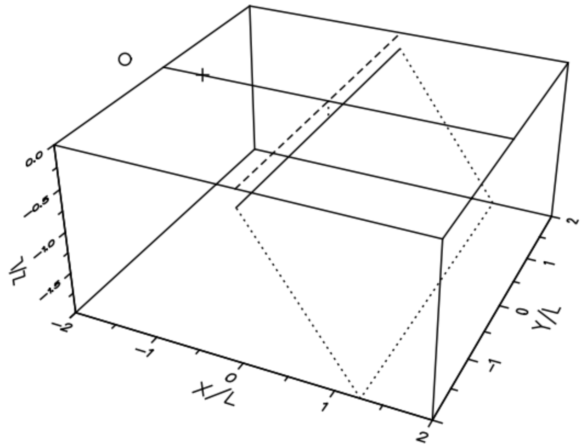
HPLANE

Geophysical EM response of perfectly conducting half-plane

User's guide to version 1.4



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Introduction

The HPLANE program computes the EM profile response of a perfectly conducting half-plane in free-space for various geophysical dipole-dipole measurement systems. The half-plane is used to model a thin, highly conductive target in resistive surroundings. The computational method is based on the analytical solution presented in the classic book of F.S. Grant and G.F West (1967): Interpretation theory in applied geophysics. HPLANE can be used for educational purposes and as an approximate interpretation tool for geophysical EM measurements.

HPLANE is a 32-bit program that can be run on a PC with 32-bit or 64-bit Windows operating system and a graphics display with a resolution at least 1024×768 pixels. Memory requirements and processor speed and are not critical factors, since the program uses dynamic memory allocation and the analytical EM solution allows very fast computation even on slow computers. The HPLANE program has a simple graphical user interface (GUI) that can be used to change the parameter values, to handle file input and output, and to visualize the EM response and the model.

Figure 1 shows a cross-section of a dipping half-plane model. The half-plane is considered to be semi-infinite, which means that it has infinite strike length and depth extent. Although the half-plane is also infinitesimally thin, it is a perfect conductor, which means that it produces the inductive limit EM response. Since the half-plane is an ideal conductor and it locates in free-space, the EM response has the in-phase (real) component only.

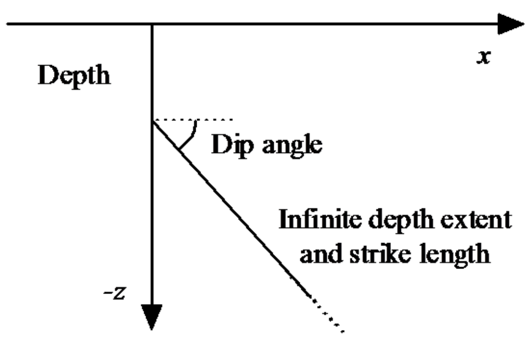

Figure 1. Cross-section of the half-plane model.

Important: The coordinate system is such that the *x* axis points left (East), *y* axis points up (North) and *z* axis points up. Although the half-plane is in free-space, which allows full freedom for system orientation, the model assumes that the plane *z*= 0 represents earth's surface and the top edge of the half-plane is always below the *y* axis (*x*= 0).

Figure 2 illustrates the three main types of measurement systems used in HPLANE program. The transmitter, *Tx*, is either a vertical (VMD) or a horizontal (HMD) magnetic dipole. The receiver, *Rx*, measures the same component as the source and the other two orthogonal response components. VMD and HMD systems are profiling methods that use a fixed spacing between the *Tx*-*Rx* pair. These methods are operated either in an in-line (as in Figure 2) or in a broadside fashion. In in-line configuration the (fictional) line connecting *Tx* and *Rx* is coincident with the profile traverse. In a broadside system the *Tx*-*Rx* line is perpendicular to the profile. The measurements are positioned at the mid-point between the *Tx*-*Rx* pair. In the fixed-VMD system, the transmitter position is fixed and the receiver moves along the profile. The measurements are placed at the receiver position and the field components are computed either with respect to the profile or with respect to the *xyz* coordinate system.

