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Trabajo Fin de Máster

SAWS, un sistema para descargar y visualizar automáticamente imágenes HRPT de satélites meteorológicos (SAWS, a system for automatically downloading and visualizing HRPT pictures from weather satellites)

Para acceder al Título de

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Autor: Marta Gómez Goitia

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Key words

HRPT, satellites, receiver, NOAA, Metop, Feng-Yun, antenna, RF, decoder, mechanical structure, motors, WXtrack, Arduino, SDRplay, LNA, automation.

1 Introduction

SAWS is a project that took place in the framework of RUAG Brains program at RUAG Space AB, a company supplier of products for the space industry in Gotherburg, Sweden. This program, which this year was in its fourth edition, selects eight students from Chalmers University of Technology also in Gotherburg, Sweden.

These eight multidisciplinary students, divided in two well-balanced teams design during one week a project proposed by the company. By the end of the week, the two teams presents its designs in a competition, having then the eight student the possibility of building the winning project during a six-week summer job at the company.

This year's RUAG Brains program, which I was part of, consisted on designing a system for automatically downloading and visualising HRPT pictures from weather satellites with some boundary conditions. So, for being able to download the pictures, an antenna with a receiver was needed, a decoder was required for being able to visualised them, and a structure to hold the antenna was also necessary.

The system had to be able to automatically track the relevant satellites, so motors were necessary in the structure to move the antenna towards the satellites. These satellites were NOAA 15,18 and 19, Metop A and B, and Feng-Yun 3A, 3B and 3C.

It had to be designed for reception of HRPT picture transmission and provide a display with the latest picture and system status, so for decoding and visualising, specific software for HRPT had to be used. Also, the antenna and RF had to be design for the HRPT frequency.

The system had to be easy to set up and operate when moved to a new location and be mechanically robust, this means the structure had to be strong and tough but not too heavy to be able to hold it. The system also needed not to have a strong dependence on the ground location, so it should have been easily set up with little effort.

Finally, it also had to be able to run from a 12 V power bus, as well as from 230 V mains. So, an electric system running from a battery and 230 V main had to be designed.

After the design was done, the system was also built, having a final product downloading and showing the HRPT pictures from the meteorological satellites.

The complete process of this system, from zero to the final product, is explain in this report, which is divided in another five different chapters:

– The second chapter explains the theoretical concepts necessary to understand the project.

– The third one details the complete design of the system from scratch, explaining all the parts and all the material involved in it.

– The fourth one describes the construction process from the design to the working system.

– The fifth one illustrates the results, from the signals received with the antenna to the final pictures, though the different result obtained in the different stages of the system.

– Finally, in the sixth and last chapter, some conclusions and future lines are exposed.

2 Technical Introduction

The system designed in this project, SAWS, is a system for automatically downloading and visualising HRPT pictures from weather satellites. Before talking about the design itself, there are some concepts that need to be explain as the image transmission system, HRPT, the satellites that have it implemented and how a receiving system works.

2.1 HRPT

HRPT stands for High-Resolution Picture Transmission and is one of the real-time systems that can be implemented in Polar Operational Environmental Satellites.

HRPT provides data from meteorological satellites at a rate of 665.4 kbps, with words of 10 bits each [1]. The resolution of these pictures is 1.1 km, meaning that each pixel represent $1.21km^2$. The transmission of this digital, time multiplexed, phase modulated data occurs at the 1.7 GHz band and is done in five spectral bands, outputs of an Advanced Very High Resolution Radiometer (AVHRR/3) [1].

2.2 Weather satellites

The meteorological satellites that have the HRPT implemented are sun- synchronous polar orbiting. Polar orbits pass over the Earth's polar regions from north to south. However, the satellite do not have to cross the poles exactly, it is still a polar orbit if they pass within 20 or 30 degrees of the poles [2]. Sun-synchronous polar orbits are those polar orbits that every time they pass the equator they do it a few constant degrees westward from previous pass longitude.

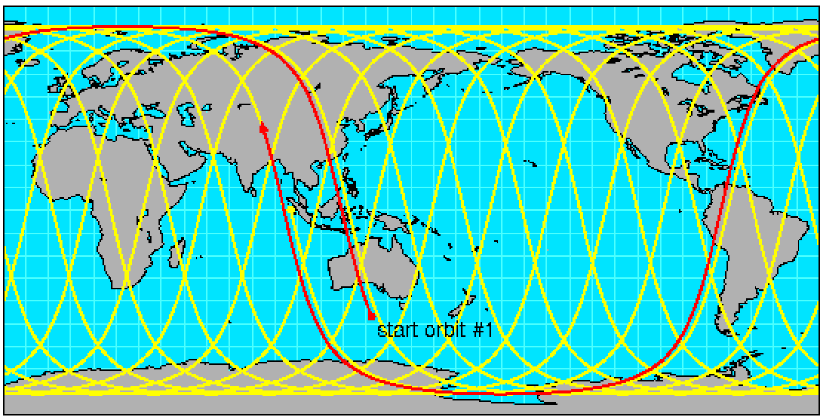


Figure 1: Ground path of a polar orbit satellite along a day.

These orbits altitudes are mainly low ones between 200 to 1000 km. Also, satellites in polar orbit pass over the North and South Poles several times a day. A schematic of the path of a sun-synchronous polar orbit satellite can be seen in figure 1.

In the particular case of the meteorological satellites involved in this project, the altitudes are between 793 and 855 km [3], taking around 100 minutes to pass over the same latitude and being visible at least four times a day from every point in the Earth, depending this number in the latitude of the location [4].

Other important characteristics about these meteorological satellites are the Right Handed Circular Polarization (RHCP) they transmit with and a wide bandwidth between 4 - 6.8 kHz.

By the time this topic was investigated for the design of the project, eight were the satellites with these features implemented, however, only six of them were properly working: NOAA 15, 18 and 19, Metop-B and Feng-Yun (FY) 3B and 3C. A table with these satellites, their carrier frequency, bandwidth and altitude is shown in table 1.

Table 1: The weather satellites from which this project receives information and their characteristics.

Satellite	**Carrier frequency**	**Bandwidth**	**Altitude**
NOAA 15	1702.5 MHz	4.0 kHz	793 km
NOAA 18	1707.0 MHz	4.0 kHz	855 km
NOAA 19	1698.0 MHz	4.0 kHz	850 km
Metop-B	1701.3 MHz	4.5 kHz	827 km
FY 3B	1704.5 MHz	6.8 kHz	836 km
FY 3C	1701.4 MHz	6.8 kHz	836 km

Other differences between the different satellites are the modulation and waveform used. While the NOAA satellites transmit BPSK signals with the waveform in figure 2; the Metop and Feng-Yun satellites transmit QPSK signals with a different kind of waveform from NOAA's in figure 3.

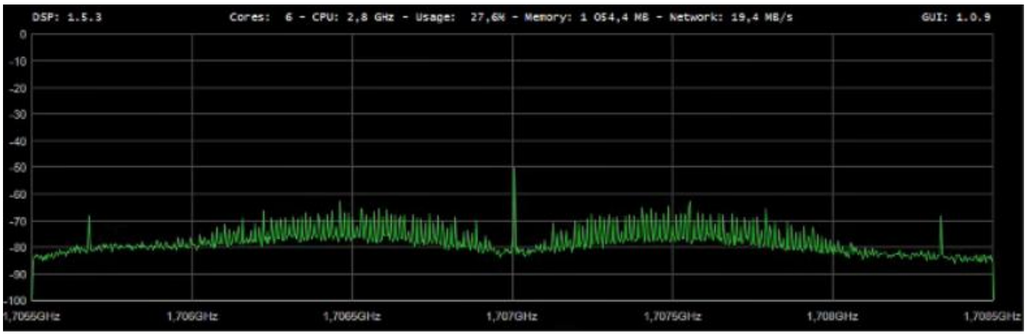


Figure 2: Waveform of NOAA's signals.

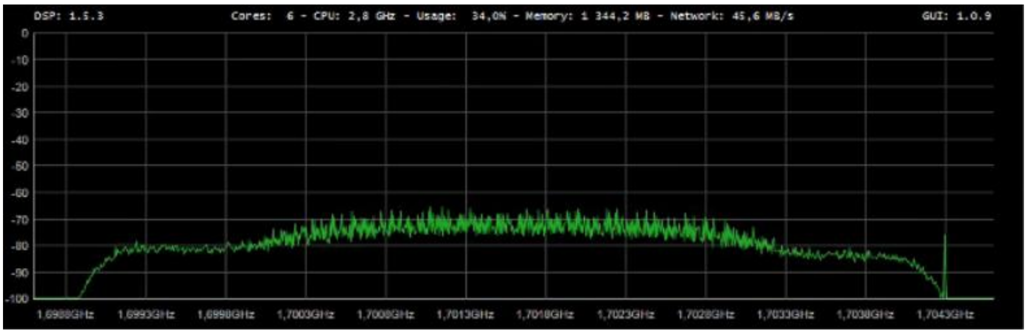


Figure 3: Waveform of Metop and FY's signals.

2.3 How HRPT reception works?

For receiving the signal from the satellites that have been commented on before, first of all an antenna is needed. It has to have a wide beam and a high gain, so for that a parabola reflector together with a feed is used. Even if the antenna is high gain a Low Noise Amplifier (LNA) is also needed, to preamplify the signal without adding more noise than necessary. The amplified signal has to be processed, and a flexible and easy way to do it is with a Software Defined Radio (SDR).

After the SDR, the signal will be ready to be decoded, so a decoded system is needed to be able to reproduced the picture downloaded.

In addition, for the antenna to stand and to be able to follow the satellites, a mechanical structure with two directional motors is needed. Together with the motors, a tracking system telling where the satellites are in real-time, is necessary for the motors to move towards the satellites.

3 Theoretical Design

The full system can be divided in four different subsystems even if they need from each other to work. This four subsystems are the RF system, the software system, the mechanical system and the electrical system. An schematic of these subsystems can be seen in figure 4.

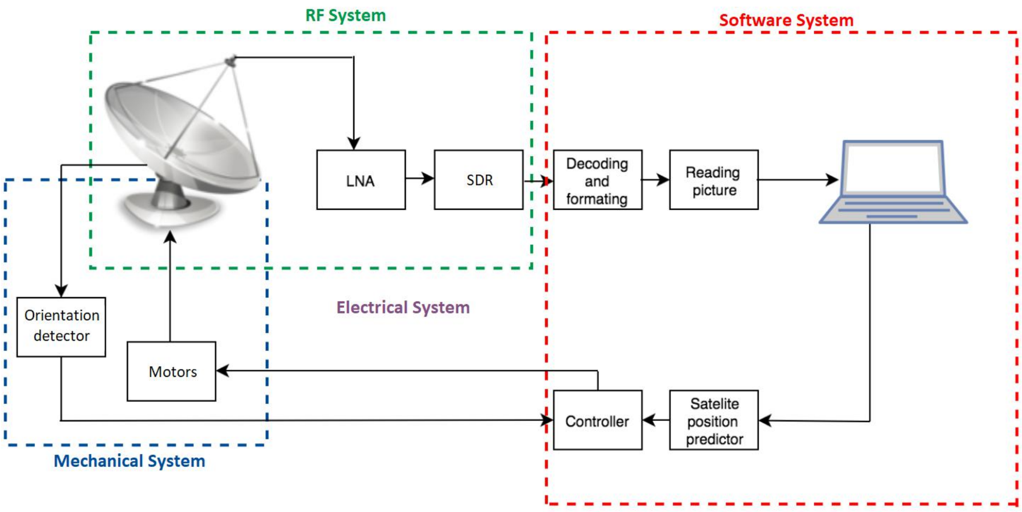


Figure 4: Schematic of the overall System Design.

3.1 RF System

The RF system contains the antenna for receiving the signal, a Low Noise Amplifier (LNA) as preamplifier for the processing and a Software Defined Radio (SDR) to make the signal processing itself.

3.1.1 Antenna

The transmitted power of the satellites is unknown, so no link budget can be calculated to estimate the necessary antenna gain. However, there is some official documentation [4], in which is said that an antenna in the order of 22 - 24 dB of gain is a good one for these reception systems. Also, as the antenna needs to follow the satellites as they pass over, a wide enough beam is needed not to easily loose the connection with them.

In order to achieve a high gain without a narrow beam-width, the best antenna option is a reflector parabola. The gain of the reflector can be estimated using [5]

$$G = 10log_{10}\,\eta(\frac{\pi D}{\lambda})^2 \quad (1)$$

Where $0.5 < \eta < 0.7$ is the antenna efficiency, D is the diameter of the dish and λ is the wavelength of the signal. So, for $\lambda = 0.1765$ m, and a gain around 22 - 24 dB, the diameter D should be around 1 - 1.2 m.

The antenna dish finally chosen was a commercial satellite TV reflector, an offset 110 by 100 cm dish: "http://www.triax.com/products/satellite/satellite-dishes/steel-dishes/td110-std-ral-7035-singlepack-wing-nut".

For the feed of the reflector, different options were considered and analysed. The best two option were a Hand-made Helical Feed and a Commercial Horn Antenna. The advantages for the Commercial Horn Antenna, as a feed for this system, are its high gain and its robustness as it is already built. However, the HRPT frequency, 1.7 GHz, is not a common one, so not many horns are available at this frequency and these ones are quite expensive. On the other hand, the Hand-made Helical Feed, even if it needs from extra design, has the advantage of natural circular polarization for receiving the signal, besides it has high gain as well. So this was the chosen feed for this project, a Hand-made Helical Feed.

This Hand-made Helical Feed consists on a helical shaped coil, a circular 3D-printed ABS plastic tube support where to twist the coil to make it more robust, and a circular ground plane with a bigger diameter than the tube. An image of the simulated Helical Feed can be seen in figure 5.

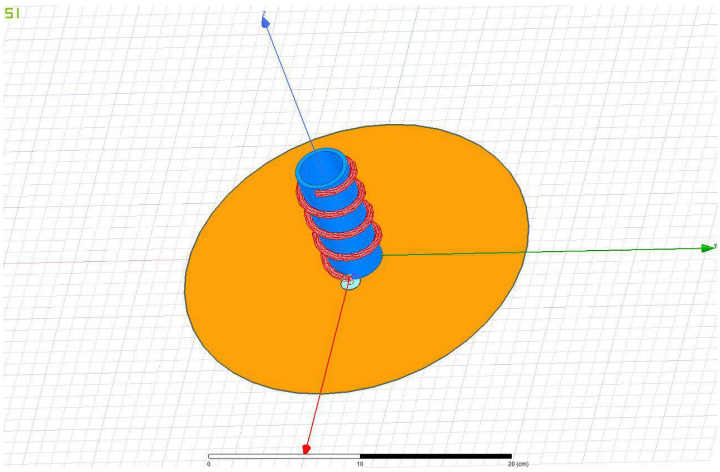


Figure 5: Image of the simulated Helical Feed.

For the design of this feed, one fundamental characteristic to have in mind is that the incoming signal have Right Handed Circular polarization (RHCP). However, the reflector inverts this polarization to be Left Handed Circular (LHCP), so the feed needs to be designed for receiving LHCP signals. This means, the feed needs to be designed with left-handed winding.

