Cave RADIO

PART 1

Communication

by Mike Bedford

If you've ever been on a tourist trip inside a show cave, you'll probably recall a time when the guide asked everyone to stand still while he turned the lights out. For many people, this would have been the first time they'd ever experienced total darkness and it would have been just that – not a glimmer of light would have penetrated the depths.

And it wouldn't have been only light which was excluded from the world above. You wouldn't have heard any audible sounds from the surface and if you'd taken a VHF radio with you, you'd have found that all the familiar stations would have been absent.

For a tourist on a trip of Wookey Hole, this total isolation only adds to the fascination of the subterranean realm. But it's a different story entirely for members of the cave rescue organisations who are called out in the event of potholing accidents. Here, a means of communication with the surface can sometimes mean the difference between life and death for a casualty. If your only experience of the world of limestone caverns is as a tourist, you may not realise that it can take many hours or even days to reach the extremities of the world's larger caves. Now, imagine that rescuers have found an injured caver on the far side of a collapse which they don't have the necessary equipment to remove. Sending someone back to the surface may take many hours, by which time, the casualty may have died of exposure. But if you can get word to the surface immediately, there may just be a chance of reaching him in time.

In this article, we're going to be investigating how electronics can offer a solution to cave communication. Specifically, we'll look at low frequency induction, earth-current communication, single-wire telephones, and guide-wire communication. But communication is only one application of electronics to caving. Whereas the idea of potholers packing electronic equipment together with their ropes, ladders and lamps may seem an odd one to come to terms with – cavers are now using electronics to assist them in photographing, surveying, conserving, studying and documenting caves. This article on cave communication forms the first in a three-part series on cave electronics, and in the remaining two parts, we'll put many of these other applications under the spotlight.

Ordinary Radio Won't Work . . .

If you drive through a long road tunnel, or even under a motorway bridge, you'll sometimes find that the car radio will fade out. The simple explanation for this is that radio waves are attenuated by conductive media such as concrete or rock. In fact, the amount of attenuation depends on the conductivity of the medium and the frequency of the radio waves. The fact that the attenuation increases with the conductivity of the medium will come as no surprise. However, what far fewer people appreciate is that the attenuation also increases with the frequency. In other words, lower frequencies will penetrate the ground more easily. Exactly how low a frequency you need depends on the

Field testing of commercial single-wire telephone equipment developed for mine rescue purposes.

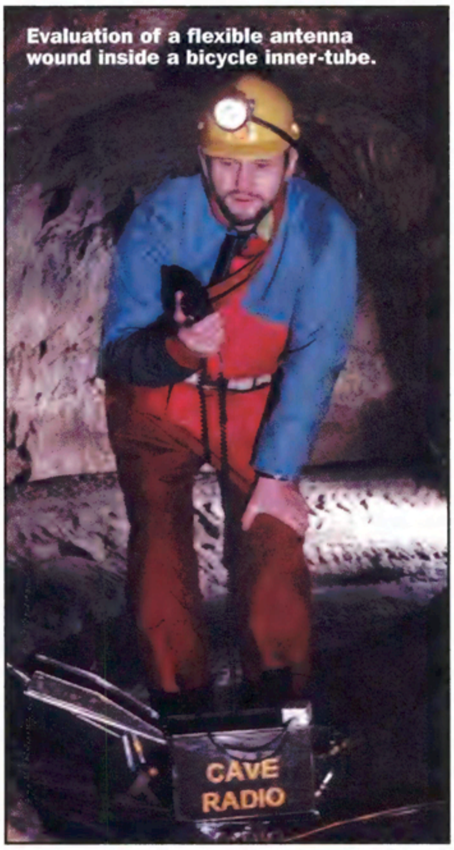
conductivity and the depth you need to penetrate. Caves occur in limestone, are rarely more than a few hundred metres deep, and to penetrate this, frequencies up to around 180kHz have been found to be useful. So, we're talking of the frequencies just below the longwave broadcast band. The areas of particular interest are officially called the VLF (Very Low Frequency) band which covers 3-30kHz and the LF (Low Frequency) band which covers 30-300kHz. The VF (Voice Frequency) band, which covers from 300Hz to 3kHz, has also been used for non-speech communication and for radio-location, as we'll see later in the series.

