



EMI ElectroMagnetic Instruments, Inc.

STRATAGEM

26716-01 REV. F

Operation Manual

For

Stratagem systems running IMAGEM Ver. 2.19

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0.0 Introduction

The Stratagem is a unique magnetotelluric (MT) system used for measuring the electrical resistivity of the earth over depth ranges of a few meters to greater than one kilometer. This system uses both natural and man-made electromagnetic signals to obtain a continuous electrical sounding of the earth beneath the measurement site.

MT systems are used to measure the electrical impedance at the earth's surface using a series of simultaneous measurements of local electrical and magnetic field fluctuations. These field measurements are made over a period of several minutes; Fourier transformed, and stored as power spectra. The surface impedance calculated from these spectral values is a complex function of frequency where higher frequency data are influenced by shallow or nearby features, and lower frequency data are influenced by structures at greater depth and distance. An MT sounding provides an estimate of vertical resistivity beneath the receiver site and also indicates the geoelectric complexity at the sounding site. In areas where the resistivity distribution does not change rapidly from station to station, the resistivity sounding is a reasonable estimate of the geoelectric layering beneath the site.

The Stratagem system consists of two basic components; a receiver and a transmitter. In the high frequency range, natural signals are typically weak and use of a transmitter can improve data quality data. For certain applications, and in some conditions, it may not be necessary to use the additional high frequency signal power that the transmitter provides.

Stratagem measurements may be effectively applied in ground water investigations, subsurface characterization at environmental study sites, mineral and geothermal exploration, and in civil engineering studies. Because this battery-powered system is compact and portable, it is productive even on rough terrain and also may be operated successfully in fairly hostile environments. The speed and portability of the Stratagem system allows for a flexible survey design. Surface impedance results are immediately displayed as a resistivity sounding and may also be processed in groups of soundings and viewed in section while on site. This flexibility enables the investigator to alter the survey design on site based on preliminary processing and examination of measurement results.

1.0 System Components

The following lists describe the components of a Stratagem system. The Standard receiver system is configured to acquire data in a frequency range from 100 kHz to 11.7 Hz. The optional receiver components are used with the standard system for acquisition in the frequency range extending from 1000 Hz to 0.1 Hz. The standard components and their interconnection are illustrated in figures 1 and 2.

Standard receiver components

- 4 ea. stainless steel electrode stakes
- 1 ea. system ground stake and ground cable
- 4 ea. buffered electrodes with 26 meter telluric cables
- 1 ea. analog front end (AFE) module
- 2 ea. magnetic field coils (model BF6)
- 2 ea. standard coil/AFE interconnect cables
- 1 ea. Stratagem signal processing console
- 1 ea. IBM compatible keyboard
- 1 ea. console/AFE communication cable
- 1 ea. console power cable
- 1 ea. operation manual
- 1 ea. 12 volt deep-cycle battery (**NOT** included with lease-pool units)

Optional receiver components

- 4 ea. non-polarizing electrodes (Cu-CuSO₄ half-cell)
- 4 ea. 100 meter telluric cables
- 2 ea. model BF10 magnetic field coils
- 2 ea. 10 meter coil/AFE interconnect cables

Transmitter components - 400 A m² system

- 2 ea. transmitter antenna assemblies
- 1 ea. central grommet
- 1 ea. transmitter module
- 1 ea. transmitter power cable and ground stake assembly
- 1 ea. transmitter controller and cable assembly
- 1 ea. transmitter storage bag
- 1 ea. 12 volt, deep-cycle battery (**NOT** included with lease-pool units)

Transmitter components - 5000 A m² system

- 2 transmitter loop assemblies
- 1 grommet-terminated mast section
- 4 cleat terminated mast sections with guy-lines
- 7 extension mast sections
- 8 heavy gauge metal stakes
- 1 transmitter module
- 1 transmitter power cable and ground stake assembly
- 1 transmitter controller and cable assembly
- One 12 volt, deep-cycle battery

Additional useful equipment

- compass (preferred type is pocket transit for orienting and leveling magnetic sensors)
- torpedo level (for leveling magnetic sensors if no pocket transit available)
- measuring tape (at least 30 meters long) or hip-chain
- water containers (for storing water used to moisten non-polarizing electrodes)

shovel or entrenching tool (for burial of magnetic sensors and placement of non-polarizing electrodes)

small sledge or geologist's hammer (for setting steel electrodes in hard soil)

multimeter (voltmeter for checking batteries, ohm-meter for checking contact resistance and continuity)

colorful flagging or plastic traffic cones (for locating sounding sites)

walkie-talkie set and battery chargers (for communicating between transmitter and receiver site)

external frame backpacks (for carrying receiver gear on cross-country surveys)

Field note-book or clipboard (for keeping field notes and thermal printer output)

Battery charger(s) for 12 volt, deep-cycle batteries

Archival system: Time-series files can be too large for storage on high density diskettes, and typical production can generate from between 50 and 100 M-bytes of time-series data in a day. The Stratagem console's hard-drive can store about 1 G-bytes of data, so a weeklong survey is apt to fill the unit's hard-drive before the job is done. Suitable storage devices will be portable, high capacity, and compatible with an MS-DOS system equipped with a parallel port. A copy of the archival system's driver should be provided on an MS-DOS formatted diskette.

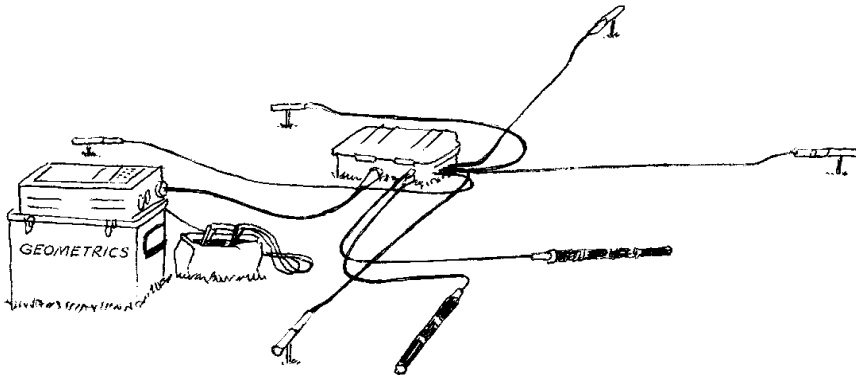
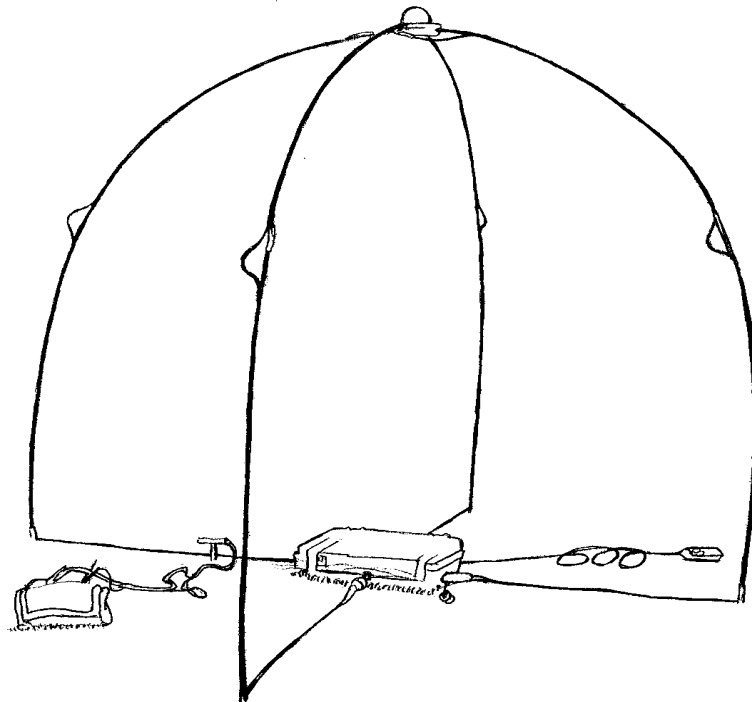


Figure 1. An illustration of the layout of the standard Stratagem receiver. All the components itemized for the standard receiver are shown here, with the exception of the keyboard.

Figure 2. An illustration of the standard Stratagem transmitter setup. All the components itemized on the 400 Am² transmitter component list are shown here.



2.0 System Initialization

Data base directory

Each time the Stratagem system turns on it automatically sets the working directory to the last created for data acquisition and executes the IMAGEM program. The system gets this directory information from a file in the IMAGEM directory named 'XQIMAGEM.BAT', WHICH is called from the console's 'AUTOEXEC.BAT' file on boot-up. This batch file configuration simplifies field procedure by only requiring the operator to turn the Stratagem on in order to access IMAGEM screen and its menu. Assuming that the console is correctly attach to the sensors, data collection can begin immediately after the unit is powered up. At this point, any data collected will be placed in the working directory and will automatically be assigned file names based on a fixed naming convention.

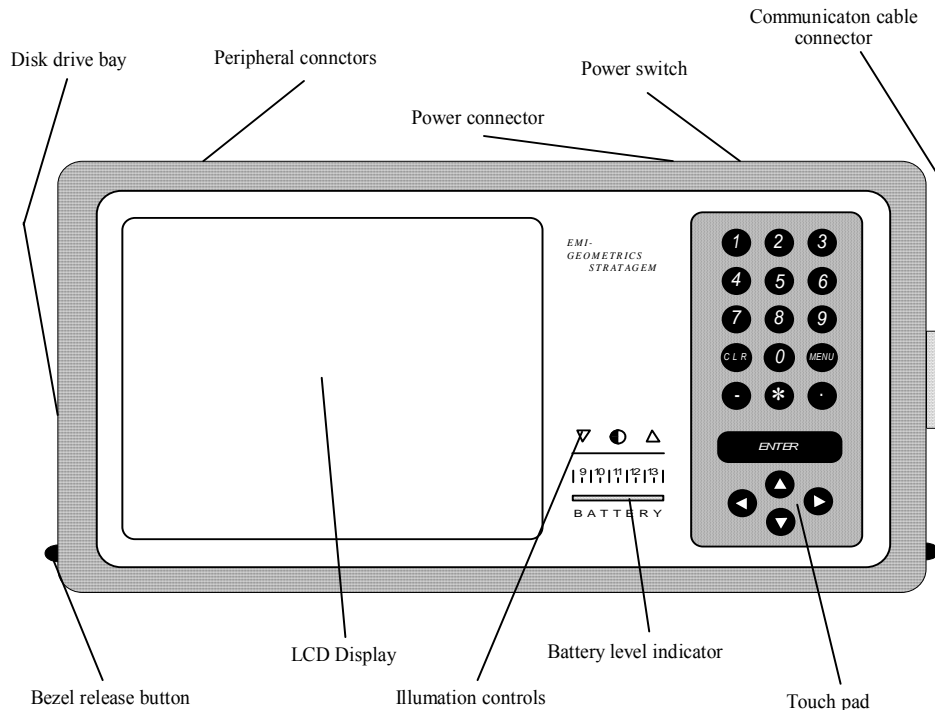


Figure 3. Top view of the Stratagem's bezel and faceplate. This assembly forms a hinged lid attached to the chassis of the console. By depressing the two buttons at the lower edge of the bezel, this lid may be lifted to gain access to the thermal printer below. All connections to the Stratagem console are through the ports located in bays on the chassis, just below the bezel. Instruments equipped for seismic data acquisition have additional connectors next to the communications connectors.

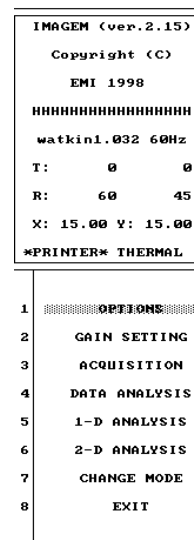
Standard initialization procedure

When a new survey begins, a new directory should be created for storing and processing the new data. This procedure is described below and may be done before arriving in the study area. The items needed are the Stratagem console, the console power cable, a 12-volt battery, and an IBM compatible keyboard. Also, in the instructions that follow, indications to type input imply that the input is terminated by pressing the 'ENTER' key. To create the data base directory:

- Connect the 12-volt car battery to the power port at the back of the console using the Stratagem power cable (Figure 3).
- Attach the computer keyboard to the external keyboard port at the back of the Stratagem console.

- Turn on the power switch at the back of the console and wait while the computer automatically loads the Stratagem software and draws the menu screen (Figure 4).
- Press the 'Esc' key. The IMAGEM program will ask if you wish to exit the program.
- Type '1'. This exits the IMAGEM program. The Stratagem receiver will now function as an IBM PC compatible computer running MS DOS.
- Type 'cd \'. This changes the working directory to the root directory.
- Type 'md DATA '. This command creates a directory named *DATA* for the storage of Stratagem data files. You should choose a directory name that is meaningful to you in regard to the name of the survey area or the nature of the survey. It is customary, but not necessary to use the same name for the directory as that specified for the survey (see 'Enter a survey name' below).
- Type 'IMAGEM'. This command runs the IMAGEM program. When running from a new directory, the program poses some queries and, based on your response, creates a group of setup files and writes them to the new directory. These queries and example responses are:
 - 'Enter the power line frequency (50 or 60 Hz)': type '50' or '60'. This entry selects the settings for system's notch filters. Enter the value, which applies, to your survey area.
 - 'Enter the starting file count (1-900)': type '###'. The number entered here is the beginning sounding number for the soundings recorded in this directory. This variable is useful in cases where more than one Stratagem system is being used on a single survey. It allows partitioning of the sound numbers by instrument. On a survey with only one system in use, a starting number of 001 would be appropriate.
 - 'Enter a survey name': type 'name'. All the sounding results will be stored with 'name' as part of their file name. The entry 'name' should be limited to a length of seven symbols in order to leave space for a prefix code that is automatically included in the data file name. For example, the first sounding for a survey named 'DATA' will write a file in the survey directory with a name 'ZDATA.001' if the starting file count entry was 001.
 - 'Enter X and Y dipole lengths': type '## ##'. This is the length of the x and y dipoles in meters. This entry requires two numbers separated with a space and they are the default x and y electrode spacing for the survey. The electrode length entry can also be modified on a site by site basis
 - 'Set up low frequency mode acquisition (y/n)': type 'y' or 'n'. If you intend to use the optional low-frequency sensors (BF-IM10) and electrodes (BE-LF), respond with the 'y' option. This will allow you to change between the standard high-frequency mode and the low-frequency mode. If you do not wish to collect the optional low-frequency soundings, type 'n'.

