

How to measure the sensitivity of VLF receivers

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In 2008, during the Summer Session Program of the International Space University, when we had 12 students assembling their VLF-3 receivers, I had noticed that there was a marked variation of sensitivity among the finished products, even after we had eliminated all the minor bugs that had crept in. Some sets were as sensitive as my own VLF-3, but others did not pick up the natural and human-made noises as well as the others. Were these differences due to variation of the characteristics of the active components, i.e. the transistors and the integrated circuits, or were there still some faults in the assembled instrument, which we had failed to spot? While such a direct comparison is revealing, it remains rather subjective and qualitative. What one really wants is to measure the sensitivity of a set, and thus compare its value with a standard or reference value.

So I set out to design and build an instrument that allows measurement of the sensitivity of a receiver. The principle of this measurement is well known from radio receivers: Every receiver produces some noise of its own, which the incoming signal has to overcome. Thus, the level of this internal noise is a measure of the sensitivity of the receiver. The usual technique requires an audio meter to measure the receiver's audio output, a source of wide-band noise, and an attenuator with which the noise can be varied in a calibrated way. The procedure is as follows:

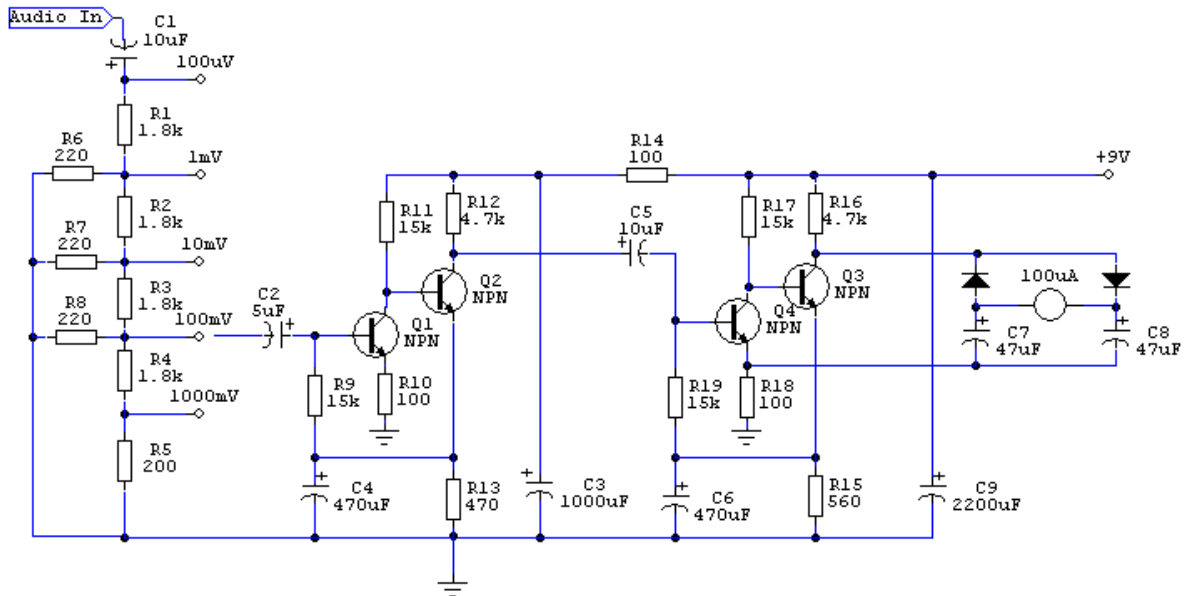
- With the noise source switched off, we measure the receiver's audio output, usually as the audio voltage at the loudspeaker or the earphones
- Then with the noise source on, we increase the noise amplitude until the audio output power is doubled – since we measure voltages, it means that the voltage should have increased by a factor of 1.414 (square root of 2).
- When this condition is met, the amount of internal receiver noise is just equal to the external noise from the source. The setting of the attenuator gives a measure of the receiver's noise level: the greater the attenuation required, the lower is the receiver's noise and hence the more sensitive the receiver is.

The picture 1 shows the completed instrument: it consists of a sensitive audio millivoltmeter whose range can be adjusted in steps between 0.1 mV and 1000 mV (seen in the top half), and an audio frequency noise source whose amplitude can be varied by means of a finely calibrated attenuator, covering attenuations between 0 and 60 dB (i.e. between no attenuation and a factor 1000000 in power) and another 40dB (factor 10000) with a toggle switch, all in the bottom part. The instrument has about the same size as the VLF-3 receiver.