All this looks quite plausible until we start to consider the wavelengths at these frequencies. A frequency of 100kHz corresponds to a wavelength of 3km and down at 300Hz, the wavelength is 1,000km. In order to be efficient, radio antennas need to be a reasonable proportion of a wavelength long, so at these frequencies, we'd be talking in terms of some rather serious antennas. This has been a major problem for the UK's radio amateurs using the new 73kHz band and explains why, so far, the longest distance communication achieved is no more than about 5 miles. But if the antennas pose a problem to radio amateurs for aboveground use, the situation is far worse in the confines of tiny cave passages. Here, anything much larger than a whip antenna would be totally impractical, yet this would be grossly inefficient for radiating at LF or VLF.

. . . But Induction Will

So far, we've been thinking in terms of conventional radio. Radio involves a transfer of electromagnetic energy through free space by a process called *radiation* and is the process which dominates at a distance of a few wavelengths from any radio antenna. This is referred to as the *far field*. However, when we look much closer to the antenna, we find something quite different. In the so-called *near field*, we find independent magnetic waves and electric waves referred to as the *induction field* and the *electrostatic field* respectively. The induction field can be generated quite efficiently by feeding an electrical signal into a multi-turn loop. Since this can be far smaller than a wavelength, this looks promising as a means of cave communication. However, unlike the far field which decays with the square of distance, the induction field obeys an inverse cube relationship. In other words, it drops off very quickly as you move away from the antenna as the phrase 'near field' would suggest. However, this is not an insurmountable problem for cave communication, since it is frequently adequate to be able to communicate from the cave to the closest point on the surface. And as we've already seen, caves are rarely more than a couple of hundred metres deep.

So, cave radio employs the principle of low frequency induction. Strictly speaking, the word 'radio' is not appropriate since no radiation is involved, but 'cave radio' is, nevertheless, a convenient term and is in widespread use. The transmitter feeds a signal into a loop and thereby sets up a



Evaluation of a flexible antenna wound inside a bicycle inner-tube.

magnetic field. At the receiver, an electrical signal is induced in a similar loop by the transmitted magnetic field. So, we can view an induction communication system as being similar in operation to that of a transformer, albeit one with a particularly large separation between its primary and secondary windings. Despite the fact that real radio employs radiation whereas cave radio works by induction, the design of the transceivers are very similar.

A small hand-held cave radio called the Molefone was first developed about 15 years ago by Bob Mackin of Lancaster University and is used extensively by cave rescue groups. More recent designs tend to use the same principles – namely around 10-40W of SSB on around 80-120kHz – but make use of more modern techniques and components. However, although the transceivers will be comparatively familiar to any radio engineers, the loop antennas are peculiar to cave radio and their design poses a major challenge.

The amount of signal generated by an induction loop antenna depends on its magnetic moment which, in turn, depends on the electrical current, the number of turns, and its cross-sectional area. Loops are normally tuned to resonance at the operating frequency in order to overcome the inductance and hence maximise the transmitted current. So, designing a loop antenna involves balancing a number of factors. So long as the transmitter's PA remains constant, the thickness of the wire would have to be increased to increase the electrical current. This increases the weight of the antenna which is another factor which has to be taken into account – portable equipment needs to be light. In fact, when you consider the fact that the induction field decays with the cube of distance, it is clear that eight times the weight of copper is needed to double the range.

Increasing the number of turns also increases the weight, but this is only part of the story.

Increasing the number of turns without also increasing the wire gauge will increase the resistance and thereby decrease the current. The other factor which affects the magnetic moment is the loop's cross-sectional area. In fact, for a given weight of wire, the most efficient transmitting antenna turns out to be a large single-turn loop. However, we now come up against another constraint – small multi-turn loops are far more practical than large single-turn loops in caves. And if this isn't enough balls to keep in the air at once, we also have to throw in the question of the Q-factor. If this is too high, the antenna won't have sufficient bandwidth for speed communication and we could run into the problem of the tuning drifting when the loop is subjected to temperature variations.