Figure 4. IMAGEM's status block and main menu. The status block shows IMAGEM's version number, the frequency mode selected ('HHHH' for high frequency mode), the last sounding number (watkin1.032), transmitter location (0 m, 0 m), receiver location (60 m, 45 m), the length of the x and y dipoles (15 m, 15 m), the printer selected (thermal for the Stratagem's internal printer). The various selections available from the main menu are described in the **Receiver operation** section.



Special initialization procedures

Spare coil replacement

Each magnetic sensor is calibrated and its calibration information is stored in data files, which must be used by the IMAGEM program to calculate the coil's response. If your system is equipped with a spare coil and this coil is put into use, the file named 'SENSORS.TBL' in the working directory must be modified to reflect the substitution of the spare coil and the calibration files supplied with the spare coil must be placed in the working directory. If you are substituting a spare coil, start by making a copy of the sensor file in the working directory by typing: 'COPY SENSORS.TBL SENSORS.BAK'.

A coil is supplied with at least two and possibly three files, which contain its calibration information. They will have names like '#####HXH6.', '#####HXL6.60H', or '#####HXL6.60H' where '#####' is an index from the coil's serial number. The 'X' in this example filename could also be a 'Y' or 'Z'. Copy these files to the working directory and take note of their names. Next, edit the file 'SENSORS.TBL' to include the names you have noted: this should only require changing the '#####' serial number portion of old calibration file name to that of the new file name. If you are uncertain about which lines in 'SENSORS.TBL' you need to edit, find the serial number on the coil which is being replaced and edit those lines which contain its serial number index followed with an 'H'.

Adding low frequency mode

Data acquisition in low frequency mode (1000Hz to 0.1 Hz) requires low frequency sensors and a low frequency location file. If low frequency acquisition was not enabled during initialization, a low frequency location file named '@L' was not created and will need to be created before low frequency data can be recorded in the current directory. The low frequency location file can be added to the current directory by following these steps: 1) exit IMAGEM and connect the keyboard; 2) rename the file '@' to '@.TMP'; 3) run IMAGEM and respond as before until you are asked about setting up for low frequency mode. Answer 'yes' to enable low frequency mode; 4) exit IMAGEM once it starts; 5) delete the file named '@' and 6) rename the file '@.TMP' to "@'. Now, when IMAGEM is run in the current directory, it will find the '@L' file and acquisition in low frequency mode can be selected.

Switching between STRATAVIEW and STRATAGEM

This procedure applies only to a console equipped as a combined StrataView/StrataGem instrument. A batch file called 'SEISOREM.BAT' is located in the directory 'D:\IMAGEM' and it contains commands needed to switch between using the instrument as a StrataView or a Stratagem. To set up the instrument for use as a Stratagem, enter the following command:

```
D:\IMAGEM\SEISOREM E
```

This changes the 'CONFIG.SYS' and 'AUTOEXEC.BAT' files to the Stratagem configuration. The system must be rebooted before using it to acquire MT data.

To use the instrument as a StrataView seismograph type the following command:

```
D:\IMAGEM\SEISOREM S
```

This will copy the 'CONFIG.SYS' and 'AUTOEXEC.BAT' file that set up the instrument for use as a StrataView. The console must be re-booted before it can be operated as a seismograph.

3.0 Field Operation

This section describes how to set up the Stratagem system and acquire soundings. In particular, we describe (1) receiver set-up and operation, (2) data collection and processing, and (3) use of the transmitter.

Prior to the physical deployment of the Stratagem hardware, you should have developed a survey plan and have created a data base directory on the Stratagem console. Creating a survey plan will be the more challenging of these two tasks since this will require you to make some decisions, which may affect the utility of the data set you produce. The survey plan is nothing more than the desired location of the various measurement sites and the frequency range recorded at these sites, but formulating an optimum survey plan will require that you consider limits on such things as field schedules, site access, acceptable horizontal resolution of the target structure, and the acceptable coverage of the target structure or the survey area. If a survey area is new to you, it is helpful to setup the system and acquire a sounding at a site which you are certain will have high priority and then base a preliminary survey plan on your observations at this initial site. Specific knowledge about the noise environment, geoelectric section, and the frequency range of interest will allow you to better estimate the recording time needed per sounding. This information will help in developing a realistic survey plan.

Receiver setup

All Stratagem cable connections are fitted with high quality, keyed, locking-ring connectors. These connectors are also capped. When cables are not connected they should be capped to prevent moisture and debris from fouling the electrical connection. When cables are connected, the caps should be mated to keep their inner surfaces clean and dry.

It is simplest to begin a station setup by placing the AFE at the center of the measurement site and use this component as a reference point for installation of the other components. Because the Stratagem measurements depend on the relative orientation of the sensors, it is also wise to select a reference direction for the survey. In the description that follows, this direction is referred to as 'X' direction. The 'Y' direction is 90° clockwise from 'X'. The complete layout is illustrated in Figure 1 and the recommended layout procedure follows.

Electrode installation

- If possible, select a site for the AFE, which is clear in the direction that the electrode cable will run.
- Install the system ground stake beside the AFE. Attach this stake (usually a spare electrode) to the threaded post on the side of the AFE module with the system ground cable.
- With a compass, find the precise orientation ($\pm 2^\circ$), relative to the site's central point, of both ends of the two perpendicular lines for the electrode cable run (+ and - 'X' and 'Y').
- For each electrode, lay out the electrode cable to the desired distance and insert an electrode stake to about half its length in the earth at that point. If the earth is hard, it may be necessary to drive the electrode stake with your boot-heel or a hammer. **DO NOT** drive an electrode stake while the buffered electrode is attached: these electrodes contain an active electronic circuit, which can be damaged by impact.
- After the electrode stake has been driven into the earth, or whenever attaching the buffered electrode to the stake, screw the buffered electrode into the stake until it is tight and then screw it back out 1/4 turn. Backing the electrode out 1/4 turn will prevent the threads from seizing due to differential thermal expansion.

- Return to the AFE to continue installing the remaining electric field sensors. On the way back, place the cable on the ground so as to minimize the effects of wind induced motion.
- Plug the electrode cables into the AFE; -'X' into X₀, +'X' into X₁, etc.

Coil installation

- Connect a coil cable (BFIM) to the 'X' coil and also to the 'HX' connection on the AFE.
- Lay the coil several meters from the AFE on ground that is fairly flat and level in the "X" direction. If no level spot is evident, use a hand-tool to excavate a suitable trench in which the coil can be leveled and aligned parallel to within +/- 2° of 'X'. Casting earth over the coil ensures that it will maintain its orientation and this also reduces microphonic wind-induced noise.
- Install the 'Y' coil following the same procedure used for the 'X' coil and locate it at least 2 meters from the 'X' coil. These coils are active electronic devices and, if placed too close together, they may interfere with one another. The coils also contain material with high magnetic susceptibility, which measurably distorts the local magnetic field. Because of this, the coils should be oriented using a technique which will keep the compass more than 0.5 meter from either coil.

Console setup

- Position the console 5 meters or more away from the AFE and coils and remove its lid. Connect it to the AFE with the serial cable. Note that the serial cable is of mixed gender: only one of its ends will mate with either component.
- Connect the car battery to the console with the power cable; BLACK to NEGATIVE and RED to POSITIVE. This completes the receiver setup. If the site installation was a team effort, it is wise to have one of the team members inspect the entire installation to insure that the sensors are correctly oriented and connected.

Receiver operation

The Stratagem console is powered by a 12-volt lead-acid battery via a console power cable. With the battery connected, the console is turned on by pressing the rocker switch on the back of the unit next to the power cable connector. It is important to securely clip the power cable leads to the battery for uninterrupted operation of the console. With the console switched on, the battery voltage is indicated by the lighted scale to the lower right of the computer screen. Screen illumination is adjustable using the button controls directly above the battery indicator. When power is turned on, the console computer performs a system check, loads DOS, and then runs IMAGEM which opens by displaying a status window and the main menu (Figure 3). The status window shows the version of IMAGEM, the name assigned to the last site recorded, the notch filter selection, the transmitter and receiver coordinates, and the dipole lengths.

Once the console is connected to the AFE and the sensors are connected to the AFE, gain setting or data acquisition can begin. The other IMAGEM functions can be used without the console being connected to the AFE. The use of IMAGEM is described in the following series of tables. These tables are structured as a series of figures depicting the various menus, prompts, and graphs comprising IMAGEM's user interface followed by an explanation. In general, data acquisition and processing follow the order in which the tables are presented.

The Stratagem console's faceplate incorporates a touch-pad labeled with number and function keys (Figure 4). All field data collection and processing can be controlled from the console's touch-pad; the IBM keyboard is not needed for operation once the survey data directory is created.

Console key	Function
1 2 3 4 5 6 7 8 9 0 - .	- Types the selected number, sign, or decimal point in the input field.
*	- Completely erases the input field
CLR	- Exit from an input field without action, - Exit from a menu without selection - Abort a time-series acquisition and return to main menu - Exit from IMAGEM and return to DOS (conformation requested)
MENU	- Print screen.
ENTER	- Accept input field. - Select highlighted menu item.
↑ ↓	- Move through menu items, up or down.
←	- Delete last character in input field.
→	- Insert space in entry field.

MAIN MENU	The IMAGEM program interface is composed of menus and structured input fields. All of these menus and input fields are accessed from the main menu. The status window above the main menu shows the version of IMAGEM, the acquisition mode (HHH for high, LLL for low), the root file name of the last sounding, the notch filter setting, the location of the transmitter (T:), the location of the last sounding (R:), the dipole lengths (X:, Y:), and the status of the printer port. The main menu selections are described below.
------------------	--

```

IMAGEM (ver.2.15)
  Copyright (C)
    EMI 1998
  HHHHHHHHHHHHHHHHHH
    rsh.006 60Hz
  T:    0    0
  R:    0    0
  X: 50.00 Y: 50.00
  *PRINTER* THERMAL
  
```

```

1  OPTIONS
2  GAIN SETTING
3  ACQUISITION
4  DATA ANALYSIS
5  1-D ANALYSIS
6  2-D ANALYSIS
7  CHANGE MODE
8  EXIT
  
```

OPTIONS calls the data display and data sorting options menu.

GAIN SETTINGS controls AFE gain settings.

ACQUISITION controls data acquisition setup and recording.

DATA ANALYSIS displays spectral information for selected soundings and is used to reprocess time-series data.

1-D ANALYSIS displays MT quantities for selected soundings and is used to reprocess crosspower data.

2-D ANALYSIS displays MT quantities for groups of soundings and is also used to perform spatial filtering and display of geoelectric sections.

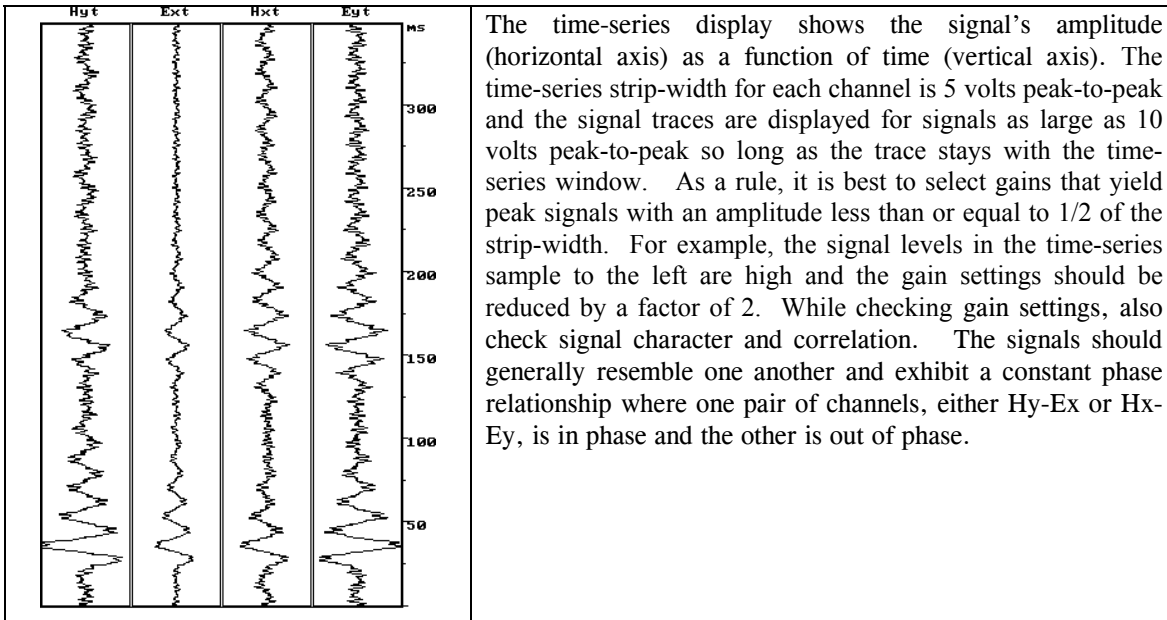
CHANGE MODE selects between the standard high frequency sensors and the low frequency ones.

EXIT quits the IMAGEM program and returns the console to DOS.

Selection of a menu item is done by using the ↑↓ keys to highlight the desired item and pressing the 'ENTER' key. Selection of a particular menu item can bring up another menu, bring up a screen with a numeric input field, or bring up a screen with a query field, depending on your choice. When numeric input is required, simply key in the number (or numbers separated by spaces) and press 'ENTER'. If a query field appears, the system requires a 'yes' or 'no' response and presents one of the responses as the default. To accept the default response press 'ENTER', otherwise press ← to clear the field, press '1' for 'yes' or '0' for 'no' and press 'ENTER' to complete the query response. Pressing 'ENTER' when an input field is empty is equal to 'no'.

