VLF through the ground experiments

Use the ground as your VLF aerial – for surprisingly good results

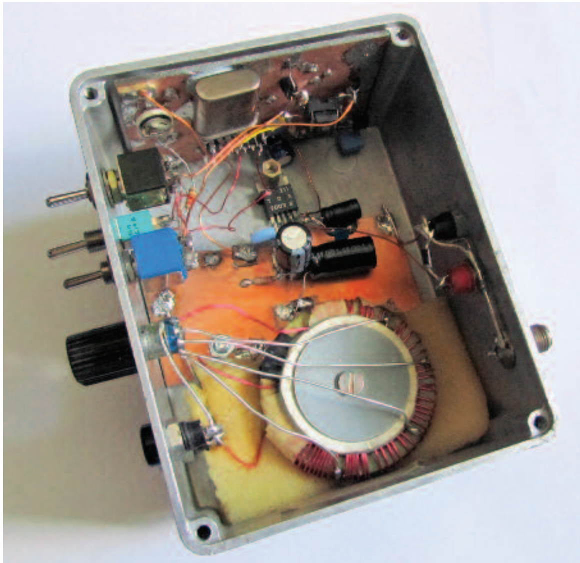


PHOTO 1: The completed VLF beacon test transmitter, capable of about 5W output.

INTRODUCTION. Recent experiments by 8.7-9.1kHz NoV holders in the UK and VLF amateur stations in Europe have focussed on radiating signals and detecting them at great distance. This inevitably requires a lot of RF power, very large transmitting antennas, huge loading coils and frequency precision. Results obtained in the last two years have exceeded all expectations, with the best radiated DX being in excess of 2700km. Nearly every month new stations appear and new records are set. A successful transatlantic amateur test around 8.97kHz is possible soon.

The work involved in engineering such a *radiating* VLF system puts most people off, but another VLF technique – earth mode – is easy to try, because it does not involve high power, big antennas and the like. The equipment required is small, inexpensive and easily built by almost anyone: this is audio frequency radio engineering, not microwaves.

EARTH MODE. Earth mode (through the ground) communication is nothing new and dates back to the early experiments of Samuel Morse in the 1840s and trench warfare in World War 1. Variations of it are in widespread use today in caving communication and mine rescue.

The basic principle is simple and shown in **Figure 1**. A VLF current is injected into the ground between two earth electrodes (A-B), setting up a current flow in the soil, water or rock. Although most of the current flows in the ground directly between the two electrodes, some current will spread out over much longer paths setting up a (weak) potential gradient between another pair of electrodes (C-D) placed in the ground some distance away. If the receiving electrodes are connected to a small preamp and a pair of headphones or computer, the signal can be detected. Attenuation rates are high (inverse cube attenuation, compared to inverse square for free space radiation), so the signal at any significant distance may be very weak indeed and buried in noise.

The earth electrode 'antenna' (the interconnecting wire and the return path within the ground) may also be considered as a loop antenna, in that part of the loop is formed by the return path in the ground. When the soil conductivity is low the return path will 'spread out' more and the effective loop area will be greater. At the remote (receiving) end, the signal can be detected using a suitably oriented loop antenna, usually placed flat on the ground. The signal may also be detected with a small E-field probe held near to the ground.

Lower frequencies propagate further through the ground with less attenuation, so signals around 1kHz are likely to be clearer than signals at 8kHz at any reasonable distance. This is not always the case though, as interference can be stronger at lower frequencies.

The sub-9kHz spectrum can be *extremely* noisy, with 50Hz (or 60Hz) mains power line emissions and their harmonics being strong to many kilohertz. With sensitive equipment the 60Hz mains network in the USA can even be detected in Europe. Other sources of VLF man-made noise include switch-mode power supplies, heavy electrical equipment, railway electronics and similar. In addition, there can be a high level of natural noise associated with lightning activity and other naturally-occurring electromagnetic phenomena.

