acquisition process much faster, and nowadays not having an almanac is no longer an issue.

- The second purpose is relating time derived from GPS (called GPS time) to the UTC international time standard.

- Finally, the almanac allows a single-frequency receiver to correct using a global ionospheric model, ionospheric delay error. These corrections are not as accurate as augmentation systems like WAAS (Wide Area Augmentation System) or dual-frequency receivers. However, it is important to make these corrections since ionospheric errors are the largest error sources for a single-frequency GPS receiver.

4.2.5 Navigation Message Upgrades

- **CNAV Navigation message**

  The Civilian Navigation (CNAV) data is an upgraded version of the original NAV navigation message. It contains higher precision representation and more accurate data. In comparison to NAV navigation message it uses a new pseudo-packetized format made of 12-second 300-bit messages analogous to LNAV frames. The information content is no longer fixed and may be chosen among several defined types. The frame type determines its information content. In order to allow some versatility to the Control Segment, messages do not follow a fixed schedule regarding the used message type.

  In CNAV, at least 1 out of every 4 packets is ephemeris data and the same lower bound applies for clock data packets. With a 32-satellite constellation, less than 75% of the bandwidth is used. Only a small fraction of the available packet types have been defined; this fact enables the system to grow and incorporate advances without breaking compatibility. There are many important changes in the new CNAV message:

    - It uses Forward Error Correction (FEC) provided by a rate 1/2 convolutional code, so while the navigation message is 25 bit/s, a 50

bit/s signal is transmitted.

– Messages carry a 24 bit CRC.

– GPS week number is now represented as 13 bits, or 8,192 weeks. it is just repeated every 157.0 years, meaning the next return to zero will not occur until the year 2137.

– There is a packet that contains a GPS-to-GNSS time offset. This allows better interoperability with other global time-transfer systems, such as Galileo and GLONASS.

– The extra bandwidth enables the inclusion of a packet for differential correction.

– Every packet contains an alert flag, to be set if the satellite data can not be trusted. This means users will know within 12 seconds if a satellite is no longer usable. Important advantage for applications such as aviation.

– Finally, the system is designed to support 63 satellites, instead of the well known 32 satellites used in NAV message.

CNAV messages begin with a 8 bit preamble whose sequence has a fixed bit pattern so it enables the receiver to detect the beginning of a message.

• **MNAV Navigation Message**

It is known as the Military Navigation (MNAV) message, however, there is not so much information about this new upgrade. As in the case of CNAV navigation messages, it is packeted instead of being framed, allowing for very flexible data payloads. Also it can implement FEC checking and advanced error detection techniques such as a CRC.

4.3   GPS Receiver Operation

A C/A code GPS receiver must be able to correlate signals from at least four satellites. calculate time delays, read the navigation message, locate GPS satellites orbits. and compute the final position from obtained pseudoranges. The key to accurate position determination process resides on timing precision in gold code sequences arrivals from each visible satellite. All GPS receivers use a microprocessor whose responsibilities consist on making the required calculations and controlling the display of data.

Most C/A code GPS receivers use an IC chip set which includes 12 parallel correlators. This allows the receiver to process signals from up to 12 satellites at the same time. This characteristic contributes to keep all signals synchronized. In opposite, some simpler receiver use a single correlation and process just four satellite signals sequentially, with consequent lower accuracy. The received GPS signals are converted to a suitable IF frequency and them, they are processed sot C/A codes can be recovered.

The IF signal is formed by the addition of a number (up to 12) which represents the exact amount of signals coming from visible GPS satellites. IF carrier signal has several BPSK (Binary Phase Shift Keying) modulations which have been assigned by the satellite. When signals are received on earth, satellite Doppler shift and earth motion have been already incorporated to it. IF signal from N visible GPS satellites has the following formula:

$$s(t) = \sum_{i=1}^{N} \{A_i C_i(t) D_i(t)_i t sin[(w_i + w_d)t - \phi_i(l_i) + \phi_i]\} \qquad (4.3)$$

where, A_i is the received signal amplitude, $C_i(t)$ is the Gold code modulation, $D_i(t)$ is the navigation message modulation, w_i is the received carrier IF frequency, w_d is the received signal Doppler shift, $\phi_i(l_i)$ is the phase shift along the path, ϕ_i is the transmitted signal phase angle.

In order to obtain successful measurements in GPS C/A code receiver is necessary to generate in the receiver an identical signal to the one received from satellite i, but without the navigation data which is previously modulated onto the transmitted signal. The originated signal counts with the correct C/A code for satellite i, its corresponding starting delay, and the correct applied Doppler shift. The locally generated signal is now multiplied by the received signal, in which different visible GPS satellites signals can be found. Finally, the output is integrated over the C/A code length of 1 ms.

The result is a constant output with 20 ms period, corresponding to a navigation data bit duration. The precise matching of the locally generated signals and the received signals from four visible GPS satellites, ensures that the local receiver's chip clocks and C/A code generators are perfectly synchronized to the received signals. When this condition is achieved, the start time of each C/A code sequence and the corresponding chip clock transition provide the high accuracy time marker. This fact makes GPS time delay measurement possible.

To obtain the corresponding pseudorange for each of the N visible satellites, the receiver need to measure $\phi_i(l_i)$ (represented on the previous equation), as time delay, then, it can recover $C_i(t)$ modulation by applying correlation. $D_i(t)$ modulation contains the navigation message as a 50 bps BPSK modulation of $C_i(t)$ signal. Both $C(t)$ and $D(t)$ signals are modulated onto the satellite signal carrier using

BPSK. Therefore they have values ± 1. BPSK signal demodulation requires a locally generated carrier which is locked to the received carrier phase. Data signal recovery needs a bit clock which is locked to the received signal bit rate. The next step consists on multiplying the signal and noise by the wanted C/A code sequence, so the signal is despread and to brought above the noise. The nominal bandwidth of the signal is 1 kHz after the correlator, since the 1023 bit C/A code sequence is repeated every millisecond.

The receiver have to be designed in order of searching all possible Doppler shifts, code sequences, and code start times, until an output is obtained from the correlator. This output will indicate that a satellite signal has been found. Once this happens, information contained in the navigation message can be used to steer the receiver to the needed parameters to acquire the rest visible satellites.

The output of the C/A code correlator with Doppler corrected IF frequency for the satellite signal with code number M is:

$$x(t) = A_m R(\tau_m - \tau) D_m(t) sin[w_m(t) - \phi_m(l_m) + \phi_m] + n(t) \qquad (4.4)$$

where $R(\tau_m - \tau)$ is the autocorrelation function of the wanted code number M, and $n(t)$ is the output from the cross-correlation process with all other codes.

The correlator output is a despread signal at baseband, which is modulated with the 50 bps navigation message. Once the C/A code has been removed applying the correlation process, it is straightforward process to demodulate the navigation message D.

The despread IF carrier is BPSK modulated by the navigation message $D_m(t)$

$$y(t) = A_m R(\tau_m - \tau) D_m(t) sin[w_m(t) - \phi_m(l_m) + \phi_m] + n(t) \qquad (4.5)$$

If signal is limited to remove any amplitude variations, which sets $A_m = 1$. Then

$$y'(t) = R(\tau_m - \tau)D_m(t)sin[w_m(t) - \phi_{m'}] + n(t) \tag{4.6}$$

The navigation message $D(t)$ is recovered after multiplying the IF signal $y'(t)$ by $sin[w_m(t) - \phi_{m'}]$ and then, low pass filtering it so the 50 bps signal is obtained. The reference carrier for BPSK demodulator can be derived from the output of the Costas loop. The demodulated message signal is $z(t)$ where:

$$y'(t) = R(\tau_m - \tau)D_m(t) + n'(t) \tag{4.7}$$

Provided that the correlation peak of $z(t)$ crosses the threshold and $n'(t)$ does not, the data message $D_m(t)$ is correctly recovered [22].

4.3.1 PRN Codes

GPS satellites transmit using pseudorandom sequence (PN) codes. All satellites transmit a specific C/A code at the same carrier frequency, L1. For that process they use BPSK modulation. The C/A code has a clock rate of 1,023 MHz and its sequence is made of 1023 bits, therefore the PN sequence lasts exactly 1.0 ms. GPS measurements are one of the few examples where relativistic effects must be taken into account, the clocks are mounted on platforms moving at very high speeds.

The P code is transmitted using BPSK modulation at the L2 carrier frequency. At the same time it is also transmitted on the L1 carrier frequency, in phase quadrature with the C/A code BPSK modulation.

The C/A and P code transmissions from all GPS satellites are overlaid in the L1 and L2 frequency bands, making GPS a direct sequence spread spectrum (DS-SS) system as it will be explained later. The receiver separates signals from individual

GPS satellites using as a reference the unique C/A code that is allocated to each satellite. At most, 12 GPS satellites can be seen by a receiver at one time. So, it is advisable that the coding gain in the spread spectrum receiver must be sufficient to overcome the interference created by 11 unwanted signals while recovering the twelfth wanted signal.

These codes are also called Gold sequences as Robert Gold described them in 1967. In the following subsection, just the generation process of C/A code sequences will be described.

C/A Code Generation - a general vision

GPS C/A Gold codes are built from two 1023 bit m-sequences, called G1 and G2. By multiplying together G1 and G2 sequences with different time offsets the different C/A codes are obtained. An m-sequence is a maximum length pseudorandom (PN) sequence, which is easy to generate with a shift register and feedback taps. A shift register with n stages can generate a PN sequence of $2^n - 1$ bits length. The bit pattern is set by the feedback taps and combining logic of the shift register. 10-bit linear feedback shift registers (LFSR) are the responsibles of generating PN sequences G1 and G2. Therefore, both sequences are 1023 bits long. The clock rate for the C/A code is 1.023 MHz, so each sequence lasts 1.0 ms. Figure 4.9 shows a generator diagram for the C/A code.

The C/A code for a particular satellite is created with an algorithm which includes the GPS satellite identification number, in that way an unique code for each satellite is created. The satellite with ID number i has a C/A code sequence $C_i(t)$:

$$C_i(t) = G1(t) \times G2(t + iT_c) \tag{4.8}$$

where T_c = clock period for the C/A code.
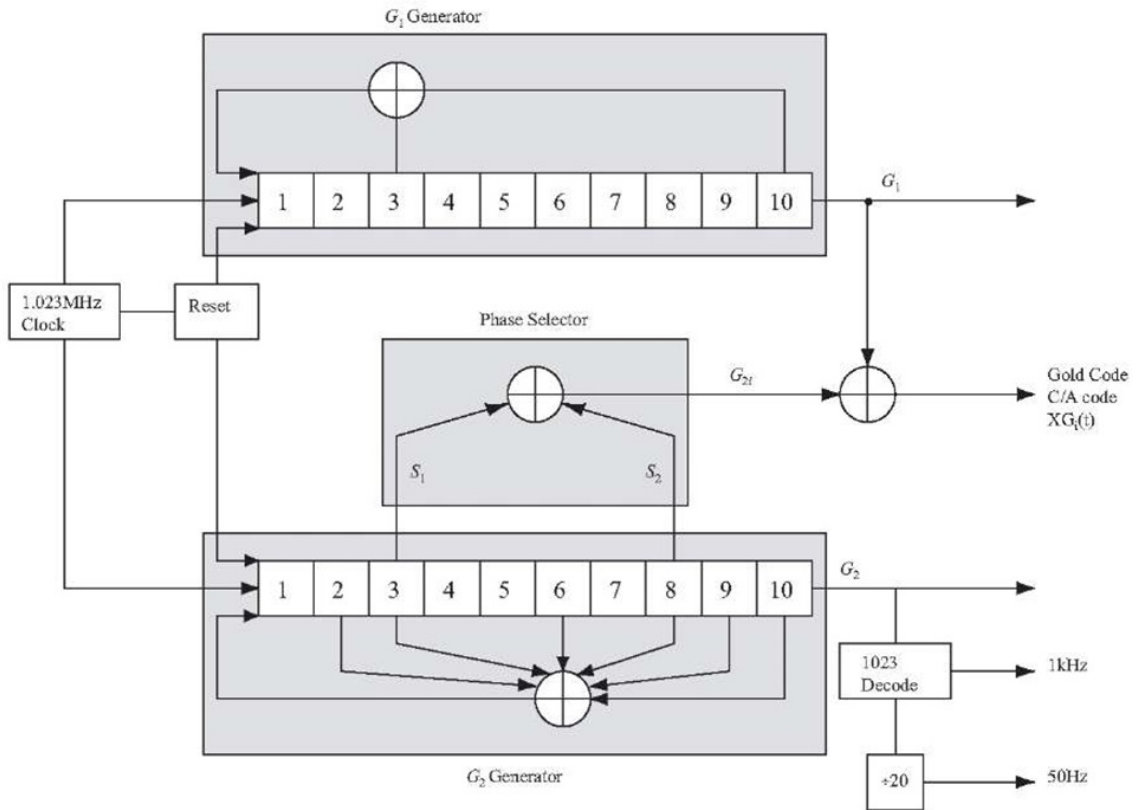
Figure 4.9: C/A code generation

There are 64 Gold sequences available for satellites numbered 1 through 64, only 37 are actually used in the GPS system. Low cross-correlation is a requirement since GPS receiver has the possibility of picking up signals from 12 satellites at the same time.

Each 1023 period, LFSR registers are restored with all 1's, forcing the code to start again. Register G_1 always have a restoring configuration of polynomial form as:

$$f(x) = 1 + x^3 + x^{10} \tag{4.9}$$

which means that states number 3 and 10 are feed back in the input. In a similar

way, G_2 register has the polynomial form:

$$f(x) = 1 + x + x^3 + x^6 + x^8 + x^9 + x^{10} \tag{4.10}$$

In order to make different satellite C/A codes, the output from both registers are combined in a special way. Register G_1 always provides its output, while register G_2 provides two of its states to an adder of module 2 so its output is generated. The state selection to realize the addition in module 2 is known as phase selection. Figure 5.4 developed in Section 5.3 shows the first 10 chips of each code in octal notation.

Since C/A code generation is an important process, Chapter 5 explains in detail the beginning of this operation. In addition, Appendix B includes a Matlab program, whose function is performing these codes.

4.3.2 Doppler frequency shift

GPS technology has to face changes on the Doppler frequency, as it was indicated in previous sections. These changes are caused by the satellite movement (transmitter) with respect to the GPS receptor.

Modifications has an effect not just on the acquisition process but also on the GPS signal monitoring. The maximum frequency shift value in L1 frequency band is around 5 kHz when it comes to a stationary receptor. On the other side, if the receiver is moving at a high speed, it i reasonable to estimate as maximum value 10 kHz.

The Doppler frequency shift over C/A code is caused by the its low chip rate. C/A code has a chip rate of 1,023 MHz, which is 1540 (1575.42/1,023) times lower

than L1 carrier frequency. From here, it can be established that *Doppler frequency over C/A code has a value of 3.2 Hz for static GPS receptors and a value of 6.4 Hz for a high-speed moving GPS receptors.*

Misalignment between the received codes and the ones locally generated can be caused by these Doppler frequency shifts over C/A codes. Doppler frequency values are importantly considered for the monitoring process.

4.3.3 Direct Sequence Spread Spectrum Reception

Until today, only spread spectrum systems have been used for commercial satellite systems. The spreading codes used in Direct Sequence Spread Spectrum (DSSS or DS-SS) systems should have good autocorrelation properties and low cross-correlation. Various codes have been developed specifically for this purposes, such as Gold and Kasami codes.

In this discussion, all DS-SS codes will be treated as pseudonoise (PN) sequences. Pseudonoise refers to the code spectrum, that seems to be a random sequence of bits (or chips) with a flat, noiselike spectrum. Most DS-SS systems generate spread spectrum signals using BPSK modulated versions of the data stream, as it will be shown in the Subsection 4.3.4.

Bits recovery from the original data stream inside the DS-SS signal is obtained once the received signal is multiplied by the same PN code which was used to generate it. The process is illustrated in Figure 4.10. Each DSSS receiver has a correlator responsible of storing such code.
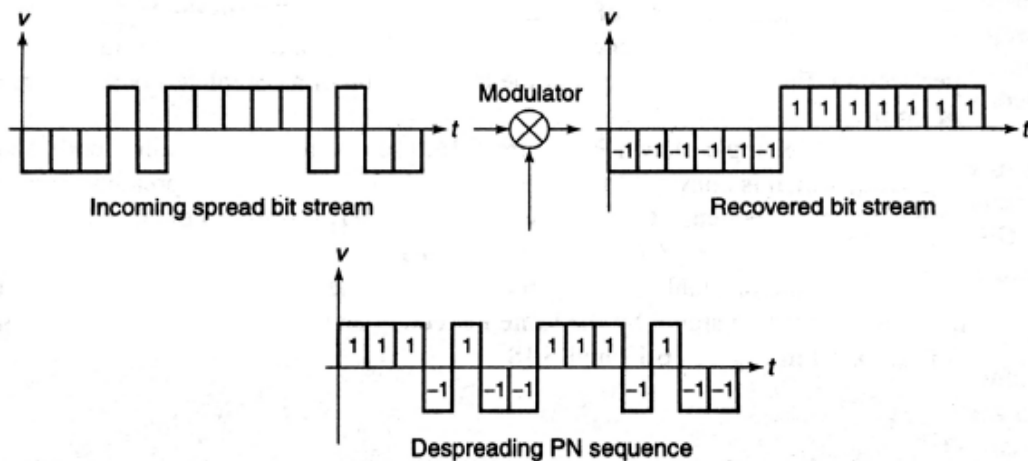
Figure 4.10: DS-SS signal correlator

The incoming signal at the left side of the figure is multiplied by the despreading code sequence in order to obtain the output at the right of the figure. In practice, a low pass filter is used instead of an integrator. In such way, it is possible to avoid the necessary synchronization of integrator content discharge (dumping) when a bit is detected. If the correct code is present in the input signal, the output of the multiplier is +1 or -1 depending on the present chip at that moment in the multiplier.

