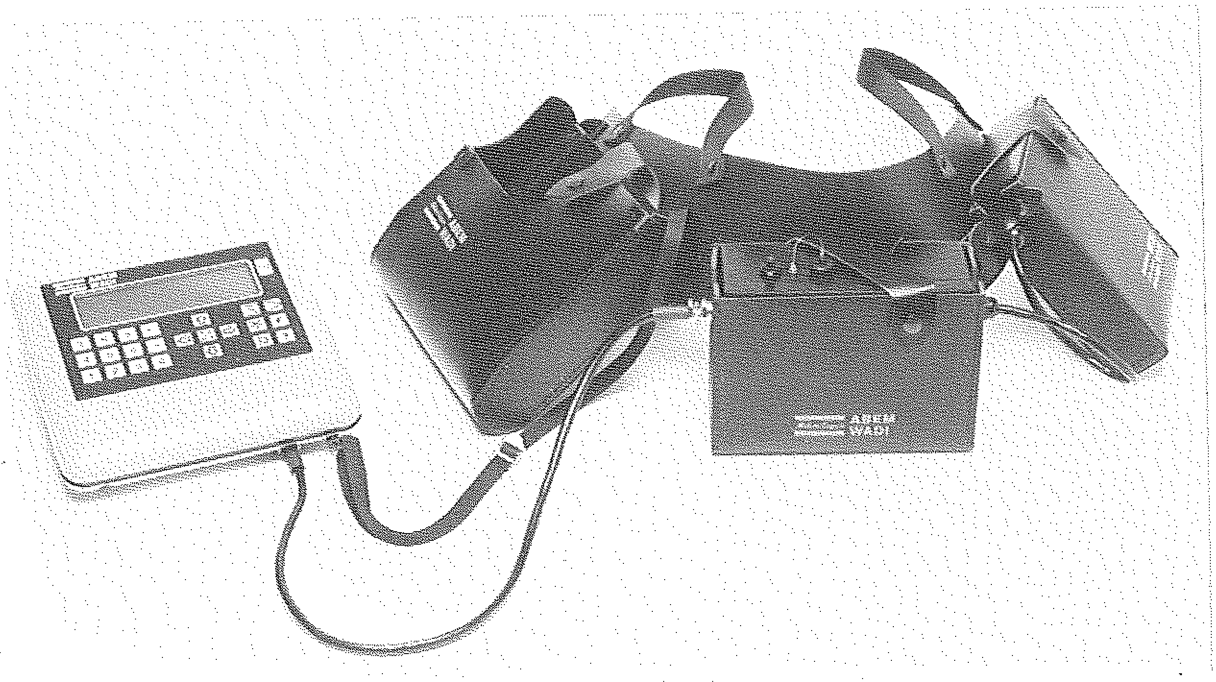
ABEM

Instruction Manual

ABEM WADI VLF INSTRUMENT

Simple, state-of-the-art water and mineral prospecting instrument.



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1 INTRODUCTION

Congratulations to your new WADI VLF instrument.

Your User's Manual explains how to use the WADI and presents the theories on which it operates. It's advisable to read this manual carefully before making your first survey. If you use and care for your WADI in accordance with the instructions and advice presented here, it will provide you with many years of outstanding service, regardless of whether you are searching for water, ore or other electrically conductive subsurface structures.

The WADI is a geophysical instrument designed to find physical structures in bedrock. These structures may be vertical or sloping, they are often many hundreds of metres long and deep and they have better electrical conductivity than the surrounding rock. Experience shows that such a structure often contain numerous cracks and substantial amounts of water. Sometimes, however, a structure located by the WADI contains an orebody.

The WADI operates on the VLF principle, and it makes use of radio waves in the VLF band sent out from distant transmitters. Appendix A presents the basic principles of VLF theory, and also explains its limitations. The WADI have a memory that can store about 4000 measurements. You can retrieve any of these measurements from the memory at any time for study. Moreover, the WADI can be connected to a printer or a computer. Appendix B presents the routines used to transmit data.

After reading this introduction, you should study chapters 2 through 5. They present basic information on how to use and maintain the WADI. The Appendices present more detailed information. Appendix C presents a detailed description of the most frequently used WADI commands. Appendix D explains certain special commands that are normally used only by specialists. These make it possible to prepare reports based on traditional VLF techniques.

Please let us know about any interesting observations, experiences or results obtained using your WADI. We will also appreciate any comments you wish to make on this User's Manual.

1.1 Inspection after unpacking

Always check the contents of the box against the packing slip that is included. Make a visual inspection of the instrument and any accessories that you have ordered. Check to see that all switches and connectors are firmly secured and that nothing has been damaged. Check the packing materials to see whether they were damaged, and save them for use in the event that your WADI has to be returned for any reason.

1.2 Report any shipping damage immediately

If the instrument was damaged during shipping, you should notify the carrier immediately. Also report the damage to your supplier immediately, making certain to specify the order number, the type of instrument and its serial number.

1.3 Warranty

Each instrument manufactured by ABEM is warranted to be free from defects in materials and workmanship. ABEM's liability under this warranty is limited in accordance with the terms of clause 9 of the General Conditions for the Supply of Plant and Machinery for export prepared under the auspices of the United Nations Economic Commission for Europe (Geneva, March 1953).

This warranty covers the servicing and adjusting of any defective parts (except for fuses and batteries). The warranty is effective for 12 months after the date on which the instrument was shipped from the factory as set forth on the bill of lading, provided that the instrument is returned carriage paid to ABEM. If the fault has been caused by misuse or abnormal conditions, ABEM will submit to the user a cost proposal before undertaking any repairs.

ABEM assumes no responsibility for steps that are either taken or not taken as the result of decisions based on the results of measurements taken with instruments made by ABEM or calculations based on software delivered by ABEM.

Please contact ABEM if a fault occurs that cannot be corrected on site. Specify the type of fault, the serial number and the type of instrument. Frequently, faults can be remedied via the telephone or telex. If this proves impossible, however, ABEM will provide you with return shipping instructions.

Fill in the Warranty Registration Card that accompanies the instrument immediately and return it to ABEM.

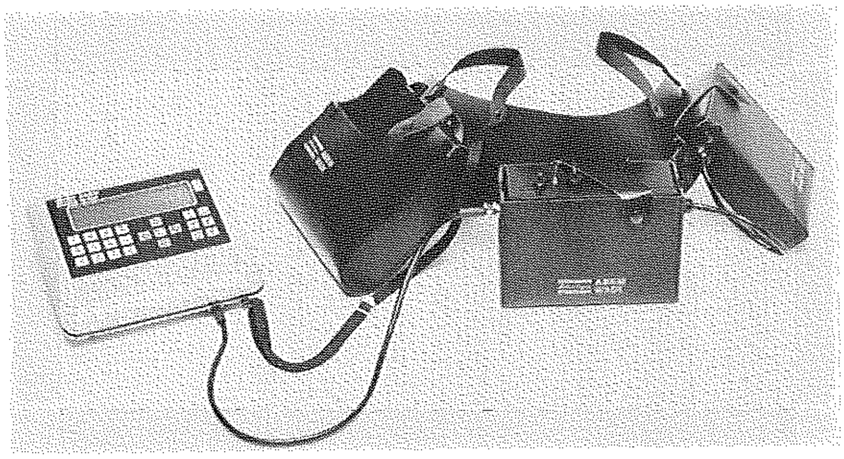
1.4 Return shipping

If possible, use the original packing materials when returning an instrument to us. If they are not available, you should preferably use a sturdy box large enough to accommodate about 80 mm of shock-absorbing material on all four sides and the top and bottom. Do not use paper, wood-wool (excelsior) or the like, since they will be compressed during shipping. Do not return the instrument until you have received shipping instructions from ABEM.

2 GETTING TO KNOW YOUR WADI

2.1 Design and construction

The WADI consists of three units:



Hand-held controller unit (with strap-type handle)	Measuring unit with battery compartment	Antenna unit

The entire WADI is mounted on a belt worn by the user. Normally, you will hold the controller unit in your left hand when measuring (insert your hand in the strap-type handle for a firm grip). When approaching or leaving the site, you can keep the controller unit in its case on the left-hand side of the belt (with the display inward). The hand-held controller unit contains the keyboard and screen (display window). It also contains a microcomputer that carries out all calculations and the memory where all measured values are stored. The WADI confirms each key depression by beeping. Moreover, the instrument beeps each time it notifies you of something.

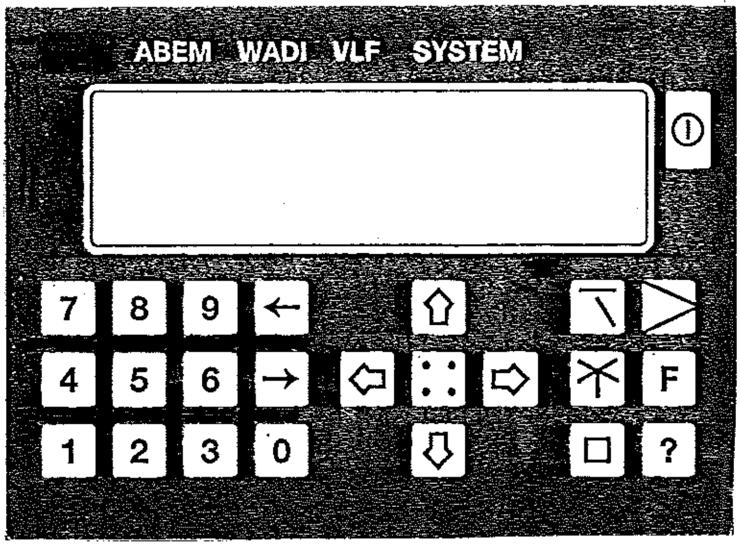
The measuring unit is carried on the back of the belt. It contains the radio receiver with amplifier, analog filters and other electronic circuitry. It also contains the batteries and a connector via which you can send information to a printer or computer. This connector can also accomodate a battery charger (if you are using rechargeable batteries). The measuring unit also contains the MASTER ON/OFF switch.

The antennas and an inclinometer are carried on the right-hand side of the belt. You should try to keep the antenna unit upright (vertical) or nearly upright while you are measuring. If the antennas tilt too much, a warning appears on the screen.

2.2 Keyboard

There are 24 keys on the WADI keyboard. They are arranged in three groups, each of which has a different colour (see the picture on next page).

The yellow keys on the numeric keypad at the left are used to enter numbers. The green keys at centre are used to set the measurement direction, distance between profiles and the between-stations interval. The red keys at the right are used to issue commands and implement certain functions. The ON/OFF key is in the upper right-hand corner so that it cannot be mixed up with the other keys.



Brief description of key functions:

ON/OFF key		Is used to turn the WADI on and off. Do not forget that the MASTER ON/OFF switch must be turned on first (located on the measuring unit at the back of the belt).
0 9	Numeric keys	Used to enter coordinates etc.
← →	Cursor movement keys	Used to move the different types of cursors (with some exceptions).
	COORDINATE key	Used to put the WADI in the coordinate entry mode and also to retrieve results from memory.
	DIRECTION keys	Used to specify a profile direction of North, South, East or West and also for certain other functions.
	INTERPRET key	When the screen indicates an interesting peak, you can press this key to obtain a quick interpretation of dip and depth of the buried object.
	STATION key	This key is used to find the transmitter that is for the moment most suitable for use at the site.
	DELETE key	You press this key when you wish to delete a result from your profile or from the memory. Be very careful when using this key!
	MEASURE key	First depression presents the results that have been stored for the profile you are now working on. Second depres-

sion executes a measurement.

F	FUNCTION key	This key is used for many purposes in combination with other keys.
?	HELP key	When you press ? and some other key, you obtain a helpful explanation of the second key's function. You thus have a brief, on-line User's Manual right on your keyboard!

```
***        Help for key - ?        ***
Help -
Press this key followed by any
key for an explanation of the
key function.
```

2.3 Selecting a suitable transmitting station

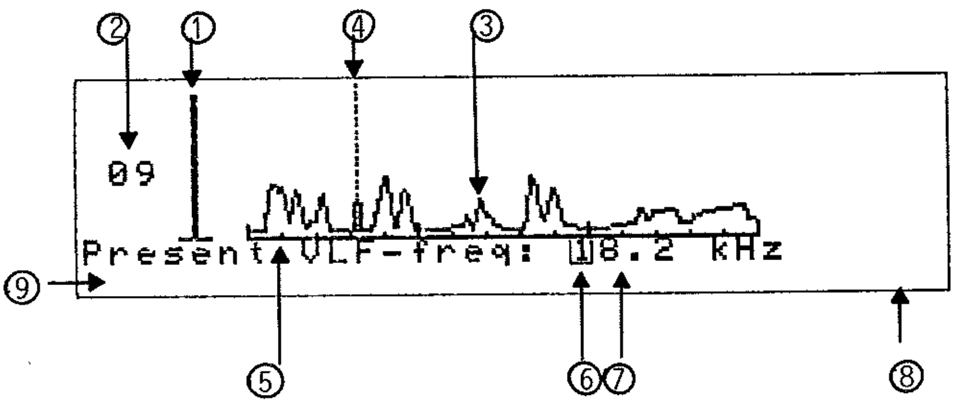
When you wish to start measuring, you must first find a stable and sufficiently strong VLF signal. Furthermore the signal should have a suitable direction for your decided profiles.

