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Building a Low-Cost Ground Station for Weather Satellite Image Reception

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Abstract

In this Thesis, a small, low-cost, portable and easily deployable ground station was built, to track and receive signals from National Oceanic and Atmospheric Administration (NOAA) weather satellites (series 15, 18 and 19) in VHF and UHF bands, process and convert these to images are presented.

A ground station, capable of receiving reasonably good quality images from NOAA weather satellites was built. The Tunstile antenna of the ground station was built using parts of an old TV antenna found on the rooftop of an apartment building. The remaining part of the ground station was built using lost-cost materials such as an RTL-SDR dongle an analog front-end software defined radio with a USB interface to computer, Low Noise Amplifier (LNA) with 23 dB gain, screws, cables and jumpers totaling less than NOK 400, supported by MATLAB and open source software.

Different software are used to activate the ground station, open source software such as WXtrack and Orbitron were used to track and predict the orbit, timing and movement of the satellite. These software can track and predict a wide range of satellites. In this Thesis, the main focus has been on tracking NOAA weather satellites.

WXtoImg was used to decode and convert signals received through virtual cabling (audio piping) in real-time from SDR# into grey scale images and uses fake colors (random colors were assigned to different features) to distinguish between geological and geographical features, including borders between nations as these are imbedded within the software. While MATLAB was used to conduct signal spectrum analysis and decoding of previously saved audio signals from SDR# to images. The chosen combination of software and hardware components made the ground station capable of tracking satellites with different power levels, as well as different modulation and error-correction schemes.

The architecture of the antenna, and the performance evaluation and analysis of the ground station were completed after repeated attempts and experiments resulting in a vast number of images.

During the Thesis, new functions of the Ground Station were discovered. By using MATLAB and other open source software, the Ground Station was capable of

exploring local FM radio stations, DAB radio signals, DVB-T TV signals, GPS signals, as well as detecting aircrafts and drones overhead.

Making a Ground Station for satellite images reception from waste and low-cost materials available in most local markets, will be particularly important for researchers, students and practitioners in income-poor and conflict countries where they have few resources and limited access to modern technology.

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1 Introduction

Thousands of satellites are currently orbiting the Earth.[1] In 1975 United Nation's member states adopted the Convention on Registration of Objects Launched into Outer Space. The Index of Objects Launched into Outer Space is maintained by the United Nations Office for Outer Space Affairs (UNOOSA). According to information from the Union of Concerned Scientists (UCS) 1,738 satellites that are orbiting the Earth are operational[2], while others that have ceased to send signals and are debris orbiting the Earth at high speed posing a considerable risk to the space industry.[3]

The satellite era began on October 4, 1957 with the launch of Sputnik 1 by the Soviet Union. The benefit of satellites in gathering and transmitting information was soon recognized. Sputnik 3, launched in February 1958, carried instruments intended to record measurements of the Van Allen radiation belts.

Satellites provide us with a unique opportunity to look at the Earth from space, enable us to communicate effectively over great distances, and provide us with much vital data and information, including information about weather, which is the main topic of this Thesis. Satellites transmit weather information to ground stations where it can be displayed and analyzed. These services were pioneered in April 1960 with the launch of the first weather satellites[4] and have been operated since by the National Oceanic and Atmospheric Administration (NOAA) in the United States, as well as by China, the European Union, Japan, Russia, and by a number of other countries. The commonly used services include Automatic Picture Transmissions (APT) and High-Resolution Picture Transmission (HRPT) of the U.S. Polar Orbiting Environmental Satellites (POES). The ground station build as part of this Thesis

[1] UNOOSA. Annual Report (2017). In 2017, a record 489 satellites (launched in 2017 and earlier) were registered with the Secretary General by 28 States and one international intergovernmental organization. UNOOSA. Available: http://www.unoosa.org/documents/pdf/annualreport/UNOOSA_Annual_Report_2017.pdf [Accessed: 02.11.2018]

[2] Union of Concerned Scientists (2017). Available: https://allthingsnuclear.org/lgrego/ucs-satellite-database-update-8-31-17 [Accessed: 02.22.2018]

[3] NASA Engineering & Safety Center (NESC). Space Debris: Understanding the Risks to NASA Spacecraft (updated 2017). Available: https://www.nasa.gov/offices/nesc/articles/space-debrisNASA [Accessed: 02.11.2018]

[4] National Oceanic and Atmospheric Administration Satellite Information Services (NOAASIS). April 1, 1960 -- TIROS I is Launched (modified 2018). Available: https://noaasis.noaa.gov/NOAASIS/ml/40yearsa.html [Accessed: 02.11.2018]

receives APT, as HRTP requires much larger investments. It is able to receive APT pictures from several satellites, such as the US NOAA[5] 15, 18 and 19 satellites.

These NOAA satellites provide a reduced resolution data stream from the AVHRR instrument to scan both the visible and the IR spectrum and take strips of images. Signal are transmitted at 137 MHz band, received at the ground station through an antenna while the satellite is overhead in orbit, and then decoded into images. When the signal has been received, they can be stored as .wav (audio) file or directly processed through the RTL-SDR platform.

The work with NOAA satellite imagery has been done using RTL SDR dongle, a Tunstile antenna made from waste and low-cost materials, and different software platforms. Series of experiments have been conducted in order to achieve optimal results, including assembling the antenna, positioning the antenna, predicting and tracking the satellite, and operating different software and commands to capture signals, and process and decode the images. The focus has been on producing images of clouds.

Students from other universities and amateur radio trackers have been able to use commercially available antennas to receive signals from weather satellites, however few have assembled these using waste materials. In most industrialized countries high quality antennas can be procured in specialty shops, however in most developing countries these are hard to find. Ground stations suitable for Afghanistan and other conflict countries should therefore be assembled using a combination of low cost and waste materials. What the study has shown is that low cost ground stations anywhere in the world are capable of receiving weather data many times a day in the specific point from satellites (where every NOAA weather satellite orbit the earth every 102 minutes) when they pass in orbit overhead.

The research conducted as part of my Thesis aims to address problems related to access of quality images and information from satellites for science and engineering students, for university and college faculty members, and for satellite enthusiasts in low income countries. Reception of quality images and extraction of relevant information can be challenging without sophisticated equipment. Through the practical part of the work with this Thesis I would like to research different ways to assemble a ground station using waste materials combined with commercially available and inexpensive components. The steps described in Chapter No. 5 will

[5] The National Oceanic and Atmospheric Administration (NOAA) is an American scientific agency within the United States Department of Commerce

form the basis of a set of *Practical Guidelines on How to set up a Ground Station for Weather Satellite Image Reception*. These will later be translated into Dari and Pashtu[6] and made available to Afghan universities through the Norwegian Afghanistan Committee (NAC).

1.1 Thesis description

Build a ground station based on the following steps:

1) Track NOAA 15, 18 and 19 weather satellites using Orbitron, WXtrack software or www.n2yo.com website and identify the times when the satellites pass over the main sample location: Tønsberg, Vestfold, Norway with all specifications;
2) Build a tunstile antenna using a combination of waste materials and of commercially available low-cost components;
3) Receive and demodulate audio signals transmitted from the satellites using an SDR dongle and store them as wave audio files;
4) Process and decode the stored files into images using WXtoImg and MATLAB software;
5) Use grayscale to temperature map curves, map the grayscale images obtained in step 4 into equivalent temperature values;
6) Assign a colour map from blue (cold) to red (hot) corresponding to the respective temperature values, and;
7) Form a heat map using the defined colour pixels.

After completion of the Thesis I will develop a set of a Step-by-Step Guideline on How to set up a Ground Station for Weather Satellite Image Reception. This will later be translated into Dari and Pashtu for use at Afghan universities, colleges and technical and vocational schools in collaboration with the Norwegian Afghanistan Committee (NAC), the Afghan Geological Survey (AGS), and the Afghanistan National Disaster Management Authority (ANDMA).

With this Thesis I hope to help students in general, and Afghan university students and students from other low-income and conflict countries in particular, to get better access to information and data from weather satellites for their different projects, by using low cost and waste materials. It is important for me that this Thesis will have a practical impact on the quality of education within the field of satellite engineering in Afghanistan and other developing countries.

[6] Dari and Pashtu are the two national languages of Afghanistan

1.2 Aims and Objective

Everyday multiple NOAA low altitude weather satellites pass above us. Each satellite transmits, with regular intervals: meteorological images containing live weather images of our different geographical areas, including Norway, and Tønsberg as the chosen location. The RTL-SDR dongle combined with a Tunstile antenna, SDR# to tune the satellite signals, and WXtoImg and MATLAB to decode and enhance images, combined with other auxiliaries, incl. virtual cabling, to download and display live images.

This Thesis will combine theory and practical work:

- **Theory:** Introduce NOAA and their weather satellites and describe the techniques used for receiving signals from NOAA satellites, and convert these into images.
- **Practical work:** Build a low-cost ground station from waste materials combined with low cost and commercially available components, and test and enhance the capability of the ground station to receive signals from NOAA weather satellites and convert these into images through MATLAB and open source software.

Goal:
The main purpose of this Thesis is to understand the process, technical and practical aspects of building low-cost ground-stations for educational purposes.

Objective No. 1:
To develop a low cost, portable and easily deployable ground station to predict, track and communicate with satellites in low earth orbit through amateur band.

Objective No. 2:
To develop and enhance a framework for SDR applications through RTL-SDR dongle and freely available software, which can open the door for countless scientific activities for students, enthusiasts and researchers.

Objective No. 3:
After completion of this Thesis, provide step-by-step guidelines to students and faculty members at the engineering and ICT departments of three Afghan universities and colleges (in the provinces of Badakhshan, Ghazni and Kabul), and technical and vocational schools, and to provide them with opportunities to communicate with weather satellites without access to expensive equipment and facilities. The ground

station can also be used to communicate with other civilian satellites in orbit and with the international space station.

Objective No. 4:
After completion of this Thesis, support the Norwegian Afghanistan Committee (NAC), the Afghan Geological Survey (AGS) and Afghanistan National Disaster Management Authority (ANDMA) in developing low-cost technical solution for conducting long term mapping of weather patterns in Badakhshan and Ghazni provinces in Afghanistan to reduce the impact of drought, flooding and other natural disasters.

1.3 Motivation

When I returned to Afghanistan in 2007, after years as a refugee in neighbouring Pakistan, to complete secondary school and start studies in information and communication technology at the Kabul University, I soon realised how detached the education system in Afghanistan was from the rest of the world. Young Afghans studied hard but had very limited access to the many technical devises and teaching-learning resources students in more developed countries would benefit from. Helping Afghan university students, and students from other income-poor and conflict countries, to get access to information and data from satellites for different projects, by using low cost and waste materials, was therefore a driving force for me both in choosing this topic for my Thesis and in implementing the practical part.

The main reason for developing low-cost, small sized and portable ground stations is to allow interested practitioners, students and researchers to receive satellite signals without access to more traditional infrastructure, such as an expensive parabolic antennas or dedicated laboratory space. This will democratize satellite engineering and make it possible for students in remote and hard-to-reach communities to access weather images from many of the civilian satellites that orbit the earth.

The ground station is designed to operate on VHF band (30 to 300 MHz, in particular frequencies around 137 MHz). It is worth noting that the ground station can also be used on UHF band (around 450 MHz) with minor modifications. This frequency band is often used by amateurs and practitioners throughout the world to access weather images.

The Thesis is based on a combination of a desk study, practical work and computer coding. During the desk study, relevant academic articles, books and research papers were studied. While during the practical work different antennas were tried and tested to choose the most effective option within the cost limitations defined by the Thesis. During the testing of antennas many different designs were tried. After extensive experiments a ground station was assembled using low cost and waste material, including waste TV rooftop antennas, an RTL-SDR dongle, and a combination of free software, that was capable of receiving reasonably good audio signals. To convert these to images extensive work was done on developing MATLAB coding.

Apart from receiving satellite signals, different FM radio stations, mobile spectrum such as 2G-3G GSM signals, DVB-T and TV signals, DAB radio signals, GPS signals, and aircraft detection were explored.

2 Background study

2.1 Satellite communication systems

Satellite communication is when communication takes place between any two Earth stations through a satellite. Electromagnetic waves are used as carrier signals. These signals carry information such as voice, audio, images or any other data between ground and space. Satellites can be used to communicate between any locations across the globe. We know that communication refers to the exchange and sharing of information between two or more entities, through any medium or channel, in other words: sending, receiving and processing information.

Since satellites are located at a certain height above the Earth, the communication between ground stations via satellite overcomes the limitation due to the Earth's curvature. This is true for all satellites, including weather satellites which is the focus of this Thesis.

2.1.1 System architecture of satellite communication

The architecture of satellite communication has three main segments, space, control and Earth segments:

- **Space segment** consists of one or more satellites that communicating with each other using inter-satellite links and communicate with the Earth using ground stations.
- **Control segments** receives and monitors satellite signals through telemetry data, and sends control commands to the satellite to make sure that functions.
- **Earth / Ground station segment** connects satellites to users, either directly or indirectly, and manages all the traffic. Ground stations can either be big structures consisting of large antenna systems, or small handsets with very small antennas. The figure below illustrates a satellite communication architecture and how it interfaces with Earth or ground entities.

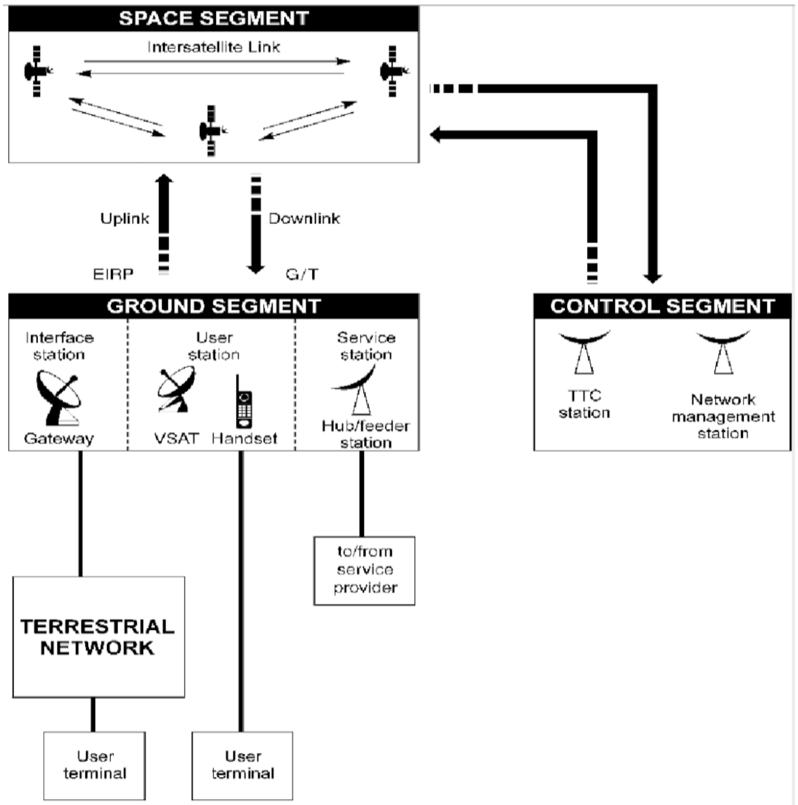

Figure 1 Satellite Communication System, interfacing with terrestrial entities[7]

2.1.2 How satellite works

A communication satellite is a microwave repeater station in orbit. A repeater is a circuit that receives signals, and then transmits them back to an Earth- or ground station. The repeater also works as a transponder, meaning that it changes the frequency band of the transmitted signals from the ones received. The frequency used to send signals into space, is called as uplink frequency. While, the frequency used to send signals by the transponder, is called a downlink frequency. The following figure illustrates this concept clearly.

[7] G. Maral & M. Bousquet (2009). Satellite Communication Systems 5th Edition. Configuration of a satellite communication system. p. 3. [John Wiley & Sons, Ltd., Publication, West Sussex, UK]

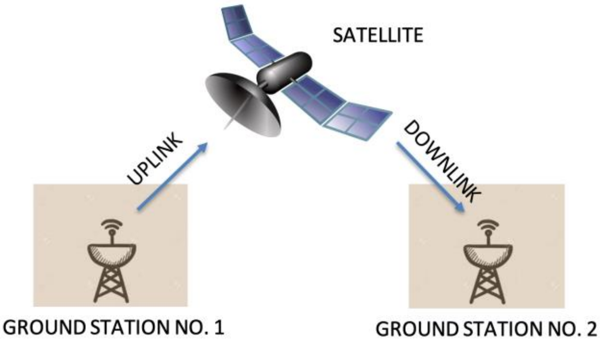

Figure 2 Concept of Uplinks and Downlinks

The process of satellite communication begins at a ground station, where an installation is designed to transmit to, and receive signals from, a satellite in orbit around the Earth. Ground stations send information to satellites in the form of high powered, high frequency, GHz range signals.

The satellite receives, strengthens and then retransmits the signals back to Earth where they are received by another or other ground station(s) in the coverage area of the satellite. The satellite's footprint is the area which receives a signal of useful strength from the satellite.[8]

2.1.3 Satellite communication services and frequency allocation

Satellite services vary from the broadcasting of weather data and information to military and intelligence services, depending on the functionality of the space and ground segment configurations. Services are provided on different frequency bands, or allocation, all with different designations so that they can be referred easily.[9]

Higher frequency bands mostly give access to greater bandwidth. However, higher frequency bands are also more vulnerable to signal degradation due the absorption of radio signals by atmospheric weather conditions, e.g. rain, ice and snow.[10]

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[8] W.C Cook (1996). The Wonderful World of Satellites. How Do Satellites Work? Available: http://www.williamcraigcook.com/satellite/work.html [Accessed: 05.11.2018]

[9] OECD (1995). Satellite Communication: Structural Change and Competition", OECD Digital Economy Papers, No. 17, OECD Publishing, Paris. Available: https://www.oecd-ilibrary.org/docserver/237382733117.pdf?expires=1559215625&id=id&accname=guest&checksum=7E2105DE1348E418EA76D579447E3AC6 [Accessed: 01.12.2018]

[10] ESA (2018). Telecommunication & Integrated Applications: Satellite Frequency Bands. Available: https://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Satellite_frequency_bands [Accessed: 01.12.2018]

Congestion has become a serious problem, especially in lower frequency bands with the increased use of satellites for multiple purposes. Due to the congestion, new technologies are being investigated for the use of higher bands instead.

The frequency spectrum lies between 0.1 MHz to 1000 GHz. The frequency range useful for satellite communication is above 100 MHz. Frequencies are categorized into different bands as explained in the table below:

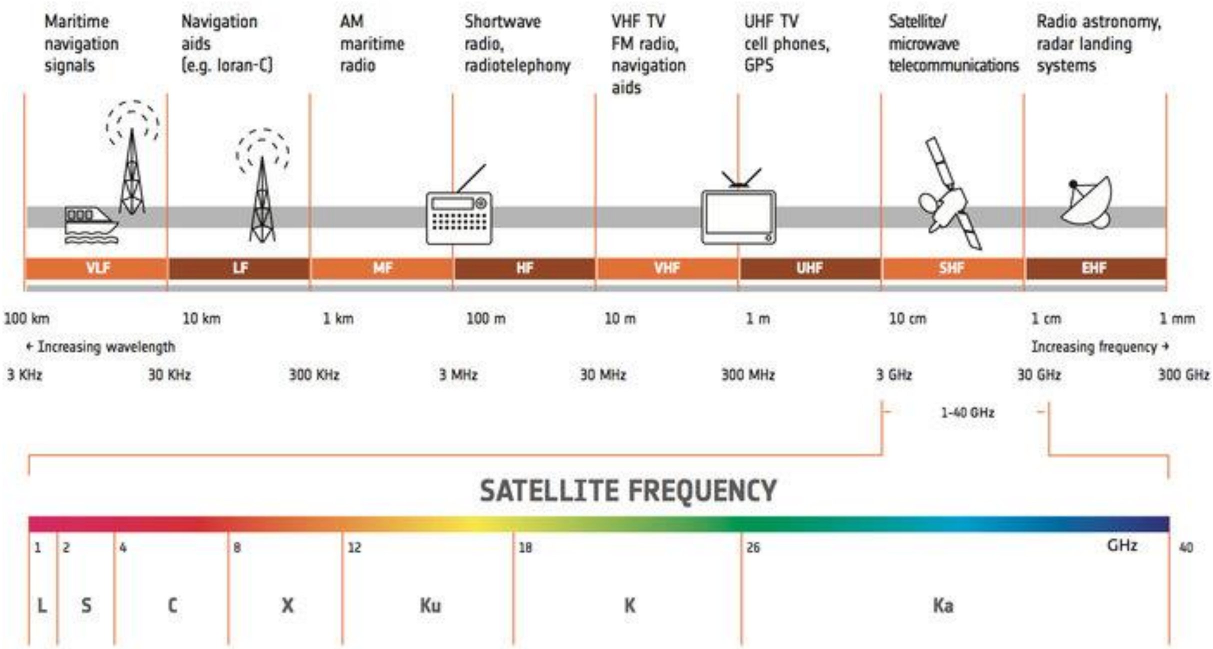

Figure 3 Satellite Frequency Bands[11]

One of the many advantages of using radio frequency is that is can be reused. When the assigned frequency band is full, the capacity of the spectrum can be increased. This is done by increasing the gain, or size, of the antenna. The capacity can also be increased by reducing the beam width, where different beams of the same frequency are directed to different geographic locations. Polarization can be used as a method to reuse a frequency; this is achieved by transmitting different information to

[11] ESA (2018). Telecommunications & Integrated Applications. Satellite Frequency bands. Available: https://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Satellite_frequency_bands [Accessed: 03.11.2018]

different ground stations by orienting the polarization 90° out of phase while using the same frequency.

2.2 Satellite types and orbits characteristics

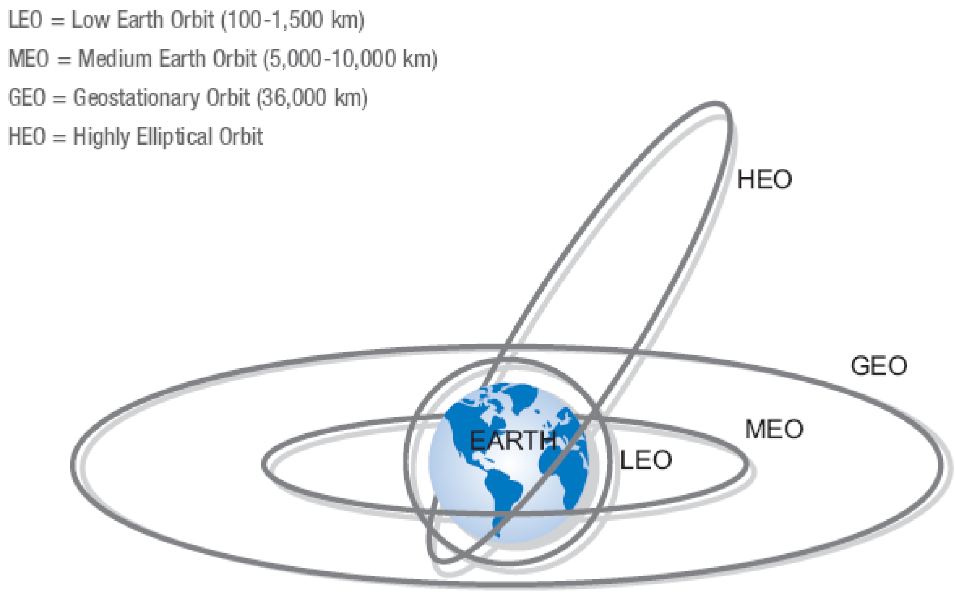

Figure 4 Satellite types and orbits characteristics[12]

Satellites are classified based on their orbital height, weight, size and functions, incl. weather, communication, navigation, Earth observation, and astronomical satellites.

The **Weight and size** of satellites vary from just a few grams (miniature satellites) to many tons. Over the past few years smaller satellites have become a platform for experimental payloads that can be planned and executed in a much shorter time-span and at much less costs than by using larger satellites.

Universities and individual researchers are now designing and developing tiny satellites, or nanosatellites, that can be launched in Low Earth Orbit (LEO). These small, or very small satellites have a short life-span, while larger satellites have a much longer life-span.[13]

[12] R.N. Gonzalez (2015). GEO, MEO & LEO Satellite. Available: https://namuragonzalez.quora.com/GEO-MEO-LEO-Satellite [Accessed: 03.11.2018]
[13] S.C. Burleigh, T. De Cola, S. Morosi, S. Jayousi, E. Cianca & C. Fuchs. Hindawi. From Connectivity to Advanced Internet Services: A Comprehensive Review of Small Satellites Communications and Networks. Wireless Communications and Mobile Computing
Volume 2019, Article ID 6243505. Available: https://www.hindawi.com/journals/wcmc/2019/6243505/ [Accessed: 05.05.2019]

Orbital height or distance from the Earth: Satellites can achieve orbit at any distance from the Earth as long as its velocity is sufficient to keep it from falling to Earth, if it is free of friction from the atmosphere of the Earth, and the gravity is strong enough to pull it back towards Earth. With increased distance between the satellite and the Earth, the longer it takes for radio or microwave frequency transmissions to reach the satellite.[14]

As can be seen in the above figure, satellites can be categorized based on their height or distance from the Earth:[15]

- Low Earth Orbit (LEO) Satellite – At an altitude of less than 1000 kilometers
- Medium Earth Orbit (MEO) Satellite – At altitudes between 1000 and 35000 kilometers
- Geostationary and Geosynchronous (GEO) Satellite – At altitudes above 35000 kilometers
- High Elliptical Orbit

2.3 NOAA Weather Satellites:

National Oceanic and Atmospheric Administration (NOAA) is a scientific agency formed in December 3, 1970 to bring together the functions of several different agencies that focuses on the conditions of the weather and temperature.[16]

The main activities of the NOAA are:

- Monitoring and observing Earth systems with instruments and data collection networks.
- Understanding and describing Earth systems through research and analysis of data.
- Assessing and predicting the changes of these systems over time.
- Engaging, advising, and informing the public and partner organizations with important information.
- Managing resources for the betterment of society, economy and environment.

[14] InetDaemon.Com (2018). Satellite Orbits. Available: https://www.inetdaemon.com/tutorials/satellite/orbits/ [Accessed: 05.11.2018]
[15] A. J. Gerber Jr., D.M. Tralli, & S.N. Bajpai (2005). Abstract: Medium Earth Orbit (MEO) as an operational observation venue for NOAA's post GOES-R environmental satellites. The International Society for Optical Engineering (SPIE). Available: http://adsabs.harvard.edu/abs/2005SPIE.5659..261G [Accessed: 05.11.2018]
[16] NOAA (2018). AVAILABLE:: https://www.noaa.gov [Accessed: 05.11.2018]

NOAA provides information of dangerous weather, charts seas, guides the use and protection of ocean and coastal resources, conducts research to provide understanding and improve stewardship of the environment.

NOAA has a series of its own weather monitoring satellites. Each carries a comprehensive set of instruments that provides data for weather and climate predictions. Every single day multiple NOAA weather satellites pass in orbit above us. NOAA weather satellites broadcast Automatic Picture Transmission (APT) signals at 137 MHz, containing live weather images of different areas of the world.

NOAA's operational environmental satellite system is composed of two types of satellites: geostationary operational environmental satellites (GOES) for short-range warning and polar-orbiting environmental satellites (POES) for longer-term forecasting. Both kinds of satellites are necessary for providing a complete global weather monitoring system. This Thesis focusses on POES satellites which revolve around the Earth in low Earth orbit.

2.4 Classification of NOAA satellites

As discussed above, the classification of satellites overall, NOAA weather satellites is classified into two categories based on their orbit and life span:

2.4.1 Geostationary operational environmental satellites (GOES):

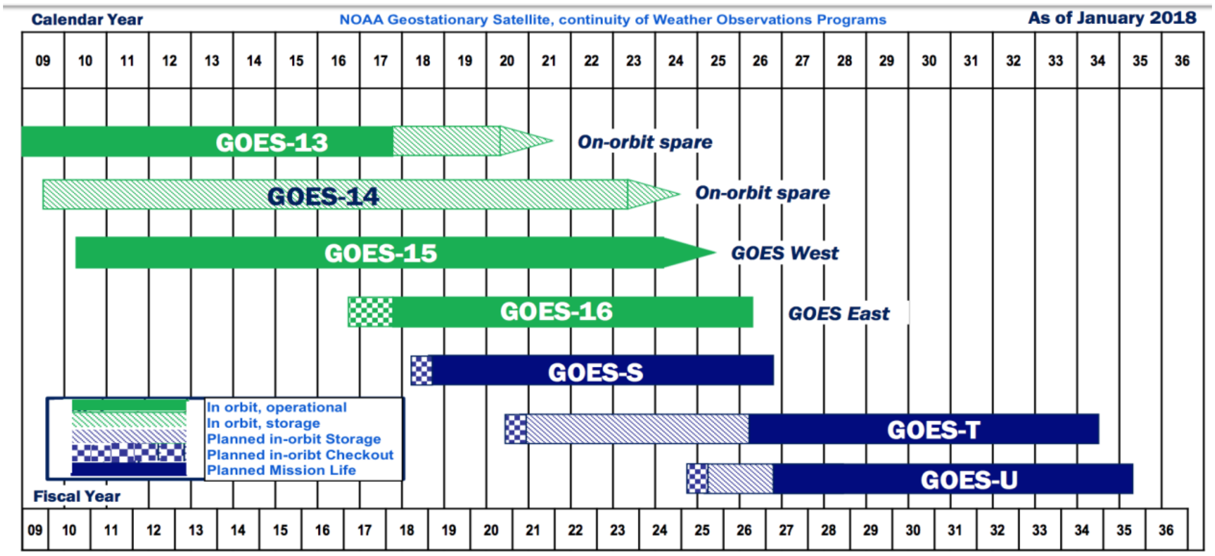

Figure 5 NOAA Geostationary Satellite: Continuity of Weather Observation Program[17]

[17] NOAA (2018). Flyout Chart. Available: https://www.nesdis.noaa.gov/sites/default/files/asset/document/GOES_Flyout_Jan_2018_Signed_Linked.pdf [Accessed: 05.11.2018]

GOES satellites provide continuous monitoring necessary for intensive data analysis as they orbit the Earth in a geosynchronous orbit (GEO) over the Equator with a speed matching the Earth's rotation. This allows them to hover continuously over one position on the Earth’s surface, high enough (approximately 25800 km) to have a full view of the Earth with just 3 satellites (NOAA 15, 18 and 19). The design enables the sensors to "stare" at the Earth. Because they stay above a fixed spot on the surface, the evolution of atmospheric phenomena can be followed with great accuracy, ensuring real-time coverage of severe storms, tropical cyclones and other meteorological events.

NOAA also uses GOES satellite images to estimate rainfall during thunderstorms and hurricanes for flash flood warnings and estimate snowfall accumulations and the overall extent of snow cover. Such data help meteorologists issue winter storm warnings and spring snowmelt advisories.

In Afghanistan, availability and dissemination of such data would help prevent hundreds of deaths every year caused by floods and flash floods, especially in Northern Afghanistan. Satellites can also be used to monitor drought. According to the UN by October 2018, have more than 2.2 million people in Afghanistan have been affected by the ongoing drought.[18]

Satellite sensors also detect ice fields and map the movements of ice on lakes and on the seas.

GOES satellites continuously monitor different regions and continents, including Europe, the Pacific and Atlantic Oceans, Central America, South America, and southern Canada, providing daily weather updates.

[18] UN OCHA (2018). Afghanistan: UN Funds allocate US$34.6M to assist 2.2M people severely affected by ongoing drought. Available: https://www.unocha.org/story/afghanistan-un-funds-allocate-us346m-assist-22m-people-severely-affected-ongoing-drought [Accessed: 05.11.2018]

2.4.2 Polar Operational Environmental Satellites (POES):

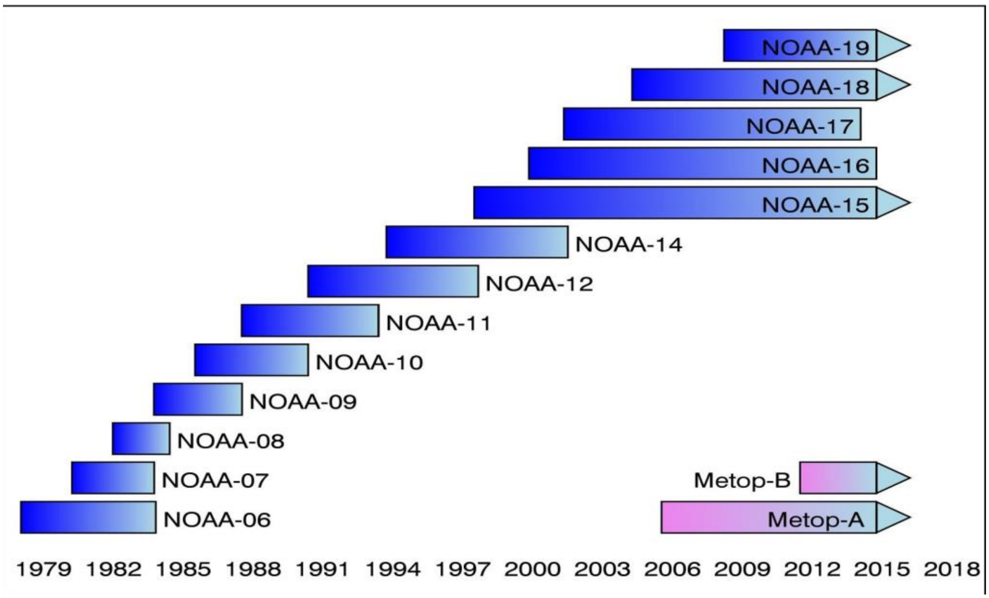

Figure 6 Polar Operational Environmental Satellites[19]

NOAA POES are the fifth generation of polar satellites from the NOAA. These satellites have been developed together with NASA and the European organization EUMETSAT which build the MetOp satellites.

Instruments onboard POESs include the Advanced Very High-Resolution Radiometer (AVHRR) and the Advanced TIROS Operational Vertical Sounder (ATOVS). EUMETSAT provided Microwave Humidity Sounder (MHS) instrument, completing ATOVS suite. These instruments provide visible, infrared, and microwave data used for a variety of applications.

Data from POES support a wide range of important environmental monitoring applications. These include weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, search and rescue.[20]

As these POESs operate at a height of 850 km, their orbit is such that they cross the geographic poles 14 times every day. Their revolution period is approximately 102

[19] DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V) Earth Observation Center. AVHRR. Available: https://www.dlr.de/eoc/en/desktopdefault.aspx/tabid-9136/19476_read-45195/ [Accessed: 05.11.2018]
[20] NOAA (2019). National Weather Service. Using Satellites for Forecasting. Available: https://www.weather.gov/ajk/OurOffice-Sat [Accessed: 01.05.2019]

minutes which permit them to span entire globe twice a day. Random ground station can therefore receive signals twice every 24 hours.

Furthermore, their orbit is Helio-synchronous (see explanation above). The image acquisition is therefore done with the same conditions every crossing of the latitude as they fly above the same location at the same time every single day.

Concerning the choice of the satellite, we chose the NOAA-15, NOAA-18 and NOAA-19 which are more operational than the other PEOSs.

