ISCTE IUL
Instituto Universitário de Lisboa

Escola de Tecnologias e Arquitectura

Radio, Satellite Communications and Tracking Station

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I would like to thank Professor Francisco Cercas and Professor Pedro Sebastião for encouraging and helping me to take up this task.

Abstract

This dissertation describes the work done to assemble and setup a radio station for satellite communications, with academic and research purposes. It begins to explain the importance of having such kind of facilities on campus, how this one in particular was setup along with all the problems that had to be solved on the way and finally are presented some results from its operation. Part of the equipment was brought back from an older setup and there was the need to update software and hardware, plus it was necessary to re-engineer the system to be compliant with the actual standards. During the development of this document, as the station was becoming operational several projects were developed concerning the use of the station for subjects related with satellite tracking, automatic control, GNSS signal processing and embedded systems. Lastly it will also be described some of the possible expansions that can be made in the near future to increase the station capabilities.

Resumo

Esta dissertação descreve o trabalho desenvolvido para montar uma estação de rádio para comunicações via satélite e a sua aplicação no meio académico e de investigação. Começa-se por explicar a importância que tem a existência de uma estação deste tipo no campus universitário, depois como é que esta em particular foi montada bem como todos os problemas que surgiram e tiveram que ser resolvidos. Finalmente são apresentados alguns resultados da sua utilização. Parte do equipamento transitou de outra estação mais antiga mas foi necessário efectuar toda uma actualização ao sistema tanto a nível de software como de hardware além de repensar toda a montagem de forma a que estação estivesse dentro dos padrões actuais. Durante o processo de escrita desta dissertação e à medida que a estação foi ficando operacional foram desenvolvidos vários projectos relacionados com rastreio de satélites, recepção e processamento de sinais de sistemas GNSS e aplicações em sistemas embebidos.

Keywords

Satellite communications, Radio station, Orbits, Tracking, Control, Radio navigation.

Acronyms

ADCS Advanced Data Collecting System.

ARISS Amateur Radio on board the International Space Station.

AX.25 Amateur X.25 Protocol.

DVB-T Digital Video Broadcast - Terrestrial.

FM Frequency Modulation.

GALILEO European GNSS named after Galileo Galilei.

GLONASS GLObalnaya NAvigatsionnaya Sputnikovaya Sistema.

GNSS Global Navigation Satellite System.

GPS Global Positioning System.

HF High Frequency (3MHz - 30MHz).

HIRS LW High Resolution Infrared Radiation Sounder with infrared Long Wave range.

ISCTE-IUL ISCTE-Instituto Universitário de Lisboa.

ISS International Space Station.

IT Instituto de Telecomunicações.

LEO Low Earth Orbit.

LF Low Frequency (30kHz - 300kHz).

LHCP Left Hand Circular Polarization.

MF Medium Frequency (300kHz - 3MHz).

MIT Massachussets Institute of Technology.

NASA National Aeronautics and Space Administration.

NOAA National Oceanic and Atmospheric Administration.

OS Operating System.

OSCAR Orbiting Satellite Carrying Amateur Radio.

PC Personal Computer.

RHCP Right Hand Circular Polarization.

SAREX Shuttle Amateur Radio Experiment.

SARP Search And Rescue signal Processor.

SDR Software Defined Radio.

SSTV Slow Scan Television.

SWR Standing Wave Ratio.

TV Television.

UHF Ultra High Frequency (300MHz - 3GHz).

VHF Very High Frequency (30MHz - 300MHz).

Contents

List of Figures

List of Tables

Chapter 1

Introduction

With the globalization and the span of telecommunications worldwide we see an increase of users and variety of needs, the satellite communications come to play a fundamental part to guarantee certain services. The communications satellite can work both as an alternative or complementing ground wave communications, helping to maintain or expand existing services making them more flexible and providing better quality of service. Hence the study of satellite communications becomes mandatory in any university or institution that gives courses or develops research in the telecommunications area [1]. Having a station ready and prepared for satellite communications and eventually other radio communications will bring an add value to the institution for it will be easier to provide practical training to students and researchers to test their work in a real system. This station can be used for demonstration as well as a platform to develop projects and thesis. It covers hardware and software applications, anything that can be related with radio communications, which brings a wide range of possibilities to the work developed here. The use of Software Defined Radio (SDR) equipment in the future will enhance the capabilities of the stations since it will be possible to test a wider range of modulation processes, capture a larger variety of signals both in spectrum and bandwidth.

1.1 Why should one have this kind of station on campus

It is not new nor recent the existence of experimental radio stations (amateur radio) in universities. In fact is something that naturally came by due to historical reasons since the development of radio communications has always been related with experiments made by amateur radio. The use of this radio stations may even be broader than it might seem, for Amateur Radio is something that in spite of being closely related to electronics and telecommunications is also interdisciplinary as it deals also with subjects related with mechanics, geography, contact with people from other countries and cultures. People from all walks of life get interested in amateur radio so it is quite possible that people from other areas of study might be interested in using this radio station.

1.2 State-of-the-art

The study of radio wave communications comes from the end of the 19th century with the first transmissions made by Hertz, Marconi, Popov and others, but the great advance was only made with the invention of the electronic valve triode which permitted the amplification of small signals. Since then, many experiments continued being done by inventors and scientists as radio was becoming an area of interest for all people involved with new technology. The first radio engineers started as radio amateurs building their homemade sets and performing experiments with electronic circuitry and antennas. As it was a new technology yet to be explored and with a foreseen high potential, some universities started having their local club stations. These stations were first built only by the students and later with support by the institution itself as it revealed to be not only a way to interest students in the sciences lectured but also in the discovery and development of new technology.

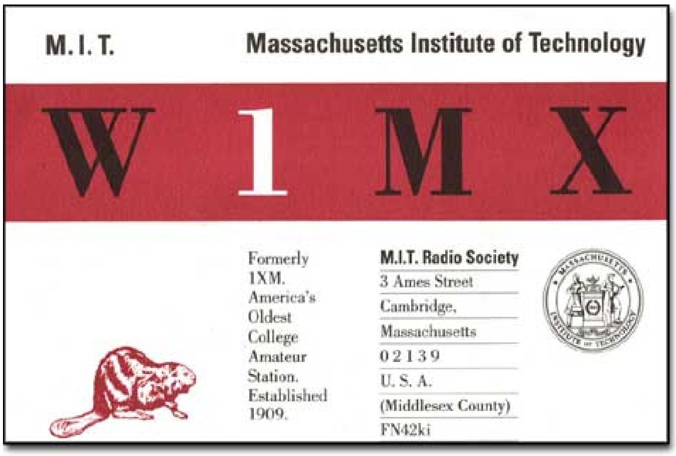

Figure 1.1: Founded in 1909 the MIT Amateur Radio Station is one of the oldest in the world

The interest in radio, even as a hobby for science oriented people, grew even more after World War II though Amateur Radio activity had been interrupted during that time. After it was allowed again there were many military surplus equipment ready to be used by this new age of experimenters [2]. The colleges and technical institutes were reviving and urging to continue the development of many technologies that had been kick-started by the war effort, radio communications was a prime among that. With the invention of the transistor in 1947 and its refinement and mass production in the 1950's brought new possibilities to radio circuits which now could use less power, had smaller size and weight. All the electronic circuitry was being re-designed to use solid-state devices

and as usual the amateur radio community was at the forefront to test the performance of this new technology. As time went by, the number of university radio clubs grew as well as the number of licensed amateurs [1] in the universities and research centers. Some of the great electronics companies that perform research and development have their own radio club, such as the case of Motorola.
As the technology continued to evolve and the space exploration became a reality with the built of the first artificial satellite (Sputnik 1), the need to develop radio equipment for satellite operation became bigger and also the development of the satellite itself. In spite of by that time only two countries in the world had the capability of launching objects into orbit that did not mean that those objects could not be built elsewhere so many other countries decide to invest in satellite design. One of the most prolific satellite developer is the university of Surrey which has obviously an amateur radio station to test their equipment and conduct satellite communications.

Figure 1.2: The Amateur Radio Station at Surrey University

This radio station is mainly dedicated to satellite communications but it does not mean that in the future it will expand its operating frequencies using ground-wave or sky-wave propagation. Currently the existing equipment does not allow operation below Very High Frequency (VHF) but that already permits testing and studying propagation phenomena using simple ground-wave, tropospheric, or even sporadic-E layer. Some of this phenomena do not occur very often but should be studied because they might cause undesirable signals to reach areas usually not covered. This is of particular importance when dealing with digital synchronised communication and explains the problems occurred early with the Digital Video Broadcast - Terrestrial (DVB-T) system in Portugal where receivers were losing synchronism because they were receiving signals from transmitters further away when they should only receive one, closer to its position.

[1] A legal amateur radio requires a licence from the country's communications authority

Figure 1.3: Aspect of the laboratory from the Amateur Radio Society in Surrey University

Obviously in the future there might be made an expansion of the station to work on the High Frequency (HF), Medium Frequency (MF) and even Low Frequency (LF) bands. There is still plenty of services on these bands used by both civilian and military communities. In spite of the shorter bandwidth, new modulation techniques and software can be developed to increase the throughput and take advantage of some of these band characteristics.

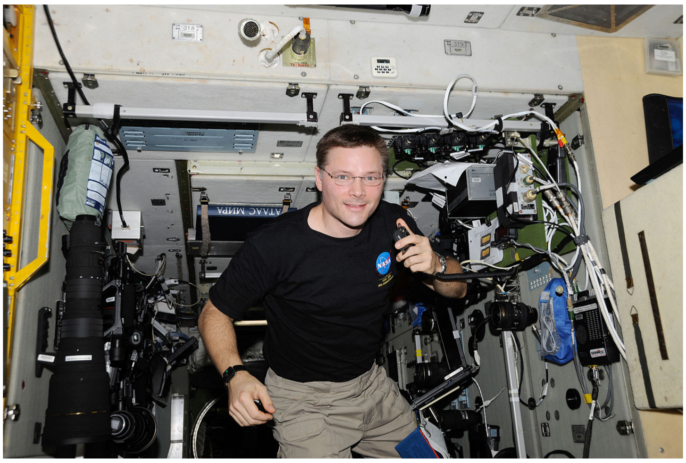

Figure 1.4: Astronaut Col. Doug Wheelock, KF5BOC, talks to earth using the amateur radio station on board the ISS

Aboard the International Space Station (ISS) there is an amateur radio station and almost all astronauts (or cosmonauts) hold an amateur radio licence. It is common to schedule radio contacts between the ISS and schools exactly to give young people the chance to talk with the astronauts and place questions about their job and life in space. There is in fact a program called Amateur Radio on board the International Space Station

(ARISS) that was created to promote this kind of events and get students interested in technological and space related subjects. The ARISS came as a followup of an older program called Shuttle Amateur Radio Experiment (SAREX) that began in 1983 when amateur radio was first used to communicate from the Space Shuttle to Earth in 1983. Usually, off the scheduled periods, the ISS has its equipment configured as a repeater for *Packet Radio* on the amateur 2m band. Sometimes, if the astronauts have some free time, they can just operate the equipment to make voice contacts with other amateur radio stations on earth and once in a while images from the ISS are sent via Slow Scan Television (SSTV). Having a radio station capable of doing this not only makes it easy the schedule of radio contacts with the ISS to members of the ISCTE-Instituto Universitário de Lisboa (ISCTE-IUL) community as well as from other institutions that may be invited to participate in events.

Figure 1.5: Satellite antenna system from the University of Michigan Amateur Radio Club

1.3 Dissertation layout

The development of the station has already produced a paper [3] presented at *Conftele 2015* also shown at the "Techdays" event. This should be the first of many other publications that may be written based on the work developed in the satellite radio station.
This dissertation comprises this first chapter, on the second chapter it is briefly described

some basic theory of satellite's technology, types of orbits and satellite construction. The third chapter explains how the station was setup, with some emphasis on the work done to adjust the antennas. This chapter also lists all capabilities and limitations of the station and its modes of operation. The fourth chapter presents some results of the data collected from several satellites, as a result of operating the station, which are discussed and compared to the state-of-the-art. Finally the fifth chapter presents the major conclusions of this work, together with some suggestions of further work.

Chapter 2

Satellite Basics

For years, even after the invention of radio and wireless communications, services were based mainly on HF communications to achieve long distances. In spite of the variations in propagation conditions on the HF bands, many services would have alternative frequencies to get the message through, but these were mainly voice or telegraphy transmissions not requiring a large bandwidth. With the advance in digital communications and video signals, the requirements for larger bandwidth systems became a necessity if one wanted to be able to get worldwide coverage or higher bit rates. The idea of using a repeater in orbit would prove to be a major breakthrough to overcome some of this limitations.

2.1 Historical resume

It all started in 1610, the German astronomer Johannes Kepler (1571-1630) used the term "Satellite" to describe the moons orbiting planet Jupiter. He also described the laws (mathematical expressions) that rule the planetary motion. These laws are still used today and for this reason the elements used to calculate the satellites position are called "Keplerian data". Later, in 1687, sir Isaac Newton (1642-1727) would determine the three laws of motion and describe universal gravity. This would be fundamental to understand orbits and satellites. Even though, in 1879, satellites were still depicted as science fiction in the book "The Begum's Fortune" by Jules Verne (1828-1905). In 1903, the russian Konstantin Tsiolkovsky (1857-1935) proposed the use of rocketry to launch spacecrafts. He also calculated the minimum speed to get an object in to orbit. In 1928 the Slovenian Herman Potočnik (1892-1929) described geostationary satellites and the use of a spacecraft in orbit for scientific experiments and observation of the Earth. In 1945 British magazine Wireless World published an article by Arthur C. Clarke (1917-2008) that shows how geostationary satellites could be used for worldwide coverage of radio and television signals. Finally the first artificial satellite, Sputnik, was launched by the former Soviet Union in 1957. It had a mass of 83.6kg and travelled in an elliptic orbit at a height between 215km and 939km above the Earth. It took 96.2 minutes to complete an orbit at an average speed of 29000km/h. Sputnik was merely a beacon and a test to prove that manmade orbiting satellites could be a reality. In 1960 the first weather satellite Tiros-1 was launched by NASA. It would transmit infrared images of the Earth's cloud cover and was capable of detecting and chart hurricanes. The first communications satellite came only in 1962, the Telsat-1 was a low-orbit satellite but capable of making the first live transatlantic telecast.

2.2 Satellites used with this station

There are several types of satellites, differences are related with size, application, durability and even evolution in technology. In the following sections it will be described just a few, which are the ones mostly used in this work.

2.2.1 NOAA Satellites

The NOAA[5] satellites where launched to provide image capture to help in the meteorologic service. This satellite program has started long ago with the launch of TIROS-1 the satellite who first sent an image of earth from orbit revealing the formation of clouds and their movement in the atmosphere. Today the operational satellites for this service and mostly used in this work are the NOAA-15, NOAA-18 and NOAA-19. Their characteristics are presented in table 2.1 that shows the last series of satellites although some of them are not functional anymore. NOAA-16 was decommissioned 9 June 2014 after a critical anomaly and NOAA-17 was decommissioned on 10 April 2013. These satellites were put in circular, near-polar sun-synchronous orbits so the surface illumination angle will remain approximately the same every time that the satellite is overhead.

Name	Launch Date	End of useful life	Features
NOAA-15	13-may-98	Secondary	1^{st} of series to support dedicated microwave instruments-suite of three Advanced Microwave Sounding Units AMSU-A1, AMSU-A2, AMSU-B
NOAA-16	21-sep-98	9-june-2014	Same
NOAA-17	21-june-2002	10-apr-2013	Same
NOAA-18	20-may-05	Secondary	HIRS LW channels/imagery improved
NOAA-19	4-feb-09	Operational	ADCS and SARP-3 upgrades

Table 2.1: NOAA-N Series of Operational Satellites

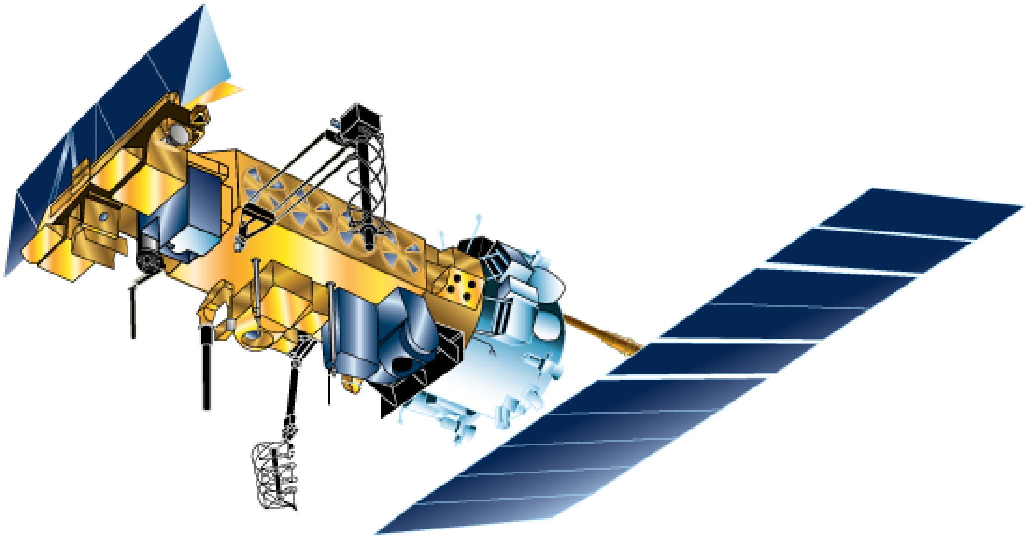

Figure 2.1: NOAA-19 is the latest satellite of the NOAA series

2.2.2 Cubesats

The Cubesat is the most innovative concept brought about for satellite development under low budget, accessible to the student community and started in 1999 at the California Polytechnic State University by professor Jordi Puig-Suari. Since then, many cubesats have been built by several groups around the world, mainly universities who use it, so students can have "hands on" approach to satellite building.

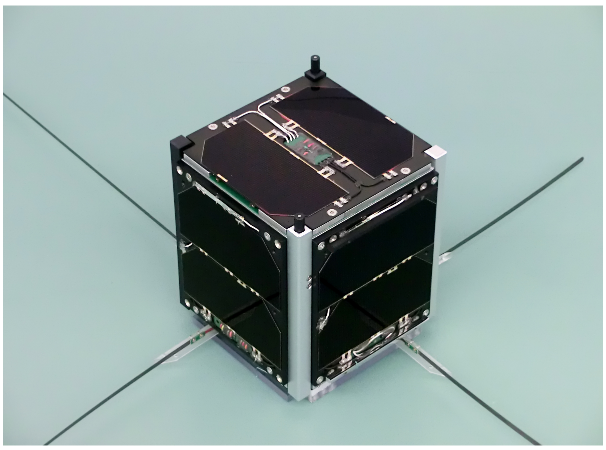

Figure 2.2: FUNCube AO-73

The base to build the satellite is a cubic case with about 10cm side which is called one unit (1U), other satellites in this category may be bigger using 2U or 3U being able to include more equipment for more experiments. These satellites usually have a short life but that is conform with its purpose which is experimentation and not to secure any permanent or commercial service.

Figure 2.3: The Delfi C3 is a 3U Cubesat

2.2.3 OSCAR Satellites

OSCAR is the designation for satellites that were launch for amateur radio use. Nevertheless, since the amateur radio focus on experimental radio communications, these satellites represent a simple way to access satellite operation since the other services are usually reserved for military or commercial use and required a more expensive and complex licensing. Some of the Cubes-sats that have been launch in recent years are used like OSCAR satellites. Unfortunately most of them don't last enough or meet the necessary requirements to get an OSCAR number and designation in spite of using frequencies within the amateur radio spectrum allocation.

2.2.4 The International Space Station

Although it is not a simple satellite but in fact a spacecraft in orbit, the ISS has amateur radio equipment on board, mostly dedicated to be used in a program called ARISS[1]. This program is intended to allow communication with the crew of the ISS by students around the world and amateur radio operators since the crew members must also be licensed as amateur radio operators to participate. As mentioned before, most of the crew members, if no all, are holders of an amateur radio licence that allows them to use the station on board. When the crew is occupied with their routine duties, the radio station is operating in automatic mode as a digipeater to relay messages in packet radio to and from amateur radio stations. In chapter 4 there are some records of packet radio frames transmitted from the ISS and received in this station.

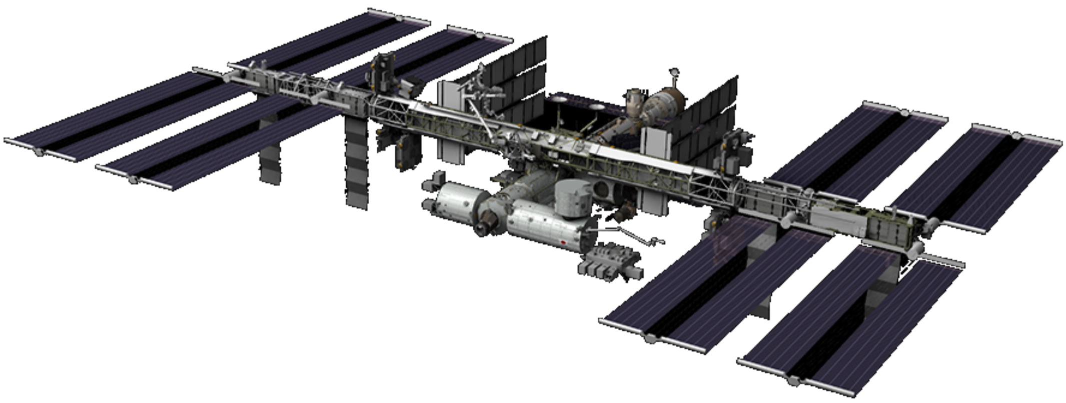

Figure 2.4: The International Space Station

[1]For more information check the website www.ariss.org

Chapter 3

Setting up the station

3.1 Antenna System

The antenna system used for satellite operation is divided in separate parts, one is a setup of Yagi-Uda antennas for VHF and UHF with a rotator capable of varying azimuth and elevation so it can track any satellite across the visible sky. Another part is a fixed parabolic antenna for the K_u band which is already pointed to a geostationary satellite. There is also antennas for Global Navigation Satellite System (GNSS) signals. All systems were setup using proper low-loss feed lines and protection against atmospheric discharges in spite of the existence of a lightning rod on the building.

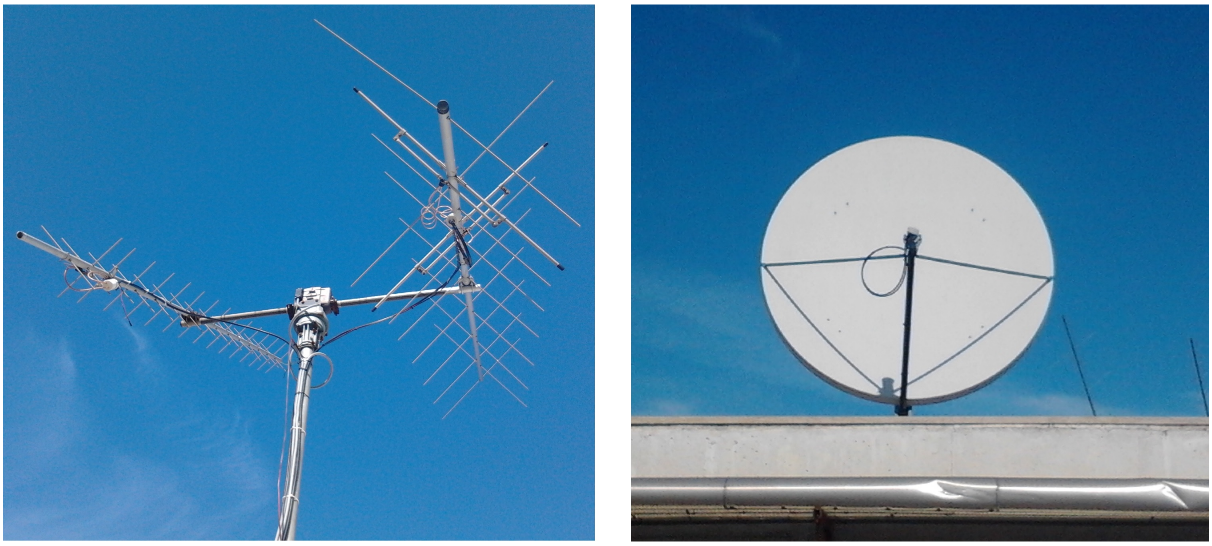

Figure 3.1: General view of the antennas at ISCTE-IUL

During the setup of the station, two antennas were mounted to receive signals from any GNSS constellations such as GPS. These antennas are connected to GPS receivers for experiments with differential GPS and academic studies related to other GNSS constellations. Some of the data collected is stored for remote access via internet allowing the cooperation and participation in projects with other universities.

