

How we assemble and use the VLF-3 receiver during the ISU summer sessions

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Every year, the International Space University holds a two-month summer school for students and professionals from all over this Earth who are interested to learn more about all aspects of space exploration and activities. They come from all disciplines and backgrounds. During this period they attend lectures and workshops, and all of them work together on one of several projects. Part of the time they join a ‘department’ of their choice and pursue activities therein. Since 1992, one of the regular activities in the Physics Department has been for the students to assemble a VLF receiver and record and analyse the sounds of natural radio. This teaches them how to build an apparatus which permits them to hear sounds they have never heard before, some of which come from space! In this article I discuss our ways of using the INSPIRE kit and report some of our experiences which might be helpful for similar activities.

Preparations

Usually, we have about 10 participants – in 2009 we had 22 – so we use 10 kits, kindly procured and brought to the site by Dr. Jim Green, who also gives lectures at the school. Thus, the kits and our box with tools are ready at the start of the activity...

The first thing is to prepare the workspace: it is very useful to group the students around a large table, with the power sockets for the soldering irons in the middle, along with some tools and material which they can thus easily share. Facing each other also offers them the possibility to chat, discuss problems and ask questions to each other. Of course, the size and shape of the room, the position of the power outlets on the wall, availability of extension cables, and the size of the tables dictate the arrangement of the tables. The tables should also be placed such that each seat has free access, so that the instructor can easily reach any workspace to help the student.

Another, separate table can be set up with any additional material, such as test instruments and spare parts. Sometimes, we also have a separate station with a more powerful soldering iron for any repair work.

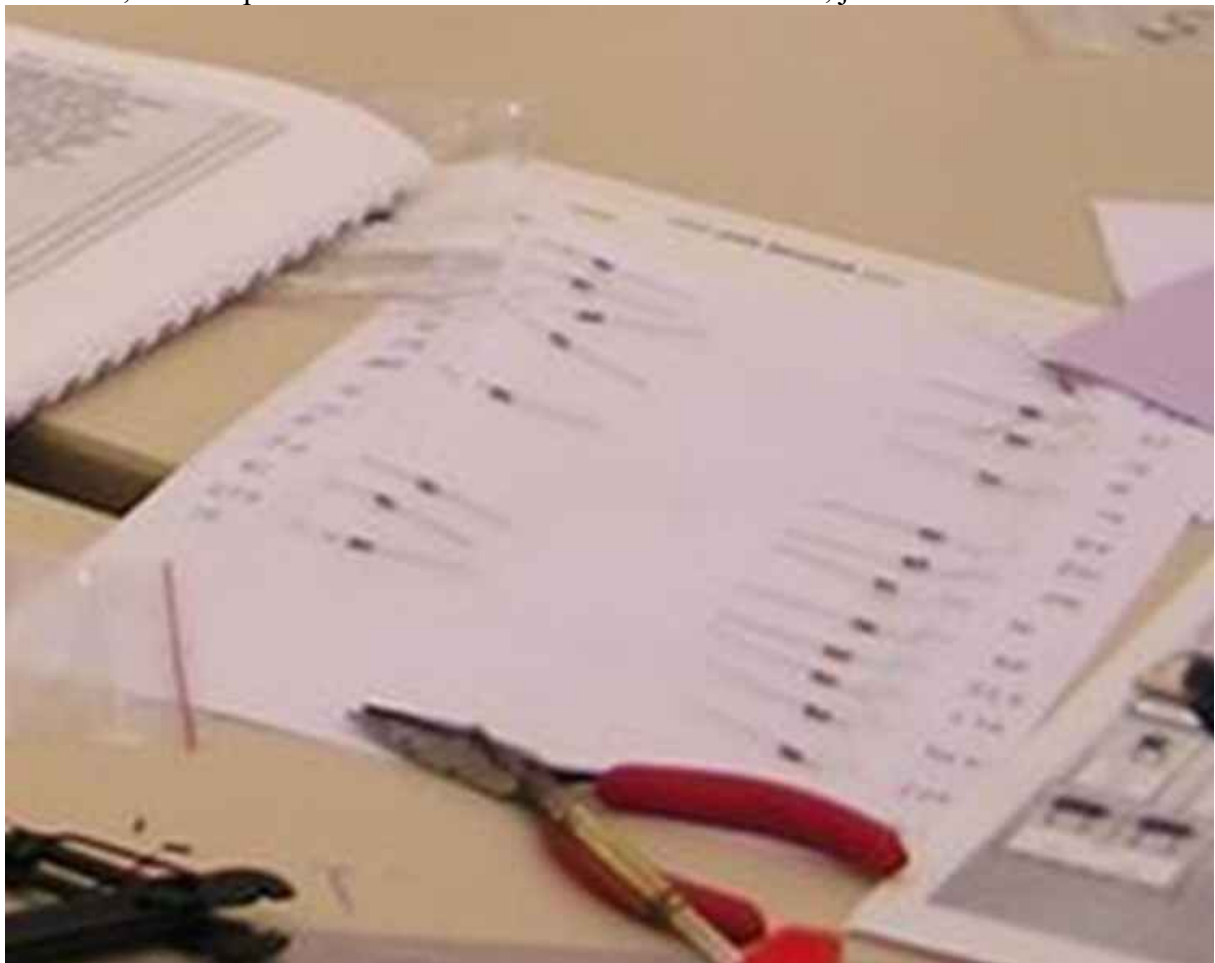
Each work place is provided with a table-mat, to protect the table’s surface against drops of hot solder and dirt – we usually place old journals there. Then there is the kit, the assembly instructions, and soldering iron with its stand. In the center, there are communal tools, such as

