Technical realization

Introduction (Choice of the card)

The objective of the first semester was to validate a communication card. For this, we have done a study on all the CubeSat made until today using a table provided in the appendix which specifies among other things the communication card used for each CubeSat. From this study we have isolated four communications cards closest to our specifications from phase 0. These cards have been compared in detail to the section…. (a completer)

At the end of these comparisons it was the ISIS card that had caught our attention.

ISIS Card

We therefore started the month dedicated to "PFE" with the objective of testing the ISIS card. The purchase of this card to carry out tests on it was not conceivable because of its cost (8500 $ the card). The idea was then to simulate the use of the communication protocol AX.25 via Matlab and Simulink, to realize the link budget with the technical characteristics of the card and then to realize some thermal and mechanical simulations of the behavior of the card within the CubeSat.

At the same time, we got closer to the French amateur radio association, AMSAT-F, through Mr. Auvray, after seeing that the association was present on many CubeSat projects. In particular, they provide the communication card of the QB50, a CubeSat whose launch and establishment of the communication were a success

It was during our first interview with Mr. Auvray that we submitted to him our decision to use the ISIS card in order to obtain his opinion and his advice based on his experience. He warned us about the problems associated with the use of this card. First of all, at the level of the modulation used by ISIS. On the manufacturer's website, the type of modulation displayed is the BPSK modulation. However, in reality it is not a real BPSK but a BPSK modified by ISIS thus forcing the use of a very expensive ISIS module (about $ 4000) for the Ground Station to decode the BPSK "owner". This element, which is of course not highlighted on the manufacturer site, raises two problems.

The first problem is that it puts ISIS in a wrong position in the legislation that regulates the development of CubeSat. In fact, a CubeSat using frequencies of amateur radio (144 - 146 MHz / 435 - 438 MHz) must be able to be listened to by any amateur radio ("ham") of the world. By implementing a modulation "owner" ISIS does not respect this rule. Discussions are underway to ensure that ISIS is aligned with this legislation.

The second problem is for the ECE³SAT team: it involves a large and inevitable increase in development costs.

Finally, although ISIS is a well-known electronics company, the use and testing in the past of several assemblies coming from their catalog has demonstrated a quality that does not justify the price displayed.

At the end of this interview we decided to go back on our choice of card to redirect us on the communication card provided by the AMSAT-F.

AMSAT-F card

AMSAT-F contact

The contact with Mr. Auvray, president of the AMSAT-Francophone association, was established at the beginning of January by e-mail exchange and was quickly realized by an appointment on the site of the Ecole Polytechnique for which he works as a consultant to the different spatial projects of the X.
It was during this meeting that we were able to discuss the different cards that we had pre-selected. This leads to the conclusions we have outlined above on the ISIS card, and to the information that will follow on the AMSAT-F card.

FUNcube & QB50 projects

The FUNcube project was undertaken by a team of 10 experienced volunteers from AMSAT-UK and AMSAT-NL. It was partly funded by a charity: Radio Communications Foundation. The FUNcube project is the creation of an Educational CubeSat to allow students to learn about the topics of radio, space, physics and electronics. The first mission is to provide a downlink telemetry that can be easily perceived by schools and colleges for educational purposes. When the satellite is not in the educational mode, it uses a transponder that can be used by radio amateurs.
The project includes the development of a simple and inexpensive ground station operating in the VHF amateur radio frequency band.

This ground station is a simple USB stick ("Dongle Pro Plus"), which allows reception of radio signals from the satellite and transfer data to a specific software (Dashboard) running under the Windows operating system. The required antenna is a basic VHF antenna such as a monopole or a dipole.

Our interest in the FUNcube is justified by its pedagogical aspect allowing the reception of telemetry but especially by the origin of its telecommunication card since it is entirely developed by AMSAT.
The correct operation of this card is now confirmed. In addition to its operation within the FUNcube, French CubeSat (X-CubeSat, CubeSat of the polytechnic school, and SpaceCube, CubeSat of the École des Mines ParisTech) taking parts of the project QB50 (The QB50 mission will demonstrate the possibility of launching a network of 50 CubeSats built by Universities Teams all over the world as a primary payload on a low-cost launch vehicle to perform first-class science in the largely unexplored lower thermosphere), also use them.

The correct operation of the telemetry operations of the FUNcube is notably verifiable on a dedicated web page where the entire amateur radio community can upload the received information.

For example, FUNcube (A0 73) data were received five times during the day of January 24, 2017.