Proceed as follows:

a) Face the direction in which you expect to walk when measuring (the direction of your survey line). To decide profile direction see appendix A4.

b) Press the STATION key (⚹). The WADI responds by presenting the radio frequency for which it is currently set. To 0-set this frequency, enter 0 0 0 (zero, zero, zero), whereupon the WADI will display 00.0 kHz.

c) Press the STATION key (⚹) again. After a few minutes the following will appear on the screen:



Explanation of the illustration:

1 This vertical bar indicates the strength of the signal "heard" by the electronic circuitry. This helps you determine the direction to the VLF radio transmitter. Turn slowly throughout 360° and observe the length of this bar. When it is shortest, the transmitter is either directly in front of or behind you. The best measuring results are obtained when the measuring direction (survey line) is perpendicular (at least within ±20°) to the direction to the transmitter.

2 This numerical value also indicates the signal strength at the site. Its scale ranges from 01 to 63. Normally, this value should lie between 15 and 30 for a useful VLF transmitter. If the signal strength is lower than 10 or higher than 50, it will be very difficult to obtain any reliable measurements. Signals that are too strong (higher than 50) are encountered when the transmitter is very close to the site. In such case, select another transmitter that provides a weaker signal.

3 A continuous curve is drawn on the display when you are searching for a transmitter. The curve represents the signal strength at different frequencies, and it has a number of peaks. Most of these peaks represent VLF transmitters. The height of each peak indicates the relative strength of the VLF radio signal (at your site). It takes about three minutes to scan the entire VLF band (15-30 kHz). If so desired, you can interrupt the scan as soon as it becomes evident that several suitable transmitters are available. Simply press the STATION key ᛉ .

4 When you have found a suitable transmitting station (after having scanned the entire band or interrupted the scanning), the WADI automatically selects the most suitable of them, and indicates its selection by means of a dotted-line cursor. Moreover, the WADI displays numerically the frequency of the selected transmitter (see 7 below). If so desired, you can select a different transmitter by moving the dotted-line cursor to some other peak on the curve. This is accomplished by pressing ⇨ or ⇦ .

5 This scale represents the frequency band (15 to 30 kHz). Graduations appear at 15, 20, 25 and 30 kHz.

6 This blinking rectangular cursor indicates where you can enter the desired frequency. For automatic scanning, you must enter 00.0 kHz. This cursor can be moved by means of the → and ← keys.

7 After scanning, the selected frequency appears here. If you enter a specific frequency yourself, no spectrum curve appears, but the signal strength appears after you press the STATION key ᛉ .

8 The names of the most prominent VLF transmitters around the world have been programmed into the WADI. If you see a word of three letters in the lower right corner of the

display, it is the name of the present active transmitter. You can identify some of the VLF transmitters by consulting the table given in Appendix A.

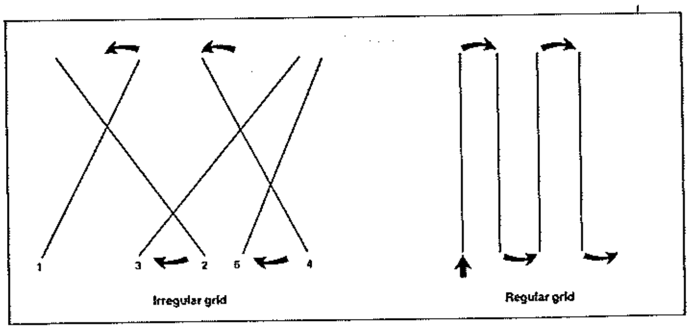
9 Different messages issued by the WADI appear on the bottom line.

The first thing you must do when conducting a WADI survey is to select a transmitter that provides a suitable signal at your site. You can use the WADI's automatic scanning function or, if you prefer, you can enter the specific frequency for a desired transmitter and then check the signal strength. The WADI locks onto the selected frequency, and remains locked on until you make a change. There are several reasons why you may wish to change frequency during measurement. For example, the transmitter might stop sending. In such case, the WADI issues a warning signal reading "VLF signal too low". Moreover, if you select a new measurement direction, such as East-West instead of North-South, it is usually necessary to find a new transmitter.

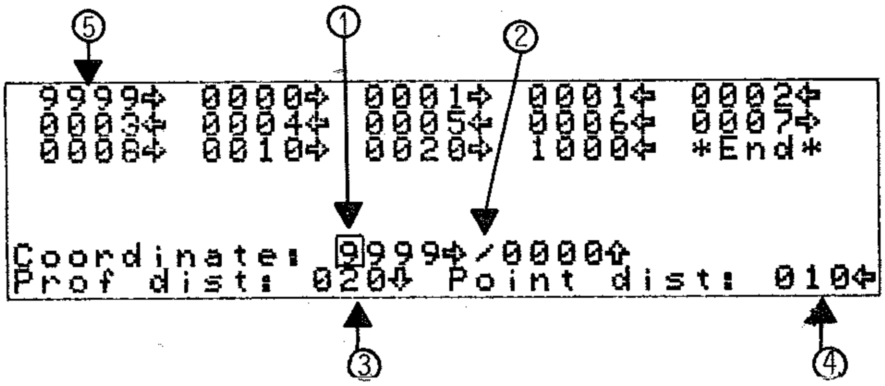
2.4 Site coordinates

Since the WADI stores all measured values in its memory, each of them must be identifiable in some way so that you can retrieve them individually as desired. The identification system used by the WADI is based on site coordinates that cover the area being surveyed. How to measure in a coordinate system is explained in section 3.5 and A5. Basically, this means that you should take your measurements along parallel lines crossing the area of interest. Along each line you take measurements at regularly spaced points located, say, 10 metres apart. When you reach the end of the line, you move a specified distance (e.g. 25 or 50 metres) left or right and then proceed back in the opposite direction along the new line. Your measurements are thus taken on a grid as illustrated below and you don't have to change transmitter during the measurements.

If there are obstacles, steep hills, etc. on the site that make measurements in a grid inconvenient or impossible, you can enter a profile distance (between-line distance) of 1 so that your lines will be numbered 1, 2, 3, 4 etc. This makes them easy to identify (see also Appendix A). Remember however, that you probably have to select a new transmitter if you continue with a new profile not parallel to the previous one.



Pressing the COORDINATE key (::) and then entering the coordinates are important steps in preparing to take measurements.



Explanation of above illustration:

1 This rectangular cursor blinks to indicate that new numeric values can be entered here. You can move the cursor by pressing the → and ← keys.

2 This is the coordinate for the next measuring point. The four digits to the left of the slash (/) specify the measurement line on which you are located. The arrow (⇨) indicates that this measurement lines is to the East of the origin. The four digits to the right of the slash (/) indicate where on the measurement line you are located. The arrow pointing upward (⇧) indicates that you are to the North of the origin.

If you wish to retrieve an already measured line from the memory of the WADI, you can enter the line's coordinate into the first field and then press the MEASURE key (>).

3 Here, you enter the profile seperation (between-line distance). Note that 25 m must be entered as 0025, etc. If you do not enter anything here, the WADI uses a profile distance of 10 m as a default and assumes that you are moving West to East when changing lines.

Observe that you are free to use any convenient length unit, e.g. metre, step, feet or yard. For convenience, however, we will use the length unit *metre* in the examples given in this manual.

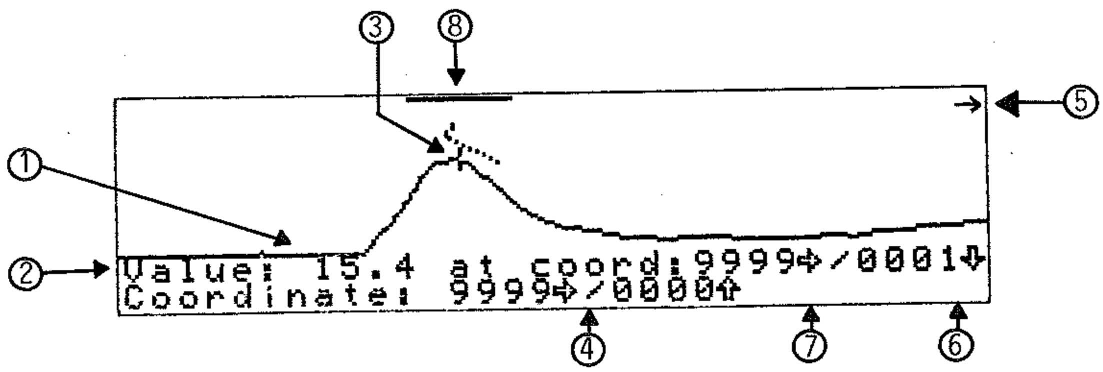
4 The point distance (between-point distance) is the distance between measurement points along the line. If you do not enter anything here, the WADI uses a point distance of 10 metres as a default and assumes that you are moving from South to North.

5 If you press the COORDINATE key (::) twice, the coordinates of all the lines already stored in the memory will appear. One line having a coordinate of 9999 ⇨ is stored

in the memory prior to delivery. It can be retrieved and activated by running the memory test (see section 2.6).

2.5 How results are displayed

After selecting a VLF-transmitter and entering the coordinates of your starting point, you can start to take measurements. The first time you press the MEASURE key (>), the WADI enters the measure mode. It is a good idea to check first to see that you and the WADI agree about the point on which you are standing. A small arrow in the upper right-hand or upper left-hand corner indicates where the next measured value will appear. When you press the MEASURE key again, the measurement is executed. After moving to the next measurement point, press MEASURE twice. Then move again and press MEASURE twice. Continue until you have measured all of the points on the line. As you take measurements, the displayed profile grows gradually until it includes the entire measurement line.



Explanation of the above illustration:

1 This is the resulting curve after filtering. Since each displayed point in this curve takes into account several points both ahead and behind the point currently being measured, the curve will change somewhat as you proceed. A value on the filtered curve is thus not complete until you have advanced at least three measurement points away from it. This illustration indicates clearly two anomalies (electrically conducting subsurface structures).

Note that if your measurement line is in an East-West or West-East direction, West always appears at left on the screen. Note also that if your measurement line is in a North-South or South-North direction, South always appears at left on the screen.

2 Messages appear on this line, and the numeric values for the actual measurement point are also displayed here.

3 This graphical cursor (short vertical bar on the curve) can be moved along the curve by means of the → and ← keys. If you hold either of these keys down, the cursor moves rapidly. The message line presents the coordinates of the point where the cursor is located.

They also presents the measured value at this point.

4 The coordinates for the next measurement point appear here. Moreover, certain warnings appear on this line.

5 This arrow shows the direction in which the next measurement result will be plotted.

6 The antenna unit must be almost vertically oriented if measurement is to be successful. An antenna-tilt warning appears in the lower right-hand corner if the antenna unit is positioned improperly. When it is positioned properly, a bar (-) appears.

If the tilt is within $\pm 10°$ the WADI will automatically perform a compensation, and you don't need to worry about it. This is indicated by either of the symbols ∧ or ∨ .

If the antenna unit tilts too much, either a black triangle pointing up or down (▲ or ▼) or a square (■) appears. In this case you have to adjust the belt with the antenna unit, or stand more upright.

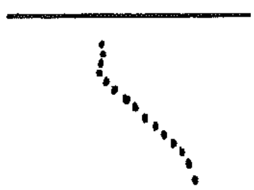
7 A number of symbols can appear in this field. They are explained in detail in Appendix D.

8 The WADI can interpret your results right on the spot. To take advantage of this sophisticated feature, proceed as follows:

a) Move the graphics cursor to the highest point on the indication of interest (commonly called an anomaly).

b) Press the INTERPRET key (⌅).

c) After a few seconds a figure like the following will appear above the curve:



The horizontal line indicates the surface of the ground. The dots comprise an approximate trace of the anomaly (tilted structure for example). Since the horizontal and vertical scales are identical, it is easy to estimate the depth to the top edge of the structure. First, measure the length of the horizontal line by moving the graphical cursor from one end of the line to the other. Then estimate the distance from the line down to the uppermost of the dots.

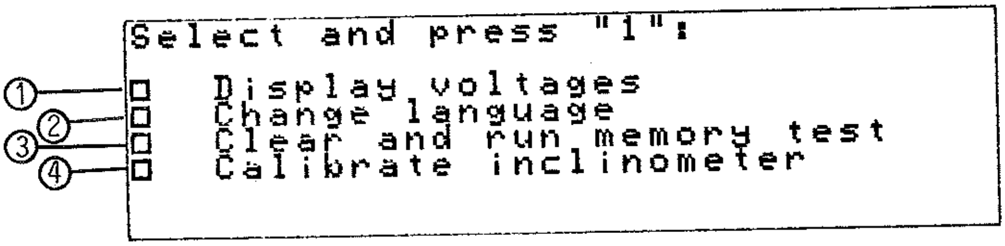
Example:
By moving the cursor from left to right you estimate the length of the line to be 30m. You then estimate the depth to the

uppermost of the dots to be around 1/5 of the length of the horizontal line. This gives you a depth estimate of approximately 6m. However, you must subtract 1m due to the fact that the WADI antenna unit is located about 1m above the surface. The depth to the indicated structure is thus about 5m.

