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COMMUNICATION METHODS IN UNDERGROUND MINES

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Communication methods in underground — mines (Part one)

By R. O. TERVO* and M. D. EVERELL**

As a result of interest expressed by the Mining Association of Canada, the following review of communication methods used in underground mines has been written. This is the first of a two-part article.

■At the request of the Mining Association of Canada, a survey was made of communication methods used in underground mines. This subject has received a great deal of attention in Europe, particularly in modern, mechanized coal mines where the goal has been to increase production and improve efficiency through automation and remote control of machinery.

The development of improved systems is continuing both in Europe and North America. The U.S.B.M. has recently sponsored the development of a coal mine rescue and survival system for long-distance "through the earth" transmission. In Europe the first long-range remote control of a mining machine by radio has been achieved (1). Conventional equipment is continually improved to meet the demand for rugged, reliable equipment that can withstand conditions encountered underground.

Communication methods in use

Several manufacturers and suppliers were questioned to determine the type of equipment available. Such sources may be found in manufacturers' directories like the Thomas Register or Fraser's Canadian Trade Directory. No attempt was made to evaluate all sources or to compare the merits of competitive equipment. Some items are discussed in the various articles reviewed in the literature survey.

Communication equipment for underground use may be classed as wired systems — telephone (including sound powered phone), loudspeaker systems, bells, horns, closed circuit television and wireless systems — radio (AM or FM) and radio with carrier cable, (with and without amplifiers).

Wired systems

The ordinary telephone should not be underrated because of its familiarity. In many mines, telephone systems may be all that is required besides bells for paging and for hoisting signals.

Though underground installations are the responsibility of the mine instead of the telephone company, the equipment suppliers can help with the planning of an efficient system and with the continual up-dating required as the system is extended.

Some of the telephones available are far from ordinary. They are designed to cope with rugged underground conditions and some incorporate safety features necessary for use in coal mines, for example.

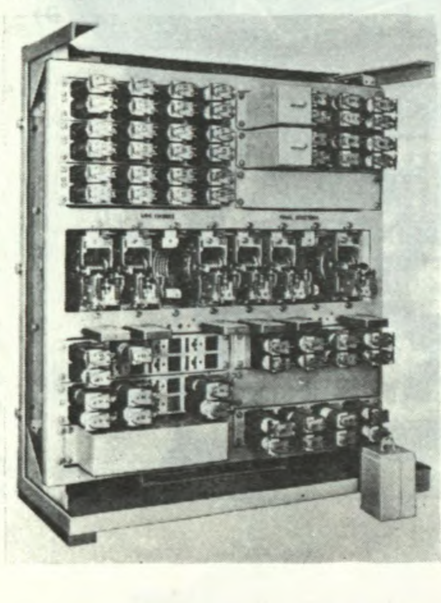
Commercial wired equipment

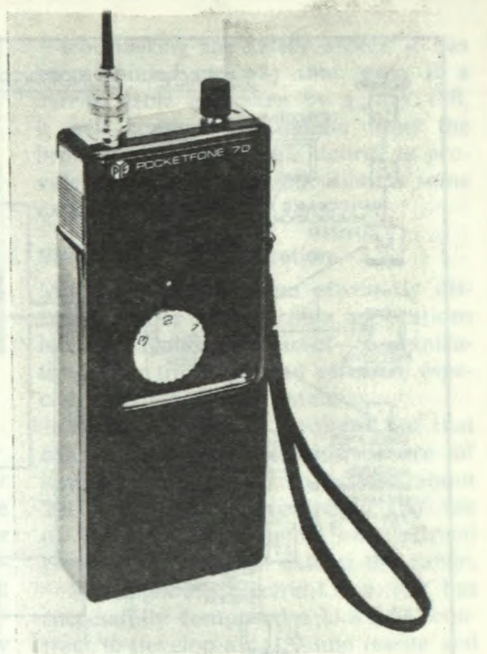
A.E.I. Telecommunications (Canada) Ltd. offer a P.A.X. system suitable for communication between surface and underground. A private fully automatic telephone exchange for as few as 10 lines can be obtained. Larger systems could utilize the 25 or 50-line exchange which can be expanded to 400 phones. With the 50-line exchange, up to 6 simultaneous conversations may take place. For conferences, up to 10 designed extensions may be connected together via a special circuit. Provision is made for staff location by dialing a special loading number followed by a personal code to operate lamps or bells.

Though A.E.I. does not offer an explosion-proof handset for underground use these are available from other manufacturers compatible with the A.E.I. system.

Another supplier of automatic exchanges or switchboard systems is Pye TMC. Pye also supplies a variety of special telephones. The Magneto telephone has a separately mounted, compact generator for ringing other units by code calling (up to 17 on a party line). The Lineman's portable telephone is self-contained, and may be used as a testing instrument or a temporary telephone station. The automatic weatherproof telephone type L81 is a tough, heavy-duty telephone in a con-corrodible, metal, weatherproof case. The portable sound powered telephone type L51 is designed for use in mines or on construction sites. It is self-contained, self-energizing, and completely independent of power supplies. It is designed for point-to-point working over two-wire lines. Many of the TMC sound powered phones can be supplied to meet intrinsic safety requirements for various gases and are recommended by the supplier for underground applications. For surface use or for surface to underground communications, a wider choice is available and Pye TMC offers assistance on system planning.