The objective is now to validate the specifications of this telecommunication card to verify that it fills our needs.

Specification of the AMSAT card

In terms of specifications, the only difference between the card used in the FUNcube and the card operating in the CubeSat of the QB50 is the frequency band used for downlink and remote control (uplink). The FUNcube uses the VHF frequency band for the downlink and the UHF frequency band for the uplink. The CubeSat of the QB50 communicate on the VHF frequency band in uplink and UHF in downlink. This is due to different objectives for both projects. The QB50 project aims to use telemetry as a simple monitoring tool while the FUNcube project wishes to make all telemetry data accessible to all radio amateurs.

As a reminder, here are the specifications of the AMSAT card:

Price	800 €
Weight (g)	70 - 100
Dimensions (mm)	90.2 x 82 cm
Operating temperature (°C)	[-20°; +50°]
Power (W) Transmitter ON < x < Receiver Only	5.78 < x < 0.57
UHF Transmitter Downlink	
Frequency	435 - 438 MHz
Protocols	AX.25 / FX.25
Data Rate (bauds)	1200 to 9600
Modulation	BPSK
VHF Receiver Uplink	
Frequency	145.80 - 146 MHz
Protocols	AX.25 / FX.25
Data Rate (bauds)	1200 to 9600
Modulation	BPSK

On paper, the characteristics of the AMSAT card correspond perfectly to the marked specifications in phase 0. Moreover, the contact we have established with Mr. Auvray will allow the team to be as close as possible in the creation phases from design to construction. Finally, the cost of the card passing through the AMSAT is divided by 10, going from $ 8,500 to about $ 800.

Software defined radio

We now want to validate the specifications of the TCS AMSAT card. For this we want to show that we can receive frames of this card and interpret them.

To be able to intercept the frames coming from the FUNcube, we have set up a ground station compatible with this telecommunication card.

Two options were then available to us:

The first consisted in the purchase of the Dongle Pro + and the AMSAT antenna sold on the AMSAT site.
The second consisted in the use of a DVB-T dongle, an LNA amplifier and a home-made antenna.

With our mentor Mr. Riquier, we judged that it would be more pedagogical to implement the second option in order to understand better the concepts implemented.

So, we used a software-defined radio composed of an RLTSDR dongle which is in fact a specific USB TNT key, SDR software that pilot our key, a satellite tracking software, a specific antenna and a pre-amplifier.

SDR: Software Defined Radio

For the software part we used the software SDRSharp, a software that allows us to pilot the key via an interface of spectrum analysis and selection of frequency, bandwidth and signal processing tools.
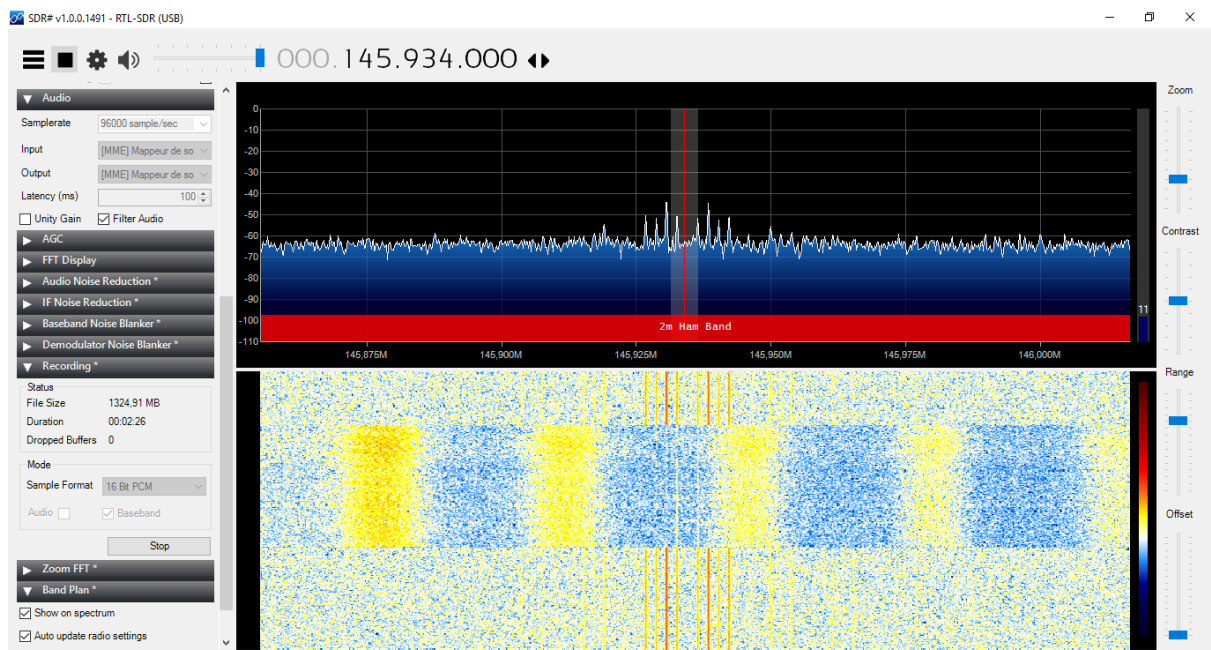
Doppler effect

