Reception of NOAA Images

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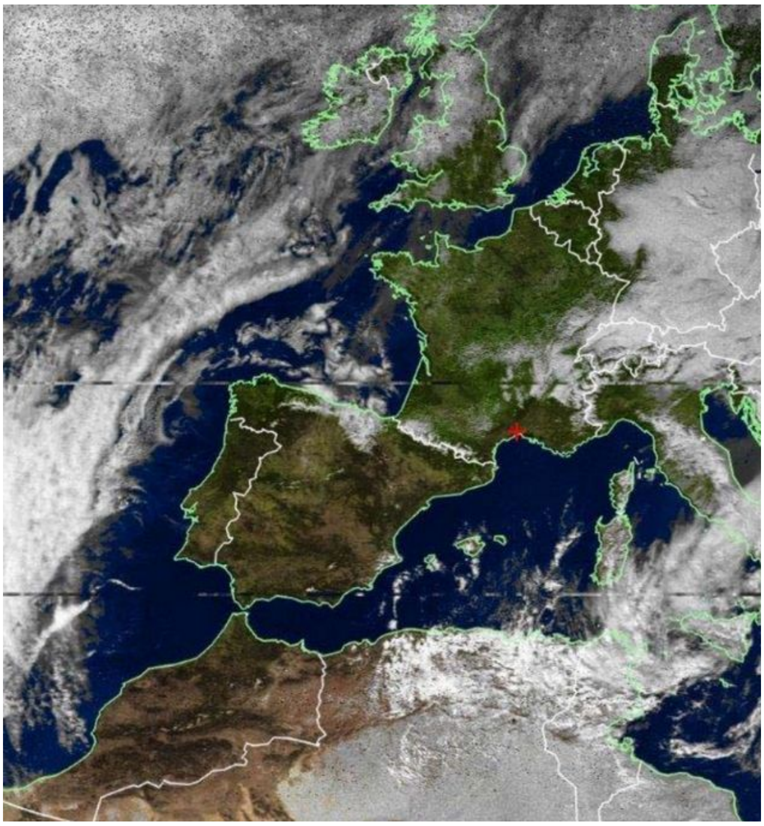

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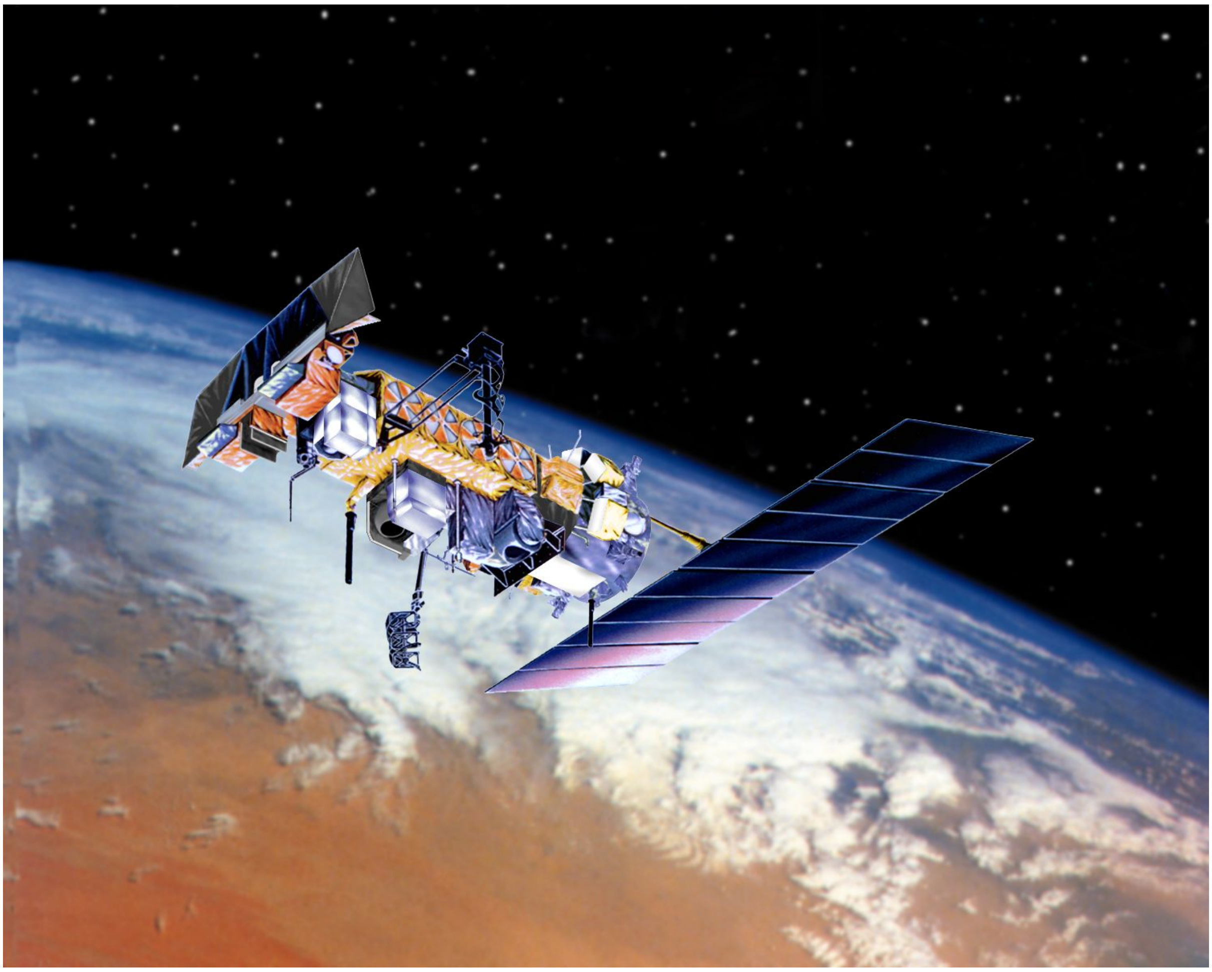
Introduction

We are all familiar with the high quality meteorological images that everyone can see on TV forecasts. These images are acquired by geostationary satellites and show the evolution of clouds and precipitation.
There are also polar satellites, evolving at far inferior altitudes, which transmit continuously meteorological images that radio amateurs can receive with low price equipment.
In this project, we are aiming at these particular satellites from the NOAA agency.

We will firstly present the NOAA mission and describe the techniques used for transmitting weather images from NOAA' s polar satellites. The main goal of this project is to understand the process in order to build a receiving antenna on the roof of the Satcom lab. We will then develop a software-defined radio receiver and focus on improving the complete system.



Artist view of a NOAA satellite above the Sahara desert

A. NOAA Agency

1. Description

NOAA KLMNN' Spacecraft Communications Radio Frequency (RF) Links (frequencies are in MHz)

The **National Oceanic and Atmospheric Administration** is an American scientific agency created in 1970, within the United States Department of Commerce, that focuses on the conditions of the oceans and the atmosphere.

The five "fundamental activities" of the agency are :

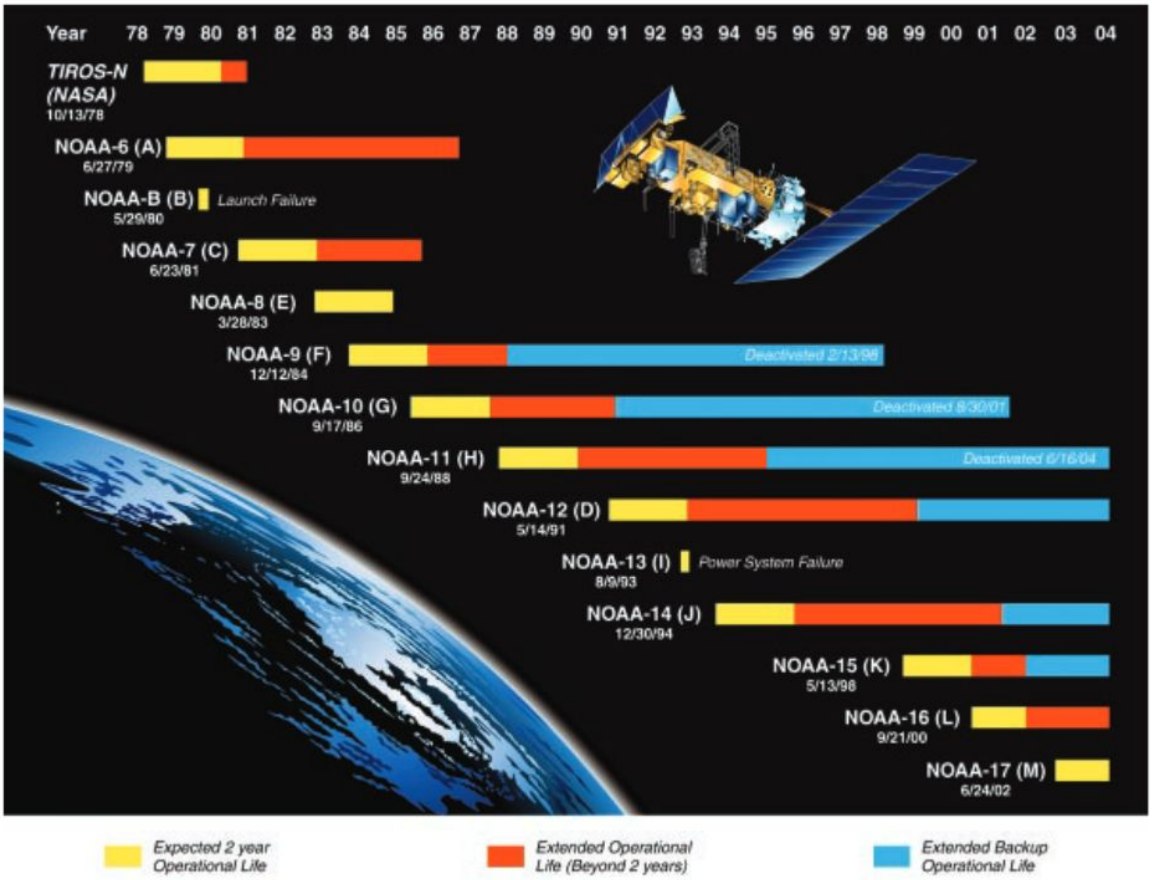
- Monitoring and observing Earth systems with instruments and data collection networks.
- Understanding and describing Earth systems through research and analysis of that data.
- Assessing and predicting the changes of these systems over time.
- Engaging, advising, and informing the public and partner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

To sum up, NOAA warns 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.

The prime customer is NOAA's National Weather Service, which uses satellite data to create forecasts for television, radio, and weather advisory services. We will focus on this type of data transmission.

NOAA's operational environmental satellite system is composed of two types of satellites: geostationary operational environmental satellites (GOES) for short-range warning and "now-casting," and polar-orbiting environmental satellites (POES) for longer-term forecasting. Both kinds of satellites are necessary for providing a complete global weather monitoring system. We will present these two categories of satellite in the next part.

2. NOAA Satellites



History of NOAA satellite launching

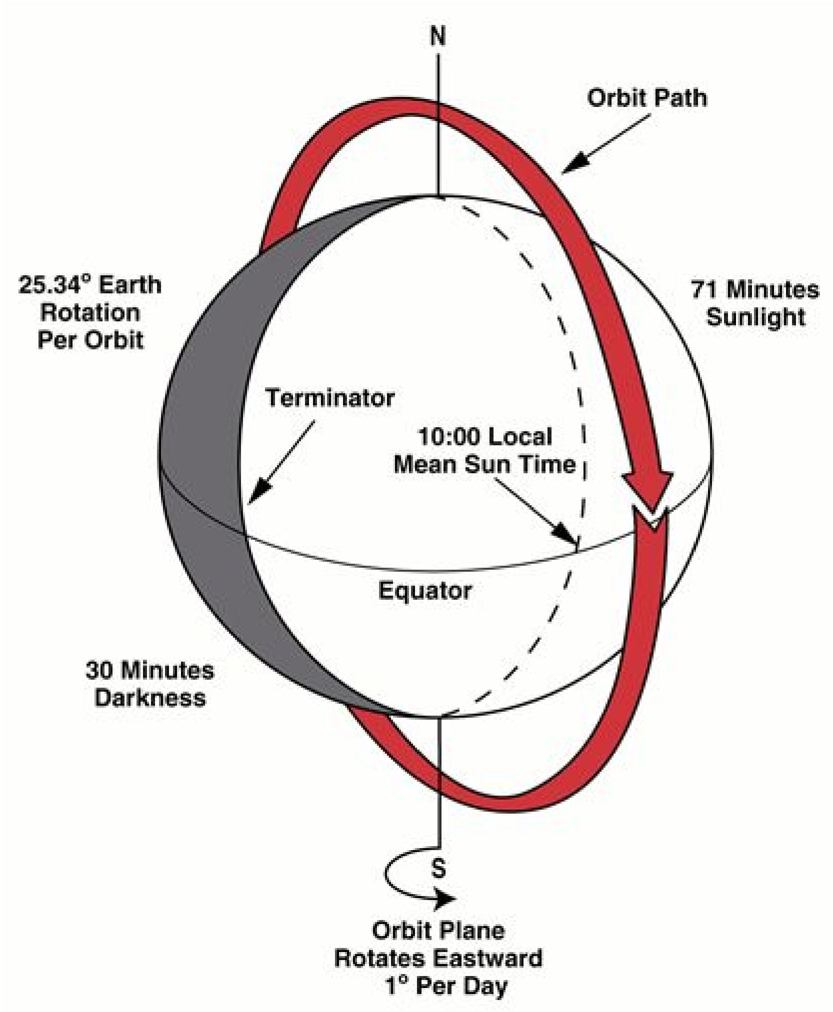
1. Geostationary Operational Environmental Satellites

GOES satellites provide the kind of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which means that they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to hover continuously over one position on the surface. The geosynchronous plane is about 35,800 km above the Earth, high enough thave with 3 satellites a full view of the Earth. The three-axis, body-stabilized 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, ensuring real-time coverage of meteorological events such as severe local storms and tropical cyclones. (The importance of this capability was proven during hurricanes Hugo (1989) and Andrew (1992)).

GOES satellite imagery is also used to estimate rainfall during thunderstorms and hurricanes for flash flood warnings, as well as estimate snowfall accumulations and overall extent of snow cover. Such data help meteorologists issue winter storm warnings and spring snowmelt advisories. Satellite sensors also detect ice fields and map the movements of sea and lake ice.

The GOES spacecraft continuously view the continental United States, the Pacific and Atlantic Oceans, Central America, South America, and southern Canada. Indeed, the geostationary satellite located above Europe is only used as a relay and this is why we cannot use the GEOS to receive images. We have to use the polar satellites.