In Figure 4.11 the analog version of the previous figure is represented. The waveform on the top corresponds to the received DS-SS signal. The second one represents the PN sequence needed to obtain the original navigation data. Which can be observed in the waveform on the bottom. To get this data, it has been implemented before the corresponding BPSK process over the resultant signal. Resultant waveform is made of the addition between the carrier and data waveforms. Third and last waveforms respectively.
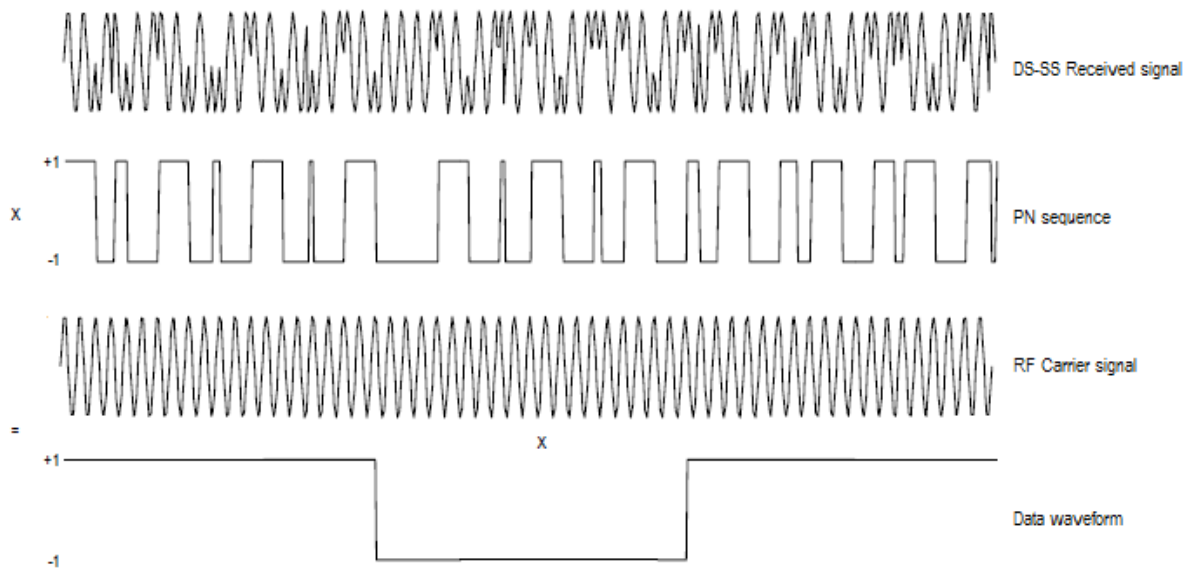
Figure 4.11: DS-SS Demodulation

4.3.4 Binary Phase Shift Keying

Practical DSSS systems use Binary Phase Shift Keying (BPSK) waveforms. Once the received signal has been despread, is time to implement BPSK demodulation. It has to be taken into account that the incoming signal and PN sequence are both BPSK waveforms with 0 degrees or 180 degrees phase shifts. Multiplication of two identical, co-phased BPSK waveforms yields an output of +1. If the phase of the input waveform is reserved (indicating that the original data bit was a 0 rather than a 1) the output is -1.

In Figure 4.12 the previously explained process is illustrated.
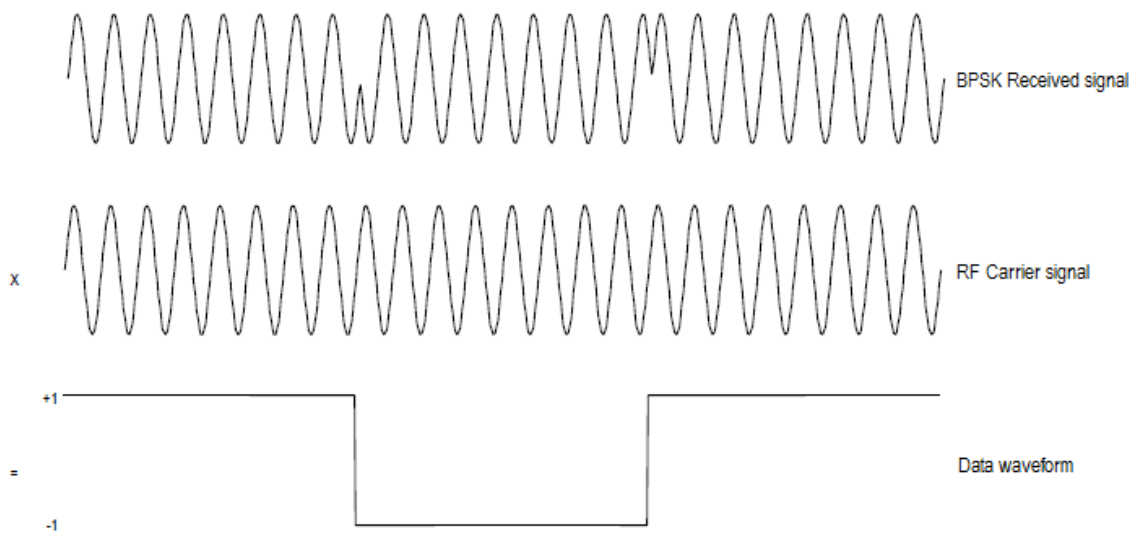
Figure 4.12: BPSK Demodulation

4.4 Distance Estimation and Positioning

The basic requirement of a satellite navigation system like GPS is that there must be four satellites transmitting suitably coded signals from known positions. Three satellites are required to provide the three distance measurements, and the fourth to remove receiver clock error. Figure 4.13 shows the general arrangement of position location with GPS. The three satellites provide distance information when GPS receiver makes three measurements of range, R_i, from the receiver to three known points. Each distance Ri can be thought of as the radius of a sphere with a GPS satellite at its center. The receiver lies at the intersection of three such spheres, with a satellite at the center of each sphere. Locally, at the receiver, the spheres will appear to be planes since the radio of the spheres are very large. A basic principle of geometry is that the intersection of three planes completely defines a point. Thus three satellites, through measurement of their distances to the receiver, define the

receiver location close to the earth's surface. There is another point in outer space where the three spheres intersect, but it is easily eliminated in the calculation process [22].
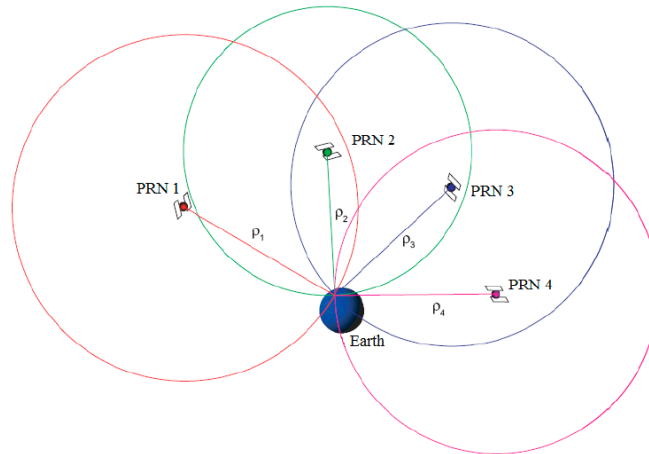
Figure 4.13: Basic GPS Positioning principle

Although the principles by which GPS locates a receiver are very simple, requiring only the accurate measurement of three ranges to three satellites is quite complex.

In order to prevent time standards in GPS control stations around the world, each GPS satellite carries four atomic clocks. The result is GPS time, a time standard that is available in every GPS satellite. Clearly, before making accurate position measurements, it is necessary to remove the time error from the receiver clock. C/A code receivers can synchronize their internal clocks to GPS time within 170 ns, corresponding to a distance measurement uncertainty of 50 m. To improve the position location error repeated measurements and integration are implemented.

One of the strength of GPS technology is its surprising ability of removing the clock error. All that is needed is a time measurement from a fourth satellite. Three time measurements are necessary to define the location of the receiver in the three

unknown coordinates x, y and z. Then, it is added a fourth time measurement so it is possible to solve the basic position location equations for a fourth unknown, the receiver clock offset error τ. Therefore, the four unknowns in the calculation of the location of the receiver are x, y, z and τ.

4.4.1 Position Location in GPS

First, the coordinates of GPS receiver and GPS satellites are defined in a rectangular coordinate system with its origin at the center of the earth. This is called the earth centered earth fixed (ECEF) coordinate system, and is part of the WGS-84 description of the earth. WGS-84 is an internationally agreed description of the earth's shape and parameters, derived from observations in many countries. WGS-84 parameters are used by GPS satellites to calculate their orbits with the accuracy required for precise measurement of the range to the satellites.
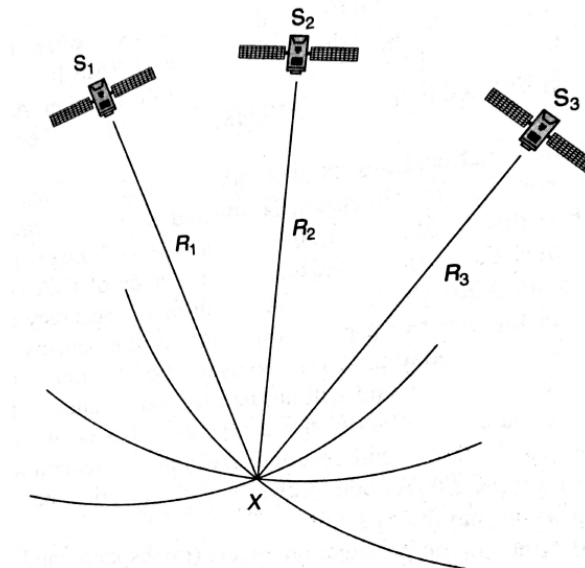
Figure 4.14: Position location

The receiver coordinates are (U_x, U_y, U_z), and the four satellites have coordinates

(X_i, Y_i, Z_i), where $i = 1, 2, 3, 4$. There may be more than four satellites signals available, but only four signals are used in a position calculation. The measured distance to each satellite is called pseudorange, PR_i. It uses the internal clock of the receiver to make a timing measurement which includes errors caused by receiver clock offset. The geometry of a GPS measurement is illustrated in Figure 4.14.

Pseudorange, denoted as PR_i, is measured from the propagation time delay T_i between the satellite (number i) and GPS receiver, assuming that EM waves travel with velocity c.

$$PR_i = T_i \times c \tag{4.11}$$

The distance R between two points A and B in a rectangular coordinate system is given by

$$R^2 = (x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2 \tag{4.12}$$

The equations which relate pseudorange to time delay are called ranging equations:

$$
\begin{aligned}
(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2 &= (PR_1 - \tau c)^2 \\
(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2 &= (PR_2 - \tau c)^2 \\
(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2 &= (PR_3 - \tau c)^2 \\
(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2 &= (PR_4 - \tau c)^2
\end{aligned}
\tag{4.13}
$$

where τ is receiver clock error (offset, or bias).

At the same instant the satellite sends the timing signal (which is actually the start of a long sequence of bits), its position is obtained from ephemeris data transmitted along with the timing signals. Each satellite sends out a data stream that includes ephemeris data for itself and the adjacent satellites. The receiver

calculates the satellite coordinates relative to the earth's center, (X_i, Y_i, Z_i). Then, using standard numerical techniques for the solution of nonlinear simultaneous equations, it solves the four ranging equations for the four unknowns.

The four unknown are the location of GPS receiver, (U_x, U_y, U_z), relative to the earth's center and the clock offset τ -known as clock bias in GPS terminology. The receiver position is then referenced to the earth's surface, and can be displayed in latitude, longitude and elevation. One these three parameters are obtained it is time to use applications such as Google Maps for getting the receiver locations. The typical accuracy for a low-cost GPS receiver using GPS C/A code is defined on 30m.

5 TOOL DEVELOPMENT

This chapter covers the work that was carried out in order to configure the available USRP, as well as detecting GPS signals with it. The whole process up to treated GPS signals is addressed in an organized order with the goal of providing better understanding of the decisions and actions taken at each stage. The chapter is divided in the same section as the LabVIEW main VI is. For each section, a figure will be provided so it can see how it was developed. In the end, the whole process will be illustrated.

5.1 Satellite signal acquisition

It represents the process through which the GPS signal arrives to the receiver and this one has to deal with all the information the GPS signal containes. In this section the signal acquisition is described using LabVIEW software. The first approach to do so was designing the well-known producer/consumer structure whose function is explained below.

5.1.1 Producer/Consumer

The Producer/Consumer design pattern is based on the Master/Slave pattern, and is geared towards enhanced data sharing between multiple loops running

at different rates.   As with the standard Master/Slave design pattern, the Producer/Consumer pattern is used to decouple processes that produce and consume data at different rates. The Producer/Consumer pattern's parallel loops are broken down into two categories; those that produce data, and those that consume the data produced. Data queues are used to communicate data between loops in the Producer/Consumer design pattern.   These queues offer the advantage of data buffering between producer and consumer loops.

The Producer/Consumer pattern approach to any application would be to queue the data in the producer loop, and have the actual processing done in the consumer loop. This in effect will allow the consumer loop to process the data at its own pace, while allowing the producer loop to queue additional data at the same time.

This design pattern can also be used effectively when analyzing network communication as it is the case described in this document. This type of application would require two processes to operate at the same time and at different speeds. The first process would constantly poll the network line and retrieve data.   The second process would take these data retrieved by the first process and analyze it. The first process will act as the producer because it is supplying data to the second process which will act as the consumer.   This application would benefit from the use of the Producer/Consumer design pattern. The parallel producer and consumer loops will handle the retrieval and analysis of data off the network, and the queued communication between the two will allow buffering of the network data retrieved. This buffering will become very important when network communication gets busy. With buffering, data can be retrieved and communicated faster than it can be analyzed.

- *Why use Producer/Consumer?*

  The Producer/Consumer pattern gives you the ability to easily handle multiple processes at the same time while iterating at individual rates. What makes this pattern unique is its added benefit of buffered communication between application processes. When there are multiple processes running at different speeds, buffered communication between processes is extremely effective [23].

In Figure 5.1 shown below, it can be observed how this structure was implemented. In this case, the input of the producer loop is the GPS received signal. This signal is queued into the producer's queue and from it the consumer is taking parts of its at its own rate. In such way, it will take only information when it can process it and then it will send this processed information as output of the consumer loop. In the figures below, just one branch from the 24 satellite systems will be shown which will be the same for rest. However, just representing one of them improves the resolution of the figure.
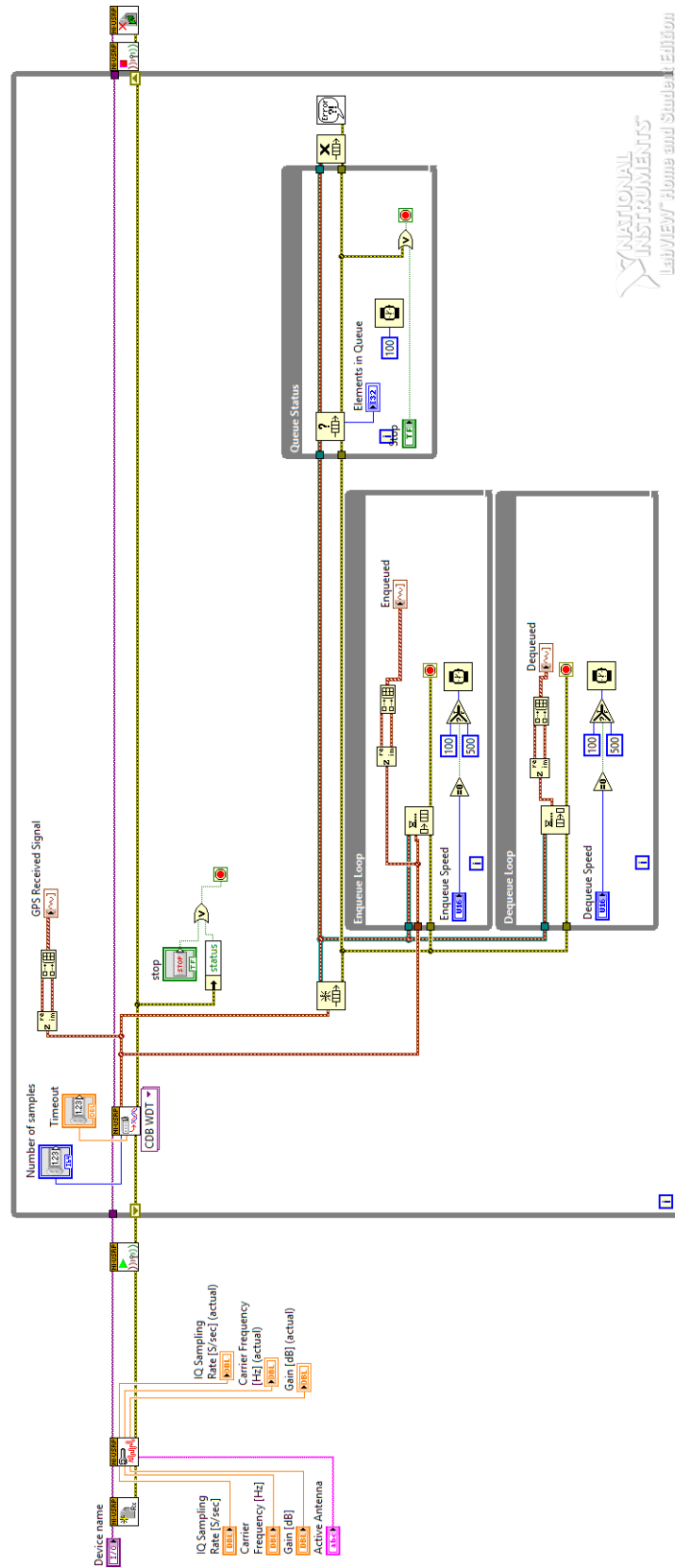
Figure 5.1: Producer/Consumer structure

5.1.2 Final design for the data acquisiton

However, after the implementation of such structure it was observed that the delay between both signals was significant. That is why it was decided to implement a new different solution. This solution is shown in Figure 5.2 and it has a simpler architecture which makes the data acquisition more reliable.

The obvious difference between both architectures can be seen in their corresponding figures. It has to be taken into account that it was just represented one of the 24 branches (one for each satellite). Therefore, if an error is produced in the second implementation is much more easily to detect where it occured.

When dealing with signals it is important to have a good monitoring over them. The minimal delay produced may cause an error in the acquisition process. With the second solution, it was possible to get the same signal in the 24 different branches.
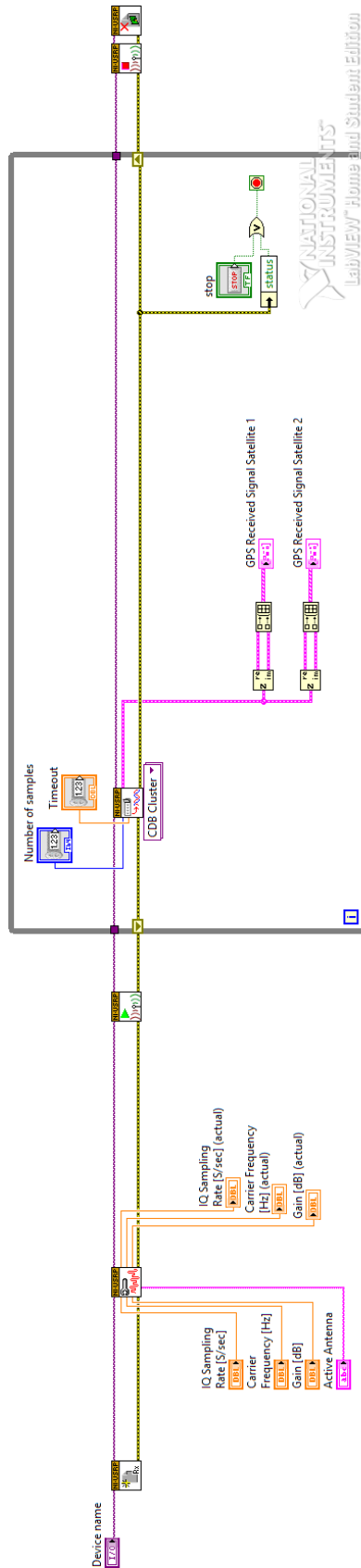
Figure 5.2: Signal acquisition

5.2 Demodulation and Decodification

The demodulation and decoding process is explained in this section. It was divided in two different operations which was carried out one after the other. Each of these operations are illustrated in Subsections 5.2.1 and 5.2.3. It is true that in the previous step the DS-SS process was explained before the BPSk demodulation, however, during the implementation it was found out that the inverse process has a better performance using LabVIEW. For that reason, in this section the BPSK process is described before than the DS-SS one.

