GPR4 Concrete Scanner

User Manual

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1 FCC Class A Compliance and Usage Limitations

This device complies with Part 15 Subpart B and Subpart F of the FCC Rules. Operation is subject to the following two conditions: (1) the device may not cause harmful interference, and (2) this device must accept any interference received including interference that may cause undesired operation.

FCC ID: 2AP78-CS1 and contains RF Module FCC ID: Z64-WL18DBMOD.

Warning: Changes or modifications to this unit not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

According to the FCC Rules Part 15 Subpart F, this device has several requirements and limitations for use. Specifically:

15.509:

(a) The UWB bandwidth of an imaging system operating under the provisions of this section must be below 10.6 GHz.

(b) Operation under the provisions of this section is limited to GPRs and wall imaging systems operated for purposes associated with law enforcement, fire fighting, emergency rescue, scientific research, commercial mining, or construction.

(1) Parties operating this equipment must be eligible for licensing under the provisions of part 90 of this chapter.

(2) The operation of imaging systems under this section requires coordination, as detailed in §15.525.

15.521:

(a) UWB devices may not be employed for the operation of toys. Operation onboard an aircraft, a ship or a satellite is prohibited.

15.525:

(a) UWB imaging systems require coordination through the FCC before the equipment may be used. The operator shall comply with any constraints on equipment usage resulting from this coordination.

(b) The users of UWB imaging devices shall supply operational areas to the FCC Office of Engineering and Technology, which shall coordinate this information with the Federal Government through the National Telecommunications and Information Administration. The information provided by the UWB operator shall include the name, address and other

pertinent contact information of the user, the desired geographical area(s) of operation, and the FCC ID number and other nomenclature of the UWB device. If the imaging device is intended to be used for mobile applications, the geographical area(s) of operation may be the state(s) or county(ies) in which the equipment will be operated. The operator of an imaging system used for fixed operation shall supply a specific geographical location or the address at which the equipment will be operated. This material shall be submitted to Frequency Coordination Branch, OET, Federal Communications Commission, 445 12th Street, SW, Washington, D.C. 20554, Attn: UWB Coordination.

(c) The manufacturers, or their authorized sales agents, must inform purchasers and users of their systems of the requirement to undertake detailed coordination of operational areas with the FCC prior to the equipment being operated.

(d) Users of authorized, coordinated UWB systems may transfer them to other qualified users and to different locations upon coordination of change of ownership or location to the FCC and coordination with existing authorized operations.

(e) The FCC/NTIA coordination report shall identify those geographical areas within which the operation of an imaging system requires additional coordination or within which the operation of an imaging system is prohibited. If additional coordination is required for operation within specific geographical areas, a local coordination contact will be provided. Except for operation within these designated areas, once the information requested on the UWB imaging system is submitted to the FCC no additional coordination with the FCC is required provided the reported areas of operation do not change. If the area of operation changes, updated information shall be submitted to the FCC following the procedure in paragraph (b) of this section.

(f) The coordination of routine UWB operations shall not take longer than 15 business days from the receipt of the coordination request by NTIA. Special temporary operations may be handled with an expedited turn-around time when circumstances warrant. The operation of UWB systems in emergency situations involving the safety of life or property may occur without coordination provided a notification procedure, similar to that contained in §2.405(a) through (e) of this chapter, is followed by the UWB equipment user.

2 IC Compliance and Usage Limitations

This device complies with Canadian RSS-220, RSS-GEN and ICES-003. Operation is subject to the following two conditions: (1) the device may not cause harmful interference, and (2) this device must accept any interference received including interference that may cause undesired operation.

IC: 2AP78-CS1 and contains RF Module IC: 451I-WL18DBMOD.

According to the RSS-220, Issue 1, Section 6.2, this device has several requirements and limitations for use. Specifically:

(a)This Ground Penetrating Radar Device shall be operated only when in contact with or within 1m of the ground.

(b) This Ground Penetrating Radar Device shall be operated only by law enforcement agencies, scientific research institutes, commercial mining companies, construction companies, and emergency rescue or firefighting organizations.

(c) This In-wall Radar Imaging Device shall be operated where the device is directed at the wall and in contact with or within 20 cm of the wall surface.

(d)This In-wall Radar Imaging Device shall be operated only by law enforcement agencies, scientific research institutes, commercial mining companies, construction companies, and emergency rescue or firefighting organizations.

(e) This device complies with Industry Canada licence-exempt RSS standard(s). Operation is Subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired Operation of the device.

Cet appareil est conforme aux normes canadiennes RSS-220, RSS-GEN et ICES-003. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

IC: 2AP78-CS1 et contient le module RF IC: 451I-WL18DBMOD.

Selon le RSS-220, Issue 1, Section 6.2, cet appareil a plusieurs exigences et limitations d’utilisation. Plus précisément:

(a) Ce dispositif radar à pénétration du sol ne doit être utilisé qu'en contact avec le sol ou à au plus 1 m du sol.

(b) Ce dispositif radar à pénétration du sol ne doit être utilisé que par des organismes d’application de la loi, des établissements de recherche scientifique, des sociétés minières commerciales, des entreprises de construction, et des organismes d’intervention d’urgence ou de lutte contre les incendies.

(c) Ce dispositif d'imagerie radar intramur doit être utilisé lorsqu'il est orienté vers le mur et en contact avec la surface du mur ou à au plus 20 cm de cette surface.

(d) Ce dispositif d'imagerie radar intramur ne doit être utilisé que par des organismes d'application de la loi, des établissements de recherche scientifique, des sociétés minières commerciales, des entreprises de construction, et des organismes d'intervention d'urgence ou de lutte contre les incendies.

(e) Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes : (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

3 Introduction

3.1 Overview

This document provides the operating and configuration instructions for the Concrete Scanner. The Scanner measures locates objects that are embedded in concrete such as rebar, pipes, and conduits, measures concrete thickness, and can located defects in concrete such as voids. The scanner can produce simple cross sections, depth slice images, or 3D images of the concrete structure. The system includes a scanner unit with an integrated radar, odometer, and power line detector, and a tablet computer. An optional long handle can be used to scan hard to reach places. The Concrete Scanner has been designed so that no cables are used in order to increase ease of use and reliability. The shipping case contains an integrated battery charging system to recharge all system components simultaneously. The entire system is stored rugged shipping case is designed for shipping and transport in rugged situations.

Figure 1: Concrete Scanner.

The system consists of the following components.

1. A hard shell shipping container with custom foam inserts for the system components.

2. A multi-port battery charging system that simultaneously charges two sensor batteries, and the tablet computer.
3. Two batteries for the sensor unit.
4. A long handle for the sensor unit.
5. The sensor unit with GPR, odometer, and power line sensors.
6. Tablet computer (may be provided separately).

