

# GEM-2 Manual

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## GEM-2 Overview

Congratulations for having purchased the GEM-2—a modern, broadband, programmable electromagnetic (EM) sensor for a variety of geophysical applications. The GEM-2 is like a computer: you can program it in many different ways. Yet, it is easy to use, simple to learn, robust in operation, and rugged in field handling. The sensor is entirely controlled by only three push buttons that navigate simple on-screen menus.

The GEM-2 consists of a sensor housing (the “ski”), the electronics console, and WinGEM software. The standard accessories include a battery charger, carrying straps, a download cable, a brief field guide, and this manual. The WinGEM software runs on Windows-based PCs. When the GEM-2 is attached to a PC, WinGEM can control its operation. WinGEM is used to initially configure the sensor and to specify the frequencies to be used for a particular survey. WinGEM plots the acquired data to verify proper operation.

A common use of the GEM-2 involves walking with the unit along a predefined survey grid. After a survey is completed, the WinGEM software is used to download the data from the GEM-2 and store it in a file on the PC for analysis. Given the positions of the ends of the grid lines, WinGEM assigns an x-y position to each data point using “dead reckoning” or interpolation and creates a separate file containing positioned survey data.

A more flexible survey technique involves connecting a GPS unit to the GEM-2 console during data acquisition. The time and positioning data from the GPS is stored along with the GEM-2's EM data. WinGEM uses the GPS data to assign an x-y position to each EM data point during the “export” function. The text file containing positioned survey data can be read by most spreadsheets and analysis programs.

Our web site, [www.geophex.com](http://www.geophex.com), provides the best information about the GEM-2 and our other electromagnetic sensors on the principles of operation, data examples, and peer-reviewed publications. Contact Geophex for support by email ([info@geophex.com](mailto:info@geophex.com)) or by phone (919/839-8515) if you have questions that are not answered by this manual or our web site.

### Specifications

Frequency band	330 Hz to 48 kHz
Multiple-frequency operation	up to 15 frequencies (recommend 3 to 5)
Power line monitoring	user-specified frequency (50 or 60 Hz)
Coil configurations	horizontal or vertical coplanar
Battery	standard 12-volt notebook computer battery pack (B905S)
Battery life	~8 hours between charges under normal use
Weight	9 pounds (4 kg)
Basic output	inphase and quadrature response in parts per million (ppm)
PC software	WinGEM for PC
Positioning	Dead reckoning or external GPS data input

## GEM-2 Console Description

The top of the GEM-2 console holds the display screen and three push buttons for controlling GEM operations. The front face includes a power switch, two DB9 connectors (one male, one female), a connector for the battery charger, and an LED that indicates the battery status.

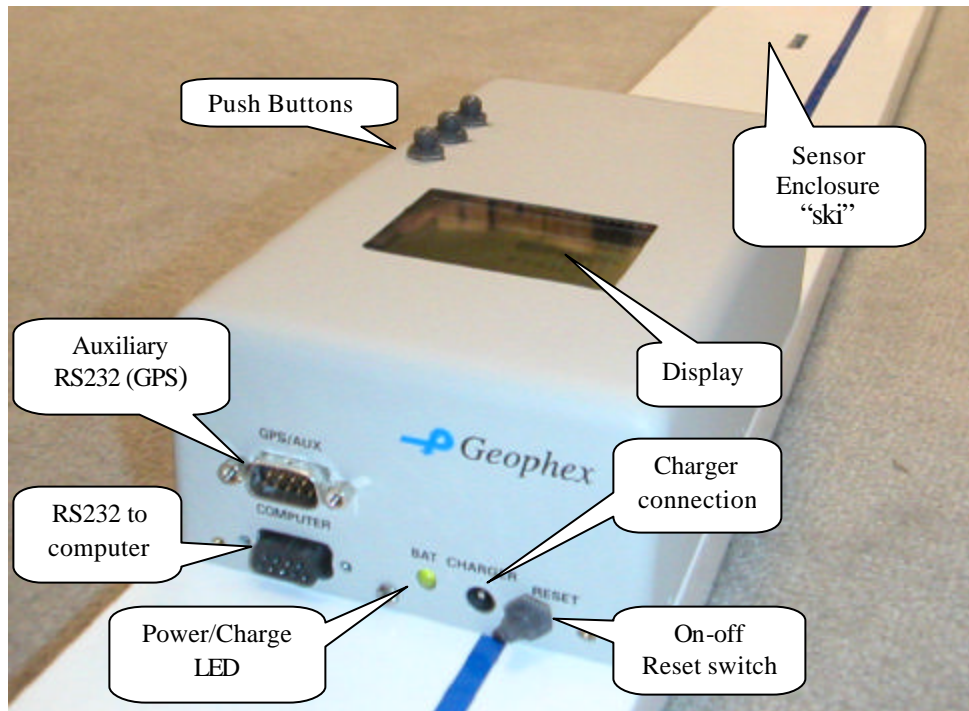


Figure 1. Photo of a GEM-2 console

**Reset Switch** An on-off switch is located on the front of the console as shown in Figure 1. On power up, the processor boots and loads its program from the internal flash card.

*The reset switch should be in the "On" position (pointing toward the LED) when the GEM is in use or the battery is being charged. When the reset switch is "On", briefly pressing any of the push buttons activates the processor. Set the switch to "Off" for storing or transporting so an accidental button press will not activate the unit and drain the battery. All configuration settings and collected data are stored in non-volatile memory so they are retained when the power is off or even when the battery is removed.*

**Female DB9 connector** The female DB9 connector provides RS232 communication to a computer. A standard RS232 DB9 cable (male-female) is supplied for connecting to a PC. The WinGEM software supplied with the system uses this connection to remotely control the GEM-2, upload new frequencies, and download survey data. The following communication parameters are used:

Baud rate	Data bits	Parity	Stop bits	Handshaking
115,200	8	none	1	none

**Male DB 9 connector** The male DB9 connector provides RS232 input from an external device such as a GPS receiver or magnetometer. The following communication parameters are used:

Baud rate	Data bits	Parity	Stop bits	Handshaking
9,600	8	none	1	none

**Connecting a GPS** When a GPS is connected to the GEM-2 console, the following conditions apply:

- ?? The GEM-2 utilizes the PPS signal provided by the GPS at pin 8 of **DB9 connector**. Serial communication is supported with GPS transmitted data at pin 2 and GPS received data at pin 3.
- ?? The GPS unit must be set to send the \$GPZDA (time of next PPS pulse) and \$GPGGA (position) strings to the console once per second.
- ?? The GEM will automatically synchronize its internal Real-Time Clock to the GPS time. The \$GPGGA strings are stored along with the EM data.
- ?? The first line on the display indicates the presence of the GPS signal by displaying the letter “G.” In addition, GPS signal quality is displayed intermittently in the bottom line of the display.

