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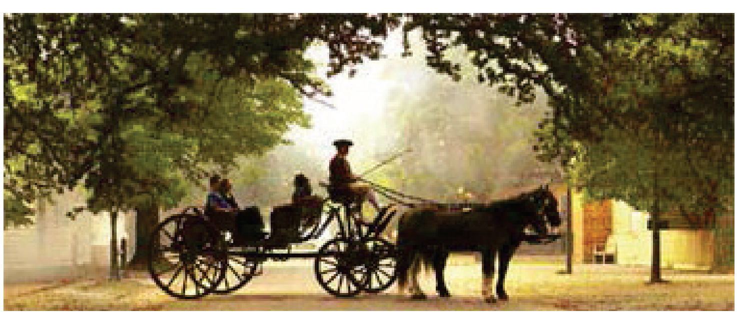

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Electric Field of Grounded Horizontal Line Transmitter for Through-the-Earth Communication

Lincan Yan and Carl Sunderman

The National Institute for Occupational Safety and Health (NIOSH)
626 Cochrans Mill Road, Pittsburgh, PA, USA
Lyan1@cdc.gov, CSunderman@cdc.gov

Abstract — An electrode-based through-the-earth (TTE) communication system sends its signal directly through the earth overburden of a mine by driving an AC current into the earth. The resultant current density is detected and communication is established. Given the noise level and the attenuation characteristics of the earth, the receiver sensitivity and transmitter power required for communication can be estimated. In an effort to estimate earth attenuation, the analytic solution for the field distribution of an electrode-based TTE communication system in a homogenous half-space is derived. The results for different transmitter (Tx)/receiver (Rx) configurations are presented.

Index Terms — Coal mine, Extremely Low Frequency (ELF), Through-the-Earth (TTE), TTE system with electrodes, Very Low Frequency (VLF).

I. INTRODUCTION

Through-the-earth (TTE) systems come in two forms [1]. The magnetic field form establishes communication by creation of a magnetic moment and detection with the induction voltage. Electrode-based forms, on the other hand, establish communication by inducing a current density within the earth medium by use of a pair of current probes. The resultant current density is detected as a voltage by a similar set of distant probes. These probes could be an insulated piece of wire tied to two electrodes grounded at distant ends, or the grounded ends could be rails, roof bolts, or grounded electric rods. The analytical field solution in a homogenous half-space for this form is developed here for various Tx/Rx configurations.

II. THE PROBLEM

The performance of electrode-based TTE system depends on factors including earth conductivity, overburden depth, the length of Tx and Rx, the relative Tx/Rx orientation. To evaluate signal reception under various conditions, the analytical solutions need to be obtained first. The surface to underground, or "downlink," communication is shown in Fig. 1. The horizontal line transmitter antenna is formed by an insulated piece of wire tied to two electrodes grounded at each end (A and B). In most cases the length, L, of this dipole transmitting antenna AB is small compared to the overburden depth, d. To investigate the behavior of the electric field around a line source antenna, we first evaluate the static voltage response at the receiver mid-point $P(\rho, \phi, z)$, as depicted in Fig. 1. The antenna wire (Tx) is situated at the surface and is aligned with the x axis. The antenna carries a current, I, where the earth medium has a conductivity of σ. The Tx and Rx are separated by distance R. The angle θ is formed by the Rx, which has a length of l, and x axis, as shown in the right side of Fig. 1.

The E-field at point P is specified as:

$$\begin{cases} E_x(x,y,d) = \dfrac{-2I}{\pi\sigma}\left(\dfrac{L-2x}{P} + \dfrac{L+2x}{Q}\right), \\ E_y(x,y,d) = \dfrac{4Iy}{\pi\sigma}\left(\dfrac{1}{P} - \dfrac{1}{Q}\right), \end{cases} \quad (1)$$

where $P = (4d^2 + (L-2x)^2 + 4y^2)^{3/2}$ and $Q = (4d^2 + (L+2x)^2 + 4y^2)^{3/2}$. The results here were validated by comparing with those using different methods [2]. The resultant voltage at Rx then is obtained as:

$$V_{Rx}(x, y, \theta, d) = \int_l \left(E_x \cos\theta + E_y \sin\theta\right) dl'. \quad (2)$$

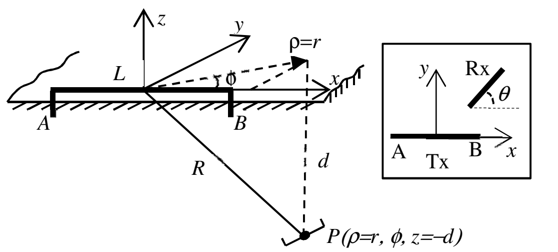

Fig. 1. Configuration of downlink finite line source antenna.

III. NUMERICAL RESULTS

Though the Rx can be sited with any angle relative to Tx, there are two configurations which are often relevant to mine communications – parallel and perpendicular. For the parallel configuration, the receiving wire is parallel to the transmitting wire and θ=0°. For perpendicular configuration, the receiving wire is perpendicular to the transmitting wire and θ=90°. The voltage induced at receiver for parallel and perpendicular configurations are plotted against the Tx/Rx separation distance for various Tx/Rx offsets in the upper (parallel) and lower (perpendicular) plots in Fig. 2.

Some conclusions can be drawn from the plots in Fig. 2. The parallel Tx/Rx configuration generally has better reception than the perpendicular one, except for separations near the null in the parallel configuration. It should be noted that the explicit forms were obtained under the assumption of the electric field being static or in an extremely low frequency (ELF) region. The non-static solution in the very low frequency (VLF) regime for a buried grounded insulated current element can be found in [3]. It is useful, however, to proceed with the static derivations to illustrate how one can gain ready insight into design parameters, such as optimum operating frequency, for electrode-based TTE systems that operate in the ELF region.

IV. CONCLUSION

The analytic solution for the field distribution of an electrode-based TTE communication system is derived. This solution is then specified for the parallel and perpendicular configurations of transmitters and receivers. The solutions provide a basic form of the propagation mechanism for electrode-based TTE communication operating at ELF (as compared to loop antennas), and can be useful for predicting and enhancing system performance for various mining environments and Tx-Rx configurations by evaluating the signal strength at receivers.

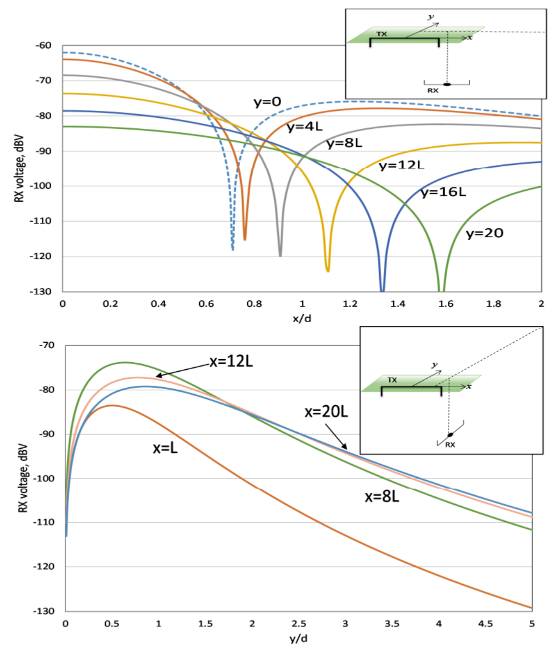

Fig. 2. Voltage at receiver for parallel (upper) and perpendicular (lower) Tx/Rx configuration, d=200m, L=20m, σ=0.01 S/m.

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH.

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