OPTIONS MENU	Selecting OPTIONS draws another status window showing the current processing and display options and a menu for changing these options.
<pre> USE <ESC> TO QUIT 1: 0 0 0 2: TENSOR MODE 3: 100000 10 0 4: 1 100 0 5: 0 1000 100 6: 0.01 100 0 7: 0.50 0.75 8: 1 2 3 4 </pre>	<p>ANTENNA LOC allows modification of the antenna location coordinates. The change takes effect on the next sounding recorded and is stored in the location file. This file entry has no effect on measurement results or calculations and is used only for bookkeeping.</p> <p>SCALAR/TENSOR selects the data component used in the display of impedance results and for 2D analysis.</p> <p>FREQUENCY SCALE selects the frequency range for viewing spectral and MT quantities.</p> <p>RESIS. SCALE selects the range extremes for viewing apparent resistivity values.</p>
<pre> 1 ANTENNA LOC. 2 SCALAR / TENSOR 3 FREQUENCY SCALE 4 RESIS. SCALE 5 DEPTH SCALE 6 DATA SCALE 7 COHERENCY LIMIT 8 CHANGE CHANNEL 9 DEFAULT SETTING </pre>	<p>DEPTH SCALE selects the depth range for viewing the Bostick transform results.</p> <p>DATA SCALE selects the data range for viewing the spectral results.</p> <p>COHERENCY LIMIT selects the coherency cutoffs used in sorting the spectral and impedance data.</p> <p>CHANGE CHANNEL selects the channel designation for reprocessing data collected with sensors connect in an order different from the expected Hy, Ex, Hx, Ey.</p> <p>DEFAULT SETTING resets to the standard option settings.</p>
<p>The input field for FREQUENCY SCALE, DEPTH SCALE, and DATA SCALE options require three values; lower limit, upper limit, and increment. An increment value of zero specifies a log scale.</p>	

<p>GAIN SETTING</p>	<p>Selecting Gain Setting is used to check signal levels and change the amplifier gain settings prior to data acquisition. Selecting the Gain Setting option leads to a series of queries described below. Note that you are given two opportunities to quit the gain setting procedure. If you continue, time-series samples will be collected and displayed for all of the acquisition bands in the current frequency mode (3 bands in High Mode, 2 bands in Low Mode).</p>
<pre> AUTOMATIC GAIN SETTING (y=1/n=0/q=4)? _____ n </pre>	<p>You have the choice of using Automatic Gain Setting (AGS), manual gain selection, or quitting and returning to the Main Menu.</p>
<pre> PEAK AMPLITUDES Hy: 0.026nT Ex: 0.110mV Hx: 0.009nT Ey: 0.290mV CONTINUE GAIN SETTING? (Y=1/N=0) _____ y </pre>	<p>Selecting either AGS or manual gain setting will display information about the current signal levels, possibly display information about power line harmonics, and provide another opportunity to return to the Main Menu.</p>
<pre> High Pass Gains: E = 10, H = 20 ACCEPT by pressing ENTER REVIEW signal level by pressing 1 CHANGE by selecting new E and H (USE -1,1,2,4,8,10,20,40, or 80) </pre>	<p>If you choose to continue with gain setting, and have selected manual gain setting, a sample of filtered time-series data will be displayed and, to its right this status window/input field will appear. The status window shows the current gain settings for E channels and H channels at these filter settings and lists input options. Pressing 'ENTER' accepts the current gains for these filter settings. Pressing '1 ENTER' displays another time-series sample. Entering two numbers, from the list ('-1','1','2'...) followed with 'ENTER' selects new gains designated by these numbers and displays a time-series sample acquired with the new gains. The first of these two gain numbers is applied to both E channels and the second to both H channels. '-1' designates an attenuation factor of 10.</p>
<pre> E-GAIN: 10 H-GAIN 20 ACCEPT HIGHPASS GAIN(y=1/n=0) _____ y </pre>	<p>If you choose to continue with gain setting, and have selected AGS, a time-series sample will also be displayed and to its right a status field and input window will appear. The status window shows the gains selected for the current filter settings and the input field allows these gains to be accepted or rejected. If they are rejected, another sample is displayed and this menu reappears.</p>



ACQUISITION

The data acquisition procedure prompts for sounding site information and sounding parameters and records sounding data. Acquisition of a sounding may be done by recording several 'passes'. Each pass is composed of one or more time-series segments in a particular band. The data acquired during each pass is stored in a time-series file and is also partially processed and stored as a cumulative 'stack' of the crosspower results for all the passes recorded since the last sounding was completed. Impedance results for this stack are displayed at the end of each pass.

```

ENTER STATION LOCATION X Y Z (meters)
242.1 Mb FREE, LAST R:      0      60
.....

```

Enter the coordinates of the acquisition site. Entering a single number changes only the X coordinate and entering a pair of numbers changes the X and Y coordinates. The Z coordinate represents the site elevation and, while it is also recorded in the location file, it is not use by IMAGEM. Meters are specified because they are assumed in the 2-D analysis calculations.

```

ENTER DIPOLE LENGTH X & Y (meters)
(lengths are greater than 0 and less than 300m)
50 50.....

```

Edit the value appearing in the input window to specify the X and Y dipole lengths. These values must be provided in meters to obtain impedance results in ohm-meters.

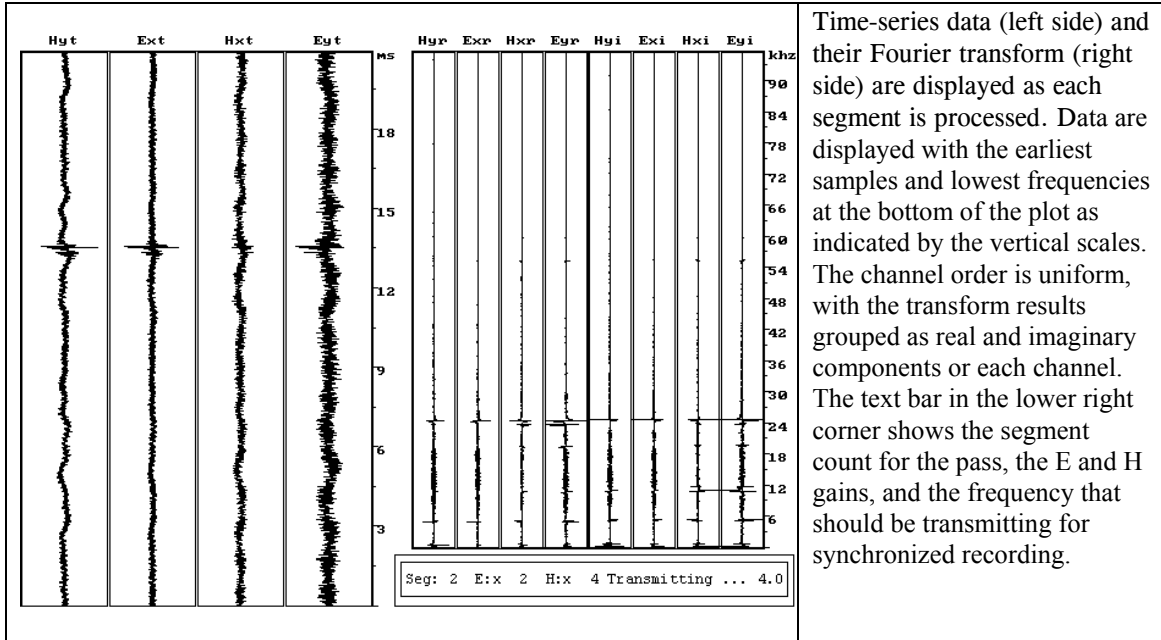
```

ENTER BAND & # SEGS.
BAND 1: 10 - 1KHz
BAND 4: 500 - 3KHz
BAND 7: 750 - 92KHz
0:SAVE, CLR:ABORT
XMT ON, USE <? 14>
1 1.....

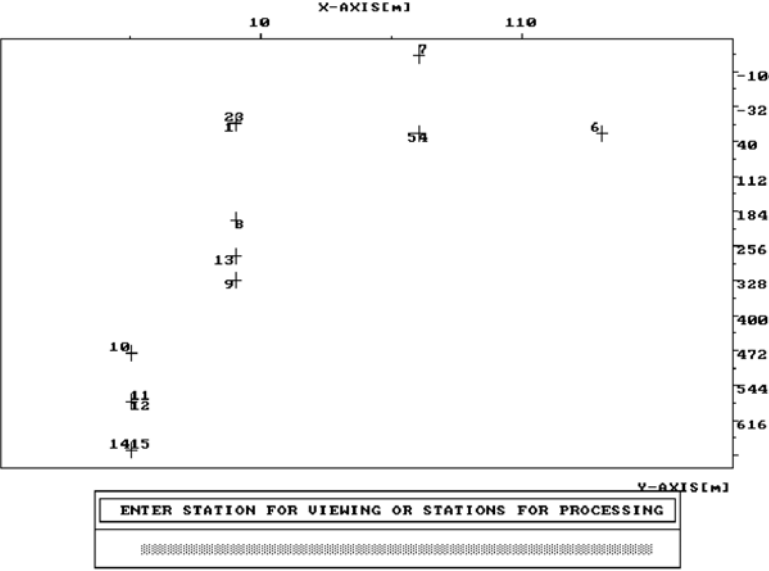
```

Edit the value appearing in the input window to specify the frequency band and the number of time-series segments you wish to record. Pressing 'ENTER' after entry of the band and segment count sends the band's gains and filter settings to the AFE and begins data acquisition. When the acquisition of a pass is complete, the segment count for each band is shown, the impedance results for the stack are displayed, and this menu reappears. You have the option of adding to the stack by repeating the procedure just described, saving the stack and returning to the main menu by entering 0, or aborting acquisition and clearing the stack by entering 'CLR'.

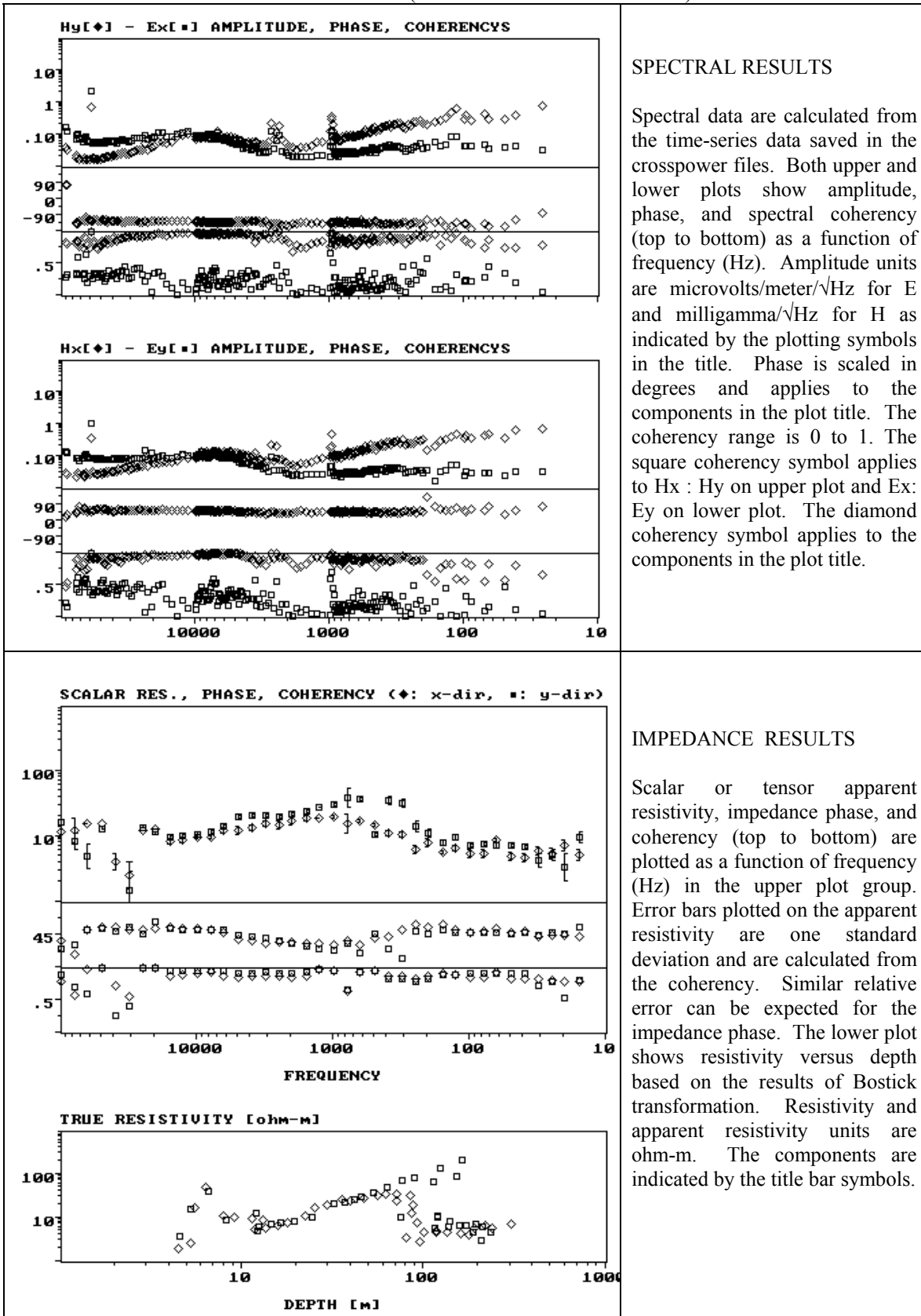
Synchronized Acquisition - When using the Stratagem transmitter, the preferred band and segment count is '7 14' indicating that band 7 will be recorded for 14 time-series segments. The transmitter is set to transmit each of its 14 different frequencies for a duration of 20 seconds. High frequency data acquisition takes about 14 seconds per segment so synchronization only requires that the transmitter controller button and the 'ENTER' key be pressed within about 3 seconds of one another.



ACQUISITION (continued)	
ABORTING ACQUISITION	Pressing and holding 'CLR' during time-series acquisition may be used to abort acquisition while acquiring data. If you use this feature, IMAGEM will return to the main menu.
<pre>DO YOU WANT TO ABORT THIS RECORD? (y=1/n=0) y</pre>	Acquisition can also be aborted between passes by pressing 'CLR'. In this case however, you will have the option to cancel the abort command by answering 'no' when this query prompt appears. This feature is included to permit recovery from an accidental keystroke.
<pre>TIME SERIES EXISTS! OVERWRITE IT (y/n)? y</pre>	If acquisition was aborted after some time-series data were collected, a time-series file will have been written to disk and will have been given the next name in the file sequence. This file is an orphan because its name has not been added to the location file. An orphan file causes the warning message at right when you next attempt to acquire data. The warning is a feature meant to prevent the accidental destruction of time-series data. If it appears, and you want to keep the data that was obtained from the aborted acquisition, you must exit IMAGEM and edit the location file so as to include this data file's name. Depending on when acquisition was aborted, it may be necessary to use the DATA ANALYSIS and the 1-D ANALYSIS procedures to finish processing the time-series results.

