Ground Station Design

AcubeSAT-COM-BC-027

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Contents

Changelog

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1 Introduction

AcubeSAT's Comms subsystem is responsible for providing a reliable communication link between the satellite and the Earth. To do so, it is required to build a Ground Station on Earth which will be able to receive the payload and telemetry data and transmit the necessary telecommands. What this actually means, is to design a structure consisting of antennas, amplifiers, filters, SDRs, cables and processors, capable of accepting, at first, the desired (in terms of frequency and power) electromagnetic waves. Additionally, it will decode and demodulate the information being "carried" on these waves and convert it to a form able to be understood by humans. Having successfully decoded the signal, we will be in a position to analyze our telemetry data in order to ensure the continuity of our mission as well as process our experiment's data to investigate eukaryotic cells' behavior in microgravity.

Regarding the aforementioned, it is quite obvious that this report is going to present **the location**, **the current design and the components of ASAT's Ground Station**. To be more precise, we begin by investigating the requirements of our mission regarding the GS. Afterwards, we'll describe the whole design and at last, we are going to focus on the components needed for the communication links and specifically speak about the parameters we need to take into consideration.

2 Requirements of AcubeSAT's Mission

In our mission we will make use of the radio amateur frequency bands and particularly, 2.4-2.45 GHz S band for the payload data and the 435-438 MHz UHF band for the TT&C, applying Time Division Multiplexing. The fundamental factor which led us to utilize S band is the large amount of payload data. To explain, a high data rate or a large communication window is necessary while images are going to be transmitted.

Having said that, it becomes quite clear that our **Ground Station** will operate on:

- **2.4-2.45 GHz S band** for downlinking the payload data
- **435-438MHz UHF band** for downlinking the housekeeping data and uplinking the telecommands.

2.1 The SatNOGs Network

Building our own Ground Station in Thessaloniki will provide us with three passes of five minutes duration, on average, per day. Considering the bit rate and the amount of data to be transmitted, it seems unfeasible to achieve our goal.

Taking into account the above requirements and constrains, AcubeSAT's Communications subsystem, decided to **be a part of** and contribute to the **Global Ground Station Network** SatNogs. Not only will AcubeSAT increase the number of passes and extend the contact time but the members of Comms subsystem will also benefit from participating in an open source, across geographical boundaries project. To explain further, AcubeSAT will be able to downlink in every SatNOGs' station as long as it is compatible with our Comms subsystem. However, uplinking through SatNOGs' stations is not feasible. Given that we won't be able to start the downlink transmission through a telecommand, we are currently working on variable ideas to tackle this issue.

3 ASAT's Ground Station

3.1 Location, Geographical Coordinates and Altitude

As we have already mentioned **ASAT GS** will be located in the centre of Thessaloniki and precisely on the roof of **Building D**, which belongs to **the Polytechnic School of Aristotle University of Thessaloniki.** In Figure 1 we can see the Faculty of Engineering and the location of Building D. According to latlong and freemaptools the geographical coordinates and altitude are:

- **Latitude:40.627233**
- **Longitude:22.959887**
- **Altitude[1]:29m/95.1 feet**
- **Height of the building** $h \approx 27m$
- **Total Altitude of GS**: $27 + 29 = 56m$

