## ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH

# Final Technical Report

# “Investigation of Improved Communication from Portable Refuge Alternatives to Facilitate Mine Escape and Rescue”

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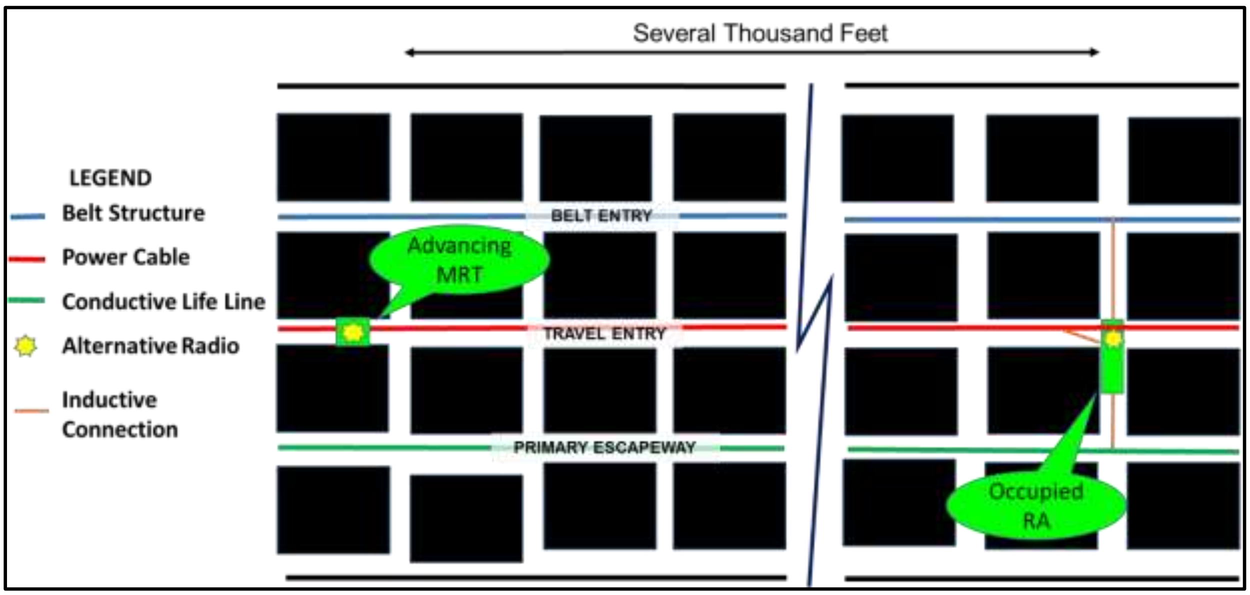
# 1.0 Executive Summary

Section 2 Emergency Response, Subsection 3(b)(E)(i) of Public Law PL 109-236 (S 2803), known as both the “Mine Improvement and New Emergency Response Act of 2006" and the "MINER Act"), requires mines operators to “provide for a redundant means of communication with the surface for persons underground, such as secondary telephone or equivalent two-way communication.” Interpretation of this portion of the MINER Act requires that mine operators must provide two separate methods of communication between the surface and miners underground. However, a mine emergency may disrupt the normal, established means for in-mine communication such as hardwired pager phone and wireless mesh node systems. If disruption occurs, miners taking shelter in a portable underground refuge alternative (RA), commonly connected to a pager phone system, do not have any other means to communicate their location and other potentially vital information to coordinate with others, either outside of the mine or approaching underground, and thus contribute to their own rescue.

The general objective of this research was to investigate relatively inexpensive, easily deployed post-event communication from inside RAs to offer alternative emergency communication links. The original research plan envisioned modification of a commercially available very low frequency (VLF) (5 kHz) through-the-earth (TTE) system along with standard RA construction. Interoperability of the VLF system with elements of a common 900 MHz in-mine radio system that comprise an emergency communication system maintained by the Mine Safety and Health Administration (MSHA) and employed by mine rescue teams (MRTs) would also be evaluated. Subsequently, consideration of an inductive, medium frequency (450 kHz) in-mine communication system as another alternative was included in the research plan without incurring any additional project time or cost. Current hurdles to introduction of alternative means for emergency communication from underground RAs include system capital and maintenance costs, ease of use, RA internal storage space constraints, and integration of the alternatives with either existing in-mine communications systems or those used during mine rescue operations. Specific objectives of this research effort were to investigate and demonstrate possible means to overcome these hurdles.

The research program consisted of collecting information to identify the most common RA types and underground mine communication systems, making minor modifications to standard radio equipment, becoming familiar with inflatable RA construction and use, and collection of field data to assess potential performance of the modified communications equipment for RA application. The program also focused on the feasibility of how the miners could use these systems.

The Innovative Wireless Technologies (IWT) 900 MHz UHF portable communications equipment and the Kutta Radios (Kutta) 450 kHz medium frequency radios are both MSHA-approved commercial off-the-shelf systems that could be integrated into both recommended RA activation and use procedures and mine rescue team operation with a relatively small amount of additional development. As suggested by the following schematic diagram, either of these two systems might serve as an alternative to provide critical information to rescue teams approaching through the mine while they are still several thousand feet from the RA. Since MRTs attempt to advance through a mine in approximately 1,000-foot increments, any alternative emergency communication range exceeding that distance could possibly make the difference between either a timely rescue or a subsequent recovery operation.




**Schematic mine plan diagram indicating how either of two alternative radio systems could allow sheltering miners to communicate with an advancing MRT.**

In the case of the IWT system, the RA occupants could employ an IWT Portable Mesh Node (PMN) signal booster stored outside the RA but then operated from inside the RA to communicate with the MRT. MSHA MRTs and many state MRTs already employ compatible IWT equipment. In the underground environment, effective communications using UHF signals require line-of-sight between units limiting their use to a common entry (as indicated in the diagram). Mine rescue protocol generally requires the team to install PMN's every 500 feet in the travel entry, but communication has been supported at distances approaching 2,000 feet, depending on underground conditions.

The Kutta system enables long distance voice communication by inductively linking signals on conductive (metal) infrastructure such as intact belt conveyor structure or large power cables that run throughout most mines. Railroad rail used for transport in some mines could also serve as an inductive path as would mandated emergency escape lifelines if constructed with a metal wire core. In this instance, a hardwire connection would be made between the RA and any or all nearby lengthy conductors. Orange lines in the diagram radiating from the RA indicate these connections. The MRT would then employ a Kutta unit as it advances in any entry containing suitable infrastructure to detect transmissions from the RA. Depending upon the continuity of the infrastructure, Kutta claims "miles" of range for 2-way voice communication. This study demonstrated robust communications up to the total 2,500-foot length of wire obtained for evaluation and used as a surrogate for mine infrastructure. The study also demonstrated interoperability of the Kutta and IWT systems such that an IWT radio was substituted for the standard Kutta hand speaker/microphone. This substitution would streamline MRT use of the Kutta radio during its advance and then possibly permit direct communication between RA occupants and the rescue operation Command Center through the IWT system once initial contact is achieved. In this instance, the back-up MRT establishing fresh air bases outby the advancing MRT might also use a Kutta radio to monitor and communicate with trapped miners. The Kutta system also offers the possibility of communication between separate occupied RAs should their radios be connected to the same mine infrastructure.

The 5 kHz Vital Alert (VA) VLF TTE communication system offers both TTE and inductive communication capabilities. However, both capabilities would be difficult for miners to set up and use to assist in their own rescue. The required MSHA-approved units are cumbersome, more costly than their non-approved counterparts, and currently not in production. Furthermore, the effective range of two-way VLF TTE communication is limited and highly dependent upon local geologic conditions. The best possible application of the current VA VLF system for the RA application would be in mines with maximum overburden thickness less than 500 feet. Even then, VLF system performance would have to be evaluated on site to assess its capability to perform effectively at a specific mine location. However, future pairing of a higher power surface-to-underground VLF TTE capability with an underground-to-surface seismic TTE capability might offer miners sheltering in RAs at depths greater than 500 feet a robust and reliable TTE communication option. Absent any other information, mine rescue operations will focus effort on RA's located in the area of the mine where miners were last known to be working. MSHA's seismic location is set-up above those locations in an attempt establish communications with the miners in or near a RA. This protocol is followed even though there is no current method or means for miners sheltered in an RA to generate seismic signals.

For inductive communication, effective transmission of the VLF signals requires that the conductor that carries those signals must be both continuous and electrically grounded, requirements that can be relaxed for Kutta medium frequency signal transmission. Since these conditions are less likely to exist after a major underground event, and the lengthy transmitter antennas necessary for VLF communications are unwieldy to employ underground, the VA inductive communication capability must be considered less robust than that offered by Kutta.

Thus, this research demonstrated that miners taking shelter in a portable RA could potentially use either of two existing voice communications systems to provide information to their underground rescuers well before the rescuers could reach the RA. Additionally, further investigation is required to develop more effective TTE communication technology to enable miners sheltering at current common mining depths to communicate with rescuers above them at the ground surface.

# 2.0 Problem Statement and Objective

## 2.1 Focus Area

This research addresses the Alpha Foundation "Mine Escape, Rescue, and Training" critical topic of priority interest, specifically "Using Refuge Alternatives as a Base of Operations".

## 2.2 Problem Statement

If a mine emergency disrupts the normal, established means for in-mine communication, miners taking shelter in a portable underground refuge chamber may not have alternative means to communicate their location and other potentially vital information to coordinate with others outside of the mine or approaching underground and thus contribute to their own rescue.

### 2.2.1 Background

After an underground mine emergency such as a major fire or explosion, mine rescue and recovery personnel need the best possible information about the location of any missing miners as well as current mine conditions to guide and focus their response. When miners are missing underground, response time is especially critical, and actual life-or-death decisions may guide the actions of the mine rescue team. Important information about the possible location of any missing miners and post-event underground conditions may be obtained by observing available personnel tracking information and the logged response of in-mine atmospheric monitors, if those systems remain in operation. Interviews can also be conducted with personnel that were underground at the time of the event but were able to successfully exit the mine. Mine atmospheric samples may be collected at portals, shafts, boreholes, or other access points for subsequent analysis.

Depending upon the nature of the emergency, however, the installed underground communications, tracking, and monitoring systems may not remain intact. Since conditions underground may be very dynamic, some personnel interview information may become outdated after only a short time. And due to the time required to collect and analyze mine atmosphere samples from a limited number of discrete points (that may be a significant distance from the actual location of the emergency event), periodic atmospheric sampling can yield only a delayed and inferred indication of current conditions within the mine.

Refuge alternatives (RAs) are designed to shelter trapped miners in a safe environment after a fire or explosion until mine rescuers can safely enter the mine to access the RA and assist the exit of trapped personnel. The regular mine communications system from outside the mine to the RA may be disrupted by the forces of an explosion, the flames or resultant heat of a fire, or the effects of a major ground control failure. In such instances, sheltering miners have no effective means to facilitate their rescue; they are fully dependent on the efforts of others to initially assume their location and, based upon that assumption, devise a plan to affect their rescue. However, if sheltered miners could either re-establish pre-existing communication means or create a new communications link with their rescuers, either through the mine or through the earth, their successful rescue could be expedited.

In response to an emergency where miners remain underground, the top priority of mine rescuers is to determine the actual location of those miners so action can be focused on getting mine rescue teams to that location. If multiple RAs are located in the area of the mine affected by a fire or explosion, the rescuers must take their best guess as to the location of the missing miners and focus their attention in that area. If overburden thickness is less than the local maximum effective communication range of a through-the earth (TTE) system, signals from an underground TTE transceiver might be detected and localized by rescue personnel employing a corresponding TTE transceiver on the surface over the RA location. Communications might then be established with those within the RA. If the mine rescuers were able to both locate and communicate with the sheltered miners, either before entering the mine or as they approached the affected area, they could direct their resources for a timelier rescue.

If trapped miners had sheltered in other nearby RAs, TTE or inductive means of in-mine communications might also be established between the refuge chambers. Critical information might then be shared between the sheltered miners and then relayed to mine rescue personnel at the surface by the chamber with the most robust communication link or with underground mine rescue teams as they approached the location of the nearest chamber.

Although several 2-way TTE communications systems have been commercialized, their widespread use in the underground mining environment has not been embraced for several reasons including significant capital and maintenance costs and cumbersome design and installation requirements that restrict their mobility. Because refuge alternatives may be moved on a relatively frequent basis, it may not practical to recover and redeploy the major elements of a through-the-earth communications system with each move. Also, installation of TTE systems is currently not explicitly required by regulation.

A grant project titled "Operational Sensitivity of Through-The-Earth Communication" was completed in 2016 by the Virginia Center for Coal and Energy Research, Virginia Tech for the Alpha Foundation for the Improvement of Mine Safety and Health (Alpha Foundation Grant AFC113-14)[1]. The project provided much useful and practical information about two types of commercially available through-the-earth communications systems available at that time. That project revealed that TTE system performance may be highly variable even at locations within the same mine. However, the project concluded that even the potentially limited communications capabilities afforded by TTE systems would be beneficial in a situation where conventional communications were completely disabled. Among three topics the report suggested for future evaluation was the expansion of TTE system functionality through interoperability with existing in-mine communications systems.

The intent of the current research effort was to evaluate and demonstrate the feasibility of modifying (1) a commercially available TTE system and (2) an inductive, medium frequency in-mine communication system along with refuge chamber construction to enable less expensive, more easily deployed post-event communication from inside refuge chambers to possibly support other alternative emergency communication links. This work also evaluated the feasibility of sheltered miners to interface both alternative communication systems with a common in-mine radio system, elements of which comprise an emergency communication system maintained by the Mine Safety and Health Administration (MSHA) and employed by rescue teams to enhance their in-mine exploration efficiency. This portion of the work was designed to demonstrate and evaluate the interoperability of these three different systems.

An explosion or fire may occur in any type of underground mine (coal, metal, and non-metal). Although the safety regulations are different for these different types of mines, the need for and use of a refuge chamber is the same: to provide protection for miners that are unable to escape from the mine because of some type of emergency. However, because of the greater inherent hazards generally associated with coal mines, such as explosive gas and dust, and their more rapidly changing location of active mining operations than metal or non-metal mines (which make portable refuge alternative use more likely), enabling post-emergency communication in coal mines was the intended research focus.

## 2.3 Objective

The overall research objective was to develop and demonstrate the technical feasibility of alternative means for reliable emergency communication between occupants of an underground RA with mine personnel on the surface and/or approaching rescue teams or occupants of other nearby refuge alternatives located underground. Modest modifications to both refuge alternative construction and commercial communication systems might better permit occupants of the RA to share critical information to assist in coordinating their rescue or escape. Specifically, current hurdles to widespread use of TTE and medium frequency systems for emergency communication from underground refuge chambers include system capital and maintenance costs, ease of use, and possible integration or parallel use with either existing in-mine communications systems or those used during mine rescue operations. The specific objectives of this research effort were to investigate and demonstrate possible means to address each of these three hurdles.

**<u>Cost:</u>** Existing TTE communications systems are currently available in both MSHA-approved (permissible) and non-permissible versions. The cost of the major permissible TTE system components is significantly greater than the cost of the comparable non-permissible system components. The additional cost of the permissible system discourages sales into the coal mining market. The proposed concept plan was to use the less expensive and more compact non-permissible version of the TTE system transceiver from inside the fresh air (non-explosive) environment of the refuge alternative and isolate that unit with intrinsically safe (IS) barriers from a IS transmitting (TX) and receiving (RX) antennas deployed outside of the chamber. A prototype IS barrier was designed, fabricated, and tested, and then demonstrated during field evaluations.

The inductive medium frequency system evaluated for application to the RA communication problem already possesses MSHA approval for use in underground coal mines. The two challenges associated with its potential use is how to (1) best employ it from within the RA and (2) interface it to the radio system employed by the MSHA mine rescue teams.

**<u>Ease of use:</u>** Equipment that is either stored inside a refuge chamber or stored outside but transported with the chamber and then easily accessed for rapid deployment would offer greater ease of use than an independent, stand-alone system. One goal would be to permit storage of a compact TTE transceiver within the refuge chamber. An IS TTE antenna would also be kept with the RA and deployed either upon RA placement or by the miners when they intend to activate the chamber. In either case, the leads for the deployed antenna would be attached to dedicated terminals on the outside of the chamber. The IS barrier would be installed inside the chamber so that the connection of the stored TTE transceiver would involve simply plugging in a connector cable between the transceiver and a receptacle inside the chamber prior to activating the TTE system.

The possibility of integrating the TTE system antenna into the actual construction of the refuge alternative, thus eliminating the need for the antenna deployment step, was also part of the investigation and evaluation plan.

A major RA manufacturer assisted in identifying and evaluating the issues associated with storing the TTE transceiver in and the antenna outside a common chamber model along with introduction of an IS barrier and its connections to both the internally operated transceiver and the externally connected antenna. Options for use of the inductive medium frequency radio system from inside the chamber were also investigated with the manufacturer's cooperation.

**Integration with existing communications systems:** The manufacturer of a common underground wireless (node mesh) mine communication system and the portable system employed by MSHA during mine rescue operations contributed by providing permissible portable radio units and signal repeater units to extend operational range. The effects of range on their operative was assessed. Also assessed were the means to integrate the operation of the wireless underground system components with the capabilities of both the TTE and medium frequency system. Successful system integration might possibly streamline the flow of communications between the sheltered miners and the mine rescue Command Center through the underground mine rescue team's communication system. A hybrid type of communication employing both wireless and alternative system components also might yield a more robust and efficient emergency communication system than either employed independently.

# 3.0 Research Approach

## 3.1 Study Design and Methodology

The proposed research plan encompassed both generalized topic investigations and focused equipment feasibility tests involving specific, but representative equipment types.

The conclusion of Alpha Foundation Grant AFC113-14[1] indicated the need to continue research in the VLF TTE communications area. Investigation and demonstration of use of a wireless system and its possible integration with a TTE system is an obvious enhancement to mine rescue communications especially with the wireless underground communication system now employed by MSHA during actual mine rescue operations. Often a sound technical problem solution overlooks important practical (logistical, policy, cultural) issues associated with its possible acceptance and implementation. As noted above, cost and ease of use issues may already be impediments to implementation of any alternative refuge chamber communication capability. To proactively address the possibility of neglecting other practical issues, the research approach was intended to investigate not only the potential effectiveness of modest communication system modifications but also the practicality of how the equipment may actually be modified and then employed during an emergency situation.

Based upon (1) a thorough review of applicable mine rescue operation procedures and requirements, (2) a survey of fielded refuge alternative types, and (3) review of the current published capabilities of state-of-the art TTE and atypical in-mine communications systems, an initial, preliminary concept of operations (CONOP) for alternative underground communication from refuge chambers was developed. The operational concept included the activation process of the underground TTE and medium frequency radio transceivers proposed for the sheltered miners, the use of the surface TTE transceiver to possibly locate and communicate with the miners underground, and subsequent use of the TTE and/or medium frequency communication technology to contact and communicate with the mine rescue team(s) approaching underground.

The two selected alternative communication systems and the wireless mine rescue communication developed for MSHA were then employed to conduct operational performance evaluations. The intent was to emulate equipment use from the most common, inflatable type of refuge chamber employed in coal mines. Testing was conducted at an underground location to simulate how miners and mine rescuers might deploy and use the systems, to assess the effectiveness of the communications systems with a surface location and a simulated advancing mine rescue team located approximately 1,000 feet from the refuge chamber.

It is recognized that this approach did not gather detailed information on all existing refuge alternative equipment deployed for use in the domestic coal mining industry. Therefore, the approach focused on the most common refuge chamber type. In addition, the approach could not anticipate and evaluate all the possible underground conditions that are known to affect TTE and other wireless communication system performance. A concerted effort was made with a mining company partner, Murray Energy Corporation (MEC), to identify field conditions which best served the objectives of the research plan. It must also be recognized that while the three communications systems selected for evaluation represent the current commercial state-of-the-art, they may not be attractive or practical for implementation by operators in all mines or in all situations.

## 3.2 Specific Tasks

The funded technical program included the four (4) specific tasks summarized below.

**Task 1: Communication System Investigation**

General characteristics of available commercial TTE and wireless communications systems employed by the US coal mining industry were researched and catalogued. These characteristics were compared to those of the three system manufacturers, Vital Alert (VA), Kutta Radios (Kutta), and Innovative Wireless Technologies (IWT), which agreed to support this investigation. Based upon the documented system equipment capabilities (including equipment integration points and requirements) and known mine rescue team operational protocols and methods, a first outline for potential use of this communication equipment by sheltered miners and rescue personnel was developed. High-level equipment performance evaluation protocols were then developed based upon this first outline. Concurrently, VA designed, constructed, and demonstrated IS barriers to isolate one of their non-IS transceivers from IS separate transmitting and receiving antennas and (2) conducted a general analysis to determine the feasibility of integrating a TTE system antenna into the construction of inflatable types of refuge alternatives (see Task 2).

Task 1 Technical Milestones:

- Produce a catalog of available TTE and wireless mine communication systems
- Investigate ability to connect and interface VA and Kutta systems with IWT equipment
- Develop a first outline of possible equipment use scenarios to enhance mine rescue
- Fabricate and test IS antenna barrier performance
- Analyze feasibility of TTE antenna integration into refuge alternative construction
- Develop initial protocol(s) for communications equipment performance evaluation

**Task 2: Refuge Chamber Investigation**

Contemporaneously with Task 1, the various makes and models of refuge alternatives deployed in domestic coal mines were investigated, focusing upon their general physical characteristics and their current in-service populations. The general characteristics of the most commonly deployed chambers deployed models were compared to the characteristics of comparable models marketed by Strata Worldwide (Strata), which also agreed to support this investigation. Representative refuge alternative physical dimensions and construction materials were discussed with VA to enable their Task 1 evaluation of integrated antenna performance. During inspection of Strata chamber models which represent a large percentage of the deployed chambers, efforts were made to identify possible locations for communication equipment storage and installation of the IS antenna barrier and external antenna connections. Combining the Task 1 outline for communication equipment use with Strata's recommended shelter activation procedures yielded a more detailed procedure to propose for emergency communication equipment deployment and use.

Task 2 Technical Milestones:

- Produce a catalog of portable refuge alternatives common in US coal mines
- Identify possible opportunities for communication equipment storage and installation
- Integrate and refine refuge alternative and communication equipment use procedures
- Evaluate feasibility of proposed chamber physical modifications for antenna integration

**Task 3: CONOP and Evaluation Methodology Development**

The draft concept of operations (CONOP) for the enhanced mine rescue communication equipment based upon the Task 1 use scenario and the Task 2 integrated use procedures was reviewed by an experienced mine rescue expert for comment. Concurrently, the draft CONOP was employed to guide preparation of field performance evaluation plans for the modified communications equipment. Cooperating coal company MEC was engaged to arrange the underground evaluations necessary to assess effective TTE and in-mine communications range. The field evaluation plans were provided to VA, Kutta, IWT, Strata and MEC for review and comment. Necessary alterations were identified and long lead-time advance preparations were initiated.

Task 3 Technical Milestones:

- Develop a formal concept of operations (CONOP) for proposed enhanced communication system use
- Prepare drafts of field evaluation plans for review
- Coordinate necessary advance site preparations

**Task 4: Equipment Field Evaluations**

The necessary test equipment was acquired from VA, Kutta, and IWT to develop familiarity with and confidence in its use and identify any necessary field evaluation plan modifications. The first phase of evaluations was conducted at surface locations where more flexible, predictable, and controlled test conditions were present. The second evaluation phase was conducted at a coal mine identified by MEC.

Task 4 Technical Milestones:

- Refine evaluation plans and schedule site visits
- Conduct Phase 1 surface evaluations
- Conduct Phase 2 mine evaluations

# 4.0 Research Findings and Accomplishments

Consistent with the overall research objective to develop and demonstrate the technical feasibility of alternative means for reliable emergency communication between occupants of an RA with mine rescue personnel and/or others trapped underground, the four technical tasks summarized in Section 3.2 were completed. Summaries of the results of each task effort are presented in this section.

## 4.1 Task 1: Communication System Investigation

This section presents the major technical milestones associated with Task 1. These are a survey of commercial mine communications systems employed in the US coal mining industry, investigation of the ability to interface the systems of the three manufacturers [Innovative Wireless Technologies (IWT), Kutta Radios (Kutta) and Vital Alert (VA)] that supported this research, modification of the VA TTE system to possibly permit its direct use from inside and RA, and feasibility assessment of TTE antenna integration into RA construction.

### 4.1.1 Mine Communications Systems

The seven types of communications systems approved for and employed in the underground coal mining industry fall into two general categories:

- Hardwired Systems
  - Pager phones
  - Addressable telephones
  - Trolley wire
- Radio Systems
  - Node-based
  - Leaky feeder
  - Medium frequency
  - Through-the-earth

The next two sections briefly describe each system type.

#### 4.1.1.1 Hardwired Systems

Many mines employ a hardwired system as one of their two required methods of communication from RAs. Such systems were the first means developed for voice communication from the surface to underground locations and between locations throughout the mine. Their long-established position in the industry results from their general reliability, ease of use, and low installation and maintenance costs. Their primary weakness for post-accident communication is the vulnerability of their wires or cables to physical damage. Figure 1 is a schematic diagram of a hardwired system.

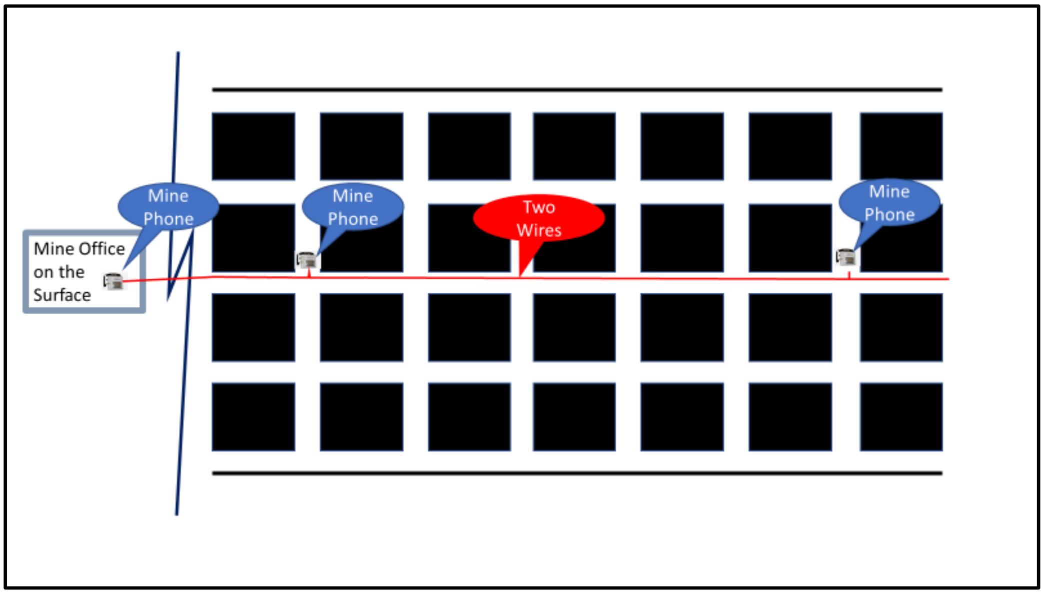



**Figure 1: Schematic diagram of a hardwired communication system.**

Mine pager systems are common. They generally consist on multiple phones connected by two isolated wires. When a page is activated on a basic pager system, it can be heard across all phones on the system. There is no capability for a private conversation or for multiple calls at the same time. Femco, Gaitronics, Genco, Intermountain Electronics, Minesafe, and Pyott-Boone Electronics are some makers of pager phones. Figure 2 offers images of some pager phone units currently available to the mining industry.

**Figure 2: Some pager phones used in the mining industry.**

Mines employing a rail haulage system often use trolley phones that perform like basic pager phones. The trolley electrical power circuit also serves as the communications system conductor. Phones are located in trolley-powered vehicles and at selected locations along or near the rail transportation system running through the mine.

Some mines employ a telephone system similar to a commercial telephone system with individually addressable units. These systems may be either separate from or integrated with the commercial telephone system on the surface. Private conversations and multiple simultaneous calls are possible. Some telephone systems also incorporate paging capabilities.

At least one RA manufacturer maintains connection terminals on the chamber exterior that allows a two-wire system to connect directly to the outside of the chamber. A comparable connection terminal inside the chamber allows the miners to install and use a pager phone while they are in the chamber.

#### 4.1.1.2 Radio Systems

The confines of the underground working environment generally limit the operating range of commercial very high frequency (VHF) (typically 30 MHz to 300MHz) and ultra-high frequency (UHF) (typically 300 MHz to 3 GHz) radios to line-of-sight operation, rarely more than 1000 feet. Therefore, radio communication systems effective for coal mining applications must employ either multiple repeater stations installed throughout the mine, other special infrastructure, or lower operating frequencies that offer longer distance capabilities.

**Node-based systems:** A node-based system is comprised of a network of portable VHF or UHF radios and signal repeaters (nodes). An "access" node captures signals from individual mobile radios while "backhaul" nodes (or other system infrastructure) relay the signals between adjacent nodes in the mine and, ultimately, to the surface. The backhaul capability may be wireless, wired, or a combination of both. Installation of multiple nodes provide communications throughout the mine, and may be configured to form a node "mesh" with multiple redundant communications paths permitting continuous communication even if some nodes are not operational. Figure 3 is schematic representation of a node-based System.

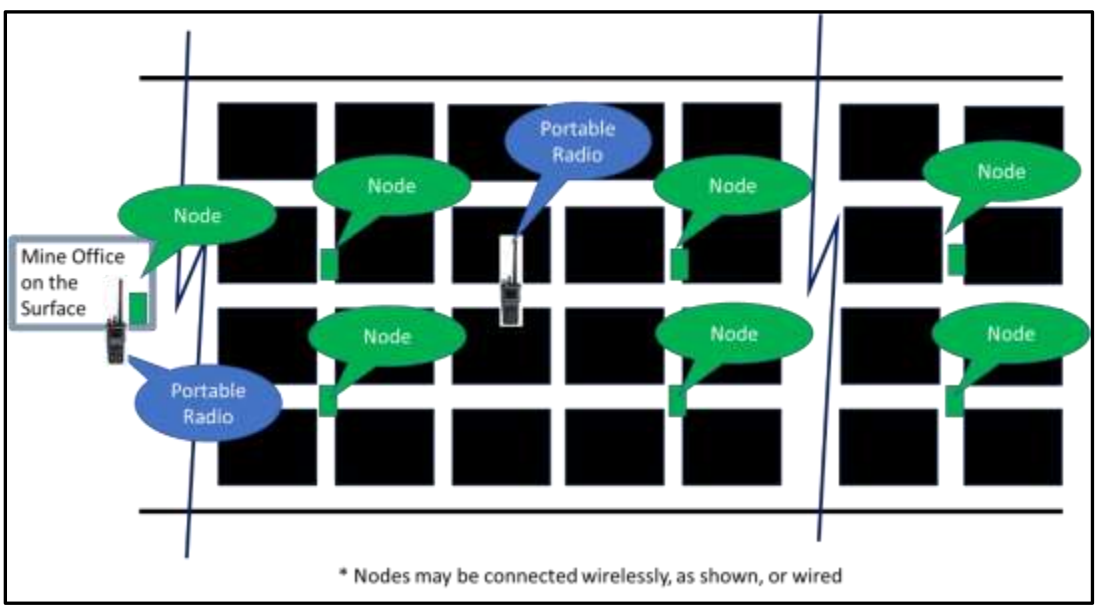



**Figure 3: Typical node-based communication system.**

Vendors include American Mine Research Inc., Conspec Controls, Immersive Technologies LLC, Innovative Wireless Technologies, InSet Systems LLC, Matrix Design Group LLC, Mine Site Technologies, Newtrax Technologies, NL Technologies, Rajant Corporation, Strata Safety Products, and Venture Design Services Inc. Figure 4 offers an example of equipment associated with a specific node-based system.

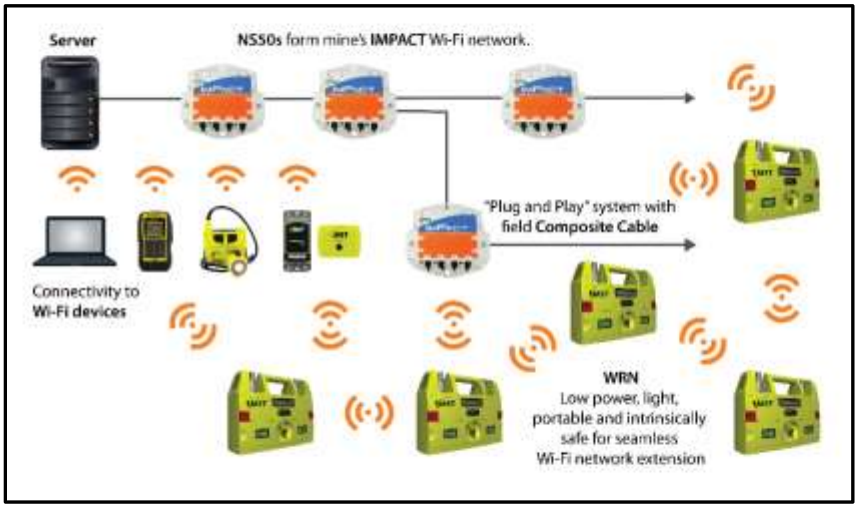



**Figure 4: Typical equipment components of a node-based system (courtesy Mine Site Technologies).**

**Leaky feeder systems:** A leaky feeder system generally involves a base station at the surface connected to an antenna system distributed underground throughout the mine. These systems also employ two-way radios operating in the VHF or UHF bands. A specially designed coaxial cable, also called leaky feeder cable, is installed along and into the normally traveled entries in the mine. The cable has openings in its outer shield to permit coupling of the radio signals into the cable enabling continuous communication coverage in these traveled entries. Since the leaky feeder cable may not be able to transport signals the entire length of a mine, signal amplifiers may also be introduced periodically along the cable to boost signal strength. In addition to carrying the RF signal, the coaxial cable may also convey power to the amplifiers if other underground supplies do not provide power. Figure 5 is a schematic representation of a leaky feeder system.