GEC-A.E.I. 25 line private automatic exchange unit.





Pye Pocketfone 70 portable unit.

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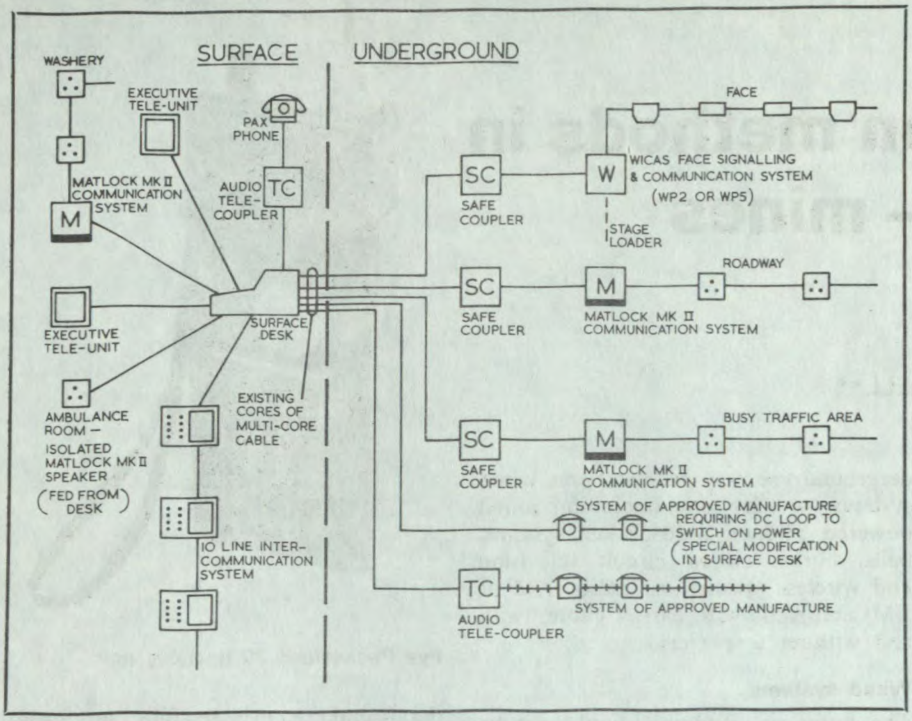


Fig. 1 Surface underground communication system by Winster

National Mine Service Co. offers the Femco loudspeaking telephone, combining telephone handsets with a built-in loudspeaker instead of a bell for paging. The Femco audio system uses handsets and loudspeakers in a wired system similar to a party-line telephone arrangement.

Another source of loudspeaker-microphone combinations is the Winster Group. Winster offers a complete surface and underground communication network as shown in Fig. 1, that incorporates the WICAS, indicating call and alarm system. About 450 of these systems are in service, including several in Cape Breton.

G.E.C. — Elliott Process Automation offer the clearcall unit system of loudspeaker communication consisting of a number of loudspeaker/microphone stations, loudspeakers with telephones, or loudspeakers only.

Carrier communication techniques

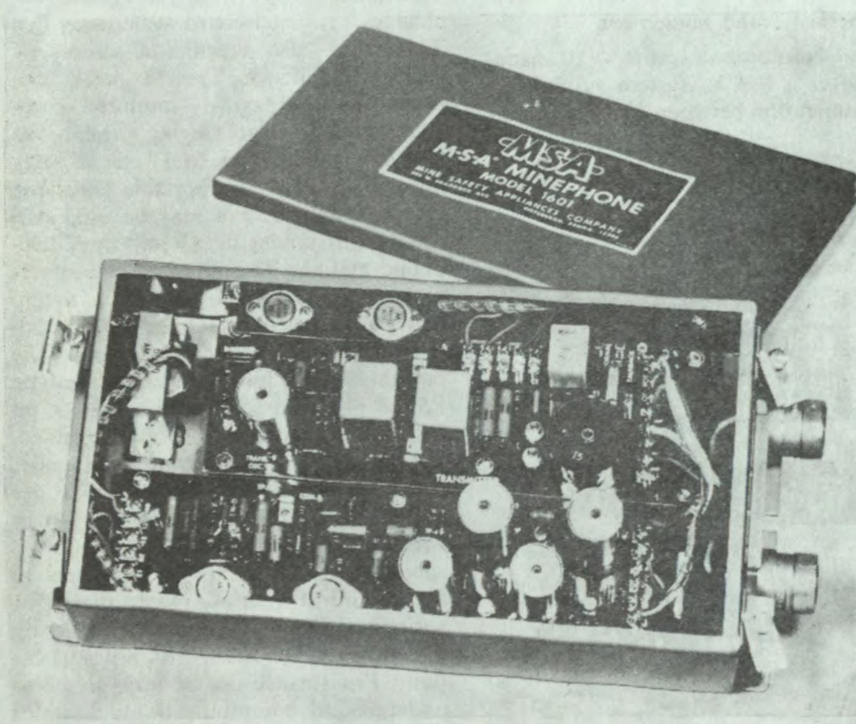
Several companies supply radio equipment utilizing signals induced into hoist cables, power and telephone lines, tracks, or other chance conductors. A considerable improvement in efficiency may result from the use of cables laid specifically for carrying induced radio-frequency messages. The type of cable used, whether single, double conductor, or coaxial, influences performance (2). Recent literature reports on the use of poorly shielded coaxial cable (3) and on the use of coaxial cable with annular slots in the shield (1). Impedance matching at the slots is accomplished with an inductance in series with the inner conductor, and with a variable capacitor across the slot in the outer conductor.