**Battery LED** The **LED** indicates the battery status as shown in the following tables:

LED color	Battery charge
Red	0 to 25%
Amber	25 to 90%
Green	90 to 100%

LED state	Battery state
Flashing	Charging
Steady	Discharging (in use)

When the battery reaches a critical value, nominally 10% depending on the battery, the system shuts down automatically. If it becomes completely discharged, it must be charged for approximately a half hour before the GEM will operate at all. In order to preserve power, the GEM will shut itself down after a period of inactivity. Press any button to reactivate.

**Charger Input** An external 24VDC standard power supply (2.3Amps, center pin positive) is provided with the sensor. The charger can stay connected to the console during normal operations. It powers the GEM-2 processor if it is active. *The battery is charged only when the GEM-2 processor is shut down.* If the battery becomes too hot (>40 degrees C), charging will stop. It may help to unplug the charger for a while to allow the battery to cool.

**Battery** A plastic sheet at the bottom of the console covers the battery compartment. A standard 12-volt, notebook-computer battery pack (B905S) supplies power to the unit. Except when the battery is damaged and, thus, to be replaced, accessing the battery compartment is discouraged.

**Flash Card** The operating software, the configuration settings, and all logged data are stored in non-volatile memory (flash card) inside the console. The amount of data that can be stored depends on the capacity of the flash card, number of RX frequencies, and base-period averaging. For example, a 64MB flash card can hold about ten hours of data for five frequencies at 30 samples per second.

## GEM-2 Console Operation

During normal field operation, three buttons located on the GEM-2 console control the sensor. Briefly pressing any of the push buttons activates the processor and displays the command menu.



Figure 2. The GEM-2 console showing the push buttons and command menu.

On power up, the user interface displays the following **Main** menu:

```

B - - - -          M:03 L:01
Main
* Run
Configure
File
Shut Down
    
```

The top line displays the system status, and event marker and survey line numbers. The meanings of the entries in the system status field are listed in the following table:

Character in status field	Indication
<b>B</b>	Battery is in use.
<b>C</b>	Power is supplied by the external charger.
<b>D</b>	Previously logged data is being downloaded to a PC.
<b>G</b>	GPS data is being received.
<b>L or P</b>	Acquired data is being stored (logged) for future download. The console beeps when logging and transmitting. 'P' indicates "Paused" logging mode.
<b>Tx</b>	Transmitter is active.

The bottom line of the LCD screen (not shown) alternately displays the remaining battery charge (%), battery current, GPS quality, and the current configuration name.

Menu navigation is simple: **Button 1** scrolls up; **Button 2** scrolls down; and **Button 3** performs the selected action. Use **Button 1** and **Button 2** to select a desired command (as indicated by the asterisk '\*' and white on black highlighting), then press **Button 3** to perform the selected command. There are main menu commands described below. Additional submenus provide for specific actions under each of these main menu items. Some menu items are used primarily for very special

circumstances or for diagnostic purposes, and are seldom used in routine operation. For the beginner, only a few commands are required to quickly start acquiring data, and these are summarized in a later section entitled *Conducting a Survey*.

## Run

In response to this command, the processor builds a transmitter current waveform (known as bit-stream) from the frequencies specified in the current configuration and starts the transmitter. Leave on the **Run** mode for at least five minutes prior to starting a survey to allow adequate warm up time. “Tx” appears in the System Status line indicating that the Transmitter is on.

**Note:** The “Tx” blinks and the console beeps to indicate a serious transmitter error. The menu changes to display the following options:

* <b>Back</b>	Stop transmitting and return to the main menu
<b>Survey</b>	Enter survey mode for “dead reckoning” positioning.
<b>Table</b>	Display the inphase and quadrature values computed for the first five frequencies. The values are updated once a second.
<b>Detection</b>	Enter audio mode for detection of buried objects.

## Survey

The **Survey** menu should be displayed constantly while acquiring data for a “dead reckoning” survey. In this mode (Note 1), normal menu navigation is interrupted and the three push buttons take on special functions. **Button 1** toggles data logging -- storing data on the flash card. Start logging at the start of a survey line and stop at the end of the line. **Button 2** flags a data record as a marker point (e.g. a survey post or reference marker) that can help in later interpretation of the data. **Button 3** exits **Survey** mode and returns to the **Run** menu.

<b>1) Log On-Off</b>	Start/stop collecting. Starting logging increments the line number (Note 2). When logging, the system beeps once every second and the system status field displays “B--L Tx”.
<b>2) Event Marker</b>	Enters an Event Marker record in the data (Note 2) and increments the Event Marker number.
<b>3) Back</b>	Return to Run menu.

Note 1: In **Survey** mode, the GEM will stop transmitting and return to the **Main** menu after one minute unless logging is active in order to conserve battery power. Use the main **Run** menu for warm up. Remember that all logged data are stored in non-volatile memory so they are securely stored even when the GEM is turned off or the battery is removed.

Note 2: Only two digits of the event marker number and the survey line number are displayed even though both values can be much larger. The survey line number (max 255) is reset to zero when logged data are deleted from the memory. The event marker number is reset only when the value reaches 10,000.

**Paused mode:** When logging is off, the **Event Marker** button can be used to toggle the **Paused** mode. A “P” appears in the status field in place of the “L.” *When Logging is restarted from Paused mode, the line number is not incremented*, thus a line that was interrupted can be resumed.

## Table

The **Table** command continuously displays the inphase and quadrature values computed for the first five frequencies, updating them once each second. This command is primarily used as a diagnostic tool or to quickly assess the magnitude of the received EM signal.

## Detection

The **Detection** (formerly **Audio**) mode uses sound to audibly indicate anomalous spots (e.g., buried objects). This mode is primarily used with other models of the GEM sensor (e.g. GEM-3) and provides the capability to quickly assess an area prior to conducting a detailed, quantitative survey, or to localize specific areas of interest. The menu changes to display the following options:

* <b>Back</b>	Return to the Run menu.
<b>Zero</b>	Set the “background” level. The next data sample acquired is taken as an offset that is subtracted from subsequently acquired data before the detection level is computed. The logged data values are not affected.
<b>Log</b>	Start collecting data. Button 3 starts and stops logging, increasing the line number. When logging, the system status field displays “ <b>B--L Tx</b> ”, but it does not beep in this mode.
<b>Decrease</b>	Decrease the sound output for a given signal level.
<b>Increase</b>	Increase the sound output for a given signal level.