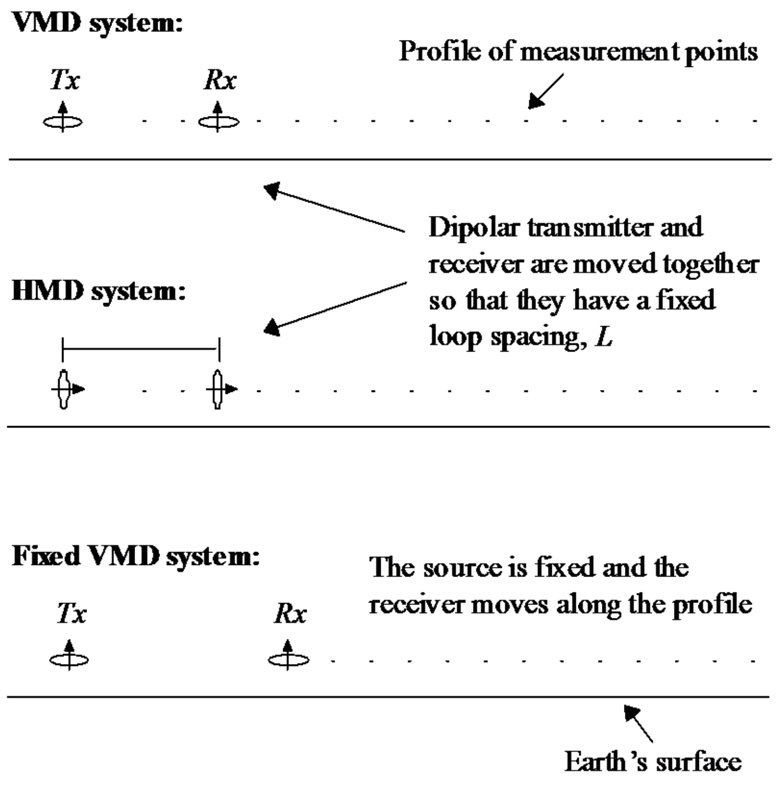

Figure 2. Schematic view of the three different measurement systems.

Installing the program

The distribution file (HPLANE.ZIP) contains the stand-alone executable HPLANE.EXE, short description file (_README.TXT), GNU GPL terms (_COPYING.txt) and the user's manual (HPLANE_MANU.PDF) in PDF format. The SOURCE sub-folder contains the Fortran90 source code. To install the program unzip the distribution file somewhere on the hard disk and a new folder appears. Additionally, create a shortcut on the desktop but make sure that the start-up folder is the same as the program directory.

Starting up

On startup the program reads its input parameters for the model and system from the HPLANE.INP file and the graph parameters from the HPLANE.DIS file. If these files do not exist, default parameters are used and the files are created automatically.

The program then computes the response and builds up the user interface shown in Figure 3. The EM response is plotted in the graph area along with a 3-D view of the model and a description of the model parameters. The model and system parameters are changed using the program controls on the left side of the HPLANE window and the items in the *Hplane* menu. The items in the *File* menu are used to save and read model and system setting in/from a *.INP file, save computation results in *.DAT file, and to save the current graph into graphics file (PS, EPS, PDF, WMF, GIF, PNG).

The 3-D model view depicts the top edge of the half-plane and the location of the profile using solid lines. The surface projection of the half-plane is drawn with dashed line. The locations where the half-plane cuts the sides of the 3-D view box are shown using a dotted line. If the profile is above the surface ($ZZ > 0$ m), the surface plane is drawn using dotted lines as well. The small circle and the cross depict the location of the transmitter and receiver, respectively. Note that the 3-D model view uses normalized coordinates (X/L, Y/L, Z/L).