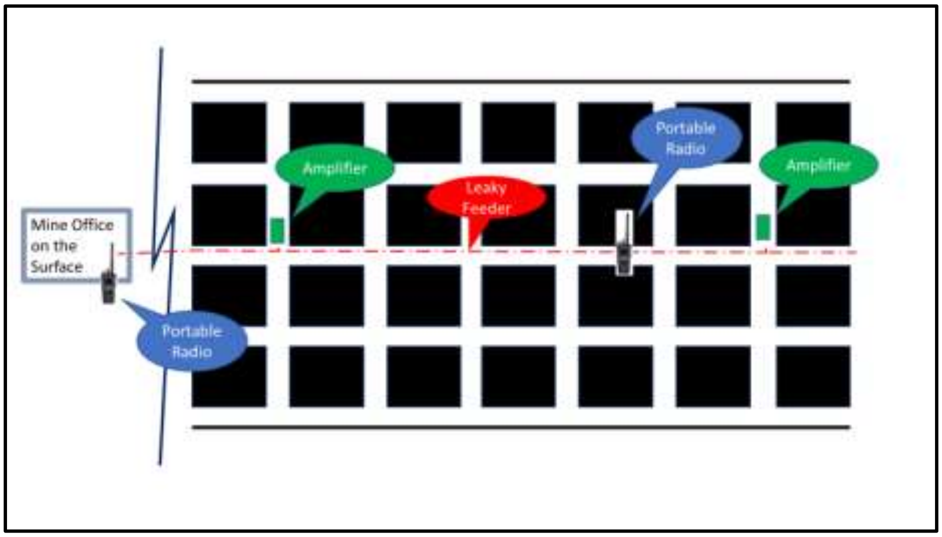



**Figure 5: Schematic of a leaky feeder communication system.**

Figure 6 represents the communication signal exchange associated with leaky feeder cable. A representative leaky feeder cable signal amplifier is shown in Figure 7.

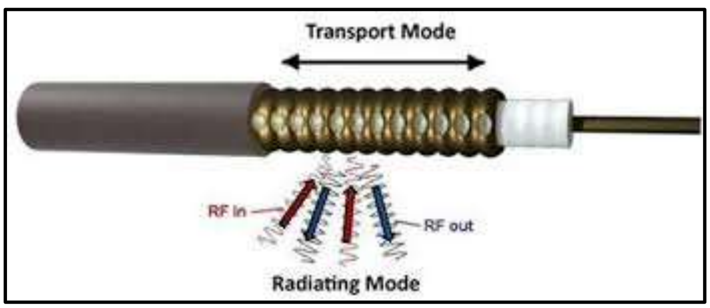



**Figure 6: Leaky feeder cable signal exchange concept.**


**Figure 7: Typical leaky feeder amplifier (courtesy of Mine Site Technologies).**

Some vendors of leaky feeder communication systems include Becker Electronics LTD, MineCom, Pyott Boone, Mine Site Technologies, Raveon, Tunnel Radio of America, and Varis Mine Tech.

**Medium Frequency Systems**: Medium frequency communications systems operate in a manner similar to leaky feeder systems with the exception that the radio signals couple into existing, continuous conductive mine infrastructure such as pipes, electrical cables, and belt conveyor structure. As with leaky feeder systems, medium frequency system communication is limited to those areas where metal conductors are present. Since they operate at lower frequencies (300 kHz to 3 MHz), the medium frequency radios and antennas are generally larger than the portable radios used by other systems making them cumbersome for miners to carry routinely. Figure 8 provides a schematic of a medium frequency system underground installation.

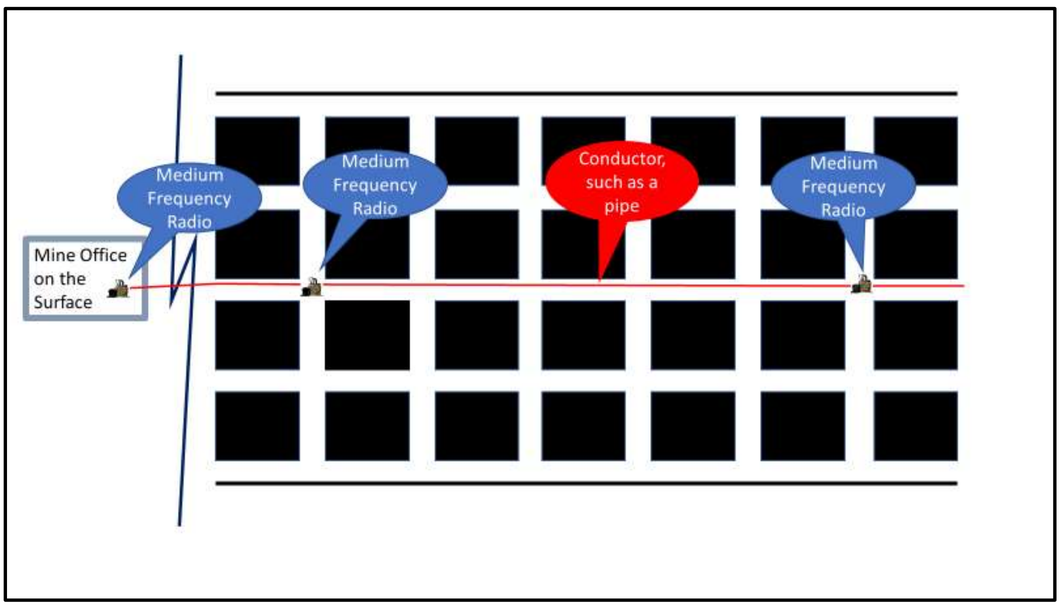



**Figure 8: Schematic diagram of a medium frequency communication system.**

The single domestic vendor of medium frequency communication equipment is Kutta Radios, Inc., and Figure 9 provides images of some of their products.


**Figure 9: Medium frequency radios (courtesy of Kutta Radios, Inc.)**

**Through-the-Earth Systems:** Through-the-earth (TTE) systems are capable of transmitting very low frequency (VLF) (3 KHz to 30 KHz) electromagnetic signals through most rock types possibly enabling communication between miners underground and personnel at the ground surface. Large, fixed antennas are required to both transmit and receive the VLF signals. These signals weaken with increasing distance, and successful communication is highly dependent on the relative antenna location both underground and at the surface above the mine. Because of their low fundamental operating frequency, TTE systems have to employ special signal processing algorithms to enable two-way voice communication. These systems can also support exchange of text messages and transmission of low speed data. Figure 10 represents the elements of a TTE system.

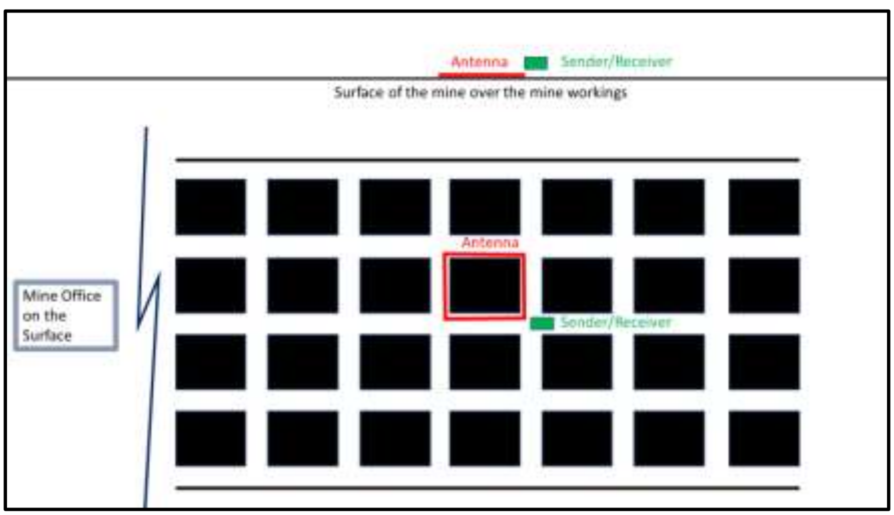



**Figure 10: Typical through-the-earth communication system.**

Some vendors of through the earth system are, E-Spectrum Technologies Inc., Lockheed Martin Corporation, Strata Products Worldwide LLC, and Vital Alert Communications Inc. Figure 11 is a photo of a Vital Alert TTE communications console.

**Figure 11: A TTE radio console (courtesy of Vital Alert Communications).**

In 2017, MSHA conducted a survey of the coal mining industry to determine the types of radio systems being employed underground on a routine basis and the percentage of this market captured by different vendors. Note that the MSHA survey did not consider hardwired communication systems.

The survey results presented in Table 1 indicated that node-based systems accounted for over 50%, of the market while leaky feeder systems accounted for over 20%.

**Table 1: 2017 MSHA Underground Coal Mine Radio System Survey Results**

| Vendor | Radio System Type | Market Share |
|---|---|---|
| Innovative Wireless Technologies | Node Based | 24% |
| Becker Electronics/Varis Mine Tech. | Leaky Feeder | 21% |
| Strata Safety Products, LLC | Node Based, TTE | 17% |
| Matrix Design Group | Node Based | 15% |
| Mine Site Technologies | Node Based | 7% |
| American Mine Research | Node Based | 5% |
| Kutta Radios, Inc. | Medium Frequency, Leaky Feeder | 5% |
| NL Technologies | Node Based | 3% |
| Venture Design Services | Node Based | 2% |
| Tunnel Radio | Leaky Feeder | 1% |

### 4.1.1.3 MSHA Mine Rescue Communication System

After the Sago and Upper Big Branch Mine disasters, MSHA worked with Innovative Wireless Technologies (IWT) to develop a state-of-the-art mine rescue communications system to overcome some shortcomings identified during those mine rescue efforts. The goal of the system is to allow mine rescue teams to explore every entry of the mine simultaneously while remaining in continuous communication with the aboveground emergency Command Center.

MSHA maintains several of the IWT systems throughout the country to provide mine rescue communications after a mine disaster. The systems are included with major caches of equipment maintained by MSHA at the Pittsburgh, PA Mine Emergency Operations Center and at the Denver CO Federal Center. They also maintain these first response communications systems at Beckley, WV, Madisonville, KY and Price, UT. In addition, several coal mining states such as West Virginia and Virginia also maintain caches of this communications equipment.

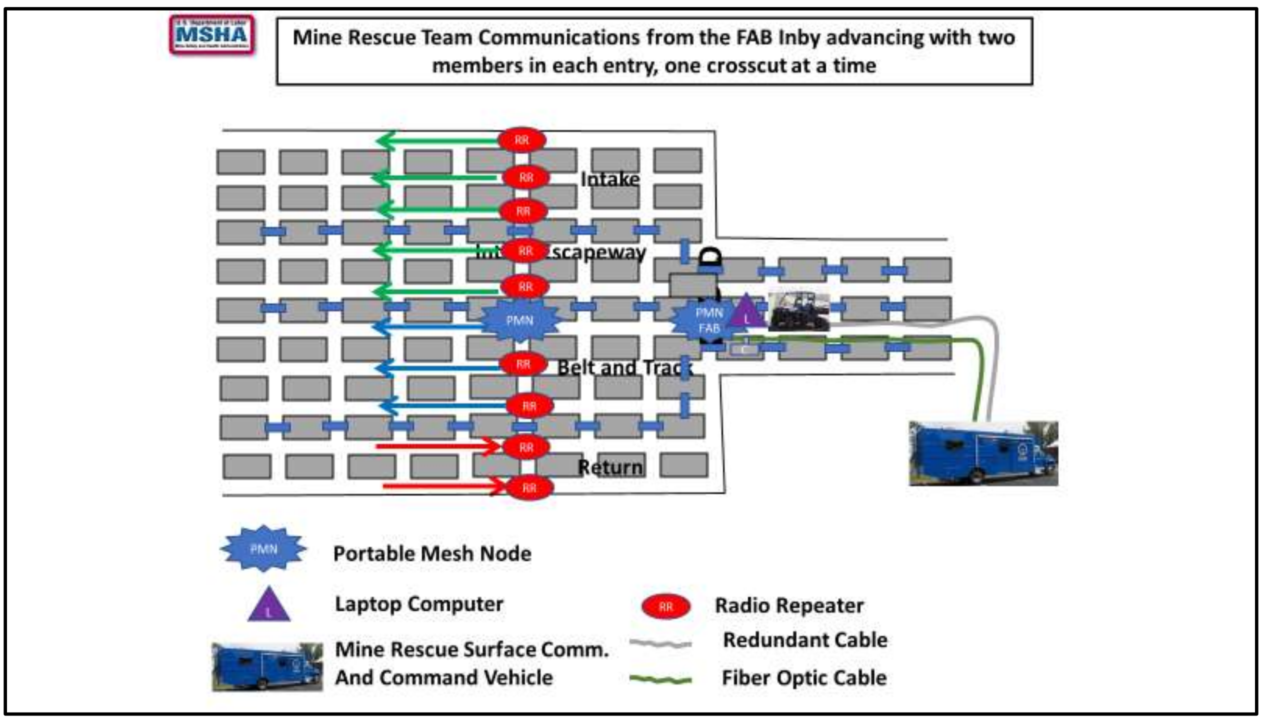



**Figure 12: Typical mine rescue communications system layout.**

Figure 12 represents a typical mine rescue communications system layout. This system consists of portable, hand-held radios ("Radio Repeaters") carried by each MRT member that also serve as a single source repeater. Portable Mesh Nodes (PMNs) with longer transmission range are then used to connect the exploring team to the Fresh Air Base or directly to the surface Command Center. The Fresh Air Base is connected to the surface Command Center through either PMNs or through a fiber optic connection. A portable gateway interfaces the wireless system to a fiber switch that connects the system through fiber optic cable to the surface Command Center. Smart batteries provide power to the various components. Both directional and omnidirectional antennas are available for the PMNs. Figure 13 shows a directional PMN in its operating configuration. Magnets firmly attach the antenna structure to the protective enclosure for the electronics and battery while allowing the antenna to be easily removed. The two branches of the antenna fold down to facilitate PMN storage and transport.


**Figure 13: A directional IWT Portable Mesh Node (PMN) as deployed is about 2 feet high and 4 feet across.**

### 4.1.2 Communications Systems and Refuge Alternative Requirements

In response to loss of life associated with a series of mine disasters in 2003 to 2005, federal legislation was passed and associated MSHA policies were enacted related to introduction and use of improved miner communication, underground miner location tracking, and RAs intended to sustain miners should they become trapped underground. The following section summarizes the current regulations pertaining to emergency RA communications.

In June of 2006, the Mine Improvement and New Emergency Response Act (MINER Act)[2] was passed in an attempt to improve the safety of miners. The Act required:

- "Each underground coal mine operator shall carry out on a continuing basis a program to improve accident preparedness and response at each mine";
- "Not later than 60 days after the date of enactment, each underground coal mine operator shall develop and adopt a written accident response plan that complies with this subsection with respect to each mine of the operator, and periodically update such plans to reflect changes in operations in the mine, advances in technology, or other relevant considerations."
- "Each such operator shall make the accident response plan available to the miners and the miners' representatives."

More specifically, the MINER Act stated, "An accident response plan under subparagraph (A) shall--

(i) provide for the evacuation of all individuals endangered by an emergency; and

(ii) provide for the maintenance of individuals trapped underground in the event that miners are not able to evacuate the mine."

It required mine operators to have underground communications systems that have certain special characteristics. It further stated that "To be approved under subparagraph (C), an accident response plan shall include the following:

(i) POST-ACCIDENT COMMUNICATIONS. The plan shall provide for a redundant means of communication with the surface for persons underground, such as secondary telephone or equivalent two-way communication.

(ii) POST-ACCIDENT TRACKING. Consistent with commercially available technology and with the physical constraints, if any, of the mine, the plan shall provide for above ground personnel to determine the current, or immediately pre-accident, location of all underground personnel. Any system so utilized shall be functional, reliable, and calculated to remain serviceable in a post-accident setting".

It further stated specific requirements for the plan that included:

"(ii) POST-ACCIDENT COMMUNICATIONS. Not later than 3 years after the date of enactment of the Mine Improvement and New Emergency Response Act of 2006, a plan shall, to be approved, provide for post-accident communication between underground and surface personnel via a wireless two-way medium, and provide for an electronic tracking system permitting surface personnel to determine the location of any persons trapped underground or set forth within the plan the reasons such provisions cannot be adopted. Where such plan sets forth the reasons such provisions cannot be adopted, the plan shall also set forth the operator's alternative means of compliance. Such alternative shall approximate, as closely as possible, the degree of functional utility and safety protection provided by the wireless two-way medium and tracking system referred to in this subpart."

Subsequently, as the mining industry, communication system manufacturers, and MSHA reacted to the MINER Act, MSHA issued several Program Policy Letters (PPLs) to establish approval guidelines for communication and tracking devices and as a general statement of policy to provide mine operators guidance in implementing means to address the Act's communication and personnel tracking requirements. Salient excerpts from PPL P11-V-01[3] issued on April 14, 2011, PPL P11-V-134 issued on April 28, 2011, and questions posed in response to P11-V-13 are presented in Appendix 9.1.

Program Policy Letter P11-V-01 was issued to establish approval guidelines for communications and tracking devices. It specifically addresses system components, line powered devices, and untethered devices, and was issued as a general statement of policy to provide mine operators guidance in implementing: (1) alternatives to fully wireless post-accident two-way communication between underground and surface personnel and (2) electronic tracking systems, both of which are required by the MINER Act. It specifically discusses aspects of two-way communications systems such as general considerations, coverage areas, permissibility, standby power, surface communications, survivability, and maintenance. The questions and answers provide specific guidance as the questions relate to the emergency response plan.

A mine's accident or emergency response plan (ERP) required by the MINER Act must include underground communications systems possessing certain special characteristics and capabilities. The redundant means of communication with the surface for individuals underground, such as a secondary telephone system or equivalent two-way communication, must meet specific requirements to be approved:

- Untethered devices not connected to an external power supply, such as hand-held radios, must provide sufficient power to facilitate evacuation and rescue following an accident. They must last at least 4 hours longer than the normal shift duration (12-hour minimum total duration). Mine-specific conditions may warrant more or less capability.
- The two-way communication system under 30 C.F.R. § 75.1600-3(a)(1)[5] (MSHA's standard for a two-way communication facility for refuge alternatives) is not required to be wireless.
- A communication system that is included in the ERP can be used as one of the two communications systems required to meet the requirements of 30 C.F.R. § 75.1600-3(a) (MSHA's standard for two-way communication facility for refuge alternatives)

- An overland link can serve as part of a redundant pathway for communication. It facilitates communication between the surface and underground when one pathway fails. It can be wired or wireless.
- Text messaging can be used for two-way communication including pre-programmed messages that provide enough information to convey status of miners, mine conditions, and appropriate emergency response information.
- If the communication only can communicate via established messages, the mine operators must ensure that all persons who work or travel underground are capable of understanding and responding to those emergency messages.
- An untethered communications device can be used while it is inside a prefabricated steel refuge alternative. There are several methods available for getting communication signals inside a steel RA. For example, external antennas and a suitable coaxial cable can be connected to the handheld device, or external antennas with a suitable transceiver can be built into the RA. Any method that requires placing holes through the structure would require sealing the holes so that the interior of the RA remains airtight and should not violate the RA approval(s) and be done according to the RA manufacturer's recommendations.
- The battery backup capability for stationary communication and tracking systems is generally at least 24 hours. The breathable air requirements for refuge alternatives is at least 96 hours.

Note that a hardwired system would have to be manually connected to a RA. Most RAs have these connectors already in place. The leaky feeder, node-based, medium frequency, and mine rescue systems all use a portable radio that would be able to transmit signals easily through the fabric of inflatable refuge alternatives (see Section 4.2 below). A TTE system may require a special connector to be installed though the wall of a RA if a portable radio is not a part of the TTE system.

On December 12, 2018, a meeting was conducted with personnel from the MSHA Approval and Certification Center in Triadelphia, WV, to discuss the current interpretation of rules for underground communication technology as applied potential use with RAs. The Code of Federal Regulations (CFR) 75.1600-3 requires that RAs shall be provided with a communications system that consists of (1) a two-way communication facility that is a part of the mine communication system, which can be used from inside the RA; and (2) an additional communication system and other requirements as defined in the communications portion of the operator's approved Emergency Response Plan. During the meeting it was disclosed that all mine operators typically provide a pager phone connection as one means of communicating with a RA and then provide a means of connecting to the regular mobile communication system used in the mine. The communication systems must be set-up and tested when the RA is moved into place. However, there are no regulations that stipulate that these standard systems must remain operable post-event.

Specifically related to one thrust of this research study, MSHA does not consider the air inside an RA to be fresh air, despite the fact that it has been treated and the harmful gases have been removed. Therefore, according to current MSHA policy, any communication equipment employed inside the living space of an RA must be approved by MSHA for use in hazardous atmospheres as either explosion proof (XP) or intrinsically safe (IS). This MSHA position was unanticipated and, unless altered in the future, will introduce additional logistical and cost issues for any future installation and use of a Vital Alert TTE system by miners sheltering within a RA.

### 4.1.3 Communication System Interoperability

In the context of this investigation, "interoperability" is defined as the ability of radios from different manufacturers and/or operating at different frequencies to interface with each other. For example, can a short-range UHF radio be employed to communicate with another UHF radio over a greater than normal distance using the capabilities of a longer-range medium frequency units connected to the UHF units? Interoperability between different systems may facilitate use of an alternative communication option by enabling miners to continue to employ during an emergency the radios they use every day.

Inquires made with all three communication system collaborators indicated that interoperability was achievable. A hardwire interface between the IWT system and VA equipment had been previously demonstrated through a separate initiative. Kutta engineers had developed a hardwire connection for UHF radios produced by other manufacturers and perceived little difficulty in replicating that effort for the IWT system.

IWT engineers indicated that their standard MSHA permissible radios work with the Vital Alert system as well as with the MSHA mine rescue communications system (another IWT product). IWT indicated their radio had been hardwired to a Vital Alert Canary Go Box. An interface cable attached to an IWT hand-held radio allows that radio to substitute and function as the hand-held speaker/microphone normally attached to the VA Canary. If a Vital Alert unit interfaced with an IWT hand-held radio were located outside of a refuge chamber, a second IWT radio inside the refuge chamber could remotely activate the VA system to both transmit and receive voice communication.

The IWT engineers also noted that standard IWT radios cannot communicate directly with the IWT MSHA mine rescue communication system that is protected by signal encryption coding. Dedicated mine rescue communications are encrypted to eliminate the possibility of unauthorized personnel either interfering with or eavesdropping on these critically important and highly sensitive communications. The engineers also indicated it is possible to modify their repeater antenna system to maximize radio communications to advancing mine rescue teams. IWT also suggested using the VA system in a horizontal (in-mine) situation.

VA personnel confirmed that they had previously worked with IWT and had successfully interfaced their TTE system with IWT 900MHz hand-held radios. VA and Strata Worldwide also have a previous but limited collaboration history. In 2015, VA discussed integration of their TTE communications systems into the Strata RAs, but Strata decided to independently pursue their own communication system.

In January 2019, Kutta Radios, Inc. (Kutta) agreed to support this research effort as Kutta has developed an MSHA-approved medium frequency radio system that does not depend on the normal in-mine communication network to be functional post-event. Evaluation of the Kutta system as another alternative could be accomplished without incurring any additional project time or cost. The Kutta Digital Radio for Underground Mines (DRUM®) system radios use parasitic propagation of signals along linear, electrically conductive mine infrastructure to send voice and data communications long distances in an underground environment. As discussed in Section 4.1.1.2 above, the medium frequency signals magnetically couple to metallic items commonly found in mine such as leaky feeder cables (powered or un-powered), phone lines, power lines, metal core lifelines, metal pipes, belt structure, and tracks to enable point-to-point voice communication and data transfer for several miles. Kutta agreed to (1) develop a physical interface similar to the previously described IWT/VA interface to connect an IWT radio to their system, also as a substitute for the normal hand-held speaker/microphone, and (2) loan of two radios for the planned field evaluations.

### 4.1.4 TTE IS Barrier Design and Bench Testing

VA was contracted to design, construct, and demonstrate function of intrinsic safety (IS) components and barriers necessary to isolate a non-IS TTE transceiver from its IS antennas. The working concept was that a less expensive and more common VA transceiver might be employed by miners occupying an RA while the large diameter transmitting antenna necessary to enable two-way TTE communications was deployed outside the RA. Figure 14 provides a schematic diagram of this prototype concept.

Rebuilding Their Future Foundation, Inc.

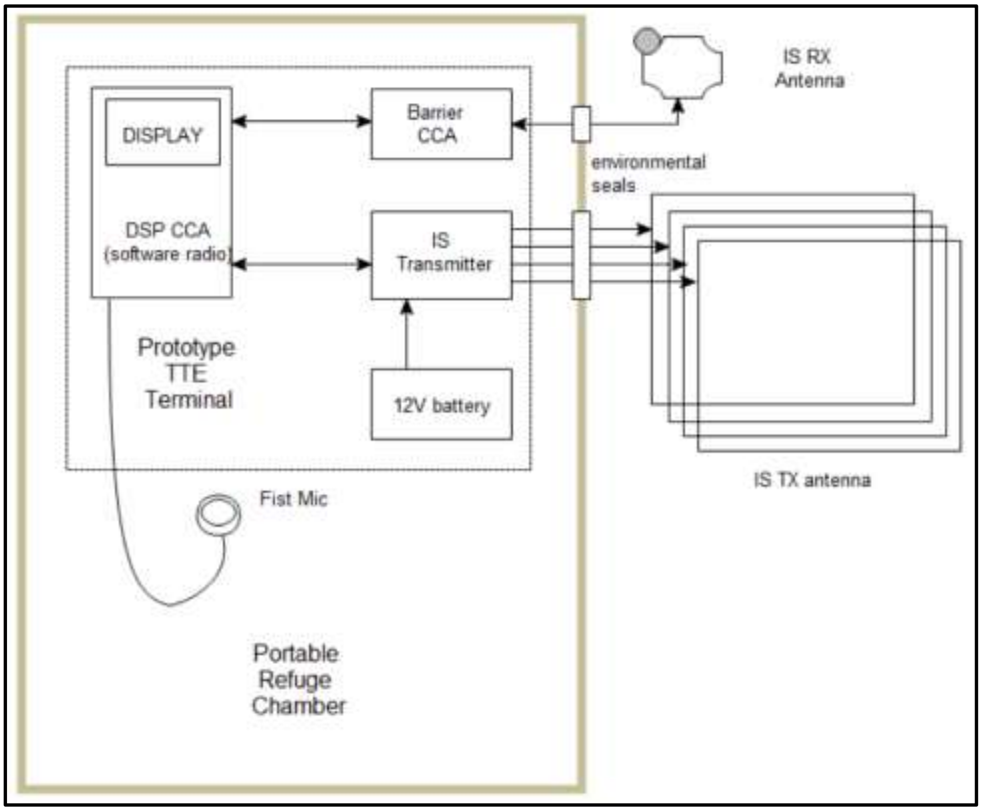



**Figure 14: Schematic representation of the VA prototype RA TTE transceiver concept.**

Inside the portable refuge chamber, the key IS components of the "Prototype TTE Terminal" are the "Barrier CCA (circuit card assembly)" and "IS Transmitter". Both of these are components VA had previously developed for use with their MSHA-approved CanaryComm-IS TTE radio, which is no longer in active production. These two components isolate any excess voltages or currents that might emanate from a standard VA production CommPac unit (the "software radio"). The heart of the software radio is its digital signal processor circuit card assembly or "DSP CCA". The "IS RX Antenna" (receiver) and the 4-conductor, 16-gauge wire "IS TX Antenna" (transmitter) deployed outside the RA are also MSHA-approved. As indicated in Section 4.1.3 above, VA would also provide the physical interface that would enable an IWT hand-held radio to substitute for the "Fist Mic" (speaker/microphone) also indicated in Figure 14. While Vital Alert did not foresee any major integration issues, they anticipated that they might need to tune their radios to better receive signals from an IWT unit and introduce a specialized "black box" to facilitate acceptable signal transfer to their software radio.

The photo of Figure 15 shows the assembled Prototype RA TTE Terminal set up for bench testing and function demonstration in December 2018. The black box immediately evident in the center of the chassis top tray is a standard VA production CommPac TTE software radio. Partially visible inside the chassis below the top tray is the IS Transmitter. A spare 12-volt rechargeable battery board assembly sits on the workbench to the right of the chassis. In this photo, the IWT hand-held radio sitting in front of the chassis is connected as the user interface to the prototype instead of the standard VA speaker/microphone. Barely visible behind the CommPac TTE software radio in the top tray is one side of the small, specialized “black box” VA constructed to facilitate acceptable signal transfer from the IWT radio.

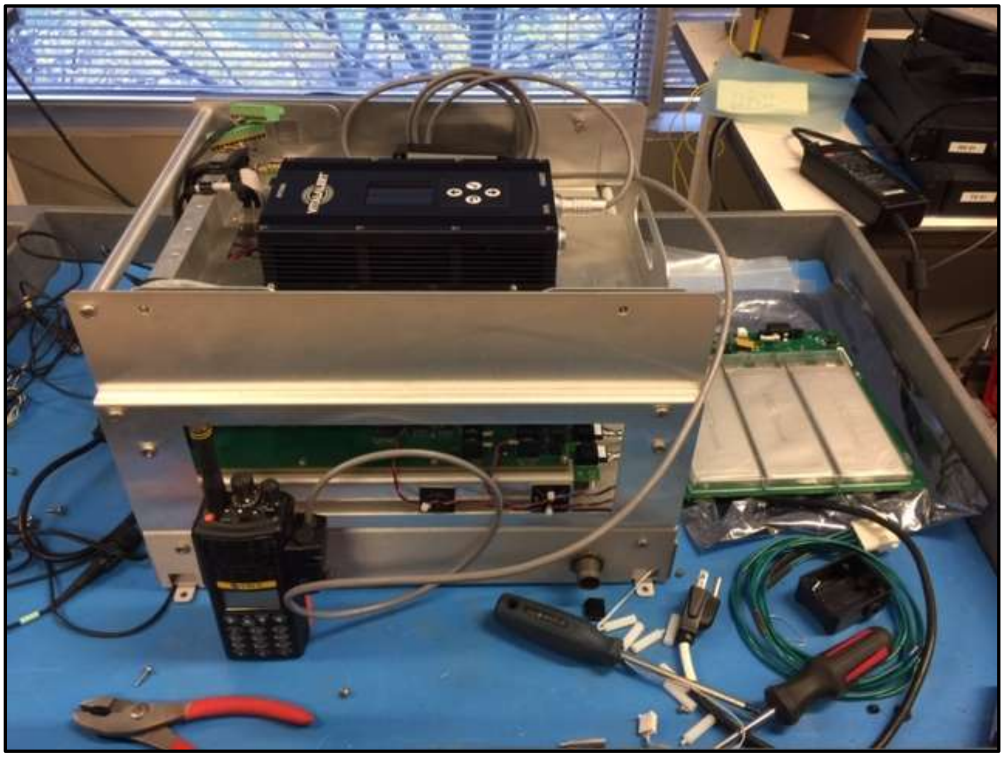


**Figure 15: The assembled Prototype RA TTE Terminal set up for bench testing and function demonstration.**

Vital Alert made all IS modifications to the Prototype RA TTE Terminal following the guidelines used to obtain previous MSHA approval for their CanaryComm-IS radio. The prototype system was successfully demonstrated and evaluated in the lab. Then the system was connected to an IWT radio using the “black box” interface. Communication remained clear and succinct.

The formal VA bench test performance data presented in Appendix 9.2 demonstrates that the integration of the Barrier CCA and the IS Transmitter with the CommPac TTE software radio to assemble the Prototype RA TTE Terminal resulted in no significant performance degradation from performance associated with the standard CommPac TTE software radio.

Also in Appendix 9.2, the theoretical analysis in its Section 4.7 suggests that a maximum anticipated TTE communication range for the Prototype RA TTE Terminal should be approximately 300 meters, or 1000 feet, both vertically through the overburden strata and horizontally through a coal mine. This maximum range is contingent upon two environmental conditions:

1. The background noise level is lower than the receiver noise floor (~9-13 dB with respect to 1 picoTesla, or 9-13 dBpT), so that the sensitivity is not degraded significantly.
2. The overburden conductivity is low, so that additional eddy current losses in the ground remain < 8 dBpT.

Additional discussion with VA indicated that useful VLF signal transmission can occur over longer distances by coupling to long conductors such as in-mine wires, metal pipelines, or track. One restriction is that the TTE signal cannot efficiently span gaps in a conductor, as can medium frequency communication systems.

### 4.1.5 TTE Antenna Integration Feasibility

VA engineers were also engaged about the possibility of integrating a TTE system antenna into the construction of refuge alternatives. The discussion focused primarily antenna configurations and methods of providing adequate antenna area, since area is the predominant factor in determining an antenna's magnetic field strength.

The approximate magnetic moment or field strength for a loop antenna can be calculated using the equation

$$M = nIA$$

where

M = the antenna magnetic moment (indicative of field strength),
n = the number of turns or coils in the antenna loop,
I = the current applied to create the magnetic field, and
A = the area encompassed by antenna.

In this instance, the maximum current (and voltage) that can be applied is limited by MSHA IS requirements. While the number of turns in the antenna may be increased, increasing the total length of the conductor used to make the turns increases the electrical resistance and decreases the current that can be generated by a specific voltage. Increasing the number of turns in a loop antenna also increases the capacitive inductance of the antenna, which also eventually diminishes antenna efficiency. Meanwhile, the encompassed area of an antenna is a product of two linear dimensions: length and width for a rectangle or radius squared times 3.14 for a circle. Therefore, maximizing encompassed area is the most effective means of maximizing antenna strength.

