Underground Radio Use in Cave Rescue Operations

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Abstract

Since 1997, the Walker County, Georgia, cave rescue team has been experimenting with low frequency underground radios for use in cave rescue communication systems. Using 185kHz single sideband radios with loop antennas, we have conducted tests in several caves in the Southeastern US. In the last year, improvements in equipment and operating procedures have increased the working range of these radios from 200 meters to almost 1,000 meters through the rock, with depth up to 250 meters. Our objective has been to develop a lightweight, mobile, underground radio communications system for use in long and deep cave systems where field phones are difficult to deploy and use. Further, we hope that such a radio system will allow an initial response team to establish communications with the surface immediately upon arrival at an accident site, providing more timely information for planning and decision making. Use of the radios in the March 1999 Ellisons Cave operation demonstrated their effectiveness as both a supplement and an alternative to wireline phone systems.

Introduction

In early 1996 Walker County Emergency Management Agency in Georgia, USA, obtained three CB Transverter cave radios made by Ian Drummond for use in cave rescues, primarily at Ellisons Cave. Deep pits and long distances have created difficulties for field-phone communications in previous incidents. The cave has entrances on opposite flanks of Pigeon Mountain, one connecting via Fantastic Pit (free-hanging, 156 meters), the other via Incredible Pit (free-hanging, 134 meters). The two pits are 1,300 meters apart, separated by winding horizontal passages that cross under the center of the mountain with typical overburden exceeding 400 meters. An accident under the center of the mountain would require field telephones to be run through more than two kilometers of passage and down pits totaling more than 215 meters in depth.

Early Tests

In the initial tests, one radio was deployed on the surface directly above Fantastic Pit and another was taken into the cave. Both radios were equipped with the one-meter-square loop antenna. As supplied, the radios were able to provide communication in the passages above Fantastic Pit and from the top of the pit to the surface 70 meters above. They could not, however, provide a link from the bottom of the pit to the entrance (335 meters horizontally, 216 meters depth), nor into the extensive horizontal passages running under the ridge of the mountain. Contact from the bottom of Fantastic Pit to the surface directly above (240 meters) was barely possible, though not of sufficient quality or reliability for rescue use. Atmospheric noise was a significant problem for the surface radio.

The rescue group wished to extend the range of the radios and through a dialogue between Bill Putnam and Ian Drummond decided to experiment with two parameters: operating procedures and antenna size. Both these methods are relatively cheap to implement compared to methods such as increasing power to 20 or even 100 watts.

The basic concept of the operating procedure was to position the surface antenna to minimize atmospheric noise, then rotate the underground antenna to maximize the received signal. This was moderately effective until we decided to try moving the surface radio into the cave entrance passage to shield it. About 30 meters into the cave the overburden has risen to approximately 20 to 30 meters. With hindsight it is possible to calculate the attenuation of the ground which turns out to be about 17dB (a factor of 7.4). The beneficial effect of this natural shielding was immediately apparent when we made our first transmission from the new location. With no other changes, we were able to achieve full communication from the entrance station to the bottom of Fantastic Pit, 400 meters straight through the limestone.

In considering the effect of antenna size, increasing the area of an antenna while keeping the wire size and number of turns constant will always increase the antenna efficiency and hence the distance that the transmitter can be from a given receiver. The effect on reception depends on whether the receiver is limited by atmospheric noise or by the electronic noise floor of the receiver. If the radio is atmospheric noise limited, increasing the antenna size will increase both signal and noise levels without changing the signal to noise ratio. However, if the receiver is noise floor limited, a larger antenna will increase the signal without increasing the noise, and hence increase the distance the receiver can hear a given transmitter. At Ellisons the deep underground radio was noise floor limited. Hence a bigger antenna would increase the distance it could hear the surface radio as well as the distance it could transmit to the surface. A two-meter-square, two-turn loop was constructed for use deep underground.

Specifications

The specifications of the cave radios were as follows:

- Operating frequency and mode: 185 kHz, choice of lower or upper sideband.
- Two watts of RF power was supplied to a one-meter-square antenna with three turns of 16 AWG (0.129 cm diameter) wire.

New Techniques and Equipment

The ideas and equipment were tested by Bill Putnam, Kris Green, Eddie Foust, and Buddy Lane in Ellisons Cave in September 1998. One radio was located about 30 meters inside the main entrance. Another was placed at the top of the first pit (40 meters deep), about 275 meters in from the entrance. Both of these radios used the one-meter-square loop. The third radio, equipped with the new two-meter loop as well as the original one-meter loop, was taken to Fantastic Pit and beyond.

When the radios were tested from the top of Fantastic Pit prior to the descent, the improvement over the previous trial was quite dramatic. At the bottom of the pit, the two-meter antenna provided excellent quality voice communication with both stations in the upper cave. The one-meter loop also gave acceptable performance (though with about half the signal strength), even though the distance to the entrance station was more than twice the distance to the surface location used in the earlier attempt. After extensive testing the underground party was able to proceed to a point 670 meters horizontally and 243 meters below the entrance and still maintain two-way voice communication. This is a major increase in the performance of the system at reasonable cost.