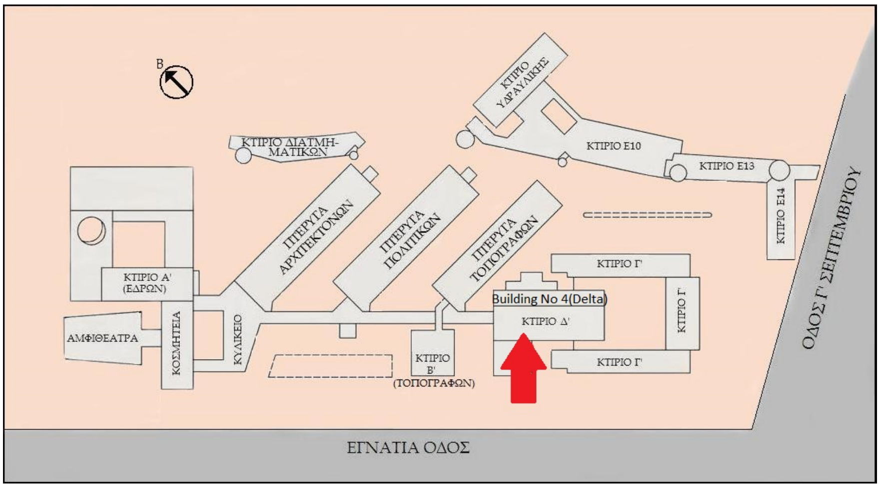
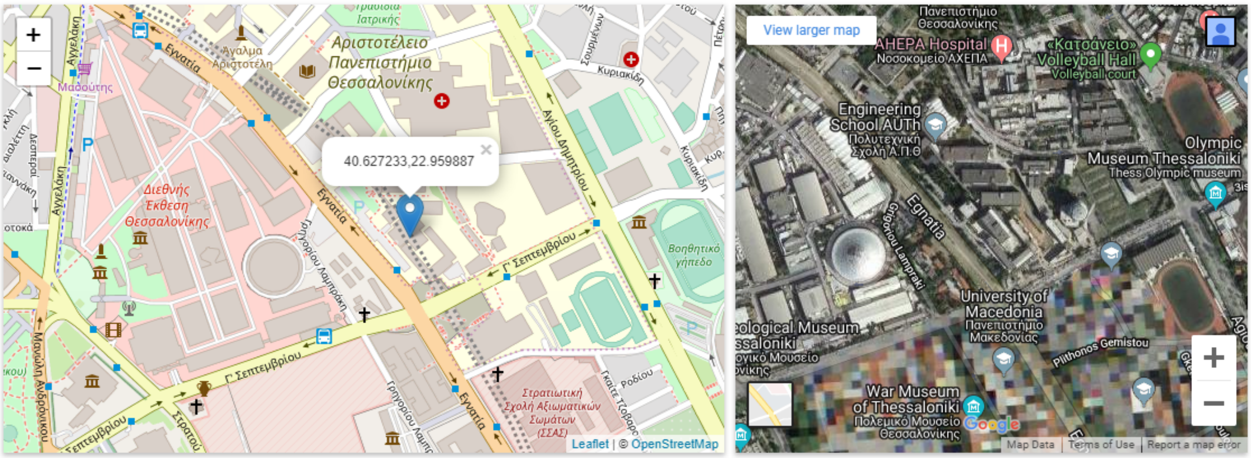


***Figure 1**: Map of the faculty of engineering of Aristotle University of Thessaloniki*

[1]height above mean sea level



Lat Long	GPS Coordinates
(40.627233, 22.959887)	40° 37' 38.0388'' N 22° 57' 35.5932'' E

