# EXPLORER E202

## A simple but effective portable device for natural radio signal reception

by Renato Romero

*Radio signals of natural origin are a fascinating subject. The first time I read an article I was bewitched by it: Beyond well known TV and Radio emissions there are some "on air" natural radio signals that really make the sky bigger. But here appears a problem: how to hear them if there are no receivers to buy? And looking for a simple and effective project to build at home, the response on mailing lists is always the same: "There are many schematics on the Internet...., look there" And then you feel confused: which will work best? Can I use my PC? How can I assemble a system to find and process natural radio signals most effectively?*
*If you are looking for a small receiver, simple to build, which runs on batteries, which works with a small antenna, which works with headphones, which also provides a good signal for PC analysis... the Explorer E202 meets all these needs.*
*Since this project is meant for beginners there are also included in the article some basic concepts: they are also mentioned in other articles on the site so If you already know these things just jump to the next paragraph.*

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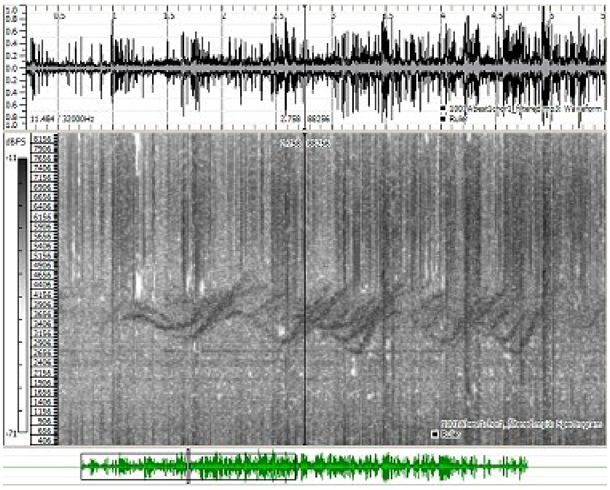
## A brief introduction about this project

This project is a receiver for base band radio signals using direct reception without frequency conversion. The frequency range from few Hz to beyond 10 kHz makes it suitable to receive radio signals of natural origin; signals not generated by human activity but by physical phenomena such as lightning and solar storms. Received signals are heard directly in your headset. The receiver amplifies the electric component of an electromagnetic signal.



It can be assembled as a compact, lightweight and extremely sensitive receiver. It functions well in the field thanks to an internal battery with autonomy of 40 hours. It will also function as a base station receiver using external power in a permanent monitoring observatory.

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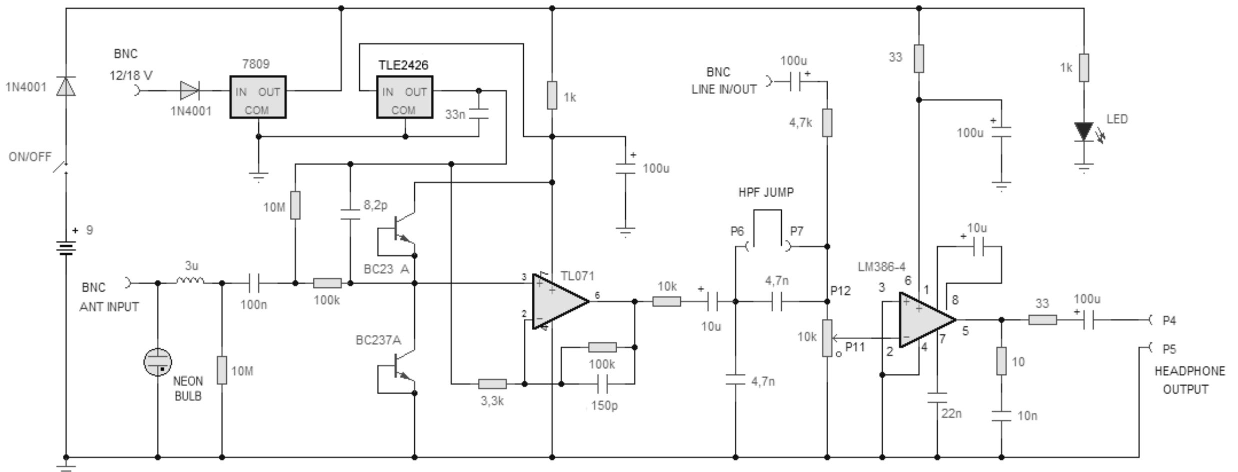
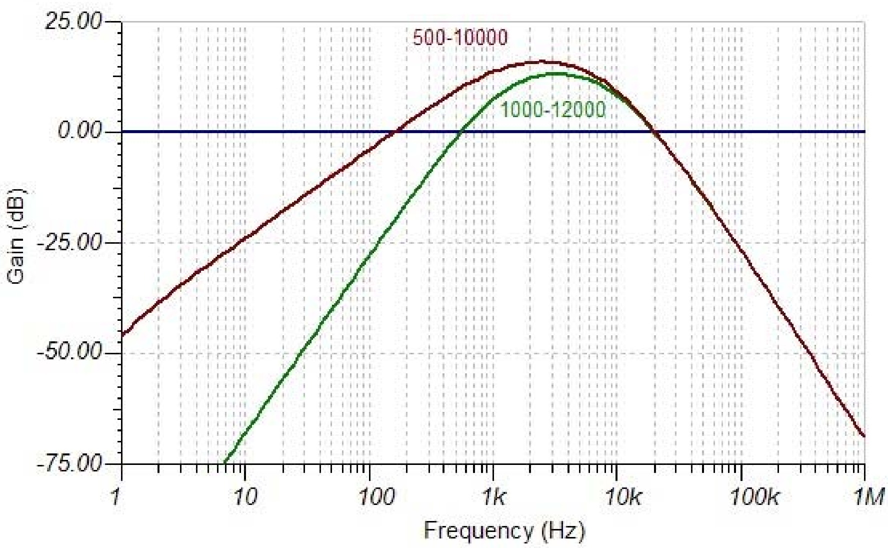
## HOW DOES THE E202 WORK?

