

Active loop AAA-1 performance at VLF and LF

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For some users LF and VLF reception is important so here some measurements of AAA-1 are performed along with suggestions to improve the reception.

AAA-1 frequency response

A small loop loaded with a low input resistance of trans-impedance amplifier has a flat frequency response to electromagnetic field intensity E . This represents the fact that the short circuit current of a small loop does not depend on frequency. The small loop can be represented as Norton equivalent circuit as shown on Fig.1 in a wide frequency range where the I_E depends only from loop inductance L and loop area A , [1].

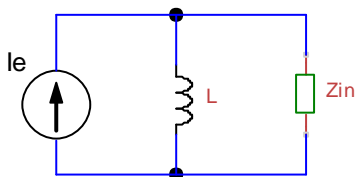


Fig.1 Current source model of a small loop. X_L must be $\gg |Z_{in}|$

Parasitic capacitances and loss resistances of the loop are ignored since they do not impact the circuit performance when Z_{in} is low

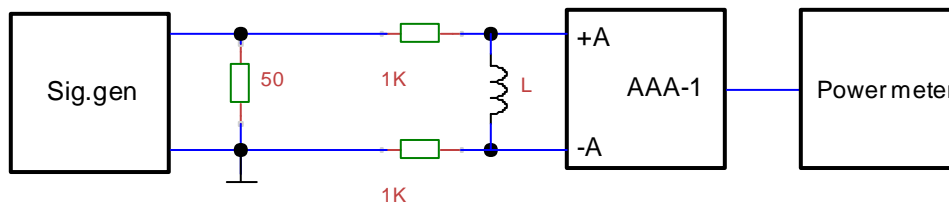


Fig.2 Measurement setup for high frequency response

The so called M factor where $M=A/L$, [2], characterizes the loop performance. We can measure the frequency response of the active antenna with a setup shown on Fig.2. A current source is simulated by inserting 2 K resistor as a source impedance which is much higher than the load of amplifier input resistance (e.g. 6 ohms) paralleled with loop inductance L .

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But this model is correct only for frequencies where the loop inductive impedance is much higher than the input Z_{in} of amplifier. For low frequencies a Thevenen equivalent circuit must be used which reflects also the physical phenomena (Faraday law) Fig.3. At these frequencies the response is not flat anymore since the loop does not work in short circuit mode. Its inductive impedance is smaller than the load impedance.

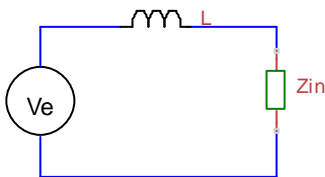


Fig.3 Small loop equivalent circuit for LF. X_L is equal or lower than $|Z_{in}|$.

Parasitic capacitances and loss resistances of the loop are ignored since they do not impact the circuit performance when Z_{in} is low.

Here the induced voltage V_E is proportional to frequency F and loop area A . We can measure the frequency response at these low frequencies of the active antenna with a setup shown on Fig.4 .

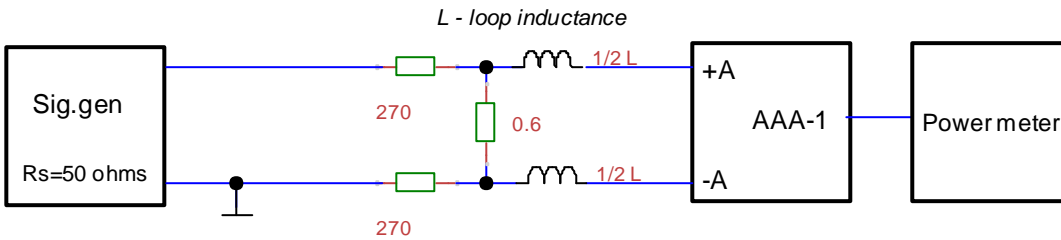


Fig.4 Measurement setup for VLF/LF response

The induced voltage V_E is simulated with a voltage source with very low internal resistance 0.6 ohms which is almost negligible to the value of load impedance (6 ohms). The amplifier is balanced but an input balancing transformer must be avoided since it will influence LF response. For this reason the loop equivalent inductance is divided in two legs in order to have a symmetrical source. For the same reason additional 270 ohms resistors are added. The amplifier is powered by a battery to avoid common mode interference and ground loops