wire strippers, small pliers, diagonal cutters, and the yellow wet sponges to clean the soldering iron's tips.



The tables are set

One important item is a sheet of paper on which all the resistors are fixed with a strip of scotch tape and labelled with their value. Since it is not the primary aim of the workshop to teach the resistor's color code to our participants (and most of them will never be faced with it again in their life), we do not want them to spend their time decoding the resistor values. However, we also provide a list of the resistors with their colors, just in case...



Labelling the resistors by their values facilitates assembly

All other components are left in their bags. The explanations and identifications as given by the VLF-3 Assembly Instructions are found to be completely adequate. A good magnifying lens can be very helpful to read the very small numbers and letters on some capacitors!

Finally, it is very useful to have one assembled receiver which shows the participants how the finished product would look like and how the components are placed.

In 2009 we had twice as many students as we had kits, so we asked them to work in pairs, and placed them at the corners of the table. Here we had also covered the tables with brown paper for extra protection:



Four teams share a table and help each other

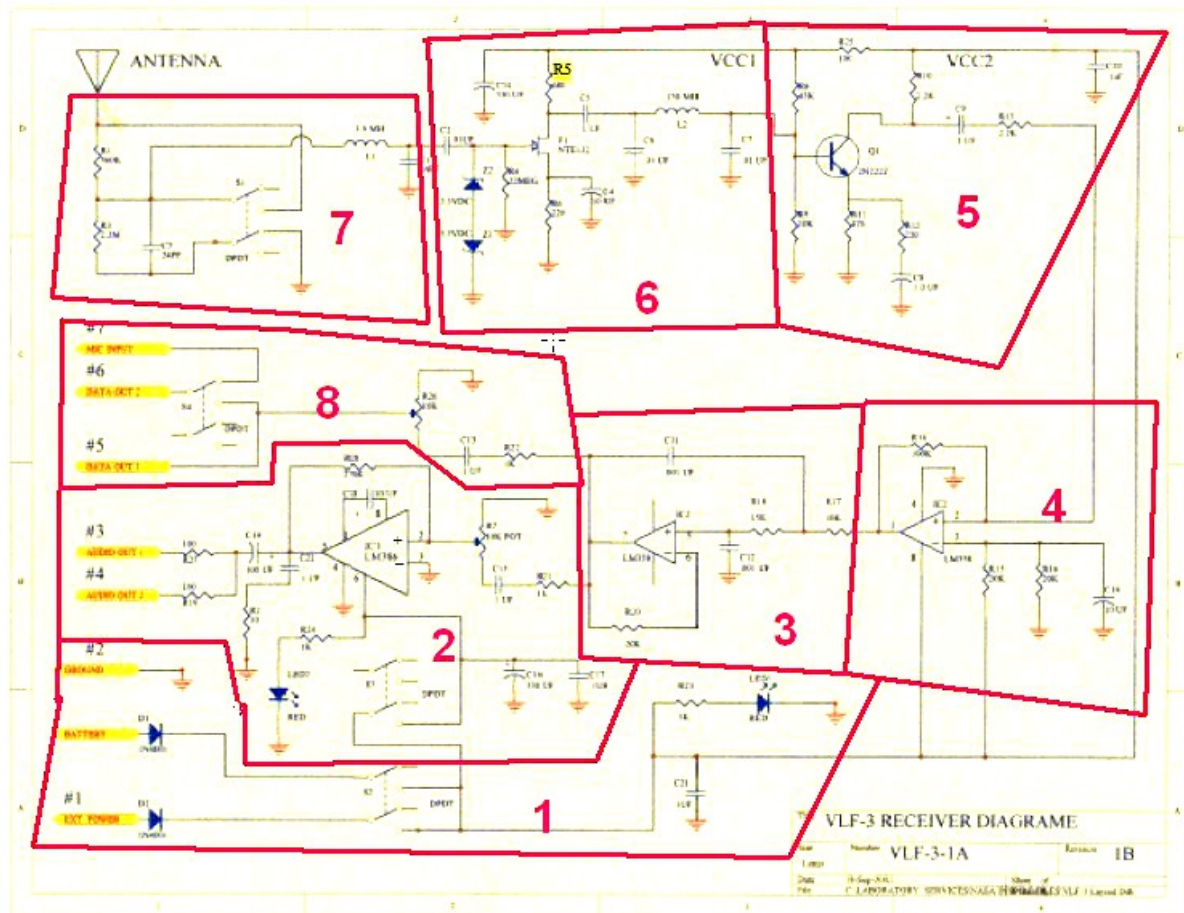
The assembly

After a presentation of VLF techniques and sound examples, we start with assembly. However, we prefer to do it in a somewhat different sequence than described in the VLF-3 Instructions, because it greatly facilitates testing and an eventual fault-finding: The circuit is divided into eight sections, and

- Every section is assembled and tested before proceeding to the next one: in this way it is easier to localize any malfunction.
- The circuit is built starting at the output end: testing is done by listening to the output. As the other sections are added, the receiver becomes progressively more sensitive, and this can also be verified.

- We also emphasize to our students that the workshop is not a speed contest, and everyone should do it at one's own pace and do a careful job! If needed, extra time to continue the work can be arranged!

The different sections are identified in the circuit schematic:



Sections of the VLF-3 receiver circuit