DATA ANALYSIS	DATA ANALYSIS is used for both reviewing existing spectral results and for recalculating crosspower values from time-series data. Recalculation of crosspower values using different coherency cutoffs is helpful when attempting to improve the impedance estimates for data with low signal to noise ratios.	
Selection of DATA ANALYSIS (or 1D ANALYSIS or 2D ANALYSIS) displays a sounding site map for soundings found in the location file. The map serves as a prompt for accurate entry of the soundings to be reviewed or reprocessed. DATA ANALYSIS options are selected on the basis of the number and order of the stations entered in the input window. These options are described below.		
	On the location map, sounding positions are indicated with a plus sign (+) and are identified by a label which is placed next to the plus sign. In order to accommodate multiple soundings, the sounding label is placed in one of the quadrants of the plus sign. In the example shown here, soundings 1, 2, and 3 were collected at the same site: there is no sounding 23. There are also no sounding numbers 54 or 1415 but there are soundings 4, 5, 14, and 15. To avoid confusion, remember that the spokes of the plus symbol divide the sounding labels.	
No entry	Use a null entry to return to the main menu.	
Enter one sounding number	IMAGEM reads the cross power file and displays spectral data.	
Enter two different sounding numbers (separated by a space)	This option selects automatic time-series reprocessing. The group of soundings specified by the two numbers is reprocessed using the present coherency cutoffs. In this mode, each segment of time-series data is displayed along with its Fourier transform as though the data were being recorded. When reprocessing of a sounding is finished, the crosspower file is written to disk and the spectral results are briefly displayed. Pressing 'CLR' will abort the automatic reprocessing and soundings which have not been completely reprocessed will not be written to disk.	
Enter a sounding number twice (separated by a space)	This input selects manual time-series reprocessing. The manual editing option also displays the time-series and transform results for the sounding number but waits for operator input after each segment is displayed. As indicated by the input field below the transform display, you can add this segment to the stack ('1'), reject this segment ('2'), or quit processing (enter '3'). Quitting processing saves the new cross power file to disk (with your permission) and displays the spectral results for the stack. The input prompt identifies the data segment by its count (C:) and location (L:) and displays its E and H gain settings. The segment count is just the segment number for the pass being reprocessed, and the location is the FFT number within the segment. Except for the lowest frequency band of the low frequency mode, all time-series segments are 12288 samples long and are processed as 3 FFTs, 4096 samples long.	
Because reprocessing overwrites the existing crosspower files ('X_files') in the working directory, you may wish to quit IMAGEM and copy existing crosspower files to a sub-directory whose name indicates the sorting used to produce this data.		

DATA DISPLAYS (for DATA and 1D ANALYSIS)




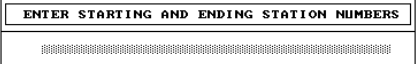

SPECTRAL RESULTS

Spectral data are calculated from the time-series data saved in the crosspower files. Both upper and lower plots show amplitude, phase, and spectral coherency (top to bottom) as a function of frequency (Hz). Amplitude units are microvolts/meter/ $\sqrt{\text{Hz}}$ for E and milligamma/ $\sqrt{\text{Hz}}$ for H as indicated by the plotting symbols in the title. Phase is scaled in degrees and applies to the components in the plot title. The coherency range is 0 to 1. The square coherency symbol applies to Hx : Hy on upper plot and Ex: Ey on lower plot. The diamond coherency symbol applies to the components in the plot title.

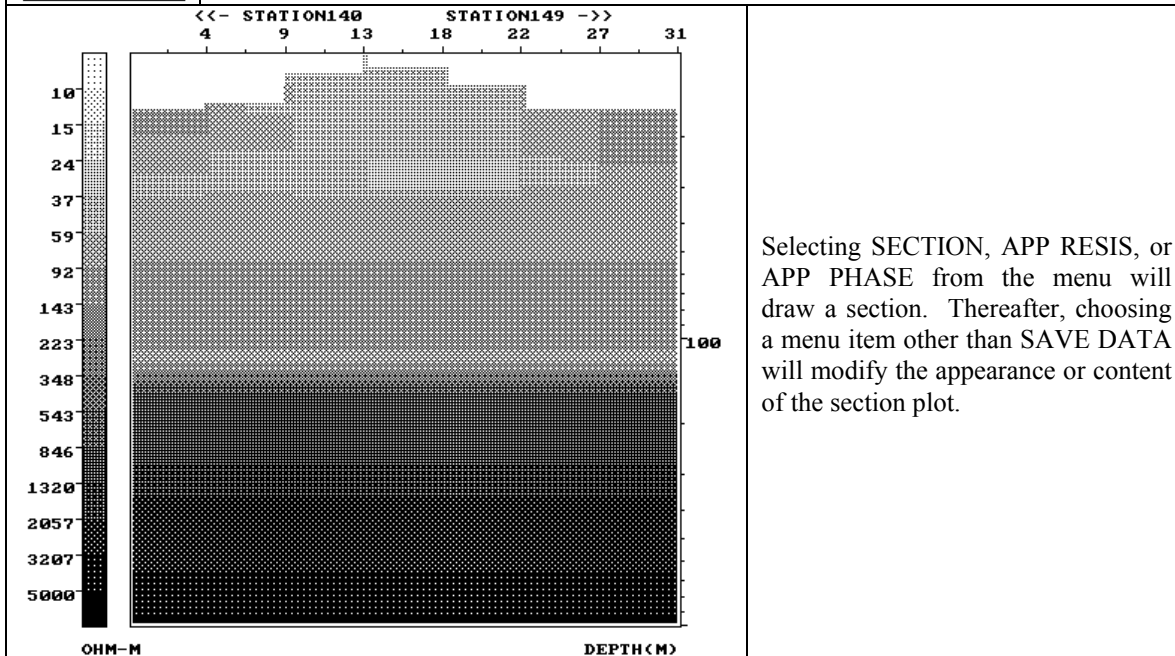
IMPEDANCE RESULTS

Scalar or tensor apparent resistivity, impedance phase, and coherency (top to bottom) are plotted as a function of frequency (Hz) in the upper plot group. Error bars plotted on the apparent resistivity are one standard deviation and are calculated from the coherency. Similar relative error can be expected for the impedance phase. The lower plot shows resistivity versus depth based on the results of Bostick transformation. Resistivity and apparent resistivity units are ohm-m. The components are indicated by the title bar symbols.

1-D ANALYSIS	This option is used for reviewing existing impedance results and calculating new impedance results from the crosspower data. Selection of this option will first display a site location map showing the relative location of the sounding numbers and an input field prompting for the entry of station numbers. (See DATA ANALYSIS for an example of the site location map.)
No entry	A null entry returns you to the main menu.
Enter a sounding number	IMAGEM reads the specified impedance file and displays the sounding results.
Enter a sounding number twice (separated by a space)	This option is used to recalculate and display the impedance results for the specified crosspower file. In this mode, the impedance data can also be edited. The apparent resistivity data are presented within highlighted bars which are selected on the basis of frequency using the arrow keys (← or →). The flashing highlight bar indicates the currently selected datum. The selected datum can be suppressed or restored by pressing 'ENTER'. Suppressed data are not used or displayed when using the 2-D option. Pressing 'CLR' generates a query, which asks if you wish to overwrite the existing impedance file. A positive response saves the edited impedance file and returns control to the main menu - a negative response returns control to the main menu without overwriting the impedance file.
Enter two different sounding numbers (separated by a space)	This option displays the impedance results for the included sounding numbers. The results are calculated from the crosspower files and, for each sounding, the display will pause with a query about printing the sounding's results. A sounding printed in this way include a complete sounding information block. It is necessary to use this option or the one above to update the impedance files from the regenerated crosspower files.
Enter three sounding numbers (separated by spaces)	Use this option to automatically suppress data at the same frequencies for those soundings specified inclusively by the first two numbers. The suppressed frequencies are those suppressed in the sounding specified by the third entry.

2-D ANALYSIS	Sounding results can be viewed in section and pseudosection using the 2-D Analysis function. Selection of this option first displays a site location map showing the relative location of the sounding numbers and an input field prompting for the entry of processing information and sounding numbers.
	The smoothing factor selects the length of the spatial filter that is applied to the data. A large factor produces a smoother section showing less structure, usually with better depth estimates. The direction factor specifies the orientation direction of the 2D section.
	Choosing an orientation of x (1) or y (2) specifies stations located along a line paralleling the x- or y-axis, respectively. Enter the starting and ending stations of the desired section.
	The xy orientation (3) allows selecting dispersed stations. As each station is specified, its impedance may be rotated by a specified amount to more accurately project its values onto the section. The order of station entry is important because this is the order they will be displayed. If a station's distance from the grid origin is not greater than the last station, it is not accepted for inclusion in the section. Entering a null field completes the station input.
2D ANALYSIS (continued)	

<pre> 2-D Zwatkin1 5 9- 14 FL: 11.70 FH:73600.00 XLEN: 60 [1] C= 1.0 <ESC> TO QUIT </pre>	<p>Once stations are selected for 2D Analysis, this status window and menu appears. The menu items described below are selected using the cursor and 'ENTER' keys.</p> <p>SECTION -- Selects ElectroMagnetic Array Profile (EMAP) transform display. This transform will apply the smoothing factor entered previously and now shown in the status window (C= ###).</p> <p>F - SCALE -- Changes the frequency scale range of the data included in the display. Limits are shown in status window. (FL: -- FH:)</p> <p>R - SCALE -- Changes the resistivity scale.</p> <p>X - SCALE -- Changes the horizontal scale of the display.</p> <p>Z - SCALE -- Changes the vertical scale of the display.</p> <p>APP RESIS -- Selects display of an apparent resistivity pseudosection.</p> <p>APP PHASE -- Selects display of an impedance phase pseudosection.</p> <p>SAVE DATA -- Saves the data currently displayed as an ASCII X, Y, Z formatted file.</p> <p>READ DATA -- Reads and displays previously saved X, Y, Z ASCII files.</p> <p>PIXELS -- Changes the cell count of the display region. More pixels give finer shading; fewer pixels yields more averaging and a block-like appearance.</p>
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MODE	Switch frequency modes. This option only has an effect if the low frequency option was selected during system setup. The MODE switch has no function without the low frequency log file created during system setup. Low frequency operation also requires non-standard sensors and their calibration files. The low frequency recording range extends from 1000 Hz to 0.1 Hz.
-------------	--

EXIT	This selection prompts for conformation about quitting IMAGEM.
<pre> DO YOU WANT TO EXIT PROGRAM (y=1/n=0)? </pre>	Answering yes quits IMAGEM and returns to DOS. No data will be lost if IMAGEM is exited accidentally. To restart, type 'IMAGEM' at the DOS command prompt or, power-cycle the console.

Transmitter set up

Transmitter Location

IMAGEM calculates the plane-wave impedance of the earth at the measurement site. For this calculation to be valid, the measurement site must be sufficiently distant from the transmitter to be located in what is termed the transmitter's far-field. As a rule, the far field begins three skin depths from the transmitter. A skin depth δ for earth resistivity ρ at frequency f is given by:

$$\delta = 500 \sqrt{\frac{\rho}{f}} \quad (\text{meters}).$$

This formula and the far-field rule have been combined as a chart in figure 5 where far-field distance is plotted versus frequency for a family of curves representing discrete earth resistivities. In order to use this chart correctly, you will need an accurate estimate of the earth's gross resistivity between the transmitter and receiver. In the absence of any knowledge about the geoelectric character of the survey area, begin by placing the transmitter 250 meters from the receiver site (500 meters for the large-moment transmitter). Refer to the section of this manual titled Data Appraisal for a description of near-field effects.

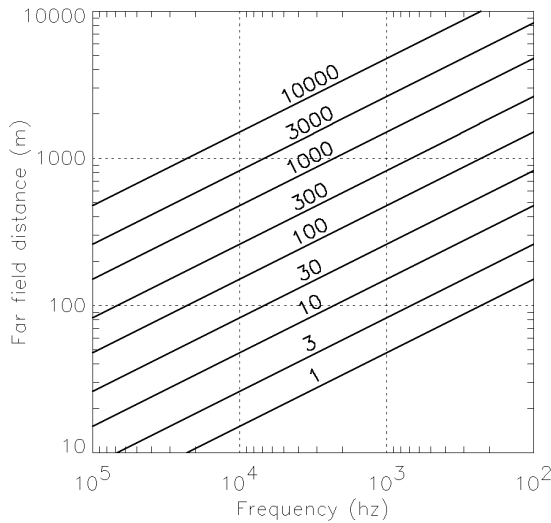


Figure 5. Far-field distances for various earth resistivities. This chart is used to predict the offset between the Stratagem's transmitter and receiver needed to acquire measurements in the transmitter's far-field region. If, for example, the earth beneath the survey area is 30 ohm-m, then the far-field for 1000 Hz is found to be 250 meters on the vertical axis by locating the intersection of the 1000 Hz and 30 ohm-m line.

Two different sized transmitters are available for use with the Stratagem: a small moment unit (400 A m^2) and a large moment unit (5000 A m^2). The large moment antenna is recommended in areas with an average resistivity of 500 ohm-meters or greater. The greater magnetic moment will allow it to be located up to twice as far away from the transmitter as the standard antenna. Under ideal circumstances, the maximum useful separation between the receiver and the standard and large moment transmitters is approximately 400 and 800 meters, respectively. Transmitter frequencies for the standard antenna are from 800 Hz to 64 kHz and for the large-loop antenna range from 400 Hz to 32 kHz.

400 A m² transmitter assembly

- The layout of either transmitter is easiest on level, open ground.
- Remove all transmitter components for their storage bag.
- Fully extend the 2 transmitter antenna assemblies and lay one atop the other to form a cross. At this point, the 4 sections of each rod-loop assembly are disconnected.
- Connect the 2 antenna assemblies by sliding the antenna rods into the central grommet where they meet at the center of the cross.

