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# Introducing the Nicola System

**When complete, the Nicola System will provide an early warning system and communication for rescue use in the Gouffre Berger. Graham Naylor outlines the system and describes progress to date.**

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**Introduction :**

Development of the Nicola System in the Isère region of France (which incorporates the Vercors and Chartreuse caving areas) is being undertaken to develop underground communication systems. This work is being performed with the help of the ADRASEC 38 (an association of radio amateurs who provide emergency communication services – equivalent to the British RAYNET) and several British cavers (Paul Mackrill, Paul Rice and myself). The development of communications systems is motivated by the requirements of the department's cave rescue team the SSSI. The tragic flooding of the Gouffre Berger in 1996 led to the loss of two lives, Torda Istvan and Nicola Dollimore. Nick Perrin (Nicola's husband) set up a fund to finance research into the development of communication systems for use in caves and in particular to allow a warning message to be given in the Gouffre Berger.
The importance of prompt communication of the status of a victim in the early stages of a rescue has long since been recognised by French rescue teams – especially in the Isere where a return to the surface can take up to 10 hours in certain of the deeper systems. Following very fruitful input from others working in the same area in Switzerland, Britain, the USA and Canada, we have produced four cave radios using the original John Hey SSB LF transmitter and receiver boards (Hey, 1995). The first two were prototype devices with which we used to demonstrate the principle. A further two were produced to rather higher standards by F6EGY (these latter devices are currently kept in the CRS Alpes headquarters ready for use by the emergency services). A simple bridge amplifier using two TDA2006s drives a transformer similar to the one Rob Gill described recently (Gill, 1998). The efficiency of the earth current technique has been demonstrated at 87kHz vertically through over 500m of rock in the Gouffre Berger and horizontally through over 900m of rock in the Dent de Crolles cave system as Jean-Jacques of the ADRASEC 38 reported in a previous issue of the CREG Journal (Fauchez, 1998a). The requirement of the Nicola system as defined by the SSSI was reliable communications through over 500m of rock. *Recently a new generation System Nicola radio has been developed called* system Nicola MK II.

**Techniques:**

There are many conditions which give rise to a variability in a communication link over such a distance:

**1 – Achievement of good ground connections**

**2 – Power coupled into the output.**

**3 – Nature of the rock strata between the transmitter and the receiver**

**4 – Background noise.**

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Being in control of all of these elements is necessary for a reliable link and is the subject of development of the "Nicola [illegible]n". I would like to outline some of the techniques we use.

**Ground Connections**

Achievement of good ground connections is essential to maximise the signal picked up at the receiver. Without going into any detail of the mechanism of the transfer of power, we can be fairly confident that if we increase the current injected into the ground we increase the received signal. Thus reducing the resistance to ground in-creases the cou-pled signal. There have been several articles on the resistance be-tween electrodes in a supposed uniform media. Unfortunately our media is rarely particularly ho-mogeneous. In practice good earth connections (resistance be-tween electrodes less than 500?) can be achieved if stout pegs are knocked into wet mud on the surface or underground electrical braid is buried in some mud or thrown into a pool of water. Braid stuffed into a crack or a rock anchor give quite poor contacts.
The requirement of making good connections even in dry passages has called for a rethink of how we should make the contact. By coupling the current into the ground through the distributed capacitance of the wire itself rather than a point-like electrode (the bottleneck of current lines in the vicinity of the electrode increases dramatically the resistance) we can achieve very low resistive impedances. The reactive component of the capacitance can be cancelled at the radio frequency by using a series inductor.
This technique has been demonstrated to give improved and clear communications through 500m of rock with capacitive contact to very dry rock. This was achieved by using a tuned inductor half way down one antenna wire, though an inductor on each antenna wire should in principle give better results. The inductor should be very carefully constructed as it should be a relatively large value (several milli-Henrys) but should have a low parasitic capacitance so as to remain inductive at the frequencies used. We constructed such an inductor by switching an array of RF inductors (up to 10mH, 1.6mH + up to 10, 840?H + up to 10, 120?H). This technique has not, however, been adopted for operations as the tuning of inductances remote from the communication set is an onerous and unacceptable complication. Furthermore the resonant voltages especially when we try and increase the output power are likely to be rather high (around 10kV!) and potentially quite lethal. Further to the letter in a recent CREG Journal on this safety issue – in a wet environment such as a bathroom or a river cave – the highest safe voltage produce by an electrical appliance is 12V! If we have several hundred volts on our antenna wires, we have wet hands (likely in a cave) and are standing up to our knees in water (not beyond the bounds of possibility in a cave) we have a recipe for passing rather more than 25mA through the human body (good chance of death). If we have dry gloves on but are kneeling down with a torn over suit (bad!) but the ground is fortunately dry, then we will probably not feel too much. Our communication set must be safe in all circumstances and is designed to save lives not to kill people. We can therefore not accept high voltages.
The alternative is to use low voltages and dramatically drop the direct contact resistance. This we have achieved by using a 10 – 20m length of electrical fence tape connected to the end of the antenna wires. This gives a distributed contact to overcome the bottleneck effect (it is equivalent to having many small earth contacts). It is important to use the type of electrical fence as tape as this lies flat much better than the string type fence wire. This is important to get the most number of contact points. The contact can be improved by putting stones on the fence wire at various locations or better still by kicking it into some wet mud (if available). Of course the most stupendous contacts are still made if the whole length can be thrown into a large pool or several smaller pools.