Andrew Antenna Co. Ltd. offers a new slotted coaxial cable, Radiax, designed to radiate and receive R.F. signals. Slots allow a controlled portion of the transmitted R.F. signal to radiate along the entire length of the cable. Conversely, a signal transmitted near Radiax will couple into these slots and be carried along the cable. The cable can be installed directly against any surface using conventional metal hardware. No standoffs or insulators are required. Accumulated dirt, oil or moisture have no appreciable effect on attenuation. Nonradiating standard Heliax cable can be used to bring the signal through areas where coverage is not necessary. Branch runs of Radiax can be used to provide wider coverage to specific areas. Radiax has been tested successfully at 30 MHz, 140 MHz and 450 MHz. A length of Radiax in a shaft may be continued above the surface and terminated in an antenna for communication to outside areas near the shaft. A 50 ohm load may also be used for a termination.

Radiax RX4-1, ½ in., and RX5-1, ⅞ in., are specifically designed for use in mines, tunnels or other narrowly enclosed areas. Both designs permit only minimal signal radiation for very low attenuation, permitting long runs of cable between repeaters. RX5-1, ⅞ in. cable is recommended when very long runs with low attenuation are required.

It is not necessary to have a physical connection between the cable and the transmitter or the receiver, although it may be advantageous to do so, in some instances, particularly for the base station. Frequency modulation (FM) is used in much of the equipment of this type to help reduce noise from static pickup.

The MSA model 1601 Minephone operates at a standard frequency of 88 kHz, with provision for changing frequencies. The supplier states these units are lightweight, compact and weather proof and can be used throughout the mine, above and below ground. The



MSA Minephone showing solid state construction.

two-way system transmits voice over standard mine power lines and adjacent telephone wire. The equipment can be used as an efficient call system for locating personnel and for speeding the handling of material and equipment. A portable, battery-powered version is available for use on locomotives or other mobile equipment. The output power is not specified in the bulletin provided by the supplier.

National Mine Service Co. supply the Femco Trolleyphone which can be operated at any of several standard frequencies in the range from 61 to 116 kHz, with up to 25 watts output power. Again, existing conductors, or special cables, may be used as the signal carrier.

G.E.C. - A.E.I. offer a carrier cable shaft inspection communication set operating at set frequencies between 40 and 150 kHz, with a power output of up to 10 watts. The hoist winding rope is suggested as the carrier cable (Fig. 2). Shafts 6,000 ft deep present no problem of signal attenuation. The manufacturer suggests that the same equipment could be used for remote control of the cage. The equipment is portable, thus it may be used throughout the mine between any two points where an electrically continuous metallic conductor is available. This conductor may be grounded at either end, as with railway lines or metal fencing.

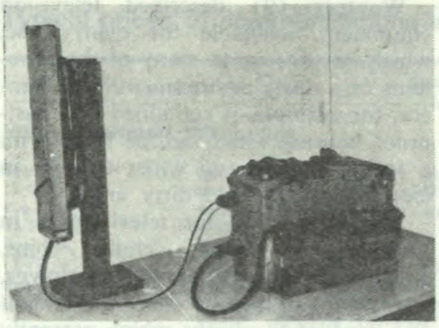
The Pye Pocketfone (3) has a range of 2.5 km over a coaxial carrier cable, with porous braid covering, called a 'leaky feeder'. The PFI model has ½ watt output at 450-470 MHz. The PF3 model is rated at 2.5 watts. The base station has an output of 15 to 30 watts into the cable to communicate with the portable units which may be as much as 50 ft away from the cable. Repeater amplifiers are located along the cable to restore signal strength to its original level.

The A.E.I. Mine Bleep system (operating at 30 kHz) is a personnel paging system using miniature receivers to pick up tone signals from a carrier cable. It is designed for one-way communication. The person called must go to a telephone or other answering system.

International Aeradio (North America) Limited is a systems company, rather than a manufacturer. They purchase the best available components, do the installation and provide maintenance afterwards.

I.A.L. have made underground installations of FM/VHF and FM/UHF radio equipment, for example for mine shafts, and are currently working on complete systems for British coal mines.

In Canada, during the past three years, a few underground installations



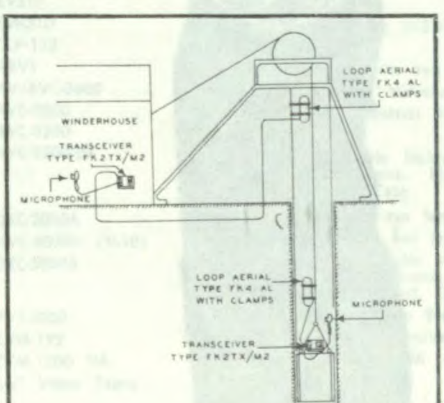
Femco Trolley phone adapted by National Mine Service for shaft inspection, using 12 volt battery pack.

have been made. These include two for research purposes, and one for remote control of trains by radio. This latter system is now working, providing remote control above and below ground.