To emphasize this point, a comparison is offered between two different antenna configurations based upon the fixed 500-foot total length of the MSHA-approved VA IS transmitting antenna. The first antenna configuration is a single turn in the form of a square 125 feet on a side. This would approximate wrapping the antenna around a coal pillar underground. The second configuration is a five-turn rectangle 40 feet long and 10 feet wide. This configuration approximates that which might be possible if the 500-foot approved antenna length were incorporated into the floor construction of one of the larger capacity inflatable RAs (see Section 4.2.1 below). As indicated in Table 2, the single-turn, larger loop configuration generates a theoretical magnetic moment over 7.5 times greater than the five-turn configuration.

**Table 2: Antenna Configuration Magnetic Moment Comparison**

| TX Antenna Configuration | Single Turn | Five Turn |
|---|---|---|
| n = the number of turns | 1 | 5 |
| I = applied current (same MSHA maximum for both configurations) | I | I |
| A = encompassed area | 125 ft. x 125 ft. = 15,525 $ft.^2$ | 40 ft. x 10 ft. = 400 $ft.^2$ |
| M = antenna moment | 15,525 (I) | 2,000 (I) |

Therefore, integrating the TTE transmitting antenna into the RA construction is in all probability not a practical idea since the smaller antenna area would greatly reduce the transmitted signal strength and severely limit the effective range of TTE communication.

## 4.2 Task 2: Refuge Alternative Investigation

On June 15, 2006, President George W. Bush signed into law the Mine Improvement and New Emergency Response Act of 2006, commonly known as the MINER Act (Public Law 109-236)[2]. The purpose of this legislation was to amend the Federal Mine Safety and Health Act of 1977 to improve safety and health in America's mines and was the most comprehensive change in federal mine safety laws in nearly 30 years. Section 3b, 2A and 2B(ii) of the MINER Act requires the mine operator to develop an accident response plan and embodied within the plan, the mine operator must “provide for the maintenance of individuals trapped underground in the event that miners are not able to evacuate the mine”.

On December 12, 2008, MSHA published the final rule, Document Number: E8-30669[5], effective March 2, 2009, establishing the requirements for refuge alternatives in underground coal mines and the training of miners in their use. This rule includes testing, performance and approval requirements. The final rule implements Section 13 of the MINER Act.

CFR 75.1506 provides the regulations for RAs including the structural, breathable air, air monitoring, and harmful gas removal components. Concurrently with Task 1, the various makes and models of approved RAs deployed in domestic coal mines were investigated focusing upon their general physical characteristics, the manufacturers' recommended procedures for use in response to a mine emergency, and their relative populations within the coal mining industry.

### 4.2.1 Refuge Alternative Types

Three types of refuge alternatives are permitted by law for use in underground coal mines: built-in-place "safe havens" and two types of moveable refuge chambers, rigid/steel and inflatable.

**Figure 16: Interior of a Strata Worldwide built-in-place Safe Haven.**

Safe havens are stationary shelters developed by taking an existing part of the mine, such as a crosscut, isolating it with one or more bulkheads, and then equipping the shelter for personnel survival and relative comfort (Figure 16). Communication lines are protected from the forces of an explosion or damage from fire because safe havens generally include either a vertical borehole drilled from the surface or protected in-mine compressed air lines to provide a breathable air supply and a reliable, hardwired communication capability. Therefore, communication to and from safe havens is not part of this study because the communication system will likely be functional subsequent to a mine explosion and/or fire.

Steel chambers, made with a rigid shell, remain the same in size, shape, and geometry even when in use (see Figure 17) unless they have been modified to meet recent new standards for providing habitable space. In that case, they may have added an optional inflatable component. These are self-contained units including breathable air and other life-support supplies sufficient to sustain their rated maximum number of occupants for a minimum of 96 hours.


**Figure 17: Strata Worldwide Steel Chamber**.

Inflatable chambers are typically stored in a protective steel housing which also contains all of the systems and materials to enable chamber deployment and subsequent personnel survival. The units increase dramatically in size when an associated sealed, impermeable fabric tent structure is deployed. The largest inflatable chambers are engineered to accommodate up to 36 persons (Figure 18).


**Figure 18: Inflated 36-person chamber.**

The four manufacturers of refuge alternatives in the United States are ChemBio, Eagle Shield LLC, MineARC Systems, and Strata Worldwide/Strata Safety Products.

**ChemBio** is the original inventor and patent holder of the LifeShelter™ that is a rugged, portable, powerless inflatable refuge shelter (Figure 19).

**Figure 19: ChemBio LifeShelter™ with deployed tent.**

ChemBio currently has four units that have received structural approval from MSHA: Model 2428-EX (capacity up to 20 persons), Model 3236-EX (capacity up to 30 persons) and Models 4042-EX and EX-A (capacities up to 34 persons).

**Eagle Shield LLC** (formerly Mine Shield) produces the Guardian Refuge Chamber. Eagle Shield currently has seven walk-in units that have received structural approval from MSHA: Model CF209A, Model CF207A, Model CF208A, Model CF208B, Model CF210A, Model CF204A, and Model CF211A

**MineARC Systems** produces controlled environments and safety technologies for the underground mining, tunneling, chemical processing, disaster relief and biotechnology industries. MineARC Systems specializes in the manufacture and supply of emergency refuge chambers, safe havens, disaster shelters, and grow chambers, as well as a range of remote monitoring, tracking and communications technologies that allow full integration in heavy industrial applications. They provide a variety of underground walk-in chambers (Figure 20). MSHA structural approval has been received for the following models: Model CS-12-77120-CB and Model CS-6-54119-CR.


**Figure 20: MineARC CoalSAFE refuge chamber in an underground mine.**

- CoalSAFE MSHA Low Seam Refuge Chamber is designed for underground coal mines with a minimum seam height of 46 in. The refuge chamber can be custom designed to client specifications, but typically features 12, 16, 20 and 24-person configurations.
- CoalSAFE MSHA Mid Seam Refuge Chamber is designed for underground coal mines with a minimum seam height of 56 in. The refuge chamber can be custom designed to client specifications, but typically features 8, 12, 16 and 20-person configurations.
- CoalSAFE MSHA High Seam Refuge Chamber is designed for underground coal mines with a minimum seam height of 74 in. The refuge chamber can be custom designed to client specifications, but typically features 12, 16, 20 and 24-person configurations.

**Strata Worldwide/Strata Safety Products** ("Strata") designs and manufactures a range of state-of-the-art emergency refuge chambers for mining and construction industries worldwide. In addition to safe havens, Strata offers a wide range of refuge chambers including rigid/steel and inflatable units (Figure 21). MSHA structural approval has been received for the following models: FAB Model S-M2624 and S-M2630, FAB Model S-M3636, S-MC3635, S-M3630, FAB Model S-M1618, FAB Model S-M1020 and S-M1016, Model S-SSC24-2018, Model S-SSC2416.75-2018, Model S-SSC8-2018, Model S-SSC7-61.75-2018. MSHA has also granted approval for the Strata Model XP-AC explosion-proof air conditioning system.


**Figure 21: Strata Worldwide portable Fresh Air Bay.**

The portable Fresh Air Bay is a portable, inflatable refuge chamber that is folded and stored in a 15psi explosion resistant skid mounted steel container (called the Strata Fresh Air Bay Skid) with wheels and a towing package. In an emergency, miners locate the skid and activate air flow using the master control valves. A hinged door on the end of the skid is opened and the folded Fresh Air Bay is manually rolled out. Inflation is initiated by pulling on an activation cable inside the tent access door. Compressed air flows both into air-tight structural beams inflated to hold the tent erect out of the Skid and into the main compartment to maintain a positive pressure and fill it with breathable air. Portable Fresh Air Bays are available in standard and custom sizes to meet specific needs. This includes custom length and heights of the structure. Standard sizes include 10-person, 16-person, 20-person, 25-person, 30-person and 36-person units.

The Strata Safety Coal Refuge Chamber is a rugged, steel-constructed emergency chamber equipped with breathable air. The units have explosion-resistant steel walls and reinforced doors, windows, and hinges designed to withstand up to 15 psi of overpressure. These chambers are available in standard and custom sizes to meet individual needs (including custom length and heights of the structure). Standard rigid chamber sizes include: 10-person, 16-person, 20-person and 24-person units with heights ranging from 64 to 72 in. Where needed, the Strata Safety Refuge Chambers can also be outfitted with an inflatable Fresh Air Bay to increase the inhabitable space in the unit.

Approximately 1,200 movable refuge alternatives are currently in place in domestic underground coal mines. Of these, Strata Worldwide/Strata Safety Products has the largest market share (over 80%) with more than 950 inflatable units and 50-60 rigid steel walk-in units in service. Most if not all of the walk-in units have been placed into underground western coal mines where seam thicknesses and corresponding mine roof height can accommodate the taller rigid units. Next, ChemBio has between 130 to 150 inflatable units underground. Eagle Shield has about 40 walk-in units located in underground coal mines. MineARC Systems has fewer than 20 walk-in units in active service.

### 4.2.2 Alternative Communication System Integration Opportunities

A visit to Strata's RA rebuild facility on October 17, 2018, provided important information related to RA construction, deployment, and use procedures. Observations were made of all components of various sized units. Representative refuge alternative physical dimensions and construction materials were noted for different chamber models to enable discussion of possible integrated antenna performance with VA. The proposed procedure for emergency communication equipment deployment and use (see Task 3 discussion in Section 4.3.2) is based, in part, upon Strata's recommended shelter activation procedures.

As discussed in Section 4.1.5 above, TTE transmitter antenna integration into even the largest inflatable RA is probably not warranted due to the diminished magnetic field strength resulting from a limited antenna area. Therefore, effective use of a TTE communication system will have to rely on a large diameter transmitter antenna being deployed either at the time of refuge chamber placement or stored with the refuge chamber for deployment at the time of need.

Possible suitable locations for alternative communication equipment storage and installation of any IS antenna barriers and external antenna connections were explored with Strata representatives.

With respect to rigid shell steel chambers (Figure 17, Figure 22), there is significant interior space available to store almost any alternative communication equipment, as indicated in Figure 23. However, it must be noted that the closed steel construction of the rigid chambers may pose a challenge to use of a hand-held UHF or VHF radio from inside the chamber: the metal shell may attenuate passage of the high frequency radio signals. To possibly transmit or receive UHF or VHF signals, the radio would have to operate immediately adjacent to the window in the chamber access door. This location would probably also limit communications to only other radios that have direct line-of-sight to the window. A more robust option would be to mount an appropriate omnidirectional UHF/VHF antenna on the outside of the chamber. That exterior antenna would then have a cable leading to the interior of the chamber with a connection that would enable the exterior antenna to be easily substituted for the hand-held unit's standard antenna.


**Figure 22: Strata Worldwide 15-person steel chamber.**

**Figure 23: Interior of a Strata Worldwide 15-person steel chamber.**

On the other hand, the fabric tent material of an inflatable RA (Figure 18) should not be an issue for transmission or reception of UHF or VHF radio signals because the fabric should not attenuate signal transmission.

The interior frame of the tent is a unique design using air-inflated, roll-flat firehoses to keep the tent fully open. Figure 24 shows an interior frame structure assembled with white hoses being pressure tested prior to installation.

**Figure 24: An assembled inflatable RA interior frame structure being pressure tested.**

As shown in Figure 25, the nature of the pressurized firehose frame creates a rigid tent support structure while enabling compact stowing within the end compartment of the fresh air bay storage and transport unit (Figure 26).

**Figure 25: Interior of the fabric tent of an inflated RA.**

**Figure 26: Insertion of a tested fabric tent assembly being in a new protective storage and transport unit.**

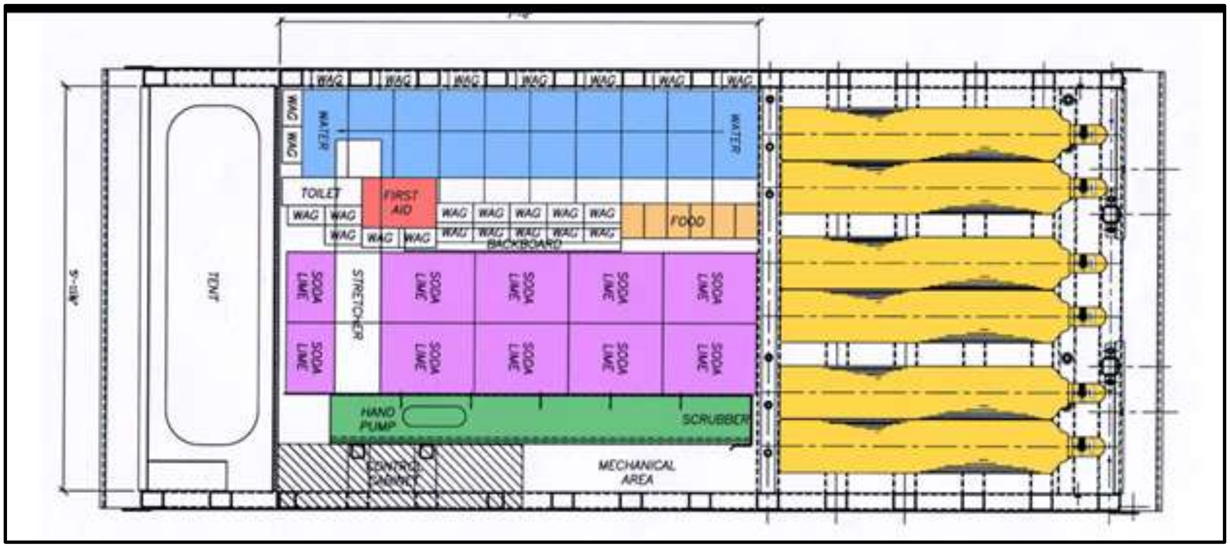


**Figure 27: A plan view showing the major items contained in a Strata inflatable RA storage and transport unit.**

Of necessity, very efficient use must be made of the volume available in the storage and transport unit for an inflatable RA. Figure 27 is a plan view showing the major items contained in a Strata unit. On the left in the figure is the rolled-up fabric tent. On the right indicated in yellow are the pressurized bottles of compressed air and oxygen necessary to inflate the tent and maintain a breathable atmosphere for the miners sheltering inside. The other colored items in the central part of the unit represent storage locations for items necessary for continued RA maintenance and miner survival. The miners can only access these items after they inflate and enter the fabric tent.

The recommended RA operating procedure does not allow the miners to exit the RA after they have entered. Therefore, only components of any alternative RA communication system that are to be operated by the miners inside the fabric tent should be stored within this central part of the unit. There is some limited space available for such storage if those communications system components are either compact or modular. It must also be noted that the standard in-service life for an inflatable RA is five (5) years, and that this central storage area can and will not be accessible for that period. Therefore, all alternative RA communication system components intended for use from within the chamber, including batteries, must also have a five-year shelf life to be effective for this application.

The only readily accessible storage area for any components of any alternative RA communication system to be operated exterior to the activated RA is indicated by the small cross-hatched "Control Cabinet" rectangle in the lower left quadrant of the Figure 27 plan view. The general location of this cabinet on Strata inflatable RAs is evident at the left-hand side of the RA storage unit of Figure 21. Figure 28 is a close-up of the access doors for the cabinet that contains the master control valves for the RA airlock purge air, tent oxygen supply, and tent atmosphere scrubber fan drive system along with a multi-gas monitor and a strobe light used to indicate RA occupancy from a distance.


**Figure 28: Close-up of the access doors for the cabinet.**

**Figure 29: The limited exterior storage capacity of the Control Cabinet.**

Figure 29 with the Control Cabinet access doors open shows that the cabinet offers only limited storage volume for alternative RA communications components to be used outside of the occupied RA. Therefore, it will be necessary to provide a separate, rugged storage container to house any large and heavy components (such as a TTE transmitting antenna) used in conjunction with an inflatable RA.

Also contained within the Control Cabinet are external connectors to allow attachment of standard hard-wired mine pager phones as indicated in Figure 30. These connectors (or others that could be designed and installed) might be employed to connect passive external components of an alternative RA communications system to extend communication's capacity to the miners on the inside of the refuge alternative. The corresponding connectors accessible from inside the inflated refuge compartment are indicated in Figure 31.

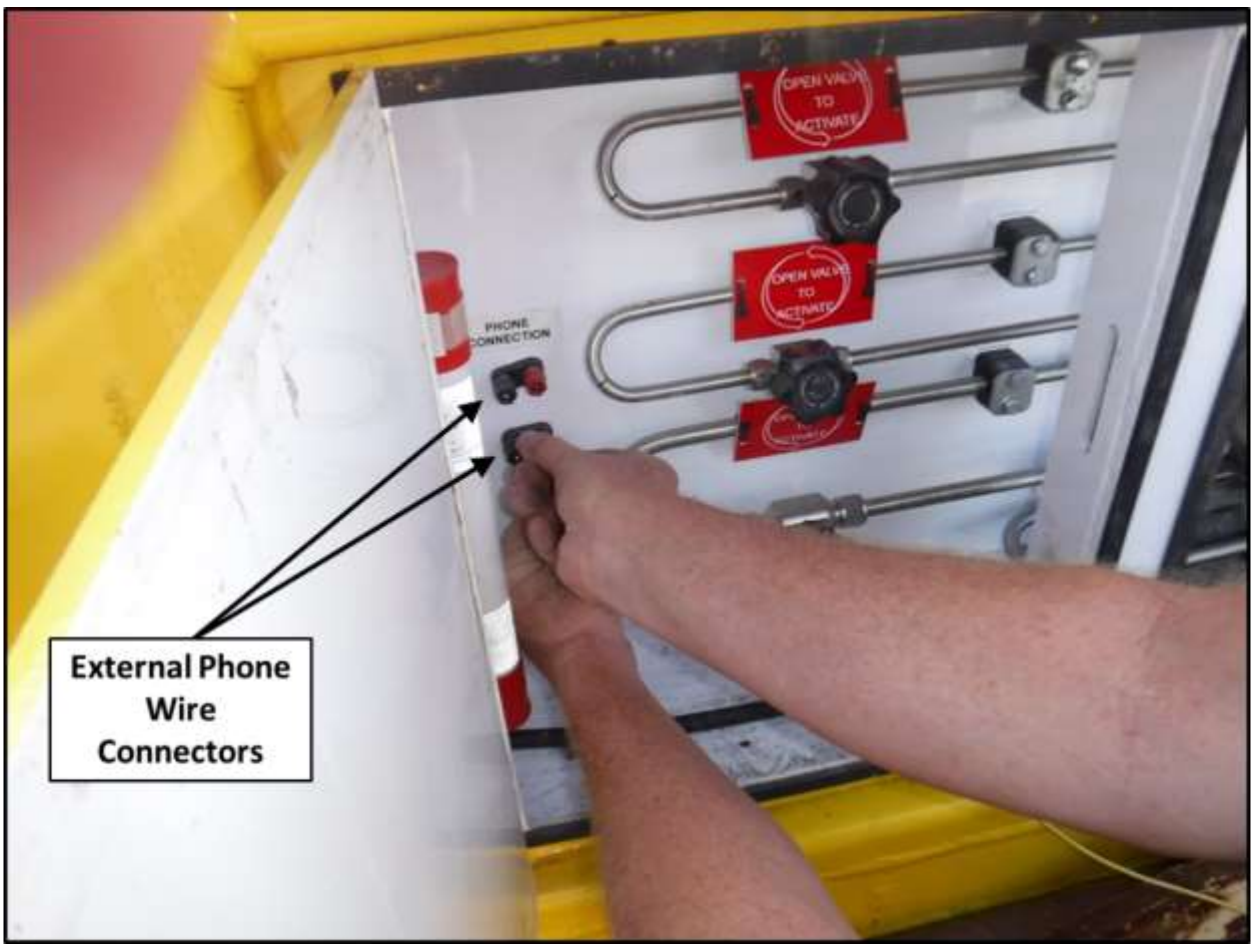



**Figure 30: Location of external connectors for standard hard-wired mine pager phones.**

**Figure 31: Standard pager phone connectors inside the inflated refuge compartment.**

The red and white wires shown in Figure 31 stored inside the RA and pre-connected to the exterior phone connection terminals might also be used by miners sheltering in an RA to establish alternative communications, if the pager phone system was not operational. Figure 32 offers a representation of how the Kutta medium frequency communication radio operated from inside the RA might employ the wires leading to the exterior terminals.


**Figure 32: Example of how miners might employ the RA pager phone connectors with a Kutta radio from inside an inflated refuge compartment.**

Strata has also developed an MSHA-approved air-conditioning unit (Figure 33). This large unit (approximately the same dimensions as a portable RA protective steel container) is intended for use with RAs in underground mines (metal, nonmetal, and coal) where excessive ambient temperatures may be encountered. To meet MSHA requirements for use in potentially explosive atmospheres, this unique AC unit employs a combination of an explosion-proof (XP) box enclosed in a nitrogen-filled chamber to isolate the air conditioner system components. If needed, a similar approach might possibly be adopted to house alternative RA communication through-the-mine or through-the-earth systems to address MSHA requirements for post-event emergency use.


**Figure 33: MSHA-approved Strata air-conditioning unit.**

## 4.3 Task 3: CONOP and Evaluation Protocol Development

Based upon anticipated VA, Kutta, and IWT equipment capabilities (including system integration points and requirements) and known mine rescue team operational protocols and methods, a first outline for potential use of this communication equipment by sheltered miners and rescue personnel was developed. Employing the RA use procedures and alternative communication equipment integration opportunities identified during Task 2, a general concept of operations (CONOP) for potential use of alternative mine rescue communication equipment was created. The CONOP was then offered to an experienced mine rescue expert for review and comment. The reviewed CONOP then guided preparation of protocols for field performance evaluations of the modified communications equipment during Task 4.

### 4.3.1 RA Alternative Communications System CONOP

#### 4.3.1.1 Introduction

Federal law requires that two communications systems must be available for use by miners in an underground refuge alternative (chamber). Generally, this requirement is addressed using a common, two-wire mine pager system and the mandated mobile communications and tracking system selected for daily use in the mine. However, during an emergency, one or both of these systems may be rendered inoperable by the events in the mine, thus impeding or eliminating the ability of miners sheltering in a refuge alternative from communicating with those intending to rescue them. The following sections describe a general scenario where other types of mine communication systems that do not rely upon maintaining the physical integrity of multiple, exposed system components to provide long-distance communication might be used by sheltering miners to communicate with those attempting to rescue them.

#### 4.3.1.2 Scenario Background Assumptions

The general concept of operations (CONOP) description begins with the following assumptions:

1. A significant emergency has occurred at the mine requiring all mine personnel to evacuate the mine.
2. A group of miners has attempted to evacuate but find all of their escape routes to be impassible.
3. The trapped miners decide to shelter in one of the portable RA units deployed throughout the mine.
4. The miners locate the nearest (or most suitable) RA.
5. The miners successfully deploy and activate the RA per the manufacturer's instructions and their training.
6. Before all the miners enter the RA, a function check of both of the required two communications systems indicates that both of these systems no longer enable (support) communication to potential rescuers outside of the mine.
7. An alternative commercial communication system approved by MSHA for emergency use is available to the miners at the underground RA site.
8. Depending upon the nature of the alternative commercial communication system, the miners outside the RA perform all tasks external to the RA necessary to enable use of the alternative system. Such tasks might be TTE, medium frequency, or UHF antenna deployment or establishing a reliable conductive connection between the RA and nearby, long-distance metallic mine infrastructure (rail, pipe, cable, belt structure) using a wire then attached to the RA's external pager phone line connectors (Figure 30).

9. The miners outside the RA then join the others sheltering inside the RA and await rescue within the design duration of the RA to maintain a breathable atmosphere and supply other life support functions.
10. The alternative commercial communication system enables the sheltering miners to inform mine rescue personnel at the surface or approaching through the mine of their survival, physical status, location within the mine, and (possibly) underground conditions near their location.

#### 4.3.1.3 Alternative RA Communication Systems

The three communications systems introduced in Section 4.1 were evaluated as alternatives. They include the VA very low frequency through-the-earth system (TTE), the Kutta medium frequency system, and the higher frequency, IWT node-based mine emergency mine rescue system. Although they have different performance attributes and capabilities, their common characteristics were employed to develop a basic CONOP generally applicable to all.

The electronics of the Vital Alert Canary CommPac TTE system are compact, portable, and designed to enable voice communication through most geologic materials to a maximum range of about 1,000 feet. Text messages may be exchanged at distances approaching 1,500 feet. An earlier, less user-friendly, more physically cumbersome, MSHA approved version of this system is available, but it is no longer in active production. Electrical safety barriers and a transmitting antenna design from this earlier version were modified and tested to isolate the transmitting and receiving antennas which located external to the RA from the system electronics that would be operated from inside the RA. The TTE system can offer both underground-to-surface and underground-to-underground communication within its design range. A smaller, matching standard Canary CommPac system can be used to communicate with the modified system from other underground and surface locations. This system's greatest drawbacks are (1) the recommended 100-foot-by-100-foot dimensions of its transmitting antenna and (2) communications range limitations resulting from adverse geologic and/or electrical noise conditions. Another, smaller antenna configuration was trialed in this study along with the ability of the VLF signals to couple onto continuous metallic mine infrastructure to extend communication range.

The Kutta Technologies Digital Radio for Underground Mines (DRUM®) is a portable wireless, medium frequency, MSHA-approved radio system. When the system's compact ferrite transceiver antenna is placed near metallic mine infrastructure such as cables, wires, tracks, and pipes, the transmitted radio signals couple into the infrastructure which then become a communication path enabling voice communication over very long distances. The radio signals may also jump some physical gaps in the infrastructure offering a potentially attractive, long-range, underground-to-underground communication capability for RA communications.

The MSHA-approved Innovative Wireless Technologies (IWT) radio system is composed of personal hand-held Sentinel™ radios and independently powered signal relay "nodes" distributed throughout a mine to create multiple, redundant communication paths. The IWT system is employed by MSHA's Mine Emergency Operations (MEO) to build a robust, capable, and secure communications network as their mine rescue teams advance through a mine. The Sentinel™ radios also are, with the aid of demonstrated interfaces, directly interoperable with both the Vital Alert Canary CommPac and Kutta DRUM® system transceivers.

Therefore, one or more or a combination of these three alternative systems could serve as a back-up to the two MSHA-required means for RA communications. Since the IWT system has interoperability with both the Kutta and the VA systems, it is possible that one IWT radio could be used to simultaneously communicate with the IWT MEO radio system, the VA TTE system, and the Kutta medium frequency system. If both the mine rescue team and the miners in an RA are equipped with either the very low or the medium frequency system components or both, these interfaces may enable an extended, forward-reaching communication capability as the mine rescue team advances into the mine.

#### 4.3.1.4 CONOP for use of an Alternative RA Communication System

The following steps describe how an alternative system might be used by sheltering miners to communicate with those attempting to affect their rescue.

1. All members of the trapped group of miners are sheltered within the RA.
2. The miners set up and test the alternative communication system equipment intended to be operated from within the RA.
3. An initial attempt is made to communicate with potential rescuers either within the mine outby the conditions blocking the miner's escape or entirely outside the mine (at the portal or on the surface above the RA).
4. If communications are successfully established, information required by both the rescuers and the RA occupants is exchanged. Go to step #9.
5. If communications are not established, the RA occupants power down their alternative communications equipment to conserve system power.
6. At a pre-established interval (example: starting every hour, on the hour), the trapped miners turn on their equipment and periodically broadcast and then listen for a response over a specified time interval (example: broadcast a brief message every minute for ten minutes).
7. If communications are not established, the RA occupants again power down their alternative communications equipment to conserve system power.
8. Steps 6 and 7 are repeated until communications between the RA and the rescue personnel are established.

9. Depending upon the circumstances associated with the emergency, and the options available to both the RA occupants and the rescue team, an appropriate communication schedule and protocol is established to enable radio communications to continue until the mine rescue team(s) can access the RA and communicate directly with its occupants.
10. Under no circumstances should the miners attempt to leave the RA to try to improve the ability to communicate via the alternative communications equipment.

#### 4.3.1.5 Basic Requirements for an Alternative Communication System

As mentioned at the end of Section 4.1.2, MSHA currently requires that any communications system used within the RA must be approved as being intrinsically safe (IS) or explosion-proof (XP). If the communication system used is not IS or XP approved, then its components must also be isolated from the atmosphere even though the system is being used inside the chamber. MSHA also requires that the two required communications systems (and by assumed extension, any additional communication system) be readily available and easily connected to the RA and that system attachment and activation do not significantly delay the entry by miners into the RA.

Therefore, basic system requirements include:

- Ability to be stored within or near the RA
- Easily accessed
- If they are not integral to the RA, either advance or rapid post-event system component deployment.
- Ease of use by miners under stress
- Low or no maintenance

#### 4.3.1.6 CONOP SME Review

Mr. Marlon Whoolery reviewed all the Section 4.3.1 information. Mr. Whoolery has over 40 years' experience in the coal mining industry, holding numerous front-line positions for both surface and underground operations. Beginning in 2000, he became involved in Mine Health and Safety Training while working as an International Representative for the United Mine Workers of America. In 2008, he obtained MSHA and State of West Virginia Surface and Underground Training Certifications, which led to his employment as the Mining Technology and Training Center (MTTC) Training Director for the United Mine Workers' of America Career Center.

As MTTC Training Director, Mr. Whoolery supervised the creation, instruction and administration of all MTTC training programs and plans while being responsible for the day-to-day operation of the facility and all training sessions. He possesses numerous specific MSHA, State of West Virginia, and National Incident Management System (NIMS) training certifications. Mr. Whoolery has been the instructor for the following classes: Command and Control Center, Responsible Person, Advanced Safety Skills, Mine Foreman/Mine Examiner, Mine Rescue, and Fire Brigades and is a member of both the Holmes Mine Rescue Association Executive and Guidance Committees and a former director of the Nationwide Mine Rescue Skills Committee.

Mr. Whoolery's comments related to the concept of alternative RA communication and its CONOP were as follows:

> *"I find the concept very well written, researched and much needed. It has been my experience as a trainer that the majority of underground miners claim they would never enter an RA, we have all heard the many terms used to describe an RA, "easy bake oven, coffin". I feel if miners are given an additional communication possibility, one that they would have to set up/assemble only helps to lessen the anxiety/mental anguish of waiting for rescue. As you know without communication from sheltering miners when a Mine Rescue Team encounters an occupied RA, in a hostile atmosphere, teams most generally only carry one or two self-contained breathing apparatuses (care vents). With this concept, the sheltered miners could provide information on the number of miners and their condition which would allow Mine Rescue Teams to be better prepared.*
>
> *I must also applaud your research that two of the systems you are considering are interoperable with MSHA's IWT system, which would expedite the rescue operations.*
>
> *In closing I must caution that if this concept is developed we must ensure the system "will work", as if it fails the trapped miners would be demoralized.*
>
> *Again well done!"*

### 4.3.2 System Evaluation Protocol Development

The draft CONOP was used to guide preparation of two field performance evaluation plans for the modified equipment associated with the three communications systems: a surface site plan and a mine site plan. The goal of both plans was to assess the effective TTE and in-mine communications ranges associated with each system while noting any significant changes in system performance when demonstrating IWT/VA and IWT/Kutta equipment interoperability. The surface site plan was to be executed first to (1) develop familiarly with and confidence in the use of all the communication equipment and (2) refine and practice procedures to be used during the mine site evaluation when efficiency in execution would be necessary to make maximum use of limited available time while working in much more challenging surroundings.

Preliminary versions of the two similar field evaluation plans were submitted to VA, Kutta, IWT, Strata and MEC for review and comment. Suggestions for improvement were incorporated in the final versions of both plans that are attached as Appendices 10.3 and 10.4.

## 4.4 Task 4: Equipment Field Evaluations

All VA, Kutta, and IWT equipment intended for field performance evaluation was received by late May 2019. Physical inspection the VA customized TTE transmitter as received revealed that it was damaged in shipment. Receipt and installation of replacement transmitter components were completed in early June. Subsequent system inter-operability bench tests revealed that the IWT radios used by VA to develop their system interface were not properly programmed to communicate with the encrypted radio system components provided by IWT that mimicked the performance of MSHA MEO and other dedicated mine rescue communications systems. After the unencrypted radios were reprogrammed by IWT, actual field evaluations commenced in mid-June.

To develop familiarity with and confidence in equipment use, the first phase of evaluations was conducted at surface locations where more convenient, predictable, and controlled test conditions were present. The second evaluation phase was conducted at a coal mine identified by MEC.

### 4.4.1 Surface Site Evaluations

An original intent was to conduct a surface evaluation at or near the Strata RA rebuild facility in Grantsville, MD, using a deployed RA unit as a base station. However, discussion with Strata following a site inspection revealed that the rebuild site located in an industrial park was not well suited for the purposes of communication equipment performance evaluation. The footprint of the rebuild shop property would not permit adequate separation between transmitting antenna for the two VA TTE radios or extension of a 2,500-foot long wire to test inductive communication with both the VA and Kutta radios. In addition, it was anticipated that the proximity of electrical power distribution system for the RA rebuild shop and other businesses in the industrial park would generate significant background noise interference with the TTE test protocol.

Therefore, alternate surface sites were identified which did have adequate space and low background noise potential.

#### 4.4.1.1 Evaluation Plan

The Surface Site Field Evaluation Plan presented in Appendix 9.3 served as a guideline for execution of all formal equipment evaluations conducted at several different surface sites.

#### 4.4.1.2 Surface Site Plan Execution

A limited test of the Kutta/IWT radio interface was conducted in Connellsville, PA, on May, 17, 2019, to verify that the radio system was received in a functional state and to develop an understanding of the basic operation and interoperability of the two different radio systems. The initial functionality tests confirmed operation of the IWT physical interface with the Kutta radio. Approximately 500 feet of 12-gauge single conductor wire was deployed on the ground surface to establish and evaluate communication between a "base station" Kutta unit interfaced with an IWT radio. Transmissions from an independent IWT radio then communicated with the connected IWT radio that then activated and received medium frequency system communications and relayed them back to the independent IWT radio. The base station equipment is pictured in Figure 34. As pictured in Figure 35, a second "remote" Kutta radio was located near the other end of the 500-foot wire.