All this noise may drown out any attempt to receive weak VLF earth mode signals unless high power is used and the receiving station is close to the transmitter. Nonetheless, people have used a few watts from an audio amplifier to cover short distances using speech.

Intrigued by the possibilities of earth mode communication, a series of experiments were carried out to see just how far such a system could cover. What follows is a summary of these tests so far. There are a lot of unknowns still to be investigated.

TRANSMITTER AND TRANSMIT 'ANTENNA'. To test the range of a simple earth mode system, a small ULF/VLF transmitter was built. This consists of a TDA2003 (replacement for the TDA2002) 5W audio amplifier IC with a keyed VLF frequency source. To generate a very stable signal source an HF crystal was divided down using a 4060 oscillator-divider IC, in much the same way used to generate a 1750Hz toneburst. Using this method, a number of stable ULF/VLF frequencies can be derived by selecting the division ratio with a switch. A beacon keyer IC programmed to send either 10wpm CW, QRSS3 or QRSS30 slow CW is used to key the VLF signal source. This was obtained from the K1EL website but there are many PIC based alternatives that would be suitable. Test frequencies used were 8.760kHz and 1.095kHz. Initially, 0.838kHz was used; this was generated by the sidetone output from the K1EL keyer, but this is unsuitable when long duration stable carriers are required. **Figure 2** shows the complete transmitter circuit diagram, designed to run from a 13.8V (nominal) lead-acid battery.

Layout is not critical. The prototype was built 'dead bug' style and housed in a small diecast box (**Photo 1**) together with a simple matching circuit consisting of an ex-PMR toroidal transformer that allows the very low output impedance of the TDA2003 to be matched to resistive loads of between 10 and 160Ω. A transformer using 3C90 core material is likely to be suitable. This allows

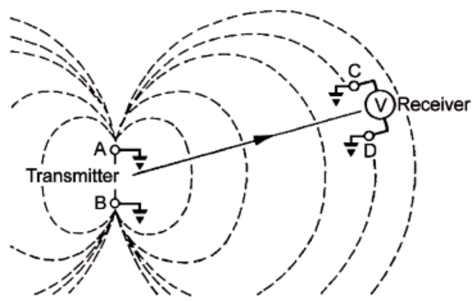


FIGURE 1: The basic principle of earth-mode communications. A VLF current injected A-B spreads out and can be detected, weakly, at another pair of points, eg C-D.

most earth electrode "antenna" systems to be matched as there is little reactive component at VLF. Tune-up is done by adjusting the match for maximum current in the 1ohm resistor in the output circuit. Although the box runs quite hot after a few minutes of transmission (especially if the system is set to send a continuous carrier), the drift is only around 0.1Hz worst case. This could be reduced considerably by separating the crystal oscillator from the PA thermally – for example putting it in a separate box that is thermally insulated. Better still, the signal could be derived from a GPS locked source or similar.

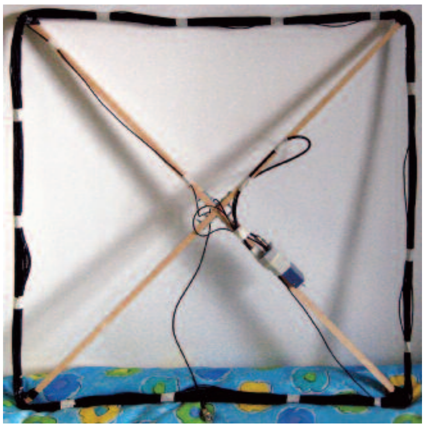


PHOTO 2: 30 turn loop receiving antenna with attached preamplifier.

For the transmit 'antenna', a 1m long copper rod was inserted into the soil at the far end of the garden and a wire brought from this into the shack, around 20m away. Another earth connection was made to the metal central heating radiator pipes. Although the pipes make their way into the road, the mains water pipes are not metal. However, this does make a very effective second ground point.

