Long-Range Cave Radio

__Ian Drummond__, VE6IXD, and __Ken Smith__, VE6AGR, have achieved a range of several kilometres using sensitive receiving methods to receive the far magnetic field, as distinct from near-field components.

Ian Drummond - "... the antenna is radiating 0.4 microwatts into the far field."
"Really small, but not zero." - **Brian Pease**

Cave radio communication devices commonly have a range of a few hundred metres, to achieve a range of 1 km has been considered outstanding. This article describes how a range of several kilometres over the surface has been achieved using small, portable, low-power devices. The basis for this increase in range is the use of sensitive receiving methods that detect the radiated magnetic field, as distinct from the near-field components.

Loop Antenna Magnetic Field

The loop antennas used with cave radios are physically and electrically small. Often 1 m square and driven with 5 W of RF power, the loop creates a magnetic field. The shape of the magnetic field, even in free space, is complex. Up to a distance of (one wavelength/2π), called the near-field, the shape of the field resembles the classic bar magnet shape with the maximum field strength along the axis of the loop. The strength of the field declines as the inverse cube of the distance from the loop and therefore the power of the field declines as the inverse sixth power. The energy in the near-field magnetic field returns to the antenna in each cycle of the RF current in the loop, being stored in the tuning capacitors before rebuilding the field in the next cycle.

Less well known is the shape of the field beyond one wavelength from the loop, the far-field of the antenna. The maximum strength of the far-field is in the plane of the loop, it declines as the inverse of the distance from the loop and therefore the power of the field declines as the inverse square law. The energy in the magnetic field at this distance from the loop does not return to the antenna, but is part of a radiating or propagating electromagnetic (EM) wave.

The far-field pattern is often ignored because small loop antennas are very inefficient at creating a far-field EM wave. For example, the 1 m square loop mentioned above is radiating less than one microwatt of RF power, out of the total 5 W delivered to the loop antenna.

What if We Could Detect Far-field Magnetic Fields?

If a cave radio device has a range of perhaps 200 m at an operating frequency of 137 kHz (2200 m wavelength), it is very difficult to increase the range by increasing the strength of the transmitter. The radio is operating in the near-field of the antenna and to double the range would require an increase in power by a factor of 64, given the inverse sixth power relationship. Not surprisingly, many attempts to increase range have focused on improving the antenna, by increasing its size or by earth injection. However, the nature of the near-field still makes any increase in range very hard won.

If a cave radio device were to operate at a range of two kilometres, at an operating frequency of 137 kHz, it is operating in the far-field, and now doubling the range requires only four times the power! An extra 2 km of range for less effort.

Increasing Range

The secret to making cave radios that work in the far-field turns out to be the use of digital modulation methods, combined with very careful receiver design. Elsewhere in this issue (Drummond,2023) there is a description of how a commercially available amateur radio transceiver was modified to operate on the amateur 2200 m band. These devices have been used with demodulation methods that allow messages to pass with signal-to-noise ratios as much as 30 dB lower than required for a single-sideband voice channel.

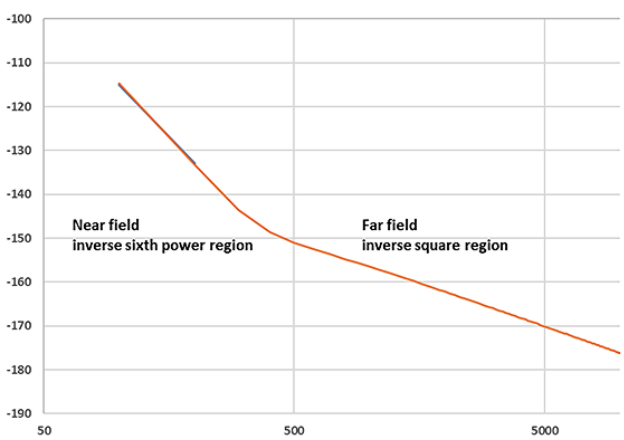
Brian Pease, using NEC 4.2, provided the data from a simulation of the magnetic field created by a 1 m loop antenna with the plane of the loop vertical, above ground with a conductivity of 0.003 S/m. The graph clearly shows the change from the near-field to the far-field rate of decay.

The second graph shows actual measurements taken along a quiet rural road in Alberta using a pair of QDX-M radios operating at 137.5 kHz and exchanging WSPR transmissions. The change from near to far field is clear, before two-way communication was lost at a distance of 5.7 km.

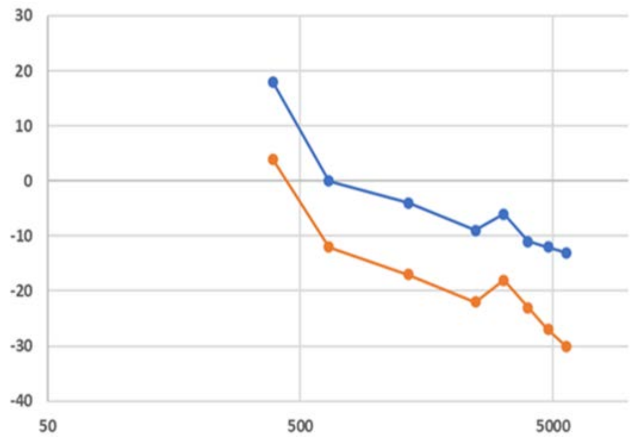
The way to long-range cave radio communications is open!

Reference

Drummond, Ian (2023) *Digital Cave Communications - Smaller, Lighter, Cheaper! CREGJ* ***124****, pp 3-5.*



Calculated magnetic field along the surface dB vs distance (m) log scale



2200m QDX WSPR, dB vs log distance (m) top line E to W, bottom W to E