In the first test, the Kutta medium frequency (MF) rod antennas were placed within close proximity of the wire at both the base and remote locations and two-way communications were established. The signal was noisy but the operators were able discern most of the words that were spoken. The test was repeated by placing the MF rod antennas in direct contact with the wire. The signal strength and clarity improved, though the signal did deteriorate at times. The Kutta MF induction clamp was then for substituted for its rod antenna and placed around the wire as indicated in Figure 36. Resultant communication was clearer with less noise. Therefore, it was concluded that the Kutta/IWT radios were indeed functional and ready for more rigorous field tests.

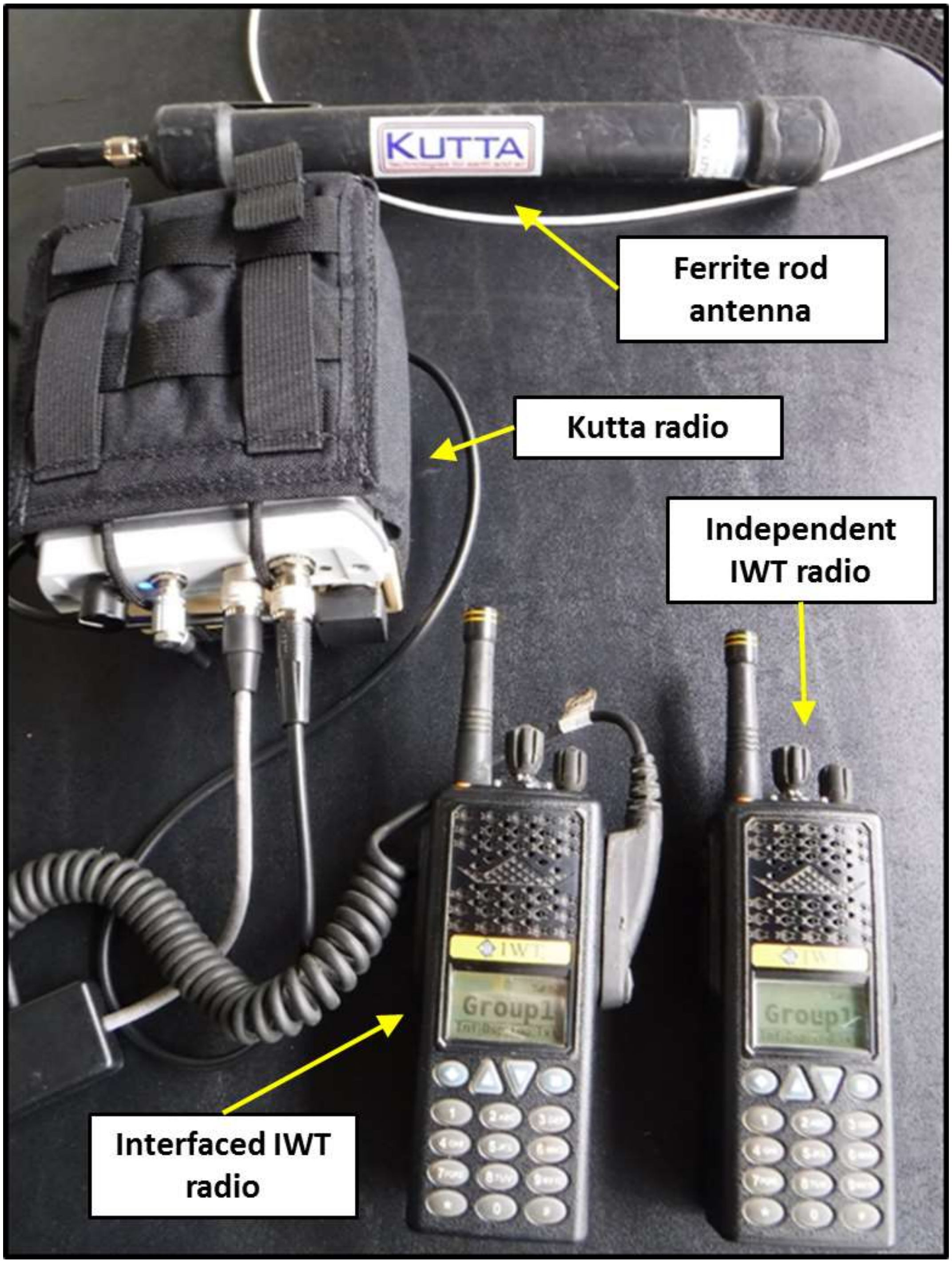



**Figure 34: The base station equipment for the initial IWT/Kutta system interface test using a ferrite rod antenna.**

Figure 35: The remote equipment for the initial IWT/Kutta system interface test.


Figure 36: The Kutta MF induction clamp substituted for the rod antenna and placed around the wire.

Once the IWT radios were reprogrammed, successful basic function tests of the VA system were conducted in Connellsville, PA, on June 16, 2019. Two-way voice communication was established employing the customized VA TTE radio at the base station connected to its 500-foot circumference, four-conductor IS transmitter antenna. A 100-foot circumference single conductor loop transmitter antenna was employed by a standard, standalone VA radio (see Figure 41) at the remote station. The edge-to-edge separation between the antennas (see Figure 38) was 107 feet.

Transmissions from the remote unit were lost when the edge-to-edge separation between the antennas was increased to 500 feet. The size of the single conductor transmitter antenna on the remote unit was then increased to a 500-foot circumference while maintaining the edge-to-edge separation at 500 feet. Increasing circumference had no positive effect. Communication was then attempted first with two 500-foot loops installed in parallel and then four 500-foot loops installed in parallel. In every case at the 500-foot edge-to-edge antenna separation distance, only one-way communication from the base station to the remote unit was possible. Once the antenna separation distance was decreased to 300 feet, intermittent two-way communication was achieved. Communication using the IWT radios in conjunction with the VA base station equipment was not possible at either the 300- or 500-foot transmitter antenna separation distance.

On June 26 and 27, 2019 formal surface field evaluations were conducted at Laurel Hill State Park located in Somerset County, PA. This park was selected as it had adequate space, few nearby overhead or buried power lines, and very few weekday visitors. Figure 37 is an aerial photo of the central portion of the park surrounding its U-shaped access road and parking area. The large blue circle on the left side of the figure represents the location of the 500-foot circumference VA base station transmitter antenna deployed on June 26th at the west end of the access road. The remote VA unit was then setup at various distances from the base station along the two straight paths indicated in the figure.

The responses associated with the two VA transmitter antenna configurations represented in Figure 38 and Figure 39 were evaluated. The only difference between Configuration #1 (Figure 38) and Configuration #2 (Figure 39) is the circumference of the VA remote unit transmitter antenna. The smaller, 100-foot circumference loop approximates the loop size that mine rescue teams might use as they advance underground. The larger, 500-foot circumference loop represents the size that would be deployed both underground near an RA and at the ground surface over an occupied underground RA. According to VA, the horizontal separation of the transmitter loop and a receiving antenna over which communication at the surface is possible should approximate both the lateral distance underground and the vertical overburden distance that TTE communication can be anticipated at a given location.

Communications using the VA and IWT equipment were initially evaluated along Survey Path #1 as indicated in Figure 37 that terminated at the bank of the stream evident in the low right corner of the figure. Figure 40 is a ground-level view along Survey Path #1. Longer Survey Path #2 was then marked out to extend the edge-to-edge separation of the two transmitting antennas to a maximum of 900 feet. Figure 41 is a photo of the VA remote unit equipment employing the 100-foot circumference transmitter antenna.

The TTE system performance observations collected along both survey lines are presented in Table 3.

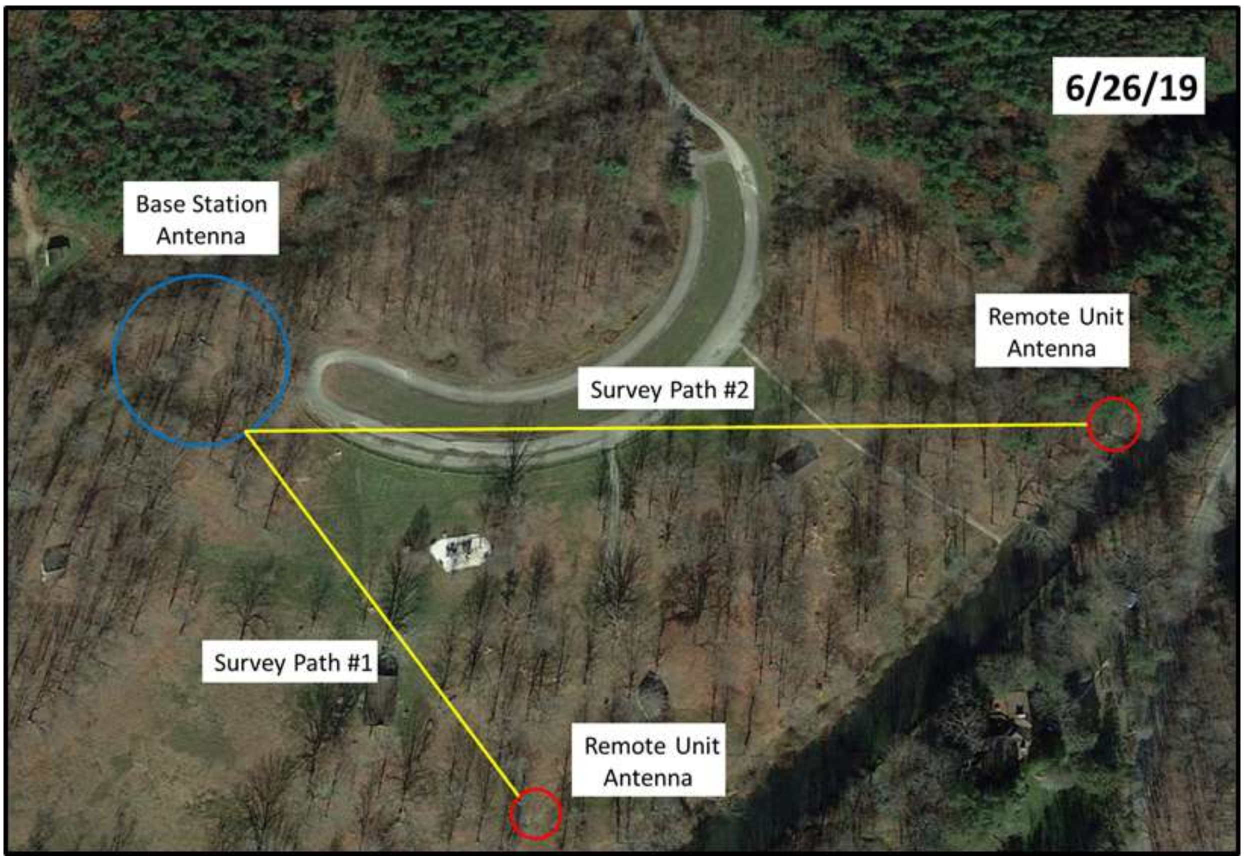



**Figure 37: An aerial photo of Laurel Hill State Park indicating equipment deployment on June 26, 2019.**

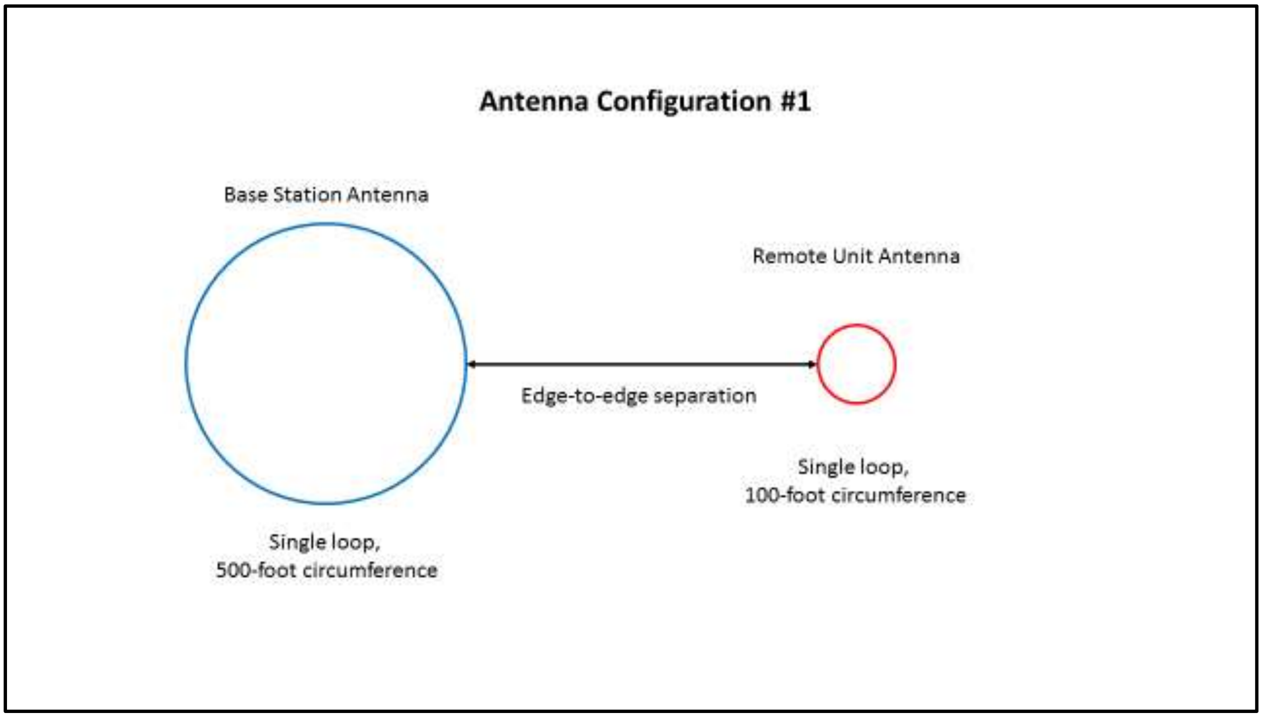



**Figure 38: VA transmitter antenna Configuration #1**

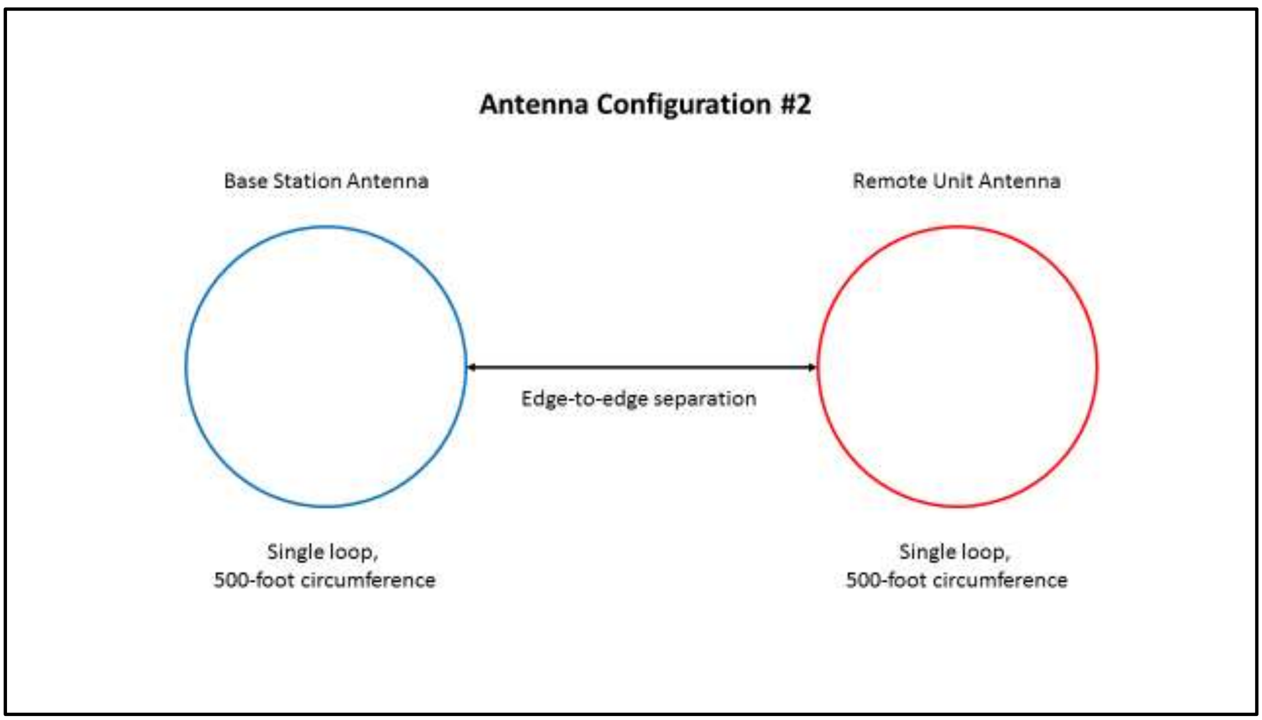



**Figure 39: VA transmitter antenna Configuration #2**

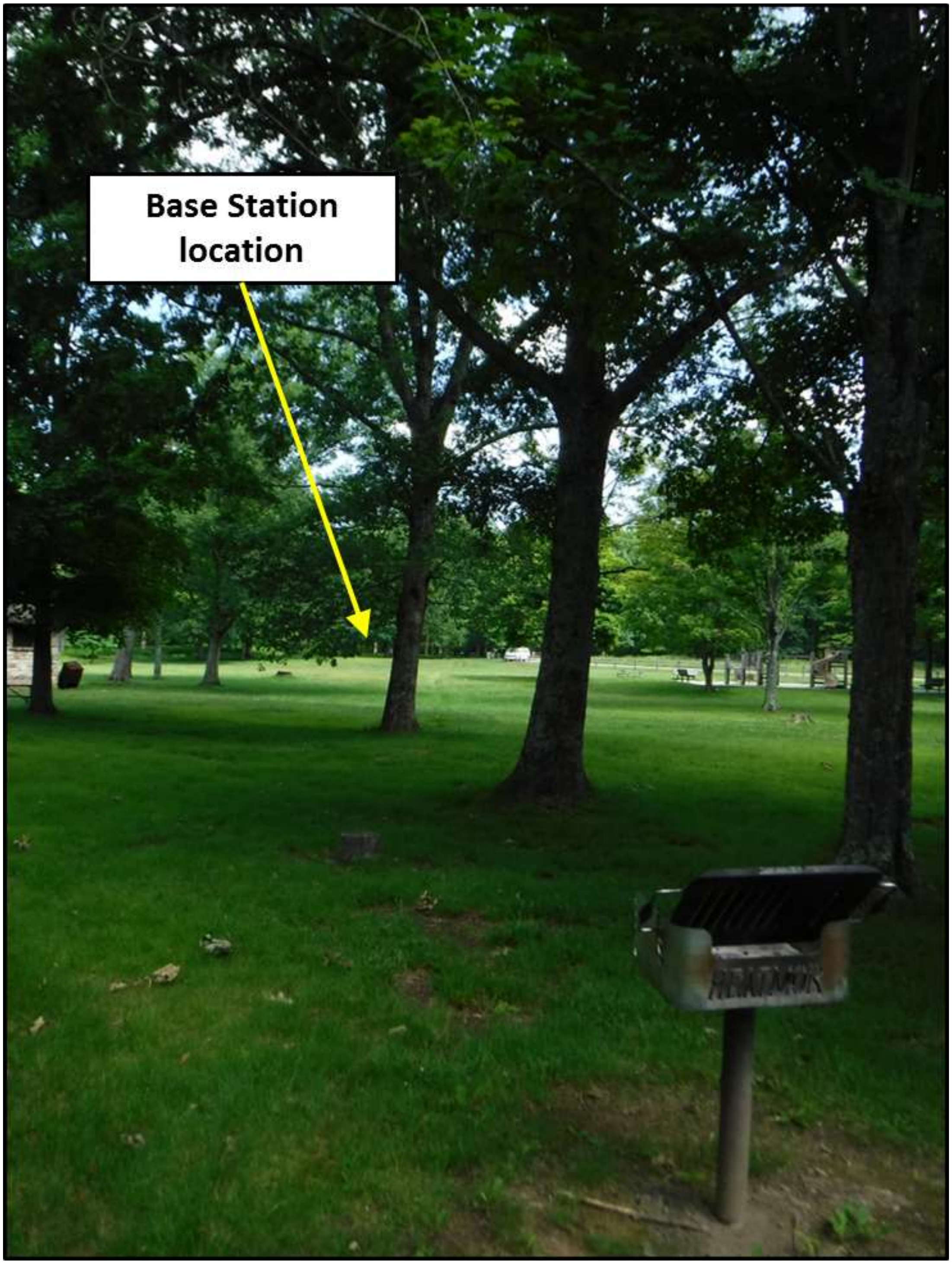



**Figure 40: View along Laurel Hill State Park Survey Path #1 looking from the farthest remote location back toward the base station**

**Figure 41: Remote VA equipment on June 26, 2019. The yellow unit is the VA receiving antenna connected to the black VA transceiver at the bottom of the photo. The VA 100-foot transmitter antenna is the red wire running diagonally across the left side of the photo.**

Inductive communication was demonstrated with both the VA and Kutta equipment deployed along a long linear conductor laid along Survey Path #2. A single 16-gauge wire, 1000 feet in length, grounded with 4-inch spikes at both ends was deployed, and the performance observations of Table 4 and Table 5 for both systems were obtained.

For the VA evaluation, 40 feet of the 16-gauge wire conductor was taped to one segment of the 500-foot circumference base station transmitter antenna. At a distance of 850 feet, 50 feet of the 100-foot circumference remote unit transmitter antenna was laid immediately adjacent to the wire as shown in Figure 42.

**Figure 42: Photo showing the red 100-foot VA transmitter wire placed adjacent to the yellow 16-gauge linear conductor wire.**

For the Kutta evaluation, only ferrite rod antennas oriented parallel to the 12-gauge wire as indicated in Figure 43 and Figure 44 were used to collect the Table 5 observations,. Altering the base station rod antenna distance between 0.5 and 6 inches from the wire did have a noticeable effect on observed communication quality.


**Figure 43: Kutta base station equipment with ferrite antenna placed parallel to the 12-gauge wire. The IWT radio interface and inductive clamp are not attached to the Kutta transceiver.**

**Figure 44: Remote unit Kutta equipment with its ferrite antenna adjacent to the long wire conductor.**

The impending arrival of a late afternoon thunderstorm prevented any further observations on June 26th.

On June 27, the surface equipment evaluation continued at Laurel Hill State Park. The different VA transmitter antenna configuration indicated in Figure 45 was employed to evaluate the effect of using a smaller-area, 5-loop antenna at the base station. That antenna configuration, pictured in Figure 47, simulated the area that might be available if the antenna were to be integrated into the construction of the large 36-person capacity Strata inflatable RA. Comparison of Figure 37 with Figure 46 notes that the Survey Path #3 used to collect VA communication observations mimics Survey Path #1 to allow direct comparison to the observations made on June 26.

Table 6 presents those observations.

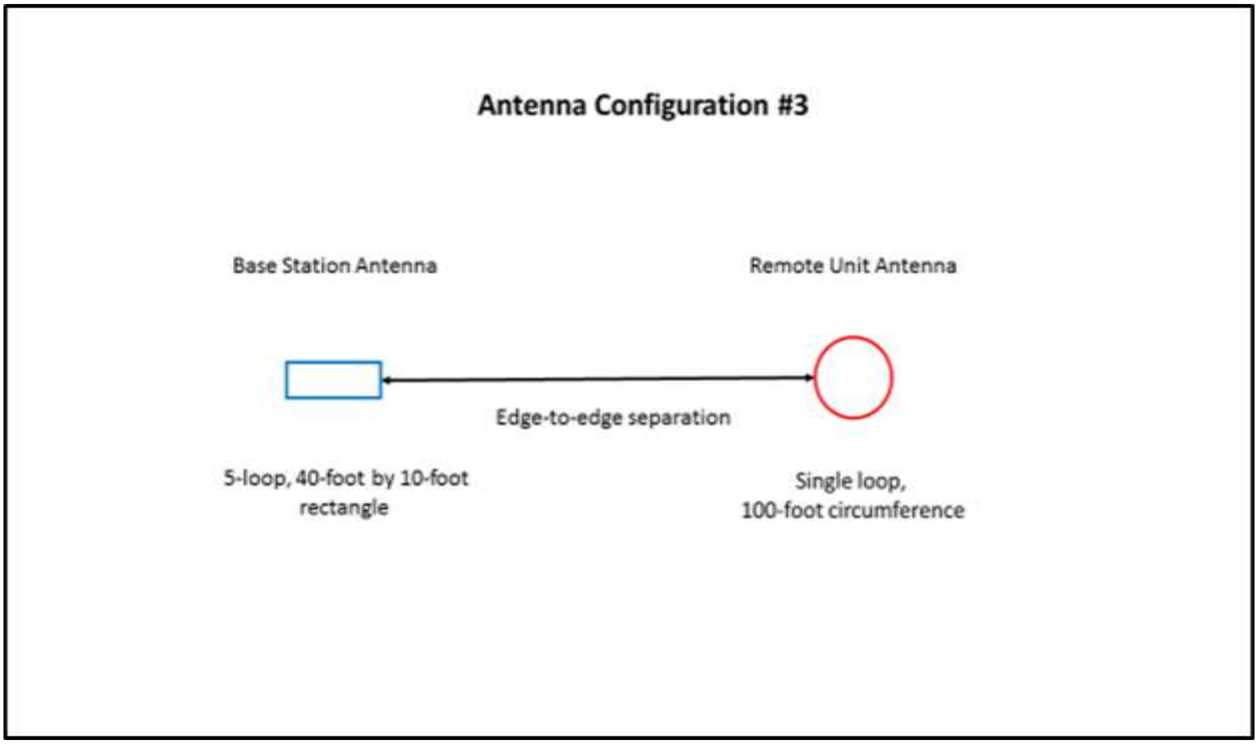



**Figure 45: VA transmitter antenna Configuration #3.**


**Figure 46: An aerial photo of Laurel Hill State Park indicating VA equipment deployment on June 27, 2019.**

**Figure 47: Smaller-area, 5-loop antenna deployed at the base station on June 27, 2019.**

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Also on June 27, more rigorous evaluations of inductive communication were conducted with both the VA and Kutta equipment.  A continuous, 2,500-foot 16-gauge single conductor was deployed from the base station location around the U-shaped parking area and along the access road to the parking area as indicated in Figure 48. Both ends of the conductor were grounded using 4-inch spikes driven into the soil. Starting at the opposite end of the conductor from the base station, inductive communications were attempted with both the VA and Kutta equipment.


**Figure 48: An aerial photo of Laurel Hill State Park indicating conductor and equipment deployment for inductive communication evaluations on June 27, 2019.**

For the VA evaluations, 40 feet of the 16-gauge wire was laid immediately adjacent to one 40-foot leg of the 5-loop base station VA transmitter antenna, as shown in Figure 49. Fifty feet of the 100-foot circumference remote unit transmitter antenna was placed adjacent to the wire. To receive transmissions, the 16-gauge wire was laid across the receiving antenna at both the base station and remote locations as shown in Figure 49 and in close-up in Figure 50.

**Figure 49: VA base station equipment for inductive communication evaluations on June 27, 2019.**

**Figure 50: Close-up photo of the optimum placement of the VA receiving antenna and conductor wire for inductive communication.**

For the Kutta evaluations, both the ferrite antenna and the inductive clamp were employed from the base location. The remote Kutta unit used only a ferrite antenna. For optimum coupling of the Kutta medium frequency signal into the wire, the ferrite antennas should be oriented perpendicular to the wire. However, for these tests, the ferrite antennas were oriented parallel to the wire to evaluate a worst-case condition.

For both the VA and Kutta system inductive performance evaluations, the appropriate IWT radio interface was substituted for both the standard VA and Kutta hand speaker/microphone at the base station for every remote location communication attempt.

Finally, following the first communication attempt at the maximum base-remote separation distance of 2,500 feet, a 1-foot gap in the 16-gauge wire was created at a distance of 2,000 feet from the base station (see the red line indicator in Figure 48) and communications were again attempted with the 2,500-foot radio separation.


**Figure 51: Aerial photo of the 7/16/19 surface test site.**

Further surface tests of the IWT and VA radio systems were conducted on and near an athletic field in Connellsville, PA on July 16, 2019. The first series of tests involved using a 500-foot, 6-conductor loop antenna on the base station and a 500-foot, single conductor antenna loop on the remote station. Tests were conducted using a base-to- remote antenna separation distances of 900, 800, 700 and 600 feet. One-way, base to the remote station communication was excellent at the antenna separation distances less than 900 ft. The second series of tests involved using the 6-conductor antenna arranged in a 10-foot by 40-foot rectangular loop at the base station and a 500-foot, single conductor antenna loop at the remote station. Communication tests were conducted using a base-to-remote antenna separation of 800, 700-, 600-, 500-, 400- and 200-foot antenna separation distances. Excellent 2-way communication was achieved at the 200-foot antenna separation distance. Communication could not be established between the base and remote station at any other antenna separation distance.

#### 4.4.1.3 Surface Site Observations

The following tables summarize all of the formal surface site data. Salient observations from each data set are noted with each table, and those observations are summarized at the end of this section.

Performance observations for the Vital Alert and IWT equipment from the Table 3 information include:

- Maximum two-way communication separation distance for the Antenna Configuration #1 was 350 feet. (The corresponding table observations are noted with yellow fill.)
- Maximum effective one-way (base to remote) communication for Antenna Configuration #1 was 800 feet.
- Two-way communication was distinct to at least a 500-foot separation distance for Antenna Configuration #2. (The corresponding table observations are noted with green fill.)
- Introduction of the IWT interface with the Vital Alert equipment at the base station had a detrimental effect on communication quality when received signal strength was weak and basic quality was marginal.

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# Table 3: June 26, 2019 VA TTE System Performance Observations

| | | Antenna Geometry | | | | Communication Quality | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Base (customized IS circuitry) 4-conductor circumference (feet) | Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Edge-to-edge antenna separation distance (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| 06/26/19 | 10:50 | 500 | 100 | 500 | Y | none | none | none | IWT to IWT through PMN on channel 8D is excellent |
| | 10:52 | 500 | 100 | 500 | N | none | none | none | no VA to VA communcation |
| | 11:04 | 500 | 100 | 250 | N | good | good | good | |
| | | 500 | 100 | 300 | N | good | good | good | |
| | | 500 | 100 | 300 | Y | poor | good | poor | base station reception garbled |
| | | 500 | 500* | 300 | Y | none | none | none | remote VA unit could not transmit; current too high message on display; possible operator error |
| | 11:58 | 500 | 100 | 350 | N | poor | good | poor | "borderline" reception at base |
| | 12:00 | 500 | 100 | 350 | Y | poor | good | poor | clear reception at remote, garbled reception at base |
| | | 500 | 100 | 400 | Y | none | good | poor | clear reception at remote, no reception at base |
| | | 500 | 100 | 400 | N | none | good | poor | clear reception at remote, no reception at base |
| | | 500 | 100 | 450 | N | none | good | poor | clear reception at remote, no reception at base |
| | | 500 | 100 | 450 | Y | | | | |
| | 13:15 | 500 | 500* | 500 | N | good | good | good | base-to-remote clear; VA base station voltage: 11.77 V; * 12 ga. Wire |
| | | 500 | 500* | 500 | Y | good | good | good | * 12 ga. Wire |
| | 13:45 | 500 | 500* | 300 | Y | excellent | excellent | excellent | clear 2-way comms; * 12 ga. Wire |
| | | 500 | 500* | 300 | N | excellent | excellent | excellent | clear 2-way comms; * 12 ga. Wire |
| | | 500 | 100 | 600 | N | none | good | poor | VA base station voltage: 12.1 V |
| | | 500 | 100 | 600 | Y | none | good | poor | base-to-remote clear; remote-to-base no RX |
| | | 500 | 100 | 700 | N | none | good | poor | base-to-remote clear; remote-to-base no RX |
| | | 500 | 100 | 700 | Y | none | good | poor | base-to-remote clear; remote-to-base no RX |
| | 15:10 | 500 | 100 | 900 | N | none | none | none | no base-to-remote communication |
| | | 500 | 100 | 800 | N | none | poor | poor | base-to-remote voice comms: need to speak very slowly for comprehension |
| | | 500 | 100 | 800 | Y | none | poor | poor | base-to-remote voice comms: need to speak very slowly for comprehension |
| | | 500 | 100 | 850 | N | none | poor | poor | base-to-remote voice break-up |
| | | 500 | 100 | 850 | Y | none | none | none | No base-to-remote communication with IWT interface employed |

**Table 4: June 26, 2019 VA Equipment Inductive Communication Observations**

| | | Antenna Geometry | | | | Communication Quality | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Base (customized IS circuitry) 4-conductor circumference (feet) | Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Edge-to-edge antenna separation distance (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| | 16:00 | 500 | 100 | 850 | N | good | good | good | First inductive communication test with single, grounded 12ga. wire between base and remote; 40' of single conductor taped to 500' VA base transmitter loop; 50' adjacent to 100' remote transmitter loop |
| | | | * 12 ga. Wire | | | | | | TESTING TERMINATED BY PRESENCE OF NEARBY THUNDERSTORM |

The only conclusion from this single Vital Alert inductive communication performance observation is that effective two-way communication was demonstrated at a distance of 850 feet.

