

Antenna parameters

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1.Introduction

Before going ahead to build your antenna, there are important facts to know.

An antenna is designed for a given frequency range. Using an antenna outside of its frequency range may deteriorate or destroy the emitter.

Antennas are also tuned for specific usage/condition and will not perform properly when used outside of the expected conditions.

Most of the antennas and documentation available on the Internet do focus the main frequency band used by radio amateur for voice exchange (3 to 30 MHz HF band commonly named decametric band or 10 meters band).

On the other side, the CanSat radio transmission occurs at 433 MHz, 868 MHz or 2,4 GHz.

As a consequence, much of the online information, designs and references are related to a frequency band way too low compared to +400 MHz radio module and this can make huge difference when designing an antenna.

2.Frequency and Wavelength

The radio communication uses a sinusoidal waveform to transmit radio signal over the air.

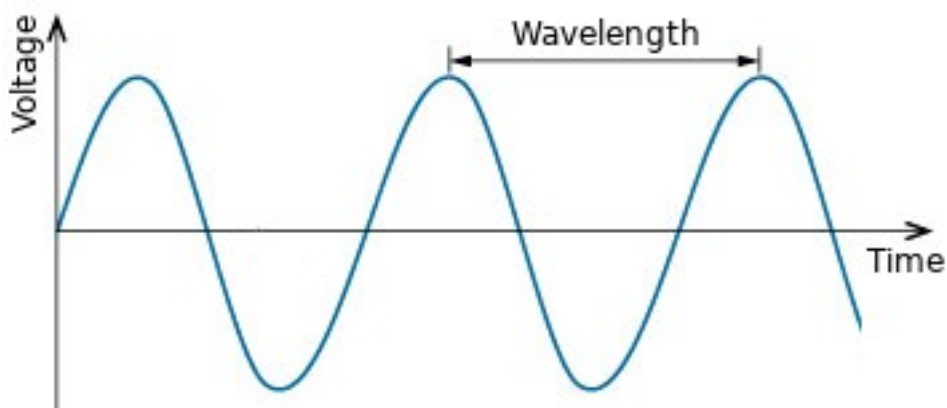


Fig 1 : sinusoidal signal

The sinusoidal waveform continuously changes over time and always repeats the same pattern (see fig 01).

The **signal repeats a given number of times each second, this is called the frequency (f, in Hertz)**. As an example, the power grid distribution network provides an AC power at 50 Hertz. The voltage changes from positive to negative 50 times per second.

The **wavelength (λ , lambda, in meters)** is the **spatial distance** between two identical points of the waveform.

2.1.Wavelength-frequency relationship

The wavelength can be calculated from frequency and vice-versa.

As a radio wave travels at the speed of light (C), the mathematical relation is:

$$\lambda = C / f \text{ with } C \text{ being the speed of light in m/s}$$

$$\lambda = 300 \cdot 10^6 / f$$

The wavelength (λ) is an essential value used to calculate/estimate the size of the antenna.

Let's calculate the wavelength for the frequency of 433 MHz (our main concerns).

$$\lambda = 300 \cdot 10^6 / 433 \cdot 10^6 = 0,6928 \text{ m (soit } 69,28 \text{ cm)}$$

2.2.Frequency band

Just for information the following table enumerates the usual Radio Frequency Band and their usual names.

From	To	Band	Description/usual name
300 KHz	3 MHz	MF	Medium Frequency
3 MHz	30 MHz	HF	High Frequency, Decametric band, 10m band
30 MHz	300 MHz	VHF	Very High Frequency
300 MHz	3 GHz	UHF	Ultra High Frequency

RFM69HCW at 433 Mhz/868 MHz, RFM96 Lora 868 Mhz and 2,4 GHz WiFi, Bluetooth modules are all inside the UHF band.

2.3.High Frequency consequence

The **lower frequency** (like HF) communication are less sensitive to the direct environment and material used for the antenna. By example, it is quite usual to have metallic boom on a HF band Yagi antenna. Wiring the coaxial cable to the antenna do not requires lot of care.

With **higher frequency** (like UHF) any little piece of metal may capture the waveform and possibly radiate parasitic electric field or interact/attenuate/destroy the target radio frequency we are working for.

Any material in the direct environment (even air gap) will interact as inductance or capacitance disturbing the target radio frequency.

Because of higher frequency:

- The Yagi antenna are usually assembled on a wood boom,
- The coaxial cable is cut in a very specific way to avoid air/dielectric gap,
- Solder join must be as small as possible,
- Antenna must be in the air for testing. The desk and direct environment will alter the antenna characteristics leading to wrong measurement.

High Frequency Antenna requires attention to details and precision in building.

Example 1:

The following picture show a **wrong driven element design** for a 433 MHz Yagi antenna. This was designed with HF antenna rules, not VHF rules.