Note that this depth estimate will never be very accurate. It is only meant as a rough estimation! The build-in interpretation should mainly be used to get the exact *location* of the conductor. Furthermore you can achieve very valuable *dip* estimates, i.e. you can see if the body is vertical or dipping to the left or the right. Be careful not to draw conclusions about the specific value of the dip in degrees!

2.6 Service menu

When you press F and then →, the service menu appears.



On the above illustration, there are four boxes to the left. A blinking cursor can be moved among these boxes using the → and ← keys. When you have moved the cursor to the desired box, press the 1 key.

1 Display voltages. This is used for servicing. The values +10 V, +5 V and -10 V supplies should be within ±5% of the nominal value. The battery voltage should not drop below +6.2 V. You should check the battery voltage daily so that you will be able to replace the batteries in time.

2 Change language. You can toggle between English and the language you ordered. Move the cursor to this box and then press the 1 key. The WADI confirms the change by displaying "Done" in the target language (the language to which you wish to change).

3 Clear and run memory test. ***Don't choose this command! All measured data in the WADI will disappear.*** This command is used primarily in connection with servicing. After moving the cursor to this box, you can press 1 and then press the coordinate key (::) twice. All existing measurements in the WADI are then erased, and the test line (the one having a coordinate of 9999⇨) is entered into the memory. This test line is used for practising interpretation etc.

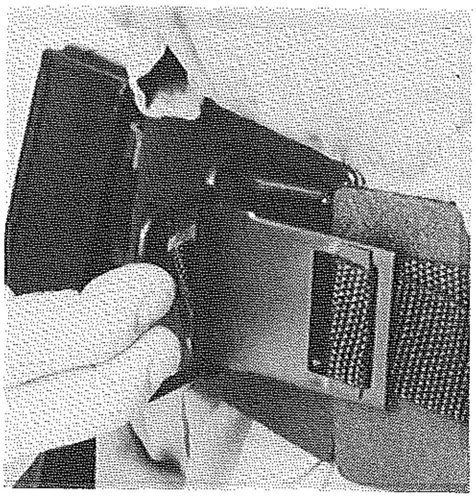
4 Calibrate inclinometer. ***Don't choose this command! If you are setting a wrong calibration, all further measurements will be useless.*** This command is used primarily in connection with servicing. If you for some reason want to perform a calibration, you need a stable stand where you can fix the antenna accurately at inclination +10°, 0°,

and -10°. Then follow the instructions that appear on the WADI screen. If you call up this calibration display by mistake, you can exit by pressing the COORDINATE key (::).

2.7 Convenient carrying belt

The WADI comes with a special carrying belt. Adjust the length of the belt so that it rests comfortably on your hips. Fasten the belt with the buckle as illustrated. Then tighten it by pulling the strap back to the left. Check that the antenna unit on the right-hand side points forward and hangs vertically.

The two straps on the WADI belt can be used as a handle when you are not wearing the belt.



3 STEP-BY-STEP MEASUREMENT INSTRUCTIONS FOR THE WADI

3.1 Planning your survey

Make a rough sketch of the site. Draw in the measurement lines so that, if possible, they cross visible structures such as hillocks, valleys, creeks etc. Give some thought to the coordinate pattern in which you wish to arrange your measurement points. You may even want to use some stakes in the field to mark the beginning and end points of the measurement lines.

Please note that you should never start to measure a profile very close to a power line. The strong field from the power line will disturb the WADI, so that the further data processing along the measurement line will be influenced by the very first measurements close to the power line. It is however possible to cross a power line with a profile.

3.2 First measurement point (starting point)

Stand on the first measurement point and face the direction in which you are going to move along the first measurement line. Turn on the WADI and, if necessary, change the screen brightness by pressing **F** ⇧ or **F** ⇩ a number of times.

3.3 Finding a suitable transmitter

Press the STATION key (ᛉ) and enter 00.0 kHz via the keyboard. Press STATION (ᛉ) again. Wait for the scanning to be completed. This takes about three minutes unless you interrupt it by pressing the STATION key (ᛉ). In some cases you might know beforehand which transmitter is most useful for the actual survey. If for example you want to measure along East-West striking lines at a site in Northern Africa, you might want to choose e.g. the french FUO transmitter directly. This is done simply by specifying the actual frequency, in this case 15.1 kHz.

3.4 Checking the signal strength and direction

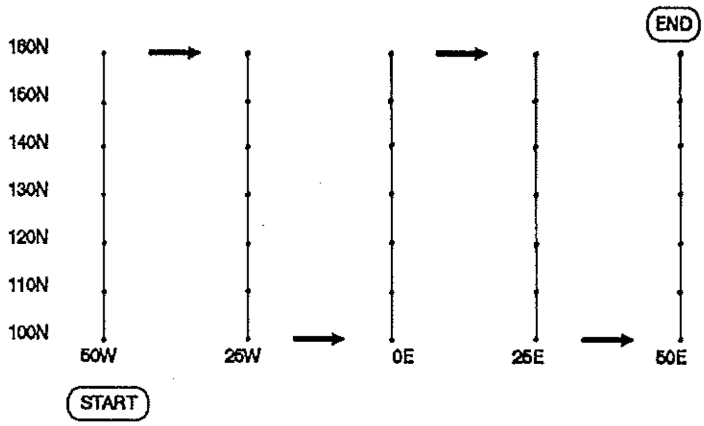
The signal strength must be between 10 and 50. If the WADI can't find any signal of sufficient strength, there may be no suitable transmitter operating in your selected direction at the moment. In this case you have to choose another measuring direction, in which a better signal is found (or postpone measuring for a while).

If the signal strength is higher than 50, you are operating very close to the selected transmitter. Move the dotted-line cursor to another frequency, then press the STATION key (ᛉ) to measure the signal strength of the new transmitter.

Turn slowly 90° and look at the bar. If the bar is at (or near) a minimum when you are at right angles (within about $\pm 20°$) to your measurement line, everything is OK. Otherwise you should select a transmitter located in a more suitable direction. (Alternatively, you could change the direction of the measurement lines).

3.5 Entering your coordinates

Enter the coordinates of the starting point, the distance between measurement points and the distance between lines. For a site arranged as shown in the following illustration, you would enter the coordinates as given:



Starting point coordinates: 0050 ⇦ / 0100 ⇧
Distance between lines: 0025 ⇨
Distance between points: 0010 ⇧

Note that your "local" North direction need not coincide with true or magnetic North.

3.6 Taking the first measurement

Press the MEASURE key (>). The WADI responds by displaying "Ready for measure". Press the MEASURE key (>) again. The very first measurement might take a little longer since your WADI must tune the antennas to the new transmitter. Hold the WADI steady while measurement is in progress. If WAIT appears on the WADI screen, just be patient.

3.7 Next measurement point

The measured value for the first point was 0.0. This is due to the fact that the WADI needs at least three points before it can start calculating and displaying the filtered curve. As your survey progresses, the filtered values will automatically be calculated and plotted.

Press the MEASURE key (>) twice. The second measurement is now completed. You can see how the WADI updates the coordinates of the measurement point using the between-point distance that you specified. Curve plotting now commences.

Please note that you can optionally at any time choose to display the originally measured data (e.g. the real part) instead of the filtered data. To display the real part you have to press the code **F ⇨ 1** before pressing the MEASURE key (>). The different display modes are given in appendix D3.

3.8 Deleting a measured value

If, for some reason, you wish to delete a measured value, simply press the DELETE key (□). Then repeat the measurement and press MEASURE (>).

3.9 Skipping a point

Let's assume that the next point is inaccessible. In such case, simply press :: followed by □. If more than one point must be skipped, you can repeat this procedure a number of times. The skipped points will not be omitted when the curve is plotted, since the measured points will be jointed by interpolation to form a contiguous curve. You can, however, see which points have been omitted when you print out your measured values.

3.10 Next measurement line

When you have reached the end of the first measurement line in your grid, you should proceed directly to the next line as shown in the drawing in section 3.2. You will now walk in the opposite direction. Press the F key followed by :: to inform the WADI that you are starting on the next line. You must repeat this procedure each time you move to a new line, when working in a grid system.

If your new line runs parallel to the previous line, you do not need to find a new transmitter. On the other hand, if the new line is in a different direction, you should repeat the STATION selection procedure as described in 3.3.

3.11 Interpreting the results

If an interesting anomaly appears on the WADI display, you can make an interpretation directly: move the cursor to the maximum of the peak and press the INTERPRET key (⇱). Mark the location of the anomaly on your site sketch and make a note indicating the direction in which it dips and the estimated depth to the upper edge. You can even stake out the location of the anomaly directly in the field. Give special attention to structures that are revealed on more than one measurement line.

If the results are difficult to interpret, it may be advisable to lay out a new series of measurement lines at right angles to the first. Do not forget to select a new transmitter for the new measurement direction, and remember to change the coordinates.

If you are searching for water, you should give special attention to places where structures intersect each other. These often provide high rates of water flow in drilled wells.

Narrow, high and symmetrical peaks may represent buried pipes or cables. Do not drill at such locations until you are sure that what you have found is not a buried man-made object. After completing your work, remember to turn off the MASTER ON/OFF switch.

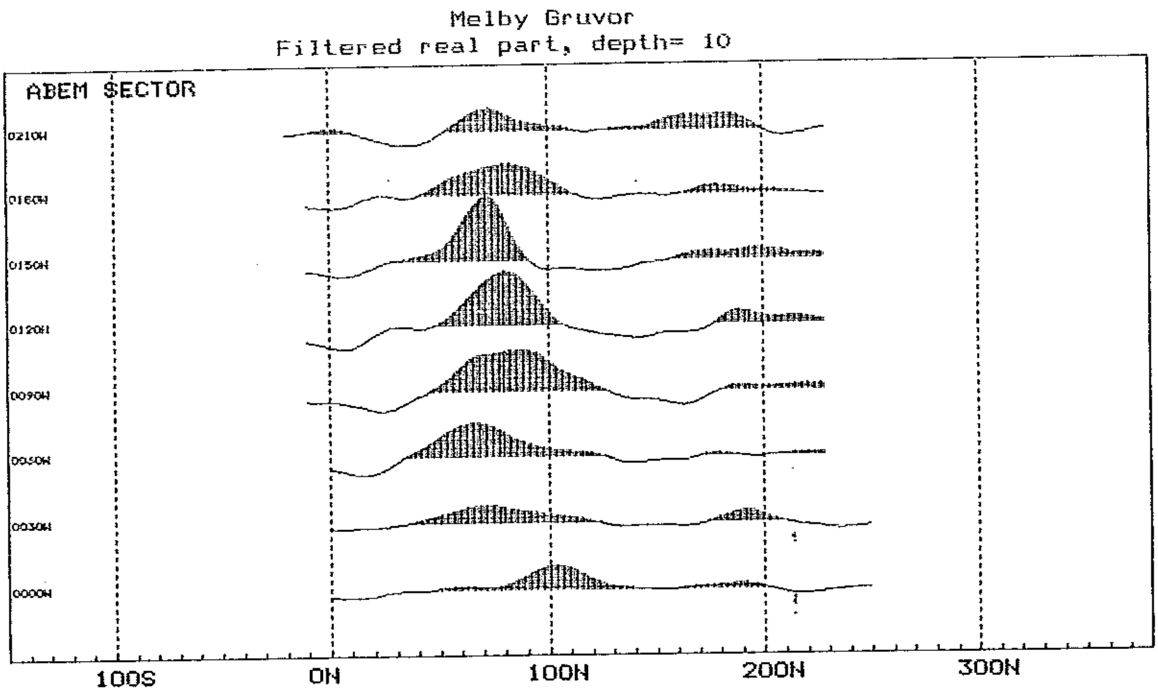
3.12 Printing out the results

A special cable (extra accessory) can be used to connect your WADI to a printer (see Appendix B). After printing, draw a map and mark in the anomalies that are of interest. Then return to the field and stake the location where you wish to drill a well.

3.13 Computer interpretation

The measured data can easily be transferred to a PC computer for further processing and plotting. A computer interpretation program SECTOR and a communication cable is optionally available for that purpose. With SECTOR you can easily transfer your data to the computer, and you can present your data on the screen as well as on paper plots (in report quality). SECTOR runs on an ordinary IBM PC, XT, AT, PS/2 or compatible, equipped with EGA, Hercules or CGA graphics. For making paper plots you need a printer (IBM compatible graphics printer, e.g. an EPSON FX-80).