The helical feed was designed with a center frequency of 1.7 GHz corresponding to a wavelength of around $\lambda = 0.1765$ m. For an unloaded helical antenna, the circumference of the coil should be on the order of one free-space wavelength, so the diameter should be about λ/π [6]. However, since the helix is loaded with a dielectric with a certain dielectric constant, the operating frequency goes down compared to an unloaded helix of the same dimensions in the order of $(\sqrt{\epsilon_e})^{-1}$, where $\epsilon_{air} < \epsilon_e < \epsilon_{ABS}$. For taking this effect into account a smaller circumference of the helix, combined with a shorter spacing between consecutive turns is designed and tweaked until desired performance is achieved

The design was simulated in High Frequency Structure Simulator (HFSS) where the dielectric value was assumed to be $\epsilon_{ABS} = 2.5$, knowing that the real values for ABS plastic are between 2 - 3.5. The final values were 4 cm for the helix diameter, 11 cm for the helix length with four turns and 20 cm for the ground plane diameter. Values for which the return loss simulation had a good performance at 1.7 GHz, as shown in figure 6.

Figure 6: Return loss Simulation for the final values of the Feed.

3.1.2 Low Noise Amplifier

Once the signal has been received by the antenna, it is not strong enough to be processed, so a preamplifier stage is needed right after the antenna feed. The musts for this amplification are a high gain and a really low noise figure, so an LNA was chosen for this task. In this project, the low cost alternative *LNA4ALL* ”http://lna4all.blogspot.com/”, shown in figure 7, was selected for its low cost and good enough performance, with a gain of about 14 dB and a noise figure below or equal to 1 dB over all range.

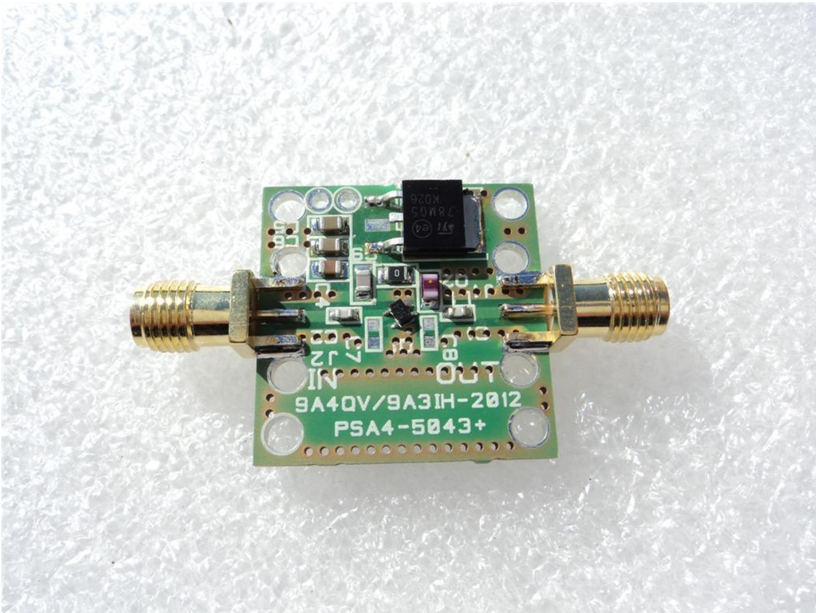


Figure 7: LNA4all preamplifier.

3.1.3 SDRplay

The use of a SDR enables a flexible and easy signal processing at a relatively low price, compared to designing and building a dedicated hardware solution.

Figure 8: Picture of the SDRplay RSP2.

In this system, the SDRplay RSP2, in figure 8, has been selected due to its frequency band in our range (1.7 GHz), its wide spectrum for the received signals (10 MHz), its 12-bits ADC and its good dynamic range.

This SDR has implemented a variable amplifier for RF Gain control, some FM/AM notch filters, as well as some selectable RF filters, and two chips. The first one is the tuner Mirics MSi001 that down-converts the frequency of the received signal, with an LNA included providing up to 20 dB, followed by some other filters. The second chip is the Mirics MSi2500 that consists of a microcontroller, a clock oscillator, a frequency synthesizer, an USB controller, a DSP processor and ADCs. All this components are shown in figure 9 as a conceptual block diagram of the SDRplay.

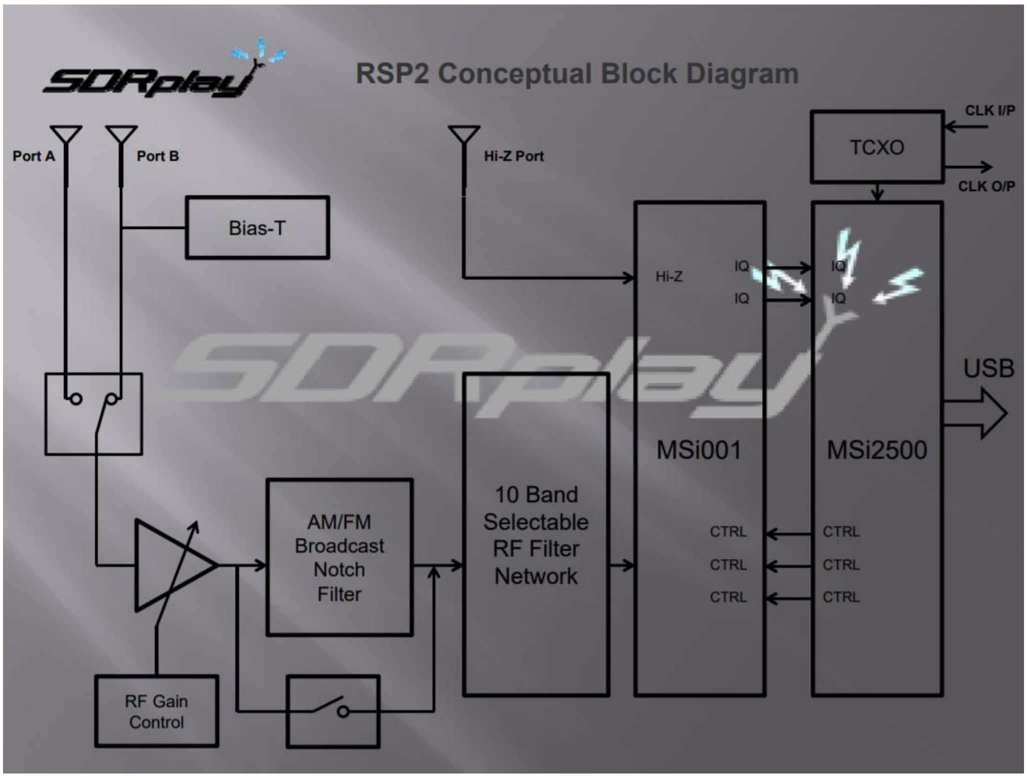


Figure 9: Conceptual Block Diagram of the SDRplay.

3.2 Software System

The Software system includes a variety of commercial software and some coding as well. Depending on their task, they can be classified in decoding or tracking software. The decoding allows to visualise the picture and the tracking tells where the satellites are to be able to move the antenna towards them.

3.2.1 Automatic tracking

With the tracking system the antenna is moved to point towards a certain satellite by knowing the satellites current elevation and azimuth angles, with reference of a certain ground location, from a satellite tracking software, WXtrack. With this information and the information about where the antenna is currently pointing, also in terms of azimuth and elevation angles, the motors are controlled using an Arduino UNO microcontroller and an motorcontroller to follow automatically the satellites in real-time.

a. Wxtrack

The WXtrack is the software used to track the satellites. This program, with the coordinates of the location of the ground antenna, calculates the azimuth and elevation angles the antenna needs to point at, to track the satellite and sends this data through the COM port for the Arduino controller program to be able to track the satellite through the pass. The calculations are done based on the Kepler data of the satellites that is often updated. A screenshot of the WXtrack software is shown in figure 10.

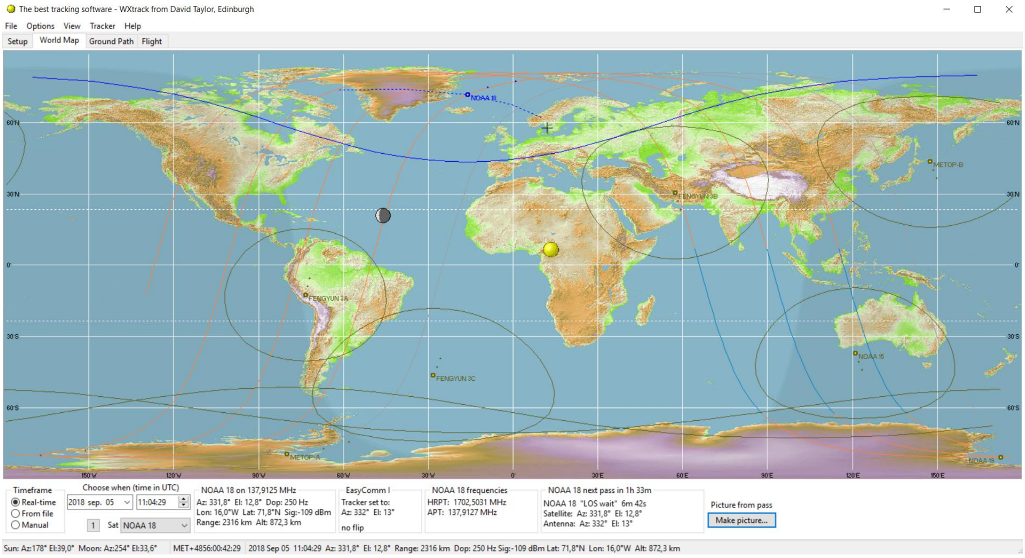


Figure 10: WXtrack software screenshot.

b. Arduino program

The Arduino uno, in figure 11, is the computer that makes the motors move for the parabola to point in the right direction, to the satellites. It obtains the elevation and the azimuth angles of the parabola with the use of an IMU (Inertial Measurement Unit) sensor. The elevation and azimuth angles of the satellite are obtained by serial communication with WXtrack.

The basic idea of the program is for the angles of the satellite and the parabola to be compared and the delta angles to be calculated. Thereafter, the delta angles should be minimised by driving the motors, and so, the satellite is being tracked.

Figure 11: Arduino Uno microcontroller board.

c. Sensor GY-85

The IMU, in figure 12, located in the parabola, is connected to the arduino Uno board to provide the antenna pointing feedback to the motorcontroller. This sensor includes an accelerometer, a gyroscope and a magnetometer. The built in accelerometer provides elevation angles, whereas the gyroscope calculates the angle in azimuth.

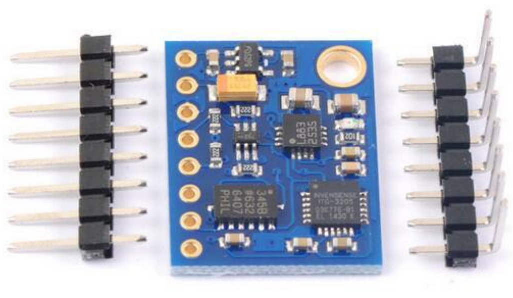


Figure 12: GY-85 IMU sensor.

3.2.2 Decoding

The incoming signal is processed with the SDRplay, and as a SDR, it needs its software to control that task. Once the signal is processed, it needs to be decoded, and then the data obtained needs a especial reader to be able to show the picture. All this stages use different software, that together with an automation program, will automatically execute the downloading of the pictures.

a. RSP Streamer

RSP Streamer is a software to control the SDRplay. It can adjust the settings for frequency, bandwidth, filters and amplifiers for the best signal reception, as observed in figure 13.

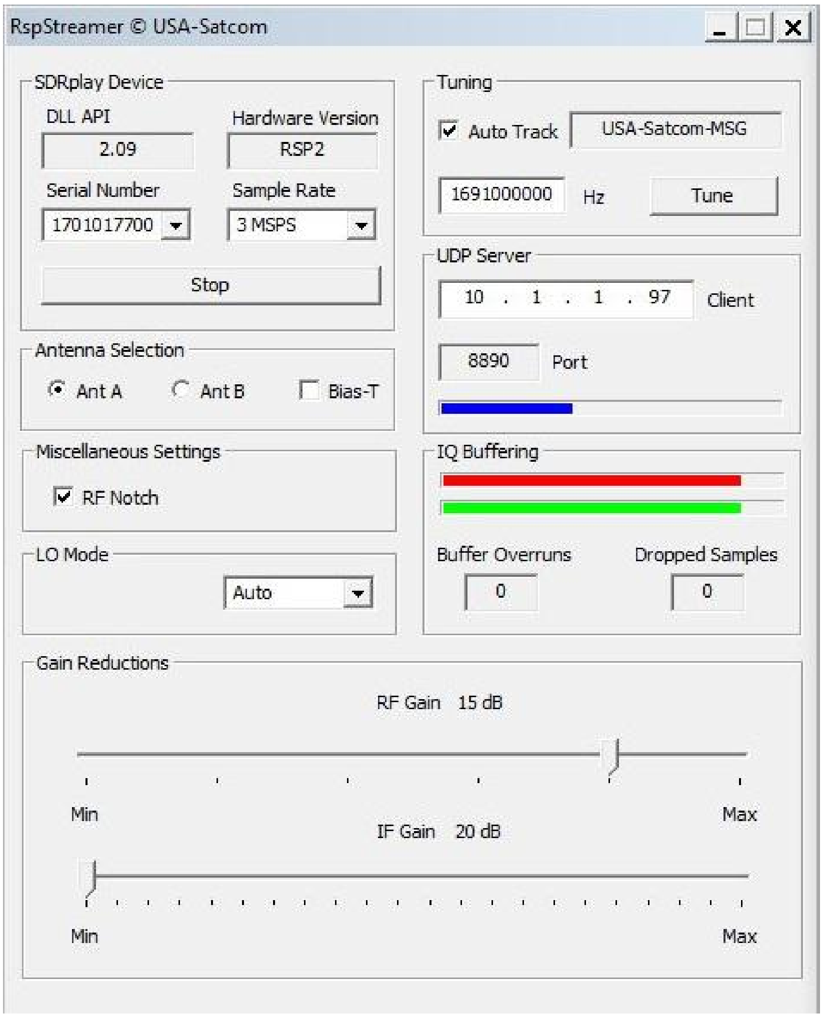


Figure 13: RSP Streamer software screenshot.

Even if this system is using the RSP Streamer to control the SDRplay, the

SDRuno is a more powerful software that comes with the hardware. The reason of using the RSP Streamer is its connection feature with other software, that is required for this system.

b. XHRPT Decoder

The XHRPT Decoder, in figure 14, is the software used to decode the received signal from the satellite and convert it to raw data for getting the picture afterwards. This program connected to WXtrack is capable of detecting when a satellite is being tracked and selects the frequency and modulation of the incoming signal. It also connects to RSP Streamer, and after synchronising the frequency of the satellite, it receives the data stream of the incoming signal just ready to be decoded.