Cave Proofing

Designing a cave radio and its associated loop antenna poses quite a technical challenge, even if it only has to work in the laboratory. But, of course, this is not the environment in which cave radios are used and the real cave environment is far more hostile to potentially delicate electronic equipment. If I were to build a cave radio for my own use, I'd carry it in a padded waterproof box and handle it with kid gloves when I opened the box to use the radio. As such, there's a good chance that it would survive, after all, I've been using a 35mm SLR camera underground for a number of years without mishap.

However, being realistic, I know that it is not reasonable to expect that cave rescuers would treat a radio with the same sort of respect. And even if they did, with the utmost care, accidents do still happen. Although I've been lucky with my camera, I know many other people who've had some expensive losses. So, cave radios must be cave proofed. This means that they need to withstand mud and water and they also need to be sufficiently robust to survive being dropped a couple of metres or knocked against a rock face.

Closely related are issues of ergonomics – cave radios need to be small and light. This is probably more of a problem in the design of the loop antenna than of the transceiver itself. Although induction allows the use of an antenna which is far smaller than a wavelength, a loop diameter of one metre still tends to be needed. Certainly, we might expect that improved transmitter and receiver designs may allow this to be reduced, but it's probably still going to be of such dimensions that it'll be cumbersome to carry in cramped cave passages. So, a major requirement is for a loop that can be folded up for transit, yet be rapidly deployed for use.

Earth Current Communication

If you're a regular reader of electronics magazines, there's a good chance that you've read articles on earth current communication. Except for use on the front-line during the First World War, there have been few serious applications, but it tends to remain popular amongst electronics hobbyists due to its novelty value and the fact that a licence is not required. Here's how it works. Take a microphone and audio amplifier as the transmitter but instead of connecting the output to a loudspeaker, attach it to a pair of copper rods driven into the ground a few metres apart. Take another audio amplifier and a loudspeaker as the receiver and here, connect a similar pair of earth rods to its input. Although you'll suffer significantly from 50Hz mains hum interference, you'll find that this setup can be used successfully over a distance of a few hundred metres.

Most earth current experimenters have restricted themselves to working above ground, but if you put an earth current transmitter on the surface and take an earth current receiver into a cave immediately below, you'll find that the earth currents also penetrate the ground to some considerable depth. Despite the possible difficulty of knocking earth rods into the solid rock floor found in many cave passages, and despite the perennial problem with mains interference, this sort of system has been used as a cheap and


Demonstrating the need for waterproofing in cave electronics. Note also that the antenna can be collapsed for transit.

Setting up a surface earth-current station.

cheerful method of cave communication. Of course, it's comparatively easy to get rid of the mains interference and this will have a very significant impact on the range. Rather than use a baseband (i.e., audio) transmitter and receiver, use an RF system. For reasons we saw when we looked at induction radio, the frequency will need to be in the VLF or LF bands, so we'd end up with transceivers virtually identical to those used as induction cave radios. Only the antennas would be different – we'd have earth rods instead of loops.

However, when we investigate further, we find that RF earth current systems and induction cave radios have even more in common. So long as they're on the same frequency, you'll find that you can receive the signal generated by a surface earth current transmitter using an induction radio with a loop antenna in the cave. Similarly, you'll find that a signal transmitted underground using an induction loop can be received on the surface using an earth current receiver. What this means, of course, is that an earth current generates an induction field in the ground and that an induction field generates an earth current. Effectively, the section of earth below the ground rods is being made to act as a huge induction loop antenna. The obvious advantage of this sort of hybrid system is that the problem of using ground rods in caves is eliminated, yet the advantage of having a very efficient antenna (i.e., the earth rods) on the surface is realised.