Figure 2: *Geographical coordinates of ASAT Ground Station*

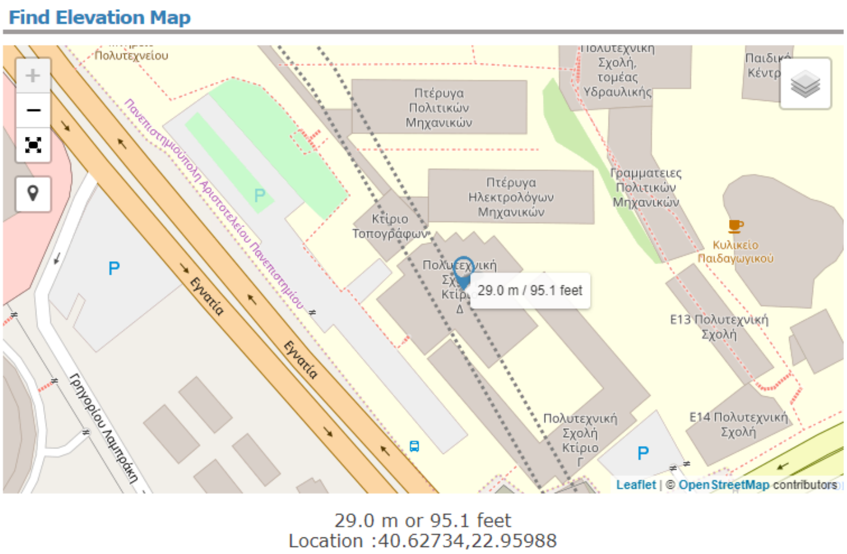


Figure 3: *Altitude of ASAT Ground Station*

3.2 Current Design

At this point we will briefly describe the block diagram of ASAT's GS. We encourage you to study the specific subsection that focuses on each component for further understanding.

Firstly, as a tracking mechanicm we are going to use this Rotator, where **both of the antennas** operating on different frequency bands will be mounted. With regards to the antenna of the S band radio we opted for TL-ANT2424B. It will provide us with a **24dBi Gain** which is an adequate value to achieve the desirable link margin as we will

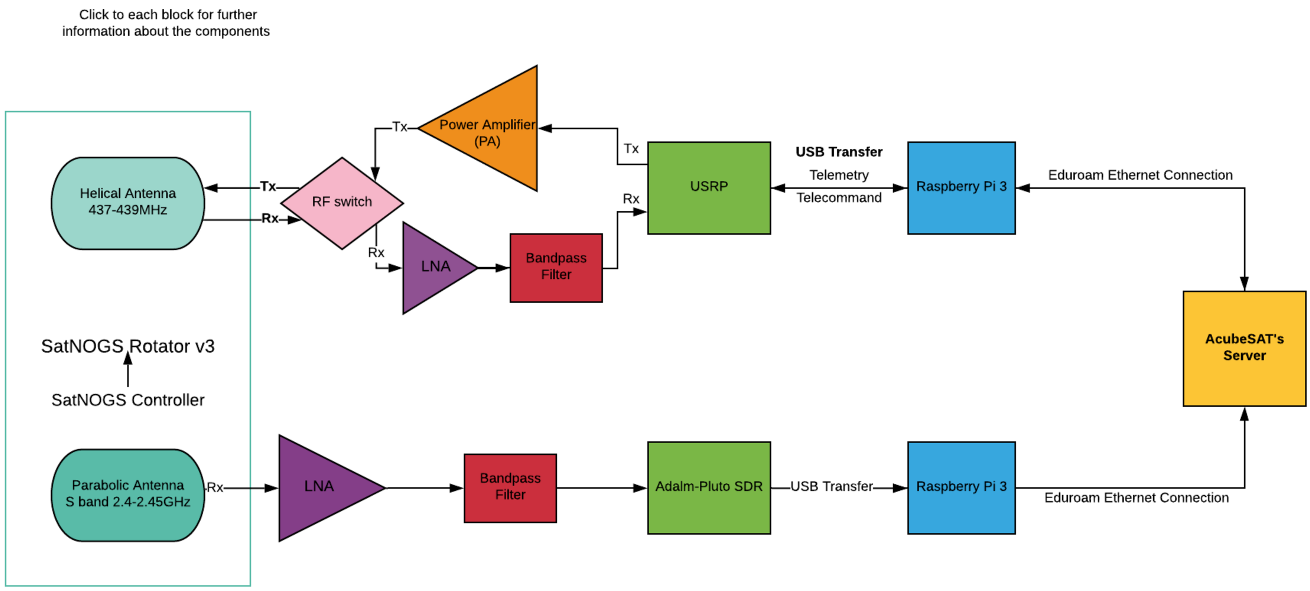


***Figure 4**: ASAT Ground Station*

explain later in this report. Afterwards, the signal goes directly to the Bandpass Filter so as to allow only the desirable frequencies to pass through and be amplified by the Low Noise Amplifier which comes next. After having been amplified, the signal travels to Adalm-Pluto SDR. When the Analog to Digital conversion and the digital processing have been completed, what comes next is the transmission of the digital signal to the Raspberry Pi 3. A USB connection has been assumed the most suitable choice for this transfer. At last, the Raspberry will utilize the **Eduroam Ethernet Connection** so as to send the payload data to our server.