Much of the radio equipment supplied by I.A.L. is manufactured by Storno Ltd. and is well suited to a communications system. Mobile and personal portable equipment is available operating either at 148 - 174 MHz or 450 - 470 MHz. In mining applications, the mobile radio equipment can be interfaced with the telephone exchange, providing a complete underground and surface system. Repeater systems are available to connect a hand-held portable unit on the surface to a hand-held portable unit underground. Selective calling, automatic dialling and remote control are all available from Storno.

Bergbau-Forschung GmbH, Germany, has developed a system (meeting coal mine regulations) using a central base station and portable units. The portable unit transmits on a frequency of 430 kHz and received at 290 kHz. The messages must pass through the base station for communication at distances up to 3 km. The output power is 0.6 W for the central station and 0.5 W for the portable units.

Fig. 2 Typical shaft phone using the hoist cable as a carrier cable (G.E.C./A.E.I.)



Considering the safety aspect, it has been pointed out (3) that, even if a carrier cable is broken by a rock fall, it will continue to radiate from the broken end, through the debris, to provide continued communication to some extent, at least.

Direct radio communication

Much of the equipment previously discussed under carrier cable applications has the capability of direct communication from transmitter to receiver, especially with modified antennas.

Wyke and Gill (4) pointed out that conventional radio techniques are of limited use underground beyond about 200 metres and recommend the use of inductive coupling to an electrical conductor nearby to extend the range.

Westinghouse Electric Corp. (5) has successfully completed a U.S.B.M. contract to develop a coal mine rescue and survival system. The voice communications system transmits directly from the surface to miners underground. The equipment operates at very low frequency between 200 and 3000 Hz. This choice of frequency was based on the fact that attenuation of electromagnetic radiation by the earth is frequency dependent. Pulses at 10 KHz can be detected at about ten times the distance at which pulses at 1 MHz can be detected. Westinghouse Georesearch Laboratory experiments over the past few years in low-frequency and through-the-earth electromagnetic wave propagation demonstrated that voice communication between the surface and underground in the mine is possible. The system developed involves voice transmissions into the mine and coded pulse signals up from underground at a depth to 2500 ft. The surface antenna is an insulated wire several thousand feet long grounded by long metal stakes at each end and connected to the transmitter by a sophisticated coupling device.

This equipment was developed on a research contract, but it may be commercially available in Canada, through Canadian Westinghouse Co. Ltd. (For photos, see CMJ July 1971, p. 36).

Consolidation Coal Co.'s Lee engineering division has successfully transmitted messages in code from inside the mine to the surface (6). In addition, two-way voice transmission was accomplished between the underground and surface at depths of several hundred feet. The use of low-frequency radio signals, as with the Westinghouse experiments, was necessary to achieve penetration through the rock. The surface transmitter has a power output of 200 watts.

Though the system is claimed to be capable of replacing conventional telephone communications it has been stated that more research is required to test its performance under different conditions in various mines before it can be considered practical.

The Coal Mining Research Institute of Czechoslovakia has developed a cap-lamp transmitter for use in locating trapped miners (7). It operates in the range of 0.7 to 0.9 MHz. It is intended only for short range (100-200 ft), weighs only about 50 gm, and operates off the cap-lamp battery. One mine has 4700 of these electric cap-lamps equipped with transmitters.

The Transvaal and Orange Free State Chamber of Mines Research Laboratory has developed a 10-watt, single sideband, portable radio transceiver for use in rescue and fire fighting underground (8). The single sideband technique is more expensive, but gives a gain in signal-to-noise ratio of 8 or 9 db over a normal amplitude modulated system. This equipment was designed for working distances through rock (quartzite) of up to 3000 ft, operating at a frequency of about 300 kHz. Even greater distances (over 6000 ft) have been attained in the vicinity of overhead trolley wires or electric cables, which act as a carrier. The development of the pre-production type transceivers was carried out in association with Plessey (S.A.) (Pty.) Limited.

Canadian Motorola Electronics Company provides portable and mobile two-way radios such as the Handi-Talkie HT 100 or HT 220. These are FM units, operating at 450-470 MHz, with a power output ranging from 50 mW to 4 watts. Also available is a 50 mW radio, UL listed for hazardous atmospheres. An optional miniature headset mounted in a safety helmet is offered with this set. Several base stations are available with up to 90 watts RF power output. For mobile use, the Mark 12 FM Mobile Radio has 20 watts RF power output, again at 450-470 MHz. Not much information was available on underground applications except that the 450 MHz band has provided the best results.

Television

Industrial closed-circuit television means the transmittal of a picture viewed by a television camera to a remote monitor viewing unit. The connection between units is by means of coaxial cable rather than by the radio-frequency wireless transmission used for domestic reception. The cable can be as long as required, therefore no particular range limitation (except cost) would interfere with its use underground.

Motorola Handie-Talkie, portable remote controller system.

Wontner (9) described television equipment, available for quarry use, which has overcome many of the problems of a dusty environment. The camera, for example, is contained in a dust-proof housing which can be fitted with a screen washer and wiper for use in extremely dusty and dirty areas.