We start with Section 1, which is the placement of the battery holder and make the connections which supplies power to the circuit board. This first step we do all together, with the instructor identifying the various components, explaining where and how to place them, and giving detailed advice to each student. The test is simply to put in the battery, turn on the receiver power switch, and see the associated LED lighting up. Either they enjoy a splendid and encouraging success, or we have to fix a small problem ...

Section 2 is the final audio amplifier, the Audio Level control and the Audio Power switch. We make a provisional connection to the Audio Output socket, using two of the wires. This is practical, as we shall need to listen to the output in all the next tests. And we make sure that we install the IC socket in the correct orientation... The test is to connect an earphone or a small loudspeaker with amplifier (one of our test equipment), turn up fully the Audio Level control, and touch pin 2 of the LM 386 IC or the “hot” solder lug of the potentiometer with the finger or a screw driver. One should hear a hum from the mains supply or at least a click when the screw driver touches.

Sections 3 and 4 are the audio preamplifiers which serve as low-pass filters. Since both sections deal with the same IC, it is best to complete them together. By now, the students acquired a good competence and confidence that they complete this part without problem. The test is to touch pin 2 of the LM 358, which should give a much louder hum or noise.

Section 5 is the low-noise amplifier stage, with the transistor Q1 already in place. The test is to touch the centre pin of the transistor, or the point where R8 and R9 meet, and the hum should be even louder. Often, it suffices to approach this point with the finger, and a faint, airy or 'spacy' hum would be heard.

Section 6 is the high-impedance front-end amplifier with the FET F1, already in place. As test we may touch the 'hot' end of the back-to-back Zener diodes, or merely come close to this section to hear the mains hum. If someone has a quartz-controlled wrist watch whose pointers are moved with a small electromagnet (like a SWATCH), holding it next to the FET will let the second ticks be audible in the earphone. This crucial test shows that the receiver has attained its proper sensitivity.

