Optimization of through-the-Earth radio communications via mine overburden conductivity estimation

by M. Ralchenko, M. Svilans, C. Samson, C. Walsh and M. Roper

Abstract ■ Through-the-Earth (TTE) radio has been proposed as a means of emergency communications in mines. The propagation of a TTE radio signal depends chiefly on the subsurface conductivity distribution. Robust forward models of signal propagation can be computed based on a realistic conductivity estimate. These models can be used, for example, to optimize frequency, estimate signal range, identify zones of anomalously strong or weak signals, or to optimize the position of the above-ground TTE radio unit. A method was developed to determine the conductivity distribution of a mine overburden using TTE radio transmission data. At multiple locations in an underground test mine, we recorded a wideband electromagnetic signal, spanning a frequency range of approximately 500 to 8,500 Hz, transmitted from a vertical magnetic dipole at the surface. Using a finite-difference time-domain forward modeling code, a layered Earth conductivity model that accounts for topography was fitted to the observed data, which minimizes the difference between the calculated and observed attenuations for each transmitter-receiver pair, for each frequency of interest.

Mining Engineering, 2018, Vol. 70, No. 7, pp. 113-120.
Official publication of the Society for Mining, Metallurgy & Exploration Inc.
https://doi.org/10.19150/me.8366

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Introduction and objective

Through-the-Earth (TTE) radio has been proposed for emergency underground communications. The most common type of TTE radio is based on the transmission and reception of signals by electromagnetic induction. These signals are in the extremely low to very low frequency range — in practice, between 400 and 9,000 Hz. This technology was historically developed for mine safety, although recently other applications have been suggested, such as communications in civilian infrastructure like high-rise buildings or tunnels, in the military, and even for wireless detonation and activation. In a coal mine, which is a setting of particular importance for TTE radio due to the higher risk of accidents, day-to-day communications can be done through a wired link. High-frequency line-of-sight systems, whose signals cannot penetrate rock, are also used for communications from nonfixed points. Another option is a leaky feeder system, which is a permutation of a line-of-sight system and a wired link, where a partially shielded coaxial cable allows the signal to "leak" (Delogne, 1982). In an incident such as a mine collapse or explosion, a TTE radio system can still provide a communication link, as wired systems can be severed, and line-of-sight systems cannot penetrate through collapsed portions of the mine, or to the surface (Forooshani et al., 2013; Yarkan et al., 2009).

In Ralchenko et al. (2015), we simulated TTE radio signal propagation using the finite-difference time-domain (FDTD) method, for an arbitrary transmitter in an arbitrary geologic structure. This modeling approach assumed a conductivity distribution based on a literature review of similar rock types. If chosen conductivities are not representative of the actual overburden, the predicted signal strength will not be correct. For example, consider Fig. 1, which shows the vertical magnetic field at a depth of 20 m (66 ft) with increasing radial distance from a vertical magnetic dipole transmitter. At 30 m (98 ft), for overburdens with low conductivities, a null with a very low