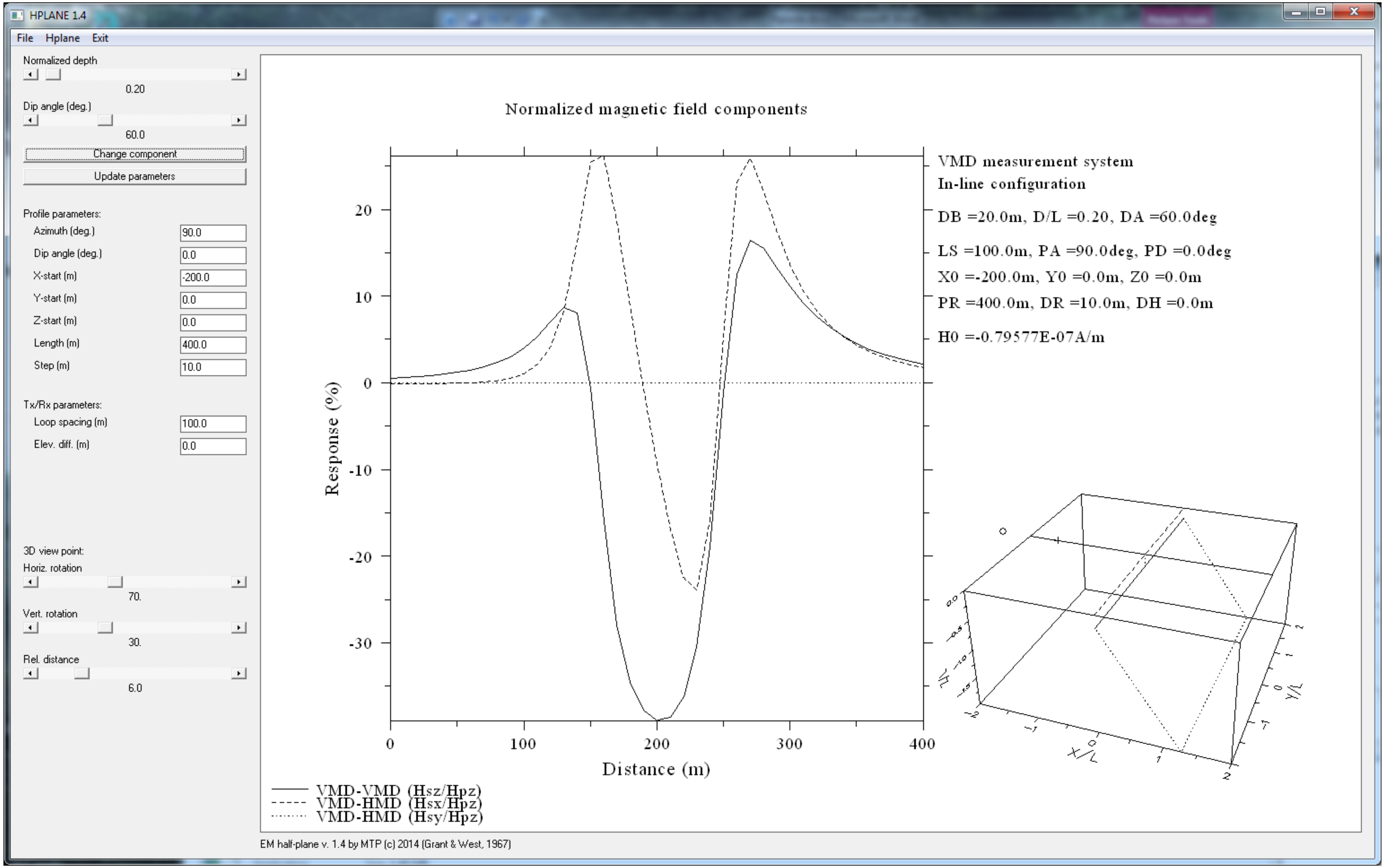

Figure 3. Screendump of the HPLANE program

Menu items

The main window of the HPLANE application contains three menus. The *File* menu contains the nine items:

Open model	Open an existing model file.
Save model	Save the model into a file.
Save results	Save results (description + response) into a file.
Read disp.	Read in new graph parameters from a *.DIS file.

Save graph as PS	Save the graph in Adobe's Postscript format.
Save graph as EPS	Save the graph in Adobe's Encapsulated Postscript format.
Save graph as PDF	Save the graph in Adobe's Acrobat PDF format.
Save graph as WMF	Save the graph in Windows metafile format.
Save graph as GIF	Save the graph in Graphic Image File format.
Save graph as PNG	Save the graph in Portaple Network Graphics format.

Selecting any of these menu options brings up a standard (Windows) file selection dialog that can be used to select an existing file or provide a name and location for new output file. Model and result files are text files. The graphs are saved in landscape A4 size as they appear on the screen.

The *Hplane* menu contains four sub-menus.

Source system ▸	Source is moving VMD or HMD or fixed VMD.
Configuration ▸	Loop configuration is either in-line or broadside.
Response scaling ▸	Response as plain ratio, per-cents (%) or per-million (ppm).
Distance scaling ▸	X axis is normalized with loop spacing or not.

