Receiving with wideband small active loops in NDB band (250 to 500 KHz)

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The purpose of this paper is to analyze the possibility to use wideband small loops as a very sensitive sensor which noise floor is limited only by the atmospheric noise in the NDB band (250 – 500 KHz). The reader has to read previous articles about wideband small loops in order to understand their behavior [1],[2],[3],[4].

1. The common base (CB) amplifier has increased noise when the loop impedance becomes small

The common base balanced (CB) amplifier as described in *[1]*, *[6]* is used as a wideband amplifier for small loop antennas. It has a typical output noise spectrum as shown on ***Fig.1*** (yellow curve). It can be seen that there is a substantial increase in noise in the region below 1 MHz where the NDB (Non Directional Beacon) band is. Note that the FET input amplifier for the electric field sensor (small dipole) of AAA-1 has much lower output noise and this phenomena almost does not exists. (AAA-1 has two amplifiers – for small loop and small dipole).

A noise modeling is made with LTspice *[7]* and the output noise plot is given in ***Fig. 2.*** It is computed for different loop inductances. As it can be seen, the noise peak is shifted to lower frequencies when the loop inductance gets higher. The loop impedance acts as a negative feedback for the internal noise source of the emitter-base junction of the input transistors of the amplifier. When the input impedance becomes very low, the gain of the circuit for this internal noise source increases. The measurements of the output noise of the commercial version AAA-1B amplifier *[6]* are shown also and they are with good agreement with the spice model – ***Fig.2***.

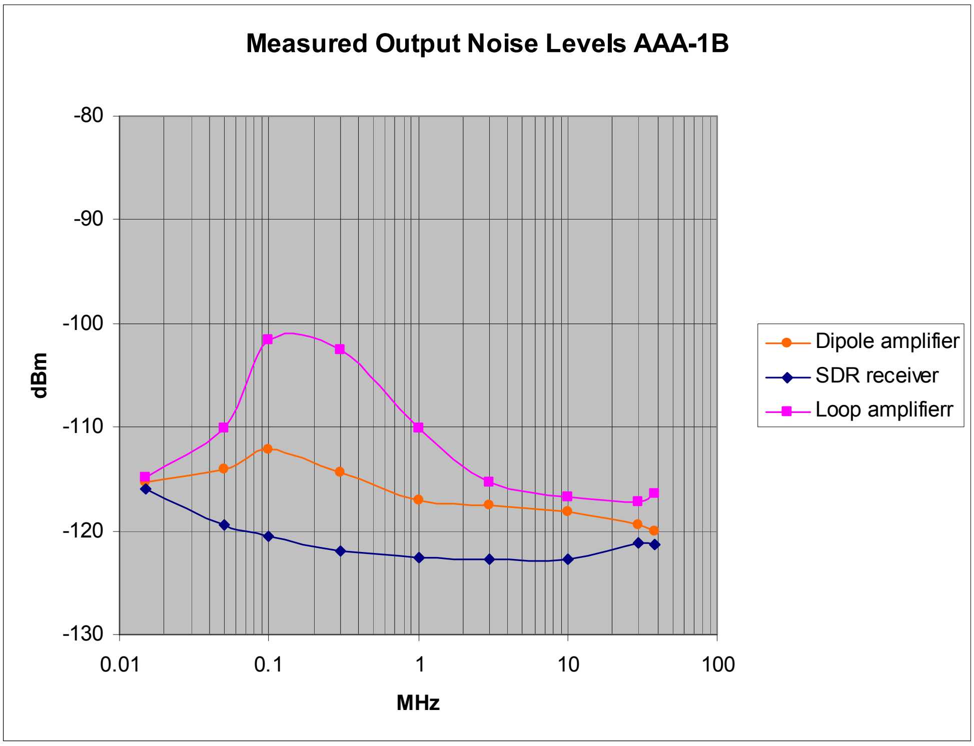

Fig. 1 *Output noise levels of the active antenna amplifier (AAA-1B) measured at 1 KHz bandwidth (BW) without antenna. The loop amplifier is measured with 2.4 uH loop inductance connected to the input. The dipole amplifier is measured with 10 pF equivalent dipole capacitance. The equivalent input noise level of a direct sampling SD receiver is given for comparison. Usually the commercial RX and TRX have similar or lower noise floor. A practical rule is that the receiver noise floor should be at least 6 dB bellow the output noise level of the antenna amplifier.*