In **Detection** mode, the GEM-2 computes a “detection signal” based on the acquired data after the background values are subtracted. Currently, the sum of the all quadrature values is used to generate an audio tone. The volume of the tone is proportional to the sum.

To set up the GEM-2 for detection mode:

- ?? With the sensor over typical ground, select and enter the **Zero** command to set the background level. This command should be repeated periodically to account for changes in ambient conditions.
- ?? Use the **Increase** command until a definite, steady tone is heard.
- ?? Then **Decrease** until no sound is audible. This sets the audio threshold.

The goal is to set the sensitivity so that noise in the background signal does not produce an audible sound, but any higher signal level does.

## Configure

The unit memory can retain up to four different configuration setups, which can be uploaded from the WinGEM program. The **Configure** command allows the user to select any of these configurations. The GEM-2 always stores the active configuration as **Setup 0** and that configuration is loaded at startup. **Setup 3** is currently reserved for internal use. The other two setups can hold alternate configurations; for example, if you wish to acquire data using two different sets of frequencies, you can create and store two configurations using WinGEM. Then use the Configure command to switch between them in the field. Note that the **Configure** command is required only for the situation described above, and is not used in typical operation.

The menu changes to display the following options:

* <b>Back</b>	Return to the main menu
<b>Setup 1</b>	Makes setup #1 current.
<b>Setup 2</b>	Makes setup #2 current.
<b>Setup 4</b>	Makes setup #4 current.

## File

The **File** command refers to the data acquired while data logging is enabled. When starting a new survey, use the **Delete** command to clear old data from the GEM-2's memory. If you don't, the new data will be simply appended to the old data, along with consecutive line numbers. When the survey is complete, **Download** the data to a PC for analysis.

When the **File** menu is selected, the menu changes to display the following options:

* <b>Back</b>	Return to the main menu
<b>Download</b>	Download survey data to a PC using the RS232 connection. A "D" appears in the status field.
<b>Abort</b>	Abort the pending download operation
<b>Delete</b>	Delete all data from memory and reset the Line number to 0 – use after downloading.



## Conducting a Survey

A common use of the GEM-2 involves walking with the unit along a predefined survey grid. Given the positions of the ends of the grid lines, the locations of data along a grid line are determined by “dead reckoning” or interpolation. See “How to Survey” on [www.geophex.com](http://www.geophex.com) for additional guidance on how to efficiently design and carry out a GEM-2 survey. The following guidelines should be useful when performing this type of survey:

- ?? In a simplest form, define a survey area made of rectangles. Break large areas into smaller, manageable areas. The data from the small areas may be combined during post processing. Place markers along the opposite boundaries of a rectangle, at an interval on the planned line spacing so that the lines may be walked sequentially with little confusion. Line spacing should be comparable to the depth to the smallest target of interest.
- ?? Keep line lengths short enough to allow easy visibility of one end of the line from the other end. This ensures that the walked lines will be relatively straight. Once laid out, the lines may be walked uni-directionally or bi-directionally. Walk at a constant speed to ensure accurate dead reckoning positions.
- ?? Remove all metal objects from the operator including watches, keys, etc. The closer the metal is to the GEM-2 ski, the greater the resultant interference or “noise.” Look for insidious offending material such as steel-toed boots and metal buttonhole protectors on rain ponchos.
- ?? Prior to commencing a survey, run the GEM-2 for approximately 5 minutes for warm up. (Note: Use the main Run menu for warm up. Under the **Run ... Survey** menu, the GEM will stop transmitting and return to the Main menu after one minute unless logging is active.)
- ?? To maximize the memory available for the survey, clear the survey memory. Otherwise the new data will be appended to any existing data, which must be removed from the file prior to assigning spatial coordinates during the **Locate** process.
- ?? For each line in the survey, the operator must start logging data as he starts walking and end logging data as he crosses the end of the line. The mechanics of this process using the console require that the **Run ... Survey** menu be kept open. Then each press of **Button 1** toggles data logging. Each start and stop of the GEM-2 data logging increments the line number that is stored with the data. The system beeps once a second when data is being logged.
- ?? Try to lay out the survey areas to avoid buildings and other obstacles. The **Locate** function in WinGEM (described in the **Data Positioning** section below) allows for obstacles within a survey area. Stop logging when you reach the obstacle, then resume logging and walking when you reach the other side of the obstacle. The Locate function allows you to combine these lines with a data gap indicating the location of the obstacle.
- ?? The data positioning process requires that the survey lines be walked sequentially. If, for any reason, a line is considered to be unusable, it should be redone right away. While post-processing of the survey data can be accomplished to correct positioning errors made in the field, experience has shown that it much more efficient (and, indeed, far more reliable) to correct errors at the earliest point in the survey process.
- ?? Keep detailed field notes including area diagram, block name, origin location and direction of first line walked, line length and line spacing, as well as the size and location of any obstacles. This information is critical to the dead reckoning positioning process.

## WinGEM Software

All of the GEM-2 functions that can be performed from the instrument console can also be performed from the WinGEM program on a Windows-based PC through the RS232 port. In general, the GEM-2 should be controlled by either the console or a PC. In most field applications, the GEM-2 is used in a standalone mode to collect data; it is then connected to the PC to download the logged data for storage, display, and conversion to text files, which may be analyzed and displayed. The basic functions of WinGEM are to:

1. initially configure the sensor and specify the frequencies to be used for a particular survey. These parameters are stored in a configuration (.GEM) file
2. for a dead reckoning survey, plot the acquired data to verify proper operation and response.
3. download the data from the GEM-2 console, assign positions to each sample using dead-reckoning or GPS data, and create a text data file that can be input to other plotting and analysis programs.

WinGEM operates in two modes that are reflected in the functions available on the menu bar. Either BASIC (default) or ADVANCED mode can be selected under the VIEW menu. After selection, the desired mode will be active the next time WinGEM is started. The BASIC mode includes all of the standard functions used to routinely download, view, and save data. The ADVANCED mode includes additional functions that address special applications, diagnostics, and calibration. WinGEM reverts to BASIC mode after a single execution in ADVANCED mode. *WinGEM should be used in the BASIC mode* unless specific functions only available in the ADVANCED mode are dictated by the application.