As far as the **UHF link** is concerned, we have already mentioned that the downlink and uplink will utilize the same frequencies by applying Time Division Multiplexing. Therefore the Helical antenna is connected straight forward to the RF switch which is also called circulator or duplexer. This device allows the received and transmitted signals to follow separate paths. With regards to the latter, the telecommands in the form of digital data are being transferred from AcubeSAT server to the Raspberry Pi 3 by Ethernet Connection. By a USB cable the data will reach the RTL-SDR where the Digital Processing and the Digital to Analog conversion take place. Then the signal goes directly to the Power Amplifier in order to be boosted and reach to a desirable power level. After the amplification, the telecommands in the form of electromagnetic waves travel through the circulator to the Helical Antenna. On the receiver side, the signal after the RF switchfollows a similar route to the signals received from the S band antenna. The route begins with a bandpass filter followed by the LNA and the RTL-SDR or USRP. As we described earlier the SDR is connected by USB to Raspberry Pi 3 which leads the digital data to AcubeSAT's server.

3.3 Rotator

An **antenna Rotator** is a device used to change the orientation, of a directional antenna. Most antenna rotators have two parts, the **rotator unit and the controller**. The controller is normally placed **near the equipment** which the antenna is connected to, while the rotator is mounted on the antenna mast directly below the antenna. Both of the antennas we have opted so far are directional. This means that a tracking mechanism is required to follow the orbit of the satellite. Therefore, we are going to build the SatNOGS Rotator v3, which we can see in Figure 5, along with the SatNOGS Rotator Controller.

Figure 5: *SatNOGS Rotator v3*

3.4 Antennas

In radio engineering, what is usually called an antenna is **the interface between radio waves propagating through space and electric currents moving in metal conductors**. There is no doubt that it comprise an essential component of all radio equipment.

Main parameters to be considered while selecting an antenna:

- **Gain**. It comprises a key performance number which combines the antenna's directivity and electrical efficiency. It describes how well the antenna **converts input power into radio waves** when operates in transmitting mode and the other way round when operates in receiving mode. Antenna's Gain is a parameter of great importance considering its influence to link budget calculation.
- **HPBM(Half Power Beamwidth)**
- **operating frequency**
- **design**, **installation and cost**
- **polarization**: In case the electric field of the radio waves transmitted, show a different polarization of those the antenna can receive, there will be a 3 dB power loss.

3.4.1 UHF 435-438MHz Antenna

Regarding the UHF link, we have decided to manufacture a Helical antenna operating on 435-438MHz, with RHCP (right hand circular polarization). The construction details and instructions are provided here by SatNOGS.

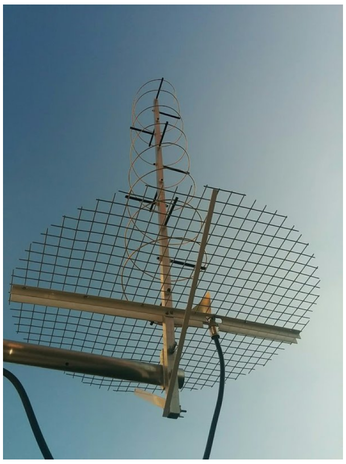


***Figure 6**: Helical Antenna operating in 435-437MHz*

Helical's antenna main characteristics:

- **Gain:12dBi**
- **RHCP**
- **operating in 435-438 7MHz**

The reasons why we selected the particular helical antenna are variable. Firstly, as long as we will use a tracking mechanism, we can utilize a **directional antenna** which will provide us a more reliable communication link due to **its directivity**. Moreover, at this moment we examine the possibility of having a turnstile antenna on AcubeSAT. The idea is that the deployable antenna which consists of two monopoles will radiate electromagnetic waves with circular polarization in case the monopoles are vertical to each other and have a 90 degrees phase offset. Thus, it is recommended to use an antenna which can receive and transmit **circular polarized** waves. The matching circuit should be designed carefully so as the input impedance to approach 50 ohm and the monopoles to show a radiation pattern similar to those that dipoles create. Last but not least, it is worth mentioning that Comms subsystem members will benefit greatly from constructing a helical antenna.

3.4.2 S band Antenna 2.4-2.45 GHz

With regards to the payload data transmission we selected the parabolic antenna presented in figure 7. Because of the limited power that AcubeSAT can provide, due to its size, it is essential to create a ground station that is able to **receive weak signals**. Thus the antenna selected for the S band should be characterized by a **high gain**. Additionally, **the size**, **mass and cost constrains** led us to choose the grid parabolic antenna TL-ANT2424B.

Its main characteristics are:

- operates in the **2.4-2.5 GHz band**
- **Gain:24dB**
- **Weather proof design**, suitable for all weather conditions
- **Installation is simple and straight forward**

***Figure 7**: Grid Parabolic Antenna operating in 2.4-2.5GHz*

3.5 RF Switch-RF Circulator

As we pointed out earlier, for the UHF link we need an RF switch in order to use the **same antenna** for transmitting the telecommands to AcubeSAT and receive the telemetry data.

What we exactly need is a **duplexer**. It's a 3-port device that allows the transmitter and receiver to use a single antenna, while operating at the same/similar frequencies. It allows two-way communication over a single channel by **isolating the receiver from transmitter**, while transmitting, and isolating the transmitter from receiver while receiving, allowing them to share **the same antenna**. In a duplexer there is **no direct path** between the transmitter and receiver. It can be thought of as a circulator(Figure 8). To elaborate, the signal from port 1 is routed to port 2 and the signal from port 2 is routed to port 3. Port 1 and Port 3 are isolated from each other.

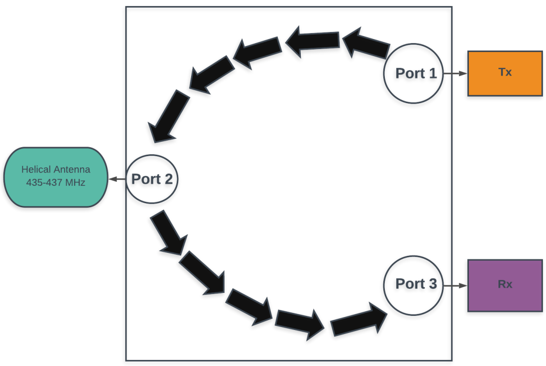


***Figure 8**: RF circulator*

The fundamental electrical parameters which characterize the performance of an RF switch are the following:

- Isolation
- Insertion Loss

- Switching Time
- Power Handling

A circulator that meets our system's characteristics is the UIYBCC5377B. Definitely, we should continue our research and compare variable such components in order to select the most suitable one for our design.

3.6 RF filter

As you may know **RF filters** are electronic components that are used to **allow or prevent selected signals or frequencies** in order to eliminate noise or pass through of unwanted signals. Having said that, placing a particular RF filter after our Ground Station's antenna and before the LNA is of great importance in order to avoid amplify the undesirable frequencies the signal may consists of. The main categories of RF filters

***Figure 9**: Mini Circuits SMA Band Pass Filter*

are the following:

- Low Pass Filter
- High Pass Filter
- Band Pass Filter

Moreover, the parameters **we need to take into account while selecting an RF filter** are the following:

- The **frequency range** that shall pass through the filter in case of a passband filter.
- The **signal power level that will pass through**, or be rejected by the filter
- The amount of attenuation allowable in the passband - **insertion loss (IL))**
- The **Group Delay** of the filter. In other words the the average time delay[2] of the composite signal suffered at each component of frequency.