Sections 7 (the switch close to the antenna terminal) and 8 (Data Level control and the Mic./Data switch) finish the assembly of the circuit board. Testing will be done after the board is attached to the front panel and all connections are done: now the antenna terminal should be as sensitive to the touch by a finger as the previous test of Section 6. One follows the Assembly Instructions for placing the circuit board to the front panel and making all the connections. This integration may be a bit tricky, but with some gentle push things do slide in place.

As antennas we usually attach a suitably stiffish wire to the antenna terminal, and instruct to always firmly touch the BNC socket or the face plate, as to provide a good earth connection. From another activity, we had multi-stranded copper wire to make dipole antennas. A 40 cm long section of this wire is sufficiently stiff to keep reasonably straight. This length suffices to pick up natural radio waves, if one holds up the receiver.



Marta listening to tweeks on Mt.Hamilton (with our last VLF-2)

Experiments for tests

When the first receivers are finished and an antenna is fitted, we do some testing inside the room, listening at various sources of electric noise: computer screens, fluorescent lamps, the power lines in the walls, the liquid crystal display of portable phones and personal organizer emit funny sounds when activated ... Listening to these noises and identifying their sources can make up one interesting exploration of its own. Here, students can realize how our electric and electronic-based civilisation pollutes the electromagnetic spectrum, which is a valuable resource!

Then, we step outside the building, and even the adjacent car park can be sufficient to pick up spherics ... and hum from street lamps, of course. But also, one can hear one's footsteps while walking: the friction of the shoe soles with the pavement which is of a different material causes the build-up of electrostatic charges with subsequent discharges. Tiny as these may be,

the VLF receiver is sensitive enough to clearly pick them up. Even noisier is it to walk over dry grass!!!

A good test position to listen to spherics is an open space, at a good distance from buildings – with all their electric noises – but also away from trees and large bushes; as these water-bearing structures absorb radio waves. Approaching a tree or standing under its branches lets all the spherics disappear, and one hears only the hiss of the receiver's internal noise.

All these tests verify that the assembled receiver works as it should be.

Our experiences

With the preparations and our assembly procedure, we find that the students complete and test Sections 1 and 2 within about two hours, some of them proceeding to Sections 3 and 4 at the end of the first half day. In Beijing in 2007, the session was in the afternoon, and one student got so excited and taken with her job, that we continued after dinner, and finished that evening! At the end of the second session, almost all finish their assembly, some of them only need to tighten the screws and do final testing. The complete assembly takes about 7 hours for everyone. Some common problems were noted:

- Imperfect solder joints: inexperienced students tend to remove the soldering iron as soon as the tin flowed to the wire. However, the VLF-3 board carries the circuit tracks on the component side, not – as it is more common – on the solder side. This may result in an apparently neat solder connection, but without the proper connection to the track on the other side. We recommend re-soldering all components – especially in Sections 3 to 7 also from the component side, by reheating the leads and applying a bit of solder. Unfortunately, this is not possible for the inductors L1 and L2. Here, one cannot but reheat from the solder side for a while and hope that the solder will flow deeply enough to make a good connection. This error occurred several times with L1: while the receiver picked up the second clicks of a watch placed near the FET, no spherics were heard with the antenna attached ... Tests inside the room are not very informative, as the strong hum pervades everything!
- The rather small size of the solder pads contributes to this effect. The board of the VLF-2 seems more suitable for beginners.
- Sometimes, resistors were swapped, for instance: 100 and 100k. This does occur to inexperienced students. So they learn to remove and re-solder resistors (see below) ... Also, under illumination of fluorescent lamps, it may be more difficult to distinguish the red and the brown bands, resulting in a misidentification of 10k and 20k resistors.
- In the board's silk screening, R11 and R12 are swapped. If one follows this indication, the gain of Section 5 will be higher than designed. In most receivers this did not appear to be a problem. However, a few sets had an almost irrepressible tendency to whistle. In one receiver, we not only corrected this fault, but also left out R12 altogether, which resulted in a performance as good as expected.

- Also, the markings for LED1 and LED2 are swapped
- Since in 2008 we had noticed a substantial variation of the sensitivities of the individual receivers, we measured the performance of each receiver. Eight receivers were measured under the same conditions, showing sensitivities within a range of about 10 dB, which is hardly noticeable. However, these measurements could not be done with best accuracy, because of the high level of mains hum in the building against which the plastic box could not present any shielding!
- As a side-line, the two LEDs contribute quite heavily to the current consumption. Why spend about 15 mA for an indication which is not really needed at daylight, while at night the LEDs seem overly bright. One could simply use higher values for R23 and R24, e.g. 3.3 kOhm.