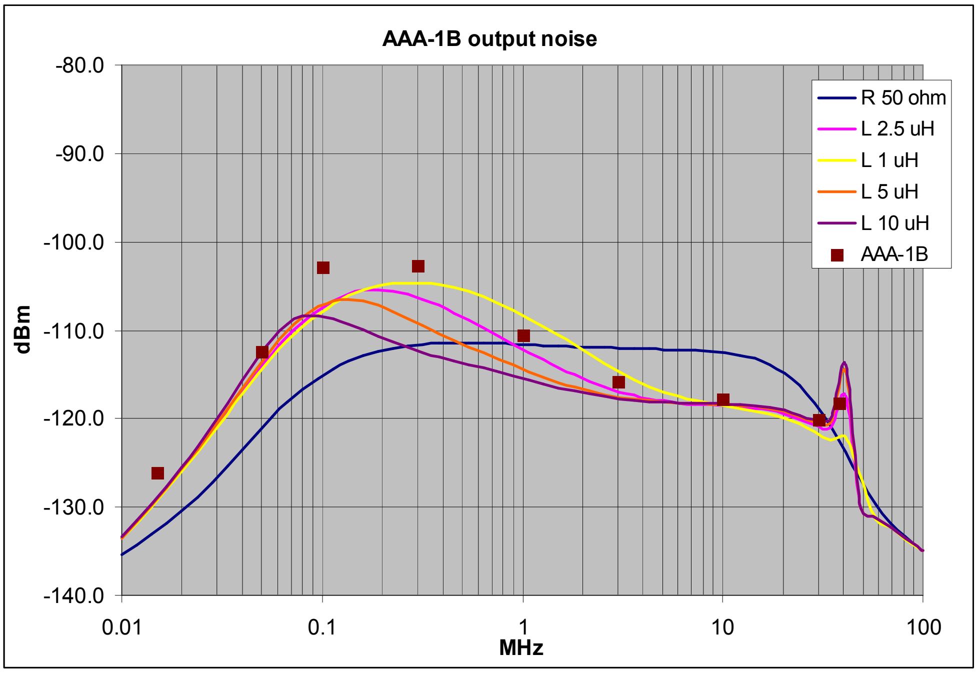

Fig.2 *AAA-1B output noise at 1KHz BW in loop mode. Spice model. The parameter is the input loop inductance. R 50 is when the input is terminated with 50 ohms. The squares are measured values of AAA-1B for 2.5 uH. The peak at 40 MHz region is from the input reject filter for the FM band. The sloping part of the plot in low frequency region is due to frequency response of the output transformer (denoted as L4.L5,L6 in [1]) Note: The output wideband transformer used in the commercial kit AAA-1 is with higher inductance to improve the LF reception - toroidal core with u=4000 and 10 turns trifiliar windings each with L= 180 uH.*

2. Crossed coplanar (CC) loops do not have any advantage to single loop below the cutoff frequency.

If we want to have good sensitivity with wideband loop we should increase the ratio $M = A/L_e$ where A is the loop area and L_e is loop equivalent inductance at the loop terminals *[2], [3]*. *M [uA/pT]* factor is a reliable measure of loop sensitivity to electromagnetic field when loaded with amplifier with low input impedance R_{in}. The wideband loop is working almost in short circuit mode and the less its inductance is the higher will be the loop current. One of the methods to increase this ratio is to use parallel connection of loops, thus increasing the loop area but reducing its inductance. The most effective method is the so called crossed coplanar (CC) loop connection *[2]* , ***Fig.3***.