The diagram of the receiver consists of two active stages with supply input protection and regulation plus a stable opamp (7809) bias supply. The TLE2426 is a “virtual ground generator”: it supplies the V/2 for the TL071 with a very low-impedance 7 milliOhm output.
The input has two stages of over-voltage protection and sets the input impedance at 5 Mohm. The first stage has non-inverting 30 db gain and converts the antenna input to a medium impedance output with level suitable for a LINE input to a PC or a portable recorder. The first stage is protected against voltage surges and has low current noise which makes the receiver sensitive to weak signals even with short antennas. The antenna is galvanically decoupled from the first stage: this prevents the static electric field from saturating the receiver during a lightning storm or when the receiver is in motion; for example during a walk.



EXPLORER E202 - PORTABLE VLF RECEIVER ©www.vlf.it Oct.2010

The second stage consists of a low impedance amplifier (LM386-4) to drive a headset which is perfect for "live" field listening. The jump HPF short-circuits a capacitor that acts as a high-pass filter. Removing the jumper between pins 6 and 7 activates a high-pass filter that attenuates low frequencies such as 50 Hz by about 30 dB. You can build it as a jumper on the board or as an external switch on the receiver box.



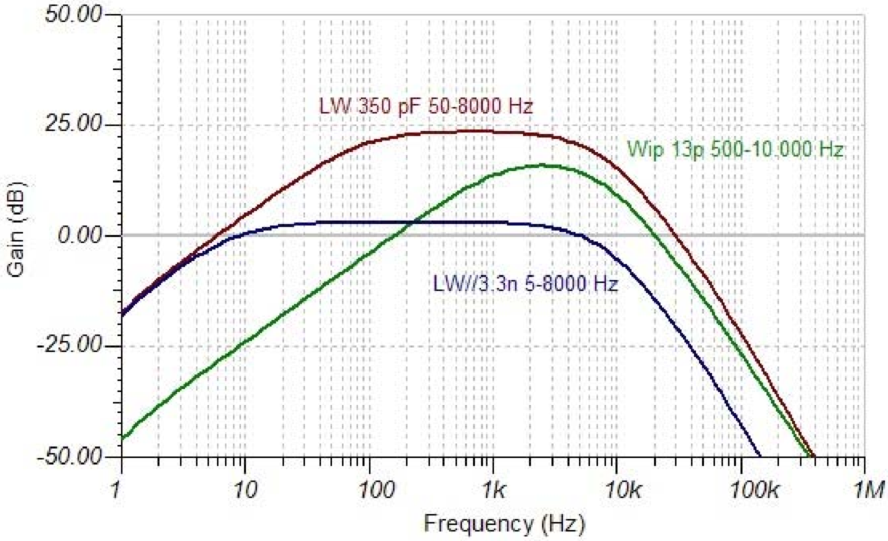

In the graph the frequency response of the receiver with a whip antenna: with (brown curve) and without high pass filter jumper (green curve).

## TECHNICAL SPECIFICATIONS

- Frequency range with a simple 75 cm stylus: 120 Hz - 10 kHz, +/- 3 dB
- Frequency range with low impedance source: 3 Hz – 10 kHz, +/- 3 dB
- Sensitivity: 1 µV/m in 1 Hz RBW @ 1 kHz using 75 cm telescopic stylus
- Internal power supply:  9V transistor battery, lasts about 40 hours
- External power supply: 12 to 18 Vcc (20 mA)
- Protected against battery polarity reversal
- Protected against external power supply polarity reversal
- Headphone output: 33 Ohm impedance (good for most walkman type headsets)
- LINE connector with double function: Line output for PC or Recorder and can also be used as an audio input to amplify an audio signal and listen with the headphones
- Antenna input: 5 Mohm impedance.

