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MSHA/OSRV

Advances in Mine Wireless Communications Solutions That Work

Tunnel Radio of America, Inc.

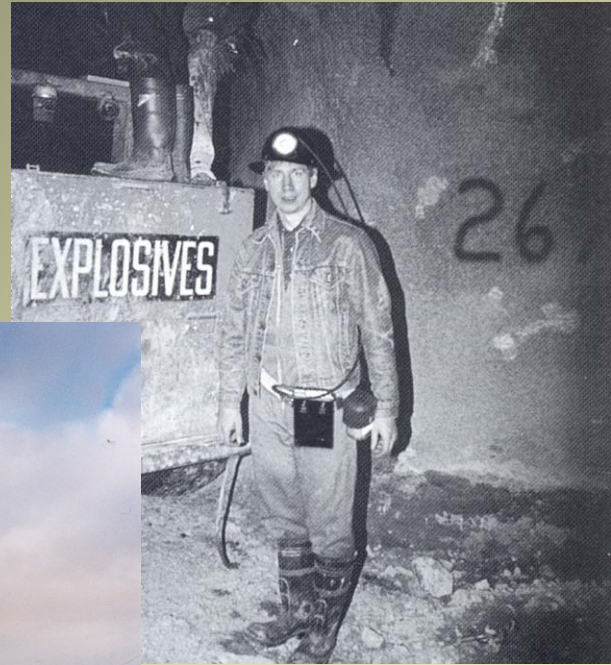
3-2006

Ideas for Today and Tomorrow
Presented by Mark D. Rose



AB44-HEAR-1E-POWERPOINT-SUBMISSION

Why do we do this stuff?



For Them!



2-Way Radio System Features...

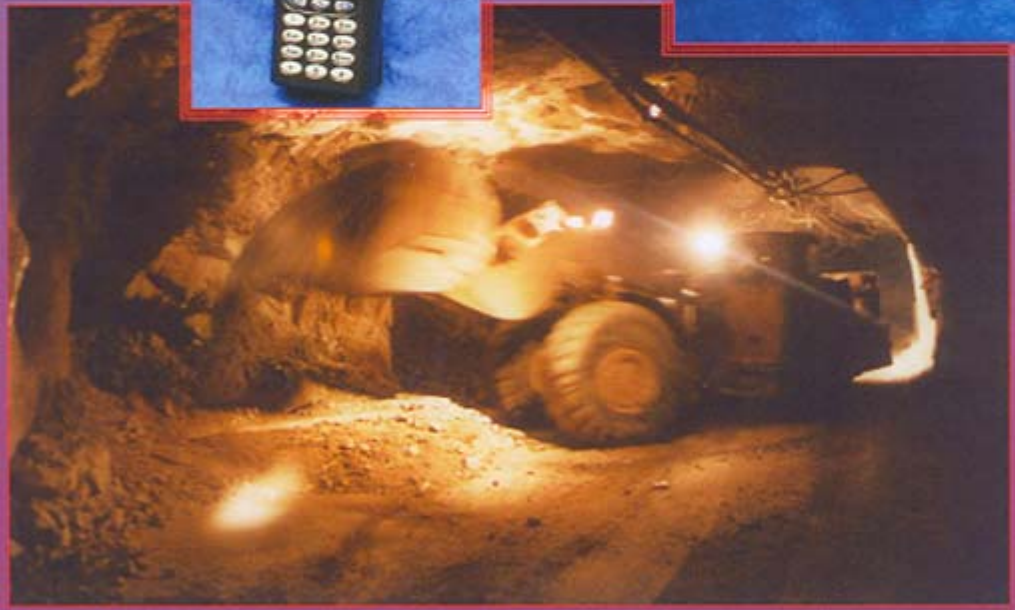


Basic System Requirements

- Person to Person wireless Communication across network
- Surface to Underground Use
- Mobile Relay Functional