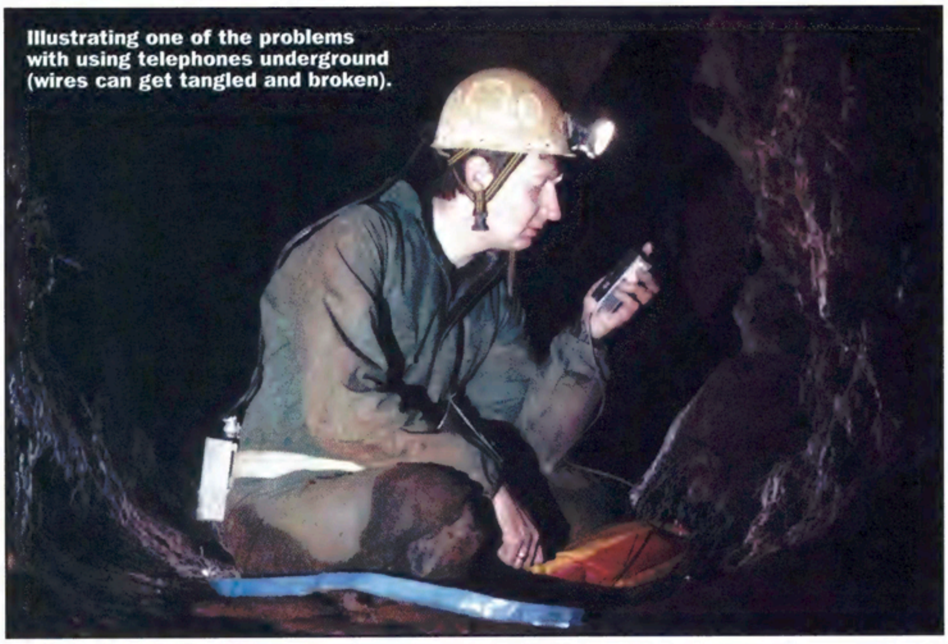
Single-wire Telephones

With the current generation of cave radios, effective communication can only be achieved at the maximum design depth if the surface party is directly above the underground party. So, cave rescue organisations make a point of knowing the surface locations which correspond to underground landmarks and are therefore able to arrange to contact the rescuers when they arrive at these particular points. Of course, this only applies to caves which have been well surveyed. But what about a rescue in a newly discovered cave? In this case, using cave radios may be a very hit-and-miss affair, and rescuers often fall back on telephones. OK, this may not sound particularly high-tech compared to induction radio and earth current communication, and there's the undoubted drawback of having to lay the line, but even here, new developments are being made.

The vast majority of telephones used for cave communication are single-wire telephones. Here, a single conductor is used to connect the two sets, the earth making up the return path. Otherwise known as the earth-return telephone for obvious reasons, the main advantage compared to a two-wire telephone is that the bulk and weight of the wire is cut by half. This is a major consideration if you're laying the line through hundreds of metres of tortuous crawling passages. Traditionally, single-wire telephones have a metal case so that the return earth path is made through the operator's body. The normal stance is with the free hand making a firm contact with the floor or the cave wall. However, more recent developments have changed all that and, in the process, brought other advantages. Single-wire telephones featuring a very high impedance input are much more tolerant of poor earthing, thereby making them more suitable for use by non-trained operators. They've been shown to work even if the user is wearing dry rubber boots and doesn't touch the wall, in fact, they've even been shown to work if the operator leaps into the air. OK, the need to communicate whilst falling down a pitch is, perhaps, low down on the list of priorities, but it does lead to an interesting and useful conclusion. The return path was obviously being made via the small capacitance between the operator and the ground. Let's take a look at why this is useful.

A single-wire telephone system lends itself to use by more than two parties. However, there are practical difficulties. If there are just two parties, then it is reasonable to assume that each will have a telephone attached to the end of the line. However, a third party would need to connect somewhere in the middle of the line. With a conventional single-wire telephone, this means stripping the wire. And if that stripped section of wire is subsequently allowed to trail in a pool of water, the signal will leak to ground and communication be lost. However, if a capacitive link to earth provides a viable alternative to a conductive link, then perhaps the same applies to the connection to the line. If users can tap into

John Hey, G3 TDZ, testing his LF induction radio in Jug Holes, Derbyshire.



Illustrating one of the problems with using telephones underground (wires can get tangled and broken).

