Design Notes

Active antennas

These are small receive-only antennas used from very low frequencies (ULF) up to HF. The most popular type consists of a small probe or whip connected to a high impedance buffer amplifier that, as it responds primarily to the electric field of a radio wave, is popularly referred to as an E-field probe. In the modern suburban environment a lot of the locally generated noise tends to be predominantly electric fields, thus E-probes are particularly vulnerable to this sort of pickup. Considerable care needs to be taken over grounding and elimination of common-mode coupling if these antennas are to perform well. A comprehensive overview of E-field antennas appeared in the July 2012 Design Notes.

An alternative active antenna is the broadband loop, or 'mag loop', which responds primarily to the magnetic field part of a radio wave. Locally generated and conducted interference is rarely magnetic in nature, so a wideband loop should have appreciably lower noise pickup than an E-probe receive antenna.

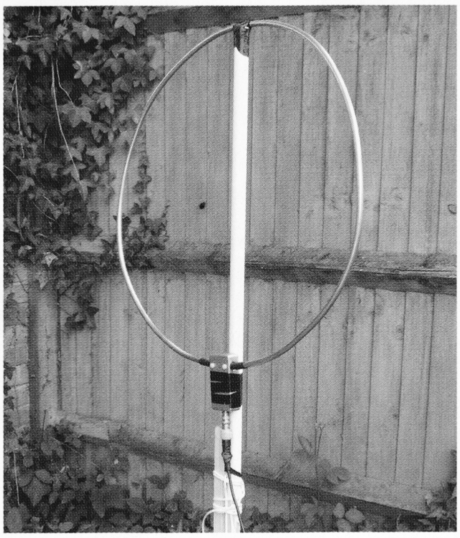

PHOTO 1: **Broadband active loop antenna, useful from 400kHz to 30MHz.**

Broadband loops

Whereas the E-probe presents a high capacitive impedance and needs a hi-Z amplifier with low input capacitance for maximum signal transfer from probe to amplifier, a small loop presents a very low and inductive impedance. The radiation resistance of a small loop is proportional to the square of the loop's area and also to the square of the frequency. At low frequencies the radiation resistance is swamped by the loss resistance of the loop, but as frequency rises the increasing inductive reactance then dominates the total impedance. At very low frequencies, therefore, the small loop will have a considerable inherent loss; just as does a small active probe at low frequencies. But this doesn't matter too much – if we use a decent low noise amplifier the background noise, at its highest at the bottom end of the RF spectrum (and even when natural and non-man-made) should dominate over the noise due to antenna loss and amplifier noise figure.

Faraday's Law gives the voltage output that will be obtained for a single turn loop of a given area, in free space, perpendicular to a magnetic field, as: $V_{RMS} = 2.\pi.A.F.H_{RMS}.\mu_0$
where A is the loop area, F is frequency, H is the field strength of the magnetic component of the RF signal in amps per metre [1] and μ_0 is the permittivity of free space, $4\pi * 10^{-7}$.

There are two ways to terminate a loop antenna. One is to connect the two ends of the loop to a high input impedance differential amplifier. Doing this, the output voltage of the loop will be unattenuated by the amplifier input impedance and given accurately by the equation above. The voltage for a given field strength rises proportional to frequency, so the loop is insensitive at the low end and over-sensitive at the top end of the spectrum. This rising frequency response is generally not at all helpful or wanted.

The alternative is to terminate the loop into an amplifier with a very low input impedance – as low as possible. Now, to see what we get to feed into the amplifier, we need to take into account all the series loss resistance terms and the reactance of the inductive component of the loop. If we can ensure the inductive reactance is significantly higher than the sum of all the resistive terms, we get a very convenient flattening of the frequency response. It works like this: as the frequency rises the voltage output of the loop rises proportionately. But the reactance of the loop's inductance, $X_L = 2.\pi F.L$ also rises with frequency. So if we ignore the real resistive terms for now, the current being fed into the amplifier is given by $I_{LOOP} = V_{LOOP} / X_L$. As both these terms are proportional to frequency, the current delivered into the amplifier for a constant field no longer depends on frequency as the terms on top and bottom of the equation cancel. At some low frequency the resistive loss terms do become significant as X_L has dropped sufficiently, so sensitivity starts to roll off. But for practical dimensions the flat response can be made to cover a wide band. A worked example illustrates things.

