Review of through-the-earth communication technologies

HAO Jian-jun, GONG Yu-qin

(*College of Electronic, Communication and Physics, Shandong University of Science and Technology, Qingdao 266590, China*)

Abstract: In this paper, development of through-the-earth communication technologies is summarized, as well as the operating principles and performances. The propagation loss, frequency band and power efficiency are also analyzed. We can know that among these technologies, the antenna induction method is more popular, but the communication system with ground electrodes is more promising due to its high energy efficiency. The communication with elastic wave (seismic) is not suitable for emergency communication when the accidents of rock burst or land slide occur.

Key words: through-the-earth communication; very low frequency; transmission attenuation

CLD number: TD65$^+$5 **Document code:** A
Article ID: 1674-8042(2014)02-0064-04 **doi:** 10.3969/j.issn.1674-8042.2014.02.013

0 Introduction

Mineral resources are main energy source for human beings, and mining can be divided into two categories of open mining and underground mining. Relative to open mining, underground mining is faced with an extremely complex and dangerous environment, especially possibilities of accidents, such as gas explosion, fires, flooding. These accidents often make existing ways of communication channels destroyed, and the position of trapped miners can not be reached, which delay the post-disaster relief. Through-the-earth communication adopts the layer medium as the communication channel, which is not affected by accidents. So the way can be effective to keep contact with the ground for the underground, and can be an emergency communication when disasters occur. Now studies of through-the-earth communication at home and abroad are divided into three kinds: antenna inductive coupling near-field communication (NFC), communication with ground electrodes and communication with elastic wave. The way of antenna inductive coupling is the best developed. Most studies focuse on it, and it also has stable products. Current communication systems are all in the ways of antenna inductive, except E-Spectrum which is the way with ground electrodes.

There are not many persons engaging in the research of elastic wave through-the-earth communication. Our group has taken part in the elastic wave through-the-earth communication since 2008, and has made some achievements. But there is no related product by using this way, and it cannot support voice communication yet. Although low-frequency electromagnetic wave method developes well and supports voice communication, it needs the large size loop antenna and the big transmiting power.

1 Communication with antenna inductive coupling

The communication of using low-frequency electromagnetic wave penetrating stratum was first proposed by Nicola Telsa in 1899. Since then, in the 1930s, American Bureau of Mines organized experts made many attempts and published a series of research reports in department of the interior, but the first set of through-the-earth communication using low-frequency electromagnetic wave was developed by South Africa[2].

The United States launched researches of through-the-earth communication after the WWII. W.C. Pritchett gave the attenuation datum of RF-electromagnetic wave (1.65 MHz) through-the-earth: the average attenuation of limestone is about 0.086 Neper/feet (2.49 dB/m), and the average attenuation of shale is 0.231 Neper/feet (6.6 dB/m)[3]. Since the 1970s, with the fundings of Bureau of Mines, R Wait and G Geyer have made lots of researches on electromagnetic wave propagation through-the-earth, and got coupling formula of the receiving antenna intensity of magnetic field[4-7]. The conclusions are: (1) when the earth is completely insulating medium, the vertical

* **Received date:** 2013-12-01
Foundation item: National Nature Science Foundation of China (No. 61272432)
Corresponding author: HAO Jian-jun (wfhjj@126.com)

magnetic field intensity of receiving antenna is higher; (2) when the conductivity of earth medium is higher, the vertical magnetic field intensity of receiving antenna is in low level; (3) when the transmitted frequency is higher, vertical magnetic field intensity of the receiveing antenna is lower.

The main architecture of through-the-earth communication system with loop antenna is shown in Fig. 1.

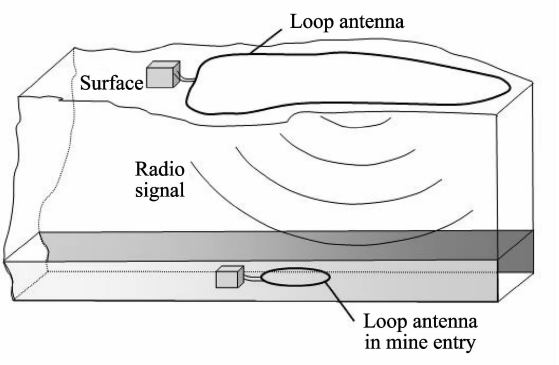

Fig. 1 The schematic diagram of through-the-earth communication with antenna inductive

The former Soviet Union published many papers and research reports about the underground communication, and convened meetings all over the country. In 1981, И Ф Огороднейчук[8] published the monograph which totally summarized research results in the field of mines of low-frequency communication of the former Soviet Union. Then, the research was stagnated before the former Soviet Union. From the 1980s to the 1990s, John Durkin from America carried on many researches about the ground conductivity and electromagnetic wave transmission, and set up a ground medium model on the basis of actual measurement data[9,10]. He got the conclusion that the speed of signal (630 Hz) attenuation was 0.09 dB/m, which was smaller than the value of theory forecast.

