

SearchPath

User Manual

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1 Introduction

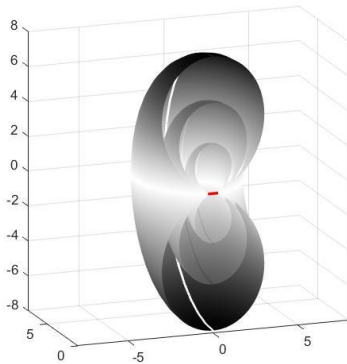
Searching for persons that have been buried in an avalanche by means of an avalanche transceiver can be quite difficult. A good understanding of the physical phenomena underlying the indications in terms of distance and direction on the display of the searching transceiver helps in defining an optimal search tactic.

The information given on the display of the searching transceiver depends on the intensity and on the direction of the magnetic field lines at the location of the searching transceiver. These parameters in turn are a function of the orientation of the buried transceiver, of the properties of the soil and of the snow layers, and of the location of the searching transceiver relative to the buried transceiver.

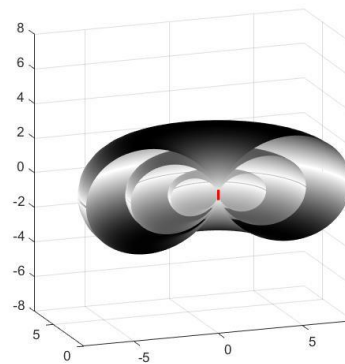
The `SearchPath` program is a means for the examination of the direction of the field lines and of the relative magnetic field strength at the location of a searching transceiver anywhere in the surroundings of a buried transceiver in transmit mode. In particular, the searching transceiver would be on a plane on or above the snow surface.

The magnetic field of a dipole in free space exhibits rotational symmetry about the dipole axis. A 3D-visualization of the field lines can be viewed as a collection of toroids with a cross section defined by the differential equation from [401]

$$\frac{dy}{dx} = \frac{3 \cdot x \cdot y}{2 \cdot x^2 - y^2}$$



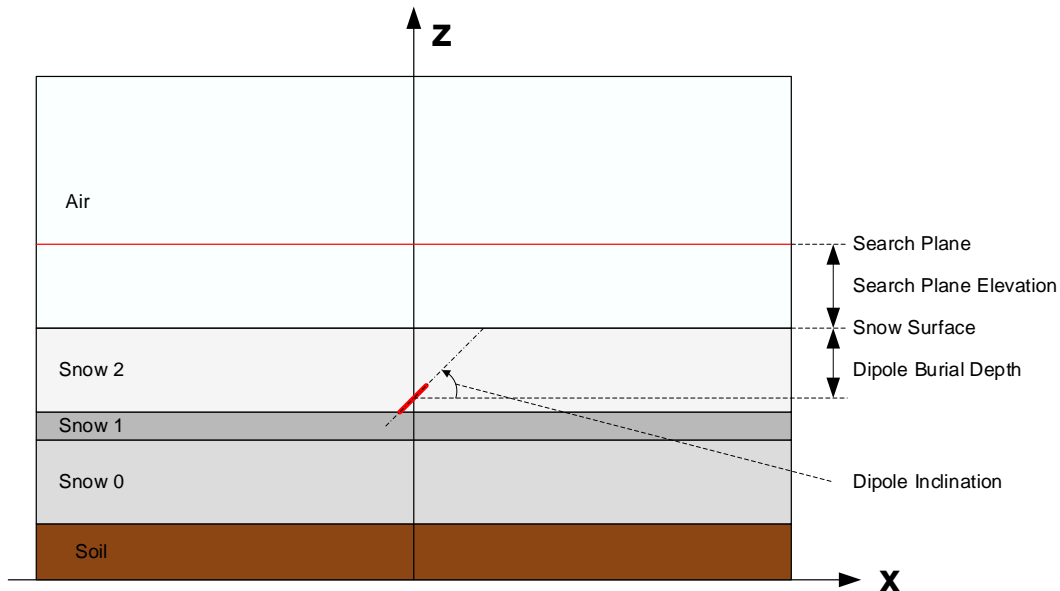
Horizontal Axis



Vertical Axis

1.1 Setup

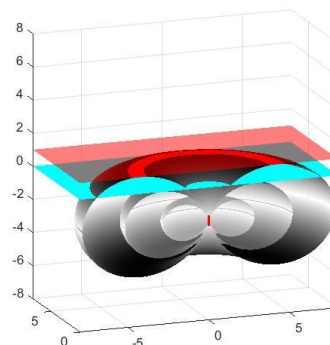
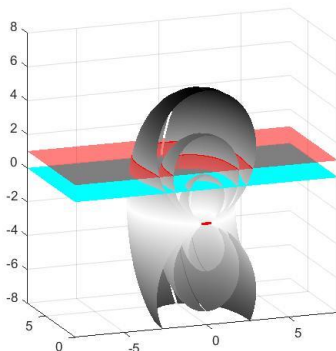
For the environment, we use a 5 layer model:



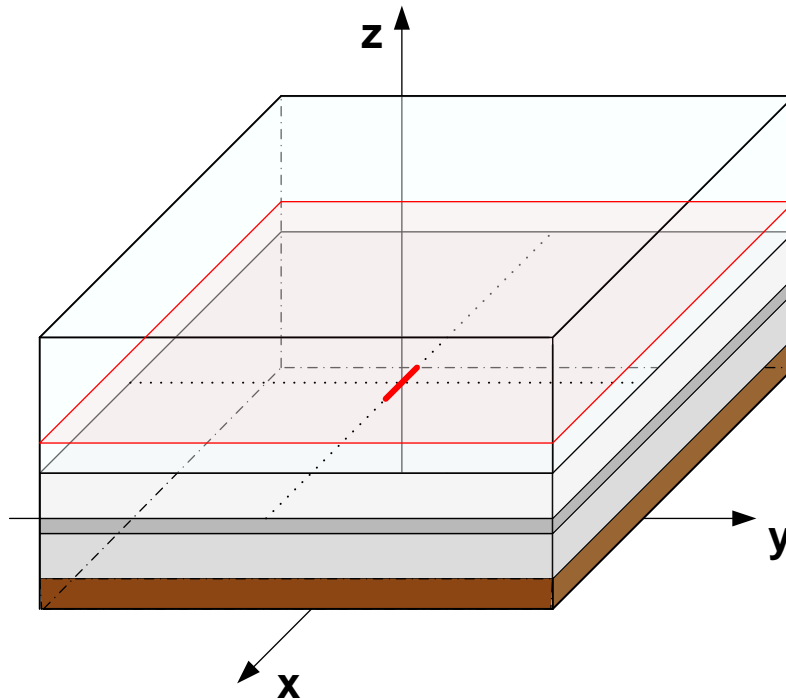
The bottom layer is made of soil. Above the soil, up to three layers of snow with different properties may be specified. On the top, there is an air layer. The individual layers are assumed to be homogenous and isotropic, i.e. the magnetic permeability, dielectric permittivity and electric conductivity will be constant and independent of the direction within the layer.