2. Polar Operational Environmental Satellites



Polar orbit trajectory

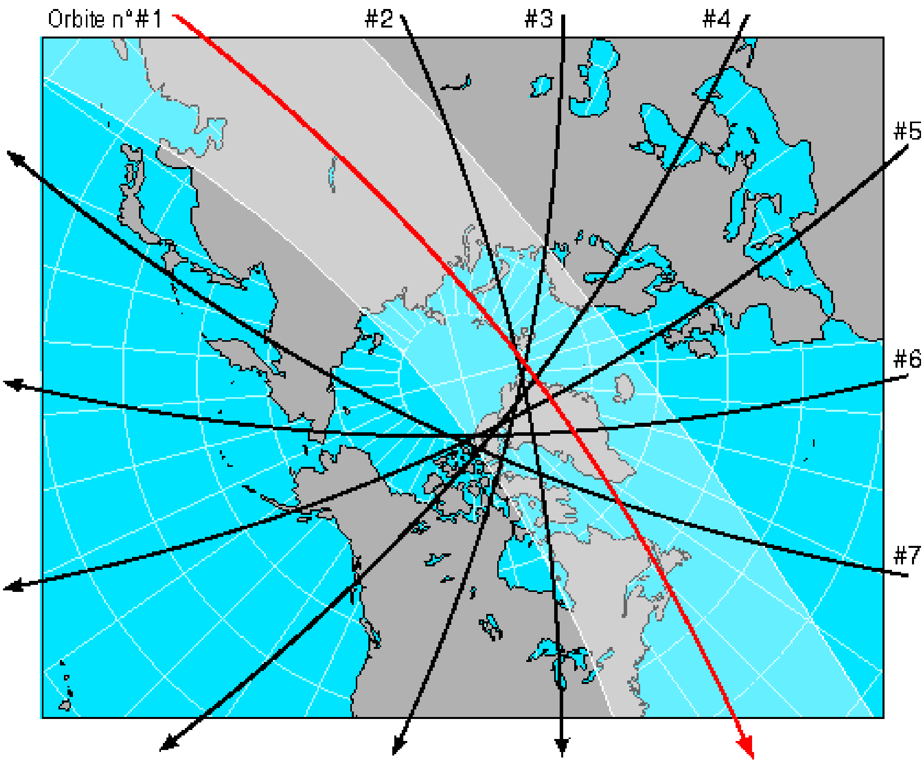
NOAA POES are the fifth generation of polar satellites from the *National Oceanic and Atmospheric Administration*. These satellites have been developed with NASA, and european organisation EUMETSAT which build the MetOp satellites.

Data from the POES support a broad range of environmental monitoring applications including 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, and many other applications.

These POES are operating at a height of 850 km. Their orbit is such that they cross the geographic poles 14,1 times per day. Their revolution period is approximately 102 minutes and permit them to span the totality of the globe twice a day. Thus, a random ground station can receive its signals twice a day, during the night and during the day.

Furthermore, their orbit is heliosynchronous, which means that the satellite flies over a given latitude at a constant local time each revolution. The image acquisition is thus done with the same conditions every crossing of the latitude because they fly above the same location every day at the same time.

The life expectancy of these different missions is of 2 years, due to the accelerated ageing of the captors in the space environment.



Heliosynchronous orbit around the North Pole

Concerning the choice of the satellite, we chose the NOAA-19 which is more operational than the other POES available. (Check on Annex 1).
We could also work with MetOp satellites, but they don't publicly broadcast their images.

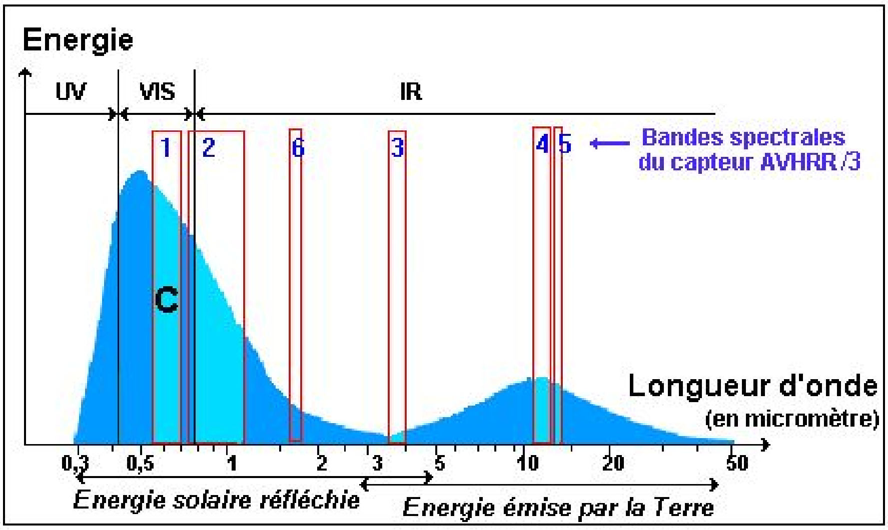
B. Images Acquisition & Transmission

NOAA POES use numerous transmission techniques. In this chapter we will focus on the transmission of weather images.

1. Satellite's on board equipment

The primary sensor on board is the **AVHRR** instrument (**Advanced Very High Resolution Radiometer**). Morning pictures are most commonly used for land studies, while photos taken in the afternoon are used for atmosphere and ocean studies, due to 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 kilometers. The satellites orbit between 833 or 870 kilometers (+/− 19 kilometers) above the surface of the Earth. The highest ground resolution that can be obtained from the current AVHRR instruments is 1.1-kilometer, which means that the satellite records discrete information for areas on the ground that are 1.1 × 1.1 kilometers, this is the size of a pixel. AVHRR data have been collected continuously since 1981.
Cross-track scanning is accomplished by a continuously rotating scan mirror that is directly driven by a brushless DC motor.

The primary 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, however, including the surveillance of land surfaces, ocean state, aerosols, etc. AVHRR data are particularly relevant to study climate change and environmental degradation because of the comparatively long records of data already accumulated (over 20 years). The main difficulty associated with these investigations is to properly deal with the many limitations of these instruments, especially in the early period (sensor calibration, orbital drift, limited spectral and directional sampling, etc.).
The AVHRR instrument also flies on the MetOp series of satellites (the picture on the left shows a real AVHRR on board a MetOp satellite taken at the Cité de l'Espace).
The MetOp satellites turn on themselves like a spinning top and scan a line of the image at each turn.



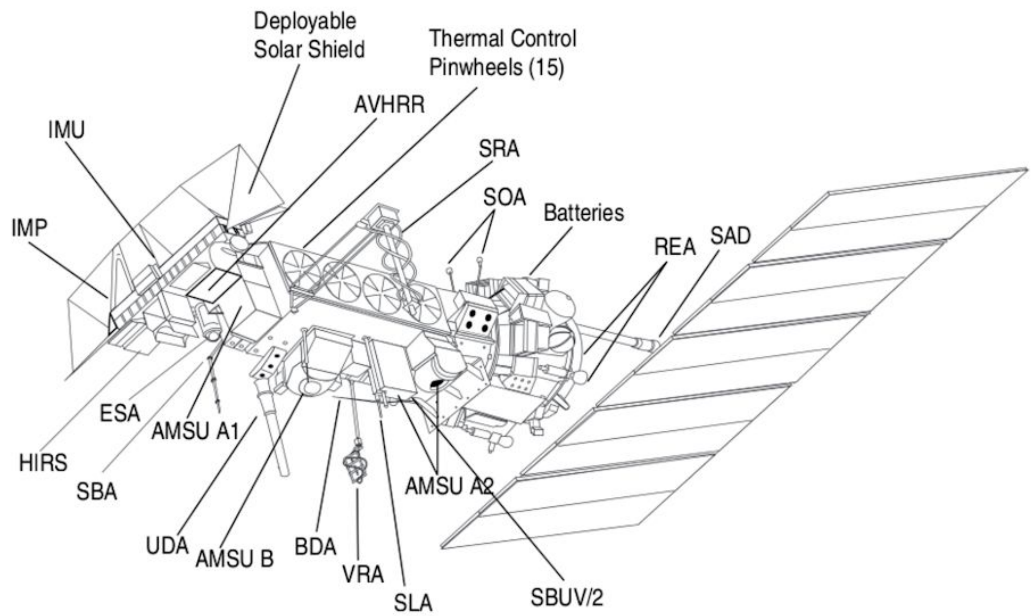
Bands of radiation wavelengths collected by AVHRR

The AVHRR is a radiation-detection imager that can be used for remotely determining cloud cover and the surface temperature. Note that the term *surface* can mean the surface of the Earth, the upper surfaces of clouds, or the surface of a body of water. This scanning radiometer uses 6 detectors that collect different bands of radiation wavelengths as shown below.

The first AVHRR was a 4-channel radiometer, first carried on TIROS-N (launched in October 1978). This was subsequently improved to a 5-channel instrument (AVHRR/2) that was initially carried on NOAA-7 (launched in June 1981). The latest instrument version is AVHRR/3, with 6 channels, first carried on NOAA-15 launched in May 1998.

AVHRR/3 Channel Characteristics			
Channel Number	Resolution at Nadir	Wavelength (um)	Typical Use
1	1.09 km	0.58 - 0.68	Daytime cloud and surface mapping
2	1.09 km	0.725 - 1.00	Land-water boundaries
3A	1.09 km	1.58 - 1.64	Snow and ice detection
3B	1.09 km	3.55 - 3.93	Night cloud mapping, sea surface temperature
4	1.09 km	10.30 - 11.30	Night cloud mapping, sea surface temperature
5	1.09 km	11.50 - 12.50	Sea surface temperature

Measuring the same view, this array of diverse wavelengths, after processing, permits multi spectral analysis for more precisely defining hydrologic, oceanographic, and meteorological parameters. Comparison of data from two channels is often used to observe features or measure various environmental parameters. The three channels operating entirely within the infrared band are used to detect the heat radiation from and hence, the temperature of land, water, sea surfaces, and the clouds above them.



AMSU	Advanced Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
BDA	Beacon Transmitting Antenna
*DCS	Data Collection System
ESA	Earth Sensor Assembly
HIRS	High Resolution Infrared Radiation Sounder
IMP	Instrument Mounting Platform
IMU	Inertial Measurement Unit
*MEPED	Medium Energy Proton/Electron Detector
REA	Reaction Engine Assembly
SAD	Solar Array Drive
*SAR	Search and Rescue
SBA	S-Band Transmitting Antenna (1 of 4 shown)
SBUV/2	Solar Backscatter Ultraviolet Radiometer
SEM	Space Environment Monitor
SLA	Search and Rescue Transmitting Antenna (L-Band)
SOA	S-Band Omni Antenna (2 of 6 shown)
SRA	Search-and-Rescue Receiving Antenna
*TED	Total Energy Detector
UDA	Ultra High Frequency Data Collection System Antenna
VRA	Very High Frequency Real-time Antenna

Description of the different system on-board a NOAA POES

2. Transmission chain

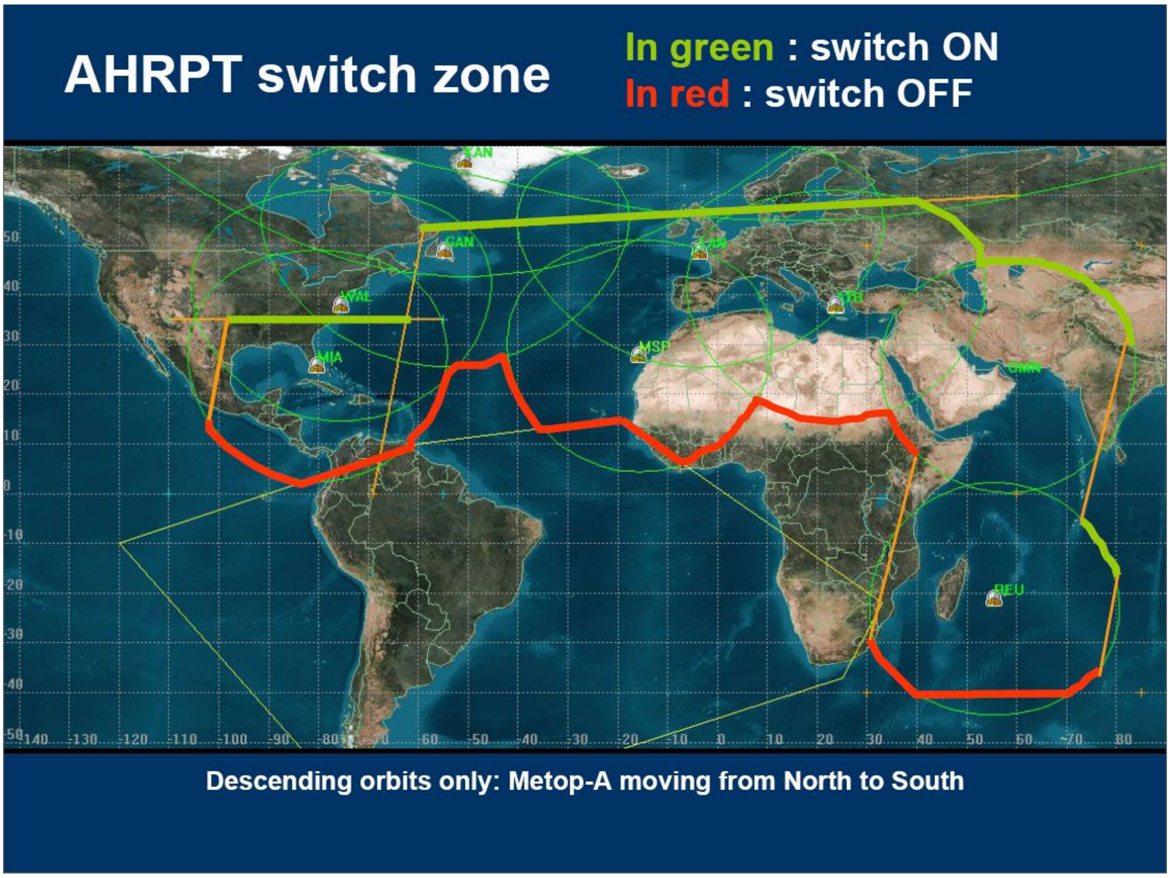
The data source is the satellite as it passes over the user's field of view. Readout of all instrument data can be achieved via **Advanced High Resolution Picture Transmission** (**AHRPT**) or **Automatic Picture Transmission** (**APT**).

This service provides local user stations with real-time transmission of data, limited to the instantaneous sub-satellite observation.

a. Advanced High Resolution Picture Transmission (AHRPT)

The NOAA direct readout AHRPT system provides data from all NOAA-K,L,M,N spacecraft instruments at a rate of 665,400 bps. The S-band real time transmission of time-multiplexed digital data consists of the digitized unprocessed output of 6 AVHRR channels. **It is however only available to NOAA or companies that pay for an encryption key necessary to decrypt the data sent by the satellite on the AHRPT channel.** These images have a higher quality, but we are not able to receive them.

On the Metop satellites, this service is the only one available and is switched off to avoid unnecessary degradation of the instruments when the satellite is passing over zones without any coverage (see map below).



Map of the active zone of the AHRPT system on board MetOp

b. Automatic Picture Transmission ✓

The **APT** system is an analog image transmission system. It was introduced in the 1960s and over four decades has provided image data to relatively low-cost user stations at locations in most countries of the world. A user station anywhere in the world can receive local data at least twice a day from each satellite as it passes nearly overhead.

It provides a reduced resolution data stream from the AVHRR instrument. Any two of the AVHRR channels can be chosen by ground command for processing and ultimate output to the APT transmitter. A visible channel is used to provide visible APT imagery during daylight, and one IR channel is used constantly (day and night).