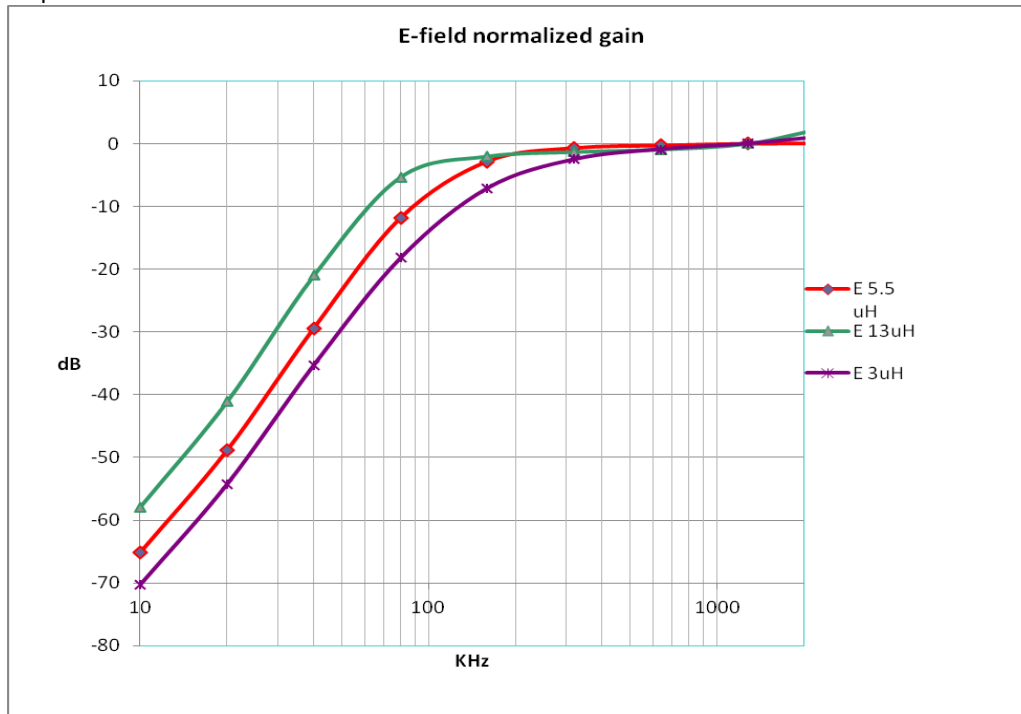


Fig.5 Low frequency response of AAA-1 for 3 different loops. Measurement setup from Fig.4 is used. The plots are normalized to 0 dB gain at flat frequency region (1280 KHz).

The measured points are at 10, 20, 40 ... KHz in octave series and at each frequency the voltage signal level is doubled (+ 6 dB) from the previous point. This represents the small loop behavior according to Faraday law. On Fig. 5 are shown normalized plots of frequency response to electromagnetic field (e.m.-field) intensity for 3 different values of loop inductance measured in random sample of AAA-1C models. It must be pointed out that the frequency response of the amplifier itself without any loop equivalent is 150 KHz at -3dB and this response is determined mainly by the ferrite transformers in amplifier and control board. When an equivalent loop inductance is connected the LF response is changed as shown on the Fig.5. The normalization means that all plots

are shifted so the gain in the flat frequency region is 0 dB. The output level is measured with *Perseus SDR* at 1 kHz bandwidth. It must be pointed out that for HF (flat) frequency region this measurement setup will give the same results as the measurements conducted according to **Fig.2**.

