Cave Radio Antennas

*In another of our 'Fundamentals' series, **David Gibson** explains why we use induction loops and grounded electrodes as cave radio antennas.*

Anyone who is involved with cave radio – either as a user or designer – knows that cave radio antennas make use of magnetic induction, and that they use either loop antennas or earthed electrodes. It is worth understanding why we make these choices because developing a better radio requires a good understanding of why it works in the first place.

The train of reasoning can begin with the idea that we wish to use 'radio' for communication. The difficulty is that radio waves are absorbed when they pass through a conducting medium like the ground. High frequencies are attenuated more than low frequencies so, whilst HF, VHF and even UHF can be used within tunnels and cave passages, we need low frequencies (say 10–100 kHz) to provide through-the-earth voice communications.

For a radio antenna to be efficient, it needs to be at least of the order of a wavelength in size. For example, a microwave dish might be ten wavelengths across. A linear wire antenna (say, a dipole) is often half a wavelength long, because it will then resonate and be more efficient to drive.

However, at the frequencies we use – broadly 100 kHz – a $\lambda/2$ antenna (λ is wavelength) would be 1500 m long whereas, to be practical, a dipole might need to be less than 3 m long, which is $\lambda/1000$. Such 'electrically short' antennas are extremely poor at radiating energy.

However, lack of radiation is not really a problem because we only want to transmit over a short distance – perhaps not more than 100 m in many situations. The field generated by a simple dipole antenna can be broken down into two parts – the far, or radiation field, and the near field. In a conductive medium, the radiation field only starts to become predominant at distances further than a skin depth – ***See box***. It can be shown that, in some circumstances, there is an optimum transmission distance of around three skin depths, however, the salient point is that we do not really need a radiating antenna at all because we are often operating well within the near field of the transmitter.

A more significant problem is that electrically-short dipoles are, by definition, not resonant – their impedance is not resistive but capacitive, which makes a traditional linear wire antenna difficult to drive. A 3 m dipole at 100 kHz would have an extremely low self-capacitance and, because the capacitance to ground (or to other parts of the equipment) would likely be higher, those leakage routes are significant. In other words, the current would not flow to the ends of the antenna, and its 'effective length' would be reduced.

For this reason, we need to encourage the current to stay in the antenna. A traditional method of achieving that aim is to use a 'top hat' above a vertical wire antenna. This comprises a wire, parallel to the ground, that increases the capacitance between the end of the antenna and ground. (The BBC Radio 4 transmitter at Droitwich, on 198 kHz is an example of this 'T-aerial' type of construction).

Loop Antennas

Clearly, a T-aerial is impractical underground, but another way to achieve the effect we want is to connect the ends of the antenna together, so that the current can flow in a circular path, through copper wires all the way. This is, of course, a loop antenna or magnetic dipole.

With a linear (electric) dipole, the current flowing in the wire generates a magnetic field. When this field is time-varying, it causes an electric field to co-exist, which gives rise to the radiation properties. The same is true of a loop, but the field generated by one side of the loop is in opposition to the field generated by the other side of the loop, so they tend to cancel. This cancellation can be minimised by making the loop as large as possible.

Hence, we use an induction loop because it is small and portable, and easier to drive than a wire antenna, rather than because, as some may say "you need a magnetic field to penetrate rock". Whilst that is true (because the electric field is attenuated due to the electrical properties of the rock) a linear wire antenna actually generates a *better* magnetic field than a loop, as it is not partially cancelled by the return path. But to take advantage of this, we must provide a means of getting the current to flow to the ends of the antenna.

Grounded Electric Dipoles

By grounding both ends of an electric dipole, the current – certainly at low frequencies, and in an electrically short antenna – will flow all the way to the end and return through the earth. This may lead you to think that what we have made is simply a large loop antenna, but the situation is more complicated than that.

What is really happening is complicated to model, and difficult to explain in simple terms. The effect of the antenna current and all the current elements in the ground combines to generate the observed magnetic field, which *could* be described as multiple 'nebulous' loops in the ground.

But if there were no grounding, and if the antenna had a large enough capacitance between the ends, then it can be shown that, for the same antenna current, the charge that built up at the ends of the antenna would generate the same field as the multiple loops in the ground. Thus, to model the antenna, it is *only* necessary to consider it as an isolated wire carrying a current all the way to its ends – i.e. an electric dipole, and the wire generates a magnetic field in accordance with the Biot–Savart law. That suggests that we should be detecting the field using an induction loop rather than another grounded dipole. However, most cave radios that use a grounded dipole for a transmitter also use it as the receiver, which may well not be optimal.

The ground will never be a good conductor compared with a wire, so a return path through a suitably distant wire will always make better use of the transmitter power than a path through the ground. This may well mean that loops are preferred to grounded dipoles for very small antennas and for very large ones.

For further information, see the many articles in the CREG Journal on grounded electrodes, induction loop design and so on. See **bcra.org.uk/pub/cregj/search.html**

Skin Depth

The degree to which an electromagnetic field is attenuated as it passes through a conductive medium can be described using a figure of merit known as the skin depth. This represents a rate of attenuation, and does not describe the actual depth at which signals are detectable or useable.

The skin depth can vary from a few metres to a few hundred metres depending on the frequency and the ground conductivity, although a systematic survey of skin depth in karst has not, as far as I know, ever been carried out