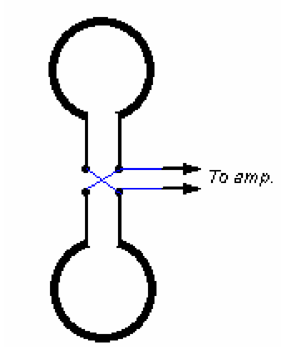

Fig. 3 *Typical parallel connection of two single turn loops in crossed coplanar (CC) scheme to reduce the equivalent inductance. The loops must lie in one plane. The equivalent loop inductance is half of the inductance of single loop and the area is twice larger.*

For wideband loops there is a cutoff frequency f_{low}

$$f_{low} = R_{in} / (2\pi L_e)$$

Below this frequency the loop current will be determined mainly from R_{in} and loop area A rather than from the loop inductance L_e and the frequency response of the loop is no more flat. This does not mean that the loop will not work, only the frequency response will be not flat but with decay of 6 dB/octave. The CC connection of the loops is effective only if the receiving frequency is above f_{low}. Below f_{low} the CC loops give lower current than a single loop with the same area. ***Fig. 4*** shows an example where two CC loops with equal area are compared. The plot of the current ratio between these loops as a function of the frequency is shown on ***Fig.4b*** . Above the f_{low} the CC loops are better performer reaching 3.5 dB higher current. But below this frequency, the single loop becomes superior reaching 6 dB at very low frequencies. The reason is that when the inductive impedance becomes very low, part the current begins to flow between the two CC loops instead to flow into load resistor *R*.

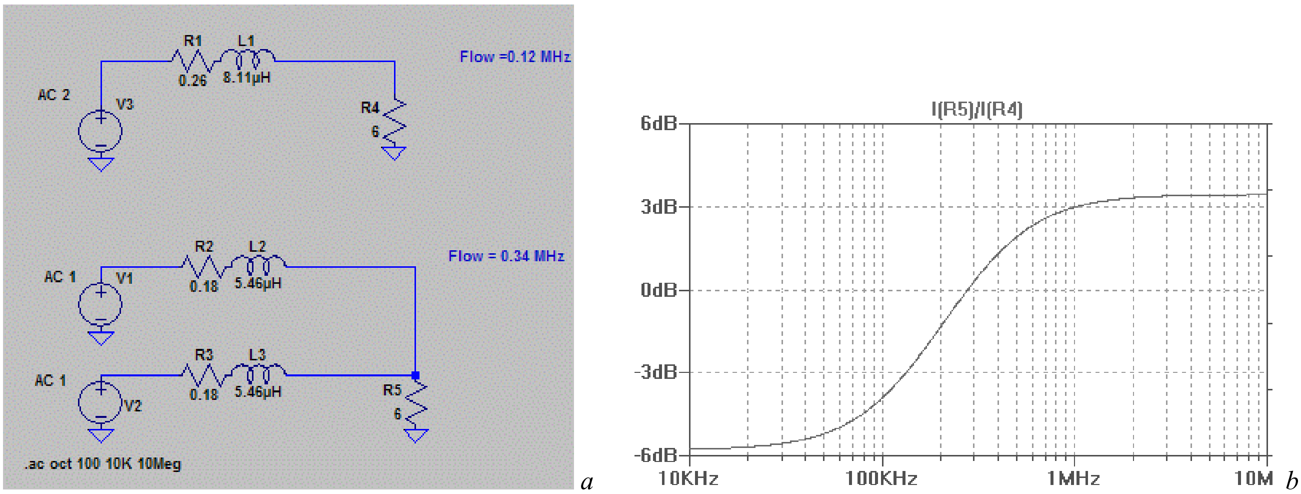

Fig.4 *Spice model of the low frequency response of a single (quad 1.41 m side) and 2 CC (two quads with 1m side) loops with equal total area and wire conductor(Cu, d=1mm). Current ratio at 6 ohms load is shown. This load represents the input impedance of a balanced CB amplifier. Note that the induced voltage V3 is twice the voltage V1 or V2, since its area is two time larger than the area of each CC loop.*

3. Example – CC loop with insufficient impedance at LF region

When using wideband CC loops for the NDB band we must take into account the above mentioned facts.

A practical example: George Muha, N2XM *[9]* has made some experiments with CB amplifier *[1]* and wideband loops including 2 CC loops to receive NDBs in frequency range 200 – 600 KHz. He was unsatisfied with CC loop performance when compared to a single loop. The loops used are as follow:

Ant.1: Single turn loop with 8 ft diameter (2.44 m) and inductance L= 8.6 uH made from alum. tube with 3/8" (9.5 mm) diam. Area is 4.52 m^2 , M = 0.54 uA/pT

Ant.2: Two CC loops each with 4 ft diameter (1.22 m) and inductance of 3.8 uH made from alum. tube with ½" (12.6 mm) diam. Total area is 2.26 m^2 and equivalent inductance of 1.9 uH. M =0.6 uA/pT

Let us compute the loop noise floor at 0.35 MHz frequency at the middle of the NDB band. ***Fig.5*** is the model and ***Fig.6*** shows the results of spice modeling for the loop current. The relative induced voltages from field are 3.3 and 0.8 V and are proportional only to loop areas. The amplifier input impedance is 6 ohms. At high frequencies the loop currents are identical since their M factor is almost the same. But at 0.35 MHz the single 8 uH loop is almost 4 dB better.

