Special Feature

CAVE RADIO

MIKE BEDFORD

Going underground with Earth Current Communications – an area where there is plenty of scope for the electronics experimenter. Help explore the secrets of below ground communications and make cave exploration safer.

A LUCKY escape and a longer stay underground than he bargained for when visiting a new kilometre long extension to Ogof Daren Cilau in the Brecon Beacons was experienced by South Wales caver Matt Ward. It was on his way back towards the entrance that a large rock dropped in a narrow section of passage just ahead of Matt and cut him off from the rest of his party. The alarm was raised and thanks to the sterling efforts of the Gwent Cave Rescue Team he was eventually freed from his confinement, remarkably not much worse for his two-day captivity.

The advance rescue team decided to lay a field telephone, normally a reliable choice, especially in unfamiliar territory like these new passages. However, the telephone did not perform well and there was never a successful link end-to-end. This was because the cable became torn apart in the arduous entrance passages.

Ogofone

The alternative communications technology was to use a Cave Radio, known locally as the "Ogofone" (ogof means cave in Welsh), and developed by Bob Williams and Ian Todd. This equipment was taken underground at quite a late stage in the incident whilst another group took the corresponding surface set to the precise spot on the hillside directly above the rock fall. From here the surface people had a line of sight back to the surface controller and could talk to him on a v.h.f. handset. Within five minutes they were also talking to the underground team through 100 metres of solid rock via the Ogofone, albeit too late to be of any help in the actual rescue. This illustrates how the lack of effective communications can often hinder cave rescue teams.

Community Contribution

World-wide, very few people are developing cave communication equipment. However, this lack of interest in the electronic side of potholing is not indicative of the popularity of caving as a sport – in the UK alone, there are an estimated 125,000 trips underground every year. The unfortunate consequences of this are the number of rescues. In 1994, the 15 rescue groups of the British Cave Rescue Council were called out to a total of 48 caving incidents involving 112 people. Sadly, five of these people didn't make it safely back to the surface.

What this means is that there's significant scope for innovation, and large numbers of people are potential beneficiaries of new developments in this area. If you take up the gauntlet, and decide to get involved in underground communication, therefore, you could make a significant contribution to the caving community.

Cave Radio

Orchestrating rescues is surely the most important use of cave radios and is probably the main motivation for people working in this area. Perhaps it's difficult to quantify the benefit of effective communications in emergencies, but there are certainly people walking about today who owe their lives to cave radios.

However, the cave rescue organisations are not the only potential users of cave radios. We could envisage, for example, the use of cave radios to prevent accidents, rather than just helping when they do occur. A caving party in touch with the surface, for instance, could be warned of impending wet weather and so make their exit before being trapped by rising water.

At the moment, cave radios are too expensive for this to be viable, but it must surely be the ultimate aim. However, even if widespread availability isn't currently a practical proposition, cave radios are used outside the rescue groups, primarily by cave surveyors, cave scientists, and, of course, those engaged in research and development of cave communications.

Molephone

Let us step back over a decade. For many years it had been known that the water thundering into the mighty shaft of Gaping Gill in the Yorkshire Dales, emerged some time later from the mouth of Ingleborough Cave, some two miles distant. However, after almost a hundred and fifty years of exploration, no connecting passage had ever been found. The complex surveys of both systems showed a number of points in Gaping Gill apparently close to points in Ingleborough Cave, but exactly which point should cavers explore to find the elusive link passage?

Since the surveyed points at the far extremities of both systems were likely to be in error, this search could have taken forever. Then, in 1983, technology came to the rescue in the form of the "Molefone", developed by Bob Mackin. Operating on 87kHz, and providing voice communication, this cave radio could also be used to pinpoint an underground transmitter from the surface. By providing additional fixed survey points in this way, the survey accuracy was improved and the likely break-through point identified. The link-up expedition was planned with military precision, TV crews and reporters alerted, and the through trip is now history.

More recently, the use of microprocessor-controlled data loggers has made scientists more productive, but frequent underground trips were still necessary to extract the collected data. Clearly the ultimate solution is to interface the data logger to a cave radio. Now, using a laptop computer interfaced to a cave radio on the surface, data can be uploaded via a telemetry link.