Of the two images, one is typically long-wave infrared (10.8 micrometers) with the second switching between near-visible (0.86 micrometers) and mid-wave infrared (3.75 micrometers) depending on whether the ground is illuminated by sunlight. However as we already said, NOAA can configure the satellite to transmit any two of the AVHRR's image channels.

The interest of the infrared image is the possibility to see through some clouds that are at low altitude (because their temperature is close to the ground temperature). It let us know roughly the height of the cloud that we see on the picture.
At high latitude, the image quality depends on the season. During winter, the sun elevation angle is not as high as in summer and the illumination of the scene is not as good.
On the infrared picture, we can distinguish river and land because of the gradient of temperature (black for the hot body and white for the coldest one). In conclusion, the image quality is better during the day and lower is the antenna latitude, higher is the difference of temperature between continents and oceans.

Line Rate	120 lines/min
Data Channels	2 transmitted 6 available
Data Resolution	4.0 km
Carrier Modulation	2.4 KHz AM subcarrier on FM carrier
Transmitter Frequency (MHz)	137.50 or 137.62
Transmitter Power (EOL)	5 W (37dBm)
Radiated Power (dBm, @ 63 degrees)	36.7
Polarization	RCP

Transmission characteristics

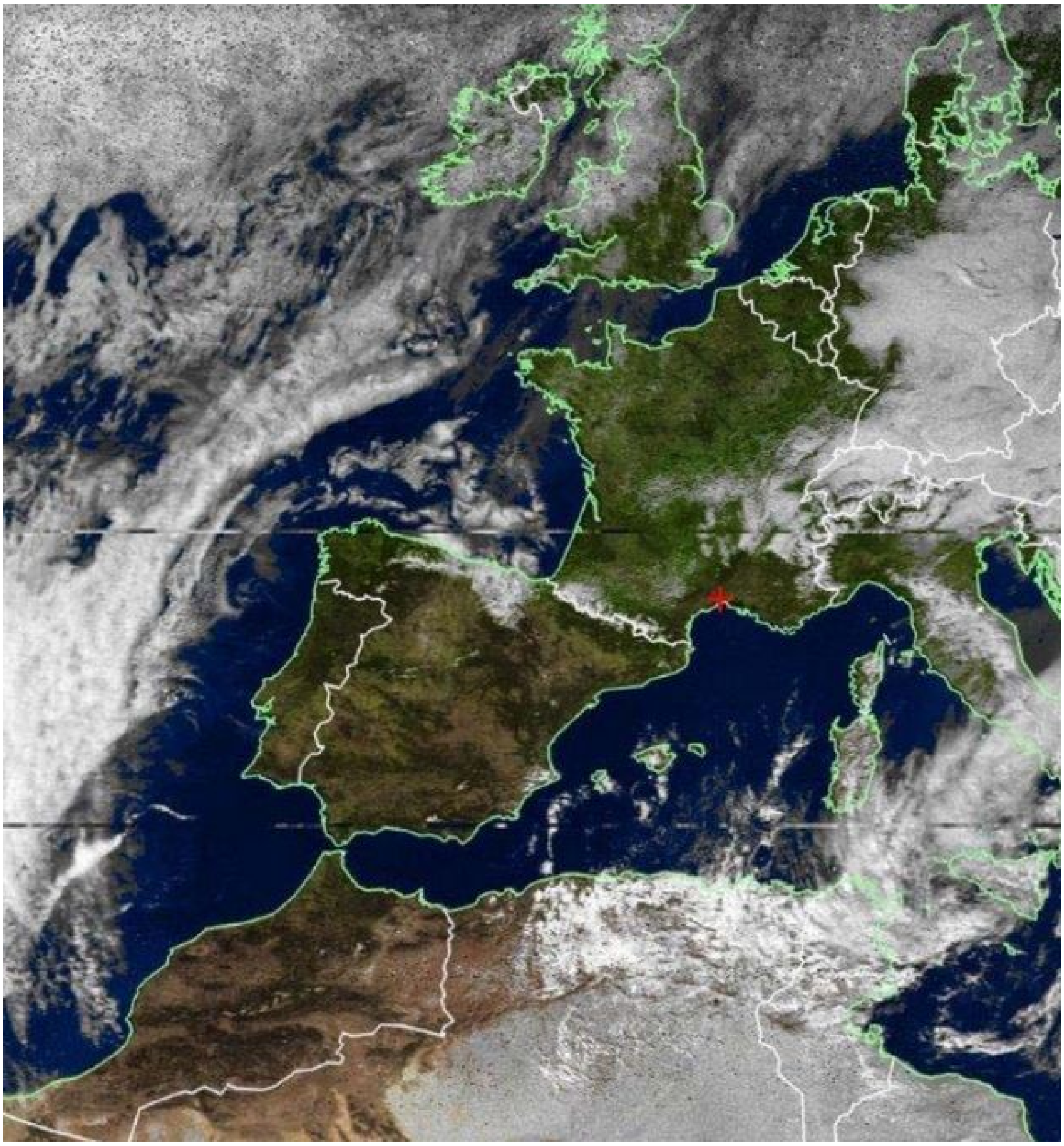


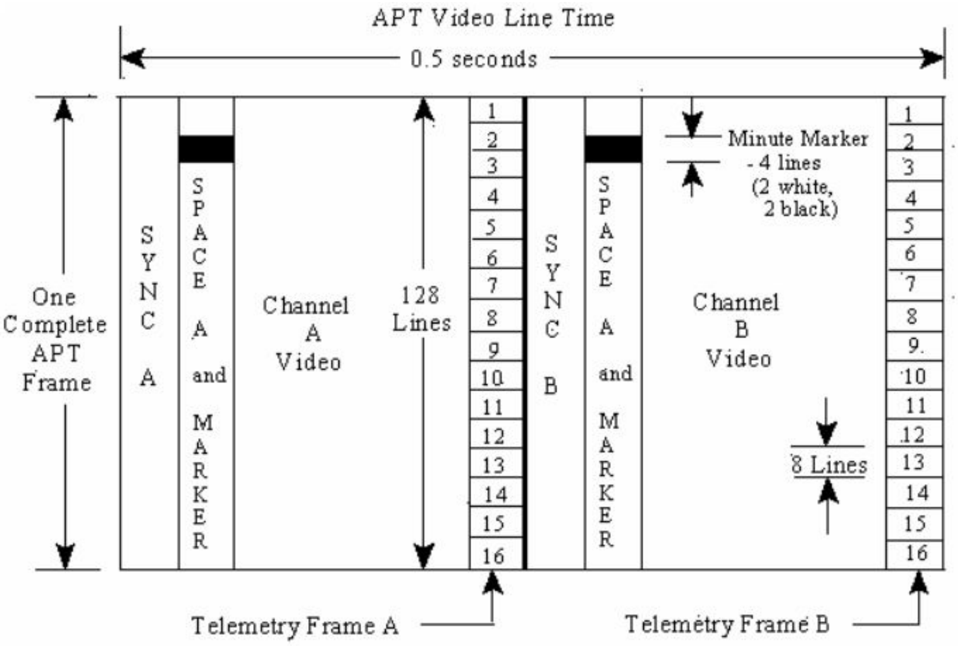
Image received by NOAA-19

I. Image coding

On NOAA POES system satellites, the two images are 4 km / pixel smoothed 8-bit images derived from two channels of the AVHRR sensor (APT only takes 1 pixel over 4 from the high resolution picture). The images are corrected for nearly constant geometric resolution prior to being broadcast; as such, the images are free of distortion caused by the curvature of the Earth (see Annex 3).
Each pixel of the image is coded by a value between 0 and 255, it's called grayscale imaging.

II. Structure

The broadcast transmission is composed of two image channels, telemetry information, and synchronization data, with the image channels typically referred to as Video A and Video B. All this data is transmitted as a horizontal scan line. A complete line is 2080 pixels long, with each image using 909 pixels and the remainder going to the telemetry and synchronization. Lines are transmitted at 2 per second, which equates to a 4160 words per second, or 4160 baud.



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

Format of an APT Frame

III. Synchronization and telemetry

Included in the transmission are a series of synchronization pulses, minute markers, and telemetry information.

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

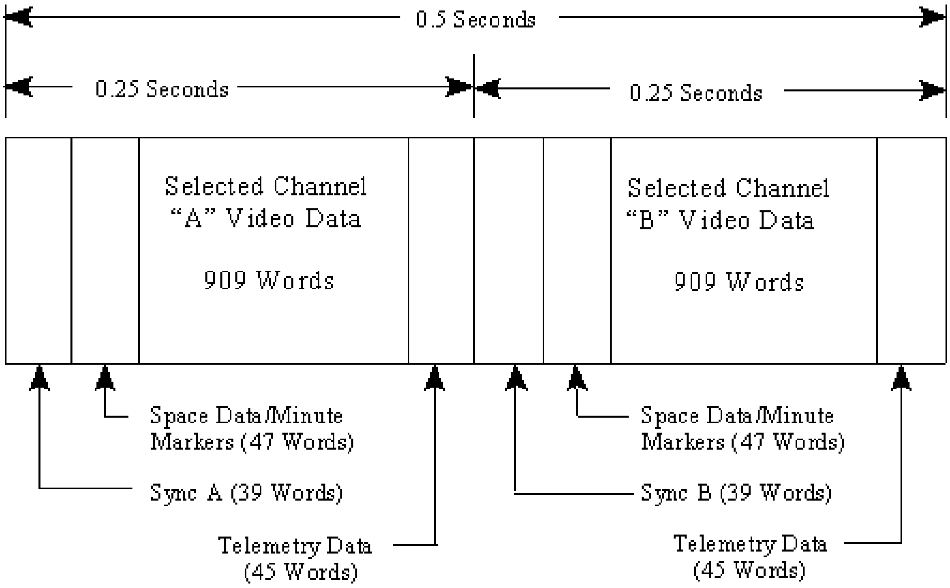
slightly over time. The minute markers are four lines of alternating black then white lines which repeat every 60 seconds (120 lines).
The telemetry section is composed of sixteen blocks, each 8 lines long, which are used as reference values to decode the image channels. The first eight blocks, called "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.

IV. Broadcast signal

The processed AVHRR instrument data AM modulates a 2400 Hz subcarrier. The satellite inserts calibration and telemetry data for each of the selected APT channels being transmitted, and AM modulates the 2400 Hz subcarrier, corresponding to the light and dark areas seen by the instrument, with the 8 Most Significant Bits (MSB) of the 10-bit data. The formatted data passes through the digital-to-analog converter, is filtered and modulated onto the 2400 Hz carrier.
The maximum subcarrier modulation is defined as the amplitude of the gray scale wedge number 8 (see diagram below), producing a modulation index of 87% ±5% (not exceeding 92%). The AM modulated subcarrier is subsequently used to FM modulate the VTX transmitter operating in the 137 - 138 MHz band.

In a nutshell, the signal itself is a 256-level amplitude modulated 2400Hz subcarrier, which is frequency modulated onto the 137 MHz-band RF carrier. Maximum subcarrier modulation is 87% (±5%), and overall RF bandwidth is 34 kHz. On NOAA POES, the signal is broadcast at approximately 37dBm (5 watts) effective radiated power.

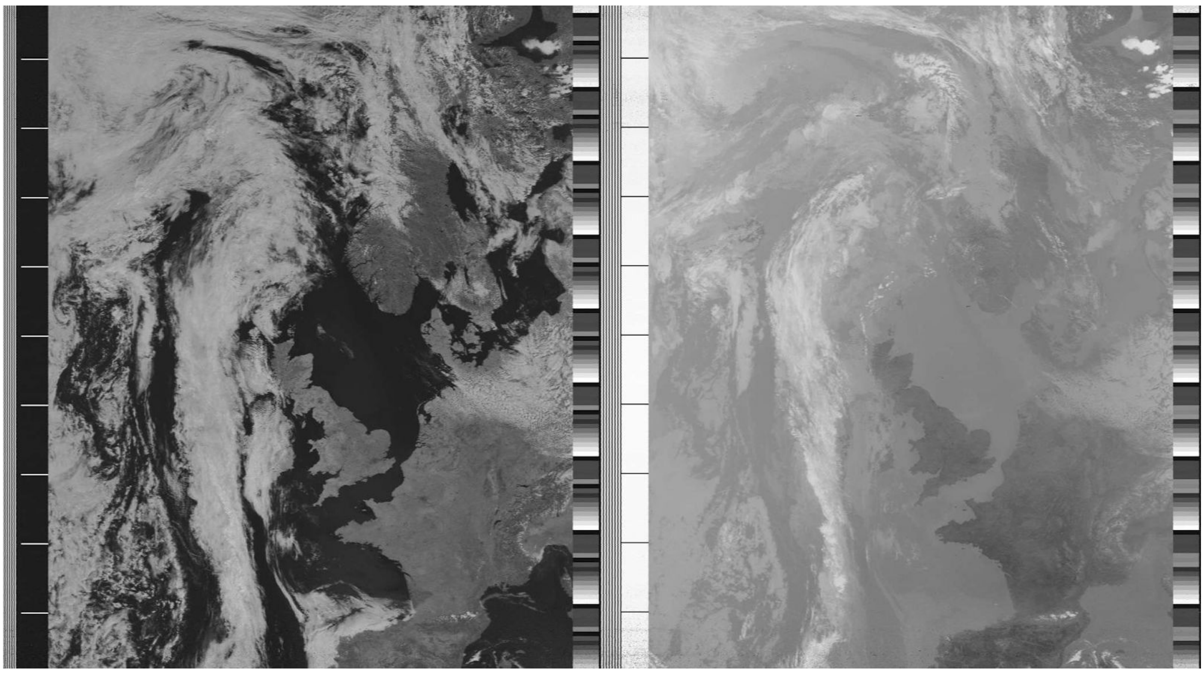
On the received images, we can directly visualize the format of the frame. We can see the synchronisation part and the minute marker on the left of the images and on the right we can see the different wedges (the grayscale).



Notes:

1) Equivalent output digital data rate is 4160 words/second
2) Video line rate - 2 lines/second
3) APT frame size - 128 lines
4) Any two of the five (six for group 505) AVHRR channels may be selected for use
5) Sync A is a 1040-Hz square wave - 7 cycles
6) Sync B is an 832-pps pulse train - 7 pulses
7) Each of the 16 telemetry points is repeated on 8 successive lines
8) Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white

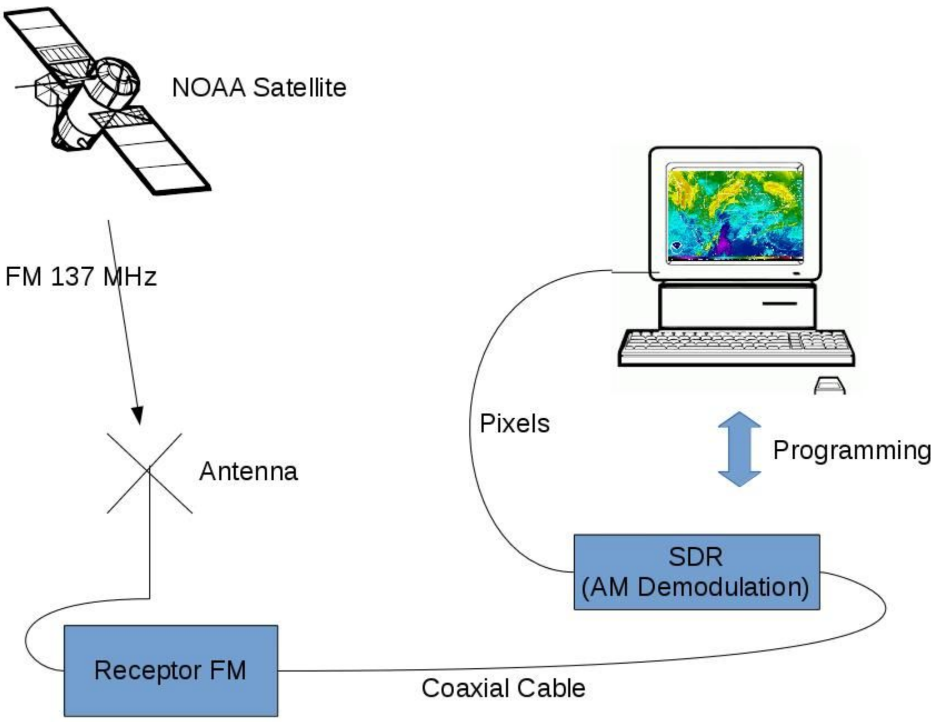
APT Video Line Format



Raw received pictures from the NOAA satellite

C. Ground Reception

1. Reception chain



Scheme of the reception chain

The goal of this project is to build an reception antenna. But in order to correctly receive the images, we need adapted equipment in addition of the antenna.

