LOCATION TECHNIQUE FOR UNDERGROUND ENGINEERING USING PROPAGATION EFFECTS OF ELF SIGNALS

Ass.-Prof. Dr. Norbert NESSLER,
Institute for Experimental Physics/Applied Physics
University of Innsbruck, Technikerstrasse 25,
A-6020 Innsbruck, Austria

Introduction and theoretical basis

Influenced by several mine disasters with dozens of miners killed and buried under rock masses in the past decade methods have been developed to locate buried miners with sufficient accuracy in shortest possible time. Through the earth propagation and communication by means of electromagnetic signals is only possible in the VLF and ELF range because of the attenuation effect of the inhomogeneous rock which increases with increasing signal frequency. Since the wavelength in this frequency range is several km, only magnetic antennas are applicable for transmitters and receivers. Unfortunately the radiation pattern of a magnetic dipole antenna (ferrite rod or loop antenna) in the near field range is not a sphere but has a more complex shape. Furthermore the conductivity of rock affects the field distribution the more, the higher the conductivity, the signal frequency and the distance from the antenna dipole. The field components of a magnetic dipole in a spherical coordinate system can be calculated as follows.

$$Hr = m/2\pi . \cos\Theta/r^3 . (1+ikr) . e^{-ikr} \quad (1)$$
$$H\Theta = m/4\pi . \sin\Theta/r^3 . (1+ikr+k^2 . r^2) . e^{-ikr} \quad (2)$$
$$H\phi = 0 \quad (3)$$

with m = n.I.A .. magnetic moment of source dipole and

$$k^2 = - i . \omega\mu\sigma + \omega^2\varepsilon\mu \quad (4)$$

Since k contains all the medium parameters it is possible to chose the signal frequency low enough to fulfill the condition $|kr| \ll 1$ even taking into accout the medium's inhomogeneity. In this case the amount of field strength reads

$$H = m/4\pi . 1/r^3 . \sqrt{1 + 3.\cos^2\Theta} \quad (5)$$

The field strength in the axis of the dipole ($\Theta = 0$) is twice as high as the field at $\Theta = 90°$, resulting in a source antenna pattern as shown in fig. 1.

In the above defined distance range the field direction in a point of reception is independent of the distance, r, and is described by

$$\tan\psi = H\Theta/Hr = 1/2 . \tan\Theta \quad (6)$$

Field strength and field direction therefor are calculable within a limited distance range and forms the basis of a location method for underground applications.

Location method

The application for the location method makes is necessary to recalculate the antenna pattern for a fixed receiving antenna while the source dipole is moved around in such a way, that field strength and field direction at the receiving location remain constant. The resulting locus for the source position is described by

$$r = \text{const.} \sqrt[3]{2/(H \,.\, \sqrt{1 + 3.\sin^2 \alpha})} \qquad (7)$$

and shown in fig. 2 with H indicating the direction of the receiving antenna. SA represents one position and the corresponding direction of the source antenna dipole.

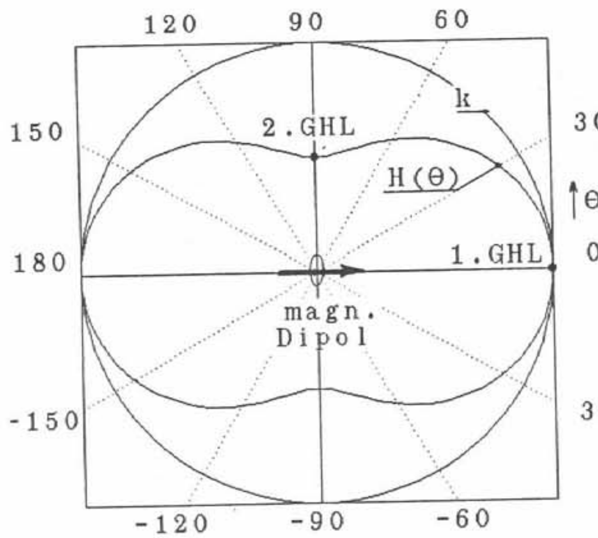

Fig.1 Source antenna pattern

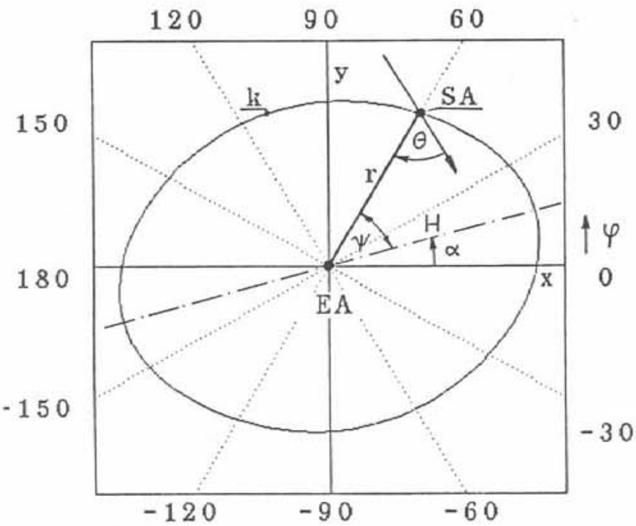

Fig.2 Locus for fixed receiver

The locus can be used in two different ways to solve location problems: 1) determination of unknown source antenna position and 2) determination of unknown receiver location.