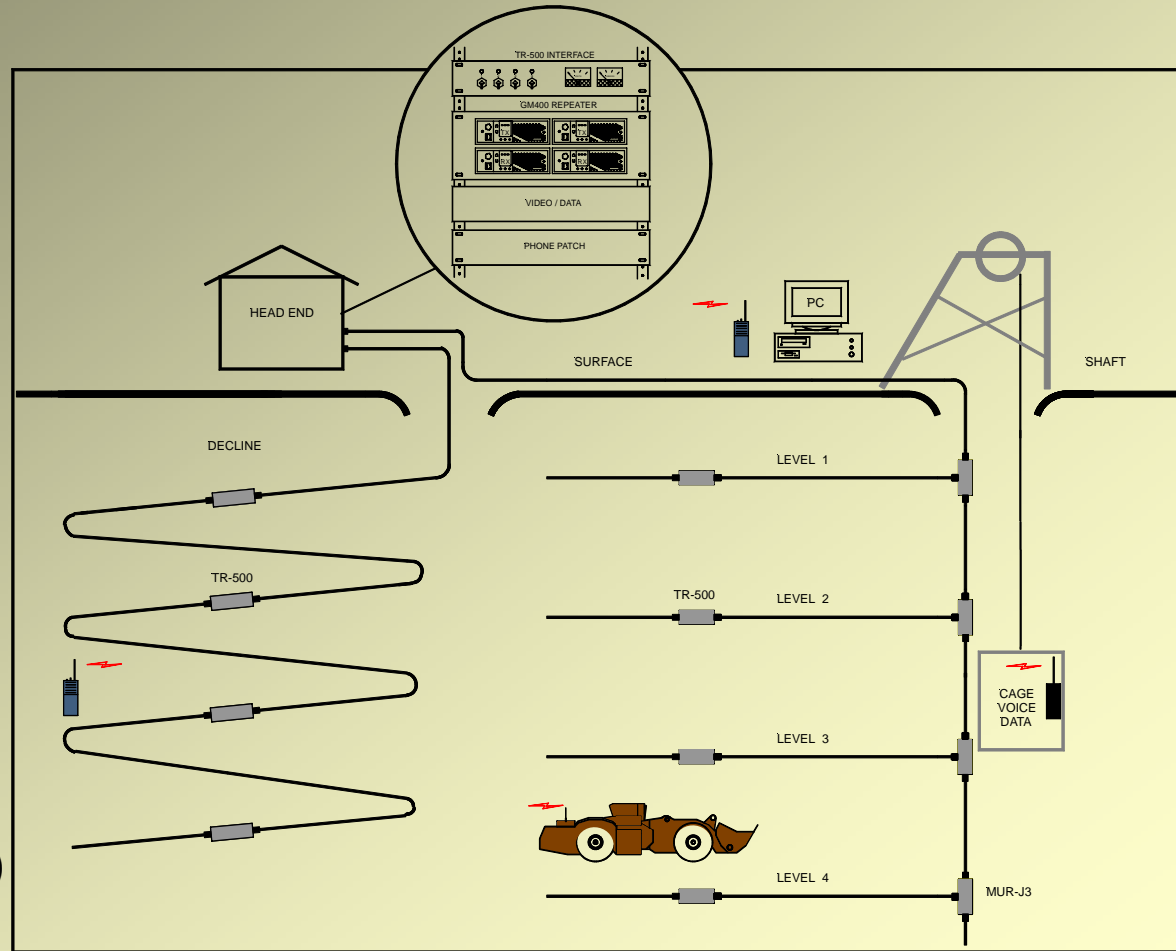
Advanced System Requirements

- Multi-Channel Capable
- Wireless Data Transmission
- Enhanced Range for Emergency Use
- Personnel & Equipment Tracking
- Emergency Operational features
- IP and Ethernet Compatible



Ultra High Frequency Communications (300 – 900 MHz) Result -

- Radio technology offering unmatched radio coverage,
- Voice + Wireless Data layer working
- Wi-PAD Tracking Compatible
- High reliability design, simple to install and service
- Fully Mine tested (2-Way)



'Leaky Feeder' VHF System



Coupling Loss at 20 Feet
65dB



UHF Antenna System



Coupling Loss at 20 Feet
<40dB



30 dB = 1000X more effective
power over VHF

UHF Bands 300 – 900 MHz

Greater Range

Obstacle passage

Hi Reflected Energy

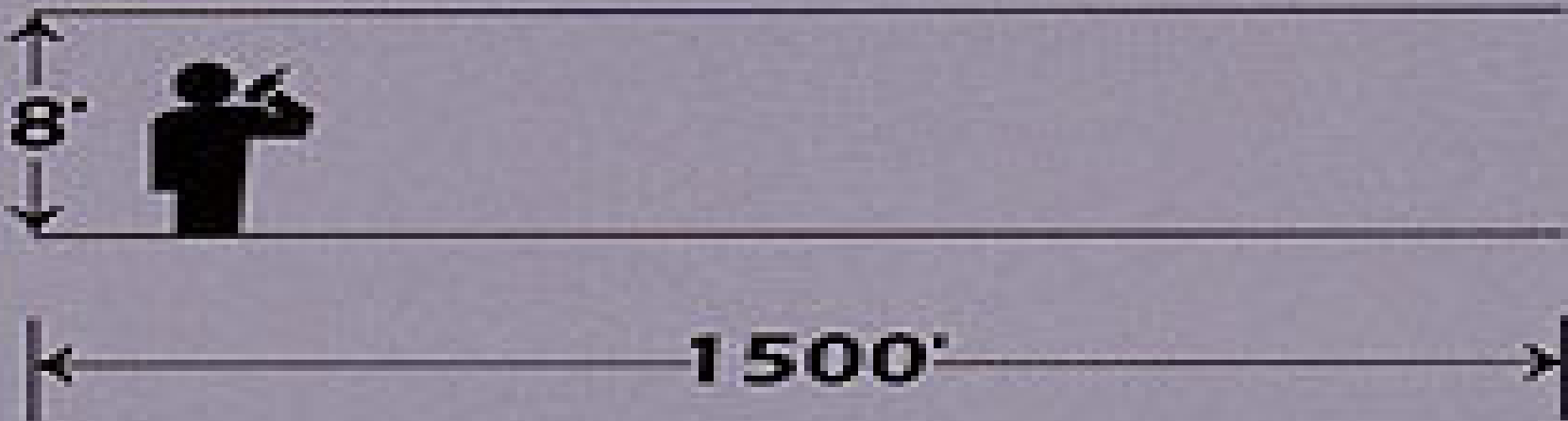
PROPAGATION IN TUNNELS

150 MHz

350 ft.

500 MHz

1000-
3000 ft.