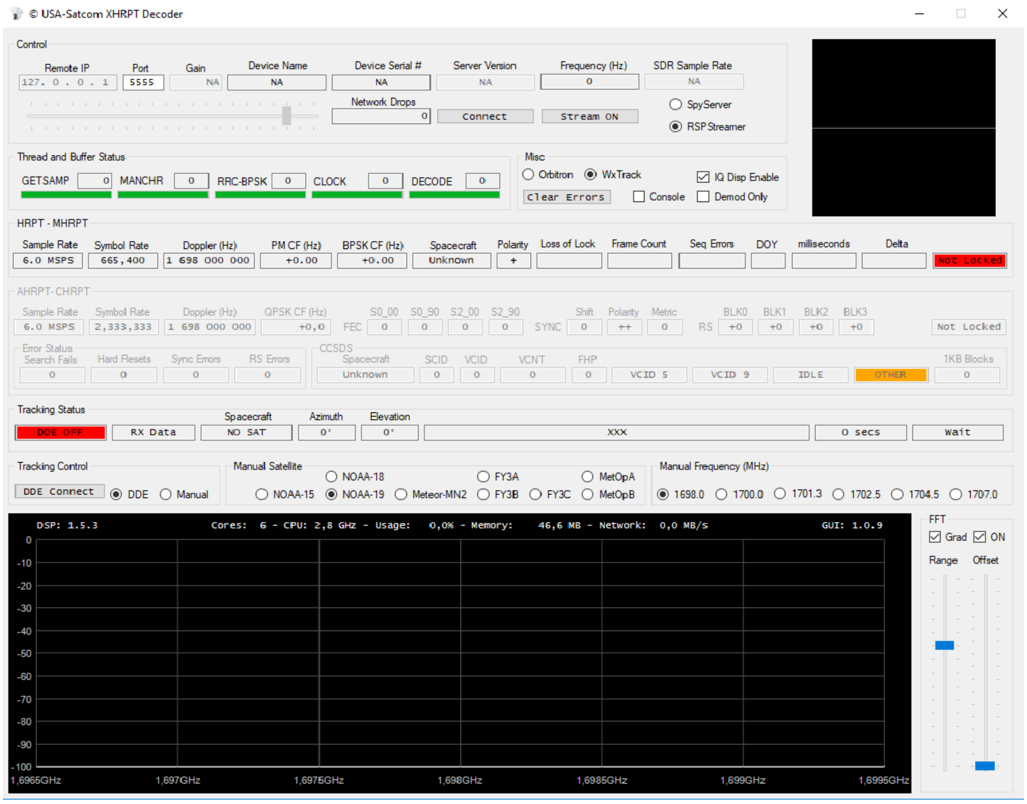


Figure 14: XHRPT Decoder software screenshot.

c. MetFY3x

For MetOp and FengYun satellites an extra decoding needs to be done, so MetFY is the software responsible of that extra decoding for getting the picture.

d. HRPT Reader

Once the data from the satellite is decoded, the raw data can be opened with this HRPT Reader that shows the photo picture got from the satellite, as observed in figure 15, as well as some other features of the land as temperature, vegetation or water vapour.

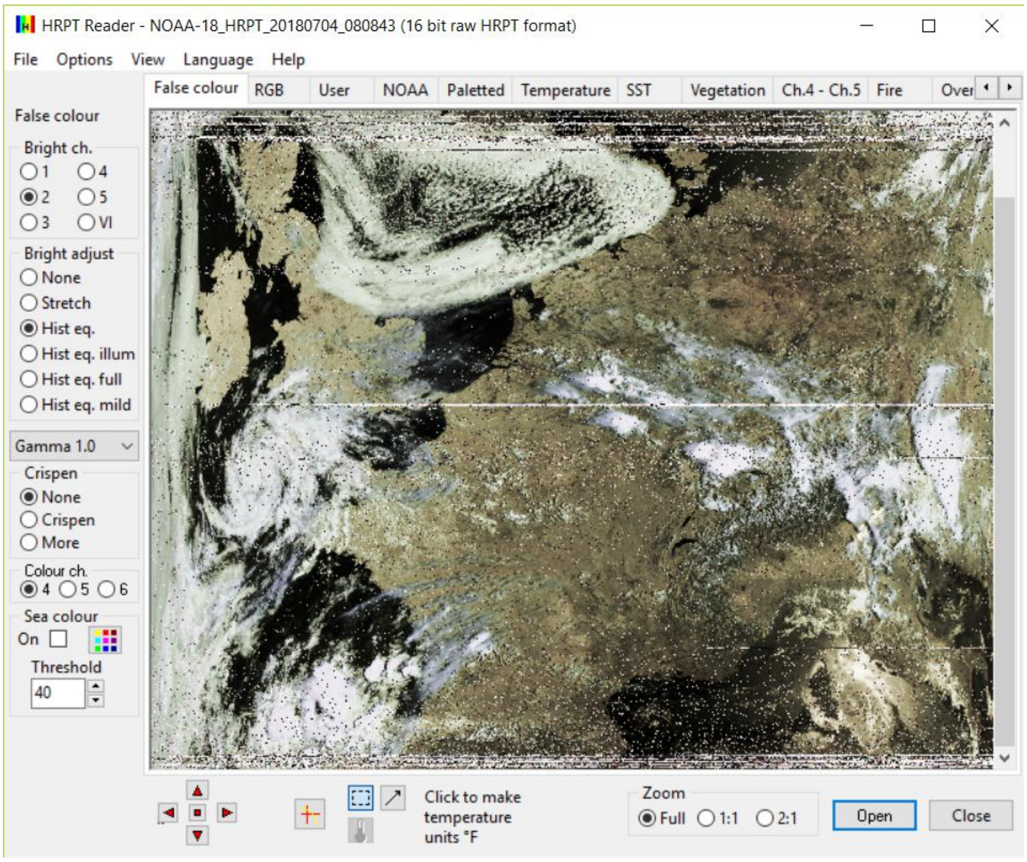


Figure 15: HRPT Reader Screenshot.

e. Automation program

The automation program connects all the decoding software, so when a new signal arrives, it detects the signal and runs all the software in order, until it gets the picture in the reader without having to manually control anything.

3.3 Mechanical System

The mechanical system consists on a aluminium structure that keeps the antenna standing and connected to the motors, also part of the structure, to be able to move the antenna to track the satellites.

3.3.1 Structure

The structure of the system is mainly made out of aluminium parts and connectors. The system is held up by a tripod structure with three legs where a base plate is mounted on. On the base plate, the mast with the vertical axis is mounted, and below the base plate, the motor for azimuth rotation is placed. The vertical mast has two sets of bearings that carry the weight of the parabola and also take up side forces to protect the azimuth motor. On top of the vertical axis, a 5mm aluminium sheet is mounted that holds the elevation axis and the motor that is controlling elevation rotation. Also on the elevation axis, two bearings have been mounted that hold the weight of the parabola and protect the elevation motor from side forces. Lastly, the parabola and RF system are mounted on to the elevation axis.

3.3.2 Motors

The system has two 12 volt DC-motors, one controlling the azimuth angle and one the elevation angle. To be able to handle large enough moments, two gearboxes have been added on each motor. Closest to each motor there is a worm gearbox that locks itself from outside forces and therefore is not transferring any unexpected strains back on the motor. Then a planet gear is added to gear the rotation down to proper speed. A detailed scheme of the complete elevation motor, the azimuth motor is exactly the same, is shown in figure 16.

Figure 16: Detailed 3D CAD model of the elevation motor.

In figures 17 and 18, 3D CAD models of the structure with the motors and the parabola mounted are shown from two different perspectives.

Figure 17: 3D CAD model of the full system

Figure 18: 3D CAD model of the full system

3.4 Electrical System

In order to enable the use of the system without the need for a main power supply, the electrical subsystem of the receiver was designed around a high-capacity 12V lead acid battery providing power for the motors, as well as the computer for the software through the use of a 12VDC to a 230VAC inverter.

In order to provide the LNA with a steady supply voltage, a voltage regulator is used to allow for the lead acid battery to power the amplifier that requires 6-9 V. The LNA can also be modified to accept power supply voltage through the output coaxial cable in a Bias-T SDRplay configuration. However, since the SDR can only supply 4.7V through its built in bias-T, the voltage regulator option was selected.

4 Physical construction

Once the system was designed, the next step was to build it. The process started with five different front lines developing at the same time that were little by little merging into one. The separate construction path are going to be explained in detailed as well as how everything merged into the final system.

4.1 RF System

The main task building the RF subsystem was to make the feed of the parabola. For that, the ABS plastic tube support was 3D-printed. This tube had a long indent where the coil should be twisted to make this task easier later on. The bottom part of this indent was a especial structure, to connect the coil to the ground plane and to the LNA and the rest of the system, and to match the impedances. At the bottom of the plastic tube, there was also a hole to connect with a screw the feed and the ground plane. All this details around the construction of the feed can be seen in figure 19.

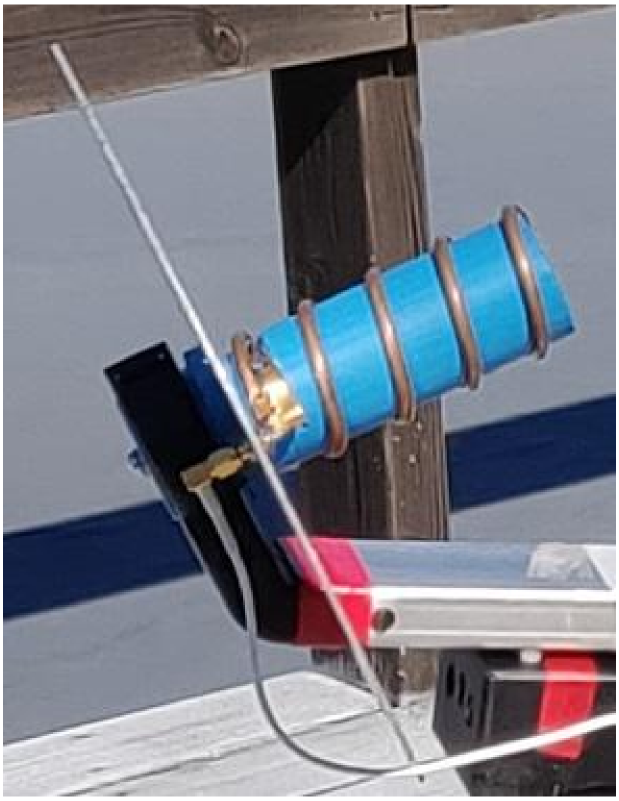


Figure 19: Feed of the antenna already built.

For the mounting to the parabola, another ABS plastic piece was 3D printed. This piece was built in a way that fit the mounting arm hardware that came with the parabola. It held the ground plane by its bottom side, but for the feed to be kept in the focal point of the reflector, a cut had to be done in the ground plane. This mounting can be seen in figure 19, but also in figure 20 from another perspective.

Figure 20: Detail of the mounting hardware of the feed.

However, the feed had to be built twice as the first time the ABS plastic inside the coil was not taken into account in the simulations and the dimensions of the first feed were not accurate. As explained in the section 3.1.1, this made the feed work at a central frequency of 1.05 GHz instead of 1.7 GHz. So, the dimensions had to be tuned and simulated again, resulting in the feed used in the final construction of the system.

The construction of the RF system was almost done with the antenna, so some tests were carried out to check the LNA, the SDRplay and the whole RF system. These test were executed with the help of a signal generator, which had a dipole as a transmit antenna for the built system to receive the signal at different frequencies and with different powers.

These first tests were carried just with the feed and the SDRplay, to check that the system was able to get signals at the desired frequency as well as, to check if the SDRplay was working as expected, and so they were. For the next tests, the use of the LNAs was introduced. There were two LNAs available to put in series for the system and they were test separated and both together. Resulting that there was some interference when using both producing an unusual rise of the noise level. So finally, the system was temporary built with just one LNA, before checking later on if the signal power that arrived to the SDRplay was high enough for the processing and the decoding. More test were done with the complete RF system, the feed with the parabola, the LNA and the SDRplay.

However, this task of testing the complete RF system was delayed because of a delay in delivering the LNAs. Affecting also this delay, to all the decoding software testing.

The final tests were carried out with the real signals. Manually, holding the parabola, pointing it to the satellites and following them approximately. The first flashes of the signal were got, checking that only one LNA was enough. During these final tests, the software for controlling the SDRplay could be configured for receiving the desired signals.

4.2 Automatic Tracking System

The construction of the automatic tracking system consisted on coding a program for the arduino microcontroller board, with the use of the WXtrack software and the IMU sensor, to send instructions to the motors.

There were two data sets essential for this program to work, and the first coding had to do with getting them. These sets were the satellite elevation and azimuth angles from WXtrack and the antenna pointing elevation and azimuth angles from the IMU sensor.

But, before the data from WXtrack could be extracted, some software configuration was needed. First, the desired satellites for tracking had to be added to the list of active satellites. Then, the ground location had to be set as the elevation and azimuth angles were different depending on the location. Because of the placement of the antenna, many times the horizon was not visible, this means that signals coming from 0 degrees of elevation were not detected. The limit for the satellites to be mostly visible was about 15-20 degrees, so this could be also configured. The automatic switch between the satellites, when these became available, was also configurable. Lastly, the Kepler data updates had also to be configured to be automatically done. The screenshot from WXtrack where most of the configurations were done is shown in figure 21, as well as the pass list showing the satellites that had passed before and the ones that were going to pass over.

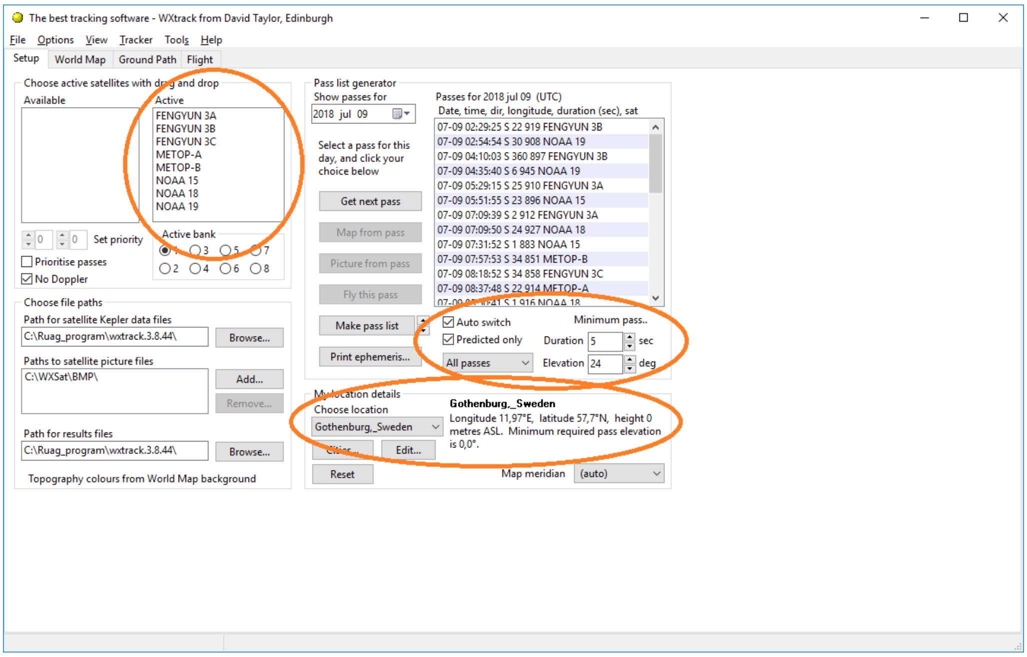


Figure 21: WXtrack settings screenshot.

For the satellite angles, a serial communication between the Arduino and the WXtrack software was needed. However, the Arduino Uno board only had one hardware serial communication implemented, used for the Arduino to connect with the computer and the Arduino software, so a software serial communication had to be implemented. For this software serial communication, a serial to USB adapter cable was used together with its drivers for the computer and the SoftwareSerial library in the Arduino software. To implement the serial communication, the WXtrack software had to be configured to send the angles through the communication port the adapter cable was connected to, and with a tracker model that the Arduino software understood. Once the connection was done, every time the WXtrack was tracking a satellite as it pass over, it sent a string with the elevation and azimuth angles that had to be converted into the numerical value of the angles to operate with them.

For the antenna angles, the values were not so easy to get, as the IMU sensor was more sensitive than a serial communication. This IMU sensor, which included an accelerometer, a magnetometer and a gyroscope, needed calibration and even though sometimes the values were not exactly accurate. Ths way, for improving these angles, an external calibration had also to be implemented. The first idea for the IMU was to use the accelerometer for measuring the elevation and azimuth angles, with the help of the magnetometer to point to north. However, the magnetometer proved to be really unstable so it was discarded from the system, and the accelerometer was not relaying for the azimuth angles.