The dipole is the equivalent to the transmitting antenna of the buried transceiver. It may be positioned anywhere within one of the snow layers or on the snow surface. Its inclination relative to the x axis may vary from 0° to 90° . The dipole is always centered on the x and y axes of the area under consideration.

The search plane is where the searching transceiver would be operated. It may be located at any elevation between the snow surface and the top of the air layer.



The space of interest is a rectangular block:



The default block dimensions are 20 meters by 20 meters by 10 meters. The above example shows a transceiver buried at the bottom of the topmost snow layer. The inclination of the transceiver antenna relative to the x axis is 0° . The search plane (red) would typically be about 80 centimeters above the snow surface.

There are no closed form solutions for the electromagnetic field in an inhomogeneous space. To solve our problem, we therefore resort to the FDTD (Finite Difference Time Domain) algorithm for numerical integration of the Maxwell differential equations within the space of interest. This method was originally proposed by Yee [100] and is treated in detail by Taflove and Hagness in [101]. For more details, see the document "Search Path Documentation.pdf".

The space of interest is divided into cubes with an edge length of 10 cm. The six update equations for each cube need to be calculated between 300 and 1'000 times, depending on the electromagnetic properties of the individual layers. So do not expect an immediate result when calculating a specific configuration. The calculation will take one to several minutes on a fast PC to complete.

2 Configuration Setup

When you start the program, it comes up with a default parameter setting:

The screenshot displays the SearchPath software interface. The main window features a large grid plot titled "X - Y Plane" with axes ranging from -10.00 to +10.00. A red dot is positioned at the origin (0,0). To the right of the plot is a "Progress" panel showing "0 out of 0 Steps" and "0 %" computing time. Below the plot are several control panels:

- Project:** Yee Cell Size: 10 cm; Must be odd numbers: x Cells: 201, y Cells: 201, z Cells: 101.
- Layers:** A table with columns for Depth [cm], μ_r , ϵ_r , and σ [S/m].

	Depth [cm]	μ_r	ϵ_r	σ [S/m]
Air	530	1.000	1.000	0.000e+00
Snow 2	160	1.000	2.000	1.000e-10
Snow 1	10	1.000	4.000	1.000e-06
Snow 0	110	1.000	1.500	5.000e-08
Soil	200	1.000	8.000	1.000e-04
- Dipole:** Burial Depth: 100 cm; Inclination: 0 Deg.
- View Plane:** x - y; H Field Profile: absolute; # of Rx Antennas: 3.
- Search Plane:** Elevation: 80 cm; Redraw button.

Buttons for Calculate, Cancel, Save, Open, Print, and Quit are also visible.

The program offers the following

2.1 Actions

2.1.1 Calculate

This button triggers the calculation of the electromagnetic field for a particular configuration. The calculation may take one to several minutes, depending on the properties of the individual layers. The progress of the calculation will be indicated in the Progress group in the upper right of the main window.

Before starting a calculation, you obviously must specify the parameters for the actual configuration. See below on how to do this.

2.1.2 Cancel

Since a calculation may take quite some time, and you may realize that some configuration parameters still need to be changed, you may cancel an ongoing calculation by clicking this button.

2.1.3 Save

Once a particular configuration has been calculated, the result may be saved to a file. The file size for one configuration depends on the number of cells.

2.1.4 Open

A saved configuration can be re-loaded again for looking at the results in different ways. Changing the view plane, the H field profile type, the number of antennas on the receiving transceiver or the elevation of the search plane does not require a new calculation, just a remake of the display.

2.1.5 Print

Use this button to print the current field line view plus all parameter settings to paper or (using Microsoft Print to PDF) to a .pdf file.

2.1.6 Quit

Click here for terminating the `SearchPath` program.

Before calculating the magnetic field lines, a specific setting must be prepared:

2.2 Parameters

2.2.1 The Project Group

The geometry of the space of interest can be changed in this group. The number of Y cells is automatically made equal to the number of X cells when a calculation is started. The Yee cell size also defines the minimum feature size: all feature sizes must be integer multiples of the Yee cell size.

The limits to these parameters are:

	Min	Max
Yee Cell Size	2	20
X Cells	21	401
Y Cells	21	401
Z Cells	21	201

2.2.2 The Layers Group

In this group, you can specify the properties of the individual layers.

Layer depth can only be specified in integer multiples of the Yee cell size. For any or all of the snow layers, you may specify a depth of 0 cm. The minimum depth of the soil layer is 1/10 of the total height.

Typical parameters are

	μ_r	ϵ_r	σ
Air	1.000	1.000	1.0e-10
Snow, dry	1.000	1.500	1.0e-8
Snow, wet	1.000	20.000	1.0e-6
Ice	1.000	3.000	5.0e-7
Soil	1.000	8.0	1.0e-4

For more information on the electromagnetic properties, see the document "Search Path Documentation.pdf".

2.2.3 The Dipole Group

The burial depth must also be an integer multiple of the Yee cell size.

The inclination may be set between 0° and 90°. Note that, with an inclination of 0°, the field lines will be exactly perpendicular to the y-z plane, so no field lines can be displayed in the y-z view. The same goes for the x-y plane view when the dipole inclination is 90° and the dipole and the search plane are at exactly the same elevation.

2.3 Presentation Mode

If this box is checked, the width of all lines in the graphics is doubled, and a bold font is used for the scaling. This mode is useful for presentations by means of a beamer and for preparing figures for publications.

The screenshot displays the SearchPath software interface. The main window is titled "SearchPath" and contains a large grid labeled "X - Y Plane". The grid has x and y axes ranging from -10.00 to +10.00. A red dot is visible at the origin (0,0). To the right of the grid is a "Progress" panel showing "0 out of 0 Steps" and "0 %". Below the progress panel are buttons for "Calculate", "Cancel", "Save", "Open", "Print", and "Quit". A checkbox labeled "Presentation Mode" is checked.

At the bottom of the interface are several control panels:

- Project:** Yee Cell Size: 10 cm. Must be odd numbers: x Cells: 201, y Cells: 201, z Cells: 101.
- Layers:** A table with columns: Depth [cm], μ_r , ϵ_r , σ [S/m].

Layer	Depth [cm]	μ_r	ϵ_r	σ [S/m]
Air	530	1.000	1.000	0.000e+00
Snow 2	160	1.000	2.000	1.000e-10
Snow 1	10	1.000	4.000	1.000e-06
Snow 0	110	1.000	1.500	5.000e-08
Soil	200	1.000	8.000	1.000e-04
- Dipole:** Burial Depth: 100 cm, Inclination: 0 Deg.
- View Plane:** x - y, H Field Profile: absolute, # of Rx Antennas: 3.
- Search Plane:** Elevation: 80 cm, Redraw button.