As tools we found useful:

- A box with an audio amplifier driving a small loudspeaker. This is convenient for the tests during assembly, allowing several persons to hear the outcome. It is connected with an audio cable to the receiver's output socket, which is attached to the circuit with two wires in a provisional way.
- A digital and an analogue multi-meter to check voltages and resistor values.
- An instrument to measure the sensitivity of audio devices (to be described in a forthcoming article). While this is not absolutely necessary, we have found it helpful to quantify each receiver's sensitivity, as a significant variation of the performance had been noticed between individual sets despite the absence of any obvious difference in the finished device or the workmanship.
- Tweezers are very helpful especially when pulling a component from the board. It allows a secure and firm grip of the component lead while reheating the nearby solder joint, but without burning the fingers. Also it serves well when pushing a lead through the solder-filled hole on the board when replacing a component.
- A steel sewing needle with a wooden handle is a great tool to re-open a solder-filled board hole: while the solder pad is reheated, one inserts the needle and keeps it moving until the solder cools off. As the needle is of steel, solder will not stick to it.



Tweezers and a steel needle are helpful repair tools



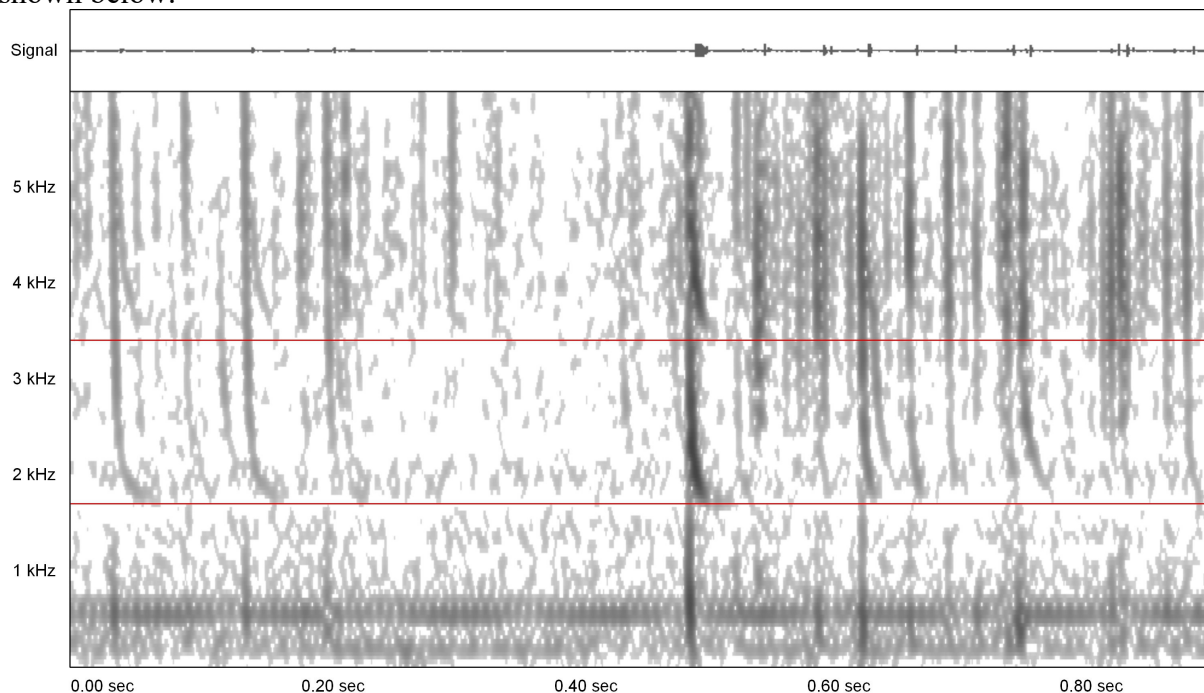
Reopening a solder filled pad can be an operation demanding concentration

Another technique of removing solder from a pad and re-open the hole is the ‘earth-quake’ technique: heat the solder pad, until the solder is well liquid, then rapidly and forcefully bang the board against the table-mat! Very effectively, this will remove all solder from the pad except for a thin coat. Of course, one has to make sure that this somewhat brutal method does not bend or damage anything on the board!