5.2.1 BPSK signal demodulation

BPSK received signal demodulation process is described in this subsection. It was implemented in the Figure 5.3 below. In this figure, it can be distinguished two different parts. The first one, on the left side, corresponds to the transformation of the received signal. This conversion was needed to perform since there is a difference on the data type for each LabVIEW function. The second part, on the right side, is the DS-SS process itself. For making it, the C/A code sequence is computed using a LabVIEW complement, known as Matlab Script. In which the Matlab code is introduced and once the program is executed the code is computed. The final output of this small program is the decodified data message. From which the necessary information to obtain the user's position is extracted.

This operation was developed in the 24 branches. using the architecture represented in the figure below. The specific values introduced in order to reproduce the operation will be specified in Section 6.
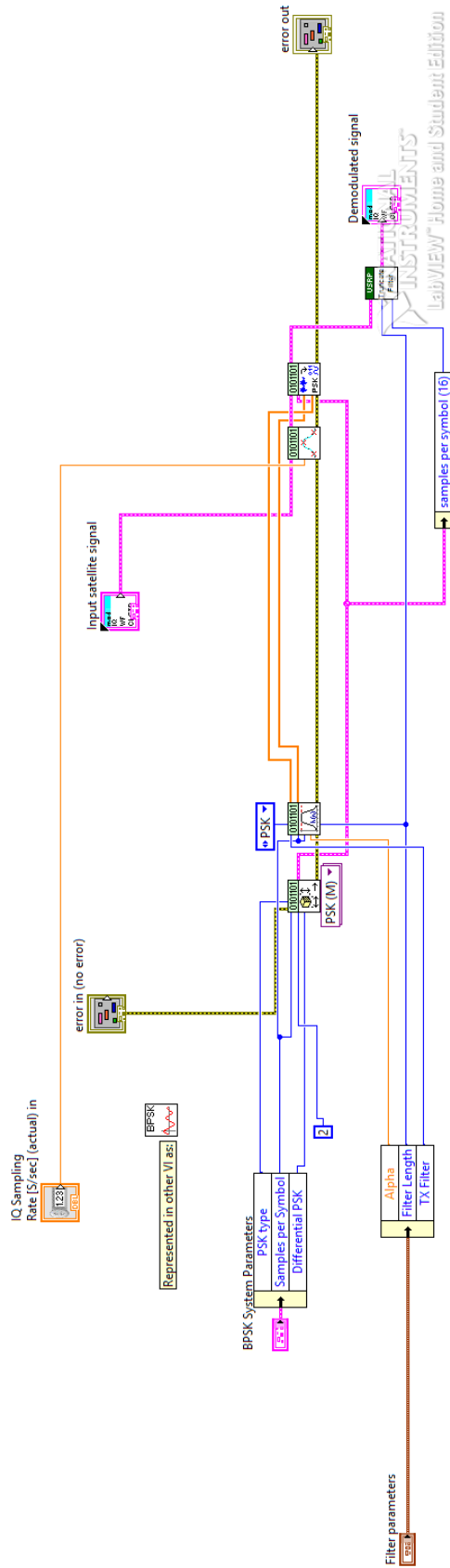
Figure 5.3: BPSK signal demodulaiton

5.2.2 C/A Code generation

In this subsection it is shown how the different C/A codes sequences were generated. As it was explained previously, they are necessary in order to demodulate the received GPS signals. Depending on the satellite from which the signals are coming from, a different bit sequence will be generated.

In order to perform this operation a Matlab code was implemented. This code reproduced the whole mechanism, which is represented on Figure 4.9. in this scheme it can be observed the two different LFSR registers, called generators G_1 and G_2, as well as the phase selector and the clock.

For a LFSR register, the input from cell number one is determined by the state of the remaining cells. Lets consider the binary sum of cells 3 and 10 in a 10 cells register is established as the input. If cells 3 and 10 have different states (one of them is 1 and the other one is 0), a 1 will be read in cell number one in the next clock pulse. If cells 3 and 10 have the same state, a 0 will be read in cell number 1. If in the beginning all cells have a 1 , after 12 clock pulses the register content will be the following sequence: 0010001110. The next clock pulse will take the 1 from cell number 3 and the o in cell number 10 and their addition will be shown in cell number 1. Meanwhile, the remaining bits are shifted one cell to the right, and the 0 in cell number 10 will be the next output bit. This process corresponds to the first register G_1, whose polynomial representation is given by: $f(x) = 1 + x^3 + x^{10}$.

Generator G_2 as a similar operation but in this case its polynomial representation is given by: $f(x) = 1 + x^2 + x^3 + x^6 + x^8 + x^9 + x^{10}$. Another important differrence between these two generators resides on their output. In the first one, as it was previously explained, the output correspondss to the content of cell 10. However, in

the second generator, the output is formed by an additional factor. This factor is

chosen depending on the satellite, this is illustrated in the Figure 5.4 below.

Satellite ID Number	GPS PRN Signal Number	Code Phase Selection	Code Delay Chips	First 10 Chips C/A Octal
1	1	2 ⊕ 6	5	1440
2	2	3 ⊕ 7	6	1620
3	3	4 ⊕ 8	7	1710
4	4	5 ⊕ 9	8	1744
5	5	1 ⊕ 9	17	1133
6	6	2 ⊕ 10	18	1455
7	7	1 ⊕ 8	139	1131
8	8	2 ⊕ 9	140	1454
9	9	3 ⊕ 10	141	1626
10	10	2 ⊕ 3	251	1504
11	11	3 ⊕ 4	252	1642
12	12	5 ⊕ 6	254	1750
13	13	6 ⊕ 7	255	1764
14	14	7 ⊕ 8	256	1772
15	15	8 ⊕ 9	257	1775
16	16	9 ⊕ 10	258	1776
17	17	1 ⊕ 4	469	1156
18	18	2 ⊕ 5	470	1467
19	19	3 ⊕ 6	471	1633
20	20	4 ⊕ 7	472	1715
21	21	5 ⊕ 8	473	1746
22	22	6 ⊕ 9	474	1763
23	23	1 ⊕ 3	509	1063
24	24	4 ⊕ 6	512	1706
25	25	5 ⊕ 7	513	1743
26	26	6 ⊕ 8	514	1761
27	27	7 ⊕ 9	515	1770
28	28	8 ⊕ 10	516	1774
29	29	1 ⊕ 6	859	1127
30	30	2 ⊕ 7	860	1453
31	31	3 ⊕ 8	861	1625
32	32	4 ⊕ 9	862	1712
**	33	5 ⊕ 10	863	1745
**	34*	4 ⊕ 10	950	1713
**	35	1 ⊕ 7	947	1134
**	36	2 ⊕ 8	948	1456
**	37*	4 ⊕ 10	950	1713

*34 and 37 have the same C/A code.
**GPS satellites do not transmit these codes; they are reserved for other uses.

Figure 5.4: C/A code phase assignation

Therefore, the first 32 codes from the table were computed. These codes were used in the process of demodulation and decoding of the GPS signals. Process that is explained and illustrated in the following subsection.

The P code generation follows the same principle than C/A code, except that in this ocassion four LFSr registers are used. Two registers are combined in order to produce X_1 code, whose length is equal to 15,345,000 chips and it is repeated every 1.5 seconds. the other two registers are combined to produce X_2 code, whose length is 15,345,037 chips. Codes X_1 and X_2 can be mixed with 37 difeerent delays over X_2 code so 37 different P code segments code are produced. These segments have a duration of one week and the first 32 sequences are associated to each satellite.

The devoped code to compute them is included in Appendix B.

With a special function from LabVIEW, the Matlab code incorporation inside of the design was implemented. This tool is known as Matlab Script and it can be seen in the figure below.

5.2.3 DS-SS signal reception

It was implemented the DS-SS signal reception using LabVIEW. As it can be observed in Figure 5.5 below, the input of these VI is the processed GPS signals coming from the BPSK process. Jointly the previous calculated C/A code sequencues the output is computed. In the figure below the process for satellite one is represent. Depending on the satllite number a different number would be introduced into the Matlab script.
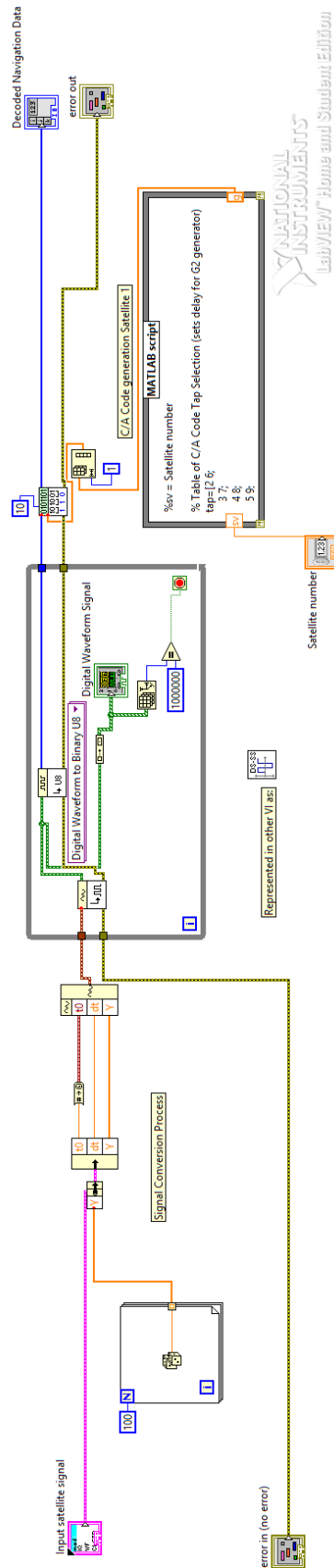
Figure 5.5: DS-SS signal reception

5.3   Data acquisition

Once the signal was demodulated and decodificated, it is possible to realise the data message acquisition. In this section, it will be defined the contents of each subframe as well as the process that was followed to obtain the necessary data from the message.

It is needed to remark that it is not enough the decoding of just one signal. The distance estimation requires four different data segments in which the information is contained. The principal data necessary to compute distance estimation is contained in subframes number one, two and three. Thus, a detailed description of these subframes is given so in the next step it will be possible to compute the distance estimation with respect to each satellite. However, for subframes number four and five, a brief description of their content is given.

5.3.1   Navigation data from Subframe 1

The data contained in the first there subframes are shown in Figures 5.6, 5.9 and 5.10. The minimal parameters used to calculate the user position are contained in these three subframes.
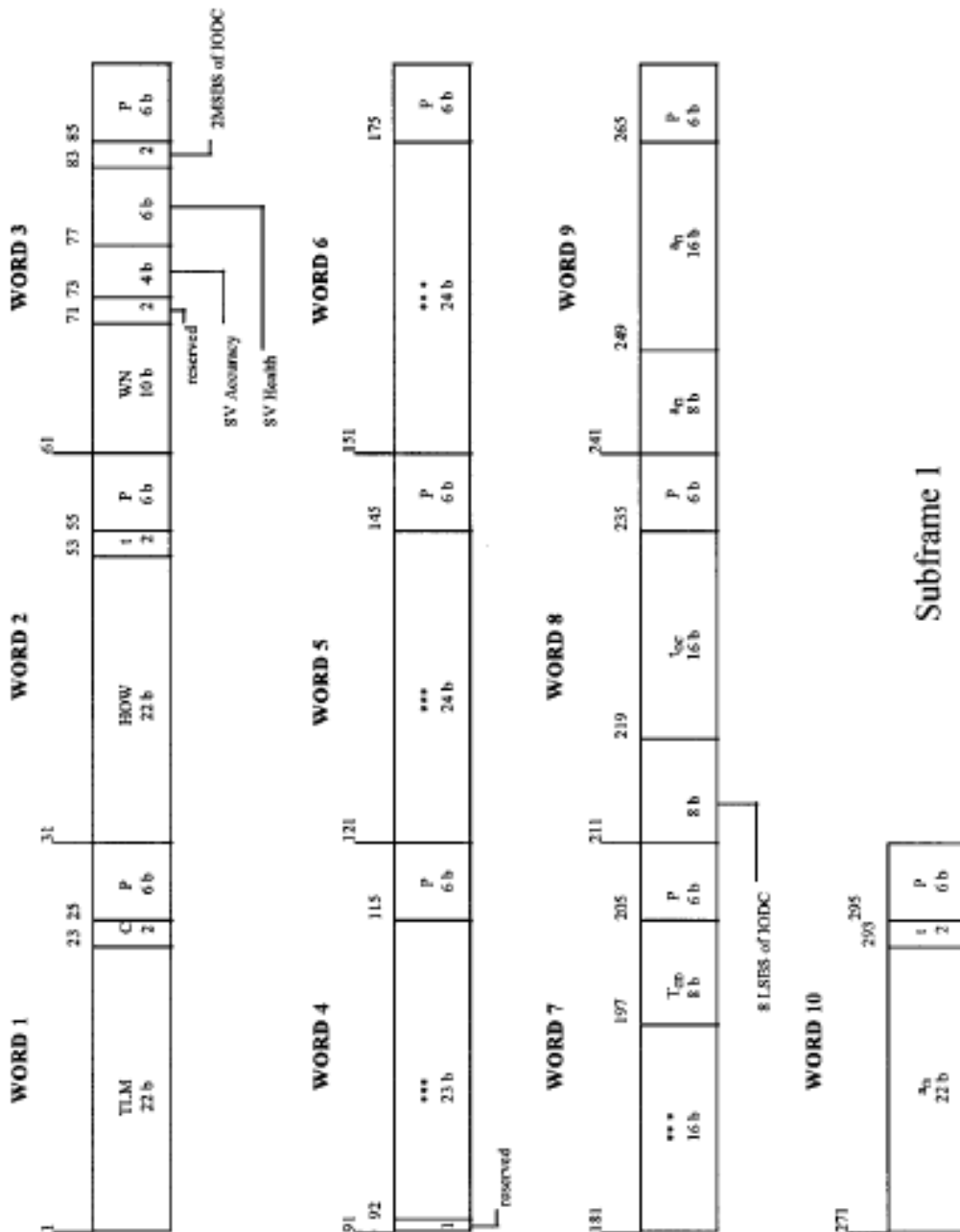
Figure 5.6: Data in Subframe 1

The data used for calculations of satellites and user locations are discussed below.

- *Week number (61-70).* This sequence represents the MSB of the Z counts and indictes the number of weeks from midnight on the night of January 5,

1980/morning of January 6, 1980. Users must count the rollover if it is over 1,023 weeks.

- *User range accuracy (73-73).* These four bits give the predicted user range accuracy, whose value N ranges from 0-15. The accuracy value X is:

  - If N is 6 or less, $X = 2^{(1+N/2)}$ (rounded-of-values $N = 1, X = 2.8; N = 3, X = 5.7; N = 5, X = 11.3$

  - If N is 6 or more, but less than 15, $X = 2^{(N-2)}$.

  - $N = 15$ will indicate the absence of an accuracy prediction and will advise the user to use that satellite at the user's risk.

- *Satellite health (77-82).* These six bits indicate the transmitting satellite health. The MSB (bit 77) represents a summary of the navigation data health.Its value reflects the following information:

  - If it is $= 0$. All navigation data are OK.

  - If it is $= 1$. Some or all navigation data are bad.

The five LSBs indicate the health of the signal components despicted in Figure 5.7. Additional satellite health data are given in subframes 4 and 5. There is maybe a difference on the data given in subrame 1 with respect the one shown in subframe 4 and 5 of other satellites. This fact is produceed since subframes 4 and 5 are updated at a differente time.

MSB	LSB
0 0 0 0 0	$\Rightarrow$ All signals OK.
1 1 1 0 0	$\Rightarrow$ Satellite *is* temporarily out—do not use this satellite during current pass.
1 1 1 0 1	$\Rightarrow$ Satellite *will be* temporarily out–use with caution.
1 1 1 1 0	$\Rightarrow$ Spare
1 1 1 1 1	$\Rightarrow$ More than one combination would be required to describe anomalies.
All other combinations	$\Rightarrow$ Satellite experiencing code modulation and/or signal level transmission problem—modulation navigation data valid; however, user may experience intermittent tracking problems if satellite is acquired.

Figure 5.7: Satellite Health Codes

- *Issue of data, clock (IODC) (83-84 MSB, 211-218 LSB).* These 10-bit IODC sequence indicate the data set issue number. Thereby it provides the user with a convenient detection of any change in the correction parameters. The transmitted IODC will be different from any value transmitted by the satellite during the preceding seven days.

- *Estimated group delay differential TGD (197-204).* This eight-bit information is a clock correction term to face the effect of satellite group delay differential.

- *Satellite clock correction parameters.* This subframe also contains the four additional satellite clock correction parameters: t_{oc}(219-234), a_{fo} (271-292), a_{f1} (249-264), and a_{f2} (241-248).

- In subframe 1 there are some reserved data fields and their locations are 71-72; 91-114; 121-144; 151-174; 181-196. All reserved data fields support valid parity within their respective words.

The ephemeris parameters in subframe 1 are listed in Figure 5.8.