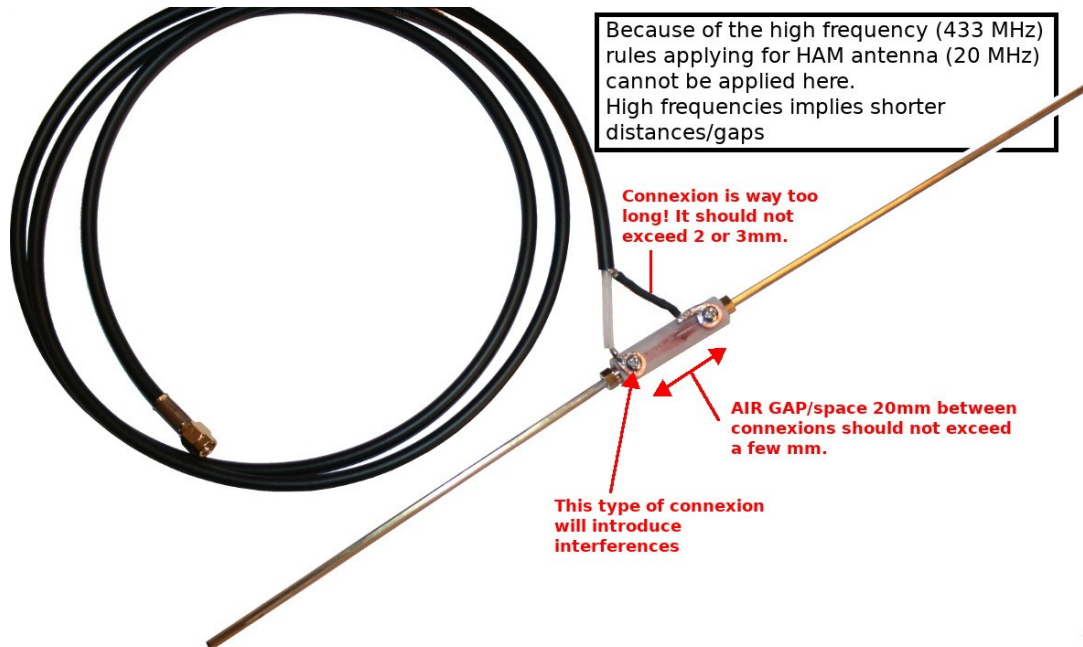


Fig 2 : wrong design for VHF antenna

Example 2:

The following pictures show **the impact of direct environment** while measuring the power return by the antenna (partially visible) to the emitter (the NanoVNA).



Fig 3: Measuring the power rejected by the antenna to the emitter

As show on the next picture, the simple fact of moving the body close to the Cansat antenna and touching the measurement unit **decreases the rejection from -21 dB to -25 dB** at the resonance frequency of 378 MHz (see cursor). In the present case,

the body and hand divided the rejected power by 2, it is an improvement... as long as your body can fly with the Cansat.

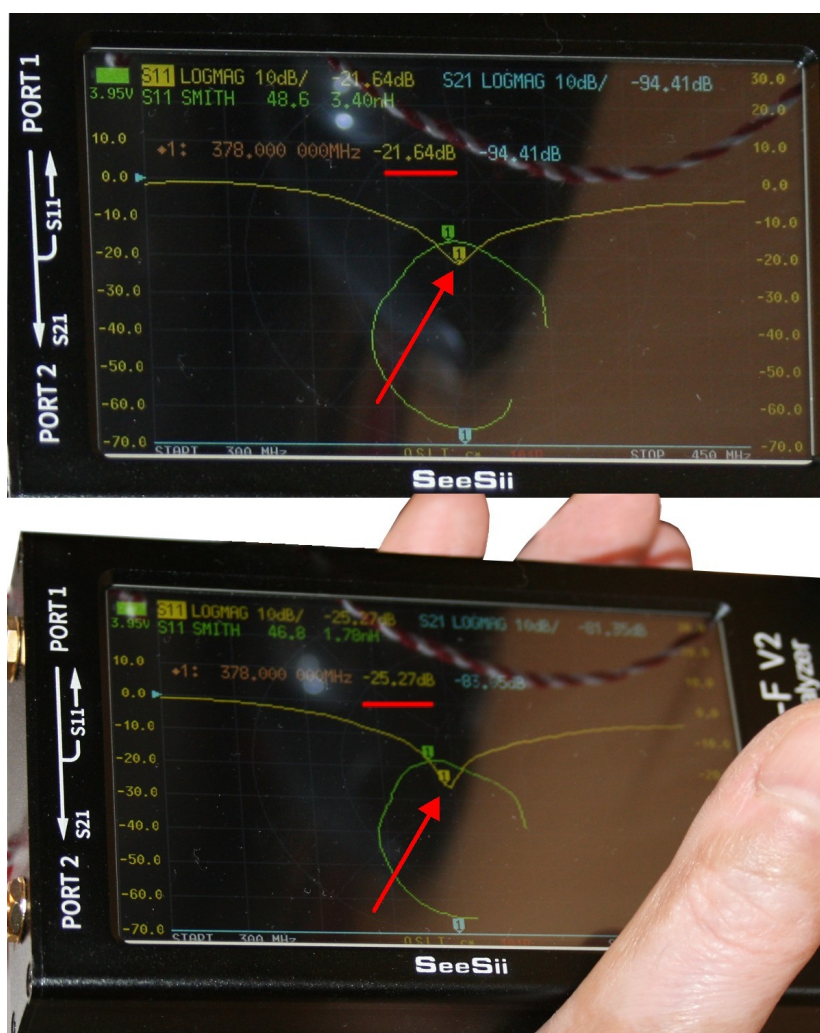


Fig 4: impact of the body close to an antenna

Example 3:

This final picture show a Yagi antenna with a wood handle right on the middle of the antenna.

The good: The handle is made with insulating material and clued.

The bad: the arm maintaining the antenna will modify the impedance of the antenna which will deteriorate signal strength (possibly avoids any communication).

