LOCATION SYSTEM WITH ELF-SIGNALS FOR UNDERGROUND APPLICATIONS WITH CODED RESPONSIVE TRANSMITTERS

Norbert NESSLER, and Norman BÖHLER INNSBRUCK UNIVERSITY INSTITUTE FOR APPLIED PHYSICS Technikerstraße 25. A-6020 Innsbruck / AUSTRIA

1 Introduction

In a mine disaster it is essential for the trapped miner's chance to survive, that they are found in a short a time as possible. Any location system perfectly working on the surface (e.g. GPS) fails inside the earth because of the surrounding conductive medium. The only way to communicate over a certain distance through rock is to use electromagnetic signals in the extreme low frequency (ELF) range. For location finding purposes the conditions are even more strict: The field distribution must be calculable and therefore not be disturbed by the surrounding (inhomogeneous) medium.

For ELF-signals wave lengths are in the range of 100km, the communication distance is below 100m, therefore any signal transmission is in the extreme near field. Furthermore only magnetic dipole sources can be realized thus the communication is a signal transmission between loosely coupled loops.

2 Theory

For the determination of the frequency range Maxwell's equations have to be solved for conductive medium. Since only magnetic dipoles are concerned, magnetic field strength only is calculated. In a spherical coordinate system these equations read:

$$H_r = m/2\pi \cdot \cos\Theta / r^3 (1 + ikr) \cdot e^{-ikr}$$
 (1)

$$H_{\Theta} = m/4\pi$$
. Sin $\Theta / r^3 (1 + ikr + k^2r^2) \cdot e^{-ikr}$ (2)

$$H_{\Phi} = 0 \tag{3}$$

with

 $m = n \cdot I \cdot A$ magnetic monent of the diploe

k complex wave number

r distance between transmitter and receiver

With the material parameters found in mines ($\varepsilon = 10$, $\mu = 1$, $\sigma = 10^{-3}$ S/m) and a distance r < 100m, |k,r| << 1 is valid for frequencies below 3 kHz, significantly simplifying equs. 1 and 2. The resultant field depends only on geometric variables.

$$H_r = m/2\pi \cdot \cos \Theta / r^3 \tag{4}$$

$$H_{\Theta} = m/4\pi \cdot \sin \Theta / r^3 \tag{5}$$

The consequence of equ. 3 is, that all field lines lay in a meridional plane. Fig 1 shows the resultant field lines of a magnetic dipole (loop antenna) in a meridional plane. The amount of (measured) field strength and direction to the radius vector source-receiver reads:

$$|H| = m/4\pi \cdot 1/r^3 \cdot (1+3 \cdot \cos \Theta)^{\frac{1}{4}}$$
 (6)

$$\tan \psi = H_{\psi} / H_{r} = 0.5 \cdot \tan \Theta \tag{7}$$

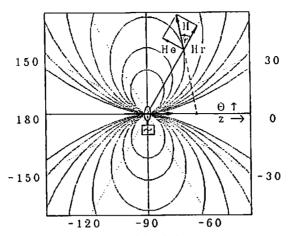


Fig. 1: Field lines of a magnetic dipole in a meridional plane.

The essential features of such a field structure for a location finding technique are:

- 1. All field lines are in meridional planes of the transmitter dipole (equ. 3), therefore any field direction vector intersects with the dipole axis. (Condition of intersection)
- 2. Field direction ψ is independent of distance (equ. 7). (Condition of constant angle)
- 3. For a constant distance r the field strength |H| for $\Theta = 0$ (transmitter and receiver coaxal) is twice as high as for $\Theta = 90^{\circ}$, for constant angle Θ the field strength decays with $1/r^3$ (equ. 6).
- 4. In order to get a constant amount of field strength |H| while walking around a dipole (a full turn of angle $\Theta = 0..360^{\circ}$) the distance must be varied by $\sqrt[3]{2} = 1,26$ and the receiver coil rotates around twice ($\psi = 0..720^{\circ}$).

3 Principle of location technique

The location technique is oriented on the needs in mines. Every miner should carry a simple, lightweight, battery-operated transmitter. A single multiturn coil forms the source dipole. The feeding oscillator is operating only "on request" for better battery economy (details see 4.1). Any miner of a group has his own coding sequence to avoid interferences between adjacent transmitters. Such a source dipole of unknow location emits a field shown in fig. 1.

For the rescue team a sophisticated receiver is used, able to measure field strength and field direction. Since neither the orientation of the transmitting dipole nor the exact dipole strength (magnetic moment of transmitter depending on battery condition) is known, the location technique must be independent of these parameters. We have analyzed and evaluated several techniques listed below.

3.1 Geometric approach

Theoretically it is possible to find the transmitter location by measuring the field direction in four appropriately selected points of reception using feature ! (Condition of intersection). Four arbitrary lines (the field directions) define one line (the axis of the transmitter) which intersects all four direction lines. The transmitter location on its axis is then calculated using feature 2 (Condition of constant angel).