As a result of careful preparations, continuous testing, and the concentrated and dedicated work of the students, each of the receivers worked properly and everyone could start listening to the signals of Radio Nature. Time permitting, in a final presentation the sound analysis software (Spectrogram by R.S.Horne) is demonstrated by sound examples and using a microphone to whistle and sing.

Observations

During the two month of its duration, the summer sessions are already filled up with many interesting but also demanding activities, including the students' team projects. Hence, the students cannot devote much time to intensive listening with their receivers. A few years ago, the time frame for the departmental activities was reshaped into a tighter layout. Thus, now there is little time for regular, extensive, and systematic observations which would be the key to detect whistlers. But we make it the point to arrange for a listening session during an excursion. Also we take up any other chance to go out in small groups, and spend some time together, listening, make recordings, and perform experiments. In 2009 we were hosted by NASA Ames Research Center, where the car park just outside our building provided an ideal testing ground, sufficiently low in hum to let everyone hear spherics, showing the decreasing hum as we walked away from the building, with some trees under which the spherics became inaudible, noisy street lamps, and lawns nearby to hear the crushing sound of our footsteps. One evening, some of us went to the baseball fields and enjoyed a loud concert of tweeks. Later, we found that we could easily locate underground power cables. An evening trip to Lick Observatory gave all the students the opportunity to hear tweeks. One recording is shown below.



**Tweeks recorded at Lick Observatory with a VLF-3 receiver and short whip antenna.
The two horizontal lines mark 1.7 kHz, near the ionospheric cut-off, and 3.4 kHz.**

Interestingly, we caught a very strong tweek which also shows up in the first harmonic (at 0.5 sec), weaker ones but also with harmonic (at 0.05 and 0.15 sec), and a pair of tweeks (at 0.65 sec) which differ in their slope, evidently coming from two different distances! Below about 600 Hz, the mains hum – here on the top of Mt. Hamilton – was as strong as in the car park back at our campus!

Below, our student Yuhua wrote up her impressions of her work in the 2007 SSP in Beijing:

An interesting receiver

On July 26th, 2007 I was very happy, because I finished my department's work - assembly of the VLF-3 receiver kit, and using my receiver I heard many kinds of radio noise from electrical equipment. This is not an easy work, usually it may need two days to finish: It contains 30 resistors, 22 capacitors, 4 diodes, 4 switches, 2 integrated circuits, 2 transistors, 2 inductors, 2 LEDs, and connectors, wires etc. But I worked very hard, with Prof. Joachim Köppen's help, I completed it within the afternoon and evening.

Joachim required us to do our assembly step by step. This receiver consists of eight sections. The first section is the power supply and one LED. By following the schematic diagram I finished that work in about one hour. Then we tested it: I turned on the switch, it worked properly. This encouraged me! I worked continuously without a rest, and I finished the assembly of the circuit board just before dinner time. Right after dinner, we started the mechanics work on putting the board onto the faceplate and in the box. There was some difficulty in my work, but we finished all the work at last!

With Joachim's help, I first heard the radio noise from the fluorescent tube - this is my first time to hear the sound of a lamp. When the antenna comes near the lamp, the sound becomes louder. Then I put my mobile phone near the antenna, and I heard its radio noise. If you dial, the sound becomes loud. The fire detector, the computer ... all emit radio noise! Joachim explained to me why I can hear the sounds. They come from the electromagnetic emission of the source, which the receiver converts into audible sounds.

Then we walked back to the dormitories while listening to the receiver all the time. On the way through the campus, the first interesting sound was my shoes. As the shoes scrape the ground, radio noise is produced. The second sound was made by all the streetlamps - every type of lamp has its own sound; the brighter the lamp is, the more noise it makes. As we were talking about the reason for the noise, a very loud sound came out of the receiver. It was just like a truck passing by - in fact it was just a bike passing by: the tyres scrape the ground, and thus make electromagnetic noise. But not all bikes make noise, because their wheels are not the same.

I used the receiver to test my portable computer, my reading lamp, the air conditioner, the water heater ... every electric device has its own electromagnetic sound. Using the receiver you can discover and listen to many interesting sounds. It is an interesting receiver.

Acknowledgments

It is with really great pleasure that I thank my friend Jim Green for having 'infected' me with the VLF virus, and for the inspiring and smooth collaboration to run these workshops.