RECEIVING 'ANTENNA' AND PREAMP. No special VLF up-converters or exotic receivers are required, as all the signal processing and analysis is done with a Windows PC using freely available software. You just need some form of antenna and preamplifier to feed your laptop's sound card input.

Four different portable receiving 'antennas' have been tested:

- an earth electrode pair with a separation of around 10m (Figure 1)
- an E-field probe
- a single turn loop laid on the ground covering an area of around 8-10 sq metres
- an 80cm square 30 turn loop resonated to the test frequency (**Photo 2**).

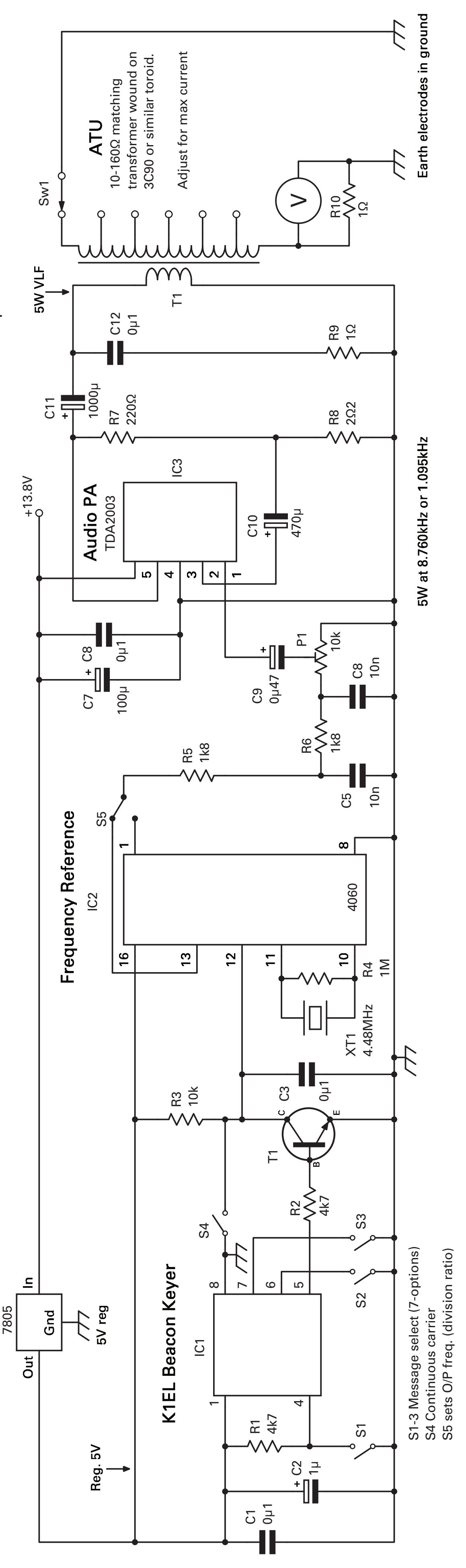
A couple of small preamps have been tried. Both use an MPF102 FET with a tuned drain circuit feeding an emitter follower. One was configured as an E-field probe with a high input impedance and the other (**Figure 3**) as a grounded gate low impedance amplifier suitable for use with an earth electrode pair. The loop antennas could be configured for use with both types of preamp by tuning the loop as a parallel tuned circuit (high impedance) or series tuned circuit (low impedance). The preamp is far from optimised, but it does work. **Photo 3** shows my dead-bug prototype, powered by a PP3 battery.

PC SOFTWARE. The two software packages I used are *Spectran* and *Spectrum Laboratory*. *Spectran* is very easy to use and can 'look' at VLF signals in bandwidths down to 0.18Hz. It provides a display showing the VLF spectrum and, if you are successful, weak earth mode signals.