Figure 3.2: GNSS Antennas

3.1.1 Yagi-Uda antennas for VHF and UHF

This antenna system includes a mast as support for a rotator with capability to move the antennas 360° in azimuth and 180° in elevation. There is an horizontal fiberglass boom that goes through the upper section of the rotator which provides elevation movement. The VHF antenna was placed on one side and the UHF antenna on the other one.

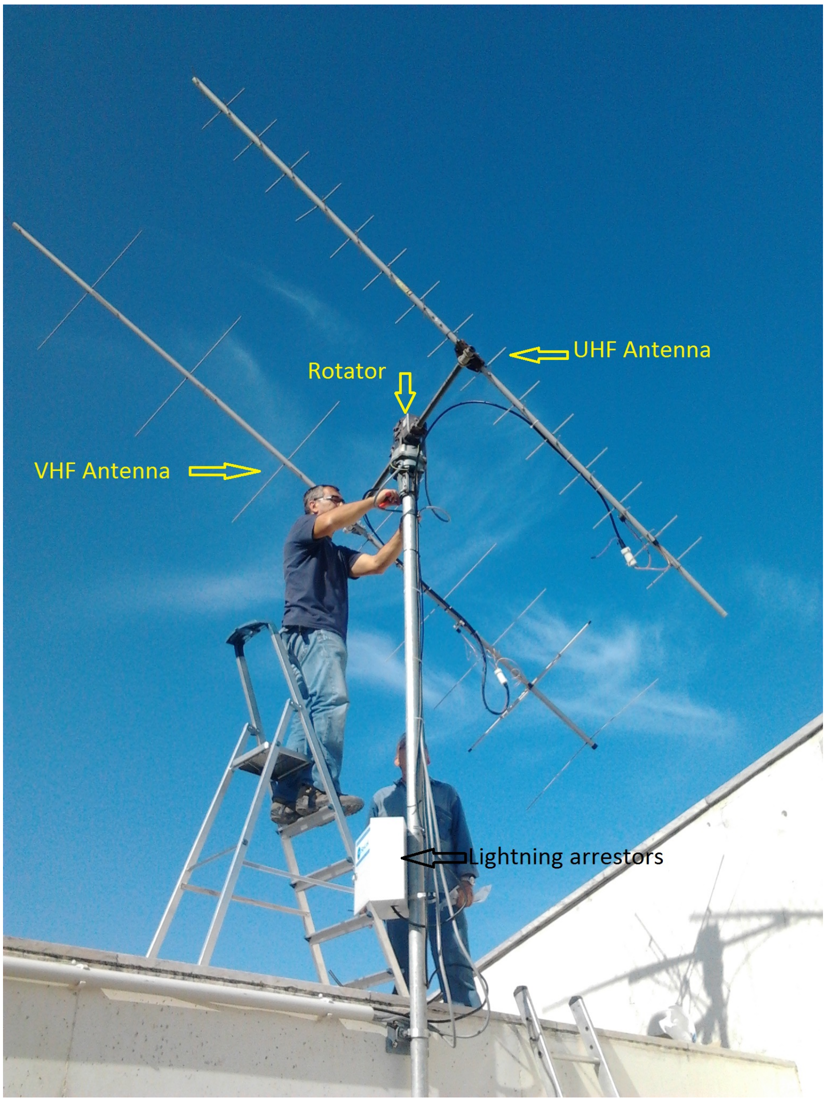

Figure 3.3: Assembling VHF and UHF antennas

This type of assemble of the Yagi-Uda antennas enables us to transmit using circular polarization. On each antenna (VHF or UHF) there are in fact two antennas supported in the same boom with their elements at 90°. The two antennas are also separated over the boom by a distance that corresponds to a quarter wavelength ($\frac{\lambda}{4}$). This can easily be seen checking the position of the driven elements. Doing so and driving both elements with this spacing, it artificially produces circular polarization with two linear polarization antennas. Obviously this circular polarization will be one of these, Left Hand Circular Polarization (LHCP) or Right Hand Circular Polarization (RHCP), depending on which antenna is ahead of the other. To be able to change from LHCP to RHCP (or vice-versa) one would have to change the antenna which is physically ahead to the back but, since the antenna elements are fixed to the boom, one must do this change electrically. Hence using a piece of coaxial cable cut exactly to half wave length ($\frac{\lambda}{2}$) and adding that to the coaxial cable feeding the antenna ahead, the phase difference imposed will make it seem like the antenna is a quarter wavelength ($\frac{\lambda}{4}$) behind and so the resulting electromagnetic field will be a circular polarized wave in the opposite direction. In this system, the piece of coaxial cable is added or removed from the feedline circuit using a relay, so it can be commanded from the radio room.

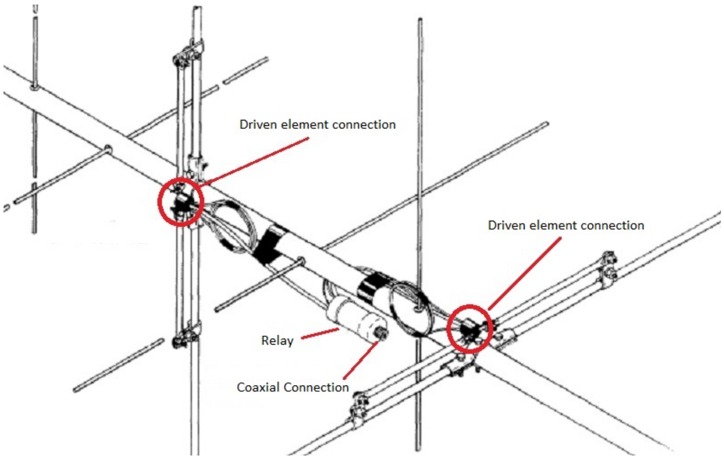

Figure 3.4: Driven element and relay connection on the VHF antenna

The reason for having the VHF and UHF antennas mounted side by side and on the same rotator is because most of the satellites used on these bands have the Uplink and Downlink frequencies on each band, for example to have Uplink on UHF and Downlink on VHF, therefore it is required to have both antennas pointing at the same satellite.

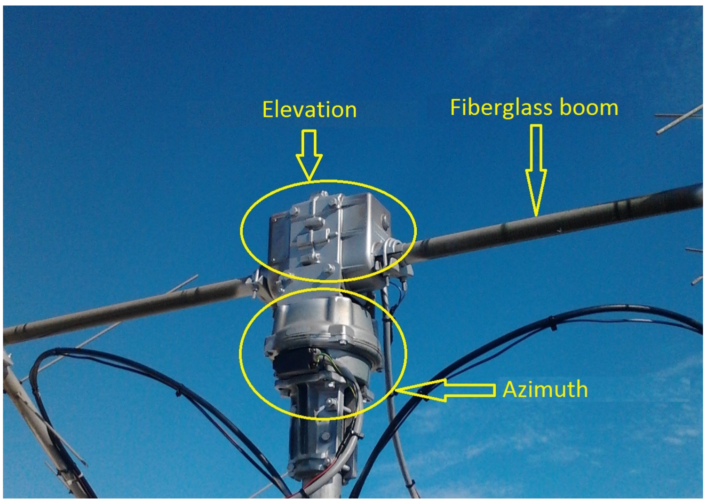

Figure 3.5: Rotator and antenna support

A little below, the rotator is tighten to the mast, where a box was mounted with lightning arrestors to protect the rest of the equipment from atmospheric discharges.

Figure 3.6: Lightning arrestors box

Beam adjustments

Just before having all things completely mounted it was needed to do some final adjustments to the bearings, so that the North corresponds to 180° in azimuth and the elevation also corresponds to the correct values on the control box. Unfortunately, only after the maintenance personal left, it was detected that the elevation was not properly set. At 0° the antennas were heading South, when they should be heading North. In spite of not being able to mechanically make the correction and after analysing the control circuit, it was found out that by swapping two wires, the elevation meter would now show the true heading of the antennas.

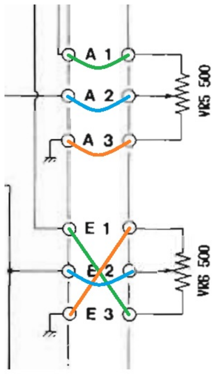

Figure 3.7: Rotator position sensor connections

Figure 3.7 shows part of the circuit diagram of the rotator and controller that corresponds to the connections between them. Inside the rotator there is a variable resistor that changes value as the rotator turns. There is a meter inside the control box that shows a reading proportional to the current in the circuit that varies with the resistor value. This is how the orientation of the antennas is shown. When the antennas were assembled they were heading North in azimuth but the rotator was at 180° in elevation, therefore when the system was put at 0° elevation it was beaming South contrarily to what was supposed to happen. It was necessary to go back to the roof and release the elevation boom, let the rotator run free for 180° leaving the antennas in the same place and then tighten the bolts again.

When this was found out, the mounting team had already left and the access to the roof is not very easy, as it needs authorization, so another solution had to be thought if the system was to be functional in a short time. Something had to be done so that the indicator could show the real elevation position. Knowing that what it does is to measure the voltage across the variable resistor that is on the rotator, if their wires were switched then it would switch the end of the scale with the beginning, swapping the positions corresponding to 0° and 180°. This solved the problem for the position indicator but then the "Down" command would in the reality lift the antennas up, so it was also necessary to swap the wires between terminals "E4" and "E5". Figure 3.8 shows the control connections in the final position with the problem solved, after everything was working correctly.

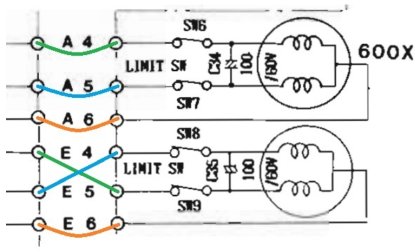

Figure 3.8: Rotator drive connection

A few months later, there was another problem with the antennas, because some strong winds forced the boom supporting the antennas to the elevation rotator to slip. That caused an error of almost 90°, so it was really necessary to correct it and verify if any other damage had occurred. Fortunately that was the only damage done by the wind and so the system was reoriented. We used this opportunity to make the corrections that lead to the cable switching which was restored to its original connection with the numbers matching the due cable and socket connections.

3.1.2 Parabolic dish for the K_u band

The station also includes a parabolic dish for use in the K_u band. This dish has $1,8m$ diameter and can be used transmitting and receiving, nevertheless it is presently setup only for receiving. There is also a separate coaxial cable already in place to connect the transmitter and amplifier for transmission with this antenna. To configure the transmitter on the K_u band it is necessary to know the exact frequency, bandwidth and modulation to be used, however a licence must be requested to use a satellite on that band for experimental purposes. Since that information depends on the experiment being done, the transmitter is not connected nor the amplifier fitted in the antenna feeder yet.

Figure 3.9: Parabolic dish

Looking at figure 3.10 the white box bolted to the support structure holds the lightnings arrestors. Figure 3.11 shows the inside of that box.

Figure 3.10: Parabolic dish and its support structure

It is imperative that all this systems are properly protected against atmospheric discharges.

Figure 3.11: Parabolic dish lightning arrestors

3.2 V/UHF antenna system

Several measurements were done to the Yagi-Uda antennas for VHF and UHF in order to determine their performance. Values of SWR, power and current consumption from power supply were taken along the band, which allowed us to build the table and graphics shown ahead. In appendix B there is a brief explanation about SWR and power.

3.2.1 VHF antenna analysis

A Standing Wave Ratio (SWR) and Power meter, model Pirostar SX-600, was used to read the values of SWR, as well as forward and reflected power at the output of the transmitter.

Figure 3.12: SWR and Power meter

A second value of SWR was computed based on the transmission line theory and the relation between forward and reflected power values. This relation is well known and is expressed in equation 3.1:

$$SWR = \frac{1 + \sqrt{\frac{P_{Ref}}{P_{Fwd}}}}{1 - \sqrt{\frac{P_{Ref}}{P_{Fwd}}}} \tag{3.1}$$

Considering that the maximum output power of the equipment is around 50W on VHF, it seems quite reasonable to assume that the computed value is more realistic than the SWR scale on the meter.

Freq. $[MHz]$	SWR Measured	Pwr Fwd $[W]$	Pwr Ref $[W]$	Current $[A]$	SWR Calculated
144,0	2,0	7,0	0,8	6,0	2,02
144,1	1,9	7,1	0,8	7,0	2,01
144,2	2,0	8,0	0,9	7,5	2,01
144,3	2,0	10,0	1,0	8,0	1,92
144,4	2,0	14,0	1,5	9,0	1,97
144,5	2,0	18,5	1,8	10,0	1,91
144,6	2,0	38,0	2,0	12,0	1,60
144,7	2,0	50,0	2,8	13,0	1,62
144,8	1,9	50,0	2,5	12,0	1,58
144,9	1,9	50,0	2,2	12,0	1,53
145,0	1,9	50,0	2,0	12,0	1,50
145,1	1,8	50,0	2,0	11,8	1,50
145,2	1,8	50,0	1,8	11,0	1,47
145,3	1,8	48,0	1,8	10,0	1,48
145,4	1,75	45,0	1,5	10,0	1,45
145,5	1,7	40,0	1,2	9,0	1,42
145,6	1,7	25,0	0,9	8,0	1,47
145,7	1,7	18,0	0,8	7,0	1,53
145,8	1,7	11,0	0,7	6,0	1,67
145,9	1,7	9,0	0,5	6,0	1,62
146,0	1,7	8,0	0,5	6,0	1,67

Table 3.1: Measurements on the VHF band

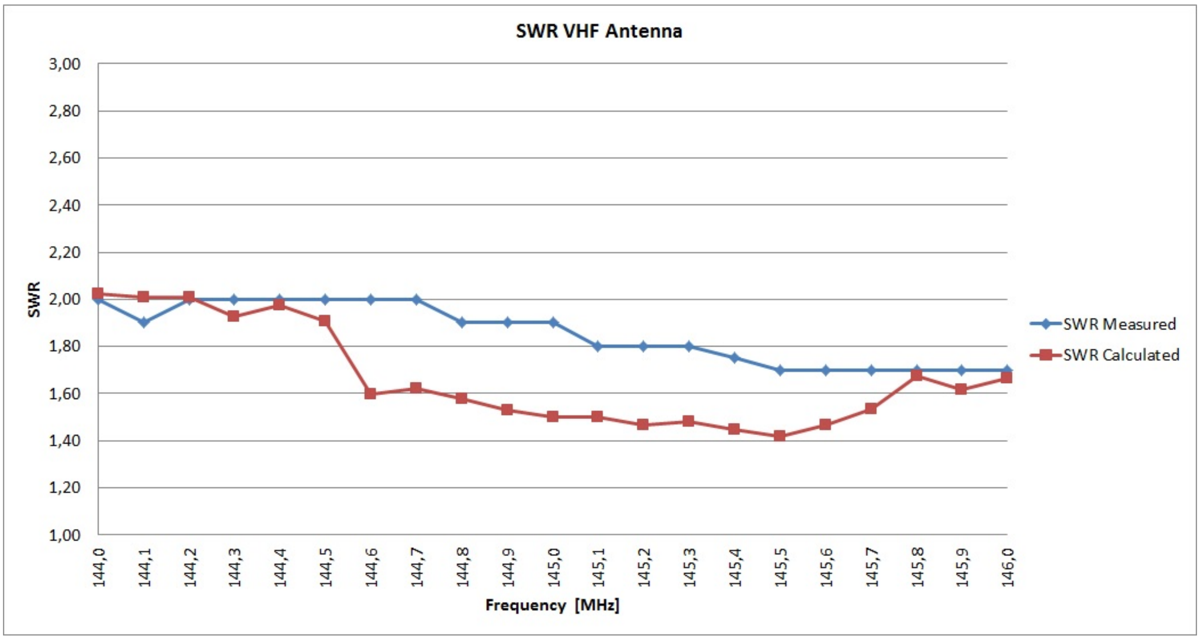

Figure 3.13: SWR readings on VHF

Comparing the values of SWR and Power one can confirm that if the SWR values go up, the output power decreases, this is due to the protection circuit built in the radio to prevent easily damaging the final power amplification stage.

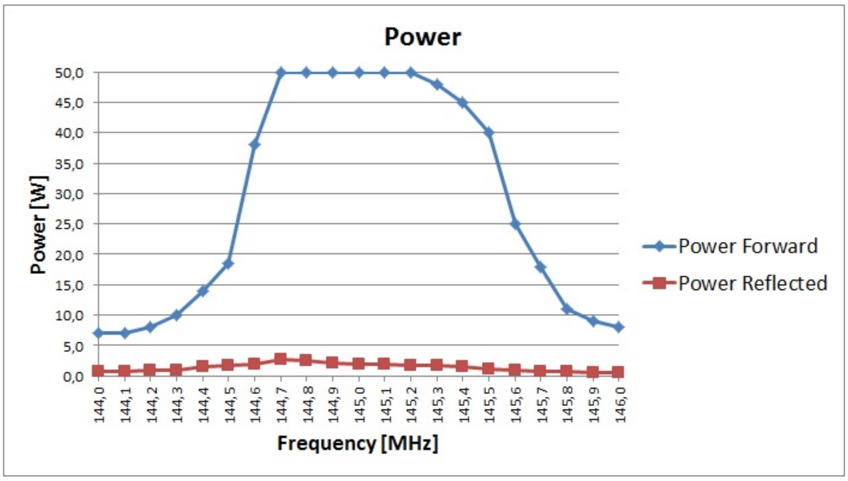

Figure 3.14: Power on the VHF band

The monitoring of the current intensity drawn from the power supply helps to evaluate the performance of the system as it normally increases as the output power increase. The graphic shows exactly that pattern, as the output power reaches its maximum so does the current reaches the top values.

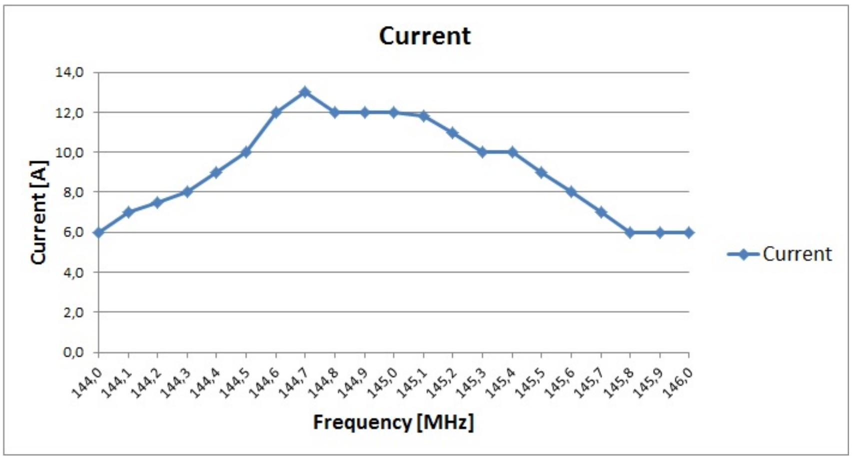

Figure 3.15: Current consumption

3.2.2 Conclusions about the measurements on VHF

Measures show a system with a value of SWR that is not perfect, but still within acceptable limits of a correctly tuned antenna. Some discrepancies from the values were found, according to the manual, although this type of measurements depend on the surrounding conditions and the better results obtained by the builder.

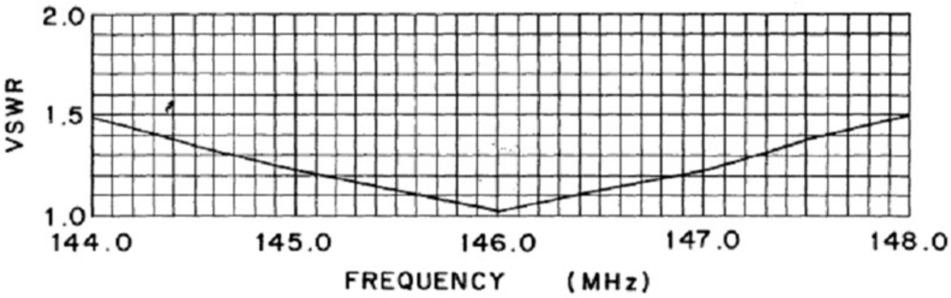

Figure 3.16: SWR according to the manual

Eventually there might have been some influence from nearby objects or the position of the cables near the feed point. On the station there is a linear amplifier that can be used to increase the output power (160W maximum) which has a built in protection to detect high SWR values and protect the electronic circuitry inside. During the tests made, the SWR protection was never turned on which means that the antenna is well tuned.

3.2.3 UHF antenna analysis

Measurements made on the UHF band shown on table 3.2 revealed that this antenna was a little out of tune. This mistuning might have been caused during the transport of the antennas with partial dismantle and then reassembled again. The antennas were only now tested and it is necessary to make an adjustment, although not critical, so they can still be used like this. As any other system exposed to the elements, this will require a periodic maintenance, so the fine tuning of this antenna system will be made on the next intervention.

Freq. $[MHz]$	SWR Measured	Pwr Fwd $[W]$	Pwr Ref $[W]$	Current $[A]$	SWR Calculated
430,0	2,00	25,0	2,0	9,5	1,79
430,5	1,80	12,5	1,0	9,5	1,79
431,0	1,90	11,0	1,0	11,0	1,86
431,5	2,30	14,0	2,0	13,0	2,22
432,0	2,60	29,0	4,0	15,0	2,18
432,5	2,70	40,0	6,5	15,0	2,35
433,0	2,50	50,0	6,8	14,0	2,17
433,5	2,20	20,0	2,0	8,5	1,92
434,0	1,90	11,5	1,0	9,0	1,84
434,5	1,90	10,5	1,0	10,0	1,89
435,0	2,10	13,0	1,5	12,0	2,03
435,5	2,50	30,0	4,0	14,5	2,15
436,0	2,50	45,0	6,0	14,0	2,15
436,5	2,30	48,0	5,0	14,0	1,95
437,0	2,00	18,0	1,5	9,0	1,81
437,5	1,75	11,5	0,9	9,5	1,78
438,0	1,90	11	1,0	10,5	1,86
438,5	2,20	16	2,0	12,0	2,09
439,0	2,60	35	5,0	12,0	2,22
439,5	2,70	45	6,5	15,0	2,23
440,0	2,50	35	4,5	10,0	2,12

Table 3.2: Measurements on the UHF band

As done before with the VHF antenna, two values of SWR were registered, one directly measured from the SWR scale on the meter and other calculated based on the relation between forward and reverse power.