Assume a one metre diameter loop made from 15mm diameter copper tube. Feed this into an amplifier with an input impedance of 4Ω. From the spreadsheet at [2] this loop has an inductance of 2.7μH. At 3.5MHz that means a reactance of 59Ω, with a loss resistance of around 0.03Ω. At 137kHz the loss resistance is 0.006Ω, with 2.3Ω reactance. At 25MHz there's still a mere 0.09Ω loss and 422Ω reactive impedance. In all cases the amplifier's 4Ω completely dominates the loss resistance. Reactance becomes numerically equal to this at a frequency of around 236kHz, giving 3dB additional loss. We consider this to be the lower cut-off. Above this frequency, up to some upper limit determined by amplifier capability and also when the loop circumference becomes a significant part (say 10%) of a wavelength, the output from the amplifier will be essentially independent of

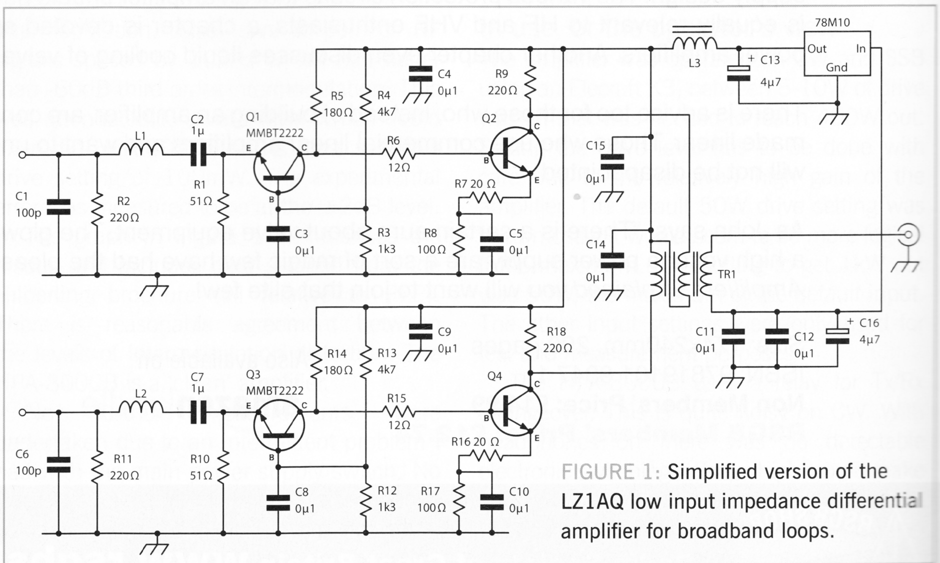

FIGURE 1: **Simplified version of the LZ1AQ low input impedance differential amplifier for broadband loops.**

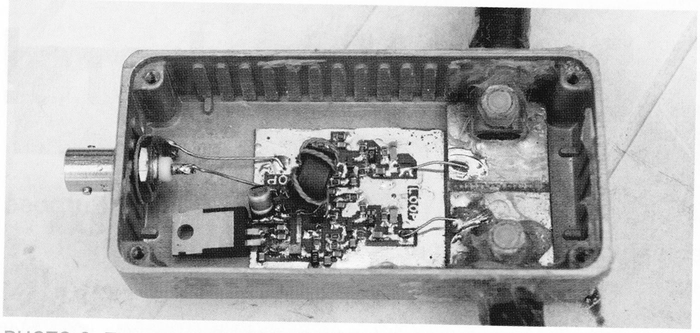

PHOTO 2: The amplifier PCB and loop termination. Waterproofing and insulation is by heatshrink tubing and silicone compound.

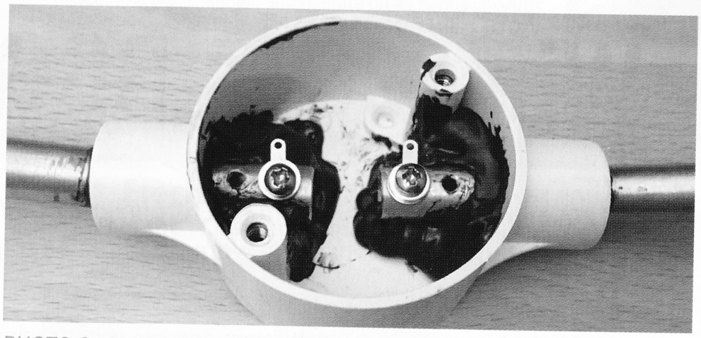

PHOTO 3: Alternative loop termination using a plastic conduit box.

frequency. Even below this lower cut-off the loop will still be useful, as real background noise is high down there and the reducing sensitivity still allows useful reception. So we now have a broadband active receive antenna that is substantially flat from LF to the middle of the HF band. It is clear that for maximum sensitivity we want as large a loop as is practical as V_{LOOP} increases faster with frequency than does the corresponding increase in X_L. But we also want to minimise the inductance to get the highest current into the amplifier. Inductance drops when the conductor diameter is increased. So the golden rule, for maximum sensitivity at the low end of the spectrum, is a large diameter loop with a large diameter conductor. For low HF operation up to, say, 10MHz (λ=30m), the loop diameter should be not much more than 1m. Note also that the loop is directional, with maximum pickup in the plane of the loop and a null broadside on. It has the same radiation pattern as a dipole except that polarisation is vertical.