In parallel with the SDR we used the software Orbitron to have a satellite tracking station with TLE (Two-Line Elements) information and automatic correction of the retroactive Doppler effect on SDRSharp.
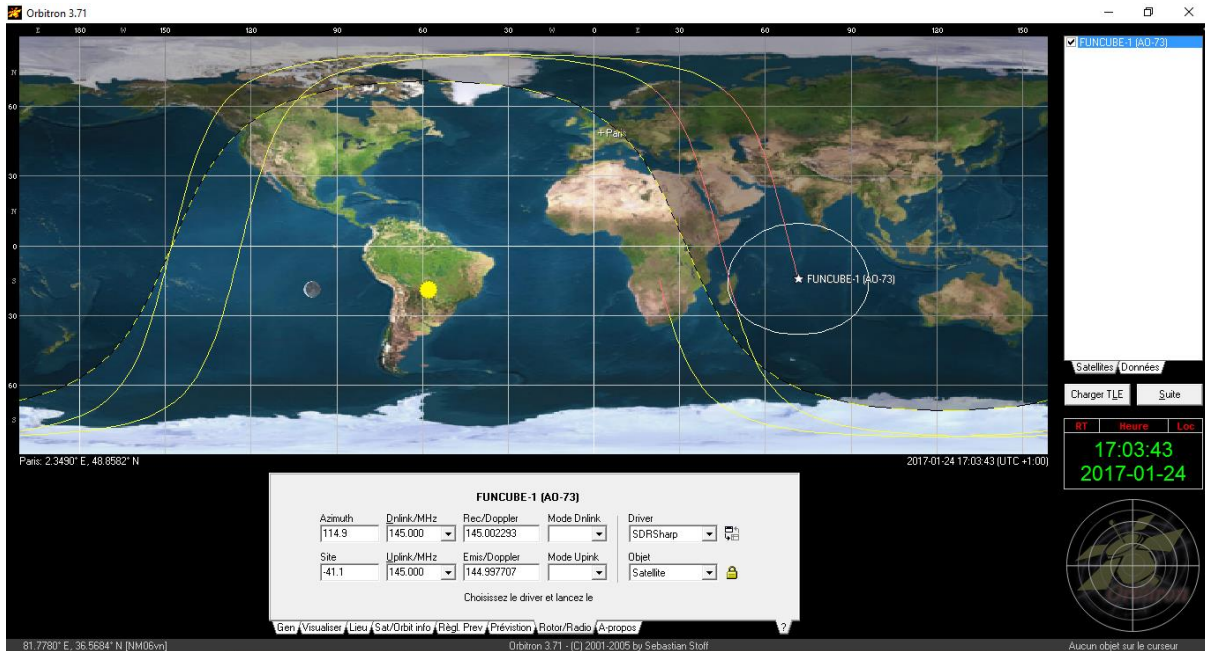
The two-line orbital parameters (TLE) are elements measured and calculated by NORAD and NASA, not only for artificial satellites, but also for space debris. They allow Orbitron to calculate the position of objects in orbit at any time because they follow the laws of Kepler and Newton.

By setting the input text files of the software, we can easily isolate the satellites we are interested in, namely the CubeSat of the AMSAT.