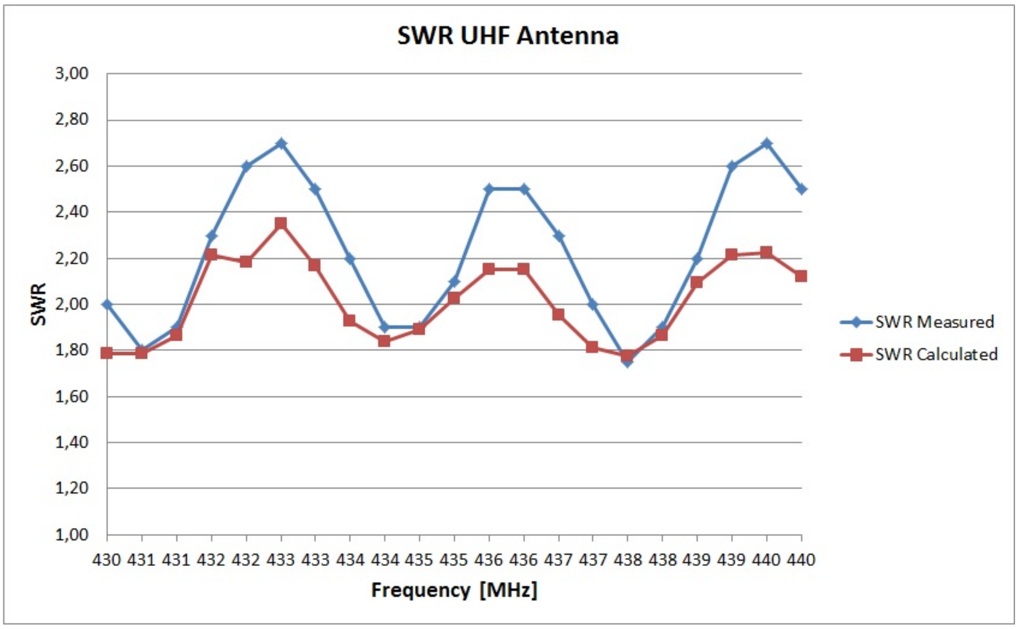

Figure 3.17: SWR readings on UHF

Comparing those values with the output power, one can say that the calculated value might be more correct as the output power really reaches its maximum values.

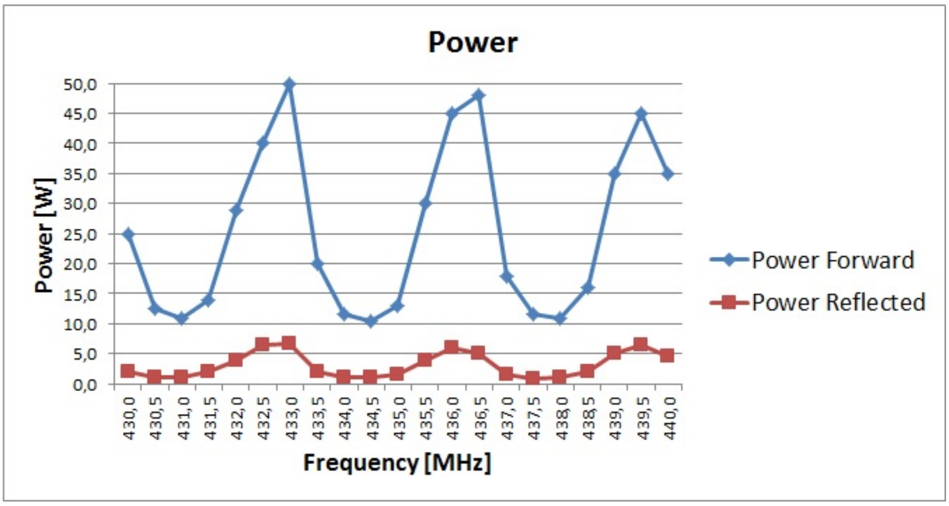

Figure 3.18: Power on the UHF band

Once more, the current consumption was registered as well to confirm that it had the same pattern of the output power confirming that there were no mistakes in the readings or any malfunction with the radio equipment.

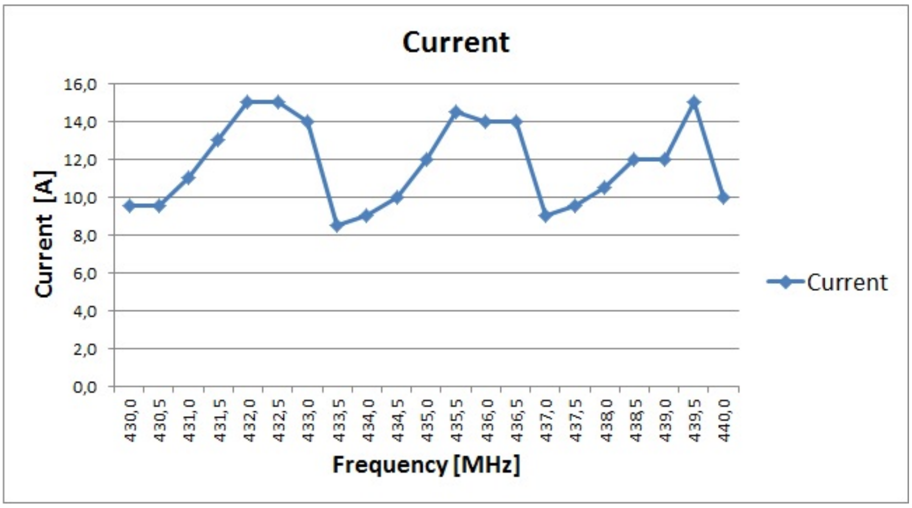

Figure 3.19: Current consumption

3.2.4 Conclusions about the measurements on UHF

The UHF antenna shows a strange SWR pattern, however it does not mean that it does not work. The antenna obviously will not perform perfectly but the receiving tests made were successful so the system operation is not compromised. However it is intended in the next maintenance routine to check what is causing these WR values.

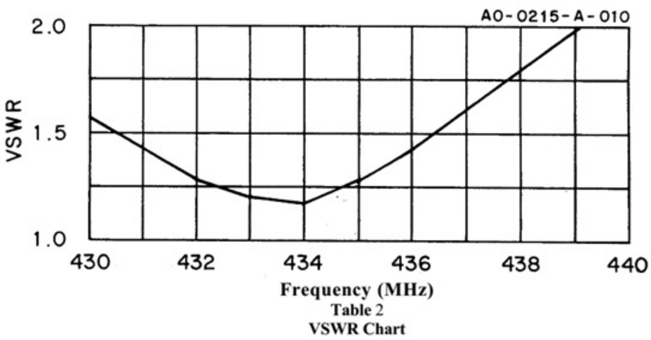

Figure 3.20: SWR according to the manual

3.3 GNSS station

The GPS is one of the most important satellite systems used worldwide, amongst the other GNSS constellations able to be received such as GLONASS and GALILEO and with a relevant importance in the study of satellite systems. For this reason there are two GNSS antennas available for use in the station, having already been used by some students and academic staff for research. As an example, there is already an automatic system controlled by a Raspberry Pi (single board computer) collecting data using a GPS receiver (Ublox evaluation kit) and sending it to a server accessible via internet.

Figure 3.21: Ublox GNSS Receiver

3.4 Radio laboratory

The radio room hosting the station was established as a result of an agreement between ISCTE-IUL and AMRAD. The antennas were placed on the top of the building and our room is just two floors below. There were some arrangements that needed to be done to get the cables through walls and ceilings. Some cable raceways were placed on the room walls to guide the RF and control cables from the antenna system, and others to increase the number of power sockets in the room, which was then prepared to accommodate the equipment of the radio laboratory.

3.4.1 Equipment in the radio lab

This room holds equipment such as radios, meters, amplifiers, computers and even a cabinet for rack mounting devices such as the transceiver for K_u band or GNSS receivers.

Figure 3.22: General view of the room

There is also a shelf to store a few books and instruction manuals of the existing equipment.

In the room there are also tables and chairs for the people working regularly in the station and a small round table for meetings or assisted demonstrations. A movable bench was used to put the main transceiver in use, along with the power supply units, an amplifier for VHF, SWR/Power meter, packet modem, PCs and monitors. We also have two PCs that are used as servers with remote access for simulation. There are plans to setup a video wall in the near future to give a better view of all the information and data received from the various systems implemented.

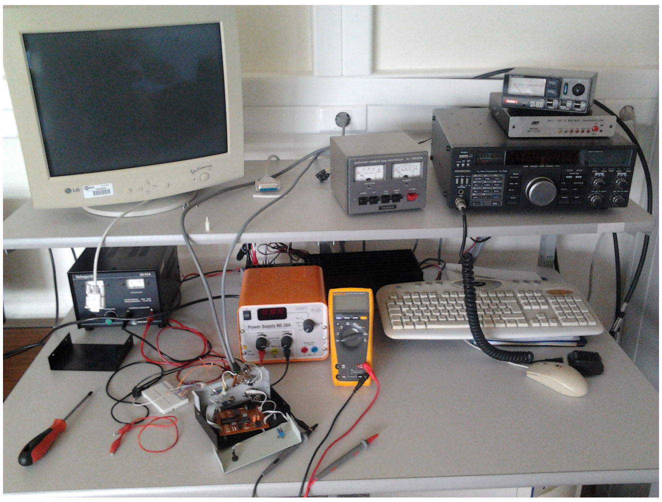

Figure 3.23: Aspect of radio bench while working on the interface

3.5 Rotator connection and control interface

The rotator is capable of turning the V/UHF antennas in both azimuth and elevation allowing to track satellites on non-geostationary orbits. The rotator control box has an 8-pin DIN connector on the back that provides the reading of the position and control of the movement in all directions. The reading of the position is done through the measurement of voltages, proportional to its position and the commands to move the rotator are done by grounding four of the pins. It works just like pressing the front panel buttons (*Up,Down,Left and Right*). All that is needed to control the rotator from a PC is an interface between this 8-pin DIN connector and any of the PC ports (USB, serial or parallel). The interface should also provide any electronics necessary to convert voltage values, isolation or any other adaptations needed.

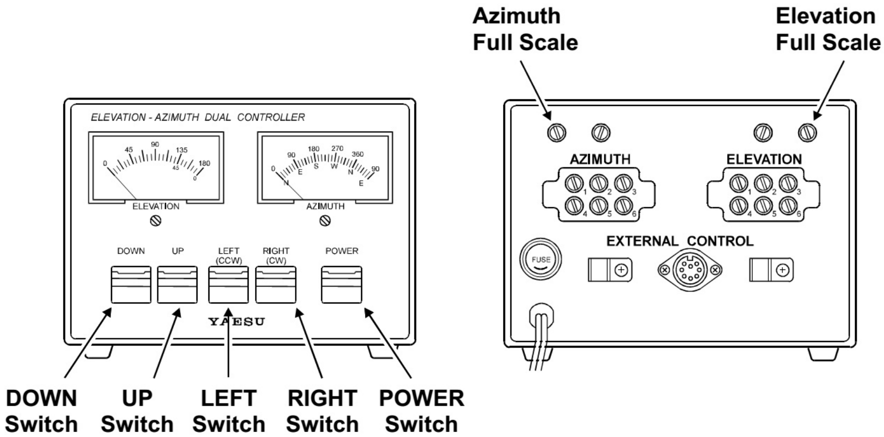

Figure 3.24: Front and back of rotator controller, as shown in the manual

Foreseing this, a small interface was built to work with any microcontroller such as an *Arduino*, so it could read the voltages that represent the position and turn the rotator accordingly. Any software developed that can interact with the microcontroller development board can then be used to control the rotator. There are two voltages that can be read from the control system, one represents the azimuth position and the other one the elevation. These voltages are measured at the control box and they change according to the position of a variable resistor inside the rotator itself. This is influenced also by the resistance of the cables so there are two variable resistors that can be adjusted to set the maximum voltage at full scale of the meter to a value up to 6V, which is the value of the voltage regulator used in the circuit. For better compatibility with the voltages used by the microcontroller circuit, the end of scale value was set to 5V on each one.

In our case and having the antenna azimuth centered at North, the 0V position corresponds to the leftmost side of the meter, which is South. As the voltage increases it means the rotator is moving the antennas clockwise towards West and at 2,5V (center of the meter) it will correspond to North until it passes by East and finally reaches again South at the end of the scale, which corresponds to 5V. The same happens with the elevation, with 0V for 0°, 2,5V for 90° and 5V at the end of the scale corresponding to 180°. This correspondences between voltages and degrees can be seen in figure 3.25.

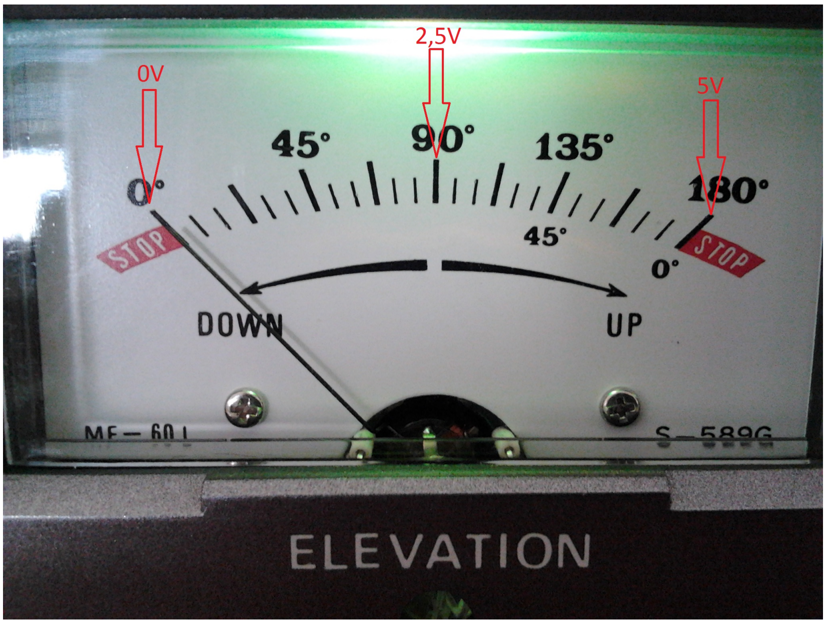

Figure 3.25: Correspondence of Degrees to Voltage

Dividing the obtained voltage by the angle we obtain the value of variation for each degree or other minimum quantity used to start the adjustment movement (ever 2 or 5 degrees). The voltage is read by the microcontroller and translated to a certain direction that is then compared with the correct direction to track the satellite. From there it can be decided which control action should be taken to point the antenna to the satellite. The tracking software sends a frame of bytes with the correct position of the antennas using a pre-established format that is decoded by the microcontroler and computed along with the values read from the rotator control box. If it is necessary to move the antenna upwards, then a signal is sent to the output port on the microcontroller board in order to ground the pin from the 8-DIN plug that corresponds to the *UP* command. To make sure that the voltage present at the pin that needs to be grounded or the current that is drained does not represent any hazard to the microcontroller output port, an interface with transistors working as switches was projected and implemented to work in between. A measurement of the voltage and current present at the control pins was made and the values were $15V$ DC and $1,3mA$ of current when grounded, therefore it is better to use a small transistor as a switch to avoid direct contact of the 15V with the pins of the microcontroller. The output port of the microcontroller will be set to 5V when the switch must be closed or to 0V if the switch should remain open, therefore toggling the transistor between conduction or cut.

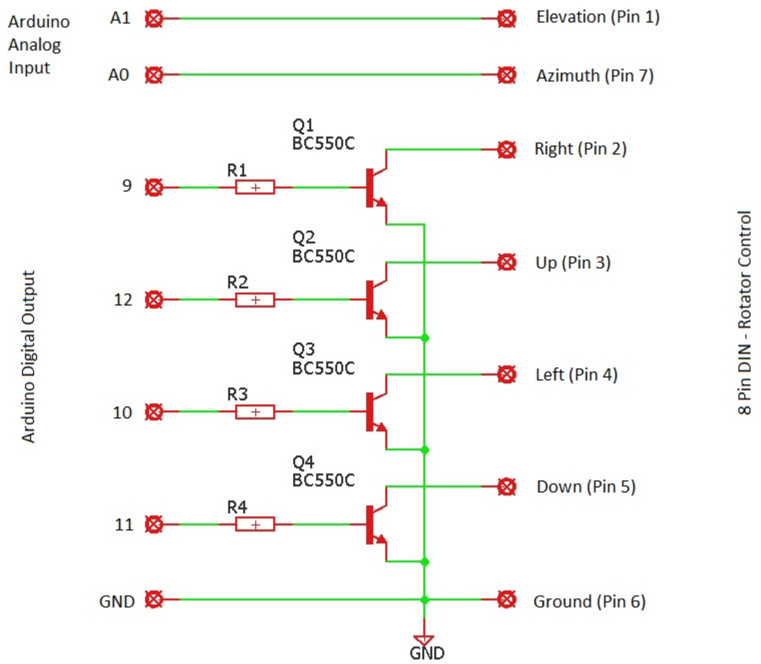

Figure 3.26: Circuit Diagram for Arduino Rotator Interface

Dimensioning the circuit

The choice of the transistor was basically made having in mind a general purpose Bipolar Junction Transistor (BJT) already known to be used in similar circuits, so the choice fell over the BC550. To use the transistor as a switch it is intended to have minimum voltage drop between Collector and Emitter when conducting in the saturation region. After analysing the datasheet it has been found out that the minimum (typical) $V_{CE_{sat}} = 0,09V$ would occur with $I_b = 0,5mA$ and $I_c = 10mA$. Knowing that que Arduino has a standard value of 5V in the digital output ports the next step was to calculate the value of the resistance to get $I_b = 0,5mA$ in the circuit as it is shown in figure 3.27.

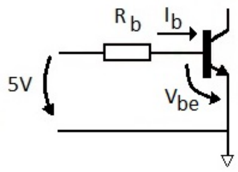

Figure 3.27: Base current circuit

Applying the Kirchhoff Voltage Law to the network will compute:

$$\begin{aligned} 5 &= R_b \times I_b + V_{be} \\ \text{since} \quad V_{be} &= 0,7V \quad \text{and} \quad I_b = 0,5mA \\ 5 &= R_b \times (0,5 \times 10^{-3}) + 0,7 \\ R_b &= \frac{5 - 0,7}{0,5 \times 10^{-3}} \\ R_b &= 8,6k\Omega \end{aligned} \tag{3.2}$$

This is how it was determined the ideal value of R_b. Obviously the real value would be in accordance to the resistor series available but never far away from keeping the V_{ce} as low as possible, so the choice was to use $8,2k\Omega$ resistors. Tests later revealed that everything worked as expected, Figure 3.28 shows the board already assembled during tests with the Arduino and rotor control.

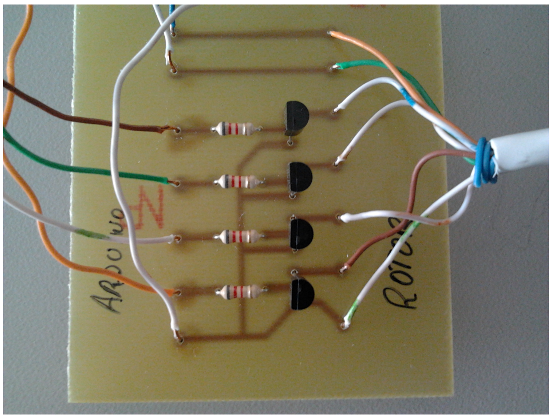

Figure 3.28: Interface board

Chapter 4

Operation with the station

After setting up all the antennas and the equipment in the radio room, the next step was to install software for satellite tracking and to decode the transmissions. Some voice communication are also possible though the voice activity on the ISS is not very frequent and most of that is done with scheduled contacts with schools. Also, most of the active satellites are using sub-audible tones for activation and the transmitter in this station is not yet equipped with that capability although that can be added later on.

4.1 Images received from NOAA satellites

4.1.1 What is an NOAA satellite

One of the most interesting signals that can be received are from de National Oceanic and Atmospheric Administration (NOAA) satellites that capture images from the Earth. The NOAA satellites are LEO satellites dedicated to take images from the earth which transmit them immediately after being captured. This images combine various data, from plain optical image to infra-red so they can all be combined and used in weather information and forecast. The frequencies used are within 137MHz - 138MHz and can be received using an FM receiver for that band. The audio signal captured is feed into a PC soundcard so it can be decoded to build the images. Some of these transmissions are sent using geostationary satellites to provide a better service for customers and they must pay a subscription to have access to those transmissions. With our station we can receive them for free and directly form Low Earth Orbit (LEO) satellites. The currently active NOAA satellites are the NOAA-15, NOAA-18 and NOAA-19.
The transmissions from these satellites can be receive using the frequencies listed below:

- NOAA-15: $137,620MHz$
- NOAA-18: $137,9125MHz$

- NOAA-19: $137,100MHz$

The NOAA-19 is obviously the most recent of the group but any of them gives good quality image transmissions.

Figure 4.1: Satellite NOAA-19

4.1.2 Software WXtoImg

The WXtoImg is the most popular software dedicated to decode signals from NOAA satellites. It can be downloaded from the internet [1]. There are three versions, the base version, the professional version and a free version which is the one used in our station and with satisfying results. The paid versions have a little more image processing to compensate for lack of bandwidth and may also use interfaces to connect hardware such as radios, rotators or GPS receivers. With our station operational it was possible to receive and decode several images from satellites NOAA-15, NOAA-18 and NOAA-19, some of them are shown in figures 4.2 and 4.3.