Now let us assume the influence of the amplifier noise. According to spice model at 0.35 MHz the output noise level is 1.15 uV @ 1KHz BW for 1.8 uH loop (CC loops). For 8.6 uH loop at 0.35 MHz the noise voltage is 0.56 uV . The difference is 6.3 dB. So at 0.35 MHz the single loop active antenna will have 10.3 dB (4 + 6.3) lower noise floor referred to the amplifier input compared to 2 CC loop, irrespective of the fact that the CC loop has slightly higher M factor. For high frequency region (above 1 MHz) these two loops will have almost identical performance. The CC loops have advantages only for frequencies above f_{low} .

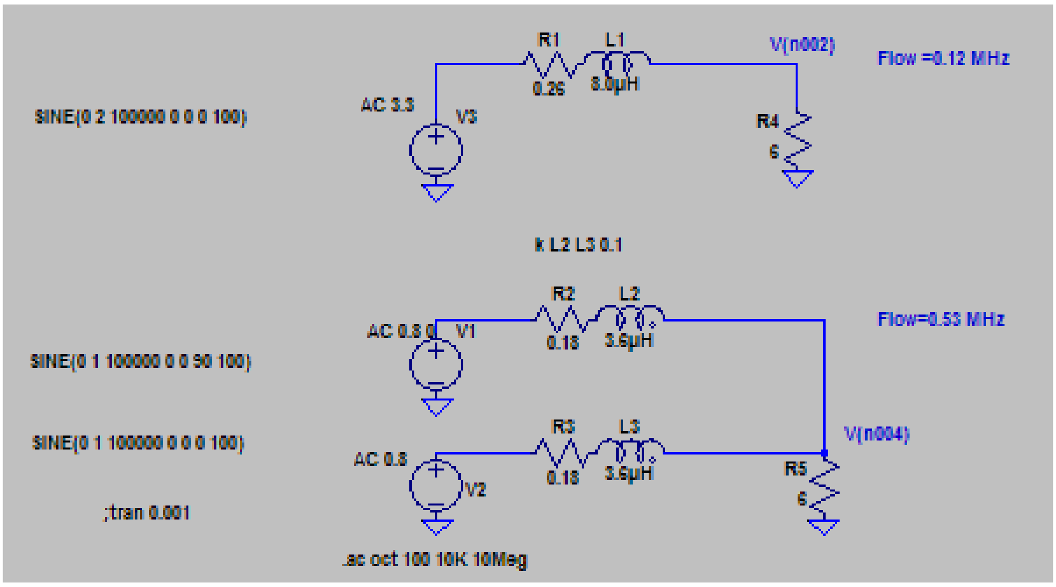

Fig.5 *Spice equivalent circuit*

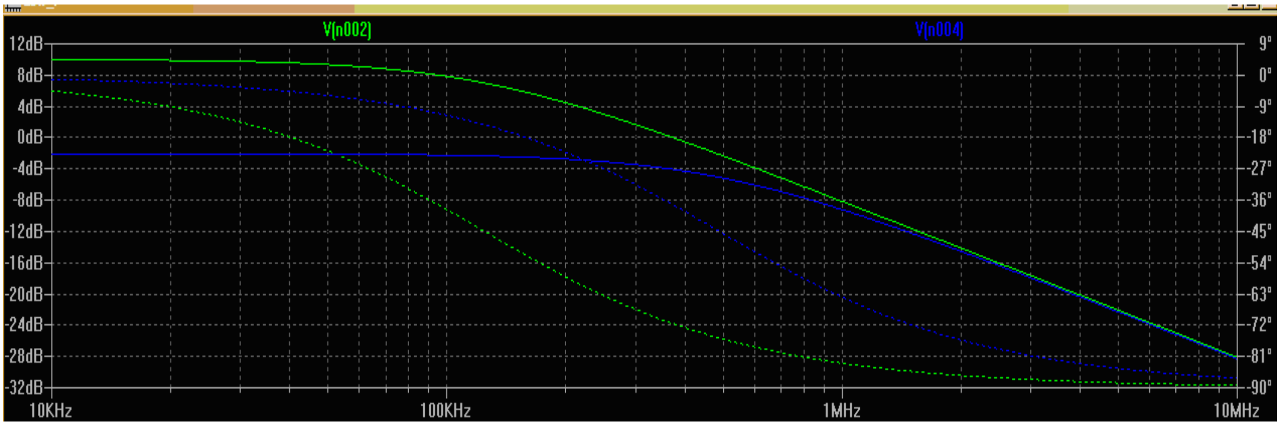

Fig.6

Frequency response of the loop current into 6 ohms load resistor. Green line is for single 8" loop and the blue one is for CC loop.

4. Example of a large CC loop for the NDB band

I am not NDB listener and I do not know what is the usual atmospheric noise floor at these frequencies. Most probably N2XM large 8 ft (2.44 m) diam. single loop will have sufficient sensitivity and larger loop is not needed with this type of amplifier. But as an example I calculated (not yet tested) a simple large 2 CC wire loop which must has theoretically 4.5 dB lower noise floor than N2XM 8 ft loop for the case if AAA-1 *[6]* or similar *[1]* amplifier is used. The loop is shown on ***Fig.7*** and is made from 2 mm diam. copper