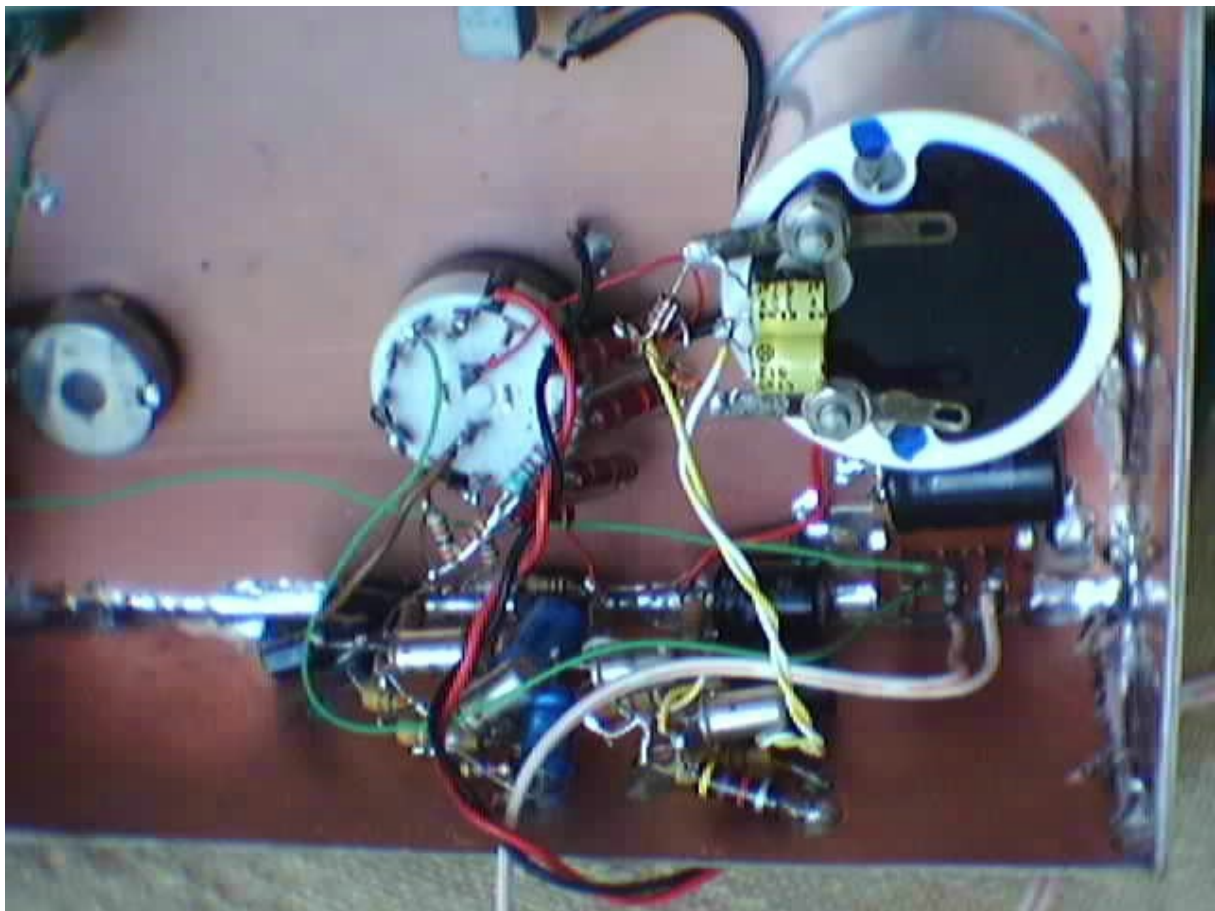
The complete Noisemeter

Let us start the description with the audio mV meter: The circuit schematics (picture 2) shows that the signal from the input socket goes through a switched attenuator, covering the range from 0.1mV to 1000 mV in five steps. From here the signal reaches a wide-band audio amplifier, built with two transistors. A strong negative feed-back established by the resistors determines the gain which is thus quite independent of the transistors and the supply voltage. As transistors any universal type such as 2N3904 or 2N2222 are suitable – in fact I built my instrument with obsolete germanium transistors which happened to feel bored in my junk box. Another amplifier follows, whose output is rectified by two silicon diodes - any universal diode such as 1N4148 will do – and feeds a 100uA moving coil meter. One notes that R15 has a different value from its equivalent R13 in the first amplifier ... These resistors determine the gain of each amplifier, and it happened that this value was the right one to get the meter to be calibrated. While the accurate calibration is of no importance for our purpose, one may well use trimmer resistors for R13 and R15 to allow easy calibration.