On the application side, Australian Mines Site Technology Company developed the PED emergency command paging system in the 1990s, whose one-way penetration distance could reach 800 m, and normal communication rate was 0.5 byte/s. And Canadian Vital Alert Company also launched their Canary series of through-the-earth communication products. In 2005, Barkand tested and researched on the "Telemag" system in a limestone mine and a running coal mine respectively, which is a half-duplex communication prototype system. The system used a bandwidth of 500 Hz to achieve real-time voice communication[11,12]. Then, PED and Canary systems also illustrated that they could realize a short voice communication. Lockheed company, Stolar Horizone company and Ultra Electronics company have developed their own through-the-earth communication system since 2011[1].

The aspect of the research is not much yet in China. SI-TU[13] and TAO[14,15] studied on schematic design of through-the-earth communication. ZHANG[16] researched of working frequency, medium conductivity, transmitting antenna size, shape and its placement on the influence of underground electromagnetic wave propagation in the case of a large loop antenna, which was mainly theoretical research.

2 Communication with ground electrode

The communication mode uses low-frequency current signal to communicate, in which the sender and receiver use two groups of electrodes inserted into the underground to send and receive signal, as shown in Fig. 2.

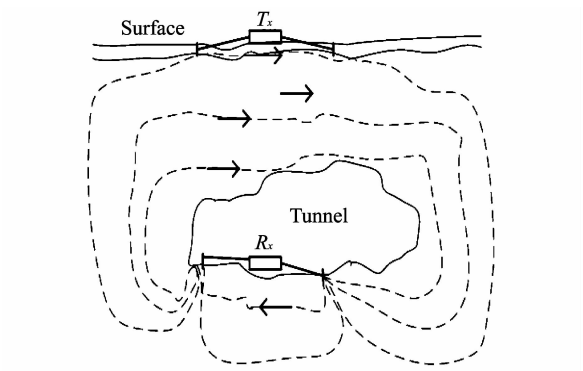

Fig. 2 The schematic diagram of through-the-earth communication with gound electrodes

The essence of communication with ground electrodes is to use current to carry information data. When the carrier frequency is low, the main part of field current is conduction current. But when the carrier frequency is high, the main part of field current is displacement current. At this time, wire, electrodes and the ground are equal to a loop antenna. So its essence is also near-field electromagnetic wave communication.

The earliest study in the aspect was from the 1960s to the 1970s, when some scholars explored the transmission performance of antenna buried underground. In 1996, Swiss researcher J Hurni built a set of through-the-rock communication system by using electrodes as antenna in the Alps Holloch cave. He used relay method to penetrate rock of 900 m successfully, which could not succeed by using a loop antenna[17]. But the report may be the earliest way of through-the-earth communication with electrodes. The GTE group of Spain Zaragona University made a lot of researches in the aspect, and also

developed a TEDRA cave communication test system[18]. Bataller researched of the ground impedance[19,20]. In 2003, British Gibson pointed out that the method of very low frequency (VLF) band had higher energy utilization efficiency than the way of antenna inductive[21].

Bataller's experiment which verified that the depth of communication with ground electrodes was related to formation conductivity, signal frequency, the current strength injected into the ground, the impedances of electrodes and soil and the material and shape of electrodes[22], and receiver sensitivity was associated with the receiver electrode gap and the impedances of electrodes and soil. The farther the gap was, the bigger the detected voltage value was; the smaller the impedances of electrodes and soil were, the bigger the detected voltage value was.

Chinese researcher XIANG et al[23] studied the communication way, and used current field to implement penetrating layer communication. Under the electromagnetic wave propagation model of constant flow field, he analyzed that the intensity of current field was inversely proportional to the cube of transmission distance.

