# "FIELD LINE" SEARCH REVISITED

Felix Meier

Felix Meier GmbH, Eglisau, Switzerland

ABSTRACT: The avalanche transceiver field line search is actually not a search along the field lines, but along the path given by the projection of the field lines onto the plane of the searching transceiver.
The shape of the magnetic field that is emanating from a buried transceiver is investigated. The projection of the field lines onto the plane of the searching transceiver is calculated in a three-layered space: air, snow and soil. It depends on the orientation of the buried transmitter's antenna and on the dielectric properties of the individual layers. Some rules for optimized searching can be derived from the results of these calculations.

KEYWORDS: Avalanche Transceiver, Magnetic Dipole, Field Lines, Field Line Search.

## 1. THE MODEL

For all our investigations, we start from the following model:

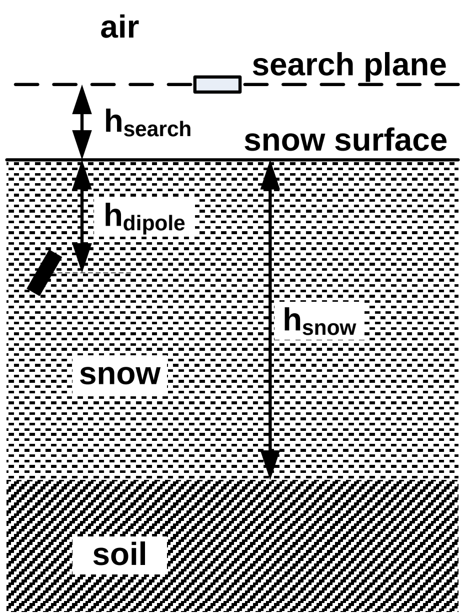


Fig. 1 the layer model

The buried transceiver is located at $h_{dipole}$ below the snow surface. Its orientation is arbitrary, and the parameter of interest is its inclination relative to the horizontal plane.

Felix Meier, Consultant, Felix Meier GmbH, Roggenfar 31, CH - 8193 Eglisau, Switzerland; phone: +41 44 867-3723; www.felmeier.com; Email: felix.meier.45@bluewin.ch

It can be anything between 0 degrees (horizontal) and 90 degrees (vertical). The average burial depth of avalanche victims is about 1 meter.

The searching transceiver is usually held parallel to the snow surface, and its typical elevation $h_{search}$ above the surface is 1 meter. The plane parallel to the snow surface at that elevation is what we term the search plane.

## 2. THE SHAPE OF THE MAGNETIC FIELD

The transmitting antenna of a transceiver is equivalent to a magnetic dipole. The magnetic field of a dipole exhibits rotational symmetry about the axis of the dipole, i.e. of the antenna. In a homogenous medium, it looks like this for a vertical axis:

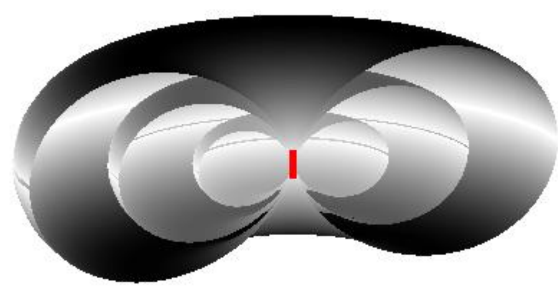

Fig. 2 vertical dipole

With a different orientation of the antenna, the shape of the field remains the same, but it is rotated (by 90º for a horizontal dipole):

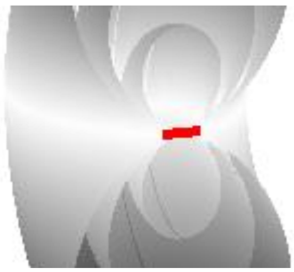

Fig. 3 horizontal dipole

## 3. THE PROJECTION OF FIELD LINES

The magnetic field at any point in space is represented by a three-dimensional vector. The length of the vector is equal to the strength of the magnetic field at the origin of the vector.

The projection of a vector onto a plane is the shade of the vector that is produced by a source of illumination that is very high above the plane:

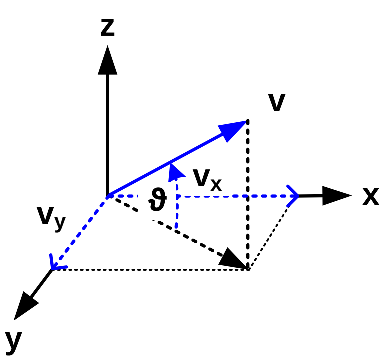


Fig. 4 projection

Within the plane, the projection can be decomposed into two orthogonal components that are parallel to the x and to the y axes of a rectangular coordinate system. The higher the angle of incidence $\vartheta$, the smaller are the components in the x-y plane relative to the length of the vector.