2.4.3 POES Operational Status:

Spacecraft data and operational status for each spacecraft and its subsystems.[21]

GREEN: Operational (or capable of)
YELLOW: Operational with limitations (or Standby)
ORANGE: Operational with Degraded Performance
RED: Not Operational
BLUE: Functional, Turned Off
BLANK: No Status Reported

Table 1 NOAA Satellites – Operational Status[22]

SPACECRAFT	OPERATIONAL STATUS	STATUS
NOAA 11	Decommissioned	RED
NOAA 12	Decommissioned	RED
NOAA 14	Decommissioned	RED
NOAA 15	AM Secondary	GREEN
NOAA 16	Decommissioned	RED
NOAA 17	Decommissioned	RED
NOAA 18	PM Secondary	GREEN
NOAA 19	PM Primary	GREEN

[21] NOAA (2017). POES Operational Status. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Downloaded 05.11.2018]
[22] Adapted based on: NOAA (2016). POES Operational Status. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Downloaded 05.11.2018]

2.4.3.1 Subsystem Status (NOAA-15):

Table 2 NOAA 15: Subsystem Status[23]

SUBSYSTEM with DESCRIPTION	STATUS
ADACS - Attitude Determination and Control System	ORANGE
AMSU-A1 - Advanced Microwave Sounding Unit-A1	YELLOW
AMSU-A2 - Advanced Microwave Sounding Unit-A2	GREEN
AMSU-B - Advanced Microwave Sounding Unit-B	RED
AVHRR - Advanced Very High-Resolution Radiometer	YELLOW
CCS - Command and Control System	GREEN
COMM - Communications System	YELLOW
DCS - Data Collection System	GREEN
DHS – Data Handling System	GREEN
DPLY - Deployment Subsystem	
EPS - Electrical Power System	GREEN
FSW - Flight Software	
GROUND - Polar Acquisition and Command System (PACS)	
HIRS - High Resolution Infrared Radiation Sounder	RED
RCS - Reaction Control Subsystem	
SARP - Search and Rescue Processor	GREEN
SARR - Search and Rescue Repeater	YELLOW
SEM - Space Environment Monitor	GREEN
THERM - Thermal Control System	YELLOW

[23] Adapted based on: NOAA (2016). POES Operational Status. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Downloaded 05.11.2018]

2.4.3.2 Subsystem Status (NOAA-18):

Table 3 NOAA 18: Subsystem Status[24]

SUBSYSTEM with DESCRIPTION	STATUS
ADACS - Attitude Determination and Control System	YELLOW
AMSU-A1 - Advanced Microwave Sounding Unit-A1	GREEN
AMSU-A2 - Advanced Microwave Sounding Unit-A2	GREEN
AMSU-B - Advanced Microwave Sounding Unit-B	GREEN
AVHRR - Advanced Very High-Resolution Radiometer	GREEN
CCS - Command and Control System	GREEN
COMM - Communications System	GREEN
DCS - Data Collection System	GREEN
DHS – Data Handling System	GREEN
DPLY - Deployment Subsystem	GREEN
EPS - Electrical Power System	GREEN
FSW - Flight Software	
GROUND - Polar Acquisition and Command System (PACS)	
HIRS - High Resolution Infrared Radiation Sounder	RED
MHS - Microwave Humidity Sounder	GREEN
RCS - Reaction Control Subsystem	
SARP - Search and Rescue Processor	GREEN
SARR - Search and Rescue Repeater	GREEN
SBUV - Solar Backscatter Ultraviolet Radiometer	RED
SEM - Space Environment Monitor	GREEN
THERM - Thermal Control System	GREEN

[24] Adapted based on: NOAA (2016). POES Operational Status. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Downloaded 05.11.2018]

2.4.3.3 Subsystem Status (NOAA-19):

Table 4 NOAA 19: Subsystem Status[25]

SUBSYSTEM with DESCRIPTION	STATUS
ADACS - Attitude Determination and Control System	GREEN
A-DCS - Advanced Data Collection System	GREEN
AMSU-A1 - Advanced Microwave Sounding Unit-A1	GREEN
AMSU-A2 - Advanced Microwave Sounding Unit-A2	GREEN
AVHRR - Advanced Very High-Resolution Radiometer	GREEN
CCS - Command and Control System	GREEN
COMM - Communications System	GREEN
DCS - Data Collection System	GREEN
DHS – Data Handling System	GREEN
DPLY - Deployment Subsystem	GREEN
EPS - Electrical Power System	GREEN
FSW - Flight Software	
GROUND - Polar Acquisition and Command System (PACS)	
HIRS - High Resolution Infrared Radiation Sounder	ORANGE
MHS - Microwave Humidity Sounder	GREEN
RCS - Reaction Control Subsystem	
SARP-3 - Search and Rescue Processor - 3	GREEN
SARR - Search and Rescue Repeater	GREEN
SBUV - Solar Backscatter Ultraviolet Radiometer	RED
SEM - Space Environment Monitor	GREEN
THERM - Thermal Control System	GREEN

[25] Adapted based on: NOAA (2016). POES Operational Status. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Downloaded 05.11.2018]

2.4.4 NOAA-N Spacecraft Status Summary:

Table 5 NOAA-N Spacecraft Status[26]

Specifications	NOAA-15	NOAA-18	NOAA-19
Spacecraft Letter	K	K	N-Prime
Catalog Number	25338	28654	33591
Operational Date	15/12/1998	30/08/2005	06/02/2009
International Designation	1998 030A	2005 018A	2009 005A
Launch Date	13/05/1998	20/05/2005	06/02/2009
Operational Status	AM secondary	PM secondary	PM Primary
GAC	Yes	Yes	Yes
LAC	No	No	No
LTAN	17:46:52	17:53:33	14:36:15
Altitude	807 km	854 km	870 km
Period	101.1 (Minutes)	102.12 (Minutes)	102.14 (Minutes)
HRPT	Yes, STX-2/MSB 1702.5Mhz	Yes, STX-3/HSB 1707.0Mhz	Yes, STX-1/LSB
APT	Yes VTX-2 137.62 MHz	Yes VTX-2 137.9125 MHz	Yes VTX-1 137.1 MHz
Inclination Angle	98.5 deg	98.74 deg	98.7 deg
Precession Rate	1.05 (min/month)	3.52 (min/month)	0.77 (min/month)

2.4.5 POES of other countries:

In addition to the United States, China, a consortium of European nations (incl. Norway), India, Japan and Russia, own and operate polar orbiting weather satellite systems. Some of these satellites have readout systems which are compatible with the US POES direct readout data products and may therefore be received by appropriately equipped ground stations.

[26] Compilation of data and information from the NOAA web-page. Available: https://www.ospo.noaa.gov/Operations/POES/status.html [Accessed: 05.11.2018]

2.4.5.1 Chinese Polar Weather Satellites:

The meteorological satellite program of China consists of both polar orbiting and a geostationary satellite. China's polar orbiting satellites have a direct readout capability fully compatible with the NOAA POES.

Feng Yun (FY-1D) was launched on May 15, 2002 it carries a 10-channel scanning radiometer. Chinese meteorological satellites provide a CHRPT direct broadcast service similar to POES HRPT data. The Chinese launched its latest Feng Yun FY 3D in 2017[27], which are their latest generation polar orbiting satellites.

2.4.5.2 European Polar Weather Satellites:

EUMETSAT (European Organization for the Exploitation of Meteorological Satellites), a consortium of thirty European nations[28], including Norway, launched their first polar orbiting meteorological satellite, MetOp-A in October 2006. This satellite carries a suite of advanced sensors and is in an orbit similar to US POES satellites. In 1998 EUMETSAT and NOAA formed an Initial Joint Polar Orbiting Satellite System (IJPS) and agreed to sharing data between systems. EUMETSAT operate MetOp satellites in a morning orbit, while the POES satellites operate in an afternoon orbit. The METOP satellites have direct readout transmission services, providing AHRPT similar to POES HRPT. The APT service is not provided, LRPT (Low Rate Picture Transmission) is provided for users of lower resolution data. The LRPT service is digital rather than analogue, requiring modification of APT receiving stations.[29]

2.4.6 International Cooperation:[30]

Due to the economic recession in the United States in the early 1980s, NOAA was forced by the US Government to reduce the high cost of space systems while at the same time effectively address the growing need to provide a complete and accurate

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[27] The World Metrological Organizations (WMO). Observing Systems Capability Analysis and Review Tool (OSKAR). Available: https://www.wmo-sat.info/oscar/satellites/view/116 [Accessed: 05.11.2018]

[28] The European Organization for the Exploitation of Meteorological Satellites is an intergovernmental organization based in Darmstadt, Germany, currently with 30 Member States (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom) and one Cooperating State (Serbia)

[29] NOAA (2009). User's Guide for Building and Operating Environmental Satellite Receiving Stations. p. 25. Available: https://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf [Accessed: 05.11.2018]

[30] NOAA OSPA (2013). International Cooperation. Available: https://www.ospo.noaa.gov/Organization/About/international.html [Accessed: 05.11.2018]

observation of the atmosphere at regular intervals as inputs to weather prediction and climate monitoring support systems.

Budgetary problems forced NOAA to start discussions and seek agreements with other international actors, especially the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT).

The goal of this cooperation is to provide continuity of measurements from polar orbits, cost sharing, and improved forecast and monitoring capabilities through the introduction of new technologies. Building upon the successful POES program, an agreement was signed between NOAA and EUMETSAT in 2013 on the Initial Joint Polar-orbiting Operational Satellite System (IJPS).

In December 2015, NOAA and EUMETSAT signed the further reaching agreement – the Joint Polar System (JPS) Agreement – extending the collaboration to the development of a new generation of polar-orbiting satellites which will provide both organizations access to observations from two complementary polar orbits in the period from 2020 to 2040. The joint operations between EUMETSAT and NOAA will include cross support for data acquisition and spacecraft monitoring through European and US ground stations located in Longyearbyen, Svalbard (Norway) and McMurdo (Antarctica).[31]

"This agreement is a new landmark in our strategic cooperation with NOAA"
Alain Ratier, Director-General of EUMETSAT

The collaboration may also include elements of the Suomi-National Polar-orbiting Partnership (NPP) between NASA, NOAA and the US Department of Defense. NPP constitutes a first step towards the next-generation Earth-observing satellite system for collecting data on long-term climate change and short-term weather conditions.

[31] EUMETSAT (2015). EUMETSAT and NOAA sign Agreement on Joint Polar System. Available: https://www.eumetsat.int/website/home/News/DAT_2867890.html?lang=EN&pState=1 [Accessed: 06.11.2018]

3 The Basic Ground Station

The main purpose of a ground station is to provide a communication point for satellites when they pass over in regular time intervals.

The advancement in micro-electronics technology and software applications, has made it easier to construct low cost basic ground station for receiving satellite signals to reproduce Automatic Picture Transmission (APT) images.

First, a polar orbiter receiving station for APT images has to be assembled, with a basic analog APT system that allows users to become familiar with satellite image reception techniques. It receives satellite radio telemetry from a fast-moving platform in space, learning the techniques of predicting satellite orbits and acquisition of signal timing, and analyzing weather patterns and temperature variations.

When planning to build a ground station for weather satellite image reception, a number of important points must be considered:[32]

- Should we buy a complete readymade system from a commercial supplier? or
- Should we buy individual components (Antenna, LNA, Receiver, Demodulator, Software, etc.) and assemble it into a ground station ourselves?
- Is the ground station is primarily intended to receive for resolution regional images (APT)? or
- Do we need high resolution or global capabilities?
- What are the financial considerations and limitations for assembling a complete ground station?

As we gain more practical experience with satellite image reception, and as the application requirements change, we may move on to higher resolution digital LRIT, HRPT, and GVAR commercial systems. In this Thesis the focus will be on low-cost, portable ground station for APT image reception.

A basic ground station typically contains the following components:[33]

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[32] NOAA (2009). User's Guide for Building and Operating Environmental Satellite Receiving Stations. p.31. Available: https://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf: [Accessed: 04.11.2018]
[33] NOAA (2009). User's Guide for Building and Operating Environmental Satellite Receiving Stations. p.31. Available: https://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf: [Accessed: 04.11.2018]

- Antenna
- Low Noise Amplifier
- Radio receiver
- Demodulator to "decode" satellite signals
- Display system to view the satellite images (e.g. personal computer)
- Computer software to manipulate images (image enhancement)
- Method to predict when the satellite will be in view of the ground station

These different components will be described in greater detail in the following sections.

Even if most base stations will consist of the same basic components, the antenna, design of the radio receiver and demodulation or decoding system will differ depending on the nature of the radio frequencies required to transmit, decode and process high speed digital images.

Before moving on to the explanation of different components making up a ground station, some very important points associated with the functionality of the ground station (how it works) will be discussed, including its connection, relation to the satellite, satellite sensors, and its functionality.

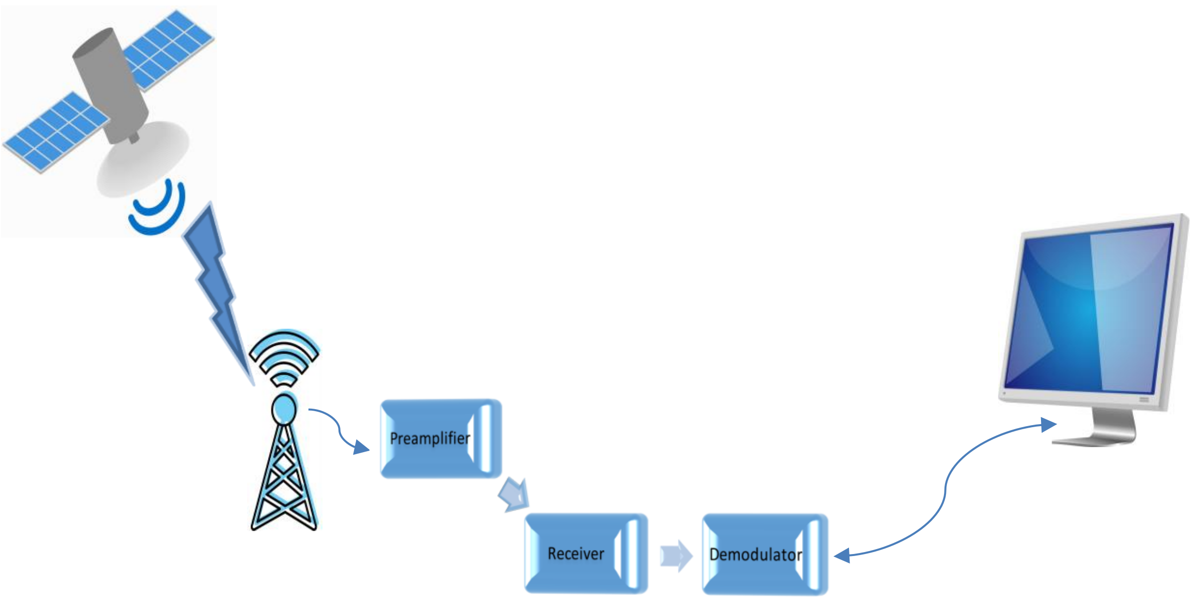


Figure 7 Components of a ground station needed to receive polar orbiting APT

3.1 Satellite's Sensors and image format:

In order to understand how the equipment of ground stations receives images from polar orbiting satellites, it is important to understand about the sensors onboard these satellites, and how images are created, formatted, modulated and transmitted from the satellites to ground stations.

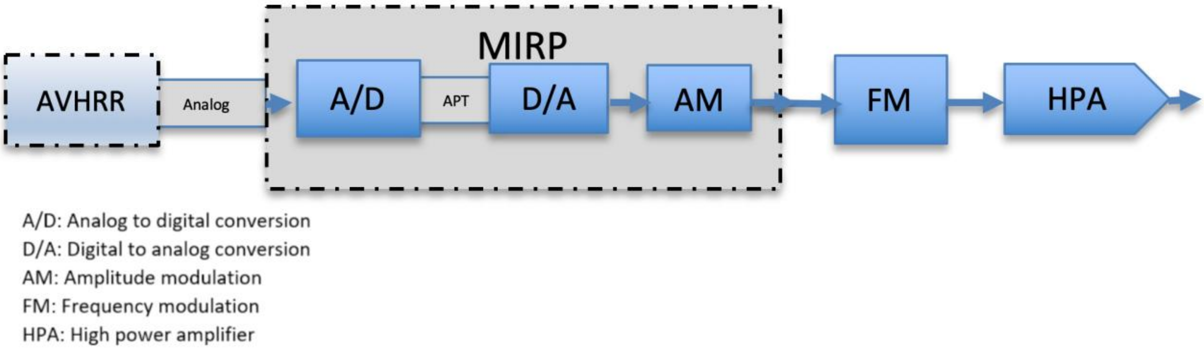


Figure 8 Satellite transmission chain

The main sensor on board NOAA satellites is the Advanced Very High-Resolution Radiometer (AVHRR) instrument. AVHRR is the latest in a long series of imaging instruments onboard polar orbiting satellites.

Morning pictures are most commonly used for land studies, while photos taken in the afternoon are used for atmosphere and ocean studies – this due to the different lighting of the Earth. Together they provide twice-daily global coverage and ensure that data for any region of the Earth are no more than six hours old. The width of the area on the Earth's surface that the satellite can **see**, is approximately 2,500 km.

These satellites orbit on an average height of approximately 520 miles (837 km)[34] above the Earth's surface. The highest ground resolution that can be obtained from the current AVHRR instruments is 1.1 km, which means that the satellite records information for areas on the ground that are 1.1 × 1.1 km (size of one pixel) for HRPT and 4×4 km for RPT. The main purpose of these instruments is to monitor clouds and to measure the thermal emission of the Earth. These sensors have proven useful for a number of other applications, including the surveillance of land-surfaces and the state of the oceans.

[34] NOAA SIS (2018). NOAA's Geostationary and Polar-Orbiting Weather Satellites. Available: https://noaasis.noaa.gov/NOAASIS/ml/genlsatl.html [Accessed: 07.11.2018]

3.1.1 System and signal descriptions:

Advanced Very High-Resolution Radiometer (AVHRR): It is the main image sensor onboard the satellite. It is a broadband (multiple channels) scanner, equipped with multiple lenses, a mirror system and other smaller sensors to sense the visible, near-infrared, and thermal-infrared parts of the electromagnetic spectrum. An Earth image can be received at any moment when the satellite is in the range of the ground station because it operates continuously. This system provides several types of images in different channels.

AVHRR Channels: It consists of up to 6 channels (depending on the model), where channel 1 depends on sunlight reflected on the Earth because the sensors are sensitive to visible light. To get visible images, the amount of light reflected must be quite high. Channel 2 detects reflected infrared energy and is the usual visible channel for APT. These two channels are the most commonly used for APT imagery. Other channels are accessible for specific use (see table below). The analog signal is processed by MIRP.

Table 6 AVHRR/3 channel characteristics[35]

Channel #	Resolution at Nadir/Pixel	Spectral Range-μM (Wavelength)	Typical uses
1	1.08 km	0.58-0.68 (visible)	Daytime cloud and surface mapping, snow and ice melting
2	1.08 km	0.725-1.00 (near-infrared)	Land-water boundaries, sea surface temperature, vegetative indexing.
3A	1.08	1.58-1.64 (near-infrared)	Snow and ice detection
3B	1.08	3.55-3.93 (Thermal)	Night cloud mapping and sea surface temperature, forest fire monitoring.
4	1.08	10.30-11.30 (thermal)	Sea surface temperature, night cloud mapping, soil moisture.
5	1.08	11.50-12.50 (Thermal)	Sea surface temperature and night cloud mapping.

[35] NOAA (2017). Advanced Very High-Resolution Radiometer – AVHRR. Available: https://noaasis.noaa.gov/NOAASIS/ml/avhrr.html [Accessed: 07.11.2018]

Manipulated Information Rate Processor (MIRP): The output of AVHRR sensors is first amplified and converted to digital information by an analog-to-digital converter (A/D), then it is processed to create different data streams which match the different signals emitted by the satellite are as follows:

High Resolution Picture Transmission (HRPT): High resolution images with all six channels and telemetry data.

Global Area Coverage (GAC): Images of all the regions of the Earth transmitted to NOAA control ground stations on command.

Local Area Coverage (LAC): HRPT data recorded from selected regions of the Earth transmitted to NOAA control ground stations on command.

Automatic Picture Transmission (APT): Analog transmission of two channels (only two of the six channels are used for APT) with reduced resolution. In daytime, APT should show visible and IR channels. In night-time, control stations normally set the satellite to replace visible channel by another IR channel with different spectral band as the visible one is no longer useful.

3.2 The proposed ground station:

The proposed ground station is low-cost and portable, and capable of tracking NOAA and other POES satellites in VHF and UHF band. Satellites broadcast signals using a system termed APT where it scans the earth 840 km below with 102 minutes intervals (the time it takes to orbit the Earth). Through a basic ground station, signals are decoded into images that are built up line-by-line. A complete APT image is built up at a rate of two lines per second. An APT signal is a data stream containing contiguous or bordering sequences of values that represents grayscale pixels of each line. This data stream produced by the amplitude modulating a 2400 Hz subcarrier with the 8 most significant bits of the 10-bit digital AVHRR data. Two of the six possible AVHRR spectral channels are multiplexed in an APT signal. This amplitude modulated subcarrier is further frequency modulated for transmission. These transmissions are received on frequencies in the 137-138 MHz band.

The considered characteristics and composition of the ground station are explained in this Thesis. After careful studying theory, gathering information and understanding the requirements, the necessary equipment was selected for the development of the ground station. The proposed ground station will also have a stereo sound-card

interface as an input to computer and an audio virtual cabling (audio piping) as the output. While an antenna, LNA and RTL-SDR dongle, required coaxial cable, and a reasonably strong computer are the required hardware. One of the main advantages is that the proposed ground station will allow for the use of any signal processing software that “understands” audio signals. The ground station will be a system of remote sensing based on AM and FM modulation techniques.
The following is the block diagram of the proposed ground station:

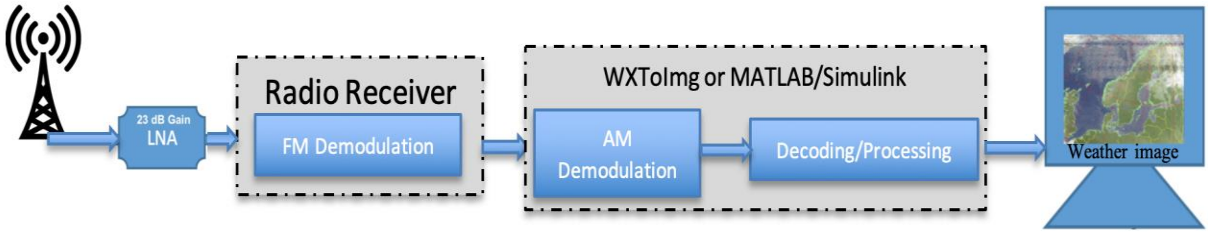


Figure 9 Model of the proposed ground station

3.2.1 Ground Station Architecture

The architecture of the proposed ground station illustrated in above is considered a simplification of other, more sophisticated and costlier ground stations.

In order to build a low cost, small and portable ground station, the following elements should be constrained:

- **Antenna**
  - The system configuration must be precise
  - It must be small enough to be easily moved from one place to another.
  - It must be simple and inexpensive.
  - It must be installed on a location where it can easily get signals and detect satellite movements.

- **Low Noise Amplifier (LNA)**
  - It should cover all frequencies of interest.
  - It should be small, inexpensive and easily available in the market.
  - It should have a noise figure less than 2 dB.
  - It should have a bias-T connection to get power from the front-end.

- **Radio-frequency front-end**
  - It must be able to provide sufficient amplification to obtain a good S/N and filtering.

- It should be able to provide power to the LNA via a bias-T set-up.
- It must be able to receive a wide FM and AM signal and produce its complex envelope.
- It should be configurable through different software which can be found for free.

- **Dual-channel ADC:**
  - It should have at least 8 and 16 bits of resolution, with a sampling rate of at least 96,000 complex samples per second.
  - It should offer a standard interface to the computer it's attached to, such as a sound card or USB device.

- **Software:**
  - It must be capable of processing signals obtained from the satellite, e.g. recording the satellite signal, storing, demodulation and display of the images taken from the satellite. Once the signal is received from the NOAA-N satellites, the audio tones must be converted (or demodulated) to represent varying levels of visible and infrared energy as processed by the satellite radiometer.
  - It should have a Computer display system as this is the most common method of displaying weather satellite images.
  - It must understand audio files should be used to demodulate the APT signals, convert it to image and enhance it.

- **The digital signal processor**
  - It may be a computer with an appropriate interface to the ADC.
  - It should have enough signal processing ability to record the samples in a standard format.

3.2.2 Link analysis (link budget)

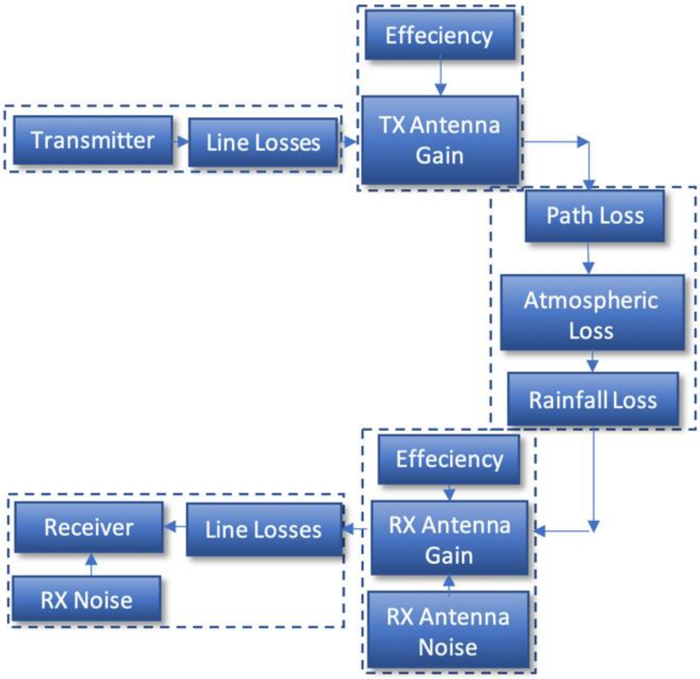


Figure 10 Link analysis

Link budget: to show the ability that the ground station can support the communication link to the satellite. It is simply stating that to know how much power we have versus how much power we need with respect to a given noise. It effects the performance of the communication system. One of the main factors is Signal-to-Noise Radio which limit the achievable performance at the receiver. To evaluate the link budget to determine the received SNR. There are many factors to link budget, in case of any major factors lacks, action must be taken to ensure that the link work properly.

SNR refer to the power of the recovered signal power to noise power, which can be used as carrier to noise ratio (CNR) for a downlink:

Friis' formula can be written as:

$$\frac{C}{No} EIRP(\lambda/4\pi r)^2 \frac{1}{lk} \frac{Gr}{Ts}$$

It is common to represent the CNR over 1 Hz of signal bandwidth (B = 1Hz), so that the resulting expression can be divided by the bandwidth to get the ratio:

$$\frac{C}{No} EIRP * \frac{1}{L} * \frac{Gr}{K * Ts}$$

- Where L is the total link losses over and above the free-space loss.
- EIRP is the product of the transmit power and transmit gain (Effective radiated isotropic power). It could be polarization loss factor, impedance mismatch loss, diffraction loss, plane-earth reflection loss.
- Gr is the receiving gain.
- *Te* is the system noise temperature and K is Boltzmann's constant:

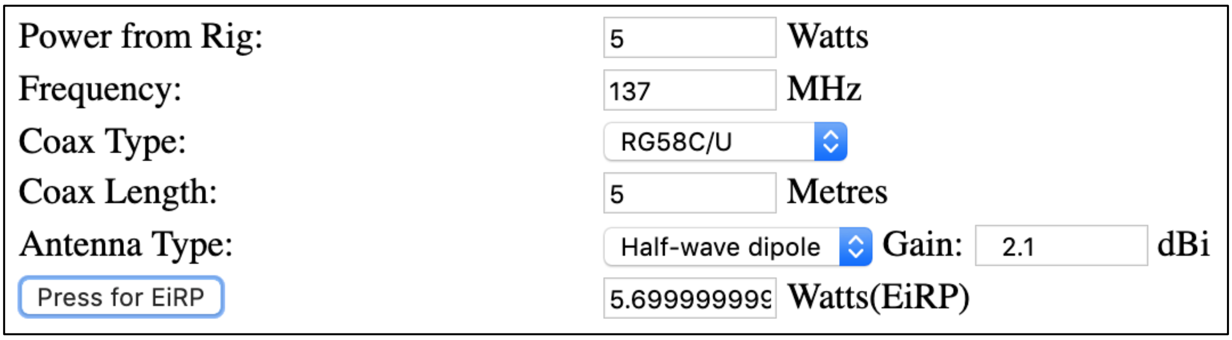


Figure 11 Calculating EiRP

Wavelength λ is calculated as:

λ = C/f

Where:

λ (Lambda) = Wavelength in meters

c = Speed of Light (299,792,458 m/s)

f = Frequency:

λ= 2,187,610m.

The free space loss:

Free Space Path Loss (FSPL) calculations are often used to help predict RF signal strength in an antenna system. Loss increases with distance, so understanding the FSPL is an essential parameter for engineers dealing with RF communications systems.

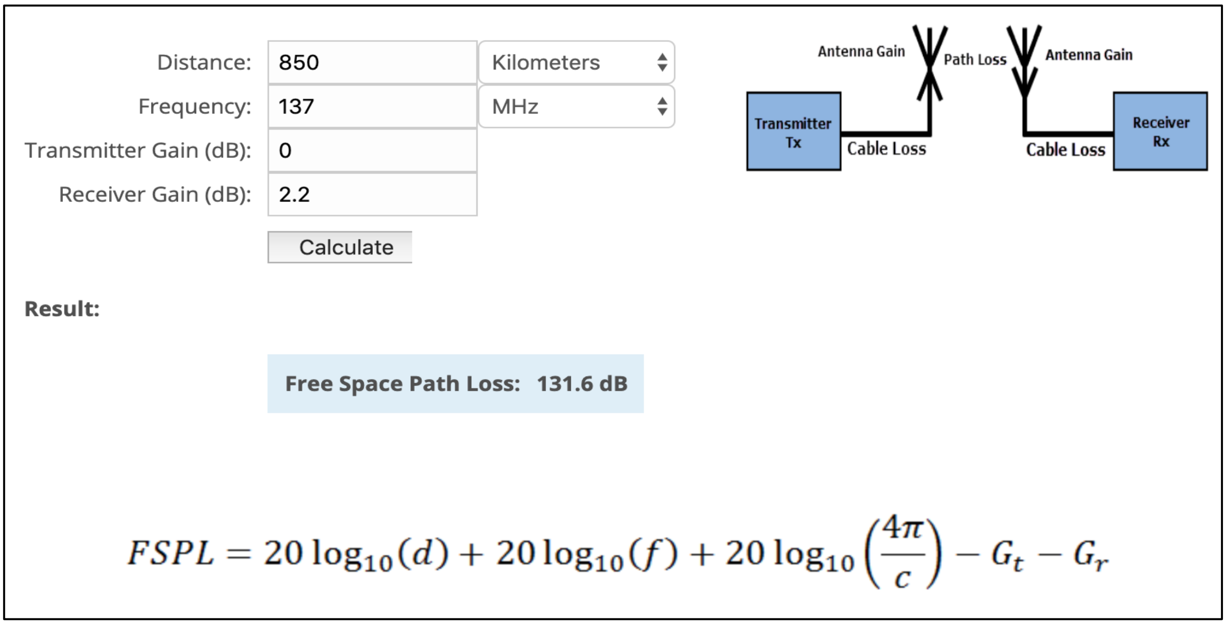


Figure 12 Free space loss

Height of the satellite from the earth:

$$L_{fs} = 20\log(4\pi * 850 * 1000) - 20\log(2.187{,}610) = 133{,}87\ dB$$

The antenna is circularly polarized with the polarization loss: L_p= 5dB and the atmospheric losses are to be L_{atm}= 0.9 dB.

$$L = (L_{fs}) + (L_p) + (L_{atm}) = 133.87 + 5 + 0.9 = 139{,}77\ dB$$

Carrier to Noise Ratio:

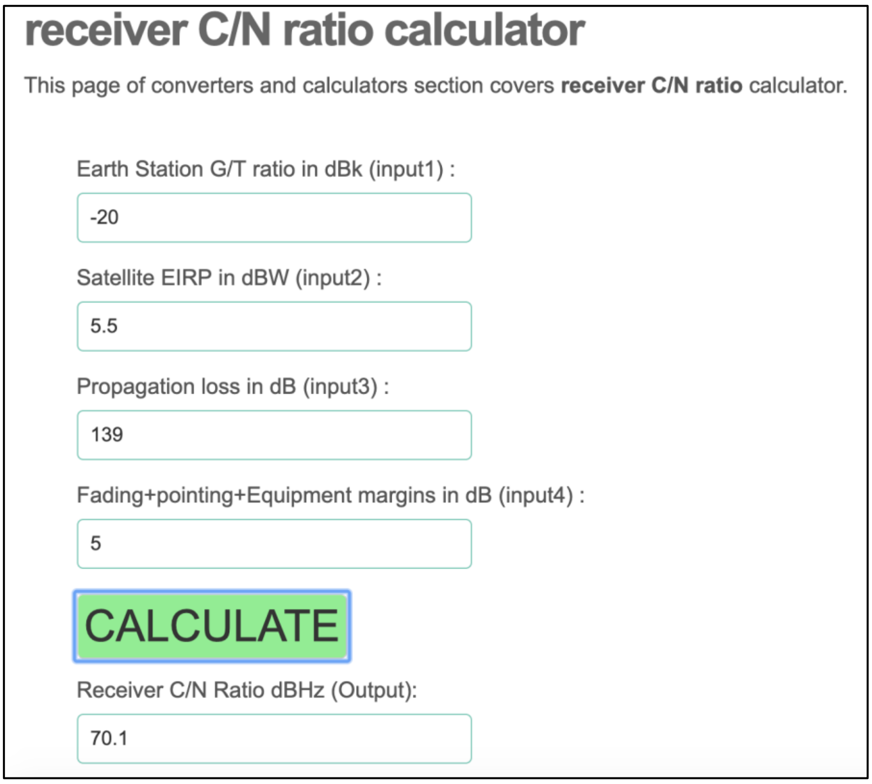


Figure 13 C/N ratio calculator

The overall result of the link analysis is optimistic and will be able to record reasonably good signals from NOAA POES weather satellites.

4 Experimental platform

The experimental platform consists of indoor and outdoor setups which are configured and installed for APT image reception. The hardware part consists of installation of antenna, cabling and LNA, and configuration of RTL-SDR dongle, while the software part consists of a number of different software capable to predict and track satellites, and signal tuning, storage, demodulation (decoding) and image processing.

All equipment, both hard- and software used in the practical implementation of this Thesis are mentioned below:

4.1 Hardware

4.1.1 Antenna system

The selected antenna for this Thesis is a tunstile antenna which is right-hand circularly polarized. The antenna is tuned to ≈ 137 MHz and designed to be both portable and easy to install. It is made from waste material (old TV antenna) found on the rooftop of the apartment building where I live in Tønsberg, and from a number of low-cost components available in the local market.

The old antenna, once used for TV reception, had long been replaced by a fibre optic cabling system and was merely left as waste. However, I used it and combined it with low cost materials as a basis for making my own antenna.

Factors affecting the design and function of the antenna:

- **Frequency band:** is the difference between the signals high and low frequencies. E.g. a signal transmitting between 50-80 MHz, has a bandwidth of 30MHz which is the operating frequency band of an antenna within which the antenna performs.
- **Polarization:** The antenna polarization is a radiated field produced by the antenna. orientation of the electric field (E-plane) of the radio wave of an antenna with respect to the earth´s surface. Circular polarization can be generated from a linearly polarized antenna by feeding the antenna by two ports with equal magnitude and with a 90˚ phase difference between them.

- **Impedance matching:** Impedance matching is the process of designing the antenna's input impedance (Zin) or matching it to the corresponding RF circuitry's output impedance, which would be 50 Ω in most cases.
- **Radiation patterns:** The strength of the energy radiated by the antenna, a graphical representation of the electromagnetic power distribution in free space which is measured in spherical coordination system (3D).
- **Directivity and Gain:** An antenna's power gain or simply "gain" is a key performance number, which combines the antenna's directivity and electrical efficiency.
- **Transmitting antenna:** The gain describes how well the antenna converts input power into radio waves headed in a specified direction.
- **Receiving antenna:** The gain describes how well the antenna converts radio waves arriving from a specified direction into electrical power.
- **Efficiency:** The total power radiated compared to the input power.
- **VSWER:** The ratio of the maximum voltage to the minimum voltage in a standing wave is known as Voltage Standing Wave Ratio.