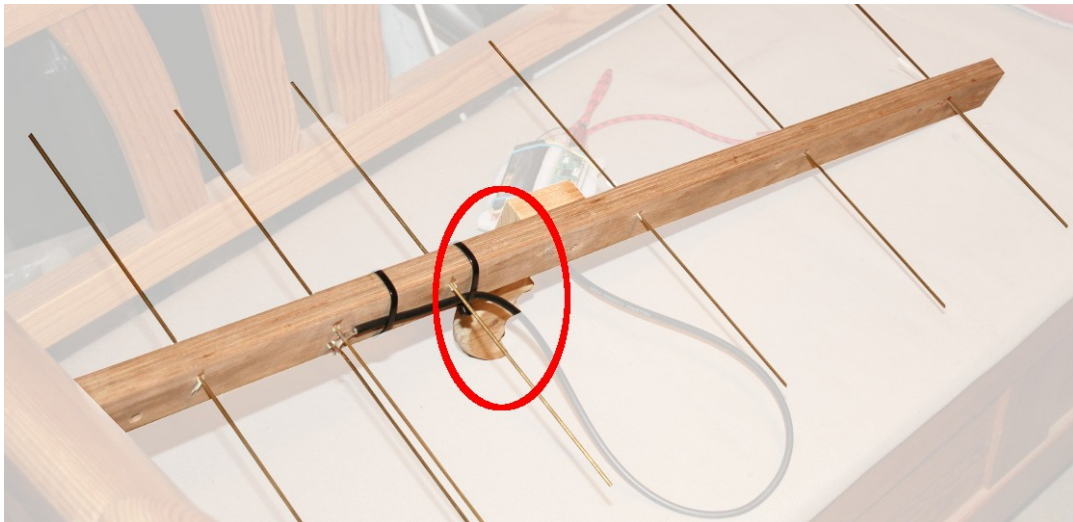


Fig 5: wrong design – handle position

The proper position for the handle will be at the end of the Yagi boom (behind the reflector).



Fig 6: right position of handle on a Yagi antenna

3. Air lost and obstacle

3.1. Air lost

The lost of the signal strength is mainly due to the air and depends of the used frequency.

Higher is the frequency and higher is the power lost in the air for a same distance.

This is the main reason why the radio amateurs do use the decametric band frequencies (3 to 30 MHz).

Regarding CanSat, lower is the frequency and better the signal strength will sustain. With a same power transmission, the 433 Mhz frequency will be more interesting than 868 MHz and 2,4 GHz. Conversely the data throughput is proportional to the frequency.

3.2.Bouncing or not bouncing

Low frequency radio transmission like AM Radio (530 to 1700 KHz) can be received on the HiFi system inside building in the middle of town. Such low frequency do not bounce on walls, building, concrete. It is because the electromagnetic wave does not interfere with the atoms of material and can pass through them.

High frequency radio transmission (433 are closer of light. Light is also an electromagnetic wave. As the light such wave do interfere with atoms of the material it reaches (EG: a wall). This will excite the atom's electrons making them jumping to an higher orbit of energy. As electrons falls back to their original orbit they then emit back the energy under the form of an electromagnetic wave. From visible light perspective, this will allows human eyes to see the color of the wall (the wall temperature will also increase due to the agitating atoms).

As the light, high radio frequency will bounce onto wall, concrete, building, woods and any kind of material. It is the reason why **we need a clear line of sight** for radio transmission.

3.3.The line of sight

Radio transmission at 433 MHz (or higher) is a high frequency wave, it follows the same rules than light! When light can't reach you then radio wave would neither.

So good communication **requires a line of sight** between the emitter and the receiver for good transmission.

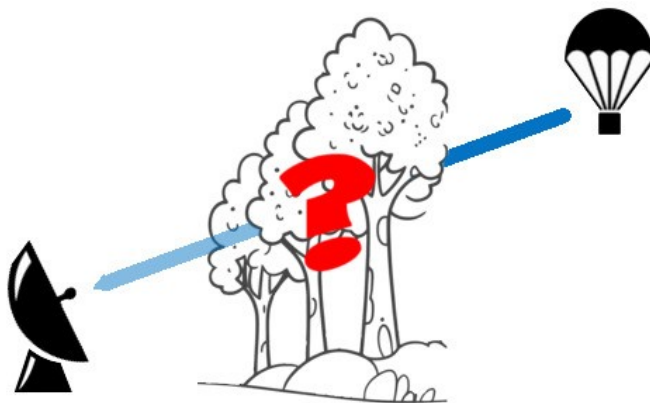


Fig 7: Grove and some wood (depend of obfuscation)

