SUMMARY REPORT OF OPERATIONAL COMMUNICATIONS WORKING GROUP

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I. SUMMARY

The work of the operational communication systems' group dealt with a range of communication needs and functions within mines, primarily along haulageways, to and within sections up to the working face itself, and in mine shafts. A mixture of communication techniques and hardware is needed to satisfy this variety of communication needs within the differing environments encountered in U.S. mines. Substantial progress, both experimental and theoretical, has been made in recent years towards developing alternative communication systems suitable for use in mines which are based on "guided" waves, including wire-less (waveguide-like propagation in mine tunnels) and wire-based systems (leaky coaxial cables or wires). Major priorities identified for further work needed to confirm (or deny) the applicability, and refine the operational specifications of promising communication systems for mine use include:

Short-Term Projects

o Cost/performance analyses of promising leaky coaxial cable and UHF radio communication systems which require further data from:

- Experimental investigation under U.S. mine conditions of the performance of potentially applicable leaky coaxial cable communication systems developed in Europe (France, Belgium, and the U.K).

- Cost estimates on these coaxial cable communication systems.

- Measurements of UHF radio propagation in low-coal mines.

- Investigation of the influence of obstacles (e.g. shuttle cars and section machinery) in the entries on UHF radio propagation in mines.

o Investigation of the problems of transmitter and receiver coupling and termination matching associated with the two-way propagation of low frequency radio waves in hoist shafts.

Longer-Term Projects

i.e. of lesser urgency or where less information is currently available.

o Investigation of techniques for coupling UHF radio to leaky coaxial cable communication systems.

o Delineation of the role of, and needed interfaces for, operational communication capability related to emergency, paging and monitoring functions.

II. OPERATIONAL COMMUNICATIONS FUNCTIONS

The communication functions under discussion in this report are primarily:

o Two-way communication along main haulageways up to 4-5 miles long, to vehicles and to maintenance personnel.

o Two-way communication in sections up to working faces; all entries near the working face should be covered, but possibly only a limited proportion of those at or near main haulageways. Communication with roving personnel at up to 3,000 feet away from main haulageways must be established. More than one kind of working face must be dealt with, i.e. room and pillar (predominant in the U.S.) and longwall.

o Two-way communication in mine hoist shafts (on the order of 10,000 feet long).

Two distinctive categories of communication are involved, the first depending upon a base station, and the other dealing with direct mobile-to-mobile communication.

Although not discussed in detail, it is recognized that the communication systems designed to fulfil these purposes may interface with other communication systems such as trolley phone, as well as play a role in assuring some emergency, paging (call alert), and one-way monitoring communication functions.

III. ENVIRONMENTAL CONSTRAINTS

The primary constraints recognized as affecting the communication systems under consideration are:

- Daily utility of equipment
- Intrinsic safety
- Ruggedness and resistance to harsh mine environment
- Available power
- Weight and size limitations
- Cost limitations

The electromagnetic noise environment at the frequencies typically proposed or employed (a few MHz up to 1 GHz) appears not to be a significant factor in determining communication system performance. A possible exception to this rule or slightly less clear-cut situation may prevail in the case of low frequency (LF) radio propagation proposed for communication in mine shafts (at frequencies of a few tens of kilohertz).

IV. OPERATIONAL COMMUNICATIONS SYSTEMS

Several alternative communication systems are in principle technically capable of satisfying the communication needs just described. A tentative conclusion in the light of our present state of knowledge is that communication along haulageways may be efficiently provided by one or more of the proposed leaky coaxial cable systems discussed later. However, leaky coaxial cable systems seem incapable of providing communications capability at more than 10 to 20 meters lateral distance from the cable. Thus in order to provide wide area communications coverage within the network of tunnels in a coal mine section, it would be necessary to string cables along most of them. The cost and practical obstacles to stringing all this cable in a continually changing section geography favor the application of UHF radio for wide area communications within a section. There is both theoretical and experimental evidence to indicate that UHF radio is capable of providing this function.

Coaxial cable, radio, and low frequency TEM radio wave transmission in the shaft are all potential candidates for providing communication in a mine shaft. No single one of these communication techniques has yet been identified as being especially advantageous in this application.

The communication techniques discussed fall under the general description of "guided" waves and comprise:

- o Wire-less (UHF frequencies)
- o Wire-based
  - Coaxial cable with periodic radiative structures (INIEX/Delogne)
  - Coaxial cable with high surface transfer impedance (braid outer conductor)
  - Coaxial cable with repeaters
  - Wire pairs
  - Single wire (including LF radio propagation in mine hoist shafts)

It is also recognized that power-line carrier communication techniques are potentially attractive for some of the communication applications under consideration; it is worthwhile to investigate power line carrier systems further, however, no serious evaluation of them was made in this workshop. Power line carrier systems are already used along the trolleyway in some mines.