Cave Radio Principles

Intuitively, most people wouldn't expect radios to work down caves. After all, a few metres of soil and pre-stressed concrete is enough to blank out car radios in under-passes. In practice, if you were to take an ordinary transistor radio a hundred metres underground, you'd be unlikely to hear anything at all. However, if your radio receiver operated in the lower part of the l.f. band, you'd be able to hear MSF, the National Physics Laboratory's standard time and frequency station, coming in loud and clear on 60kHz.

The reason for this surprising result is that the absorption of radio waves by rock depends on the frequency, with low frequencies being the most efficient at penetrating the ground. Without going into all the theory, it is suffice to say that to achieve communication to a depth of a couple of hundred metres – the maximum depth of most British caves – radios tend to operate in the 800Hz to 150kHz region.

Now, the standard radio antenna, against which the efficiency of other antennas is compared, is called a dipole and is half a wavelength long. OK receiving antennas don't have to be half or even a quarter wavelength long, and telescopic car antennas are indeed far shorter than this at MW and LW. However, the receiving antenna is only one part of the system. The transmitting antenna responsible for radiating the *BBC Radio 4* LW signal is of significant proportions as you'll know if you've driven past the transmitting site at Droitwitch. The fact is that if both transmitting and receiving antennas are significantly shorter than quarter of a wavelength, then the overall system would be grossly inefficient.

Returning to our typical cave radio frequencies, and converting to wavelengths, we get a range of about 2km to 400km, so, we would have to surmise that small portable cave radios are impractical. Huge antennas would be required yet caves are not renowned for their spaciousness.

All that has been said so far relates to "*conventional*" radio, communication by the transfer of power through free space by electromagnetic radiation. However, as an alternative to normal radio, which employs the so called "far field", "near field" communication can be used.

Much closer than half a wavelength from the transmitting antenna, localised magnetic and electrostatic fields exist and can be received by induction or capacitive coupling, respectively. The near magnetic field, referred to as the "induction field" looks particularly promising since it can be generated effectively using small loop antennas.

The induction field is not suitable for long distance communication since it decays with the cube of distance, but it is eminently suitable for cave radios, since it is rarely further than a few hundred metres from a cave to the surface. The technique employed by cave radios, therefore, is referred to as *low frequency induction*. Fig. 1 illustrates the principle of conventional cave radio, and you'll notice the familiar "bar magnet" field lines associated with inductive communications.

Earth Current Signalling

Take a microphone and audio amplifier, feed the output into a step-up transformer, and connect the transformer secondary to a pair of copper rods driven into the ground a few metres apart. Now connect the input of another audio amplifier to two more ground rods a couple of hundred metres away. Attach a pair of headphones and you'll find that anything spoken into the distant microphone will be clearly audible.

Surface signals being received underground using an inductive loop "aerial."

Our heading picture shows caver Rob Gill setting and testing a surface hybrid earth/current baseband transmitting rig.

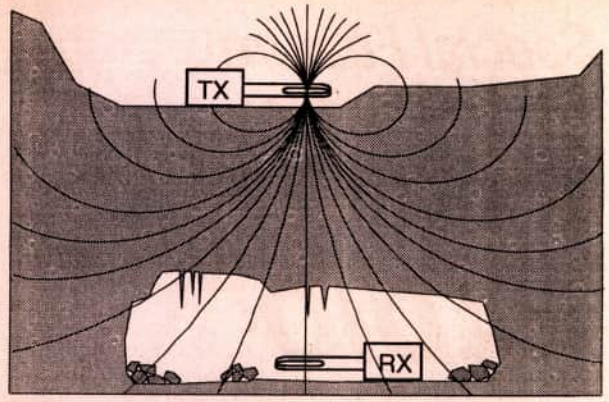

Fig. 1. Conventional Cave Radios operate by low frequency (l.f.) induction. This can be viewed as akin to the operation of a transformer but with very loose coupling between primary and secondary windings.

This technique is called "*earth current signalling*", and was first demonstrated over 100 years ago. Shortly afterwards, Marconi developed radio and so this early form of wireless (in the most literal sense of the word) communications was never developed, except briefly for use on the front line during WW1.

Earth current signalling has continued to fascinate electronics enthusiasts though, and articles have regularly appeared in the amateur electronics press. Its popularity probably lies in the fact that an operating licence is not required, but it is doubtful that many people have found any genuine applications for it.