Parameter	Location	Number of Bits	Scale Factor (LSB)	Effective Range**	Units
WN: Week number	61-70	10	1		week
Satellite accuracy	73–76	4			
Satellite health	77–82	6	1		
IODC: Issue of data, clock	83–84	10			
	211–218				
T_{GD}: Satellite group delay differential	197–204	8*	2^{-31}		seconds
t_{oe}: Satellite clock correction	219–234	16	2^4	604,784	seconds
a_{f2}: Satellite clock correction	241–248	8*	2^{-55}		sec/sec^2
a_{f1}: Satellite clock correction	249–264	16*	2^{-43}		sec/sec
a_{f0}: Satellite clock correction	271–292	22*	2^{-31}		seconds

*Parameters so indicated are two's complement, with the sign bit (+ or −) occupying the MSB.
**Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

Figure 5.8: Ephemeris Parameters in Subframe 1

5.3.2 Navigation data from Subframes 2 and 3

Figures 5.9 and 5.10 show the corresponding content of subframes 2 and 3.
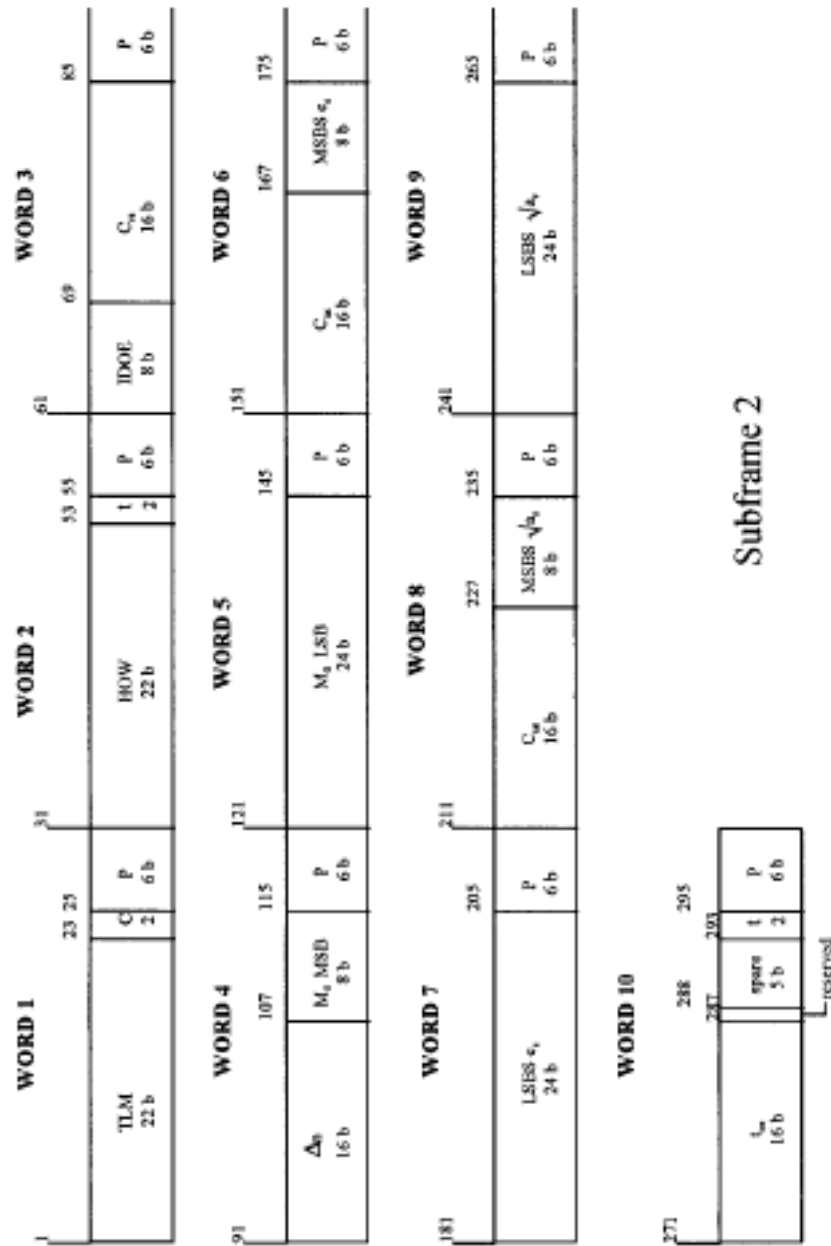
Figure 5.9: Data in Subframe 2
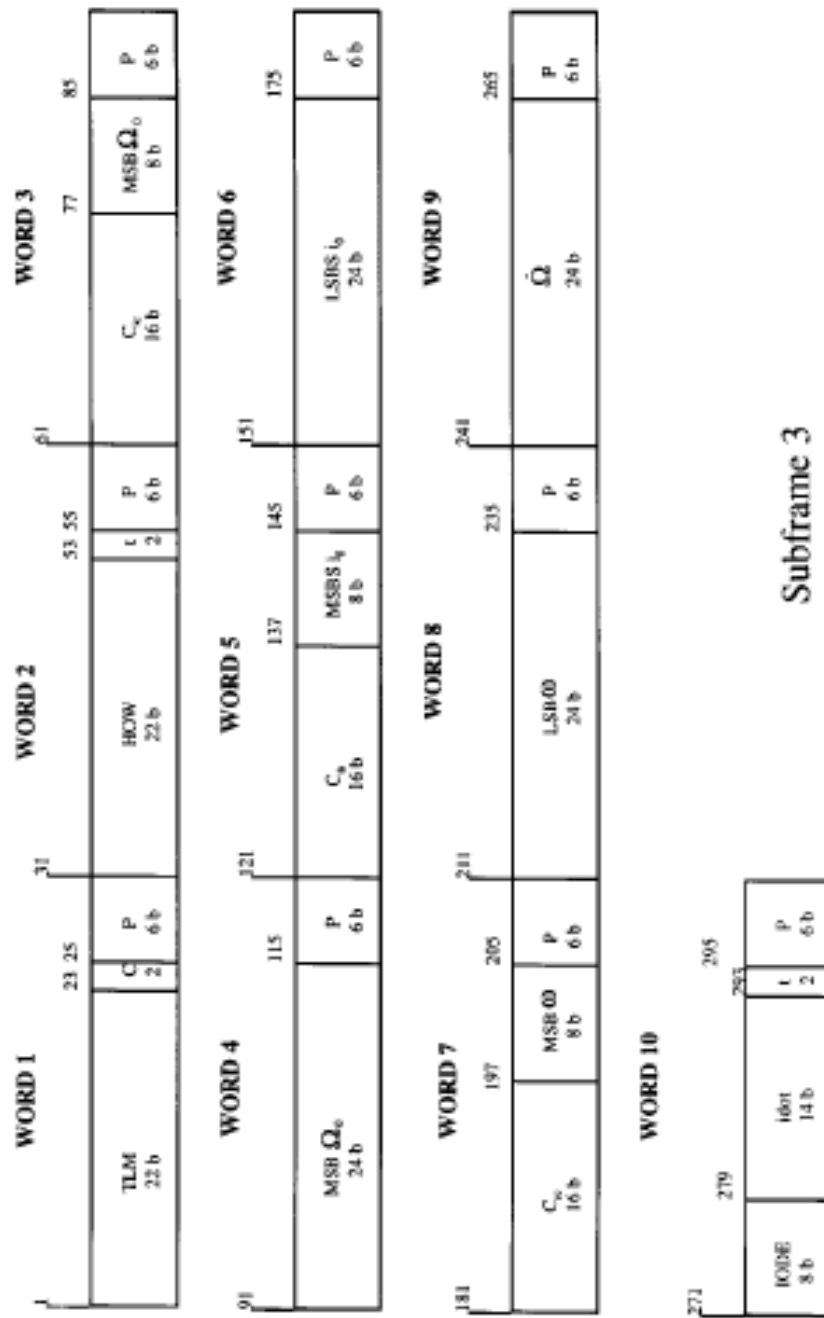
Figure 5.10: Data in Subframe 3

Figures 5.11 and 5.12 represent the ephemeris data contained in subframes 2 and 3:

- *The issue of data, ephemeris (IODE).* This parameter has 8 bits and it is found in both subframes 2 (61-68) and 3 (271-278). It equals the 8 LSB of the IODC, whose length is 10 bits. The IODE helps the user on the detection process if a change in the ephemeris representation parameters was produced. The transmitted IODE will be different from any value transmitted by the satellite during the preceding six hours. Whenever these three terms, two IODEs from subframes 2, 3 and the 8 LSBs of the IODC, do not match, a data set cutover has occurred and new data must be collected. A change in both IODE words supposes there was a change in subframe 2 and 3 data. Cutovers in new data will occur only on hour boundaries, except for the first data set of a new upload. At any time during the hour, the first data set may be cut in. Therefore, the satellite may transmit it for less than one hour. Additionally, the t_{oe} value for at least the first data set transmitted by a satellite after an upload, will be different from that prior transmitted value to the cutover.

- *The rest of the ephemeris data.* This information is reflected in Figures 5.11 and 5.12.

- *Spare and reserved data fields.* In subframe 2 bit 287 is reserved and bits 288-292 are spared. All spare and reserved data fields support valid parity within their respective words. Contents of spare data fields are alternating ones and zeros until they are allocated for a new function. Users are warned about the possibility of changes in spare data fields [24].

Parameter	Location	Number of Bits	Scale Factor (LSB)	Effective Range	Units
IODE	61–68	8			(see text)
C_{rs}: Amplitude of the sine harmonic correction terms to the orbit radius	69–84	16	2^{-5}		meters
Δn: Mean motion difference from computed value	91–106	16*	2^{-43}		semicircles/ sec
M_0: Mean anomaly at reference time	107–114; 121–144	32*	2^{-31}		semicircle
C_{uc}: Amplitude of the cosine harmonic correction term to the argument of latitude of argument of latitude	151–166	16*	2^{-29}		radians
e_s: Eccentricity	167–174; 181–204	32	2^{-33}	0.03	dimensionless
C_{us}: Amplitude of the sine harmonic correction term to the argument of latitude	211–226	16*	2^{-29}		radians
$\sqrt{a_s}$: Square root of the semimajor axis	227–234; 241–264	32	2^{-19}		meters$^{1/2}$
t_{oe}: Reference time ephemeris	277–286	16	2^4	604,784	seconds

Figure 5.11: Ephemeris Parameters in Subframe 2

Parameter	Location	Number of Bits	Scale Factor (LSB)	Effective Range	Units
C_{ic}: Amplitude of the cosine harmonic correction term to angle of inclination	61–76	16*	2^{-29}		radians
Ω_e: Longitude of ascending node of orbit plane at weekly epoch	77–84; 91–114	32*	2^{-31}		semicircles
C_{is}: Amplitude of the sine harmonic correction term to angle of inclination	121–136	16*	2^{-29}		radians
i_0: Inclination angle at reference time	137–144; 151–174	32*	2^{-31}		semicircles
C_{rc}: Amplitude of the sine harmonic correction term to the orbit radius	181–196	16*	2^{-5}		meters
ω: Argument of perigee	197–204; 211–234	32*	2^{31}		semicircles
$\dot{\Omega}$: Rate of right ascension	241–264	24*	2^{-43}		semicircles/ sec
IDOE	271–278				(see text)
idot: Rate of inclination angle	279–292	14*	2^{-43}		semicircles/ sec

Figure 5.12: Ephemeris Parameters in Subframe 3

5.3.3 Navigation data from Subframes 4 and 5

Both subframes 4 and 5 are subcommutated 25 times each. The 25 versions of these subframes are named as pages 1 to 25 of each superframe. With the possible exception of "spare" pages and explicit repeats, each page contains the information in words 3 through 10, whose extension is from bits 91-300. Subframe 4 has six different formats, however only five of them are shown in Figure 5.14. The pages are divided in the following described way depending on its format. Five pages (1,6,11,16, 21) are in one format. Six pages (12, 19, 20, 22, 23, 24) are in other format. Page 18 is in another format as it is the case of page 25 which is in a different one. Finally four pages (13, 14, 15, and 17) are in the remaining format. There are a total of 17 pages. Pages 2, 3, 4, 5, 6, 7, 8, 9, and 10 are not shown

because they have the same format as page 1 through 24 of subframe 5. Subframe 5 has two different formats as shown in Figure 5.14.
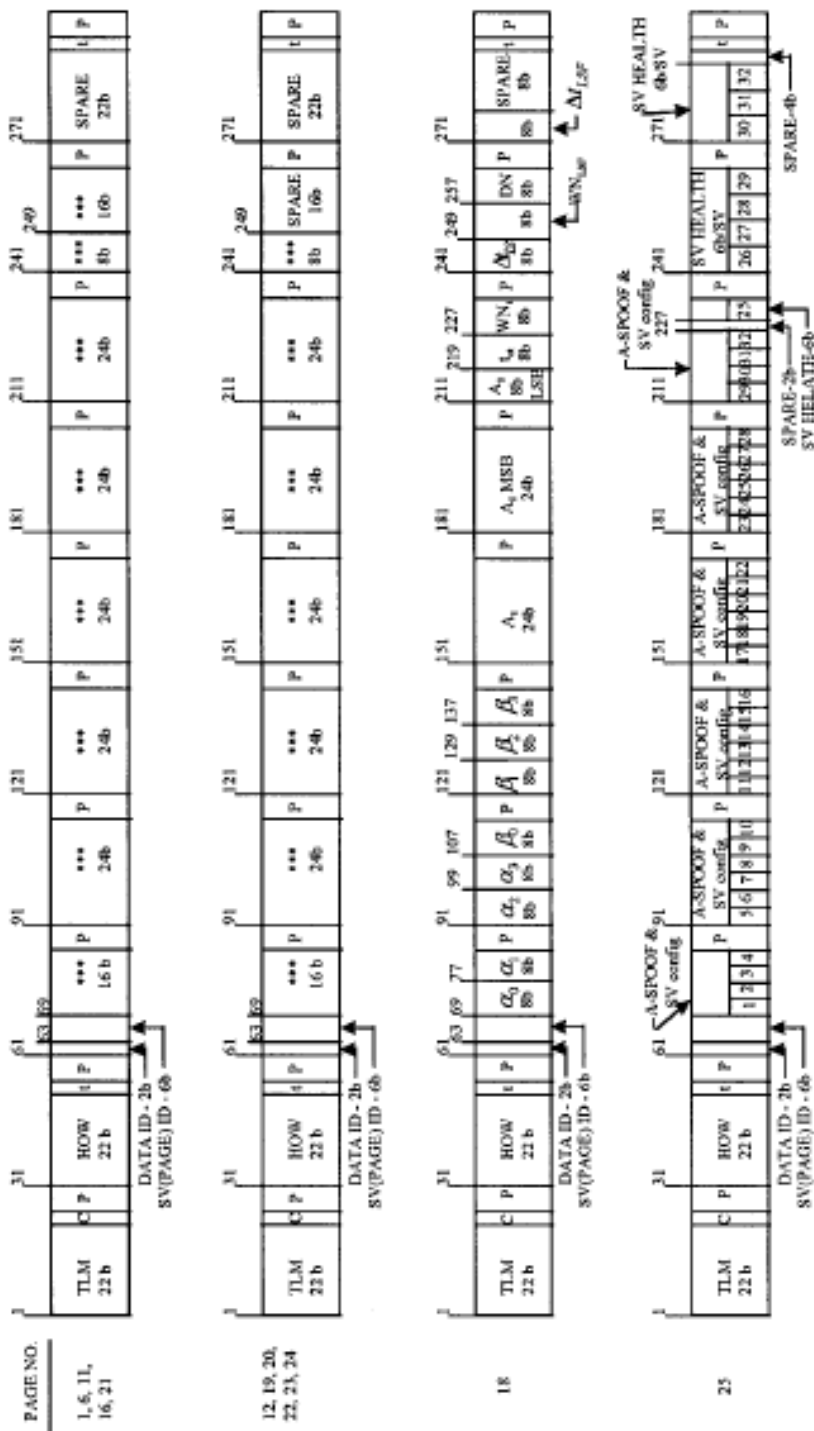
Figure 5.13: Data format for Subframes 4 and 5
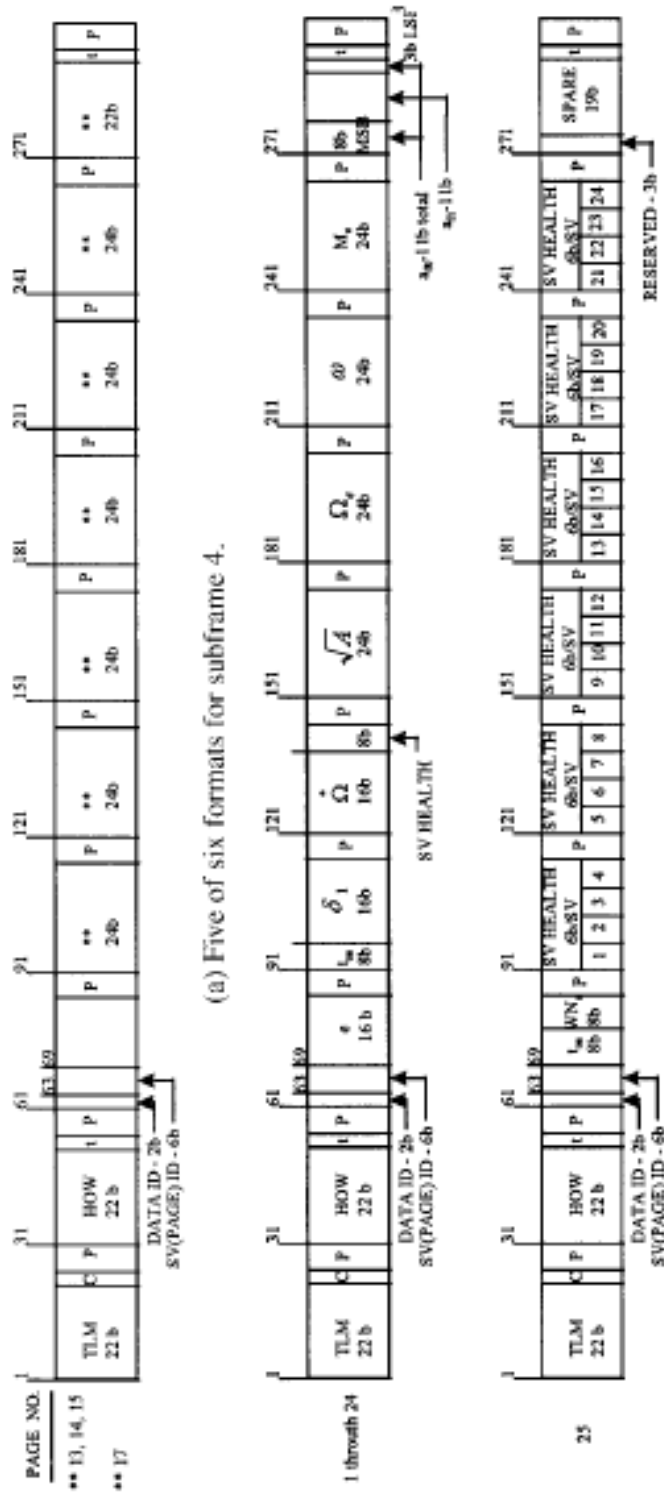
Figure 5.14: Five of six formats for Subframe 4. Two formats for Subframe 5

The information in subframes 4 and 5 and its applications are listed below:

- *Subframe 4:*

    - Pages 2, 3, 4, 5, 7, 8, 9 and 10 contain the almanac data for satellite 25 through 32. These pages may be designated for other functions. The satellite ID of that page defines the format and content.

    - Page 17 contains special messages.

    - Page 18 contains ionospheric and universal coordinated time (UTC).

    - Page 25 contains antispoof flag, satellite configuration for 32 satellites and satellite health for satellites 25–32.

    - Pages 1, 6, 11, 12, 16, 19, 20, 21, 22, 23 and 24 are reserved.

    - Pages 13, 14, and 15 are spares.

- *Subframe 5:*

    - Pages 1–24 contain almanac data for satellites 1 through 24.

    - Page 25 contains satellite health for satellites 1 through 24, the almanac reference time and the almanac reference week number.

- *Almanac data.* The almanac parameters provided in subframes 4 and 5 are: $e_s, t_{oa}, \Omega, \sqrt{a_s}, \Omega_e, \omega, M_0, a_{f0}, and a_{f1}$. The almanac data are much less accurate than the detailed ephemeris data of subframes 2 and 3. However, the almanac data are valid for longer time periods and do not require frequency updates.

- *Translation of GPS time to UTC time.* In page 18 of subframe 4 the parameters in Figure 5.15 are included.

Parameter[**]	Number of Bits	Scale Factor	Effective Range[***]	Units
A_0	32[*]	2^{-30}		seconds
A_1	24[*]	2^{-50}		sec/sec
Δt_{LS}	8	1		seconds
t_{ot}	8	2^{12}	602,112	seconds
WN_r	8	1		weeks
WN_{LSF}	8	1		weeks
DN	8[****]	1	7	days
Δt_{LSF}	8[*]	1		seconds

[*]Parameters so indicated are two's complement, with the sign bit (+ or −) occupying the MSB.
[**]See Figure 5.9a for bit allocation in subframe 4.
[***]Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.
[****]Right justified.

Figure 5.15: UTC Parameters

- *Ionospheric data.* In page 18 subframe 4, there are eight ionospheric data: α_0 (69–76), α_1 (77–84), α_2 (91–98), α_3 (99–106), β_0 (107–114), β_1 (121–128), β_2 (129–136), β_3 (137–144). These data can be used to correct the time received from the satellite for ionospheric effect.

5.4 Positioning

In this section the necessary computations in order to obtain the pseudo distances are developed. Therefore, after data segments in which position information is contained, were extracted from the whole demodulated navigation message it is time to calculate the rough distances.