What is more, the party was not over. The entrance radio, shielded by the overburden, was now noise floor limited and could use a loop larger than one-meter to extend the two-way range. Who knows how large the deep underground loop could be before atmospheric noise becomes a factor in limiting its performance? And finally, we have been using only two watts output power, while the antennas have been constructed to handle up to 20 watts. Boosting the power is expensive compared to enlarging the antenna, but we can consider it when we reach the practical limits of antenna size.

We also decided to try coaxial extension cables for the entrance station antenna so that we may position the loop within the cave and the operator outside at the entrance with other rescue personnel. This will allow the radio and operator to be protected from adverse cave environments and still take advantage of natural noise shielding while providing for centralized communications at the entrance during rescue operations. Feed line loss is almost negligible at 185 Khz, so noise pick-up will be the determining factor on cable length and type.

This technique was tested in November 1998 by Bill Putnam and Diane Cousineau at Ellisons Cave. We used a 30-meter coaxial cable (50 ohm, commonly used for computer networking) to place the antenna about 25 meters inside the cave with the base unit and operator located just outside the cave entrance. Communication between the entrance and the Warm Up Pit area was easily achieved, with no noticeable adverse effects from the use of the extension. We feel comfortable that extensions up to 100 meters should be useable without loss of signal.

Further Tests

On January 6, 1999, Bill Putnam, Diane Cousineau, Jeff Adams, Eddie Foust, Geri Foust, Kris Green, and Damon Keyes returned to Ellisons cave for additional testing. The team was now equipped with two-meter loop antennas for all radios, as well as a four-meter antenna for the deep station. We also carried a 30-meter coaxial extension cable for use with the entrance radio antenna.

Fixed stations were set up at the cave entrance and at the top of Fantastic Pit, and the third radio (the "deep station") was taken down the 178-meter pit and through the lower levels of the cave. The entrance station was about 70 meters inside the cave entrance to take advantage of the natural shielding and warmer in-cave temperature. Both fixed stations in the upper cave used the new two-meter loop antennas. The deep team carried both two-meter and four-meter loops.

Using the two-meter loops on all stations, working range was extended to about 670 meters through the rock, a 22% increase from the previous figure of 550 meters. Using the four-meter loop at the bottom station, we worked a maximum range of 850 meters. At that distance the two-meter loop did not work and the four-meter loop was marginal. I believe that the four-meter loop would have been OK at 800 meters. That represents a 44% increase from the earlier trip. Surface noise was a problem at the entrance station, even though it was 50 to 75 meters into the cave. That may have been due to stormy weather to the west.

We tried the two-meter loop at all stations. It worked fine out to the North Pole (550 meters), but was not as good as we had hoped at the Gnome Creamery (670 meters from the Entrance station, 610 meters from the Fantastic Pit station). We could reach the entrance with it, which we could not do last time, and the bottom crew could hear them faintly but clearly, but the entrance station could only copy about 50% of our transmission due to background noise. The Fantastic Pit station could copy 100%—they were about 60 meters closer and had better shielding from the background noise. I believe that the extra shielding rather than the shorter distance was the key. The four-meter loop gave much better results, with 100% copy from bottom to entrance, but it was still faint. It was solid for contact with the Fantastic Pit station.

At the final station, the W90 Junction (850 meters from the Entrance station, 790 meters from the Fantastic Pit station), the two-meter loop barely reached the Fantastic Pit station with about 30% copy. The four-meter loop reached both the Entrance and Fantastic Pit stations with 100% copy, but was very faint. The Entrance station had a lot of trouble understanding us due to the faint signal and high background noise.

Based on this, I believe that the maximum working range of the current radios using two-meter loop antennas is about 670 meters if both stations are well shielded from background noise. Using the four-meter loop for the bottom station increases the working range to about 800 meters, an increase of about 18% over the two-meter loop. It will be necessary to test the radios in other caves and other regions to before we can be confident that these figures are generally applicable.

We also made a number of tests and observations about antenna orientation, which confirmed our previous observations. Laying the antennas flat on the ground reduces the range dramatically. In that configuration the radios barely reach from the Entrance to the bottom of Fantastic Pit. The best performance is always obtained by holding the antenna in a vertical plane and rotating it about a vertical axis so that both antennas are in the same azimuth plane. This technique requires that all antennas be used underground for shielding from surface noise.

The four-meter loop was difficult to deploy and use underground. We did not have a frame for it, but used a combination of "clothesline" and poles made from the two-meter frame to raise and orient the loop. Raising it was not too difficult, but changing the orientation was. We hung the antenna from a five-millimeter accessory cord "clothesline" strung across the passage at the proper orientation. The top corners of the loop were secured to the line using electrical tape. We then joined the PVC segments of the two-meter loop frame to make two 2.8-meter poles, which we used to hoist the line until it was about four meters off the floor. The bottom corners were secured to handy rocks with bungee cords. This method would work OK as long as you have two, four-meter poles, 15 meters of cord, and places to tie it off in the right orientation. The proper orientation can be determined from a map of the cave showing the station locations.