The loop inductances represent different single turn loop sizes **Table 1**:

Name	L [uH]	Area [m ²]	M [uA/pT]	Type	Size	Conductor	X _L @ 20 KHz [ohm]
Loop1	3	0.92	0.31	Circular	D=1.1 m	tube d=14mm	0.4
Loop2	5.5	2.25	0.41	quad	side 1.5 m	tube d=14mm	0.7
Loop3	13	3.92	0.30	triangle	side 3 m	wire d=1.5 mm	1.6

Table 1

AAA-1 performance at VLF and LF

A question arise what is the ability of AAA-1 to receive signals from 10 KHz to 100 KHz ? The above measurement will help to give an answer.

Loops	F KHz	L2 uH	Area m ²	E field noise	E field noise	Flat region output @ 1 MHz (1KHz BW)		Corrected LF region output		P _E - P _A dB
				(uV/m) / (Hz ^{1/2}) db	1 KHz BW uV/m	Output E field noise V _E uV	Output E field noise P _E dBm	Output E field noise P _E dBm	Amp output int. noise P _A dBm	
Loop 1	10	3	0.92	20	333	280	-58.0	-128.0	-120	-8
	20	3	0.92	10	105	85	-68.4	-123.4	-118	-5.4
	30	3	0.92	8	84	68	-70.3	-113.3	-115	1.7
	50	3	0.92	0	32	27	-78.4	-108.4	-114	5.6
Loop 2	10	5.5	2.25	20	333	367	-55.7	-120.9	-120	-0.9
	20	5.5	2.25	10	105	111	-66.1	-115.0	-118	3
	30	5.5	2.25	8	84	89	-68.0	-106.0	-114	8
Loop 3	10	13	3.92	20	333	273	-58.3	-116.3	-120	3.7
	20	13	3.92	10	105	82.6	-68.7	-108.7	-118	9.3
	30	13	3.92	8	84	66	-70.6	-100.6	-114	13.4

Table 2

On **Table 2** are presented the calculations for the noise floor at VLF/LF frequencies at the output of AAA-1 for 3 different loop antennas. The ambient noise level at these frequencies is taken from **[3]**.

The noise level given there is as a spectral density at 1 Hz bandwidth and is recalculated for 1 KHz bandwidth in order to compare the noise levels. We can calculate with reasonable accuracy the output levels in the flat frequency regions. Then from **Fig.5** plot we can correct the gain for LF and in this way we will obtain the output noise level due to ambient noise.

Here is an example for Loop 3 case:

At 20 KHz we have 10 dB (uV/m)/(Hz^{1/2}) noise density. At 1 KHz bandwidth we will have 105 uV/m field intensity. For 105 uV/m level we will have 111 uV signal at AAA-1 output which is -68.7 dBm ambient noise level. This calculation is for the flat frequency region e.g. 1 MHz. From green curve on **Fig.5** at 20 KHz we have -40 db gain which gives that with the same input noise level we will have : -68.7 - 40 = -108.7 dBm at the output at 20 KHz. The amplifier noise floor at this frequency is 118 dBm so we have +9.3 dB higher noise level from the

input ambient noise. This means that we can hear the ambient noise and the reception will be not noise limited by the antenna and amplifier but only from the ambient noise.

Experiment

I have made an experiment with Loop 3 at semi-urban location where the man made noise levels at these frequencies are probably modest. The notebook, SDR – Perseus and AAA-1C are powered by a battery to avoid conducted noise. For example, when my Thinkpad notebook is connected to mains there is a heavy broadband noise with peak at 40 KHz. The triangle loop is with 2.7 m side made with 1.6 mm diam. copper wire. The feeder is 15 m FTP cable with CM balun 150 μ H near the antenna side. The balun inductance is insufficient for these frequencies but that was available for the moment. The FTP shield after the balun is grounded with a 1 m metal rod inserted into the soil. The lower part of the loop is 1 m above the ground.

As it turns out I have high noise levels above 100 KHz but VLF/LF regions are relatively quiet. **Fig. 6** shows a spectrum from 9 to 32 KHz. The ambient noise level at 1 KHz BW, $F=13$ KHz is -113.3 dBm. The expected ambient noise level at this frequency from **Table 2** is somewhere between -108 and -116 dBm.