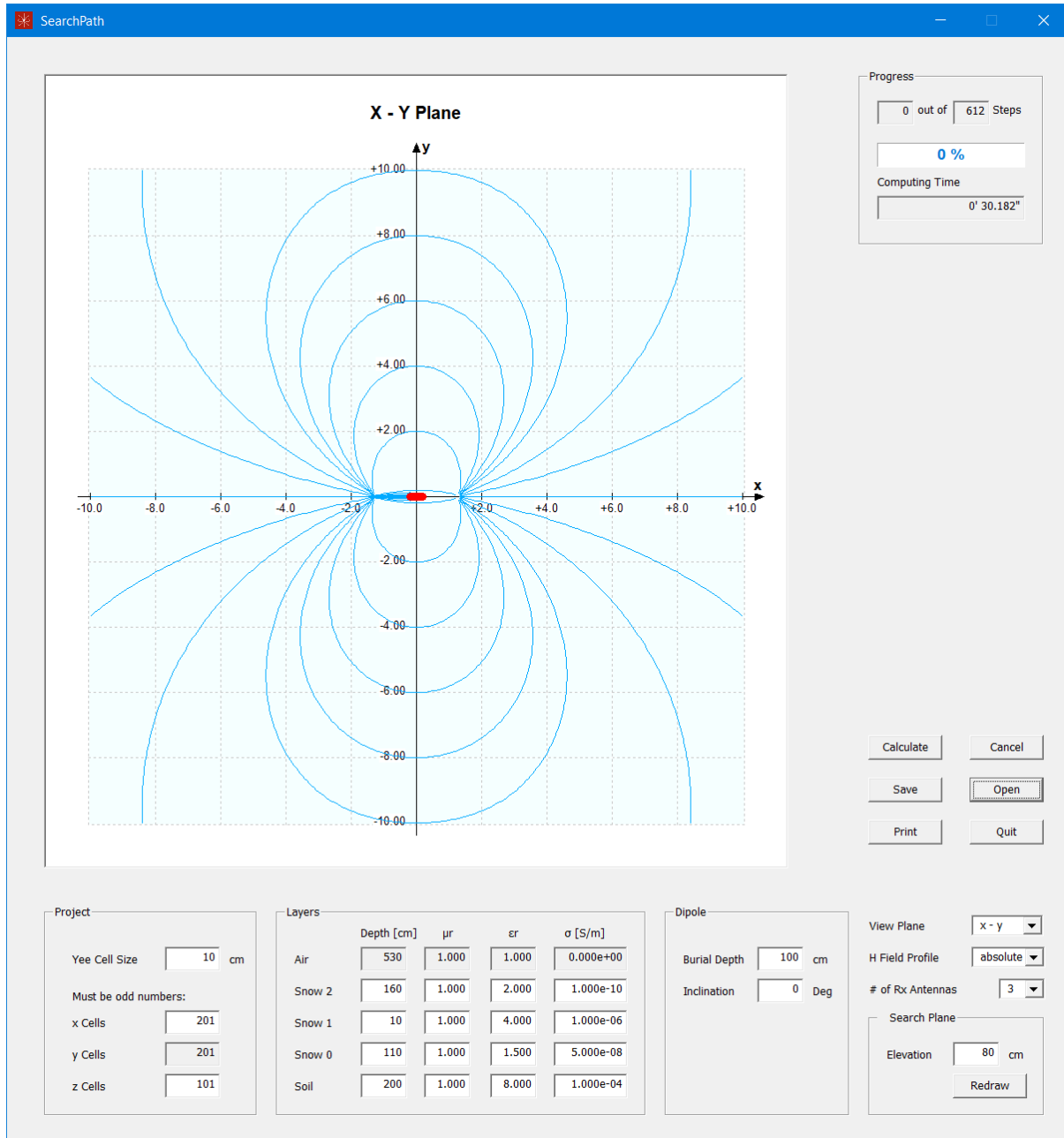
2.4 View Options

Once a calculation has been completed or a file has been loaded, the view options can be changed without re-calculating. There are several options to look at the results:

2.4.1 The View Planes

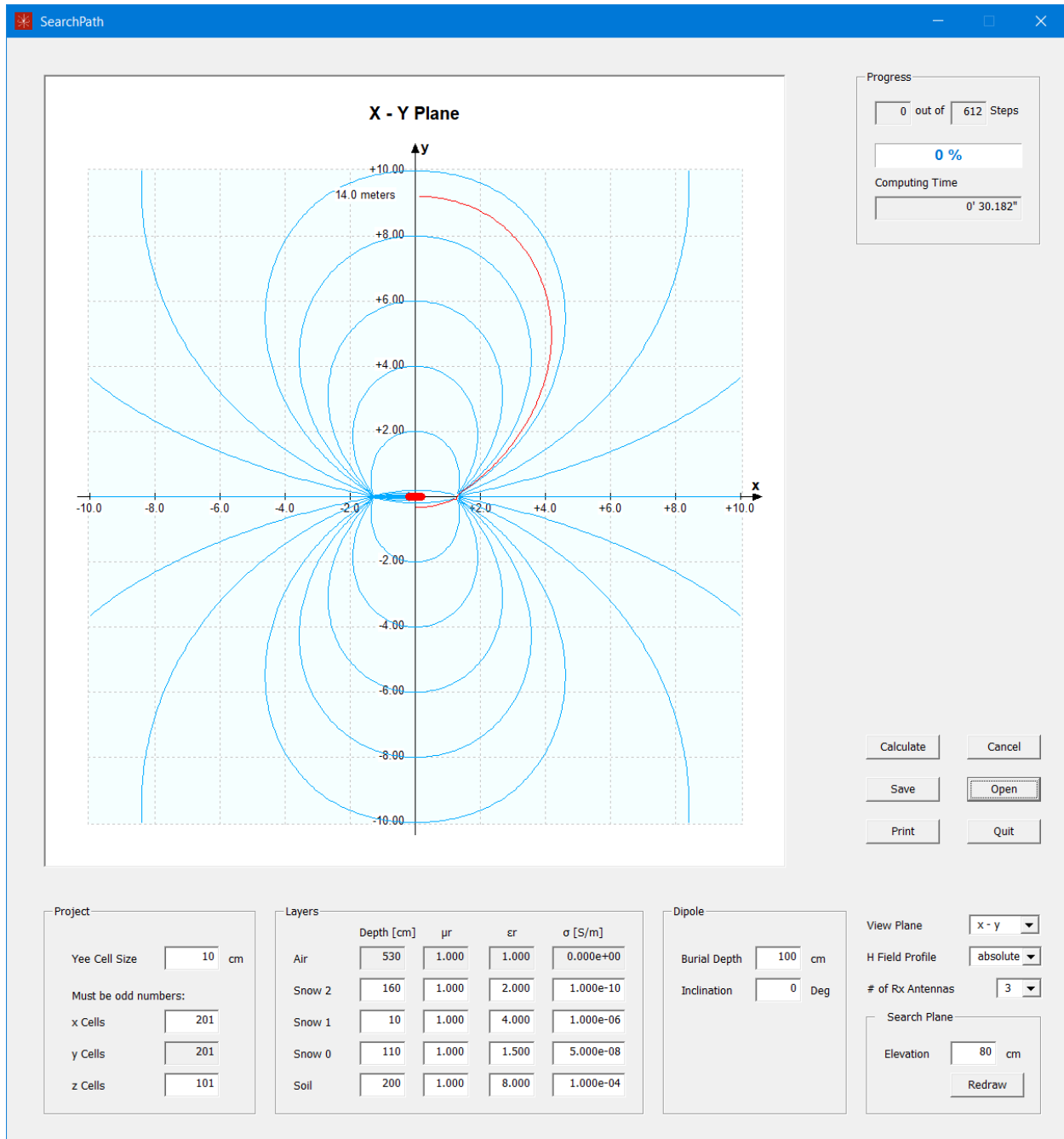
The shape of the field lines is visualized in three planes:

2.4.1.1 The X-Y View

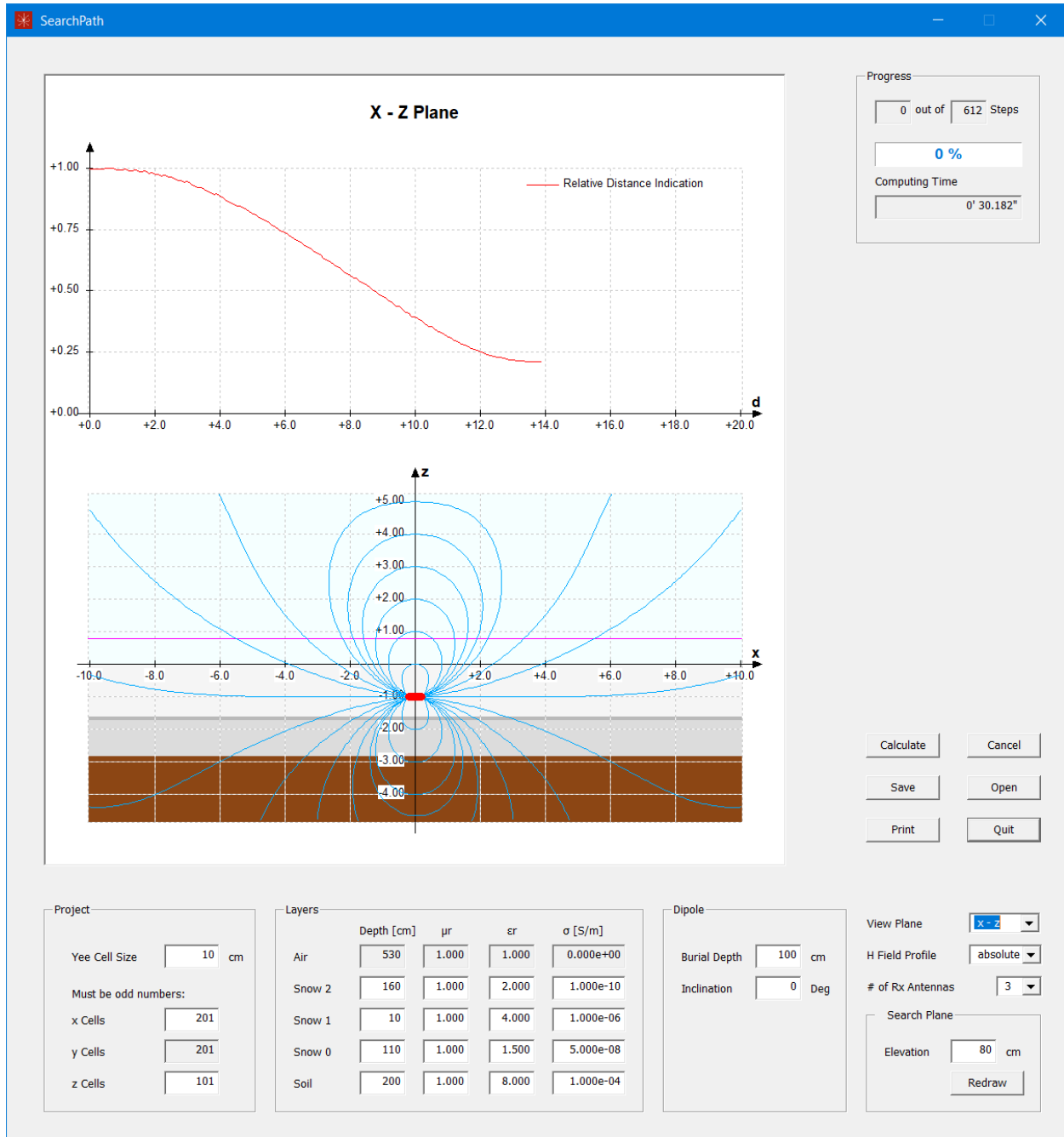


This view shows the direction of the field lines on the search plane. This is what is used by transceivers for producing the direction information. The lines depend on the z difference (burial depth plus search plane elevation) between the dipole and the search plane: the larger the difference, the farther away from the actual dipole location the x axis intersection points will be.

A right click inside the curves area will show the shortest search path. Right clicking another location will show a new search path. Clicking any place outside the curves area, but still within the curves window, will remove the search path again:

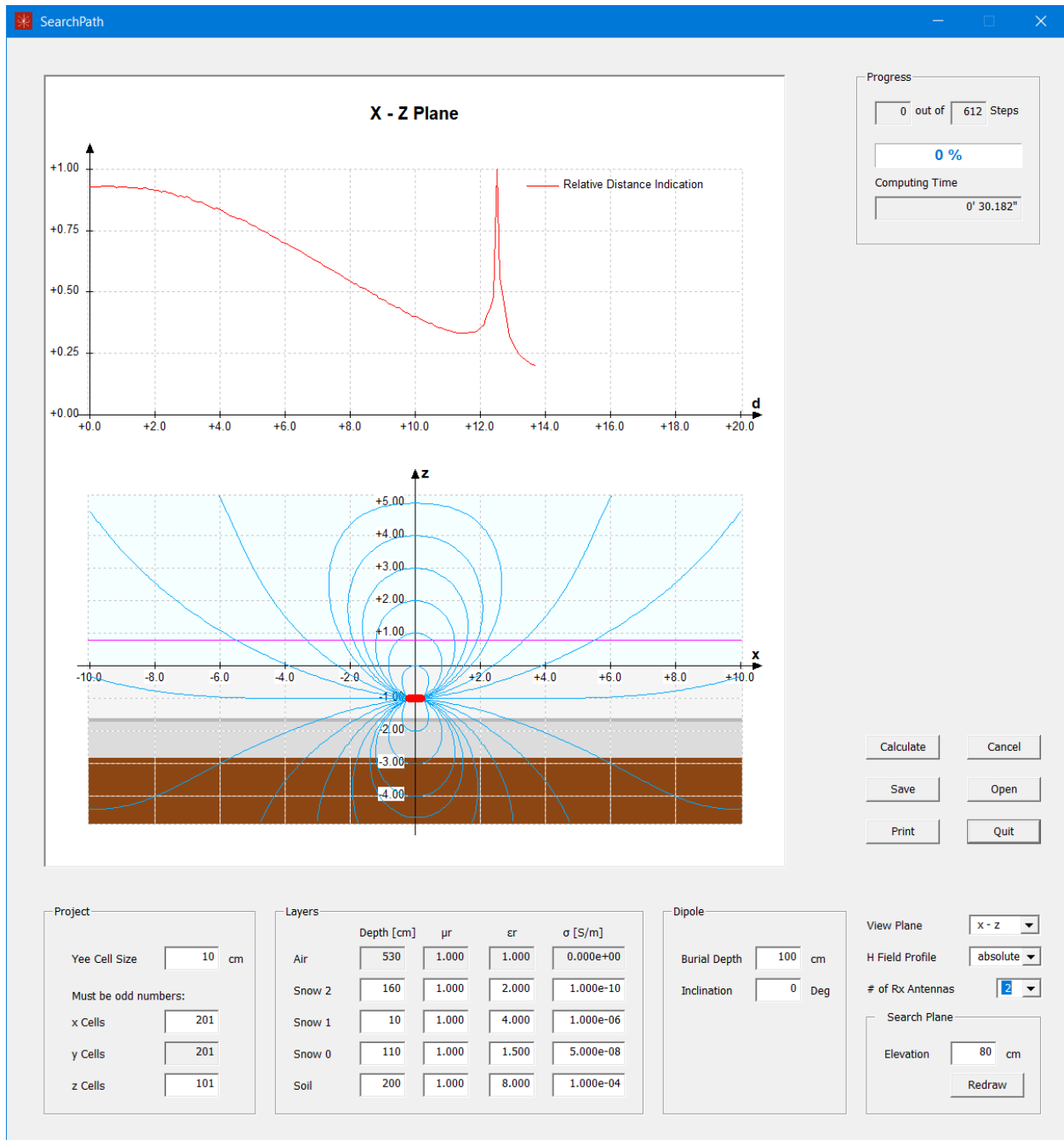


Another item of interest is the change in distance information as the searching user proceeds along the search path. This can be viewed in the x-z plane when a search path has been activated in the x-y plane:



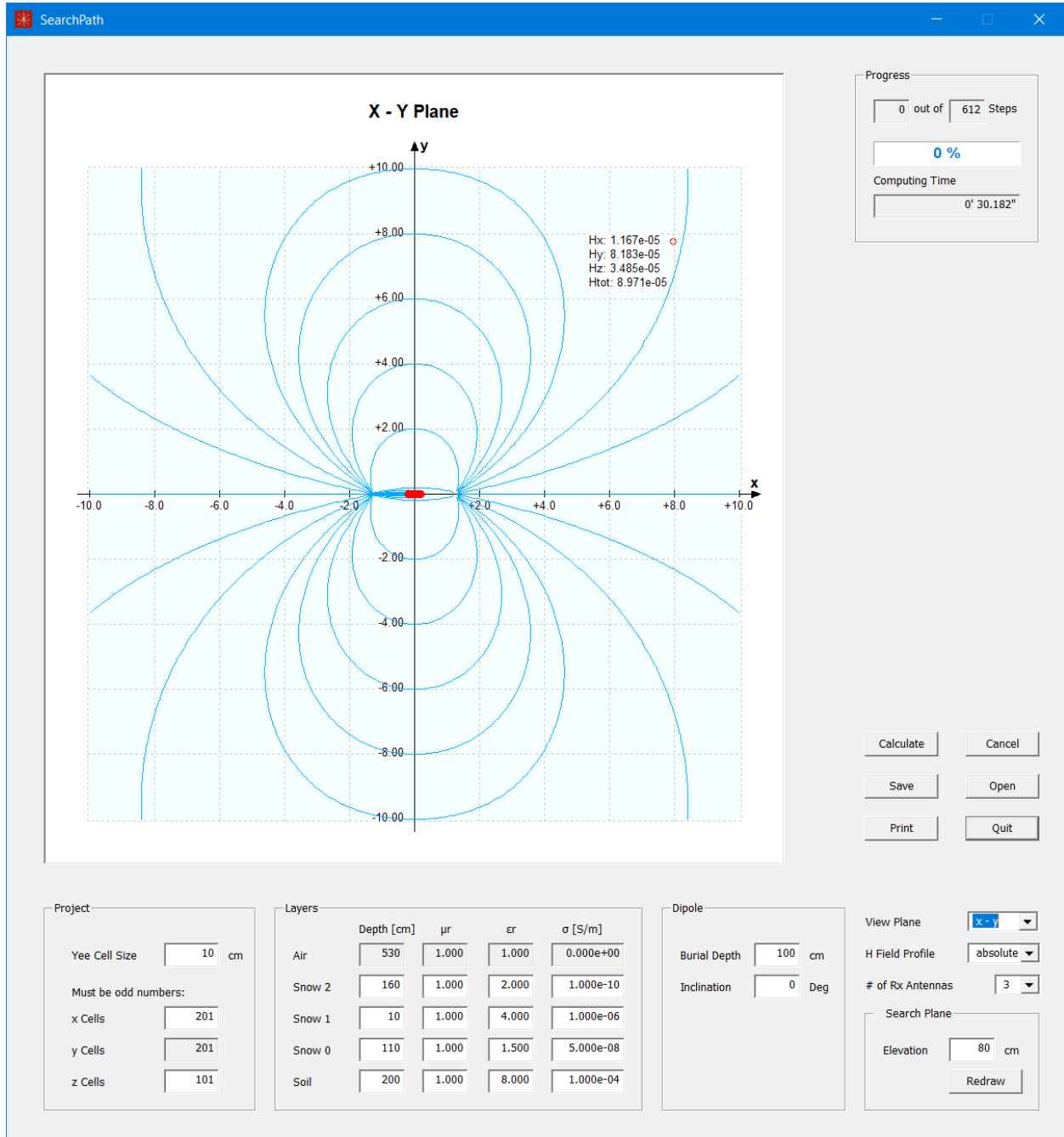
With a starting point near the y axis, the distance indication will initially not change much when following the direction of the field lines! After an initial decrease, it might even increase slightly again.

When the searching transceiver is equipped with two antennas only, things change:



At the point where the search path intersects with the x axis, the distance indicated will be very large due to the fact that the H_x and H_y components of the magnetic field are very small in that region. A good reason for getting rid of two antenna transceivers!

