PRACTICA
FOUNDATION

User manual

Volterra 3

Date: 3 March 2020
Product version: 3
Manual version: 1.0

Thank you for choosing the Volterra 3

The Volterra 3 is an instrument that measures earth resistivity. It can be used to perform Vertical Electrical Soundings (VES) or Horizontal Electrical Profiling (HEP). It was created by PRACTICA Foundation to serve the needs of geohydrologists, in particular for the siting of new boreholes. By introducing an affordable instrument with a user-friendly interface, it has been our aim to bring the potential of geophysics to a much broader audience.

Please note that the interpretation of resistivity measurements is not easy, and should ideally be done by skilled geophysicists.

The instrument has been carefully designed and constructed, and has been thoroughly tested in our workshop. If handled with care, and following the instructions in this manual, it should provide many years of service.

As we are still developing and expanding our range of affordable geophysics equipment, we would like to learn from your experiences. We would be very grateful for stories about how and where you use the instrument, and what your experiences have been.

The best way to reach us is by sending us an email to: *support@practica.org*

Our office address is:
PRACTICA Foundation, Geulweg 16, 3356 LB Papendrecht, The Netherlands

Phone: +31 (0) 786 150 125

Website: practica.org

WARNING

HIGH VOLTAGE!

The Volterra 3 delivers high voltages and currents that can potentially be **lethal** to people and animals.

The Volterra 3 should only be operated by properly trained personnel. Equipment, electrodes and cables must **at all times** be under the supervision of qualified personnel. It is the responsibility of the operator to eliminate risks of accidents.

Always consider all electrodes connected to the device to carry dangerous current. Never touch the cables or electrodes when the device is operating. Be sure to remove curious onlookers and stray animals from the site. Read the **Safety Instructions** in this document before using the instrument.

Warranty

PRACTICA warrants this product to be free from defects in workmanship and materials for a period of two years from the original invoice date. If the product proves defective during this warranty period, PRACTICA, at its option, will either repair the defective product without charge for parts and labor, or will provide a replacement of equal value in exchange for the defective product. Such repair or replacement is subject to verification of the defect or malfunction and proof of purchase as confirmed by the original dated invoice.

In order to obtain service under this warranty, the Customer must notify PRACTICA of the defect before the expiration of the warranty period and make suitable arrangements for the performance of service. The Customer shall be responsible for packaging and shipping the defective product to the PRACTICA office in the Netherlands, carriage paid.

Costs for return shipping and insurance will be incurred by the customer. Customer shall be responsible for paying all duties, taxes, and any other additional charges required in order to ship the product.

This warranty does not include:
* Any condition resulting from other than the use for which the product was intended
* Any condition resulting from incorrect or inadequate maintenance or care
* Damage resulting from attempts by non-PRACTICA personnel to repair the product
* Damage resulting from misuse, abuse, negligence, accidents or shipping damage
* Damages incurred during transportation

PRACTICA disclaims any implied warranties of merchantability or fitness for a particular purpose. PRACTICA will not be liable for any indirect, special, incidental, or consequential damages irrespective of whether PRACTICA has advance notice of the possibility of such damages.

Table of contents

1. Preface

1.1 Description of the user

The product is intended for the end user of the Volterra 3. This manual is part of the product. It contains important information on safety as well as the installation, use and disposal of the product.

Please familiarize yourself with all the included information before using the product. The product may only be used as described in this manual and for the specified application scenarios.

As a user, you should be experienced in performing earth resistivity measurements. The resulting data should be interpreted by skilled geophysicists.

This product can only be used by persons over the age of 21 years old.

1.2 Explanation of safety warnings

	When a message has the danger icon shown on the left, it is essential that the user reads it **before** using the device. Resistivity devices such as the Volterra 3 create high voltages that can potentially be dangerous to people and animals. Reading the safety messages will ensure the user can handle the device safely and responsibly.

1.3 Before using the product

Read and understand this manual and its safety instructions before using this product. Failure to do so can result in serious injury or death.

Follow all the instructions. This will avoid electric shocks or other hazards that may result in damage to property and/or severe or fatal injuries.

The product shall only be used by persons who have fully read and understand the contents of this user manual.

Keep all safety information and instructions for future reference and pass them on to subsequent users of the product.

The manufacturer is not liable for cases of material damage or personal injury caused by incorrect handling or non-compliance with the safety instructions. In such cases, the warranty will be voided.

1.4 Obtaining documentation and sending feedback

The latest version of this document can be found on the PRACTICA Foundation website at practica.org.

Documentation in paper form can be ordered by contacting us at support@practica.org.

Feedback about the product can be also be send to support@practica.org. We appreciate your comments.

2. Description of the Volterra 3

2.1 Intended use

The Volterra 3 is intended to be used to measure earth resistivity, for example during groundwater development activities. Other uses include determination of salt water intrusion, or locating fracture zones.

As a user, you should be experienced in performing earth resistivity measurements. The resulting data should be interpreted by skilled geophysicists.

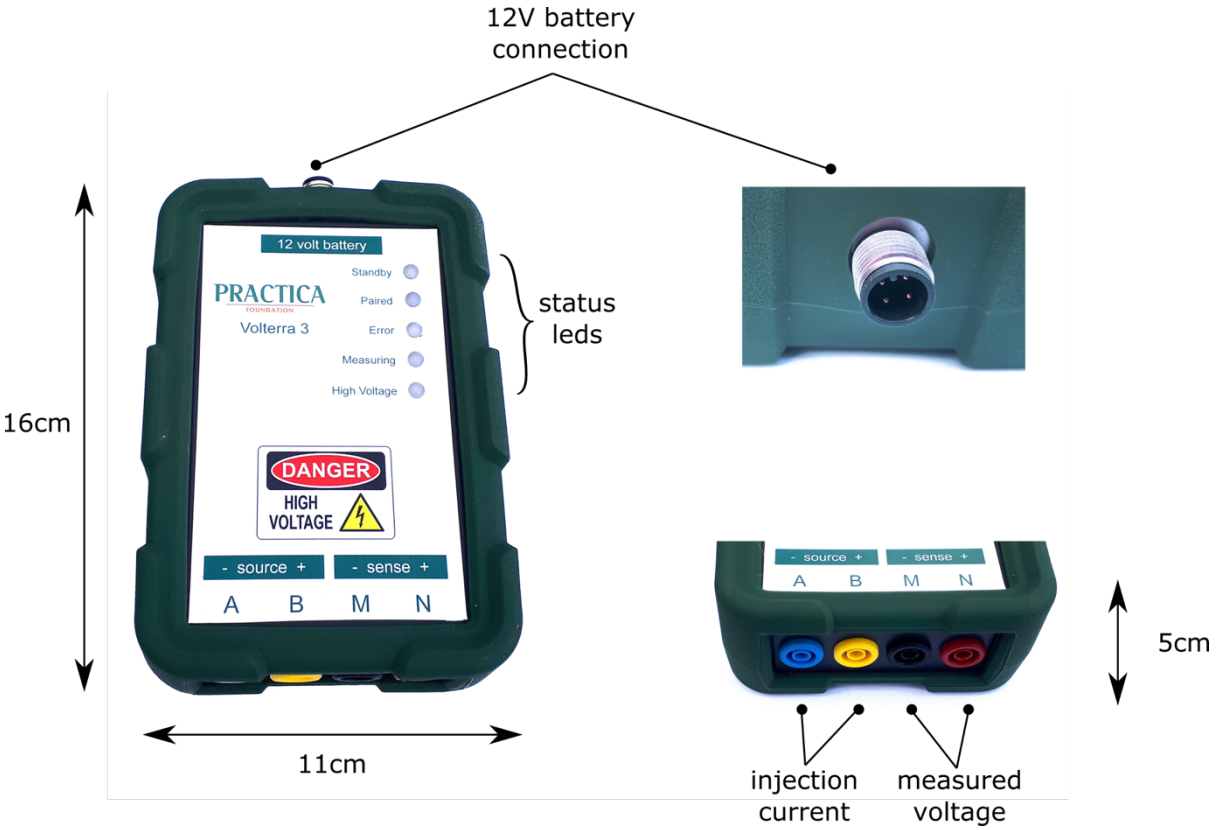
Reasonably foreseeable misuse

The Volterra 3 is **NOT** intended for the following purposes:

- Measurement of ground resistance of earthing systems such as lightning rods or ground pins
- Measurement of resistance of electrical components such as resistors

2.2 System overview

The Volterra 3 device measures 16 x 11 x 5 cm and has a silicone rubber cover. The device is shown below.



2.2.1 Status LEDs

The Volterra 3 has a series of indicator LEDs on the front plate. The tables below describes the LEDs, and the way there are used.

LED	Colour	Function
Standby	green	The Volterra is powered up and standby to receive a Bluetooth connection request.

Paired	blue	The Volterra has been paired to an Android device through Bluetooth.
Error	red	There is an error condition. The specific error is sent to the Android device.
Measuring	amber	Blinks when a measurement is taking place
High Voltage	amber	Blinks when the high voltage is active

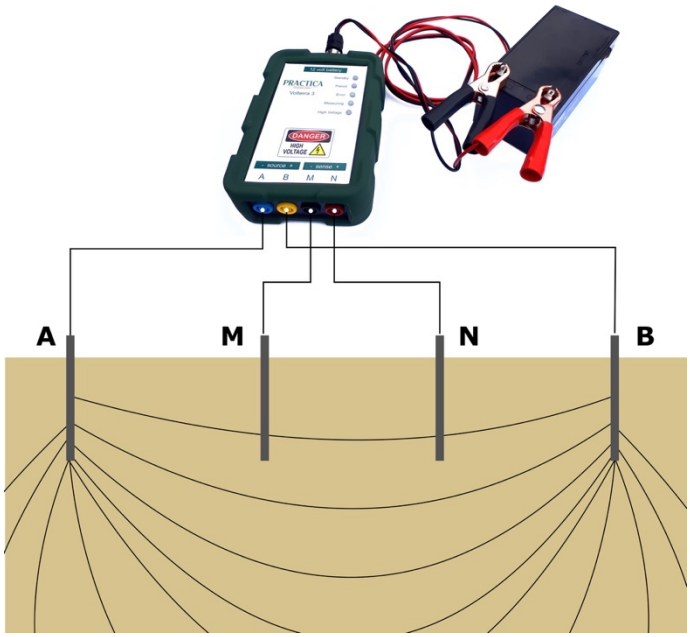
NOTE: When a measurement is taking place, the Measuring and High Voltage LEDs both blink.

NOTE: Some error conditions are automatically handled by the Volterra application on the Android device. This is for example the case when the resistivity of the soil is very high, and a lower power setting is needed. Even though the Volterra will indicate an error condition, the Android device with the Volterra application will automatically adjust the power setting and try again.

2.2.2 Battery connection

The Volterra 3 is connected to a 12V battery using the connector cable, as shown below. When you use a small battery, make sure the clamps don't come into contact with each other. Tape can be a useful tool to insulate part of the clamp. Note the battery is NOT included in the product, and needs to be procured separately.

2.2.3 Field connections
The image below shows how the Volterra 3 is connected to the 4 electrodes in the ground.



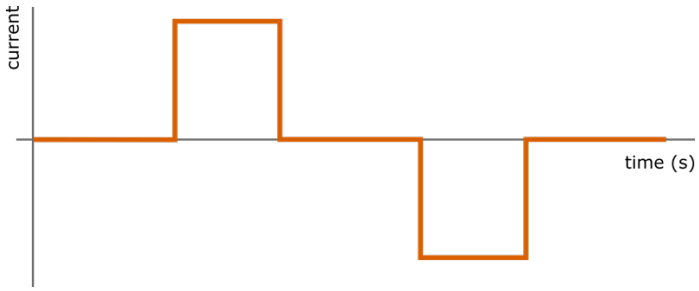
A resistivity measurement measures the electrical resistance of the earth. To do this, it uses a four-point voltage measurement, with electrodes *A*, *M*, *N* and *B*. A voltage is applied to the outer electrodes *A* and *B*, which causes a current to be injected into the earth, which runs from electrode *A* to electrode *B*. Two further electrodes, *M* and *N*, are placed at different locations, away from *A* and *B*. The voltage between *M* and *N* is measured. The specific locations of *A*, *M*, *N* and *B* are determined by the array type used, such as Wenner, or Schlumberger.

From the measured current and voltage, a resistance value is calculated as R = V / I. Finally, the apparent resistivity of the earth, denoted ρ_a, is calculated as $\rho_a = k \cdot R$. Here, k is the so-called geometric factor, which is dependent on the relative locations of the four electrodes.

NOTE: the order of the connections on the Volterra device (A,B,M,N) is different than the order of the electrodes as they are placed in the ground (A,M,N,B). This can be a source of confusion. Please make sure that the connections are made in the right way.

2.2.4 Measurement principle

The Volterra 3 injects a current into the ground consisting of positive and negative pulses. This is done for two reasons: to avoid the build-up of polarization, and to be able to subtract the self-potential of the ground. The profile of a single measurement current cycle is shown in the image below.



A complete measurement consists of a number of cycles, which are added up (stacked) to reduce the noise level. Usually, between 5 and 15 stacks are used.

2.3 Technical data

Dimensions	160 mm x 110 mm x 50 mm
Voltage input	12V battery (car or motorcycle battery, not included)
Electrode connections	4 x banana jack, for A, B, M and N electrode connections
Max Power	10 watts
Max Voltage	600 V
Max Current	1 A
Resistivity measurement	Square waveform for polarization reduction, linear background potential compensation, 25 Hz low-pass filtering, median measurement of resistivity. Result is resistivity (V/I), without geometric factor.
Stacking	Minimum 5 stacks, max number configurable, automatic adaptive stack number up to max depending on signal strength
Settings	Automatic and manual power settings and waveform duration settings
Protection	Protected against shorting outputs and against over voltage
Enclosure	ABS plastic with rugged silicone corner protection
Communication	Bluetooth with android phone
Operation	Android app 'Volterra' (commands and data processing). Includes measurement settings and progress, and optional full waveform display for troubleshooting. Includes battery status indication.
Safety	Automatic 'warning pulses' before start of measurement, shutdown after loss of Bluetooth connection, software stop.

2.4 Components of the Volterra 3

The components of the Volterra device, as included in delivered package, are:

- The Volterra device
- A 12V connector cable with battery clamps
- A carrier bag
- 4 colour-coded banana-plug connectors
- An Android smartphone app downloadable from Google Play

NOTE: due to excessive cost of transport and restriction of transport, a 12V battery is **NOT** included. Therefore, for the device to function, the following two items need to be purchased by the user:

- A 12V battery of at least 4Ah, sealed, maintenance free, for example a small motorcycle battery or car battery
- A 12V battery charger

These items are widely available at hardware stores or motorcycle shops.