As you can see in our design we use two **RF bandpass filters**, one for the telemetry and one for the payload data downlink, the former allowing the band of 435-438MHz and the latter of 2.4-2.45MHz.

3.7 Low Noise Amplifier- LNA

A Low Noise Amplifier is one of the most important parts of the RF front end. The signal received by the antenna is very close to noise level and any degradation of SNR of the signal will make the signal level go below the noise floor. This will cause the

[2]The phase delay of any filter is the amount of time delay each frequency component suffers in going through the filters (If a signal consists of several frequencies.

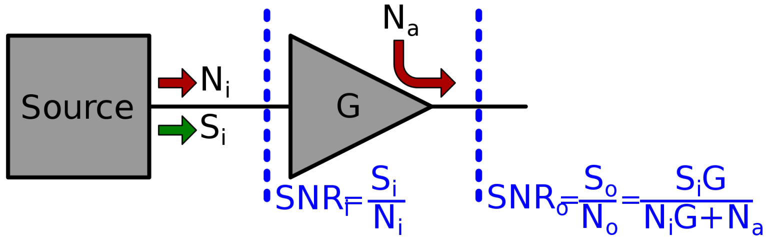


***Figure 10**: The source outputs a signal of power and noise of power. Both signal and noise get amplified. However in addition to the amplified noise from the source, the amplifier adds additional noise to its output denoted . Therefore the noise SNR at the amplifier's output is lower than at its input.*

signal to be lost. the Noise Figure of the system is mainly determined by Noise Figure of the first device if the gain is very high. As LNA has a very low noise figure and a very high gain, the noise figure of the system is very low. Parameters to be considered while selecting LNA:

- **Gain** With a low noise figure, an LNA must have **high gain.** An LNA without high-gain allows the signal to be affected by LNA circuit noise and the signal may become attenuated. As a result **LNA's high gain** is an important parameter we need to take into consideration. Like noise figures, LNA gain also varies with operating frequency.
- **Linearity** If the signal is broadband, the linearity of the LNA matters. Linearity means that the Harmonics are not produced.
  IP3 stands for **3rd order intermodulation products.** It is a well-known parameter that gauges linearity in radio frequency (RF) functions and components. As we may know linearity is a critical parameter for amplifiers thus we need to take into consideration the IP3 value when we select LNA. Speaking about LNAs, the close-by intermodulation products that occur between two or more tones in close proximity are the most detrimental.
  IP3 is linked to essential parameters such as the input and output power of a device. The design aim of amplifiers, VCO etc is **to obtain highest IP3** without sacrificing current consumption (bias circuit), gain, and size.
  We want to have this number **as high as possible** The LNA with the IP3 (OIP3) number higher the 30dBm is already considered the high IP3 LNA.
- **Noise figure (NF) and noise factor (F)** are measures of degradation of the signal-to-noise ratio (SNR), caused by **components in a signal chain.** It is a number by which the performance of an amplifier or a radio receiver can be specified, with **lower values indicating better performance.** The noise factor is defined as *the ratio of the output noise power of a device to the portion thereof attributable to thermal noise in the input termination at standard noise temperature To (usually 290 K).* The noise factor is thus *the ratio of actual output noise to that which would remain if the device itself did not introduce noise*, or the ratio of input SNR to output SNR. The **Noise Figure** is simply the noise factor expressed in decibels (dB). The noise figure helps determine the **efficiency of a particular LNA.** LNA suitability for a particular application is typically based on its noise figure. In general, a low noise figure results in better signal reception.
- **Matching Circuits** This means that the input and the output must be matched to

50 Ω for optimal performance. If there is a mismatch the signals may get reflected and damage the amplifier.