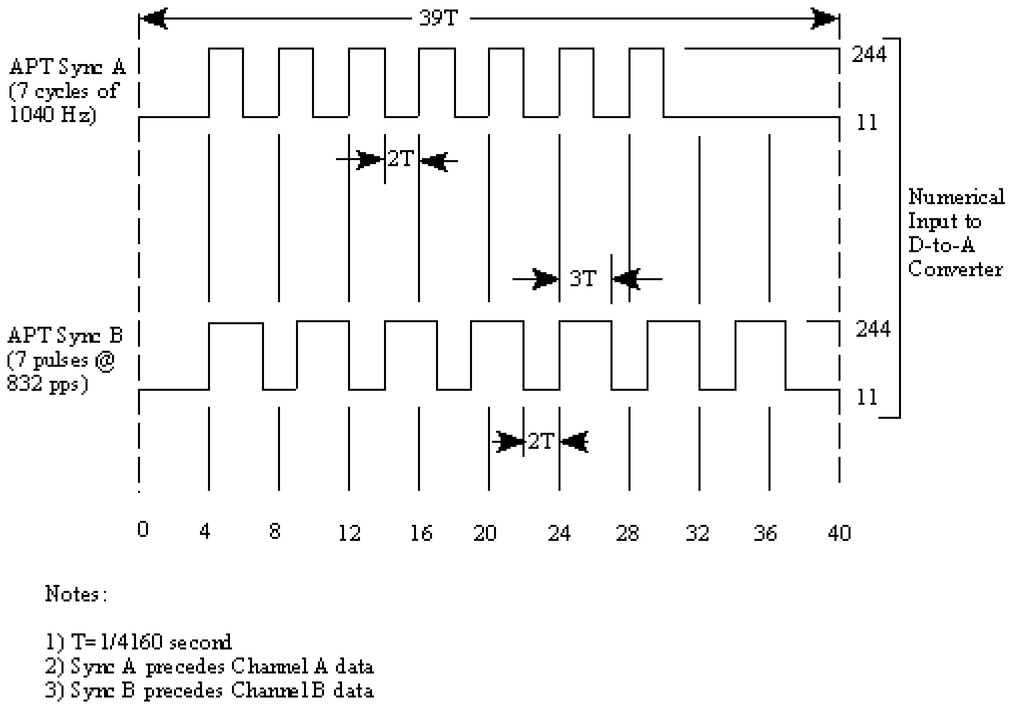
Front face of National Instruments USRP (SDR)

2. Demodulation

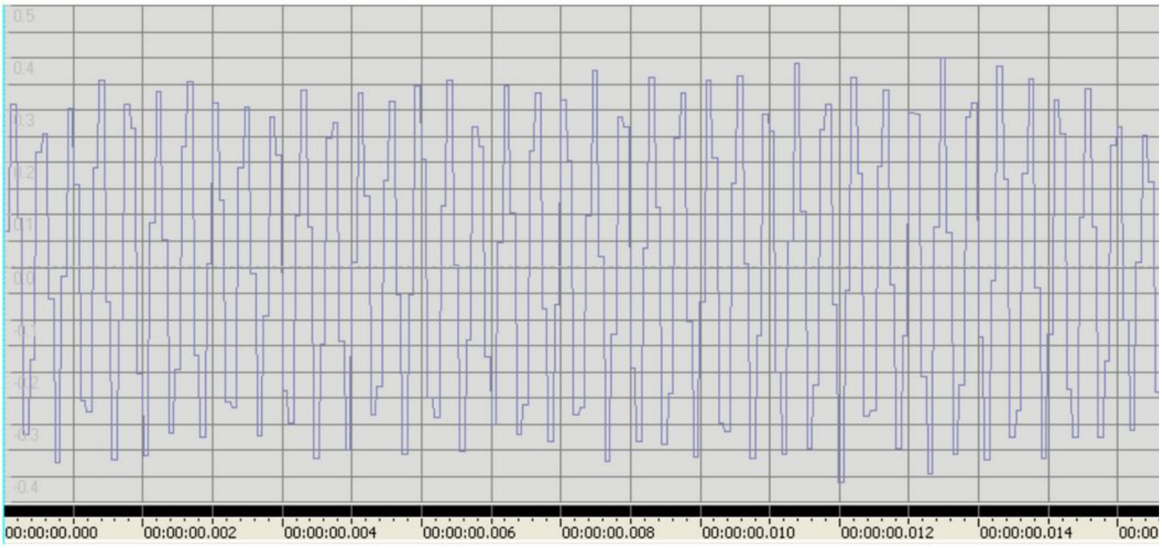
As we have already seen, the external frequency modulation of the signal is done with a 37 kHZ bandwidth, so we need a radio receptor that complies with this bandwidth in FM mode. It should also be able to constantly modify the frequency because of the Doppler effect. An AFC circuit (Automatic Frequency Compensator) is therefore required.
Once the FM carrier is demodulated, in output we get the AM modulated signal.

Thus, we have to demodulate a second time the 2400 Hz subcarrier knowing that it is coded on a 256-level with a maximum subcarrier modulation equal to 87% (±5%).

We use the synchronization scheme detailed below to calibrate our AM demodulation process :

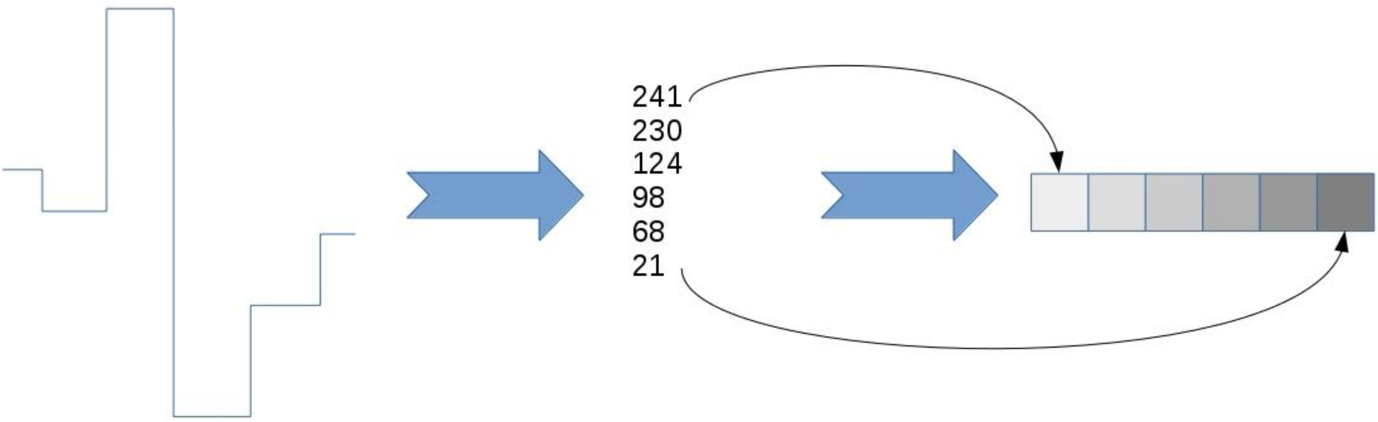


APT Synchronisation Line



Example of the AM Modulated signal received during 15 ms

In the second part of this project, we will have to program the amplitude demodulation in Labview.
For demodulation, we will use a DSP which multiplies the signal with a cosine function at the same frequency and then filters in order to keep only the source signal.
After that, the signal is sampled at the right frequency and we can retrieve the value of each word, its digital 8-bit code that gives the level of gray of each pixel.



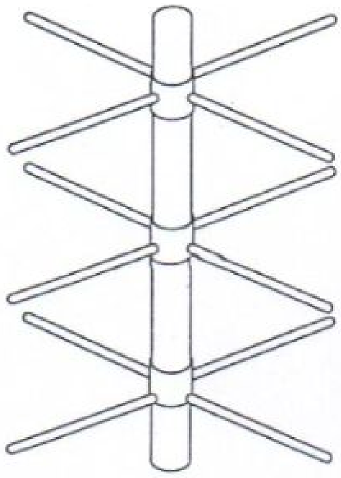
Scheme of decoding process

3. Antenna Choice

We have to specify the characteristics of the reception antenna. We cannot use any antenna, it has to fulfill some requirements. In addition, we want to construct an antenna with an affordable price, we cannot permit ourselves to choose a too complicated antenna.

First of all, the antennas of the NOAA satellites are right hand circularly polarized. It is then logical to have a receiving antenna polarized as the emitting antenna.
A second parameter that we first had in mind was the antenna diagram. As the considered satellite is not geostationary whereas moves in the sky, we cannot have a dish that directly points towards the satellite.
Having an isotropic antenna with the same gain in every direction is a solution to that problem, this type of antenna would be able to receive the signal of the satellite while it is moving in the sky above our location. We don’t have to move it once installed on the roof.
Thirdly, as the NOAA APT weather satellites broadcast their signal at about 137 MHz, we have to make sure that the signals can be received by the chosen antenna.
Thus, we at first searched for right hand circularly polarized antennas with an isotropic gain.

The main antennas that radio amateurs use are the Turnstile Antenna and the Quadrifilar Helix (QFH) Antenna, which is a bit more complicated to build but is said to have better results.



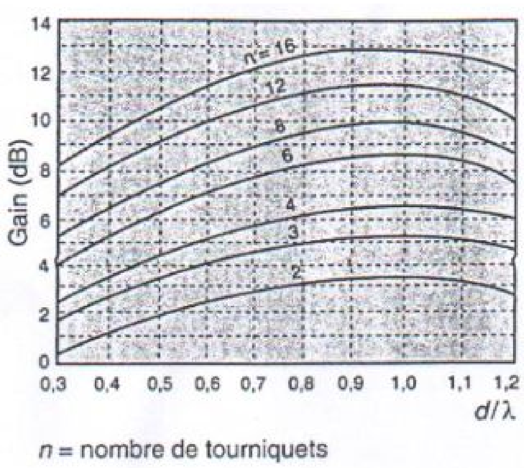
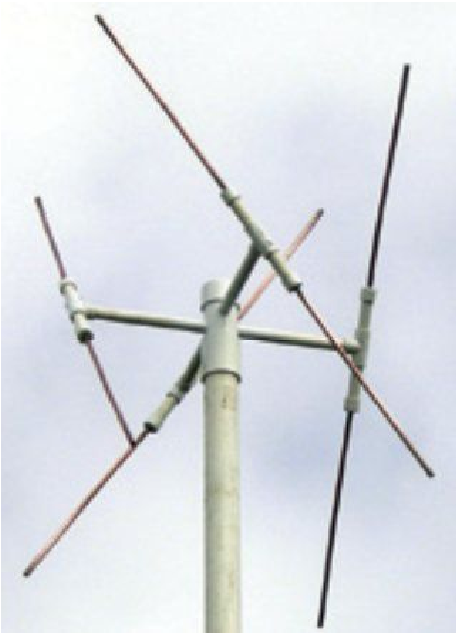


Illustration of the Turnstile antenna

QHF antenna

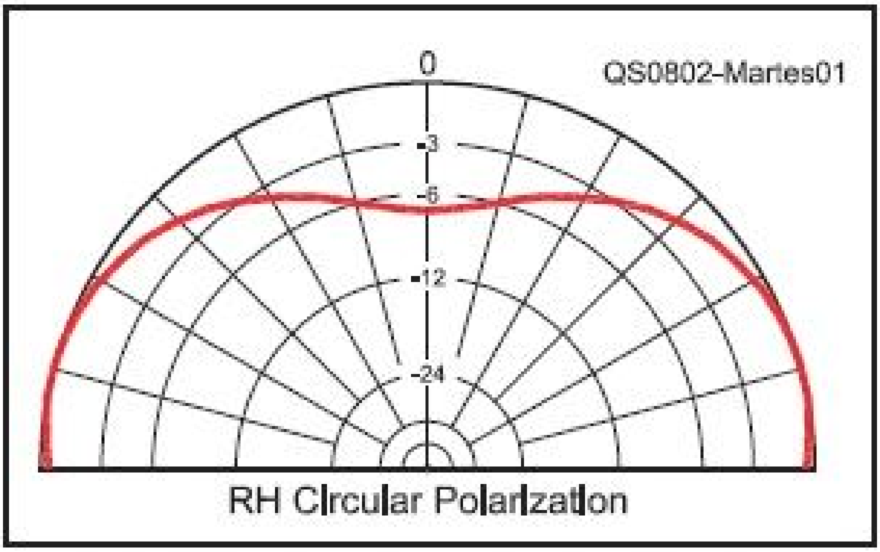
The specified requirements led us to find these two antennas previously described.
However, these antennas are isotropic which means that they have the same gain towards the ground. They are thus very sensitive to ground reflexions, and these reflexions can be important.

We searched for an antenna having a constant gain in the upper directions and without any gain towards the ground, meaning that these antennas will have less noise of multipath signal coming from the surface of the earth. By doing this we may be able to keep only the direct path (LoS) signal.