## RECEIVER CHARACTERISTICS

The receiver frequency response is strongly influenced by the type of antenna used. This is because, due to the low frequencies involved and the high input impedance, the antenna does not behave as an antenna itself but as a field probe. It could not be otherwise: a real antenna for 1 kHz frequency should be 75 km high.

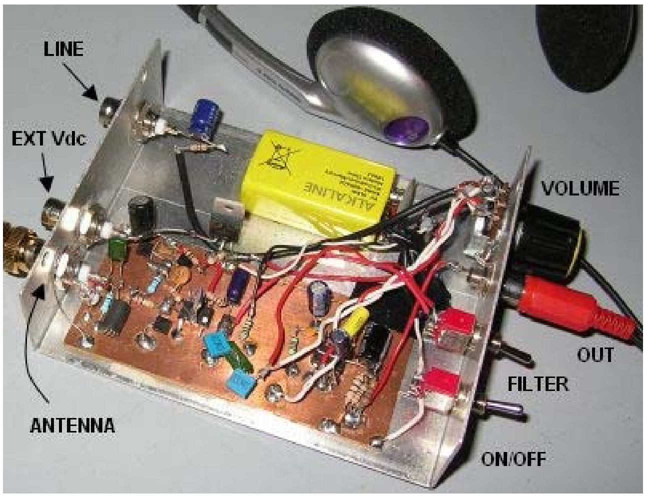



The graph, which is purely indicative shows varied frequency responses. Represented here are the curves of gain between the voltage detected by the antenna and the output voltage to the LINE output jack of the receiver with three different antennas:
Green curve: telescopic antenna directly on the receiver
Brown curve: 45 m long wire antenna (350 pF equivalent) directly connected to the receiver
Blue curve: the same long wire connected to the receiver by 30 m of RG58 cable. The gain is significantly reduced to the advantage of linearity at low frequencies

## RECEIVER CONNECTIONS

On the scheme is suggested the use of three BNCf sockets:
one for the connection of the stylus or a wire antenna
one for the output signal to be sent to line input of a recorder or a PC
one for an external power supply: from 12 to 18 V thus compatible with power taken from a car cigarette lighter.

They provide a good and stable mechanical and electrical connection, also where the receiver is used as a base receiver for unattended monitoring station, and reliability is an important requirement.
The headset connection can be a standard 3.5 mm stereo jack, so you can use the receiver with a standard player headset (connect the L and R channel together, in parallel).
The circuit must be enclosed in a metal box, and the metal box itself must be connected to circuit ground. It is essential for proper working of this receiver.




One way to build the E202 Receiver.

## POWER SUPPLY

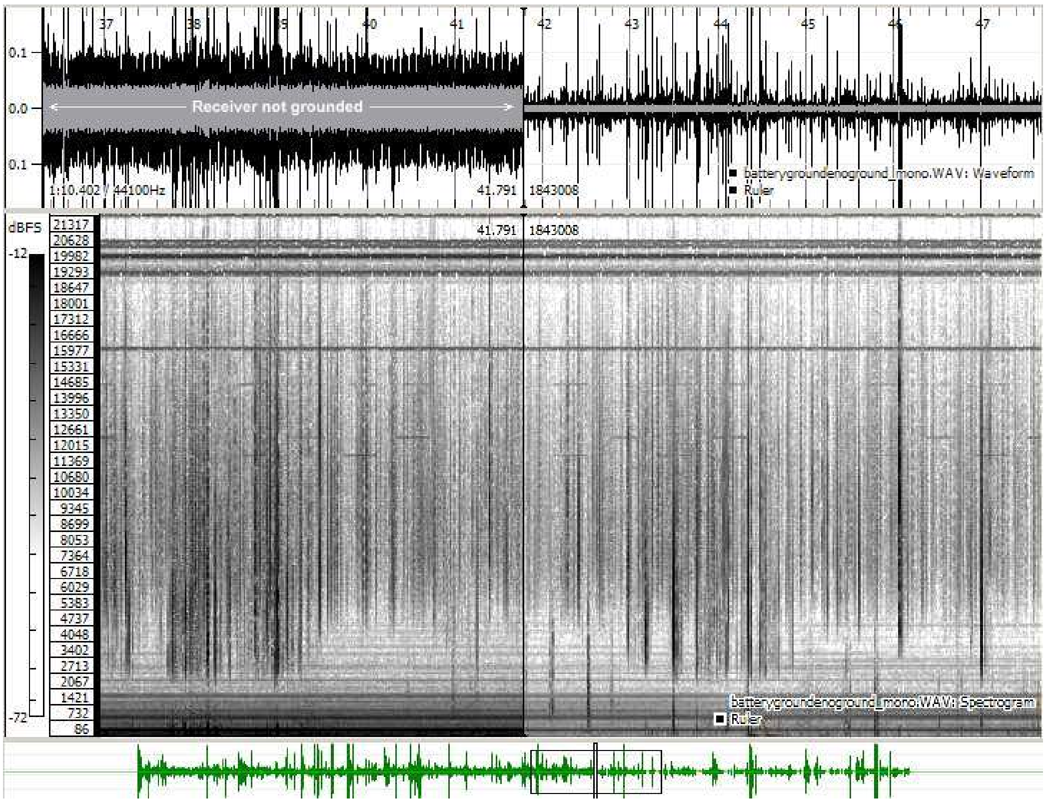
The receiver can be powered by an internal 9 V battery or by an external voltage between 12 and 18 V supplied from a source like a portable battery or a motor vehicle. The external voltage is internally stabilized by a 7809 IC before being used by the circuit to minimize the influence of noise on reception. Both connections are protected against reverse polarity. Current drain at a medium volume setting is 10 mA. It ensures autonomy of more than 40 continuous hours with a standard 9 V alkaline battery. The receiver operates from 18 V down to 6 V: below this voltage the signal may sound distorted and the input stage overloading with interfering signals like telex and other types of RF signals. Under these conditions simply replace the battery.