The LNA is necessary to **be as close as possible** to the antenna in order to minimize the cable losses.

3.8 High Power Amplifier-HPA

A radio frequency power amplifier (RF power amplifier) is a type of electronic amplifier that converts a low-power radio-frequency signal into a higher power signal. RF power amplifiers drive the antenna of a transmitter.

Parameters to be considered while selecting a PA

- **Gain** The gain should be large. It depends on the requirements of the link budget.
- **Input Power**: A PA consuming lower power is preferred when power is limited.
- **Maximum Input Signal Power for avoiding Saturation** If the input power is very large the device goes in saturation thus does not give the desired gain.

In our case, a Power Amplifier is essential when we transmit the telecommands regarding the uplink. You can take a closer look at the list of Power Amplifiers we have gathered so far. Each of them operates on UHF 437-438MHz.

3.9 SDR

Software-defined radio (SDR) is a radio communication system where components that have been traditionally implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on a personal computer or embedded system.

3.9.1 Adalm Pluto SDR, 2.4-2.45 GHz

The SDR we have selected for the payload data downlink is Adalm Pluto, manufactured by Analog Devices.

***Figure 11**: ADALM-Pluto SDR*

3.9.2 UHF 435-438MHz, SDR

As far as the SDR for the TT&C, it is necessary to study further the following two options:

- Lime SDR Mini
- USRP

Notes we need to take into consideration regarding the above SDRs:

- **USRP-UB210** is thought to be a wise choice considering its features. Unfortunately, its cost is significantly high. In contrast to this, **LimeMini SDR**'s cost is around 200 euros. It seems that it comprises an inexpensive way to transmit and receive through UHF band. Moreover, its features satisfy our system's requirements as well.

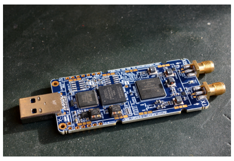


Figure 12: *LimeSDR-Mini*

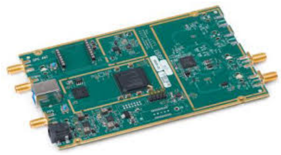


Figure 13: *USRP-UB210*

3.10 Raspberry Pi 3

As a microprocessor we are going to use the Raspberry Pi 3.

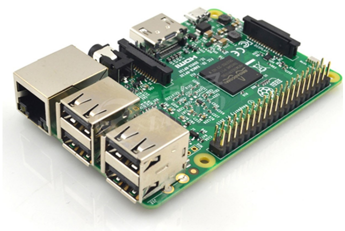


Figure 14: *Raspberry Pie 3*

3.11 Cables

- At least **10 Coaxial Cables** for the RF connections
- **2 USB cables** (connection between SDR and Raspberry)
- **2 Ethernet cable**s (connection between Raspberry and Eduroam Net)

3.12 Next Steps:

- **Select and order LNA** both for the S, 2.5-2.45 GHz, and the UHF, 435-438MHz, bands.
- **Select and order Power Amplifier** for the UHF 435-438 MHz link.

- **Select and order circulator** for the UHF 435-438 MHz link.
- Order the necessary cables
- Take some testing measurements using the **3d printed QFH antenna**, which has already been built.

***Figure 15**: Anastasis exhibiting the QFH antenna*

The QFH antenna (figure 15) gives a broad coverage which means that it does not need a tracking control mechanism. Thus, immediately we can begin our testing measurements to ensure that our equipment as well as our current design work properly and proceed to any changes if needed.

References

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[3] https://wiki.satnogs.org/Main_Page

[4] https://nuwaves.com/

[5] https://www.aero.iitb.ac.in/satelliteWiki/index.php/Main_Page

[6] https://www.mwrf.com/components/consider-these-factors-when-selecting-lna-mmic