Items needed for resistivity measurements

To complete a full resistivity measurement, more is needed than only the device. Below, we list the recommended kit needed. A full kit can be purchased from PRACTICA, but can also be sourced locally.

Items for the complete kit:

- Volterra 3 device + 12V battery + battery charger
- 4 electrodes, stainless steel, length 45-50 cm, diameter 12-20 mm
- 4 heavy hammers

- 2 AB cables, each with the length of half the maximum AB distance. For a depth of investigation of 40 meters, use 120 meter per cable.
- 2 MN cables, each with a length of 1/3 of the AB cables. For a depth of investigation of 40 meters, use 40 meters per cable
- 3 whistles or walkie-talkies, for signaling purposes
- 2 measuring tapes of at least the length of the AB cables.
- 4 pairs of rubber gloves
- 4 pairs of rubber boots

3. Safety instructions

3.1 High voltage

The Volterra 3 delivers high voltages (up to 600 Volts) and currents that can potentially be lethal to people and animals. The following safety guidelines should be followed at all times:

The Volterra 3 should only be operated by properly trained personnel.

Equipment, electrodes and cables must at all times be under the supervision of qualified personnel. It is the responsibility of the operator to eliminate risks of accidents. The operator is always responsible for having full control of the entire cable layout.

Always consider all electrodes connected to the device to carry dangerous current. Never touch the cables or electrodes when the device is operating.

Be sure to remove curious onlookers and stray animals from the site. Animals such as goats and rats like to nibble the cables.

Staff that handle the electrodes should wear rubber boots and rubber gloves for extra protection.

Ensure clear communication procedures between staff, by means of walky-talkies or whistles.

Always check the quality of cables, clamps and connectors before usage.

An example process for a safe measurement can be described as follows:

1. An operator should stand next to the Volterra device and be in charge of handling the Android application.
2. The operator turns on the Volterra device by connecting the 12V battery, and connects to the device using Bluetooth.
3. The operator makes sure the Volterra device is not active, and signals a "**all clear**" signal to the other staff.
4. The staff connects the cable clamps from the electrodes, and removes the electrodes from the soil.
5. The staff places the electrodes in a different location, and reattaches the clamps.
6. The staff both signal "**electrodes ready**" signal to the central operator.
7. The operator gives a '"**measurement starting**" warning signal
8. The operator starts the measurement, and waits for completion
9. The operator gives the "**all clear**" signal, after which the sequence repeats from step 4.

3.2 Lightning

Lightning strikes can cause severe damage to the cables and equipment, and can be highly dangerous to people. Even if a lightning storm is kilometers away, it can induce strong currents in long cable layouts. Therefore, when a lightning storm is expected to approach, remove all electrodes and cables, and wait for the storm to pass safely to at least a distance of 10 kilometers.

3.3 Water

Water and electricity don't mix. Keep the device and cable connections dry at all times. As the device can be operated through Bluetooth, the whole device can be placed inside a plastic bag or container, in case of rain. Don't operate the device in heavy rain.

Wear rubber boots to be electrically isolated from the ground, and rubber gloves.

3.4 Heat

Overheating might lead to inaccurate results. Don't operate the Volterra device in intense sunlight. Use a sun shield to keep the device in the shade.

4. Operation

4.1 Measurement preparation

Before a measurement is conducted, the equipment needs to be laid out. A typical procedure is:

1. The location of the measurement is chosen, with a view of unrestricted access to land in a straight line from the center in two directions, to the extent of the length of the cable (usually about 120m)
2. The operator checks if the measurement can be conducted safely. Stray animals and curious onlookers should be kept at a safe distance.
3. Two tape measures are laid down extending from the center
4. A list of distances between the electrodes is used to determine the measurements to be done. If the Drillers' Toolbox app is used, this is built in.
5. The electrodes are placed at the first measurement position.
6. The cables are connected to the electrodes, and to the Volterra device.
7. The measurement is done in a safe way (as described in section 3.1)
8. The electrodes are placed at the next position, and the process is repeated.

4.2 Connecting the device

To operate the device, connect it to a fully charged 12V battery with the connector cable, as shown below:

NOTE: Please take care to connect the red clamp to the **+** pole of the battery, and the black clamp to the – pole of the battery. If the clamps are reversed, the Volterra will not function.

When small batteries are used, make sure that the clamps don't touch each other, as this will lead to damage to the battery. Use tape to insulate clamps to prevent this.

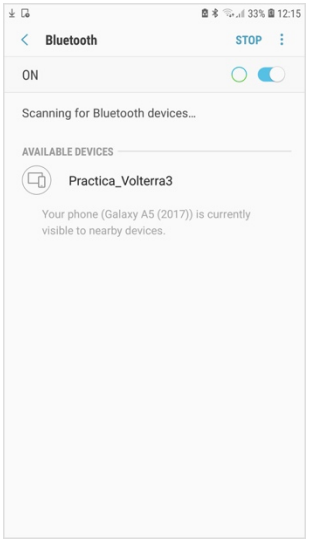
When powered on, the Volterra 3 will respond by beeping and cycling through all the status LEDs. When this is done, the green 'standby' led will blink. The device is now ready to accept a Bluetooth connection.

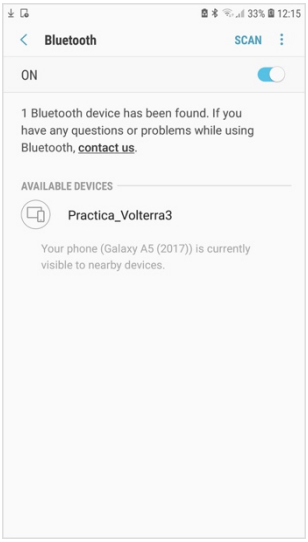
Bluetooth connection

The Volterra 3 uses Bluetooth to communicate with an Android smartphone. The coupling between the android device and the Volterra needs only to be done once. After that, the Volterra application will automatically try to connect to the last Volterra device it had contact with.

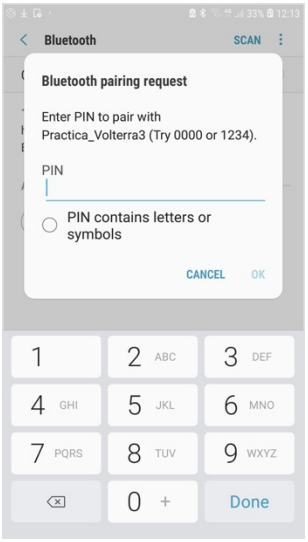
Setting up the Bluetooth connection

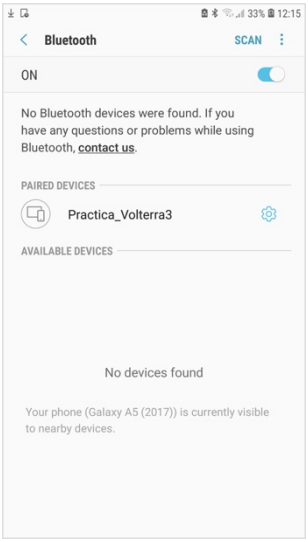
1. Power up the Volterra 3
2. On your Android device, go to the Bluetooth settings in the settings menu
3. Turn on Bluetooth and scan for devices.
4. The Volterra device should show up. In some cases, the name might not be shown yet.