Eventually, the accelerometer was used to measure the elevation angles and the gyroscope to calculate the azimuth angles, fixing a lateral of the structure to always point north. With this solution, the elevation angle gave accurate values, but the gyroscope for the azimuth angle needed more tuning. The gyroscope gave the angular velocity, so to calculate the angle, a time was needed. However, the time had to be measured in the code, not being able to find the exact time measure for which the antenna was moving. As a way to control this deviation, an external switch was mounted for the antenna to hit it when the azimuth angle was zero. Also, another switch was mounted for a better calibration of the elevation angle.

Once these angles were obtained a series of routines were programmed for getting the convenient instructions for the motors. A flowchart of the most essential functions of the Arduino program that are going to be explained is shown in figure 22.

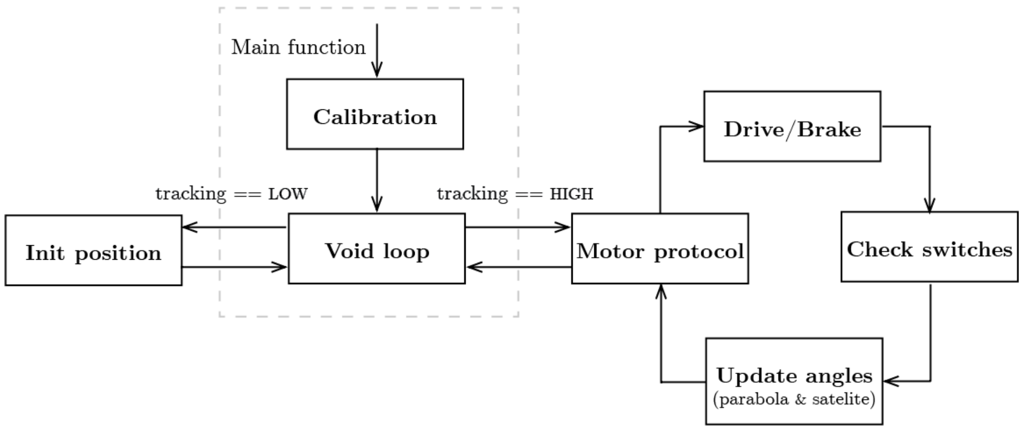


Figure 22: Arduino program Flowchart.

First of all, an initial calibration routine was programmed. In it, the IMU was started with its set up run, and the external calibration was also done with respect to the external switches. After the calibration was done, the antenna went to a initial position where to always return when finishing tracking a satellite, and the main loop was started.

In this main loop, it was checked if there was an available satellite to track. If not, the antenna moved to or stayed in the initial position. If there was a satellite available, the tracking started. When a satellite was available, the routine for running the motors was called, which in turn called more subroutines.

This other subroutines were in charge of driving the motors in the different directions and braked them when the antenna was at the desired position. They also checked if the switches had been hit and updated the external calibration to correct, if necessary, the values of the antenna angles. While doing all these tasks, the program was always checking the real-time satellite angles, and when there were not satellites being tracked, the program checked constantly for a satellite to be available.

In the subroutine to drive the motors, two special features had been implemented for a correct performance of the system. The program always checked for the shortest path to the satellite and moved the motor this way. This means, the antenna did not always move clockwise, if a satellite had an azimuth angle of 300 and the antenna was at the initial position, the motor moved anticlockwise. One of the main reasons for this shortest path was for the electrical and connection cables not to get entangled. Also, to avoid the entanglement, it was fixed that the antenna could only move 360 degrees in either direction. And every time it happened, the antenna had to go back at least a complete lap to the initial position, as when a satellite was being tracked, the range of angles was never more than 360 degrees.

The main problem with this subsystem, not taking into account that coding is not a quick and easy thing, was the delay in the delivering. The motors were supposed to arrive during the first building week of the project, but they arrived more than two weeks later, when there was merely left three weeks of the project, delaying this process a lot.

All the routines, subroutines and features of this tracking system involved a process of testing, tuning and improving the code almost until the last minute of the project. And even though the system was running and was able to track satellites, there were still details that could had been improved.

4.3 Decoding System

The construction of the decoding system did not involve a lot of coding like the tracking system, the main duty was to control, configure and connect all the software involved in the decoding and the reading of the pictures. The only coding needed was a python script to make this whole decoding process automatic.

The RSP Streamer was the first software in the decoding chain. For configuring it, the sample rate of 6 MSPS had to be selected. The SDRplay had two possible antenna inputs, so the antenna input to which the antenna was connected to had to be selected. This software had also options to control the LO Mode, the IF Automatic Gain Control (AGC) and the Gain Reduction, controlling the LNA for the RF Gain and the IF Gain for the best signal. Once all the configuration about the SDRplay was done, the connection to the decoding software, the XHRPT Decoder, had to be also configured. For that, the UDP Server in terms of client and port had to be fixed for them to be the same as the ones in the XHRP Decoder. A sreenshot of how this software configurations ended up, is shown in figure 23.

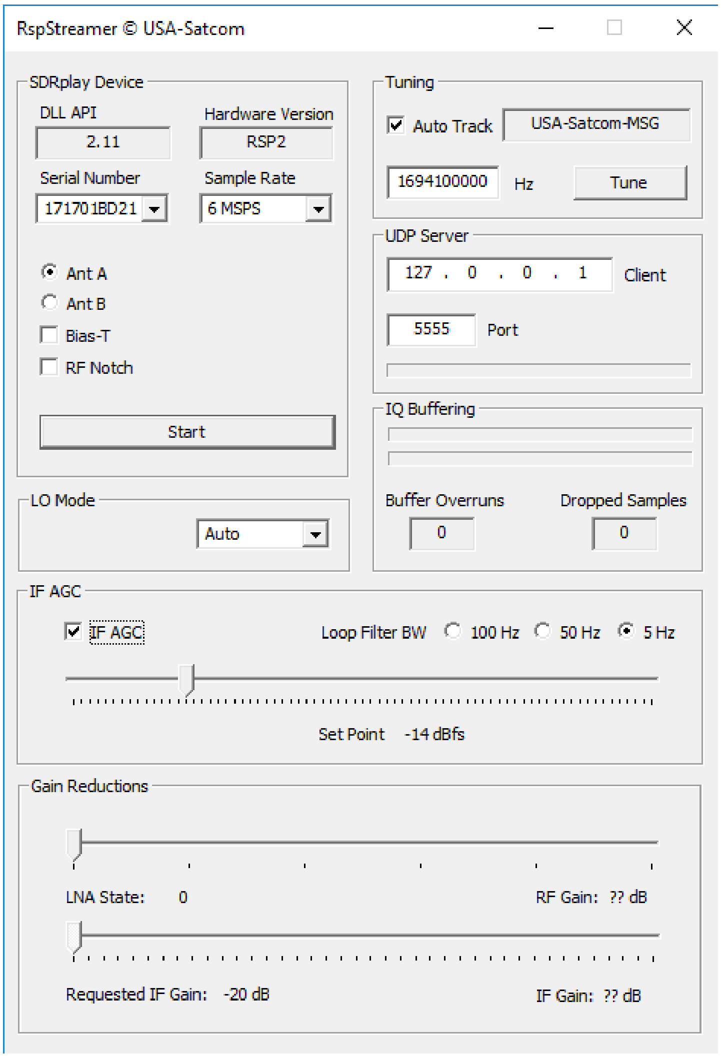


Figure 23: RSP Streamer final configuration screenshot.

The next software was the XHRPT Decoder, as the RSP Streamer was connected to it, for receiving its processed signal. The configuration of this software was almost done by itself and its connection to the WXtrack. It just needed to selected how its two software connections were going to be, as it could receive signal from the RSP Streamer or a Spy Server, and it could receive information on the satellites through the WXtrack or Orbitron, another similar software. After RSP Streamer and WXtrack were selected just clicks on the connection buttons were needed.

Having the software opened, the RSP Streamer, the WXtrack and the XHRPT Decoder, the order on how to properly connect them was: in the XHRPT Decoder push the 'DDE Connect' in Tracking Control section and 'Connect' and 'Stream On' in the Control section; then in the RSP Streamer push the 'Start' button. Nothing had to be done in the WXtrack at this step.

With this configuration, the decoding of the signal was properly configured just to start receiving. In the figure 24, the RSP Streamer and the XHRPT Decoder were working together with WXtack even if this last one is not shown on the figure. From the WXtrack, information about the satellite currently being tracked was sent to the XHRPT Decoder, so it selected on its settings the satellite, its frequency and its signal characteristics. Also, there could be observed that both software were synchronised as the RSP Streamer took the XHRPT Decoder frequency.

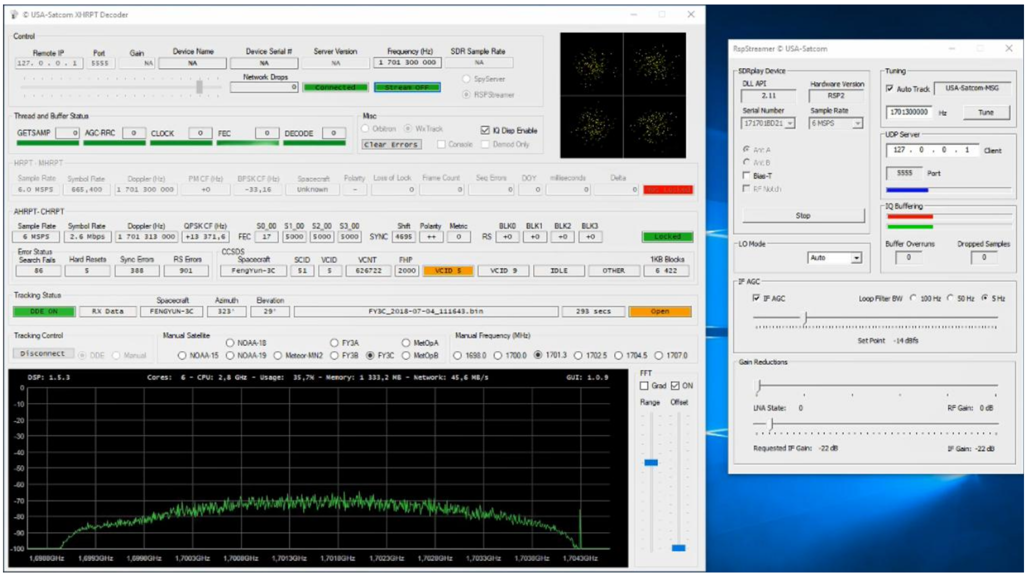


Figure 24: RSP Streamer and XHRPT Decoder are synchronised receiving a signal.

Once the tracking of the satellite was ended, the XHRPT Decoder created a file with the decoded signal. For NOAA satellites, the decoding done was enough getting a raw16 file. However, MEtop and Feng-Yun satellites needed an extra decoding from MetFy3x. This extra decoding could be done with a De-Randomizer and Reed-Salomon features. For Metop signals non of them was needed, but for the FY signals the Reed-Salomon decoder had to be selected.

Once all the decoding was done, the decoded signal file could be open with HRPT Reader, just selecting if the satellite was coming from north or south for the direction of the picture. This HRPT Reader had many options for observing the picture downloaded, it could be the picture in false colours, in RGB colours, showing the surface temperature, the sea surface or the vegetation.

All this steps could be done manually, however, the system had to be automatic, so an automation program was written in python for making the process of decoding completely automatic. This program, as can be observed in figure 25, had two main threads. One that checked constantly when a new file was created in the XHRPT Decoder, setting some global variables for the other thread to know when there was a new one. The second thread, when was told of a new signal file, processed this new file, deleting old decoding ones as the interesting information were the pictures. The file was then opened with the HRPT Reader, after extra decoding if necessary, publishing this new picture as a JPEG file and uploading to Twitter for its distribution. Finishing this process by setting back the global variables for when a new signal came.

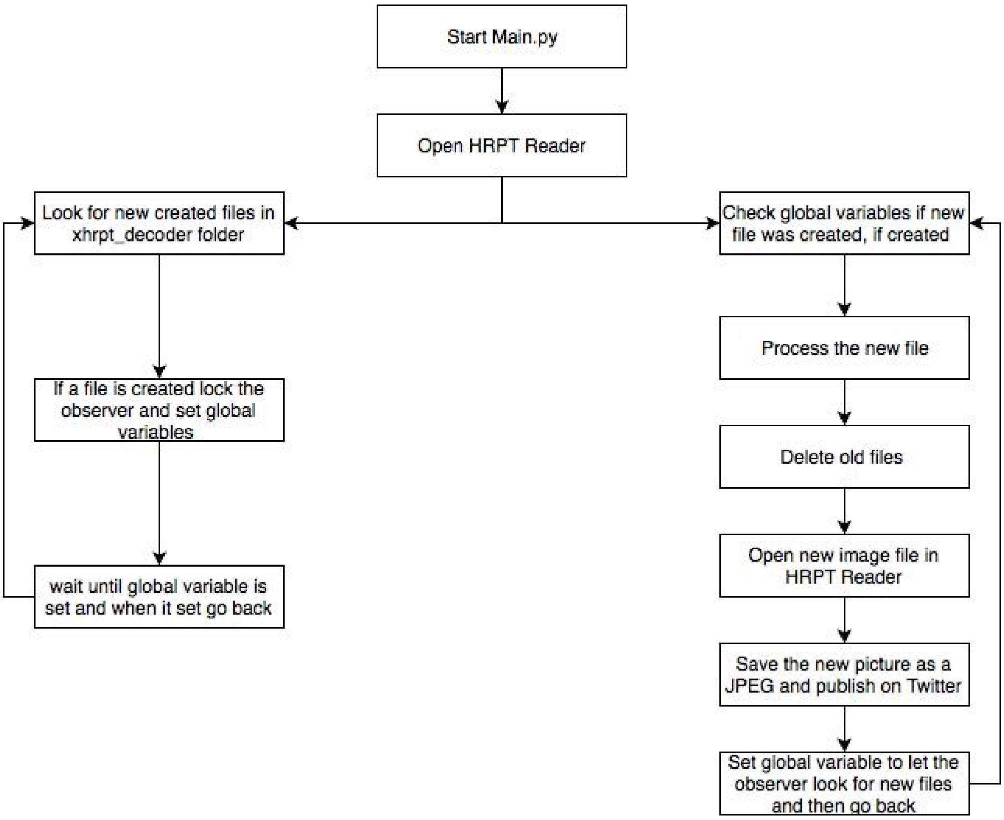


Figure 25: Flowchart of the automation program.

4.4 Mechanical System

The construction of the structure was made based on the design with aluminium parts that were joined with screws. In the next figures, 26, 27 and 28, the different parts that composed this aluminium structure are shown, and a picture of the complete structure is in figure 29.

Figure 26: Legs of the structure.