Laying of the wire can be a time-consuming task.

the line capacitively, then it would no longer be necessary to strip the wire. Cave communication experimenters have recently conducted successful trials using high impedance single-wire telephones and capacitive couplers.

However, the single-wire telephone technique need not be limited to baseband with its inevitable mains interference problems. An RF carrier-based single-wire telephone has a number of advantages, indeed, a system operating at about 30kHz is currently under development for use in mine rescues. Additional benefits over the audio approach include the ease of capacitive coupling to the line, and the fact that capacitive repairs to broken lines can be made simply by 'tying together' the broken ends.

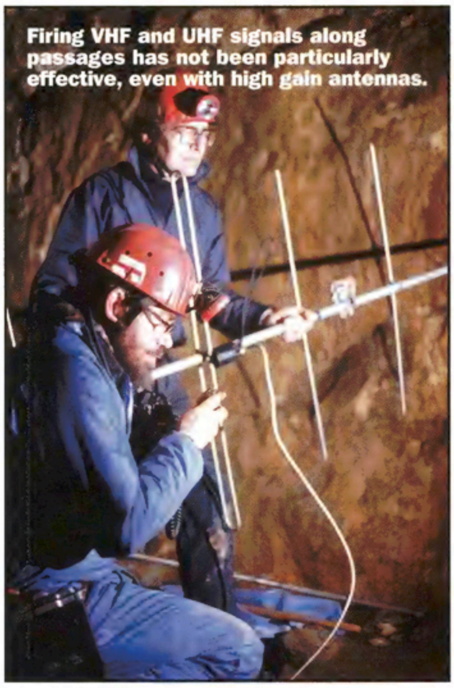
Other Methods

Induction radio, earth current communication and single-wire telephony are not the only possible methods of cave communication, indeed, many other techniques have been attempted and at least one other method is regularly used by cavers.

Before induction radio became a reality, tests with transmitting sound waves through the rock were conducted by mining companies. Although a degree of success in sending and receiving signals by the use of small explosive charges was demonstrated, a high rate of data transfer was clearly not achievable. Most other methods rely on radio communication, albeit using more conventional frequencies than those used for through-rock induction. Even though VHF and UHF radio is particularly inappropriate for penetrating the rock between a cave and the surface, there has been some experimentation with firing signals along the cave passages.

The major problem, of course, is that cave passages are highly convoluted so communication much beyond line-of-sight would have to rely on some sort of reflection or wave-guide effect. So far, little success has been achieved, although the higher frequencies appear to be the most effective. Somewhat more successful, however, is the use of conventional HF, VHF or UHF radios in conjunction with a guide-wire – a wire laid along the cave passage. In a way, this is similar to the single-wire telephone approach, especially if we're comparing with those telephones which use an RF carrier. Certainly, the same drawbacks

Single-wire telephones can sometimes provide a solution where induction radio can't. Here, a capacitive coupler (foreground in blue) is being tested.



Firing VHF and UHF signals along passages has not been particularly effective, even with high gain antennas.

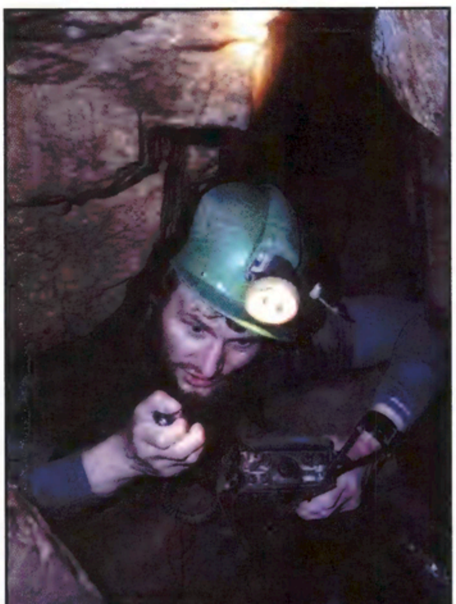
Main caving areas within the UK.

apply, primarily that of having to lay and maintain the line. However, at the higher RF frequencies which tend to be used for guide-wire communication (the 27MHz Citizen's Band is a common choice), the basic mechanism is quite different – radiation rather than conduction is predominant – and a far looser coupling to the line is required. In practice, effective communication can be achieved over many hundreds of metres using unmodified CB rigs by simply holding their whip antennas close to the line.