## VOLUME REGULATION

The circuit has only one control: the headphone volume. The receiver is broadband and without conversion so you do not need the tuning operations that take place in an ordinary radio. Volume is adjusted by a potentiometer on the bottom of the receiver. The volume control on the headphone cable must always remain at maximum. When located near power lines the volume in the headphones may be extremely loud so use this precaution: before you switch on the receiver, put the volume to zero. Turn the receiver on and then gradually turn up the volume. When using the receiver connected to a PC or recorder via the LINE output, once setup is optimized, set the volume control to minimum if not using the headset.

## STYLUS ANTENNA AND GROUND REFERENCE

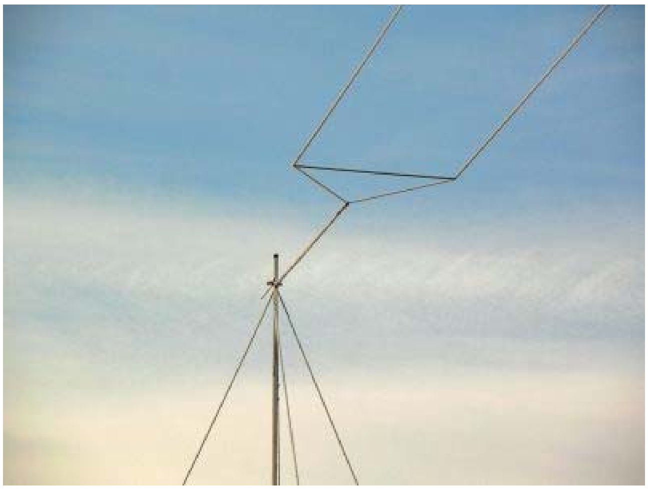
The receiver operates by sensing the potential difference between stylus antenna and a ground reference; the latter consisting of the operator's body touching the metal box of the receiver. Raising the receiver higher above ground provides more signal. The reference ground is also essential for the correct operation of the receiver, so if you do not hold the receiver by hand it is necessary that the receiver is connected to an Earth ground. For example if the receiver is placed on a tripod the impedance of the stylus is very high, so even a simple carpenter's nail, stuck ten cm in moist soil acts as a near-perfect ground. The whip antenna should be connected directly to the receiver antenna jack without connecting cables.



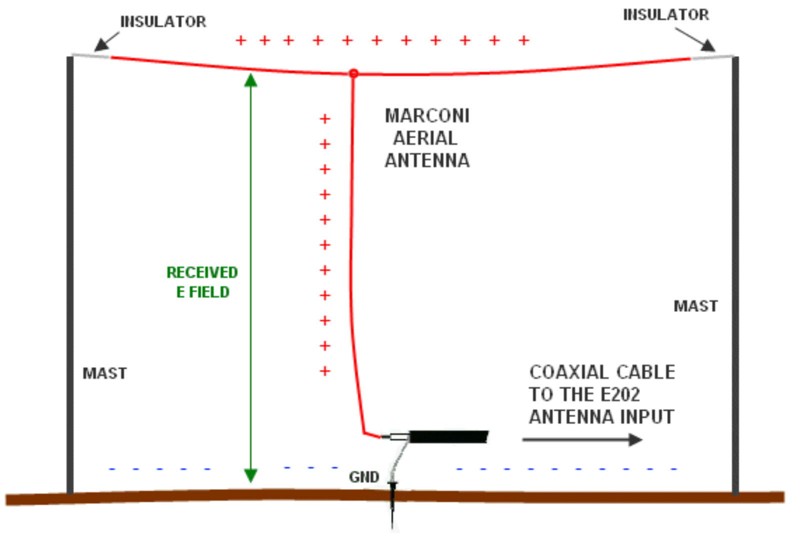

In the picture above is a signal received in my garden with the E202 and 75 cm stylus, without and with receiver connected to ground. Left part without ground connection and Right part with it on. The ground connection reduces the hum noise by 20 dB. Signal processed with Sonic Visualizer software.