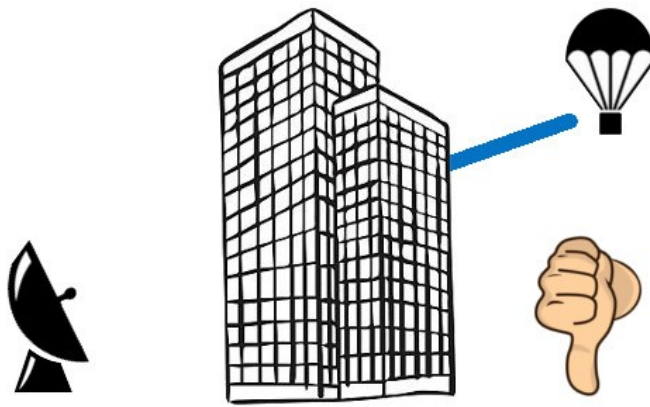


Fig 8: Buildings obfuscate the sight of view



Fig 9: Clear sight of view

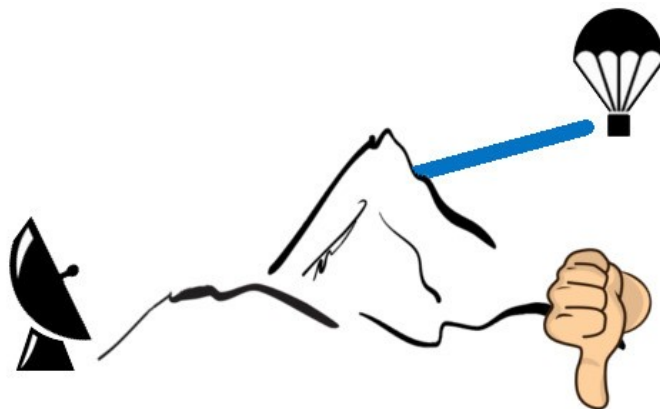


Fig 10: natural obfuscation (hill)



Fig 11: lightly rainy (depend of obfuscation)

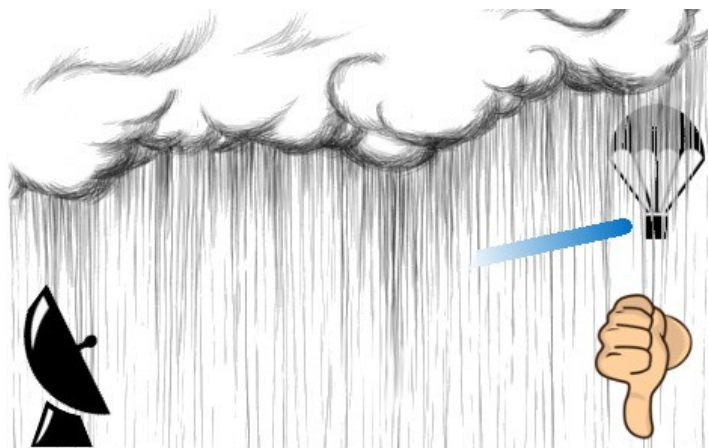


Fig 12: heavy rain is a severe obfuscation (for light and radio)

4. Ground plane

4.1. Importance of ground plane



Fig 13: common antenna

When seeing antenna in the wild, we do usually see a wire/tube pointing toward the sky. This picture leads us to a miss-conception where people forgot another piece as important as the antenna himself: **the ground plane**.

In the real world, an electrical circuit must be a closed loop to work properly. So the energy emitted to the air must be compensated by some energy coming from the ground under the antenna. It is the so called **ground plane**.

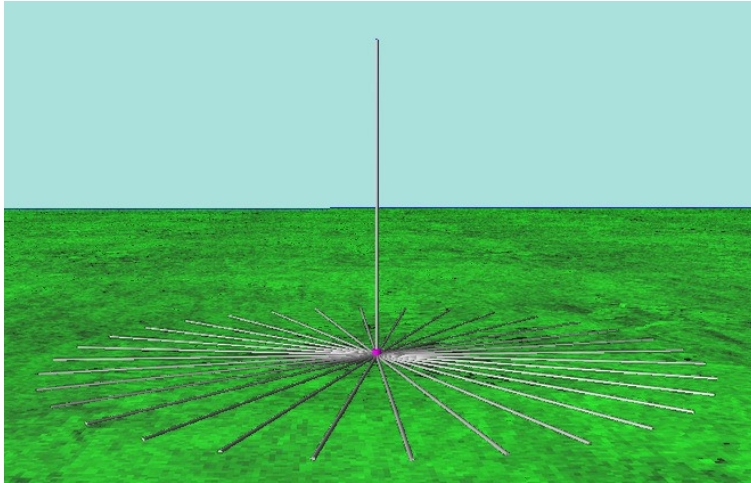


Fig 14: ground plane representation

It is like having many wires lay down on the floor (see image above), connected to the coaxial ground, and allowing some current to flow back to the emitter!

The natural impedance of earth ground is 50 Ohms.
This is why the radio emitter/receiver devices usually have a 50 Ohms impedance.

Note: Resistance is used for DC current. Impedance is for AC current and vary with the frequency.

The ground plane is so important that radio amateur do also reinforce it with extra wiring around the antenna.



Fig 15: Example of ground plane reinforcement

4.2.Cansat: simple ground plane

The Cansat is flying in the air under a parachute. As the consequence, the ground plane is initially limited to those offered by the radio module himself.

The image here below shows a single pole antenna (a piece of wire) soldered onto the RFM69 antenna pad. The **antenna is placed perpendicular** to the board PCB which act as ground plane.

Properly designed PCB contains a layer of copper made of a single piece (or almost) called "Ground Plane" and acting as a ground plane. Thank to the PCB ground plane, the antenna output pads offers an impedance close to 50 Ohms (great to connect an antenna).