- Connect the remaining antenna sections by sliding the antenna rods into the opposing sockets.
- Form the articulated antennas into a pair of bows by clipping the cord at the end of each antenna to the ring at its opposite end.
- Flip one of the antenna bows into a vertical position and then the other. The assembled antenna will be free standing when the planes defined by the antenna bows are perpendicular. (See Figure 2)
- Lay the transmitter module flat on the point where the antenna cords cross. Connect the antenna cables to the module with each cable's ends connected to opposite sides of the module
- Connect the transmitter controller switch to the transmitter module.
- Connect the transmitter battery cable to the module. Drive the ground stake attached to the battery cable into the earth.
- Connect the battery cable to the 12 volts car battery, BLACK to NEGATIVE, RED to POSITIVE.

5000 A m² transmitter assembly

- This procedure requires 2 people. In you're alone, get help.
- Locate the tape marks on the transmitter cables that indicate the cable's center and corners.
- Layout the cables to form a cross with their intersection at the center mark.
- At the corner mark, attach a mast section that is terminated with a cleat. This is done by removing the cleat pin, placing the cable in the slot, and reinserting the cleat pin. The corner mark should be at the pin.
- Attach an additional section of mast to the cleat section and bring it to a vertical position. Have your assistant play out first one guy-line and then the other to form a 'V' that points at the cable's center mark.
- While bracing the mast have your assistant tie off the guy-lines on driven stakes. On completion, the corner mast should be free standing and vertical being braced by the guy-lines and the slack transmitter cable.
- Repeat the corner mast installation on the opposite side of the transmitter cable. Position this mast so that, when vertical, the center point of the cable is just touching the ground.
- Install the corner masts on the other transmitter loop.
- Place the cables in the slotted grommet attached to mast section and bring the mast section to vertical.
- Raise the mast section and have your assistant insert another mast section beneath it. Repeat until the central mast is 4 sections high.
- Revisit each corner mast to check that they are vertical and are well tied off. Some tension adjustments on some guy-lines may be needed to keep all the masts vertical and all the suspended cable taut.

- Install the remaining transmitter components as described above for the small moment unit.

Transmitter operation

The Stratagem transmitter is self-tuning. It is designed to sense its load and transmit an optimum suite of frequencies. Because of this, the large moment transmitter's output is about an octave lower than that of the standard transmitter. Such transmitter variation is of no operational concern: the Stratagem system is sensitive to all frequencies within its acquisition band.

The transmitter is operated by a switch at the end of the 5 m controller cable. The transmitting frequencies are changed automatically with the same cycle rate as the receiver's data acquisition software. It is therefore important that the onset of signal transmission begin within two or three seconds of the start of the synchronous acquisition band. This may be accomplished by signaling between the receiver and transmitter or by following a transmit and receive schedule. Experience has shown that signaling via hand-held radios is the better of these two options.

Controlled source acquisition is simple. The receiver operator selects the data acquisition option and sets the band particulars at '7 14'. When the transmitter operator has pressed the transmitter switch, the receiver operator presses 'ENTER'. Close examination of the time-series and Fourier transform display should show evidence to the transmitter's signal. The indicator lights on the controller switch will blink with a varying rhythm while it operates and when they stop the transmit run is finished (about 4.5 minutes). In the event of a false start at the transmitter, the transmit sequence can be restarted at any time by pressing the start button.

During the course of a typical survey it will be necessary to move the transmitter. If the standard transmitter is not being moved far, and path to the new location is clear of obstacles, it is simplest to lift the assembled antenna dome and carry it. The standard antenna weighs only a few kg, so this move may be done with two people or by a single person in two trips by the following procedure:

- Disconnect the battery.
- Disconnect the antenna cables from the transmitter module and replace the end caps.
- Attach the cables to the antenna poles using tie-wraps or the end cap tethers.
- Lift the antenna and carry it as a unit to the new site.
- Move the transmitter module, control switch, and battery to the new site.
- Attach the cables to the transmitter module.
- Attach the switch and control line.
- Attach the power supply cable and battery to the transmitter control module.
- Check all connections and cables.
- Standby for the receiver operator's transmit start signal.

Transmitter safety considerations

The Stratagem transmitter is designed for safe and convenient field operation. Some simple operating rules will make the system run smoother and safer.

- Wherever possible, set the antenna ground stake. Although this may not be possible when the ground is frozen or rocky or when the site is paved, good grounding makes the system safer.
- When operating the transmitter, stand at least 3 m away from the antenna dome.
- Always connect the power last at set-up and disconnect it first at tear down.

4.0 Trouble-shooting

The Stratagem system is designed to collect high frequency MT data in difficult areas. If the system is not performing as you expect and the reason is not obvious, you will need to do some trouble shooting. This section contains a set of tables to quickly locate procedures most likely to resolve a problem with the system. We recommend that you read through this chapter completely before fielding the system for the first time. Remember that the Stratagem has a printer and that pressing the 'MENU' key on the console prints the current screen. In the course of trouble shooting it is easy to become confused about the effect of a prior action. Printing the result of each test and annotating the printout should help you proceed systematically.

Data Appraisal

Trouble must be observed before trouble-shooting begins and, for the Stratagem system, this means reading and understanding the results seen in the various data displays. Described in the preceding section, these displays are the time-series display, the power spectra display, and the impedance results display.

Signal correlation

The naturally generated magnetotelluric field is the super-position of random signals at many frequencies and is expected to appear chaotic. Nevertheless, natural field events are usually correlated among all four channels. Also, the electric and magnetic fields are coupled for the sources we are interested in, so the time-series signature of a particular channel should appear similar to its complimentary orthogonal component. This means that the phase and amplitude of E_y should resemble H_x and the phase and amplitude of E_x should resemble H_y . You should be suspicious whenever one channel is frequently uncorrelated with the others or is constantly off scale. Such conditions are usually first seen during the gain-setting procedure and, rather than continuing with routine recording, you should start trouble shooting when you see them.

Noise contamination or instrument malfunction of a more subtle nature may not be apparent in the time-series display but should be evident in the coherency data on either the spectral display or the impedance display. In particular, you should suspect an instrument problem if the coherency of one impedance mode is consistently low. Also be suspicious when like channels (E_x - E_y or H_x - H_y) have consistently high spectral coherency. An extreme structural discontinuity could create these types of coherency relationships but the more common culprits are cultural noise sources or component malfunctions.

Correlation of impedance components

A particular relationship is expected between the apparent resistivity curve and the impedance phase curve for valid sounding results. This relationship applies to either mode and is:

$$\phi = \frac{\pi}{4} \left(1 - \frac{\partial(\log \rho_a)}{\partial(\log T)} \right)$$

where ϕ is impedance phase, ρ_a is apparent resistivity, and T is period. It means that you should observe a dip in the phase response when you see an increase in the apparent resistivity as the period increases (frequency decreases). Conversely, an increase in the phase response should accompany a decrease in the apparent resistivity as period increases. Slight departures from this relationship are expected because of the normal low-level scatter in the data but when an entire portion of the sounding curve fails to obey it, the probable cause is that bias was introduced by cultural noise sources. As a rule, if the impedance phase is excessively high, the noise source is inductive. This type of noise can be observed by placing the Stratagem's transmitter too close to the receiver for the plane wave assumption to be valid. Similarly, noise signals that depress the phase below its expected value are due to grounded electrical sources. Soundings in remote areas with high contact resistance are apt to yield soundings with abnormally low impedance

phase values for those portions of the sounding where natural field strength are low: the elevated electrode noise arising from the high contact resistance is the noise source. A similar effect is produced when spurious current is injected near the receiver site: The current in the noise source generates a magnetic field that is abnormally low relative to the voltage variations detected by the electrical field sensors.

Station placement

Is the system malfunctioning or is there is a problem with the measurement site? Measure sites should be placed well away from sources of electrical power generation and consumption and sites with mechanical activity. These sources include power lines of any size, electric fences, pipelines with cathodic protection, radio transmitters, metal windmills, and operating engines of all kinds. If you suspect that cultural noise is the source of a problem, its influence should disappear or be greatly reduced if you double the distance between it and the receiver site. Quiet receiver sites and good transmitter sites should avoid close proximity to large aggregations of metal such as stacked drill rod or irrigation pipe, railroads, metal sheds, and massive metal fences. Stock fencing is not a problem unless it is within several meters from the receiver coils.

Sensor vibration caused by the wind or flowing water will introduce noise into the sensors and, particularly when making measurements in the low frequency mode, will degrade the quality of the sounding. When making measurements in the high frequency mode, excessive vibration of the magnetic sensors may drive their output amplifiers into saturation. Burial of the magnetic sensors may be necessary to reduce wind vibration to an acceptable level.

It is not always possible to avoid noisy sites, but it is important to be able to differentiate between them and problems with the measurement equipment. For this reason, you should consider starting a survey with soundings at those sites that appear to be in an area relatively free of culturally generated noise. Later, if equipment problems are suspected, the first site can be reoccupied for a system check.

Parallel sensor test

The goal of trouble-shooting is to isolate the cause of a problem. Because the Stratagem has two sets of sensors, isolating sensor problems can be accomplished by comparing sensor output. This technique is called a parallel sensor test. The procedure is similar to setting up the system to acquire a normal sounding. Instead of placing the magnetic field sensors at right angles, however, they are laid flat and parallel to one another about two meters apart. The telluric channels are also laid out in a parallel fashion: the X0 and Y0 electrodes are inserted in the earth at a common point and the X1 and Y1 electrodes are also inserted in earth at another common point. It is best if the orientation of the telluric lines is perpendicular to the orientation of the magnetic field sensors.

During gain setting and acquisition, the electric field channels on the time-series display should be identical, as should the magnetic field display. The proper measurement result of the parallel sensor layout is a set of similar spectra and sounding curves for the two impedance modes. This means that the spectral coherency of like channels (Ex-Ey or Hx-Hy) should be high for a parallel sensor test. If the system is trouble-free, differences between the two modes should be very small and low spectral coherency should be restricted to the portion of the spectrum where field strengths are lowest. These are frequencies where low signal strength allows the system's noise floor to account for a proportionately larger fraction of the measured signal. If it is windy and significant differences in the modes are seen at lower frequencies, the coils may need burial to suppress wind induced noise. It is wise to always begin a new survey with a parallel sensor test and repeat it from time to time as a means of gaining assurance that the system's sensors and signal conditioning components are functioning properly.

Gain settings

It has been found that some gain settings can degrade the data quality when recording near powerful radio transmitters. This is a result of the placement of AFE's first two gain stages ahead of its various filter elements (Figure 5). This design has the advantage of increasing the Stratagem's sensitivity in the higher frequencies where signal strengths are relatively low. The low-frequency degradation is caused by high frequency saturation in one of the gain stages ahead of the filter elements, and it is difficult to see in the

lower frequency time-series data because of the smoothing effects of the low-pass filter and notch stages. The remedy for this degradation is to reduce the gains. Use the gains settings found to be acceptable in the high frequency band as a guide for setting the low frequency gains when you suspect high frequency saturation. These band and gain combinations are summarized in the following table.

If the maximum HF gain is:	Use LF and BP gains of:
x1	x1 or x10
x2	x1, x2, or x10
x4	any gain except x80
x8 or greater	any gain

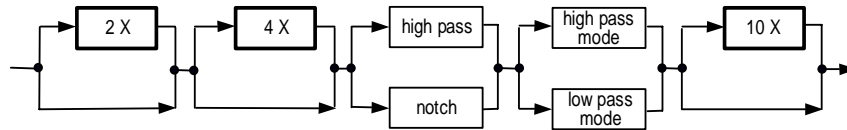


Figure 5. The signal path through the AFE consists of five serial blocks with each block containing two pathways. Gain pathways are set so that their product equals the value chosen during the gain setting procedure. The high-pass/low-pass mode pathways are selected using the mode option in the main menu. The high-pass/notch pathways are set automatically depending on the mode setting and the high-pass mode band selection.

Contacting Geometrics

If you are unable to isolate or correct a problem with the Stratagem system, you should contact Geometrics and be prepared to provide specific information about the problem. Communicating directly with Geometric's technical staff is best when the data values appear to be incorrect. If this is impractical because of time zone differences or field schedules, try to send examples of the problem, either as printout or data files. Also indicate which system you have and describe environmental conditions in the study area.

Hardware trouble shooting guide

RECEIVER NOT WORKING		
symptom	possible cause	remedy
Stratagem won't turn on or turns off soon after turn on	Low battery	Check battery with multi-meter and replace or recharge battery if below 11 volts under load.
Stratagem won't turn on	Battery cable not well connected	Check for correct polarity and clean, tight connections at battery terminals.
	Broken battery cable	Disconnect power cable and check for continuity and isolation with multi-meter.
	Blown fuse	Check fuse with multi-meter. If blown, replace fuse only with one of equal type and rating. Fuse is located in printer bay to the left of the printer stand. Note: a blown fuse is usually an indication of another electrical problem. If problem repeats, note conditions and contact Geometrics.
	Console malfunction	The console power supply may be faulty and can be check by examining its status as indicated by LED lamps inside the console case. Before doing this, contact Geometrics. Also, operation in extreme temperatures can be a factor in instrument failure. Avoid operating below -15 C or above 40 C in direct sunlight.
System taking too long to finish sounding and show results.	System hard disk almost full and DOS is searching for small empty fragments of disk space.	The first prompt that appears after selecting ACQUISITION reports the amount of storage remaining on the console hard-drive. If is full, archive all data files and delete time-series files from console hard drive.
Time series on all channels appears dead	Communication cable not well connected	Disconnect and reconnect comm. cable. Note: comm. cable is bi-gender and connections must match with component.
Time series display shows one dead channel	Poor connection between cable and component	Check connections. Make sure contacts are clean and dry and that connector's locking ring is engaged. Visually check for damaged cable or connector. Replace if damaged.
	Bad sensor or sensor cable or signal channel	The most efficient strategy for isolating a dead component is to divide the troublesome portion of the system in two and discover in which half the problem lies. If, for example, a magnetic field channel appeared to be dead, start by interchanging coil cable inputs to the AFE and then view another time-series sample in using Gain Setting. If the dead channel now appears to be the other magnetic component, the problem is with the cable or coil: otherwise the problem is in the AFE, comm. cable, or console. In this way you can locate the individual sensor or cable that is not working and replace it with a spare. If you don't have a spare for the failed component, contact Geometrics.
Console screen blank	Adjusted screen intensity	Use the illumination controls on the console's faceplate to change the screen intensity.
	Screen is over-heated by long exposure to direct sunlight	Shade the console screen and wait for it to cool sufficiently for visual contrast.