Integrated Wireless Systems

Wi-PAD
Wireless Tagging Tracking

TMS
Data Acquisition

Mine Stat Voice-Alert
Remote Operation

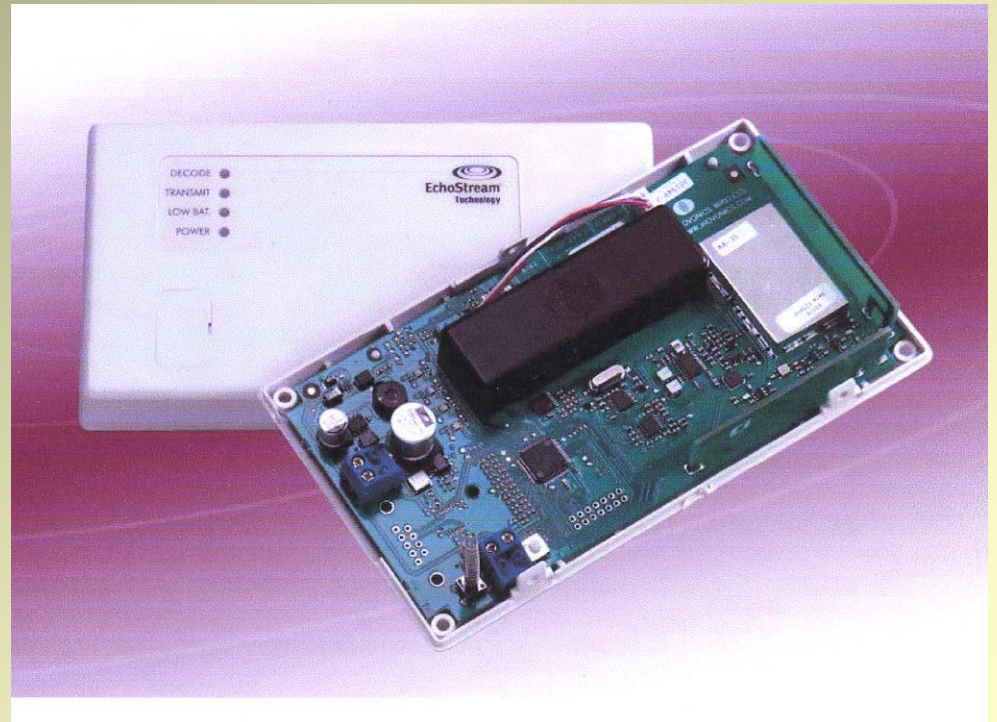
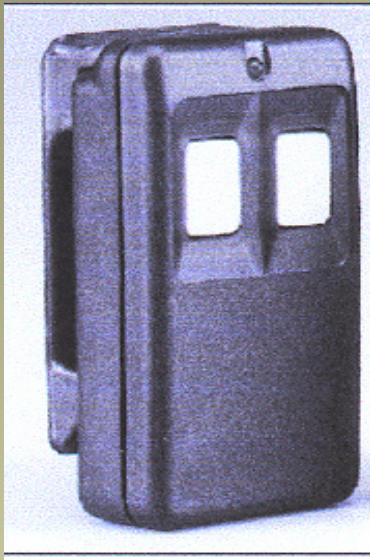
Radio Over IP



T-PAD

Wireless Personal Alert System

- Tag incorporates emergency and man-down alert
- Position Reporting to Capture software
- Cableless network between reader/repeaters
- High Post Event survivability & 24 hour Batt
- Quick damage repair cycle



T-PAD Personal Alert Device

Personal ID tag and communicator



- ◆ **Features**
- ◆ **Continuous Location Transmission**
- ◆ **Man-Down Alert**
- ◆ **Emergency Button Alert**
- ◆ **Signals are captured to near Reader Repeater and passed wirelessly to host**
- ◆ **3 year battery life**
- ◆ **Small size**
- ◆ **May be integrated into Portable battery case**
- ◆ **VoIP transmission capable**