wire. A single mast can be used (8 to 10 m high). Two quad loops are used as a CC loop each with 3 m side. The single quad loop inductance is 19 uH and the equivalent CC inductance is 9.5 uH ($X_L = 21$ ohms @ *0.35 MHz*, f_{low} *= 100 KHz, M = 0.95* uA/pT). Here the benefit of CC loop connection can be used since the CC loops are with much higher than 6 ohms impedance at these frequencies. This antenna will have a pattern of a small loop to much higher frequencies (up to 30 MHz) compared to a single loop where 0.1 wavelength perimeter is the upper limit *[2]*. Additional orthogonal loop can be mounted on the same mast in order to have two directions. The dynamic range of the amplifier is probably sufficient to stand to the signals induced in such large loop but additional measurements are needed to prove that.

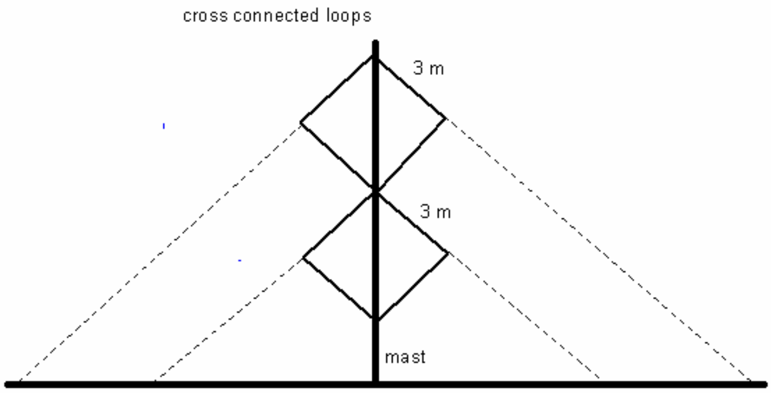

Fig.7 *High sensitivity large CC loop for LF and NDB reception, made with wire on a single mast. The dashed lines are fixing ropes.*

5. Comparing small loop and small vertical dipole in NDB band

Two records were made in the same place and time in the NDB band with Perseus DDC (direct digital conversion) receiver. The location was rural, far from urban places and the power supply was from batteries. There were no nearby noise sources at least to 3 km distance. This location might be assumed as electromagnetically extremely quiet. AAA-1 amplifier was used in loop (***Fig.8***) and dipole mode (***Fig.9***).