**Table 5: June 26, 2019 Kutta Equipment Inductive Communication Observations**

| | | Antenna Geometry | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | | Remote | | | | Communication Quality | | | Comments |
| Date | Time | Type (ferrite rod or inductive clamp) | Separation (inches) | Type (ferrite rod or inductive clamp) | Separation (inches) | Grounded single 12 ga. conductor length (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| 06/26/19 | 16:12 | ferrite | 0.5 | ferrite | 0.5 | 850 | N | good | good | good | first test with conductor; 40' of single conductor taped to 500' VA base transmitter loop |
| | | ferrite | 3 | ferrite | 0.5 | 850 | N | poor | poor | poor | intermittent 2-way voice communication |
| | | ferrite | 6 | ferrite | 0.5 | 850 | N | none | none | none | no communication possible |
| | 16:19 | | | | | | | | | | TESTING TERMINATED BY NEARBY THUNDERSTORM |

The Table 5 inductive communication performance observations for the Kutta equipment include:

- Effective two-way communication was demonstrated at a distance of 850 feet when the Kutta ferrite antennas were positioned parallel to and very close to the wire conductor.
- Increasing the antenna to wire separation had an adverse effect on communication quality.
- NOTE: Kutta recommends that orienting the ferrite antenna perpendicular to the conductor is necessary to enable maximum signal coupling

**Table 6: June 27, 2019 Vital Alert Equipment Communication Observations**

| | | Antenna Geometry | | | | Communication Quality | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Base (customized IS circuitry) 4-conductor circumference (feet) | Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Edge-to-edge antenna separation distance (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| 06/27/19 | 8:49 | 100 | 100 | 250 | N | excellent | excellent | excellent | loud and clear 2-way comms |
| | 8:51 | 100 | 100 | 250 | Y | good | poor | poor | remote could hear base transmissions but could not make out words |
| | | | | ~275 | probable buried water line running approximately perpendicular to survey line axis | | | | |
| | 8:54 | 100 | 100 | 300 | Y | good | none | poor | no reception at remote |
| | 9:00 | 100 | 100 | 300 | N | good | good | good | base could hear remote TX clearly; "fairly clear" reception of base TX at remote |
| | 9:07 | 100 | 100 | 350 | N | poor | poor | poor | remote could hear 10-count from base, but garbled |
| | 9:13 | 100 | 100 | 350 | Y | poor | poor | poor | very weak, unintelligible reception at remote |
| | 9:19 | 100 | 100 | 400 | Y | none | none | none | no reception at remote |
| | 9:21 | 100 | 100 | 400 | N | none | none | none | |

Performance observations for the Vital Alert and IWT equipment from the Table 6 information are:

- Maximum effective two-way communication separation distance for the Antenna Configuration #3 was 300 feet. (The corresponding table observations are noted with yellow fill.)
- Maximum one-way (base to remote) communication for Antenna Configuration #1 was 350 feet.
- Introduction of the IWT interface with the Vital Alert equipment at the base station again had a detrimental effect on communication quality when received signal strength was weak and basic quality was marginal.

**Table 7: June 27, 2019 VA Inductive Coupling Communication Observations**

| | | Antenna Geometry | | | | Communication Quality | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Time | Base (customized IS circuitry) 4-conductor circumference (feet) | Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Edge-to-edge antenna separation distance (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| 06/27/19 | 10:20 | 100 | 100 | 2500 | N | excellent | excellent | excellent | loud and clear 2-way comms |
| | | 100 | 100 | 2500 | Y | excellent | excellent | excellent | |
| | | 1-foot separation of single conductor created 2000 feet from base | | | | | | | |
| | 10:40 | 100 | 100 | 2500 | N | none | none | none | no communication achieved in either directon |

The more extensive Table 7 inductive communication performance observations for the Vital Alert equipment include:

- Effective two-way communication was demonstrated at a distance of 2,500 feet. (The corresponding table observations are noted with green fill.)
- Introduction of the IWT/VA interface had no apparent effect on communication quality.
- The 1-foot separation in the conductor effectively eliminated communication past the separation.
- Eliminating the ground connection at one end of the conductor effectively eliminated communication.

**Table 8: June 27, 2019 Kutta Inductive Coupling Communication Observations**

| | | Antenna Geometry | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | | Remote | | | | Communication Quality | | | Comments |
| Date | Time | Type (ferrite rod or inductive clamp) | Separation (inches) | Type (ferrite rod or inductive clamp) | Separation (inches) | Grounded single 12 ga. conductor length (feet) | IWT Radio interface at Base (Y/N) | Base signal reception of remote | Remote signal reception of base | General system perfomance | Observations or comments |
| 06/27/19 | 10:25 | ferrite | 0.5 | ferrite | 0.5 | 2500 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 2500 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 2500 | Y | good | poor | poor | ~60% reception at base, ~10 reception at remote; greater separation distance (~20') between IWT radios at the base seems to improve communication clarity |
| | | ferrite | 0.5 | ferrite | 0.5 | 2500 | Y | none | none | none | ~5% reception at base, only mic key detected at remote |
| | 10:30 | ferrite | 0.5 | ferrite | 0.5 | 2500 | N | excellent | excellent | excellent | loud and clear 2-way comms again demonstrated |
| | | | | | | | | | | | |
| | | clamp | 0 | ferrite | 0.5 | 2000 | Y | none | none | none | can hear mic keys 2-way, but no voice comms |
| | 1-foot separation of single conductor created 2000 feet from base | | | | | | | | | | |
| | 10:43 | clamp | 0 | ferrite | 0.5 | 2500 | N | good | good | good | can send page signals; ~90% reception at remote w/static, ~60% reception at base w/static |
| | | ferrite | 0.5 | ferrite | 0.5 | 2500 | N | none | none | none | can hear mic keys 2-way with static; no voice comms |
| | Test of inductive coupling along a single 12-ga. conductor, diminishing lengths, grounded at both ends with 4-inch spikes | | | | | | | | | | |
| | | clamp | 0 | ferrite | 0.5 | 1500 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 1500 | Y | none | none | none | can hear mic keys 2-way with static; no voice comms |
| | | clamp | 0 | ferrite | 0.5 | 1000 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 1000 | Y | good | none | poor | can receive remote TX at base; remote cannot receive base TX |
| | | clamp | 0 | ferrite | 0.5 | 900 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 900 | Y | good | none | poor | stronger remote TX at base; remote cannot receive base TX |
| | | clamp | 0 | ferrite | 0.5 | 800 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 800 | Y | good | poor | poor | even stronger remote TX at base; weak/intermittent reception of base TX at remote |
| | | clamp | 0 | ferrite | 0.5 | 700 | N | excellent | excellent | excellent | |
| | | clamp | 0 | ferrite | 0.5 | 700 | Y | excellent | poor | poor | strong base reception, "borderline" remote reception |
| | | ferrite | 0.5 | ferrite | 0.5 | 700 | Y | excellent | good | good | slight improvements, less static at base, slightly clearer reception at remote |

Inductive communication performance observations for the Kutta equipment from the Table 8 data include:

- Clear, effective two-way communication was demonstrated at a distance of 2,500 feet when the Kutta ferrite antennas were positioned parallel to and very close to the wire conductor. (The corresponding table observations are noted with green fill.)
- Substitution of the Kutta inductive clamp for the ferrite antenna at the base station generally improved communication quality.
- A 1-foot separation in the conductor diminished the quality but did not eliminate two-way Kutta communications along the conductor.
- Introduction of the IWT/Kutta interface at the base station had an apparent detrimental effect on communication quality. (The corresponding table observations are noted with yellow fill.)
- When evaluating the IWT/Kutta interface using an independent IWT radio to activate the Kutta radio through a second IWT radio substituted for the Kutta speaker/microphone (see Figure 34), increasing the separation between the two IWT radios at the base station improved the overall quality of the supported two-way communications.

In summary, the surface site test results demonstrated the following:

- 500 feet was the maximum lateral edge-to-edge separation for the largest Vital Alert (VA) through-the-earth base station and remote unit transmitter antennas configurations which permitted effective two-way voice communication. As anticipated, this separation distance diminished when smaller transmitter antenna geometries were employed.
- Configuring the base station antenna to simulate its integration into an inflatable refuge alternative reduced the effective voice communication range to roughly 200 to 300 feet.
- Inductive coupling of the VA signals into a single, 2,500-foot long continuous conductor grounded at each end demonstrated excellent voice communication capability over that distance.
- Introduction of a 1-foot gap in the single conductor eliminated VA communication past that gap.
- Loss of conductor ground also eliminated VA inductive communication capability.
- Inductive coupling of the Kutta Radios medium frequency signals into the same single, 2,500-foot long continuous conductor also demonstrated excellent 2-way voice communication capability over that distance.
- Introduction of a 1-foot gap in the grounded conductor degraded but did not eliminate Kutta voice communication past that gap.
- Introduction of the interfaces to permit IWT radio interoperability with both the Vital Alert and Kutta systems apparently introduced transmitted signal losses that diminished the performance and effective voice communication range of both host systems.

### 4.4.2 Mine Site Evaluations

Following a series of meetings with MEC upper management personnel, a meeting was held on July 17, 2019, at the Monongalia County Mine (formerly known as the CONSOL Energy Blacksville No. 2 Mine) to coordinate the mine site evaluation program. It was mutually agreed to conduct the horizontal underground and vertical through-the-earth (TTE) radio communication evaluations on August 6$^{th}$ and 7$^{th}$. Suggestions received from mine personnel during the meeting related to four (4) underground locations along the 5 North Mains potentially possessing suitable evaluation conditions then permitted subsequent reconnaissance of the surface areas over those locations prior to the August execution dates.

#### 4.4.2.1 Test Plan

The Mine Site Field Evaluation Plan presented in Appendix 9.4 served as the guideline for planning and execution of the formal equipment evaluations conducted at the Monongalia County Mine.

#### 4.4.2.2 Plan Execution

A surface reconnaissance trip was made to the MEC Monongalia Mine on July 31, 2019, to determine the condition of the surface areas near the proposed underground evaluation locations.

Figure 52 is an aerial photo showing the four potential surface locations that are labelled UG1 through UG4. The land in the area of the study sites is that typically found in southwestern Pennsylvania: hilly with steep slopes and some flat valleys covered in vegetation (mostly trees and some dense vegetative overgrowth). The main roads in the area are paved with asphalt that degrades to crushed limestone in places. The access roads are rough and not paved, and some have been improved with crushed limestone. In places, the roads have become rutted from vehicular use and erosion. The surface area and conditions of the roads as seen in the aerial imagery provided by MEC (taken on October 5, 2016), did not necessarily match the actual ground conditions.


**Figure 52: Aerial photo showing the four potential surface locations, UG1 through UG4.**

Table 9 presents estimates for the depth of overburden at each potential underground evaluation site based on seam elevations provided by MEC and surface topographic information.

**Table 9: Overburden Estimates for Each Potential Site**

| Potential TTE Evaluation Site | Overburden Thickness |
|---|---|
| UG1 | 698 |
| UG2 | 923 |
| UG3 | 686 |
| UG4 | 766 |

Actual surface conditions at only three of the four sites (UG1, UG3 and UG 4) could be inspected. UG2 (the site with the greatest overburden thickness) was inaccessible due to bad road conditions. Based on this reconnaissance, two sites (UG1 and UG4) appeared have the most favorable surface and overburden conditions. At the surface for UG1, there was a maintained property with an open the side yard area well suited to deploy a TTE transmitter antenna loop. UG4 was located close to an open gravel parking area and equipment staging yard at the site of the MEC Roberts Run Shaft. Good communication between the surface and the underground mine was possible near this shaft site using the mine's normal communication system.

UG1 was selected as the better site at which to conduct the TTE performance evaluation. This selection was made because the staging yard at UG4 was very active handling new longwall shields that were being lowered down the shaft. That activity and the presence of normally operating high voltage mine power distribution equipment at the shaft location was anticipated to produce a high level of electromagnetic background noise in the vicinity of UG4 which would have a detrimental effect on TTE communication.

Figure 53 is a closer aerial view of UG1 upon which the which the outline of the mine plan underground has been superimposed in grey along with a series of colored concentric circles with radii increasing in 50-foot increments from 50-feet to a maximum of 250 feet. The purpose of the circles was to aid in locating offset antenna locations for testing if surface to underground communications could be established. The perspective of three different ground-level photos and one local landmark (a footbridge crossing a small stream) are indicated with white arrows. Figure 54 is an expanded aerial view indicating measured distances of UG1 from two fixed surface points.

Figure 55 is the ground-level "Picture 1" noted in Figure 53. Figure 55 offers a good representation of the general UG1 surface conditions and notes the locations of the two fixed points indicated in Figure 54. While there is some vegetative overgrowth, much of the area is maintained as a lawn for the nearby home. Permission was obtained from the property owner to set up the TTE surface station in the lawn area adjacent to the house.

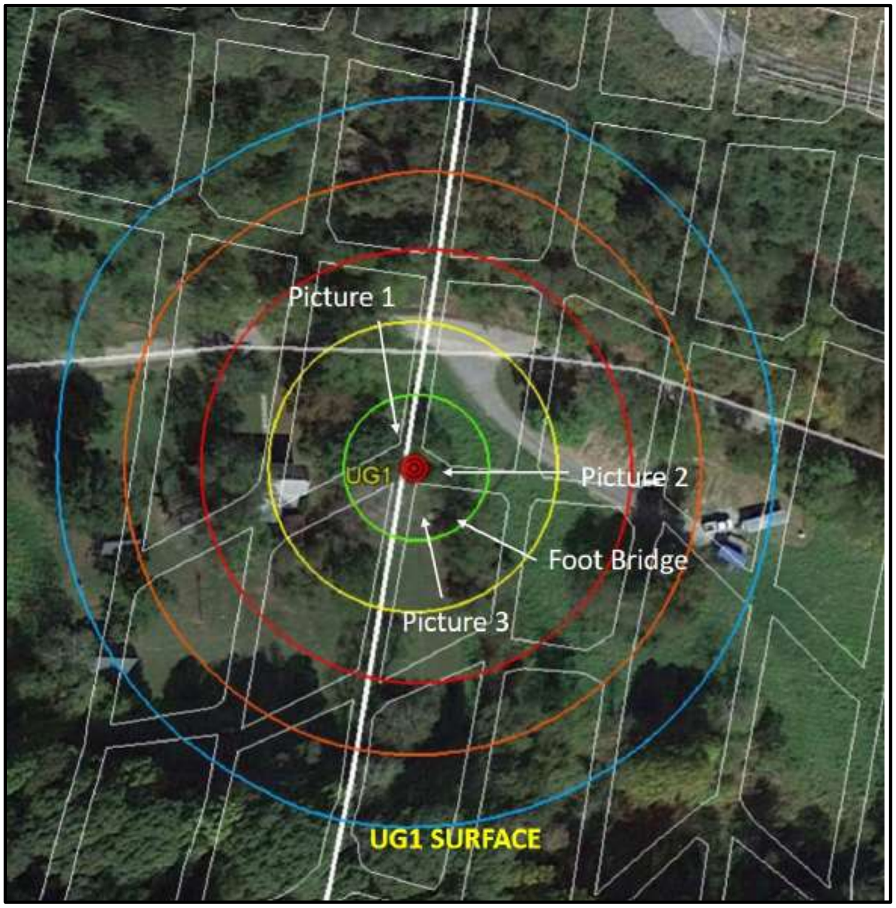


**Figure 53: The mine plan and concentric circles with radii increasing in 50-foot increments superimposed on a closer aerial view of UG1.**

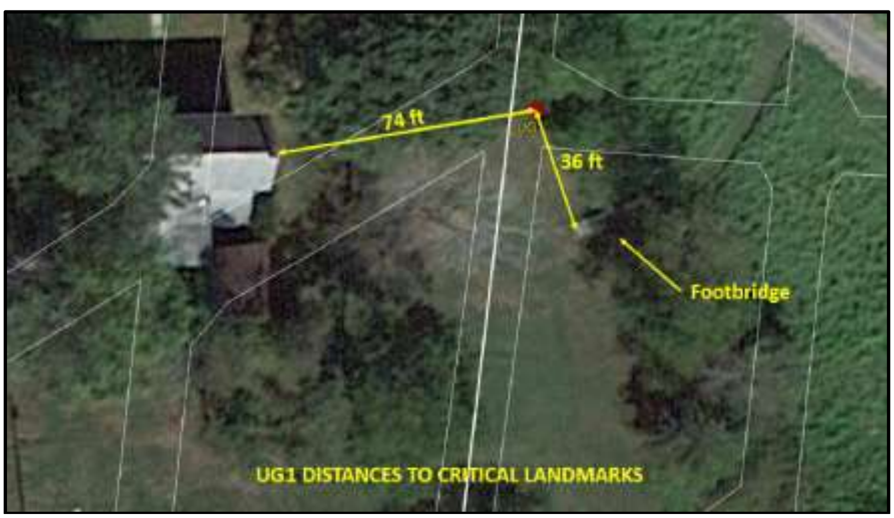


**Figure 54: Even closer aerial view of UG1 noting measured distances to two fixed surface points.**

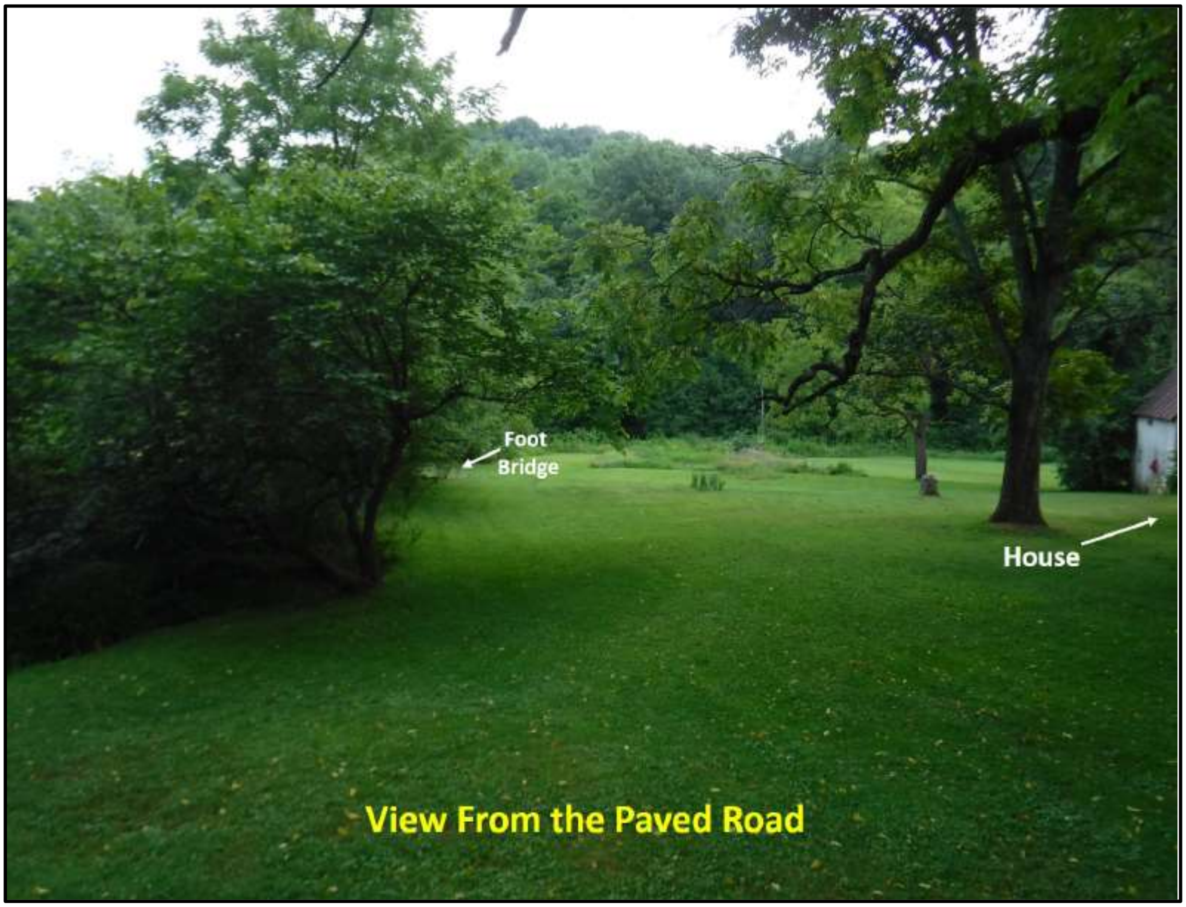


**Figure 55: "Picture 1" noted in the aerial image of Figure 53.**

Following selection of UG1 as the site for the TTE evaluation, an adjacent area near the Roberts Run Shaft was selected for evaluating lateral communications through the mine. Both are indicated in Figure 56. The red outline indicates the pillar immediately below the UG1 surface site. The green outline indicates the area selected for the lateral communication evaluations. Both sites are bounded by the track entry and primary escape way. Individual crosscuts are labeled with numbers increasing from 39 on the right to 60 on the left-hand side of Figure 56.

It is important to note the presence of the following major mine power equipment located near the Roberts Run Shaft and in the general vicinity of the underground study sites:

- Load center in crosscut 52 on lower side (relative to the Figure 56 map orientation) of the track entry.
- Rectifier in crosscut 51 on upper side of the track entry.
- Rectifier in crosscut 49 on upper side of the track entry.
- Belt power center with three variable frequency drives in crosscut 48 on the upper side of track entry

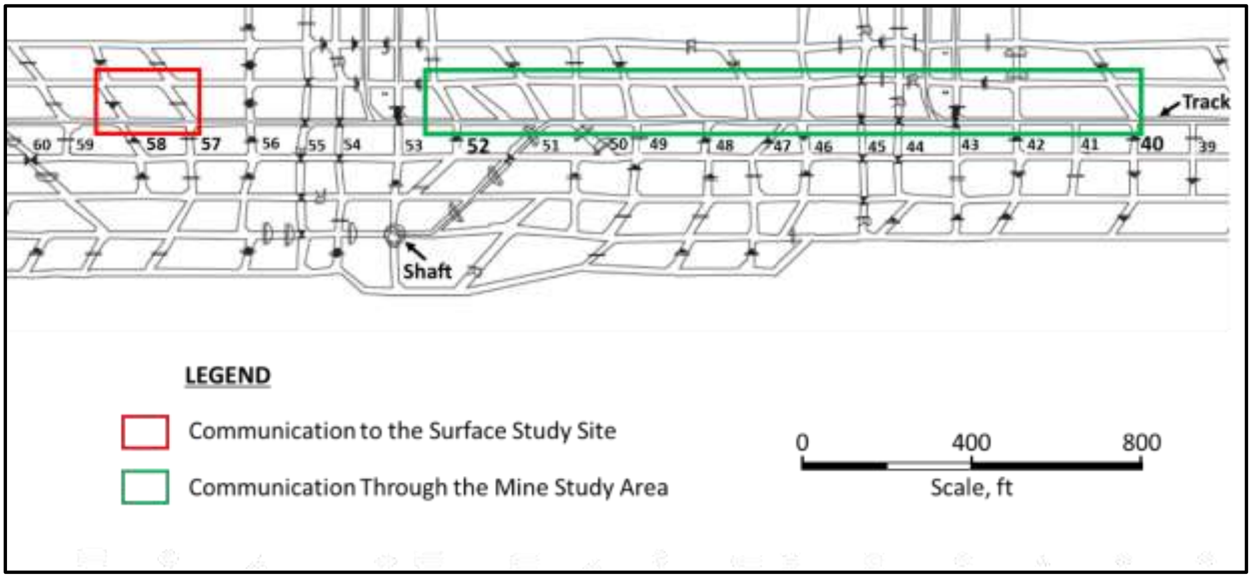


**Figure 56: Mine plan indicating the areas selected for the communication equipment performance evaluations.**

Lateral communication evaluations for both the VA and Kutta equipment interfaced with the IWT radios were conducted on August 6, 2019, and a vertical communication evaluation of the VA and IWT equipment was conducted on August 7.

**<u>August 6, 2019 Lateral Communication Evaluations:</u>**

Figure 57 and Figure 58 are closer views of the mine map indicating the manner in which both the VA base station and remote unit transmitter antennas were deployed along with the location of their receiver antennas. The base station antenna locations and geometry were kept constant to represent antennas deployed near an occupied RA. The base station radio location was maintained in the primary escape way at the intersection with crosscut 52. The transmit antenna was looped around the pillar defined by crosscuts 51.5 and 52 and the track and primary escape way entries.

The remote unit (representing equipment that might be employed by a MRT) was moved to locations progressively farther from the base. Two different transmitter antenna configurations were evaluated at each remote unit location. Figure 57 indicates the "pillar" configuration where a 500-foot long VA transmitter antenna was deployed so that it encircled different pillars. Each of those pillars was also bounded by the track and primary escape way entries. While this configuration would yield the greatest antenna area and thus the greatest transmitted signal strength, it might be difficult for a MRT to implement during rescue operations. Figure 58 indicates the "entry" or "cruciform" configurations where the remote unit transmit antenna was deployed along the ribs of the primary escape way with side projections into the intersecting crosscuts. These "entry" configurations might represent antenna deployments that would be more realistic for an advancing MRT to implement. Comparison of the two figures demonstrates that the total area of the "entry" antenna configurations is significantly less than the areas associated with the "pillar" configurations.

The following list explicitly describes each of the remote VA unit transmitter set-up geometries with the "X" notation indicating an "entry" or "cruciform" geometry:

- Set-up #1: wrap around pillar crosscut 48 to crosscut 49 along track and primary escape way entries
- Set-up #1X: looped along primary escape way entry with extensions into crosscuts 48 and 49
- Set-up #2: wrap around pillar crosscut 46 to crosscut 47 along track and primary escape way entries
- Set-up #2X: looped along primary escape way entry with extensions into crosscuts 46 and 47
- Set-up #3: wrap around pillar crosscut 45 to crosscut 46 along track and primary escape way entries
- Set-up #3X: looped along primary escape way entry with extensions into crosscuts 45 and 46
- Set-up #4: wrap around pillar crosscut 43.5 to crosscut 44 along track and primary escape way entries
- Set-up #4X: looped along primary escape way entry with extensions into crosscut 44
- Set-up #5: wrap around pillar crosscut 40 to crosscut 42 along track and primary escape way entries

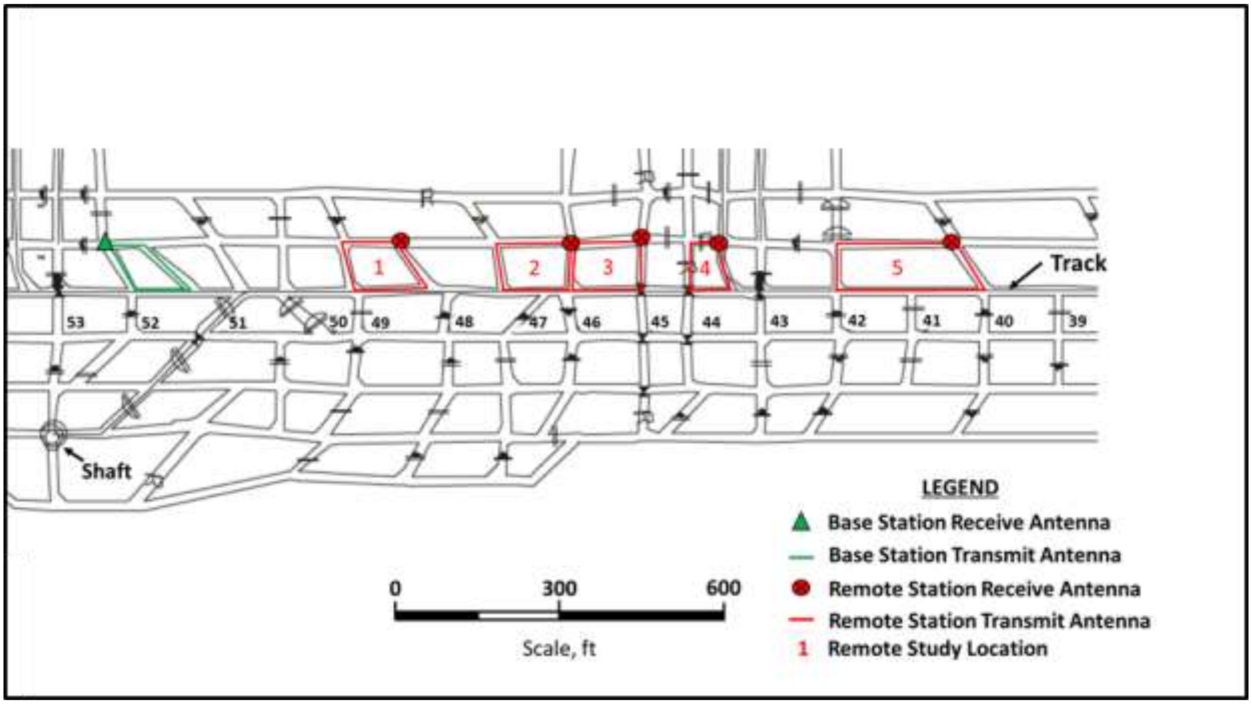


**Figure 57: August 6, 2019 equipment distribution with VA remote unit transmitter antenna "pillar" configurations.**

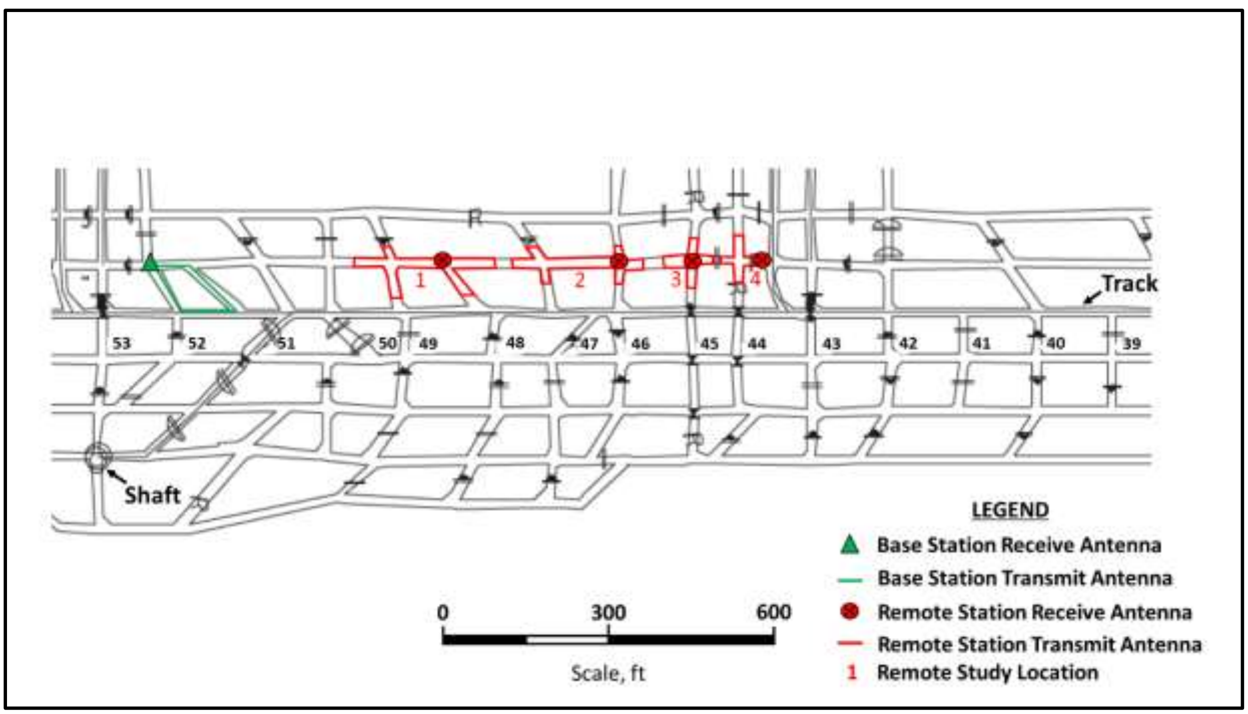


**Figure 58: August 6, 2019 equipment distribution with VA remote unit transmitter "entry" or "cruciform" configurations.**

To evaluate both the VA and Kutta equipment inductive communication performance under controlled conditions, 1,500 feet of 16-gauge single conductor insulated wire was deployed down the primary escape way from the base station radio location in crosscut 52 to the final remote station radio location at crosscut 40, as indicated in Figure 59. The 16-gauge wire served as a surrogate for mine infrastructure (a power cable, belt conveyor structure) that might be employed by sheltering miners during an actual emergency. An attempt was made to ground both ends of the 1,500-foot wire using 6-inch spikes driven into the mine floor. This attempt may have been stymied by the presence of dry, poorly consolidated floor material at the base station end of the wire.

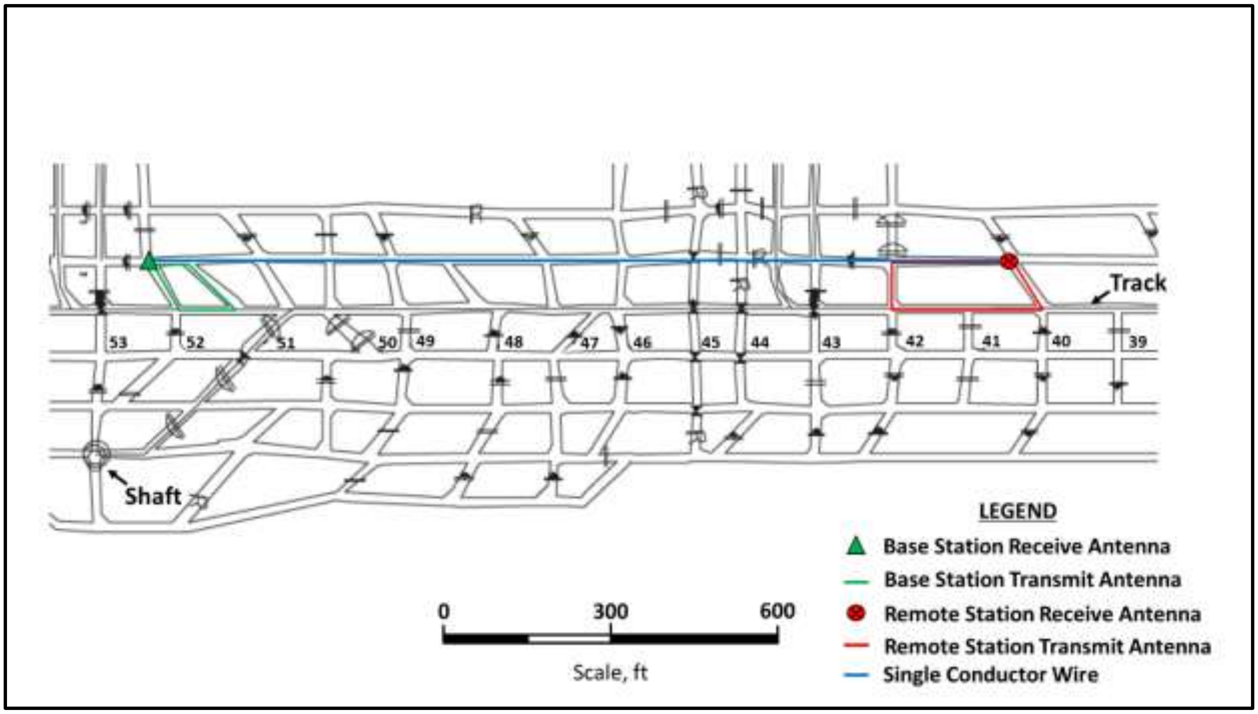


**Figure 59: Path of the single 16-gauge wire used for the inductive communication evaluations.**

For the VA inductive performance evaluation, both the base station and remote unit transmitter antennas were realigned to be less than 1-foot from the grounded, 1,500-foot 16-gauge wire deployed along the primary escape way. The base station antenna had 90-foot length parallel to the wire. The remote unit antenna had an approximate 200-foot long thin loop parallel to the wire. At the base station, the VA receiver antenna was not moved to allow the wire to pass over the antenna. Therefore, its position was not optimized for inductive signal reception. The wire was placed over the receiver antenna at the remote location as shown in Figure 50.

