A small LF loop antenna

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This paper describes a loop antenna for receiving purposes in the frequency range 10 kHz to 150 kHz; with reduced performance it can be used up to 600 kHz. The antenna is mainly intended for quick direction finding of unidentified utility radio stations. The prototype was built for indoor use. This is possible because it picks up much less noise from the mains than wire antennas, which are most often useless indoors, in particular at frequencies below 50 kHz.

Design considerations

Receiving antennas can be characterised by their “effective height” h_{eff}. The output voltage U for an electrical field strength E is then given by

$$U = h_{eff} \cdot E$$

The effective height of a loop antenna is

$$h_{eff} = \frac{2\pi n A E \cos\varphi}{\lambda},$$

where n is the number of turns, A is the loop area, λ is the wavelength, and φ is the angle between loop plane and transmitter. As we see, the loop’s output voltage is inverse proportional to λ, or proportional to the frequency f.

Actually the loop senses the magnetic field, not the electrical field. But in the far field of a transmitting antenna (a condition that is usually met), electric and magnetic field vector are simply related by a factor. This is the reason why the output voltage can be expressed in terms of the *electrical* field strength E.

At 30 kHz, the effective height of a single turn loop of 1 m diameter is only 0.5 mm. This is very small compared to an E-field antenna of similar size: The theoretical value for a 1 m vertical rod over a conducting surface is h_{eff} = 0.5 m. So why not increase the number of turns to, say, 1000? Unfortunately the more turns, the larger the inductance L and hence the larger the inductive reactance $X = 2\pi f L$ in series with the “generator “voltage U. In multi-turn loops, L increases by a factor of about $n^{1.8}$. Furthermore, the inductance and the loop’s stray capacitance form a resonant circuit, which may limit the usable frequency range.

On the other hand, if the loop is connected to an amplifier with a very low input impedance, the inductance can be used to compensate for the U ~ f property. Please refer to [1] for a thorough discussion of this approach. If the amplifier’s input resistance is less than the inductive reactance at the lowest frequency of interest, the output voltage is independent of frequency. The low resistance also damps the stray parallel resonance to Q << 1. Due to the (almost) shortened loop inductance, this kind of antenna is completely insensitive to the E-field.

The loop shown in figure 1 has an inductance of 1.2 mH; its resonance frequency is about 350 kHz. At 10 kHz, the reactance is 75 ohms. With an amplifier input resistance between 30 and 100 ohms, however, the sensitivity was found to be insufficient for frequencies above 70 kHz, compared to my other active antennas, a Rhode & Steward HE-011, and a Wellbrook ALA1530 loop. For this reason, a slightly different design was chosen: Instead of using a “zero input impedance” amplifier, the loop is terminated by a load of a few kohms (the observed gain lack was not caused by the amplifier; the circuit used in the first tests had a flat frequency response up to well beyond 500 kHz).

Figure 1. The prototype loop has 40 turns and a diameter of about 38 cm.

Circuit description

There is nothing special with the amplifier shown in figure 2. With the load resistance R1 = 2.2 kΩ, the Q factor of the loop’s inherent parallel resonance still fairly below 1, hence the resonance does not cause problems. The feedback circuit of R5, R6 and C3 makes the signal loss at low frequencies less severe. Since the antenna was intended for radio monitoring rather than for precise measurements, no further effort was taken to obtain a flat frequency response. Resistor R7 in series with the amplifier output ensures stability when using a long cable.

The circuit is powered remotely through the antenna cable. The splitter made of L1 and C7 can be used, but other power supplies for active antennas might do as well. I use the 24 V supply for the R&S HE-011. A clean supply voltage is mandatory. Switching regulators (e.g. tapping the PC power supply) will usually cause problems, but linear power supplies can also be noisy. Integrated regulators like the LM317 or the 78xx series need a large capacitor of 1000 µF or more at the *input* terminal to reduce the noise in the LF and VLF range, in parallel to the common 100 nF.