A World of Darkness

It's a reasonable assumption that most readers won't know a great deal about the world beneath their feet. So, to put this series into context and, perhaps, to explain why cavers find this world of darkness so fascinating, here's a bit of background information. The map shows that the main caving areas in the UK are Ireland – the British areas most frequented by potholers are the Yorkshire Dales, the Derbyshire Peak District, South Wales and the Mendip Hills. What drives many potholers is the hope of finding a new cave, of going where no man has gone before. To other cavers, the challenge is one of pitting themselves against nature – many of the more difficult caves require a high degree of skill, stamina and endurance. For yet others, the fascination is simply one of experiencing this harsh yet beautiful world of stalactites, stalagmites, underground rivers and waterfalls, of fossils and of strange rock formations. Finally, there are those whose interest is in some specialist discipline, perhaps in researching cave hydrology, biology or archaeology, perhaps perfecting cave photography, or perhaps developing electronic equipment for use by the caving community.

May people ask "which is the UK's longest cave?", "which is the deepest?", or "which has the largest chamber?", but the figures are in a constant state of flux since cavers are always pushing back the boundaries. One of the most recently discovered caves in the UK is Ogof Draenen in South Wales. So far, 58.3km of passages have been discovered, many of them boasting lavish decorations, and new passages are being found at the rate of 2km per month. But pride of place for the longest cave in the UK still goes to the Lancaster Hole/Ease Gill System in the Yorkshire Dales, with over 70km of known passages and many different entrances.



With a guide-wire, small hand-held amateur or CB rigs can be quite effective.

Caves like those mentioned above are a far cry from the sanitised environment of the show cave with its electric lights, hand-rails and concrete paths. If you want an introduction to a 'real' cave, to see nature in the raw, then Gaping Gill, also in the Yorkshire Dales, could provide you with that opportunity. Twice a year, local caving clubs set up a motor-driven winch to lower members of the public into its depths. This cave is also one of superlatives. Your trip into Gaping Gill will be via a 385-foot vertical shaft from the surface, and you'll land in the UK's largest cave chamber – supposedly large enough to house York Minster – into which Britain's tallest single-drop waterfall lands.

Caution

My aim in writing this article is to communicate some of my fascination of caving, and in particular, my fascination with the challenges of cave communication. My hope is that some of you will decide to experiment in this field and perhaps help to develop improved cave radios. You could even help save lives as a result of your work.

However, don't forget that caves are potentially dangerous places – if it wasn't for this fact, then there would be no need for cave rescue groups and no need for cave communication. I don't say this to frighten you off, and most of the risks can be virtually eliminated if you take care. But if you're not an experienced caver, you certainly shouldn't go underground unescorted. By all means, start experimenting and carry out tests above ground, but when the time comes for the acid test, find some experienced cavers to show you the ropes. Ideally, make contact with CREG (see Further Information) and perhaps attend one of their field meetings. CREG members will share your interest in electronics, whereas members of your local caving club probably won't have the slightest inclination to help you test a cave radio.

Further Information

If the idea of cave electronics appeals to you, a good first step would be to make contact with the Cave Radio & Electronics Group (CREG) of the British Cave Research Association (BCRA). CREG is the world's most active group dedicated to the development of electronic equipment for caving, with around 200 people subscribing to its publications. The quarterly *CREG Journal* contains a broad mix of practical and theoretic articles and will keep you up to date on what's happening in this fascinating field. And if you're just starting out in cave electronics, there's a wealth of background information to be found in back issues of the *CREG Journal*. For details and an application form, send an SAE to: Bill Purvis, 35 Chapel Road, Penketh, Warrington, WA5 2NG. You may also like to take a look at the CREG Web site at `http://www.sat.dundee.ac.uk/~arb/creg.`