Tunstile antenna design

The formula for calculating the approximate length of a dipole is:

- Dipole length in feet: 468 / frequency in MHz:
- Dipole length in meter: 143 / frequency in MHz:

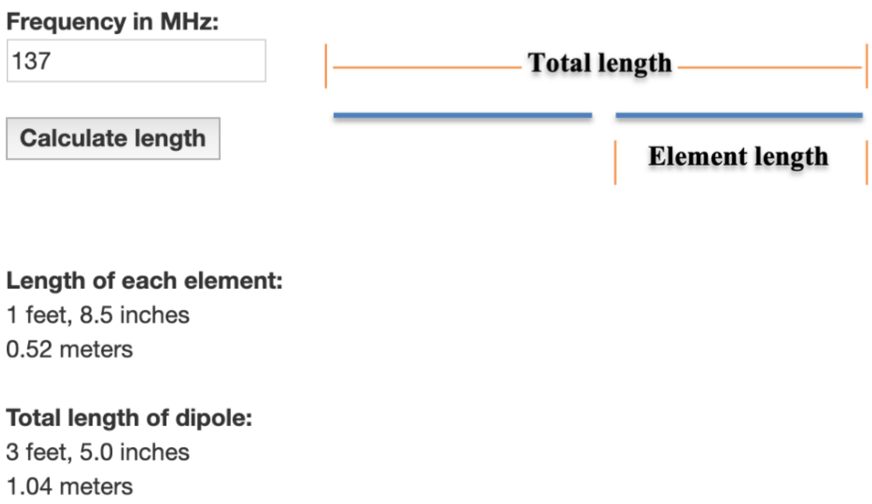


Figure 14 Shows the design estimation for building a dipole antenna

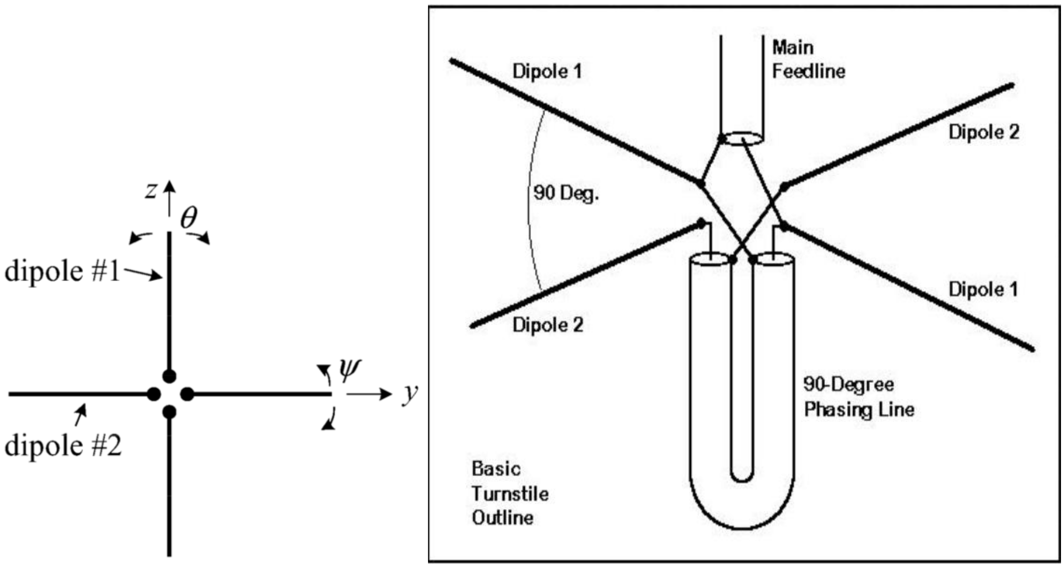


Figure 15 Shows the basic geometry of a single Tunstile antenna[36]

Antenna radiation pattern:

A Tunstile antenna or crossed-dipole antenna, is a radio antenna consisting of a set of two pair of identical dipoles, antenna mounted at right angles to each other and fed its phase quadrature with the same amount of current. By combing two bays of half wavelength to each other and they are existed in phase to modify their radiation pattern. The tunstile antenna is omnidirectional and circularly polarized. It produces an isotropic pattern in the dipoles plane (θ-plane) of linearly (along θ') polarized wave. In all other directions, the wave is elliptically polarized that works in VHF and UHF band and mostly used for Satellite communication.

The vertical radiation pattern is modified which results in cancelling some of the horizontal radiation. This results in a decrease in energy radiated at high vertical angles and increases the energy radiated in the horizontal plane, causing a significant gain in a horizontal direction without altering the overall horizontal directivity pattern.

[36] E.S. Pires, P.I.L. Ferreira, G. Fontgalland, M.A.B. de Melo, R.M. Valle & T.P. Vuong (2008). Design of a UWB Antenna for Sensor and Wireless Systems Applications. IEEE Xplore. DOI: 10.1109/ICUWB.2008.4653446. Vol. 3 p. 186

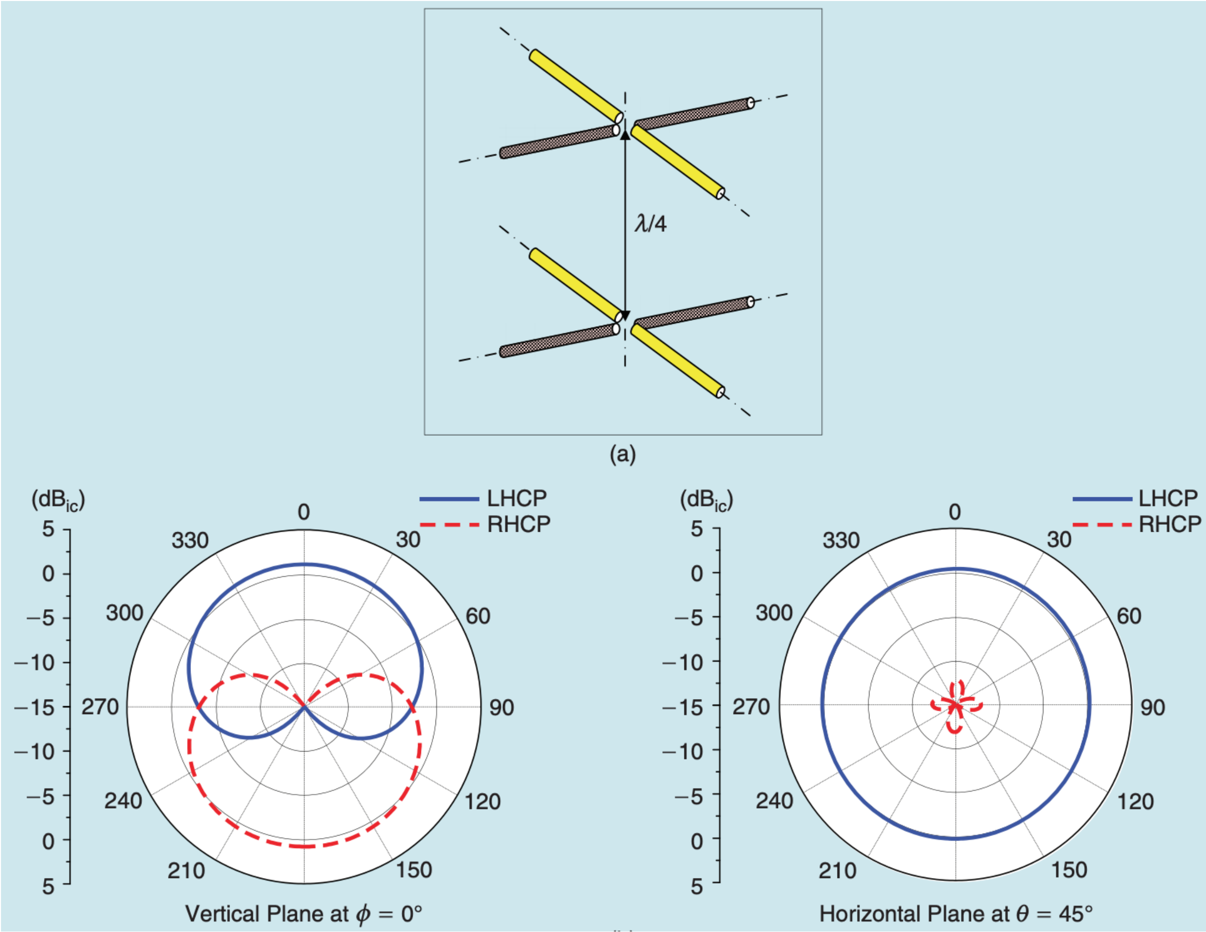


Figure 16 Radiation pattern of the tunstile antenna[37]

Two pair of dipoles:

Each set of parallel elements constitute a two-element, with the top element being the driven element and the bottom element being the reflector, so a tunstile might just be two crossed dipoles, but adding the (slightly longer) reflectors below provides an upwards gain and a corresponding suppression of unwanted signals coming in horizontally.

[37] Son Xuat Ta, R.W. Ziolkowski & Ikomo Park (2015). Crossed Dipole Antennas: A Review. IEEE Antennas and Propagation Magazine. October, 2015. DOI: 10.1109/MAP.2015.2470680. p. 110.

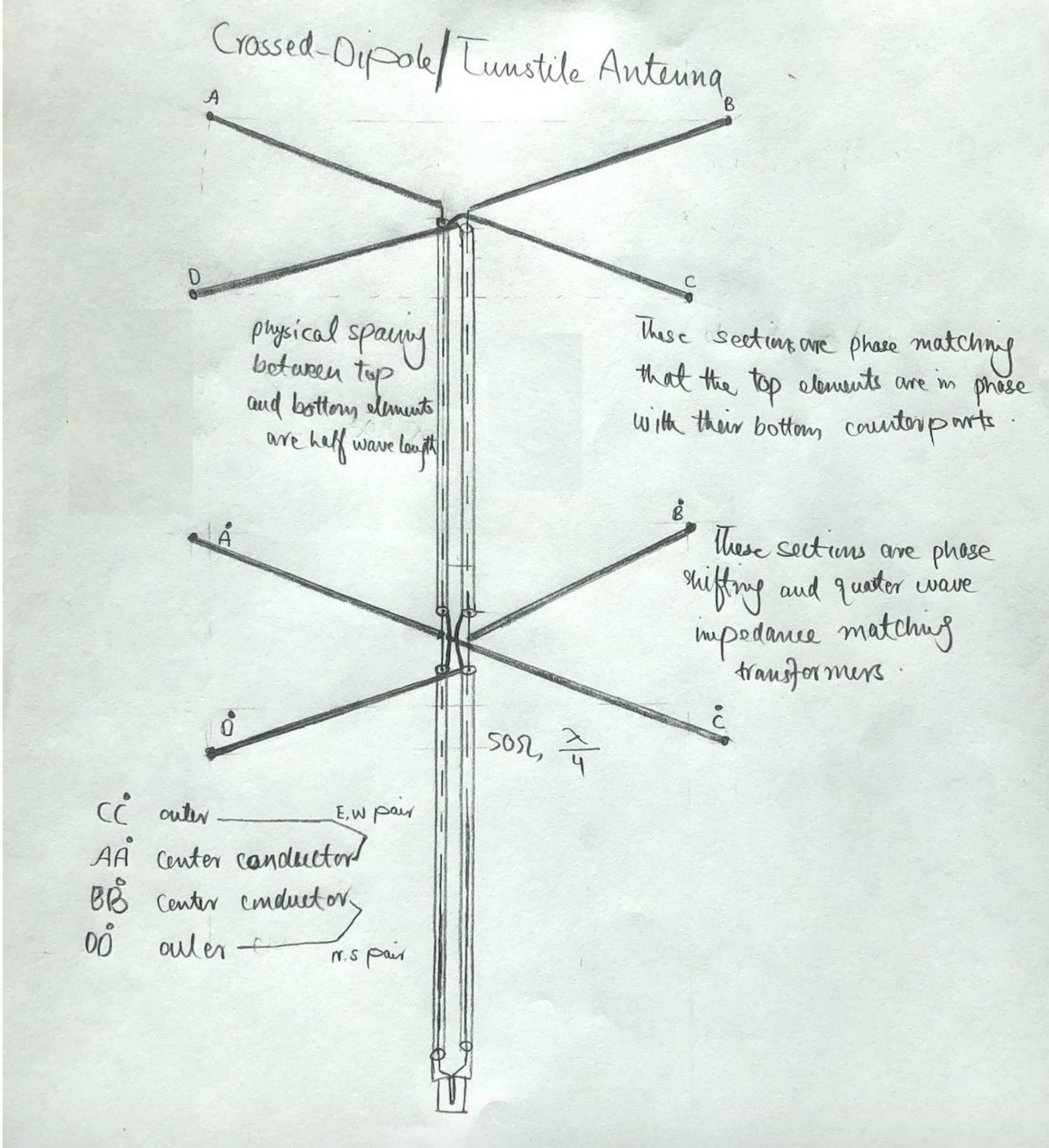


Figure 17 Crossed dipole / Tunstile antenna design

Table 7 Antenna specifications

Antenna Type	Crossed-Dipole / Tunstile Antenna
Frequency	≈ 137 MHz
Impedance	50 Ω
Polarization	Right hand circularly polarized in vertical direction
Bandwidth	40 KHz to 16 MHz
SWR	≤1.3
Max. Rx Power	27 dBm
Connectors	SMA female and female cables and adaptors
Total Height	Approx. 1m
Total Weight	Approx. 1kg

Tunstile antenna Technical description:

- The antenna is built from waste materials and a few other low-cost components.
- The four rod which are used for dipoles are connected to each other with the coax-cable configuration with 90 degree to each other.
- The total length of the dipole is approximately 1 meter while each its element is 0.51 meters.
- The length of the rods is determined by the frequency range used which is 137 MHz band the calculation is shown in the formula above.
- A dipole is in total ½ wavelength, with each element being ¼ wavelength.
- The antenna is optimized for weather image reception from orbiting weather satellites like the NOAA-N series and other weather satellites in the frequency range of VHF and UHF, ideally ≈137 MHz band.
- The antenna work in axial-mode, which receives signal at right-hand circularly polarized corresponding to the satellite transmission.
- Linear, horizontal polarization (top dipole pair) in the horizontal-plane for man-made interference suppression.
- Reflector (bottom dipole pair), to create a directional characteristic for fading suppression, caused by multipath propagation due to ground reflections.
- The antenna with reflector is ideal for receiving right-hand circular polarization when the satellite is directly overhead and has an omni-directional, horizontally polarized pattern for signals arriving parallel to the ground.
- The two dipoles are 90˚ apart and are fed with equal amount of current in phase quadrature.

Figure 18 Equipment necessary to build the antenna

A construction model for the design for the tunstile antenna was selected after repeated tests and experiments. The diameter and length of the dipoles influenced the reception quality. The wavelength determined greater reception power of the signals received. Together, these factors decided the level of stability in the connection between the ground station and the satellites.

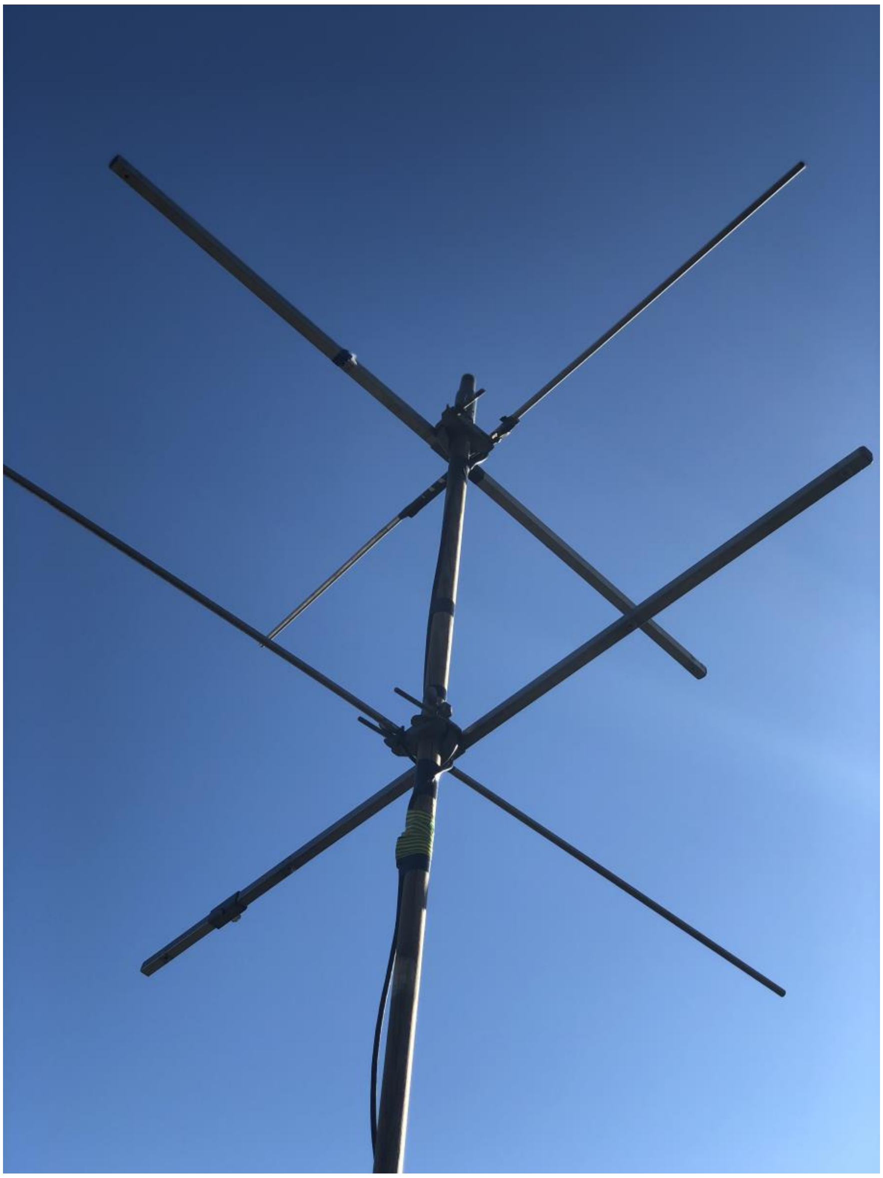


Figure 19 Final design of the tunstile antenna

4.1.2 Low Noise Amplifier (LNA):

The LNA used in this Thesis is a LNA4HF model which is easily commercially available and commonly used by satellite hobbyist and students. The chosen LNA has the following specifications:

- Less than 1 dB nominal noise figure.
- 23 dB gain offered at 137 MHz.
- Female SMA connectors on the input and output for easy connectivity.
- Quad mounting holes for variety of installations options.
- Powered via bias-T, 3.0 – 5VDC. Low current consumption requirements of 35 mA (max).

Figure 20 LNA4HF

4.1.3 RTL-SDR Dongle:

A software defined radio used for VHF/UHF satellite signals reception and can be used for many other practical projects. It has many high-quality band-pass filters and an integrated LNA. Modulation process take place at the RTL2832U with 8-bits and available as a USB dongle.

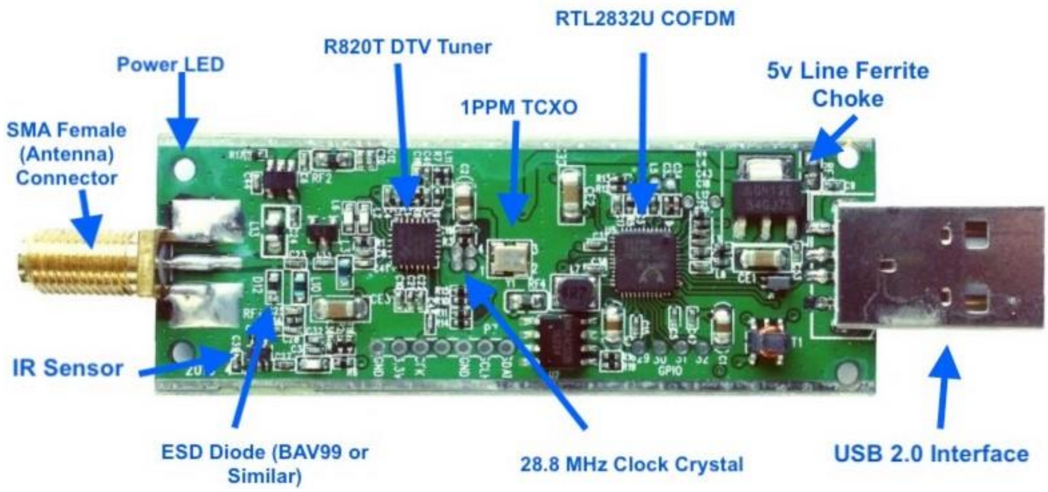


Figure 21 RTL-SDR Dongle inner structure[38]

[38] Adjusted from a photo from RTL-SDR.com (2016). NEW RTL-SDR BLOG UNITS NOW AVAILABLE IN STORE: (RTL2832U). Available: https://www.rtl-sdr.com/new-rtl-sdr-blog-units-now-available-in-store-hf-via-direct-sampling-software-switchable-bias-tee-less-noisespurs/ [Accessed: 07.11.2018]

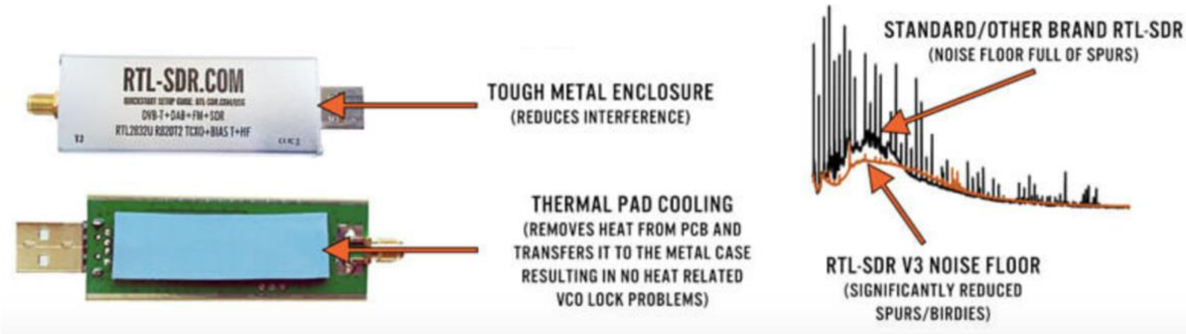


Figure 22 RTL-SDR Dongle outer structure[39]

One of the best value RTL-SDR currently available on the commercial market has been used for this Thesis, with several improvements over generic brands, including:

- Rafael Micro R820T2 tuner with the following components on its chip: LNA, Mixer, Fractional PLL, VGA and LDO
- 1 PPM temperature compensated oscillator (TCXO)
- SMA F connector, with a passive cooling aluminium case
- Software switchable bias-T circuit
- Additional ESD protection
- Lower overall noise and built in direct sampling for HF reception.

Some of the basic specifications of the RTL-SDR dongle used for this Thesis are as follows:

Table 8 Basic specifications of the RTL-SDR dongle

USB interface	RTL2832U
Tuner Chip	Rafael Micro R820T
Bandwidth	Up to 2.4 MHz stable (without loss)
ADC	RTL2832U 8-bits resolutions
Frequency range	24 MHz – 1700 MHz
Typical input impedance	Up to 72 Ohms
Typical current draw	270 – 280 mA

[39] RTL-SDR.com (2016). BUY RTL-SDR DONGLES (RTL2832U). Available: https://www.rtl-sdr.com/buy-rtl-sdr-dvb-t-dongles/ [Accessed: 07.11.2018]

4.1.4 Computer system:

A reasonably strong and up-to-date computer. The sound card is the ADC demodulating interface, together with other software explained in the software section below are used to view the processed and decoded images. The computer should ideally have a newer version of Windows operating systems.

4.2 Software:

Together with hardware, software is critical to setting up a ground station for weather satellite image reception at VHF band. The structure, function and configuration of hardware for ground station are explained above.

Software is needed to process the signal received from the satellite, e.g. recording the satellite signal, storing, demodulation and display of the images taken from the satellite. Once the signal is received from the NOAA satellites, the audio tones must be converted (or demodulated) to represent varying levels of visible and infrared energy as processed by the satellite radiometer. Computers are the most common method of displaying weather satellite images.

4.2.1 Tracking and predicting the satellite:

Different tracking software exist, such as Orbitron and WXtrack, which have been developed for users to follow or track any satellite of interest. These software give information about the speed of satellites, their position in the sky, frequency, altitude, elevation angle, azimuth, and distance from the ground station. In order to receive APT video using direct reception, accurate information concerning location, movement and the exact times that the satellites can be received in any given area (for this Thesis: Tønsberg), is required. This is necessary as signal reception is only possible while the satellites are above the ground station's horizon. Different software used for tracking and predicting the NOAA satellites in this Thesis are Orbitron and WXtrack, but also the N2YO website.

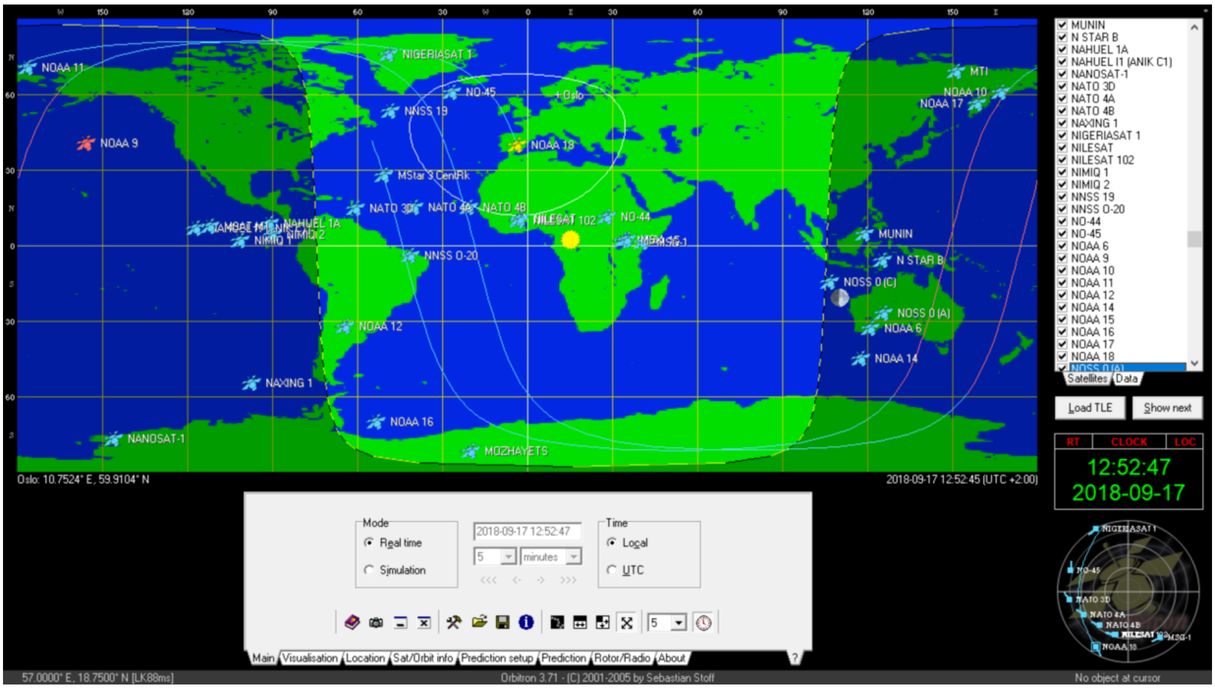


Figure 23 Screenshot using Orbitron software

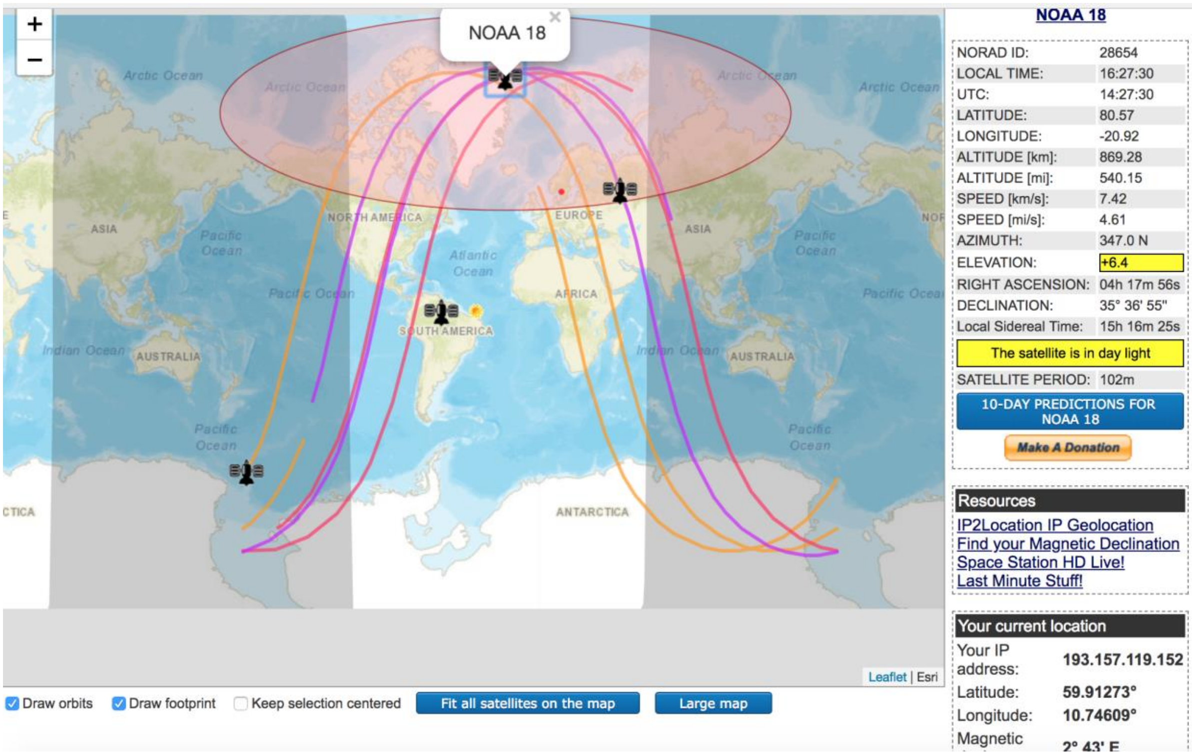


Figure 24 Screenshot using N2YO website

4.2.2 SDR# software:

SDR# is currently one of the most common SDR software used with the RTL-SDR. It's easy to set up and use. It should be noted that the RTL-SDR dongle is not a plug-and-play device as it needs to be installed. Its functionality is explained in greater detail in practical section, but here is a simple snapshot on how it looks.[40]

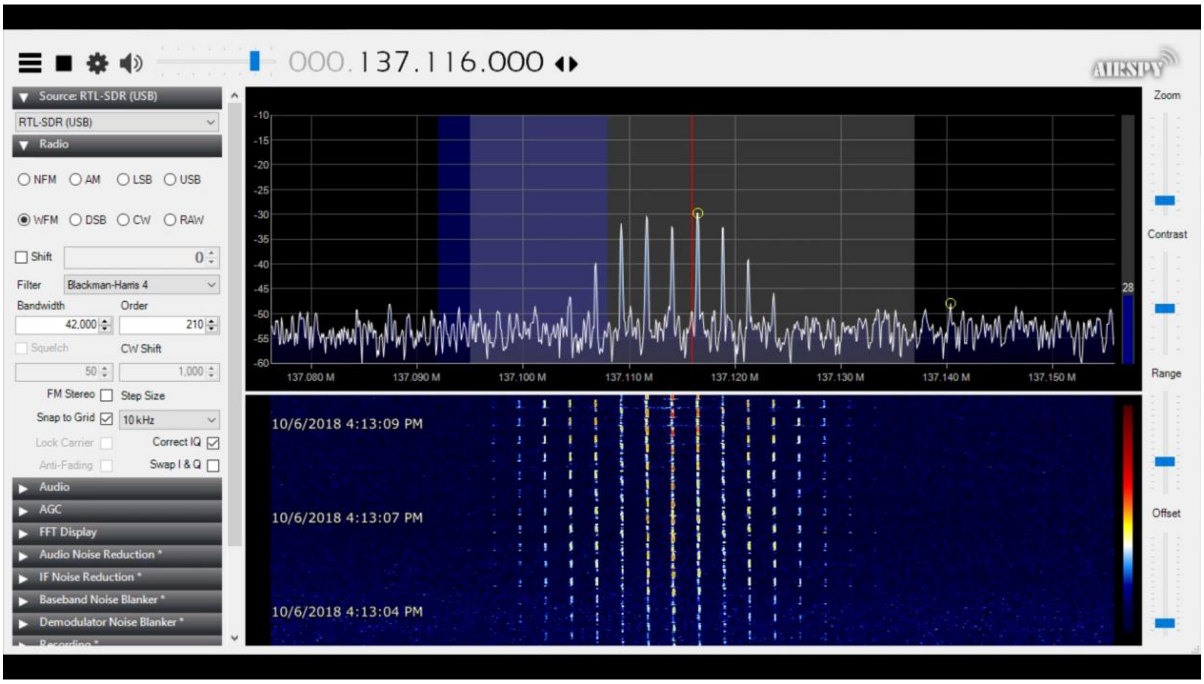


Figure 25 Screenshot using SDR# software

40 For more details: https://www.rtl-sdr.com/rtl-sdr-quick-start-guide/

4.2.3 WXtoImg:

An open source weather satellite software used to decode APT signals, and inform about the times and frequencies of when NOAA satellites are passing overhead. It automatically predicts and track NOAA satellites. After updating the Kepler's data, it records, auto process audio and raw image file, and convert it to a real-time image.

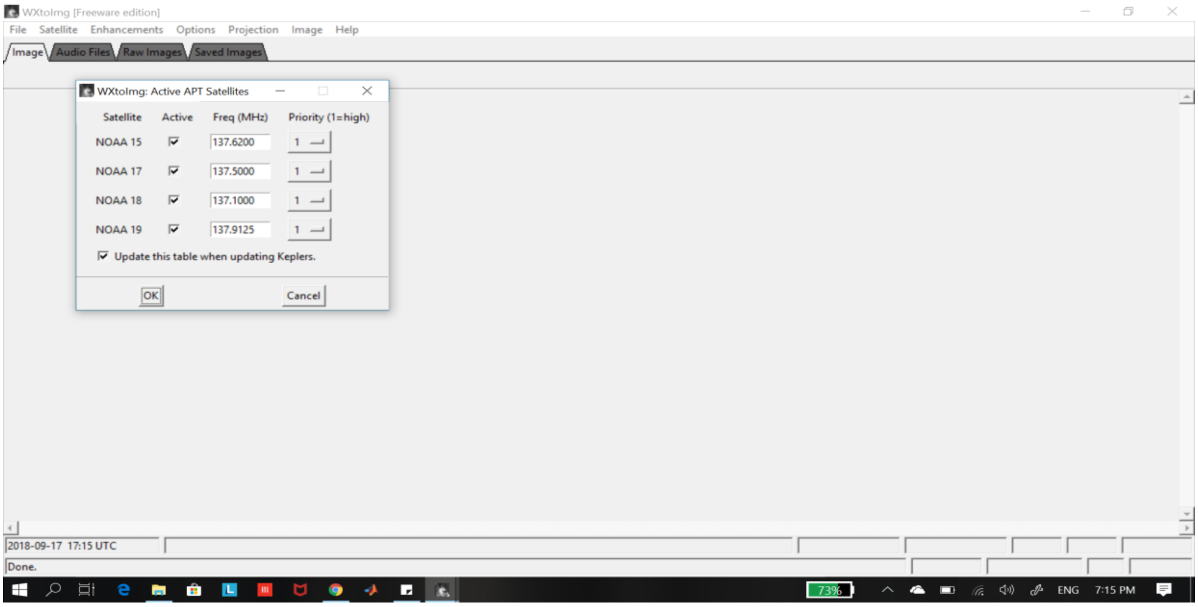


Figure 26 Screenshot using WXtolmg software

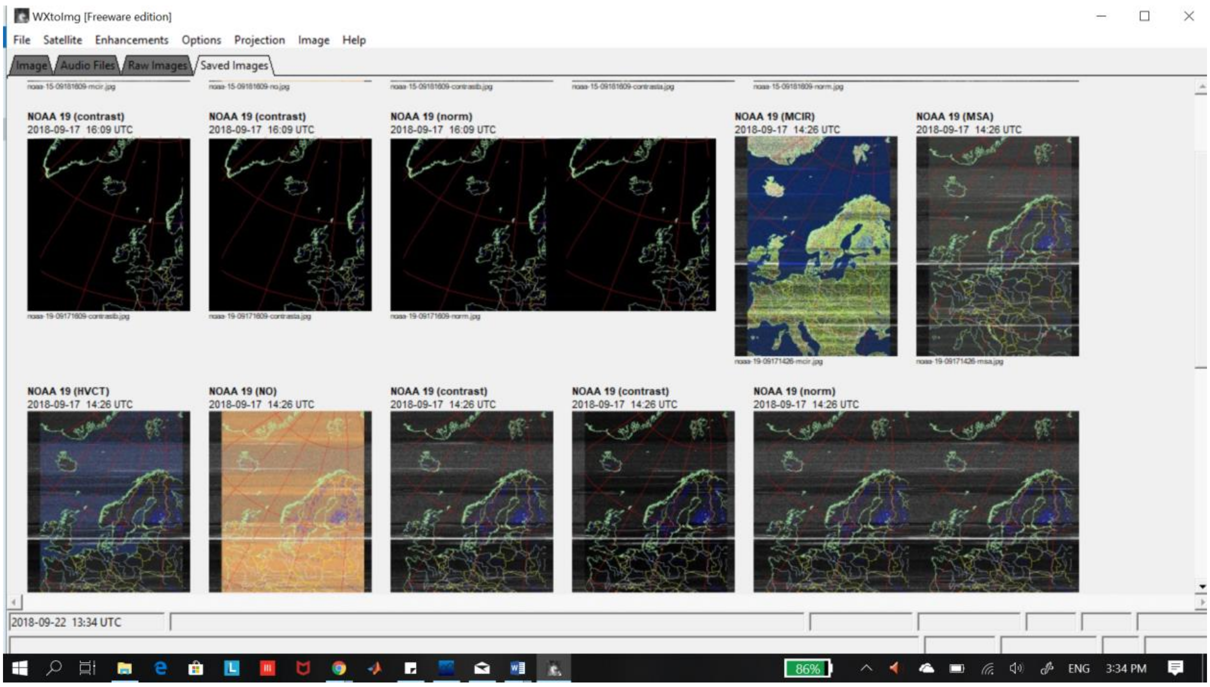


Figure 27 Screenshot using WXtoImg software

Using WXtoImg and SDR# together make a good combination, as SDR# records audio files and WXtoImg decodes and converts audio files into image which can be seen in the following image.