## EXPLORER E202 WITH WIRE ANTENNA

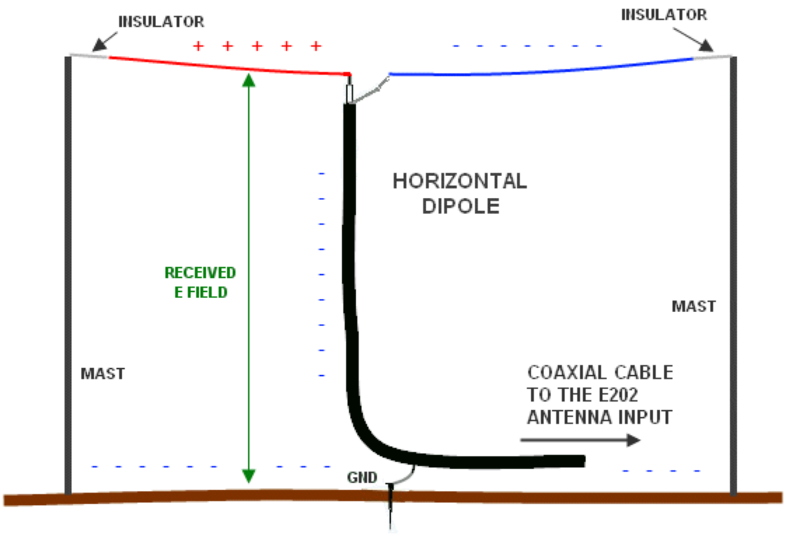
Although the project was designed to work with short and portable antennas, the receiver works very well with long wire antennas too. Large wire antennas extend the sensitivity especially at very low frequencies, allowing reception of Schumann resonances and 82 Hz signals of Zevs network (direct to submerged submarines). With the wire antenna you may use a coaxial cable connection between antenna and receiver. The length should not exceed one third of the length of the antenna. The coaxial cable at VLF behaves essentially like a capacitor: that coupled with the wire antenna capacity, acts as a divider, reducing the signal.
A meter of RG58 connected to a 1m stylus loses 99% signal power strength, reducing the reception by 20 dB. A wire antenna of 15 meters, for example, can tolerate a cable to the receiver of 5 meters length. The picture below is a winter view of my Marconi antenna with dual capacitive hat: the antenna is 11 meters high and is 45 meters long.




Electrically the Marconi antenna is nothing more than a vertical antenna with a tip that splits and goes horizontally, making a hat. This configuration gives great performance on low frequencies, and for this reason it is also widely used by the military to transmit signals in the VLF band.




The dimensions are not critical because the antenna is not resonant: 3 meters vertical and 6 meters horizontal are sufficient to provide a large increase in efficiency compared to a 75 cm stylus; especially in the reception of frequencies below 100 Hz.




The figure above shows how a horizontal dipole behaves at VLF frequencies. The receiver is not differential but referred to ground, so the received component will always be the vertical one, even with the antenna placed horizontally. This is because the antenna is much shorter than the signal wavelength and therefore does not behave as an antenna but as a field probe. It detects the vertical voltage between two points: the ground and the antenna.

The use of large wire antennas usually reduces the effect of hum noise by increasing the SN ratio: especially when compared to a stylus placed in the same position. Set up in a backyard or a garden next to a house they can be an excellent solution with greatly improved SN ratio.

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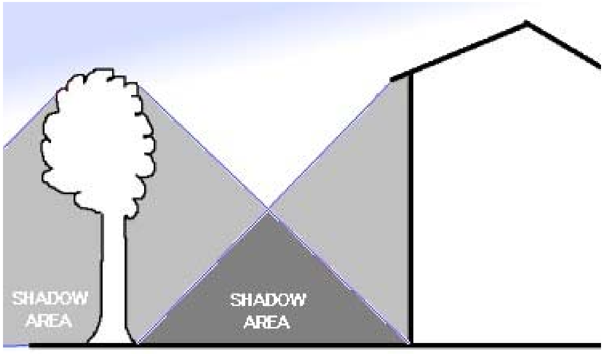
## THE SHIELDING

Not all places provide good reception. When available, open spaces are ideal locations: away from structures that will bring the ground point as high as buildings, trees or metal masses.

To view the limits on VLF reception you can imagine that the structures create shadows.