T-PAD tracking and UHF 2-Way Network

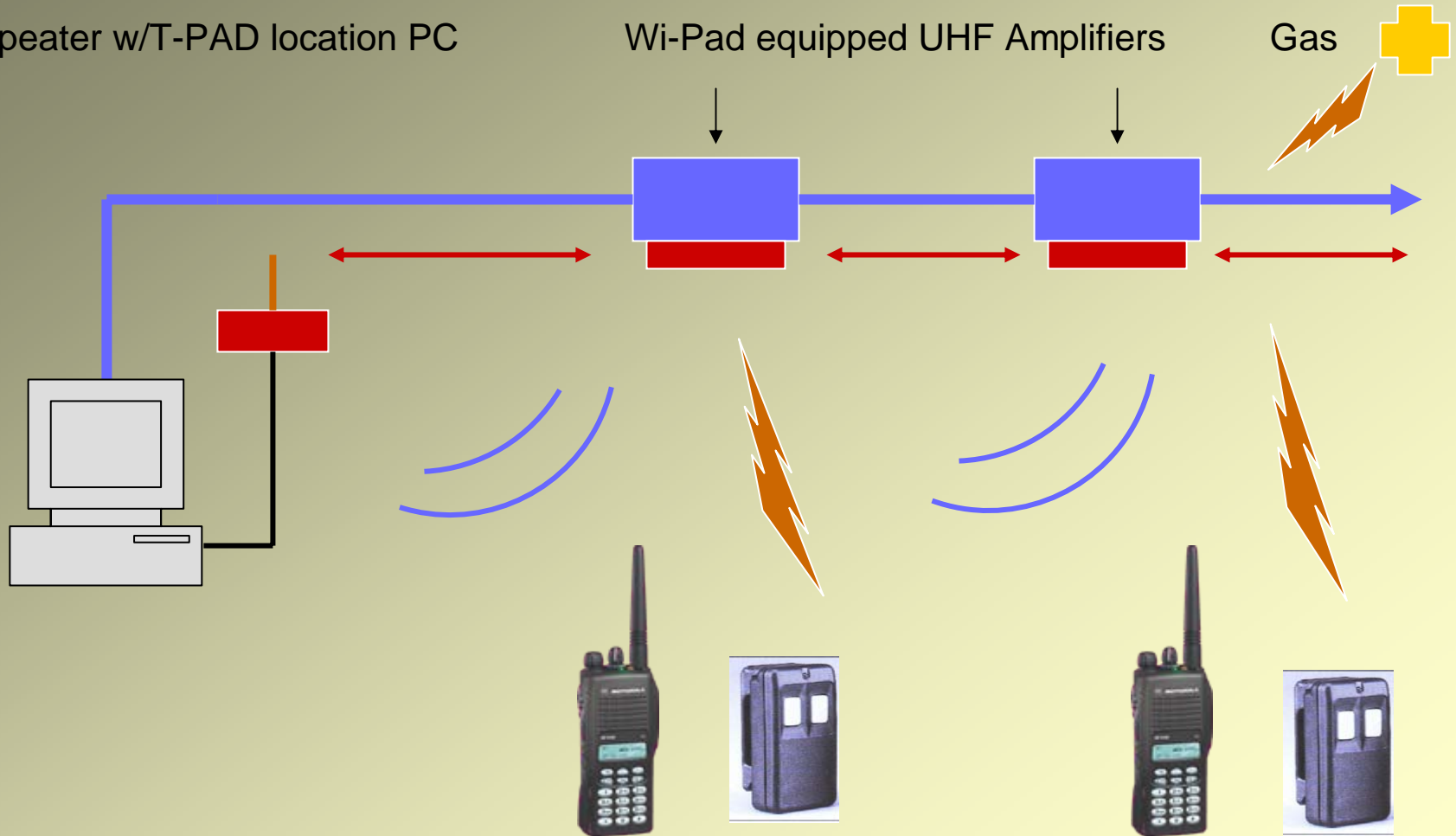
100% Wireless Wi-PAD layer

UHF Radio layer

Repeater w/T-PAD location PC

Wi-Pad equipped UHF Amplifiers

Gas



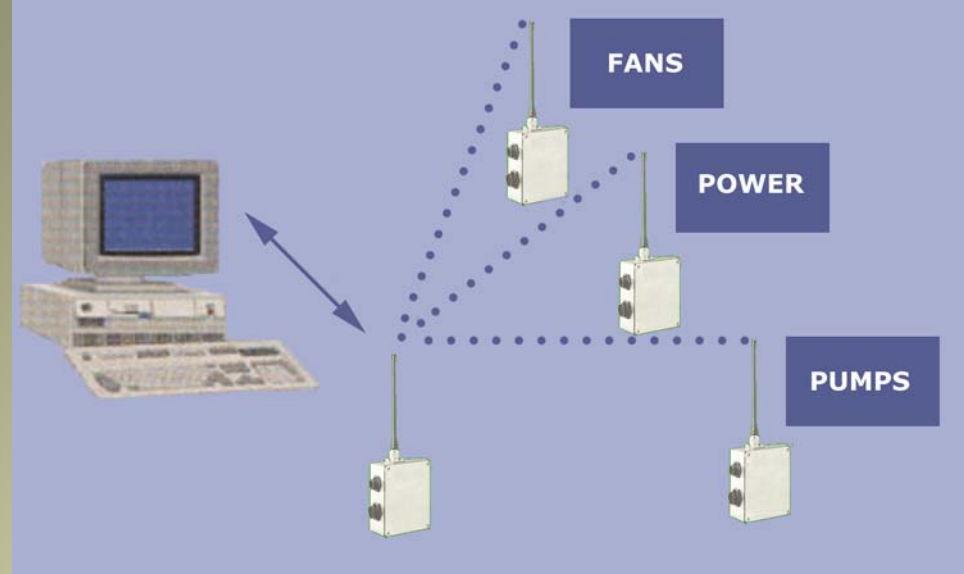
TMS

Tunnel Monitoring System

Wireless Data Monitoring and Control

Key Benefits

- Wireless monitoring of utilities and vehicles via PC
- Get Real-Time Overview of System with innovative SCADA based software
- TMS + complements Modbus based software platforms
- Compact, low cost radio RTU units with excellent service record



Features

- Control and Monitor Utilities
- Diagnostics for Radio system
- Comprehensive Offsite Capabilities
- TMS+ 128 KB long range wireless databuss
- Gas sensing, rock mechanics data collection & ?

Mine-Stat

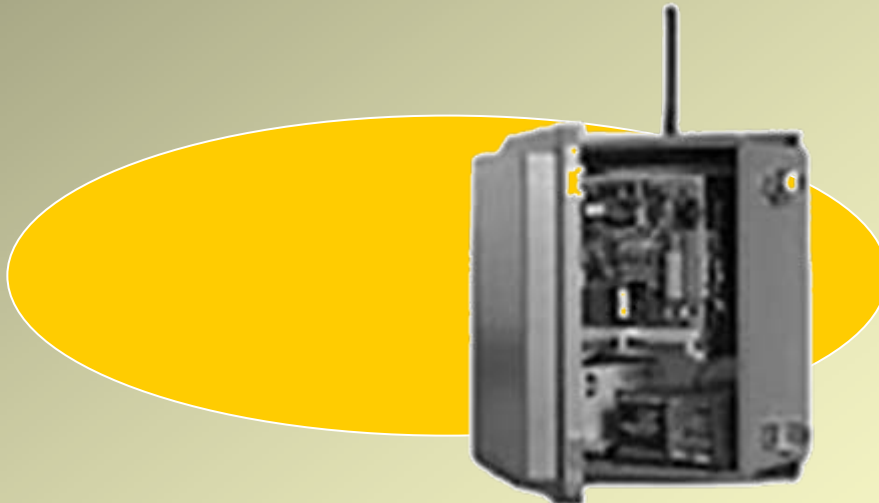
Control and status

Key Benefits

- Remote control equipment with Portable Radio from anywhere in the mine/surface
- Immediate remote ACK of command
- Voice response ACK of commands optional
- Dry contact closure or mom, AC relay, PLC control, remote stench release