Example of output from SECTOR:



4 CARE AND MAINTENANCE

4.1 Batteries

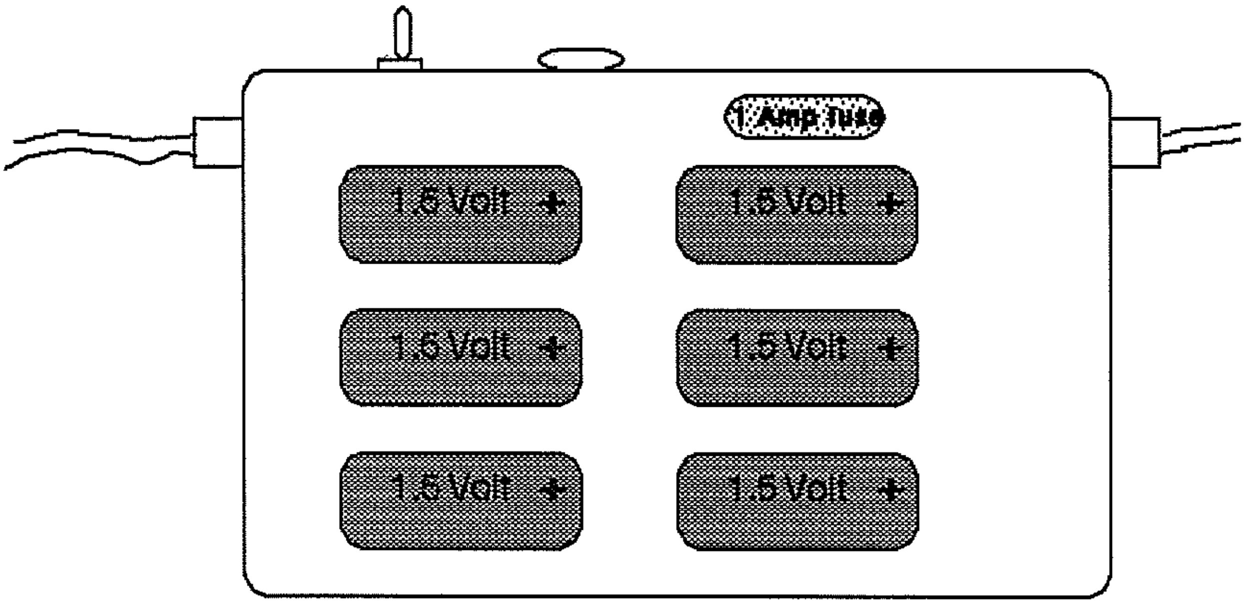
Your WADI contains six standard 1.5 V batteries of type R 20 (also called D-cells). Alkaline batteries will operate the WADI for about 50 hours, and dry batteries for about 25 hours. These times are shorter at low temperatures (it's a good idea to wear a heavy coat outside the belt in winter). If you expect to carry out extensive measurements in cold climate, we recommend the use of rechargeable NiCd batteries. To be on the safe side, charge these batteries every night. After completing a day's work, always turn off the MASTER ON/OFF switch to save the batteries.

WARNING!
If the instrument is to remain idle for a long period, you must remove the batteries. Leaking batteries can seriously damage electronic circuits. Observe that the leaking acid is very hazardous, avoid contact with skin and eyes!

Only recharge batteries of NiCd type. If you try to recharge other types of batteries there is a great risk for explosion!

4.2 Replacing the batteries

Open the battery compartment using a screwdriver. Insert the batteries in their holders in the directions indicated by the marks on the holders. Screw the cover firmly in place. Dispose of used batteries properly.

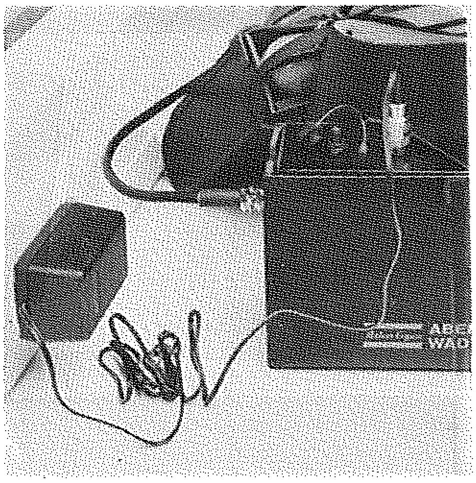


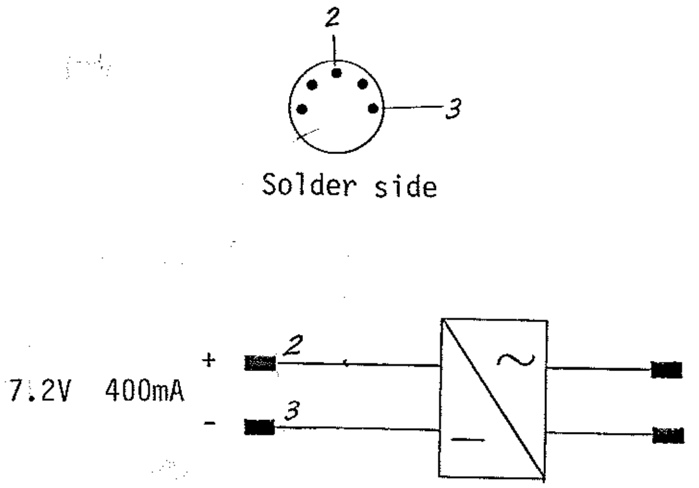
4.3 Fuses

A 1 Amp fuse is mounted in a holder inside the battery compartment. To replace this fuse, pull out the old fuse and insert a new one.

4.4 Charging the batteries

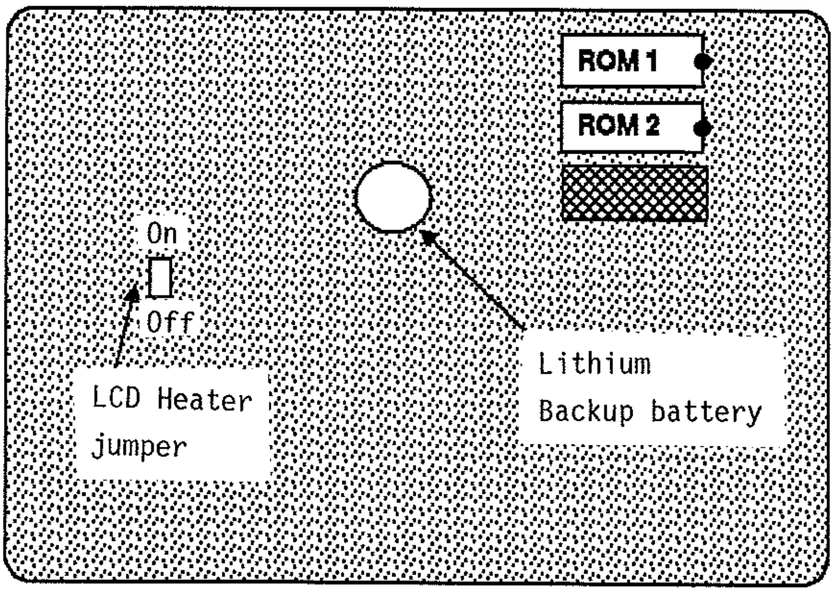
Rechargeable NiCd batteries (extra accessory) can be charged via the printer/computer connector, which is located in the battery compartment. Connect the battery charger as shown in the illustration. Charge the batteries overnight. Do never try to recharge non-rechargeable batteries! In the figure below is shown which of the pins in the contact that are used for recharging.





4.5 Replacing the ROM (contains the program)

You may wish to replace the ROM (Read Only Memory) if, for example, you want to change to a different non-English language. Open the controller unit by removing the four screws in the corners, and then carefully remove the two ROM packages in the upper right-hand corner from their sockets using a screwdriver. Then insert the new ROM 1 in socket No. 1 and the new ROM 2 in socket No. 2. Be very careful to check that none of the leads are bent and that all of the leads enter the proper holes in the socket. Be sure that the small notch on the ROM chip are oriented to the same side as the small notch on the socket.



4.6 Replacing the lithium battery

The lithium battery in the controller unit keeps the WADI memory energized when the regular batteries are removed or become low. This lithium battery will last for several years of normal use. Open the controller unit, replace the battery making certain to turn it the right way and then screw the controller unit firmly together again.

4.7 Screen heater

The screen, which is an LCD (Liquid Crystal Display) does not function well at low temperatures. A heater has thus been built into the WADI. This heater turns on automatically when the temperature drops below the freezing point. You can disconnect this heater by moving a jumper (see illustration above) inside the controller unit.

4.8 High temperatures

In areas with high solar radiation the WADI LCD display can become dark and difficult to read. This is due to heat absorption. Try to avoid long time exposure of the display in direct sun light.

4.9 Cleaning

Keep your WADI clean. Wipe it off with a soft, dry cloth or a cloth moistened with a mild detergent. Never use benzine, alcohol or any chemical cleaning agent.

5 SCREEN WARNINGS AND MESSAGES

The WADI will display its operation in a number of ways. If something unusual happens, an error message or warning appears on the screen.

Message	Action
VLF frequency out of range.	Select a frequency within the range 15 to 30 kHz.
No VLF station found.	Repeat the scanning with the antenna in a different direction.
Inclination too high.	Adjust the tilt of the antenna unit.
Invalid coordinate.	You have probably specified the same directions (East-West for example) for lines as well as points. Check and then correct your mistake.
Printer not ready.	Printer not turned on or not ON-LINE. See Appendix B.
Data memory full.	Remove one measurement line from the memory or clear the entire memory if your results are already printed or saved.
No data in profile (i.e. measurement line)	Normally not an error, you are simply being told to start a new measuring line. If you try to print a profile without data you will get this message also.
Voltage error: -10 V.	Replace the batteries. If this error persists, contact your supplier for advice.
Voltage error: + 5 V.	Same as above.
Voltage error: +10 V.	Same as above.
Voltage error: battery.	Same as above. If NiCd batteries are being used in your WADI, they must be charged.
A/D converter error.	Contact your supplier.
Bad tuning.	Try to tune again by selecting a frequency as described in 2.3. If you get this message frequently contact your supplier.

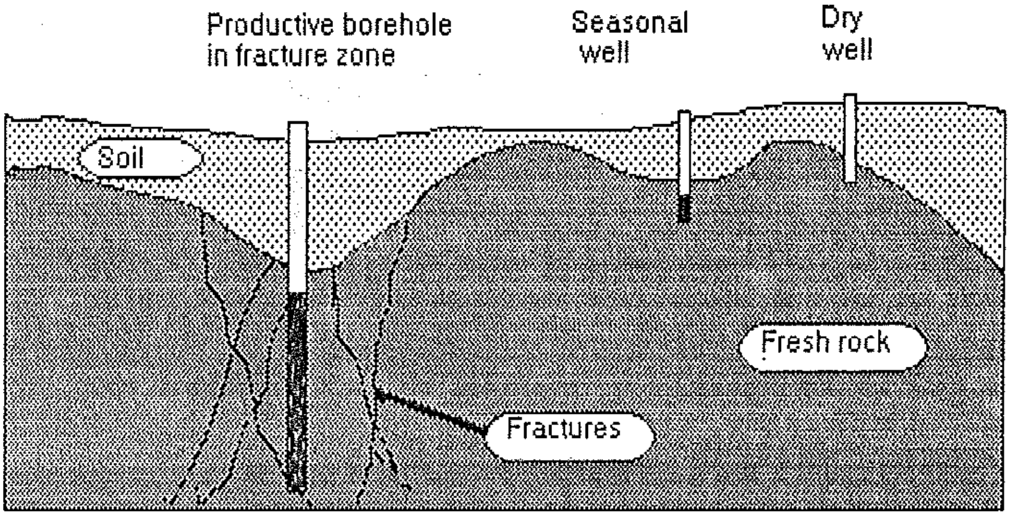
High noise level.	Try again. If the fault persists, skip the point in question and try the next point. If the fault still persists, you should change to another transmitter.
VLF signal too low.	Change to another transmitter.
VLF signal too high.	Change to another transmitter.

APPENDIX A
VLF MEASUREMENT THEORY

Contents:

A1 General background

Good drinking water can be obtained from fracture zones in hard rock. But drilling without previous site investigation seldom yields water in usable quantities. Effective water development programmes must include carefully conducted geophysical and geological investigations.



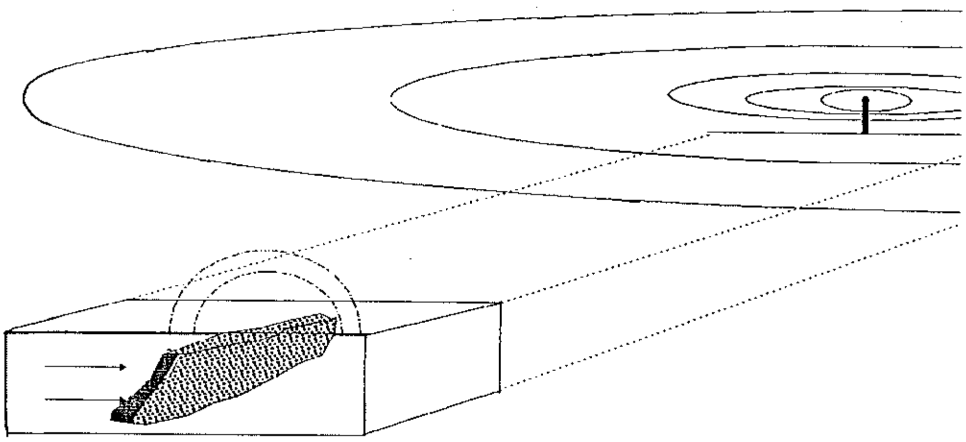
Highly productive water wells are obtained by drilling in rock that is broken along joints and small fractures. The WADI finds structures where useful quantities of underground water may be trapped in rock fractures and cavities, thus enabling drillers to select the most promising sites for their wells.