5. Select the Volterra device, and click 'Pair'
6. The phone will ask for a confirmation code. Enter the code '**1234**'
7. The Volterra should now show up as a paired device.


Bluetooth
SCAN
Bluetooth pairing request
Enter PIN to pair with Practica_Volterra3 (Try 0000 or 1234).
PIN
PIN contains letters or symbols
CANCEL
OK
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
0 +
Done


Bluetooth
SCAN
ON
No Bluetooth devices were found. If you have any questions or problems while using Bluetooth, contact us.
PAIRED DEVICES
Practica_Volterra3
AVAILABLE DEVICES
No devices found
Your phone (Galaxy A5 (2017)) is currently visible to nearby devices.

4.2 Getting the Volterra Android app

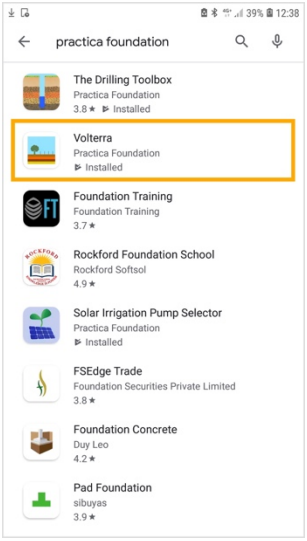
Getting the Volterra app

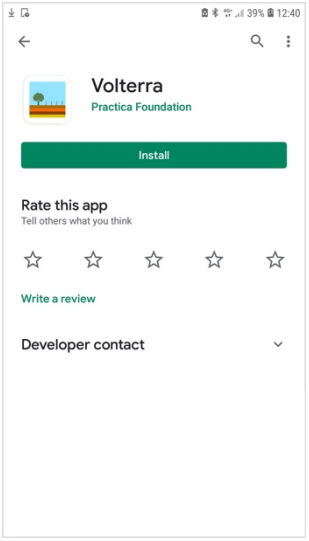
1. On your phone, go to the Google Play Store.

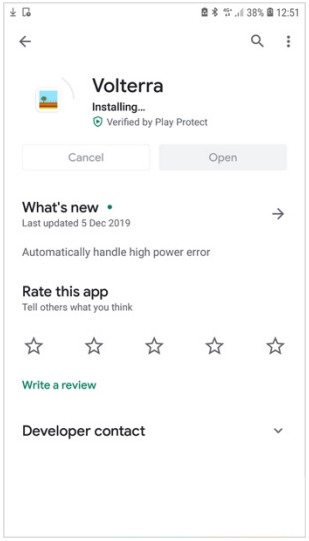
2. Search for “Practica Foundation”. In the list, select “Volterra”.

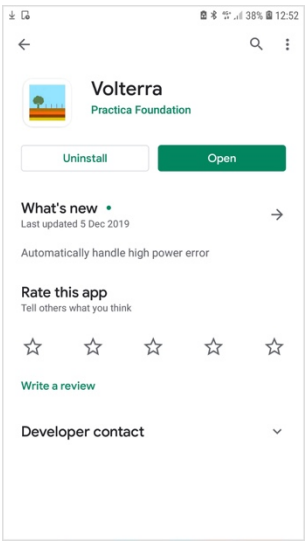
3. Click ‘Install’.

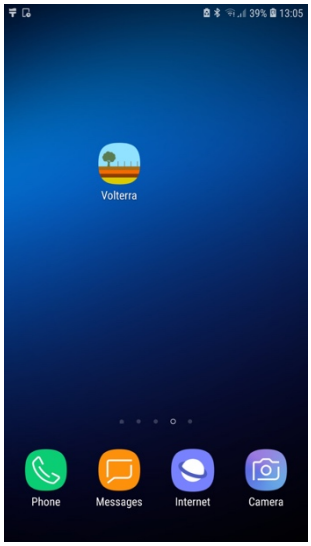
4. When the app has installed, put a link to it to the home screen of your phone.









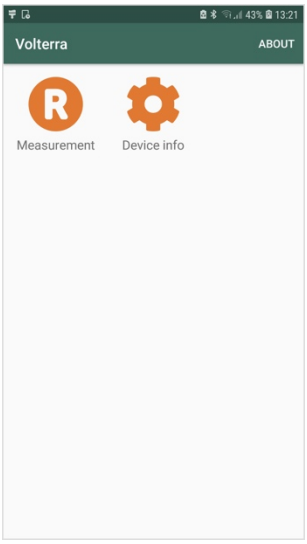


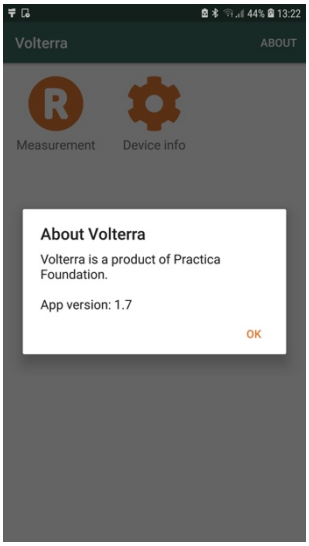
4.3 The Android app user interface

The home screen

1. The home screen contains two main buttons, “Measurement” and “Device info”, and an “About” button.

2. When the About button is clicked, the version information of the app is shown.





Bluetooth connection

1. When Measurements or Device Info is selected for the first time, the app first needs to connect to the Volterra device by Bluetooth. A connection screen is shown.

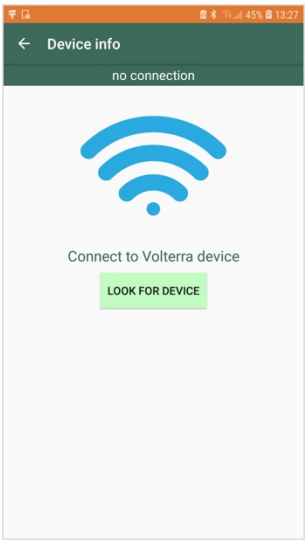
2. Make sure the Volterra device is powered on.

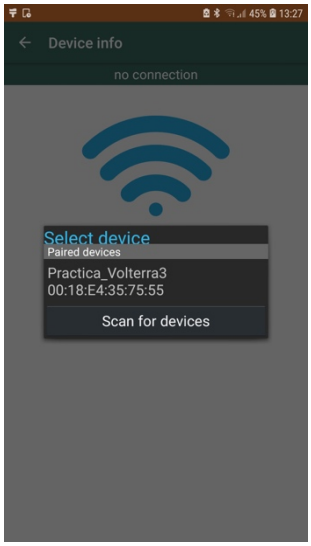
3. Make sure the phone is already paired to the Volterra device, as explained above.

4. Click ‘Look for device’

5. From the list of paired devices, select the Volterra device.

6. The app connects to the Volterra device. The blue led lights up when a connection has been made.





Device info

1. Make sure the Volterra device is powered on.
2. From the home screen, select ‘Device Info’.

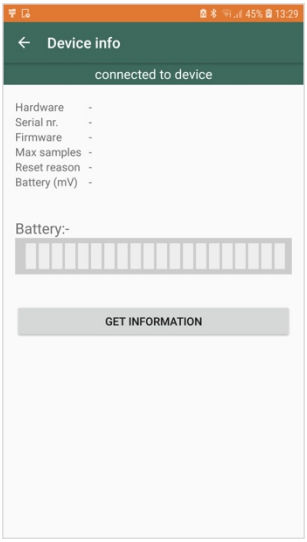
3. The app should connect to the Volterra device automatically. This is shown by the line ‘connected to device’ at the top.