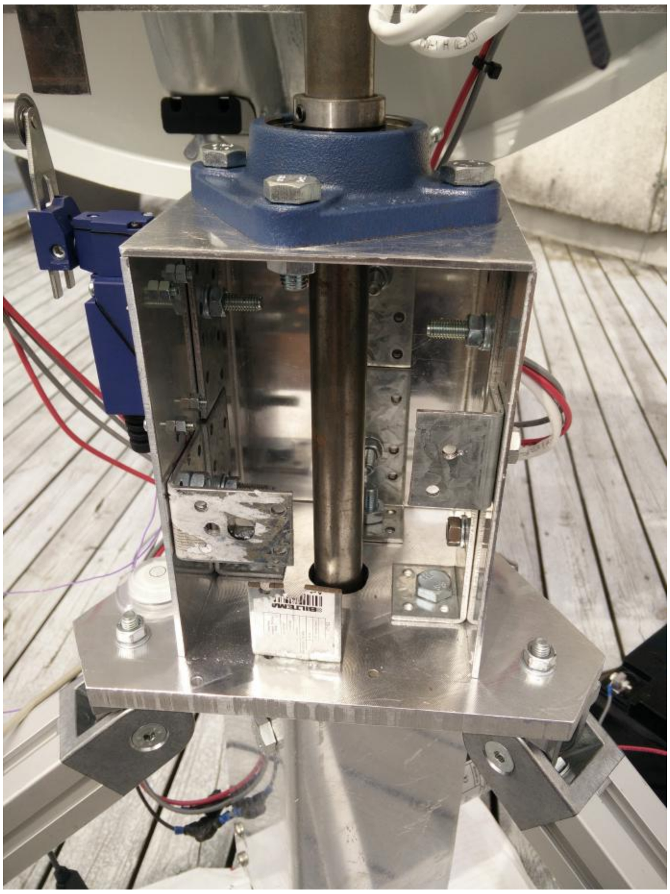


Figure 27: Inside of the Mast of the structure already joint to the legs.

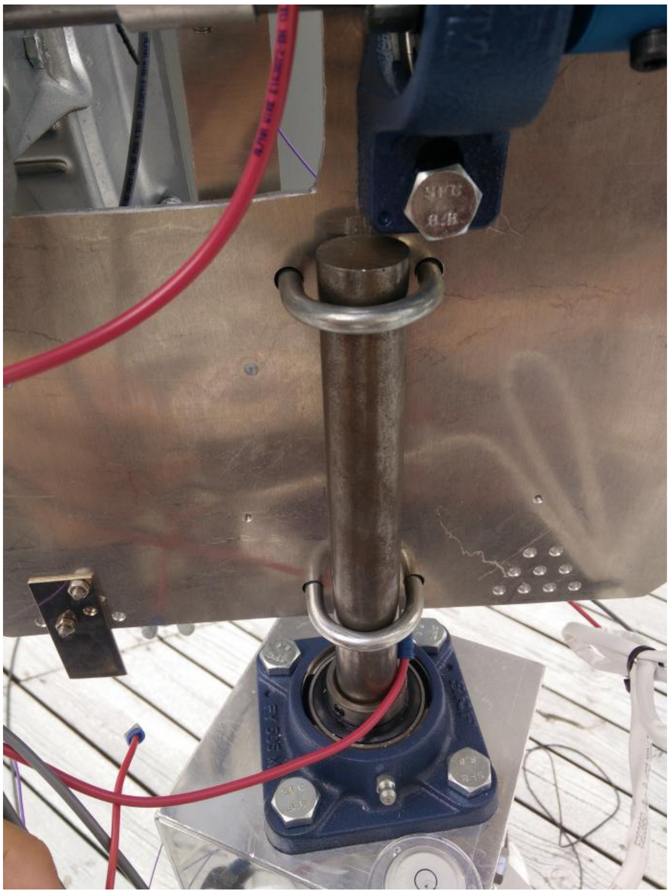


Figure 28: Backside of the clamp that holds the sheet for the elevation axis.

Figure 29: Complete aluminium structure.

Once, this structure was complete, as it is already observed in figure 29, the parabola was mounted to the sheet of the elevation axis, and held as shown in figure 30.

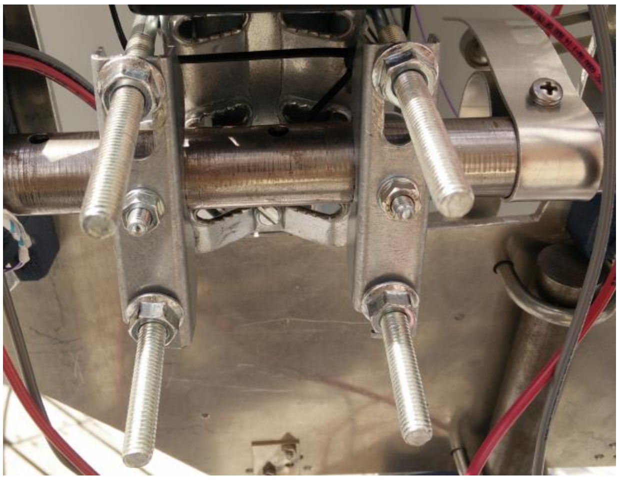


Figure 30: Mounting of the dish to the structure.

The arm of the dish could be mounted through the system that was already built in the parabola as shown in figure 31, where is also observed how the parabola was attached with screws to its fastenings.

Figure 31: Front of the dish showing the mounting for the arm that holds the feed.

At this point of the mechanical construction, the motors where not ready to be mounted in the structure as they were still being programmed. However, the rest of the system was ready to do some tests. So, tests with these parts were carried out.

With the antenna mounted in the structure without the motors, which means it could be manually and freely moved, and with the help of a compass in the floor and an elevation meter in the arm of the dish, satellites were tracked.

During the first tests, which were carried out without the decoding process just the software for the SDRplay to observe signals, nothing was detected. And as it was known from the first tests with the antenna, it was able to get signals, so a process of reviewing everything was done to find the mistake. The problem was in the offset of the parabola, as it was not being aware that it was an offset dish. After this was solved, meaning that when pointing to elevation 0, the antenna was really pointing to 26 degrees, various satellites were tracked with the complete decoding chain, being able to get signal from the three type of satellites and pictures from all of them.

Once, the motors were programmed and ready to be tested in the structure, they were mounted as shown in figures 32 and 33 for the azimuth motor on the bottom of mast of the structure and in figures 34 and 35 for the elevation motor in the sheet on the top of the mast.

Figure 32: Picture of one perspective of the azimuth motor mounted on the structure.

Figure 33: Picture of other perspective of the azimuth motor mounted on the structure.

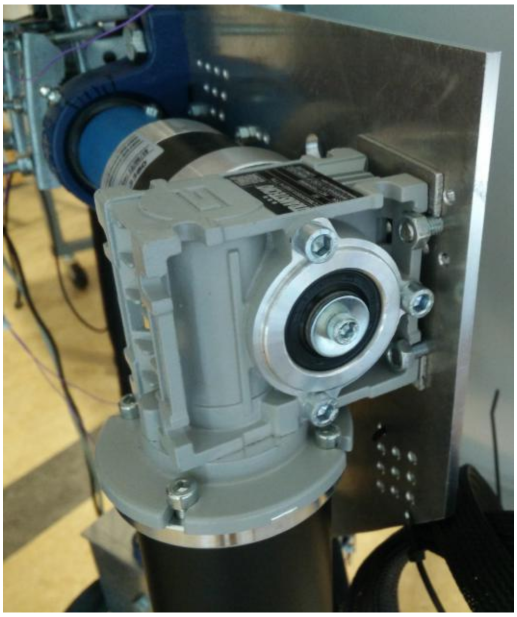


Figure 34: Picture of one perspective of the elevation motor mounted on the structure.

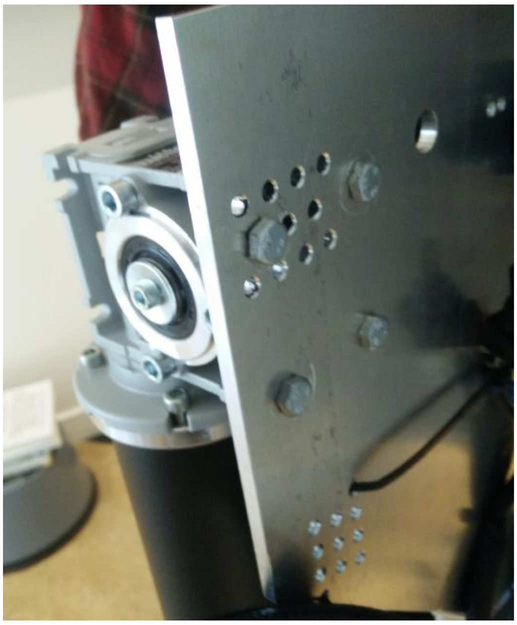


Figure 35: Picture of other perspective of the elevation motor mounted on the structure.

These motors were attached to the structure through the 3D-printed plastic tube, in figure 36, that on one side had the shape of the motors output and on the other was ready to hold the axis and be fasten to it through a screw.

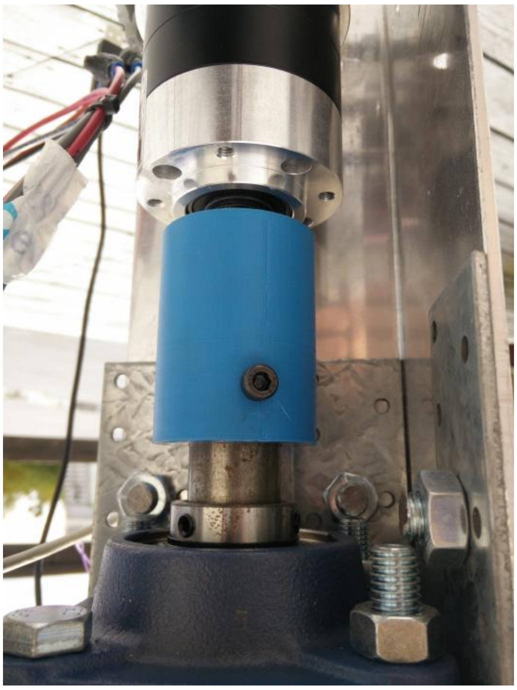


Figure 36: 3D-printed plastic tube connecting the motors to the structure.

For the Arduino board and the microcontroller, as well as the IMU sensor, an electronic box was used to enclosure them and to help them get attached to the system in the backside of the parabola as shown in figure 37.

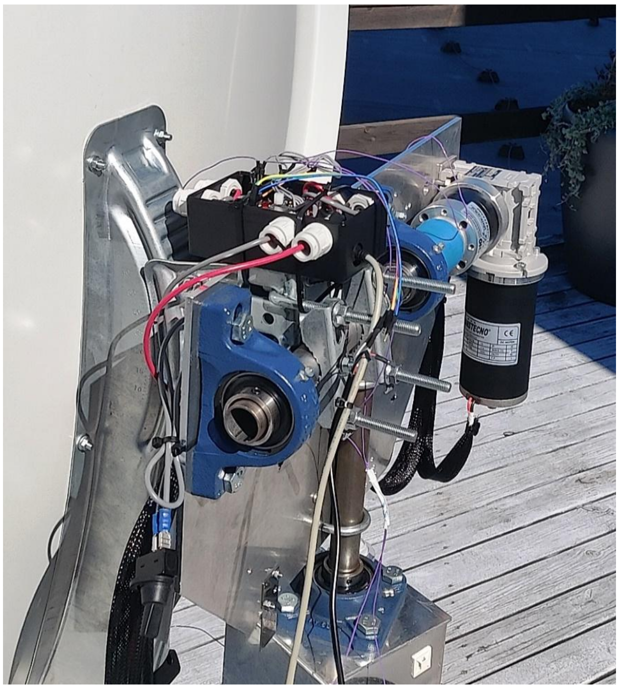


Figure 37: Electronic box attached at the back of the parabola for the Arduino board and the motorcontroller.

As commented when explaining the construction of the automatic tracking program, two external switches were added to the structure for an extra calibration of the antenna angles, these two switches mounted can be observed in figures 38 and 39.

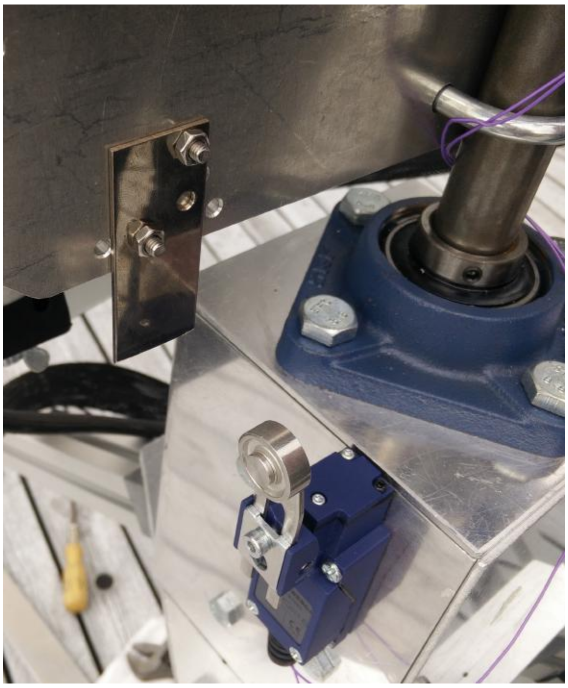


Figure 38: Azimuth switch mounted on the structure.

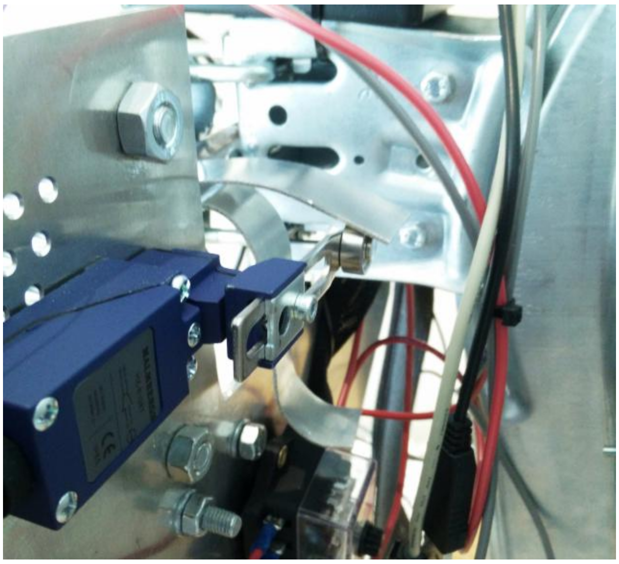


Figure 39: Elevation switch mounted on the structure.

After the mounting of the motors more tests were done on how they work, to keep on debugging the performance, before testing the complete system tracking satellites.

When the performance was close to desired one, the tests tracking the satellites with the complete system were carried out. Getting good signals and pictures at least once from every type of satellite.

4.5 Electrical System

Once the mechanical system was constructed, the electrical system was ready to be wired up with the high-capacity 12 V lead acid battery, that could be easily charged from a main power supply.

First, for the RF System, the LNA needed to be powered up. As explained in the design, the LNA was connected through a voltage regulator to the 12 V battery, for the 6-9 V that it required. To enclosure these two components, together with a fuse to protect the LNA from high currents, and to secure them, they had been integrated in an electronics box, in figure 40, so that it could also be easily attached to the arm of the parabola.

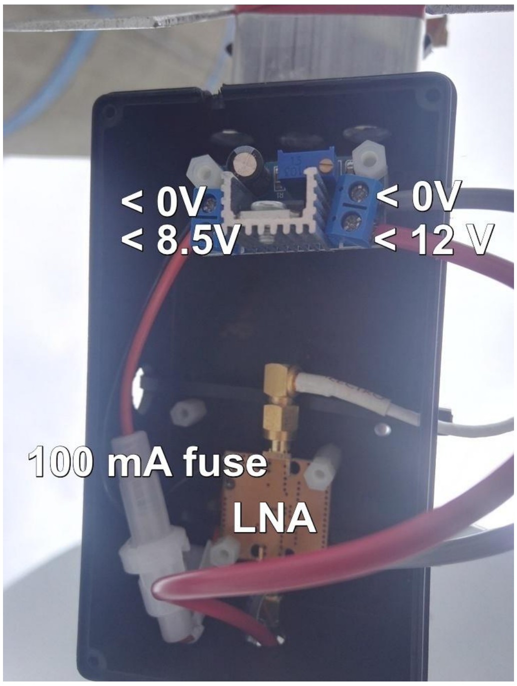


Figure 40: Electronic box with the LNA and the voltage regulator.