The small loop antenna consists of two circular loops with 0.7 m diam. in CC connection exactly as described in *Fig.3.6, Fig.3.7* of Antenna part of Technical manual of AAA-1 *[6]*. The measured inductance of each loop is 2.2 uH and the CC impedance is 1.1 uH. (*M=0.38 uA/pT* , f_{low} *= 0.96 MHz*). The dipole antenna consists of these same loops acting as arms of a vertical dipole making a "fat" dipole with two arms of 0.7 m. (this mode is possible with AAA-1 amplifier when *J1a* and *J1b* are in *ON* positions).

The noise floor (output noise) of this setup, without antenna but with substitute inductance, is approximately -101 dBm @ 1KHz BW of the loop amplifier and -113 dBm for the dipole amplifier as shown on ***Fig.3*** *[6]* .

The measured S/N ratio of the dipole mode is better with 4 to 5 dB compared to loop mode (***Fig.8,9)***. Note that in the loop mode, the band noise is -101.2 dBm at 1 KHz BW (on Perseus S-meter) which is almost equal to the amplifier output noise with substitute inductance at the input. The band noise for the dipole mode is -104.9 dBm which is much higher than the output noise of the dipole amplifier (with substitute 15 pF capacitance at the input) which is -113 dBm. Obviously the reception in loop mode is limited by the internal noise of the amplifier. The reception with the dipole is limited only by the atmospheric noise even for this very short dipole.

These two CC loops are small for this frequency. Larger loops are needed with better *M* factor *[3]* and lower f_{low}. The limitations are from the weak loop current and also from increased amplifier noise due to low impedance of the loops at these frequencies (2 ohms at 0.3 MHz).

This comparison between electric and magnetic sensors was made in extremely quiet electromagnetic environment. In urban conditions it is very difficult to make the electric dipole mode so quiet. The conducted noise coming through the cable is the main source *[8]* and it is very difficult to be removed without good RF ground. In urban conditions the loop mode usually gives better S/N ratios.

6. Conclusions

- If an amplifier described in *[1], [6]]* is used for NDB and we need higher sensitivity, the loop size and inductance must be larger (6 – 10 uH) in order to avoid the above mentioned noise effect. *The* *impedance of the CC loops must be higher than input impedance of the amplifier at the lowest frequency of interest in order to use the CC loop advantages.* If this requirement is not fulfilled, a single loop with the same total area will give better results.