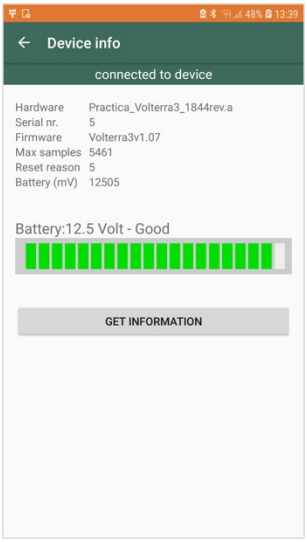
4. Click on ‘Get Information’.

5. The information is retrieved from the Volterra device and displayed. Information contains serial number,

hardware and software version and battery level, among others.

6. The state of the battery is also shown as an indicator bar, which is coloured green, orange, or red, depending on the voltage level of the battery. If the bar shows up as orange, it is time to charge the battery.





The information items shown in the Device Info screen include the hardware and firmware versions, the serial number, and other information. If there is a problem and you want to contact us, please include this version information in your communication.

Measurements

1. On the home screen, click “Measurement”. The screen at the right is opened, with the title ‘Resistivity’.

2. The app will connect to the Volterra automatically.

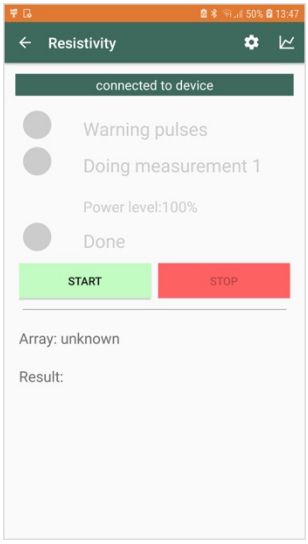
3. The screen contains two icons at the top, one for settings, and one to show the graph of the measurement.

4. The grey circles and text will display the progress of the measurement.

5. The measurement is started by the green ‘Start’ button, and stopped by the red ‘Stop’ button.

6. When the Volterra app is used without the Drillers’ Toolbox app, the Array (spacing between the A, M, N and B electrodes) is unknown.

7. When the measurement finishes, the result is displayed at the bottom of the screen.



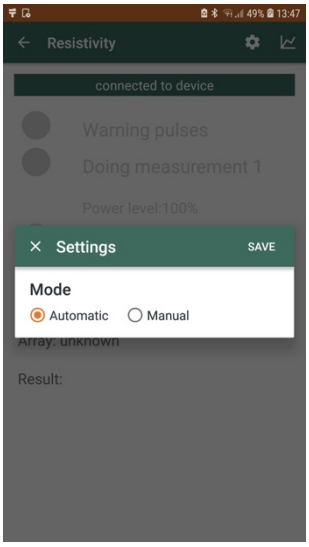
Settings

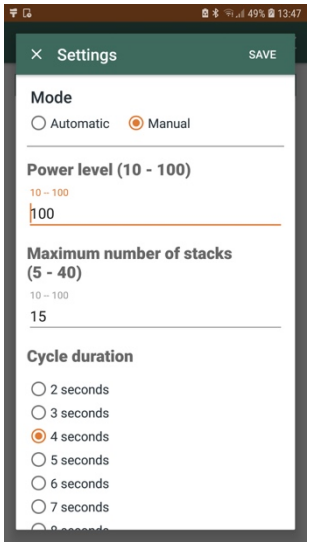
1. While in the Measurement screen, click on the settings icon at the top.

2. Two options are shown, “Automatic” and “Manual”. If you want to change the automatic settings, select ‘Manual’.

3. The power level, maximum number of stacks, and cycle duration can be changed.

4. Click ‘Save’ to save the settings.





Setting	Meaning
Mode	The Automatic mode uses default settings. It also automatically adjusts the power level if required.
Power level	The amount of power the device uses. Usually, this can be left at 100%. Sometimes, when the resistivity of the soil is very high or very low, a lower power level can be required to do a successful measurement. When the automatic mode is used, this is handled automatically.
Maximum number of stacks	The maximum number of repeated measurements the device takes and adds up. The higher this number, the more accurate the results. Usually, a setting of 15 is sufficient. In addition, the device only performs the number of stacks necessary to reach a stable result.
Cycle duration	The length in seconds of a single measurement cycle. The device uses a sequence of a positive and negative pulse, as shown in section 2.2.4

4.4 Measurement process

Starting a measurement

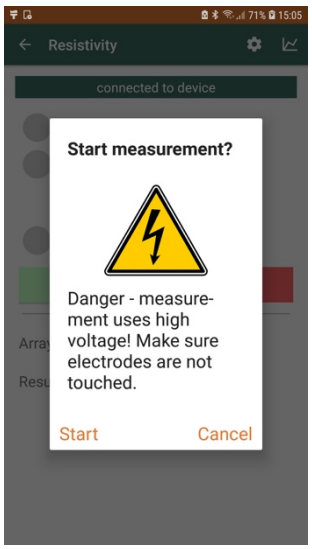
1. Connect the Volterra device to the four electrodes, as shown in section 2.2.3

2. Power on the Volterra device

3. In the app, select ‘Measurement’.

4. Make sure it is safe to do a measurement.

5. Click the ‘Start’ button. A warning screen is shown. Click ‘Start’ to start the measurement.

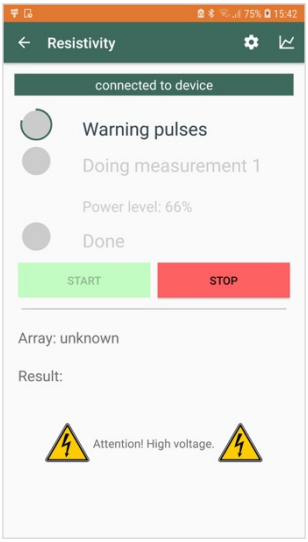


Warning pulses

Before the Volterra device injects the full current into the ground, it emits a series of warning pulses as a safety feature. These pulses are of increasingly high voltage but of very short duration. If a person is in contact with the electrodes, the pulses will act as a warning signal.

The warning pulses take roughly 10 seconds to complete, after which the actual measurement is started automatically.

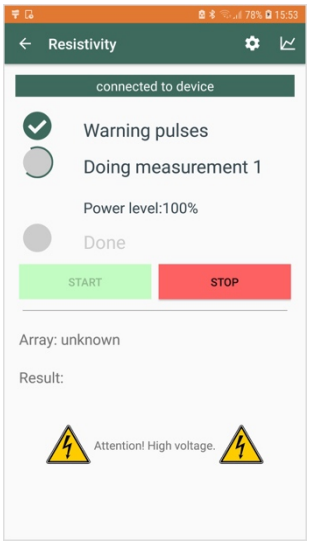
When the Volterra device produced high voltages, the device beeps and blinks the 'measuring' and 'high voltage' LEDs.