However, earth current signalling is potentially valuable, specifically in the area of cave communication. Furthermore, it provides plenty of scope for experimentation. First let's take a look at some background information.

As with virtually any communication system, experimenters with earth current signalling will soon find that the signal strength decreases as the distance between the transmitter rods and the receiver rods is increased. Another familiar result is that communications efficiency can be improved by increasing the separation between the two transmitter rods and/or between the two receiver rods.

Of course, all this is what would, intuitively, be expected and is readily explained by assuming that the ground is a two-dimensional network of resistors and that communication is achieved by conduction. What most experimenters don't consider, however, is that the earth isn't two-dimensional, it also has depth. So, if you take the receiving set-up down a cave, and knock the ground rods into the floor of a cave passage you will be able to achieve communication through the earth. In Fig. 2, earth current communications is shown modelled as a 3-D resistor network with a surface transmitter being received both on the surface and in a cave passage.

The other thing most earth current experimenters don't realise is that conduction isn't the only possible communication model. When an alternating current passes through the earth, a magnetic field will be generated, so we could argue that the receiver operates

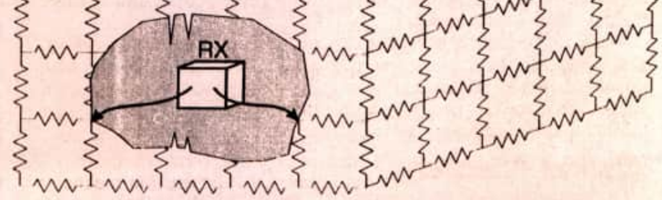

Fig. 2. Earth current communication can be remodelled by considering the earth as a rectangular grid of resistors. However the earth also has depth, so a signal injected on the surface can be received in a cave.

by detecting this magnetic field. For a conventional set-up, this is probably splitting hairs, but if true, there will be other means by which the signal could be detected.

We've already seen that cave radios operate by magnetic induction, so if an earth current signal does generate a magnetic field, it should be possible to detect it using an induction receiver. Similarly, an earth current receiving rig should be able to receive an inductively generated signal. A number of people are now starting to experiment with hybrid earth current/induction radio systems for rescue use and have shown that the technique is viable. The main advantage over pure induction cave radios is that the surface party can achieve coverage over a wide underground area with one widely spaced pair of rods. Using conventional cave radios, at maximum depth, the surface party has to track the underground party across the surface to maintain contact. This, in fact, is one of the main reasons that cave radios are not used universally during rescues in horizontally extensive caves such as that in Daren Cilau mentioned earlier.

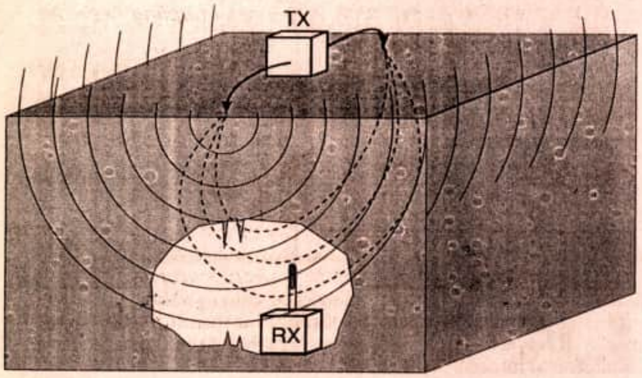

Fig. 3. The current flow in the earth, resulting from injecting a signal into ground rods, forms a series of huge underground loops. Just like an induction transmitter, a magnetic field is therefore generated and can be received underground using an induction loop.

Note that the field pattern differs from the familiar "bar magnet" pattern associated with an induction loop transmitter due to the combined effect of multiple "loops."

In Fig. 3, we see a hybrid system in action. Here, an earth current transmitter is being received inductively underground. It should, perhaps, be pointed out that the magnetic field lines are different from those in Fig. 1 because the current path makes up an infinite number of underground loops, all contributing to the overall field pattern.

So far one important fact has been glossed over. The earth current system outlined in this section operates at "audio frequencies". In technical jargon it is a *baseband* system. You'll remember, however, that the Molefone referred to earlier operated at 87kHz, as does the Ogofone.