In a park with trees, behind a wall, in a cave the electric field is zero, and the VLF receiver will not receive anything.

Same is true for a balcony, a room in an apartment, a courtyard surrounded by walls: they are not compatible sites to receive VLF signals.

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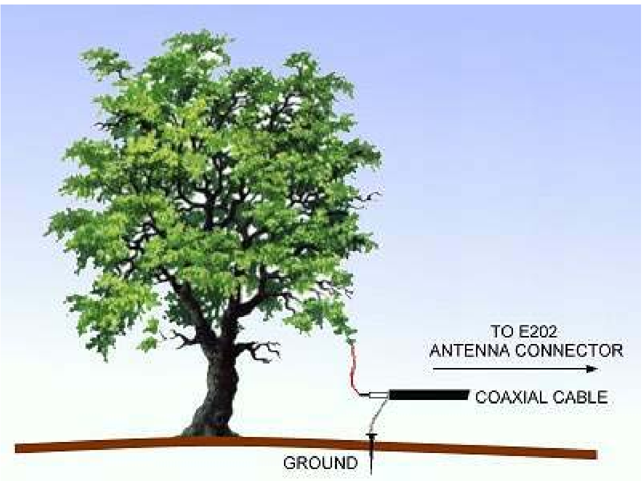
## THE TREE THAT WORKS AS AN ANTENNA

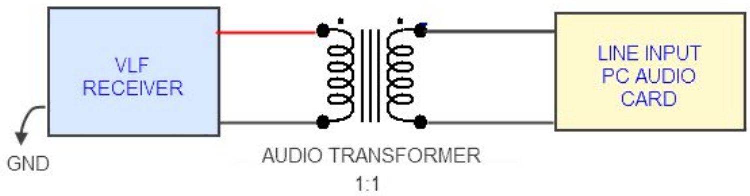
No, it is not a legend: a tree can really work as antenna.

For the reasons stated above under a tree you do not receive VLF signals. The plant with its high water content is conductive, so it carries the ground plane up to its peak. Within a forest, the receiver is almost completely silent. But the tree can be used as an antenna with some success, mostly due to its size and height. To use the tree as an antenna connect the hot antenna lead to a screw fastened into the trunk or a limb as high as possible. Then connect the antenna cold pole to ground at the tree’s base. In case of Electrical Storms immediately disconnect the receiver from the tree.