### Installation

WinGEM software is distributed on a CD-ROM included with each GEM-2. The latest version of WinGEM can be downloaded from [www.geophex.com](http://www.geophex.com). Note that WinGEM v.3 requires version 43c or later of the GEM-2 software. The **Help...About WinGEM...** menu displays the version information for both WinGEM and the GEM-2 software.

If the installation program does not start automatically when the CD-ROM is loaded in your PC, locate and run SETUP.EXE which will display a series of screens like other Windows program installations. It is recommended that WinGEM be installed in the default (WinGEM) directory. SETUP will copy all of the necessary files to the specified path on your disk drive, then add shortcuts to the **Start** menu and desktop. Use either shortcut to execute the WinGEM program. The CD-ROM also contains a copy of the configuration file for your particular sensor (e.g. **GEM2-0010\_survey.GEM**). The installation program does not copy it to your hard drive, but you should copy it to the installation directory manually. Keep this file handy in case you ever need to restore the original sensor settings.

### Using WinGEM

Connect a PC to the console via the standard serial communications cable, switch on the console, and start up the WinGEM program. WinGEM automatically establishes communication with the console using the default baud rate of 115,200. When WinGEM is first executed, a simple menu is displayed above a blank screen as shown below.

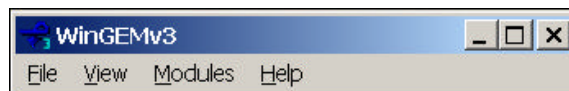


Figure 3. Default WinGEM menu



## WinGEM Functions

The most commonly used functions can be initiated by clicking a button on the toolbar. They are also available via the menus.

The **Transmit** button starts and stops activation of the transmitter coil.

The **Store** button toggles storing data directly onto the PC as it is acquired in a text (.csv) format. A dialog box opens to specify a path and filename where the data will be stored. This is equivalent to logging data on the GEM-2, then subsequently downloading and converting to a text file.

The **Download, Replay, Export, and Locate** toolbar buttons invoke functions that manipulate logged data. These functions are described in later sections.

The **Null EM** toolbar button toggles “nulling” of the data in the graph. When nulling is turned on, the next data sample acquired is taken as a background value that is subtracted from subsequently acquired data. The graphs then emphasize changes from this background state. *Note that nulling only affects the displayed data -- not the raw data being logged or stored to a file.*

The **Control ... Battery Status** command reports the current status (percent of full charge and other parameters) of the GEM battery. In addition, WinGEM periodically displays the battery charge on the status bar.

Use the **File ... Power Off** command to turn off the GEM-2 when it is not in use.

## WinGEM Graphs

Figure 5 shows the default layout of the WinGEM screen with a Time Graph (stripchart) window above and a Frequency Graph (EM spectrum) below. When transmitting, the Time Graph shows a time history of the inphase (solid lines) and quadrature (dashed lines) data for all frequencies. Typically, the last 25 seconds of acquired data are plotted. The Frequency Graph shows an instant EM spectrum. Both graphs are updated once per second.

The scale of the graphs may be altered by clicking the zoom buttons on the left side of the window. For example, the **z+** button zooms in (decreases) the upper limit of the axis scale. The **fit** button toggles autoscaling and rescales the axis to fit the currently plotted data. The size of these windows may be adjusted by ‘clicking and dragging’ the borders separating them.

Right clicking the Time Graph displays a context menu with several options:

- ?? **Show Points** adds a docking window that lists data values for a particular curve (see Figure 5). The drop down list that selects which curve to display also associates each curve’s color and style (solid or dashed) with its frequency and type (inphase or quadrature).
- ?? **Point marks** adds markers to the individual data points.
- ?? **Trace mouse coordinates** displays the coordinates of the mouse cursor in axis units.
- ?? **Zoom ... Zoom tool** displays a rectangle that can be repositioned by dragging. Then **Zoom ... Apply** zooms the graph so that the data in the selected area fills the axis space.
- ?? **Autoscale Y to recent data** starts autoscaling like the **fit** button on the zoom toolbar, but it immediately rescales the Y axis to fit the most recent data (2.5 seconds). *This function is so useful (e.g. after nulling) that it is assigned to the function key F8.* Click on the Time Graph to make it active before pressing **F8**.
- ?? **Properties** displays a property sheet that controls several aspects of the chart. In particular, you can specify the axis limits and hide/show individual curves.

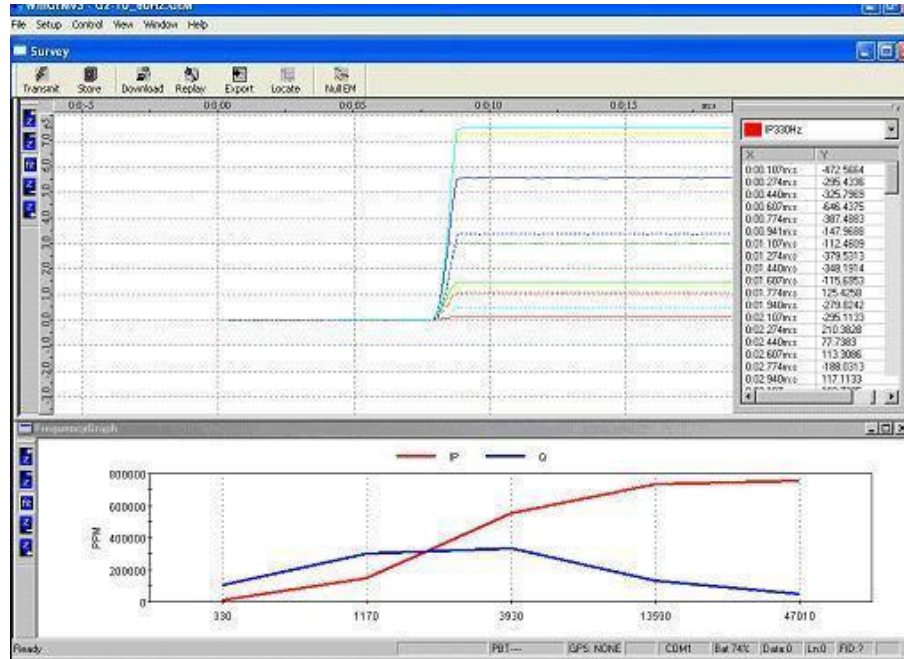


Figure 5. Time and Frequency graphs showing the response to a target after nulling.