Fig. 6 Single turn triangle wire loop with 2.7 m side

The reception with this setup is quite satisfactory. The time transmitters at MSF @ 60 KHz (17 kW, 2200 Km), RBU @ 66.6 KHz (10 kW, 2100 Km) and DCF77 @ 77.5 KHz (50 kW, 1500 Km) are very loud during all the day. The front to side loop ratio measured for DCF77 is 19 dB. S/N ratio is 35 dB. The lowest frequency where any stations are heard is 11.9 KHz where the Russian Alfa beacon is clearly identified just the loop must be directed to East. On 24th October 2025 the Grimeton Radio Station SAQ [7] had a transmission at 17.2 KHz. On **Fig.8** the spectrum is shown. The CW signal was readable 100%. On the following figures some illustrative examples of VLF/LF receptions are shown with the same setup.

Receivers for LF/VLF

Since AAA-1 has internal output noise floor at these frequencies somewhere between -120 to -116 dBm at 1 KHz BW (see **Table 2**), a receiver with the same or lower noise floor is needed. I have tested Perseus and SDRplay RSP-duo – both give good results. RSPDuo was tested both with SDR Uno and SDR Console software and VLF/LF reception was good and similar to that with Perseus SDR.

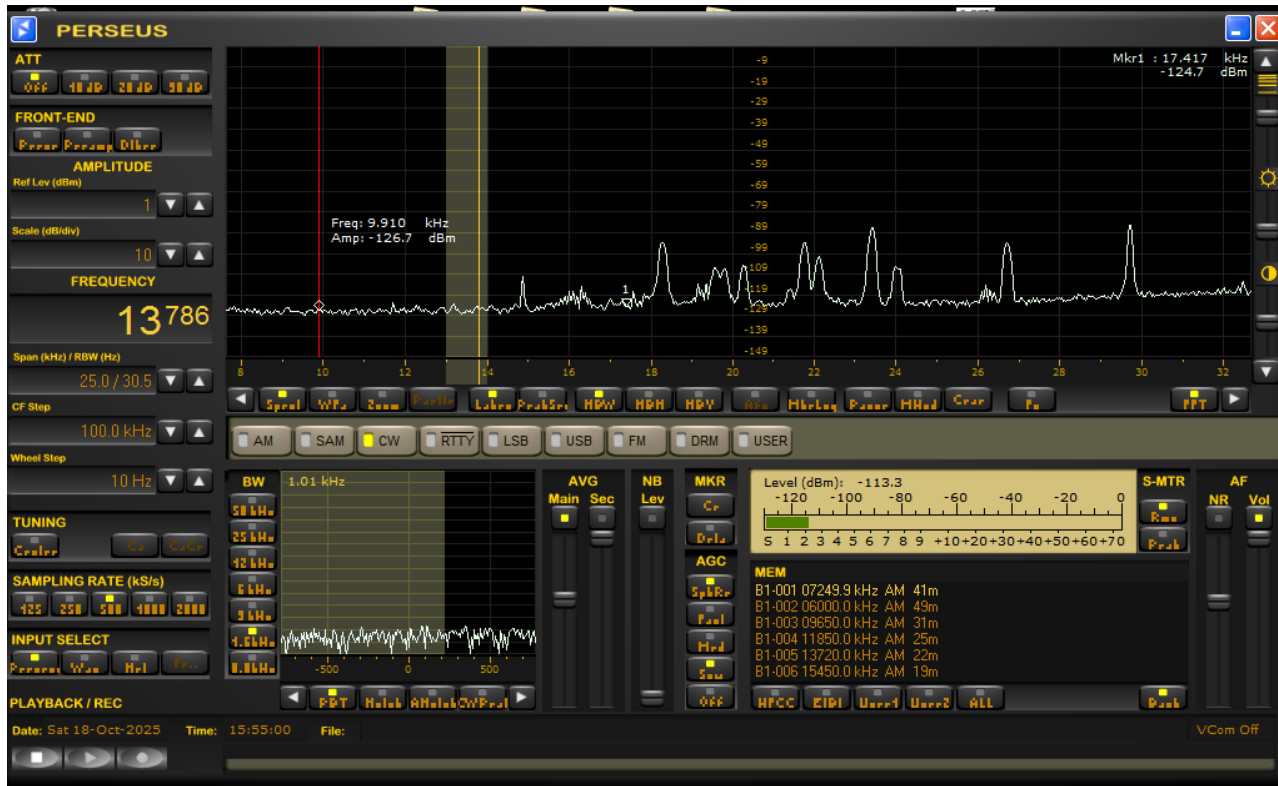


Fig.7 Measured VLF/LF spectrum with AAA-1C active antenna and Perseus SDR. 17:00 local time (14:00 UTC) 18th October 2025. Location is KN12KD. Loop is at NW/SE (315/135 deg. azimuth) direction. Numerous navy digital transmissions are seen and very weak peaks from Russian Alfa station. The ambient noise level at 14 KHz is -113.3 dBm. The peak at 18.3 KHz is from French navy station HWU -87.7 dBm. The peak at 23.4 KHz is from German navy DHO38 -79.8 dBm.

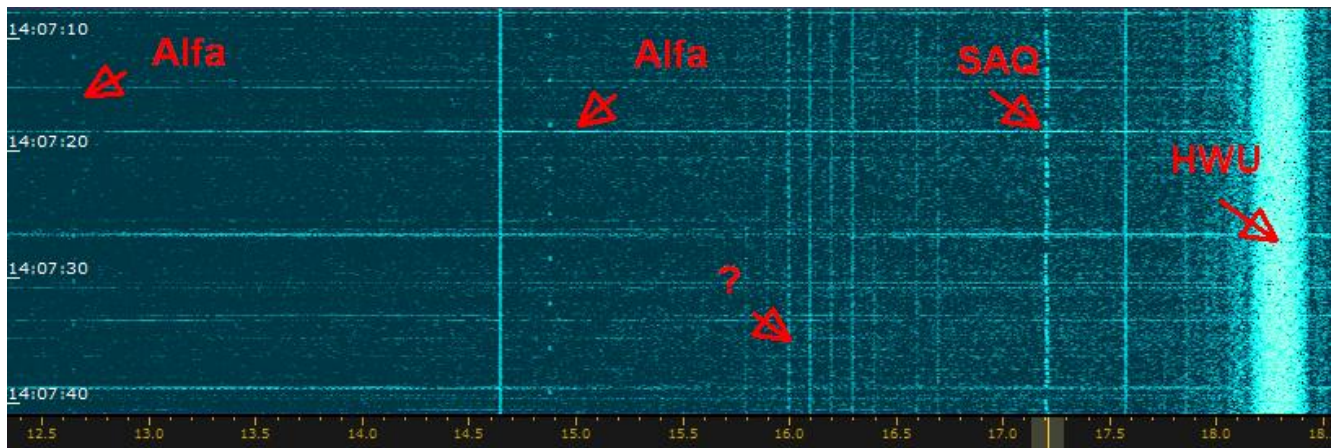


Fig.7 Grimeton Radio Station SAQ CW transmission on 24th October 2025 at 17.2 KHz, starting at 14:00 UTC (17:00 local time) Distance is 2100 Km. ERP 8 KW.