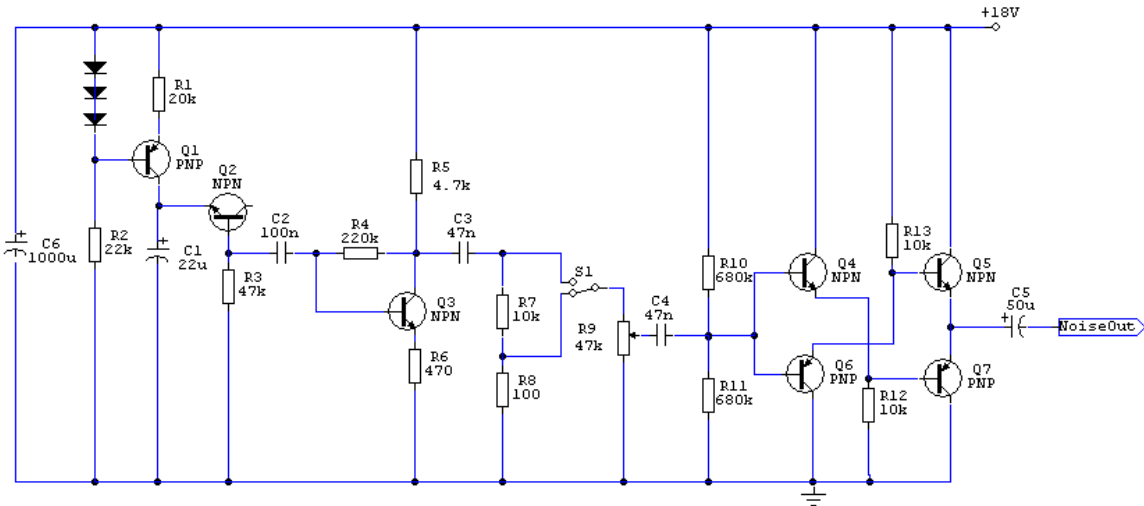
The circuit diagram of the audio mV meter

Picture 3 shows this part of the instrument. The circuitry was soldered in free-style directly on the printed circuit boards out of which the entire enclosure is made. This offers a ground connection everywhere it may be wanted, as well as an electrically shield of the entire instrument against electronic noise and hum that is usually present in our rooms.