Features

- Wireless remote control
- UltraComm or TROIP system compatible
- Integrated radio, antenna, battery, and power supply
- User programmable
- Fast installation – self contained unit



Advanced Digital Safety Signaling Options

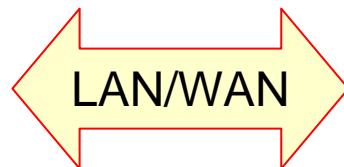
Programmable features in SOA Portables

- **One Button Emergency Signaling from Portable**
- **User I.D. is Displayed and Logged to Console**
- **Emergency All-Call From Console**
- **Radio Check Features**
- **Man-Down and Lone Worker capable**



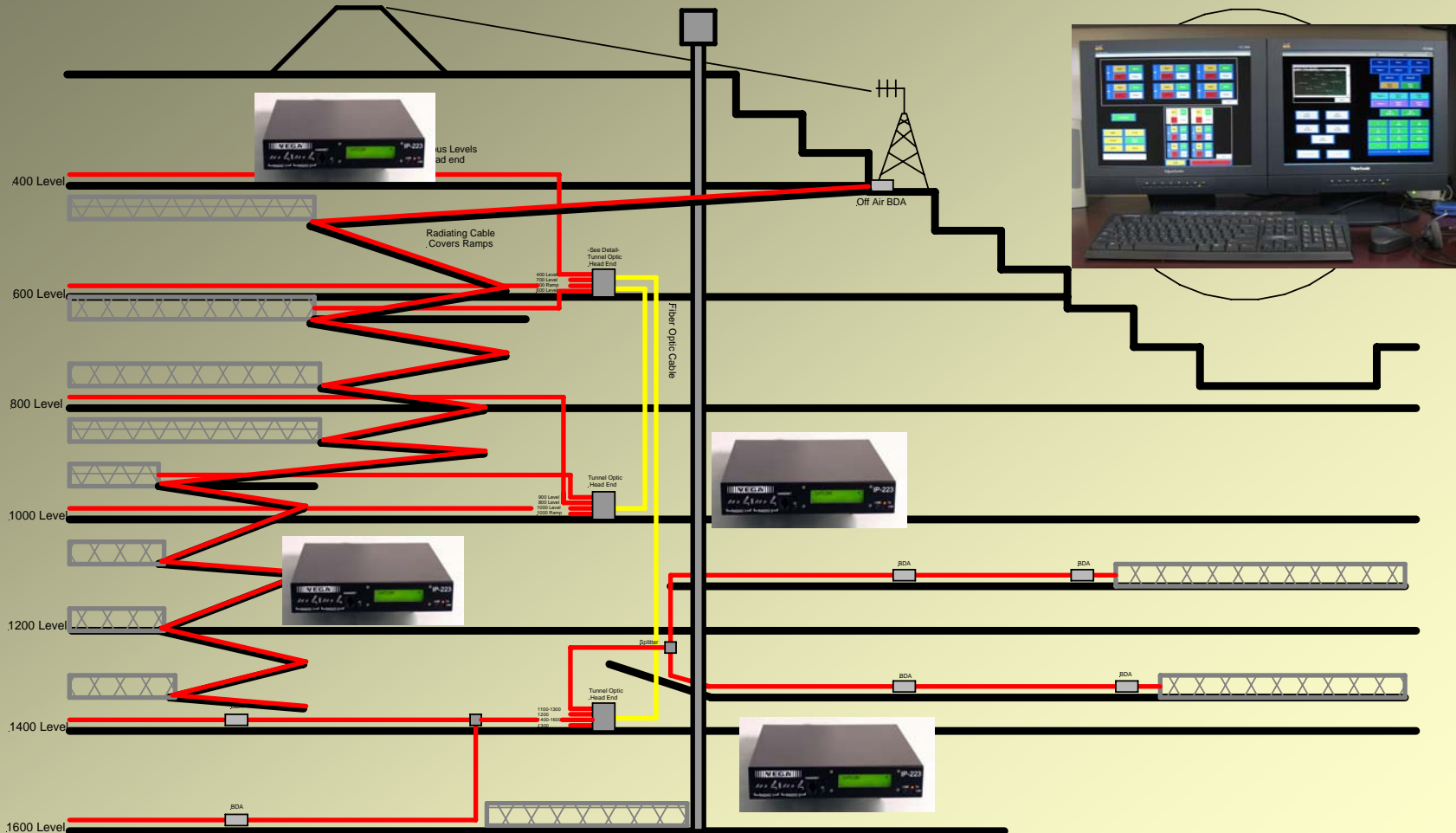
TROIP IP-Based Mine Radio – How it works

- ◆ Convert audio into data packets for network transfer
- ◆ Audio is divided into 10-40ms packets, compressed and put on the network
- ◆ Packets are transferred, decompressed, converted to analog and played
- ◆ Existing LANs, WANs and Internet allow for radio connection to dispatch facilities
- ◆ ROIP units incorp wireless node, all voice traffic stored for retrieval
- ◆ Position location captured to server display in control room



Tunnel Optic TROIP System Application

- Uses TROIP UHF Repeaters
- Simulcast operation of all nodes
- Uses Standard Ethernet Highway
- Location of transmissions Captured
- T Configuration Provides Redundancy



Ideal Applications for TRIOP

- ◆ Remote/redundant/emergency back-up radio control systems
- ◆ Affordable technology migration
- ◆ Maximizing Mine Ethernet installation
- ◆ Interoperability

Closing thoughts – Finally!