[1]Download is available from the official web site www.wxtoimg.com

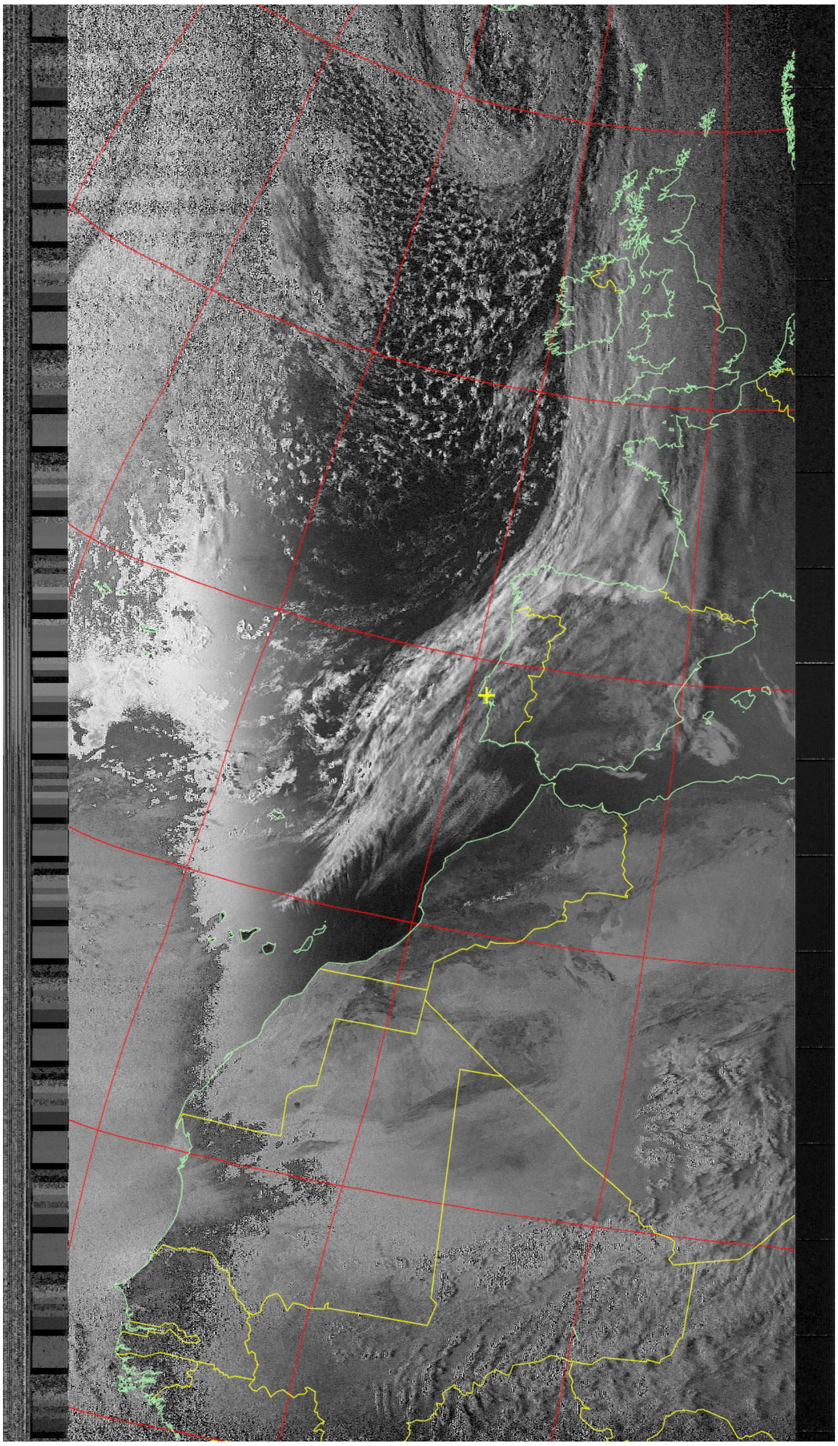

Figure 4.2: Image captured from NOAA-18

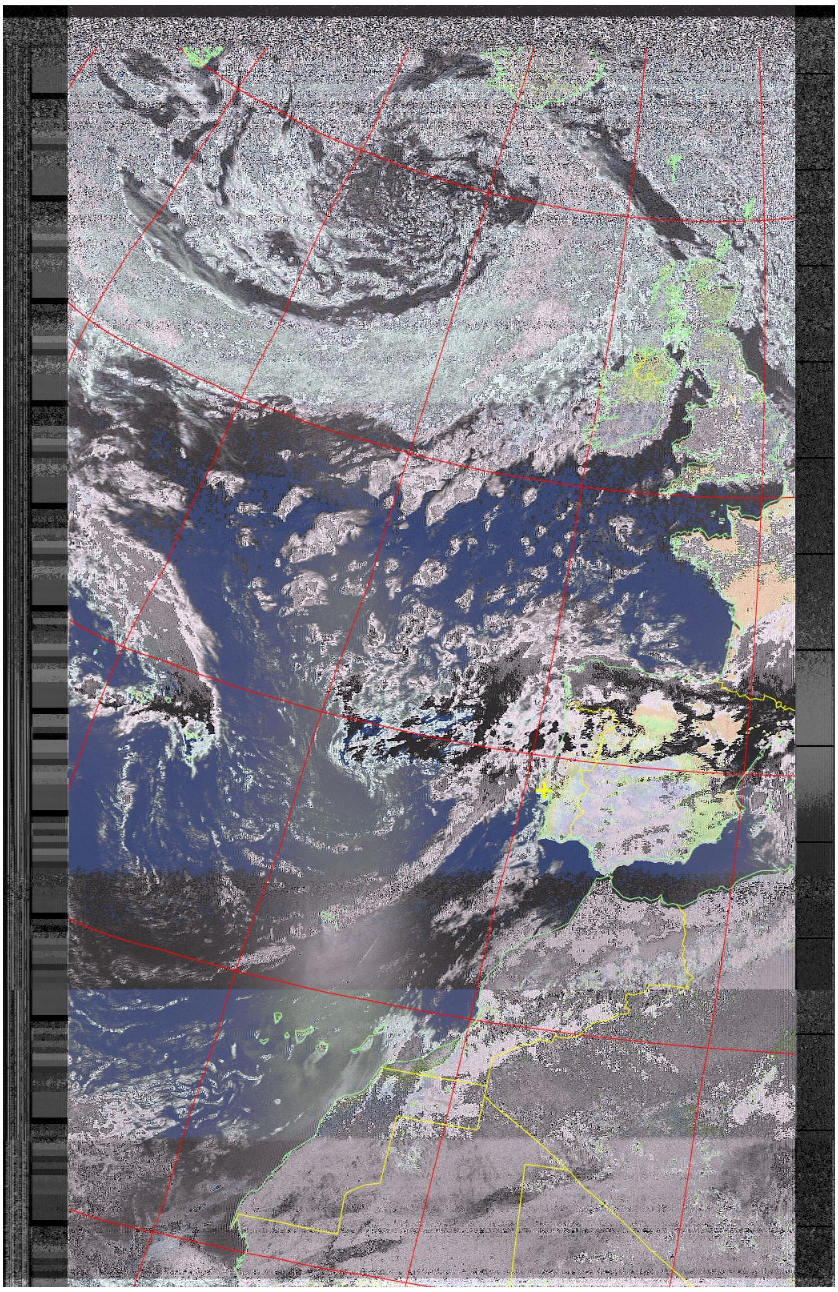

Figure 4.3: Image captured from NOAA-19

4.2 Data received from satellite AO-73

4.2.1 Description of the AO-73

The Cubesat AO-73, also known as FUNcube-1 is a 1U cubesat ($10 \times 10 \times 10cm$) built in a joined venture of British and Dutch entities, it was launched on November 21^{st}, 2013 on a Dnepr rocket. AO-73 was placed in a $682 \times 595km$ sun-synchronous orbit, inclined $97,8°$. An image of the satellite can be seen on figure 4.4.

Figure 4.4: Image of AO-73 (FUNcube-1)

The AO-73 was built with educational purpose, it has an inverting SSB/CW transponder with $300mW$ PEP (on eclipse) and a telemetry beacon on $145,935MHz$ BPSK $30mW$ (on eclipse) or $300mW$ (illuminated). Its transponder frequencies are:

- Uplink: $435,150 - 435,130MHz$
- Downlink: $145,950 - 145,970MHz$

The fact of being an inverting transponder means that it will invert the mode and the band edge, for example an uplink LSB signal on $435,155MHz$ would be sent downlink on $145,965MHz$ USB. Apart from this, there is still the Doppler shift correction that has to be done. Usually one should compensate the Doppler shift adjusting the uplink frequency to try to maintain the downlink frequency to avoid interference with other users.

4.2.2 Receiving telemetry signals from AO-73

For telemetry reception it is necessary to install the software that was built for that purpose which is called "FUNcube-1 Dashboard". The software is free and can be downloaded from the internet. Several tests of reception of telemetry from AO-73 were made with the station and an example of the data received is shown in figure 4.5.

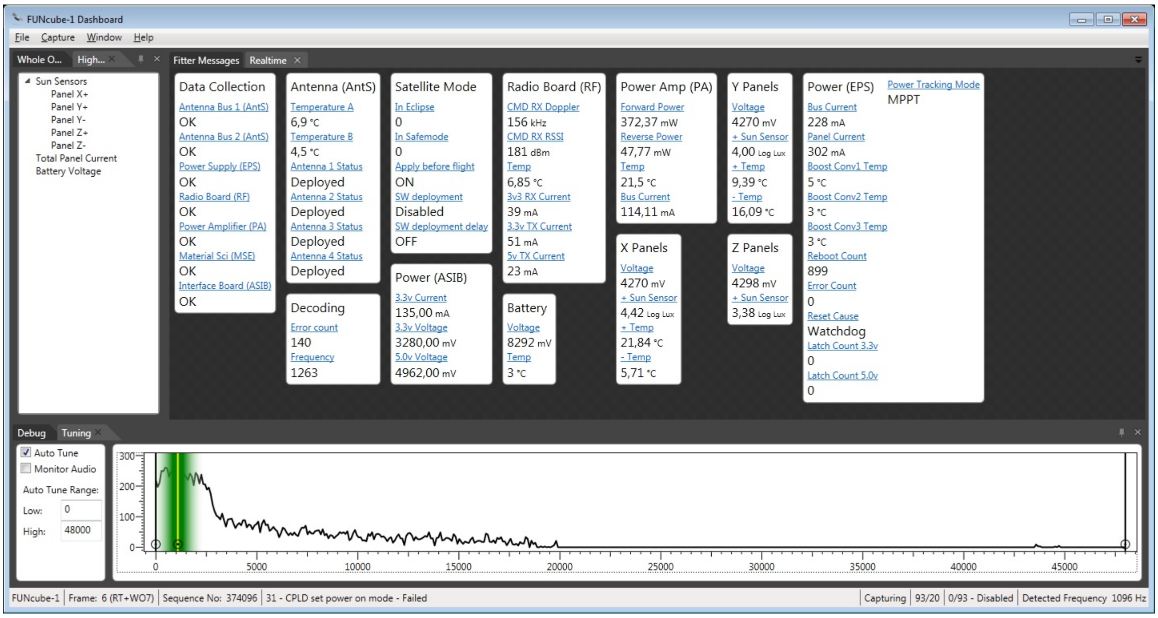

Figure 4.5: Decoding AO-73 Telemetry

4.3 Data received from satellite Delfi-C3

4.3.1 Description of CubeSat Delfi C3

This satellite fits in the category called "CubeSats" which implies that que shape is of a small cube or group of $100 \times 100 \times 100mm$ cubes and with a mass of about $1,33Kg$. It was built at Delft University of Technology as part of satellite development project called the Delfi program[2].It was launched on April 28^{th}, 2008 from India. This in particular is a 3-unit CubeSat, hence the number "3" in the designation and is built as a stack of 3 cubes. It has a total structure length of $326,5mm$ and a cross-section of $100 \times 100mm$, although the total external length is $340,5mm$, which includes the support feet at both ends.

This satellite was intended to be used as a transponder and obviously with capability to transmit telemetry about the status of the system. Since it was launched in 2008, some of its features have already become inoperative but its primary telemetry transmitter is still operational during sunlight periods on the following frequency and mode: $145,870MHz$, 1200 Baud BPSK, AX.25[3] $100mW$. Using the proper software to decode the transmission, one can connect the audio signal from the radio to the input of a PC sound card and decode the telemetry.

[2] Consult www.delfispace.nl for more information about the Delfi program

[3] AX.25 is a modified version of the X.25 protocol, for more information see bibliography [8]

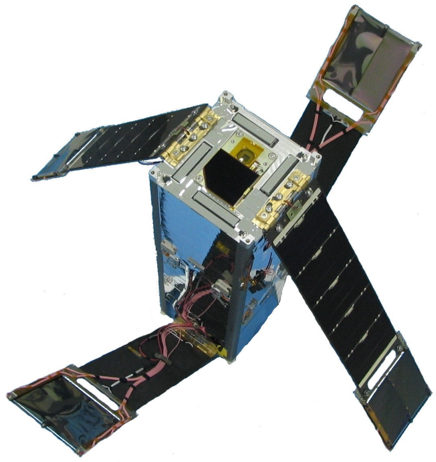

Figure 4.6: Delfi-C3

4.3.2 Software and Data

The software used was specially designed to receive Delfi-C3 telemetry and is called RASCAL (version 1.1.1). It requires Java runtime environment and runs in several operating systems (Windows, Linux, Mac OS, etc). When the audio signal from the radio is connected to the PC soundcard it is then necessary to adjust the frequency to compensate the Doppler shift to receive the telemetry.

The software RASCAL expects a BPSK signal with a center frequency of $1600Hz$ therefore when receiving on USB mode one must tune the receiver $1600Hz$ below the real transmitted frequency signal as well as compensate for the Doppler shift. The RASCAL has itself a small capacity to deal with the Doppler shift but only up to $\pm 200Hz$ which may not be enough, so frequency adjustment on the receiver is still required as the Doppler shift on VHF can go up to $\pm 3500Hz$. Once the frequency is correctly adjusted the software will show the "sync" with the light green on the "Frequency" box meaning that the telemetry packets are starting to be decoded. Looking at the "Terminal" area, one can see the AX.25 packet frames. The center area of the screen is full of small windows with telemetry information such as temperatures, voltages, etc. All the information received can later be sent to the Delfi program staff to help them with the project. The RASCAL software uses the anonymous "guest" account by default for submitting decoded telemetry, however, users are encouraged to request a user account specifying some base information including Name, Callsign and Locator (Maidenhead gridsquare).

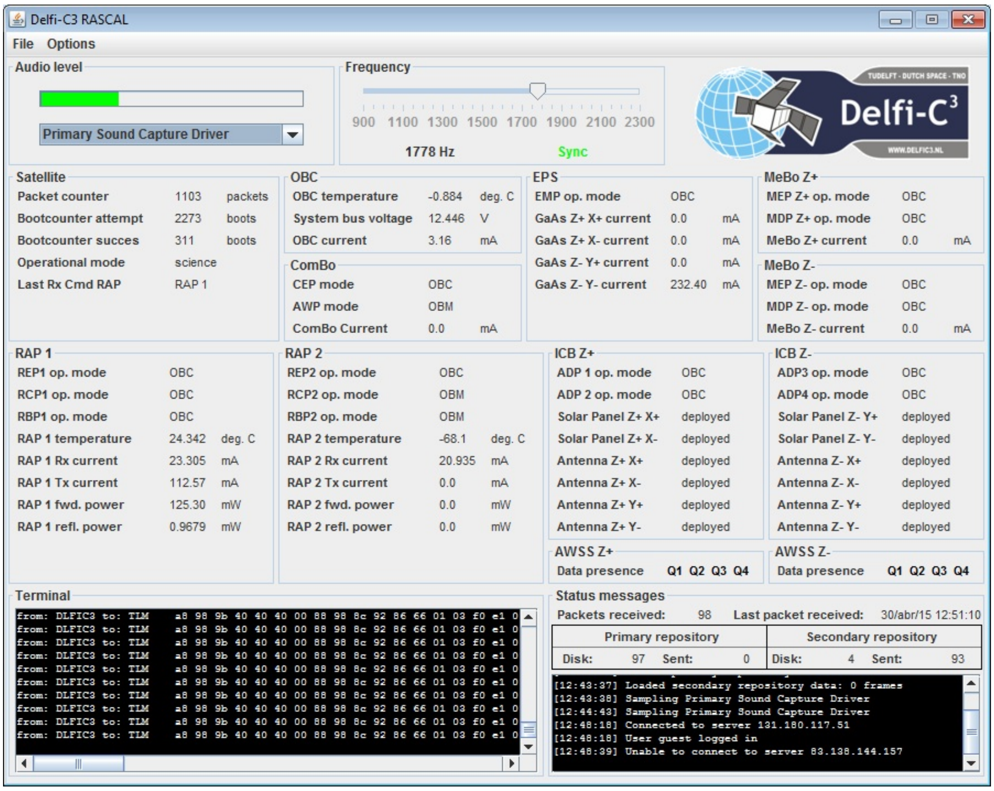

Figure 4.7: Receiving telemetry from Delfi-C3

4.4 The International Space Station (ISS)

The ISS is most of the time available only as a packet radio repeater since the crew is usually busy and can not spend much time operating the station. Furthermore, there are already schedules for contacts between the ISS and schools that fill most of the time the astronauts spend on the radio. Nevertheless there is always the possibility to get lucky and manage to make a voice contact with one of the astronauts. Unfortunately by the time this dissertation was completed we did not get any chance of contacting the ISS.

4.4.1 Packet radio from the ISS

As mentioned previously, the ISS has its radio equipment working as a packet radio repeater so at least we managed to record some transmissions that can be shown in figure 4.8.

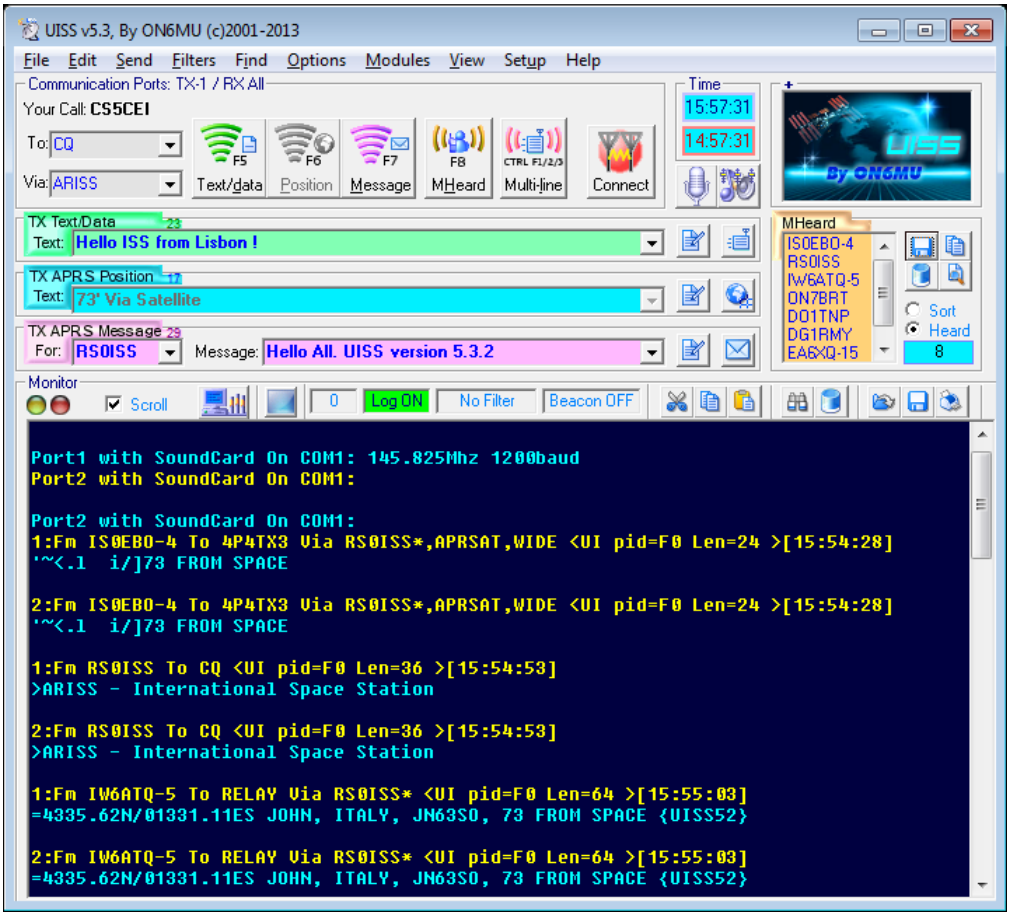

Figure 4.8: Receiving Packet Radio from the ISS

The lines in the lower part of the screenshot show the traffic to and from the ISS automatic repeater. This was done using a packet radio software called UISS specially made to use with the ISS. The interface used is the PC soundcard and the software is capable of decoding the packet frames directly from the audio coming out of the speaker connection. Looking at the screenshot, near the top right corner there is a small box with the title "MHeard" where the callsigns of the stations heard using the ISS as a packet repeater are listed.

4.5 Direct radio contacts (not via satellite)

In spite of its actual setup being mostly oriented to satellite operation it is also possible to use it for direct communications with other stations. The station has an official amateur radio callsign given by the Portuguese national authority (ANACOM) which allows any holder of an amateur radio license and member of the IT/ISCTE-IUL to operate it and establish radio contacts with other stations. As a demonstration of that capability and particulary exploring some rare propagation phenomena that occurs only when certain conditions arise, such as tropospheric ducting or sporadic-E reflection.

A small logbook with contacts was made and presented in table 4.1 where are listed chronologically. The *Call* field identifies the callsign of the station, just like CS5CEI is the call from the station at IT/ISCTE-IUL, the frequency is show in MHz, the *Mode* refers to the type of modulation (**U**pper **S**ide **B**and or **C**ontinuous **W**ave). The *RST* is a type of signal strength and audio quality evaluation based on three parameters the ***R**atio **S**ignal and **T**one* , the first is the audio quality classified by the listener and it is measured in a scale from 1 to 5, being 1 imperceptible and 5 totaly perceptible, the second refers to the signal strength shown in the equipment meter and finally the third describes que quality of the tone from 1 to 9 being 1 the worse and 9 the best as a clear audio note and it is not used in voice communications but only on Morse code or digital transmissions. The *S* or *T* in the logbook top is just to distinguish the report **S**ent from the report **R**eceived. Finally there is the *Locator* which is explained in appendix C, and refers to the geographic location of the station.

Date	Time	Call	MHz	Mode	RST-S	RST-R	Locator
26-06-2015	14:55:00	CT2JVP	144,300	USB	59	59	IN51qc
30-06-2015	12:46:00	EA8DBM	144,300	CW	559	559	IL18oh
08-07-2015	15:55:00	EA8TJ	144,280	USB	59	53	IL19rj
22-06-2016	09:33:00	EA8AVI	144,300	USB	59	59	IL28fc
22-06-2016	09:46:00	EA8TJ	144,300	USB	55	55	IL18rj
29-06-2016	13:25:00	F4FHV	144,300	USB	59	55	JN15or
29-06-2016	13:27:00	F0FYP	144,300	USB	55	55	JN37lo
29-06-2016	13:35:00	F5DQK	144,300	USB	57	58	JN18gr
29-06-2016	13:37:00	PA5Y	144,300	USB	55	57	JO21vo
29-06-2016	13:42:00	F4ALP	144,300	USB	55	55	JO10op
29-06-2016	16:28:00	PA4EME	144,290	USB	59	59	JO20wx
29-06-2016	16:28:00	DL1KDA	144,290	USB	59	59	JO30ep
29-06-2016	16:28:00	DK1VC	144,290	USB	59	59	JO31rg
29-06-2016	16:29:00	DK9TF	144,290	USB	59	59	JO31nf
29-06-2016	16:30:00	DL9DBJ	144,290	USB	55	55	JO21vh
29-06-2016	16:31:00	F5DQK	144,290	USB	55	55	JN18rg
29-06-2016	16:32:00	DL6YBF	144,290	USB	57	59	JO31ox
29-06-2016	16:33:00	ON5DRE	144,290	USB	57	59	JO20kw
29-06-2016	16:34:00	F8DLS	144,290	USB	59	58	JN11se
29-06-2016	16:36:00	PA3BIY	144,290	USB	59	59	JO22hb
29-06-2016	16:36:00	PA3EAQ	144,290	USB	55	55	JO31ci
29-06-2016	16:37:00	F5GNR	144,290	USB	55	55	IN87ji
29-06-2016	16:43:00	PE1ITR	144,300	USB	59	59	JO21qk
29-06-2016	16:43:00	ON8AB	144,300	USB	59	59	JO10tw
29-06-2016	17:14:00	PD1AHM	144,290	USB	59	59	JO21wf

Table 4.1: CS5CEI - Logbook

4.6 Operation

Operating the station requires the use of hardware and software that must be turned on and running. In this chapter it has already been described which satellites have already been tracked and what software was used. Since the station can receive several signals from different satellites, the PC controling the station has software to decode and store data, specially when dealing with telemetry from cubesats. However, the procedures to receive are quite similar and most of the time the only difference is exactly in the software running to decode the signal. All signals are injected to the PC using the external speaker output from the receiver connected to the soundcard input, so to monitor the audio it has been connected a pair of speakers to the soundcard output. These speakers are not mandatory since the station can be operated remotely and no one is there to listen, but when the operator is present at the station it can be helpful to listen to the audio coming from the radio. The hardware used for most of the operation is the V/UHF transceiver since it can be used for several satellites and modes of communication. Only the GNSS and the Ku systems have each one dedicated receiving equipment. The following section shows an example of all the steps that must be done to receive a signal from a satellite.

4.6.1 Example of operation

As an example, it will now be described how to receive an NOAA satellite transmission using the station with automatic tracking of the satellite. Apart from the powering of the equipment, everything else can be done remotely by accessing the PC that controls the system via internet. A list of procedures to start up the hardware system can be listed below:

- Turn on the PC that controls the station.
- Turn on the DC power supply and the radio.
- Turn on the Arduino (just plug in the DC adapter).
- Turn on the Rotator control.

After this, it should be started the software, there are icons on the desktop for each of this actions for easy access:

- Start the satellite tracking software Orbitron.
- Start the WiSP DDE Client software.
- Start the software WXtoimg, which decodes the signal from the NOAA.

Figure 4.9: Icons to click on the desktop

Now that all necessary software is running, one must choose which satellite is going to be tracked and received. In this example let us assume that is the NOAA-19, so in Orbitron we click on the NOAA-19 icon from the list on the right side of the screen.

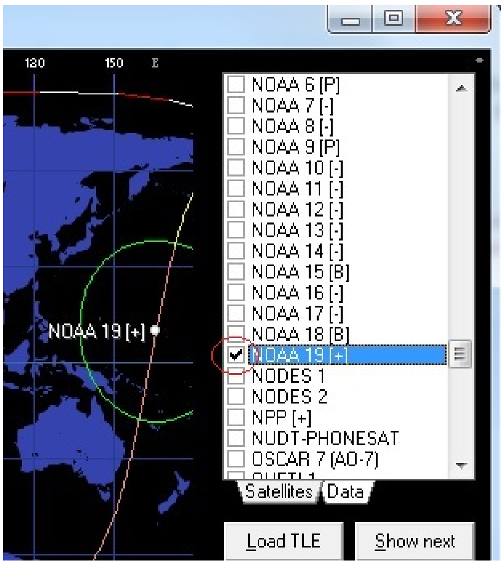

Figure 4.10: Select tracking of NOAA-19

Then we must confirm that Orbitron is sending the tracking information to WiSP DDE Client, by clicking on the icon shown in figure 4.12. The name of the satellite should appear on the WiSP DDE Client window as well as the information about antenna direction (elevation and azimuth) and frequency for uplink and down link.