For the Kutta inductive performance evaluation, both the ferrite antenna and the inductive clamp were employed at the base station to couple signal into the wire. Only the remote unit employed a ferrite antenna. When employed, the rod antennas were oriented perpendicular to the 16-gauge wire per the recommended Kutta operating procedure. The IWT interface was employed at the base station alternating with the standard Kutta speaker-microphone.

It must be noted that using one IWT repeater near the base station, independent direct IWT-to-IWT radio communication was possible along the primary escape way from the base station location at crosscut 52 to personnel operating the remote units until they reached the stopping at crosscut 44.

**<u>August 7, 2019 Vertical Communication Evaluations:</u>**

To facilitate execution of the vertical communication evaluation of the VA equipment, underground-to-surface voice communications were enabled by employing MEC Monongalia County Mine Kenwood UHF radios operating on the "Maintenance" band with signals being carried by repeaters located at the top and bottom of the Roberts Run Shaft.

As indicated in Figure 60, the base station radio was set up in crosscut 57 on the left (west) side of the track entry. The base station transmitter antenna was looped around the pillar defined by crosscuts 57 and 58 and the track and primary escape way entries. Half-inch holes were drilled in the crosscut stoppings between the track and escape way entries to accommodate passage for the blue 4-conductor IS base radio transmit antenna. Figure 61 and Figure 62 are photos of the underground base station radio equipment set up in crosscut 57.

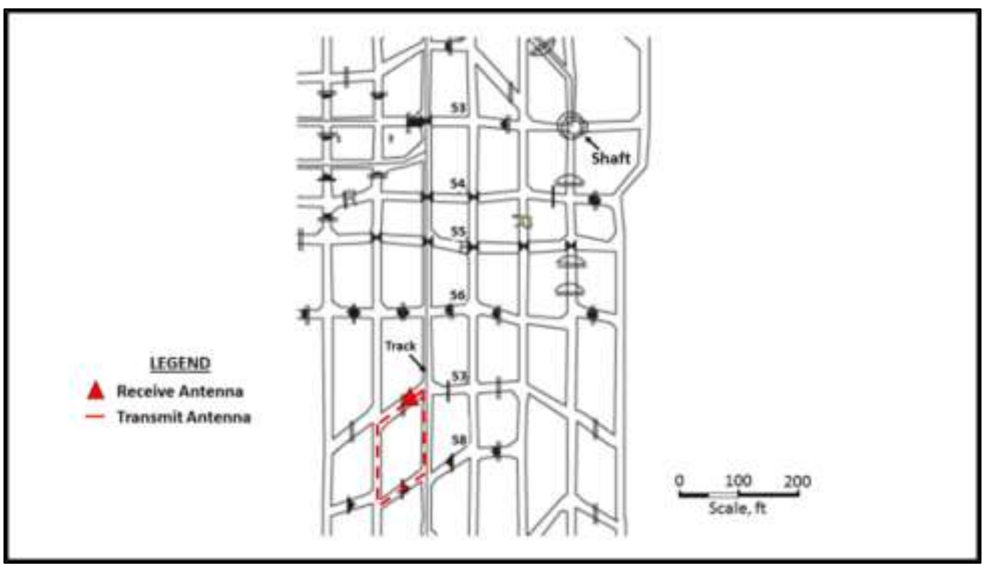


**Figure 60: Underground base station antenna locations for the August 7, 2019 VA vertical communication evaluation.**

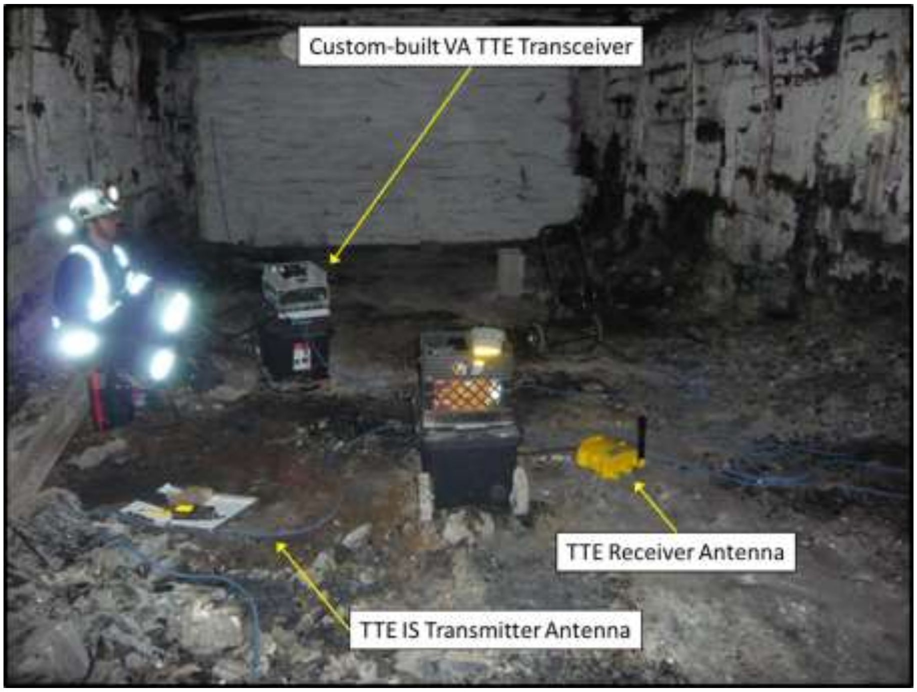


**Figure 61: August 7, 2019 underground base station equipment looking toward the primary escape way. The blue cable is the IS transmitter antenna; the yellow box is the receiver antenna.**

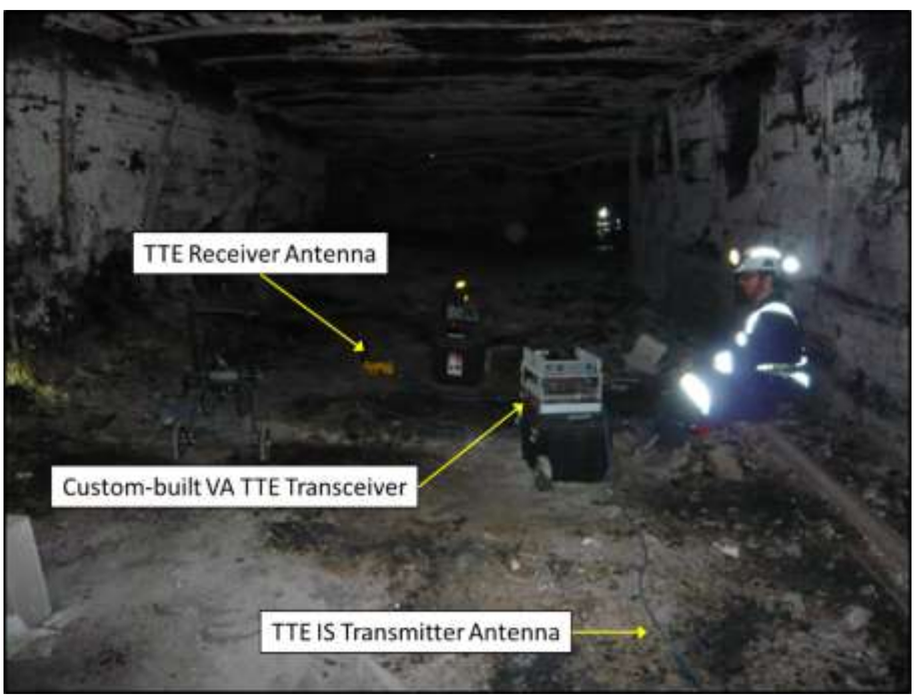


**Figure 62: August 7, 2019 underground base station equipment looking toward the track entry. The VA custom-built radio is in the foreground.**

At the UG1 surface site, the 500-foot long transmitter antenna was deployed above the base station set-up location in a nearly ideal vertical superposition as indicated on the aerial photo of Figure 63. Figure 64 and Figure 65 are ground-level views of the UG1 surface equipment set-up.

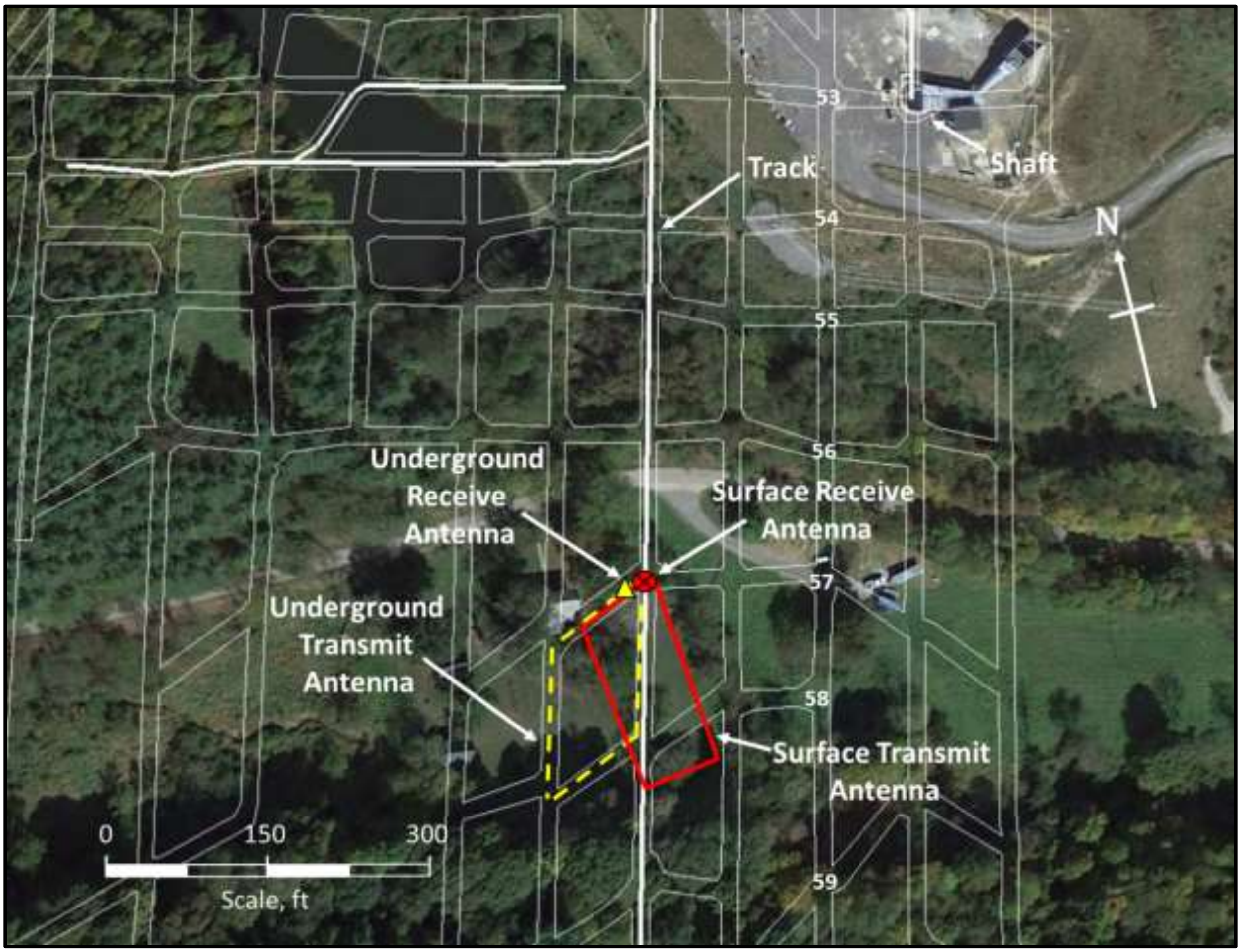


**Figure 63: Aerial photo of UG1 indicating the relative positions of both the underground and surface VA antennas on August 7, 2019.**

**Figure 64: VA equipment set-up at UG1 on August 7, 2019.**

**Figure 65: Close-up photo of the remote unit VA equipment at UG1 on August 7, 2019. The yellow wire is the remote unit's 500-foot circumference transmitter antenna.**

### 4.4.2.3 Mine Site Observations

The following tables summarize all of the formal mine site data. Salient observations from each data set are noted after each table, and those observations are summarized at the end of this section.

**Table 10: VA Lateral Underground Communications Data**

| Date | Time | Distance from Base Station to Remote Station (feet) | Antenna Geometry: Base (customized IS circuitry) 4-conductor circumference (feet) | Antenna Geometry: Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Antenna Geometry: Approx. edge-to-edge antenna separation distance (feet) | IWT Radio interface at Base (Y/N) | Base signal reception at Remote (excellent, good, poor, none) | Remote signal reception at Base (excellent, good, poor, none) | General system perfomance (excellent, good, poor, none) | Observations or Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| 08/06/19 | 12:45 | ~500 | Station A | Set Up #1 | 350 | N | Excel | Excel | Excel | IWT communications on channel 7 clear at ~500 using one PMN at base |
| | | | | Set Up #1 | 350 | Y | Excel | Excel | Excel | |
| | 13:07 | | | Set Up #1X | 275 | N | Excel | None | Poor | Remote TX loop is cruciform shape in escapeway and cross cuts; can see Remote TX indication at Base, but no voice received; 1-way Base to Remote comms only: no Kutta Radio communication possible |
| | 13:11 | | | Set Up #1X | 275 | Y | Excel | None | Poor | |
| | | | | Set Up #1X | 275 | N | Excel | None | Poor | Changed number of carriers on VA units from 36 to 16 [S10M] |
| | 13:40 | ~750 | | Set Up #2 | 650 | N | Excel | Excel | Excel | Returned to 36 carriers [I10M]; IWT communications loud and clear |
| | | | | Set Up #2 | 650 | N | | | | Mine belt start-up elevated noise level |
| | | | | Set Up #2 | 650 | Y | Good | Good | Good | 2-way communications became "sketchy" with some in and out signal loss and "helicoptering" of voice comms, possibly due to higher level of background noise |
| | 14:00 | | | Set Up #2X | 575 | N | Excel | None | Poor | Remote TX loop is cruciform shape in escapeway and cross cuts |
| | | | | Set Up #2X | 575 | Y | Good | None | Poor | |
| | 14:37 | ~1,000 | | Set Up #3 | 800 | N | Excel | Excel | Excel | Some background noise interference noted; IWT comms loud and clear; no Kutta comms |
| | | | | Set Up #3 | 800 | Y | Excel | Excel | Excel | |
| | 14:55 | | | Set Up #3X | 850 | N | Excel | None | Poor | |
| | | | | Set Up #3X | 850 | Y | Excel | None | Poor | |
| | 15:42 | ~1200 | | Set Up #4 | 1000 | N | Excel | Excel | Excel | IWT comms loud and clear; no Kutta comms |
| | | | | Set Up #4 | 100 | Y | Excel | Excel | Excel | |
| | 16:55 | ~1565 | | Set Up #5 | 1250 | N | Excel | Excel | Excel | Had to add 100' of wire to Remote TX antenna to get around larger pillar; no IWT response at 1,550' with single PMN: Remote radio at cross cut |
| | | | | Set Up #5 | 1250 | Y | None | None | None | Intermittent orange/green display observed at Base; another background noise level increase |
| | | | | Set Up #5 | 1250 | N | None | None | None | VA units set for 16 carriers [S10M] |
| | 17:00 | | | Set Up #5 | 1250 | N | None | None | None | VA units set for 8 carriers [E10M] |

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Performance observations for the Vital Alert and IWT equipment from the Table 10 information include:

- Maximum two-way communication separation distance for the "pillar" remote unit transmit antenna configuration was 1,250 feet, but communication was not sustainable at that range due to high, variable underground EM background noise levels.
- Only one-way (base to remote) communication was observed when employing the "entry" or "cruciform" remote unit transmit antenna configuration. Maximum range for one-way communication was 850 feet.
- Background EM noise levels observed at the base station ranged from 30 dBpT to 72 dBpT
- Introduction of the IWT interface with the Vital Alert equipment at the base station had no apparent effect on communication quality.
- Direct, independent communication between IWT radios was possible along the primary escape way to a distance of at least 1,200 feet using a single PMN at the base station. The stopping at crosscut 44 in this entry apparently eliminated IWT communication past that point.

The maximum two-way VA communication range of 1,250 feet observed during the underground evaluation greatly exceeded the comparable maximum range of 500 feet observed during the surface site evaluations (see Section 4.4.1.3). Therefore, it was suspected that the presence of the railroad track in the track entry adjacent to both the base station and remote unit transmitter antennas when employing the "pillar" antenna configuration had influenced VA system performance.

To assess this possibility, VA subsequently conducted the following theoretical analysis. Assume that the maximum intrinsically safe (IS) transmitter moment is 5734 $Am^2$, for based on a 1.4 amp current transmitted across 4 loops measuring 32 m x 32 m (105 ft. x 105 ft.). For such a transmitter moment, the expected signal strength at a horizontal separation of 1000 feet is 27 dBpT. During the underground testing, values as much as 45 dB higher were observed. The simplest explanation for the higher signal strength is inductive coupling of the transmitted signal to railroad tracks. Figure 66 shows the simulation results, generated using VA's finite-difference time-domain (FDTD) modeling tool, that demonstrate what occurs when a transmit loop is placed in the presence of railway tracks underground. A typical low noise floor in the mine was 30 dBpT. For ideal voice communications (SNR > 12 dB), a range of 700–800 feet can be expected. In comparison, when the transmitter is placed next to railway tracks, a range of about 1,500 feet can be expected. The range, even with railway tracks, is also affected by the conductivity of the surrounding rock. Based on the vertical TTE observations, a conductivity of 0.03 S/m was used for this simulation.

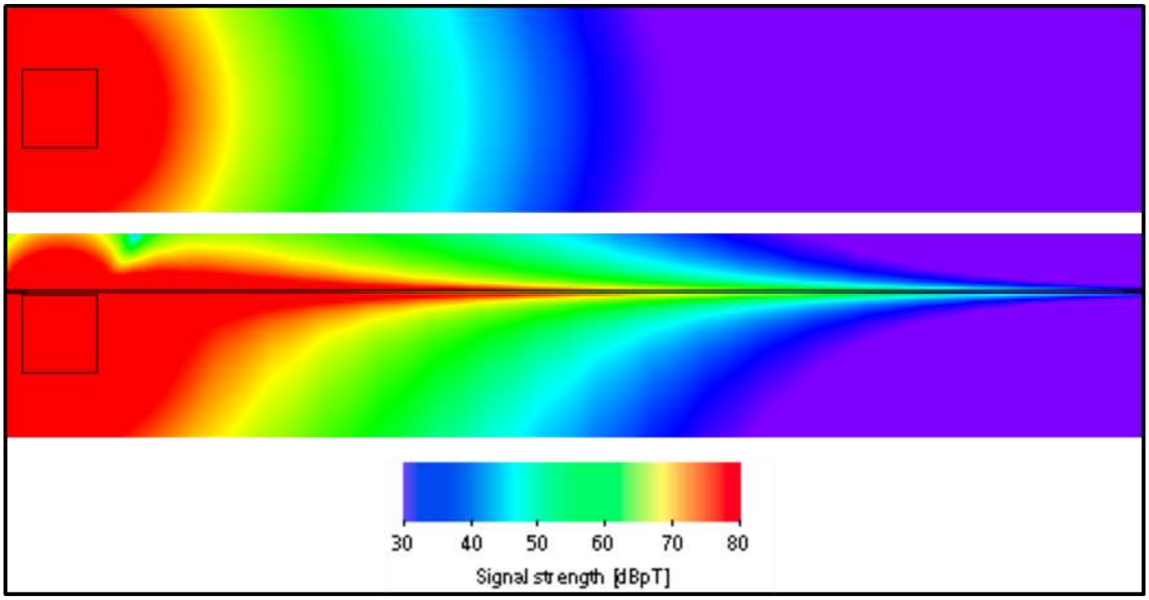


**Figure 66: Comparison of signal strength, expressed as total magnetic field, for a case without coupling (top) and with coupling (bottom). The simulation is a bird's-eye view 1,600 feet long by 325 feet wide. The transmitter antenna is shown as a square.**

The VA theoretical simulation confirms that the observed extended communication range was due to unintended signal induction in the underground railroad tracks.

Table 11 presents the observations from the intentional evaluation of VA inductive performance along the grounded 16-gauge wire deployed along the primary escape way with the remote unit transmit and receive antennas well removed from the track entry.

**Table 11: VA Inductive Underground Communications Data**

| Date | Time | Distance from Base Station to Remote Station (feet) | Antenna Geometry | | | IWT Radio interface at Base (Y/N) | Base signal reception at Remote (excellent, good, poor, none) | Remote signal reception at Base (excellent, good, poor, none) | General system perfomance (excellent, good, poor, none) | Observations or Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Base (customized IS circuitry) 4-conductor circumference (feet) | Remote (standard VA unit) single 16 ga. conductor circumference (feet) | Approx. edge-to-edge antenna separation distance (feet) | | | | | |
| | 15:05 | ~1500 | Intentional inductive test | Set Up #5A | 1250 | N | Good | Good | Good | Base and Remote TX antennas repositioned to be <1' from grounded 1500' single conductor wire along different lengths of the wire (90' for Base, ~200' for Remote); Base RX antenna not relocated to optimum position relative to the wire; reverted to 36-carrier settings [S-I10M]; some minor transmission delay was noted in VA communications; IWT system worked OK. |

The conclusion from this single VA inductive communication performance observation is that effective two-way inductive communication was demonstrated at a distance of at least 1,250 feet, a distance comparable to that evidenced by the Table 10 observations.

**Table 12: Kutta Inductive Underground Communications Data**

| | | Antenna Geometry | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Base | | Remote | | | | Communication Quality | | | |
| Date | Time | Type (ferrite or inductive clamp) | Orientaion ) | Type (ferrite or inductive clamp) | Orientaion and Separation (inches) | Grounded single 16 ga. conductor length (feet) | IWT Radio interface at Base (Y/N) | Base signal reception (excellent, good, poor, none) | Remote signal reception (excellent, good, poor, none) | General perfomance (excellent, good, poor, none) | Observations or comments |
| 08/06/19 | 14:40 | ferrite | perpendicular | ferrite | perpendicular | 1,500 | N | excellent | excellent | excellent | Remote end not grounded |
| | | ferrite | perpendicular | ferrite | perpendicular | 1,500 | Y | good | good | good | some static now present during communications; increasing IWT to IWT separation at the Base improved voice quality somewhat. |
| | | inductive | NA | ferrite | perpendicular | 1,500 | Y | poor | poor | poor | 2-way communication possible, but difficult due to static |
| | 14:45 | inductive | NA | ferrite | perpendicular | 1,500 | N | excellent | excellent | excellent | |

The Kutta equipment performance was then also evaluated over the total length of the 1,500-foot wire in the primary escape way. The Table 15 inductive communication performance observations for the Kutta equipment include:

- Effective two-way communication was demonstrated at a distance of 1,500 feet when the Kutta ferrite antennas were positioned perpendicular to and very close to the wire conductor.
- Substitution of the inductive clamp for the ferrite antenna at the base station had no noticeable effect on communication quality. This suggests that equivalent signal coupling to a conductor may be achieved using either a clamp or a ferrite rod antenna placed as recommended by Kutta, perpendicular to and near the conductor.
- Introduction of the IWT radio interface at the base station again had an adverse effect on communication quality, which again diminished with increasing separation between the two IWT radios.

On August 7, 2019, vertical TTE communications were attempted between VA radios deployed at the UG1 underground and surface locations. Despite repeated attempts employing different VA radio settings as indicated in Table 13, no TTE communication in either direction could be achieved. The only conclusion from this single VA TTE communication performance attempt is that effective two-way vertical communication could not be demonstrated through an overburden thickness of approximately 700 feet.

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**Table 13: VA TTE Communications Data**

| Base Station Transmit Time | UG Base Antenna Configuration | Surface Remote Antenna Location | System Communcation Setting | IWT Radio Interface (Y/N) | Reception Quality Base (UG) | Reception Quality Remote (Surface) | Comments |
|---|---|---|---|---|---|---|---|
| 11:42 | Base Station B set-up | UG1 vertical set-up | 36 carrier [S10M] | N | none | none | UG to surface communications enabled by MCC Kenwood radios operating on the "Maintenance " band |
| 11:46 | | | 8 carrier [E10M] | N | none | none | Base location noise levels observed to be very high and variable ranging between 40-75 dBpT |
| 11:51 | | | 36 carrier [I10M] | N | none | none | |
| 12:10 | | | 36 carrier [I10M] | N | none | none | Base set as "primary"; Remote set as "secondary" radio |
| 12:14 | | | 36 carrier [I10M] | N | none | none | Base set as "secondary"; Remote set as "primary" radio |

VA subsequently conducted another theoretical analysis based upon the detailed underground and surface field observations. Again, assume that the maximum intrinsically safe (IS) transmitter moment is 5734 Am$^2$, based on a 1.4 A current transmitted across 4 loops measuring 32 m x 32 m (105 ft. x 105 ft.). The reported noise levels at the surface ranged between 3 and 21 dBpT, with a mean value of 13 dBpT. A typical sedimentary overburden (a mix of sandstone, limestone, and shale with no unusual groundwater conditions such as a highly saline aquifer) has a bulk conductivity of 0.01 S/m. For an overburden thickness of 700 feet, the expected magnetic field at the surface, if the IS unit is underground, is approximately 32 dBpT, as indicated in Figure 67. Such a signal-to-noise ratio (SNR) would be more than sufficient to establish a communications link from the primary (underground base station) radio to the secondary (surface remote unit) radio. However, if the bulk conductivity is raised to 0.05 S/m, the signal at the surface decreases to approximately 11 dBpT, which is insufficient to establish signal synchronization between the two radios. For a more favorable conductivity of 0.03 S/m, the expected signal strength is 20 dBpT, which would also most likely be insufficient to establish signal synchronization.

Based upon the both the underground and surface SNR values observed during the evaluation period and the VA signal decay analysis, it was that the local overburden conductivity was too great to allow vertical TTE communication at the UG1 location.

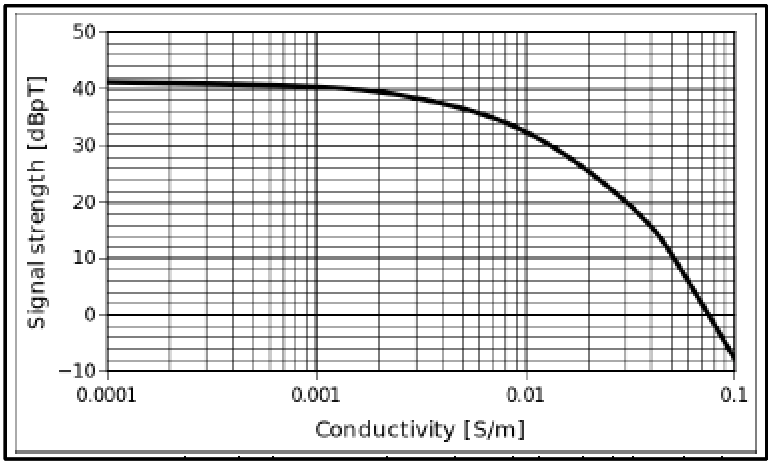



**Figure 67: Decay in signal strength with increasing conductivity of an overburden with a thickness of 700 feet.**

# 5.0 Publication Record and Dissemination Efforts

To date, the only public notification of the project is an abstract for an oral presentation entitled "Investigation of Improved Communication from Portable Refuge Alternatives to Facilitate Mine Escape and Rescue". This abstract was accepted on October 7, 2019 for technical presentation during the 2020 Society of Mining, Metallurgy & Exploration Inc. Annual Convention and Exposition to be held in Phoenix, AZ, February 23-26, 2020.

# 6.0 Conclusions and Impact Assessment

The following paragraphs present the performance observations and conclusions related to each of the evaluated systems. An overall conclusion is provided at the end of this section.

**Vital Alert TTE Communication System**

The primary attractiveness and utility of the VA system is its ability to transmit VLF signals through earth materials and thus offer a potential means for RA occupants to communicate with rescuers either above them on the ground surface or approaching laterally through the mine openings. However, the effectiveness of the VA system to provide those communications is limited by several physical constraints:

- Large transmitter antenna dimensions that will be cumbersome to deploy and maintain underground near a RA and employ by advancing MRTs.
- The range of effective TTE signal transmission restricted by both geologic and ambient surface background noise conditions to distances less than most current and projected domestic coal mining depths. Note that post-event underground EM noise levels are anticipated to be very low due to probable post-event cut-off of all mine power.

- Current MSHA policy that requires electrical equipment used inside a RA to be approved most likely increasing both VA system component size and cost.

While inductive communication along conductors is also possible with the VA radios and may extend the lateral range of effective communications, this possibility has significant constraints:

- The host conductor must be grounded at both ends.
- The VLF signals cannot hop across breaks in the conductor.

Also, the current VA operational protocol establishes a “primary” (“master”) unit which communicates with a “secondary” (“slave”) unit. The primary unit establishes the communication data format with which the secondary unit must be aligned. Multiple “secondary” units may communicate to a single “primary”. However, two secondary units may not be able to communicate directly with each other within the current VA protocol. For the RA application, having to assign one unit the primary status may pose an issue, perhaps interfering with the possibility of enabling RA-to-RA lateral, in-mine TTE, and/or inductive communication.

The base unit VA radio employed in this study was a custom-designed, prototype system which combined both IS and non-IS components. The remote VA radio employed was not designed to be IS, which is acceptable if it is to be used either above ground or in fresh air underground. The MSHA-approved version of the VA radio (which offers comparable performance) has greater size and weight than units employed in this evaluation. Therefore, it would be a greater challenge to determine how and where the components of the MSHA-approved version might fit into the RA rigid steel storage container. Greater size and weight would also be a hindrance to rapid MRT movement and thus discourage the MRT from using the MSHA-approved version as it advances inby the FAB. While the more compact, non-IS VA radio might be employed just outby the FAB, the limited, 500-foot lateral TTE communication range demonstrated during this study suggests that there would be little advantage offered by its use. A rapidly advancing MRT would quickly cover the few hundreds of feet of TTE communication range provided by the VA system. While under favorable circumstances VLF inductive communication with the VA equipment might significantly extend its effective underground communication range, the observed performance of the medium-frequency system discussed in the next paragraphs appears to offer a better inductive communication option.

Note that the evaluated VA radios are intended to enable two-way TTE communications and are designed to be compact, portable, and limited in their transmitted power by MSHA IS requirements on the underground unit. If only one-way signal transmission from the ground surface to a receiver underground was required, a larger, more powerful VLF transmitter could be developed for that purpose.

**Kutta Radios Medium Frequency System**

Inductive communication with the Kutta radios along the continuous conductors employed in this evaluation demonstrated robust two-way voice communication over a lateral distance of at least 2,500 feet. Communication quality at that distance indicated that greater distances are well within the capability of this equipment. Kutta claims underground communication has been supported over “miles” of infrastructure. The conductor carrying the voice communication does not have to be grounded thus qualifying insulated cables as potential communication path candidates along with metal belt structure, pipes, and track that may be in the mine. Any breaks in the conductor will diminish signal strength but will not necessarily eliminate communication past the break. While the units obtained on loan from Kutta were not the DRUM® radios that have received MSHA approval, the performance characteristics and capabilities of the loaned units are identical to those of the DRUM® radios.

Both the evaluated and DRUM® radios are compact so they could be stored in an exterior compartment of a RA storage unit to permit periodic inspection and maintenance, including battery replacement. The radios are simple to set up and intuitive to use which would make them easy to employ by both RA occupants and MRT members. Since there is no hierarchy in the role of different units, multiple Kutta radios can communicate simultaneously along the same conductor. This attribute might also enable communication between groups of miners sheltering in separate underground RAs should their radios employ the same mine infrastructure as a signal carrier.

The primary limitation of medium frequency communication is the need for the presence of an extended continuous (or nearly continuous) conductor on which to induce and transmit signal. Larger diameter electrical power cables are resilient and may well survive a roof fall, fire, or explosion. Mine belt structure is not as resilient to these emergency events, but it runs long distances and could, under certain circumstances, remain intact inby the area most affected by the event possibly permitting long-distance communication between RA occupants and a MRT that has advanced past the site of the event. The same scenario might play out with the emergency lifeline maintained in the primary escape way that leads to many RAs. However, the lifeline would have to be constructed with a metal cable core to serve as the extended conductor. There may be other suitable metal mine infrastructure that survived the event.

When employed per the manufacturer’s instructions, the Kutta radios worked well. The only impediment noted in their performance was when the IWT radio interface was introduced at the base station. Use of the IWT interface had the apparent effect of reducing transmission quality through the introduction of some system noise. This effect diminished as separation increased between the IWT radio interfaced to the Kutta radio and another IWT radio then used as the base station speaker/microphone. Kutta engineers suspect that the multiple digital conversions introduced by use of this three-radio base station configuration may be the cause for the observed quality reduction, but this suspicion has not been investigated.