The *Exit* menu has two items. *Restart wide/norm* is used to close and restart the whole GUI using a screen aspect ratio that suites either old 4:3 displays or widescreen displays (eg. 16:10). When changing from normal to widescreen mode the program asks for an aspect ratio value relative. Value between 0.7-0.8 is good for most widescreens.

OK to exit is used to confirm the exit operation. On exit the current model and results are automatically saved in the HPLANE.INP file. Errors that are encountered before the GUI starts up are reported on the console window. Run-time errors arising from illegal parameter values are displayed on the screen.

Program controls

The two slide controls at the top of the left pane of the HPLANE window define:

DE = Depth to the top of the half-plane normalized with loop spacing (real)
DA = Dip angle (degrees) (90°= vertical half-plane) (real)

The *Change component* button is used to change the EM response components shown in the graph. When the slide widgets (discussed above) are applied, the response is computed automatically. When the text fields (discussed below) are edited, the EM response is computed only after the *Update parameters* button is pressed.

The next seven text fields define profile parameters:

PA = Profile azimuth (degrees) (real) (90°= perpendicular to half-plane)
PD = Profile dip (degrees) (real) (90°= vertical downwards)
X0 = Start *x* position (m) (real) (the distance to the half-plane)
Y0 = Start *y* position (m) (real) (merely as a reference value)
Z0 = Start *z* position (m) (real) (used for AEM and borehole systems)
PR = total length of the profile (m) (real)
DP = step between measurement points (m) (real)

The last five text fields define source and receiver parameters:

LS = Loop (dipole) spacing (m) (real)
DH = Transmitter-receiver dipole height difference (m) (real)
TX = Transmitter *x* position (m) (real) (for fixed VMD source only)
TY = Transmitter *y* position (m) (real) (for fixed VMD source only)
TZ = Transmitter *z* position (m) (real) (for fixed VMD source only)

Few notes on model and system parameters

Depth *DE* is given a positive value although *z* axis is positive upwards. The slide widget restricts the depth between 0.01×LS and 5×LS. Dip *DD* is taken from the positive *x* axis (East) towards positive *z* axis (downwards) and the slide widget restricts it between -90 and 90 degrees. If *DD*= 90° the half-plane is vertical downwards. Profile azimuth *AS* is taken from the positive *y* axis towards positive *x* axis and it can vary freely (normally -180°<*AS*<180°). If *AS*= 90°, the profile is perpendicular to the half-plane and points towards East. Profile dip *PD* is taken from the horizontal plane and it can vary freely (normally -90°<*PD*<90°). If *PD*= 90° the profile is vertical downwards. *DH* is the elevation difference of the transmitter dipole from the receiver. If *DH*>0 the transmitter locates "higher" than the receiver (if the profile is horizontal). This parameter should be used only when modeling some air-borne or cross-borehole measurement systems.

In VMD and HMD systems the direction of the source dipole axes and the computed field components are related to the profile direction. HMD is directed along the profile and VMD is directed perpendicular to the profile. Thus, VMD is vertical magnetic dipole and HMD is horizontal magnetic dipole only when the profile is horizontal (*PD*= 0°). If the profile is dipping (up or down), the VMD source will have horizontal component and HMD will have vertical component that depend on profile azimuth and dip angle. The user must be careful when dealing with oblique and dipping profiles, since the orientation of the response components can become unclear.

In general, *Hsx* is the axial component, *Hsz* is perpendicular to the axial component (and *PD*) and to the profile direction (*SA*), and *Hsy* is horizontal and perpendicular to the other two components (follow the right-hand rule). This means that the field components coincide with the xyz coordinate system only when *SA*= 90° and *PD*= 0° (in which case the profile is horizontal, parallel to *x* axis and perpendicular to the half-plane).

The *Hsx/Hpx* response component of in-line HMD-HMD system represents co-axial system and broadside HMD-HMD represents co-planar system. In VMD and HMD systems the measurements are positioned at the mid-point between the *Tx*-*Rx* pair. Note, however, that the results of the output file are presented using only the profile distance (not the actual *xyz* coordinates). Although in free-space the VMD and HMD systems obey reciprocity, the source is normally behind the transmitter in in-line configuration and left to the receiver in broadside configuration. The initial (starting) positions of the source and receiver are shown in the 3-D model view using an open circle and a plus sign, respectively. Loop spacing values less than zero (LS<0 m) are used to interchange the positions of the source and the receiver. This option affects only the horizontal response components of the VMD and HMD systems.