Amplifiers

For a low input impedance two types of amplifier technology are available. The opamp virtual earth arrangement has a theoretically zero input impedance due to its 100% negative feedback. However, opamps are tricky to use at high frequencies, can have stability issues and are often quite expensive devices. We won't consider them here (although they are frequently used for loops specifically for ultra-LF to LF receiving). The other contender is a bipolar transistor operated in common base (CB). A bipolar in CB with a few tens of mA collector current will have an input resistance of a couple of ohms. In fact, if the internal bond wires of the transistor were lossless, the CB input resistance is given by $1 / 40.I_C$, where I_C is the collector current in amps. So 25mA gives 1Ω. In practice, the bond wire resistance increases this. (As a complete aside, look what happens to the CB input impedance when $I_C = 500\mu A$).

One important area is balance. If the two ends of the loop each terminate in a different impedance to earth when they enter the amplifier (such as a single-ended CB stage) then the whole loop will have a component that acts as a single vertical probe antenna – it will be unbalanced. This will undo all the good work of making it respond only to H fields. So a differential amplifier is essential, with equal impedance to ground on each side so common mode E-field pickup is cancelled.

A practical amplifier design

Chavdar Levkov, LZ1AQ has done a fair amount of work on loops and amplifiers **[3]** and has come up with a good, repeatable design for a balanced amplifier for broadband magnetic receiving loop antennas in the 0.6 to 1m diameter range. Two identical common base stages feed into common emitter gain blocks. After combining their outputs with 180° phase shift, the result is a differential amplifier, minimising common mode pickup. The outputs from the two identical stages are combined in a centre tapped transmission-line transformer and the input impedance between the two emitters is around 4Ω. **Figure 1** shows a slightly simplified version of LZ1AQ's design, built onto the PCB shown in **Photo 2**. The capacitors and inductor on the input are a low pass filter to prevent overload from strong 88 – 108MHz broadcast signals.

The Itchen Valley Amateur Radio Club has taken this on as a club project and a proper silk-screened and solder resist coated PCB is to be developed and kits of parts provided. As well as providing an amplifier for members' loops, the PCB will also serve as an introduction to and practice in SMT construction techniques. DC is fed to the amplifier through the coax via a DC bias tee at the shack end, which will also be part of the project.

Photos 1 and **2** show my first version of a 0.6m diameter loop using 10mm copper tube. **Photo 3** shows how Glyn, M0XGT has waterproofed the loop ends of his breadboard as they enter a plastic conduit box. By some pure fluke (and a failure of Murphy's Law), my PCB fits perfectly into his box!

Toroidal cores

The toroidal output transformer is important for combining the output from each side of the two identical front end amplifiers. It is a transmission line (TL) design making use of a trifilar winding; two of the conductors forming the centre tapped primary, the third wire the secondary. A TL transformer is not dependent on the characteristics of the core material as the tight winding of the twisted wires gives the signal coupling. The purpose of the ferrite core is merely to give enough impedance between the two ends of each winding to make them independent by having a very high resulting shunt reactance. For applications like this, the best core material is one designed for low frequency use as it has the highest specific inductance. Switch mode PSU designs have made a huge range of ferrite cores available to us. Paul, M1CNK identified a suitable 10mm diameter core made from N30 material **[4]**. Tests using a few turns of bifilar winding as a 1:1 50Ω transformer suggested a TL design that is essentially flat and substantially lossless over at least 400kHz to several tens of MHz. The lower frequency limit is set by the number of turns sufficient to give enough inductance to decouple the ends from each other. The upper limit is where the length of wire is no longer 'short' when compared with a wavelength.

One club member expressed reservations about passing DC through the secondary winding – which is needed in the circuit shown to extract the DC supply from the coax. He wondered about saturation of the core and any resulting non-linearity. A few experiments on a test transformer suggested there was a small amount of degradation and the inductance changed, but at a level that would almost certainly go unnoticed for practical purposes at the 120mA supply current here. But this clearly could be an issue for more critical applications and needs some evaluation.

Websearch

[1] RF field strengths are more usually specified in terms of their electric component E, in V/m. For a radiative wave this is directly related, via Ohms law, to the magnetic field H via the impedance of free space, 120.π, or about 377Ω. So H = E / 377. In the 'near field', typical of local QRM situations, this relationship does not hold.

[2] www.g4jnt.com/DownLoad/Magloop.xls

[3] tinyurl.com/DN-12-17-B or www.lz1aq.signacor.com/docs/wsml/wideband-active-sm-loop-antenna.htm

[4] tinyurl.com/DN-12-17-B or http://uk.farnell.com/epcos/b64290l38x830/ferrite-core-toroid-n30/dp/1422735

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