4 Operation

This section provides operating instructions for conducting surveys, generating reports, and recharging the batteries. Before starting survey, the needs to determine the area to be surveyed and how that area will be covered. Typically, there are two types of surveys that are conducted: a single line survey that produces a cross section view, or a multi-line survey that produces a 3D view. Surveys consist of one or more straight-line scans. The concrete surface must be clean and dry.

Figure 2. Concrete Scanner as stored in its shipping container.

4.1 Hardware Assembly

During normal storage and transportation, the Concrete Scanner is packed in its shipping case. Proceed as follows to assemble the unit for surveying.

1. Open the shipping container (see Figure 2) and disconnect the charging cable from the tablet.
2. Remove the scanner and the tablet from the shipping case. Remove one of the batteries from the shipping case and attach it to the scanner.
3. If the long handle will be used, remove the three pieces of the long handle from the shipping case: the wide handle, the telescoping tube, and the scanner clamp. Mount the scanner clamp to the scanner, then attach the telescoping tube, and finally attach the wide handle. Adjust the telescoping tube as desired.
4. The tablet computer can be located in one of four locations during the survey (see Figure 3): on a stand, on the long handle, on the scanner, or held in-hand. For most surveys, the use of the stand is recommended.
    a. For the stand arrangement, connect the long handle and telescoping tube, and then insert the tube into the holder in the shipping case. Mount the tablet holder to the wide handle on the stand and then mount the tablet.
    b. For the long handle arrangement, mount the tablet holder to the wide handle and then mount the tablet.
    c. For the scanner arrangement, mount the scanner clamp to the scanner and then attach the wide handle. Finally, mount the tablet holder to the wide handle and then mount the tablet.
    d. For the in-hand arrangement, attached the hand strap to the tablet.

Figure 3. Different tablet locations can be used for different survey types.

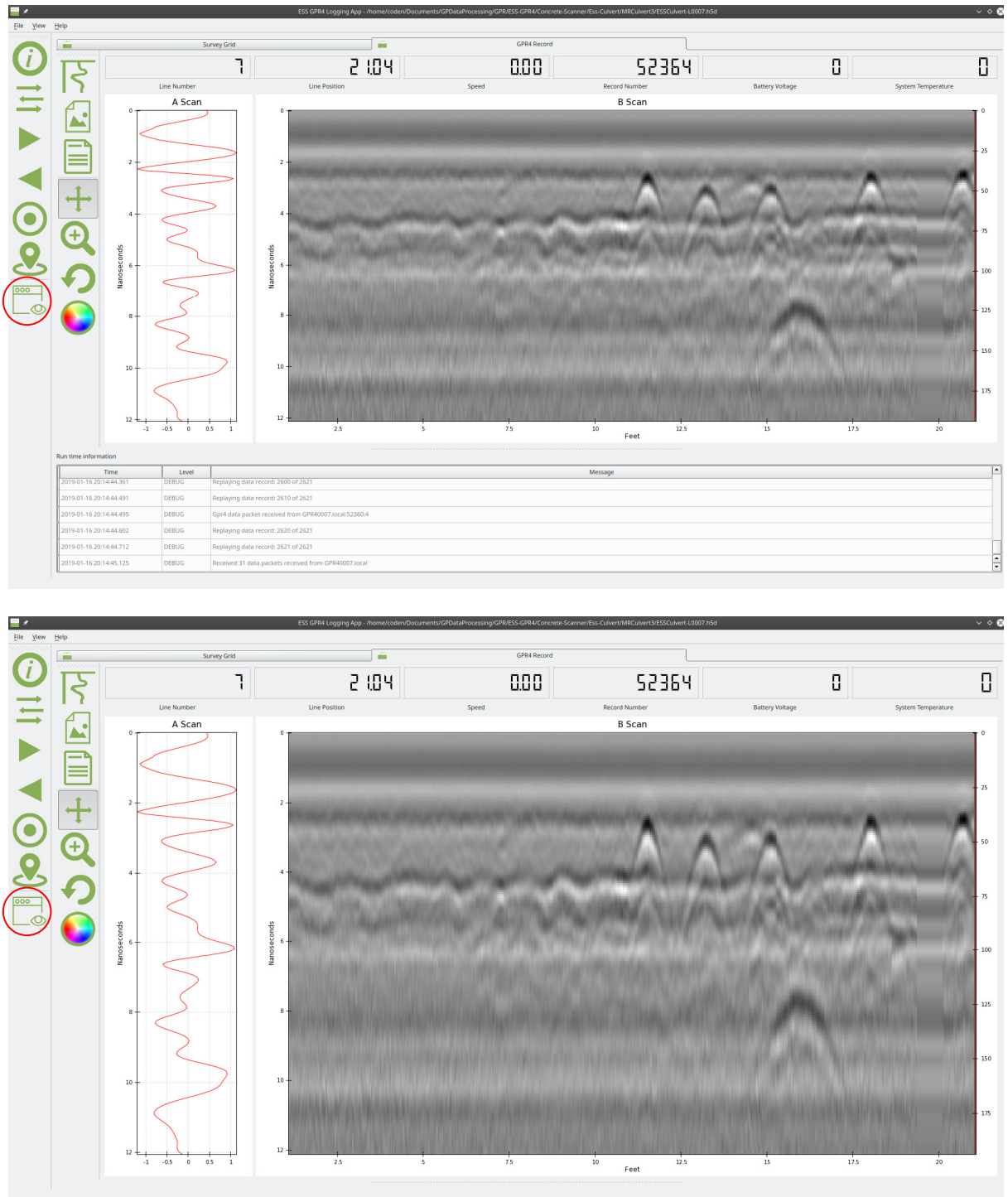

Figure 4. Upper panel shows acquisition program with status panel visible and lower panel has status panel hidden. Use the circled icon to hide/show the status panel.

4.2 Conduct a Single Line Survey

A single line surveys is a quick method that is usually used to find where a small number of subsurface conduits intersects the survey line. To conduct a survey, proceed as follows.