Certainly cave radios can operate at baseband, and this was, in fact, the first technique employed. However, in the interests of reduced power consumption, reduced antenna mass, and increased efficiency, these were soon replaced by carrier-based designs. Of course, earth current systems could also operate above the audio band and this would indeed be necessary for inter-operation with cave radios.

Experimental Suggestions

In this section, some areas where the constructor could get involved in experimenting with earth current communication underground will be suggested. However, first some very important safety guidelines must be highlighted. It would be irresponsible to entice inexperienced people into caves without adequate supervision. After all, the main aim in writing this article is to help make caving safer, so it would be wholly inappropriate if the end result was to generate "customers" for the cave rescue groups.

It is probably stating the obvious but potholes provide opportunity for getting lost, getting stuck, being crushed by falling rocks, falling down pitches, drowning, and suffering hypothermia. However, if you're sensible, a trip underground is not especially dangerous, and most of these hazards can be virtually eliminated.

First and foremost, if you're not a caver, being sensible means only going underground in the company of people with caving experience. One approach would be to make contact with a local caving club, although you'll probably find that most of the members won't share your enthusiasm for electronics. More appropriate, given your motivation for going underground, would be to make contact with the Cave Radio & Electronics Group of the British Cave Research Association. Details are provided near the end of this article.

One other introductory comment before we get down to business – licensing. The author chose to offer this article to *Everyday with Practical Electronics* rather than an amateur radio magazine because it concerns an area where non-licensed electronics enthusiasts can take part on the same footing as radio amateurs.

Although you need a licence to experiment with inductive communication, the l.f. band is not covered by the amateur radio licence in the UK, so everyone would have to work under a Test and Development licence. With earth current communications, however, you probably don't need a licence at all, though the situation is far from clear. Certainly it has always been assumed that earth current work doesn't require a licence.

However, since the use of low frequency inductive communication is controlled in the UK, and since we are now admitting to the fact that an earth current does generate an induction field, would the Radiocommunications Agency (RA) now take a different view? So long as you work at baseband, there should be no problem. If you were to experiment at 87kHz in order to interact with an induction radio, on the other hand, it would be wise to check it out with the RA first.

Practical Work

So, warnings and preparatory comments out of the way, what practical experiments on underground earth current communications could you carry out? First of all, let's make it clear that no pratical circuits are going to be presented here. Quite a lot can be done with off-the-shelf equipment, and even when custom equipment is required, very simple circuits can often be used.

For example, to generate a baseband earth current, all you need is a source of an audio signal – a cassette recorder or microphone for example, a standard audio amplifier, a step-up transformer and a pair of ground rods. The underground induction receiver can also be very simple.

In the system demonstrated to the author, the receiver was based on an old transistor radio. All the r.f. circuitry had been bypassed, so that the ferrite rod antenna was connected directly to the audio amplifier. This is by no means an optimum receiver, but even with this simple set-up, quite a lot can be learned.

A number of avenues for experimentation come to mind. For example, how well does a single pair of ground rods "flood" a cave system with an induction field? Does one pair of rods fire most of the signal at right angles to the line between the rods, as dipole antennas do, or does it give an omnidirectional field pattern? If we get directional coverage, can the situation be improved by using extra rods?

We know that signal strength can be improved by increasing the spacing between the ground rods, but there are clearly practical limits to the separation between them. So, what other methods could be used to improve efficiency? Is it best to use longer rods, or thicker rods? It has been suggested that better than either of these options is to replace each rod with a hexagonal array of rods – but does this work in practice?

What has just been described are preliminary but nevertheless important experiments. To go beyond this initial stage, however, you'll probably need to improve the receiver. As with all induction radios, you'll find that there is a pay-off between antenna size and performance.

In general, the easiest way to improve the performance of a loop is to increase its cross-sectional area, although large diameter loops are obviously not suitable for use in small cave passages. For this reason, ferrite rods are sometimes used to increase the antenna's effectiveness. Another means by which loops can be made much more efficient is to tune them to resonance, but for speech communication, the *Q*-factor mustn't be so high as to reduce the bandwidth below 3kHz.

Interference radiated from overhead mains cables on 50Hz and multiples thereof, is another problem, even in the remote areas where most of the UK's caves are located. To get maximum performance out of baseband systems, therefore, notch filters would probably be required.