The WADI is a state-of-the-art geophysical instrument designed for easy use. WADI's results are convincingly consistent. The same results are obtained no matter who uses the instrument. A built-in program makes it possible to interpret measurements immediately, right on the site. However, like other geophysical instruments, the WADI simply finds physical structures in the ground and bedrock. The WADI cannot guarantee that these contain water. Nonetheless, the VLF principle on which the WADI is based has an excellent track record when it comes to finding useful quantities of water in hard rock.

This User's Manual deals primarily with water prospecting. However, you should remember that the WADI can also be used to search for ore-bodies and for other subsurface electrically conductive structures.

A2 VLF principles

The WADI utilizes the magnetic components of the electromagnetic field generated by military radio transmitters that use the VLF frequency band (Very Low Frequency, 15-30 kHz). They are used mostly for long-distance communication. A VLF antenna is typically made up by a long vertical cable - often with a length of several hundred of metres - feeded with a strong signal. The power is typically 300-1000 kWatt. The magnetic field lines from such a transmitter is horizontal, with the "field lines" aligned in concentric circles around the antenna, as illustrated below:



Such VLF transmitters are operating in a number of countries. Some of the most useful VLF transmitting stations are tabulated below:

Location	Designation	Frequency (kHz)	Power (kW)
Bordeaux, France	FUO	15.1	500
Rugby, Great Britain	GBR	16.0	750
Helgeland, Norway	JXN	16.4	350
Gorki, USSR	ROR	17.0	315
Moscow, USSR	UMS	17.1	1000
Yosamai, Japan	NDT	17.4	500
Oxford, Great Britain	GBZ	19.6	550
Annapolis, USA	NSS	21.4	400
Northwest Cape, Australia	NWC	22.3	1000
Hauderfehn, V. Germany	DMB	23.4	
Laulualei, Hawaii, USA	NPM	23.4	600
Buenos Aires, Argentina	LPZ	23.6	
Cutler, Maine, USA	NAA	24.0	1000
Seattle, USA	NLK	24.8	125
Aguada, Puerto Rico	NAU	28.5	100

At some places on the earth you may find "local" transmitters which are more convenient to use.

Electrically conductive structures on the surface or underground, even when covered with thick overburden, affect locally the direction and strength of the field generated by the transmitted radio signal. A weak secondary field builds up around the geological structure. This field can be measured and analysed. The WADI measures the field strength and phase displacement around a fracture zone in the rock. In order for induction to occur, the structure must be aligned (roughly) towards the transmitter. In most countries, the WADI can "hear" a number of transmitters, and it is designed to select automatically the one that is most suitable.

A3 Limitations and sources of errors

There are certain cases where the VLF method cannot be expected to work well. Examples include areas having horizontal layers of soil and rock and very few fracture systems (often encountered in young sedimentary rock). Moreover, if the top soil is electrically conductive (salty soils and clay beds for example), it will be difficult to obtain information about structures in the underlying rock.

In the case of water prospecting in areas with horizontal layers and a horizontal aquifer, the most useful geophysical method is the Vertical Electrical Sounding method (VES)[1].

It should be noted, however, that certain structures which do not contain water may be good electrical conductors, and therefore be detectable by the WADI. Examples are ore-bodies and as well underground as overhead electrical cables. As a result, it is often impossible to obtain good results in urbanized areas. Under certain conditions, however, the WADI can be used to find underground pipes and cables.

The VLF method has been used for many years to search for ore. If so desired, the WADI can be told to display the real and imaginary components in the same way as conventional VLF instruments. This is described in greater detail in Appendix D.

A4 Planning ahead

To ensure best results, you must plan your measurement strategy well in advance. Before starting, think through the following questions and decide how you wish to answer them.

- Where do I intend to take measurements?
- In which parts of the site can disturbances be encountered?
- Which measurement direction shall I select?
- What is the most suitable between-point distance?

---

[1] The ABEM SAS 300B Terrameter together with the sophisticated computer program SUPER-VES provides you an effective and very robust tool for water prospecting in this case.

Useful tips on planning a suitable strategy:

1 Study all old measurement results that are available.

2 Concentrate your measurements in areas where vegetation is thickest. Select preferably areas with topographical structures such as long ridges or valleys. It is better to work in low-lying terrain than on high plateaus.

Your measurement lines should be oriented at right angles to the terrain structures (brook, creek, river, fault etc.). If there is no clear evidence of how these structures are arranged, you may find that aerial photographs, topographical maps and satellite pictures are helpful. If these are not available, you can conduct trial surveys in different directions.

In the worst case, it may be necessary to conduct measurements in two passes: one in an East-West direction and then one in a North-South direction for example.

The between-point distance should be based on the estimated depth to the top of the structures being sought. For water prospecting, it is often advisable to use a between-point distance of 10 metres or 5 metres.

A5 Measuring in a coordinate system

The WADI is well suited for measurements in a grid system. It provides each measured value with a line coordinate and point coordinate. This is particularly advantageous if you measure at constant intervals along a line and provide a constant between-line distance.

The WADI permits you to add new measurement points between the old ones in areas of particular interest - a very valuable feature.

For large site investigations, it is often advisable to commence by staking out the grid on site. (In areas where there are few obstructions, it may suffice to stake out the beginnings and ends of the measurement lines). Move from point to point using a compass and measuring tape.

A typical coordinate system can be arranged as shown in the following illustration. Every point has a unique coordinate, e.g. the point A has the coordinates 0E/0025N.

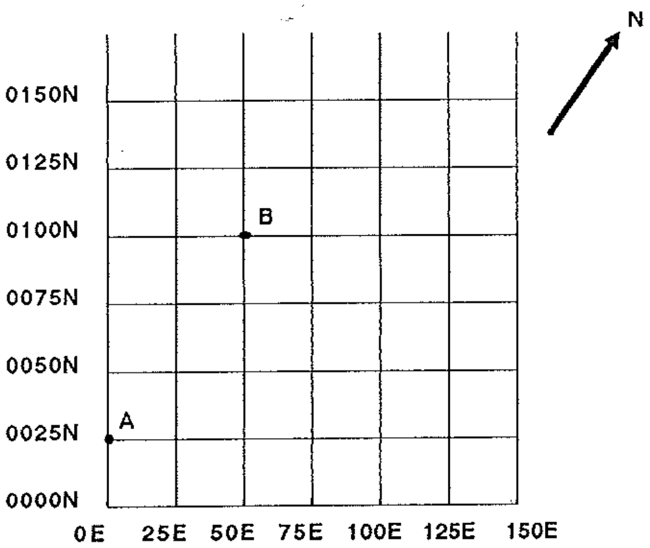
As another example, suppose your intention is to start a WADI survey at point B in southerly direction, taking measurements every 5 metres and then continue with the next line to the East.

Then the following starting coordinates should be entered:

0050 ⇨ / 0100 ⇧ indicates the point at which you start.

025 ⇨ indicates the between-line distance and the direction to the next line (East).

005 ⇩ indicates the between-point distance and the direction in which you will move along the line (South).



In the next example a visible strike direction is observed (in the vegetation or in the topography). The strike direction is approximately in the East-West direction, and you plan to make some WADI profiles perpendicular to the interesting area.

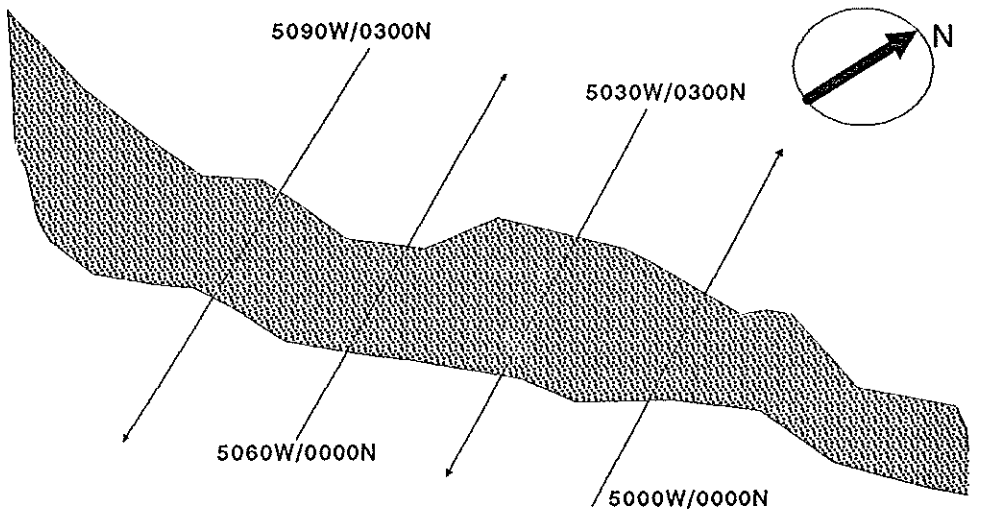
In this case you can e.g. name the profiles 5000W, 5030W etc., because you want a 30 meter spacing between the lines. The starting point is called 5000W/0000N. If you want to measure with a point distance of 10 meter you should enter the following coordinates into the WADI:

5000⇦/ 0000⇧ Indicates the starting point

030⇦ Indicates the profile seperation, and the direction to the next line.

010⇧ Indicates the between-point distance along the profile, and the direction in which you will move.

To turn over from profile 5000W to 5030W (which goes in the opposite direction), you simply press F :: at the end of profile 5000W.



A6 Physical principles of VLF

When the electromagnetic field from a VLF transmitter passes trough a conductive body, secondary currents will grow up in the body. This is the principle of induction. These secondary currents will in turn generate a magnetic field - a secondary field - which will try to repell the primary field.

Only a body with a low electrical resistivity can genereate secondary fields. In the following table is given some characteristic values for the resistivity *r* for some materials.

	r	*p*
Hard rock (granite)	> 5000 Ohm-m	> 300 m
Clay	10-100 Ohm-m	15-40 m
Dry sand	200-5000 Ohm-m	50-300 m
Wet sand	50-200 Ohm-m	30-60 m
Fresh water	50-200 Ohm-m	30-60 m
Saline water	1-10 Ohm-m	4-15 m

Besides the resistivity *r* is also given the penetration depth *p*, defined as:

$$p = 500 \cdot \sqrt{(r/f)} \quad \text{[metre]}$$

where *r* is the resistivity in Ohm-m and *f* the frequency in Hz. By inserting a typical VLF frequency of f=15.6 kHz in the above equation, we get for the penetration depth:

$$p = 4 \cdot \sqrt{r} \quad \text{[metre]}$$

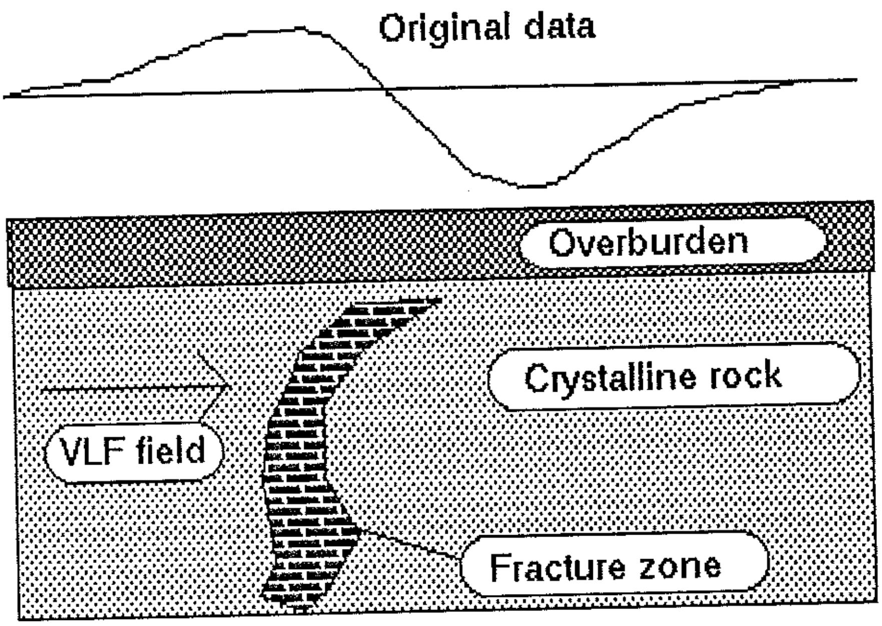
This simple equation can for all practical purposes be used over the whole VLF frequency band. When the electromagnetic wave has reached the depth *p*, it has loosed too much energy to create any induction. Therefore, *p* is the approximate depth to which we can "see" with the WADI.