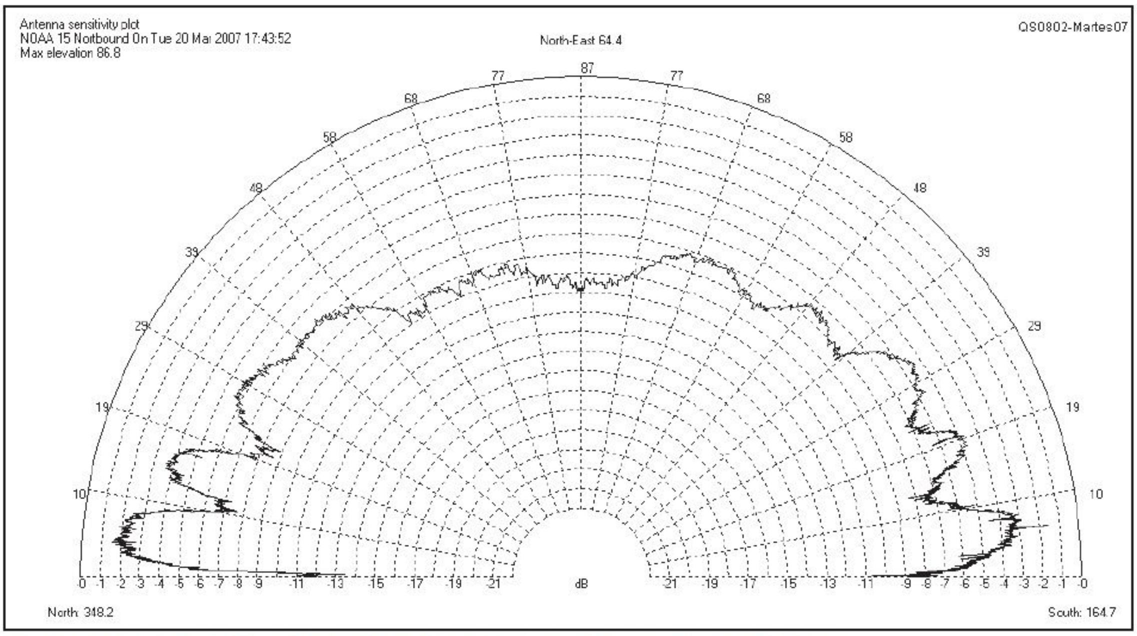


Double-cross antenna

The Double-cross antenna meets these specifications. The gain on the upper part of its radiation pattern is almost constant so that we can receive with the same intensity the satellite flying.
As we can see on the images below, the perfect radiation pattern would be 12 dB lower at zenith considering we receive the signal 12dB stronger at zenith compared to horizon.



Shape of the ideal gain for an isotropic antenna for receiving signal from POES



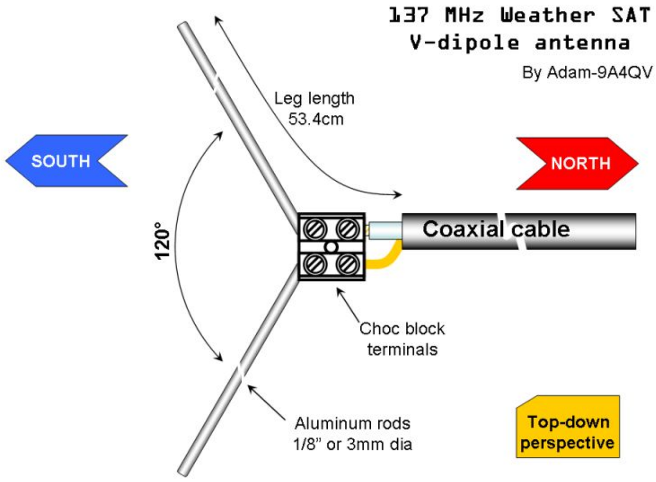
Measured gain on the double cross antenna for every elevation angle

However, these antennas also receive very well the vertical polarisation of the many (and very strong) terrestrial signals close to the 137 MHz frequency such as FM Radio.

X- polarization	**Vertical**	**Horizontal**	**RHCP**	**LHCP**
Vertical	0dB	-20dB	-3dB	-3dB
Horizontal	-20dB	0dB	-3dB	-3dB
RHCP	-3dB	-3dB	0dB	-20dB
LHCP	-3dB	-3dB	-20dB	0dB

Typical values of cross polarisation attenuation

An idea would be to use an antenna that is less sensitive to this kind of noise, by using the cross-polarization losses.



V-Dipole Antenna

The V-Dipole Antenna is a very simple antenna model proposed recently by a radio amateur. Since the antenna is horizontally polarized, all vertically polarized terrestrial signals will be reduced by 20 dB (See tables above).
The principle of this antenna is that by arranging a dipole into a horizontal 'V' shape, the radiation pattern will be directed skywards in a figure 0 (zero) pattern. This will be optimal for satellites travelling in front, above and behind the antenna. Since polar orbiting satellites always travel North to South or vice versa, we can take advantage of this fact simply by orienting the antenna North/South.
As the satellites broadcast in circular polarization there will be a 3 dB loss in this design from using a linear polarized antenna. But this may be considered as almost negligible compared to other attenuations.

We completed a small table with a summary of the different characteristics we highlighted before.

	Advantages	Drawbacks
Double-Cross	-No Gain in the ground direction -circularly polarized	-Hard to mount
Turnstile	-Isotropic -circularly polarized -easy to mount	-gain in the direction of the ground
V-Dipole	-easy to mount -less sensitive to vertical polarized signals	-Horizontally polarized -gain in the direction of the ground

We chose the Double-Cross Antenna for now, which presents a sufficiently good reception and seems to be affordable. We plan to create a foldable version of it in order to move it easily and to be able to store it.

Antenna Construction

Antenna Description

Picture of our Double-Cross antenna on the roof of Satcom's lab

The double cross antenna is composed of two crossed pairs of equidistant dipoles, spaced a quarter wavelength from each other and making 30° with the vertical. Each dipole has a length of half a wavelength.

Our Double-Cross Antenna was created foldable as planned. The upper part of the antenna can be removed and the arms can be turned as to be stored horizontally. The reception of the antenna is sufficiently good, we thus achieved our objectives.

Design

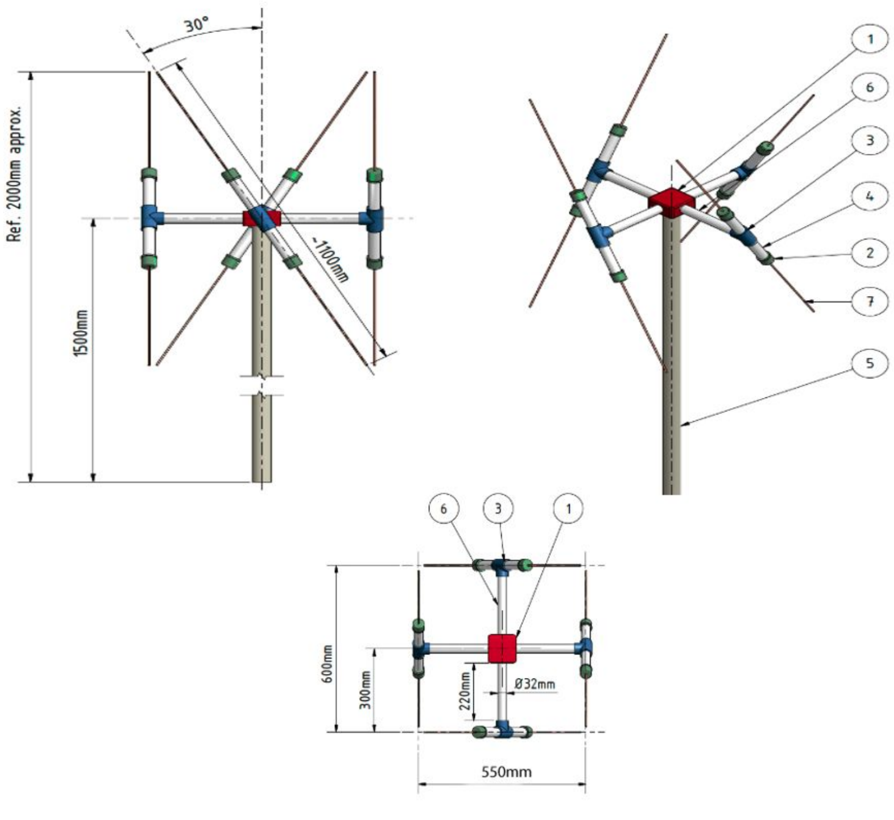
As we have seen previously in this document, we chose to receive the images from NOAA 19 which transmits at a frequency of 137.1 MHz. We must thus design the antenna with the corresponding wavelength with is calculated below :

$$\lambda = \frac{c}{f} = \frac{3 * 10^8}{137.1 * 10^6} \approx 2.188m$$

(Since the other NOAA satellites transmit at frequencies close to 137 MHz, we are able to receive their signals as well because the difference is negligible).

We can deduce the dipole length and the distance between the dipoles which are respectively half a wavelength and a quarter wavelength:

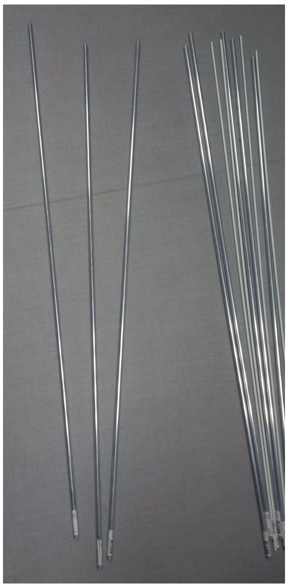
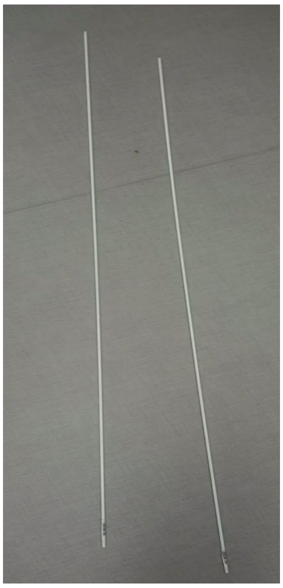
$$\frac{\lambda}{2} \approx 1.1m \qquad \frac{\lambda}{4} \approx 55cm$$



Scheme of the antenna with the dimension

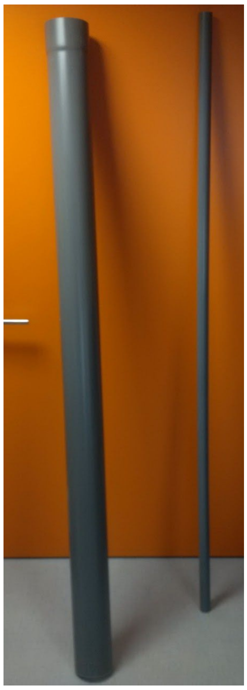
List of all the needed components

- 8 metallic tubes of 1m long / 1 cm of diameter (8 half-dipôles of length 55cm)
- 4 composite rods of 0.3 cm diameter and 50 cm long (4 rods, used to consolidate the half dipoles)

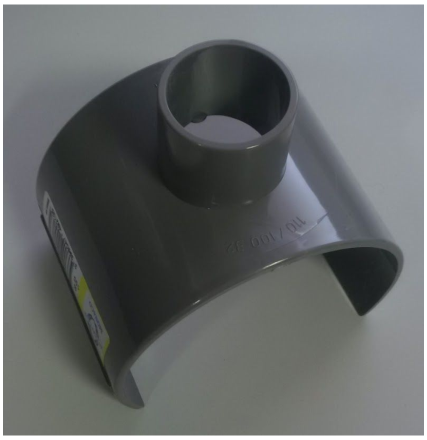



- adapter for the mast and a cap (part of the antenna that can be removed, the arms will be connected to the adapter)
- 4 pvc caps of 3,2 cm diameter (to close the hole in the arms)
- 1 pvc tube of 2m height and 10 cm diameter (the mast)
- 1 pvc tube of 2m de height and 3.2cm diameter (4 arms of 27cm)





- 4 selles of 10 cm / 3.2 cm diameter (used to fix the arms on the adapter of the mast)
- 8 male connectors
- dominos to interconnect cables
- notched stem and bolts to fix possibly moving parts




- 6 meters of coaxial cable of 50 Ohm
- resin and glue

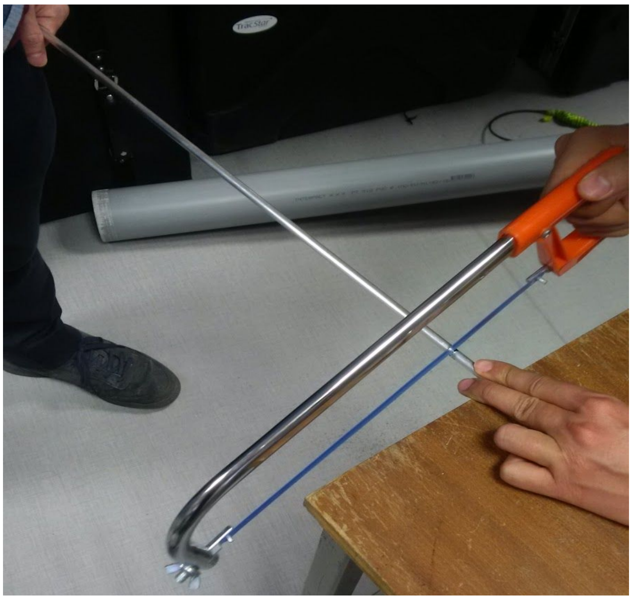

Tools necessary for the construction of the antenna :

-Saw
-Drill
-cutting pliers
-cutter

Tutorial

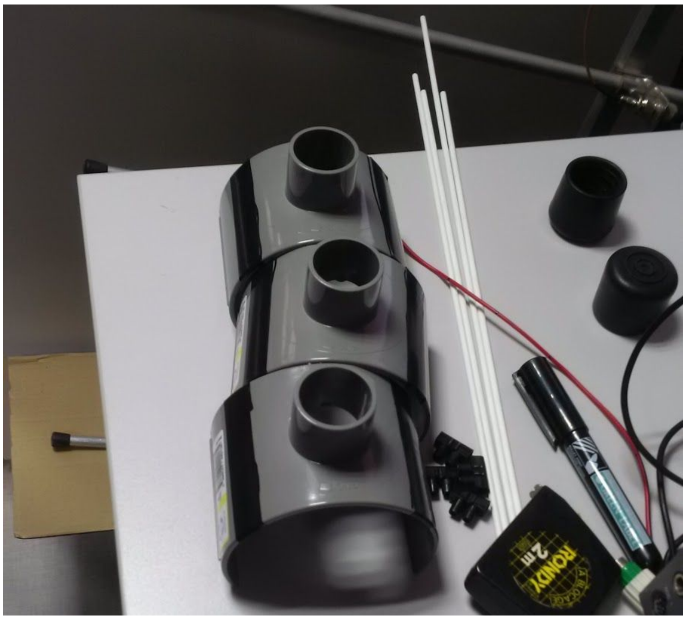
Step 1:
Measure and saw the pvc tubes to make the four antenna arms of 27 cm.

Step 2:
Saw the metallic tubes in 8 pieces of 55cm to make the 8 half-dipoles. (We do not saw the composite rods because they go entirely through the dipole and the arm).



Step 3:

Saw the sides of the selles sont that we can position them around the mast.



Step 4:

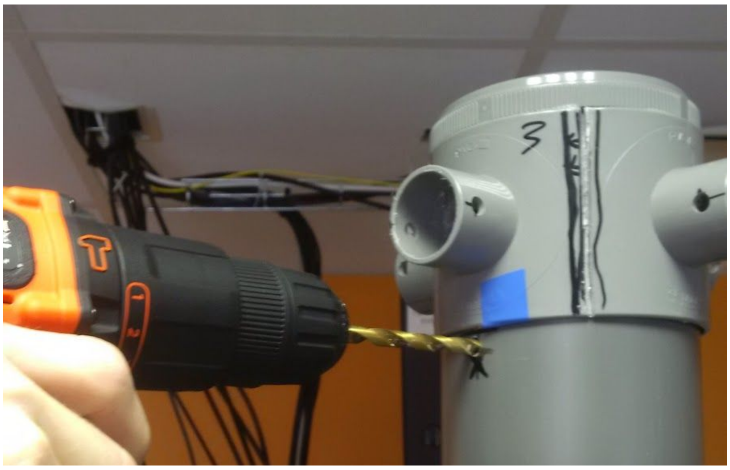
Glue the selles on the pvc adapter (avoid gluing the cap to the selles)

Step 5:
Drill holes inside the selles and though the pvc adapter so that you can slide the connexion cables of the arms inside.