### Data Download

Upon completion of a survey, connect the GEM-2 to the PC to download the data to a PC using WinGEM as follows:

- ?? Click the **Download** button on the toolbar (or the **Download Data** command under the **File** menu).
- ?? A **Store to** dialog requests the directory and file name of the file to be created.
- ?? As the download process proceeds, a special window monitors the progress of the download and allows the user to abort the operation. Do not be concerned if the download window indicates that a number of communication errors have been encountered. All sectors containing errors are automatically downloaded repeatedly until all errors are corrected.

After the file is saved, the user can optionally **Replay** the data. The data is read from the file and plotted at an accelerated speed for quick review.

### Data Export

After the raw (binary) data is downloaded to a \*.gbf (GEM Binary File) file, the next step is to export or convert it to a format that can be read by most spreadsheets and analysis programs. WinGEM has two functions for this process depending on how positions are to be assigned to the data. For a dead reckoning survey, use the **Locate** function (see the “Data Positioning” section below). If the data includes GPS records or if assigning positions is not required, use the **Export to (\*.CSV) file** command as described below:

- ?? Click the **Export to (\*.csv) file** command under the **File** menu.
- ?? Then a **File to be exported** dialog selects the input, binary (\*.gbf) file to be converted. The output csv file is given the same name with a .csv extension. In addition, a configuration file (\*.gem) with the same name is created.

- ?? If the raw data includes \$GPGGA records from a GPS unit, the export program assigns X and Y coordinates to each EM sample by interpolating between the GPS records. The latitude-longitude data in the GPS strings can be stored as decimal degrees. Alternatively, they can be converted to UTM coordinates (in meters) for the user-specified zone using the WGS-1984 or NAD83 geodetic reference. A third output file (\*\_GPS.csv) contains just the GPS data.
- ?? The inphase and quadrature data are listed in parts per million (ppm). Optionally, the EM data can be converted to “apparent conductivity” and “magnetic susceptibility” by imagining that the earth below the sensor is represented by a homogeneous and isotropic half-space.
- ?? A second dialog requests the GEM type, GPS zone, and desired position units. The optional conductivity and susceptibility computations require the coil radius and sensor height.

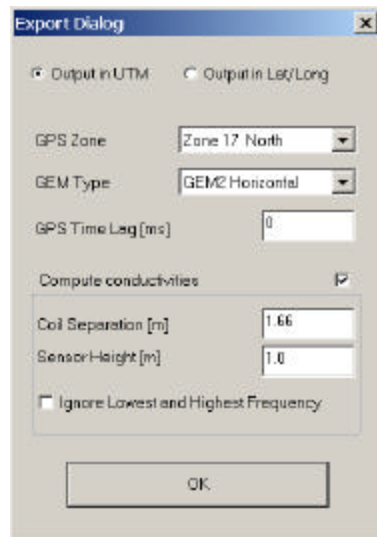


Figure 6. Information for export

The output *csv* file can be edited with a text editor or a spreadsheet program. Figure 7 shows a typical *csv* file in Microsoft Excel.

Line	Sample	X	Y	Mark	Status	GPSStat	Time[ms]	Time[h:mm:ss.sss]	PowerLn	L_90Hz	Q_90Hz	QSum	EC90Hz[mS/m]	TotalEC[mS/m]	MSusc90Hz[1/1000]
0	0	0	0	3	0	0	4.8E+07	132604.478	1.19E-04	-2005.81	789.888	789.888	131272	131272	15.4077
0	1	0	0	3	0	0	4.8E+07	132604.678	1.16E-04	-2006.89	791.453	791.453	131543	131543	15.416
0	2	0	0	3	0	0	4.8E+07	132604.878	1.16E-04	-2006.92	791.697	791.697	131585	131585	15.4163
0	3	0	0	3	0	0	4.8E+07	132605.078	1.16E-04	-2006.63	791.868	791.868	131615	131615	15.4141
0	4	0	0	3	0	0	4.8E+07	132605.278	1.16E-04	-2006.47	792.474	792.474	131720	131720	15.4128
0	5	0	0	3	0	0	4.8E+07	132605.478	1.16E-04	-2006.06	792.971	792.971	131806	131806	15.4096
0	6	0	0	3	0	0	4.8E+07	132605.678	1.17E-04	-2005.82	793.117	793.117	131831	131831	15.4078
0	7	0	0	3	0	0	4.8E+07	132605.878	1.17E-04	-2005.32	793.628	793.628	131920	131920	15.4039
0	8	0	0	3	0	0	4.8E+07	132606.078	1.07E-04	-2002.71	790.473	790.473	131373	131373	15.3837
0	9	0	0	3	0	0	4.8E+07	132606.278	1.11E-04	-2005.08	793.919	793.919	131970	131970	15.4021
0	10	0	0	3	0	0	4.8E+07	132606.478	1.12E-04	-2005.44	794.158	794.158	132011	132011	15.4048

Figure 7. GEM data in CSV format

The first two columns contain the Line and Sample numbers identifying each sample.

If the data contain GPS records, the interpolated X and Y coordinates are listed in the next two columns. Otherwise, these columns contain zeros. The *Mark* column contains a number that changes for those samples flagged with an Event Marker. A non-zero value in the *Status* column indicates a problem with the data (e.g. ADC overload). The 7th column displays the GPS Status or quality parameter if a GPS unit is attached to the GEM-2. The 8th and 9th columns are time-of-day in two formats – milliseconds and hours, minutes, and seconds. The 10th column is the magnitude of power line noise (at the power line frequency) in milli-Gauss. These data can be used to produce a map of power line contamination in the survey area. The inphase and quadrature data (in ppm) for each

received frequency are listed in the next columns.  $QSum$  is the sum of all the quadrature values. If the **Compute conductivities** option was selected, the apparent conductivity [milli-Siemen per meter] for each frequency is listed followed by the total apparent conductivity and the magnetic susceptibility [nondimensional, multiplied by 1000] calculated for each frequency.

### Data Positioning

If the stored raw data does not include location information from a GPS unit, X and Y coordinates can still be assigned to each EM data sample using a technique called *dead reckoning*. The **Locate** button on the WinGEM toolbar initiates this process. Upon selection of the **Locate** function, the dialog depicted in **Figure 9** appears requesting details about your survey lines.