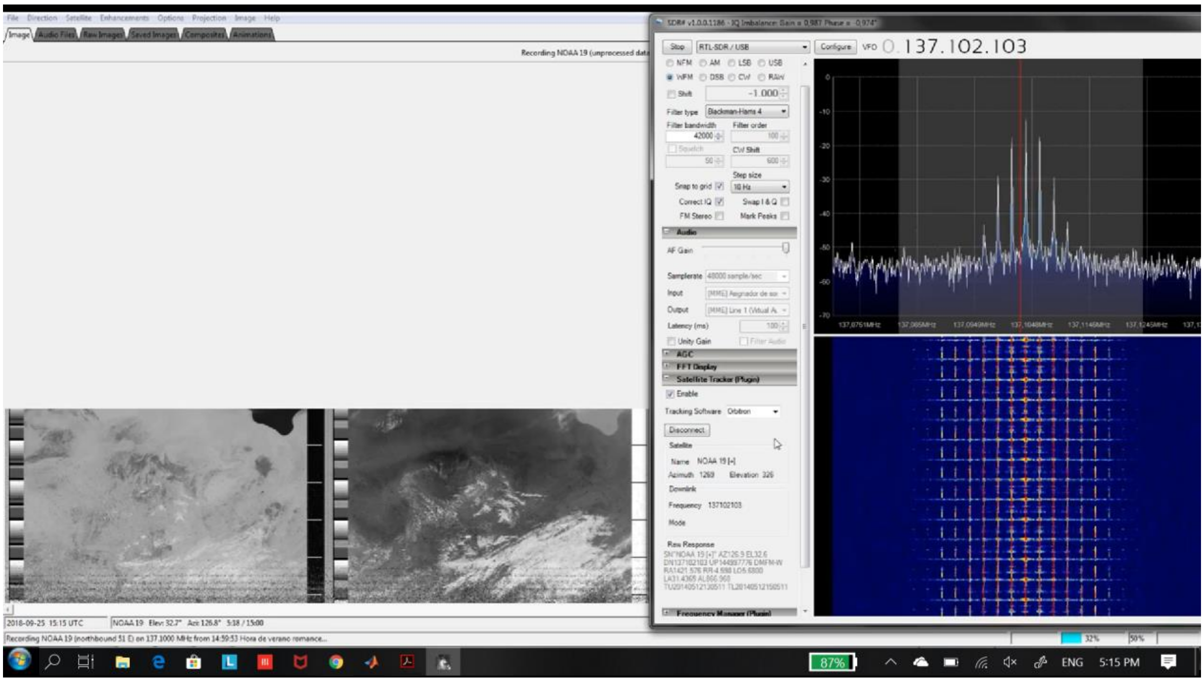


Figure 28 Screenshot using WXtolmg and SDR# software

4.2.4 MATLAB-Simulink:

MATLAB is a technical computing language used mainly by scientists, engineers, students and practitioners. RTL-SDR can be used to acquire and sample RF signals transmitted in the frequency range 25 MHZ to 1.7 GHz. MATLAB-Simulink can be used to program receivers using first principles DSP algorithms. Signals that RTL-SDR hardware can receive include: FM and DAB radio, VHF and UHF signal bands, GSM signals, 3G and LTE mobile radio, and GPS and satellite signals. MATLAB alongside RTL-SDR is used in this Thesis to process and demodulate signals in practical sense. Audio files recorded through SDR# are decoded to images in MATLAB. The following figure shows the audio file being processed in frequency and time domain.[41]

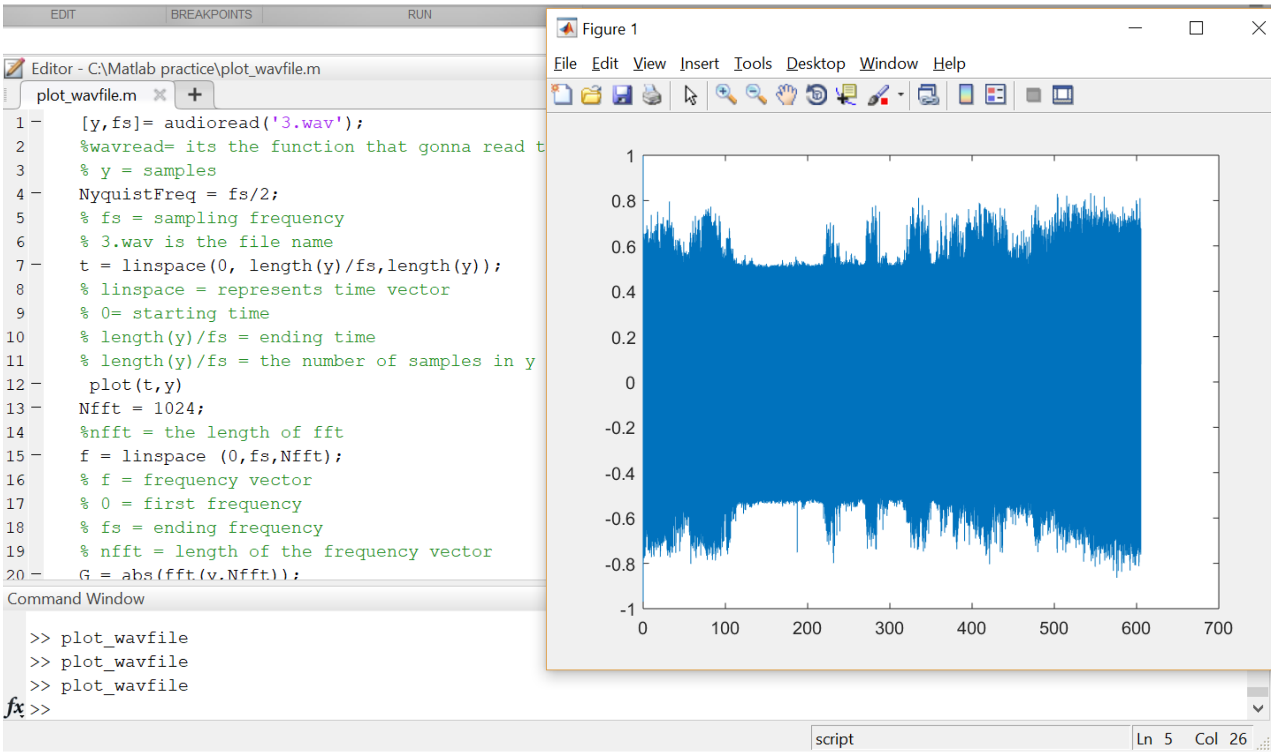


Figure 29 Screenshot using MATLAB

[41] RTL-SDR (2018). Software defined radio for engineers: Free university level text book with PlutoSDR examples. Available: https://www.rtl-sdr.com/tag/matlab/ [Accessed: 01.12.2018]

5 Setting up a ground station:

5.1 Ground station configuration block model

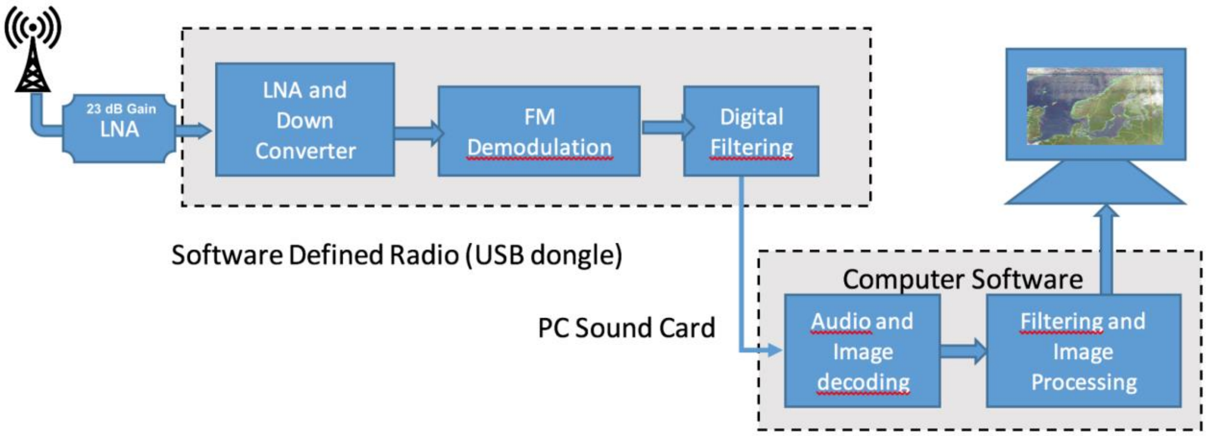


Figure 30 Configuration / Architecture of ground station block model

The architecture of the ground station that was built as part of this Thesis includes the following components:

- Tunstile antenna designed to be portable and easily deployable and tuned to ≈137 MHz. The antenna is homemade and built from waste materials, including old TV antennas, and inexpensive commercial components that are easily available in the market. Two different antennas were constructed to see which are able to receive the best images.
- LNA based on the Mini-Circuits PSA4-5043+ MMIC amplifier. It offers a gain of 23.5 dB at ≈137 MHz, with a theoretical noise figure of less than 1 dB. It can be powered by a 6 to 9-volt battery or by a bias-T power connection from the RF front- end (RTL-SDR dongle).
- RTL-SDR dongle has been chosen as the RF front-end (receiver), which is a software-defined radio configured specifically for the reception of VHF band satellite signals. The RTL-SDR is a quadrature front-end with multiple high-quality band-pass filters and an integrated LNA. The noise figure at ≈137 MHz is 3.5 dB. It integrates an ADC at 192,000 complex samples per second at 16 bits per sample and is used as USB interface.

- The digital signal processor used is simply a general-purpose laptop computer. Any modern computer is able to handle the sampling rate produced by the front end easily.
- Different Software were installed and configured on the laptop. These are used for all the tasks involved, from predicting and tracking specific satellites, to recording and processing received signals, converting them to images, and to enhance the images received.
- Virtual audio cabling is done to connect SDR# software to the WXtoImg software that decodes signals to images.

5.2 APT Signal processing and image recovery

Active NOAA satellites (15, 18 and 19) were tracked in 137 - 138 MHz band using the ground station developed as part of this Thesis. The technical and practical detail of different processes performed in the ground station, such as satellites tracking, frequency tuning to 137 MHz band, signal receiving, and image recovery are all explained in the following sections:

5.2.1 Structure and frame format:

The APT automatic analog picture transmission system used is designed to produce real time video images that are received and decoded by the low-cost ground station. The data stream is produced by amplitude modulating a 2400 Hz sub-carrier with the 8 most significant bits out of the 10 bits of AVHRR data extracted for each word within the two selected channels, which are then multiplexed. AVHRR rate is approximately 360 lines per minute for still images, and 120 lines of video per minute (or 128 lines per 64 second telemetry frame).

A visible channel is used to provide visible APT imagery during daylight, and one IR channel is used constantly (day and night). During the process of getting APT signals, the system inserts calibration and telemetry information that results in the APT structural format shown in the image below, while using WXtoImg software.[42] [43]

[42] NOAA (2009). User's Guide for Building and Operating Environmental Satellite Receiving Stations. p.8-9. Available: https://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf: [Accessed: 09.11.2018]
[43] A. Stampfl & W.G. Stroud (1963) NASA. Goddard Space Center. NASA Technical Note: TN D- 1915. The Automatic Picture Transformation (APT). p.3.

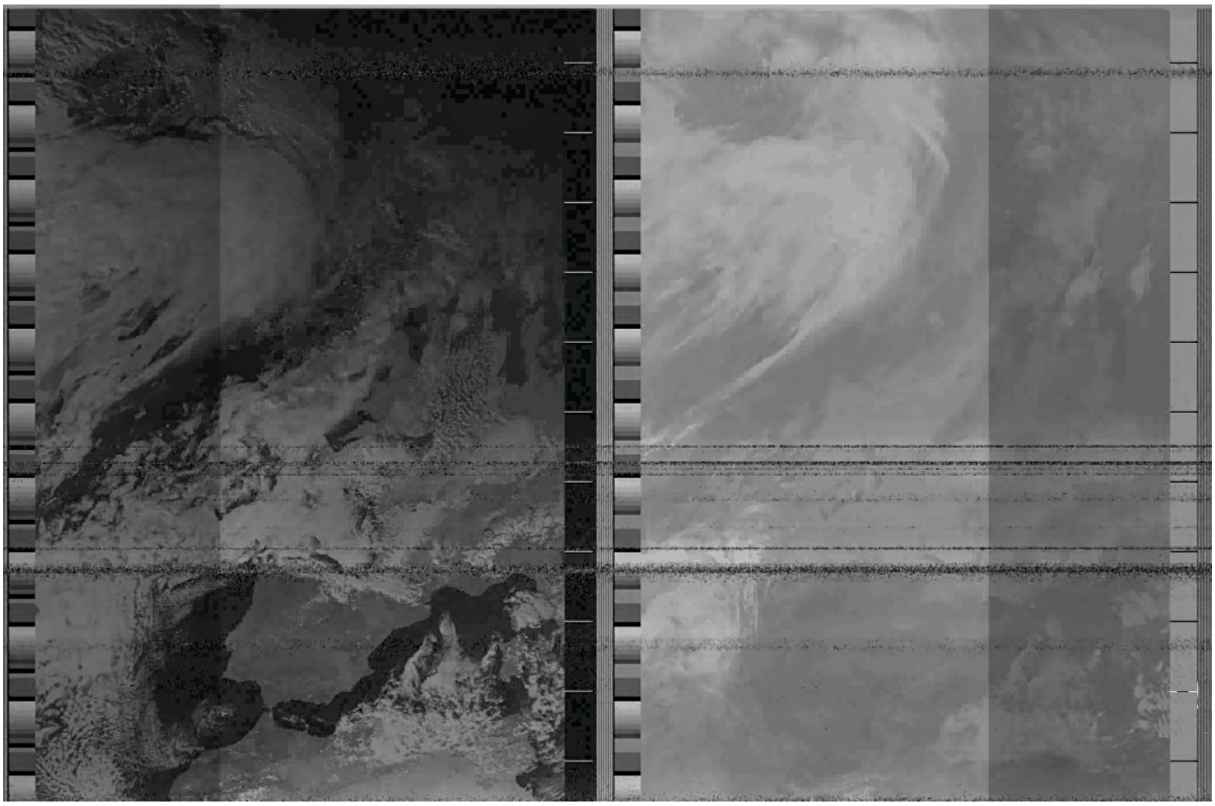


Figure 31 Screenshot using WXtolmg software

Broadcasted transmissions are made of two channels for the image:

- Synchronization
- Telemetry information

A complete APT Video Line Time is 2080 pixels long (990 pixels for each image). One APT line is composed of one line for Channel A video followed by one line for Channel B video.[44]

Telemetry frame:

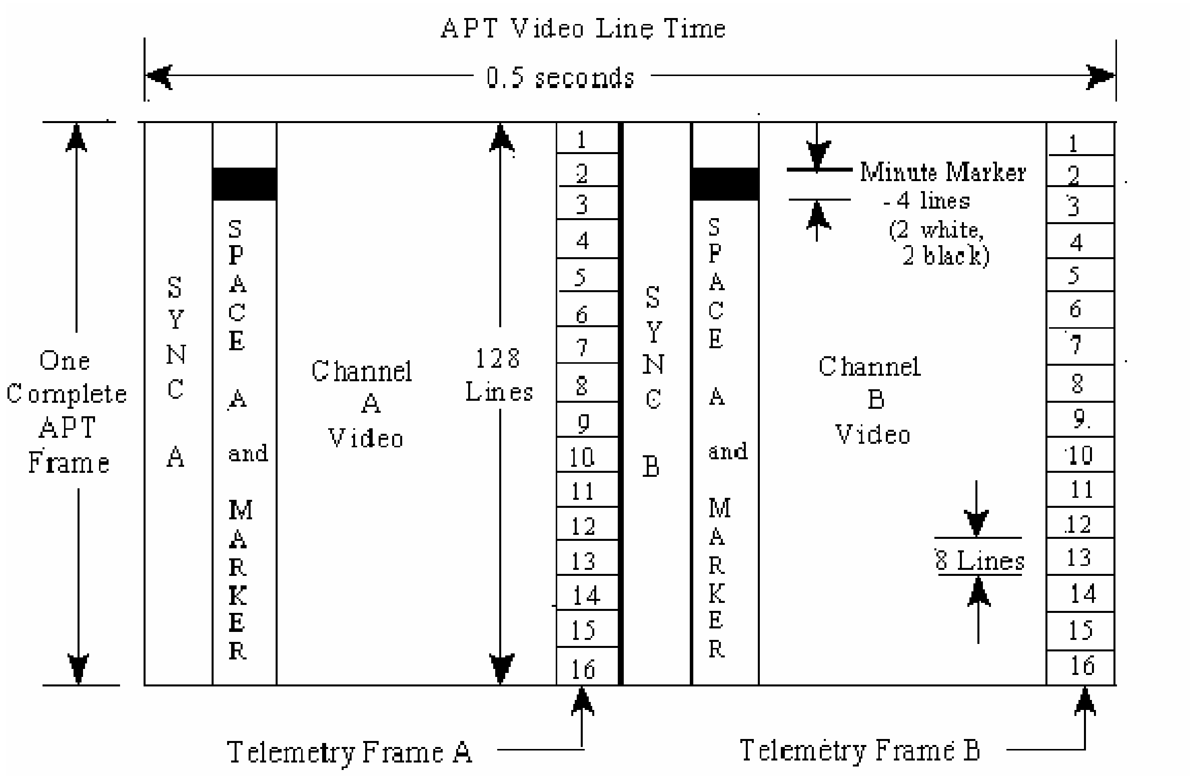
- Video channels A and B have their own telemetry frame
- Every telemetry frame consists of 16 points (wedges): height of 128 video lines
- Telemetry frame rates are 1 frame per 64 seconds (just above one minute)
- Every telemetry point is repeated on 8 successive APT lines

Space and minute marker:

- Time between two successive markers is one minute

[44] Institut Supérieur de l'Aéronautique et de l'Espace (ISAE). Radio Logicielle pour la Formation (RALF). 2.2.2 APT Frame format (2015). Available: https://sourceforge.isae.fr/projects/weather-images-of-noaa-satellites/wiki/Apt_ [Accessed: 09.08.2018]

- Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white
- B video is always an IR channel (Ch. 4 usually), so spaces are white and minute markers black
- When A Video is a visible channel, spaces are black and minute markers white; otherwise it appears like B video



WEDGE #1 1	WEDGE #2 2	WEDGE #3 3	WEDGE #4 4	WEDGE #5 5	WEDGE #6 6	WEDGE #7 7	WEDGE #8 8
Zero Modulation Reference 9	Thermistor Temp. #1 10	Thermistor Temp. #2 11	Thermistor Temp. #3 12	Thermistor Temp. #4 13	Patch Temp. 14	Back Scan 15	Channel I.D. Wedge 16

Notes:
1) Each telemetry frames consists of 16 points
2) Telemetry frame rate is 1 frame per 84 seconds
3) Each telemetry point is repeated on 8 successive APT video lines

Figure 32 ATP Frame Format[45]

[45] NOAA (2009). User's Guide for Building and Operating Environmental Satellite Receiving Stations. Figure IV-7 APT Frame Format, p. 40. Available: https://noaasis.noaa.gov/NOAASIS/pubs/Users_Guide-Building_Receive_Stations_March_2009.pdf: [Accessed: 09.09.2018].

In the figure above, we can see an example of how APT frame images are received. Each line is 0.5 seconds in length and contains two equal 0.25 seconds of the first channel (visible or IR) and 0.25 seconds of a second channel (IR).

Each 0.25 seconds segment contains:

- A specific sync pulses.
- Space data with 1-minute timing inserts.
- Earth scan imagery from a selected AVHRR channel.
- A telemetry frame segment

5.2.2 APT Transmission Characteristics:

Table 9 APT transmission characteristics

Line Rate	120 Lines per minute
Data Channels	2 transmitted, 6 available
Data Resolution	4.0 km
Carrier Modulation	2.4 KHz AM subcarrier on FM carrier
Transmitter Frequency (MHz)	137MHz - 138 MHz
Transmission Power (EOL)	5 watts (37 dBm)
Radiated Power (dBm, @ 63 degrees)	36.7
Polarization	RCP

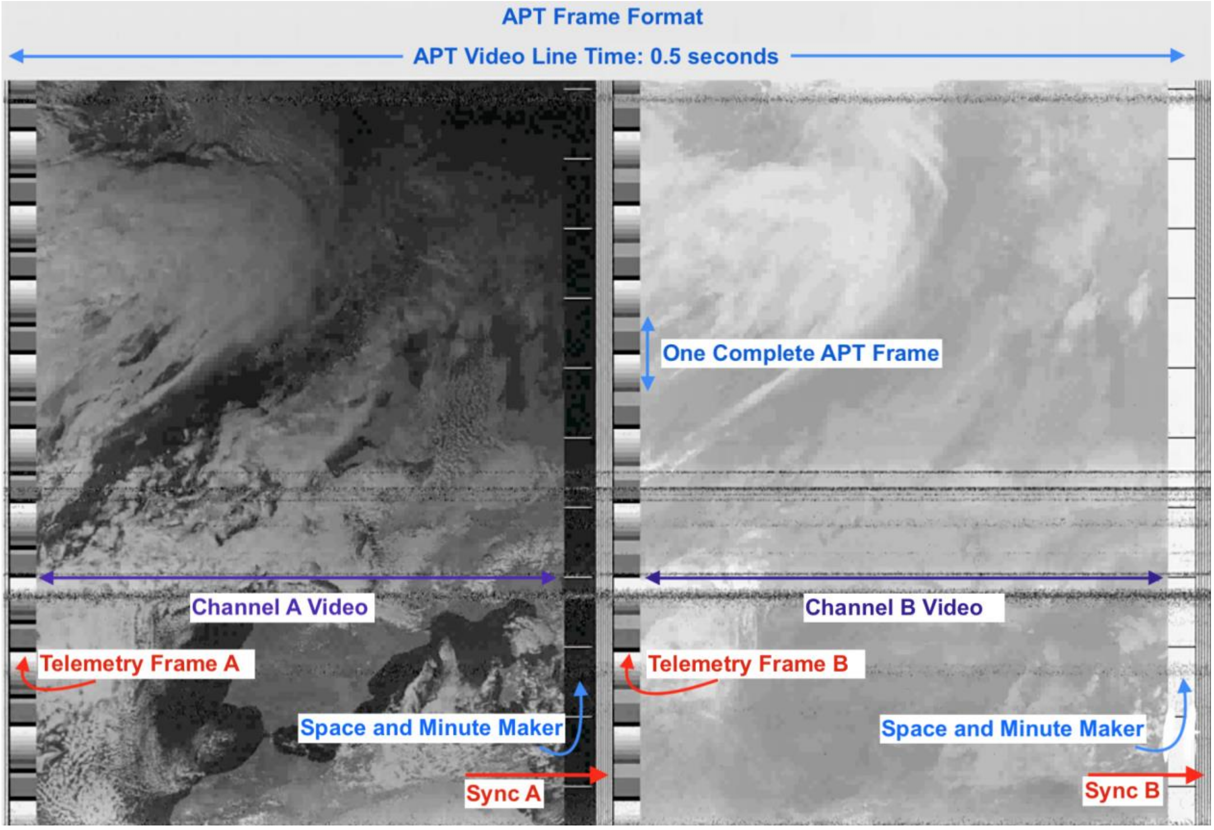


Figure 33 Screenshot with explanations

5.2.3 APT format Parameters:

Table 10 APT format parameters

Frame Parameters	Rate	1 frame per 64 seconds
	Length	128 lines
	Format	Explained above
Line Parameters	Number of sensor channels	2
	Number of words/sensors	909
	Number of words	2080
	Format	Can be found in the above figure
	Rate	2 lines per second
	Line sync format	Can be found in the above figure
Word Parameters	Digital to analog conversion accuracy	8 MSB´s of each 10-bit word
	Rate	4160 words per second

5.2.4 Image Coding:

On NOAA POES satellites, the two images are 4 km / pixel smoothed 8-bit images derived from Channel A and B of the AVHRR sensor. The images are corrected for nearly constant geometric resolution prior to being broadcast. The images are free of distortion caused by the curvature of the Earth.[46]

One of two images is typically long-wave infrared (10.8 μm) with the second switching between near-visible (0.86 μm) and mid-wave infrared (3.75 μm) depending on whether the ground is illuminated by sunlight or not. NOAA can configure its satellites to transmit any two of the AVHRR's image channels.[47] See Image under 5.2.5.

5.2.5 Telemetry information and Synchronization:

There are series of telemetry information, minute makers and synchronization pulses. The synchronization information, transmitted at the start of each video channel, allows the receiving software to align its sampling with the baud rate of the signal, which can vary slightly over time. The minute markers are four lines of alternating black then white lines which repeat every 60 seconds (120 lines).

The telemetry section is made of sixteen blocks, each 8 lines long, which are used as reference values to decode the image channels. The first eight blocks, called "wedges," begin at 1/8 max intensity and successively increase by 1/8 to full intensity in the eighth wedge, with the ninth being zero intensity. Blocks ten through fifteen each encode a calibration value for the sensor. The sixteenth block identifies which sensor channel was used for the preceding image channel by matching the intensity of one of the wedges one through six. Video channel A typically matches either wedge two or three, channel B matches wedge four.

The first fourteen blocks should be identical for both channels. The sixteen telemetry blocks repeat every 128 lines, and these 128 lines are referred to as a frame.

---

[46] E. Delpech & B. Quemin (2013). IMT Atlantique, ISAE and INP ENSEEIHT. Reception of NOAA Images. p. 14.
[47] E. Delpech & B. Quemin (2013). IMT Atlantique, ISAE and INP ENSEEIHT. Reception of NOAA Images. p. 13.

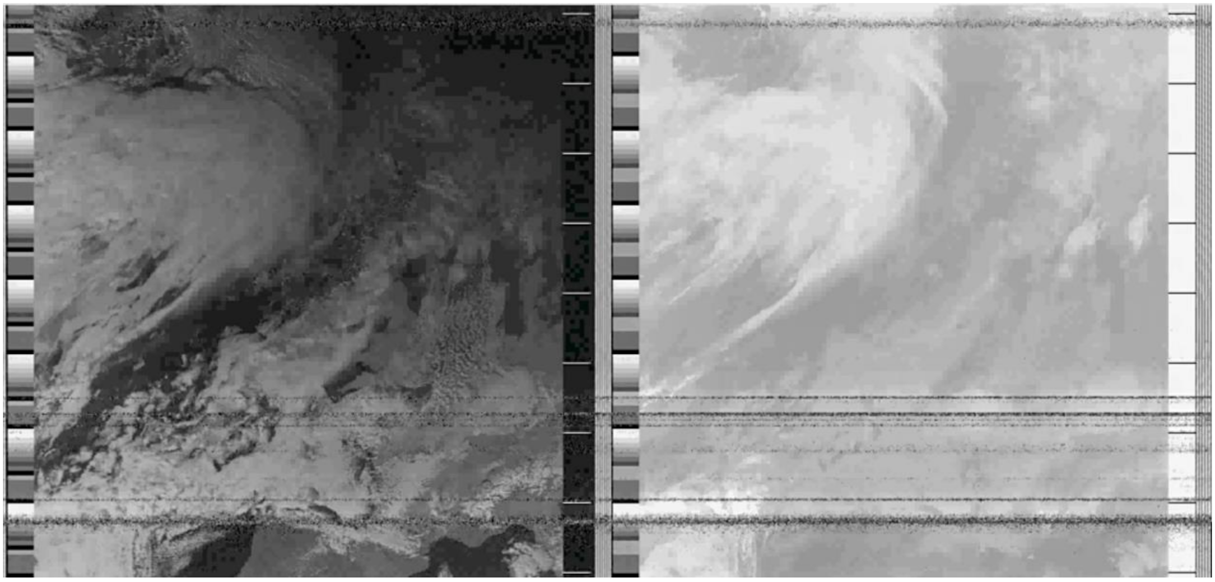


Figure 34 Using WXtoImg software

5.2.6 Broadcast signal:

The signal is a 256-level amplitude modulated 2400 Hz subcarrier, which is frequency modulated onto the ≈137 MHz-band RF carrier. Overall RF bandwidth is 34 KHz. NOAA POES satellites broadcasts signals at approximately 37dBm (5 watts) effective radiated power.[48]

During daytime passes, the APT format shows the visible data and IR data. During night-time passes, ground control stations may command satellites to insert data from another IR channel to replace the visible channel, as the visible channel data would appear all black during a night-time pass. The two IR channels would sample slightly different spectral bands, and thus would appear different from each other.[49]

This signal broadcasted by the satellite is tuned by the SDR# software with VHF frequency band. This section can be merged with the tuning the frequency band.

5.2.7 Broadcasting parameters:

Table 11 Broadcasting parameters

Equivalent output digital data rate	4160 words per second
Video line rate	2 lines per second

[48] E. Delpech & B. Quemin (2013). IMT Atlantique, ISAE and INP ENSEEIHT. Reception of NOAA Images. p. 16.
[49] C.H. Vermillion (1968). Constructing Inexpensive APT Ground Stations. Report. NASA Office of Technology Utilization.

APT frame size	128 lines
Channels may be used	Any two of the available 6 channels can be used
Channel A sync	1040 Hz square wave – 7 cycle
Channel B sync	832 pps pulse train – 7 pulse
Each of the 16 telemetry points is repeated on	8 successive lines
Minutes makers are repeated on	4 successive line, with 2 line black and 2 lines white

5.3 Procedure for APT Image Reception:

After making all necessary preparations, careful study of the theory, software was installed and configured for APT signals reception and into images. The following steps have been followed to receive quality satellite images:

- Tracking and predict the satellite.
- Tuning the proper and exact frequency band (≈137 MHz).
- Receiving and recording the signals.
- Decode the signal to image.

First, the RTL-SDR dongle was set up, the audio piping method was installed and configured. Audio piping (a windows stereo mix, VB-cable (free) or virtual audio cable) will allow the audio signals from SDR# to be passed on to WXtoImg, the signal decoding program used in this Thesis.

To make sure that the system works properly, the male (SMA) plug of the coaxial cable was plugged into the RTL-SDR dongle through LNA. APT signals were audible once they had been demodulated in FM mode, and tuned in SDR# in ≈137 MHz band. By listening to the "tick" and "beep" sounds of signals being received from the satellite, it can determine if the antenna is working properly, and the software setup has been done correctly. The SDR# was checked when the satellite was moving overhead in orbit. The radio receiver was tuned to the correct frequency (depending on available satellites within range), while listening to signals captured directly through SDR#.

The first simple tunstile antenna that was built from waste material and inexpensive components was a right hand circularly polarized antenna. The second antenna that was built, was a directional antenna, which managed to receive signals of less quality (with noise and distortion) and needed to be moved around in search of the satellite. Therefore, the omnidirectional tunstile antenna was chosen for this Thesis, as it was able to receive signals of reasonably good quality.

5.4 Image recovery using software:

Software is critical to setting up a ground station for weather satellite image reception. Software are needed to process signals received from satellites, including recording satellite signals, storing, demodulation and display of images. Once signals have been received from NOAA satellites, audio tones must be AM demodulated (converted) to represent varying levels of visible and infrared energy as processed by the satellite radiometer and displayed as images.

The following important features were considered when selecting the most suitable software:

- Predict and track NOAA satellites.
- Capture and display NOAA satellite data.
- Ingest and store automated images in different graphic file formats.
- Enhance the colour of images.
- Process and enhance multi-spectral (IR and visible) images.
- Calibrate automatic IR channel temperatures (which is how land and oceans can be distinguished).
- Grid maps automatically along geopolitical borders, indicating coastlines, and where longitudes and latitudes can be marked.
- Ensure that cloud formations are visible.

Key issues for the setup and use a software for image reception:
The software program installation and its proper configuration and testing for the type of demodulator card (RTL-SDR dongle), the user has a choice of capturing new satellite images, displaying and enhancing images. APT software programs generally have five main functions:

1. Initial configuration and system setup
2. Satellite image capture and scheduling
3. Satellite prediction and tracking
4. Viewing and enhancement of satellite imagery
5. Image animation

5.4.1 Tracking satellites:

NOAA satellites pass overhead at regular intervals of the day. Signals appearing at ~137 MHz can best be received when satellites are overhead.

Table 12 Satellite tuning frequencies

NOAA-15	137.6200 MHz
NOAA-18	137.9125 MHz
NOAA-19	137.1000 MHz

Currently only NOAA satellites 15, 18 and 19 are operational, each using different frequencies. Satellites can be tracked and predicted using Orbitron and WXtrack free software and websites like **www.n2yo.com** that can easily be found on the internet.

When tracking the satellite, the following information is sought:

- Speed
- Emission frequency
- Position
  - Longitude
  - Latitude
  - Altitude
  - Distance from the ground station
  - Elevation angle
  - Azimuth
- Coverage area in graphical form.

Knowing the location of the ground station (Tønsberg), the three operational have been tracked, and it was established precisely when and for how long it would be possible to receive signal. The website used for the purpose of predicting and tracking satellites in real time revolving in its orbit over the target area was www.n2yo.com which shows all the necessary information in the following image.