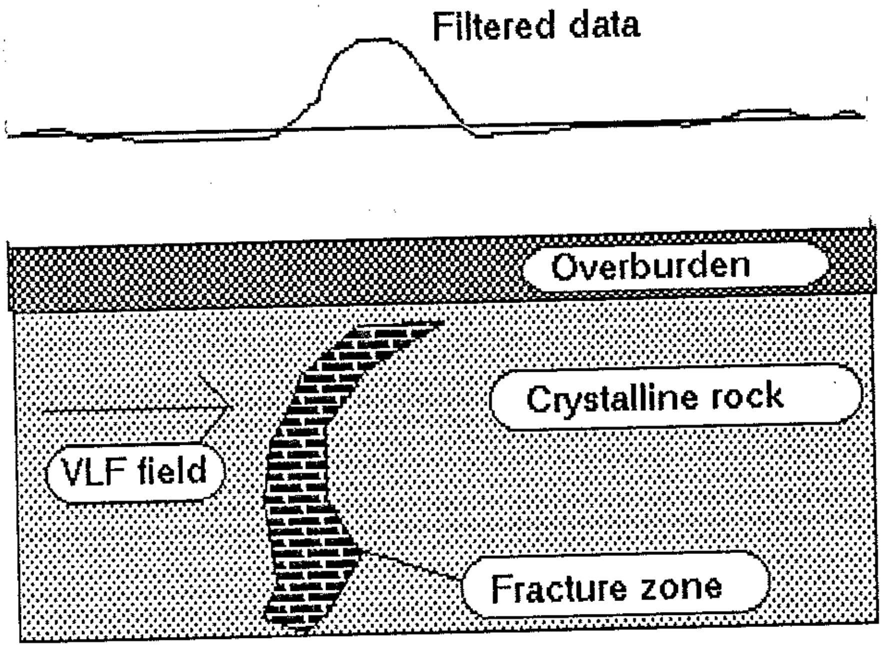
In order to create any secondary field, a body must have a minimum size and a sufficient low resistivity. Normally the strike length of the body must exceed about 50 m, and the depth extend must exceed about 10 m for induction to occur. The thickness of the body, however, need only be about 0.5-1 m. Furthermore the field from the VLF transmitter must pass perpendicular through the body, i.e. the direction to the transmitter is in the strike direction of the body.

To summarize: *the VLF method is useful for the detection of elongated, steeply dipping low-resistivity bodies.*

The WADI detects the ratio (in %) between the vertical and the horizontal components. Because the primary field from the transmitter is horizontal, the "normal" reading on the WADI will be zero. Even in the presence of horizontal lying conducting layers of e.g. clay or saline water, the reading will be zero. Only in the case of steep conductors any VLF anomaly will appear.

The deviation from the normal readings are called anomaly. For a steeply dipping conductor the typical anomaly will look like the one sketched in the following figure:





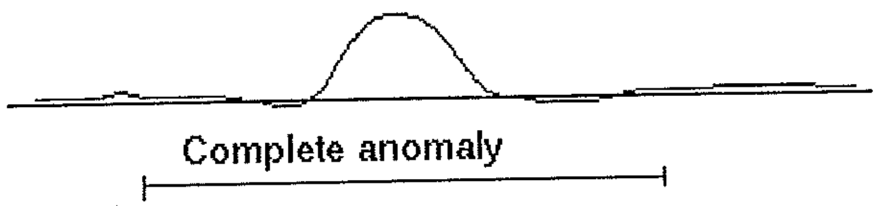
The upper figure shows the typical behaviour of an original VLF anomaly: a maximum occur to the left and a minimum to the right of the conductor. The above sketched anomaly can be imagined to be the real part, i.e. that part of the resulting field which are in phase with the primary field from the VLF transmitter. (The WADI instrument will also measure an imaginary component which are 90° out of phase with the primary field).

This way of plotting the VLF anomaly is not suitable in all cases: if a complicated geology with several conductors exist, it will often be almost impossible to distinguish between the seperate anomalies. The filtering method, as discribed in appendix D6, provides an effective tool for converting this complex kind of anomaly to a much more attractive anomaly with a single peak right above the conductor. This is demonstrated in the lower of the above figures. In this simple example we could easily locate the conducting body from the original data (upper figure), but in the real life it is often much easier to locate the interesting zones from the filtered data.

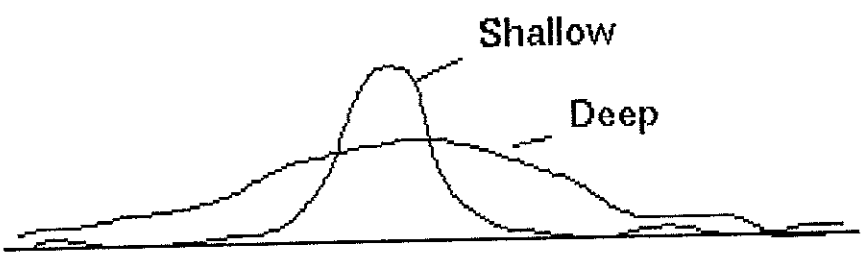
A7 Typical anomalies

The WADI instrument will always display the filtered real part by default. Therefore it is important to have some basic understanding of the behaviour of typical anomalies, in order to be able to recognize an interesting object.

First of all it is very important to make the length of the profile sufficient. It is impossible to make any reliable interpretation unless the anomaly is completely covered. What we mean by a complete anomaly is illustrated in the figure below:

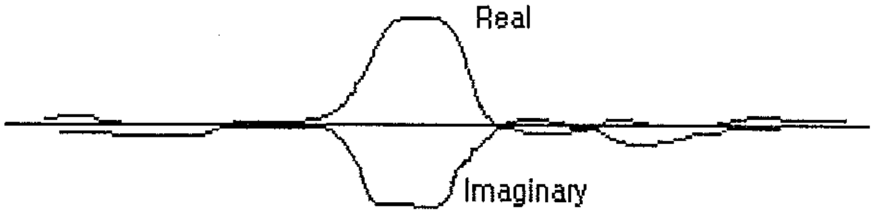


Observe how the curve goes from around zero to a clear maximum and back to zero. An anomaly is characterized by its size, i.e. height and width. In the next figure is illustrated the difference between a shallow and a deeper seated conductor:

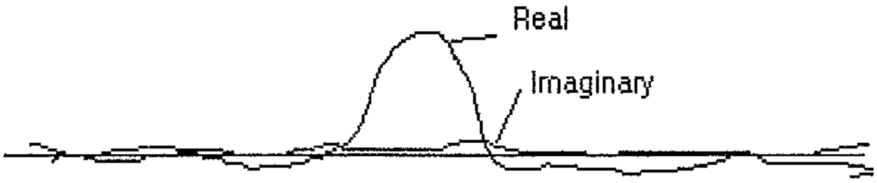


We observe that for a conductor at greater depth, the width of the anomaly will increase and the height will decrease. A small amplitude can, however, also be caused by a conductor which is not a very good conductor.

Because the WADI instrument registrates not only the filtered real part (i.e. equivalent current density), but also the imaginary part, the next two figures illustrates the information contained in the filtered imaginary part. In the case of a very good conductor (ore body or fracture zone containing saline water) the anomaly in the filtered imaginary part can be of the same size as the anomaly in the filtered real part, as illustrated below:



Even though we have shown both the filtered real and imaginary part on this plot, the WADI instrument will only display one of the components in turn. To switch between different display modes, see section D3. The next figure illustrates the behaviour above a structure with a comparatively high resistivity, e.g. a water filled fracture zone. In this case the amplitude of the imaginary part is typically much smaller than that of the real part.



Genarally speaking an anomaly in the imaginary part is much more difficult to interpret than in the real part. Therefore all interpretation should be based on the filtered real part (as shown by default by the WADI). The filtered real part will *always* show a positive peak above a conductor, while the imaginary part can show as well a positive as a negative peak, depending on the conditions of the overburden layer. The imaginary part is of some value when making the final decisions above the quality of the conductor.

A8 Hints for interpretation

For a general description of the VLF method it is adviseable to refer to the geophysical litterature, e.g. "Principles of Applied Geophysics"[2]. Here we will only give some hints useful in VLF interpretation.

a) Collect data of high quality. Even with the best instrumentation and the best software, the quality of the final interpretation will depend on the original data.

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[2] D. S. Parasnis, Principles of Applied Geophysics, Fourth edition, Chapman and Hall, London.

<u>Typical operational errors are:</u>

* Undersampling, which means that the operator has chosen to measure with a point distance which is too large to resemble the anomalies from shallow conductors. Normally a point distance of 10 metres will be suitable, but in the case of shallow conductors (5 metres or less) use 5 metre.

* Misorientation, which means that the operator has changed the measuring direction along the profile. Use a compass if you have problems in keeping the direction.

* Too short profiles. Normally the length of a profile should be at least 200 metres to resemble a complete anomaly. Furthermore you should always measure at least 50 metres (preferably 100 metre) on both sides of an interesting anomaly. In case of doubt take some more measurements.

* Anomalies are not completely covered. Remember to continue measuring until the interesting anomaly (peak) is completely described, see the illustration. An anomaly is complete if the readings starts at zero, shows a clear positive peak and then decreases to zero again.

* A VLF transmitter in a very bad direction has been used. Please remember to check that you have maximum signal strength in the profile direction, and minimum strength perpendicular to the profile. The tolerance is about $\pm 20^\circ$ from this ideal direction.

* Always remember that a profile direction almost perpendicular to the conductor strike will give the best results. If you do not know anything about the geological strike, measure along profiles in two perpendicular directions.

* Mismatch with the coordinates, making it impossible to make a correlation between parallel profiles. Please note that the coordinates used in WADI are relative, i.e. "N" need not be true magnetic north, but can be any other direction as e.g. 70° West. Furthermore you should remember the coordinate convention: a North-South striking profile must have the extension "E" or "W" (⇨ or ⇦ on the WADI), and the measuring points along this profile must have the extension "N" or "S" (⇧ or ⇩ on the WADI).

b) Base your decisions mainly on the filtered real part (i.e. current density). If you are looking for water, you should go for large positive anomalies in the filtered real-part curve.

c) Water filled fracture zones are characterized electrically as moderately good conductors. The corresponding VLF anomaly, as e.g. the filtered curve displayed on the on the WADI, will normally show a significant maximum in the filtered real part and only a very small anomaly in the imaginary part.

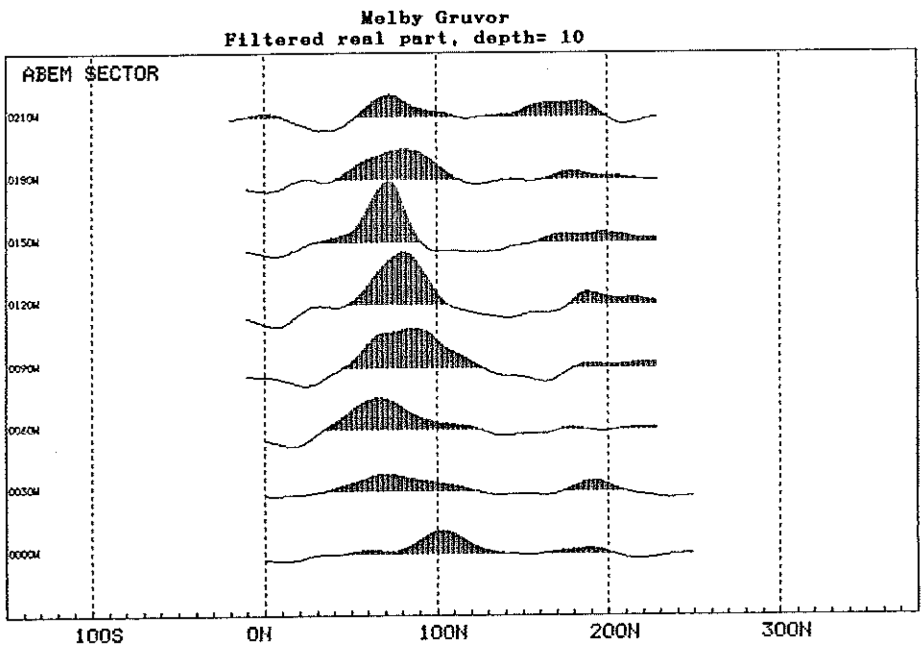
Very good conductors, as e.g. mineralizations or fracture zones with saline water, will in general show very large anomalies in as well the real as the imaginary part.

d) Before making any decisions you should check the data quality. Be aware that an anomaly in the original data manifest itself by a nonsymmetrical (almost antisymmetrical) curve, with a maximum to the left and a minimum to the right of the conductor. The filtered curve, on the contrary, will show a maximum right above the conductor. The WADI will automatically show the filtered real part, but can even display the other components (see D3).

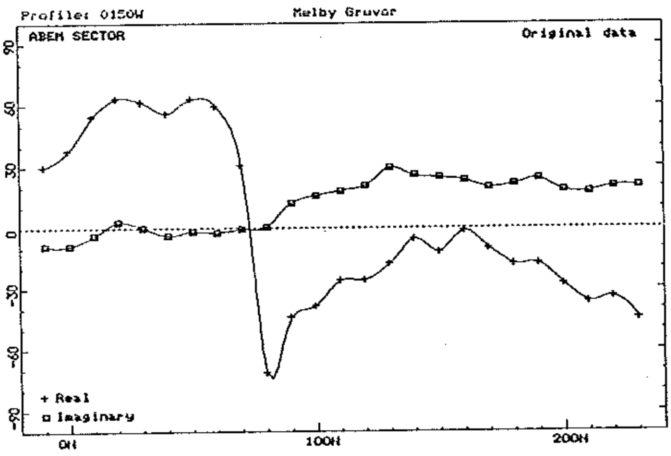
e) The computer program SECTOR from ABEM will provide you with valuable help in the interpretation.