For VMD source systems the normalization is made using the free-space vertical magnetic field ($Hp=Hpz$) at the distance of loop spacing and the columns are the vertical field (Hsz/Hp), the field along the profile (Hsx/Hp) and the perpendicular component (Hsy/Hp). For HMD system the normalizing field is the horizontal magnetic field ($Hp=Hpx$) and the columns are the axial field (Hsx/Hp), vertical field (Hsz/Hp) and the remaining perpendicular component (Hsy/Hp).

In fixed VMD system, the normalization is made using the same *Hpz* component as in VMD system. This means that $Hp=Hpz$ is computed at the distance of loop spacing and elevation difference (*LS* and *DH*), i.e., not at rowing receiver locations. For fixed-VMD system, the configuration mode (in-line vs. broadside) defines the field components, which are either related to the profile direction (as in VMD and HMD systems) or to the true *xyz* coordinates.

File formats

Graph parameter file (HPLANE.DIS)

Editing the HPLANE.DIS file allows translating the graphs into another language by. Note that the format of the HPLANE.DIS file must be preserved. If the format of the file becomes invalid, one should delete the file and a new one with default parameter values will be generated automatically the next time the program is started. The file format is shown below.

```
0.01  5.00  0.01
   0.  180.    1.
  32   28   24   22   20
   1    1    1    1
 350  300  0.55  0.85  0.80
1000 145.  25.   6.

Normalized magnetic field components
```

```
VMD measurement system
HMD measurement system
Fixed VMD meas. system
In-line configuration
Broadside configuration
Profile components
XYZ-components
Distance
Response
VMD-VMD (Hsz/Hpz)
VMD-HMD (Hsx/Hpz)
VMD-HMD (Hsy/Hpz)
HMD-HMD (Hsx/Hpx)
HMD-VMD (Hsz/Hpx)
HMD-VMD (Hsy/Hpx)
```

- The 1.st line defines the minimum, maximum and step values used in the scale widget that defines the normalized depth (*D/L*). Similarly the 2.nd line defines the minimum, maximum and step value used in the scale widget of the dip angle. Note that depth must be greater than 0 and dip angle must be between -90 and 270 degrees.
- The 3.rd line defines five character heights. The first one is used for the main title and the graph axis titles, the second height is used for the axis labels, the third height is used for the plot legend text, the fourth height is used for the model description text, and the last height is used for the axis labels in the 3-D model view.
- The 4.th line defines parameters that modify the graph appearance. The first one can be used to include (1) or exclude (0) the model information text to/from the top-right corner of the page. The second one can be used to include (1) or to exclude (0) the model view to/from the bottom-right corner of the page. The third parameter is used to define the corner where the legend text is positioned. Values 1-4 put the legend in SW, SE, NE or NW corner of the page (outside the graph). Values 5-8 put the legend in the SW, SE, NE, or NW corner inside the graph. The default values are 1, 1, 7. The fourth parameter defines whether or not widescreen mode is active (0/1).
- The 5.th line defines the *x* (horizontal) and *y* (vertical) distance of the origin of the main graph (in pixels) from the bottom-left corner of the page, and the length of the *x* and *y* axes relative to the size of the remaining (origin shifted) width and height of the plot area. The total size of the plot area is 2970×2100 pixels (landscape A4). The last parameter defines the screen aspect ratio for widescreen mode.

- The first parameter on the 6.th line defines the size (in pixels) of the square area reserved for the 3-D model. The position of the model area is always next to the lower right corner of the response graph. The remaining three parameters define horizontal and vertical viewing angles and a perspective viewing distance for the 3-D model view.
- The following lines define various text items of the graph (max. 40 characters). These are: the main title of the graph (60 chars.), the system configuration in the description text (60 chars), the axis titles of the graph, and legend texts used for the different response components of the graph.. Depending on the response and distance scaling (defined in *Hplane* menu), the units are automatically added after the axis titles (eg. "%" or "ppm" for the *y* axis and "*S/L*" or "m" for the *x* axis). Note, that *xyz* suffices are used for the response components, although this may not be the case if the profile is not parallel to *x* axis.