Through-the-earth communication with electrodes uses field current of the earth as conductor to communicate, and has high energy coupling efficiency. But in the band of extremely low frequency (less than 30 Hz), the way relies heavily on the conductive property of the earth medium, so it is greatly influenced by formation conditions. In the band of high frequency, the influence is less.

3 Communication with elastic wave

The first mention of using the elastic wave to take through-the-earth communication was from the bulletin of American Bureau of Mines[24]. In 2005, M. Ge detailed a method of processing received signal to locate the vibrations produced by the trapped miners hitting weight. Its principle was to use the elastic wave of mechanical vibrations to transmit information[25]. Since 2007, our group has researched on through-the-earth communication with elastic wave, and has achieved some results about channel characteristics[26-28]. The main causes of elastic wave propagation attenuation are wavefront divergence, stratification, inhomogeneous and non-perfect elastic of earth medium and so on. Among these factors, wavefront diffusion, scattering and dielectric absorption are the main factors causing signal attenuation, and non-perfect elastic of the layer causes medium absorption the most.

According to Futterman model[29], assuming that elastic wave propagation velocity is a constant within each layer, using common sandstone of mine as an example, we calculate absorbing attenuation of elastic wave, assuming that quality factor Q of sandstone is 40, and longitudinal wave speed is 2 000 m/s. The result is that when the frequency is 630 Hz, the absorb attenuation is about 0.212 dB/m, which is more than its propagation attenuation.

Actually, elastic wave propagation attenuation not just includes medium absorb attenuation, and it also includes wavefront diffusion, reflection attenuation of interface and scattering attenuation. By overall consideration, the attenuation of elastic wave in shallow strata is about 2-3 dB/m[30,31].

Through-the-earth communication with elastic wave uses the layer as transmission medium, and relies on mechanical property of the layer. If there is a goaf in the middle of overload, it influences the way of communication with elastic wave greatly. In addition, in the events of caving and rock burst, the way of using mechanical vibrations to send information can not be used rashly, so its usage occasions are limited.

4 Conclusion

The ways of antenna inductive coupling and ground electrodes both belong to electromagnetic method. Compared with electromagnetic method, elastic wave method has a disadvantage in the aspects of transmission attenuation and is influenced by the layer structure obviously. In addition, as a post-disaster emergency communication, communication of elastic wave does not apply in the cases of caving and rock burst.

References

[1] Yenchek M R, Homce G T, Damiano N W, et al. NIOSH-sponsored research in through-the-earth communications for mines: a status report. Industry Applications Society Annual Meeting (IAS), 2011 IEEE, 2012, 48(5): 1700-1707.

[2] Wadley T L. "Underground communication by rocks in gold mines on the witwaterrand," South Africa wet. Nywerheid-Navorsingsraad, Johannesburg, South Africa, Telekommunikasies Navorsing Laboratorium TRL, 1946.

[3] Pritchett W C. Attenuation for radio frequency waves through the earth. Geophysics, 1952, 17(2): 193-207.

[4] Wait J, Spies K. Sub surface electromagnetic fields of a circular loop of current located above ground. IEEE Trans Antennas propagate, 1972, 1(10): 520-522.

[5] Geyer R G. Constraints of affecting through-the-earth electromagnetic signaling and location techniques. Radio Science, 1976, 11(4): 323-342.

[6] Wait J R. Electromagnetic surface impedance for a layered earth for general excitation. Radio Science, 1980, 15(1): 129-134.

[7] Hill D A, Wait J R. Theoretical noise and propagation models for through-the-earth communication. National