As already indicated, the ultimate aim with earth current communications must be to obtain interpretability with l.f. induction radios. Since these are relatively sophisticated SSB transceivers, however, this does require a modicum of experience in conventional r.f. circuit design.

However, one other area for experimentation does come to mind. You'll remember that in the section "Cave Radio", it was suggested that if all cavers were to carry radios, they could be warned of impending bad weather and so many rescues could be obviated. Although two-way cave radios offering speech communication will probably always be too expensive for this, there is an alternative. Each underground party carries a cheap compact receiver which can detect an induction field on a specific audio frequency. On receipt of this signal an alarm is sounded.

Slightly more sophisticated, we could envisage a unit which reacted to perhaps three different audio frequencies and illuminated one of three different coloured l.e.d.s. These could be interpreted in various ways, perhaps "get out of there", "get out of there quickly", and "all clear", for example.

With a conventional cave radio transmitter, this system may not be workable. Communication is in one direction only, so unless the underground party keeps exactly to a pre-arranged schedule, the surface party won't know exactly where they are. Since induction-to-induction systems require reasonably accurate alignment of transmitting and receiving loops at maximum range, this wouldn't provide the reliable warning mechanism which is required. However, if an "earth current transmitter" is able to saturate the cave system with signal, then it would be eminently suitable.

The Cave Radio & Electronics Group

Hopefully this article has given you some food for thought and it is the author's hope that some readers might decide to do some experimentation in this area. The major motivation for developing cave communications equipment is surely to help the cave rescue organisations, so it would be a shame if the experimenter were to develop something but didn't have the opportunity for their work to be publicised.

The Cave Radio & Electronics Group (CREG) of the British Cave Research Association (BCRA) is the UK's body dedicated to the development of communication and other electronic equipment for use in caving. Through a quarterly *Journal*, which covers a wide range of topics, the CREG acts as a clearing house for the dissemination of news and ideas, in addition to publishing practical circuits. Also of potential interest to readers, field meetings are held twice a year around the country and provide an opportunity to share ideas in a practical way.

You'll also notice from the short bibliography, that the CREG has already published many practical and theoretical articles relating to induction radio and earth current communications. If you do intend to start experimenting in this area, it might be an idea to take a look at these articles – they could save you from "re-inventing the wheel". For details of membership of CREG please send a stamped, self-addressed envelope to Mike Bedford at 4 Holme House, Oakworth, Keighley, W. Yorks. BD22 0QY. □

Bibliography

Venturing Underground with VLF Radio, Mike Bedford, Radio Communications, Vol. 71, No. 1 (January 1995).

An introduction to LF induction radio for caving. Describes the use of cave radios for radio-location and gives practical circuits for an 874Hz transmitter and receiver.

An Introduction to Earth-Current Communications, David Gibson, CREG Journal 17 (September 1994).

A mainly theoretical introduction to earth current for use in cave communication. Also discusses earth current/induction hybrid systems. Quite mathematical.

Earth Current/Induction Field Experiments, Rob Gill, CREG Journal 19 (March 1995).

Description of experiments to show the viability of hybrid earth current/induction field systems as postulated by David Gibson in his article above.

SHOP TALK

with David Barrington

Simple Theremin

The small handheld box for the *Simple Theremin* came from **Rapid Electronics** (☎ ***01206 751166***), code 30-0270. The printed circuit board is a tight-fit in the case and the edges may need "rubbing down" slightly to fit.

Other handheld cases could be used and most of our component advertisers should be able to offer a suitable alternative. If another case is used it should be plastic and not metal, since this will adversely affect the range of the instrument.

We understand that the BR195 lock-fit transistors and the 100µH inductors are available at a "surplus" price from **Greenweld Electronics** (☎ ***01703 236363***). The specified miniature potentiometer seems to be fairly expensive and will take some finding locally. The only listing we have found is from **Farnell Electronic Services** (☎ ***01279 626777***) and is carried under the Bourn 50 series range.

Most of our component advertisers should carry stocks of the Philips type trimmer capacitor and can usually be found listed as a "film dielectric" trimmer. The 38mm diameter loudspeaker, with an "alnico" magnet, is another part which should be widely available. It is most important that a speaker with an alnico or colmar magnet be used, as the popular "ferrite" magnet type will be too large for the p.c.b.