In the following,promising communication systems are identified and their current state of development described. Problems and areas where additional data or further theoretical understanding are needed are listed, and priorities for future development work are suggested.

A. UHF Radio (U.S.)

1. State-of-the-Art

Marked progress has recently been made in understanding the characteristics and capabilities of UHF radio wave propagation along coal mine tunnels. Measurements taken in mines by Collins Radio indicate that effective communication can be provided throughout most of a typical U.S. coal mine section by UHF radio. A theoretical analysis carried out by Arthur D. Little, Inc. (ADL) staff based upon the hypothesis of waveguide propagation is in agreement with the Collins measurements in several important respects. The theoretical model is believed to reflect the basic structure of UHF radio wave propagation in coal mine tunnels, although it is presently not intended to give accurate signal loss estimates around corners when either the transmitter or receiver is near the corner (less than 50-100 feet). In those cases the model's loss assymtotes will over estimate the loss.

During the workshop an apparent violation of the reciprocity theorem was discovered in an application of the ADL theory to extend Collins Radio's data for a determination of the extent of coverage provided by UHF communication within a section. This apparent violation is believed to result from an application of the ADL model in a region where it is invalid, namely in the corner loss situation just mentioned. The reciprocity theorem must be respected, and a refinement of the model is needed to predict transmission loss around a corner when either the transmitter or receiver is nearby the corner. Collins Radio has re-evaluated the section coverage predicted for UHF radio which can be deduced from their data and extrapolated by the ADL theory, assuming the reciprocity theorem holds. The results of this computation are attached; they are very encouraging.

Leaky coaxial cable communication systems operating between 2-20 MHz appear incapable of providing communication along cross-cuts in which they are not strung, and hence appear both costly and unlikely of implementation for communication in the grid of many tunnels which constitute a section. UHF radio is likely to be more effective in this situation of areal rather than essentially linear or tubular communication coverage. In summary, both theoretical and experimental results obtained to date warrent further development of UHF radio techniques for providing practical communications in coal mine sections.

2. Future Development Programs

(a) Short-Term

No measurements have yet been taken of UHF radio wave propagation in low-coal mines, which constitute a significant fraction of U.S. coal mining activity. These measurements are needed to determine if the different geometry of low-coal as against high-coal mine tunnels permits practical communication of UHF.

Additionally information is needed on the influence of obstacles in entries and tunnels on UHF radio wave propagation. In a coal mine "obstacles" such as section machinery and shuttle cars are inherently present. Some of these obstacles can block the major portion of an entry and may wipe out effective communication to various areas of the mine section as they move around. Multipath propagation effects may help in overcoming this problem; at any rate, data are urgently needed.

Less urgently, it would be revealing to obtain UHF propagation data of higher frequencies (above 1 GHz) where critical tests of the ADL theory, including the selection of the optimum operating frequency, would be possible. In practical terms these measurements are not, as already mentioned, of the highest urgency, as the use of a frequency above 1 GHz for mobile UHF radio is improbable since it would entail significantly more expensive (because non-standard equipment). Standard UHF frequencies for mobile communication are in the 450 MHz band, and the 960 MHz band soon to be opened by the FCC. It may additionally be noted that the FCC may not in any case approve non-standard UHF frequencies for underground mobile communication, even though in principle, use of non-standard frequencies is acceptable for underground use as long as no leakage to the surface occurs. The basis for this attitude may be explained by the ease with which mobile, as against fixed communications gear, may be taken out of the mine for personal use.

The Bureau of Mines should also delineate clearly the alternatives and practical considerations associated with the placing of the UHF transmitter (and possibly repeaters) to provide the best communication coverage within a section, taking account of its continually changing features.

(b) Long-Term

A future scenario may be envisaged in which a leaky coaxial cable communication system is in use along mine haulageways, whereas UHF radio provides communication up to working faces. In this situation the effective exploitation of all the advantages of these two communication techniques would be enhanced by the ability to couple them together. The techniques, costs, and performance of methods practicable to accomplish this coupling should be investigated.

B. Leaky Coaxial Cable Communication Systems (Europe)

1. State-of-the-Art

Three major classes of coaxial cable communication systems designed for use in mines have been reported as being in various stages of development in Europe.