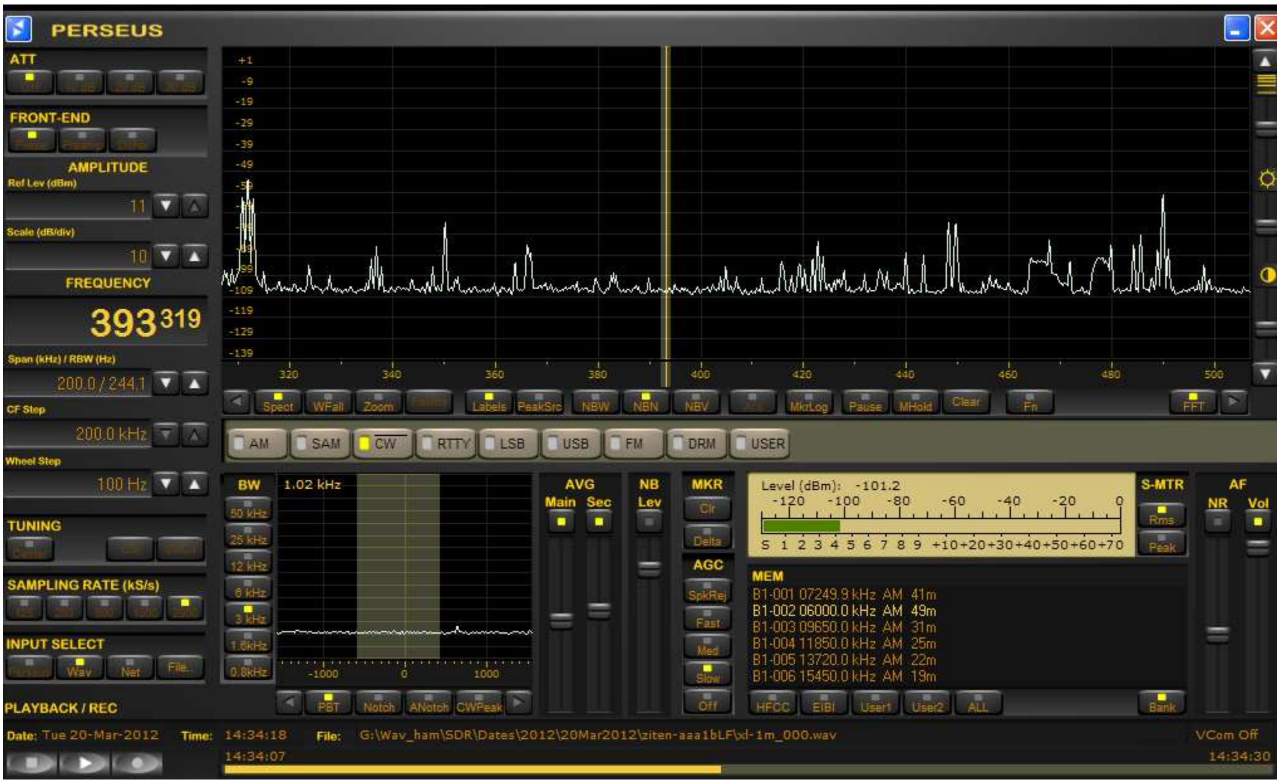

Fig.8 *NDB band record with 2 CC loop antenna*

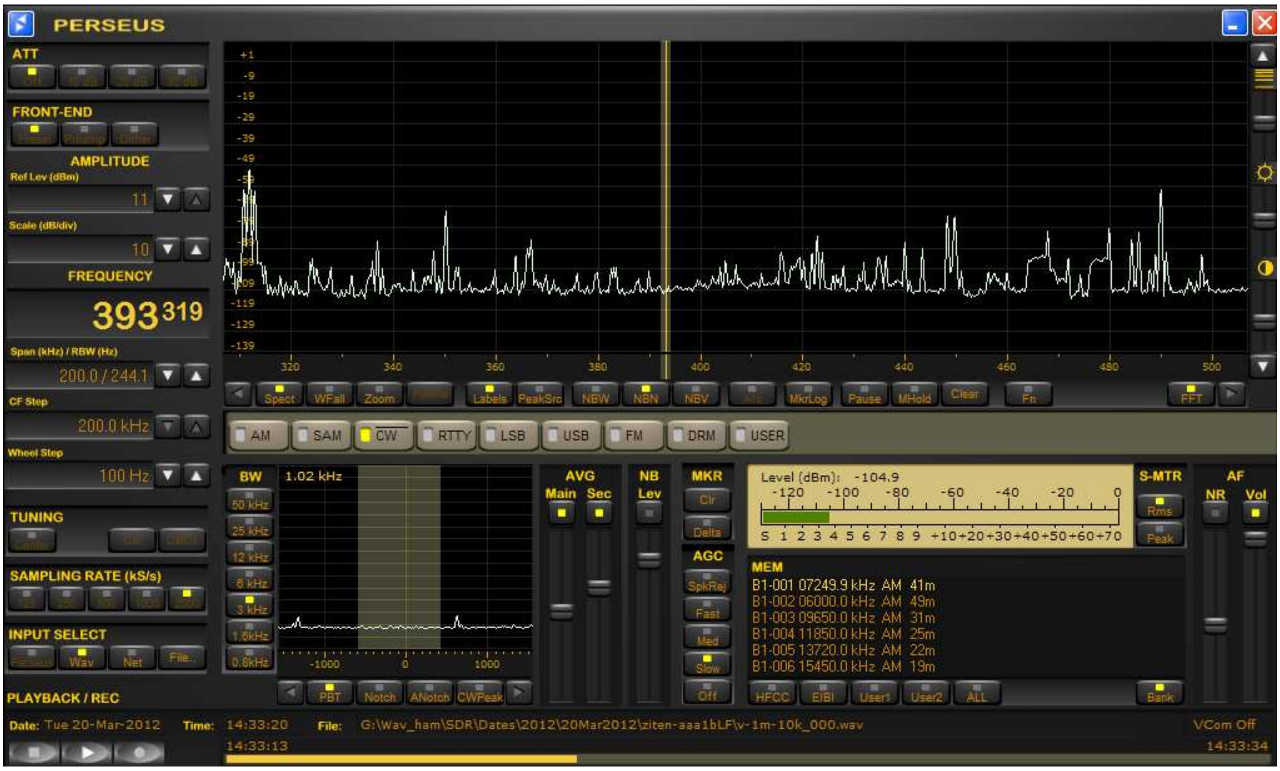

Fig.9 *NDB band record with small vertical dipole antenna*

- Big CC loops can be used, but a knowledge of the local atmospheric noise floor is needed in order not to oversize the loop. It might happen that modestly sized loops will have acceptable noise floor for specific locations. My 2 CC loop (each loop with 0,96 m diam. *L= 1.4 uH*, *M=0.53*, f_{low} *= 0.71 MHz AAA-1B amp.*) has noise floor almost 10 dB down from the usual local (atmospheric and man made) noise level so for me there is no reason to build bigger loop.
- There is a simple test which must be performed by every serious NDB listener. Measure the output noise floor of your amplifier as a function of frequency by substituting the loop inductance with inductance with the same value. Then connect the loop to the amplifier input and measure again the band noise level (at the same bandwidth!). If the increase is above 6 dB we can assume that the loop sensitivity is sufficient. This experiment is not so easy to be made because the measurements of the amplifier noise floor must be performed without any external noise contribution. The substituting inductance must be wound on toroidal core not to pick up any external noise. DDC SDR radios must be used for receiver. They have stable and flat frequency response in the region of interest and the software permits to set the measurement bandwidth precisely. Most reliable results will be if the whole setup is powered with batteries (including the notebook) and performed at a place where there are no electromagnetic noise sources (e.g. outside the house). Save the amplifier noise floor plot as a reference and then you can measure at any time the atmospheric noise and to know whether your antenna system is limited by the internal noise floor or only by the atmospheric noise. (users of AAA-1 can use the noise plot given on ***Fig.1)*** .