The motors were powered up from the battery through the motorcontroller, in figure 41, which controlled when the motors had to move and at which speed, and provided the power for that movement. The motorcontroller was powered directly from the battery through a fuse, the same as for the motors that were powered from the motorcontroller through a fuse. The fusebox with the three connections can be seen in figure 42.

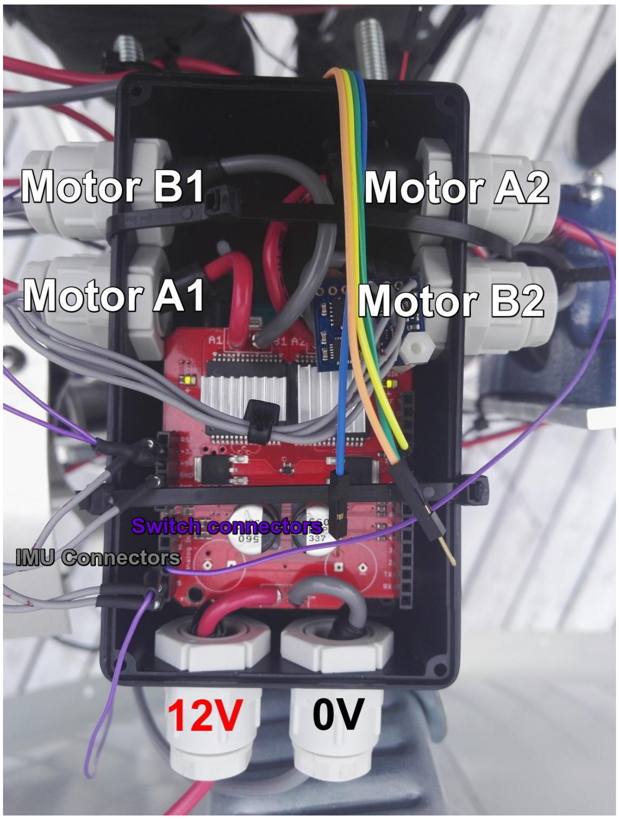


Figure 41: Control box to power the motors.

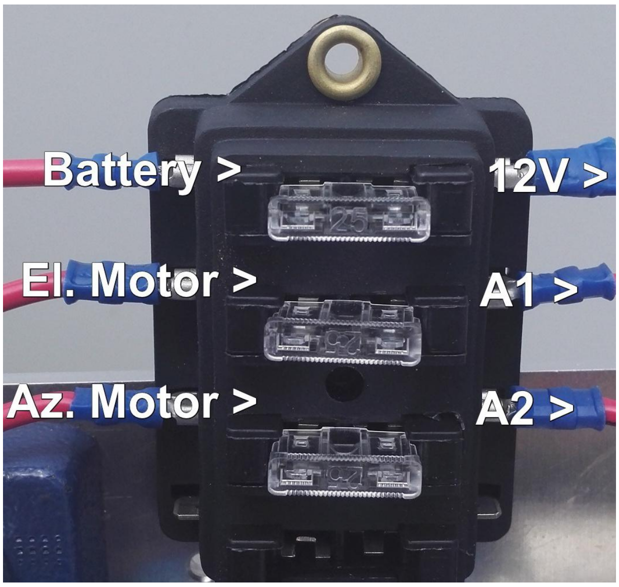


Figure 42: Fusebox for the fused to protect the component from high currents.

The cables used for connecting the different part were made to be long enough for the antenna to be able to twist more than one lap. For better looking cables they were covered with a trim.

Then, the power consumed by the computer was measured during one tracking and decoding process, checking that the power given by the inverter was enough to power up the computer together with one monitor.

To sum up the electric subsystem, a flowchart is shown in figure 43.

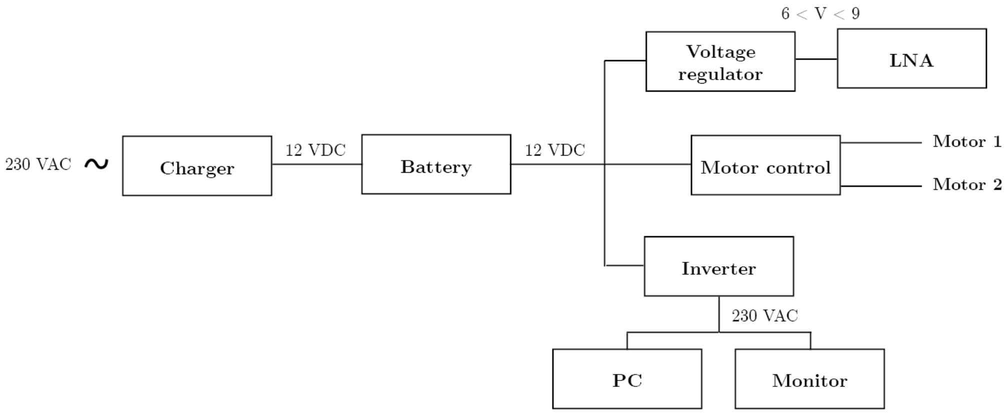


Figure 43: Flowchart of the electric system.

Finally, the resulting system had the appearance shown in figure 44.

Figure 44: Picture of the final system

5 Results

As commented in the Physical Construction section (4), the first flashes of a satellite signal happened once the construction of the antenna was finished. The setup of the receiving system was the antenna connected to the LNA and to the SDRplay, controlled by the official SDRplay software, SDRuno. The signal, shown in figure 45, was from NOAA 15 satellite at the frequency of 1702.5 MHz, and was caught on the 25th June 2018 at 8:45h when the satellite was at 232 degrees in azimuth and 80 degrees in elevation.

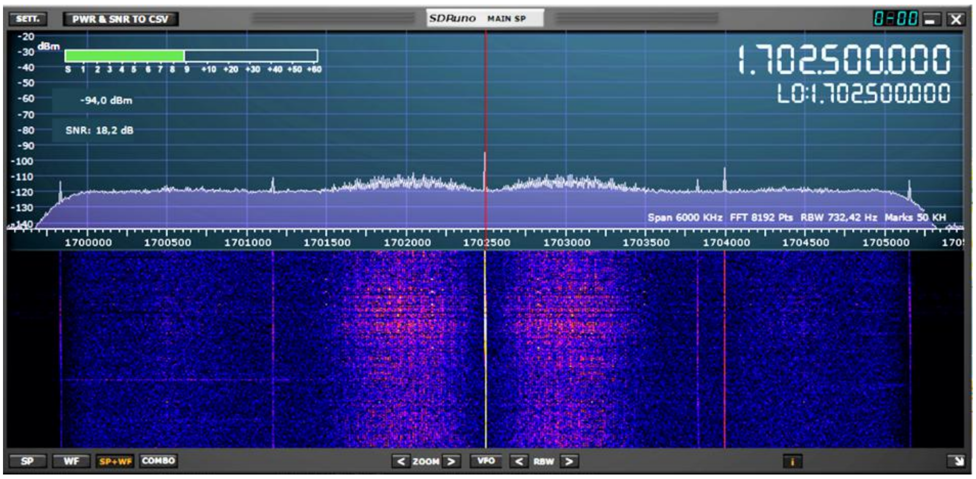


Figure 45: First signal received manually by the RF System in the SDRuno software.

Also, with the same setup, a NOAA 19 signal was caught the same day at 15:58h at the frequency of 1698 MHz when the satellite was at 115 degrees in azimuth and 62 degrees in elevation, this signal is shown in figure 46.

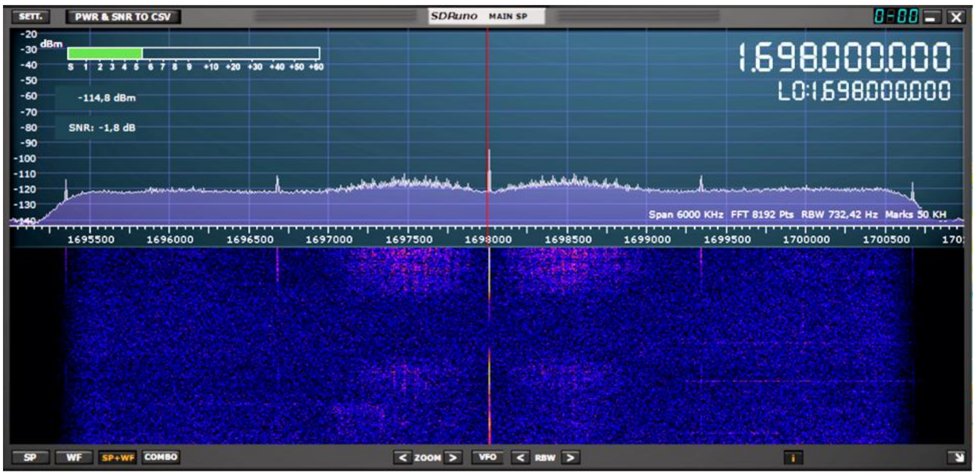


Figure 46: Second signal received manually by the RF System in the SDRuno software.

The next results took place once the mechanical structure was built without the motors, so the antenna could be mounted and moved manually. Controlling manually the azimuth and elevation of the antenna with a compass and an elevation meter, satellites were tracked with the complete decoding chain.

The first satellite tracked with this system setup was NOAA 15. The reason for this was that a signal from it had been already received, so it was known that the system worked for this satellite. Furthermore, NOAA satellites were the most reliable ones it terms of transmitted signal and power. This first pass from NOAA 15 was a trial one, were the options in the processing software had to be tuned, and in which the two mates moving the antenna tested the best way to move it. Even though, the decoder did not lock the signal for much time, a small, noisy picture was got. The signal in the decoder at one point during the pass can be seen in figure 47 and the picture downloaded from the pass is shown in figure 48, where barely nothing can be seen in it.

Figure 47: NOAA 15 signal in the decoder on 03/07/2018.

Figure 48: NOAA 15 picture on 03/07/2018.

When taking about locking a signal in the decoder, it means that the signal was good enough for the decoder to detect it was signal from the satellite being tracked. This could be observed in the decoder below the constellation of the signal, in one of the 'Locked/Not Locked' button depending on the modulation of the satellite. In figure 47, it can be seen that the green, 'Locked' button was on, because the signal in that moment was good enough. However, during this pass the button was most of the times red, 'Not Locked', that is why the picture was so small. The noise in the picture had to do with the constellation of the signal, as if it had a small Signal to Noise Ratio (SNR), a noisy picture was downloaded. Continuing about the 'Locked' of the signal, it did not have to be continuous, it could be locked during a while at one moment of the pass, and during another while in every other moment. This caused that the picture could be not continuous either, as the way the downloading worked was that the different horizontal lines of 1 pixel long were sent multiplexed in time. So, the time the signal was lost was the corresponding part of the picture that got lost.

After this first trial pass, NOAA 18 satellite was tracked. This time, the tracking was a really good one to have been made manually, with a long period of 'Locked' signal. The receiving signal was also much less noisy, as observed in the higher SNR of the constellation. So, overall the picture was much better than the first one. The signal in the decoder can be seen in figure 49 and the picture can be observed in figure 50 where it can be distinguished UK and Ireland, Denmark, the Scandinavian peninsula and other western parts of Europe.

Figure 49: NOAA 18 signal in the decoder on 03/07/2018.

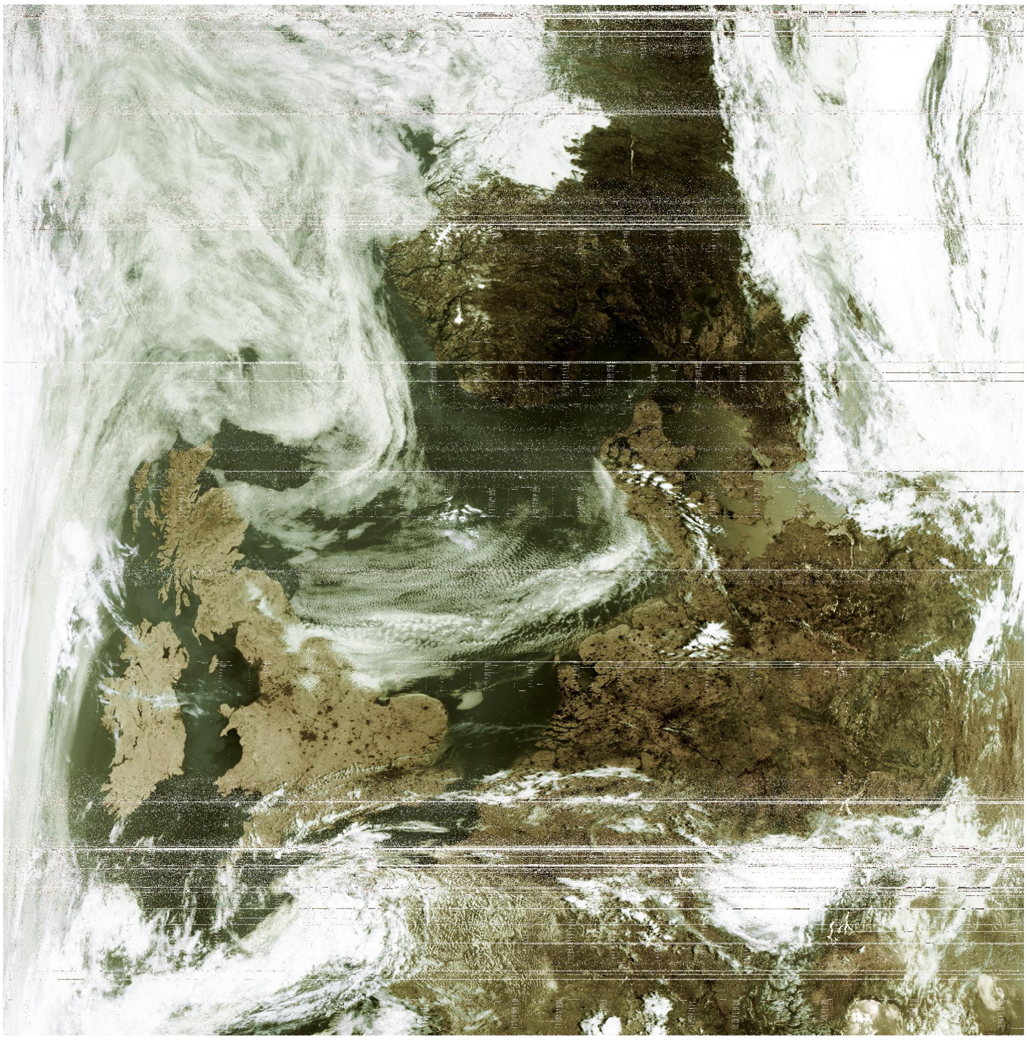


Figure 50: NOAA 18 picture on 03/07/2018.

With this same system setup, more satellites as Metop-B, FY 3C and NOAA 18 were tracked. As a sample of other satellites, one pass of Metop-B and one of the FY 3C are shown. The signals for both Metop and FY had the same modulation and waveform, so just the signal from the FY 3C pass is shown in figure 51.