1. Turn on the power to the sensor unit. The power switch should glow with a green light.
2. Boot up the tablet computer and log in. Enable mouse pointer using the mouse icon on the task bar if desired.
3. Connect to the sensor unit via WiFi. On the task bar, press the WiFi network icon  , then select the network connection for the Concrete Scanner. The name of the connection will be the serial number of the scanner (e.g., GPR40123). It will take 30-60 seconds after the sensor box has been powered up for the network to appear on the tablet. Select the network connection for the scanner and wait for it to connect. Windows will ask if you would like to connect automatically. If you enable automatic connection, then this step can be skipped for future surveys.
4. Start the data acquisition program by touching and holding the *EssGpr4LoggingApp* icon on the desktop. The program will startup, connect to the scanner, and start updating with data. Figure 4 shows the acquisition program screen. There is a status panel that shows status messages, but in most cases the user can hide this panel so that the plotting area is larger. The green light on the scanner's power button will flash when it is connected to the acquisition program on the tablet computer. Users can pan and zoom the plots in the acquisition program. To pan, simply click on the plot and drag. To zoom, click on the plot, press *z*, then click and drag to draw the zoom box. For an alternate zoom method, click on the plot, the press *shift-up-arrow*, *shift-down-arrow*, *shift-left-arrow*, or *shift-right-arrow* to zoom in the vertical or horizontal direction. The reset the plot, click on it and then press *esc*.
5. The acquisition program has several views that can be selected by clicking on the appropriate tab on the top of the screen: *Survey Grid*, *GPR4 Record*, and optionally *Documentation*. Each tab has its own toolbar with functions dedicated to that view.
6. The *GPR4 Record* tab has standard A-scan and B-scan plots that are customary for most GPR systems. The plot parameters can be changed by pressing the *Plot parameters* button  (see Figure 5). For most users, the default settings will be sufficient. For those interested, the dialog functions are described below.
    a. *Use automatic range gain* When this is selected the program automatically increases gain with increasing range to compensate for signal attenuation with range. The gain profile is automatically readjusted at the start of each line.
    b. *Automatic zero time* Use this setting to move the first arrival to the beginning of the plot.
    c. *Antenna combination* For the Pavement Scanner, this should always be set to *TxA RxA*.
    d. *Depth/Time units* Select the units for the vertical scale on the B-scan. The most basic units are sample number (*Samples*). Sample number multiplied by the digitizer sample period gives sample time (*Nanoseconds*). Sample time multiplied by the medium velocity gives distance (*Centimeters*, *Inches*, *Meters*, *Feet*).
    e. *Depth/Time range* Users can opt to display the full range, half range, quarter range, or eighth range. Users may wish to display only a shallow portion of the

usable range when interested in the more shallow portions of the surveyed range (depth).

f. *Velocity of medium* The velocity of EM waves is dependent on the material type. In order to properly convert from time of flight to depth, the velocity of the medium must selected (see *Depth/Time units* above). Select the medium type and the corresponding dielectric constant. The EM velocity is $v = c/\sqrt{\varepsilon}$ where v is the EM wave velocity, c is the speed of light in a vacuum, and ε is the dielectric constant of the medium.

Air	ε = 1
Dry concrete/indoor/mature - Dry soil	ε = 4
Damp concrete/outdoor - Damp soil	ε = 6.5
Moist concrete/outdoor/young - Moist soil	ε = 9
Wet concrete/outdoor/young - Wet soil	ε = 16
Saturated concrete/outdoor - Saturated soil	ε = 25

g. *Distance units* Select the units for the horizontal scale on the B-scan (*Centimeters*, *Inches*, *Meters*, *Feet*, *Seconds*).

h. *Distance range* Select the horizontal range of the B-scan in distance units (*10*, *20*, *50*, *100*, *200*).

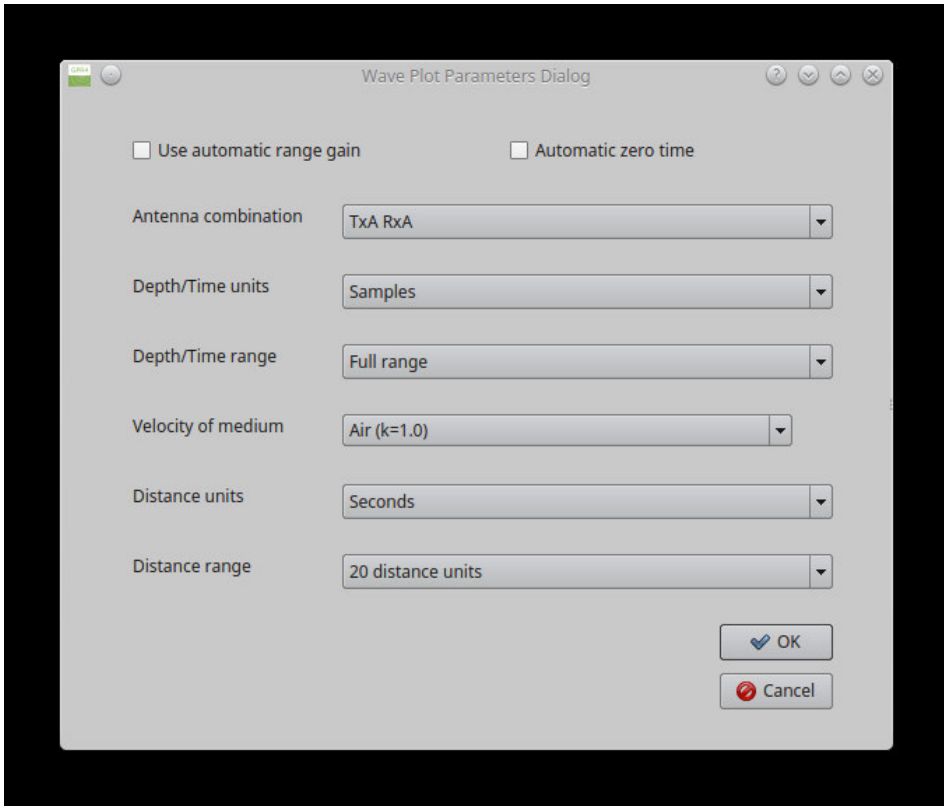

Figure 5. The plot configuration dialog.

The *GPR4 Record* tab also has buttons for saving the B-scan image and generating a short report. The image can be saved as a PNG, BMP, or JPG file. The report will be saved as a PDF file, and will contain the survey metadata and the B-scan image.

7. Before beginning a survey, it is important to capture information about the jobsite. Press the *Jobsite information* button to bring up the dialog shown in Figure 6. The information entered into this dialog will be listed in any reports that will be generated by the software. To type into dialog field, click on the field to place the cursor, then press the icon on the taskbar to bring up the keyboard.
    a. Enter the *Project Name*, *Site Location*, *Site Description*, *Operator*, *Survey Mode*, *Notes*, *Service Provider*, and *Equipment Model*. The *Date Recorded* and *Time Recorded* fields will be updated automatically.
    b. *Map Frame Parameters* Select the distance *Units* (feet or meters). The *Latitude*, *Longitude*, and *Elevation* parameters will be updated automatically once the survey begins using the GPS sensor in the sensor unit. The *Magnetic Declination* and *Map System* fields are not used with the Pavement Scanner.
    c. *Local Frame Parameters* Select the distance *Units* (feet or meters). Enter the bearing of the first survey line in the *Line 1 Azimuth* field. The software will use this value to correctly orient images on maps that are exported as KMZ or HTML files.