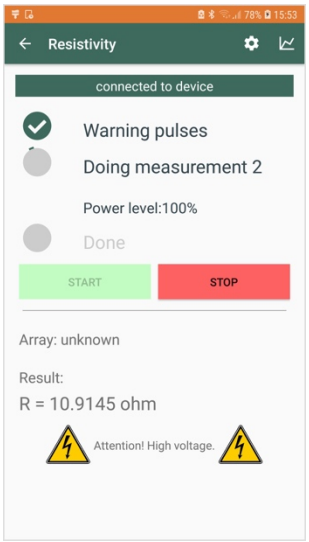


Measurement

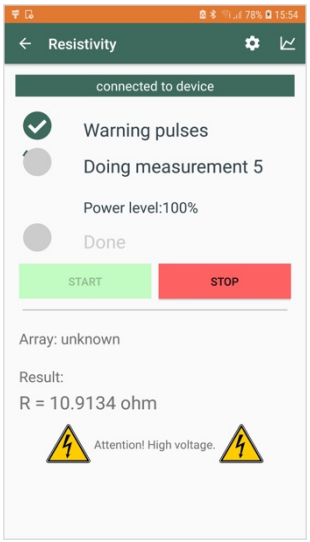
After the warning pulses are completed, the measurements are performed. Multiple measurements are stacked together to reduce the noise level.

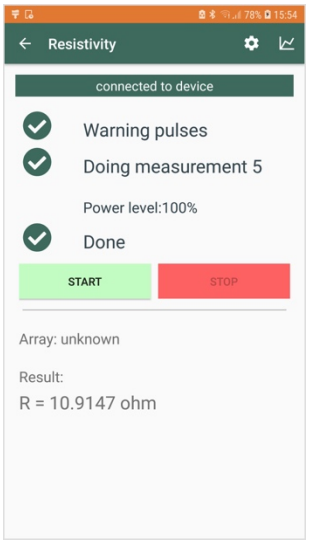
A minimum of 5 stacks are done. The measurements continue until the maximum number of stacks is done, as set in the settings, or if the resistance value has converged.





When the measurements complete, the final resistance value is displayed.





NOTE: the value displayed is the resistance with unit Ohm. From the measured current and voltage, the resistance value is calculated as R = V / I.

The apparent resistivity of the earth, denoted ρ_a, is calculated as

$$\rho_a = k \cdot R.$$

Here, k is the so-called geometric factor, which is dependent on the relative locations of the four electrodes, and is equal to:

$$k = \frac{2\pi}{\left(\frac{1}{C_1P_1} - \frac{1}{C_1P_2} - \frac{1}{C_2P_1} + \frac{1}{C_2P_2}\right)}$$

Where C_1 and C_2 are the current electrodes, and P_1 and P_2 are the potential electrodes, and C_1P_2 means the absolute distance between C_1 and P_2, for example. In the case of a Wenner electrode arrangement, the geometric factor is:

$$k = 2\pi a,$$

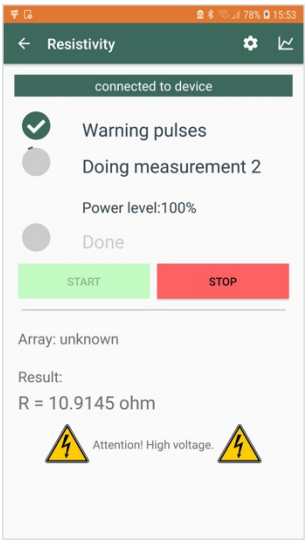
with a the distance between electrodes.

NOTE: If the Volterra app is used together with the Drillers' Toolbox app (described below), this is all handled automatically.

Displaying the graph

To see the shape of the measurements, a graph can be displayed. This can help in judging the measurement quality, and to troubleshoot any problems.

1. While in the Measurement screen, click on the graph icon at the top.



OPTIONAL – Using the Drillers' Toolbox app

The Volterra 3 device operates with the Volterra Android app. The result is a raw measurement of the resistance – the user needs to record the data herself, and compute the right geometric factor to use, based on the position of the electrodes.

To make the measurement process easier, it is highly recommended to use the Drillers' Toolbox app created by PRACTICA. Among other functionality, it offers a seamless interface to the Volterra app, built-in lists of electrode distances, capture of geolocation, automated calculation of the resistivity.

For the full description, please refer to the Drillers' Toolbox manual, which can be found here. Here you can find how to get the app, how to create a profile, and how to create a project. The explanations below assume you have already done this.

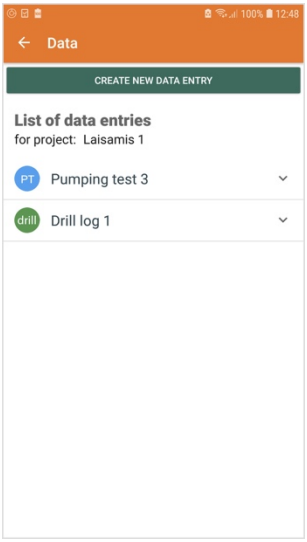
Setting up a VES survey

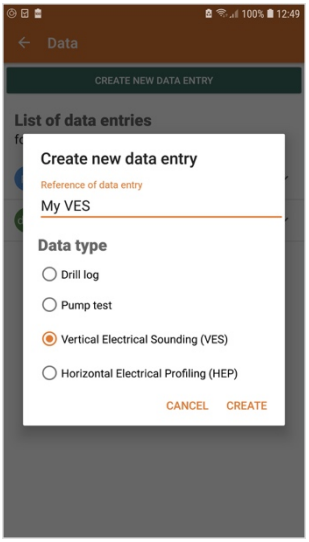
Select the data icon on the home screen. Click on ‘Create new data entry’ and select VES (Vertical Electrical Sounding). Give the data entry a name. After you click ‘Create’, the new entry will appear in the list.

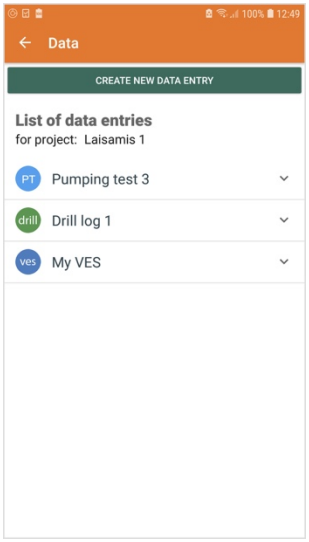
When you first open the item by clicking on it, the settings screen will be shown. Here, you can capture a geolocation by clicking on ‘Get geolocation’. Manual entry is also possible.

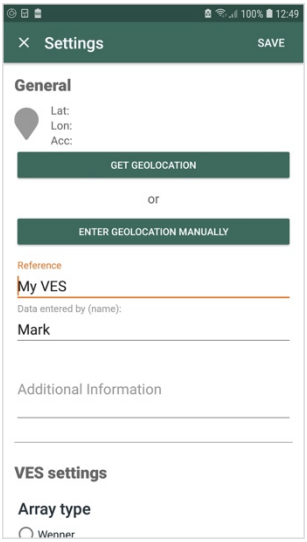
Further down the page, select the electrode array type (Wenner or Schlumberger), and the input method. For the input method, select ‘Practica Volterra device’.

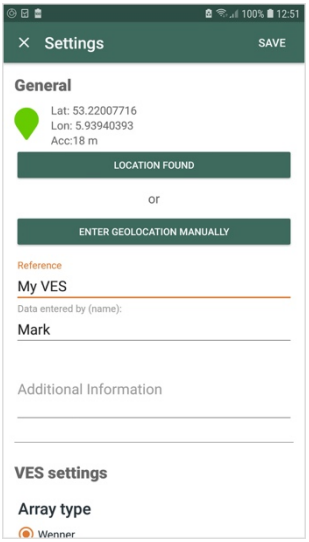
Click ‘Save’ to save the settings.