Result file (.DAT)*

The following text illustrates the output file (*.DAT) format:

```
# ----------------------------------------------------
# Results from HPLANE: the EM response of a half-plane
# ----------------------------------------------------
# HPLANE model file
#  20.00   60.00
#  90.00    0.00   -200.00      0.00      0.00    400.00   10.00
#   100.00    0.00   1   1   0   0
# ----------------------------------------------------
# Description:
#   Depth to the top   DE=     20.00
#   Dip angle          DA=     60.00
#   Profile azimuth    PA=     90.00
#   Profile dip        PD=      0.00
#   Profile x-start    X0=   -200.00
#   Profile y-start    Y0=      0.00
#   Profile z-start    Z0=      0.00
#   Profile length     PR=    400.00
#   Point spacing      DR=     10.00
#   Loop spacing       LS=    100.00
#   Height difference  DH=      0.00
#   Measurement system: VMD-VMD  (IS= 1)
#   Meas. configuration: In-line (IC= 1)
# ----------------------------------------------------
# Transmitter start and end positions:
```

```
#   X-position   TX=   -250.00 -     150.00
#   Y-position   TY=      0.00 -      -0.00
#   Z-position   TZ=      0.00 -       0.00
# Receiver start and end positions:
#   X-position   RX=   -150.00 -     250.00
#   Y-position   RY=     -0.00 -      -0.00
#   Z-position   RZ=      0.00 -       0.00
# ----------------------------------------------------
# Dist, Hsz/Hp, Hsx/Hp, Hsy/Hp, Hsz, Hsx, Hsy, Hp

 0.0 0.5118E-02 -0.7365E-03 0.5768E-10 -0.407E-09 0.586E-10 -0.459E-17 -0.7958E-07
10.0 0.5974E-02 -0.7533E-03 0.6353E-10 -0.475E-09 0.599E-10 -0.505E-17 -0.7958E-07
20.0 0.7031E-02 -0.7453E-03 0.6961E-10 -0.559E-09 0.593E-10 -0.554E-17 -0.7958E-07
etc...
```

Note that the output data file contains a copy of the model file *.INP. The format of the model file should become clear from the example above, since the description text defines the parameters in the same order as they appear in the input file. The four last parameters in the model file define the numerical (integer) values of the measurement system (1= VMD, 2= HMD, 3= fixed VMD), configuration (1= in-line (or profile components), 2= broadside (or *xyz* components)), response scaling (0= plain ratio, 1= %, 2= ppm), and distance scaling (0= no scaling, 1= x axis is normalized with loop spacing). For historical reasons the #-character is used to make comment lines for the Gnuplot plotting program.

The EM response is located at the end of the output data file. The first column is the profile coordinate (distance from the beginning of the profile). Columns 2-4 show the normalized EM response. Columns 5-7 are the actual secondary field components (the order of the components is the same as in columns 2-4). The eighth column contains the constant, normalizing field component (*Hp*= *Hpz* or *Hpx*). Note that the dipole moment of the source is always 1.0 Am^2.

Reference:

Grant, F.S. & West, G.F., 1967: Interpretation theory in applied geophysics. McGraw-Hill, New York, p. 520-528.

Additional information:

Originally, I made the HPLANE program at the University of Oulu in October 2001, when I worked as a researcher funded by a grant from Outokumpu Foundation addressed to Prof. Sven-Erik Hjelt. Further modifications to the software were made in September 2002 and March 2003, after I had received a grant from Tönning Foundation. Version 1.4 is the first release under GNU General Public License (GPL) accompanied by the Fortran90 source code demonstrating the use of DISLIN graphics library in building graphical user interfaces.

HPLANE is written in Fortran-90 style using Intel Visual Fortran 11.4. The graphical user interface is based on the DISLIN graphics library (version 10.2) by Helmut Michels (http://www.dislin.de). Since DISLIN library is available on other operating system the HPLANE program could be compiled and run, for example, on Mac and Linux without modifications. See the comments regarding parameter IPLA in the source code. If you find the computed results erroneous or if you have suggestions for improvements, please, inform me.

Note that although the profile can pass through the half-plane, the source and the receiver can never coincide with the half-plane. This case is handled inside the computational code by adding a small value to the radial distances if they should become zero. Be warned that this can produce artifacts to the computed results, especially when the profile coincides with the top of the half-plane.

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