The application for television is in observing conveyors, chutes, bins, crushers, etc. for hangups, breakdowns, and for a myriad of other equipment and production checks which presently require manpower.

Stephen (10) described an underground installation for supervising manless transfer points on conveyors.

The use of video-tape recorders in mines would allow the recording and subsequent playback of equipment demonstrations or other important operations which require study.

Telemetering and remote control

Communication is often thought of as conversation between people. In industrial applications, this concept should be widened to include communication from machine to man, from man to machine, or from machine to machine. Mechanization and automation require data transmission to a decision making centre, whether the decisions are made by man or by computer. Telemetering refers to the transmission of data to come central recording or control point. If many sources of data must be accommodated, then a system of time division or frequency division multiplexing allows the transmission of more than 200 channels over a single pair of wires. Multiplexing techniques have been described in detail by Bennett (11), Billing (12), as well as by Hartill (14).

Extensive use has been made of remote and automatic control at Bevercotes Colliery (13) in almost all of the colliery operations, and production control has been centralized with overall supervision from a control room on the surface. A data transmission system, with frequency division multiplexing, enables the remote operation of manless transfer points and the interchange, between plant and control stations, of information relating to production, safety, and maintenance.

Hartill (14) described remote control of underground conveying systems using closed-circuit television and various telemetry systems. Sensing devices were developed to detect conveyor sequence, belt slip, bearing temperature, general temperature (conveyor gearhead or gearboxes), belt alignment, torn belts, or blocked chutes.

Dreisbach (15) described mine haulage automation. He pointed out that remote control of a locomotive still requires an operator, but a completely automated locomotive would go through its cycle of operation after a button was pushed to initiate the cycle. Though this has been accomplished on the surface, the author expects it could be done just as well underground. The problem comes back to communication with the locomotive, the carrier type of communication being most suitable for underground applications.

In the complex underground haulage system at LKAB in Sweden, an IBM 1710 system is being used to determine the destination and routes of ore trains. This system still makes use of a locomotive operator who receives his instructions from the computer. Various functions can be automated, such as track sanding, bell ringing, horn blowing, use of headlights, as well as coupling and uncoupling. A fail-safe system could apply emergency braking in case of loss of control through power failure, for example. Car counting and detection of derailments can be included in the system.*

*Editor's note — for LKAB and other Swedish applications of automation and remote control see CMJ, March 1972.

Mine Equipment Co. has provided radio equipment for remote control of underground diesel locomotives. This equipment operates at a frequency of 460 MHz with a power output of 100 mW with 6 channels and control tones. The range required in one mine was up to 400 ft and this was accomplished without a separate carrier wire. The 9 ft x 9 ft drift contained ventilation, water, and air piping as well as roof bolts and screens. □

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Representative list of communications equipment suppliers

A.E.I. Telecommunications (Canada) Ltd., 419 Notre Dame Ave., Winnipeg 2, Manitoba. (Telephone systems)

Pye TMC, 15 Sheffield St., Toronto 385, Ontario. (Telephone, mobile and carrier equipment)

Winster Products (Engineering) Ltd., Manners Ave., Ilkeston, Derby, England DE78EF. (Communication systems)

MSA Canada, 148 Norfinch Dr., Downsview, Ontario. (Phone and carrier systems, shaft phones)

English Electric — AEI (Canada) Ltd., 766 King St. W., Toronto 139, Ontario (representing G.E.C.-Elliott Automation Ltd.). (Audio and mobile radio — carrier)

Canadian General Electric Company Ltd., 532 McGaughey Ave., North Bay, Ontario (Mobile radio)

Canadian Westinghouse Co. Ltd., Electronic Systems Div., P.O. Box 510, Hamilton, Ontario. (Mine safety and survival system)

National Mine Service (Canada) Ltd., 19 Timber Rd., P.O. Box 82, Elliot Lake, Ontario. (representing FEMCO phone, audio and carrier equipment)

DIFCO, Inc., P.O. Box 238, Findlay, Ohio 45840, U.S.A. (Radio remote control systems for locomotives)

Mine Equipment Co. Ltd., P.O. Box 1130, North Bay, Ontario. (Radio control of locomotives)

Canadian Motorola Electronics Company, 185 Cedar St., Sudbury, Ontario. (Portable and mobile two-way radio)

Andrew Antenna Co. Ltd., 606 Beech St., Whitby, Ontario. (Heliax coaxial cable and Radiax slotted coaxial cable for carrier systems)