Note that substitution of an IWT handheld radio for the Kutta speaker/microphone could streamline MRT use of the Kutta radio during the team's advance through the mine toward an occupied RA. IWT unit substitution would then possibly permit direct communication between RA occupants and the rescue operation Command Center through the IWT mine rescue communications system once initial contact has been made. After establishing contact, the back-up MRT establishing fresh air bases outby the advancing MRT might also then use a Kutta radio to monitor and communicate with the trapped miners, alleviating the advancing MRT of this responsibility.

**IWT UHF System**

Once properly programmed, all the IWT radios and the two IWT Portable Mesh Nodes (PMNs) operated reliably and without incident for the duration of the evaluation program. The initial inability to trigger the VA radio using the IWT radio interface demonstrated the sensitivity of the interface operation to minor differences in IWT unit software/firmware and the importance of insuring that the appropriate IWT programming is uniformly applied.

The interfaces developed by VA and Kutta for the IWT radios also worked reliably and as intended. However, their introduction apparently resulted in some VA system signal amplitude loss that only became apparent when the VA system performance became marginal as base station and remote unit separation increased. As mentioned above in the Kutta Radios observations, the IWT interface had the apparent effect of reducing transmission quality through the introduction of system noise that decreased as IWT radio separation at the base station increased. The positive effect of increasing IWT radio separation suggests that something about the IWT unit operation may also contribute to noise generation.

Independent use of a second set of IWT radios operating on a separate channel provided a reliable, alternative means for communications that greatly improved field program efficiency. Using a single PMN unit to boost signal strength between two IWT handheld units, excellent two-way voice communication was demonstrated underground at a range of 1,200 feet during the mine site evaluations. A stopping across in the entry eliminated IWT communication past 1,200 feet. Good quality communications at that point suggest that greater effective range, perhaps approaching 2,000 feet, would have been possible had the stopping not been present. While standard mine rescue protocol generally requires the MRTs to install PMN's every 500 feet in the travel entry, communication has been observed over distances of 2,000 feet, depending on conditions.

This observation suggests that in mines that employ an IWT system for routine communications, having a supplemental PMN available for operation from within a RA could provide an advantage for the RA occupants. Following power cut-off because of a mine emergency, the backup batteries in the IWT components installed in the mine should enable undamaged units to function for an additional period of approximately 72 hours of continuous operation. After that time has elapsed, the IWT system will fail. If rescue of the RA occupants was delayed past that elapsed time, the occupants could then still employ their individual handheld IWT radios with the supplemental PMN to communicate with advancing rescuers as the rescuers approached within range. Since both the IWT handheld radios and PMNs have MSHA approval, their use in this circumstance would not be restricted.

In mines employing wireless communications systems from other vendors, a PMN and an IWT handheld radio operated from within the RA could also enable voice communications with an approaching IWT-equipped MRT at a significant distance from the RA.

**Strata Worldwide:**

As noted in Section 4.2.1, approximately 80% of the movable RAs currently in place in domestic underground coal mines are inflatable units. Therefore, the focus of this study was on alternative communication issues related to inflatable RAs and not rigid metal shelters which pose fewer communication equipment storage and use challenges.

The recommended procedure to occupy any RA does not allow occupants to leave the RA after activating and entering the unit. Therefore, any alternative communication system equipment or materials to be employed exterior to the RA must be securely stored in an exterior-opening compartment to remain safe from damage during RA moves and still be accessible for periodic servicing (example: battery maintenance). Since the typical service life of a RA is five (5) years before it must be refurbished, any communication equipment stored within the interior of a RA must have a minimum 5-year operational shelf life.

Strata has made very efficient use of the available volume of an inflatable RA storage unit leaving little space for storage of additional equipment. This is especially true for space accessed from the storage unit exterior. Given that all the evaluated radios are battery operated, the powered system components to be used from within the RA must either be stored intact in a RA compartment with exterior access or stored without batteries in an interior space while the batteries are stored separately in an exterior-accessible compartment where they can be periodically checked. In the latter case, the miners occupying the RA would have to bring the batteries into the RA and install them in the appropriate alternative radio unit.

The potential bulk of some alternative communication system components (examples: VA transmitter antenna, IWT PMN unit) will likely prohibit their integrated storage in an inflatable RA unit. Note that there is adequate volume in a deployed RA to operate the electronics of any of the evaluated communication alternatives from within the tent structure. Therefore, a more workable concept may be to store any alternative emergency communication in a separate, protective cache that would be moved along with the RA. This concept would address the storage and accessibility issues and battery maintenance concerns. And perhaps the cache could also be designed to better enable more efficient and rapid deployment of specific emergency communication equipment.

**Conclusions**

This research was successful and its objective achieved in that it demonstrated that, subsequent to a mine emergency, either the Kutta medium frequency or the IWT UHF radios might permit miners taking shelter in a portable underground RA to provide key information to underground MRTs thousands of feet before the rescuers could reach the chamber. The information the miners could provide could be the difference between a timely rescue and an unfortunate recovery.

The previous discussions indicate that two technologies offer miners using a refuge alternative a potential, near-term capability to communicate with rescuers advancing toward them through the mine. These two options address the three hurdles listed in Section 2.3 as barriers to the widespread introduction of alternative emergency communication means from underground refuge chambers: system capital and maintenance costs, ease of use, and possible integration or parallel use with either existing in-mine communications systems or those used during mine rescue operations. Limited available volume in inflatable RA storage containers along with the need to maintain batteries necessary to power any alternative emergency communications equipment will probably require a separate storage container to protect that equipment.

Both the IWT portable communications equipment and the Kutta medium frequency radios are MSHA approved commercial off-the-shelf systems capable of integration into existing RA operation with relatively small equipment modification and investment. Miners can employ both systems from inside an activated RA. Either of these two systems might provide critical information to rescue teams while they are still a significant distance from the RA, perhaps several thousand feet, as suggested by the schematic diagram of Figure 68.

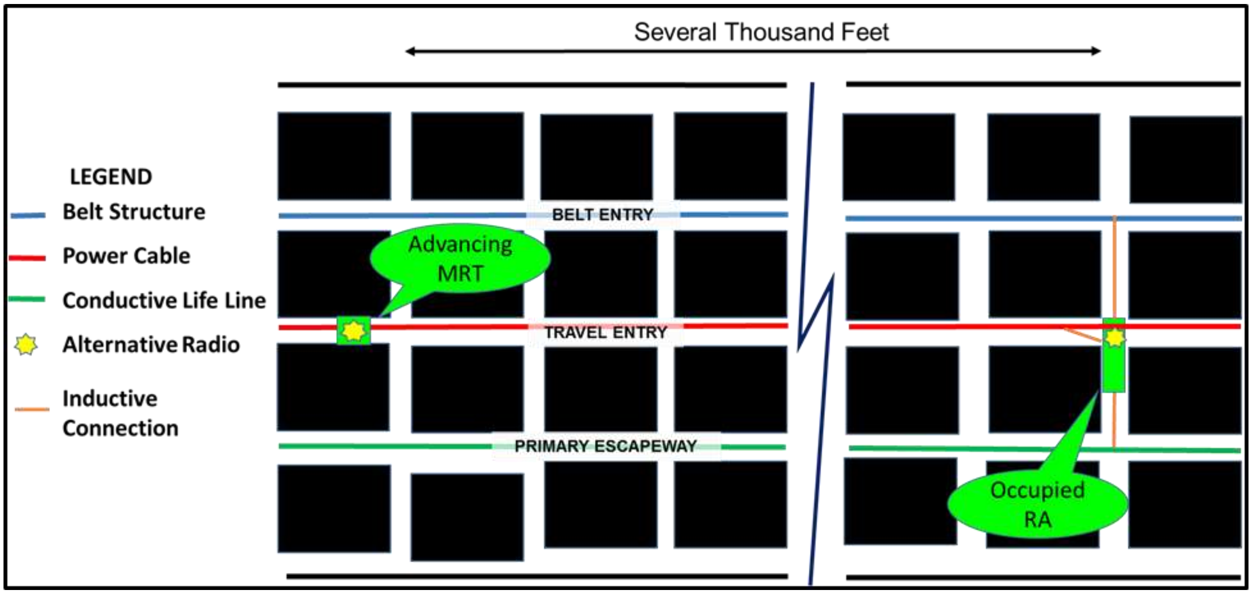



**Figure 68: Schematic diagram indicating how two alternative radio systems could allow sheltering miners to communicate with an advancing MRT.**

In the underground environment, effective communications by the IWT UHF signals require line-of-sight between units limiting their use to a common entry (as indicated in the schematic diagram) and ranges up to about 2,000 feet, under optimum conditions. The Kutta system enables long distance voice communication by inductively linking signals on metal infrastructure such as intact belt conveyor structure, large power cables, and/or possibly metal core emergency escape lifelines. A hard wire connection would be made between the RA and any or all nearby lengthy conductors. Orange lines in the diagram radiating from the RA indicate these connections. The MRT would then employ a Kutta unit as it advances in any entry containing suitable infrastructure to detect transmissions from the RA. This study demonstrated robust communications up to the total 2,500-foot length of wire obtained for evaluation as a surrogate for mine infrastructure. Kutta claims communication is possible along "several miles" of continuous underground conductor.

The modest additional training necessary to operate either of these systems could readily be incorporated into the existing training the miners receive on RA operation and use. Mine rescue teams already have access to IWT mine rescue communications systems. MRTs could incorporate the Kutta Radios medium frequency units into their equipment inventory at a relatively small cost.

The Vital Alert TTE system offers both TTE and inductive communication capabilities. However, both capabilities would be problematic for miners to set up and use to assist in their own rescue. The required MSHA-approved units are cumbersome to use, more costly than their non-approved counterparts, and currently not in production. The effective range of TTE communications is limited and highly dependent upon local geologic conditions. In order to evaluate the maximum effectiveness of the TTE system, testing was purposely conducted in a mine where the overburden thickness was at or near the anticipated upper limit of the system's known capabilities rather than at a mine site with less overburden. The best possible application of the VA TTE system for the RA application would be in mines with overburden thickness less than 500 feet. Even if it had communicated successfully at the attempted greater depth, future VLF TTE system performance would have to be evaluated on site to assess its capability to perform effectively at a specific mine location. For inductive communication, effective transmission of the VLF signals requires that the conductor that carries those signals must be both continuous and electrically grounded, unlike the Kutta medium frequency signals. Since these conditions are less likely to exist after a major underground event, the VA inductive communication capacity must be considered less robust than that offered by Kutta.

# 7.0 Recommendations for Future Work

Additional investigation and development is necessary in two areas to deliver to the mining industry functional options that offer additional capability to communicate between RA occupants and their rescuers. The first area could provide in the near-term two options for extension of lateral, in-mine communications for trapped miners. The second area would require a longer time to investigate and develop a more robust vertical TTE communication option.

**Lateral, In-mine Communication**

With only modest additional development, miners sheltering in an RA could reasonably use two of the three systems evaluated to assist in their rescue. They are the portable mesh node (PMN) from the mine rescue communication system developed by IWT and the Kutta Radios medium frequency DRUM®. Both of these systems are capable of extending communication laterally through the mine workings from the RA to advancing rescuers. Both can be operated using one radio from within the RA.

As noted above, PMN use from RAs in mines already employing an IWT communication system would possibly extend the time that sheltering miners could communicate with approaching MRTs. In mines normally employing wireless communications from other vendors, a PMN and an IWT handheld radio operated from within the RA could enable voice communications with an approaching IWT-equipped MRT at a significant distance from the RA. The only additional work necessary to enable the IWT alternative communication capability in either situation would be:

1. Design and implement appropriate protective storage for the additional IWT equipment either in or near the RA.
2. Develop guidelines, instructions, and training for equipment use in emergencies.

3. In the case of application in mines that do not normally employ IWT communications, possibly offer a simplified handheld radio with a single, standard "emergency" operation channel.

The primary need to fully and effectively implement the Kutta medium frequency system is development and demonstration of reliable means to provide an inductive connection between the RA and nearby belt structure and/or power cables extending outby. This connection would link those long, linear conductors to the available external RA phone connections and thus allow the RA occupants to employ those conductors using the Kutta DRUM®. The connection to belt structure could be as simple as a heavy-duty, spring-loaded clamp affixed to a major structural component to make a continuous electrical connection. A power cable connection might take the form of a scaled-up version of the Kutta inductive clamp so that it could surround a larger diameter power cable. Alternatively, a less attractive cable connection option might be design of a "vampire tap" clamp with sharp projections capable of penetrating the power cable's rugged insulating cover to provide a direct electrical connection. Of course, the vampire tap could only be used if the power cable was not energized.

As noted above, the emergency lifeline maintained in the primary escape way that leads to many RAs might also be employed for communications by the Kutta unit, if the lifeline has a metal cable core and remains intact after the event. In a manner similar to the scenarios proposed in the previous paragraph, a simple, effective, and MSHA-approved means to electrically connect the lifeline to the external RA phone connections would have to be developed and tested. Also, it can be anticipated that multiple splices of various types would be present along the length of the lifeline. The effect of those splices on overall Kutta communication performance should also be evaluated to assess the true viability of utilizing the lifeline as an alternative communication option.

**Vertical TTE Communication**

Additional effort is needed to identify and develop a more effective means that miners in an RA could use to reliably communicate directly with the surface above the RA. The observations of this study reinforce the fact that current two-way VLF TTE technology offers only limited capabilities. Therefore, the VA system must somehow be improved or another means to communicate through-the-earth must be developed or enhanced.

MSHA has made significant improvements in recent years in advancing the capabilities of their emergency seismic location system. The MSHA location system is founded on the theory that if trapped miners could produce detectable seismic signals, rescuers on the surface can identify the underground location of the trapped miners. Tests conducted at a number of mines throughout the country have yielded exciting results. Anticipating that trapped miners would employ a RA, the known underground RA storage points could make miner location via seismic detection more efficient and accurate. When no other information is available, mine rescue operations will focus their efforts on RAs located in the area of the mine where miners were last known to be working. MSHA's seismic location system will be set-up above those locations in an attempt establish communications with the miners in or near the RAs.

However, current use of the seismic location system depends on miners being able to hammer on the roof or on a roof bolt. This is impossible if miners are located in an RA, and there is currently no means for miners to produce seismic signals from inside a deployed RA. To address this situation, it would be desirable to remotely activate from inside the RA an energy source to create a signal that could be detected by the MSHA seismic location system.

This envisioned source located outside the RA would be activated by miners inside the RA using an approved radio (IWT, Kutta, or the mine's standard unit). This seismic generator would be applied against the mine roof and create a signal that could be detected and decoded by the MSHA system. The work would include the development and design of the seismic generator, its IWT/Kutta/mine radio interface, and the testing of the system at mines throughout the country with different depths and strata.

The seismic approach would only support one-way (underground-to-surface) communication. Its transmissions may also be limited to simple impulses that would serve initially to locate the miners underground. To enable surface-to-underground communications, VA could enhance their VLF radios so that a unit at the ground surface might transmit with additional power to increase effective transmission range through the overburden. A VA radio operating at the surface would not be restricted either by IS limitations on transmitter antenna voltage and current or antenna dimensions (within reason).

Underground, the RA occupants would detect the VLF voice or text messages from the surface using the very compact VA system 3-component receiver antenna. This passive receiver could be easily designed to be IS. During a mine emergency with mine power shut down, the RA EM environment should have very low background noise, a very beneficial situation to detect even weak VLF signals from the surface. Rescue personnel at the surface could pose questions with "yes" or "no" response to which the miners underground could, for example, transmit one seismic impulse for "yes" or two impulses for "no". In this manner, cumbersome but useful two-way TTE communications might be enabled by development of a hybrid VLF/seismic approach. Perhaps of equal importance, the miners underground will know they have been located and can actively contribute information to facilitate their own rescue.

Both the short term, lateral communication option development and longer term, vertical TTE communications investigation are recommended as areas of future work.

# 8.0 References


1. Alpha Foundation Grant AFC113-14 Final Technical Report, "Operational Sensitivity of Through-The-Earth Communication", July 2016
2. https://arlweb.msha.gov/MinerAct/2006mineract.pdf
3. MSHA Program Policy Letter P11-V-01, April 14, 2011: "Approval of Communication and Tracking Devices Required by the Mine Improvement and New Emergency Response Act of 2006 (MINER Act)"
4. MSHA Program Policy Letter P11-V-13, April 28, 2011: "Compliance with Post-Accident Two-Way Communications and Electronic Tracking Requirements of the Mine Improvement and New Emergency Response Act (MINER Act)"
5. https://www.federalregister.gov/documents/2008/12/31/E8-30669/refuge-alternatives-for-underground-coal-mines


# 9.0 Appendices

## 9.1 Related MSHA Program Policy Letter (PPL) Excerpts

### 9.1.1 Communication Excerpts from PPL P11-V-01

MSHA prepared Program Policy Letter P11-V-01 on April 14, 2011 to discuss the Approval of Communication and Tracking Devices Required by the Mine Improvement and New Emergency Response Act of 2006 (MINER Act) The policy letter was issued to establish approval guidelines for communication and tracking devices. The policy stated: "The following guidelines are being administered by the Approval & Certification Center when processing applications for approval of communication and tracking products for those underground mines or operations required to have permissible equipment:

1. Any component or system used to provide voice, text, or signaling data (e.g., tracking) that is intended to remain operational in the event of an emergency is considered a telephone or signaling device and evaluated under 30 C.F.R. Part 23.
2. Line powered devices must be equipped with a standby power source to allow continued operation in the event the line power is lost during an emergency. The standby power source must be capable of providing additional operating capacity (24 hours minimum) based on a 5% transmit time, 5% receive time and 90% idle time, denoted as 5/5/90, duty cycle.
3. Untethered communication devices, such as hand-held radios, and individually worn/carried tracking devices, such as tracking tags, must provide at least 4 hours of operation in addition to the normal shift duration (a minimum of 12 hours of operation) based on a 5/5/90

duty cycle. Additionally, these individually-worn/carried tracking devices must provide a low power warning.

4. When operating under standby power, all components of a communication or tracking system must be MSHA-evaluated as intrinsically safe, or housed in an MSHA certified explosion-proof enclosure. Communication and tracking system components include any interconnecting cables. The standby power source must be intrinsically safe within 20 seconds after loss of line power. This would include the in-coming line power cable (back-feed protection).

5. The cable supplying power to the system and all cables between communication and tracking components must be MSHA-approved as flame-resistant or enclosed in MSHA-approved, flame-resistant hose conduit. These cables must be protected from mechanical damage by position, MSHA-approved, flame-resistant hose conduit, metal tubing or troughs. Cables worn by the miner are exempt from these requirements.

6. All non-intrinsically safe cables of a communications and tracking system must be provided with short-circuit protection. Cables shall be protected against short circuits by devices set to trip at no more than 70% of the minimum available short circuit current. The clearing time of the short-circuit protective device must be less than the time required to cause cable damage by any short-circuit or 10 seconds whichever is less. Cables supplied from non-intrinsically safe low-energy sources need not be protected by short-circuit protection devices provided:

   1. The cable receives power from a Class 2-listed power supply (maximum voltage of 30 Volts and maximum power of 100 VA), and
   2. The output is protected with a fuse or circuit breaker with a trip setting less than or equal to the ampacity of the cable, and
   3. The system can identify short circuits in the cable and an operator can manually remove power from the cable.
   4. Large intrinsically safe batteries (greater than 5 kg) that are evaluated in accordance with the battery enclosure requirements of §§ 7.44(a), (b), (d), (e), (f), (h), (l) and (m) will not be subjected to the MSHA intrinsic safety drop test.
   5. Standby power sources that include rechargeable batteries must be designed or equipped with means to mitigate the explosion hazard of battery off-gassing. Examples of available mitigation techniques include venting of the enclosure or automatic de-energization when an explosive gas concentration reaches 20% of the lower explosive limit of the gas.
   6. A justification detailing the minimum safe distance to blasting circuits, detonators, and explosives must be provided by the approval applicant for any radio frequency (RF) device. One acceptable method of justification is through the calculation of the electric field strength and comparison of this value to the acceptable limits published by the Institute of Makers of Explosives (IME) in Standard Library Publication (SLP-

20). For this calculation, the near field/far field boundary is assumed to be three times the wavelength of the radiate frequency unless the applicant justifies a different distance. The approval applicant must specify the maximum output

7. Person-wearable tracking tags are considered portable apparatus and therefore are subjected to the MSHA intrinsic safety drop test. Machine-mounted (asset) tracking tags are subjected to an impact test.
8. Cap lamps powering communication and/or tracking related components are required to meet the performance requirements specified in § 19.9(a) when both the cap light and communication and/or tracking component are in operation. To assure sufficient operational capability in various scenarios, the cap lamp battery should be capable of providing sufficient power to effectively operate the communication and/or tracking component for four hours beyond the 10-hour minimum for the cap lamp.
9. Where lightning arrestors for conductors between surface and underground locations are required, system approval documentation must specify the lightning arrester used to comply with §§ 57.12069 and 75.521, and to ensure that it does not invalidate the Part 23 approval."

### 9.1.2 Communication Excerpts from PPL P11-V-13

MSHA prepared Program Policy Letter P11-V-13 on April 28, 2011 to provide guidance for Compliance with Post-Accident Two-Way Communications and Electronic Tracking Requirements of the Mine Improvement and New Emergency Response Act (MINER Act). The policy letter was issued as a general statement of policy that provides mine operators guidance in implementing: (1) alternatives to fully wireless post-accident two-way communication between underground and surface personnel and (2) electronic tracking systems, both of which are required by the MINER Act. The two-way communication alternatives (or "partially wireless" systems) include infrastructure underground to provide untethered communications with miners.

The policy stated: "The following guidance is provided to assist mine operators in developing post-accident two-way communication between underground and surface personnel and electronic tracking for their Emergency Response Plans (ERPs), as required by the MINER Act. The MINER Act requires, by June 15, 2009, a plan be submitted that provides for a post-accident communication system between underground personnel and surface personnel via a wireless two-way medium and an electronic tracking system that permits surface personnel to determine the location of any persons trapped underground. If these provisions cannot be adopted, the MINER Act requires that ERPs must set forth an alternative means of compliance that approximates, "as closely as possible, the degree of functional utility and safety protection provided by the wireless two-way medium and tracking system" referenced.

With respect to tracking, because electronic systems currently are available and MSHA approved, new ERPs and revisions to existing ERPs should provide for electronic tracking of persons underground. However, because fully wireless communications technology is not sufficiently developed at this time to permit use throughout the industry, this guidance addresses acceptable alternatives to fully wireless communication systems. New ERPs and revisions to existing ERPs should provide for alternatives to fully wireless communication systems.

This guidance represents MSHA's current thinking with respect to two-way communication and electronic tracking for use in mine emergencies. It does not create or confer any rights for any person nor does it operate to bind mine operators or any other members of the public. Mine operators can use an alternative approach or system to provide two-way communication or electronic tracking, if the approach or system satisfies the requirements of applicable statutes and regulations. If you are a mine operator, miners' representative, or miner and want to discuss another approach or system, you may contact the MSHA District Manager for the area in which the mine is located. Other interested parties may contact the individuals identified in this PPL. References to the District Manager in this PPL refer to the Agency's existing consultative process for approving mine plans, as opposed to the process for enforcement decisions related to citations."

**Two-Way Communication System**

In accordance with Section 2 of the MINER Act, until fully wireless systems are available, operators must set forth in their Emergency Response Plans the reasons that they are proposing alternative systems, that is, that wireless systems are not available, and provide an alternative that approximates, as closely as possible, the degree of functional utility and safety protection provided by a wireless two-way communications system. While operators and District Managers must consider mine-specific circumstances in determining appropriate two-way communications systems, this guidance outlines the features MSHA believes would best approximate the functional utility and safety protections of a fully wireless system, given the limitations of current technology. As noted, operators and others may propose other approaches or systems, and the District Manager will exercise his discretion in evaluating them. Communications systems that are already in use may need to be updated to comply with the MINER Act requirements to approximate the utility and safety protections of a fully wireless system.

1. General Considerations - An alternative to a fully wireless communications system used to meet the requirements of the MINER Act for post-accident communication either can be a system used for day-to-day operations or a stored system used in the event of an accident. Examples of currently available technologies that may be capable of best approximating a fully wireless communications system include, but are not limited to,

leaky feeder, wireless or wired node-based systems, and medium frequency systems. Any alternative system generally should:

a. Have an untethered device that miners can use to communicate with the surface. The untethered device should be readily accessible to each group of miners working or traveling together and to any individual miner working or traveling alone.
b. Provide communication in the form of two-way voice and/or two-way text messages. If used, pre-programmed text messages should be capable of providing information to the surface necessary to determine the status of miners and the conditions in the mine, as well as providing the necessary emergency response information to miners.
c. Provide an audible, visual, and/or vibrating alarm that is activated by an incoming signal. The alarm should be distinguishable from the surrounding environment.
d. Be capable of sending an emergency message to each of the untethered devices.
e. Be installed to prevent interference with blasting circuits and other electrical systems.

2. Coverage Area
   a. The system must provide coverage throughout each working section in a mine.
   b. The system also generally should provide continuous coverage along the escapeways and a coverage zone both inby and outby strategic areas of the mine. Strategic areas are those areas where miners are normally required to work or likely to congregate in an emergency and can include belt drives and transfer points, power centers, loading points, refuge alternatives, SCSR caches and other areas identified by the District Manager. While a coverage zone of 200 feet inby and 200 feet outby strategic areas normally should be adequate, the District Manager may require longer or shorter distances given circumstances specific to the mine.
   c. The District Manager may approve alternative coverage areas to those areas identified in 2(b), such as adjacent entries, for reasons such as radio frequency interference or other factors that may reduce the coverage area at the identified strategic areas.
   d. Miners should follow an established check-in/check-out procedure or an equivalent procedure when assigned to work in bleeders or other remote areas of the mine that are not provided with communications coverage.
   e. Communications for refuge alternatives must be provided as required under 30 C.F.R. §75.1600-3.
3. Permissibility - The communication system must be approved by MSHA to comply with 30 C.F.R. part 23 and applicable policies.
4. Standby Power for Underground Components and Devices
   a. Stationary components (infrastructure) generally should be equipped with a standby power source capable of providing sufficient power to facilitate evacuation and rescue in the event the line power fails or is cut off. In many mining situations, at least 24 hours of standby power based on a 5% transmit time, 5% receive time, and

90% idle time duty cycle (denoted as 5/5/90) should be adequate, but mine- specific conditions may warrant more or less standby power capability. The system should display whether it is operating on-line or with standby power and give an indication of the state of charge of standby power.

b. Untethered devices, such as hand-held radios, generally should provide sufficient power to facilitate evacuation and rescue following an accident. In many mining situations, at least 4 hours of operation in addition to the normal shift duration (12-hour minimum total duration) based on a 5/5/90 duty cycle should be adequate, but mine-specific conditions may warrant more or less capability. This total operation time can be achieved via spare portable devices or cached batteries if the device is approved for battery replacement in the hazardous area.

5. Surface Considerations
   a. The surface portion of the communication system generally should include a line-powered surface component with a standby power source to ensure continued operation in the event the line power is interrupted.
   b. The communication system should be configured to allow communication between underground personnel and the communication facility required under 30 C.F.R. § 75.1600-1 where a person who is always on duty when miners are underground can receive incoming messages and respond immediately in the event of an emergency. The person should be trained in the operation of the communication system and knowledgeable of the mine's Emergency Response Plan.
   c. The communication system can be monitored from a remote site. However, the mine site must have full system capability.
6. Survivability
   a. The post-accident communication system generally should provide redundant signal pathways to the surface component. The system should display pathway interruptions and system malfunctions.
      i. Redundancy means that the system can maintain communications with the surface when a single pathway is disrupted. Disruption can include major events in an entry or component failure.
      ii. Redundancy can be achieved by multiple systems installed in multiple entries, or one system with multiple pathways to the surface; provided that a failure in one system or pathway does not affect the other system or pathway.
   b. If system components must be installed in areas vulnerable to damage (such as in front of seals), protection against forces that could cause damage should be provided.
7. Maintenance
   a. The equipment manufacturer generally should provide a maintenance schedule and checklist to the mine operator.

b. The mine operator should:
  i. Establish and follow a procedure to provide communications during system or component failures in the event that an accident occurs before the failure can be corrected. This procedure should include restoring at least 24 hours of standby power for the infrastructure.
  ii. Examine the infrastructure and verify on a weekly basis that it is maintained in proper operation condition. In the event of any failure that results in the loss off communication, repairs should be started immediately and the system restored to operating condition. A record of the examination should be kept and made available to an authorized representative of the Secretary and miners.
  iii. Examine the untethered devices on a daily basis to verify that they are maintained in proper operating condition.
  iv. Follow the manufacturer's maintenance recommendations.

### 9.1.3 Questions and Answers on the PPL P11-V-13

MSHA prepared questions and answers on the Program Policy Letter P11-V-13 on May 24, 2011. These questions and answers related to Refuge Alternative communications are as follows:

**Emergency Response Plan (ERP) Development**

7. Can a mine operator change the communication and/or tracking system specified in its ERP after the ERP has been approved?

A: Yes, provided that a revised ERP, which identifies the new system and contains supporting rationale, is submitted to and approved by the District Manager. In submitting such a revised ERP, the operator should provide information that will permit the District Manager to determine whether benefits associated with the new system justify any installation delay associated with the change.

8. Should mine operators specify the systems that they will install to provide communication and tracking or can they merely state that they will provide communication and tracking capability consistent with the MINER Act?

A: Each ERP should specify the systems that will be installed.

9. What components/systems must be listed in the ERP submittal -- each component/system or just the type of system?

A: Each component/system should be identified in the ERP submittal. Part 23 approved components/systems should specify the MSHA approval number. Components/systems pending MSHA approval should specify that approval is pending.

10. Do explicit Miner Act and/or 30 C.F.R. Part 75 requirements pertaining to emergency response need to be restated in an ERP?

A: Provisions that are explicitly required in the MINER Act or 30 C.F.R. Part 75 do not need to be included in an ERP, as the operator's obligation is clear and is derived from the statute or standard.

14. Do the communication and tracking systems have to be approved by MSHA?

A: Yes. Under MSHA's existing standards, all such systems are required to be approved by MSHA for compliance with Part 23.

**Two-Way Communication Systems**

20. If a fully wireless two-way communication system becomes available, will mine operators be required to install this type of system?

A: As technical advances are made, MSHA will review advances in systems that enhance miners' ability to evacuate or otherwise survive in an emergency and make a determination at that time.

23. Is the two-way communication system under 30 C.F.R. § 75.1600-3(a)(1) (MSHA's standard for a two-way communication facility for refuge alternatives) required to be wireless?

A: No.

24. Can a communication system that is included in the ERP be used to meet the requirements of 30 C.F.R. § 75.1600-3(a) (MSHA's standard for two-way communication facility for refuge alternatives)?

A: Yes, for one of the two communication systems required for refuge alternatives.

25. What does redundancy mean?

A: Redundancy involves the duplication of system functions to ensure that those functions will survive some level of damage to the system; in the context of communications systems, it is used to describe a system that can maintain communications with the surface when a single communication path is disrupted. Redundancy can be achieved by two or more communication systems installed in two or more entries, or one communication system with two or more pathways to the surface; provided that a failure in one system or pathway does not affect the other system or pathway.

27. Can text messaging be used for two-way communication?

A: Yes. Text messaging is acceptable for two-way communication including pre-programmed messages that provide enough information to convey status of miners, mine conditions, and appropriate emergency response information.

30. Can an untethered communications device work while it is inside a prefabricated steel refuge alternative (RA)?

A: Yes, there are several methods available for getting communication signals inside a steel RA. For example, external antennas and a suitable coaxial cable can be connected to the handheld device, or external antennas with a suitable transceiver can be built into the RA. Any method that requires placing holes through the structure would require sealing the holes so that the interior of the RA remains airtight and should not violate the RA approval(s) and be done according to the RA manufacturer's recommendations.

**Maintenance**

50. What are the permissibility examination and maintenance requirements of communication and tracking equipment?

A: Communication and tracking equipment must be examined and maintained for permissibility in accordance with 30 C.F.R. part 75 requirements as addressed in Program Policy Letter P11-V-03, Electric Equipment; Examination, Testing and Maintenance (March 7, 2011). Thus a certified electrician would not be required to conduct the examination; however, the examination must be conducted by a trained person. A record of such examination is not required.

**Additional Questions**

62. How does MSHA explain the inconsistency between battery backup capability for stationary communication and tracking systems (generally at least 24 hours of backup power capability) and the breathable air requirements for refuge alternatives (at least 96 hours of breathable air)?

A: The difference is based on technological considerations. MSHA recognizes that miners sheltered in refuge units for up to 96 hours may benefit from more than 24 hours of backup power for communication and tracking systems. However, at the time Program Policy Letter P11-V-13 was posted, there were very few commercially-available stationary communication and tracking systems that could provide more than 24-hours of backup power capacity. MSHA also recognizes there is a difference between the recommended standby power for infrastructure and operational power for handheld devices, which was also dictated by the state of technology. While the Agency expects that backup power capabilities will evolve, the Program Policy Letter was posted so that operators and miners could derive benefit from a full range of available technologies.

63. Do you have to go inside a refuge alternative (RA) to inspect the communications system?

A: Alternative provisions can be made for verifying operability of a communications system. Mine operators should consult with the RA manufacturer to make a determination of how this should be accomplished without compromising the integrity of the RA.

64. Do communication and tracking systems used in conjunction with a RA require approval under 30 C.F.R. Part 23 or Part 7?

A: All post-accident communication and tracking systems, regardless of their use, will be approved for use under 30 C.F.R. Part 23.

65. What is the requirement for surface areas of mines with regard to Federal Communications Commission (FCC) regulations?

A: Mine operators have a responsibility to ensure they are in compliance with applicable FCC requirements as well as MSHA requirements.