Once selected, we have access to a lot of satellite information:

Name	FUNCUBE-1 (AO-73)
Satellite number	39444
Designation	COSPAR 2013-066-AE
Epoch	(UTC) 2017-01-22 13:52:11
Orbit # at Epoch	16946
Inclination	97.652
RA of A. Node	72.597
Eccentricity	0.0059136
Periapsis argument	24.811
Orbit per day	14.81312310

Orbit period	1h 37m 12s (97.20 min)
Semi-major axis	7 003 Km
Periapsis x Apoapsis	584 x 667 Km
Bstar (aerodynamic drag	0.000045873 1/ER
Average anomaly	335.593
Model	SGP4

We also have access to the downlink emission frequency and Doppler calculation:
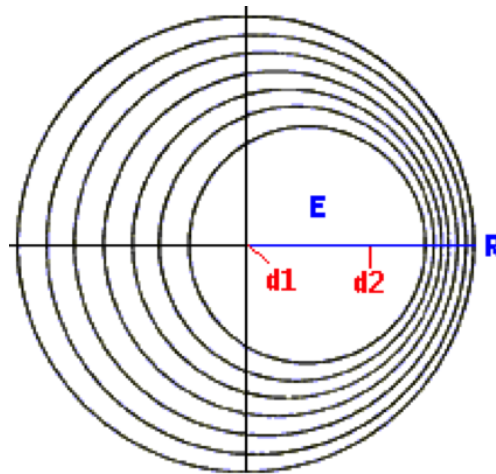
Theory of operation: If a transmitter moves from a point d1 to a point d2, we can note that an immobile observer will see the frequency of the observed signal increase as the emitter approaches and decreases as the object gets away. This is the Fizeau Doppler effect encountered in spatial communications when at least one of the elements (RX or TX) is mobile. This is due to the fact that we observe a compression of the electromagnetic waves due to the displacement per unit of time. In other words, in a second, there are more. In the reversed way, we observe a decompression when the satellite goes away which is accompanied by a decrease in frequency.

Through various case studies and the opinion of our contact at AMSAT, Mr. Auvray, we decided to take this effect into account.

The Orbitron software allows us to control the frequency selection of SDRSharp by taking into account the value of the Doppler in real time.
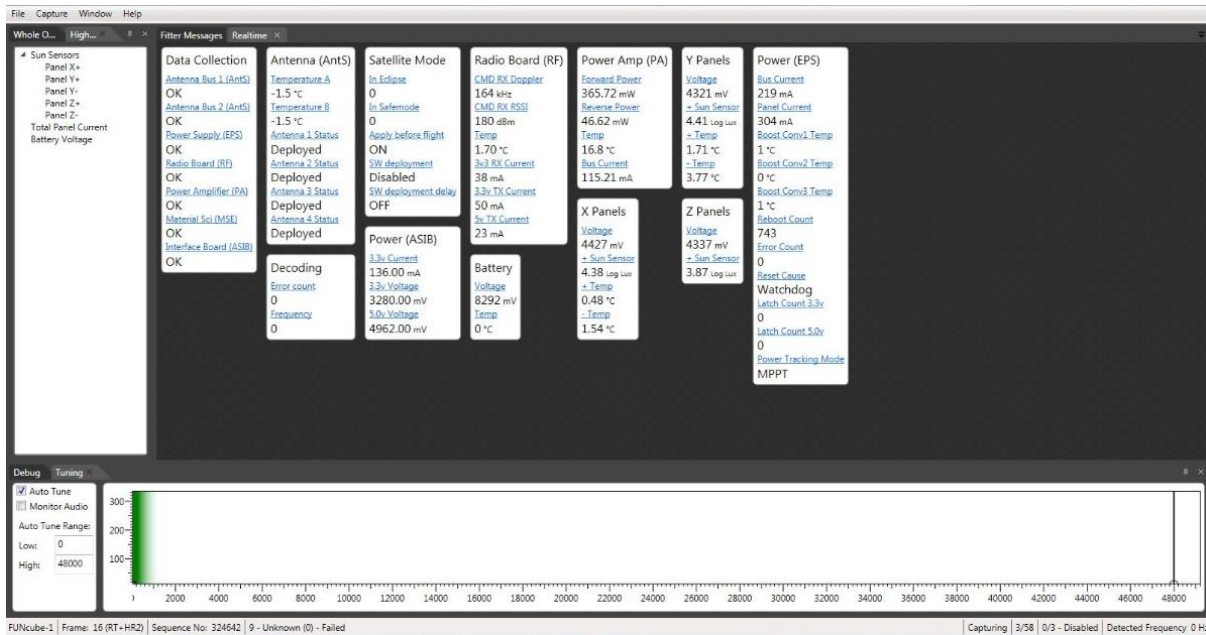
Demodulation

For the demodulation, we had several choices.