Typical prices of communications equipment

Item	Description	Canadian price
Sound powered telephones		
Pye TMC L-50	Wall mounting heavy duty telephone in weatherproof aluminum case, Howler signalling (S42331/F150)	$151 ea.
Pye TMC L-51	Portable Field Telephone with Howler signalling (S36689/F150)	$80 ea.
Pye TMC L-70	Bulkhead mounting intercom telephone with generator and buzzer signalling (S56324/F150) (way and 'OFF' selector)	$126 ea.
Pye TMC L-76	Bulkhead mounting intercom telephone with 12 way switch in aluminum weatherproof case with grey hammered finish, Howler signalling (S536432/F150)	$174 ea.
Two-way radio with carrier cable		
MSA 1601 Minephone	Two-way radio, Carrier type, about 40 watts output at 88 kHz. Used for hoist to cage, or cage to cage (also can be used for locomotive to locomotive or dispatcher)	$3500 for 2 sets
Pye Pocket fone	Two-way radio, 150 mW to 2.5 watts, 450-470 MHz —	
	PF1T UHF Pocketfone transmitter	$189 ea.
	PF1R UHF Pocketfone receiver	$299 ea.
New Pocket-fone 70 Series	PF2UH, ½W, portable two-way radio	$765 ea.
	PF3UHF, 2.5 watts, portable two-way radio	$1230 ea.
	Repeater base station with Duplexer	approx. $2000 ea.
	Lossy carrier cable, per foot	$1.50-$2.
Radiax	Slotted coaxial cable per foot	.60-$1
International Aeradio (North America) Limited		
Storno/IAL 660 Series mobile	450-470 MHz 12-channel FM mobile radio including antenna, control box and cables.	$1,200
Rank Precision Industries/IAL handheld PL201 series	450-470 MHz handheld portable, 1.4 watts R.F. output including re-chargeable battery and carrying harness.	$ 730
Storno/IAL handheld portable (intrinsically safe)	450-470 MHz hand-held portable, 300 mw output for use in dangerous atmospheres.	$1,050
Storno/IAL 600 series mobile	148-174 MHz 12-channel F.M. mobile radio including antenna, control box and cables.	$1,050
Rank Precision Industries/IAL handheld portable TR.1007 series (MITRE)	148-174 MHz belt mounted personal portable including re-chargeable battery and carrying harness.	$ 755
Storno/IAL handheld portable (intrinsically safe)	148-174 MHz hand-held portable for dangerous atmospheres.	$ 970
Two-way and mobile direct communication		
Motorola 220 Series "Handie-Talkie" Two-way radio	Hand-held portable 450-470 MHz, FM, 1 watt R.F. output	$999 to $1195
Same as above	4 watt R.F. output basic model	$1289
Motorola 100 Series "Handie Talkie" Two-way radio	450-470 MHz, FM, 100 mW RF output	$979
Motorola HT Series Two-way radio	450-470 MHz, FM, 50 mW, for hazardous atmospheres	$1165
Mark 12 Multi-Channel FM Mobile Radio	450-470 MHz, 20 watts RF output, 12 channel	$1619
"Pageboy II" Radio Pager	FM receiver "beep" signal only	$450
"Pageboy" Tone-and-Voice Radio Pager	FM receiver 200 mW audio tone output, 150 mW audio voice output	$450
Television		
EV310	1" Sony Videocorder	$ 4,400
EVR310	Remote Control Unit for EV310	$ 115
CLP-113	Colour Pack for EV310	$ 1,295
ARV1	Automatic Replay Unit for two EV's	$ 1,080
AV/AVC-3400	½" Battery Operated Videocorder/Video Camera Ensemble	$ 1,775
AVC-3000	Video Camera for Industrial Surveillance Use (No viewfinder)	$ 295
AVC-3200	Camera only	$ 420
AVC-3200-DX	Video Camera Ensemble Including Camera AVC-3200, Tripod, Microphone, Zoom Lens, Electronic Viewfinder AVF-3200, Cables and Carrying Case	$ 900
DXC-2000A	Sony TV Camera, 25 mm lens	$ 1,595
AVC-4000A (V-10)	Studio Camera, 15-150 mm lens	$ 2,950
DXC-5000A	Sony two tube NTSC Color Video Camera, including built-in 6X1, F2 Zoom Lens, Electronic Viewfinder, CN-1 Color Control Board, Camera Control Unit, Camera Cable and ND Filters	$10,800
PVJ-3030	5" diagonal Monitor/Video Black and White	$ 225
CVM-192	19" diagonal, Monitor/Receiver	$ 395
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	30 minute playing time	24
1" Video Tapes	32 minute playing time	$ 45.50
	63 minute playing time	69.50

Communication methods in underground mines — (Part two)

by R. O. TERVO* and M. D. EVERELL**

The August issue described in general terms various types of both wired and wireless systems, and listed equipment available on the market. In this concluding installment, the authors go into the theory of radio propagation and conclude by pointing out the relative merits of the various systems.

■A good review of the subject of radio propagation underground was given by Hughes and Hartill [16] with a description of practical applications and problems encountered. The authors indicate that the range of useful frequencies for communication in general is from 15 kHz to 10,000 MHz or higher. As previously mentioned, Westinghouse experiments [5] (Part one, Aug.) were conducted at even lower frequencies for through-the-earth transmission and the Westinghouse system for coal mine rescue and survival uses equipment operating between 200 and 3000 Hz. No mention has been found of communication equipment operating above 460 MHz.

Finkelstein and Erdem [17] have considered radio propagation from a theoretical viewpoint and have done experiments to test their analysis.

The theoretical analysis considered the transmission of signals through geological strata and along the line of sight between transmitter and receiver on a roadway underground. Allowing for the presence of discontinuities or cracks would be a great complication theoretically. To simplify the analysis, the rock strata were considered to be homogeneous, quasi-conducting, and having constant electrical properties. For such a medium, an optimum working frequency exists for a given separation of loop aerials. The areas of the two loop aerials affect signal strength directly, and the loops must be in the same plane for maximum coupling. The formula developed by the authors contains three terms representing the contributions of the radiation field, the induction field, and the electric or mutual inductance coupling field to the e.m.f. picked up by the receiving antenna.