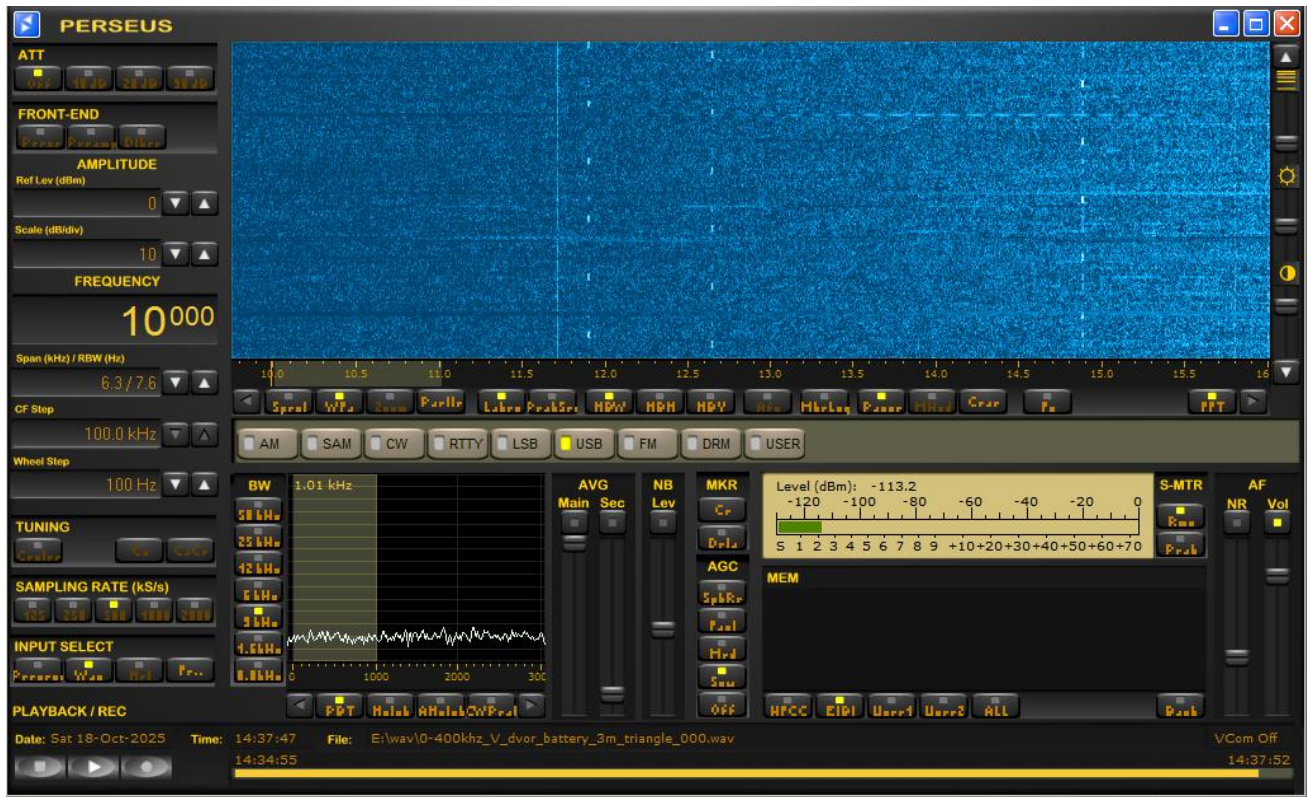


Fig.8 Russian Alfa navigation station reception from 11.9 to 14.9 KHz. The same setup as on Fig.6 but the loop is NE/SW (225/45 deg. azimuth) direction. 3 frequencies are detected. Probably there are several transmitters at different locations on each frequency since there are very slight traces on the same frequencies shifted slightly by time. Output ambient noise level at F=10 KHz is -113.2 dBm and is 5 dB above active antenna noise floor.