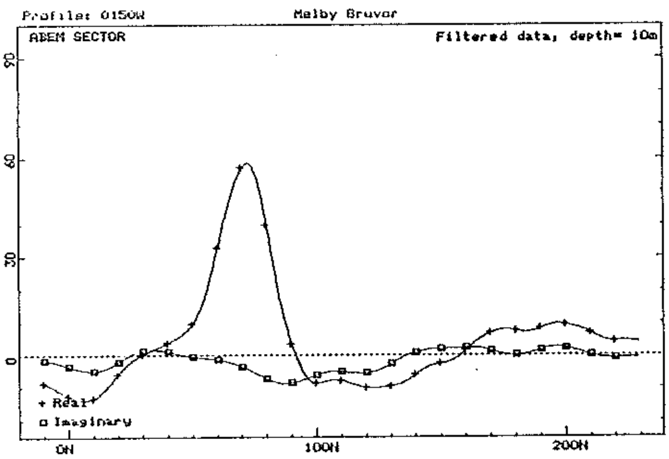
A9 Field example

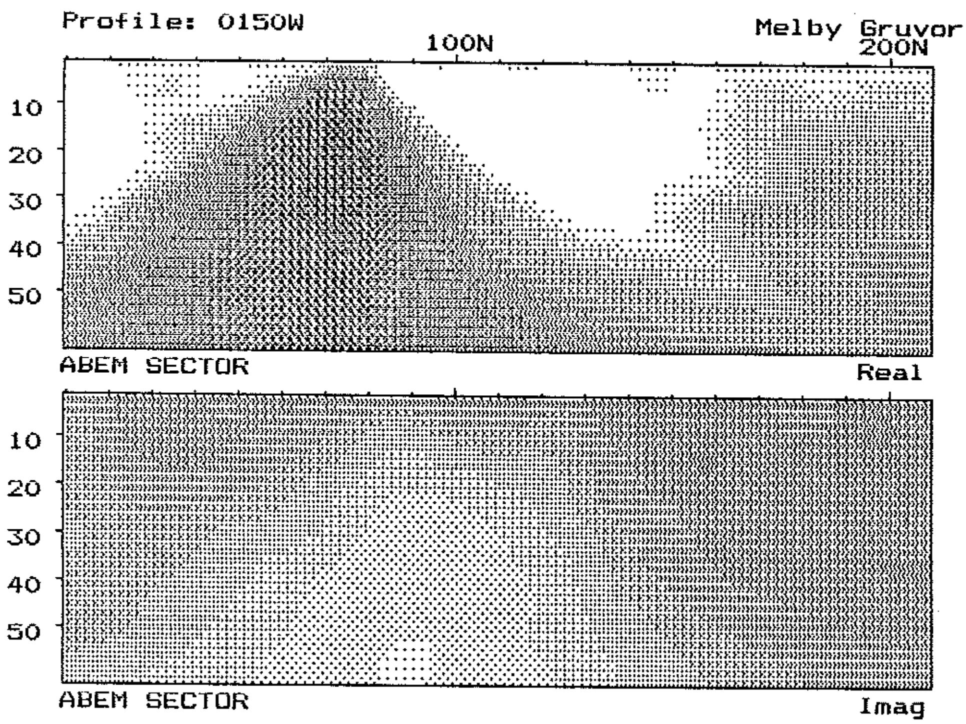
On the island of Väddö in the Stockholm peninsula eight parallel profiles crossing a known fracture zone has been measured with the WADI. All the profiles together are shown on the "Multi profile plot" below. On all the profiles a clear indication (positive peek) of the conducting body is seen around coordinate 80N-100N. Furthermore a very small anomaly is observed around coordinate 200N.



As an example we will take a close look at profile 150W. In the four figures on the next page the original data (upper figure) is presented together with the filtered data (middle figure) and the vertical cross section (lower two figures). The fracture zone is easily identified on the real part filtered curve. In the imaginary part almost no anomaly att all is visible. A very plausible explanation is that the resistivity in the fracture zone is quite large. If the zone had been filled with saline water, the anomaly in the imaginary part would have been much larger.


Profile: 0150W
Melby Gruvor
ABEM SECTOR
Original data
90
60
30
0
-30
-60
-90
+ Real
□ Imaginary
0N
100N
200N


Profile: 0150W
Melby Gruvor
ABEM SECTOR
Filtered data, depth= 10m
90
60
30
0
+ Real
□ Imaginary
0N
100N
200N


Profile: 0150W
100N
Melby Gruvor
200N
10
20
30
40
50
ABEM SECTOR
Real
10
20
30
40
50
ABEM SECTOR
Imag

The lower two figures on the previous page shows a vertical cross section from the actual profile. This section is calculated by running the filtering process at successively increasing depth, and representing the calculated value (i.e. equivalent current density) by a grey shading. From this plot we conclude that the zone is quite shallow and slightly dipping towards South. It appears to be easy to set a drill hole based on this representation.

The plots presented in this section are produced by the SECTOR program running on a PC with a dot matrix printer.

APPENDIX B
OUTPUT TO PRINTER AND COMPUTER

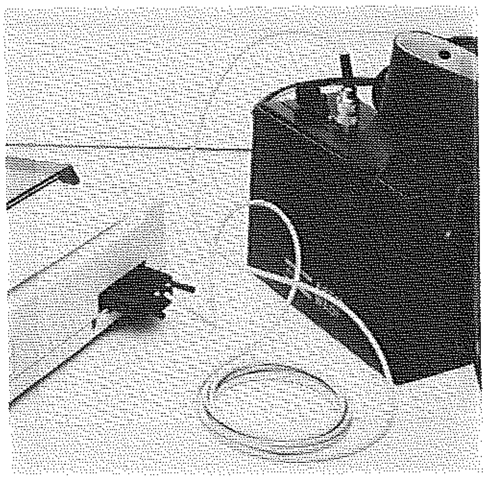
Contents:

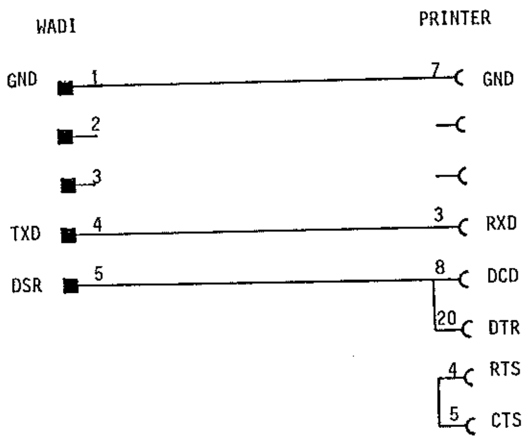
B1 Selecting and installing a printer

The WADI can be connected to an serial-interface PC-compatible dot matrix printer via a special cable (extra accessory). The serial interface must be set for:

- Baud rate 9600
- Word length 8 bits
- Parity None
- Stop bit 1

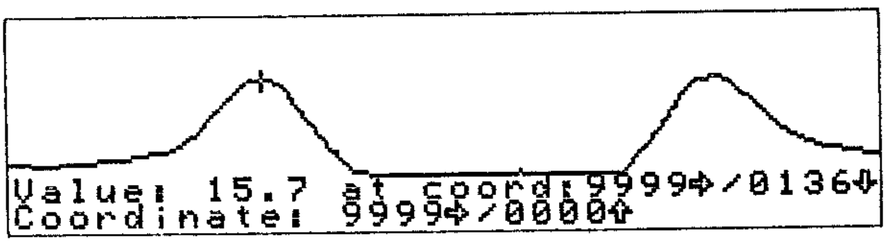
The printer must be ON-LINE.
A photography of the connection is shown in the figure below, together with a sketch of the printer cable.





B2 Printing the screen content

After connecting the printer, you can print out the content of the screen by pressing F and then 0 (zero). A sample printout is shown below.



B3 Printing a measurement line curve (profile)

First, select the line (profile) that is to be printed. Press the COORDINATE key :: twice to get a directory listing. Then enter the line coordinate.

Now specify the type of curve that is to be plotted:

F ⇨ 0 provides the normal curve, i.e. current density.

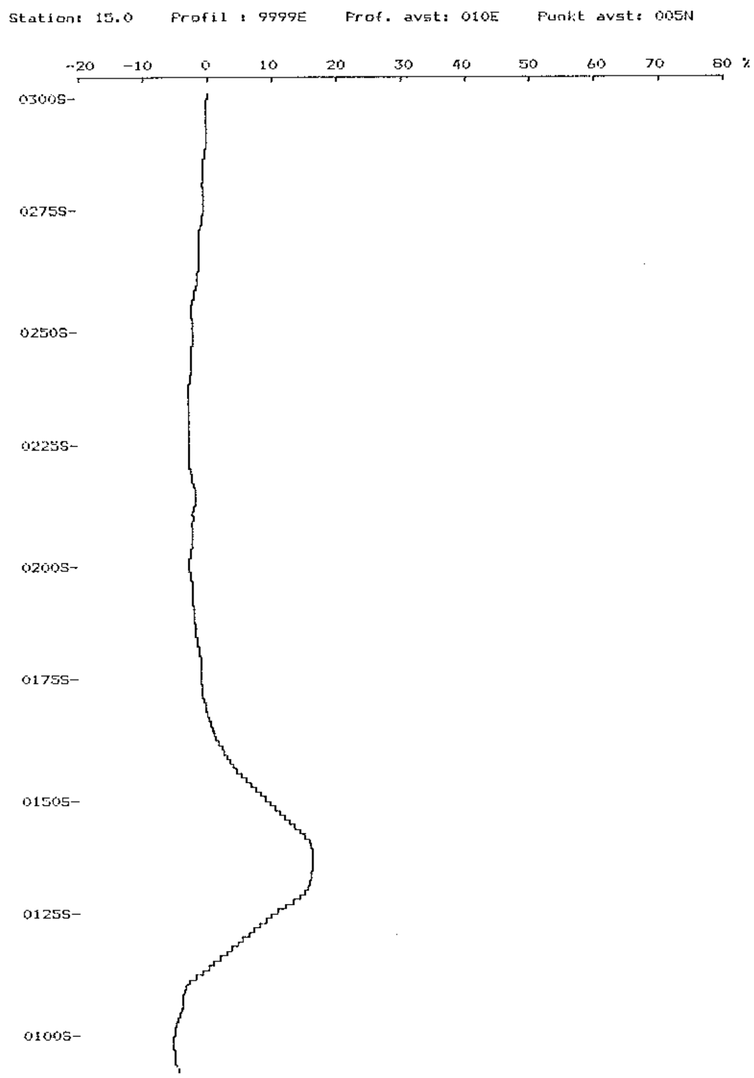
F ⇨ 1 provides the original real part (tilt angle).

F ⇨ 2 provides the filtered imaginary component.

F ⇨ 3 provides the original imaginary part (ellipticity).

The last three are described in greater detail in Appendix D.

Finally, press F followed by 1 (F1). The printer will now plot the curve as shown in the illustration below.



B4 Printing numeric data or transmitting to a computer

Numeric data can be transmitted by pressing F and then **2** (F2). If you are transmitting to a computer, its serial interface must be set in the same way as the printer interface (see section B1 above). Data is transmitted in the following formats:

Line coordinate	5 ASCII characters + <LF><CR> Example: "0130E<LF><CR>"
Frequency in kHz[3]	5 ASCII characters + <LF><CR> Example: "Q15.3<LF><CR>"
Type of curve	4 ASCII characters + <LF><CR> i.e. any of: "____<LF><CR>" or "__Re<LF><CR>" or "F_Im<LF><CR>" or "__Im<LF><CR>"
Point coordinate, value . .	5 ASCII char + <,> + 6 ASCII char + <LF><CR> Example: "0295S,-01.4M<LF><CR>" M means measured, a space instead means interpolated

(This item is repeated, once for each coordinate of the profile)

End of data	3 ASCII characters + <LF><CR><SUB>) i.e. "END<LF><CR><SUB>"

The special characters mentioned above are:

<LF> Line feed, ASCII code 10
<CR> Carriage return, ASCII code 13
<SUB> Also called Control-Z or End-of-File (EOF), ASCII code 26
_ Indicates space, ASCII code 32