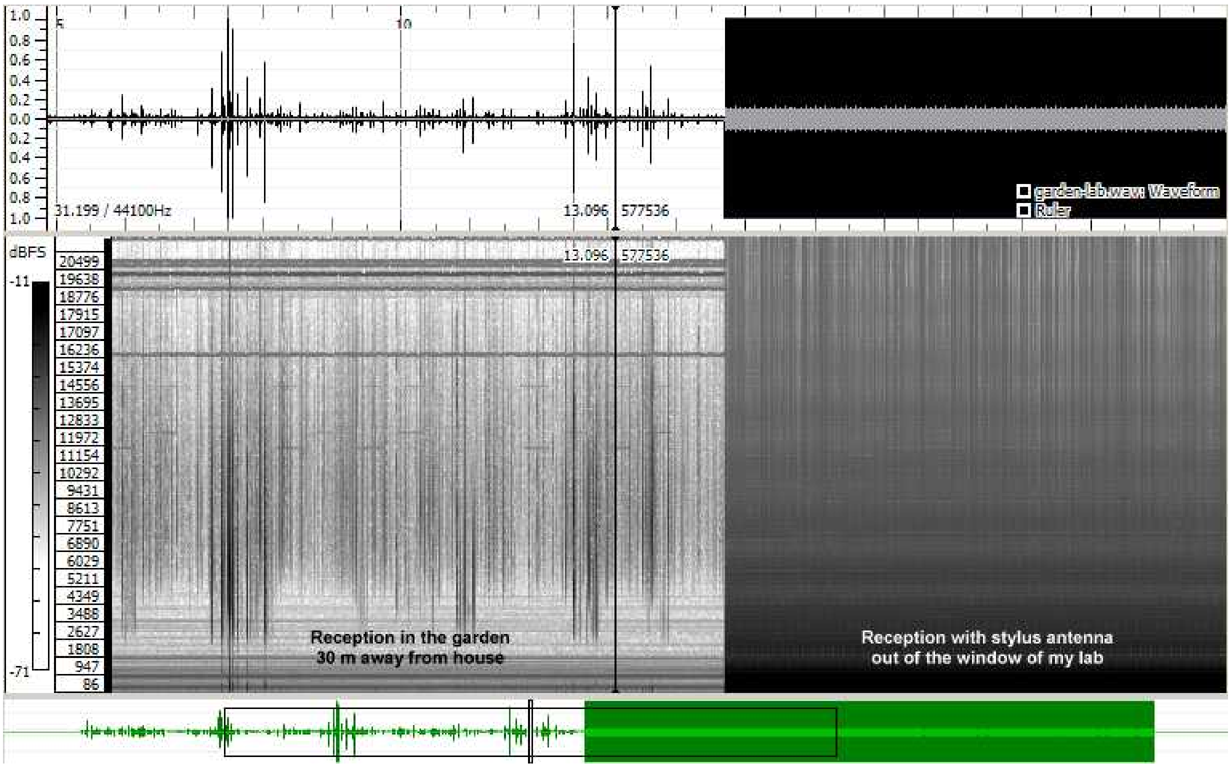

## GALVANIC ISOLATION

Reception starts with simple play, but, after a while comes the need to acquire signals to study and analyze them. We must therefore have a suitable recording device. The sound card of a PC is an excellent way to good quality and low cost recording to readily analyze signals from a receiver. The computer, however, may be the source of signals in the VLF band, which can interfere with the reception of natural radio signals. The computer and receiver must therefore need to be placed as far apart as possible and the receiver must be connected to an earth ground as well. This sometimes may not be enough because the noise can also propagate through the cable connecting the PC to the receiver. It is difficult to quantify this trouble because it varies from PC to PC, but it is easy to check with the headset: if connecting the cable to the PC LINE the receiver suddenly becomes noisy, it means that the PC is inducing noise to the receiver. It is necessary, in this case to isolate the signal line, interrupting the metal continuity. This requires the use of a 1:1, 600 ohm audio transformer, to connect the receiver to the PC with galvanic isolation.




## HUM NOISE

In addition to the shielding effect, it is necessary to move away as far as possible from the signal emitted from the mains at 50/60 Hz: switching power supplies, electric engines, televisions, computers... with their emissions completely obscure the natural radio signal. Just think that in your home the level of hum is 120 dB higher than natural radio signals: one million times greater in voltage!




In urban areas it is therefore very difficult to find appropriate locations, while in the open countryside away from the power lines hum noise disappears allowing excellent of reception of natural radio signals.

## MICROPHONIC EFFECT

The Stylus produces a microphonic effect: it behaves like a microphone: at times motion of the receiver/antenna gives the impression of listening to a microphone input instead of an antenna. It is said in these situations that you "hear the wind". This is not a fault of the receiver but it is the direct effect of how electric field receivers work: the whip antenna works very similar in fact to a condenser microphone. This happens whether we are moving with the receiver in hand or whether it is the wind vibrating the antenna. In a permanent observing station this problem is minimized by using large wire antennas, very stretched, or tens of kilograms heavy antennas so that they are mechanically stable.

## FALSE SIGNALS

Walking with the receiver in hand it is possible to hear other types of signals. Synthetic clothing, during movement, emit small electrostatic discharges that are detected by the receiver: the same phenomenon that produces the sparkle of pajamas in the dark. The gravel courtyard or street, stepped on, may emit piezo-electric signals that you hear with the receiver headphones and is very similar to the sound of gravel under your shoes, only much stronger. Small insects, fluttering their wings near the antenna modulate the earth's static field: a signal similar to the hum of their wings can be heard clearly in the headphones.

## USE OF THE PORTABLE RECEIVER DURING STORMS

The circuit input is protected from transient voltage and can withstand shocks of several thousand volts without damage. It is not recommended for reasons of safety to use it when the weather is bad: If during a walk in the mountains storm clouds are gathering over your head it is not appropriate to continue with reception.
For the same reason we should not seek shelter under a tree, or handle sharp metal objects:
Do not use the portable receiver outdoors during a thunderstorm!!!

Two pictures, taken from my garden during a stormy afternoon.

## PERMANENT VLF OBSERVATIONS DURING STORMS

Where the wire antenna is external and the receiver is inside the risks are lower for the circuit: the input stages are well protected so relatively close lightning usually will not damage the receiver. The probability of damage is more or less similar to a common radio receiver connected to the antenna. The use of this receiver at fixed locations for long periods of time revealed substantial protection even with discharges within a few hundred meters away. If the location is uninhabited it is advisable to unplug the receiver from the PC, to avoid a surge from damaging the computer's sound card. However, avoid touching the equipment: good sense suggests that with a storm in progress is not very healthy handling equipment connected to an external antenna.

## USING THE RECEIVER AS AN AUDIO MONITOR

The line output can also be used as input. Disconnect the antenna and connect a BNC coaxial cable with alligator clips to the LINE output jack. A signal introduced this way will be heard in the headphones. If more gain is needed move the BNC/alligator cable to the Antenna input jack. The LINE input offers a medium impedance with up to 40 dB gain to the headset: this lets you use the receiver as an audio tester to verify your VLF installation. For example in a monitoring station, where you have several receivers installed, a quick check with headphones will allow you to determine which signal lines are working properly and which are not, without the help of computers.