For these computations, ranging equations are needed:

$$(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2 = (PR_1 - \tau c)^2$$

$$(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2 = (PR_2 - \tau c)^2$$

$$(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2 = (PR_3 - \tau c)^2 \tag{5.1}$$

$$(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2 = (PR_4 - \tau c)^2$$

They were implemented in a small Matlab program, whose final results correspond to the application output, that is: latitude, altitude and longitude measurements. The fragment of code designed for computing this operation is inlcuded in Appendix B. Its inputs are composed by the three pseudo distances, the receiver clock error τ and the three coordinates of each satellite.

5.5 Whole VI of the project

This may be the section in which the whole process developed is reflected. Figure 5.16 represents just a part form the whole image. To achieve a suitable resolution in the figure, it was decided that just two branches out of the 24 existing ones are shown. Each of the branches that can be observed in the figure, performs the same action. The only difference between them is the C/A code sequence. As it was explained in previos chapters, each satellite has an associated C/A code therefore, this same scheme was followed in this implementation.

The input of this application is the received GPS signal while the output is formed by:

- Latitude, longitude and altitude coordinates for each of the four different resulting satellites.

- The corresponding pseudo distances of each satellite with respect to the user's position on the Earth.

This data is introduced in previously mentioned Matlab code whose outputs are the user's receptor coordinates. Finally in order to know the exact user location, latitude and longitude measurements should be introduced in a geographic

application to know the exactly position of the user, as it is the case of the well-

known application Google Maps.
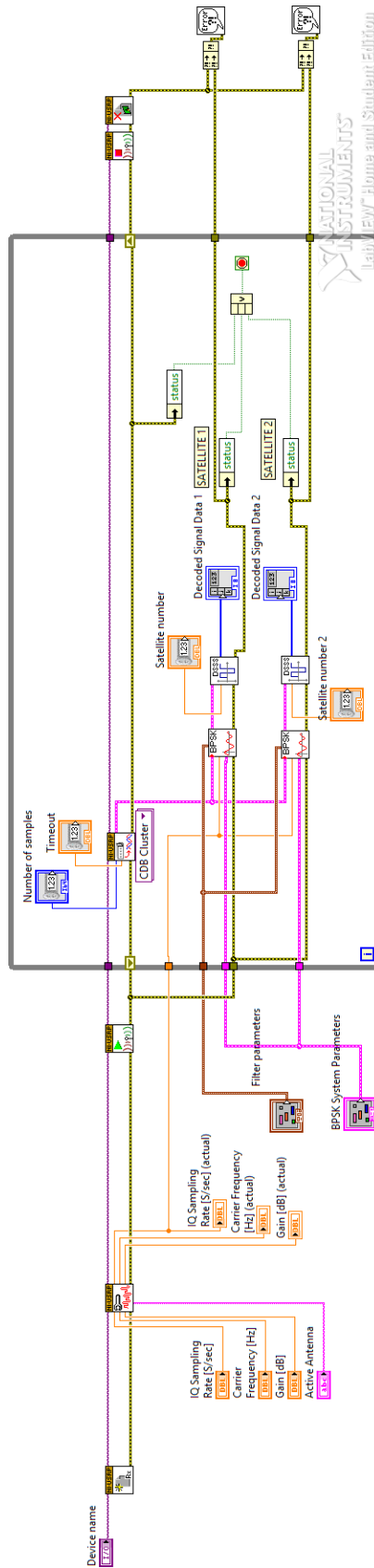
Figure 5.16: Whole application

6 TESTING AND RESULTS

This chapter will show how the proof of concept application was tested and present the results that were obtained during the analysis.

6.1 Testing

In order to realize some tests over the application it was needed to divide the whole process in small parts. These divisions are specified below and they are an approximation of the sections from Chapter 5. In this section the necessary tests of the application are describing, however, their corresponding results are analyzed in Section 6.2.

6.1.1 USRP Configuration

The first step implemented was testing the USRP configuration. In order to do so, the data contained in the following table were introduced on the LabVIEW program. To show the results, two different test were made, in the first one wrong data was introduced while in the second one the data inrtoduced was correct.

Device name	192.168.10.2
Carrier frequency	1,575.42 MHz
IQ rate (S/sec)	500k
Gain	12,00 dβ

Table 6.1: NI-USRP Configuration

6.1.2 Testing satellite signal acquisition

In order to perform the satellite signal acquisition, it was designed a system formed by 24 structures each of them corresponds to each of the 24 satellites. As it was explained in the previous section, two different solutions were defined in order to achieve this operation. Therefore, to compare them two tests were developed. The first one consists on the GPS signal acquisition using the Producer/Consumer structure. The second step consists on the test implemented over the simpler architecture. In order to get a good vision about the test, in the first case just one branch will be implemented while in the second one, two branches will be reproduced.

The data needed for both tests are given in the following table:

Device name	192.168.10.2
Carrier frequency	1,575.42 MHz
IQ rate (S/sec)	500k
Gain	12 d β
Active Antenna	RX1
Number of samples	1000
Timeout	10

Table 6.2: Satellite signal acquisition. Configuration

6.1.3 Testing DS-SS signal reception

In order to check this part, it was necessary to design a small program in which it is possible to observe how the spreading spectrum technique is done. This program is illustrated in Figure 6.1. From the test it will be taken into account two different measures, the first one corresponds to the Bit Error Rate (BER). This parameters reflects the efficacy of the program. The second one corresponds with the inverse specific inverse DSSS process. It will be possible to check how this technique works and if it does it propertly. The values from the different inputs are given in Table

Messege Bits	1000
Spreading Sequence Length	4
Noise (bit flip probability)	0.030000
PN Sequence Order (Message)	9
User-Base Bit Pattern	101101

Table 6.3: DS-SS Parameters
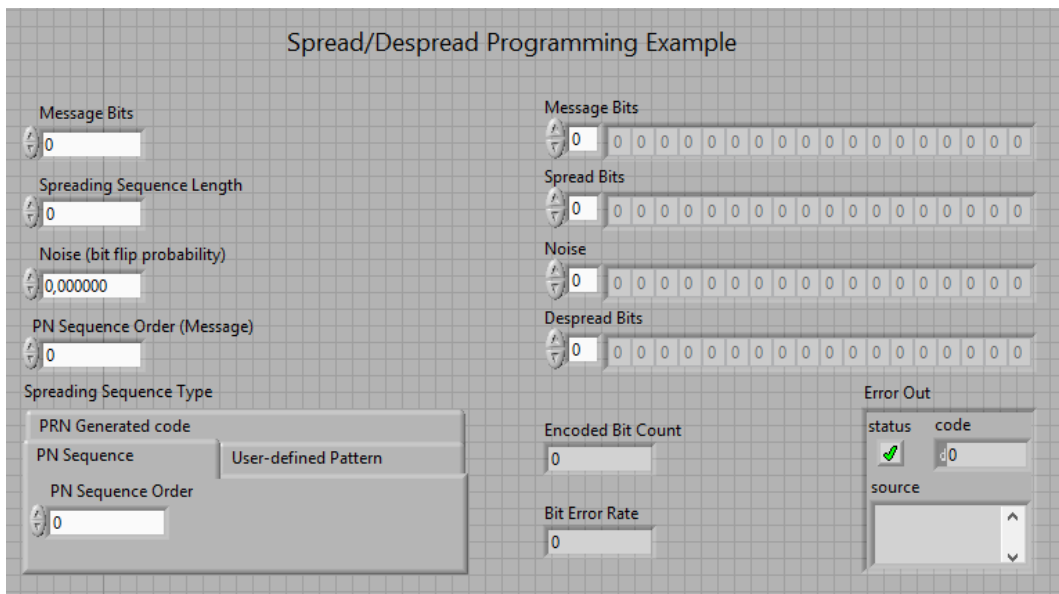
Figure 6.1: Testing DS-SS signal reception

6.1.4 Testing BPSK signal demodulation

As in the previous case, it was needed to design a small program which performs BPSK demodulation but also the modulation process. This situation is depicted in Figures 6.2 and 6.3. With this new application, this part from the whole program will be tested. In order to carrying out these modulation and demodulation process the data contained in Table 6.4, Table 6.5a and Table 6.5b was introduced to the LabVIEW program.

Device name	192.168.10.2
Carrier frequency	1,575.42 MHz
IQ rate (S/sec)	500k
Gain	12 dβ
Active Antenna	TX1/RX1
Enabled Channel	1

Table 6.4: BPSK Configuration

TX Filter	Root Raised Cos
Alpha	0.50
Filter Length	8

(a) Filter Parameters

Choose a PSK Format	BPSK
Samples per Symbol	16
PSK type	normal
Differential PSK	disable

(b) BPSK Parameters
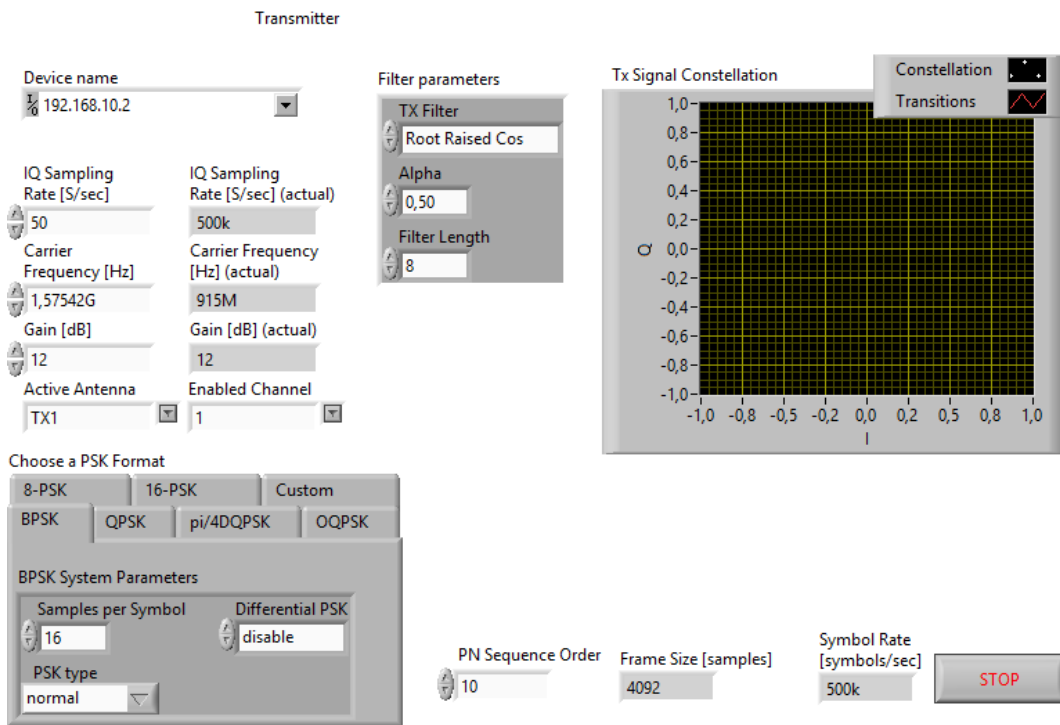
Figure 6.2: BPSK Transmitter. Modulation process
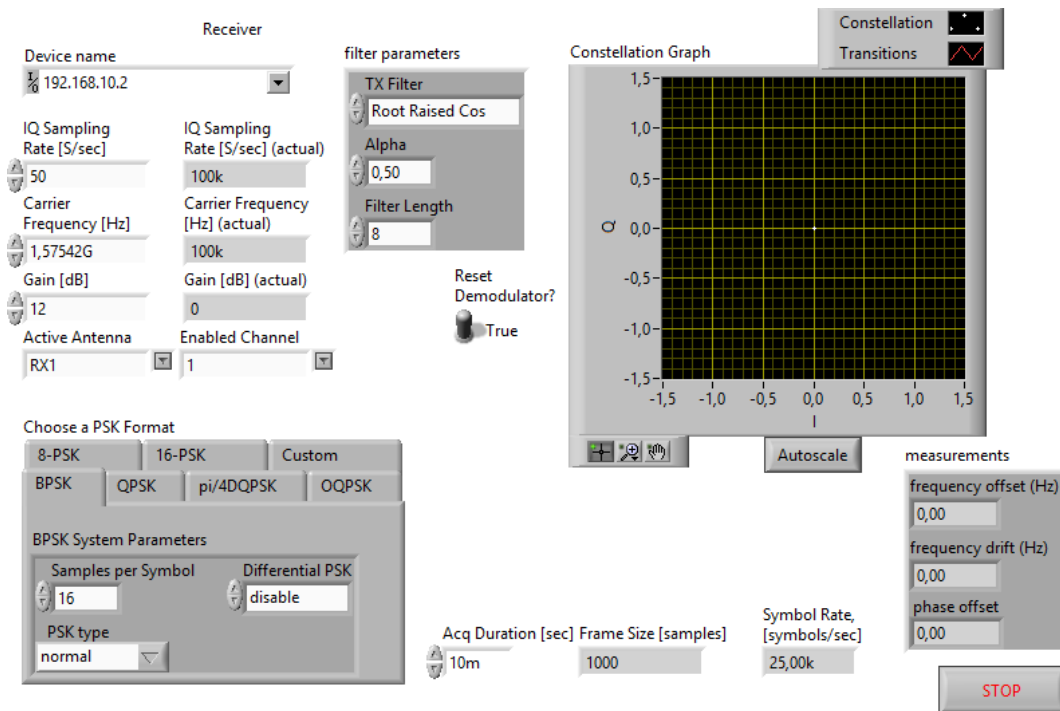
Figure 6.3: BPSK Receiver. Demodulation process

6.1.5 Testing positioning

For testing this part of the application, Ranging's equations were implemented in a Matlab program. The contents of this program are given in Appendix B. Morover, the data shown in Table 6.6 were needed to calculate the user's postion. Their values correspond to the assumed ones obtained from LabVIEW. As it was explained in previos chapters, the inputs of these equations are formed by the sateliite's coordinates, three pseudo distances and the receiver clock error τ. All this data was obtained from the navigation message.

Satellite	NAVSTAR 51	NAVSTAR 68	NAVSTAR 75	NAVSTAR 21
Number	(16)	(27)	(10)	(73)
Latitude	19.18º N	53.82º N	27.14º N	21.14º N
Longitude	2.20º W	2.26º W	27.25º E	15.67º W
Altitude (km)	20,345.29	20,182.47	20,230.84	21,426.56
Pseudo distance (km)	20,481	20,239	20,575	21,573

Table 6.6: Positioning Parameters

The value for τ is fixed to 1 μ s, the corresponding value for the worst possible scenario. This value gives a difference of 300 m in the user's position estimation.

In order to verify the truthfulness of this calculation, a GPS state application was applied. With this application it was checked from which satellites the receiver should get the signals. Its name is *Satellite Check - GPS Status* and its corresponding logotype is shown below.
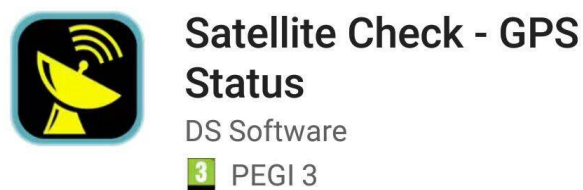
Figure 6.4: Satellite Check - GPS Status Application

In addition to this Android application, a web page called *N2YO.com* was used too. In this web page it was possible to obtain the satellites information so the checking becomes more accurated besides the trajectory of the satellites mentioned in the table. Its url is:

http://www.n2yo.com/whats-up/?c=20

And the corresponding figure is:

Figure 6.5: GPS Satellite Trajectory. (Source: N2YO.com)

It is necessary to remark that with this test just the performance of the programs designed in Matlab will be checked.

6.1.6 Testing the whole application

It has to be indicated that this test could not be implemented. In the beginning of the project it was decided that the GPS implementation will be used with the usual GPS signal. However, as the project moved on, it was discoverd that this solution would be more complicated that it was thought. For that reason, the idea of developing a GPS receptor whose received signal was from another USRP emerged. However, this condition was not so easy to satisfy and in the end it was impossible to test if the whole application works properly.

The development of the first idea is considered as a future work and it is explained in the Subsection 7.2.5.

6.2 Results

In this section, the results for the situations explained in the previous section are analyzed and shown in its corresponding tables.

6.2.1 USRP Configuration

In order to check the USRP configuration was the appropriate one the following test were developed. In Figure 6.6 after introducing wrong parameters we can see how LabVIEW informs about the produced error. However, in the posterior tests the data was correctly introduced in the USRP and the signal was received by the receptor.
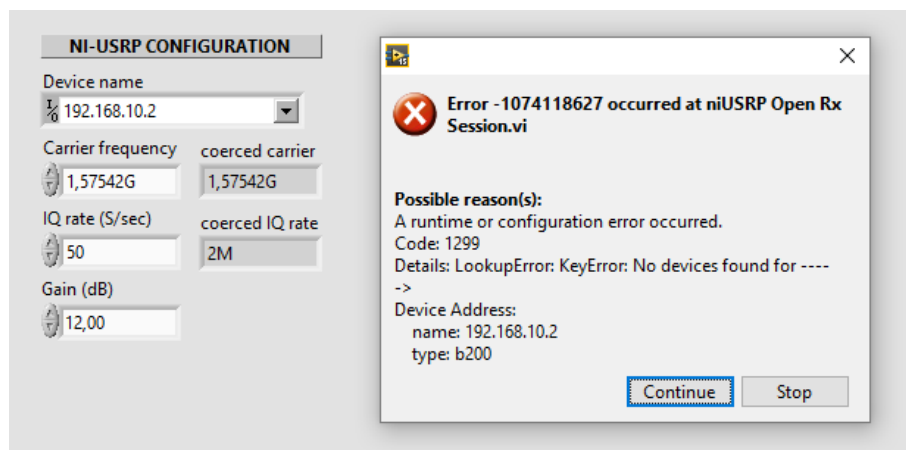
Figure 6.6: Error on USRP Configuration

6.2.2 Satellite signal acquisition

Once the tests were explained in the previous section, in this subsection their results are shown. It has to be taken into account that in the first test just one branch from the whole system will be shown. On the other side, in the second test two branches will be involved. In such way all the figures will have a better

resolution allowing a better observation. However, it is important to remark that the same procedure was followed in the rest of the branches. Figure 6.7 represents the corresponding results to the first test.
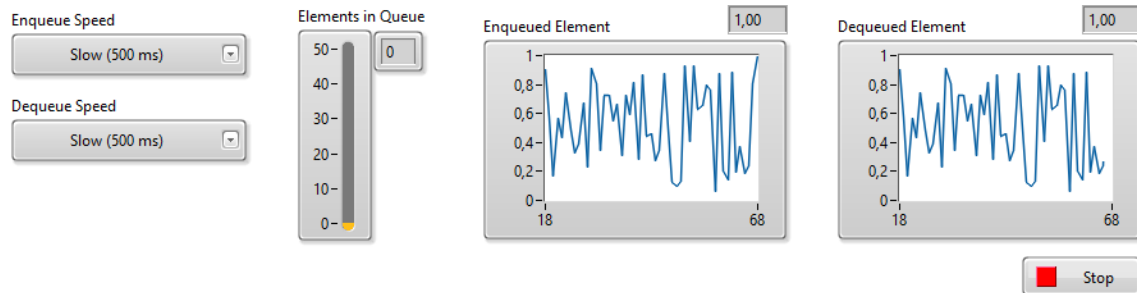
Figure 6.7: Results of signal acquisition by Producer/Consumer structure

As it can be observed in the figure, there is a small delay between the signal coming from the producer loop and the one coming from the consumer loop. Fact that makes a better solution the one implemented next. In Figure 6.8 it can be observed how the signal is properly displayed in two different branches.
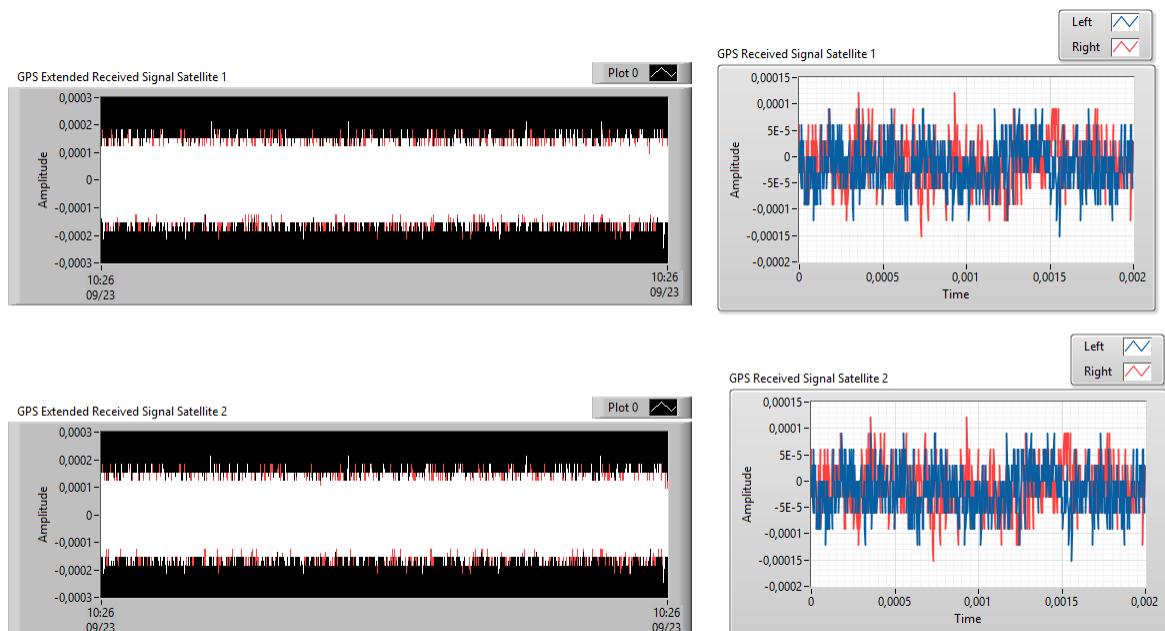
Figure 6.8: Results of signal acquisition. Simpler structure

In this figure there are two different graphs for each of the branches. Even it is indicated on their corresponding title, they were used so a general vision of the signal (graph on the left) was displayed as well as a more detailed version (graph on the right).