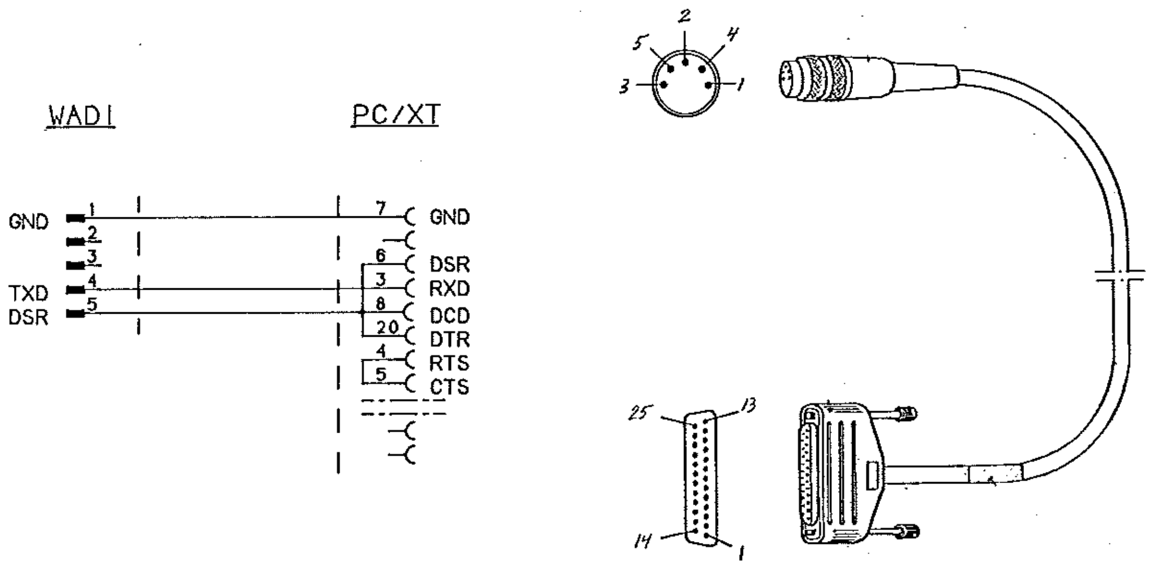
<u>Example</u>:

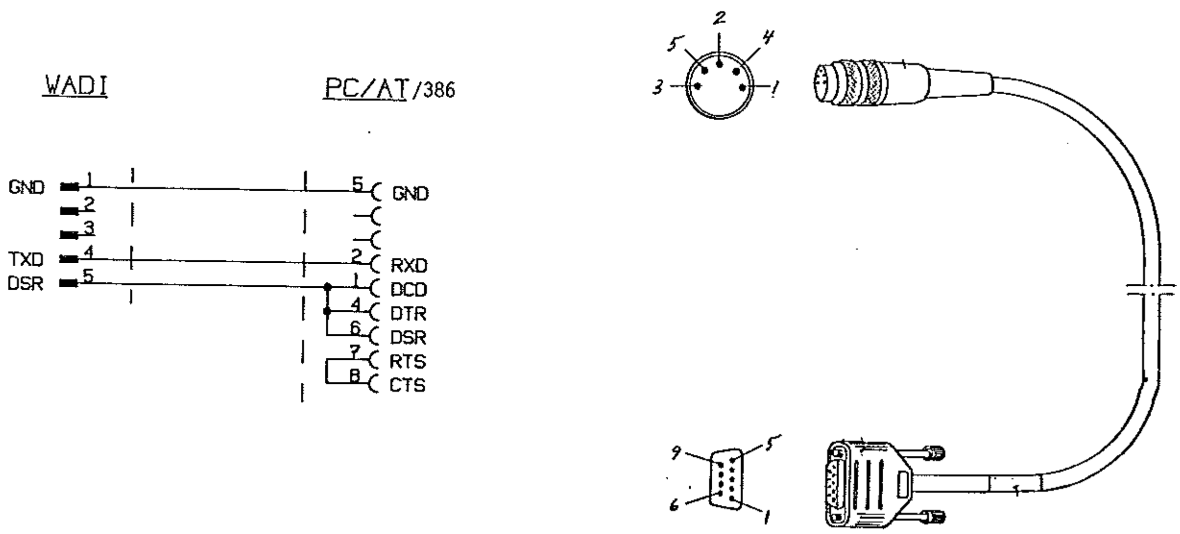
```
9999E              (Line number)
Q23.4              (Frequency 23.4 kHz)
  Re               (Real part data)
0300S, 00.0M       (Point coordinate, value)
0299S, 00.2        (M means measured, othervise interpolated)
0298S, 00.8
0297S, 01.3
0296S, 01.4M
  .
  .
0270S,-01.5M
0269S,-01.4
0268S,-01.2
0267S,-00.9
0266S,-00.8
0265S,-00.8M
END                (End of file)
```

---

[3] Observe that the character "Q" preceeds the frequency. On WADI's delivered before december 1988 this line is *not* included.

For convenience we supply the wiring diagram for the computer connection cables. Observe that different cables are needed for connecting a WADI to a printer, a PC/XT and a PC/AT. These cables are supplied optionally by ABEM.





APPENDIX C
BUILT-IN COMMANDS

Contents:

Since many WADI functions can be evoked by pressing a number of keys in sequence, our designers were able to limit the number of control keys.

The most commonly encountered commands are explained below:

C1 ⓘ ON/OFF

When you press this key briefly, the WADI starts. If a situation arises in which you wish to cancel the function you are working with, you can restart the WADI by holding down this key for 2 seconds.

If the WADI does not start, the following may have occurred:

- MASTER ON/OFF switch is turned off.
- Battery voltage is too low.
- Fuse has blown.

Section 4.2 and 4.3 explain how to replace the batteries and the fuse.

If the WADI is left on for more than five minutes without being used, the power turns off automatically.

C2 ? HELP MENU

When you press and then press one or two other keys, information about the function normally provided by the one or two other keys appears.

C3 F → SERVICE MENU

You can move the cursor up and down on the service menu by pressing the and keys.

After selecting the desired function, press 1 to execute it.
If you enter the calibration routine for the inclinometer by mistake, you can exit from it by pressing the COORDINATE key (::). *Read section 2.6 before choosing this command!*

C4 STATION

After pressing this key you can enter a specific frequency if you wish to use a particular transmitter. Then press a second time to determine the signal strength. You can also invoke automatic scanning by entering 0.00 kHz.

The ⇨ and ⇦ keys are used to change the frequency by moving the dotted-line cursor after the WADI has scanned automatically.

C5 :: COORDINATE

Pressing this key brings up the coordinate menu. The coordinates (between-line distance and between-point distance) can then be entered. While this menu is shown, you can press to advance to the next point without any measurement having been entered. This is useful when one or more points along a line are inaccessible (under water or on a steep hill for example).

C6 F :: CHANGING TO A NEW LINE

Pressing these keys changes the line coordinate to the next line and reverses the measurement direction (through 180°). The measurement point coordinate is not changed.

C7 :: :: CHECKING MEMORY CONTENT

When the COORDINATE key :: is pressed twice, the measurement lines that have been stored in the memory are presented. Measurement line (profile) 9999 is entered prior to delivery, and it can be displayed on the screen after selecting the "Memory test" option on the service menu.

C8 > MEASURE

The first time you press this key, the profile measurement line specified in the line coordinate field appears. If the measurement line curve (profile) is longer than the screen, only one part can be viewed at a time. You can scroll the display to the left or right by pressing the ⇨ and ⇦ keys in order to view other parts of the curve.

When you press the MEASURE key (>) a second time, measurement is executed.

C9 :: □ SKIPPING A MEASURING POINT

If you for some reason want to skip the next measuring point, simply press :: followed by □ .

C10 INTERPRET

When you press this key, a simple interpretation of the depth and dip of the anomaly that has been found appears, if you have placed the graphical cursor on the anomaly's highest point. To move the cursor, press → or ← .

C11 □ DELETE

When you press this key immediately after having taken a measurement, the measured value in question is deleted. The entire measurement line is deleted if you press **F** and then □ and then 7.

The entire memory is cleared (deleted) if you press **F** and then □ and then 9.

When using the DELETE key □ , be very careful not to delete anything by mistake.

C12 F ⇧ or F ⇩ SCREEN BRIGHTNESS

To make the screen more bright, press **F** and then ⇧ .

To make the screen darker, press **F** and then ⇩ .

APPENDIX D
COMMANDS INTENDED FOR VLF SPECIALISTS

Contents:

D1 Measured components

The WADI measures both the vertical and horizontal components of the magnetic VLF field. By normalizing the vertical component by the horizontal component we get the ratio of vertical to horizontal field. This ratio is generally a complex number, because the secondary field from a subsurface conductor is generally not in phase with the primary field. The real part of the ratio corresponds to the tilt angle of the resultant field (strictly speaking, the tilt of the polarization ellipse formed by the primary and the secondary field). The imaginary part corresponds to the ellipticity, i.e. the ratio of minor to major axis of the polarization ellipse. Both the real and the imaginary components are measured. Before the data is stored, the measured values are corrected for minor antenna tilt errors. Note, that sometimes the real part is named "in phase" and the imaginary part "quadrature".

D2 Automatic sign changing

In conventional VLF measurement systems, it is usually necessary to know the direction of measurement before interpreting the results. In the WADI, the sign is changed automatically when you change to a reverse measuring direction on a new line (F ⁘). As a result, all parallel measurement lines can be compared directly.

D3 Changing the display mode

Normally, the WADI displays measured data as equivalent current densities calculated from the in-phase measurements. Raw data is always stored in the memory, thus making it possible to plot the data in any of the forms:

Command	Data	Code
F ⇨ 0	Filtered tilt angle (current density)	No code
F ⇨ 1	Raw real part data (in-phase)	Re
F ⇨ 2	Filtered imaginary data	F Im
F ⇨ 3	Raw imaginary data (out-of-phase)	Im

The code is displayed in the lower right-hand corner of the screen. When the WADI is turned off, the display returns to its normal mode. The command selected here remains in effect when you print out data and when you transmit numeric values to a computer. Notice that you can change the display mode any time during a measurement.

The imaginary component often provides an indication of the conductivity of the structure that has been found. For water filled fracture zones the imaginary part is normally much smaller than the real part, whereas it can become of the same magnitude as the real part when measuring across e.g. ore-bodies.

D4 Calculating field strength

The code indicating the signal strength (see section 2.3) have a certain relationship to the absolute field strength measured in Amps per metre. Code 45 corresponds approximately to a field strength of 10^{-4} A/m. Each step corresponds to 1.5 dB. A four-step increase in the code thus means that the field strength is doubled. As an example, code 29 means that the field strength is 6.25 10^{-6} A/m.

D5 Changing the filter

In the formula for calculating the equivalent current density (see below) the result depends on the between-point distance. You can change the filtering by changing the between-point distance (press and then enter the new distance in the correct field) and then recalling the curve to the screen. These calculations give a picture of how the structure varies with depth. Do not forget to reset the between-point distance before continuing your measurements.

D6 Calculating current density

Traditionally the interpretation of VLF measurements have been based directly on the real and imaginary curves (also called tilt angle and ellipticity). Since these curves can be very difficult to interpret (because of antisymmetrical behaviour, topographic effects and certain other factors), different types of filtering techniques have been used to extract interesting information. The WADI uses a filter designed by Karous and Hjelt[4] to clarify the data. The output from this filter is an equivalent current density at a certain "depth" in the ground. The current density is calculated as follows:

$$I(0) = K\,(-0.102\,H_{-3} + 0.059\,H_{-2} - 0.561\,H_{-1} + 0.561\,H_{1} - 0.059\,H_{2} + 0.102\,H_{3})$$

K is a constant that depends on the between-point distance (dx).

H_i is the i'th measurement point behind (-) or in front of (+) the point where the calculation is performed. The error introduced by the filter is claimed to be less than 8% for the inversion of a single current line.

The filter can be used separately to obtain in-phase (real) and

[4] Linear filtering of VLF dip-angle measurements, in Geophysical Prospecting 31, 1983, page 782-794.

quadrature (imaginary) components of the anomalies, thus providing corresponding components of the current density. By applying the filter for different between-point intervals (dx, 2dx, 3dx etc.), one can study the way that current densities vary with depth, thus obtaining a depth section of the profile.

GLOSSARY

ABEM — "Aktiebolaget Elektrisk Malmletning", one of the earliest producers of geophysical instruments in the world. ABEM was founded in 1923, and was controlled by the Atlas Copco group a during a long period until 1988 when SGAB, the Swedish Geological Co, took over.

Anomaly — A characteristic behavior in data measured along a profile. It is often an indication on some interesting geological object, e.g. a fracture zone. Please observe that the word 'anomaly' means 'something which is not normal'. A normal VLF and WADI profile (i.e. when no conductive zones are present) will show nothing, i.e. zero.

Filtering — A numerical method by which one can extract only a certain part of the information contained in data, and leave out the remaining. With the WADI filtering we can extract an equivalent current density at a specified depth with a simple mathematical operation.

Geophysics — A scientific discipline, situated somewhere between physics, geology and mathematics.

Resistivity — Characterizes the electrical resistance of a material. The dimension is Ohm-metre.

Fracture zone — Due to stress in the earth crust, small fractures (sometimes even large!) will often arise in crystalline rock. The most interesting zones for water prospecting is those with a thickness of around 1-5 metres, and extending to the surface of the crystalline rock. A fracture zone consists of crushed rock.

Inclinometer — A device, build into the WADI, for measuring the tilt of the antennas. The inclinometer can measure the tilt with an accuracy of 0.2°, and the WADI will automatically compensate the reading for this tilt.

Strike direction — The direction of an elongated geological objekt, e.g. a fracture zone.

Dip — The angle between horizontal and the plane of e.g. a fracture zone.

VLF — Very Low Frequency. A military radio signal, used for communication. The frequency is 15-30 kHz.