	Power supply fault	Open console's lid and see if any of the three green LED's are dim or off. If so, contact Geometrics
No printer output	Out of paper or improper paper feed	Open console lid and replace or re-feed paper. Paper replacement instructions are listed on underside of lid.
	Ribbon cable disconnected	Check that the blue ribbon cable is connected to the parallel port at the back of the console.

MEASUREMENT RESULTS ARE SUSPECT		
symptom	possible cause	remedy
Signal levels of electric field channels significantly different than magnetic channel levels	most likely not a problem	Electric fields will be high on resistive earth and low on conductive earth. Use GAIN SETTING to obtain reasonable signal levels.
Signature of one or both E-field channels looks odd	possibly a bad installation	Check E-field sensor connections, check electrode installation, check for ground stake installation and connection. Also examine the pins and sockets on the electric field sensor's connectors at the AFE. Look for bent pins or sockets that have been pushed back into their rubber housing.
	possibly poor contact conditions	If the ground is frozen or rocky, consider moving the electrode to a nearby spot with better contact conditions or engineer a better contact point by the addition of soil, anti-freeze/salt mixtures, or clay and water. As a rule, lower contact, resistance translates into better data and the extra effort needed to lower contact resistance below about 10 k-ohms is usually worth while. Ground contact problems are more common at lower frequencies where nonpolarizing electrodes are used. When using nonpolarizing electrodes, we recommend checking contact conditions on each dipole with a multimeter before acquiring data.
Signature of one channel looks odd	possibly a bad channel	Perform a parallel sensor test. If a component is malfunctioning, it can be isolated by performing a series of parallel sensor tests in conjunction with a component interchange procedure as described above. A negative result indicates that the odd looking signal is the peculiar to the site.
	site specific	Near surface structures can noticeably affect the appearance of signal. Compare sounding results with those from adjacent sites. Consider reoccupying and re-record a prior site for performance comparison.

TRANSMITTER NOT WORKING		
symptom	possible cause	remedy
No indicator lights on transmit	Low battery	Check battery with multi-meter; recharge or replace if standby voltage is below 12.0 volts.
	Bad installation	Check the installation. The battery polarity may be wrong, antennas may not be connected to the transmitter, or controller cable is not connected.

	Blown fuse	There is a fuse inside the transmitter. Before checking this fuse, DISCONNECT THE TRANSMITTER FROM THE BATTERY. It will be necessary to remove the fasteners securing the transmitter's lid to inspect the fuse. Remove the fuse from its holder on the circuit board on the upper left-hand side of the transmitter and check its continuity with an ohm-meter. If it is open, replace it with a new fuse having an identical rating. Failure to use an identical fuse can cause serious damage to the transmitter. Before reconnecting the battery to the transmitter, close its lid and reinstall the fasteners.
	Broken component(s)	Contact Geometrics.
One indicator light not on	Bad installation	The antenna on slave circuit is not connected to transmitter. Turn off power and check antenna connection.
	Broken component	Contact Geometrics
Transmitter signal not apparent in received signal	Transmitter located too far from receiver.	Move the transmitter closer to the receiver site. You should be able to see the transmitter's signal in the time-series data when the standard transmitter is within 200 m of the site (400 m for the large moment transmitter).
	High noise levels at receiver site.	If coherent noise levels are high at the receiver site they may overpower the transmitter's signal. Turn off noise source or move site.

5.0 Theory

Electromagnetic waves

The electromagnetic waves of interest to the MT practitioner are described by Maxwell's equations. In differential form they are

$$\nabla \times \mathbf{E} = -i\omega\mu\mathbf{H} \quad (\text{Faraday's Law}) \quad (1)$$

$$\nabla \times \mathbf{H} = (\sigma + i\omega\varepsilon)\mathbf{E} \quad (\text{Ampere's Law}) \quad (2)$$

$$\nabla \cdot \mathbf{H} = 0 \quad (3)$$

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon \quad (\text{Coulomb's Law}) \quad (4)$$

where \mathbf{E} is the electric field, \mathbf{H} is the magnetic field, σ is conductivity, ε is permittivity, and ρ is free electric charge. Here the notation \mathbf{E} and \mathbf{H} indicates vector harmonic time dependency

$$e^{-i\omega t} = \cos(\omega t) - i \sin(\omega t)$$

so that the peak instantaneous vector value \mathcal{E} of \mathbf{E} is given by

$$\mathbf{E} = \text{Re}(\mathbf{E}e^{i\omega t}).$$

where ω is angular frequency ($2\pi f$), $i=\sqrt{-1}$, t is time and Re indicates the real part. A differential equation for \mathbf{E} is obtained by taking the curl of equation (1) and substituting equation (2) to get

$$\nabla \times \nabla \times \mathbf{E} = -i\omega\mu(\sigma + i\omega\varepsilon)\mathbf{E}.$$

It is customary to let $k^2 = -i\omega\mu\sigma + \omega^2 \mu\varepsilon$ and apply the vector identity

$$\nabla \times \nabla \times \mathbf{A} = -\nabla^2 \mathbf{A} + \nabla(\nabla \cdot \mathbf{A})$$

to obtain

$$\nabla^2 \mathbf{E} + k^2 \mathbf{E} = 0, \quad (5)$$

where we have also assumed that there is no free charge present ($\tilde{\mathbf{N}} \cdot \mathbf{E} = 0$). Equation (5) is the Helmholtz equation for \mathbf{E} and k is the propagation constant. The source of MT signals is in the atmosphere where the conductivity is near 0, and here the propagation constant is

$$k = \omega\sqrt{\mu_0 \varepsilon_0}.$$

In the earth

$$k \approx \sqrt{-i\omega\mu\sigma}$$

because, for earth materials, $\sigma \gg \omega\varepsilon$ at the frequencies we are interested in.

Propagation of electromagnetic waves

A fundamental assumption when interpreting MT measurements is that the source fields impinge on the earth as uniform plane waves: the \mathbf{E} and \mathbf{H} fields are constant in planes perpendicular to the direction of propagation. For a plane wave propagating into a uniform earth, where the z direction is positive

downward, we need only consider the field components E_x and H_y and can set the other components of the \mathbf{E} and \mathbf{H} fields to zero. With

$$\nabla^2 \times \mathbf{E} = \nabla^2 E_x \hat{x} + \nabla^2 E_y \hat{y} + \nabla^2 E_z \hat{z}$$

equation (5) becomes

$$\frac{d^2 E_x}{dz^2} + k^2 E_x = 0 \quad (6)$$

because the plane wave does not vary in the x and y directions. This differential equation has a general solution

$$E_x = E_0^+ e^{-ikz} + E_0^- e^{ikz}$$

where the coefficients E_0^+ and E_0^- are constants which can be found by applying boundary conditions. Because of the requirement that a wave not gain amplitude in the direction of propagation, the coefficients E_0^+ and E_0^- represent the amplitudes of the electric field waves traveling in the +z direction (downward) and -z direction (upward) respectively. For a plane wave propagating in a uniform earth, E_x is 0 at an infinite depth because we are infinitely far from the plane wave source. This implies that E_0^- represents the amplitude of a reflected wave, and in a uniform earth where there are no reflectors, its amplitude must also be zero. So

$$E_x = E_0^+ e^{-ikz} = E_0^+ e^{-iz\sqrt{-i\omega\mu\sigma}} = E_0^+ e^{-z(1+i)\sqrt{\omega\mu\sigma/2}}$$

or

$$E_x = E_0^+ e^{-z\sqrt{\omega\mu\sigma/2}} e^{-iz\sqrt{\omega\mu\sigma/2}} .$$

The term with the imaginary exponent represents the wave component of the electric field and the term with the real exponent defines the decay of the wave's amplitude with depth. It is convenient to specify distance in terms of the wavelength and, where EM waves penetrate conductors, it is customary to use one radian as the standard distance. This distance is called a skin depth. One wavelength is 2π radians so one skin depth is a bit less than one sixth of a wavelength. Wavelength is given by

$$\lambda = \frac{2\pi}{\kappa}$$

so one skin depth is given by

$$\delta = \frac{1}{\kappa}$$

where the wave number κ is

$$\kappa = \sqrt{\frac{\omega\mu\sigma}{2}} \text{ so}$$

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} = \sqrt{\frac{1}{4\pi^2 10^{-7}}} \sqrt{\frac{\rho}{f}} \approx 503 \sqrt{\frac{\rho}{f}} \text{ (meters)}$$

At the earth's surface ($z = 0$) and from equation 6, $E_x(0) = E_0^+$. At the skin depth δ , the amplitude of the down-going wave has decreased to

$$E_x(\delta) = E_0^+ e^{-1}$$

which is 1/e or about 37 percent of its surface value. If a reflective layer existed at a depth δ , then the reflected, up-going wave would also be attenuated by 37 percent resulting in a total attenuation of about 86 percent relative to the surface value of the down going wave.

The presence of uniform plane-waves implies that the wave's source is distant: nearby sources are likely to generate waves with a spherical wave front that will not be uniform in the survey area. If sources are nearby, equations 1 and 2 are incomplete; they lack the appropriate source terms for a complete description of the fields and their interaction. Because it is difficult to specify sources that are beyond our control, it is best if they can be avoided. Both experimental results and numerical simulations indicate that at distances greater than 3 skin depths (1/2 wave length) from an electromagnetic transmitter, the uniform, and plane portion of the waves are dominant and at 6 or 7 skin depths (1 wave length) the waves are completely uniform and plane relative to the precision with which we can measure them.

Impedance

In the air, above a uniform earth, we expect to find an electromagnetic field composed of electromagnetic waves propagating downward and reflected waves propagating upward. This situation is described for an electric field component by

$$E_x^0 = E_0^+ e^{-ik_0 z} + E_0^- e^{-ik_0 z} \quad (7)$$

The coefficient subscripts '0' indicate that this expression applies to layer 0, (the air) and the superscripts indicate the direction of travel (positive down). In a uniform earth (layer 1) there are no reflectors so:

$$E_x^1 = E_1^+ e^{-ik_1 z} \quad (8)$$

The propagation constants in these expressions are:

$$k_0 = \omega \sqrt{\mu_0 \epsilon_0} \quad \text{and} \quad k_1 = e^{i\pi/4} \sqrt{\frac{\omega \mu}{\rho}}$$

A solution for the unknown constants in equations 7 and 8 is obtained by enforcing the conditions that E_x and H_y must be continuous at the earth-air boundary. Applying Faraday's law to 7 and 8 gives the magnetic fields

$$H_y^0 = \frac{E_0^+}{\eta_0} e^{-ik_0 z} + \frac{E_0^-}{\eta_0} e^{-ik_0 z} \quad \text{and} \quad H_y^1 = \frac{E_1^+}{\eta_1} e^{-ik_1 z}$$

where η_0 and η_1 are the intrinsic impedance of the air and the earth given by

$$\eta_0 = \frac{i\omega\mu_0}{ik_0} = \sqrt{\frac{\mu_0}{\epsilon_0}} \quad \text{and} \quad \eta_1 = \frac{i\omega\mu_0}{ik_1} = \sqrt{\omega\mu_0\rho} e^{i\pi/4}$$

Equating E and H fields at $z = 0$ yields

$$E_1^+ = E_0^+ + E_0^- \quad \text{and} \quad \frac{E_1^+}{\eta_1} = \frac{E_0^+}{\eta_0} - \frac{E_0^-}{\eta_0}.$$

The solution of these equations yields the amplitude of the transmitted wave and the reflected wave:

$$E_1^+ = \frac{2\eta_1}{\eta_0 + \eta_1} E_0^+ \quad \text{and} \quad E_0^- = \frac{\eta_1 - \eta_0}{\eta_0 + \eta_1} E_0^+.$$

These equations lead to expressions for the electric and magnetic field in the air in terms of impedance of the air and earth give by

$$E_x^0 = E_0^+ \left[e^{-ik_0 z} + \frac{\eta_1 - \eta_0}{\eta_1 + \eta_0} e^{-ik_0 z} \right] \quad \text{and} \quad H_y^0 = \frac{E_0^+}{\eta_0} \left[e^{-ik_0 z} - \frac{\eta_1 - \eta_0}{\eta_1 + \eta_0} e^{-ik_0 z} \right].$$

Similarly, in the earth we have

$$E_y^1 = E_0^+ \frac{2\eta_1}{\eta_1 + \eta_0} e^{-ik_1 z} \quad \text{and} \quad H_v^1 = E_0^+ \frac{2}{\eta_1 + \eta_0} e^{-ik_1 z}.$$

At the surface of the earth, these two sets of expressions are equal and the ratio of E_x/H_y is called the surface impedance Z . For the case of a homogeneous earth, $Z = \eta$. This is the basis for defining the apparent resistivity ρ_a : it is the resistivity of a homogeneous earth, which would yield the same surface impedance as measured over an inhomogeneous earth at a particular location and frequency. Because

$$\eta_1 = \frac{E_x}{H_y} = e^{i\pi/4} \sqrt{\omega\mu_0\rho} \quad ,$$

we can write

$$\rho_a = -\frac{i}{\omega\mu_0} \left(\frac{E_x}{H_y} \right)^2.$$

In general, apparent resistivity is complex (e.g. the IP phenomena), but we restrict our attention to the real component which is defined as

$$\rho_a = -\frac{i}{\omega\mu_0} \frac{|E_x|^2}{|H_y|^2}.$$

Impedance estimation

Modern magnetotelluric systems are designed to record variation of both the electric and magnetic fields in two orthogonal directions and use these records to calculate the surface impedance at a measurement site. The surface impedance Z is complex, frequency dependent, and, due to the presence of noise and earth structures, is also a tensor:

$$\overline{E}(\omega) = \overline{Z}(\omega) \cdot \overline{H}(\omega) \quad \text{or} \quad \begin{aligned} E_x &= Z_{xx} H_x + Z_{xy} H_y \\ E_y &= Z_{yx} H_x + Z_{yy} H_y \end{aligned}.$$

It can be helpful to think of the surface impedance tensor as a two input, two output linear system where the inputs are the magnetic field components and the outputs are the electrical field components. This

formulation of surface impedance is preferred over the scalar formulation because, when the source fields are nearly plane waves, the impedance elements Z_{ij} are time invariant. The scalar surface impedance

$$Z_{ij} = \frac{E_i}{H_j}$$

is easier to calculate but can vary as the direction of the source fields vary. The Stratagem system makes use of both controlled and natural source fields and its processing includes the tensor formulation.