**Power Coupling**

In principle we can couple more power in to the output stage to get a better contact by simply using a high power amplifier. There are however several words of caution.
We have only limited power available from our portable batteries and so we would like the efficiency of the amplifier to be as good as possible (Fortunately we have a complementary supply of 13Ah lithium cells which give a good autonomy). Class A amplifiers give little distortion but are very thirsty on current. The TDA type amplifiers, are class AB, are convenient to use but are quite lossy in that they can not use the full voltage swing at the output.
We have experimented with switch mode amplifiers and have demonstrated that it is possible to encode an SSB signal with a PWM wave. The start of the pulse encodes the phase of the SSB wave while the pulse width gives the amplitude. A series LC filter before the output transformer allows the PWM signal from a full bridge MOSFET switching circuit to be reconverted to the SSB signal. Unfortunately the circuit I built was not too linear between amplitude and pulse width (I used the SGS chip 3525) which led to a distorted modulation. Also at high power levels the inductor used in the output filter should be quite large so as not to saturate introducing distortion. The lesson here was that we might gain 3dB in efficiency and put out an extra 10dB but if we are not careful we can loose at least 10dB in intelligibility of the modulation and use up 7dB (i.e. five times) more power from the batteries with no overall gain. This as we say requires further work!
Similarly as we drive up the power we start getting feedback problems in the transmitter. Based on our experience I can give the following tips. With large antennas the large RF field can be picked up by the microphone and feed through the AF amplifiers (the radio frequency is fairly low remember!). The AF power load in the power stage can lead to AM AF on the power lines that again gets in to microphone circuit and into the mixer again (so good filtering between stages for AF as well as RF is required). Using a voltage regulator for the microphone and mixer might be a good idea. The half voltage reference level derived from a potential divider and a unity gain op-amp in the John Hey circuit can feedback this ripple very efficiently into the microphone circuit if the potential divider doesn't have a capacitor. Though the circuit diagram includes this capacitor the printed circuit boards don't! So, in short, use sound analogue circuit practices and watch out for coupling (careful of those wiring looms! I have to admit my wiring practices are a sad mess!)

**Nature of the Rock**

The nature of the rock can be very variable so 1000m of rock in one place may be less absorbing than 300m of rock in another place. Shale beds and poor limestone block the signal but good solid limestone will pass the signal well.

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This effect is clearly de[illegible] to the undergrou[illegible] the Hall of the[illegible] ar [illegible] on. Due to the sl[illegible] ds within the Se[illegible] hat accumulate mo[illegible] year (se[illegible] chez, 1998b) we achieved very good results on both 87k[illegible] d cross-section) through about 600m of rock. Contact was also made from another underground station to the Hall of the Thirteen (with the Nicola system) but not from underground to the surface. Here the distance is nearly 1km and distant storms were perturbing the surface reception. The conclusion is that being vertically above or through the shortest distance of rock does not always give the best contact. For operations we use a loop type receiver (e.g. Lowe receiver with loop or a Molefone) to search on the surface for the best signal. The best location can be anticipated from a knowledge of the geological relief (see geological cross-section) but local conditions may be quite profound (a cutting, rock exposure, a stream, a hollow).

**Background Noise**

The background noise can be very strong, especially with earth contacts. The background noise comes from atmospheric disturbances (particularly bad later in the day, in the summer and during storms). The Loran navigational transmitter gives rise to periodic noise as does any nearby motorised equipment. The farmers' electrical fences can also give wide band LF noise spikes.

The issue of the modulation frequency is an important issue and though 137kHz is slightly less troubled by atmospheric noise, 87kHz gives better transmission through more absorbing rocks. The noise problem is particularly acute on the surface and tends to be rather attenuated underground leading to the frequent situation that the underground team can hear the surface fine, but the surface can not hear the underground team.

To overcome this we intend to develop digital communications (sending BPSK and using the ability of a phasing receiver to detect phase). This should ensure return communication in conditions when the surface is troubled by static, though in extreme cases the surface team may disconnect the antenna wires and take cover.