Spectrum Laboratory (SL) is an altogether more powerful, but more complex, package and this allows receiver bandwidths down to a few micro-Hertz if required. Another useful feature of *SL* is the ability to lock the system to a VLF MSK signal or to a GPS reference allowing the sound card frequency to be corrected automatically. This gives incredible frequency accuracy and stability allowing one to look in extremely narrow bandwidths for long periods of time. *SL* can also be used to generate stable carriers for QRSS or DFCW tests. Using *SL* with the antennas and preamps mentioned earlier it has been possible to copy VLF amateur stations from across Europe testing around 8.970kHz, even though their ERPs are in the low milliwatt region. Antenna positioning to minimise noise pickup can be critical though.

EARTH MODE RANGES. Initial tests were within a few hundred metres of the home QTH near Newmarket. The beacon was set running and I ventured out into the fields behind my house looking for the signal using a handheld loop antenna, preamp and a pair of headphones. Using the 5W transmitter at 838Hz, the best range possible was 500m. Using a laptop PC with Spectran, this range

FIGURE 2: The complete VLF earth mode beacon transmitter.



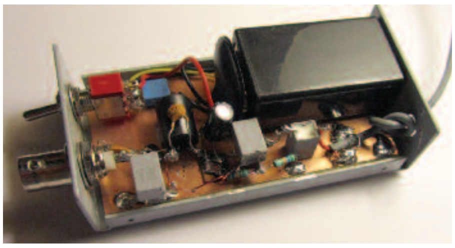


PHOTO 3: Prototype preamplifier.

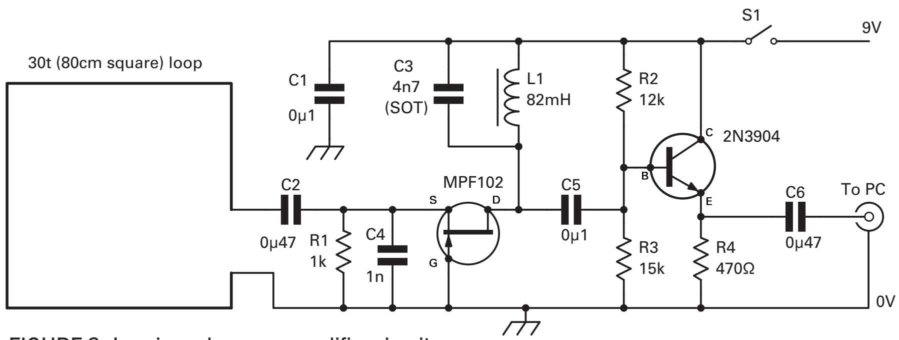


FIGURE 3: Low impedance preamplifier circuit, suitable for earth electrodes or a series tuned loop input.

was gradually increased in a number of directions both on the chalk uplands to the south of the QTH and into the peat-soil fens to the north and west. Initially ranges of 1-2km were covered but eventually 5.6km was achieved in QRSS3. A great time was had last summer going out in the car to find places where the signal could and could not be copied.

The most recent test used QRSS30 (30 second dot period CW) or a continuous carrier (briefly interrupted to confirm identification) at 8.7605kHz with Spectrum Lab software in its frequency locked mode at the receiver. Signals have now been detected at 10dB S/N in an 11mHz bandwidth at a range of exactly 6km using a small earth electrode receiving antenna. The signal was also detected using a single turn loop on the ground, but was somewhat weaker. This is definitely not the maximum DX possible with the current system.

UTILITIES ASSISTANCE? Unless one lives on a remote moor or island with no mains water or buried pipes and cables for miles around, it is very likely that the propagation of an earth mode signal is affected by the presence of the network of buried metalwork that criss-crosses the landscape. Initially I believed my signals were propagating with the aid of buried metal water pipes. Some weeks ago the water company did some repairs and I discovered that my local water pipes are not metal, nor do they contain 'tracer' cables. Any 'utilities assistance' is hard to quantify but signals at any distance are stronger close to roads. Certainly earth mode works without buried pipes, but the presence of buried metalwork does influence results.