(a) INIEX/Delogne system (Belgium) employing regularly spaced radiating devices.

Much experimental and theoretical investigation of this system has been performed including trials at the Bruceton, Pa. experimental mine of the USBM. The optimum operational frequency is believed to fall in the range of 2-20 MHz. Prototype installations are on order in Belgium, at a price of about $2500/km. Firm production sales prices are not yet available. The INIEX/Delogne scheme appears potentially suitable for application in U.S. mines, although several uncertainties regarding performance/cost trade-offs in typical U.S. mine environments still have to be resolved, as discussed below. These uncertainties are connected in particular with the restraint in U.S. mines, in contrast to Europe, of having to install the cable close to the rib with consequent increases in attenuation, over a more central location in the tunnel, and with the influences on performance of dirt and water on the cable and on the radiative devices.

(b) Coaxial cable with high surface transfer impedance -- specially designed "leaky" braid outer conductor (France).

Theoretical investigations carried out at the University of Lille in France indicate that effective communication along several miles of mine haulageway may be achieved by use of a coaxial cable whose braid outer conductor is designed for "optimum" leakage of radiation. Experimental investigations of this scheme in a French mine are planned to be carried out in a few months' time. The optimum operational frequency is believed to be between 5-10 MHz.

Similar uncertainties exist with regard to the effects of dirt, water, and proximity to the walls of the tunnel on the performance of the proposed French scheme in U.S. mine environments,as were mentioned in the context of the Belgian cable system.

(c) Coaxial Cable with Repeaters (U.K.)

It has been reported that coaxial cable communication systems incorporating repeaters are being tested experimentally in the U.K. At this workshop little information on the cost and performance of this system was available. Additional uncertainties in the performance and cost evaluation of this system are introduced by questions associated with the reliability and maintainability of the repeaters that can realistically be expected in a mine environment.

2. Future Development Programs

(a) Short-Term

Progress achieved in Europe in the development of the coaxial cable communication systems mentioned above should be carefully and continually monitored and evaluated. In particular,cost estimates and further operating performance data should be obtained as soon as possible.

Nevertheless, European results, while valuable and to date encouraging, cannot be directly applied to the different environment of U.S. mines. In particular it appears impossible to install communication cables in U.S. mines in the locations recommended by European researchers. Specifically cables will have to be installed close to the ribs or walls of tunnels. Accordingly different attenuation rates, and correspondingly different optimum operating frequencies or trade-offs between the rate of "leakage" of power and total communication system length may prevail than in the European situation. Experimental investigations in U.S. mines with the proposed European coaxial cable systems are required before their applicability in this country can be definitively confirmed or denied, and if confirmed, operational specifications written (frequency, design of radiative structure or "leaky" outer conductor, and so forth).

(b) Long-Term

As was discussed in the section on UHF radio, techniques for coupling coaxial cable systems to UHF radio communication should be investigated.

C. Simple Wire Systems (Europe)

1. Wire Pairs

The technical feasibility of communication via waves propagated along wire pairs is well established, and the coupling between and characteristics of the unbalanced and balanced modes of propagation are well understood. However the sensitivity and lack of resistance of simple wire pairs to the deleterious effects of the mine environment (dirt, water, rough handling) tend to rule them out as practical implementations of in-mine communication systems.

2. Single Wire

A single wire communication system is impractical as a solution to a mines' operational communication needs along haulageways or in sections, although a similar type of communication system operating in the low frequency (LF) range holds promise for use in mine shafts.

D. Low Frequency Radio in a Hoist Shaft (U.S.)

1. State-of-the-Art

Theoretical investigations at ADL have analyzed the propagation of LF radio waves in deep (10,000 feet) hoist shafts in which the hoist cable is the only metal conductor present. Propagation losses of approximately 2dB over 10,000 feet at frequencies near 50 kHz have been computed. This is a very encouraging result.