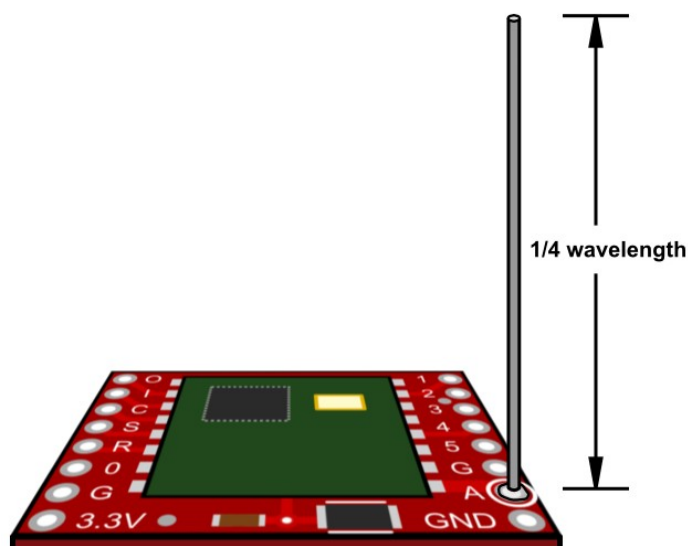


Fig 16: RFM radio module in use

Note: calculation details of such antenna will be detailed in next chapter

Even when the single pole antenna is properly calculated and tuned, the limited size of the ground plane will limit the communication distance (about 500m).

4.3.CanSat: improved ground plane

It is also possible to **create a ground plane** to match the single pole antenna. The final antenna may be called *ground plane antenna*.

When properly designed and assembled the *ground plane antenna* could increase the communication distance from 500 to over 2 Km.

The following picture show one of the most common ground plane antenna using 4 elements positioned toward the ground. Such antenna also exists with 3 ground element.



Fig 17: example of single pole antenna with ground plane.

The position, the angle and the length of the ground elements is critical for getting the appropriate impedance (which should be 50 Ohms for a RFM69 Radio Module).

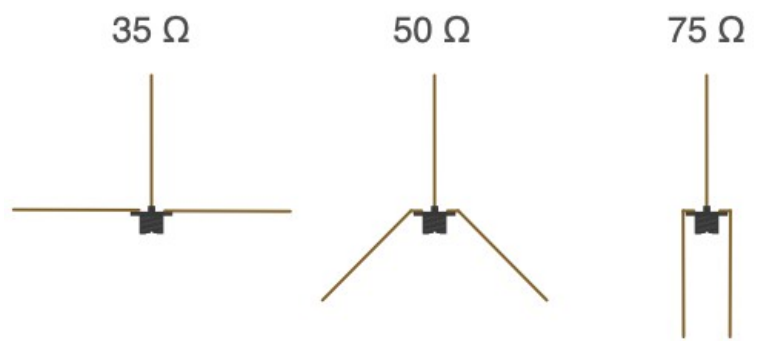


Fig 17bis : ground plane angle and impedance

The design for the Cansat ground plane antenna is detailed in next chapters.

4.4.CanSat: messing with ground plane

It is quite easy to make an error with the antenna and ground plane.

On the following picture, the ground plane is not perpendicular to the antenna! This results in a very poor transmission efficiency.

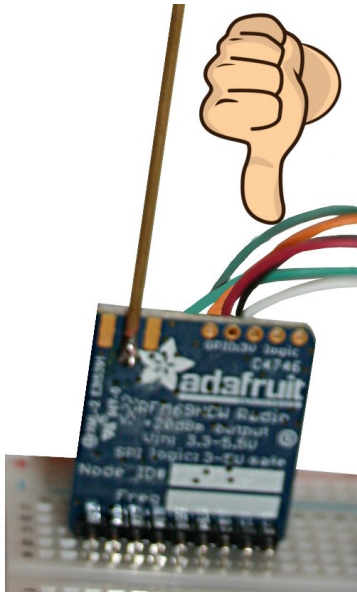


Fig 18: ERROR in mounting the antenna

5.Impedance matching

The various elements involved in the transmission chain **must have impedance match** (otherwise the impedance must be adapted to make them compatible).

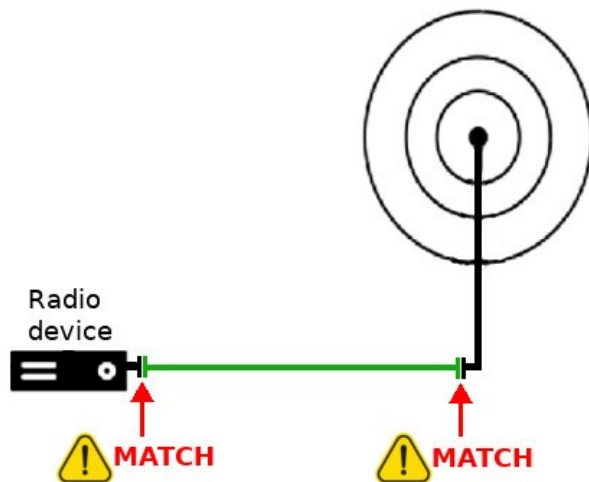


Fig 19: Impedance matching

The impedance is the like a resistance (that resist to the current flow) but applies to an alternative current circuit like the radio waveform we want to send to the air. **Impedance varies with the frequency.**

Regarding the CanSat, the RFM69 radio module have a 50 Ohms impedance. As consequence, RF connector, RF coaxial and antenna must all have an impedance of 50 Ohms at the target frequency (say 433 MHz).

5.1.Wrong matching consequence

Wrong impedance matching will lead to power transfer lost and signal reflection being the cause of deficient radio communication (lower efficiency and degrade signal quality).

Impedance mismatch will **cause overheating** and the signal reflection **can destroy the emitter amplifier**.