The first option is that we can either use an open source amateur radio software: MULTIPSK. This one allows us to demodulate the signal modulated in BPSK in real time. To send the stream from SDRSharp to MULTIPSK, we have installed Virtual Audio Cable which allows to direct the output of SDR to the input of the demodulator.
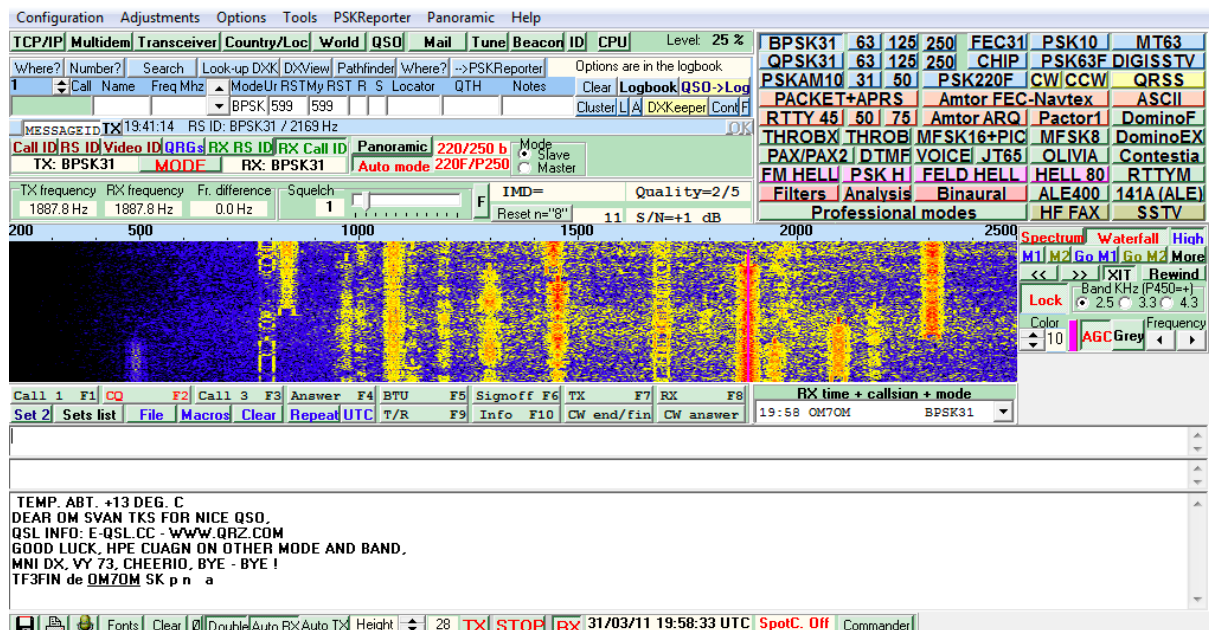
The second option is to use a more specific software that only works with the FUNcube and its associated dongle. This is the FUNcube Dashboard software which is dedicated to the telemetry of this CubeSat.

The software's interface is a high level of programming: We can't see any treatment of data and that we access directly to the data of telemetries interpreted in background by this dashboard:

In the same way, the software is provided with the virtual audio gateway as input and the software identifies and interprets in real time the signal which must be at 1200 bauds in BPSK modulation. From the moment this software recognizes an AX-25 frame, it translates it into telemetry data.

We have tried both post-processing methods to compare the received data.

Dongle

Concerning the Dongle, as mentioned above, we had the possibility to use the dongle proposed by the AMSAT (the dongle pro +), however its cost (180€) as well as discussions with our mentor Mr. Riquier convinced us to use The following TNT USB key:

A traffic receiver for HF and a scanner for VHF and UHF are obviously the most suitable equipment. That said, it is possible to transform this simple USB TNT to 19 € into an RTL-SDR receiver to cover in reception the frequencies VHF / UHF with a software.

This key contains the RLT2832U chip and the R820T2 tuner. It competes perfectly with the usual scanners since it covers from 30MHz to 1500MHz, and this with two spectrum analyzers:

- A 2D: frequency / amplitude
- A 3D: "waterfall" frequency / amplitude / time

The disadvantage of this USB kit is that the antenna supplied with it is not suitable for the use we want to make of it. To overcome this problem, we started the realization of an antenna optimized for our study

Antenna realization

So we decided to manufacture an antenna for VHF and UHF bands.

We were targeting the frequency of the FUNcube in telemetry which is 145.935MHz. This is why we decided to manufacture an antenna called Yagi-Uda 3 elements.