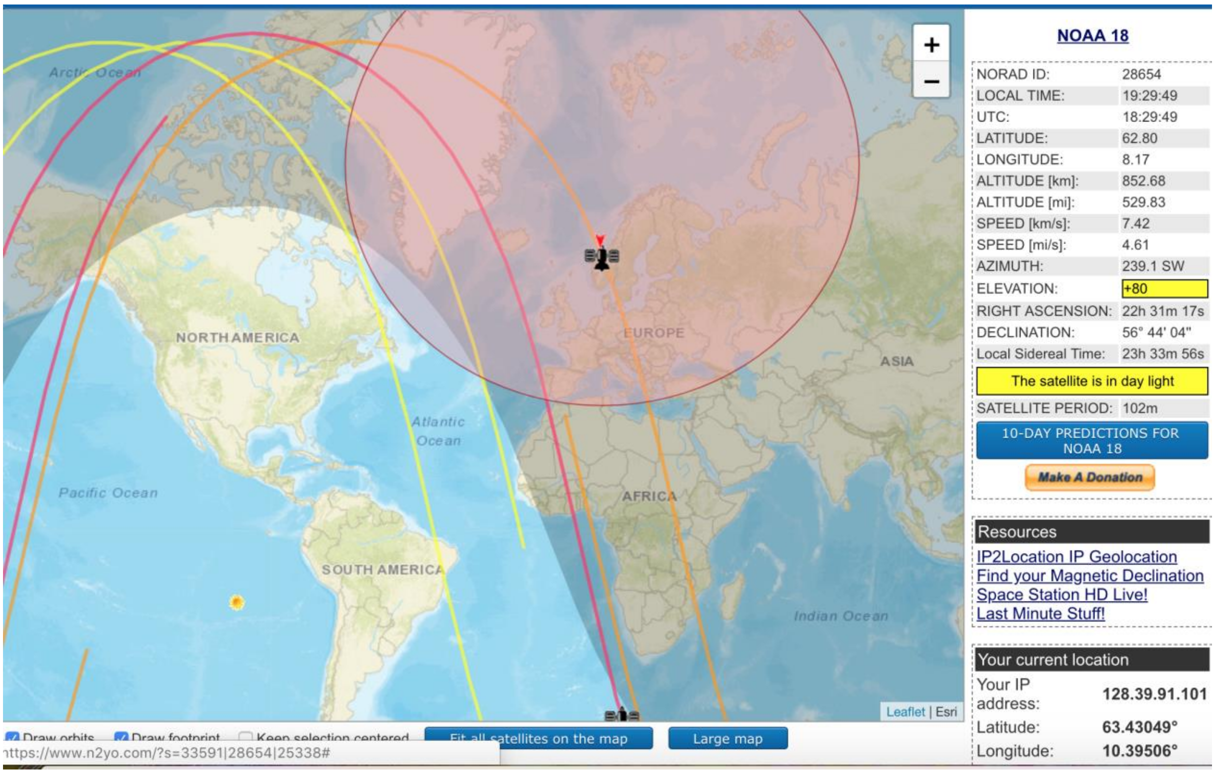


Figure 35 Screenshot of orbit and coverage area of satellites using www.n2yo.com

As NOAA satellites revolve around the Earth every 102 minutes with a different orbit, it is easy to track and predict the position of the satellites and wait for the next orbit revolution over Tønsberg.

5.4.2 Prediction and Tracking Specifications of NOAA-N:

As we chose to predict and track NOAA-N satellites, the geographical information in the table varies for different locations of the satellites. But most of the information can be the same due to its structure and functions. Updated information can be found on the same website. The following are the specification for NOAA-N to predict and track over my area (Tønsberg):

Table 13 NOAA prediction and tracking specifications
Tracking data using the n2yo webpage

Specifications	NOAA-15	NOAA-18	NOAA-19
NORAD ID	25448	28654	33591
Local Time	18:41:47	19:29:49	13:33:22
UTC	16:41:47	18:29:49	11:33:22
Latitude (km)	64.39	62.80	76.35

Longitude (km)	14.66	8.17	29.65
Speed (km/s)	7.45	7.42	7.42
Azimuth	61.1 ENE	239.1 sw	14.6 N
Elevation	+71.8	+80	+13.1
Declination	66° 09′ 09″	56° 44′ 04″	41° 51′ 56″

5.4.3 Tuning the frequency band:

Different software was used for radio interface to connect the ground station to satellite such as SDR#, Ham Radio Delux (HRD), High Definition Software Defined Radio (HDSDR), and more. Some are open sourced and easily available on the internet. SDR# is the most commonly used SDR program for tuning satellites in VHF and UHF band with RTL-SDR, as it is easy to setup and use.

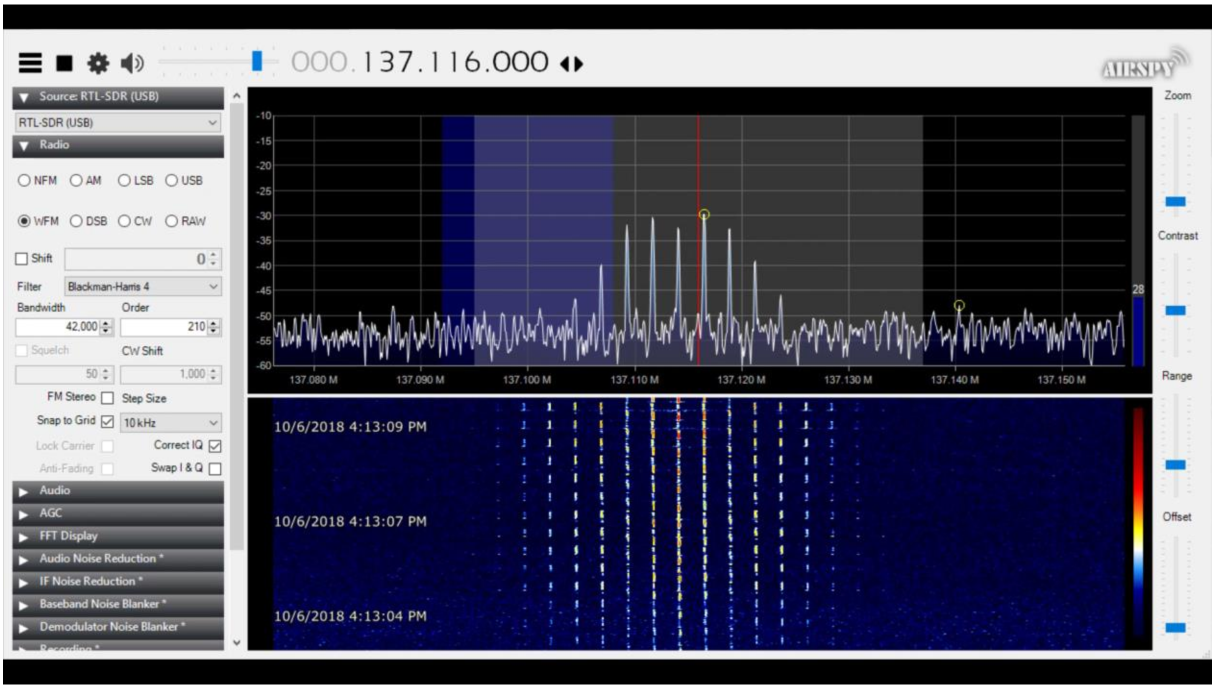


Figure 36 Screenshot showing clear signal reception of NOAA 19 using SDR#

The image shows the detail explanation of the SDR# software:

The SDR# has large spectrum and waterfall display. It is easy to adjust the spectrum and frequency can be kept constant with holding the shift key, the signal can be recorded and play back and can be saved as audio file (.wav) for WXtoImg or MATLAB/Simulink to decode later. WFM is selected as radio communication mode for NOAA weather satellite signal reception, while NFM, AM, LSB, USB, RAW and CW can be selected for other radio services. The following figures shows the SDR# while recording the signal at ≈137 frequency band.

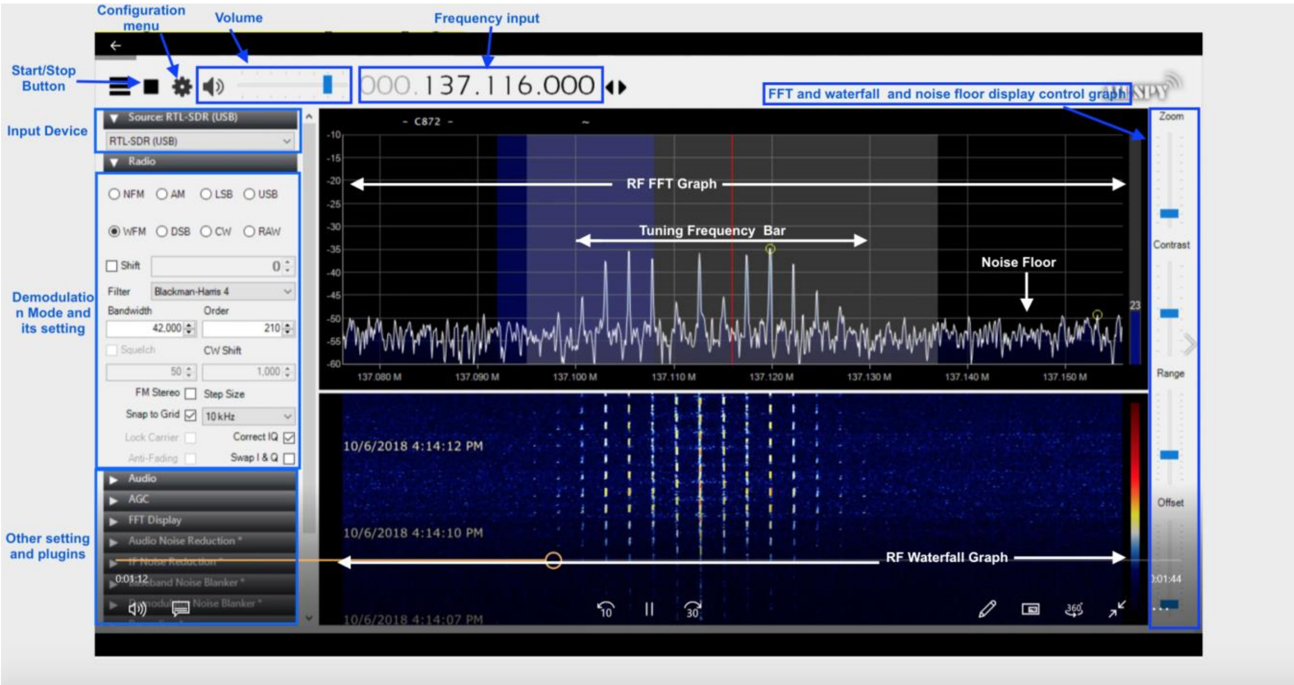


Figure 37 Screenshot of SDR# first page

Steps to be completed before initiating signal reception:

- Increase the RF gain from zero to a higher value in the configure menu.
- Reduce the range slider on the right of the SDR# window to about -70 (minus).
- Enable the 'Correct IQ' setting to remove the center spike if using an R820T / R820T2.
- Turn off the 'snap to grid' setting, or adjust the PPM offset accordingly.
- Set the 'Radio Mode' for signal demodulation to WFM.
- RF FFT graph can be zoomed for showing better result of relevant frequency signals.
- All hardware related setting, such as control the FR gain, sampling rate/bandwidth of RTL-SDR optimization should be adjusted in the configuration menu.
- Most of the software related configuration such as Digital Signal Processing (DSP), and optimization are in the main windows.

5.4.4 Receive and record the APT signal:

5.4.4.1 APT signal flow (AM demodulation):

Signals are received at the frequency range of ≈137 MHz band, with the bandwidth of 40 KHz. 2.4 KHz subcarrier signals have to be FM demodulated to produce a distinctive Tick-Tock sound, which indicates that signals have been received in SDR#.

Through virtual audio cabling configuration to the computer soundcard, frequency modulated (tuned and recorded through SDR#) signals, are received at the output of the radio receiver. The AM demodulation and the processing are conducted through WXtoImg and MATLAB to process and decode signals and extract APT images.

5.4.5 Decoding the signal and displaying the image:

There are different software that can be used for processing the received signal, decode it and display the images. Some of the basic techniques are processed such as filtering, demodulation, image enhancement, map overlapping for the desired area. We have used software which are explained below:

WXtoImg software:
Has been used for signal processing and image decoding. As the wav (audio) signal is automatically received from the SDR# software by through virtual cabling, the audio signal is processed, and the image is decoded here. The following images demonstrates some practical scenes of the software.

In the image, we see four tabs, which are explained respectively as follow:

- Image tab: This tab is used to convert the recorded or captured signal to the APT frame format. Here we can see the images from two different channels A and B as explained above. After predicting and tracking the satellite over the area, the Kepler’s data is updated and clicking on Auto record to start the process.
- Audio files: The SDR# tuned the NOAA-19 satellite frequency, and the signal is strong enough which can be seen in the image. At the same time, the signal is piped to WXtoImg for processing which can be seen on the left-hand side.

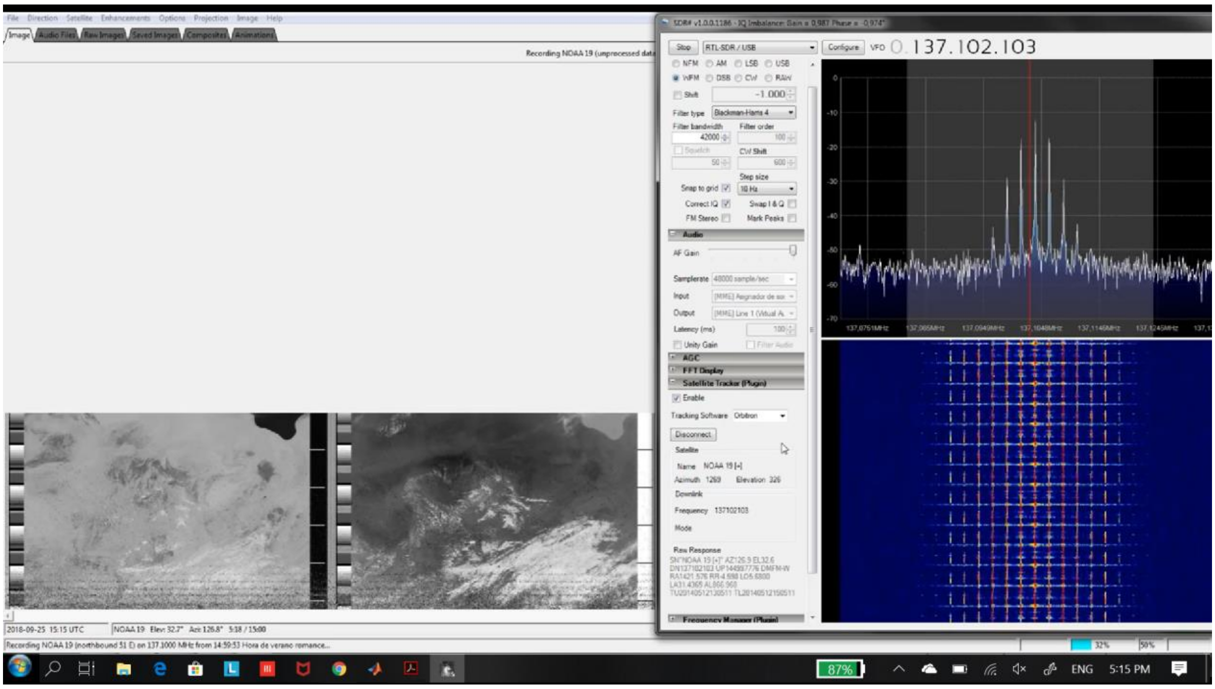


Figure 38 Screenshot showing four tabs in the WXtoImg software

The following four images shows the different stages, from decoding to the processing and enhancing the images. The small pictures inside the snapshot taken from the software shows, that different attempt has been made on different interval of time and different NOAA satellites, where some images are reasonably good, and some are not very good quality.

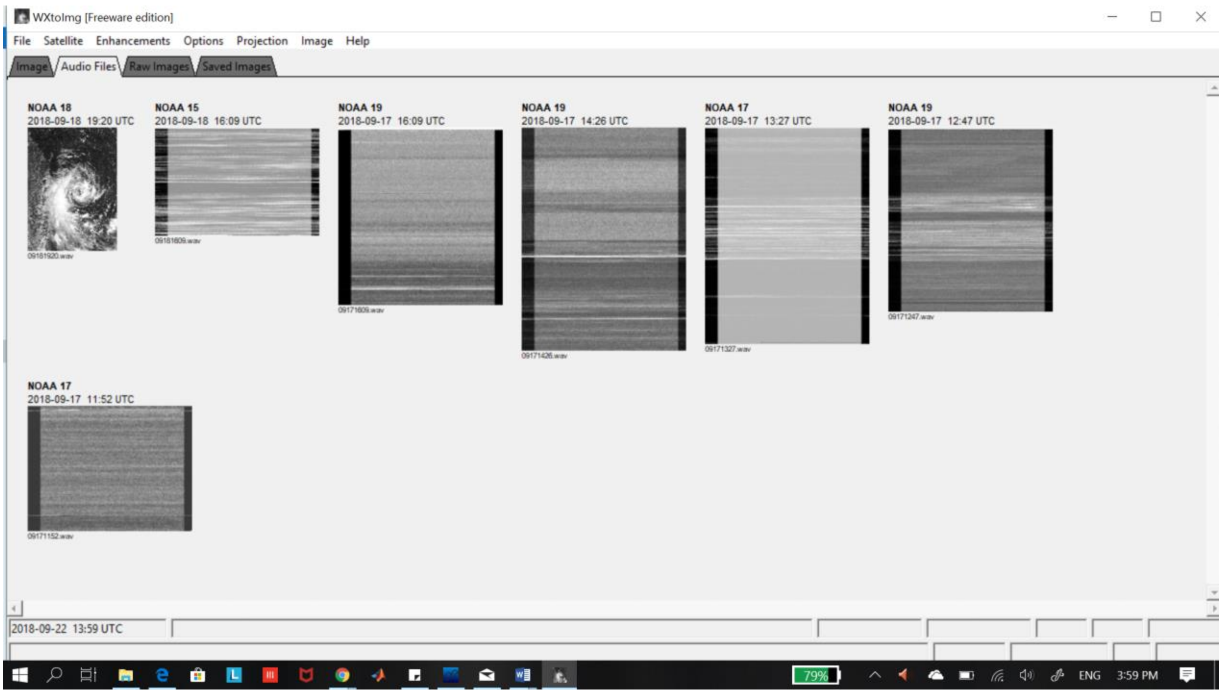


Figure 39 Screenshot using WXtoImg software

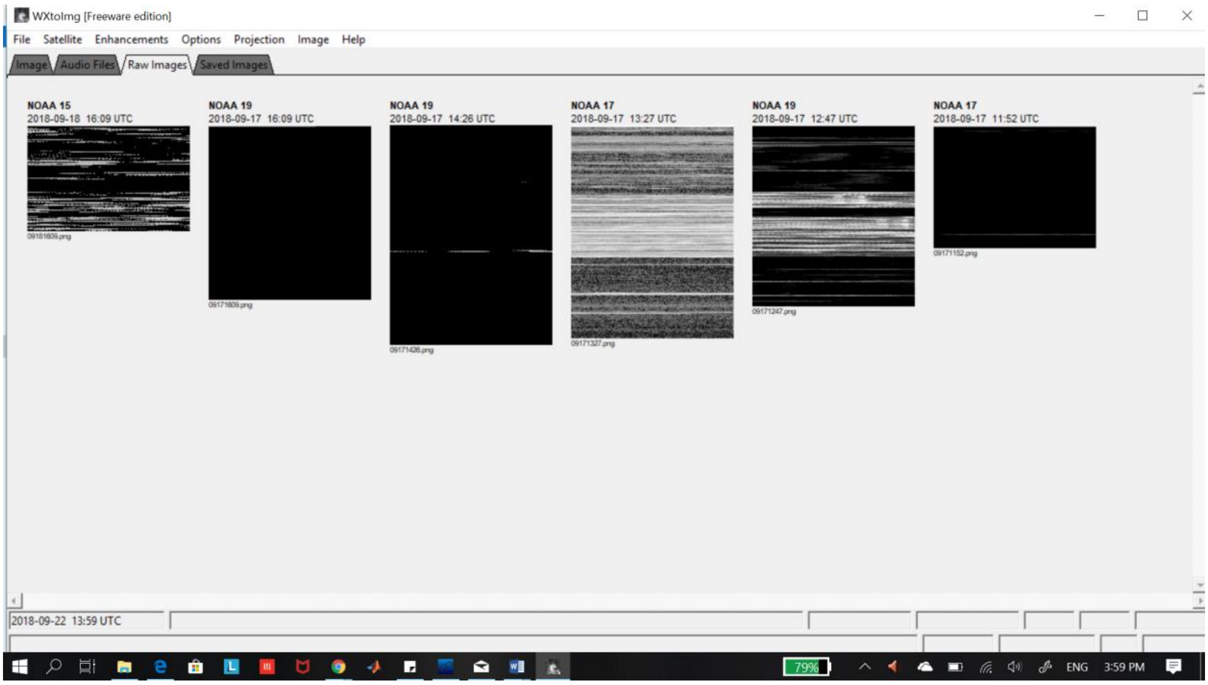


Figure 40 Screenshot using WXtoImg software

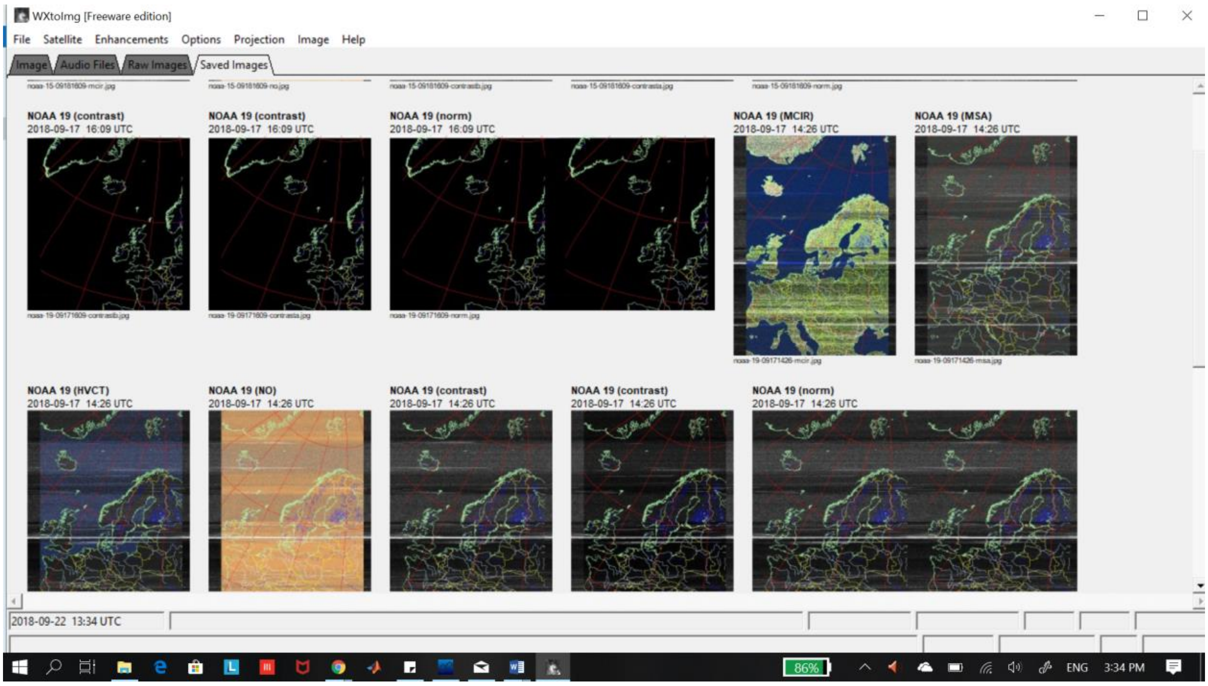


Figure 41 Screenshot using WXtoImg

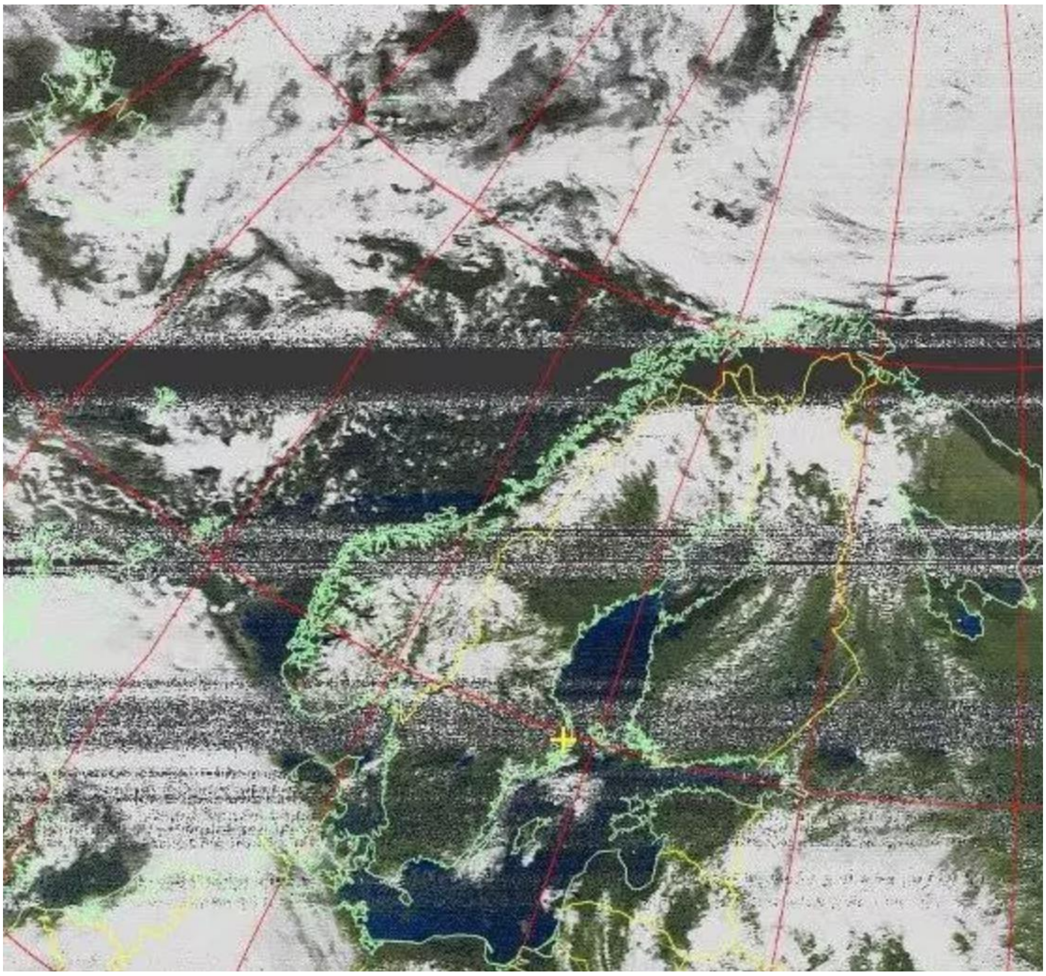


Figure 42 Screenshot using WXtoImg

Once the software (WXtoImg) has been installed in the computer, several set up must be done.

- Update Kepler's: It is necessary to know the real next pass and the duration of each NOAA satellite. This should be updated periodically. The whole satellite pass list can also be downloaded.
- Setting up 'mixer control': The advanced options in microphone properties are set as channel 2.16 bit, 96 KHz. It is important for virtual audio cabling between SDR# and WXtoImg signal processing.

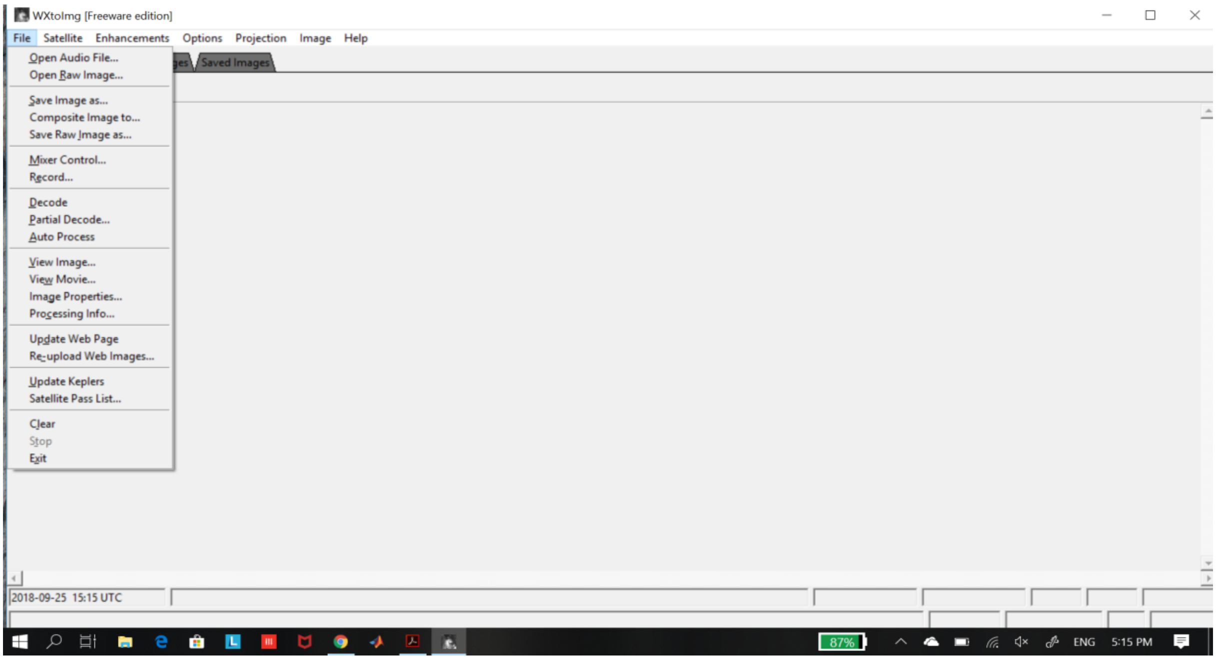


Figure 43 Screenshot using WXtoImg

- Active APT Satellite: Tick the desired satellites to receive – Currently NOAA 15, 18 and 19 are operational.
- Satellite type specification: it is necessary to activate the 'Autodetect APT satellite'.
- Ground station location: It can be added automatically, if there is a small region, or by writing manually the coordinates. The last option is recommended for big cities or places not recognized by the program.

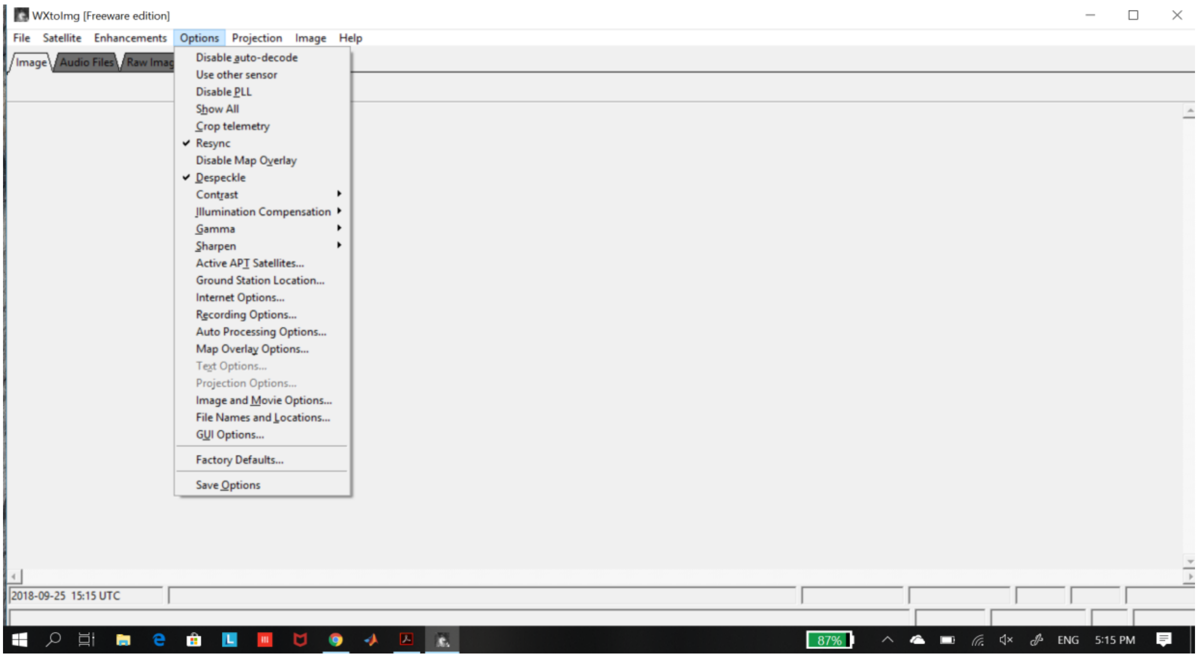


Figure 44 Screenshot of option menu on WXtoImg

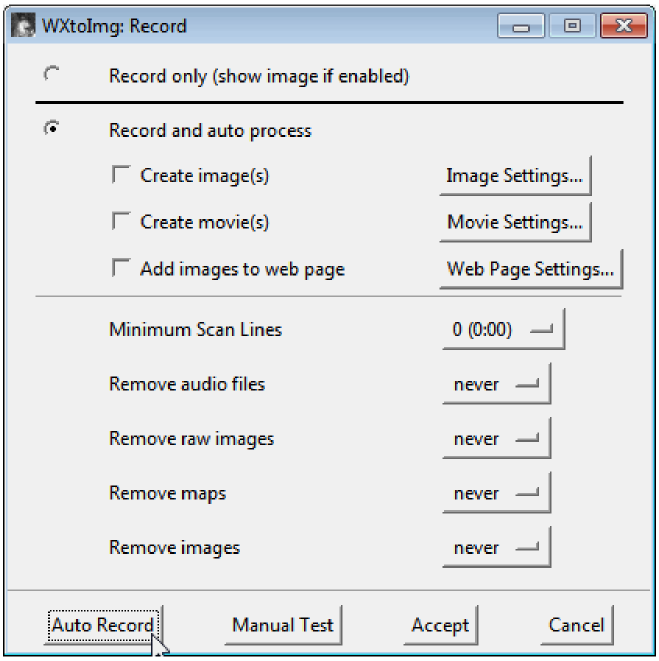


Figure 45 Screenshot of the Menu pager for Recording

- Record: The program can be set in two options: either only “record” or “record and auto process”. In this Thesis “record and auto process” has been used. Once the “Auto Record” button is pressed, the recording and decoding will start when the satellite appears on the horizon and stop when the satellite goes out of view according to the times in the satellite pass list. While recording, if the volume bar in the bottom right hand corner is in red or yellow color, it should be adjusted in Windows to either increase or decrease the volume until the volume bar has a green color. Once the record is completed, an audio file will have been saved in the folder. /Pictures/WXtoImg/audio.

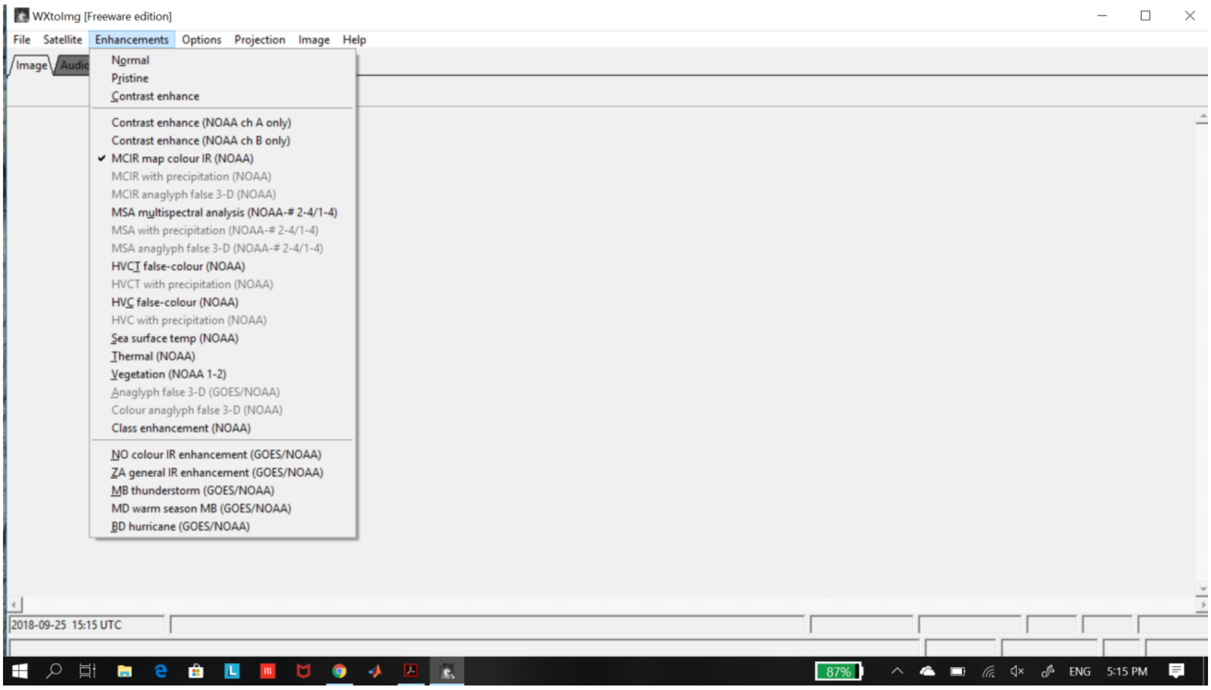


Figure 46 Screenshot of Image Enhancement Menu

- Enhance: Different enhancements can be used in the picture from the enhancement menu such as,
  - MCIR map colour IR (NOAA)
  - Sea surface temp (NOAA)
  - HVCT false colour (NOAA)
  - And many more options
- Open audio file: we can get "raw audio file" from SDR# and process and decode.