**Tests in the Gouffre Berger**

On the 23rd of August this year we made a descent of the Gouffre Berger with the Devon Speleological society to try and make contact from the lower half of the cave. This is something that is of critical importance during rescues from this part of the cave as well as being of great interest to parties exploring the cave. A radio contact from the lower part of the cave allows an updated report of the weather conditions before an underground team engages itself in the more aquatic sections. Such a system, had it been available in 1996 would have saved lives. The provision of such a facility is a major goal of the Nicola foundation.

A remarkably clear (in both directions) voice link was established from the Grand Canyon to a path just above the village of Fournel. The excitement was intense as this is the first time such a link has been established, and with a telephone-like quality. The different links established are shown in the diagrams. During the establishment of the first link to the surface from the Grand Canyon, a two way link was first made with a surface Molefone. At nearly 500m this is probably a record for a Molefone! The surface Molefone received clearly the strong signal from the earth current Nicola system in the Grand Canyon due to its efficient power coupling. The underground earth current receiver could just hear the Molefone (though weakly) due to the relatively noise free underground environment and the efficiency of signal collection of the earth coupling. berger1.gif

When the surface Molefone was replaced by an earth current Nicola system, the speaker practically leapt out of the underground set, so loud was the signal. The success of this link must be due to a large extent the low resistance of the earth electrodes made underground using electric-fence tape. The placing of these electrodes, though easy, is very critical and requires a little practice in order to achieve less than 300W between terminals. At this level of earth resistance the capacitive impedance of the wires is negligible. Unfortunately the day of the tests the cave was not rigged to the bottom, but as can be seen from the vertical section, the thickness of limestone is no thicker at the bottom of the cave and we are quite confident that it will work at –1000m. The system was left installed with one prototype set underground (which gave a poorer but still quite acceptable performance)berger4.gif.

The DSS were able to use the system for the duration of their exploration of the system. One member was even able to talk to his wife in the UK thanks to a cellular phone on the surface. This communication from the lower part of the Berger to the UK has to be a remarkable first! Though we do not yet have enough working sets of the Nicola System to allow such a provision to be performed on a regular basis, but is hoped to be made available in the near future with the production of our next generation devices.

**Operational Issues**

The devices we currently use operate at 87.15kHz USB and are compatible with the Molefones owned by the rescue team in France, despite the slight shift in frequency. The shift gives a shift in the tone of the voice and a slight loss in intelligibility. Molefone-type devices using a loop aerial are useful on the surface to allow the location of the strongest signal. Due to variable surface geology and surface topological features, the signal to noise ratio can vary dramatically. Once a good location has been found, the earth current radio can be installed there.

This technique was used in order to establish the link with the lower part of the Berger and the surface though in fact the point used was, in fact, close to that identified from the geological map as the theoretically best location. We also use a Lowe 150HF receiver (which operates down to

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30kHz) on the surface [illegible] gives a very clear [illegible] reception and w[illegible] with earth electrodes. It is superior to all our home built apparatus.
L[illegible]ers are also used u[illegible] ve with [illegible] party to a stationary underground base station [illegible] base s[illegible] must be an earth current type to allow the long distance communication to the surface and also to give a strong surface signal which must compete with the surface noise.
A 3-position beacon has been produced which plugs in to the microphone socket (and supplies itself with a few microamps from the PTT pull up resistor) using the sound generator chip UM3561. Three distinct sounds can give three pre-agreed messages such as: alignment, party found rescue over, flood coming take cover for cases where reception is week and voice can not be understood. The circuit uses a 7555 which automatically switches between emission and reception every 5 seconds. This is used during alignment etc. to allow another party to intercept it.
A more portable loop suitable for underground use and allowing reception during progression in the cave has been made using house wiring flexible conduit. The conduit when twisted forms a double loop, which can be carried over the shoulder but by untwisting, can form a large single loop for transmission.
Future Developments
The development of a small pager, that is active during normal progression in the cave, is still required in order to pass simple messages such as “please get your radio out we want to talk”, or “change to plan B”. We have demonstrated the operation of a simple pager using an earth current emitter on the surface and a Rugby receiver type detector (very small) carried in the pocket underground. This device had a limit of reception at about 500m but was quite erratic due to the fact it detects sudden drops in the carrier. Unfortunately by moving the ferrite rod around, spurious sudden drops in the carrier are frequently detected. A triple orthogonal ferrite rod should be tried.
We hope to re-layout the complete transceiver system on a single surface mount board with power amplifier and transformers included. The board should also allow the emission of the carrier alone which can be used as a call sign to activate a buzzer at the receiver in order to ‘wake up’ the other party. To this end the following components have been identified as interesting: AD607, TDA7396 and the Newport transformer 1015. The board should have output IQ facility to allow BPSK detection and emission using a microcontroller chip on a separate board which should also allow interfacing to a further link (e.g. VHF set, cellular phone, SWT etc.).
There are plenty of ideas and most of these have long been discussed within the CREG Journal. Unfortunately there are not enough hours in the day. What is clear, however, is that there is a very high demand here in France for good underground communication systems.

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