5.2. Matching and SWR measurement

When buying an antenna, its impedance is usually detailed into into the datasheet. Note that commercial antenna are usually designed for a range of frequency and targets radio amateurs. As a consequence, the impedance will not perfectly match for the entire frequency range supported by the antenna. The radio amateurs do use a SWR meter (Standing Wave Ratio) that quantifies the amount of power return by the antenna to the emitter. By monitoring the SWR meter during operation, the radio amateur knows when the antenna start mismatching with the emitter (in other words, when the impedance goes wrong and too much power is lost).

Note: SWR should stay below 1,5 and preferably as close as possible of 1. At SWR=1, all the power is transmitted to the air.

When creating a CanSat antenna, everything starts with calculation for the target frequency. The antenna should theoretically have 50 Ohms impedance and a perfect SWR of 1. Unfortunately, real live sensitively deviates from the theory and the calculated antenna may offers somewhat disappointing performance. Fortunately, a Vector Network Analyser configured to display SWR can be used to tune the antenna. The SWR must be as close as possible of 1 for the target frequency.

The “Single Pole Antenna” chapter details the design and tuning procedure with great details. The procedure is identical for all kind of antenna.

6. Coaxial cable

A conductor is used between the radio device and the antenna. The type and quality of that connector can possibly degrade/destroy the impedance matching making your radio setup completely useless.

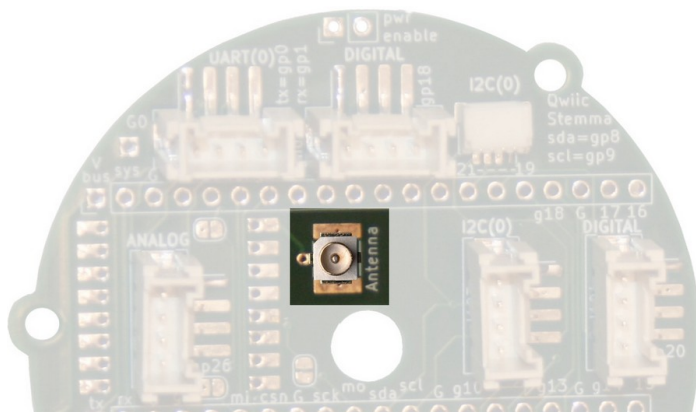
The antenna must be connected to the radio module and coaxial cable must be used for this connection (other non-coaxial cable will creates impedance matching and excessive power lost).

Keeps in mind that even a coaxial cable will create a power lost. The quantity of power lost into the cable depends on its quality (say its composition: type of braid, central conductor, dielectric).

As rule of thumb: thicker is the coaxial cable, lower is the lost caused by the cable

6.1. Inside the Cansat

Because of space constraint in the CanSat, the selection of coaxial cable is very limited. Connection in the CanSat is usually done on a μ FI (aka uFI aka I-PEX) connector.

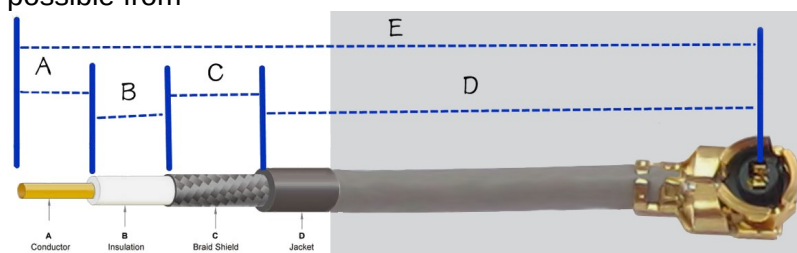
Fig 20: μ FI connector

Two options are possible:

1. Use a good quality μ FI to SMA cable adapter. This allows to plug a radio antenna (which have a SMA Male connector).

Fig 21: μ FI to SMA converter

2. Use a good quality pigtail adapter. This allows to solder directly antenna onto a coaxial + μ FI connector. Note that solder must be done with precision as close as possible from

Fig 22: Pigtail with μ FI connector

6.2. The ground station

Ground station usually uses a Yagi directional antenna (to maximize receiving gain in a given direction).

Without the space constraint of the CanSat, the ground station can use better quality material. One of the most obvious improvement is the usage of higher quality coaxial between the receiver radio module and the antenna relying on SMA connector for connection

The selection of a good coaxial cable is essential for the setup. A great reference is RG58 Coaxial because of its bigger diameter and its appropriate dielectric suited for higher frequency we use.



Fig 23: RG58 coaxial cable

Features of the RG58 coaxial

- 50 Ohms impedance
- Stained copper core
- Stained copper shield braid
- PEE dielectric

7.Connectors

The aim for radio connector is to connect the various components together.

Connections are also an important part! They must ensure the continuity of the core and the shield between connections points while (1) preserving the impedance, (2) avoiding signal to escape and (3) avoiding parasitic signal to enter the cable.

It is quite easy to ruin a signal with bad quality connector or wrong/poor cable to coaxial junction assembly.

This chapter will describes the main connectors you may get-in-touch-with when participating to CanSat. Keeps in mind that many other radio connectors do exists.

7.1.µFI / I-PEX

The µFI is a very common connector. It is used to place an antenna connection within projects where few space remain available. It is also used to move the antenna away from the main board.

µFI connector is a SMD (Surface Mount Device) on which a antenna or converter cable is connected.



Fig 23bis: µFI connector

See the point “6.1 Inside the Cansat” for more details about this connector.

7.2.SMA

The SMA is the type of connector to use with Cansat. It is related the range of frequency used in the radio transmission.