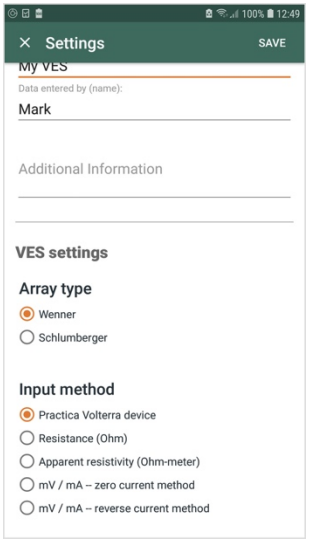












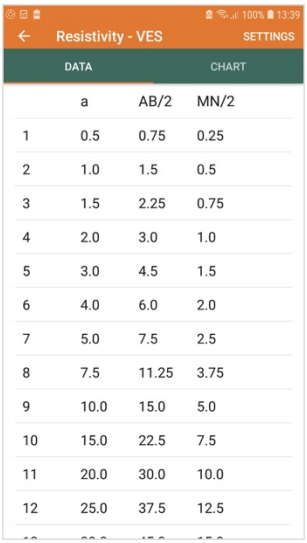
Doing a measurement

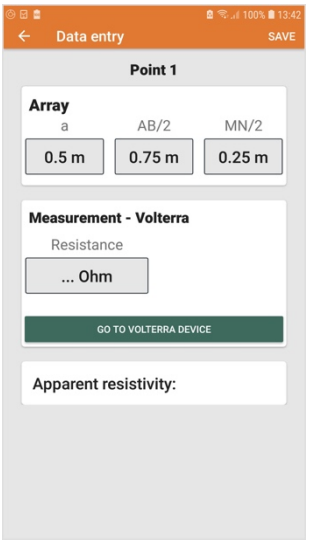
Turn on the Volterra device.

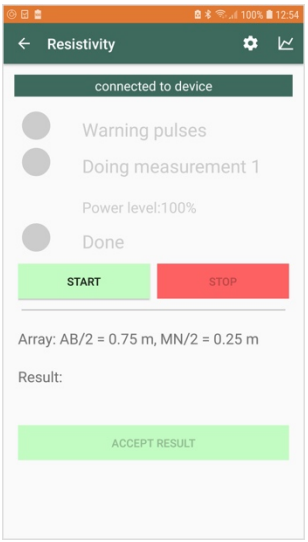
A list of electrode spacings is shown. Position the electrodes correctly and select the right item.

A screen is shown with the electrode spacings of the measurement. Click on ‘Go to Volterra device’. This will open the Volterra app on the phone, and transition to it.

In the Volterra app, do the measurement as described above in section 4.4.



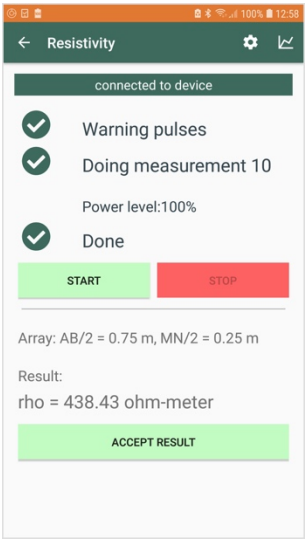


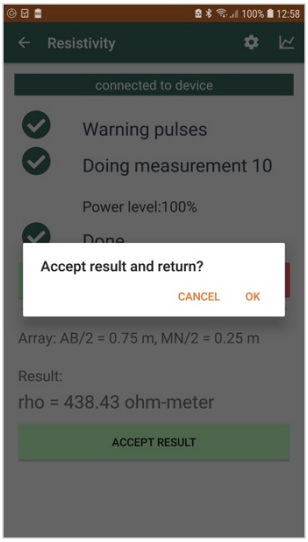


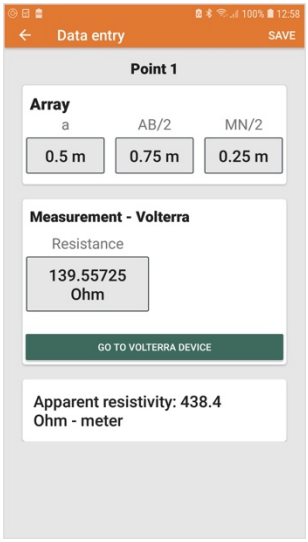
Note that the Volterra app is now aware of the electrode spacings, and will calculate the resistivity.

When the measurement is done, click on ‘Accept result’. Click on ‘ok’ to confirm. This returns to the Drillers’ Toolbox app, and shows the result.

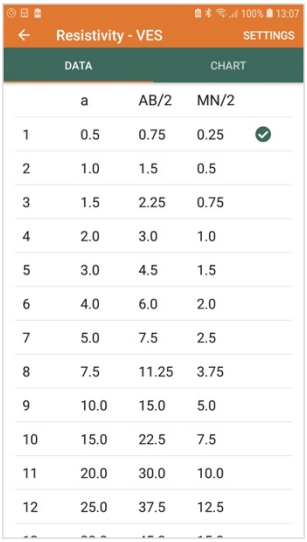
When you go back to the list, you see a green checkmark for the measurements that have been done.



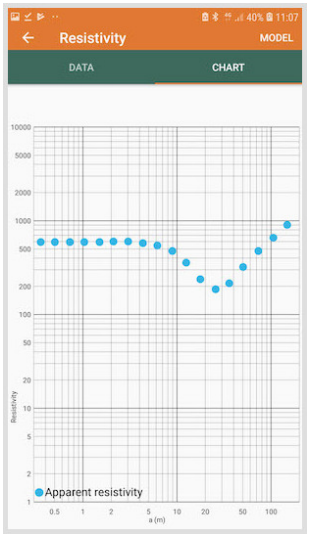




Select the ‘Chart’ tab to see a chart of the results.

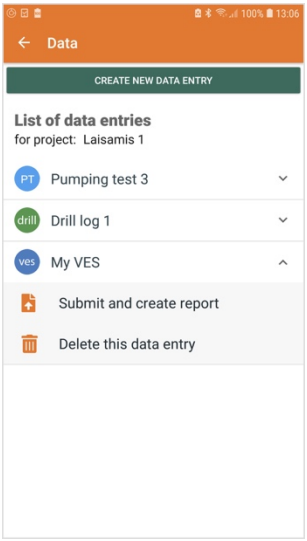


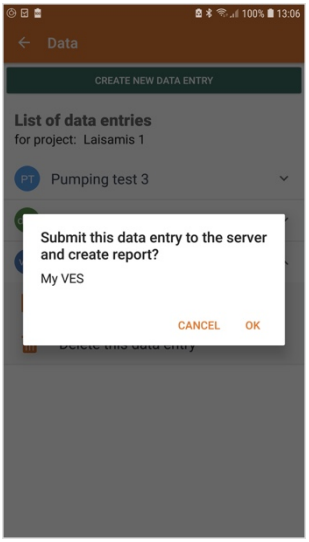
	a	AB/2	MN/2
1	0.5	0.75	0.25
2	1.0	1.5	0.5
3	1.5	2.25	0.75
4	2.0	3.0	1.0
5	3.0	4.5	1.5
6	4.0	6.0	2.0
7	5.0	7.5	2.5
8	7.5	11.25	3.75
9	10.0	15.0	5.0
10	15.0	22.5	7.5
11	20.0	30.0	10.0
12	25.0	37.5	12.5



Getting the data report

When all the measurements are finished, you will want to submit the data and receive the data report. To do this, click on the small arrow next to the data entry. Next, click ‘Submit and create report’. Confirm by clicking ‘Ok’.