Drill each pvc arm at 22.5cm. This hole needs to be slightly wider than the diameter of the composite rod so that it can go through the arm with the Woven copper shield and the Copper core of the coaxial cable. The dipole will be placed there.

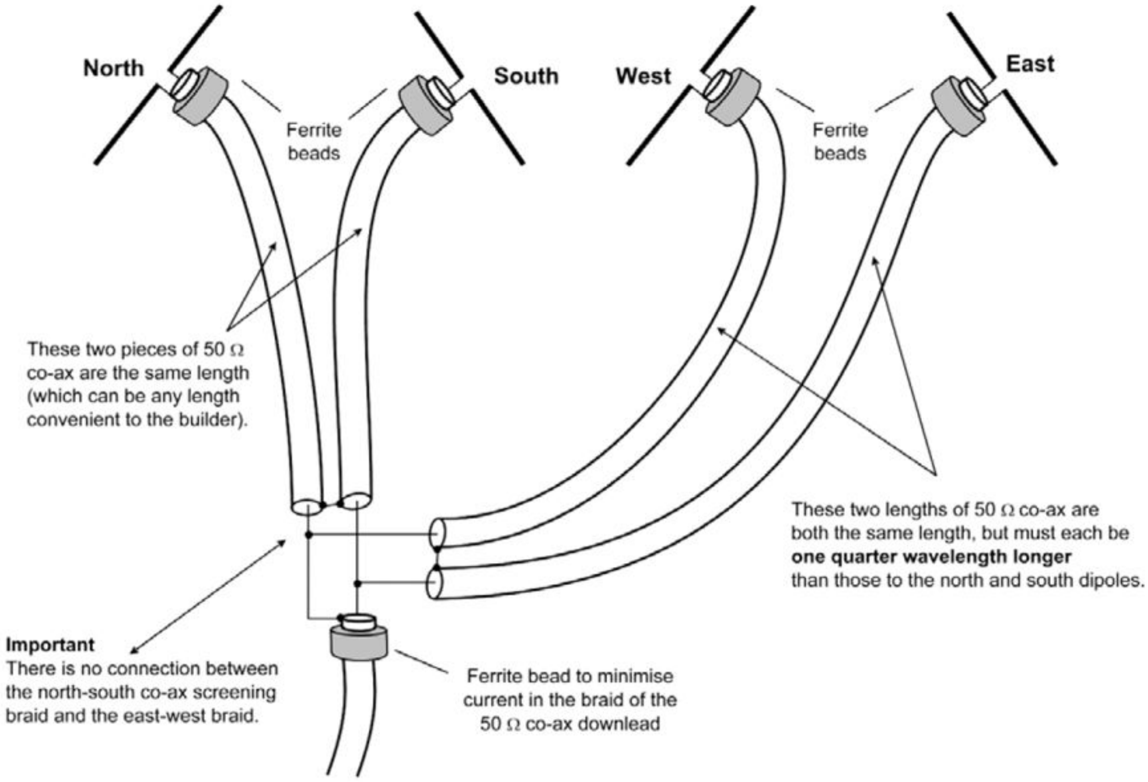

File the drill holes. Then drill the other side of the arm, where is enters the selle, in order to put a notched stem and solidify the whole. You need to make sure at that moment that the dipole makes and angle of 30 degrees with respect to the vertical.

Drill as well the part of the adapter that enters the mast so that we can solidify the whole with a notched stem

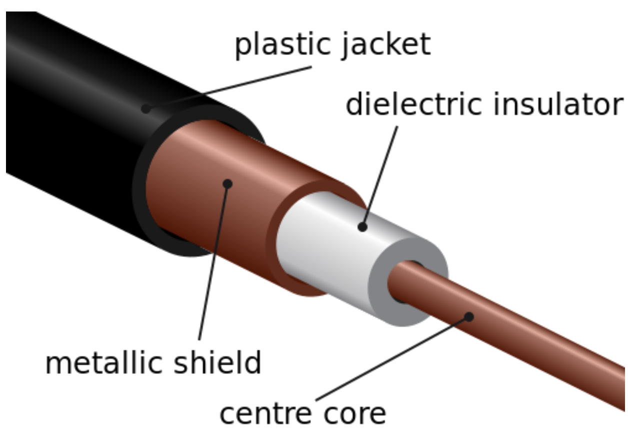


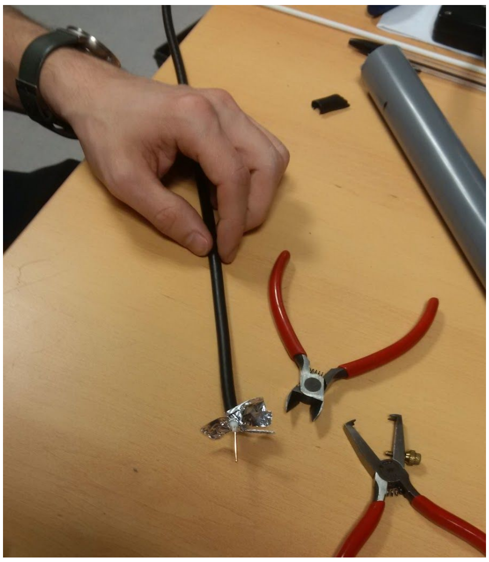
Step 6:

Cutt two coaxial cables of 40 cm long. (You can choose the length, we took the size of an arm + more or less 10 cm). See scheme below.
Cut two other cables of 40 cm long + a quarter wavelength, thus 90 cm.
You need a last cable of 2 meters long that will go through the mast.



At each end of the cables, you need to separate the center core from the metallic shield. For that you need to strip the cable and twist the metallic shield.



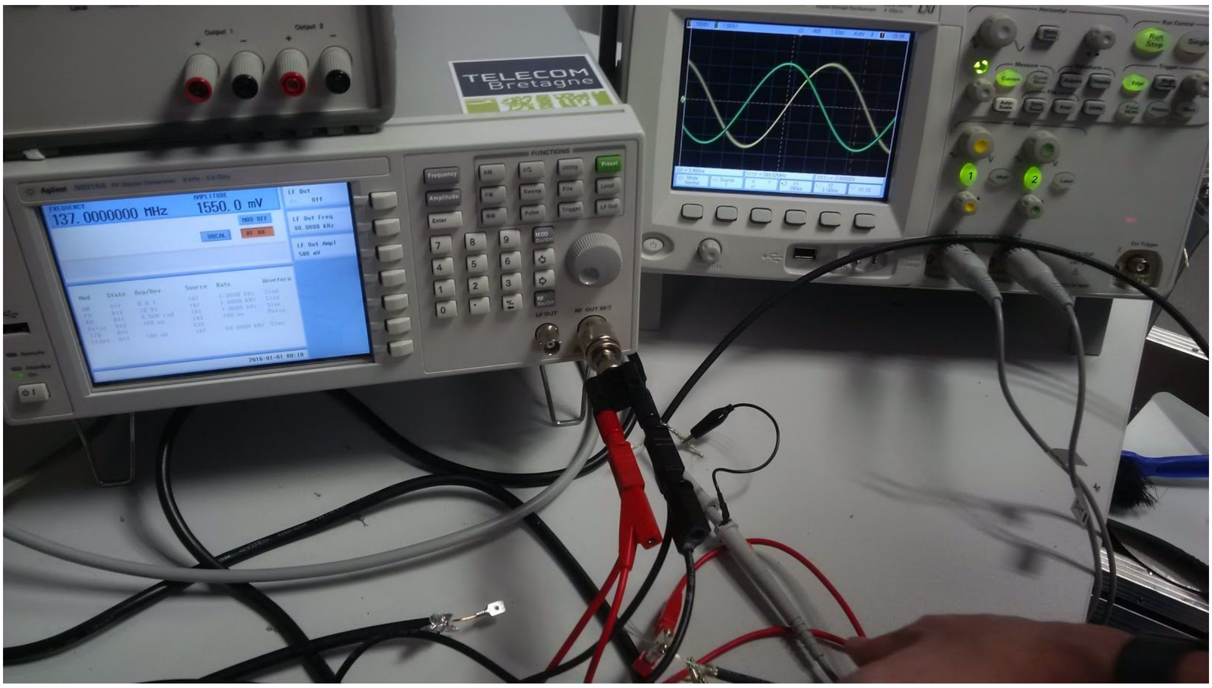


Step 7:

You slide the centre core in one of the holes of the pvc arm and you slide the metallic shield in the opposite hole. Then you slide through the arm the composite rod.

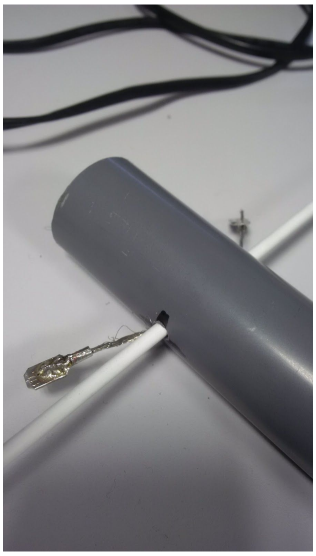
Step 8:

You have to check that the adjacent cables have a phase shift of Pi/2 because of the length difference of a quarter wavelength.
For that we generate a signal of 137 Mhz on the signal generator and we connect two cables of different length. We can then check if the output of the cables are dephased of Pi/2 as we see on the following picture.



Step 9:

Solder the connectors on the coaxial center core and on the metallic shield.



Step 10:

Put the caps on the arms and fill the end of the arms until the composite rod with resin to solidify the whole. Check regularly that there is no contact between the centre core and the metallic shield with a multimeter.

Step 11:
Put the metallic tubes on the composite rods and stick them together with glue.
Solder the connectors to the metallic tubes and protect the whole with solid scotch. Check that the connections still work and that the metallic tubes conduct.

Step 12:

Put the arms on the adapter and slide the notched stems so that everything stays stabilized. The half-dipoles connected to the center core of the coaxial cable must be pointed to the sky.

Connect the coaxial cables together with the dominos respecting the following scheme :

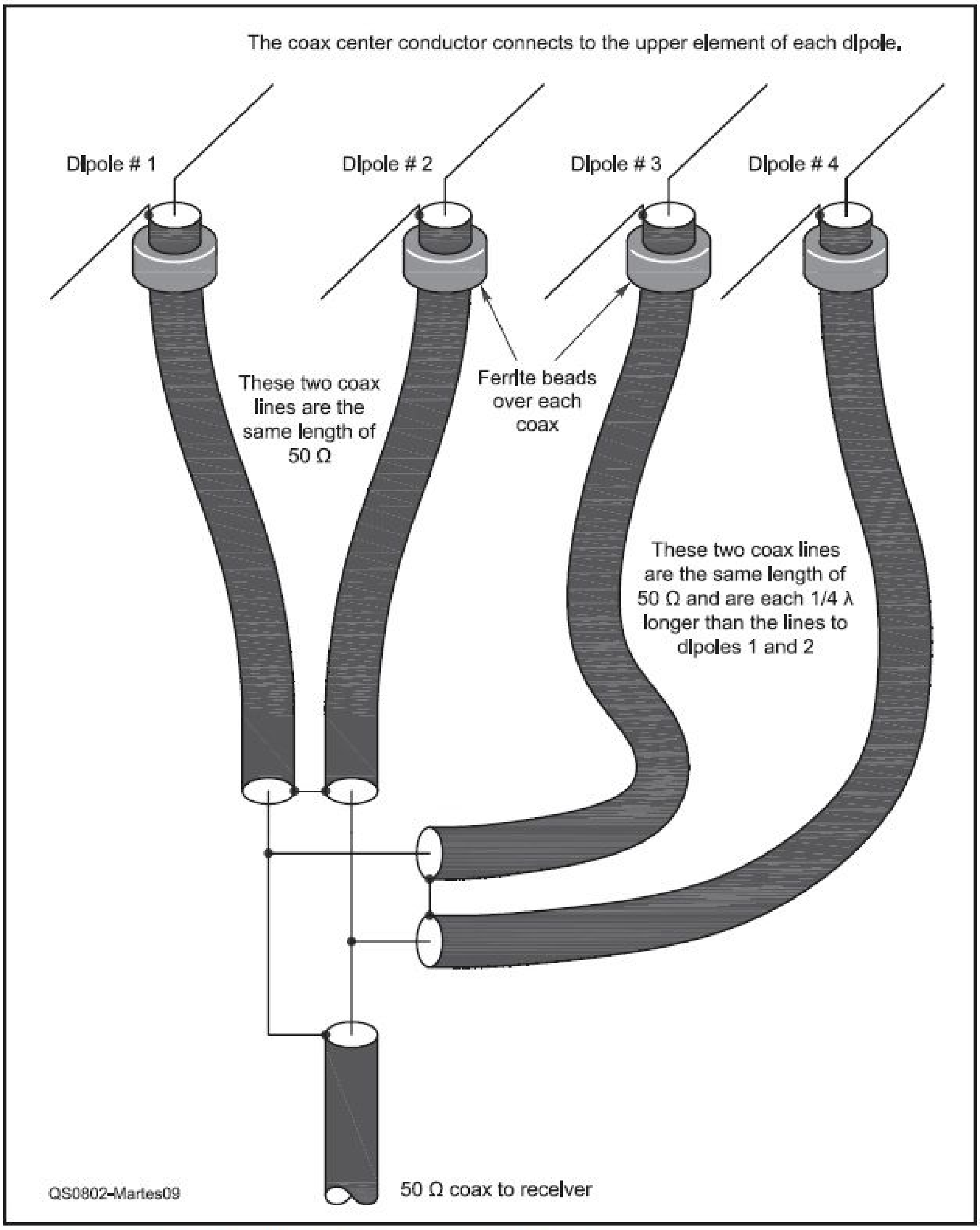
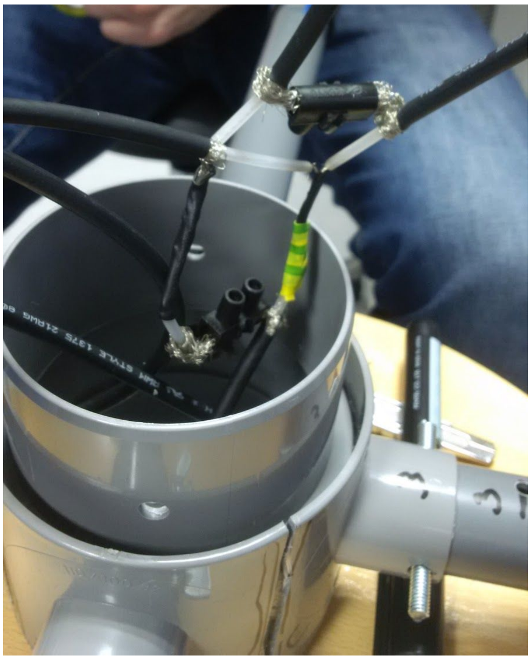
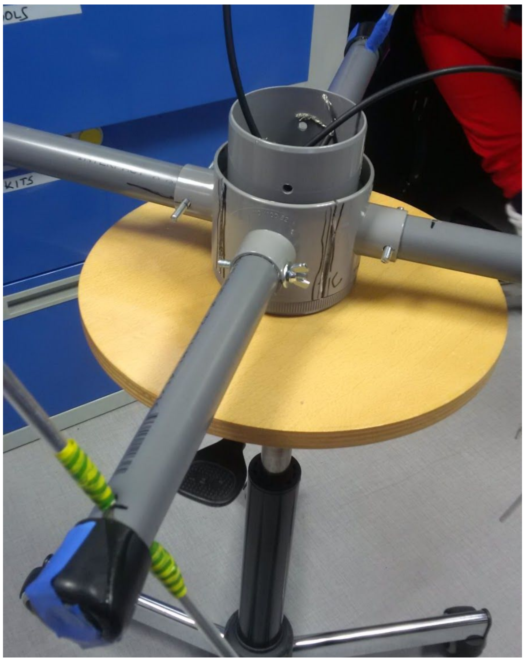
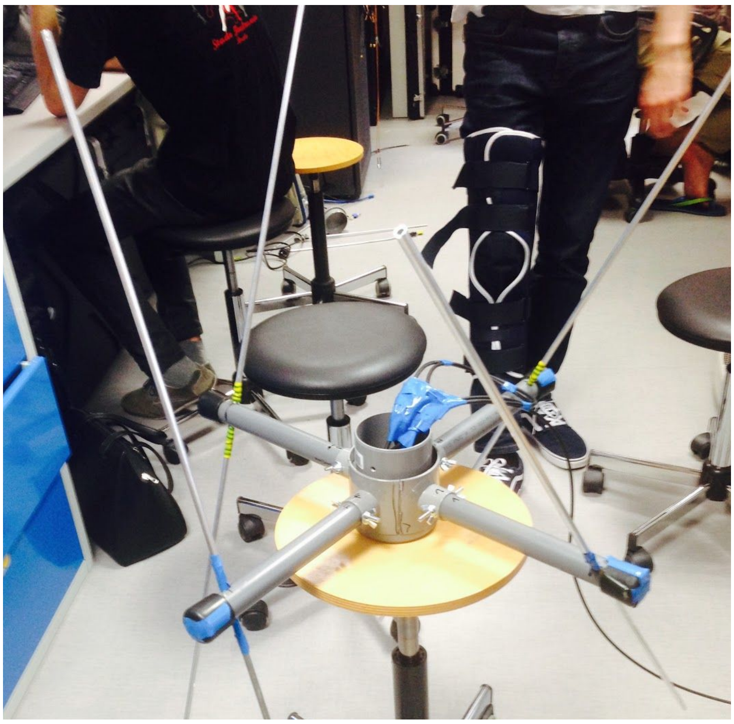