The Yagi-Uda is a type of antenna that has an active element, the dipole, which will be fed with high-frequency signals. In front of the dipole takes place a slightly shorter element, this element is called "director". Behind the dipole is positioned a slightly longer element called "reflector".
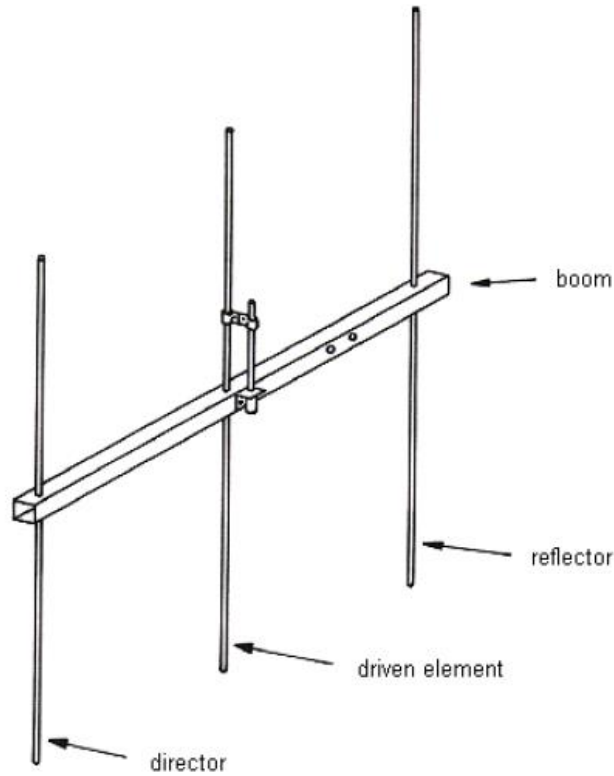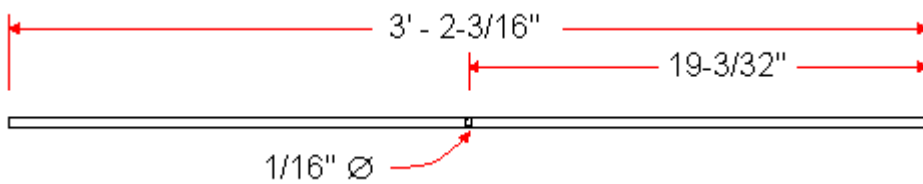
We made this antenna with a square aluminum profile and 8 mm aluminum rod.
Concerning the length of the dipoles, it was chosen according to the frequency of emission of the FUNcube:
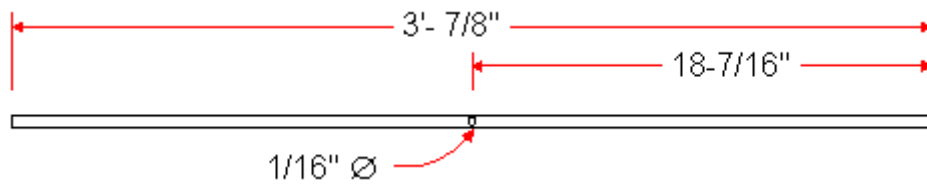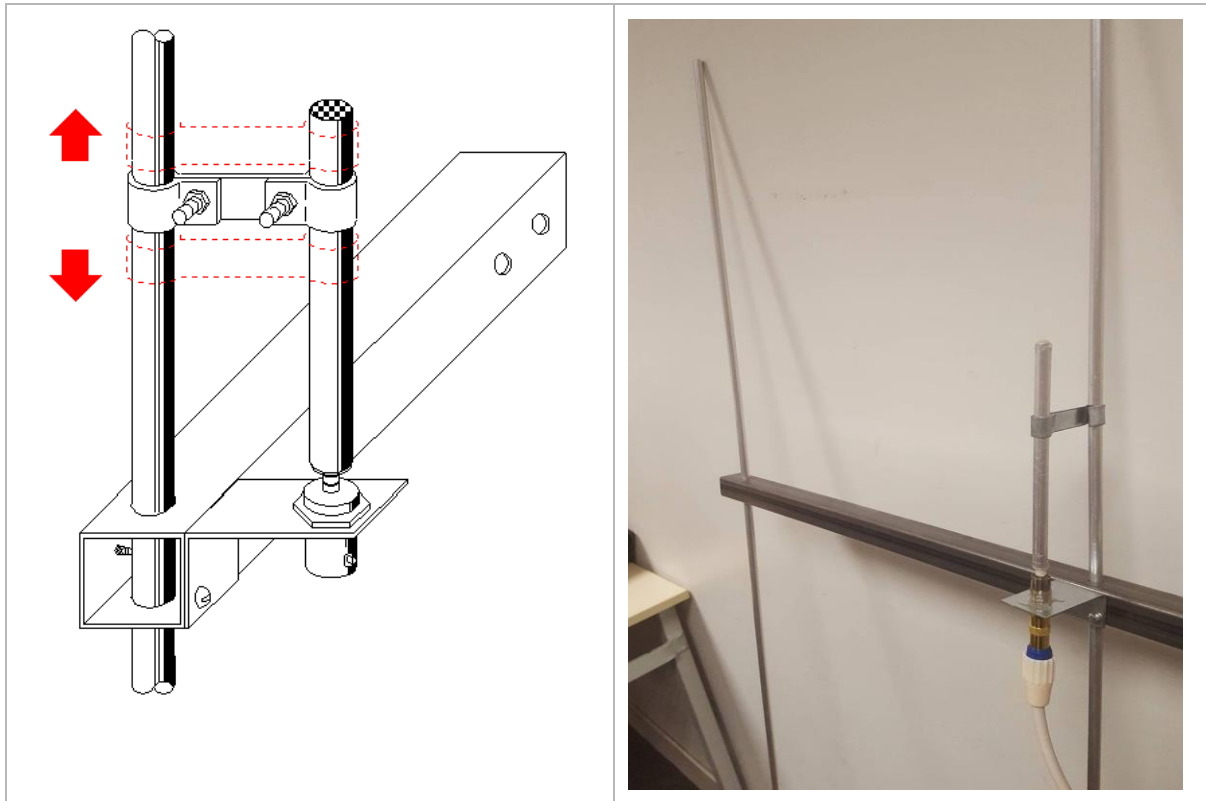
Reflector:
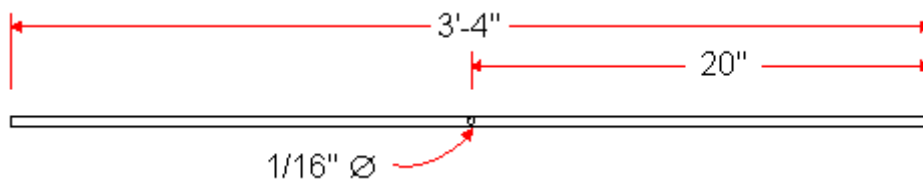
Conductor:

Director:

To tune the antenna impedance, we installed a gamma match element as follows:

Operation theory:

We will focus on the electrical part of the electromagnetic wave.

The first element that is flooded by the field is the director. It absorbs part of the radiation but like any physical element, it re-emits a part of this energy. Its size, slightly less than half the wavelength, makes it re-emit to the back, in the direction of the electromagnetic wave.

At time t+1, the dipole (also called radiator) is flooded by the field which is now reinforced since we find the original field plus the re-emitted field. The dipole will convert the electromagnetic field into a voltage usable by our receiver by induction. The wave continues to move in space and now reaches the reflector. This reflector will behave as the director, absorb but also re-emit but this time forward because it is longer than the wavelength / 2.
This re-emitted field will reinforce the field induced by the dipole.

Preamplifier

After several failures of reception of the FUNcube in Paris, we looked for the cause of the problem of operation of our ground station.
At this stage of the implementation we have made several assumptions:

- The configuration parameters of the software and / or the TNT key are not correct,
- The environment in which we are doing our tests is too dense and have too much noise for our spectrum analyzer.

After checking all the settings of the SDR we tried again to pick up the FUNcube, without success.

Then, we decided to buy a preamplifier to allow us to get rid of the surrounding noise and target the frequency of emission of the CubeSat with a higher gain. During the last tests we were at -40dB and above around the VHF frequency of the FUNcube.

Here are the specifications of the chosen preamplifier:

This is the LNA4ALL, a preamplifier and a low-pass filter (LNA), with SMA Female connectors, for VHF and UHF frequencies covering all bands from 28 MHz to 2500 MHz (2.5Ghz).
We chose this one because it allows to improve very clearly the reception performance, on all bands VHF and UHF up to 2.5Ghz, of a TNT key RTL-SDR.
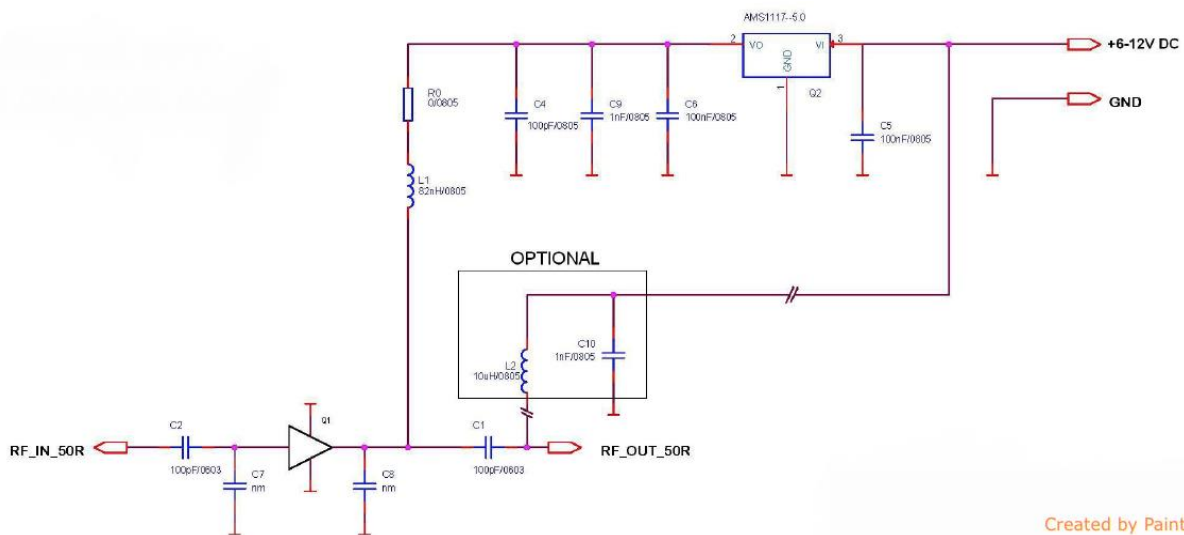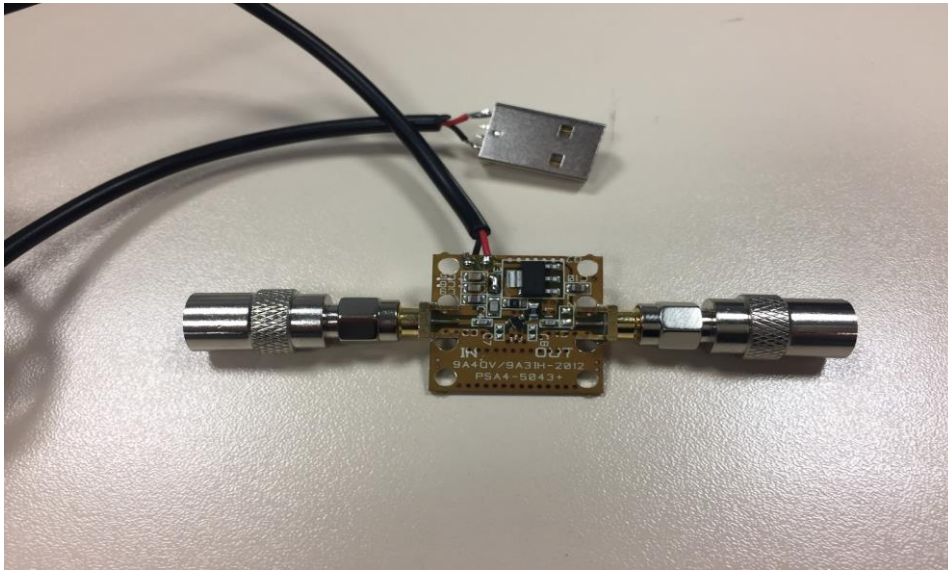
LNA + SMA adapters - Coax + power supply modification

Application	Frequency MHz	Gain dB
HAM radio	28	21
HAM radio	50	22
HAM radio	70	22
Broadcast	100	22
Air traffic	120	23
HAM radio	145	23.5
HAM radio	435	23.5
DVB-T	600	22
ADS-B	1090	18
HAM radio	1296	17
SETI	1400	16
WBFM link	2200	12
HAM radio	2320	11.5

Theoretical gain LNA

Before buying the amplifier, we did some research to see if we could do it ourselves. We then found the electrical scheme of the LNA as well as the routing. We then envisage to realize the LNA ourselves but we discussed with Mr. Houelle who advised us to buy the LNA to not waste time and guarantee the efficiency of component.

Here is the routing as well as the electrical diagram on which we would have relied to realize the LNA.