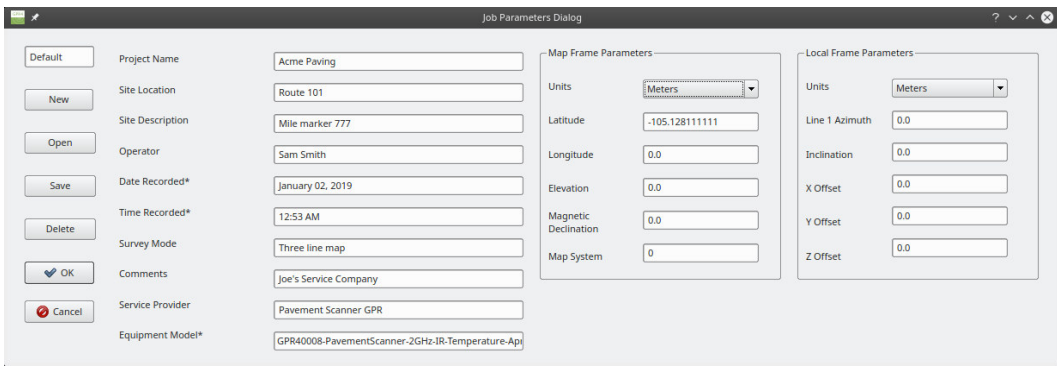

Figure 6. Jobsite information dialog.

8. Move the scanner to the start position of the line. Press the *Previous line* button until the proper line number is displayed at the top of the screen. This action can also be accomplished by pressing the rocker button on the radar unit to the ***left*** momentarily. Each time this button is pressed, the system runs through a line initialization sequence which tasks a few seconds. When the user hears an audible beep from the tablet, the initialization sequence has completed. Therefore, users should wait until the audible beep is heard before another line request.
9. The GPR data can be recorded for later playback and examination if desired. When locating intersecting conduits, some users may choose not to record the data. Select *File*, *New*, and then choose a location and name for the database file. When ready to begin the survey, press the *Record data* button. This action can also be

accomplished by pressing the rocker switch on the radar unit ***up*** momentarily. The button should appear activated to indicate that data are being recorded. Move the cart along the survey line to conduct the survey.

10. Move the cart along the survey line until the scanner moves beyond the conduit of interest. Roll the scanner backwards on the line until the scanner is positioned directly over the conduit and mark the position on the concrete surface with a marker. While recording data, a marked fiducial can be placed in the datafile by pressing the  icon.
11. If data recording was enabled, press the *Record data* button  to turn off recording after the cart has traversed the entire survey line. The button should appear inactivated. This action can also be accomplished by pressing the rocker switch on the radar unit ***down*** momentarily.
12. If no further surveys are to be conducted, power down the sensor and odometer. Disassemble the survey cart and return all components to the shipping case.

4.3 Conduct a 3D Survey

Users usually conduct 3D scans when depth slices or 3D views of the subsurface are desired. To conduct a 3D survey, proceed as follows.

1. Turn on the power to the sensor unit. The power switch should glow with a green light.
2. Boot up the tablet computer and log in. Enable mouse pointer using the mouse icon on the task bar if desired.
3. Connect to the sensor unit via WiFi. On the task bar, press the WiFi network icon  , then select the network connection for the Pavement Scanner. The name of the connection will be the serial number of the scanner (e.g., GPR40123). It will take 30-60 seconds after the sensor box has been powered up for the network to appear on the tablet. Select the network connection for the scanner and wait for it to connect. Windows will ask if you would like to connect automatically. If you enable automatic connection, then this step can be skipped for future surveys.
4. Start the data acquisition program by touching and holding the *EssGpr4LoggingApp* icon on the desktop. The program will startup, connect to the scanner, and start updating with data. Figure 4 shows the acquisition program screen. There is a status panel that shows status messages, but in most cases the user can hide this panel so that the plotting area is larger. The green light on the scanner's power button will flash when it is connected to the acquisition program on the tablet computer. Users can pan and zoom the plots in the acquisition program. To pan, simply click on the plot and drag. To zoom, click on the plot, press *z*, then click and drag to draw the zoom box. For an alternate zoom method, click on the plot, the press *shift-up-arrow*, *shift-down-arrow*, *shift-left-arrow*, or *shift-right-arrow* to zoom in the vertical or horizontal direction. The reset the plot, click on it and then press *esc*.
5. The acquisition program has several views that can be selected by clicking on the appropriate tab on the top of the screen: *Survey Grid*, *GPR4 Record*, and optionally *Documentation*. Each tab has its own toolbar with functions dedicated to that view.

6. The *GPR4 Record* tab has standard A-scan and B-scan plots that are customary for most GPR systems. The plot parameters can be changed by pressing the *Plot parameters* button  (see Figure 5). For most users, the default settings will be sufficient. For those interested, the dialog functions are described below.
    a. *Use automatic range gain* When this is selected the program automatically increases gain with increasing range to compensate for signal attenuation with range. The gain profile is automatically readjusted at the start of each line.
    b. *Automatic zero time* Use this setting to move the first arrival to the beginning of the plot.
    c. *Antenna combination* For the Pavement Scanner, this should always be set to *TxA RxA*.
    d. *Depth/Time units* Select the units for the vertical scale on the B-scan. The most basic units are sample number (*Samples*). Sample number multiplied by the digitizer sample period gives sample time (*Nanoseconds*). Sample time multiplied by the medium velocity gives distance (*Centimeters*, *Inches*, *Meters*, *Feet*).
    e. *Depth/Time range* Users can opt to display the full range, half range, quarter range, or eighth range. Users may wish to display only a shallow portion of the usable range when interested in the more shallow portions of the surveyed range (depth).
    f. *Velocity of medium* The velocity of EM waves is dependent on the material type. In order to properly convert from time of flight to depth, the velocity of the medium must selected (see *Depth/Time units* above). Select the medium type and the corresponding dielectric constant. The EM velocity is $v = c/\sqrt{\varepsilon}$ where v is the EM wave velocity, c is the speed of light in a vacuum, and ε is the dielectric constant of the medium.

Air	ε = 1
Dry concrete/indoor/mature - Dry soil	ε = 4
Damp concrete/outdoor - Damp soil	ε = 6.5
Moist concrete/outdoor/young - Moist soil	ε = 9
Wet concrete/outdoor/young - Wet soil	ε = 16
Saturated concrete/outdoor - Saturated soil	ε = 25

    g. *Distance units* Select the units for the horizontal scale on the B-scan (*Centimeters*, *Inches*, *Meters*, *Feet*, *Seconds*).
    h. *Distance range* Select the horizontal range of the B-scan in distance units (*10*, *20*, *50*, *100*, *200*).