Figure 9 — Harness for Double Cross using 50 Ω coax.

Step 13:

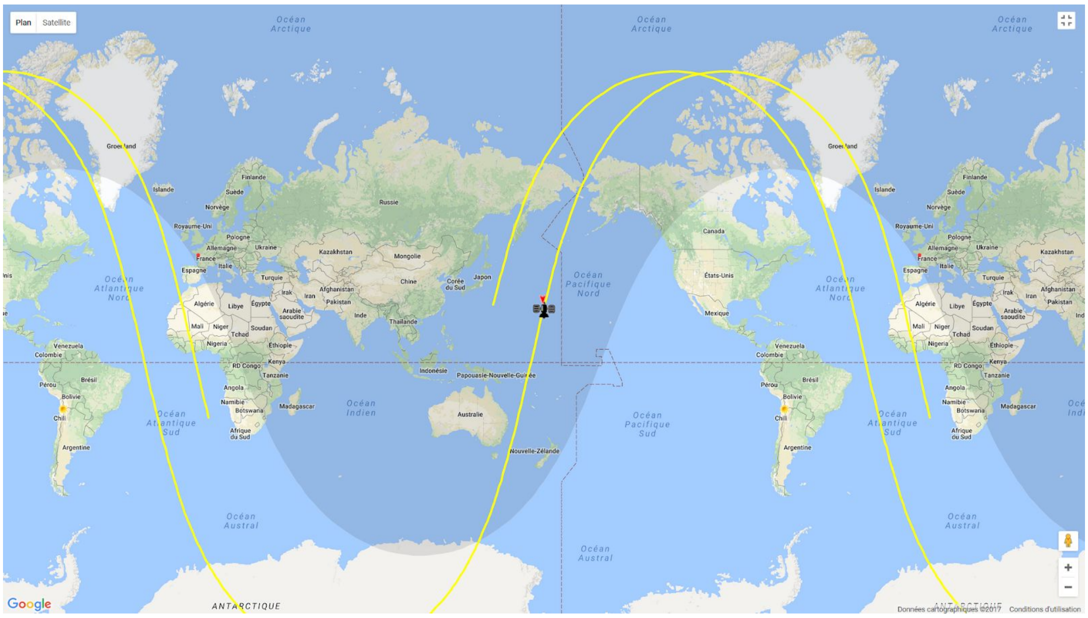
Connect the mast cable with the other cables. After checking that all the connexions are correct with the multimeter, recover the whole with scotch to avoid any disconnexion.



Step 14:

Since we want our antenna to be stored, we need to use male/female coaxial plugs in order to part the cable.
The copper core needs to go in the center of the plug and to be isolated from the metallic shield, then you solder the copper core to the male plug and you isolate the metallic field with scotch.

Tracking software



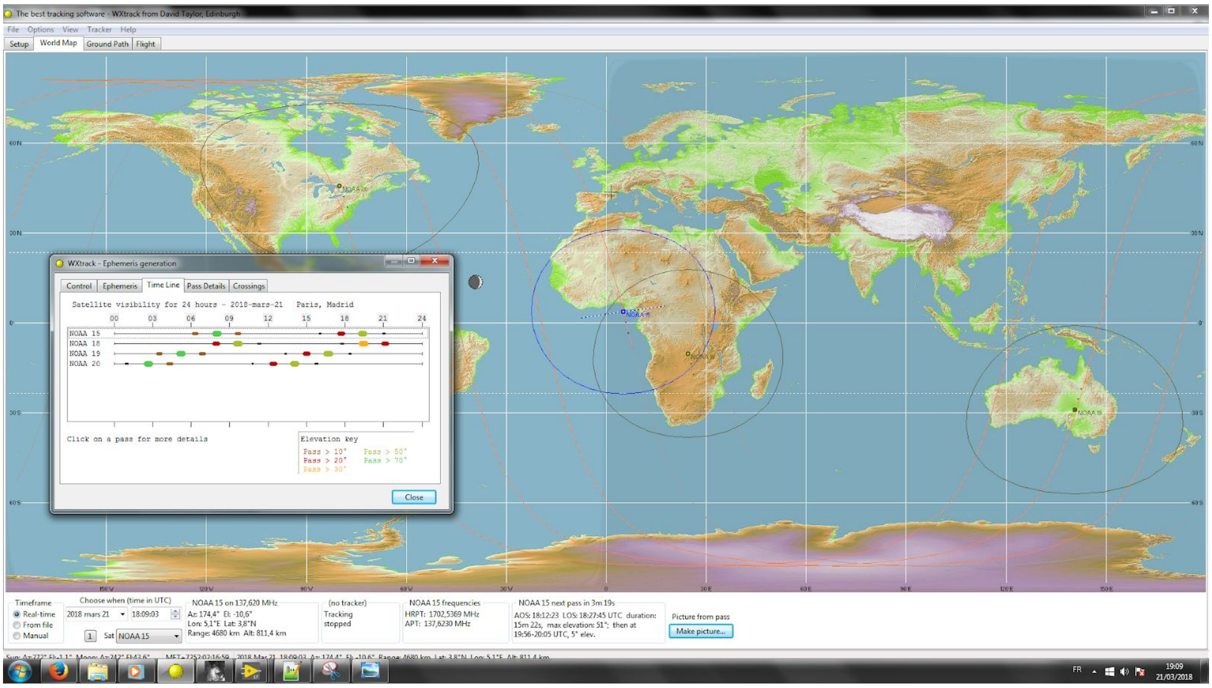
A live orbit trajectory of NOAA-19

Different tracking softwares exist, such as WXTrack, which have for purpose to follow any satellite of interest. It gives information about the speed of the satellite, its position in the sky, their emission frequency, their altitude, elevation angle, azimuth, and distance from the ground station.

Knowing the location of our antenna (Toulouse), we can follow a given satellite and we can precisely know when and for how long we will be able to receive its signal.

To make sure that our antenna works, we plugged the male plug of the coaxial cable to a radio receiver. As an APT signal is audible once demodulated in frequency, we can determine easily if the antenna is correctly working or not just be listening to it.
We checked on WXtrack when a satellite was flying by Toulouse, we turned on the radio receiver to the correct frequency depending on the available satellite and we listened to the signal directly at the output of the receiver.

FM Radio receiver



WXTrack Capture

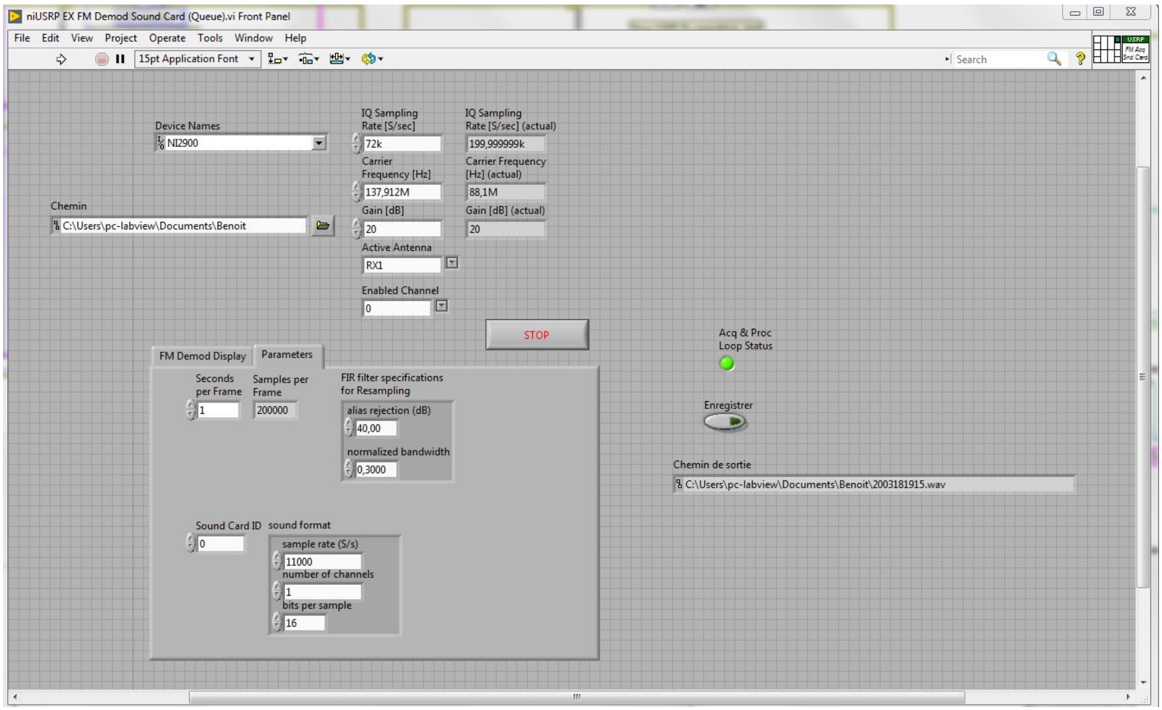
On the capture above we can see the ephemeris of the different satellites. The software also gives details about the doppler effect and we can manually compensate the effect by changing the reception frequency.

Labview Design

The cable inside the mast of our antenna is connected to another coaxial cable on the roof that goes through the ceiling and into the satcom lab.

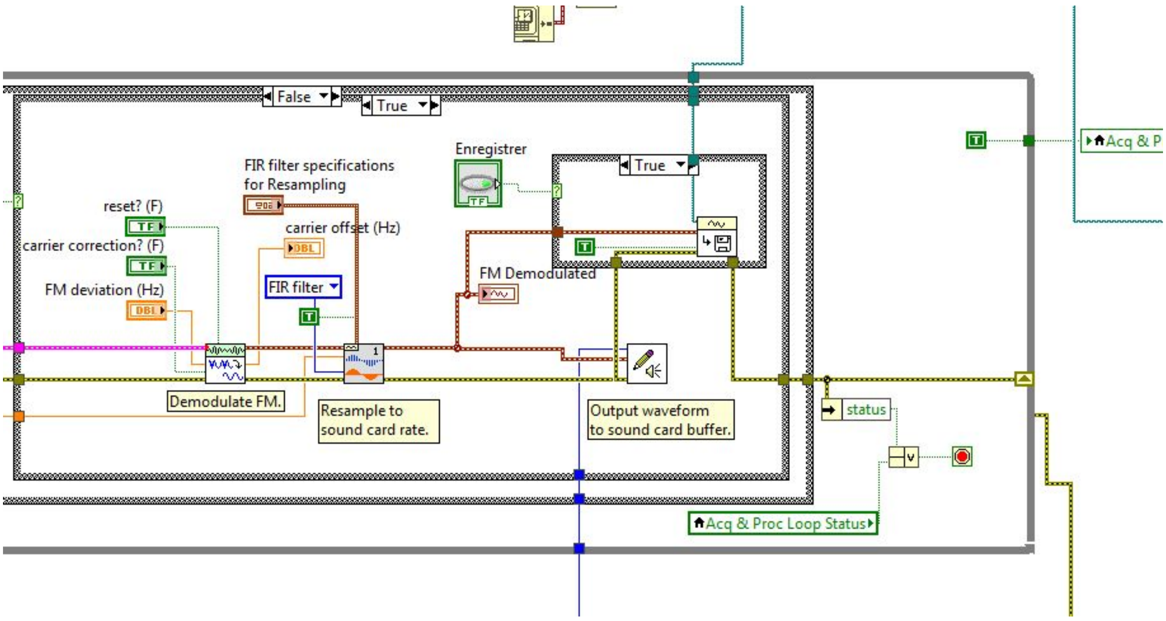
To correctly receive the signal, there are three different solutions :

1. Either we plug the cable into the FM Radio Receiver as we have seen before. Then we set the correct frequency corresponding to the satellite passing over and we manually correct the doppler effect. Then we plug the FM Demodulated signal to the computer microphone and record it into a wav file by using Labview. The radio cannot adjust the bandwidth very properly but it filters and treats the signal in order to maximize the SNR gain. Thus, this solution gives very good audio results.