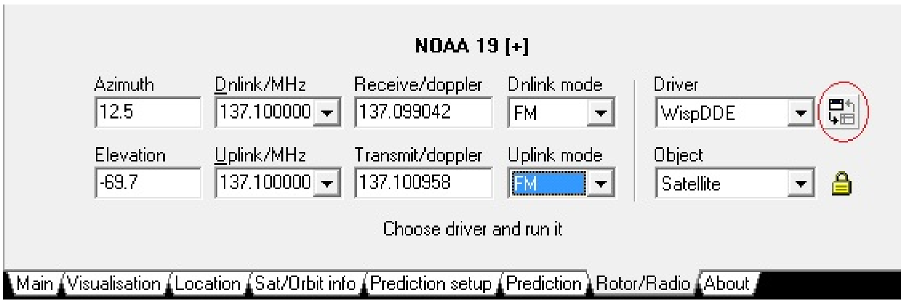

Figure 4.11: Activating WiSP DDE

In this example, since we are only receiving and the doppler effect is not relevant for this type transmission, the frequency may remain fixed at the downlink value ($137,100MHz$) and no more commands to the radio are needed during the reception period by selecting "NONE" in the *selected radio* option at the bottom of the WiSP DDE window.

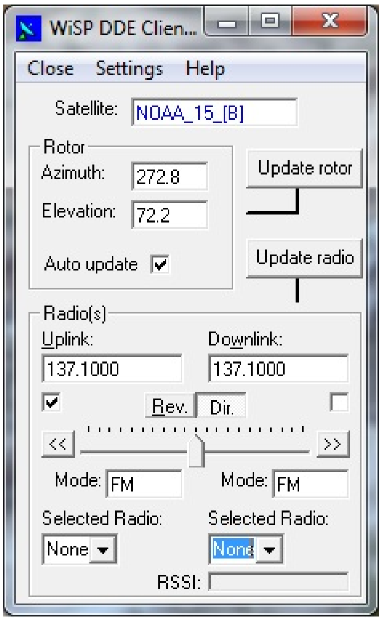

Figure 4.12: WiSP DDE window

At this point the rotator is being be controlled by the tracking software making it possible the automatically track the satellite as it passes through the sky. The following steps will be:

- Prepare software WXtoImg to begin decoding the signal, this is done by clicking in the top menu on "File", then the option "Record" and a new window will show up.
- In the new window select option "Record and autoprocess" and at the bottom of the window choose "Auto record".

- When the image starts forming, check the audio level at the bottom right corner of the window and adjust the audio either on the radio output or the soundcard input controls so that it shows a green background (that should be between 50% and 85%).

The "Auto record" will make use of the information about keplerian elements and the software capability of also predicting the passage of the satellite. This is the most practical way to receive the signal. The option "Manual test" may also be used but it will immediately start building the image either the signal is coming or not, and the stoping of the recording must be done manually too. Other options shown in that window may be later explored by the user.

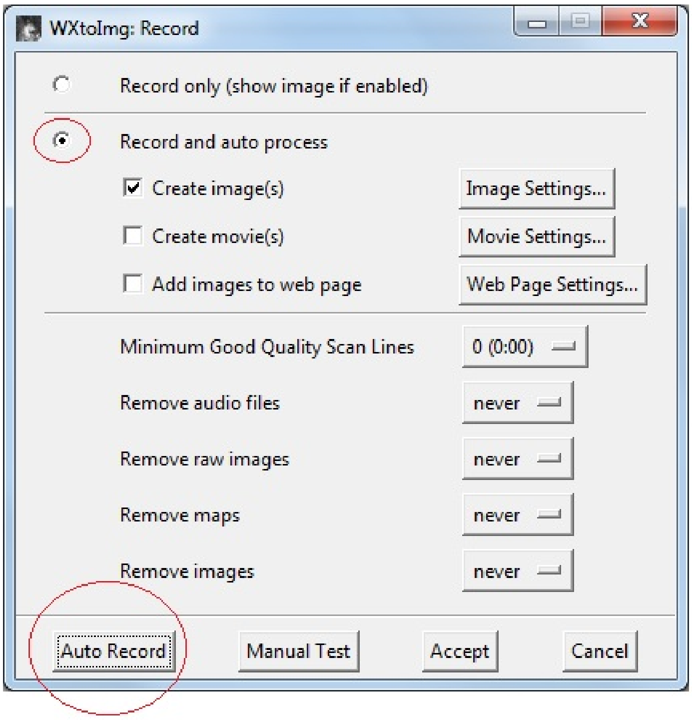

Figure 4.13: wxtoImg recording options

In the automatic mode the software will know when to stop receiving data so as to start to processing the images immediately. The images will be stored in a specific folder at "C:\Users\Satcontrol\Pictures\wxtoImg\images" with a name associated to the satellite, including date and type of image. Although it has been only shown one example of images for each NOAA satellite, the software wxtoImg generates 10 different types images, as explained in appendix E.

Chapter 5

Conclusions and future work

5.1 Conclusions

According to what was initially proposed a radio station was built, capable of performing satellite tracking, transmitting and receiving with signal processing and data storage. There is a new platform for the development of research projects as well as academic studies on campus. The evaluation of the station performance is quite good, many signals from different satellites were received using the equipment available. Also, the steps needed to setup correctly all the parts together so that we could have the station working properly and automatically with possible remote control, were defined.

Many problems needed to be solved along the way and a thorough knowledge of some aspects of the system were developed, particulary concerning the communication between the PC and other equipment such as the radio and the rotator. Only then it was possible to develop and configure the software and hardware to run properly. A serious analysis of the available resources at the beginning was also done so it could be possible to use the main hardware although keeping the old Operating System (OS), software and hardware for backup purposes. The new setup is now compatible with the latest versions of OS and hardware.

The goal of this dissertation was met as a satellite radio tracking station is now fully functional. Several tracking systems were developed during the project period, demonstrating its versatility and capability of drawing the participation of various members of the academic community. There are already several projects and thesis in development having this station as a working base.

The benefits of having this kind of station in the University was demonstrated by referring historical examples from other countries and the type of projects that can be developed. Also some recent events and possibilities were referred, such as the radio connection with the ISS and the fact that it has become so popular among the academic and scientific community. The text includes the explanation of the satellites mostly used by this station. It focus on the details about the satellites building, launching and type of orbits, as well as the features that one can use.

One of the inherent results was the requirements and steps to accomplish strategic objectives to build a station for satellite tracking. The several sections that compose this dissertation describe the most relevant parts of the station, such as the radiation system used for each band, the radio equipment, the control system and several interfaces interconnecting the whole station to properly operate. There is also a thorough explanation about the motorized system for the V/UHF antennas, the details of each part, mechanical and electrical. It explains how to generate different circular polarizations based on linear polarized antennas.

The operation of the station was demonstrated as well as the results obtained by using different satellites and there is also reference to the radio contacts made directly with other stations. For each satellite it is also explained what frequencies are used, type of transmissions and software used for data decoding. The quantity and quality of this data is the benchmark of the station performance. The results of this research were published in a conference [3].

5.2 Future projects and expansion

Once again, it is reminded that one, if not the most important purpose of this station is to provide a working platform for the development of studies and projects related with radio and satellite communications. Therefore, as the station was being setup and tested, a few ideas came along about its future expansion. The introduction of SDR equipment to alow greater bandwidth reception and easier data handling is one of these ideas. Also there is the possibility of expanding the coverage to lower frequencies and eventually study phenomena related with radio wave propagation, narrow bandwidth signals and the revival of the communications on the HF, MW or LW bands using new digital modulation techniques. Some of this is already being studied with the acquisition of some SDR equipment for testing. Other upgrades can be made, such as including tone squelch capability to the V/UHF transceiver so it will become able to use FM voice satellites, which are the most popular currently. Another possible feature that might be quickly implemented is a remote control (via internet) to power the equipment on and off.

Appendix A

Orbits

A.1 Gravitational field

To describe what an orbit is, one should first begin with the study of gravitation. The *Universal Gravitational Theory* states: *"Every point mass attracts every single other point mass by a force pointing along the line intersecting both points. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between them"*. Traducing this into a mathematic expression it can be written as equation A.1.

$$F = G\frac{m_1 \cdot m_2}{r^2} \tag{A.1}$$

Where:

F is the force between masses

G is the Gravitational constant $6.673 \times 10^{-11} N(m/kg)^2$

$\mathbf{m_1}$ is the first point mass

$\mathbf{m_2}$ is the second point mass

r is the distance between masses

The *Gravitational Field* of an object is the region around any other object with mass can sense this force attracting each other.

A.2 Kepler's Laws

Another important aspect to determine the orbits of satellites comes from the study done by Johannes Kepler on the planetary orbits that came up resumed in what are called the *Kepler's laws of planetary motion*:

- **First Law:** The path of the planets around the sun is elliptical in shape, with the center of the sun being located at one foci.
- **Second Law:** An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time.
- **Third Law:** The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun.

Obviously this was about the planets around the sun but the same principle applies to any other two masses who suffer gravitational pull such as satellites around the earth. Also, to get a better notion of how they can be used, one must translate it to mathematical expressions being the first law simply defined by the ellipse geometric form in figure A.5 and its equation A.2.

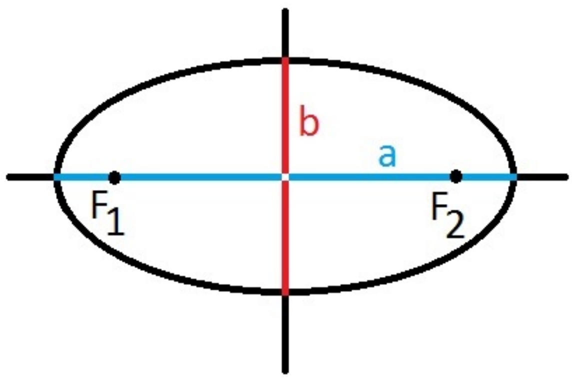

Figure A.1: Ellipse, axis and foci

$$e = \frac{\sqrt{a^2 - b^2}}{a} \tag{A.2}$$

Where:

e is the eccentricity of the ellipse

a is the major axis

b is the minor axis

$\mathbf{F_1}$ and $\mathbf{F_2}$ are the foci

The second law can simply be explained drawing the orbit plane shown in figure A.2 where one can easily identify areas A_1 and A_2 as well as respective distances S_1 and S_2. If the satellite travels both distances in the same time then both areas will be equal. As a consequence of this it follows that the velocity at S_1 is greater than that at S_2.

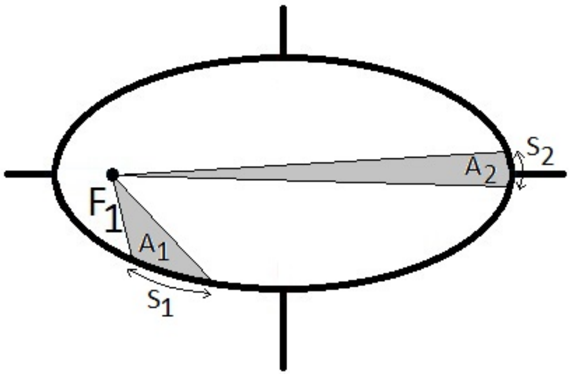

Figure A.2: Areas and distances travelled

For satellite orbiting the Earth, the third law can be put directly in equation A.3 remembering that the mean distance corresponds to the semi-major axis of the ellipse (a). This happens because the mass difference is so big that the barycenter may be considered the center of the Earth. This model considers a perfect spherical Earth, uniform mass and no atmospheric drag. Some adjustments are done when dealing with real Earth conditions, but that is not relevant to explain the orbits theory, which is the case.

$$a^3 = \frac{\mu}{n^2} \tag{A.3}$$

Where:

a is the mean distance

$\boldsymbol{\mu}$ is Earth's geocentric gravitational constant: $3,98600 \times 10^{14} m^3/s^2$

n is the mean motion of the satellite

$\mathbf{F_1}$ and $\mathbf{F_2}$ are the foci

A.3 Terms and definitions for Earth orbiting satellites

There are terms which were crated to define certain aspects or characteristics of the satellites orbiting the Earth[4].

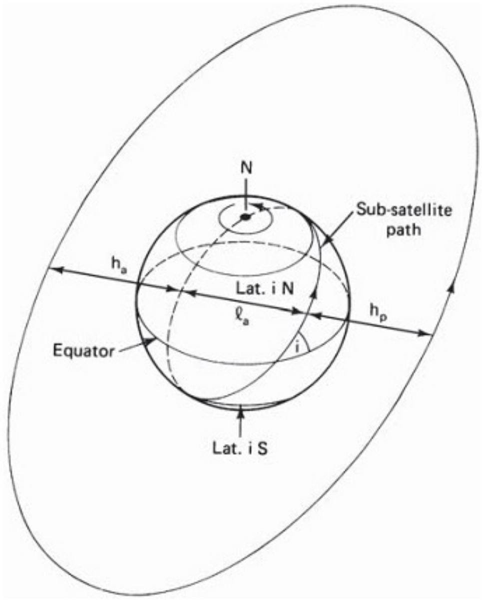

Figure A.3: Apogee height h_a,perigee height h_p, and inclination i where l_a is the line of apsides.

Apogee: The farthest point from earth.

Perigee: The closest point to earth.

Subsatellite path: This is the path traced out on the earth's surface directly below the satellite.

Line of apsides: The line joining the perigee and apogee through the center of the earth.

Ascending node: The point where the orbit crosses the equatorial plane going from south to north.

Descending node: The point where the orbit crosses the equatorial plane going from north to south.

Line of nodes: The line joining the ascending and descending nodes through the center of the Earth.

Inclination: The angle between the orbital plane and the Earth's equatorial plane. It is measured at the ascending node from the equator to the orbit, going from east to north.

Prograde orbit: Also known as *direct orbit* it is an orbit in which the satellite moves in the same direction as the Earth's rotation.

Retrograde orbit: An orbit in which the satellite moves in a direction counter to the Earth's rotation.

Argument of perigee (ω): The angle from ascending node to perigee, measured in the orbital plane at the Earth's center, in the direction of satellite motion.

Mean anomaly: Mean anomaly M gives an average value of the angular position of the satellite with reference to the perigee.

True anomaly: The true anomaly is the angle from perigee to the satellite position, measured at the Earth's center.

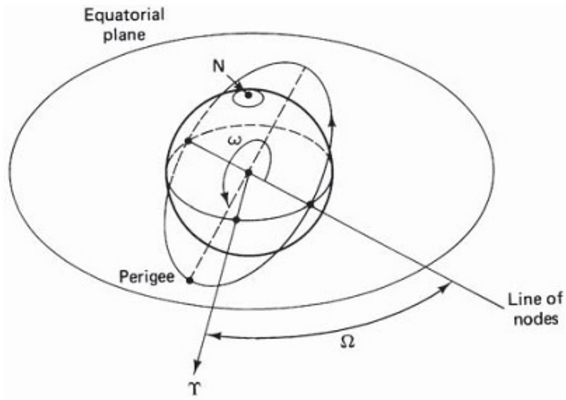

Figure A.4: The argument of perigee ω and the right ascension of the ascending node Ω

The *right ascension of the ascending node* defines completely the position of the orbit in space. The position of the ascending node is previously specified. But because of the spinning of the Earth, while the orbital plane remains stationary [1], the longitude of the ascending node is not fixed, and it cannot be used as an absolute reference. For the practical determination of an orbit, the longitude and time of crossing of the ascending node are frequently used. However, for an absolute measurement, a fixed reference in space is required so the reference chosen is the first point of Aries, also known as the vernal, or spring, equinox. The vernal equinox occurs when the sun crosses the equator going from

[1]Some slow drift happens but it is not relevant now

south to north, and an imaginary line drawn from this equatorial crossing through the center of the sun points to the first point of Aries (represented by γ) known as the line of Aries. The right ascension of the ascending node is then the angle measured eastwards, in the equatorial plane, from the γ line to the ascending node, shown in figure A.4 as Ω.

A.4 Orbital elements

There are six orbital elements usually referred as *"keplerian element set"* which is the information needed to track the satellite as they define its orbit trajectory. Two of them characterize the shape of the ellipse, one is the semimajor axis a and the other is the eccentricity e. Another element is the mean anomaly M_0 which gives the position of the satellite in its orbit at a reference time designated *epoch*. The argument of perigee ω is the fourth element and the last two are the inclination i and the right ascension of the ascending node Ω.

A.5 Geostationary Orbit

The geostationary orbit is a special orbit for satellite operation since from the point of view of an earth observer the satellite appears to be steady in the sky. This makes it a "high value" orbit since it is the preferred by broadcasting and telecommunication companies. When using satellites in this orbit, it is not necessary to have a motorized tracking system, all it is needed is to point the antenna once to the satellite and leave it that way. This makes the use of geostationary satellites simpler and cheaper, regarding hardware needs. Of course the satellite is not really steady, in fact what happens is that at this distance from the Earth the velocity of the satellite around the Earth is synchronized with Earth's rotation. One complete rotation of the Earth takes the same time as one complete orbit of the satellite around the Earth. For this to happen, one must find the correct distance where the satellite should be.
Using the Kepler's laws and the time it takes for the Earth to complete a single turn it is possible to estimate the altitude at which the satellite must be. Knowing that the sidereal day[2] is exactly 86164,09 seconds and that the orbital period is given by equation A.4.

$$P = \frac{2\pi}{n} \tag{A.4}$$

Where:

P is the period in seconds

[2]A mean sidereal day is the time the Earth takes to make one rotation relative to the vernal equinox

n is the mean motion of the satellite

This follows that:

$$n = \frac{2\pi}{P} = \frac{2\pi}{86164,09}$$
$$n = 7,292 \times 10^{-5} rad/s \tag{A.5}$$

From Kepler's third law:

$$a^3 = \frac{\mu}{n^2}$$
$$a = \sqrt[3]{\frac{3,986005 \times 10^{14}}{7.292 \times 10^{-5}}} \tag{A.6}$$
$$a = 42164,618 km$$

Since the orbit is circular the semi-major axis is also the radius and considering the Earth's radius, at the equator, of 6378,137 km, a geostationary satellite should be placed at an altitude approximately of $42164,618 - 6378,137 = 35786,481km$. With three satellites equally spaced and over the equatorial orbit it is possible to cover almost the entire world missing only the areas near the poles. This is what is used for commercial broadcasting satellite services which was one of the main reasons to justify the placement of geostationary satellites and why this orbital zone was so sought after. The geostationary orbit also marks the transition between the MEO (*Medium Earth Orbit*) and HEO (*High Elliptical Orbit*).

A.6 Low Earth Orbit

In the previous section it was described the geostationary orbit but the altitude at which satellites can be placed can be much lower. In fact, taking into account the services foreseen, different orbits can be chosen according to their characteristics. The first zone that can be used and closer to Earth is called *Low Earth Orbit* (LEO). It consists of circular orbits at heights between 500 and 1500km. This will provide a satellite footprint[3] with diameters of 3000 to 5000km. To achieve global coverage it is required to used several satellites building what is called a *constellation*. Since these satellites are so low, they will be moving quite fast so the Doppler shift must be taken into account. Also each satellite might be "visible" from a fixed point on Earth for a few minutes, usually less than 10 minutes. In some cases, this requires that the users have some kind of tracking

[3] Satellite footprint refers to the area on the Earth's surface covered by the satellite

system to follow the satellite over the sky and a system to adjust frequency to compensate the Doppler effect. Meanwhile since they are closer to the user, the power requirements to reach the satellite are quite low so this is an ideal system for mobile or portable operation. In order to get a 24h service and global coverage this system requires several orbital planes with different inclinations. The LEO systems also enable high digital data rates, lower propagation delay and greater flexibility to launch several satellites in a single run. Examples of these constellations are the systems Iridium and Globalstar.

Figure A.5: Iridium satellite constellation

A.7 Medium Earth Orbit

The medium Earth orbit satellites are usually at an altitude of 10000 to 20000km. This orbit is very similar to LEO in the way that the orbits are also circular and are used several planes and several satellites to achieve 24h service and worldwide range. Nevertheless, since the altitude is higher, footprints have diameters around 8000 to 9500km which results in a lower number of satellites needed and lesser orbit planes required. The Doppler shift is not so significant as with LEO but it is still needed to be taken into account. Since the distances are longer, this requires antennas with higher gain and higher transmission power. Propagation delays are greater than on the LEO system but they are still acceptable. This kind of orbits are used for global coverage systems such as the ICO system.

A.8 High Elliptical Orbit

These orbits have na elliptic form and an inclination of $63,4°$ with the perigee very close to the Earth and the apogee varying from 39100 to 53600km. This asymmetry allows long periods with the satellite in range from 6 to 12 hours, making it look steady in the sky near the apogee because the movement is very slow. For continuous services it is necessary to do the handover from the descending satellite to the ascending satellite. The minimum number of satellites is calculated dividing 24h by the time in range of each one.It is possible to get 24h services with wide spread orbital planes, few satellites and minimum elevation angles of 55° to 60°. The services provided lay mostly on regional or little more areas, such as some proposed to use in Europe.These satellites can be used with high minimum elevation angles even at high latitudes. It allows the coverage of very well defined regions. Nevertheless it requires high power and high gain antennas because the distance is larger than for geostationary satellites, so portable or mobile terminals are not suited. There is also a large and variable propagation delay and the necessity of "handover". The elevation angle is not stable and has a little variation. The life time of these satellites is shorter because they cross high radiation areas.

Appendix B

SWR and Power relation

In transmission line theory there are some basic concepts that will now be recalled to demonstrate the relation between SWR and power. When a transmission line is connected to an impedance (Z_L) different from its characteristic impedance (Z_0) it will reflect some of the power. The voltage along the transmission line will be the result of the sum of the two components *forward* (V_{fwd}) and *reflected* (V_{ref}).The associated power will have the same designation and is proportional to the square of the voltage.

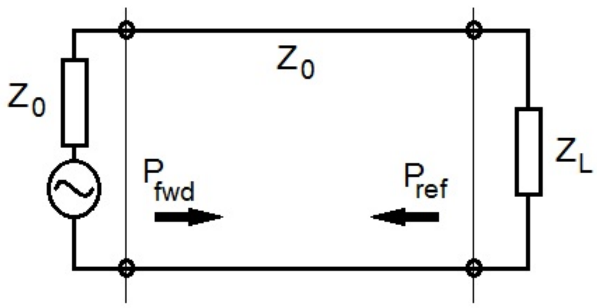

Figure B.1: Generator with output impedance equal to line impedance Z_0 connected to load Z_L

The reflection is measured by a parameter named "reflection coefficient" and is represented by Γ which is a complex number. The magnitude of the reflection coefficient $|\Gamma|$ can be calculated through:

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{B.1}$$

$$|\Gamma| = \frac{V_{ref}}{V_{fwd}} \tag{B.2}$$

And the SWR:

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{B.3}$$

Knowing that:

$$P_{fwd} = \frac{V_{fwd}^2}{Z} \text{ and } P_{ref} = \frac{V_{ref}^2}{Z} \tag{B.4}$$

Hence:

$$|\Gamma| = \frac{V_{ref}}{V_{fwd}} = \frac{\sqrt{P_{ref} \times Z}}{\sqrt{P_{fwd} \times Z}} = \sqrt{\frac{P_{ref}}{P_{fwd}}} \tag{B.5}$$

So the SWR equation can be written as:

$$SWR = \frac{1 + \sqrt{\frac{P_{Ref}}{P_{Fwd}}}}{1 - \sqrt{\frac{P_{Ref}}{P_{Fwd}}}} \tag{B.6}$$

This way, one can compute the SWR value based on readings of forward and reflected power.

Appendix C

Radio Wave, Ground-wave and Sky-wave

The most usual form of radio wave propagation on V/UHF occurs when radio waves propagate along the surface of the earth and that is usually called *Ground-wave*. There is also another way called *Sky-wave* which occurs with reflection of radio waves in the ionosphere. Usually this happens on lower frequencies, below the $30MHz$.