## 9.2 VA Prototype RA TTE Terminal Bench Test Performance Data

# 5 Prototype Performance Measurements

### 5.1 TX Current

The prototype unit was connected to a test load creating a current of just under 1.4A in each TX antenna output with TX level = 100% . The composite TX current waveform (current in all four loops) is shown in Figure 6. The sensitivity of the current monitor is 1A/100mV, so the peak current is 5.28A in 4 loops, or 1.32 A per loop, just under the maximum 1.4 A/loop.

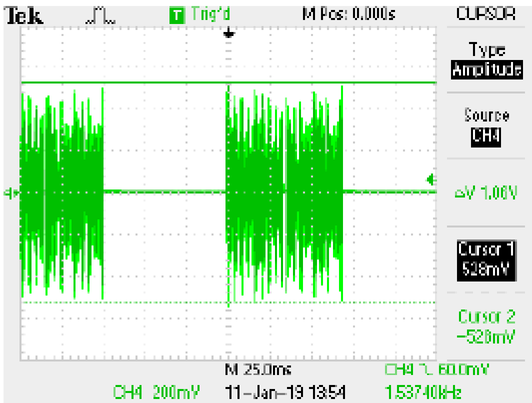



Figure 7 TX current waveform using IHM modulation

### 5.2 Over-current Protection

Over-current protection was tested by shorting one of the antenna wires to ground. Figure shows the TX waveform during this test; the TX waveform on three loops is shut down by a short circuit on the 4th loop. The over current condition was reported on the F1 and F3 LEDs.

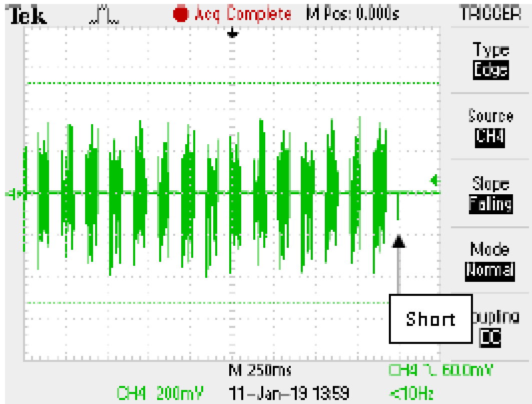



Figure 8 TX Over-current protection test

### 5.3 Receiver Noise Floor

The receiver noise floor was measured using test loads in place of the 3 ferrite antennas. The measured noise is compared with a standard CommPac receiver in the table below, for both Primary and Secondary terminal modes. The RX noise floor was averaged over 20 measurements in each case.

Table 1 RX Noise Floor Measurements

| Receiver Channel | Average Rx Noise Floor (dBpT), IHM Modulation at 4 kHz | |
|---|---|---|
| QPSK Modulation | IS Prototype | CommPac Terminal |
| X channel | 10.8 | 9.6 |
| Y channel | 7.8 | 6.1 |
| Z channel | 7.0 | 5.9 |
| IHM Modulation | IS Prototype | CommPac Terminal |
| X channel | 13.8 | 13.8 |
| Y channel | 11.9 | 12.0 |
| Z channel | 12.9 | 12.1 |

This measurement indicates that the receiver noise floor of the IS prototype is essentially the same as for a standard CommPac VLF receiver.

The minimum signal level for high quality voice communications is 13 dB above the noise floor, and 10 dB above the noise floor for text communication.

Using switched antenna selection, the minimum signal levels (i.e. at a site with environmental noise << 10dBpT) are then:

Voice Communication: 24 dBpT

Text Communication: 20 dBpT

*Note: While IHM modulation requires a slightly higher signal level, it provides better performance than QPSK when the noise is concentrated at the power line harmonic frequencies.*

## 5.4 Interoperability Test

Interoperability of the IS prototype terminal with the standard CommPac receiver was verified against a standard checklist using the default radio configuration settings provided in the Appendix. The interoperability test results are summarized in Table 2. For these tests a multi-turn test TX antenna was used, together with the standard RX antenna. The standard 5m loop antenna was used for the CommPac radio, coiled to reduce the Dipole Moment for short range operation.

Table 2 Interoperability Check List

| Interoperability Test | Result | Comments |
|---|---|---|
| IS terminal QPSK Sync (Primary) | OK | *SNR = 35dB, @ Rx level = 64 dBpT* |
| IS terminal IHM1 Sync (Primary) | OK | *SNR = 17 dB (max possible)* |
| CommPac QPSK Sync | OK | *SNR = 28 dB @ Rx level = 56 dBpT* |
| CommPac IHM Sync | OK | *SNR = 17 dB (max possible)* |
| BER test (QPSK) | < 0.01% | *No bit errors in > 1-hour transmission at 30dBpT* |
| BER test (IHM) | < 0.01% | *No bit errors in > 1-hour transmission at 30 dBpT* |
| CanaryGUI connection | OK | *Note: Tx current not displayed at IS terminal* |
| Voice transmission | OK | |
| Voice reception | OK | |
| Data transmission | OK | *Input from GUI* |
| Data reception | OK | *Reported on IS terminal screen* |
| IWT radio voice input | OK | *Voice from far end TTE to mobile IWT net radio.* |
| IWT radio voice output | OK | *Voice from mobile ITW net radio to far end TTE* |

## 5.5 Power Consumption Tests

| | |
|---|---|
| IS Terminal only consumption: | 0.80 A at 12.0V = 9.6 W |
| With Rx antenna connected: | 0.89 A at 12.0V = 10.7W |
| TX Enabled (QPSK 100%)[1]: | 0.99 A at 12.0V = 11.9 W |
| Calculated Battery Endurance | 117 W-hr./11.9W = 13.4 hours |
| EXT DC Input Current[2] | 1.1 A at 12.3V (13.5W) |

Notes:

1. Test Tx antenna; loop resistance = 2 ohms
2. Charger input current measured with system operating and 0.1A battery charge current

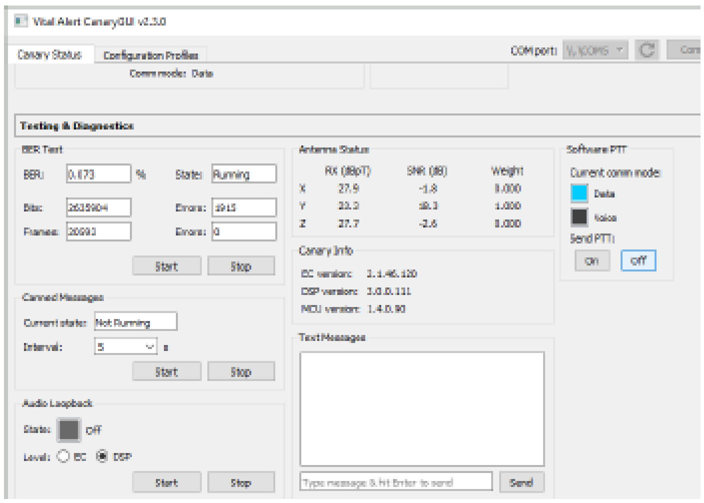
Rebuilding Their Future Foundation, Inc.

### 5.6 Receiver Sensitivity Test

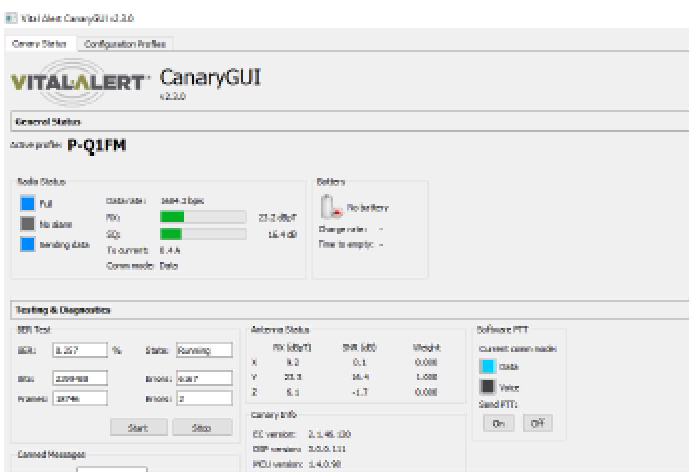
The receiver performance tests were made using test jigs in place of the TX and RX antennas, to eliminate background noise from the measurements. The minimum signal level for full radio synchronization and a low data error rate < 0.5% was 24 dBpT (pk) for QPSK for both the Alpha-IS radio and the standard CommPac radio for real-time voice at 1600 bps. Sample BER test screens are shown below for the link when set up with the Alpha-IS terminal configured as the Primary terminal.

**BER Test: QPSK modulation**

**Alpha-IS Terminal**



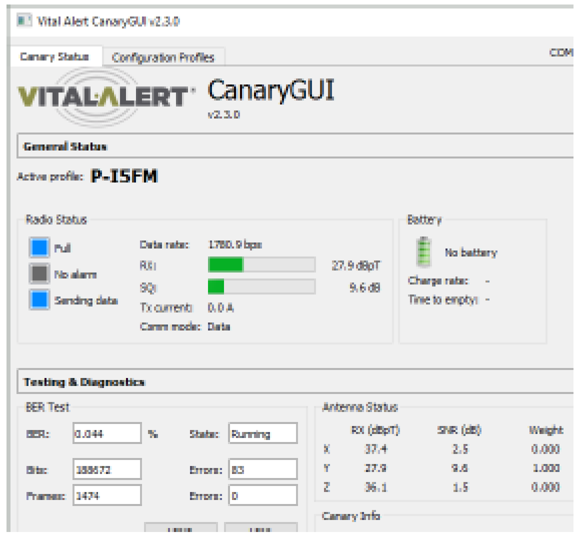

**CommPac Terminal**



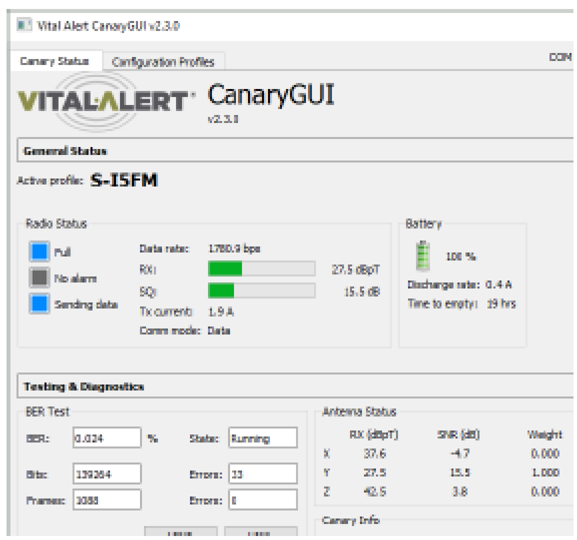
Note: a configuration with the TX level set to 10% was used to avoid over-driving the test jig.

**BER Test: IHM modulation**

**Alpha-IS Terminal**




**Comm Pac Terminal**




The sensitivity of the receiver with IHM modulation is about 3 dB higher than for QPSK, due to the lower average signal level. IHM only provides an advantage over

QPSK at locations where the noise is concentrated at the power-line harmonic frequencies.

## 5.7 Maximum Range

In order to be MSHA compliant the intrinsically safe transmitter has an antenna size of 32m x 32m and uses four separate current limited loops, each carrying a peak current of 1.4A. The total dipole moment is then 5734 $Am^2$. Given the size of the antenna and the transmitter voltage, the antenna current and dipole moment are easily calculated, and closed-form expressions can be used to determine the B-field amplitude at a given distance from the antenna along its axis in free space, i.e. along the vertical path to the surface. For the Intrinsically Safe antenna described above, the static B-field amplitude in free space is + 32.5 dBpT. As the current specified is the peak permissible current, this is the peak amplitude of the magnetic field.

This level is 8 dB above the QPSK receiver sensitivity, and indicates that communications over 300m range is possible provided:

a) The background noise is lower than the receiver noise floor, so that the sensitivity is not degraded significantly.

b) The overburden conductivity is low, so that additional eddy current losses are < 8 dB.

The background noise can be surveyed using the receiver in Secondary Mode, while monitoring the signal level on the display or GUI. The attenuation produced by the overburden is more difficult to assess, because a) the overburden in carboniferous formations comprise many layers of widely differing conductivity, and b), there are no closed form expressions available for this complex structure. In order to resolve this type of problem Vital Alert has developed a tool using the Finite Difference Time Domain (FDTD) method. Experience gained using this tool to model the overburden of a number of mine sites has shown that even with quite moderate conductivity values, the additional attenuation at 300m can be in the 10-20 dB range. This will attenuate the signal below the receiver threshold for real-time voice communications.

However, the receiver sensitivity at lower bit rates is improved because the receiver bandwidth, and hence input noise level is reduced. Operating at 160 bps, instead of 1600 bps reduces the noise by a factor of $\sqrt{10}$ or 10 dB. While this data rate is at the limit acceptable for voice messages, it is quite adequate for real-time text communications.

## 9.3 Surface Site Field Evaluation Plan

# Refuge Alternative Enhanced Communication Surface Site Test Plan

Revision 3.0
20 May 2019

Contract #: AFC719-57

Rebuilding Their Future Foundation, Inc.
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Rebuilding Their Future Foundation, Inc.

**The following draft test plan is presented by the Rebuilding Their Future (RTF) Foundation as the basis for further discussion and refinement with Strata Products Worldwide (Strata).**

## Background

Federal law requires that two communications systems must be available for use by miners in an underground refuge alternative (chamber). Generally, this requirement is addressed using a common, two-wire mine pager system and the mandated mobile communications and tracking system used in the mine. During an emergency, one or both of these systems may be rendered inoperable by the events that occurred in the mine, thus impeding or eliminating the ability of miners sheltering in a refuge alternative from communicating with those intending to rescue them.

Other types of mine communication systems do not rely upon maintaining the physical integrity of multiple, exposed system components to provide long-distance communication. However, the use of these systems has not been investigated in the context of enabling post-event communications from within a refuge alternative (RA). Modest modifications to both RA construction and these alternative commercial communication systems would possibly permit occupants of the refuge alternative to share critical information such as their location, number, individual physical condition, refuge alternative status, and surrounding in-mine conditions to assist in coordinating their rescue or escape.

## Objective

The objective of the proposed field tests is to collect realistic communications data to demonstrate the feasibility of improved means for reliable emergency communication between occupants of an underground RA with rescue personnel on the surface and/or approaching rescue teams or occupants of other nearby RAs located underground.

## Test Equipment, Personnel, and Material Logistics

**<u>Test Equipment</u>**: Data will be collected with the following commercial communications equipment modified as necessary for the RA application:

- **Modified Vital Alert (VA) Canary CommPac system:** The Vital Alert Canary CommPac system is a very low frequency, portable through-the-earth (TTE) system designed to enable voice communication through most geologic materials to a range of about 1000 feet. Text messages may be exchanged at distances approaching 1500 feet. Electrical safety barriers and a transmitting antenna design employed from an earlier MSHA-approved version of this system have been introduced to isolate the transmitting and receiving antennas which would be located external to the RA from the system electronics that would be operated from inside the RA. Figure 1 provides an indication of the approximate size of the modified Canary CommPac electronics package. A smaller, matching standard Canary CommPac system will be used to communicate with the modified system from other underground and surface locations.

***Figure 1.*** *Vital Alert Canary TTE communications system.*

- **Innovative Wireless Technologies (IWT) radio system:** The hand-held Sentinel™ radios are components of the MSHA-approved, node-based mine communications system developed by IWT (see Figure 2). The IWT communications system is employed by MSHA's Mine Emergency Operations teams. VA has developed an interface that links the Sentinel™ radios to the VA TTE system to provide interoperability capability between the two radio systems. The portable mesh node and gateway units shown in Figure 2 will also be employed to establish a comparative basis for basic IWT system performance under the same test conditions presented to the other systems.
- **Kutta Technologies (Kutta) DRUM system:** The Kutta Digital Radio for Underground Mines (DRUM) is a portable wireless, medium frequency, MSHA-approved radio system. When the transceiver antenna (see Figure 3) is placed near metallic mine infrastructure such as cables, wires, tracks, and pipes, the medium frequency radio signals couple into the infrastructure which then become

communication paths to enable voice communication that can extend long distances.  Kutta has also developed a prototype interface that links the IWT Sentinel™ radios to their transceiver to provide interoperability between the two radio systems.


***Figure 2**. IWT node-based mine rescue communication system components*


***Figure 3.**  Kutta DRUM transceiver unit with its cylindrical antenna in the foreground*

**<u>Personnel:</u>**  It is anticipated the following individuals will participate each day in the data collection exercise:

- **Strata**
  - One site contact/liaison/supervisor
- **Rebuilding Their Future (RTF) Foundation**
  - Michael Trevits
  - John Urosek
  - Steven Cotten

**Material Logistics**: The following equipment and materials will be provided by the indicated parties to enable execution of the test plan. (Numbers in parenthesis indicate the number of units to be supplied):

- **Strata:**
  - Interior access to one (or more) deployed RAs [While this would be ideal, it is not an absolute requirement.]
  - Interior building location with a table and chairs for four (4) people
  - Restroom facilities
  - Visitor tags (3)
- **RTF:**
  - Vital Alert stationary (underground) TTE transceiver system (1)
  - Vital Alert roving (underground and surface) TTE transceiver system (1)
  - Vital Alert ferrite antennas (2)
  - IWT hand-held radios (2)
  - IWT Sentinel hand-held radios with interfaces (2)
  - IWT Permissible Mesh Node (PMN) (2)
  - Kutta Technologies DRUM medium frequency system transceivers (2)
  - 1000-foot spools of 16-gauge wire (5)
  - Hardware to emulate proposed communication system interfaces with Strata RAs (1)
  - Notebook computer (1)
  - Mechanical tool box (1)
  - Electrical tool box with miscellaneous supplies (1)
  - Measurement tapes or rollers (2)
  - Copies of the approved test plan (5)
  - Tent or canopy to shelter surface team and equipment (1)
  - Visitor PPE (safety glasses, boots, gloves, reflective coveralls or vests )
  - Back-up or spare communication system and computer components (as necessary)

## Location [TBD]

**General:** A Strata commercial site or other surface site with a Strata RA that can be deployed will be employed to collect data. The deployed RA will serve as the base from which all other measurements are made as complimentary communications equipment is moved away from that operating from the base. During test execution, there should be reasonable access to open surface locations located up to 2000 feet away from the base location. Ideal site requirements include the following:

**Surface Base Location:**

- Easy access
- A deployed RA
- A site engineering map indicating site dimensions and locations of site infrastructure (buildings, pipelines, power lines)
- Minimum 500-ft. separation from any large, active electrical equipment or site power distribution, including 220-volt lines
- Ability to deploy a 100-ft. by 100-ft. square antenna at or near the site
- Ability to deploy a minimum of 2,000 feet of wire linearly away from other parallel and continuous metal infrastructure (power cables, water or sewer pipes)

**Surface Remote Locations:**

- Series of periodic surface locations located linearly up to a minimum of 2,000 feet away from the base location
- Reasonable access by surface transportation
- At each individual location, a minimum 500-ft. separation from any significant active electrical equipment or power distribution lines, including 220-volt power lines
- Area to deploy a 100-ft. by 100-ft. square antenna at (or very near) each location

Note that final selection and actual use of specific base sites and remote locations may depend on commercial operation activities and weather conditions encountered on the days available for test execution. To minimize disruption to Strata operations, testing may be performed on weekends or non-production daylight shifts.

## General Test Approach

The approach is to make observations and conduct initial data collection with (1) a commercial very low frequency (VLF) TTE communication system, (2) a commercial medium frequency radio system, and (3) commercial hand-held radios using repeaters to simulate connection to the Mine Emergency Communications system and also interfaced with the TTE system and medium frequency system. At the mutually selected Strata location, a base station will be set-up to simulate the site of an RA deployed underground, and a series of remote surface locations will be occupied to simulate communications between the RA and rescuers located both on the surface and approaching through the mine.

**Performance Tests:**

1. From the base station, identify and map the nearby metal infrastructure and power distribution equipment.
2. At the base station, set-up the stationary TTE communications system interfaced with the IWT hand-held Sentinel radio, deploying the large (100 ft. by 100 ft.) TTE transmitting antenna configuration.
3. Set up the IWT PMN.
4. Conduct a range test with both the TTE and IWT systems by evaluating communication performance at 250-foot intervals from the RA base location starting at 250 feet from the RA and extending outward to at least 2,000 feet.
5. Reconfigure the TTE transmitting antenna to a more compact, 15 ft. by 50 ft. configuration.
6. Repeat step 4 for the TTE only.
7. Deploy the 2,000-foot test wire along the linear path connecting the identified remote locations.
8. Conduct range tests at 250-foot intervals along the 2,000-foot wire with both the TTE and IWT systems by evaluating communication performance at 250-foot intervals from the RA base location starting at 250 feet from the RA and extending outward to at least 2,000 feet.
9. Reconfigure the TTE transmitting antenna to its large (100 ft. by 100 ft.) configuration.
10. Conduct a range test at 250-foot intervals along the 2,000-foot wire with only the TTE system.
11. At the base location, substitute a small ferrite TTE antenna located adjacent to the 2,000-foot test wire for the large TTE transmitting antenna.
12. Repeat step 10.
13. Interrupt the continuity of the 2,000-foot test wire.
14. Repeat step 10.
15. Restore continuity of the 2,000-foot test wire.
16. Substitute the medium frequency system antenna for the TTE system ferrite antenna adjacent to the 2,000-foot test wire.
17. Repeat steps 12 through 14 with the medium frequency system.

## Detailed Execution Protocol

A detailed execution plan for each day of test execution will be developed with and approved by Strata site management after the test site has been identified. A minimum of two (2) days is currently envisioned to complete the anticipated scope of testing. The detailed daily plans will be organized under the major activities listed below. The anticipated duration of each activity be will indicated in each activity heading leading to a target schedule for activity completion and a total time forecast.

1. Arrival and Mine Orientation [X.X hours]
2. Mine Travel, Site Inspection [X.X hours]
3. Test Preparation [X.X hours]
4. Data Collection [X.X hours]
5. De-mobilization, Mine Travel [X.X hours]

## 9.4 Mine Site Field Evaluation Plan

# Refuge Alternative Enhanced Communication Mine Site Test Plan

Revision 3.1
15 July 2019

Contract #: AFC719-57

Rebuilding Their Future Foundation, Inc.
P.O. Box 721
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**The following draft test plan is presented by the Rebuilding Their Future (RTF) Foundation as the basis for further discussion and refinement with Murray Energy Corporation (MEC).**

## Background

Federal law requires that two communications systems must be available for use by miners in an underground refuge alternative (chamber). Generally, this requirement is addressed using a common, two-wire mine pager system and the mandated mobile communications and tracking system used in the mine. During an emergency, one or both of these systems may be rendered inoperable by the events that occurred in the mine, thus impeding or eliminating the ability of miners sheltering in a refuge alternative from communicating with those intending to rescue them.

Other types of mine communication systems do not rely upon maintaining the physical integrity of multiple, exposed system components to provide long-distance communication. However, the use of these systems has not been investigated in the context of enabling post-event communications from within a refuge alternative (RA). Modest modifications to both RA construction and these alternative commercial communication systems would possibly permit occupants of the refuge alternative to share critical information such as their location, number, individual physical condition, refuge alternative status, and surrounding in-mine conditions to assist in coordinating their rescue or escape.

## Objective

The objective of the proposed field tests is to collect realistic communications data to demonstrate the feasibility of improved means for reliable emergency communication between occupants of an underground RA with rescue personnel on the surface and/or approaching rescue teams or occupants of other nearby RAs located underground.

## Test Equipment, Personnel, and Material Logistics

**Test Equipment**: Data will be collected with the following commercial communications equipment modified as necessary for the RA application:

- **Modified Vital Alert (VA) Canary CommPac system:** The Vital Alert Canary CommPac system is a very low frequency, portable through-the-earth (TTE) system designed to enable voice communication through most geologic materials to a range of about 1000 feet. Text messages may be exchanged at distances approaching 1500 feet. Electrical safety barriers and a transmitting antenna design employed from an earlier MSHA-approved version of this system have been introduced to isolate the transmitting and receiving antennas which would be located external to the RA from the system electronics that would be operated from inside the RA. Figure 1 provides an indication of the approximate size of the modified Canary CommPac electronics package. A smaller, matching standard Canary CommPac system will be used to communicate with the modified system from other underground and surface locations.

***Figure 1.*** *Vital Alert Canary TTE communications system.*

- **Innovative Wireless Technologies (IWT) radio system:** The hand-held Sentinel™ radios are components of the MSHA-approved, node-based mine communications system developed by IWT (see Figure 2). The IWT communications system is employed by MSHA's Mine Emergency Operations teams. VA has developed a prototype interface that links the IWT Sentinel™ radios to the VA TTE system to provide interoperability capability between the two radio systems. The portable mesh node and gateway units shown in Figure 2 will also be employed to establish a comparative basis for basic IWT system performance under the same test conditions presented to the other systems.
- **Kutta Technologies (Kutta) DRUM system:** The Kutta Digital Radio for Underground Mines (DRUM) is a portable wireless, medium frequency, MSHA-approved radio system. When the transceiver antenna (see Figure 3) is placed near metallic mine infrastructure such as cables, wires, tracks, and pipes, the radio signals couple into the infrastructure which then become communication paths to enable voice communication that can extend long distances. Kutta has also developed a prototype interface that links the IWT Sentinel™ radios to their transceiver to provide interoperability between the two radio systems.


***Figure 2**. IWT node-based mine rescue communication system components*


***Figure 3.** Kutta DRUM transceiver unit with its cylindrical antenna in the foreground*

**<u>Personnel:</u>** It is anticipated the following individuals will participate each day in the two-day data collection exercise:

- **MEC**
  - Two mine escorts
- **Rebuilding Their Future (RTF) Foundation**
  - Michael Trevits
  - John Urosek
  - Steven Cotten
  - Possibly, one representative from Vital Alert (Mike Roper?)

**<u>Material Logistics</u>**: The following equipment and materials will be provided by the indicated parties to enable execution of the test plan. (Numbers in parenthesis indicate the number of units to be supplied):

- **MEC:**
  - Appropriate underground transportation for up to five people and the RTF test equipment [see RTF list below] (1)
  - Mine map(s) of the selected underground test site(s) (TBD)
  - Overburden depth and general geologic description above the selected underground site(s) (TBD)
  - Visitor cap lamps (3-4)
  - Visitor self-contained self-rescuers [SCSRs] (3-4)
  - Visitor tags (3-4)
  - Possibly, appropriate transportation to a surface site for two people, the mobile TTE transceiver system, and other surface site support equipment [see RTF list below]

- **RTF:**
  - Vital Alert stationary (underground) TTE transceiver system (1)
  - Vital Alert roving (underground and surface) TTE transceiver system (1)
  - IWT Sentinel hand-held radios (2)
  - IWT Sentinel hand-held radios with interfaces (2)
  - IWT Permissible Mesh Node (PMN) (2)
  - Kutta Technologies DRUM medium frequency system transceivers (2)
  - 500-foot spools of 12-gauge wire (5)
  - Hardware to emulate proposed RA communication system interfaces (1)
  - Notebook computer (1)
  - Mechanical tool box (2)
  - Electrical tool box with miscellaneous supplies (2)
  - Measurement tapes and/or rollers (2)
  - Copies of the approved test plan (5)
  - Visitor PPE (mine helmet, mine belt, safety glasses, metatarsal boots, gloves, reflective coveralls or vests)
  - Tent or canopy to shelter surface team and equipment (1)
  - Back-up or spare communication system and computer components (as necessary)

## Location [TBD]

**General:** Underground entries in the selected MEC mine will be employed to collect data. One underground site will be identified to simulate the RA location and serve as the base from which all other measurements are made. During test execution, there must also be reasonable access to the surface location directly over the underground base.

Ideal site requirements include the following:

**Underground Base:**

- Reasonable access by underground transportation
- Minimum 500-ft. separation from any active load center or other major mine power distribution equipment
- Ability to deploy at or near the site an antenna of 500-foot total length in an approximate 125-ft. by 125-ft. square
- Ability to deploy 2,500 feet of wire down an “empty” entry containing no other continuous metal infrastructure (track, power cable, water pipe, belt structure)
- Nearby access to a “travel” or “belt” entry containing continuous metal infrastructure (track, power cable, water pipe, belt structure)

**Surface Location:**

- Located directly above the underground base location
- 1,000 feet or less of overburden (to improve probability of establishing/demonstrating TTE communication.
- Reasonable access by surface transportation
- Minimum 500-ft. separation from any significant active electrical equipment or power distribution lines (including 220-volt power lines)
- Area to deploy an antenna of 500-foot total length in an approximate 125-ft. by 125-ft. square at (or very near) the site
- Area to offset the 125-ft. by 125-ft. square antenna about 250 feet from the first antenna deployment site

**Secondary Surface-to-Underground Communication Capability**

- Ability for the surface and underground teams to communicate independently from using the TTE system.
- Possible suggestion: Surface team mobile (cell) phone to mine office (dispatcher?), mine office (dispatcher) to underground team via routine in-mine communications means.

Note that final selection and actual use of specific sites and/or entries may depend on in-mine and surface and weather conditions encountered on the days available for test execution. To minimize disruption to mine production and operations, testing may be performed on weekends or other non-production shifts.

## General Test Approach

At the mutually selected mine location, a base station will be set-up underground to simulate the site of a deployed RA. The approach is to make observations and conduct initial data collection with (1) a commercial very low frequency (VLF) TTE communication system, (2) a commercial medium frequency radio system, and (3) commercial hand-held radios using repeaters to simulate connection to the Mine Emergency Communications system and also interfaced with the TTE system and medium frequency system.

**Day One - Underground Tests:**

1. Identify a base station site where the roving TTE and the medium frequency systems could be employed for long-range communications monitoring and testing.
2. At the underground base station, identify and map the mine’s nearby metal infrastructure and power distribution equipment.
3. Set-up the stationary TTE communications system interfaced with the IWT hand-held Sentinel radio, deploying the large (125 ft. x 125 ft.) single loop TTE transmitting antenna configuration.
4. Set up one IWT PMN.
5. Set up the medium frequency system with its IWT radio interface
6. Conduct a roving range test with the TTE, the medium frequency, and the IWT systems by evaluating communication performance at 250-foot intervals from the simulated RA base location starting at 250 feet from the base and extending outward to 2,500 feet down both the “empty” and “travel” entries.
7. Reconfigure the TTE transmitting antenna to a small (10 ft. x 40 ft.) five loop configuration.
8. Repeat step 6 for the TTE only.
9. Deploy the 2,500-foot test wire down the “empty” entry with 40 feet adjacent to the TTE antenna. Ground each end of the test wire.
10. Conduct a range test down the “empty” entry with both the TTE and the medium frequency systems interfaced with the IWT radios by evaluating communication performance at 250-foot intervals from the simulated RA base location starting at 250 feet from the base and extending outward to 2,500 feet
11. Reconfigure the TTE transmitting antenna to its large (125 ft. x 125 ft.) configuration again maintaining 40 feet of the conductor adjacent to the TTE antenna.
12. Conduct a range test down the “empty” entry with only the TTE system by evaluating communication performance at 250-foot intervals from the simulated RA base location starting at 250 feet from the base and extending outward to 2,500 feet.

13. Interrupt the continuity of the 2,500-foot test wire.
14. Repeat step 10.
15. Connect the medium frequency system from the base station to nearby linear metallic mine infrastructure in the “travel” entry and relocate the small ferrite TTE antenna adjacent to the linear metallic mine infrastructure in the “travel” entry.
16. Repeat step 10 in the “travel” entry using both the TTE and the medium frequency systems interfaced with the IWT radios.
17. Continue as far outby (or inby?) as communication with either or both of the two radio systems will allow.

**Day Two – Underground-to-Surface Tests:**

Coordination of TTE testing between the surface and underground is always a challenge, especially if the quality of the initial TTE communications is poor. Test execution may be expedited if a second, alternative communication method is available (example: cell phone communication from the surface site to the mine portal and then from the mine portal to the underground site) as suggested above on page 5. At the underground base station location, set-up the stationary TTE communications system interfaced with the IWT Sentinel hand-held radio, deploying the large (125 ft. x 125 ft.) TTE transmitting antenna configuration.

1. Concurrently, set up the mobile TTE communications system at the surface location directly over the underground site using its standard (125 ft. x 125 ft.) transmitting antenna configuration.
2. Establish and evaluate TTE communications between the underground and surface sites along with any effect of employing the interface with the IWT radio.
3. Offset the TTE mobile transceiver system and its antenna approximately 250 feet from its original location.
4. Re-establish and evaluate TTE communications between the underground and surface sites.
5. Return the mobile TTE communications system to its original surface location over the underground site.
6. Concurrently, reconfigure the transmitting antenna for the underground system to its small (10 ft. x 40 ft.) five loop configuration.
7. Repeat steps 2 through 5.

## Detailed Execution Protocol [TBD upon mine site selection]

A detailed execution plan for each day of test execution will be developed with and approved by MEC mine management after the test site has been identified. A minimum of two (2) days is currently envisioned to complete the anticipated scope of testing; one day for in-mine investigations, one day for underground-to-surface TTE investigations.

The detailed daily plans will be organized under the major activities listed below. The anticipated duration of each activity will be indicated in each activity heading leading to a target schedule for activity completion and a total time forecast for each day.

1. Arrival and Mine Orientation [X.X hours]
2. Mine Travel, Site Inspection [X.X hours]
3. Test Preparation [X.X hours]
4. Data Collection [X.X hours]
5. De-mobilization, Mine Travel [X.X hours]

## 9.5 Vital Alert Radio Operating Profile Characteristics

| Profile Identifier Code | Number of Carriers | Transmitter power (percent of maximum) |
|---|---|---|
| I01M | 36 | 20% |
| I05M | 36 | 50% |
| I08M | 36 | 80% |
| I10M | 36 | 100% |
| S10M | 16 | 100% |
| E10M | 8 | 100% |
| S02M | 16 | 20% |
| E02M | 8 | 20% |

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