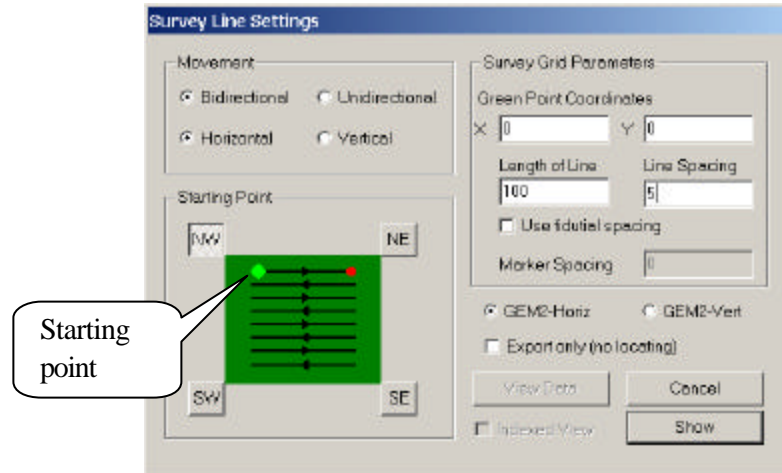


Figure 8. WinGEM's Locate dialog for positioning survey data

The light green point on the diagram represents the starting point of your first line. This point is positioned by selecting the appropriate compass point (SW, NW, NE or SE). Then set the appropriate movement flags and enter the survey grid parameters – coordinates of the starting point, line length, and line spacing. Select either **GEM2-Horiz** or **GEM2-Vert** to indicate the orientation used.

Check the **Export only (no locating)** checkbox to quickly export the data with calculated apparent conductivity values. The data is exported with no position information.

Select **Show** to move to the next screen which is depicted in **Figure 10**.



Figure 9. WinGEM data position plot and manipulation/export pop-up box

Using the information provided, **Locate** associates the line numbers in the downloaded data with the matching grid lines. Data points within a line are spaced uniformly between the line end points. A preliminary grid is displayed showing a plot of the located data points.

Clicking the right mouse button while the cursor is over the plot activates the popup menu shown above. The grid can be rotated and the line ends can be moved to match any irregularly shaped survey grid. For example, in the figure above, four endpoints in the upper left corner have been shifted and two lines have been combined with a gap where an obstacle prevented data collection. Use **Delete Selected Lines** to remove any “bad” lines.

Line endpoints may be selected by left clicking and dragging a selection area or the endpoints can be individually selected by left clicking while holding down the Control key.

After the grid has been modified to depict the actual survey grid, the data may be exported in a comma separated value (csv) format using the **Export (\*.csv)** command. The file format is the same as described in the “Data Export” section. The calculated X-Y position is in the third and fourth columns.

These files may then be imported into third party software such as Surfer<sup>?</sup> to be gridded, then contoured or otherwise presented as a two-dimensional map.

## WinGEM ADVANCED Menu

The sections above describe all of the WinGEM BASIC menu functions that are required for routine acquisition and processing of survey data. These functions are all that most GEM-2 users will need; however, WinGEM includes many advanced functions in order to meet the needs of special applications, to perform sensor diagnostics, and to enable sensor calibration. Note that sensor calibration is usually performed only at the factory. Use the **View ... Change** Menu command to select the ADVANCED menu if required. Exit and restart WinGEM to activate the alternate menu. Some of the more commonly used advanced functions are described below.

### Configuration

The GEM-2 is configured with the factory default settings. The physical parameters describing the coil and calibration parameters should never need to be changed, so these functions are not described in this manual. However, there are a few settings that you might desire to change.

The user can modify some of the parameters by selecting **Change Frequencies** from the **Setup** menu. WinGEM downloads the current configuration settings from the GEM-2 and displays them in a series of dialogs. The **User Settings** dialog is shown in Figure 10.

### Changing power line frequency and averaging factor

Select the appropriate **Power line frequency** (60 or 50 Hz) for your location. This value determines the frequencies allowed and the basic sampling period, called the **Base Period**. The default Base Period for GEM-2 set to 1/30 second for 60Hz areas and 1/25 second for 50Hz areas. Within a single Base Period, the GEM-2 completes the entire series of operation: transmitting a multifrequency waveform, digitizing two-channel received signals, performing discrete sine and cosine convolutions at each transmitted frequency, and computing and storing the raw ppm values of the inphase and quadrature response at each transmitted frequency. The powerline-based Base Period is to minimize interference from powerlines and other EM noise sources.

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<sup>?</sup> Surfer is a Registered Trademark of Golden Software, Inc.



The value entered in the **Averaging factor** field determines the number of base period results to average to produce one data sample. Increasing this value increases the time interval between samples and decreases the “noise” in the data. The **Power line frequency** and the **Averaging Factor** together determine the **Output data rate** (samples per second). For example, a 60Hz power line frequency and an averaging factor of 3 would result in an output data rate of 10 samples per second. For walking surveys, averaging three to four base periods is recommended.

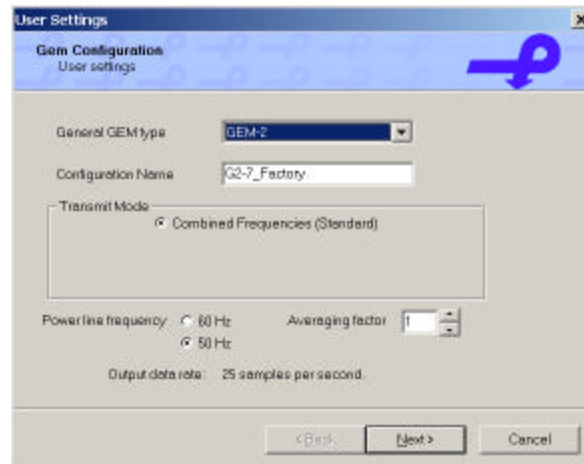


Figure 10. User settings dialog

## Changing frequencies

Clicking the *Next* button brings up the **Transmitter Frequencies** screen as shown in Figure 11.

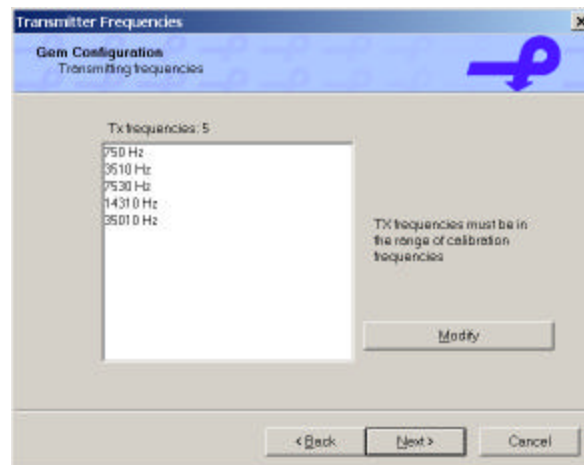


Figure 11. Transmitter frequency selection screen

To change any of the frequencies, select it in the **Tx frequencies** list and click the **Modify** control button. Then the **Frequency Edit** dialog is displayed as shown in Figure 12.