5.4.6 Demodulation and decoding APT signal using MATLAB / Simulink:

When RTL-SDR dongle is connected to the computer running MATLAB / Simulink it enables the implementation of DSP and SDR algorithms tuning the device to the center frequency of an FM radio station, demodulate and decode the received samples, and output the resulting audio signal to the speakers of the computer. As the entire demodulation process is carried out in software, it is called software defined radio implementation in MATLAB.

The RTL-SDR setup is represented in the following block diagram, where RF signal are received at the antenna, quadrature down-converted by the RTL-SDR, and *In-Phase /Quadrature Phase (IQ)* samples are presented to the computer running MATLAB. The receiver design is implemented using the appropriate DSP algorithms to demodulate the signal to baseband and extract the information signal. This might be audio, video, image, or data.

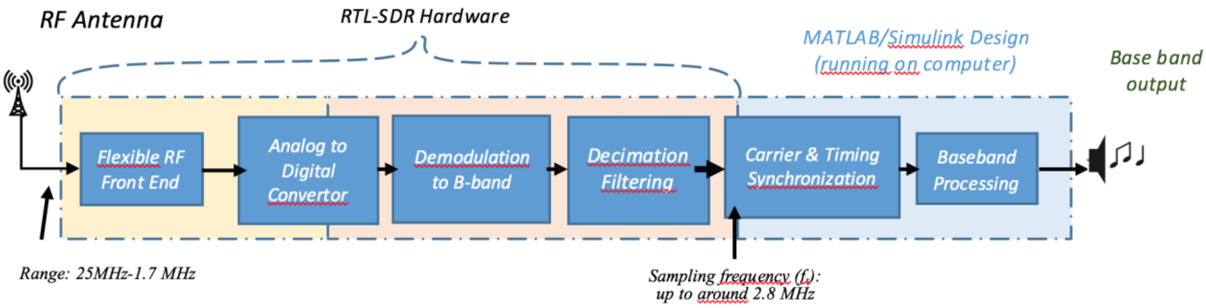


Figure 47 Screenshot of Image Enhancement Menu[50]

5.4.7 Checklist of Hardware/Software for RTL-SDR using MATLAB:

Using MATLAB / Simulink as a tool to demodulate and decode the received samples and output the resulting audio signal to the speaker of the computer. The following components will be needed for a successful demodulation and decoding:[51]

- RTL-SDR dongle.
- Reasonably strong computer.
- Latest version of MATLAB / Simulink.
- MathWorks Communications System Toolbox.
- MathWorks DSP System Toolbox.
- MathWorks Signal Processing Toolbox.
- RTL-SDR Hardware Support Package

The last four are the toolboxes can be found on MathWorks. These should be installed to support the RTL-SDR dongle. The following image shows the configuration of RTL-SDR dongle Simulink block and the MATLAB system object with identical parameters.

[50] B. Stewart, K. Barlee, D. Atkinson & L. Crockett (2017). University of Strathclyde. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. p.4
[51] Illustrated based on B. Stewart, K. Barlee, D. Atkinson & L. Crockett (2017). University of Strathclyde. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. p.6-7

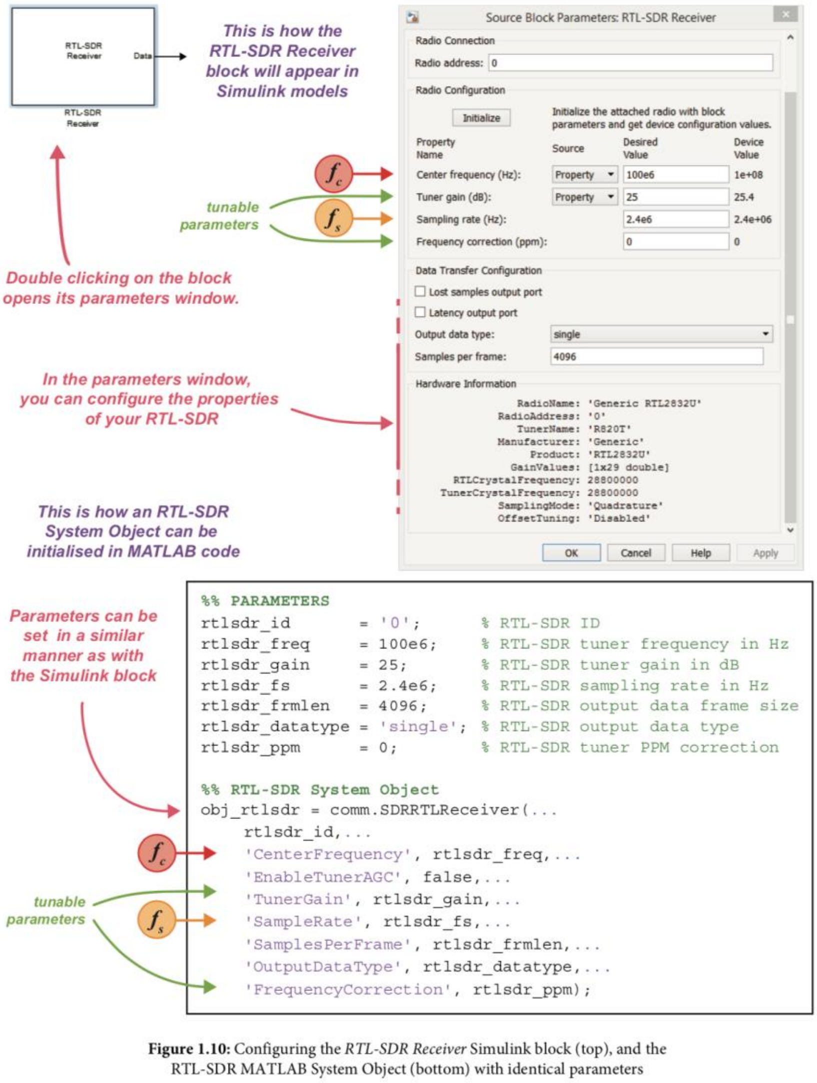


Figure 48 RTL-SDR dongle configuration, Simulink block and the MATLAB system object with identical parameters[52]

The following images demonstrate the process carried out by the RTL-SDR dongle, down-converting an RF signal to an IF, then digitizing to baseband (The process shown in the block diagram runs right to left, rather than left to right). The parameters of baseband sampling rate, fs, the tunable gain K, and the RF center frequency, fc are set in the Simulink RTL-SDR dongle block or MATLAB system object.

[52] R. Stewart, K. Barlee, D. Atkinson & L. Crockett (2017). University of Strathclyde. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. p.18

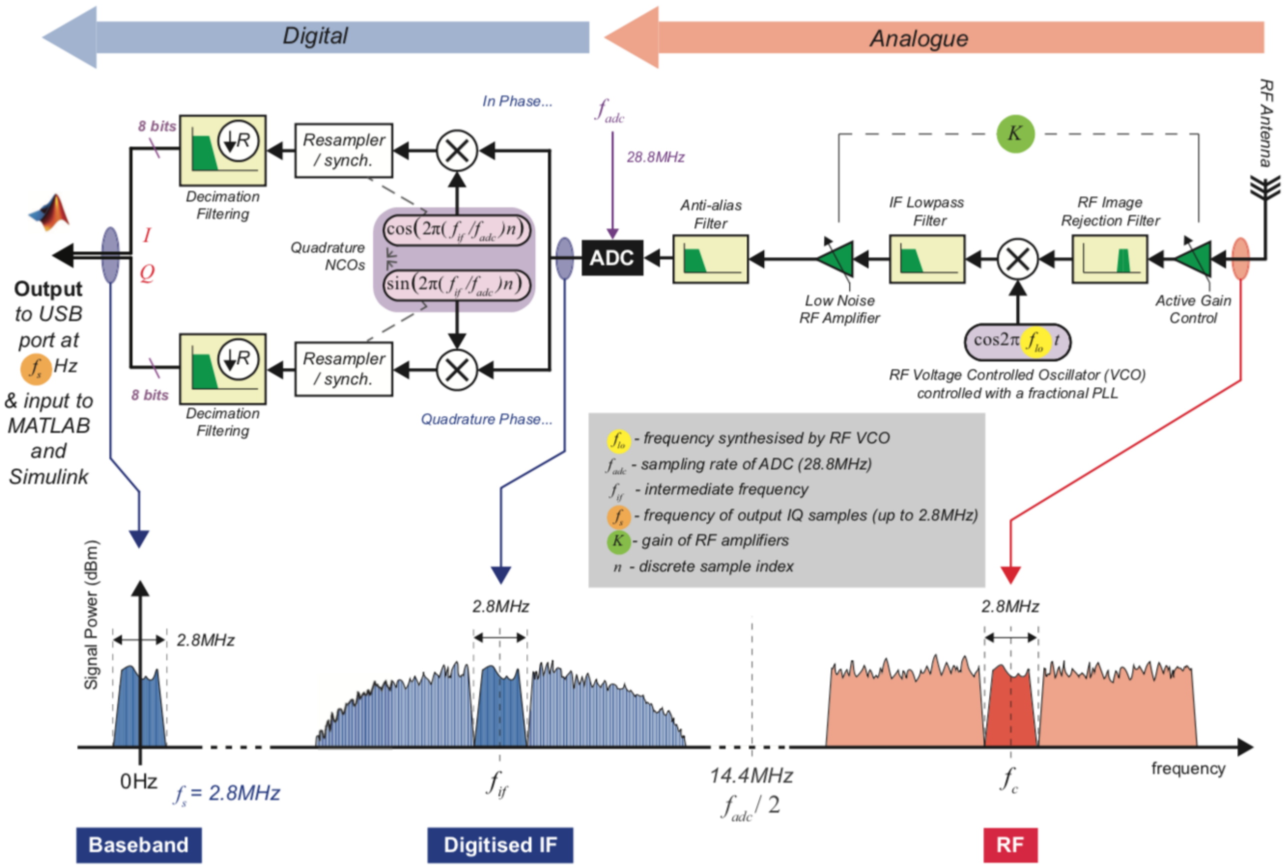
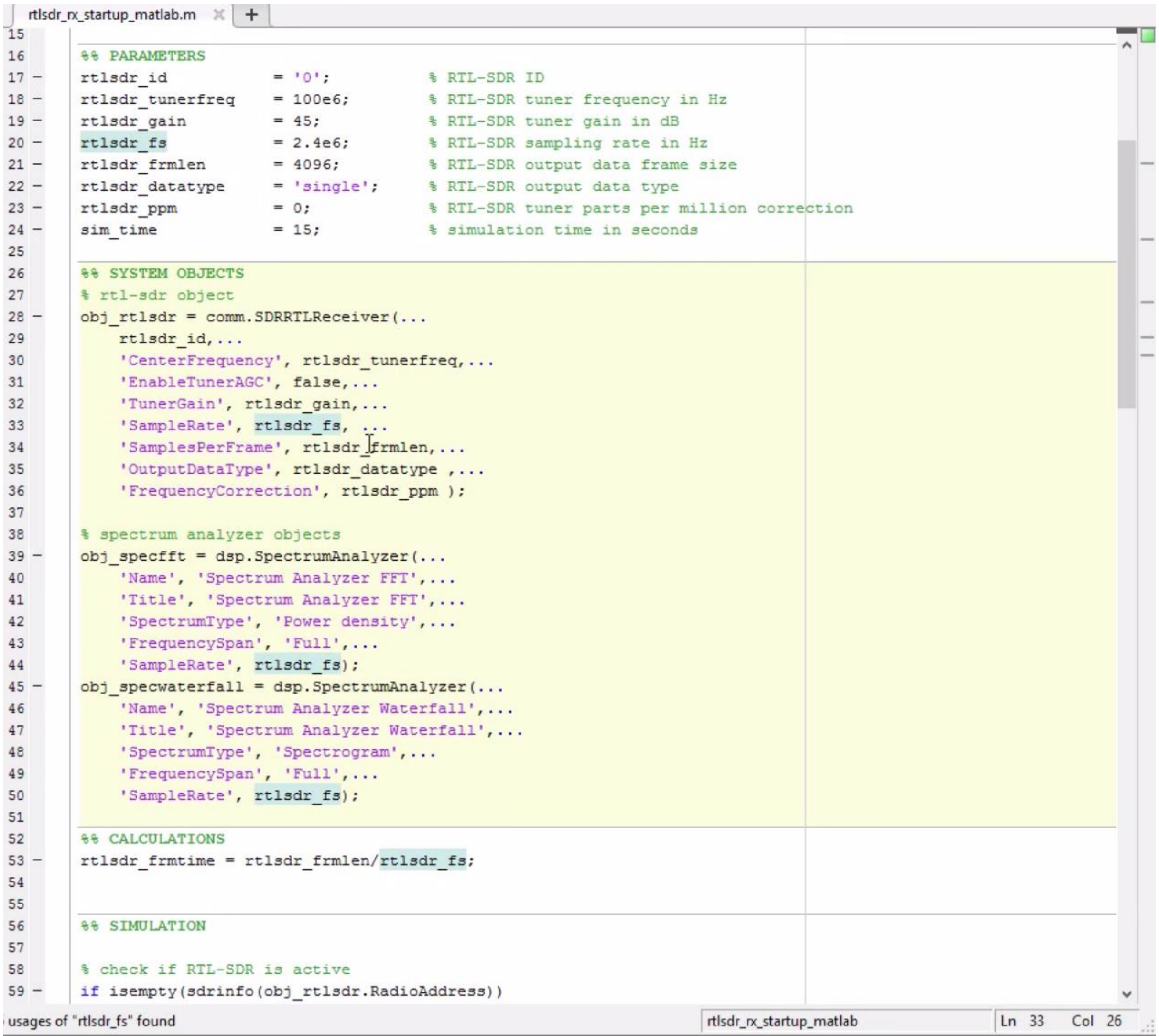


Figure 49 Down-converting baseband signal to digitalize IF Signal[53]

[53] R. Stewart, K. Barlee, D. Atkinson and L. Crockett (2017). University of Strathclyde. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. p.19

The following image shows the installation and configuration of RTL-SDR dongle and test for spectrum analyzer.



```
%% PARAMETERS
rtlsdr_id           = '0';          % RTL-SDR ID
rtlsdr_tunerfreq    = 100e6;        % RTL-SDR tuner frequency in Hz
rtlsdr_gain         = 45;           % RTL-SDR tuner gain in dB
rtlsdr_fs           = 2.4e6;        % RTL-SDR sampling rate in Hz
rtlsdr_frmlen       = 4096;         % RTL-SDR output data frame size
rtlsdr_datatype     = 'single';     % RTL-SDR output data type
rtlsdr_ppm          = 0;            % RTL-SDR tuner parts per million correction
sim_time            = 15;           % simulation time in seconds

%% SYSTEM OBJECTS
% rtl-sdr object
obj_rtlsdr = comm.SDRRTLReceiver(...
    rtlsdr_id,...
    'CenterFrequency', rtlsdr_tunerfreq,...
    'EnableTunerAGC', false,...
    'TunerGain', rtlsdr_gain,...
    'SampleRate', rtlsdr_fs, ...
    'SamplesPerFrame', rtlsdr_frmlen,...
    'OutputDataType', rtlsdr_datatype ,...
    'FrequencyCorrection', rtlsdr_ppm );

% spectrum analyzer objects
obj_specfft = dsp.SpectrumAnalyzer(...
    'Name', 'Spectrum Analyzer FFT',...
    'Title', 'Spectrum Analyzer FFT',...
    'SpectrumType', 'Power density',...
    'FrequencySpan', 'Full',...
    'SampleRate', rtlsdr_fs);
obj_specwaterfall = dsp.SpectrumAnalyzer(...
    'Name', 'Spectrum Analyzer Waterfall',...
    'Title', 'Spectrum Analyzer Waterfall',...
    'SpectrumType', 'Spectrogram',...
    'FrequencySpan', 'Full',...
    'SampleRate', rtlsdr_fs);

%% CALCULATIONS
rtlsdr_frmtime = rtlsdr_frmlen/rtlsdr_fs;


%% SIMULATION

% check if RTL-SDR is active
if isempty(sdrinfo(obj_rtlsdr.RadioAddress))
```

rtlsdr_rx_startup_matlab.m

```
    'SpectrumType', 'Spectrogram',...
    'FrequencySpan', 'Full',...
    'SampleRate', rtlsdr_fs);

%% CALCULATIONS
rtlsdr_frmtime = rtlsdr_frmlen/rtlsdr_fs;


%% SIMULATION

% check if RTL-SDR is active
if isempty(sdrinfo(obj_rtlsdr.RadioAddress))
    error(['RTL-SDR failure. Please check connection to ',...
        'MATLAB using the "sdrinfo" command.']);
end

% reset run_time to 0 (secs)
run_time = 0;

% run while run_time is less than sim_time
while run_time < sim_time

    % fetch a frame from the rtlsdr
    rtlsdr_data = step(obj_rtlsdr);

    % update spectrum analyzer windows with new data
    step(obj_specfft, rtlsdr_data);
    step(obj_specwaterfall, rtlsdr_data);

    % update run_time after processing another frame
    run_time = run_time + rtlsdr_frmtime;

end

end
```

Figure 50 AM demodulation of the APT using MATLAB coding: Demodulation and decoding of audio file to image[54]

It has been explained above, how to install and configure the RTL-SDR dongle in MATLAB. Here the focus is on how to convert Audio (.wav) file received from the satellite and recorded in SDR# software to image are as follow:

[54] Run in MATLAB based on R. Stewart, K. Barlee, D. Atkinson & L. Crockett (2017). University of Strathclyde. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. p.39-40

The following image shows the captured audio file through SDR# in spectrum analyzer:

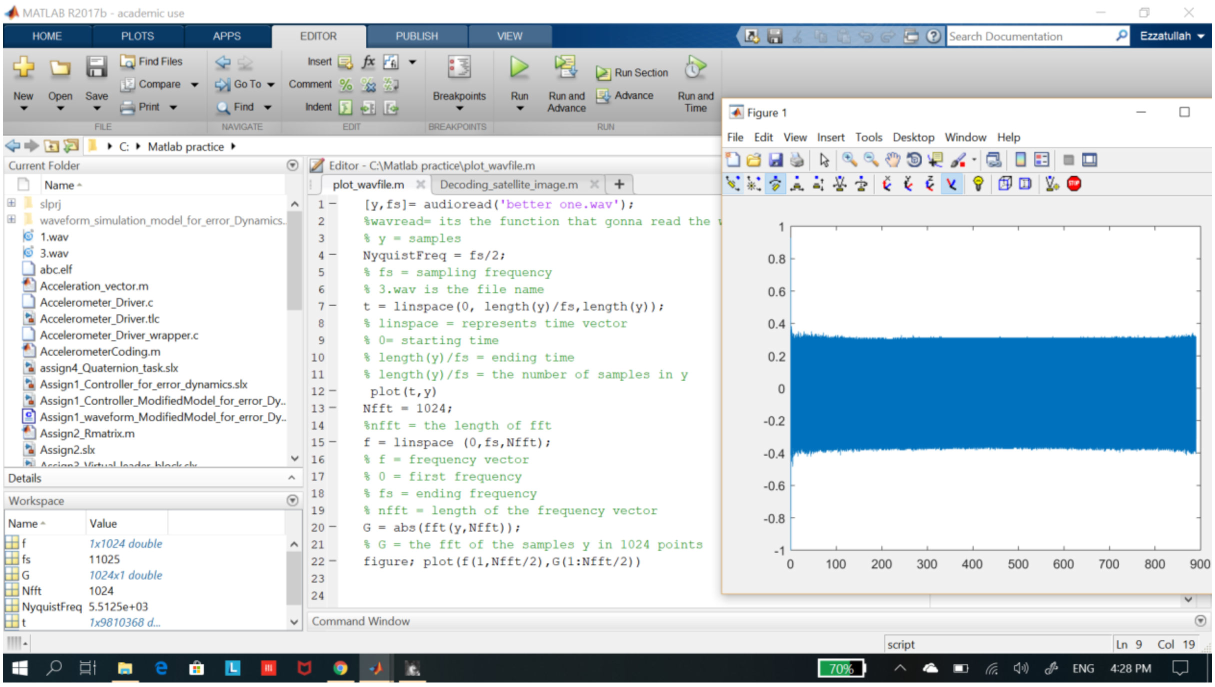


Figure 51 Screenshot using SDR#

5.5 Decoding image using MATLAB:

To process and obtain the image from the signal (wav file) received from the satellite, it is important to understand the processing of the corresponding signal.

The following is the schematic block diagram which shows different blocks of signal processing and image generation:

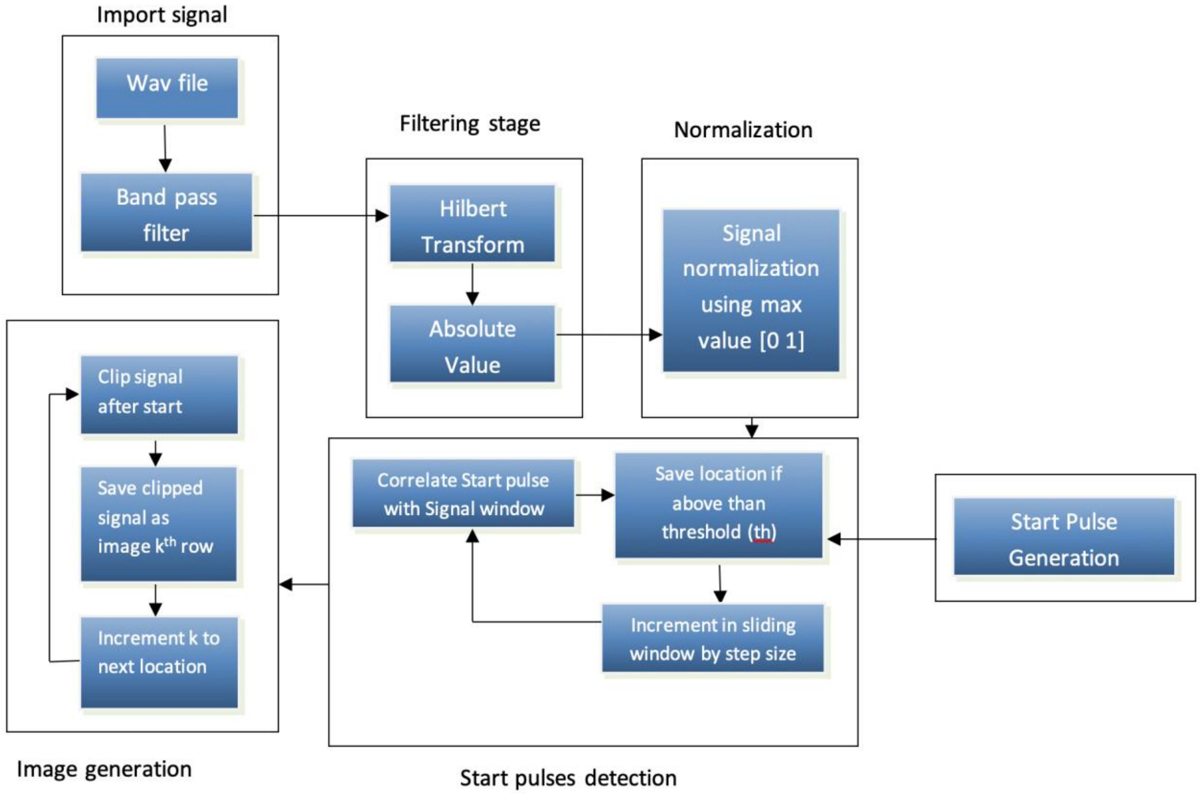


Figure 52 Schematic block diagram showing different blocks of signal processing and image generation

Input block (Imported signal):

The raw signal which is a FM demodulated signal recorded by SDR# software and saved as audio (wav) file. The original signal is read by MATLAB and band-pass filtered which have noise and unnecessary frequencies. Pre-processing steps include: exclude the unnecessary frequencies and passing only the needed frequency signals. Envelope detection process where the Hilbert-transform method is being used. This is done using band-pass filter of order 100 with passing frequencies of 550 < w < 5000:

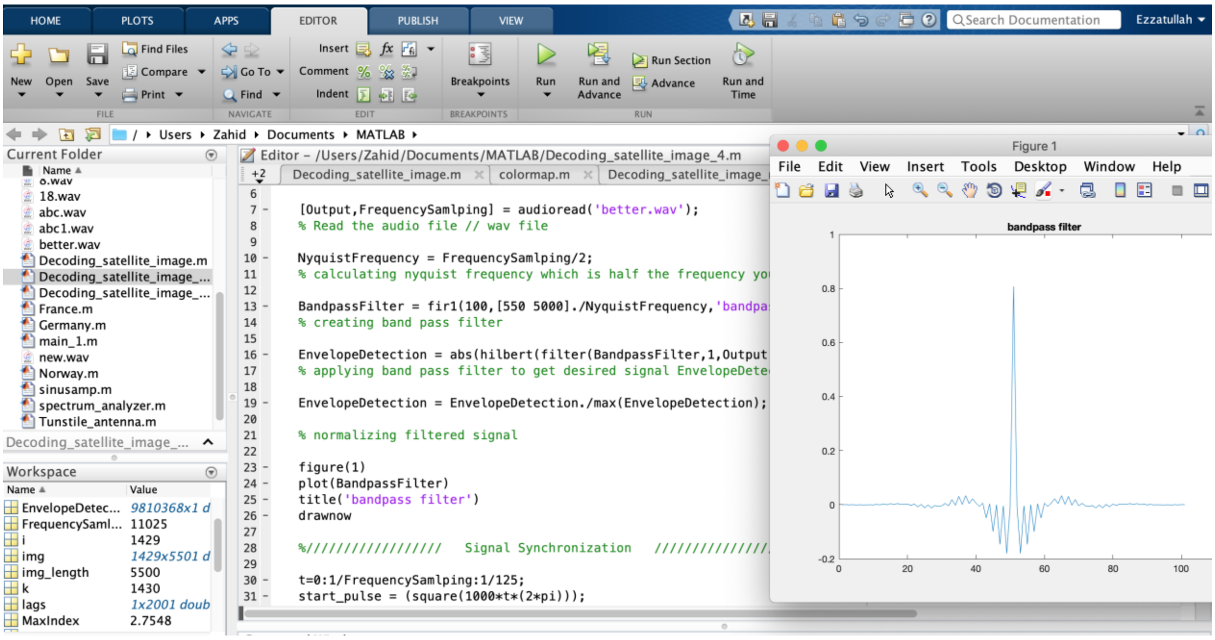


Figure 53 MATLAB code and the band-pass filtered signal

Signal synchronization: Next step is to find the start-pulses from the signal. The image data is present between every two start-pulses, so it is needed to identify the exact location of the start-pulses. For this, a start-pulse is created manually, threshold is defined, the slices of the signal are scanned, the sync-pulses are located, and the values of the pulses are compared to the threshold value, and determined. To find the location, the correlation between the signal and the manually built start-pulse, is created. The synchronization is achieved by correlating the normalized AM demodulated signal, and as a result the square sync-pulse is generated.

Sync-pulse generation: The time period ‘t’ is calculated for the IR frequency of 1000 Hz.

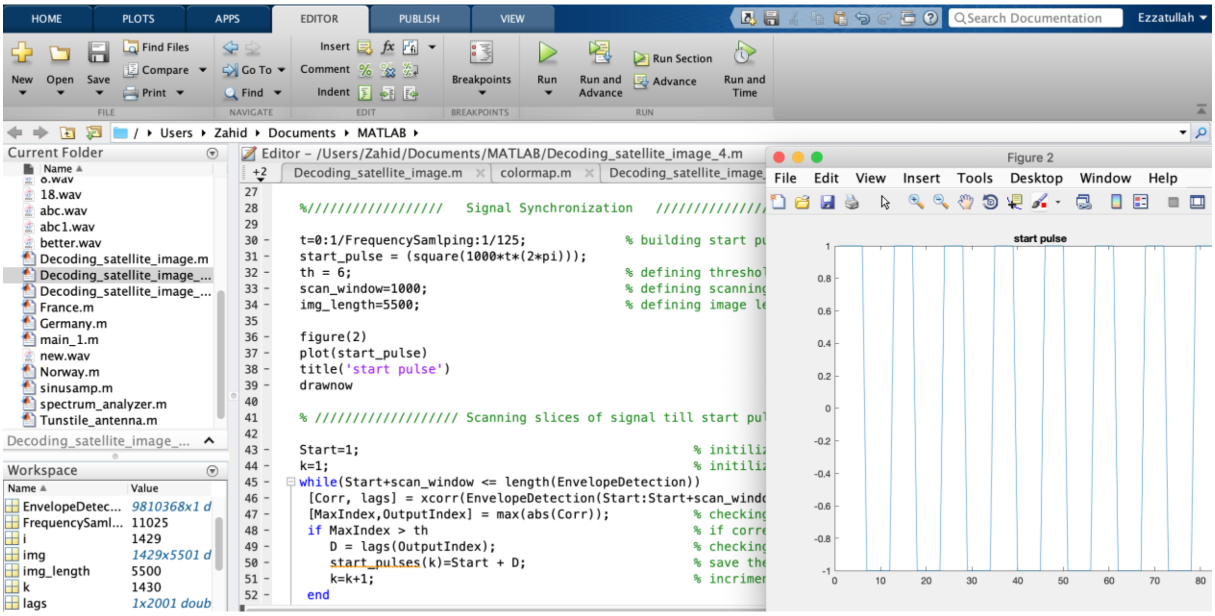


Figure 54 The sync-pulse is generated using MATLAB

Correlation: We can see clearly in the following image which signal starts with a noisy start-pulse. Image data are divided into frames, separated by the sync pulses, marking the start and end of each data frame. The start-pulse is correlated to find the location using the manually created start pulse, as the location is considered the beginning of the next slice. The slice length is approximately half of the sampling frequency (f_s). The sampling-frequency of the recorded signal from NOAA is around 1040 Hz.

X-correlation done to locate the sync pulses, which is important in the process of decoding images.

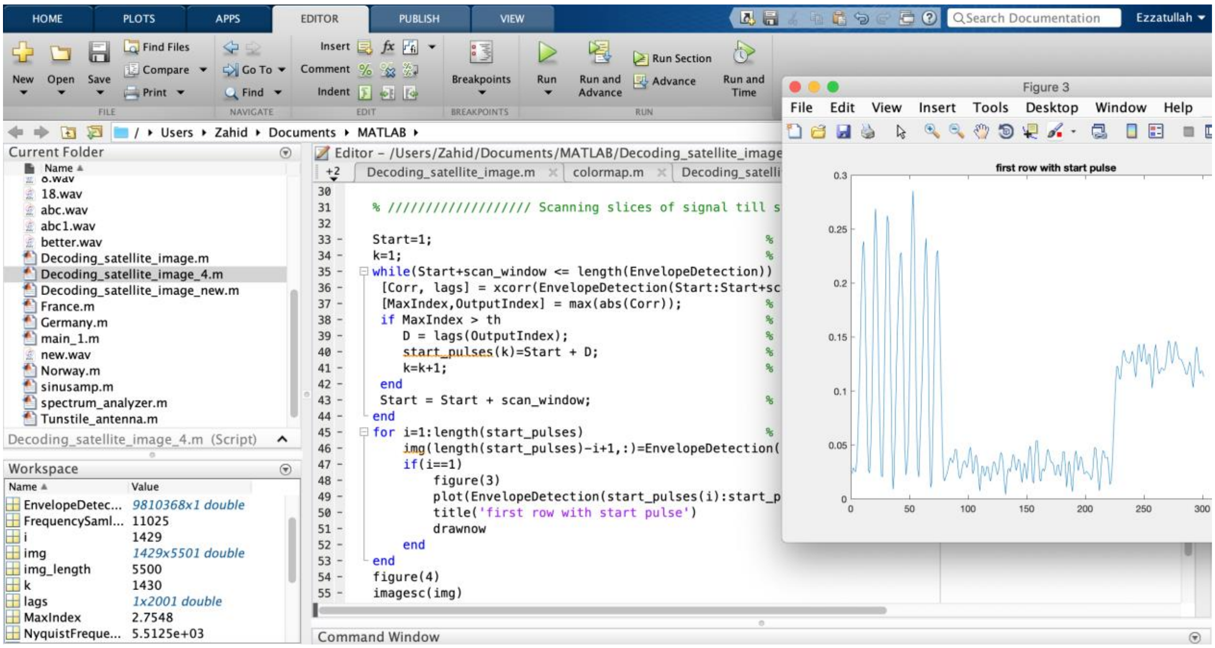


Figure 55 X-correlation to locate sync pulses

Once the location is stored in the array format, the signal between two start pulses must be extracted and store in the same image area format to build a complete image.

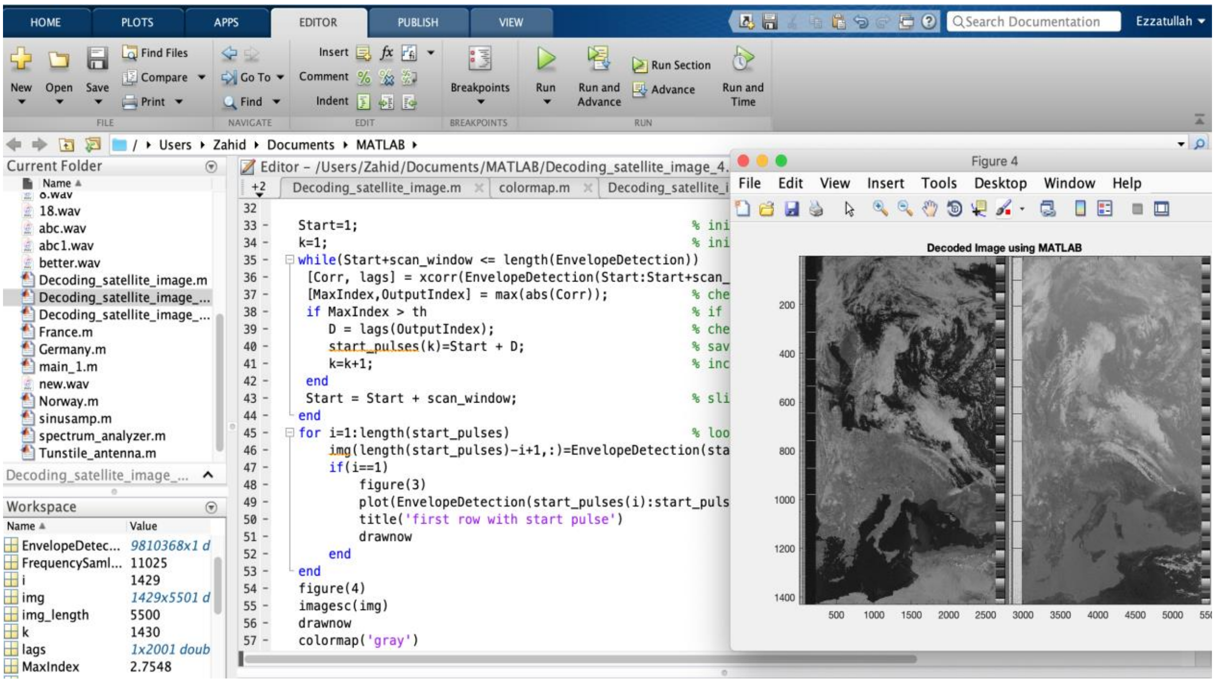


Figure 56 Screenshot from MATLAB

6 Conclusion and discussion

The main achievements of this Thesis:

- A small, portable and low-cost ground station, with a Tunstile antenna capable of receiving reasonably good quality images from NOAA POES weather satellites, series 15, 18 and 19, was built;
- The Ground Station was installed, configured and prepared;
- Signals were received, processed and decoded;
- Sound signals were recorded with the help of SDR# and converted to images through MATLAB and WXtoImg, and;
- All hardware and software were tested before use.