    The *GPR4 Record* tab also has buttons for saving the B-scan image  and generating a short report  . The image can be saved as a PNG, BMP, or JPG file. The report will be saved as a PDF file, and will contain the survey metadata and the B-scan image.
7. The *Survey Grid* tab shows how the linear traverses making up the survey will be arranged. This step can be skipped when only conducting a single scan line. These traverses are planned using the button and the dialog shown in Figure 5. To type

into dialog field, click on the field to place the cursor, then press the  icon on the taskbar to bring up the keyboard.

a. *Grid type* Select either *Single line*, *Parallel lines*, or *2D grid* (cross hatch). When conducting pavement surveys, select either *Single line* or *Parallel lines* depending in the width of the area to be scanned.
b. *Line directions* Select either *Same direction* or *Alternating*.
c. *Lines in X-axis direction* These parameters specify the beginning and ending coordinates of the lines in the X-direction, and also the distance between them.
d. *Lines in Y-axis direction* These parameters specify the beginning and ending coordinates of the lines in the Y-direction, and also the distance between them. Because lines in the Y-direction are not used for pavement scanning, these fields can be ignored.
e. *Saving the configuration* The *New, Open, Save,* and *Delete* buttons can be used to save/recall the dialog settings to/from a named configuration. This is useful when conducting a series of jobs with a similar layout.

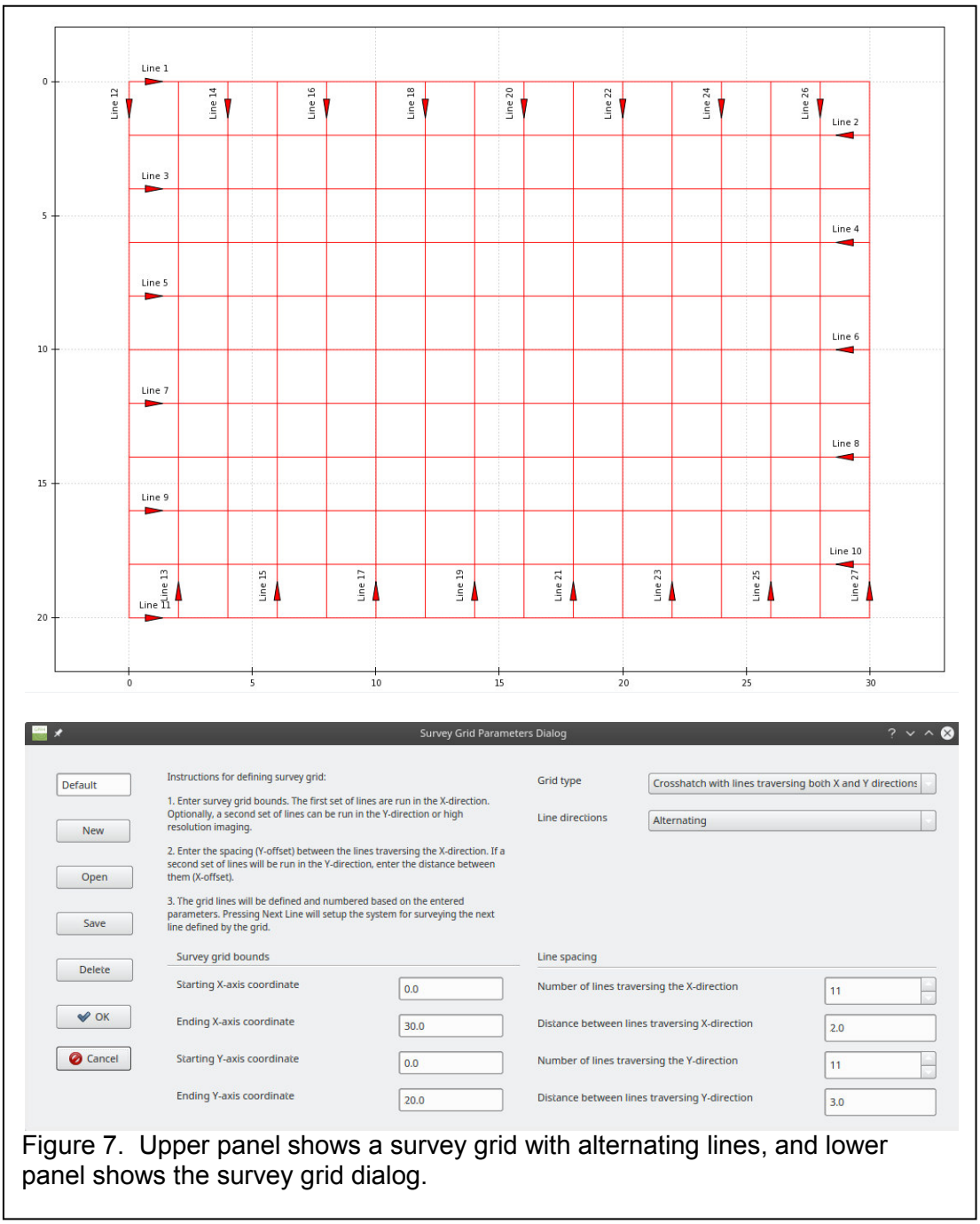

Figure 7. Upper panel shows a survey grid with alternating lines, and lower panel shows the survey grid dialog.

8. Before beginning a survey, it is important to capture information about the jobsite. Press the *Jobsite information* button to bring up the dialog shown in Figure 6. The information entered into this dialog will be listed in any reports that will be generated by the software. To type into dialog field, click on the field to place the cursor, then press the icon on the taskbar to bring up the keyboard.

a. Enter the *Project Name*, *Site Location*, *Site Description*, *Operator*, *Survey Mode*, *Notes*, *Service Provider*, and *Equipment Model*. The *Date Recorded* and *Time Recorded* fields will be updated automatically.
b. *Map Frame Parameters* Select the distance *Units* (feet or meters). The *Latitude*, *Longitude*, and *Elevation* parameters will be updated automatically once the survey begins using the GPS sensor in the sensor unit. The *Magnetic Declination* and *Map System* fields are not used with the Pavement Scanner.
c. *Local Frame Parameters* Select the distance *Units* (feet or meters). Enter the bearing of the first survey line in the *Line 1 Azimuth* field. The software will use this value to correctly orient images on maps that are exported as KMZ or HTML files.

9. Move the scanner to the start position of the first line. Press the *Next line* or *Previous line* buttons  until the proper line number is displayed at the top of the screen. Each time that one of these buttons is pressed, the system runs through a line initialization sequence which tasks a few seconds. These actions can also be accomplished by pressing the rocker switch on the radar unit ***left*** or ***right*** momentarily. When the user hears an audible beep from the tablet, the initialization sequence has completed. Therefore, users should wait until the audible beep is heard before another line request.
10. Select *File*, *New*, and then choose a location and name for the database file. When ready to begin the survey, press the *Record data* button . The button should appear activated to indicate that data are being recorded. This action can also be accomplished by pressing the rocker switch on the radar unit ***up*** momentarily. Move the cart along the survey line to conduct the survey.
11. Users can place markers in the data file when the line traverses a point of interest (usually an obvious surface feature). While recording data, a marked fiducial can be placed in the datafile by pressing the  icon.
12. When the cart has traversed the entire survey line, press the *Record data* button  to turn off recording. The button should appear inactivated. This action can also be accomplished by pressing the rocker switch on the radar unit ***down*** momentarily. Place the cart at the beginning of the next line. Make sure that the cart is precisely at the beginning of the line, otherwise there will be registration errors that appear on the map output. Press the *Next line* or *Previous line* buttons  until the proper line number is displayed at the top of the screen. Finally, press the *Record data* button . The button should appear activated to indicate that data are being recorded. Move the cart along the survey line to conduct the survey.
13. Repeat steps 9 through 12 as necessary to cover all of the lines in the survey grid. When the cart has traversed the final survey line, press the *Record data* button  to turn off recording. The button should appear inactivated. This action can also be accomplished by pressing the rocker switch on the radar unit ***down*** momentarily. If no further surveys are to be conducted, power down the sensor and odometer. Disassemble the survey cart and return all components to the shipping case.