FURTHER WORK. In recent VLF radiated tests, receive bandwidths as low as 42µHz were used with transmissions consisting of a steady carrier on a very accurately known frequency for hours or days. One can only guess the possible earth mode range with 100-200W of long, highly stable transmissions, much larger transmitter earth electrode spacing and better optimised receiving systems . With such a system a small but significant *radiated* signal may also be created as well as the earth mode through-ground signal, so the ultimate earth mode range may be hard to determine accurately. DK7FC/P has achieved a range of just less than 50km using a 600m baseline earth electrode antenna and a few hundred watts, but this was because some of his signal was being radiated.

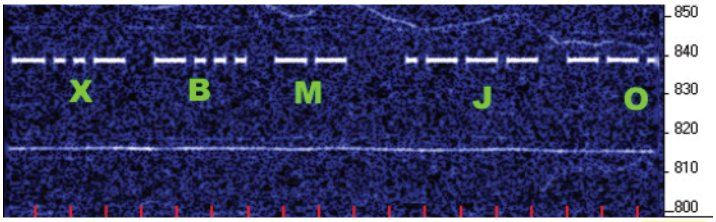


FIGURE 4: Typical result, received 2.5km from the 4W earth mode Tx. SNR > 30dB in QRSS3 with signal audible in Spectran's BPF in circuit.

On one occasion my best results were obtained with one receiving electrode placed in a fenland water drainage ditch. Upcoming tests are planned along fenland rivers and at the seaside with one TX electrode in the water and one on the land – with a similar set-up at the receiving end further along the coast.

Another recent test was 8.760kHz WSPR. G6ALB, located 3km to the west of me, transmitted around 40W into earth electrodes and his VLF WSPR signal was copied very well using just a small handheld E-field probe feeding an up-converter in my upstairs shack. The S/N suggested just a few watts would have been sufficient. This mode has a great potential for VLF earth mode tests.

Tests at greater range require the assistance of more suitably equipped receiving stations. Care is needed to minimise noise pickup and the laptop PC needs to be frequency locked so that very narrow bandwidths can be used for long periods of time. A number of VLF 'grabbers' (stations relaying their VLF screenshots to the internet in real time) active within, say, a 20km range of a given earth mode beacon would be helpful to check coverage.

Incidentally, all the antennas, preamps and weak signal techniques used for earth mode tests are equally applicable to radiated DX tests at VLF. Indeed 5 European amateur VLF stations have so far been copied around 8.97kHz at G3XBM using the receiving kit described, with best DX over 1000km. G3XIZ and DK7FC/P have even been copied around 8.97kHz when using my transmitting earth electrode system as the antenna.

LICENSING. As a result of recent correspondence with Ofcom it appears they have no interest in earth mode from a licensing perspective – as long as the tests cause no 'Undue Interference'. My understanding – note this is *not* a legal statement – is that an NoV is *not* required for VLF earth mode tests *as long as no significant signal is radiated* and no Undue Interference is caused. When asked in writing to confirm this as a correct understanding, the Ofcom official declined to comment further... The energy actually *radiated* by a low power earth mode station is unlikely to exceed a few picowatts, ie an extremely small amount, but it is worth keeping a log of transmissions so any potential interference can be checked.

MORE INFORMATION. Any audio power amplifier could be used for the transmitter and there are numerous 100-200W amplifiers available ready built from a number of sources. 5W TDA2003 ICs are available cheaply from many internet sources. The Sub-9kHz website has a lot more information about the tests carried out so far as well as lots of information about ongoing radiated experiments at VLF.

As mentioned earlier, to receive amateur VLF signals does not require large antennas or complex equipment and more participants in both earth mode and radiated DX experiments would be welcomed by the VLF amateur community. Worthwhile experiments are possible with very simple equipment at ULF/VLF, especially using earth mode. I hope this article has shown that low cost experimental amateur radio is still alive and well.

WEBSEARCH

Sub-9kHz website:
https://sites.google.com/site/sub9khz/home

Software for VLF reception:
https://sites.google.com/site/sub9khz/software

Sub-9kHz Yahoo group:
http://tech.groups.yahoo.com/group/sub9khz/