The following picture shows an SMA PCB connector to be soldered on the radio module side (on the edge of the PCB). As seen on the, this is a female connector. The cable that plug into it must have a pin in the center (being male).



Fig 24: SMA female connector (radio module side)

When not possible to solder the connector directly on the PCB then a converter cable μ FI to SMA will also expose a female SMA connector.

As visible on the figure 25, an SMA coaxial cable do connects with its male connector and expose another SMA female connector at the other end.



Fig 25: SMA coaxial cable

The antenna should expose an SMA Male connector.

Note: while building antenna, the coaxial can be soldered directly on the driven element. This must be done with caution because high frequency signal is very sensitive to dielectric, air gap, flying wire (even a few mm).

7.3.RP-SMA

The RP-SMA is look very similar to SMA but uses a male connector with a center pin on the radio side. RP-SMA is use for material at GHz frequencies like Bluetooth/WiFi.



Fig 26: RP-SMA connector

RP-SMA should not be used within CANSAT project. Because of the SMA & RP-SMA likeness, it is easy to confuse them.

However, it is easy to salvage RP-SMA connector from deprecated WiFi device/antenna/modem. Such connector can be converted to SMA with the help of an RP-SMA to SMA adapter (having a male connection on each side).

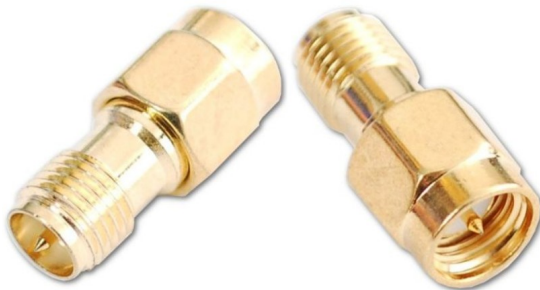


Fig 27: RP-SMA to SMA adapter

8. Antenna material

As the CanSat radio does operate at higher frequency, the usual radio amateur material operating in the decametric band could not be used for 433/868Mhz communication.

Restriction will apply on the material selection.

8.1. Antenna elements

As a rule of thumb, any conductive materials will work (except stainless steel) for radio communication.

Precise soldering task will be required to build the CanSat antenna and Base station antenna. That reduces the selection to materials compatible with stain based solder.

- Single-strand copper wire
- Copper tube
- Single-strand brass wire
- Brass tube

When high frequency signal travels along a large section of conductive material, the current tends to travel on the external side of the conductor (not in the center). This is the so called "the skin effect" and the reason why tube can be used for CanSat antennas

Stripping copper wire is a possibility. However getting them perfectly straight is not so easy that it may appears.

For our initial experiments, we do used:

- Brass Tube, 1,5mm diameter
- Brass hexagonal bar, 2mm large (from side to side)



Fig 28: Brass hexagonal bar

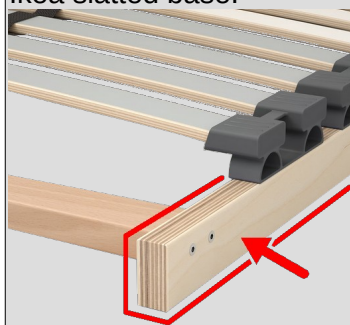
8.2.Boom element

As any metallic items will interact with the high frequency signals, the ideal boom should be made of wood.

15mm x 15mm section boom is a common reference for building high frequency antenna (like Yagi). Except the antenna elements, no metallic items should be present on the antenna and plastic element should be as limited as possible (because it act as a dielectric at high frequency).

As the element, the boom must be perfectly straight!

For our initial experiment we used 20x40mm playwood (length from 60cm to 2m depending on wanted number of directors). The playwood was salvaged from an Ikea slatted base.



9.Shortening factor

The element length needs to be shorten when its diameter increases. The Shortening factor is the relation tying together the both parameter. This factor is difficult to find for new comers but there is a solution.

As the calculation based on the theory relies on ideal material/conductor (0mm diameter, no resistance, etc) the real antenna based on real material having some diameter. As a consequence, the real antenna will be shorter than the calculated one.

The good new is that antenna can be tuned to the right size with a Vector Network Analyzer.

Remarks:

- Large diameter element will produce antenna with good performance over a wider frequency range. For this reason, the commercial antenna are made with wide tube (to satisfy as much as customer possible).
- Smaller diameter element will produce antenna with great performance over a narrower frequency range.

10.Polarization

The radio wave are electromagnetic wave exactly as the light. As the light, the radio wave is polarized. Looks for experimentation about polarization of the light to get a clear idea about concept of polarization..

That means that emitter and receiver must share the same polarization to ensure the receiver to get the maximum power from the emitter.

