RADIO FREQUENCY COMMUNICATION SYSTEMS IN UNDERGROUND MINES

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ABSTRACT:

Due to the high attenuation of radio frequency (RF) signals in underground mines and the statutory power restriction of communication gadgets especially for coal mines, the wireless communication systems have restricted applications in the underground mines. The paper discusses different radio frequency communication techniques being employed for Indian underground mines. Experiments were conducted in the laboratory as well as in the underground coal mines for medium wave frequency (MF), very high frequency (VHF) and ultra high frequency (UHF) electromagnetic propagation as well as induction technique to meet different types of mining conditions. The detailed results have been presented in this paper.

INTRODUCTION:

Underground mines, which are characterized by their tough working conditions and hazardous environments, require fool-proof mine-wide communication systems for smooth functioning of mine workings and ensuring better safety. Proper and reliable communication systems not only save the machine break down time but also help in immediate passing of message from the vicinity of underground working area to the surface for speedy rescue operation. Therefore, a reliable and effective communication system is also an essential requisite for safety in underground mines. All existing systems are based on line communication principle (wired) [1], hence these are unable to withstand in the disaster conditions as well as formidable in inaccessible places. Non-symmetric mine topology and complex mine structure put further hindrance on the way of line communication. Therefore, wireless communication [1] is indispensable, most reliable, convenient system and must to combat such disaster situations.

Frequency modulated (FM) transceivers with directional or active antenna [2] linked with leaky feeder cables and repeater amplifiers at regular intervals can be used for reliable and appropriate mine-wide communication systems for underground mines [3]. The portable transceivers are being used so that it can be carried even in inaccessible places in underground mines. In nutshell, RF communication would be the most suitable and reliable communication system for safety application in the coal mines. It would also help to increase production and productivity in mines.

COMMUNICATION TECHNIQUES

The communication systems required for an underground mine can be divided into following four categories based on purposes and locations:
(i) Shaft communication (ii) Straight gallery communication (iii) Mine-wide communication and (iv) Trapped miner communication

Shaft Communication:

Bell signaling system is being used today in most of the Indian underground mines. But this system is having its own drawbacks. Therefore, a need exists for improved hoist communications between the skip and the hoist operator. A induction theory based communication system using hoist/guide rope as a carrier current is being developed. This system provides reliable two-way voice communication between moving cage and hoist man. The system transmits and receives radio frequency (RF) energy over a transmission line through hoist/guide rope. The system also utilizes transceivers that communicate with each other by RF currents superimposed on a cable. The system consists of one base station attached with a loop antenna of 485 KHz frequency and a shoulder antenna attached with a transceiver set of the same frequency. During transmission, the sending transceiver feeds its loop antenna with a frequency modulated (FM) carrier. The antenna induces a signal into the hoist rope, which travels up and down the hoist rope and is picked up by the transceiver attached with shoulder antenna. The loop antenna and shoulder antenna operates as both a transmitting and receiving element. The loop antenna with the base station is clamped with hoist/guide rope at a point just above the cage.

Straight Gallery Communication:

Radio system covers voice communications within the underground mine. In the ultra high frequency (UHF) band, attenuation is relatively low in the straight mine entries and is significantly higher when the signal propagates around a corner or when a massive piece of machinery is in the path of propagation. At frequencies in the range of 200-4000 MHz, a coal mine tunnel act as a low-loss dielectrics and dielectric constants in the range of 5-10.

The cutoff frequency for rectangular tunnel/mine galleries can be roughly estimated as [4]:

$$F_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}\ (Hz) \quad (1)$$

Where a and b represent tunnel width and height, respectively. m and n are numbers of half wavelengths (hybrid electromagnetic modes HEM_{mn}) that will fit in the a and b dimension. µ and ? are the dielectric and permeability constants.

The low-loss dielectric oversized waveguide supports many hybrid electromagnetic modes HEM_{mn}. Laakman and Steier [5] have shown that the propagation constant $?_g$ associated with each mode (m, n) can be expressed explicitly, provided that the transverse dimensions a and b as well as wavelength ? verify the following inequalities:

$$\frac{m\lambda}{4a} << 1 \quad \text{and} \quad \frac{n\lambda}{4b} << 1 \quad (2)$$