Using wideband loops for low frequency range is a bit of challenge. Careful planning is needed. One of the problems is fundamental – the induced loop voltage linearly decreases with frequency. Compare it with a voltage sensor (small dipole or whip), where the induced voltage does not depend on frequency. This is the main reason why it is much easier to achieve good results in LF region with FET voltage amplifier and short whip. But the loops have one important advantage – for these frequencies where vertical polarization is prevailing, the loops have good directivity which can not be reached with omnidirectional voltage sensor.

Sofia, March 2015

Links

[1] Levkov.Ch. LZ1AQ, *Very Weak Signal Reception with Small Magnetic Loop Antenna,* 2010
http://www.lz1aq.signacor.com/docs/fa-eng/Weak_signals-mag_loop_engl.htm

[2] Levkov.Ch. LZ1AQ, *Wideband Active Small Magnetic Loop Antenna,* 2011
http://www.lz1aq.signacor.com/docs/wsml/wideband-active-sm-loop-antenna.htm

[3] Levkov.Ch. LZ1AQ, *Experimental Comparison of Small Wideband Magnetic Loops,* 2013
http://www.lz1aq.signacor.com/docs/experimental-comparison-v10.pdf

[4] Levkov.Ch. LZ1AQ, *Receiving Phased Array with Small Electric or Magnetic Active Wideband Elements. Experimental Performance Evaluation.* 2013
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[5] Spreadsheet to Calculate the Parameters of Small RX Loop. 2012
http://www.lz1aq.signacor.com/docs/w-loop-calc-v10.xls

[6] Active Antenna Kit Technical Documentation.
http://www.active-antenna.eu , http://active-antenna.eu/amplifier-kit/technical-documentation/
http://active-antenna.eu/tech-docs/1_ActiveAA_DandS_20.pdf
http://active-antenna.eu/tech-docs/2_ActiveAA_Mount_20.pdf
http://active-antenna.eu/tech-docs/4_ActiveAA_QA_21.pdf
http://www.active-antenna.eu/tech-docs/3_ActiveAA_Antena_11.pdf

[7] LTspice http://www.linear.com/designtools/software/

[8] Levkov.Ch. LZ1AQ, *Reducing the Noise in Dipole Mode with Common Mode Filter.* 2014
http://active-antenna.eu/tech-docs/comm-filter-ftp-10.pdf

[9] George Muha, N2XM. *Personal communication*. 2015

Revision History

1.2 May 2015, Fig.1 was for AAA-1; models AAA-1Band C have lower noise levels.

Rev.1.2