GEM-2 is configured at the factory for 3 frequencies (1170, 3930, and 13590 Hz for 60 Hz power line or 1175, 3925, and 13575 Hz for 50 Hz power line). The transmitter power is shared among all frequencies, which decreases the available magnetic moment to each frequency as the number of frequencies used increases. We recommend not exceeding about five frequencies on a GEM-2.

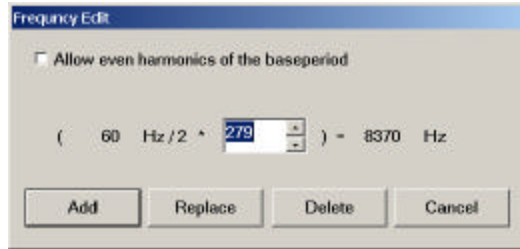


Figure 12. Frequency edit screen

At this stage, the user can **Add**, **Delete** or **Replace** frequencies as required. Select a frequency by entering an odd multiple of the base period frequency. Selecting frequencies in this manner minimizes the effect of noise from electrical EM sources. All frequencies must be within the range of the factory-set calibration frequencies.

Once all the desired changes have been made, click **Next** to proceed to the **Receiver Frequencies** screen, which looks similar to Figure 12. The list of RX frequencies is initially set to the TX frequencies. You can add, delete, or replace frequencies using the **Modify** button and the **Frequency Edit** dialog. As a default, the GEM-2 has an additional RX frequency at the powerline frequency to monitor the powerline-induced noise level along the survey lines.

Click **Next** again to view corrections which are applied to the inphase and quadrature values resulting from the calibration procedure. Click **Next one** final time, then click **Finish** to upload your changes to the GEM or **Cancel** to retain the original settings.

Because data logged with a new set of frequencies will be inconsistent with previously logged data, a dialog (Figure 13) is displayed suggesting that any old logged data be deleted.

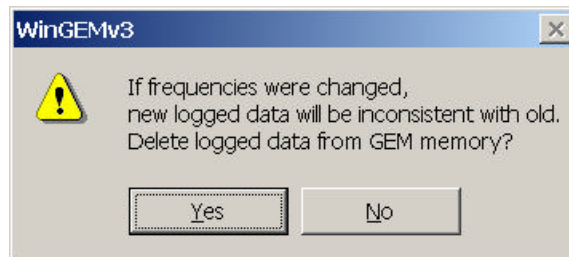


Figure 13. Dialog suggesting that logged data be deleted.

Use the **Save Setup As** command under the **File** menu to create a file containing your modified configuration. Do not overwrite the original, factory provided configuration file. You can maintain several configurations with different sets of frequencies.

Use the **File ... Load Sensor from file** command to select the desired configuration. If you have more than one GEM sensor, be careful to load a configuration appropriate for the sensor in use.

### Checking for Interference

All EM sensors are subject to interference by noise from ambient EM sources. The GEM-2 is designed to minimize the effects of noise. First, the base period and frequencies are chosen to avoid the noise from powerlines and other electrical sources. Secondly, the inphase and quadrature data are computed for narrow frequency bands that can be chosen to avoid noisy frequency ranges.

### Passive Monitoring

The GEM-2 monitors for noise during data acquisition. The power line frequency itself is monitored automatically. The standard GEM-2 output data contain the amplitude of the power line noise.

If noise is anticipated at frequencies other than the power line frequency, the GEM-2 can monitor them as well. The list of RX frequencies can contain frequencies that are not TX frequencies for passive monitoring. Use the *Setup ... Change Frequencies* command to add the frequencies to be monitored to the list of *Receiver Frequencies*. Check the *Allow even harmonics of the base period* checkbox in the *Frequency Edit* dialog to enter frequencies that are multiples of the power line frequency.

The amplitude of the power line noise or the inphase/quadrature data for the passive frequencies may be used to produce a map of noise contamination in the survey area. This passive monitoring of environmental noise is a unique feature not available in any other EM system.

### Other Advanced Functions

**Momentary Logging** — A special data logging mode is supported. If you enter a non-zero value for the *Interval to Log Data* via the *Control ... Momentary Logging* command (ADVANCED menu mode), samples are logged for the specified number of seconds each time the Logging button is clicked. This mode can be useful for recording data at a number of distinct locations.

**Momentary Storing** — Similar to momentary logging, the *Pause Store* button can be used to temporarily stop storing data directly to the PC (e.g. between survey lines). Click it again to resume storing data and increment the line number.

**Control ... Momentary Storing** is analogous to *Control ... Momentary Logging* -- samples are stored for the specified number of seconds each time the *Pause Store* button is clicked.

Note the difference between the Logging and Storing actions. Storing is a WinGEM function. It requires that the GEM be connected to a PC. A readable file is created directly. Therefore it is convenient for laboratory testing. Logging is a GEM function. It can be controlled via the GEM console. The data must be downloaded to a PC for analysis. Logging is typically used for fieldwork.

**Stored Configurations** — The ADVANCED mode Setup menu contains several commands (*Activate Saved*, *Save Active*, and *Delete Saved*) for accessing the four configurations stored in the GEM memory.

**Filters** — The GEM-2 processor performs some smoothing of the inphase and quadrature values in time before the base period averaging mentioned above. A moving median filter is applied followed by a moving average filter. Using the *Control ... Advanced Commands ... Filters* command you can change the number of samples used in these two filters.

The *Control ... Advanced Commands ... Set new BX-Error Level* command lets you change the minimum BX level used to detect transmitter malfunction.

**Capturing Raw Data** — The raw digitized signals from the RX and BX coils can be captured and downloaded for analysis. Use the *Control ... Advanced Commands ... Set Raw Data Capture Size* command to specify how many base periods of raw data are to be captured (and not processed). Start transmitting. The *Control ... Advanced Commands ... Capture Raw Data* command initiates data capture. The captured time series data is automatically downloaded and written to a separate text file with a “\_BxRx.ts.txt” extension.

**Modules** — Additional special-purpose functions may be available via the *Modules* menu.

## Frequently Asked Questions about the GEM-2

### *What is the Depth of Exploration for GEM-2?*

This is a very complex question because the answer depends on many factors, particularly on ground conductivity, target volume, and ambient electromagnetic noise. Based on many analyses and field data, we estimate the GEM-2 should be able to see about 30-50m in resistive areas (>1000ohm-m) and about 20-30m in conductive areas (<100ohm-m). This figure assumes an ambient noise level of 5ppm. The noise level is generally high in urban areas and low in rural areas. For typical applications, we do not recommend the GEM-2 for depths greater than 50m. For more discussion on this subject, consult the “Skin-depth Nomogram” in “GEM-2 Principle of Operation” on our web site.