6.2.3 DS-SS signal reception

For the first part of the test, several measurements were implemented. Their results are shown in Table 6.7. These values represent the different values for the BER produced in each tests. The BER varies as it can be observed in the following table, depending on the number of bits whose transmission was wrong and the noise introduce to the system.

Messege Bits	Noise	Despreaded Bits	BER
111111101000	0.92	0000000010110	0.917
111111101000	0.00	111111101000	0.000
111111101000	0.52	010101100110	0.500

Table 6.7: BER results

It can be seen that as the Noise value, also named bit flip probability, increases the BER value increases too. Another influential factor is the number of message bits, it was tested that as the number increases the BER value does it too.

This second part of the test is illustrated in Figure 6.9. It can be seen how the original data is combinig with the PRN sequence to produce the spreading sequence and then how it realizes the inverse process to obtain the despreading sequence which should be equal to the initial data.
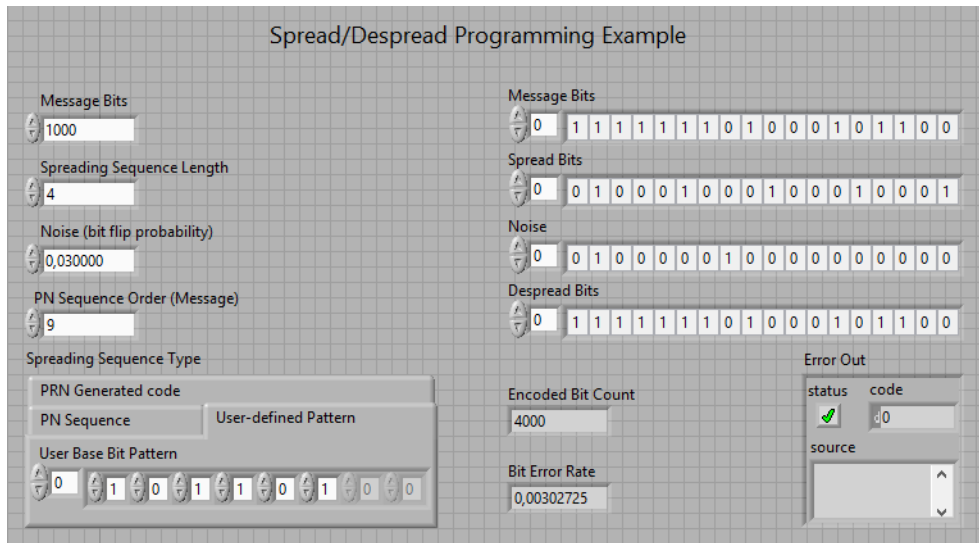
Figure 6.9: Testing DS-SS signal reception

6.2.4 BPSK signal demodulation

In this subsection, results for BPSK testing are described. In Figures 6.10 and 6.11 the test is performed obtaining the expected results. As it was explained in previos section, BPSK is a two symbol technique. Fact that can be observed in the graph, in which both symbols are well differentiated.
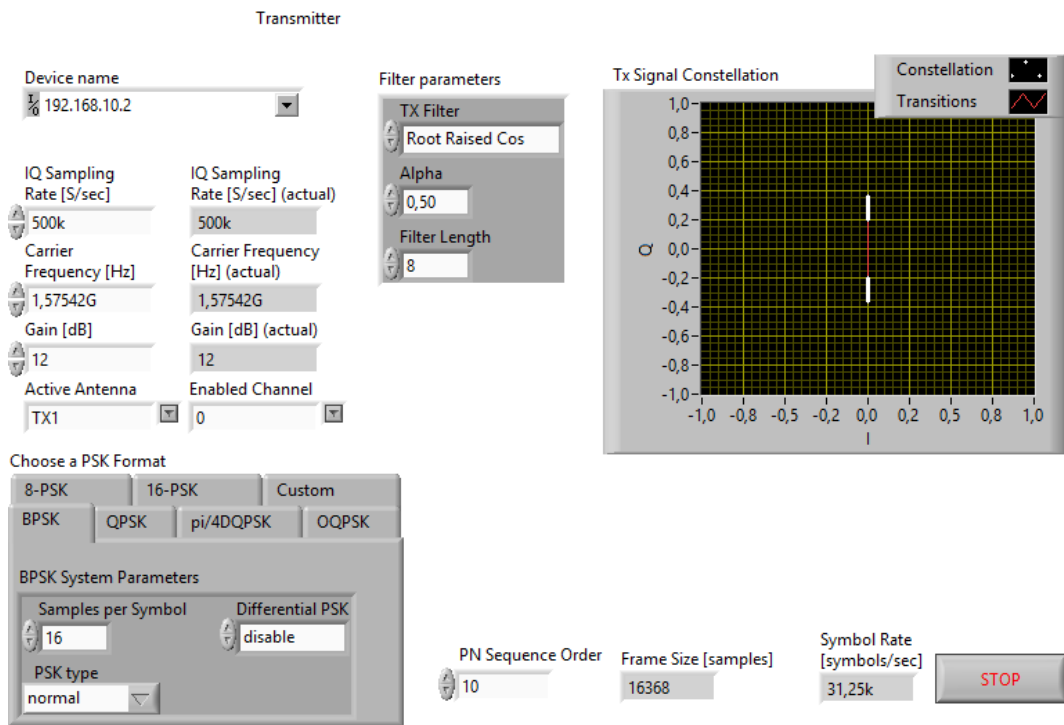
Figure 6.10: BPSK Transmitter Results
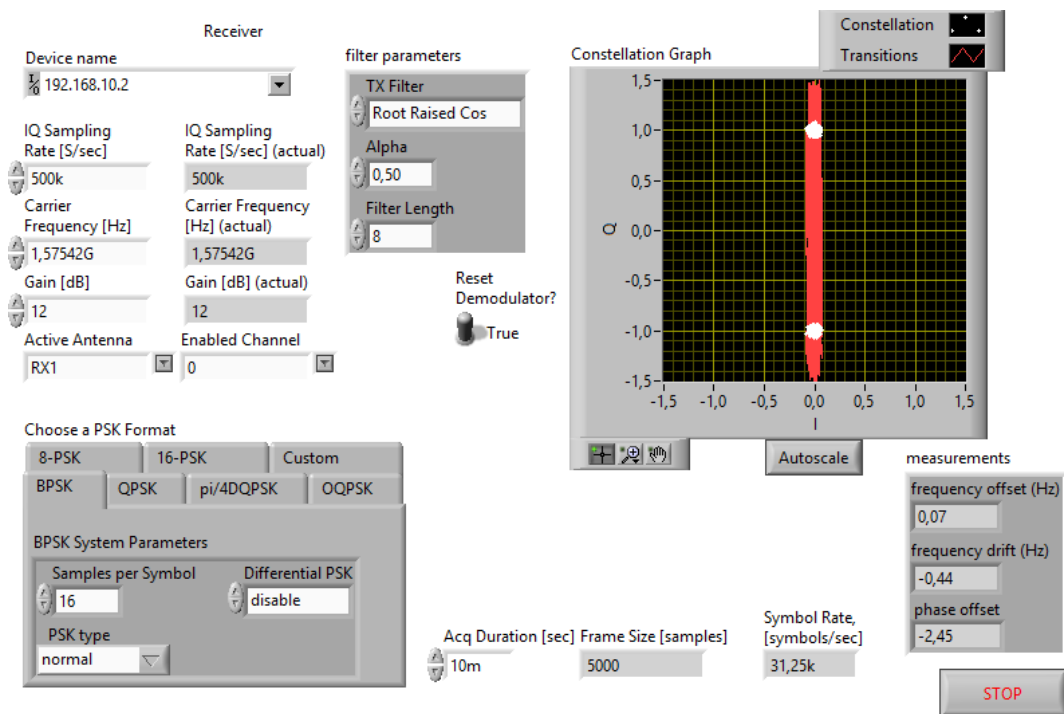
Figure 6.11: BPSK Receiver Results

6.2.5 Positioning

The corresponding result obtained from Satellite Check - GPS Status application is shown in Figure 6.12. In this figure the closest satellites to the actual receptor position are represented. These are: NAVSTAR 51, NAVSTAR 68, NAVSTAR 75 and NAVSTAR 36, whose corresponding number on the figure is 16, 27, 10 and 73 respectively.
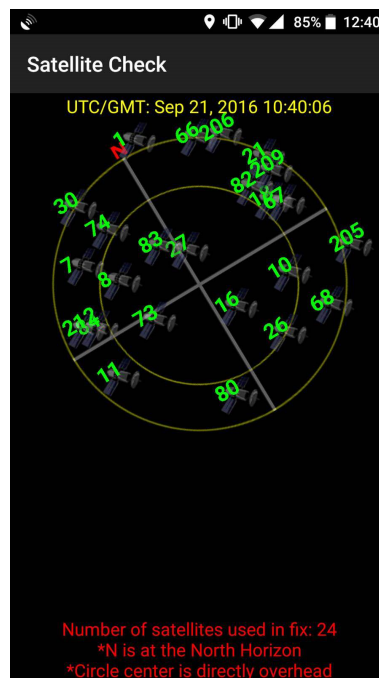
Figure 6.12: Satellite check results

Once all the necessary data was obtained, it was introduced in the Matlab code whose results are given in Table 6.8. As it can be checked the obtained coordinates corresponds to the actual ones.

Latitude	Longitude	Altitude
40.3312º N	3.7619º W	663.7877 m

Table 6.8: User's coordinates

In addition to this data, the intersection between the four spheres was ploted

too. Figure 6.13 represents this visual concept. The four four spheres corresponding to the satellites are represented on the top while the sphere corresponding to the Earth is representing on the bottom. The Matlab code is included in Appendix B.
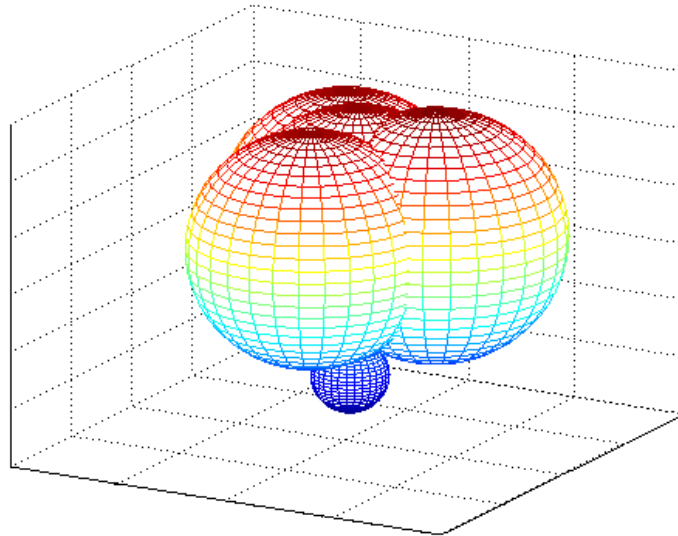
Figure 6.13: Spheres' intersection

To realize the final checking, the three coordinates obtained from the Matlab code are introduced in Google Maps, getting as a location:
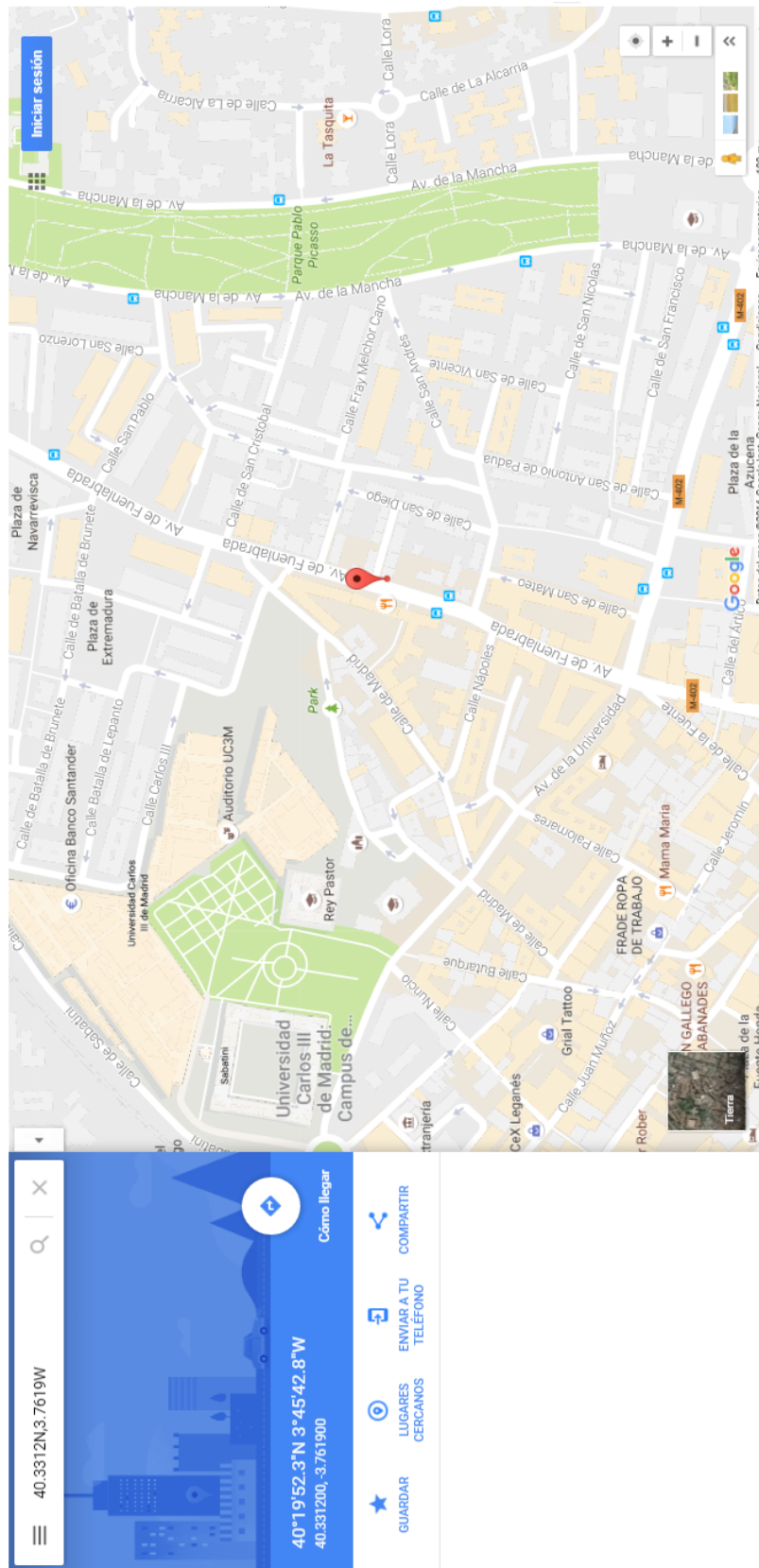
Figure 6.14: Google Maps result. *(Source: Google Maps)*

7 PROBLEMS ENCOUNTERED AND FURTHER DEVELOPMENT

This chapter will comment the most important obstacles that arose while developing the project, as well as their solution or workaround. Finally, a series of future tasks to be developed are suggested.

7.1 Problems encountered

In this section, the problems encountered during the project development are listed.

7.1.1 Signal overloading

This problem was the first that it was needed to face. In the beginning of the project, the main action was centered on the navigation data acquisition. However, when it was tried to obtain all this information there was an overloading. There was too many information to process so our system was not able to perform its operation. For that reason, it was necessary to find a solution to this problem since if it was not possible to control this amount of data it would be really complicated to realize the rest of the project.

After some researching, the producer/consumer structure explained in Section

5.1.1 was estimated as the best solution for it. With the implementation of this
structure it was possible to control de ammount of data avoiding the excess of it in
the system. Moreover, it supposed a good improvement for the whole system since
in that way it was much easier to control the data losses.

7.1.2 C/A and P codes

GPS technology was farily new free developed when the project was started so
there was not as much information as it was expected in the beginning. The idea
of carrying out these 32 C/A codes, at the same time the signals were detected it
may suppose a high amount of data to assimilate. For that reason, some others
options were explored and after trying different processes, it was found the solution
of developing these codes using another program, in this case they were implemented
on Matlab. After the codes were generated with the code shown in Appendix B they
were introduced as bit sequences in LabVIEW.

Furthermore, it was impossible to find P code sequences since as it was explained
in previos sections, these codes are not of public access. It is true that they are not
essential for the development of the project but the decoding made was not as precise
as it was supposed to be.

However, as the project moved foward, more information was made available
and developers shwowed their experiment's results which greatly helped to verify
the outcomes of this project. National Instrument developers also started to release
their personal work so that more people got involved in the technology and could
contribute to the GPS ecosystem.