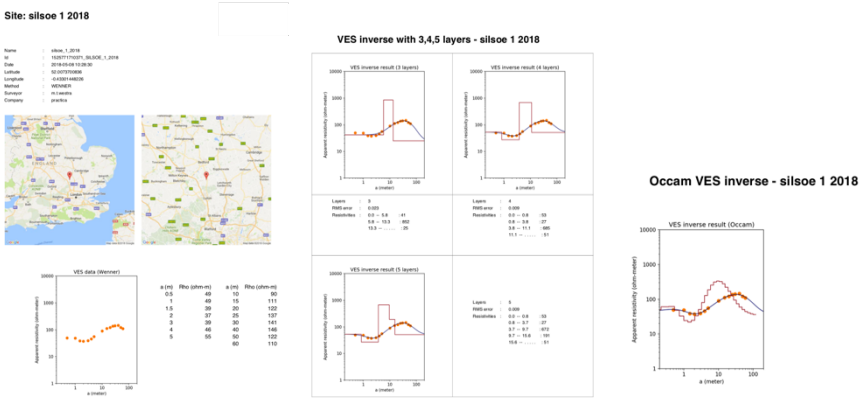


Next, check your email for the report to be delivered. This might take a few minutes.

The data report

The data report contains the meta-data such as name and location, a map of the location, the raw data, a chart of the data, and various models (3,4,5 layer models and Occam's inverse model), that can be used to support interpretation.

In addition, the email contains a link to the raw data in Excel format.



5. Maintenance

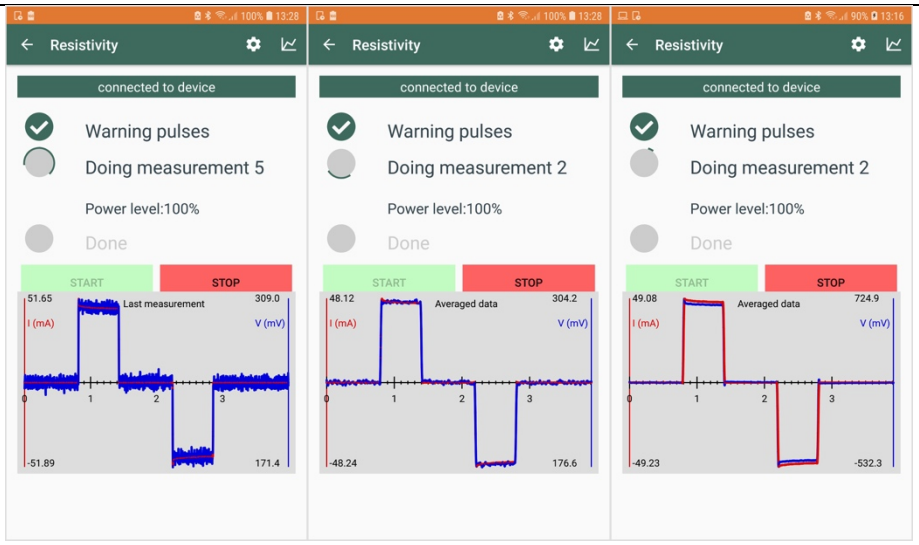
The Volterra 3 device should be treated as a sensitive measurement instrument. That means:

- Keep the device stored in its bag
- Keep the device dry at all times
- Keep the device clean of dirt and sand, especially near the plugs
- Make sure the device is not exposed to external shocks – provide extra padding if rough conditions are expected

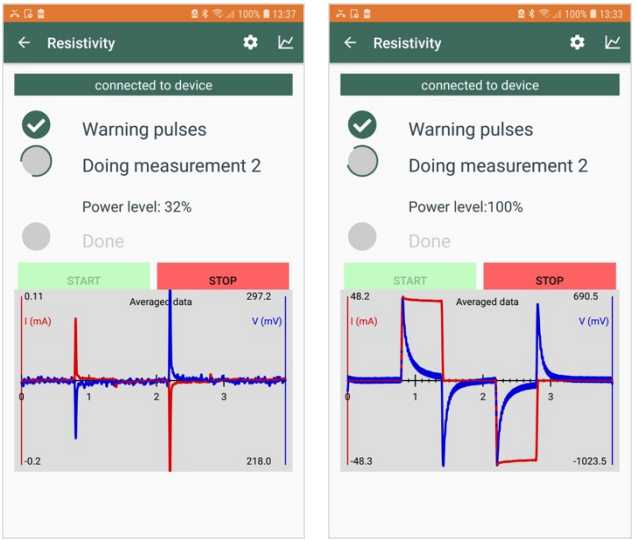
Very frequent charging can lead to a degraded lifetime of batteries. Therefore, batteries should be charged only when needed. Use the Android app to check the power level of the battery regularly and charge the battery when the app indicates the level is low.

6. Troubleshooting

Problem	**Possible solutions**
The device doesn't turn on	Check if the battery is fully charged. If needed, charge the battery first. Check if the clamps have not been put on the battery in the wrong way. Check the quality of the battery cable, and the connection to the Volterra device.
I can't connect to the device through bluetooth	Make sure Bluetooth is turned on. Reconnect the device to Bluetooth using the process explained in section 4.3. First remove the device from the paired devices list, and reconnect to it. Check if your smartphone can connect to other devices using Bluetooth
I get strange results	Strange results can have many causes. Sometimes, the cause can be in the ground, for example a buried metal pipe, or fencing that provides a shortcut for the electricity. Strange results can also be caused by the equipment. Usually, in those cases there is a problem with the cables. To troubleshoot, try this: • Check if the clamps are attached to the electrodes • Check if the cables are properly attached to the clamps and the banana connector • Check the cables for visible damage To conduct these checks, it can be useful to have a voltmeter with resistance measurement capability. These can be used to check the integrity of cables, for example, as these should show near zero resistance. Finally, you can look at the graph of the measurement. Both the last measurement and the averaged measurement can be displayed. Different problems lead to different forms of the graphs. Below, we show a few examples. The shape of the graph can be used to find the problem, and to check whether the problem has been fixed.



Above: three good measurements. The current (red) and voltage (blue) graphs should more or less display a square wave, with the voltage curve following the shape of the current curve. Sometimes, sharp spikes are present at the start of the voltage curve – this is not a problem.



Left: result when one of the current electrodes is not connected. Right: result when one of the voltage electrodes is not connected.

7. Disposal

7.1 Disposing the Volterra device

The Volterra 3 device does not contain an internal battery, and therefore can be disposed of as regular electronic waste – the same as radio's, television sets or other measurement instruments. Dispose of electronic devices in appropriate recycling facilities or community drop-off points.

7.2 Disposing of 12V batteries

Used lead-acid batteries contain lead, lead compounds and sulfuric acid and are classified as hazardous waste. They should not be disposed of with the regular garbage, as their toxic contents may leach from landfills into the environment.

Dispose of batteries in appropriate recycling facilities, hazardous waste facilities, or at designated drop-off sites in your community. In many cases, retailers such as car parts or motorcycle dealers will accept dead or used batteries.

In addition, properly store and care for used batteries before you dispose of them to minimize the risk of fire and dangerous chemical leaks.