Unknown source position

The source antenna consists of a single magnetic dipole antenna and is assumed to be located at an unknown position with unknown orientation. To find the source position it is necessary to measure the field amplitude and field direction emitted by the source in at least two properly spaced points of reception. For any point of reception therefor a locus according to equ. 7 can be calculated assuming that the dipole strength of the source is known. Two such locii intersect in two points which indicate two possible source locations (fig. 3). A third locus, drawn from the measured values in a third point of reception, eliminates the ambiguity.

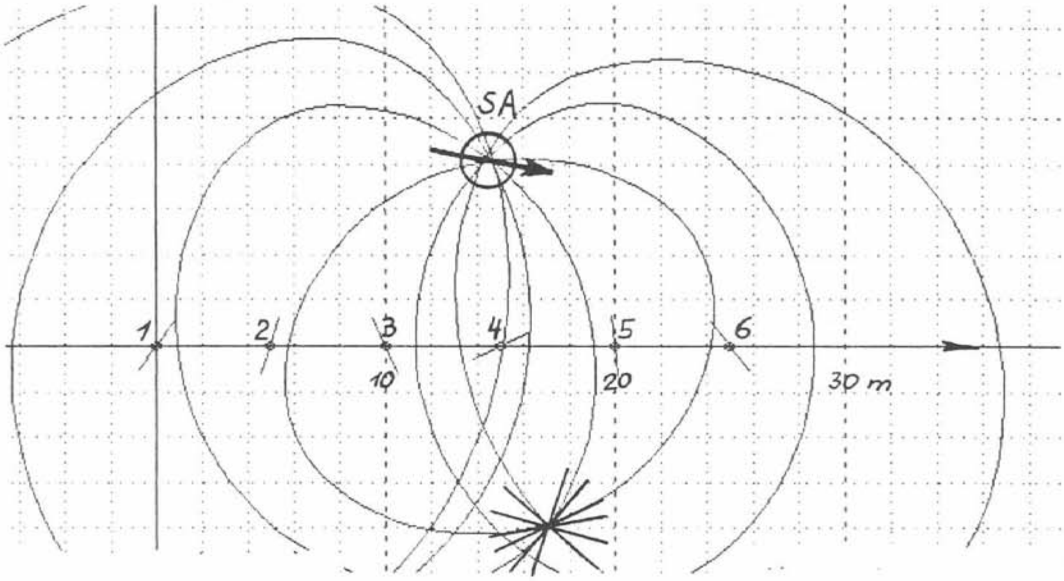

Fig.3 Two locii plus source direction determine the unknown source location.

In case the source dipole strength is not known sufficiently accurate a common zoom factor for the locus remains unknown. This unkown factor can be determined either by an increased number of measurements and variation of the zoom factor for coinciding intersections or using the direction information according to equ 6 as a second parameter. Since the source antenna is assumed to stay in its position during measurement, the source direction calculated for the "estimated" location must be the same for any locus.

Unknown receiver position

The inverse problem of that one described above is the determination of the receiver position relative to the known source location and source orientation. In this case both, the source and the receiver remain at their respective position. The movement of the reveiver in this case is replaced by three source antenna orientations. Field strength and field direction at the receiver location for any of the source orientation determine one locus each. The locii are concentrically, but differ in orientation and size as shown in fig. 4.

The source dipole strength must be known in this case. The common intersection of three such locii indicate two possible source locations. Because of the symmetry of the problem the ambiguity cannot be solved by invreasing the number of source orientations.

In most appliocations physical constraints enable to distinguish, which position is the correct one. If this is not applicable, the strong distance dependence of field strength ($1/r^3$) is used as an indicator: moving the reciever towards the estimated source position must be accomplished with an increase of field strength amount.

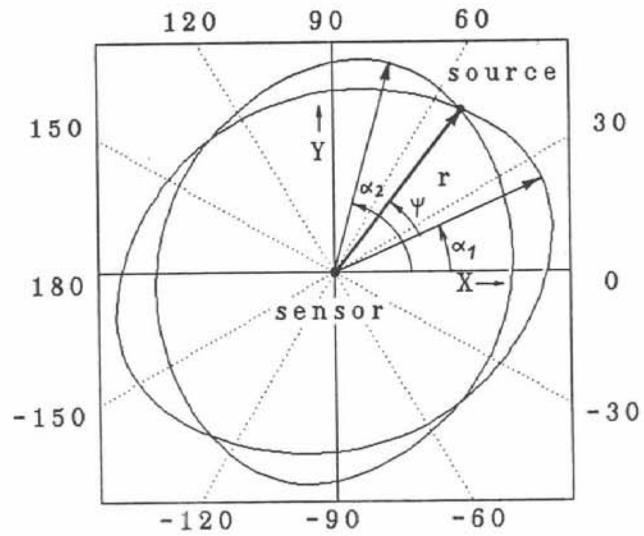

Fig.4 Two concentrical locii determine four possible source locations.

Summary and conclusion

The "locus technique" uses the near field pattern of a receiving antenna system in a dipole field to get a first information of the source position. By proper movement of either the receiving system or the source antenna, a sufficient number of information can be achieved to determine the source or receiver location, respectively. A typical application of the first method, unknown source position, is the search for a trapped or buried miner after a mine disaster or simply the search for a borehole which did not meet the target gallery. The second method, unknown receiver position, has its typical application on an unmanned mining machine, which measures its own position relative to a source antenna system.

References

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