7.1.3 Signal alignment

In the previous section it was detailed the fact that in the signalling process there is an important alignment on them. This perfect synchronization between the code which is included in the received signal and the one included in each of the PRN sequence, is important in order to obtain a valid solution. However, the idea of making these synchronizacion using LabVIEW was not so easy as it was expected. It has to be taken into account that it is necessary to introduce several clocks of different time periods and be working with them during the whole process. Fact that is complicate since there is more than one action to perform.

Fortunately, during some testing it was seen that if this synchronization is not present in the whole process it is possible to obtain a final solutionn. This solution is not as precise as it would be with this characteristic introduced but it was enough to achieve some of the project objectives.

7.2 Further development

This section will addres further development to be done if this work is continued in the future. This project gives a basis (both theorical and practical) for those interested in using or developing a complete application that takes advantage of GPS to provide context awareness. Therefore the most critical points to focus in the future are described in the next subsections.

7.2.1 Incorporation of a Positioning Application

Once the whole process was developed it was time of computing the GPS receiver position. In order to do it, it was necessary the introduction of this data in an

application capable of assimilate this kind of information. In particular, Google
Maps was used so after determining the values for the three needed coordinates,
altitude, latitude and longitude, they were transfered to this application and the
corresponding location was obtained.

LabVIEW has good properties among them, it counts with the possibility of
performing this idea. This innovation will make the project more attractive and
complete.

7.2.2 Control on signal alignment

As it was detailed in the previous section from the chapter, the introduction of
this factor will make the project more efficient. The measurements obtained will
be closer to the real one and the final solution will be improved. This fact only
supposes the introduction of different parameters in each of the VI from the project.
With this parameters it will be possible to realize a check on the signal alignment
and obtain in a better way the results.

The signal aspect will be enhaced so as the distance estimation will be more
accurate. It has to be remarked that this fact is not a limitation but with this
improvement the operation between all the signals produced during the process will
have a better appearance. Thus, if it is used as educational purpose the global
procedure will have a better reproduction getting a more general vision of the GPS
system.

7.2.3 C/A Code Generation within LabVIEW

Instead of computing these seqeunces in an external software, its general process can be developed using LabVIEW software. LabVIEW counts with the necessary LFSR registers implemented on the C/A code generation process. One optimal option will be to generate them before searching for GPS signals. In such way, the system will be able to develop all the actions included on the project with a reasonable timing.

Another possibility to consider could be including the Matlab code, detailed in Appendix B, using the Matlab Script feature contained in LabVIEW. This features allows to introduce the corresponding code and it implements it. Choosing the appropriate inputs and output it is possible to generate each of the C/A codes. Thus, the final project will have a complete version made all using LabVIEW features.

7.2.4 Whole navigation data structure analysis

In Section 5.3 it was explained the whole navigation data contents. As it was described, there are five different subframes and in each of them there is different information. In this project it was used just information contained in the three first subframes, while the one contained in subframes four and five was not taken into account. This subframes are formed by additional data, whose contents are not so important.

Therefore, if this information is taken into account in the analysis the final result will improve. This aspect is important and it has as advantage its ease.

7.2.5 Development of a real GPS receptor

As it was explained in Section 6 the only way this application works properly is if the received signal comes from another USRP. Even though in the beginning of the development the main idea was trying design an universal GPS receprtor as the project was moving on it was found out that dealing with the received signal will be really complicated. Besides, for decoding this signal more fields are needed and the access to them is not possible. For that reason, among others, the project took a different path.

In the following figure, it is shown how an universal GPS receptor should be implemented. It can be seen that is a more complicated process than the one used in this project. Morover, LabVIEW counts with a useful tool know as Modulation Toolkit, that makes easier this work.

Figure 7.1: A starting version for a real GPS receptor

8 PLANNING AND BUDGETING

This chapter shows the planning for the whole project from start to end. It includes all the necessary tasks throughout this time period. Finally, once the duration and the actions required to carry out the project are specified, it will be specified the total budget based on the amount of time that is needed and the resources that were used.

8.1 Planning

Planning is a crucial part to successfully complete any project within resources availability (time, budget, workforce, etc.). It should include a detailed breakdown of the involved tasks, as well as an estimation of the time needed to carry out each of them. In addition, the person or team in charge of executing each action should also be included. Although, this is not included since every task was performed by the project author.

The actions breakdown shown in Table 8.1 are grouped into the stages that were specified and described in Section 1.3. It is important to notice that the project was developed part-time with an estimated work time of 25 hours per week. Therefore, in order to make it more clear, the planning was done based on weeks.

Finally, in Figure 8.1 is depicted the Gantt chart so it offers a more visual for-

mat of the project planning. This chart allows to quickly illustrate the tasks and

schedule that were followed.

Stage	Task	Start	End	Weeks
1	GPS Systems research	21/03/2016	03/04/2016	W12-W13
	USRP acquisition	04/04/2016	10/04/2016	W14
2	USRP configuration	11/04/2016	17/04/2016	W15
	LabVIEW support study	18/04/2016	24/04/2016	W16
	GPS Signal study	25/04/2016	01/05/2016	W17
	Detection application development	02/05/2016	08/05/2016	W18
3	BPSK support study	09/05/2016	15/05/2016	W19
	DSSS support study	16/05/2016	22/05/2016	W20
	Demodulation implementation	23/05/2016	29/05/2016	W21
	Decoding implementacion	30/05/2016	05/06/2016	W22
	LabVIEW code development	06/06/2016	19/06/2016	W23-W24
4	Distance analysis	20/06/2016	26/06/2016	W25
	Positioning implementation	27/06/2016	03/07/2016	W26
	LabView code development	04/07/2016	10/07/2016	W27
5	LabVIEW whole implementation	11/07/2016	24/07/2016	W28-W29
	LabView and USRP interaction	25/07/2016	31/07/2016	W30
6	Application testing	01/08/2016	07/08/2016	W31
	Results analysis	08/08/2016	14/08/2016	W32
7	Thesis writing	15/08/2016	18/09/2016	W33-W37
	Thesis revision	19/09/2016	25/09/2016	W38

Table 8.1: Tasks breakdown
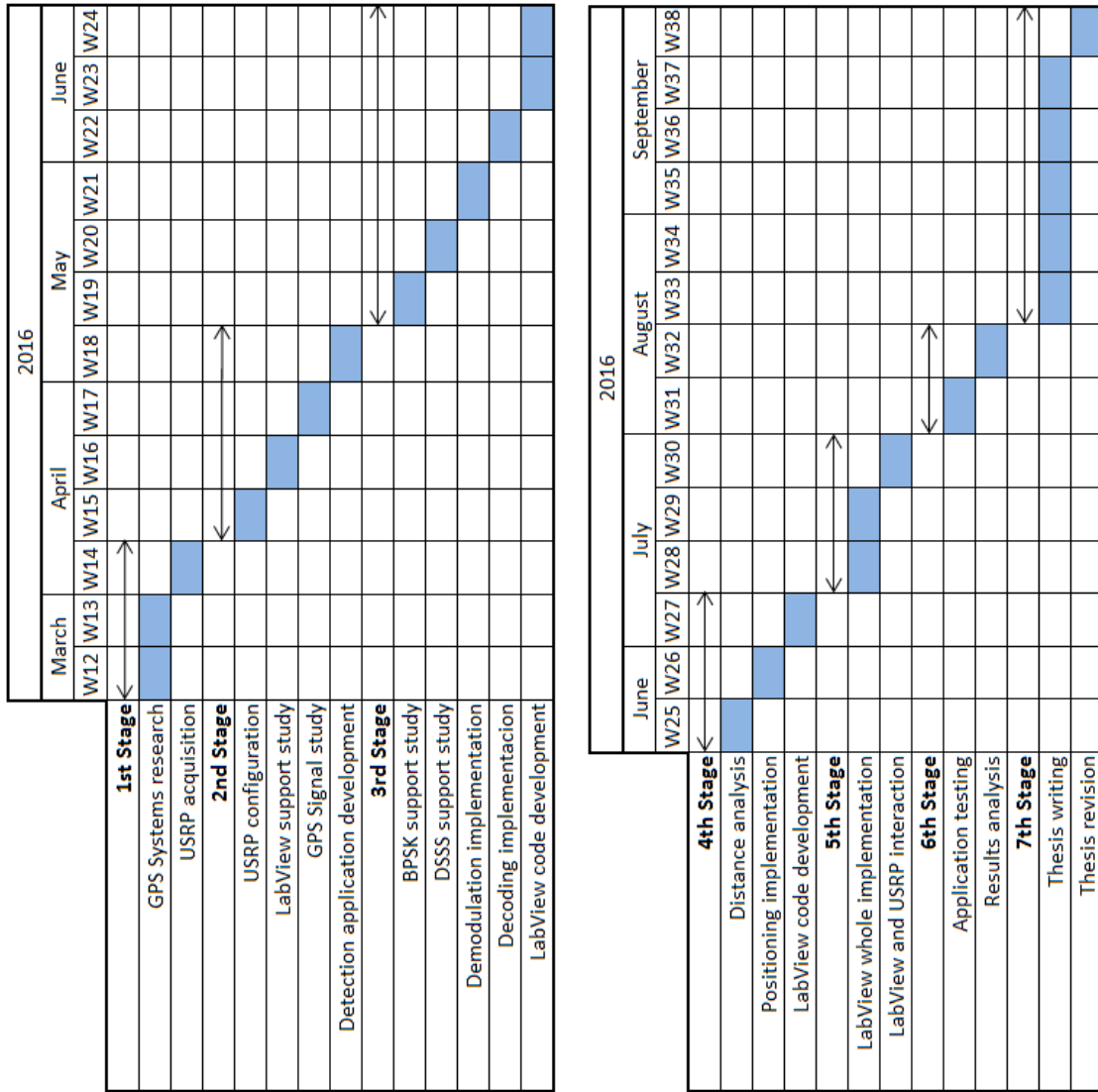
Figure 8.1: Gantt chart

8.2 Budgeting

The budget must include all the costs associated to the project from start to end. Staff and material related expenses should be taken into account, as well as any other extra costs that there may be. This was done following the Carlos III university template [25].

Full name	Proffesional category	Devoted time (hours)	Worker costs per hour (€)	Total cost (€)
Pintor Sousa, Irene	Junior Engineer	675	25	16,875
Gil Jiménez, Víctor Pedro	Senior Engineer	68	45	3,060
			Total	19,935

Table 8.2: Personal budget

Description	Cost (€)	Project devoted time (%)	Devoted time (months)	Depreciation period (months)	Attributable cost (€)
Samsung 300E5A	599	100	5.6	60	55.90
NI USRP-2920	2820.30	100	4.5	60	211.52
Cable Assembly SMA to SMA	37.30	100	4.5	60	2.80
Dual-band Vertical Antenna	37.30	100	4.5	60	2.80
Tri Band Vertical Antenna	60.60	100	4.5	60	4.55
USRP MIMO Sync and Data Cable	92.10	100	4.5	60	6.91
3 m Ethernet cable	4.50	100	4.5	60	0.34
				Total	284.82

Table 8.3: Equipment budget

It is necessary to add the software license used throughout the project. This license has a prorated value of 120.00 €.

In addition, a 20% of indirect costs are included in order to take into account costs not considered in Tables 8.2 and 8.3, such as Internet connection, shipping rates, etc. The 21% added value tax in Spain is computed as well.

Description	Cost (€)
Personal costs	19,935
Equipment costs	284.82
Software costs	120.00
Indirect costs	4,067.96
Taxes	5125.63
TOTAL	29,533.41

Table 8.4: Total budget

Finally the added value tax for Spain (21%) is added, resulting in a total project budget of *twenty-nine thousand, five hundred and thirty-three euros and fourty-one cents.*

9 CONCLUSIONS

This chapter will bring to an end the thesis by presenting the conclusions reached on GPS System and SDR technologies, as well as stating some personal opinion about the project itself.

9.1 General conclusions

GPS is a well-known and popular technology that has been used for a long time in many industries. The arrival of its use in several devices has set the basis to open new possibilities across differents sectors so that the GPS ecosystems keeps growing. The underlaying reason for this is a radical change that makes this technology strongly oriented towards frequent, quick, short and precise data signaling. This has resulted in a very efficient protocol whih offers very exact location, this making GPS suitable for many new applications.

Among all these fresh opportunities, the GPS devices development is one of the most compelling ones, so it was studied to gain extensive knowledge about hoe they can enable context awareness and location capabilities. This is a combination no other technology can offer yet. This fact is further empowered by the free usage given by the Unites States of America Government. Therefore it can takes advantage of the already established and spread GPS ecosystem.

GPS technology has experienced quick growth since it was released and there are already several new developements and improvements available. However most of them are strongly oriented towards USA GPS system. which may pose a problem for the popularization of this technology. Fortunately, a new GPS system, named Galileo, is currently developing and its final functionally is going to provide Europe with an equal GPS system as the one implemented by USA.

One of the project's goals was putting this technology into practice by developing a LabVIEW proof of concept application oriented to GPS signals tracking within a USRP peripheral. But before this, several development stages were needed to hace the necessary knowledge. The very first one involved GPS signals detection and data acquisition, which was the key to proximity awareness. Once this is achieved, the magic of this technology is quickly sensed since it enables automatic content delivery to a receptor when this is in an area whose coverage is good enough.

However, it is needed to remark that this process is not so easy as it can be thought. The problem arises when the USRP receptor tries to acquire GPS signals. In fact, it was needed to face two different isssues, the first one appears in the first step taken, that is, the acquisition of the GPS signal. In LabVIEW for acquiring signals originating from the satellites it is needed a cluster whose data type is named as *complex waveform (DBL)*. While the rest of the demodulation and decodind processes should be implemented using a *complex data waveform* whose components are different to the previous mentioned kind of data. It was possible to implement a change of data type but in this way some parts of information were lost, besides the fact that the system increases its complexity. For that reason, it was decided to implement a GPS receptor which uses GPS signals emitted by a satellite made using USRP technology too. The second one was produced due to the signal decoding.

The GPS signal coming from the twenty-four different satellites has a coding whose access is not possible, and there are a lot of field from the navigation message that can not be decoded.

Finally, special emphasis was placed on the positioning estimation for the GPS receptor. This was described in Chapter 6 in which it was seen that an acceptable accuracy can be achieved when it is tested. Although, there is still room for improvement and further work should be done on this project, as discussed in Chapter 7 in which plenty of possibilities were addressed. Focus should be placed on navigation data handling since it negatively affects to positioning estimation becoming the main source of errors.

As a summary, GPS receptor implemented using USRP technology can be an acceptable positioning solution. It is important to stand out that the main objetive of the project was achieved. This process can be shown with a teaching purpose and its different stages can be tested. However, it should not be left out that USRP GPS receptor is just an approximation. As a consequence, rather sooner than later, URSP technology will be widely used to provide improved and customized user experiences and services.

9.2 Personal conclusions

Personally, I am very satisfied with all the work developed during these months. I have learned a lot about technical aspects, but also I have gained a great experience by facing a challenging situation. This includes time management, project organization, facing unknown and open subjects, etc. among others.

Choosing a subject was not an easy task. However, the first time I heard about

this topic I realize that it was very appealing to me. This made it fairly easy for me to carry out the state of the art research, as well as trying to test as many thing as possible. I always have found interesting this kind of technology, for that, I decided that my Bachelor thesis should cover a topic with similar characteristics.

I have to recognize that it was not so easy as I expected in the beginning. Writing a Bachelor thesis supposes a huge effort since the own author is the responsible of setting the corresponding standards. I was lucky of having the support of my supervisor, Víctor, who prevented me from starting with enough time so that I could finish the project on time. I really think it was important to keep a positive attitude even when things did not work as expected.

However, there is always room for improvement. For example, the task of decoding the GPS signal was quite hard for me and took more time than I expected. GPS systems is a new technology which is being developed during these days, fact that makes even more difficult to find information about it. It is necessary to remark that its decoding process is not so easy as it seems. I would have liked to test the whole system, but this was unfeasible because of the previously mentioned reasons.

Nevertheless, as I said in the first paragraph, I have very positive feelings about all the hard work done for my Bachelor thesis.

Appendices

A   Extended abstract

Following the Carlos III University requirement, in this Appendix a extended abstract about the information contained in this document will be given. It will be divided in the main parts as the document is. It included the principal aspects treated in the reports as well as the most important information about the developed work.

A.1   Introduction and Goals

In this section it will be summarize the general idea of the main topic as well as the possible impacts that the developed application would have on the society. Moreover, the different regulations Global Positioning Systems has to face will be remarked. The section will finish with the description of the its structure.

The main goal of this project is to study GPS Receptor system and to analyze their usage for localization purposes by developing and testing a visual proof of concept application. The leading reason for conducting it is to face a challenging project whose topic is a expanding technology of huge potential market. Using an Universal Software Radio Peripheral, known as URSP. it can be shown how the signals are transmitted and what is the process for demodulating and decoding these received signals. As a result, it could be used with some teaching purposes.

With all the previously mentioned objective, it is arrived to the most significant motivation of this work. This project was chosen so in a future it can be used with teaching purposes. In such way, it will help putting this knowledge into practice and create a proof of concept about Global Positioning System on a visual way.

The project was divided in seven different stages. The first step was making an extensive research about GPS system so it was achieved a deep understanding about this technology. This stage culminated with the acquisition of an Universal Software Radio Peripheral, known as USRP. The second stage includes a GPS signals studying, besides a brief introduction into the LabVIEW software. The third one contains the DSSS decoding and BPSK demodulation processes of the received GPS signal. In such way, it is lead to the fourth stage in which the distance and position estimation was developed. In the fith stage, all the previos mentioned processes were put into practice developing an application. To probe the design has a good performance in stage sixth some test were running and its corresponding results were analyzed. Finally. the last stage consists on the document composition.

Besides the well-known software LabVIEW, some parts of the project were developed using Matlab software.

Respect to the regulatory comliance it has to be indicated the important role of ECSS organization. This organisation is responsible of controlling and keeping a good maintenance of the spatial activities.

To complete the overview of the topic a brief description about the actual socio-economic context is given. In this description it can be observed some data which reflects revelant aspects of the spanish economy as well as the actual situation of the spanish society. It is necessary to consider that during the last year, the population of

Spain has suffered a slow decrease on its number. The responsible of it is a reduction on the vegetative growth whose prediction for future years reflects a similar situation.

Over the last years, the spanish economy has suffered the effects as a consequence of a real important economic crisis. In fact, this crisis has had a global effect on all the core nations. It has produced an effect on the companies and states so they have reduced their investments over the last years. The first reduction was over the projects related to research and new technologies, same projects as the one it is been carried out in this document. Fortunately, this crisis is subsiding and this fact is visible for all the economic sectors.

A.2 State of the Art

The main topic of this project will be introduced, its structure will be described and finalliy the relationship betweem the implemented device and the ones that already exists on the market will be given.

Global Positioning System (GPS) is a satellite network that orbit the earth at fixed points above the planet and beam down signals to anyone on earth with a GPS receiver. It consists on a constellation made by 24 operational satellites and 3 backup satellites. This constellation started running around 1990 and it became fully operational in 1993.

Nowadays GPS navigation devices besides being high-technology products, they represent an important application in our daily life. In order to perform this growth, there is a GPS modernization program. Inside of it it can be found the Galileo project, implemented by the European Union jointly with the European Space Astronomy Centre (ESAC).

A.3 Work environment description

This chapter will introduce the main components of the project to the reader, explain how they work and reveal their capabilities to provide context awareness. The different available specifications will also be described, along with a brief introduction to the lastest developed radiocommunication systems, SDR. Finally, information about USRP peripheral will be provided.