Another option in this view is to examine the actual values of the H field components. These are shown when pressing the left mouse button anywhere within the curves space:



The H field components are relative values !

For determining the search path, the program uses the following criteria:

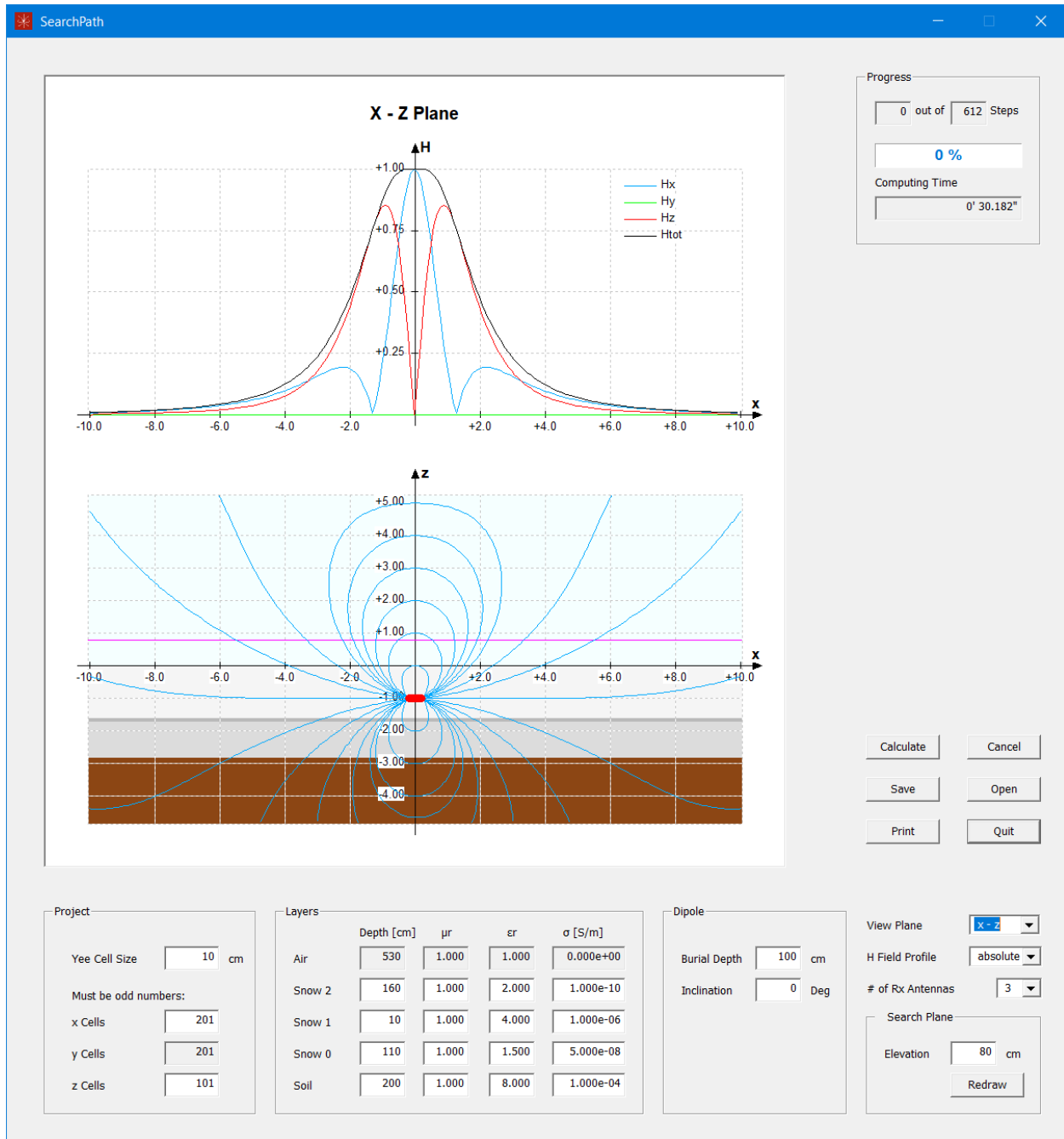
- The search path must lie entirely the curve area.
- If the distance indication increases or decreases in both directions at the starting point, the shorter one of the possible paths is selected.
- If the distance indication increases in one direction and decreases in the other direction, then the path with decreasing distance indication is chosen.

The program may run into the same problem as a person doing a search: when the field lines are nearly perpendicular to the search plane, the direction indication may become unreliable. The program then uses a best effort approach to resolve the situation. In practice, the problem may be less accentuated since a searching transceiver will rarely be perfectly aligned with the search plane.

At these locations, the H_x and H_y components are very small, which will lead to numerical problems. Also, a small lateral movement may change the direction information considerably. The best tactic to overcome these problems is to focus on the distance information and find the direction where distance decreases.

2.4.1.2 The X-Z View

The X-Z view shows the field lines in the vertical plane containing the dipole and defined by the x and z axes and the profile of the H field components at the search plane elevation:

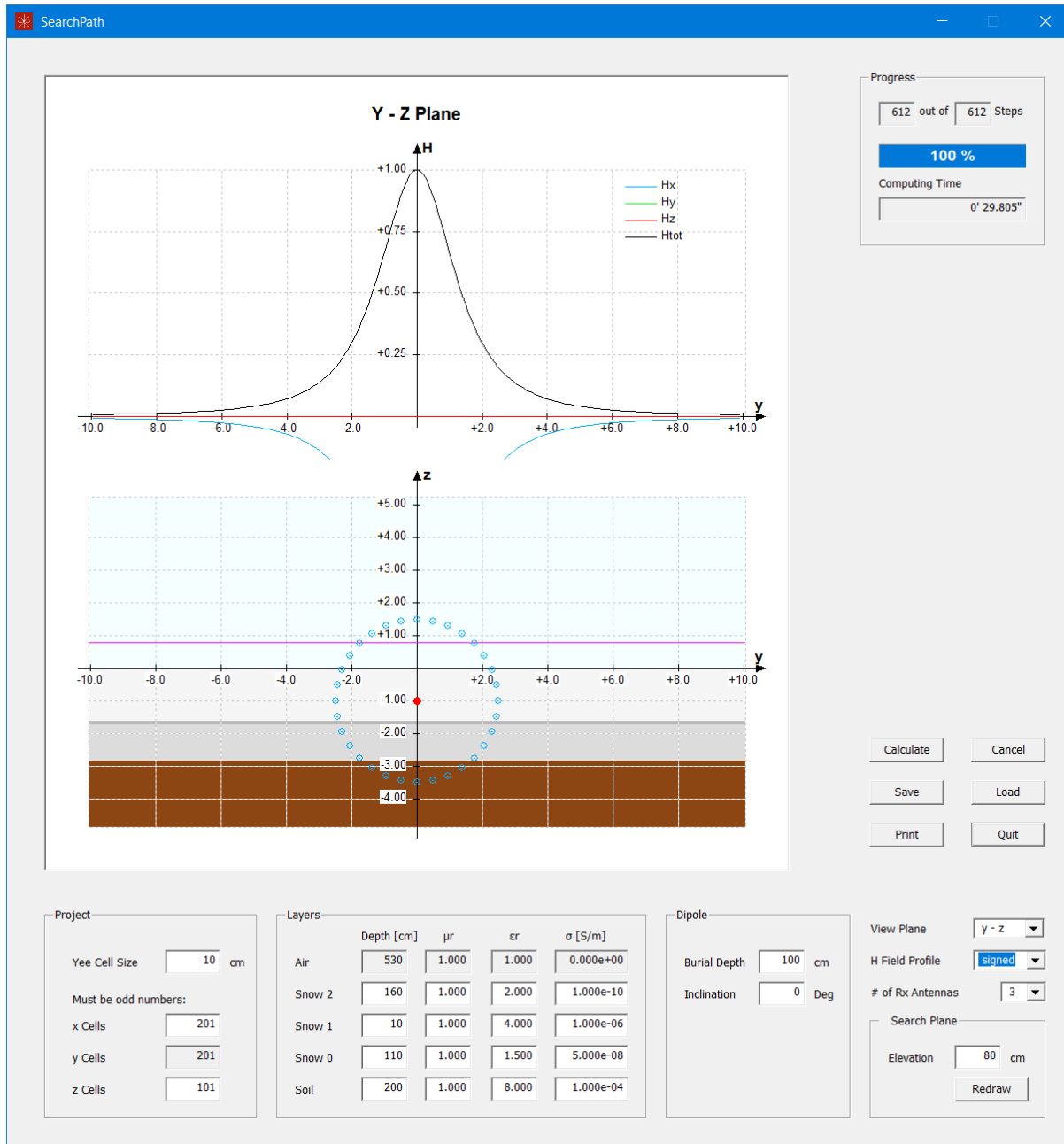


In the lower half of the field line display, the effects of the soil can be seen: the field lines going out from the dipole axis start raising at some distance from the dipole.

Again, the H field numerical values are relative.

2.4.1.3 The Y-Z View

The Y-Z view shows the field lines in the vertical plane containing the dipole and defined by the y and z axes and the profile of the H field components at the search plane elevation:



In this particular case (dipole inclination of 0°), the field lines are exactly perpendicular to the y-z plane, so they can only be shown as dots. At other dipole inclinations, the field lines will look similar to the ones in the x-z plane.

2.4.2 The H Field Profile Presentation

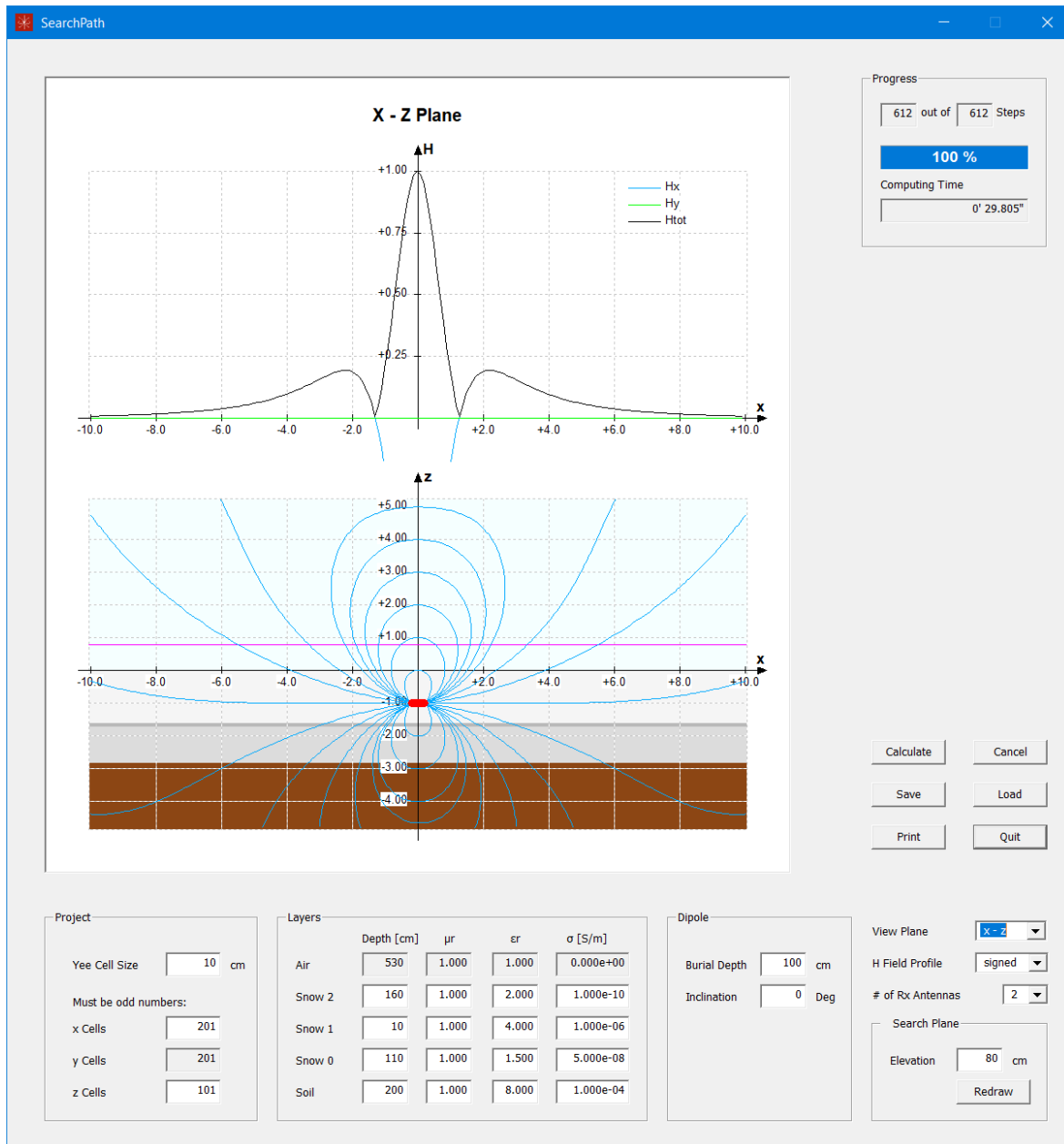
For viewing the H field profile, there are two items that may be changed:

2.4.2.1 Signed / Unsigned H Field Values

The H field profile may be shown with unsigned (default) or signed values. Note that the signs will change 457'000 times per second !