On a searching transceiver, the components $v_x$ and $v_y$ are measured by the respective antennas. From their values, the direction as well as the distance is calculated and then forwarded to the display. The direction is given by the arctangent ($v_y/v_x$), and the distance is about proportional to the inverse of the third root of the length of the vector. As can be seen, the length of $v_x$ and $v_y$, which are proportional to the strength of the H field at a certain point, becomes very small at high angles of incidence. This may have a negative influence on the performance of the searching device. This effect can be mitigated by introducing a third antenna that is parallel to the z axis.

## 4. HORIZONTAL ORIENTATION

This is a cross-section at the axis of a horizontally oriented dipole in a homogenous medium (assuming that all layers have identical properties):

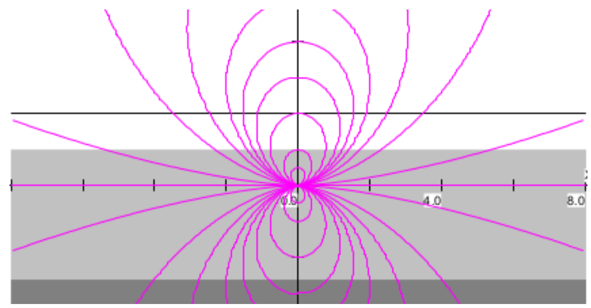


Fig. 5 horizontal dipole

The larger the distance from the buried transceiver, the lower the angle of incidence $\vartheta$ will be. The H field components in the search plane will be maximized. This configuration provides the best search range.

At a distance corresponding to about 1.5 times the burial depth, $\vartheta$ is 90º. The $v_x$ and $v_y$ components are approaching zero, and so there is no valid direction indication. Without a z – Antenna, which is orthogonal to the x and y antennas, there will be no signal to the searching transceiver.

Looking at the directions of the projections onto the search plane, there are two points where the directions converge. These points correspond to the places where $\vartheta$ is 90º.

When following the direction indication, the search path will be curved and about 1.4 times as long as the straight path to the target. The straight path is 29% shorter than the curved path, so using it would result in some savings in search time. But this is a worst case situation; all axis inclinations above 0º give better results, and so do all starting points that are not on a line that is perpendicular to the dipole axis.

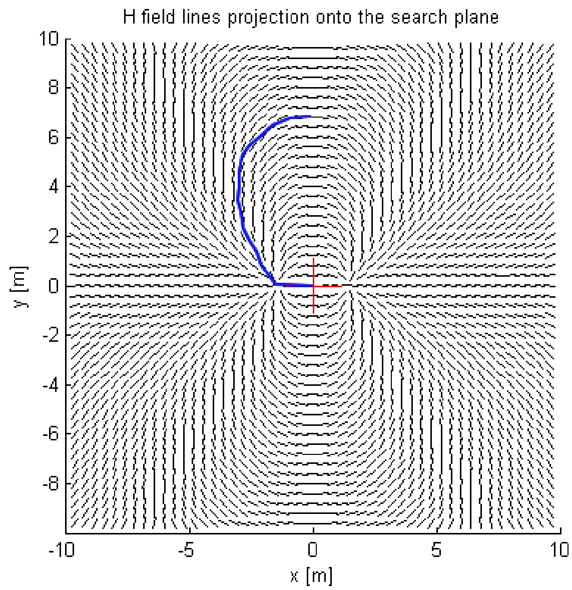


Fig. 6 horizontal dipole search path

Assuming equal distribution of inclinations and location of the starting point, the mean savings in search time by following a straight path would be less than 10%.

Note that, in order to be able to provide a straight path to the location of the buried transceiver, the searching transceiver would need to know about the antenna orientation of the buried transceiver. This in turn would require all transceiver manufacturers to agree on a standard for a second communication channel, since the 457 kHz frequency cannot be used for this purpose. Also, at large distances, where this would be most helpful, the direction indication may become inaccurate due to the dielectric properties of the snow and soil layers (Ayuso et al. 2007). And finally, the computational resources that would be required would probably be far more than what can be made available in a transceiver.