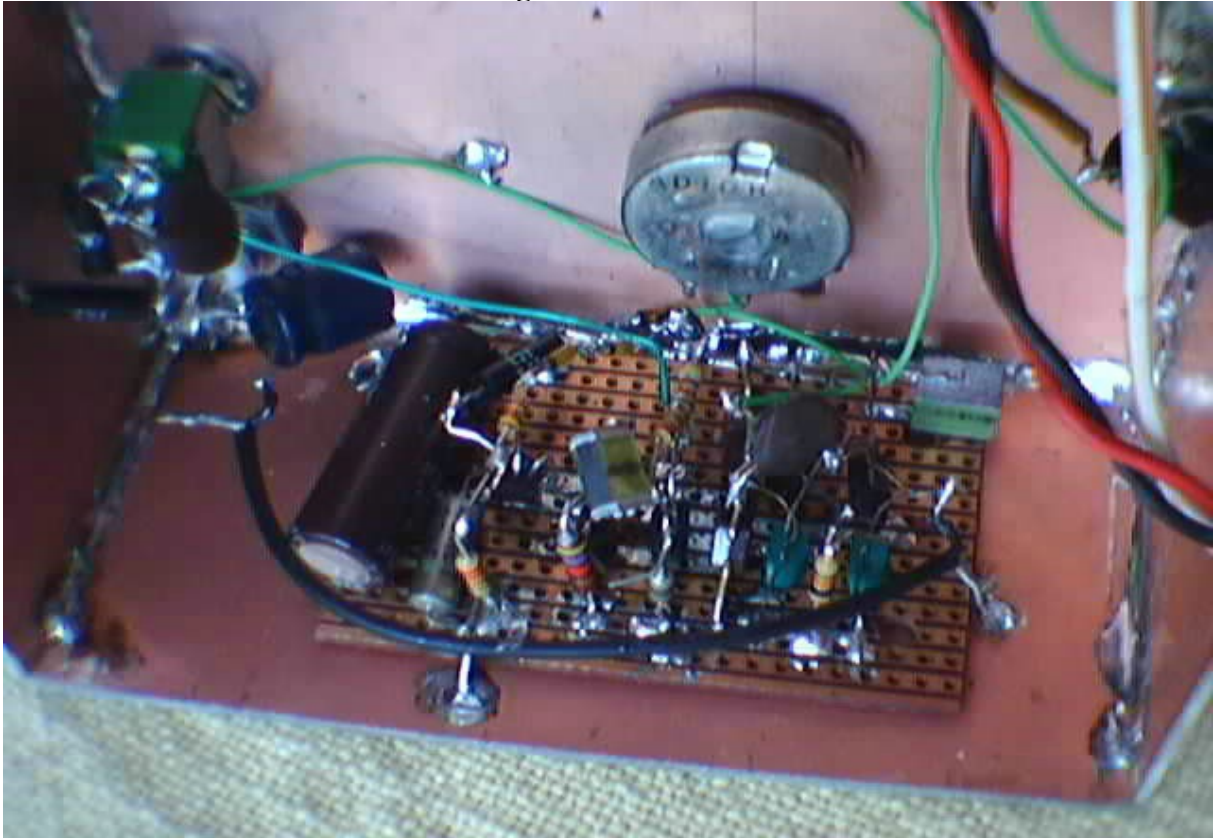


The mV meter

The audio noise is produced by operating the base-emitter junction of a silicon transistor Q2 in reverse bias. Q1 and three silicon diodes constitute a constant current source, which will make the noise output independent of the battery voltage. The noise generated in R3 is amplified by a single transistor stage, passes through a switched 40dB attenuator (R7/R8), then through potentiometer R9 which provides a continuously variable attenuation. A low output impedance buffer of two pairs of complementary transistors (for instance 2N3904/2N3906) provides a signal which is largely independent of the receiver's input impedance. The noise source was constructed on a small piece of printed circuit board which is soldered to the enclosure.



Circuit diagram of the noise source



The noise source and the variable attenuator

An important point is the calibration of the variable attenuator: potentiometer R9 should preferably be of the logarithmic variety, as used for volume control in radios, because then the dial will be divided in dB with almost equal steps. Since for the VLF receivers we deal with audio frequencies only, this calibration can be done easily and accurately, by measuring with a digital ohmmeter the resistance R between the earthy terminal and the wiper, and dividing it with the total resistance R9. The dial is marked in dB using the formula $dB = 20 \log(R/R9)$. When the wiper is at the top 'hot' end, we mark the dial with 0dB – but please note that depending on their construction the potentiometer's end positions usually give a constant resistance value over a certain angle. At the bottom 'cold' end, the dB marks would crowd together, so that it is more sensible to mark the 5 and 10 dB steps only.

Because for the proper operation of the constant current source, the noise generator requires a voltage higher than provided by a single 9V block battery; I use two of them in series, and hence need two power switches, one of which is linked with the sensitivity switch for the mV meter; but any other suitable arrangement would also do. One battery feeds the mV meter, and both together supply the noise source. The current drain is 17mA for the mV meter, and 5 mA for the noise source. Since this is not a heavy consumption, and the use is limited for a few seconds only, even already used 9V batteries (which have only 6 or 7 V) will still give service for many measurements.

The procedure is straightforward:

- Connect the VLF-3 earphone output to the input of the mV meter
- Connect the noise source output to the BNC socket for the VLF-3 antenna
- Turn the noise generator's variable attenuator to maximum
- Switch on receiver, noise source, and mV meter
- Turn up the volume of the VLF-3 until the mV meter shows a deflection of 71 percent of full scale (i.e. one half of the power at full scale, the red mark on the meter's dial)
- Decrease the noise generator's attenuator until the meter shows full scale
- Read off the attenuator value

Apart from comparing different receivers, we may also determine the absolute level of the internal noise. If we calibrate the mV meter by other means, such as an oscilloscope, we may directly measure the noise generator's output at minimum attenuation. In my instrument I get about 200mV. When a receiver measurement yields an attenuation of 60dB, it means that the noise level of this receiver is about 200 μ V. The VLF-3 has about 100 μ V internal noise, when the input low-pass filter is switched in, and about 1 μ V when it is switched out. Would one then leave the filter switched off? Not in the places where I live and work, because of the presence of strong AM radio stations in the medium and long wave range. If I leave the filter out, I can directly hear these stations much louder than any spherics! For a 1.5m long whip antenna, spherics come at a level of about 1 to 10 mV, quite far above the noise level; whistlers are often somewhat weaker, but signals at night are substantially louder.

The neat thing about having a noise source is that we now have a signal available for receiver tests, that is of a strength similar to what we like to observe, but it is on our table – we do not need to take our receiver out to our quiet testing spot every time we made a change or an adjustment to the circuitry. Furthermore, the signal is constant, so that we can compare the receiver's performance, and we no longer are subject to the spherics level changing from day to day. This is a great help when building or modifying a VLF receiver.

This summer, the instrument had the opportunity to make itself very useful. We tested all the 10 receivers which the students had built. While my own VLF-3 would need an attenuation of about 65dB, any receiver which would obtain a value between 60 and 70 dB would also pick up well the spherics when tested outside. However, there was one which needed 22 dB, and another one 55 dB ... both showed plenty of hum signals when taken around in the room, but both fell completely silent when taken outside! A poor solder connection in the front end turned out to be the culprit. After reheating the connections, everything was fine!

We did encounter some problems: when testing the receiver inside the building – where hum and computer hash were abundant – some of these nasty signals entered the VLF-3 receiver directly, because the circuit in its plastic enclosure has no benefit of shielding. Thus, our measurements might not be too accurate, as one could hear those sounds with no antenna attached!



We just found that Danielle's receiver has its sensitivity up to specifications!