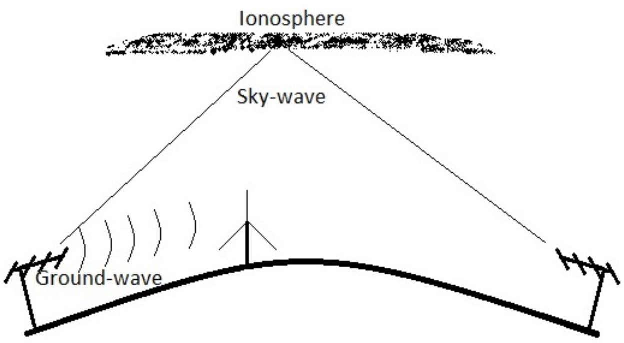

Figure C.1: Ground-wave and Sky-wave propagation

C.1 Tropospheric propagation

The troposphere is the lowest portion of the atmosphere which mostly influences our weather as well as ground-wave radio propagation[6]. It contains 80% of the atmosphere mass and 99% of its vapor, beginning at the surface and going up as high as $20km$ near the equator, $17km$ in mid-latitudes and $9km$ near the poles. The height varies not only with the latitude but also with the seasons, being greater in the summer. At the upper boundary of the troposphere there is a temperature inversion called tropopause which separates the troposphere from the stratosphere. The pressure of the atmosphere is greatest at surface and decreases with height. Because the temperature of the troposphere decreases with height (by approximately 6, 5°C/km) and saturation vapor pressure decreases with decreasing temperature, the water vapor content of the atmosphere decreases strongly with altitude. The troposphere has irregularities in temperature, pressure, and water vapor content due to stratification and turbulence, and it is believed that the irregularities and their effects on electromagnetic wave refraction are the basis for tropospheric scatter.

C.1.1 Refractivity and the low atmosphere

The ground-wave communications are greatly affected by the refractivity of the environment, in particular the lower part of the atmosphere. The atmospheric refractivity N (also know as reduced refractivity index) can be defined by the equation C.1 where n is the refractivity index relative to the vacuum ($n \approx 1$):

$$N = (n - 1) \times 10^6 \tag{C.1}$$

The refractivity also depends on the temperature T[K], water vapor tension $e[mb]$ and atmospheric pressure $p[mb]$ through the empiric formula shown in equation C.2.

$$N = \frac{77,6}{T} \times (p + 4810 \times \frac{e}{T}) \tag{C.2}$$

This formula is one of many empiric formulas used by the ITU[10]. If one chooses the typical earth surface conditions values, $T = 300°K, p = 1000mb, e = 10mb$ then $N = 300$ which is the typical value of "N" at the earth surface and it results in $n = 1,00300$ which is not much different from 1. One can now show the variation of N with altitude in figure C.2, The variation with altitude can be expressed using the formula for "average atmosphere" shown in equation C.3.
The variation of N with altitude in Figure C.2 is shown both according to equation C.3 and a simplified version represented by the dashed line, according to equation C.4, which consists of the two first terms of the series development of equation C.3. The values of h are in km.

$$n(h) = 1 + 315 \times 10^{-6} \times e^{-0,136 \times h} \tag{C.3}$$

Hence, using equation C.1:

$$N(0) = 315$$

$$\left.\frac{\partial N}{\partial h}\right|_{h=0} = -43km^{-1}$$

Resulting in the simplified version:

$$N = N(0) - 43 \times h \quad \text{(C.4)}$$

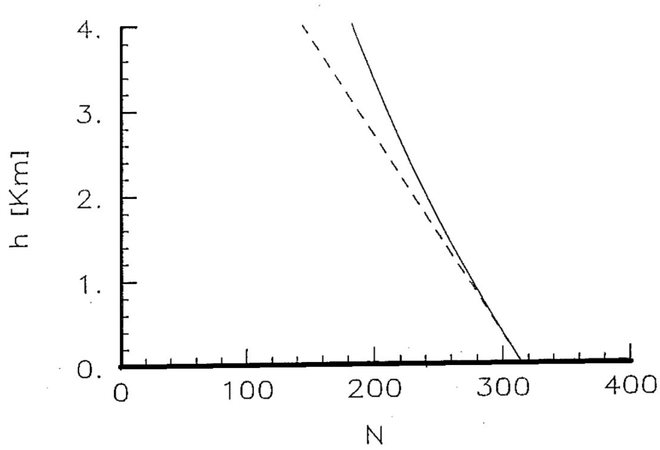

Figure C.2: N index and height

There is another parameter designated *Modified refractivity index (M)* which includes the earth radius $a = 6370km$ and is given by equation C.5.

$$M = N + 10^6 \times \frac{h}{a} \quad \text{(C.5)}$$

This index is used because it is better for ray tracing in radio wave propagation studies, this may fall a little of topic here, but it is from this index graphics that one can briefly explain tropospheric radio transmissions. In figure C.3 various profiles of $M(h)$ are shown and each may differently influence the propagation of radio waves.

Through the analysis of the $M(h)$ profiles one can see that sometimes there are inversions in refractivity variation with altitude. These inversion will cause the creation of layers that will work as a giant planar waveguide commonly denominated as *Ducts*. These ducts will set a path for the propagation of radio waves much beyond the usual reach. Some of the radio contacts made between the station built here and other radio stations in places such as the Canary islands where possible due to this phenomena. This also explains how sometimes TV broadcasting signals are received beyond its usual coverage area. In recent years, with the advent of digital TV (DVB-T), this phenomena caused interference and loss of synchronism in the receivers making impossible to continue with the single frequency network that was originally planed, changing it to a multi-frequency network to avoid this problem. Most of this interference occurs near the coast line because the water vapour from the ocean is one of the most contributing factors to this inversions

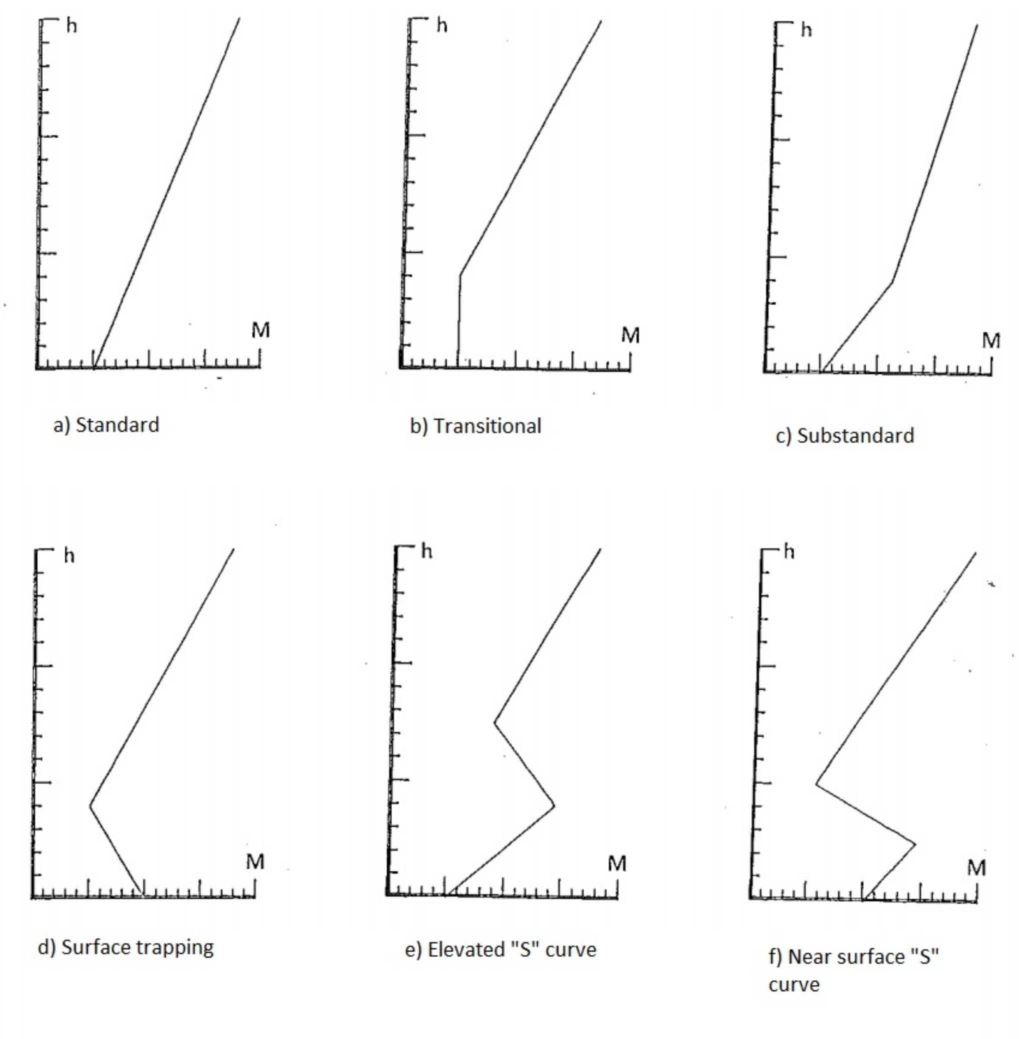

Figure C.3: Examples of M(h)

of refractivity and the creation of ducts. Figure C.4 shows exactly the relation between the $M(h)$ index and the formation of these planar waveguides.

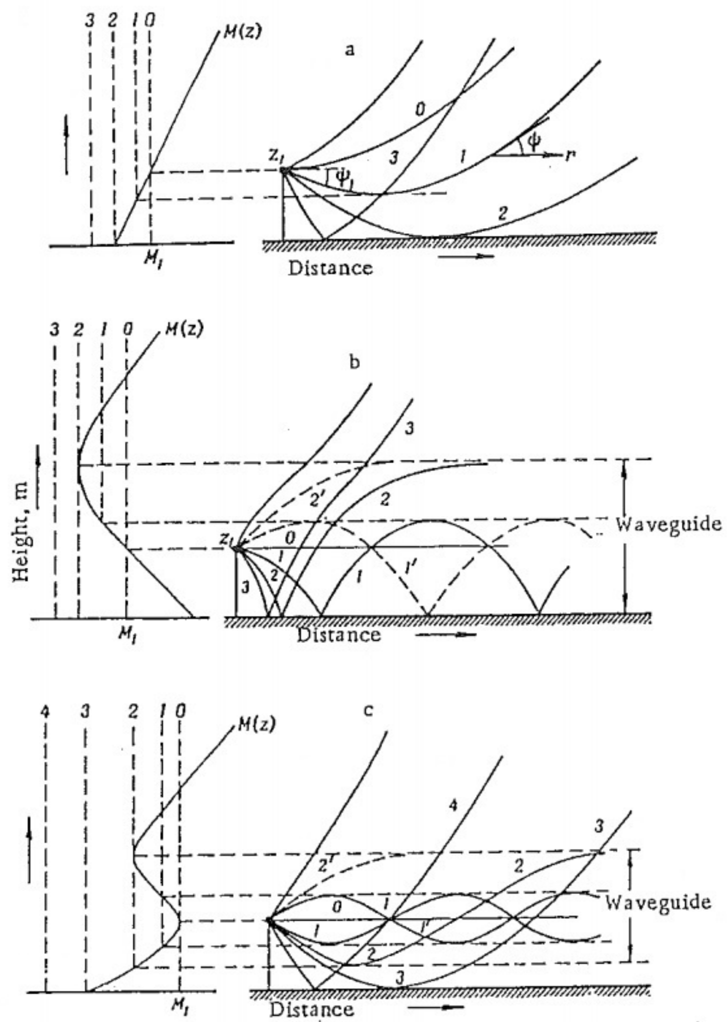

Figure C.4: M(h) variations and radiowave trajectory

C.2 Sporadic E

There are also records of long range radio transmissions on the VHF band even beyond the ones via tropospheric ducting, these are known as *Sporadic E* skips related with a different phenomena that will now be explained. In radio propagation studies, it has been known for many years that the reach of skywave propagation by ionospheric reflection is severely affected by the intensity of the ionisation plus the hight at which the reflection layer is. Furthermore this layers are distinct, they have different characteristics and may absorb or reflect the radio waves depending on the frequency. These layers are called D, E, and F, although this last one during day time splits into two called F1 and F2, as depicted in figure C.5. The D and E layers appear only during day time period and are more absorptive, specially de D layer. This explains why most of the medium wave and short wave communications have higher range during the night. The VHF and above frequencies, are not particulary affected by this layers but more by the tropospheric conditions presented in the previous subsection.

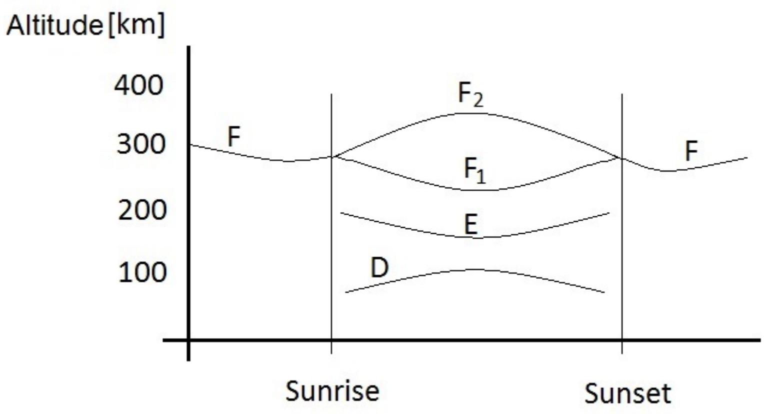

Figure C.5: Ionosphere Layers

The so called *sporadic E* is not a real layer but more likely cloud shaped areas with intense ionization formed at the same height as the E layer. This highly ionized areas will reflect VHF signals and build a path for long range skip which makes possible to receive signals thousands of kilometers away. This skips may not be just a single hop and in this last case it increases even more the range of communications. The size and duration of this reflection areas cannot be clearly predicted but there are already some studies that explain when they are most likely to happen. They may happen at any time but the probability is higher during the summer months and they are also usually stronger when the sunspot cycle is at its peak. The higher the sunspot numbers the stronger the ionization will be, just like on the other ionosphere layers.

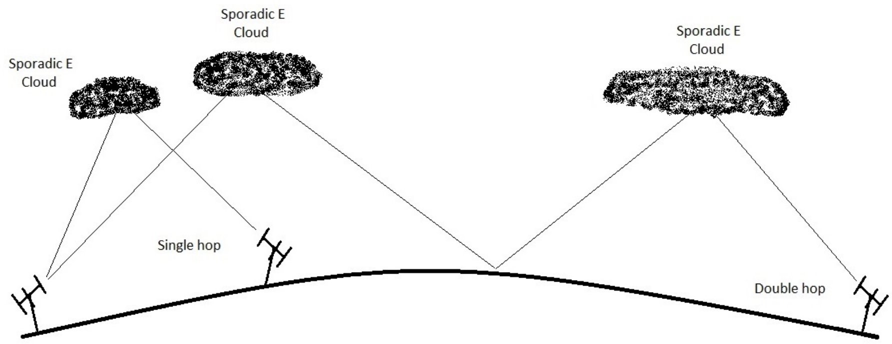

Figure C.6: Single hop and double hop

C.3 Gridsquare Maidenhead Locator System

At the end of chapter 4 there is a table showing a list of radio contacts (Logbook) where one of the columns is named "Locator" and is filled with a six character code of two letters followed by two numbers and again two letters. This code represents an area where the radio stations were located in a system called *Gridsquare Maidenhead Locator System* or commonly referred to as the *QTH*[1] *Locator* or simply *Locator*.

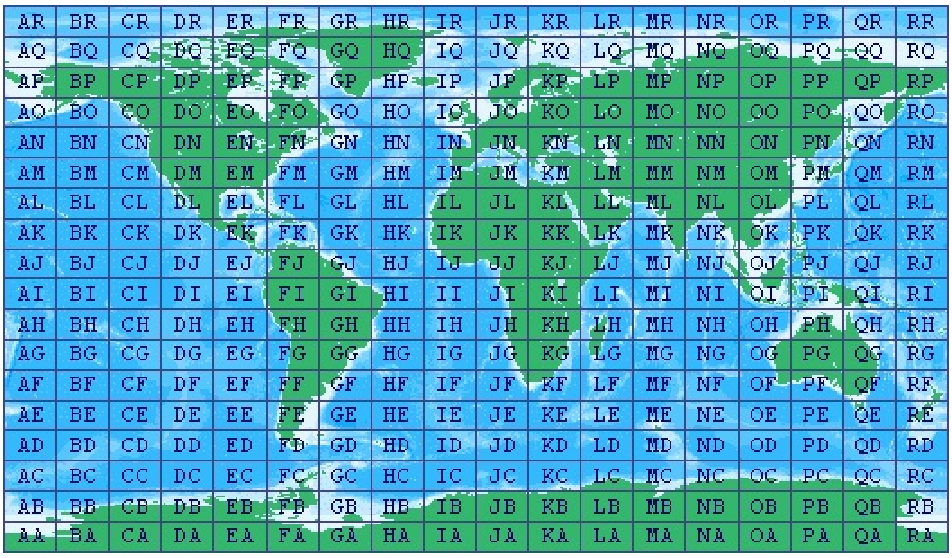

Figure C.7: Gridsquare Fields over the World

This is a geographic co-ordinate system used by amateur radio operators. Dr. John

[1] QTH is one of many three letter abbreviations started always with the letter "Q" for radio communications and refers to the geografic location of a radio station

Morris, (whose amateur radio callsing was G4ANB) originally devised the system and later a group of other enthusiasts of VHF communications, meeting in Maidenhead, England in 1980, adopted it. The system would replace an older one that covered only the European continent and would be adopted worldwide. This system divides the world in 324 fields using 18 alphabet letters (from "A" to "R") along and across the globe surface (see figure C.7). Each field is represented by the first pair of letters in the locator six character code. Within each field there is a subdivision dividing it in a 10x10 grid called squares where each one represents 1° of latitude by 2° of longitude. A pair of numbers from "00" to "99" is used to represent each square as seen in figure C.8 which justifies where the alternative name "grid squares" comes from. A third division is then made inside each grid square, now using again two letters that increase even more the precision of the location. These are called subsquares and combine 24 letters from "A" to "X". A fourth pair was also defined which encodes with base 10 just like the second pair (square) but it is not really used as it may have been seen in the log where only 6 digits are shown. The Maidenhead locator system has been explicitly based on the WGS 84 geodetic datum since 1999. In IARU Region 1 rules, VHF distance calculations are carried out between Maidenhead subsquare centres assuming a spherical Earth. This results in a small error in distance, but makes calculations simpler and, given the inherent imprecision in the used input data, it is not the biggest error source. Many of the modern GPS receivers have the capability of showing the position in this format.

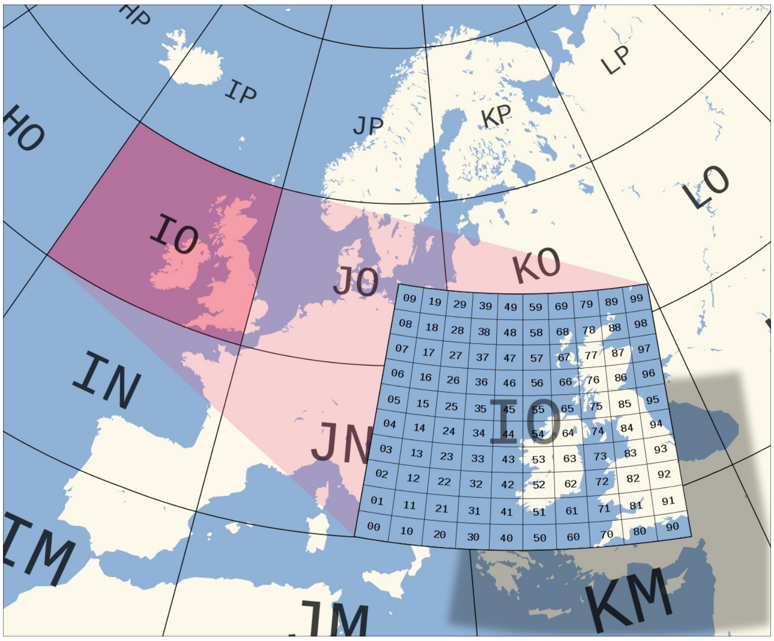

Figure C.8: Maidenhead grid over Europe

Appendix D

Paper - Educational Satellite Tracking Station

Educational Satellite Tracking Station

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Abstract

This article describes the setup of a new satellite communications station to help students in this research area. The station covers the VHF, UHF and Ku bands, it has transmitting and receiving capability in some bands, as well as motorized antennas which is an essential feature to track satellites in some orbits. This facility is a valuable tool for researchers and can be available worldwide since the station can also be accessed remotely and it can store and share all types of data received. This paper describes the main features and functionality of the station, as well as some data collected with it, namely meteorological images and telemetry signals.

Keywords: Satellite communications, VHF, UHF, Ku bands, motorized antennas, satellite station, meteorological images, telemetry signals.

I. INTRODUCTION

Satellite communication systems appeared as a man's desire to extend the radio communications range. It all began with an idea of Sir Arthur C. Clarke [1] who proposed a geostationary satellite communications system with three satellites for worldwide communications, although it took more than 20 years (April 1965) to launch the first commercial Geostationary satellite, Intelsat I Early Bird. Presently we can reach virtually any point in our planet using different satellite constellations and orbits.

Satellite systems are increasingly important for many applications of everyone's life today providing support for navigation and aviation, space exploration, support for agriculture, meteorology, soil exploration, astronomy, remote sensing of objects and many others [2] [3] [4]. An important application of satellites is on global radio navigation systems [5] and nearly all smartphones, cars, and many other electronics appliances such as cameras, have a receiver to estimate its position and help to navigate.

As any other field of science, satellites systems will continue to evolve and help on all related fields in a perfect symbiosis. It is very important to have a satellite centre in a university to allow research in these areas, as we can see in for example in Surrey, UK [6]. This was the main motivation for setting up a satellite station at ISCTE-IUL with the collaboration of Instituto de Telecomunicações. Room facilities become possible with an agreement and protocol signed recently with the "Associação Portuguesa de Amadores de Rádio para a Investigação, Educação e Desenvolvimento" (AMRAD) which also helped in the licensing and setting up of crucial components, such as antennas and transmission equipment.

Satellite communications are in fact a multidisciplinary subject so other courses and researchers from different areas will benefit from the existence of such facilities on campus. The existence of such station will also contribute for cooperation between teaching and research institutions. The fact that there are many new satellites being launched for experimental and educational purposes facilitates and encourages researchers to keep up with the pace. The majority of the micro-satellites (also known as CubeSats) which have been launch in recent years were built in Universities and other Universities are encouraged to track the satellites and receive the telemetry signals transmitted in order to help in the project giving information about the satellite performance. The information about most of these systems is easily available [7] [8] [9] [10] allowing researchers to participate and follow these studies. In this paper we describe the main features of this station already installed as well as some encouraging results obtained in its operation.

The remainder of this paper is organized as follows: section II briefly describes the state of the art, section III describes the station and its operation capabilities, section IV presents examples of data collected with the operation of this station from the various satellites. Finally, section V summarizes and presents the main conclusions.

II. STATE OF THE ART

The use of amateur radio stations in Universities and research centres goes back in time. Since the beginning of last century several radio club stations were build and are related to references in the electronics and telecommunications teaching and research, such as MIT or Harvard in the USA and Surrey[11] in the UK. It is said that one image is worth a thousand words, imagine just how much it is worth a vivid example of what is being taught, that is what the purpose of having such a station is all about. Following this line of thought we can already see examples like Surrey where they have been building real satellites for more than 20 years and recently many other Universities around the world are building CubeSats that, in spite of being smaller and cheaper, they must cope with the space environment which is more complicated than building a terrestrial beacon or repeater.

Figure 1 - The Surrey University has a long history with radio and satellite research.

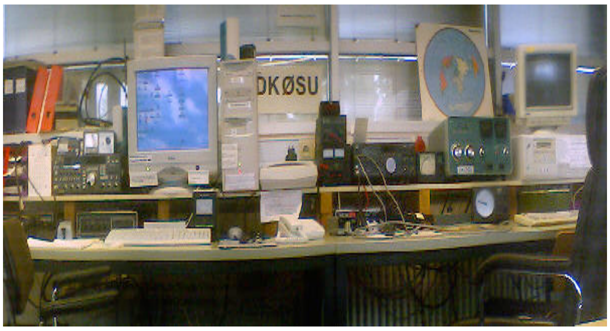

Figure 2 - Part of the radio station at the Univ. of Stuttgart.