In this case, the propagation constant is given by:

$$\gamma_g = \alpha_g + j\beta_g \quad (3)$$

With

$$\alpha_g = \frac{1}{a}\left(\frac{m\lambda}{4a}\right)^2 \mathrm{Re}\left|\frac{\varepsilon_r^*}{\sqrt{\varepsilon_r^* - 1}}\right| + \frac{1}{b}\left(\frac{n\lambda}{4b}\right) \mathrm{Re}\left|\frac{1}{\sqrt{\varepsilon_r^* - 1}}\right| \quad (4)$$

and

$$\beta_g = \frac{2\pi}{\lambda}\left|1 - \frac{1}{2}\left(\frac{m\lambda}{4a}\right)^2 - \frac{1}{2}\left(\frac{n\lambda}{4b}\right)^2\right| \quad (5)$$

Where

$$\varepsilon_r^* = \varepsilon_r - j\sigma/\omega\varepsilon_0 \quad (6)$$

Where ε_0 and ε_r are the free-space permittivity and relative permittivity, respectively. ω and σ are the angular frequency and the conductivity, respectively. Note that Re means real part of the variable.

Equation (4) indicates that the attenuation of the radio wave propagation in an empty, straight and unobstructed rectangular tunnel is proportional to λ^2/a^3 and λ^2/b^3 and thus decreases as the square of the frequency but only if the wall roughness remains small. Equation (5) represents the phase difference of different HEM_{mn} mode with respect to propagation in free space.

An electromagnetic wave travelling along a rectangular tunnel in a dielectric medium can propagate in any one of a number of allowed waveguide modes. All of these modes are lossy modes because any part of the wave that impinges on a wall of a tunnel is partially refracted around the surroundings and partially reflected back into the waveguide. The refracted part propagates away from the waveguide and represents a power loss. The attenuation rates of the waveguide modes depend almost entirely on refraction loss. The overall loss in strength, in a straight gallery, is the sum of propagation loss and the insertion loss of the transmitting and receiving antennae. It has been found that the total loss is minimal in the range of about 450-1000 MHz, depending on the desired communication distance and tunnel dimension.

Mine-Wide Communication

Large attenuation of radio wave in hard concrete coal strata posses a problem in covering the large communication range. Labyrinth path and complex geological conditions of mines further put hindrance in wireless communication. Corners and bends in underground mine galleries present the obstacles to the propagation of UHF radio waves. But if an active antenna is placed near / at the turn of the path, the signal may be amplified to give better communication. Further, we can not go for higher wattage of transceivers due to intrinsic safety limit in hazardous area (i.e. coal mine). In order to establish mine wide communication system keeping in view of all the above conditions, we propose leaky feeder cables as antenna as well as transmitting lines.

A leaky feeder [2, 3] allows signals to leak out of or into itself at a controlled rate. It effectively behaves as a long antenna that can guide radio waves around corners and bends. The communication system is featured by very high frequency (VHF) frequency modulated (FM) high band operation in the 146-174 MHz with an acceptable radio frequency (RF) power output as required for an underground mine. The cable is characterized by excellent frequency response over the required spectrum to meet the specifications of mine industries. It may be fire resistant, water resistant, etc. according to the needs of the same. Line amplifiers are inserted after every 350 meters of the cable to automatically compensate for the RF loss or other additional loss in the cable. These amplifiers operate independently in both the forward and reverse directions. All equipments connected to the cable are powered from the cable itself. The VHF transceivers with intrinsically safe within 2 watts with loop antenna and leaky feeder cable as transmitting media followed by repeater at regular intervals would be used for communication through galleries. Due to skin effect phenomena, the radio waves emit (leak) in larger periphery through leaky feeder cables and with help of repeater, the attenuated waves can be further amplified. By placing repeaters at regular intervals, the entire mine area can be covered.

Trapped Miner Communication

In underground mines, sometimes due to fissured strata, the roof or side wall of a gallery collapse, miners get trapped inside sealed area. Many miners get trapped beneath the big chunk of fallen roof. A communication link between the trapped miner [1, 6-7] and rescue team is essential to find out the actual location of trapped miner for rescue operation. Studies revealed that attenuation of low frequency is comparatively lower through coal block. The low frequency tone signal modulated over RF signal 457 kHz can be transmitted through large thickness of coal block.

DEVELOPMENT AND FIELD TRIALS

Instrumentation Division of Central Mining Research Institute, Dhanbad is actively engaged in development of various wireless communication systems for different locations in underground mines. Some of the developed systems were experimented in the field and described below.

Leaky feeder based RF communication system [1-3] would be established for communication in mine labyrinth gallery in recent future.

The carrier current system working on induction theory was used for shaft communication and also experimented in galleries for line-of-sight communication working on the same principle.