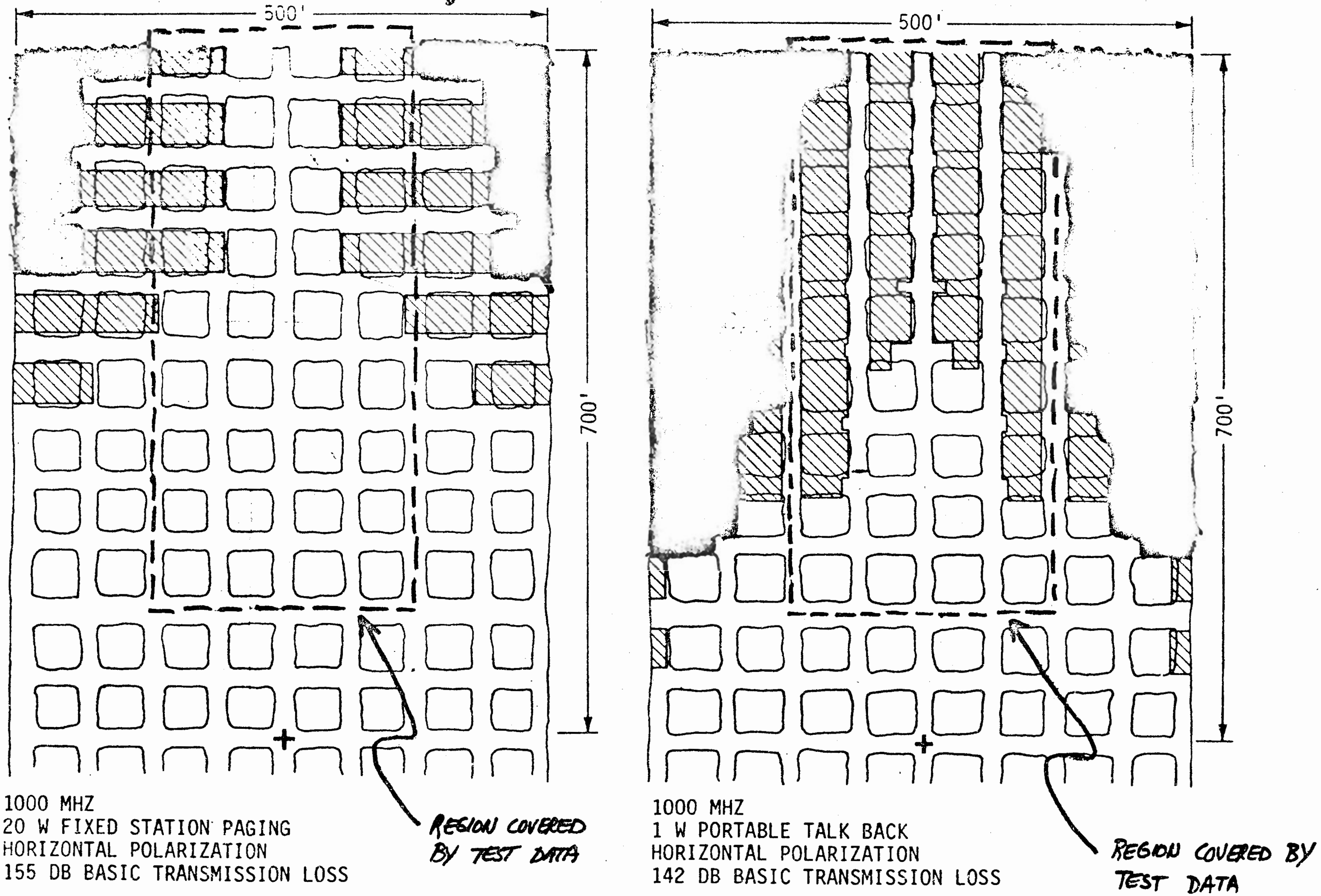
2. Future Development Programs

(a) Short-Term

Two difficulties with respect to LF propagation in hoist shafts have been identified. Firstly, the large penetration of the wave into the rock outer conductor may present a problem with regard to coupling the transmitter or receiver to the transmission line with a minimum of insertion loss. The amount of the insertion loss that can be tolerated has not yet been specified; it may be quite large, in view of the remarkably low transmission losses calculated. The coupling problem merits attention to determine, for example, how closely to the theoretical distribution of the vertical component of current density,in the fundamental propagation mode, should the actual driving current be distributed.

Secondly, in order to minimize reflections, both ends of the hoist cable-shaft transmission system must be terminated in approximately the characteristic impedance of the transmission line. Further work is needed to resolve the question of how, how well, and how expensively matching terminations may be provided.

DARK REGIONS INDICATE, NOT COVERED BY UHF RADIO
(Ignore diagonal lines)



1000 MHZ
20 W FIXED STATION PAGING
HORIZONTAL POLARIZATION
155 DB BASIC TRANSMISSION LOSS

1000 MHZ
1 W PORTABLE TALK BACK
HORIZONTAL POLARIZATION
142 DB BASIC TRANSMISSION LOSS

PREDICTED COVERAGE OF MINE SECTION BY UHF RADIO

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