Radio stations, as shown in Figure 2, are used for several projects such as testing the satellite hardware while it is being built; tracking, control and operation of satellite signals when in orbit; tracking and operation with stratospheric balloons for satellite simulation.

Figure 3 – Example of a payload with circuitry to be launch in a balloon (MIT Amateur Radio Society).

Sometimes high altitude balloons are also used to carry transmitters and other electronics, as shown in Figure 3, such as GPS or cameras. The ground station, as in any satellite system, is essential to control and monitor the signals received from the balloon.

III. DESCRIPTION AND FUNCTIONALITY

The station currently deployed at ISCTE-IUL is composed by three different sections, one for GPS application, one for *Ku* communications and another one for VHF/UHF communication, as depicted in Figure 4.

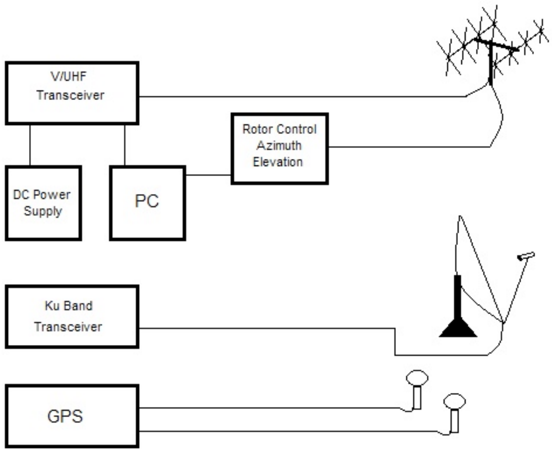

Figure 4 - Basic station diagram.

The GPS equipment consists of two independent antennas fixed on the building's ceiling that can be connected to different GNSS (Global Navigation Satellite Receivers) receivers. Presently, they are connected to a LEA-M8S/LEA-M8T u-Blox M8 module capable of receiving raw data from both GPS, GLONASS, GALILEO and BEIDOU constellations. A system is being set up to continuously monitor these satellite constellations and store its results in a local database. As with the other components of this station, a web based access is being developed to allow remote access and control of some of its functionalities, after proper user identification and validation.

The VHF/UHF station has a pair of crossed element Yagi-Uda antennas that allow transmission in circular polarization (left or right commanded by a switch in the radio control room). The VHF/UHF antennas have motorized support capable of turning 360º in azimuth and 180º in elevation. The rotator control is connected to a personal computer (PC) for automatic tracking of the satellites. The PC connects also to the transceiver to control both frequency and operation mode (FM, SSB, FSK, *etc.*). New software is also being developed to interconnect the radio with the tracking software so as to compensate for the Doppler shift automatically. The PC also runs a software to decode the signals received from the satellites.

Another valuable functionality being developed is the complete station access and control, both for emission and reception, with similar functionalities to the GNSS station, namely the possibility to remotely collect data received from the satellites.

When first mounted, the antenna system was tested to check its performance and behaviour. Several measures were made including Standing Wave Ratio (SWR), transmitted power, reflected power, current consumption from the power supply. Table 1 and Figure 5 show some of the values measured that were useful to fine tuning the system. These values clearly show that the antenna needed a little adjustment to get que values of SWR lower to an optimum value of 1:1.1 or as close as possible to that.

As we can see, tuning of the antennas and controlling the performance of the equipment is also part of the "hands on" research projects that this station provides. There are plans to setup another antenna for 1,2GHz band that is covered by our transceiver. Unfortunately the latest satellite working on this band is currently malfunctioning so we are waiting for another to be launched soon [12].

This station is also capable of communicating in the amateur radio bands, which in turn allow transmitting to satellites. These bands are commonly used by CubeSats [13] so part of the antenna system is optimized to be used in the amateur radio bands. Since amateur radio bands are specially dedicated for experimental purposes, it is only obvious that this station takes advantage of it to accomplish its research purposes. There are also plans to expand this station to operate into another amateur radio slots that are available throughout the RF spectrum from hundreds of kilohertz to tenths of GigaHertz.

Freq. [MHz]	SWR	Pwr. Inc. [W]	Pwr. Ref.[W]	Current [A]
144,0	2,50	5,5	1,0	6,0
144,1	2,50	6,0	1,0	6,0
144,2	2,50	7,0	1,0	6,5
144,3	2,50	8,0	1,4	7,5
144,4	2,45	10,0	1,5	8,0
144,5	2,45	12,5	1,8	8,5
144,6	2,40	16,0	2,0	10,0
144,7	2,40	35,0	3,0	11,0
144,8	2,30	40,0	3,3	12,0
144,9	2,30	50,0	4,0	14,0
145,0	2,20	50,0	4,0	14,0
145,1	2,20	50,0	4,0	13,0
145,2	2,20	40,0	3,0	12,5
145,3	2,20	35,0	2,5	9,0
145,4	2,20	17,0	1,9	8,0
145,5	2,10	12,5	1,5	7,0
145,6	2,10	10	1,0	6,0
145,7	2,10	8	1,0	6,0
145,8	2,10	6,5	0,8	6,0
145,9	2,10	6	0,8	6,0
146,0	2,10	5	0,8	6,0

Table 1: Measures made with the VHF antenna system.

Finally, for the Ku band there is a parabolic antenna that can be connected to any simple DVB-S receiver or to our proper transceiver, in case we need to do any transmission tests. The Ku antenna is also prepared to have a feeder mounted on it for transmission tests whenever necessary. The use of transmission in the Ku band requires special authorisations and will only be requested when any experiment is already prepared and clearly defined. Meanwhile reception is always possible without any special licensing.

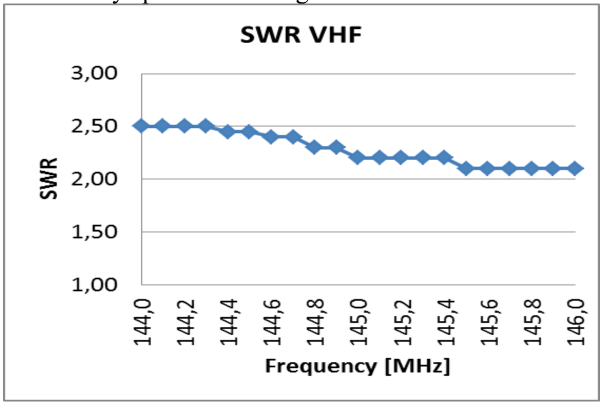

Figure 5: SWR measurements made with the VHF antenna.

Apart from satellite signals, these antennas can also be used to receive signals from space within their frequency band, that is, they can also be on radio-astronomy activities. Finally, this station can also communicate with the International Space Station (ISS). The ISS includes amateur radio equipment and it is part of their activities to use it regularly according to the Amateur Radio on the International Space Station (ARISS) program [14]. The ISS is easily reachable and it is possible to contact it using either voice or data communication, for example, it is possible to receive images collected from space from it. Most of the time the ISS operates on the packet radio digipeater mode [15] at 145.825MHz.

A complete video wall is also being developed to show and monitor most of the signals and images being received by this station.

IV. EXAMPLES OF DATA COLLECTED

In this section we present some examples of data collected by our station at ISCTE-IUL, from some weather satellites and telemetry from CubeSat's. The collected meteorological images are shown in Figure 6 and Table 2 lists some CubeSat's from which we could get telemetry signals, as shown in Figures 7 (Delfi C-3) and Figure 8 (AO-73).

Satellite name	Orbit Type	Frequency [MHz]
NOAA-15	LEO	137.620
NOAA-18	LEO	137.912
Delfi-C3	LEO	145.870
FunCube-1 (AO-73)	LEO	145.935

Table 2 - Satellite information.

The software used to decode the weather satellite images was WXtoImg which is the standard for decoding the National Oceanic and Atmospheric Administration (NOAA) satellite transmissions. Data received was processed so the satellite images are overlaid with maps for better perception of the corresponding locations. Our station is capable of storing these images and signals which can be further processed and so help researchers at other research institutions or universities.

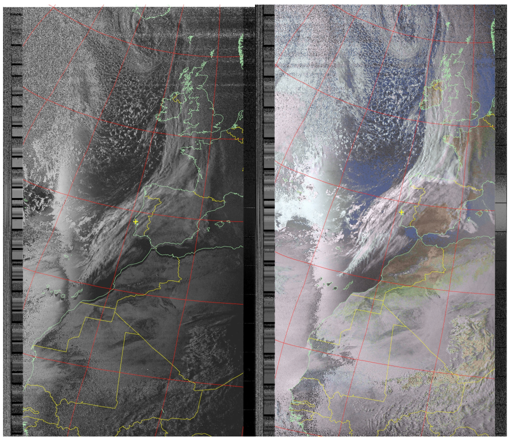

Figure 6: Images obtained from NOAA-15 and NOAA-18 decoded by WXtoImg.

Telemetry from CubeSats was decoded using dedicated software provided by the owners of the satellite, so in fact each one has a different software.

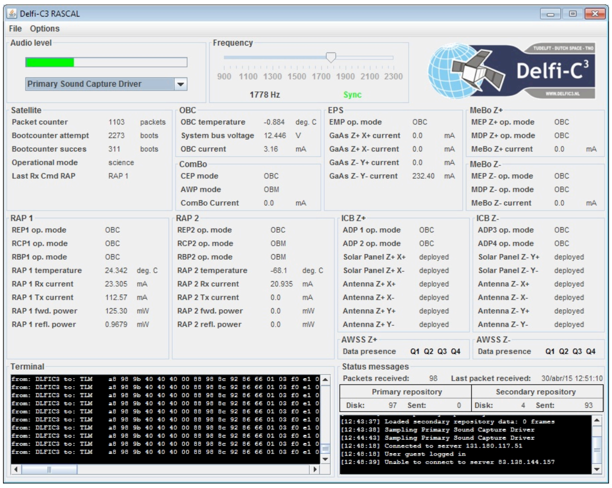

Figure 7: Telemetry reception from Delfi-C3.

Figure 8: Telemetry reception from AO-73.

Telemetry signals give information most of the on board equipment, such as battery voltage, solar panel voltage and temperature, antenna status (deployed or not), power amplifier status (forward and reflected power) temperature and current consumption, reboot counts, *etc.*.

The spectrum scope shown in Figure 8 helps to correctly tune the carrier frequency that is continuously changing due to the Doppler effect.

Although this station is not completely deployed, the already installed equipment and features, together with the possibility to remotely access and share data, will certainly potentiate collaboration with other universities and research centers. For example, entities that launch satellites need to know about its performance and signals collected in different zones of the globe, so we can already cooperate with them. In turn, with the gained experience of different projects in this area we can also cooperate with those institutions to jointly build our own satellite.

V. CONCLUSIONS

In this paper we have presented the main reasons for having a satellite station and its benefits for research activities in this area.

The main functionalities of the station, operating in the VHF/UHF and Ku bands, were briefly described and some results of its operation, namely data collected and measured, was also presented.

In the future this station will continue to evolve so as to be an important facility to researchers in this area, not only at this university but also with many others worldwide, so it is a contribute to the progress of science.

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[7] http://www.celestrak.com/NORAD/elements/ (accessed June 2015).

[8] http://www.jpl.nasa.gov/news/ (accessed June 2015).

[9] http://www.goes.noaa.gov/index.html (accessed June 2015).

[10] http://www.eumetsat.int/website/home/index.html (accessed June 2015).

[11] https://www.ussu.co.uk/ClubsSocieties/societies/ears/Pages/home.aspx (accessed June 2015)

[12] http://www.amsat.org/ (accessed June 2015)

[13] http://www.cubesat.org/ (accessed June 2015)

[14] http://www.ariss.org/ (accessed June 2015)

[15] https://www.tapr.org/pr_intro.html (accessed June 2015)

Appendix E

Images generated from NOAA satellite transmissions

The software used for decoding and processing the transmissions from the NOAA weather satellites generate in fact 10 different files with different images that can be used for other analysis. All these images are automatically stored and therefor might be available for studies such as the infrared values captured from the scanned area. The satellite has various sensors and cameras, so along with a main image there is more data associated with it and it is then processed by the software at the end of the transmission. The images recorded have their name associated with the satellite, date, time and type of information. In the name "noaa-15-09081747-bd" means it was from satellite NOAA-15, received on the 8^{th} September at $17:47$, the next letters (bd,no,hvct.. etc) refer to the type of image that is related with enhancements of contrast, infrared measurements, introduction of color over sea and land areas. Detailed information about all the possible images or small videos that can be created with wxtoImg can be consulted in this manual that is available for free download at *http://wxtoimg.com/support/wxgui.pdf*. As an example there is a list below of all the images generated at one single passage of NOAA-15, and in each caption there is the real name of the image as generated by the software.

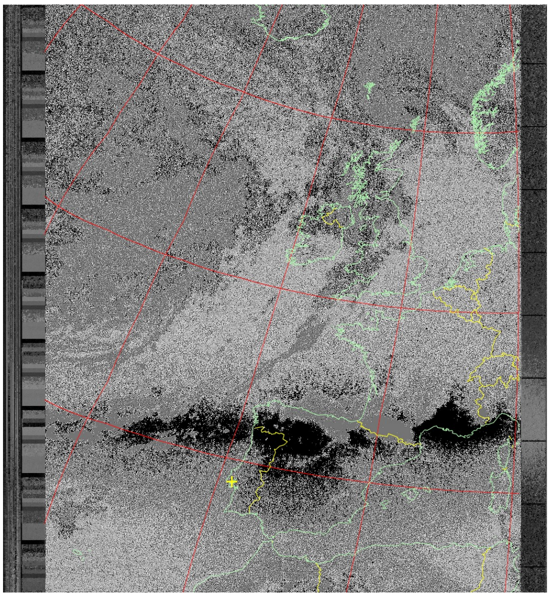


Figure E.1: noaa-15-09081747-bd

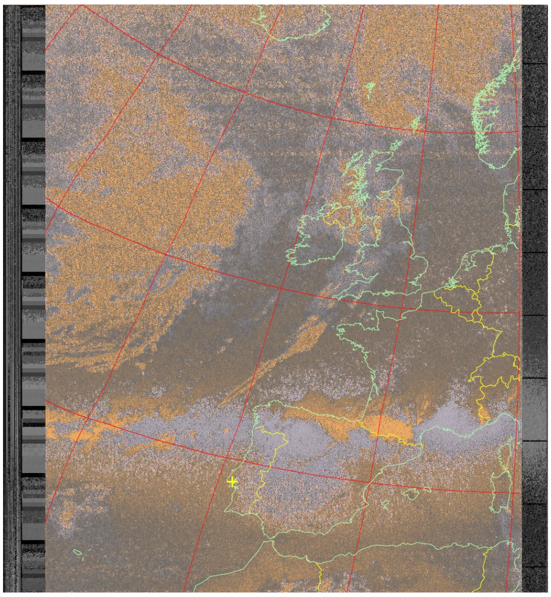


Figure E.2: noaa-15-09081747-no

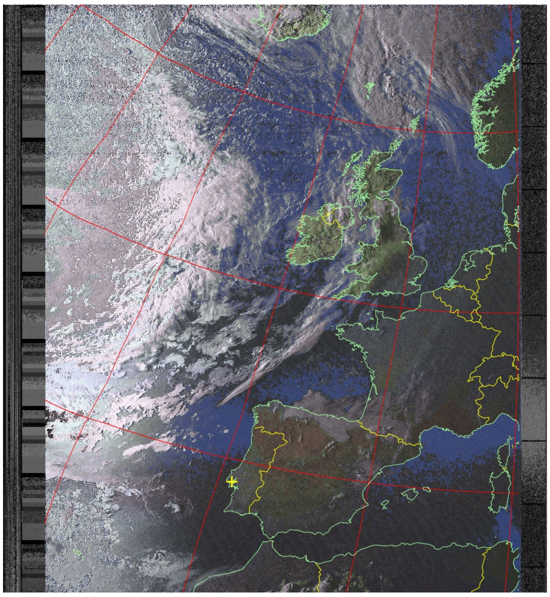


Figure E.3: noaa-15-09081747-hvct

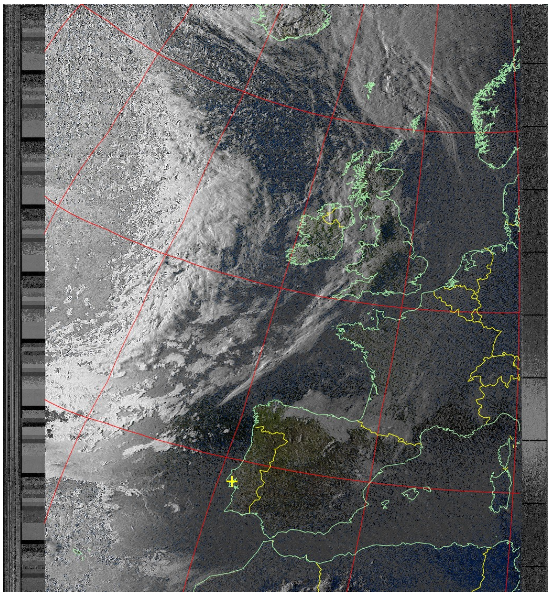


Figure E.4: noaa-15-09081747-msa

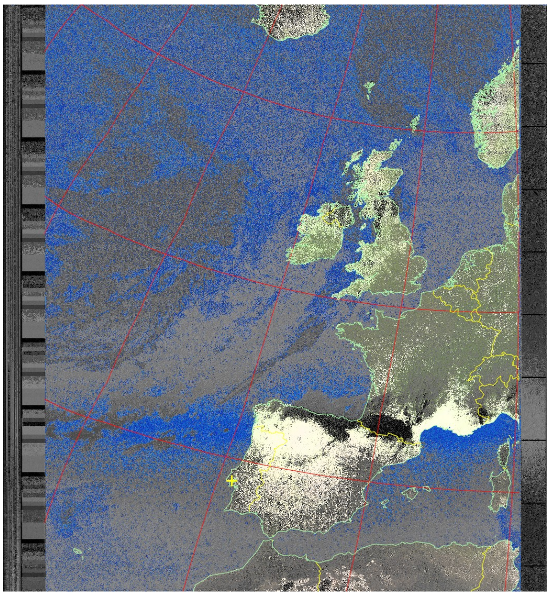


Figure E.5: noaa-15-09081747-mcir

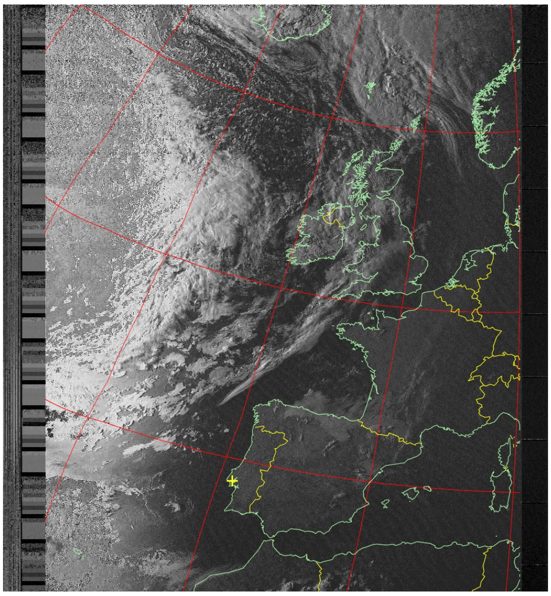


Figure E.6: noaa-15-09081747-contrasta

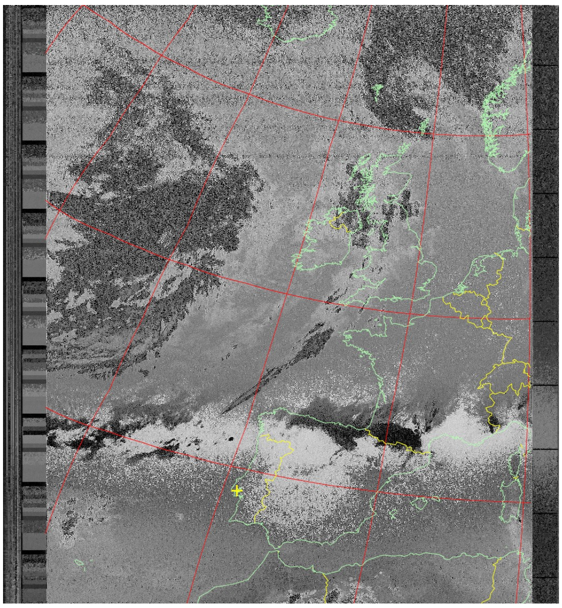


Figure E.7: noaa-15-09081747-contrastb

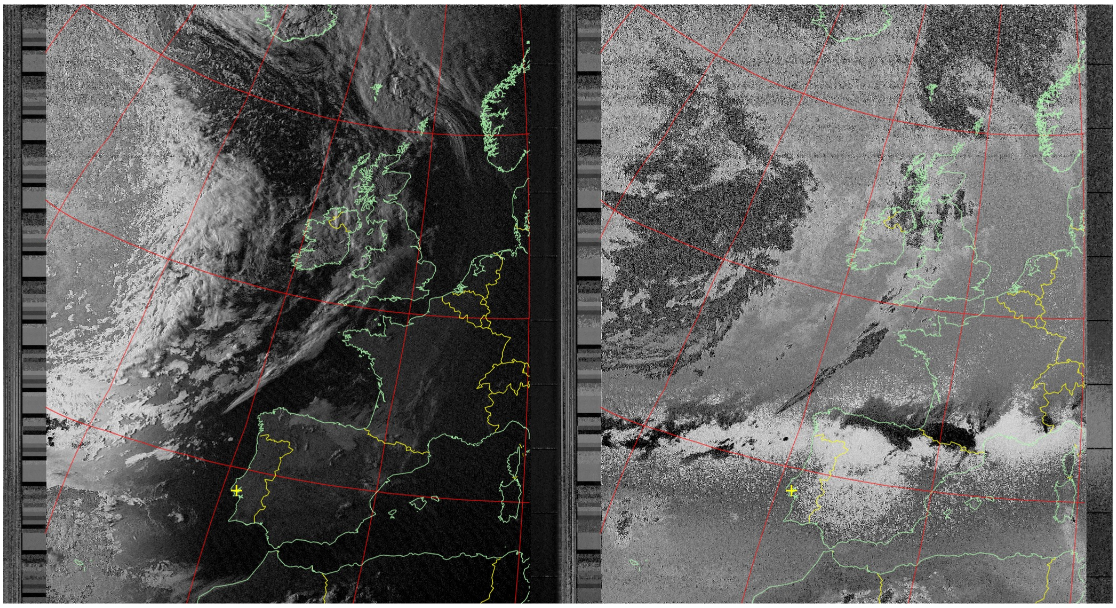


Figure E.8: noaa-15-09081747-contrast

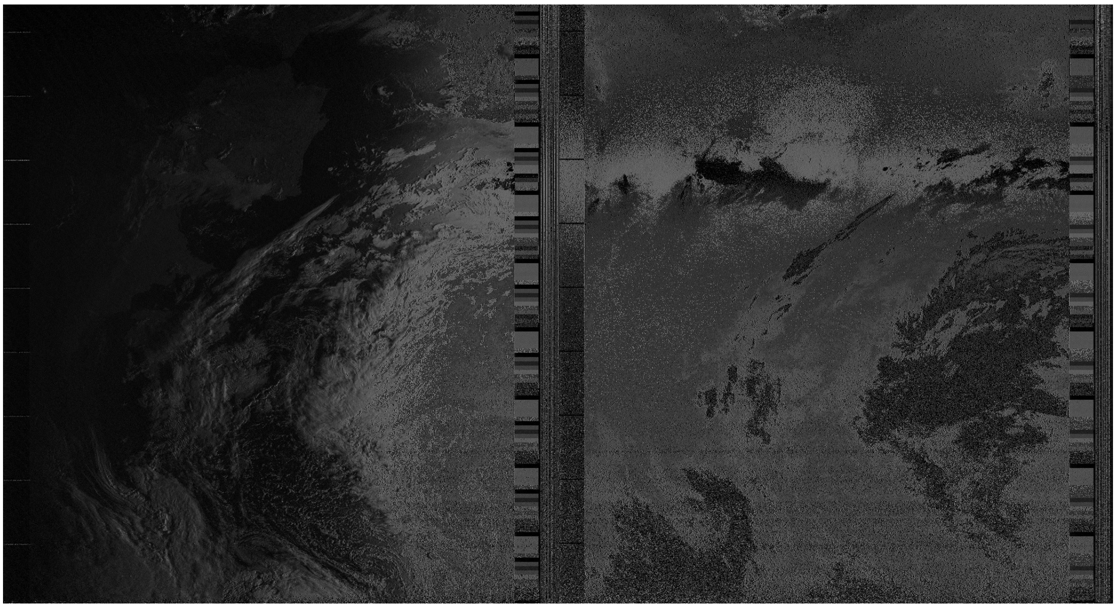


Figure E.9: noaa-15-09081747-pris

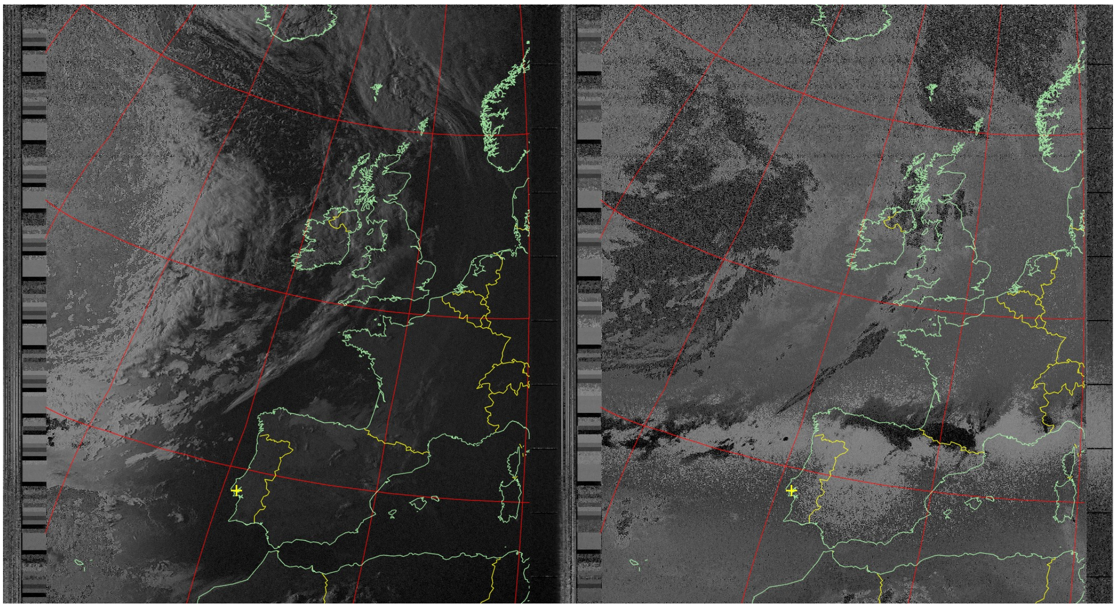


Figure E.10: noaa-15-09081747-norm

Appendix F

Transistor Datasheet

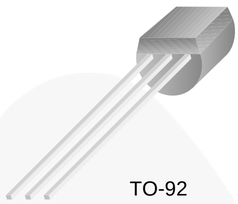
FAIRCHILD

November 2014

BC546 / BC547 / BC548 / BC549 / BC550
NPN Epitaxial Silicon Transistor

Features

- Switching and Amplifier
- High-Voltage: BC546, V_{CEO} = 65 V
- Low-Noise: BC549, BC550
- Complement to BC556, BC557, BC558, BC559, and BC560