- ◆ Mining as an Industry, why are we 19 out of 20?
- ◆ How can we move up to the top 5?
- ◆ A safer work environment
- ◆ A high tech work environment
- ◆ The American Miner needs well deserved public support, we need media help to fix it!
- ◆ Mining – The savior of our economy?
- ◆ “The Lord your God is bringing you into a good land, a land with streams of water, with wheat and barley, a land where bread will not be scarce and you will lack nothing; a land where you can MINE (dig) iron and copper out of the hills. “ Duet 8:6-9

MINING, God’s plan for a sound economy!

A Tribute to the Men who started it all...

- ◆ The late Albert (Al) Isburg
- ◆ US Bureau of Mines



- R.W. Bob Haining
- British Coal Board



Advances in Underground Mine Wireless Communications - Technologies that work

Mark D. Rose Tunnel Radio of America

A number of 2-way wireless systems are currently in use world-wide in mining, yet less than 10% of US mines incorporate such systems due to various reasons, mostly economic in nature. A number of foreign countries including Brazil, Peru, South Africa, Sweden, Europe, China, Canada and Chili operate some of the most advanced systems in the world and yet the US lags far behind in the implementation of these technologies.

It is difficult to conceive why broader use of 2- way wireless is not employed in the unseen and dangerous working conditions inherent to underground mines. Economic issues rank high on the list; however, so many systems have been introduced in the US with such poor results that many operators have given up on seeking new wireless technologies. Many systems have been far overrated and when installed found to operate poorly.

A Step Forward - VHF (150-174 MHz) "Leaky Feeder" Revolution

In the early 1980's, Dr. David Martin, engineers Robert W. Haining and Roger Parsons ⁽¹⁾ were commissioned by British Coal to research every conceivable method to communicate wireless underground. Their final and most practical solution was the "Feed Forward" amplifier method. This system incorporated a VHF repeater signal through a chain of bi-directional amplifiers, connected by "leaky feeder" or radiating coax cable. Power requirements of the network was low and with a simple 13.8 VDC power supply on the surface, 10,000's feet of mine galleries could have reliable, predicable IS radio coverage, up to 100 meters laterally from the radiating cable. Commercial portable radios were employed, and no dispatcher was required due to use of a repeater radio base station, a major improvement over older technologies.

Subsequent to this definitive work, Mr. Haining installed systems in South Africa and Canada with encouraging results. Soon dozens of hard rock mines were enjoying mine-wide 2-way communications around the world and reports were coming in documenting huge efficiency and safety enhancements. Now in day to day operation, any miner could have reliable wireless communications with low cost portable radios readily available from many commercial vendors.

Many US hard rock mines employed this technology successfully including the Homestake and Henderson mine complexes, the largest in North America. Greens Creek Mine, the US's #1 silver producer ⁽²⁾ installed the first of these systems in 1988 that has been in continuous uninterrupted operation since, credited for daily efficiency and safety of life in a number of instances.

Due to the fact that radio frequency propagation in confined spaces is dependent on wavelength, a brief discussion and simple calculation will help the reader better understand the issues at hand;

A radio wavelength is calculated with the following formula:

$$\frac{468}{1 \text{ MHz}} = \frac{1}{2} \text{ wave antenna radiator in feet}$$

Where the ½ wave for 1 MHz = 468 ft, or where ½ wave for 4.68 MHz = 100 ft. And further, 160 MHz = 2.92 ft (35") and UHF 450 MHz = 1.04 ft (12.48") ⁽³⁾

An understanding of wavelength and antenna operation is important relative to propagation in tunnels. The most efficient antenna is a pure copper wire related to this calculation capturing the corresponding wavelength over the air. The electromagnetic RF wave is then converted to electrical energy and feed to a receiver set the desired frequency.

The Coal Dilemma

On the coal scene things were different. In coal VHF signals dropped off, with many systems having a range of 50ft or less from the overhead "leaky " antenna cable network. This is do to the full wavelength of VHF (150-174 MHz) radio band - about 6 ft.

Conversely, US and Canadian hard rock mines were enjoying great success and valuable safety benefits from reliable VHF and UHF systems, while coal was left behind in a mire of poorly working Low frequency systems, the approved solution of choice at the time.

VHF limitations in Coal

Vhf systems with a wavelength of 6 feet easily absorbs in coal resulting in short range. The 6 ft wave cannot travel down a low seam trackway or around a pillar but a few dozen feet before getting scattered. VHF also has poor metal penetration characteristics; an example is if a beltway is in the path from portable radio to the receiving radiating cable, the signal will be blocked, even if the total distance path is less than 75 ft. Vehicles and equipment such as power centers will also block the 6 ft wave, severely limiting range from cable.

On the positive side, Vhf is far clearer than LF (low frequency) systems and hand portable units far more convenient and useful. Vhf also is impervious to EMI (electro-magnetic interference) that weighs heavy on LF/MF systems. Vhf, if correctly installed, offers a predicable solution and is proven in several coal installations with 6 ft + seams, and even provides adequate coverage in lower seams if close to the cable e.g. +/-50ft.

UHF systems - 300 MHz to 3000 MHz

UHF systems operate in the frequency range from 300 MHz -3 GHz and have a $\frac{1}{4}$ wave of <6". This short wave has far different transmission properties in narrow passages in mines.

Rugged portable handsets are available in 150, 450, 800 and 900 MHz versions hardened for mining. 450 MHz networks exist today and have proven capability and perform far better around corners and through stoppings to some distance. Tests very due to irregularity of reflection surfaces and the aperture in mines, but generally speaking, a 20 – 30 dB improvement is typical over 150 MHz VHF systems amounting to 200 – 1000X more radio energy with UHF.