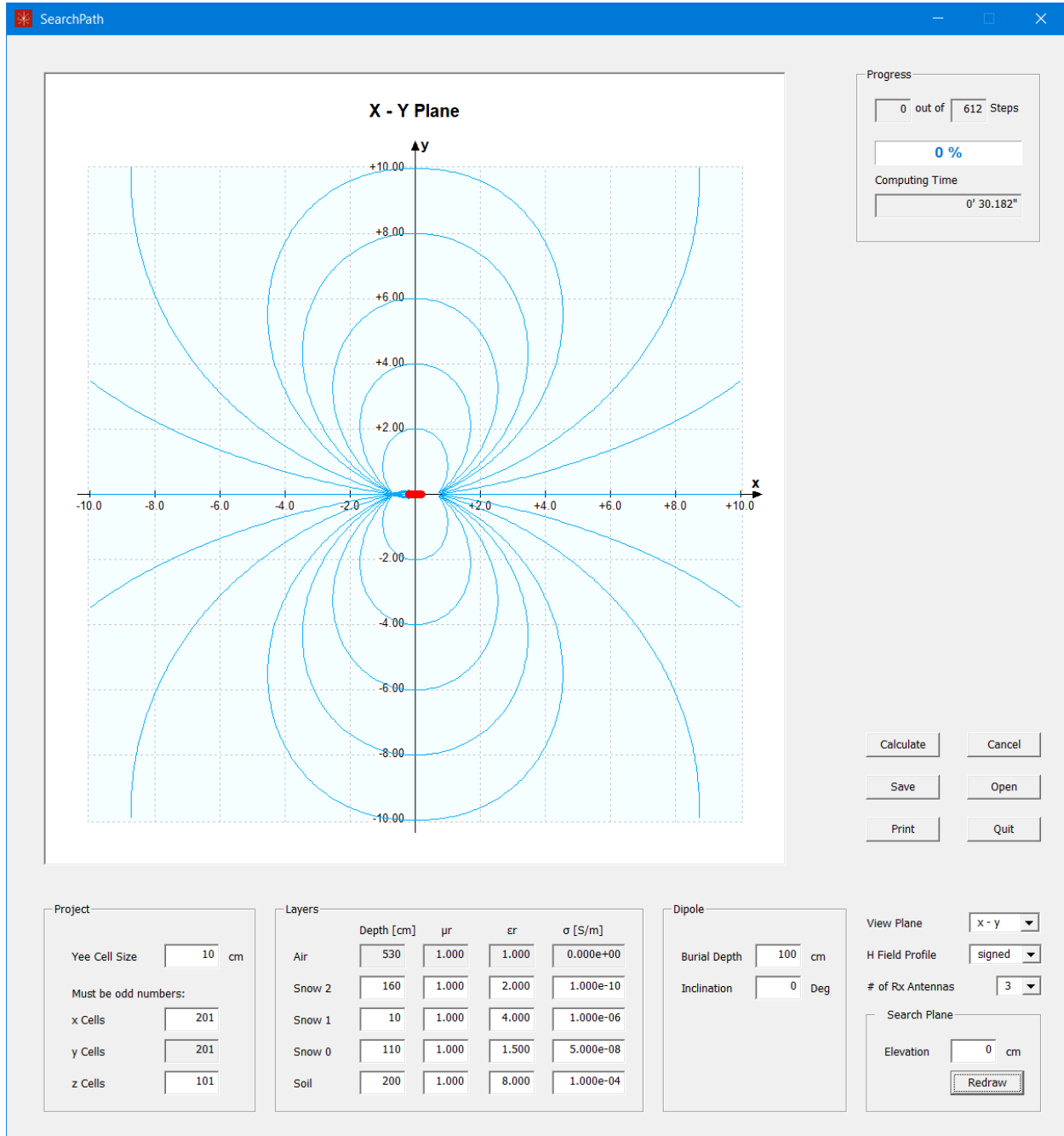
2.4.2.2 The Number of Antennas in the Searching Transceiver

The profile may be shown for a 3 antenna transceiver (default) or for a 2 antenna transceiver.



2.4.3 The Search Plane Elevation

While searching, the transceiver may be moved anywhere along or above the snow surface. This will then have an influence on the x axis intersection points:



The lower the elevation of the searching transceiver, the more the intersection points will move towards the location of the dipole. After changing the search plane elevation, you must click the "Redraw" button to update the curves.

3 Resources

3.1 Memory

The main array with all the E and H field values for every cell is made of ((X Cells) x (Y Cells) x (Z Cells)) cells. Each field value takes 4 bytes at `float` precision, and there are 6 field values. Add some bytes for the storage of the previous values on the face layers. So this is an estimate of memory that should be available to the application:

X Cells	Y Cells	Z Cells	~Bytes
21	21	21	223'000
201	201	101	97'933'000
401	401	201	775'705'000

3.2 Computing Power

The calculation for a space of 201 by 201 by 101 cells takes 300 to 800 steps depending on the layer properties and results in a calculation time of about 30 seconds on an Intel® Xeon® W-2102 CPU with a clock frequency of 2.9 GHz.

3.3 Display

The vertical number of pixels of the display must be at least 1080.

3.4 Operating System

The application has been tested on computers running under Windows 7 and Windows 10.

4 References

For more references on the subjects, see the document "Search Path Documentation.pdf".

4.1 Algorithms

- [100] Yee, K.S.; Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media; IEEE Trans. On Antennas and Propagation, Vol. 14, No. 3, May 1966, pp. 302 - 307.
- [101] Taflove, A., Hagness, S. C., M. E.; Computational Electrodynamics, The Finite Difference Time Domain Method; 3rd Edition, Artech House Inc. 2005

4.2 Layer Properties

4.2.1 Snow

- [200] Ayuso, Cuchi, J.A., N., Lera, F., Villarroel, J.L.; Avalanche Beacon Magnetic Field Calculations for Rescue Techniques Improvement; in: [2007 IEEE International Geoscience and Remote Sensing Symposium](#), pp. 722-725, 2007.
- [201] Evans, S.; Dielectric Properties of Ice and Snow – A Review; J. Glaciol. 5, 773–792 (1965)

4.2.2 Soil

- [300] Liu, Ning; Soil and site characterization using electromagnetic waves; Thesis (Ph.D.)—Virginia Polytechnic Institute and State University, 2007, Chapter 2.
- [301] Electrical Characteristics of the Surface of the Earth; ITU Recommendation ITU-R P.527-3, 1992.
- [302] Scott, J.H.; Electrical and Magnetic Properties of Rock and Soil; United States Department of the Interior, Geological Survey; Open-File Report 83-915, 1983.

4.3 Others

- [400] Ayuso, N., Cuchí, J.A., Lera, F., Villarroel J.L.; A deep insight into avalanche transceivers for optimizing rescue; Cold Region Science and Technology, Vol. 111 (2015), pp. 80-94.
- [401] Mc Tavish, J. P.; Field pattern of a magnetic dipole; Am. J. Phys. Vol. 68, No. 6, June 2000; pg. 577-578