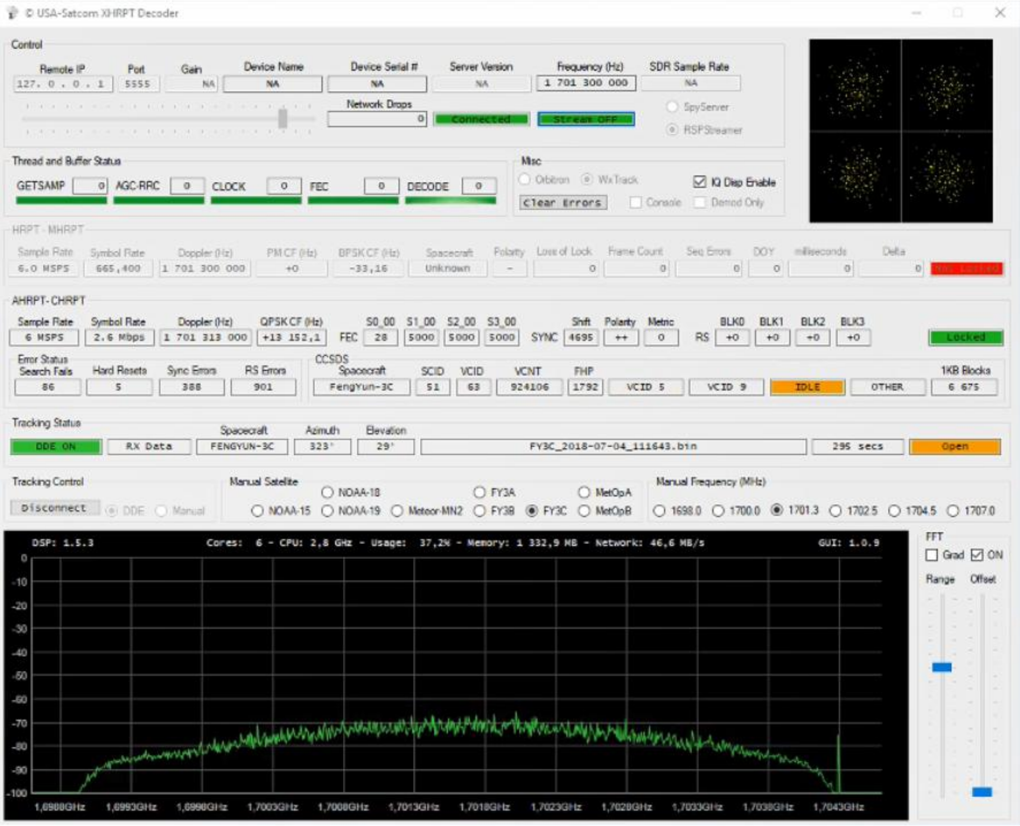


Figure 51: FY 3C signal in the decoder on 04/07/2018.

And the pictures from that FY 3C pass and a Metop-B are shown in figures 52 and 53, respectively.

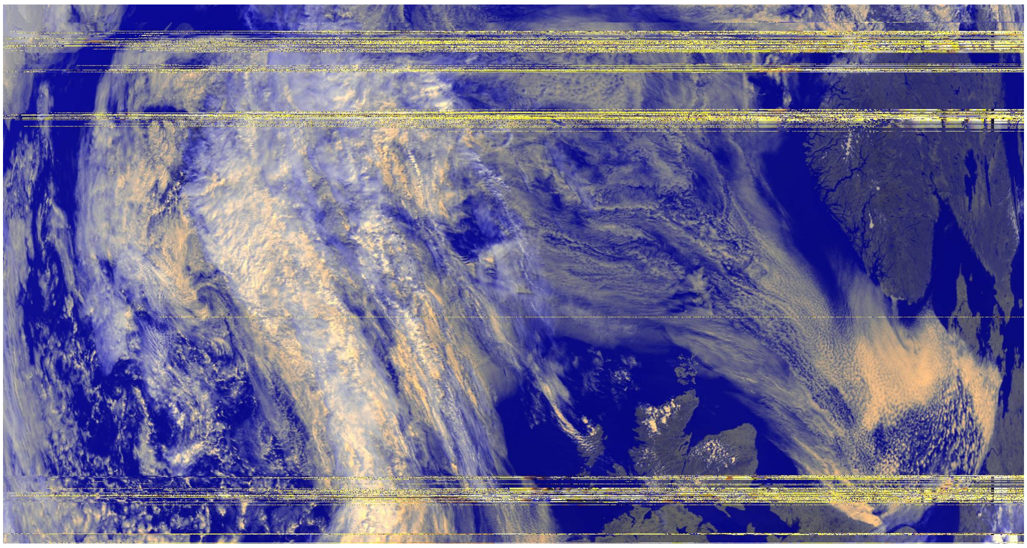


Figure 52: FY 3C picture on 04/07/2018.

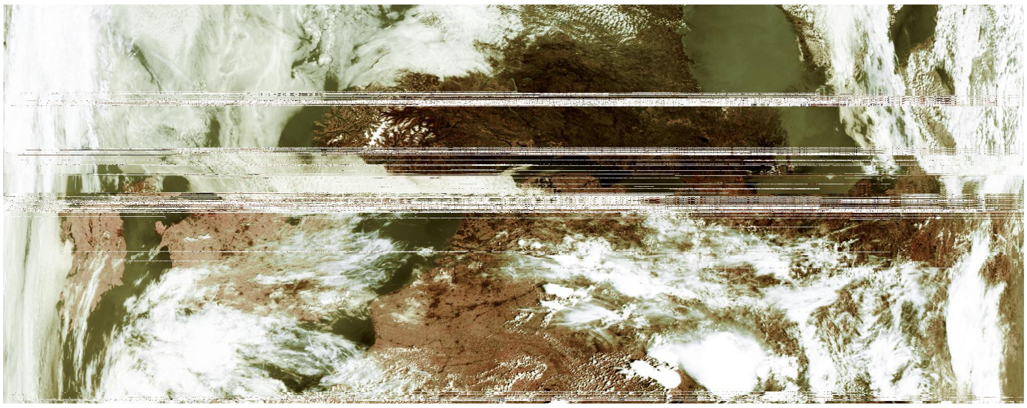


Figure 53: Metop-B picture on 04/07/2018.

The pass for the FY picture in figure 52 was quite west from ground location, so most of it was the ocean covered by clouds. However, in the right bottom of the picture there was the north of the British Isles and in the right top of it the Scandinavian peninsula. In the Metop-B picture in figure 53, the coverage zone is similar to the one in the NOAA 18 picture in figure 50. However, it was clearly a noisier pass, and at some time in the middle of it, there was a 'Not Locked' period where there could be notice a bar of the Earth was missing with Denmark and north Great Britain.

The next and final results, came when the motors were programmed and working almost as desired, even though some small adjustments were done while tracking more satellites.

The first satellite tracked with this new setup was again a NOAA to be secure that not receiving any signal meant that there was a problem in the system. The pass was from NOAA 18 on 10 July 2018 and was the best of all the passes the system have ever made. The signal of this satellite can be seen in figure 54, and can be observed how good it was the constellation with a really high SNR. This had the consequence of a barely noisy picture that can be seen in figure 55. This picture was the best not only because of the low noise, but also for the long time the antenna was tracking the satellite, from low elevation on the way up to low elevation on the way down, being able to see in the picture from the north of Sweden to the north of Spain, more than 20 degrees on latitude.

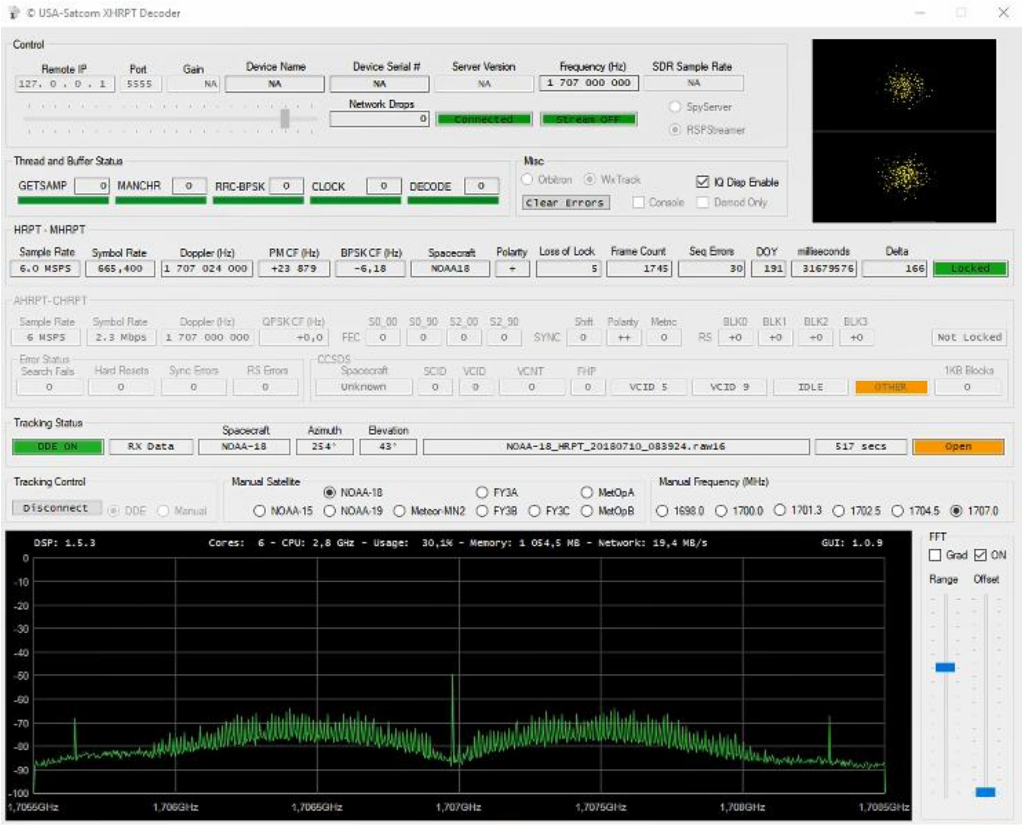


Figure 54: NOAA 18 signal in the decoder on 10/07/2018.

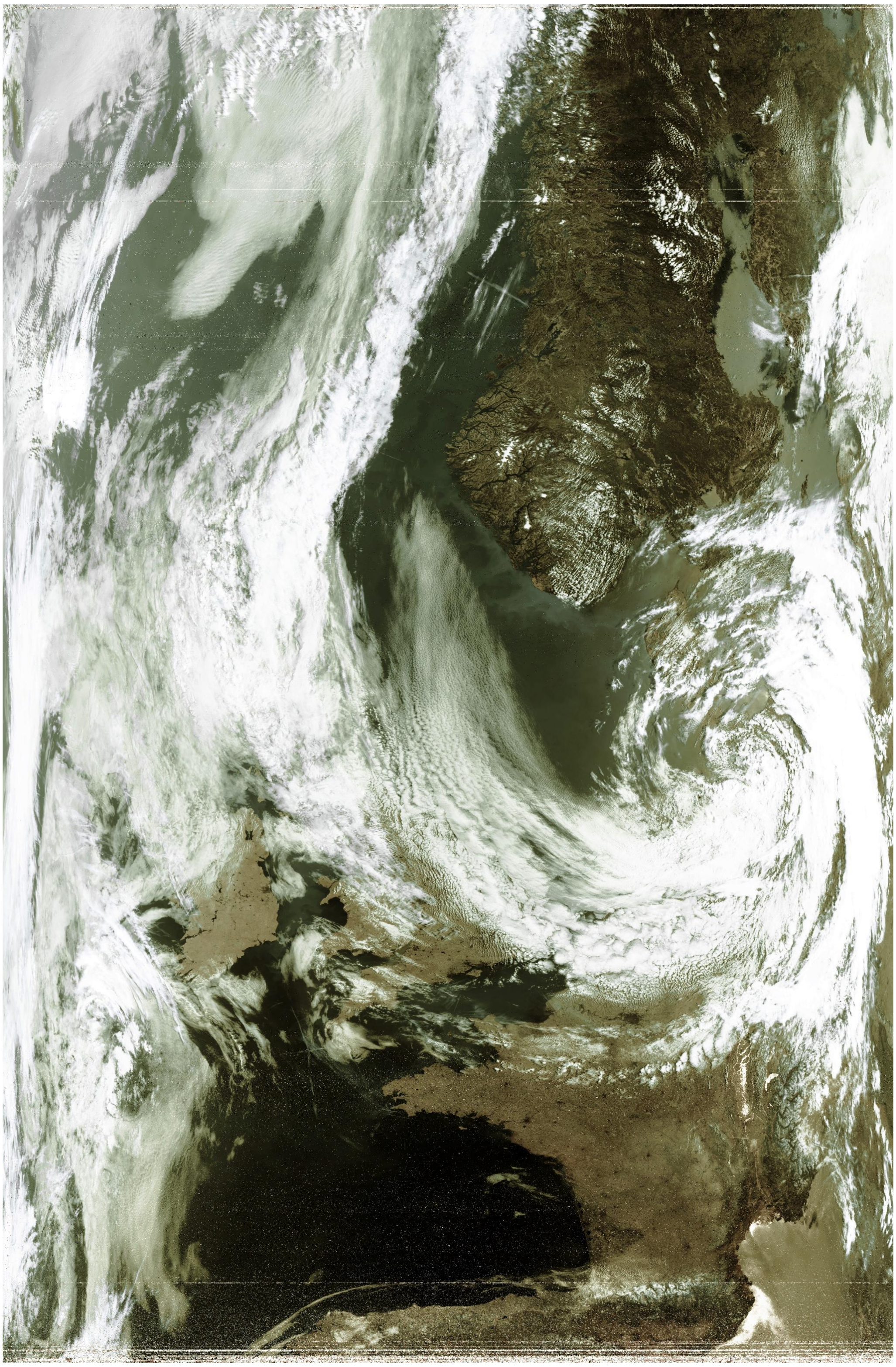
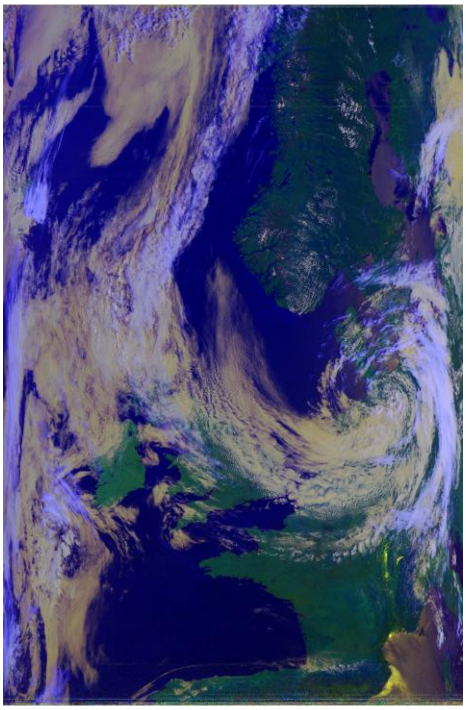
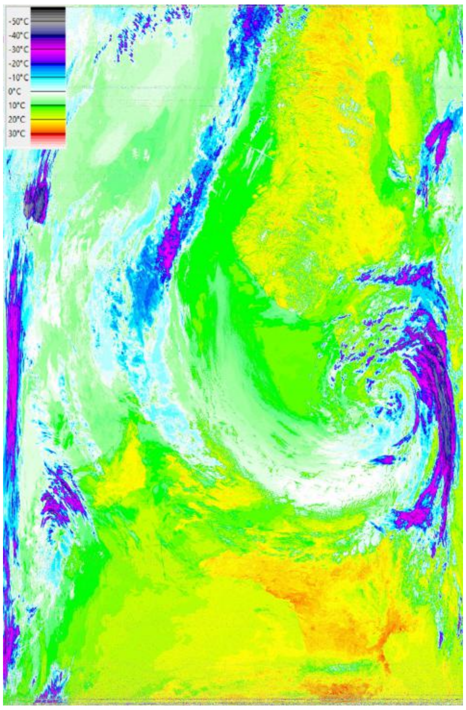


Figure 55: NOAA 18 picture on 10/07/2018.