This means that even without a supporting wireless infrastructure or DAS (distributed and amplified antenna system) in operation, UHF band 2-way radio provides surprising point to point communications if needed in an emergency.

VHF 150 MHz equipment is almost useless without a supporting DAS (antenna and amplifier) infrastructure in coal mines where UHF performs well point to point without a supporting infrastructure, a key element in an emergency.

The Wavelength Issue

With a 1/4 wavelength of 6" or less, UHF has been demonstrated to communicate thousands of feet line-of-site in mines. As early as 1981, the USBM ⁽⁴⁾ conducted studies verifying this characteristic in a soft rock mine, documented by tests conducted by the late Mr. Al Isburg at Black River Mine in Kentucky in 1981.

It should be noted that Black River currently employs a 450 MHz UHF system and enjoys complete mine wide wireless radio coverage using portable radios, a tribute to Mr. Isburgs' work. As there are currently about 15 UHF systems operating in the US, the proof is in the performance and industry acceptance.

What is generally found is that mines that use wireless do not know the difference unless capability is compared in on-site tests.

UHF systems also enjoy several other radio magnetic wave propagation characteristic enhancements over other technologies, as few are here listed;

1. Decreased Body Absorption.

It is a proven fact that a body absorbs radio frequency energy. A hand or body mounted VHF radio will degrade a radio signal up to 26 dB where a UHF radio will absorb at a factor of 16 dB = 10 times less! The end result is 10x or better reception and transmission from the same radio used in the UHF bands. ⁽⁵⁾

2. Lower Reflection Coefficient.

Where a signal is not-line-of-sight, (bounced around a corner or behind a stoppage) from the source transmitting element, the signal to the target portable will be absorbed and lowered. Lower frequency VHF signals will absorb up to 100 - 1000x (20-30dB) more than UHF signals in the same mine structure, reducing the signal to unusable levels where the UHF signal will be sufficient to allow communications.

3. Compact Point Antenna Use

Radiating elements of a VHF antenna will exceed 6 ft in length, requiring a large ungainly sized antenna, (like a large roof mount TV antenna) to mount in a narrow gallery. UHF antennas on the other hand are compact (24"x 12"x 2" or smaller), high gain, (10X) and can be easily mounted to beam a signal.

UHF antenna's can be used anywhere, providing many coverage options and the ability to beam the signal for enhanced radio coverage - like down a trackway in an emergency. These bands are capable of transiting beyond a damaged or fire ridden zone to and from rescue crews or even to the surface.

Summing the above signal enhancements, UHF equipment offers improved coverage along the line of 40 dB, or 10,000 times over lower frequency equipment.

4. Wireless data collection capabilities

The UHF band allows easy integration of wireless data equipment as many manufacturers' have chipsets available to accomplish this task at UHF. Also due to the nature of UHF range, wireless sensors for gas detection, e.g. methane, CO and rock mechanics functions are now a reality in mines. This wireless data highway can include tagging and position location.

Distribution Techniques used in UHF

Now that research, physics and experience has shown these upper bands most effective in mines, how do we get the signal in there?

DAS

Known as the **Distributed Antenna System**, this type of antenna and amplifier network is required to **positively** distribute a radio frequency signal underground from a surface source. In mining, the source is a radio repeater or "mobile relay". These are defined by the Federal Communications Commission. ⁽⁶⁾

The "Mobile Relay" radio rebroadcasts any received signal in the mine and retransmits, on a different channel, almost at the same instant, the same audio received into the mine network mine-wide. Two frequencies are used, one to receive and one to retransmit. The net result is all communications are instantly relayed through the DAS network of active components, passives, antenna's and coax in the mine to effected portable units with excellent reliability.

Fiber Optic Based DAS

This network uses SM (Single Mode) dedicated fiber optic cables to interconnect remote radio "nodes" in the mine to create "cells". Each cell has a coverage area or zone. These zones can be expanded with a combination of DAS interconnection. They allow broad band multi-carrier expansion, even extension of cellular services U/G in mines. Cells require independent power feed.

TROIP - Tunnel Radio Over Internet Protocol

If a mine currently employs an Ethernet MM (multimode) fiber optic or CAT 5 network underground, radio cells can be installed as a network device. Using this version of VoIP, base station radios may be integrated into Ethernet, LAN or WLAN infrastructure. TROIP systems provide position location of portable transmissions and digitized voice logging with little additional equipment.

The negative of these FO and IP based systems is vulnerability to damage post incident. Backup schemes can be employed to provide local relay of UHF signals into critical zones. A positive is that integrated service of radio and IT. In some cases these systems may become part of a back up scheme.

Current 2-way handset signaling capabilities

Wireless FM commercial 2-way radios are currently available with many digital signaling enhancements. *Man-down, Radio-Check, Hot Mic, Lone Worker* and *Emergency Alert* to mention a few.

These capabilities include technologies that are built-in to portables and compatible with a number of advanced computer aided display and command capabilities. A number of these systems are in use in U/G mines daily, resulting in a safer workplace where all workers are accounted for and assured a quick response if an accident occurs.

Tagging - Tracking systems

Personnel tracking systems operate on the concept that a small, low power transmitter is attached inside a cap battery or small pager sized unit carried by the miner. Also referred to as an RFID system this “tag” transmits a unique digital ID signal over-the-air wireless in frequencies typically ranging from 130 KHz, 400 MHz, 915 MHz or higher. The ID signal is “captured” (if within receiving range) by a fixed “reader”.

Operation of the reader is more complicated. Once the man-tag signal is received, (generally, the tag needs to be within 60 ft of the reader), ⁽⁷⁾ and the entire message correctly captured, the reader then resends a serial data signal into a hard-line collection or other network. This data includes the tag number and the reader location.