Telecommunications and Information Administration Institute for Telecommunication Sciences, Boulder, Colorado, U.S.A., 1982.
[8] Огороднейчук И Ф. Underground low frequency wireless communications. Wu Rongguang, translated. Beijing: Coal Mining Industry Publishing House, 1981.
[9] Durkin J. Apparent earth conductivity over coal mines as estimated from through-the-earth electromagnetic transmission tests. U.S. Department of the Interior, Bureau of Mines Report of Investigations, 1984.
[10] Durkin J. Earth conductivity estimates from through-the-earth electromagnetic transmission tests. IEEE Transactions on Geoscience and Remote Sensing. 1991, 29(2): 300-307.
[11] Chirdon D, Barkand T, Damiano N, et al. Emergency communication and tracking committee underground communication and tracking systems tests at consol energy inc., mcelroy mine. Mine Safety and Health Administration, Technical Support, 2006.
[12] Barkand D, Damiano W, Wesley A, et al. Through-the-earth, two-way, mine emergency, voice communication systems. Department of the Interior, Bureau of Mines Report of Investigations, 2006.
[13] SI-TU Meng-tian. A plan and key technology for solving the problem of underground communications. China Engineering Science. 2001, 3(7): 64-69.
[14] TAO Jin-yi. Study of antennas for VLF through earth radio communication system. Journal of Taiyuan University of Technology, 1999, 30(2): 139-144.
[15] TAO Jin-yi. Discussion on some questions about through earth radio communication system. Journal of Taiyuan University of Technology, 2000, 31(6): 47-50.
[16] ZHANG Qing-yi, ZHU Jian-ming. Study on propagation characteristics of the VLF through the earth communication channel. Chinese Journal of Radio Science. 1999,14 (1): 36-40.
[17] Hunri J, Ebi C. Alpine cave radio earth-current at Holloch. CREG Journal, 1996, (25): 4-5.
[18] Villarroel J L, Cuchi J, Mediano A, et al. TEDRA, the development of a software defined cave radio. CREG Journal, 2007, 67: 4-6.
[19] Bataller V, Munoz A, Molina P, et al. Earth electrode contact measurement in through-the-earth communications. DCIS'09, Zaragoza, 2009.
[20] Bataller V, Munoz A, Gaudo P M, et al. Electrode impedance measurement in through-the-earth communication applications. IET Microwaves, Antennas & Propagation, 2012, 6(7): 807-812.
[21] Gibson D. Channel characterization and system design for sub-surface communications. PhD Thesis. University of Leeds, 2003.
[22] Bataller V, Munoz A, Molina P, et al. Improving medium access in TTE VLF-LF communications. Journal of Communications, 2009, 4(4): 284-294
[23] XIANG Xin, LUO Yi, YI Ke-chu, et al. Channel analysis on underground mine communication by electrical field through stratum. Coal Geology & Exploration, 2005, 33(4): 77-79.
[24] Bureau of Mines Staff. Underground mine communications, control and monitoring. U. S. Department of Interior, Bureau of Mines, Information Circular I 28.27: 8955, 1985.
[25] Ge M. Efficient mine microseismic monitoring. International Journal of Coal Geology, 2005, 64(1/2): 44-56.
[26] HAO Jian-jun, WANG Feng-ying. Multipath characteristics of through-the-earth stratified medium channel of elastic wave signal communiaction. Journal of China Coal Society, 2011, 37(4): 695-699.
[27] HAO Jian-jun, ZHAO Yuan, GUO Yin-jing. Power loss characteristics of plane elastic wave signal propagating in stratified earth medium channel. Journal of China Coal Society, 2011, 36(1): 211-214.
[28] LI Hui, HAO Jian-jun. Experimental studies on characteristics of bpsk signal transmitting in through-the-earth communication channel. Minging Engineering Research, 2012, 27(3): 73-76.
[29] Futterman W I. Dispersive body waves. Geophys Res, 1962, 7(13): 5279-5291.
[30] Dikmen U. Modeling of seismic wave attenuation in soil structures using fractional derivative scheme. Journal of Balkan Geophysical Society, 2005, 8(4): 175-188.
[31] Kennett B, Abdullah A. Seismic wave attenuation beneath the Australasian region. Australian Journal of Earth Sciences, 2011, (58): 285-295.

透地通信技术的回顾与进展

郝建军，巩玉琴

（山东科技大学 电子通信与物理学院，山东 青岛 266590）

摘　要： 本文主要介绍了透地通信技术的发展，透地通信机理及其性能；并对透地信号的传播衰减、信道的带宽和系统的功率利用效率进行了分析。可知：在目前研究的技术中，天线感应方式应用最广，但由于地电极方式能量效率高，因而是比较有前景的。弹性波透地通信方式由于使用振动源会产生弹性波信号，因而不适合在发生岩爆和冒顶时使用。

关键词： 透地通信；超低频；传输衰减

引用格式： HAO Jian-jun, GONG Yu-qin. Review of through-the-earth communication technologies. Journal of Measurement Science and Instrumentation, 2014, 5(2): 64-67. [doi: 10.3969/j.issn.1674-8042.2014.02.013]