A second application of the receiver as a testing instrument is through the use of an oscilloscope probe connected to the antenna input. The signal can be extracted from the LINE output to be placed directly into the sound card: in this case the amplification is fixed and the PC can function as an audio band oscilloscope. Simultaneously, the detected signal can be heard in the headphones, setting the volume control to adjust the level. A convenient audio signal tester to determine what is working in any type of audio circuit.

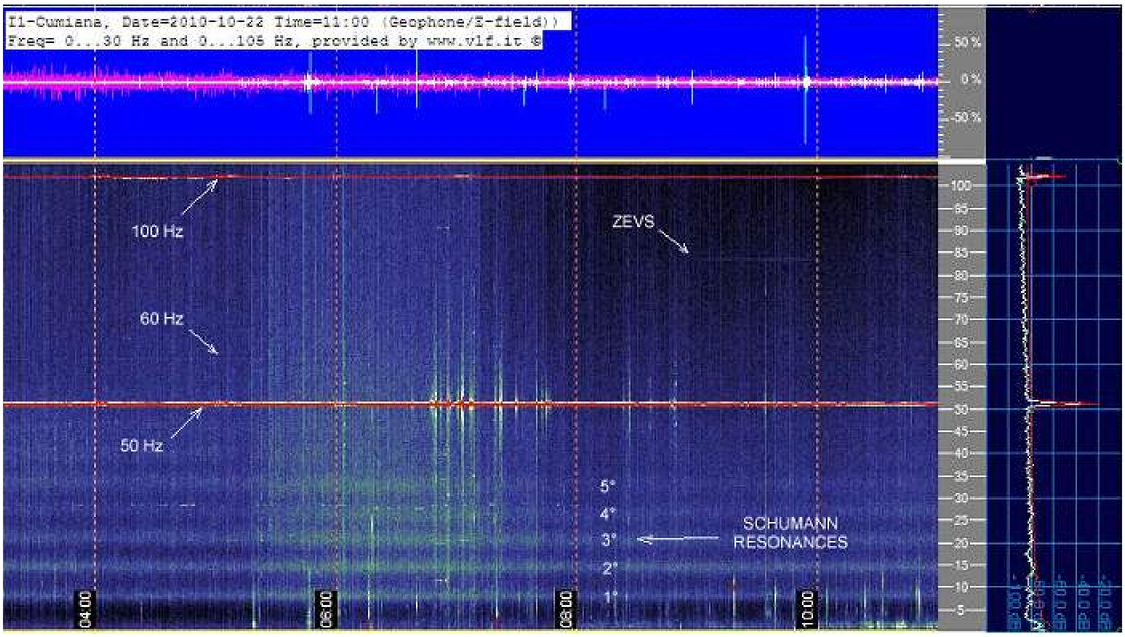
## SIGNAL ANALYSIS: THE SPECTROGRAM

The spectrogram is a graphical representation of the signal and shows how the frequencies evolve in time. The spectrogram provides great help for studying and identifying the source of the received signals. There are several free programs that perform this function. Among the most popular there are:

- SpectrumLab, http://www.qsl.net/dl4yhf/. The most complete, but, complex to use: it is the arrival point.
- Spectran, http://www.weaksignals.com, more limited but easy to use: good to start with.
- Sonic Visualizer http://www.sonicvisualiser.org/ Not useful for real-time analysis but very good for wave files, post processing and representation.

## WHAT YOU HEAR AND WHAT YOU CAN'T HEAR

If we have found a place outside and away from power lines, signals present 24 hours a day are statics: similar to the sound of dust on the old vinyl disks, they provide a constant crackle.
These are the signals radiated by lightning strikes that fall within a few thousand miles from the listening position. They are the first test indication that the receiver is alive and working. At night the propagation phenomena distort these signals causing effects similar to twittering: these signals are called “tweeks”. In periods of strong solar activity some other phenomena can occur such as Whistlers and Chorus.
Many signals cannot be heard, but only appear in spectrograms due to being either lower or higher in frequency than the range of our hearing. Here is a sample reception below 100 Hz:




In the spectrogram above, developed with SpectrumLab and obtained on a received signal with a Marconi wire antenna, are visible: the Schumann resonances, a 82 Hz Zevs signal from a Russian submarine broadcast network, 50 Hz network, the first harmonic at 100 Hz and the weak 60 Hz signal of American power grid.

## COMPONENTS AVAILABILITY

The receiver is simple and components are easy to find in any electronics shop, or from international distributors by purchasing on their web sites.

A commercial version of this receiver is distributed by SISTEL (http://sistel.albedo.it)

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## REFERENCES

For a more complete description of VLF signals refer to the Book: RADIO NATURE and also listen to examples posted on www.vlf.it, in the "Signals Galleries".

Many thanks to Dave Ewer for the English revision.

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