The low K metalised or ceramic plate capacitors should be generally available and not cause too much concern. They are certainly currently listed by **Cirkit** (☎ ***01992 448899***).

If readers do experience difficulty in locating parts for the *Simple Theremin*, kits and complete units are available from **Longwave Instruments, Dept EPE, 23 Ashley Lane, Hordle, Lymington, Hants SO41 0GB.** (☎ ***01425 610849***). Ready made, the Simple Theremin costs £49.99 and a full specification Theremin is available for the sum of £350. A MIDI converter unit will be marketed by them shortly.

The printed circuit board for the *Simple Theremin* is available from the *EPE PCB Service*, code 952 (see page 735).

Comprehensive Security System

Some of the items called up for the *Comprehensive Security System* may prove elusive to locate locally.

If you take up the PIR sensor option you will find prices vary quite considerably and it might be well worthwhile shopping around. A sensor is currently being listed by **Bull Electrical**(☎ ***01273 203500***) for the sum of £8 (code Mag8P5) and also by **Mailtech** (☎ ***01584 831475***) from £6.50 to £11.75 each. Before ordering check that they have relay outputs.

The small buzzer (code KU56L), keyswitch (CJ94C) and the "staccato" electronic siren (YZ03D) were all purchased from **Maplin**. The 12VA mains transformer also came from the same source, order code DM28F.

An empty alarm bell box, alarm sticker and the 12V 2AHr. lead acid battery were purchased from **Electrovalue** (☎ ***01784 442253***). We understand that the range has changed recently. The *n*- channel MOSFET was also purchased from the same source.

The bell wire and the domestic dual light switch, although not listed in their advertisements, are stocked by **Bull Electrical** (see above) and **J&N Factors** (☎ ***01444 881965***).

Quite a large number of our advertiser stock security/intruder switches, micro-switches and pressure mat switches, all at fairly reasonable prices in comparison to "superstores".

Low-Range Ohmmeter Adaptor

There should be no problems when shopping for components for the *Low-Range Ohmmeter Adaptor.*

The multi-turn potentiometers are usually the cermet type and the most common range usually comes in anything from 18-turns to about 25-turns. The only point to watchout for is that they will fit on the p.c.b., although there is a certain amount of "play" in the connecting wires.

The other points to watchout for are: the "test" terminals ***must*** be all metal types, and that the pushbutton test switch is a low-profile type so that it does not short circuit any components in the small plastic box.

The small printed circuit board is available from the *EPE PCB Service*, code 926.

Vandata

One or two "special" components for the *Vandata* project need highlighting as they many not be available from local suppliers.

We shall start off by tackling the relays. Although it is quite possible to use other relays, it is suggested that the ones specified be used as others many not fit on the printed circuit board.

The 10A mains relay is listed by **Maplin** as their "Ultra Miniature High Power" type, code YX97F. They also supplied the 16A (12V 170 ohm coil) Automotive type relay, code JM26D (16A/12V car relay).

The reed relay switches are RS components and are available from **Electromail** (☎ ***01536 204 555***), their mail order outlet. The code number to quote is 338-147.

The MBR2045 Schottky diode, 5mm multicolour l.e.d.s and a suitable slotted heatsink all came from Maplin. Codes GX35Q, YH75S and FL58N. The heatsink could be fabricated from 40mm × 20mm aluminium plate.

The turret pins for mounting the reed relays were ordered from the above company, code JM04E (two packs required). The screw-terminal locks and 18s.w.g. and 20s.w.g. enalled wire should be available generally.

If you wish to use identical cases, these were ordered from Maplin, codes LL05F for the boot unit and KC93B for the display unit.

The two printed circuit boards for the *Vandata* are available from the *EPE PCB Service*, codes 953 (Boot) and 954 (Display) respectively.

Finally, as there are high currents associated with "car electrics", any additional inter-linking wires should be rated identically to the existing coupling cables that many need "breaking" into. These should be available from any good caravan and car accessory shops or garages specialising in caravan spares.

Hum-Free Battery Eliminator

We cannot foresee that any component buying problems are likely to occur for readers wishing to construct the Hum-Free Battery Eliminator project.