The contribution of each of these fields decreases with distance, but they are all equal if the distance separating the aerials is $\lambda m/2\pi$ in which λm is the wavelength of the radiation in the separating medium. At shorter distances such as used in the authors' study, only the mutual inductance field is of significance and the formula simplifies to —

$$V_r = (j\omega S_r S_t N_r N_t \mu I_t/4\pi)(1/r^3)e^{j(\omega t - kr)}$$

where

- r = distance between aerials,
- V_r = e.m.f. induced in receiving aerial,
- S_r = area of receiving aerial,
- N_r = number of turns in receiving aerial,
- S_t = area of transmitting aerial,
- N_t = number of turns in transmitting aerial,
- I_t = current flow in transmitting aerial,
- μ = permeability of media between aerials,
- k = $\omega(\mu\epsilon)^{\frac{1}{2}}$,
- ϵ = permittivity of media between aerials, and
- ω = angular frequency

This leads to the conclusion that, at a given frequency, the e.m.f. induced in the receiving aerial, V_r, varies inversely with the cube of aerial separation. An optimum working frequency exists for a given separation of aerials because V_r is then a function of frequency only. A similar conclusion was reached for transmission along roadways.

Experimental confirmation of the theory was tried underground in Northern United Colliery. The frequency range covered was from 50 kHz to 1 MHz at an average transmitter output of 1 watt. The experimental site was wet, with pools of water on the floor. Rock samples were checked for conductivity and dielectric constant. These

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showed anisotrophy of the electrical properties by a factor of 2.

The conductivity of the rock increased with frequency, varying from 7.0 $m\Omega^{-1}/m$ at 50 KHz to 35 $m\Omega^{-1}/m$ at 1 MHz. Dielectric constant values carried from 47.0 at 50 kHz to 27.6 at 1 MHz.

The transmitter and receiver aerials were located around a corner from each other. Measurements of receiver output were made at 60, 100, 170, and 300 kHz, moving the receiver until no observable output was obtained. No pickup was observed above 300 kHz.

The authors conducted their line-of-sight experiments along a straight roadway, about a half mile long. The frequency range covered was from 60 to 900 kHz. There were no metallic conductors along the roadway except for steel arches that supported the roof.

The authors concluded that transmission through the rock strata in that mine was feasible for distances of about 100 m at a frequency of 300 kHz. (The theory had predicted an optimum at 170 kHz).

For line-of-sight transmission along the mine passageway, a range of 1 km was attained at a frequency of 60 kHz.

Martin [18] reviewed radio propagation experiments and mentioned experiments in railway tunnels at frequencies higher than those mentioned above. Apparently as the frequency is increased above 300 kHz, the attenuation first increases and then decreases rapidly at frequencies where the tunnel can be regarded as a waveguide.

Along straight unobstructed roadways, the range may be only 200 metres at 85 to 170 MHz but may be 400 metres at 460 MHz, at the same power level.

Martin and others have concluded that the best results can be obtained from using pickup to and from a transmission line that consists of an open weave shielded coaxial cable which acts as a leaky feeder. This type of feeder is less subject to extraneous influences such as dirt or moisture than the ribbon type of feeder. Martin observed that a certain frequency gave the maximum range. This optimum frequency varied between different types of cable, depending on attenuation characteristics and the leakage field coupling the line to the mobile apparatus.

For ribbon and coaxial feeders, Martin reported optimum frequency is about 27 MHz. Because compact hand-portable sets in the U.K. are not readily available below the VHF low band, the frequency range from 71 to 88 MHz has been selected for long-range speech communications. Martin reviewed mobile radiotelephones, e.g. Pye Bantam, Ultra Electronics Cub, and the G.E.C. Courier.

A new development has been the replacement of the whip antenna by a flexible helical coil antenna on the G.E.C. Courier. This is more convenient in length and performs better than strap or body-worn aerials.

Liégeois has studied the coaxial cable with annular slots [1], (Part one, Aug.) both theoretically and in practice. Dewar and Beal [19] have made a theoretical analysis of coaxial-slot surface wave launchers, for use in communication and control in a high-speed, guided, ground-transportation system. The annular slots provide a means of radiating power from the cable along its length.

Liégeois [2] (Part one, Aug.) reviewed European experience in radio communications underground. Both German and Belgian radios (Telechar) were mentioned that operate in the International 27-MHz band. The Telechar used a two-wire carrier cable. Liégeois reviewed the equipment available from various sources. Operating frequencies used were 13 kHz, 67.5 kHz, 140 kHz, 263 kHz, 350 kHz, 27 MHz, 150 MHz, 174 MHz, and 460 MHz. Both FM and AM transmitter-receivers were listed in this group. A bifilar carrier cable was recommended to increase range. A problem of mutual interference may occur if more than one base station exists. The choice of AM or FM may be dictated by the technique chosen to eliminate this interference.