VHF and UHF transceivers of 160 MHz and 450 MHz with 1 W output power have been used in a straight gallery for line-of-sight communication as well as for the cage communication.

Medium frequency transceivers of 457 KHz and 50 mW transmitting power have been used to establish voice communication link between trapped miner and rescue team.

Field Trials

The field trials were performed in 9th and 12th pits of the Bagdiggi Colliery (depth around 200 m from ground to surface), BCCL, Nandira mine (inclined mine), Talcher area, MCL and Chinakuri Mine (depth around 612m from ground to surface), ECL with, UHF transceivers, VHF transceivers, trapped miner locators and induction theory based communication system.

The VHF and UHF transceivers were tried in straight galleries of the underground mine for line-of-sight communication purpose. It was observed that the range of UHF transceivers was about 300 m (width around 4 m) as shown in figure 1 from B to A and the range of VHF transceivers is about 75 m.

The trapped miner locator had a range of about 30 m in a straight gallery and was able to penetrate a 3-4 m thick wall.

The induction theory based communication system was tried in moving cage and was observed that the communications were established properly with the person available at the surface and person available in the moving cage as shown in Fig. 2.

The cage communication was also done with the UHF transceivers as shown in Fig. 2. The communication was made from surface (A) to moving cage (B) and then to pit bottom (C). It was also observed that the communication extended to a further 10 m from pit bottom (C) to (D).

The other experiment was performed for line-of-sight communication in the underground gallery using the same induction theory based communication system. It was observed that the communication could be made to the point up to which the continuous induction is possible.

The experiment was also performed with trapped miner locator in 12th pit of the Bagdiggi mine as shown in figure 3. The transmitting and receiving ends of the system were available with persons A and B standing in the 8th seam and 7th seam, respectively. The parting between both the seams is about 12-15 m. The signal was loud and clear. But the system still needs some modifications.

CONCLUSIONS

With successful field-trials at several mines, it is felt that an effective and reliable wireless communication system can be established in an underground mine. Depending on the width of mine galleries and cage dimensions, optimum frequency selection of transceivers can be done to enhance the coverage distance. The communication tools of the shaft communication system can not only be used for effective communication in a moving cage but also can genuinely be further used in galleries with the support of induction materials in any form. Leaky feeder communication system, though not used in the field trials, is analyzed to be one of the most competent wireless VHF communication systems that exist today in underground mines.

The coverage distance of all different communication system is found to be satisfactory in spite of the attenuation occurring due to irregular structure of mines. The proposed communication tools can, thus, be adopted to replace the age-old wired (landline telephones) communication system.

ACKNOWLEDGEMENT

Authors are thankful to Director, Central Mining research Institute, Dhanbad for giving permission to present the paper. Authors are also grateful to mine management of Bagdiggi Colliery of BCCL, Nandira Mine of MCL and Chinakuri Mine of ECL for providing necessary help during the field studies. Sincere thanks are also due to the DIT, MCIT, Govt. of India, for sponsoring this development project.

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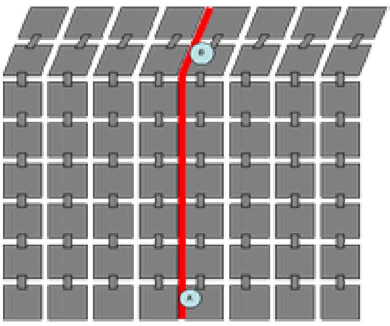

Fig. 1: Schematic diagram underground mine gallery

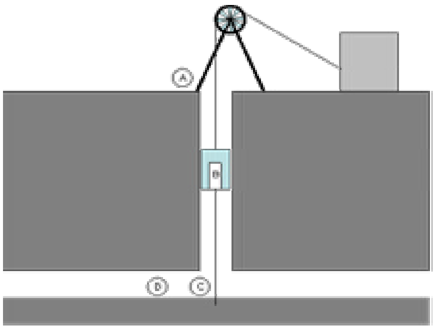

Fig. 2: Schematic diagram of a mine shaft

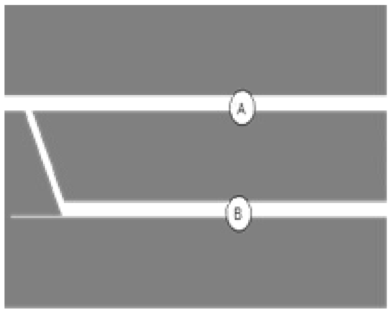

Fig. 3: Schematic diagram of 7th and 8th seams of Bagdiggi mine