1. Collector 2. Base 3. Emitter

Ordering Information

Part Number	Marking	Package	Packing Method
BC546ABU	BC546A	TO-92 3L	Bulk
BC546ATA	BC546A	TO-92 3L	Ammo
BC546BTA	BC546B	TO-92 3L	Ammo
BC546BTF	BC546B	TO-92 3L	Tape and Reel
BC546CTA	BC546C	TO-92 3L	Ammo
BC547ATA	BC547A	TO-92 3L	Ammo
BC547B	BC547B	TO-92 3L	Bulk
BC547BBU	BC547B	TO-92 3L	Bulk
BC547BTA	BC547B	TO-92 3L	Ammo
BC547BTF	BC547B	TO-92 3L	Tape and Reel
BC547CBU	BC547C	TO-92 3L	Bulk
BC547CTA	BC547C	TO-92 3L	Ammo
BC547CTFR	BC547C	TO-92 3L	Tape and Reel
BC548BU	BC548	TO-92 3L	Bulk
BC548BTA	BC548B	TO-92 3L	Ammo
BC548CTA	BC548C	TO-92 3L	Ammo
BC549BTA	BC549B	TO-92 3L	Ammo
BC549BTF	BC549B	TO-92 3L	Tape and Reel
BC549CTA	BC549C	TO-92 3L	Ammo
BC550CBU	BC550C	TO-92 3L	Bulk
BC550CTA	BC550C	TO-92 3L	Ammo

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter		Value	Unit
V_{CBO}	Collector-Base Voltage	BC546	80	V
		BC547 / BC550	50	
		BC548 / BC549	30	
V_{CEO}	Collector-Emitter Voltage	BC546	65	V
		BC547 / BC550	45	
		BC548 / BC549	30	
V_{EBO}	Emitter-Base Voltage	BC546 / BC547	6	V
		BC548 / BC549 / BC550	5	
I_C	Collector Current (DC)		100	mA
P_C	Collector Power Dissipation		500	mW
T_J	Junction Temperature		150	°C
T_{STG}	Storage Temperature Range		-65 to +150	°C

Electrical Characteristics

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter		Conditions	Min.	Typ.	Max.	Unit
I_{CBO}	Collector Cut-Off Current		V_{CB} = 30 V, I_E = 0			15	nA
h_{FE}	DC Current Gain		V_{CE} = 5 V, I_C = 2 mA	110		800	
$V_{CE}(sat)$	Collector-Emitter Saturation Voltage		I_C = 10 mA, I_B = 0.5 mA		90	250	mV
			I_C = 100 mA, I_B = 5 mA		250	600	
$V_{BE}(sat)$	Base-Emitter Saturation Voltage		I_C = 10 mA, I_B = 0.5 mA		700		mV
			I_C = 100 mA, I_B = 5 mA		900		
$V_{BE}(on)$	Base-Emitter On Voltage		V_{CE} = 5 V, I_C = 2 mA	580	660	700	mV
			V_{CE} = 5 V, I_C = 10 mA			720	
f_T	Current Gain Bandwidth Product		V_{CE} = 5 V, I_C = 10 mA, f = 100 MHz		300		MHz
C_{ob}	Output Capacitance		V_{CB} = 10 V, I_E = 0, f = 1 MHz		3.5	6.0	pF
C_{ib}	Input Capacitance		V_{EB} = 0.5 V, I_C = 0, f = 1 MHz		9		pF
NF	Noise Figure	BC546 / BC547 / BC548	V_{CE} = 5 V, I_C = 200 μA, f = 1 kHz, R_G = 2 kΩ		2.0	10.0	dB
		BC549 / BC550			1.2	4.0	
		BC549	V_{CE} = 5 V, I_C = 200 μA, R_G = 2 kΩ, f = 30 to 15000 MHz		1.4	4.0	
		BC550			1.4	3.0	

h_{FE} Classification

Classification	A	B	C
h_{FE}	110 ~ 220	200 ~ 450	420 ~ 800

Typical Performance Characteristics

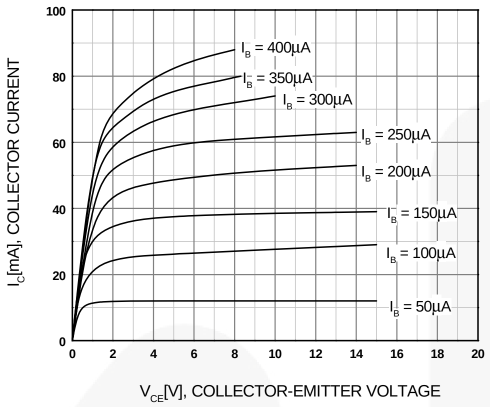


Figure 1. Static Characteristic

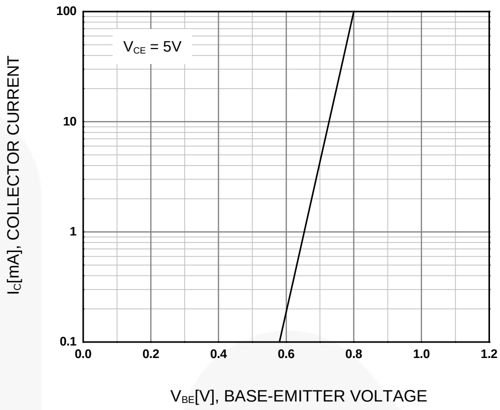


Figure 2. Transfer Characteristic

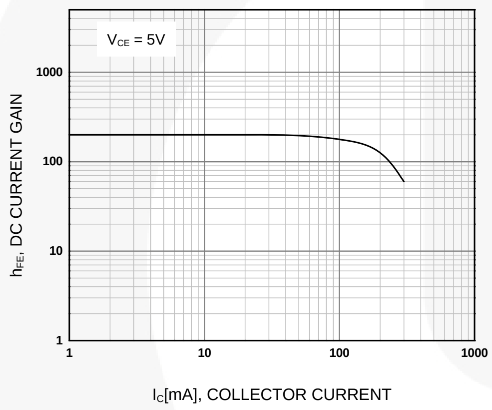


Figure 3. DC Current Gain

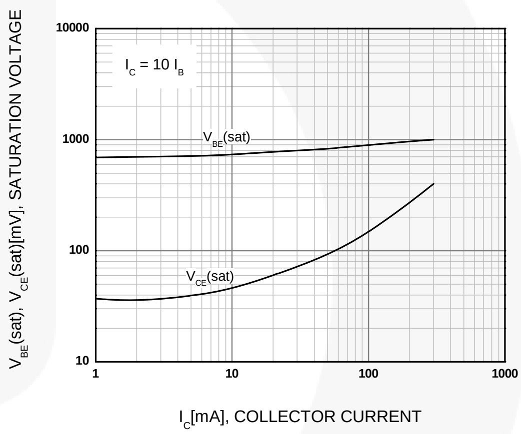


Figure 4. Base-Emitter Saturation Voltage and Collector-Emitter Saturation Voltage

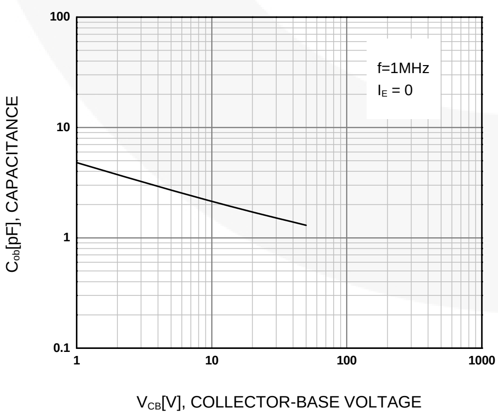


Figure 5. Output Capacitance

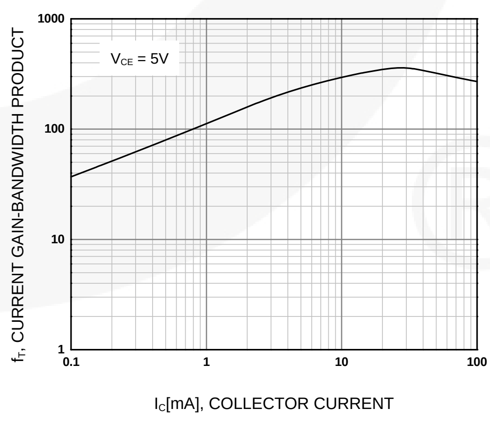
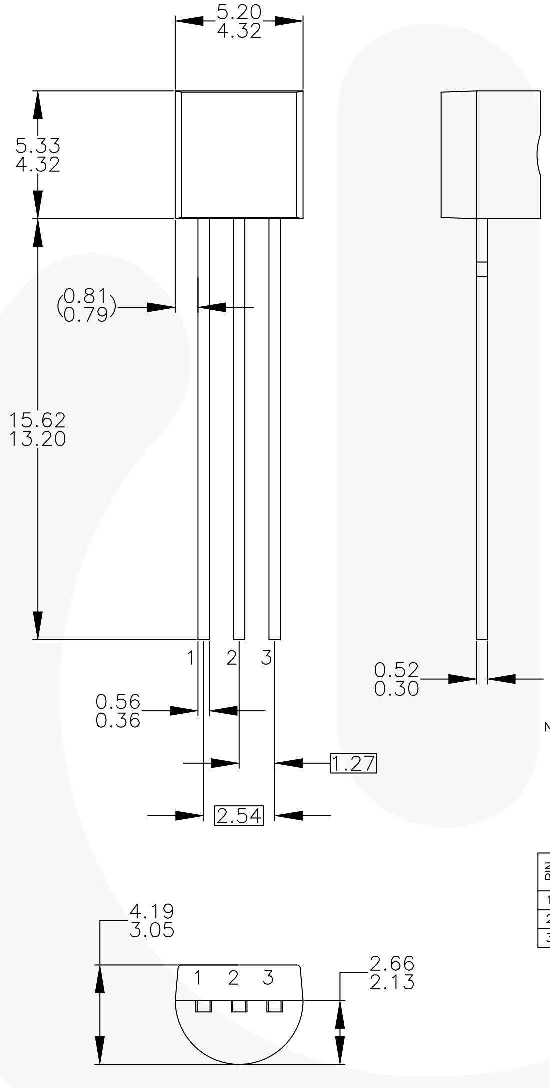


Figure 6. Current Gain Bandwidth Product

Physical Dimensions



NOTES: UNLESS OTHERWISE SPECIFIED

A) DRAWING WITH REFERENCE TO JEDEC TO-92 RECOMMENDATIONS.
B) ALL DIMENSIONS ARE IN MILLIMETERS.
C) DRAWING CONFORMS TO ASME Y14.5M-1994.
D) TO-92 (92,94,96,97,98) PIN CONFIGURATION:

PIN	92			94			96			97			98		
	P	F	M	P	F	M	B	F	M	P	F	M	P	F	M
1	E	S	S	E	S	S	B	D	G	C	G	D	C	G	D
2	B	D	G	C	G	D	E	S	S	B	D	G	E	S	S
3	C	G	D	B	D	G	C	G	D	E	S	S	B	D	G

LEGEND:
P - BIPOLAR E - EMITTER D - DRAIN
F - JFET B - BASE S - SOURCE
M - DMOS C - COLLECTOR G - GATE

E) FOR PACKAGE 92, 94, 96, 97 AND 98: PIN CONFIGURATION DRAIN "D" AND SOURCE "S" ARE INTERCHANGEAGLE AT JFET "F" OPTION.
F) DRAWING FILENAME: MKT-ZA03DREV3.

Figure 7. 3-Lead, TO-92, JEDEC TO-92 Compliant Straight Lead Configuration, Bulk Type

Physical Dimensions (Continued)

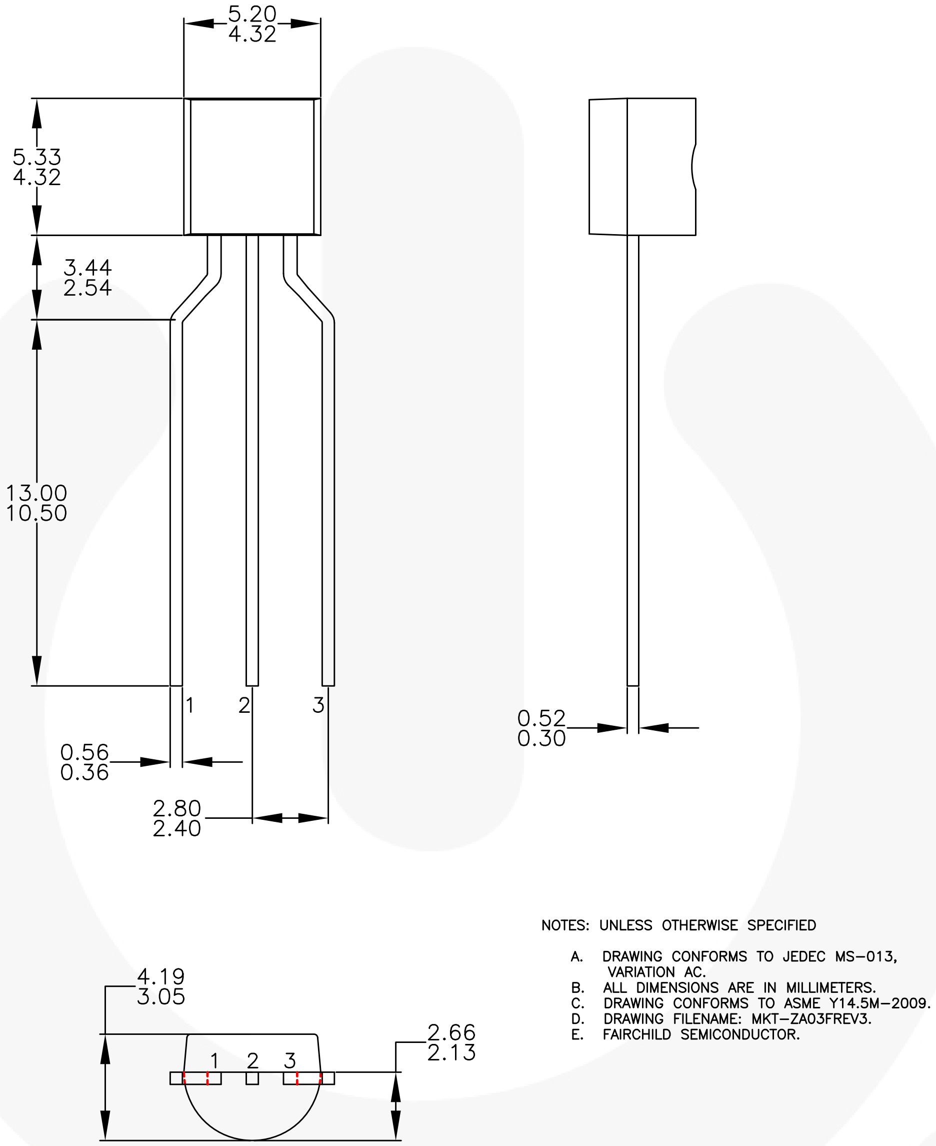


Figure 8. 3-Lead, TO-92, Molded, 0.2 In Line Spacing Lead Form, Ammo, Tape and Reel Type

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Rev. I72

Appendix G

Arduino Code

```
#include <SoftwareSerial.h>
#include <stdint.h>
#define rxPin 10
#define txPin 11

SoftwareSerial mySerial = SoftwareSerial(rxPin, txPin);



int up = 4;
int down = 12;
int left = 8;
int right = 7;
int onoff = 13; //Arduino Connected

int antennaInputAzimuth = 0; //Setup Input Value
int antennaInputElevation = 1; //Setup Input Value


float elevationAngle = 0.0;
float azimuthAngle = 0.0;
float elevationVolts = 0.0;
float azimuthVolts = 0.0;
int elevationVal = 0;
int azimuthVal = 0;

float minAzimuthVal = 0.1; // Mininum azimuth volts value
float minAzimuthAngle = -180.0; //Minumim azimuth degrees value
```

```
float maxAzimuthVal = 5.0; //Maximum azimuth volts value
float maxAzimuthAngle = 180.0; //Maximum azimuth degrees values

float minElevationVal = 0.1; //Mininum elevation volts value
float minElevationAngle = 0.0; //Minumim elevation degrees value
float maxElevationVal = 5.0; //Maximum elevation volts value
float maxElevationAngle = 180.0; //Maximum elevation degrees values


bool go = false;
byte valsSoft[16];
float elevationSoft = 0.0;
float azimuthSoft = 0.0;
float azI = 0.0;
float azD = 0.0;
float elI = 0.0;
float elD = 0.0;

uint8_t CTS = 5;  // CLEAR TO SEND
uint8_t RTS = 6;  // REQUEST TO SEND

void setup() {
  Serial.begin(9600);
  mySerial.begin(9600);
  pinMode (onoff, OUTPUT);
  pinMode (up, OUTPUT);
  pinMode (down, OUTPUT);
  pinMode (left, OUTPUT);
  pinMode (right, OUTPUT);
  pinMode (antennaInputAzimuth, INPUT);
  pinMode (antennaInputElevation, INPUT);
  pinMode (CTS, OUTPUT);
  pinMode (RTS, INPUT);

  pinMode (rxPin, INPUT);
  pinMode (txPin, OUTPUT);




}

void loop() {
```

```
// READ ANTENNA POSITION
elevationVal = analogRead(antennaInputElevation); //Read analog
    input value
elevationVolts = adcValue_to_Volts(elevationVal); //Convert value
    to volts
elevationAngle = antenna_Elevation_Value(elevationVolts); //Compute
     angle from voltage value

azimuthVal = analogRead(antennaInputAzimuth); //Read analog input
    value
azimuthVolts = adcValue_to_Volts(azimuthVal); //Convert value to
    volts
azimuthAngle = antenna_Azimuth_Value(azimuthVolts); //Compute angle
     from voltage value

  readDataFromSoft();

if(go == true){
if ((azimuthSoft != azimuthAngle) || (elevationSoft !=
    elevationAngle)) {
  if ( elevationSoft > elevationAngle + 2) {
    digitalWrite(4,HIGH);
    digitalWrite(12,LOW);
  } else {
    if (elevationSoft < elevationAngle - 2) {
      digitalWrite(4,LOW);
      digitalWrite(12,HIGH);
    } else {
      digitalWrite(4,LOW);
      digitalWrite(12,LOW);
    }
  }

  if (azimuthSoft > azimuthAngle + 3) {
    digitalWrite(7,HIGH);
    digitalWrite(8,LOW);
  } else {
    if (azimuthSoft < azimuthAngle - 3) {
      digitalWrite(7,LOW);
      digitalWrite(8,HIGH);
    } else {
      digitalWrite(8,LOW);
```

```
        digitalWrite(7,LOW);
      }
    }
    delay(250);

  }else{

    go = false;
    delay(3000);
  }
  }
}

// ------------------------------------------------------------------
//                        ANTENNA INTERFACE
// ------------------------------------------------------------------

float antenna_Azimuth_Value(float azimuthValAux) {
  return (((azimuthValAux - minAzimuthVal) * (maxAzimuthAngle -
     minAzimuthAngle)) / (maxAzimuthVal - minAzimuthVal)) +
     minAzimuthAngle;
}

float antenna_Elevation_Value(float elevationValAux) {
  return (((elevationValAux - minElevationVal) * (maxElevationAngle -
      minElevationAngle)) / (maxElevationVal - minElevationVal)) +
     minElevationAngle;
}

// Convert the analog reading (which goes from 0 - 1023) to a voltage
    (0 - 5V):
float adcValue_to_Volts(int adc) {
  return adc * (5.0 / 1023.0);
}


// ------------------------------------------------------------------
//                        SOFTWARE INTERFACE
// ------------------------------------------------------------------


void readDataFromSoft() {
```

```
  if (mySerial.available()>0){

  for(int i=0; i<15;i++){  // 16 reads will guarantie a complete
     frame in the array
     valsSoft[i]=mySerial.read();
     }
  int i=0;
  while(valsSoft[i]!='W'){ // Looking for the start of the frame
    i=i++;
  }
  float azI = (valsSoft[i+1]-'0')*100 + (valsSoft[i+2]-'0')*10 + (
     valsSoft[i+3]-'0');
  float elI = (valsSoft[i+5]-'0')*100 + (valsSoft[i+6]-'0')*10 + (
     valsSoft[i+7]-'0');
  float elD = 0; // Decimal values are not required with this rotator
  float azD = 0; // Decimal values are not required with this rotator

  azimuthSoft = azI;// + azD/100;
  elevationSoft = elI;// + elD/100;
  if (azimuthSoft > 180) azimuthSoft -= 360;
  go = true;
  }
}
```

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