Capture of the audio recording VI

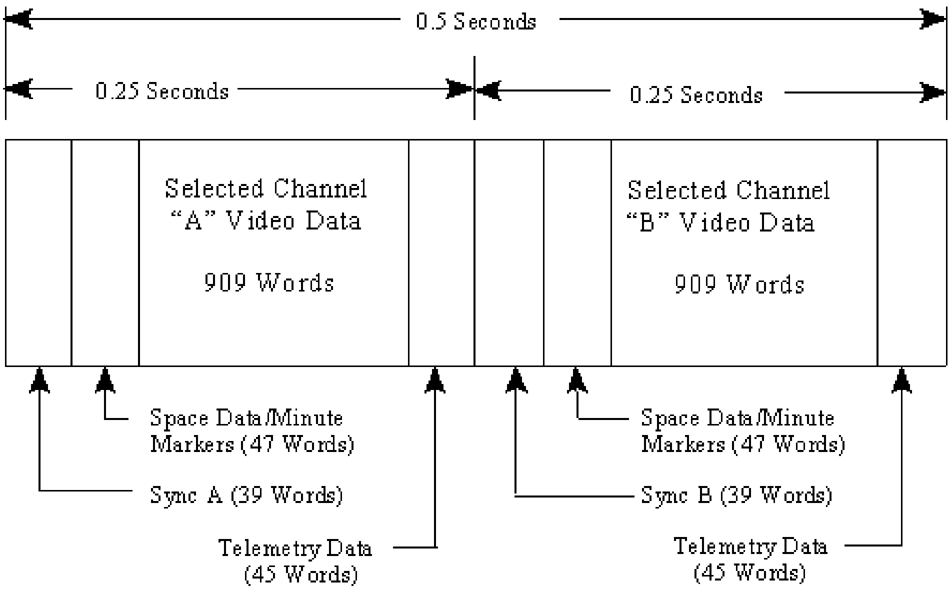
2. Or we can plug the cable directly into the USRP NI-2900 with a coaxial adaptor. Once the USRP is connected to the computer, we can launch our labview program and proceed with the FM demodulation on the received signal. We can set a tighter bandwidth and input the reception frequency. We could have coded an automatic correction for the doppler effect, but unfortunately we did not have the time.

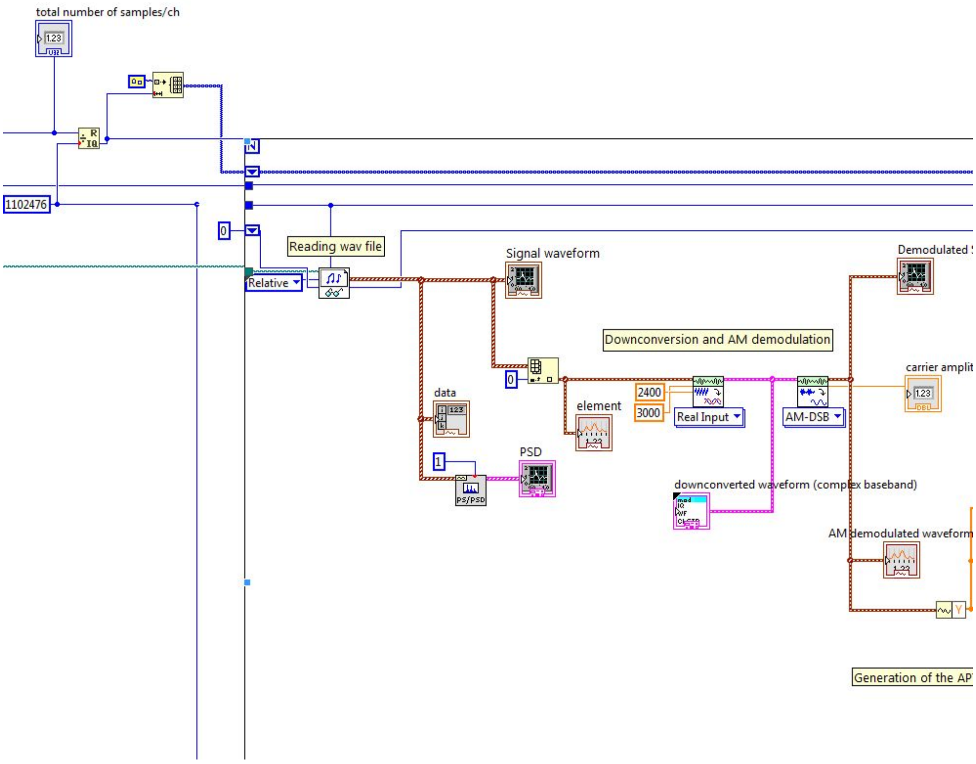


Capture of the frequency demodulation VI

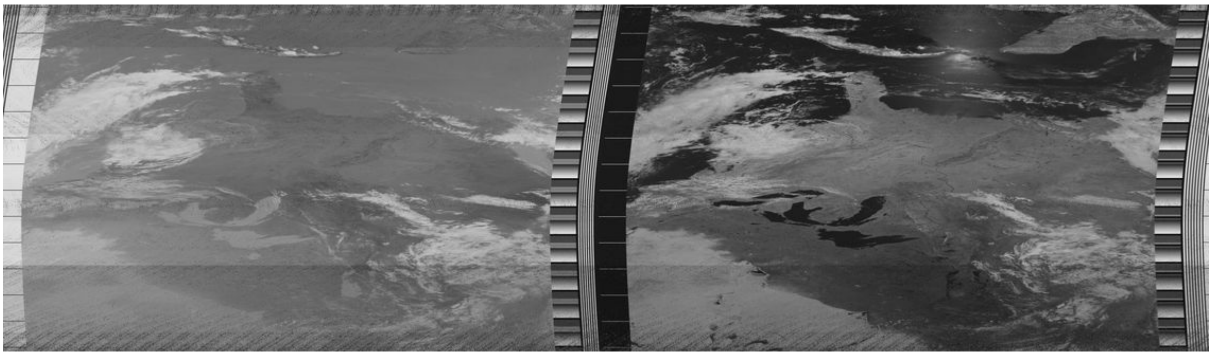
The output of both solutions is a wav. file containing our signal.

Then we use this .wav file as an input to another VI that will AM Demodulate the signal and perform the decoding of the APT frame. Tt is able to draw line by line a picture of the received image.
This VI uses a cross correlation function to adjust the beginning of each row of the image with the beginning of a synchronized pattern.





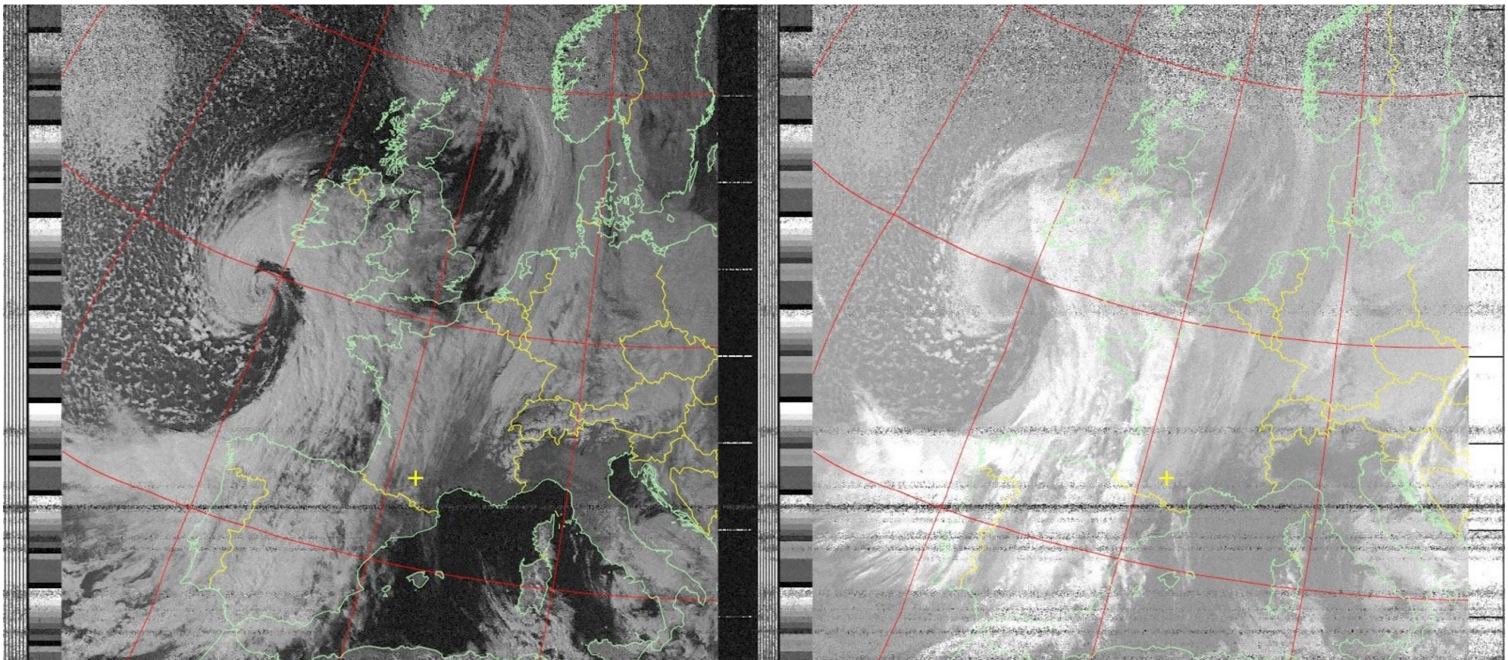
Capture of the AM Demodulation VI

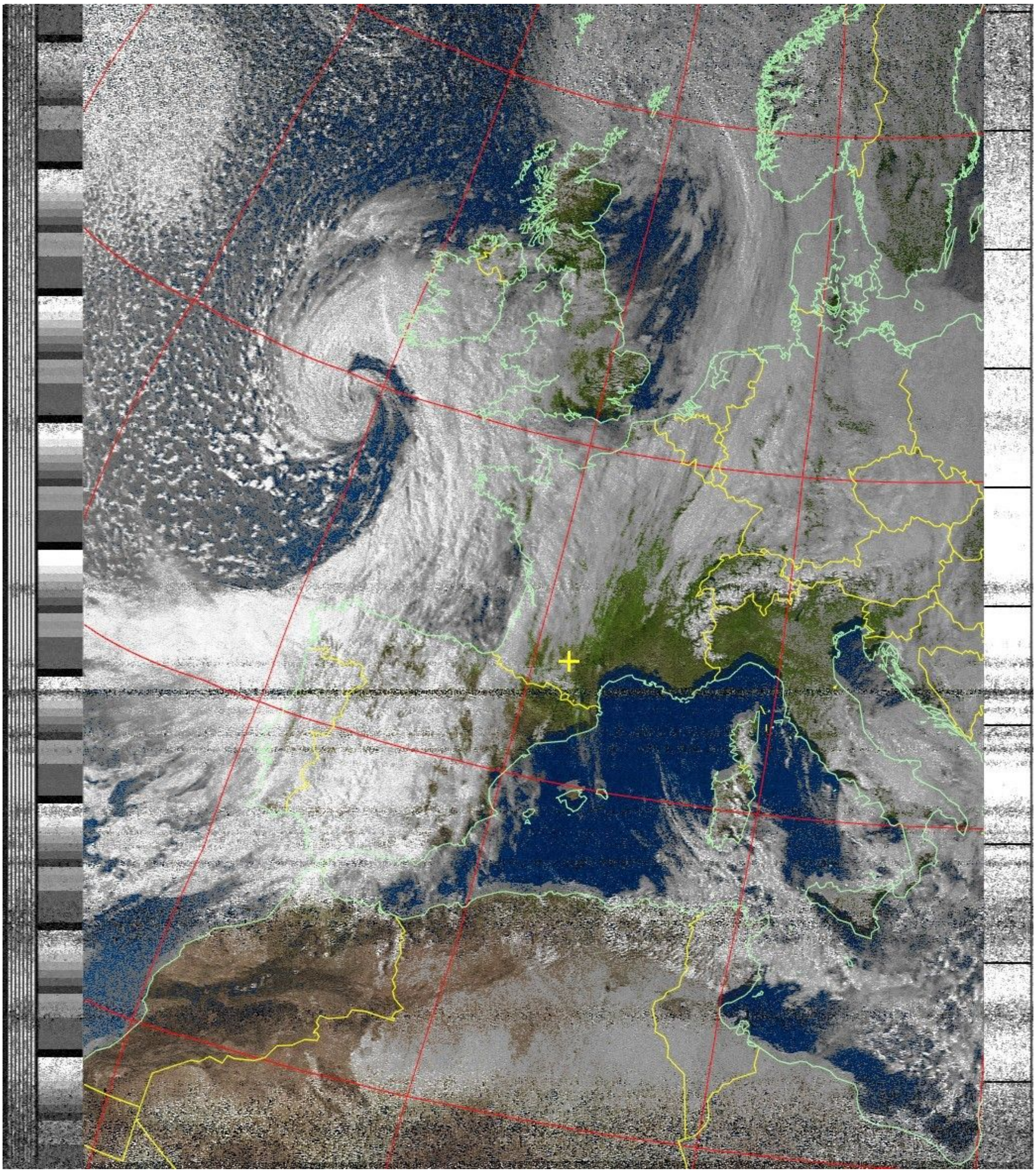


Result of the WeatherImageDecoder VI

3. The third solution is the easiest one. There are several free softwares available online which do all the operations. We used WXToImg.
We can directly plug the output of the Radio Receiver or you can feed the software your .wav file and the software does the rest of the AM Demodulation and decoding.
It has many options and can combine the IR and visible spectrum image for a better visualization of the received image.

Here are some of our images that were decoded and treated by the WXToImg software :





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Annex

Annex 1

Every satellite having a certain life expectancy, il is necessary to know which modules of each NOAA satellite is properly working. We can then choose the best satellite to study.

NOAA-15 Spacecraft Status Summary

Spacecraft Letter: K
Catalog Number: 25338
Operational Date: 12/15/1998

International Designation: 1998 030A
Launch Date: 05/13/1998
Operational Status: AM Secondary

GAC: Yes
LAC: No
LTAN: 17:46:52
Altitude: 807km
Period: 101.1 (minutes)

HRPT: Yes STX-2/MSB 1702.5 MHz
APT: Yes VTX-2 137.62 MHz
Inclination Angle: 98.5 deg
Precession Rate: 1.05 (min/month)

Subsystem Status:

Subsystem	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

Live status of the sub-system on board NOAA-15

NOAA-19 Spacecraft Status Summary

Spacecraft Letter: N-Prime
Catalog Number: 33591
Operational Date: 6/02/2009

International Designation: 2009-005-A
Launch Date: 02/06/2009
Operational Status: PM Primary

GAC: Yes
LAC: Yes
LTAN: 14:36:15
Altitude: 870km
Period: 102.14 (minutes)

HRPT: Yes STX-1/LSB
APT: Yes VTX-1 137.1 MHz
Inclination Angle: 98.7 deg
Precession Rate: 0.77 (min/month)

Note: HIRS filterwheel motor current increases on July 2, 2013. 12 IR channels NEdNs exceed specs, products unusable on July 8, 2013. FLT MTR was put in Hi PWR mode and FLT Wh HSG Htr was turned on July 10. NEdNs reduced. Data re-evaluation is on-going.

Subsystem	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	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	Green
SEM	Space Environment Monitor	Green
THERM	Thermal Control System	Green

Live status of the different sub-system on board NOAA-19

We see that this spacecraft is much more operational than NOAA-15 which has numerous captors with a weak operational status.

Figure 4.2.3-1. APT Linearization.