4.4 Replaying Data

The ESS Concrete Scanner allows replaying data so that plots can be re-examined and new reports can be generated. To replay data, follow the instructions below.

1. Insure that the scanner unit and odometer are switched off.
2. Start the data acquisition program by touching and holding the *EssGpr4LoggingApp* icon on the desktop. Select the *Pavement Condition* tab.
3. Press the button and input the desired grid layout that will be used when re-plotting the data.
4. Select *File*, *Open*, and then the file to replay. Repeat as necessary to replay multiple lines.
5. The data will replay over the course of a few minutes. When the replay is finished, users can generate reports and maps as desired.

4.5 Generating Maps and Reports

After a survey has been conducted, reports can be generated.

- To save an image of the either the pavement density map or the pavement temperature map, press the icon. Select the appropriate image (density or temperature) and then the desired image file type (PNG, BMP, or JPG).
- Two types of reports can be generated. The first is a PDF file that contains the job information metadata, the calibration information, the measured pavement density statistics, and finally images of the pavement density map and pavement temperature map. The second is a CSV file that contains the job information metadata, the calibration information, and the measured pavement density measurements. The CSV file can be imported by other software packages (i.e. a spreadsheet) for further analysis and plots. Press the button and select the desired report type and file name.

4.6 Advanced Data Processing, Depth Slices, and 3D Views

The *EssGpr4LoggingApp* does not have the capabilities to generate depth slices or 3D views of the subsurface. To generate these views, use the companion program *ESSentialUnderground* that is distributed with the system.

4.7 Charging the Batteries

There are three rechargeable batteries in the system that provide sufficient power for operation over a full day. The battery in the scanner unit provides power for about 5 hours. A second battery is provided so that surveying can continue after the first is depleted. Additionally, the Microsoft Surface Pro 4 tablet contains a battery that will provide 5-8 hours of continuous operation depending on screen brightness settings. The shipping container contains an integrated battery charger that can simultaneously charge all of the batteries with only a single external power connection. The system is designed to be charged overnight so that all of the batteries are ready for use during the work day. To charge the batteries, follow these steps.

1. Switch off the scanner unit.
2. Remove the battery from the scanner unit and place it in one of the scanner battery charging ports in the shipping case. Place the spare scanner battery in the other charging port.
3. Connect the tablet charging cable to the tablet computer.
4. Plug the main charger power cable into 120/220 VAC mains power.
5. All batteries should charge in 4-5 hours, and all of the charge indicator lights will be green when all of the charge cycles have completed.

4.8 System Care, and Cleaning

The pavement density system kept clean and free of debris. The sensor unit can be cleaned with water and a mild detergent.

5 Theory

5.1 Theory of Operation

The concrete scanner uses ground penetrating radar (GPR) to characterize the surface beneath the sensing unit. The GPR sends a low-energy impulse of electromagnetic (EM) energy towards the surface. Some of this energy penetrates into the subsurface and some is reflected back towards the sensor unit. The amount of reflected energy depends on the contrast in dielectric constant and electrical conductivity of the concrete and embedded objects. By measuring the travel time of these waves, the depth to the reflectors can be determined in a manner analogous to a fish finder. By moving the scanner over the surface and detecting object beneath it, a 2D or 3D cross section of the subsurface can be obtained.

High frequency radar waves (i.e. 2 GHz) provide better spatial resolution than lower frequency radar waves, but they attenuate quickly as the travel through the subsurface. Subsequently they cannot detect objects deeper than about two feet. Lower frequency radar waves (i.e. 750 MHz) are able to penetrate more deeply (to about four feet) but do not provide as much detail in the subsurface images.

6 Appendix

6.1 Digitizer Settings

The default settings for the digitizer are sufficient for nearly all surveys. Advanced users may choose to change these settings (see Figure A1). To view or change the digitizer settings, select (*File*, *Settings*).

1. *Trace Sample Rate* Select the desired number of traces per second. Using fewer traces per second gives a higher signal to noise ratio and increased depth of investigation. However fewer traces per second will result in fewer traces per foot (meter) at a given traverse speed.
2. *Sample Rate* Select the sample rate used for each A-scan. Normally a sample rate of 8 GHz is used for antennas with center frequencies less than 1 GHz, and 16 GHz is used for antennas with center frequencies greater than 1 GHz.
3. *Num Samples* Select the number of samples for each A-scan. A value of 512 samples will work for most situations. Note that using a large number of samples (1024 or more) may limit the *Trace Sample Rate*.
4. *Channel A/B Holdoff* The GPR digitizer has two channels: A and B. The holdoff time can be adjusted independently for each channel. The B channel can only be adjusted in 4 ns increments relative to the A channel. Normally, users will not need to change these values.

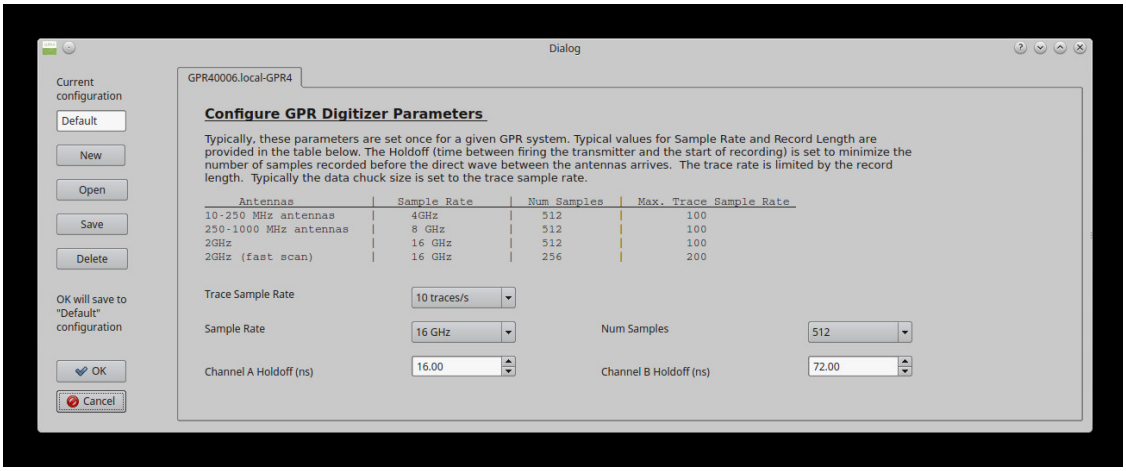

Figure A1. Digitizer settings dialog.