APT signals, from the three active NOAA satellites, were received, demodulated and decoded by the ground station to form images. Signals were received from the NOAA satellites during pre-identified times of the day depending on when they passed overhead in orbit, and the results were quite different depending on various factors.

The first try with a simple dipole antenna did not produce good results. After building a tunstile antenna the results improved. A model for the design for the tunstile antenna was selected after repeated tests and experiments. The diameter and length of the dipoles influenced the reception quality. While the wavelength determined the reception power of the signals received. Together, these factors decided the level of stability in the connection between the satellite and the ground station.

The antenna is built from waste materials and some other low-cost components. The four rod which are used for dipoles are connected to each other with the coax-cable configuration with 90 degree to each other. The total length of the dipole is approx. 1m while each its element is approx. 0.51m. The length of the rods is determined by the frequency range used which is 137 MHz. A dipole is in total ½ wavelength, with each element being ¼ wavelength. The antenna with reflector is ideal for receiving right-hand circular polarization when the satellite is directly overhead and has an omni-directional, horizontally polarized pattern for signals arriving parallel to the ground.

MATLAB and WXtoImg software were used for image decoding. WXtoImg is designed to decode audio APT signals taken from SDR# software in real-time for image generation, while MATLAB was used to decode stored audio APT signals.

Low-resolution APT format (analog) transmissions from NOAA satellites are optimal for transmissions of grey scale images. These transmissions use two standard audio channels with up to 3.5 km lower spatial and 8 bits radiometric resolution. The maximum subcarrier modulation is approximately 87% out of an overall RF bandwidth ranges between 34-40 kHz.

NOAA POES satellites revolve the earth in sun-synchronous orbits with an average height of 854 km over the earth's surface. The satellite movement in the orbit is predetermined and scheduled on hourly bases throughout the year. The satellite moves around a degree per day to synchronize its orbit, and a full loop around the earth take 102 minutes.

When the satellites pass over a specific region (in this case Tønsberg, Vestfold), the satellite's AVHRR radiometers sense the radiation emitted by the earth´s surface in five different wavelength channels (1, 2, 3A, 3B, 4 and 5). The AVHRR uses channel no. 1 (daytime cloud and surface mapping) and 2 (land-water boundaries)[55] to measure the intensities of the radiations and form readable images. These intensities are initially amplitude modulated (AM) through a 2400 Hz subcarrier, and then again frequency modulated (FM) onto a 137 MHz main carrier.

When the satellite appears over the horizon, the edge of the image is slightly cramped, as it gets closer the resolution of details in the image gradually improves. At the end of orbit the signal gets weaker and the image begins to disappear in noise as the satellite slips behind the skyline.

The antenna constructed as part of this Thesis is not only guaranteeing reasonably good quality reception of images from weather satellites. However, the quality of the images also depends on weather conditions, place of installation and sufficient height compared with the surroundings. Mounting the antenna close to tall structures will affect the quality of the signals received.

Software defined radios (SDR) is a communication system differing from more traditional hardware-based radios as modifications no longer require physical intervention, where components (e.g. filters, mixers, modulators and demodulators, and detectors) are largely software-based. This has led to lower productions costs and increased flexibility for radios to support multiple waveform standards.

This Thesis is an important contribution to research on weather patterns in low-income countries, as it guides students, practitioners and researchers to get hand-on practical experience in building seemingly sophisticated satellite reception systems using easily available low cost and waste materials.

[55] NOAA SIS (2017). AVHRR. Available: https://noaasis.noaa.gov/NOAASIS/ml/avhrr.html [Accessed: 10.12.2018]

The following images illustrate parts of the practical work done in this Thesis:

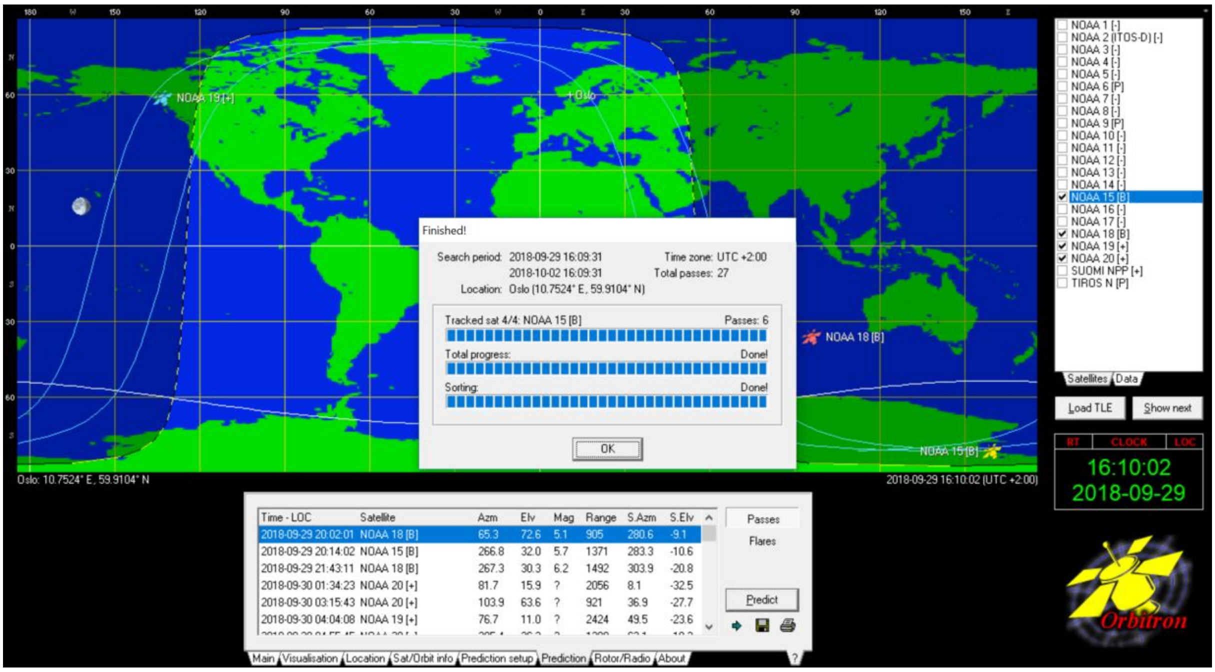


Figure 57 Screenshot of NOAA-N satellites characteristics update and orbit tracking with Orbitron

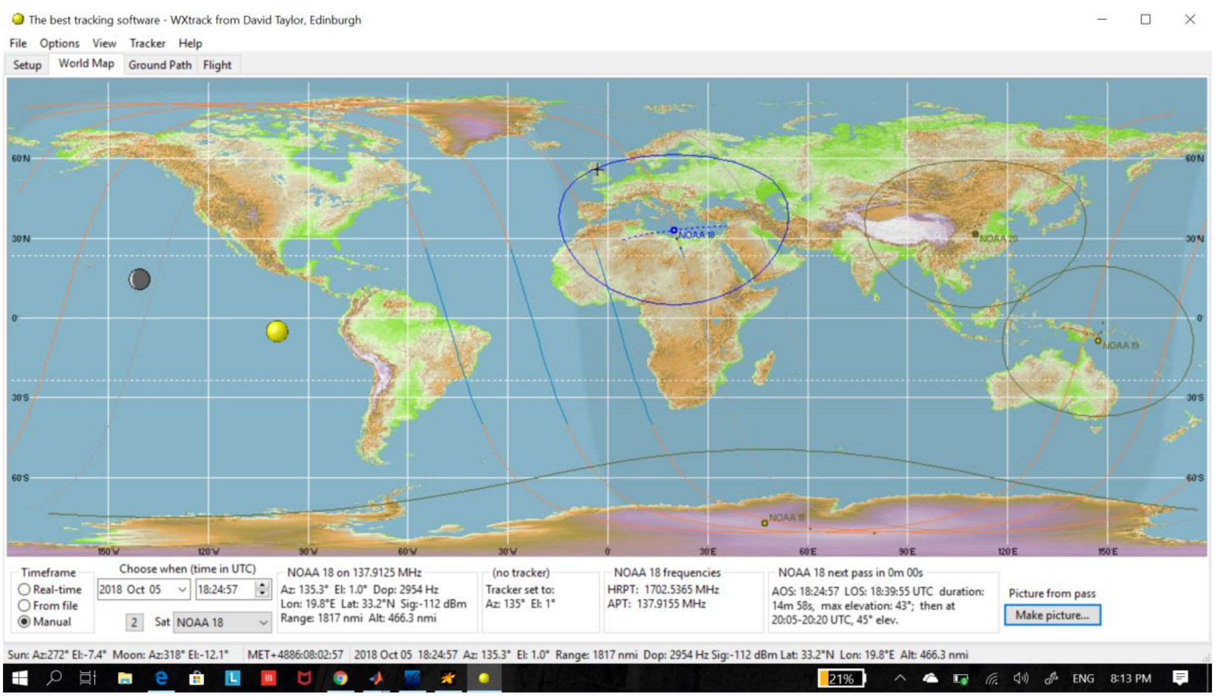


Figure 58 Screenshot of satellite prediction through WXtrack

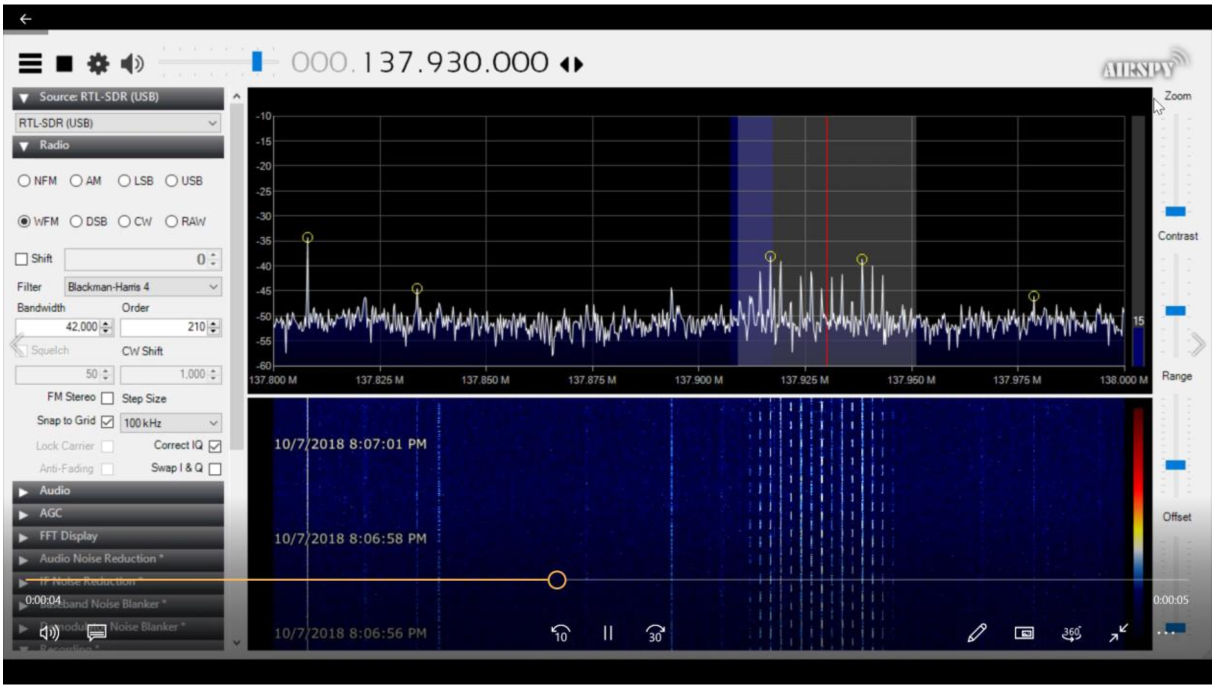


Figure 59 Image of tuned NOAA-18 frequency with dispersed signal in SDR#

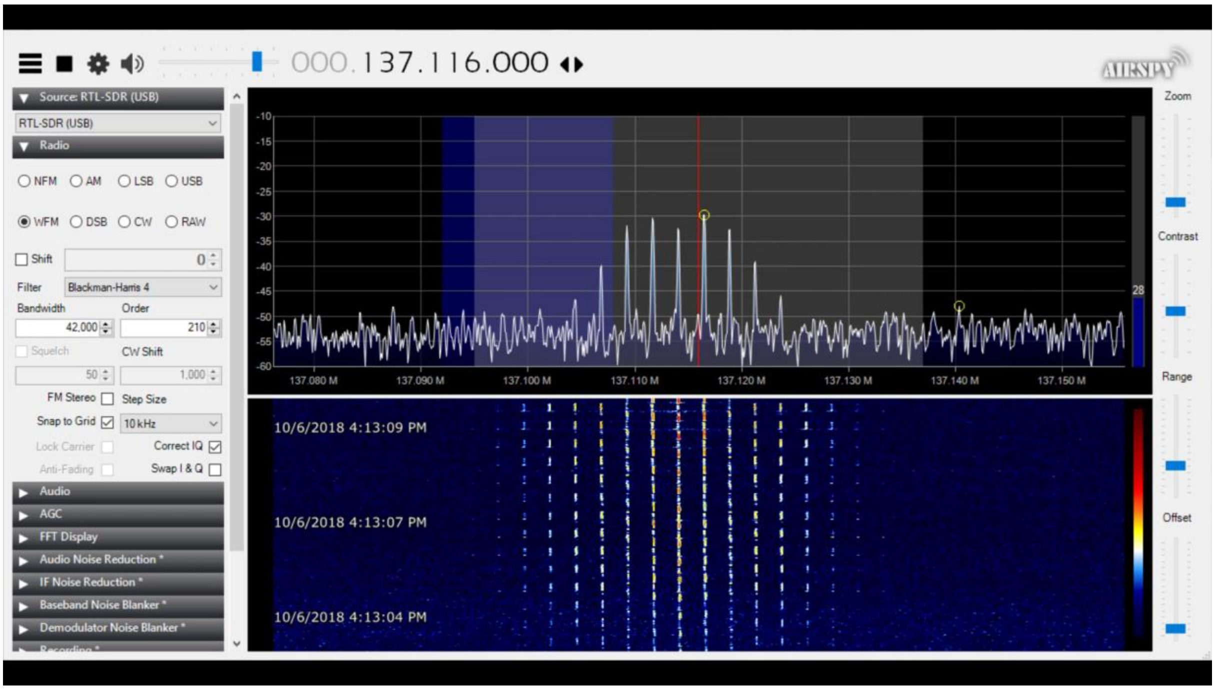


Figure 60 Image of tuned NOAA-19 frequency in SDR# with clear signal

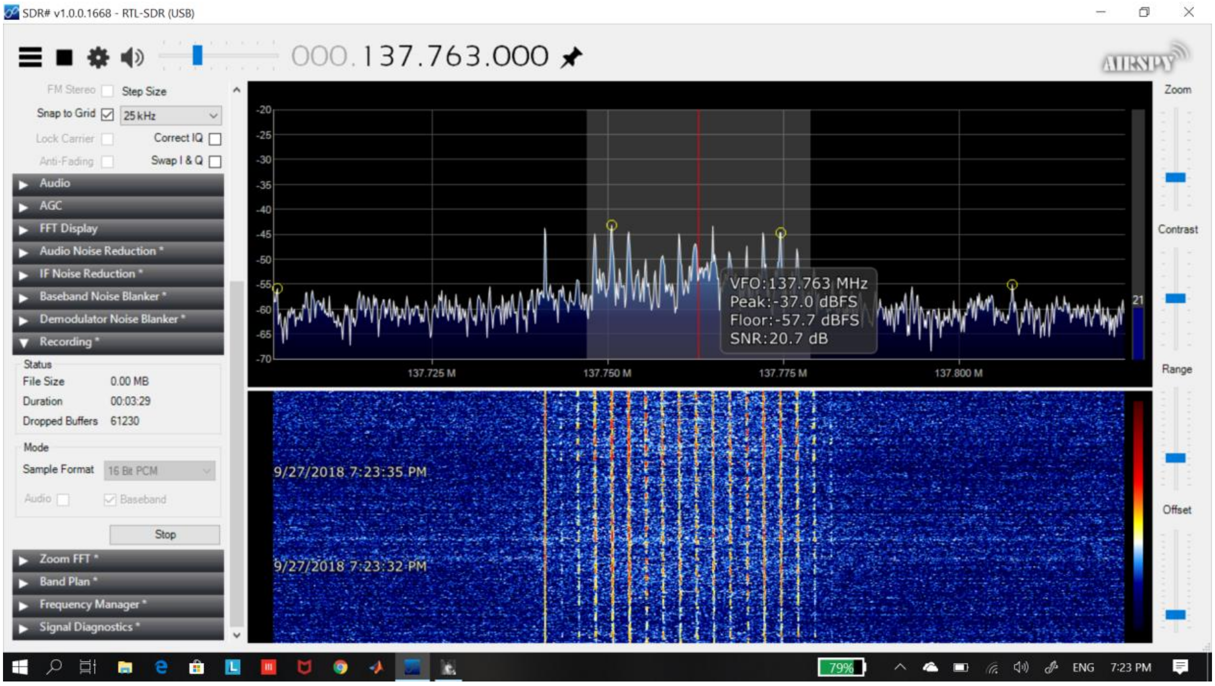


Figure 61 Tuned NOAA-15 frequency signal in SDR# with noise and distortions

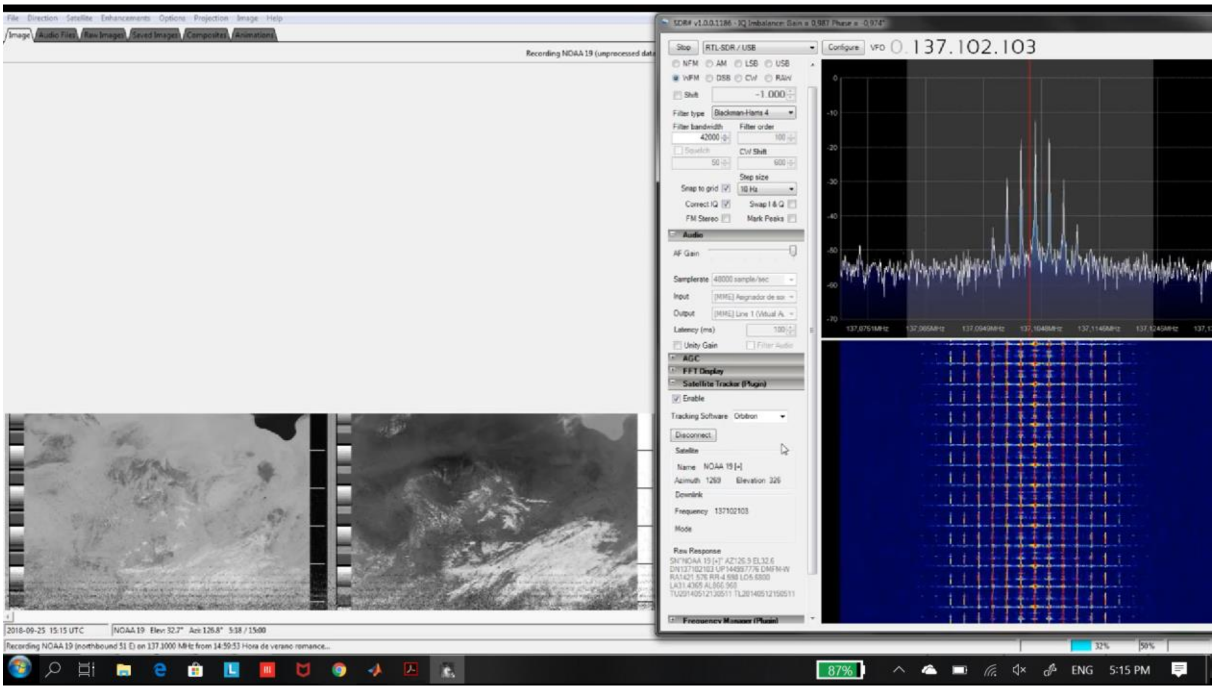


Figure 62 Screenshot of signal reception with image processing using WXtoImg

In the above screenshot, both SDR# and WXtoImg software are seen at the same time, while SDR# tuning the frequency for NOAA-19 and passing the received signal to WXtoImg for image decoding as could palette or channel A and B.

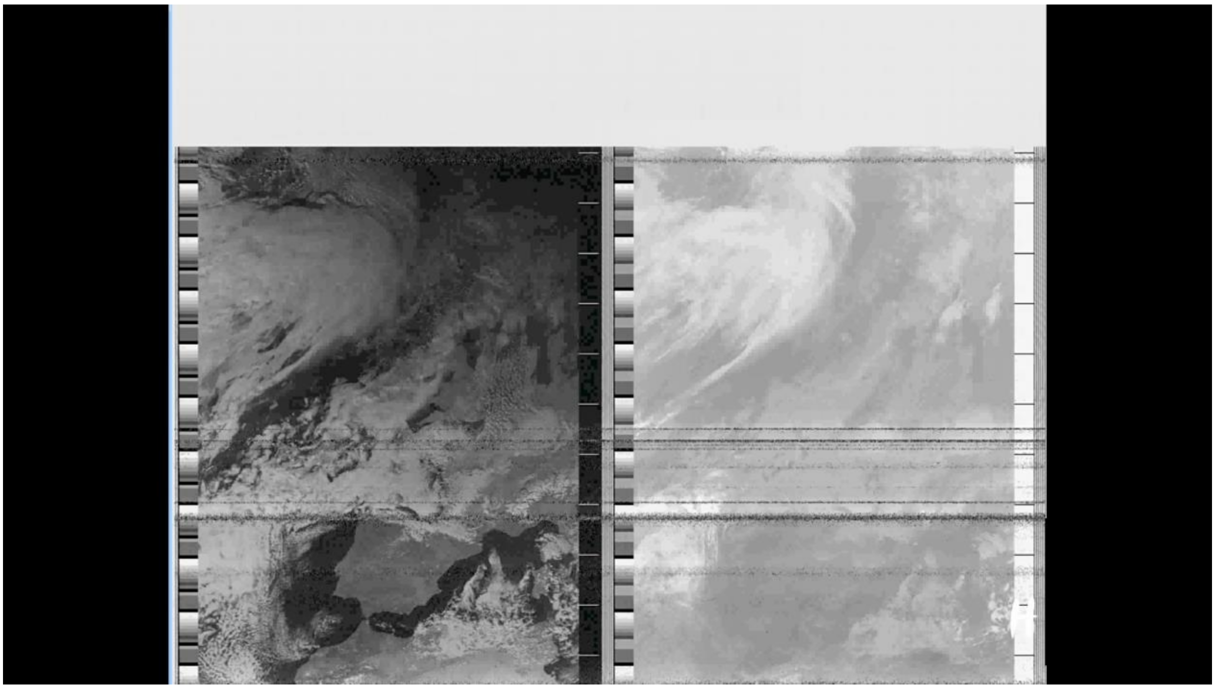


Figure 63 Screenshot of Channel A and B with weather formations – APT Grey Scale Palette using WXtoImg

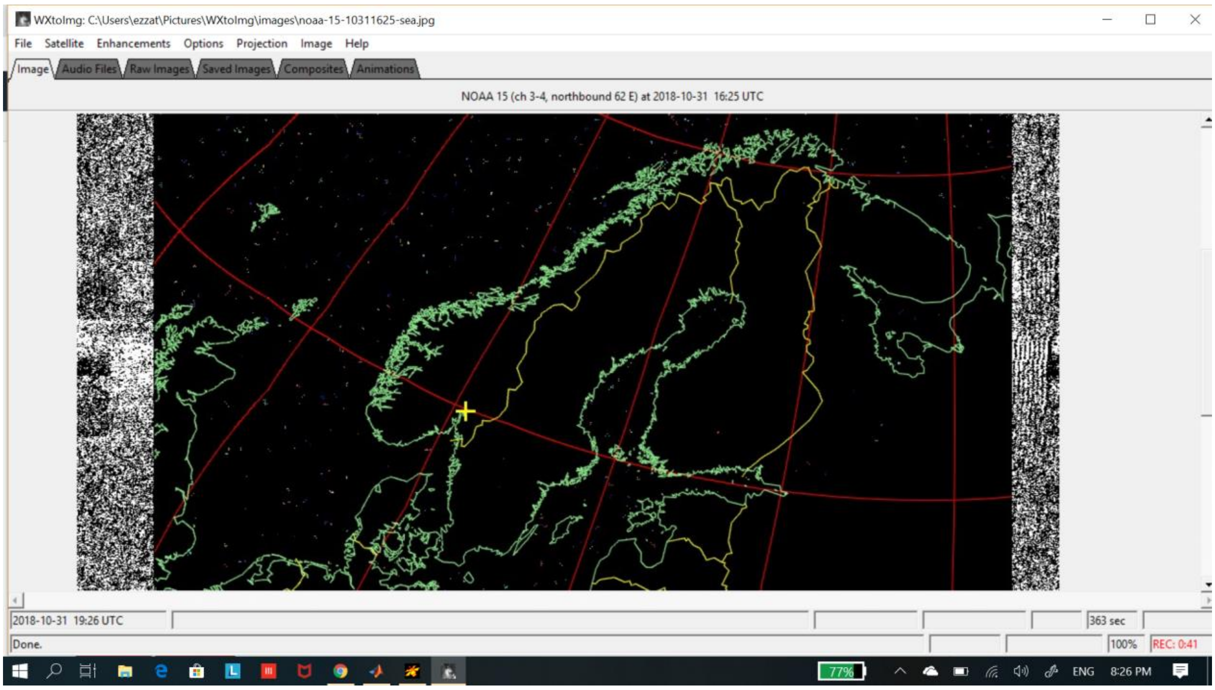


Figure 64 Screenshot of night image with clear land border image in abc mode using WXtoImg

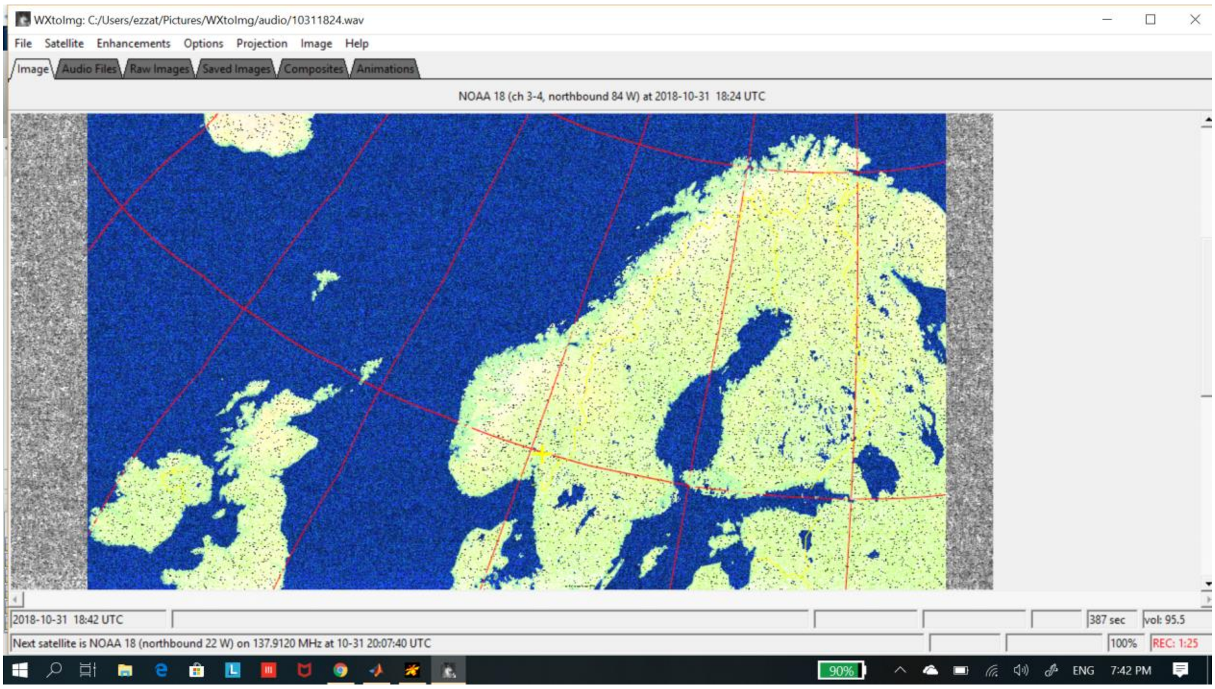


Figure 65 Image with of NOAA-18 in vegetation mode using WXtoImg

Vegetation mode: Requires the rarely available NOAA APT sensor 1 and 2 images (seen during the test phase after satellite launch). A vegetative index is built up and this is used so that land will be colored green, water dark blue, and clouds white. No palette is used for this enhancement and the output is not temperature normalized.

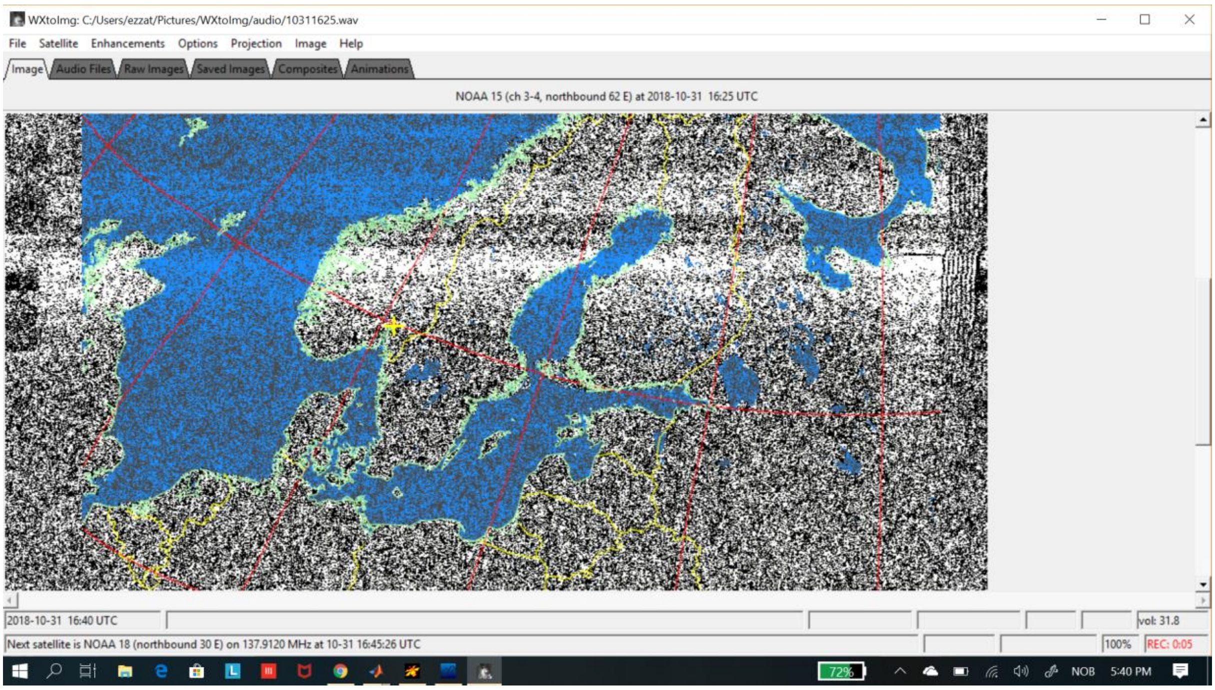


Figure 66 Image with noise and distortion in vegetation mode using WXtoImg

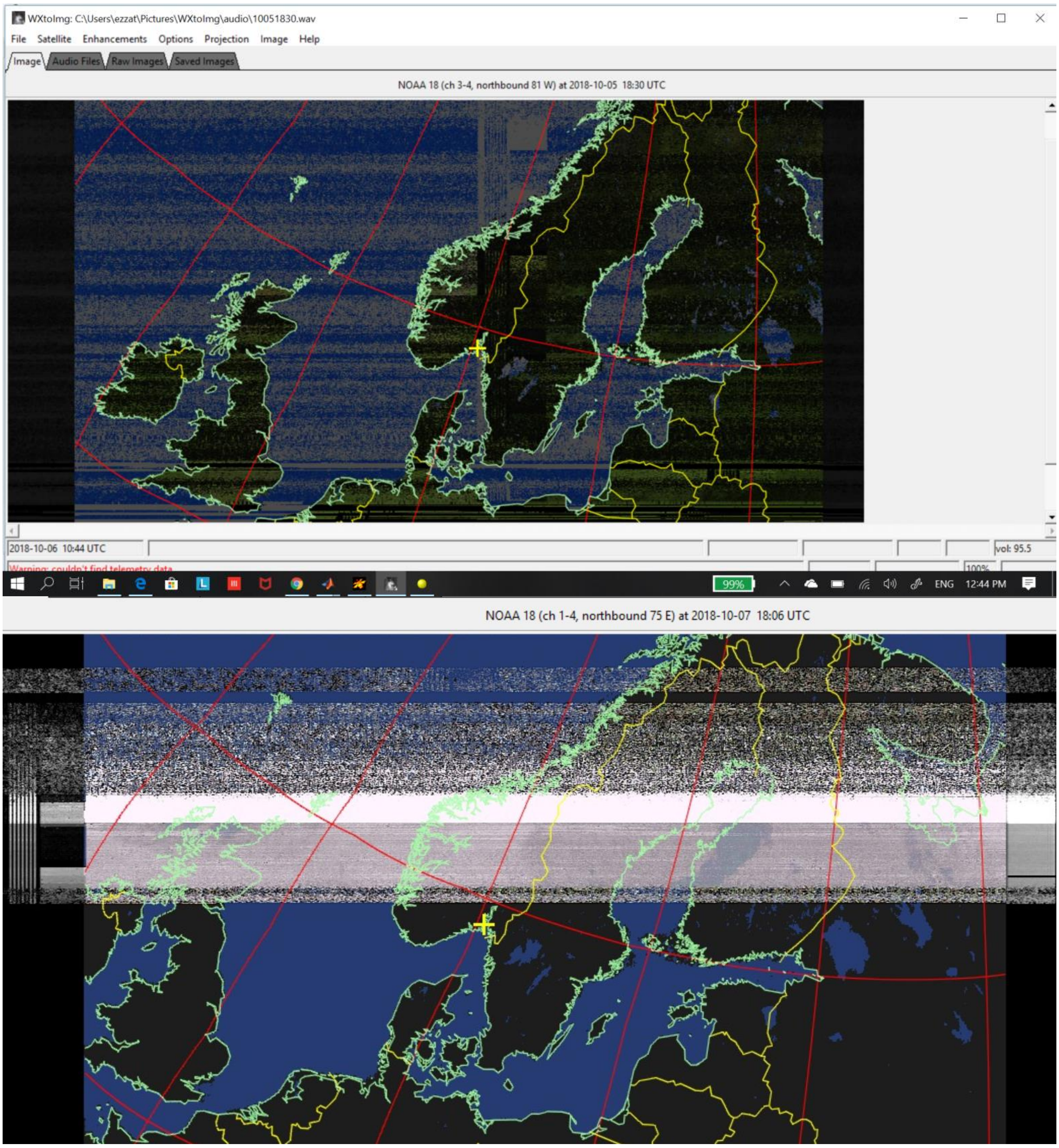


Figure 67 Image with noise and distortion in sea surface temperature mode using WXtoImg

Sea surface temperature mode: Creates a false color image from NOAA APT images based on sea surface temperature. Uses the sea surface temperature derived from just the sensor 4 image to color the image. Land appears black and cold high cloud will also appear black. The sea surface temperature is blue but may be incorrect due to the presence of low cloud, or of thin or small clouds in the pixel evaluated, or from noise in the signal. The above two screenshots show the noise and distortion which changed the sea color to greyish, also the white tape shows that the mode is changed during the process.