As a practical note for any future operations in Ellisons, placing a radio at the top of the Warm Up Pit should give adequate shielding and allow communication with locations in the bottom cave out to and beyond the mid-point between Fantastic Pit and Incredible Pit. If atmospheric conditions are quiet, a station at the Entrance can also reach the mid-point of the cave. The two-meter loops are adequate, but the four-meter loop does give clearer communication at the extreme range. It is possible to use the two-meter loop to determine the desired orientation and then erect the four-meter loop to match.

March 1999 Rescue Operation

On March 10, 1999, the cave radios were put to the test in an actual mission when the Walker County cave rescue team was called to Ellisons cave for a caver stranded on rope in 134-meter Incredible Pit. The radios were used to provide essential communications for command and control of the operation. Unfortunately, the team arrived to find the stranded caver already dead, probably from hypothermia and/or harness hang syndrome, so the operation was a recovery rather than a rescue.

One radio was deployed on the surface at the Incident Command location at the top of the mountain about 75 vertical meters above the Stairstep Entrance to the cave. A second radio was set up in the Waterfall Room at the bottom of the entrance pit. That one was about 45 meters below the entrance and about 120 meters below the Incident Command station. The third radio was taken down to the top of Incredible Pit, about 75 meters below the entrance and about 150 meters below the Incident Command location. The two underground radios were sent in with the initial response team and deployed immediately upon arrival at the designated locations.

From the Waterfall Room to Incredible Pit was 152 meters at bearing 80 degrees and down 45 meters. From the Waterfall Room to Incident Command was 230 meters at bearing 160 degrees, and up 120 meters. From the top of Incredible Pit to the Incident Command station was about 260 meters at bearing 195, and up 150 meters.

The antenna at the Incident Command station on the surface was initially deployed flat on the ground to minimize background noise. Later it was found that it worked better in a vertical orientation for communication with the Waterfall Room station. Background noise prevented communication with the Incredible Pit station except for occasional faint reception during lulls in the noise. The noise was not too bad until the sun rose, caused varying difficulties through the day, and subsided somewhat after sunset.

The Waterfall Room station was able to communicate clearly with both of the other stations, and was used as a relay throughout the operation. Its antenna was initially deployed horizontally to match the surface station, but we soon found that the vertical orientation worked better. When the Incredible Pit station came on the air, we found an orientation that allowed communication with both stations without moving the antenna. It was vertical, and oriented at approximately 80 degrees. At that time the other two stations both had their antennas in the horizontal orientation. The Waterfall Room antenna remained in its vertical orientation for the rest of the operation. Some background noise (probably distant lightning) was heard late in the operation (Wednesday evening) but it did not cause a problem.

Wired field telephones (U.S. military surplus) were also deployed as far as the second pit, 100 meters beyond the Waterfall Room, but they failed mid-way through the operation. Hand-held VHF radios were used at the entrance pit and at the second pit to communicate up and down the drops. The cave radios were the primary communication channel for command and control, and provided excellent service until the very end of the operation, when batteries began to fail after over 15 hours of use.

The almost 90-degree angular separation between the Incident Command station and the other two stations helps explain why the Incident Command and Incredible Pit stations could not communicate directly. Had we oriented the antennas better, we might have been able to gain direct communication. We did not use a map to try this. The Incredible Pit antenna could not have been oriented along a 195-degree azimuth because of the passage size and shape (narrow canyon running along bearing 80 degrees).

The Next Generation

We have two projects underway to improve the efficiency and range of the radios. The first is the development of a combined transceiver/transverter unit, combining a 20-meter amateur radio transceiver with the 185 khz transverter. By integrating the two components, we can decrease overall package size and decrease power consumption. The current system uses a citizen's band radio to drive the transverter, and most of the 5-watt output of the CB is wasted. The ½-watt output of the 20-meter ham transceiver is better matched to the transverter's input power requirement, so less power is wasted.

The second project is the development of an in-line booster amplifier capable of output at 2, 6, or 20 watts. This external amplifier is coupled in-line between the transverter and the loop antenna and is user-selectable for low, medium, and high power transmission. Our antennas are already designed for 20 watts, so no modifications will be required to take advantage of the higher power level. We hope that by boosting the power to 20 watts we can achieve through-the-rock communication of more than 1,000 meters.

Summary

We are satisfied that the concepts of shielding the surface radio in a cave entrance, and using an asymmetric antenna configuration can significantly increase the range of cave radio systems at relatively low cost and low operational complexity. Our experiences in the March 1999 Ellisons Cave operation demonstrated effective use of the cave radio systems in actual mission conditions. The radios provided critical communications with rapid deployment, and functioned as intended while conventional wireline phones failed. We hope that further development and testing will increase the working range to more than 1,600 meters through the rock, allowing wireless voice communication to the bottom of the deepest caves in North America.

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