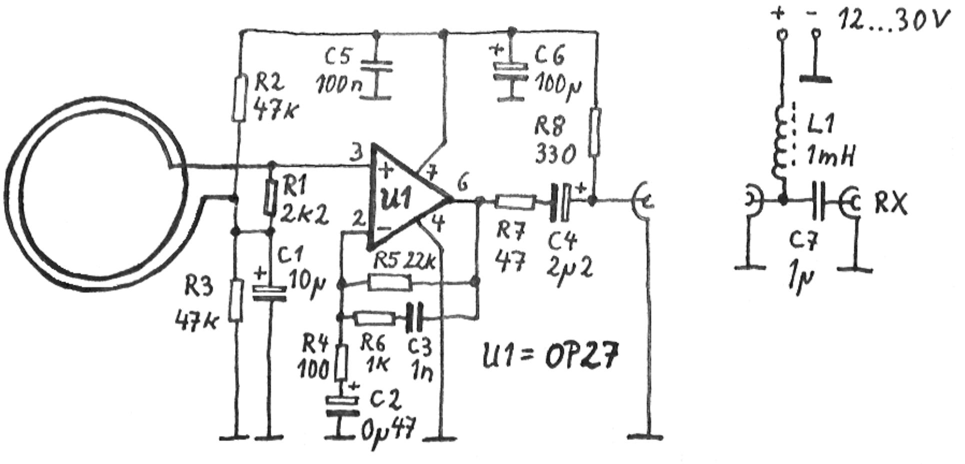

Figure 2. Circuit diagram of the loop amplifier

Construction

As can be seen from the quick-and-dirty prototype in figure 1, the construction can be kept very simple. The loop has a diameter of about 38 cm and 40 turns, which needed a little less than 50 metres of wire. Neither the diameter, nor the number of turns nor the exact shape are critical. The loop is easier to wind on some kind of bobbin, a box for example. You can bend the antenna into a circular shape afterwards. I used 1.5 mm² “electrician’s wire” (diameter including insulation 2.7 mm, core diameter 1.4 mm). Thinner wire is ok; with a 0.5 mm wire, the inductance will increase by less than 20 percent and the resistance still does not matter. With thick wire, however, the antenna can be built without a supporting structure; the loop in fig. 1 is held together simply by cable binders.

The amplifier was built in a conventional technique (with old-fashioned components that still have wires…) on a small piece of strip-line Veroboard material (figure 3). An OP27 was chosen for U1 “because it was there”. Other types like LT1028, or so-called audio op-amps like LM833 (a dual op-amp) will probably also work. Anyhow, everything said here should be taken as ideas for own experiments rather than as a bullet-proof recipe; the whole thing can still be optimised.

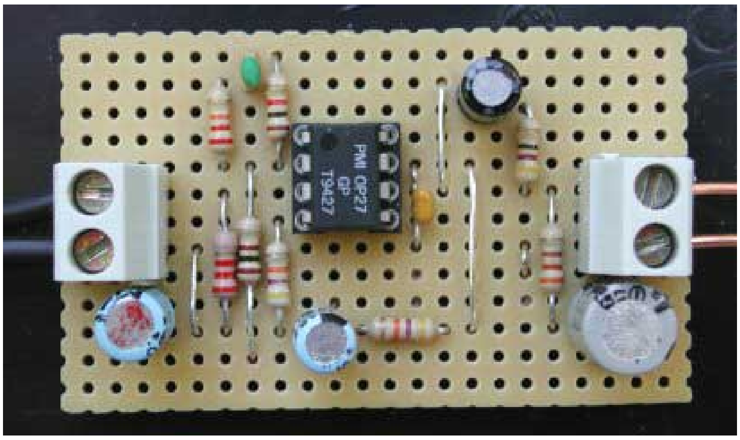

Figure 3. The amplifier circuit

Practical experiences

The results with this antenna of course strongly depend on the local noise floor. While writing this, I can hear Alpha navaid stations [2] Krasnodar and Novosibirsk on 14.88 kHz, with the loop two arm lengths away from the computer. When the PC is off, the beeps are audible on the other two Alpha frequencies 11.9 and 12.65 kHz as well.

Below about 250 kHz, the antenna has very sharp bearing minima. You can at least distinguish whether a station is located in direction NW or in NNW (or in the opposite directions of course, as bearings with loops are ambiguous). A precise direction calibration down to the one degree level is pointless, not only due to the semi-rigid construction, but also due to the portable character of the antenna, since the deviation strongly depends on the environment.

As a consequence of the non-zero termination resistance, the loop is a bit sensitive to electrical field components and to capacitive coupling at higher frequencies, and above 250 kHz, the antenna slightly “squints”. That is, bearing is still possible, but the angle between the two minima is not exactly 180°, and the antenna should be rotated without grasping the loop itself. Below about 100 kHz, however, the loop is completely insensitive to touching.

References

[1] Marco Bruno, IK0ODO: *Thinking about Ideal Loops*. February 2001. Available at www.vlf.it.

[2] Trond Jacobsen: *The Russian VLF Navaid System Alpha, RSDN-20*. July 2000. Available at www.vlf.it.

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