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Loop Antenna Sensitivity

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How can one estimate the sensitivity of a loop antenna? And how sensitive should a loop antenna be for state of the art performance in the MW band? The purpose of this note is to discuss these two questions.

Ideally, the best way to estimate the sensitivity of a loop antenna is to measure it. But that requires a shielded room and calibrated test equipment which are beyond the means of most hobbyists. Fortunately, in his article "Ferromagnetic Loop Aerials For Kilometric Waves," Wireless Engineer, Feb. 1955, pages 41-46, J. S. Belrose derived some formulas which can be used to make quite accurate estimates of loop antenna sensitivity. He showed that the signal to noise ratio of a tuned loop is given by

$$\text{Signal/Noise} = \frac{66.3\ NA\,\mu\text{rod}}{\sqrt{\Delta f}}\sqrt{\frac{Qf}{L}}\ E$$

where N is the number of turns of the loop coil, A is the area in square meters enclosed by one turn of the loop coil, μrod is the rod permeability (see Belrose's article for a graph for converting the initial permeability μ to rod permeability μrod), Δf is the bandwidth in Hertz seen at the detector of the receiver, L is the inductance in Henrys of the loop coil, and E is the field strength in volts per meter of the received signal. For an air core loop, μ rod = 1. In Belrose's article it was pointed out that the noise which limits the sensitivity of a loop antenna is thermal noise due to the resistive component of the loop antenna impedance. We will call this noise loop coil noise.

The noise floor of a loop antenna is defined as the voltage equal to a field strength which produces a signal to noise ratio of 1. The noise floor of a loop antenna is the voltage equal to the loop coil noise. Solving the previous equation with Signal/Noise = 1 we get the following.

$$\text{Noise Floor} = \frac{1}{66.3\ NA\ \mu\text{rod}}\sqrt{\frac{\Delta fL}{Qf}}\ \text{volts}$$

The variables in the above equation are dependent on each other to some extent, but for the sake of discussion let us assume that L = 154 μH (so that a 660 pF capacitor tunes the loop to 500 KHz), that Δf = 2 KHz (which is about the minimum useable bandwidth), that Q = 100 (a not unreasonable value for a loaded loop coil), and that f = 1 MHz. For these assumptions we get the following.

$$\text{Noise Floor} = \frac{0.837}{NA\ \mu\text{rod}} \times 10^{-6}\ \text{volts}$$

With the assumptions above, a 2 foot square air core loop has 14 turns, a 1 foot square air core loop has 22 turns, a 6 inch square air core loop has 36 turns, and a Space Magnet rod (12" long by 9/16" diameter, μ = 400) has 30 turns. The air core loops have μrod = 1, while the Space Magnet rod has μrod = 150. We can also convert to other bandwidths by multiplying by the square root of one half the bandwidth in KHz. Thus we get the following.

Air Core And Ferrite Rod Loop Noise Floors

	2 KHz BW	4 KHz BW	8 KHz BW
2 foot	0.14 μV	0.20 μV	0.28 μV
1 foot	0.34 μV	0.48 μV	0.68 μV
6 inch	0.83 μV	1.2 μV	1.7 μV
Space Mag.	0.79 μV	1.1 μV	1.6 μV

So what do these numbers mean? Can you hear anything on a 1 foot air core loop that you can't hear on a Space Magnet? Can you hear anything on a 2 foot air core loop that you can't hear on a 1 foot air core loop? It all depends on the kind of signal you want to hear and the minimum man-made and power line noise at your location. As I have said in previous articles, if you live in a large urban area, I doubt that you will ever hear anything on a 1 or 2 foot air core loop antenna which you cannot hear equally well on a Space Magnet or similar ferrite rod loop antenna. Incidentally, I have wound coils on all kinds of ferrite rods, bundled, not overlapped, overlapped, close wound, spaced over the entire length of the rod, you name it ... I've tried them all. As long as you use at least 4 rods of μ = 125 bundled and overlapped, or at least 7 rods bundled and not overlapped, the noise floors are all virtually identical. Also, based on listening tests, the noise floor of a 6 inch loop is virtually identical with the noise floor of a Space Magnet, which agrees with the numbers in the table above. Ralph currently uses 10" ferrite rods made by gluing together 10 ferrite cylinders of μ = 125 which are 1" long by 1/2" diameter. The noise floor of his ferrite rod loops is identical to the Space Magnet based on my listening tests (this is the Great Little Loop sold by Radio West). So my following remarks about the Space Magnet apply to any well designed ferrite rod loop and to the 6 inch air core loop.

As I have remarked in previous articles, I am fortunate to live in a small town where ambient man-made and power line noise occasionally fall to very low levels. On those occasions (and only on those occasions) I can hear a very definite difference between the Space Magnet and a 1 foot air core loop. On a few weak daytime signals the 1 foot air core loop (and of course the 2 foot air core loop) will produce clear audio when the Space Magnet produces no audio at all. The amps of my loops have been equalized so that the output signal levels of all of my loops are virtually identical. Consequently, I have concluded that this difference between the 1 foot air core loop and the Space Magnet is due to the lower noise floor of the 1 foot loop.

About once a year the daytime noise levels at my location (Ruston, LA) drop to super low levels. On these occasions I can often hear WOAI San Antonio on 1200 KHz fading in and out of the noise while the R-390A meter sits solidly on 0. Yesterday was such a day, and provided me with a rare opportunity to try to hear a difference between the 1 foot air core loop and the 2 foot air core loop. (My ferrite rod loops and 6 inch air core loop were producing no audio at all from WOAI, just thermal noise from the loop coils.) Maybe I wanted to hear a difference, but it did seem like I could follow WOAI deeper into the ambient noise with the 2 foot loop than with the 1 foot loop. And it did seem that WOAI was clearer on the 2 foot loop than on the 1 foot loop when WOAI was in the clear above the background noise. However, there was no dramatic difference between the 1 foot and 2 foot loop like there is between the 1 foot (or 2 foot) loop and the Space Magnet.

When signal levels are much higher, such as when DXing domestic channels or foreign splits at night, there is no difference between what you can hear with the various loops. However, there are some situations where a 1 foot air core loop might produce clear audio when a ferrite rod loop does not. Unfortunately, I am not in a position to compare loops for most of those situations. A few times a year I can hear Dakar Senegal on 765 at local sunset when noise levels are low and adjacent channel signal levels are low. I have always used a 2 foot air core loop for those receptions, but I expect a 1 foot air core loop would be equally good, while a ferrite rod loop would not. ECNA DXers often report TA reception just before and at local sunset. I expect that a 1 or 2 foot air core loop would be better than a ferrite rod loop in that situation if ambient noise is low. WCNA DXers often report TP reception at and just after sunrise. Again, I expect that a 1 or 2 foot air core loop would be better if ambient noise is low.

For these reasons, I have developed a 1 foot air core loop and companion two FET amp which is not much larger than a Space Magnet or Great Little Loop, but which has a demonstrably better noise floor. This loop will be described in a future article.