The advantage of this method is, that no amplitude measurement is necessary, ist disadvantage is an unsolvable ambiguity (higher order equations) and the unavoidable lack in accuracy. Although the field direction can be measured with sufficient precision (sharp minimum perpendicular to the field direction) minor distortions along with gliding intersections

between direction line and transmitter axis can cause large errors in calculated transmitter location.

3.2 Field strength approach

Field strength |H| is strongly depending on the distance between transmitter and receiver (Feature 3, decay with 1/r³). If the magnetic moment of the transmitter is known, this can be used to determine distances from the point of reception. These distances define circles (spheres) of possible transmitter locations. The common intersection of at least three non collinear circles is the location of the transmitter. (This method is similar to that used to find trapprd skiers in avalanches).

The advantage of this methode is the simplicity of the mere amplitude measurement, it is perfectly suited for vertical orientation of the transmitter axis with measurements in a horizontal plane. In this case all field directions in points of reception are also vertical.

The disadvantage is that the magnetic moment of the transmitter is not exactly known (battery dependent) and therefore the distances contain an unknown factor $\sqrt[3]{m}$. m has to be varied for best fit (higher order equation). Furthermore this method neglects the angular dependence for arbitrary orientation of the transmitter axis. The maximum error for one distance can be 26% (Feature 4), but the total error in the point of intersection may add up significantly. The possible errors are smaller than with methode 3.1, but for mining purposes still not negligible.

3.3 Combined method

This method combines amplitude and field direction measurement taking into account angular dependences. Fig. 2 shows the inverse of feature 4, the kurve k of possible transmitter locations (transmitter locus), that causes a field of strength |H| in the direction α . The transmitter locus is defined by

$$r = \sqrt[3]{\frac{m}{2\pi |H| \sqrt{1 + 3\sin^2\psi}}}$$
 (8)

In any possible transmitter location its dipole direction is definded according to equ. 7.

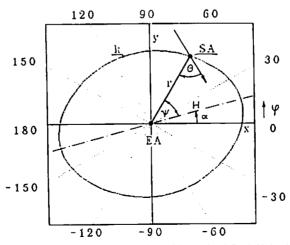


Fig. 2: Transmitter locus for fixed receiver location with received field |H| in the direction α.

Using these loci instead of circles of method 3.2, combined with a (graphically supported) fit of transmitter dipole strength, m, the transmitter location can be found as shown in fig. 3a for a location measurement performed in a mine. To prove the transmitter location the directions of transmitter orientation for any locus must roughly coincide. A wrong selection as shown in fig. 3b would result in a randomly distributed transmitter orientation.

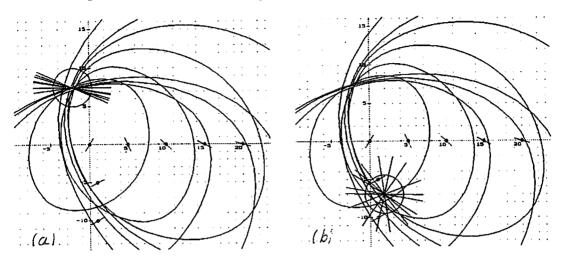


Fig. 3: Correct location of the transmitter with approximately coinciding directions (a) and wrong selection of transmitter location (b) indicated by randomly distributed directions.

4 Electronic circuit of transmitter and receiver

4.1 Miner's transmitter

The transmitter to be carried by the miner is liminted in weight and therefore in battery capacity. For battery economy a low power "wake up" receiver circuit is included to respond on a coded 8 bit signal. The "wake up" code is transmitted by the device at the rescue team and activates the miner's transmitter for a short time. The signal from the quartz controlled oscillator (feeding a resonant L-C-circuit in an H-switching arrangement) is then received by the rescue team who measures field direction and field strength. After that period the miner's transmitter resets in the stand by mode, waiting for the next "wak up" call.

4.2 Receiver

The receiver uses three mutually orthogonal multiturn loops (antenna cube) with amplifiers and bandpass filters each. A switching circuit allows measurement of the signal of each single antenna (H_x , H_y , H_z) and the analog sum of two, resp. (H_{xy} , H_{yz} , H_{zx}). These six voltages allow the calulation of absolute field strength amplitude $|H| = \sqrt{(H_x^2 + H_y^2 + H_z^2)}$ and field direction, the eightfold ambiguity (+ or - sign of the signals) is solved by the analog sums of H_{ij} .

5 Conclusion

At Innsbruck University a system is developed, which allows to locate trapped miners, "lost" boreholes or determine the relative position of two underground locations. A light-weight, battery operated transmitter (only active on request) emits an ELF-field, of which amplitude and direction is measured in at least three points. A (notebook-) computer program allows direct evaluation in situ. This method is patented.