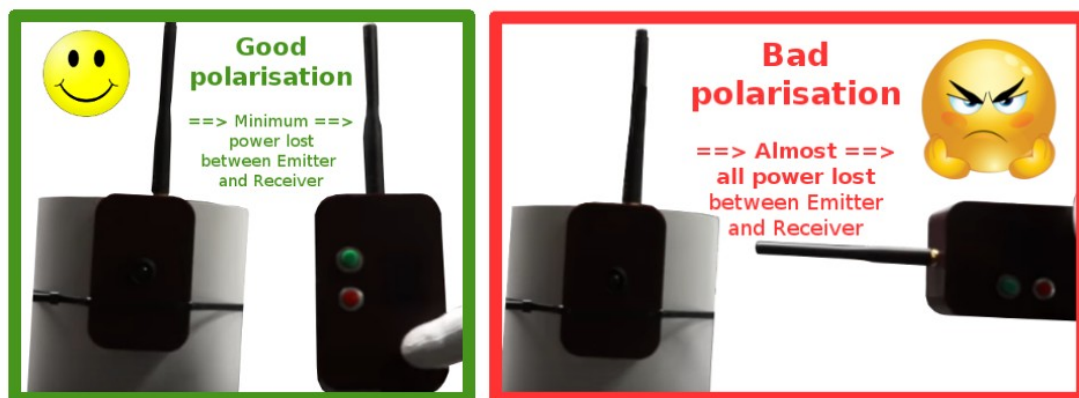


Fig 30: Good and bad polarization of signal

Polarization have relatively few impact on short distance but will have a significant impact on long range communication like needed for CanSat.

Practical example

The figure 31 shows the CanSat V2 suspended in a tree. The picture highlight the antenna (violet) pointing to the sky and a ground plane (blue).

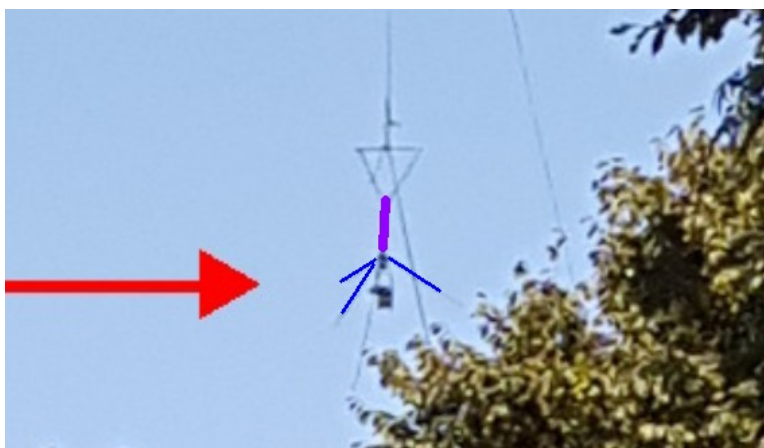


Fig 31: CanSat emitter

The figure 32 and 33 were taken at 2.2 Km from the emitter.

- The wrong polarization (figure 32) ruin the data transmission impossible.
- The good polarization (figure 33) instantaneously capture the message data. Notice that antenna element is toward the sky and ground element toward the ground.

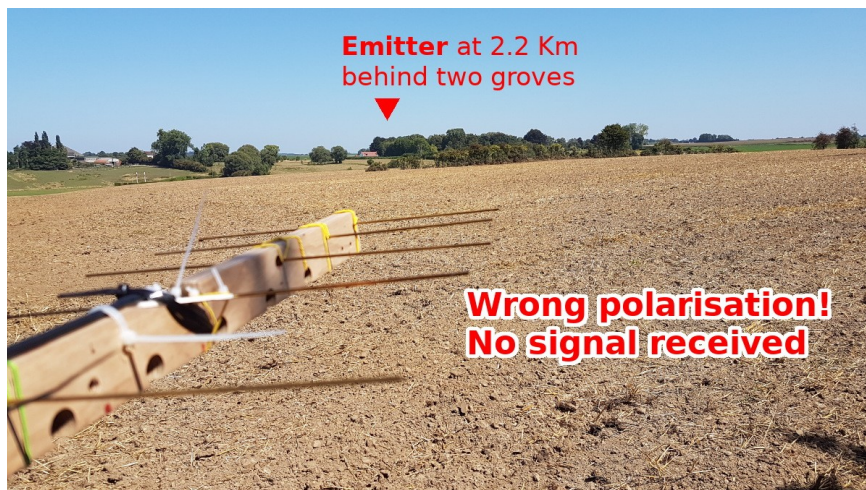


Figure 32: Yagi antenna kept horizontally

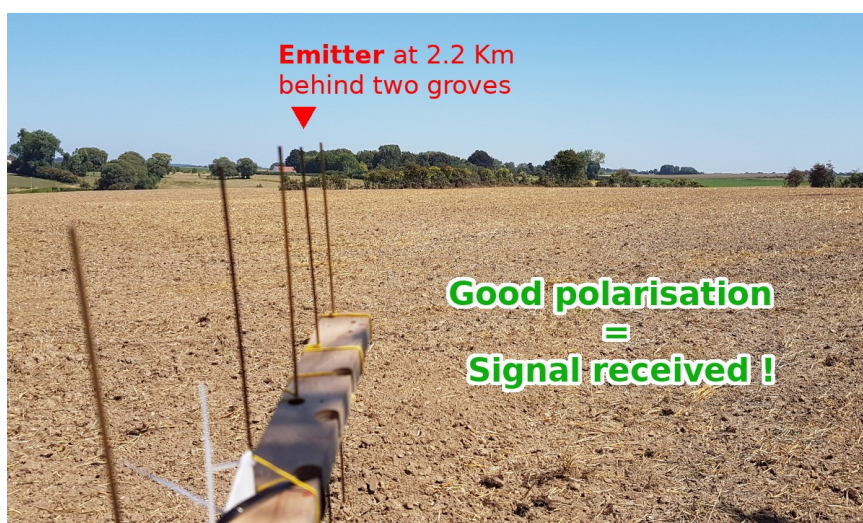


Figure 33: Yagi antenna kept vertically