LabVIEW is a highly productive development environment for creating custom applications that interact with real-world data or signals in fields such as science and engineering. In this project it was used the version 2015. This version was the only compatible version with the Windows 10 software. In the following sections, there will be explained the different components implemented on the design. As well as, the controls and interfaces with their functions involved on the process.

Software Defined Radio (SDR) is a radiocommunication system where components that have been typically implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system. Inside this group is included the USRP technology. Universal Software Radio Peripheral (USRP) is a flexible and affordable transceiver that turns a standard PC into a powerful wireless prototyping system. Paired with LabVIEW Communications System Design Software, USRP transceivers help you prototype a wide range of single-channel and MIMO wireless communications systems [19].

A.4 GPS Signal

In this section it will be introduced a description of GPS signal structure as well as the process to be followed in order to demodulate and decode this signal, as well as, a explanation of the navigation message is give. The projetct was designed in the same way at it is exaplined in this section. Figures about the representation of Labview application will not be provide but they can be seen in Chapter 5.

GPS signals are transmitted in two radio frequencies of the UHF band, known as the L band by the IEEE. These two frequencies are called as L1 and L2, both of them are derived from the common frequency f_0. The signals are formed by three components: carrier, navigation data and sequence spread spectrum. Navigation data is defined as the detailed information about each satellite's position and the network which is modulated on top of both the C/A and P(Y) ranging codes at 50 bps, needed by GPS receiver.

A.4.1 GPS Receiver Operation

A C/A code GPS receiver must be able to correlate signals from at least four satellites. calculate time delays, read the navigation message, locate GPS satellites orbits. and compute the final position from obtained pseudoranges. The key to accurate position determination process resides on timing precision in gold code sequences arrivals from each visible satellite. All GPS receivers use a microprocessor whose responsibilities consist on making the required calculations and controlling the display of data.

A.4.2 PRN Codes

GPS satellites transmit using pseudorandom sequence (PN) codes. All satellites transmit a specific C/A code at the same carrier frequency, L1. GPS measurements are one of the few examples where relativistic effects must be taken into account, the clocks are mounted on platforms moving at very high speeds. The C/A and P code transmissions from all GPS satellites are overlaid in the L1 and L2 frequency bands, making GPS a direct sequence spread spectrum (DS-SS) system as it will be explained later. The receiver separates signals from individual GPS satellites using as a reference the unique C/A code that is allocated to each satellite.

A.4.3 Direct Sequence Spread Spectrum Reception

Bits recovery from the original data stream inside the DS-SS signal is obtained once the received signal is multiplied by the same PN code which was used to generate it. The incoming signal is multiplied by the despreading code sequence in order to obtain the output. In practice, a low pass filter is used instead of an integrator. If the correct code is present in the input signal, the output of the multiplier is +1 or -1 depending on the present chip at that moment in the multiplier.

A.4.4 Binary Phase Shift Keying

Practical DSSS systems use Binary Phase Shift Keying (BPSK) waveforms. Once the received signal has been despread, is time to implement BPSK demodulation. It has to be taken into account that the incoming signal and PN sequence are both BPSK waveforms with 0 degrees or 180 degrees phase shifts. If the phase of the input waveform is reserved (indicating that the original data bit was a 0 rather than a 1) the output is -1.

A.4.5 Distance Estimation and Positioning

The basic requirement of a satellite navigation system like GPS is that there must be four satellites transmitting suitably coded signals from known positions. Three satellites are required to provide the three distance measurements, and the fourth to remove receiver clock error. Although the principles by which GPS locates a receiver are very simple, requiring only the accurate measurement of three ranges to three satellites is quite complex. All the obtained data is introduced in the Ranging equations given as a result the user's location.

A.5 Tool development

This chapter covers the work that was carried out in order to configure the available USRP, as well as detecting GPS signals with it. Since the whole process was explained in the previous section, here new information will not given. To see the corresponding LabVIEW figures go to Chapter 5.

A.6 Testing and results

In this secction are described several tests that were carried out in order to check the application performance and their corresponding results. Among the implemented tests the most important ones proved the correct functioning of the signal acquisition, DS-SS signal reception. BPSK signal demodulation and distance estimation. The results obtained in all the previously mentioned tests were positive and demonstrate the proper functioning of each part from the application.

A.7 Problems encountered and further development

During the preoject's development there wer found out more than one problem. However, the most important one will be the only one detailed in this section. This problem corresponds to the complexity found when the satellite signal was acquired. Due to the difference bewteen some functions in LabVIEW it was impossible to design a GPS receptor which was able to receive sateliite signal. For that reason, in this project it was developed a GPS receiver that uses as satellite signal, a signal implemented by another USRP. Therefore, as the most striking further development it is found the design of a GPS receptor, using USRP technology, capable of assimilating satellite signals.

A.8 Planning and budgeting

To give an overview of the whole process it will be said that it was developed during six months, in which all the stages previously explained were carried out. After including all the necessary elements. a total project budget of *twenty-four thousand, five hundred and seventy-five euros and twenty-four cents* results.

A.9 Conclusions

One of the project's goals was putting this technology into practice by developing a LabVIEW proof of concept application oriented to GPS signals tracking within a USRP peripheral. But before this, several development stages were needed to hace the necessary knowledge. The very first one involved GPS signals detection and data acquisition, which was the key to proximity awareness. Once this is achieved, the magic of this technology is quickly sensed since it enables automatic content

delivery to a receptor when this is in an area whose coverage is good enough.

However, it is needed to remark that this process is not so easy as it can be thought. The problem arises when the USRP receptor tries to acquire GPS signals. In fact, it was needed to face two different isssues, the first one appears in the first step taken, that is, the acquisition of the GPS signal. To deal with it, a complicated process should be implemented in LabVIEW. This process does not assures the problem will be fixed since some data can be lost. For that reason, it was established to design as an alternative an USRP GPS receptor which receives the signal coming from another USRP. The second one was found out when the decoding process was developed. In this process some important information is needed and there is not access to it.

Finally, special emphasis was placed on the positioning estimation for the GPS receptor. It was seen that an acceptable accuracy can be achieved when it is tested. Although, there is still room for improvement and further work should be done on this project.

As a summary, GPS receptor implemented using USRP technology can be an acceptable positioning solution. It is important to stand out that the main objetive of the project was achieved. This process can be shown with a teaching purpose and its different stages can be tested.

Personally, I am very satisfied with all the work developed during these months. It was a hard work since it was the first time I faced a topic, such GPS system, by my own. During the development rhere were a lot of new concepts that I did not know before, and in some ocassions I did not how to solve their corresponding problems. Furthermore, it was the first time I use LabVIEW as software what makes

more complicated to achieve the final goal.

Nevertheless, as I said before, I have very positive feelings about all the hard work done for my Bachellor thesis.

B Matlab codes

B.1 C/A Codes Generation

The C/A code generation was divided in two steps. The first one is computed in `cacode.m` in which the C/A code is computed, while in `generationCode.m` it is implemented the whole calculation for all the C/A code depending on the satellite number.

cacode.m

```
function g=cacode(sv,fs)
% function G=CACODE(SV,FS)
% Generates 1023 length C/A Codes for GPS PRNs 1-37
%
% g: nx1023 matrix- with each PRN in each row with symbols 1 and 0
% sv: a row or column vector of the SV's to be generated
%     valid entries are 1 to 37
% fs: optional number of samples per chip (defaults to 1), fractional
%     samples allowed, must be 1 or greater.
%
% For multiple samples per chip, function is a zero order hold.
%
% For example to generate the C/A codes for PRN 6 and PRN 12 use:
% g=cacode([6 12]),
% and to generate the C/A codes for PRN 6 and PRN 12 at 5 MHz use
% g=cacode([6 12],5/1.023)
%
% For more information refer to the "GPS SPS Signal Specification"
% http://www.navcen.uscg.gov/pubs/gps/sigspec/default.htm
%
% Dan Boschen 12-30-2007
% boschen@loglin.com

% Revision History
% rev 1.0 Dan Boschen 4-15-2007   Initial Release
%
% rev 1.1 Dan Boschen 7-15-2007   Corrected error with taps for PRN30,
%     should be [2,7] was
```

```matlab
%                incorrect as [1 7]. Thank you Jadah Zak for finding this.
%
% rev 1.2 Dan Boschen 12-26-2007 Fixed column index error when ceil ~ L
%         Thank you Jared Meadows for finding this.
%
% rev 1.3 Dan Boschen 12-30-2007 Changed comment "first order hold" to
% "zero order hold".
%
% rev 1.4 Dan Boschen 6-1-2010   Updated email address in comments

if nargin<2
   fs=1;
end

if (max(sv)>37) || (min(sv)<1) || (min(size(sv))~=1)
   error('sv must be a row or column vector with integers between 1 and
     37\n')
end

if fs<1
   error('fs must be 1 or greater\n')
end

% force integers
testint=round(sv)-sv;
if testint ~= 0
   warning('non-integer value entered for sv, rounding to closest
     integer\n');
   sv = round(sv);
end

% table of C/A Code Tap Selection (sets delay for G2 generator)
tap=[2 6;
     3 7;
     4 8;
     5 9;
     1 9;
     2 10;
     1 8;
     2 9;
     3 10;
     2 3;
     3 4;
     5 6;
     6 7;
     7 8;
     8 9;
     9 10;
     1 4;
     2 5;
     3 6;
     4 7;
     5 8;
     6 9;
     1 3;
     4 6;
     5 7;
     6 8;
     7 9;
```

```matlab
        8 10;
        1  6;
        2  7;
        3  8;
        4  9
        5 10
        4 10
        1  7
        2  8
        4 10];

% G1 LFSR: x^10+x^3+1
s=[0 0 1 0 0 0 0 0 0 1];
n=length(s);
g1=ones(1,n); %initialization vector for G1
L=2^n-1;

% G2j LFSR: x^10+x^9+x^8+x^6+x^3+x^2+1
t=[0 1 1 0 0 1 0 1 1 1];
q=ones(1,n);  %initialization vector for G2

% generate C/A Code sequences:
tap_sel=tap(sv,:);
for inc=1:L
    g2(:,inc)=mod(sum(q(tap_sel),2),2);
    g(:,inc)=mod(g1(n)+g2(:,inc),2);
   g1=[mod(sum(g1.*s),2) g1(1:n-1)];
   q=[mod(sum(q.*t),2) q(1:n-1)];
end

%upsample to desired rate
if fs~=1
  %fractional upsampling with zero order hold
  index=0;
  for cnt = 1/fs:1/fs:L
    index=index+1;
    if ceil(cnt) > L   %traps a floating point error in index
      gfs(:,index)=g(:,L);
    else
      gfs(:,index)=g(:,ceil(cnt));
    end
  end
  g=gfs;
end

%In order to convert the '-1' in '0' the following command is performed
g(g==-1)=0;
```

generationCode.m

```matlab
% This program computes the 24 different C/A codes for each of the
% satellites.
% It calls the 'cacode' function 24 times, introducing the
    corresponding
% satellite number.
% Each C/A code has Gi name where i is the satellite number
```

```
G1=cacode(1);
G2=cacode(2);
G3=cacode(3);
G4=cacode(4);
G5=cacode(5);
G6=cacode(6);
G7=cacode(7);
G8=cacode(8);
G9=cacode(9);
G10=cacode(10);
G11=cacode(11);
G12=cacode(12);
G13=cacode(13);
G14=cacode(14);
G15=cacode(15);
G16=cacode(16);
G17=cacode(17);
G18=cacode(18);
G19=cacode(19);
G20=cacode(20);
G21=cacode(21);
G22=cacode(22);
G23=cacode(23);
G24=cacode(24);
```

B.2 Ranging equations

In this section the user's positioning estimation is implemented using Matlab. For thtat. there are three different steps- The first one corresponds to the code made by `final.m`. This small program calls to the method developed in `getPosition.m`, which corresponds to the second step. Finally the third step is performed in `equations.m`, whose contents corresponds to the well-known Ranging equation. In addition to these equations the data obtained for the satellites postion. clock error and satellite pseudo distances with respect to the Earth are introduced.

final.m

```
clc
clear all
close all

% Final program whose outputs are the obtained values for the user's
% position (latitude, longitude and altitude)
[Ux Uy Uz] = getPosition();
Ux
Uy
```

Uz

getPosition.m

```
function [lat long alt]=getPosition()
% Conversion factor: 1 degree = 111319.9 m (aprox)
k = 111319.9;

% It calls the function equations
fun = @equations;
x0 = [0, 0, 0];
x = fsolve(fun, x0);

lat = x(1)/k;
long = x(2)/k;
alt = x(3);
```

equations.m

```
function [F] = equations(U)

% The listed values corresponds to the obtained data from the
    navigation
% message. Among them there was obtained: altitude, latitude and
    longitude
% for each of the four satellites. Clock error and finally the pseudo
% distances from the satellites to the user's position on the Earth

% Values for satellite number ONE
lat1 = 19.18;
long1 = -2.2;
alt1 = 20345.29e3;
% Values for satellite number TWO
lat2 = 53.82;
long2 = -2.26;
alt2 = 20182.47e3;
% Values for satellite number THREE
lat3 = 27.14;
long3 = 27.25;
alt3 = 20230.84e3;
% Values for satellite number FOUR
lat4 = 21.4;
long4 = -15.67;
alt4 = 21426.56e3;
% Light speed (vacuum)
c = 3e8;
% Clock error
tau = 1e-6;

% Conversion factor: 1 degree = 111319.9 m (aprox)
k = 111319.9;

% Values of the pseudo distances
PR1 =    2.048146e+007; % Satellite ONE
PR2 =    2.023858e+007; % Satellite TWO
```

```matlab
PR3 =      2.057539e+007; % Satellite THREE
PR4 =      2.157036e+007; % Satellite FOUR

% These are the Ranging equations were all the previous data is
    introduced
F(1) = (lat1*k − U(1))^2 + (long1*k − U(2))^2 + (alt1 − U(3))^2 − (PR1
    − tau * c)^2;
F(2) = (lat2*k − U(1))^2 + (long2*k − U(2))^2 + (alt2 − U(3))^2 − (PR2
    − tau * c)^2;
F(3) = (lat3*k − U(1))^2 + (long3*k − U(2))^2 + (alt3 − U(3))^2 − (PR3
    − tau * c)^2;
F(4) = (lat4*k − U(1))^2 + (long4*k − U(2))^2 + (alt4 − U(3))^2 − (PR4
    − tau * c)^2;
```

B.3   Spheres intersecction

In order to get a visual solution of the intersection between the satellites spheres

and the Earth. code developd in `esferas.m` was developed.

esferas.m

```matlab
clear all
close all
clc
%%%%%%%%% CREATING INTERSECTION BETWEEN SPHERES %%%%%%%%%
% In this program the intersection between the four spheres and the
    Earth
% will bre performed.
% It represents the corresponding sphere for satellite ONE
[x1,y1,z1] = sphere(30);
% Whose pseudo distance with respect to the receptor is equal to 20481
    km.
% This distance corresponds to the radius of the sphere
x1=x1*20.481;
y1=y1*20.481;
z1=z1*20.481;
% And its coordinates are: latitude=19.18N, longitude=2.20W and
% altitude=20345.29km
% These three coordinates represent the center of the sphere
mesh(x1+19.18, y1−2.20, z1+18.2) % where (a,b,c) is center of the
    sphere
hold on
% It represents the corresponding sphere for satellite TWO
[x2,y2,z2] = sphere(30);
% Whose pseudo distance with respect to the receptor is equal to 20239
    km.
% This distance corresponds to the radius of the sphere
x2=x2*20.239;
y2=y2*20.239;
z2=z2*20.239;
% And its coordinates are: latitude=53.82N, longitude=2.26W and
% altitude=20182.47km
% These three coordinates represent the center of the sphere
```

```matlab
mesh(x2+53.82, y2-2.26, z2+18.1)
hold on
% It represents the corresponding sphere for satellite THREE
[x3,y3,z3] = sphere(30);
% Whose pseudo distance with respect to the receptor is equal to 20575
    km
% This distance corresponds to the radius of the sphere
x3=x3*20.575;
y3=y3*20.575;
z3=z3*20.575;
% And its coordinates are: latitude=27.14N, longitude=27.25E and
% altitude=20230.84km
% These three coordinates represent the center of the sphere
mesh(x3+27.14, y3+4.25, z3+18.0)
hold on
% It represents the corresponding sphere for satellite FOUR
[x4,y4,z4] = sphere(30);
% Whose pseudo distance with respect to the receptor is equal to 21573
    km
% This distance corresponds to the radius of the sphere
x4=x4*21.573;
y4=y4*21.573;
z4=z4*21.573;
% And its coordinates are: latitude=21.14N, longitude=15.67W and
% altitude=21426.56km.
% These three coordinates represent the center of the sphere
mesh(x4+21.14, y4-15.67, z4+17.9)
hold on
% It represents the EARTH
[x5,y5,z5] = sphere(30);
% The radius of this sphere is equal to 6371km
x5=x5*6.371;
y5=y5*6.371;
z5=z5*6.371;
% In this case there is not coordinates since the Earth is the
    reference
% point
mesh(x5, y5, z5)
hold on
```

C   User's manual

In this manual a user guide is given in order to be able of executing the developed work in this project. It is assumed the previous LabVIEW installation (version 2015) as much as all the needed packet. Also it is needed a Gigabit Ethernet port available in the computer as well as the Windows Operating System.

USRP peripheral assembly Each USRP kit has the following hardware and complements:

- One transceiver

- Power cord

- Ethernet cable

- One antenna

Firstly, the USRp should be located on a fixed plataform with good air circulation. Now it is time to connect one of the Ethernet cable ends to the USRP port and the other one to the computer. Then, the antenna should be connected to the USRP receive port (RX1) and finally it is possible to connect the power cable to the peripheral and to a 230V connection. Like this, the USRp should be complete connected.

Remark: It would be necessary to knoe the IP direction associated to the USRP. In order to check this IP direction the 'NI-USRP COnfiguration USRP' program should be open. Then, press the button *Find Devices* and after that, if everything is correctly connected the IP direction should be displayed.

Open and execute the application In order to begin with the application, it is necessary to go to the folder in which the program 'final.vi' is found. Once it is pressed the front panel and the block diagram will be open.

Now is time to introduce the data explained during the report. Among them the most importan one is the USRP configuration shown in Figure C.1. Moreover the filter and the BPSk parameters should be introduced. The program will be executed once the white arrow in the left top is pressed. Also this operation can be performed if the command 'CTRL + R' is introduced.
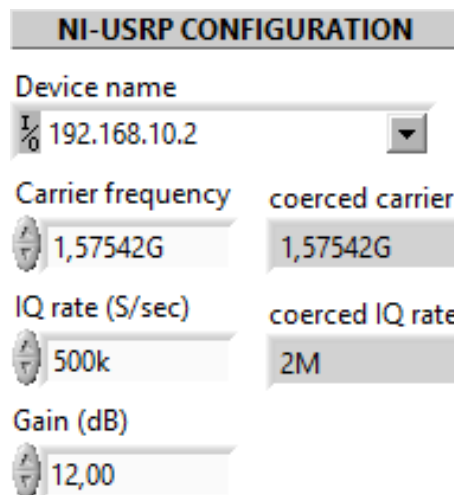

Figure C.1: USRP Configuration

After all this procedure the corresponding data will be obtained.

Closing the application Once the program was tested and used it is recommended

to stop it before clossing. For that just pressing the red button on the left top (next to the previously mentioned white arrow).

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