Depth of exploration for a given earth medium is determined by the operating frequency. Therefore, measuring the earth response at multiple frequencies is equivalent to measuring the earth response from multiple depths. Hence, such data can be used to image a 3-D distribution of subsurface objects. Results from several environmental sites indicate that the multifrequency data from GEM-2 is far superior in characterizing buried, metallic and non-metallic targets to data from conventional single-frequency sensors. For handheld sensors, the transmitter-receiver coil separation is inherently small and has little to do with the depth of exploration.

### *How Do You Calibrate the GEM-2?*

There are two calibration sets with complex values (i.e., inphase and quadrature), each as a function of frequency. The calibration is performed at Geophex and stored in your GEM software. No other calibration should be required. The two calibration sets are:

1. Amplitude calibration - this is done using a "Q coil" with known radius, number of turns, resistance, and inductance. It mainly sets the amplitude scale.
2. Free-air calibration - The sensor output must approach zero when you move it away from any conductor. Of course, this is hard to do on earth. Airborne sensors are flown at a great height. The required height is typically 5-10 times of the coil spacing. For GEM-2, we raise the sensor 6 to 10m above ground (we have a pulley on a branch of a pine tree in our back yard), and we call the sensor response there the "free-air values". This calibration does depend on the ground conductivity, but it is simply a DC offset.

For most applications, a precise calibration is not critical. Normally, we are interested only in relative values – deviations from a base value that appear as “bumps” in a map or profile. The calibration factors (multiplier and DC offset) affect the absolute values of the data but not the appearance of the “bumps”. We suggest that you do not change the amplitude calibration.

The offset calibration can be a problem over a very conductive or resistive area, when one wants an absolute conductivity map. In this case, if you know the background conductivity from other measurements (DC resistivity, for instance), you can simply add or subtract a constant from the entire dataset so that it fits the background. Still, the process does not change the map appearance.

A ferrite rod (permeable but not conductive) produces a constant inphase and zero quadrature response at all frequencies. We sometimes use ferrite for a quick calibration check. Our older manual described the procedure, but we deleted it since we decided that it is not necessary.

### *Does the GEM Drift in Time?*

The GEM-2 is designed to minimize the temporal drift in a quite different way from all other instruments. The GEM-2 ski contains three coils that are precisely maintained in their relative

separations amongst each other. Any small changes in the relative separations can cause a shift (or drift) in the signal level. The GEM-2 coils are permanently entombed in a “ski” structure made of synthetic materials that has a low thermal expansion coefficient and, therefore, their relative locations are firmly fixed. The sensor is designed to “linearly” expand or contract following the ambient temperature. This linear expansion precisely maintains the relative positions and, therefore, the bucking condition. This feature is quite unique for this design. Owing to this careful design and manufacturing, the GEM-2 has not shown any appreciable drift.

Another important feature is the way the console (which is a big chunk of metal) is designed and mounted on the ski. The console is located where the field gradient is minimum so that its slight displacement would cause little shift in the signal. There are no moving parts in the console. The battery is internal and not removable. If you think the sensor may be drifting, tighten the screws that mount the console to the ski; but please do not over tighten. Diurnal temperature changes should not be a significant cause.

### ***What is the Quickest Way of Plotting the GEM Data?***

Most simple GEM surveys (geological, geotechnical, and environmental) do not require navigational aids, such as GPS. The operator steadily walks across a survey area between two opposite rectangular boundaries in a back-and-forth fashion at fixed line spacing. We call this a “dead-reckoning” survey.

For dead-reckoning data, WinGEM’s Locate function assigns coordinates to each data point by uniformly spacing the data point between the line endpoints. WinGEM generates Comma Separated Values (csv) text files that contains X, Y, I1, Q1, I2, Q2, etc., where X and Y are the data coordinates and the rest are the inphase and quadrature data for frequency 1, 2, 3, and so forth. These files can be loaded into most spreadsheet programs such as Microsoft Excel. The data from individual lines can be plotted.

The data files can be loaded into third party software such as SURFER or Geosoft to make 2-D maps. SURFER is the most commonly available 2-D plotter. For such a dead-reckoning survey, the operator can view the whole dataset on contoured maps within minutes after the survey is completed.

### ***How Do You Integrate GEM and GPS Data?***

GEM-2 models after 2002 have a separate DB9 connector for sending GPS data directly into the GEM console. For GEM-2 models before 2002, an RS232 download cable connects to the GEM console via a Bendix connector and the other side to a normal PC connector. All commercial GPS units (Trimble, Novatel, etc.) have standard data output that can be merged with the GEM output in this way. The GPS data strings are stored (logged) along with the EM data. WinGEM’s Export function assigns X,Y coordinates to each data sample by interpolating between the locations in the GPS strings.

When the GEM-2 is connected to a PC, the GPS strings are sent out the serial port along with the EM data.

### ***How Do You Convert the GEM-2 Data to Apparent Conductivity and Susceptibility?***

Using WinGEM’s Export or Locate function, the GEM-2 ppm data can be converted to apparent conductivity and magnetic susceptibility at each frequency used for the survey. For a discussion of the theory and practical assumptions involved in these calculations, see the article by Huang and Won (2001), entitled “Conductivity and Susceptibility Mapping Using Broadband Electromagnetic

Sensors,” published in the Journal of Environmental and Engineering Geophysics. The article may be viewed from the Geophex website.

***How Do You Invert GEM-2 Multifrequency Data to a Layered Earth?***

A program for inverting the GEM-2 data to a Layered Earth Model can be downloaded from the “[About Geophex](#)” page of our web site.. This program is provided for informational purposes only. It should be considered as Beta version software. We request users to work with our Geophex scientists to improve it. The primary author is Dr. Haoping Huang at Geophex. The code makes a 2-D cross-section based on continuous 1-D interpretation.

***How do I Learn More about the GEM Sensors?***

The Geophex website, [www.geophex.com](http://www.geophex.com), provides ample information about the GEM sensors, design and operating principles, survey tips, manuals, and downloadable software. The site also carries many journal articles related to the GEM sensors, which can be viewed or printed. For more information and questions, please contact Geophex.

***Where do I send my questions?***

Please direct all technical questions to Mr. Alex Oren at [oren@geophex.com](mailto:oren@geophex.com)