The collection network feeds a **computer with software** that time stamps and displays the information and location in tabular form and/or on a mine map CAD drawing showing reader and people locations. Some readers allow wireless connection if a mine-wide radio system is installed.

Collection network

Readers, tags and their *radio range* set the resolution of the miner location. **Readers require a wireline, radio or network connection to the host computer on the surface to pipeline the data back to the host computer to operate.** Readers also require continuous power - like 120 VAC.

One system of this type has been successfully installed in a US coal mine manufactured by Marco Inc. A critical issue is the shielding of man tag transmissions while traveling in man carts.

Other systems use multiple readers to triangulate tag position.

Wi-PAD - Wireless Personal Alerting Device

This exciting new technology operates similar to RFID reader/tagging systems except for the following critical differences;

- 1. The “reader” unit is also a wireless “repeater” where readers are NOT dependant on a WIRED interconnection scheme to pass data to the surface. Each Wi-PAD responder incorporates a 900 Mhz Spread Spectrum transceiver continuously capturing and relaying Wi-PAD tag information eventually terminating at a host collection/display computer on the surface. Readers also employ a 24 hour rated battery backup.**
- 2. The Wi-PAD tag is multi-functional. This personal device not only sends a signal to the reader/repeater for location purposes, but also is capable of sending an emergency alert or Man-Down signal, where if left in a horizontal position for a predetermined time a signal is transmitted to the reader/repeater network and outside to the capture computer.**
- 3. Wi-PAD capture software. Once the Wi-PAD tag information is passed out of the wireless network chain, the decoded serial data is feed into a capture/display software. This software locates individual Wi-PAD tags, displays current location and movement history, and provides miner to surface emergency alert notification.**

Advantages of Wi-PAD

Wi-PAD advantages over conventional RFID tagging tracking systems are numerous

1. **Wi-PAD tags are interactive devices**

Wi-PAD offers emergency signaling independent of the physical condition of the person, where conventional RFID tag systems are dumb transmitters, capable of only transmitting blind ID signals to a potentially severed capture location network.

2. **Wi-PAD tags are a signaling communicator *and* locator**

Wi-PAD tag units offer not only location information but the ability of the miner to wirelessly alert the surface of an emergency condition, a failure in RFID tag systems or LF one-way alert systems. In addition, even if disabled and/or fallen, the Wi-PAD tag ***automatically*** signals the surface and alerts such condition to the capture software. This critical information includes ***time, location and initiation method***, manual or man-down - instantly. The above information is critical in planning a rescue operation and can reduce recovery time significantly. VoIP transmit capability forthcoming with Wi-PAD.

3. **The Wi-PAD repeater/reader.**

The fact that each Wi-PAD reader/repeater creates its own **wireless communications link between readers**, independent of infrastructure **provides the best hope for continued system operation post-event in a mine emergency**. In addition, each reader unit carries a battery back-up feature with 24hours of operation after the power mains are off, a major advantage over A/C powered readers that require hardwire interconnection and power.

4. **Simple reader system repair.**

The reader repeaters, even if destroyed or damaged in an accident can be quickly replaced by advancing rescue crews or via robots, reestablishing any broken link that may occur between the trapped crews and the surface. As the units operate for 24 hours on a single battery, mains power restoration is not required to patch damaged zones.

5. **900 Mhz SS technology**

Wi-PAD incorporates 900 MHz Spread Spectrum wireless technology, impervious to interference and providing an excellent range to power ratio for both Wi-PAD tag wireless range and inter-repeater link-up capabilities.

STS - Smart Tag system

A new tagging system not requiring a reader is currently operable. More information is forthcoming on this exciting technology and manufacturing development is underway. These units use INS (Inertial Navigation System) technology and report X/Y location data wireless to a host computer to pin point personnel. STS tags update position via wireless and may be incorporated with Wi-PAD in the future.

A final safety thought - Smart Refuge Chambers

A buried phone line to the refuge chamber is a low cost, quick install safety and communications solution for mines. This same line can remote control a wireless UHF base radio and incorporate a tag reader. Miners in distress would know that if other communication links were destroyed, a backup system exists in and near the chambers.

Summary

The technologies explained in this paper may be successfully employed and used creatively to provide **reliable** wireless radio coverage in any mine. **All** systems have limitations. They cannot reach every corner of a mine in reasonably designed configurations.

No mine is impervious to communication interruption, no less than if wireless is lost in a city impacted by any natural catastrophe. Reasonable redundancy and useful wireless 2-way coverage in underground mines will make a dramatic improvement in safety, increase productivity and peace of mind as proved many times over in current installations world-wide.

A miner with a rugged, UHF long range personal radio has a powerful safety tool in time of need. Deployment of wireless technologies (like multiple wireless rock mechanics and/or gas sensors) that can **prevent** accidents is a **proactive** approach to safety enhancement in underground mines. Unfortunately, thousands of men and women are at work in "inner space" without wireless communications in the United States.

Funding, misinformation, government support and knowledge gaps are the real issues separating the mining industry from enjoying the efficiency and safety enhancements of modern wireless 2-way voice and data communications.

Mines are varied in nature and structure. Creative application of wireless 2-way or tagging/tracking in mines without overly stringent legislation is key in allowing the ingenuity of the American way to flourish in the wake of any possible government mandates. Mine operators must work with wireless industry professionals to develop the best most efficient and best solution for each application. Let's move forward in a cooperative spirit, raising the standard to the highest practical level and watch what happens to productivity and safety in our mining industry – I believe the returns will soon speak for themselves.

Mark D. Rose

March 13, 2006

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