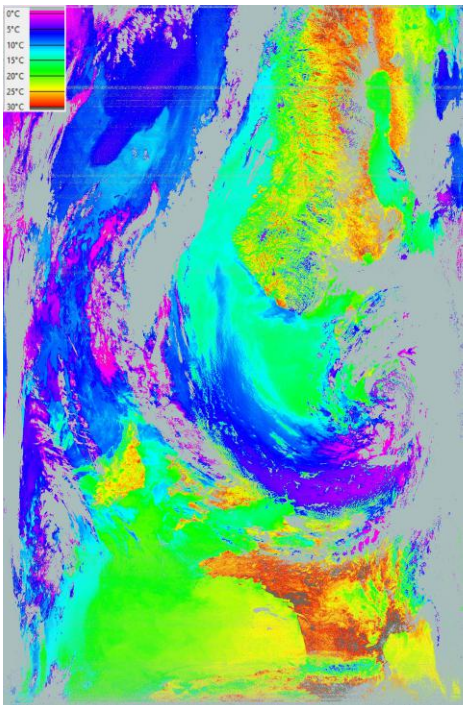
The pictures shown to this point were with the false colours feature in the HRPT Reader, however, it could be seen also in RGB colours, and maps of the temperature, the sea surface temperature or the vegetation, all these from the last pass of figure 55 can be seen in figure 56.



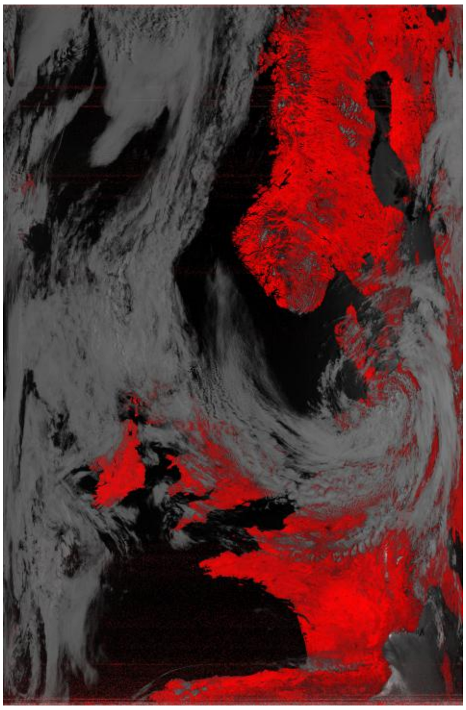
(a) RGB colours.



(b) Temperature.



(c) Sea Surface Temperature.



(d) Vegetation.

Figure 56: NOAA 18 pictures with different features on 10/07/2018.

NOAA 19, Metop-B, FY 3B and 3C satellites were also tracked. NOAA 19 picture is in figure 57 and had a lost of signal while going above Scandinavia. Metop-B can be seen in figure 58 and was only 'Locked' above the Scandinavian peninsula. FY-3B picture is in figure 59 and covered the same zone as Metop-B in figure 58. And FY 3C picture is shown in figure 60 and covered a longer picture from north Europe than FY 3B and Metop-B, figures 58 and 59.

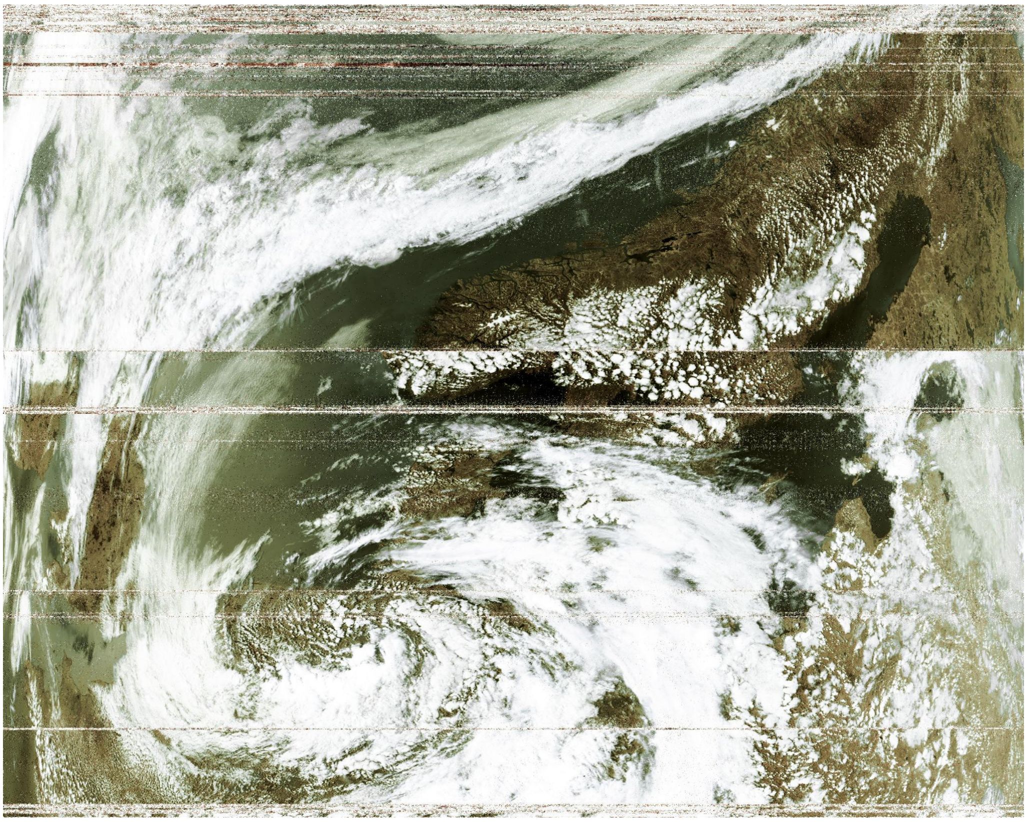


Figure 57: NOAA 19 picture on 10/07/2018.

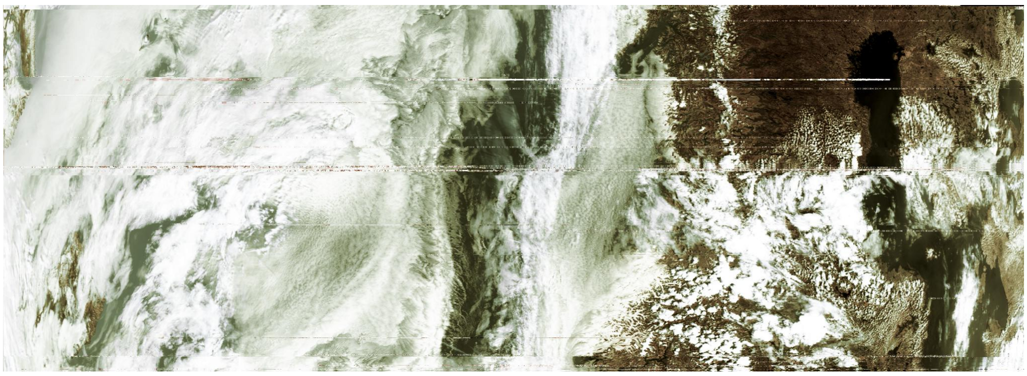


Figure 58: Metop-B picture on 12/07/2018.

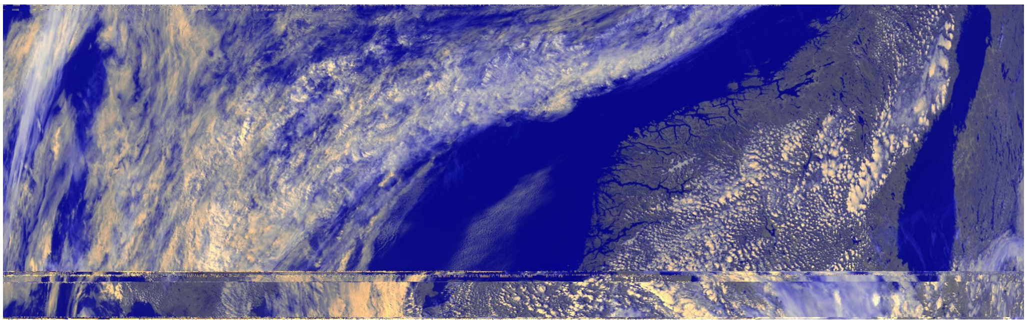


Figure 59: FY 3B picture on 10/07/2018.

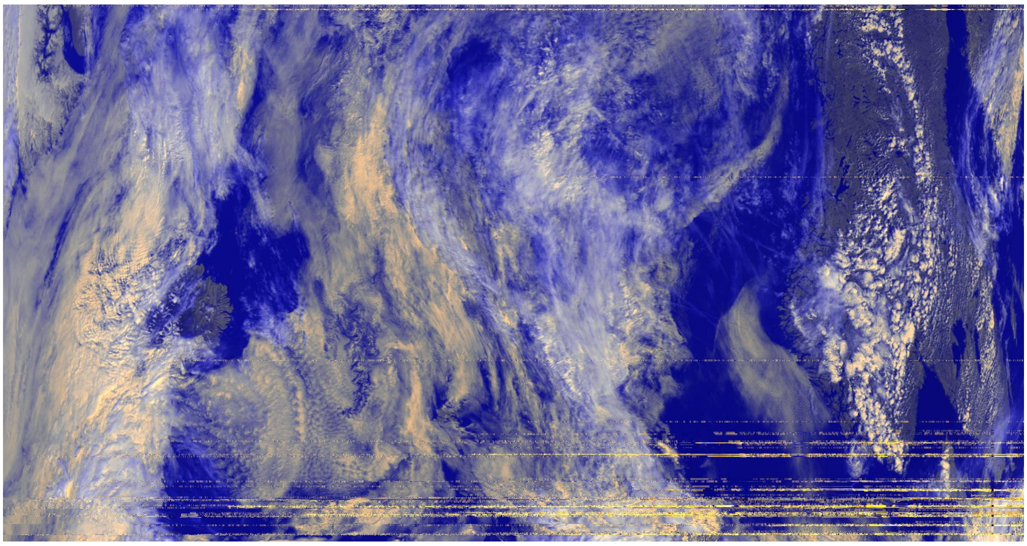


Figure 60: FY 3C picture on 11/07/2018.

The reason why these pictures did not have a good tracking was that, as explain in the mechanical system construction section (4.4), there were still some issues to solve about the IMU controlling the actual position of the antenna when moving. So, because of those small mismatches in the azimuth angle that could not be fixed, the antenna lost the satellite at some point in the pass.

When analysing the pictures, the location and countries observed in them had been commented. However, as meteorological satellites that these were, the clouds and other meteorological phenomena were the most important observation. In figure 61, a picture from NOAA 18 satellite, the clouds predominate over the earth in the picture. Moreover, a storm could be notice above Germany and Poland.

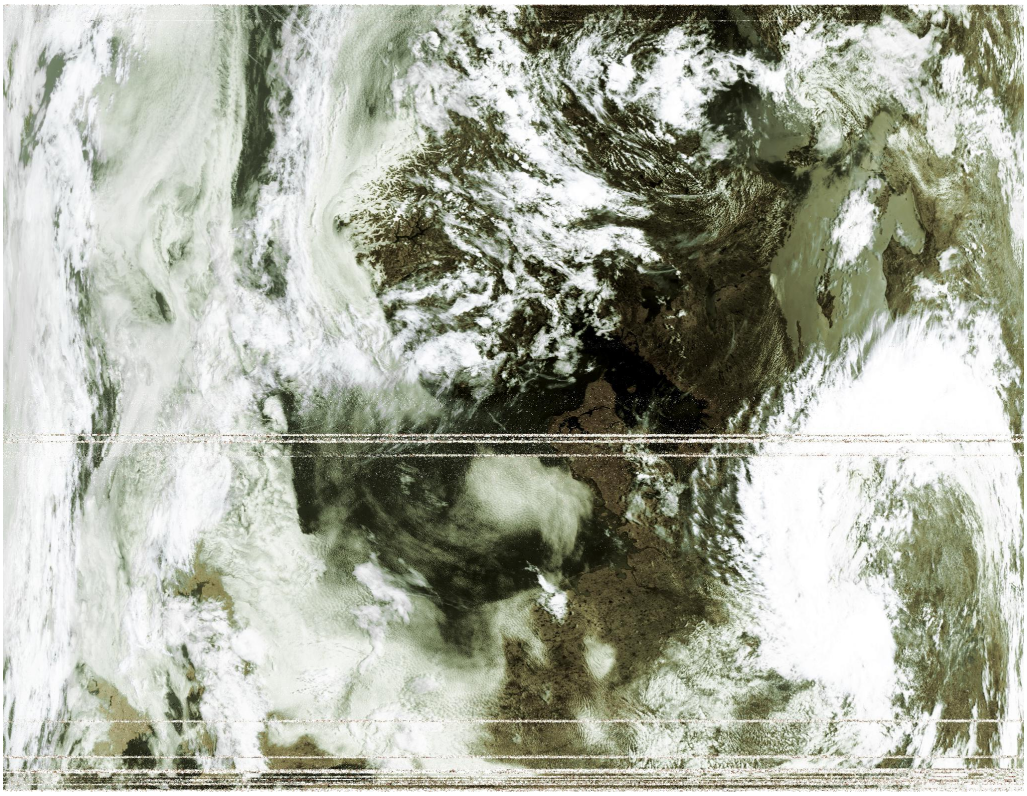


Figure 61: NOAA 18 picture on a cloudy 12/07/2018.

6 Conclusion and future lines

The system designed and built in this project was capable of automatically downloading and visualising HRPT pictures from weather satellites. Even the basis of the first design is the same as the design presented in this report, there were a lot of details that had to be changed during the building process for this system to perform as it did by the end of the project.

Even the system was able to visualise the automatically downloaded pictures, there have been some issues, as have been commented during the report, that did not work exactly as desired. Due to the project time restrictions, some of those issues could not be fixed, but also there were some initial requirements of the project as weather proofing and a mechanically robust system, that could not be neither fulfil. That is why there is further work to do.

First, the main and more important improvement is getting a more accurate way to determine the current azimuth angle of the antenna, as the way to do it from the gyroscope included in the IMU sensor was not exactly accurate. Also, a way to know when the antenna is pointing north shall be implemented, as the magnetometer in the IMU could not be reliable at all. A further improvement in this terms can be the addition of a GPS, so the coordinates of the ground location do not have to be manually added.

Still on the mechanical subsystem, making the mechanical structure more robust is a must, for being able to leave the system in a permanent location without supervision, to track satellites by itself with the automation already implemented. But, for that, the weather proofing is also needed, some parts can be easily waterproofed as the electronic boxes, however, some parts of the motors were not waterproof at all, so an extra work is needed.

Another improvement involving the mechanics but also the electrical subsystem has to do with the entanglement of the electric cables around the structure.

Getting into the telecommunications part of the system, further investigation and work can be done into the matching impedance of the antenna feed. A better LNA, with higher gain and lower noise figure, would improve the received signals, improving also the downloaded pictures. Also about the LNA, further investigation about the problem when using two LNAs in series can be done.

Furthermore, a bandpass filter at 1.7 GHz with 50-100 MHz of bandwidth can be also added to filter undesired signals for improving the quality of the HRPT reception.

Finally, an improvement to take the system a step up can be done by implementing a 3G or 4G dongle, allowing the system to send its results and upload them to the internet, as well as, uploading the satellites data without the need of depending on a Wi-Fi connection.

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