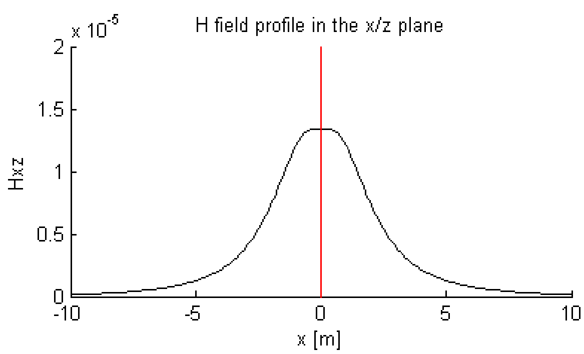


Fig. 7 horizontal dipole

The peak of the H field profile in the search plane is quite flat in this configuration, so it is difficult to establish the location with the maximum signal or minimum distance indication in a pinpoint search.

Without a third (z) antenna, the profile would look different:

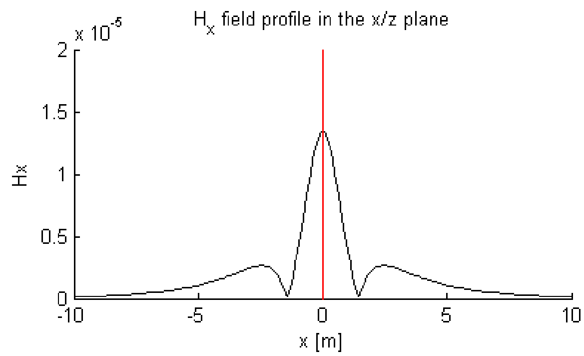


Fig. 8 horizontal dipole

There are two nulls on either side of the target location, resulting in a very large distance indication. The benefit of a third antenna in the z axis is that it avoids this puzzling phenomenon.

Another characteristic of this configuration is that distance indications are not isotropic:

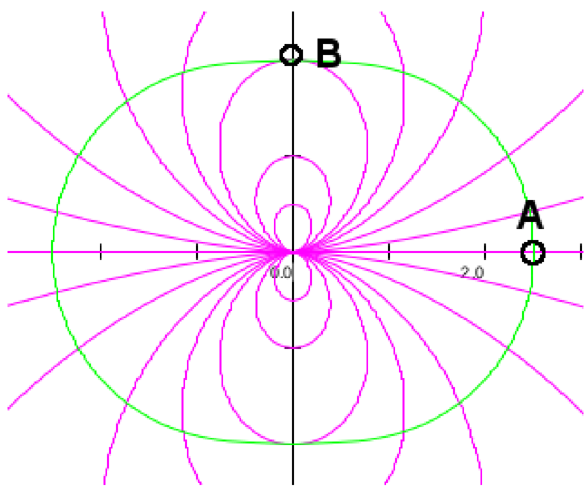


Fig. 9 equal distance indication

The distance indicated at point B will be the same as the distance indicated at point A, although the real distances to the target are different by 20%.

5. VERTICAL ORIENTATION

This is a cross-section at the axis of a vertically oriented dipole in a homogenous medium:

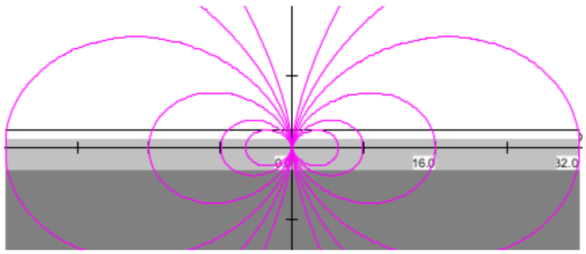

Fig. 10 vertical dipole

Note that, if the searching transceiver is far from the location of the dipole, then the angle of incidence $\vartheta$ is close to 90°. As a consequence, the H field components in the search plane will be quite small. This reduces the search range, and it also causes the direction indication to be less robust because of the poor signal to noise ratio.