Olaf [20] reviewed research work in Germany on the choice of frequency of transmission and the conclusions reached by various investigators. Carrier cables proved advantageous at all frequencies from 10 kHz to 460 MHz. Though attenuation is greater at high frequencies, coupling problems are easier to solve.

LIMITATIONS ON USE OF RADIO TRANSMITTERS

The Canadian Explosive Atmospheres Laboratory, Fuels Research Centre, EMR, was asked to comment on limitations to using a radio transmitter in Canadian coal mines. The federal certification officer, G. K. Brown, replied,

"The coal mine operator has to inform the provincial mines inspection branch of any electrical apparatus he proposes to use underground and must obtain their acceptance of its use. They will not, to the best of my knowledge, accept any electrical apparatus for use in a coal mine unless it has been certified suitable for such use by an acceptable certifying authority. Such acceptable authorities include our Department, the U. S. Bureau of Mines, and the U.K. Certifying Authority."

The use of carrier cable rather than free radiation may be influenced by the requirements of the U.S. Bureau of Mines and of the Canadian Standards Association on stray signal loss where electric blasting is used. One supplier has limited his equipment to carrier type for this reason.

The C.S.A. Standard Z 65-1966 concerns electric blasting caps and radio transmitters. Tables II and III on page 13 of that standard show the mini-

Equipment for putting down escape openings for coal mine rescue projects. This is part of an elaborate system developed by Westinghouse Electric Corporation to meet requirements of U.S.B.M. contract.

mum distance required from blasting operations —

Effective radiated power Watts	Minimum distance Feet
5 — 25	100
25 — 50	150
50 — 100	220
100 — 250	350
250 — 500	450
500 — 1000	650

For mobile transmitters, the following distances are required —

Transmitter power Watts	Minimum distance Feet
1 — 10	10
10 — 30	20
30 — 60	30
60 — 100	60

The distance given is the minimum permissible distance between the nearest part of the vehicle or of the portable set and the nearest part of the blasting circuit.

J. A. Darling, manager, Canadian Explosives Research Laboratory, Mining Research Centre, has stated their tests have indicated the radii shown are adequate.

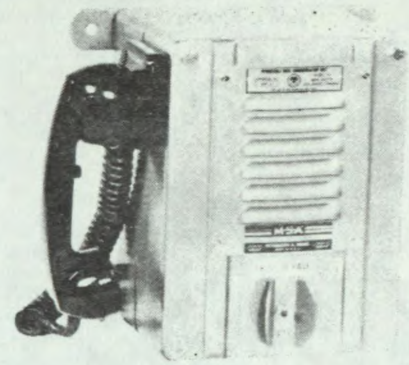
The greatest hazard occurs at high powers and low frequencies. Mobile radios generally operate at low power and high frequency and have vertical antennas which do not couple well to the usual horizontal blasting circuit. However, their mobility increases the potential hazard.

The Department of Transport and Communications was questioned about regulations. W. J. McCurdy, telecommunications regulations branch, advised that "there are no regulations governing the use of radio communication equipment in underground mines except that the equipment used must be up to the required standards, using the proper frequency assigned, and have a licence to operate".

CONCLUSIONS

Though all of the communication methods used on the surface may be used underground, there are limitations on the use of certain equipment. Telephone systems may be limited by the distances involved in a mine. A prohibitively large number of stations might be required for complete coverage. Radio transmission is limited to short distances because of attenuation by the surrounding rocks and to low powers by safety considerations related to the use of explosives.

Carrier cable systems increase the range of radio and permit lower pow-



Permissible underground pager and communication system with loud hailer-M.S.A.

ers with attendant safety improvement. It is not always necessary to use special cables although there are many advantages to doing so, especially for communication along the cable. Carrier systems are working well for shaft phones and remote control of locomotives.

Closed circuit television has been used to improve production by observing conveyors and other potential bottlenecks and to relieve the mine personnel involved in these tasks for other duties.

As automation progresses and remote control of equipment becomes possible, data transmission to and from machinery and computers will be necessary. This can be done over multiwire cables or over a single pair using multiplexing techniques.

The trend in Europe is in the direction of carrier cable equipment with portable units for the workers. This appears to be the best solution from the worker safety point of view because a trapped or injured miner needs to have equipment on his person, or nearby, to call for help.

In Canada, not much investigation seems to have been done to determine the type of equipment most suitable for the Canadian mining industry. Certain standard equipment is available and custom engineered systems can be obtained at greater cost.

It would be worthwhile for the Mining Research Centre to determine the effectiveness of commercial or experimental radio equipment in various locations underground. The test sites could be chosen to include what appeared to be favorable locations as well as those where difficulty could be predicted.

The benefit to the mining companies from the information obtained in these proposed tests would be in knowing the type of radio equipment likely to be effective in a particular type of mine. Presently, the choice of frequency, power, type of modulation (FM or AM), whether or not to use a carrier cable, and what kind, present a bewildering picture to someone not acquainted with radio equipment.

These variables could possibly be related to the properties of the rock in a particular mine, as compared with other mines, taking into account the extent and geometry of mine passages, to help the mine operator decide on radio equipment. At present, it would be easy to show that radio equipment performs poorly underground, but with the right choice of equipment and conditions of use a working installation would result that would contribute to improved efficiency and greater worker safety.

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