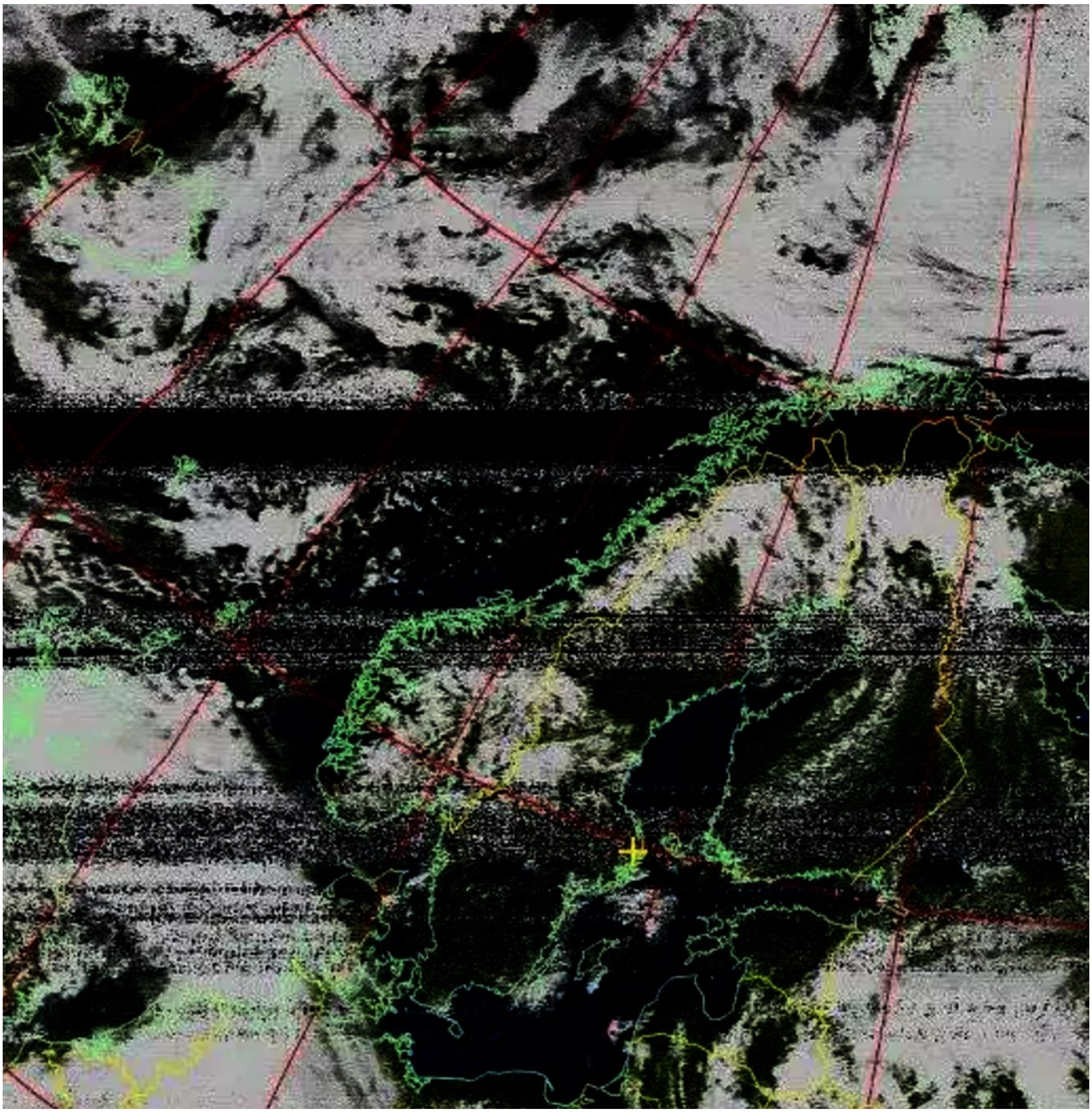


Figure 68 Image showing clouds with some noise and distortion using WXtoImg

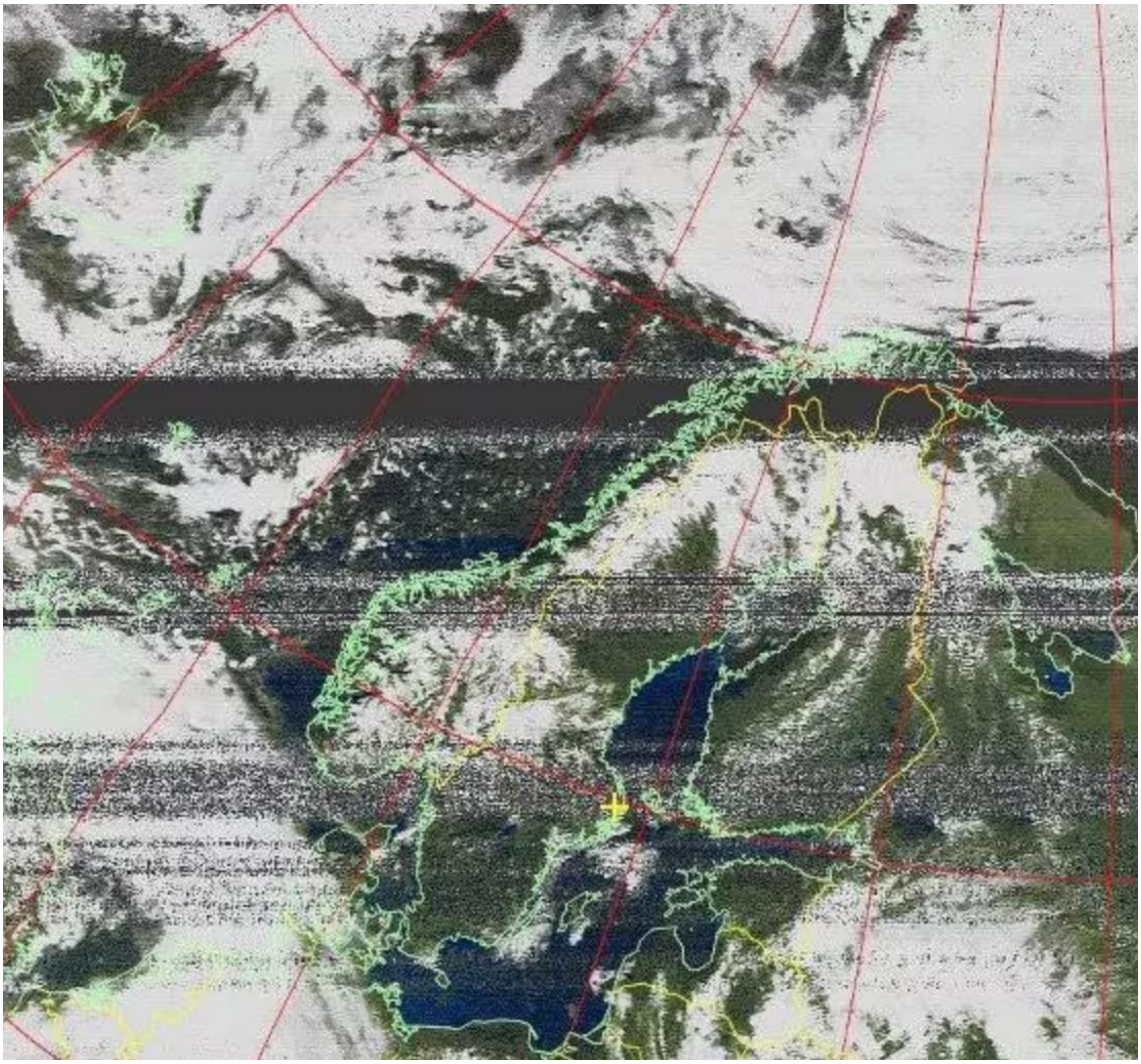


Figure 69 Image showing clouds with noise and distortion using WXtoImg

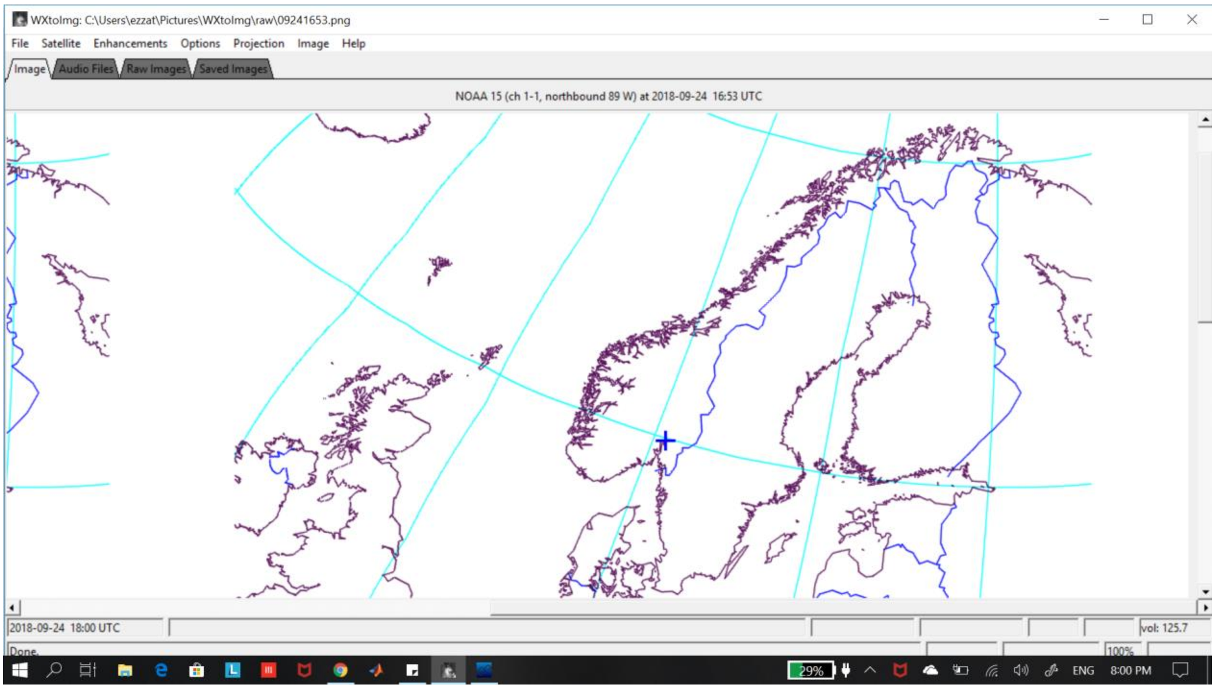


Figure 70 Processed image from NOAA-15 in WXtoImg which is clear negative colors

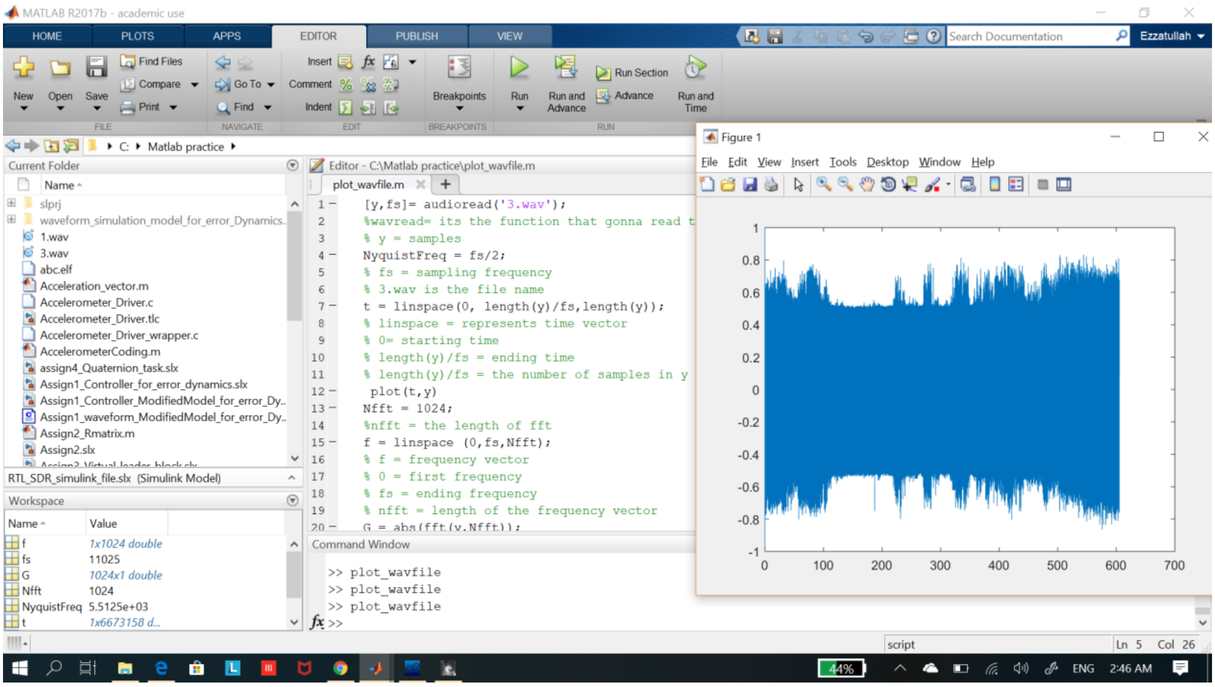


Figure 71 Decoded audio (.wav) file recorded from satellite with noise and distortion through spectrum analyzer using MATLAB

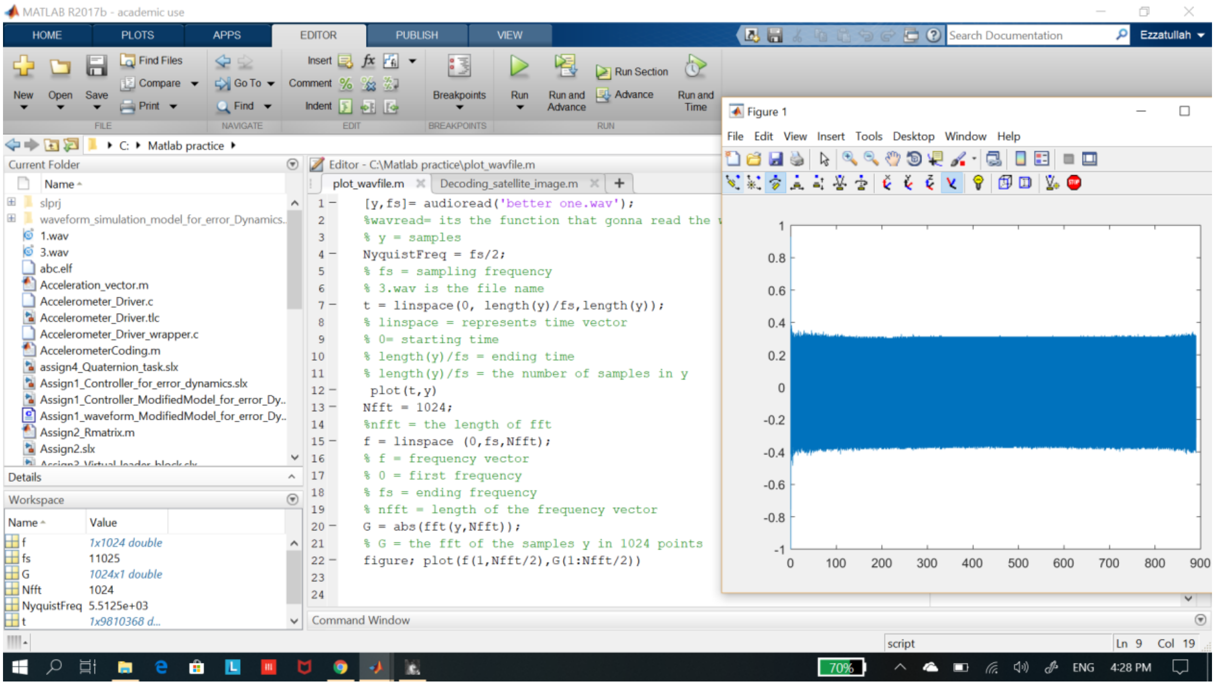


Figure 72 Decoded audio (.wav) file recorded from satellite with no noise through spectrum analyzer using MATLAB

The above two images are the audio recoded through SDR# software and decoded in MATLAB which are shown in spectrum analyzers. The first image is full of noise and distortion while the second one is free from noise.

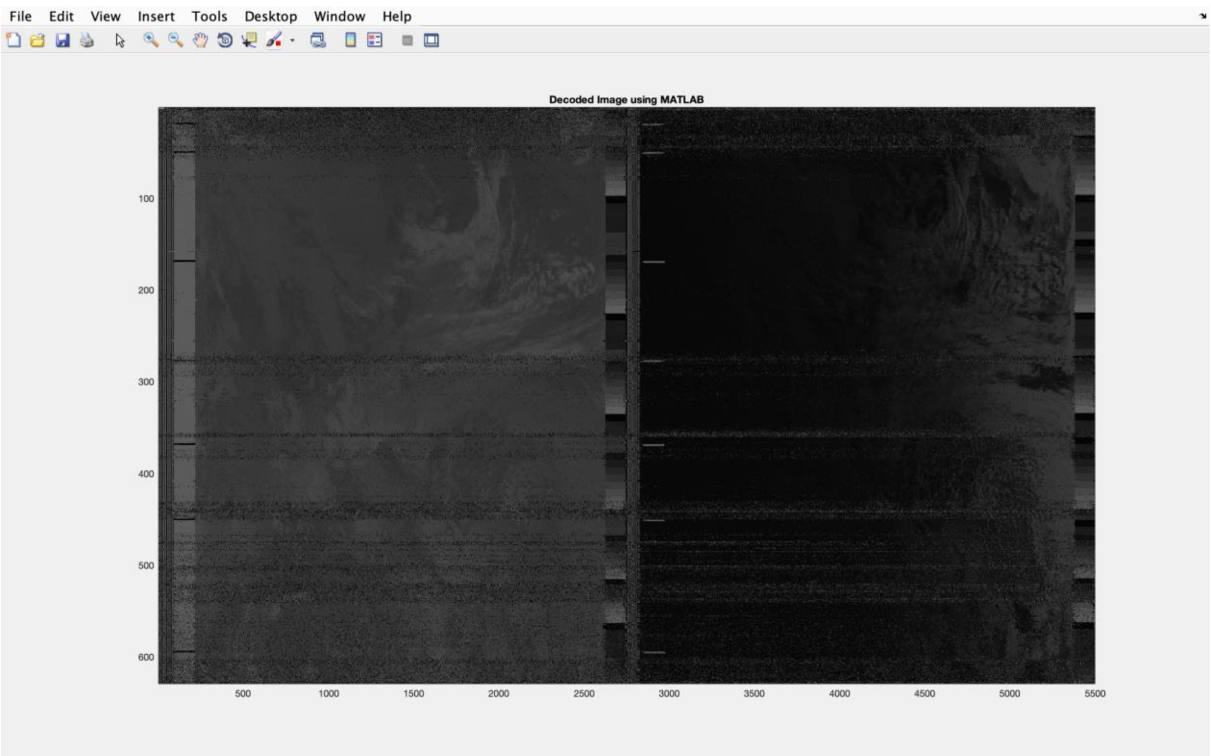


Figure 73 The screenshot demonstrates dark cloud palette of channel A and B with a bit of noise

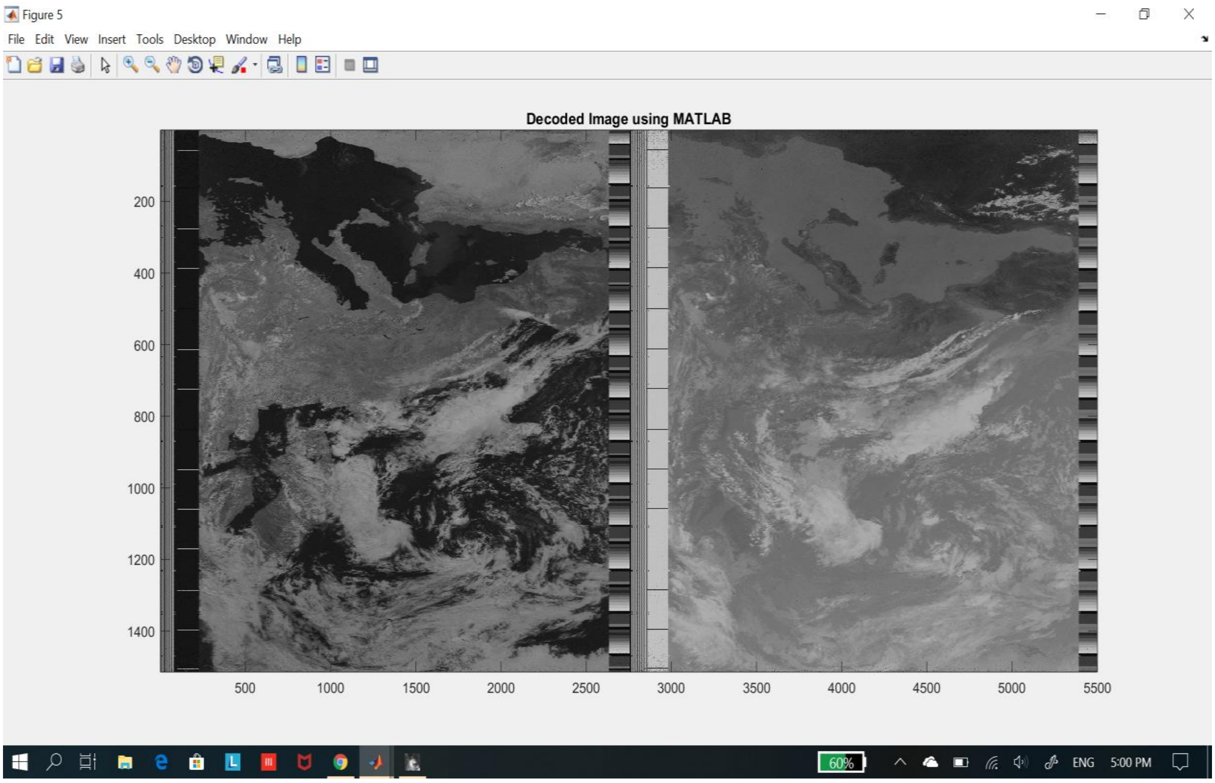


Figure 74 Decoded audio (.wav) file to cloud palette image with better result using MATLAB

The second image (Figure 71) shows a better-quality image of the sea, ground and cloud compare to the image in Figure 70.

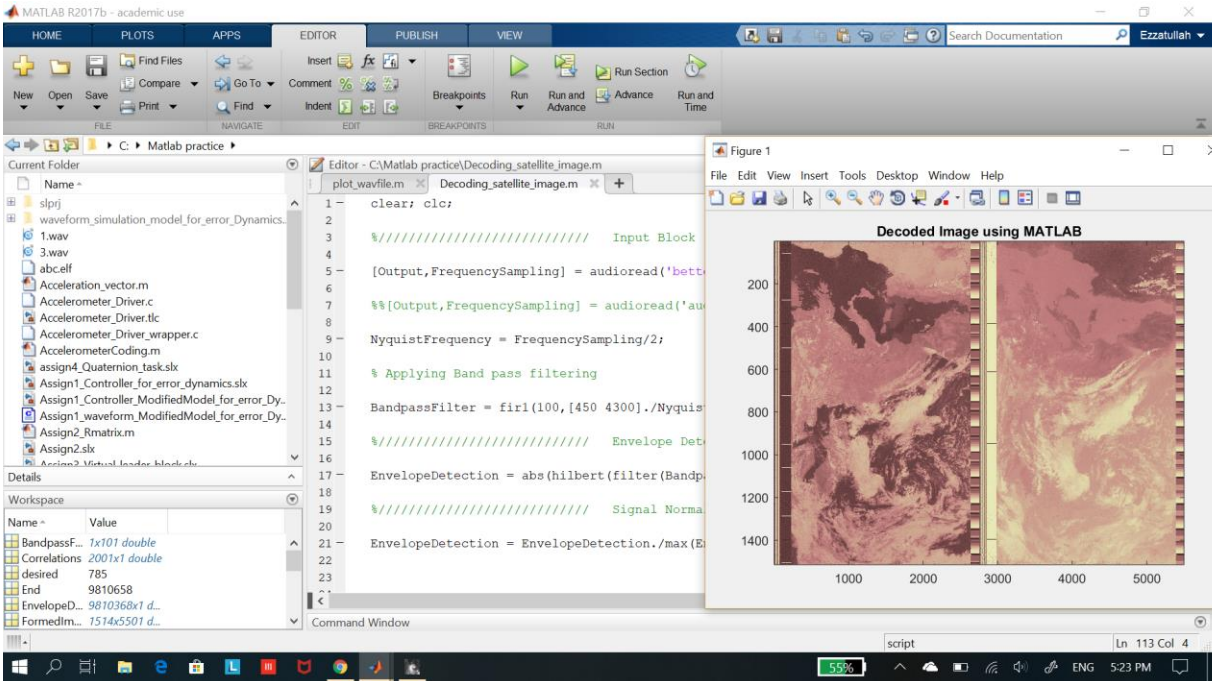


Figure 75 Decoded audio (.wav) file inverted image to cloud surface temperature using MATLAB

.

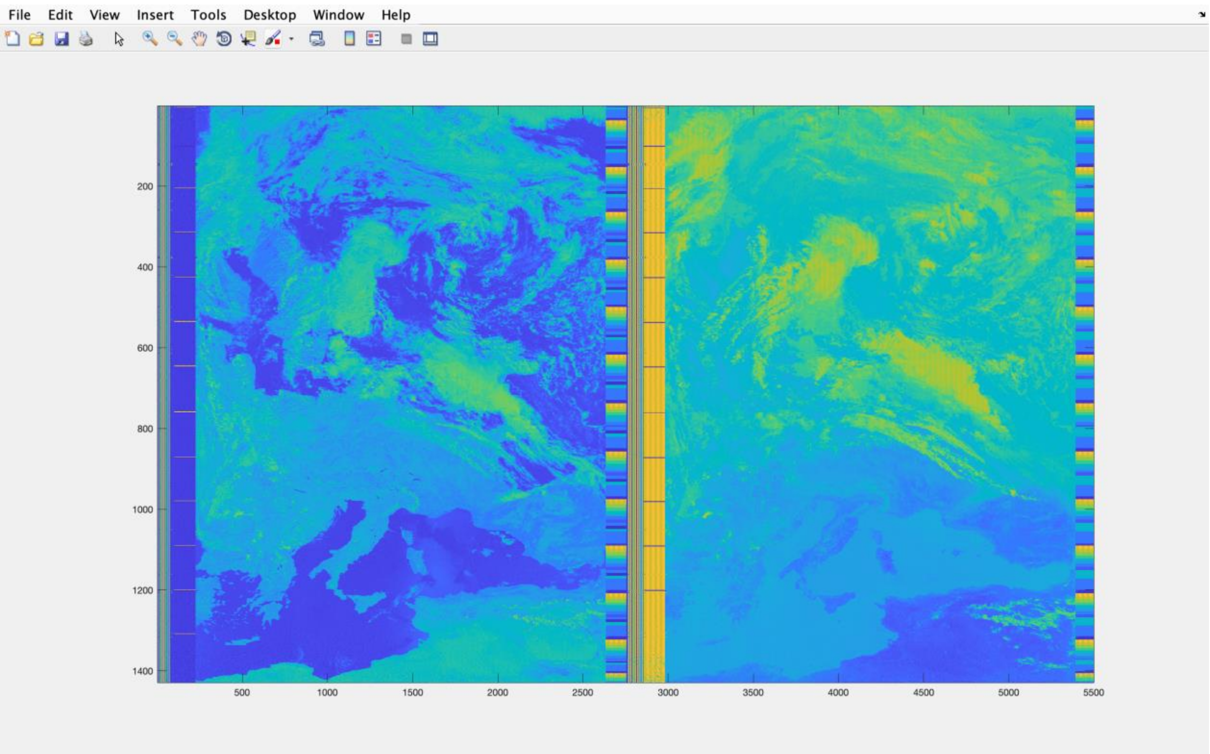


Figure 76 The above image shows cloud temperature in false color. It is a good way of visualizing cloud temperatures using MATLAB.

7 Future Work

This Thesis has provided practical guidance on how a ground station for satellite signal reception can be built by combining low- and high-tech solutions, which can pave the way for other innovative projects using an RTL-SDR dongle, home-made antenna, MATLAB and open source software to:

- Explore FM radio stations, mobile spectrums (2G-GSM & 3G-UMTS), DVB-T digital TV signals and DAB radio signals;
- Be used as a HAM radio station;
- Detect drone and aircraft and movement;
- Receive GPS signals, and;
- Implement many other applications.

Further work can be done to enhance the current ground station and explore the possibilities of developing other low-cost solutions to gain access to other satellite remote sensing applications.

RTL-SDR dongle Pro+ or HackRF-one are advanced versions that can be used for receiving HRPT (High resolution) signals. Aside from using MATLAB and WXtoImg software, GNU-radio can be used to design and build a receiver to recover satellite signals. Alternatively, to the Tunstile antenna, a quadrifilar-Helix antenna, which is also circularly polarized, and have strong signal reception capability can be used.

MATLAB can be used to develop different algorithm for thermal maps generation, based on the analysis of the infrared images.

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List of Acronyms

ADACS	Attitude Determination and Control System
ADC	Analogue to Digital Converters
AGS	Afghan Geological Survey
AM	Amplitude Modulation
AMSU	Advanced Microwave Sounding Unit
ANDMA	Afghanistan National Disaster Management Authority
ATP	Automatic Picture Transmissions
ATOVS	Advanced TIROS Operational Vertical Sounder
AVHRR	Advanced Very High-Resolution Radiometer
BDA	Beacon Transmitting Antenna
CCS	Command and Control System
DAB	Digital Audio Broadcasting
DCS	Data Collection System
DHS	Data Handling System
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V
DSP	Digital Signal Processor
EPS	Electrical Power System
EPS	EUMETSAT Polar System
ESA	Earth Sensor Assembly
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FFT	Fast Fourier Transform
FGPA	Field-Programmable Gate Array
FM	Frequency Modulation
FSW	Flight Software
FY	Feng Yun
GAC	Global Area Coverage
GEO	Geostationary Orbit
GHz	Gigahertz
GOES	geostationary Operational Environmental Satellites
GPS	Global Positioning System
GVAR	Glyph Variations Table

HEO	Highly Elliptical Orbit
HIRS	High Resolution Infrared Radiation Sounder
HRPT	High Resolution Picture Transmission
IJPS	Initial Joint Polar Orbiting Satellite System
IMP	Instrument Mounting Platform
IQ	In-Phase / Quadrature-Phase
IR	Infrared
JPS	Joint Polar System
KHz	Kilohertz
LAC	Local Area Coverage
LEO	Low Earth Orbit
LNA	Low-Noise Amplifier
LRIT	Long Range Identification and Tracking
LRPT	Low Rate Picture Transmission
MEO	Medium Earth Orbit
MEPED	Medium Energy Proton / Electron Detector
MHS	Microwave Humidity Sounder
MHz	Megahertz
MMIC	Monolithic Microwave Integrated Circuit
NAC	Norwegian Afghanistan Committee
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering & Safety Center
NOAA	National Oceanic and Atmospheric Administration
NOAASIS	NOAA Satellite Information System
NPP	National Polar-orbiting Partnership
OSKAR	Observing Systems Capability Analysis and Review Tool
PACS	Polar Acquisition and Command System
POES	Polar Operational Environmental Satellites
RCS	Reaction Control Subsystem
REA	Reaction Engine Assembly
SAD	Solar Array Drive
SAR	Search and Rescue
SARP	Search and Rescue Protector
SARR	Search and Rescue Repeater
SBA	S-Band Transmitting Antenna
SBUV	Solar Backscatter Ultraviolet Radiometer

SDR	Software Defined Radio
SEM	Space Environment Monitor
SLA	Search and Rescue Transmitting Antenna (L-Band)
SOA	S-Band Omni Antenna
SRA	Search-and-Rescue Receiving Antenna
TCXO	Temperature Compensated Oscillator
TED	Total Energy Detector
TIROS	Television Infrared Observation Satellite
UCS	Union of Concerned Scientists
UDA	Ultra High Frequency Data Collection System Antenna
UHF	Ultra High Frequency
UN	United Nations
UN OCHA	UN Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office for Outer Space Affairs
US	United States
UTC	Coordinated Universal Time
VHF	Very High Frequency
VRA	Very-High-Frequency Real-time Antenna
WMO	World Metrological Organizations

Appendix No. 1: MATLAB Coding – Spectrum analyser

The following MATLAB coding are to show the audio (.wav) file recorded in SDR# in spectrum analyser.

```
[Output,FrequencySampling]= audioread('new.wav');

% wav read = it is the function that going to be read the audio(.wav) file
% Output = samples
% Frequency Sampling = sampling frequency
% 3.wav is the file name

NyquistFrequency = FrequencySampling/2;
% Sampling frequency is divided by 2 according to Nyquist theorm.
t = linspace(0, length(Output)/FrequencySampling,length(Output));
% linspace = represents time vector
% 0 = starting time
% length(Output)/FrequencySampling = ending time
% length(Output) = the number of samples in Output
 plot(t,Output)
Nfft = 1024;
%nfft = the length of fft
f = linspace (0,fs,Nfft);
% f = frequency vector
% 0 = first frequency
% fs = ending frequency
% nfft = length of the frequency vector
G = abs(fft(y,Nfft));
% G = the fft of the samples y in 1024 points
figure; plot(f(1,Nfft/2),G(1:Nfft/2))
```

Appendix No. 2: MATLAB Coding – Signal Decoding.

Decoding and converting the audio (.wav) file to cloud image taken from the NOAA POES satellites.

```
%////////////////////////////   Input Block   ////////////////////

[Output,FrequencySampling] = audioread('abc.wav'); % Read the audio file // wav file
%%[Output,FrequencySampling] = audioread('.wav file name');
NyquistFrequency = FrequencySampling/2;                    %NyquistFrequency

% Applying Band pass filtering
```

```
BandpassFilter = fir1(100,[500 5000]./NyquistFrequency,'bandpass');

%///////////////////////////  Envelope Detection  ////////////////////
EnvelopeDetection = abs(hilbert(filter(BandpassFilter,1,Output)));   % Hilbert transform

%///////////////////////////  Signal Normalization  ////////////////////
EnvelopeDetection = EnvelopeDetection./max(EnvelopeDetection);   % Signal Normalization
.. -mean / Standard deviation (max-0)
figure(1)
plot(BandpassFilter)
title('bandpass filter')
drawnow


%////////////////  Signal Synchronization  ///////////////
Time=0:1/FrequencySampling:1/125;
SyncPulse = (square(1000*Time*(2*pi)));  % Generating start pulse wave (which is square
pulse)

% Correlation the SynchPulse and signal'

Threshold = 6;    %  The value of the pulse(Correlation) is compared to the threshold value
set
scan_window = 1000;            % defining scanning window
img_length = 5500;             % defining image length

figure(2)
plot(SynchPulse)
title('start pulse')
drawnow

% ///// Scanning slices of signal till start pulse is located //////////

Start=1;                    % initilizing start postion of signal
k=1;                        % initilizing k (stores the position of start pulses found)

while(Start+scan_window <= length(EnvelopeDetection))      % loop to scan whole filted
signal

 [Correlation,lags] = xcorr(EnvelopeDetection(Start:Start+scan_window),SynchPulse); %
scanning to detect start pulse
 [MaxIndex,OutputIndex] = max(abs(Correlation));        % checking the maximum
correlation found
 if MaxIndex > threshold                    % if correlation is above than the threshold
value, take the data as start pulse
   Desired = lags(OutputIndex);                 % checking where exactly the correlated data
found in scanning window
```

```
   start_pulses(k)=Start + Desired;                % save the start pulse location in start_pulses
array to use in future
   k=k+1;                           % increment the k by 1
 end
 Start = Start + scan_window;               % slide the scanning window to next scanning part
end
for i=1:length(start_pulses)               % loop to build the image using start pulses location
   img(length(start_pulses)-
i+1,:)=EnvelopeDetection(start_pulses(i):start_pulses(i)+img_length);     % crop the signal
just after start pulse upto image length
   if(i==1)
      figure(3)
      plot(EnvelopeDetection(start_pulses(i):start_pulses(i)+300));
      title('first row with start pulse')
      drawnow
   end
end
figure(4)
imagesc(img)
drawnow
colormap('gray')
title('Decoded Image using MATLAB')
drawnow
```