However, this configuration also has its advantage: The directions of the projection of the H field lines onto the search plane point straight to the location of the buried transceiver, resulting in the shortest possible search path from all starting points:

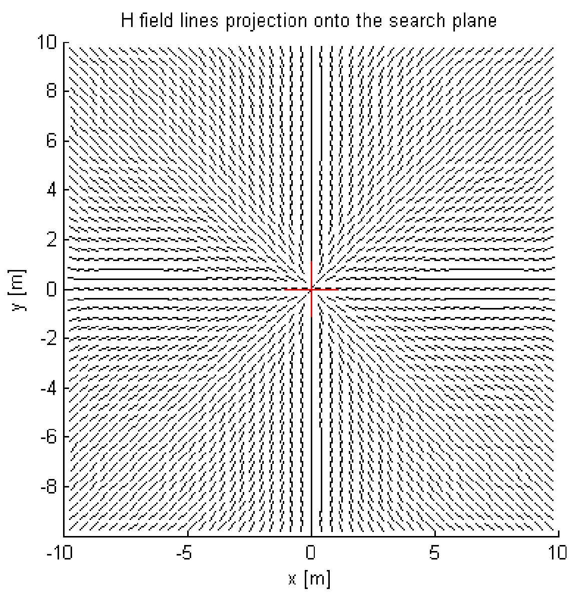


Fig. 11 vertical dipole search path

Again, we can compare the H field profiles. With a third antenna, it is:

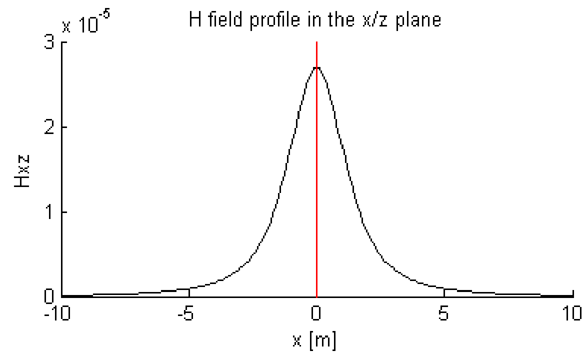


Fig. 12 vertical dipole

Without the third antenna, there are the well-known double maxima. So having a third (z) antenna does provide a significant benefit.

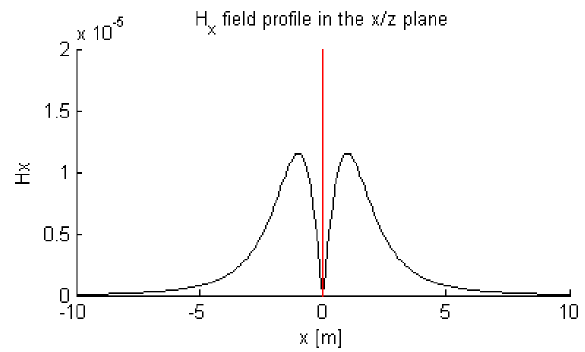


Fig. 13 vertical dipole

6. INTERMEDIATE ORIENTATIONS

Axis orientations between horizontal and vertical do result in hybrids of these variants. As an example, we show the H field profile for an axis inclination of 30°.

Note that the peak is not exactly above the location of the buried transceiver. This is yet another reason for not spending too much time on a pinpoint search with a transceiver, but for changing to probing.

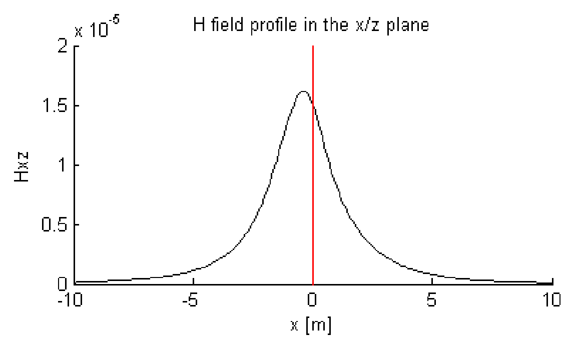


Fig. 14 30° inclined dipole

## 7. LAYER PROPERTIES

The air, snow and soil layers involved exhibit different dielectric properties.

Some indications about numerical values can be found in references (Kuriowa 1954), (Yiosida et al. 1958), (Takei 2001) and (Mellor 1977) for snow and (Fano 2001) and (ITU 1992) for soil. The parameters for snow are heavily dependent on porosity, water content, grain type, impurities and temperature, whereas, for soil, water content and temperature have a major influence.

At distances close to the buried transceiver, different dielectric properties of the snow and soil layers have been found not to have a noticeable influence on the direction of the projections of the field lines onto the search plane. So the direction indications on a searching transceiver will be accurate. At larger distances > 20 meters, however, there is some influence as has been shown by Ayuso et al. (2007). But for all practical purposes, it can be neglected.

If the differences in layer properties are to be taken into account, the closed form solution of McTavish (2000) to the H field lines does not apply any more. It must be replaced by a numerical integration of either the Sommerfeld integrals (Sommerfeld 1909), (Sommerfeld 1926) or Maxwell's equations for the electromagnetic field (Taflove 2005).