6.2 Software Installation

If the tablet computer has not yet been setup for use with the Concrete Scanner, proceed as follows. The thumb drive that was distributed with the system will be needed.

1. The tablet computer must use the Windows 10 operating system. The following tablet computers are approved.
    a. Microsoft Surface Pro 4
    b. Microsoft Surface Pro 6

   c. Microsoft Surface Go
   d. Panasonic Toughpad FZ-G1
2. Turn on the tablet, wait for it to boot up, and then log in.
3. Press the Window icon in the lower left corner, then select ***Settings*** (the gear shaped icon). Select ***System***, ***Display***, and set the ***Resolution*** to 1920 x 1200. Then set the ***Orientation*** to ***Landscape***. Finally, set ***Rotation*** lock to ***On***. Close the ***Settings*** window.
4. Press the Window icon in the lower left corner, then select ***Settings*** (the gear shaped icon). Select ***System***, ***Power & Sleep***, and under ***Sleep*** set the tablet so that it ***Never*** goes to sleep under battery power or when plugged in. Close the ***Settings*** window.
5. Press and hold the task bar. Make sure the following options are checked:
   a. Show touch keyboard button
   b. Show touchpad button
6. Connect the thumb drive to the tablet's USB port.
7. Copy these files from the thumb drive to the desktop.
   a. installEssPythonDistribution-x.x.x-(date).exe
   b. installEssGpr4LoggingApp-x.x.x-(date).exe
   c. installESSentialUnderground-x.x.x-(date).exe
8. Touch and hold the *installEssPythonDistribution-x.x.x-(date).exe* file on the desktop, then select ***Open***. Follow the prompts to install this package.
9. Touch and hold the *installEssGpr4LoggingApp-x.x.x-(date).exe* file on the desktop, then select ***Open***. Follow the prompts to install this package.
10. Touch and hold the *installESSentilUnderground-x.x.x-(date).exe* file on the desktop, then select ***Open***. Follow the prompts to install this package.

6.3 Log File

The acquisition program writes a log file with all of the contents of the status panel. This file is overwritten each time the program runs. It can be useful to refer to this file to help diagnose problems. It is located in the user's home directory on this path:

\.Earth_Science_Systems\EssGpr4LoggingApp\scripts\EssGpr4LoggingApp.log.

6.4 Emissions

6.4.1 Health and Safety

ESS GPR systems emit electromagnetic radiation from the radar sensor, the WiFi adapter, and the Bluetooth adapter (if present). The electromagnetic radiation from ESS GPR radar sensors is many times less than that from cellular telephones. ESS GPR systems can be operated anywhere cellular telephones are permitted. The health and safety hazards posed by ESS GPR systems are less than those posed by cellular telephones.

6.5 Limited Warranty

Earth Science Systems, LLC (ESS) warrants the Concrete Scanner hardware unit (PRODUCT) to be free from defect in material and workmanship under normal use for a period of one year from the date of shipment. Any computer systems purchased with the product are subject to the manufacturer's warranty and not the responsibility of ESS.

Except as specified above, the PRODUCT is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, the use or result of use of the product in terms of correctness, accuracy, reliability, currentness or otherwise. The entire risk as to the results and performance of the PRODUCT is assumed by you. If the PRODUCT is defective or used improperly, you, and not ESS or its dealers, distributors, agents, or employees, assume the entire cost of all necessary servicing, repair or correction.

ESS 's obligation is limited to repairing or replacing parts or equipment which are returned to ESS, transportation and insurance pre-paid, without alteration or further damage, and which in ESS 's judgment, were defective or became defective during normal use. Before returning any equipment to ESS, a Return Material Authorization (RMA) number must be obtained. Please call the Customer Service Manager at Earth Science Systems, LLC who will assign an RMA number. Be sure to have the serial number of the unit available.

6.6 Batteries

The Pavement Scanner uses LiFePO4 batteries, which are one of the most efficient and long lasting batteries available. They tolerate more charge/discharge cycles than all other popular battery chemistries. For transportation purposes, they are considered lithium ion batteries and their shipment falls under UN3481. They can be shipped via air on both passenger and cargo planes, or via standard ground transportation. The following label must be present on the outside of the shipping container.