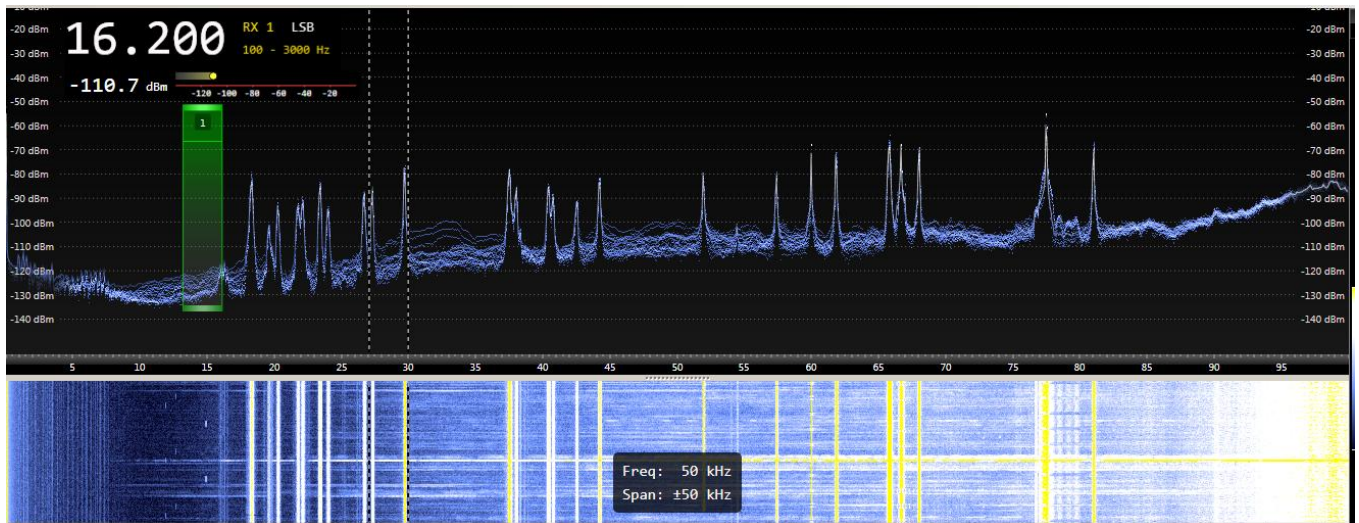


Fig.9 0 to 100 KHz spectrum at 22:00 UTC (01:00 local time) on 19th Oct. 25. Perseus SDR with SDR Console software. The persistent mode in SDR Console is switched on. As can be seen the conditions are not the best. In the zone between 0 and 7 KHz numerous 50 Hz harmonics are seen. Alfa traces are also visible. Above 100 KHz the man made noise at this location becomes very high.

Comments

- AAA-1 can perform satisfactorily at VLF and LF if using a suitable loop.
- Use bigger loop in quiet places. E.g. Loop3 will give good results
- Use RX with low noise floor at VLF and LF. at least -120 dBm (BW 1 KHz) at 10 KHz.
- For Urban and semi-urban locations noise floor probably is much higher than the levels used in this analysis and even Loop1 will do the job. Check the noise floor at 1 KHz BW at 20 KHz with the existing loop. If it is higher at least with 6 dB compared to noise floor of AAA-1 without connected loop then there is no need to make bigger loop.
- At these frequencies M factor does not represent the loop performance. For bigger LF loops a thin wire can be used. There is no need to use copper or aluminum tubes. The inductance and Q-factor are not so important just the area. At 20 KHz 3 m side triangle wire loop has 1.6 ohm impedance and 0.09 ohms loss resistance, The same loop with 14 mm copper tube has $L=8.8 \mu\text{H}$, $X_L = 1.1 \text{ ohms}$, 0.01 ohms Rloss. At 6 ohms load the difference will be less than 1 dB. The spreadsheet at <http://www.lz1aq.signacor.com/docs/w-loop-calc-v12.xls> is used for these calculations.
- Multiple turn loops can be used in order to decrease the physical loop size but not more than 2 or 3 turns. Bear in mind that e.g. 2 turns has twice the area but 4 times the inductance and the HF performance will be reduced substantially.
- Crossed coplanar loops have 6 dB lower gain at LF compared to single loop with the same total area [5].

Links:

1. <http://www.lz1aq.signacor.com/docs/wsmf/wideband-active-sm-loop-antenna.htm>
2. <http://www.lz1aq.signacor.com/docs/experimental-comparison-v10.pdf>
3. <http://www.vlf.it/naturalnoise/naturalnoise.htm>
4. <http://www.lz1aq.signacor.com/docs/w-loop-calc-v12.xls>
5. http://www.lz1aq.signacor.com/docs/loops-in-ndb-band/wideband_loop_ndb_band_11.pdf
6. https://en.wikipedia.org/wiki/Grimeton_Radio_Station