## 8. NEAR FIELD LIMIT

The H field of a magnetic dipole is made of components that are dependent on the inverse square root of distance and on the inverse third root of distance. At short distances, the components depending on the inverse third root dominate. At some distance that is dependent on the frequency in use, the components that are dependent on the square root will take over. The distance where both components are of equal importance is termed the near field limit.

For the 457 kHz frequency used by transceivers, the near field limit in air is located at 104.4 meters. Its value is also dependent on the dielectric properties of the media involved; in snow it may be as low as 50 meters.

When preparing the figures in this paper, all components of the H field have been taken into account.

## 9. SOFTWARE

The software `MDipole` for visualizing cross-sections of the magnetic field in a homogenous space can be downloaded for free from

http://felmeier.com/en/software/mdipole.shtml

It will be useful to anyone who is interested into the details of transceiver operation. The curves given by `MDipole` are all based on the solution of the differential equation for the H field given by McTavish (2000).

The software `PropChar` for calculating the propagation characteristics including the near field limit as a function of the dielectric and magnetic properties of a medium can be downloaded for free from

http://felmeier.com/en/software/propchar.shtml

For the calculation of the H field line projections onto the search plane and of the H field profiles in a space made of three layers with different dielectric properties, a Matlab® program using the FDTD (Finite Difference Time Domain) algorithm (Taflove 2005) has been implemented. Such a program takes a huge amount of resources in terms of memory and computing time, so its use is limited to research applications. But the conclusions that can be drawn from the results are still of interest.

## 10.CONCLUSIONS

The following practical advice can be derived from the earlier sections:

A third antenna is very helpful for pinpoint search.

When getting into the pinpoint search, do not rely too much on direction indications.

Do not spend much time on pinpoint search by means of your transceiver. Start probing early.

A horizontal transmitter does give better range. So, in that respect, an intelligent transmitter does make sense.

A vertical transmitter will result in the shortest search path, but also in reduced range.

The gain in search time that could possibly be achieved by a straight line indication to the location of the buried transceiver does not justify the complexity and the resources that would be required for implementation.

## CONFLICT OF INTEREST

This work was not supported financially or materially by any manufacturer of avalanche transceivers.

## ACKNOWLEDGEMENTS

The author would like to thank Mr. Willy Zurkirch for a review of the paper and for valuable suggestions.

Professor Lorenzo Luini of the Politecnico di Milano suggested the use of the FDTD algorithm for investigating the multiple layer configurations.

## REFERENCES

Ayuso, N., Cuchí, J.A., Lera, F., Villarroel, J.L, 2007: Avalanche Beacon Magnetic Field Calculations for Resuce Techniques Improvement. *Proc. of 27th Intenational Geoscience And Remote Sensing Symposium (IGARSS)*, Barcelona, Spain.

Fano, W. G. and V. Trainotti, 2001: Dielectric properties of soils. *IEEE Conference on Electrical Insulation and Dielectric Phenomena*, 75–78.

ITU, 1992: Electrical Characteristics of the Surface of the Earth. *ITU Recommendation ITU-R P.527-3*.

Kuroiwa, K., 1954: The Dielectric Property of Snow. *Proc. IGU*, Rome.

Mc Tavish, J.P., 2000: Field pattern of a magnetic dipole. *Am. J. Phys.* Vol. 68, No. 6, June 2000, pp. 577 – 578.

Mellor, M., 1977: Engineering Properties of Snow. *Journal of Glaciology*, Vol 19, No.81, pp 15-65.

Sommerfeld, A., 1909: Über die Ausbreitung der Wellen in der drahtlosen Telegraphie. *Annalen der Physik*, Vol. 333, Issue 4, pp 665 – 736.

Sommerfeld, A., 1926: Über die Ausbreitung der Wellen in der drahtlosen Telegraphie. *Annalen der Physik*, Vol. 386, Issue 25, pp 1135 – 1153.

Taflove, A., Hagness, S. C., 2005: *Computational Electrodynamics*. Artech House, Inc.

Takei, I., Norikazu, M., 2001: The Low Frequency Conductivity of Snow Near the Melting Temperature. *Annals of Glaciology*, 32 pp 14-18.

Yiosida, Zyungo; Oura, Hirobumi; Kuroiwa, Daisuke; Huzioka, Tosio; Kojima, Kenji; Kinosita, Seiiti, 1958: Physical Studies on Deposited Snow. V.*; Dielectric Properties. *Contributions from the Institute of Low Temperature Science*, 14: 1-33