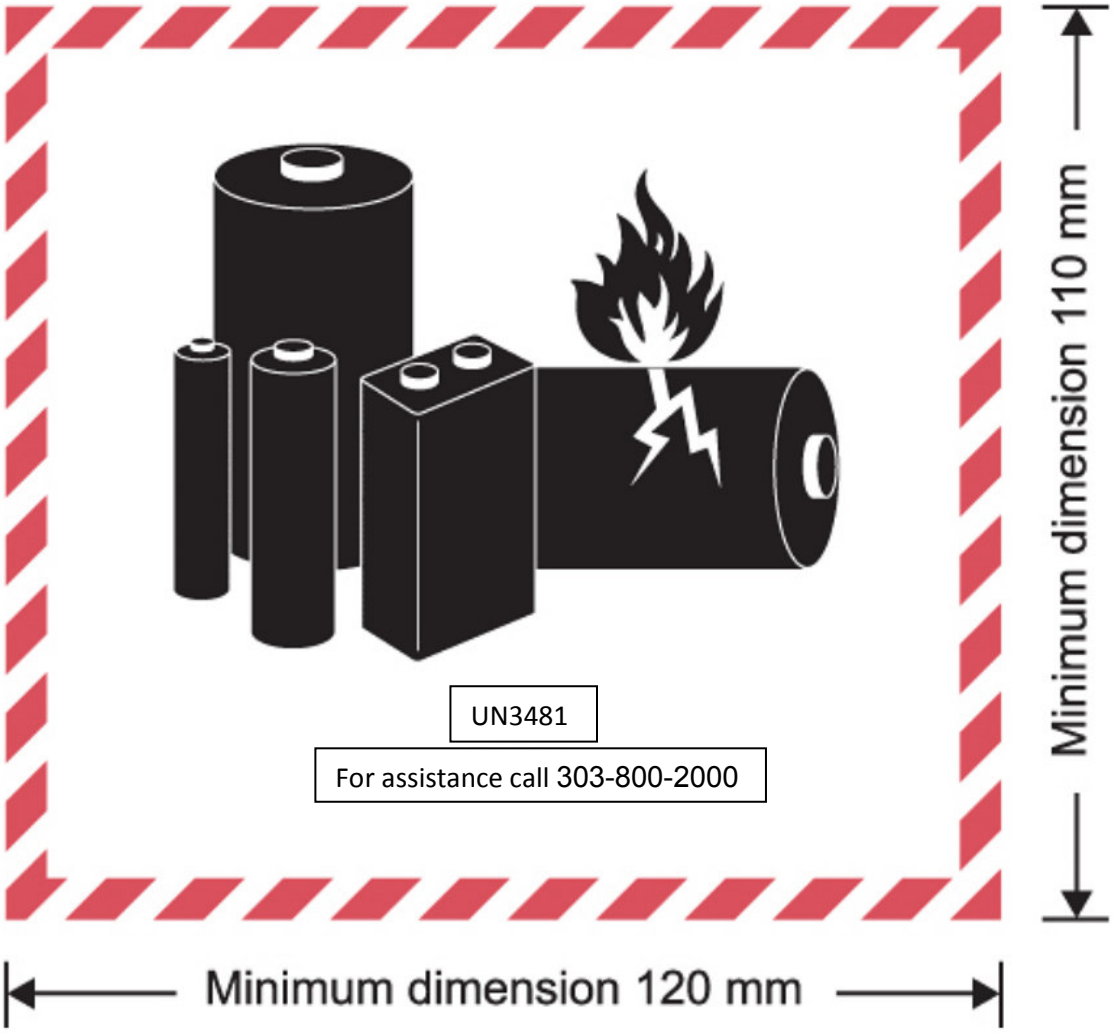

Figure A2. Shipping label for container with batteries.

6.7 Technical Support

Technical support is provided by ESS between the hours of 9:00 AM and 5:00 PM MST at 303-800-2000.

6.8 Specifications

- 2 GHz bi-static radar antenna
- 750 MHz bi-static radar antenna
- Electric field sensor for detecting power lines or tracer signals
- Magnetic field sensor for detecting power lines or tracer signals
- Includes rugged IP67 tablet computer
- Dimensions: 12 x 8.9 x 8.5 inches including wheels and skid plate
- Shipping container dimensions: 20 x 14 x 10 inches
- Weight: 7.71 lbs
- WiFi connection between sensor and tablet
- Removable tablet computer allows data analysis from vehicle or office
- Durable construction with IP65 ingress protection
- Positioning systems includes odometer, GPS, and optional inertial measurements.
- Optically coupled odometer eliminates cables and interference to magnetic sensors
- Short handle for surveys within arm's reach
- Long handle for floor surveys rotates and locks into different positions
- Rechargeable LiFePO4 battery provides 5-6 hours of use. Includes second battery for all day use.
- Shipping case contains chargers for two batteries and the tablet computer
- 3D imaging and mapping software

6.9 Data File Format

Data recorded by the GPR system are stored using the HDF5 file format. HDF5 allows storage of large datasets in complex data structures. In addition to the data stored in an HDF5 file, the files provide all of the data type and format information needed for reading the data. A helpful utility for quickly browsing HDF5 file is the HDFView utility which is freely available from the HDF5 Group (https://www.hdfgroup.org/downloads/index.html). The HDF5 Group provides free software interfaces for HDF5 in most popular computer languages including Fortran, C, Java, Python, and Matlab. Figure A3 is a screenshot from HDFView showing the contents of an H5 file recorded by the sonic logging system. On the left is a tree structure that lists the datasets in the file. The JobInformation dataset contains information about the jobsite. There is a folder for each data server (e.g., gpr4, odometer, irTemperature, pavementDensity, etc.) on each node (e.g., the logger or the probe), and each folder contains configuration information and data. As shown below, the detailed format of each dataset is included in the file. This self-describing feature of HDF5 files along with the open software interfaces allows the data to be easily read by user-developed software.

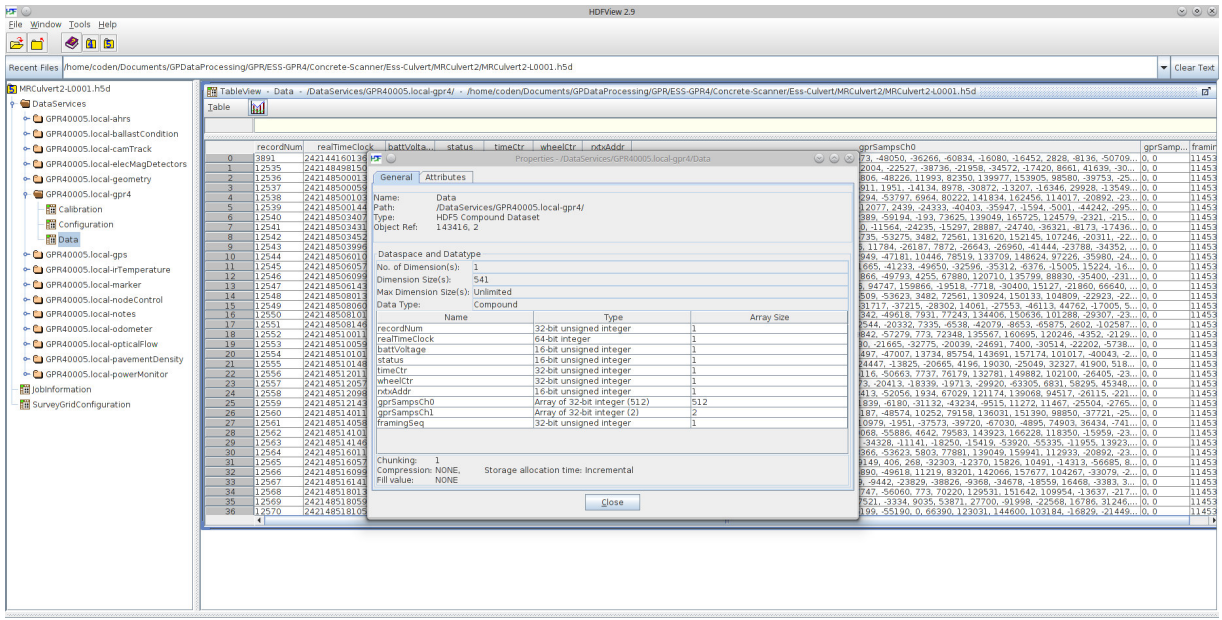

Figure A3. Screenshot from HDFView showing the contents of an H5 file recorded by the sonic logging system.

6.10 License Agreement

End User License Agreement (EULA) for EssGPR4LoggingApp

This is a legal agreement between Earth Science Systems, LLC and you, the Customer. By installing this software, you accept all the terms and conditions of this agreement. Upon your acceptance of this Agreement, Earth Science Systems, LLC grants you a non exclusive license to use one copy of the Software, provided that you agree on the following.

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Wheat Ridge, CO 80033
USA

EssGpr4LoggingApp and ESSentialUnderground have been bundled with open source software as listed below. Notable bundled projects include: Python, Qt, VTK [BSD], and HDF5. Python modules include (Pyside, Chaco [BSD], Mayavi [BSD], Matplotlib [BSD], Numpy [BSD], and Scypi [BSD]).