The tensor impedance can be calculated from a number of records (N) using the least-squares method where the difference between a measured electric field component is minimized relative to the predicted electric field component. For example just considering E_x , H_x and H_y

$$\psi = \sum_{i=1}^N (E_{xi} - Z_{xx}H_{xi} - Z_{xy}H_{yi})(E_{xi}^* - Z_{xx}^*H_{xi}^* - Z_{xy}^*H_{yi}^*)$$

and minimization with respect to Z_{xx} and Z_{xy} requires

$$\frac{\partial \psi}{\partial \text{Re}Z_{xx}} = \frac{\partial \psi}{\partial \text{Im}Z_{xx}} \quad \text{and} \quad \frac{\partial \psi}{\partial \text{Re}Z_{xy}} = \frac{\partial \psi}{\partial \text{Im}Z_{xy}}$$

which yields

$$\langle E_x H_x^* \rangle = \langle H_x H_x^* \rangle Z_{xx} + \langle H_y H_x^* \rangle Z_{xy} \quad \text{and} \quad \langle E_x H_y^* \rangle = \langle H_x H_y^* \rangle Z_{xx} + \langle H_y H_y^* \rangle Z_{xy}$$

where, for example

$$\langle E_x H_x^* \rangle = \frac{1}{N} \sum_{i=1}^N E_{xi} H_{xi}^*$$

is an average cross power density spectrum and E_x is the discrete Fourier transform of the measured field \mathcal{E}_x . The (*) symbol indicates complex conjugation. The two cross power expressions above combine to yield

$$Z_{xx} = \frac{\langle E_x H_y^* \rangle \langle H_y H_x^* \rangle - \langle E_x H_x^* \rangle \langle H_y H_y^* \rangle}{\langle H_x H_y^* \rangle \langle H_y H_x^* \rangle - \langle H_x H_x^* \rangle \langle H_y H_y^* \rangle} \quad \text{and} \quad Z_{xy} = \frac{\langle E_x H_y^* \rangle \langle H_x H_x^* \rangle - \langle E_x H_x^* \rangle \langle H_x H_y^* \rangle}{\langle H_y H_y^* \rangle \langle H_x H_x^* \rangle - \langle H_y H_x^* \rangle \langle H_x H_y^* \rangle}$$

and expressions for Z_{yx} and Z_{yy} are obtained in a similar way.

The surface impedance is usually expressed as apparent resistivity and impedance phase and they are calculated from the surface impedance components as

$$\rho_{ij} = \frac{1}{\omega \mu_0} |Z_{ij}|^2 = \frac{.2}{f} |Z_{ij}|^2 \quad \text{and} \quad \phi_{ij} = \tan^{-1} \left(\frac{\text{Im}(Z_{ij})}{\text{Re}(Z_{ij})} \right)$$

whether they are based on scalar or tensor calculations.

Appendix

Example database directory

Figure A1 shows the contents of a typical database directory after the acquisition of several soundings. This directory lists calibration files, a calibration table, a configuration file, and three types of data files.

```

Volume in drive D has no label
Volume Serial Number is 1C3F-1BD0
Directory of D:\GEOC

[.]                [.]                @                AN9402.60H      BN9402.60H
CN9402.60H        DN9402.60H        EXC9402.60H      EXN9402.60H      EYC9402.60H
EYN9402.60H        MN9402.60H        NN9402.60H        SENSORS.TBLXTEST.001
XTEST.002         XTEST.003         XTEST.004         XTEST.005         XTEST.006
XTEST.007         XTEST.008         XTEST.009         XTEST.010         XTEST.011
XTEST.012         XTEST.013         XTEST.014         XTEST.015         XTEST.016
XC9402.60H        XN9402.60H        YTEST.001         YTEST.002         YTEST.003
YTEST.004         YTEST.005         YTEST.006         YTEST.007         YTEST.008
YTEST.009         YTEST.010         YTEST.011         YTEST.012         YTEST.013
YTEST.014         YTEST.015         YTEST.016         YC9402.60H        YN9402.60H
ZTEST.001         ZTEST.004         ZTEST.005         ZTEST.006         ZTEST.007
ZTEST.008         ZTEST.009         ZTEST.010         ZTEST.011         ZTEST.012
ZTEST.013         ZTEST.014         ZTEST.015         ZTEST.016         ZTEST.002
ZTEST.003
66 file(s)        23,453,624 bytes
                  419,758,080 bytes free
    
```

Figure A1. The '@' file contains location information for the data files. Data files are named automatically as they are created: files beginning with 'Y' (Y_files) contain the raw time-series data; files beginning with 'X' (X_files) contain the calculated crosspower spectra from the corresponding time-series file; and files beginning with 'Z' (Z_files) contain the impedance data from which the apparent resistivity and 1-dimensional resistivity soundings are calculated. The file named 'SENSORS.TBL' contains a list of the names of the various calibration files. In the example directory, the files with the '60H' extension are the calibration files.

Using the Stratagem with an external printer and key board

The thermal printer in the stratagem is selected via a ribbon cable located in the console's connector bay on the back of the unit. When the ribbon cable's connector is removed from the printer port, the thermal printer is disconnected and the port is available for use with another printer or with a data storage device. The IMAGEM program is designed to work with the HP DeskJet Portable, HP320, and HP340 printers. Use of other HP models or printers from another manufacture may present difficulties.

An external keyboard can be connected to the console via the connector located in the console's connector bay on the back of the unit. The keyboard can be used instead of the console's keypad for acquisition and data processing. Keyboard function keys correspond to the menu selections on the basis of their respective numbers.

Running IMAGEM on an IBM compatible computer

IMAGEM can be run on most IBM compatible computers. Install the programs listed in Figure A2 in a directory named 'IMAGEM' and either type or add the string 'PATH=C:\IMAGEM;%PATH%' to your system's AUTOEXEC.BAT file. To reprocess or view Stratagem data on your system, change directories so that the data is in the current directory and type 'IMAGEM'. Typing 'IMAGEM C' will run IMAGEM in color mode and make viewing, printing, and processing your data more colorful (on color systems). The print-screen feature imbedded in IMAGEM is invoked by pressing 'SHIFT #' and, if an HP340 printer is connected to the host computer, color plots are produced.

```

Volume in drive is DEMO
Directory of C:\IMAGEM

.                <DIR>
..               <DIR>
DOS4GW  EXE      254,556 05-31-94 10:00a
XQIMAGEM BAT  36 04-11-97 12:22p
IMAGEM  EXE      246,778 12-11-96 09:39a
5 file(s)      501,366 bytes
0 dir(s)      314,951,808 bytes free
    
```

Figure 2A. These files are needed to run IMAGEM on an IBM compatible computer.

Data transfer

Most users will want to transfer their data files from the Stratagem console to a personal computer. There are a number of ways to do this including the use of Zip drives, backup tape drives, LapLink or other peer to peer connections.

In order to facilitate the transfer of data files from the Stratagem EH4 console to a personal computer running MS Windows, Geometrics has installed a 3COM Ethernet network card in the Stratagem console. Both the Stratagem console and the personal computer must have the NetBEUI network protocol installed. This software comes preinstalled on the Stratagem EH4 console, and is available from the Windows installation CD from all Windows programs except Windows XP. For Windows XP the NetBEUI drivers must be downloaded from Microsoft's web page. Network transfer can be accomplished using the provided network cables and your network-equipped computer. Your computer network must have Microsoft NetBEUI protocol enabled. The Stratagem will communicate at 10 or 100 megabits per second. A crossover cable is provided for direct connection to your computer's network card. A straight-through cable is provided for connection to a hub.

Communicating from the Windows computer to the Stratagem

This document describes network connections to transfer data from a network equipped Stratagem system to a Windows 9x or NT computer. It is assumed that the Windows computer is equipped with a network card and already has the NetBEUI protocol implemented.

The network connection provided on the Stratagem uses a 10Base T connection utilizing RJ45 jacks. Two network cables are provided, a "Crossover" cable for direct connection between the Stratagem and the computer network card, and a "Straight-through" cable for connection between the Stratagem and a network hub. Communication setup will depend on the computer used to back up the system. Select the setup that applies to your system from the following list:

- **General**

1. Connect the "Crossover" cable between the Stratagem and the computer network card or connect the "Straight" cable between the Stratagem and your network hub.
2. Connect power to the Stratagem and turn it on.
3. Boot and log onto your computer.

- **Windows 95 and Windows 98**

Use the Find -> Computer item on your computer's Start menu to locate the Stratagem on the Network. The Stratagem's name will be STRATAGEM.

- **Windows NT 4.0, Windows 2000 and Windows XP**

1. Open Windows Explorer. Click on the Menu item, Tools. Select Map Network Drive on the Tools drop down list.
2. Enter the computer name and shared directory name in the dialog box. For instance the entry would be, [\\STRATAGEM/D-DRIVE](#), to mount D:\ from the Stratagem. Each shared drive on the Stratagem has a similar name.

You can now use standard Windows tools to copy files and folders from the Stratagem to your computer. If you have difficulties transferring data check the follow:

- To go directly from the Stratagem console to a Windows computer you must have the cross-over cable connected from the Stratagem 3COM 515 10/100 BASE-T Ethernet card connector to your computer Ethernet card connector.
- You must first have the NetBEUI network protocol installed.
- If you are running Windows 98, to verify that NetBEUI is installed go to SETTINGS, CONTROL PANEL, NETWORK, CONFIGURATION and to see if NetBEUI is one of the installed configurations. If it is not then it must be installed.
- If you are running Windows 2000, to verify that NetBEUI is installed go to SETTINGS, CONTROL PANEL, NETWORK AND DIALUP CONNECTIONS, LOCAL AREA CONNECTION. Then click the Properties button and check the list to see if NetBEUI is one of the installed configurations. If not then it must be installed.
- If you are running Windows XP, to verify that NetBEUI is installed go to CONTROL PANEL. Then switch to Classic View and click on Network Connections. Right click on Local Area Connection and select Properties from the menu and check the list to see if NetBEUI is one of the installed configurations. If not then it must be installed.
- After NetBEUI is installed, you must set up your computer by giving it a network computer name and sharing a drive. Go to SETTINGS, CONTROL PANEL, NETWORK, IDENTIFICATION to see if there is a computer name already given. If not a computer name must be assigned, for example JOE.
- To share a drive on computer JOE go to Windows Explorer and right click on the drive you want to share. Click on SHARING and enter your computer name in the field SHARE NAME, for example JOE-C. "Shared as" must be checked as well as "Access type Full".
- Turn on and connect a keyboard to the Stratagem console. It will boot up into the IMAGEM software. Exit to the DOS command prompt. Type in "net" and press the "enter" key to bring up the "Disk Connections" menu. Type "\", your computer name, and shared drive name into the "Path" field, for example \JOE\JOE-C. When you hit "Enter" the connection should be displayed in the "Current Connections" field. You may exit the menu by hitting the ESC key. You can now access the computer as the G-drive on your Stratagem console and use all the standard DOS commands to copy files from your Stratagem console to your PC.

Data formats

Location file

This is the '@' file and it contains the location and other information that is specific to each of the soundings in the data base directory. The first line in this file contains two values: the notch filter fundamental frequency and the starting station number. The second line contains the starting station and if the starting station was selected as '1' then this will be a dummy station (0). Each line that follows will represent the location of one station and will include the following fields:

Station name

Transmitter location; x, y, and z coordinates in meters

Receive location; x, y, and z coordinates in meters

Electric field sensor dipole length; x and y length in centimeters

Gain and filter setting settings for high, low, and mid-band frequency ranges; hexadecimal

Time-series files

The Y_file is a binary file containing time-series data as a sequence of blocks. Each block is a record for a segment of time-series and is preceded by a header containing specific information about the block. These files consist of 2-byte integer, low-high byte words and each block in the file contains data in the following order.

- decimation exponent
- segment number: count for the current band where the initial count = 0
- gain - filter setting register:, unsigned
- xlength: x dipole length in cm
- ylength: y dipole length in cm
- length: no of points in data, (number of channels * number of times)
- number of channels
- 1st channel's data, 1st time
- 2nd channel's data, 1st time
- 3rd channel's data, 1st time
- 4th channel's data, 1st time
- 1st channel's data, 2nd time
- 2nd channel's data, 2nd time
- 3rd channel's data, 2nd time
- 4th channel's data, 2nd time
-
-
- 4th channel's data, length/number of channels

Crosspower files

The X_file is an ASCII file containing the results of auto-power and crosspower spectral density calculations. These so-called crosspower results are calculated from time-series data stored in file Y_file with the same root name and extension. The crosspower file is 19 columns wide and each column is 11 characters long. For example:

```
6.250e+000 2.930e+000 2.100e+001 5.204e+007-1.727e+009 3.523e+006 .....
7.500e+000 2.930e+000 0.000e+000 0.000e+000 0.000e+000 0.000e+000 .....
.
.
```

The data on each line correspond to a single frequency, and the units for the crosspower values are geophysical: H in Gamma; E in mV/km. The data values are listed by column number in Table A1.

Columns 1- 3	Columns 4 - 7	Columns 8 - 11	Columns 12 - 15	Columns 16 - 19
Freq (Hz)	CH1*CH1	re(CH2*CH1)	re(CH3*CH1)	re(CH4*CH1)
bandwidth (Hz)	im(CH1*CH2)	CH2*CH2	re(CH3*CH2)	re(CH4*CH2)
# of averages	im(CH1*CH3)	im(CH2*CH3)	CH3*CH3	re(CH4*CH3)
	im(CH1*CH4)	im(CH2*CH4)	im(CH3*CH4)	CH4*CH4

Table A1

For frequencies where no crosspowers are available, ‘# of averages’ value is 0. The notation CHi *CHj indicates the spectral density of channel i and channel j which is:

$$\left\langle CH_i CH_j^* \right\rangle_{\omega=\omega_1} = \frac{1}{\Delta\omega} \int_{\omega_1 - \frac{\Delta\omega}{2}}^{\omega_1 + \frac{\Delta\omega}{2}} CH_i(\omega) \cdot CH_j^*(\omega) d\omega$$

where

$$CH_i(\omega) \cdot CH_j^*(\omega) = \frac{1}{n_ave} \sum_{k=1}^{n_ave} ch_{i,k}(\omega) \cdot ch_{j,k}^*(\omega)$$

and $ch_{i,k}$ is the spectra for the k^{th} time-series from channel 'i'. (*) indicates complex conjugation and $\Delta\omega$ is the bandwidth.

Impedance files

The Z_file is an ASCII file containing the results of impedance calculations performed on the X and Y files bearing the same root file name and extension. The results are ordered by frequency and the values for each frequency occupy 2 lines with a total of 15 values per frequency. Each value is 11 characters long. An example of the format of data for a single frequency is:

```

11.2      0.5841      257      25.7      0.5052      168      43.5
153.379   34.161     11.034   -215.523   10.252     -129.447   -164.482   -86.834

```

The impedance variables are listed by column number in Table A2.

Column	Line 1	Line 2
1	frequency in Hz	re $Z_{xx}/\sqrt{(\omega\mu_0)}$
2	ExHy coherency	im $Z_{xx}/\sqrt{(\omega\mu_0)}$
3	ExHy scalar apparent resistivity	re $Z_{xy}/\sqrt{(\omega\mu_0)}$
4	ExHy scalar phase	im $Z_{xy}/\sqrt{(\omega\mu_0)}$
5	EyHz coherency	re $Z_{yx}/\sqrt{(\omega\mu_0)}$
6	EyHx scalar apparent resistivity	im $Z_{yx}/\sqrt{(\omega\mu_0)}$
7	EyHx scalar phase	re $Z_{yy}/\sqrt{(\omega\mu_0)}$
8	<blank>	im $Z_{yy}/\sqrt{(\omega\mu_0)}$

Table A2

Conversion of time-series to spectral data

High frequency mode data

IMAGEM automatically converts the stored time-series data to spectra and uses the spectra to calculate the crosspower and impedance results. This section describes the conversion procedure and provides information that is necessary for those users who wish to reprocess time-series data using algorithms other than those incorporated in IMAGEM.

Calculation of the MT spectra requires reading both the time-series data and calibration data from various files. The file named 'SENSORS.TBL' found in the working directory contains an ordered list of calibration files that apply to the time-series data in this directory (Y_files). Using the example data base directory of figure A1 as a model, the calibration files and their significance is described in Table A3.

File Name	Calibration data	Used for
yn9402.60h	Channel 1 high pass	Hy
en9402.60h	Channel 2 high pass	Ex
xn9402.60h	Channel 3 high pass	Hx
en9402.60h	Channel 4 high pass	Ey
yc9402.60h	Channel 1 low pass	Hy
ec9402.60h	Channel 2 low pass	Ex
xc9402.60h	Channel 3 low pass	Hx
ec9402.60h	Channel 4 low pass	Ey
dn9402.60h	Gain <d>	All channels
cn9402.60h	Gain <c>	All channels
an9402.60h	Gain <a>	All channels
bn9402.60h	Gain 	All channels
mn9402.60h	Gain <m>	All channels
nn9402.60h	Gain <n>	All channels

Table A3

All calibration files are ASCII with an identical six-column format. The factors on each line correspond to a single frequency and are listed by column number in Table A4.

Column	Factor
1	Frequency (Hz)
2	Imaginary
3	Real
4	Factory calibration coherency
5	Amplitude
6	Phase (degrees)

Table A4

The following procedure generates the IMAGEM spectral results:

- 1) Open a time-series file for processing and set the crosspower stack equal to 0. The crosspower stack is a array with dimensions great enough to store the number of frequencies produced by the FFT results multiplied by 16 (the number of unique values obtained by cross multiplying the complex spectral values of the 4 data channels).
- 2) Read a segment of time-series from the file and calculate FFTs for the 4 channels.
- 3) Calculate the sampling rate on the basis of $(192\text{k samples/sec}) / (2^{\text{decimation}})$ and use this value to convert the FFT result to raw spectra.
- 4) For each frequency, normalize the raw spectra for the electric field channels by a factor of $(1/5f)$ and form crosspowers from the spectra by computing the products $S_K S_L^*$ where K and L indicate channel numbers. Note that $S_K S_L^*$ equals $S_L S_K^*$ and it is not necessary to duplicate this calculation.
- 5) For each frequency, add the crosspowers to the crosspower stack.
- 6) If the end of the time-series file has not been reached, go to step 2) and repeat.

- 7) Sum the crosspower data in exclusive frequency groups centered on the calibration frequencies (see step 8 below). The ranges for the various sums extends from midpoint to midpoint between the calibration frequencies. In the IMAGEM program, only those spectra with the highest scalar coherency (either HyEx or HxEy) are included in this summation. These coherency bins are: 1-.8, .8-.6, .6-.3, and .3-0.0 and coherency is calculated as:

$$C_{xy} = ((\text{real_HyEx})^2 + (\text{imag_HyEx})^2) / (\text{Hy}^2 * \text{Ex}^2)$$

$$C_{yx} = ((\text{real_HxEy})^2 + (\text{imag_HxEy})^2) / (\text{Hx}^2 * \text{Ey}^2)$$

- 8) Construct calibration tables. Calibration tables are constructed using the calibration factors contained in the calibration files as well as the data acquisition parameters identified in the time series files' gain-filter setting register (REGISTER). REGISTER should be converted to a hexadecimal for the calculations described below. For example, the gain-filter register value of 1576 converts to a hexadecimal value of 682. 682 Hex converts to a binary value 0000 0110 1000 0010 indicating that the calibration factors should be calculated for high pass data with gains of 4 on the electric field channels and 8 on the magnetic field channels.

To construct the calibration tables proceed as follows:

- a) Open the file named 'sensors.tbl' (e.g. Table A3) and read the names for 14 calibration files it contains. For each of these files (I) read the first three columns of data in these files where I = 0 through 13. As shown in Table A4, these columns correspond to 1) calibration frequency, 2) real coefficient (re_coef), and imaginary coefficient (im_coef). There will be 293 rows (J) of calibration factors in each of the 14 files corresponding to each of 293 common calibration frequencies.
- b) Construct the complex coefficients coef(K) for each frequency J as follows:

$$\text{coef}(K) = \text{REAL}(\text{re_coef}(K+L)) + \text{IMAG}(\text{im_coef}(K+L)) \times 5.0 \times \text{SQRT}(72900 / (\text{re_coef}(M)^2 + \text{im_coef}(M)^2))$$

where K = 0, 1, 2, or 3 corresponds to input channels: hy, ex, hx, ey. M = 1 if the high pass filter is in: that is if (REGISTER AND '80'XL) is true for the time series segment being processed. Otherwise M = 5. L = 4 if the high pass filter is in: that is, if (REGISTER AND '140'XL) is true for the current time-series segment. Otherwise L = 0.

- c) Apply electric channel gains (K = 1 and 3) to the complex coefficients coef(K) based on the value of gain/filter register. Obtain the gain index, N, by comparing REGISTER to the following values: ['10'XL, '4'XL, '1'XL, '2'XL, '8'XL]. That is, N = 0, 1, 2, 3, 4 depending on which hex value it matches. Modify the complex coefficients as follows:

$$\text{coef}(K) = (\text{coef}(K) \times \text{Complex_cal}(N+8)) \times (\text{Complex_cal}(13)^* / (\text{Complex_cal}(13) \times \text{Complex_cal}(13)^*))$$

where Complex_cal(#) is a complex value composed of the re_coef(#) and im_coef(#) and * indicates complex conjugation.

- d) Multiply coef(1) by 1.e-8 x xlenght and coef(3) by 1.e-8 x ylength to normalize for the electrode cable lengths.
- e) Apply magnetic channel gains (K = 0 and 2) based on the value of gain/filter register. As with the electric field channels, obtain the gain index, N, by comparing REGISTER to the following values: ['0'XL, '800'XL, '200'XL, '400'XL, '1000'XL]. That is, N = 0, 1,

2, 3, 4 depending on which hex value it matches. Modify the complex coefficients as follows:

$$\text{coef}(K) = (\text{coef}(K) \times \text{Complex_cal}(N + 8)) \times (\text{Complex_cal}(13)^*) / (\text{Complex_cal}(13) \times \text{Complex_cal}(13)^*).$$

Again, Complex_cal(#) is a complex value composed of the re_coef(#) and im_coef(#) and * indicates complex conjugation.

- f) For each frequency, J, construct three calibration tables AMP, RR, and AA. AMP is the cross product of the magnitude of the four channel coefficients squared. That is, for each channel, K and L:

$$\text{AMP}(J,K,L) = \text{Magnitude}^2(\text{coef}(J,K,L)) \times \text{Magnitude}^2(\text{coef}(J,L,K)).$$

Similarly, construct RR and AA:

$$\text{RR}(J,K,L) = \text{Real}(\text{coef}(J,K,L)) \times \text{Real}(\text{coef}(J,L,K)) + \text{Imaginary}(\text{coef}(J,K,L)) \times \text{Imaginary}(\text{coef}(J,L,K))$$

$$\text{AA}(J,K,L) = \text{Real}(\text{coef}(J,K,L)) \times \text{Imaginary}(\text{coef}(J,L,K)) - \text{Imaginary}(\text{coef}(J,K,L)) \times \text{Real}(\text{coef}(J,L,K))$$

- 9) Apply calibration tables to the crosspower stack of step (7) and divide the result by the bandwidth and the number of averages (number of FFTs times the number of frequencies in the spectral average) to obtain crosspower results scaled in mV/m for the electric fields and Gamma for the magnetic fields. Calculate the crosspowers Xpr by applying the calibration tables as follows:

$$\text{Xpr}_{J,K,L} = (\text{RR}_{K,L} \times \text{S}_K \text{S}_L + \text{AA}_{K,L} \times \text{S}_K \text{S}_L) / (\text{AMP}_{K,L} * \text{bandwidth})$$

where bandwidth = 2.93

Low frequency mode data

A procedure similar to the one described above is used to calculate spectral results for the low frequency mode time-series data (V_files). The only differences are in the format of some of the calibration files and the formula used to apply the low frequency factors to the raw spectra. The names of the 5 low frequency mode calibration files are listed in the file named 'SENSORL.TBL'. The contents of these files are as follows:

- First file: LF calibration file for hy sensor
- Second file: LF calibration file for ex sensor
- Third file: LF calibration file for hx sensor
- Fourth file: LF calibration file for ey sensor
- Fifth file: LF gain calibration file

The file format for the electric field and gain calibration have the same six column format as the high frequency calibration files described above. The low frequency calibration files for the magnetic sensors (hx, hy) have a simpler three column format that consists of FREQUENCY, AMPLITUDE, and PHASE, in that order. This format must be converted to a complex format, and these new coil calibration factors must be calculated from values obtained from interpolants corresponding to the same frequencies found in the gain calibration file. This new set of calibration factors is represented as F(i) in Table A6 below.

Bit	Function	Channels 1 and 3	Channels 2 and 4
C=	Sensor factor	10•F5•F(i)	1.0E-7•length(i)•F(i)
1	x2 electric field gain		C•2
2	x4 electric field gain		C•4
3	x10 electric field gain		C•10
4	x 0.1 electric field gain		C/10
5	extra x4 electric field gain		C•4
10	x2 magnetic field gain	C•2	
11	x4 magnetic field gain	C•4	
12	x10 magnetic field gain	C•10	
13	x 0.1 magnetic field gain	C/10	

Table A6

Conversion of spectral data to impedance data

The scalar apparent resistivity values found in the impedance files are calculated from the spectral autopowers for E and H using the following relationships:

$$\rho_x = (0.2 / \text{freq}) * E_x^2 / H_y^2$$

$$\rho_y = (0.2 / \text{freq}) * E_y^2 / H_x^2$$

The coherency function γ^2 is obtained from

$$\gamma_{ij}^2 = \frac{|E_i H_j^*|^2}{E_i H_j}$$

The tensor impedance values found in the impedance file are calculate from the crosspower files using the following relationships:

$$Z_{xx} = \frac{\langle E_x H_x^* \rangle \langle H_y H_y^* \rangle - \langle E_x H_y^* \rangle \langle H_y H_x^* \rangle}{\langle H_x H_x^* \rangle \langle H_y H_y^* \rangle - \langle H_x H_y^* \rangle \langle H_y H_x^* \rangle}$$

$$Z_{xy} = \frac{\langle E_x H_x^* \rangle \langle H_x H_y^* \rangle - \langle E_x H_y^* \rangle \langle H_x H_x^* \rangle}{\langle H_y H_x^* \rangle \langle H_x H_y^* \rangle - \langle H_y H_y^* \rangle \langle H_x H_x^* \rangle}$$

$$Z_{yx} = \frac{\langle E_y H_x^* \rangle \langle H_y H_y^* \rangle - \langle E_y H_y^* \rangle \langle H_y H_x^* \rangle}{\langle H_x H_x^* \rangle \langle H_y H_y^* \rangle - \langle H_x H_y^* \rangle \langle H_y H_x^* \rangle}$$

$$Z_{yy} = \frac{\langle E_y H_x^* \rangle \langle H_x H_y^* \rangle - \langle E_y H_y^* \rangle \langle H_x H_x^* \rangle}{\langle H_y H_x^* \rangle \langle H_x H_y^* \rangle - \langle H_y H_y^* \rangle \langle H_x H_x^* \rangle}$$

where $\langle AB^* \rangle$ is a complex value formed from the real and imaginary parts of AB as provided in table A1. The quantity $\langle AA^* \rangle$ is an autopower and is therefore real-valued.

Both the scalar and tensor impedance data are also frequency averaged from the spectral data on the basis of 10 frequencies per decade. Only those spectral data having a coherency higher than the impedance coherency limit are included in this average.